COMMISSIONING OF THE LOW-ENERGY PART OF LINAC4

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FOR THE COMMISSIONING TEAM

THE BIG PICTURE : LHC LUMINOSITY

$$\mathcal{L} = \frac{\gamma}{4\pi} \times f_r \times \frac{F}{\beta^*} \times n_b \times N_b \frac{N_b}{\varepsilon_n}$$

From optics at Interaction point

From machine design and limitations (e cloud)

Brightness from Injectors : defined at low energy

N_b	number of particles per bunch
n_b	number of bunches
f_r	revolution frequency
ε_n	normalised emittance
β^*	beta value at Ip
F	reduction factor due to crossing angle

LHC INJECTOR CHAIN :

Linac2 (50 MeV) 1978 length 40 m
160mA , 100 µsec , 1 Hz
Max Space Charge Tune Shift reached
↓
PS Booster (1.4 GeV) 1972 – radius 25 m
4 rings stacked
Output energy already upgraded twice
↓
PS (25 GeV) 1959 – radius 100 m

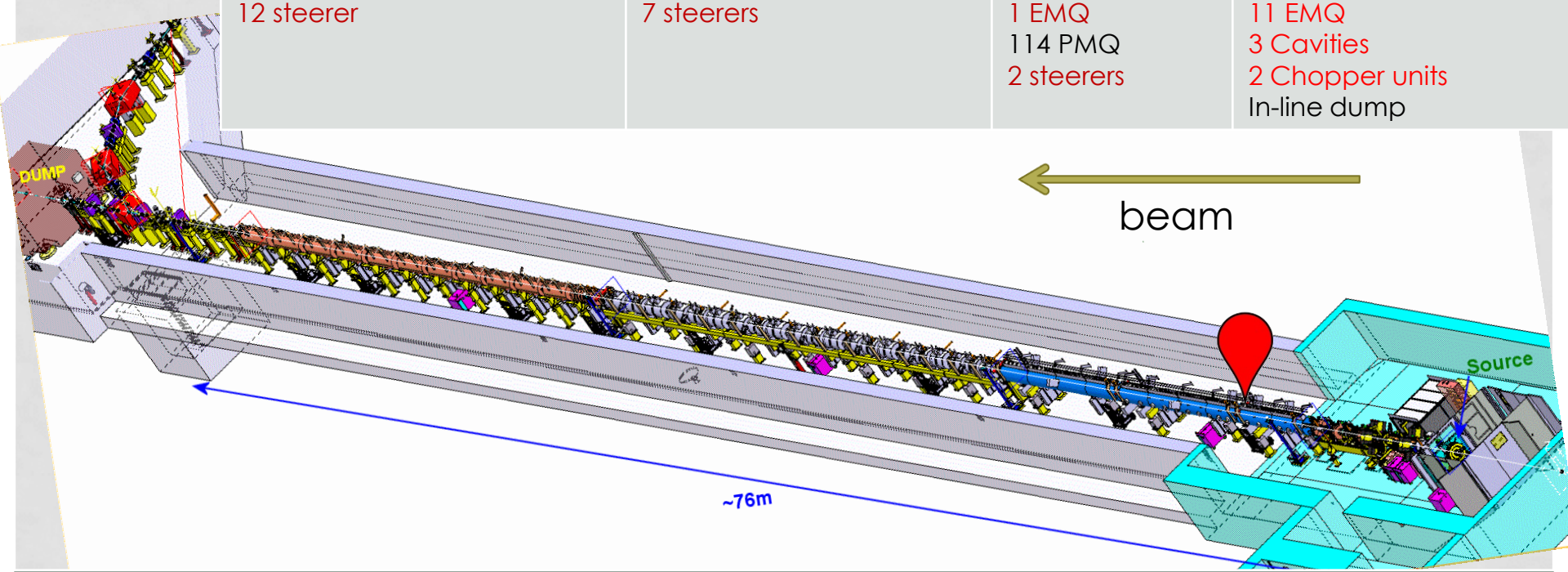
↓
SPS (450 GeV) - 1976 radius 1100 m

PRESENT AND EXPECTATION

LINAC2		LINAC4
protons	Charge exchange injection (reduce emittance)	H-
160mA	Lower current means better beam quality	70mA peak 40 mA after chopping
50 MeV	Space charge tune shift at PSB injection is half	160 MeV
1 π mm mrad	Smaller emittance	0.4 π mm mrad
100 μsec 1Hz	Longer injection in the PSB (100turns)	400 μsec 1Hz
200 MHz / 40 m	RF frequency that is not widespread anymore. No components "off the shelf".	352 MHz / 80 m
Since 1978	Tanks, vacuum, mechanics are aging.	All new component
No longitudinal matching at injection	30-50% of the beam lost at injection	Fast chopping at 3MeV Energy painting with the last accelerating modules

LINAC4 machine layout- 352MHz

Π-mode	CCDTL	DTL	Pre-injector
160 MeV	100 MeV	50 MeV	3MeV
23 m 12 Modules 8 Klystrons: 12MW 12 EMQ 12 steerer	25 m 7 Modules 7 Klystrons : 7 MW 7 EMQ + 14 PMQ 7 steerers	19 m 3 Tanks 3 Klystrons : 5 MW 1 EMQ 114 PMQ 2 steerers	9 m Source(s) 2 solenoids RFQ 11 EMQ 3 Cavities 2 Chopper units In-line dump

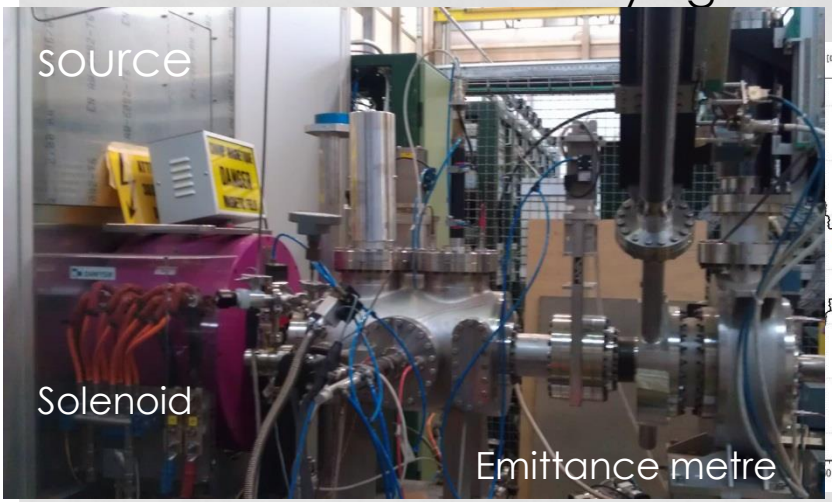


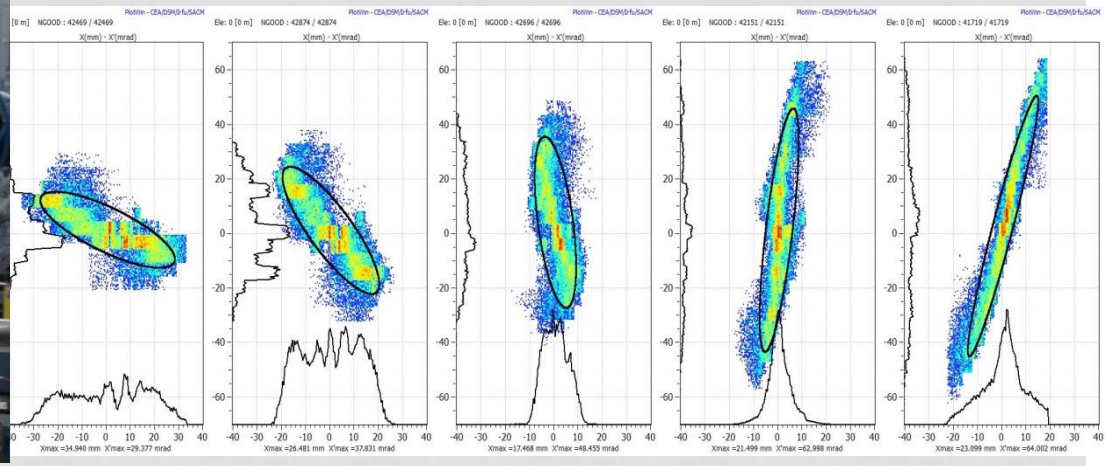
Commissioning stages

160 MeV	105 MeV	50 MeV	12 MeV	3 MeV	45 keV
End 2015	August 2015	May 2015	Well advanced	Chopping demonstrated	Not the final source

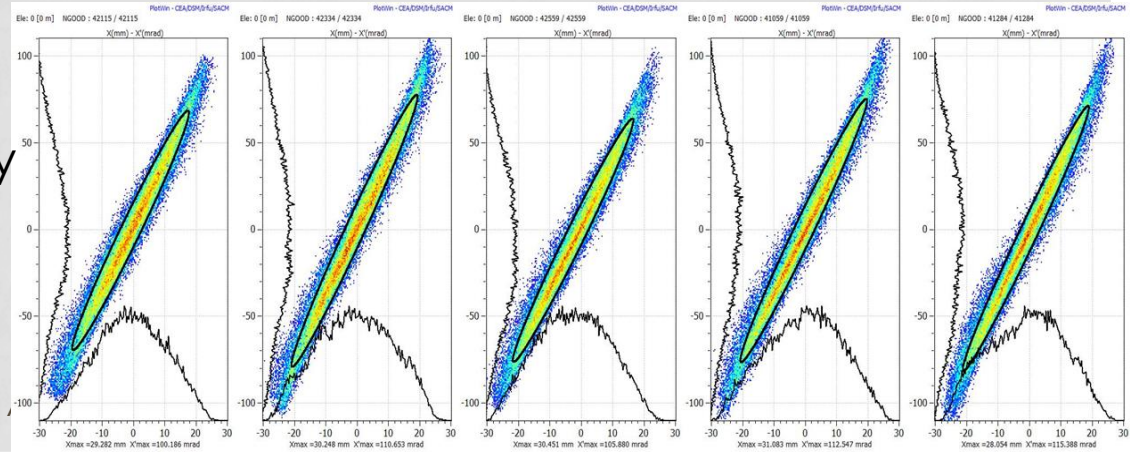
MEASUREMENTS AT 45 KEV

1- take measurements varying solenoidal field and generate in tracking code



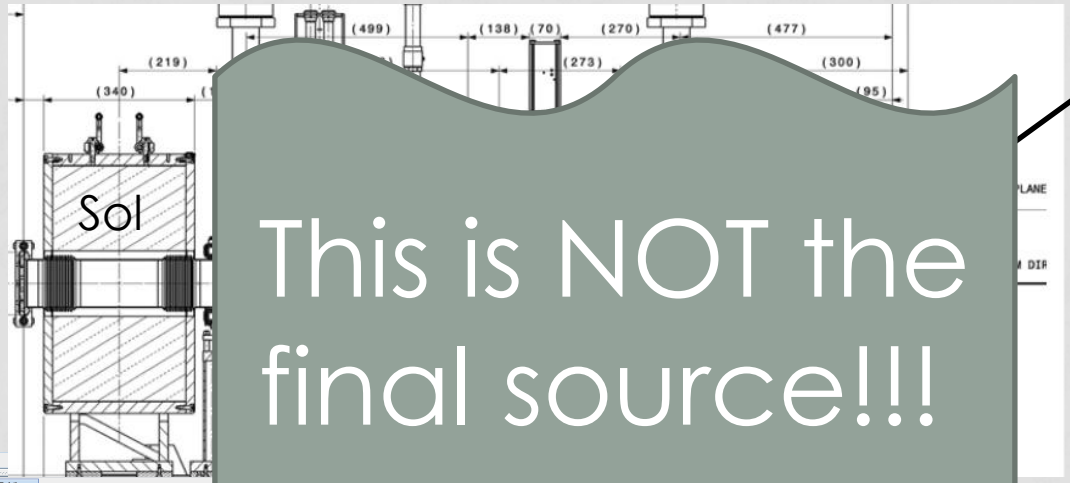


2 – back-trace to source out

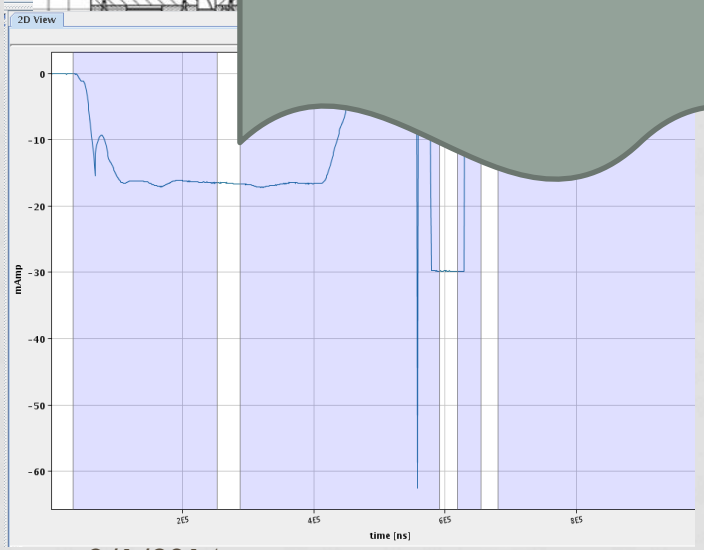


3 - Result : we have an empirical input beam distribution that very well represents the dynamics in the LEBT and the rest of the accelerator (remember HB2010)

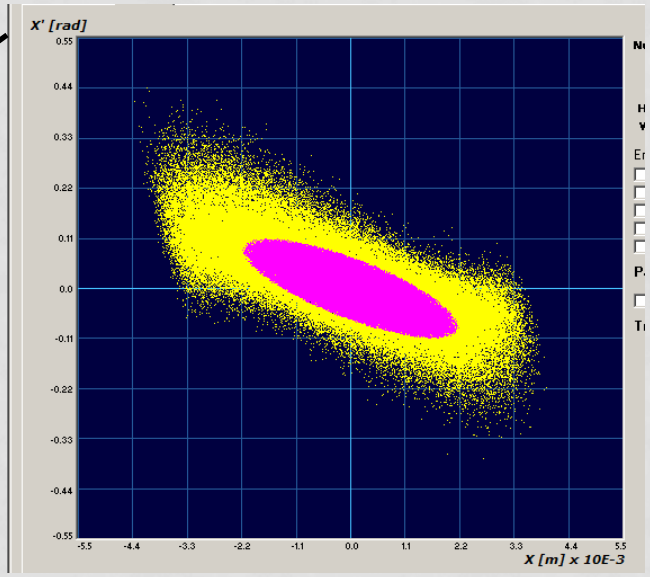
AT THE RFQ INPUT PLANE



This is NOT the final source!!!

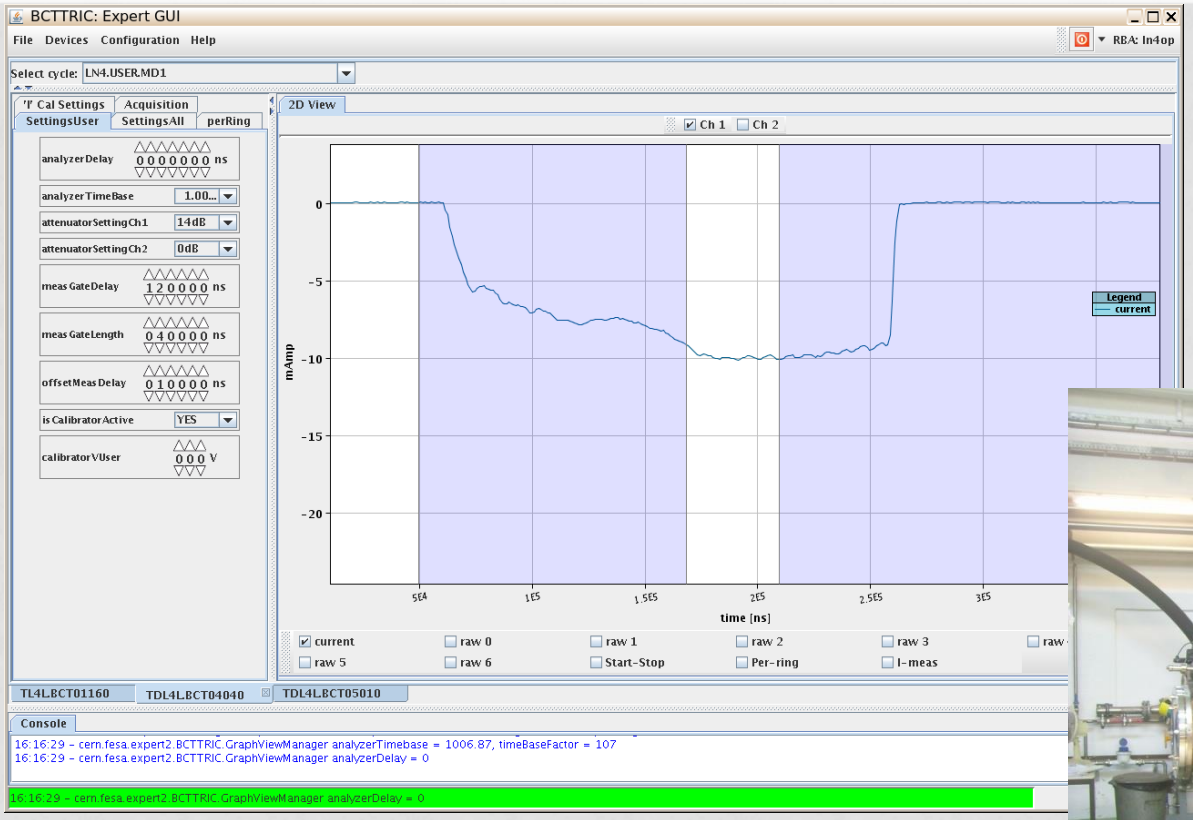


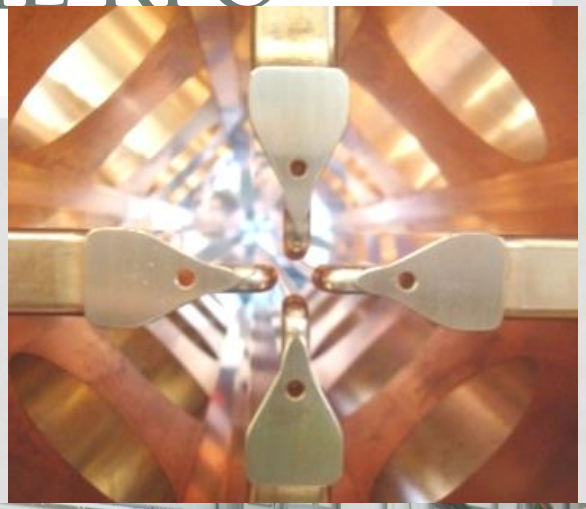
Measured current : 16mA for 200μsec.



Comparison of **measured emittance** (yellow) and RFQ acceptance (pink). The expected transmission thru the RFQ is 75%. (PARMTEQ + TOUTATIS)

FIRST BEAM THRU THE RFQ



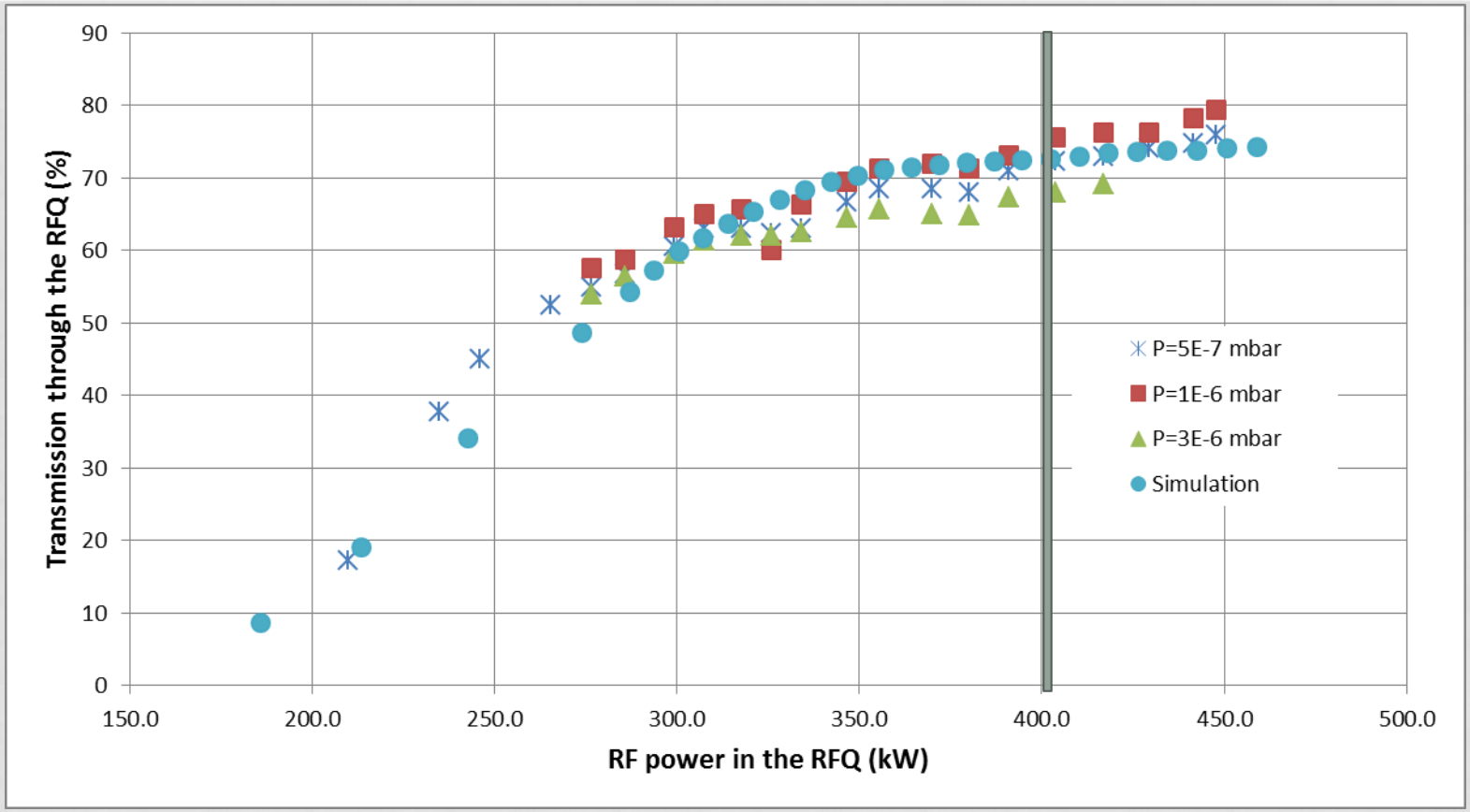


Wednesday 13/03/13 at 16h10
10mA H- accelerated to 3 MeV

AT 3 MEV : 4 BURNING QUESTIONS

- Does the RFQ work?
- Does the chopper chop?
- If yes , does it degrade the emittance of the thru beam ?
- Can the beam be matched to the DTL (permanent magnet, not much flexibility….)?

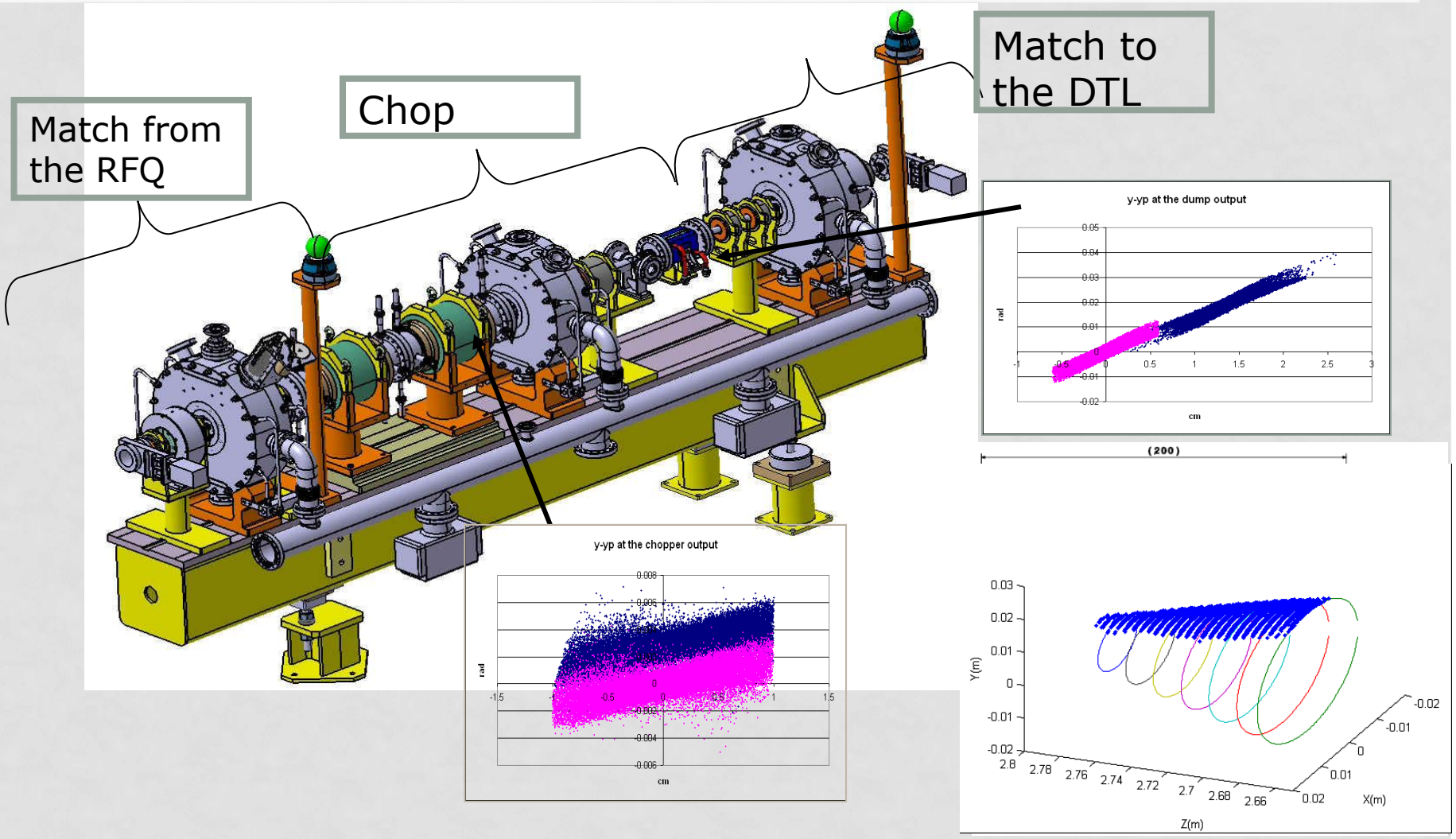
1-RFQ TRANSMISSION



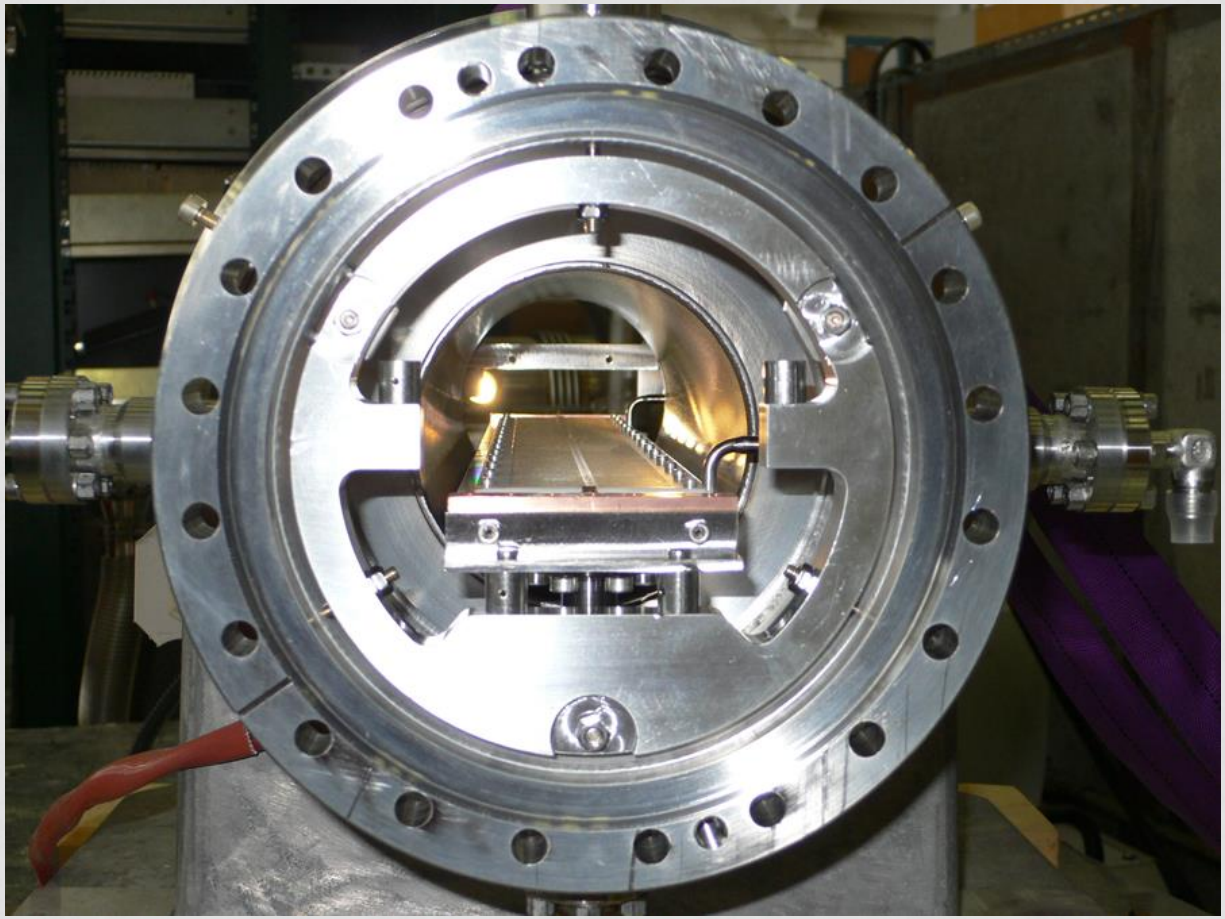
RFQ Transmission vs. RF power for different pressure in the LEBT (neutralisation). The nominal RFQ power is 400 kW.

2-"CHOPPING"

REMOVING MICROBUNCHES (150/352) TO ADAPT THE 352MHZ LINAC BUNCHES TO THE 1 MHZ BOOSTER FREQUENCY



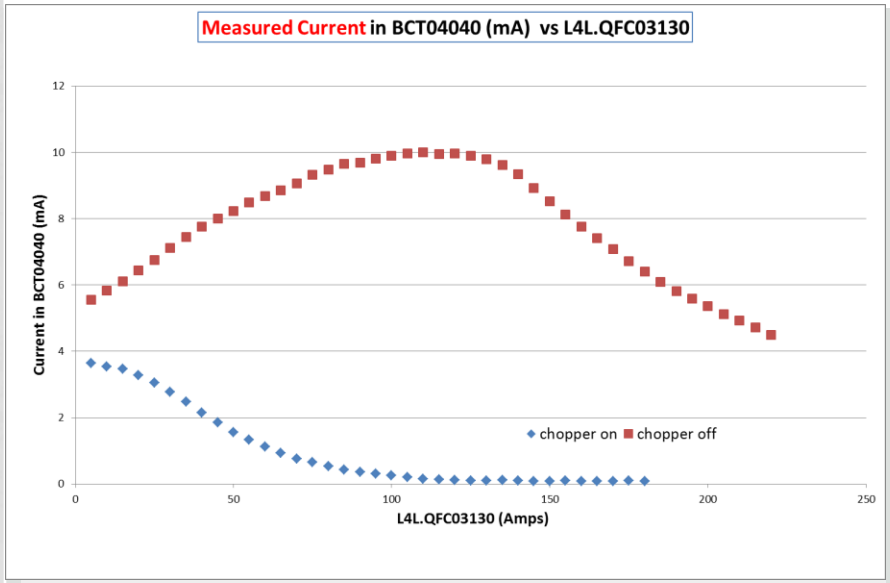
CHOPPER DEVICE

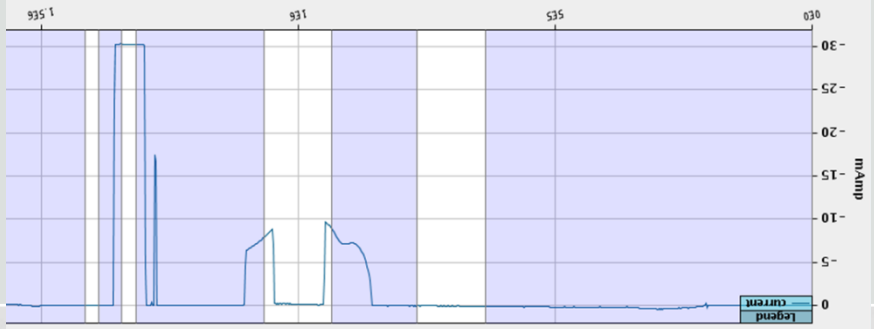


- Meander line on ceramic board
- Housed in a quadrupole
- 700 Volts
- Rise/fall time : 2nsec

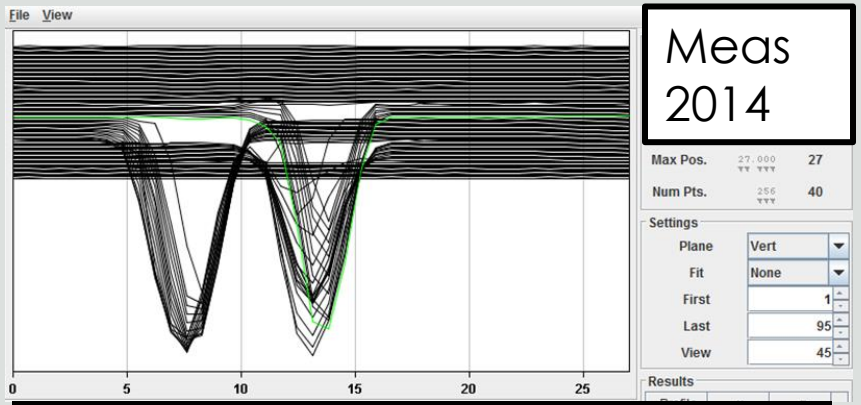
2-BEAM CHOPPING

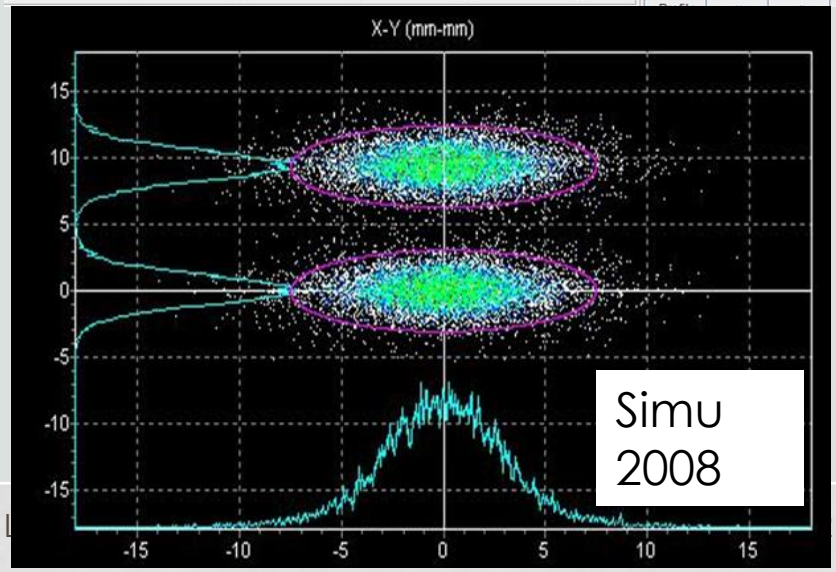
At the BCT after the inline dump

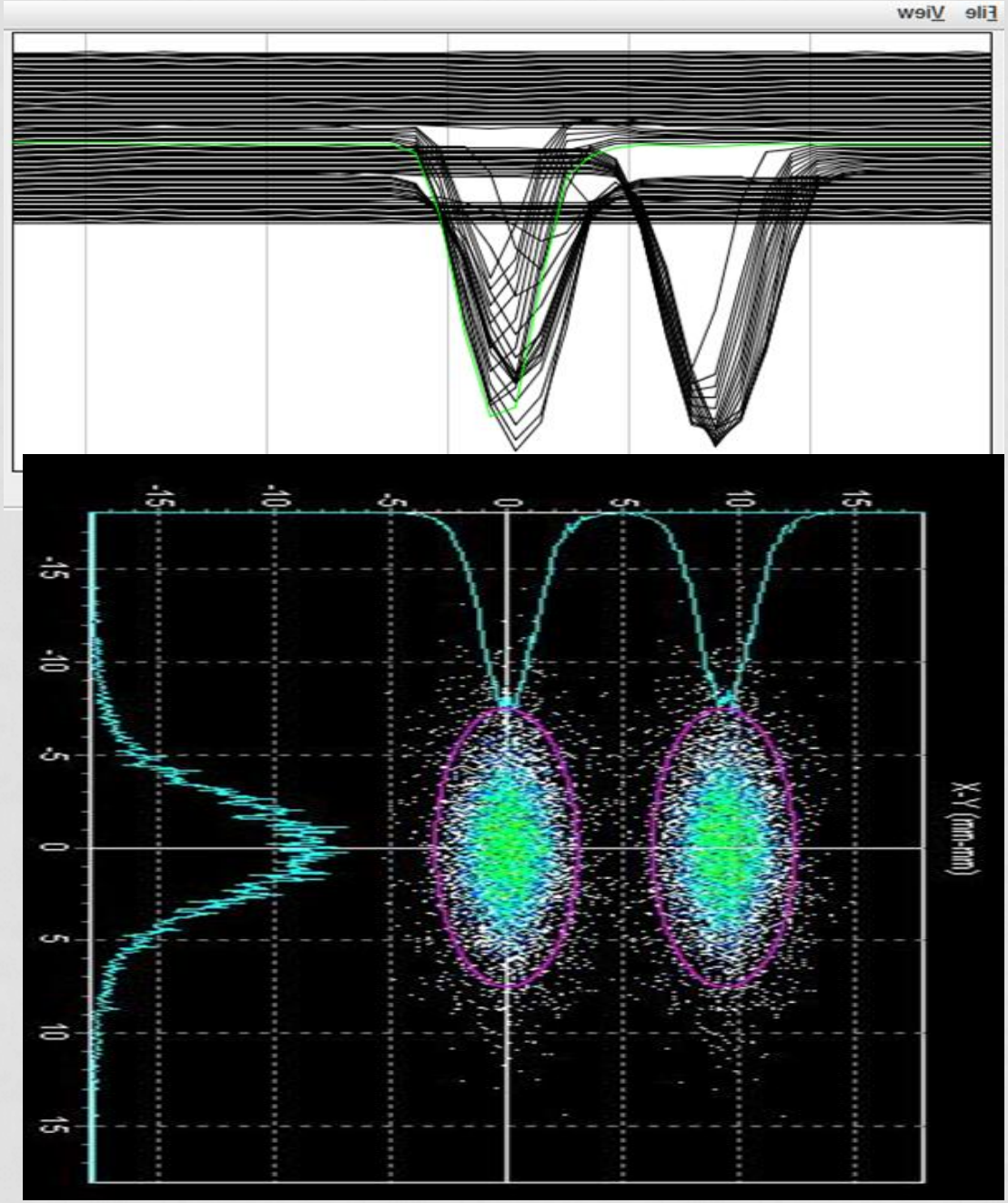




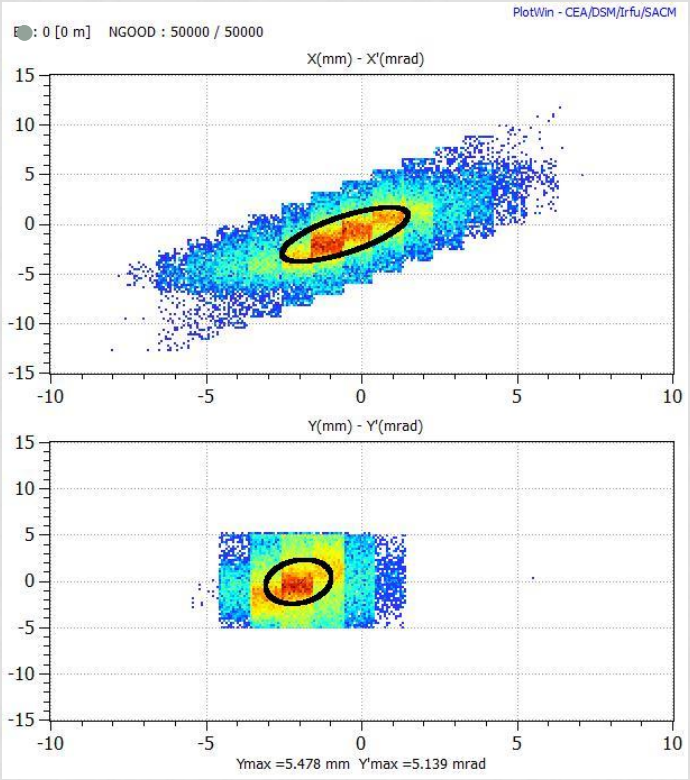
At the wire scanner before the dump

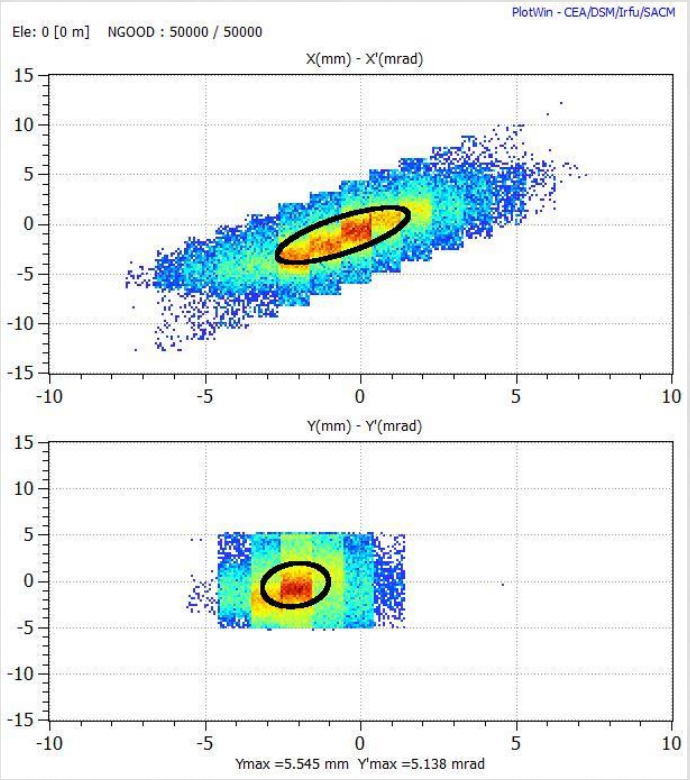





File View
X-Y (mm-mm)
-15
-10
-5
0
5
10
15

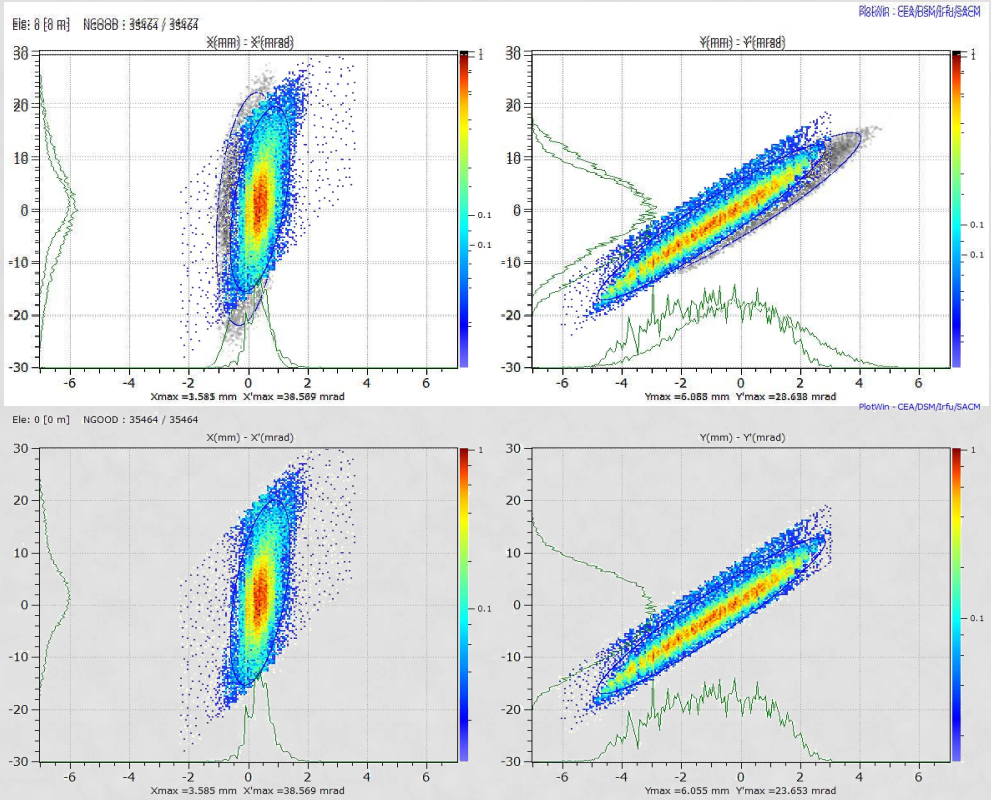
3-EMITTANCE OF THE THROUGH BEAM

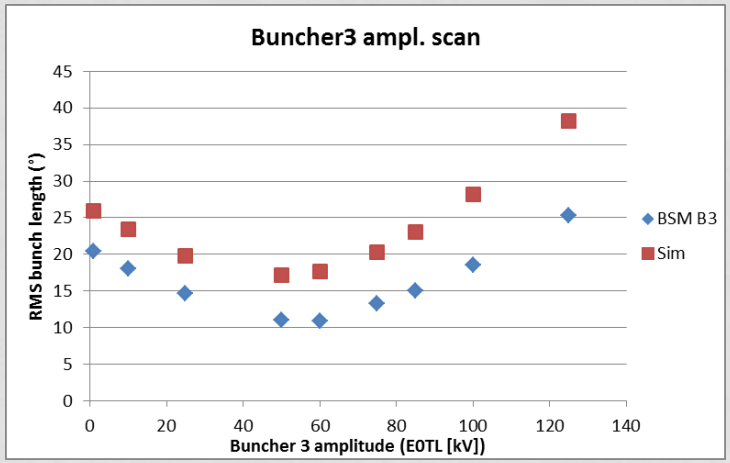




Emittance measured with chopper off (left) and with chopper on (right) downstream the inline dump

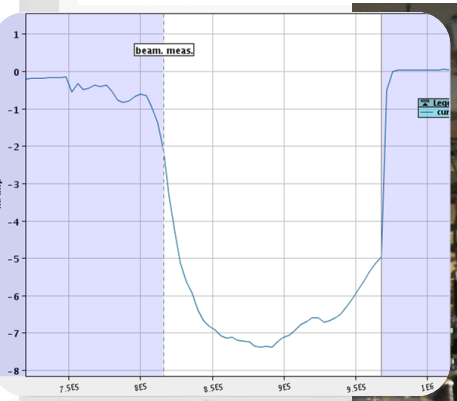
4-MATCHING TO THE DTL



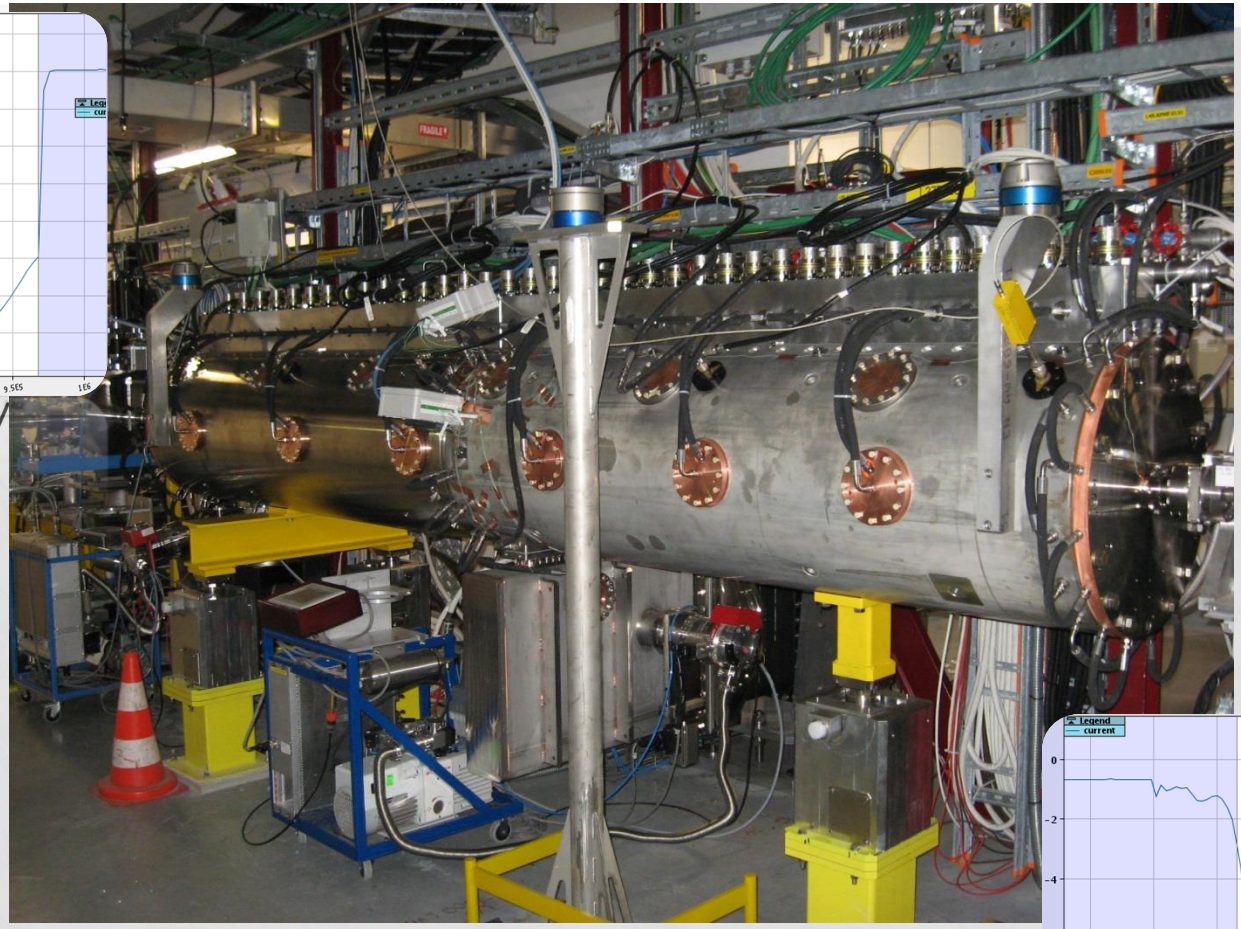


simulation codes (TraceWin and Travel) predict 95% transmission thru the DTL for the measured beam.

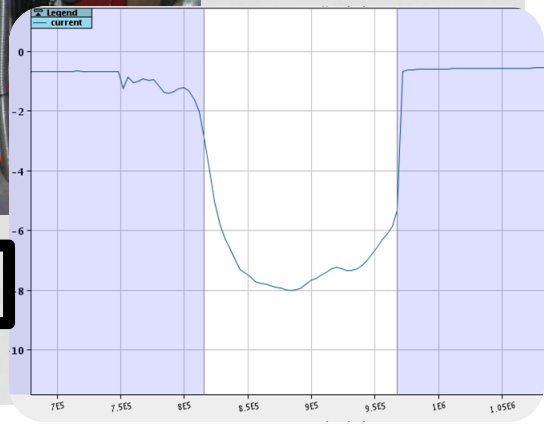
FROM 3 TO 12 MEV



BCT at 12 MeV



BCT at 3 MeV



August 6th , 7.5 mA going in, 7.5 mA accelerated

SO FAR …..

- Acceleration 45 keV to 12 MeV is validated
  - RFQ holds the voltage, accelerates and responds to changes in RF power
  - The chopper chops
  - DTL tank1 accelerates the beam without losses

EMITTANCE, ENERGY SPREAD, ETC ETC

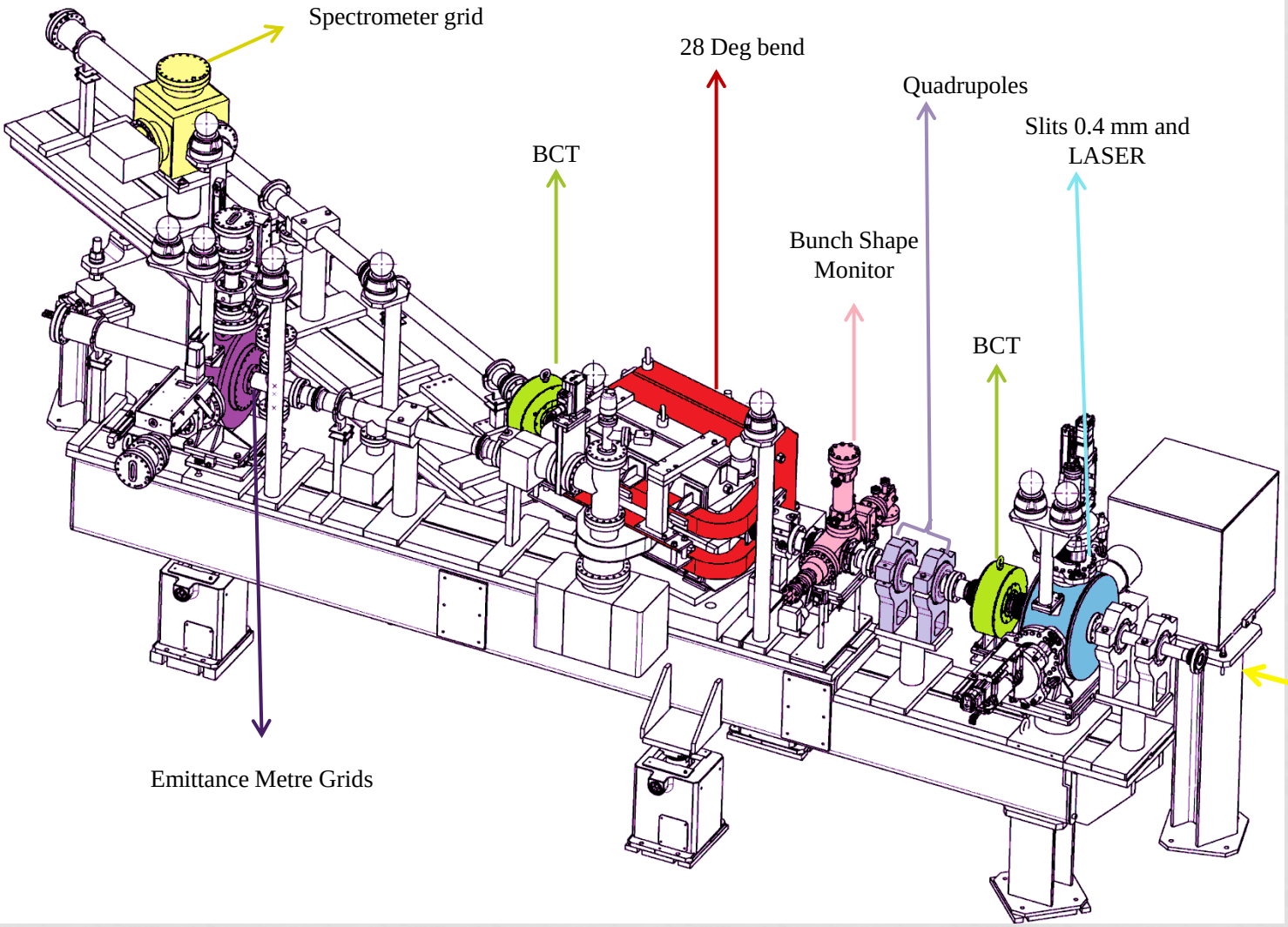
longitudinal emittance
is rms normalised
pi deg MeV

Deg at 352MHz

transverse emittance
is rms normalised
pi mm mrad

target value is 0.4

THE MEASUREMENT BENCH



Spectrometer

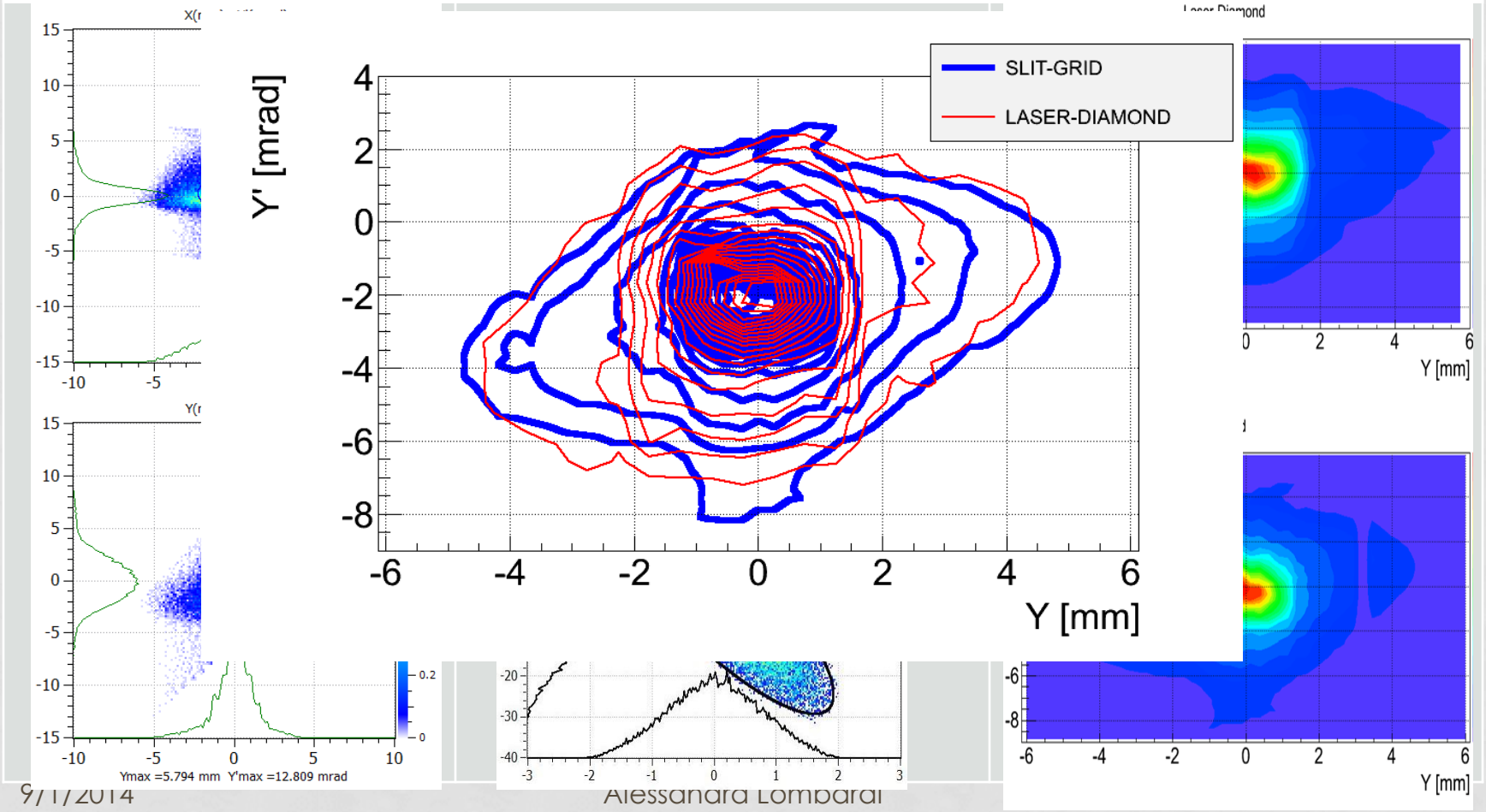
Bunch Shape Monitor

Slit and Grid Emittance

Laser + Diamond

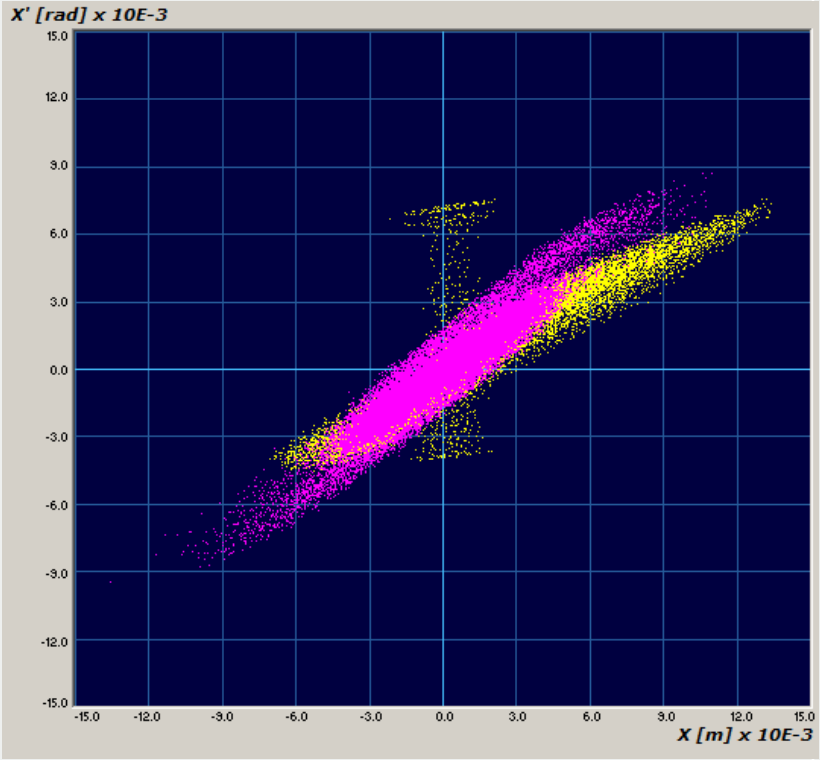
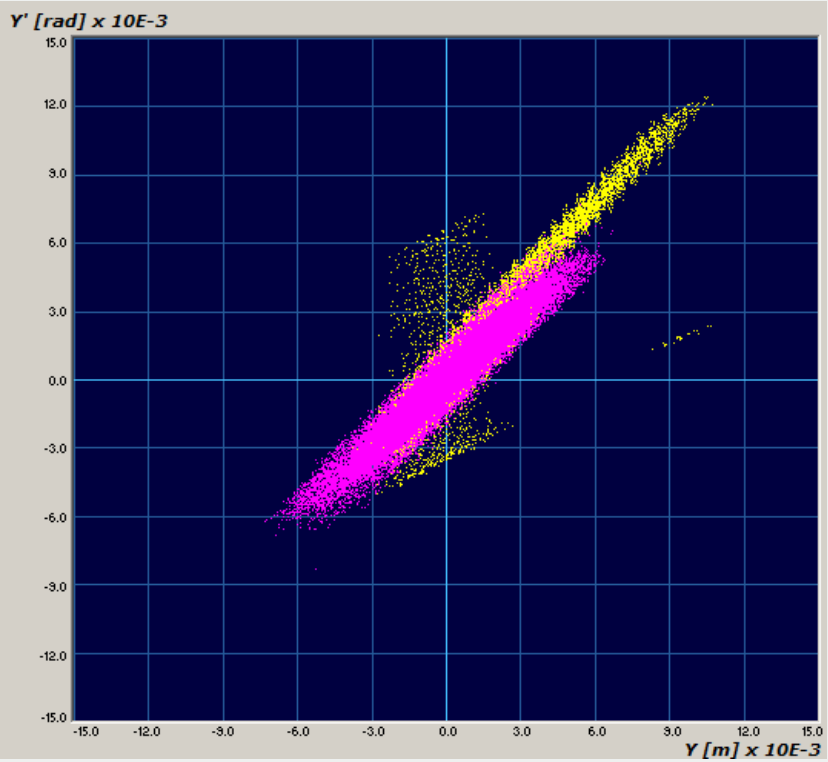
RMS NORMALISED TRANSVERSE EMITTANCE AT 3 MEV SEEMS TO BE 0.3 PI MM MRAD

Slit-and-grid	From profile meas	Laser + diamond



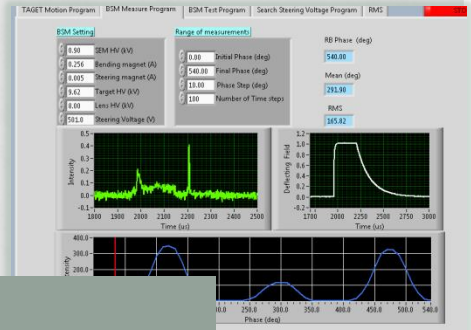
RMS NORMALISED TRANSVERSE EMITTANCE AT 12 MEV SEEMS TO BE WHAT WE EXPECT

Slit-and-grid (yellow) compared to expectation (pink)

Horizontal	Vertical
	

Emitt rms normalised = 0.35 π mm mrad

LONG EMITTANCE AT 3MEV-INDIRECT

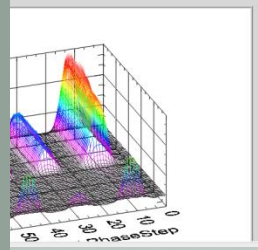


Reconstru

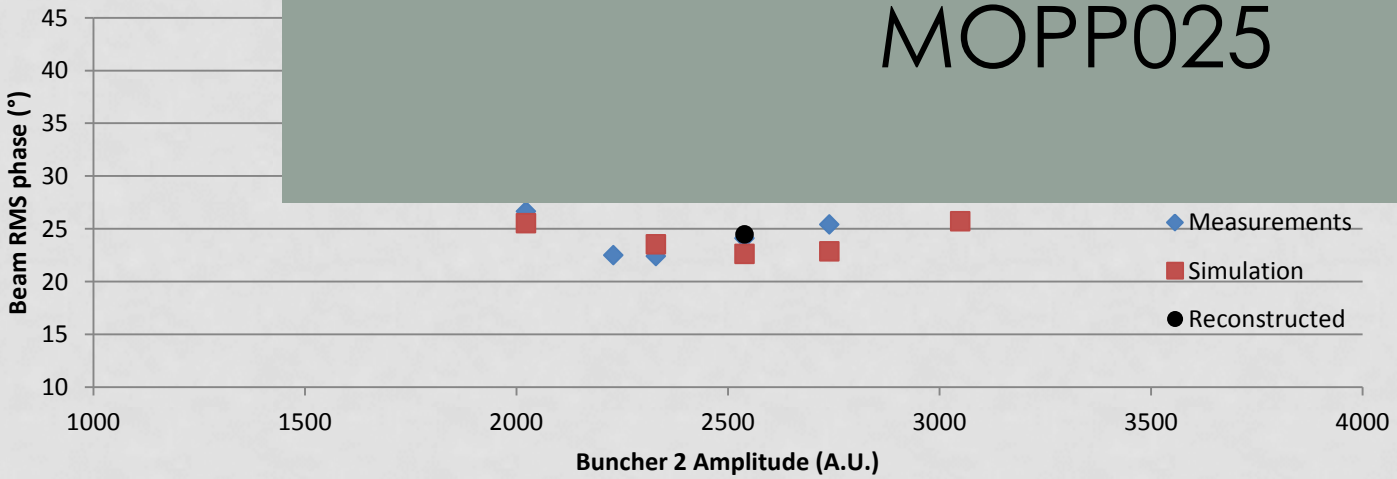
VISIT

THPP033/TUPP100

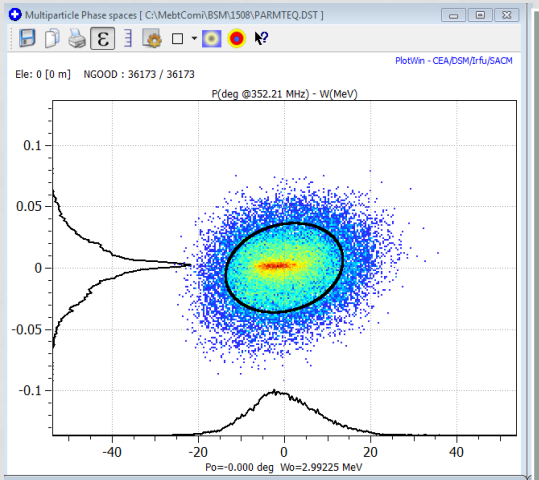
MOPP025

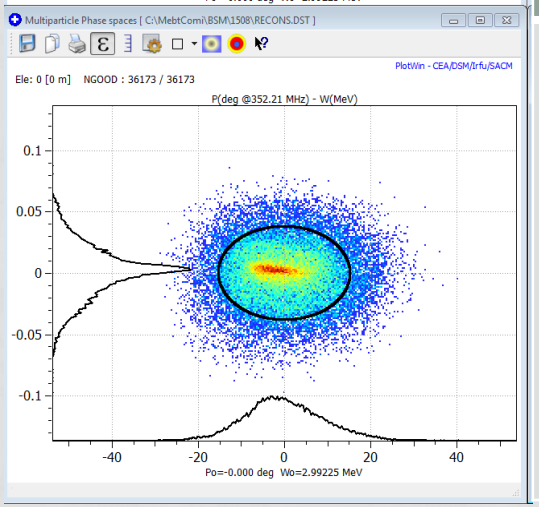


hape



LONG EMITTANCE AT 3 MEV -INDIRECT





Measured from phase profiles

Alpha=0.2
Beta =380. deg/MeV
Emitt =0.16 deg MeV

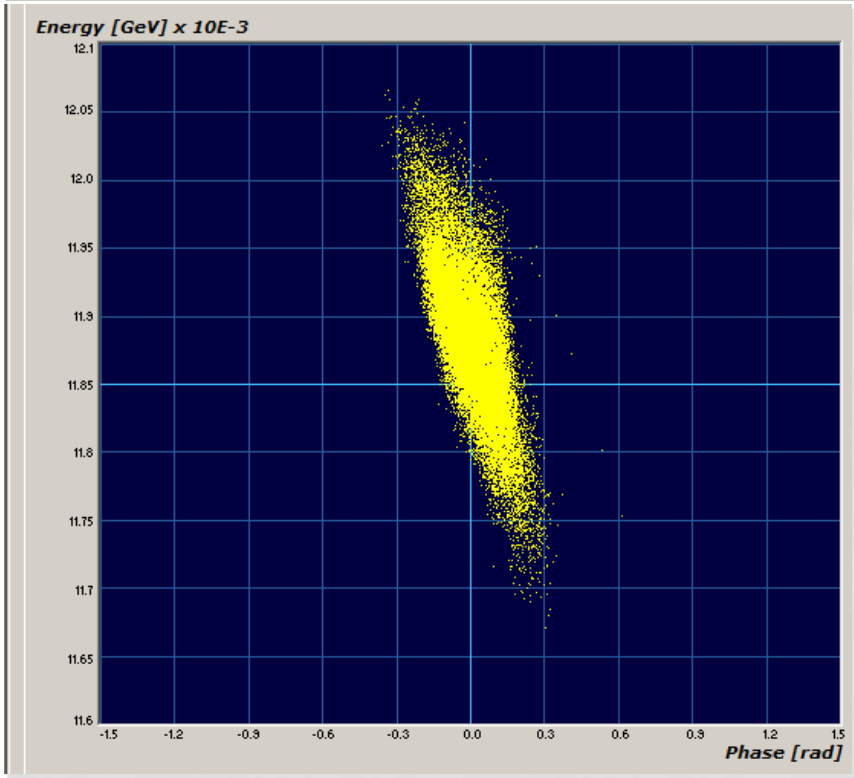
Expected from simulations :

Alpha= 0.0
Beta = 400 deg/MeV
Emitt = 0.19 deg MeV

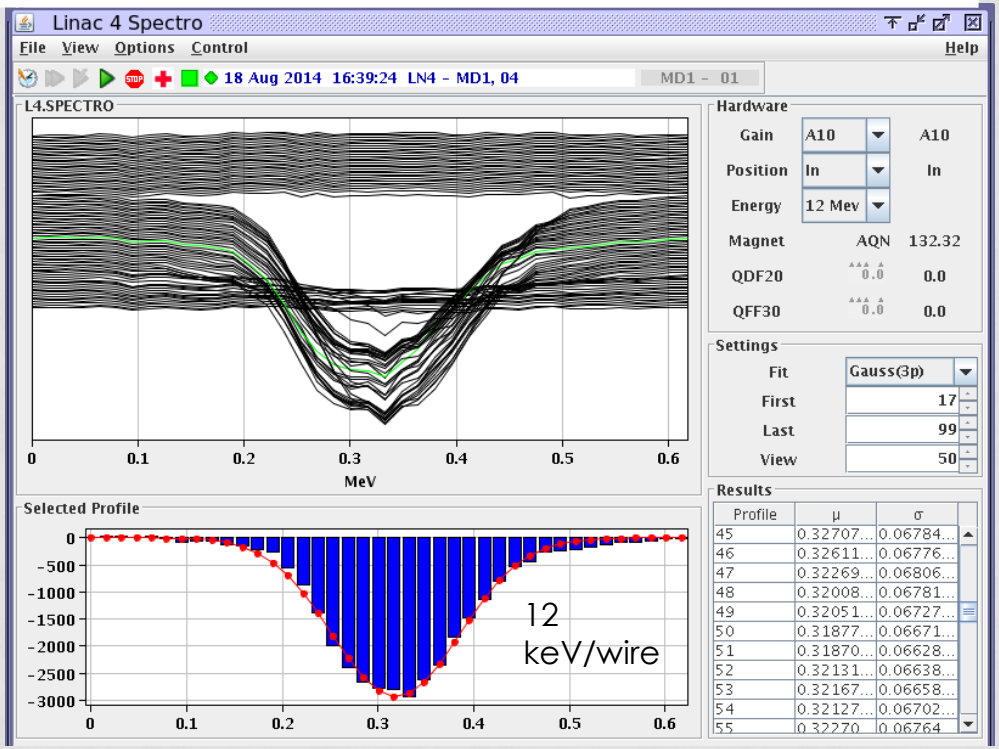
Energy spread
Expected from simu : 21 keV
Measured from phase : 22 keV
Spectrometre : 19 keV

SPECTROMETRE -AT 12 MEV

rms energy spread : 49.2 keV (simulations)



rms energy spread : 52.8 keV (measured)



SO FAR….

Acceleration 45 keV to 12 MeV is validated

Emittance Measurements confirm that the beam behaves according to code predictions. (PARMTEQ, PATH, TRACEWIN)

Reconstruction technique and diagnostic performance are validated !

Reconstruction is based on :

1) Finding first guess with conventional matrix inversion.
2) Fine tuning the guess by forward tracking and best fitting the measurement's data

(MISTAKES MADE AND)……LESSONS LEARNT

1) A 10 Watt beam (10mA, 3MeV, 300 μsec, 1Hz) can drill a hole through a bellow

2) Dia

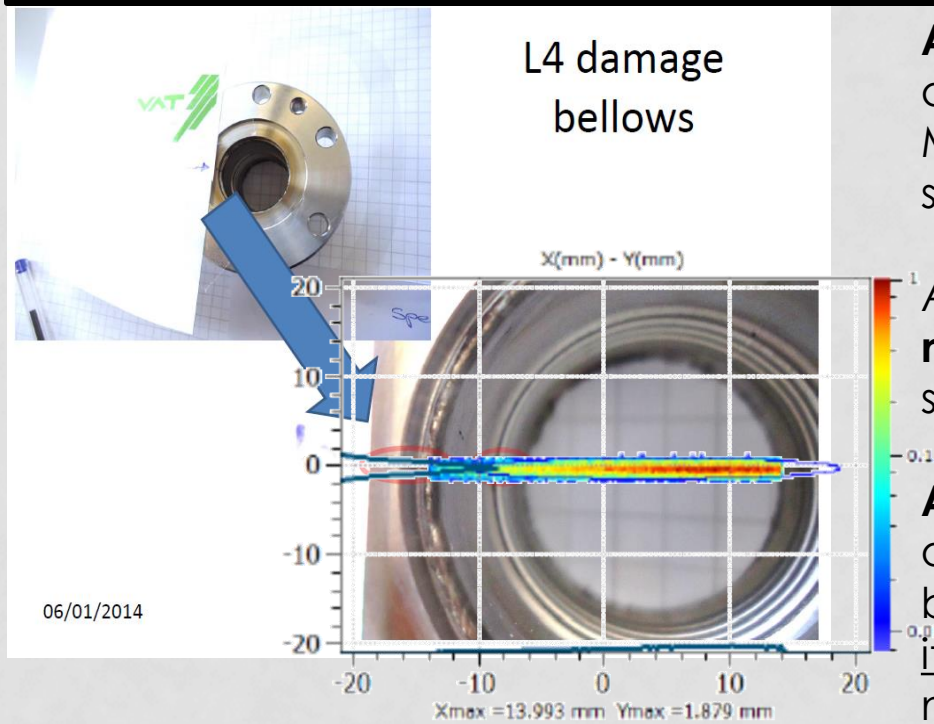
3) Effe

4) DTL tank1 can act as a longitudinal monitor

VISIT THPP033 and TUPP038

YOU CAN DO SO MUCH WITH SO LITTLE
(AND THIS IS NOT ALWAYS A GOOD THING)

On December 12 at 16:30 a severe vacuum leak was observed in the MEBT line. It was located on the bellow downstream the first buncher cavity, on the left side when looking down the beam line.

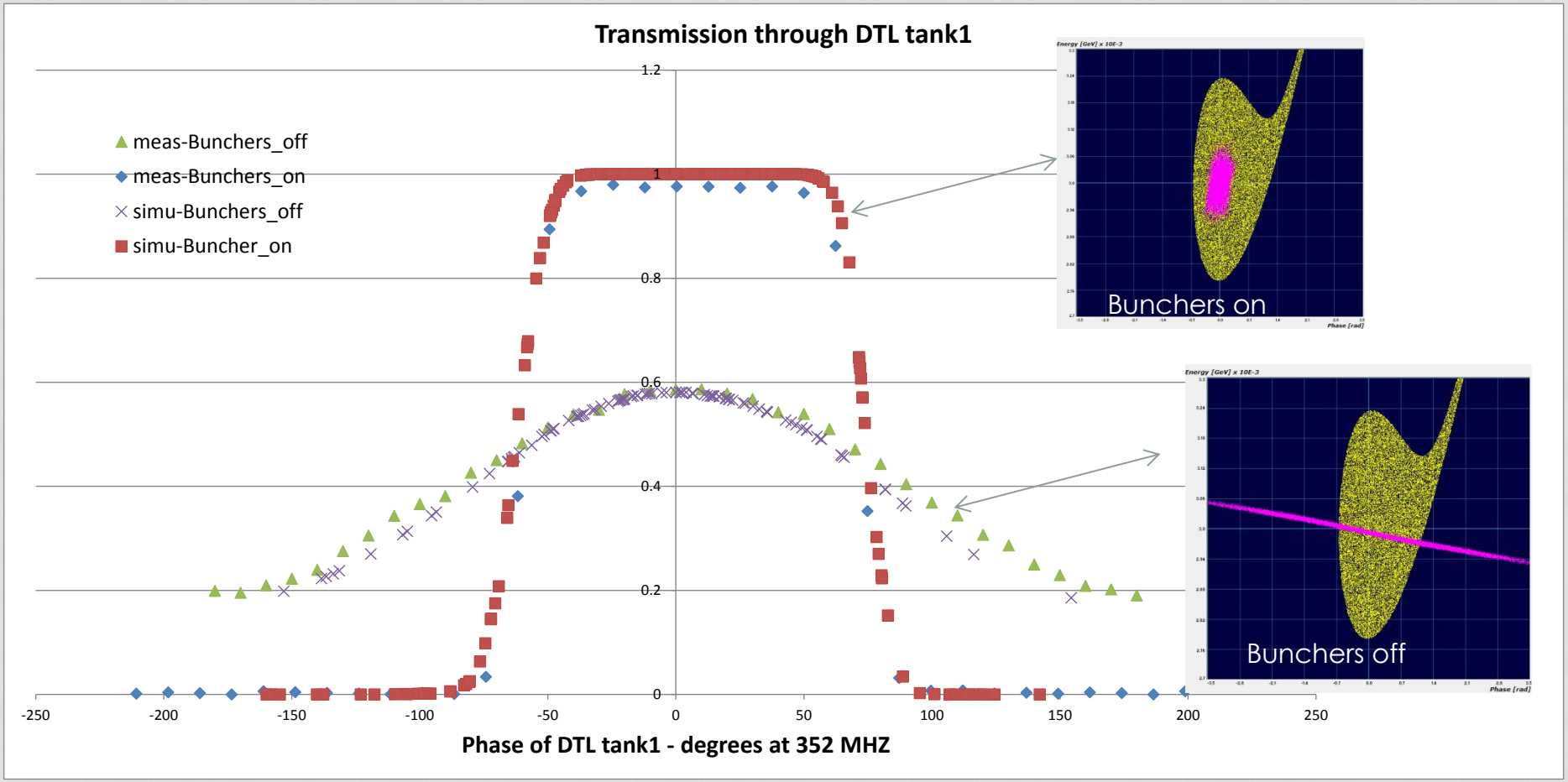


A severe misalignment between the RFQ and the MEBT that was not present at the 3 MeV test stand and was later confirmed by survey

An optic that favoured **amplification of this misalignment** whilst focusing the beam to sub mm size in the other direction

A phase advance such that the loss occurred on the "wave" (or lip) of the bellow which is only 200 microns thick and <u>it is an aperture limitation</u> (25.1 mm vs 28 mm of adjacent vacuum chamber).

DTL ACCEPTANCE AND BUNCHER SETTINGS



SUMMARY

- The LINAC4 has been commissioned up to 12 MeV with a temporary source. Only 148 MeV to go! (3 commissioning stages over 6 are done)
- **The agreement between measurement and simulations is very good**, thanks to the time we have dedicated to generate a distribution from measurements at the low energy end – HB2010. Simulation have been our guide and give us a hint of where to look in case of problems (e.g. alignment issues)
- **We have validated transverse and longitudinal emittance reconstruction methods** which will be extensively used for the next stages of commissioning
- We have not yet experienced full space charge effects, which will come with the new source.

VISIT THESES POSTERS!

- On longitudinal measurements : MOPP025
- On transverse measurements and reconstruction :
  THPP033/TUPP100 and TUPP038
- On the source : TUPP036
- On laser- based emittance measurement : TUPP035
- On the Radio Frequency Quadrupole : THPP037
- On the DTL : TUPP089, *SUPG018*, *THPP036, THPP0*
- On LLRF : THPP027