EUROPEAN UNION

GUVERNUL ROMÂNIEI

Structural Instruments 2014-2020

Project co-financed by the European Regional Development Fund through the Competitiveness Operational Programme
"Investing in Sustainable Development"

eli nuclear physics

Extreme Light Infrastructure-Nuclear Physics
(ELI-NP) - Phase II

IFIN-HH

ELI-NP Experimental Capabilities Update

Dan Stutman for the ELI-NP Team

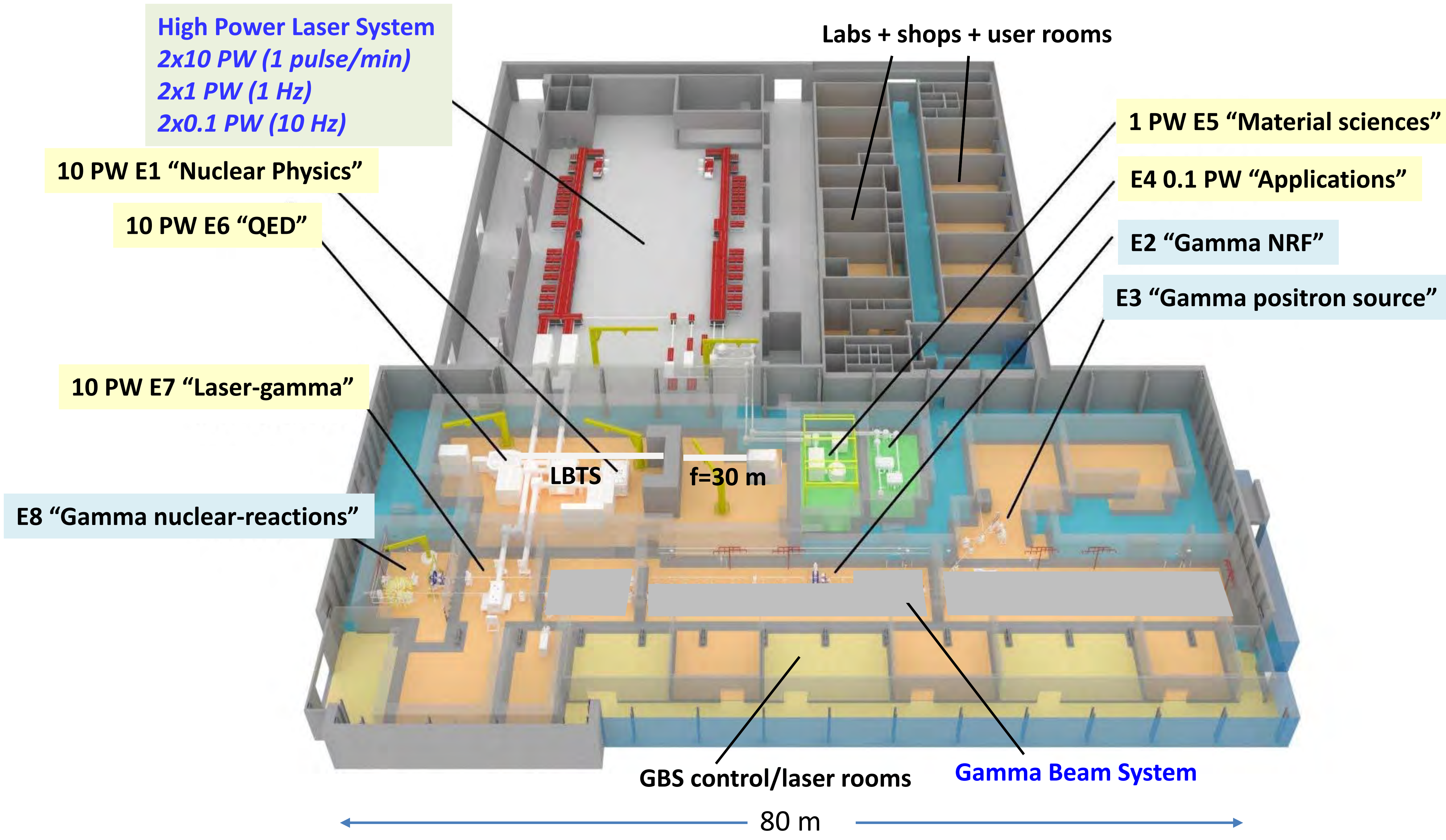
US-ELI JOINT WORKSHOP September 2019

ELI-NP: two extreme light sources in one facility

Magurele

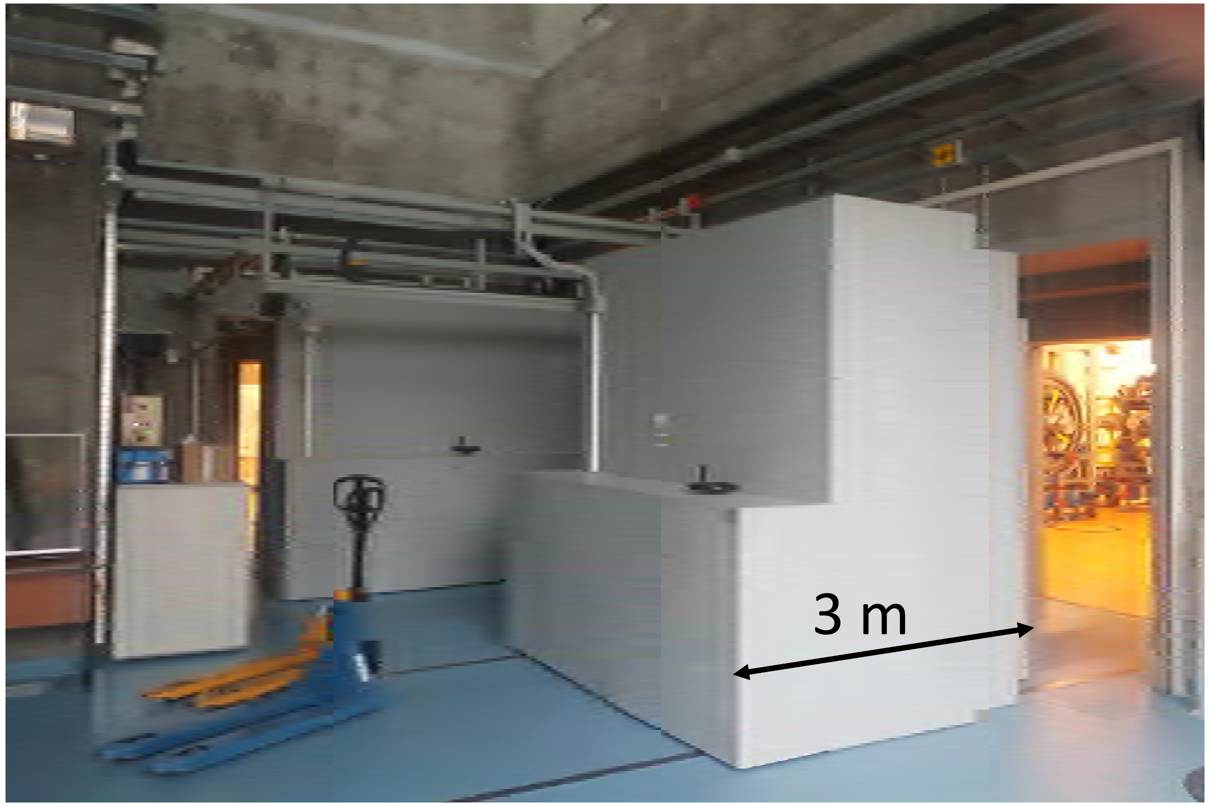
Bucharest

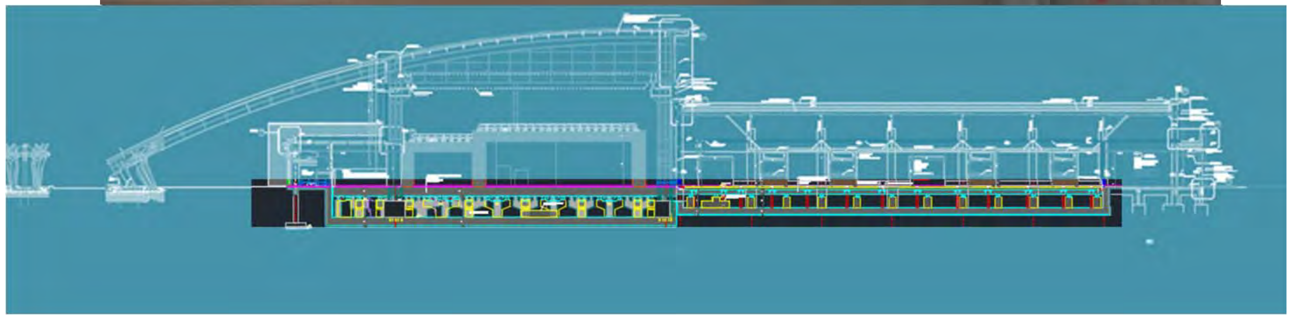
- High power laser system: *2 x 10 PW maximum power (March 2019)*
- High intensity gamma beam system: *high brilliance & variable energy up to 20 MeV (2022)*
- 8 experimental areas: *laser + laser, gamma, laser +gamma*
- Workshops, laboratories, offices, guest house, cafeteria
- International research center with many surrounding physics institutes



High Power Laser System
2x10 PW (1 pulse/min)
2x1 PW (1 Hz)
2x0.1 PW (10 Hz)
Labs + shops + user rooms
10 PW E1 "Nuclear Physics"
10 PW E6 "QED"
1 PW E5 "Material sciences"
E4 0.1 PW "Applications"
E2 "Gamma NRF"
E3 "Gamma positron source"
10 PW E7 "Laser-gamma"
LBTS
f=30 m
E8 "Gamma nuclear-reactions"
GBS control/laser rooms
Gamma Beam System
80 m

Heavily shielded, vibration free experimental building specially designed for laser-based nuclear physics experiments





- Shielding for high energy nuclear radiation
- 120,000 ton, ±1 µm @ 10 Hz stable “optical table” made of 1.5 m thick concrete

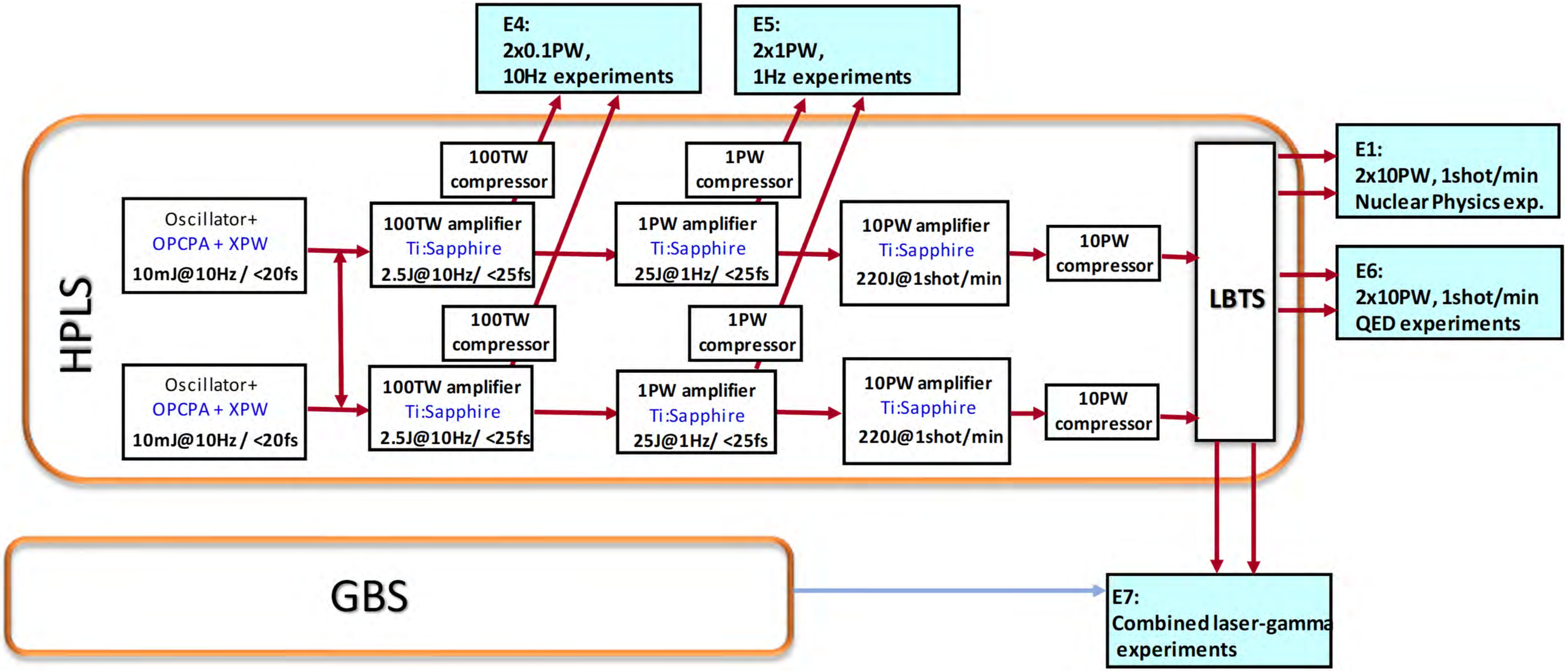
Long term scientific directions

- *Exotic Nuclear Physics and astrophysics*
- *Nuclear Physics experiments to characterize laser – target interaction*
- *Photonuclear reactions*
- *QED and fundamental physics*
- *Applied research*

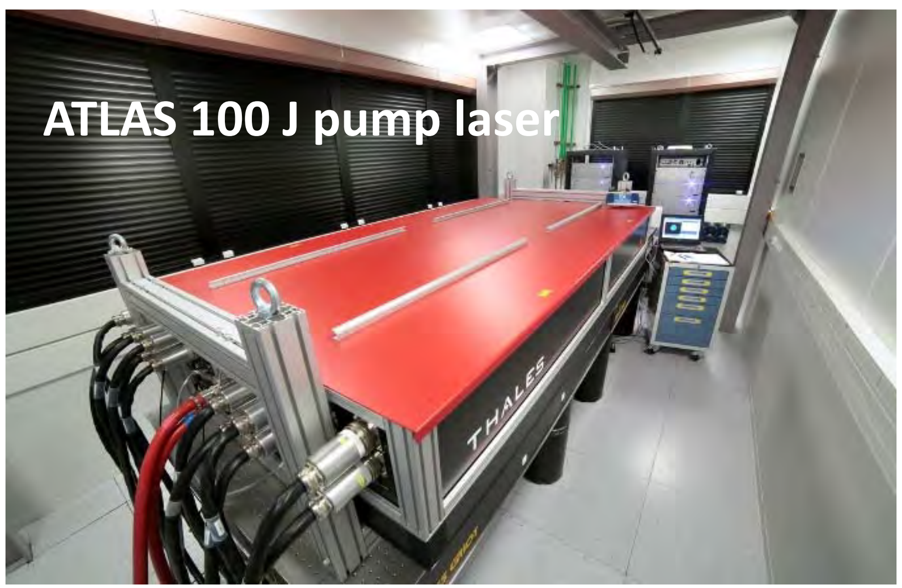
Start of operations: laser experiments gradually 2019-2020, gamma experiments 2023

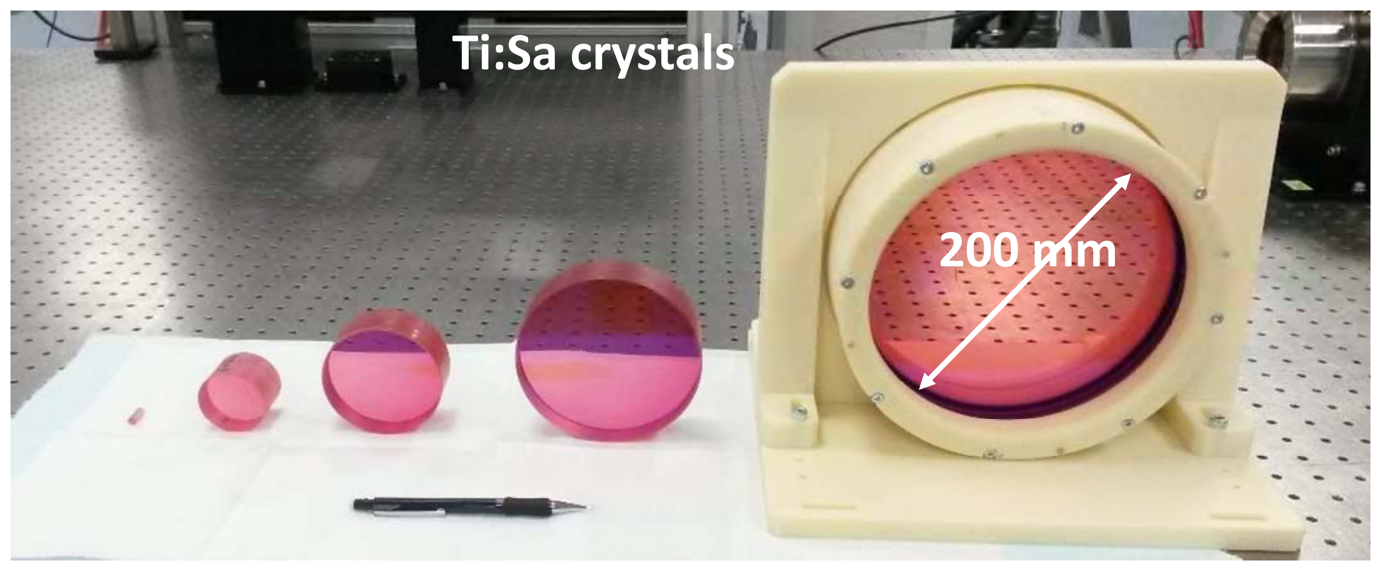
High Power Laser System (HPLS)

High Power Laser System designed and built by Thales, France

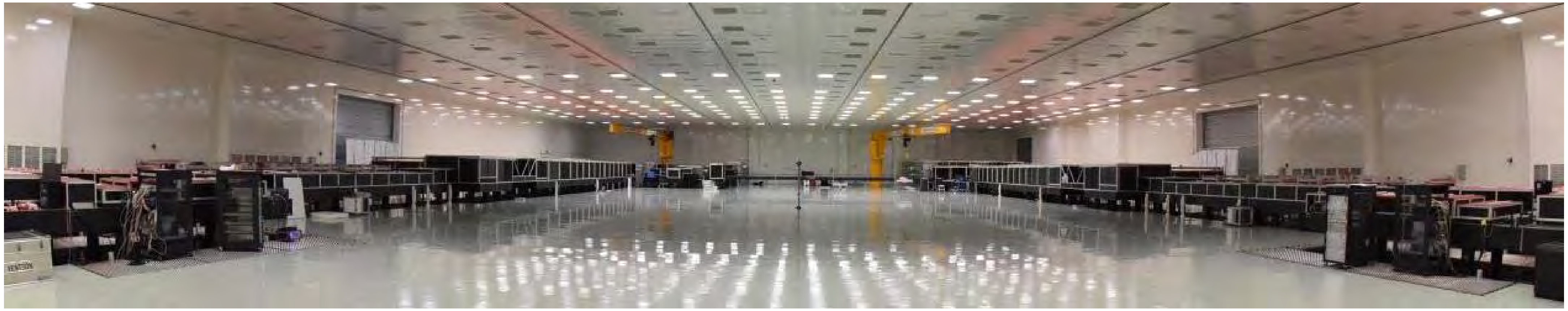


Key laser components successfully manufactured

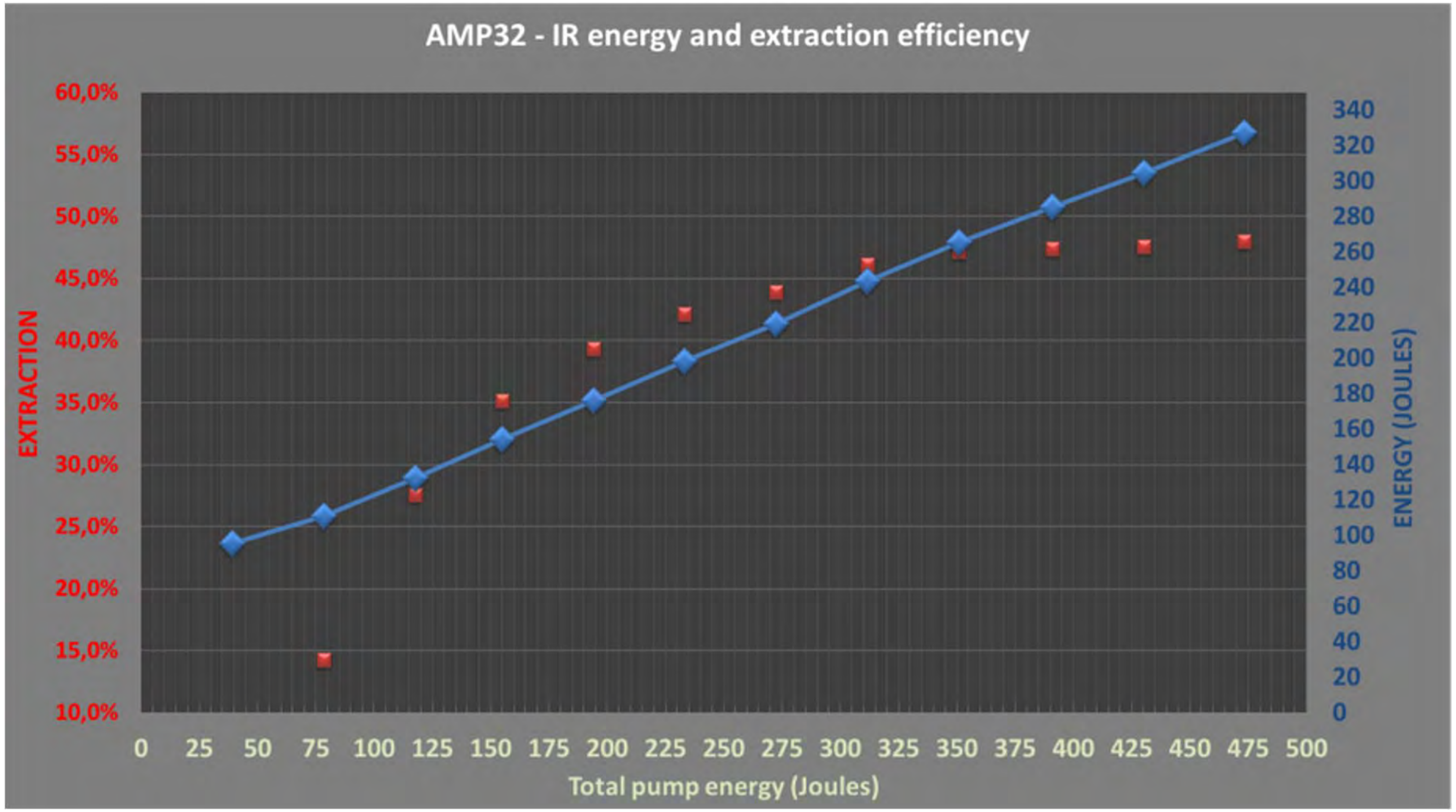


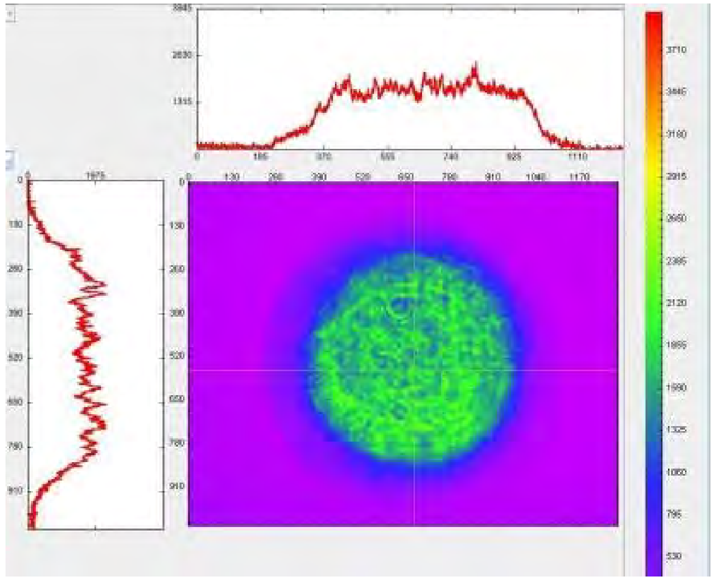


December 2018 – The two arms integrated



March 2019 – 10PW laser beam demonstration

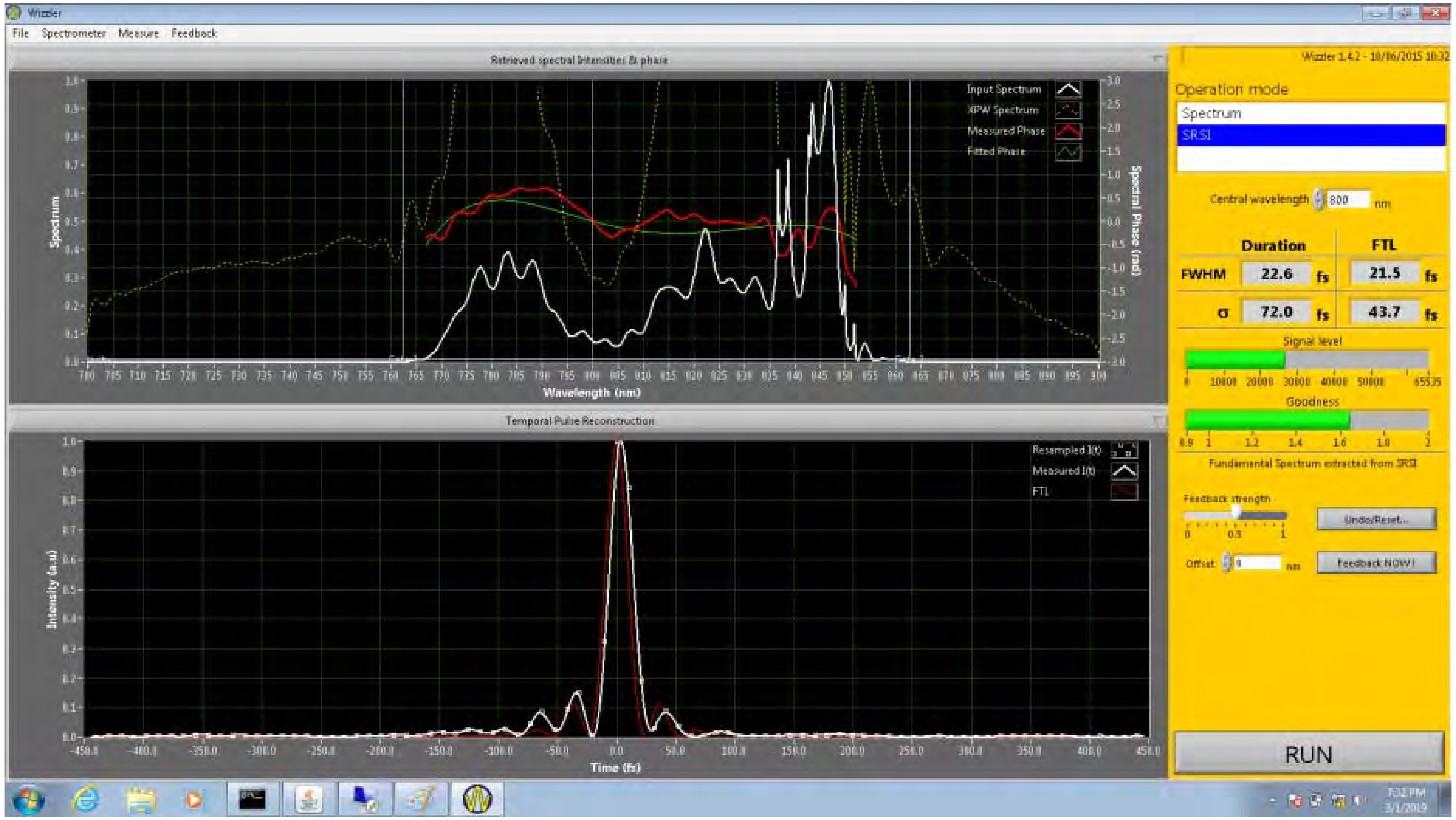


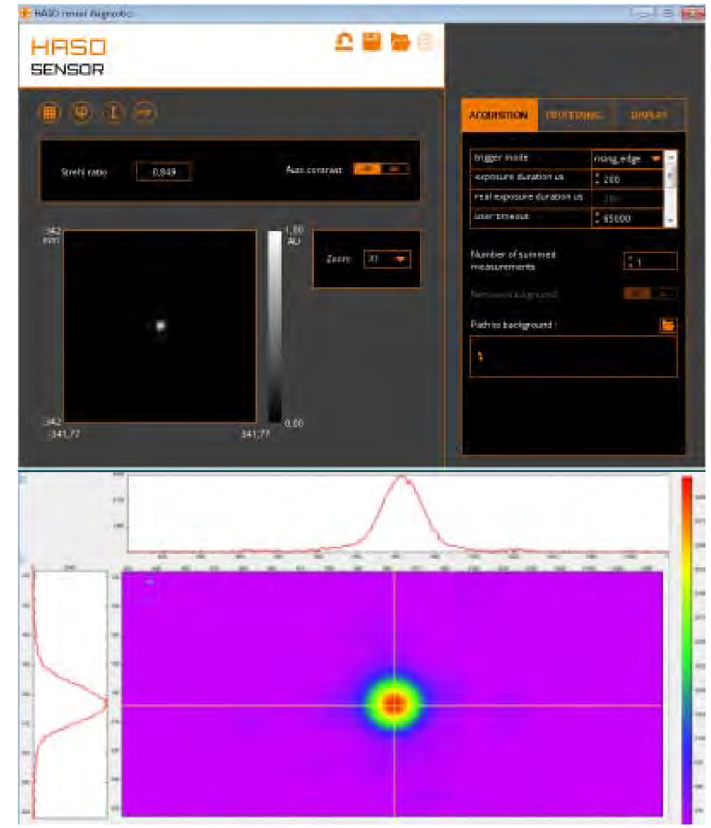


Near field beam profile recorded at output of the last amplifier running at 327J

Pump energy limited at 80% of the total capacity on last amplifier

March 2019 – 10 PW laser beam demonstration

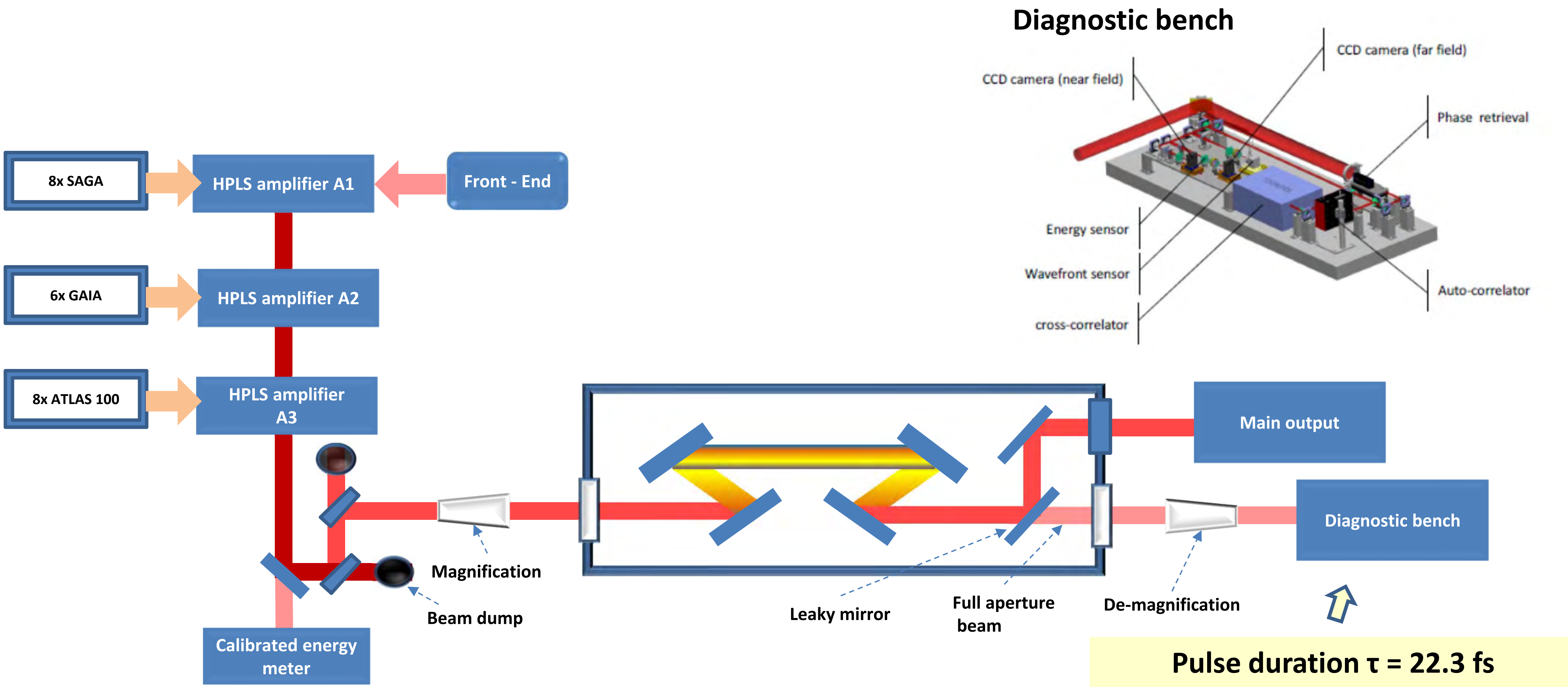




Far field beam profile recorded at output of the compressor and after wavefront correction: Strehl ratio 0,85

- Good temporal contrast: 10^{-13} on hundred ps scale, 10^{-12} on ps scale
- Few microradian pointing stability

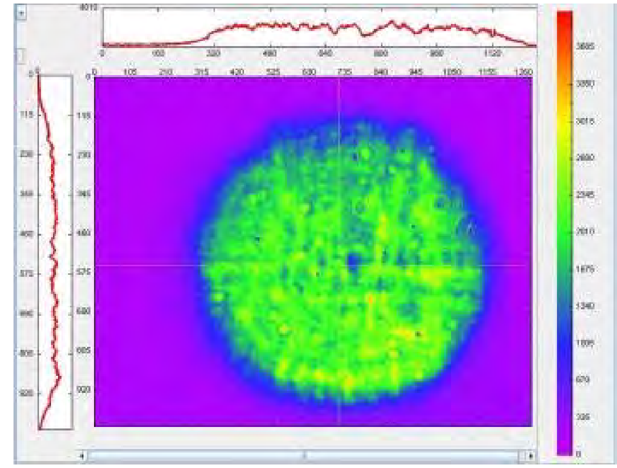
Energy and duration of 10 PW output measured at full beam size



Pulse duration τ = 22.3 fs
Compressor efficiency η = 0.742
Energy before compressor E = 327 J

$P = \eta E/\tau = 10.8$ PW

April 2019 – Stable amplification demonstrated also in second 10 PW beam



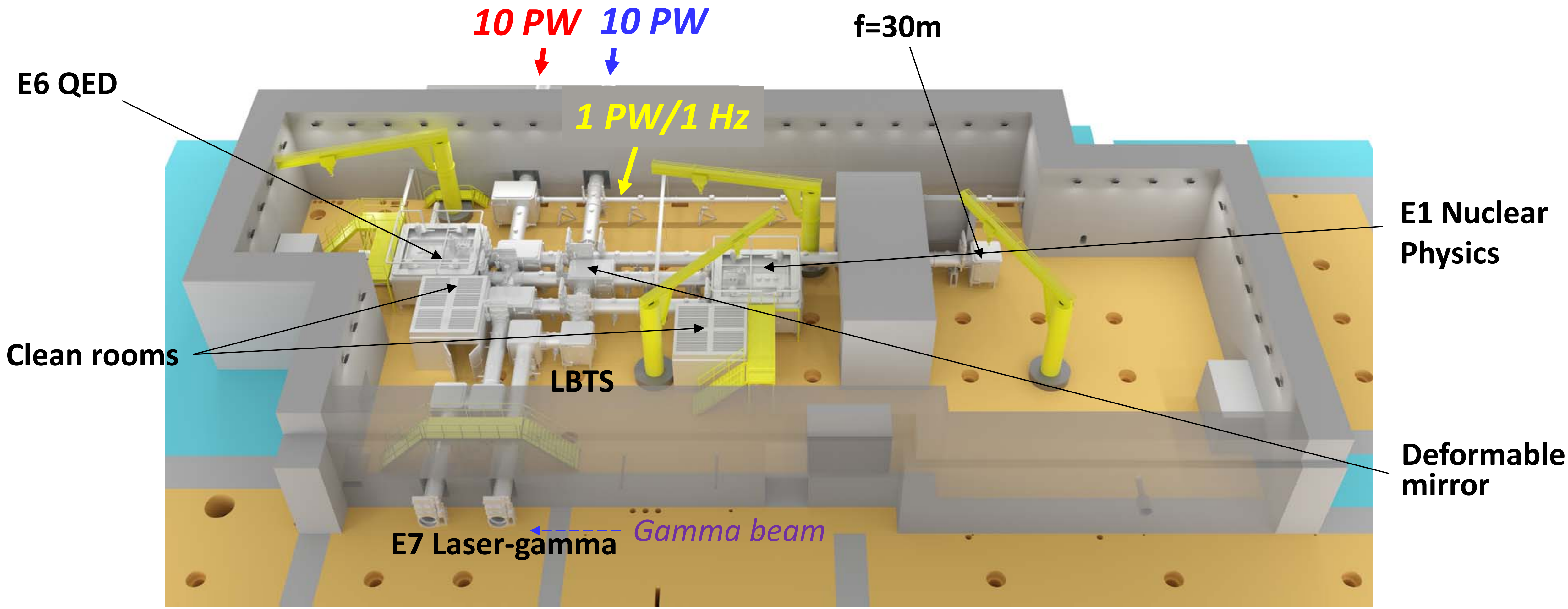
Near field beam profile recorded during long term test over 90 minutes:

- **Average energy 300J**
- **RMS stability < 2%**

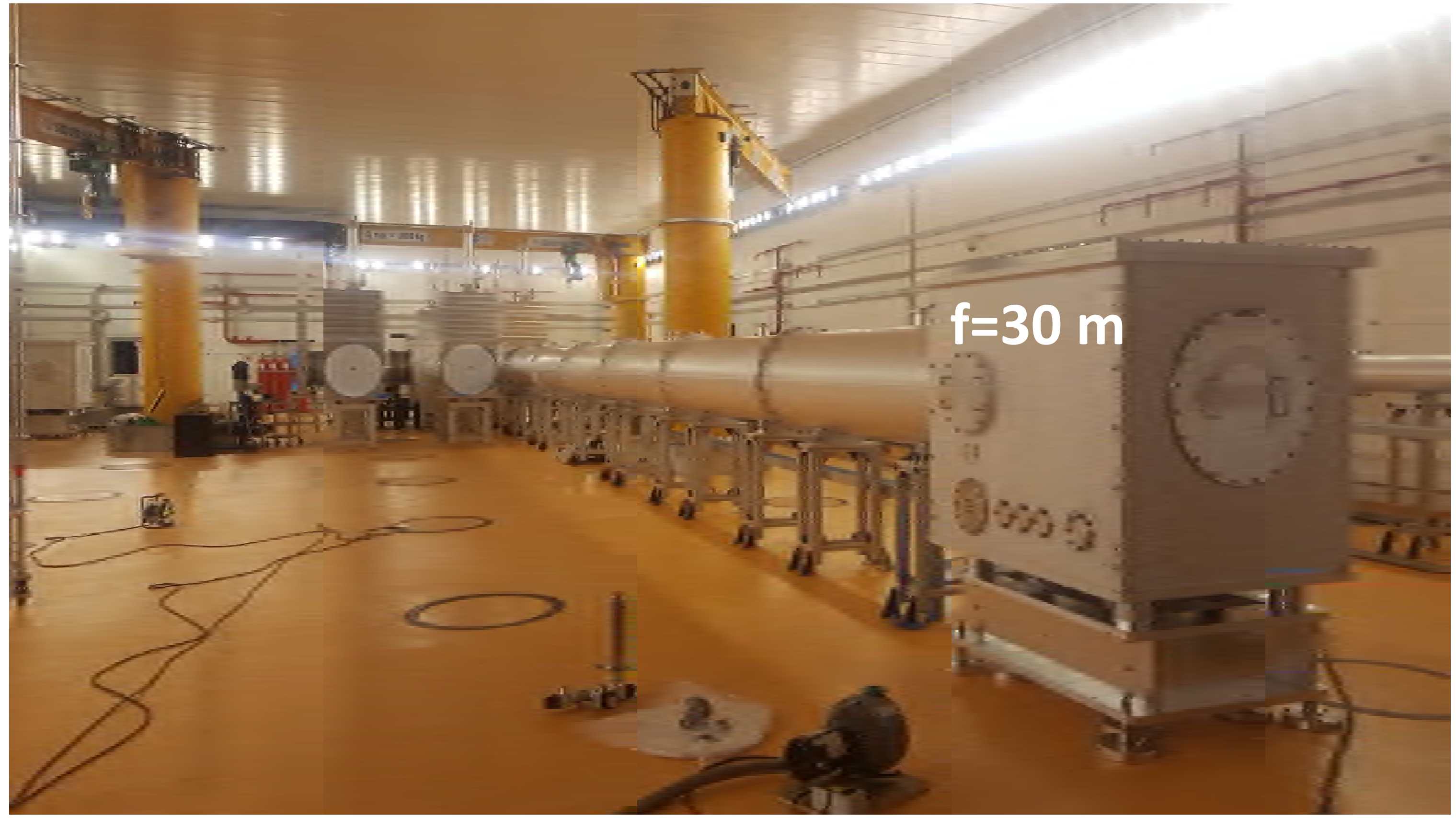
- High Power Laser System commissioning nearing completion
- Soon ready for experiments

Laser Beam Transport System (LBTS)

LBTS designed by ELI-NP and built by Thales and ALSYOM, France

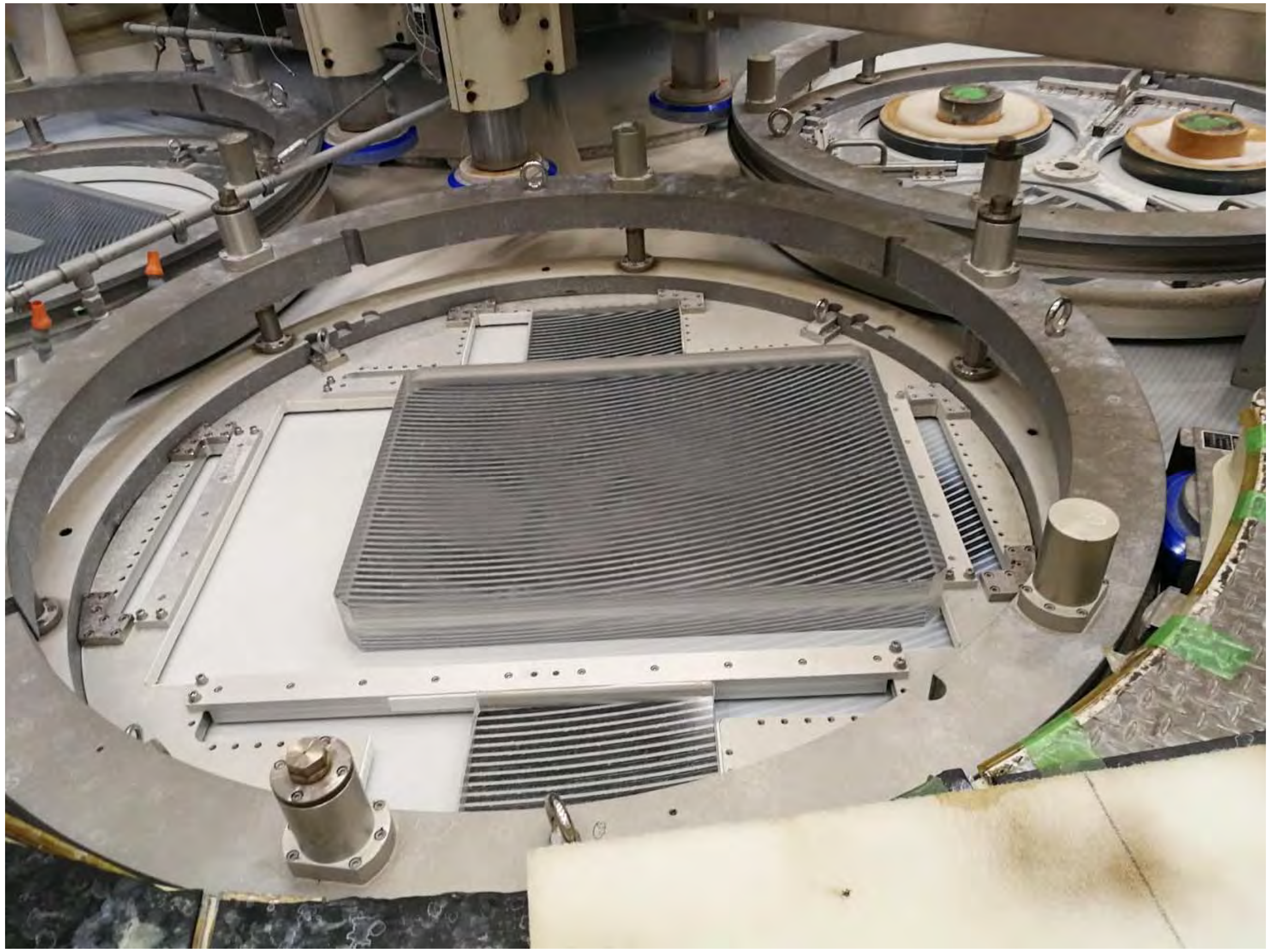


- 2x10 PW beams + 1 PW/1Hz auxiliary beam to any of three experimental areas
- f=30 m F/50 mirror for electron LWFA at 10 PW
- 1 PW deformable mirror, provision (turning box) for 10 PW deformable mirror



LBTS construction nearing completion, soon commissioning

Meter-size 10 PW beam transport mirrors finalizing construction



February 2019

- Acquisition of 10 PW focusing mirrors ongoing (tender on-line now)

Laser experimental areas

Laser driven experiments

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

Extreme electric fields (10^{15} V/m)

Strong-field QED

10 PW laser + solid target

↓

PW γ-source "QED plasma"

10 PW laser + GeV LWFA electrons

↓

Radiation reaction
Breit-Wheeler pairs
QED vacuum

"Commissioning"

Extreme light pressures (Tbar)

Nuclear Physics with Lasers

10 PW radiation pressure acceleration of *dense* ion beams

↓

Nuclear reactions in plasma

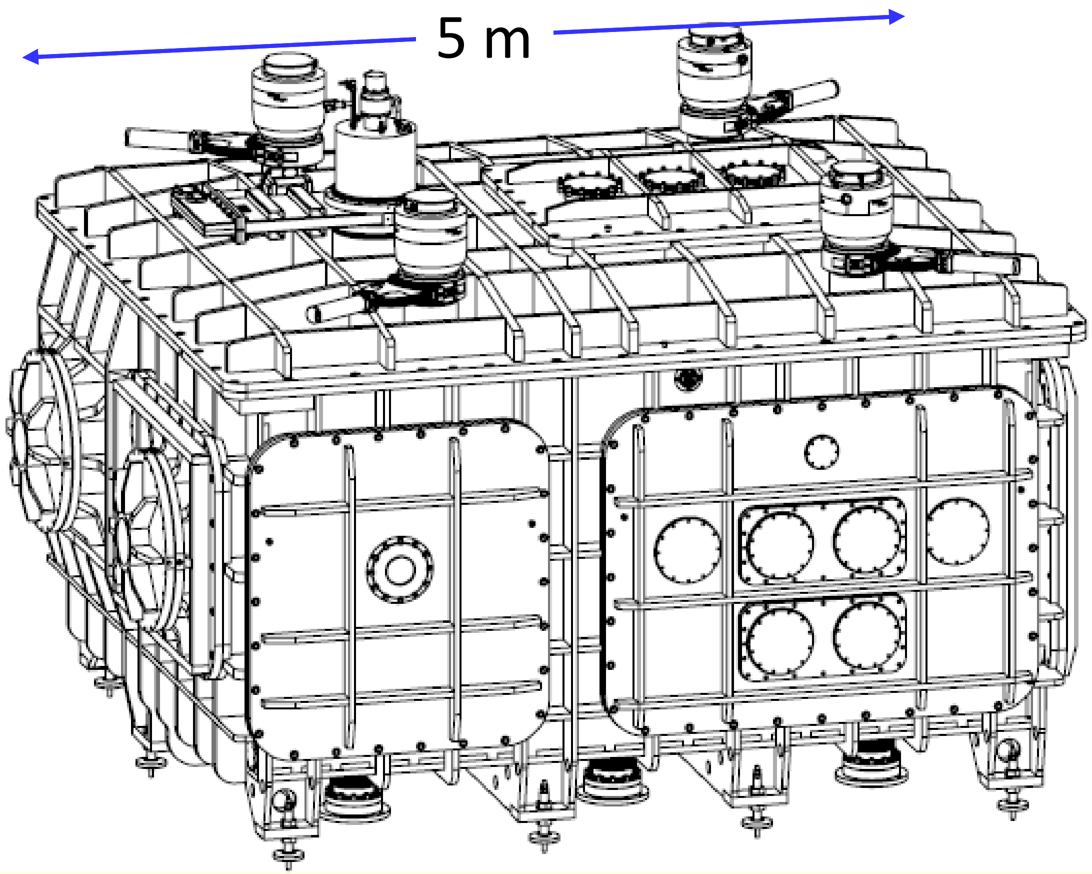
Ultra-intense neutron source

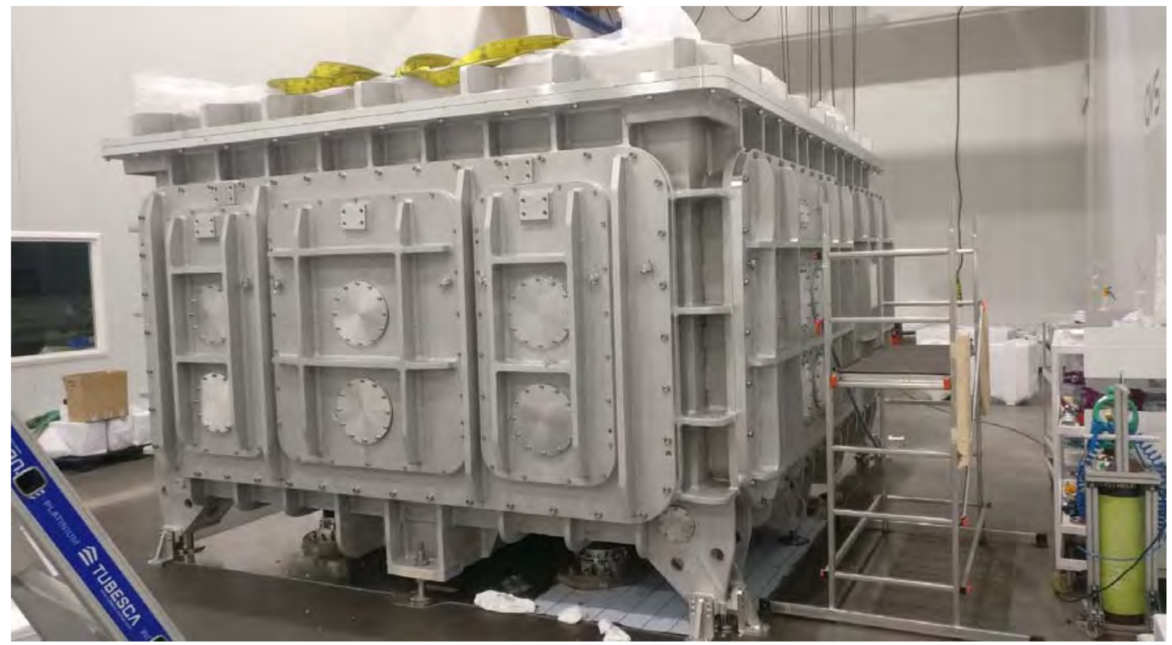
Neutron-rich nuclei

Goals of commissioning experiments:

- **physics based validation of laser experiments system at full power**
- **start developing particle beams for nuclear physics and QED experiments**

Construction of 10 PW E1 and E6 interaction chambers nearing completion



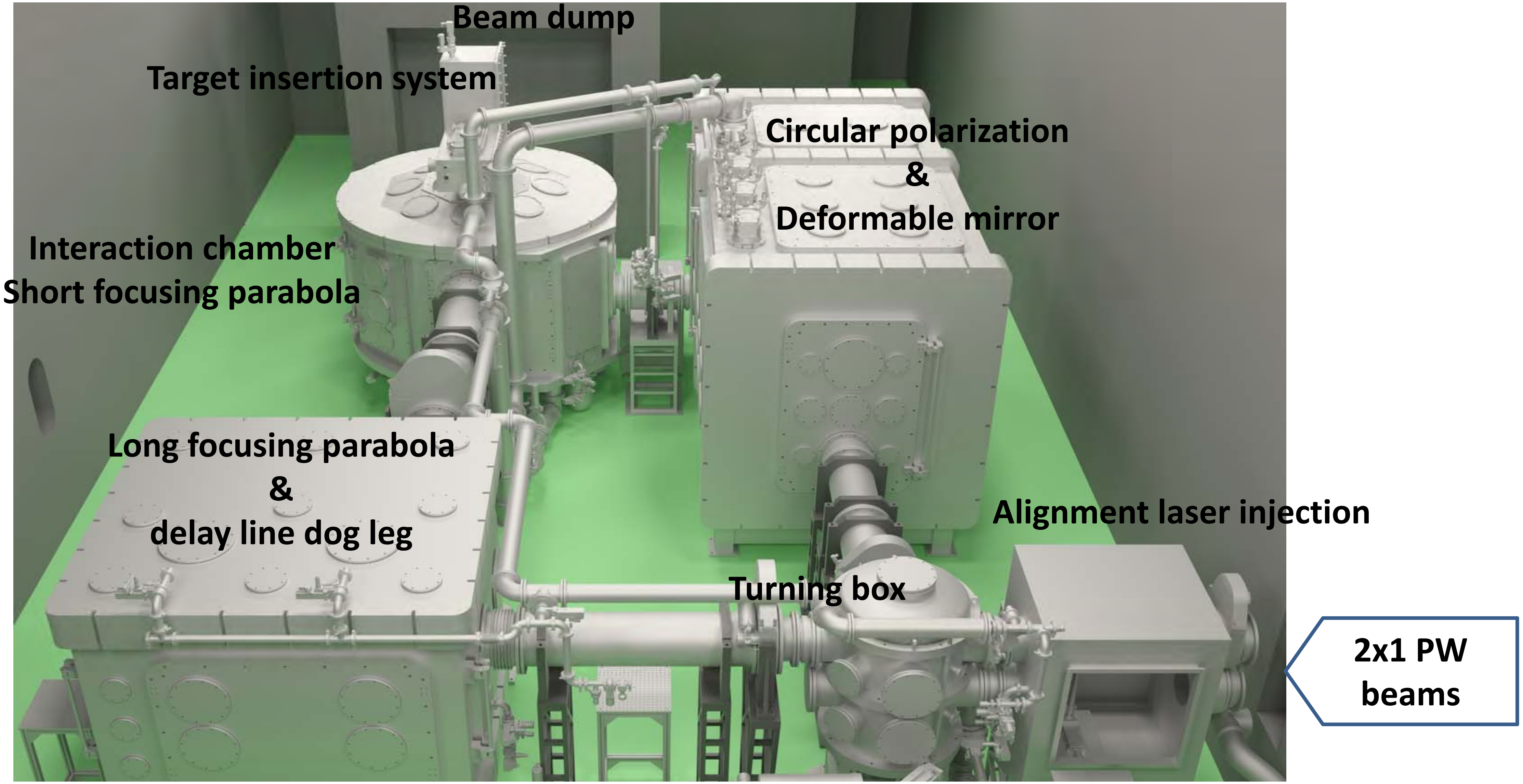


- Two identical Al chambers of 5 x 4 meters
- Floor supported Al optical tables for vibration insulation
- Wide range of 2x10 PW optical setups possible

Installation of 2x0.1 PW E4 experimental area to be completed Nov 2019

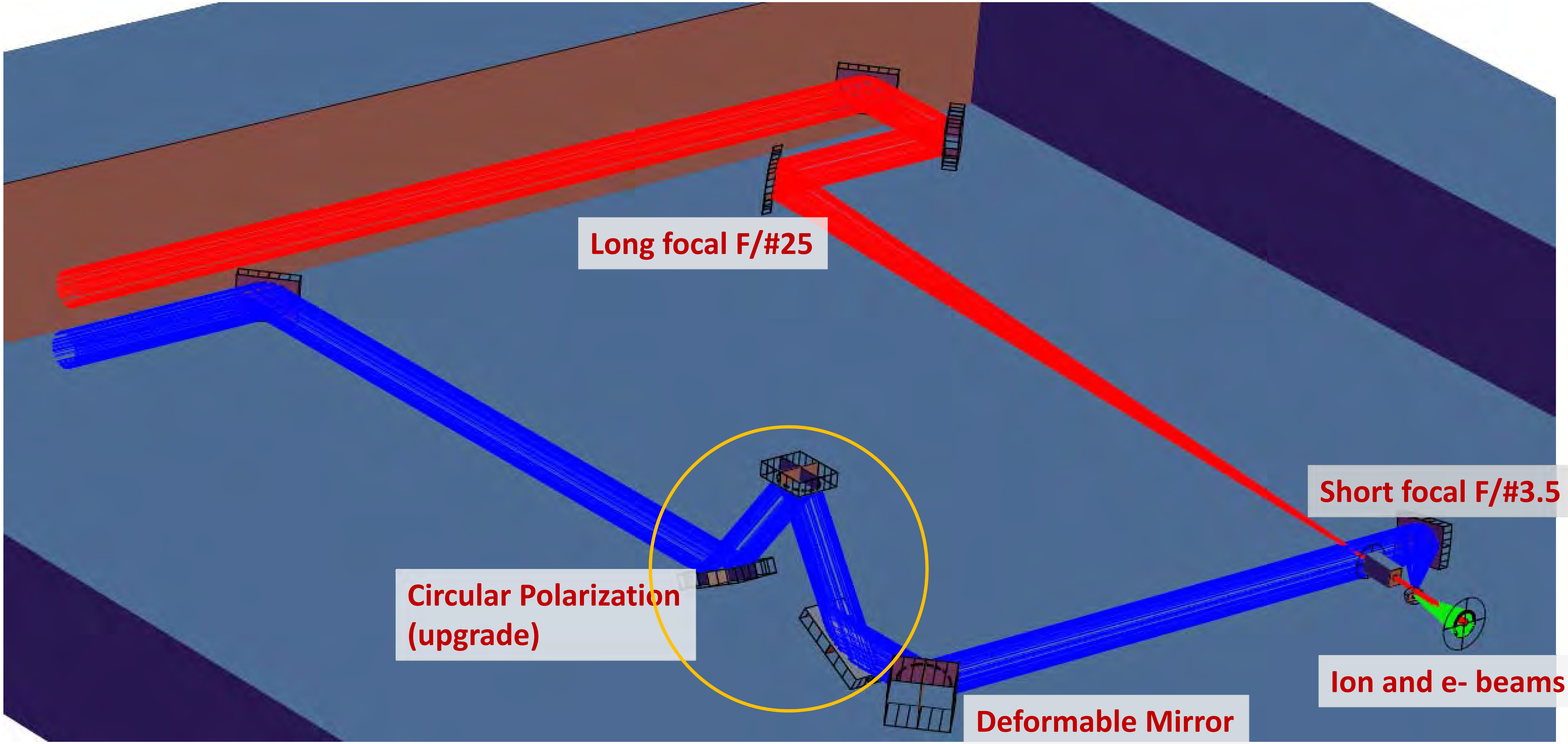
Designed for experiments with multiple laser beams in ultrahigh vacuum (e.g. axion search) and for applications (e.g. X-ray phase contrast imaging)

Installation of 2x1 PW E5 experimental area to begin Dec 2019



- Designed for material science and biomedical experiments with simultaneous mixed radiation fields
- 2x1 PW/1Hz synchronized beams to any of the vacuum chambers

E5 optical layout designed for simultaneous electron and ion beams



ISAB approved commissioning experiments - physics based validation of entire experimental system at full power

- 10 PW E1 - solid target experiments:
  - *Demonstrate extreme focal intensity through laser-γ conversion ("γ-flash")*
  - *Demonstrate 200 MeV proton acceleration (neutron generation add-on)*
  - *Dense ion beams for nuclear physics*

  All experiments use a single setup with only target thickness changed

- 10 PW E6 - gas target experiments:
  - *10 PW laser wakefield acceleration of GeV electron beams*

- 1 PW E5 - solid + gas target experiments:
  - *Benchmark TNSA proton acceleration*
  - *Benchmark LWFA electron acceleration*

- Experiments to be performed by ELI-NP researchers and international expert users

E1 10 PW solid target commissioning setup

Target

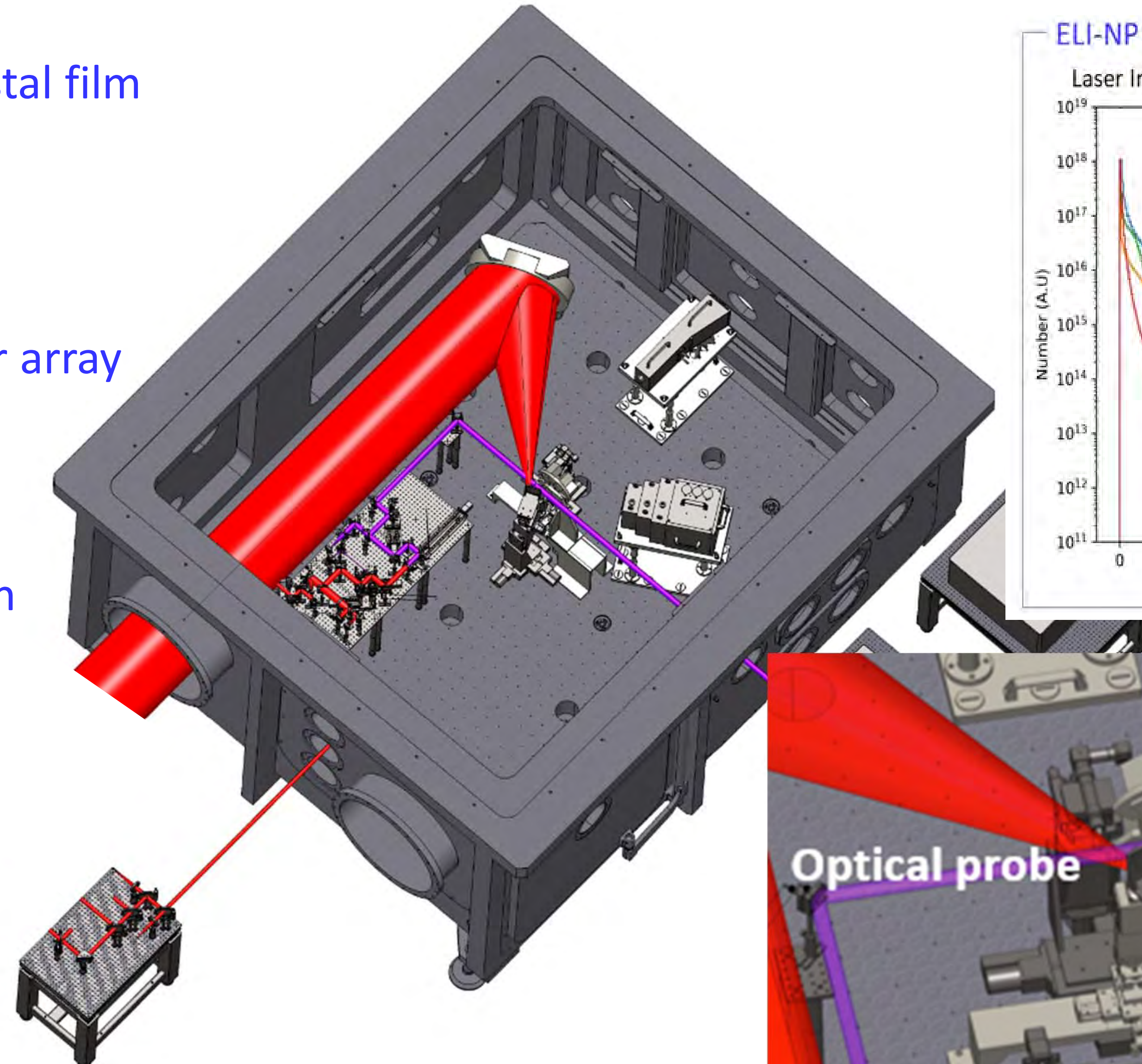
0.1-10 µm CH foils or liquid crystal film

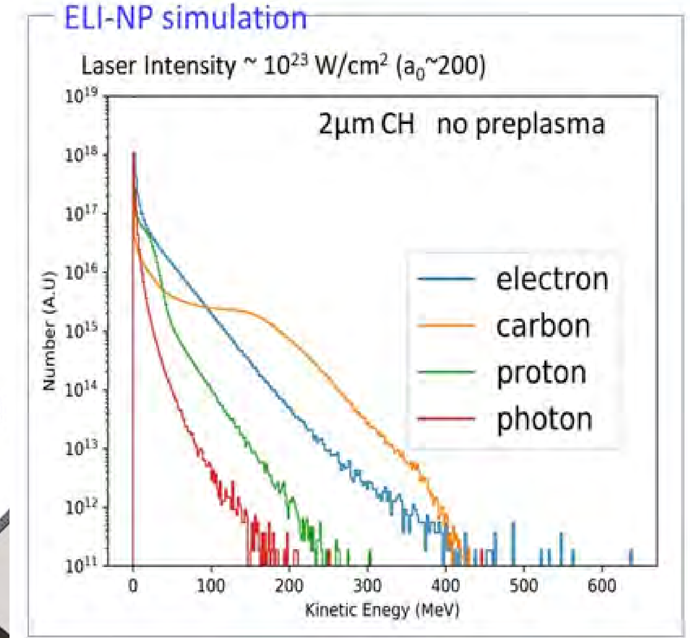
Instrumentation

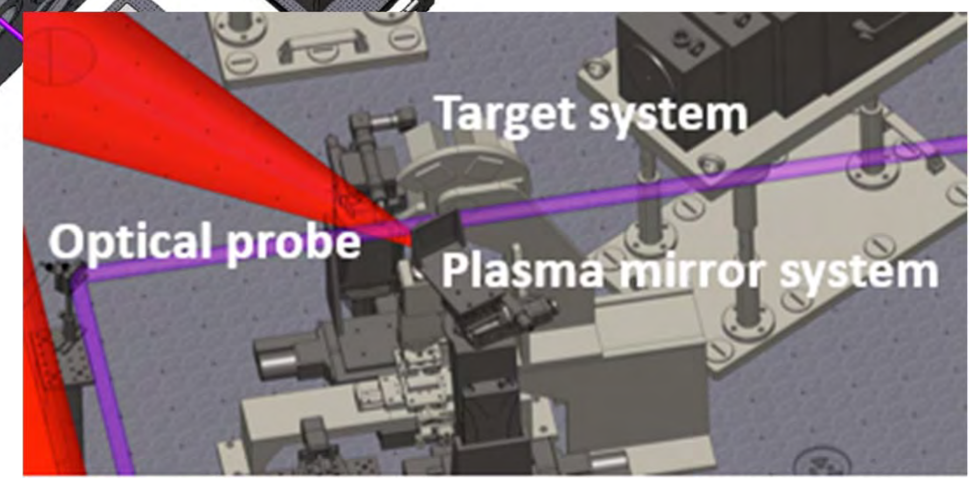
Laser/target alignment system
Plasma mirror
CsI energy-resolved calorimeter array
Forward-gamma spectrometer
Optical Probe
Thomson Parabola
Passive: RCF, CR39/IP, Activation

Detection

All-optical (scintillators + FO)
Muon detector to confirm GeV gammas

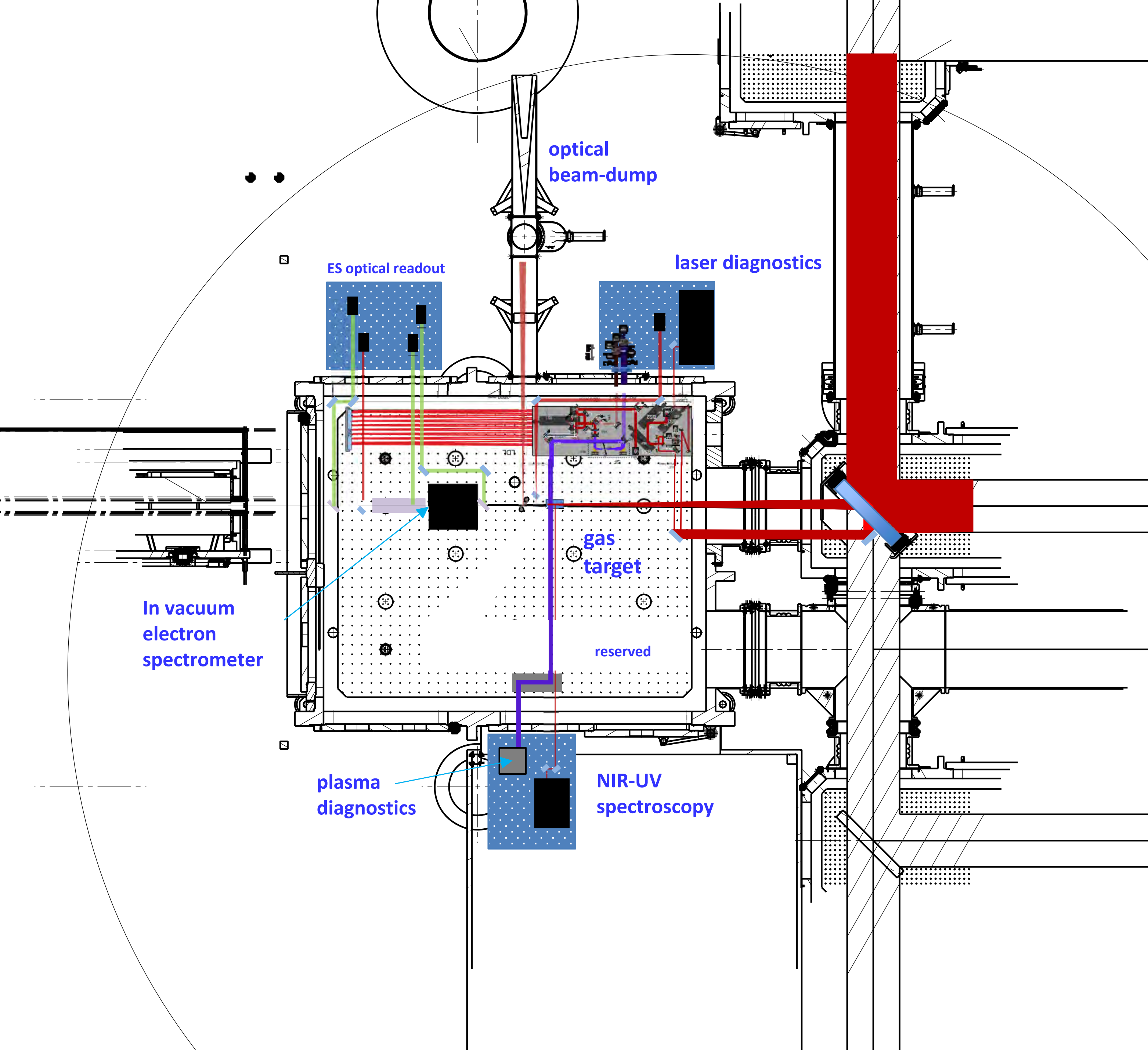






Instrumentation will also be available to users for "Day-1" experiments

E6 10 PW gas target commissioning setup



Instrumentation

5 GeV in-vacuum electron spectrometer

Laser beam diagnostics

Probe beam plasma diagnostic

NIR to UV spectroscopy

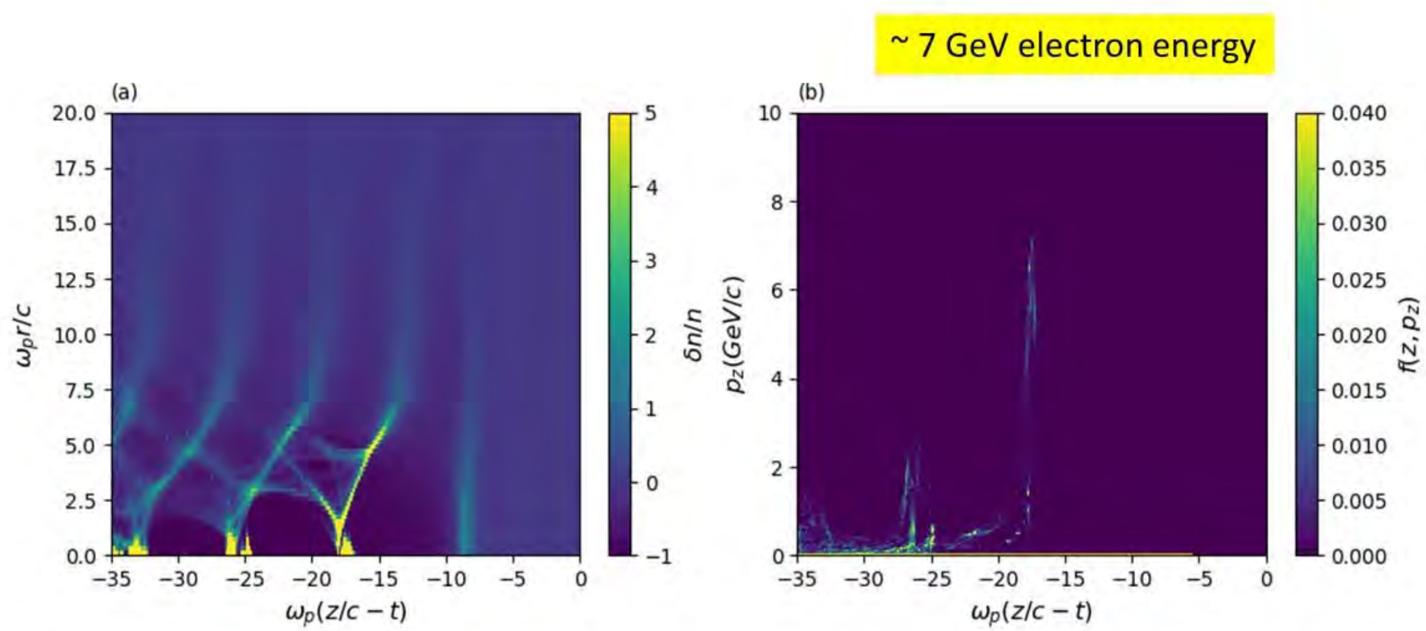
Optical beam dump

Variable length (1-5 cm) gas cell target

US scientists already have key roles in the ELI-NP commissioning experiments

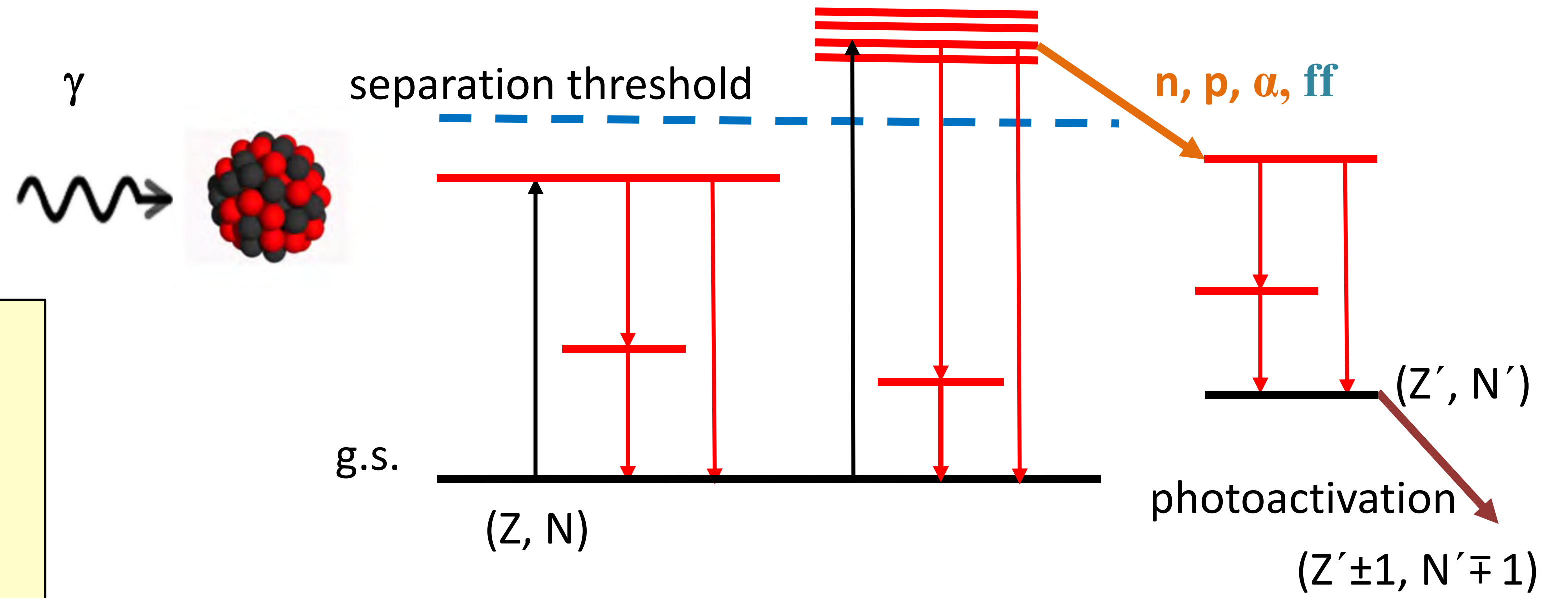
A Arefiev, F Beg (UCSD) – *Laser-gamma conversion*
D Gordon (NRL) – *10 PW LWFA theory*
K Krushelnick (U Michigan) – *10 PW LWFA experiment*
D Schumacher (OSU) – *Liquid crystal plasma mirror & target*
S Regan (LLE) – *Plasma diagnostics*

Wake and Beam Phase Space after 5 cm LWFA at 10 PW
D Gordon, NRL, State Department Science Fellows Program



Gamma Beam System (GBS)

Nuclear Physics with Gamma Beam System



ELI-NP Gamma Beam System:

- Inverse Compton scattering
- < 20 MeV energy
- ≤ 0.5% bandwidth
- ~10^4 γ/s/eV,
- ≥ 95% linearly polarized

Status: *under contracting*

Nuclear Physics:

Nuclear Resonance Fluorescence (NRF)

Giant/Pigmy Dipole Resonances (GANT)

Photodisintegration (γ,n), (γ,p), (γ,α)

Photofission (γ,ff)

Applications:

Nuclear forensics
Material science with positron beams,
industrial and medical application

Gamma experimental areas

NRF measurements – ELIADE setup

Gamma : 8 segmented Ge Clover det.
4 $LaBr_3(Ce)$ det.

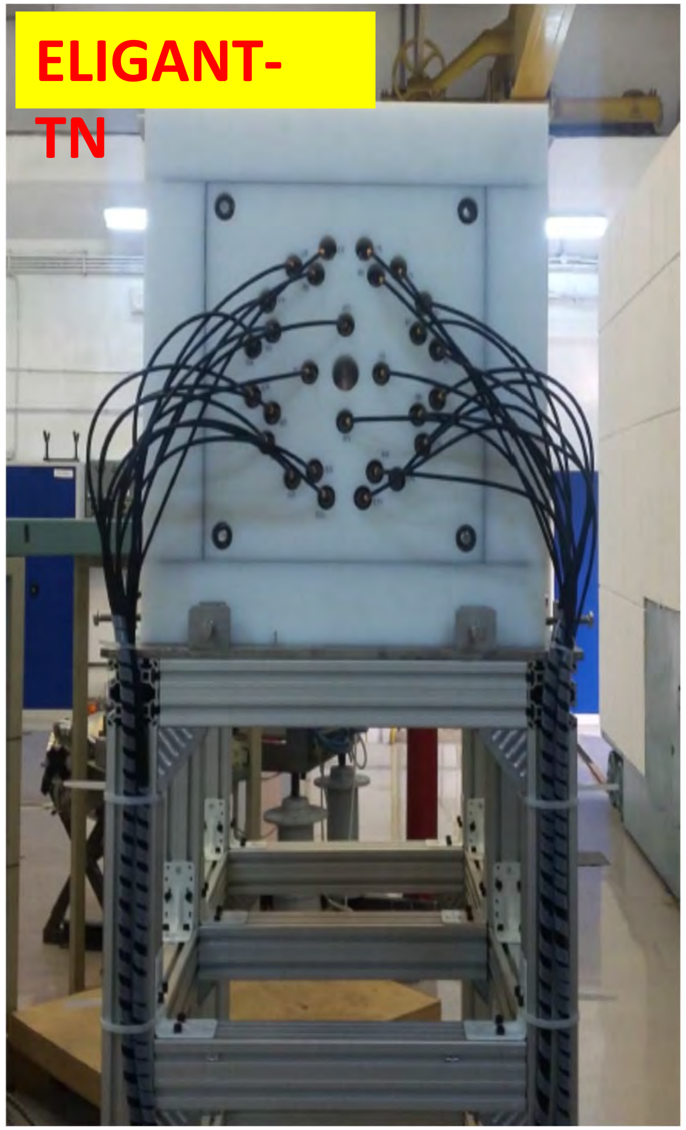
- Self-absorption measurements (Γ_0/Γ_i)
- Low-energy dipole response (e.g. Actinides)
- Dipole response and parity measurements for weakly-bound nuclei
- Investigation of the Pigmy Dipole Resonance
- Rotational 2^+ states of the scissor mode
- Constraints on the 0νββ-decay matrix elements of the scissors mode decay channel: ^{150}Sm

Detectors and EDAQ ready

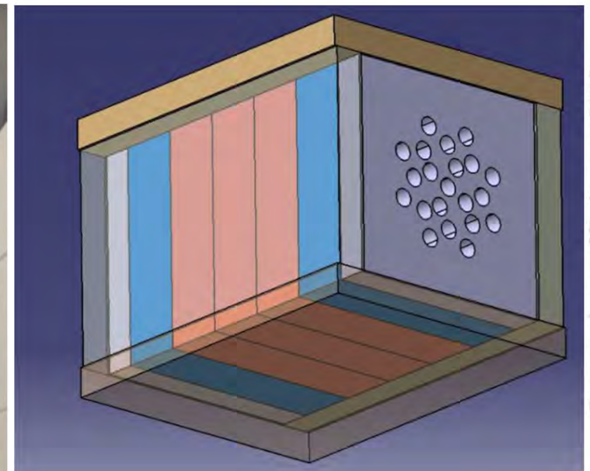
Mechanical structure ready

Ready for experiments – December 2019

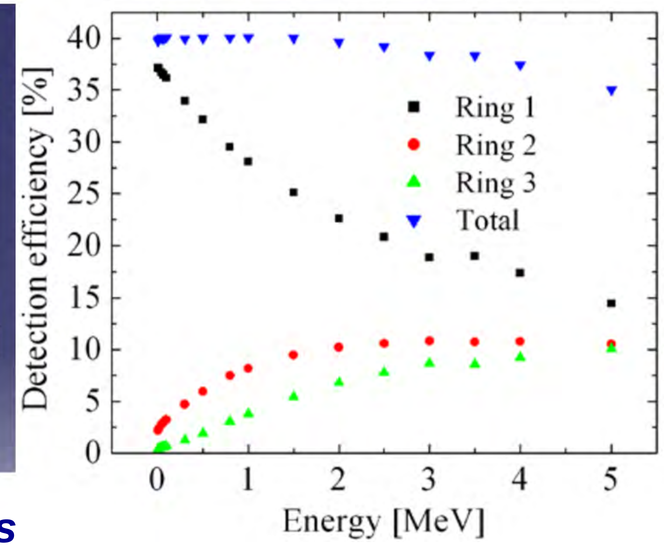
(γ,n) cross sections measurements – ELIGANT-TN



Ready for experiments – July 2018

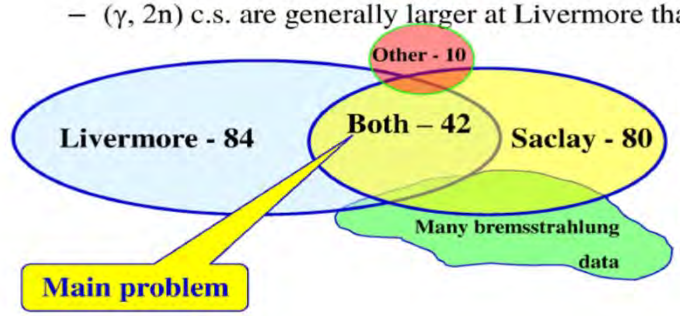


Neutron: 28 ^{3}He detectors



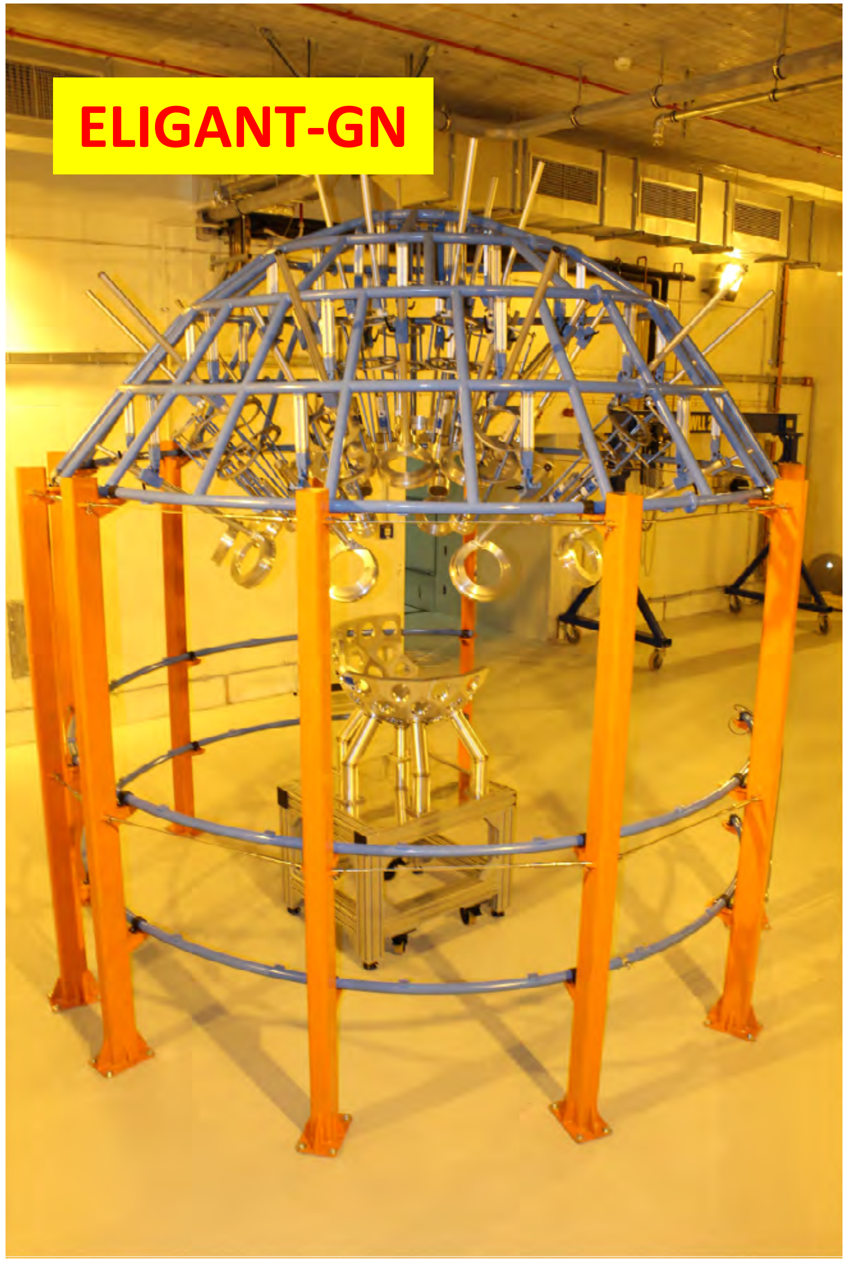
Systematics of the photonuclear C.S. measurements

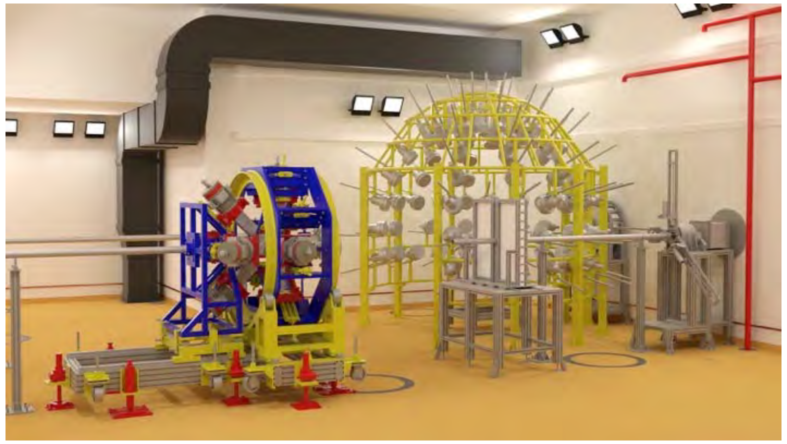
- Most of the photoneutron cross section measurements were performed in period 1962 – 1986 using quasi-monochromatic annihilation – QMA photons using positron in flight annihilation at two major facilities:
  - Saclay (France) Photonuclear Data Library – IAEA 2000
  - Lawrence Livermore National Laboratory (USA)
- Large discrepancies in (γ,xn) c.s. measured at the two facilities:
  - (γ, 1n) c.s. are generally noticeably larger at Saclay than at Livermore
  - (γ, 2n) c.s. are generally larger at Livermore than at Saclay.



No systematic way to resolve the discrepancies: <u>New and reliable measurements are required!</u>

Giant Dipole Resonance measurements – ELIGANT-GN





Gamma : ***30 $LaBr_3$ and $CeBr_3$***
Neutron: ***20 ^{7}Li glasses***
30 Liquid Scint.

Day ONE:
studies of GDR and PDR decay (^{90}Zr, ^{208}Pb)

- combine with information from (γ,n) experiments
- combine with information from (γ,γ') experiments (*e.g.* Polarization)
- γ-decay to gs and excited states as a function of excitation energy

Detectors and EDAQ ready

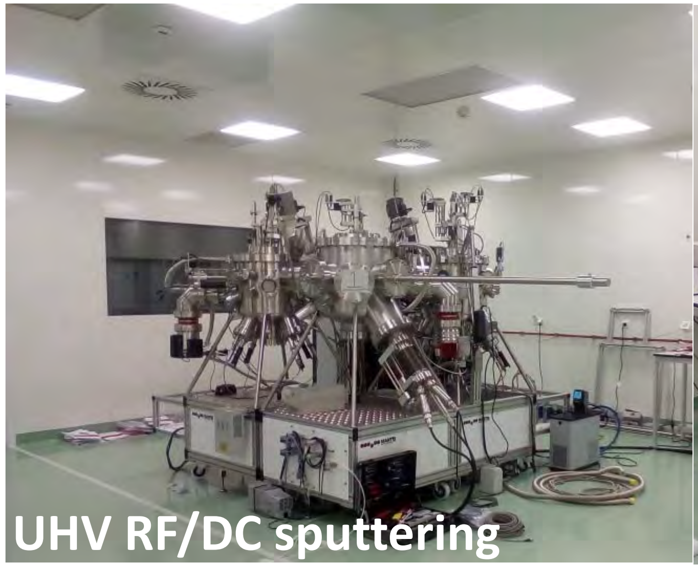
Mechanical structure ready

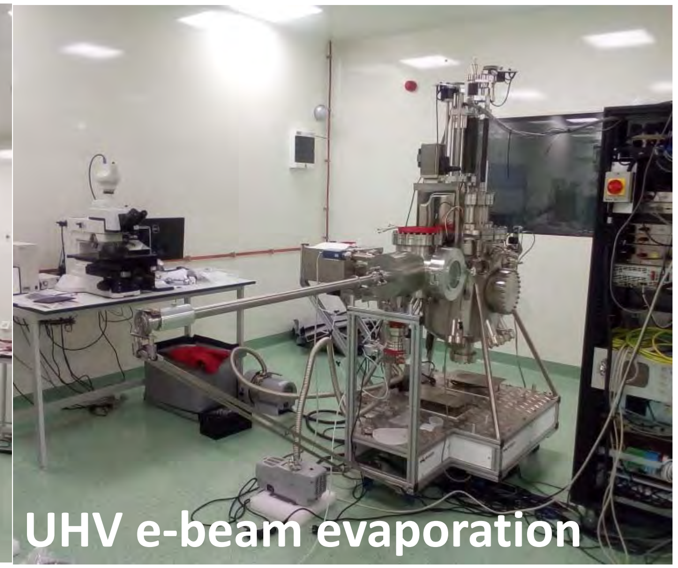
Ready for experiments – December 2019

Supporting laboratories

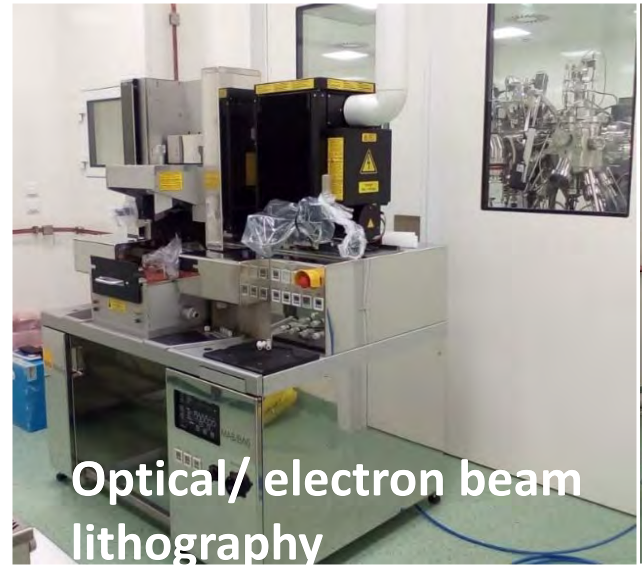
ELI-NP Targets Laboratory capabilities

Deposition techniques

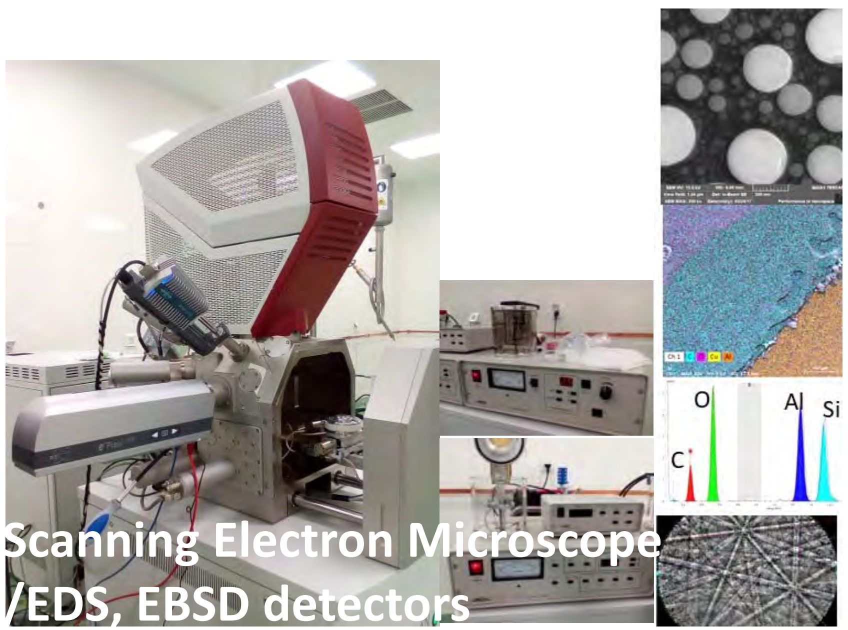


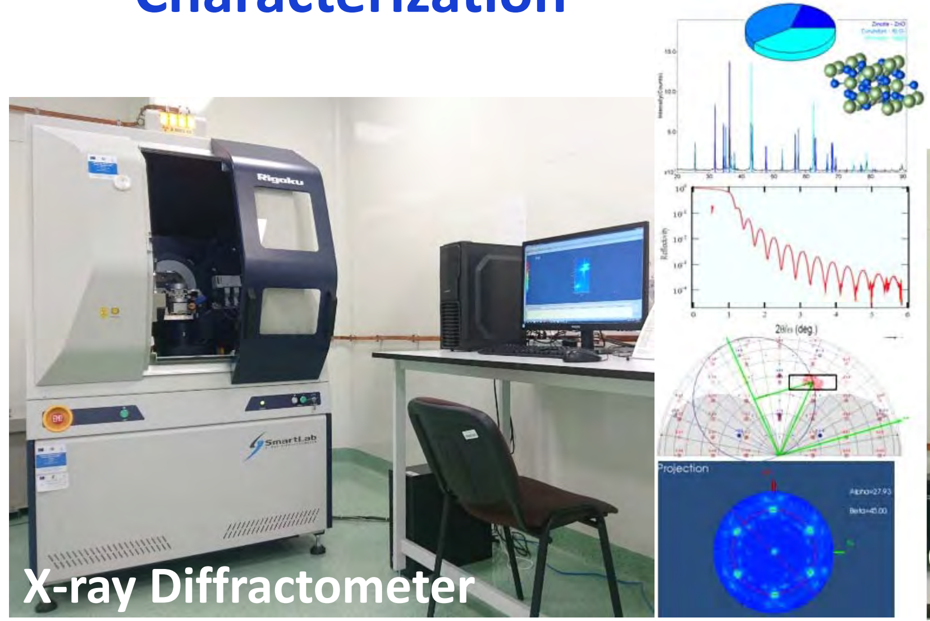


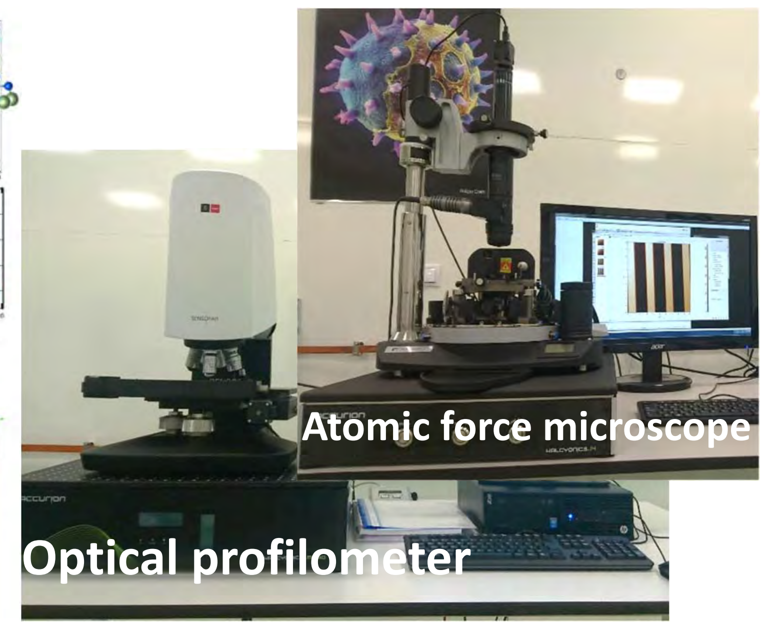
Structuring techniques



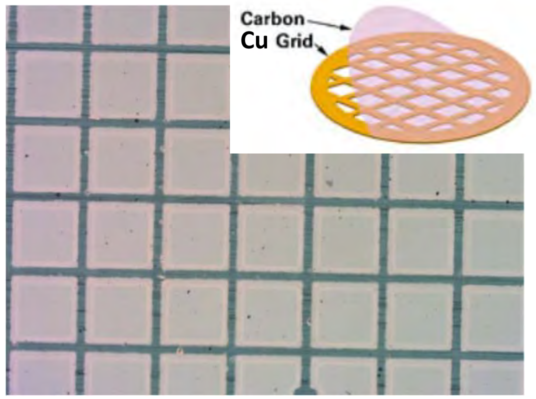
Characterization



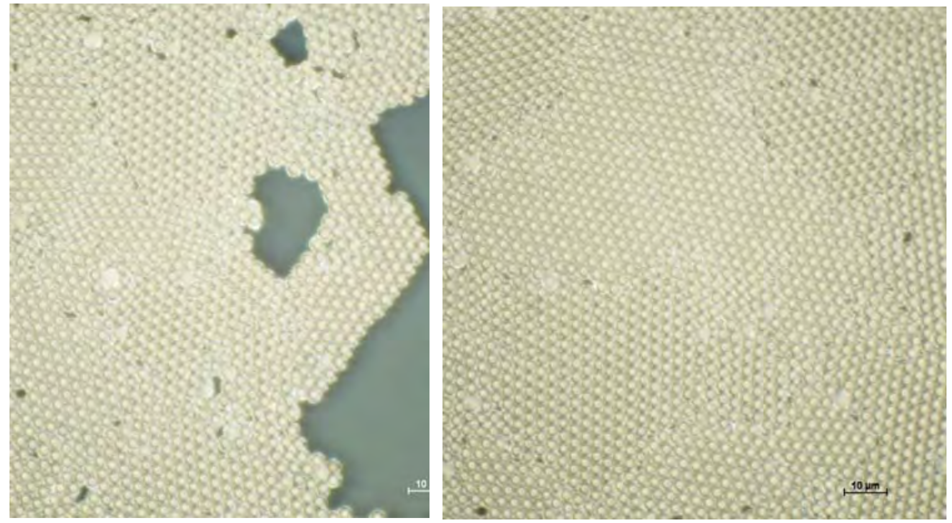




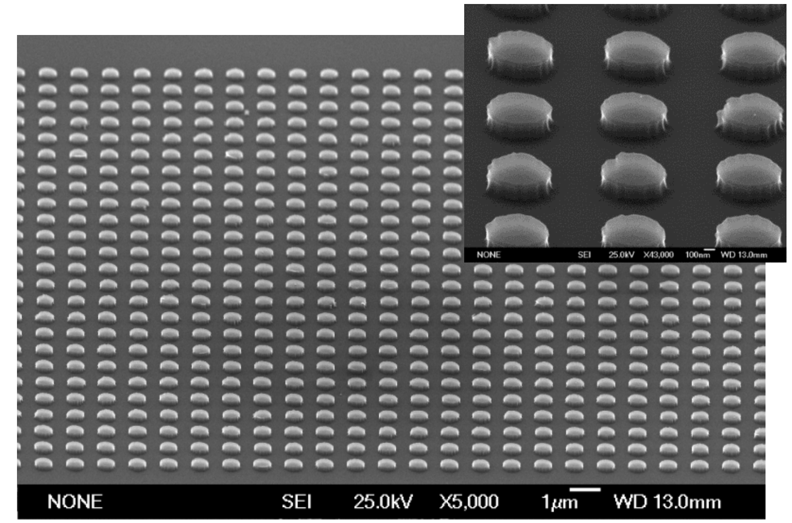
Production of nano/μ-structured targets and of free-standing targets has begun



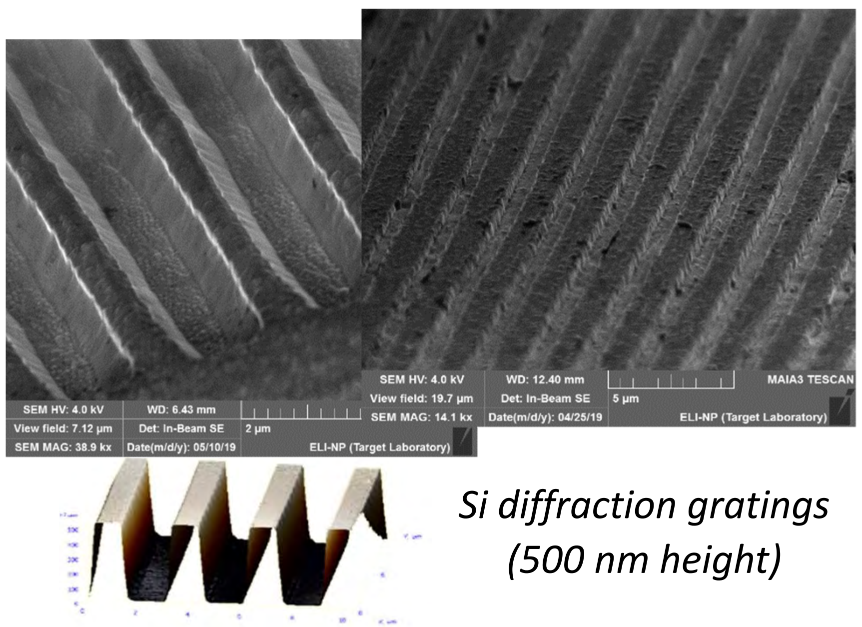
Free-standing C film (15 nm) on Cu grid for high-power laser ion acceleration



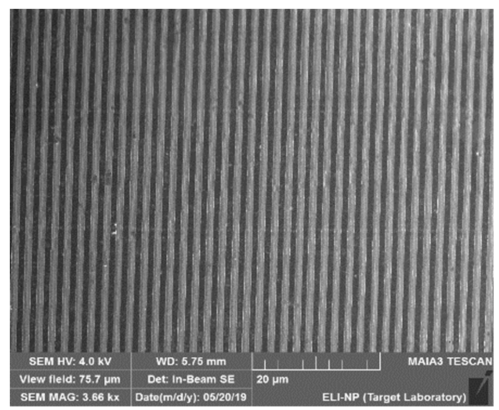
Plastic microspheres on Si substrate for enhanced laser absorption, on the front side of the target



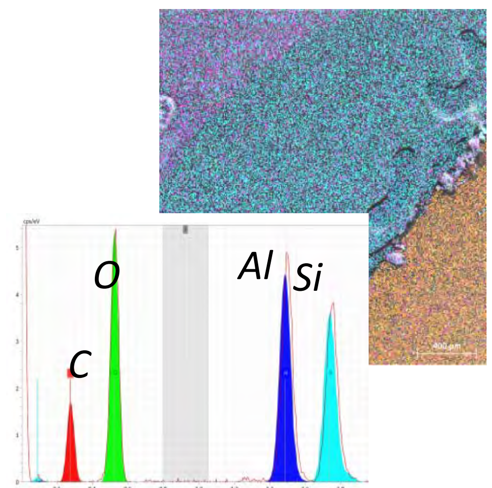
Au and Cr (right) nano-dots fabricated by electron beam lithography (EBL)



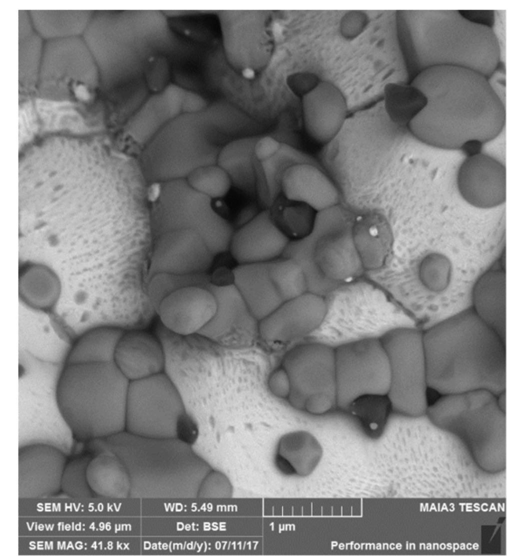
Si diffraction gratings (500 nm height)



Metallic gratings (Au, Cr, 600 nm height) for front side laser absorption amplification



Elemental composition and mapping with Energy Dispersive Spectroscopy (EDS)

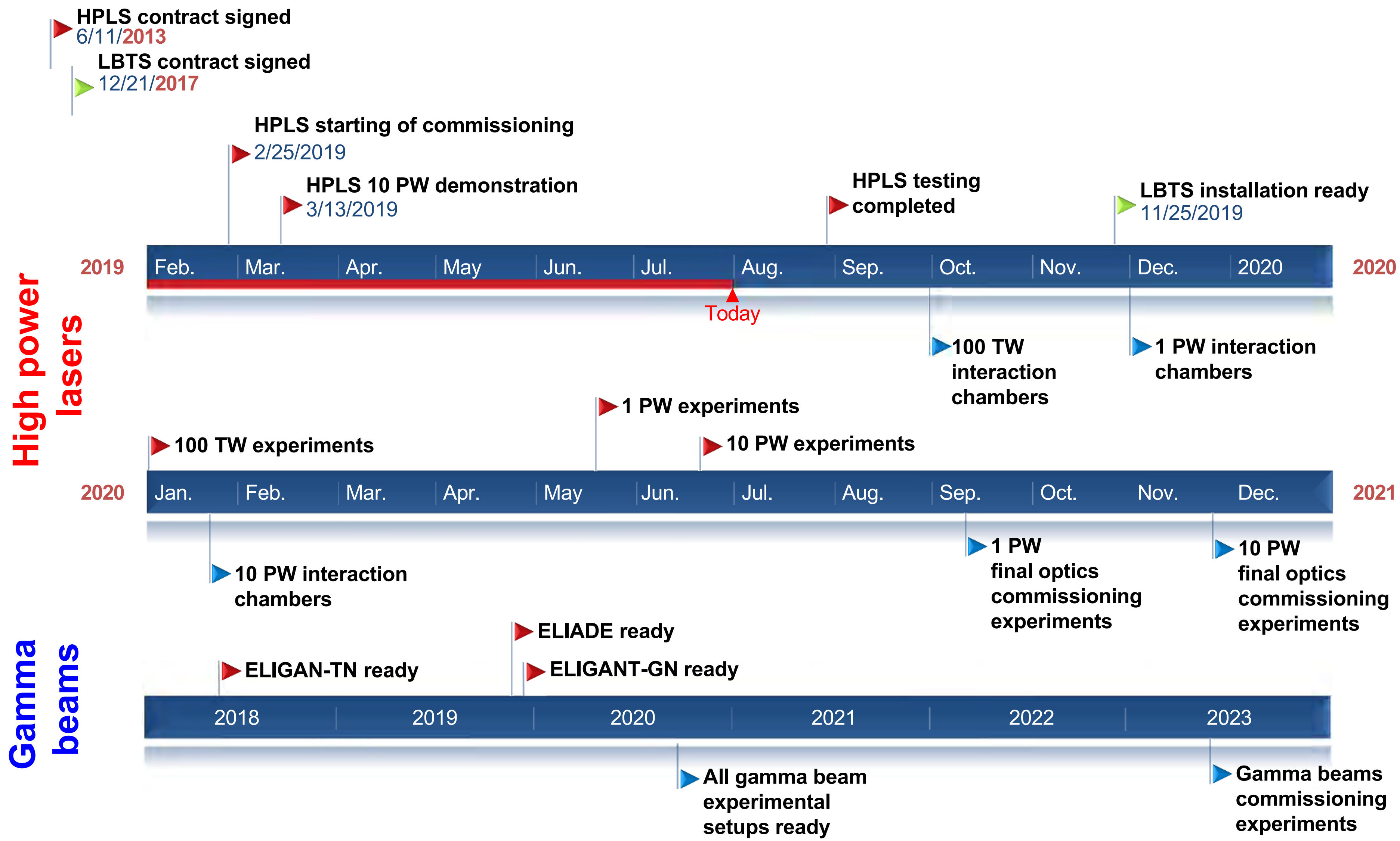


Phase composition in Scanning Electron Microscopy

Additional laboratories and workshops ready to assist user experiments

- Optics Laboratory
- Diagnostics Instrumentation Laboratory
- Dosimetry Laboratory
- Detectors Laboratory
- Radiobiology Laboratory
- X-Gamma Optics Laboratory
- Mechanical workshop
- Vacuum workshop
- Electronics workshop

Timeline and milestones



ELI-NP User Workshop

Nuclear Physics

10 PetaWatts, World Premiere at ELI-NP Măgurele High Power Laser!

ELI-NP USER WORKSHOP 2019

Home | Programme | Registration | Venue | Information | Contact

1st ELI-NP User Workshop

October 7th-11th, 2019
Măgurele-Bucharest, Romania

Useful information

Dates:

October 7-11th / Magurele (Bucharest), Romania

Format of the workshop:

The workshop will consist of two main sections. The first one (Mon-Wed) is dedicated to experiments based on the high-power lasers. The second one (Wed-Fri) is dedicated to experiments based on the high intensity gamma photon beams.

Each of the sections will comprise presentations of the status of implementation and the capabilities of the equipment in the facility, aims of the commissioning experiments, and contributed talks by external researchers presenting new ideas for future experiments at ELI-NP.

Round-table discussions and a visit to the experimental areas of the facility will allow for a better understanding of the experimental capabilities and a fruitful exchange of ideas between the

Organizing Committee

Kazuo A. Tanaka, ***Scientific Director***
Calin A. Ur, ***Technical Director***
Dimiter L. Balabanski
Dan Stutman
Ioan Dancus
Marian Toma
Ovidiu Tesileanu
Catalina Oprea, ***Workshop secretary***
Alexandra Carlig, ***PR***
Laurentiu Serban, ***IT***

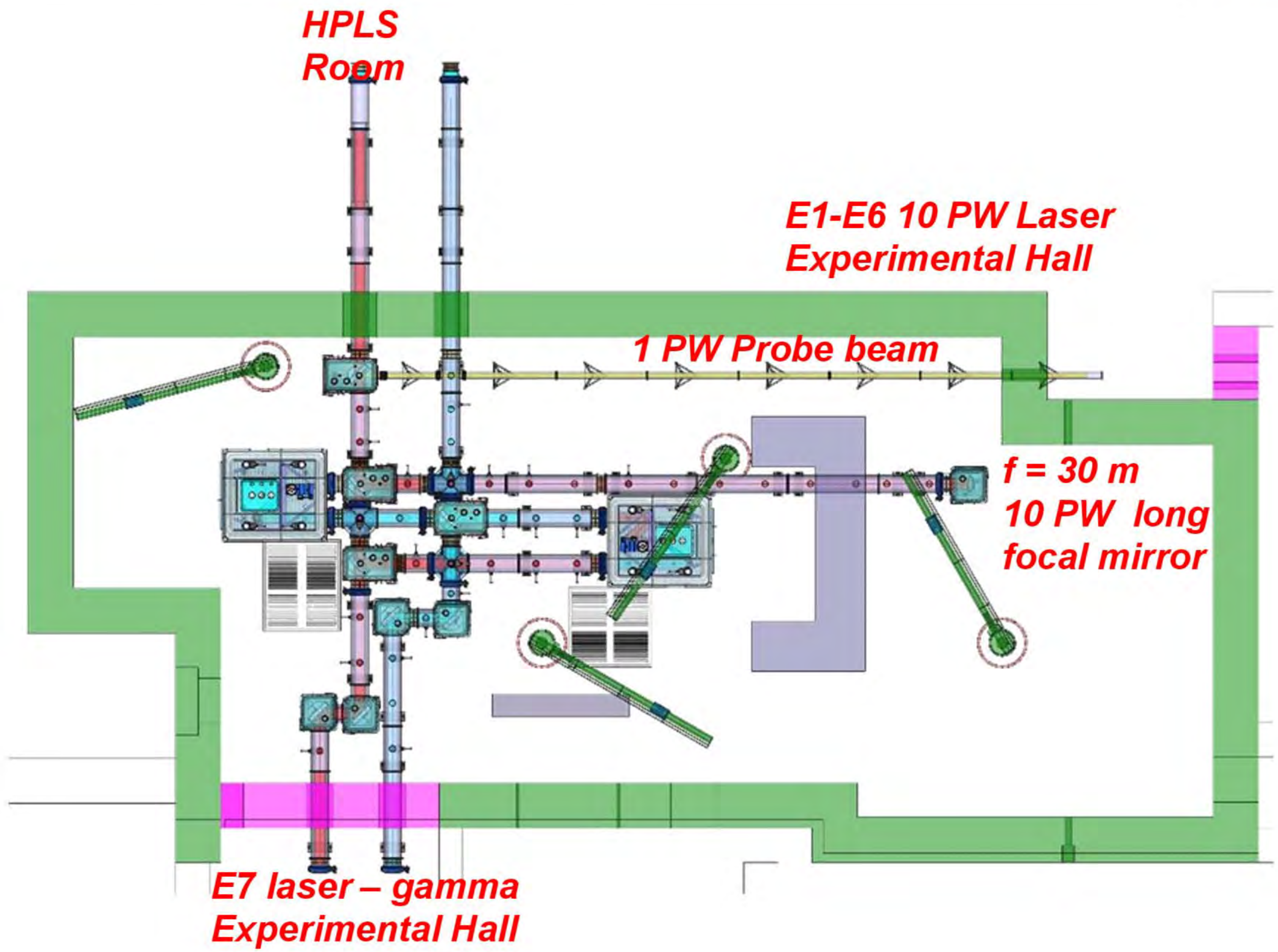
Important Dates

October 7 – 11, 2019
First User Workshop for Commissioning and Day-1 experiments @ELI-NP

Summary

- The implementation of ELI-NP is progressing well
- First laser experiments to begin Dec 2019
- US scientists already have key roles in ELI-NP commissioning experiments
- Strong US presence at 1st ELI-NP User Workshop
- US researchers can make breakthrough science at ELI-NP

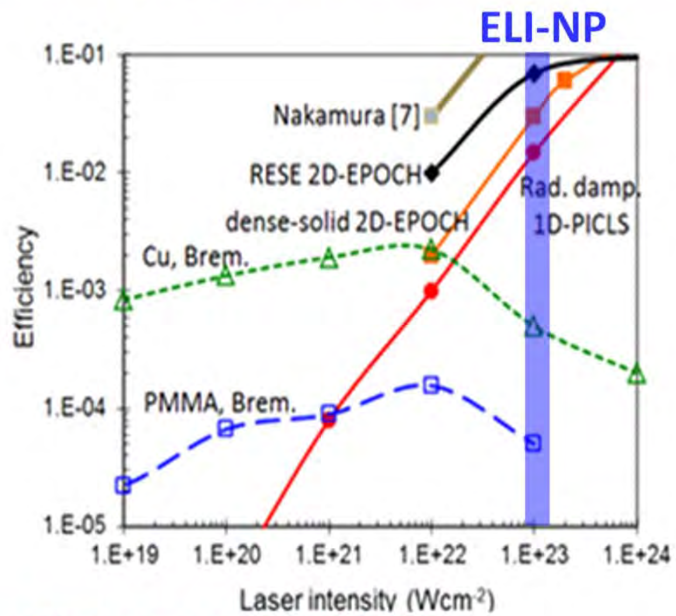
2 x 10 PW LBTS @ ELI-NP



How to Measure Extreme Light?

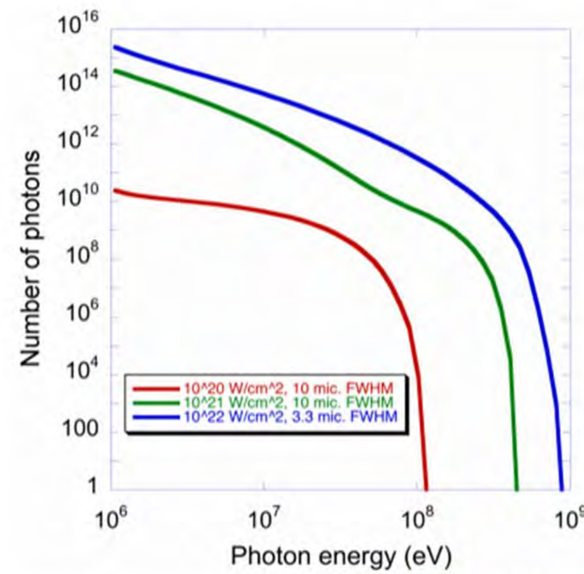
Ultra intense γ source

Solid target conversion efficiency



P McKenna et al, ELI-NP TDR2

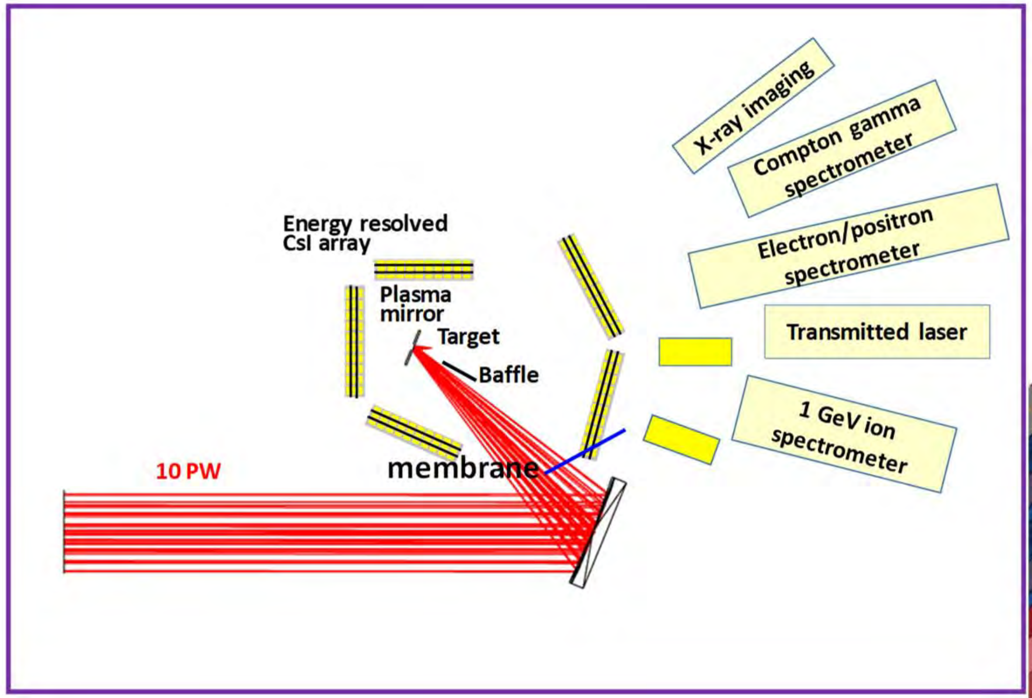
Gamma spectra



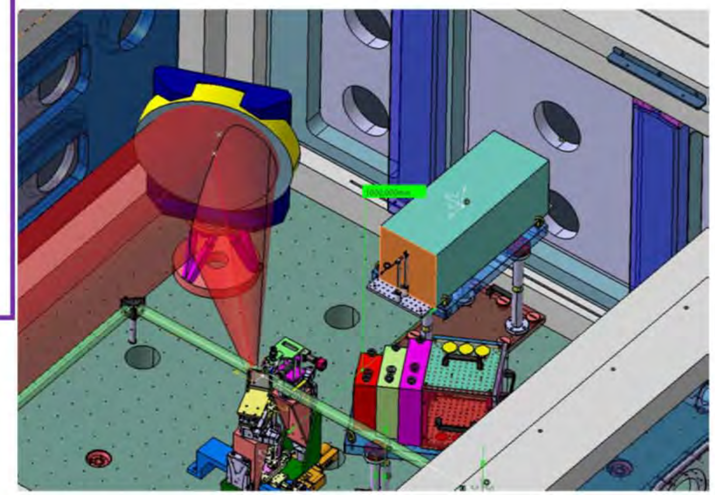
J.Fuchs @ ELI-NP

- **Goal: demonstrate extreme focal intensity of 10 PW lasers**
- **Tens of % laser-γ conversion efficiency in low-Z target (PW gamma source)**
- **Scale conversion efficiency with nominal intensity**

How to Measure Extreme Light?



Measurement methods/detectors from nuclear spectroscopy

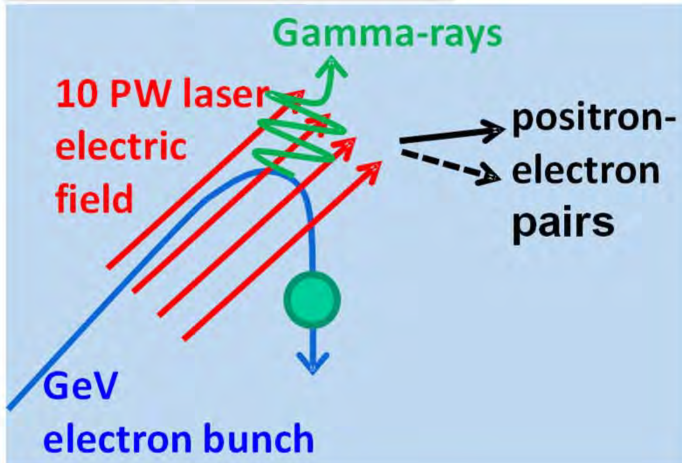


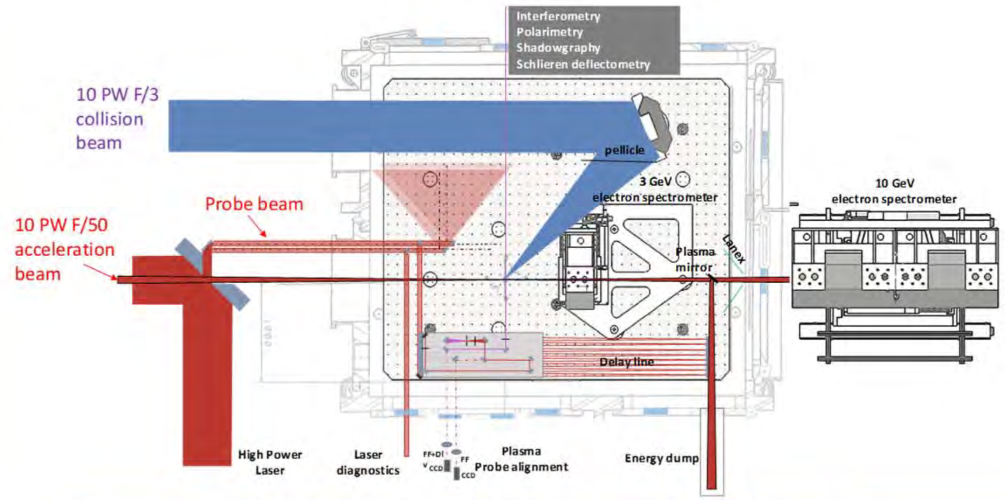
- **Few micron thick plastic target**
- **Intensity scaling of laser-γ output by scanning target through focus**
- **Energy and angle resolved gamma detectors**
- ***Plasma mirror for debris and laser back-reflection protection***

Studies under Extreme Conditions

Nuclear Physics

Strong-field QED





Collision of multi-GeV e-beams with intense laser beams (>10^{22} W/cm^2)

- **Synchrotron radiation or Nonlinear Compton:**

  $$e^- + n\gamma_L \rightarrow e^- + \gamma_R$$

- **Breit-Wheeler pair production:**

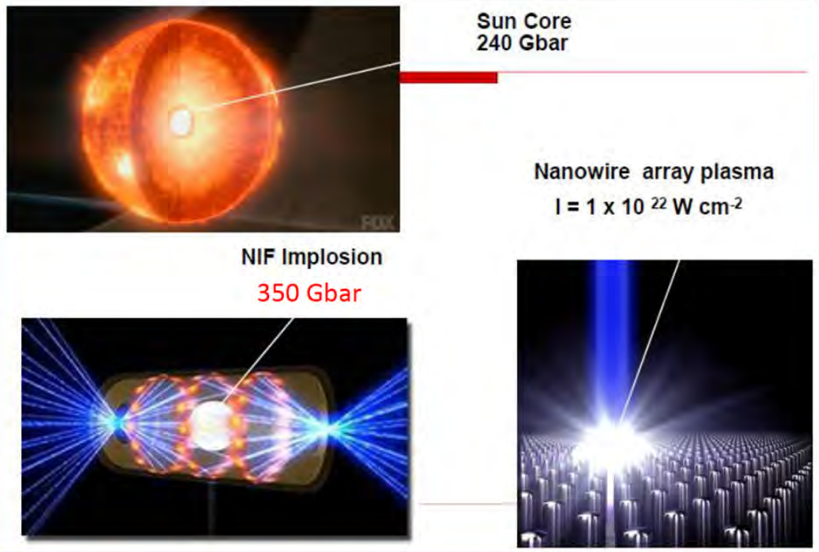
  $$\gamma_R + n\gamma_L \rightarrow e^- + e^+$$

Radiation Reaction

- QED theory verified to high precision in weak fields but never in strong fields
- BW process (light + light -> matter) yet to be experimentally proved

G.Breit and J.A.Wheeler, Phys. Rev. 46 (1934) 1087

Laser Driven Neutron Sources



Path to Extreme pressures by irradiation of aligned arrays of nanowires
⟶
Ultrahigh-energy density physics

A.Pukhov, Heinrich Heine Univ.

Deuterated nanowires arrays D-D fusion
intense high energy neutron bursts

I = 10^{19} W/cm^2, 60 fs, ultrahigh contrast >10^{11}
E_n = 2.45 MeV
⟶ n-flux = 2.2 x 10^6 n/J/shot

In the wires: 10 Gbar – pressure
2 GJ/cm^3 – thermal energy density

A.Curtis et al., Nature Communications. (2018) 9:1077