CYC 2019

22-27 SEPTEMBER
CAPE TOWN

22nd International Conference on Cyclotrons and their Applications

CONFERENCE GUIDE

science & technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

NRF National Research Foundation 20 1999-2019

iThemba LABS
Laboratory for Accelerator Based Sciences

CONFERENCE GUIDE

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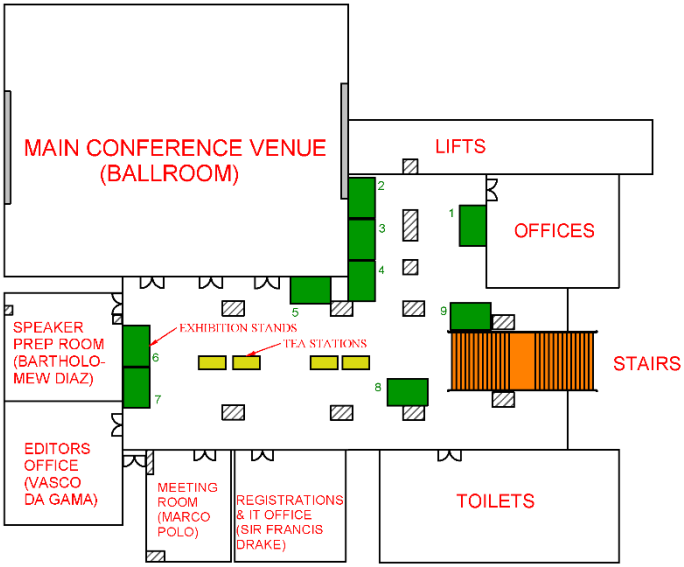
EXHIBITION AND VENUE



The exhibition will be open from Monday 23 Sept 10:40 - to Friday 27 Sept 10:30

EXHIBITOR INFORMATION

Stand 1: AccelSoft

AccelSoft Inc. publishes, markets and distributes software used for the design, simulation and performance analysis of particle accelerators. These software packages provide valuable tools through user-friendly graphic interfaces developed specifically for the particle accelerator community. AccelSoft makes charged particle optics design and simulation a pleasure rather than a chore!

Stand 2: Accutronics

Accutronics have been in business since 1973 supplying a wide range of satellite communication products, RF and Microwave Components, EMF monitoring equipment, RF over Fibre systems and as well as power supplies. Accutronics supply to organisations where quality and reliability are the primary requirement, so Accutronics only represent manufacturers with like-minded philosophies.

Stand 3: MicroMatter Technologies Inc.

Micromatter is a world leading manufacturer of carbon thin films and foils for beam stripping in particle accelerators. Micromatter offers pure nano-crystalline diamond-like carbon (DLC) foils produced by pulsed laser deposition, layered boron containing DLC as well as graphene foils.

Stand 4: Sumitomo Heavy Industries, Ltd.

Sumitomo Heavy Industries has always strived for technological innovation and applies cutting-edge technologies wherever possible. The company operates in a broad range of business areas ranging from manufacturing equipment and infrastructure to fields making use of the latest advanced technology.

Stand 5: Sigmaphi Accelerator Technologies

Sigmaphi has been providing turnkey systems and components for particle accelerators to major research labs and proton therapy system providers for more than 30 years.

Our 200 highly skilled employees can design, make and measure:

- Complete particle transport beam lines, from optics to installation and alignment
- High precision magnets: resistive, superconducting, permanent magnet based, in vacuum
- Turnkey injection or extraction systems
- Ultra-stable power supplies
- RF power solutions : Solid state amplifiers, Klystron modulators

Stand 6-7: IBA

Based on longstanding expertise, IBA RadioPharma Solutions supports hospitals and radiopharmaceutical distribution centers with their in-house radioisotopes production by providing them global solutions, from project design to the operation of their facility. In addition to high-quality technology production equipment, IBA has developed in-depth experience in setting up GMP radiopharmaceuticals production centers.

Stand 8: Best Cyclotron Systems/Best ABT

Best Cyclotron Systems, Inc. (BCSI), offers radioisotopes and production capabilities for nuclear medicine and radiotherapy with its range of **cyclotron systems**. BCSI's mission is to create technology to provide healthcare options for various needs around the world.

Stand 9: OCEM Power Electronics

With almost 80 years of history, **OCEM Power Electronics** is a leading company in power electronics for scientific and industrial research, with a flexible customer-oriented approach and main commitment in Plasma physics, Particle accelerators, Superconductivity, Radio Frequency Systems, Transportation, Food processing and Medical Particle Therapy.

Welcome from the IOC and SPC Chair

It is a great pleasure, as Chair of the International Organising Committee (IOC), to welcome all the delegates to the 22nd International Conference on Cyclotrons and their Applications (CYC2019) in Cape Town, also referred to as the Mother City of South Africa. The conference returns to Cape Town after 24 years since the successful hosting in 1995, which was also the first hosting on the African continent. For iThemba LABS it is a great honour to host this prestigious conference, one of the longest running conferences, which started in 1959.

CYC2019 will give you the opportunity to meet and interact with accelerator physicists, engineers and students, as well as representatives from a number of companies that supply components in the field of accelerator technologies. The Scientific Programme Committee (SPC) managed to compile a very interesting and exciting programme comprising of 14 invited talks and 38 contributed orals, as well as 73 poster presentations, which will cover developments in the field of cyclotron particle accelerators and their applications. The majority of the abstract submitted to CYC2019 fit into the themes *Cyclotron Technologies* and *Operations and Upgrades*. This reflects the vigorous development in the various fields of accelerator physics such as ion sources and radio-frequency (RF) technology. A significant number of contributions were also submitted and is to be presented under the theme *Cyclotron Applications.* This largely covers medical applications, the production of radiopharmaceuticals for cancer treatment and testing of electronic components for radiation hardness. As observed from previous conferences the theme *Theory, Models and Simulations* also received a number of abstracts. Under this theme, concepts such as beam stripping, space charge effects, beam transmission and modelling of the cyclotron RF system will be presented. The theme *Cyclotron and FFA Concepts, New*

projects also received a healthy number of abstracts reflecting the innovative and progressive developments in the field.

With this programme the IOC and SPC strive to foster good relations between the various cyclotron institutes around the world, which will hopefully lead to constructive international collaborations. These international collaborations lead to rapid development which, in the end, will result in applications that benefit society. We therefore ask that this conference should not only be about exchanging knowledge, but also about creating good friendships and collaborations between the delegates that will not only benefit ourselves and our institutes, but ultimately society as a whole.

I want to convey my sincerest gratitude to the industrial companies and international institutes for sponsoring CYC2019. Without your financial support it will be difficult to host CYC2019 in the current format.

I want to thank all of you for making an effort to attend this conference at the southern tip of Africa. I wish you a fantastic time in Cape Town and I hope that you would, if you have some extra time, explore the beautiful surrounds and the rest of our beautiful country.

Lowry Conradie, iThemba LABS
CYC2019 IOC and SPC Chair

Welcome from the LOC Chair

As Chair of the Local Organizing Committee (LOC) it is my pleasure and privilege to welcome all our esteemed delegates and their accompanying partners to Cape Town. A special welcome is extended to our foreign guests who travelled from far afield to attend this auspicious event. The 22nd International Conference on Cyclotrons and their Applications (CYC2019) is proudly hosted by iThemba LABS at The Westin Hotel in Cape Town, South Africa from 22 to 27 September, 2019.

Cape Town and iThemba LABS has a proud history of hosting the cyclotron conference. In October 1995, the 14th edition of this conference was hosted in Cape Town. At this conference the delegates had the distinguished honour of receiving an opening address by one of the greatest sons of Africa and Father of our Nation, Dr Nelson Rolihlahla Mandela. Continuing on this trajectory the LOC, in close cooperation with the International Organizing Committee (IOC) and the Scientific Programme Committee (SPC), has invested greatly to ensure we again present a successful, informative and fruitful conference.

The conference is hosted in the Central Business District (CBD) of Cape Town in close proximity to the historic Bo-Kaap, situated on the slopes of Signal Hill above the city centre and is a historical centre of Cape Malay culture. A water taxi operates between the conference venue and the Victoria & Alfred (V&A) Waterfront, situated on the Atlantic shore, Table Bay Harbour. The City of Cape Town offers delegates easy access to restaurants and shops. Delegates can experience some of the most renowned tourist attractions such as Table Mountain Cableway, Robben Island, the African Penguins at Boulders Beach, spectacular beaches on the Atlantic Seaboard, and the Stellenbosch Wine Routes, one of the biggest tourist attractions in the Western Cape.

To make the conference experience especially memorable delegates will be treated to an aquatic experience and the majestic views of the Atlantic Seaboard during the Welcome and Banquet functions, respectively. Furthermore, a site visit is planned for participants to view the accelerator facilities of iThemba LABS.

Once again, I wish you a pleasant stay in Cape Town. We strive to show our guests the true spirit of Ubuntu ("the belief in a universal bond of sharing that connects all humanity"), as displayed in the character of the people of our Rainbow Nation.

Muneer Sakildien, iThemba LABS
CYC2019 LOC Chair

COMMITTEES

INTERNATIONAL ORGANISING COMMITTEE

Name	Surname	Institute	Country
Patrick	Bertrand	GANIL	France
Sytze	Brandenburg	KVI	Netherlands
Yuri	Bylinski	TRIUMF	Canada
Lowry	Conradie	TLABS	South Africa
Andrea	Denker	HZB	Germany
Mitsuhiro	Fukuda	RCNP	Japan
Ralf	Gebel	FZJ	Germany
Boris	Gikal	JINR	Russia
Pauli	Heikkinen	JYFL	Finland
Yves	Jongen	IBA	Belgium
Marc	Loiselet	UCL	Belgium
Donald	May	TAMU	United States
Yoshiharu	Mori	RRI	Japan
Koji	Noda	NIRS	Japan
Hiroki	Okuno	RIKEN	Japan
Danilo	Rifuggiato	INFN	Italy
Hermann	Schweickert	ZAG	Germany
Mike	Seidel	PSI	Switzerland
Vijay	Shanker Pandit	VECC	India
Susan	Smith	STFC	United Kingdom
Andreas	Stolz	NSCL	Unites States
Damon	Todd	LBNL	United States
Wenlong	Zhan	IMP	China
Tianjue	Zhang	CIAE	China
HongWei	Zhao	IMP	China

SCIENTIFIC PROGRAMME COMMITTEE

Adelmann	Andreas	PSI	Switzerland
An	Shizhong	CIAE	China
Brandenburg	Sytze	KVI-CART	Netherlands
Conradie	Lowry	iThemba LABS	South Africa
Denker	Andrea	Helmholtz Centre Berlin	Germany
Gammino	Santo	INFN-LNS	Italy
Kleeven	Wiel	IBA	Belgium
Mori	Yoshiharu	Kyoto University	Japan

Okuno	Hiroki	RIKEN	Japan
Schippers	Marco	PSI	Switzerland
Winklehner	Daniel	MIT	United States

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Hugo Barnard	hbarnard@tlabs.ac.za	Strategic Planning & Communications
Vanessa de Jongh	vanessa@tlabs.ac.za	JACoW Proceedings Secretary

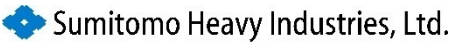
INTERNATIONAL ORGANISING COMMITTEE (IOC) MEETING

Tuesday 24 September

12:55-14:00

Venue: Prince Edward Meeting Room, Mezzanine level, Westin Hotel

The organisers of CYC2019 gratefully acknowledge the sponsors and exhibitors



GENERAL INFORMATION

Local weather

Cape Town is never out of season, with a particularly good, long summer from November to March. These are the most popular months for visitors, who come to enjoy the 11 or more hours of sunshine every day. The average summer temperature in Cape Town is 24.3 ^{o}C, with January and February temperatures averaging 26 ^{o}C. February is the driest month of the year, with 15 mm (0.6 inches) of rain.

Currency

The local currency is the South African Rand (ZAR). The Rand comes in a range of coins (R1 = 100 cents) and note denominations of R10, R20, R50, R100 and R200. Foreign exchange facilities are widely available and can be found at the V&A Waterfront, Cape Town International Airport and at bureau de change in various major shopping centres. Automated Teller Machines (ATMs) accept most international bank and credit cards. The ATMs are available 24/7. South Africa has a modern and sophisticated banking and commercial system, and most shops and hotels accept all major credit cards. You are advised to be alert when conducting banking transactions and do not disclose your PIN to anyone.

VAT: South Africa has a Value Added Tax system of 15% on purchases and services. Foreign visitors can reclaim VAT on collective purchases of more than R250. VAT Refund Offices can be found at: Ground level, International Departures, Cape Town International Airport Tel: + 27 21 934 8675.

Tipping

A 10% tip is standard in restaurants. Tables of over eight people often have an automatic service charge added to the bill. A tip of R5 to R10 per piece of luggage is acceptable for porters in hotels and at airports. In some shopping areas, uniformed attendants will either take a fee or offer to mind your car for a tip.

Banking and shopping hours

Most shops and businesses are open between 09h00 and 17h00 on weekdays and on Saturdays until 13h00. Major malls tend to stay open later: up to 21h00 during the week, on weekends and on most public holidays. Government agencies keep to limited weekday only hours, often closing around 15h00.

Most banks close at 15h30 weekdays, but are open on Saturday mornings (from around 09h00 to 11h00). Muslim-owned businesses close between noon and 14h00 on Fridays.

Local couriers can help you ship your purchases home and deal with formalities. Check with Cape Town Tourism Visitor Information Centres for contacts. Postage stamps are available at Post Offices, as well as at some Cape Town Tourism Visitor Information Centres.

Credit cards

Credit cards are widely accepted in South Africa, especially MasterCard and Visa. Nedbank is an official Visa agent, and Standard Bank is a MasterCard agent – both have branches across the country.

Electricity

The South African electricity supply is 220/230 volts AC 50 HZ. With a few exceptions (in deep rural areas), electricity is available almost everywhere. International adaptors are available in most hotel rooms. In South Africa the power sockets used are of type D / M, using three-prong (round pin) plugs.

Mobile phones

Roaming mobile network services are available in South Africa. If you wish to join a South African mobile network, you can buy or hire a cell phone at the airport or at most of the major shopping centres. Local SIM cards may be purchased at the airport and at local shopping centres.

Transport

UBER & TAXIFY is available and a safe option for transport in Cape Town. You can use a debit or credit card to pay, or there is a cash option. See uber.com or taxify.eu for more information.

Metered taxis can be found at the Cape Town International Airport, on Adderley Street in the CBD and at several points in the V&A Waterfront. Rates are charged per km and a minimum fare usually applies. Avoid unmarked cars or casual offers of transport services. All hotels would also be able to assist with booking of taxis and tours, contact the concierge to assist. All major car-hire companies operate from the airport and city.

MyCiti is a bus rapid transit service with feeders, which forms part of a greater Integrated Public Transport driven economic development strategy of the City of Cape Town Municipality in South Africa. The MyCiTi Airport station is right on the doorstep of the main Airport terminal with level access into the arrivals and departures hall for both domestic and international flights. Transfers between the Airport and the city offer great value for money, and the MyCiTi's multi-day travel packages also offers the opportunity to visit many of Cape Town's top tourism sites and leisure destinations. (https://myciti.org.za/en/home/). The GoMetroApp provides information and timetables for Metrorail, Golden Arrow and MyCiti transport services.

Central City routes - 27 October 2018

Security tips

Avoid carrying large sums of cash, carrying cameras or video cameras in plain sight and leaving belongings unattended. **Heed the advice of your hosts**, Cape Town Tourism Visitor Centre staff or locals on where to go after dark. Try not to walk alone. Do not allow strangers to assist you in any way at **ATMs**. **Street children and beggars** may approach you for a handout. Many social workers counsel against giving money to the children as it usually gets handed over to an older person or is used to purchase drugs. At night, park in a secure, well-lit area.

To report any safety incident, phone the following numbers:

- All emergencies from your cell phone – 112
- All emergencies from a landline – 107
- South African Police Services (SAPS) – 10111

Cape Town Tourism in partnership with Protection and Emergency Services run a successful **Visitor Support Programme** to assist you further, should you be involved in an incident. Contact Tourism Safety officers: Neo: 082 554 2010 or Cynthia: 072 447 1504

WiFi Network

South Africa has a well-developed communications infrastructure. A number of cell phone providers offer national coverage and there are well-established landline phone networks. Internet and WiFi are easily accessible in most urban areas.

The Westin Hotel offers complimentary Internet. WiFi is available throughout the Hotel for guests.

The Conference WiFi:

Wi-Fi code: CYC2019
Password: CYC2019!

Conference Hotel

The Westin
Convention Square, Lower Long St, Cape Town, 8000
Phone: 021 412 9999

Free parking will be available at The Westin for CYC2019 delegates.

Conference Registration Desk

Registration will be available on Sunday evening 22 September during the Welcome Cocktail at the Two Oceans Aquarium from 18:00-21:00. The Conference Registration desk will be available during conference hours at the conference venue.

About Cape Town

Cape Town is a multi-cultural and multi-linguistic city with a fascinating history. The city owes its diversity to everyone; from slaves from Malaysia, Indonesia, Madagascar and Mozambique to Dutch, English and French explorers; from indigenous Khoi and San people to local African tribes. Cape Town is also colloquially named the Mother City.

Through the ages the region was given different names by the old seafarers. The Portuguese explorer, Bartholomew Diaz officially was the first to sail round the southern tip of Africa in 1488, and he called it the Cape of Storms. King John II of Portugal renamed it to the Cape of Good Hope and Sir Francis Drake later reported it to be the fairest cape of all.

On 6 April 1652 the United East India Company (VOC) established, under the command of Jan van Riebeeck, a supply station on the shore of Table Bay for Dutch ships sailing to East Africa, India, and the Far East. This was the first permanent European settlement in Southern Africa. Cape Town outgrew its

original purpose as a supply station at the Castle of Good Hope, becoming the economic and cultural hub of the region.

Cape Town is also a very prominent city in the fight against social injustices. It is where Nelson Mandela was incarcerated for twenty-seven years, spending eighteen years of his life on Robben Island, just off the coast of Cape Town. The island has subsequently been declared as a UNESCO Heritage Site. It is also in this city that Mandela addressed the crowds at the Cape Town City Hall mere hours after his release from prison in 1990. The city also houses the Nobel Square, which is a public square in the Victoria & Alfred Waterfront, housing life-sized sculptures of South Africa's four Nobel Peace Prize Laureates: Nelson Mandela, FW de Klerk, Desmond Tutu and Albert Luthuli.

Cape Town is the legislative capital of South Africa, the primary city of the Western Cape Province and is the hub of the City of Cape Town's metropolitan municipality. The Parliament of South Africa sits in Cape Town. The other two capitals are located in Pretoria (the executive capital where the Presidency is based) and Bloemfontein (the judicial capital where the Supreme Court of Appeal is located).

Apart from its bustling harbour and cobbled streets and colourful houses of the Bo-Kaap, Cape Town is known for landmarks such as Table Mountain, Signal Hill and Cape Point, but also for its natural setting in the Cape Floristic and Cape Winelands regions. Located in a CI biodiversity hotspot, the city of Cape Town has one of the highest levels of biodiversity of any equivalent area in the world. These protected areas are a World Heritage Site, and an estimated 2,200 species of plants are confined to the Table Mountain reserve alone.

Cape Town is home to 64% of the population of the Western Cape Province and one of the most multicultural cities in the world, reflecting its role as a major destination for immigrants and expatriates to South Africa. The city was named the World Design Capital for 2014 by the International Council of Societies of Industrial Design. In 2014 Cape Town was named by both The New York Times and The Daily Telegraph the best place in the world to visit.

About iThemba LABS

iThemba LABS operates the largest cyclotron facility in the Southern Hemisphere of which the K200 separated sector cyclotron (SSC) is at the Western Cape site. It is a variable energy machine that can accelerate light and heavy ions. Two smaller cyclotrons act as injector accelerators for the SSC, one providing intense beams of light ions, and the other, beams of polarized light ions or heavy ions. A 3 MV Tandetron is used mainly for research, utilizing ion beam analysis techniques. A K11 cyclotron produces the radioisotope Flourine-18, which is used by the local nuclear medicine facilities for imaging purposes.

Accelerators at the Gauteng site include a 6 MV tandem accelerator with a specialized high energy analysis system for Atomic Mass Spectrometry (AMS) and two low energy electrostatic accelerators for ion implantation and other surface science studies.

The accelerated charged particles are used for basic nuclear physics research, radioisotope production, radiobiology research related to particle therapy, and applications such as radiation hardness testing of electronic components used in satellites and detector calibrations. As a means to contribute to the human capital development mandate of the NRF, iThemba LABS have various collaboration agreements and joint training programmes with Higher Education Institutions and research laboratories around the world. The laboratory also provides a platform for SA based researchers and postgraduate students to access global research facilities such as CERN, JINR and GSI/FAIR. To maintain and increase the excellence of the research and training activities, as well as respond to the demands from the research and isotope supply, iThemba LABS has developed a globally competitive research strategy and a related research infrastructure acquisition plan, based on the South African Isotope Facility (SAIF) project, which has two components: The ACE-Isotopes and the ACE-Beams. The first phase consists of the acquisition of the C70 cyclotron and the Low Energy Radioactive Beam (LERIB) project, which will make iThemba LABS internationally competitive by expanding the nuclear astrophysics research and the study of neutron-rich nuclei, and materials research using rare isotopes.

Social Functions

Welcome Reception

A welcome reception will be held on **Sunday 22 September** from 18:00 onwards at the **Two Oceans Aquarium** on the V&A Waterfront. Buses will depart from The Westin at 18:00 to the Aquarium. Registration for the conference will be open from 18:00 onwards, followed by the reception in the magnificent Predator Exhibit area. You will be able to explore the impressive and beautiful marine life displayed at the Aquarium during this time. Buses will return to The Westin at the end of the function at 21:30.

The exciting, newly revamped ***Predator Exhibit*** gives you the chance to experience a close encounter with some of the most misunderstood species in South Africa's oceans. Meet the shiver of ragged-tooth sharks, watch schools of giant yellowtail hunt for their next meal and watch the curious, but territorial, yellowbelly rockcod stand its ground to much larger predators. Whether you relax in front of the exhibit's large window, or spiral around the accessible viewing ramp - there is a “jawesome” underwater world to discover.

Tour to iThemba LABS and Dinner

A tour of iThemba LABS facilities will take place on Wednesday **25 September** from 14:00 onwards. Delegates are invited to a spitbraai (lamb on the spit) after the tour. Buses will depart from the Westin Hotel at 14:00 to iThemba LABS and return to the Westin Hotel after dinner.

Conference Dinner

The Conference banquet will be held at **The Bungalow Restaurant** in Clifton on **Thursday 26** September.
This restaurant is right on the Atlantic Ocean and will offer a beautiful sunset while sipping your arrival drinks and enjoying scrumptious canapés. You will be welcomed by the sounds of a local Marimba Band and will be treated to a delicious 2 course meal. Buses will depart from the Westin Hotel at 17:35 and return after the dinner.

Things to do in Cape Town

The main feature of **Table Mountain** is the level plateau approximately three

kilometres (2 mi) from side to side, edged by impressive cliffs. The plateau, flanked by Devil's Peak to the east and by Lion's Head to the west, forms a dramatic backdrop to Cape Town. This broad sweep of mountainous heights, together with Signal Hill, forms the natural amphitheatre of the City Bowl and Table Bay harbour. The highest point on Table Mountain is towards the eastern end of the plateau and is marked by Maclear's Beacon, a stone cairn built in 1865 by Sir Thomas Maclear for trigonometrical survey. It is 1,086 metres (3,563 ft) above sea level, and about 19 metres (62 ft) higher than the cable station at the western end of the plateau.

The **Victoria & Alfred (V&A) Waterfront** in Cape Town is situated on the Atlantic shore, Table Bay Harbour, the City of Cape Town and Table Mountain. Situated in South Africa's oldest working harbour, the 123 hectares (300 acres) area has been developed for mixed-use, with both residential and commercial real estate. The Waterfront attracts more than 23 million visitors a year

Kirstenbosch enjoys great popularity with residents and visitors. From the gardens several trails lead off along and up the mountain slopes and these are much used by walkers and mountaineers. One of the trails, up a ravine called Skeleton Gorge, is an easy and popular route to the summit of Table Mountain. On the slopes above the cultivated parts of the garden a contour path leads through forests to Constantia Nek to the south.

Chapman's Peak is the name of a mountain on the western side of the Cape Peninsula, between Hout Bay and Noordhoek in Cape Town, South Africa. The western flank of the mountain falls sharply for hundreds of metres into the Atlantic Ocean, and a spectacular road, known as Chapman's Peak Drive, hugs the near-vertical face of the mountain, linking Hout Bay to Noordhoek.

Cape Point is situated within the Table Mountain National Park, within a section of the park referred to as Cape of Good Hope. This section covers the whole of the southern tip of the Cape Peninsula and which takes in perhaps 20% of its total area. The Cape of Good Hope section of the park is generally wild, unspoiled and undeveloped and is an important haven for seabirds. The vegetation at Cape Point consists primarily of Peninsula Sandstone Fynbos.

The most popular recreational spot is **Boulders Beach**, but the penguins are best viewed from Foxy Beach, where newly constructed boardwalks take visitors to within a few meters of the birds. It is also a popular swimming beach, although people are restricted to beaches adjacent to the penguin colony.

Stellenbosch Wine Routes is one of the biggest tourist attractions in the Western Cape. http://www.wineroute.co.za/. A variety of soils and locations ideally suited to flourishing of a wide variety of grape cultivars, has seen Stellenbosch continue to dominate the South African wine scene in terms of quality. With the growing acceptance of South African wines globally, Stellenbosch remains at the forefront of growth in the wine industry.

In 1971 Stellenbosch became the first wine region in South Africa to establish a wine route as an organised network of wineries at which the tourist could experience the product of the vine and tune into the soul of the region's winelands. The Stellenbosch Wine Routes currently provide a co-ordinated network of more than 150 wineries, each offering a unique cellar-door experience for the wine-lover and tourist.

Bus Schedule

Sunday 22 September:

18:00: Depart Westin Hotel to the Aquarium for Welcome Function

21:30: Depart the Aquarium for Westin Hotel

Wednesday 25 September:

13:35: Depart Westin Hotel for iThemba LABS

22:00: Depart iThemba LABS for Westin Hotel

Thursday 26 September:

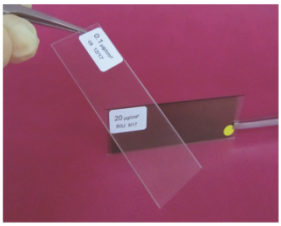
17:35: Depart Westin Hotel for The Bungalow for Conference Banquet

23:00: Depart The Bungalow for Westin Hotel

Arizona Carbon Foil Co. Inc.

We are the Leading manufacturer of Carbon Foils used in cyclotrons worldwide!

If you are using a cyclotron, chances are, you are already using our foils. Carbon foils made by ACF-Metals are used in nuclear, and space physics, time-of-flight studies, optical, chemical, medical, and microscopy research. These are the most popular stripper/extractor foils involved in manufacturing and research using particle accelerators.



Our foils are used in accelerators worldwide! Amorphous carbon foils (ACF) have highest purity, uniformity, and stability. Natural isotopic composition is carbon-12 with 1.1% carbon-13. Thicknesses of 0.1 µg/sq.cm up to 2000 µg/sq.cm are always in stock, on glass substrates, freestanding, or mounted.

Polycrystalline Graphite (PCG) foils are easier to handle, as efficient as amorphous carbon foils, and have in-beam lifetimes competitive with arc-evaporated foils.
Standard areal densities 400 µg/sq.cm to 20 000 µg/sq.cm are kept in stock at all times.

Mounted stripper/extractor foils for extended lifetimes:

- Arc evaporated foils and PCG foils.
- Multiple fork styles of Aluminum, Graphite, and other materials.
- Guaranteed delivery anywhere in the world without damage.

Buy Direct from the Manufacturer and Save!

Ph: 520.325.9557 ACF-Metals.com contact@acf-metals.com

ABSTRACTS

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23-Sep-19 09:00 – 09:30	Ballroom

MOW — Conference Opening
Chair: J.L. Conradie (iThemba LABS)

OPENING 09:00 30 **Welcome and Introduction to the 22nd International Conference on Cyclotrons and their Applications**

23-Sep-19 09:30 – 10:40	Ballroom

MOA — Facility Development and Upgrades
Chair: Y. Bylinskii (TRIUMF)

MOA01 09:30 30 **Recent Experimental Results of the Accelerator Drive System with a Sub-Critical Nuclear Reactor (ADS) Program**
Y. Ishi*, Y. Fuwa, Y. Kuriyama, Y. Mori, H. Okita, K. Suga, T. Uesugi (Kyoto University, Research Reactor Institute)*
A series of study on the accelerator driven system (ADS) has been carried out since 2009 at KURNS. In these studies, Kyoto University Critical Assembly (KUCA) has been used as sub-critical system connected with the proton beam line from FFAG accelerator facility. A profile of accelerator facility and experimental results, including the first evidence of the transmutation of minor actinides at ADS, will be presented.

MOA02 10:00 20 **Operating Status and Upgrading of Cyclotron in Lanzhou**
W.Q. Yang *(IMP/CAS)*
Heavy Ion Research Facility in Lanzhou (HIRFL) is a cyclotron, synchrotron and storage ring accelerator complex, which accelerates ions of Hydrogen to Uranium from low to medium energy. HIRFL operates more than 7000 hours a year. The efficiency of the HIRFL operation was improved up to 75%. In HIRFL, 25 kinds of beams are provided annually. In the past five years, 61 kinds of new beams with different ions, different charge states and different energies have been produced. In HIRFL, more than 200 user science experiments have been completed. Users come from universities, enterprises and research institutes at home and abroad. HIRFL was built-up in 3 periods, lasting about half century. Under strong support of the national maintenance and renovation budget for large scale fundamental science and technology facilities from the Chinese Academy of Sciences (CAS), many aspects of the infra-structure of HIRFL were upgraded or renewed to improve the operation stability and reduce the failure time. The operation status and improved plan of HIRFL will be showed in this paper.

MOA03
10:20 20

Status Report on GANIL and Upgrade of SPIRAL1

***O. Kamalou**, P. Delahaye, M. Dubois, A. Savalle (GANIL)*

The GANIL facility (Grand Accélérateur National d'Ions Lourds) at Caen is dedicated for acceleration of heavy ion beams for nuclear physics, atomic physics, and radiobiology and material irradiation. Nowadays, an intense exotic beam is produced by the Isotope Separation On-Line method at the SPIRAL1 facility since 2001. New demands from the physics community motivated the upgrade of being upgraded of this facility in order to extend the range of post-accelerated radioactive ions. A 2 MEuro project allowed the profound modification of the facility and the commissioning was achieved in 2017. The status of this facility and the last results will be presented. The review of the cyclotron operation from 2001 to 2019 will be presented as well.

23-Sep-19 11:10 – 12:20 Ballroom

MOB — Facility Development and Upgrades

Chair: R. Gebel (FZJ)

MOB01 11:10 30 **Recent Progress in RIKEN RI Beam Factory**

***O. Kamigaito**, T. Dantsuka, M. Fujimaki, N. Fukunishi, H. Hasebe, Y. Higurashi, E. Ikezawa, H. Imao, M. Kidera, M. Komiyama, K. Kumagai, T. Maie, T. Nagatomo, T. Nakagawa, M. Nakamura, T. Nishi, J. Ohnishi, H. Okuno, K. Ozeki, N. Sakamoto, K. Suda, A. Uchiyama, T. Watanabe, Y. Watanabe, K. Yamada (RIKEN Nishina Center) Y.M. Miyake (RIKEN)*

Recent efforts concerning the accelerators of the RIKEN RI Beam Factory (RIBF) have been directed towards achieving higher beam intensities of very heavy ions such as xenon and uranium. In this respect, this paper presents the recent upgrade programs conducted in the past few years, such as modification of the RF resonators of the RIKEN Ring Cyclotron and improvements of the charge strippers. The current performance level of the RIBF accelerator complex, as well as a future plan to further increase the beam intensities, are also presented.

MOB02 11:40 20 **Progress With a New Radioisotope Production Facility and Construction of Radioactive Beam Facility at iThemba LABS**

***J.L. Conradie**, J.K. Abraham, H. Anderson, L.S. Anthony, F. Azaiez, S. Baard, R.A. Bark, A.H. Barnard, P. Beukes, J.I. Broodryk, B. Cornelius, J.C. Cornell, J.G. De Villiers, H. Du Plessis, W. Duckitt, D.T. Fourie, M.E. Hogan, I.H. Kohler, C. Lussi, J. Mira, H.W. Mostert, C. Naidoo, F. Nemulodi, P. Papka, M. Sakildien, V.F. Spannenberg, G.F. Steyn, N. Stodart, I.L. Strydom, R.W. Thomae, M.J. Van Niekerk, P.A. van Schalkwyk (iThemba LABS)*

With the termination of the neutron and proton therapy programs at iThemba LABS, the use of the Separated Sector Cyclotron (SSC) has now shifted to nuclear physics research with both stable and radioactive-ion beams, as well as biomedical research. A dedicated isotope production facility with a commercial 70 MeV H-minus cyclotron has been approved and both the cyclotron and isotope production target stations will be housed in the vaults that were previously used for the therapy programs. The status of this new facility will be reported. In the future the SSC will mostly be used for nuclear physics research, as well as the production of isotopes that cannot be produced with the 70 MeV H-minus cyclotron. At present the production of the alpha-emitting radionuclide Astatine (211At) with a 29 MeV alpha beam is being investigated. Progress with the construction of a facility for production of radioactive beams will be discussed. There will also be reports on development work on the ECR ion sources and progress with implementation of an EPICS control system.

MOB03
12:00 20

GFS-2 - The New Gas-filled Separator for Super-Heavy Elements in JINR. A Guided Walk through the Genesis of the Project from First Thoughts to Completion

W. Beeckman, *S. Antoine, F. Forest, PJ. Jehanno, P. Jivkov, M.J. Leray, X. Milpied, C. Nignol, O. Tasset-Maye (Sigmaphi) A.G. Popeko, V.K. Utyonkov (JINR/FLNR)*

The brand-new Superheavy Element Factory at the Flerov Laboratory of Nuclear Reactions (FLNR) in JINR, Dubna, is under completion, with the high-current DC-280 cyclotron fully installed and tested having Argon beams available for first tests. To improve the efficiency of studies on heavy and superheavy nuclei, it will deliver a wide range of species with high intensity, which in turn require effective separators providing high suppression of unwanted reaction products. The first experiment fed by the cyclotron, GFS-2, is a universal gas-filled separator for synthesis and study of the properties of heavy isotopes, based on the QvDhQvQhD scheme. The presentation describes its study and design in close collaboration between FLNR and Sigmaphi, starting from the initial demand in 2015 and going through the different steps, up to its construction in 2017 and installation in 2018. A second system, GFS-3 is ready to be installed by the end of 2019.

MOP001 **Design and Commissioning of RF System for SC200 Cyclotron**

G. Chen, *C. Chao, Y. Chen, K.Z. Ding, G. Liu, X.Y. Long, Z. Peng, Y. Song, C.S. Wei, X. Zhang, Y. Zhao (ASIPP) L. Calabretta, A.C. Caruso (INFN/LNS) O. Karamyshev (JINR/DLNP) G.A. Karamysheva, G. Shirkov (JINR)*

The SC200 proton therapy superconducting cyclotron is currently under construction by ASIPP (Hefei, China) and JINR (Dubna, Russia). The radio frequency (RF) system which provides an accelerating electric field for the particles, has been designed and tested in a high-power commissioning. The RF system consists of RF cavity, Low-level RF control system, RF source, transmission network and so on. The main performances of RF cavity meet design and use requirements in the cold test. The RF cavity achieved with an unload Q factor of 5200 at the resonant frequency of 91.5 MHz, 60 kV (Center)~120 kV (Extraction) accelerating voltage and coupling state of S11 <-30 dB. The low-level RF (LLRF) system has been tested with an amplitude stability of <0.2% and a phase stability of <0.1 degree in the high-power commissioning. What is more, the cavity operated in a ~50 kW continuous wave state after 4 weeks RF conditioning. Some risks have exposed at higher power test, but related solutions and improvements have been developed. In future work, the target of RF system is effective operation under the overall assembly of cyclotron after further optimization and RF conditioning.

MOP002 **Recent Progress on Ion Source of SC200 Cyclotron**

Y. Zhao, *G. Chen (ASIPP) L. Calabretta (INFN/LNS) O. Karamyshev (JINR/DLNP) G.A. Karamysheva, G. Shirkov (JINR) S.W. Xu (USTC)*

A 200 MeV compact superconducting cyclotron for proton therapy, named SC200, is under development by collaboration of ASIPP (Hefei, China) and JINR (Dubna, Russia). The ion source is a significant subsystem of the cyclotron. A hot cathode internal ion source has been designed and tested for SC200 cyclotron. The ion source has been successfully arc discharged on the test bench. The extracted beam current has been measured over 100 μA and filament lifetime of ion source exceeded 100 h, which indicated that the ion source meets the design requirements. The performance of the ion source was verified under different working conditions, such as gas flow and arc voltage. In addition, in order to meet the assembly accuracy of cyclotron, the design of mechanical structure is also being optimized.

MOP003 **Optimal Design and Fluid-Solid Coupling Thermal Analysis of Sc200 Superconducting Proton Cyclotron Electrostatic Deflector**

Y. Xu, *K.Z. Ding, X.Y. Huang (ASIPP)*

In recent years, the study of proton therapy equipment has received increasing attention in China. Hefei CAS Ion Medical and Technical Devices Co., Ltd. (HFCIM) is developing a proton medical device based on the superconducting proton cyclotron. The electrostatic deflector (ESD) is the first extraction component of the SC200 superconducting cyclotron, which uses a high-intensity electric field to strip the beam from the track. Due to its compact structure, the fierce interaction between the proton beam and

the deflector septum, causing a great loss of beam and unwanted excess heat accumulation and radiation. In order to minimize the risk of damage caused by the proton beam loss, the fluid solid-thermal coupling analysis of the deflector was performed by applying computational fluid dynamics (CFD) on FEM code. The maximum temperatures of the septum in various cases of the cooling water speed, the septum thickness and material have been investigated respectively. The result based on analysis provide a valuable reference for the further optimization on the material selection and structural design for ESD.

MOP004 **Beam Dynamics Simulation of the Extraction for a Superconducting Cyclotron SC240**

Z. Wu, *K.Z. Ding, J. Li, Y. Song (ASIPP) Z. Zhong (HFCIM)*

In order to diversify the company's cyclotron, a design study has been carried out on a 240 MeV superconducting cyclotron SC240 for proton therapy, which is based on our experience in design of SC200. In order to increase turn separation and extraction efficiency, resonant precessional extraction method is employed in the extraction system. A first harmonic field generated by trim rods is added to introduce beam precessional motion. Its effects on phase space evolution and turn separation increase is studied by a high efficiency beam dynamics simulation code. According to the study, its amplitude and phase has been optimized to meet the requirements of extraction beam dynamics. Based on beam dynamics simulation, the parameters of extraction system elements (electrostatic deflectors and magnetic channels) and trim rods are chosen. The field perturbations produced by trim rods and magnetic channels are analyzed. Extraction efficiencies and beam parameters for different initial beam parameters have been calculated.

MOP005 **Preliminary Design Study of the 14 MeV Compact Isochronous Cyclotron for Isotopes Production.**

F. Jiang, *G. Chen, Y. Chen, K.Z. Ding, Z. Wu (ASIPP)*

Compact isochronous cyclotrons which accelerate negative hydrogen ions in the energy range 10^{-30} MeV have been widely used over the last 40 years for production of medical isotopes and other applications. A 200 MeV superconducting proton cyclotron have been designed by ASIPP for radiotherapy. For diversifying products, the goal of development is to produce a 14 MeV proton beam by cyclotron (SC14). This cyclotron can moderate beam intensity be used for production of most medical and industrial isotopes. A PIG source and stripping extraction were employed in SC14. The magnet system is composed of one set of room-temperature coils and four straight sectors with a yoke. The design and technical considerations on hills, betatron oscillation optimization, and stripping extraction have been presented. The issue of vertical focusing is briefly discussed.

MOP006 **The Design and Simulation on the Extraction System for CYCIAE-50**
S. An, *F.P. Guan, L.L. Guan, P. Huang, L.Y. Ji, M. Li, Y.L. Lv, S.M. Wei, L.P. Wen, H.D. Xie, J.S. Xing, T.J. Zhang, X. Zheng (CIAE)*
A 50 MeV H^- compact cyclotron (CYCIAE-50) as a proton irradiation facility is under construction at China Institute of Atomic Energy. The proton beam with the energy of 30 MeV to 50 MeV and the current of 10 μA will be extracted by a single stripping extraction system. In order to reduce the beam loss, the combination magnet is fixed inside the magnetism yoke. The positions of stripping points for the different extraction energy are calculated and the extracted beam trajectories after stripping foil are simulated in detail in this paper. The extracted beam distribution after stripping foil and the extracted beam characters will be studied in this paper. The beam parameters after extraction will be given by the extracting orbit simulation. The design on the whole stripping extraction system has been finished and will be presented in this paper.

MOP007 **The Design and Calculation on the Injection and Central Region for CYCIAE-50**
L.Y. Ji, *S. An, F.P. Guan, P. Huang, X.L. Jia, Y.L. Lv, C. Wang, S.L. Wang, T.J. Zhang, X. Zheng (CIAE)*
A 50 MeV cyclotron (CYCIAE-50) is been building at China Institute of Atomic Energy. CYCIAE-50 is a compact H^- cyclotron with the proton beam energy of 30 MeV to 50 MeV and the beam current of 10 μA. A multicusp H^- ion source with the beam current of 3 mA will be used for this machine. The design on the injection and central region of CYCIAE-50 has been finished. The way of matching the beam from ion source to central region and the design of central region will be present in this paper. In addition, some significant problems in central region will be discussed, including radial alignment, axial focusing, longitudinal focusing and energy gain, etc.

MOP008 **Mechanical Design of Beam Lines for a 230 MeV SC Cyclotron at CIAE**
M. Yin, *S. An, F.P. Guan, Y.L. Lv, G.F. Pan, F. Wang, F. Wang, S.M. Wei, L.P. Wen, T.J. Zhang, F.Zhu. Zhu (CIAE)*
To develop the proton beam transfer system which used in the field of proton therapy, the mechanical design of proton beam lines based on the CYCIAE-230 has been finished at the China Institute of Atomic Energy (CIAE). The proton beam transfer system includes the beam lines, beam dump, gantry, nozzle, couch, image guidance system, etc. Two beam lines are designed at CIAE this moment. One is for the nozzle system, the other is for the beam dump. The beam lines include four systems: the energy selection system, the beam transportation systems, gantry system, beam dump. The beam lines are very compact in order to match the beam optics and the space limitation. The gantry can be rotated ±180°. There are several key components in beam lines, such as magnets, degrader, beam diagnostics component, vacuum component, etc. The designed mechanical tolerance of the magnets is limited less than 0.1 mm. There are at least four targets on each magnets for collimation and all the components can be adjusted in three dimensions. The magnets are being manufactured

now. The mechanical design of proton beam lines based on the CYCIAE-230 will be presented in this paper.

MOP009 **RF System Design for CYCIAE-50**

***J.Y. Wei**, X.L. Fu, B. Ji, P.Z. Li, Y.L. Lv, Z.G. Yin, T.J. Zhang (CIAE)*

The 50 MeV cyclotron is a proton irradiation device designed for space science research that simulates a spatial proton environment. The radio frequency (RF) system is one of the important systems of the 50 MeV cyclotron CYCIAE-50. The RF system operates at 65.5 MHz and the acceleration voltage at the central position is about 50 kV. The RF system consists of a RF power source, transmission line, low level RF (LLRF) and cavity. The two RF cavities are connected at the central region of the cyclotron by a RF bridge, the cavity is a $\lambda/2$ wavelength symmetrical structure, and the cavity applies fourth harmonic to accelerate beams. The RF power source consists of a three-stage amplification link with a rated output power of 23 kW. The LLRF system used a modular design, including an amplitude stabilization module and a cavity tuning module. The required amplitude stability of the accelerating voltage is 0.1%. At the same time, it is ensured that the eigen-frequency of the cavity is stable when the cyclotron is running. The RF system of the CYCIAE-50 is compact, stable, reliable and easy to maintain.

MOP010 **Proton Beam Line Design for CYCIAE-50**

***S.M. Wei**, S. An, L.L. Guan, Y.L. Lv (CIAE)*

The cyclotron Center at the China Institute of Atomic Energy (CIAE) is now developing a medium-energy proton irradiation device that provides a proton beam with an energy range of 30 MeV to 50 MeV to simulate a space proton radiation environment, which has a significant impact on spacecraft. A beam transport line is designed for irradiation effect study based on the 50 MeV compact cyclotron, which requires continuous adjustment of the beam energy and the beam spot on the target requires high uniformity. The proton beam extracted from the cyclotron is adjusted to the energy required by using the degrader, then the proton beam is bended and focused. In order to obtain uniform large-diameter beam spot on the target, a wobbling magnet is installed on the beam line to uniformly sweep the proton beam on the target and finally obtain the proton beam with energy of 30 MeV - 50 MeV, current of 10 μA and beam spot of 20 cm * 20 cm on the target.

MOP011 **Magnetic Field Measurement and Shimming for a Medical Compact Cyclotron**

***L.L. Guan**, S. An, T. Cui, P. Huang, X.L. Jia, M. Li, F. Wang (CIAE)*

A compact cyclotron is developed by Cyclotron Accelerator Research Center at China Institute of Atomic Energy (CIAE) to extract 14 MeV proton beam for medical radioisotopes production, so as to meet the market demands of early diagnosis of malignant tumors, cardiovascular and cerebrovascular diseases. Owing to the small size and limited space of small medical cyclotrons, critical requirements are imposed on magnetic field measurement. For this reason, a magnetic field measurement system, with high-precision and high-stability, suitable for small cyclotrons is adopted

and then an efficient magnetic field shimming method is used, which greatly reduces the construction period. It provides a strong guarantee for the stable operation of medical small cyclotrons.

MOP012 **A Digital Approach of Beam Phase Measurement and Regulation System**
***Y. Wang**, X.T. Lu, J.Y. Wei, L.P. Wen, Z.G. Yin, T.J. Zhang (CIAE)*
A superconducting cyclotron, namely CYCIAE-230, is developed by China Institute of Atomic Energy (CIAE) as a proton source for cancer therapy. In general, there are several ways to regulate the magnet field for a fix frequency cyclotron. One of them is to measure the beam phase with respect to the radio frequency (RF) cavity. The beam phase stability control system of CYCIAE-230 superconducting cyclotron is designed to measure the beam phase and using it to adjust the current setting of main magnet power supply. The reported system includes a high-resolution resonator type beam phase probe, a digital frequency down conversion and phase detector module, a digital PID controller and a digital power supply adjustment interface. This paper summarizes the numerical analysis of high-resolution phase probe, and will give the design of digital frequency reduction phase discriminator, the core algorithm of digital controller, and the digital power control interface. A prototype has been manufactured and tested with CYCIAE-100 cyclotron, the results will also be evaluated in this paper.

MOP013 **Mechanical Modifications of the Median Plane for the Superconducting Cyclotron Upgrade**
***G. Gallo**, L. Allegra, L. Calabretta, G. Costa, E. Messina, M.S. Musumeci, D. Rifuggiato, E. Zappalà (INFN/LNS)*
The Superconducting Cyclotron (CS) is a three sectors, compact accelerator with a wide operating diagram, capable of accelerating heavy ions with q/A from 0.1 to 0.5 up to energies from 2 to 100 MeV/u. Recently a significant upgrade has been proposed to increase the light ion beam intensity by means of extraction by stripping. For the implementation of the new extraction mode, many relevant modifications are needed in the median plane. The biggest upgrade action is the replacement of the present superconducting magnet with a new one, compatible with the beam trajectory and envelope in the extraction by stripping. Of course, the extraction by stripping mode implies the installation of two stripper systems, one in a hill and the other in a valley, that allow to extract all the ions requested by the users. Finally, since the present electrostatic extraction mode will be maintained, several relevant mechanical issues have to be faced when switching from one extraction mode to the other one, the location of one electrostatic deflector being the same as the stripper system. The focus of this paper will be the presentation of the different mechanical features involved in the upgrade.

MOP014 **3-D Magnetic Optimization of the New Extraction Channel for the LNS Superconducting Cyclotron**

L. Neri, *L. Allegra, L. Calabretta, G. D'Agostino, G. Gallo, D. Rifuggiato, A.D. Russo, G. Torrisi (INFN/LNS)*

The upgrade of the Superconducting Cyclotron operating at INFN-LNS is the main objective of the general upgrade of the LNS facility, consisting in the enhancement of light ion beam intensity. To overcome the present maximum power of 100 W of the beam extracted by electrostatic deflector and achieve a beam power as high as 10 kW, the implementation of the extraction by stripping method has been proposed. Intense ion beams with mass in the range 10 to 40 amu (^{12}C, ^{18}O, ^{20}Ne, ^{40}Ar) in the energy range of interest (15-70 MeV/u) will be delivered to the NUMEN experiment, as well as used for production of in-flight radioactive beams. The present work consists in the optimization of the magnetic channels needed to limit the radial and axial beam envelopes. The design of the magnetic channels has been accomplished by fully three-dimensional magneto-static simulations using Comsol Multiphysics and a custom transport code developed in Matlab along the last year at INFN-LNS. The effect of a magnetic shielding structure in the extraction channel is presented, together with the possibility of producing a magnetic gradient from an asymmetric coil.

MOP016 **Vertical Focussing with a Field Gradient Spiral Inflector**

A.H. Barnard, *J.I. Broodryk, J.L. Conradie, J.G. De Villiers, J. Mira, F. Nemulodi, R.W. Thomae (iThemba LABS)*

Traditional spiral inflectors suffer from vertical defocussing, leading to beam loss. In this study the electrode shape of an inflector is modified to intentionally produce transverse electric field gradients, which have a significant influence on the optics. This is done by placing the traditionally parallel electrodes at an angle relative to each other in the transverse plane, creating a quadrupole field on the central path. Varying the electrode angle along the path length creates an alternating-gradient effect. The electrode entrance and exit faces are also shaped to create quadrupoles inside the fringe field. By numerical optimisation a design with good vertical focussing is obtained. Experiments show a roughly 100% increase in transmission in cases where the buncher is turned off. However, high losses at extraction are observed with the buncher turned on, due to RF-phase spread introduced by longitudinal defocussing in the inflector. This results in an improvement of only 20% during normal cyclotron operation, and shows that an inflector should ideally focus vertically and longitudinally at the same time. Ongoing work to achieve such combined focussing is described.

MOP017 **Research on Metallic Ion Beam Production With Electron Cyclotron Resonance Ion Sources**

S.L. Bogomolov, *A.A. Efremov, K.I. Kuzmenkov, D.K. Pugachev, Yu. Yazvitsky (JINR) J.L. Conradie, D.T. Fourie, N.Y. Kheswa, J. Mira, F. Nemulodi, R.W. Thomae (iThemba LABS)*

Many experiments in nuclear physics request the production of metallic ion beams. All elements from lithium up to uranium are of interest and

most of them are required as a specific isotope which demands commonly enriched materials. Depending on the material properties beams of rare isotopes can be produced from solid materials or solid compounds. In this report the results of experiments carried out under a collaboration of JINR and iThemba LABS on the production of metallic ions from Electron Cyclotron Resonance Ion Sources (ECRIS) using resistive oven evaporation, Metal Ions from VOlatile Compounds (MIVOC) method and sputtering technique will be presented.

MOP018 **Simulation of the Axial Injection Beam Line of DC140 Cyclotron of FLNR JINR**

N.Yu. Kazarinov, *J. Franko, G.G. Gulbekyan, I.A. Ivanenko, I.V. Kalagin (JINR)*

Flerov Laboratory of Nuclear Reaction of Joint Institute for Nuclear Research carries out the works under creating FLNR JINR Irradiation Facility based on the cyclotron DC140. The facility is intended for SEE testing of microchip, for production of track membranes and for solving of applied physics problems. The main systems of DC140 are based on the DC72 cyclotron ones that now are under reconstruction. The DC140 cyclotron is intended for acceleration of heavy ions with mass-to-charge ratio A/Z within interval from 5 to 5.5 up to two fixed energies 2.136 and 4.8 MeV per unit mass. The intensity of the accelerated ions will be about 1 pμA for light ions (A<86) and about 0.1 pμA for heavier ions (A>132). The injection into cyclotron will be realized from the external room temperature 18 GHz ECR ion source. The simulation of the axial injection system of the cyclotron is presented in this report.

MOP019 **The Results of Magnetic Field Formation and Commissioning of Heavy-Ion Isochronous Cyclotron DC280**

I.A. Ivanenko, *K. Gikal, G.G. Gulbekyan, G.N. Ivanov, I.V. Kalagin, V.A. Semin (JINR)*

The DC280 cyclotron is the new accelerator of FLNR Super Heavy Elements Factory. It was commissioned in the beginning of 2019. DC280 is intended for production of high intensity, up to 10 pmkA, beams of heavy ions with mass to charge ratio A/Z= 4 - 7. The wide range of accelerated ions from helium to uranium and smooth variation of extracted beam energy in the range W= 4 - 8 MeV/n are provided by varying of level of main magnetic field from 0.64 T till 1.32 T. The DC280 magnetic field was formed in a good conformity with results of computer modeling. In spite of commissioning of cyclotron still is in progress, the first experiments gave the intensity 1.35 pmkA of $^{84}Kr^{14+}$ and 10 pmkA of $^{12}C^{+2}$. At the present work the results of calculations, magnetic field measurements and first experiments are presented.

MOP020 **Simulation of the Beam Extraction System of DC140 Cyclotron of FLNR JINR**

N.Yu. Kazarinov, *G.G. Gulbekyan, I.A. Ivanenko (JINR)*

Flerov Laboratory of Nuclear Reaction of Joint Institute for Nuclear Research carries out the works under creating FLNR JINR Irradiation Facility based on the cyclotron DC140. The facility is intended for SEE testing of microchip, for production of track membranes and for solving of applied physics problems. The main systems of DC140 are based on the DC72 cyclotron ones that now are under reconstruction. The DC140 cyclotron is intended for acceleration of heavy ions with mass-to-charge ratio A/Z within interval from 5 to 5.5 up to two fixed energies 2.136 and 4.8 MeV per unit mass. The intensity of the accelerated ions will be about 1 pμA for light ions (A<86) and about 0.1 pμA for heavier ions (A>132). The beam extraction system consists of electrostatic deflector and two magnetic channels. The simulation of the extraction system of the cyclotron is presented in this report. The extracted beams characteristics outside the cyclotron, that will serve as initial conditions for the design of experimental beam lines of FLNR JINR IF are determined.

MOP021 **Simulation of Beam Extraction from TR24 Cyclotron at IPHC**

N.Yu. Kazarinov, *I.A. Ivanenko (JINR) T. Adam, F.R. Osswald, E.K. Traykov (IPHC)*

The CYRCé (CYclotron pour la ReCherche et Enseignement) TR24 cyclotron is used at IPHC (Institut Pluridisciplinaire Hubert Curien) for the production of radio-isotopes for diagnostics, medical treatments and fundamental research in radiobiology. The TR24 cyclotron produced and commercialized by ACSI delivers a 16-25 MeV proton beam with intensity from few nA up to 500 μA. The TR24 is a compact isochronous cyclotron with normal-conducting magnet and stripper foil for the beam extraction. The calculation model for OPERA 3D program code is described. The magnetic field map in the working region of the cyclotron is generated. The beam characteristics outside the cyclotron, that will serve as initial conditions for the design of future beam lines are determined.

MOP022 **System of a Novel Multi-Orbital Beam Bunching and Extraction from the U-120M Cyclotron**

M. Cihak, *R. Behal, P. Krist, T. Matlocha, J. Stursa, V. Zach (NPI)*

We introduce the bunching system for a time structure control of the U-120M cyclotron beam. The system is based on a unique pulsed vertical deflection of the selected final orbits of the internal accelerated beam of the H^- ions to an extractor-stripper (a thin carbon foil positioned below the cyclotron median plane). A set of home-made programs have been developed for simulations and parameters determination of the system. Results of some simulations (i.e. dimensions of the deflection system, parameters of the pulsed high voltage power supply, position of the stripper, beam trajectories, beam parameters, beam losses, Be target position etc.) are presented. The system will be used for fast neutron generation and consequently for spectrometric measurement of neutron energy by the time of flight (ToF) method. The system will provide beam bunch interval up to 1000 ns range of a defined beam time structure (up to beam bunch period to beam bunch width ratio min 100).

MOP023 **Synchronization and High Speed High Voltage Switcher for Pulse Bunching System of the Cyclotron U-120M**

P. Krist, *D. Poklop, J. Stursa (NPI) V. Cervenka (HiLASE Centre, Institute of Physics ASCR, v.v.i.) J. Vozáb (Radan s.r.o.)*

Pulse bunching system for neutron time of flight (ToF) measurements on the cyclotron U-120M exploits a unique pulsed vertical deflection of the selected final orbits of the internal accelerated beam of the H^- ions to an extractor-stripper. This system is described in details on an individual poster of this conference. A key device is the pulse HV power supply (HV switcher) which is supplying the deflector and elevates H^- ions in defined time structure to an extractor-stripper. The developed HV switcher is based on the SiC MOSFET transistors. It can provide HV pulses with the following pulse parameters: amplitude up to 13 kV, front edge less than 20 ns, flat top 20 ns, back edge less than 20 ns and repetition frequency up to several hundred of kHz. We have also developed the pulse synchronization with the cyclotron RF (25 MHz), which enables to set up front edge of bunching pulses within 2pi with accuracy 80 ps. Human-machine interface is based on SCADA software Reliance and PLC Tecomat Foxtrot. The time waveforms of the real pulses are part of the presentation.

MOP024 **Development of a Replacement for the Long Radial Probe in the Ring Cyclotron**

R. Dölling, *G.G. Gamma, M. Rohrer, P. Rüttimann, R. Senn (PSI)*

The long radial probe in the ring cyclotron is in operation since 1976. It can deliver a radial profile by moving a 30 um carbon fiber through all but the first seven turns at full beam current. However, in recent years the measurement has been plagued by artifacts generated from plasma, charging of surfaces and other not identified causes. In addition, the mechanical movement stalls from time to time due to an overconstrained mounting of the rails at the bending vacuum chamber. A test setup for a new probe is under preparation. Additional diagonal wires and vertically moving fingers will provide information on the vertical beam profile and halo. A phase probe is foreseen as well as electrodes to suppress the plasma locally. The concepts of measurement and mechanics will be discussed as well as aspects of cabling, vacuum, radiation hardness and shielding.

MOP025 **Fast Recharging of Electrostatic Injection or Extraction Septa**

R. Dölling *(PSI) J. Brutscher (Private Address)*

Discharges of the electrostatic injection or extraction septa of the ring cyclotron result in a beam switch off and a consecutive ramp-up of beam current in approximately half a minute (beam trip). This causes a significant fraction of the total unplanned downtime of the HIPA facility. We propose mechanisms to overcome this: After the spark and discharge of the septum, the low capacitance septum may be recharged within a millisecond from the long high voltage cable. Correspondingly, the beam is interrupted, but also lost, only for this short time. Previously, the interruptions were not seen as a significant disadvantage for most of the experiments using the beam. However, recently a damage of the target of the spallation source SINQ, to which the beam is delivered, has been observed

and it is not clear if the thermal cycling resulting from the beam trips contributed to this. The properties and use of a possible recharge setup will be discussed.

MOP026 **Field Mapping of Sumitomo Superconducting Cyclotron**
***Y. Ebara**, M. Hirabayashi, Y. Kumata, Y. Mikami, T. Morie, T. Tsurudome, H. Tsutsui, J.Y. Yoshida (SHI)*
Sumitomo Heavy Industries, Ltd. has been developing a 230 MeV, 4 T superconducting isochronous cyclotron (SC230) for a new proton therapy system. In this project, to obtain the isochronous field, a new mapping system had been developed, and magnetic field mapping was conducted. This mapping system measured the field of SC230 using six Hall probes, which were calibrated in field from 2.6 T to 6.0 T. The positions of Hall sensors were swept by a linear stage and a rotary stage. To confirm the reproducibility of the mapping, a test was conducted. In this test, the field mapping was done before and after reassembly operation. The difference between the two measured average magnetic fields was smaller than 2 gauss in all radius region. In addition, a change in the field due to machining of the pole faces was also confirmed for future reference. The field of SC230 was successfully measured using this mapping system. On the basis of the result, shimming and coils centering were completed and required isochronous field was obtained.

MOP027 **Development of a Pepper-Pot Emittance Meter for High Power Ion Beams**
***S. Nomura**, Y. Aoki, H. Kitami, Y. Mikami, T. Takahashi (SHI)*
An emittance meter based on the pepper-pot technique has been designed and tested, dedicated to high power ion beams such as 20 mA of 30 keV H^- ion beam from an ion source of boron neutron capture therapy (BNCT) cyclotron. It was specially designed for its high robustness against heat load and high accuracy in emittance measurement. For the robustness, we use a thicker copper plate for the pepper-pot mask with water-cool channels. The accuracy was investigated in terms of the hole shape (its diameter and depth) by using a GEANT4 application for tomographic emission (GATE), which is a Monte Carlo simulation platform. It was found that the measurement accuracy is increased as aspect ratio (hole diameter divided by hole depth) of the hole increased then saturated. Since the hole diameter and depth are needed to be small and thick, considering high heat input to its mask and screen, so we optimized the pepper-pot mask. As a result, the accuracy might be around 10% in the normalized 4-rms emittance range 0.7 to 1.8 pi mm-mrad.

MOP028 **Design of 5.8 MHz RF Electrode for AMS Cyclotron**
***D.H. Ha**, J.-S. Chai, M. Ghergherehchi, H.S. Kim, J.C. Lee, H. Namgoong (SKKU)*
Accelerator Mass Spectrometry (AMS) is a powerful method for separating isotopes, and electrostatic tandem accelerators are widely used for AMS. Sungkyunkwan University is developing AMS that can be used in a smaller space based on cyclotron. Unlike conventional cyclotrons used in PET or proton therapy, cyclotron-based AMS provides high turn number and high

resolution. In this study, we proposed a cavity with a frequency of 5.8 MHz and an accelerating voltage of 300 V to accelerate the particles in the cyclotron. The proposed cavity was designed as an electrode and verified by CST Microwave studio.

MOP029 **Design and Manufacture of 10 kW, 83.2 MHz 4-way Power Combiner for Solid State Amplifier**

***D.H. Ha**, J.-S. Chai, M. Ghergherehchi, H.S. Kim, J.C. Lee, H. Namgoong (SKKU)*

The purpose of this study is to improve the insertion loss of a 20 kW solid-state RF power amplifier and the power coupling efficiency by reducing reflected power. For this purpose, a power combiner, which is a core component of a solid-state RF power amplifier, was designed and fabricated. The 4-way power combiner employs the Wilkinson type, which has excellent power coupling efficiency and isolation, and operates at 83.2 MHz. This paper covers the design and cold test results.

MOP030 **Cold Test of RF Cavity for 10 MeV Cyclotron**

***J.C. Lee** (SKKU)*

The 10 MeV cyclotron was designed for next version in Sungkyunkwan University, after the SKKUCY-9 had developed for medical application for PET. The RF cavity, which generates the electric field in cyclotron, was designed based on a half-wavelength resonator and optimized to improve the unloaded quality factor. The design specifications of RF cavity were resonance frequency 83.2 MHz, Q_0 5830 and dee voltage 40 kV with geometrical values resonator length 560 mm, dee angle 35° and stem radius 16 mm. The RF cavity of the SKKUCY-10 was fabricated and installed inside the electromagnet, and RF characteristics were measured with a network analyzer. The resonance frequency, coupling coefficient and characteristic impedance were measured at 83.2 MHz, 0.98 and 50 ohm, respectively. The resonance frequencies were measured according to temperature as 15-21°C, and the values was analyzed 6.5 kHz/°C. The tuning range of resonance frequency was achieved ±0.5 MHz according to the position of the fine tuner.

MOP031 **Design of High Sensitive Magnet and Beam Dynamics for AMS Cyclotron**

***H. Namgoong**, J.-S. Chai, M. Ghergherehchi, D.H. Ha, H.S. Kim, J.C. Lee (SKKU)*

To produce a carbon-14 for Accelerator Mass Spectrometry (AMS), AMS Cyclotron magnet was designed. For the AMS system, Cyclotron magnet has been required high mass resolution. In order to realize high mass resolution, the phase error is designed within ±10 and the mass resolution was 5000. We used CST particle studio and Cyclone for beam dynamics simulation of this cyclotron magnet. This paper describes the AMS cyclotron magnet and beam dynamics design.

MOP032 **Control System in 10 MeV Cyclotron Based on IoT**

***M. Mohamadian**, H. Afarideh, S. Babaee, H. Pashaei, N. Salmani (AUT) , M. Ghergherehchi (SKKU)*

The Internet of Things (IoT) is one of the new most advanced technologies in the world. One of the application of this technology is using it in

places where remote control is preferred or it needs to control various processes at different times throughout the day. The cyclotron accelerator is one such system in which the start-up process until radio medicine production requires continuous monitoring and inspection. In this research, we have tried to use the internet of things technology in the process of cyclotron control system specially in fine tuning section.

MOP033 **Basic Design of a Modular RF Power System for a 10 MeV Cyclotron**
***F. Babagoli Moziraji**, H. Afarideh (AUT) M. Dehghan (Shahid Beheshti University), M. Ghergherehchi (SKKU)*
In this paper, the basic design of an RF power source for a 10 MeV cyclotron accelerator is presented. The source can generate 15 kW (CW) power at the operating frequency of 71 MHz using solid state power amplifiers. The authors provide a step-by-step explanation of the design process. It is carried out in three sections; (1) RF design characteristics of the cyclotron power calculation, (2) using of solid state modular amplifiers as the main RF power source (3) development of novel RF high power combiners. The purpose of the design is to achieve the best performance of the RF system, as well as decreasing overall size by using modular SSPAs.

MOP034 **Beam Stripping Interactions Implemented in Cyclotrons with OPAL Simulation Code**
***P. Calvo**, C. Oliver (CIEMAT) A. Adelmann, M. Frey, A. Gsell, J. Snuverink (PSI)*
Beam transmission optimization and losses characterization, where beam stripping interactions are a key issue, play an important role in the design and operation of compact cyclotrons. A beam stripping model has been implemented in the three-dimensional object-oriented parallel code OPAL-cycl, a flavor of the OPAL framework. The model includes Monte Carlo methods for interaction with residual gas and dissociation by electromagnetic stripping. The model has been verified with theoretical models and it has been applied to the AMIT cyclotron according to design conditions.

MOP035 **Design of Beam Orbit on Extraction of 250 MeV Superconducting Cyclotron**

H.J. Zhang*, K. Fan, Y. Yan (Huazhong University of Science and Technology, State Key Laboratory of Advanced Electromagnetic Engineering and Technology,) Y.-N. Rao (TRIUMF) L.G. Zhang (HUST)*

A superconducting cyclotron based on proton therapy facility is being developed at Huazhong university of science and technology. Due to the compact size of the main magnet, the beam orbits at the extraction region are distributed densely, which creates difficulties for beam extraction leading to severe beam loss. In order to deal with these challenges, the orbit precession method has been employed in the extraction system design. In this paper, we introduce a method of employing a first harmonic field near the nu_r=1 resonance where the beam energy is about 249 MeV to adjust the amplitude of beam orbit oscillation. The optimum amplitude and phase of the first harmonic field are designed to obtain a large turn separation in the extraction region. Three different ways of generating the first harmonic field are compared for optimization.

MOP036 **The Magnetic Field Design of Cyclotron at IMP**

Q.G. Yao *(IMP/CAS)*

A cyclotron magnet is studied at Institute of Modern Physics, Chinese Academy of Sciences (IMP, CAS), and the whole magnet system include one main magnet, and other magnetic gradient correctors, which is used to accelerate the Kr26-beam. The structure of superconducting coils and room-temperature iron core is adopted for the main magnet. This paper describes the magnetic field design of the cyclotron, and several shimming methods are used to meet the isochronous magnetic field of Kr26-beam, including pole face shimming method and side shimming method. The final optimization results show that the error between simulation and theory value is small.

MOP037 **The New Lines for the High Power Beams of the LNS Super-Conducting Cyclotron**

L. Calabretta*, G. D'Agostino, L. Neri, D. Rifuggiato, A.D. Russo (INFN/LNS)*

The LNS Superconducting Cyclotron will be modified to allow for the extraction by stripping of ion beams with power up to 10 kW. A new extraction line has been designed to transport these beams and match the acceptance of the existing beam transport line. The extracted beams should have an energy spread lower than ±0.4% so the new extraction line has to compensate the correlation energy-position of the beam and produce an achromatic waist of the beam at the common starting point of the existing transport lines. The experiment NUMEN is the main user of the high power beams. The beam after impinging on the target and crossing the spectrometer MAGNEX has to be transported to a well shielded beam dump. Stable beams with power of few kW will be used to produce in-flight radioactive beams by means of the Fragment Separator FRAISE. This line section will be used also to reduce the energy spread of stable beams down to 0.1%, as requested by the NUMEN experiment. The beam optics features of all the described beam lines will be presented.

MOC — Cyclotron Technology, Ion Sources and Upgrades

Chair: P.M.T. Heikkinen (JYFL)

MOC01 16:00 30 **Moving the Frontiers of the Production of Intense Beams of Highly Charged Ions With ECR Ion Sources**

L.T. Sun *(IMP/CAS)*

Electron Cyclotron Resonance (ECR) ion source has always been regarded as the most powerful machine to produce intense highly charged ion beams, which is essentially important for the development of heavy ion cyclotrons and linacs. Worldwide ECR ion source development has stepped into the era of 4th generation that needs to solve series of technical and physics problems. Nevertheless, the 3rd generation ECR ion sources are still the most advanced machines to produce very intense highly charged ion beams, such as 0.66 emA Ca^{12+}, 1.4 emA Ar^{12+}, 0.8 emA Xe^{27+}, 16.7 eμA Xe^{42+}, 0.68 emA Bi^{31+}, 3 eμA Bi^{56+}, 400 eμA U^{34+} and so on. These results can obviously improve the existing heavy ion facilities performance and have fundamental impact to the development of future facilities as well. This paper will review the worldwide achievements on high performance ECR ion source development in recent years.

MOC02 16:30 20 **A Pathway to Accelerate Ion Beams up to 3 GeV with a K140 Cyclotron**

D.Z. Xie*, L. Phair, D.S. Todd (LBNL)*

The capabilities of the K140 88-Inch Cyclotron at Lawrence Berkeley National Laboratory (LBNL) have been extensively enhanced through generations of electron cyclotron resonance ion sources (ECRISs). The cyclotron has evolved from a light-ion accelerator into a proton to uranium accelerator and has accelerated ultra-high charge state heavy ions, such as xenon and uranium. Recently, with $^{124}Xe^{49+}$ ions injected from VENUS (a 3rd generation ECR ion source) the 88-Inch Cyclotron reached a new record of ~ 2.6 GeV. This is an energy increase of about fifteen-fold over what this K140 cyclotron could achieve when it started operation almost six decades ago. A 4th generation ECR ion source, MARS-D, is under development and will further raise the output energy of the cyclotron. With the higher ion charge states produced that are anticipated with a new ECR ion source, the 88-Inch Cyclotron ought to be able to accelerate ion beams of energies of 3 GeV and higher for the radiation effects testing community. This paper will present and discuss the development of the MARS-D ECR ion source and the 88-Inch Cyclotron's recent and possible future achievements.

MOC03
16:50 20

Upgrade of the PSI Injector 2 Cyclotron

***M. Schneider**, J. Grillenberger (PSI)*

The high intensity proton accelerator facility at PSI is capable of providing beam currents of up to 2.4 mA at a kinetic energy of 590 MeV. PSI is following an upgrade plan to further increase the beam power and to further minimize proton losses. Up to now, this has mainly been achieved by the installation of high gradient copper resonators in the Ring cyclotron and the installation of more powerful RF-amplifiers. Currently, PSI follows a similar approach for the Injector 2 cyclotron providing 72 MeV protons for the injection into the 590 MeV Ring cyclotron. In order to increase the turn separation in the injector cyclotron which results in lower relative beam losses, the two 150 MHz resonators operated in accelerating mode are replaced with two 50 MHz Aluminum resonators providing higher acceleration voltage. This paper describes the status of the upgrade, i.e., the replacement of the first resonator and related hardware.

TUA — Cyclotron Applications: Isotopes

Chair: H. Schweickert (ZAG)

TUA01 08:30 30 **Radioisotopes Production in Accelerators & Cyclotrons Use**

J.-M. Geets *(IBA)*

The production of important medical radioisotopes mainly started with particle accelerators but, shortly after, some of them where totally forgotten due to the availability of nuclear reactors. SPECT isotopes where available in limited quantities with the first high energy positive ions machine; around 1985, the evolution of particle accelerator and the discovery of powerful negative ions cyclotron led to the creation of new companies. In the 1990's, new compact and automated cyclotrons were instrumental in the development of PET radioisotopes (mainly ^{18}F). Target design followed the beam power increase of such medium energy cyclotron as well as the need for new radioisotope with solid target. Recently, some companies are proposing very small cyclotrons for 'on the spot' production at the point of use. There was revival of studies of Tc99m production with cyclotrons while some industrial players are looking at electron accelerators to produce the mother isotope Mo-99.The future seems bright for medical radioisotopes production with the replacement of old multi-particle or high energy accelerators by modern cyclotrons; there are new worldwide network of 30 & 70 MeV.

TUA02 09:00 20 **Novel Irradiation Methods for Theranostic Radioisotope Production With Solid Targets at the Bern Medical Cyclotron**

S. Braccini *(LHEP) C. Belver-Aguilar, T.S. Carzaniga, G. Dellepiane, P. Haeffner, P. Scampoli (AEC) P. Scampoli (Naples University Federico II)*

The production of medical radioisotopes for theranostics is essential for the development of personalized nuclear medicine. Among them, radiometals can be used to label proteins and peptides and their supply in quantity and quality for clinical applications represents a challenge. A research program is ongoing at the Bern medical cyclotron, where a solid target station with a pneumatic delivery system is in operation. To bombard isotope-enriched materials in form of compressed powders, a specific target coin was realized. To assess the activity at EoB, a system based on a CZT detector was developed. For an optimized production yield with the required radio nuclide purity, precise knowledge of the cross-sections and of the beam energy is crucial. Specific methods were developed to assess these quantities. To further enhance the capabilities of solid target stations at medical cyclotrons, a novel irradiation system based on an ultra-compact ~50 cm long beam line and a two-dimensional beam monitoring detector is under development to bombard targets down to few mg and few mm diameter. The first results on the production of Ga-68, Cu-64, Sc-43, Sc-44 and Sc-47 are presented.

TUA03 09:20 20 **The Use of PSI's IP2 Beam Line Towards Exotic Radionuclide Development and its Application Towards Proof-Of-Principle Preclinical and Clinical Studies**

***N.P. van der Meulen**, R. Eichler, W. Hirzel, S. Joray, D.C. Kiselev, R. Sobbia, A. Sommerhalder, Z. Talip, H. Zhang (PSI) S. Braccini (AEC)*

Paul Scherrer Institute runs a High Intensity Proton Accelerator (HIPA) facility, where a maximum of 100 μA protons is gleaned from high intensity 72 MeV protons from Injector 2, a separated sector cyclotron, into the IP2 target station. These protons irradiate various targets towards the production of exotic radionuclides intended for medical purposes. Many radiometals in use today are for the diagnosis of disease, with the most popular means of detection being Positron Emission Tomography. These positron emitters are easily produced at low proton energies using medical cyclotrons, however, development at these facilities are lacking. The 72 MeV proton beam is degraded at IP2 using niobium to provide the desired energy to irradiate targets to produce the likes of ^{44}Sc, ^{43}Sc, ^{64}Cu and ^{165}Er. Once developed, these proofs-of-principle are then put into practice at partner facilities. Target holders and degraders require development to optimize irradiation conditions and target cooling. Various options are explored, with pros and cons taken into consideration based on calculations and simulations.

TUA04 09:40 20 **Characterization of Neutron Leakage Field Coming from ^{18}O(p,n)^{18}F Reaction in PET Production Cyclotron**

***M. Schulc** (Nuclear Research Institute Řež plc) Z. Matej (Masaryk University)*

This paper shows a new method for characterization of the secondary neutron field quantities, specifically neutron spectrum leaking from ^{18}O enriched H_2O XL cylindrical target in IBA Cyclone 18/9 in the energy range of 1-15 MeV. Spectrum is measured by stilbene scintillation detector in different places. The neutron spectra are evaluated from the measured proton recoil spectra using deconvolution through maximum likelihood estimation. A leakage neutron field is an interesting option for irradiation experiments due to quite high flux, but also to the validation of high energy threshold reactions due to relatively high average energy. Measured neutron spectra are compared with calculations in MCNP6 model using TENDL-2017, FENDL-3, and default MCNP6 model calculations. TENDL-2017 and FENDL-3 libraries results differ significantly in the shape of the neutron spectrum for energies above 10 MeV while MCNP6 gives incorrect angular distributions. Activation measurements of different neutron induced reactions support characterization. The 18F production yield is in a good agreement with TENDL-2017 proton library calculation within respective uncertainties.

TUA05
10:00 20

Vanadium-48 Production Yield Investigation Using TiO_2 Nano Powder Targets

***M. Ghergherehchi**, J.-S. Chai (SKKU) H. Afarideh (AUT)*

Vanadium-48 (t1/2=15.98d) has been considered as a cyclotron radiopharmaceutical for PET applications. In this research, Vanadium-48 has been produced through the proton bombardment of the natural TiO_2 Nanopowder (50 nm, 99.9%) target via natTi(p,xn)48V reaction using a 30 MeV cyclotron by developing an aluminium disc targetry. The titanium target was irradiated by 10 μA current with 16 MeV proton beam energy. Obtained activity of ^{48}V was compared with calculated theoretical activity for the thick targets. Moreover, ^{48}V production yields were investigated to evaluate of Nano-size materials effects on the yield of production. Resulted data show good agreement between experimental and calculated values, and also Nano-size materials effects as well.

TUB — Cyclotron Applications: Medical

Chair: A. Denker (HMI)

TUB01 10:50 20

Status of the Development of a Fully Iron-free Cyclotron for Proton Beam Radiotherapy Treatment

D. Winklehner *(MIT) L. Bromberg, J.V. Minervini, A. Radovinsky (MIT/PSFC)*

Superconducting cyclotrons are increasingly employed for proton beam radiotherapy treatment. The use of superconductivity in a cyclotron design can reduce its mass by an order of magnitude and size by a factor of 3-4 over conventional resistive magnet technology, yielding significant reduction in overall cost of the device, the accelerator vault, and its infrastructure. In the presented work, we go a step further and remove the iron yoke, generating the magnetic field with a combination of superconducting coils only. Eliminating the iron yoke has two key benefits. First and foremost, the overall weight can be reduced by almost another order of magnitude. Secondly, eliminating all magnetic iron from the flux circuit results in a linear relationship between field and coil current, which allows smooth scaling of the magnetic field and thus the output energy, thereby removing the need for a degrader. Here we describe the status of the design of such an iron-free cyclotron, currently under development at the Plasma Science and Fusion Center at MIT, with coil and cryostat calculations as well as beam dynamics studies and treatment plan considerations pertaining to this type of cyclotron.

TUB02 11:10 20

SC230 Superconducting 230 MeV Proton Cyclotron for Therapy

O. Karamyshev*, S. Gurskiy, G.A. Karamysheva, D.V. Popov, G. Shirkov, S.G. Shirkov, V.L. Smirnov, S.B. Vorozhtsov (JINR) V. Malinin (JINR/DLNP)*

A 230 MeV cyclotron is under development in DLNP JINR (Dubna, Russia) and ASIPP (Hefei, China). The cyclotron is designed to be a simple and reliable machine, however despite its low magnetic field remains compact and lightweight.

TUB03 11:30 20

MRI-Guided-PT: Integrating an MRI in a Proton Therapy System

E. Van Der Kraaij*, J. Smeets (IBA) L. Bertora, A. Carrozzi, A. Serra (ASG) S. Gantz, A. Hoffmann, L. Karsch, A. Lühr, J. Pawelke, S. Schellhammer (OncoRay) B. Oborn (CMRP)*

Integration of magnetic resonance imaging (MRI) in proton therapy (PT) has the potential to improve tumor-targeting precision. However, it is technically challenging to integrate an MRI scanner at the beam isocenter of a PT system due to space constraints and electromagnetic interactions between the two systems. We assessed the technical risks and challenges, and present a concept for the mechanical integration of a 0.5T MRI scanner (ASG MR-Open) into a PT gantry (IBA ProteusONE). Finite element simulations assess the perturbation of the gantry's elements on the homogeneity of the scanner's static magnetic field. MC simulations estimate the effect of the scanner's magnetic field on the proton dose deposition. To test the technical feasibility, a first experimental setup was realized at the PT center in Dresden, combining a 0.22T open MRI scanner with a static

proton beam line. Results show that the image quality is not degraded by proton beam irradiation if the acquisition is synchronized with beam line operation. The beam energy dependent proton beam deflection due to the scanner's magnetic field is significant and needs to be corrected for in treatment planning and dose delivery.

TUB04
11:50 20

On-Line Dynamic Beam Intensity Control in a Proton Therapy Cyclotron
S. Psoroulas, *P. Fernandez Carmona, D. Meer, D.C. Weber (PSI) D.C. Weber (University of Zurich, University Hospital)*

Modern proton therapy facilities use the pencil beam scanning (PBS) technique for the treatment of tumours: the beam is scanned through the tumour volume sequentially, i.e. stopping the beam at each position in the tumour for the amount of time necessary to deliver the prescribed dose for that position, and then moving to the next position (dose-driven delivery). This technique is robust against fluctuations in the beam current. Modern cyclotrons however offer very stable beam currents, and allow regulating the beam intensity online to match the requested beam intensity profile as a function of time ('time-driven' delivery). To realise time-driven delivery at the COMET cyclotron at PSI, we have designed a beam intensity controller which is able to partially compensate for the non-linearity and the delay introduced by the physical limitations of the beam line elements and its drivers; this is particularly important when trying to achieve a very fast modulation of the beam, as required by the clinical plans. Experimental results have shown good performance for most current clinical scenarios, though we are investigating more advanced solutions for higher dose rates scenarios.

TUP001 **Beam Dynamics Code Development for High Power Cyclotron**
***S. Shin**, G. Hahn, T.-Y. Lee, B.H. Oh (PAL) M. Chung (UNIST)*
This presentation describes the development of a beam dynamic simulation code for a cyclotron. Starting from a description of beam dynamics, lattice functions were determined and the solutions for the 2nd order nonlinear Hamiltonian were revised. Based on the description of the beam dynamics in the cyclotron, a simulation code was also developed for cyclotron design. In addition, we also introduce the plan to study high power cyclotrons.

TUP002 **Conceptual Design Study of K911 Superconducting Cyclotron for Helium Ion Therapy**
***G. Hahn**, S. Shin (PAL) S. Hahn, J. Park (SNU)*
As an alternative solution to the typical proton or carbon therapy, we compared radio-biological properties of helium ions to others, estimated a specification of accelerator and beam, and designed a magnet of a superconducting cyclotron for helium ion therapy. A maximum acceleration energy was calculated by using Geant4 and a beam current requirement of the ion source was estimated by applying the conventional beam transmission ratio of a cyclotron and an energy selection system. Finally an isochronous superconducting cyclotron magnet was designed, calculated by using Opera3D and evaluated by a 3D particle tracking code. The HTS coil was considered and a heat load caused from neutral particles generated by the beam loss was calculated.

TUP003 **Design of a 4-Way Radial Gysel Power Combiner With High Isolation at 71 MHz for Irancyc-10 Accelerator**
***M. Dehghan**, F. Abbasi (Shahid Beheshti University) H. Azizi (ILSF) F. Ghasemi (NSTRI)*
Power combiners are commonly used in accelerators RF power system. Gysel combiner, is able to handle of 10 kW continuous wave power. In the paper a 4-way Gysel power combiner is proposed as a modification of the common 2-way Gysel combiner for Irancyc10 cyclotron at 71 MHz. The combiner has several advantages such as high power-handling capability due to the external resistors, decreasing in occupational size by using of the meandered rectangular coaxial transmission line and high isolation among its output ports. Full wave electromagnetic and thermal simulations performed in HFSS and ANSYS. The combiner, had an overall loss of 0.3 dB at operation frequency, input port return loss and output isolation better than -30 dB.

TUP004 **Integration of EtherCAT Hardware Into the EPICS Based Distributed Control System at iThemba LABS**
***J.K. Abraham**, W. Duckitt (iThemba LABS)*
iThemba Laboratory for Accelerator Based Sciences (iThemba LABS) has, over the past 30 years, carried out several upgrades to its control electronics and software. This culminated in the adoption of EPICS as the defacto distributed control system at the lab. In order to meet the chang-

ing technology and user requirements, iThemba LABS adopted EtherCAT as its new industrial communication standard. Building on an open EtherCAT master implementation and prior community development, iThemba LABS has successfully integrated a variety of EtherCAT hardware into its EPICS control system. This paper presents the open source software toolchain that has been developed and is used at iThemba LABS and showcases several hardware installations at the facility and abroad. Community involvement and future plans for this initiative are also presented.

TUP005 **Three Years Operation of CYCIAE-100**

***T. Ge**, L.C. Cao, Z.H. Fu, S.G. Hou, B. Ji, H. Jiang, S.Q. Li, Y.Q. Li, Z.W. Liu, Y.L. Lv, G.F. Pan, L. Wang, L.P. Wen, Z.G. Yin, T.J. Zhang (CIAE)*

The 100 MeV high intensity proton cyclotron (CYCIAE-100) developed by China Institute of Atomic Energy is a multi-purpose variable energy AVF cyclotron. Its design specifications are: energy from 75 to 100 MeV continuously adjustable, beam intensity 200 μA, beam current can be extracted in both directions. CYCIAE-100 was commissioned to extract 100 MeV proton beam for the first time in July 2014. The first physics experiment was carried out in November 2016. By June 2019, the design specifications of CYCIAE-100 was commissioned and the maximum beam power was 52 kW. The beam intensity range from 1 pA to 520 μA is achieved, and the beam stability is about 1% for 8 hours. Several typical physics experiments have been carried out. Such as: The physics experiment of CYCIAE-100 driving ISOL device to generate radioactive nuclear beam, SiC and SRAM proton irradiation experiments, calibration experiment of high-energy proton electron total dose detector probe, etc. At present, the beam time for CYCIAE-100 is about 5,000 hours, providing effective beam time for more than 3,000 hours for many users at home and abroad, and the other beam time for beam development.

TUP006 **The Injection and Chopper-Based System at Arronax C70XP Cyclotron**

***F. Poirier**, F. Bulteau-harel, X. Goiziou, C. Koumeir, H. Trichet (Cyclotron ARRONAX) G. Blain, M. Fattahi, F. Haddad, J. Vandenborre (SUBATECH)*
***F. Poirier** (CNRS - DR17)*

The multi-particle cyclotron of the Arronax Public Interest Group (GIP) is used to perform irradiation up to hundreds of μA on various experiments and targets. To support low and high average intensity usage and adapt the beam time structure required for high peak intensity operation and experiments such as pulsed experiments studies, it has been devised a pulsing system in the injection of the cyclotron. This system combines the use of a chopper, low frequency switch, and a control system based on the new extended EPICS network. This paper details the pulsing system adopted at Arronax, updates and results for various intensity experimental studies performed with alpha and proton beams. Updated work on the simulation of the injection is also shown, specifically towards high intensity future irradiation.

TUP007 **Operational Experience in the Treatment of Ocular Melanomas with a new Digital Low-level RF Control System**

T. Fanselow, *J. Bundesmann, A. Denker, U. Hiller (HZB) J.K. Abraham, J.L. Conradie, W. Duckitt (iThemba LABS)*

Ocular melanomas have been treated for the last 20 years at the Helmholtz-Zentrum Berlin in collaboration with the Charité Universitätsmedizin Berlin. However, parts of the initial control system electronics date back to the 1970s, when the machine was installed. Facing a critical shortage of legacy and obsolete components and with the downtime due to failures in the electronics on the increase, a decision was made to install the digital low-level RF control system, developed by iThemba LABS, on our K=132 cyclotron. A short description of the installation and commissioning process, which occurred in April 2017, and the experiences of the first 2 years of operation with the new digital low-level RF control system is presented.

TUP008 **The Cyclotron TR-FLEX at the Center for Radiopharmaceutical Cancer Research at Helmholtz-Zentrum Dresden-Rossendorf**

M. Kreller, *T. Knieß (HZDR) S. Preusche (Helmholtz-Zentrum Dresden-Rossendorf)*

The new Center for Radiopharmaceutical Cancer Research was established at Helmholtz-Zentrum Dresden-Rossendorf e.V. to centralize the main units: a high current proton cyclotron, a radiopharmaceutical production – GMP unit including quality control, laboratories for PET-radiochemistry, chemical and biochemical laboratories and laboratories for small animal imaging. The cyclotron TR-Flex was put into operation in 2017 and it is equipped with two extraction ports. Both are movable to adjust the proton energy in the range from 15 MeV up to 30 MeV. One extraction port is coupled with a combination magnet and two beam lines. A [^{123}I]I-gas target station is installed at the first beam line and a four-port target selector at beamline two and at the second extraction port. Two [18F]F-water targets, a [^{18}F]F2-gas target, a [^{11}C]CH_4-gas target, a [11C]CO_2-gas target, a 30° and a 90° solid state target are mounted on the target selectors. In our contribution we report our experience of the new cyclotron during the first two operation years. Typical beam parameters and the reliability of the TR-FLEX are presented. Furthermore we describe the new home-built Radionuclide Distribution System.

TUP009 **Cyclotron Cavity Pollution Recovery**

J. Dabin, *P. Cailliau (IBA)*

In a cyclotron, RF cavities are usually among the most reliable subsystems, provided minimal care and maintenance. Nevertheless, several parameters may affect cavity performance after several years of operation. To name a few typical causes of degradation are: decreasing vacuum quality, various gas loads or gas qualities triggering adverse effects, deposition of highly emissive material on the cavity due to overheating of components like pass-through connectors, accidental use of chemicals or not-suitable greases. The cavity status can be monitored but, in the worst cases, the RF tuning may become difficult and it is important to apply methods in

order to recover a better cavity Q-factor. In this paper, cases of cavity pollution will be shown, their potential root causes discussed and some recovery methods described.

TUP010 **Buncher for the Optimization of the Injection of a 70 MeV Cyclotron**
***P. Antonini**, A. Lombardi, M. Maggiore, L. Pranovi (INFN/LNL) L. Buriola (Univ. degli Studi di Padova)*
The design of an injection buncher for the 70 MeV cyclotron in use at LNL labs of INFN is under way. This buncher is to be installed between the ion source and the injection, to match the injected beam to the acceptance angle of the injection. The planned design is a 3/2 β-λ double-gap driven with one or two harmonics of the 56 MHz RF frequency. Remotely-driven variable capacitors will be used for easy tuning of the matching box from the control system. The mechanical layout and simulations will be presented.

TUP011 **Upgrade of the Central Region of the Superconducting Cyclotron at INFN-LNS**
***G. D'Agostino**, L. Calabretta, D. Rifuggiato (INFN/LNS) W.J.G.M. Kleeven (IBA)*
The Superconducting Cyclotron (CS) at INFN-LNS is regularly operated with beam power up to 100 W. The present efforts in upgrading the cyclotron are directed towards an increase of beam power up to 10 kW for ions with mass number A < 40 and energies between 15 and 70 AMeV by means of beam intensity increase. Moreover, a beam energy spread of 0.1% FWHM is requested by the NUMEN experiment at INFN-LNS. We plan to achieve high beam power by increasing the efficiency of the injection and extraction processes. The current extraction efficiency is about 60%. We expect to increase it to a value close to 100% by extracting the specific ion beams by stripping and no longer by electrostatic deflectors. A spiral inflector is used to bent onto the median plane the ion beams produced by the two ECRIS. Including the effect of a drift buncher placed in the axial injection line, the current injection efficiency stays around 15%. The study of an upgraded CS central region is ongoing at INFN-LNS. Beam tracking up to the extraction system is also considered to evaluate the beam energy spread at the extraction. The paper presents the preliminary results of computational simulations of this study.

TUP012 **Upgrade of the iThemba LABS Neutron Beam Vault to a Metrology Facility**
***N.B. Ndlovu**, P.P. Maleka, F.D. Smit (iThemba LABS) , P.P. Maleka (iTL-NMISA-UCT-PTB-IRSN-NPL, Collaboration Team)*
Quasi-monoenergetic neutron beams are produced at iThemba LABS facility by the Li(p,xn) reaction. With the proton beams available from the separated sector cyclotron, the neutron energy range from about 30 MeV to 200 MeV can be covered almost continuously. This facility has been designated by the NMISA as an entity responsible for providing traceability for the medium and high-energy neutron measurements in South Africa. The facility first became operational in the late 1980s. Plans are underway to install proton monitors in the beamline to provide continuous informa-

tion about the proton beam spot during experiments and to install neutron beam collimators with an optimized conical shape. In addition, to reduce the effect on epithermal background, Monte Carlo (MC) simulations are being conducted to provide an optimized configuration with respect to neutron beam profile and neutron background in the experimental area.

TUP013 **Ione Cyclotron for Radiopharmaceuticals Production and Research**
S.M. Miliebari *(King Faisal Specialist Hospital and Research Centre)*
The radio pharmaceuticals production and distribution facility at King Abdul Aziz University , Jeddah, Saudi Arabia, "Ione" ; started with FDG production using PETtrace 880 cyclotron. The facility designed with production expansion for more tracers with spacious labs and a second cyclotron bunker for uninterrupted and reliable operation. ITEL from ITALY, doing the operation until our trained staff are ready. The facility accessible by University faculty for research and development as well as training. We will explain the facility components, design and activities which cover radioisotopes and radio pharmaceuticals production and distribution in addition to research, training, and advisory services.

TUP014 **Deflecting System Upgrade Initial Simulations for 37 MeV Cyclotron at NPI Řež**
T. Matlocha *(NPI)*
NPI Řež U-120M multi-particle variable energy cyclotron system for positive particles extraction consists of three electrostatic deflectors, one active magnetic channel and an electromagnetic bump exciter. The deflectors transmission ratio for deuterons, alpha particles and Helium 3 ions is rather low, usually about 10%, for protons it is far below 5%. Based on experience from other cyclotron laboratories, the general concept of the extraction system has been modified. The last two electrostatic deflectors were replaced with two magnetic channels. In the early stage of the upgrade, simulations were performed for protons at 28 MeV and Helium 3 at 44 MeV without the magnetic bump exciter. The extraction efficiency and beam losses along the extraction path are evaluated. The presented modified extraction system simulations suggest promising results. The total transmission ratio of the deflecting system has increased significantly, allowing work to continue and expect a positive final result. However, questions remain about the ideal final concept.

TUP015 **First Results of a Beam Ellipticity Monitor at HIPA**
P.-A. Duperrex*, E. Johansen (PSI)*
A Beam Ellipticity Monitor (BEM) has been developed and installed on the high energy 590 MeV beam line of the High Intensity Proton Accelerator (HIPA) at PSI. The purpose of this prototype has been to evaluate the possibility to monitor the beam current, position and ellipticity of the proton beam using a single system. It is made of 8 magnetic poloidal pickups that measure the 2nd harmonic of the signal induced by the beam current. This paper presents the BEM design, its implementation on the machine and the results obtained during the first year in operation. Future developments based on this prototype will also be discussed.

TUP016 **New Monitor for High Power Proton Beam Centering on Target**

***P.-A. Duperrex**, P. Baumann, D.C. Kiselev, D. Reggiani (PSI)*

The high intensity proton accelerator (HIPA) at the Paul Scherrer Institut (PSI) delivers 590 MeV c.w. proton beam with currents of up to 2.4 mA, i.e. 1.4 MW beam power, For experiments of nuclear and material research the beam is directed to the 4 or 6 cm graphite 1 Hz rotating target (Target E). Centering the beam on the target is an important task for the operation and has safety issues if the beam does not follow the calculated beam optics. Transmission monitoring has been the standard method to optimize the beam position, though not very sensitive. A new method is currently being tested that provides more sensitive off-axis detection method. It consists of grooves that are milled at each side of the target. Beam current measurements after the target may detect these groove modulations that reveal how much off-axis the beam is. Concept and experimental results will be presented.

TUP017 **Manufacturing and Commissioning of Cyclotrons in a Series Production at Varian**

***O. Boldt**, M. Eichel, S. Lucht, L. Netterdon, A. Roth, M. Seher, M. Wiesner (VMS-PT) , T. Stephani (Varian Medical Systems Particle Therapy GmbH)*

On 16th March 2019, Varian celebrated the 10th anniversary of first patient treatment in the Munich Proton Center, Germany. Since the first cyclotron installation, 22 more 250 MeV superconducting isochronous proton cyclotrons have successfully been manufactured, commissioned, and tested in our Troisdorf production line. During this process, an increasing experience with the cyclotron's internal mechanisms and underlying physics allowed for a nowadays significant faster commissioning lead time without having changed the hardware setup substantially. Furthermore, we can already verify full clinical performance of each cyclotron in the factory test cells before delivery to the customer. Essential improvements in the areas of qualification of magnetic field configuration, RF conditioning, and beam commissioning are presented.

TUP018 **Design of Gas Target for Medical Cyclotron**

***G. Yang**, X.L. Jia, G.F. Song, F. Wang, F. Wang (CIAE) R.R. Johnson (UBC)*

A small cyclotron (CYCIAE-14) with extraction 200 μA/14 MeV for medical isotope production has been developed at CIAE, which has two extraction pipes with four target stations. The cyclotron is mainly used for the production of C-11, O-15, N-13, F-18 and other commonly used medical isotopes. According to the requirements of cyclotron, this paper mainly introduces the design of the gas target system suitable for the production of C-11 isotope drugs. According to the beam energy, intensity, envelope size and other factors, the target is designed as 150 mm length and 13 mm to 15 mm diameter of the two ports with 200 PSI calculation. The cooling is designed with the maximum beam power of 1.4 kW. This paper also introduces the mechanical structure design of the gas target, including material, pressure resistance, sealing and other design considerations. At present, the design and fabrication of the gas target has been completed, and relevant experimental studies are being carried out on the CYCIAE-14. The experimental results will also be shown in this paper.

TUP019 **Recent Extensions of JULIC for HBS Investigations**

***O. Felden**, R. Gebel (FZJ)*

At the Forschungszentrum Jülich (FZJ) the energy variable cyclotron JULIC is used as injector of the Cooler Synchrotron (COSY) and for low to medium current irradiations of different types. Recently a new target station was set up and is mainly used for tests of new target materials, neutron target development and neutron yield investigations with high power proton or deuteron beam in perspective of a high brilliance accelerator based neutron source (HBS) with the Jülich Center for Neutron Science. The neutrons are produced exposing material targets or compounds to proton or deuterium particles of relative low final particle energy in the MeV range and will be optimized for neutron scattering to be realized at reasonable costs. Beside this, ToF-experiments are performed to investigate and optimize the pulsing structure for HBS. The target station is installed inside an experimental area offering space for complex detector and component setups for nuclear and neutron related experiments. But it is used for other purposes like electronic or detector tests and irradiation as well. This report briefly summarizes the history of JULIC and the activities for its future perspectives.

TUP020 **Beam Properties at the Experimental Target Station of the Proton Therapy in Berlin**

***J. Bundesmann**, A. Denker, J. Holz auf der Heide (HZB)*

Beside the Therapy station for ocular tumors we have an experimental area to deliver protons and other ions. At this place there is also the possibility to do High Energy Pixe measurements on samples from cultural heritage. The positioning of the samples under test is possible by means of an xy-table with an range of 500x500 mm^2 and a load of at least 50 kg, reproducibility ±0.1 mm. We can change the beam size between 1 mm diameter as focused beam and up to 50 mm diameter with different scattering foils and homogeneous dose spread. We can deliver beam intensities from single protons up to 10^{12} protons/cm^2*s. The energy can be set to 68 MeV with a single Bragg peak, spread out Bragg peaks with a mechanical range shifter or absorber plates to reduce the energy. The timing properties range from quasi DC to a single pulse width of 1 ns with a repetition rate up to 2.4 MHz. Instead of a scattering foil to increase the beam spots we also can use beam scanning with the focused beam to reduce the beam losses. We will show the different beam properties at the experimental target area for radiation hardness testing of solar cells, optical elements and electronics under test.

TUP021 **Towards FLASH Proton Irradiation at HZB**

***G. Kourkafas**, J. Bundesmann, A. Denker, T. Fanselow, J. Röhrich (HZB) V.H. Ehrhardt, J. Gollrad, J. Heufelder, A. Weber (Charite)*

The HZB cyclotron has been providing protons for eye-tumor treatment for more than 20 years. While it has been very successful using conventional dose rates (20 Gy/min), recent studies indicate that rapid irradiation with very high dose rates (FLASH) might be equally efficient against tumors but less harmful to healthy tissues. The flexible pulsing schemes of

the HZB cyclotron can provide beams with variable time structures, covering a wide unexplored range of peak and average currents within the FLASH requirements (>40 Gy/s in <500 ms). This paper presents the machine parameters and the experimental setup which will allow HZB to deliver different FLASH irradiation modes for in vivo investigations.

TUP022 **Status of a 70 MeV Cyclotron System for ISOL Driver in Rare Isotope Science Project in Korea**

***J.-W. Kim**, J. Kang, J.H. Kim (IBS)*

A 70 MeV H^- cyclotron, commercially available for medical isotope production, will be used as an ISOL driver for rare isotope science project (RISP) in Korea. The cyclotron is scheduled to produce a first beam at the end of 2021. In fact the building to house the cyclotron is almost complete and the cyclotron system needs to fit into the existing building, which brings some challenges in equipment installation and adaptation to utilities. A beamline to transport a high-current proton beam into the SOL target has been designed and will be presented along with the status of the cyclotron system.

TUP023 **RF system R&D for Cyclotron at IMP**

***X.W. Wang** (IMP/CAS)*

Heavy Ion Medical Mechine(HIMM) projects is presently developing a 7 MeV cyclotron at IMP. The RF system comprises two separated resonators driven by independent amplifiers and the phase and amplitude allowed independently adjustment for beam intensity modulation. The RF system of HIMM cyclotron has been operating for three years. In order to meet the high demand of high stability of medical equipment, we start with EMC and reliability to carry out the rectification. The work include four aspects: (1) Increase the mechanical deformation strength of the cavity. (2) Improve system cooling. (3) Improve the tuning resolution of the system. (4) Improve system EMC. The RF system of HIMM-LZ projects has been running stable for a long time. The system is gradually closer to the product. The system phase stability is ±0.2° and amplitude stability is ±0.045%. The detail will be shown in the paper.

TUP024 **Muon Cyclotron for Transmission Muon Microscope**

***T. Yamazaki**, Y. Nagatani (KEK, Tokai Branch)*

A transmission muon microscope is an unprecedented tool which enables its users to reconstruct 3D image of living cells non-destructively. Muons can gain penetrative power as their energy increase, though electrons above 1 MeV start to trigger electromagnetic showers and protons above 1 GeV cause nuclear reactions. Muons accelerated up to about 10 MeV are able to penetrate a living cell (~ 20 um), which is impossible with ultra-high voltage (1 MeV) electron microscopes. In order to accelerate muons, efficient acceleration is necessary because the lifetime of muons is only 2.2 µs. In addition, it is important to accelerate muons without increasing their energy dispersion. A cyclotron with a flat-top acceleration system is the best suited for the transmission muon microscope and is being developed at the muon facility of KEK/J-PARC. In this poster, the transmission

muon microscope project and the development of the muon cyclotron will be presented.

TUP025 **Feasibility Study for Converting the CS30 into a Variable Energy Cyclotron for Isotopes Production Using the Internal Target System**
F.M. Alrumayan *(King Faisal Specialist Hospital and Research Centre) H.F. Akhdar (Al-Imam Mohammad Ibn Saud University) H.A. Kassim (KSU)*
This paper report the possibility of converting the fixed energy beams of the CS30 cyclotron into a variable energy and use them for isotopes production. The CS-30 Cyclotron is characterized by its fixed energy beam, being approximately 26.5 MeV for protons, at maximum radius of 42 cm. Production of solid targets based isotopes takes place when the target is positioned horizontally inside the cyclotron tank. In its final position, the target plate interrupts the beam from completing its orbit and nuclear reactions take place. It turned out that it is possible to move the target system, mechanically, further in and interrupts the beam orbits at a lower energy. In this case low energy-produced isotopes, such as Ga-68, can be produced at higher beam current reaching up to 100 μA. However, beam radius of curvature may not be the same at lower energy as it is in the higher energy. This is under-stood from geometrical point of view for target shape at certain radius. Calculations are made to determine the calibration curve of proton beam energies at different radii. Results are reported in this work.

TUP026 **Embedded Local Controller for the CS-30 Cyclotron**
A.M. Hendy*, F.M. Alrumayan (King Faisal Specialist Hospital and Research Centre)*
The Embedded Local Controller is used for the purpose of upgrading our old CS-30 cyclotron control system. It is installed inside the cyclotron vault and connected to the control room using CAN serial bus. This is to avoid adding more wires from cyclotron vault to the outside, because there is no room for extra wires in the feedthrough conduits. The system is carefully designed to be fault tolerant so that it can run in a radiation environment without failure. Details of the design and field test results are presented.

TUP027 **Target System Development for Therapeutic Radioisotope Production**
S.Y. Oh *(KIRAMS)*
Therapeutic radiopharmaceuticals for cancer treatment have been attracting much attention recently. At-211 and Sn-117m are two such radioisotopes with significant amount of potential for therapeutic use. A solid target station capable of producing At-211 and Sn-117m produced using an alpha particle beam was developed. Unlike Bi-209, which is used in the production of At-211, concentrated Cd-116, which is used in the production of Sn-117m, is expensive. The target size of Cd-116 should be carefully adjusted to produce the optimal amount needed for beam irradiation. A fully automatic variable four sector collimator was developed to remotely control the beam size, while preventing radiation exposure, so that the beam can be irradiated only to the adjusted target size. In addition, a low-temperature cooling system was used to increase the production efficiency by increasing the cooling effect of the target. Flow and ther-

mal analyses were conducted on the developed collimator and the low-temperature cooling system using the ANSYS simulation software.

TUP028 **Bremsstrahlung Photons Emission in 28-GHz Electron Cyclotron Resonance Plasma**

M.J. Kumwenda *(Korea University)*

High-energy bremsstrahlung photons emission beyond a critical energy from electron cyclotron resonance (ECR) heating has long attracted much attention and its nature has not yet been revealed. We have first measured the azimuthal angular distribution of the bremsstrahlung photons from 28-GHz ECR ion source at Busan Center of KBSI. Three round type NaI(Tl) detectors were used to measure the bremsstrahlung photons emitted radially at the same time. Another NaI(Tl) detector was placed downstream from the ECR ion source for monitoring photon intensity. The ECR ion source was operated at RF power of 1 kW to extract 16O beam with a dominant fraction of O^{3+} and O^{4+}. Geant4 simulations were performed to take the geometrical acceptance and energy-dependent detection efficiency into account due to large non-uniformity in the material budget. We extracted true bremsstrahlung energy spectra from the 28-GHz ECR ion source using the inverse-matrix unfolding method. Azimuthal angular distributions of bremsstrahlung photons were found to be in a coincidence with the structure of ECR ion source and the shape of ECR plasma.

TUP029 **A 15-MeV/nucleon Strong-focusing Ion Cyclotron for Radioisotope Production**

C. Johnstone *(PAC) R.B. Agustsson, S. Boucher, S.V. Kutsaev, A.Yu. Smirnov (RadiaBeam)*

Cargo inspection systems exploit the broad bremsstrahlung spectrum from a 6-10 MeV, low-duty cycle electron accelerator which in the presence of significant backgrounds presents challenges in image and material identification. An alternative approach is to use ions which can excite nuclear states either directly, or through generation of secondary high-energy signature gammas produced from nuclear interactions in a target. RadiaBeam is designing a compact sector isocyclotron 1.25 m in radius, with high-gradient cavities to accelerate multi-ion species up to 15-20 MeV/u with large turn-to turn, centimeter-level separation for low-loss extraction without lossy foil stripping. A strong-focusing radial field profile will be optimized in a separated-sector format for control over machine tune simultaneous with isochronous orbist requirements for high-current (~0.5 mA) operation. Innovation in injection will be introduced to replace the high-loss central region. Non-security applications of the cyclotron include medical isotope production, ion radiobiology, as well as material science research and ion instrumentation development.

TUP030 **Reinforcement Learning Based RF Control System for Accelerator Mass Spectrometry**

H.S. Kim*, J.-S. Chai, Kh.M. Gad, M. Ghergherehchi, D.H. Ha, J.C. Lee, H. Namgoong (SKKU)*

Accelerator Mass Spectrometry (AMS) is a powerful method for separating rare isotopes and electrostatic type tandem accelerators have been widely

used. At SungKyunKwan University, we are developing a AMS that can be used in a small space with higher resolution based on cyclotron. In contrast to the cyclotron used in conventional PET or proton therapy, the cyclotron-based AMS is characterized by high turn number and low dee voltage for high resolution. It is designed to accelerate not only ^{14}C but also ^{13}C or ^{12}C. The AMS cyclotron RF control model has nonlinear characteristics due to the variable beam loading effect due to the acceleration of various particles and injected sample amounts. In this work, we proposed an AMS control system based on reinforcement learning. The proposed reinforcement learning finds the target control value in response to the environment through the learning process. We have designed a reinforcement learning based controller with RF system as an environment and verified the reinforcement learning based controller designed through the modeled cavity.

TUP031 **Design and Construction Progress of Cyclotron Based Proton Irradiation Facility for Space Science**

***Y.L. Lv**, S. An, T. Cui, T. Ge, B. Ji, X.L. Jia, S.L. Wang, T.J. Zhang (CIAE)*

The proton irradiation facility for space science research and application consists of a 50 MeV proton cyclotron, two beam lines and two radiation effect simulation experimental target station. The 50 MeV proton cyclotron (CYCIAE-50) is a compact negative hydrogen ion cyclotron with the proton beam energy from 30 MeV to 50 MeV, and the beam intensity is from 10 nA to 10 μA. The cyclotron is about 3.2 m in diameter, 3.5 m in total height and 80 tons in total weight. The diameter of the pole is 2000 mm, the outer diameter of the yoke is 3200 mm, and the height of magnet is 1500 mm. The cyclotron uses an external multi-cusp H^- ion source. Then the H^- beam is injected into the accelerating orbit by the spiral inflector. The cyclotron frequency is about 16 MHz. The RF system is a pair of λ/2 RF cavities driven by a 25 kW transmitter. The fourth harmonic accelerating frequency is about 65 MHz. The proton beam is extracted by a single movable stripping carbon foil with the stripping extraction efficiency of 99%. The 50 MeV cyclotron has now been designed in detail, and its main components, such as the main magnets and RF cavities, are being manufactured in the factories in China.

TUP032 **A 230 MeV Proton Cyclotron for Proton Therapy With Resistive Coil**

***O. Karamyshev**, G.A. Karamysheva, G. Shirkov, S.G. Shirkov, V.L. Smirnov, S.B. Vorozhtsov (JINR)*

A new cyclotron is needed for DLNP JINR to deliver a 230 MeV proton beam for hadron therapy. Besides a superconducting cyclotron it is also a good option to use a conventional copper water-cooled coil. Such a solution allows us to achieve a lower price compared to superconducting options, however it becomes slightly heavier. The power consumption is kept low compared to other existing 230 MeV cyclotrons.

TUP033 **A Cyclotron for Boron Neutron Capture Therapy and PET Isotope Production**

O. Karamyshev *(JINR)*

The cyclotron that delivers high intensity 13 MeV proton beams required for neutron production for BNCT, can also be used for PET isotope production. The cyclotron is designed to be simple and reliable.

TUP034 **Study of MERIT Ring for Intense Secondary Particle Production**

H. Okita *(Kyoto University, Research Reactor Institute)*

An intense negative muon source Multiplex Energy Recovery Internal Target (MERIT) for the nuclear transformation to mitigate the long-lived fission products from nuclear plants, has been proposed. For the purpose of proof-of-principle of the MERIT scheme, a FFA (Fixed Field Alternating focusing) ring has been developed and beam experiments have been carried out. In this conference, the results of this study will be reported.

TUP035 **Development of a Center Region for New Sumitomo Cyclotron**

N. Kamiguchi*, Y. Mikami, H. Tsutsui (SHI)*

We at Sumitomo Heavy Industries, Ltd. have been developing a new AVF cyclotron which employs a super-conducting magnet. This cyclotron purposes proton therapy fields and is most compact and high intensity among AVF cyclotrons which can accelerate to 230 MeV. In this paper we report and focus on its center region. The center region consists of bellows. The PIG ion source with hot cathode is located at the center of the cyclotron. As this cyclotron has 3 T magnetic field, the filament receives the Lorentz force strongly. To avoid the filament deformation, AC current heating is newly introduced into this ion source. The over 40 μA output have been already confirmed in our test bench. The extraction of the proton beam is conducted with an RF electric field. On one counter dee electrode a beam chopper is equipped and on the other counter dee electrode, phase slits, a pair of vertical beam dumpers and a beam probe are equipped. To control the beam current, static electric beam choppers deflect the beam direction vertically. C-H coils are put on outside of the center region in the valley. In this paper, the concept of the center region of this new cyclotron will be discussed.

TUP036 **Optical Design of an AVF Weak-Focusing Accelerator**

C. Hori*, T. Aoki, T. Seki (Hitachi Ltd.) T. Hae, H. Hiramoto (Hitachi Ltd., Hitachi Research Laboratory)*

A trend of proton beam therapy (PBT) systems is downsizing their footprints. We have proposed a new weak-focusing accelerator with cotangential beam trajectories, which is downsized compared with existing Hitachi PBT accelerators by utilizing a superconducting magnet. The larger main magnetic field by the superconducting magnet, however, requires septum magnets to generate larger magnetic field for beam extraction. For relaxing the specification of the septum magnets, we consider an AVF weak-focusing accelerator. The magnetic fields of its hills and valleys can be designed with maintaining the magnetic fields averaged along the beam trajectories. Thus, by locating the septum magnets at one of the valleys and extracting the beam from the valley, the specification is relaxed with

keeping its footprint. In this study, we designed the optics of the accelerator by the transfer matrix method. The magnetic field in the valleys is smaller than the magnetic field averaged along the maximum energy trajectory by 0.2 T. We also evaluated magnetic field gradients required of its peeler and regenerator, to find that they are reasonable strengths.

TUP037 **Compact Cotangential Accelerator for Particle Therapy**

T. Hae, *H. Hiramoto (Hitachi Ltd., Hitachi Research Laboratory) T. Aoki, C. Hori, Y. Nakashima, F. Noda, T. Seki (Hitachi Ltd.)*

A new type accelerator without using an energy degrader is being developed for the next generation particle therapy system. Since the new type accelerator utilizes weak focusing magnetic field and frequency modulated RF acceleration, the accelerator size can be same level of a superconducting synchrocyclotron. The new type accelerator characteristically has a cotangential trajectory. In other words, there is a trajectory concentrated area by eccentrically orienting the helical trajectory to one side. To realize variable energy beam extraction from the trajectory concentrated area, we devised an extraction scheme that uses a transverse RF kicker, peeler and regenerator magnetic fields. In this extraction scheme a beam energy can be controlled by an applied time of an acceleration RF voltage. In addition, the beam current and the beam pulse width can be controlled by the voltage pattern of the RF kicker. An energy degrader is expected to be unnecessary in this new type accelerator, hence there will be no beam loss and no unwanted radiation due to the energy degrader. In this presentation, we describe the extraction scheme and the accelerator design including its control system.

TUC — Status Reports

Chair: T.J. Zhang (CIAE)

TUC01 15:50 30 **Review and Current Status of the 70 MeV High Intensity Proton Cyclotron at Legnaro**

***M. Maggiore**, P. Antonini, A. Lombardi, L. Pranovi (INFN/LNL)*

In 2017 the new cyclotron has been successfully commissioned and started the operation at Laboratori Nazionali di Legnaro (LNL) of INFN . The cyclotron is the proton driver foreseen for the Selective Production of Exotic Species (SPES) project, providing the high power beam for radioactive ion beams (RIBs) production by the ISOL technique. The SPES facility is today under construction and first low energy RIBs are expected to be available on 2021. The facility has been designed in order to exploit the versatility of the cyclotron in terms of wide range of energy and beam current extracted: 35-70 MeV energy and 20 nA - 500 μA of average current. Moreover, the possibility to extract at the same time two proton beams allows to share these both for experimental physics session and applications. In particular, at LNL a collaboration between private company and public institution will lead to a profitable synergy in R&D of new radioisotopes and the related production. In the session the results of the commissioning and the operation of cyclotron will be presented as well as the description of the SPES facility together with its potentiality in nuclear physics research and applications.

TUC02 16:20 20 **Status of the HZB Cyclotron**

***A. Denker**, J. Bundesmann, T. Damerow, T. Fanselow, D. Hildebrand, U. Hiller, C. Rethfeldt, J. Röhrich, S. Seidel (HZB) D. Cordini, J. Heufelder, R. Stark, A. Weber (Charite)*

For more than 20 years eye tumours are treated in collaboration with the Charité - Universitätsmedizin Berlin. The close co-operation between Charité and HZB permits joint interdisciplinary research. Irradiations with either a sharp, well focused or a broad beam, either in vacuum or in air are possible. In addition, a 60Co-source for gamma-irradiations is available. Experiments now comprise dosimetry, detector comparisons, ambulant mouse irradiations, including class I gene-modified mice. Furthermore, radiation hardness tests on detectors, CCD-cameras and other electronics are performed. In order to improve the beam diagnosis between the 2 MV injector Tandetron and the cyclotron a harp has been installed, leading to new beam line calculations for the injection line. The accelerator operation for therapy as well as on-going experiments and results will be presented.

TUC03 16:40 20
AGOR Status Report
S. Brandenburg *(KVI)* ***S. Brandenburg****, B.N. Jones, M.-J. van Goethem (KVI-CART)*
The operations of the superconducting cyclotron AGOR over the past years will be reviewed. Reliability issues encountered after nearly 25 years of operation and mitigation measures to warrant reliable operation for the coming decade will be discussed. The research performed with AGOR has significantly shifted from fundamental physics to radiation biology and medical radiation physics in collaboration with the Groningen Proton Therapy Center and radiation hardness studies. The radiation biology programme will be substantially expanded in the coming years with a new beam line for image guided preclinical research. For this programme new dose delivery modalities including scanning, spatial fractionation and very high dose rates will be developed. In addition a new programme has been started on the production of exotic nuclei, for which a new superconducting solenoid fragment separator will be developed. For the radiation hardness testing a cocktail beam at 30 MeV/amu with several ion species up to Xe has been developed and is now routinely delivered for experiments. A cocktail at 15 MeV/amu up to Bi is under development.

TUC04 17:00 20
Status of the Cyclotron Facility at Research Center for Nuclear Physics
H. Kanda*, M. Fukuda, S. Hara, T. Hara, K. Hatanaka, K. Kamakura, H.W. Koay, S. Morinobu, Y. Morita, M. Nakao, K. Omoto, T. Saito, K. Takeda, H. Tamura, Y. Yasuda, T. Yorita (RCNP)*
Research Center for Nuclear Physics (RCNP), Osaka University operates a K140 AVF cyclotron and a K400 ring cyclotron and promotes the nuclear physics, accelerator physics, material science, nuclear medicine and related scientific fields. In the recent years, we operated the CAGRA campaign and Grand-RAIDEN+CAGRA campaign experiments for taking advantage of the low background environment of the RCNP experimental halls and the high quality beams. We have successfully completed the low energy muon beam line, MuSIC. We have been carrying out a program of the upgrade of the K140 AVF cyclotron which continued working since 1973. We aim at 10 times higher intensity for the proton beam than before and further stability of the operation. We also carried out the upgrade of the cyclotron building and related facilities to handle beams with higher intensity. From 2019, the RCNP started the Research Center of Subatomic Sciences as the International Joint Usage/Research Center in Japan. These upgrades are the most important programs to extend the function of the newly established center.

WEA — Magnet Design, RF and Upgrades

Chair: Y. Jongen (IBA)

WEA01 08:30 30 **Future of High Field Superconducting Magnets**

G.L. Sabbi *(LBNL)*

Excellent mechanical and electrical properties make Niobium-Titanium (NbTi) the preferred conductor for accelerator magnets with operating fields up to 8 T. In order to surpass this threshold, materials with higher critical field are required. Among these, Niobium-Tin (Nb_3Sn) is in the most advanced state of development. Nb_3Sn wires carry sufficient current densities to sustain coil windings operating in the 15 T range, and can be produced in multi-km lengths with uniform properties. Following extensive R&D programs, Nb_3Sn technology is enabling a 10-fold increase of the LHC luminosity, opening the way to its application in future higher energy colliders. The use of High Temperature Superconductors such as YBCO and Bi-2212 is also being actively explored to surpass the intrinsic limits of Nb_3Sn. While these materials can in principle support operating fields well above 20 T, many technological challenges need to be addressed to exploit their fundamental properties in practical magnet designs. The most significant achievements to date, remaining issues and future directions are discussed.

WEA02 09:00 20 **The Developments of the RF System Related to the K-800 Superconducting Cyclotron Upgrade**

A.C. Caruso*, L. Calabretta, G. Gallo, A. Longhitano, D. Rifuggiato, A. Spartà, G. Torrisi, E. Zappalà (INFN/LNS)*

The K-800 superconducting cyclotron has been in operation at Laboratori Nazionali del Sud for almost 25 years. It has been subjected to continuous upgrades and modifications since 1994: the RF couplers have been redesigned, the new dees have been changed from aluminium to copper, as has the new central region from radial to axial injection of the beam, the hybrid configuration solid state - tube of the power amplifiers, the digital LLRF, etc. The next scheduled important upgrade of the Cyclotron mainly consists in a new extraction beam line able to support the increase of the beam current intensity. The accelerated beam will be extracted in two ways: by stripper and by electrostatic deflector and, consequently, one of the most important features of the new upgrade is the new cryostat. Further upgrades and refurbishments of the other main parts of the cyclotron, such as a new liner, the modification of the RF cavities and dees, the refurbishment of HLRF-LLRF, the insertion of the stripper extraction system, to name but a few, are in progress, too. This work focuses on the RF system upgrade.

WEA03
09:20

Design for Upgrading the RCNP AVF Cyclotron

M. Fukuda, *S. Hara, T. Hara, K. Hatanaka, K. Kamakura, H. Kanda, H.W. Koay, S. Morinobu, Y. Morita, K. Nagayama, M. Nakao, K. Omoto, T. Saito, K. Takeda, H. Tamura, D. Tomono, Y. Yasuda, T. Yorita (RCNP)*

The upgrade program of the RCNP K140 AVF cyclotron was started in 2019 to provide a high-quality intense beam for nuclear physics experiments and ion beam applications such as RI production and soft-error rate testing of semiconductor devices. The beam quality and intensity will be improved by increasing an extraction voltage of ion sources from 15 to 50 kV. The axial beam injection system will be modified to meet the condition of the increased injection energy. A single Dee electrode with a span angle of 180 degrees will be replaced by two 87 degree Dee electrodes. A new RF resonator was designed to cover a frequency range from 18 to 36 MHz to accelerate staple particles using acceleration harmonic mode of h=2 which maximizes the energy gain and turn separation by the double Dee system. A sub-harmonic bunching system will be applied to an injected beam to match the particle revolution frequency with that of the K400 ring cyclotron. Two gradient correctors will be placed in the extraction region to implement double-focusing for matching the extracted beam to the MEBT system. In this paper, the detailed design of the upgraded AVF cyclotron will be discussed.

WEB — FFA Concepts, Beam Dynamics and Simulations

Chair: Y. Mori (KEK)

WEB01 10:10 30 **Status of FFAs (Modelling and Existing/planned Machines)**

J.-B. Lagrange *(Imperial College of Science and Technology, Department of Physics)*

Since their rebirth two decades ago, great progress has been made in Fixed Field alternating gradient Accelerator (FFA) design, with different optical concepts and technological developments. Several machines have been built, and others are planned. The talk will review the recent progress around the world.

WEB02 10:40 20 **Surrogate Models for Particle Accelerators**

A. Adelmann *(PSI)*

Precise accelerator simulations are powerful tools in the design and optimization of exiting and new charged particle accelerators. We all know from experience, the computational burden of precise simulations often limits their use in practice. This becomes a real hurdle when requiring real time computation. I will demonstrate two techniques, based on Polynomial Chaos Expansion and Deep Neural Networks that hints a path forward, towards precise real time computing. The examples will be based on linear accelerators and cyclotrons.

WEB03 11:00 20 **Factors Influencing the Vortex Effect in High-Intensity Cyclotrons**

C. Baumgarten *(PSI)*

We discuss the main factors that have potential influence on the space charge induced vortex motion of particles within high intensity bunches (curling of bunches, Gordon 1969) in isochronous cyclotrons. Firstly the phase slip due to deviations from strict isochronism determines if the bunches of a specific turn are above, below or at "transition", and hence whether stable vortex motion of the bunches is possible at all. Secondly there are possible longitudinal and transversal effects of rf acceleration, the former depending on the bunch phase ("bunching" or "debunching"), the latter depending on the gradient of the accelerating voltage. Very high accelerating voltages in the first turns call the applicability of adiabatic approximations and analytic methods into question. The influence of the rf acceleration is expected to be significant only at low beam energy, i.e. should have small or even negligible effect beyond the central region of compact machines. The phase slip however is expected to determine the stability of vortex motion up to high energies. The different processes will be described.

WEB04 11:20 20 **BDSIM Simulation for the Complete Radionuclide Production Beam Line on PSI Cyclotron Facility from Beam Splitter to Target Station**

H. Zhang, *R. Eichler, J. Grillenberger, W. Hirzel, S. Joray, D.C. Kiselev, J.M. Schippers, J. Snuverink, R. Sobbia, A. Sommerhalder, Z. Talip, N.P. van der Meulen (PSI) L.J. Nevay (Royal Holloway, University of London) L.J. Nevay (JAI)*

The beam line for radionuclide production on the PSI Cyclotron Facility starts with an electrostatic beam splitter, which peels protons of a few tens of microampere from a beam around two milliampere. The peeled beam is then guided onto a target station for routine production of a variety of radionuclides. Beam Delivery Simulation (BDSIM), a Geant4 based simulation tool, enables the simulation of not only beam transportation through optics elements like dipoles and quadrupoles, but also particle passage through components like collimator and degrader. Furthermore, BDSIM facilitates user built elements with accompanying electromagnetic field, which is essential for the modeling of the first element of the beam line, the electrostatic beam splitter. With a model including all elements from beam splitter to target, BDSIM simulation delivers a better specification of the beam along the complete line, for example, beam profile, beam transmission, energy spectrum, as well as power deposit, which is of importance not only for present operation but also for further development.

WEB05 11:40 20 **Beam dynamics and preliminary design of the RFQ Direct Injection Project**

D. Winklehner *(MIT)*

Injecting beam into a compact cyclotron from an external ion source usually requires a low energy beam transport line (LEBT) with several beam shaping elements (magnets and a buncher), the transfer through the cyclotron axial bore hole, and finally, bending the beam into the median plane using a spiral inflector. In the RFQ Direct Injection Project we are combining LEBT, buncher, and axial transfer within one element, the RFQ (Radio Frequency Quadrupole), which is inserted axially into the cyclotron yoke. This is a very compact solution that offers an excellent bunching efficiency. To accommodate the small diameter that is available in the axial bore hole together with a low RF frequency of 32.8 MHz, a split-coaxial RFQ type was chosen. Longitudinal and transverse de-bunching are mitigated by an internal re-bunching cell, and an external electrostatic quadrupole, respectively. The preliminary design phase of this project has been concluded and the RFQ is currently under construction at Bevatech GmbH in Germany. Here, we present the beam dynamics simulations, showing the feasibility of the system, and the preliminary design of the RFQ and test cyclotron with central region.

WEC — Young Scientists

Chair: A. Adelmann (PSI)

WEC01 13:15 20 **Conceptual Design of an Axial Injection System for High-Temperature Superconducting Skeleton Cyclotron (HTS-SC)**

H.W. Koay*, M. Fukuda, H. Kanda, M. Nakao, T. Yorita (RCNP)*

A compact high-current accelerator is highly desirable for short and effective Boron Neutron Capture Therapy (BNCT) as well as radio-isotopes production in a hospital environment. In accordance with this, a compact high-temperature superconducting skeleton cyclotron (HTS-SC) was proposed. HTS-SC is an air-core K-80 cyclotron with a relatively smaller extraction radius of 40 cm for a 50 MeV H^+ and 40 MeV D^+ beam. Owing to its compactness, a relatively high central magnetic field (>2.4 T) remains as a significant challenge for high current injection. This work describes a preliminary design of the axial injection system of HTS-SC using a spiral inflector. Besides, the transverse beam dynamics are also discussed in order to investigate the upper limit of injection current.

THA — Beam Dynamics, Simulations and Control

Chair: D. Winklehner (MIT)

THA01 09:00 30 **Precise Modelling and Large Scale Multiobjective Optimisation of Cyclotrons**

J. Snuverink*, A. Adelmann, C. Baumgarten, M. Frey (PSI)*

The usage of numerical models to study the evolution of particle beams is an essential step in the design process of particle accelerators. However, uncertainties of input quantities such as beam energy and magnetic field lead to simulation results that do not fully agree with measurements. Hence the machine will behave differently compared to the simulations. In case of cyclotrons such discrepancies affect the overall turn pattern or alter the number of turns. Inaccuracies at the PSI Ring cyclotron that may harm the isochronicity are compensated by 18 trim coils. Trim coils are often absent in simulations or their implementation is simplistic. A realistic trim coil model within the simulation framework OPAL is presented. It was used to match the turn pattern of the PSI Ring. Due to the high-dimensional search space consisting of 48 simulation input parameters and 182 objectives (i.e. turns) simulation and measurement cannot be matched in a straightforward manner. Instead, an evolutionary multi-objective optimisation with more than 8000 simulations per iteration together with a local search approach was applied that reduced the maximum error to 4.5 mm over all 182 turns.

THA02 09:30 20 **Recent Developments of the Open Source Code OPAL**

A. Adelmann *(PSI)*

After a general introduction of OPAL, I will introduce a set of new features available with version 2.0. All new features will be presented together with examples of ongoing research projects. In the OPAL-cyc flavour, a robust way of generating matched distributions with linear space charge is introduced. A new method for describing fixed field accelerators (FFAs) in a very general way will be shown. A new element TRIMCOIL can be used to correct for field-errors in cyclotrons and FFAs. The OPAL was extended to allow the specification of multi objective optimisation problems, which are then solved with a built in NGSA-II genetic algorithm. A new feature SAMPLER allows you to setup and run random or sequential parameter studies and seamless utilisation of a vast number of computing cores. Future plans such as the new AMR-Solver for preceise neighbouring bunch simulations will presented.

THA03
09:50 20

React Automation Studio: A New Face to Control Large Scientific Equipment

***W. Duckitt**, J.K. Abraham (iThemba LABS)*

A new software platform to enable the control of large scientific equipment through EPICS has been designed. The system implements a modern tool chain with a React frontend and a PyEpics backend as a progressive web application. This enables efficient and responsive cross platform and cross device operation. A general overview of React Automation Studio as well as the system architecture, implementation at iThemba LABs, community involvement and future plans for the system is presented.

THB — High Power Cyclotrons and Diagnostics

Chair: A. Adelmann (PSI)

THB01 10:40 30 **Review of High Power Cyclotrons and Their Applications**

L. Calabretta *(INFN/LNS)*

The projects and studies of Cyclotron proposed to drive subcritical reactors are presented in this review. The early isochronous cyclotron cascades, proposed about twenty years ago, and the evolution of these layouts up to the most recent solutions based on superconducting cyclotrons are here described. The newest ideas and their development perspective and the different applications field will be discussed.

THB02 11:10 20 **Production of 70 MeV Proton Beam in a Superconducting Cyclotron**

V.L. Smirnov*, S.B. Vorozhtsov (JINR)*

Production of 70 MeV proton beams with help of a cyclotron-type facility is one of highly requested tasks presently. Such beams are used for medical applications including direct tumor irradiation and also for production of medical isotopes. The applications mentioned above dictate corresponding requirements imposed on the beam quality and intensity. For proton therapy treatment it is sufficient to have 300-600 nA output beam current with rather strict tolerance on the transverse beam quality. On the other hand, for the isotope production the major requirement is high enough beam intensity (hundreds μA) with less demanding beam quality. Nowadays, for production of the proton beams in the energy range considered cyclotrons with resistive coil weighting ~200 tons are mostly used. In these cyclotrons two extraction methods - with electrostatic deflector and with stripping foils - can provide somewhat different quality of the output beam. In given report a possibility of using a superconducting cyclotron instead of room-temperature one is considered. To this end, acceleration of various ions was investigated with analysis of the main facility parameters and resulting output beams.

THB03 11:30 20 **Conceptual Design of TR100+: An Innovative Superconducting Cyclotron for Commercial Isotopes Production**

***Y.-N. Rao**, R.A. Baartman, Y. Bylinskii, T. Planche (TRIUMF)*

Utilizing dedicated cyclotrons to produce medical isotopes is an arising technology in hospitals across Canada. Thus, in January 2015, the CycloMed99 team, led by TRIUMF, demonstrated a breakthrough in producing the world's most highly used medical isotope, technetium-99m (Tc-99m), on existing medical cyclotrons. Now we propose to design an innovative superconducting cyclotron for production of commercially valuable radioisotopes. This project will be focusing on a proton energy of 70-150 MeV and proton current of 2 mA. In this energy range, numerous increasingly demanded radioÂnuclides can be produced, either as parent nuclei for generator use, or directly as a active pharmaceutical ingredient, e.g. Strontium-82 (^{82}Sr), Actinium-235 (^{235}Ac) and Bismuth-213 (^{213}Bi). Our machine shall be designed to accelerate H^{2+}, by injection from external ion source and extraction by stripping. This shall allow to simultaneously extract multiple cw proton beams of variable currents and potentially variable energies to multiple experimental stations with extremely high extraction efficiency. The basic parameters of the machine and the simulations of stripping extraction will be presented.

THB04 11:50 20 **Development of a Transparent Profiler Based on Secondary Electrons Emission for Charged Particle Beams**

***C. Thiebaux**, Y. Geerebaert, F. Magniette, P. Manigot, M. Verderi (LLR) G. Blain, F. Haddad, N. Michel, N. Servagent, T. Sounalet (SUBATECH) B. Boyer, É. Delagnes, F.T. Gebreyohannes, O. Gevin (CEA-IRFU) F. Haddad, C. Koumeir, F. Poirier (Cyclotron ARRONAX)*

The PEPITES project aims at realizing an operational prototype of an ultra-thin, radiation-resistant profiler able to permanently operate on mid-energy (O(100 MeV)) charged particle accelerators. PEPITES uses secondary electron emission (SEE) for the signal because it requires only a minimal thickness of material (10 nm); very linear, it also offers a great dynamic. The lateral beam profile is sampled using segmented electrodes, constructed by thin film methods. Gold strips, as thin as the electrical conductivity allows (~ 50 nm), are deposited on an as thin as possible insulating substrate. When crossing the gold, the beam ejects the electrons by SEE, the current thus formed in each strip allows the sampling. The technique was validated at ARRONAX with 68 MeV proton beams for intensities from 100 fA to 10 nA. SEE is characterized up to 100 nA at ARRONAX and medical energies at CPO. Electrodes were subjected to doses of up to 10^9 Gy without showing significant degradation. A demonstrator with dedicated electronics (CEA) will be installed at ARRONAX and used routinely. The performances of the system and its behavior over time will thus be characterized.

THC — Radioactive Beams and New Concepts

Chair: S. Brandenburg (KVI)

THC01 13:40 30

SHE Factory: Cyclotron Facility for Super Heavy Elements Research

I.V. Kalagin, *S.L. Bogomolov, S.N. Dmitriev, B. Gikal, G.G. Gulbekyan, I.A. Ivanenko, G.N. Ivanov, N.Yu. Kazarinov, M.V. Khabarov, Y.T. Oganessian, N.F. Osipov, S.V. Pashchenko, V.A. Semin (JINR) V.K. Utyonkov, A.V. Yeremin (JINR/FLNR)*

The synthesis of heavy and the heaviest elements and the study of their nuclear and chemical properties are of highest priority in the basic research programme of the Flerov Laboratory of Nuclear Reactions. The synthesis of super heavy elements (SHE) with atomic numbers 113-118 has been achieved in the 48Ca-induced reactions. The International Unions of Pure and Applied Physics (IUPAP) and Chemistry (IUPAC) recognized the priority of Dubna in the discovery of elements 114-118. The seventh period of the Periodic Table has been completed. In accordance with the development program, the first in the world SHE Factory was built at the Laboratory on the basis of the new DC280 cyclotron which was commissioned in 2019. DC-280 has to provide intensities up to 10 pmkA for ions with atomic masses over 50. The main task of the Factory is the synthesis of new chemical elements with atomic numbers 119 and higher, as well as a detailed study of the nuclear and chemical properties of previously discovered superheavy elements. The Factory are being equipped with target materials, new separators and detectors for the study of the nuclear, atomic and chemical properties of the new elements.

THC02 14:10 20

First Beams Produced by the Texas A&M University Radioactive-Beam Upgrade

D.P. May, *J. Arje, B.T. Roeder, A. Saastamoinen (Texas A&M University Cyclotron Institute) F.P. Abegglen, H.L. Clark, G.J. Kim, G. Tabacaru (Texas A&M University, Cyclotron Institute)*

The first test beams of radioactive ions produced by the ion-guide-online (IGISOL) system coupled to the charge-breeding electron-cyclotron-resonance ion source (CB-ECRIS) have been accelerated to high energy by the Texas A&M K500 cyclotron. The radioactive ions are first produced by energetic light ions, mainly protons, provided by the K150 cyclotron and subsequently impinging on foil targets. Low charge-state ions are then swept by a flow of helium gas into an rf-only sextupole ion guide which transports them into the plasma of the CB-ECRIS. This operation as well as the tuning of the K500 cyclotron and transport lines will be described. In addition, the efforts to increase the intensity, purity and variety of the radioactive beams accelerated for eventual experiments will be discussed.

THC03 14:30 20 **Design of Accelerator Mass Spectrometry Based on a Cyclotron**

H. Namgoong*, J.-S. Chai, M. Ghergherehchi, D.H. Ha, H.S. Kim, J.C. Lee (SKKU)*

In this paper, we present a cyclotron-based accelerator mass spectrometry system. Conventional AMS systems use tandem accelerators for generating carbon-14 beams. We have developed an ion source, RF buncher, cyclotron, triplet quadrupole, detector and dipole magnet for an AMS system.

THC04 14:50 20 **3D Printing for High Vacuum Applications**

C.R. Wolf *(HS Coburg) F.B. Beck, L. Franz, V.M. Neumaier (Ernes)*

This thesis deals with the manufacture of parts made by 3D printing for high vacuum application. Different components are printed and examined for their vacuum suitability. As shown furthermore, conventionally made standard components can be welded vacuum-tightly to 3D-printed parts, which enables cost-effective production of more complex components, such as a vacuum chamber. In addition, functional components can already be realized during the manufacturing process. The integration of a system of flow channels directly into the wall of a vacuum-chamber is just one example. Thus, such a vacuum-chamber can be heated during evacuation and effectively cooled in later operation.

THD — Cyclotron Technology: Ion Sources, Injection and Extraction

Chair: D. Rifuggiato (INFN/LNS)

THD01 15:35 30 **Physics and Technology of Compact Plasma Traps**

D. Mascali *(INFN/LNS)*

ECR Ion Sources are deemed to be among the most performing ion sources feeding particle accelerators, cyclotrons in particular. Improvements of their performances strictly depend on the knowledge of plasma physics in compact magnetic traps. The paper will comment on the results obtained by the INFN-LNS team and international collaborators by means of a multi-diagnostics setup able to monitor the evolution in space and time of several plasma parameters, simultaneously with beam extraction and analysis in the LEBT, in single vs. double frequency operations, including the RF power and magnetic field scalings, and exploring regimes dominated by plasma turbulence. The results are relevant for the operations of existing ion sources and for the design of new ones. Compact magnetic traps fashioned in a similar way of ECRISs can be considered as an experimental environment by itself: we are exploring this opportunity relying to the in-plasma measurements of radionuclides lifetimes (in particular, beta-decaying elements): CosmoChronometers or nuclei involved in the s-process nucleosynthesis are among the case studies, opening new perspectives in the nuclear astrophysics field.

THD02 16:05 20 **Central Region Upgrade for the Jyväskylä K130 Cyclotron**

T. Kalvas*, P.M.T. Heikkinen, H.A. Koivisto (JYFL) E. Forton, W.J.G.M. Kleeven, J. Mandrillon, V. Nuttens (IBA)*

The Jyväskylä K130 cyclotron has been in operation for more than 25 years providing beams from H to Au with energies ranging from 1 to 80 MeV/u for nuclear physics research and applications. At the typical energies around 5 MeV/u used for the nuclear physics program the injection voltage is about 10 kV. The low voltage limits the beam intensity due to the strong divergence of beams extracted from ECR ion source magnetic field and space charge effects. Especially the beams from the 18 GHz ECRIS HIISI just recently commissioned at Jyväskylä are typically space-charge limited at such voltages. To mitigate these effects the central region of the K130 cyclotron is being upgraded aiming at increasing the injection voltage by a factor of 2. The new central region has separate spiral inflectors for harmonics 1-3 in a common housing and they can be changed via the axial bore. The upgrade is expected to enable the full potential of HIISI in beam production, leading to intensity increase of m/q<5 gaseous element beams by up to a factor of 10 compared to production with the older 14 GHz ECRIS. Design study of the new central region and the status of the whole project is presented.

THD03
16:25 28

An Improved Concept for Self-Extraction Cyclotrons

W.J.G.M. Kleeven*, E. Forton (IBA)*

A study is made for an improved concept of self-extraction in low and medium energy cyclotrons to be used for production of medical isotopes. The prototype of the self-extracting cyclotron was realized around the year 2001. From this machine, currents higher than 1 mA were extracted and transported to a Pd-10^3 production target. However, at the higher intensities, the extraction efficiency was dropping to about 70-75%, and the extracted emittance was rather poor, leading to additional losses in the beamline. Several improvements of the original concept are proposed: i) the beam coherent oscillation (as needed for good extraction) is no longer generated with harmonic coils, but is obtained from a significant off-centring of the ion source, ii) the cyclotron magnet has perfect 2-fold symmetry, allowing the placement of two internal sources and dual extraction on two opposite hill sectors, iii) a substantial improvement of the magnetic profile of the hill sectors. Simulations show an extraction efficiency up to almost 95% and emittances at least a factor 3 lower as compared to the original design. The new magnetic design is shown, and results of beam simulation are discussed.

FRA01 08:30 30

A New Solution for Cost Effective, High Average Power (2 GeV, 6 MW) Proton Accelerator and its R&D Activities

T.J. Zhang *(CIAE)*

The 100 MeV compact cyclotron, CYCIAE-100 was approved to start the construction in 2011, and the first proton beam was extracted on July 4, 2014. In 2017, the 200 μA proton beam development was conducted, and in 2018, the production of high power beam from 20 kW to 52 kW had been delivered successfully to the beam dump. Due to the successful construction of 435 tons magnet for CYCIAE-100, it has been proved that the gradient adjustment of magnetic field along radius can effectively enhance the vertical focusing during the isochronous acceleration. This key technology was applied to the general design of a 2 GeV CW proton accelerator, the energy limitation of the isochronous machine is increased from ~1 GeV to 2 GeV, by our contribution of the beam dynamics study for high energy isochronous FFAG. This paper will introduce CIAE's engineering experience of precision magnet, high power RF systems, and the advantages of beam dynamics simulation based on large-scale parallel computing. The cost-effective solution for such a 2 GeV high power circular accelerator complex will be presented in detail after the brief introduction about the high power proton beam production by the CYCIAE-100.

FRA02 09:00 20

Status of Sumitomo's Superconducting Cyclotron Development for Proton Therapy

H. Tsutsui*, Y. Ebara, M. Hirabayashi, N. Kamiguchi, Y. Kumata, Y. Mikami, T. Morie, T. Takahashi, T. Tsurudome, J.Y. Yoshida (SHI)*

Sumitomo Heavy Industries, Ltd. is developing a compact superconducting isochronous 230 MeV cyclotron SC230 for proton therapy. It is designed to output 1000 nA proton beam for high dose rate cancer treatment. The cyclotron magnet including a liquid helium free cryostat has been fabricated and magnetic field has been measured. Magnetic field distribution and parameters such as horizontal and vertical tunes agreed well with the original design. A 120 kW solid state RF system is under test. Other components such as ion source, electrostatic deflector, are being fabricated. After individual components will be tested, they will be assembled and beam test will be scheduled in a new test site. In this paper, a brief introduction of our proton therapy system development status and future plan will be presented. Beam dynamics in the cyclotron will be discussed.

FRA03
09:20 20

Energy Reduction of Varian's ProBeam 250 MeV Cyclotron to 226 MeV

***A. Roth**, E.M. Akcöltekin, O. Boldt, F. Klarner, H. Röcken, T. Stephani, J.C. Wittschen (VMS-PT)*

With the superconducting 250 MeV isochronous proton cyclotron, Varian uses a powerful accelerator for the ProBeam particle therapy systems. However, data from clinical operation has shown that the vast majority of treatments is only making use of proton ranges of less than 30 cm WET, i.e. beam energy of 218 MeV at the patient. This led to a decision at Varian in Dec 2018 to conduct a redesign program with the goal to reduce extraction energy of the ProBeam cyclotron to 226 MeV. We present our comprehensive beam dynamics simulation program for 226 MeV acceleration and extraction. This actually shows that only a reduced main coil current and adapted magnetic shimming process, as well as a slightly lower RF frequency is needed for re-tune. Furthermore, results indicate that a similar performance as compared to the 250 MeV machine can be expected. The small hardware adaption is already realized, and a first of its kind (FOIK) 226 MeV cyclotron is built by seamless integration into our production process. The magnetic field measurement and shimming campaign is completed, inhouse RF and beam commissioning is planned for early autumn 2019. We report on FOIK machine status and performance.

FRA04
09:40 20

Cyclotrons Based Facilities for Single Event Effects Testing of Spacecraft Electronics

***P.A. Chubunov**, A.S. Bychkov (ISDE), V.S. Anashin (United Rocket and Space Corporation, Institute of Space Device Engineering) I.V. Kalagin, S.V. Mitrofanov (JINR)*

Space radiation is the main factor limiting the operation time of the onboard equipment of the spacecraft due to the radiation effects occurring in the electronic components. With a decrease in the size of semiconductor structures, the sensitivity to the effects of individual nuclear particles increases and hitting one such particle can cause an upset or even failure of a component or system as a whole. Since the phenomenon occurs due to the impact of a separate particle, these radiation effects are called Single Event Effects (SEE). To be sure that the electronic component is operational in space, ground tests are necessary. SEE tests are carried out on test facilities that allow accelerating heavy ions from C to Bi to energies from 3 to a few dozen MeV/A. Cyclotrons are best suited for this purpose. In this paper, the installations created by request of ISDE based on the cyclotrons of FLNR JINR are described.

FRB — FFA Concepts, Upgrades and RF

Chair: A. Stolz (NSCL)

FRB01 10:30 30 **Designing Cyclotrons and FFAs From Their Orbits**

T. Planche *(TRIUMF)*

This study is limited to the case of fixed field accelerators with median plane symmetry. Under this assumption, we show how the infinitesimal motion of a particle around its closed orbit is entirely determined by the shape of the neighbouring closed orbits. We will thus have reduced the problem of tune calculation to a pure problem of geometry. This property is particularly useful to produce isochronous field maps – consistent with Maxwell's equations – as the problem can be reduced to the numerical optimization of only 5 to 10 geometrical parameters. To illustrate this point we show a few cyclotron designs where either the vertical tune, or both the vertical and the horizontal tunes are maintained constant for the entire energy range, with the noticeable exception of the first few turns. All results presented in this study are benchmarked against CYCLOPS simulations.

FRB02 11:00 20 **FLNR JINR Accelerator Complex for Applied Physics Researches: State-of-Art and Future**

S.V. Mitrofanov*, P.Yu. Apel, V. Bashevoy, V. Bekhterev, S.L. Bogomolov, J. Franko, B. Gikal, G.G. Gulbekyan, I.A. Ivanenko, I.V. Kalagin, N.Yu. Kazarinov, V.A. Skuratov, A. Tikhomirov (JINR)*

The main activities of FLNR, following its name – are related to fundamental science, but, in parallel, plenty of efforts are paid for practical applications. Certain amount of beam time every year is spent for applied science experiments on FLNR accelerator complex. The main directions are the production of the heterogeneous μ- and nano-structured materials; testing of electronic components (avionics and space electronics) for radiation hardness; ion-implantation nanotechnology and radiation materials science. Status of all these activities, its modern trends and needs will be reported. Basing on FLNR long term experience in these fields and aiming to improve the instrumentation for users, FLNR accelerator department announce the design study for a new cyclotron, DC140, which will be dedicated machine for applied researches in FLNR. Following the users requirements DC140 should accelerate the heavy ions with mass-to-charge ratio A/Z of the range from 5 to 8 up to fixed energies 2 and 4.8 MeV per unit mass. The first outlook of DC140 parameters, its features, layout of its casemate and general overview of the new FLNR facility for applied science will be presented.

FRB03
11:20 20

3D Radio Frequency Simulation of the LNS Superconducting Cyclotron

G. Torrisi, *L. Allegra, L. Calabretta, A.C. Caruso, G. Gallo, A. Longhitano, L. Neri, D. Rifuggiato (INFN/LNS)*

An upgrade plan of the Superconducting Cyclotron operating at INFN-LNS is ongoing. In this paper, a 3D numerical model of the Cyclotron radio frequency cavity is presented. Simulations include the coaxial sliding shorts, liner vacuum chamber, coupler, trimming capacitor and the Dees structures. CST microwave studio software has been used for the eigenmodes computation and scattering parameter evaluation in the frequency range between 15 and 48 MHz. Moreover, 3D COMSOL Multiphysics simulations have been carried out in order to couple the electromagnetic field solution to a custom beam-dynamics code developed in Matlab. RF simulations are mandatory also in order to analyze the field in the beam region and evaluate the impact of different Dees geometry and eventual field asymmetries. Time evolution of accelerated beam and electromagnetic field make also possible to verify the magnetic field synchronization. Experimental validation of the developed model will be also presented.

Boldface papercodes indicate primary authors

— K —

— Y —

Yamada, K. MOB01
Yamazaki, T. **TUP024**
Yang, G. **TUP018**
Yang, W.Q. **MOA02**
Yao, Q.G. **MOP036**
Yasuda, Y. TUC04, WEA03
Yazvitsky, Yu. MOP017
Yeremin, A.V. THC01
Yin, M. **MOP008**
Yin, Z.G. MOP009, MOP012, TUP005
Yorita, T. TUC04, WEA03, WEC01
Yoshida, J.Y. MOP026, FRA02

— Z —

Zach, V. MOP022
Zappalà, E. MOP013, WEA02
Zhang, H. TUA03, **WEB04**
Zhang, H.J. **MOP035**
Zhang, T.J. MOP006, MOP007, MOP008, MOP009, MOP012, TUP005, TUP031, **FRA01**
Zhang, X. MOP001
Zhao, Y. MOP001, **MOP002**
Zheng, X. MOP006, MOP007
Zhong, Z. MOP004
Zhu, F.Zhu. MOP008

Sunday 22 September 18:00-21:30 Registration and Welcome Reception (Venue: Two Oceans Aquarium)

Monday 23 September

MOW	Conference Opening, Chair: Lowry Conradie
08:00	Registration
09:00	Welcome, Introduction
MOA	Facility Development and Upgrades, Chair: Yuri Bylinsky
09:30	MOA01: Yoshihiro Ishi - Recent Experimental Results of the Accelerator Drive System with a Sub-Critical Nuclear Reactor (ADS) Programme
10:00	MOA02: Weiqing Yang - Operating Status and Upgrading of Cyclotron in Lanzhou
10:20	MOA03: Omar Kamalou - Status Report on GANIL and Upgrade of SPIRAL1
10:40	Tea
MOB	Facility Development and Upgrades, Chair: Ralf Gebel
11:10	MOB01: Osamu Kamigaito - Recent Progress in RIKEN RI Beam Factory
11:40	MOB02: Jacobus Conradie - Progress With a New Radioisotope Production Facility and Construction of Radioactive Beam Facility at iThemba LABS
12:00	MOB03: William Beeckman - GFS-2 - The New Gas-filled Separator for Super-Heavy Elements in JINR. A Guided Walk through the Genesis of the Project from First Thoughts to Completion
12:20	Lunch
14:00	MOP POSTER SESSION
15:40	Tea
MOC	Cyclotron Technology: Ion Sources and Upgrades, Chair: Pauli Heikkinen
16:00	MOC01: Liangting Sun - Moving the Frontiers of the Production of Intense Beams of Highly Charged Ions With ECR Ion Sources
16:30	MOC02: Damon Todd - A Pathway to Accelerate Ion Beams up to 3 GeV with a K140 Cyclotron
16:50	MOC03: Markus Schneider - Upgrade of the PSI Injector 2 Cyclotron

Industrial Exhibition 08:30-18:00 in the Old Harbour Lobby

Tuesday 24 September

TUA	Cyclotron Applications: Isotopes, Chair: Hermann Schweikert
08:30	TUA01: Jean-Michel Geets - Radioisotopes Production in Accelerators & Cyclotron Use
09:00	TUA02: Saverio Braccini - Novel Irradiation Methods for Theranostic Radioisotope Production With Solid Targets at the Bern Medical Cyclotron
09:20	TUA03: Nicholas Philip van der Meulen - The Use of PSI's IP2 Beam Line Towards Exotic Radionuclide Development and its Application Towards Proof-Of-Principle Preclinical and Clinical Studies
09:40	TUA04: Martin Schulc - Characterization of Neutron Leakage Field Coming from 18O(p,n)18F Reaction in PET Production Cyclotron
10:00	TUA05: Mitra Ghergherehchi - Vanadium-48 Production Yield Investigation Using TiO2 Nano Powder Targets
10:20	Tea
TUB	Cyclotron Applications: Medical, Chair: Andrea Denker
10:50	TUB01: Daniel Winklehner - Status of the Development of a Fully Iron-free Cyclotron for Proton Beam Radiotherapy Treatment
11:10	TUB02: Oleg Karamyshev - SC230 Superconducting 230 MeV Proton Cyclotron for Therapy
11:30	TUB03: Erik Van Der Kraaij - MRI-Guided-PT: Integrating an MRI in a Proton Therapy System
11:50	TUB04: Serena Psoroulas - On-Line Dynamic Beam Intensity Control in a Proton Therapy Cyclotron
12:10	Lunch
13:50	TUP POSTER SESSION
15:30	Tea
TUC	Status Reports, Chair: Tianjue Zhang
15:50	TUC01: Mario Maggiore - Review and Current Status of the 70 MeV High Intensity Proton Cyclotron at Legnaro
16:20	TUC02: Andrea Denker - Status of the HZB Cyclotron
16:40	TUC03: Brian Jones - AGOR Status Report
17:00	TUC04: Hiroki Kanda - Status of the Cyclotron Facility at Research Centre for Nuclear Physics

Industrial Exhibition 08:30-18:00 in the Old Harbour Lobby

Wednesday 25 September

WEA	Magnet Design, RF and Upgrades, Chair: Yves Jongen
08:30	WEA01: GianLuca Sabbi - Future of High Field Superconducting Magnets
09:00	WEA02: Antonio Caruso - The Developments of the RF System Related to the K-800 Superconducting Cyclotron Upgrade
09:20	WEA03: Mitsuhiro Fukuda - Design for Upgrading the RCNP AVF Cyclotron
09:40	Tea
WEB	FFA Concepts, Beam Dynamics and Simulations, Chair: Yoshiharu Mori
10:10	WEB01: Jean-Baptiste Lagrange - Status of FFAs (Modelling and Existing/Planned Machines)
10:40	WEB02: Andreas Adelmann - Surrogate Models for Particle Accelerators
11:00	WEB03: Christiaan Baumgarten - Factors Influencing the Vortex Effect in High-Intensity Cyclotrons
11:20	WEB04: Hui Zhang - BDSIM Simulation for the Complete Radionuclide Production Beam Line on PSI Cyclotron Facility from Beam Splitter to Target Station
11:40	WEB05: Daniel Winklehner - Beam dynamics and preliminary design of the RFQ Direct Injection Project
12:00	Lunch
WEC	Young Scientists, Chair: Andreas Adelmann
13:15	WEC01: Hui Wen Koay - Conceptual Design of an Axial Injection System for High- Temperature Superconducting Skeleton Cyclotron (HTS-SC)
13:35	Introductory Talk and then Depart for Site Visit and Barbecue at iThemba LABS

Industrial Exhibition 08:30-14:00 in the Old Harbour Lobby

Thursday 26 September

THA	Beam Dynamics, Simulations and Control, Chair: Daniel Winklehner
09:00	THA01: Jochem Snuverink - Precise Modelling and Large Scale Multiobjective Optimization of Cyclotrons
09:30	THA02: Andreas Adelmann - Recent Developments of the Open Source Code OPAL
09:50	THA03: William Duckitt - React Automation Studio: A New Face to Control Large Scientific Equipment
10:10	Tea
THB	High Power Cyclotrons and Diagnostics, Chair: Andreas Adelmann
10:40	THB01: Luciano Calabretta - Review of High Power Cyclotrons and Their Applications
11:10	THB02: Victor Smirnov - Production of 70 MeV Proton Beam in a Superconducting Cyclotron
11:30	THB03: Yu. Bylinskii - Conceptual Design of TR100+: An Innovative Superconducting Cyclotron for Commercial Isotopes Production
11:50	THB04: Christophe Thiebaux - Development of a Transparent Profiler Based on Secondary Electrons Emission for Charged Particle Beams
12:10	Lunch
THC	Radioactive Beams and New Concepts, Chair: Sytze Brandenburg
13:40	THC01: Igor Kalagin - Cyclotron Facility for Super Heavy Elements Research
14:10	THC02: Donald Philip May - First Beams Produced by the Texas A&M University Radioactive-Beam Upgrade
14:30	THC03: Donghyup Ha - Design of Accelerator Mass Spectrometry Based on a Cyclotron
14:50	THC04: Christian Rüdiger Wolf - 3D Printing for High Vacuum Applications
15:10	Tea
THD	Cyclotron Technology: Ion sources, Injection and Extraction, Chair: Danilo Rifuggiato
15:35	THD01: David Mascali - Physics and Technology of Compact Plasma Traps
16:05	THD02: Taneli Kalvas - Central Region Upgrade for the Jyväskylä K130 Cyclotron
16:25	THD03: Willem Kleeven - An Improved Concept for Self-Extraction Cyclotrons
17:35	Depart for Conference Dinner (Venue: The Bungalow)

Industrial Exhibition 08:30-18:00 in the Old Harbour Lobby

Friday 27 September

FRA	New Projects, Beam Dynamics, Simulations and Applications, Chair: Marco Schippers
08:30	FRA01: Tianjue Zhang - A New Solution for Cost Effective, High Average Power (2 GeV, 6 MW) Proton Accelerator and its R&D Activities
09:00	FRA02: Hiroshi Tsutsui - Status of Sumitomo's Cyclotron Development for Proton Therapy
09:20	FRA03: André Roth - Energy Reduction of Varian's ProBeam 250 MeV Cyclotron to 226 MeV
09:40	FRA04: Vasily Sergeevich Anashin - Cyclotrons Based Facilities for Single Event Effects Testing of Spacecraft Electronics
10:00	Tea
FRB	FFA Concepts, Upgrades and RF, Chair: Andreas Stolz
10:30	FRB01: Thomas Planche - Designing Cyclotrons and FFAs From Their Orbits
11:00	FRB02: Semen Mitrofanov - FLNR JINR Accelerator Complex for Applied Physics Researches: State-of-Art and Future
11:20	FRB03: Lorenzo Neri - 3D Radio Frequency Simulation of the LNS Superconducting Cyclotron
	Conference Summary and Announcement of Host Institution for CYC2022, Chair: Lowry Conradie
11:40	Conference Summary presented by Andrea Denker
12:05	Announcement of the Host Institution for CYC2022
12:20	End of Conference

Industrial Exhibition 08:30-10:00 in the Old Harbour Lobby

CYC 2019 22-27 SEPTEMBER CAPE TOWN