10th International Conference on Radiation Effects on Semiconductor Materials, Detectors, Devices
October 8-10, Florence (I)

ELIMED

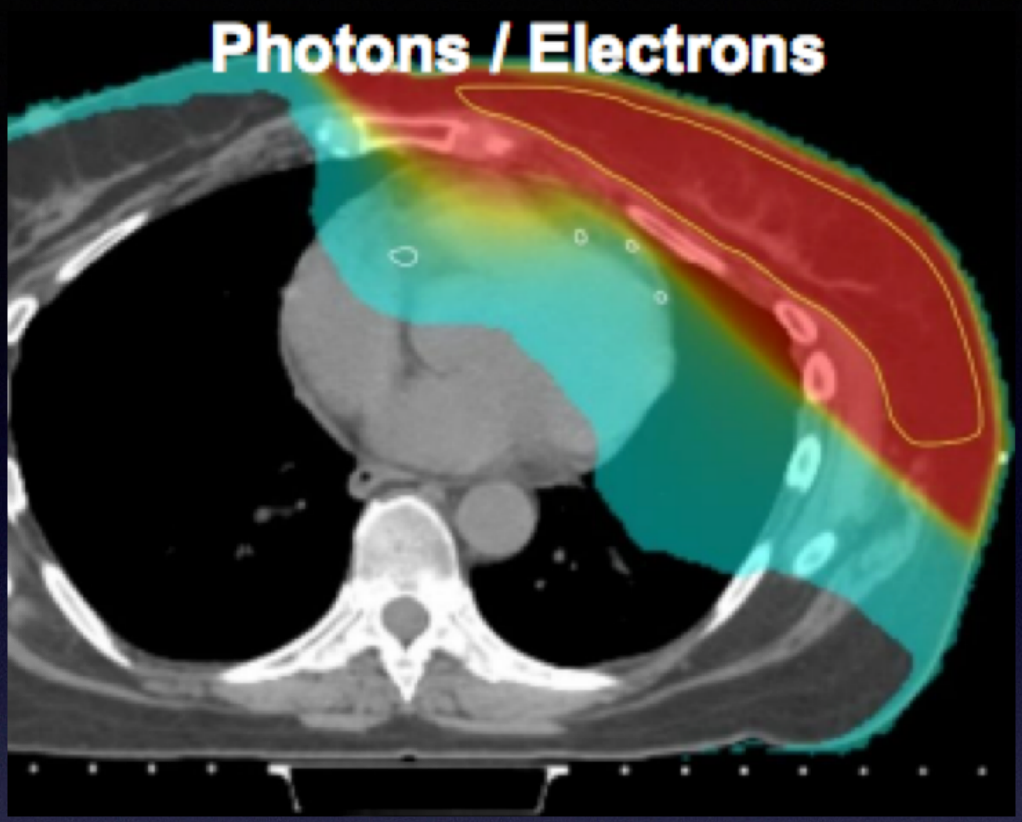
ELI-Beamlines MEDical applications

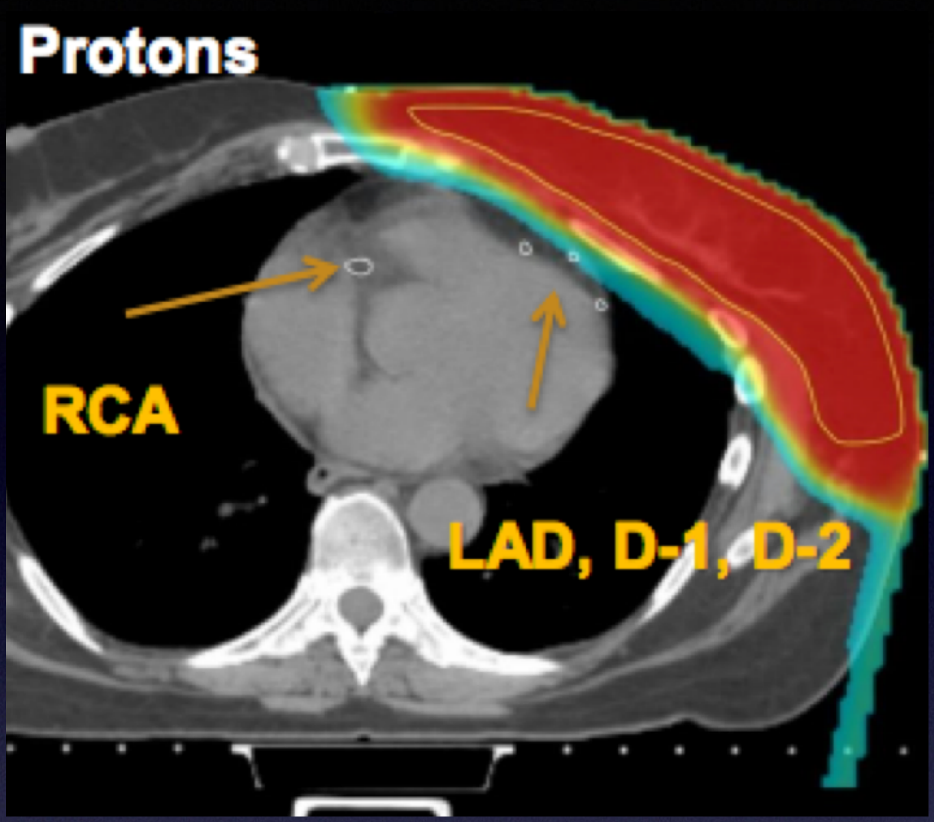
Dr GAP Cirrone, PhD, Med. Physicist
Italian Institute for Nuclear Physics (INFN)
Catania, Italy
On behalf of the ELIMED project

OUTLINE

Can laser-accelerated ions be feasible for medical purposes ?

Hadrontherapy: breast treatment





Potential impact

Coronary artery stenosis

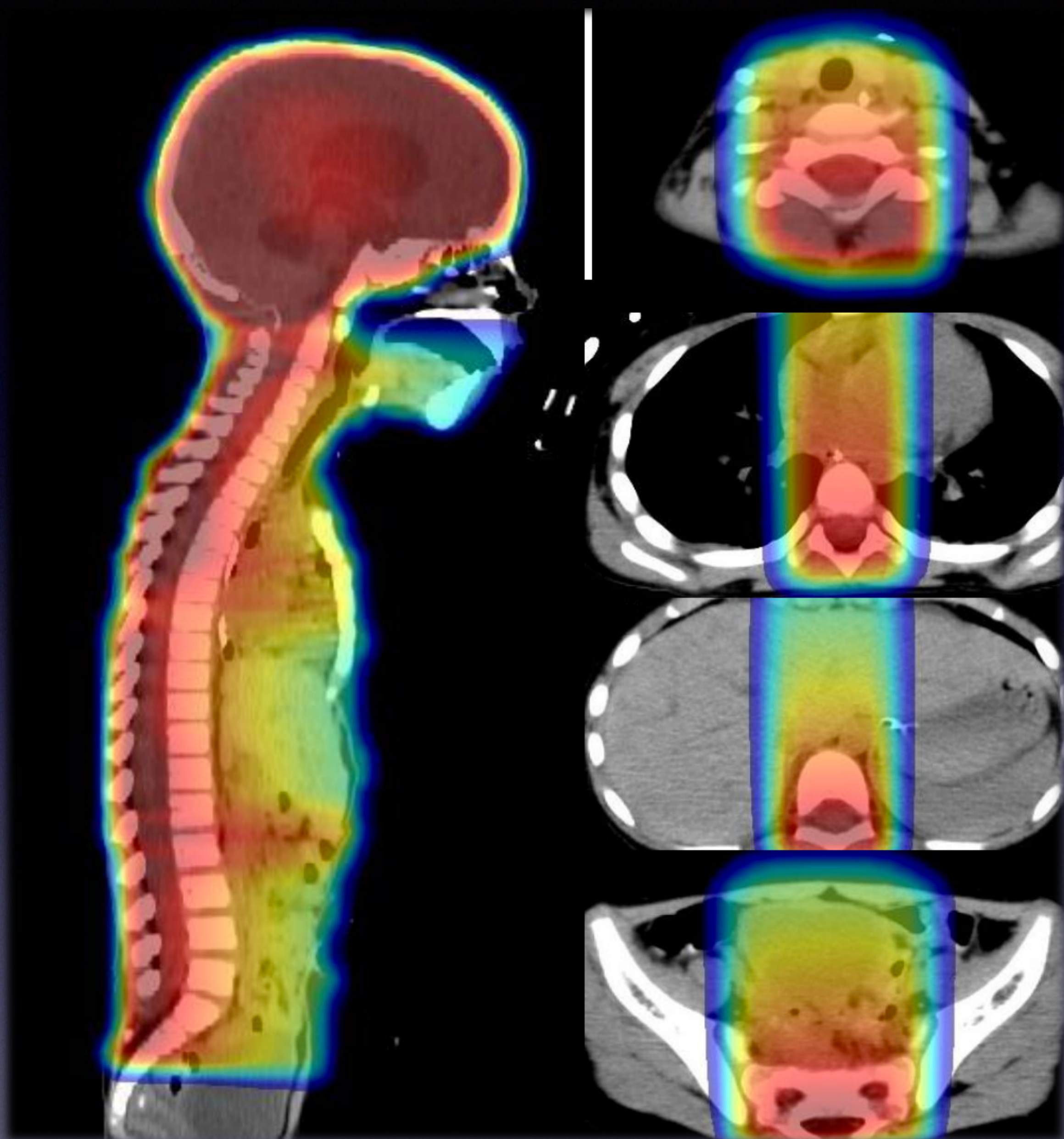
Secondary malignancy

Lung function

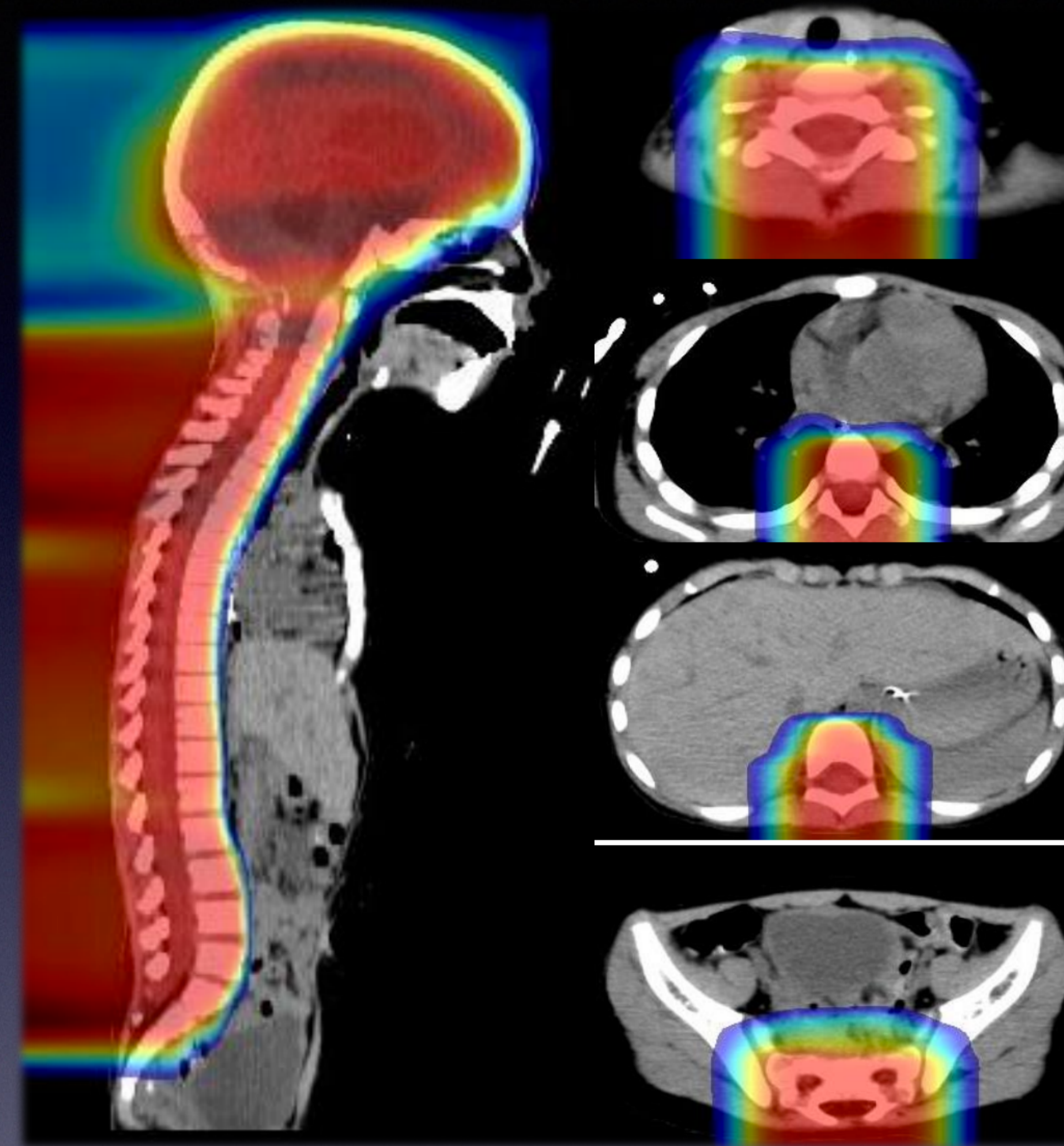
	Left-sided breast cancer	Right-sided breast cancer
Coronary arthery disease	25%	10%
Chest pain	26%	12%
Myocardial infarction	15%	5%

Harris ERR et al.
Late cardiac mortality and morbidity in early stage breast cancer patients after breast conservation treatment,
J. Clin. Oncol. 2006 24 (25)4104

Hadrontherapy: the medulloblastoma



x-Ray therapy



Protontherapy

Mirabell RA et al.
Potential reduction of the incidence of radiation-induced second cancers by using proton beams in the treatment of pediatric tumor,
Int. Jour. Rad. Onc. Phys. 2002, 54 (3) 824

Hadrontherapy: the medulloblastoma

Reduction of secondary tumour risk: medulloblastoma case

Pediatric Medulloblastoma: The yearly risk of getting a secondary tumor was estimated to be 8 times greater with X-rays than with proton therapy [2]

Tumor Site	Proton Therapy	X-rays/IMRT
Stomach and esophagus	0%	11%
Colon	0%	7%
Breast	0%	0%
Lung	1%	7%
Thyroid	0%	6%
Bone and connective tissue	1%	2%
Leukemia	3%	5%
All Secondary Cancers	**5%**	**43%**

This chart compares the rates of secondary tumors for a pediatric patient treated for medulloblastoma.

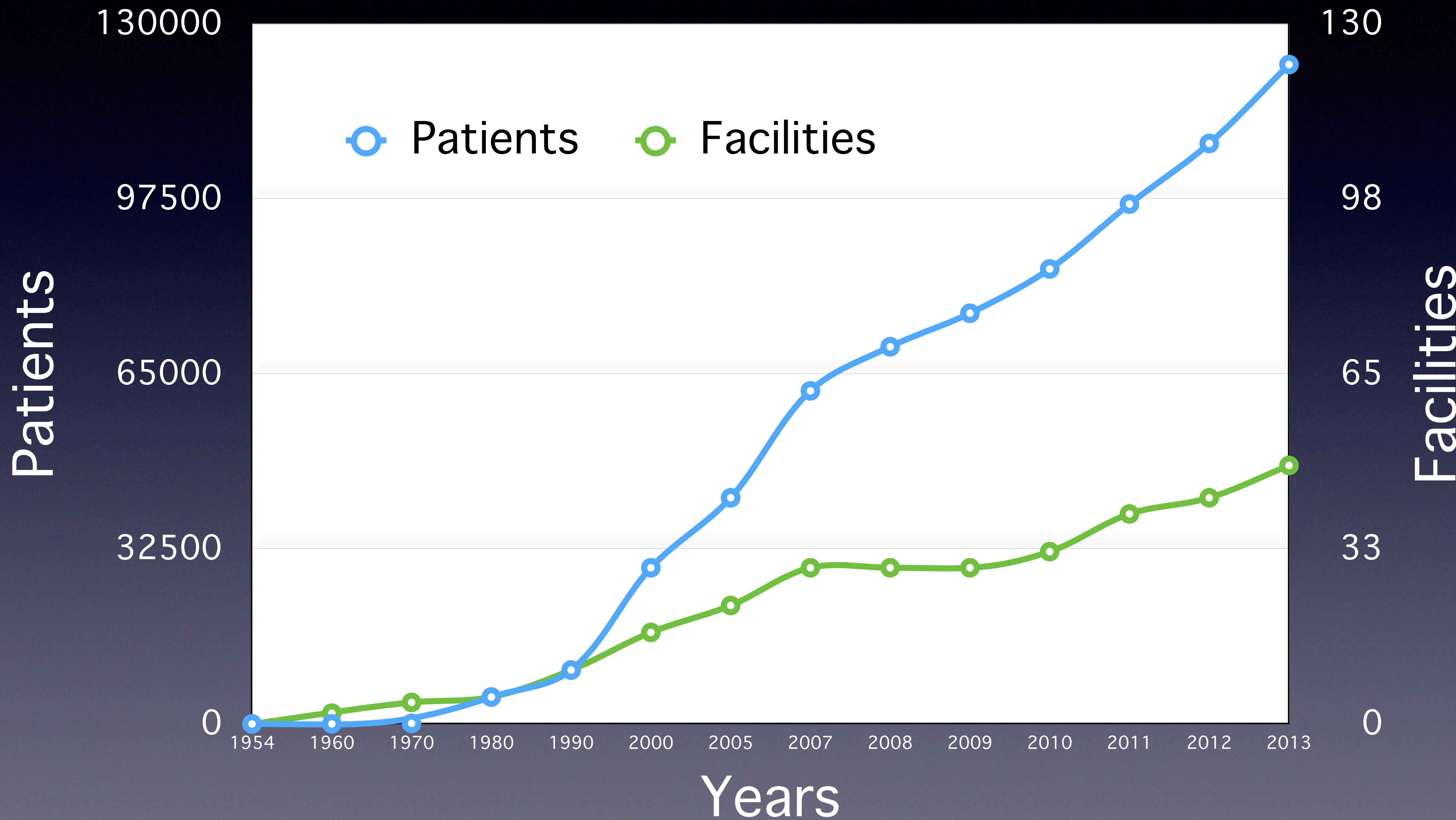
Data shown are from a study that compared treatment plans.

IMRT= intensity modulated radiation therapy (a type of X-ray therapy)

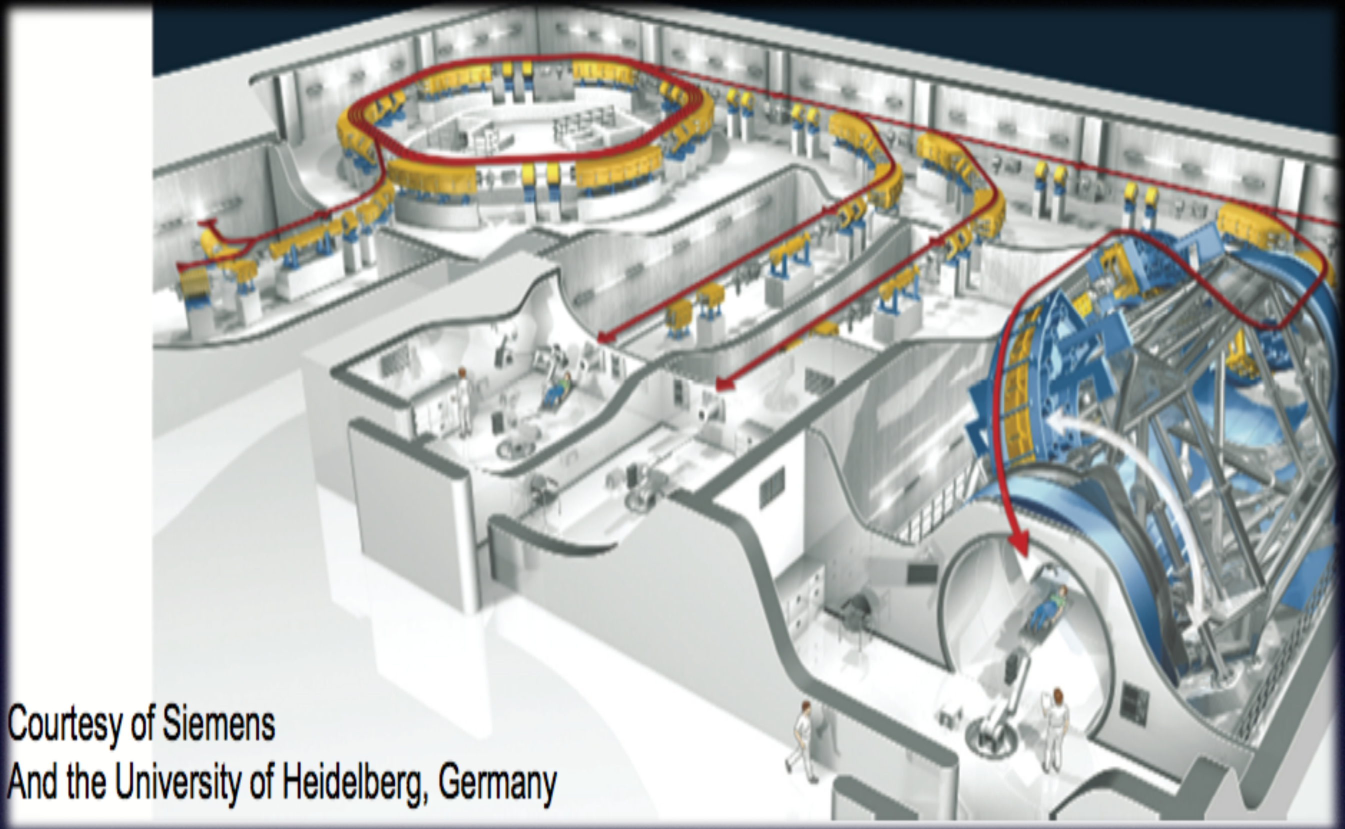
Mirabell RA et al.
Potential reduction of the incidence of radiation-induced second cancers by using proton beams in the treatment of pediatric tumor,
Int. Jour. Rad. Onc. Phys. 2002, 54 (3) 824

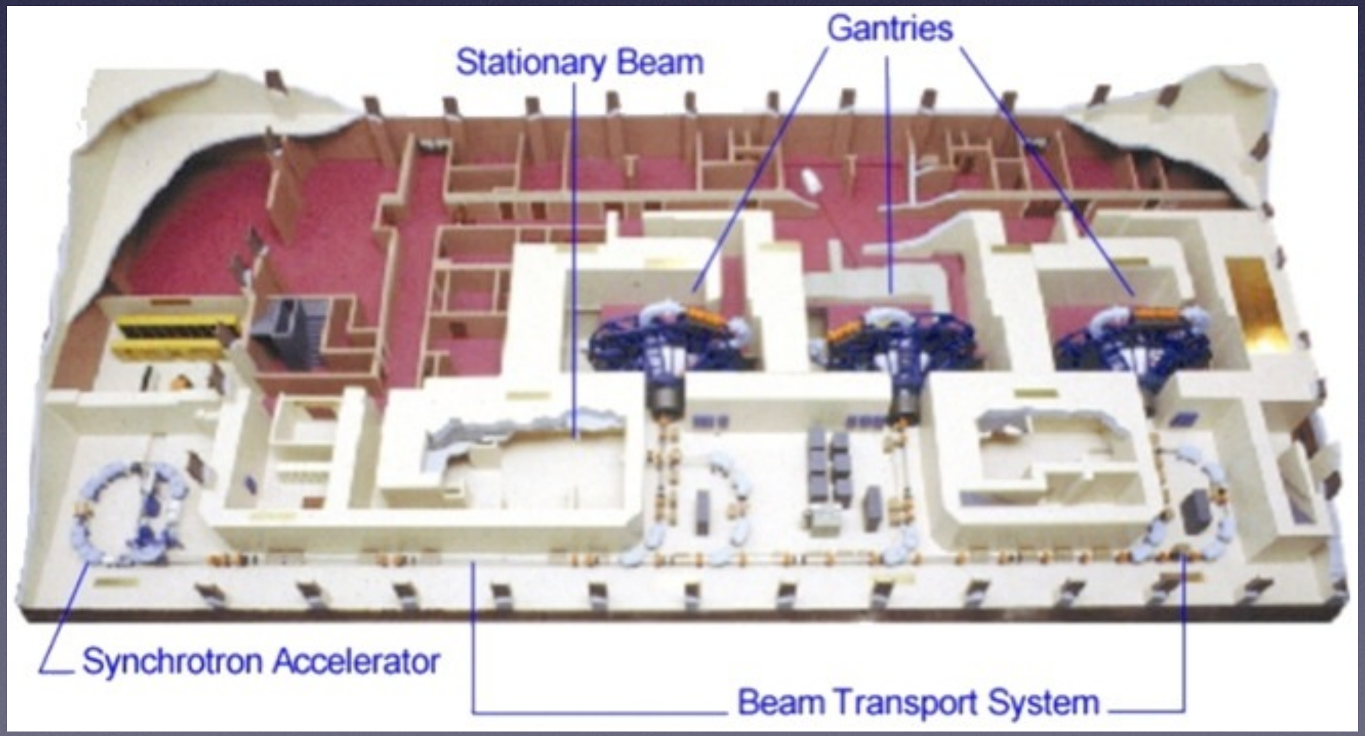
Hadrontherapy faces a fast growing demand

Facilities in operation 40 Under realisation 36



Particle Therapy Cooperative Group (PTCOG)
http://www.ptcog.ch





Complex

Huge

Expensive
(order of 100 M€)

Limited

Charged particle therapy—optimization, challenges and future directions

Jay S. Loeffler and Marco Durante

Abstract | The use of charged particle therapy to control tumours non-invasively offers advantages over conventional radiotherapy. Protons and heavy ions deposit energy far more selectively than X-rays, allowing
a higher local control of the tumour, a lower probability of da
and the chance for a rapid recovery after therapy. Charged p
located in areas that surround tissues that are radiosensiti
limited. Current trial outcomes indicate that accelerated ior
treatments, which might be beneficial as the success of su
the expertise and experience of the surgeon and the locatic
number of controlled randomized clinical trials have made c
Therefore, although the potential advantages are clear and
controversial. Research in medical physics and radiobiology
the benefits of this treatment.

Loeffler, J. S. & Durante, M. Nat. Rev. Clin. Oncol. advance or ... lication

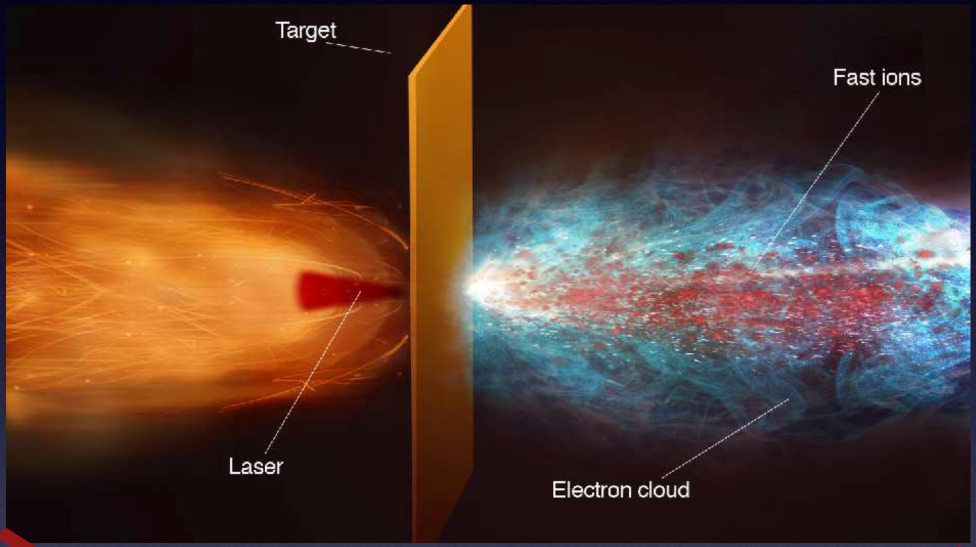
Research and development in the field of accelerators should be towards a reduction of costs, while maintaining or improving the performances of the current machines. Possible new accelerators for CPT[122] include synchrocyclotrons, rapid cycling synchrotrons, fixed-field alternating gradient rings, cyclotron–linac combinations, dielectric wall accelerators, and laser-driven plasma accelerators.[123] These options are at very different stages of design maturity, but all offer promising design features to offset the shortcomings of current synchrotrons, including fast scanning capabilities, reduced size, complexity and power consumption, increased dose rate capability, and ultimately a lower cost and a shorter treatment time.[14]

Research of a “dream” solution

can we reduce size, complexity and cost without loosing the quality ?

Research of a “dream” solution

can we reduce size, complexity and cost without loosing the quality ?



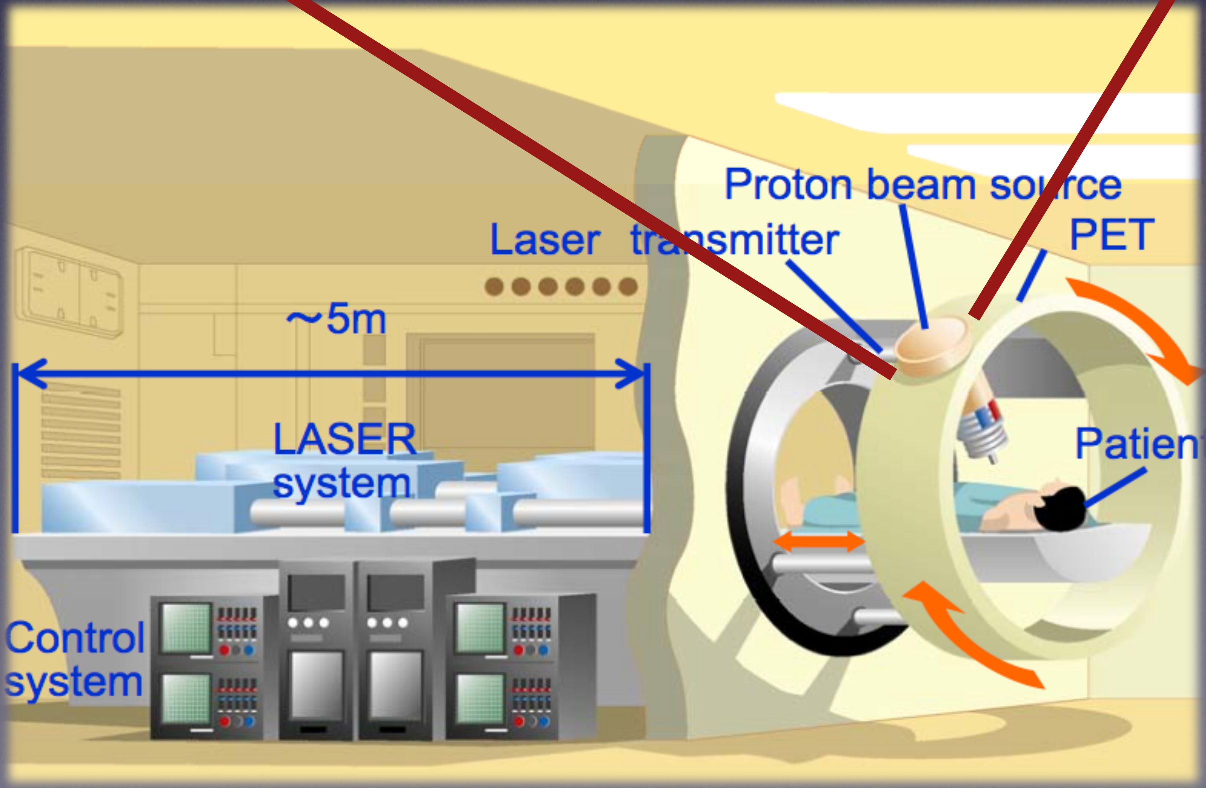
Simple

Small

Cheap (order of 10 M€)

Widespread

Multi-beam and modalities

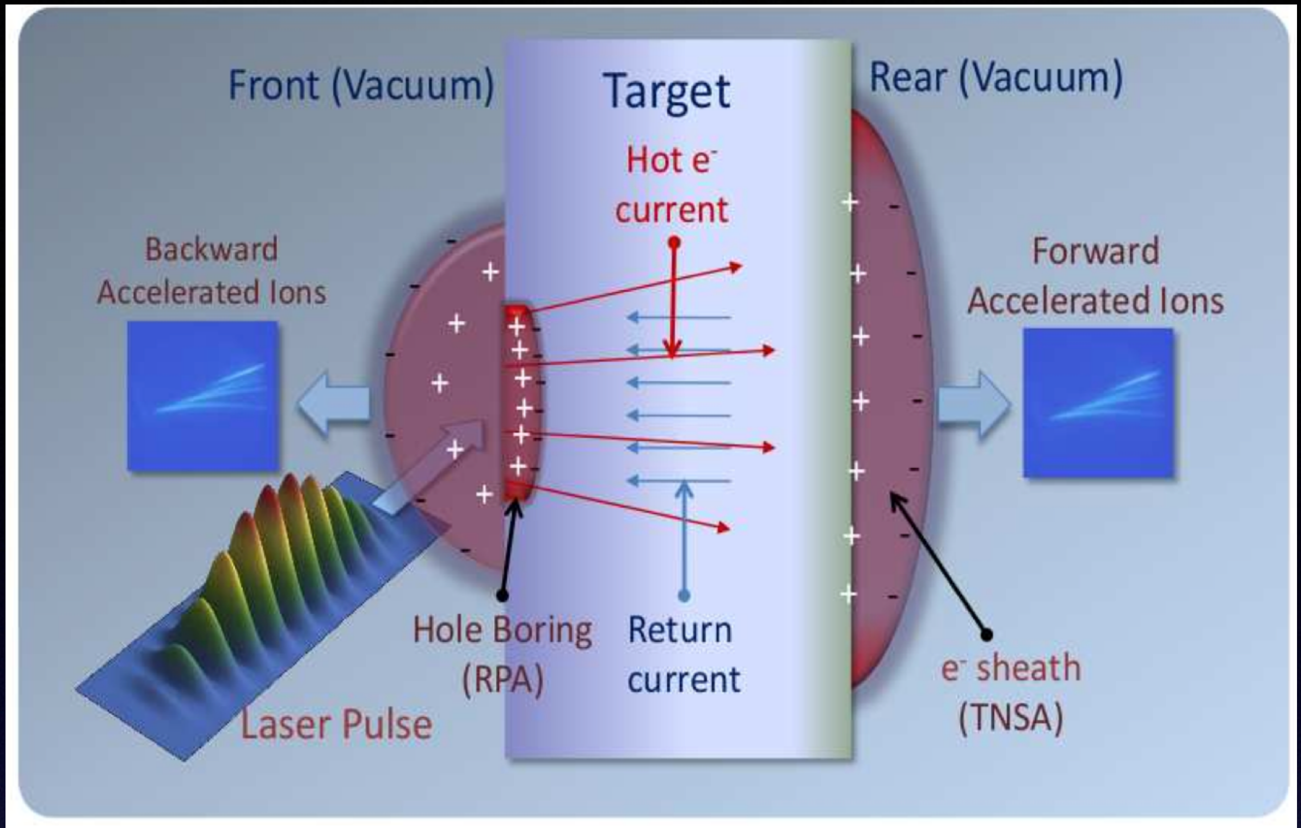


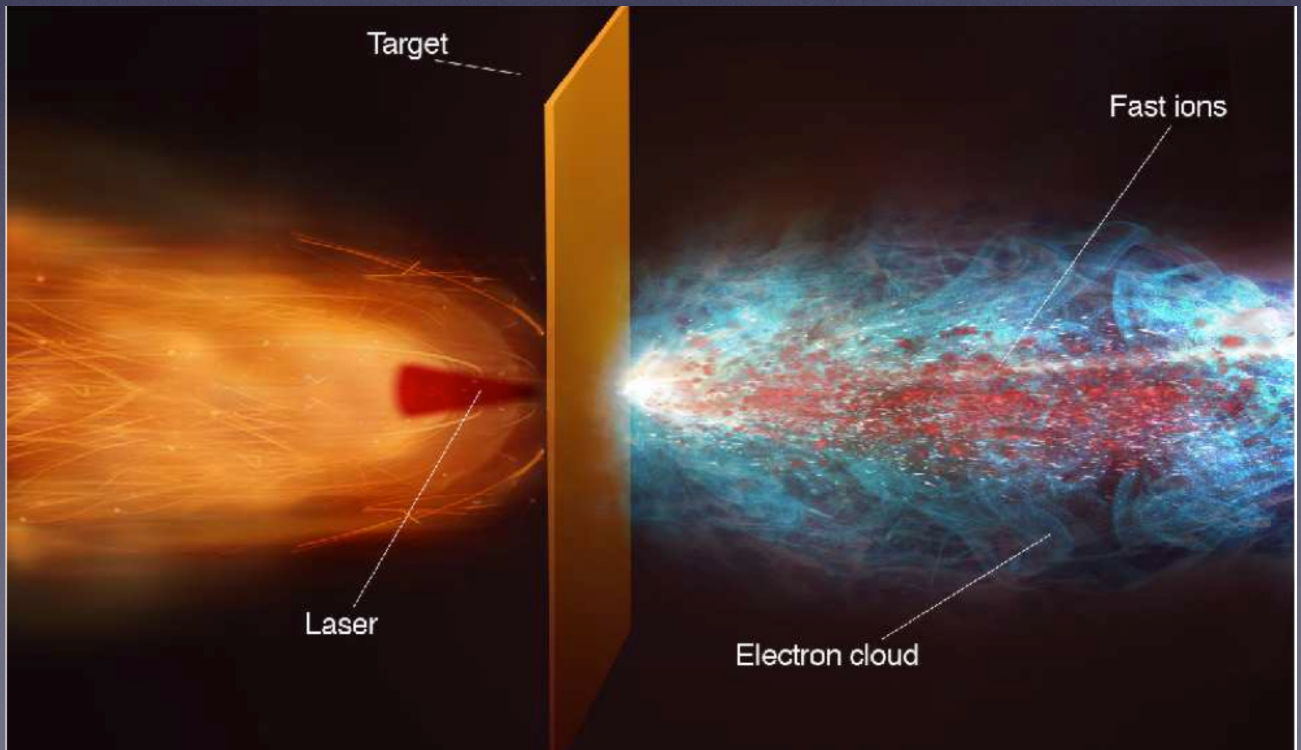
An intense laser field ($> 10^{18}$ W/cm^2) blows-off electrons from a target surface

A strong electric field (TW/m) is created able to accelerate protons

Acceleration mechanism are under study and many aspects have been still understood

Acceleration devices more compact by a factor of 1/10 - 1/100





Acceleration mechanisms

Mechanism	Laser intensity [W/cm2]	Expected maximum protons/ions energies [MeV]
Target Normal Sheath Acceleration (TNSA)	10	15 - 100
Coulomb explosion	> 10	quasi mono-energetic 50 - 70
Radiation Pressure Acceleration (RPA)	10	quasi mono-energetic >1000

Maximum energies and spectra

65+ MeV Protons from Short-Pulse-Laser Micro-Cone-Target Interactions[1] S.A. GAILLARD, FZD/UNR, K.A. FLIPPO, D.C. GAUTIER, D.T. OFFERMANN, J.B. WORKMAN, F. ARCHULETA, R. GONZALES, T. HURRY, R.P. JOHNSON, S. LETZRING, D.S. MONTGOMERY, S.M. REID, T. SHIMADA, LANL, T. LOCKARD, Y. SENTOKU, UNR, M.M. LOWENSTERN, J.E. MUCINO, AOSS, U of M, Ann Arbor, D.B. GALL, U of Mo, Columbia, E. D'HUMIERES, U. Bordeaux 1, M. GEISSEL, M. SCHOLLMEIER, SNL, M. BUSSMAN, T.E. COWAN, T. KLUGE, J.M. RASSUCHINE,

LLNL Laboratory (US)
65 MeV

Towards radiation pressure acceleration of protons using linearly polarized ultrashort petawatt laser pulses

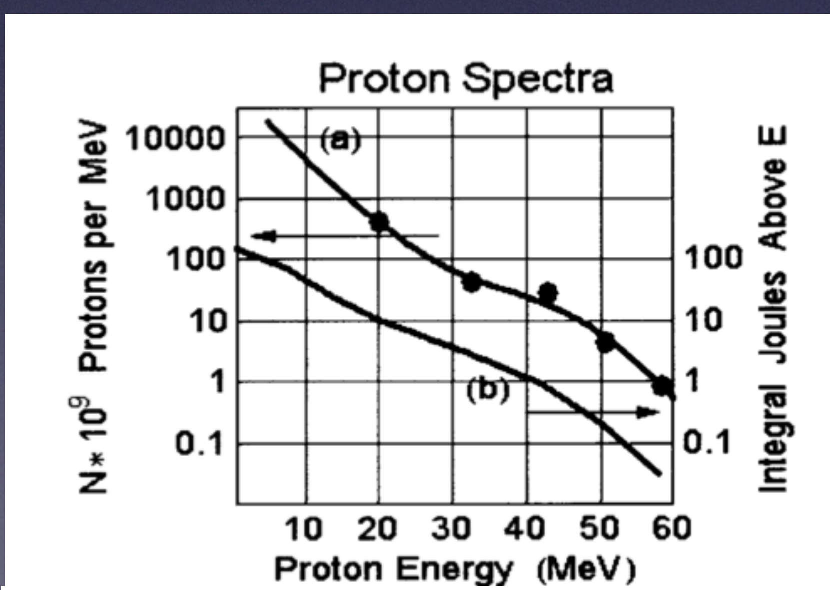
I Jong Kim, Ki Hong Pae, Chul Min Kim, Hyung Taek Kim, Jae Hee Sung, Seong Ku Lee, Tae Jun Yu, Il Woo Choi, Chang-Lyoul Lee, Kee Hwan Nam, Peter V. Nickles, Tae Moon Jeong, Jongmin Lee

(Submitted on 1 Apr 2013)

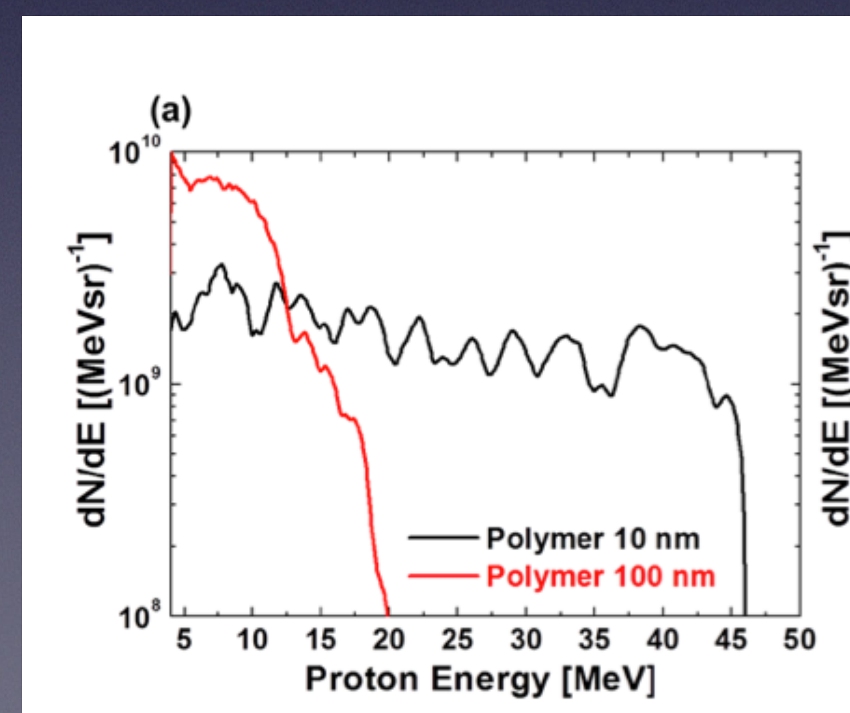
Particle acceleration using ultraintense, ultrashort laser pulses is one of the most attractive topics in relativistic laser-plasma research. We report proton/ion acceleration in the intensity range of 5x1019 W/cm2 to 3.3x1020 W/cm2 by irradiating linearly polarized, 30-fs, 1-PW laser pulses on 10- to 100-nm-thick polymer targets. The proton energy scaling with respect to the intensity and target thickness was examined. The experiments demonstrated, for the first time with linearly polarized light, a transition from the target normal sheath acceleration to radiation pressure acceleration and showed a maximum proton energy of 45 MeV when a 10-nm-thick target was irradiated by a laser intensity of 3.3x1020 W/cm2. The experimental results were further supported by two- and three-dimensional particle-in-cell simulations. Based on the deduced proton energy scaling, proton beams having an energy of ~ 200 MeV should be feasible at a laser intensity of 1.5x1021 W/cm2.

Comments: 33 pages
Subjects: Plasma Physics (physics.plasm-ph)
Cite as: arXiv:1304.0333 [physics.plasm-ph]
(or arXiv:1304.0333v1 [physics.plasm-ph] for this version)

APRI-GIST Laser facility (2013)



Snavely et al. (2000), Phys. Rev. Lett. 85, 2945.



What we need for treatment ?

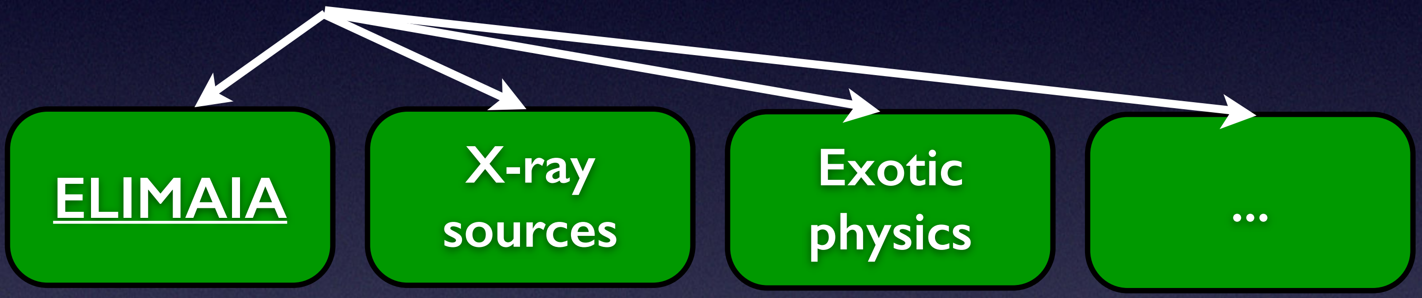
	Conventional beams	Laser-driven beams
Maximum energy	250 MeV 400 AMeV	?
Current	order of nA	?
Monochromaticity	$\Delta E/E \leq 10$	?
Stability, reproducibility, control, absolute dosimetry	Less that 3%	?
Radiobiology	Almost known	?

ELIMED idea was born in 2012 as a collaboration network in this field

GAP Cirrone, INFN-LNS. (I)
D Margarone, ELI-Beamlines (CZ)

ELI (Extreme Light Infrastructure)

new type of European large scale laser infrastructure specifically designed to produce the highest peak power (10 PW) and focused intensity;



ELI (Extreme Light Infrastructure)

new type of European large scale laser infrastructure specifically designed to produce the highest peak power (10 PW) and focused intensity;

- ELI-Beamlines (Czech Rep.)
  - ELIMAIA
  - X-ray sources
  - Exotic physics
  - ...
- Ungary
- Romania
- tbd

ELI (Extreme Light Infrastructure)

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  - ELIMAIA
  - X-ray sources
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  - ...
- Ungary
- Romania
- tbd

ELIMAIA:

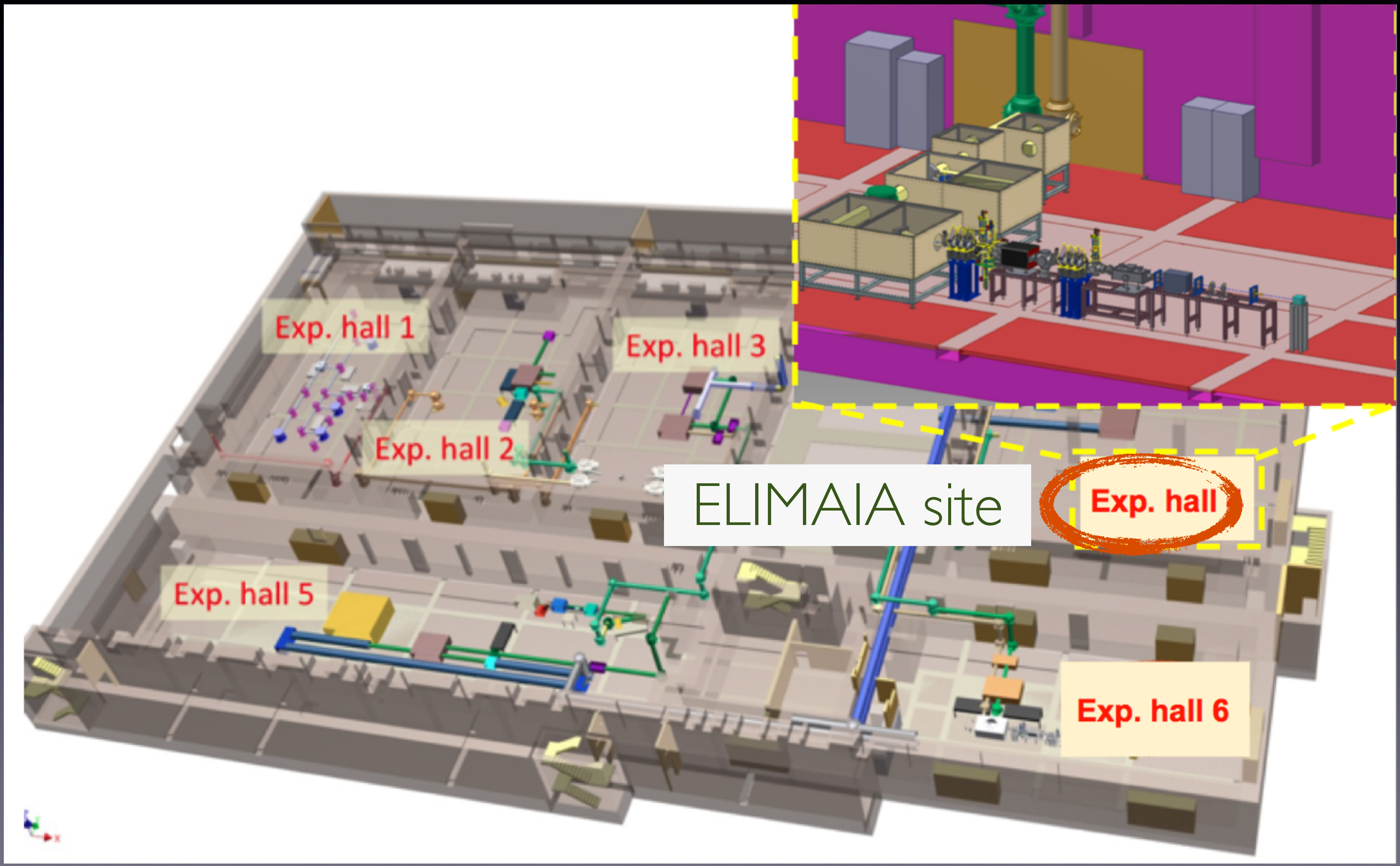
ELI Multisiplinary Applications of laser-Ion Acceleration

- ELIMAIA is an ELI-Beamline facility
- ELIMED is a collaboration network around ELIMAIA

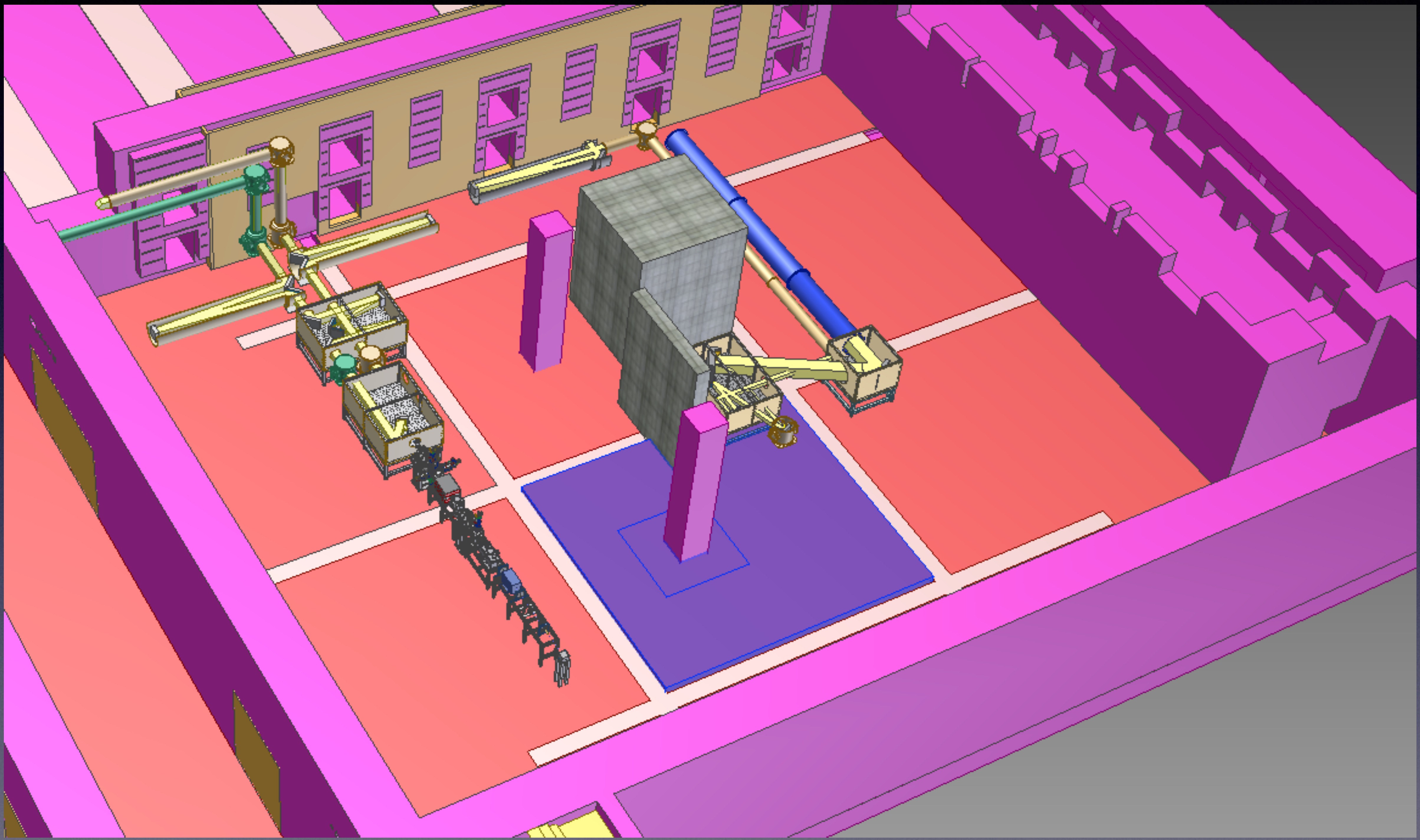
Study, design, realization of innovative elements for laser-driven particle beams to be used in multidisciplinary applications

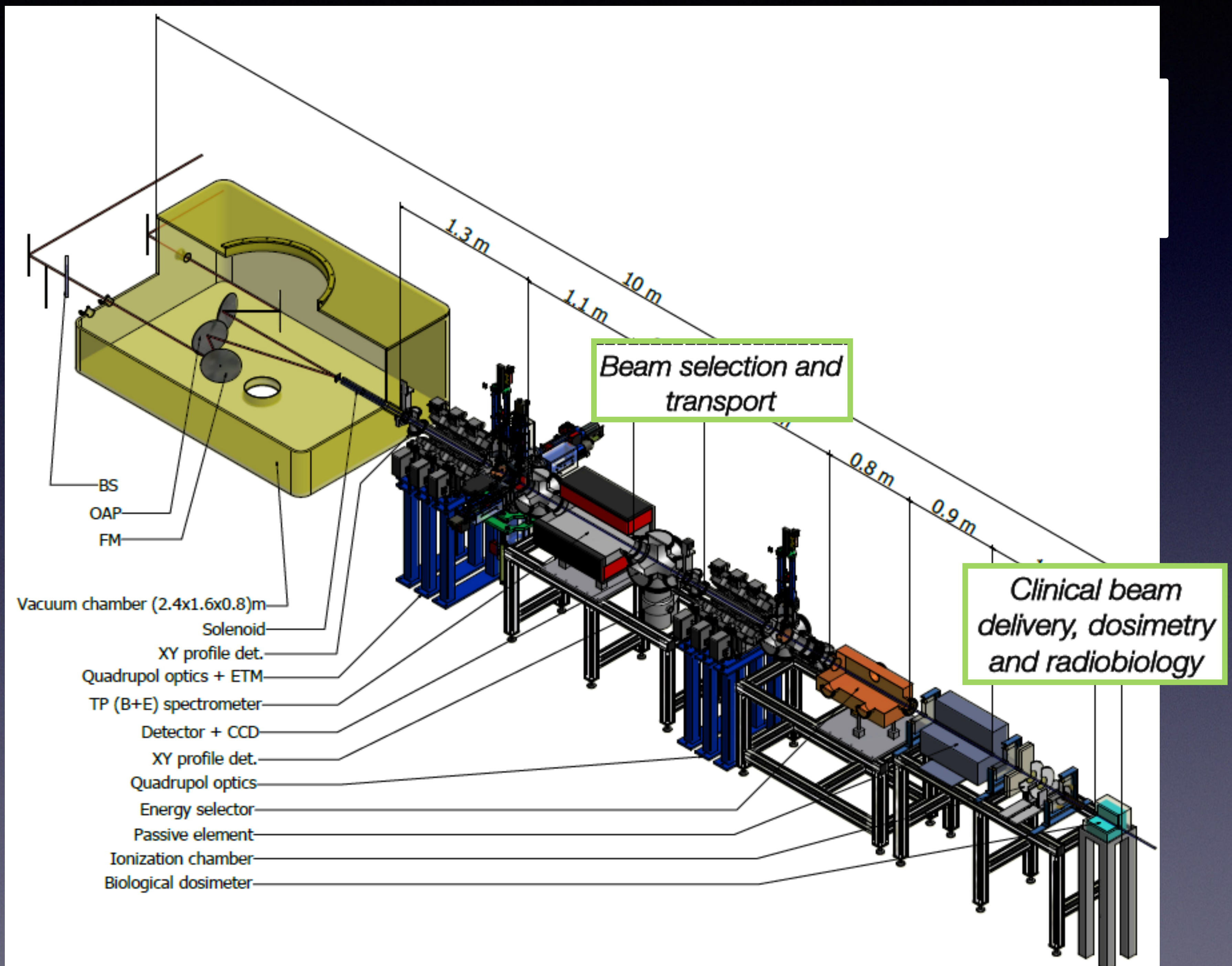
ELIMED
is a network

- Fyzikální ústav AV ČR, v.v.i.
- INFN Istituto Nazionale di Fisica Nucleare
- Queen's University Belfast
- Alma Mater Studiorum Università di Bologna
- Técnico Lisboa
- Sapienza Università di Roma
- The University of California 1868
- Azienda Ospedaliero-Universitaria Policlinico-Vittorio Emanuele
- HZDR Helmholtz Zentrum Dresden Rossendorf
- KPSI Kansai Photon Science Institute
- University of Belgrade / Универзитет у Београду
- ITA Istituto Tecnologie Avanzate Laboratorio Nano Tecnologie
- Consiglio Nazionale delle Ricerche Istituto di Bioimmagini e Fisiologia Molecolare
- Fondazione Bruno Kessler

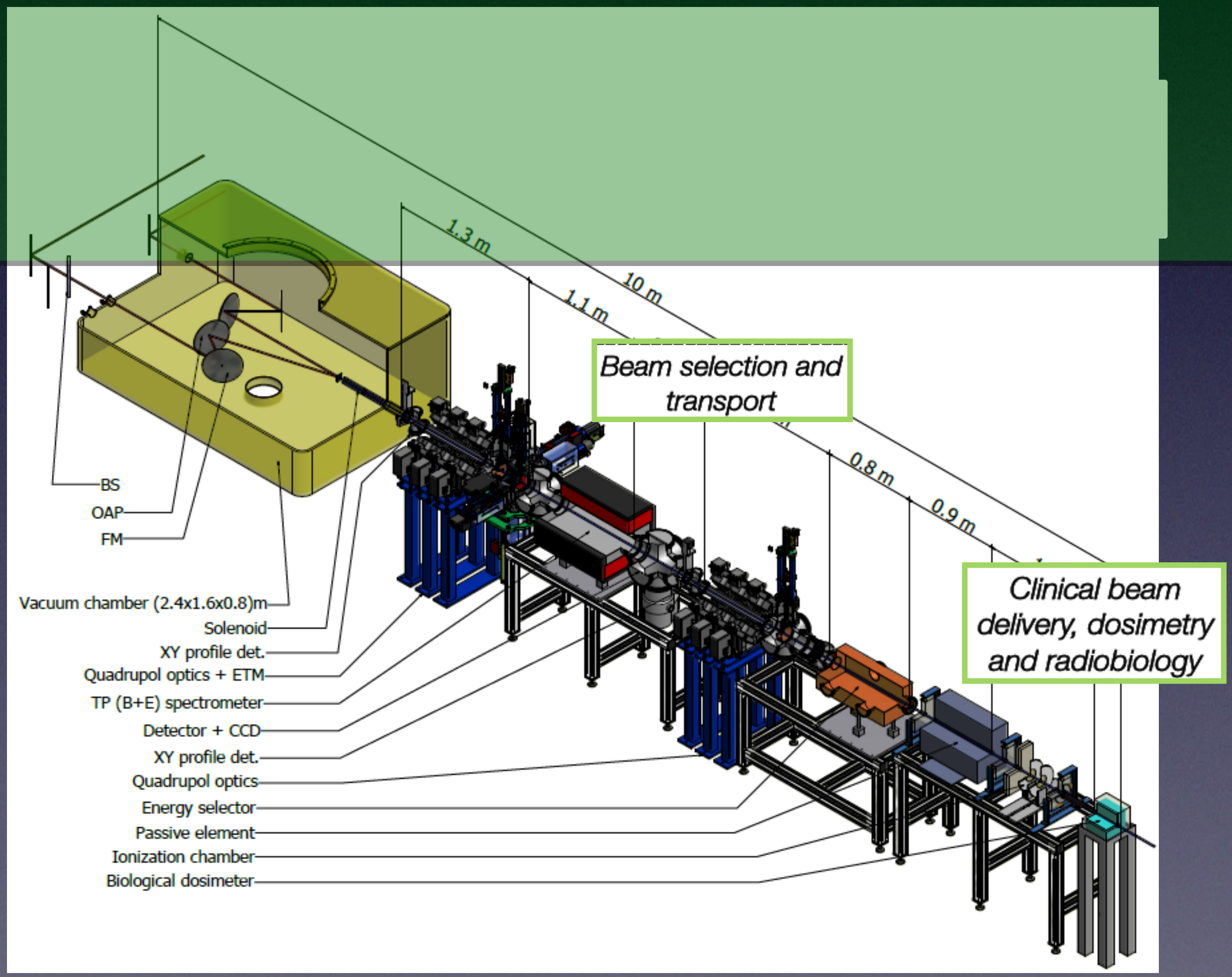


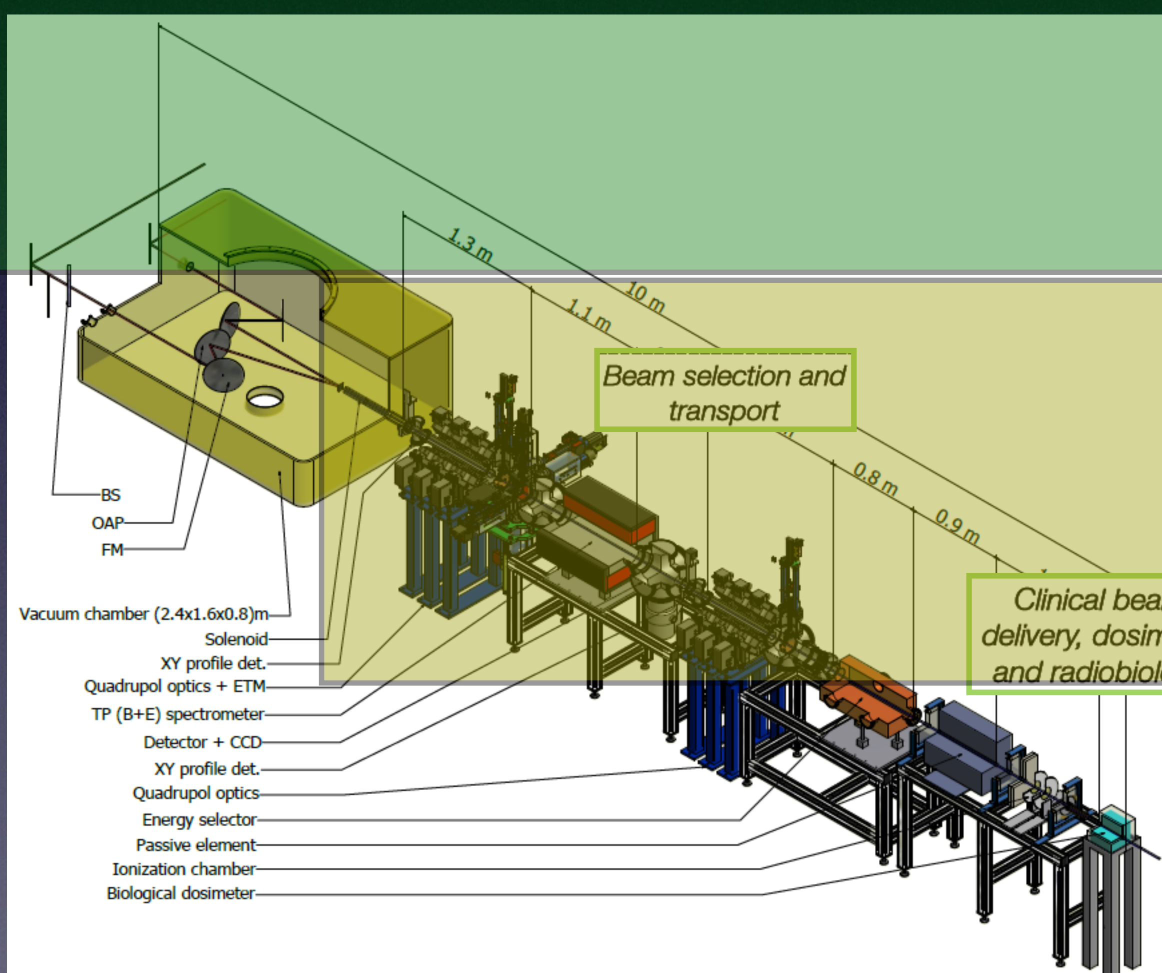
Exp. hall 1
Exp. hall 3
Exp. hall 2
ELIMAIA site
Exp. hall
Exp. hall 5
Exp. hall 6




1.3 m
10 m
1.1 m
0.8 m
0.9 m
Beam selection and transport
Clinical beam delivery, dosimetry and radiobiology
BS
OAP
FM
Vacuum chamber (2.4x1.6x0.8)m
Solenoid
XY profile det.
Quadrupol optics + ETM
TP (B+E) spectrometer
Detector + CCD
XY profile det.
Quadrupol optics
Energy selector
Passive element
Ionization chamber
Biological dosimeter

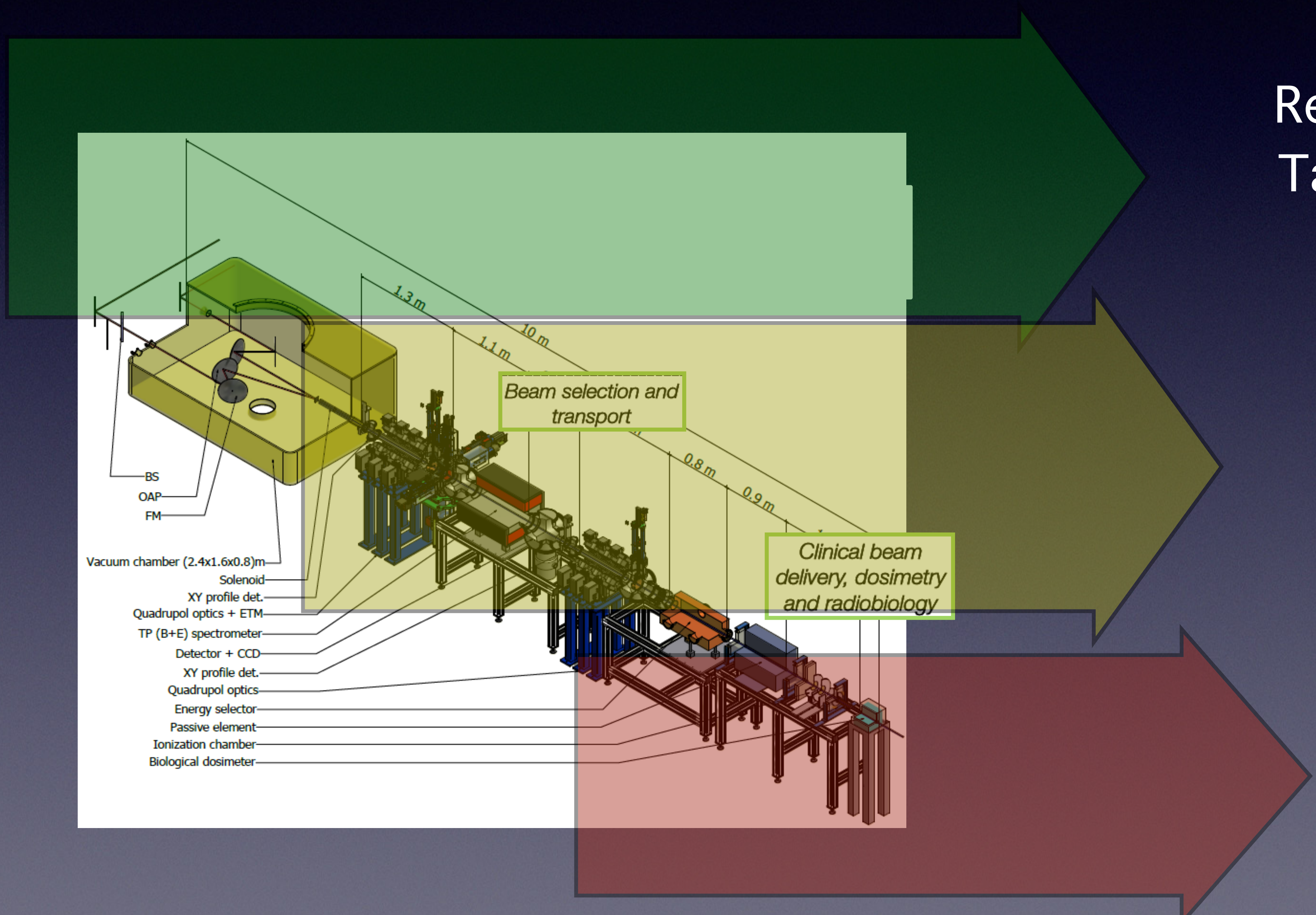
Research area 1: Target and laser interaction





Research area 1: Target and laser interaction

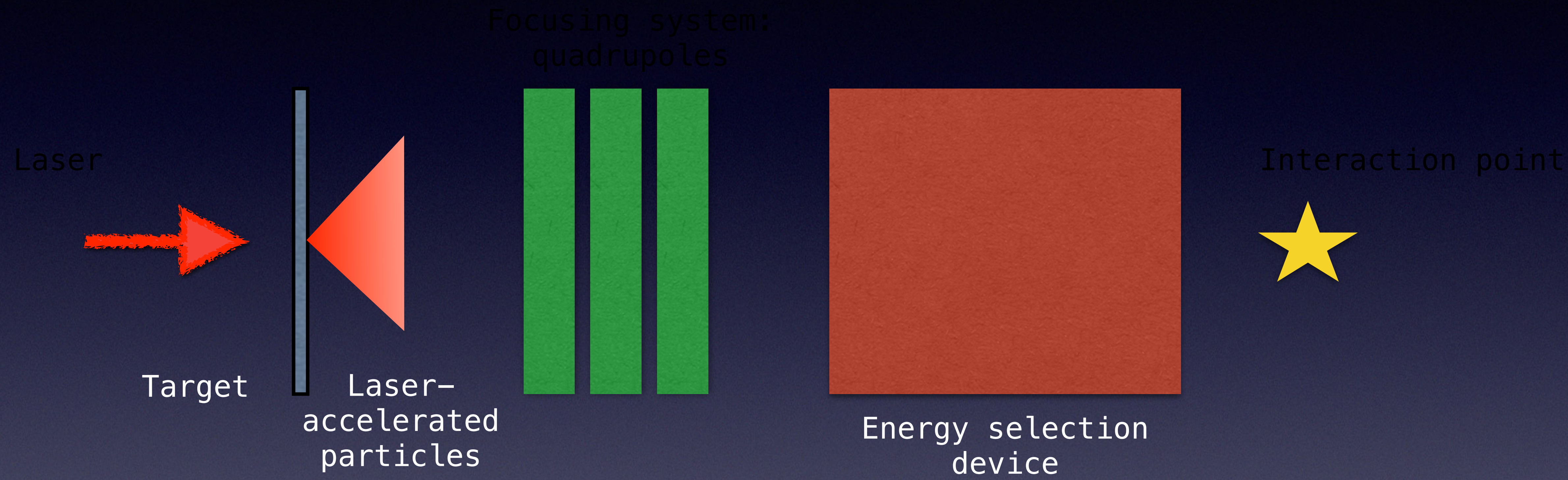
Research area 2: Beam handling and diagnostic



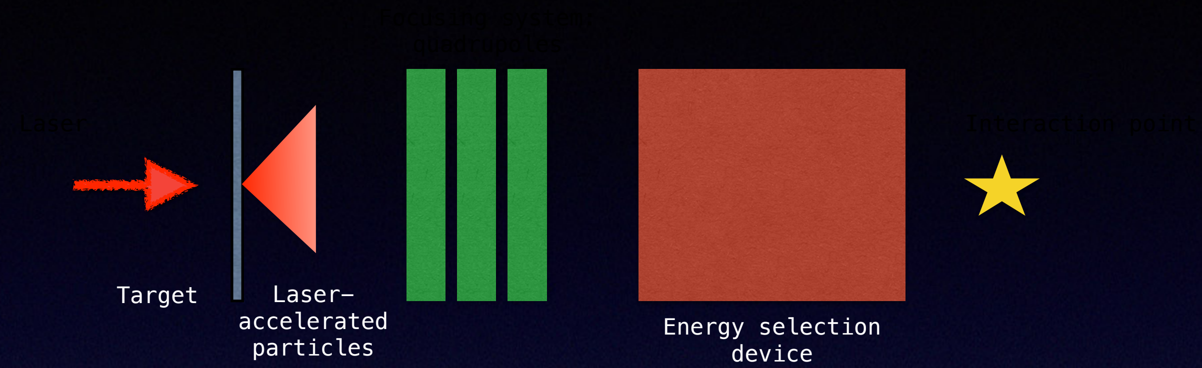
Research area 1:
Target and laser interaction

Research area 2:
Beam handling and diagnostic

Research area 3:
Dosimetry and radiobiology

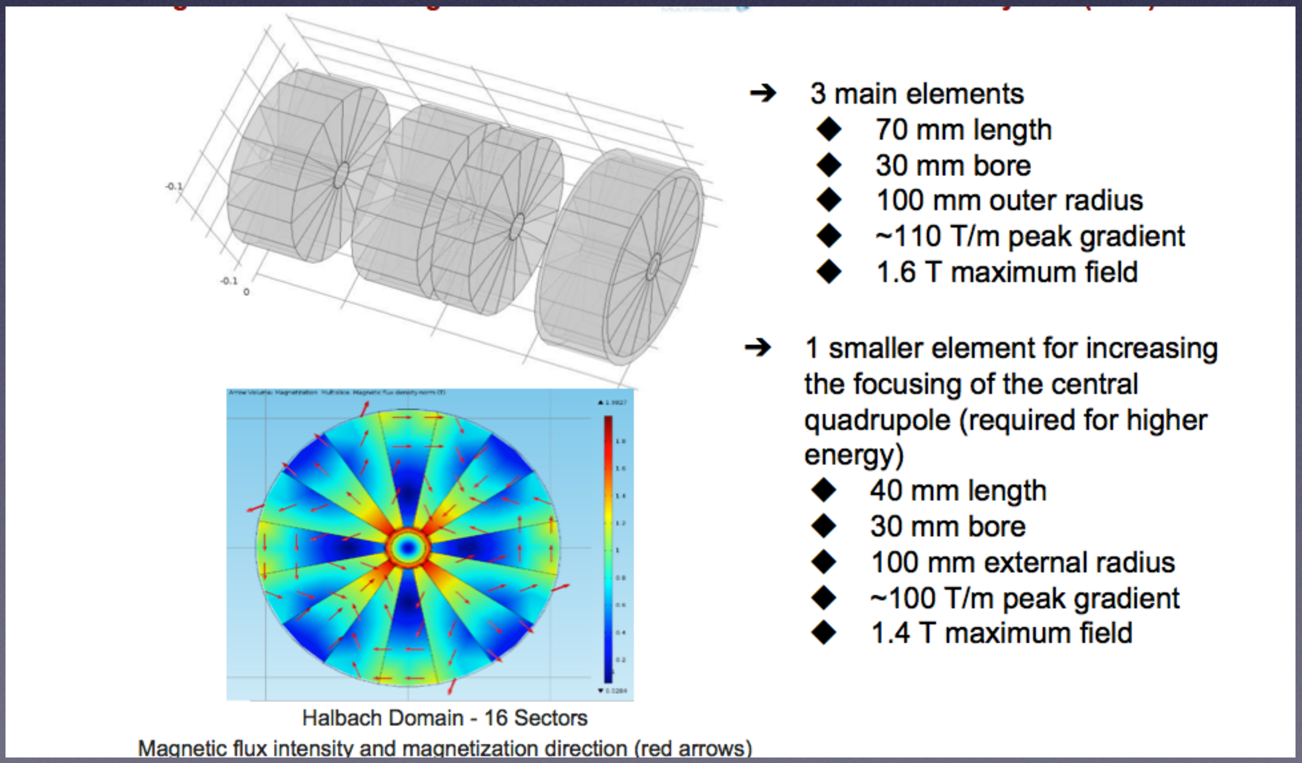


Focusing system:
quadrupoles
Laser
Interaction point
Target
Laser-
accelerated
particles
Energy selection
device



Study of a quadrupole system prototype

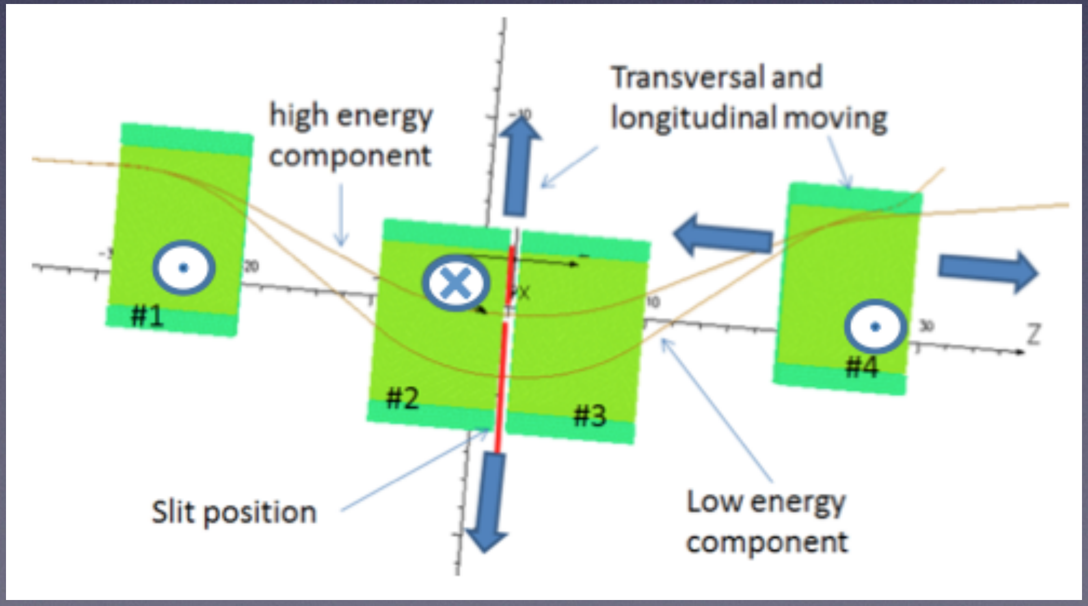
Optimization for focusing up to 30 MeV protons



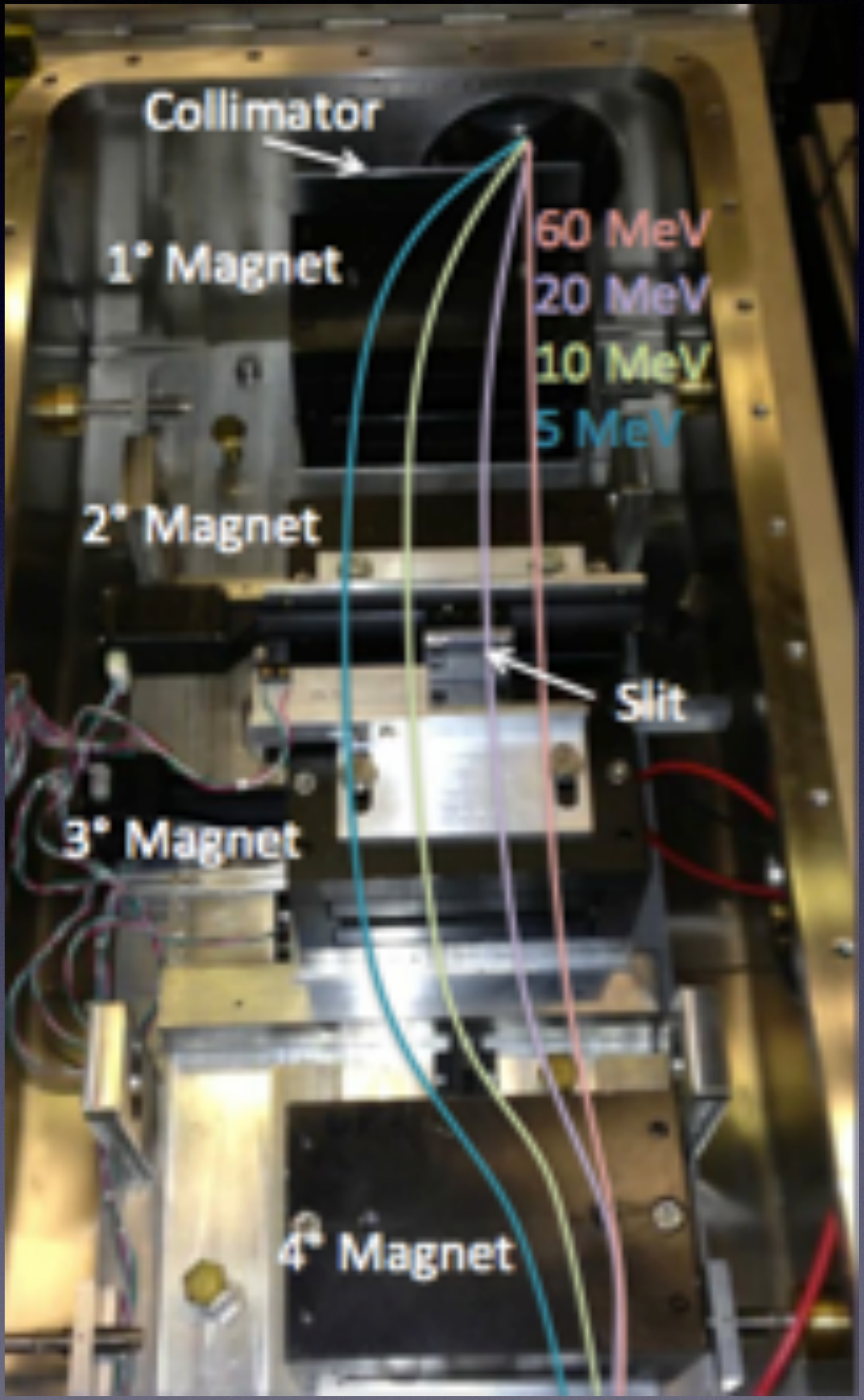
ESS Prototype already developed @ INFN-LNS:

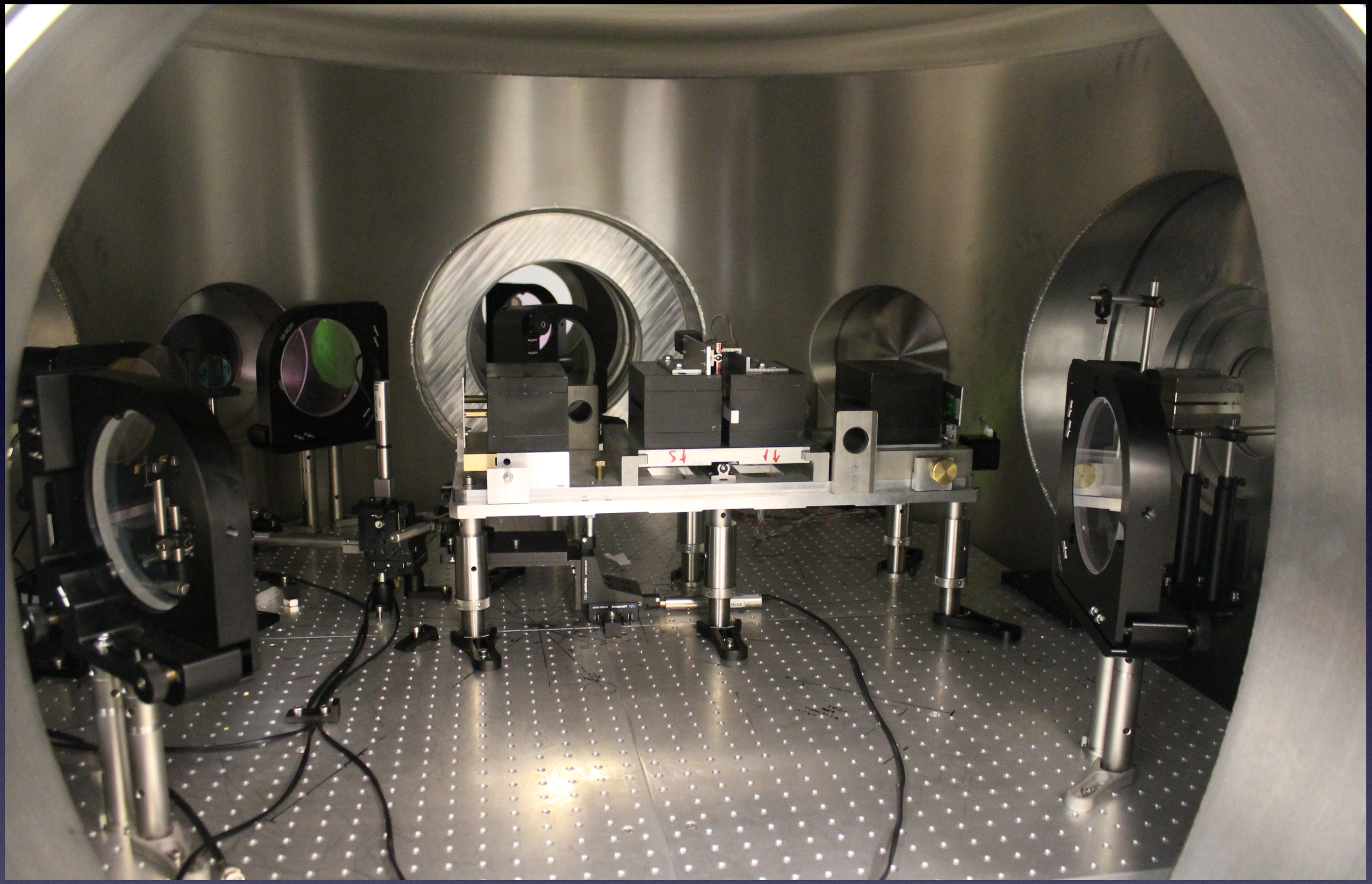
Wide energy range (1–60 MeV)

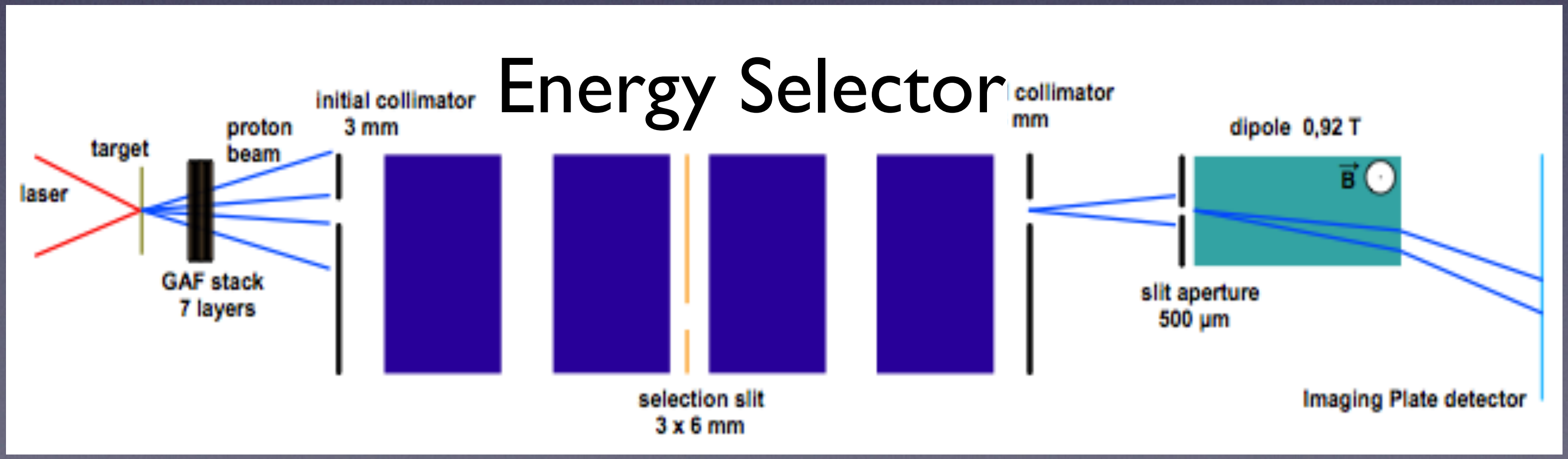
Controlled energy spread (1-30 %)



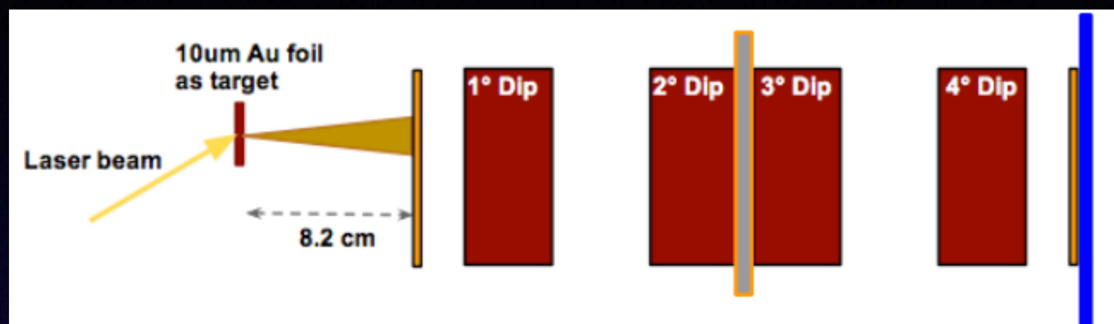
Typical laser-driven experiment

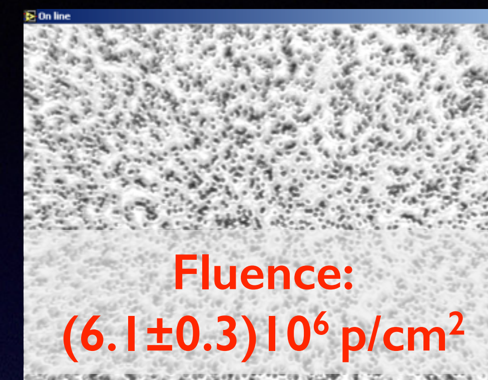






Energy spread, fluence and transmission efficiency



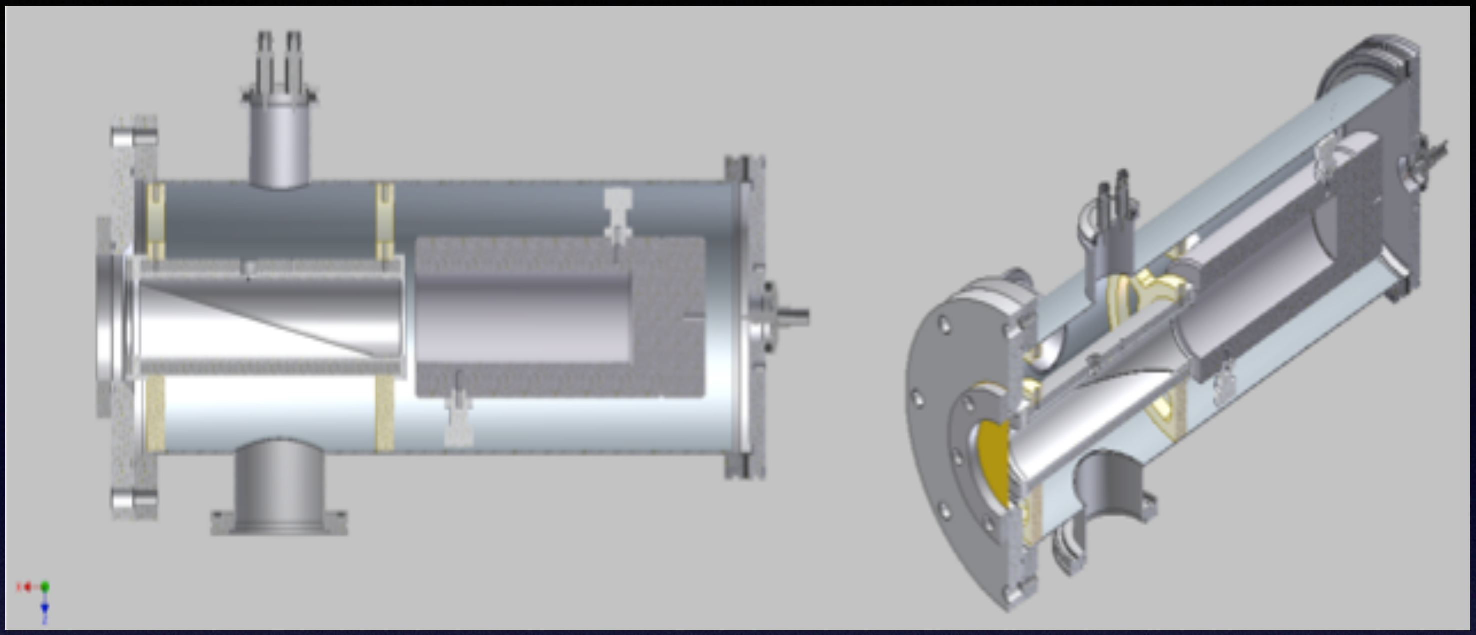


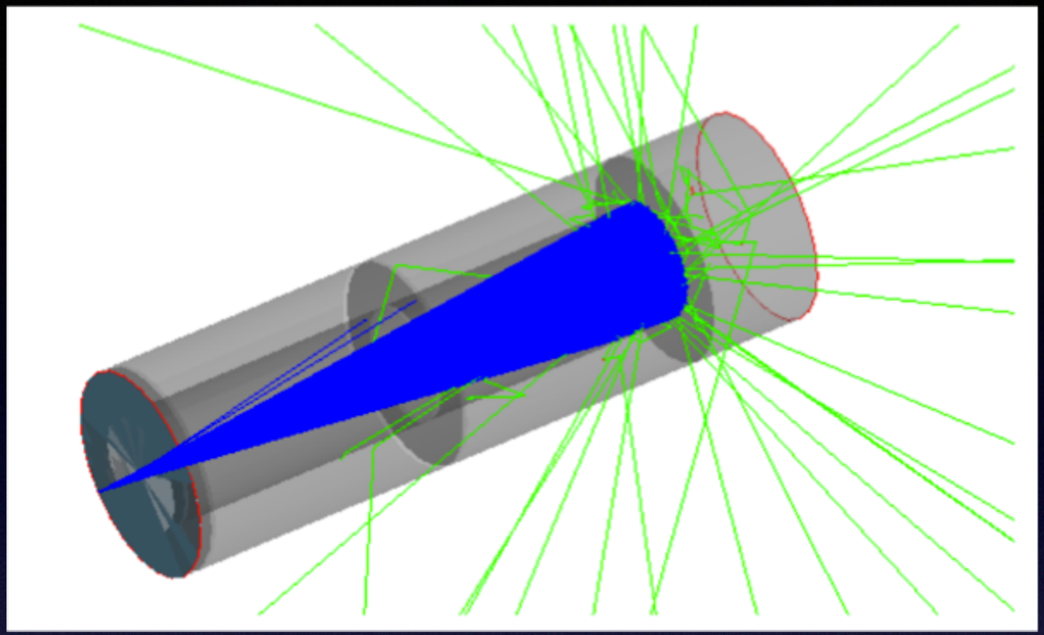
CR39 placed after the final collimator

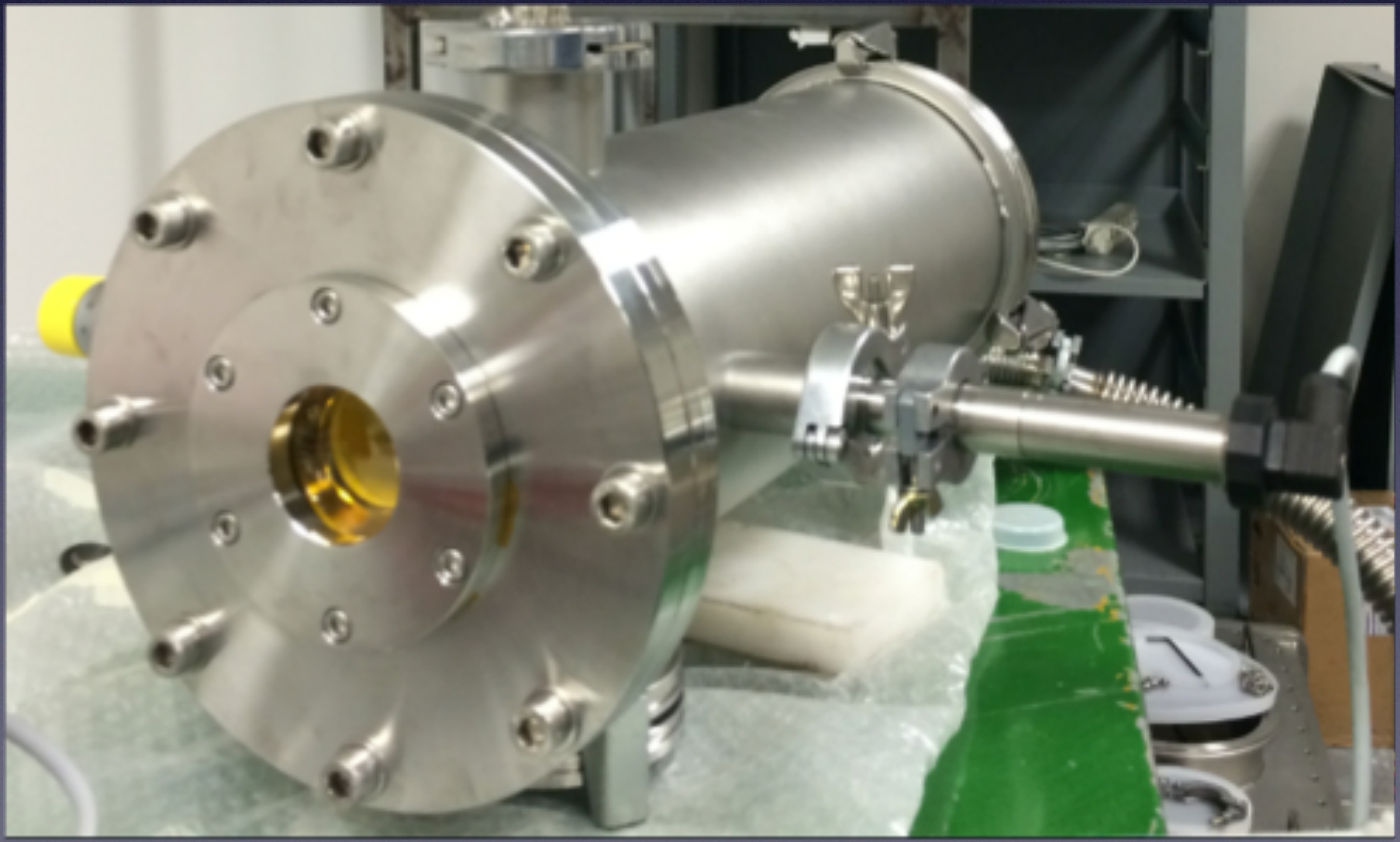
Energy range(MeV)	E±ΔE (MeV) Experiment	Energy Spread (%)	E±ΔE (MeV) Geant4 Simulation
3.9 —> 4.5	4.2 ± 0.3	±7	4.5 ± 0.2
4.1 —> 4.7	4.4 ± 0.3	±7	//
4.2 —> 4.8	4.5 ± 0.3	±7	//
4.0 —> 4.6	4.3 ± 0.3	±7	//
6.3 —> 7.3	6.8 ± 0.5	±8	7.0 ± 0.6
6.6 —> 7.9	7.3 ± 0.6	±8.5	//

Transmission efficiency	All the spectrum N	Only the energy range 4MeV±7% N NR
Experimental	1.6e-3 (0.1%)	1.7e-2 (1.7%)

R&D on absolute dosimetry







a new concept of Faraday Cup for absolute dosimetry of high-pulsed laser-driven beams

Diamond detector, SiC, SEM, pixellated detectors … under consideration

R&D on dosimetry and radioiology

New detectors and dosimetry

- Dose-rate issues
- Instability
- Many different radiations

Are biological effects the same?

Summarising the status

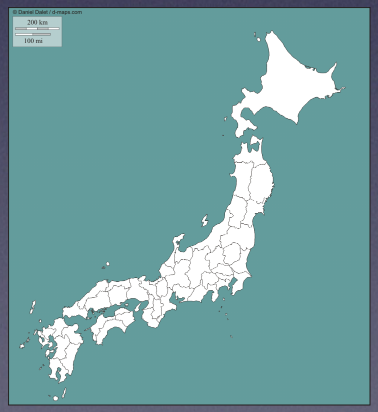
	Conventional beams	Laser-driven beams
Maximum energy	250 MeV 400 AMeV	😃
Current	order of nA	😃
Monochromaticity	$\Delta E/E \leq 10$	Broad beam: optical solutions, target solutions?, both? 😟
Stability, reproducibility, control, dosimetry	Less that 3%	😱
Radiobiology	Almost known	😟

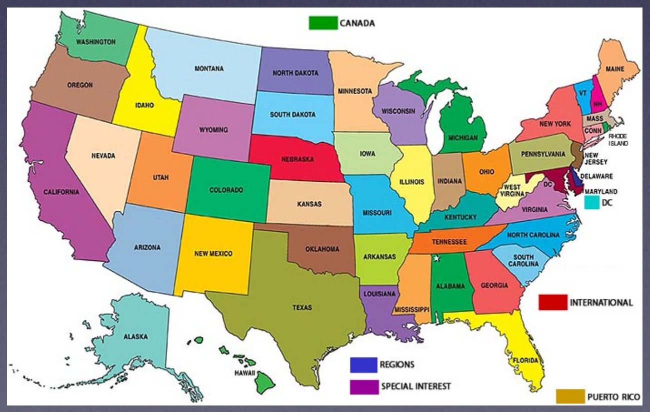
COST Institution	15
Int. Partner Country	2
Int. Organisation	1

COST Institution 15

Int. Partner Country 2

Int. Organisation 1





Join our group, fellows for:

expert on Monte Carlo

expert on charged particles transport

Thanks for your attention

Hadrontherapy

Conventional radiotherapy

Protontherapy