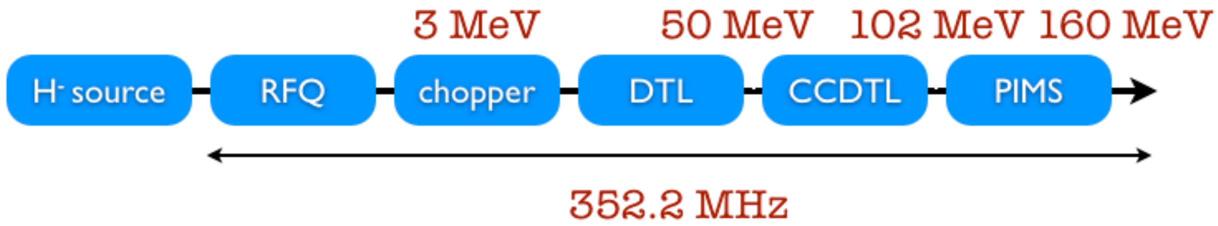
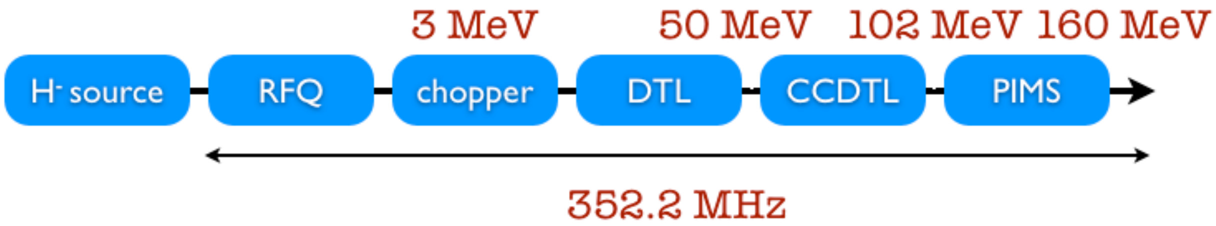


Beam Diagnostics at CERN's Linac-4

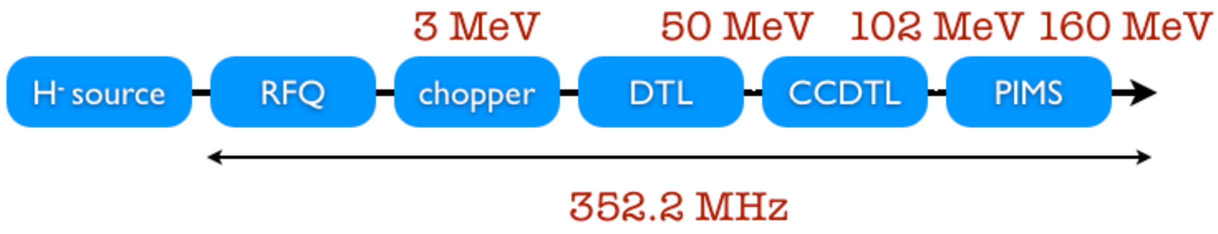
Ditanet Workshop Massy-Palaiseau (Paris)

26 & 27 September 2011

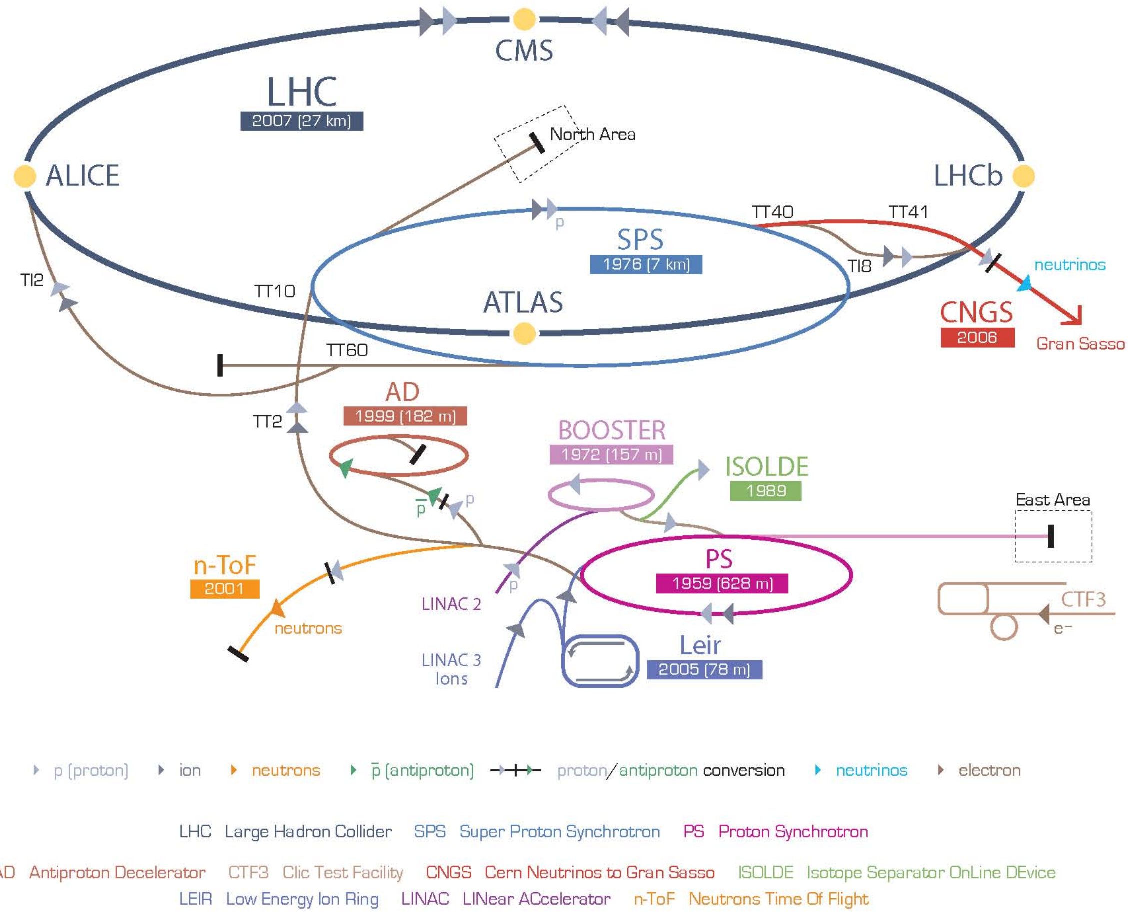
Uli Raich CERN BE/BI

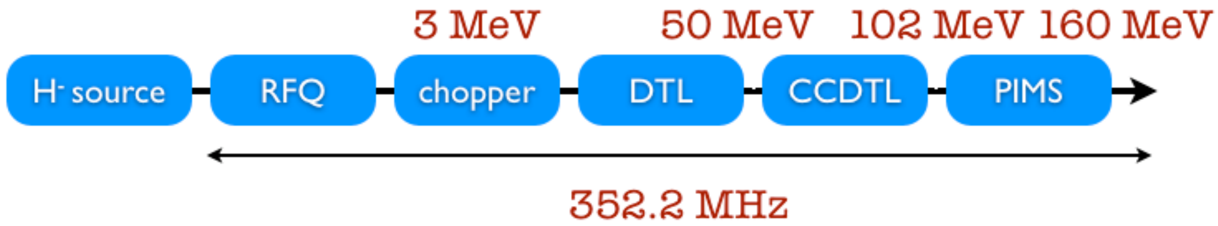


The LHC and its injectors



The LHC injector chain



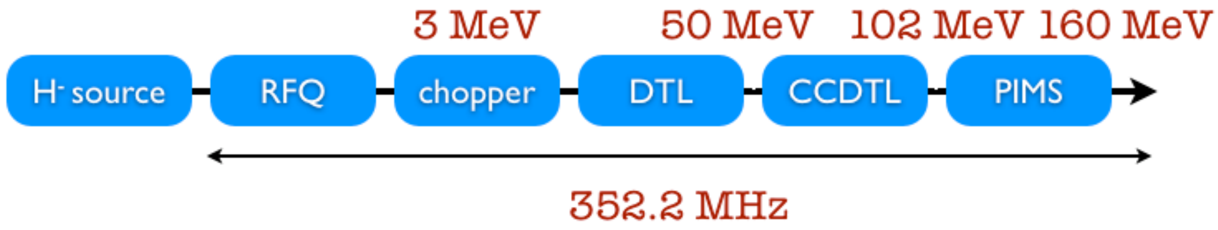


Why an injector upgrade?

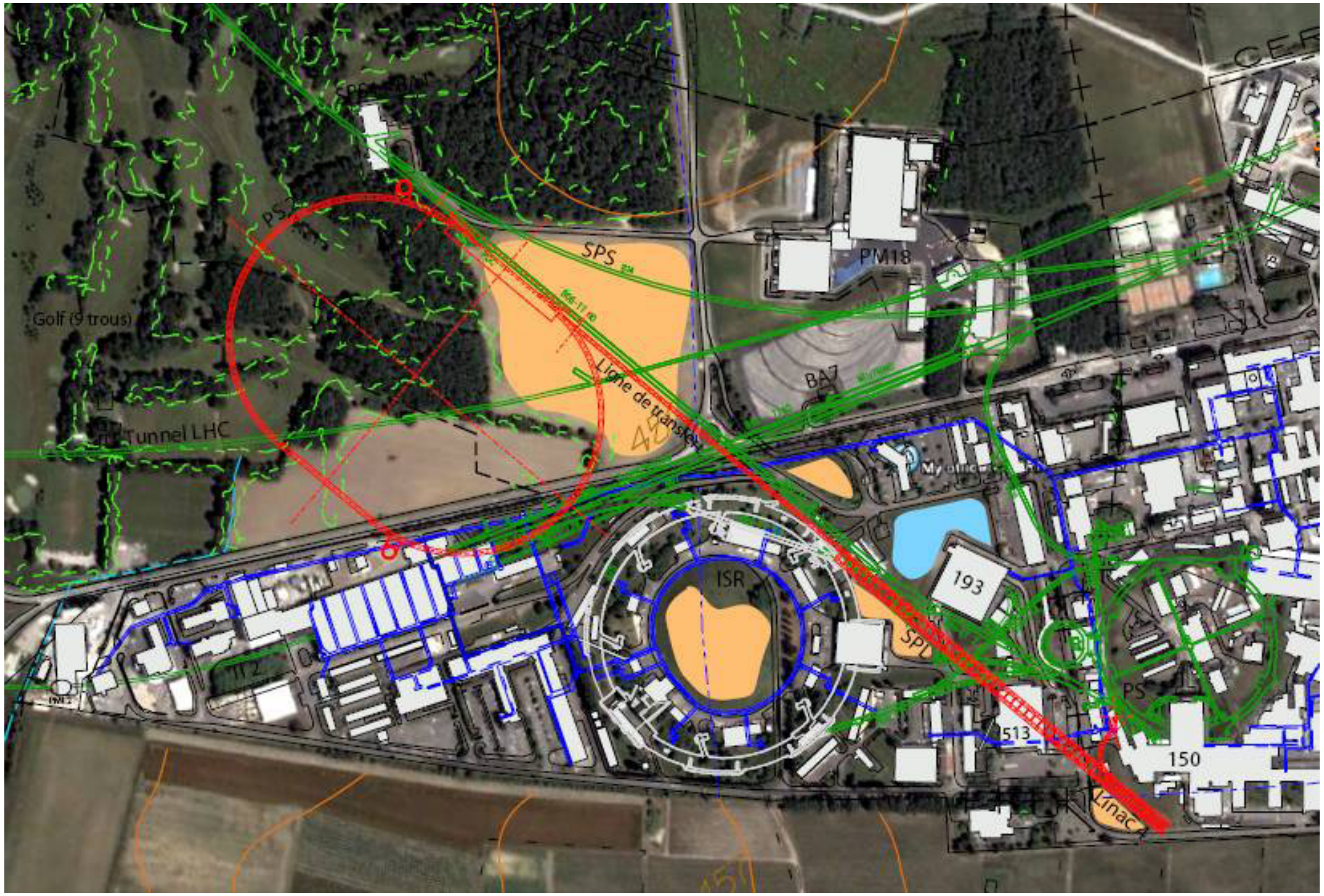
Performance limitations: The nominal luminosity can be reached with the current injector chain but the ultimate luminosity needs higher brightness, which cannot be achieved with the current chain.

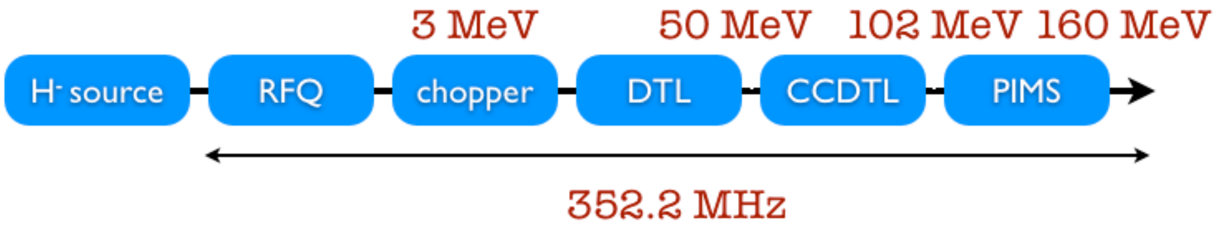
Reliability: Linac-2, Booster and PS are old machines which had problems in the past. Vacuum leaks, radiation damage on the PS magnets etc.

Nominal	1 x 10^{34} cm^{-2} s^{-1}	1.15 x 10^{11} ppb
Ultimate	2.5 x 10^{34} $cm\text{-}^{2}s^{-1}$	1.7 x 10^{11} ppb

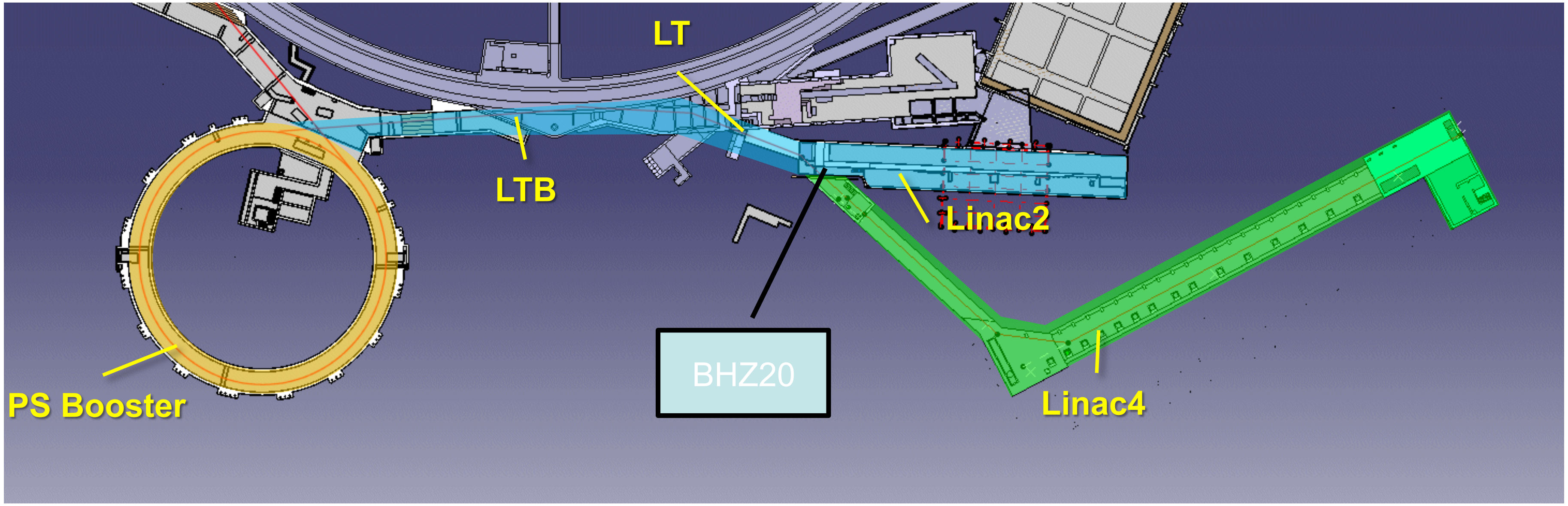


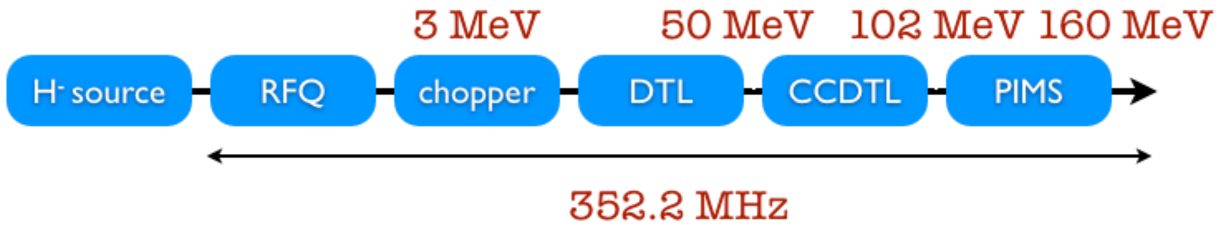
A new injector chain for the LHC



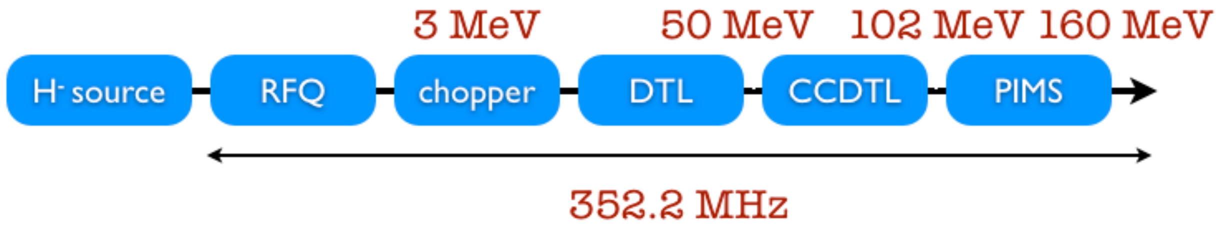


First phase of injector upgrade: Linac-4



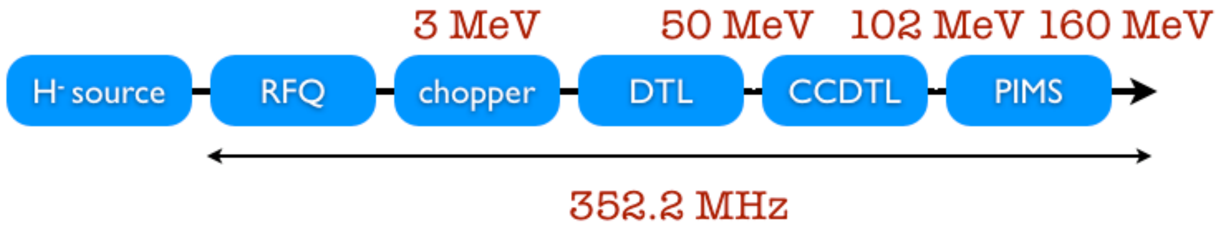


Current State



Linac-4 parameters

Ion Species	H^-	
Output Energy	160	MeV
Bunch Frequency	352.2	MHz
Max. Repetition Rate	2	Hz
Max. Pulse length	1.2	ms
Max. Beam Duty Cycle	0.24	%
Beam Chopping Factor	62	%
Chopping scheme	222 transmitted, 133 empty buckets	
Source current	80	mA
RFQ output current	70	mA
No. of particle per pulse	10^{14}	
Transverse emittance	0.4	π mm mrad



Linac-4 Layout

H-	RFQ	CHOPPER	DTL	CCDTL	PIMS
	95keV	3MeV	3MeV	50MeV	94MeV – 160MeV
RF volume source (DESY) 35 kV Extrac. +60kV Postacc.	Radio Frequency Quadrupole (IPHI) 352 MHz 6 m 1 Klystron 1 MW	Chopper 352 MHz 3.6 m 11 EMquad 3 cavities	Drift Tube Linac 352 MHz 18.7 m 3 tanks 3 klystrons 4 MW 111 PMQs	Cell-Coupled Drift Tube Linac 352 MHz 25 m 21 tanks 7 klystrons 6.5 MW 21 EMQuads	Pi-Mode Structure 352 MHz 22 m 12 tanks 8 klystrons ~12 MW 12 EMQuads

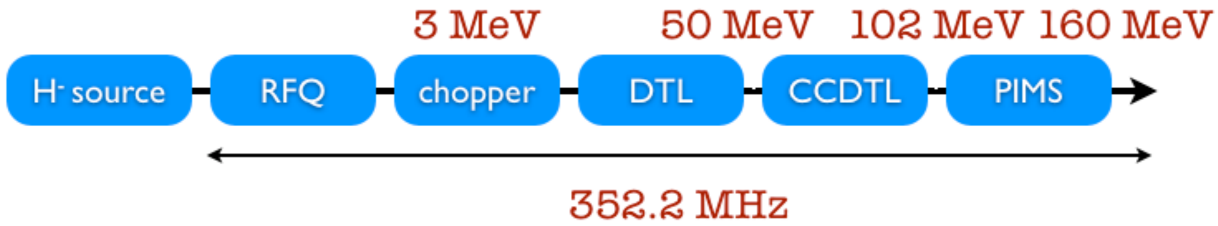
Total Linac4:
80 m,
18 klystrons

RF Duty cycle:
0.1% phase 1 (Linac4)
3-4% phase 2 (SPL)
(design: 10%)

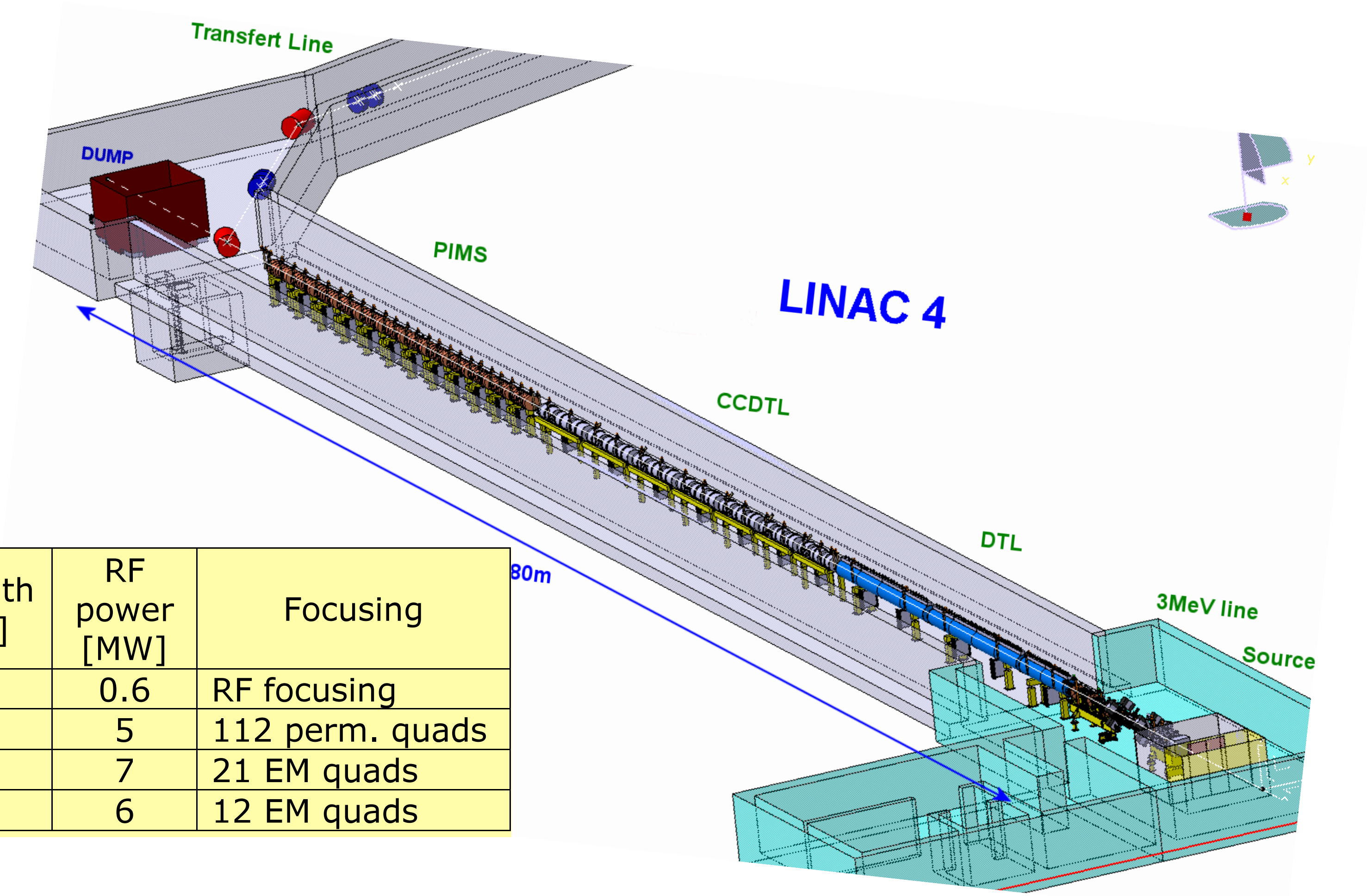
4 different structures,
(RFQ, DTL, CCDTL, PIMS)

Ion current: 40 mA (avg. in pulse), 65 mA (bunch)

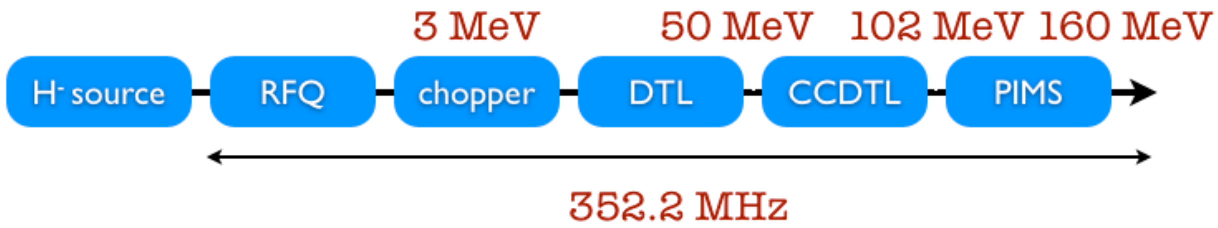
Slide by M. Vretenar



Layout of the Linac

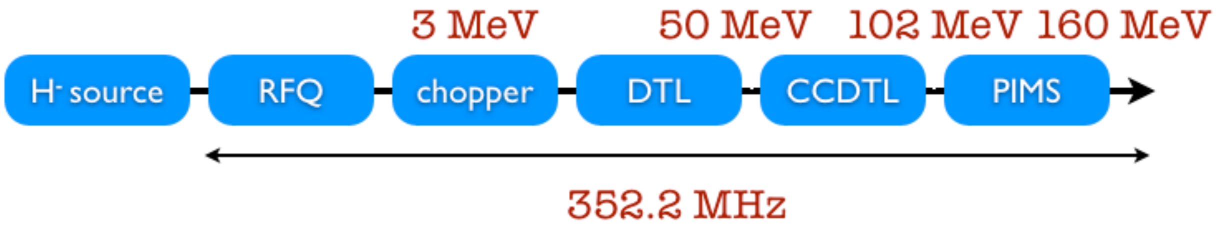


	Energy [MeV]	Length [m]	RF power [MW]	Focusing
RFQ	0.045 – 3	3	0.6	RF focusing
DTL	3 – 50	19	5	112 perm. quads
CCDTL	50 – 102	25	7	21 EM quads
PIMS	102 – 160	22	6	12 EM quads

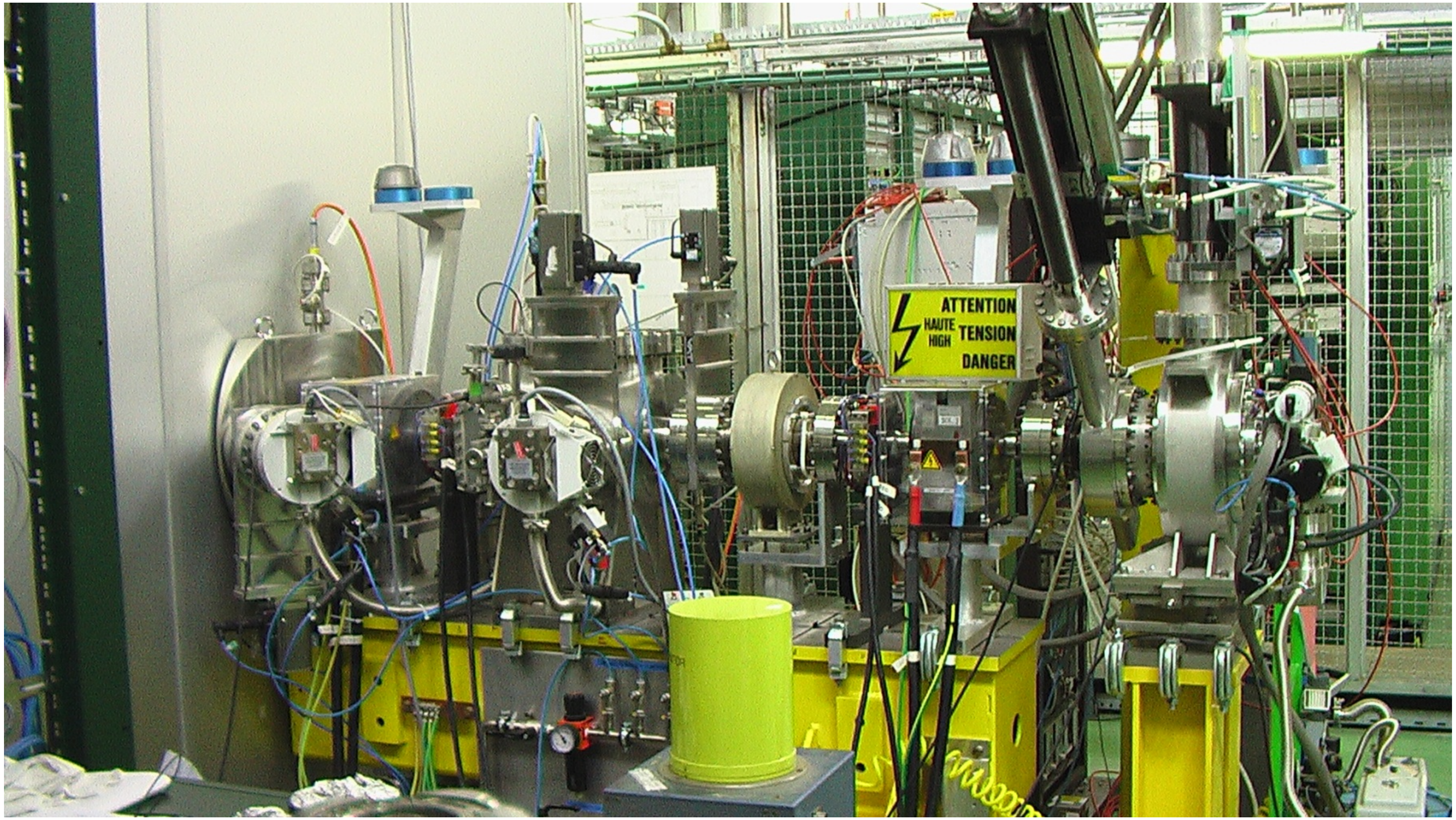


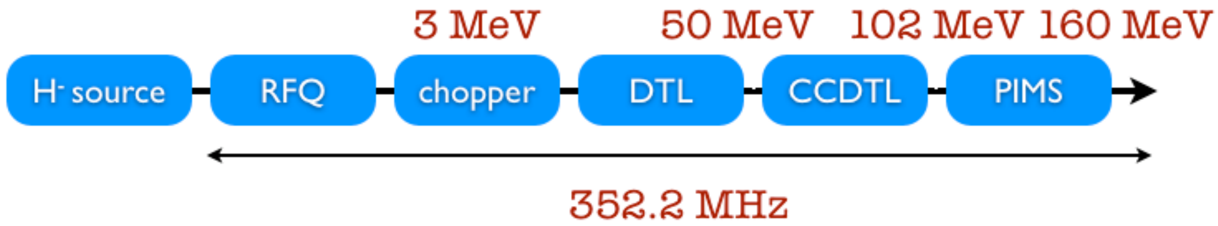
Parameters to be measured

- Intensity at different energies (connected to interlock system)
- Beam trajectory and energy (phase)
- Beam profile
- Energy spread, will be measured at low energy up to 3 MeV only
- Transverse emittance at 45 keV, 3 Mev, 12 MeV, 160 MeV
- Chopping efficiency
- Bunch shape
- Beam loss (connected to interlock system)
  max. beam loss: 1 W/m
  not more than 1 full beam pulse may be lost
- Diagnostics for charge exchange injection into the Booster

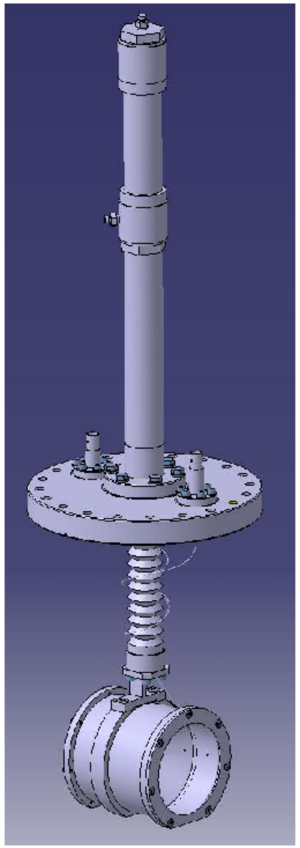


Source and LEBT

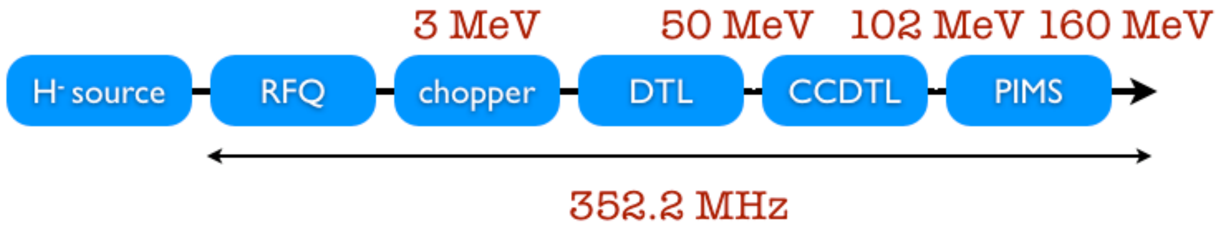




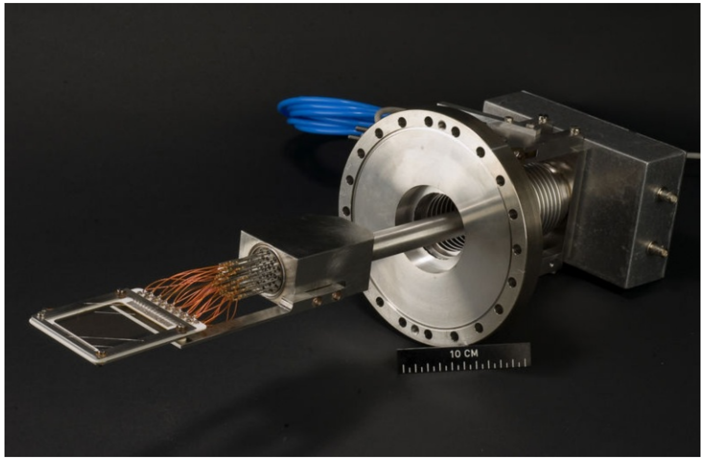
Faraday Cup

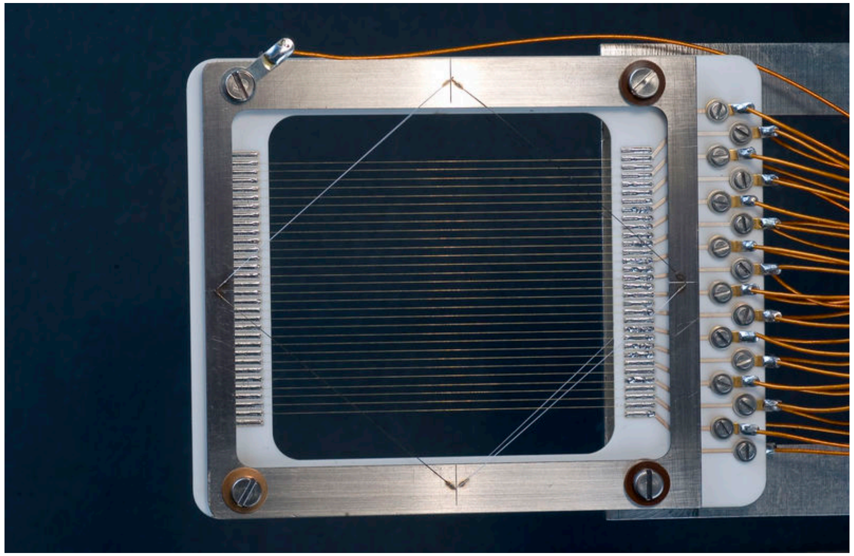


- Source intensity measured by a retractable Faraday Cup
- Secondary electron emission will be suppressed by polarization voltage which also eliminates parasitic electrons created in the source (HV installation to be done)
- Pneumatic in/out mechanism on PLC like LEIR is available
- Oscilloscope will be used for signal observation
- For final operation a 1 MHz sampling ADC is foreseen

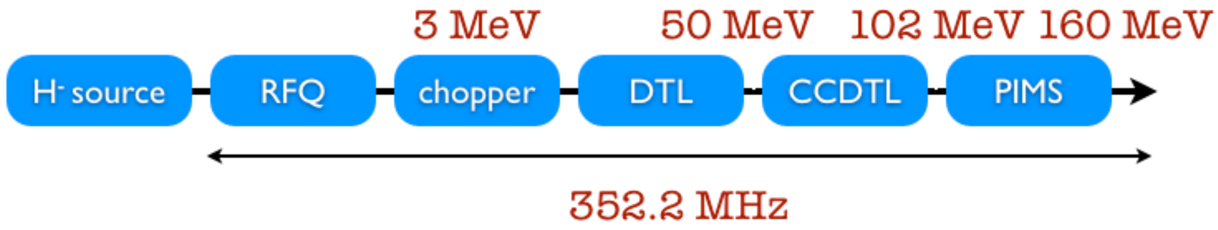


SEMGrids for Profile Meas.

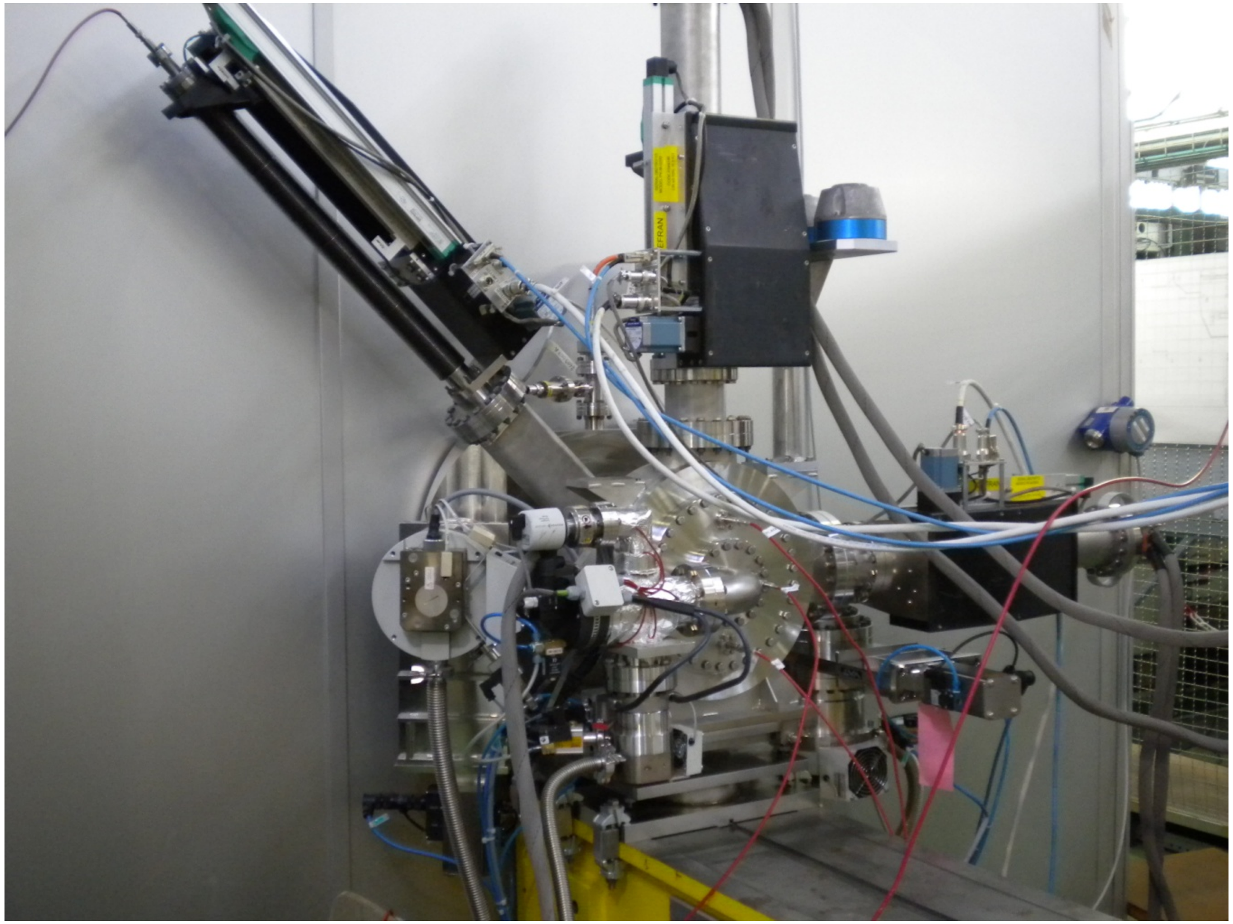




- SEMGrid resolution: up to 0.5mm, up to 36 wires
- New analogue electronics for 36 under design
- Needs time resolved measurements (200 kHz)
- New VME readout card has been developed (36 channels), series of 50 cards have been produced
- In/out mechanism by motor with PLC control



Transverse Emittance Measurement



Slit and grid phase space scanner

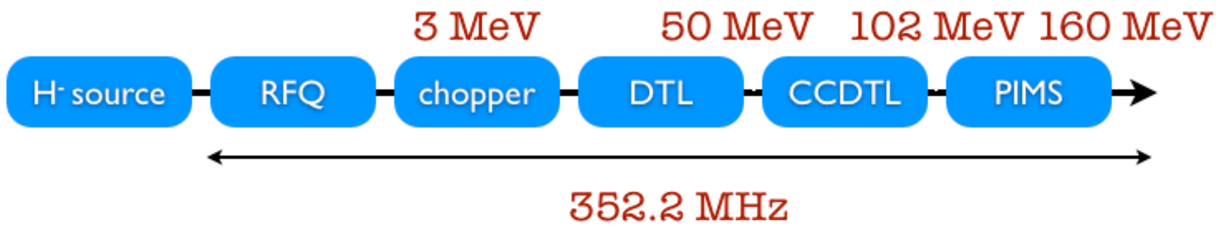
L-shaped 0.1mm slit moves under 45 degrees

Slit and grids move independently
Positioning precision: 50 µm
Movement PLC controlled

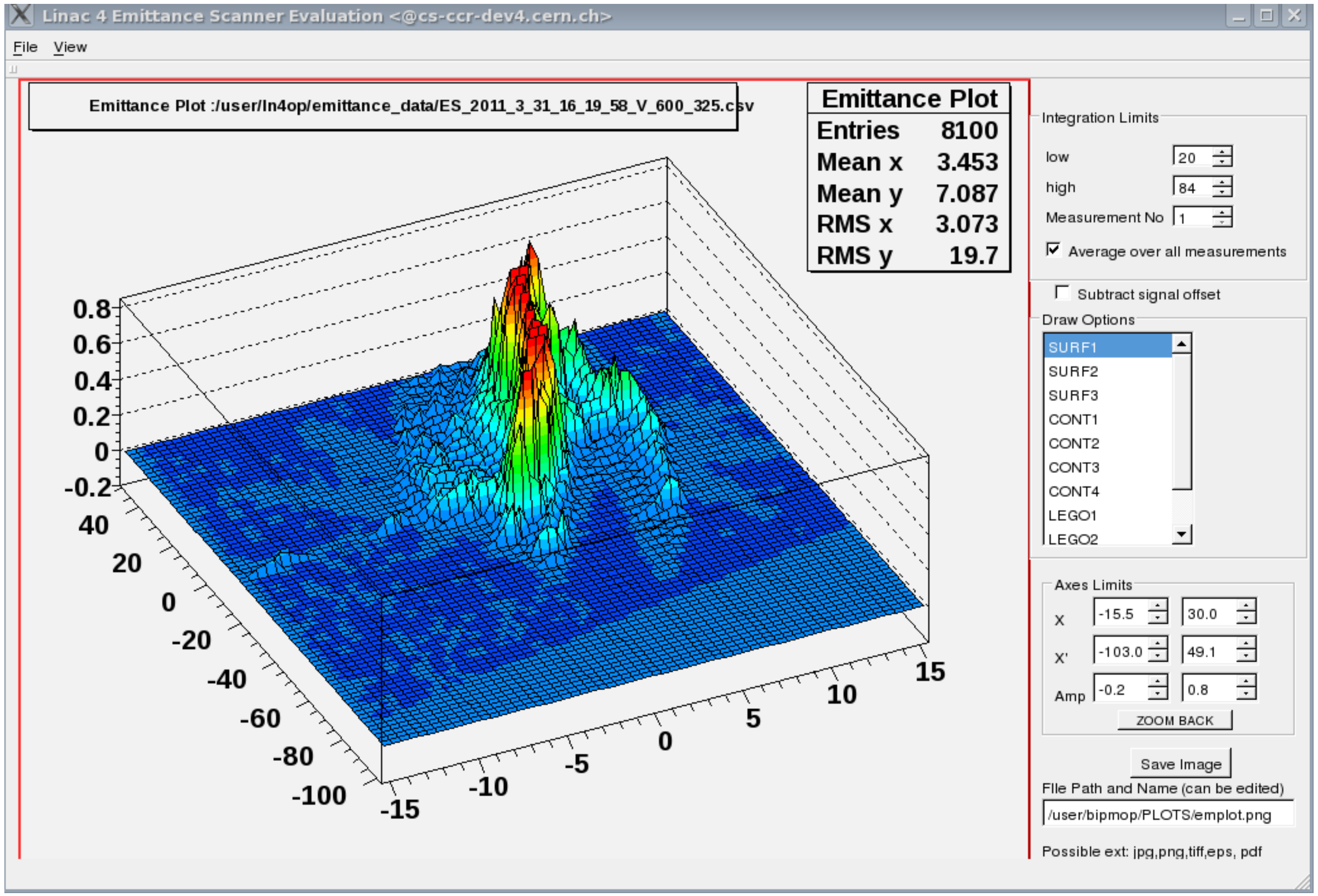
Slit and grids mounted in 2 independent vacuum boxes which can be separated

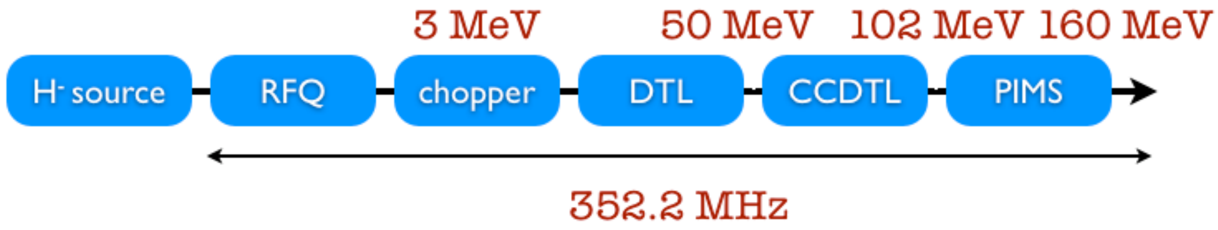
Horizontal and vertical SEMGrid
- wire distance .75 mm
- 40 signal wires
- readout with home built 36 channel 250 kHz ADC
- time resolved profiles

Faraday Cup



Emittance Evaluation





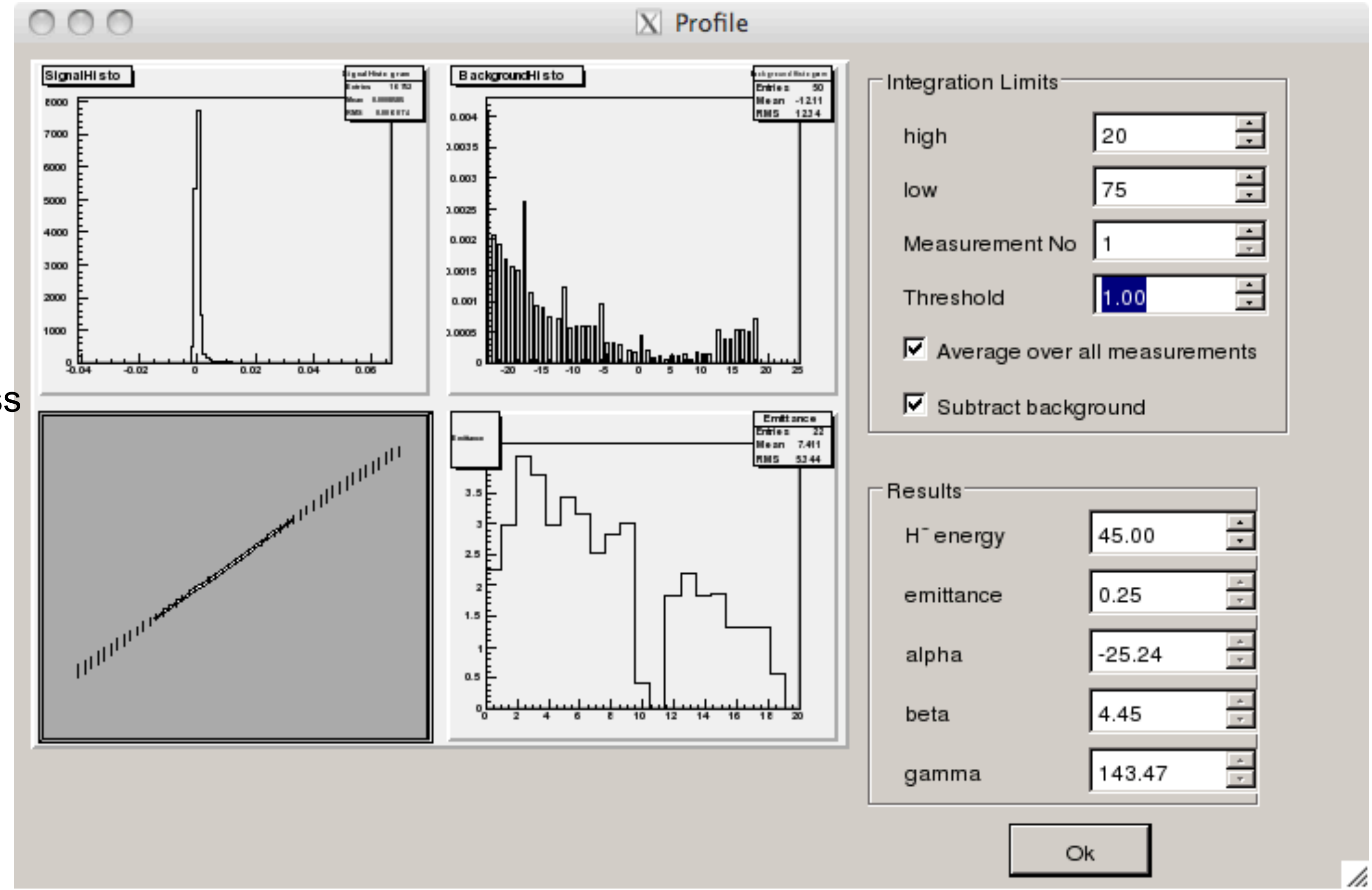
Pseudo Scubexx evaluation

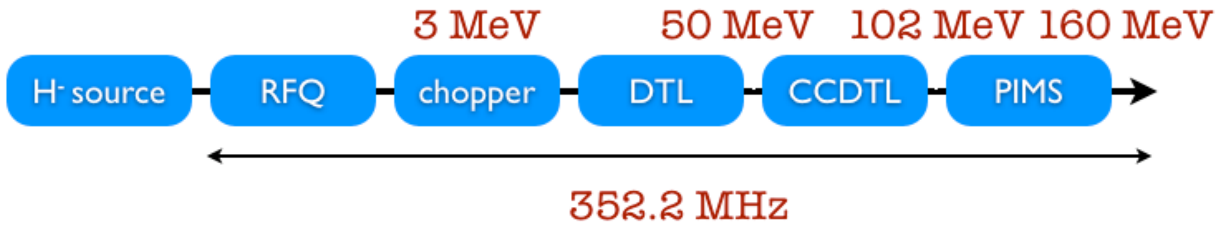
Histogram of signal levels

Background for each slit Position

Emittance Plot

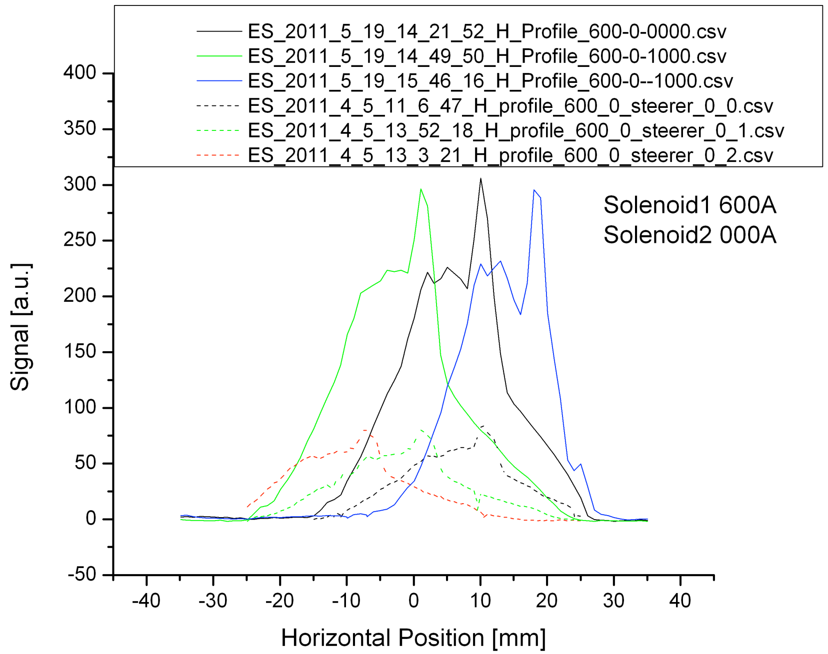
Emittance when taking less and less channels around peak



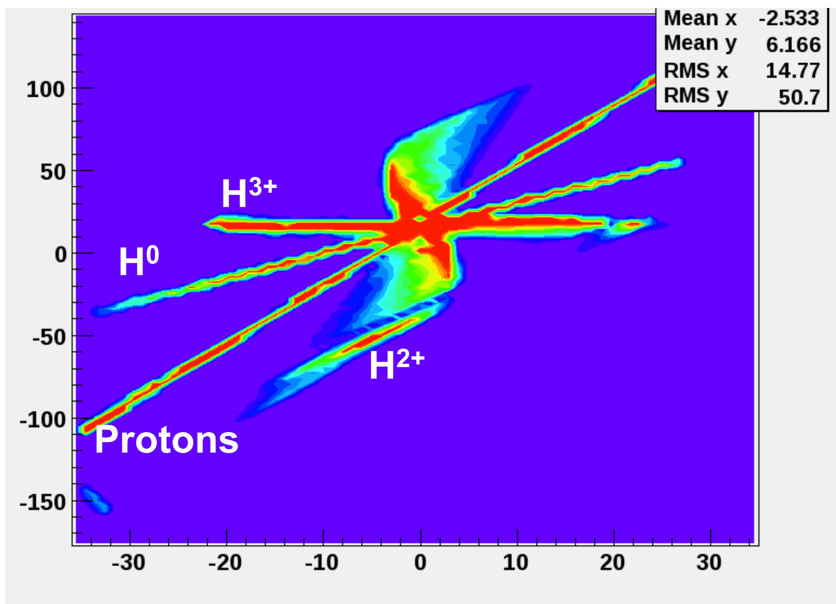


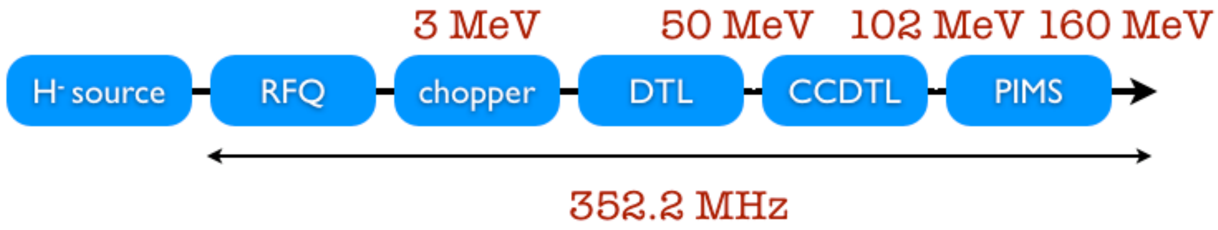
Source Test Stand – Measurements Examples

Profile Measurement with Slit and Faraday Cup

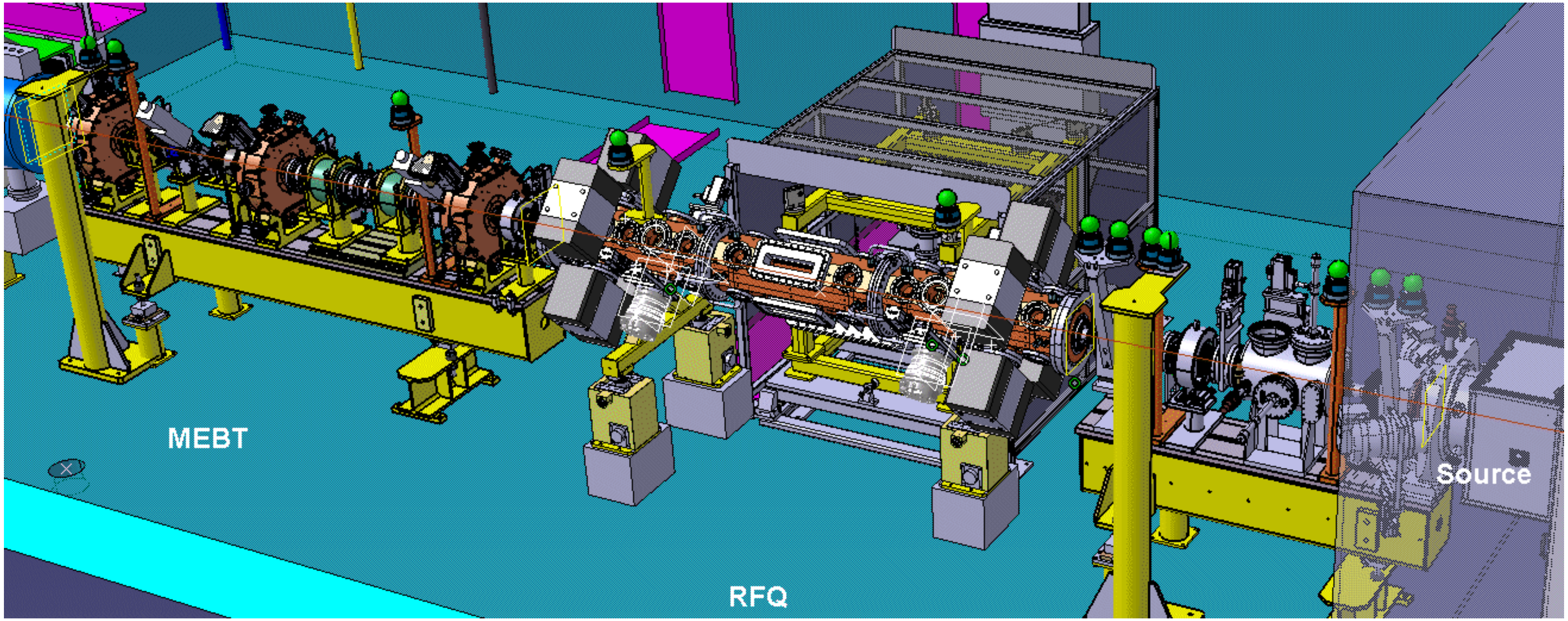


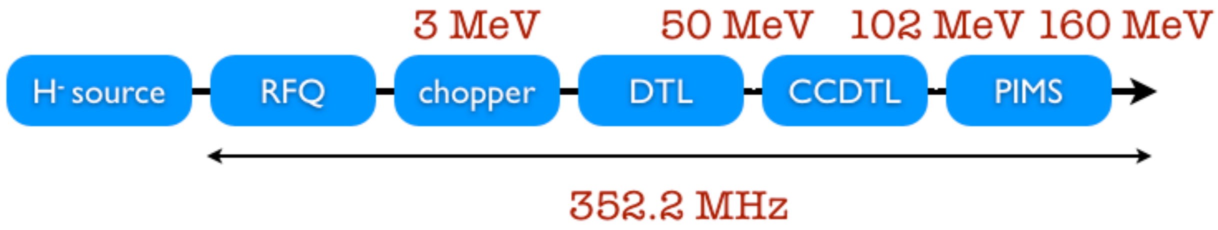
Emittance-meter measurement after 1st solenoid



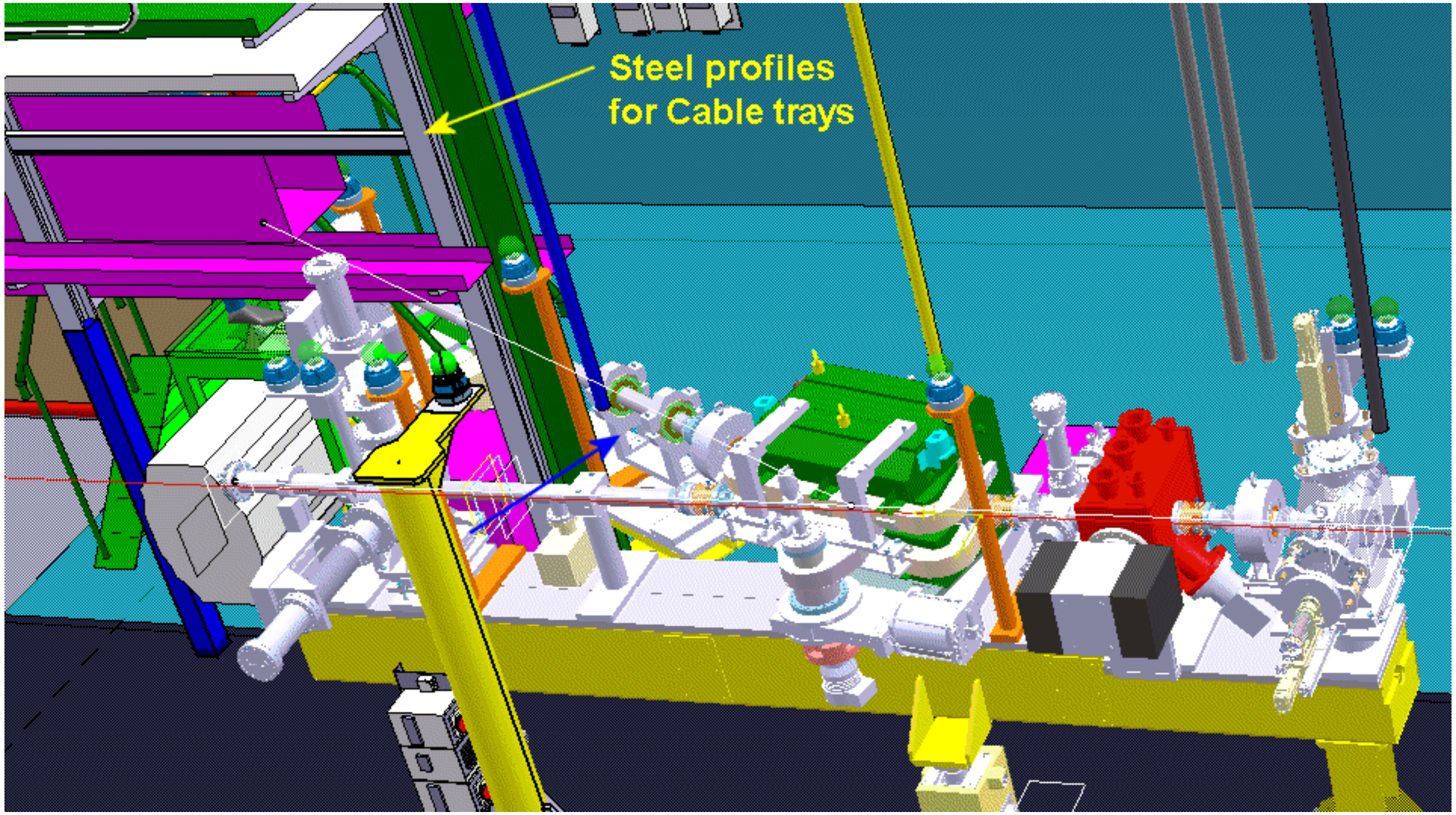

3 MeV
50 MeV
102 MeV
160 MeV
H- source
RFQ
chopper
DTL
CCDTL
PIMS
352.2 MHz

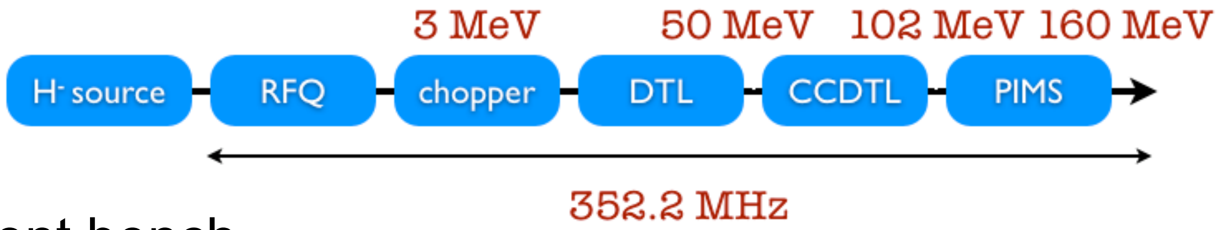
RFQ + 3 MeV


MEBT
RFQ
Source

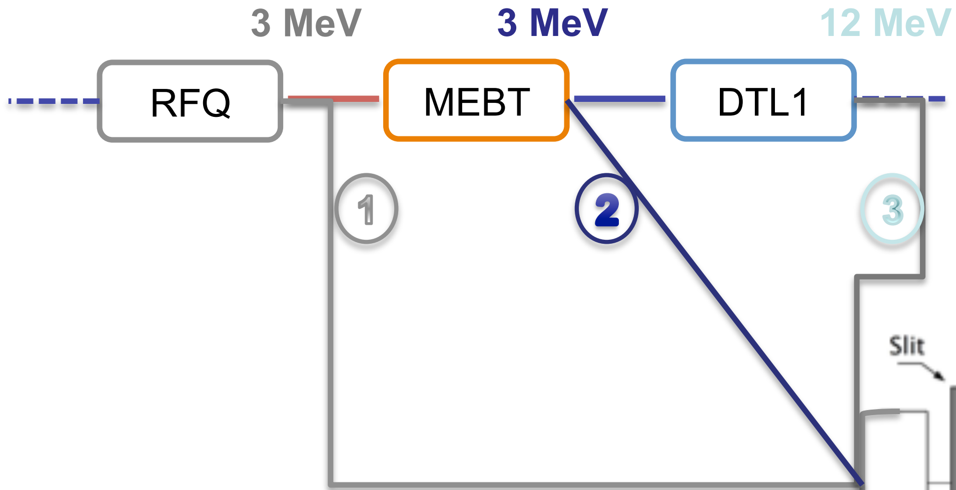


3 MeV Measurement line for commissioning only



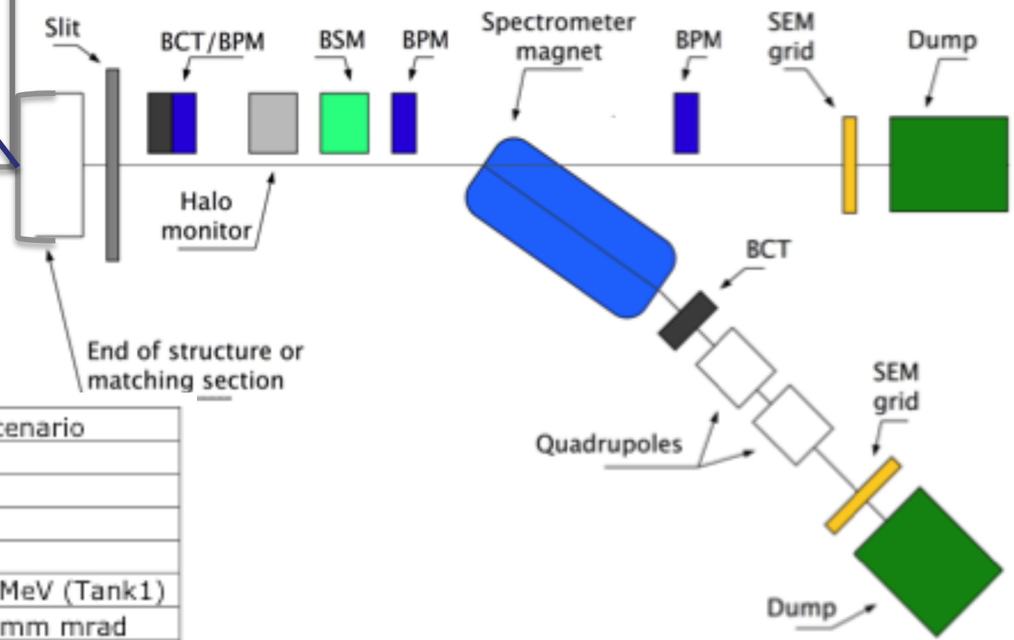


3 MeV measurement bench

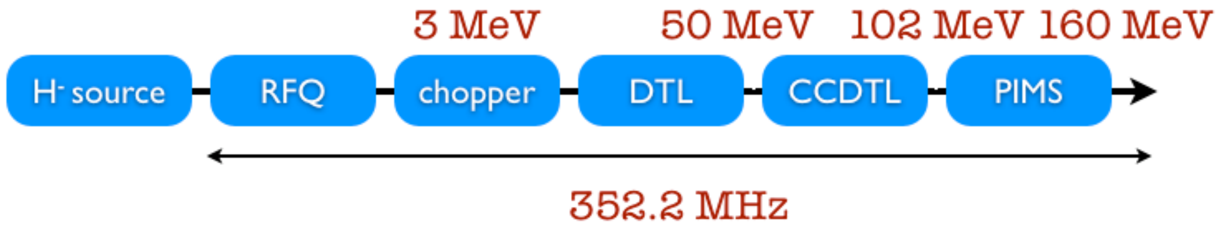


Laboratory test stand (from Jan 2012) (1) + (2)

Linac 4 Tunnel (from 2013) (1) + (2) + (3)



	Commissioning scenario	
Pulse length	50-100 μs	
Rep rate	1Hz	
Max beam current	65mA	
Average beam current (after chopping)	40 mA	
Beam energy	3MeV (RFQ, MEBT), 12 MeV (Tank1)	
Beam emittances at structure output planes (RMS norm)	RFQ	0.3 mm mrad
	MEBT	0.3 mm mrad
	DTL tank1	0.3 mm mrad



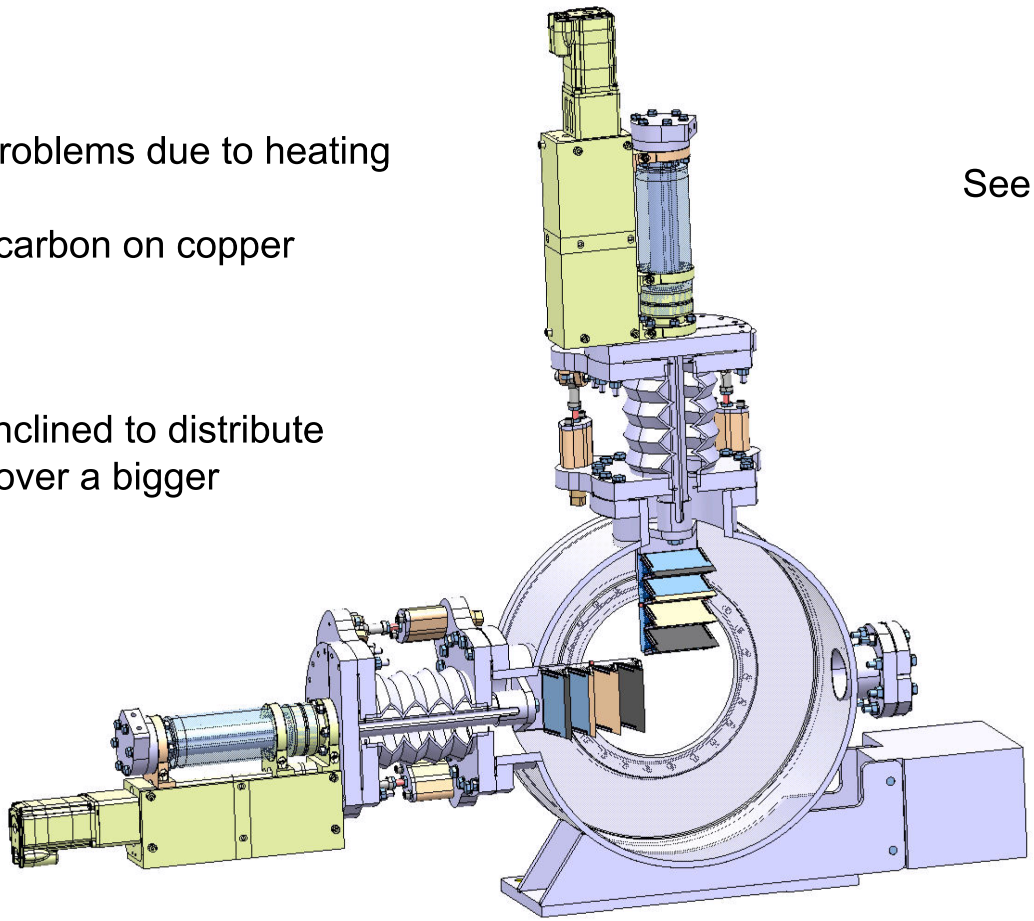
Slit at 12 MeV

Mechanical problems due to heating

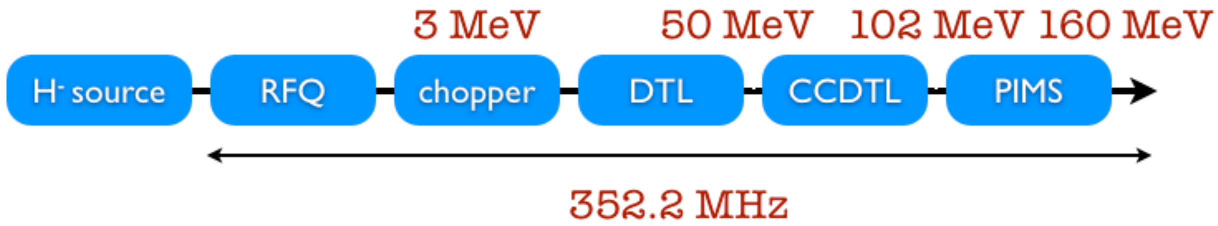
Slit material: carbon on copper

Water cooled

Slit material inclined to distribute thermal load over a bigger surface.

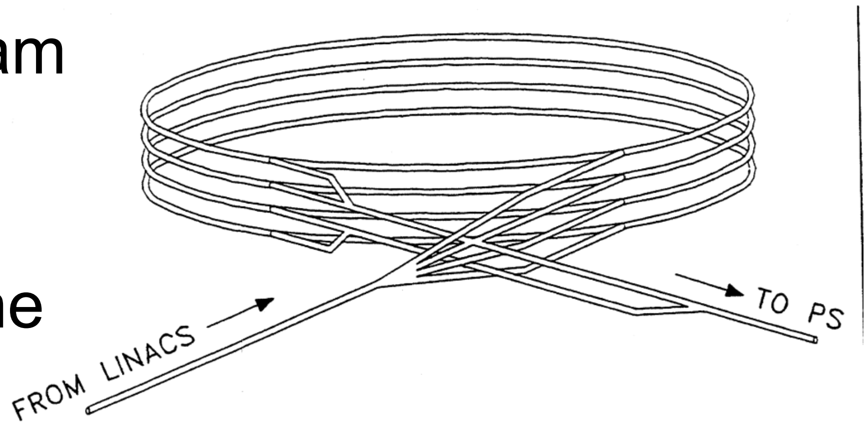


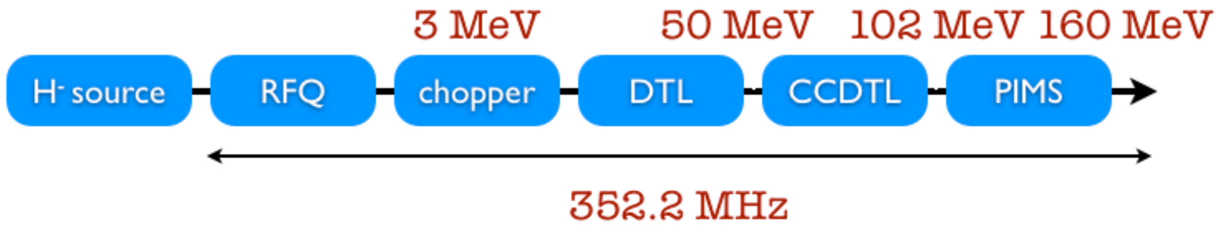
See B. Cheymol's talk



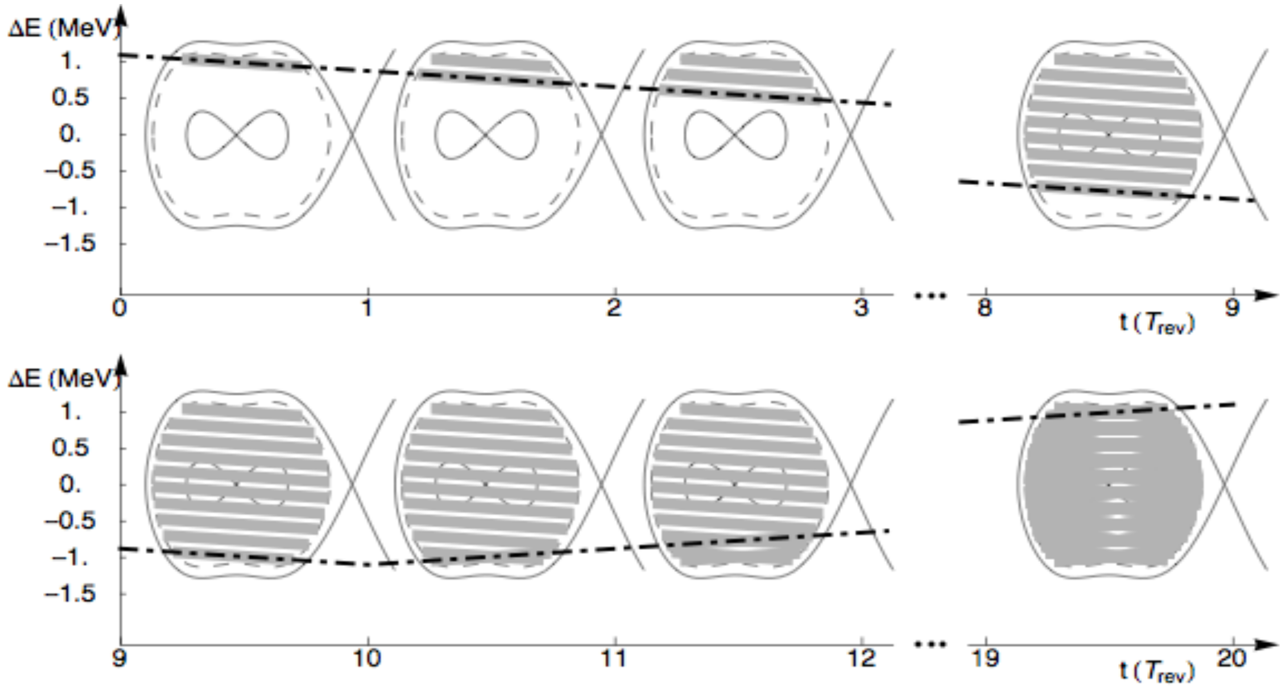
Chopper

- Losses at 160 MeV must be minimized
- Chopper eliminates unstable beam and during rise of the Booster distributor
- Chopped beam is injected into the RF buckets of the Booster
- Correct functioning of the chopper must be monitored





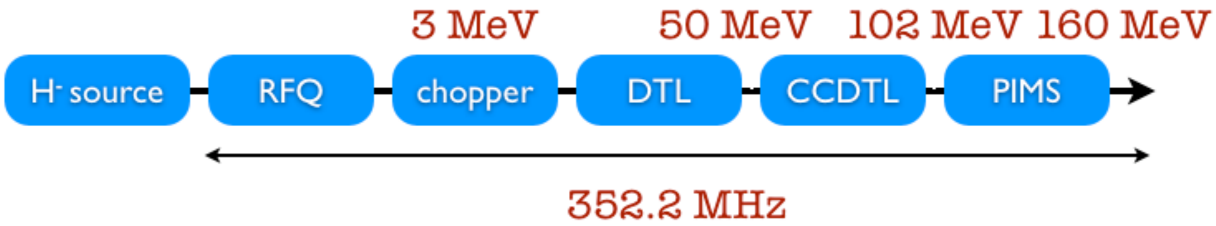
Longitudinal Painting for maximum Brightness



Basic idea:

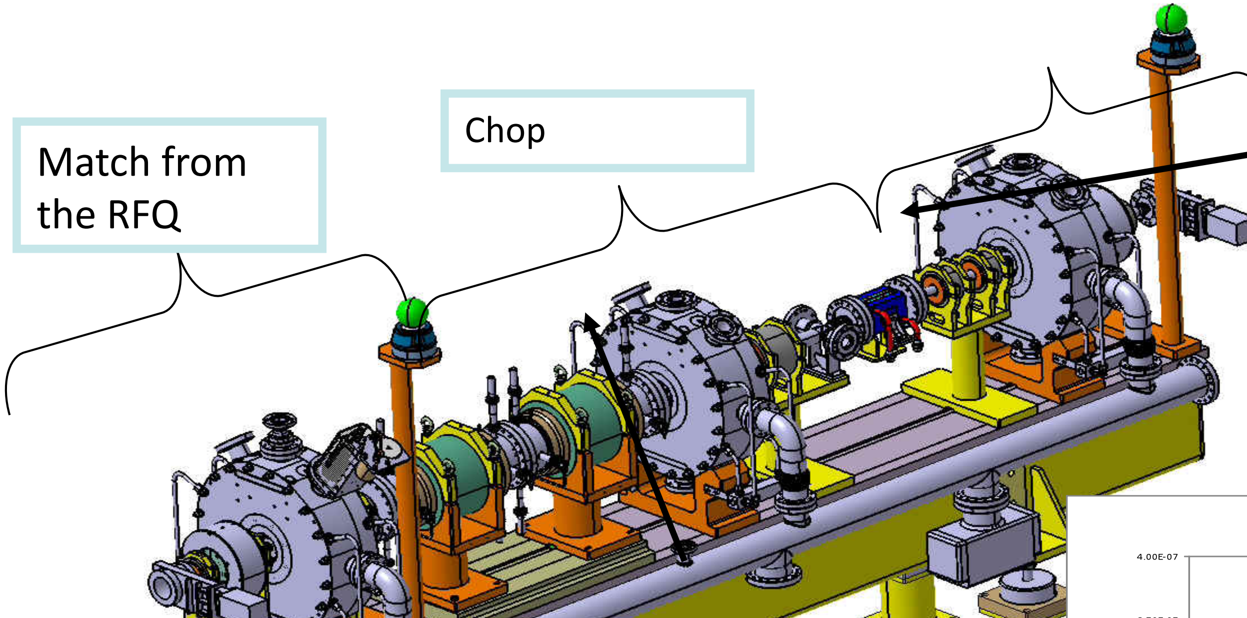
- Saw-tooth shape energy offset (w.r.t PSB synch energy) variations of Linac4 beam
- Switch beam on and off if it is inside bucket (with margin)
- Inject into waiting **accelerating** bucket !!

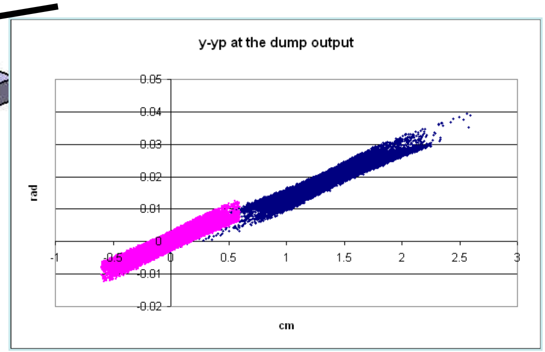
- Longitudinal painting is baseline to fully profit from the increased PSB injection energy

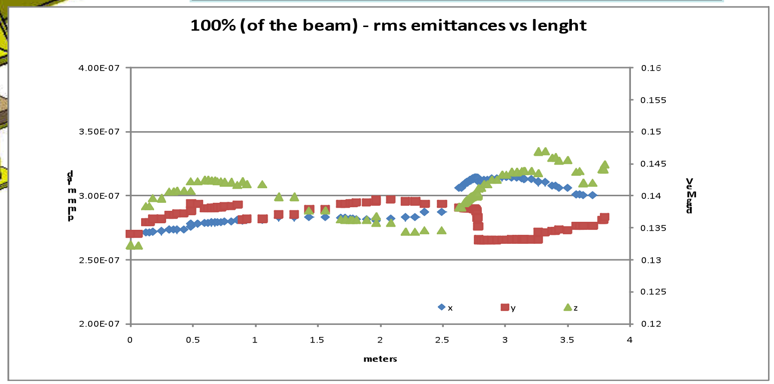


“chopping”

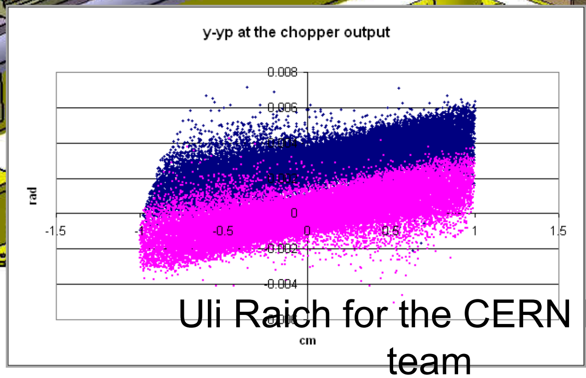
removing microbunches (150/352) to adapt the 352MHz linac bunches to the 1 MHz booster frequency



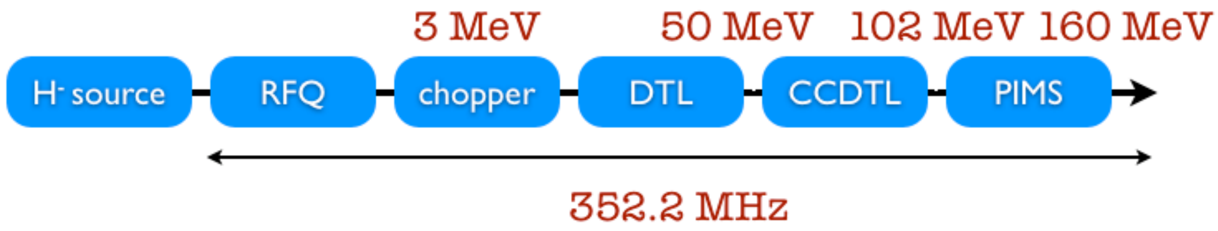




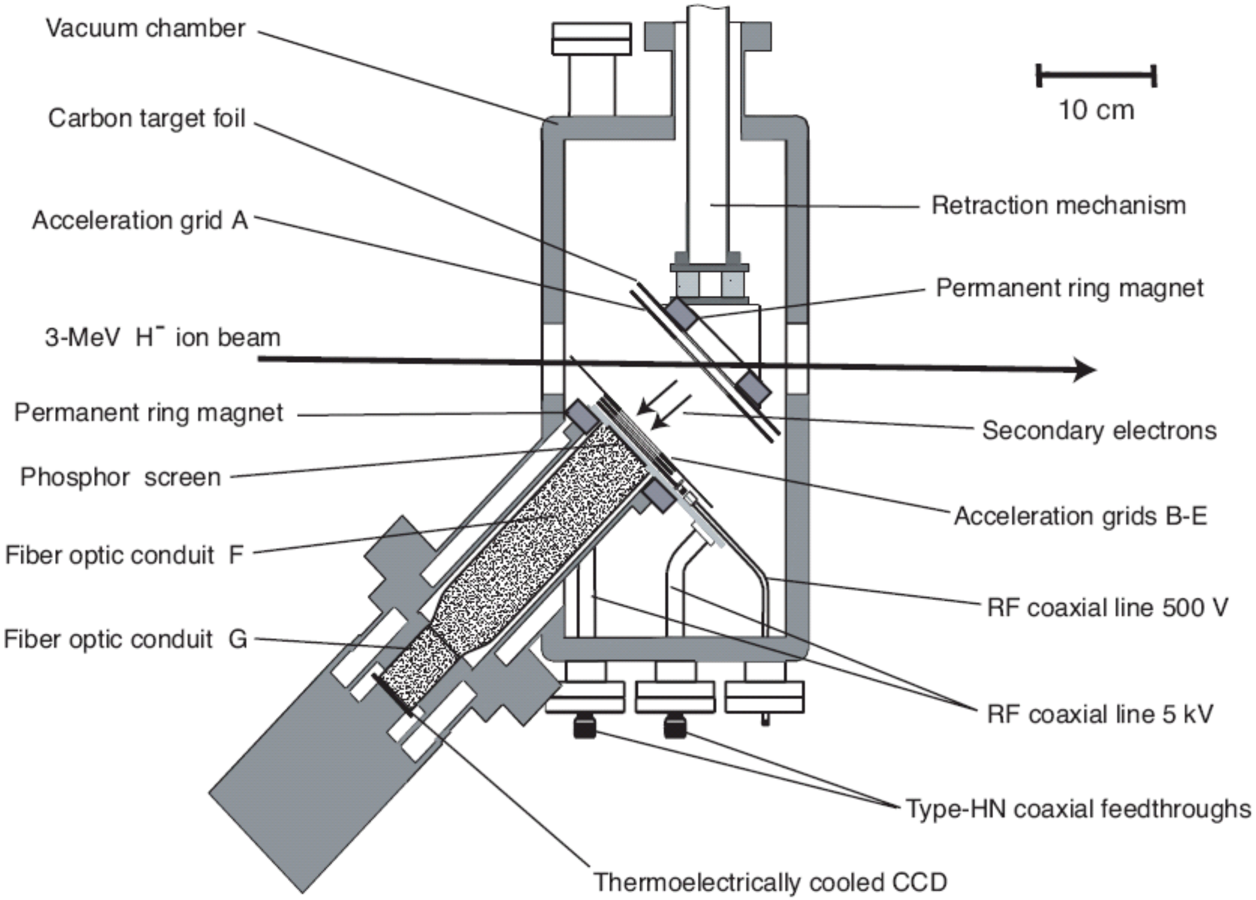
Emittance increase 20-30%

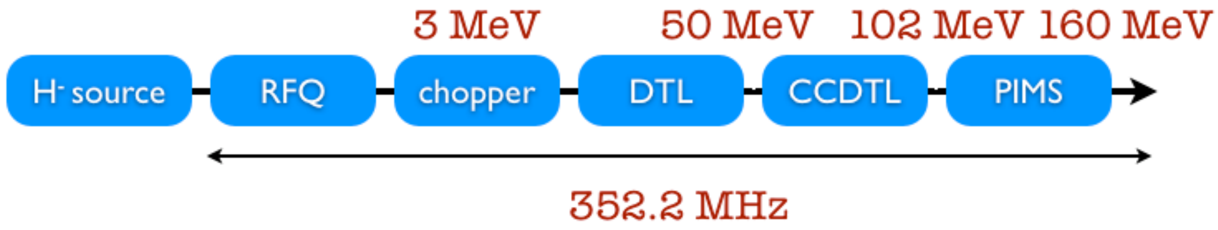


Slide courtesy of A. Lombardi



Halo Monitor





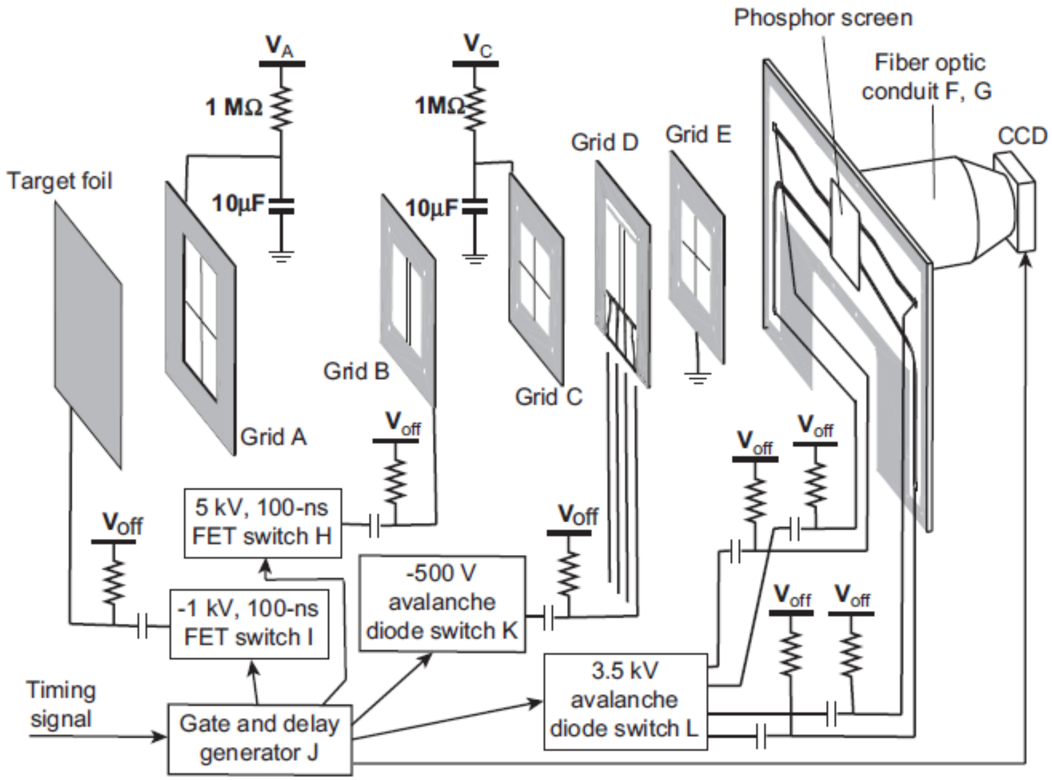
Functioning of Halo Monitor

Gate off, 0.8 kV (foil 0.8 KV)
electrons re-absorbed

Initial acceleration:
Target foil -1 kV vB -5 kV
Electrons absorbed in aluminum Layer

3.5 kV pulse -> 6kV through reflection seen by phosphor rise-time 500ps

1 kV pulse on Grid D switch off flourescence



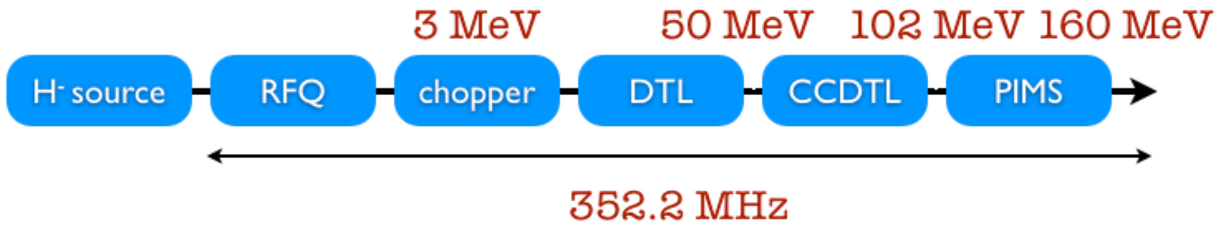


Photo of Halo Monitor

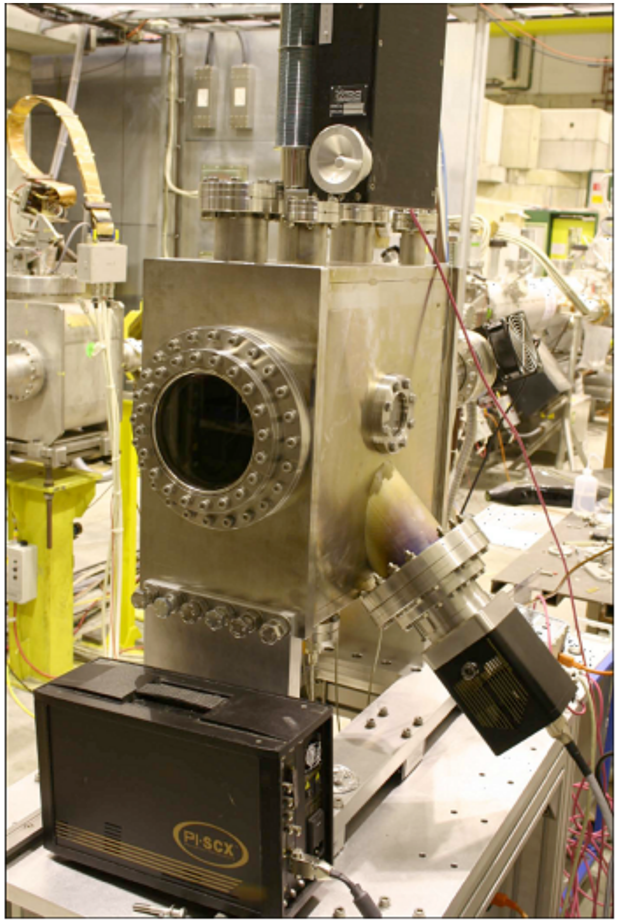
Individual buckets will be chopped out

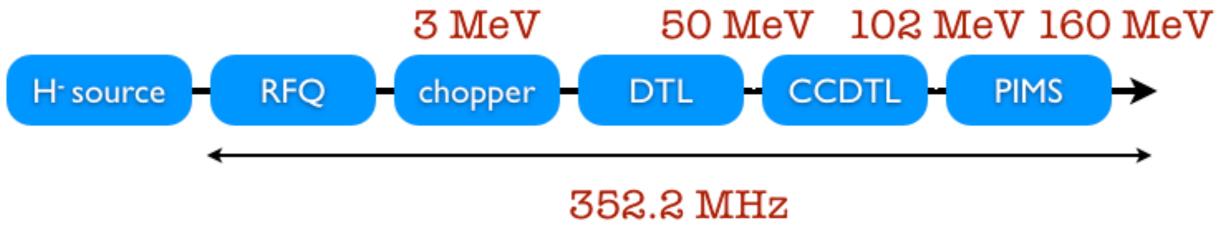
352 MHz <> 2.8 ns between buckets

Must be able to measure 1000 ions in the chopped beam in the vicinity of 5 10^8 ions

Beam traverses thin carbon foil and creates secondary Electrons which are accelerated towards a Phosphor screen

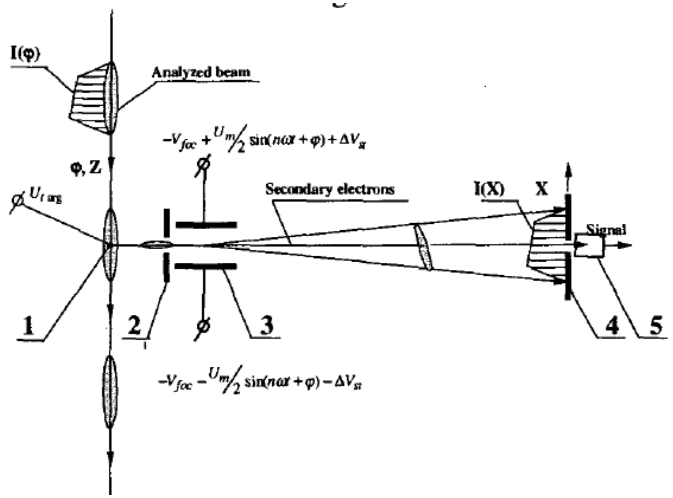
Monitor can be gated off during the intense beam and switched on within 500 ps

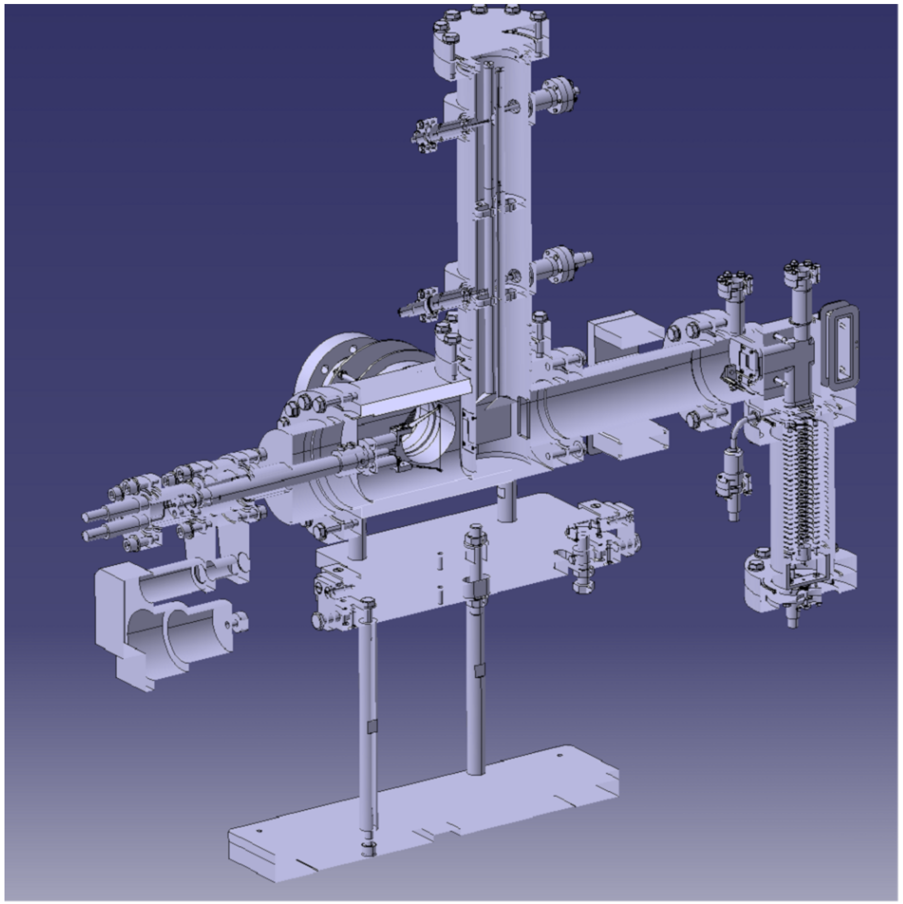


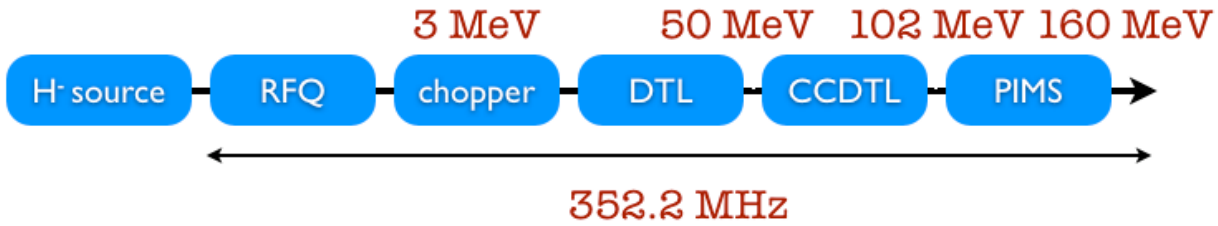


Bunch Shape Monitor

- Device built at INR Troitsk
- Will be assembled in October and tested on the 3 MeV measurement line

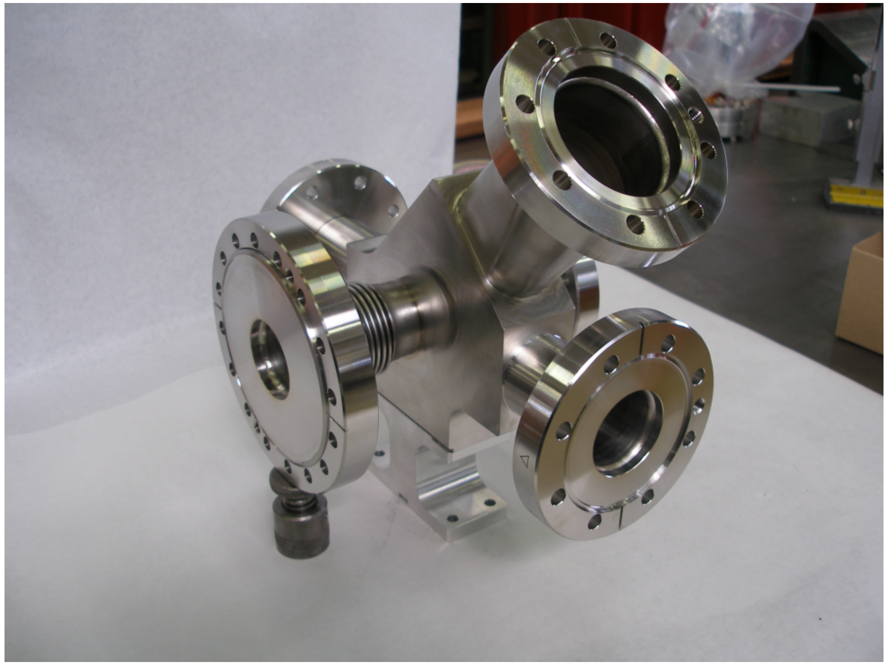


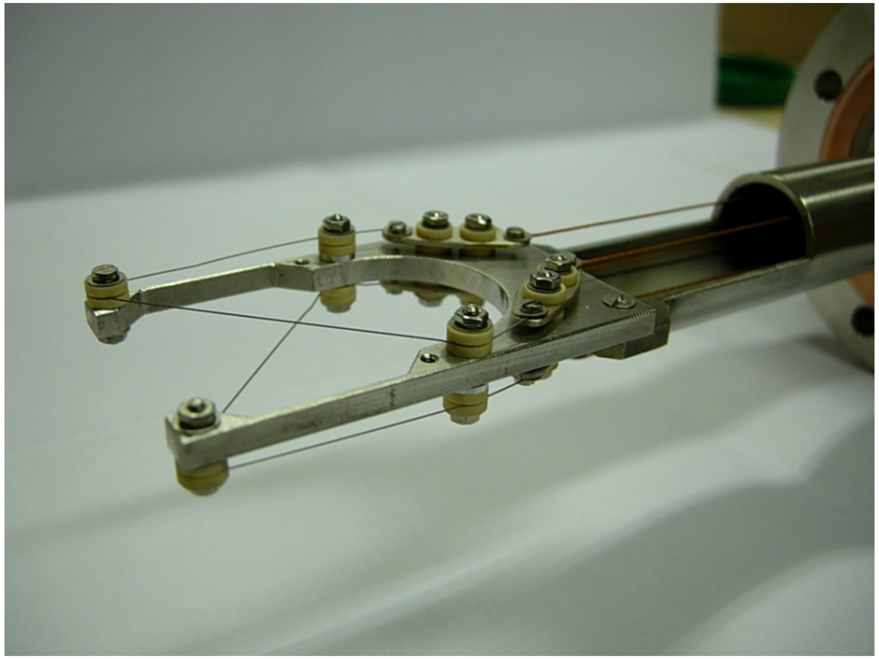


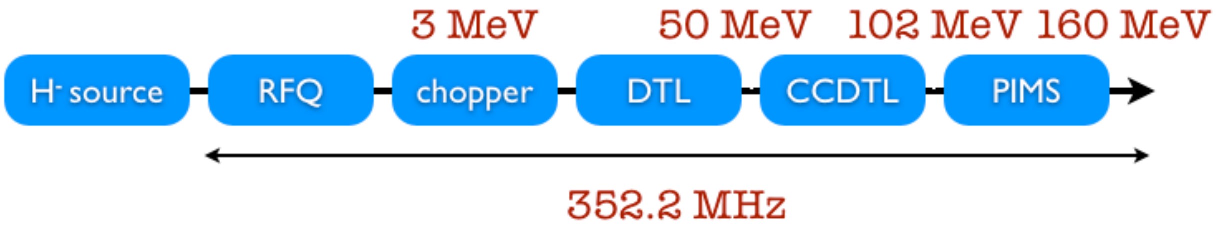


Wire Scanners

Uses carbon wires
Beam pulse restricted to 100 μs for heating reasons

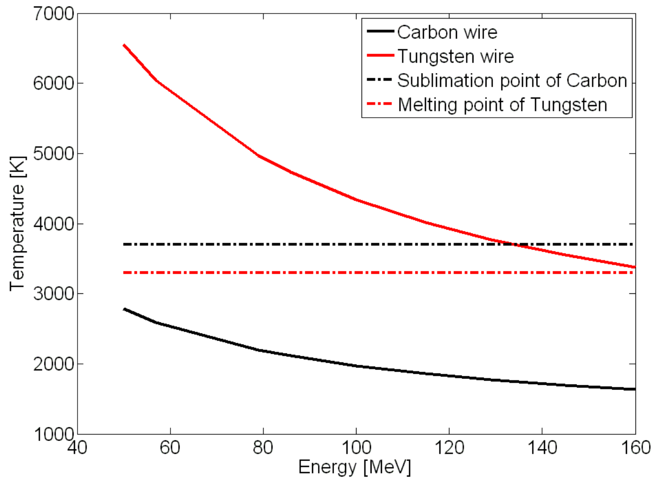


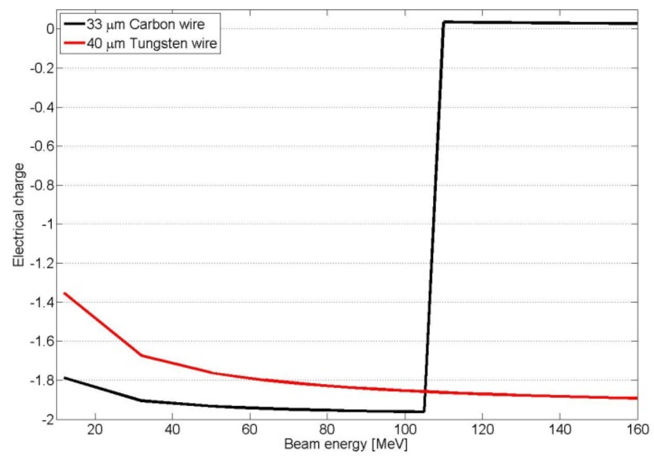




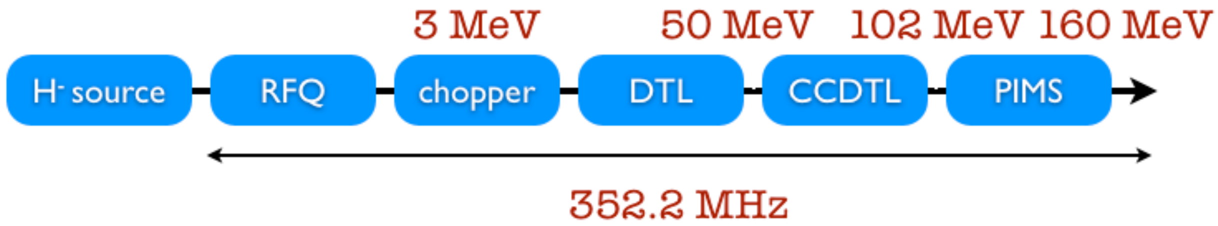
SEMGrid Wires and Wire Scanners

- Simulations of energy deposition done
- Simulation of signal levels to be expected
- New, time resolved electronics under preparation
- Fabrication of grids with carbon wires





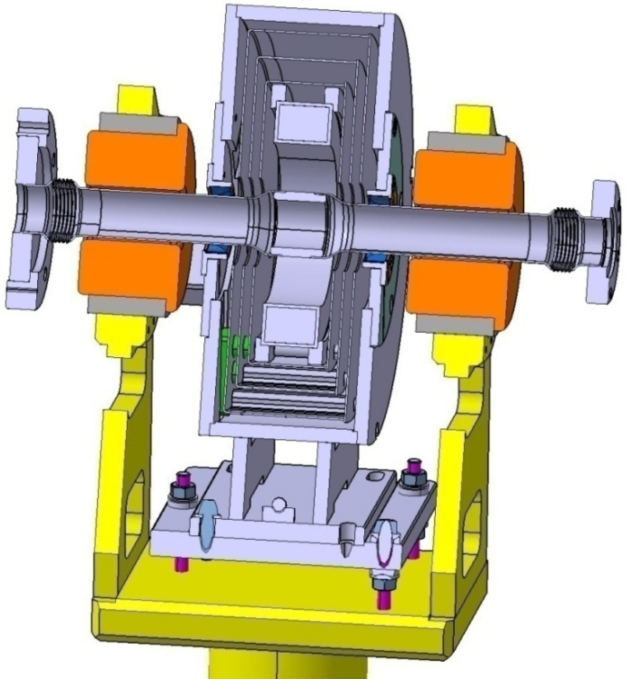
40 mA, 400 μs, σ_x=1mm, σ_y=2mm

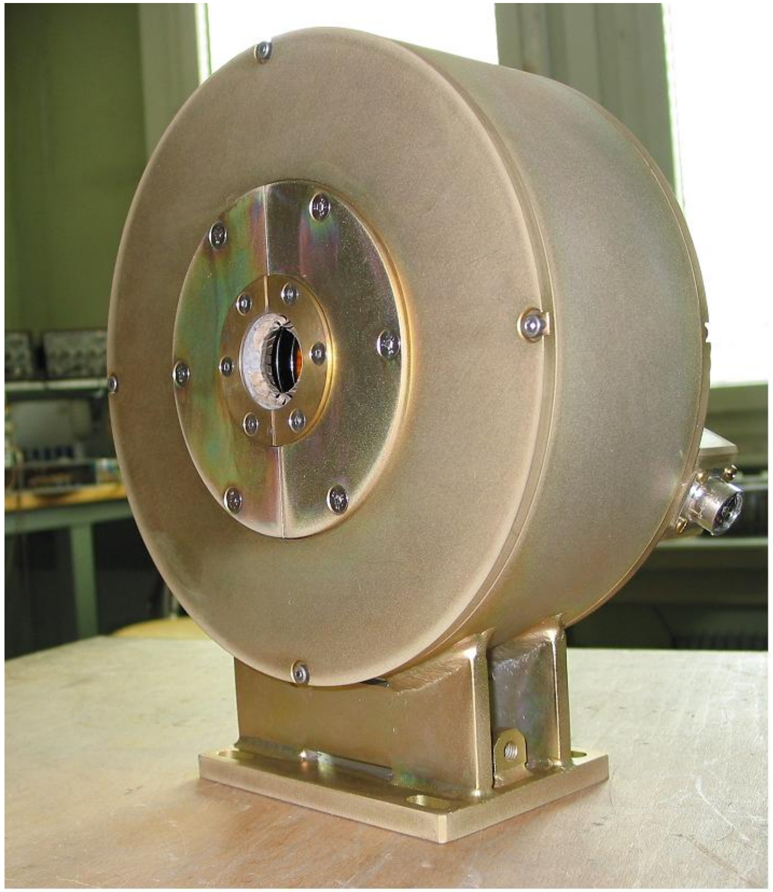


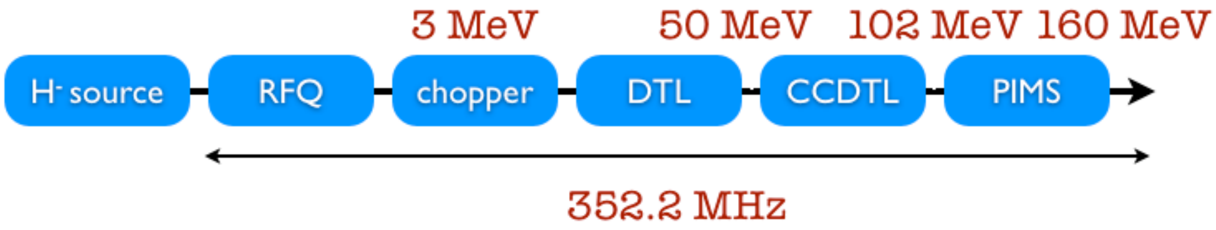
Current Transformers

Good magnetic shielding avoids interference from nearby pulsing quads

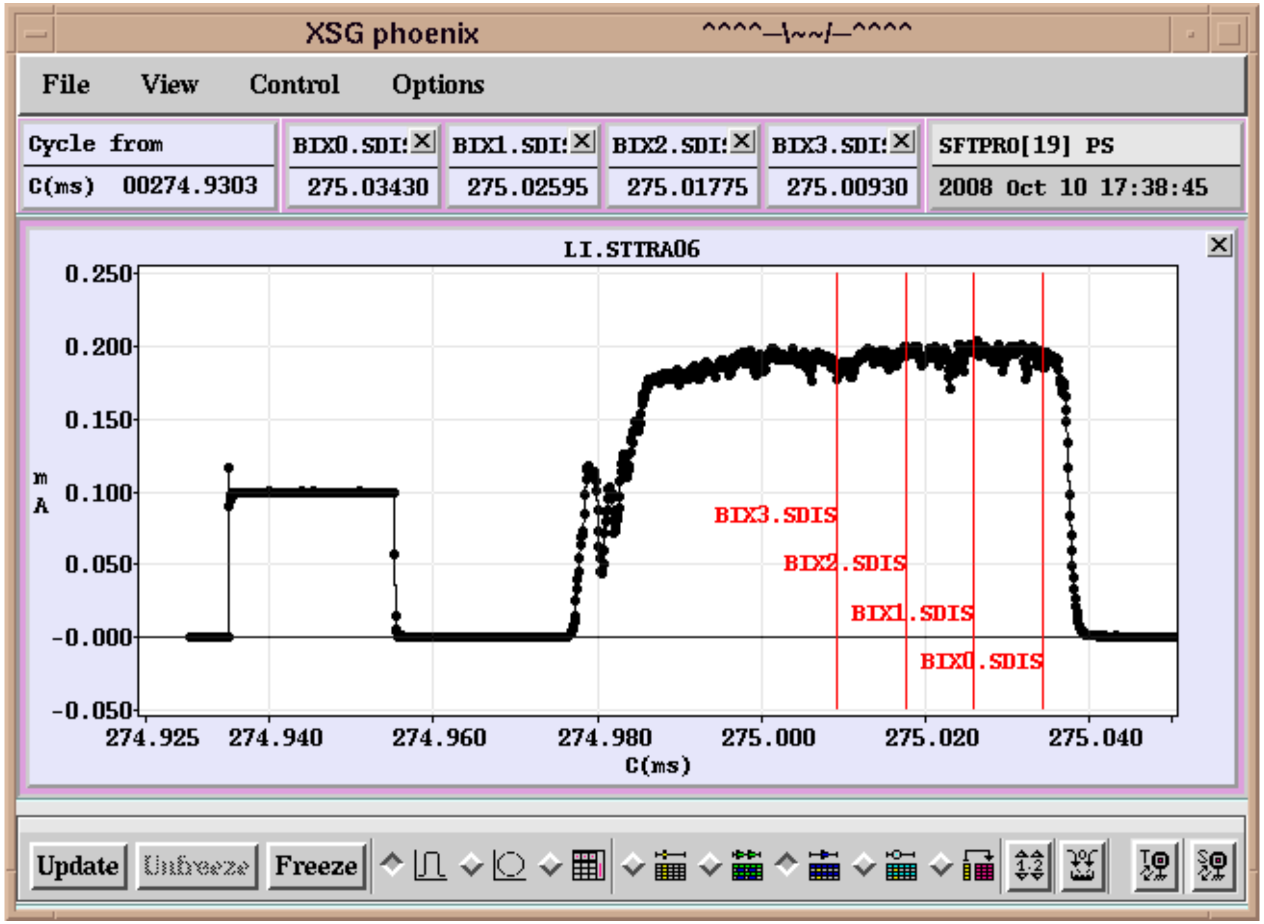
Shielding simulation and test measurements have Been done







Typical Transformer Signal



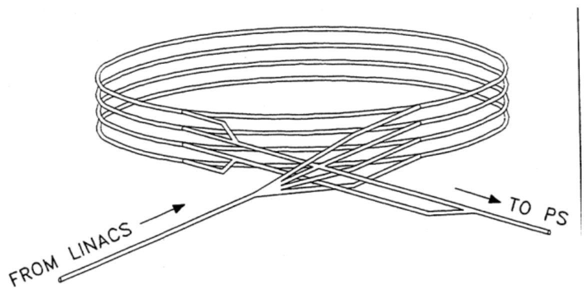
Calibration signal before each beam pulse

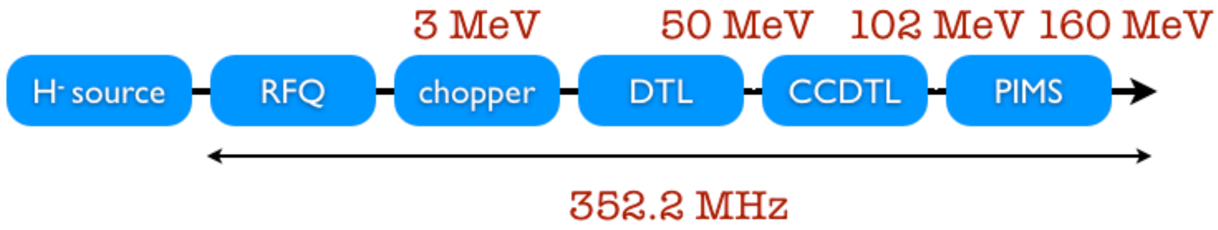
Digitization of 400 μs pulse at 10 MHz

Acquisition of Booster distributor timings

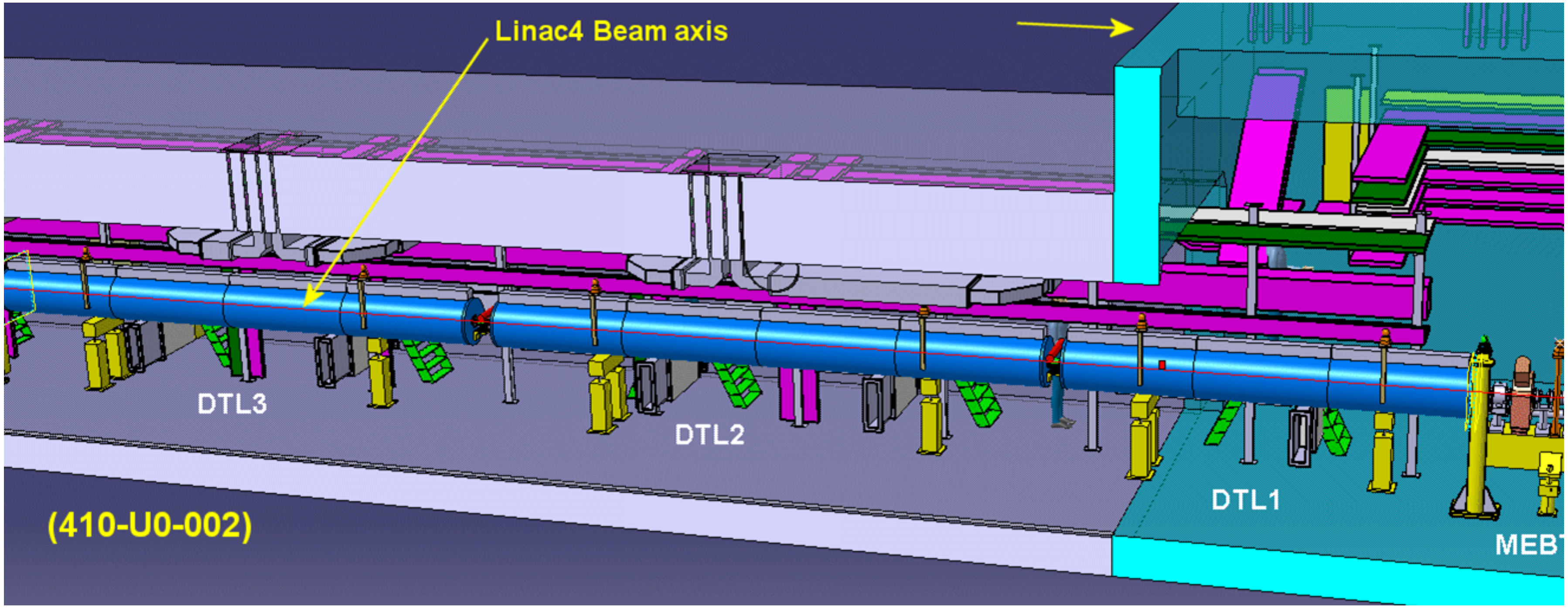
Measures
- total intensity
- intensity per Booster ring

Background suppression by software



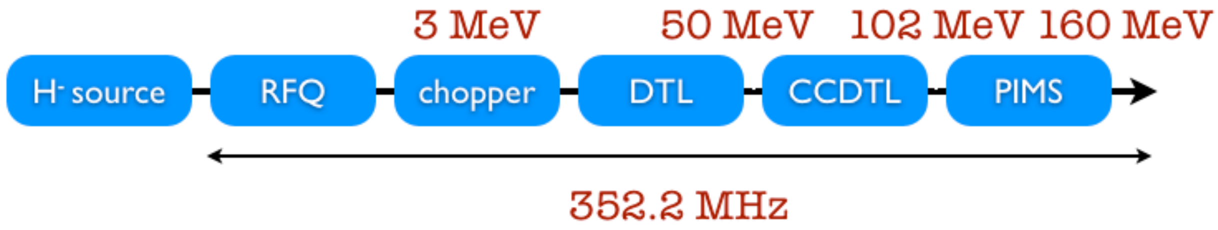


DTL

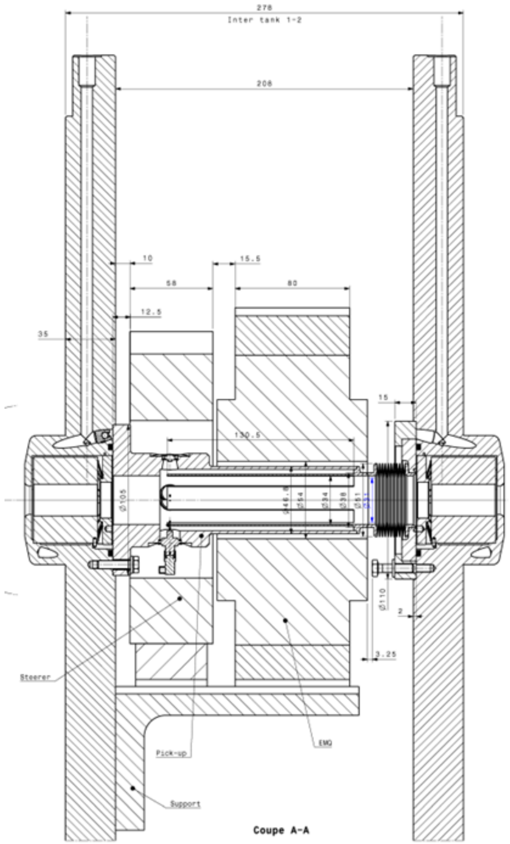


3 BPMs
1 BCT
1SEMGrid

Very little space, needed dedicated design for all devices



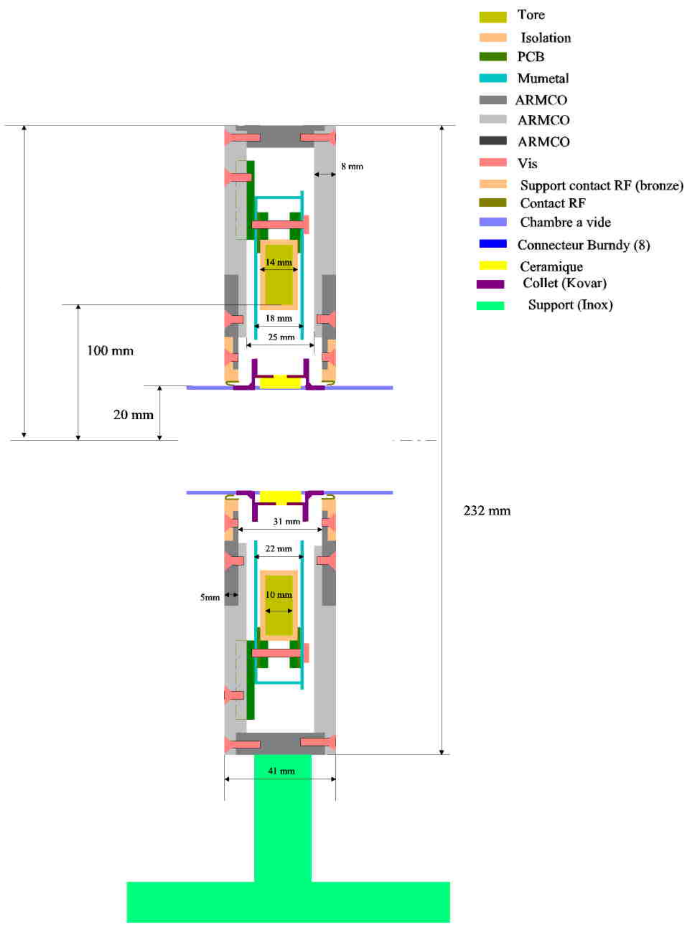
Inter-tank regions

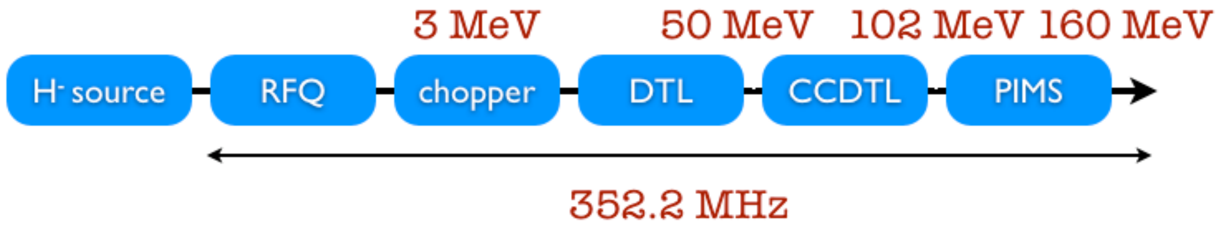


Very little space

Special design to limit Longitudinal dimensions

BPM built inside a quad





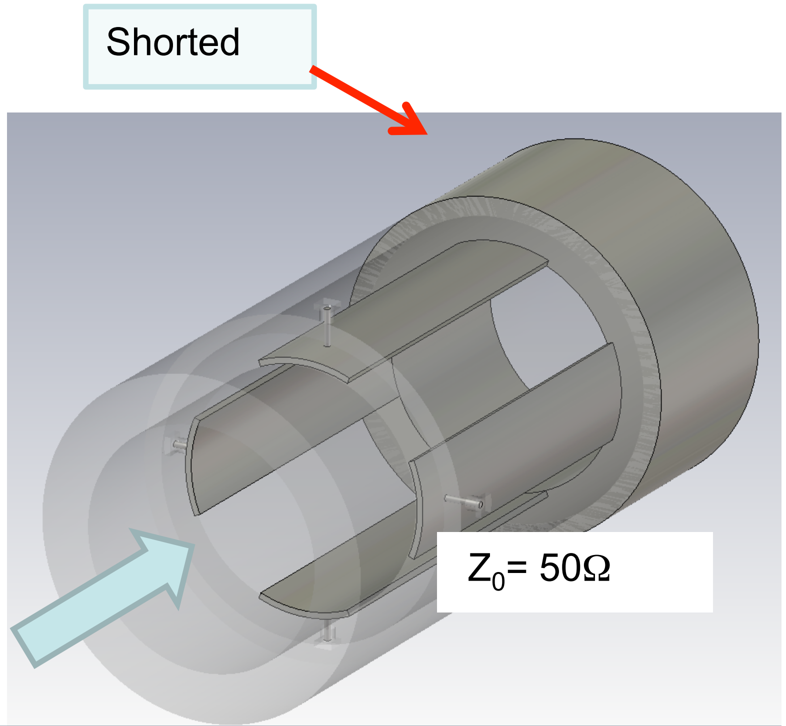
BPMs: Shorted stripline

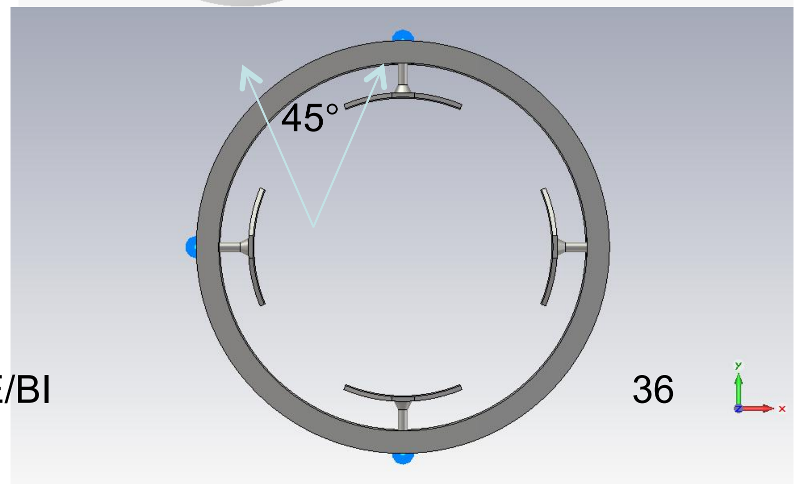
- Linear
- Fair sensitivity
- Compact
- Cheap
- Not beta-dependent

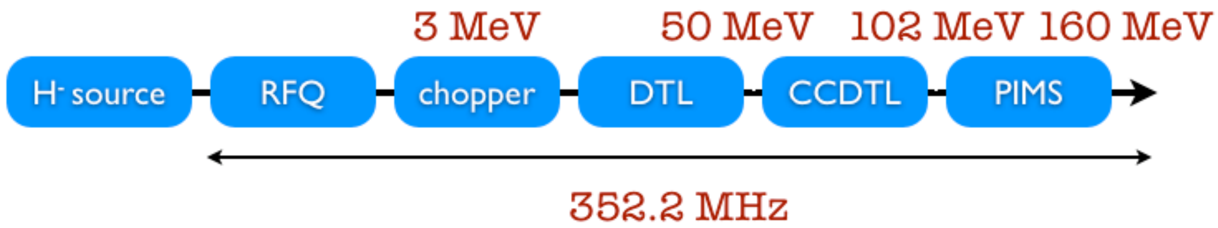
$$V_U(t) = \frac{\phi_{elec}\cdot Z_0}{4\cdot\pi}\cdot\left[I_B(t) - I_B(t-\frac{2\cdot l}{c})\right]$$

$$V_u(f) = \frac{\phi_{elec}\cdot Z_0}{2\cdot\pi}\cdot I_B(f)\cdot e^{j\theta}\cdot\sin\left(\omega\frac{l}{c}\right)$$

- But highly resonating







Pick-Ups: What should be measured?

Absolute beam position with respect to an external reference.

Relative beam intensity measured by two consecutive pick-ups.
Absolute beam intensity after calibration with BCT.

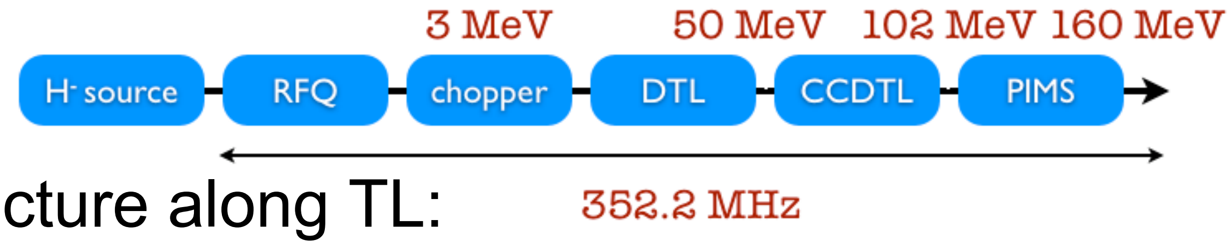
Absolute beam phase with respect to distributed RF reference.

TOF flight between two pick-ups.

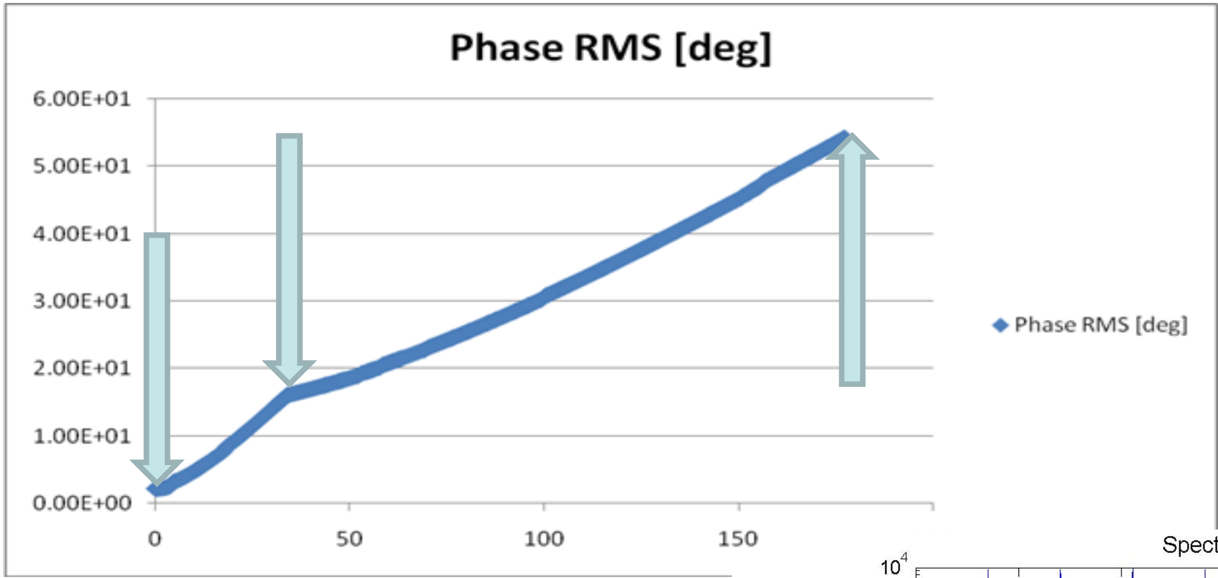
Low freq. cut off = 15 Hz

$1/\sigma_{bunch}$ = 50 GHz

- **Int. = 10^9/bunch**
- **Pulse l.= 400μs**
- **I ave. = 40mA**
- **σ_{bunch} = 20ps – 777ps**
- **F_B = 352MHz**



Bunch structure along TL: Concerns



End of Linac

Φ_{RMS} = 2.5°

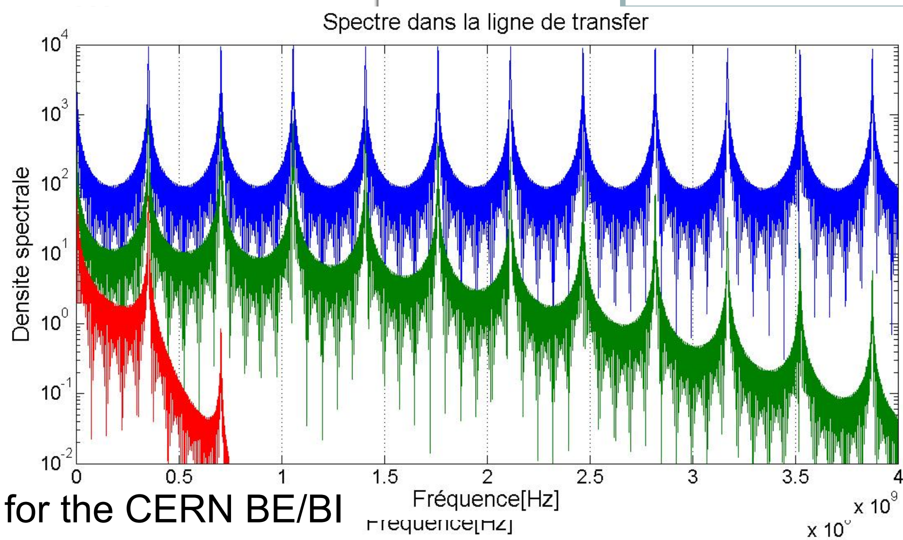
Debuncher

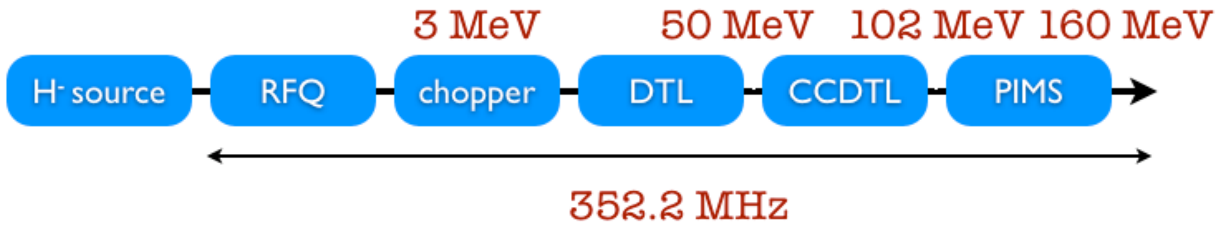
Φ_{RMS} = 17°

PSB Stripper foil

Φ_{RMS} = 55°

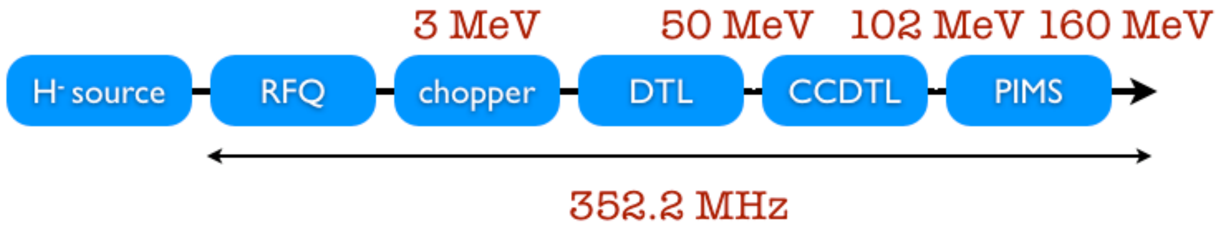
Beam energy at 160MeV





List of instruments

Instrument	number	location	energy	details
Faraday Cup	2	LEBT	45 KeV	only scope
Emittance meter	1	LEBT, MEBT	45 KeV 3 MeV – 12 MeV	
BPMs	31	MEBT - Booster	3 MeV – 160 MeV L2-Booster transfer	Pos, intensity Phase
SEMGrids	18	LEBT – Booster	45 KeV – 160 MeV	
Transformers	16	LEBT - Booster	45 KeV – 160 MeV	
BSM	1	MEBT - PIMS	3 MeV – 160 MeV	Russian coll
Halo Monitor	1	MEBT	3 MeV	M. Hori (finished)



List of Instruments

Instrument	number	Location	energy	details
Wire Scanners	6	MEBT, CCDTL, PIMS	3 MeV – 160 MeV	
BLMs	26	MEBT - Booster	3 MeV – 160 MeV	
TV screens	7	Booster inj	160 MeV	Emittance + inj.
Laser Wire tests	1	MEBT - Booster	3 MeV – 160 MeV	R&D for SPL