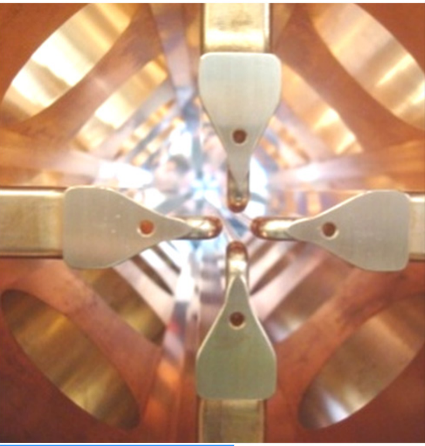
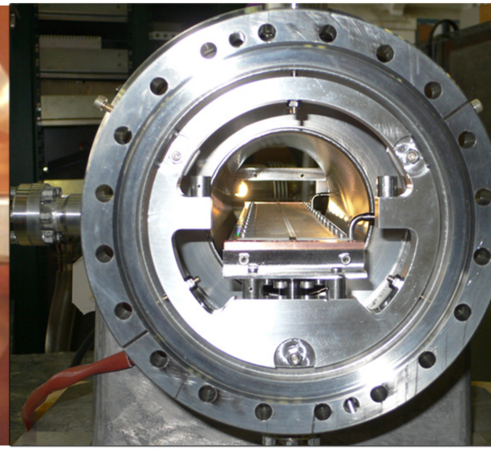
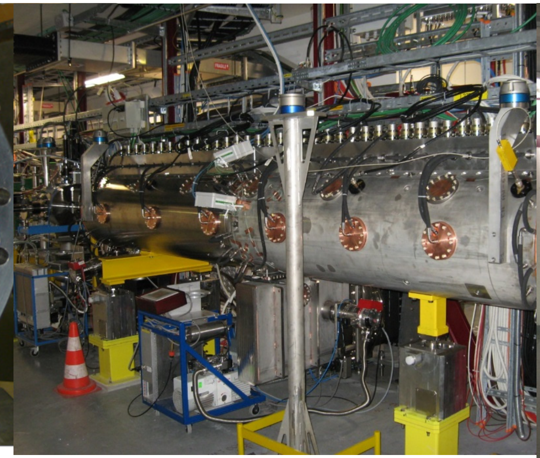
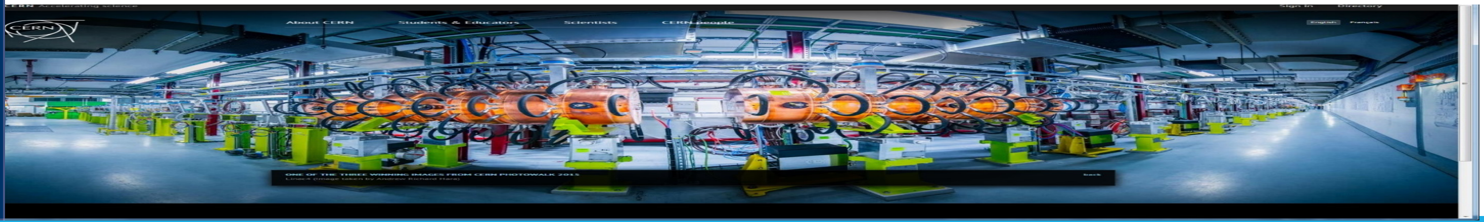





The LINAC4 project

ALESSANDRA M LOMBARDI FOR THE LINAC4 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

Current from the linac

-peak current (space charge effects) stays the same through the linac,

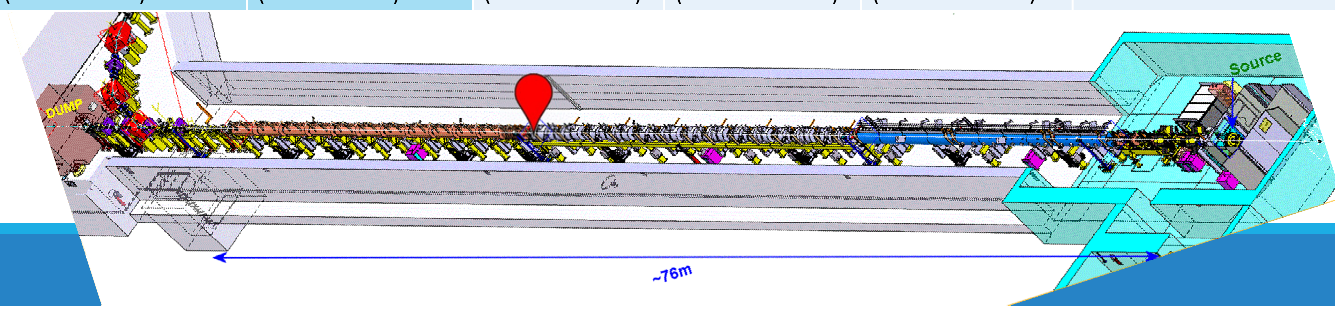
-average current along the bunch : determined by the chopping pattern, typically 50% less

-number of protons in the PSB : average current x number of turns (limited by emittance in the PSB)

-requirement on the peak current from the source depend on the injection scheme in the PSB see **THPM9X01**.

Status of commissioning / installation

LINAC4 machine layout- 352MHz					
Pre-injector (9m)		DTL (19m)		CCDTL (25m)	Π-mode (23m)
3MeV		50 MeV		100 MeV	160 MeV
SOURCE Plasma Generator Extraction e-Dump LEBT 2 solenoids Pre chopper	RFQ CHOPPER LINE 11 EMQ 3 Cavities 2 Chopper units In-line dump	3 Tanks 3 Klystrons : 5 MW 1 EMQ 114 PMQ 2 steerers		7 Modules 7 Klystrons : 7 MW 7 EMQ + 14 PMQ 7 steerers	12 Modules 8 Klystrons: 12MW 12 EMQ 12 steerer
Beam Commissioning stages					
45 keV	3 MeV	12 MeV	50 MeV	105 MeV	160 MeV
Not yet the final source – details later (50mA standalone) (30mA-Nov15)*****	Octobre 2013 (10mA- Aug 14) (30mA-oct 15) (20mA-Nov15)	August 2014 (10mA- Aug 14) (20mA – Nov15)	November 2015 (20mA – Nov 15)	June 2016 (20mA – June16)	Octobre 2016



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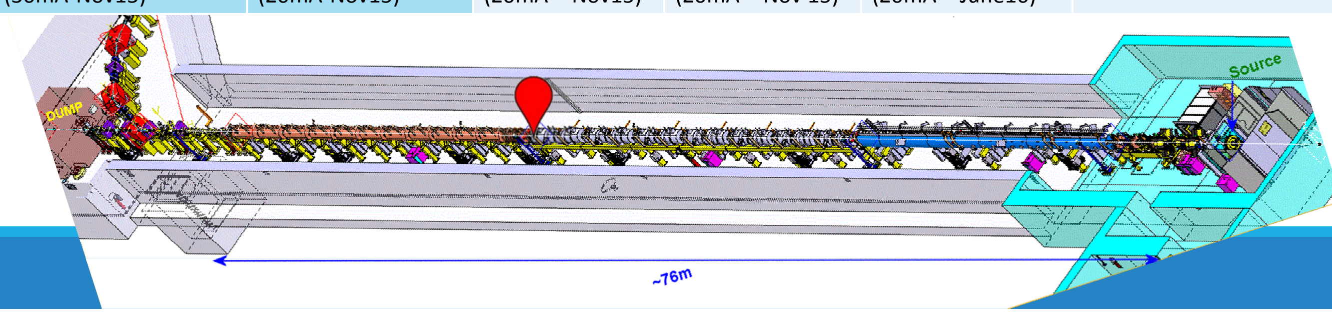
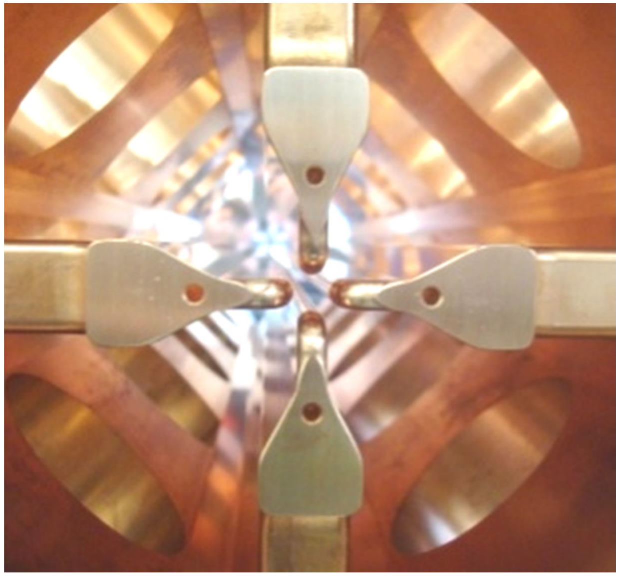
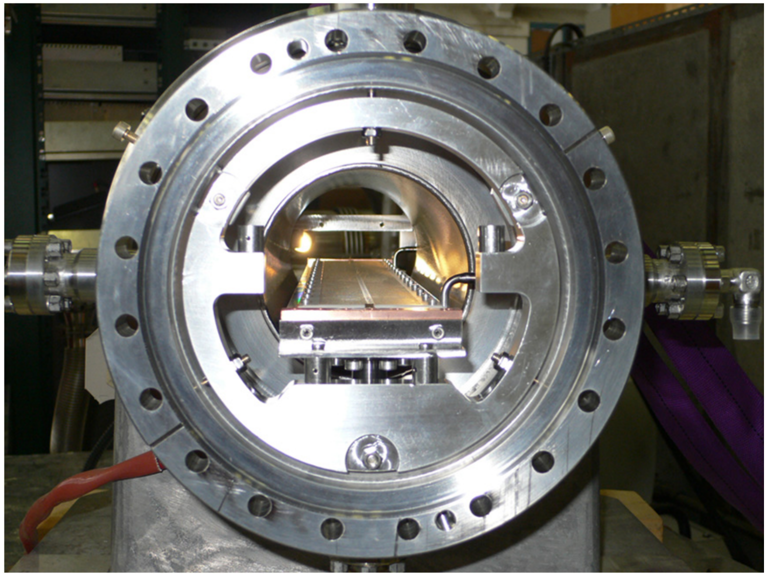


Preinjector

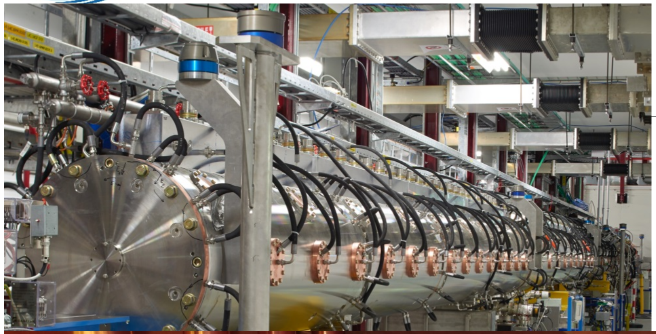


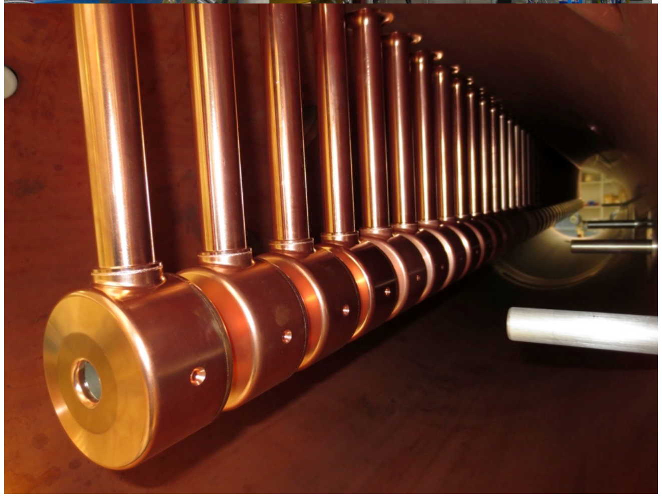
3 MeV/ 352 MHz/ 3 m long RFQ
Commissioned with beam 2013



Fast chopper, functionality validated 2013
Risetime<10nsec/ extinguish factor 100%

DTL



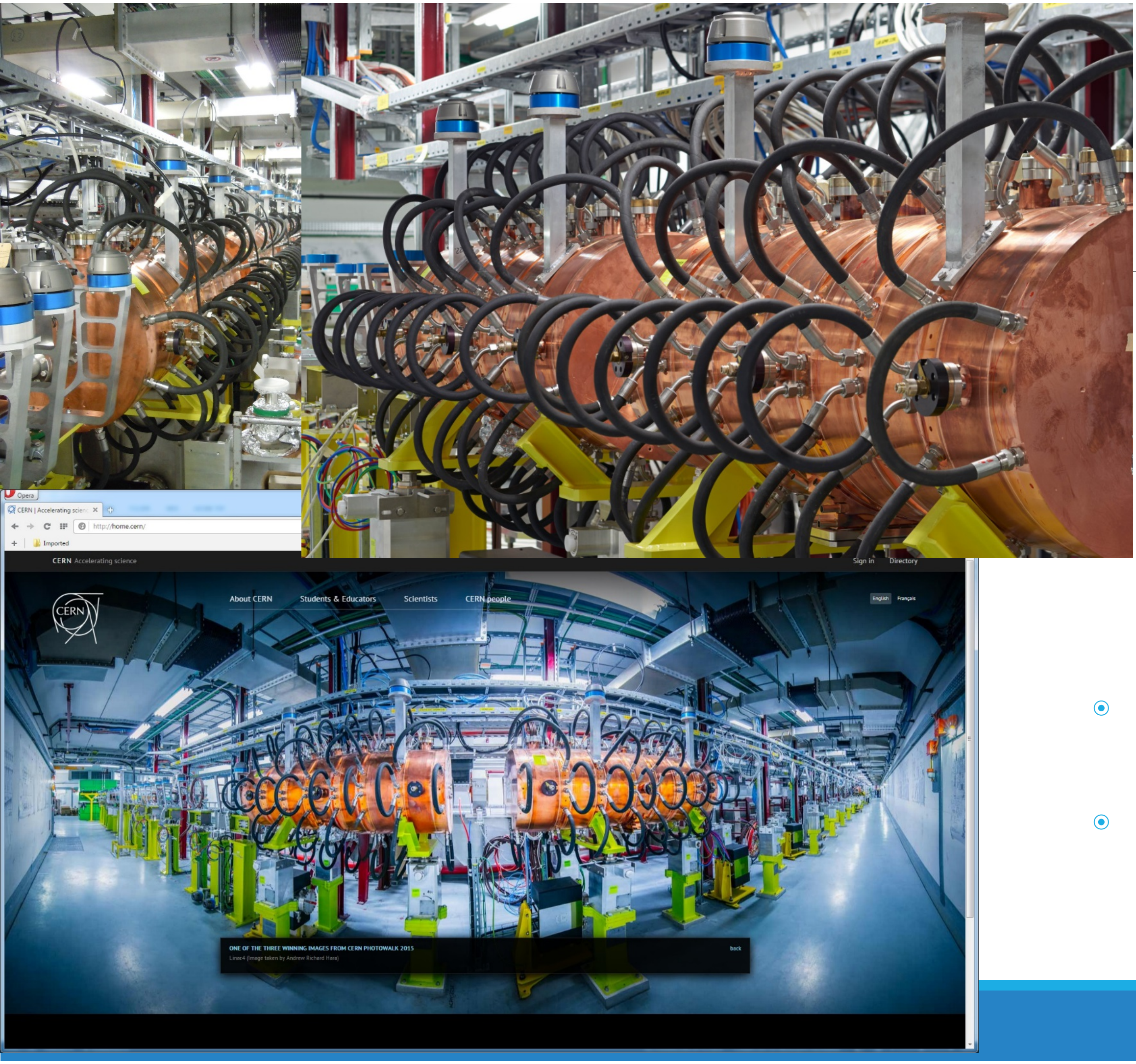


- Designed for ≥30 years of reliable operation with up to 10% duty cycle
- Rigid self supporting steel tanks assembled from <2m long segments
- Tank Design almost without welds, heat treated after rough machining
- PMQs in vacuum for streamlined drift tube assembly
- Adjust & Assemble: Tightly toleranced Al girders w/o adjustment mechanism
- Spring loaded metal gaskets for vacuum sealing and RF contacts
- Easy to use patented mounting mechanism
- Additional C-seal and temperature probe channel employed for leak testing
- Increased gap spacing in first cells of T1 to reduce breakdown in PMQ fields
- Cooled RF-port & vacuum grid in AISI 304L tank for 10% duty-cycle

CCDTL

- construction by BINP and VNIITF in Russia, assembly at CERN
- 7 modules of 3 accelerating cavities (3 gaps each) and 2 coupling cells,
- quadrupoles outside of RF structure,
- copper plated stainless steel,
- time-consuming assembly because of high number of C-shaped metal seals, several attempts necessary to achieve vacuum tightness,
- around 1 month of conditioning needed to clean surfaces,
- non-trivial support mechanics because of 12 support points per module,
- all drift tube centres are aligned within ±0.1 mm
- first-ever CCDTL in a working machine!

PIMS



- Bulk copper, no RF seals, discs and rings are tuned and electron-beam welded at CERN
- Long qualification period for series production (~3 years), critical point was precision machine large pieces of copper (10 - 20 um on 500 mm diameter pieces)
- Conditioning time of prototype: 24 hours
- First low-beta pi-mode structure to go into operational machine

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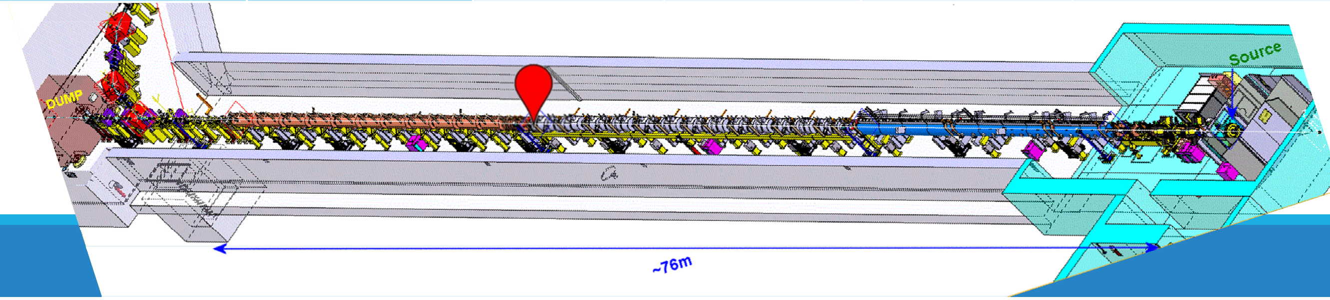

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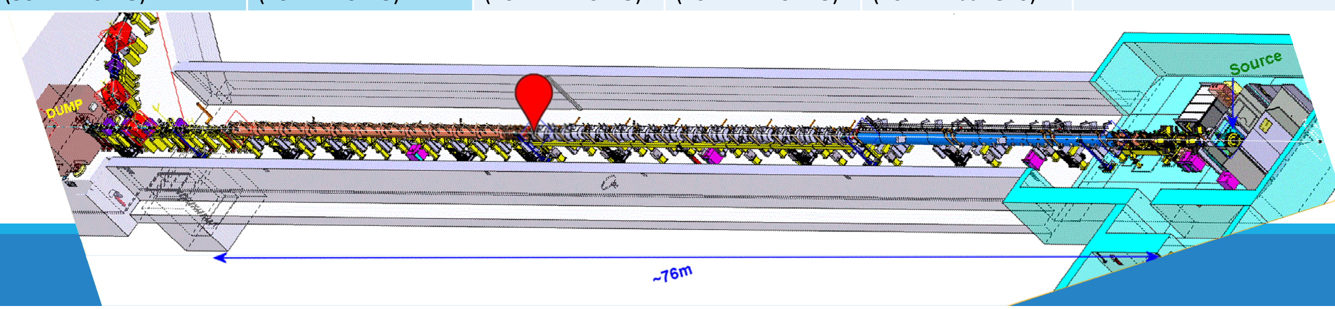


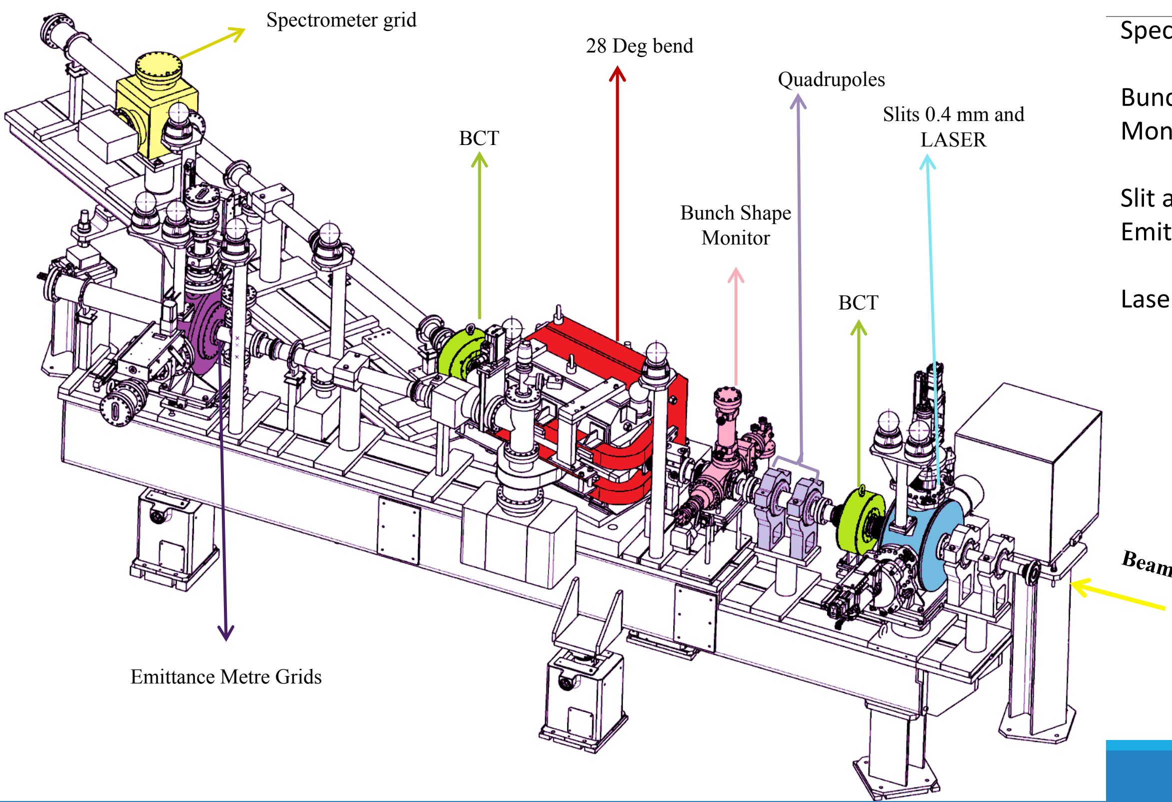
Commissioning (and an eye to operation)

- up to 12 MeV : direct measurement of emittance and spectrometer

-from30 MeV : indirect measurements only with a dedicated bench (extra diagnostics)

-eventually : only the diagnostics integrated in the linac itself

The low energy measurement bench



Spectrometer

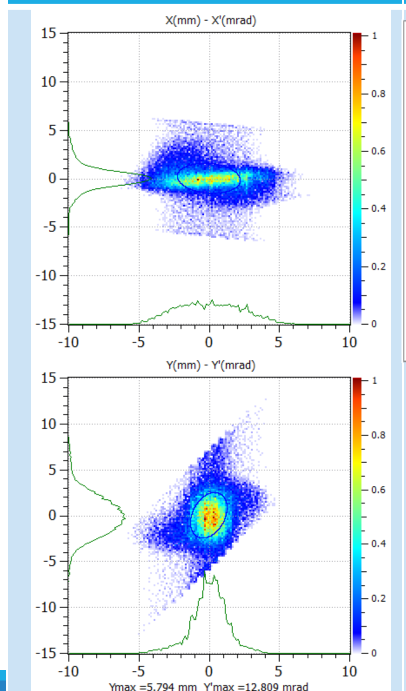
Bunch Shape Monitor

Slit and Grid Emittance

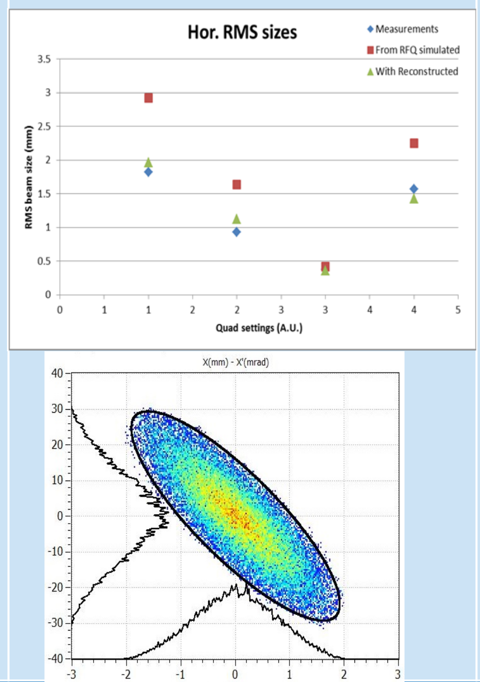
Laser + Diamond

rms normalised Transverse emittance At 3 MeV seems to be 0.3 pi mm mrad

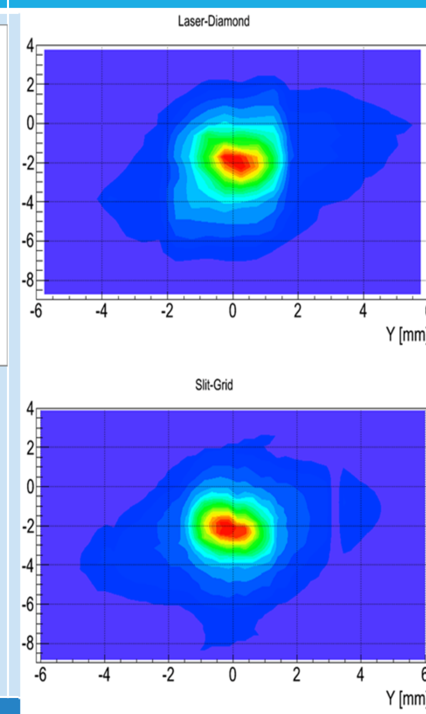
Slit-and-grid



From profile meas

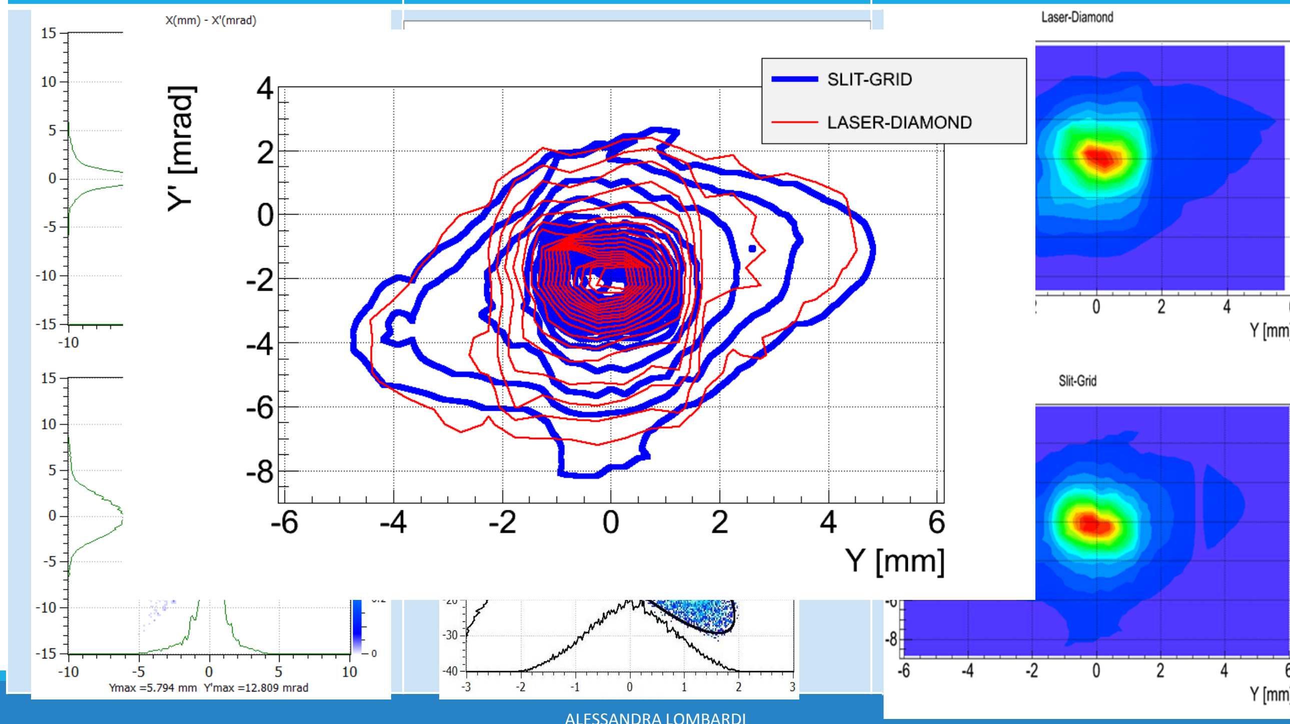


Laser + diamond



rms normalised Transverse emittance At 3 MeV seems to be 0.3 pi mm mrad

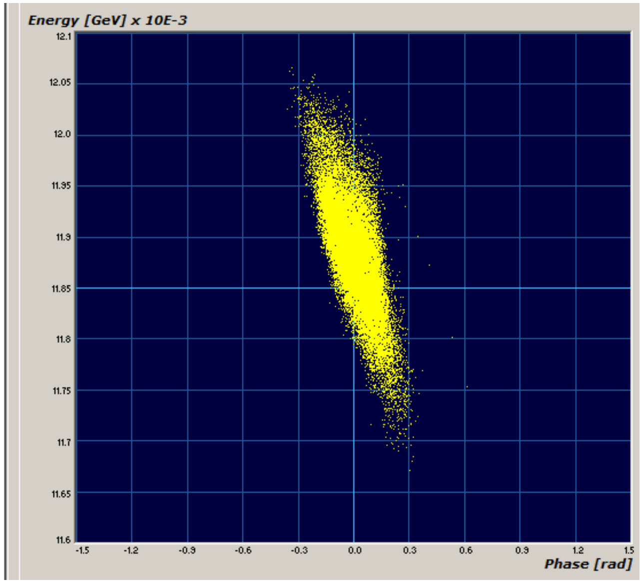
Slit-and-grid	From profile meas	Laser + diamond

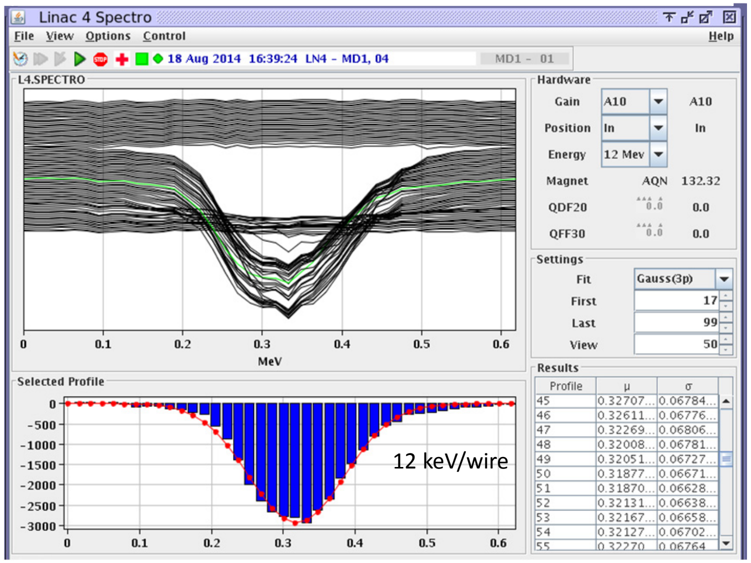


Spectrometre -At 12 MeV

rms energy spread : 49.2 keV (simulations)

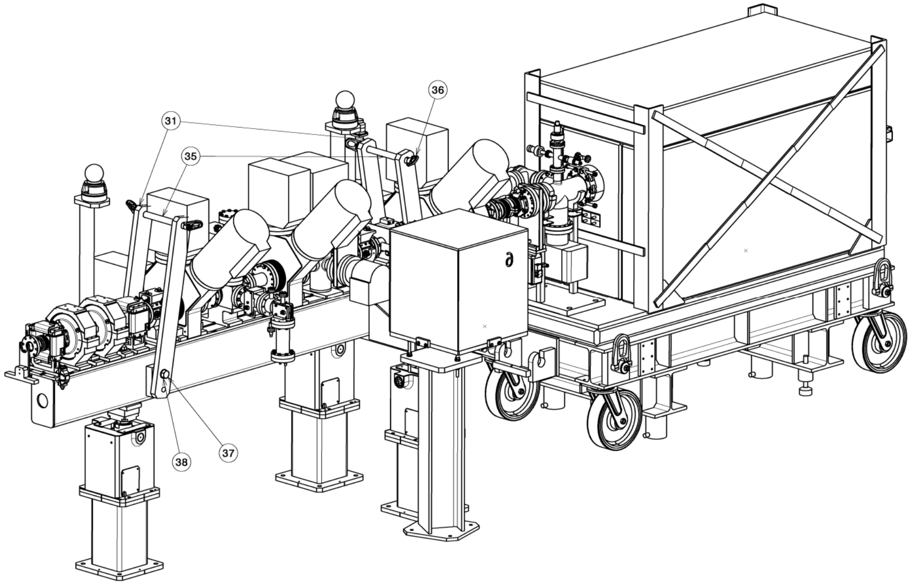
rms energy spread : 52.8 keV (measured)





High energy bench at 50 MeV

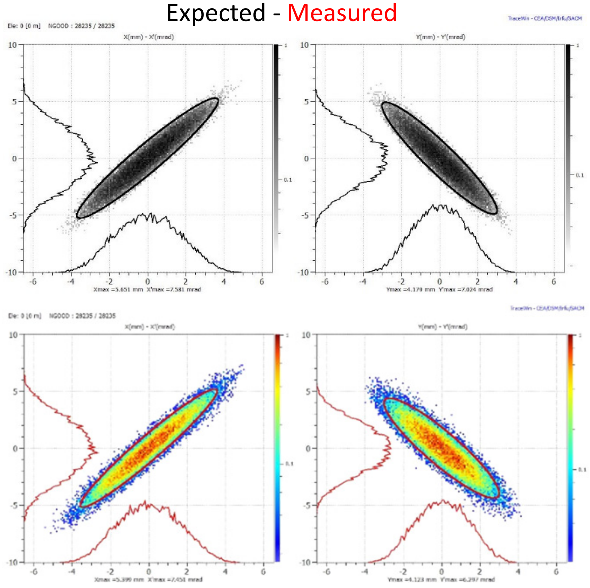
1) Three profile harps and 3 wire scanners at the appropriate phase advance (about 60degrees) for an indirect emittance measurement
2) A Bunch shape Monitor
3) A lasing station (transverse profile measurement via stripping)
4) Monitors for Time o Flight



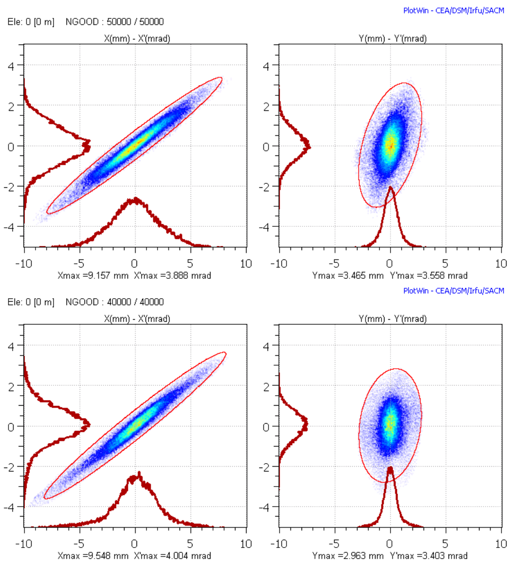
Emittance at 50 MeV and 80 MeV

Transverse emittance at 50MeV

Expected - Measured



Transverse emittance at 80MeV



2D transverse phase space reconstructed from profile measurements using

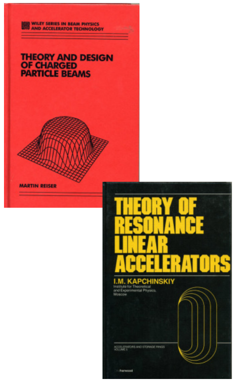
“Forward method”

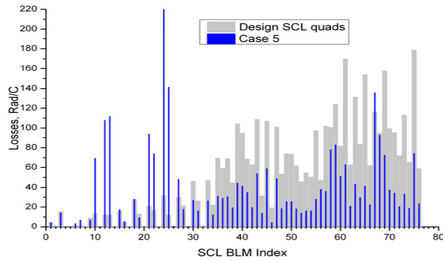
“Tomographic reconstruction techniques”

see **WEPM1Y01**

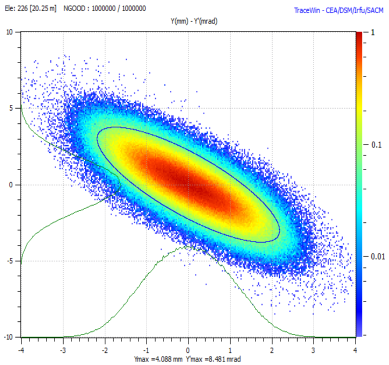
Why such a good agreement?

Let me bring you back to HB2010 WG-B report talk : shall we go by ……





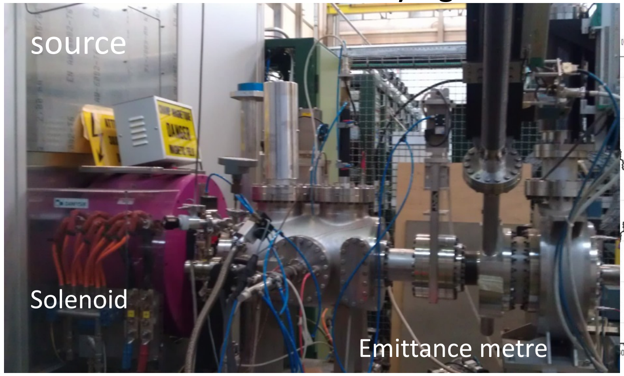
Empirical optimisation of the loss pattern by reducing quadrupole gradients?   TH01A03

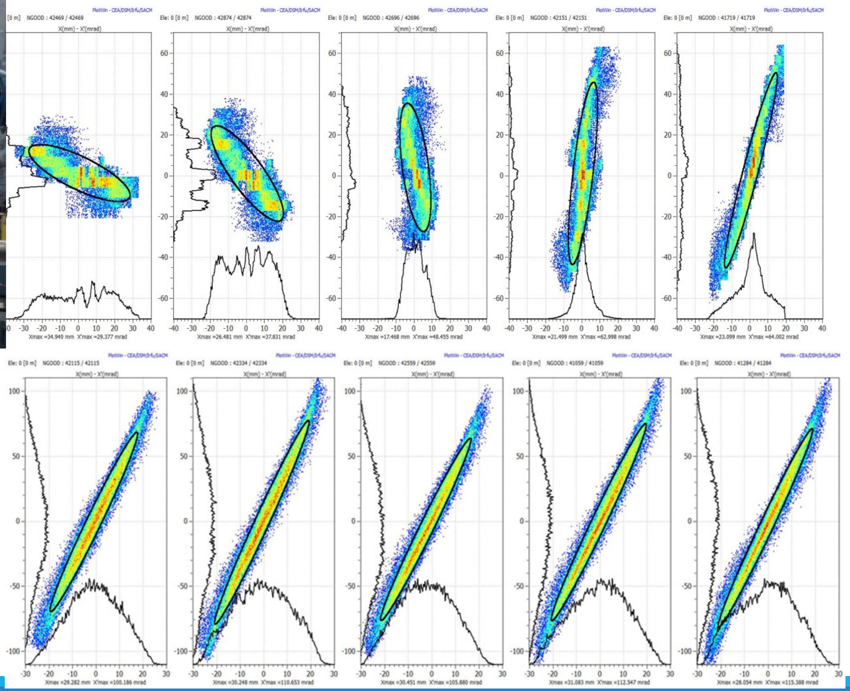


Measured beam input distribution which includes halo pre-existing in the beam.

Extensive measurements at 45 keV

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



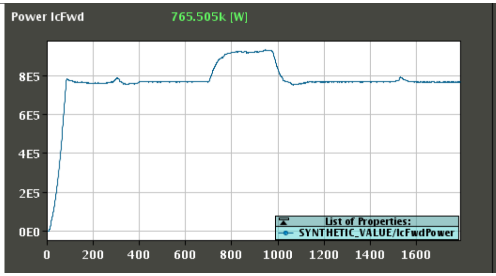


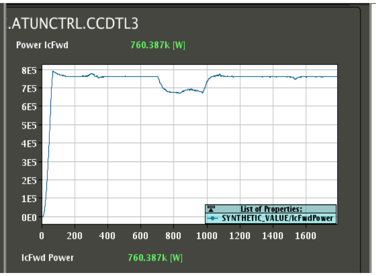
2 – back-trace to source out

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

Setting longitudinal parameters

1) observation of beam loading



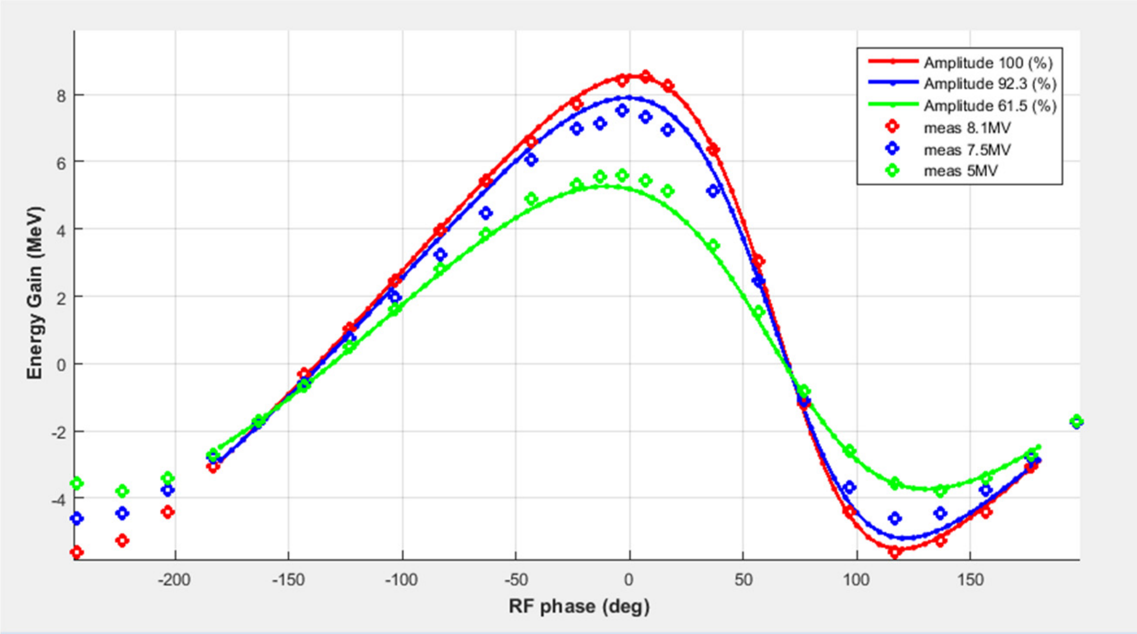


2) time- of- flight

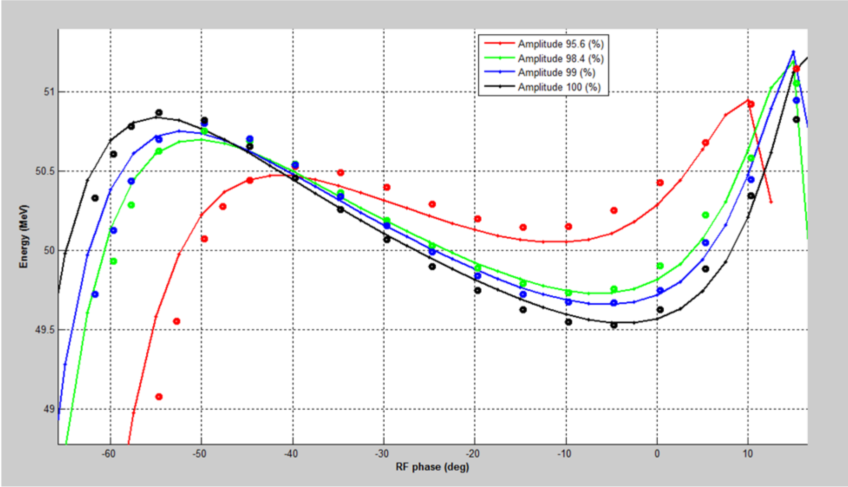
3) observing the transmission through a the RF bucket of a cavity located downstream

4) reconstruction of longitudinal emittance from phase profile measurements (see **WEPM1Y01**)

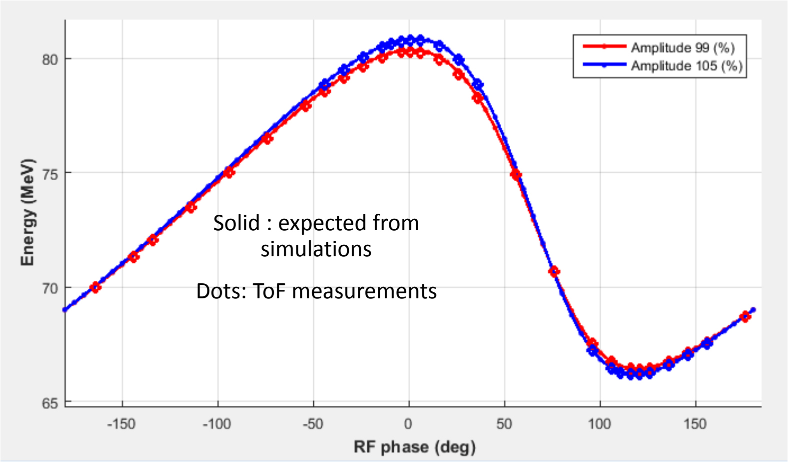
Energy gain from beam loading vs phase



Time-of-flight

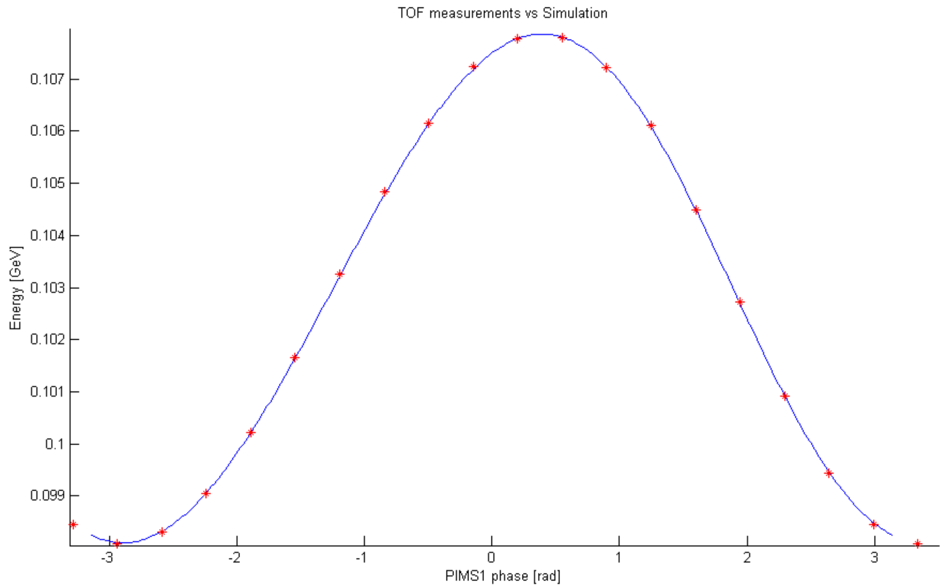


50 MeV : Energy measurement vs DTL tank3 Phase for different amplitudes

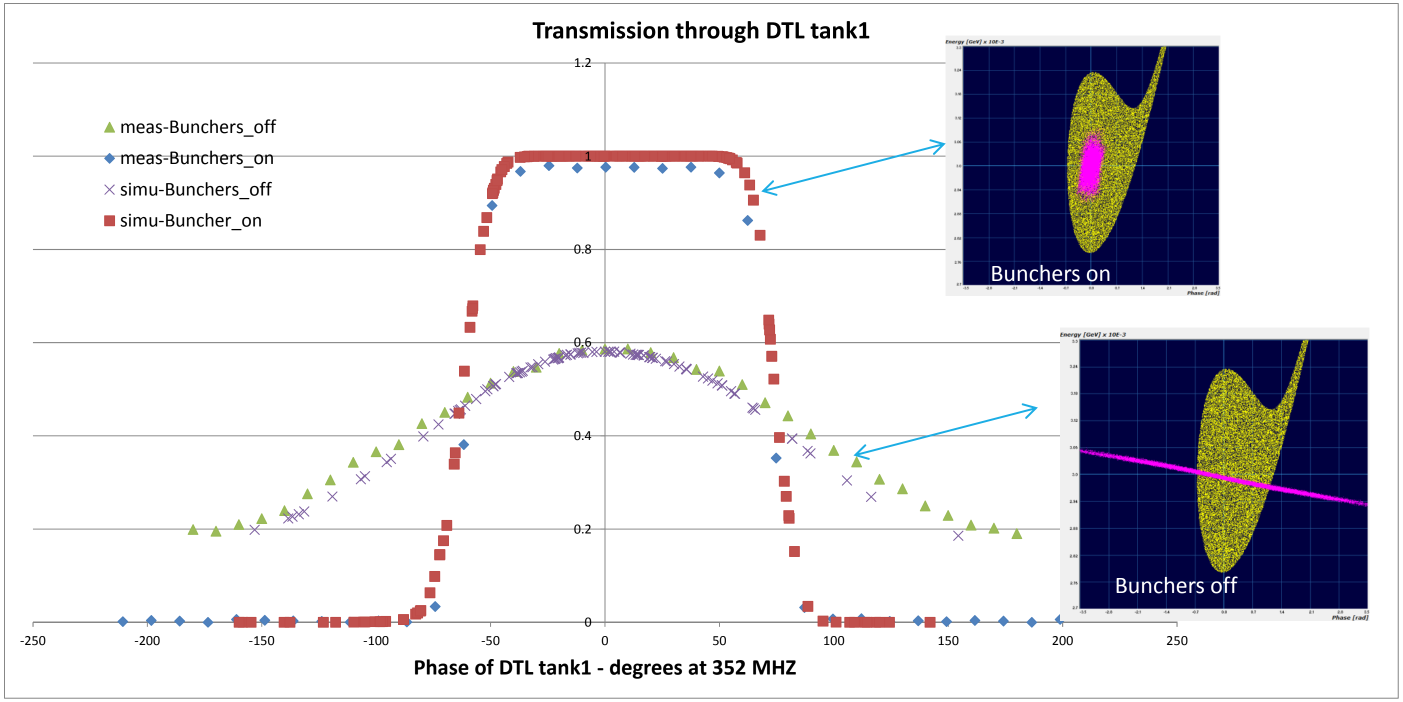


80MeV : Energy measurement vs CCDTLmodule4 Phase for different amplitudes

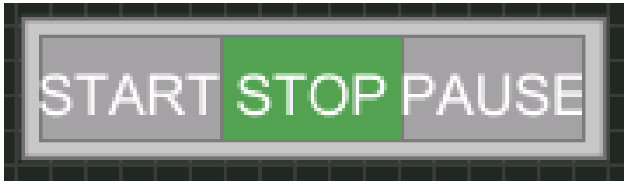
Time of flight at 105 MeV

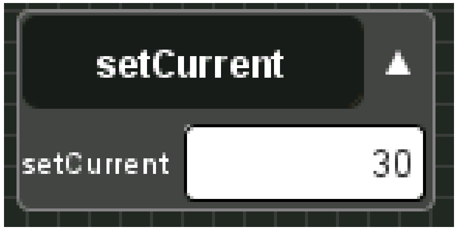


DTL acceptance and buncher settings



Autopilot for the H- source

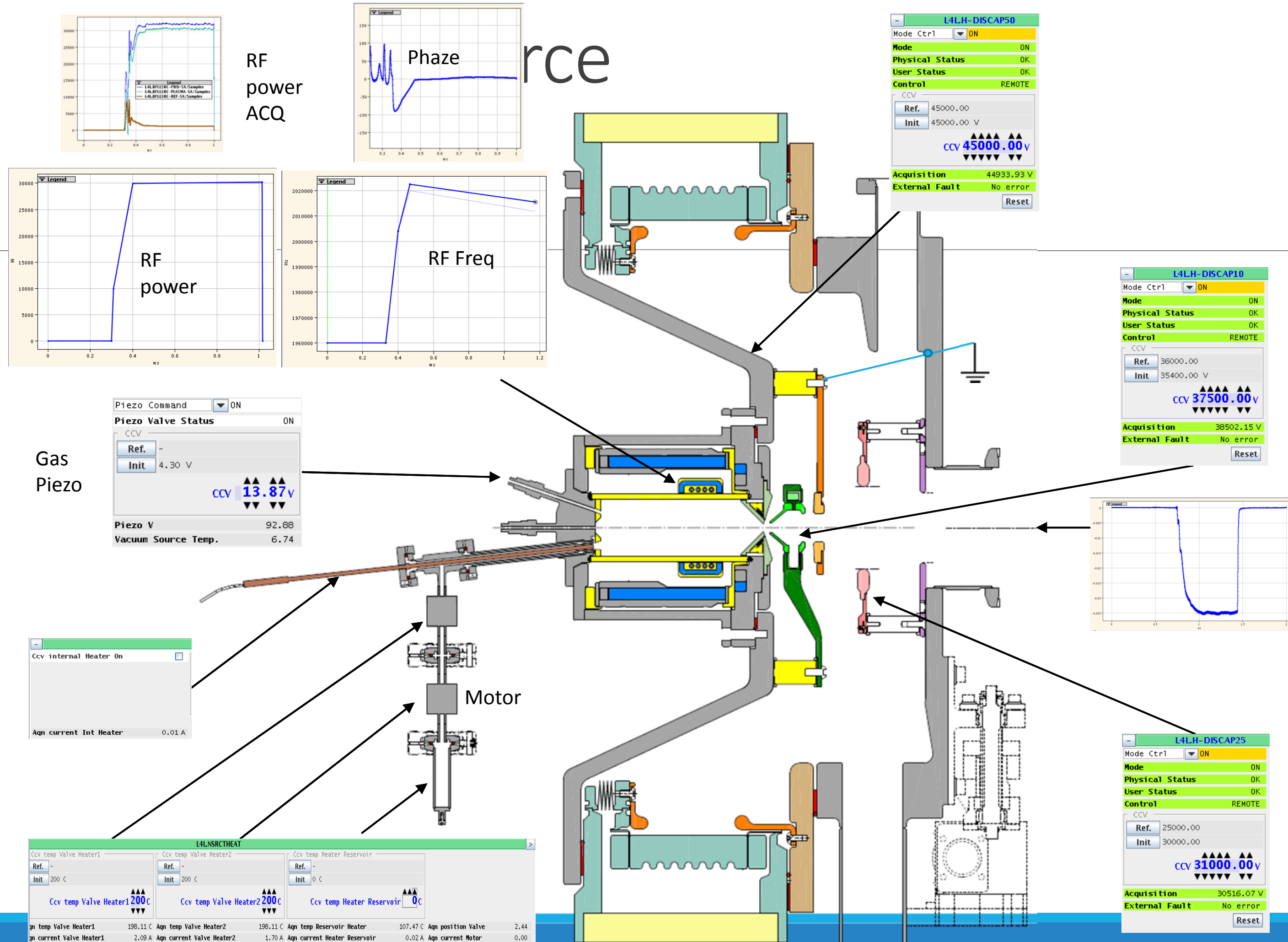




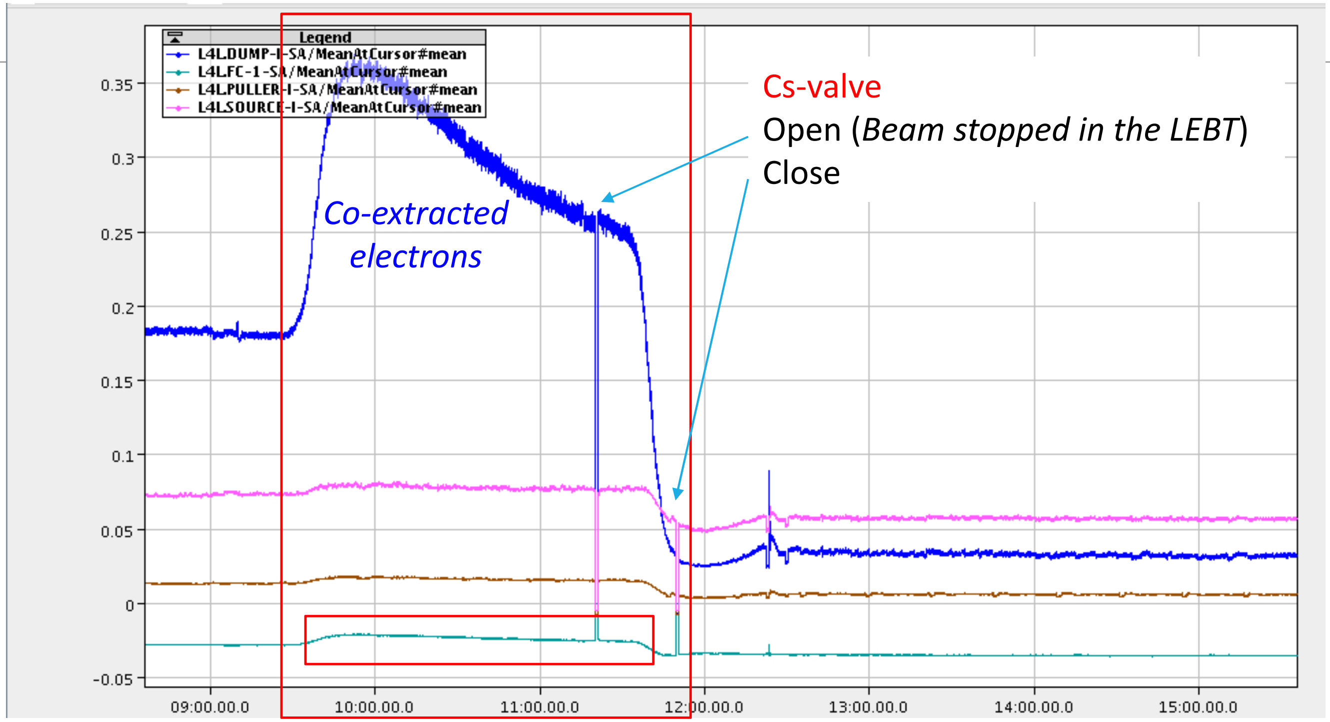
Autopilot:

- Linac4 IS Operates with monthly cesiations:
  - All plasma parameters slowly drift
  - Tuning of the RF-frequency and power
  - Tuning of the pulsed hydrogen injection

rce


RF
power
ACQ
Phaze
RF
power
RF Freq
L4LH-DISCAP50
Mode Ctrl ON
Mode ON
Physical Status OK
User Status OK
Control REMOTE
Ref. 45000.00
Init 45000.00 V
CCV 45000.00 V
Acquisition 44933.93 V
External Fault No error
Reset
L4LH-DISCAP10
Mode Ctrl ON
Mode ON
Physical Status OK
User Status OK
Control REMOTE
Ref. 36000.00
Init 35400.00 V
CCV 37500.00 V
Acquisition 38502.15 V
External Fault No error
Reset
Gas
Piezo
Piezo Command ON
Piezo Valve Status ON
Ref. -
Init 4.30 V
CCV 13.87 V
Piezo V 92.88
Vacuum Source Temp. 6.74
Ccv internal Heater On
Aqn current Int Heater 0.01 A
Motor
L4LH-DISCAP25
Mode Ctrl ON
Mode ON
Physical Status OK
User Status OK
Control REMOTE
Ref. 25000.00
Init 30000.00
CCV 31000.00 V
Acquisition 30516.07 V
External Fault No error
Reset
L4LNSRCTHEAT
Ccv temp Valve Heater1 200 C
Ccv temp Valve Heater2 200 C
Ccv temp Heater Reservoir 0 C

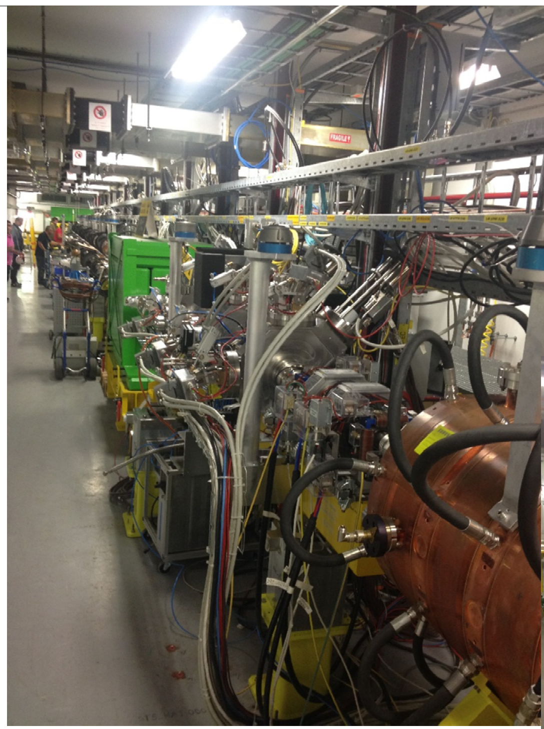
Cesiation under Autopilot



e/H too high - > Dump current too high -> RF power maxed out -> H- current reduced, yet stable

Autopilot kept conditions optimal, despite temperature variations caused by heating of Cs.

Linac4 Installation : almost completed



What next – planned activities

Complete the commissioning until 160MeV

Half-sector test

Reliability run – test bed for reliability models and fault recovery schemes

Half Sector Test (HST) – Mitigate Risks for Future PSB H^- Injection Section

No experience at CERN with H^- charge-exchange injection →

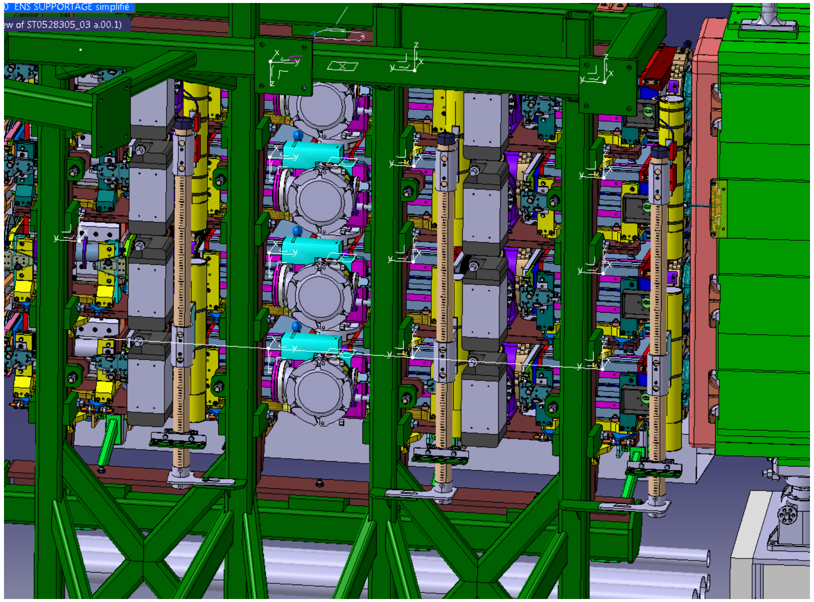
Extremely compact and complex section (4 rings and very limited space) LS2

Performance evaluation of future H^- injection equipment:

- **H^- stripping foil unit** (stripping foil efficiency etc.), injection **chicane magnets** with integrated **H^0/H^- monitor** and **dump** for unstripped/partially stripped particles**, instrumentation** (stripping foil current monitor, sensitivity check for H^0/H^- monitor, viewing screen at stripping foil location , diamond and ionisation chamber BLMs)**, interlocks, controls**…

Input for potential design modifications if Linac4 connection in LS2

Operational experience with new hardware and controls to reduce PSB re-commissioning times



Potential

The peak current limit for beam stability is 80mA – 3 times what we run today

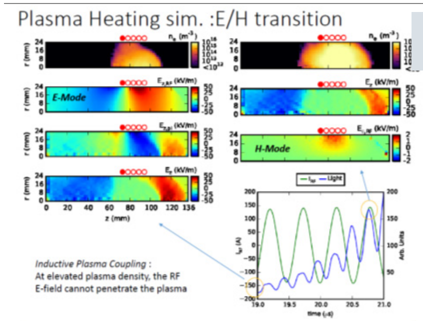
The duty cycle limit is 5% - 10 times what we run today

The chopping pattern (sequence of 352MHz micro-bunches) is extremely flexible and can be repeated at frequency up to 20MHz.

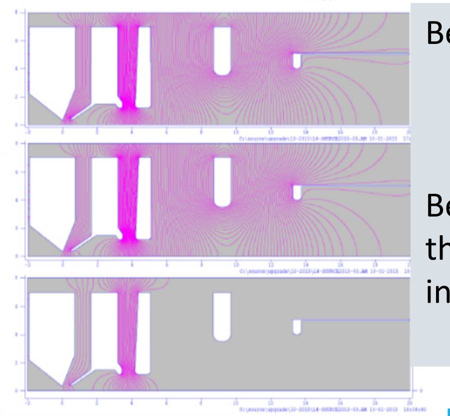
Linac4 can also

- accelerate protons
- Provide a beam with energies 30MeV, 50 MeV and insteps of about 10MeV up to 160 MeV

To exploit that potential



Beam formation



Beam extraction

and

Beam transport through the pre-injector

Experimental activies in a test stand