Performance of Linac4 instrumentation during commissioning

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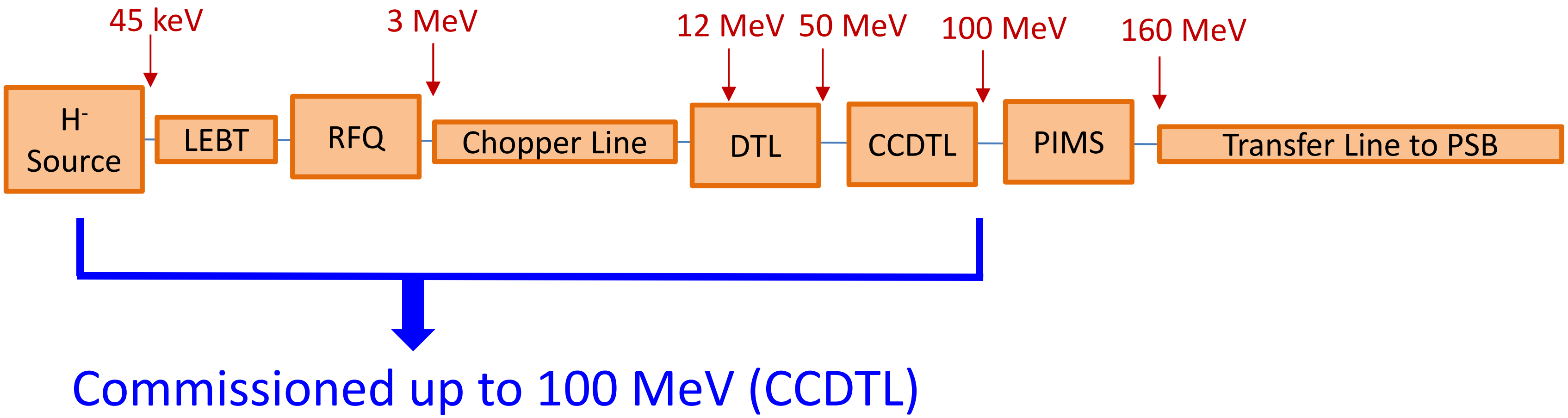
on behalf of the CERN Beam Instrumentation Group

Outline

- Linac 4 layout
- LEBT Beam instrumentation
- MEBT instrumentation and the chopper
- Beam intensity measurements (BCTs)
- Beam transverse profile measurements (WS, grids, laser)
- 3 and 12 MeV slit-and-grid emittance meter and Laser
- Longitudinal measurements (BSM and spectrometer)
- 50/100 MeV Emittance measurements
- Energy measurements using Time of Flight
- Conclusions and outlook

Linac-4 commissioning stages



- The LEBT instrumentation is temporarily extended with a slit/grid emittance meter
- MEBT line transformer and wire scanners show chopper performance
- Temporary 3/12 MeV measurement line
- Temporary 50/100 MeV measurement line
- Beam characterization with operational diagnostics at 160 MeV

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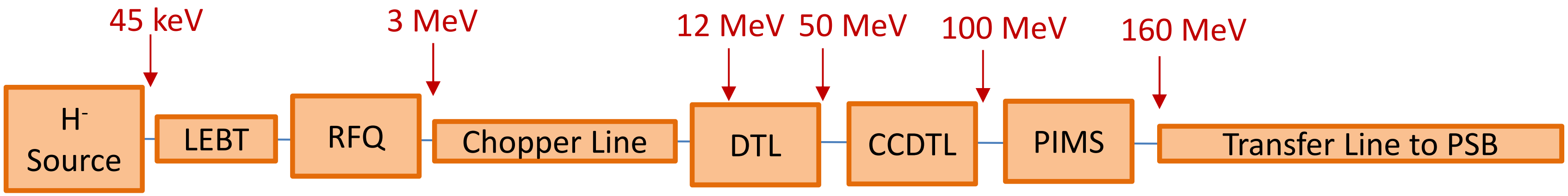
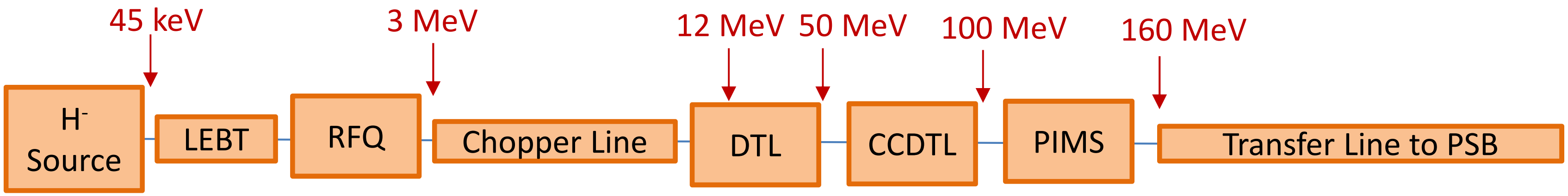


Comm

- The LE … mittance meter
- MEBT … ce
- Tempo
- Tempo
- Beam

Linac-4 commissioning stages



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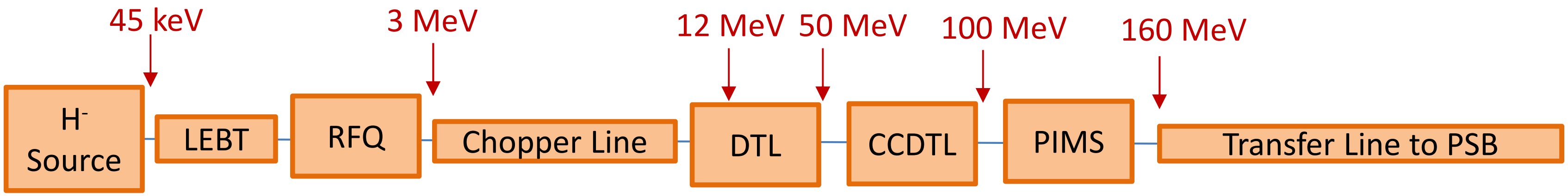

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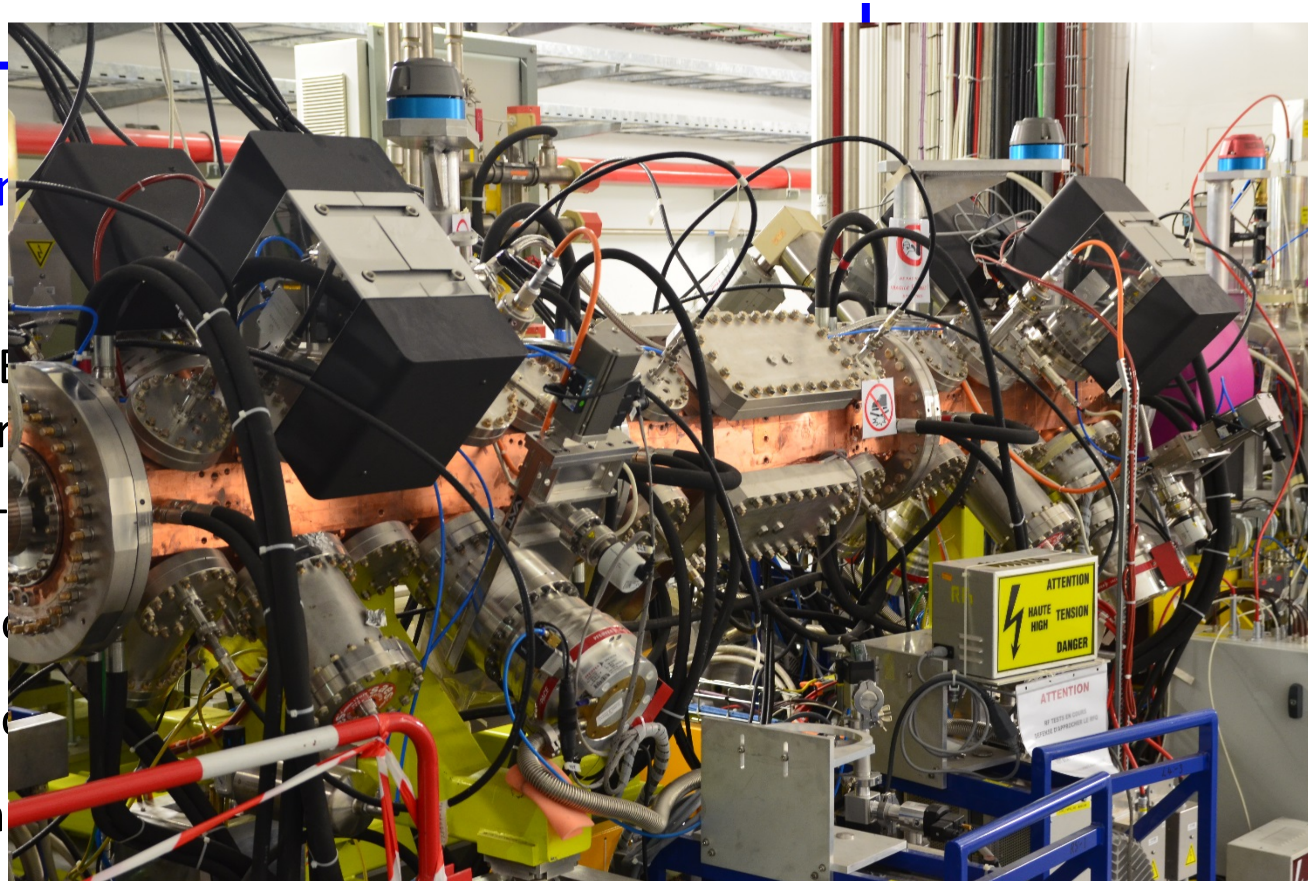

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Linac-4 commissioning stages

45 keV → H⁻ Source | LEBT | 3 MeV → RFQ | Chopper Line | 12 MeV → DTL | 50 MeV | CCDTL | 100 MeV → PIMS | 160 MeV → Transfer Line to PSB

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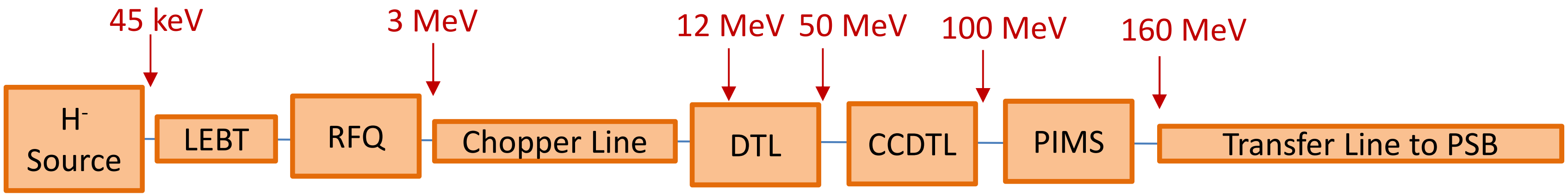

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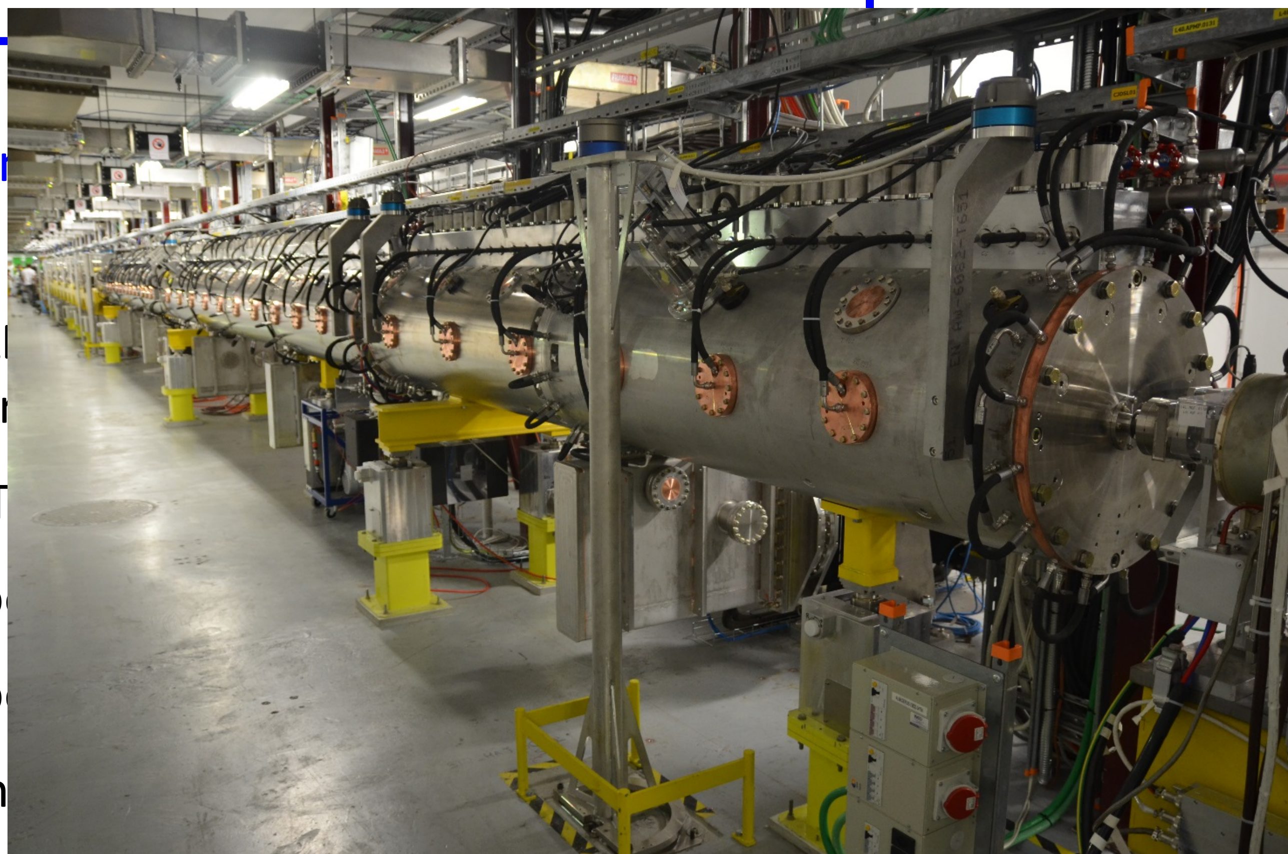

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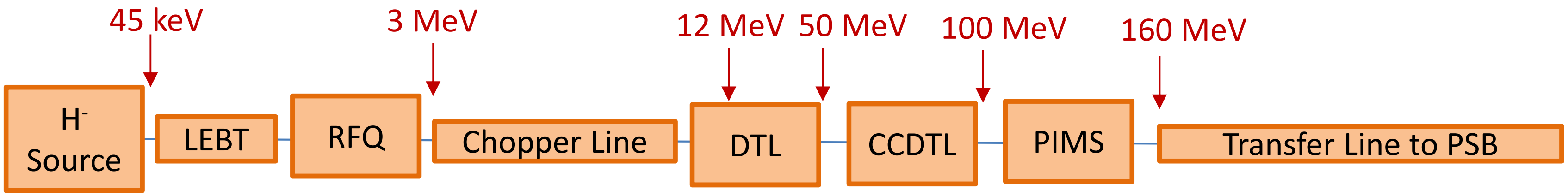
Linac-4 commissioning stages



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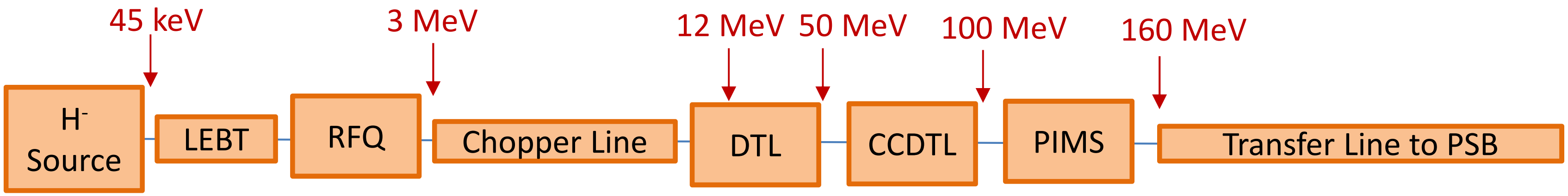
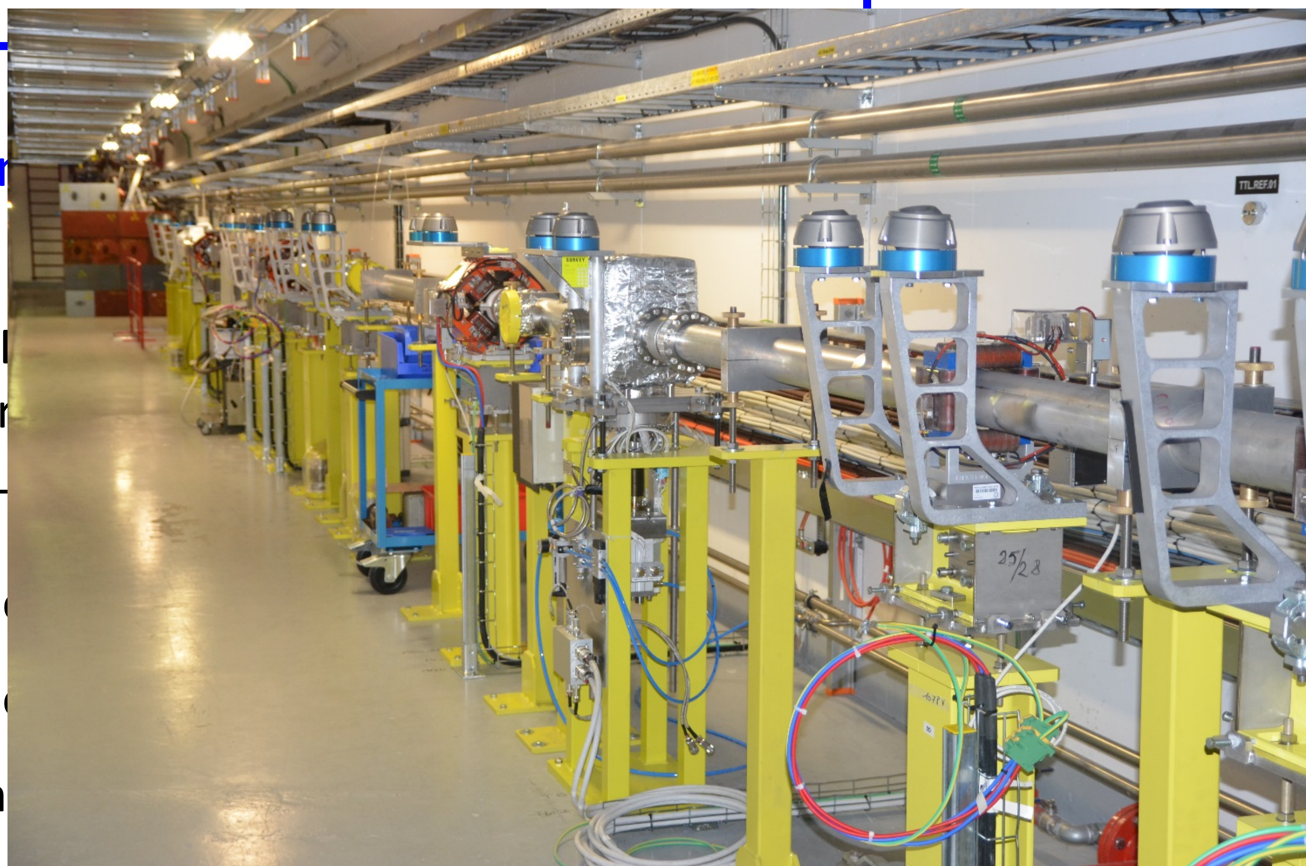
Linac-4 commissioning stages





Comm

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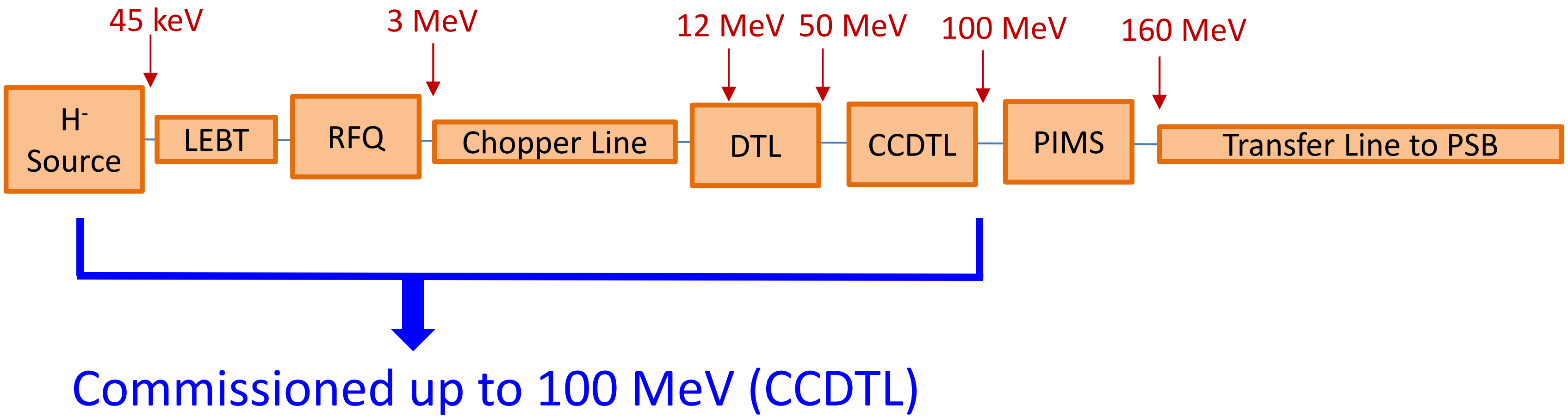
Linac-4 commissioning stages



- The LEBT instrumentation is temporarily extended with a slit/grid emittance meter
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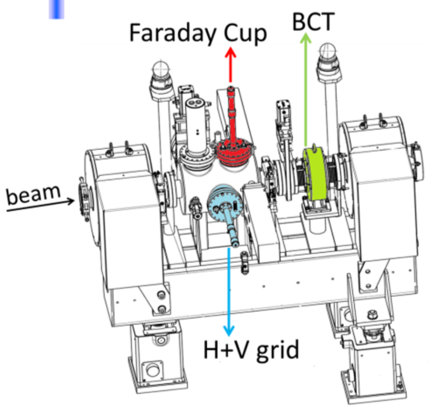
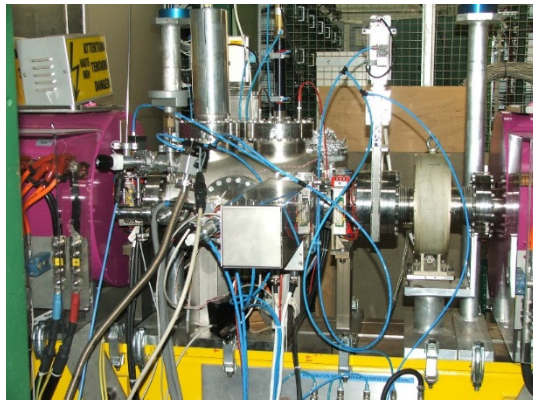
LEBT Beam instrumentation @ 45 keV

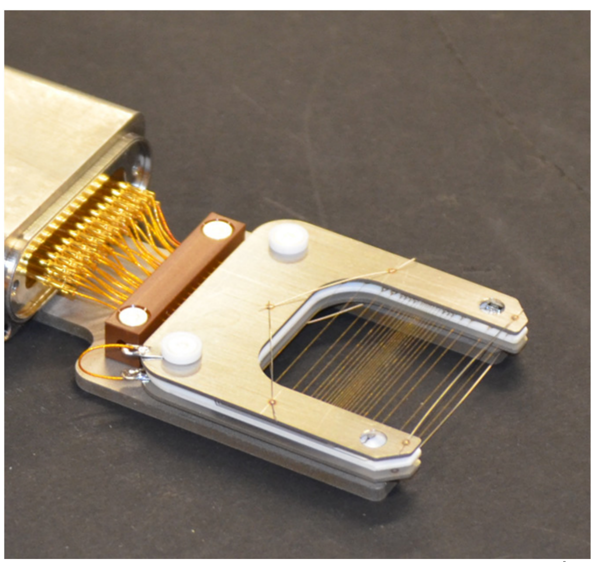


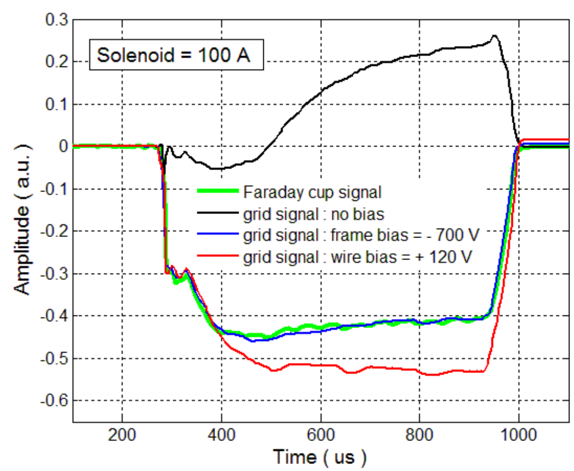


We expected a positive signal on the wire (proton stopping in the wire, SEY: 3.5) but the signal is dominated by suppression of SEM through the H^- beam

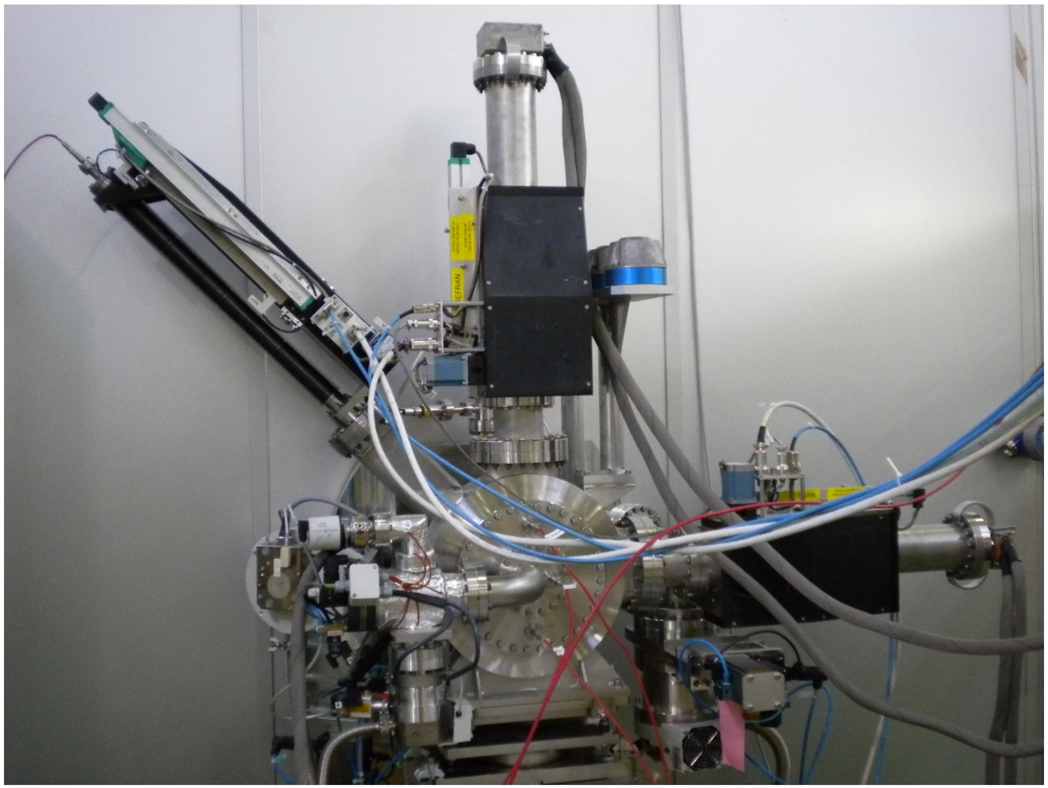
Polarizing the wire grid frame with -700V pushes the secondary electrons back onto the wire and the wire grid works in charge collection mode (negative signal).

Polarizing the wire positively has the same effect but attracts distorting the signal.





Temporary slit/grid Emittance Meter



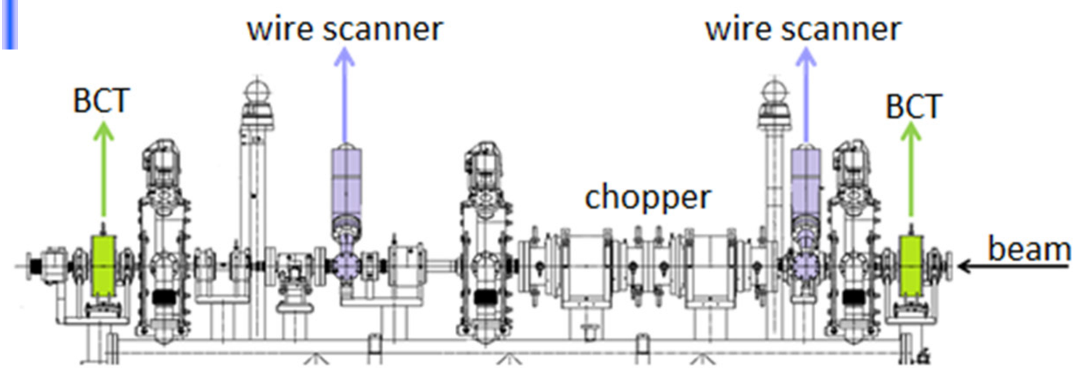
A slit/grid emittance meter was temporarily installed:

- Immediately after the source
- After the first solenoid
- After the second solenoid

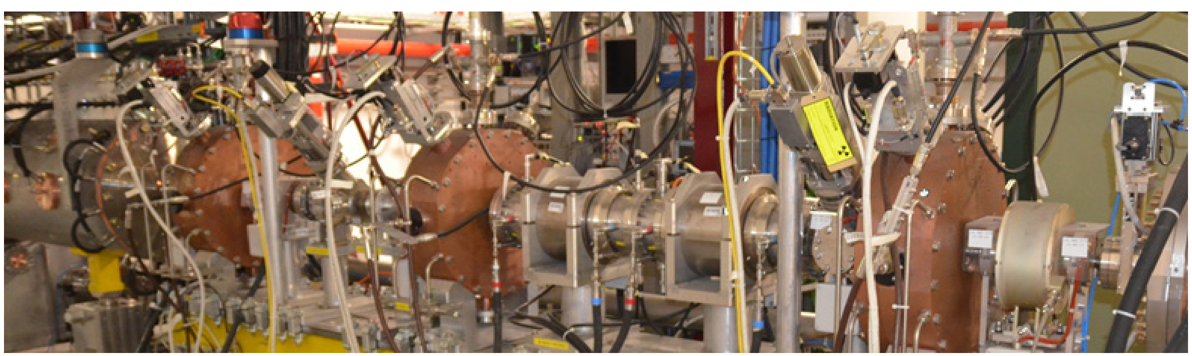
Stainless steel plate with L-shaped slit of 200 um

Hor. and ver. Grids with 48 wires of 1 mm pitch movable on stepping motor

MEBT and chopper @ 3 MeV

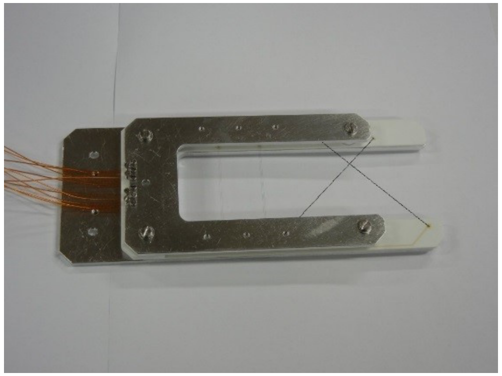


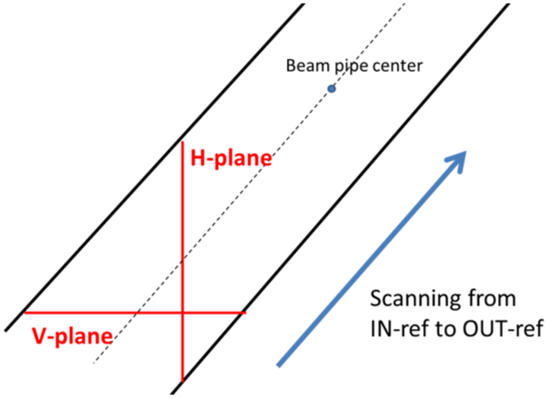
Measure transmission through RFQ:
(first BCT)
Chopper action longitudinal:
(second BCT)
Transverse: second wire scanner

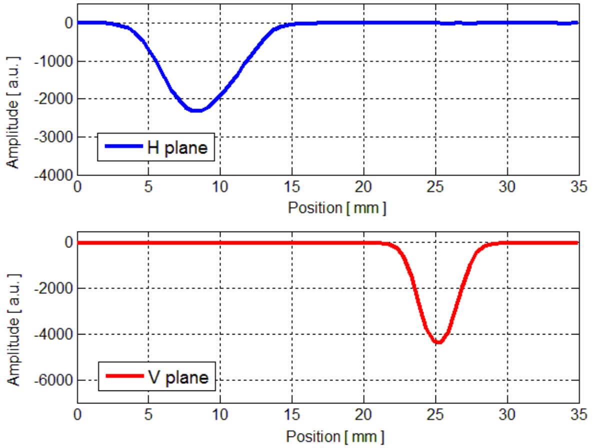


Wire scanners @ 3 MeV

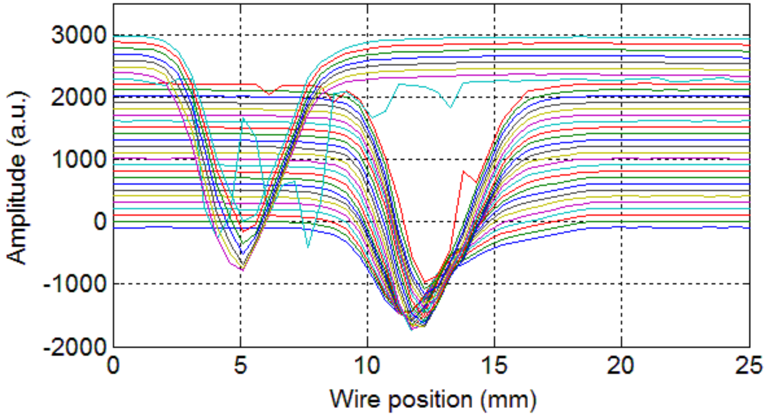
- 33 µm Carbon wires mounted in L-shape on the same fork support and scanning the beam at 45 degrees (one scanning position per pulse)







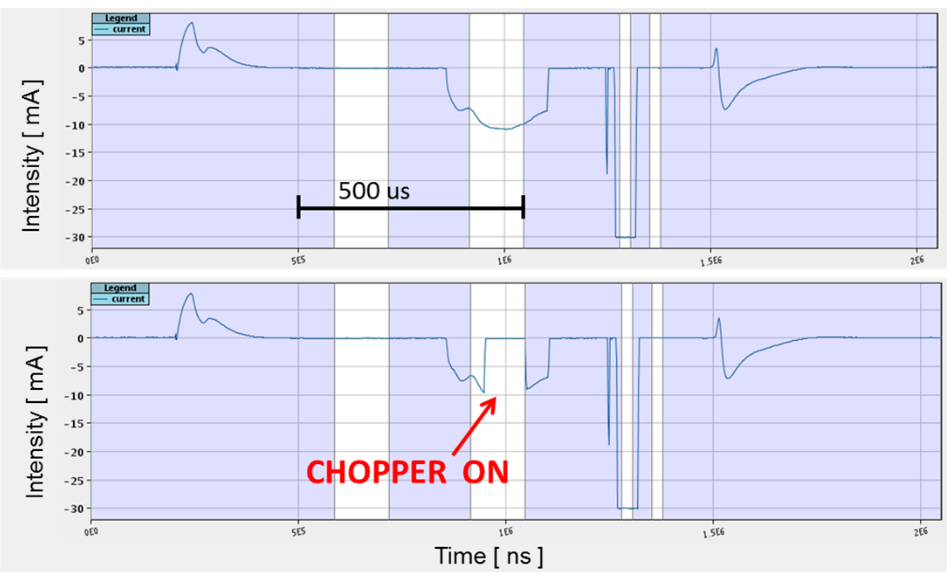
- Time resolution of 4 µs within the beam pulse (250 kHz ADC) → WS2 showing the vertical displacement of the chopped beam

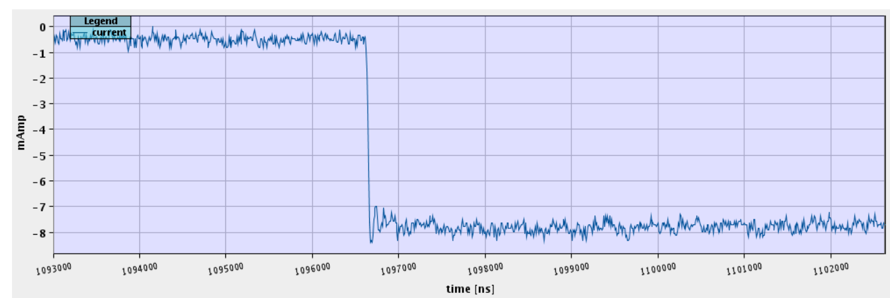


Vertical transverse profiles along the beam pulse with chopper ON

Intensity measurements

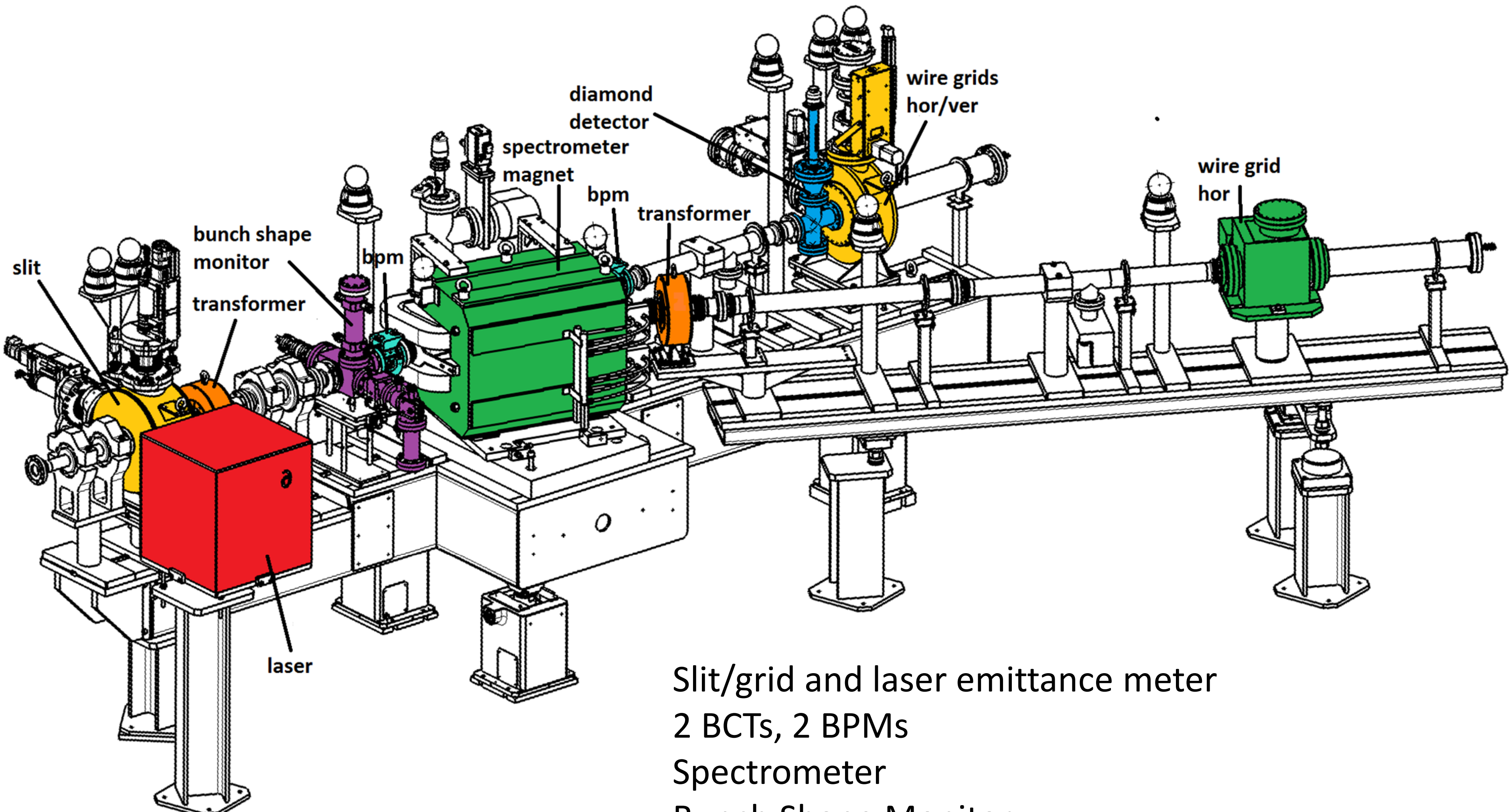
- H^- source current = 15-20 mA (new H^- source ≈ 30-40 mA)
- BCT features : calibration pulse, magnetic shielding
- Fundamental to optimize transmissions through RFQ , MEBT and the Linac cavities (DTL, CCDTL, PIMS)
- First evidence of the chopper operation (rise/fall time < 10 ns)





Sampling frequency: 100 MHz

3/12 MeV measurement line

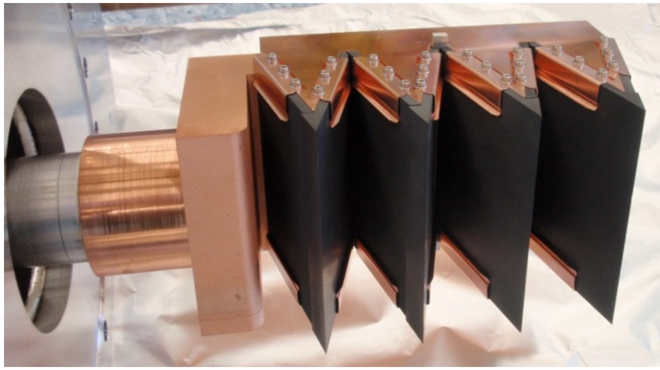


Slit/grid and laser emittance meter
2 BCTs, 2 BPMs
Spectrometer
Bunch Shape Monitor

Slit-grid and Laser Emittance Meter

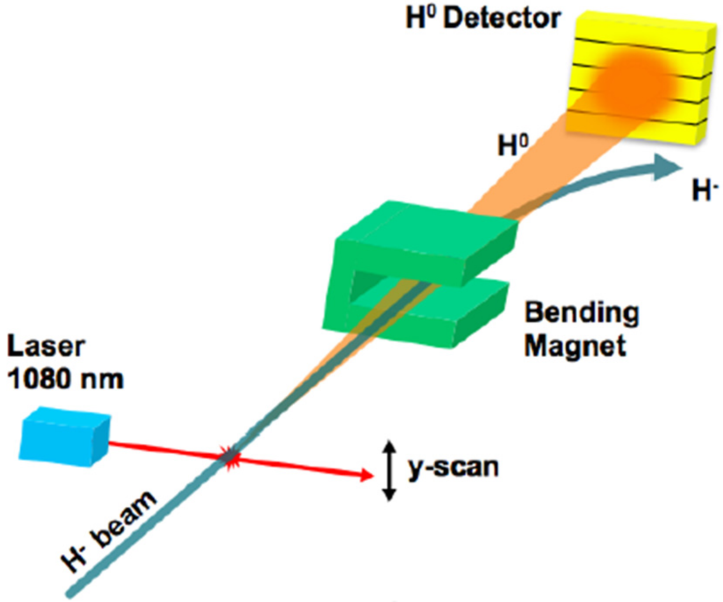
Slit/Grid

- Slits (H+V)= 2 blades system, each consisting of a harmonica shaped, water cooled copper structure covered by graphite plate, gap = 200-300 μm
- Wire grids (H+V) = 48 Carbon wires, pitch of 0.75 mm, metallic frames up- and down-stream at 5 mm distance



Laser + Diamond Detector

- A fine laser beam neutralizes a small part of the H^- ions.
- The resulting H^0s are extracted from the beam through the spectrometer magnet
- The angular distribution of the H^0s is measured with a diamond detector



Emittance Meter validation

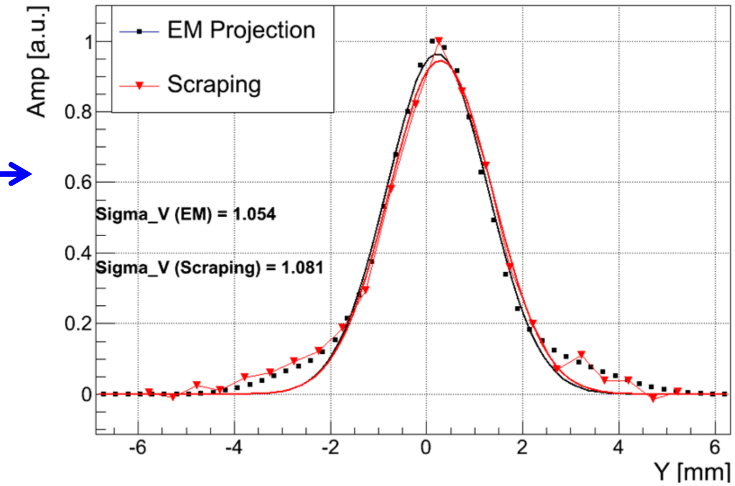
- Beam profile (EM projection) cross-checked with the beam profile obtained by using the slit as a scraper and by reading the remaining beam current on a downstream BCT.

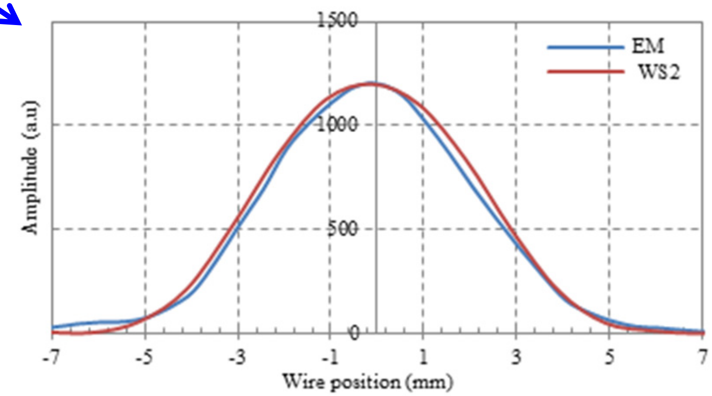
- Beam profile measured by WS2 cross-checked with the profile obtained from emittance measurements (phase spaces) back-tracked (PATH) to the same location of WS2.

- Agreement with the emittance measurements by:
  - quad scanning + profile measurements
  - prototype laser emittance meter

Table 1: Transverse emittance

Method	Ex norm rms	Ey norm rms	Threshold
Slit-grid	0.27	0.24	1%
Laser-diamond		0.27	0.1%
From profiles	0.31	0.34	0.5%

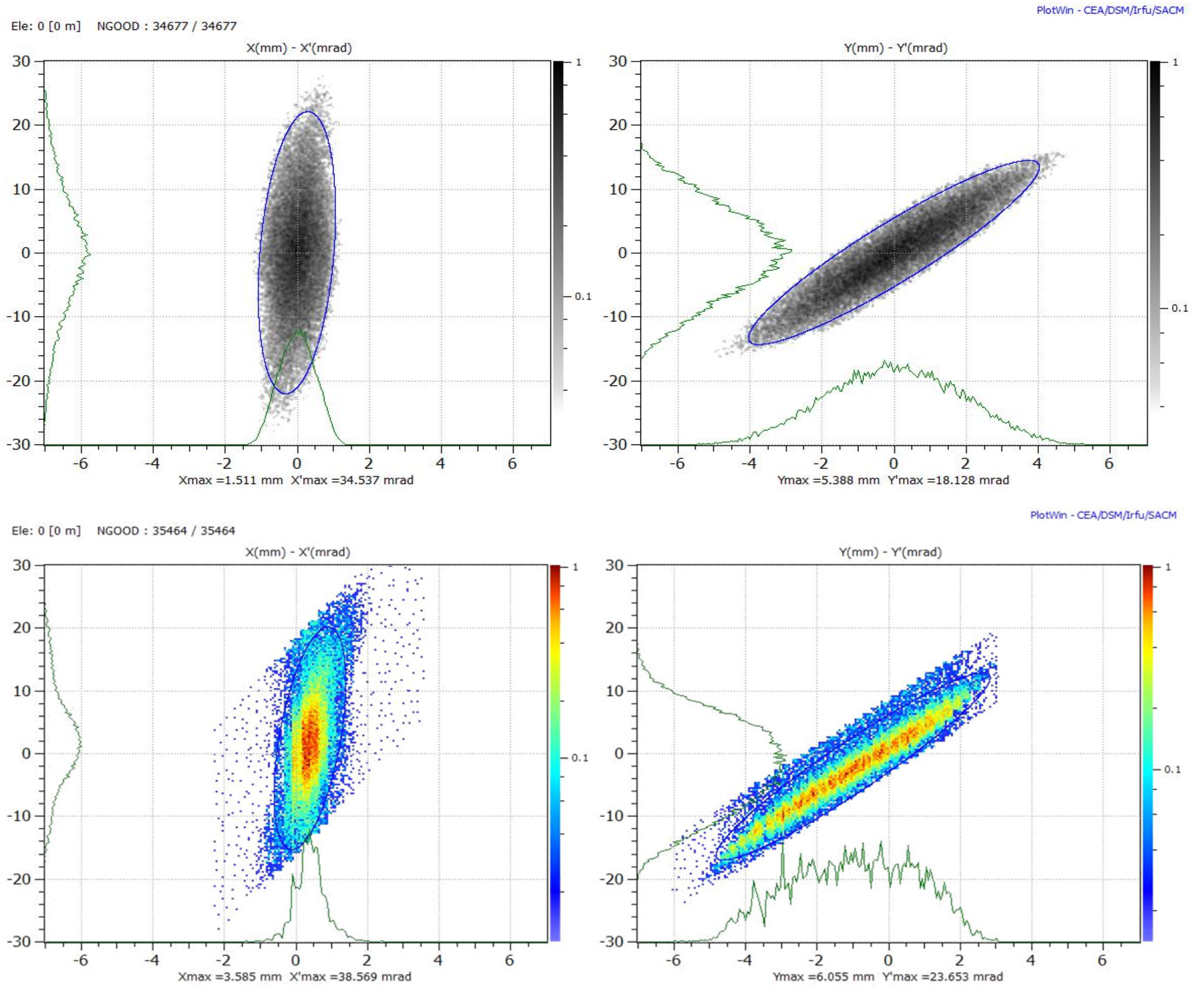




M.Y.Satri, et al. “Transverse beam profile measurements in the Linac4 MEBT” – Linac14 conf proceed.

A.M.Lombardi, “Commissioning of the low-energy part of Linac4” – Linac14 conf proceed.

3 MeV beam matched to DTL1

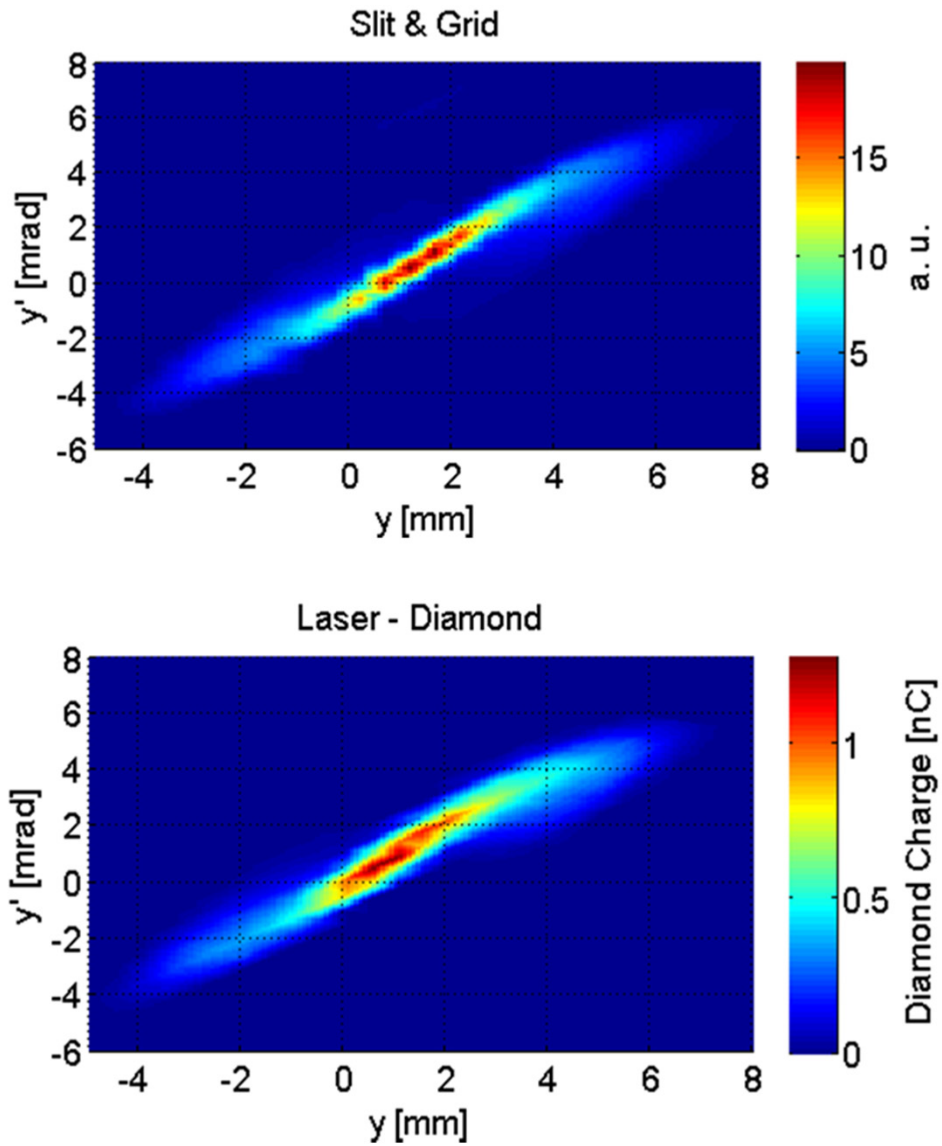


Expected matched beam

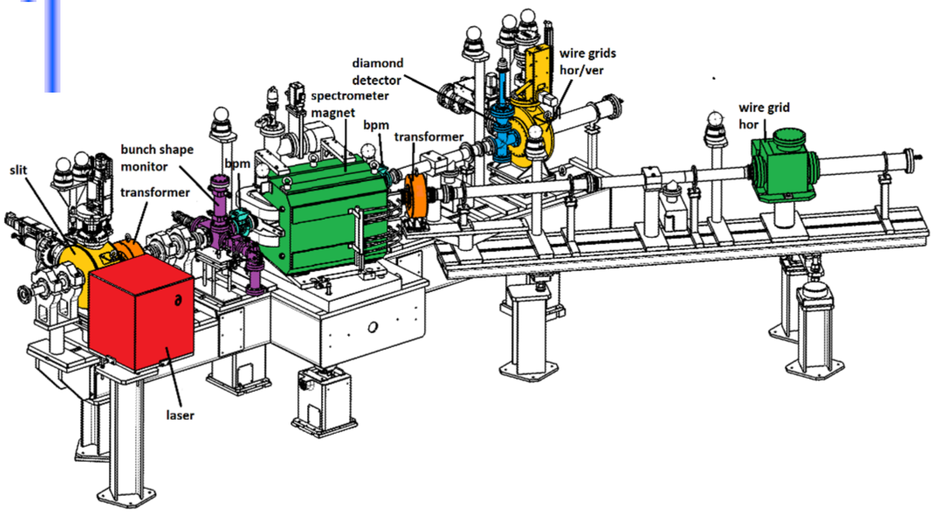
Measured matched beam

A.M.Lombardi, "Linac4 commissioning overview" – LIU-day, 11 April 2014

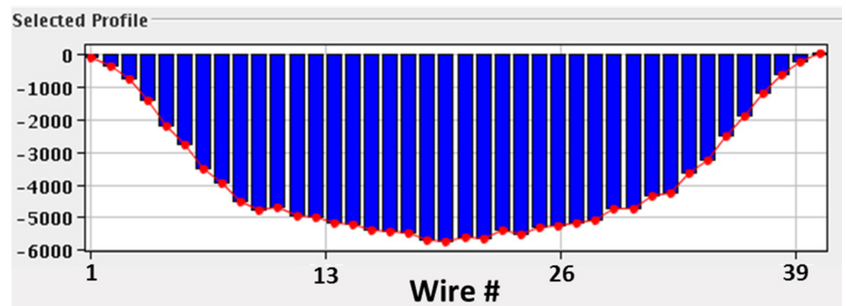
Comparison slit/grid - laser



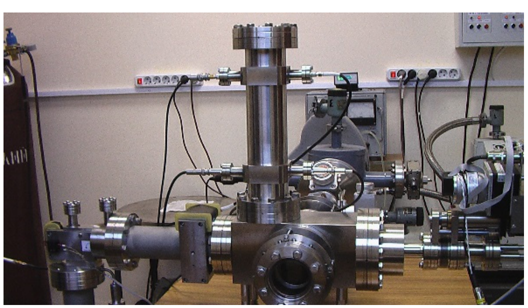
Longitudinal measurements

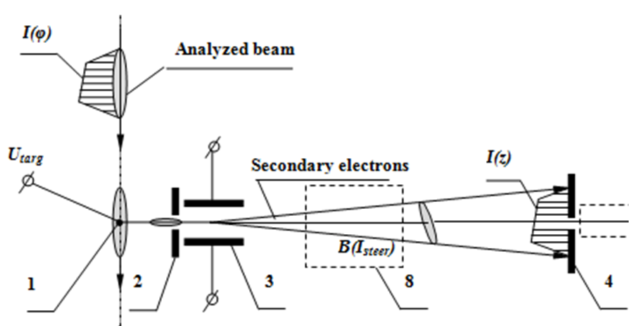


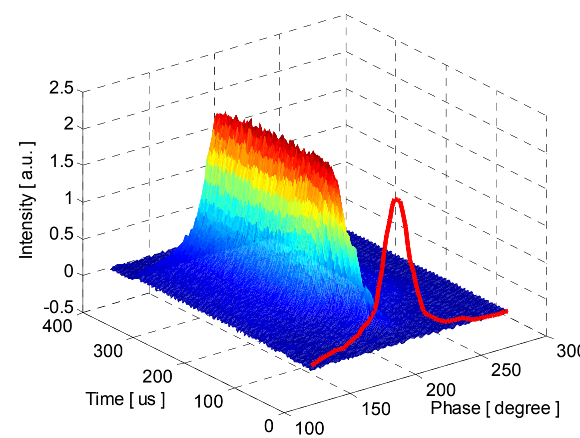
<u>Spectrometer grid</u>: 40 Carbon wires, 0.75 mm pitch, frame bias = -700V @ 3 MeV, same but less critical @ 12 MeV.



<u>Bunch Shape Monitor</u>: developed at INR (Russia) by A. Feshenko, measures the longitudinal distribution of a micro-bunch, phase resolution = 1 degree (= 8 ps), time resolution = 1 μs.



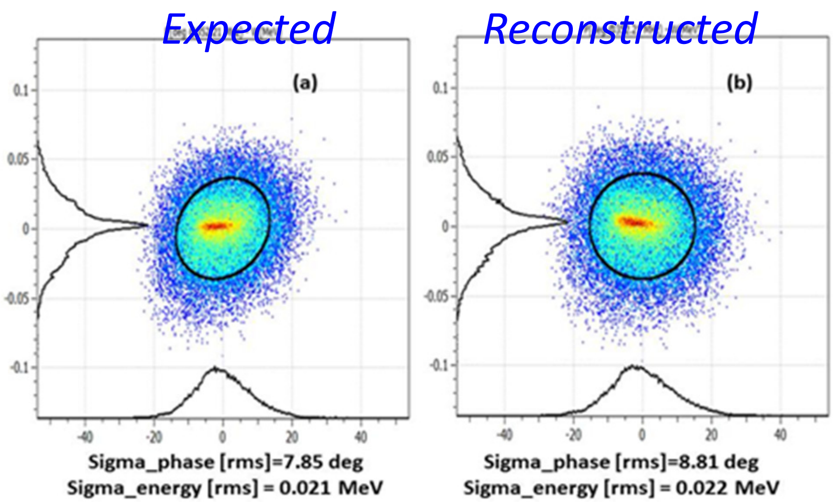




Longitudinal measurements

- Spectrometer successfully used for
  - phase tuning of the 3 MEBT bunchers
  - energy spread measurements

- BSM successfully used to
  - phase tune the 3 MEBT bunchers (spectrometer cross-check)
  - measure the micro-bunch longitudinal distribution
  - obtain indirect measure of the longitudinal emittance



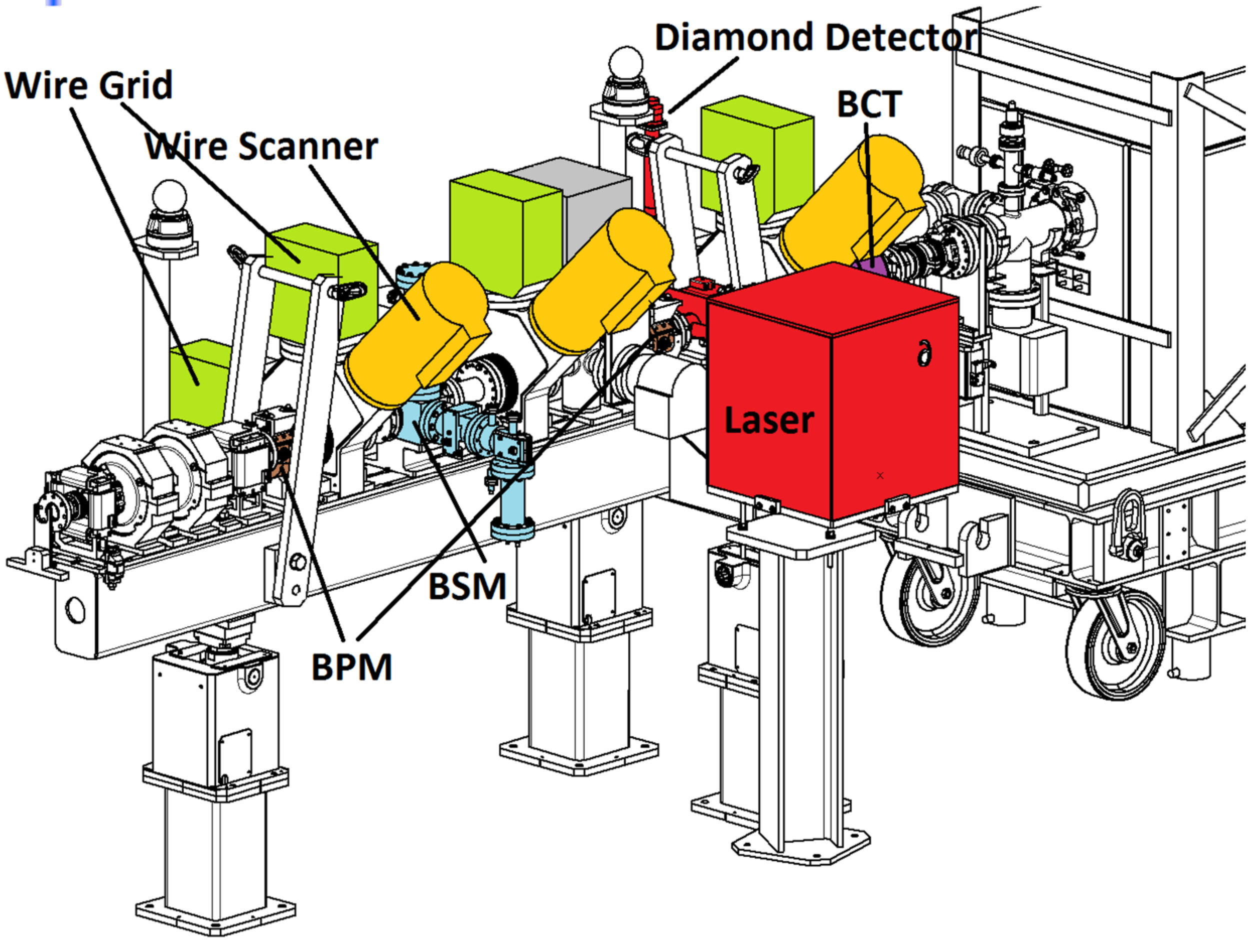
@ 3 MeV:

Method	ε_{rms} deg MeV	ΔW MeV
simulations	0.19	0.022
From BSM phase profiles	0.16	0.021
spectrometer	-	0.019

A.M.Lombardi, “Commissioning of the low-energy part of Linac4”, LINAC14 Conf.Proc.

G.Bellodi, V.A.Dimov, J.B.Lallement, A.M.Lombardi, U.Raich, F.Roncarolo, F.Zocca, M.Y.Satri, “Longitudinal beam profile measurements in Linac4 commissioning”, LINAC14 Conf.Proc.

50/100 MeV Measurement Line

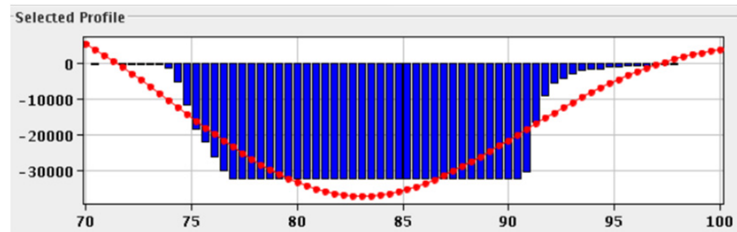


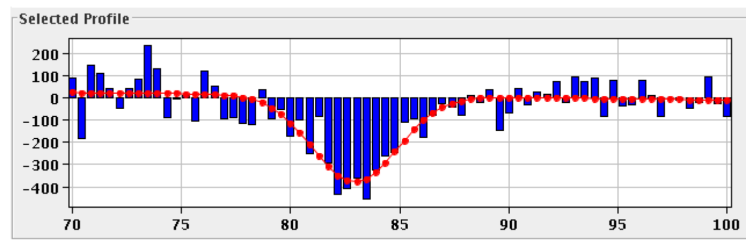
- 3-Profile Emittance Meter
- Wire Scanners and Grids at the same position
- Laser & Diamond detector profile measurement
- BSM
- BPMs measure beam energy via ToF
- Transformer

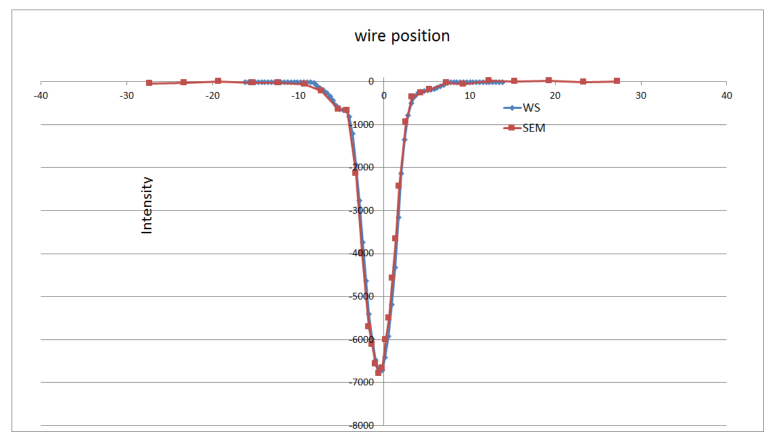
Transverse Profiles

Transverse profiles may be distorted due to crosstalk induced by stripped electrons.
Grids and wire scanners are installed in the same vacuum vessel to estimate the importance of the effect.
Crosstalk between hor and ver wires on the L-shaped wire scanner can be directly observed

Difference in profile width observed: ~1.5%





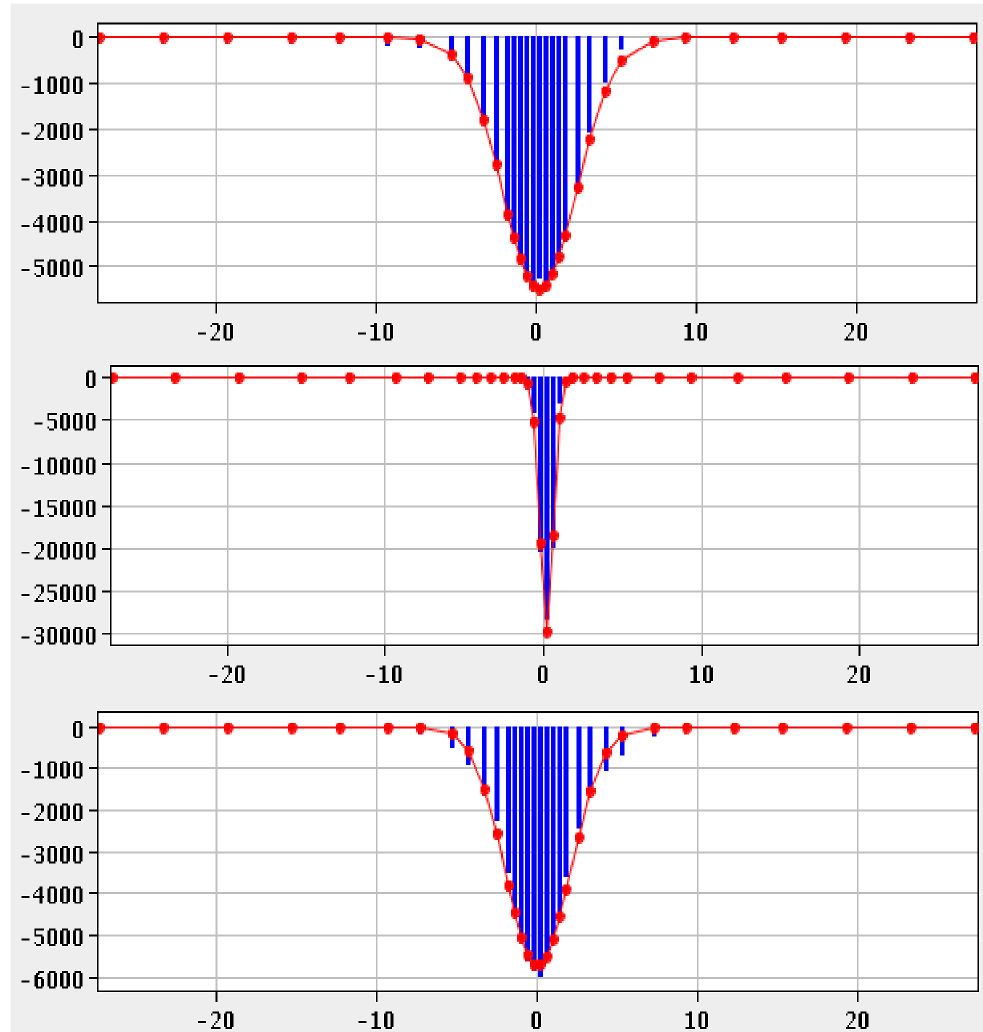


Emittance calculation using 3 profiles

We measure 3 profiles around a waist.
Only one grid or scanner is used at a time.

Stripped electrons would introduce errors in the downstream device.

Calculations with linear matrix transformations give wrong results because of strong space charge.



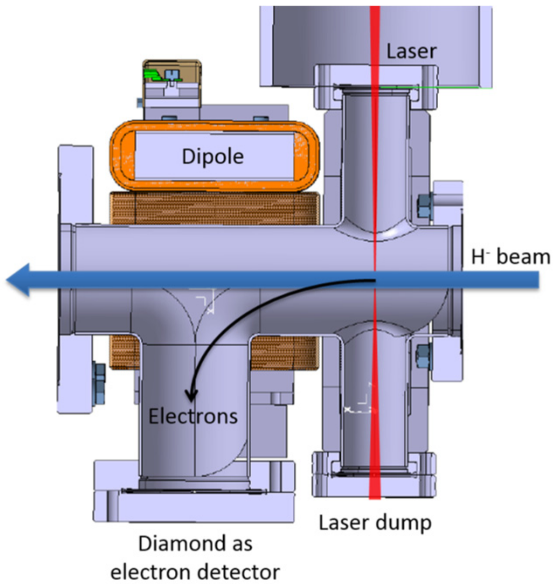
Linear transformations give a first estimation for the Twiss parameters.
This is used to generate a particle distribution which is followed with tracking code taking non-linear effects into account and the result is compared with measurement.

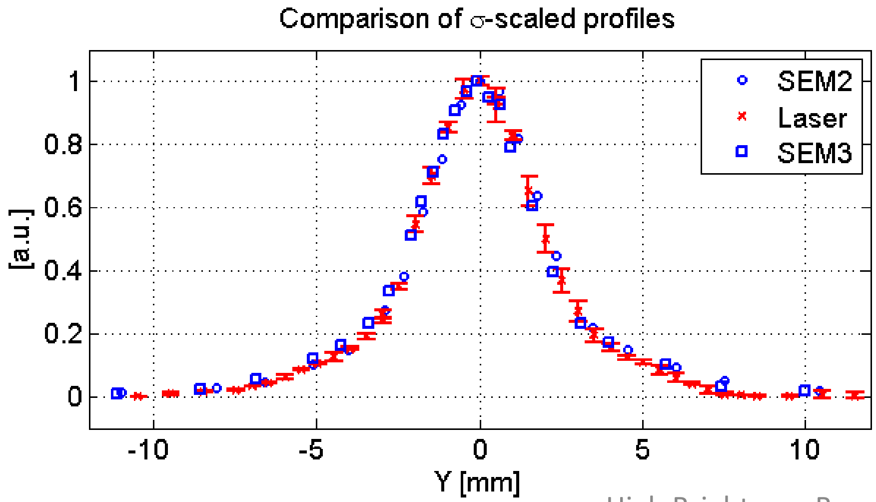
The Twiss parameters are iteratively modified until the simulation coincides with measurement ("forward method") (see WEPM1Y01)

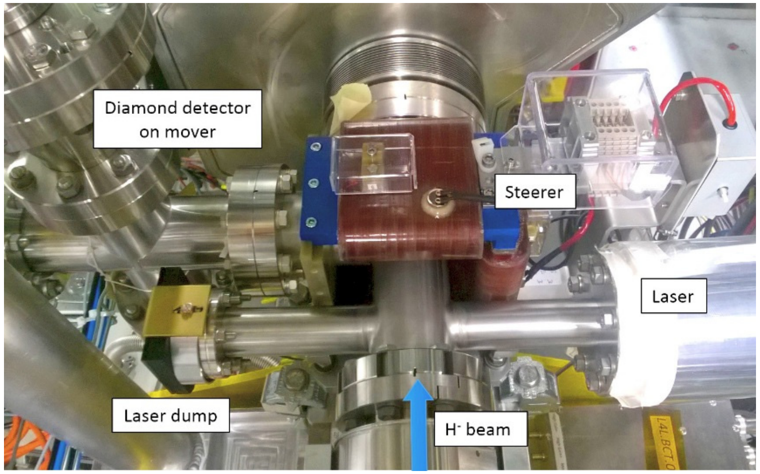
Comparison to laser profile

Without a strong bending magnet H- and H0 cannot be separated.
A weak magnet allows separation of H- and stripped electrons, which are detected in a diamond detector.

By moving the laser (and the diamond detector) the profile can be measured and compared to the wire grids.

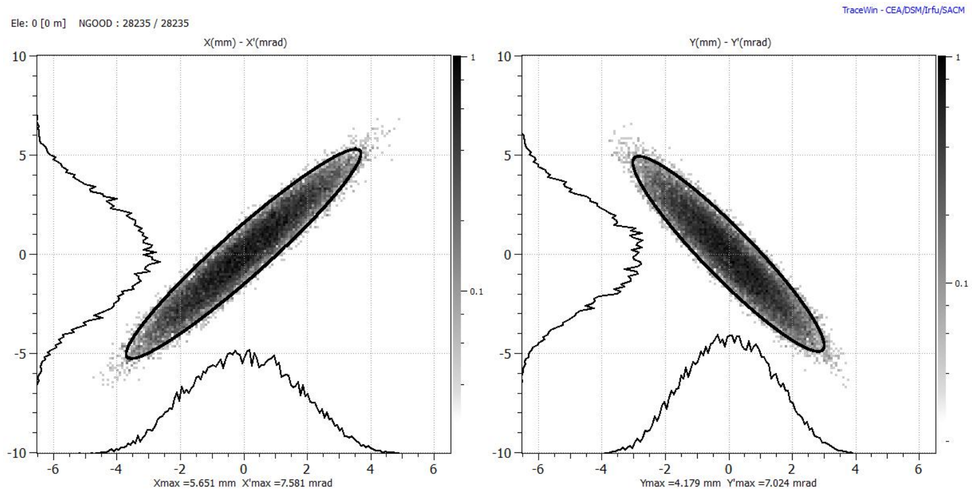




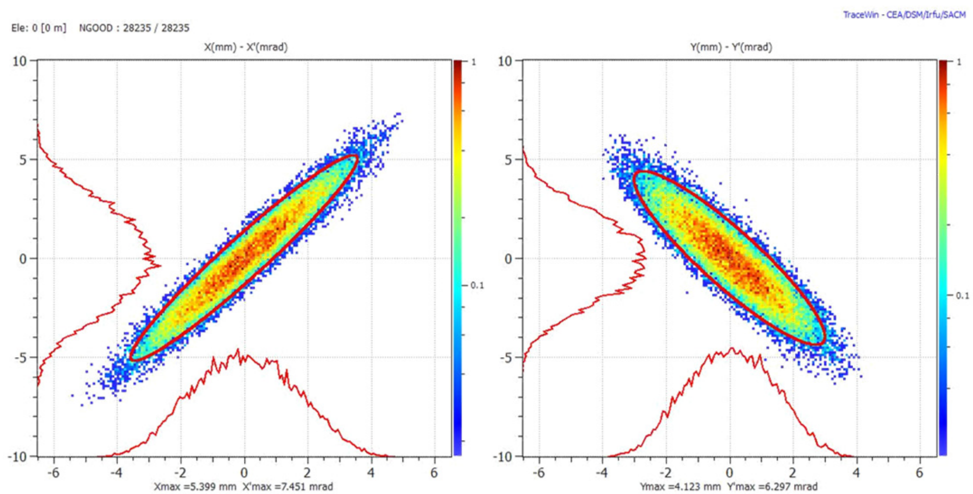


50/100 MeV Measurement Line

Expected

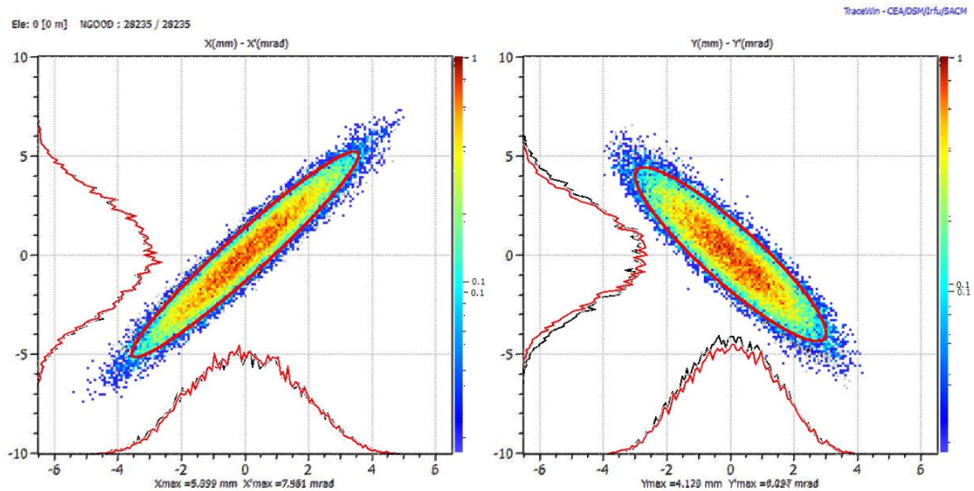


Measured



50/100 MeV Measurement Line

Expected



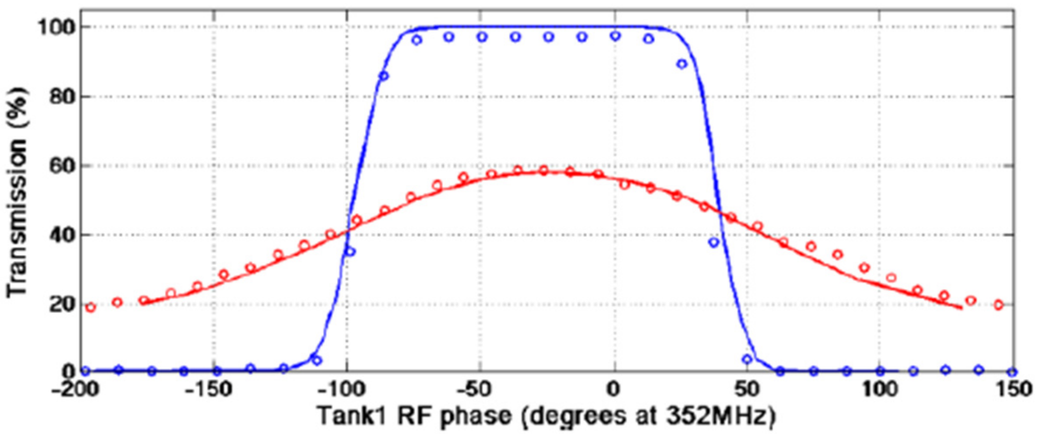
Measured

Adjusting DTL1 RF parameters

We measure transmission through the RFQ with 2 BCTs for nominal DTL1 RF amplitude and different phase settings and compare to theoretical curves

red: all bunchers in MEBT switched off

blue: all bunchers on with nominal with nominal RF settings



50/100 MeV Measurement Line

The BPMs can measure

- Position
- Relative intensity
- Phase

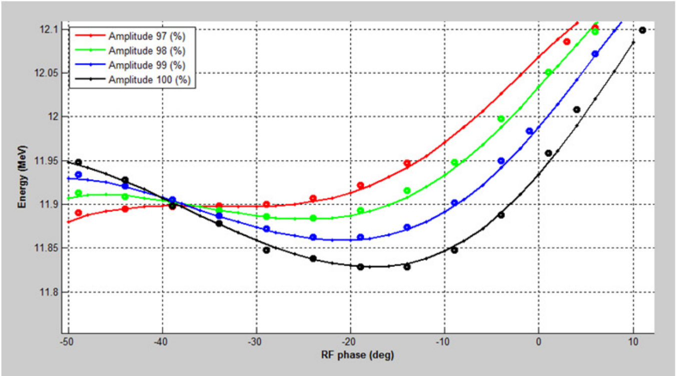
For a fixed RF amplitude the cavity exhibits a characteristic energy-versus-phase curve.

The average energy is measured through phase comparison between 2 BPMs.

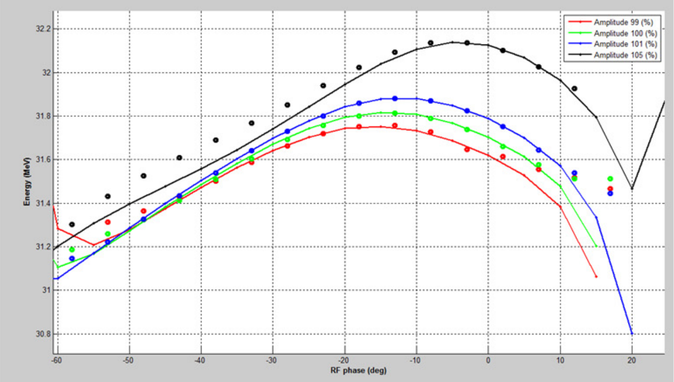
The distance for full RF cycles is calculated and the non-integer part is measured.

Using different BPM pairs ensures data integrity

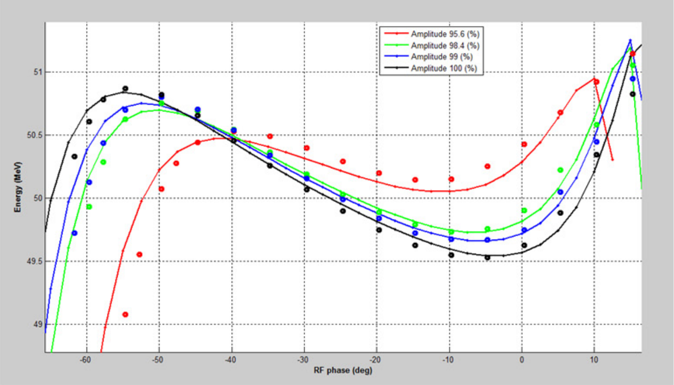
DTL1



DTL2



DTL3



Conclusions & Outlook

- Linac4 commissioning up to 100 MeV ended successfully.
- Beam instrumentation performance proved to be very good and essential to validate the beam dynamics.
- Beam instrumentation on the temporary benches have been successfully used to fully characterize the beams at 3,12,50 and 100 MeV. Most instruments will be recuperated and re-installed in the transfer line at 160 MeV
- Comparison of results between different instruments show good agreement
  - Spectrometer - BSM - BPM phase measurements
  - Slit/grid – laser
- Comparison between simulation and measurement show good agreement

At the end of the year beam at 160 MeV will be produced and sent to the dump and tests for charge exchange injection will take place.