EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2007-2013

Project co-financed by the European Regional Development Fund

Sectoral Operational Programme
„Increase of Economic Competitiveness"
"Investments for Your Future"

Extreme Light Infrastructure – Nuclear Physics (ELI-NP)

Materials and biological systems under irradiation at ELI-NP

Presents **Mihail Cernaianu** on behalf
of the "Nuclear physics with High Power Lasers" Team

eli Nuclear Physics

IFIN-HH

2006 – ELI on ESFRI Roadmap

ELI-PP 2007-2010 (FP7)

ELI-Beamlines (Czech Republic)

ELI-Attosecond (Hungary)

ELI-Nuclear Physics (Romania)

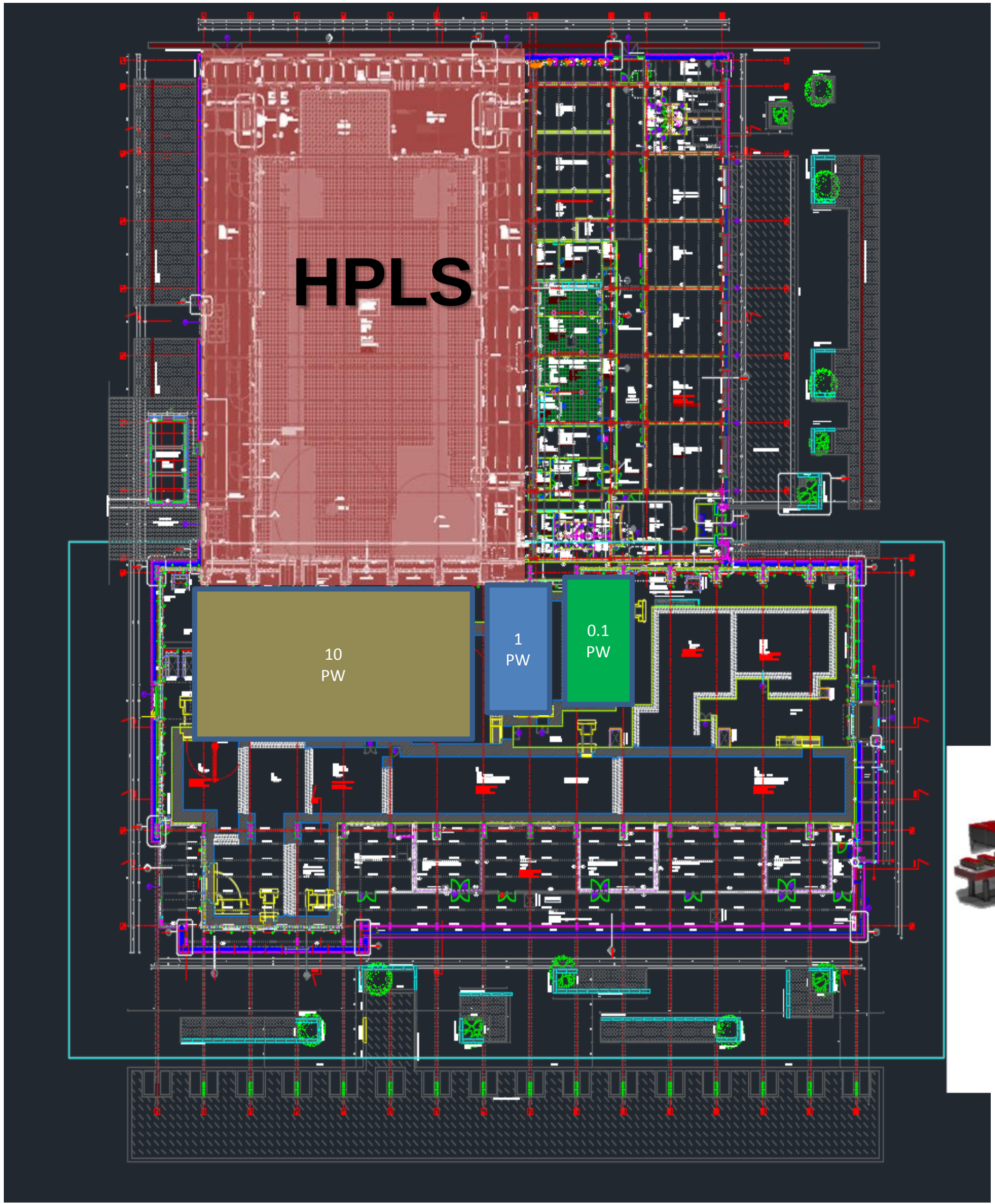
ELI-DC (Delivery Consortium): 2010

Legal entity: April 2013

Czech Republic, Hungary, Romania, Italy, Germany, UK

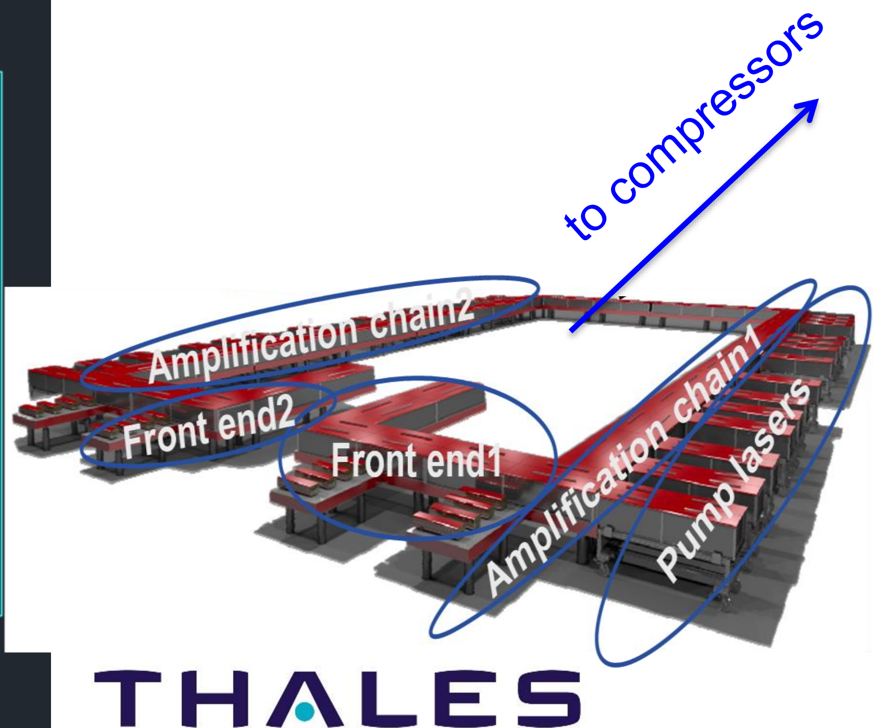
Buildings operational

ELI-NP HPLS

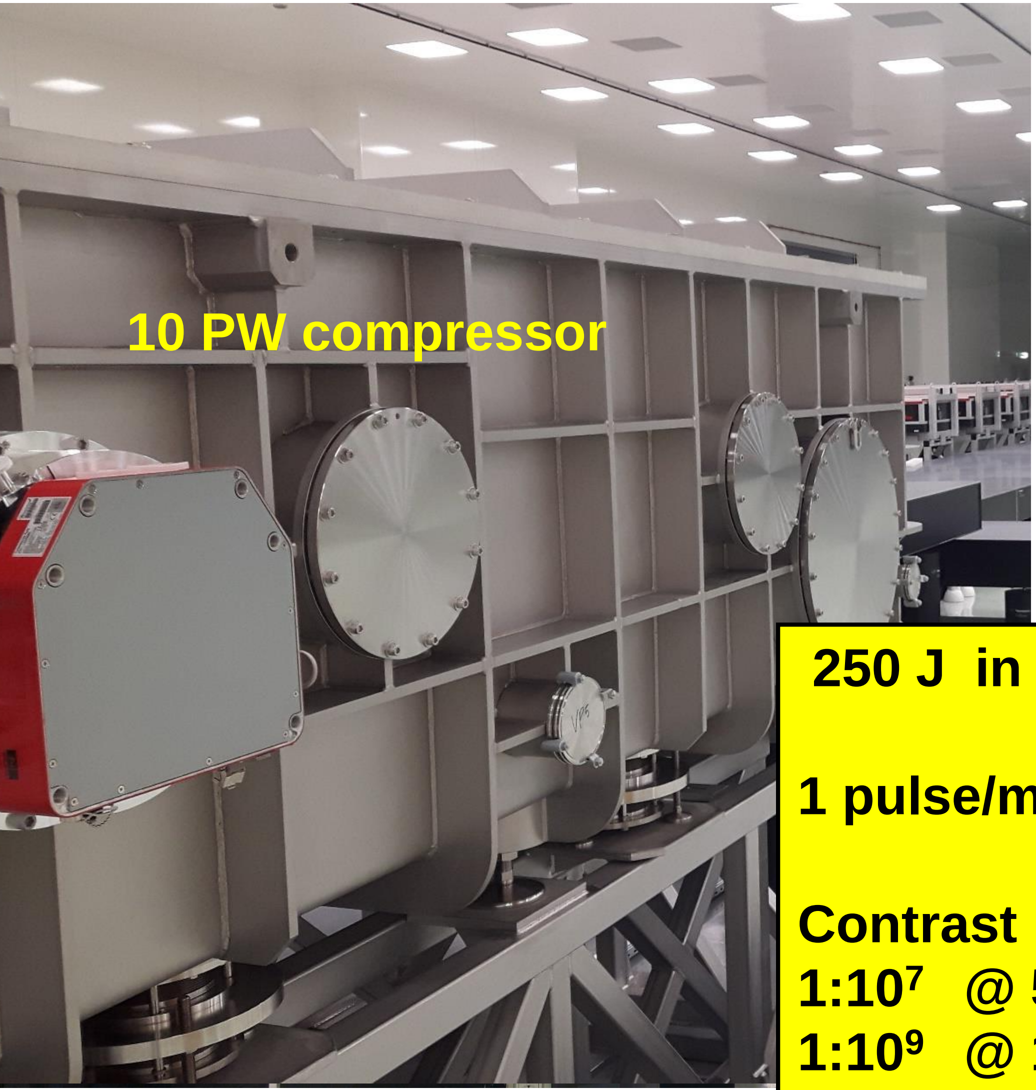


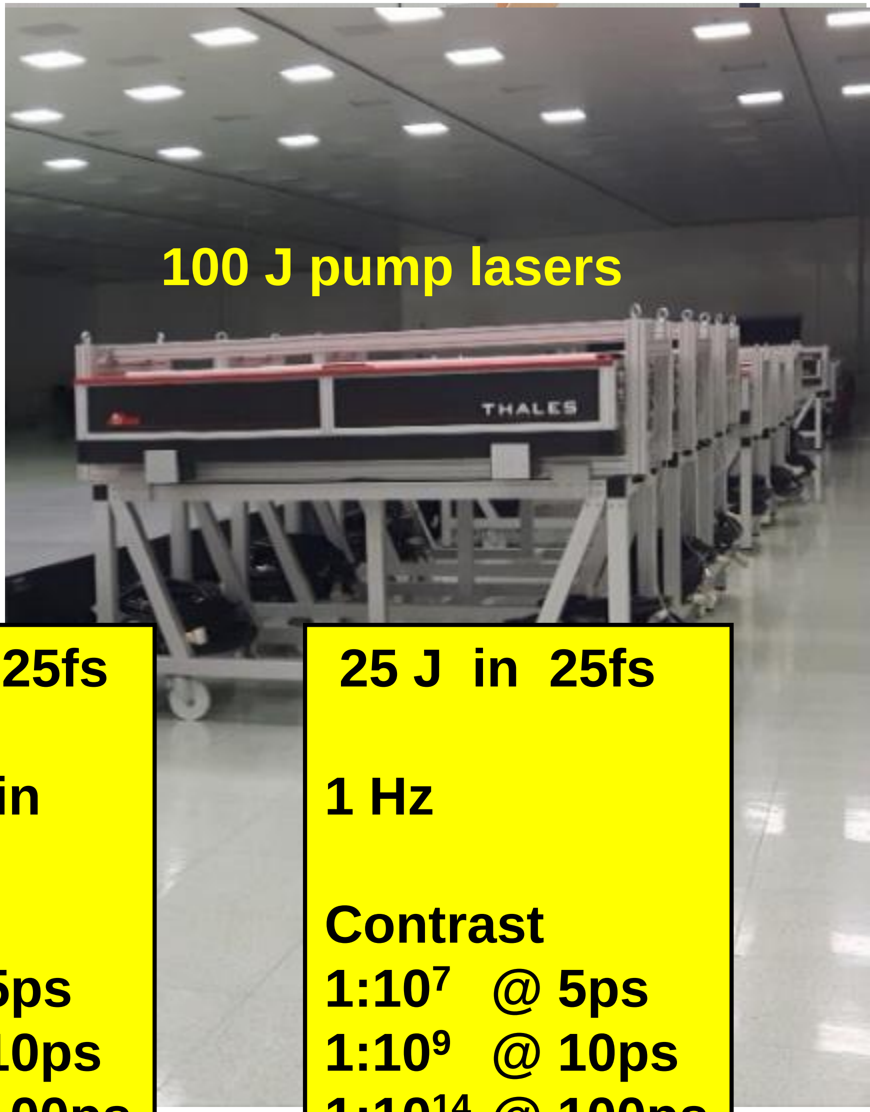
*High **P**ower **L**aser **S**ystem*

2 x 0.1 PW
2 x 1 PW
2 x 10 PW



Installation of 2x10 PW Thales lasers underway





250 J in 25fs

1 pulse/min

Contrast
1:10^7 @ 5ps
1:10^9 @ 10ps
1:10^{14} @ 100ps

25 J in 25fs

1 Hz

Contrast
1:10^7 @ 5ps
1:10^9 @ 10ps
1:10^{14} @ 100ps

10 PW lasers will enable unique experiments from Day-1

Extreme light intensity (<10^{23} W/cm^2)

Extreme electric fields (10^{15} V/m)
Strong-field QED

10 PW laser + solid target
→ **Ultra-intense PW γ-source**

10 PW laser + 10 GeV LWFA electron beam
→ **Non-linear Compton, Radiation reaction, Breit-Wheeler pairs**

Extreme light pressures (Tbar)
Nuclear Physics with Lasers

Radiation Pressure Acceleration of GeV near solid density ions
→ **Neutron-rich nuclei production**
→ **Ultra-intense neutron source**
→ **Nuclear reactions in plasmas**

- **Day-1 experiments reviewed by ELI-NP International Scientific Advisory Board**

1 PW: Applications of Material Science

- testing new materials for fusion and fission energy application
- testing of new materials for accelerator components
- testing materials for space science (electronics components, hypervelocity impacts)

- surface and volume modification; micro- and nano-technology
- biological science research (effects on bio-molecules, cells)
- testing radiation hardness and developments of detectors
- irradiated optical components testing

Testing of new materials for accelerator components

High power targets: production targets for radioactive beams, neutrinos, spallation targets

- collaborations: RADIATE, PASI

Secondary collimators for HL-LHC

- innovative materials are needed for accelerator collimator jaws for the upgrade of the LHC

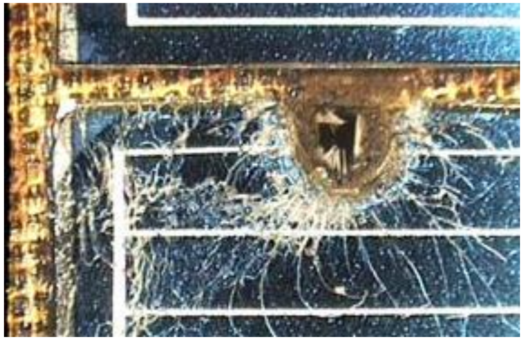
- aims of collimator material experiments at ELI-NP: testing of novel materials under extreme conditions (accidental beam impact), quantifying of material damage for LHC operating scenarios

Dynamic Response of Structural and Functional Space Materials to Micro-Meteoroid Impacts

Space environments are very hostile to spacecraft materials and components:

- combined action of radiation,
- extreme temperature,
- vacuum conditions,
- hypervelocity micro-particles:
  - investigated using shock waves induced with flyers launched in high-power laser impacts on specially designed targets.
  - experiments can be performed on pristine materials
  - samples exposed to increasing cocktail doses of particles, simulating the natural radiation exposure in space.

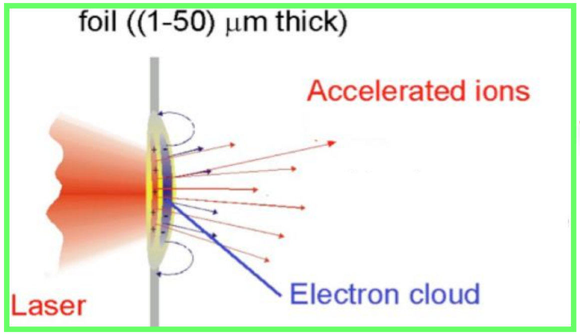
19 mm crater in the High-Gain Antenna of the Hubble Space Telescope



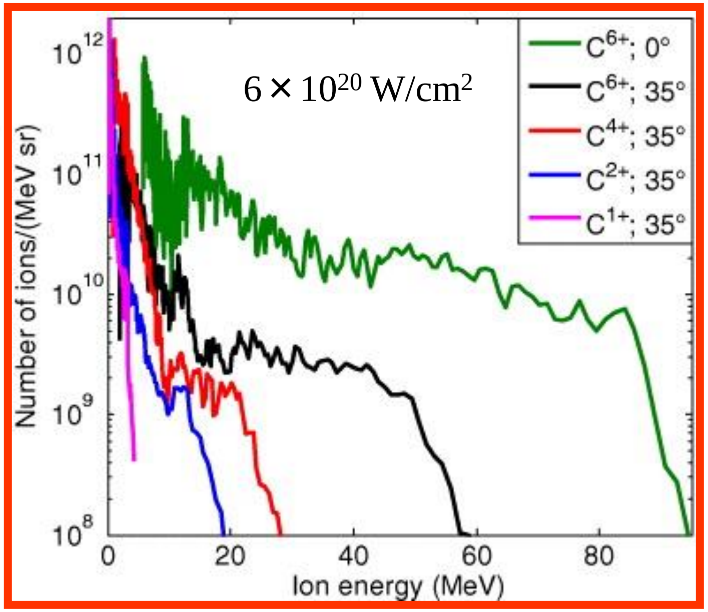
Thousands of impacts on solar panels

Ground testing of space materials in extreme conditions

- Radiation environment for ground testing ideally similar to the satellite environment
- Conditions difficult to achieve by traditional accelerator facilities
- Cosmic radiation includes protons, helium and heavier ions, electrons, neutrons, and UV radiation leading to complex damage of materials
- Energy spectrum of laser TNSA accelerated particles is quite similar to the natural one
- Vacuum and extreme temperatures as well as thermal cycling alter physical properties and lead to material fatigue.
- Impacts of micro-meteoroids and orbiting man-made debris damages on spacecrafts

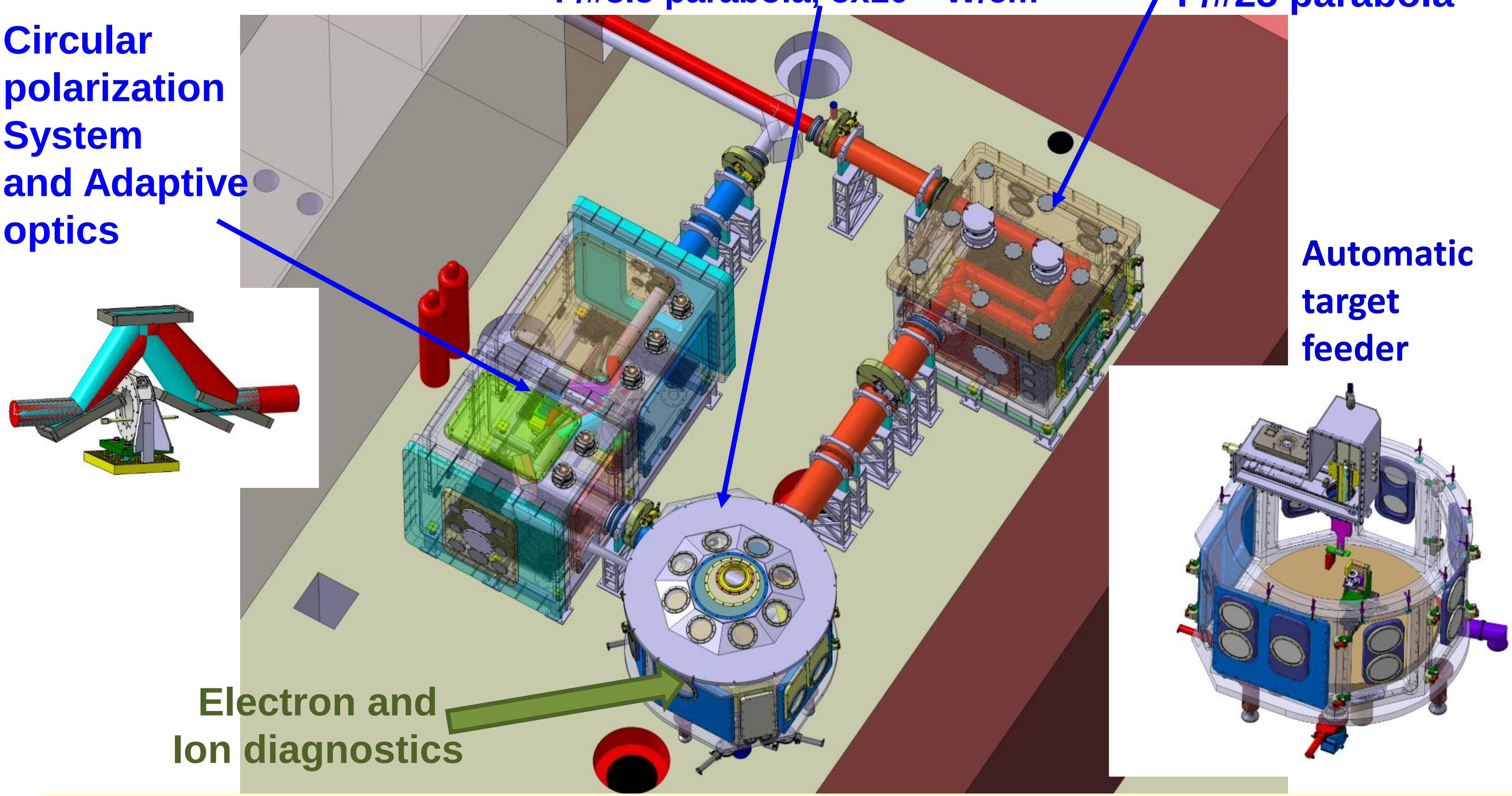


TNSA - Target Normal Sheath Acceleration
10^{18} - 10^{20} W/cm^2



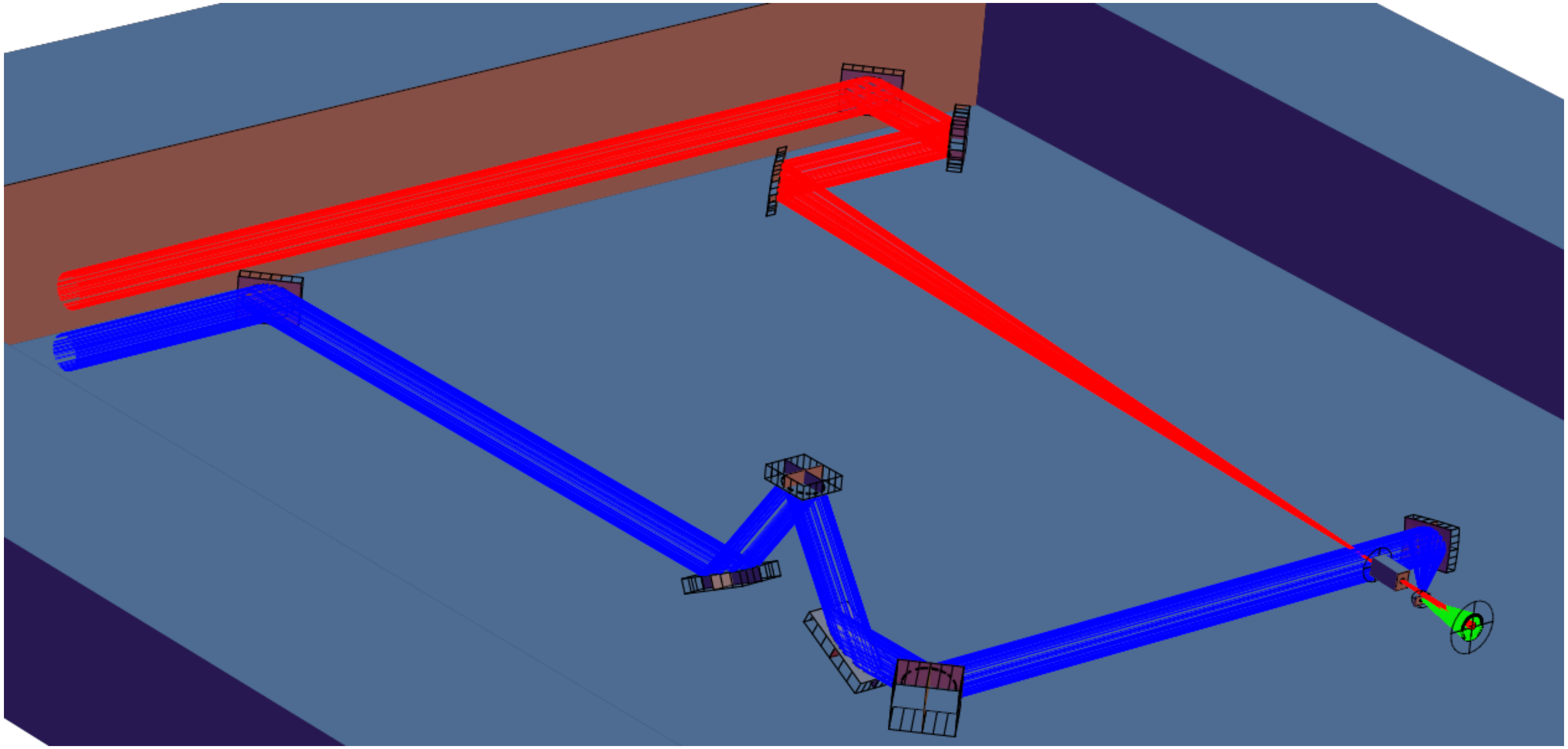
A. Macchi et el. Rev of Mod. Phys, 85 (2013) 751
D.C. Carrol et al., New J. of Phys. 12 (2010) 045020

2x1 PW Experimental Area under tender



- Synchronous electron/ion/gamma beams for materials, bio studies
- Mirror based Circular Polarization (CP) system
- Compare RPA at 1 PW with LP, CP, and helical-phase beam

2x 1 PW area multiple configurations



- Short OAP configuration for high-Z ion acceleration
- Long OAP for e- acceleration
- Combined configurations
- Upgrade possible with two long OAP

2019: Preparatory experiments of high-Z ion acceleration

Biological effects of laser generated multi-component radiation mimicking cosmic rays at ELI-NP

Project goals

Stage I

1. Deleterious vs beneficial biological effects of cosmic-like radiation on normal/diseased eukaryotic cells and normal/transgenic small lab animals (*in-vitro* and *in-vivo* studies)

2. The response of cells/tissues/organisms to acute or repeated dose exposures to cosmic-like radiation

3. The underlying mechanisms of cell-cosmic ray interaction (genomic and proteomic approach)

4. Effect at biological level of synergistic effect of cosmic radiation and thermal stress due to extreme temperatures environment and also on the immune system

Stage II

1. Design and preclinical testing of counter-measures to limit deleterious effects (biological and therapeutic approaches, regenerative therapies using stem cells)

2. Design and testing of personalized multicomponent radiotherapy for resistant, aggressive tumors with minimization of side effects by using nanoparticles

Motivation

- To understand cellular response to radiation in space
- To improve available models
- To evaluate risk (biological and health effects) for astronauts in long-term missions
- To establish radiation dose limits for deep space exploratory missions
- To develop radioprotection tools, dosimetry and regenerative therapies
- To develop personalized alternative treatments in multicomponent radiation therapy with targeted nanoparticles for aggressive and complex tumours

Outcome - what we will return to the society

A. Re(evaluation) of radioprotection measures for humans in space conditions (and at ELI-NP)

B. Input for design of more efficient shielding and new materials against cosmic rays and space environment

C. New multi-component radiotherapy medical technology in combination with methods from nanomedicine

D. Input for design of a multicomponent irradiation medical equipment and the associated dosimetric model

E. Specific knowledge and understanding of sinergistic effect of multicomponent radiation on biological systems

F. Development of dosimetric methods and equipment for multicomponent radiation

What do we need to develop this research direction

A. Cocktail of radiation production at ELI-NP

Particle source	E (daily operations)	E_{max} (upper limit)	Divergence	Reference
Proton	20 MeV	60 MeV	±20°	R. Prasad [6]
Electrons	1 GeV	2 GeV	±0.057°	K. Nakajima
Neutrons	20 MeV	60 MeV		C. Zulick [7]
Gamma[*]	1 GeV	2 GeV		

B. A Bio/Cell Culture Laboratory Unit (20 m^2) – to be available at ELI-NP
- for initial processing of biological samples and to support the irradiation experiments

C. Evaluation and quantification of biological effects on samples
- to be delivered by “Victor Babes” National Institute of Pathology, Romania

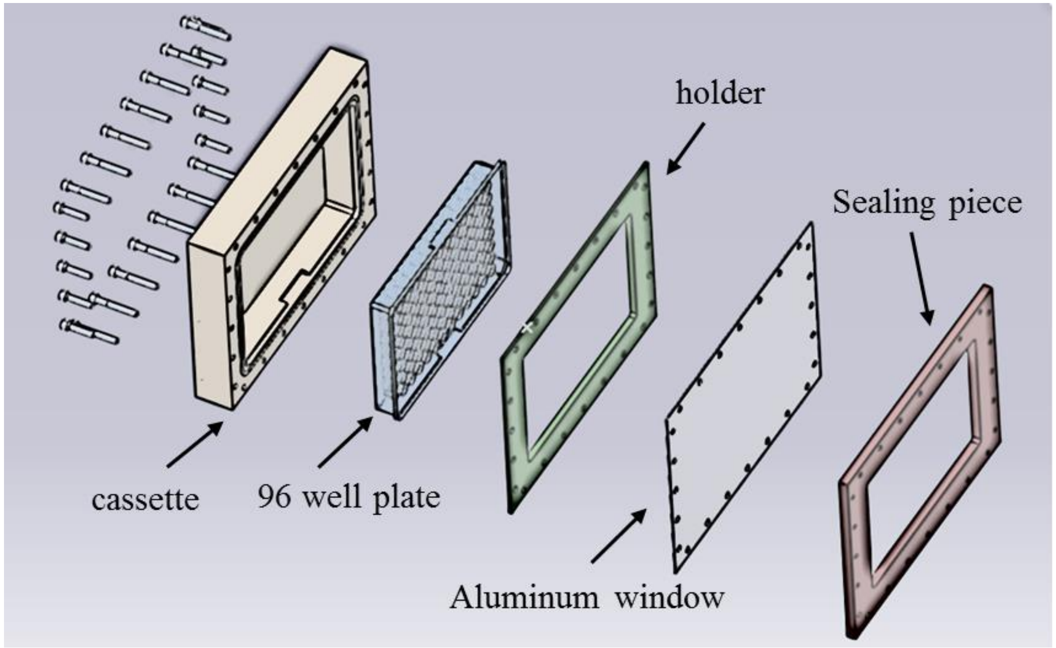
Nuclear Physics

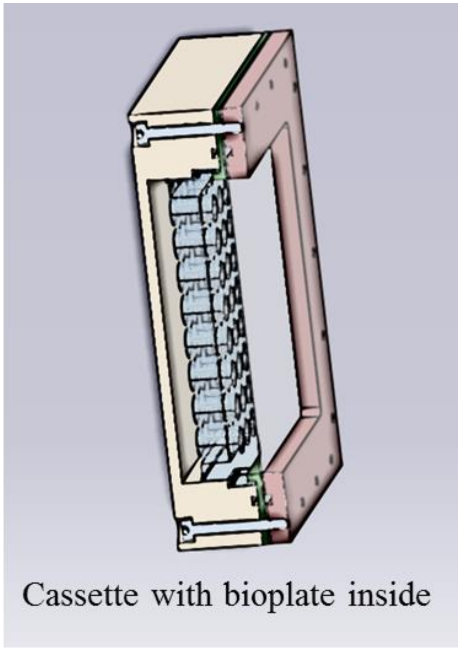
Biological sample irradiation setup with secondary beams

96 well plate

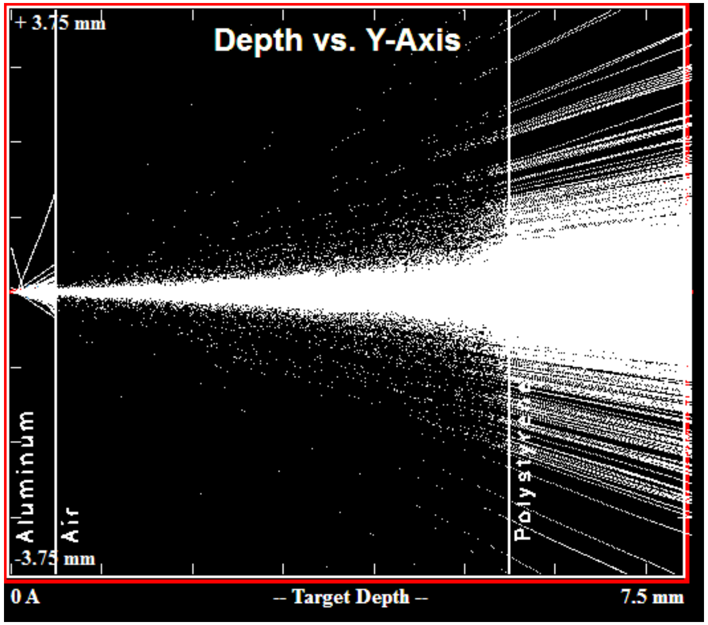
Cell monolayers are usually grown inside a standard 96 well plate (127.7 x 85.48 x 14.6 mm)

The plate is sealed with Titer Tops® sealing film (mainly polyethylene)
The 96 well plates are made of hard plastic (polystyrene).



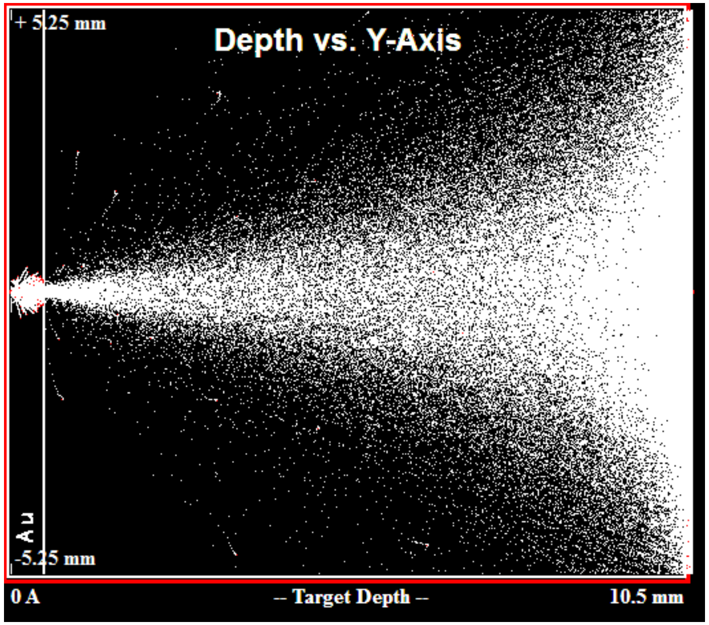


Irradiation of the cell monolayer should be performed through the back of the plate (polystyrene wall)



- SRIM-TRIM simulation results for a 20 MeV proton beam passing through an Al window (0.5 mm), an air layer (5.0 mm) and the polystyrene plate wall (2.0 mm).

-The beam incidence angle is 0 and the cell monolayer at the right of the polystyrene bioplate wall.



- SRIM-TRIM simulation results demonstrating that a 20 MeV proton beam passing through an Au window (0.5 mm) will distribute more uniformly.

- The beam incidence angle is 0.

Effects induced by low dose “mix” of secondary radiation beams

Proposed irradiation protocols:

- Separate irradiations:
  - proton single dose irradiation (dose domain 0-5 Gy)
  - electron single irradiation (dose domain 0-5 Gy);
  - reference X ray or gama irradiation (dose domain 0-5 Gy);

- Repetitive irradiations – sequences of exposures of lower doses (0.1-0.5 Gy), up to total doses of 5 Gy

- Alternative irradiations in the experiments of bystander and adaptive responses: low dose irradiations (<0.5Gy) followed by repetitive or single irradiations of doses up to 2-5 Gy

The alternative irradiation protocols will combine exposures to different beam types (protons, electrons, gamma, brilliant X)

The irradiation regimes will include repetitive low fluence exposures, single short high fluence exposures or combination of them

- **Phase-II of ELI-NP implementation progressing well**

- **Technical and scientific challenges in 10 PW commissioning experiments :**
  - **laser and optics protection**
  - **plasma and nuclear diagnostics**

- **Collaboration opportunities in experiments, diagnostics, targetry**

- **www/eli-np/jobs**

Thank you!