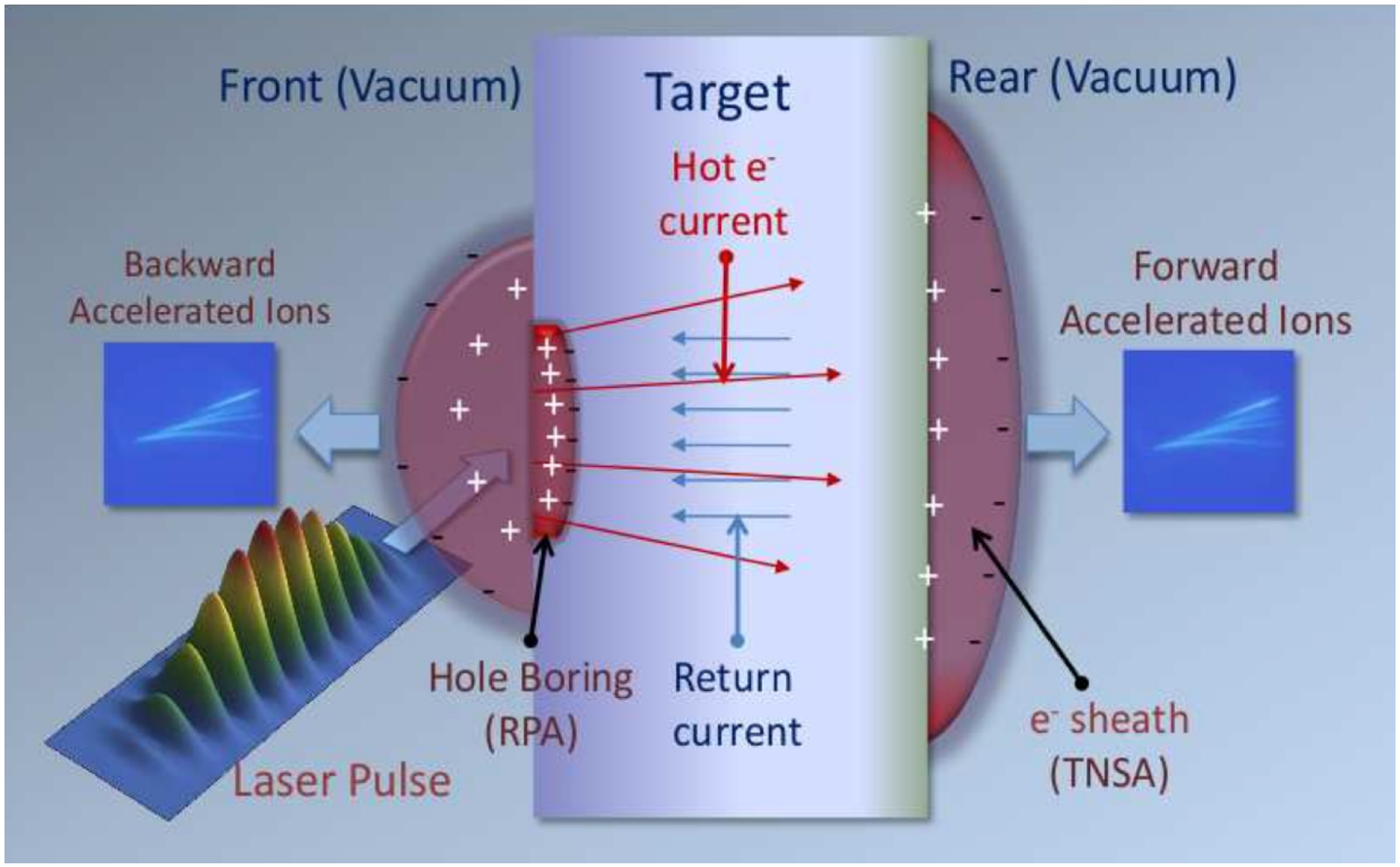
# ELIMED

# An Users' open beamline for laser-accelerated ions

*GAP Cirrone, INFN-LNS*

# Ion acceleration with high power lasers

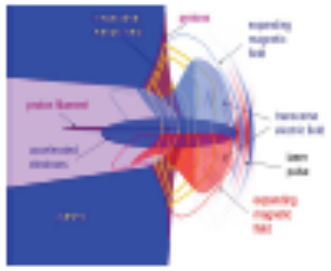




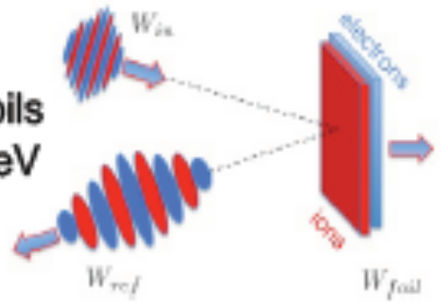

| Laser characteristics | |
|---|---|
| **Power** | PW order ($10^{15}$ W) |
| **Duration** | fews femto seconds |
| **Intensity** | $10^{21}$-$10^{23}$ W/cm$^2$ |

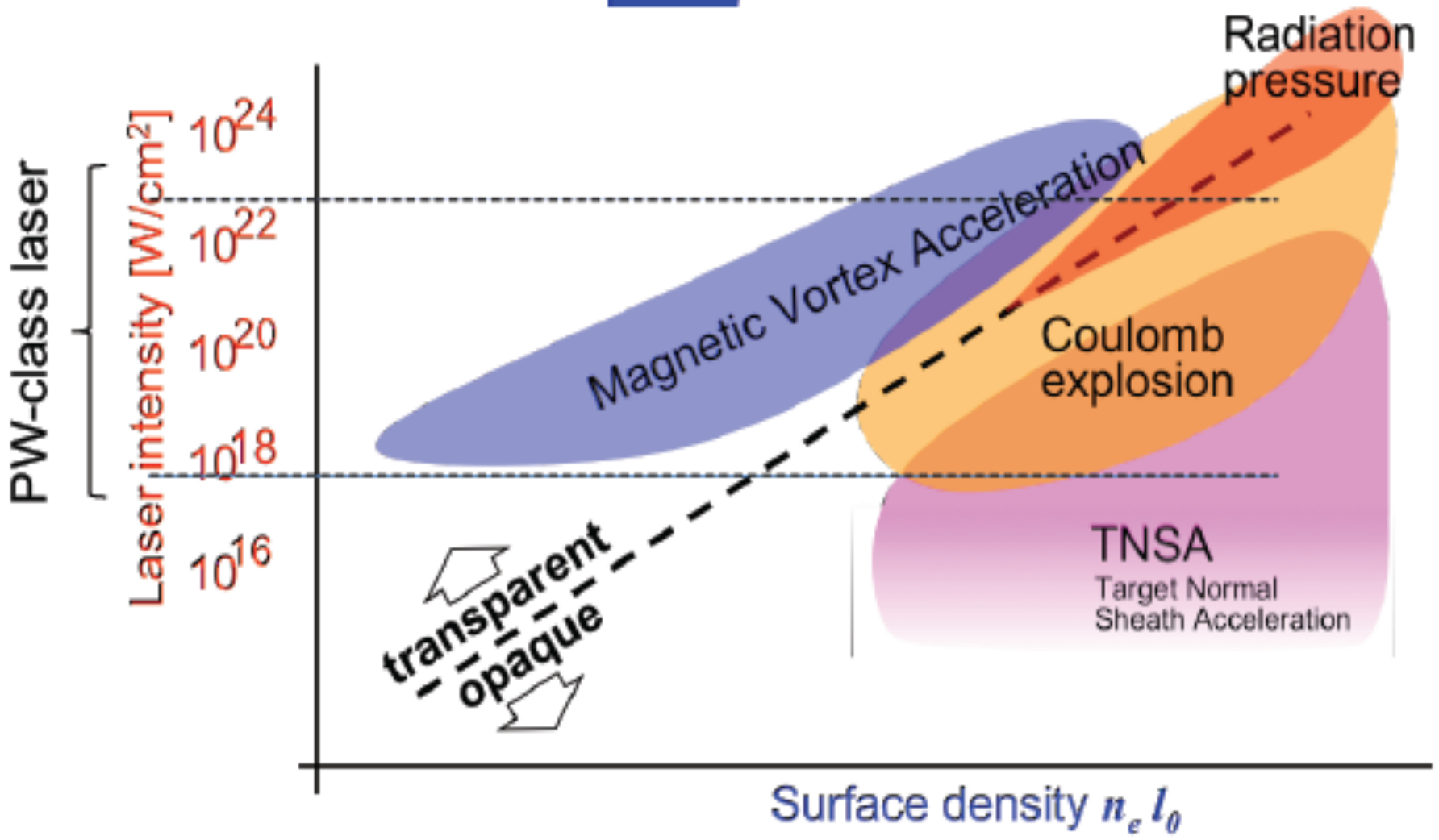
| Accelerated beams | |
|---|---|
| **Beams** | gamma, electrons, ions, |
| **Energies** | MeV/GeV in broad spectra |
| **Intensities** | $10^{9}$-$10^{12}$ |

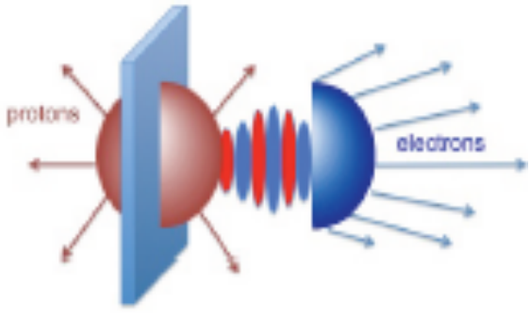
**MVA**
Laser: High Intensity
Target: Near Critical Density slab
Ion Energy: hundreds of MeV to GeV



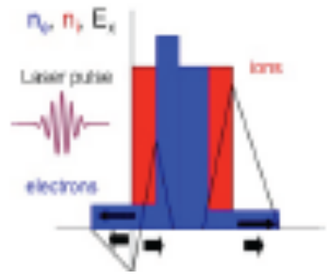
**RPA & CE**
Laser: High Intensity
Target: Thin solid density foils
Ion Energy: hundreds of MeV



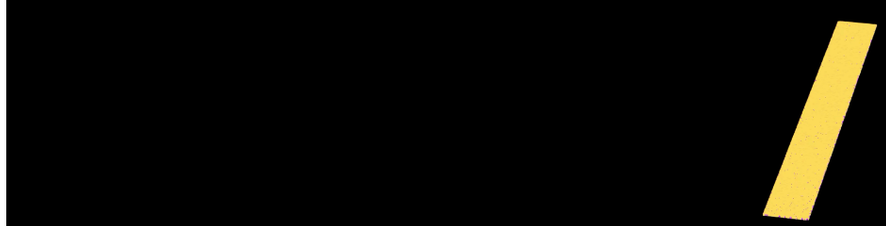

**TNSA**
Laser: Low Intensity
Target: Thick solid density foils
Ion Energy: ~100 MeV



# Laser-driven ion acceleration from plastic target

2D particle-in-cell simulation of the interaction of high-intensity laser pulse (parameters are relevant to L3 laser and thus ELIMAIA beamline) with a micrometer-thick flat plastic target. Acceleration of both protons (pink color) and carbon ions (green color), to maximum energy 150 MeV/nucleon and 40 MeV/nucleon, respectively, can be clearly distinguished in the visualization as well as different ion acceleration mechanisms (from the target front side and from its rear side). Such high-energy protons and ions have a great importance for various foreseen applications in Physics, Biology, Medicine, Chemistry, Materials Science, Engineering, and Archaeology.

Time: 2 [fs]

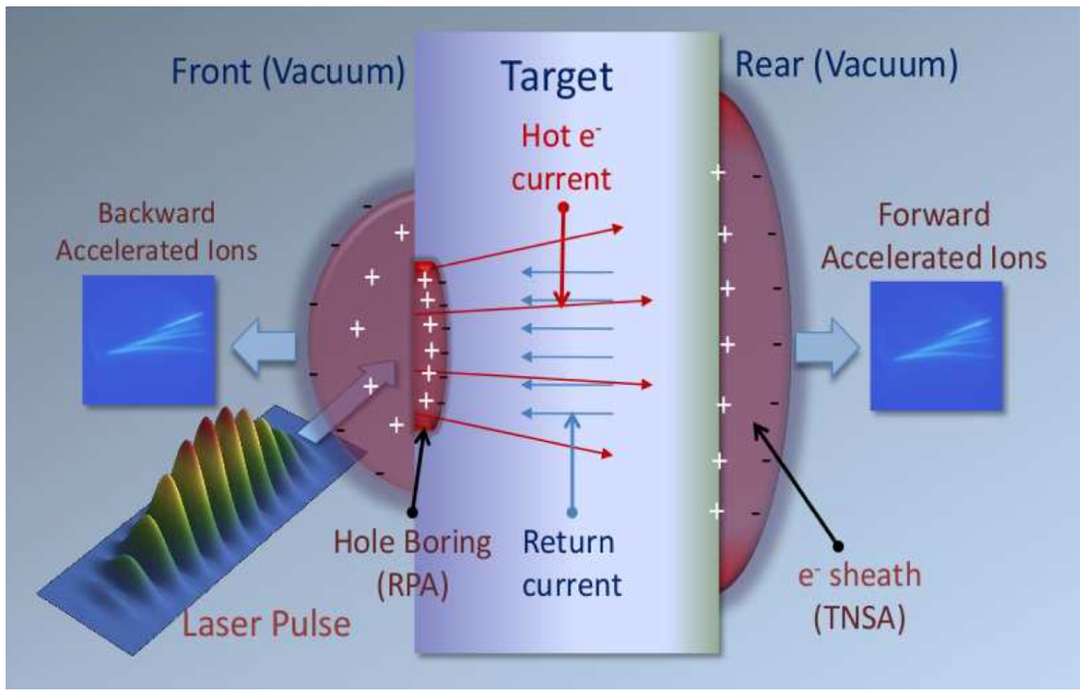


carbon energy $[MeV/nucleon]$
0.01 0.1 1 10

proton energy $[MeV/nucleon]$
0.1 1 10 100

ax [ ]
0.5 1 2 5

ay [ ]
-100 0 100



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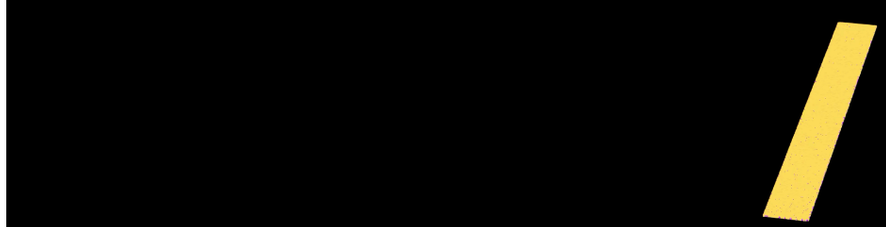

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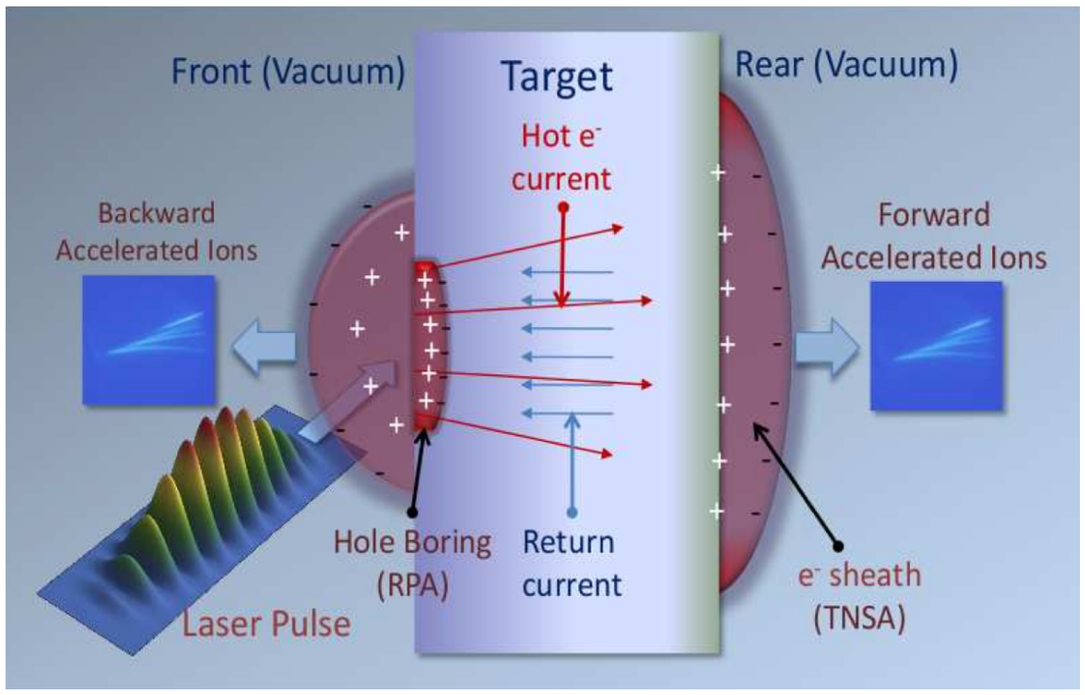


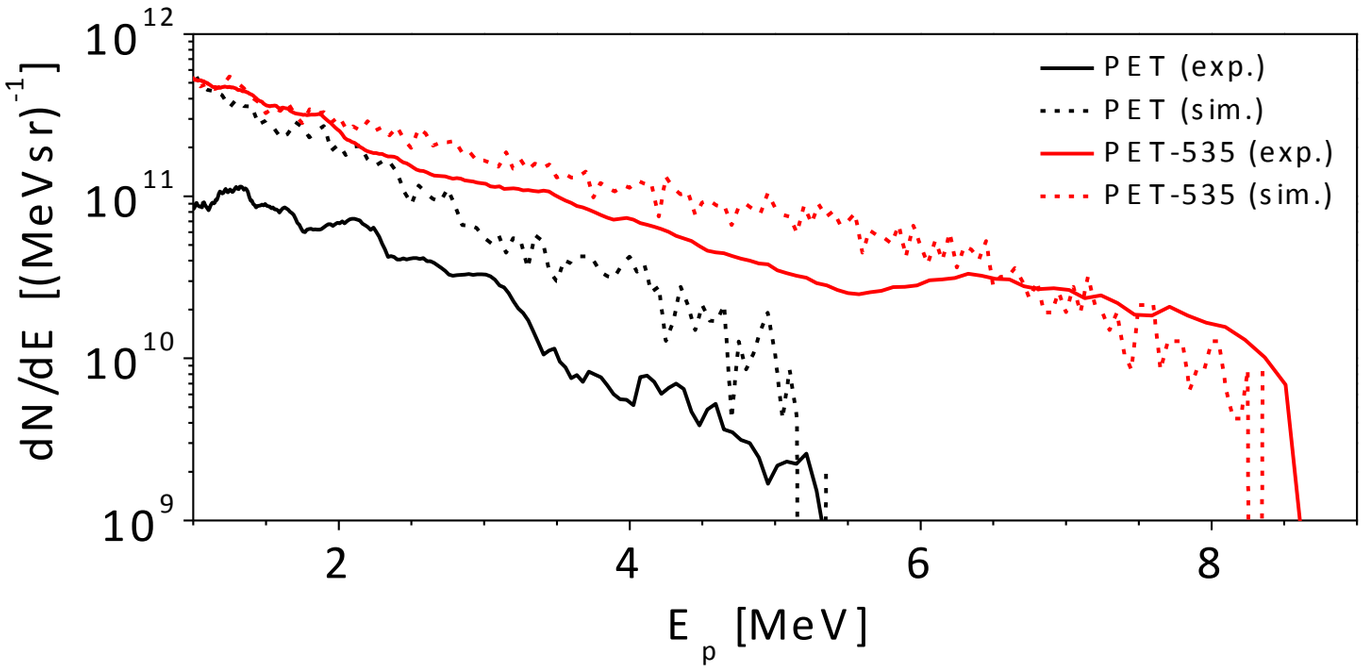

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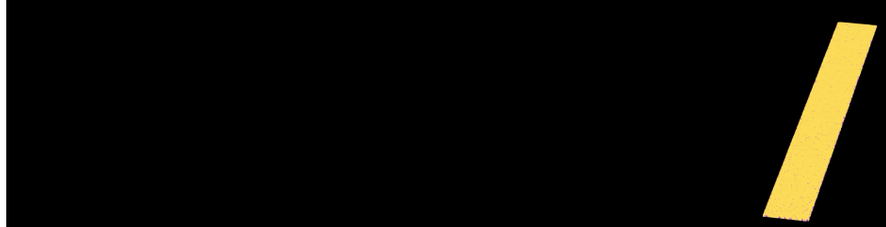

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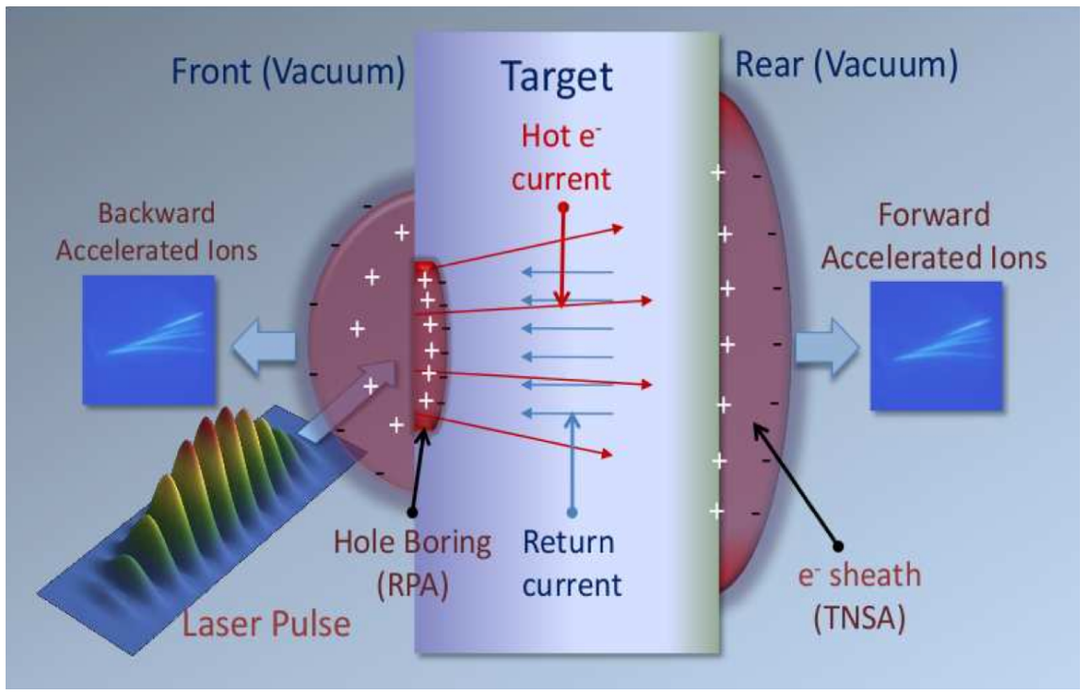
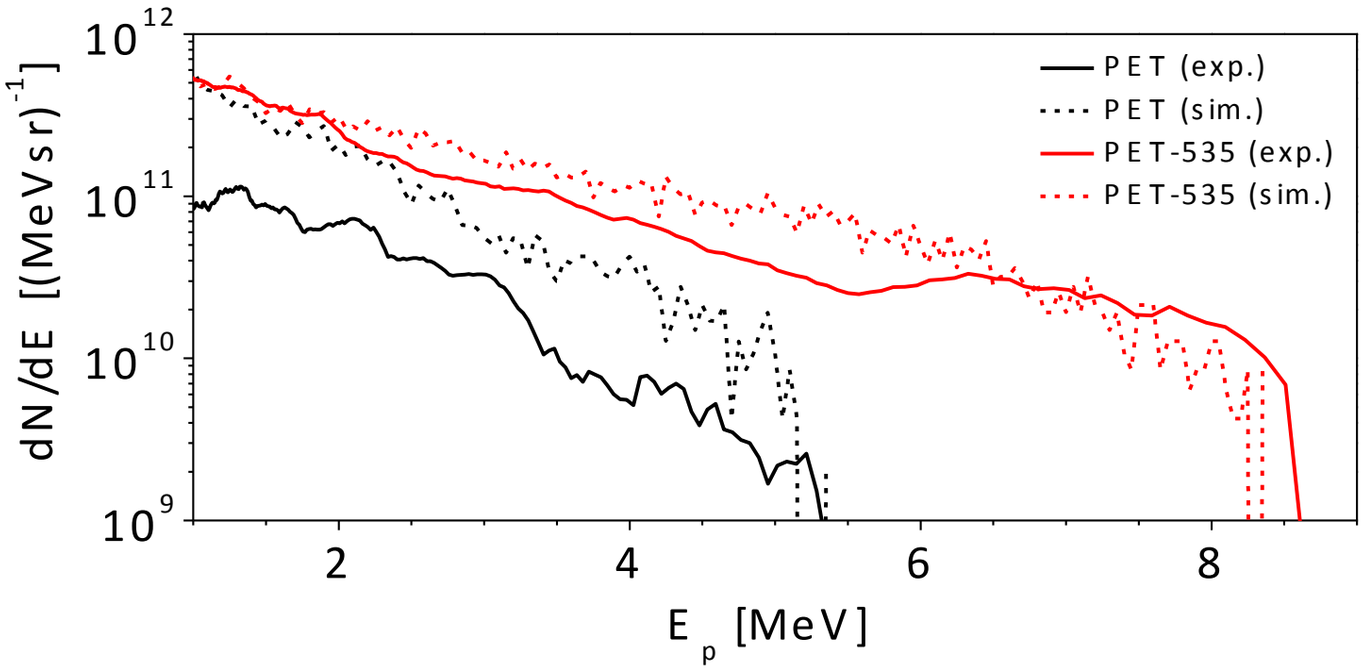
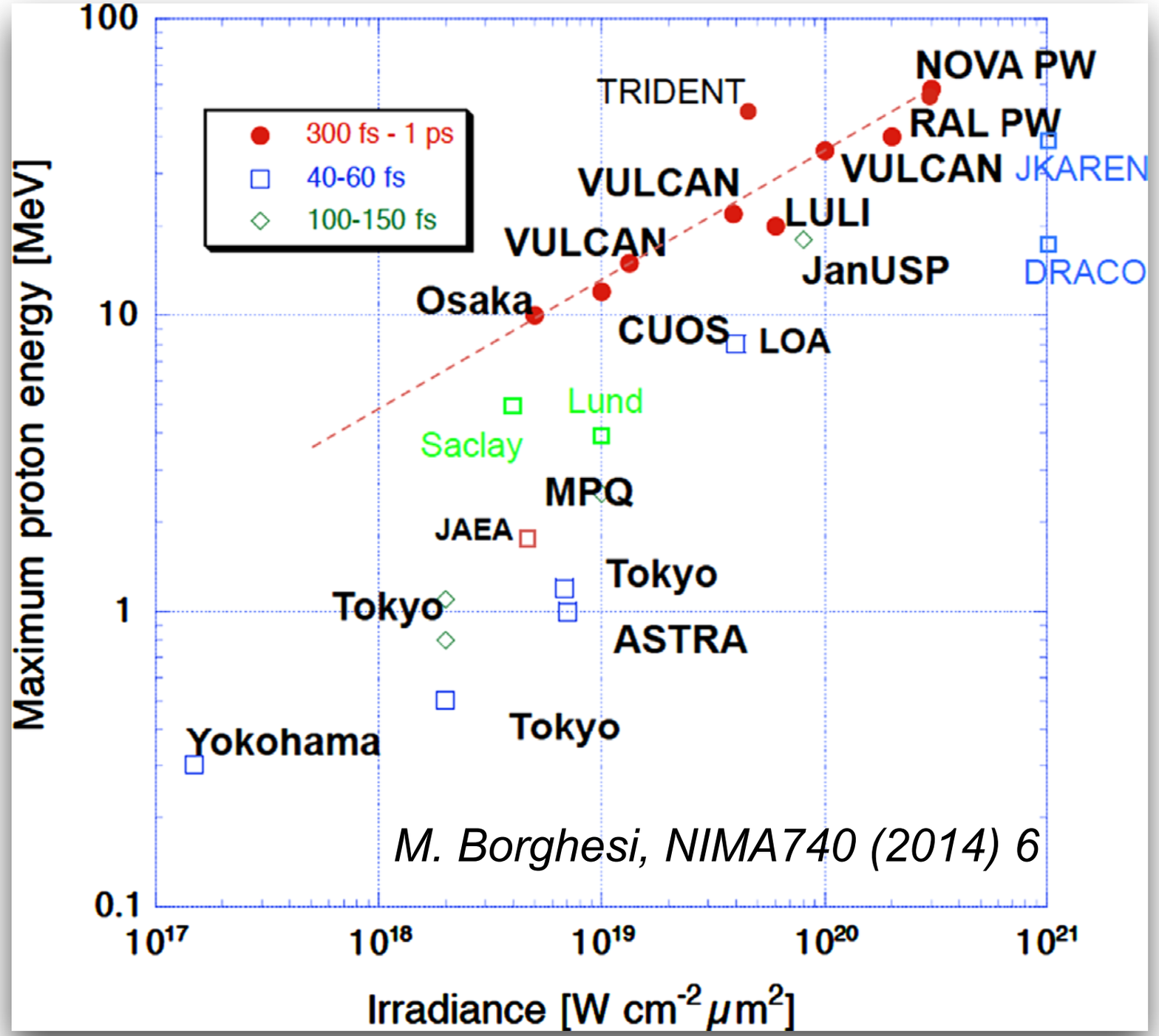


# Ion acceleration with high power lasers






## 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.)
- Ungary
- Romania
- tbd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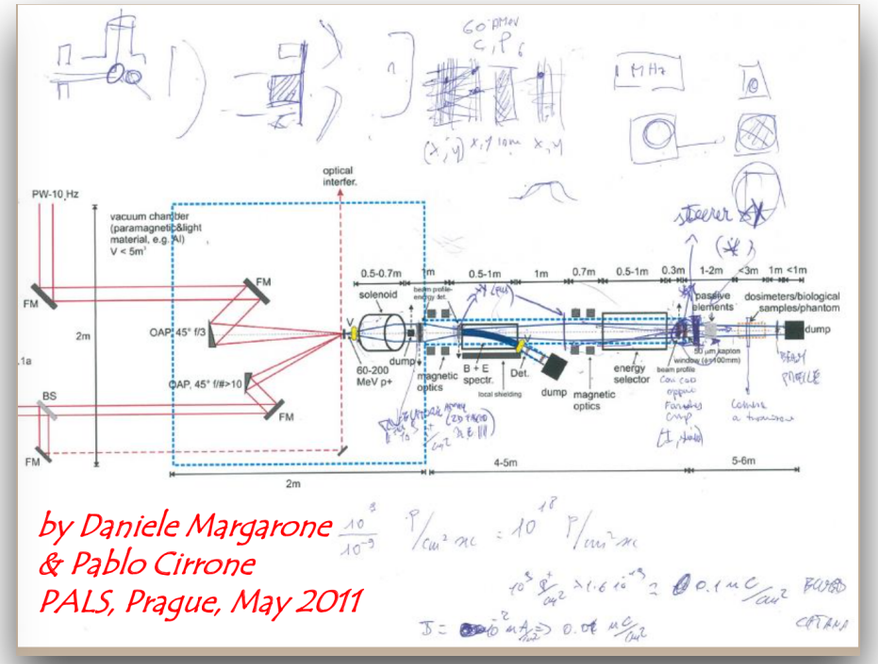
- ELIMAIA
  - ELIMAIA: (ion accelerator + user station)
    ELI Multidisciplinary Applications of laser-Ion Acceleration
- ELIMED
  - ELIMED: (transport and dosimetry)
    ELI MEDical and multidisciplinary applications

# ELIMED history



## 2011




*by Daniele Margarone*
*& Pablo Cirrone*
*PALS, Prague, May 2011*

## 2012

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

INFN

**Memorandum of Understanding for a scientific and technolo**
**collaboration towards medical applications at ELI Beamline**

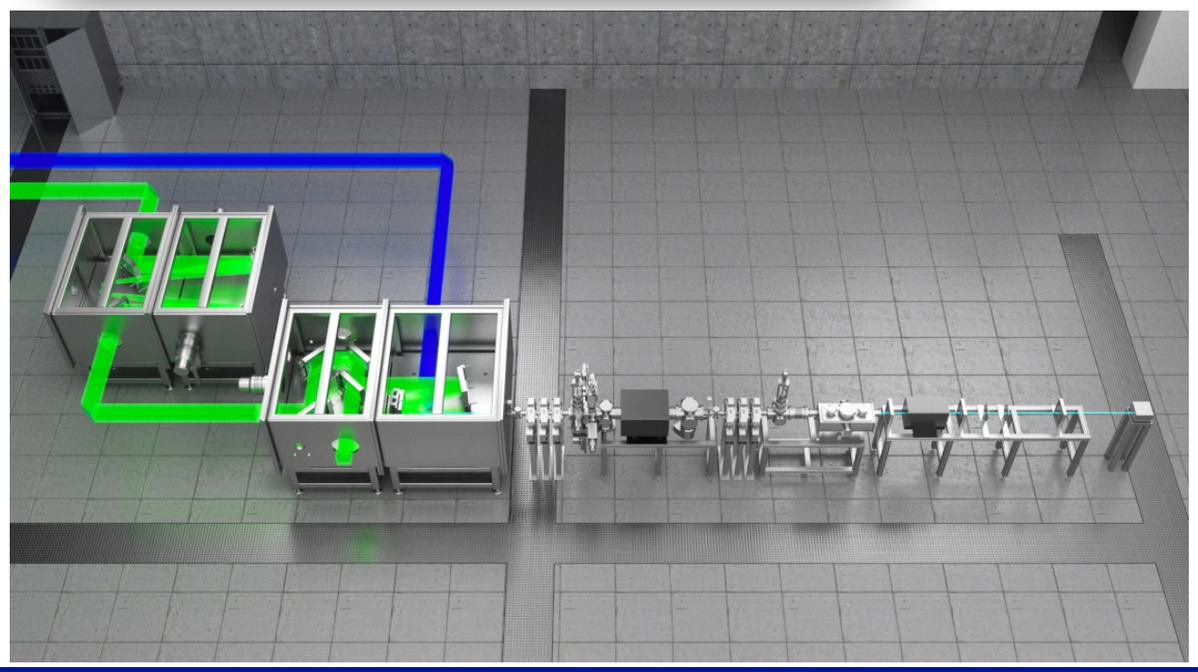
**Between the**

***EII-Beamlines, Institute of Physics of AS CR, public research institution (F***
**Prague, Czech Republic**

**And**

***Laboratori Nazionali del Sud (LNS), of INFN, public research institution,***
**Catania, Italy**

## 2013



## 2014

**4. WORK SUBJECT-MATTER; WORK SCOPE**

**4.1.** The Contract concerns the design, assembling, performance optimization, and delivering to the Client at the Client's Place of Business of a complete transport beamline and a number of dosimetric endpoints that will enable the users to apply laser-driven ion beams in multidisciplinary fields in accordance with this Contract (hereinafter the "***System***"). Furthermore, the scope of this Contract mainly encompasses (i) various training services to be provided to the Client's personnel in compliance with Article 13 of this Contract (ii) a royalty free licence, if any according to Article 14, to use the System for the purposes of the use of the ELI-Beamlines Project after completion and (iii) the possible realization of the Additional System, subject to the exercise of the Call Option right by the Client under par. 4.6 (the System and the other parts of the works/services are hereinafter referred to as the "***Works***").

– 5 DIC. 2014

Signed in Prague on 8/12/2014

Signed in Rome on _____

On behalf of: **Fyzikální ústav AV ČR, v. v. i.**

Signature: _____
Name: Prof. Jan Řídký, DrSc.
Title: the Director

On behalf of: **INFN, Instituto Nazionale di Fisica Nucleare**

Signature: _____
Name: Prof. Fernando Ferroni
Title: the President

ISTITUTO NAZIONALE DI FISICA NUCLEARE
IL PRESIDENTE
Prof. Fernando Ferroni

# ELI-Beamlines, Prague (CZ)

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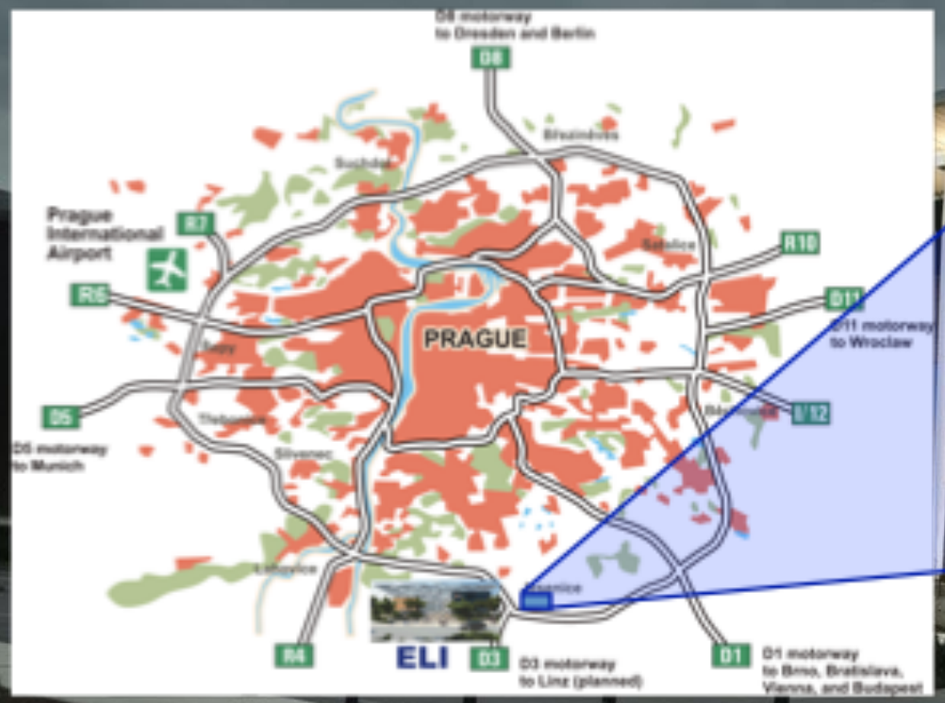
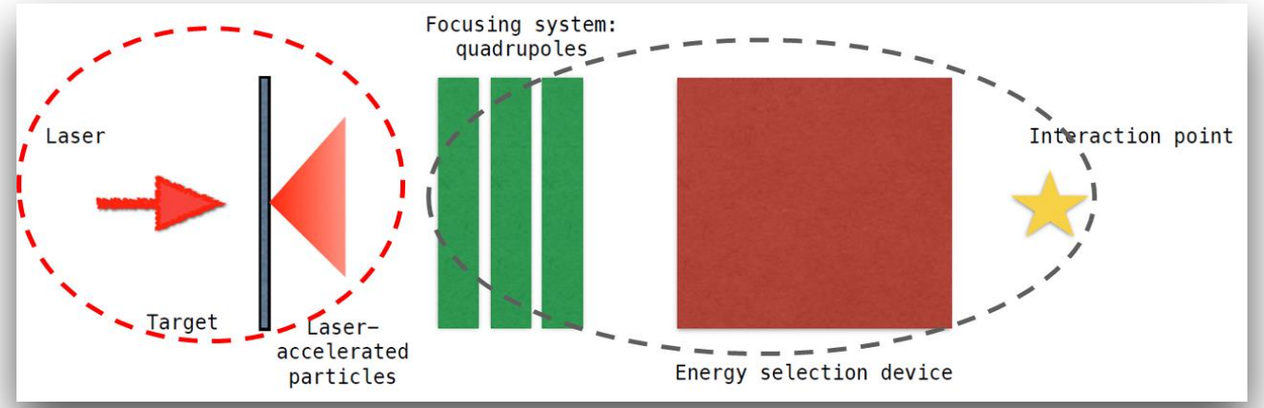
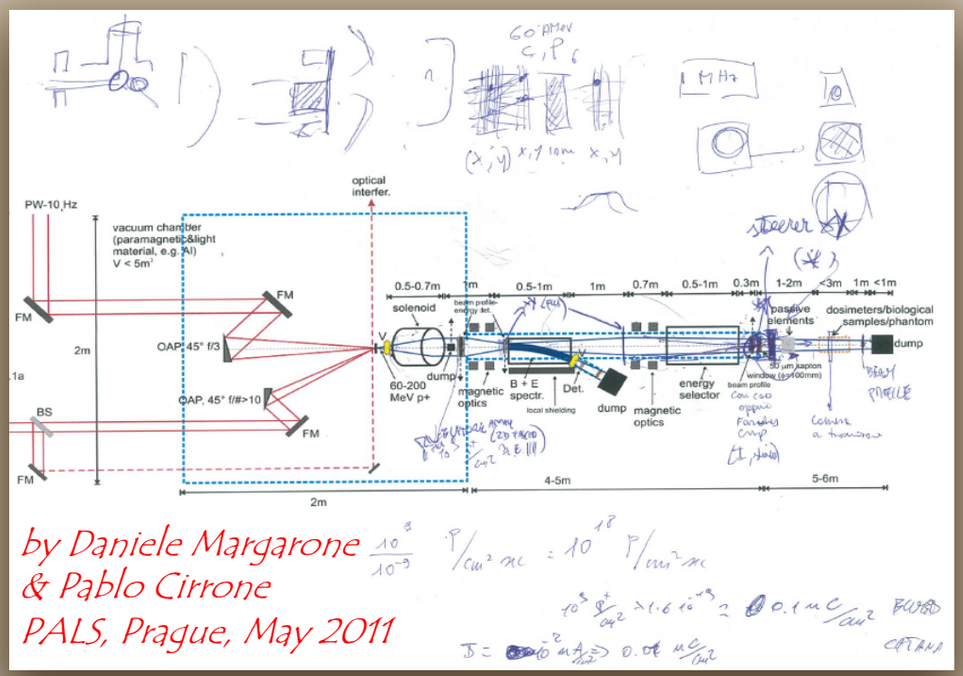


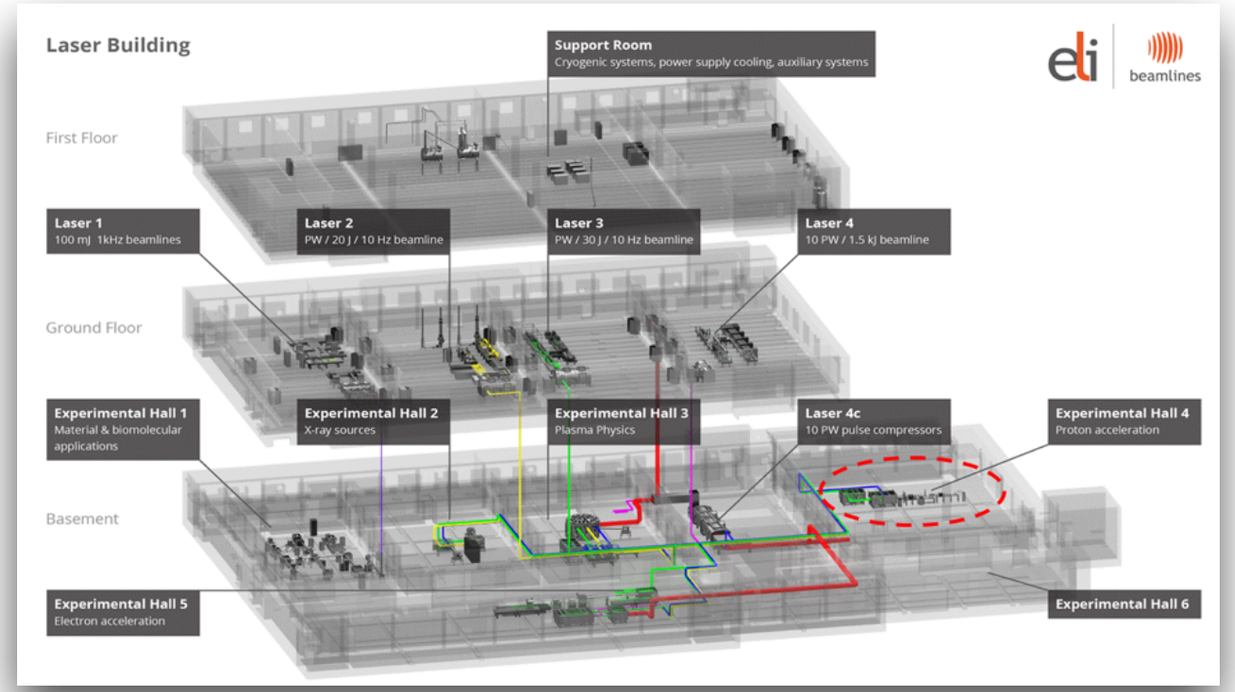


# ELIMED beam line concept



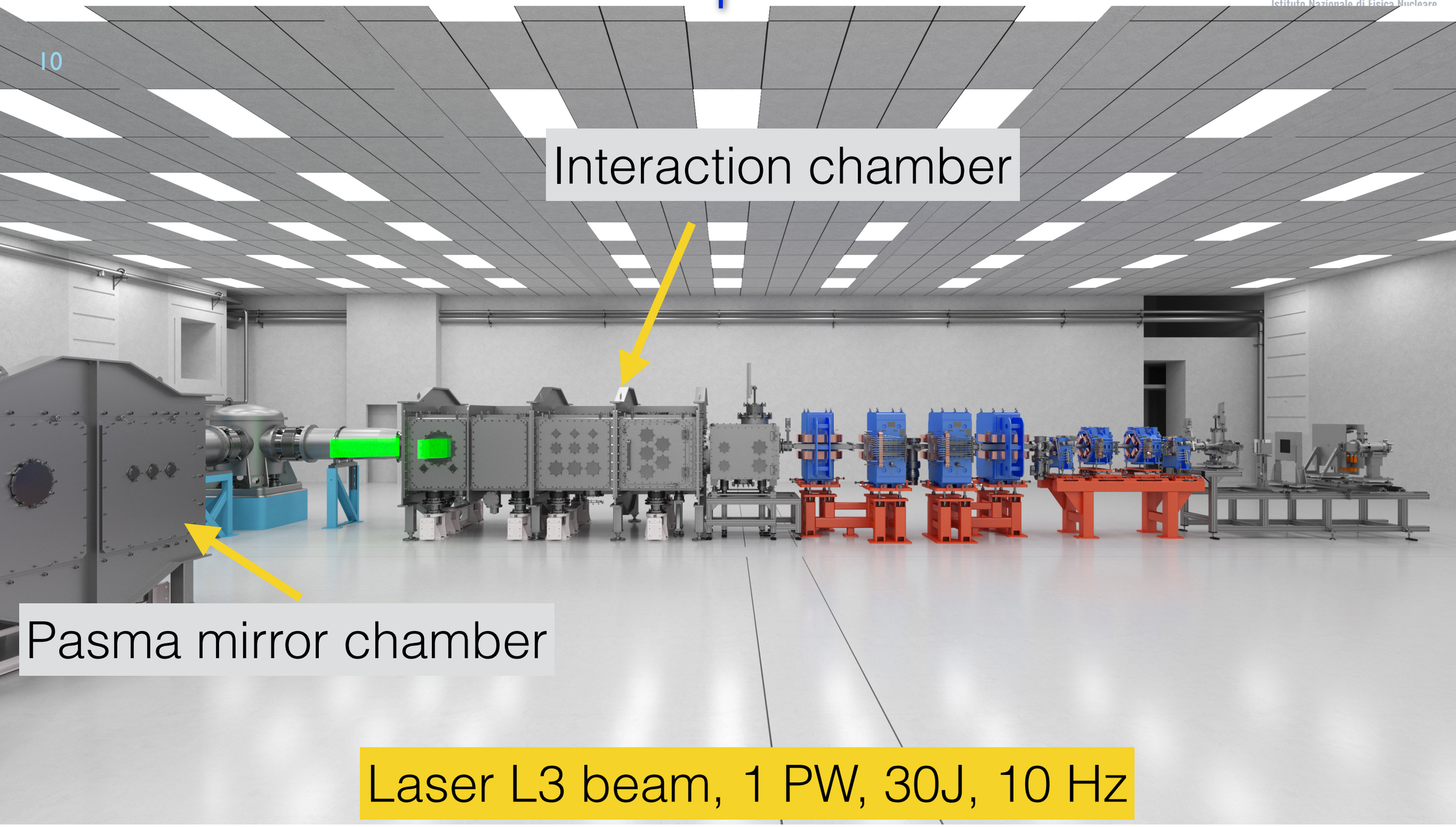


# ELIMAIA-ELIMED Experimental Hall





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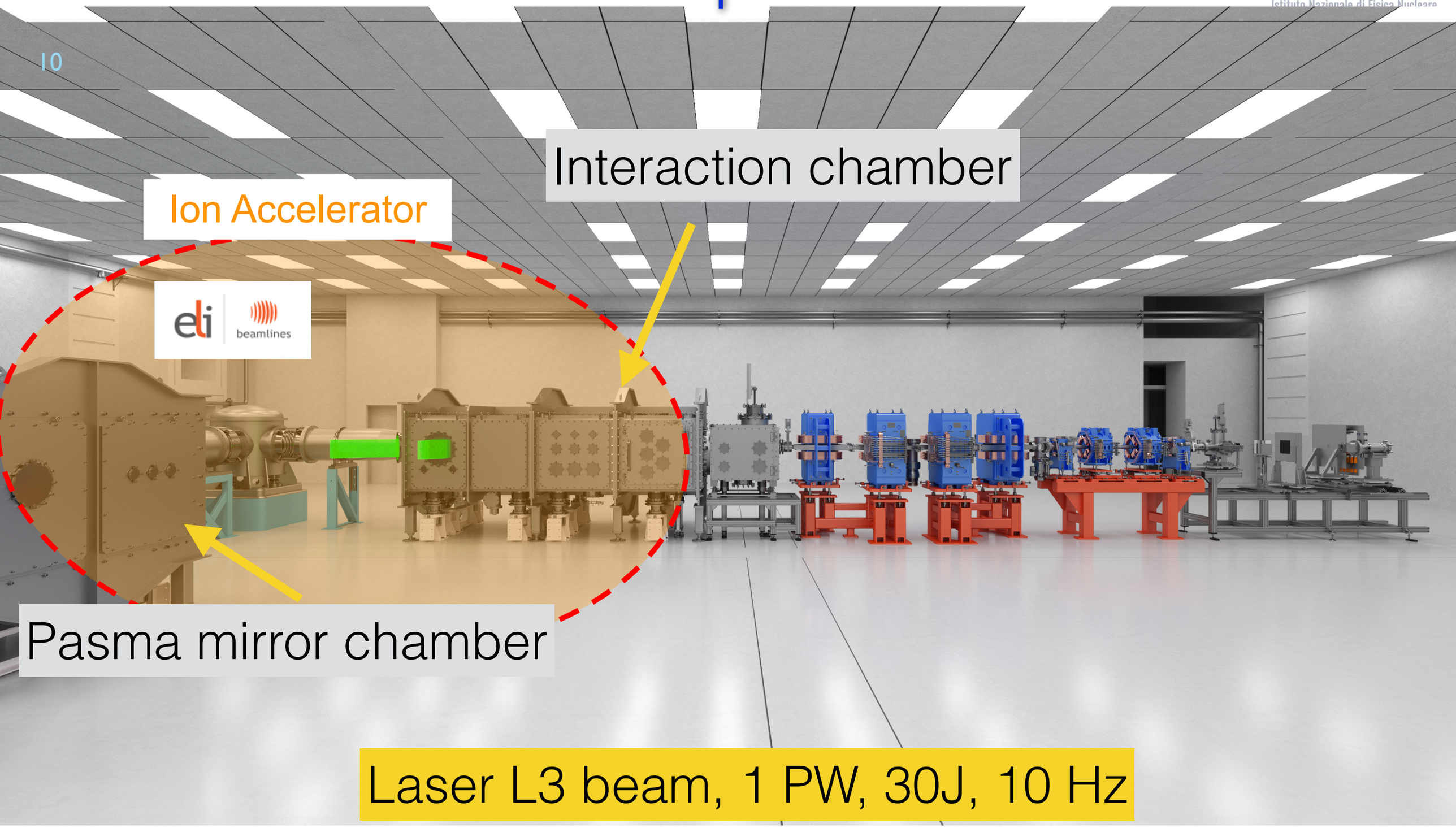

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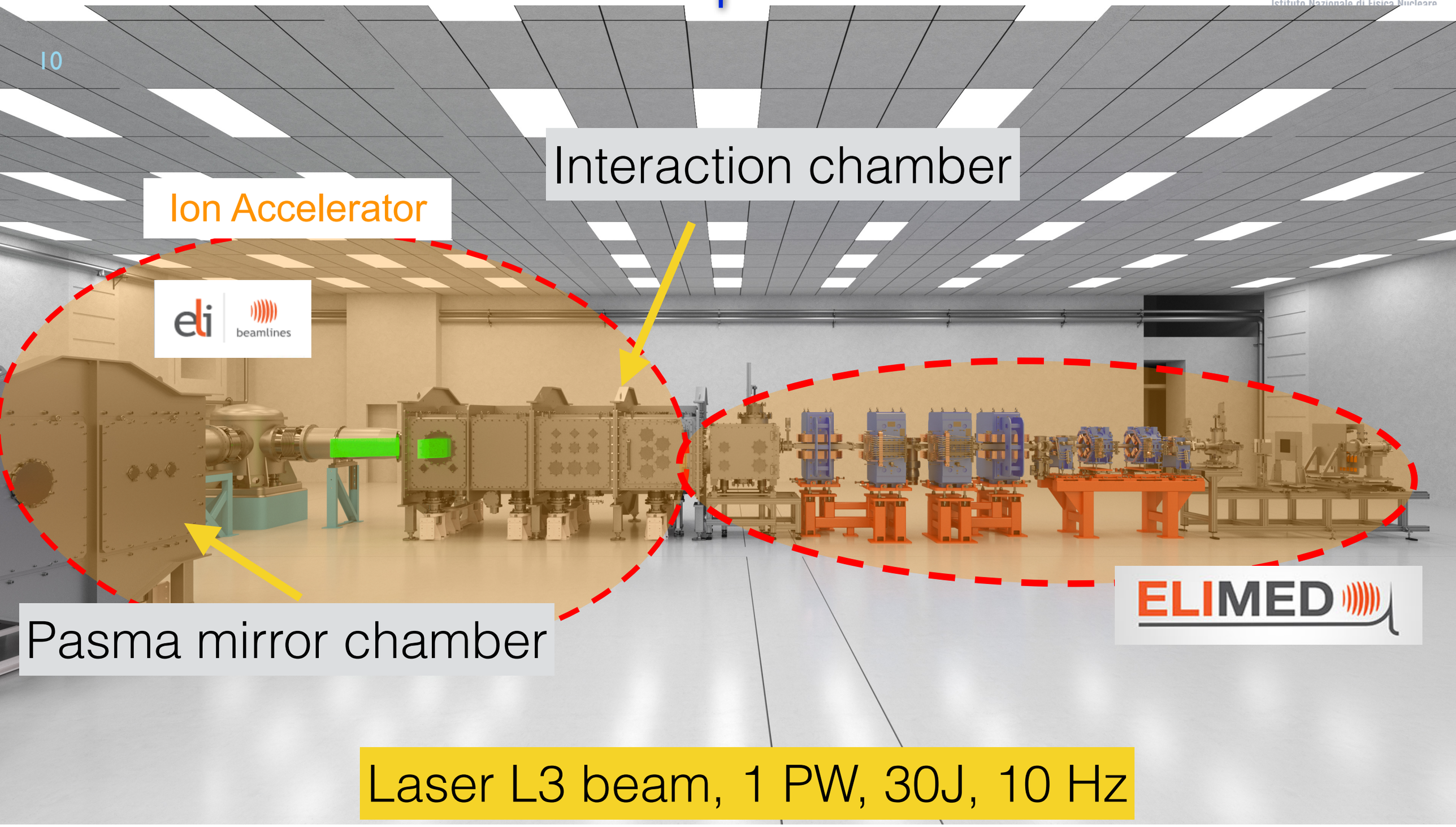
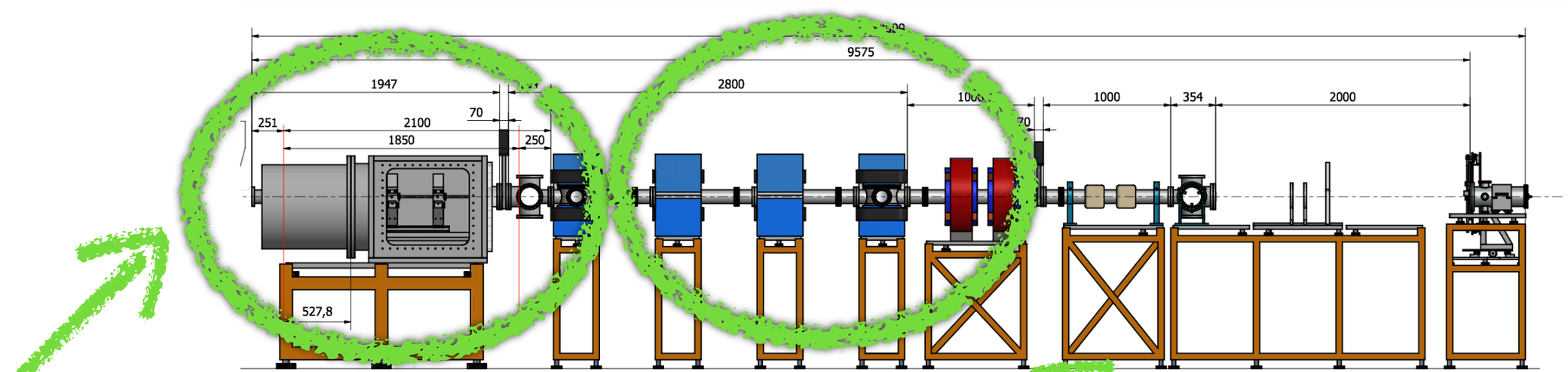
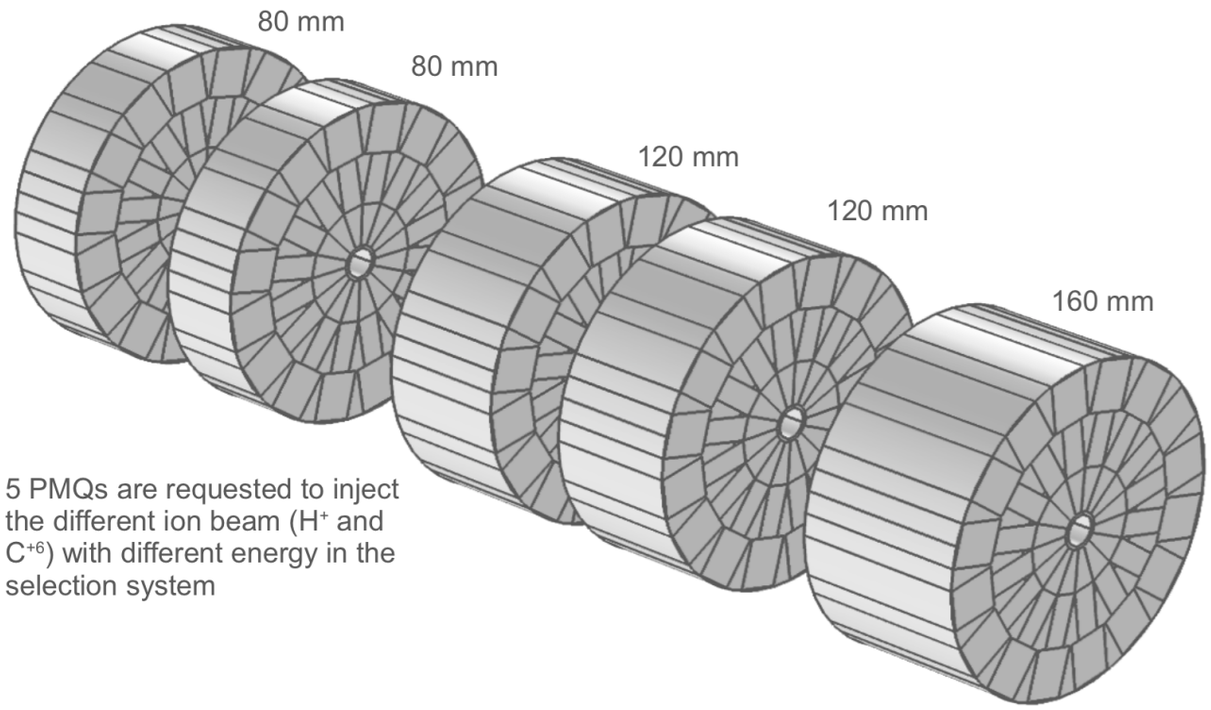


# ELIMED transport elements



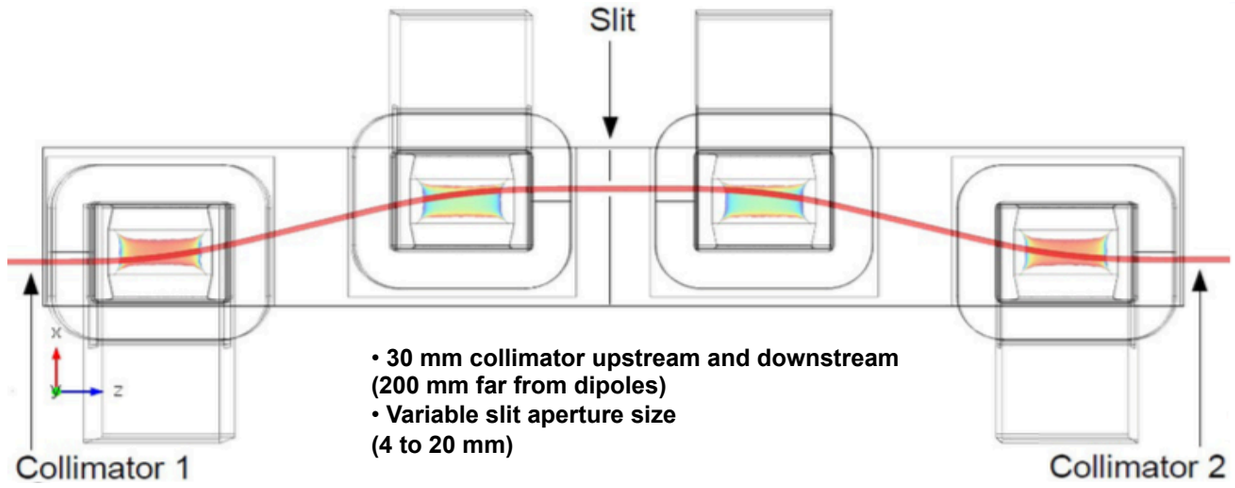



## Collecting and focusing




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

## Energy selection

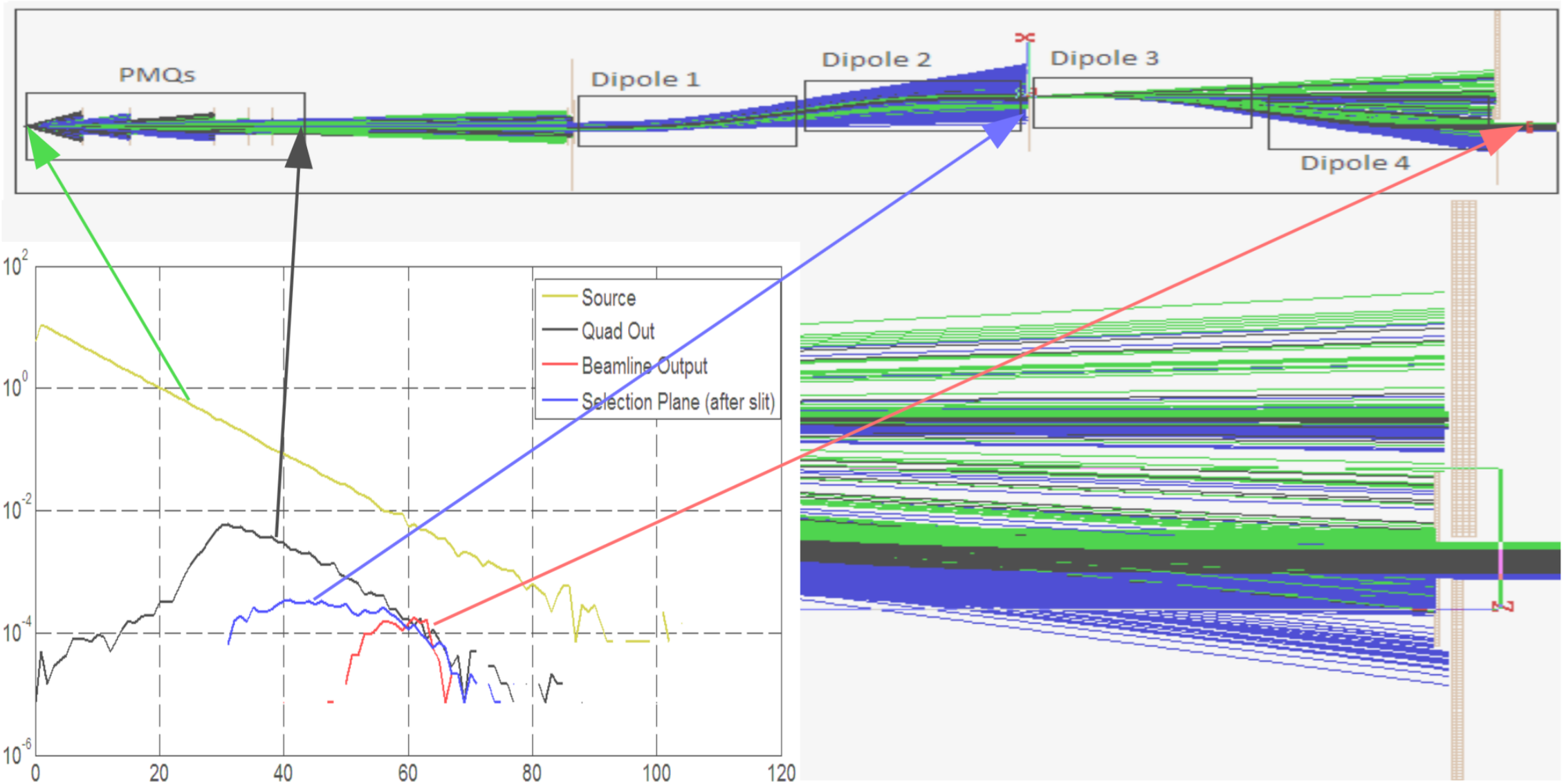


# Beam transmission



Angular divergence = 5° (FWHM)

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



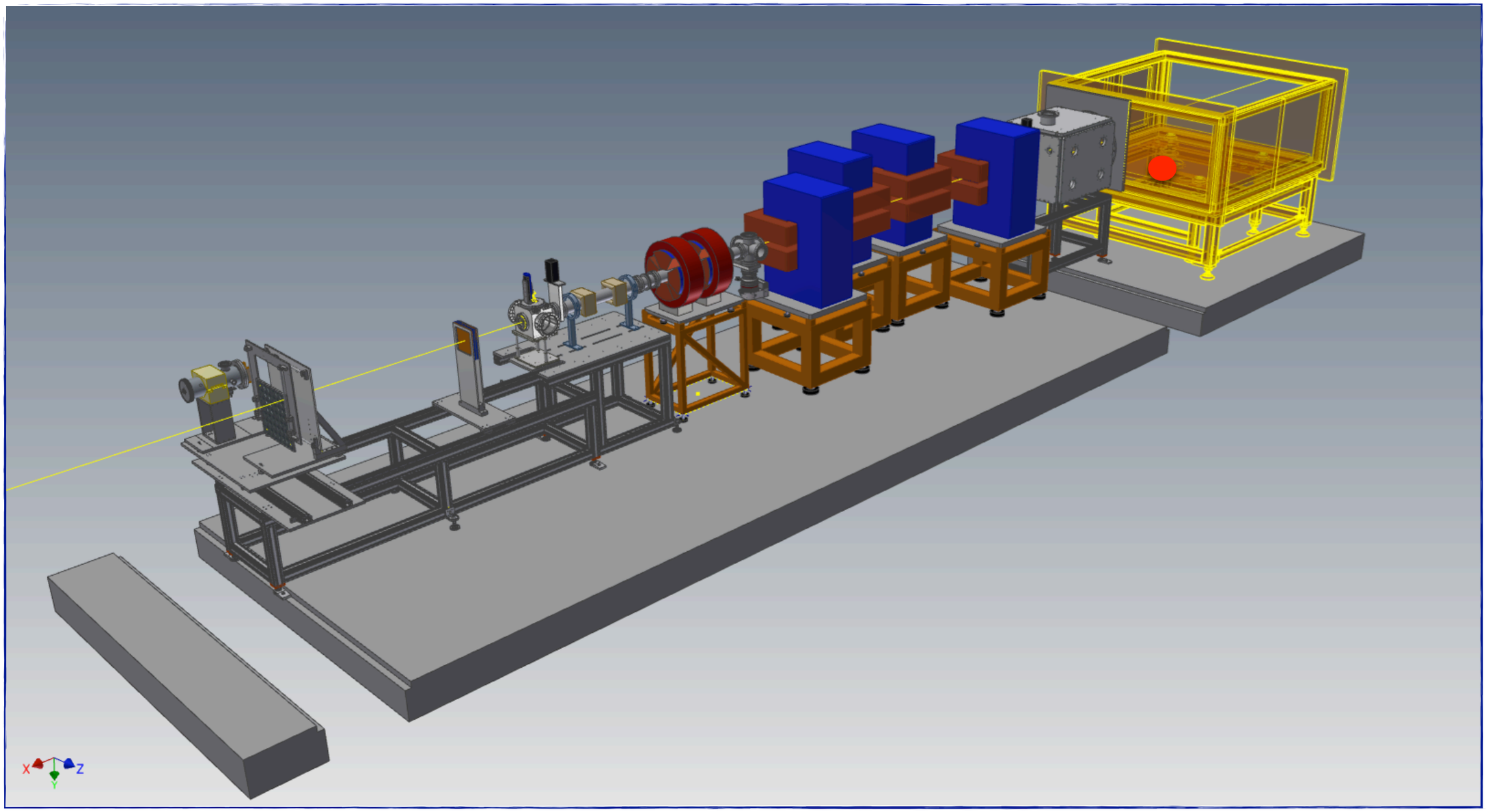
# Which diagnostic and dosimetry?

We will have 10^9 protons in 10 nsec
Corresponding to a dose rate of the order of 10^9 Gy/min

Fast, dose-rate independent, on-line

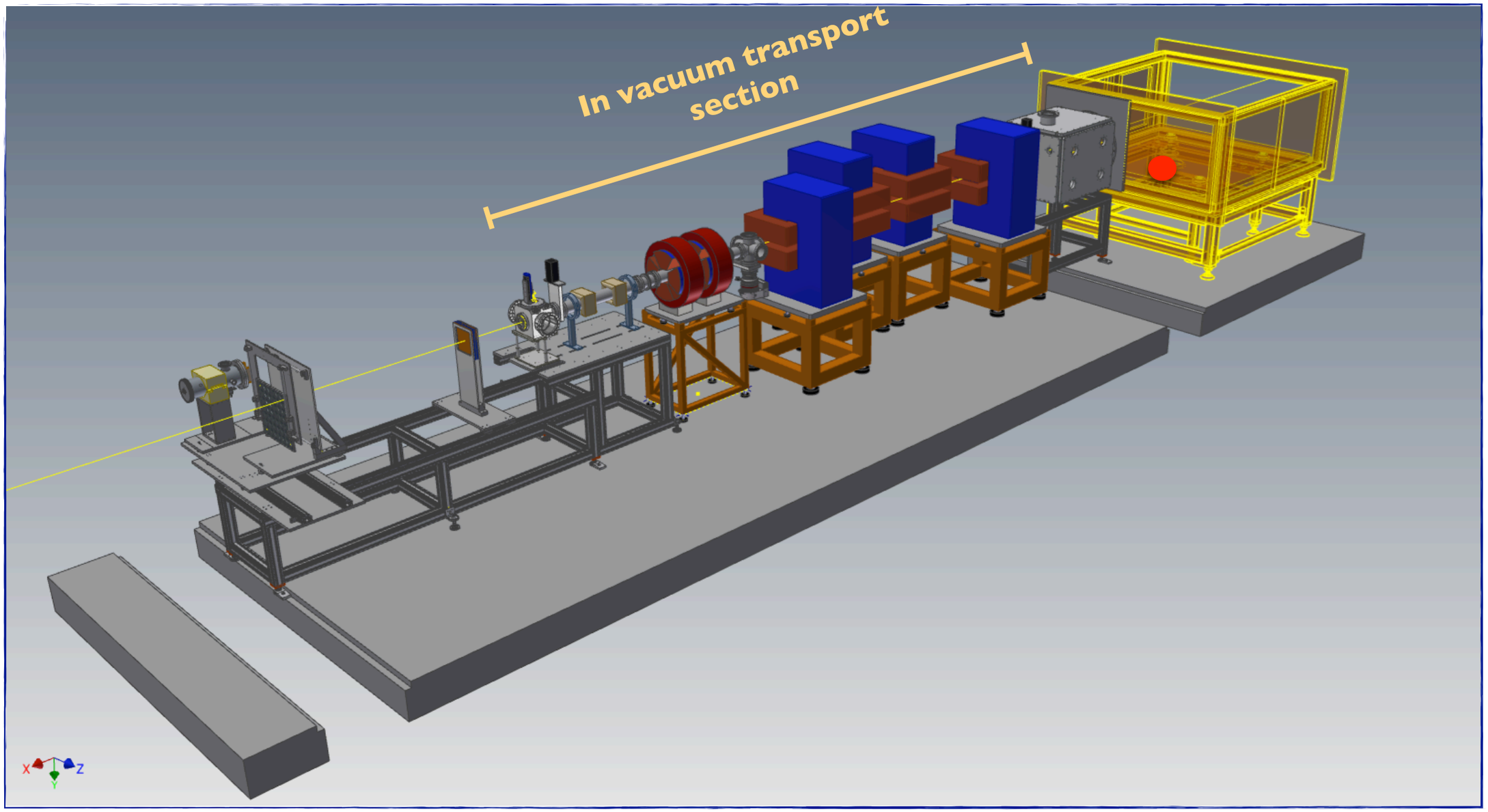
# The ELIMED beamline diagnostics system





# The ELIMED beamline diagnostics system





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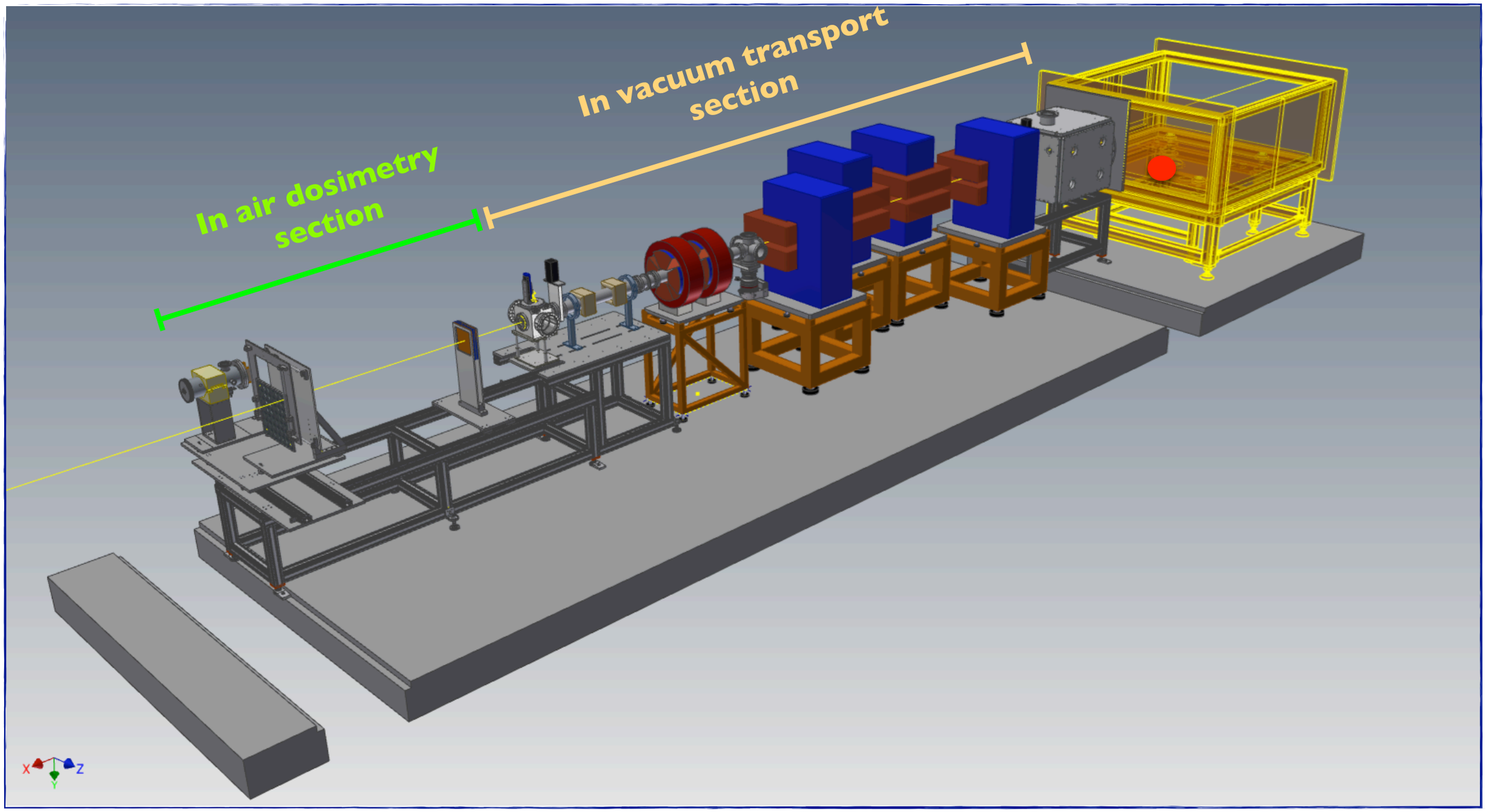

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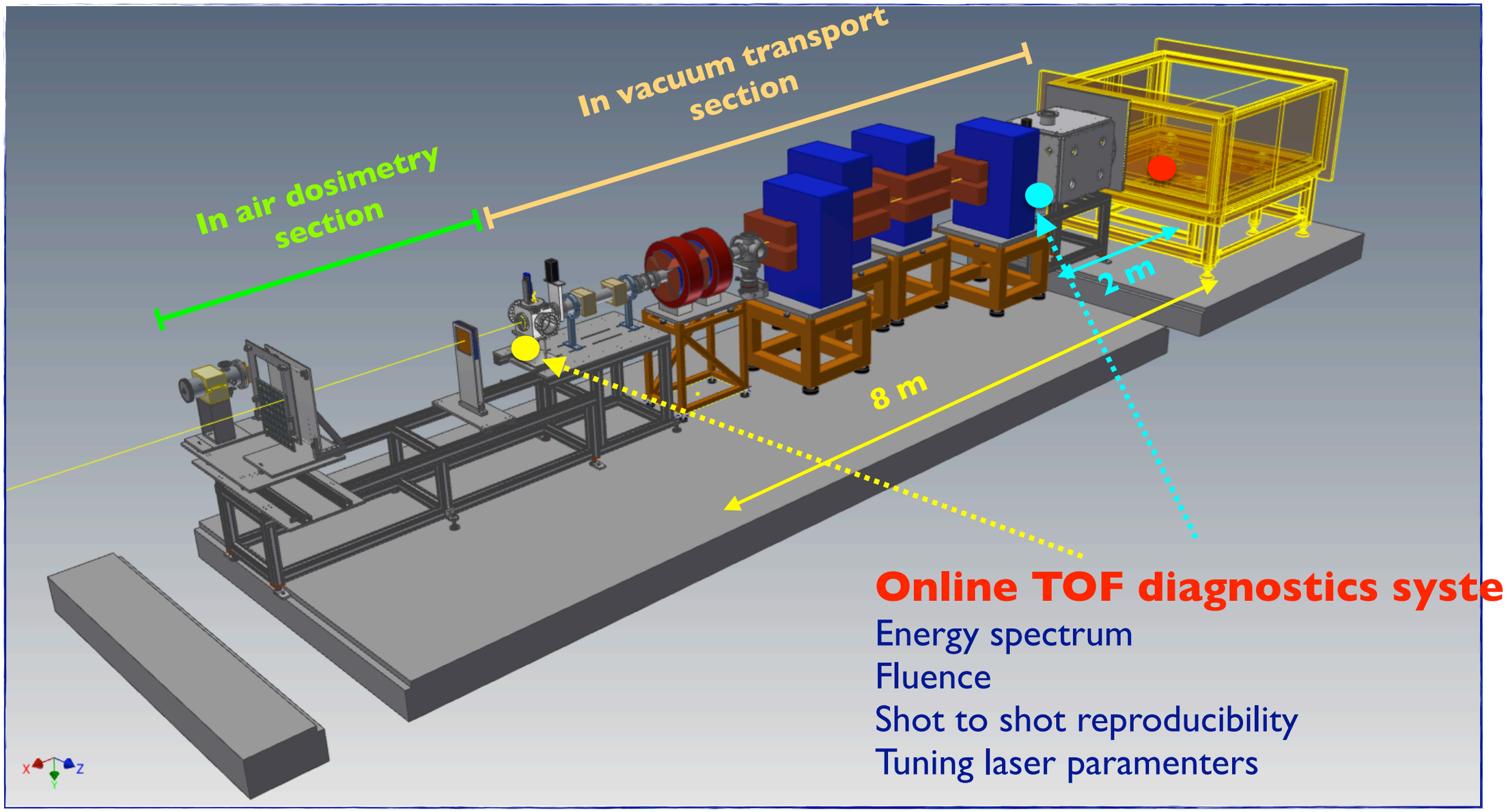

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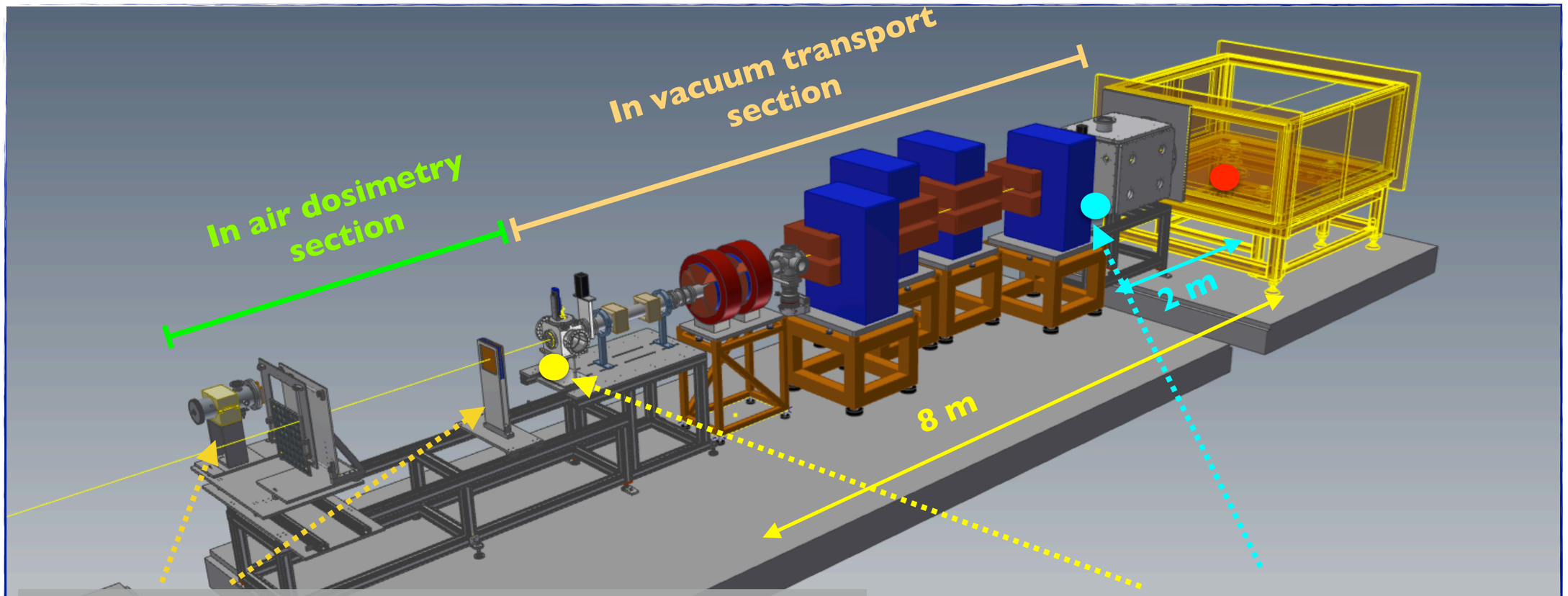



**Absolute dosimetry**

Absolute dose with Faraday Cup

Correction of ion recombination with a multi-gap chamber

On-line dose monitoring and sample irradiator

**Online TOF diagnostics system**

Energy spectrum

Fluence

Shot to shot reproducibility

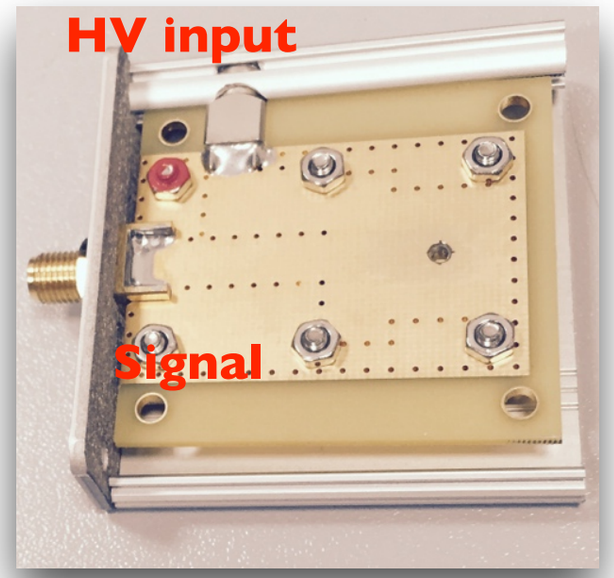
Tuning laser paramenters

# Beam diagnostic



***Main goal:*** *ONLINE proton energy spectrum and fluence measurement along the beam line*

**pCVD**




**Substrate thickness: 100 µm**
**Electrode size: 3 mm diameter**
**Detector capacitance: 4 pF**
**Bias voltage: 200 V**

***high radiation diamond detector***
***linear response for very high intensity***
***(up to $10^9$ ppp )***

## *Detector requirements*

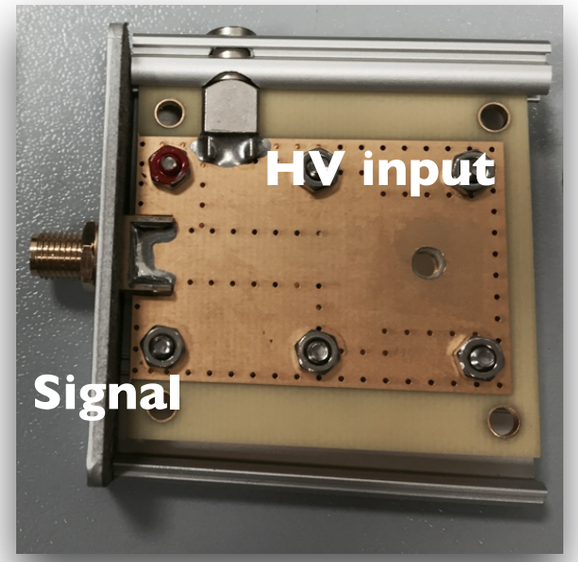
**Radiation hardness**
**(up $10^6$ and $10^{12}$ ppp)**

**Time resolution**
**(of the order ns)**

**Low-capacitance detector**
**(ten's of pF)**

**Thickness**
**(between 10's and 100's µm)**

**sCVD**

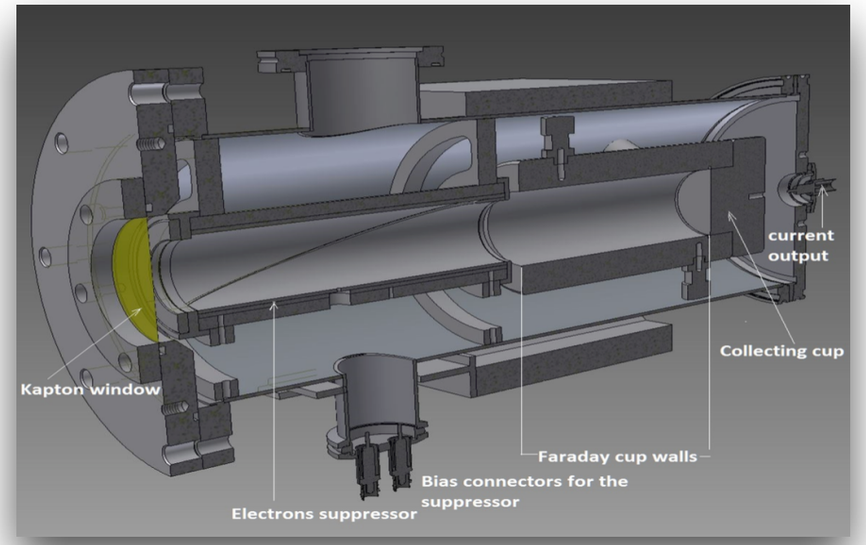


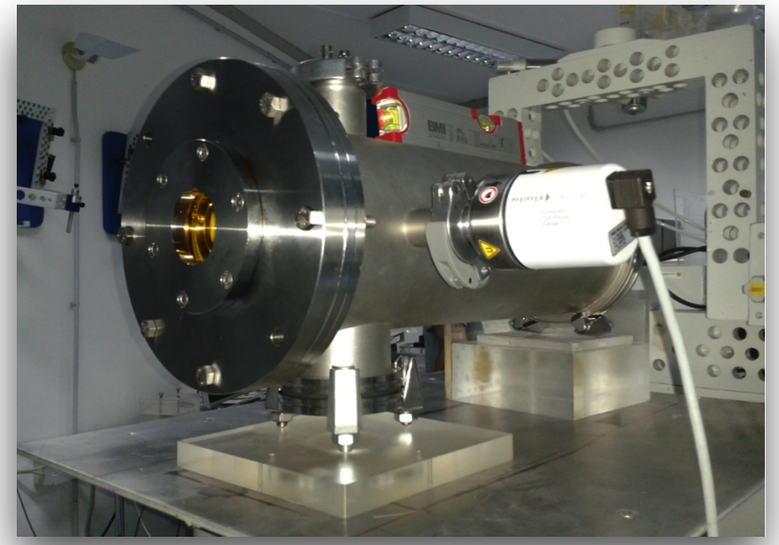

**Substrate thickness: 500 µm**
**Electrode size: 4 mm diameter**
**Detector capacitance: 3 pF**
**Bias voltage: 400 V**

***good time resolution***
***excellent signal-to-noise ratio***
***(low noise)***

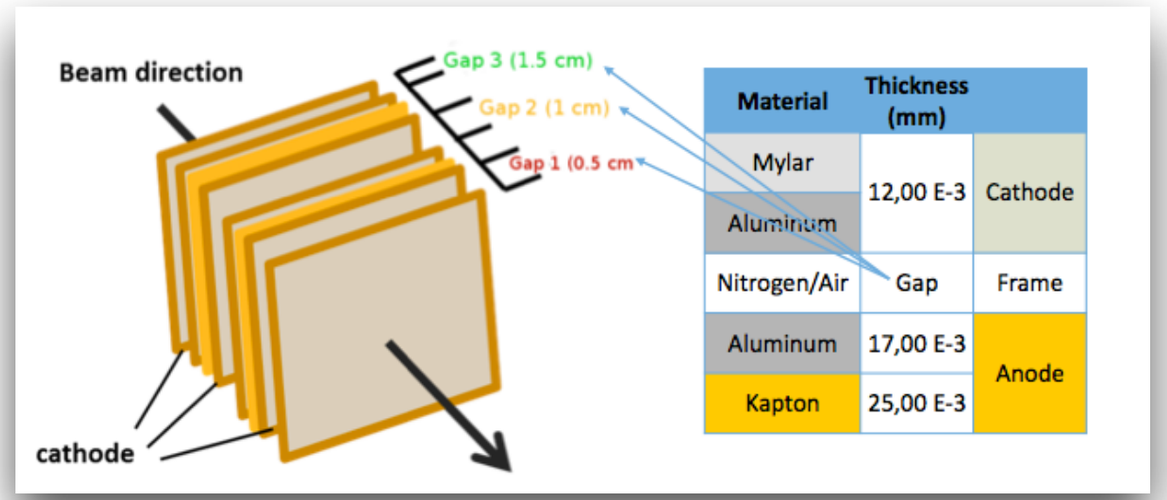
# Absolute dosimetry



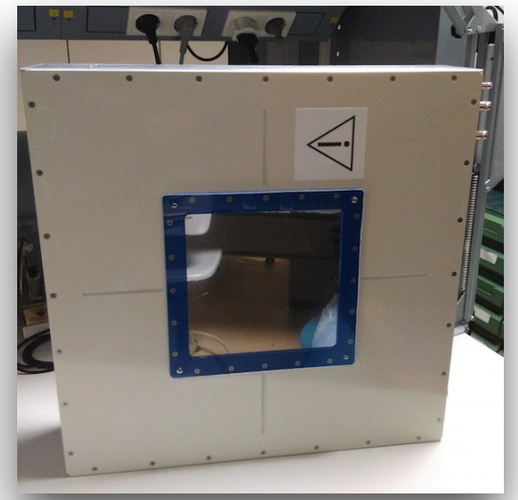


Faraday cup based detector for the absolute determination of the released dose




| 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 | |



Dual-gap transmission ionisation chamber, calibrated against the Faraday cup for the on-line measure of the released dose

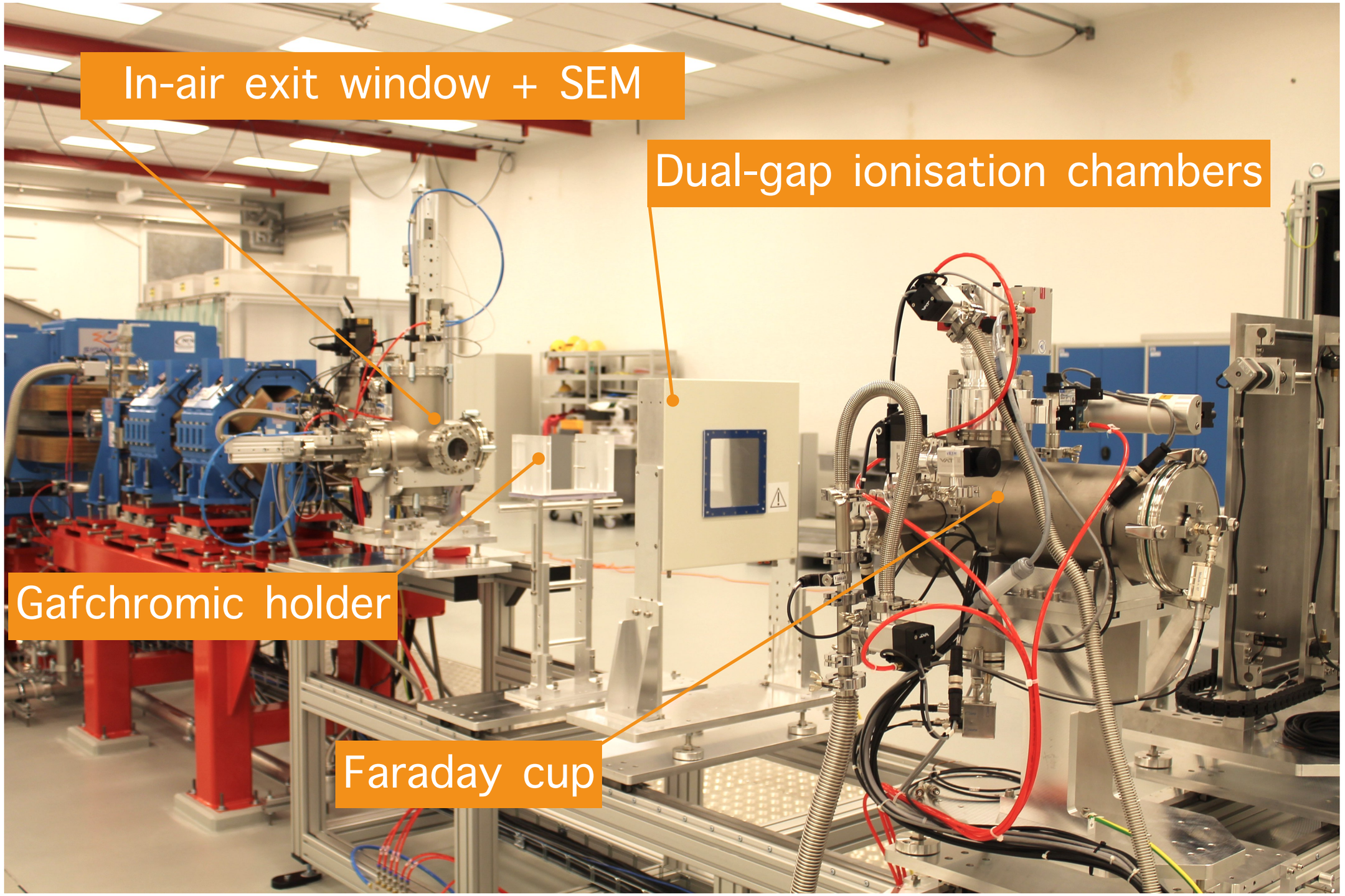
# July 2018




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

# System installed at ELI





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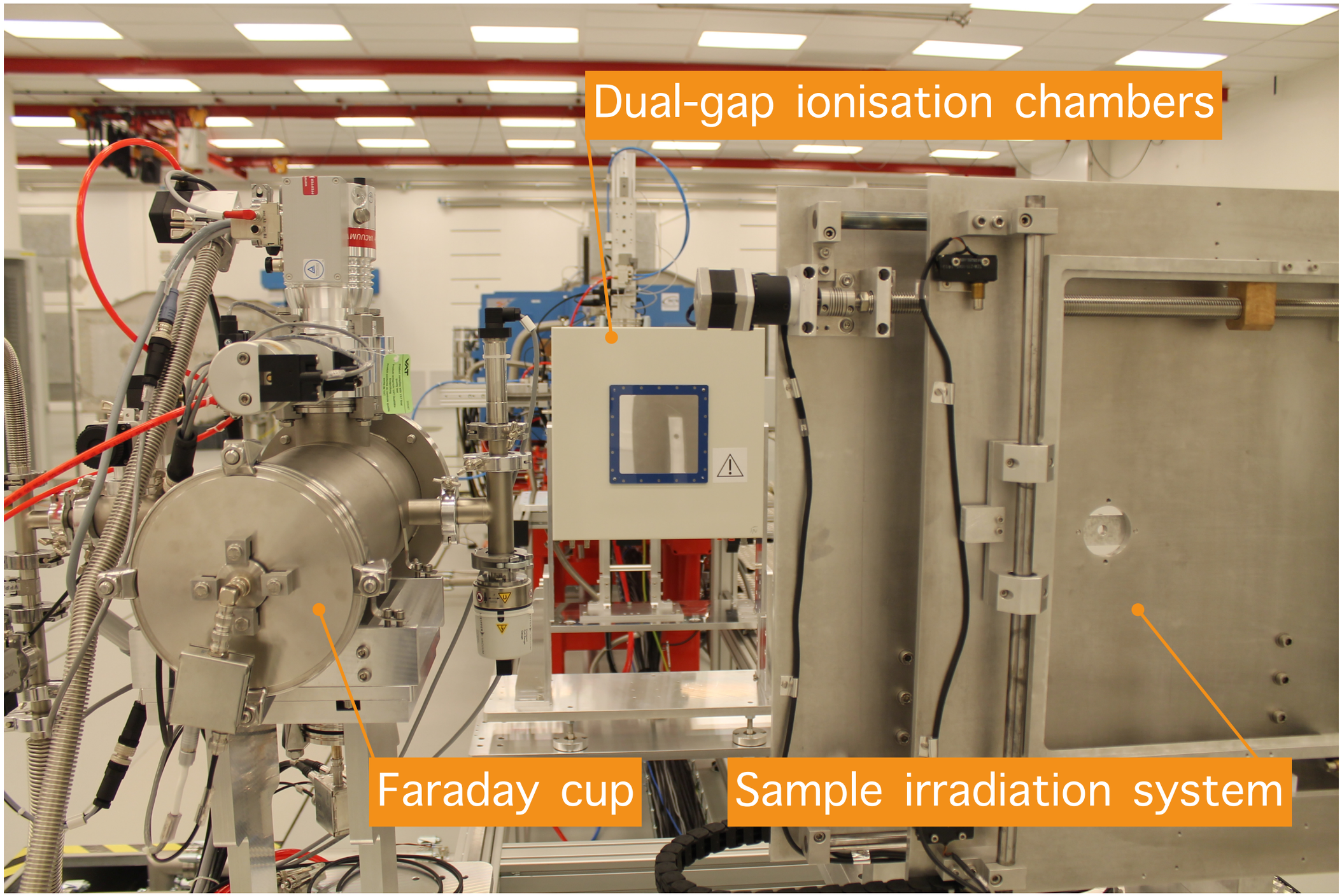


# Sample irradiation system



Istituto Nazionale di Fisica Nucleare

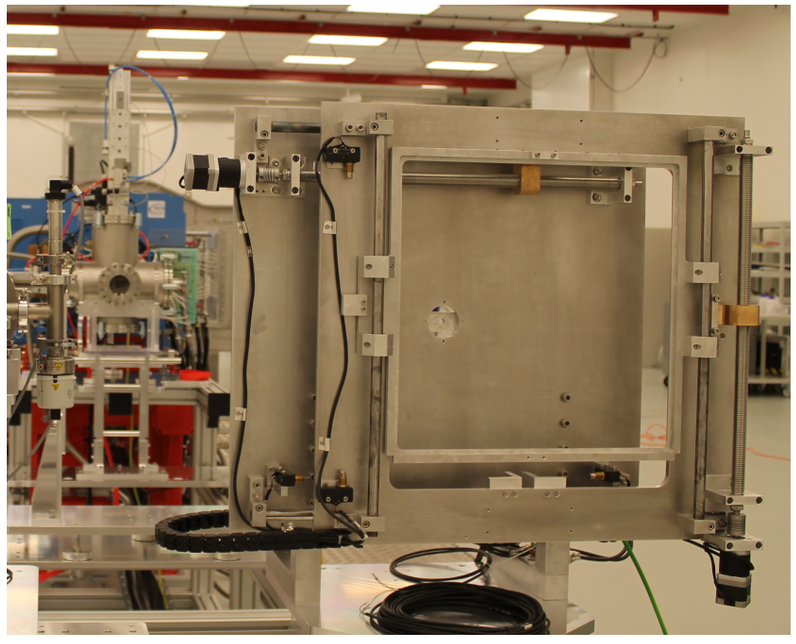
Radiobiology

Cultural heritage

Radiation damage

Proton imaging

Detector and dosimetry tests-bench



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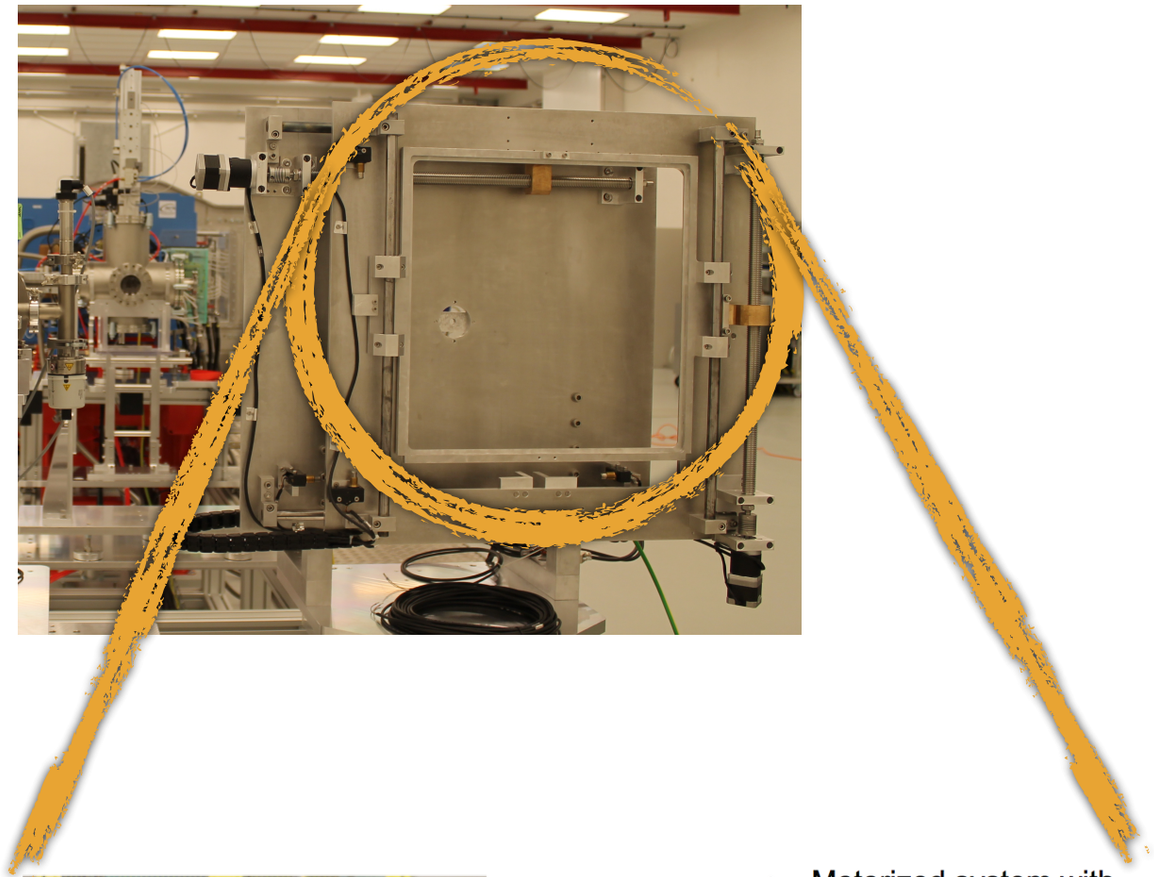
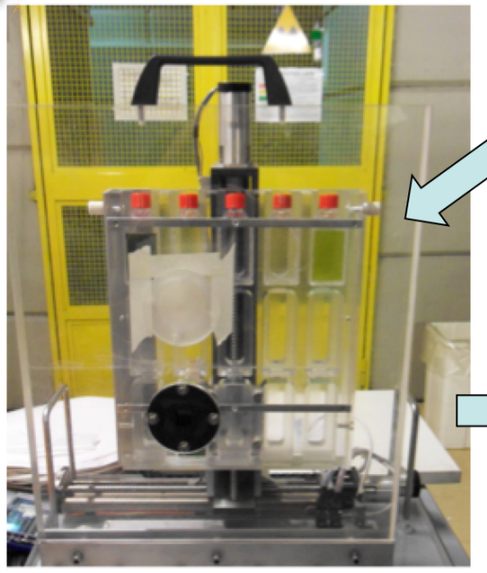
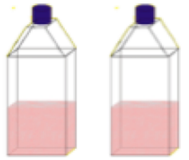
Proton imaging

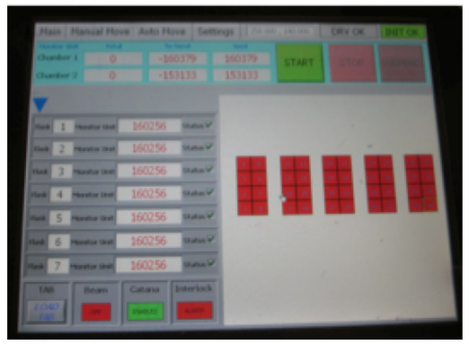
Detector and dosimetry tests-bench







- Motorized system with 100 um precision
- Remotely controlled
- Interfaced with beam control system
- Real time dose-rate monitoring



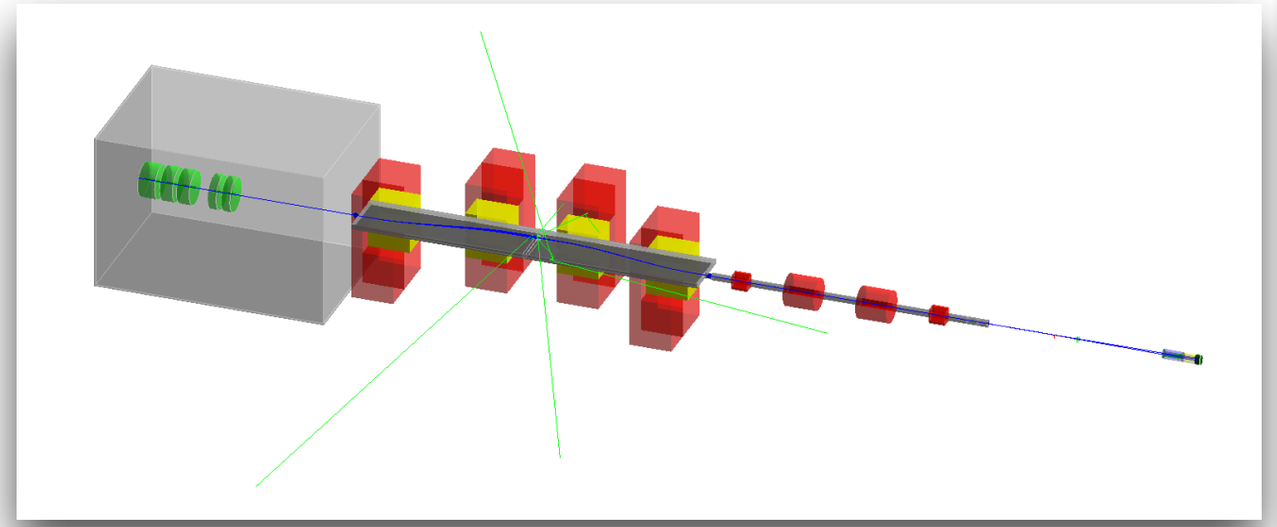
# Monte Carlo simulations

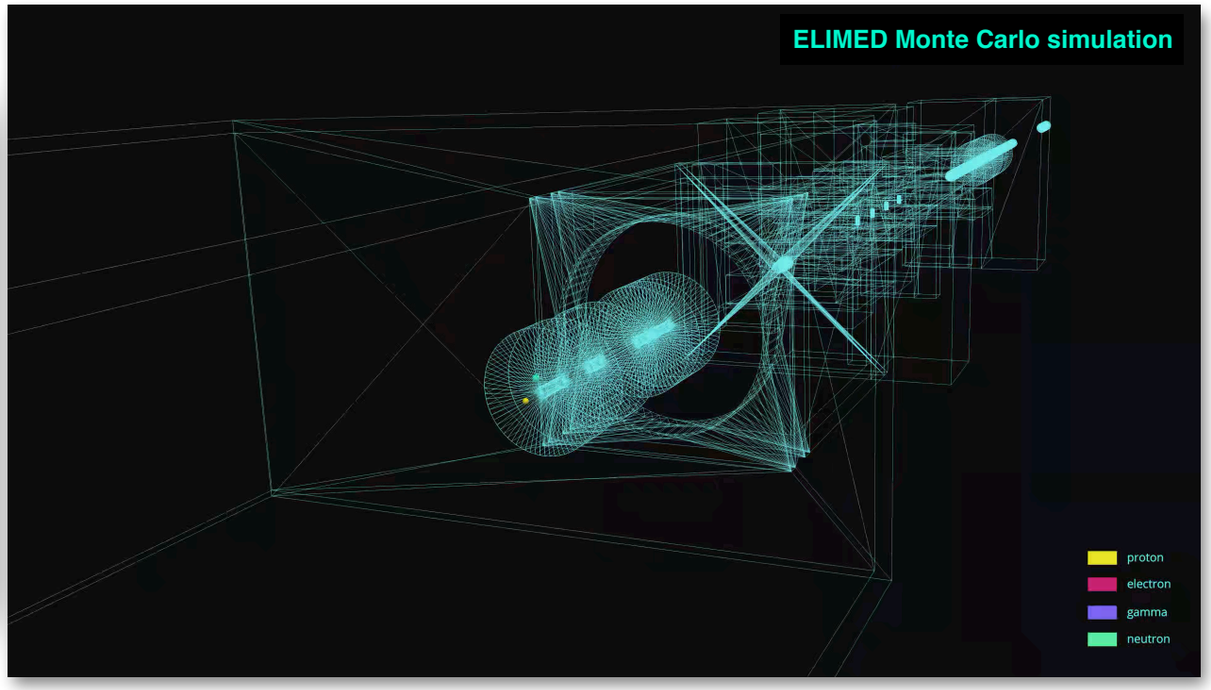


A Geant4 application fully simulates the beamline and will be at the User disposal for their experimental plans

Dose, LET, RBE, secondaries production, rdioprotection, etc

Any specific source and geometry can be implemented



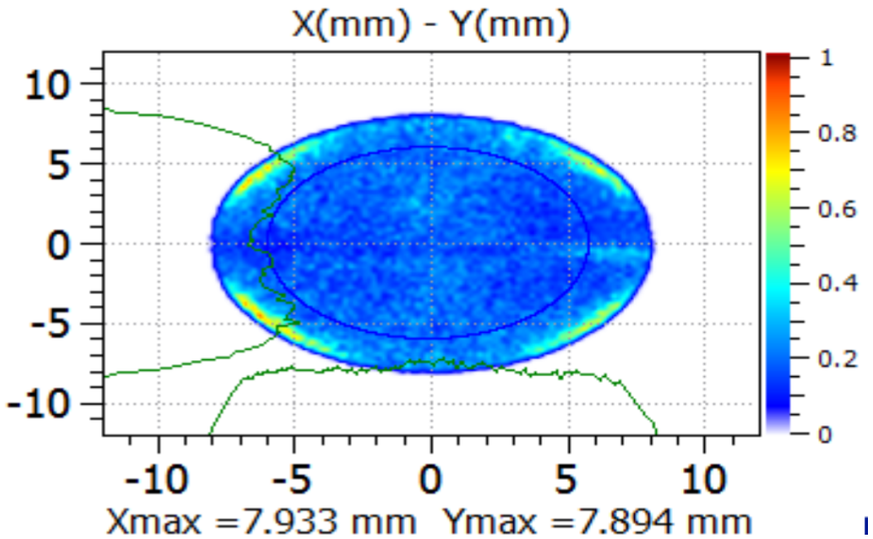


# Expected beams features

## Beamline commissioning: within 2019

Angular divergence: 5° (FWHM)

Angular divergence: 12% (9.2 *$10^7$ H+/bunch)




60 MeV case

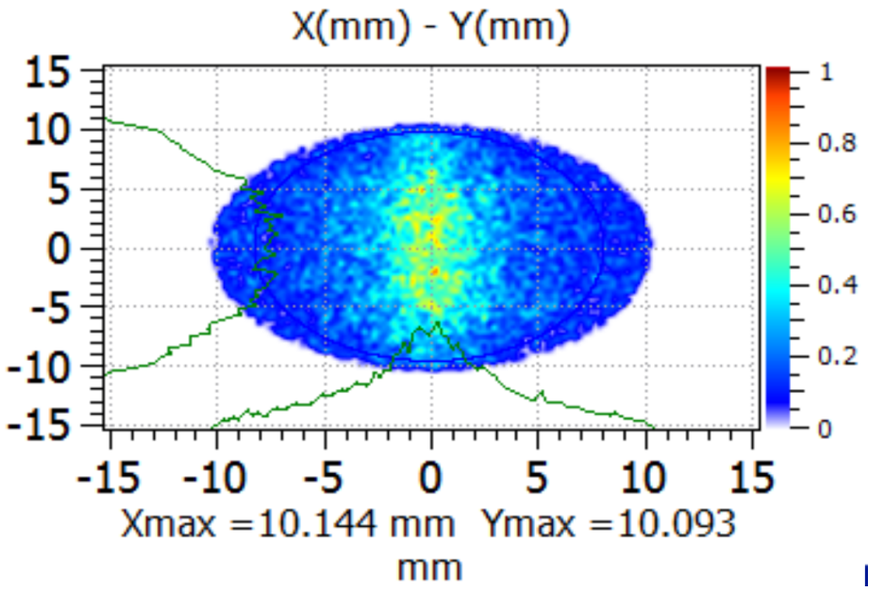
Dose: 0.05 Gy/bunch

Fluence: 3*$10^7$ $H^+/cm^2$

Dose rate: 10^5 Gy/sec

Angular divergence: 5° (FWHM)

Angular divergence: 14% (3.2 *$10^9$ H+/bunch)




30 MeV case

Dose: 0.35 Gy/bunch

Fluence: 3.4*$10^8$ $H^+/cm^2$

Dose rate: 10^8 Gy/sec

# Expected beam features and steps



Beamline commissioning: within 2019

First phase: 2020 - 2021

Beam: 30 MeV proton beams, 10° angular aperture

Intensity: > 10^5 Gy/sec

Beam spot size: uniform on (at least) 2 cm

First experiment with dosimetry and cells irradiation:

First six months 2020

Already in 2019 preliminary test with lower energy protons for Users interested

IV ELIMED Workshop end 2019 (begin 2020)

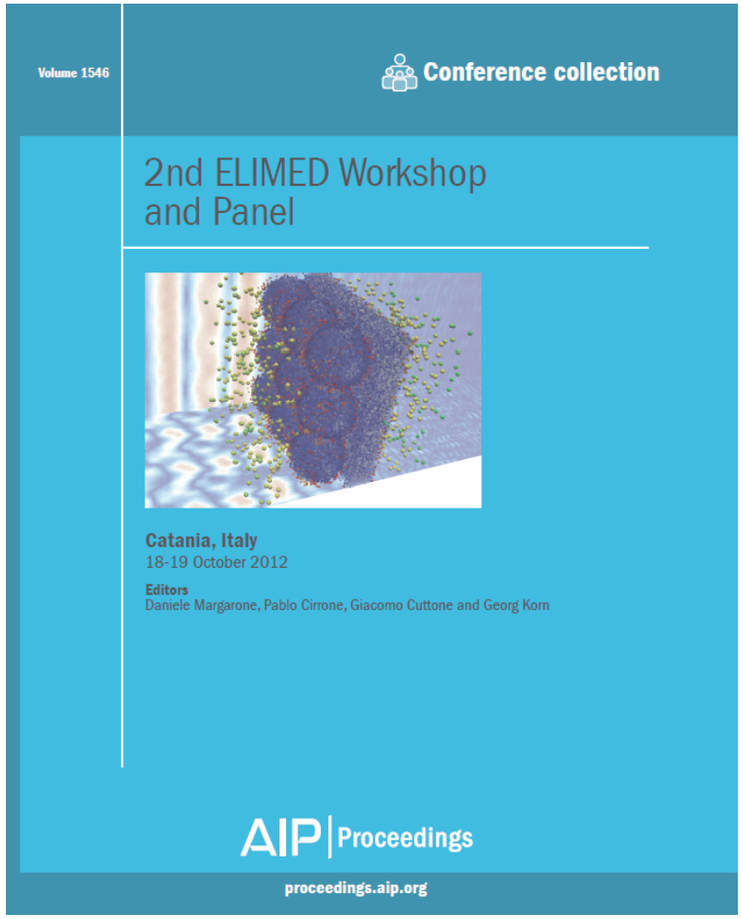
TÉCNICO LISBOA

Fyzikální ústav AV ČR, v.v.i.

Queen's University Belfast

INFN Istituto Nazionale di Fisica Nucleare

SAPIENZA Università di Roma



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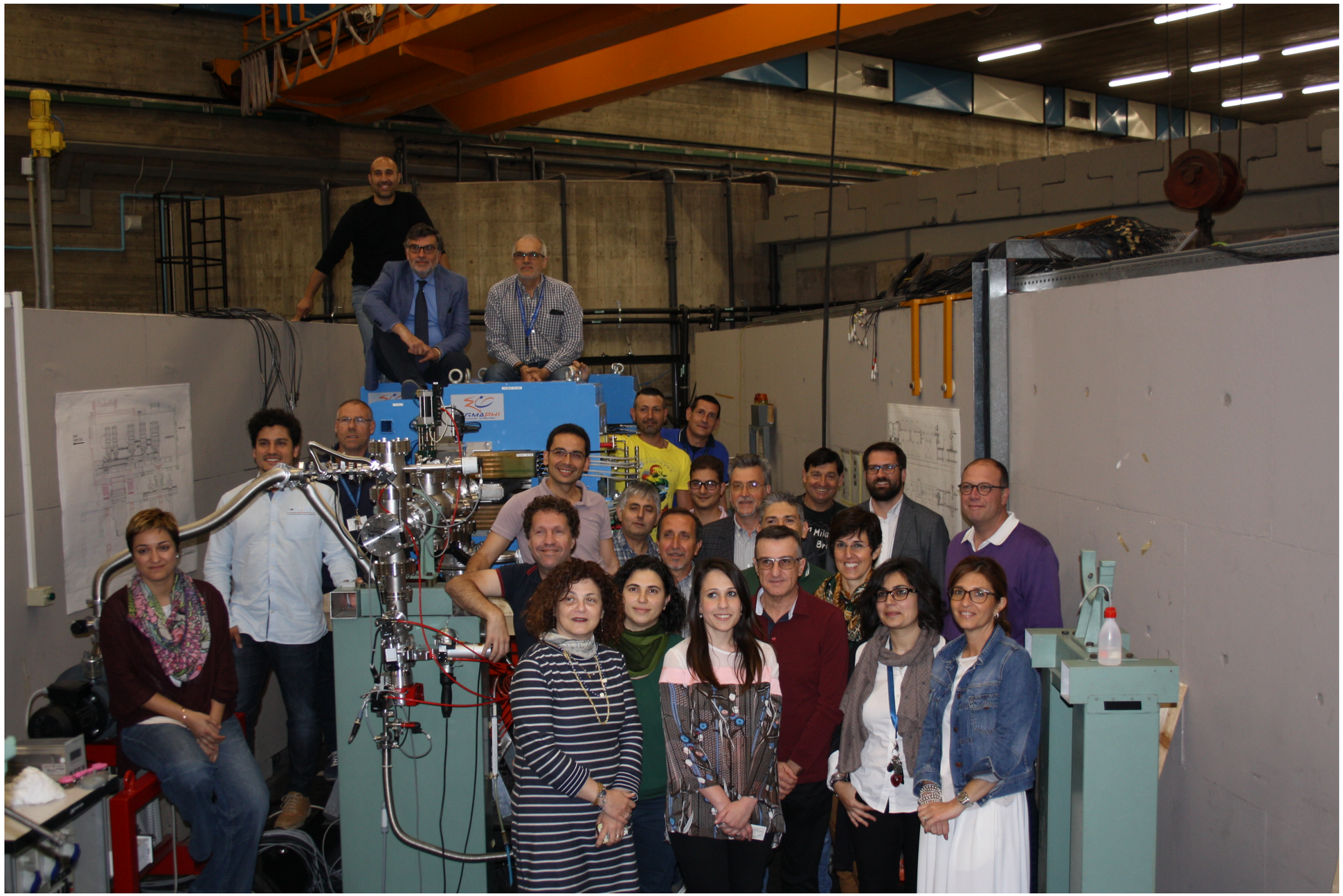
Istituto di Bioimmagini e Fisiologia Molecolare

THE UNIVERSITY OF CALIFORNIA 1868

# Thank you



# ELIMAIA-ELIMED Experimental Hall