Beam Diagnostics for Commissioning and Operation of the FAIR Proton Linac

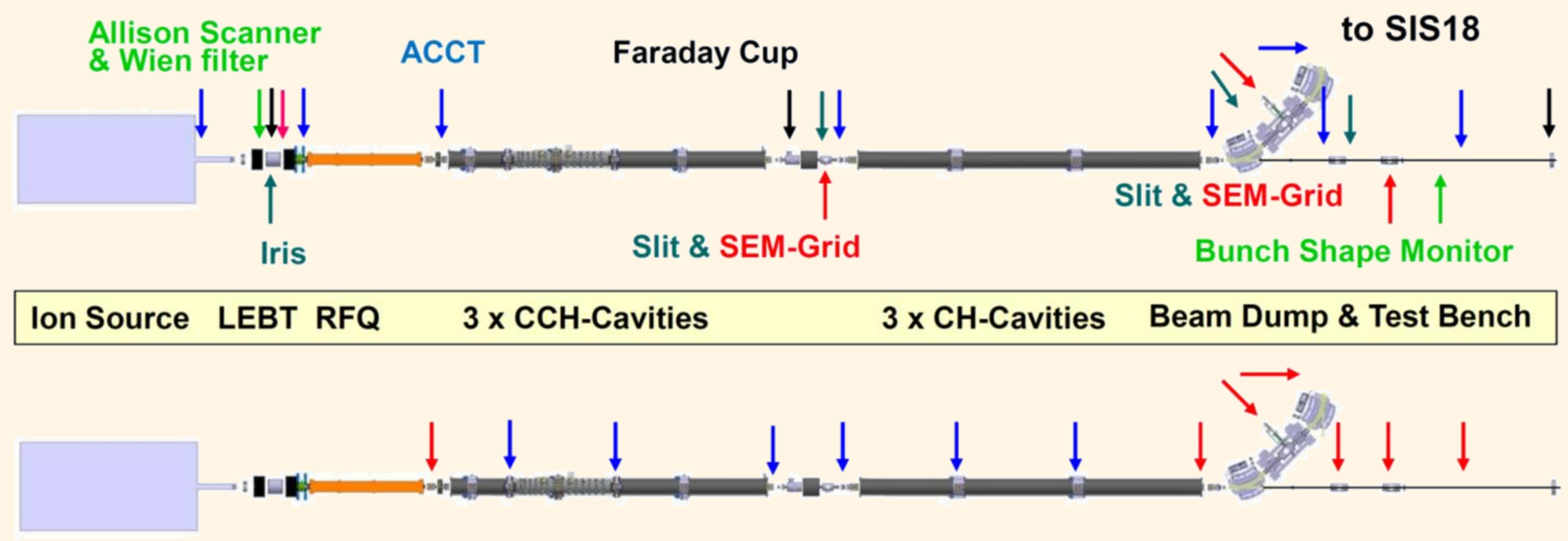
T. Sieber, P. Forck, S. Udrea
GSI Helmholtz-Zentrum für Schwerionenforschung, Darmstadt, Germany
J. Herranz, A. Vizcaino
PROACTIVE, Barcelona, Spain

IPAC 2021
MOPAB315

Abstract

For the planned antiproton experiments at FAIR a dedicated proton injector Linac is currently under construction. It will be connected via the old UNILAC transfer beamline to SIS18 and has a length of ~30 m. The Linac will accelerate protons up to a final energy of 68 MeV at a pulse length of 35 µs and a maximum repetition rate of 4 Hz. It will operate at 325 MHz and consists of a new so called "Ladder" RFQ type, followed by a chain of CH-cavities, partially coupled by rf-coupling cells. We have worked out a diagnostics system, which allows detailed measurement and study of all beam parameters during commissioning and later during regular operation. The diagnostics devices will - in a first step - be installed on a diagnostics testbench for stepwise commissioning. We present the concepts for Linac and testbench with some special emphasis on energy measurements with spectrometer and Secondary Electron eMission (SEM-) grid profile measurements.

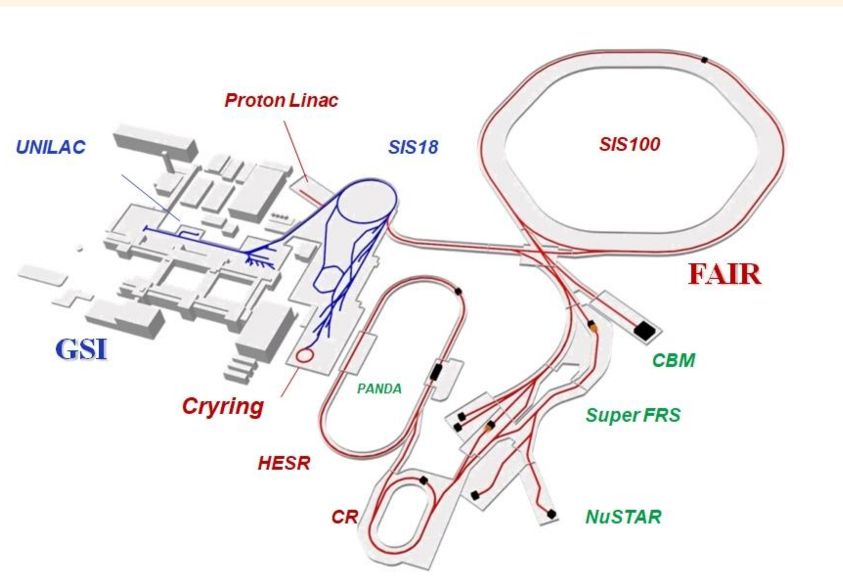
FAIR Proton Linac Diagnostics



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	1 4	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)

FAIR @ GSI



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**

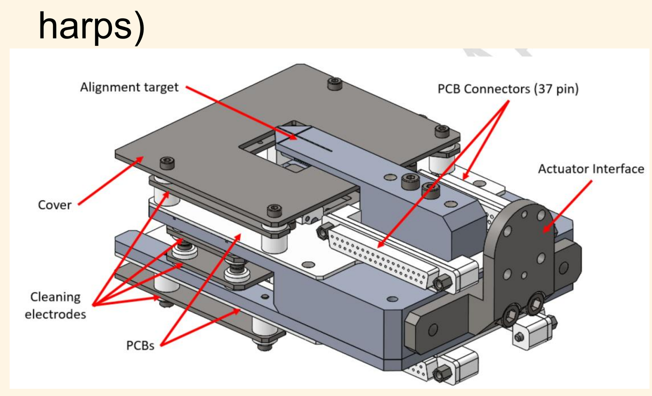
Basic Linac parameters

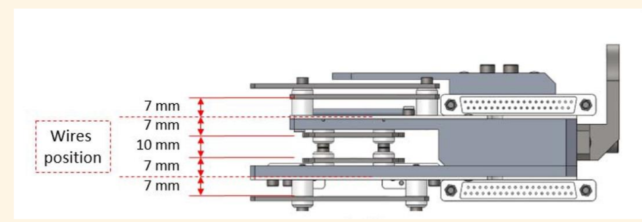
Beam energy	**68 MeV**
Beam current (op.)	**35 mA**
Beam current (des.)	***70 mA***
Beam pulse length	**36 µs**
Repetition rate	**4 Hz**
Rf-frequency	**325.224 MHz**
Tot. hor. emit. (norm.)	**2.1 / *4.2* µm**
Tot. mom. spread	**$\leq \pm 10^{-3}$**
Linac length	**≈ 35 m**

SEM Grid Design

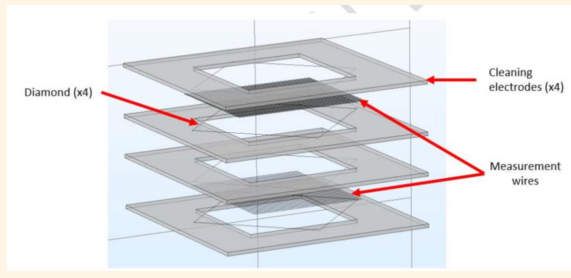
SEM Grids designed by PROACTIVE:

- 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)



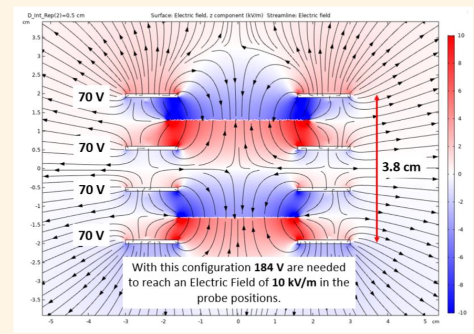


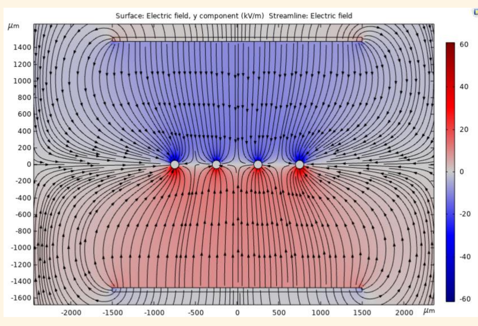
Harp Simulations



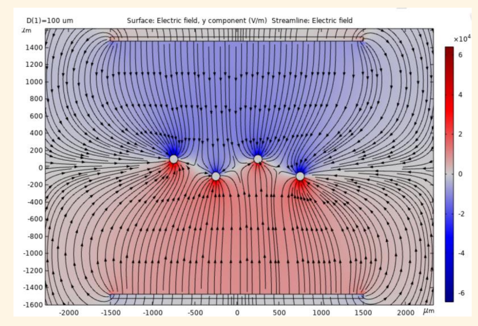
Model to study the filed configuration for different wire / grid geometries

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

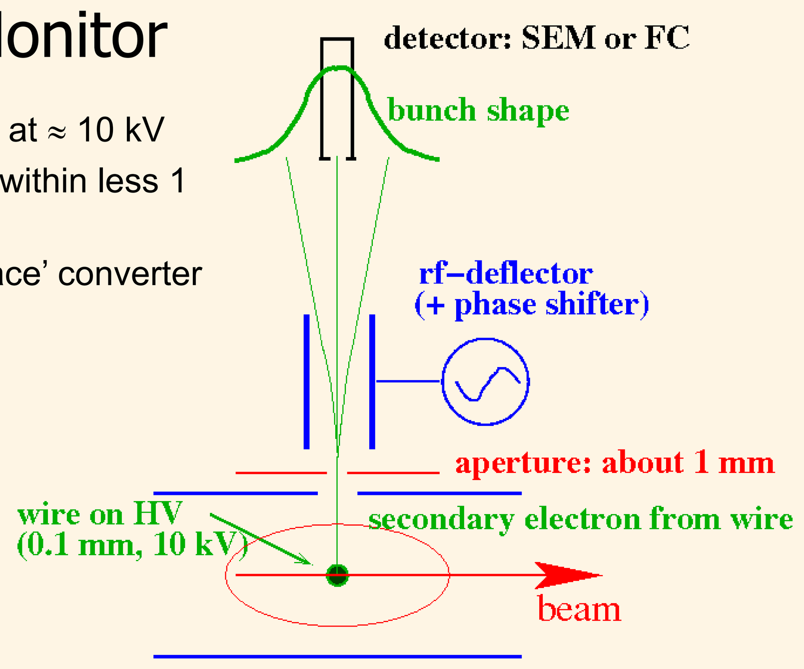


alternative setup to avoid field free region between wires

Bunch Shape Monitor

- insertion of a 0.1 mm wire at ≈ 10 kV
- emission of secondary e⁻ within less 1 ps
- rf-deflector as 'time-to-space' converter
- detector with a thin slit
- slow shift of the phase
- resolution ≈1° < 10 ps

Status:
INR Moscow can produce such monitor. Status: Order has been placed

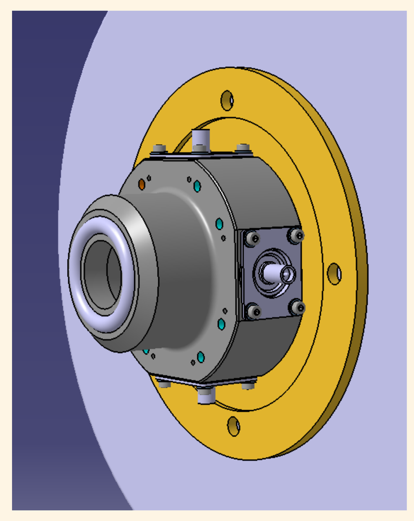


Beam Transformers

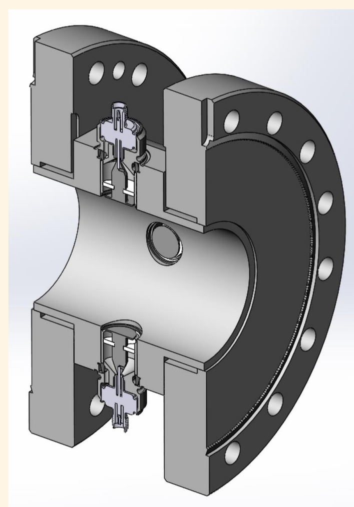
- **Type:** Bergoz 'in flange' type for CF100, $\varnothing_{inner}$ = 48 mm and length 40 mm for **all** locations
- Basic operation tool, input for transmission control
- DAQ: µTCA based system in progress
- Beam loss control via pulse-by-pulse transmission measurement

Flange	CF 100
Inner diameter	47.7 mm
Insertion length	40 mm
Resolution	≈ 2 µA for full BW
Bandwidth	1 MHz → **mod. to 3 MHz**
Number of ranges	1 → **mod. to 3** Full scales: 100/10/1 mA
Test input	no → **mod. to yes**

BPM Mechanical Design

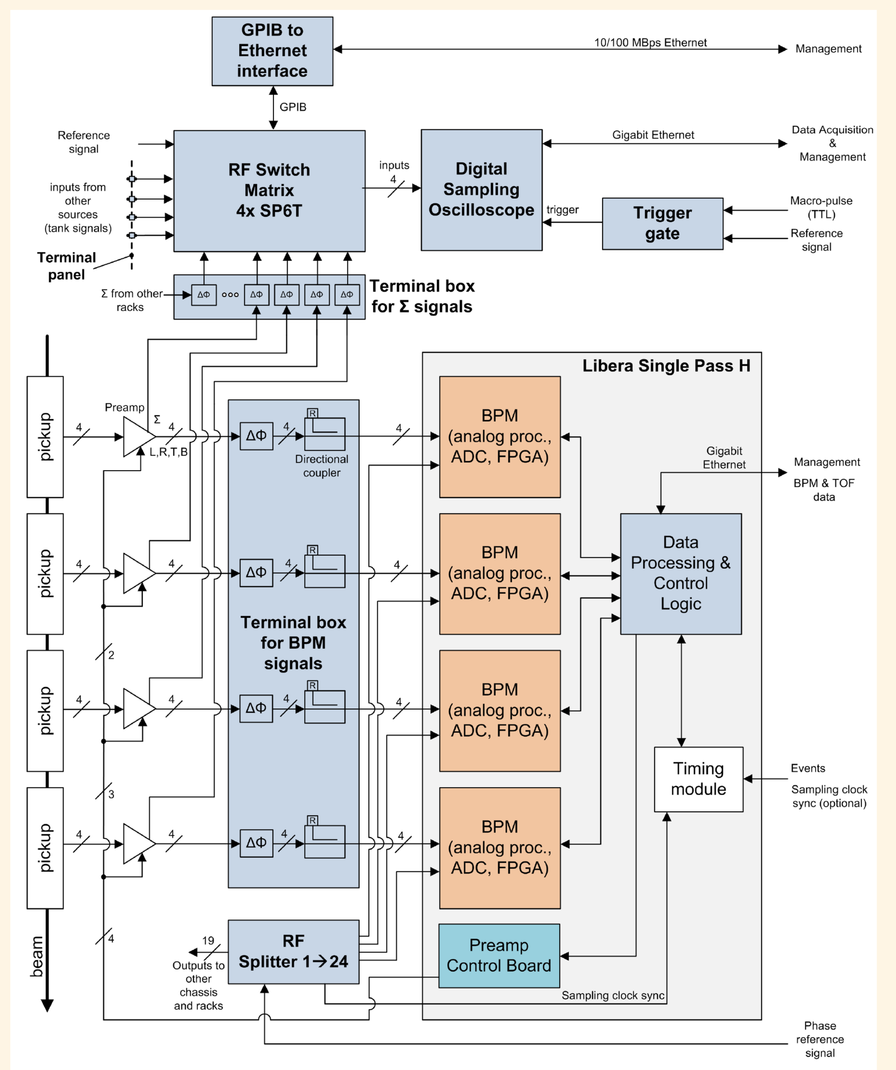


„inter Tank" type, mounted to triplet



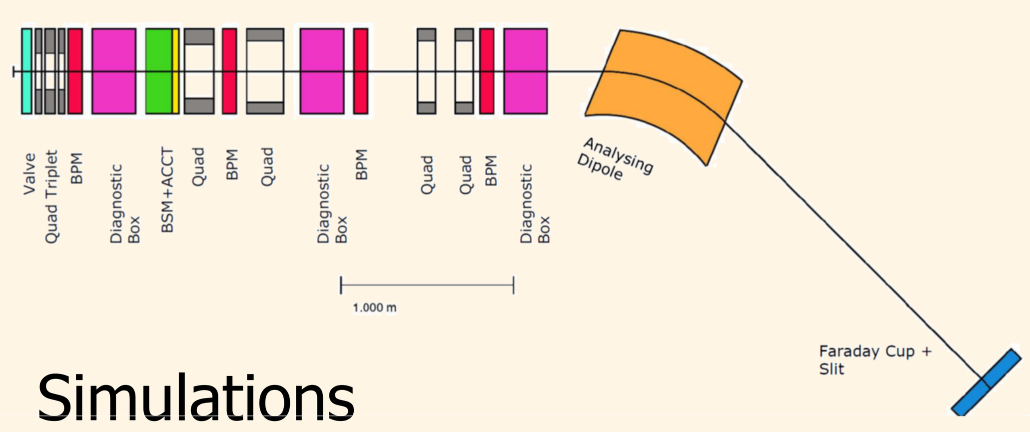
„beamline" type

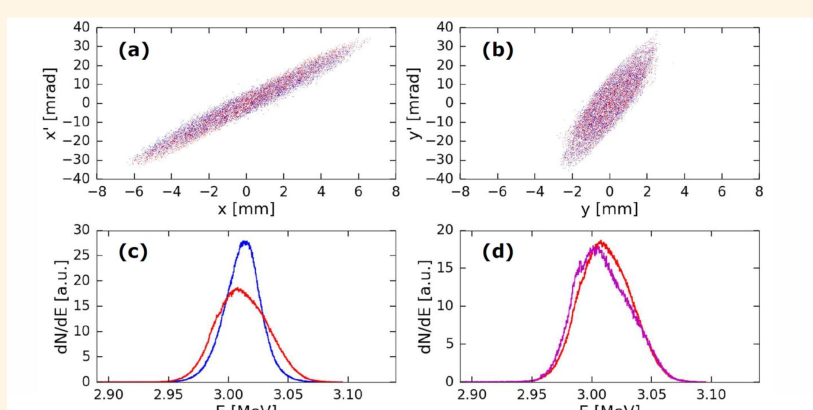
BPM Electronics Scheme



Test Bench and Spectrometer Design

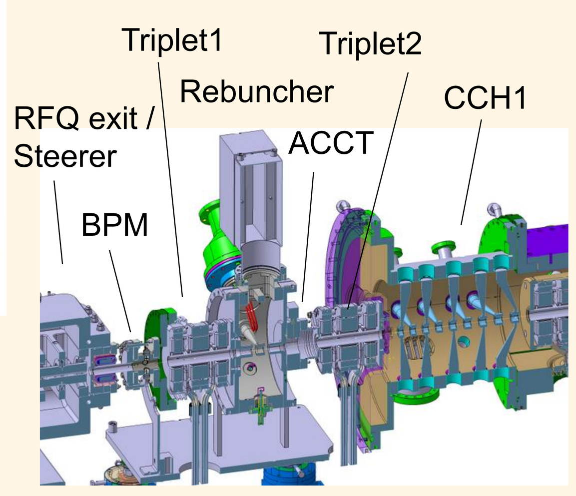
- Test Bench used for the stepwise commissioning of the pLinac
- Includes all types of beam instrumentation devices to be used with the pLinac after the RFQ (i.e. $E_k \geq 3$ MeV)
- Will be equipped with beam optics (quadrupoles, steerers) and a dipole for energy spread measurements





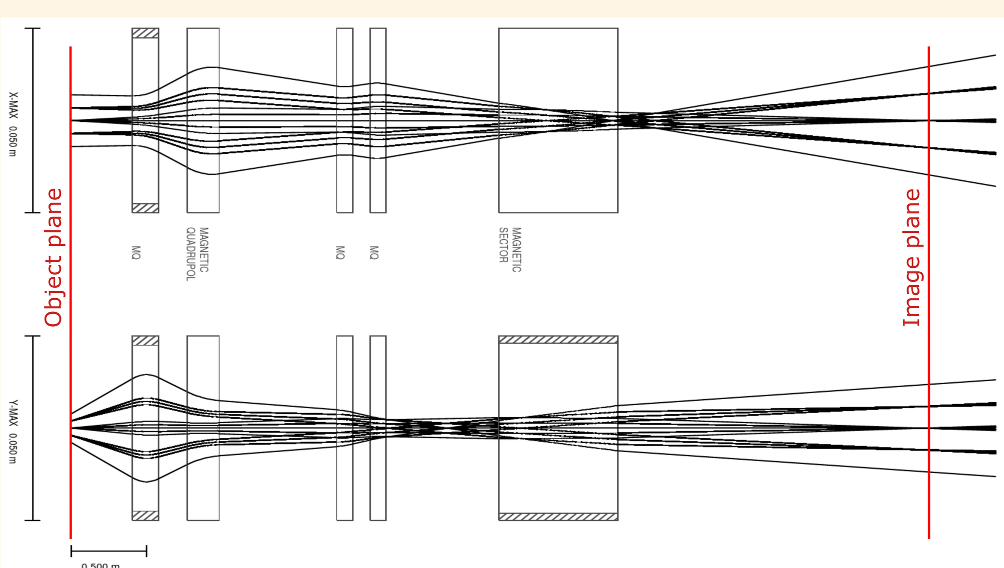
(a) and (b): Phase space projections after a 125 mm drift from the end of the RFQ rods without (blue) and with (red) space charge effects.
(c): Energy spectra after the same drift, colors have the same meaning
(d): Energy spectra before (red) and behind (magenta) a 2 mm wide slit placed after the 125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

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

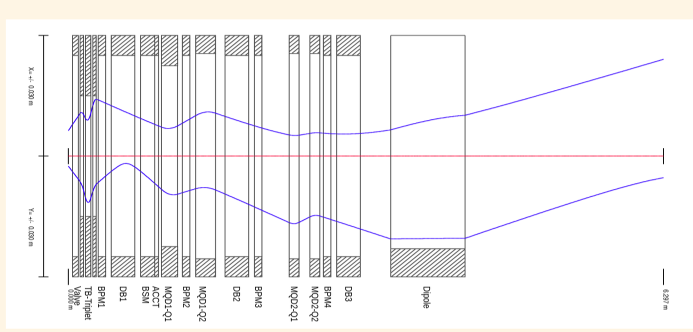


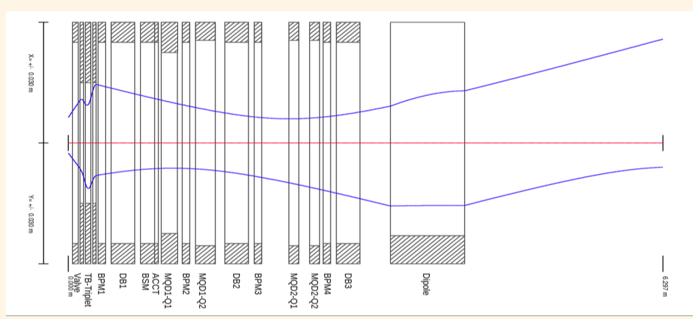
- Effect of space charge ion energy distribution calculated
- Investigation of energy distribution position dependence
- Beam transport with pLinac MEBT triplet
- Spectrometer operation requires additional quadrupoles

Simulations

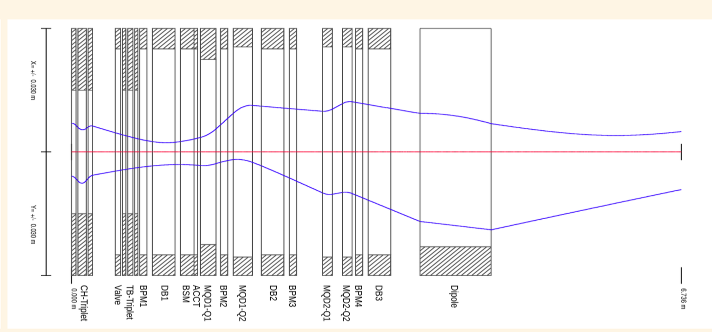


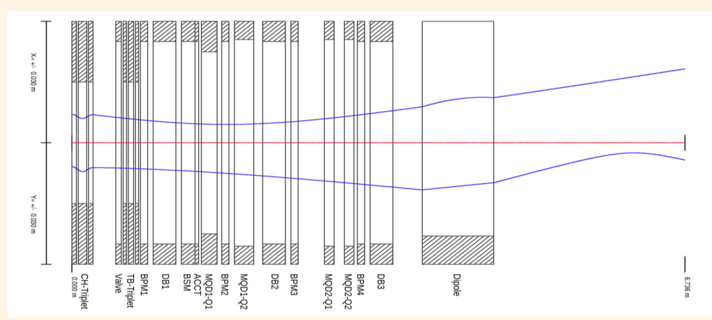
Design calculation for spectrometer, object plane is a slit in the first diagnostic box. Image plane is the slit in front of the final Faraday Cup





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





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