Status of the ELIMED beam-line

Valentina Scuderi
(on behalf of the ELI-Beamlines and INFN collaboration)

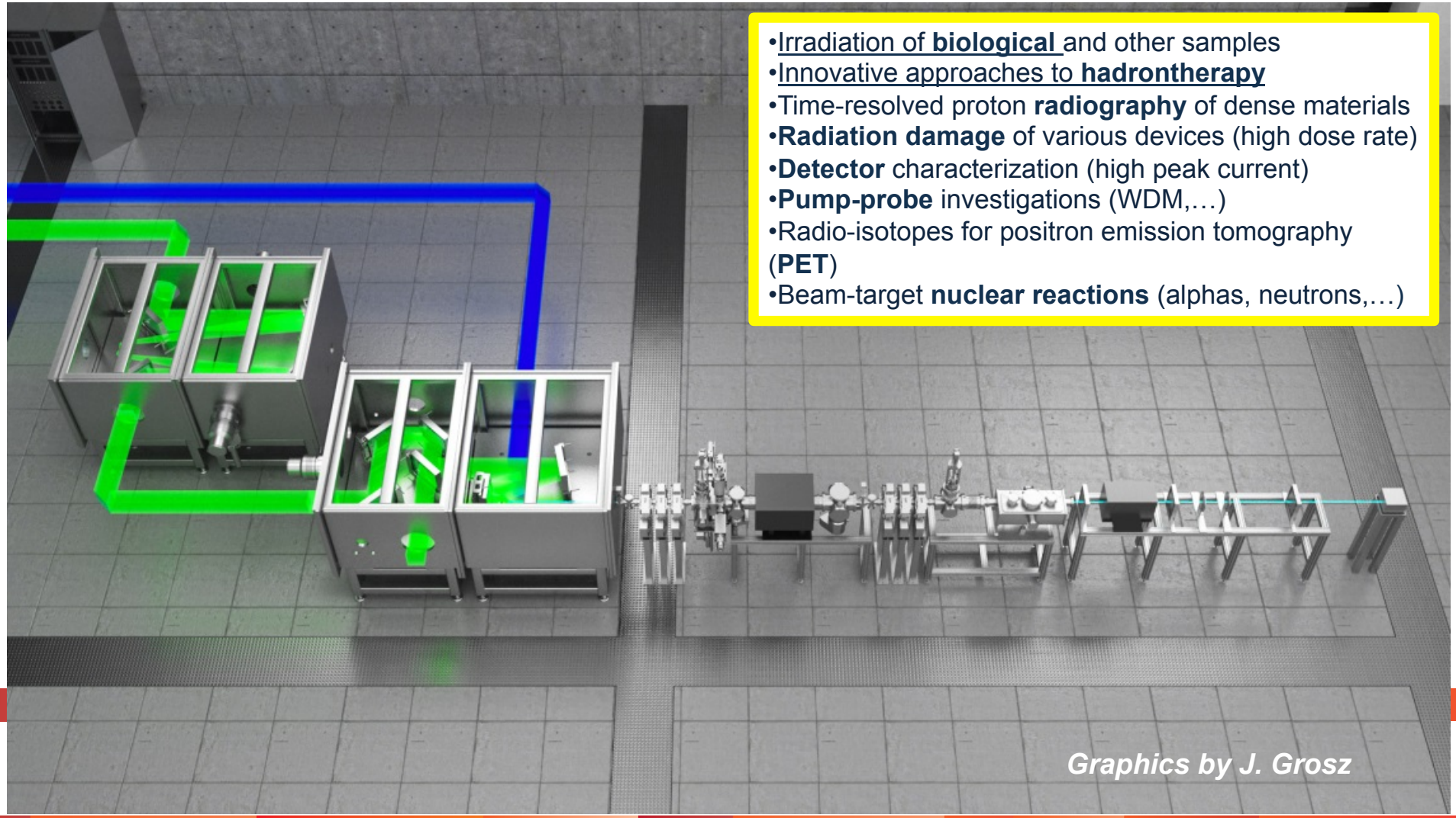
ELI-Beamlines Project
Institute of Physics of the ASCR
Prague, Czech Republic

Workshop on High Energy Density Physics with BELLA-i
Lawrence Berkeley National Laboratory
January 20 – 22, 2016

ELIMAIA: a user beamline

ELI Multidisciplinary Applications of laser-Ion Acceleration

Courtesy of D. Margarone



- Irradiation of **biological** and other samples
- Innovative approaches to **hadrontherapy**
- Time-resolved proton **radiography** of dense materials
- **Radiation damage** of various devices (high dose rate)
- **Detector** characterization (high peak current)
- **Pump-probe** investigations (WDM,…)
- Radio-isotopes for positron emission tomography (**PET**)
- Beam-target **nuclear reactions** (alphas, neutrons,…)

Graphics by J. Grosz

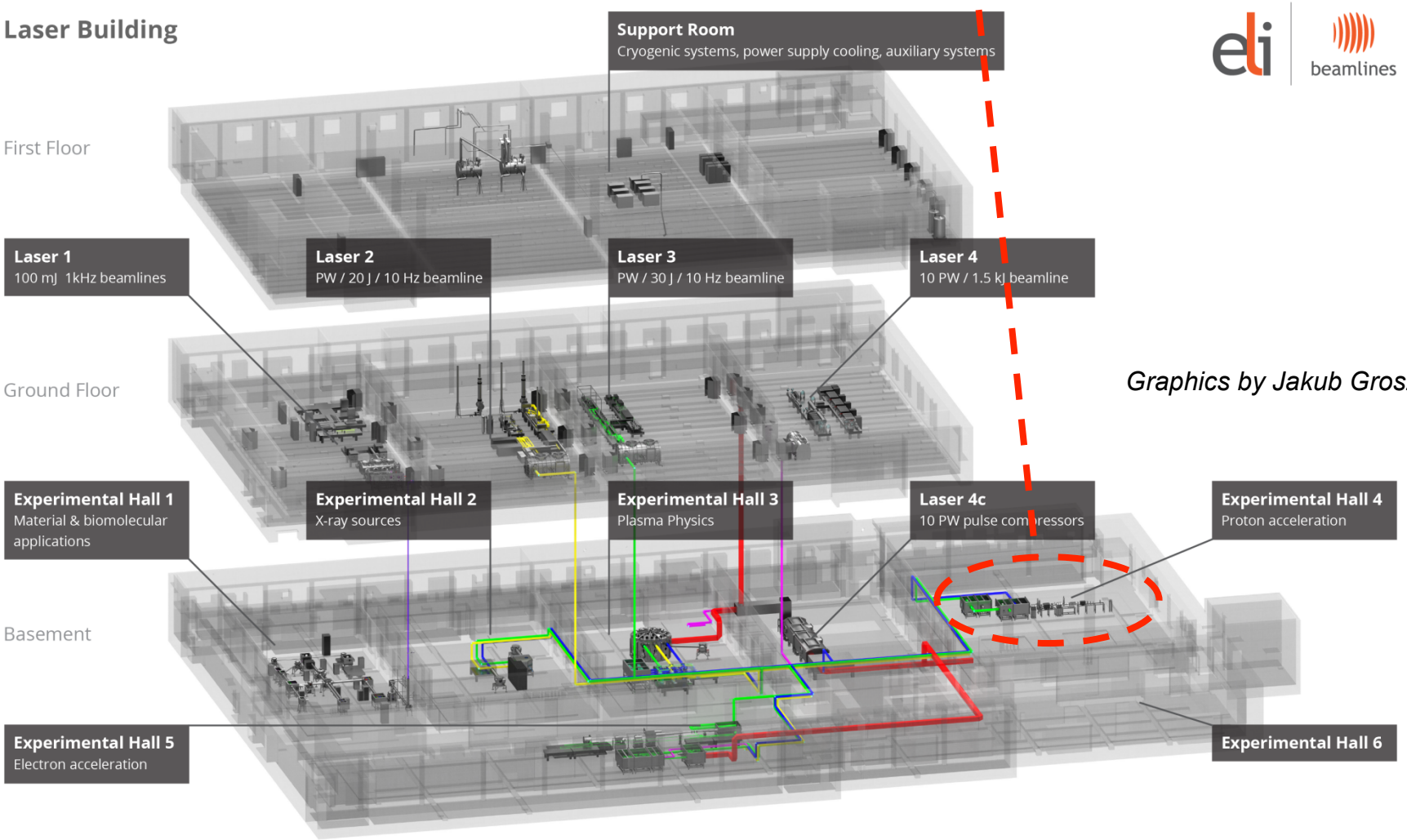
ELIMAIA user requirements

Typical user requirements

- Wide **energy** and **fluence** range
- Small energy spread (**quasi-monoenergetic** beams)
- **Homogeneous** transverse beam distribution
- Shot-to-shot **stability** (energy and fluence)
- Variable beam spot size
- Full beam **control** (fluence and dose) with < 5% error
- Possibility of in-air irradiation (e.g. bio-samples)
- Use of different ion species (H, He, C, …)

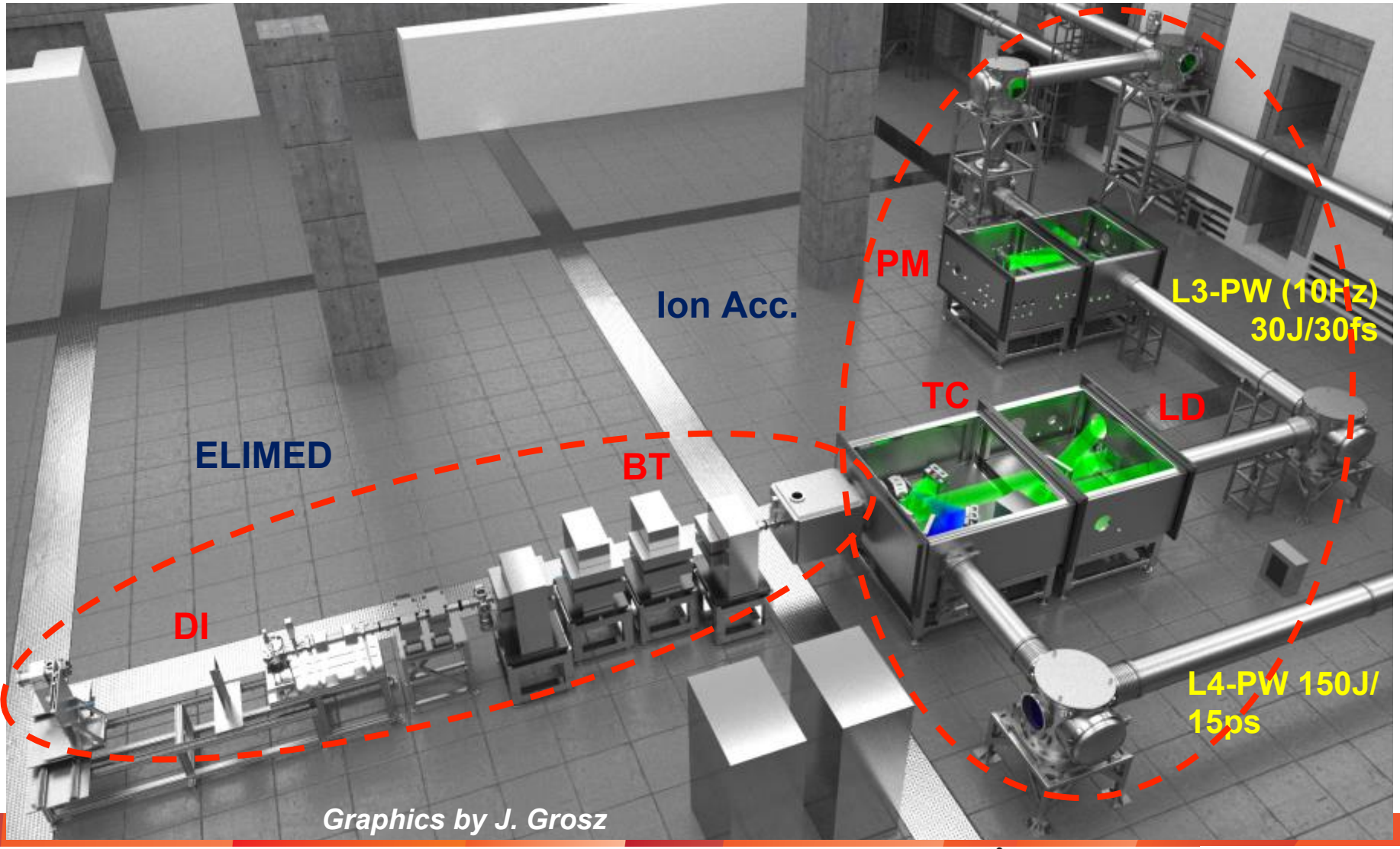
Beam Parameters	Enabling Experiments	Flagship Experiments
Energy range	1-60 MeV/u	1-250 MeV/u
Ion No./laser shot	$>10^9$ (10% BW)	$>10^{10}$ (10% BW)
Bunch duration	0.1-1 ns	0.1-1 ns
Energy spread	±5%	±2.5%
Collimation Degree	±0.5°	± 0.2°
Ion Spot Size	0.1-10 mm	0.1-10 mm
Repetition rate	0.01-10 Hz	0.01-10 Hz

ELIMAIA location



Graphics by Jakub Grosz

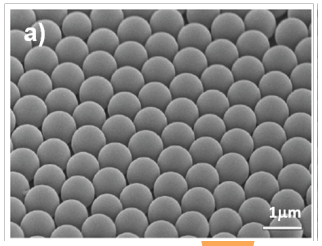
ELIMAIA development



Courtesy of D. Margarone

Ion Acceleration R&D (energy and No.)

PRL 109, 234801 (2012) PHYSICAL REVIEW LETTERS week ending 7 DECEMBER 2012



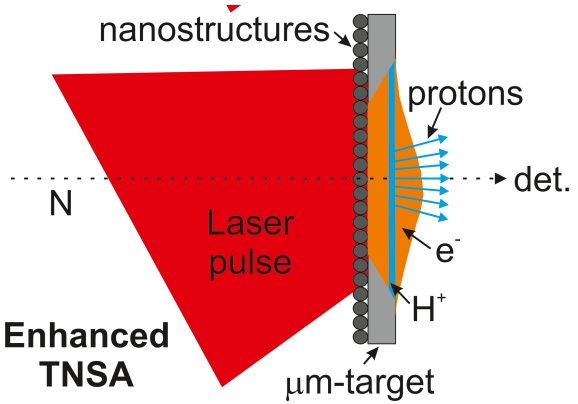
Laser-Driven Proton Acceleration Enhancement by Nanostructured Foils

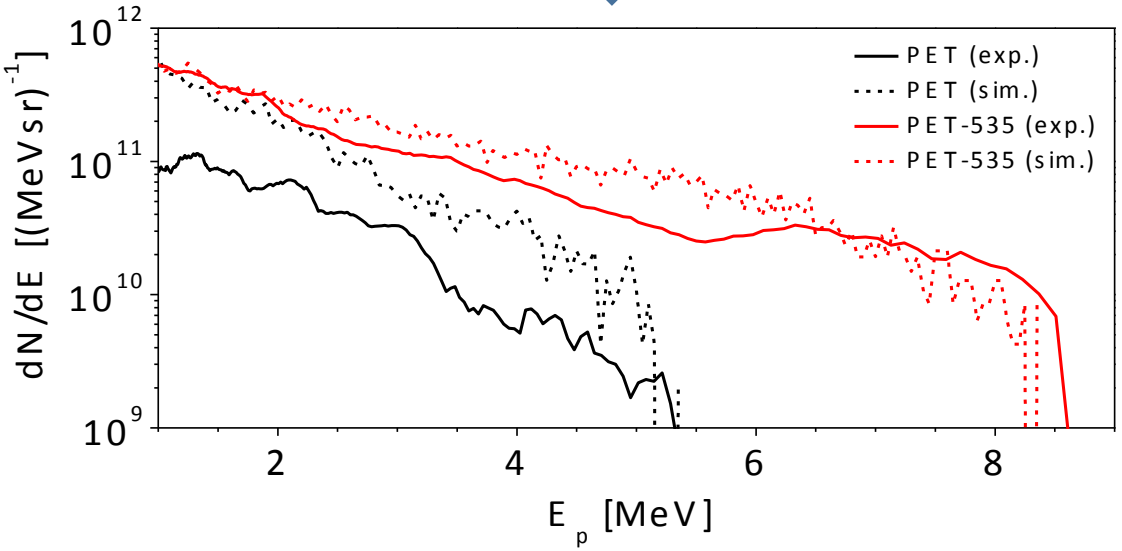
D. Margarone,[1] O. Klimo,[1,2] I. J. Kim,[3] J. Prokůpek,[1,2] J. Limpouch,[1,2] T. M. Jeong,[3] T. Mocek,[1] J. Pšikal,[1,2] H. T. Kim,[3] J. Proška,[2] K. H Nam,[3] L. Štolcová,[1,2] I. W. Choi,[3] S. K. Lee,[3] J. H. Sung,[3] T. J. Yu,[3] and G. Korn[1]

[1]*Institute of Physics of the ASCR, ELI-Beamlines/HiLASE project, Na Slovance 2, 18221 Prague, Czech Republic*
[2]*Czech Technical University in Prague, FNSPE, Brehova 7, 115 19 Prague, Czech Republic*
[3]*Advanced Photonics Research Institute, GIST, 1 Oryong-dong, Buk-gu, Gwangju 500-712, Republic of Korea*
(Received 3 June 2012; published 3 December 2012)

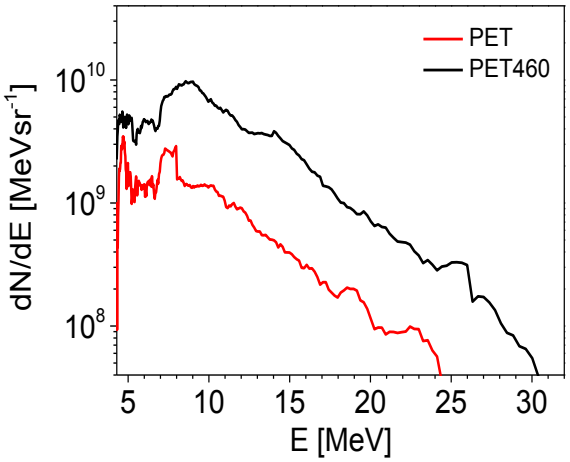
Stealth target for ion acceleration!

- Max. proton energy increment: **62%**
- Conversion efficiency increment: **570%**





Ion Acceleration R&D (beam quality)

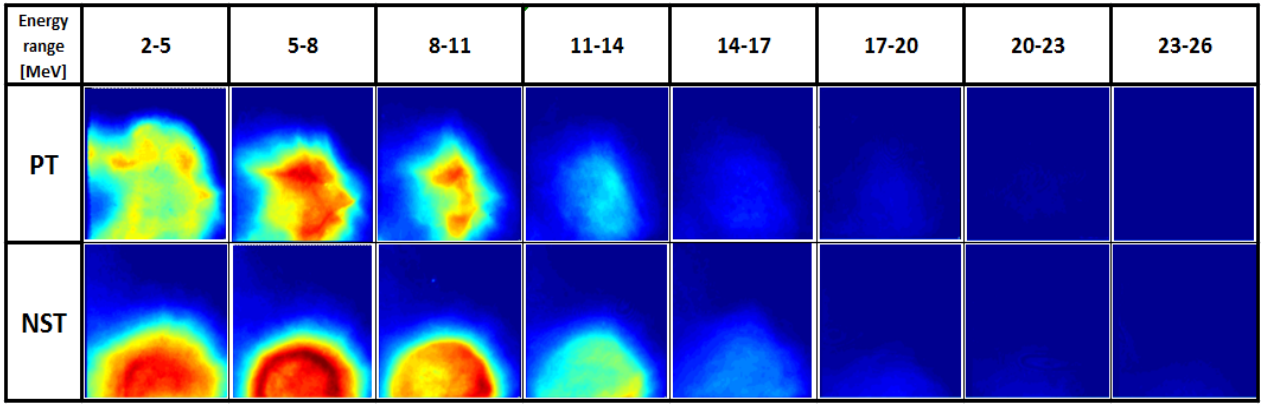


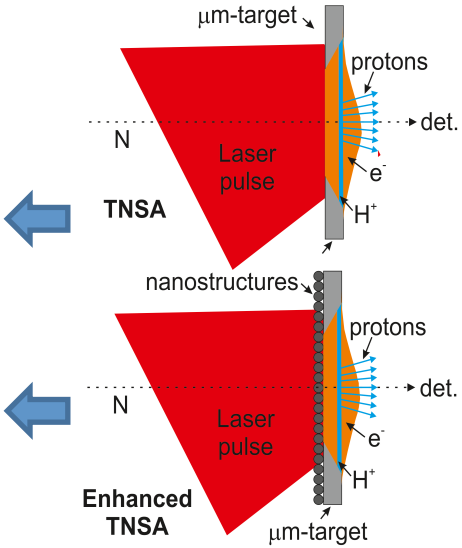
PHYSICAL REVIEW SPECIAL TOPICS—ACCELERATORS AND BEAMS **18,** 071304 (2015)

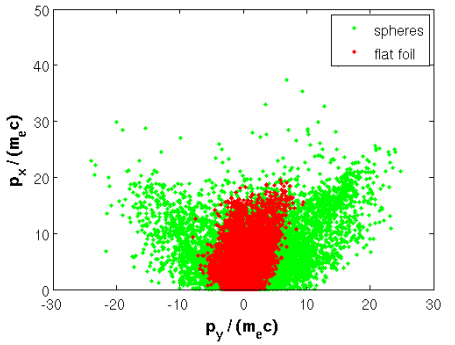
Laser-driven high-energy proton beam with homogeneous spatial profile from a nanosphere target

D. Margarone,[1] I. J. Kim,[2,3] J. Psikal,[1,4] J. Kaufman,[1,4] T. Mocek,[5] I. W. Choi,[2,3] L. Stolcova,[1,4] J. Proska,[4] A. Choukourov,[1,6] I. Melnichuk,[6] O. Klimo,[1,4] J. Limpouch,[1,4] J. H. Sung,[2,3] S. K. Lee,[2,3] G. Korn,[1] and T. M. Jeong[2,3,*]

Exp at APRI-GIST: Scaling laws and improvement of proton beam **spatial profile!**







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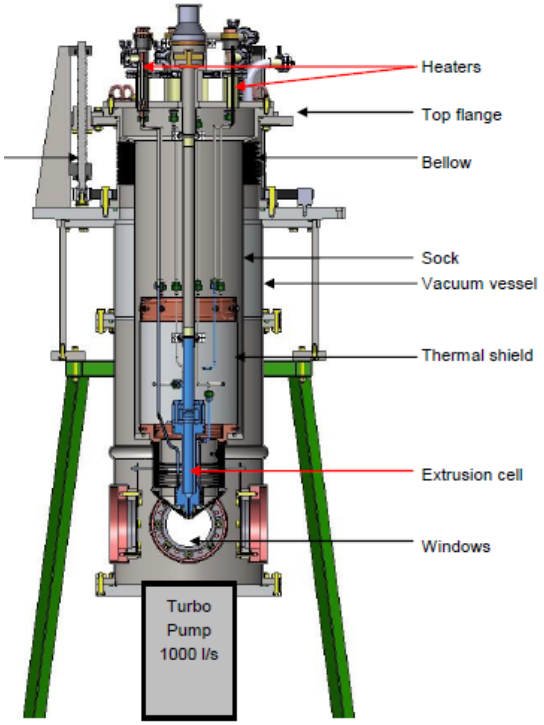
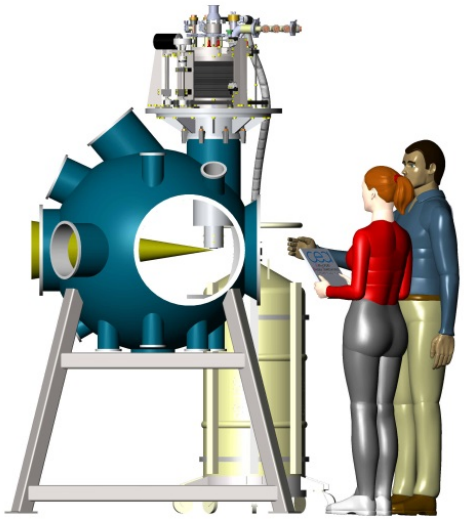
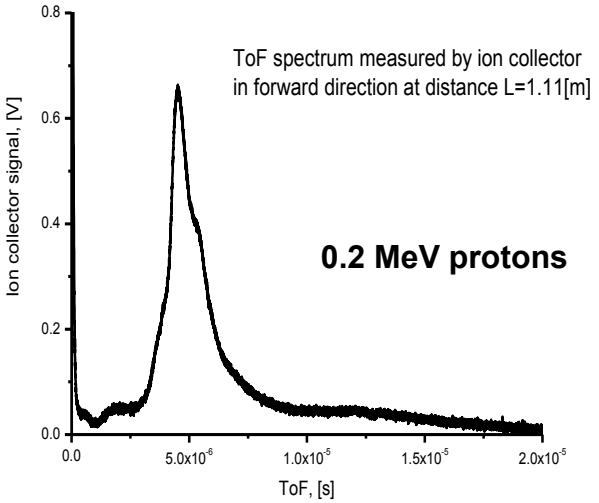
High rep. Rate cryo-target @ ELI-BL





- Target parameters: H_2 62 μm thick, 1 mm wide
- Laser parameters: **109 J**, 300ps, 6 mm from nozzle



Solid H test-1 @ CEA –Grenoble
(J.P. Perin et al., SPIE 2015, Prague)

Solid H test-2 @ CEA –Grenoble
(J.P. Perin, D. Chatain,, A. Velyhan, D. Margarone, July 2015)

Exp. @ PALS
(A. Velyhan, D. Margarone, J. Dostal, J. Ullschmied. D. Chatain et al.)
August & December 2015

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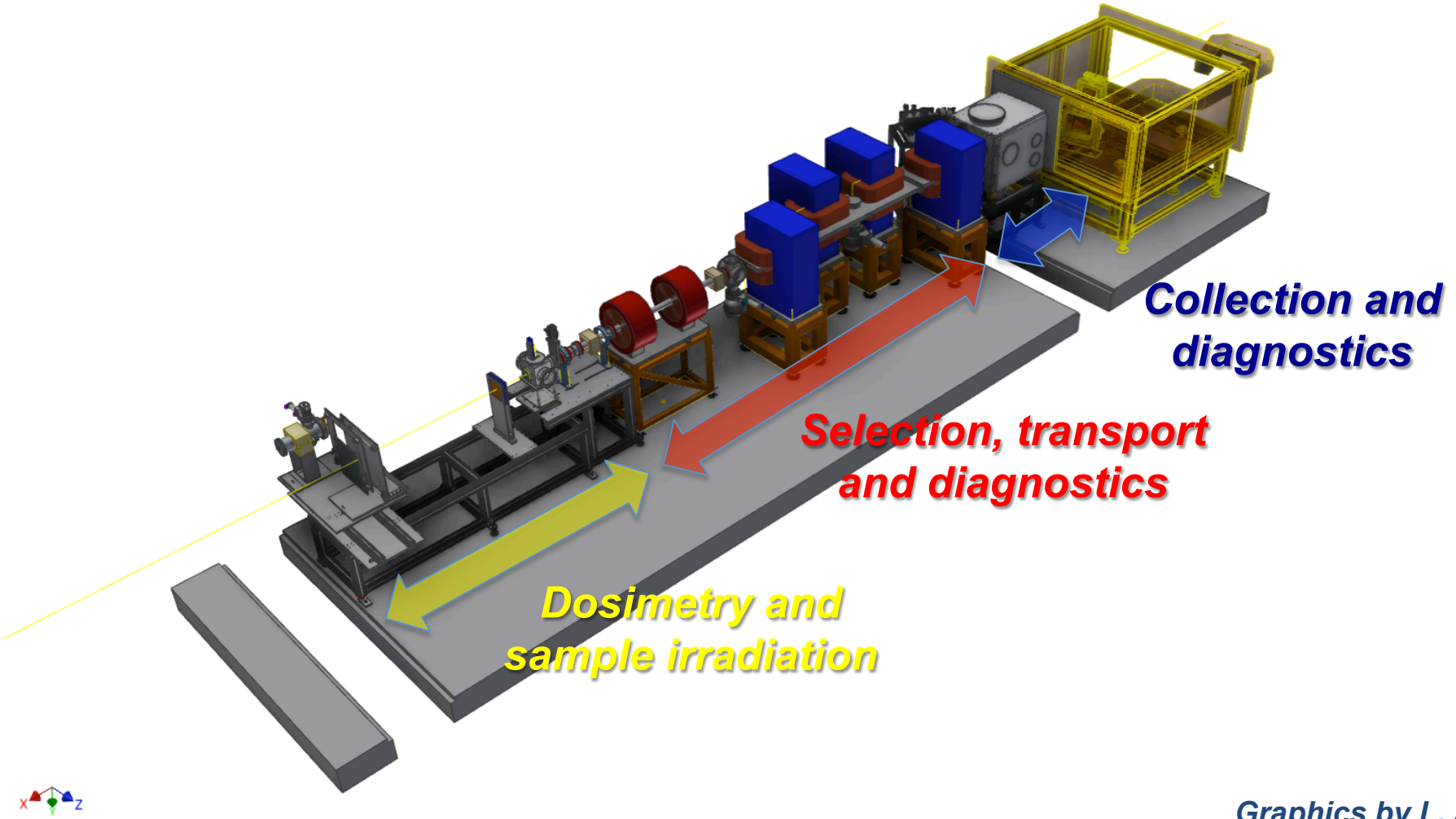
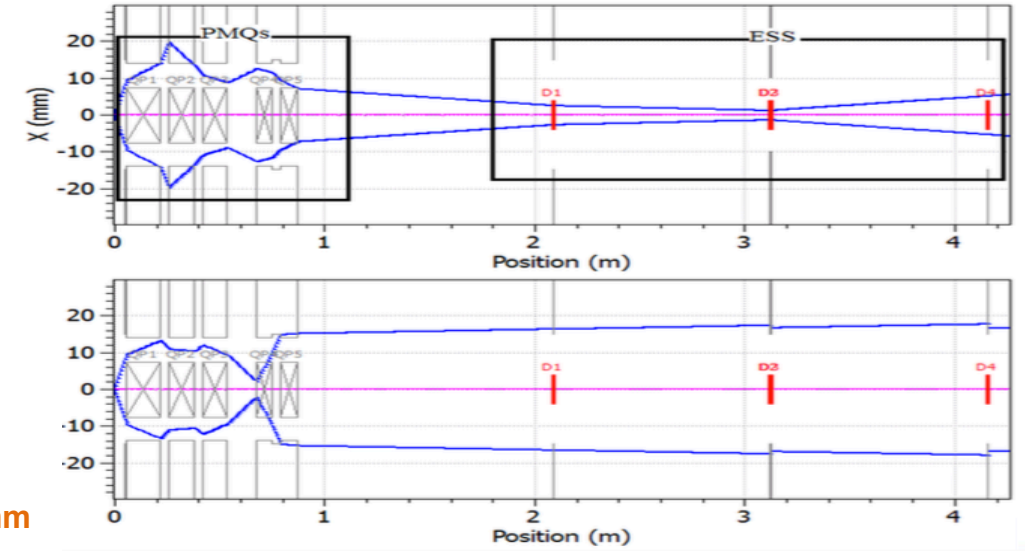
ELIMED beam line layout

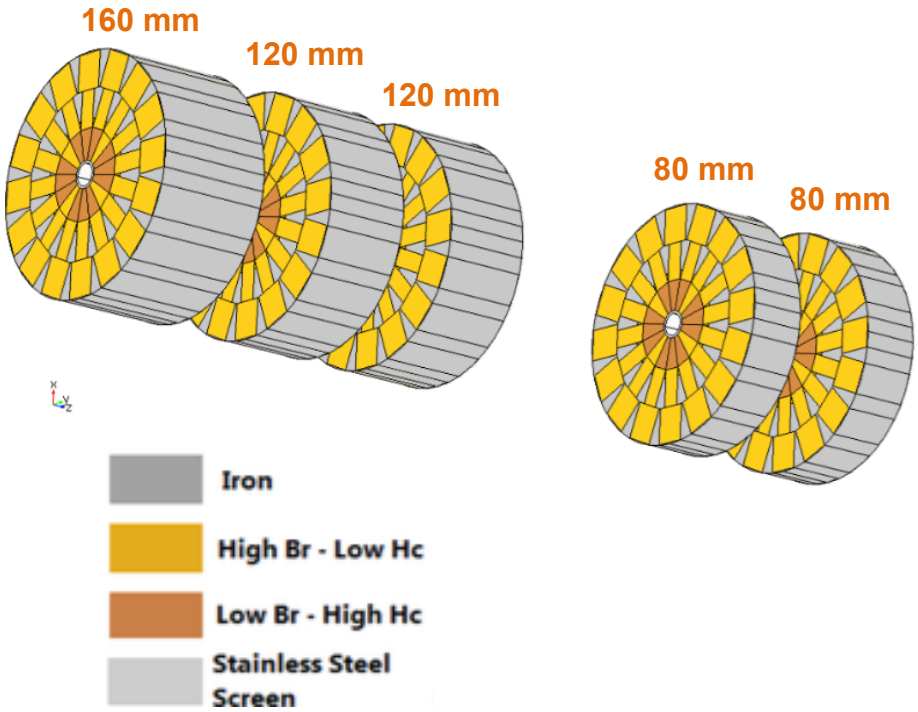


Graphics by L. Allegra

ELIMED collection system: Permanent Magnet Quadrupoles

Linearized chicane to define the PMQs set up according to the matching conditions:
1) Waist close to the slit on the radial direction
2) Parallel beam on the transverse plane





5 PMQs Hybrid multi-array

- Inner Halbach trapezoidal sectors
- Two external rectangular hybrid arrays
- Outer diameter: 325 mm
- 36 mm magnetic bore

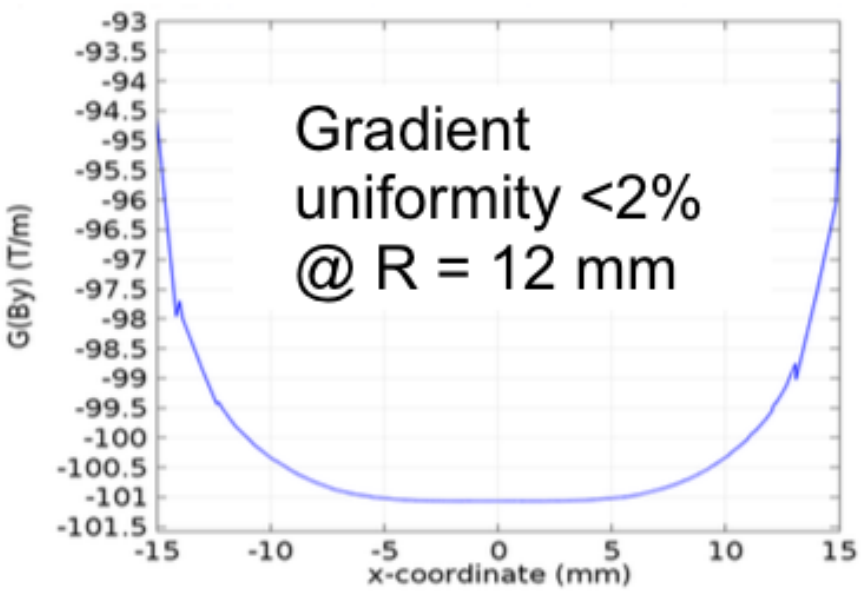
(3 mm shield + 30 mm net bore)

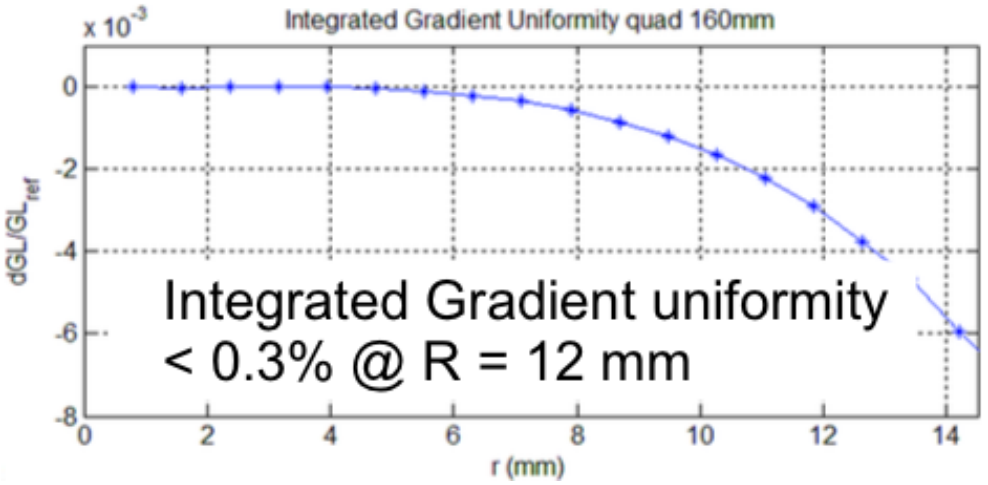
Courtesy of F. Schillaci

Collection system: Permanent Magnet Quadrupoles

Magnetic field features:

- 3 main magnetization directions
- Gradients: ≈ 100 T/m
- Gradient uniformity: < 2% @ R = 12 mm (80% bore)
- Integrated gradient uniformity < 0.3% @ R = 12 mm (80% bore)

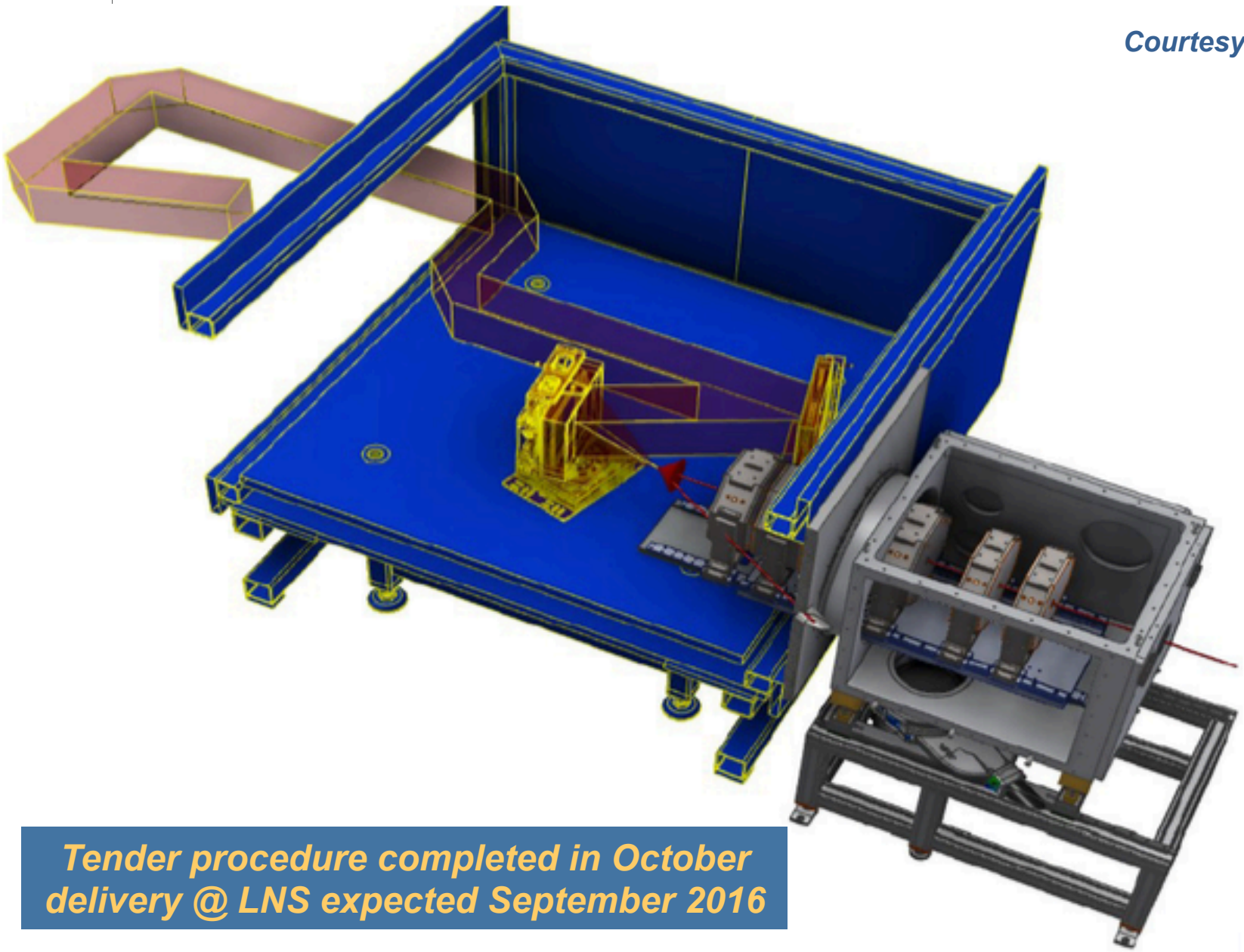




Courtesy of F. Schillaci

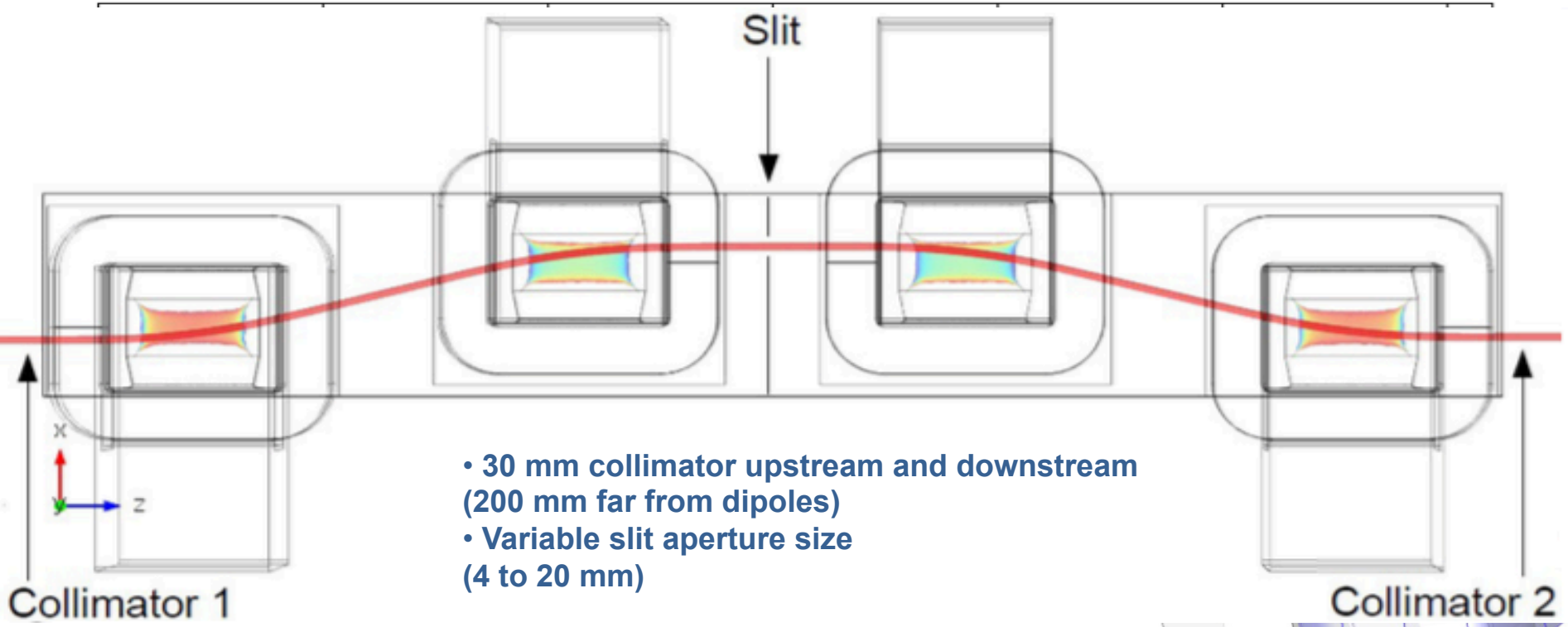
PMQs and Mechanics

Courtesy of L. Allegra



Tender procedure completed in October delivery @ LNS expected September 2016

ELIMED selection system: energy selector



- 30 mm collimator upstream and downstream (200 mm far from dipoles)
- Variable slit aperture size (4 to 20 mm)

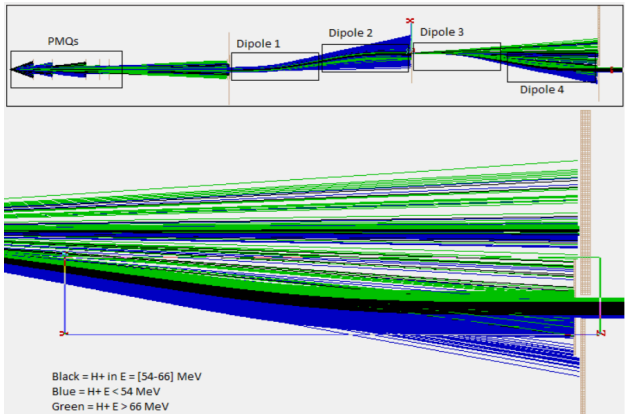
n° of Dipoles	B field	Geometric length	Effective length	Gap
4	0,085 – 1,2 T	400 mm	450 mm	59 mm
Good Field region (GFR)	**Field uniformity**	**Curvature radius**	**Bending angle**	**Drift between dipoles**
100 mm	< 0,5 %	2,5293 m	10,10° (176,3 mrad)	500 mm

Courtesy of F. Schillaci

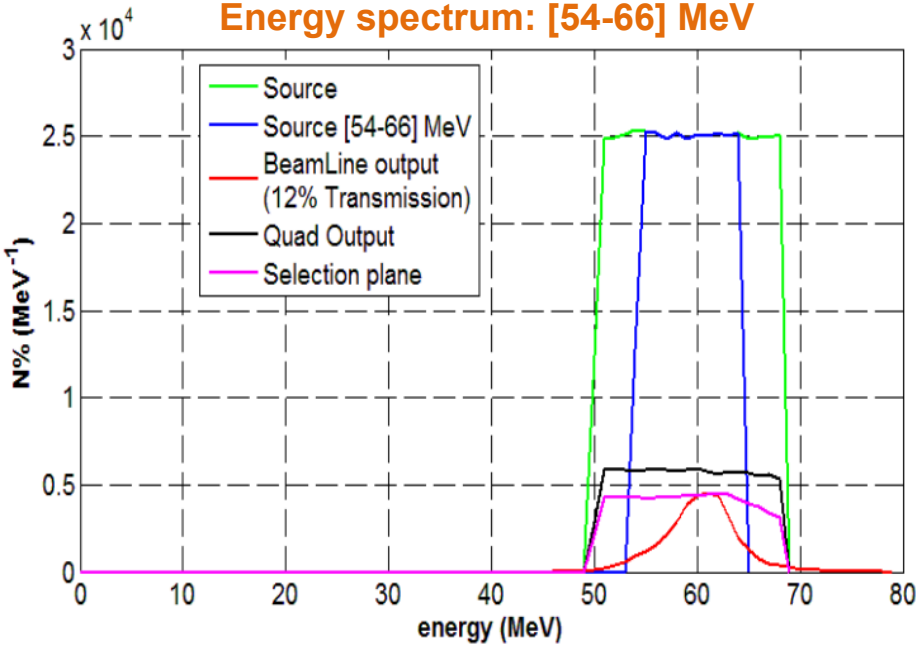
ELIMED beam transport

PIC simulation for ELIMAIA source: TNSA-like proton beam

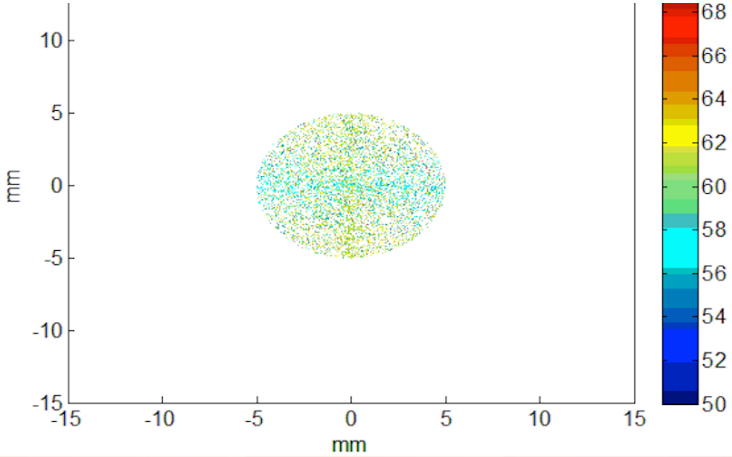
- Exponential energy distribution
- Cut-off: 105 MeV
- Beam spot size: 40μm diameter
- Angular divergence at 60 MeV: 5° FWHM



Energy spectrum: [54-66] MeV



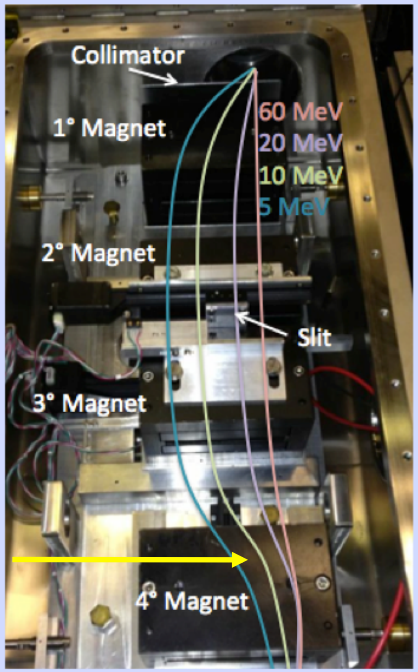
Angular divergence < 6mrad
Transmission efficiency: 12%



Courtesy of F. Schillaci

ELIMED R&D: beam transport and selection prototypes

ESS test experiment @ TARANIS (Queen's University of Belfast)

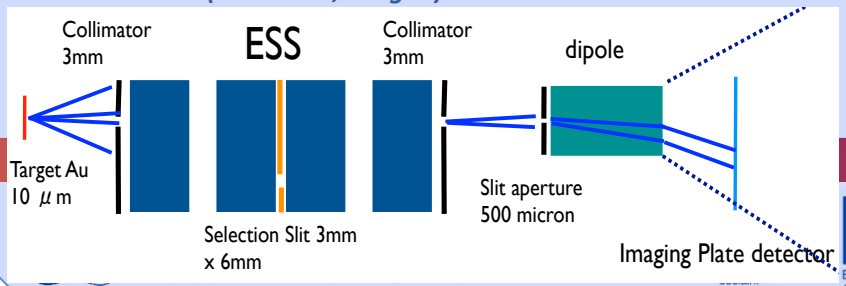


INPUT BEAM
Ep: 1-10 MeV (ΔE/E=100%)

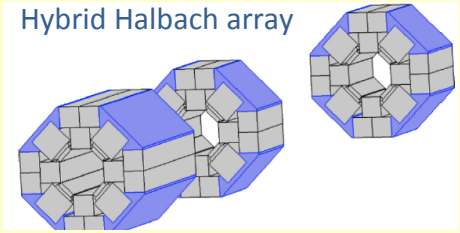
SELECTED BEAM
Ep : 4.5 ± 0.3 MeV
(ΔE/E = 13%)

Ep : 7.4 ± 0.6 MeV
(ΔE/E = 16%)

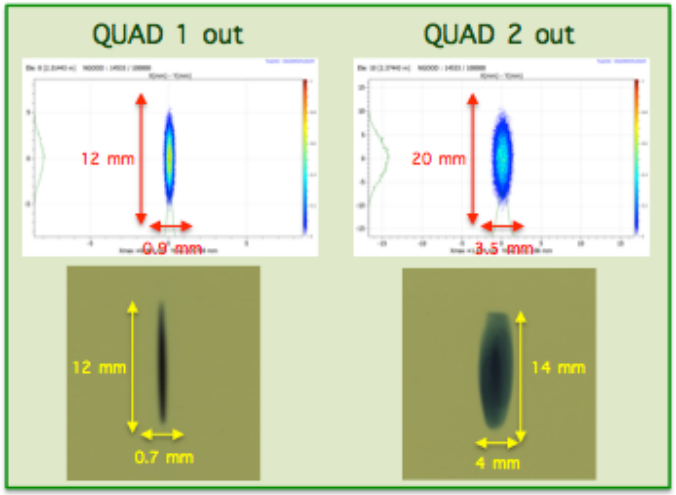
V. Scuderi et al. (SPIE 2015, Prague)



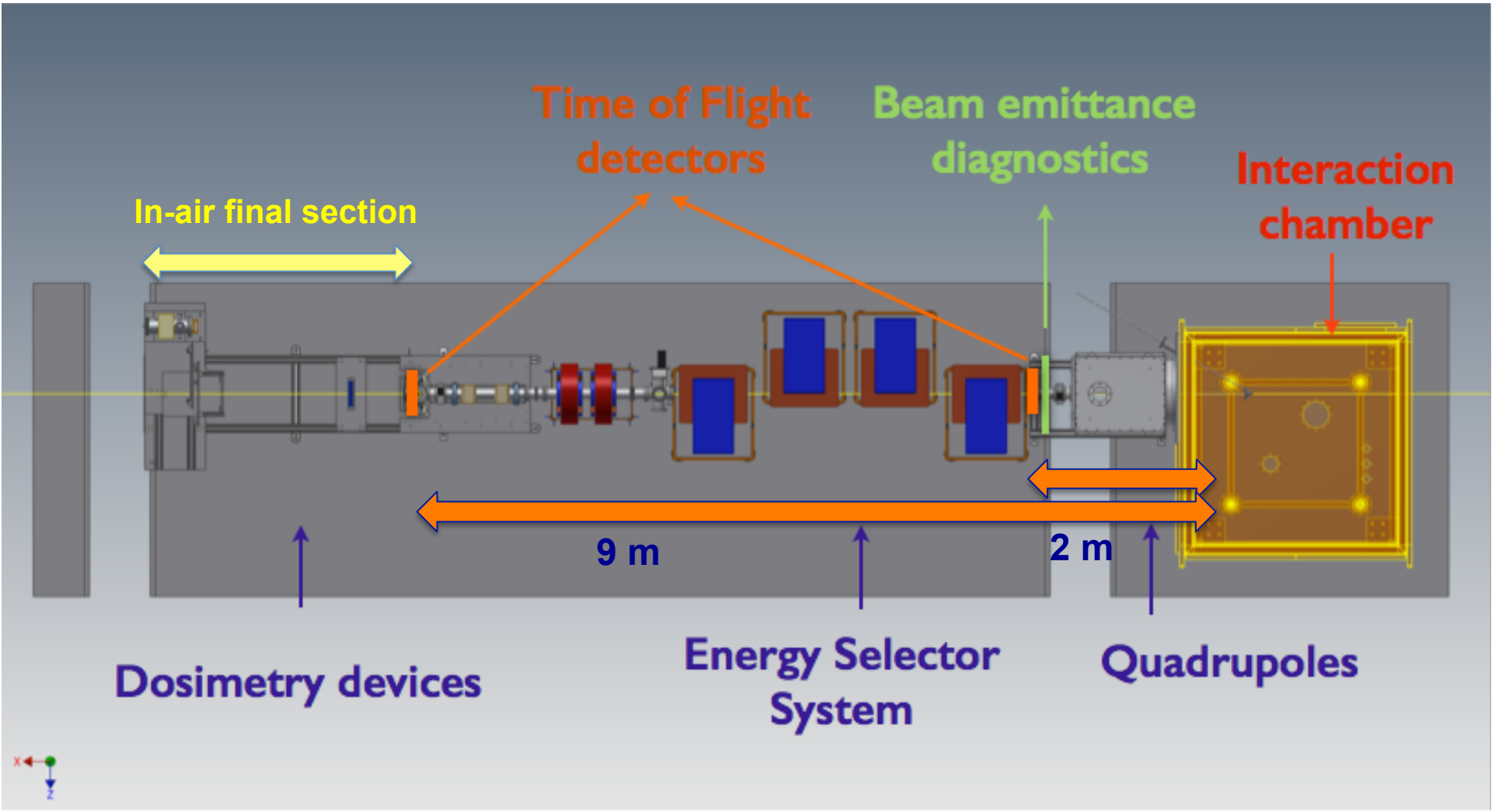
Permanent Magnet Quadrupoles (PMQs) prototype characterization at LNS-INFN



4 MQs
Net bore 20 mm
Lengths: 2x80mm; 2x40mm
Gradients: 103 T/m; 100 T/m

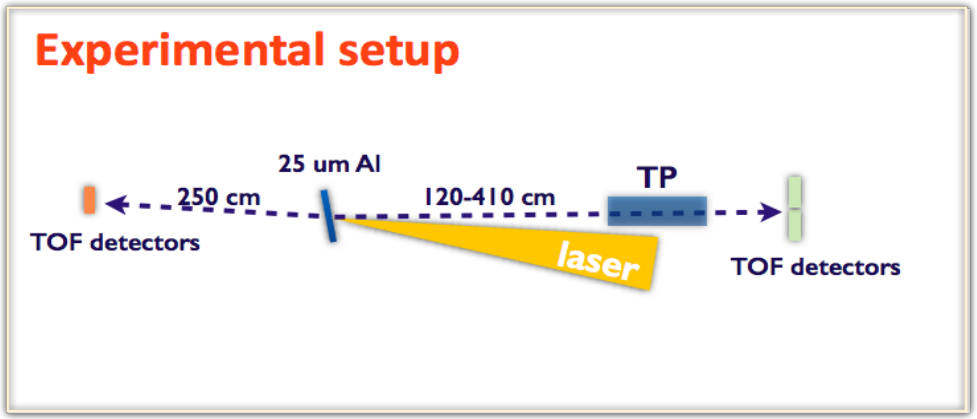


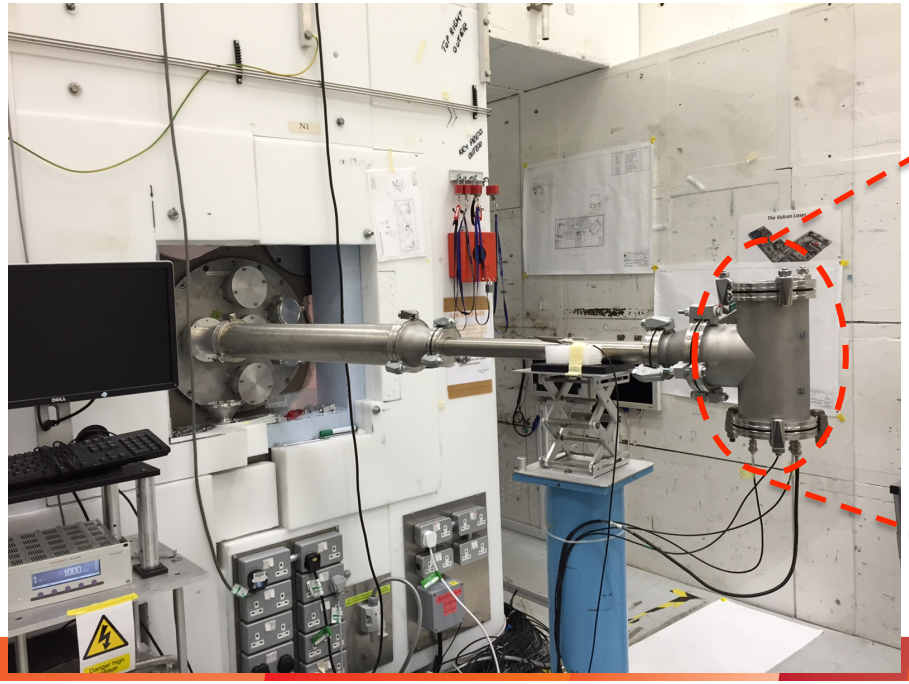
Diagnostics for the ELIMED beam-line

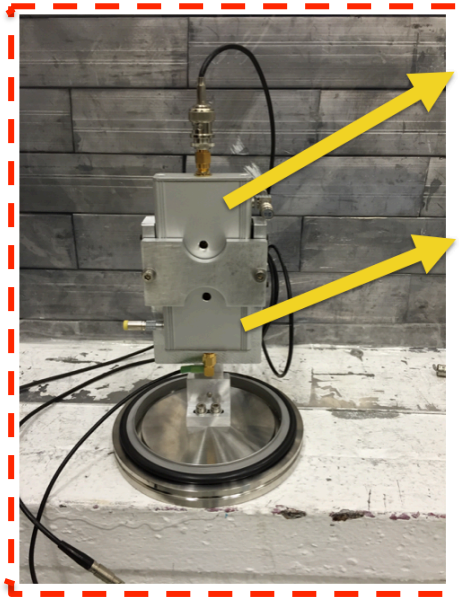


ELIMED TOF diagnostics test with the VULCAN PW laser @ RAL (UK)

VULCAN Laser parameters
Power: 1 PW
Intensity: 10^{21} W/cm^2
Energy: 650 J
Time pulse: 500 fs
Target: 25 um Al

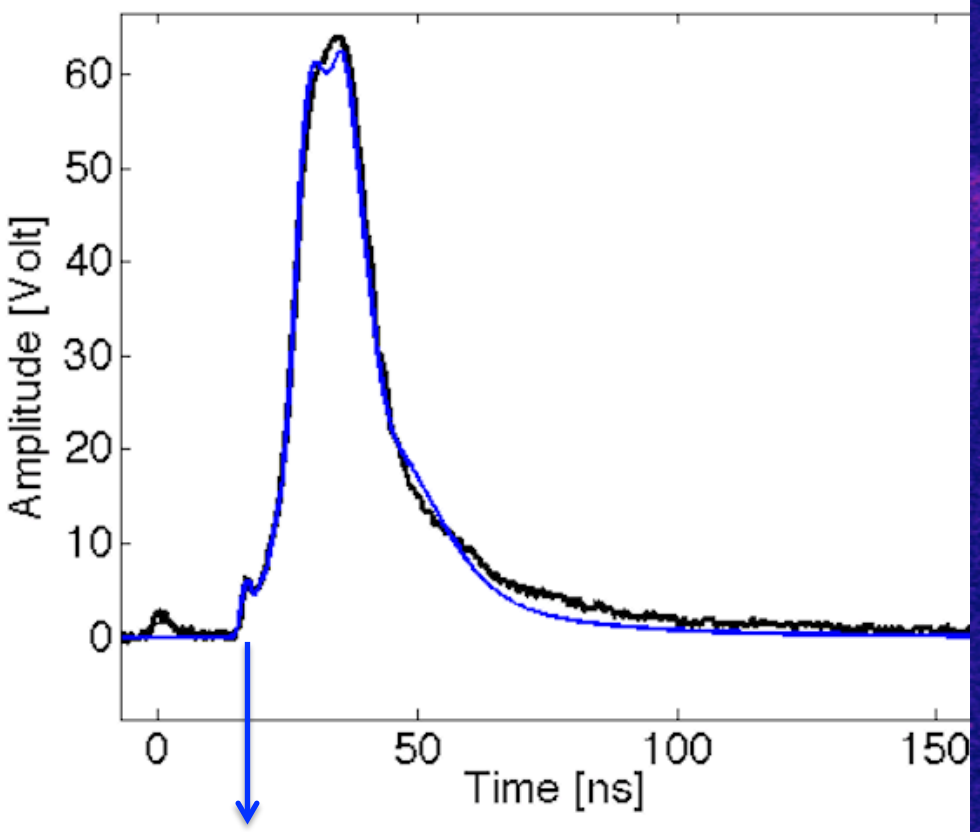






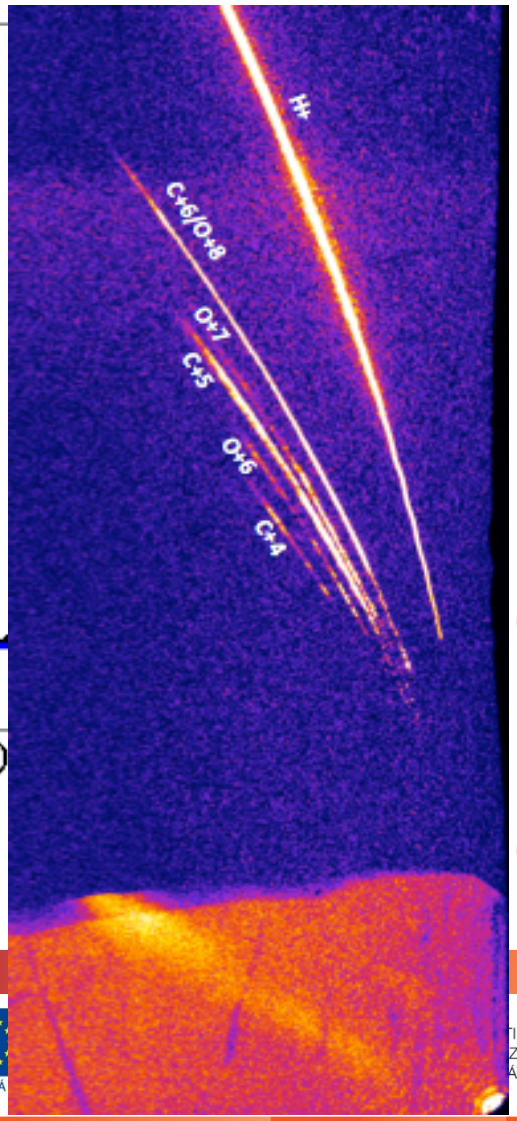
TOF measurements with the VULCAN PW laser @ RAL (UK)

pCVD @ 122 cm in *backward* direction
50 μm Kapton filter



Proton cut-off @ 28 MeV
Time resolution ~ ns
Energy resolution < 10%

TP spectrum @ 122 cm in *backward* direction



TP parameter:
B= 1 T
B length = 5 cm
E= 19kV/cm
Electrode length= 15 cm
Pinhole= 200 um
Target-Pinhole = 125 cm
B-IP = 27 cm

Max ^{12}C energy ≈ 80 MeV
(ToF@122 cm=34 ns)

Max ^{16}O energy ≈ 105 MeV
(ToF@122 cm=34 ns)

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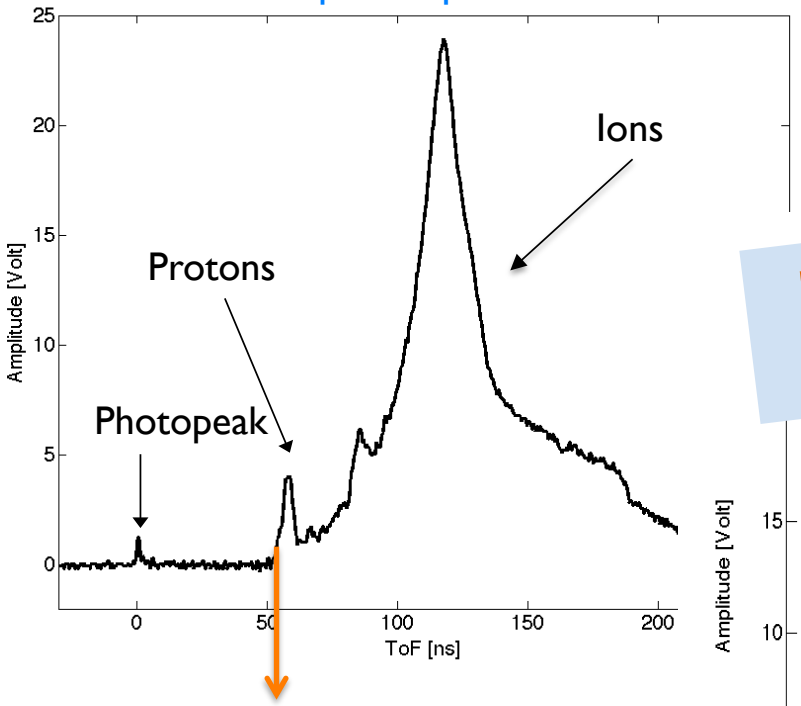
TOF measurements with the VULCAN PW laser @ RAL (UK)

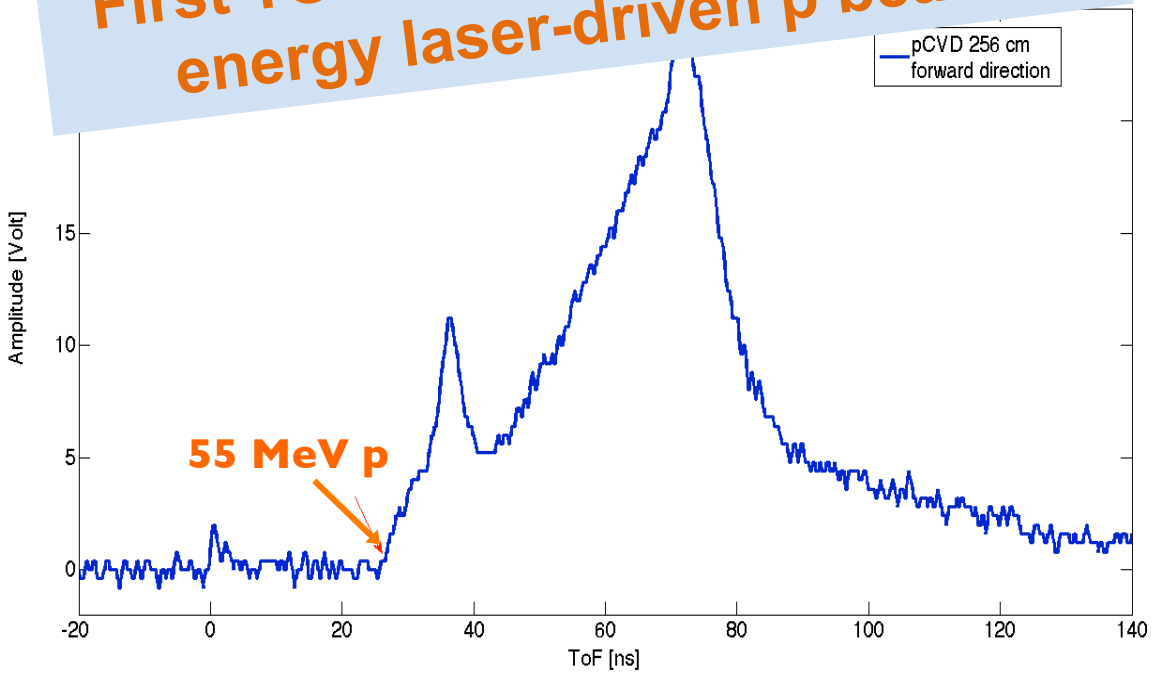
pCVD @ 410 cm in *backward* direction
50 μm Kapton filter



Proton cut-off @ 30 MeV
Time resolution ~ ns
Energy resolution <10%

pCVD @ 256 cm in *forward* direction
50 μm Al filter

First TOF measurements of high energy laser-driven p beam



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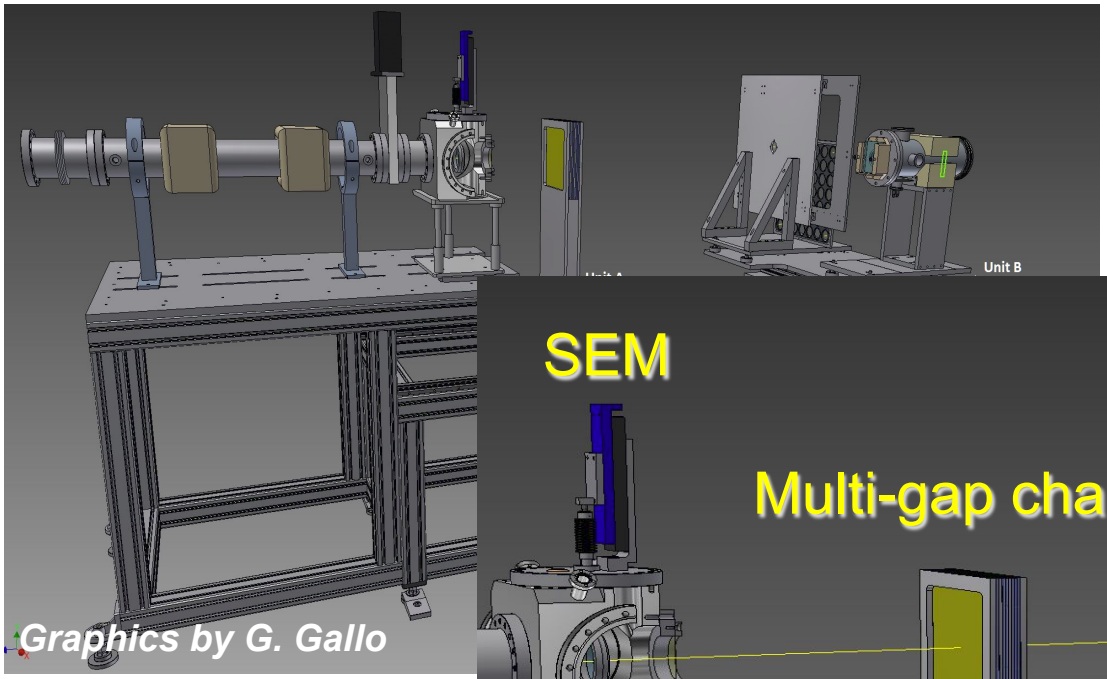
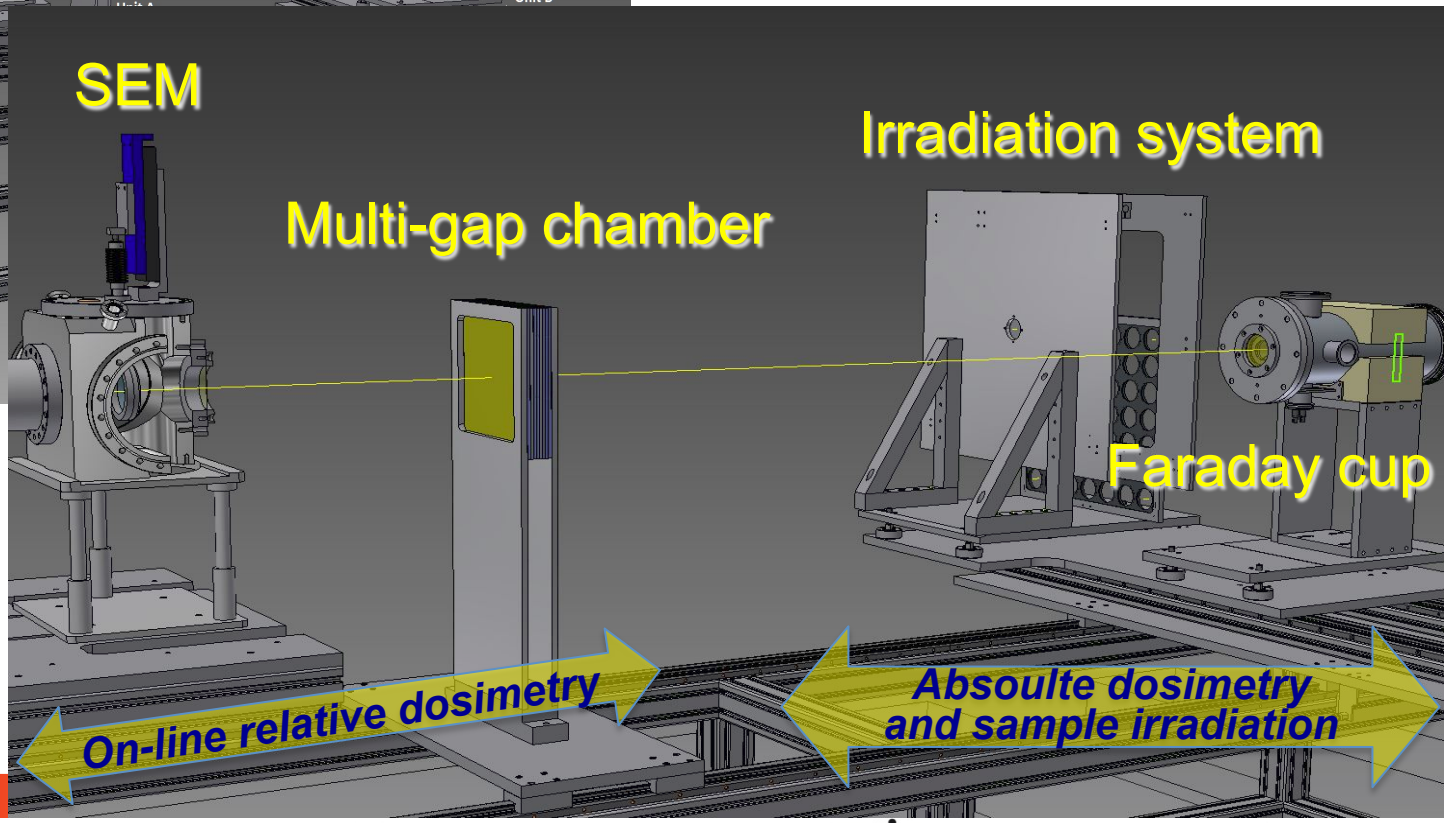
ELIMED R&D (dosimetry)





Passive detectors:

- ***RCF***
- ***CR39***

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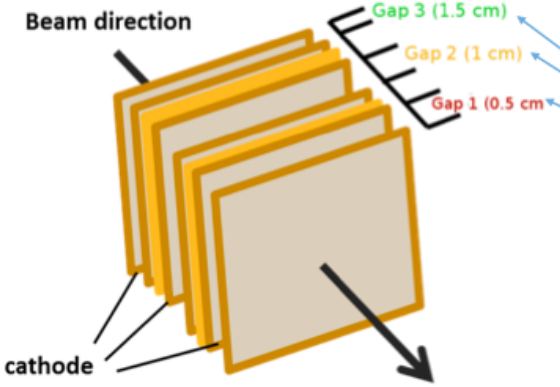
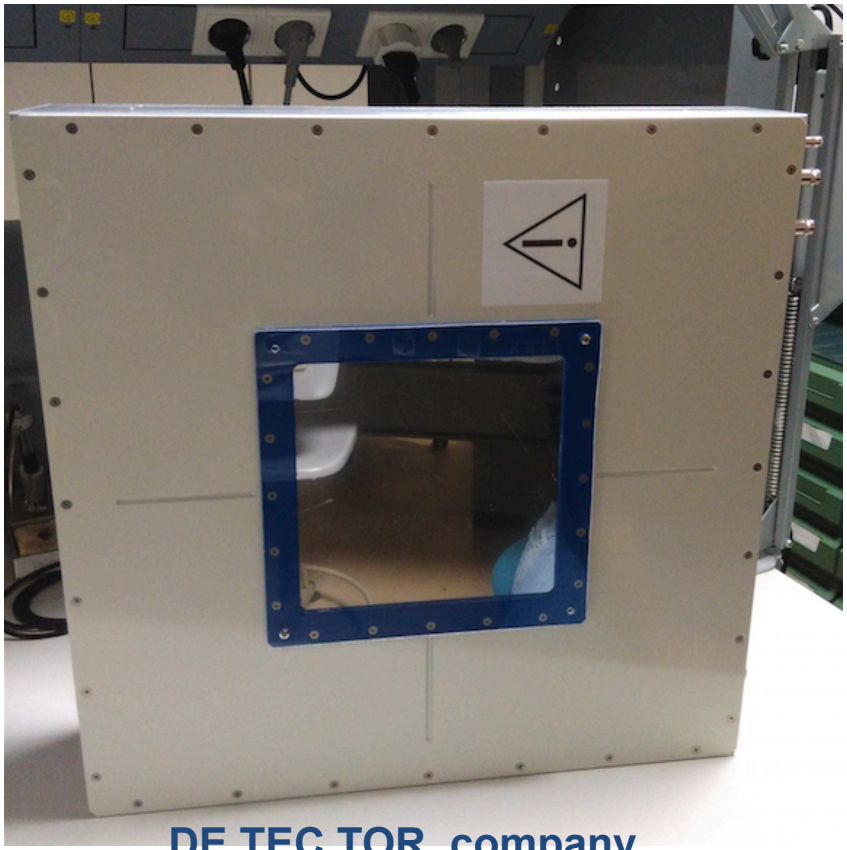
Multi-gap chamber prototype



Material	Thickness (mm)	
Mylar	12,00 E-3	Cathode
Aluminum		
Nitrogen/Air	Gap	Frame
Aluminum	17,00 E-3	Anode
Kapton	25,00 E-3	

Collaboration with Turin INFN section

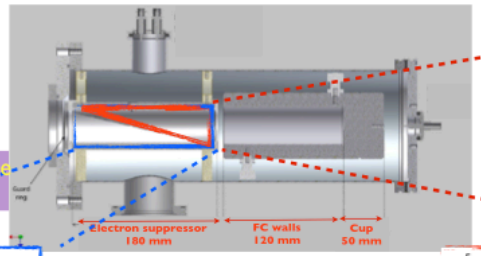


DE.TEC.TOR. company

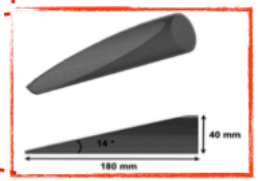
Thanks to the the different gaps we can correct for the charge recombination effects at very high beam intensity

Preliminary tested at LNS CATANA proton therapy facility

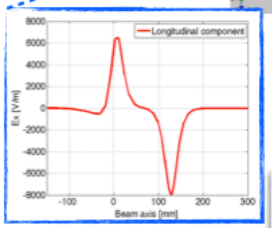
Faraday cup: absolute dose measurement



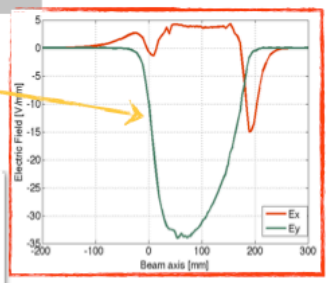
Special beveled electrode

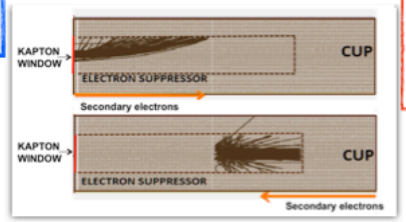


Electric field along the beam axis

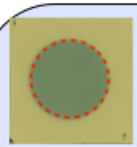


High transverse electric field component

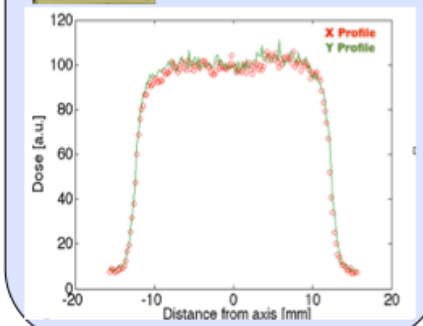


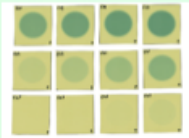


$$D_w = \frac{1}{A} \cdot \frac{\int (S(E))_w N(E) dE}{\int N(E) dE} \cdot \frac{Q}{e} \cdot 1.602 \cdot 10^{-10} \quad (Gy)$$

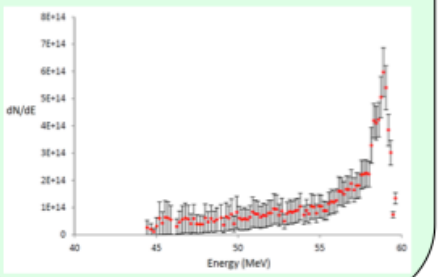


Single RCF for effective area measurements

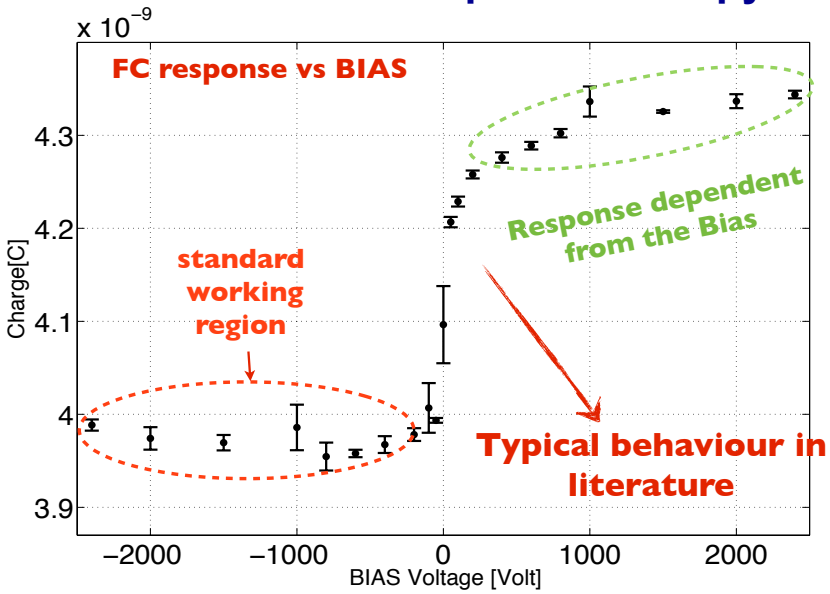




RCF stack for energy spectrum measurements



Tested at LNS CATANA proton therapy facility



XY scintillating fiber plane and scintillator stack prototypes development in progress

Absolute charge and charge collection efficiency measurements with TANDEM beams performed last December

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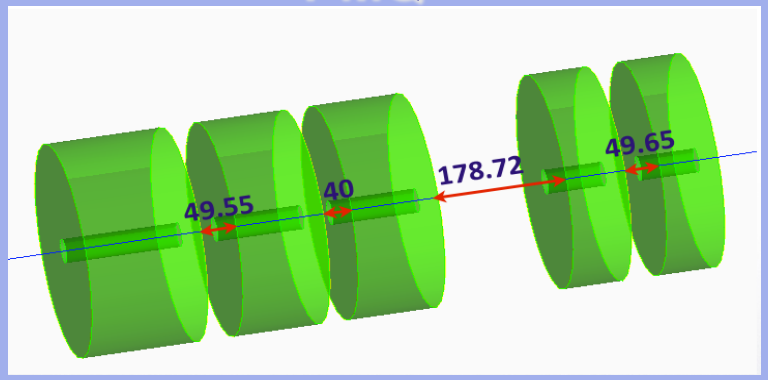
ELIMED Geant4 simulation

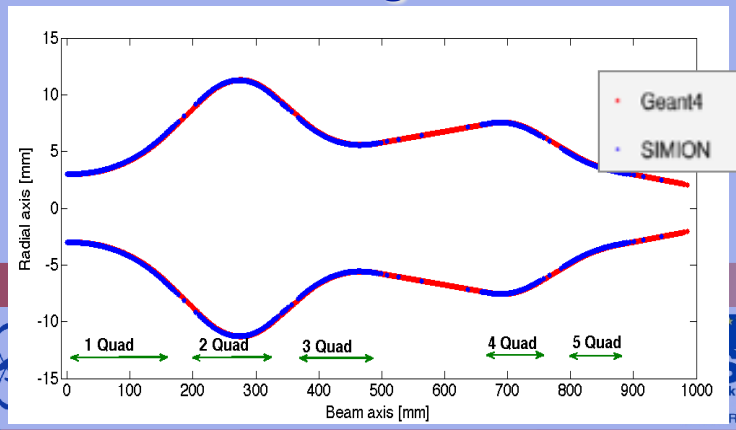
Main requirements of the application

- Accurately simulate the **particle source** using PIC
- Implement **magnetic** and **electric fields** described by maps
- Provide a **graphical user interface** to easily modify geometry
- Provide tools to easily retrieve **output** information on specific ***virtual*** **planes**
  - **Energy** spectrum, **emittance**, **fluence**, **dose**
  - The secondary radiation produced along the beam line

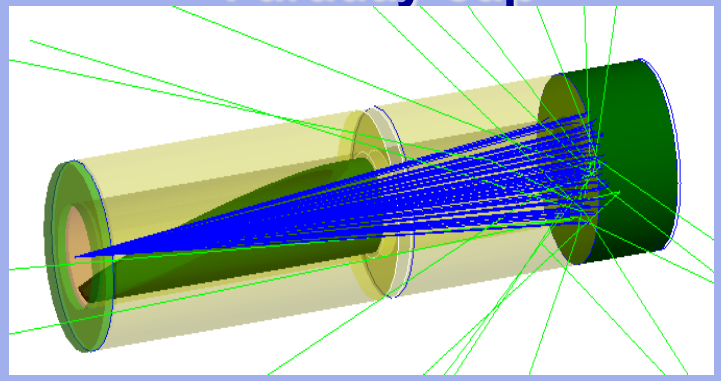
PMQ



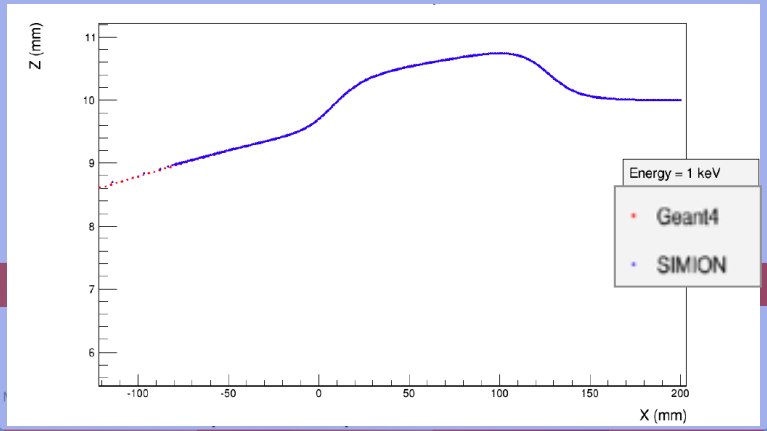
*Tracks in **magnetic fields***



Faraday cup



*Tracks in **electric fields***



Summary

- ✓ Feasibility study and design of the main BTL elements completed, tender procedures launched
- ✓ TOF diagnostics realized and tested with a PW laser
- ✓ Dosimetric system design completed, prototypes tested with conventional proton beams
- ✓ MC tool for the BTL simulation developed and tested

Collaboration

INFN:

Attili Andrea , Calabretta Luciano, Candiano Giacomo, Cirrone Pablo, Cuttone Giacomo, Giordanengo Simona, Giove Dario, Larosa Giuseppina, Leanza Renata, Manna Rosanna, Marchese Valentina, Marchetto Flavio, Milluzzo Giuliana, Pandola Luciano, Petringa Giada, Pipek Jan, Romano Francesco, Sacchi Roberto, Schillaci Francesco

ELI-Beamlines:

Georg Korn, Daniele Margarone, Andrey Velyhan, Lorenzo Giuffrida, Scuderi Valentina, Jan Kaufman, Filip Grepl

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esf evropský sociální fond v ČR
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INFN and ELI-Beamlines announce the

III ELIMED Workshop

will be held at INFN-LNS Catania
September 7- 9, 2016

Thank you for your attention

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