Design and Test of Beam Diagnostics Equipment for the FAIR Proton Linac

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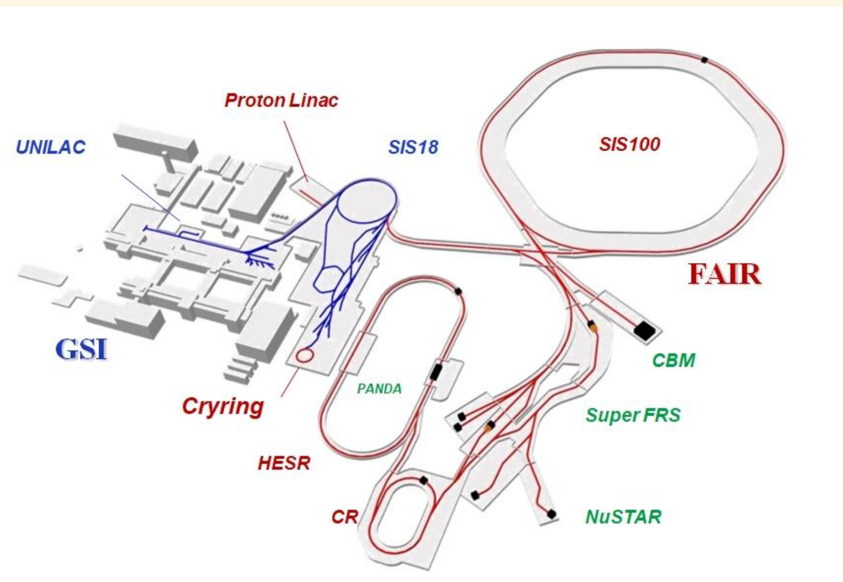
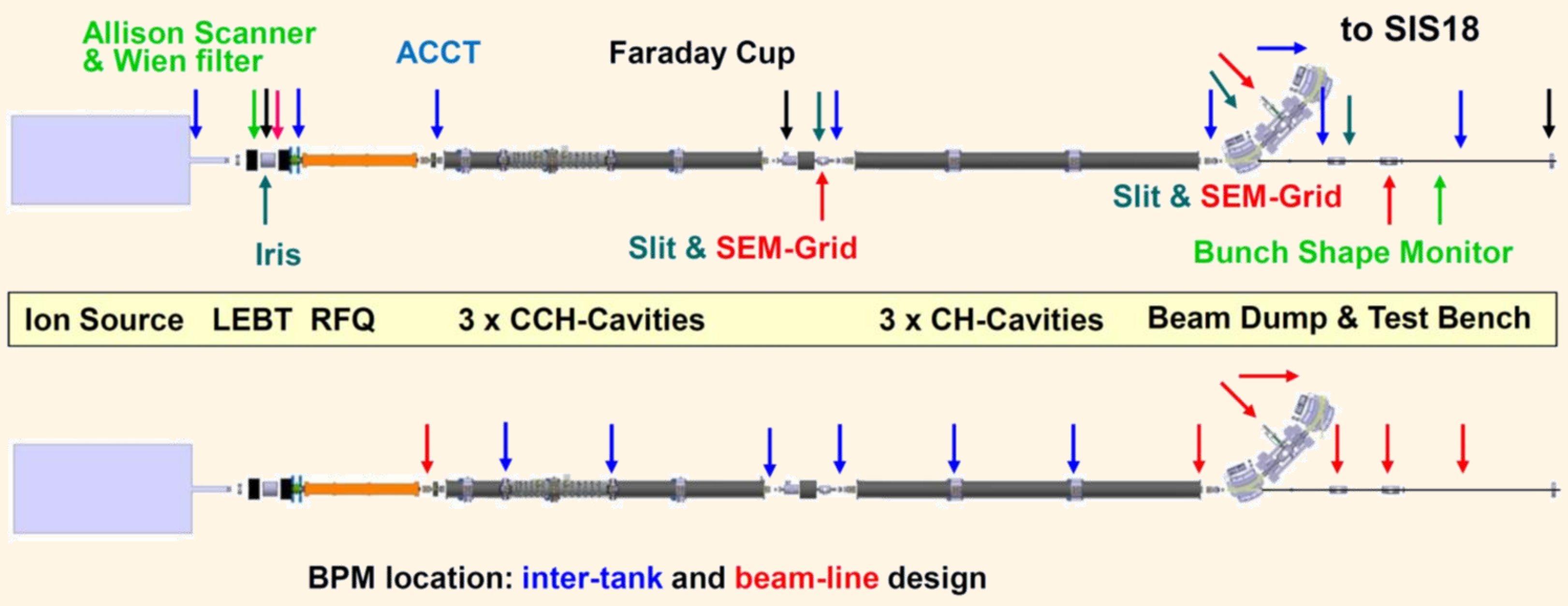
Abstract

A dedicated proton injector Linac (pLinac) for the Facility of Antiproton and Ion Research (FAIR) at GSI, Darmstadt, is currently under construction. It will provide a 68 MeV, up to 70 mA proton beam at a duty cycle of max. 35µs / 4 Hz for the SIS18/SIS100 synchrotrons, using the existing UNILAC transfer beamline. After further acceleration in SIS100, the protons will mainly be used for antiproton production at the Pbar ANnihilations at DArmstadt (PANDA) experiment. The Linac will operate at 325 MHz and consists of a novel so called 'Ladder' RFQ type, followed by a chain of CH-cavities, partially coupled by rf-coupling cells.
We present the beam diagnostics system for the pLinac with special emphasis on the Secondary Electron Emission (SEM) Grids and the Beam Position Monitor (BPM) system. We also describe design and status of our diagnostics testbench for stepwise Linac commissioning, which includes an energy spectrometer with associated optical system. The SEM grids and BPMs have been tested with proton and argon beams during several beamtimes in 2022. The results of these experiments are presented.

FAIR @ GSI



FAIR Proton Linac Diagnostics



BPM location: inter-tank and beam-line design

Parameter	Device	#	Nondestr.	Remarks
Current	Transformer	9	Yes	Dynamic Trans-mission Control
	Faraday Cup	3	No	Mainly as Beam Dumps
Profile	SEM Grids	4	No	Standard
Transv. Emit-tance & Halo Scraping	Slit Grid	3	No	Standard
Position & Mean Energy	Button BPMs	14	Yes	Position, TOF & Relative Current
Bunch Shape	New BSM / Feschenko	1	Yes / No	Under Development
LEBT: Charge state	Wien Filter	1	No	Standard (CEA)
LEBT: Emittance	Allison Scanner	1	No	Standard (CEA)

The proton Linac:

- Serves as an injector for the FAIR synchrotrons
- High pulse current during 30 µs multi-turn injection
- Effective acceleration by CH type cavities
- Novel acc. structures ("Ladder" RFQ, CH)
- Sensitive longitudinal beam dynamics

⇒ **High demands for beam diagnostics**

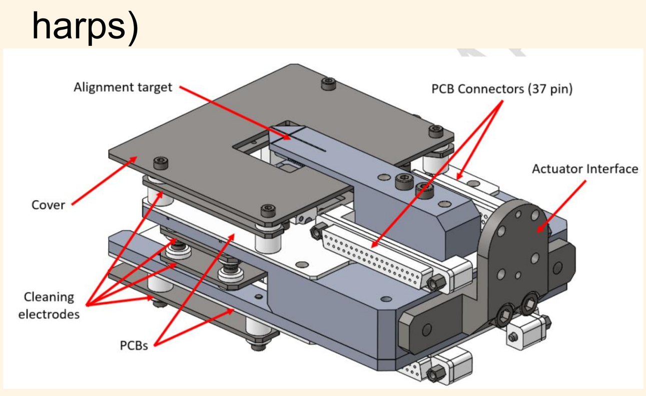
Basic Linac parameters

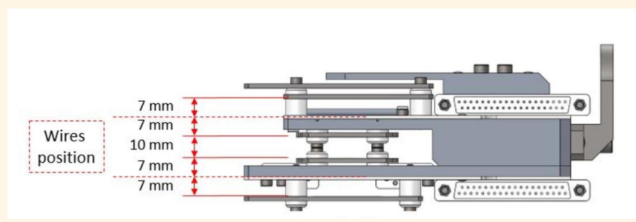
Beam energy	**68 MeV**
Beam current (op.)	**35 mA**
Beam current (des.)	***70 mA***
Beam pulse length	**36 µs**
Repetition rate	**4 Hz**
Rf-frequency	**325.224 MHz**
Tot. hor. emit. (norm.)	**2.1 / *4.2* µm**
Tot. mom. spread	**≤ ± 10^{-3}**
Linac length	**≈ 35 m**

SEM Grid Design

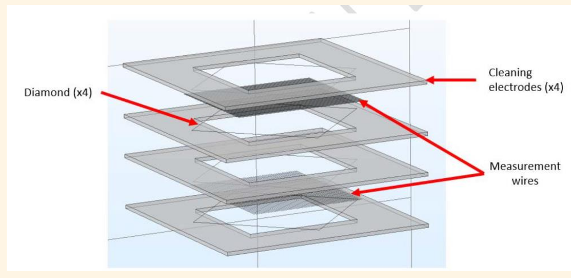
SEM Grids designed by PROACTIVE:

- Design based on PCB in combination with mech. stretching system
- 0.1 mm wires, 0.5 mm wire pitch
- detector area 32 x 32 mm
- used for beam alignment/operation and emittance measurement (grids and harps)



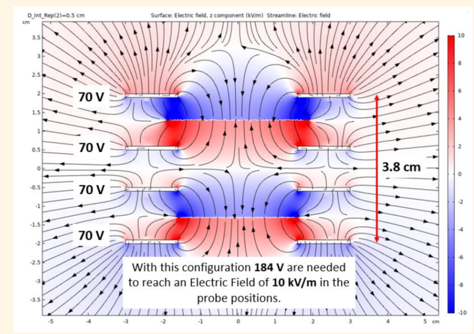


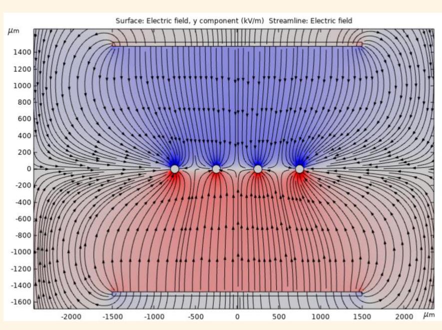
Harp Simulations



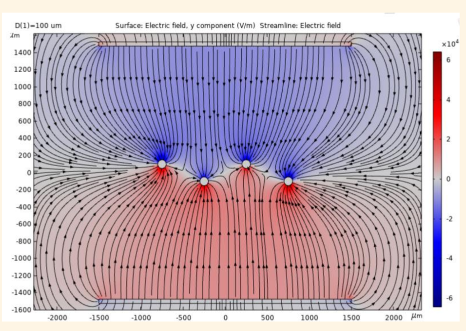
Model to study the filed configuration for different wire / grid geometries

Optimization with respect to highest possible gradient at most compact setup and lowest applied voltage. 10kV/m required to bend electrons away from neighbouring wires



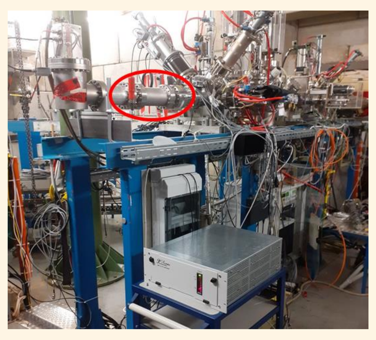


Standard co-planar wire arrangement



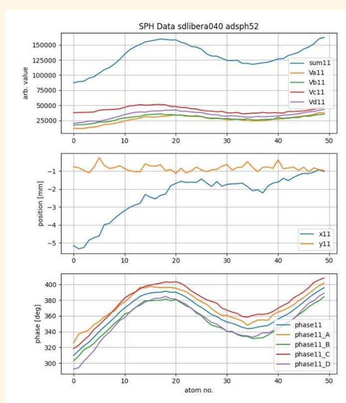
Alternative setup to avoid field free region between wires

BPM Test Measurements

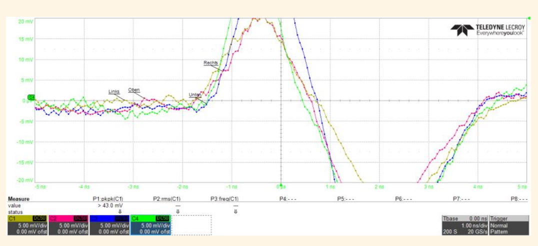


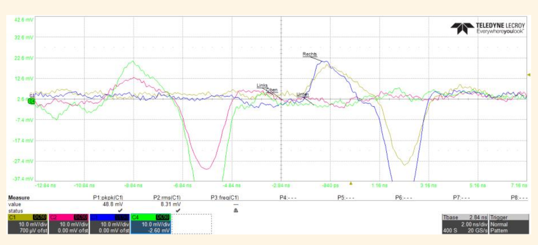
Test setup at UNILAC

BPM electronics racks



Position and phase from LSPH

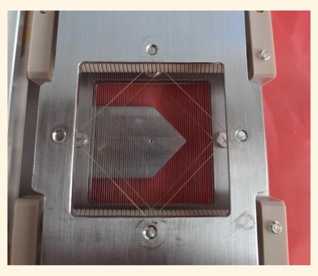


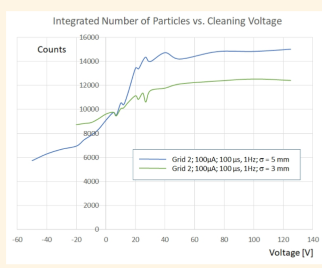


Position (left) and phase (right) measurement with scope

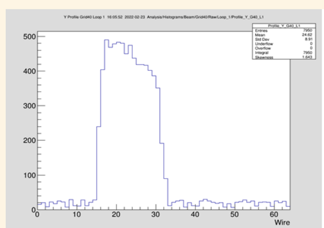
SEM Grid Acceptance Tests

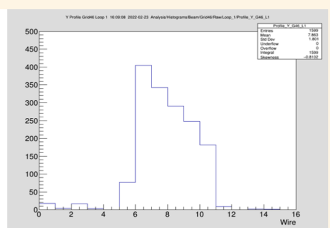
Grid mounted to feedthrough DN160CF





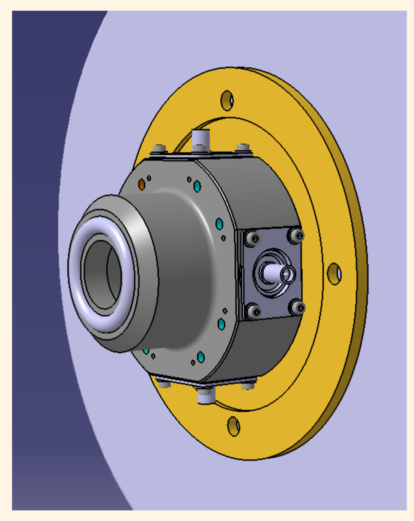
Cleaning electrode → Voltage optimization



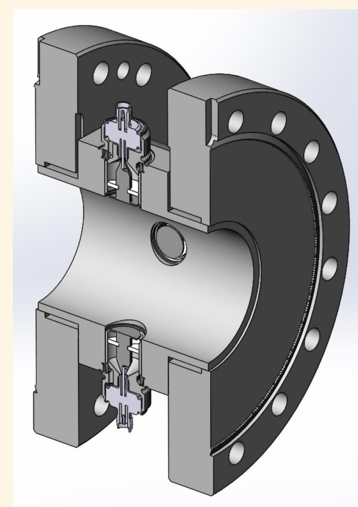


Comparison pLinac grid (left), UNILAC grid (right)

BPM Mechanical Design



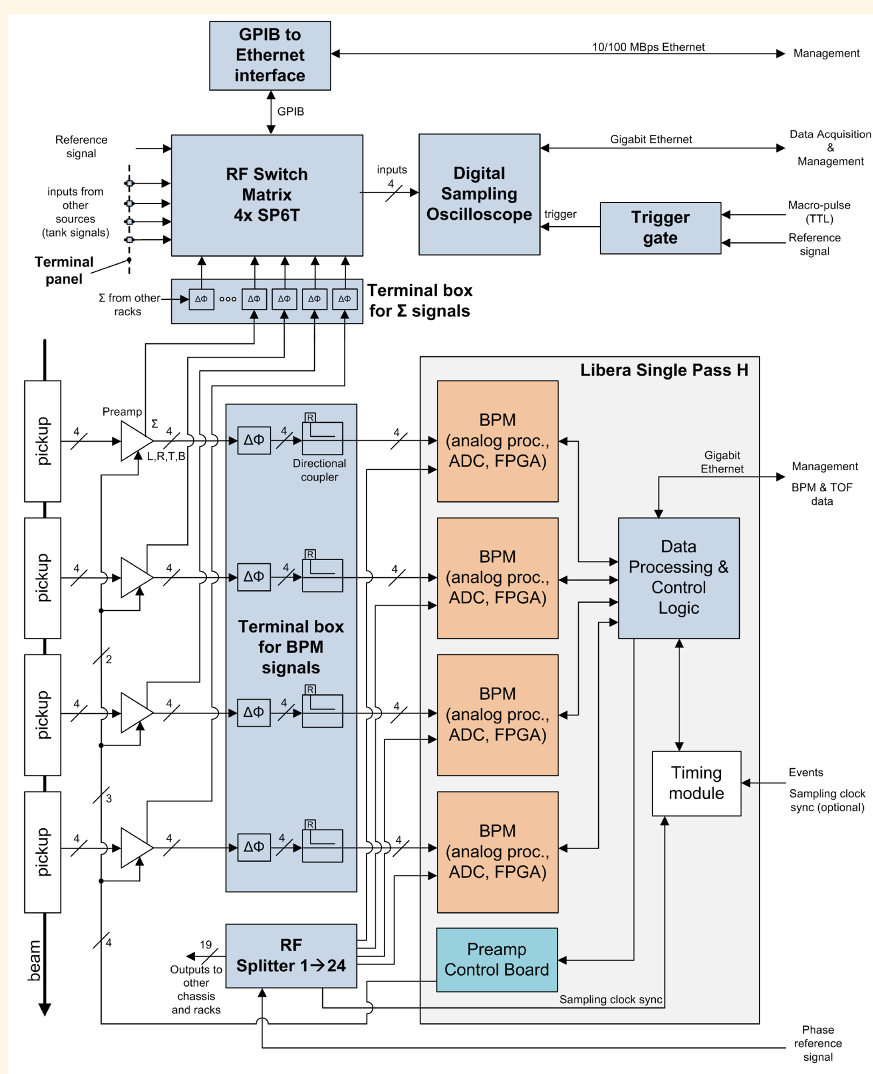
„inter Tank" type, mounted to triplet



„beamline" type

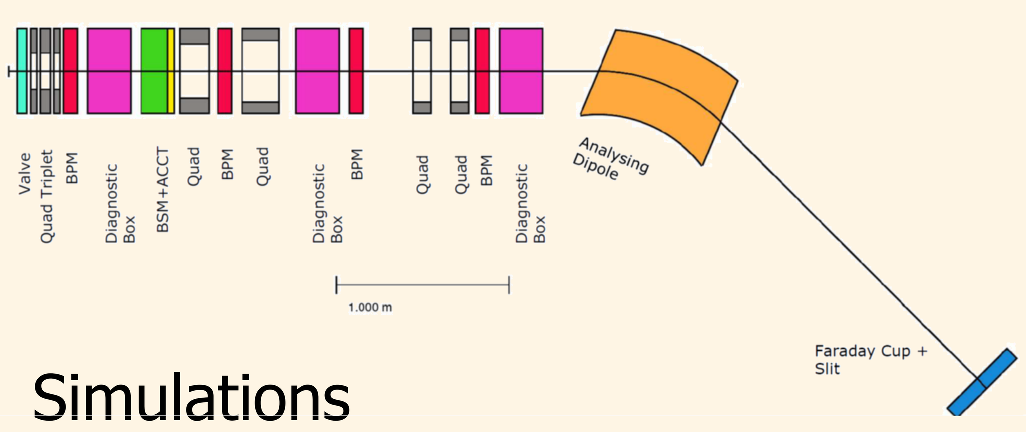
NTG Button

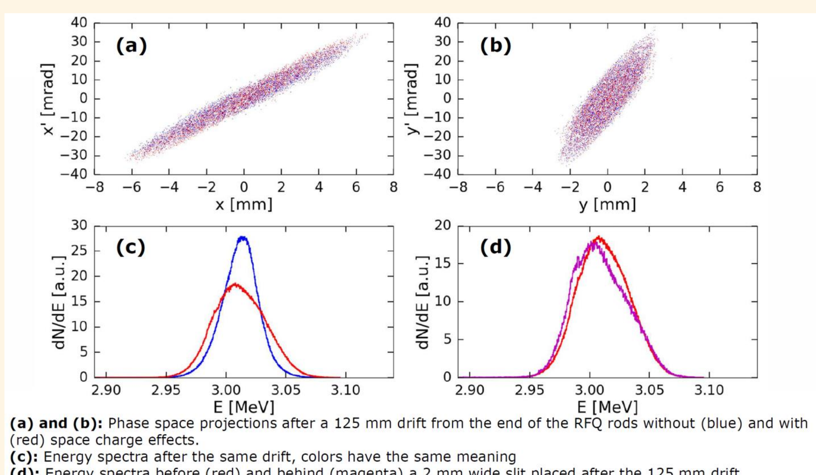
BPM Electronics System LSPH



Test Bench and Spectrometer Design

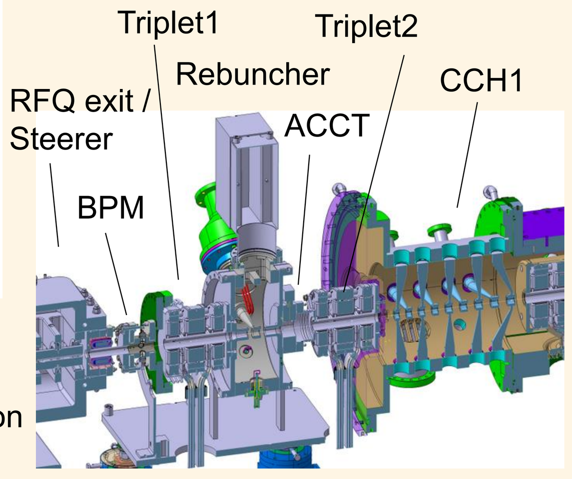
- Test Bench used for the stepwise commissioning of the pLinac
- Includes all types of beam instrumentation devices to be used with the pLinac after the RFQ (i.e. $E_k \geq 3$ MeV)
- Will be equipped with beam optics (quadrupoles, steerers) and a dipole for energy spread measurements





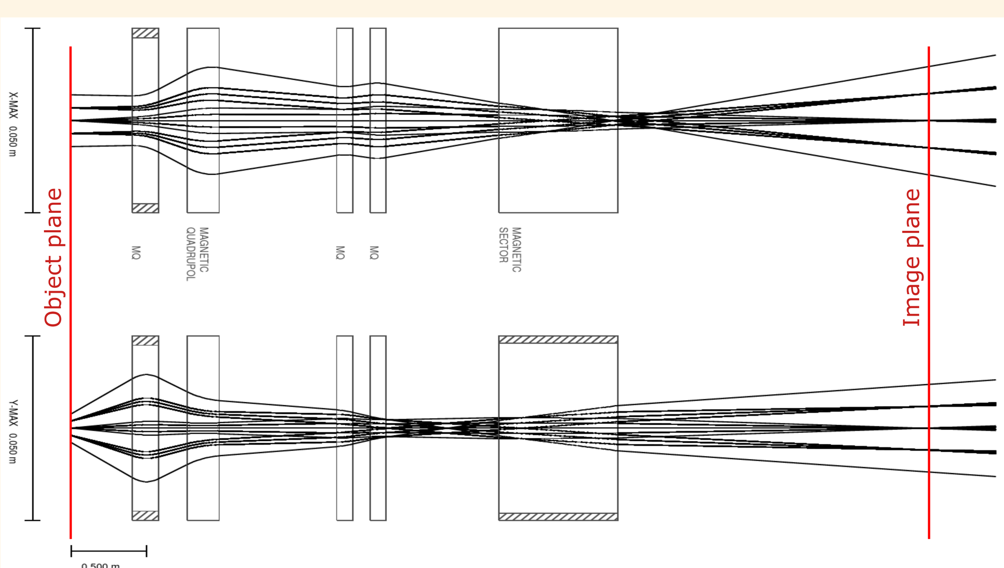
(a) and (b): Phase space projections after a 125 mm drift from the end of the RFQ rods without (blue) and with (red) space charge effects.
(c): Energy spectra after the same drift, colors have the same meaning
(d): Energy spectra before (red) and behind (magenta) a 2 mm wide slit placed after the 125 mm drift

pLinac RFQ rebuncher / MEBT section, with compact triplet lens to catch divergent beam from RFQ → beam transport similar to Test Bench

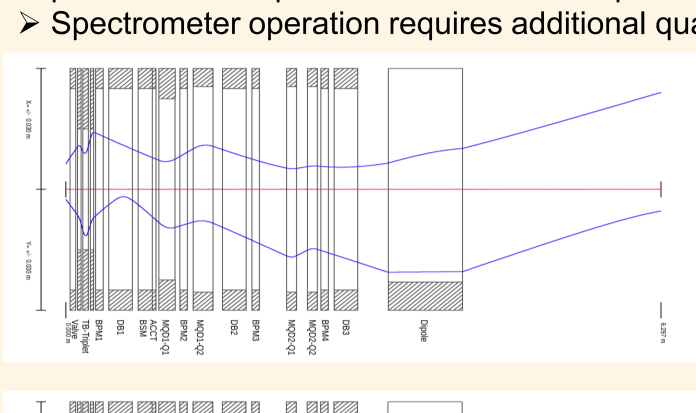


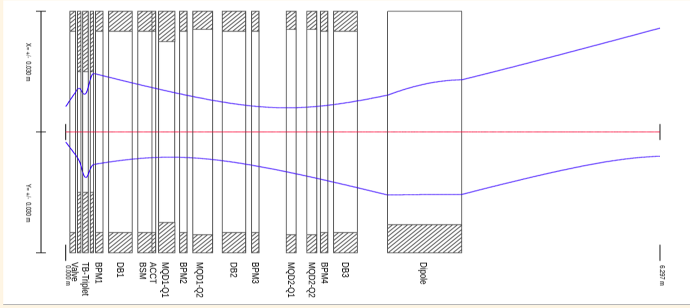
- Effect of space charge on the ion energy distribution calculated
- Investigation of energy distribution dependence on position
- pLinac MEBT triplet used for beam transport
- Spectrometer operation requires additional quadrupoles

Simulations

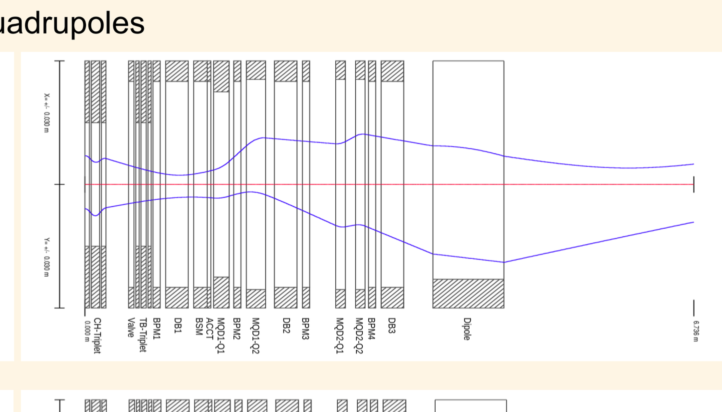


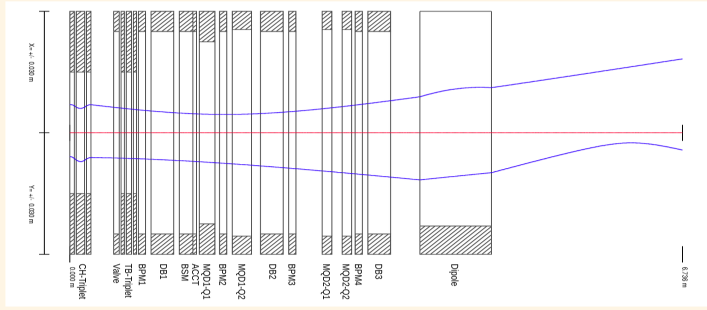
Design calculation for spectrometer, object plane is a slit in the first diagnostic box. Image plane is the slit in front of the final Faraday Cup





Beam transport from RFQ, spectrometer mode (upper), transport mode (lower)





Beam transport from CCH3, spectrometer mode (upper), transport mode (lower)