Innovative handling and transport solutions for laser-driven ion beams

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on behalf of the ELIMED Collaboration

Targetry for Laser-driven Proton (Ion) Accelerator Sources: First Workshop
Institute for Advanced Study (IAS), Garching, Germany, 9–11 Oct 2013

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ELIMAIA beamline in Prague
ELI Multidisciplinary Applications of laser-Ion Acceleration

Why *ELIMAIA?*

Realization of a facility at ELI-Beamlines
as first User's beam line to study the laser-driven proton (ion) application:

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

ELIMAIA First Phase

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

$\Longrightarrow$ **a good candidate for a demonstration-case**

- A medical application is the most demanding in terms of beam characteristics and performances. It will require:

  - Target investigation
  - Beam delivering system
  - Diagnostic tools suitable for non-conventional beams
  - Innovative technique for absolute and relative dosimetry, radiobiology

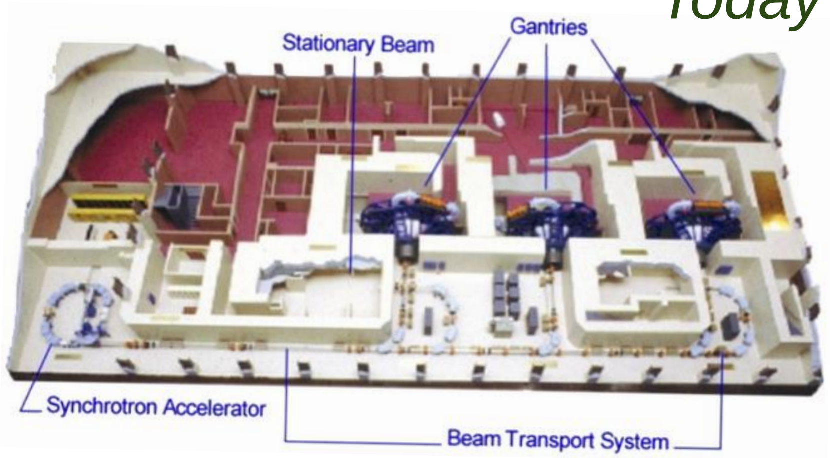
Hadrontherapy, a potential user case

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

Spread is limited as respect conventional facility:

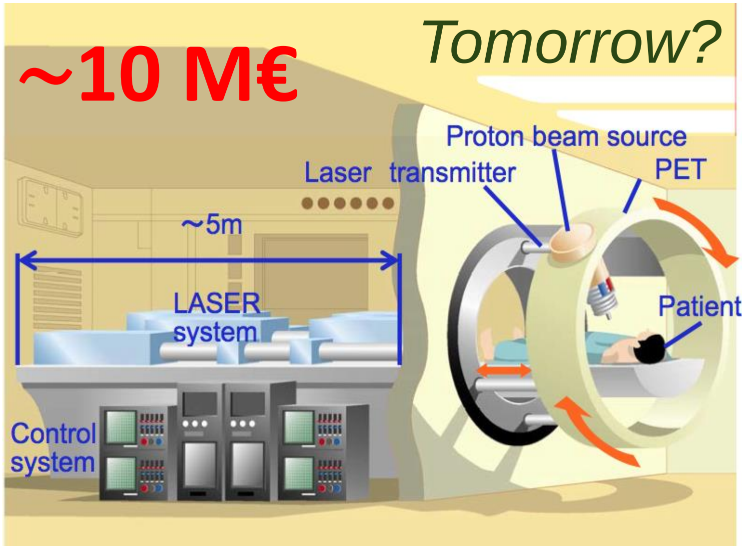
- High complexity for the beam production, acceleration and transport
- High cost: 150-200 M€, ~70 M€ for the eye therapy

Today



Why laser-driven proton beams?

- ***Compactness***
- ***Cost-reduction***
- ***Innovative treatment modalities:***
  - Variable energies in the accelerator (no degraders needed)
  - Short beam pulses (very useful for fast scanning and to reduce organ motion issues)



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Typical laser-driven ion beam characteristics

eli beamlines

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)

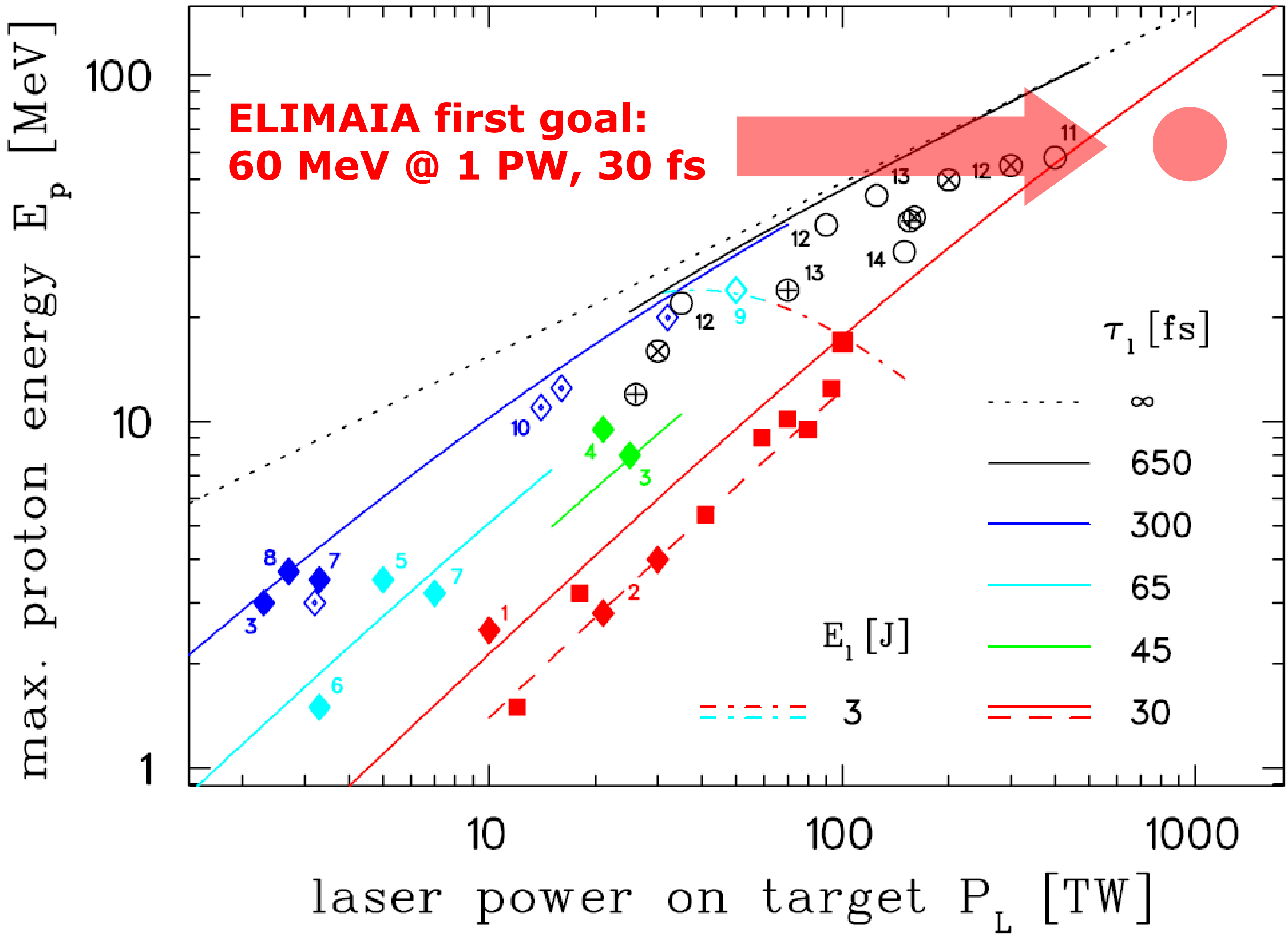
Challenges

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

Solutions to study and control the beam parameters

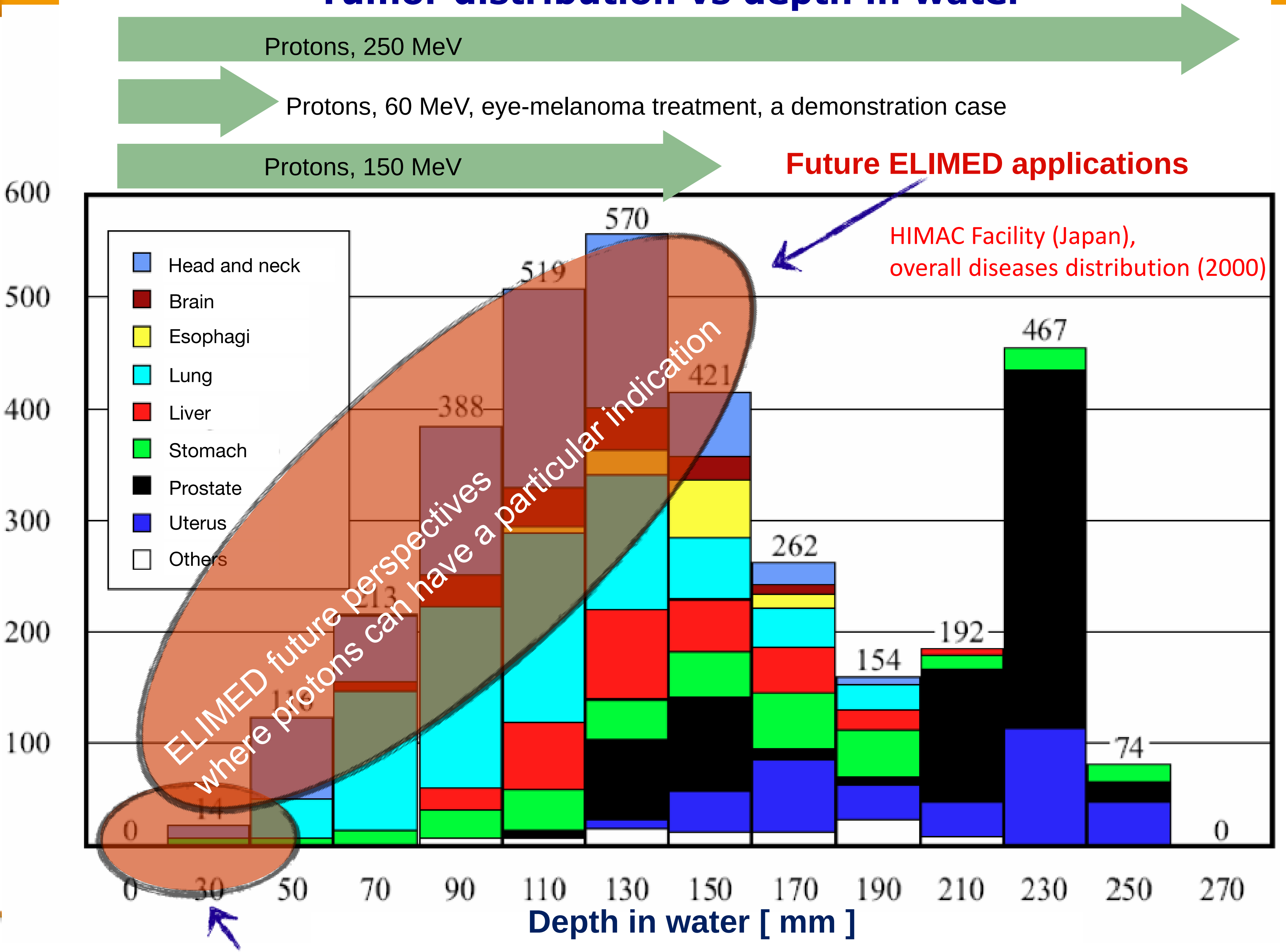
Target with special shape and composition

Systems for the beam handling and energy selection



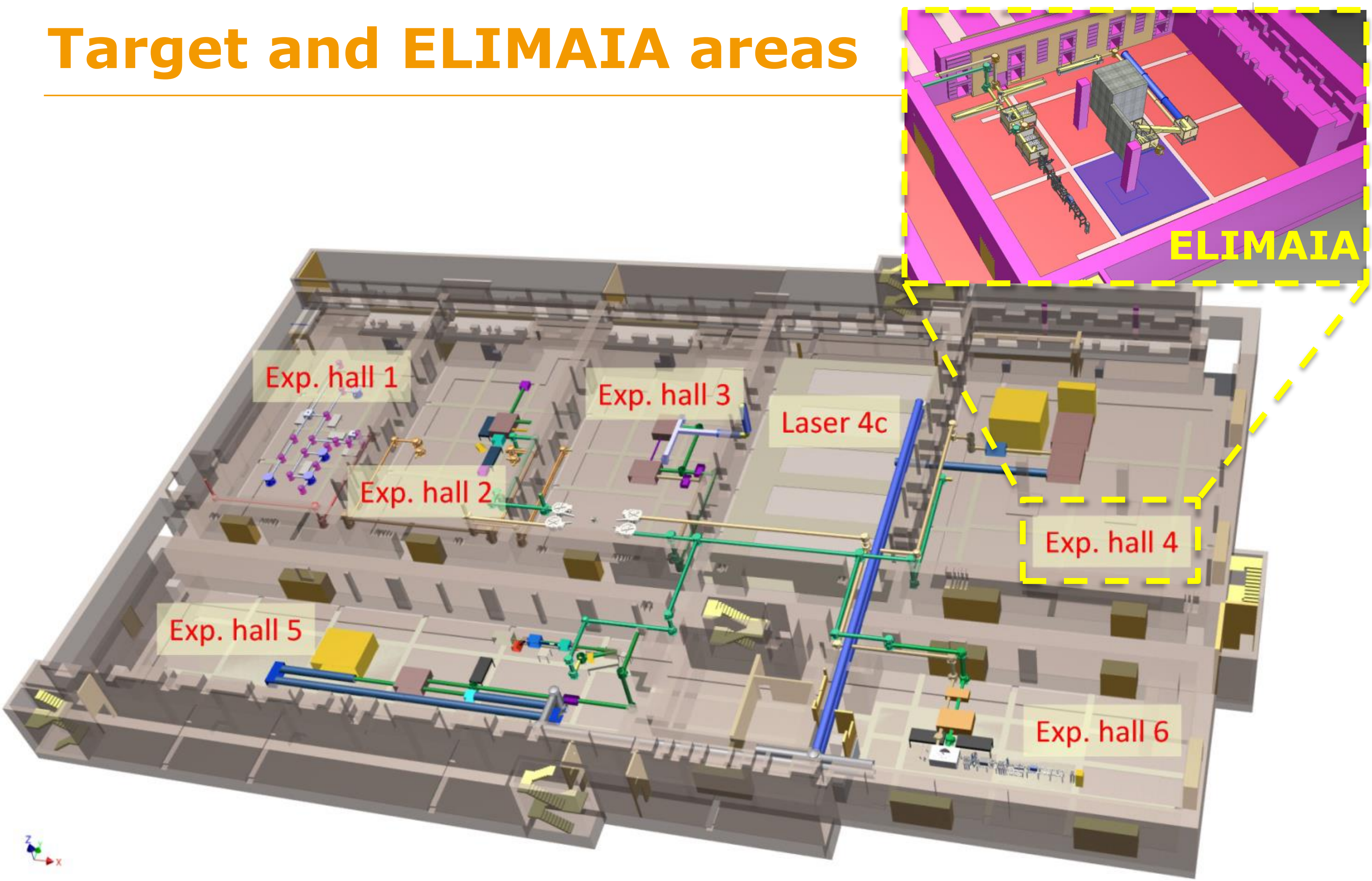
K. Zeil et al., New Journal of Physics 12 (2010) 045015

Tumor distribution vs depth in water

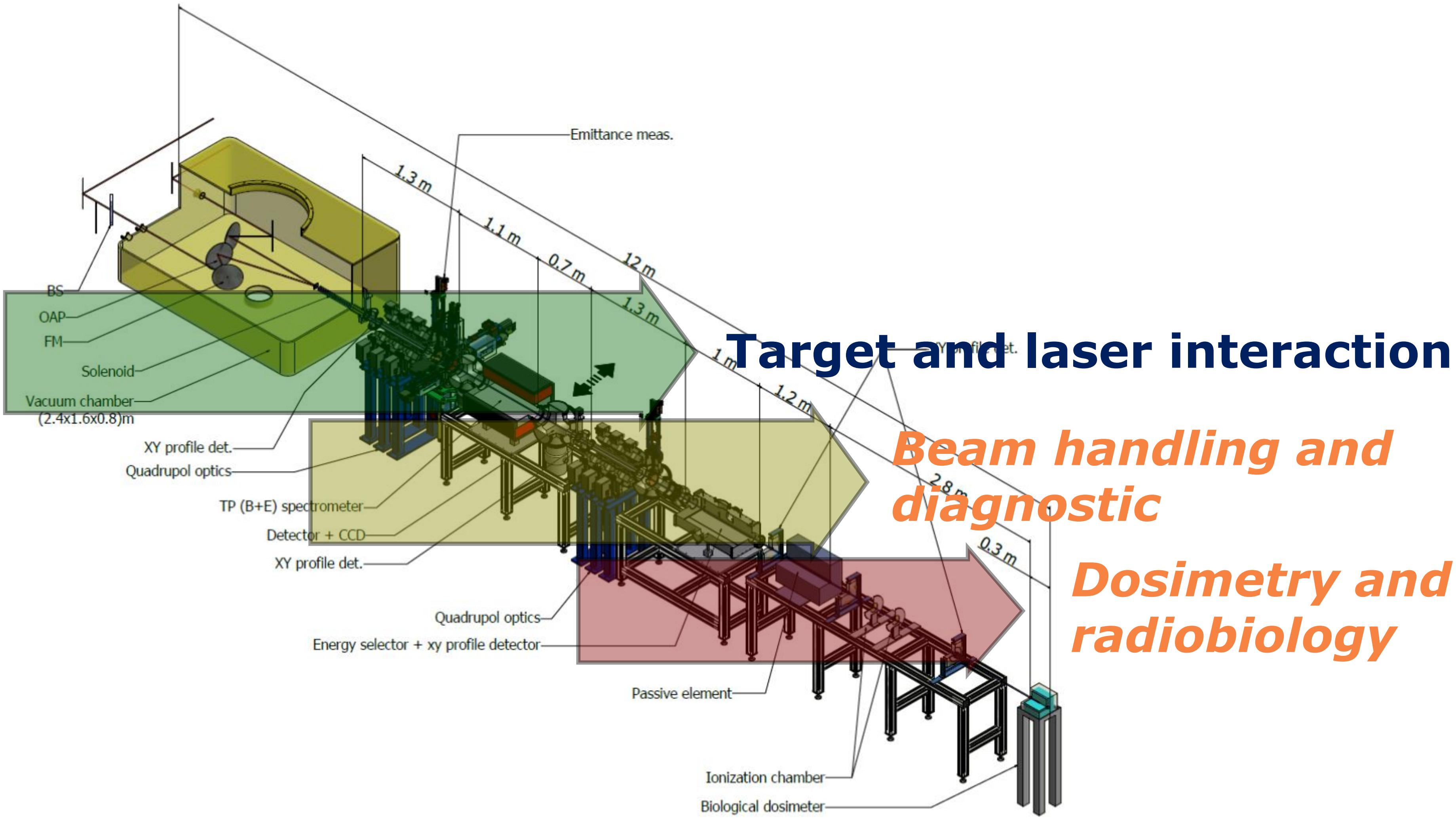


Demonstration of eye proton-therapy, ELIMAIA first phase, 2016-2017

Target and ELIMAIA areas



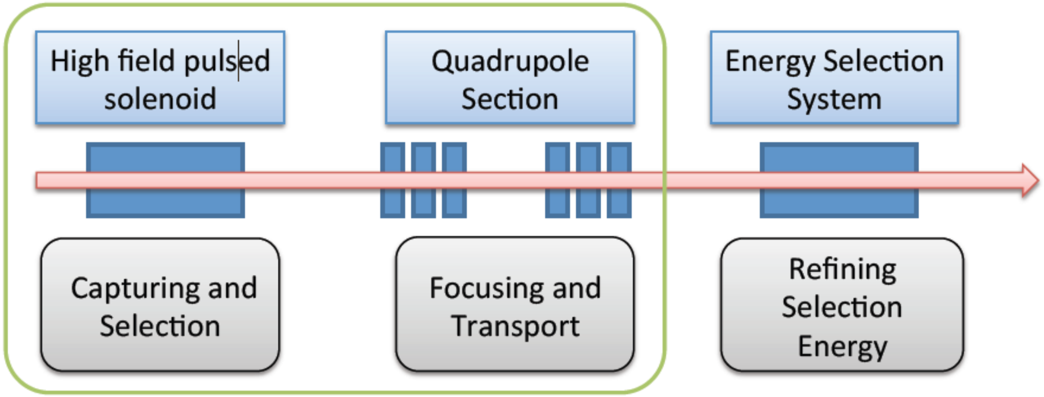
The future ELIMAIA beamline



Beam Handling and Diagnostic

Goal: study of new particle transport solutions to obtain a beam suitable for multidisciplinary applications

Beam transport ideas



- **Tunably**
  deliver beam of different energies, energy spread and species

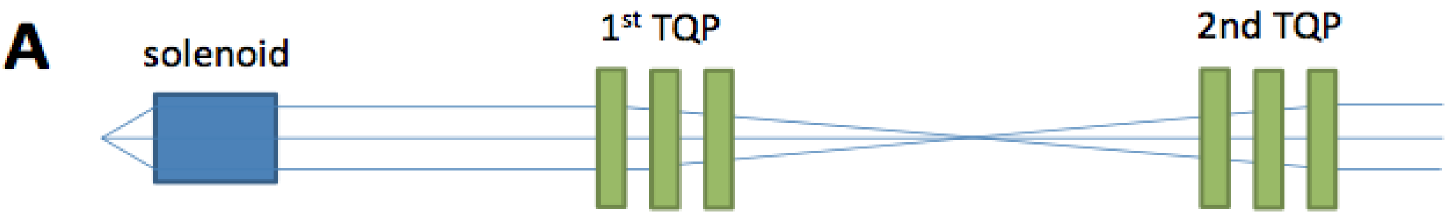
- **Large acceptance**
  Control the large chromatic emittance due to the high energy spread of the transported beam

- **Modularity**
  Flexibility to meet different experimental set-up and new ideas for Users experiments

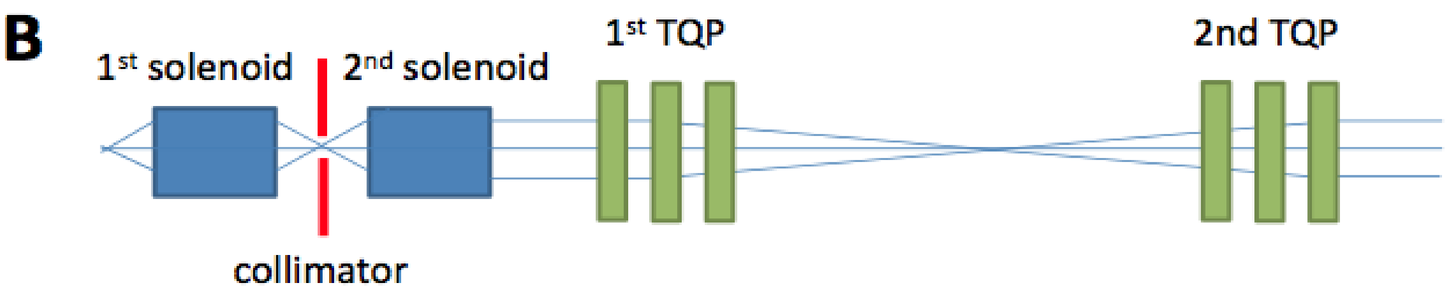
- **Cost effective**
  Use of only conventional device

Beam transport ideas

Possible layout of collecting and transport sections



Maximize the transmission efficiency (>50%), but low optimization in energy spread (>50%)



Maximize the energy spread of the pre-selection beams (<40%) but low transmission efficiency (<30%)

Beam handling and transport solutions AIP Conf. Proc. 1546, pp. 34-43;

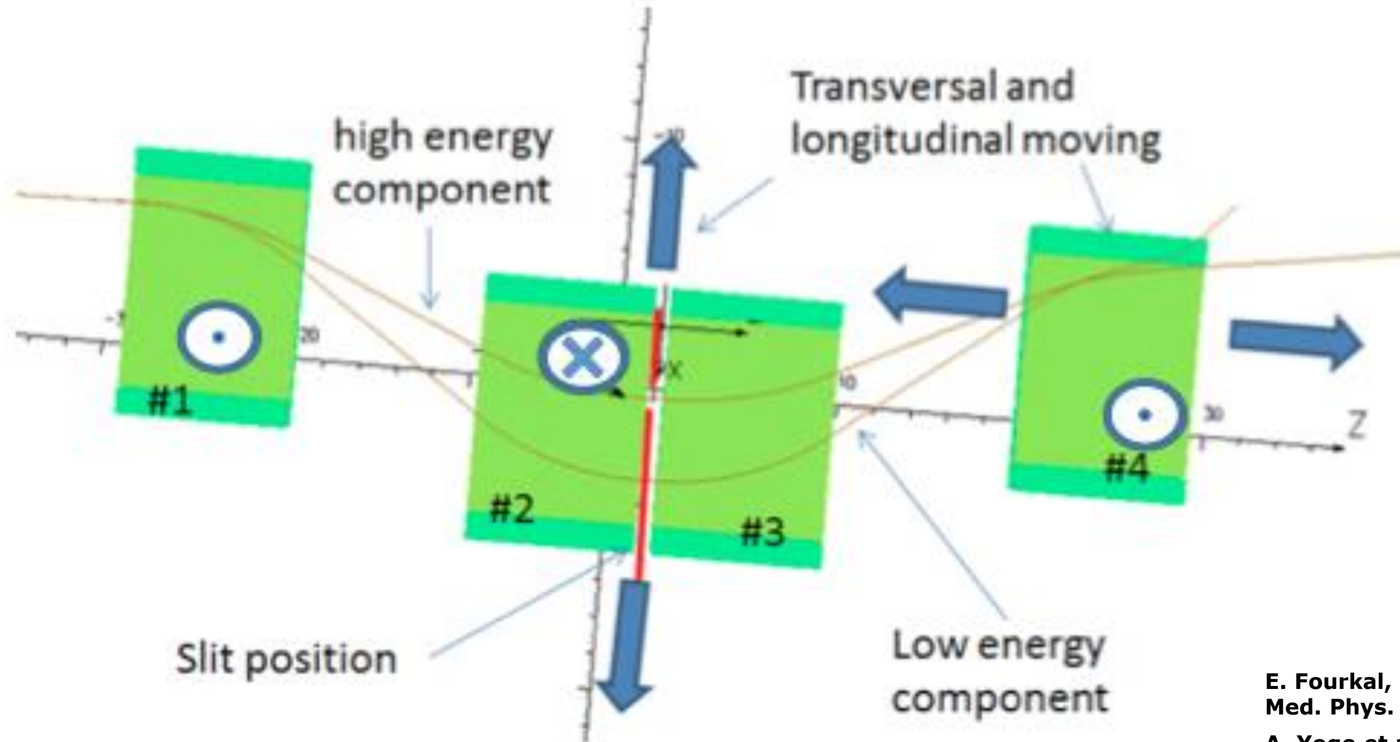
Beam transport ideas:
The Energy Selection System (ESS)

➢ **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 %)**
- **Compact design**
- **Passive magnetic elements**

ESS prototype: working principles



E. Fourkal, J. S. Li, M. Ding, T. Tajima, and C.-M. Ma Med. Phys. 30, 1660 (2003);

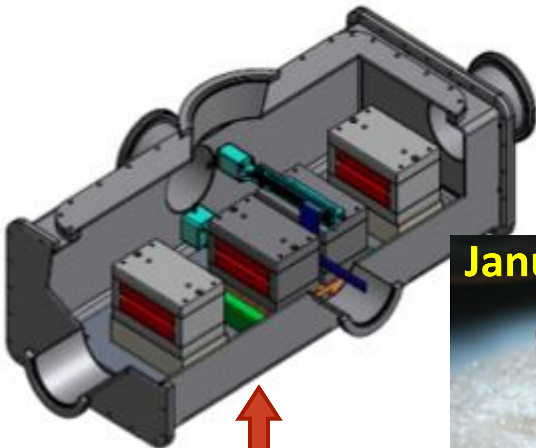
A. Yogo et al. App. Phys. Lett. 98 053701 (2011)

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

ESS prototype realization @ LNS (CT)

eli beamlines

Design, Construction and Assembly of the ESS



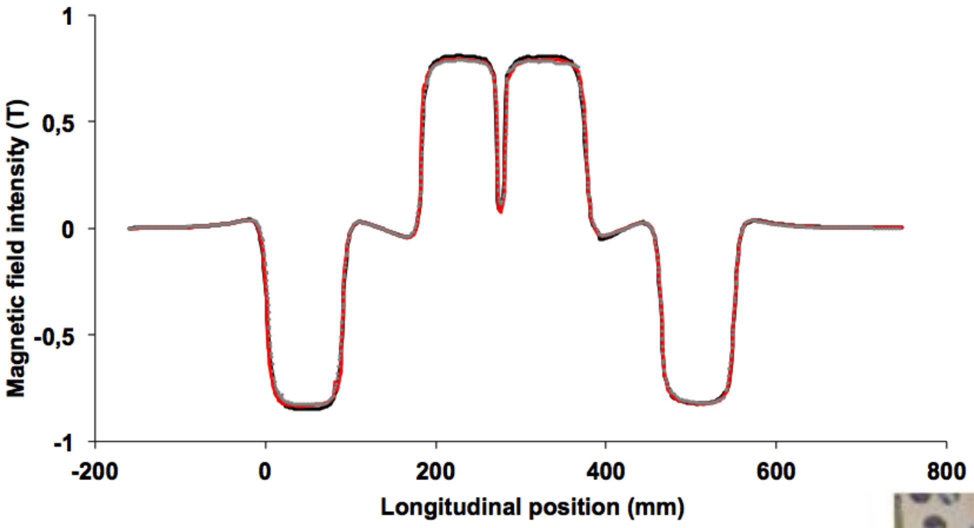
Technical design

The First dipole prototype

The ESS

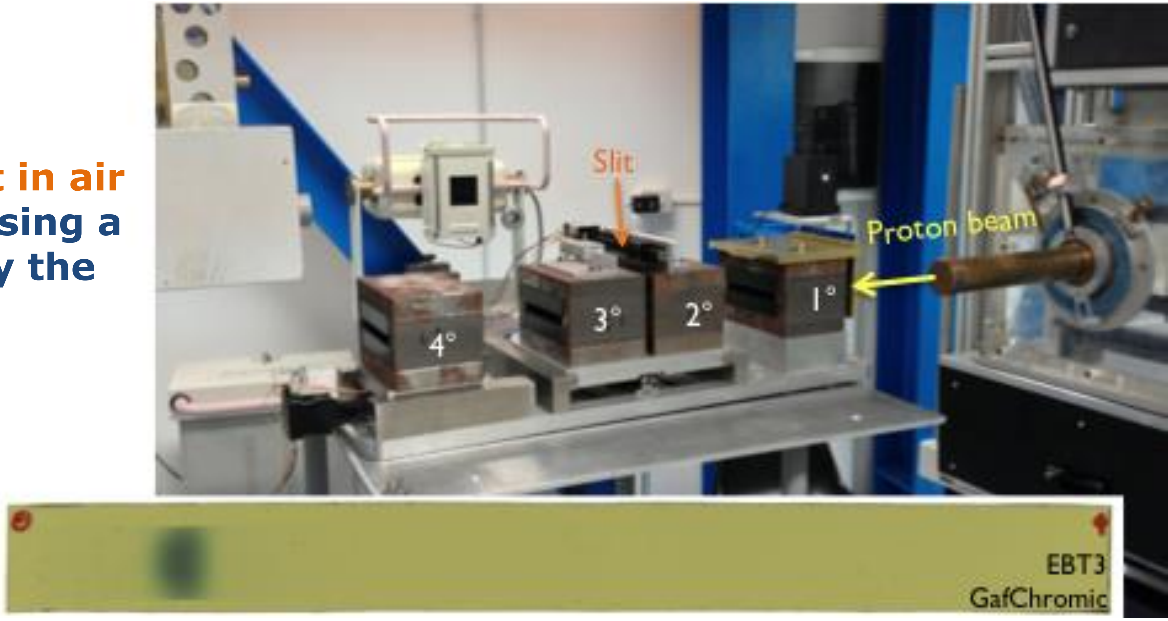
The ESS inside the vacuum chamber

Status of the ESS prototype @ LNS (CT)



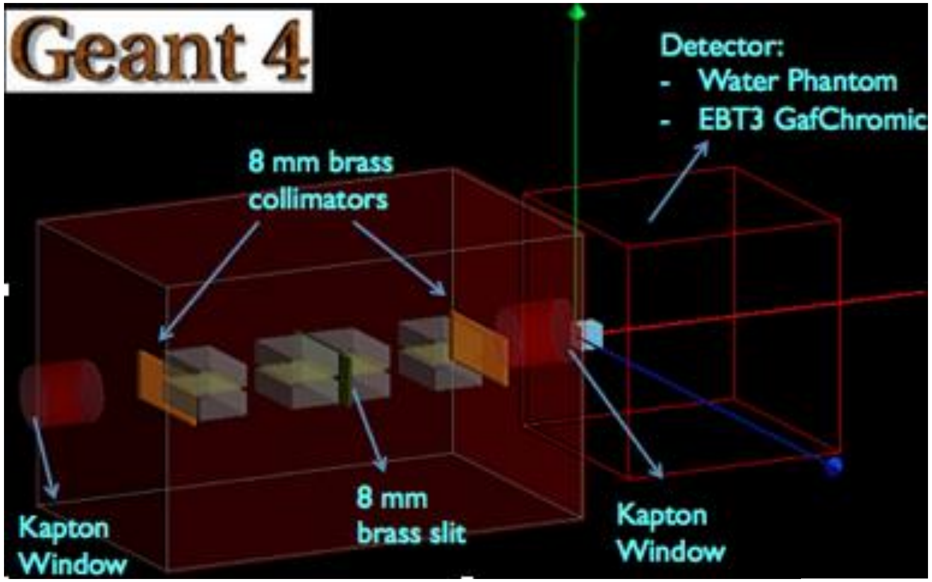
Magnetic fied profiles measured on the 3 axes along the radial plane

April 2013: First experimental test in air on the ESS prototype @ CATANA using a 62 MeV proton beam delivered by the Superconductive Cyclotron



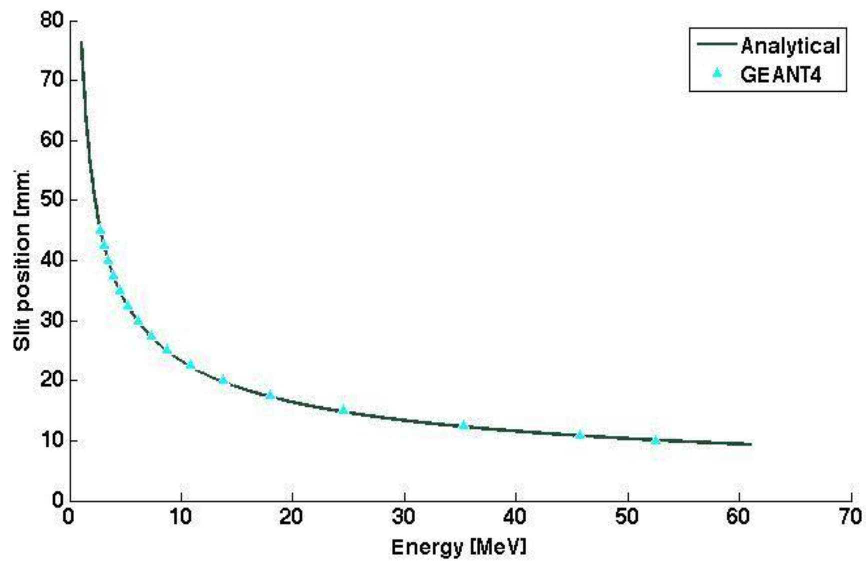
ESS Geant4 simulation

Monte Carlo Simulation of the ESS



Entrance energy	0-80 MeV
Beam shape	Uniform
First collimator hole size (diameter)	3 mm
Slit hole size	1 mm
Slit Material	W, 6 mm thick
Final collimator hole size (diameter)	1 mm
Window material	Kapton

ESS simulation: Magnetic field treated with the hard-edge approximation



Monte Carlo Simulation for the Transport Beamline
AIP Conf. Proc. 1546, pp. 63-69

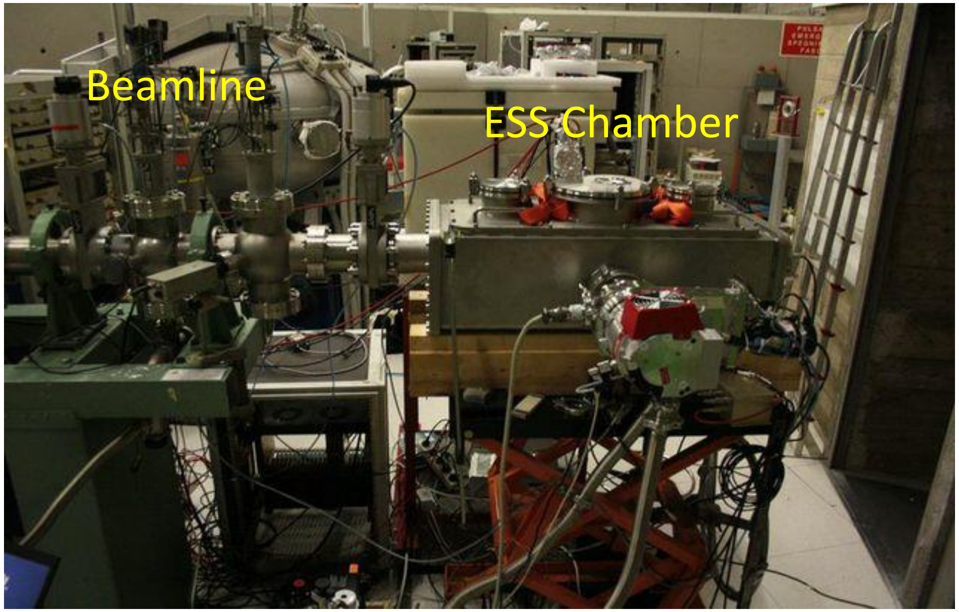
ESS calibration @ LNS *September 2013*

Calibration performed using the proton beam delivered by the TANDEM at LNS

Proton energies: 4.5 - 12 MeV

Experimental run aims:

- **Calibration of the slit position as function of the beam energy**
- **4° dipole position calibration**
- **Beam profile**
- **Transmission efficiency**
- **Validate ESS simulation**



Monte Carlo activity with Geant4

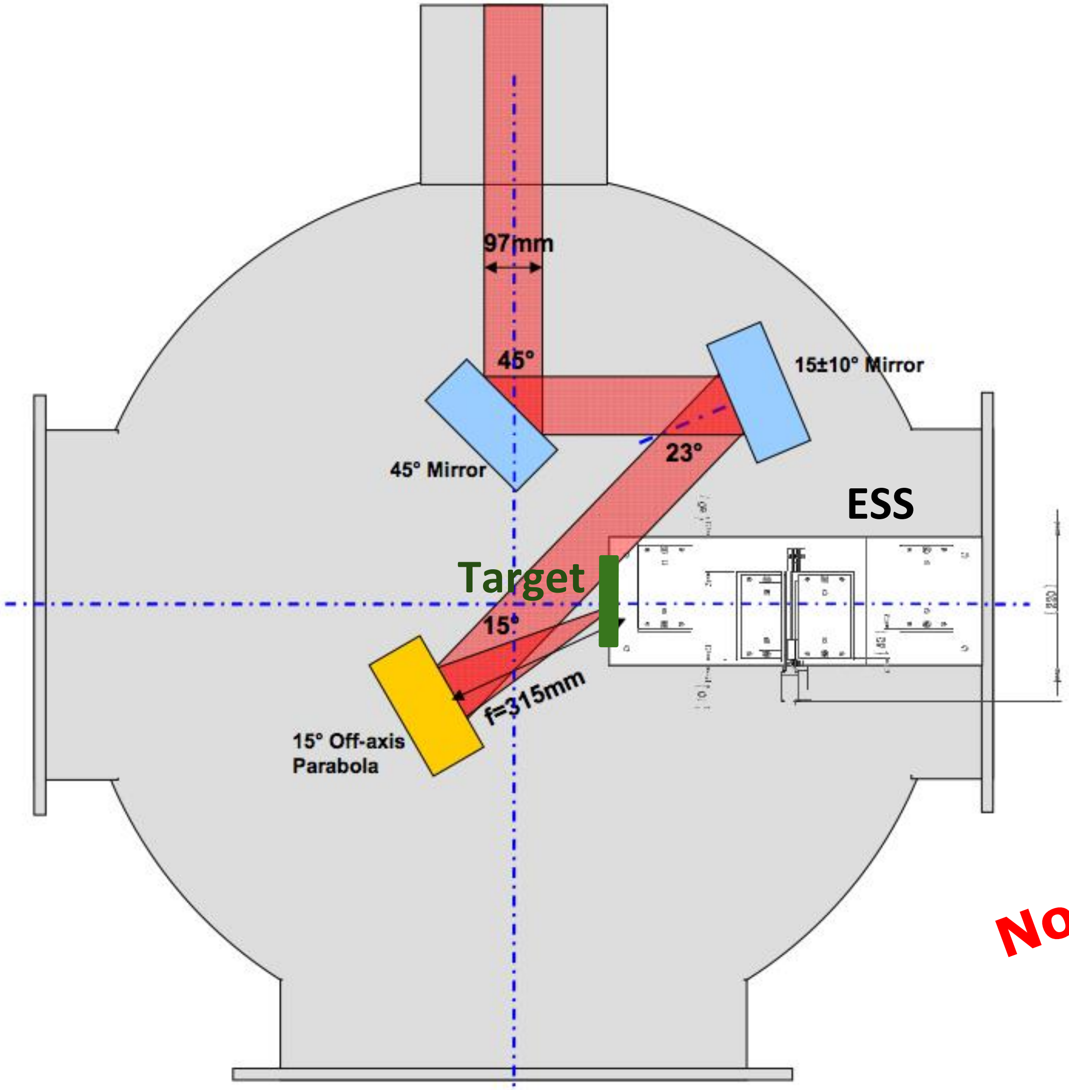
eli beamlines

- **Design and optimization of the ELIMED beamline**

  - **Energy selection system**
  - **Transport beam line optimization**
  - **Irradiation approach**
  - **Radioprotection and dosimetry**

- **Simulation of the available test-site facility TARANIS (UK), LULI (F), JAEA (Japan) for an accurate delivered dose evaluation**

The TARANIS experiment



Laser beam (Ti:sapphire-Nd:glass)
Intensity -> **10^{19} W/cm^2**
Pulse duration -> 700 fs
laser wavelength ->1053 nm

Proton beam detectors:
- **CR-39**
- **RCF, GafChromic**
- **Si** detector (Surface barrier or Strips)
- **SiC**
- **Diamond** detector

November-December 2013

Dosimetry and radiobiology

Study and design of a dosimetric system for dose measurements and irradiation of bio-samples

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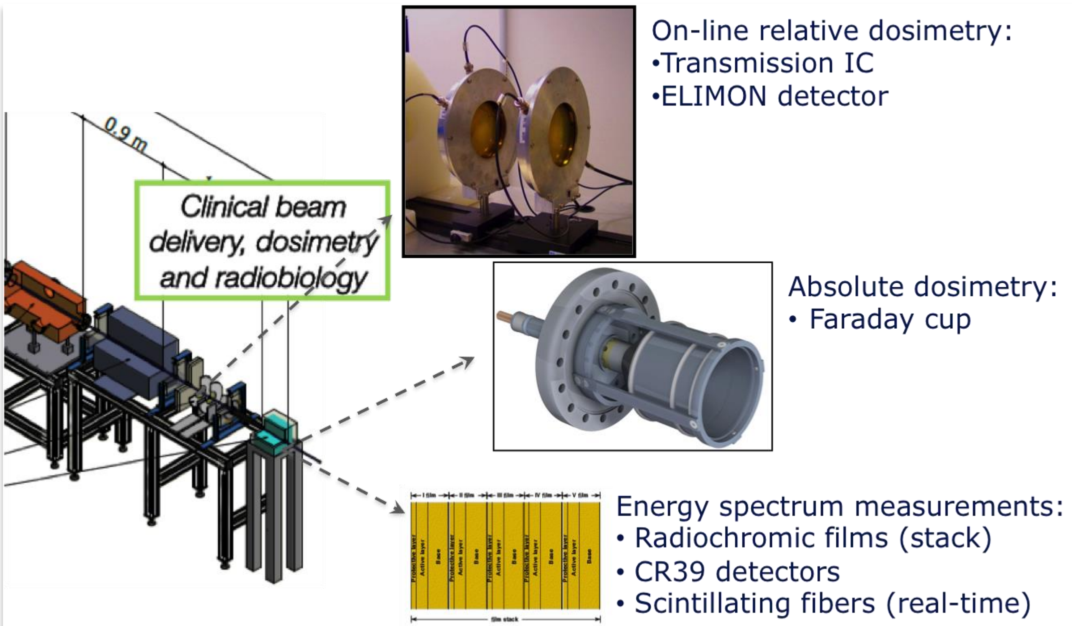
Dosimetric system

Solutions adopted for relative dosimetry:

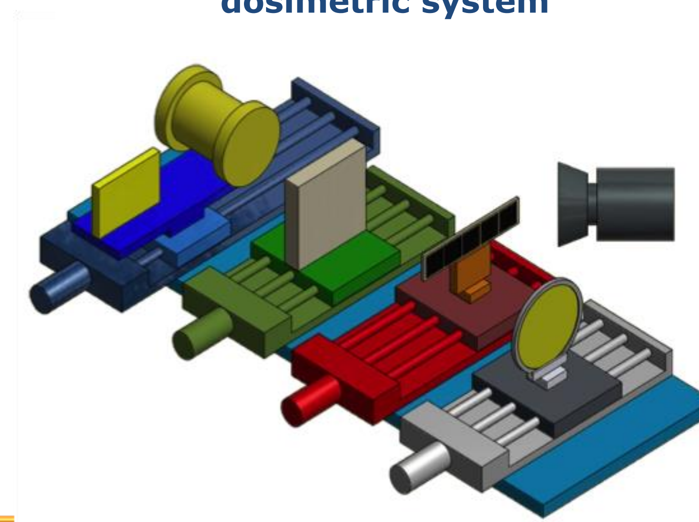
- **GafChromic films (passive)**
- **High-rates Transmission chamber (on-line)**

Solutions adopted for the absolute dosimetry:

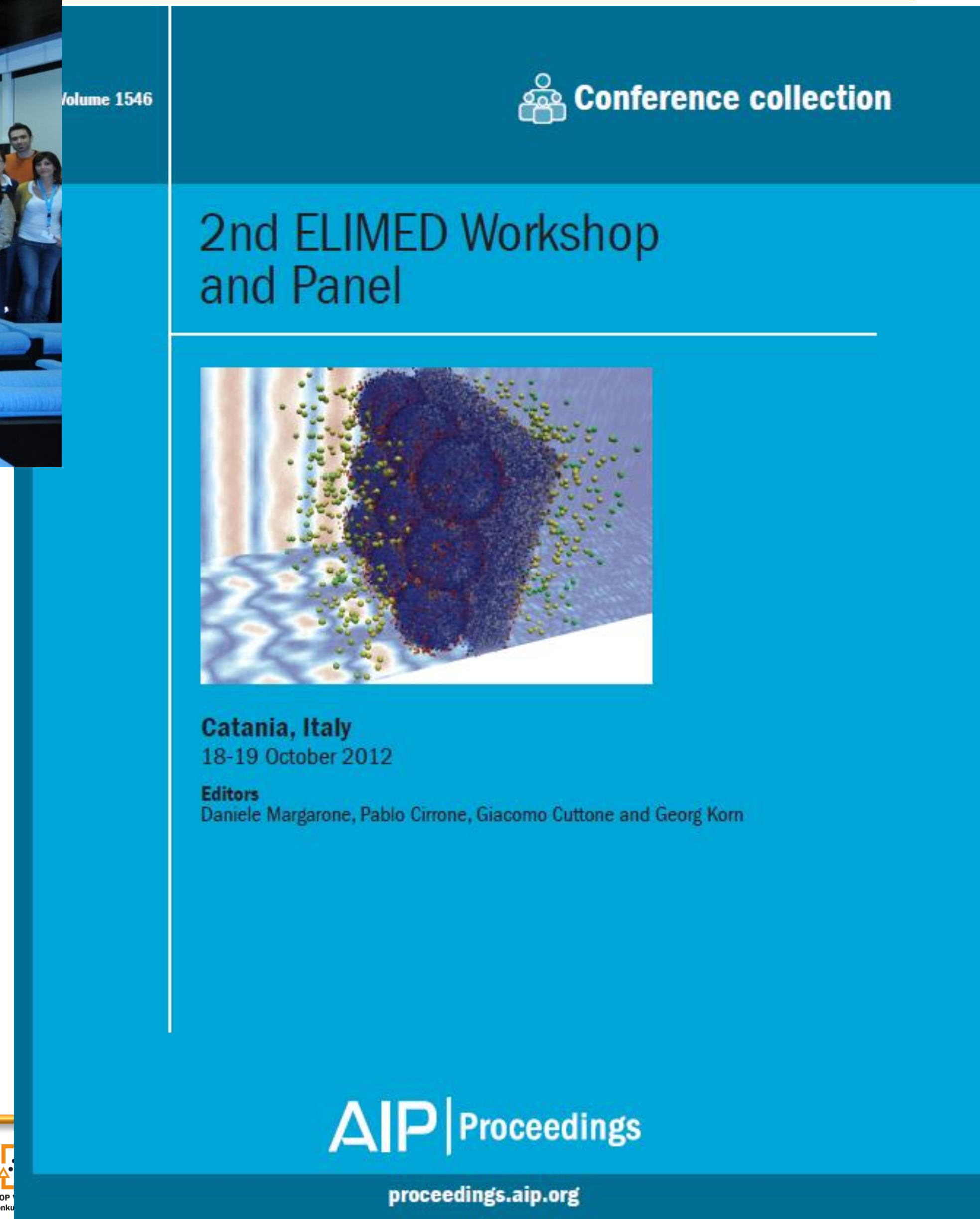
- **Faraday cups coupled with:**
  - **GafChromic/CR39 stacks for energy spectrum and beam spot measurements at the entrance (passive)**
  - **Scintillating fibers for energy spectrum measurements (on-line)**



Preliminary design of a dedicated dosimetric system




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