eli beamlines

ELIMED: a future Hadrontherapy concept based on the laser-driven beams

Valentina Scuderi

on behalf of the ELIMED Collaboration

esf evropský sociální fond v ČR | EVROPSKÁ UNIE | MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY | OP Vzdělávání pro konkurenceschopnost | Fyzikální ústav Akademie věd ČR, v. v. i.

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The ELIMED project @ ELI-Beamlines

ELIMED

ELI-Beamlines MEDical and multidisciplinary applications

Realization of a multidisciplinary irradiating facility with laser-generated ion beams:

- **Irradiation of biological and other samples**
- **Radiation damage on different components**
- **Demonstration of new irradiation modalities for radiotherapy**
- **Detectors characterization**
- **Pump probe investigations**

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What users generally require:

- Wide energy and fluence range
- Homogeneous lateral beam distribution
- Stability in terms of energy and fluence distributions
- Variable beam spot size (from 2 mm up to 40 mm)
- Beam control (diagnostic and dosimetry) with < 5% errors
- Possibility of in-air irradiation
- Different ion species

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ELIMED phase 1

- Investigating the possibility to use the laser-driven ion beams generated at ELIMED for **Hadrontherapy** application:

⇒ **a good candidate for a demonstration-case**

- **A medical application is the most demanding in terms of beam characteristics and performances because:**

  - It requires the best effort in the development of the beam delivering system;
  - It requires the best effort in the development of the diagnostic tools of this non-conventional beams;
  - Efficient beam transport, absolute and relative dosimetry and radiobiology are challenges in this context;

Hadrontherapy, a potential user case

...and a possible future for laser-driven based hadrontherapy facilities ?

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Hadrontherapy: one of the most advanced and pioneering treatment modalities:
40 facilities nowadays in operation

Limitations to the hadrontherapy spread:
huge dimensions, complexity and high cost:
150-200 M€, ~70 M€ for the eye therapy

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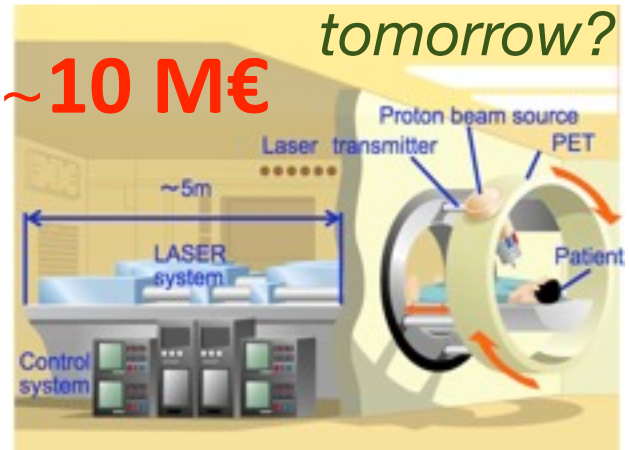
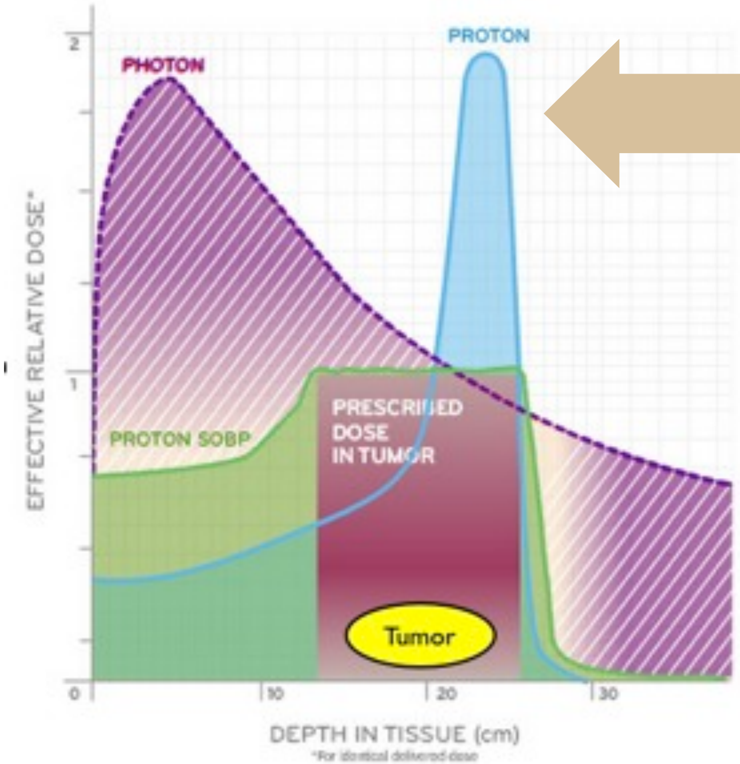
- Why laser-driven proton beams?
  - ***Compactness***
  - ***Cost-reduction***
  - ***Innovative treatment modalities***

~10 M€

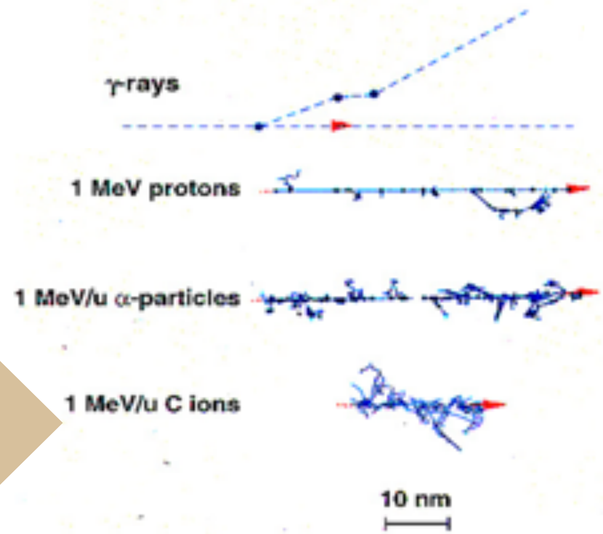


Why Hadrontherapy ?



Physical advantages

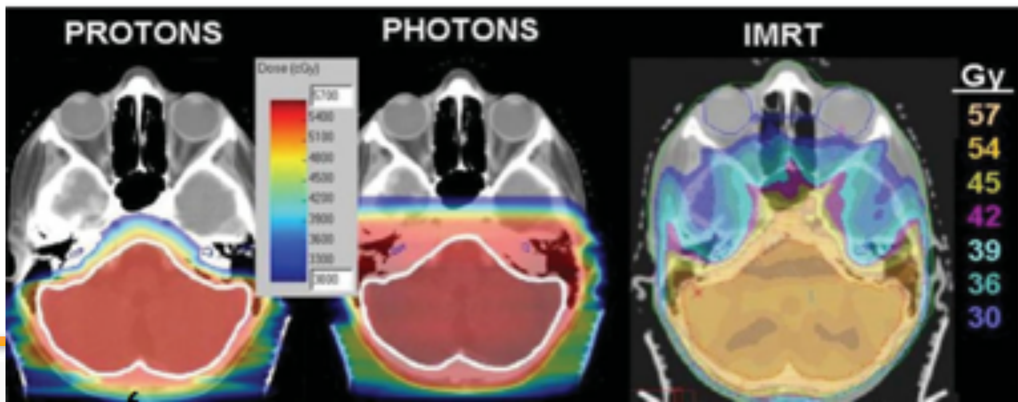
Biological advantages



Density of secondary electrons is higher for charged radiation and enahance the DNA double strand break

Image from Greco C. Current Status of Radiotherapy With Proton and Light Ion Beams. American CANCER society April 1, 2007 / Volume 109 / Number 7

Protons permit precise tumor irradiation minimizing doses to healthy tissues



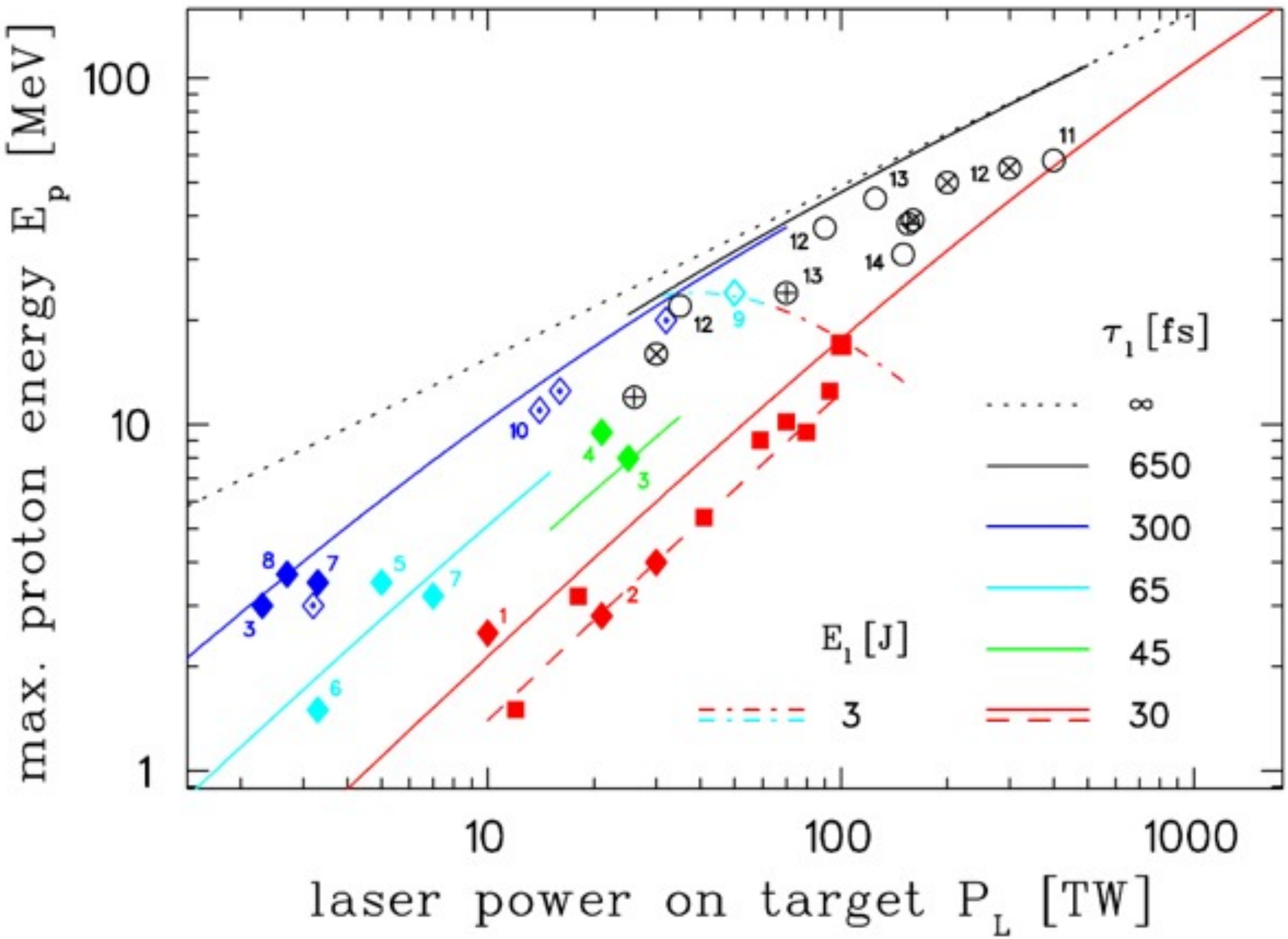
Typical laser-driven ion beam characteristics

Benefits

- **Large accelerating field (GV/m)**
- **High flux and high dose-rate per bunch: ~ 10^9 Gy/sec**
  (~ 10 Gy/sec maximum for conventional accelerators)

Challenges

- **Very short particle bunch duration: < 100 psec**
  (> 5 nsec for conventional accelerator)
- **Tunable energy spectrum**
- **Significant angular divergence (±25°)**



K. Zeil et al., New Journal of Physics 12 (2010) 045015

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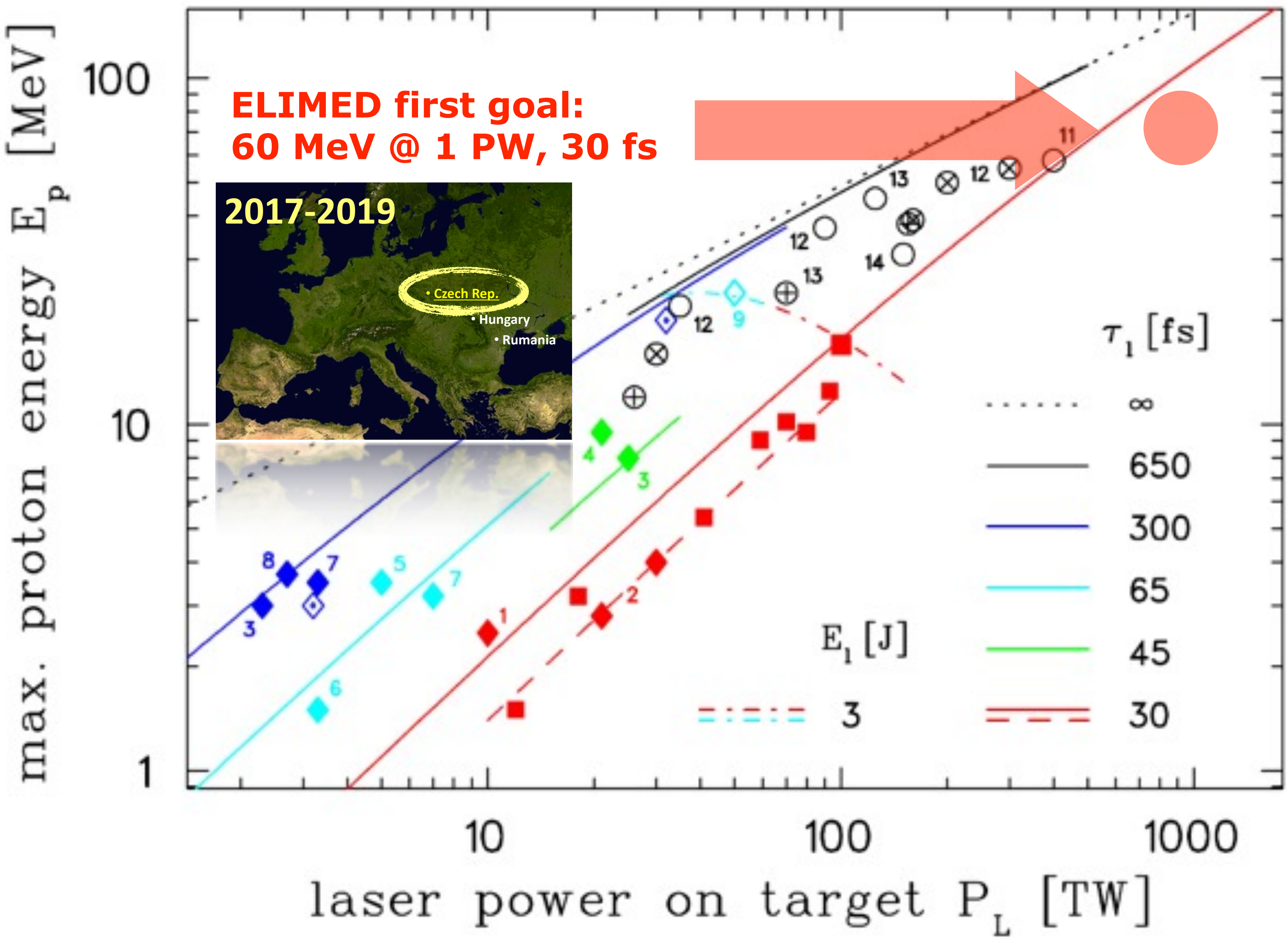

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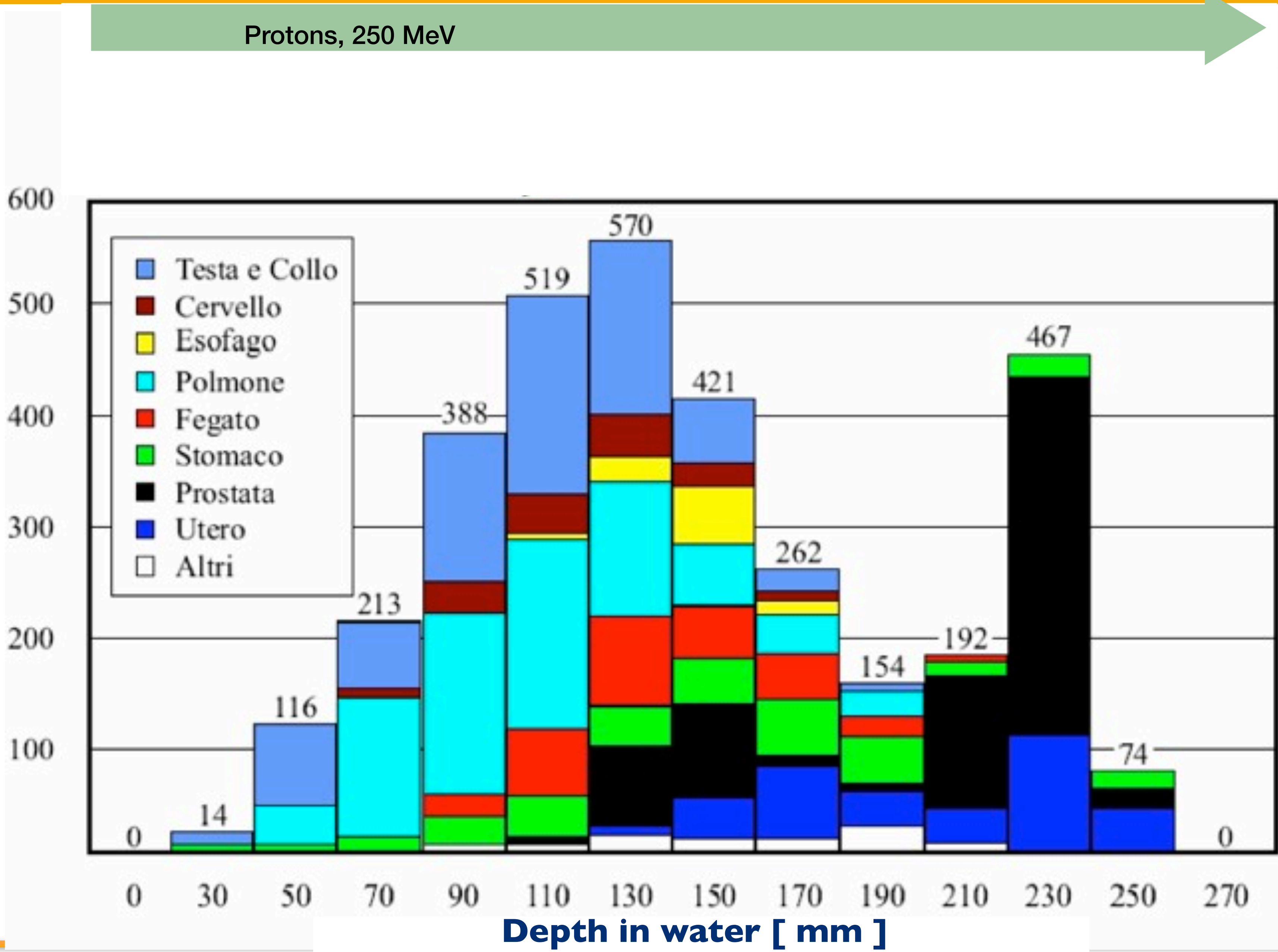
Tumor distribution vs depth in water



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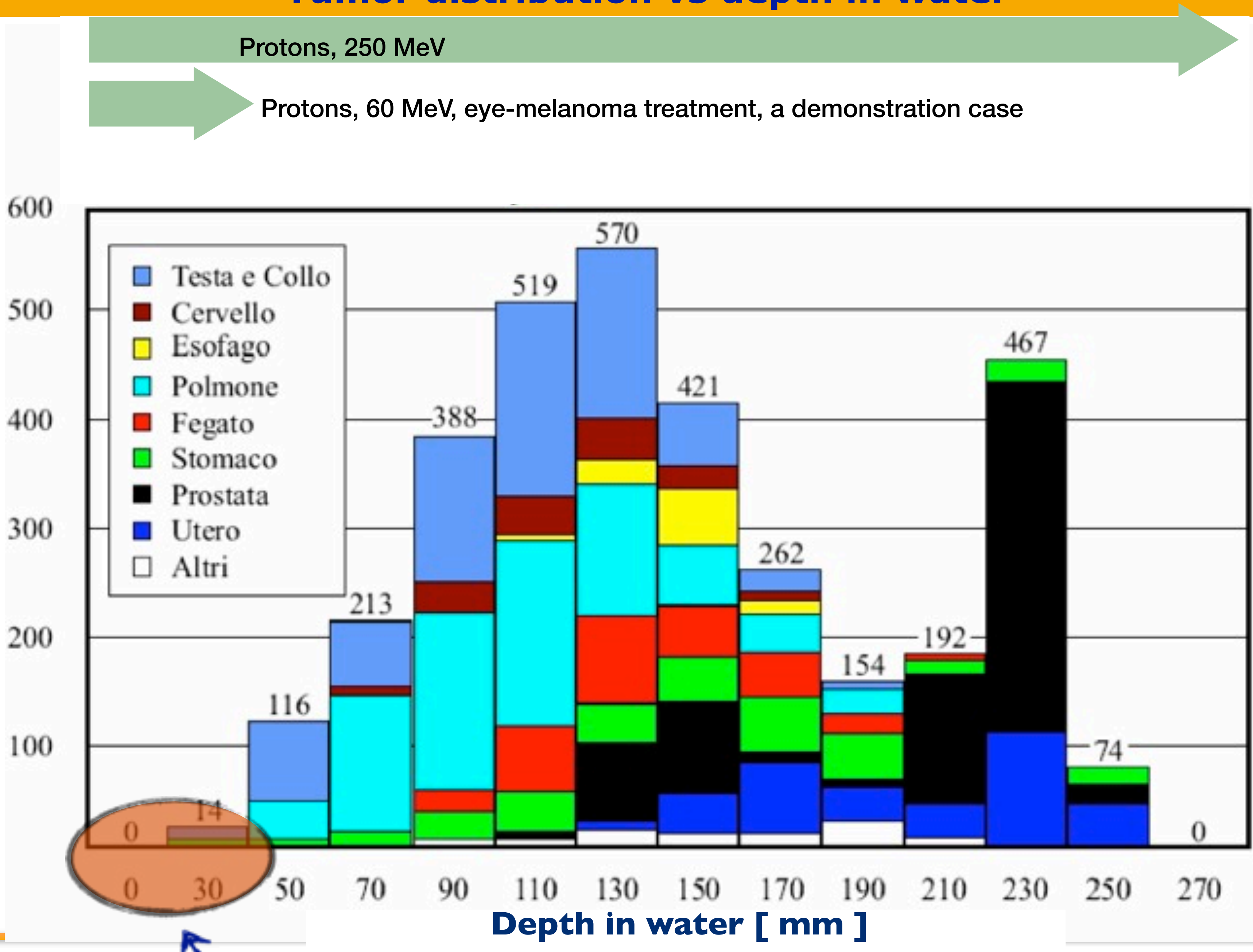

Demonstration of eye proton-therapy, ELIMED first phase, 2016-2017

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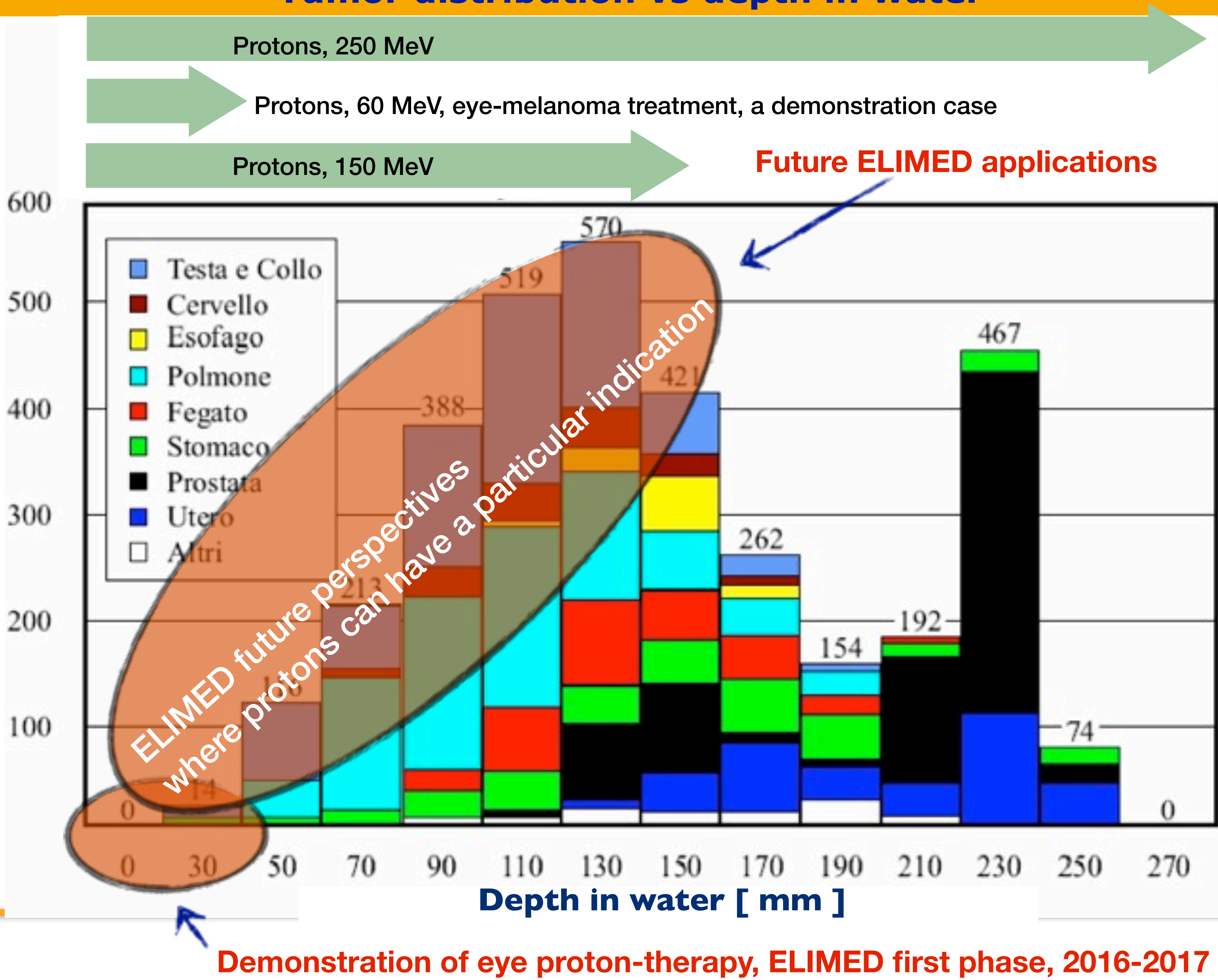


TÉCNICO LISBOA

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

SAPIENZA UNIVERSITÀ DI ROMA

Queen's University Belfast

KPSI Kansai Photon Science Institute

FONDAZIONE BRUNO KESSLER

Berkeley UNIVERSITY OF CALIFORNIA

Fyzikální ústav Akademie věd ČR, v. v. i.

2nd ELIMED Workshop and Panel, 18-19 October 2012 @ INFN-LNS, Catania

Azienda Ospedaliero Universitaria "Policlinico - Vittorio Emanuele" Catania Presidio "Gaspare Rodolico"

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Università degli Studi di Catania

University of Belgrade
Универзитет у Београду

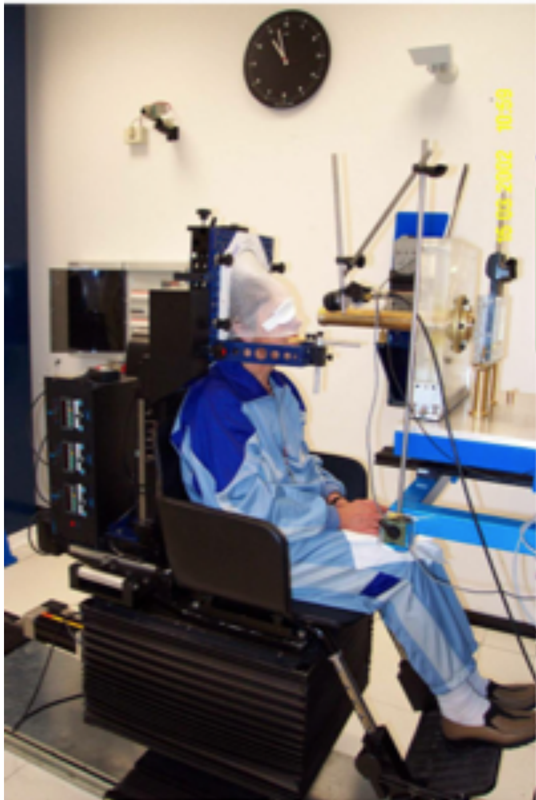
INFN

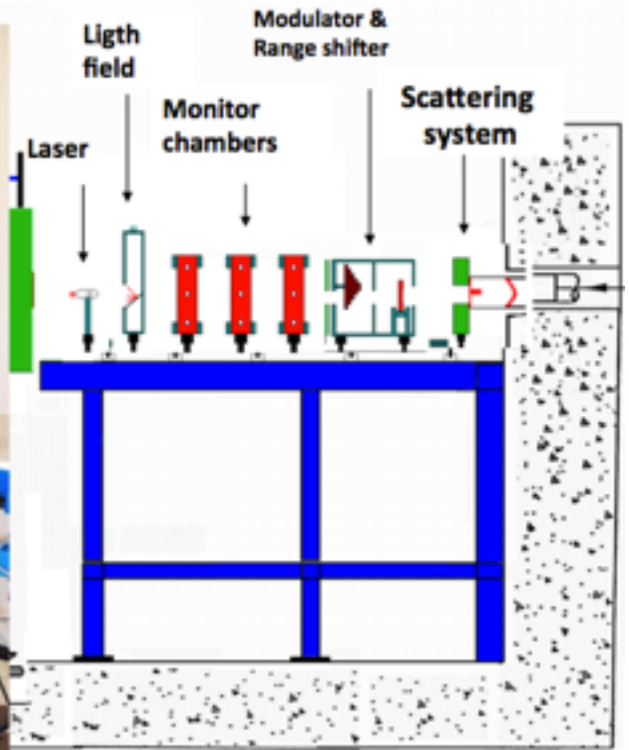
ITA Istituto Tecnologie Avanzate Laboratorio Nano Tecnologie

Consiglio Nazionale delle Ricerche
Istituto di Bioimmagini e Fisiologia Molecolare

The Italian eye proton therapy center

CATANA → **Hadrontherapy Centre and Advanced Nuclear Applications**





Target volume and dose

Uveal melanoma
(eye melanoma: rear but very aggressive disease)

-30-40 mm of spot size required

-60-70 MeV maximum energy is required

-60 CGyE in 4 fractions of 15 CGyE for 4 consecutive days, duration between 20-50 sec in average

Project started in 1996
First patient: March 12, 2001
More than 300 patients treated

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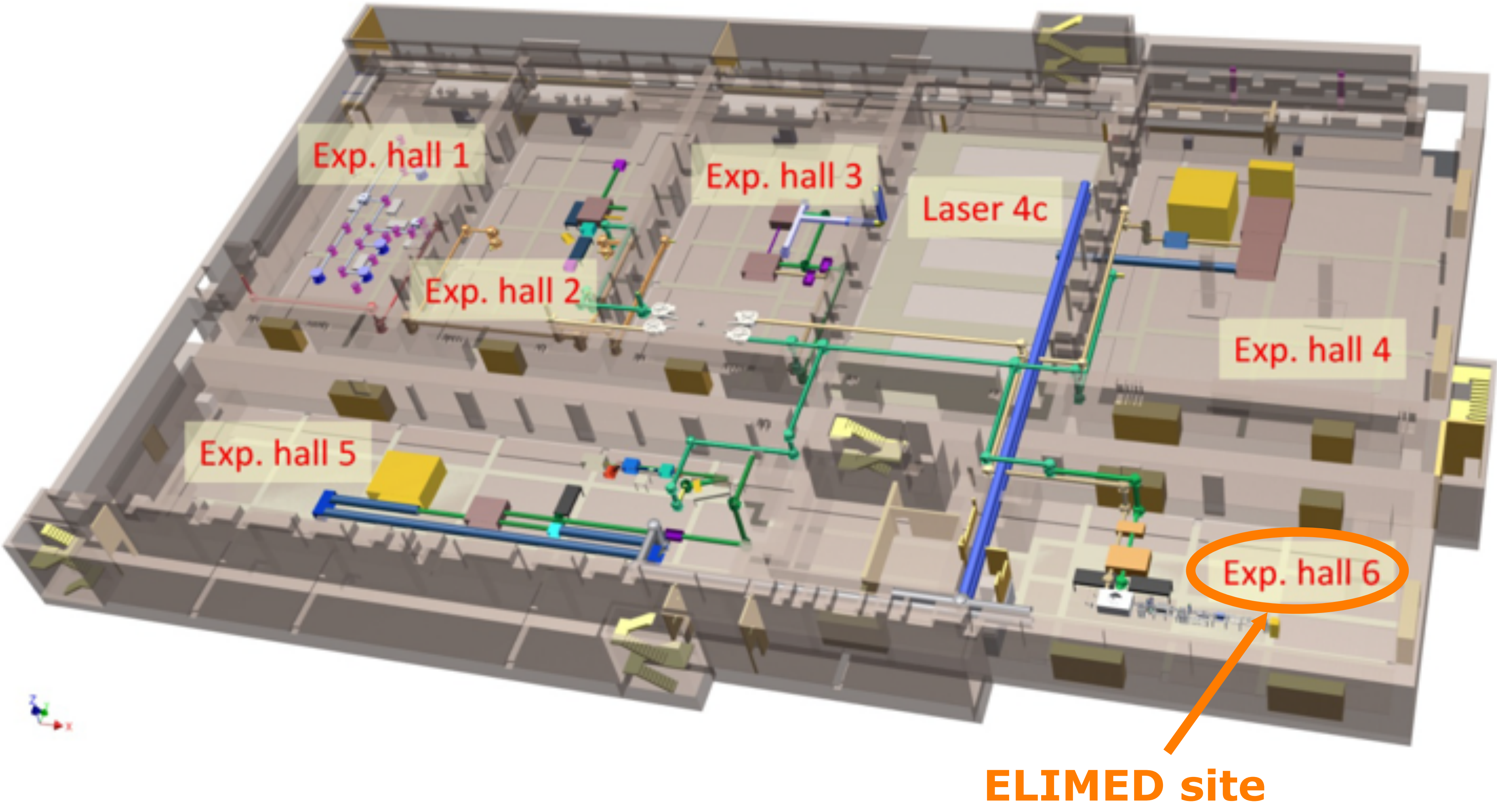
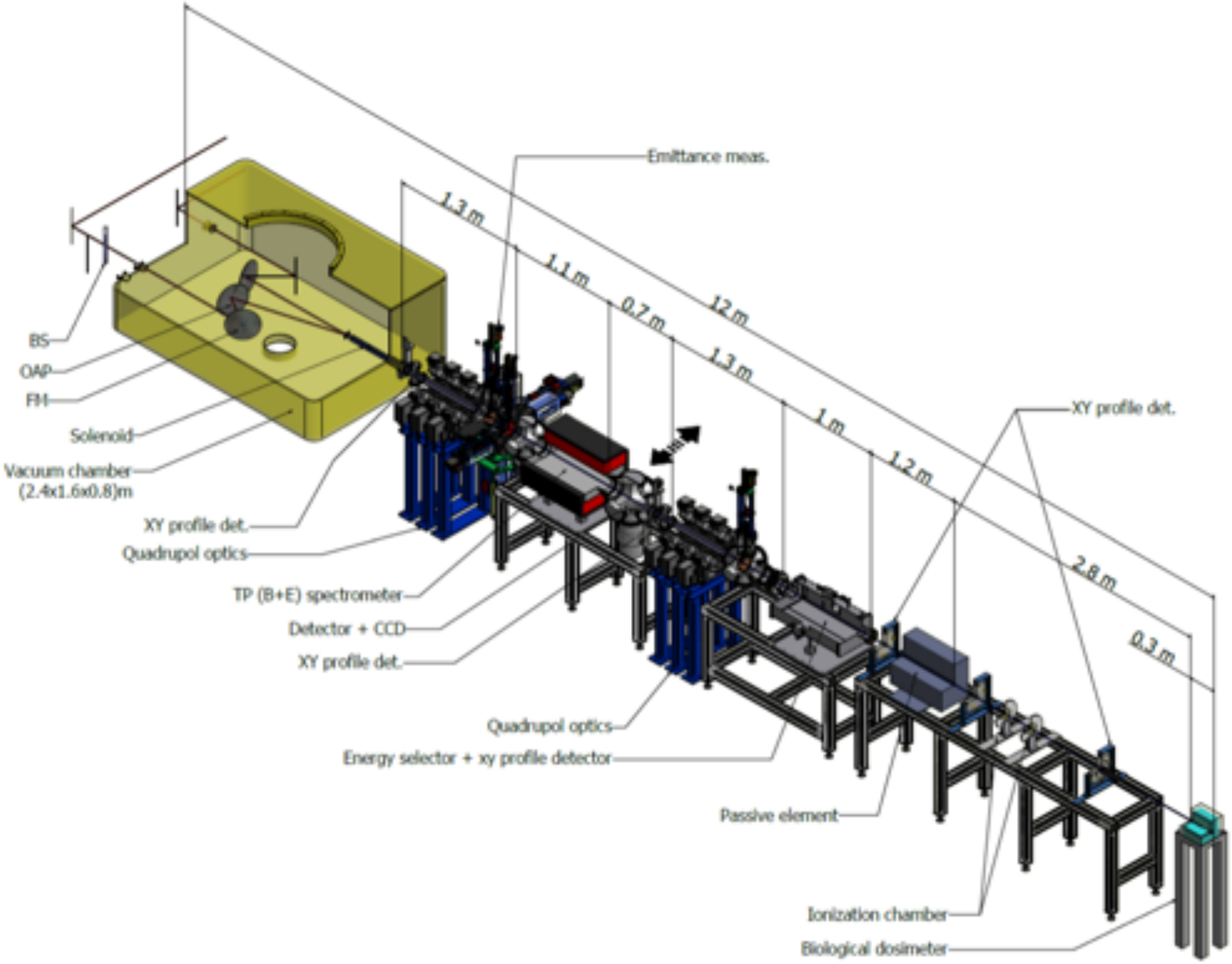
ELIMED area at ELI-Beamlines



The future ELIMED beamline



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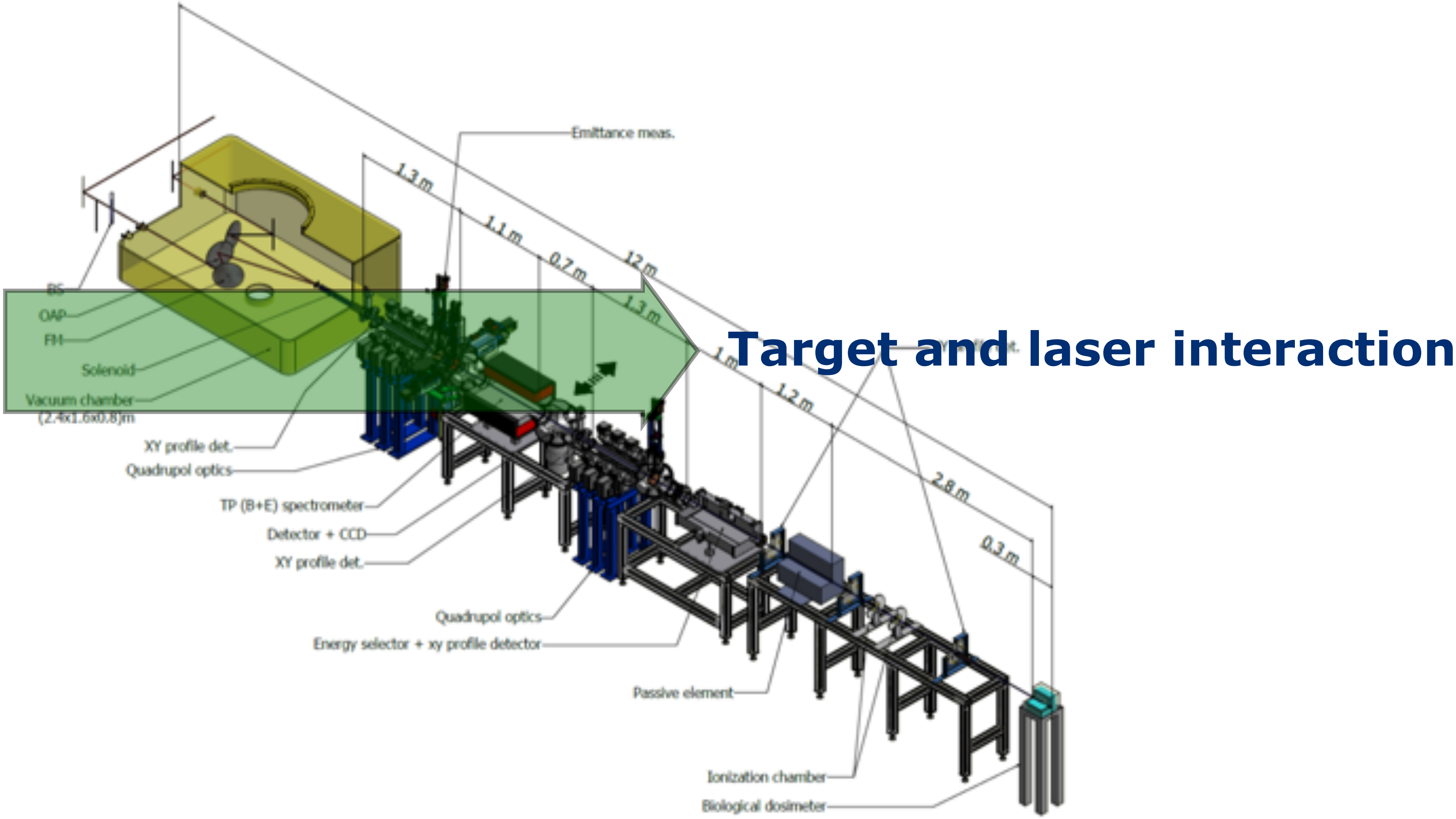

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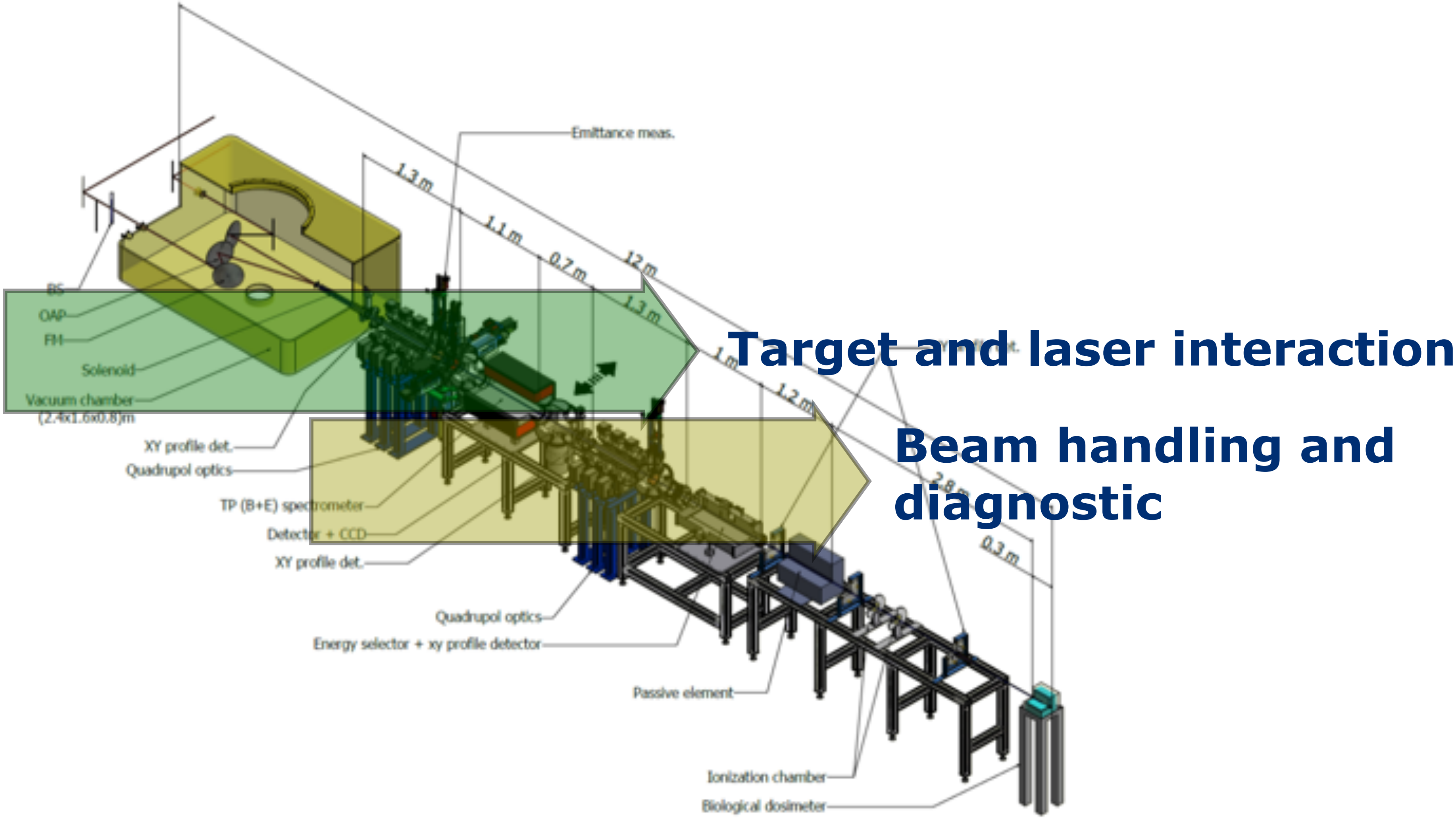

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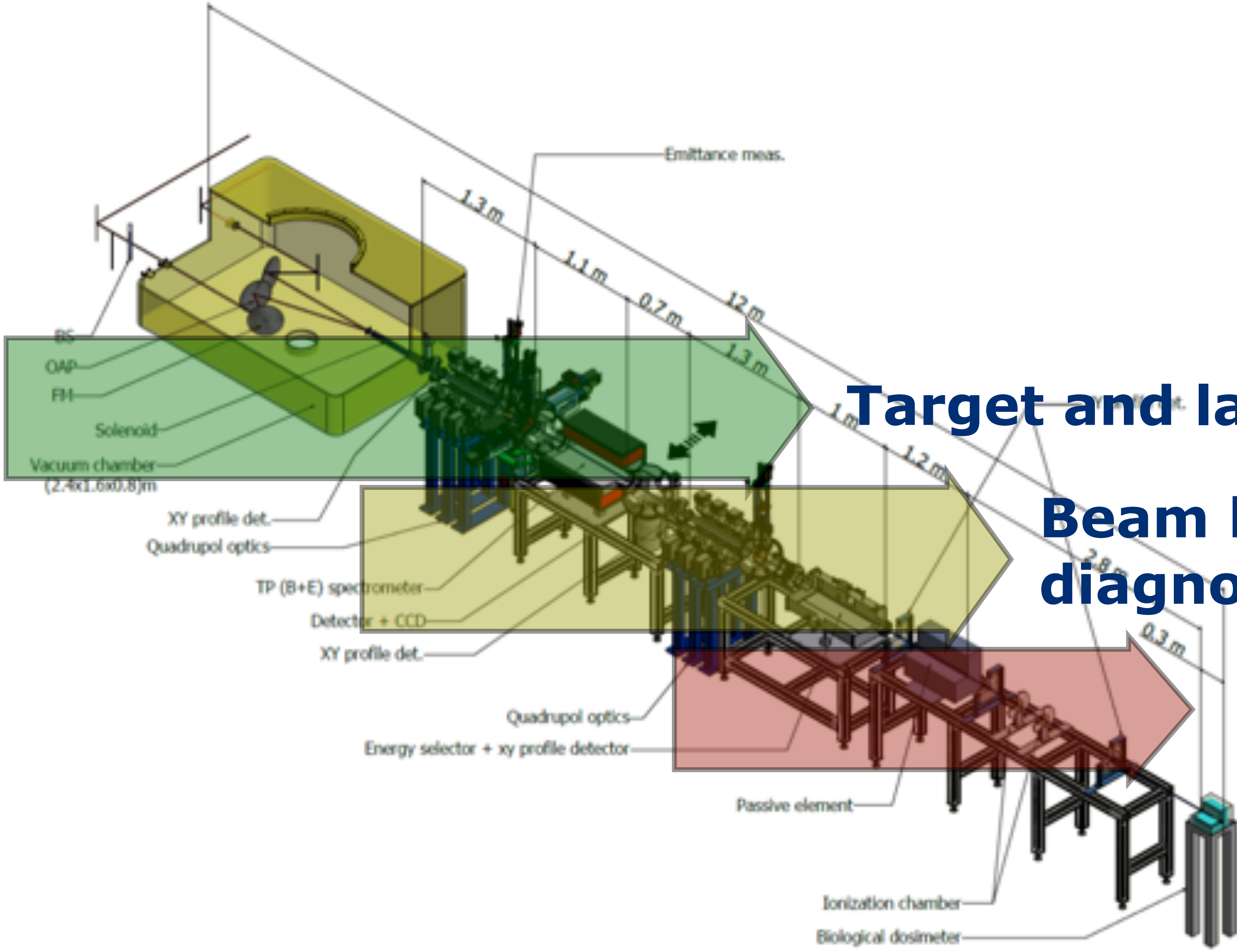

Beam Transport, Selection and Diagnostic

- Tunable → deliver beams of different energy, energy spread and species
- Large Acceptance→ Control the large chromatic emittance due to the high energy spread of the transported beams
- Modularity is an additional key point → flexibility to meet different experimental setups and new ideas for Users experiments
- Cost effective → only conventional devices use (high reliability)

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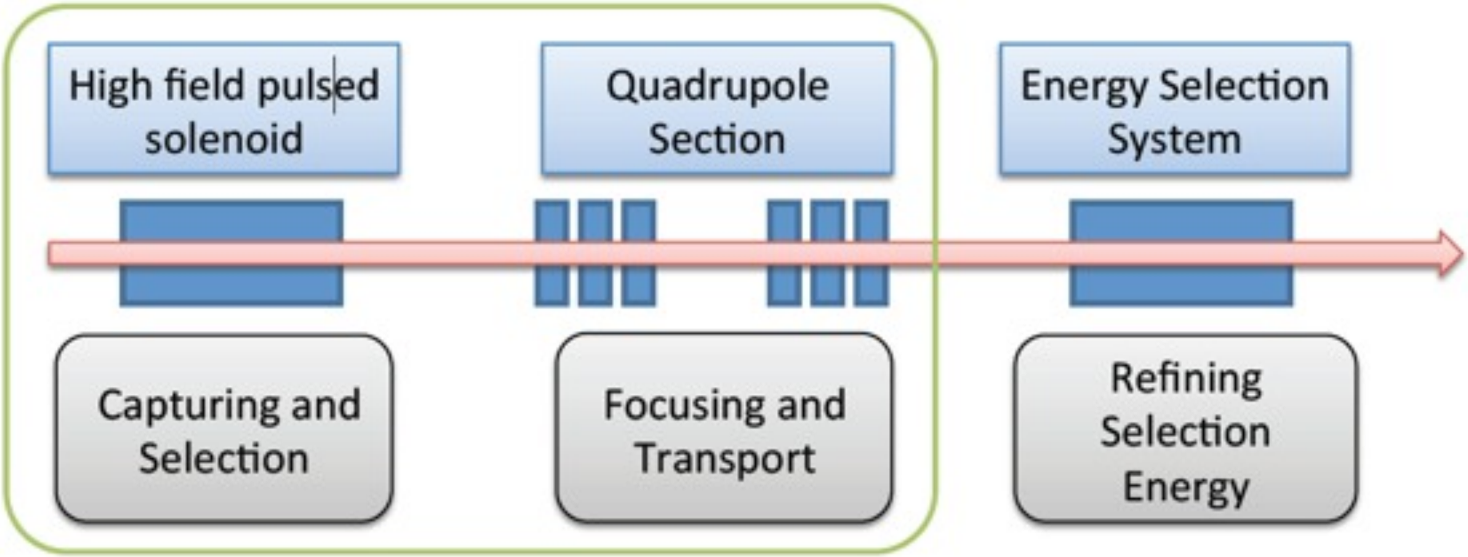


Energy Selector System (ESS)

- Final and finest step in the energy selection

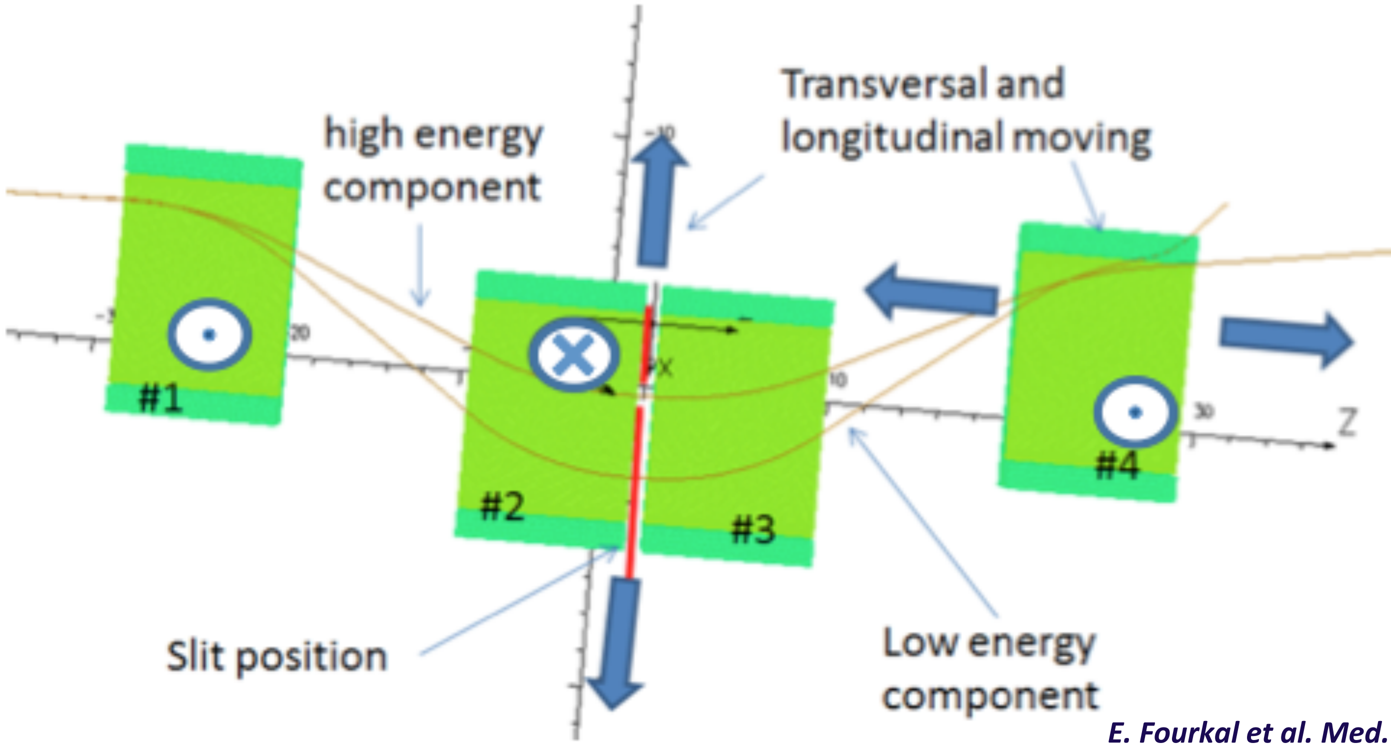
Energy Selector System (ESS)

➢ **Final and finest step in the energy selection**

ESS Prototype already developed @ LNS-INFN:

- **Wide energy range (1 – 60 MeV)**
- **Controlled energy spread (1 - 30 %) - related to the transmission efficiency and clinical necessities**
- **Compact design**
- **Passive magnetic elements**

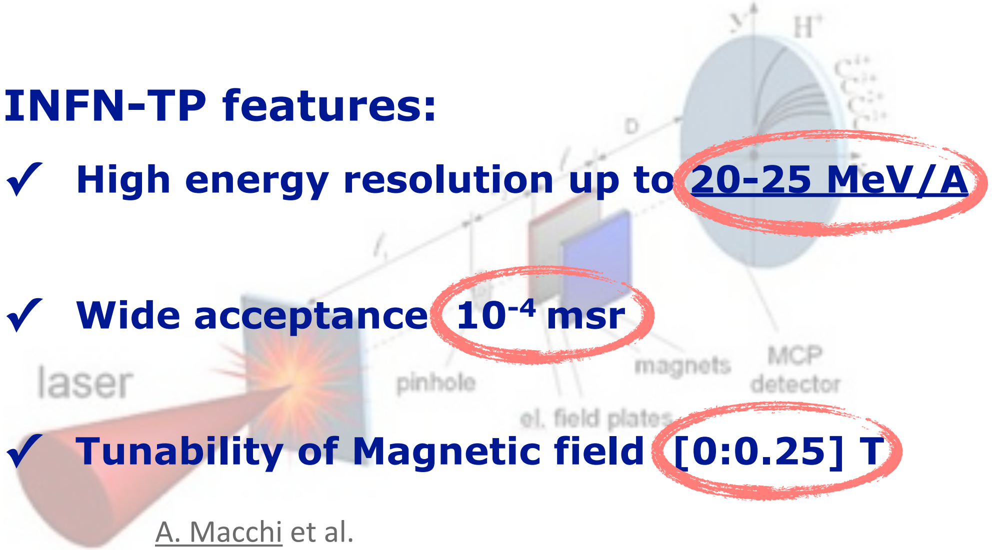
ESS prototype: working principles



E. Fourkal et al. Med. Phys. 30 (7) 2003

- **Transversal moving of the slit permits the energy selection**
- **Transversal moving of #2 and #3 dipoles to decrease the selectable low energy limit**
- **Longitudinal movement of dipole #4 permits to compensate the magnetic field asymmetries of the whole structure**

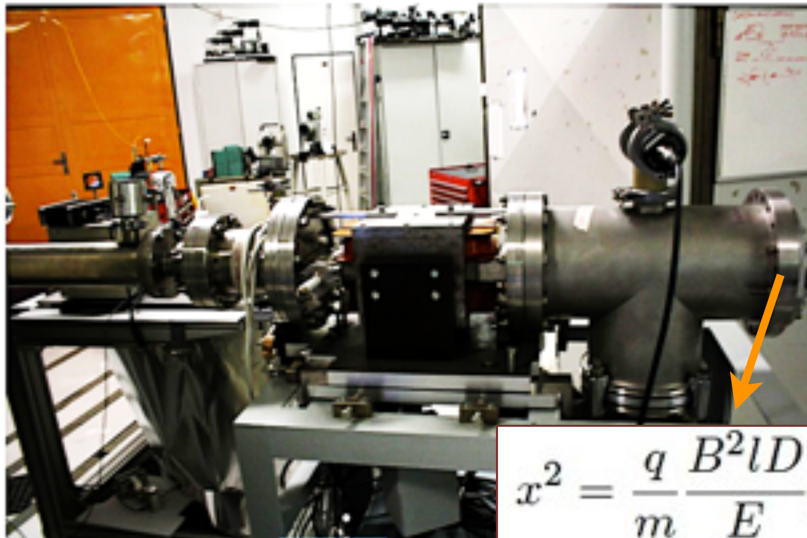
The INFN-LNS Thomson Spectrometer



INFN-TP features:

- ✓ **High energy resolution up to 20-25 MeV/A**
- ✓ **Wide acceptance 10^{-4} msr**
- ✓ **Tunability of Magnetic field [0:0.25] T**

A. Macchi et al.
Accepted for publication on Reviews of Modern Physics (2013)



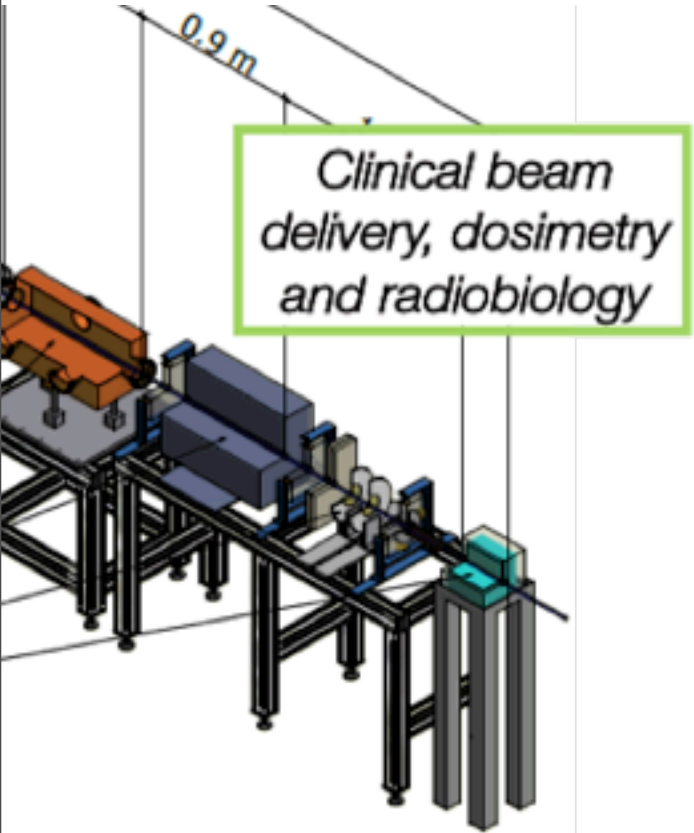
$$x^2 = \frac{q}{m}\frac{B^2 l D}{E} y$$

The INFN Thomson Spectrometer has been developed within the *INFN-LILIA* project
(G.A.P. Cirrone, G.Cuttone, C. de Martinis, D. Giove, A. Fazzi, G. Turchetti, S. Sinigardi)

The INFN-TP has been tested as laser-driven ion beam diagnostic system within the *ELIMED* collaboration during an experimental campaign

➡ PALS in Prague, May 2012 and February 2013

Dosimetry and radiobiology



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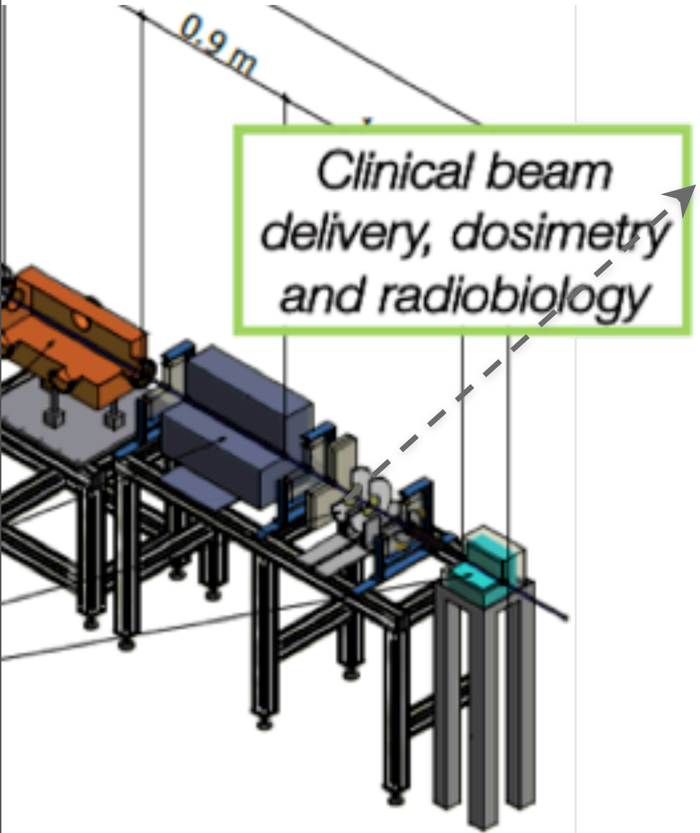
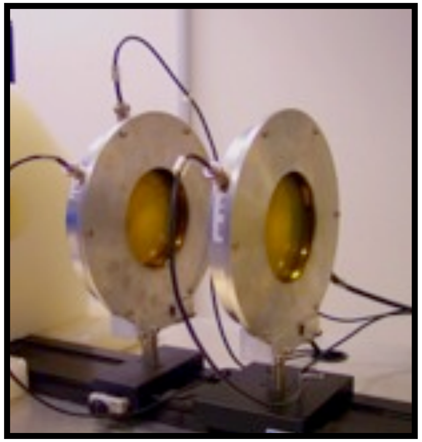
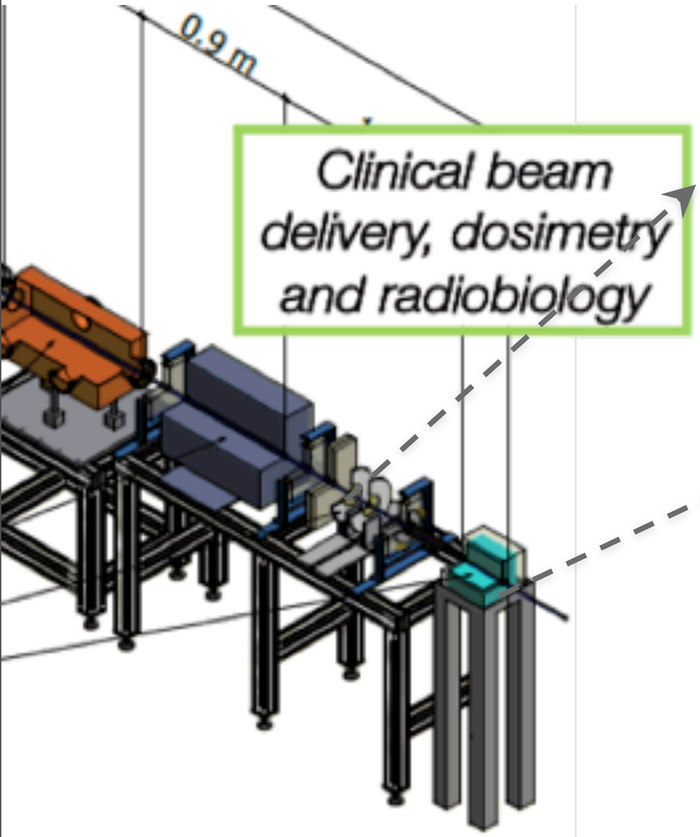
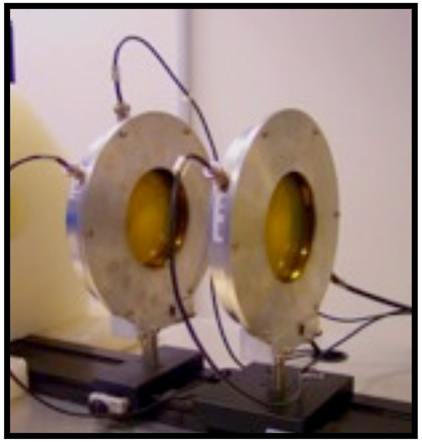




On-line relative dosimetry:
•Transmission IC
•ELIMON detector

Dosimetry and radiobiology





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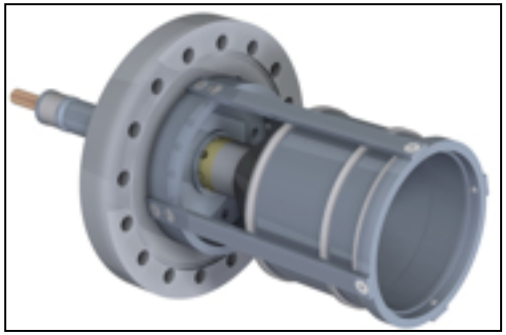
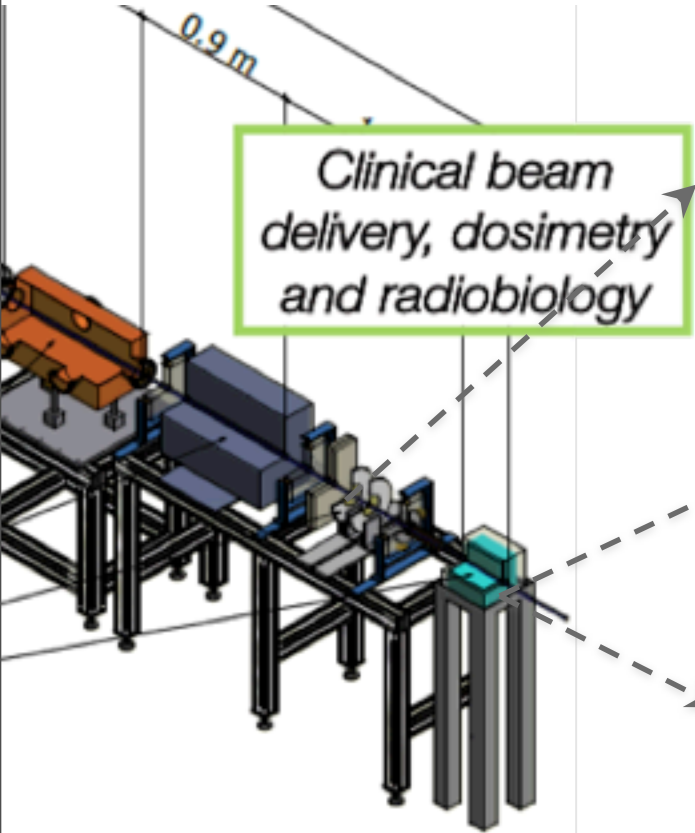
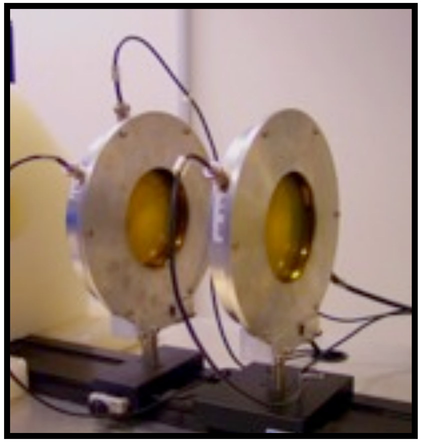


Absolute dosimetry:
• Faraday cup

Dosimetry and radiobiology





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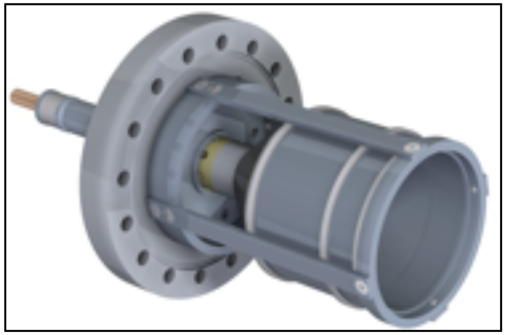

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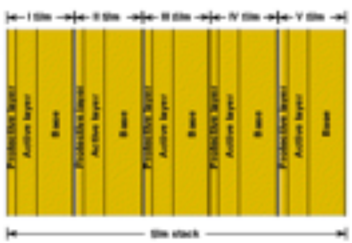

Energy spectrum measurements:
• Radiochromic films (stack)
• CR39 detectors
• Scintillating fibers (real-time)

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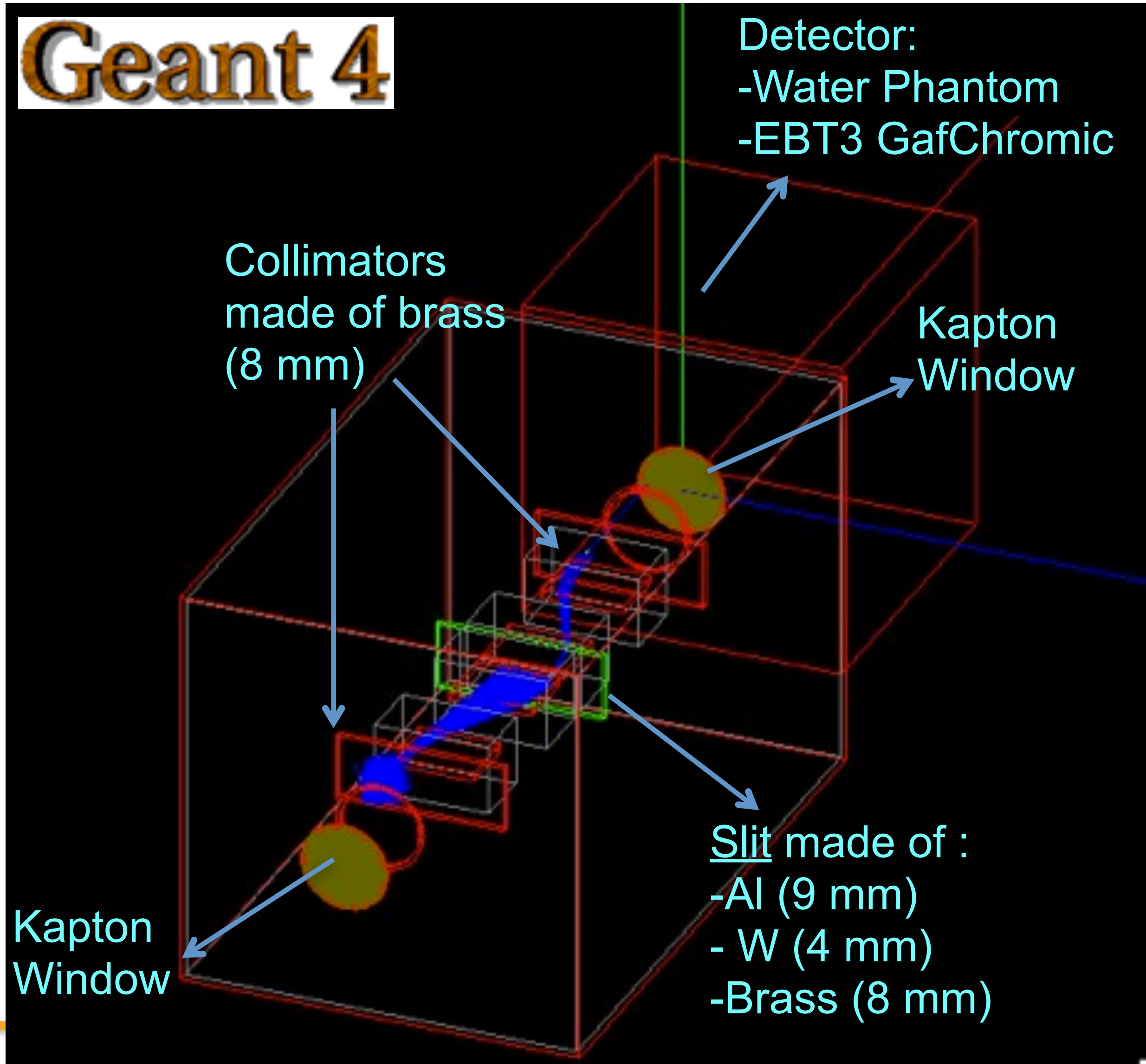
Monte Carlo activity with Geant4

Monte Carlo activity with Geant4

- **Design and optimization of the ELIMED beamline**
  - **Energy selection system**
  - **Transport beam line optimization**
  - **Irradiation approaches**
  - **Radio-protection and dosimetry**

- **MC simulation of the available test sites (FLAME, TARANIS) for the final dose evaluation in the preparatory phase**

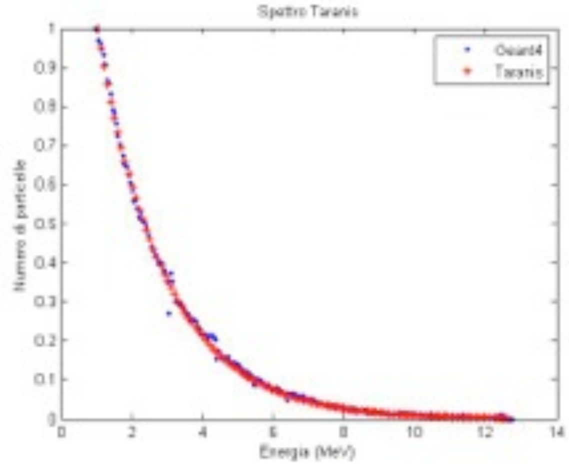
ESS Geant4 simulation



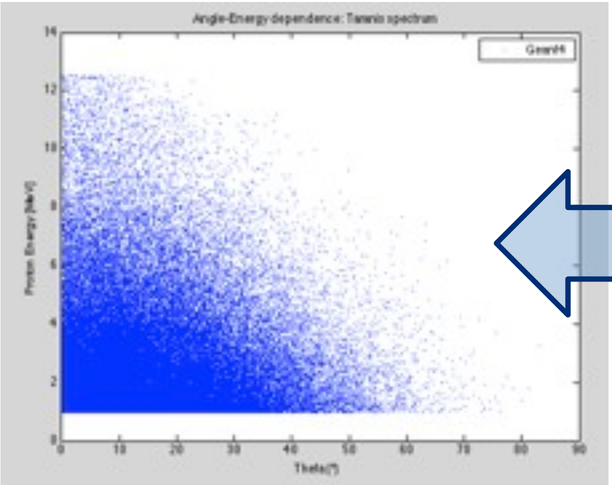
Preparation to the TARANIS run

$$\frac{dN}{dE} = 2.15 \times 10^{11} \exp(-0.44E) \;\; MeV^{-1}$$

for $1\,\mathrm{MeV} \le \mathrm{Ep} \le 12\,MeV$ (T. Dzelzainis, et al ...)



- The following energies have been selected:
  - 4, 6 MeV
- Geometrical configuration:
  - Collimators diameters: 3 mm
  - Slit diameter: 3 m



Angular dependence, come from RCF analysis, implemented in the simulation input

Collaboration

Giuseppe A. P. Cirrone, Daniele Margarone, Mario Maggiore, A. Anzalone, S. Bijan Jia, Marco Borghesi, Stepan S. Bulanov, Sergei Bulanov, S. Cavallaro, M. Carpinelli, M. P. Cutroneo, G. Cuttone, M. Favetta, S. Gammino, Jiri Limpouch, Ondrej Klim, Georg Korn, Lorenzo Manti, A. Musumarra, Ivan Petrovic, Jan Prokupek, Jan Psikal, Marcella Renis, Aleksandra Ristic-Fira, Francesco Romano, Francesco P. Romano, G. Schettino, Francesco Schillaci, Valentina Scuderi, C. Stancampiano, S. Ter-Avetisyan, B. Tomasello, Lorenzo Torrisi, Antonella Tramontana, S. Tudisco, Andriy Velyhan

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Thank you for the attention