eli

E4 technology and applications

Lorenzo Giuffrida

Head of department of Ion Acceleration and Application of High Energy Particles

Lorenzo.Giuffrida@eli-beams.eu

Summary

- ELIMAIA user beamline;
- ELIMAIA commissioning:
    - ✓ Experimental results
- ELIMED

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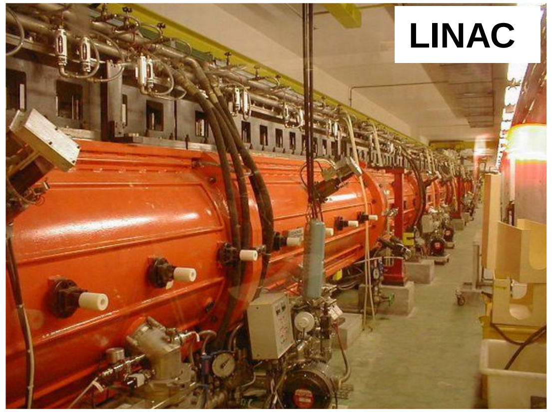
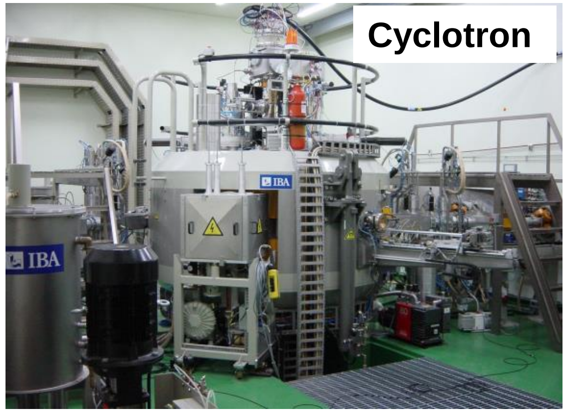
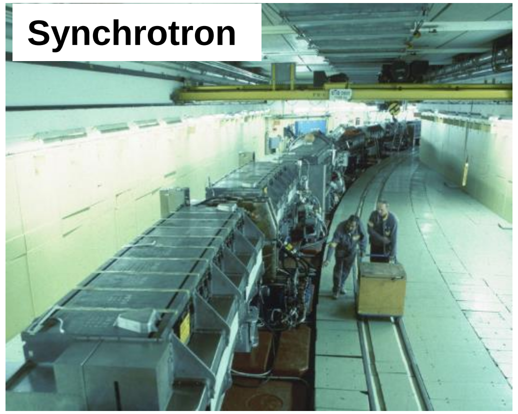
Concept of laser-plasma acceleration

Conventional Accelerators



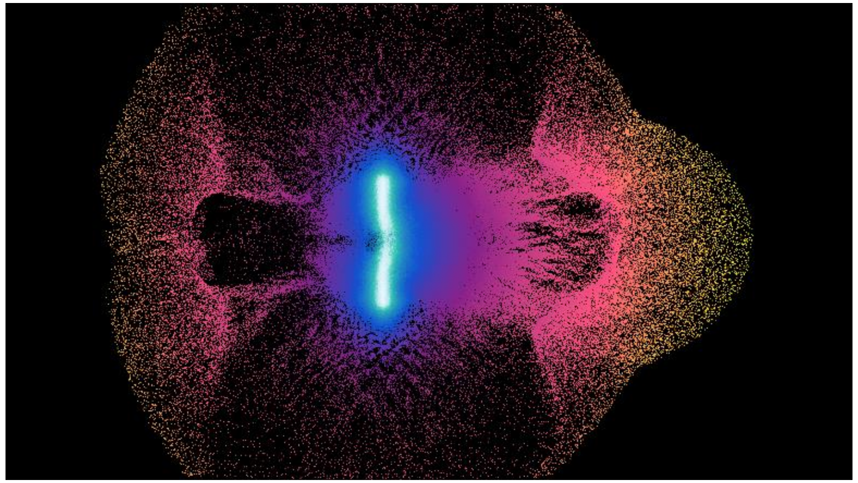




E_{max} ~ 50 MV/m

L_{acc} ~ 1-10 m

Laser-Plasma Accelerators



E_{max} ~ 1 TV/m

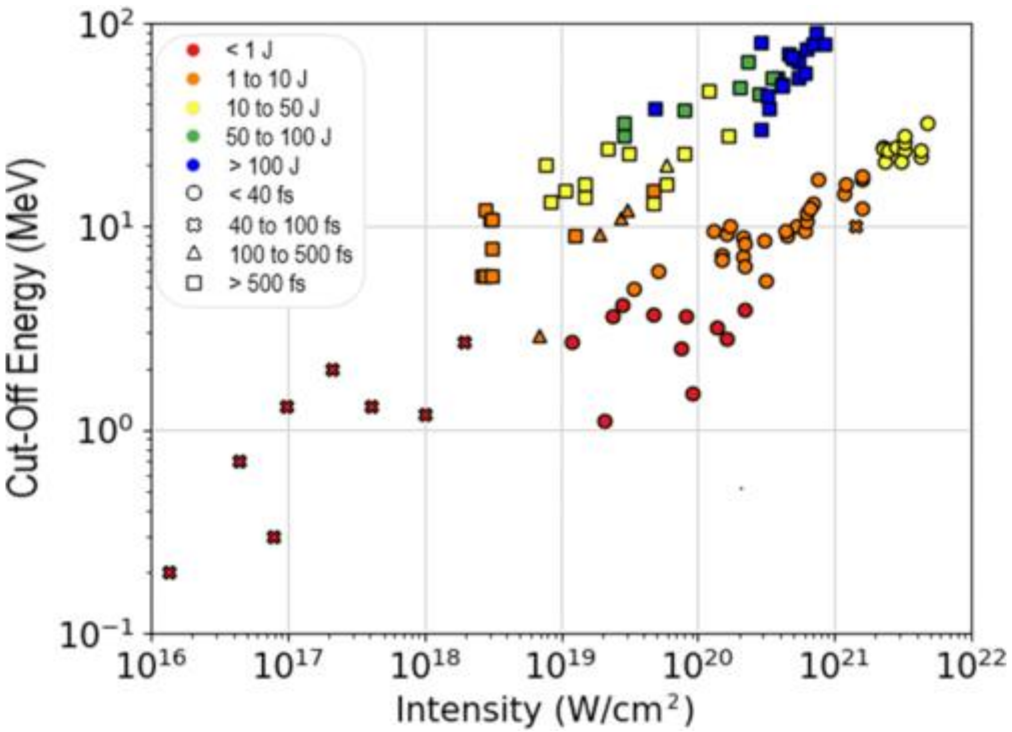
L_{acc} ~ 1 μm

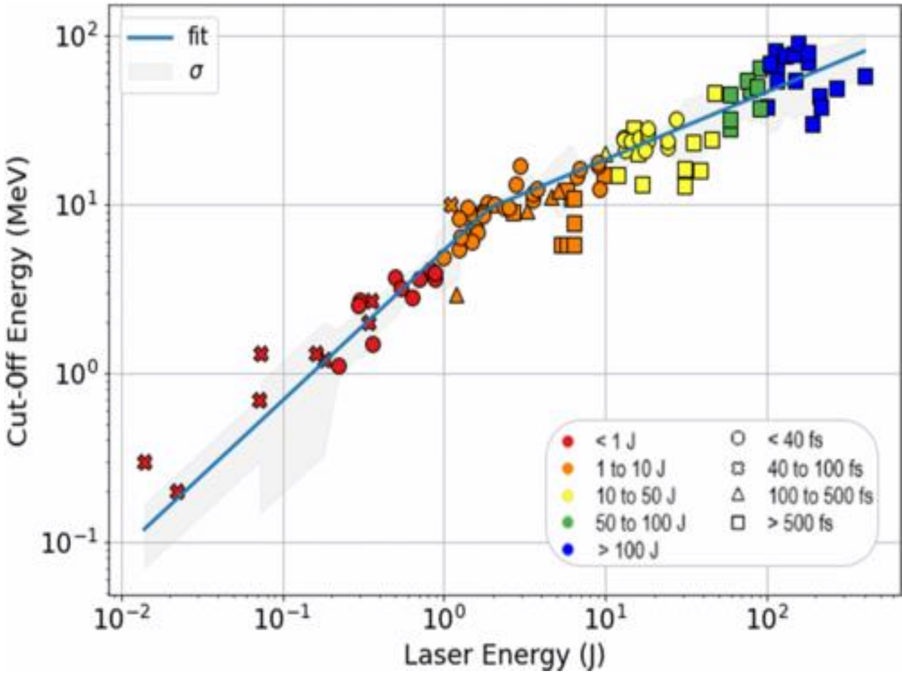
10,000 smaller!

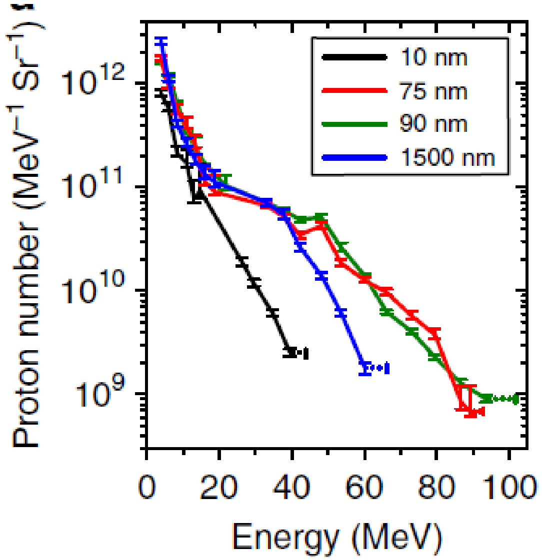
Compact Accelerator

Ion Acceleration experimental scaling

Experimental scaling law for protons:
Zimmer, PRE 2021





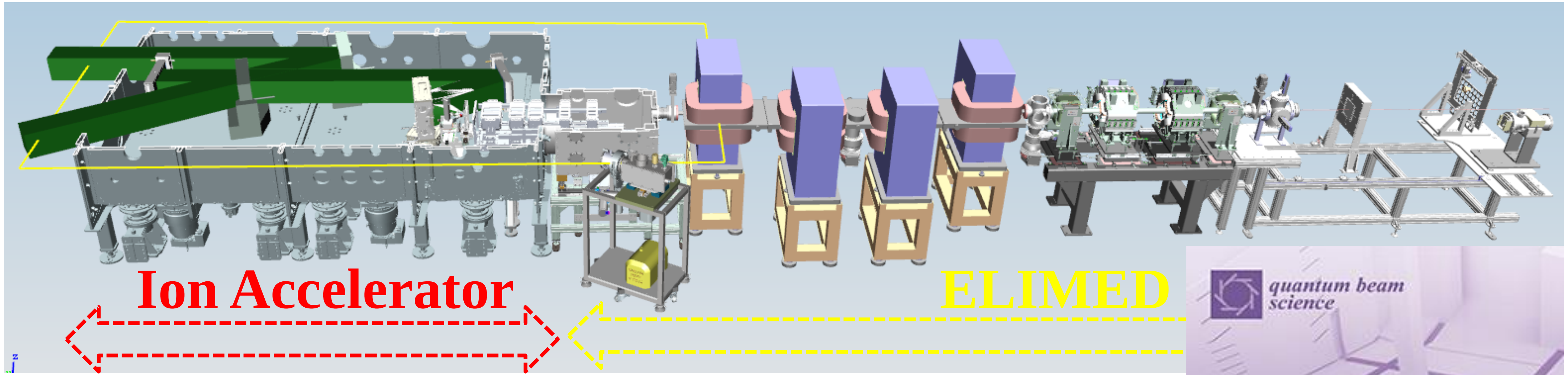


Higginson et al., Nat. Comm. (2018)

ELIMAIA technical development

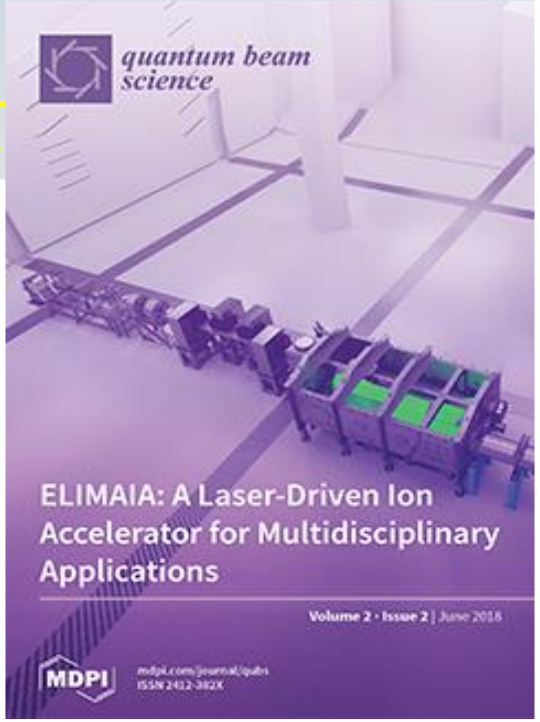
ELI Multidisciplinary **A**pplications of laser-**I**on **A**cceleration

Acceleration, Collimation & Diagnostics | **Selection, Transport & Diagnostics** | **Dosimetry & Sample Irradiation**



- *D. Margarone et al., "**ELIMAIA: A Laser-Driven Ion Accelerator for Multidisciplinary Applications**", Quantum Beam Science 2 (2018) 8*

- *G.A.P. Cirrone et al., "**ELIMED-ELIMAIA: The First Open User Irradiation Beamline for Laser-Plasma-Accelerated Ion Beams**", Frontiers in Physics 8 (2020) 564907*
- *F. Schillaci et al., "**The ELIMAIA Laser-Plasma Ion Accelerator: Technology Commissioning and Perspectives**", Quantum Beam Sci. 2022, 6(4), 30*

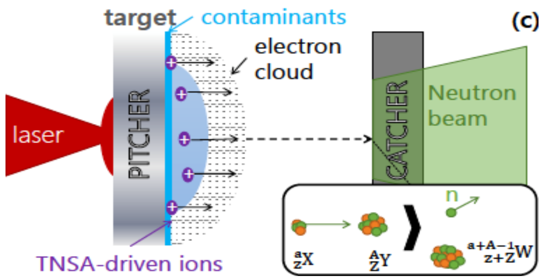


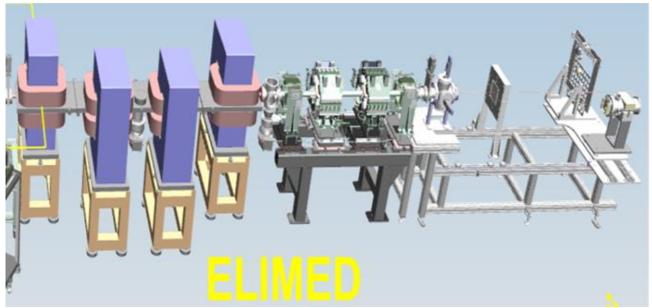
Scientific & Societal Impact

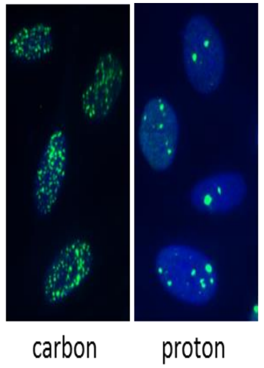
Laser-plasma accelerator:
- ✓ Advanced laser-driven ion mechanisms
- ✓ Laser-driven nuclear reactions
- ✓ Ion stopping power with tunable ion source

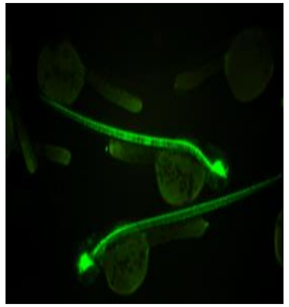
Multidisciplinary user applications (ELIMED)
- ✓ Radiobiology, cancer treatment (hadrontherapy & BNCT), medical imaging
- ✓ Radiation chemistry with protons & neutrons (pulsed radiolysis of water, management of nuclear waste)
- ✓ Space radiation (electronics, radiobiology in space)
- ✓ Material analysis for cultural heritage (PIXE, XRF, DPAA)
- ✓ Non-destructive inspection of massive objects with proton & neutron radiography

Neutrons from Pitcher-catcher







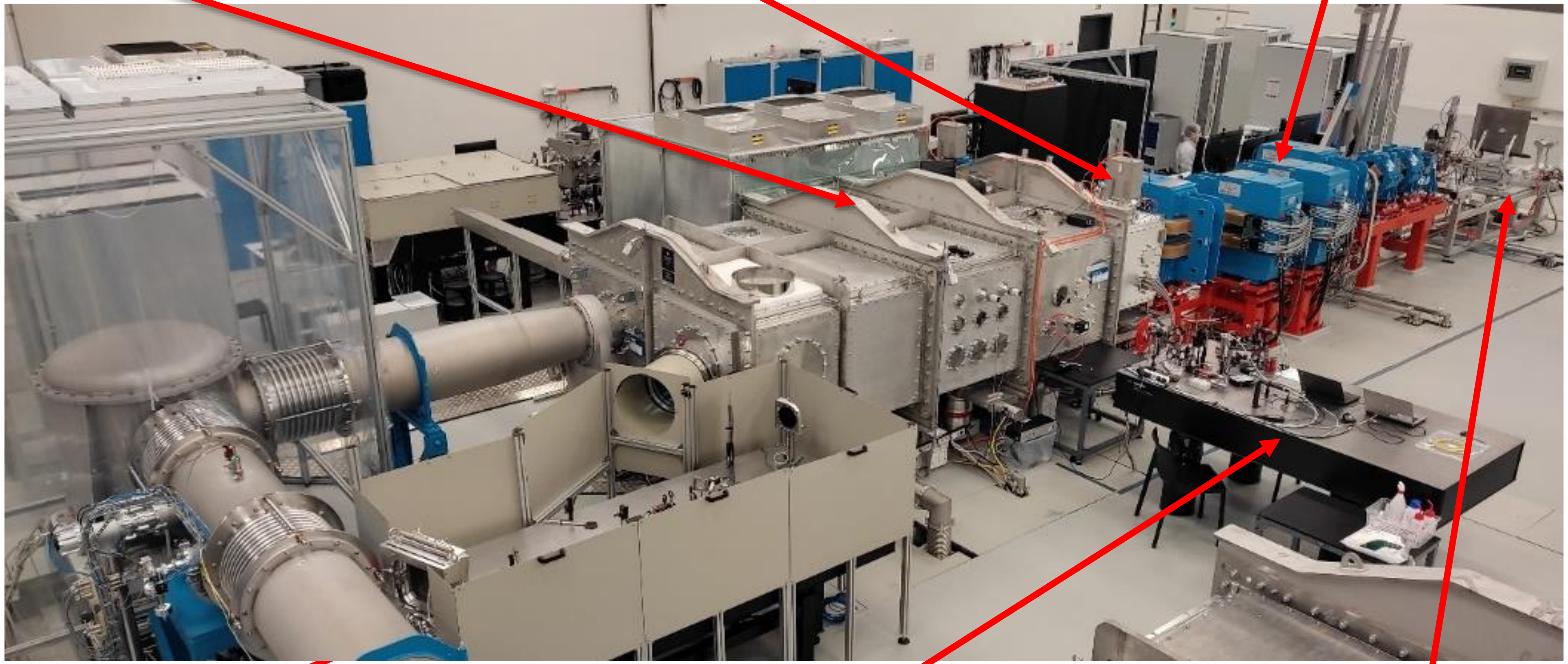


Setup overview

Interaction chamber

Ion and gamma diagnostic stations

Ion beam transport



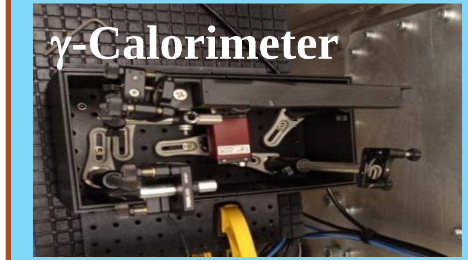
In-air laser diagnostic station (BDS) – ***on-shot & full-power***

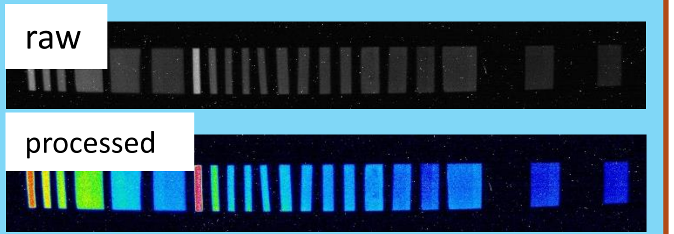
Laser Alignment and Plasma diagnostic stations

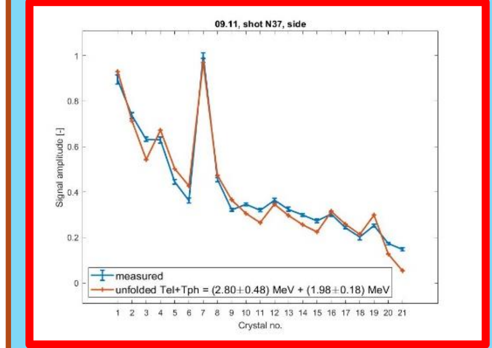
Ion Dosimetry and sample irradiation

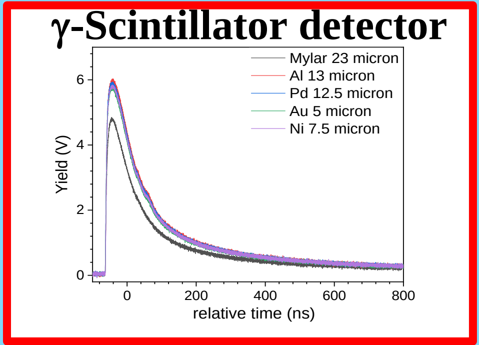
Online laser/plasma/ion diagnostics

X/γ-ray diagnostics

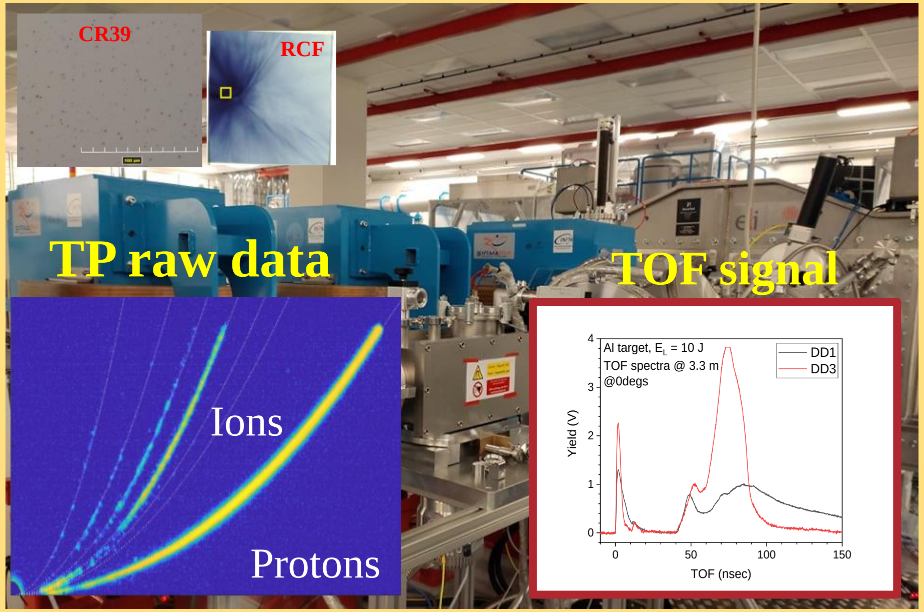




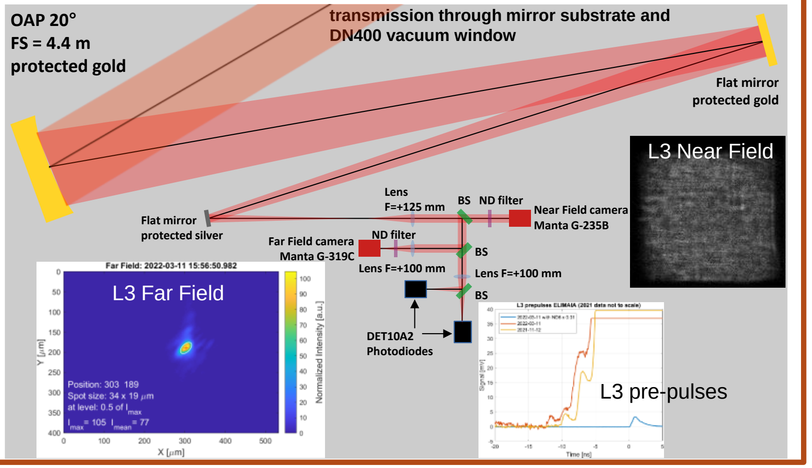




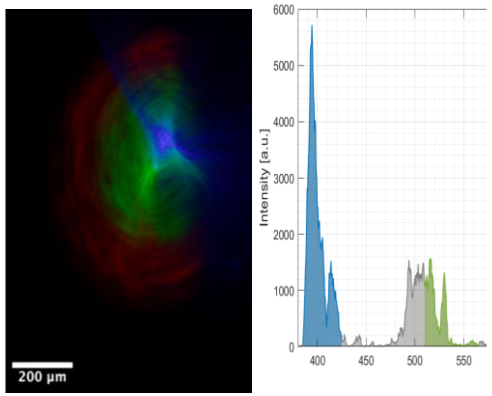
Ion diagnostics



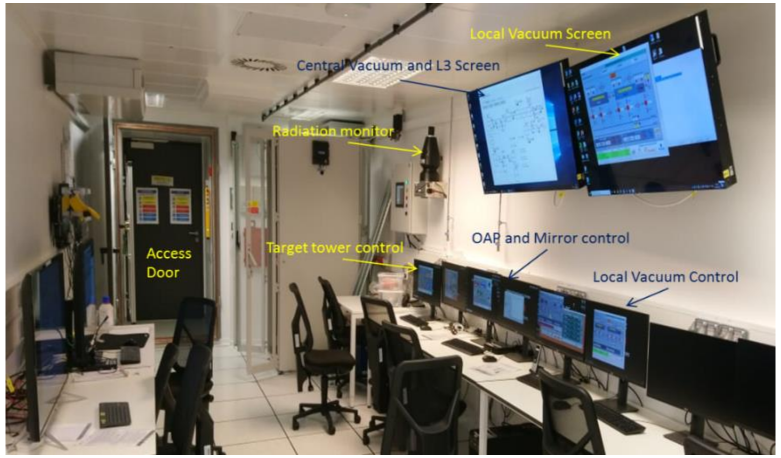
On-shot laser diagnostics



Plasma imaging/ spectroscopy



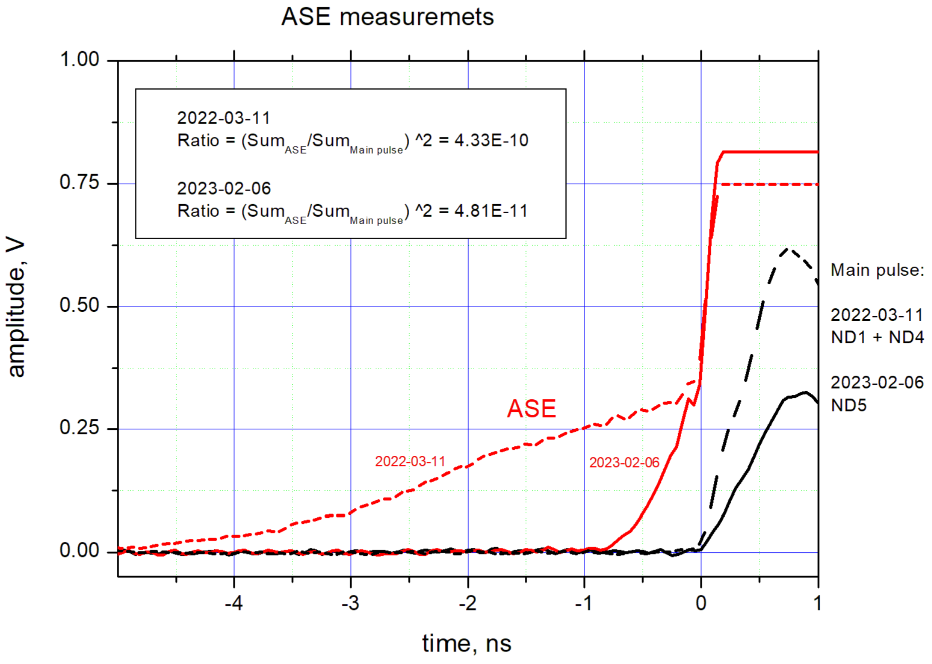
Online data analysis (1-10 Hz)



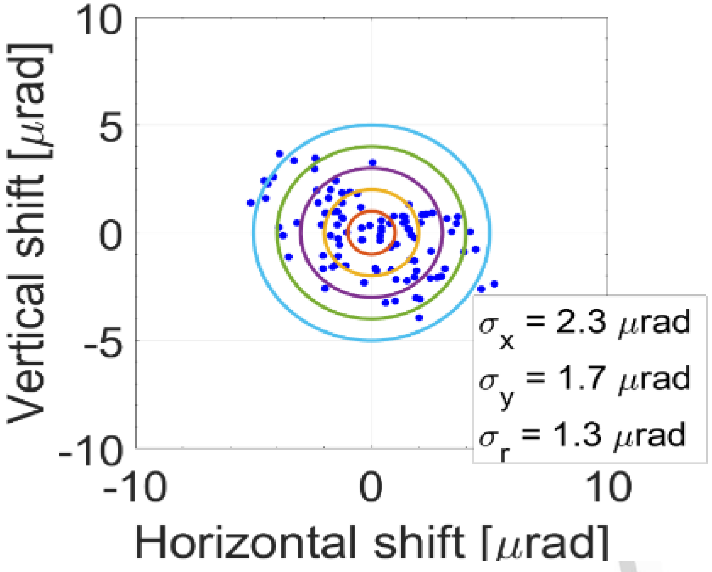
HAPLS laser system

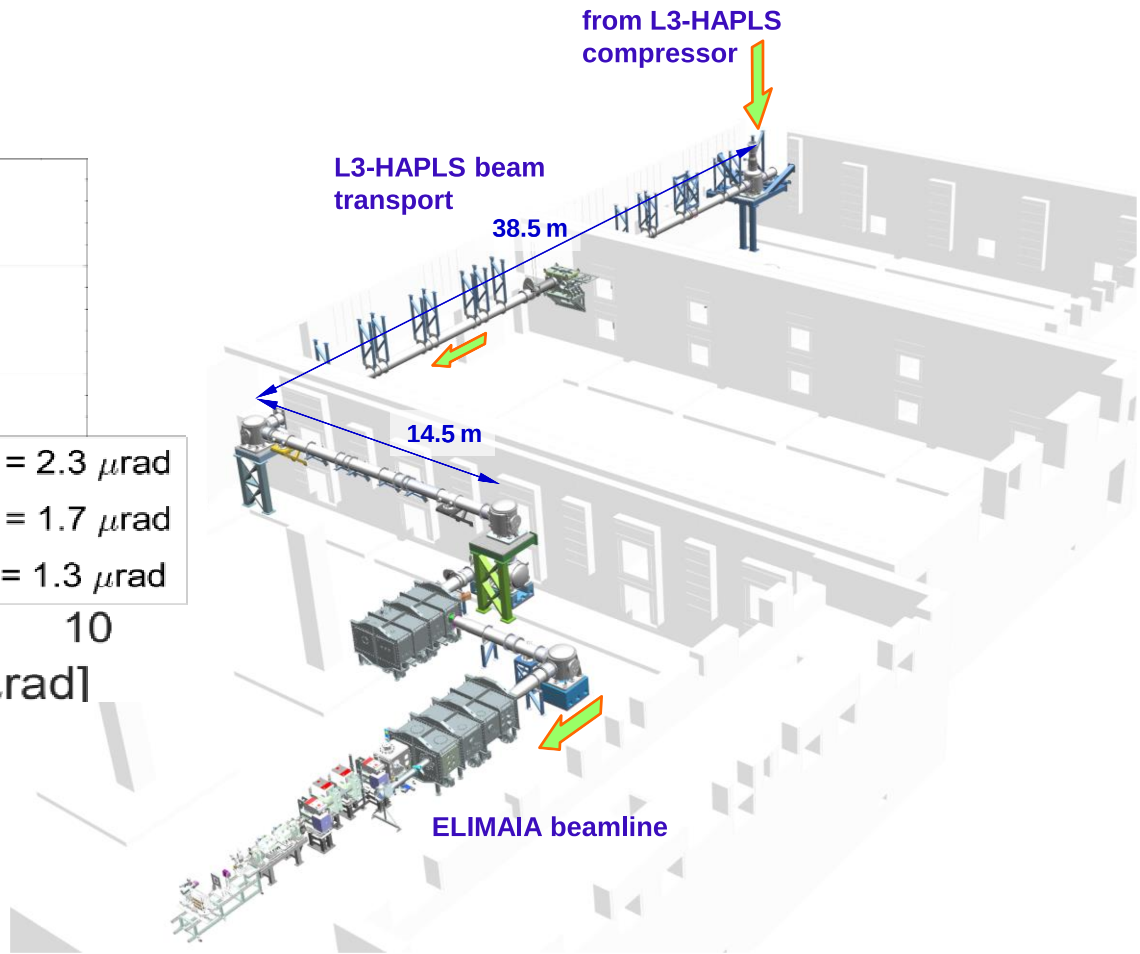
Laser energy >10 J
Pulse duration < 30 fs
Laser Intensity > 10^{21} W/cm^2
Rep. rate ~ 1 Hz

ns-pedestal contrast level $5*10^{-11}$



Pointing stability (shot-to-shot linear fluctuation on target <1 µm rms)





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Laser-plasma accelerator commissioning @ ELIMAIA beamline

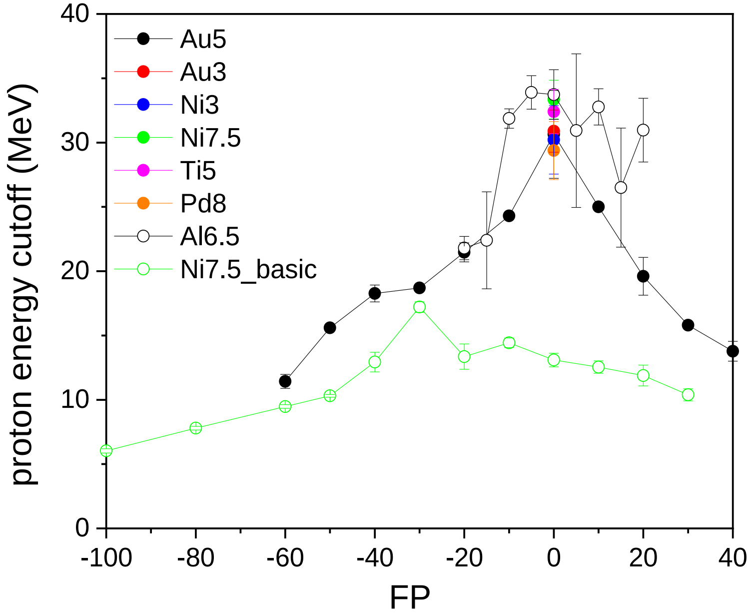
ELIMAIA laser-plasma ion accelerator commissioning for evaluating:

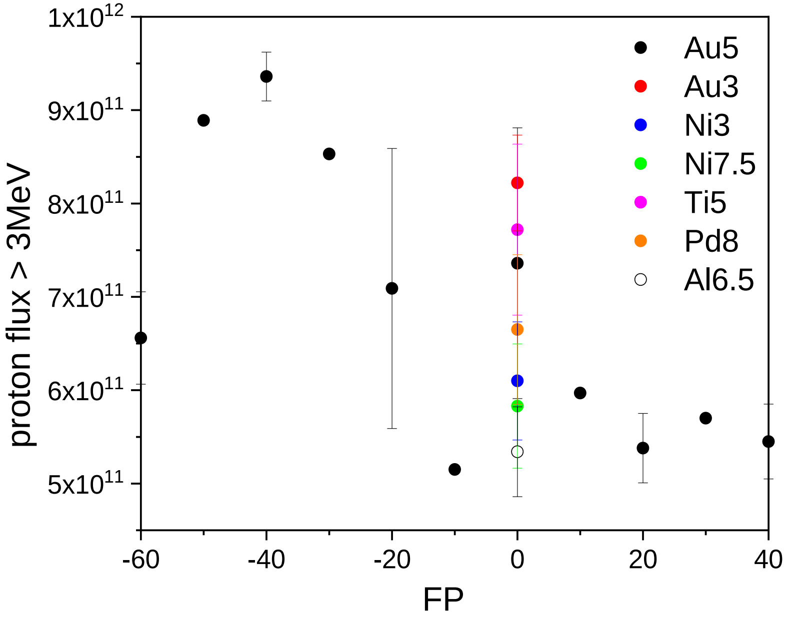
- the performances of the plasma accelerator (accelerating proton beams cut-off energy and flux per shot);
- shot-to-shot reliability both in single shot and repetition rate (0.5 Hz) mode.

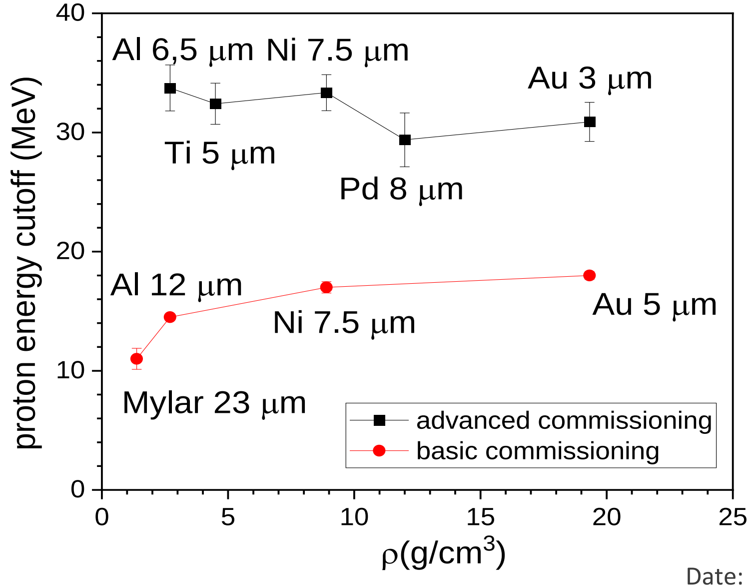
Two phases:

- Basic commissioning: accelerator performances@ poor laser contrast;
- Advanced commissioning: define the input proton beam for the ELIMED user station basic commissioning using high quality contrast level.

Laser-plasma accelerator advanced commissioning *high ns-contrast level*







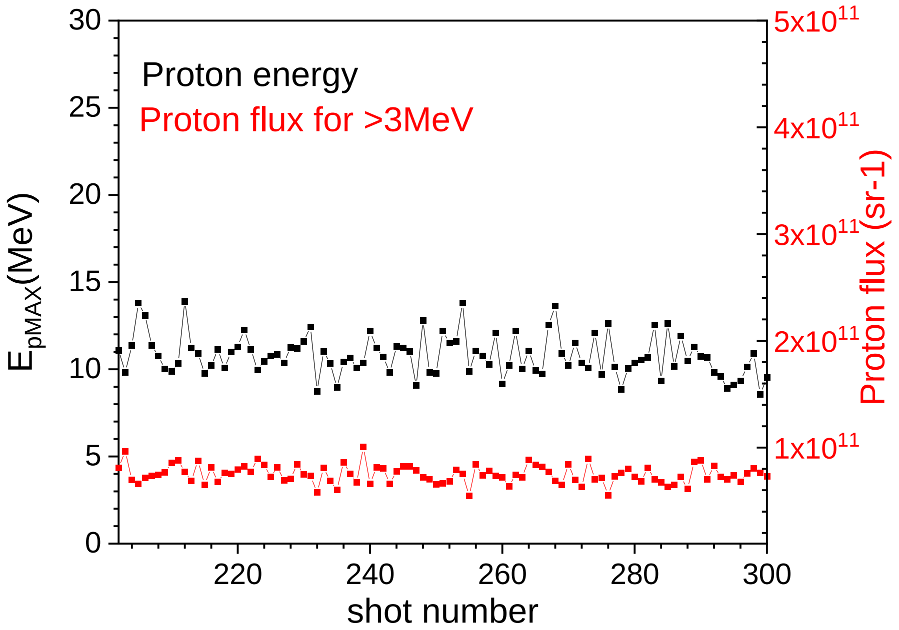
Main information

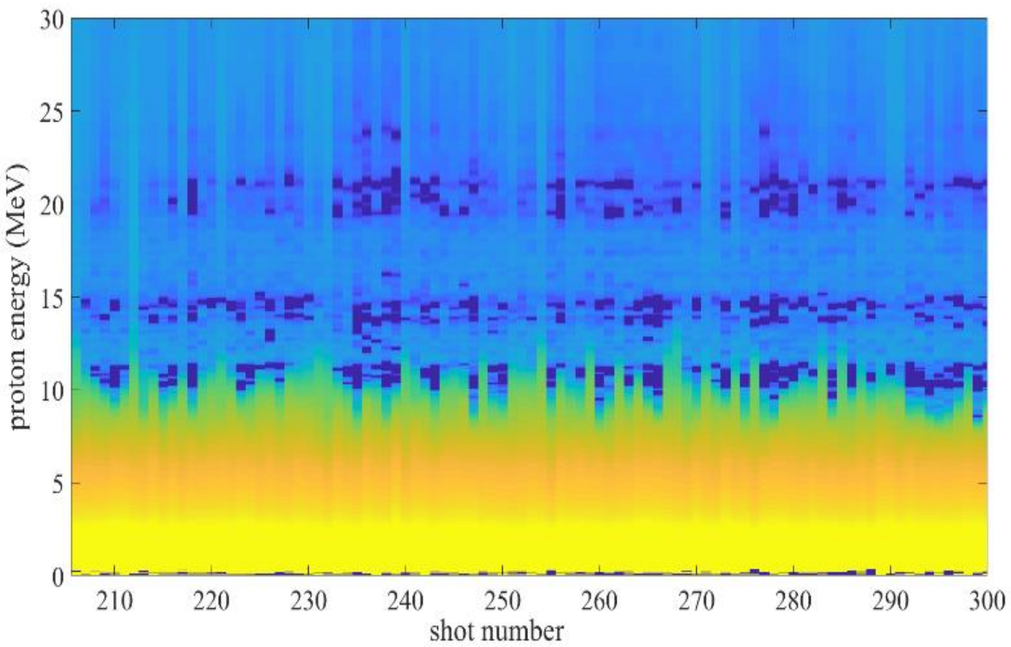
- ✓ Max cut-off energy > 30 MeV;
- ✓ Proton fluxes @ 3 MeV >>1e11 protons;
- ✓ Max ion signal without defocusing

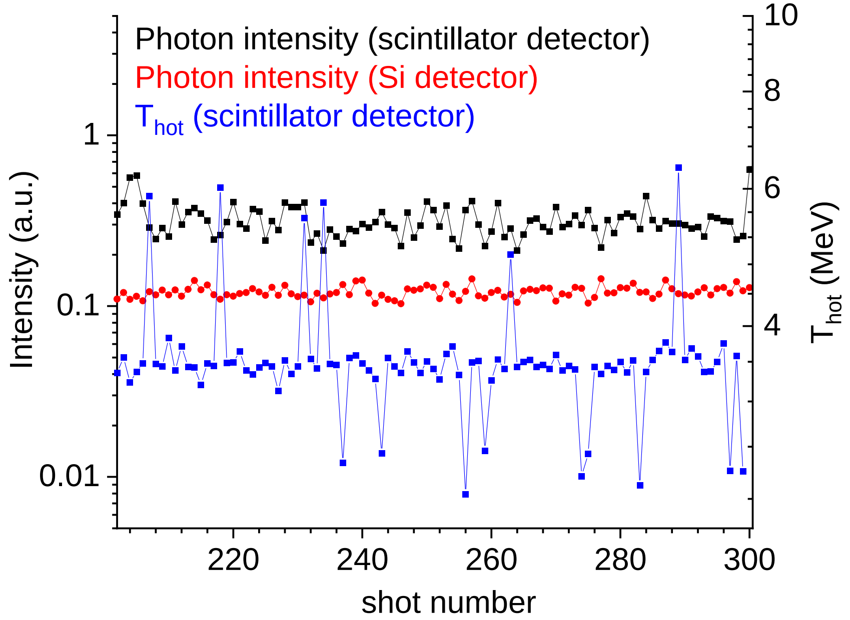
	Low ns-contrast	High ns-contrast
Max cut-off energy	<20 MeV	>30 MeV
Proton fluxes @ 3 MeV	~1e10	>>1e11
Best signal	Negative defocusing	On hard focusing

Rep. rate series @10^{21} W/cm^2

fluctuation evaluation







ate:

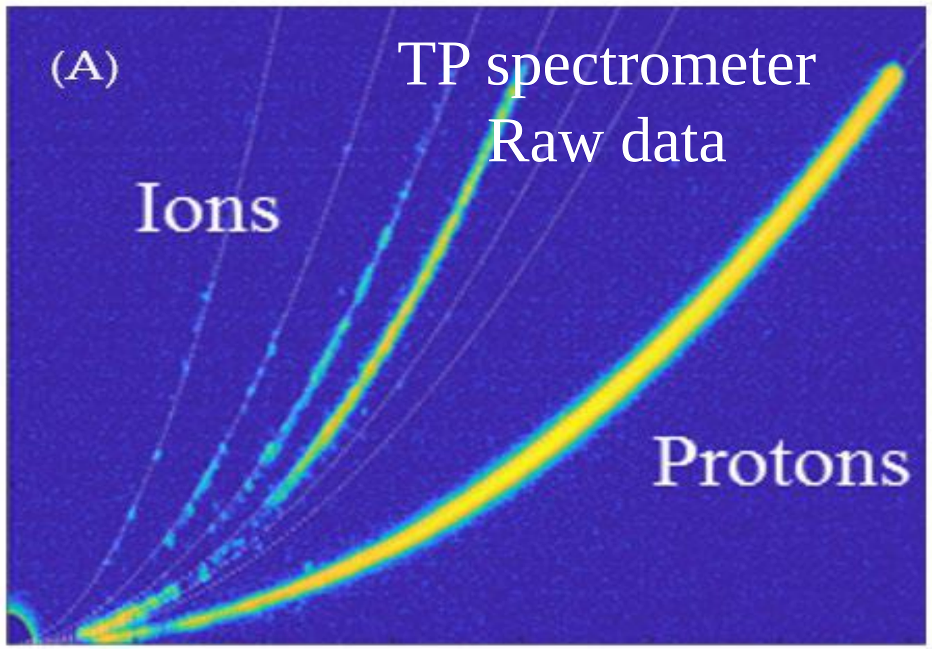
Fluctuations		100 consecutive shots @ 0.5 Hz
Laser energy	0.2%	9.58±0.02 J
Laser intensity @FWHM	2.7%	(1.33±0.04)*10^{21} W/cm^2
T_{hot}	1.1%	3.502±0.037 MeV
Photon flux	1%	
E_{pMAX}	1.1%	10.79±0.12 MeV
Proton flux >3 MeV	1.2%	7.5*10^{10}±8.9*10^8 sr-1

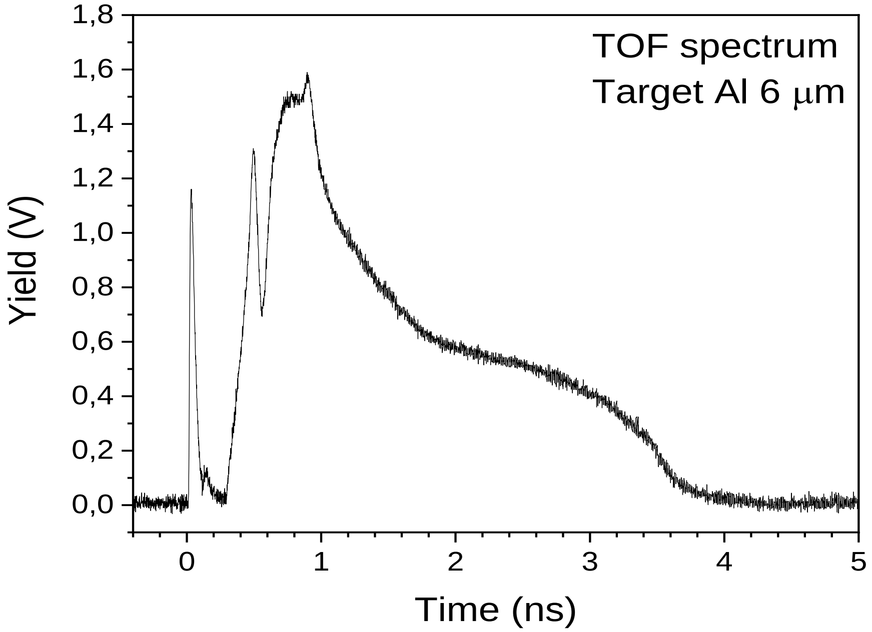
Consistency on ion diagnostics

Are we sure about the measured signal???

Comparison of different ion diagnostics

TP results vs TOF results





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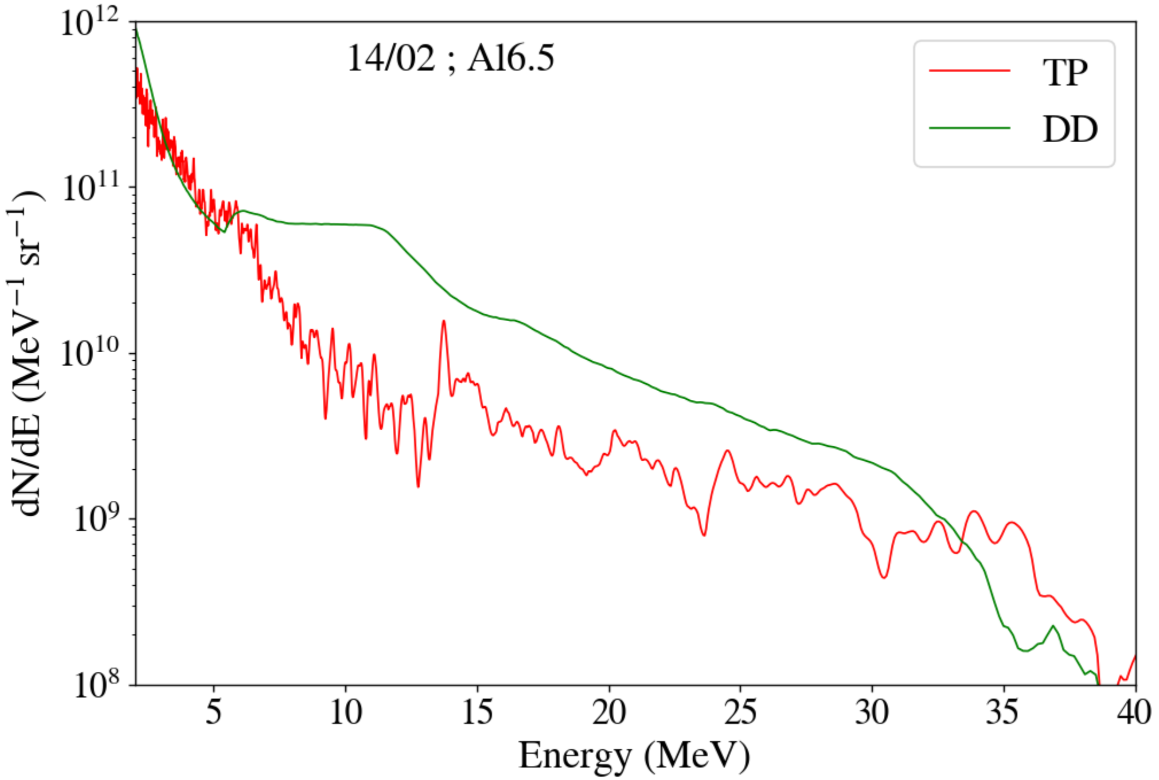

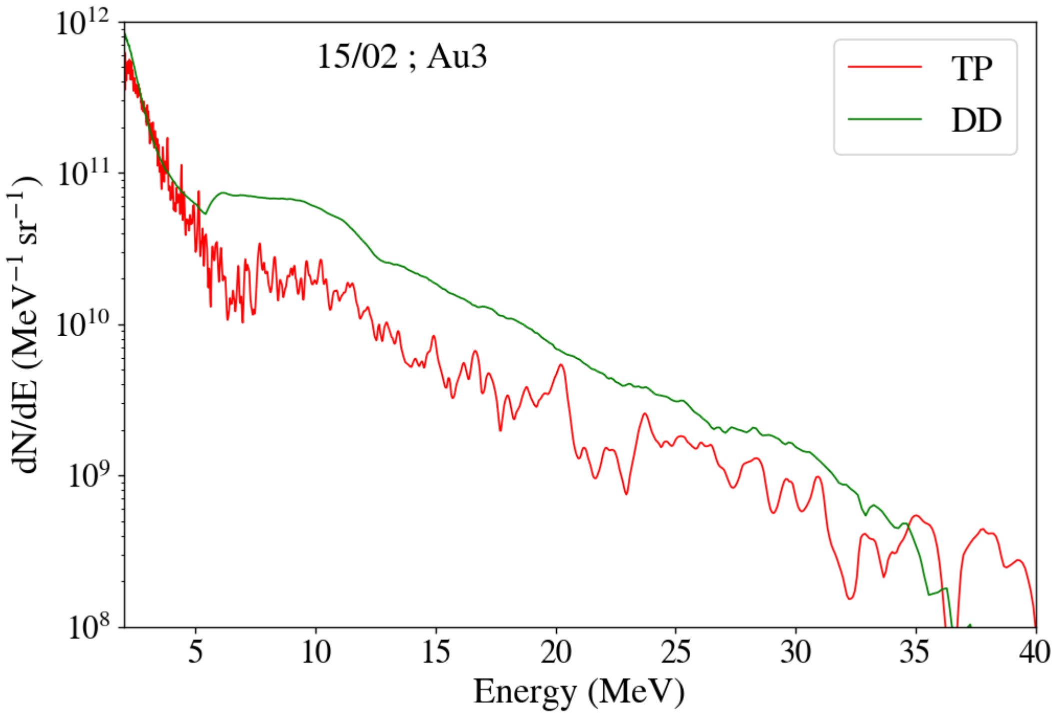

Consistency on ion diagnostics

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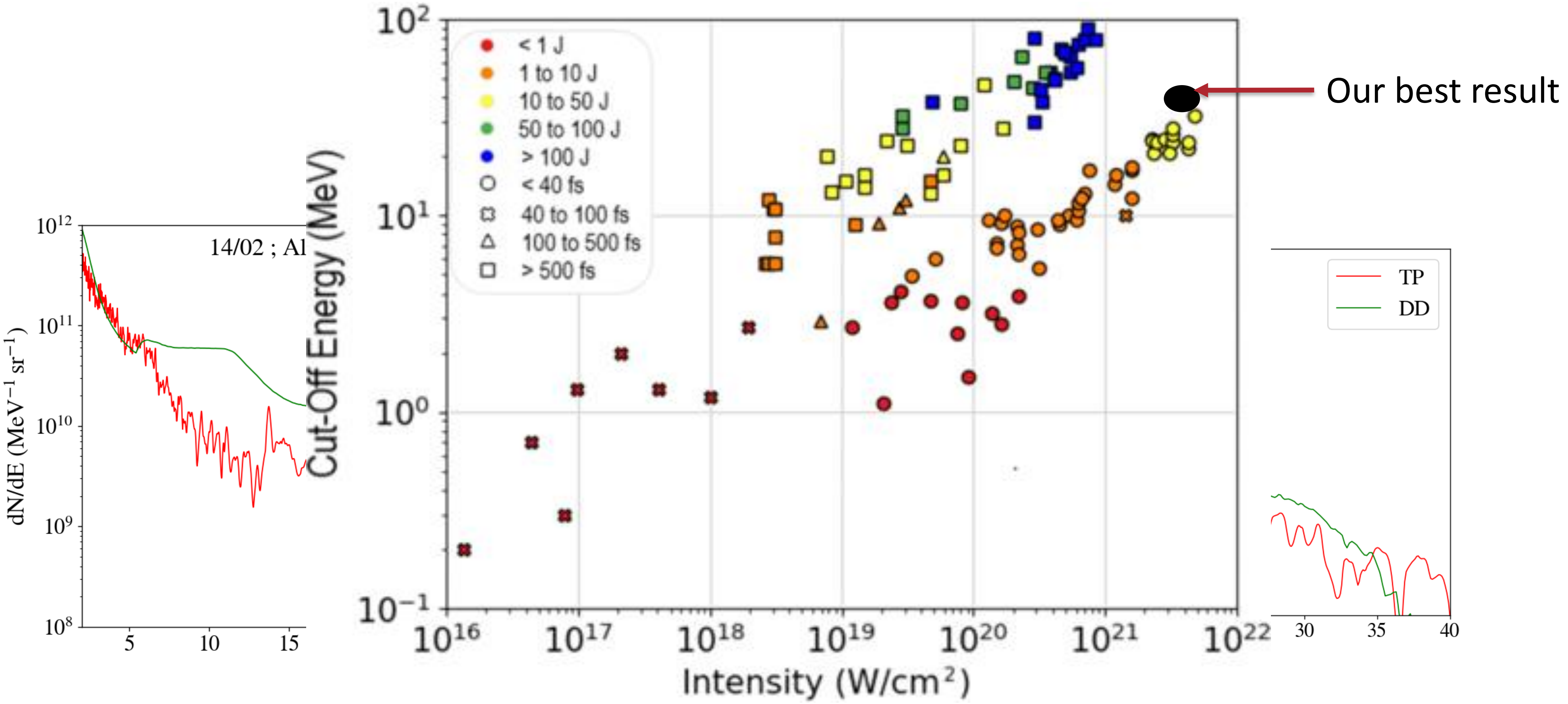
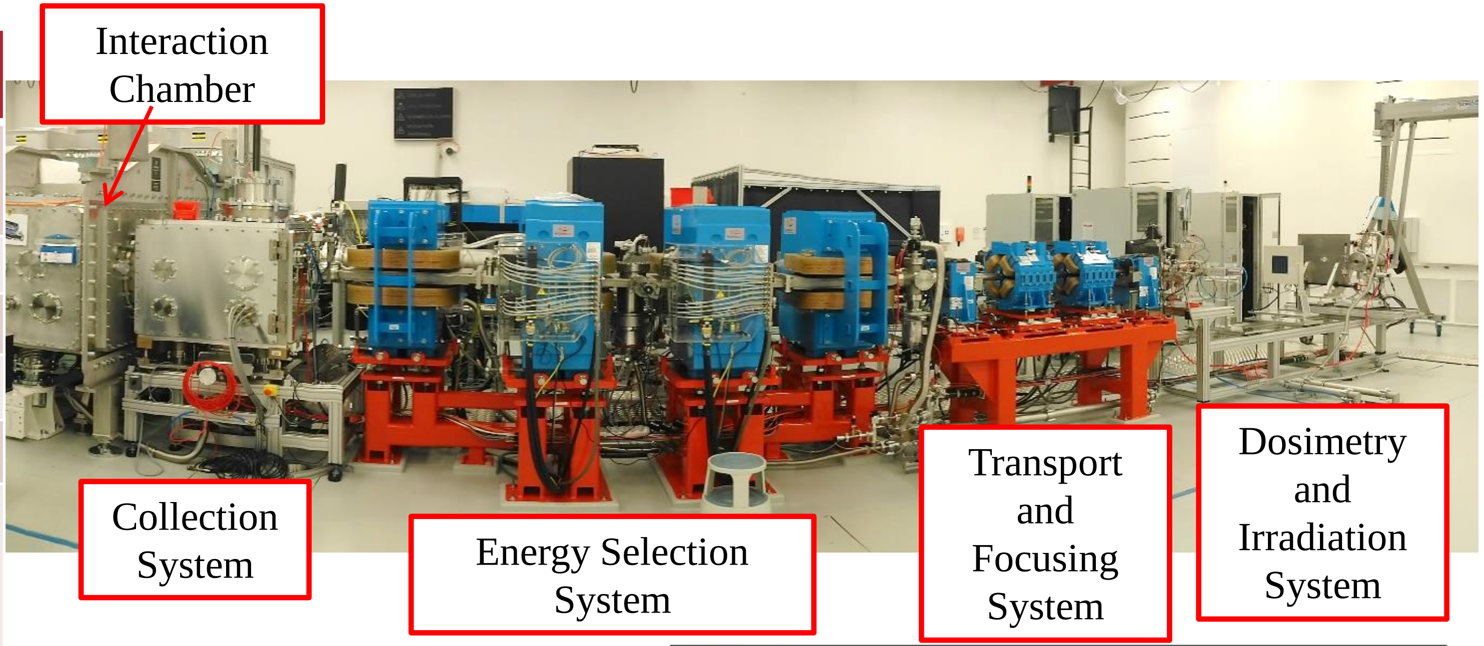


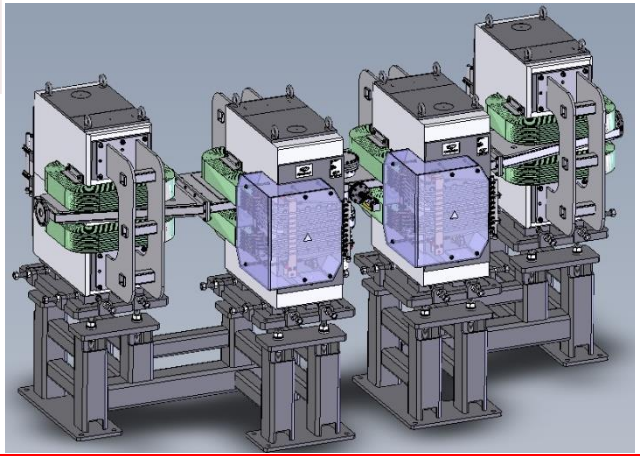
- ELIMAIA user beamline;
- ELIMAIA commissioning:
  - ✓ Experimental results
- ELIMED

ELIMED section

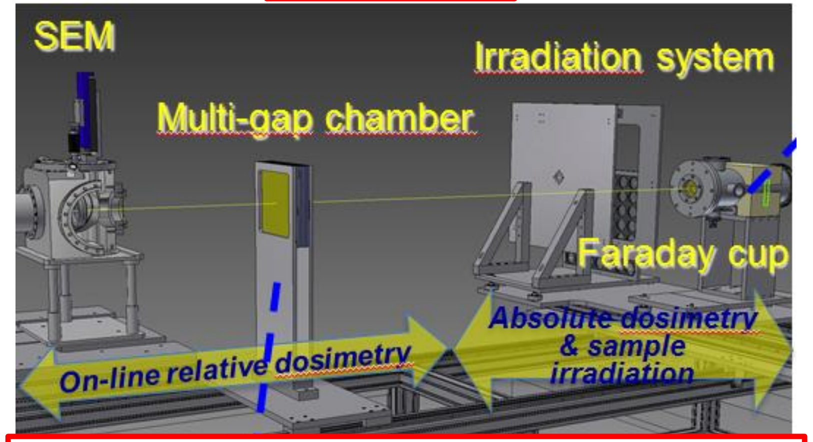
ELIMED Station	Design parameters @ user sample
Proton energy	5-60 MeV (angular spread and PMQ limited)
Ions/shot	$1\cdot10^{8}$-$1\cdot10^{10}$/sr
Bunch duration	~10 ns
Ion beam aperture	~ 1 deg (FWHM)
Ion beam spot size	0.1-10mm (FWHM)
Repetition rate	• Static setup allows for CW beams. • Up to 1Hz in active energy modulation mode



Collection System:
5 PMQs, 36mm magnetic bore, 100 T/m gradient with 2% uniformity



Energy Selection system:
4 electro-dipoles, 55mm bore, 0.06 – 1.226 T with 0.5% uniformity, linear resolution with slit aperture size, active energy modulation possible

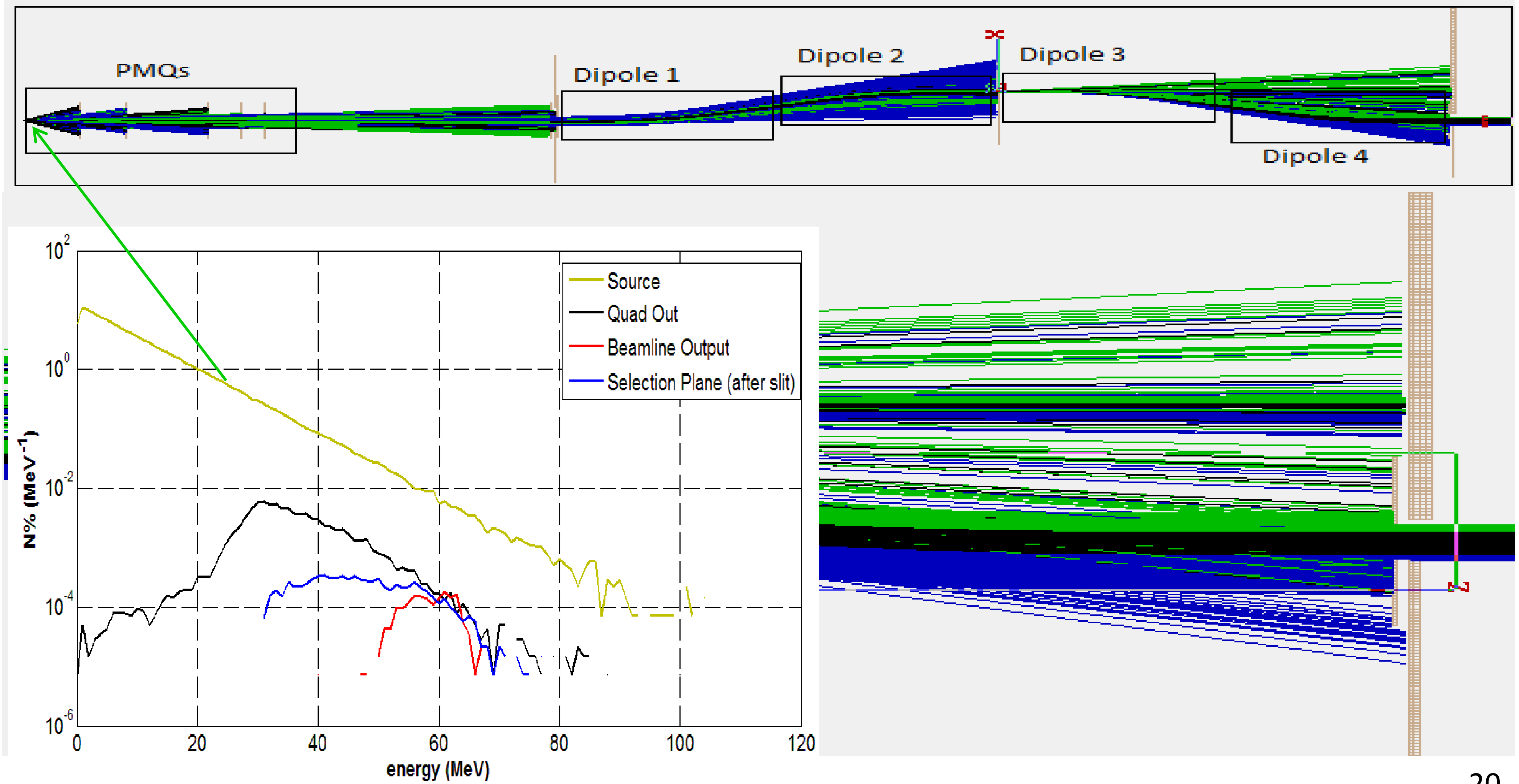


Dosimetry and Irradiation System:
SEM for beam current monitor, Multi-gap chamber for relative-online dosimetry, FC for absolute dosimetry, automated sample irradiation system

Beam transport: TNSA-like protons

Angular divergence = 5° (FWHM)

Transmission efficiency ~12% (9,2e7 H^+/bunch)



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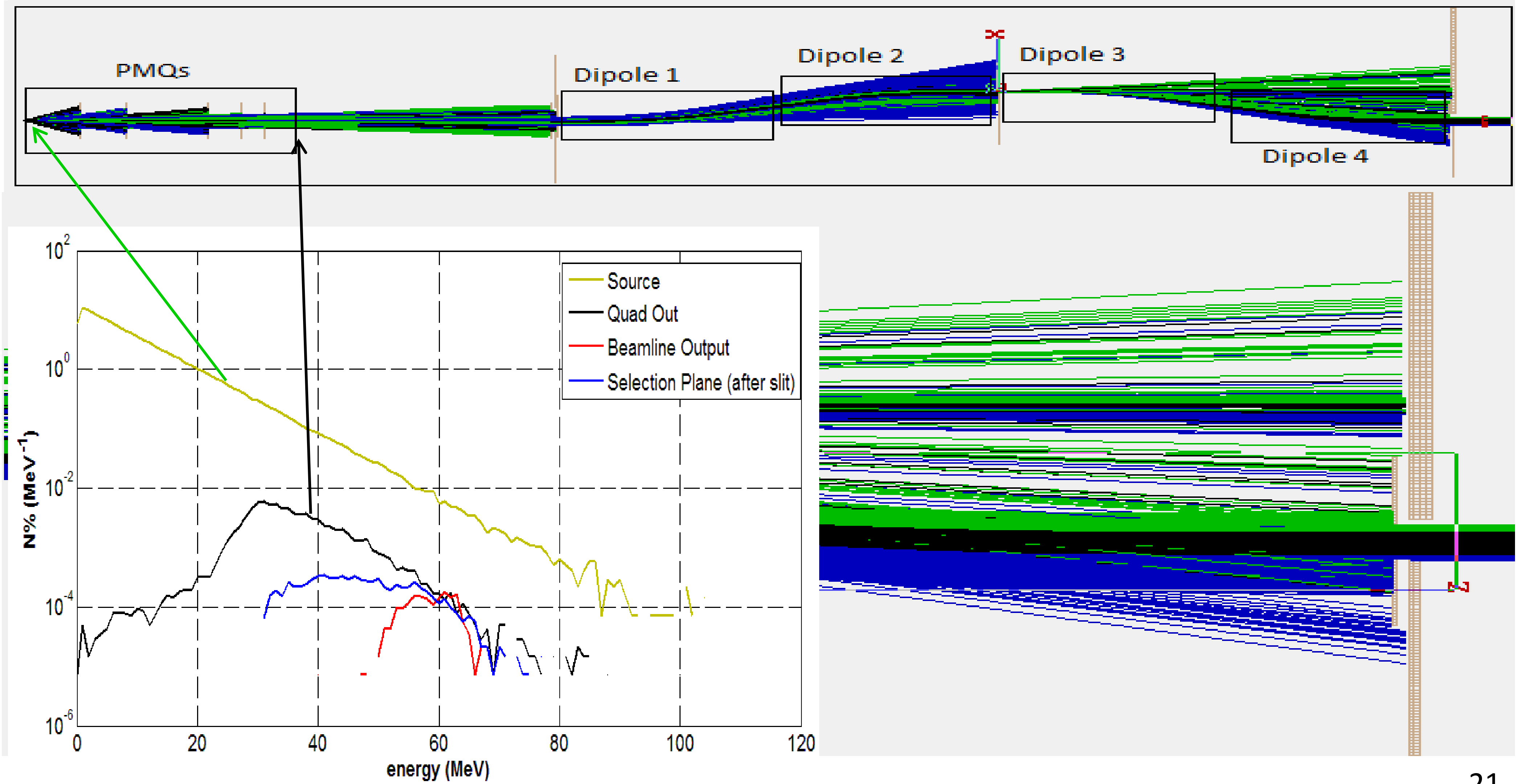

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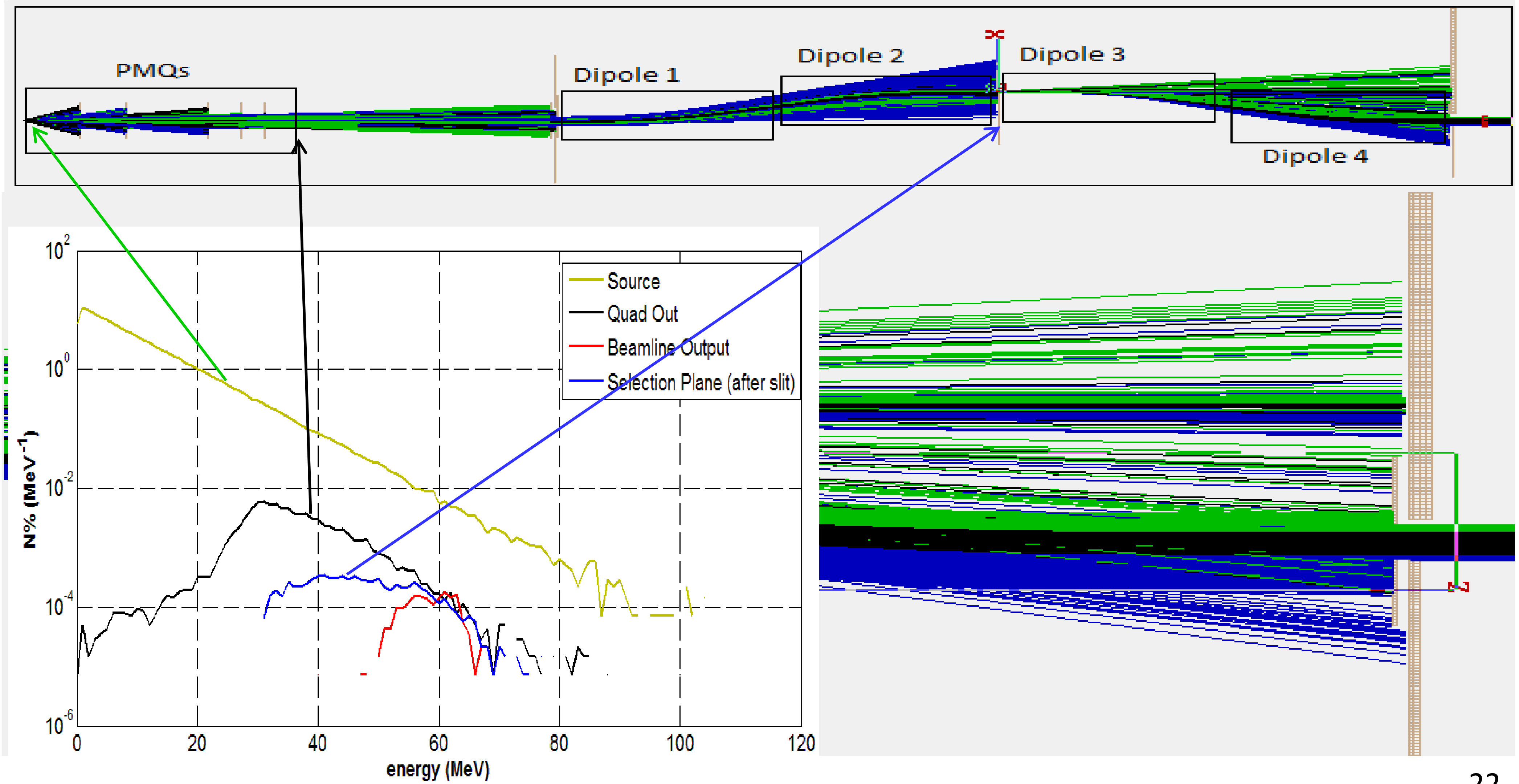

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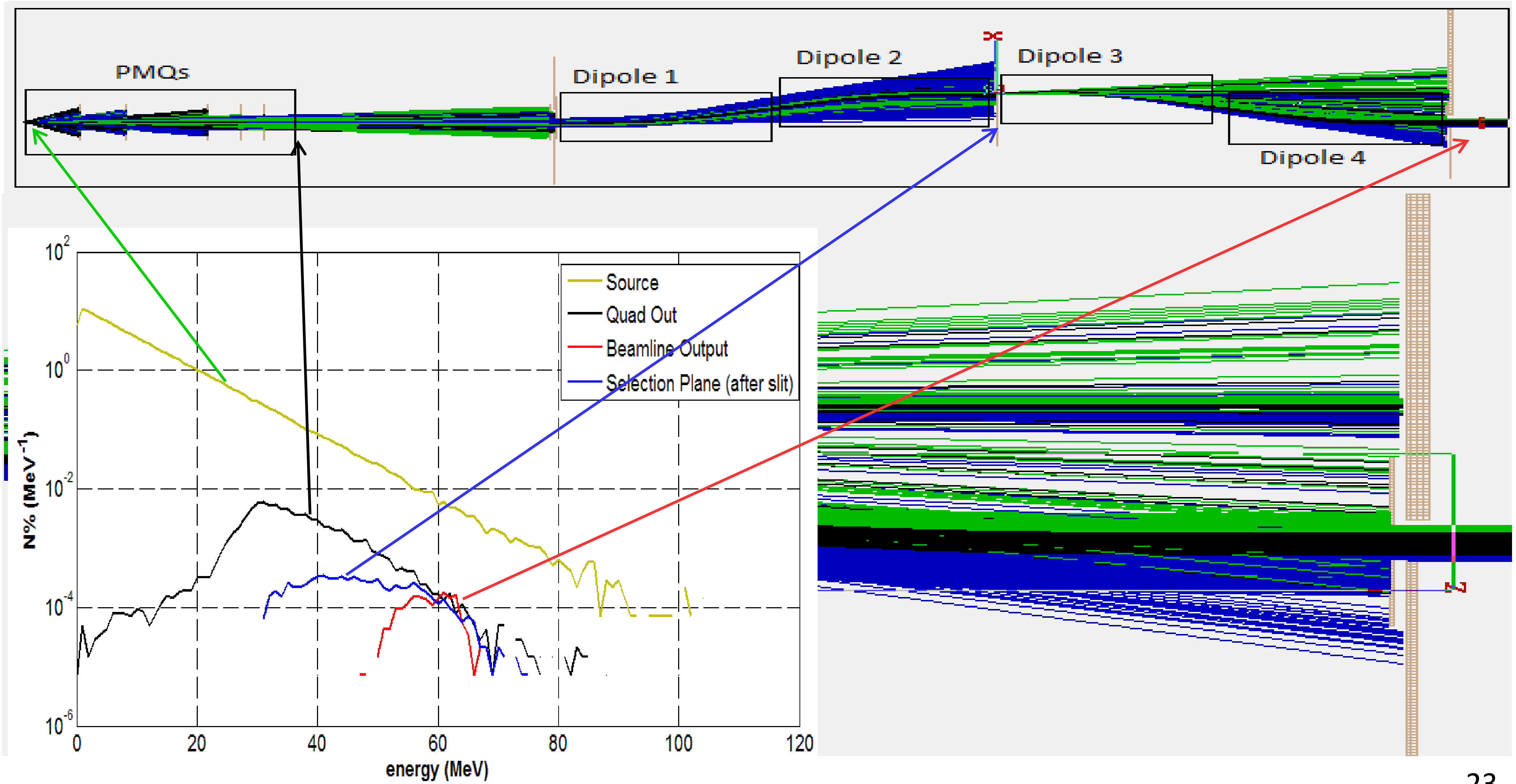

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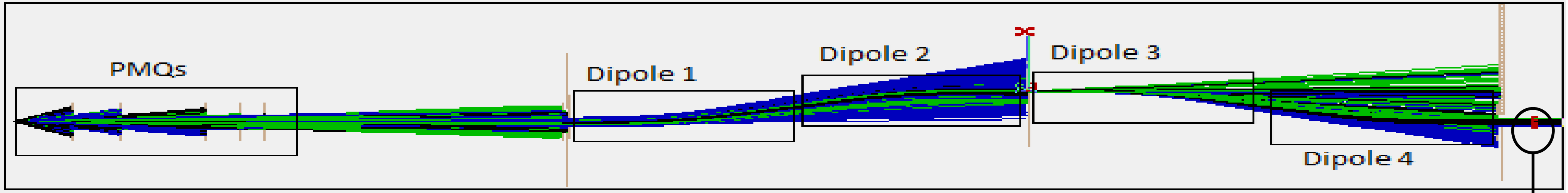
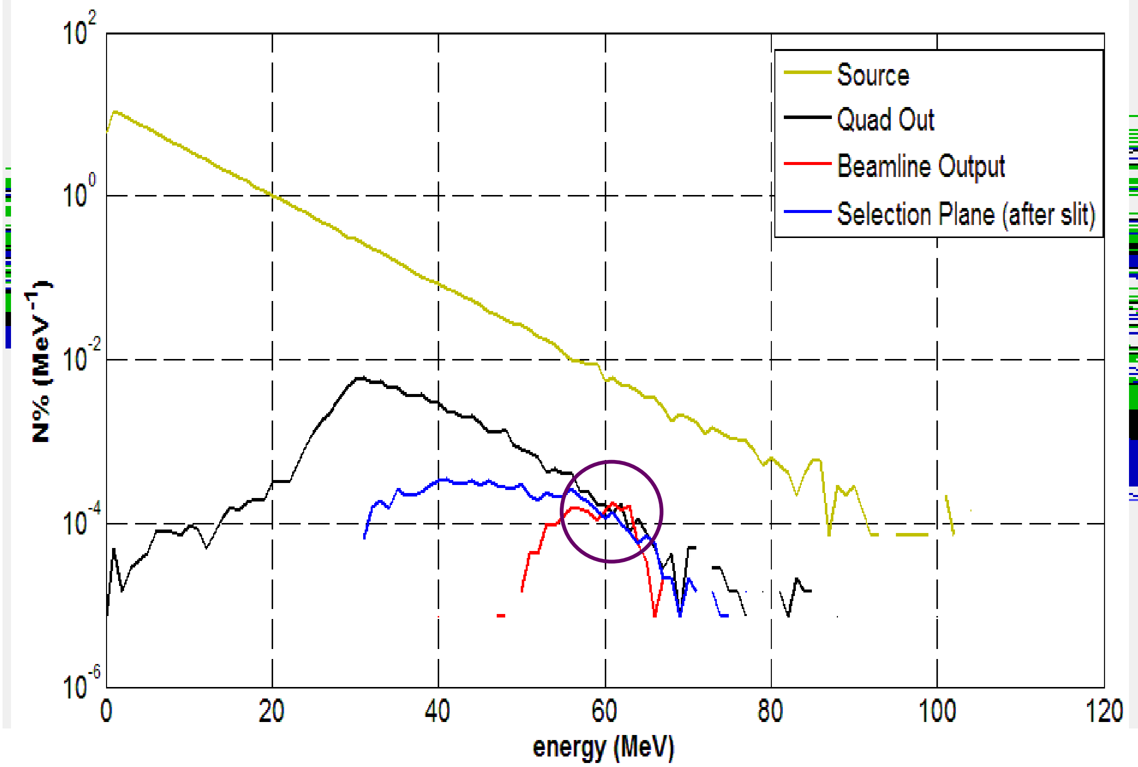
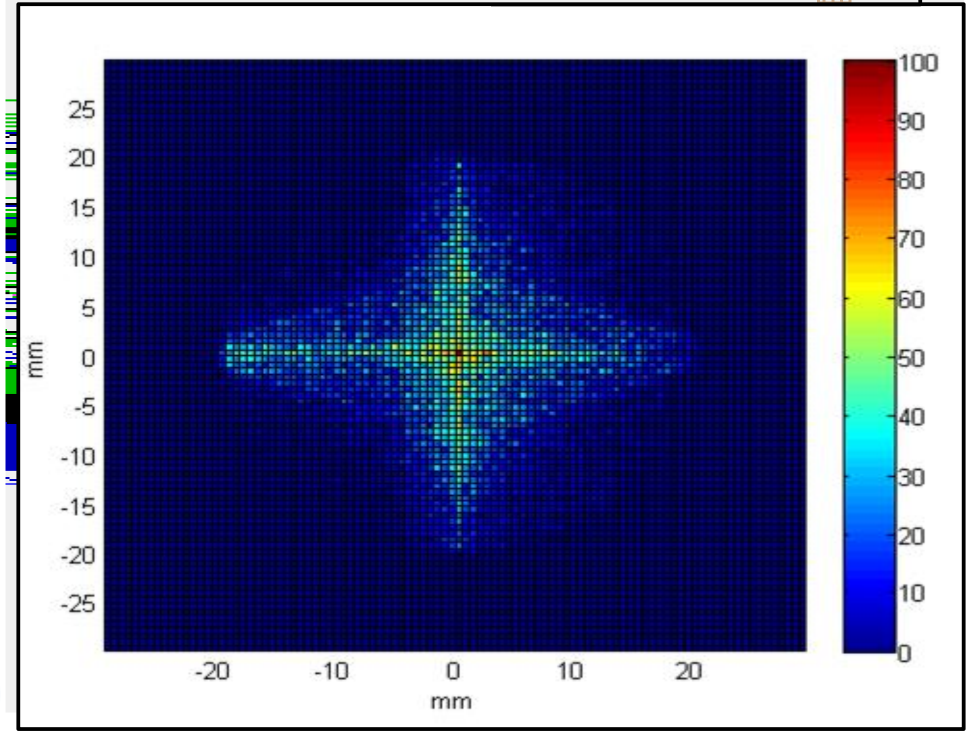
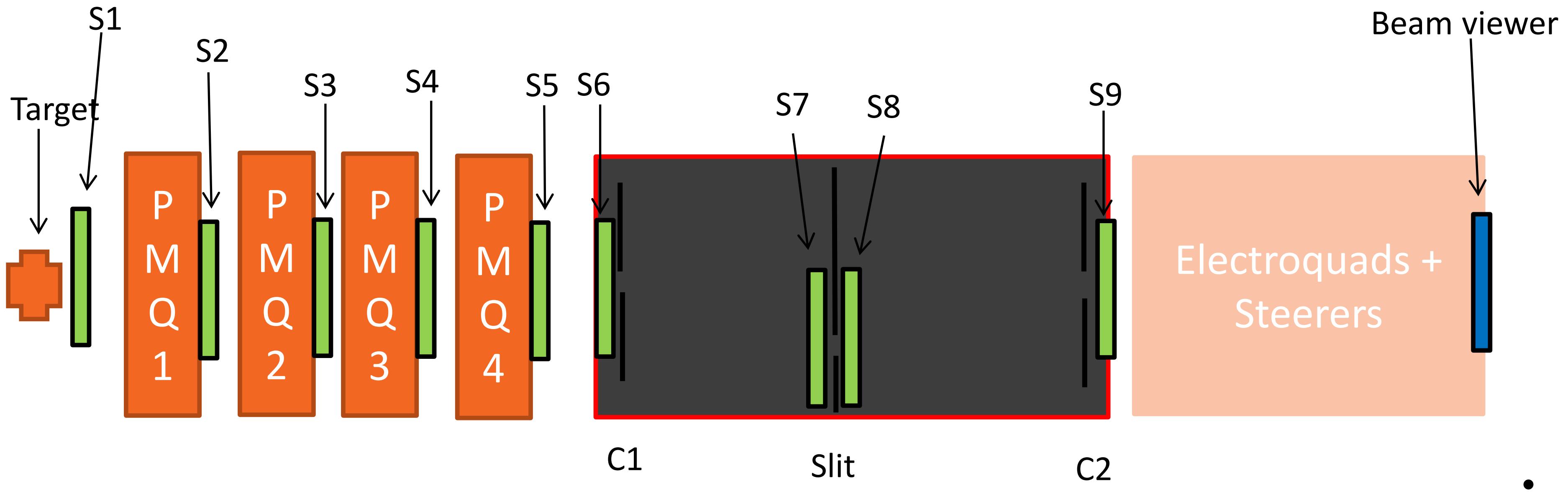
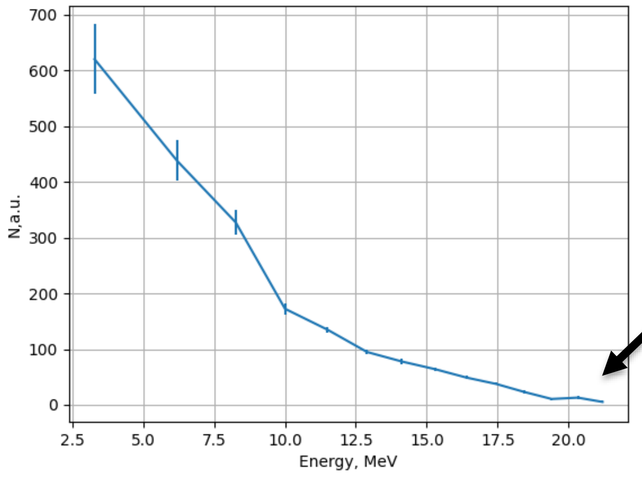


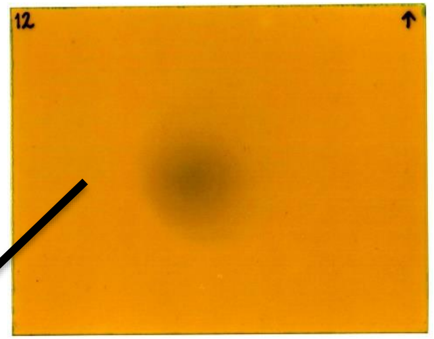




ELIMED commissioning







- In-vacuum ion beam optics study for the different subsystems of ELIMED (Collection, Selection and Focusing)
- Energy resolution study of the selection system
- In-air dosimetric characterization of the ion beam

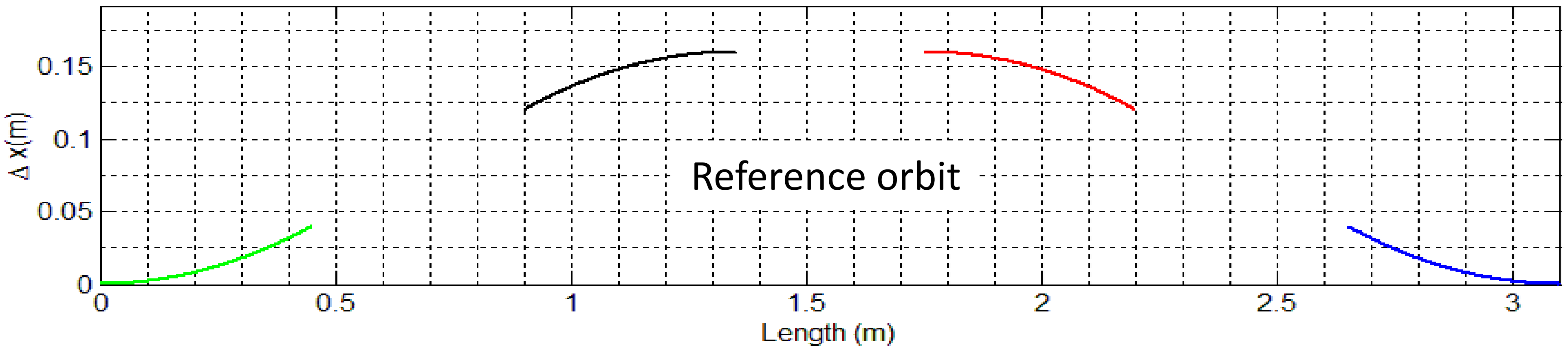
Thank you
for your attention!

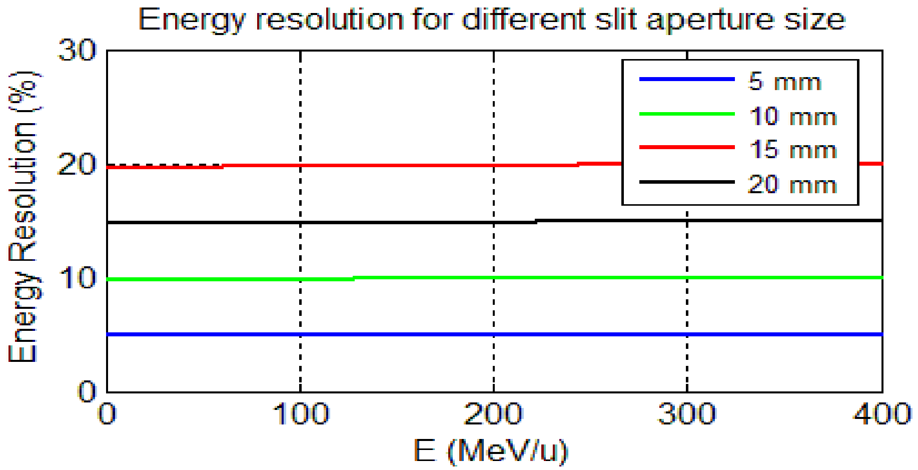
Heading of the slide

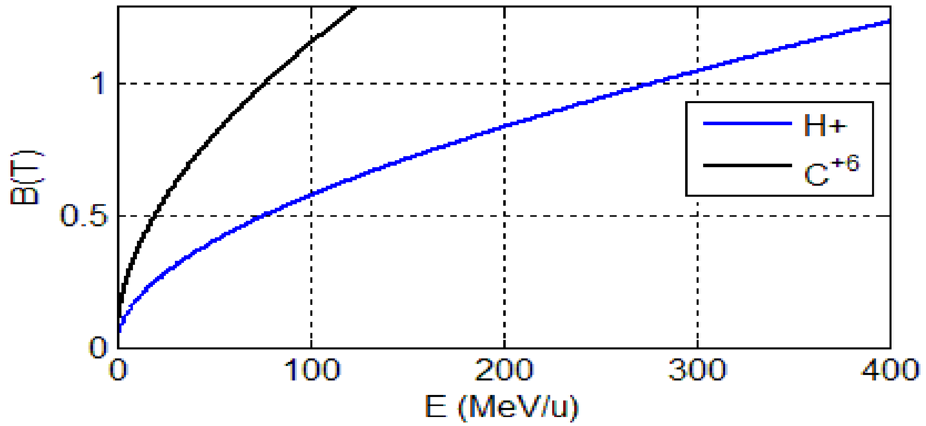
Heading of the slide

Energy selector
Reference orbit and layout

ESS Features







Magnetic chicane based on a bunch compressor scheme
Path length: 3,168m
Two collimators φ = 30 mm, selection slit s x 20 mm.

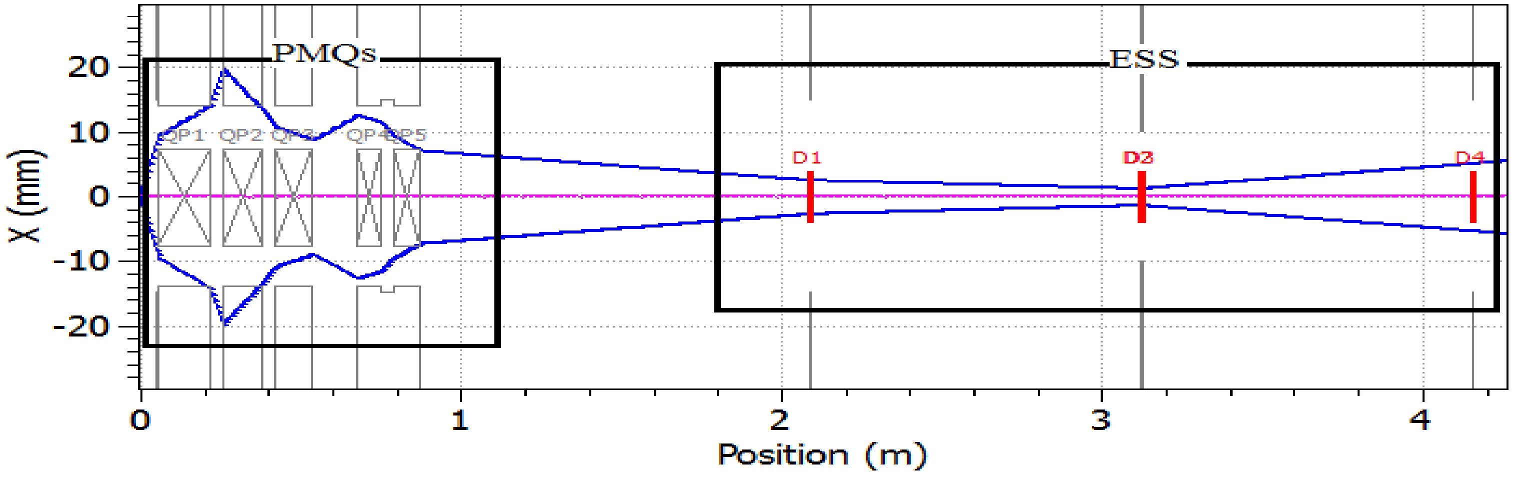
Collection and Selection systems matching conditions

Linearised chicane to define the PMQs set up according the (general) matching conditions:

1) Waist close to the slit on the radial direction M_{12}=0
2) Parallel beam on the transverse plane M_{44}=0
3) Fixed beam dimensions at the selection plane (20x20mm)
4) Transmission efficiency of 10% is ensured

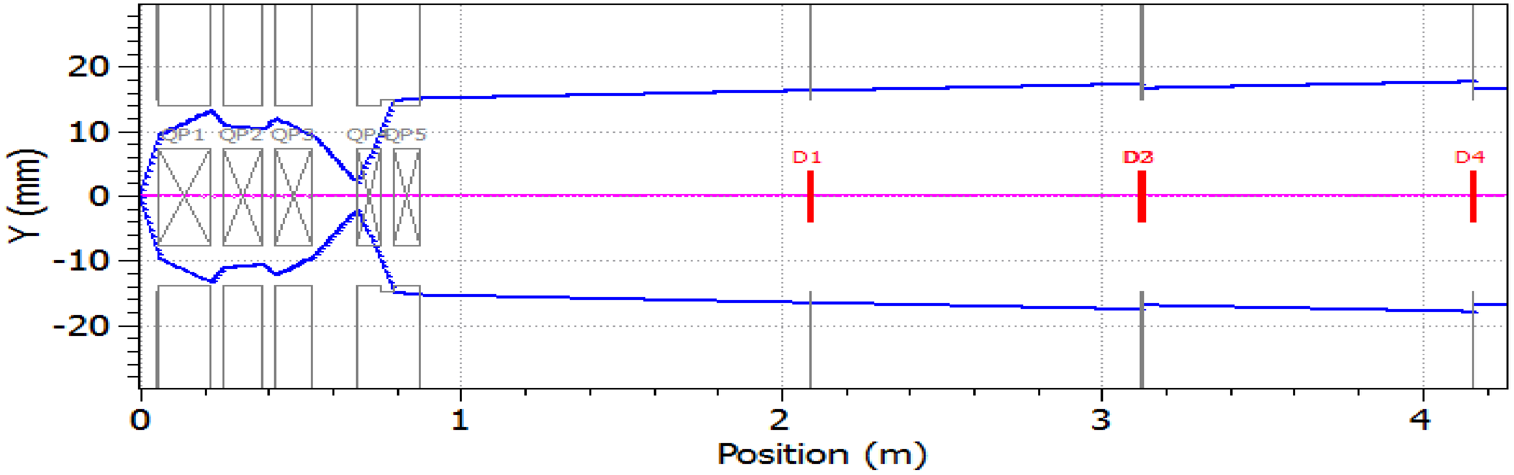
4 conditions require 4 quads

Originally they were 2x160 and 2x120
One of the longest was cut in 2 to match condition for all energies as cost effective solution



Input Beam:

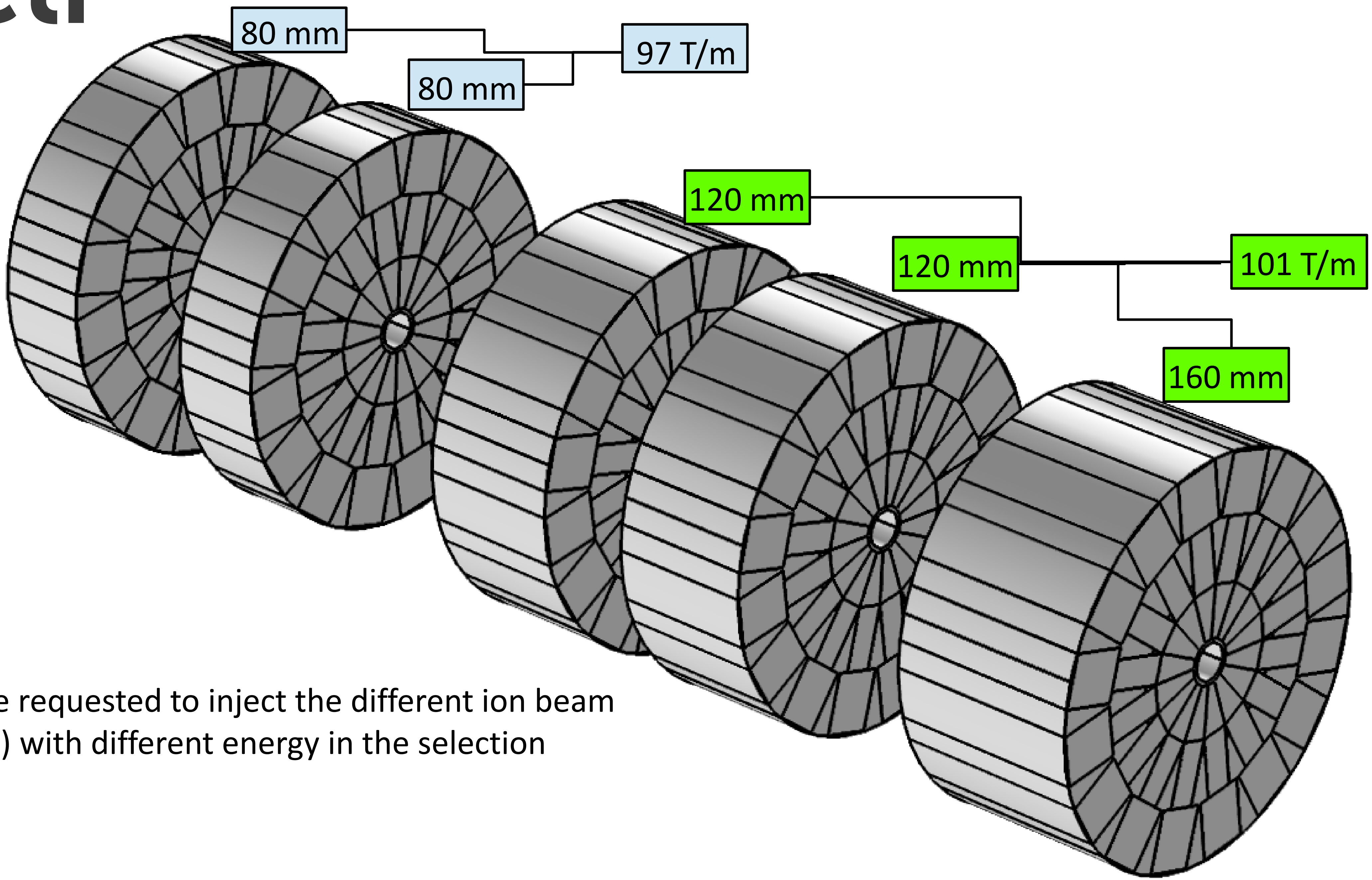
- 60 MeV
- ±10° uniform angular spread
- ~40 μm diameter



Constraints:

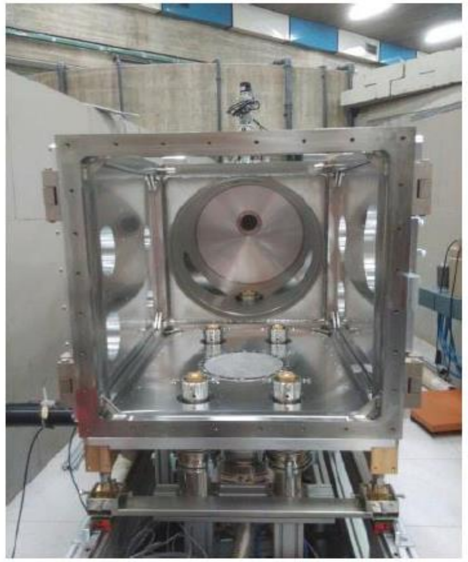
- Target-Quad1 minimum distance: 50 mm
- Minimum distance between Quads: 40 mm
- Target-ESS distance 2.05 m

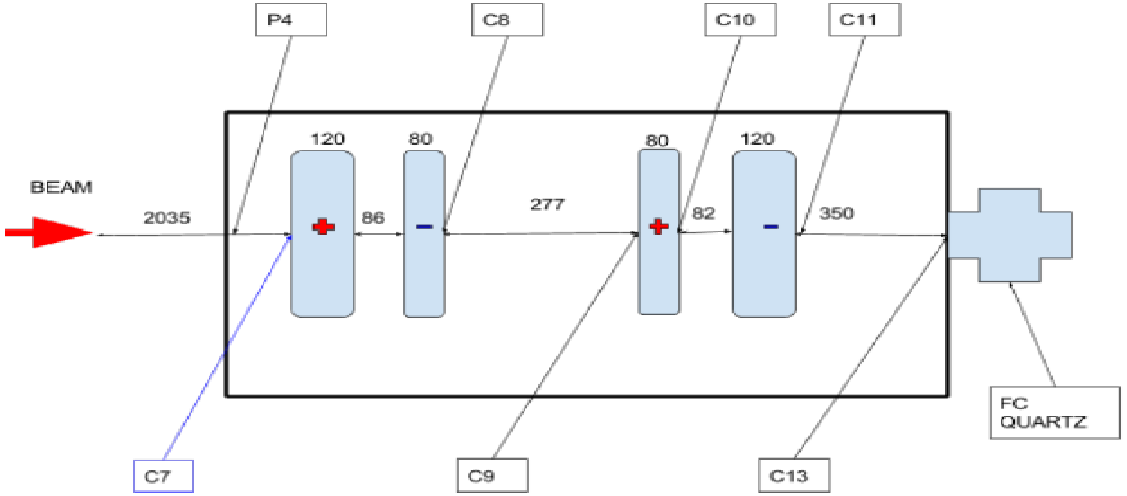
Collection systems



5 PMQs are requested to inject the different ion beam (H^+ and C^{+6}) with different energy in the selection system

ELIMED Collection system





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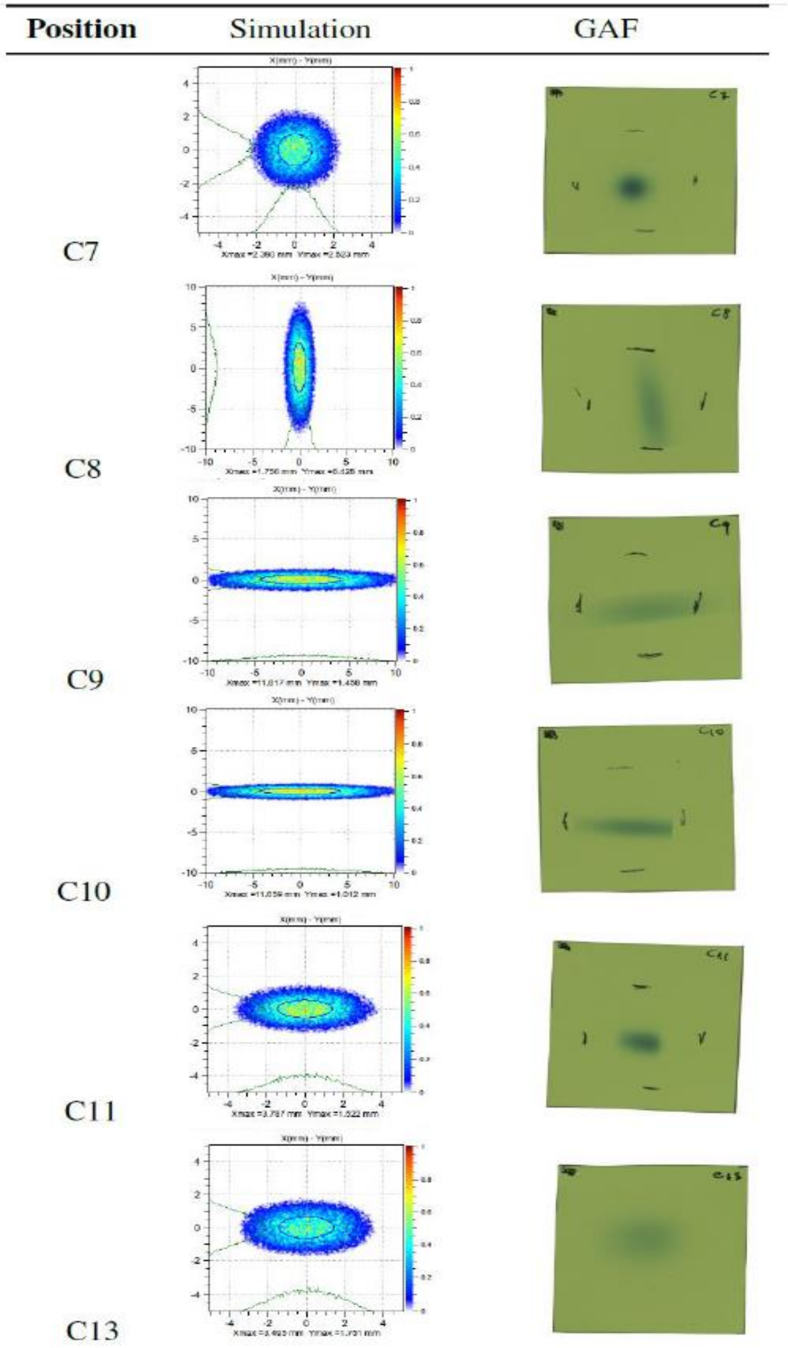
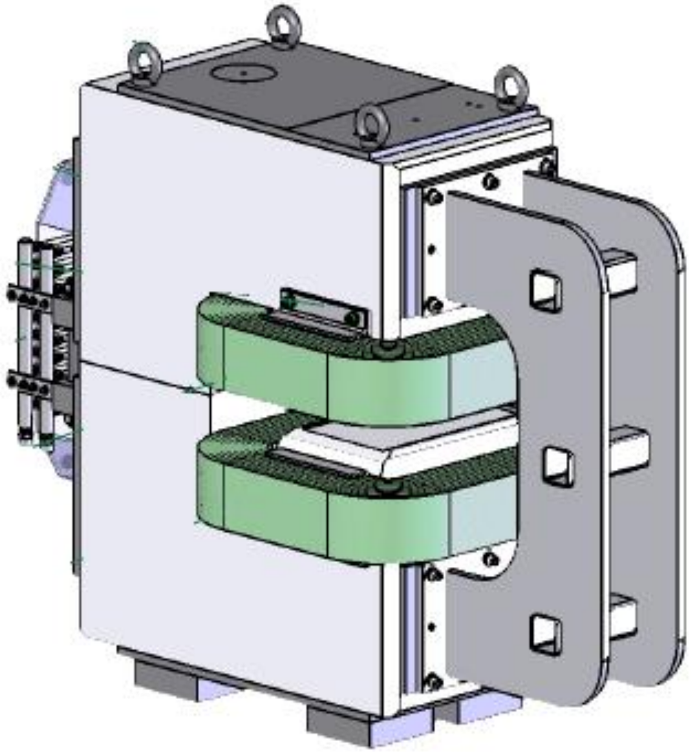


Energy Selector Features

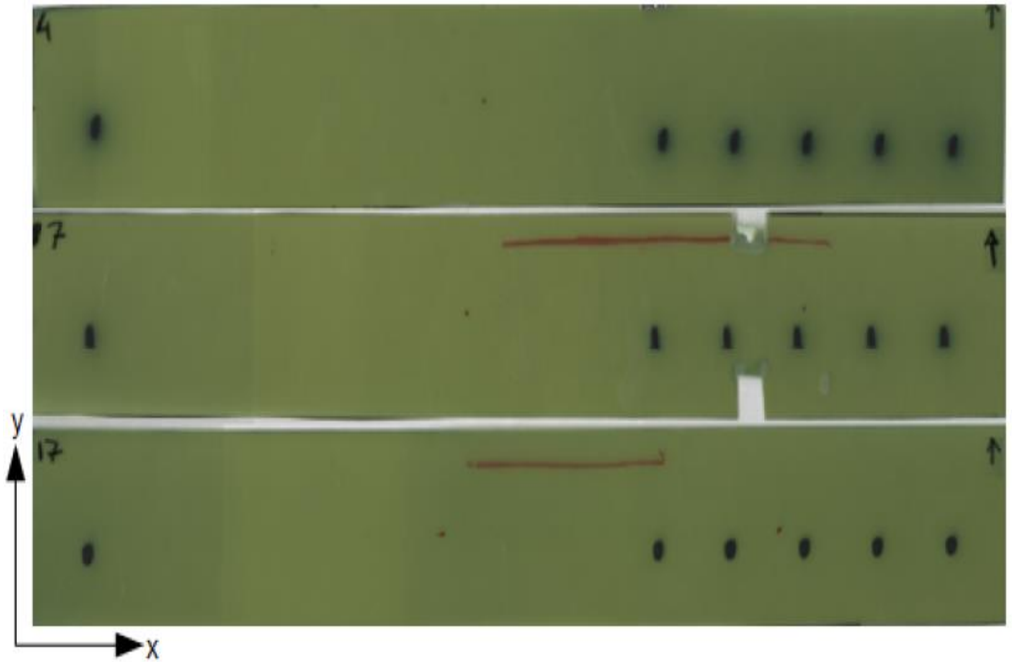
n° of Dipoles	B field	Geometric length	Effective length	Gap
4		400 mm		
Good Field region (GFR)	**Field uniformity**	**Curvature radius**	**Bending angle**	**Drift between dipoles**
100 mm	< 0.5 %	2.570 m	10.10°	500 mm



- Magnet efficiency: 97%
- Packing factor: 99% (1 mm lamination)
- 116x116 mm coil section (10x10 turns, 0.4 mm of insulator, 4 mm water channel)
- Max current: 300 A
- Total weight: 2.6 Tons
- < 28 kWatt in total

Reinforcemente to guarantee 42 mm inner clearence in the vacuum chamber

Calibration at INFN LNS



62 MeV

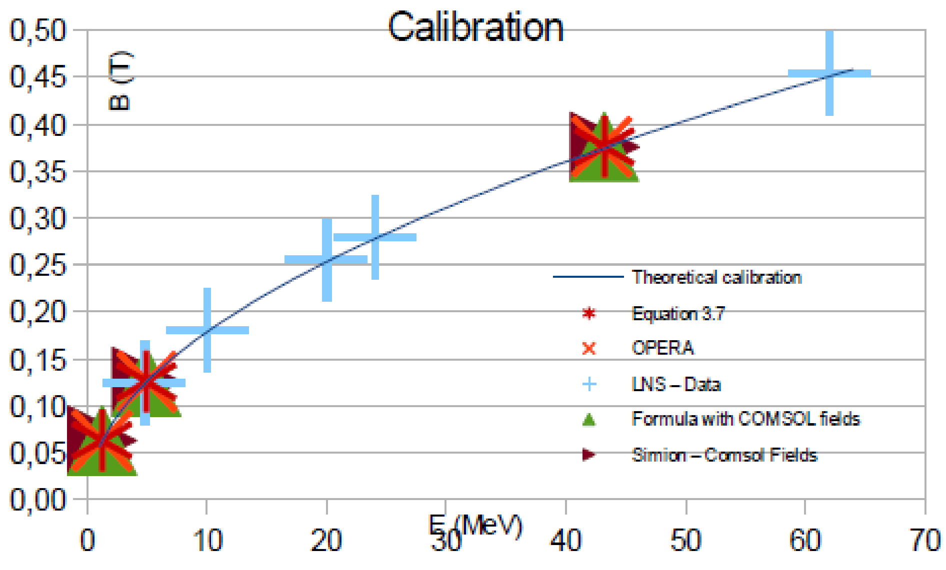
24 MeV

10 MeV

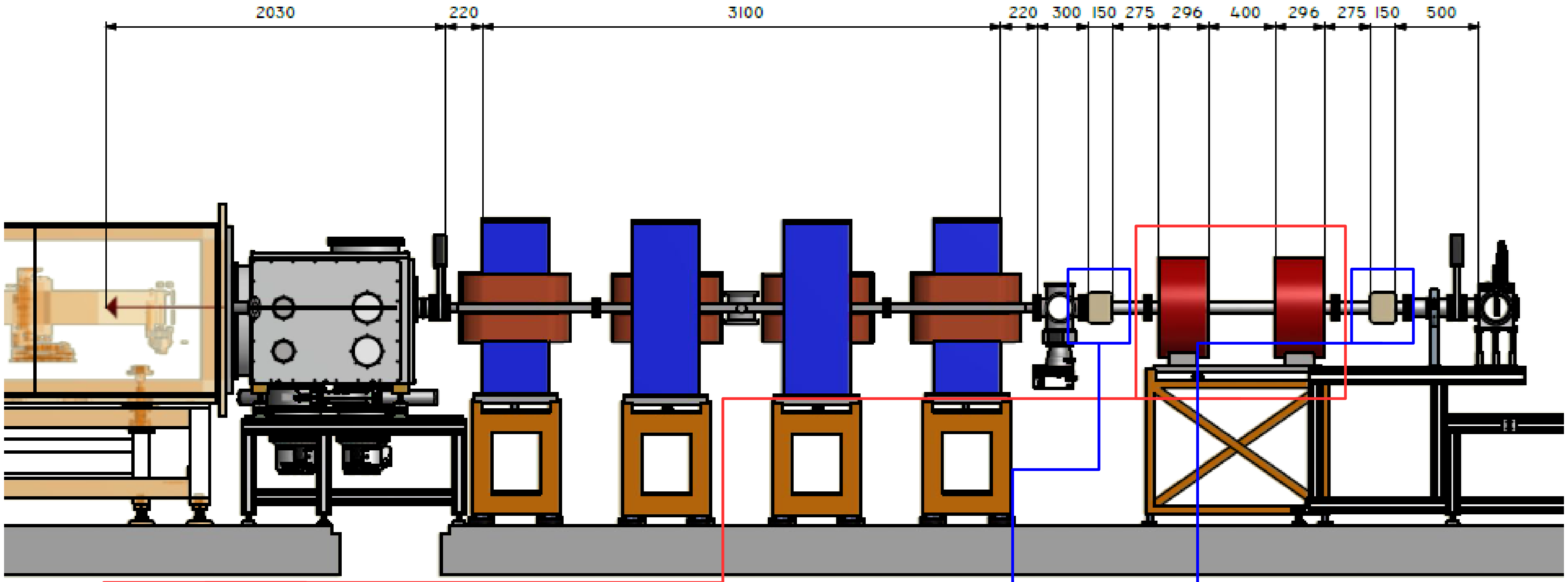
GafChromic films set up on the selection plane

B field [G]	Nominal position [mm]	Measured position [mm]	Deviation [%]
3630,3	127,5	128	0,4
4084,1	142,5	143	0,3
4537,1	160	160,5	0,3
4991,7	177,5	177	-0,3
5445,5	192,5	193,5	0,5

Data for 62 MeV Protons



Quads and Steerers



Quads Specs:

Iron length: 296mm
Packing factor 98%
Effective length: 331.5 mm
Gradient (max): 10T/m
Bore: 70 mm
GFR: 55 mm

Correctors Specs:

xy steering magnets
B max: 300 gauss
Geometrical length: 150mm