CHALLENGES FOR NUCLEAR PHYSICS RESEARCH AT THE ADVANCED GAMMA BEAM SYSTEM OF ELI–NP
Extreme Light Infrastructure in a Nutshell

**Extreme Light Infrastructure**

**Pan–European Research Center**

**Target:** implement the world’s largest laser research infrastructure

**Infrastructure:** distributed over three complementary pillars (CZ, HU, RO) – **user facilities**

**Strategy:** first ESFRI project to be fully implemented in newer EU member states

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**Extreme Light Infrastructure in a Nutshell**

**ELI–DC**

**ESFRI**

**ELI-PP**

**ELI-ALPS**

**ELI-NP**

**parallel implementation**

**initiation**

**joint operation**

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2008  2011  2013  2017

**PP**  **MoU**  **ELI-DC International Association**  **ELI-ERIC**
Extreme Light Infrastructure – Nuclear Physics

Nuclear Physics research with extreme electromagnetic fields

Host for two major systems

Based on the National Physics Platform in Magurele (Bucharest)

2 x 10 PW High–Power Lasers System

High Brilliance Gamma Beam System
Extreme Light Infrastructure – Nuclear Physics

- Nuclear Physics

  **Nuclear Photonics**
  - Nuclear Resonance Fluorescence
  - Photo–fission & Exotic Nuclei
  - Photo–disintegration and Nuclear

- Laser Ion driven nuclear physics
  - Laser–Target interaction characteristics

- Nuclear Physics diagnostics to
  - Laser–Target interaction characteristics

- Applications
  - based on high intensity laser and very brilliant ©
    - beams complementary to the other ELI pillars

complementary to other ESFRI Large Scale

Nuclear Physics Facilities (FAIR, SPIRAL2)
ELI–NP Implementation Timeline


ELI–NP White Book
Feasibility Study
Cost estimate 293M€
Preparation of the Application
E.C. Eval. & Funding Approval
Building
Procurement Laser System
Laser System – installation
Procurement Gamma Beam
Gamma Beam – installation
Experimental Areas TDR
Recruitment
ELI–NP – Building Status
Towards TDR of experiments with intense laser beams at ELI-NP
June 27-28, 2013 – Bucharest-Magurele (Romania)

Towards TDR of experiments with brilliant gamma-ray beams at ELI-NP
July 25-26, 2013 – Bucharest-Magurele (Romania)
• *building the main working groups*
• *conveners and local liaisons*

ELI-NP TDRs at Midway – High Power Laser March 16-17, 2014 – Bucharest-Magurele (Romania)

ELI-NP TDRs at Midway – SystemGamma Beam System
March 16-17, 2014 – Bucharest-Magurele (Romania)
• *added new working groups*
• *applied physics*

ELI-NP Science Program and Instruments: Technical Design Reports
February 18-20, 2015 – Bucharest-Magurele (Romania)
• *final TDRs*
• *definition of the experimental setups*

June 2015 – Scientific evaluation of the TDRs by ISAB
The High–Power Lasers System  

**2 x 10 PW**

**APOLON–type HPL based on OPCPA**

HPLS architecture
- dual front–end
- two arms

→ 6 outputs

- 2 x 0.1 PW 10Hz
- 2 x 1 PW 1Hz
- 2 x 10 PW 0.1Hz

Provided by THALES Optronique & Thales Romania
ELI–NP HPLS Parameters

This refers to the Sub-Systems Specifications of the HPLS laser 10PW outputs #01 and #02.

<table>
<thead>
<tr>
<th>Requirement # (i=1,2)</th>
<th>Parameter</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPLS - 10PW #0i REQ-1</td>
<td>Peak Power</td>
<td>≥ 10 PW +/- 10%</td>
</tr>
<tr>
<td>HPLS - 10PW #0i REQ-2</td>
<td>Central wavelength</td>
<td>In the range of 700-1000 nm</td>
</tr>
<tr>
<td>HPLS - 10PW #0i REQ-3</td>
<td>Pulse energy</td>
<td>Together with the pulse duration shall correspond to the proposed peak power</td>
</tr>
<tr>
<td>HPLS - 10PW #0i REQ-4</td>
<td>Pulse duration</td>
<td>≤ 50 fs</td>
</tr>
<tr>
<td>HPLS - 10PW #0i REQ-5</td>
<td>Repetition rate</td>
<td>10 Hz</td>
</tr>
<tr>
<td>HPLS - 10PW #0i REQ-6</td>
<td>Strehl Ratio</td>
<td>≥ 0.9</td>
</tr>
<tr>
<td>HPLS - 10PW #0i REQ-7</td>
<td>Intensity contrast (ns range)</td>
<td>≥ 1:10^{13}</td>
</tr>
<tr>
<td>HPLS - 10PW #0i REQ-8</td>
<td>Intensity contrast (ps range)</td>
<td>≥ 1:10^{13}</td>
</tr>
<tr>
<td>HPLS -10PW #0i REQ-9</td>
<td>Pointing Stability</td>
<td>≤ 2 μrad</td>
</tr>
<tr>
<td>HPLS - 10PW #0i REQ-10</td>
<td>Pulse Energy stability</td>
<td>≤ 5% rms</td>
</tr>
<tr>
<td>HPLS - 10PW #0i REQ-11</td>
<td>Laser system synchronization</td>
<td>≤ 200 fs</td>
</tr>
<tr>
<td>HPLS - 10PW #0i REQ-12</td>
<td>Warm Up Time</td>
<td>≤ 3 h</td>
</tr>
</tbody>
</table>

Intensity ~$10^{24}$ W/cm$^2$
Laser Driven Nuclear Physics

Convener: M. Roth (TUD)  ELI-NP Liaison: F. Negoita (IFIN-HH)

1. Nuclear fusion reactions from laser-accelerated fissile ion beams
   P. Thirolf (LMU) et al.
   Goal: Production of nuclei around rich N~126 waiting point

2. Nuclear (de-)excitations induced by lasers
   F. Hannachi (CENBG/IN2P3) et al.
   Goal: Observation of NEET/NEEC processes in plasma. Changes in nuclear T_{1/2}

3. Nuclear reactions in laser plasma
   S. Tudisco (LNS/INFN) et al.
   Goal: Understanding screening effect in plasma conditions

4. Neutron production and other applications
   4.1 Hot plasma confinement for high flux neutron generation
      S. Moustaizis (TU.Crete) et al.
   4.2 Neutron production in light ion reactions
      S. Kar (QUB), J.Fuchs (LULI) et al.
   4.3 Muon-source and muon catalysed fusion
      S.R.Mirfayzi, S.Kar (QUB)

I. Combined laser/gamma

Topic Stellar photoreaction

\[ e + \gamma + A \text{ in } E7 \]
Production and photoexcitation of isomers

GBS \(\text{MeV} \gamma\)

LPA \(\sim \text{MeV} e^-\)

H.Utsunomiya (Konan U.) et al.
Laser Driven Nuclear Physics

Nuclear (de-)excitations in plasma

**NEET** observed in cold targets. Never observed in plasma.

**NEEC** was never observed.

Significant changes in lifetimes are predicted in plasma conditions:

<table>
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<tr>
<th>Level</th>
<th>Lifetime (s)</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>$17/2^+$</td>
<td>$3.53 \text{ ns}$</td>
<td>$2429.80 \text{ keV}$</td>
</tr>
<tr>
<td>$21/2^+$</td>
<td>$6.85 \text{ h}$</td>
<td>$2424.95 \text{ keV}$</td>
</tr>
<tr>
<td>$13/2^+$</td>
<td>$46 \text{ ps}$</td>
<td>$2161.90 \text{ keV}$</td>
</tr>
<tr>
<td>$5/2^+$</td>
<td></td>
<td>$0 \text{ keV}$</td>
</tr>
</tbody>
</table>

F. Hannachi (CENBG/IN2P3) et al.
Laser Driven Nuclear Physics

Astrophysics – Study of screening factor – The method and cases

The method requires measuring high energy neutrons


S. Tudisco (LNS/INFN) et al.
Laser Particle Acceleration – RPA

Short pulse high–power lasers → strong charge separation by laser–matter interaction → intense electric fields → ion acceleration

Target Normal Sheath Acceleration (TNSA)

- Conversion of laser radiation into kinetic energy of relativistic electrons in μm thick targets
- Electrons move and recirculate through the solid target and appear at the surfaces where give rise to intense longitudinal electric fields

Radiation Pressure Acceleration (RPA)

- Direct action of the ponderomotive force of the laser on the surface electrons
- Ultrathin targets (< 100–200 nm)
- Highly efficient energy conversion (> 60%)
- Ions and electrons accelerated as a neutral bunch → avoid Coulomb explosion
- Solid state beam density: $10^{22} – 10^{23}$ e/cm$^3$

To produce 1 GeV protons in $t = 1$ laser period we need $I \approx 1.2 \times 10^{23}$ W/cm$^2$. Ions pulled by the charge separation field move together with electrons.
**System with outstanding key features**

- High peak brilliance ($>10^{21}$ ph/s $\cdot$ mm$^2$ $\cdot$ mrad$^2$ $\cdot$ 0.1%bw), high spectral density ($>0.5 \cdot 10^4$ ph/s $\cdot$ eV), tunable energy (0.2 – 19.5 MeV), quasi-monochromatic ($\text{relative bandwidth} < 0.5\%$), high degree of linear polarisation.
ELI–NP Gamma Beam System Concept

THE SOLUTION: Inverse Compton Scattering of laser pulses on relativistic electron pulses

- high intensity / small emittance e− beam from a warm LINAC
- very brilliant high rep./rate int. laser
- small collision volume

Brilliance

E_e\sim 8 \text{ eV}
E_{\gamma} \lessapprox 19.5 \text{ MeV}

\gamma-ray beam with < 0.5% Good bandwidth ➞ Collimated \gamma beam
ELI–NP Gamma Beam System

Provider – EuroGammaS Association

**Academic Institutions**
INFN (Italy), Sapienza University (Italy), CNRS (France)

**Industrial Partners**
ACP Systems (France), ALSYOM (France), COMEB (Italy), ScandiNova Systems (Sweden)

... and sub – contractors

**Academic Institutions**
STFC (UK), ALBA Cell (Spain)

**Industrial Partners**
Amplitude Systems (France), Amplitude Technologies (France), Cosylab (Slovenia), Danfysik (Denmark), Instrumentation Technologies (Slovenia), M&W Group (Italy), Research Instruments (Germany), Toshiba (Japan)
Main Components of the Gamma Beam System

1) **Warm electron RF Linac** (innovative techniques)
   - multi–bunch photogun (32 e− microbunches of 250 pC @100 Hz RF)
     - 2 x S–band (22 MV/m) and 12 x C–band (33 MV/m) acc. structures
     - low emittance 0.2 – 0.6 mm·mrad
     - two acceleration stages (300 MeV and 720 MeV)

2) **High average power, high quality J–class 100 Hz ps Collision Laser**
   - state–of–the–art cryo–cooled Yb:YAG (200 mJ, 2.3 eV, 3.5 ps)
   - two lasers (one for low–Eγ and both for high–Eγ)

3) **Laser circulation with μm and μrad and sub–ps alignment/synchronization**
   - complex opto/mechanical system
   - two interaction points: Eγ <  3.5 MeV & Eγ < 19.5 MeV

4) **Gamma beam collimation system**
   - complex array of dual slits
   - relative bandwidths < 5 x 10⁻³

5) **Gamma beam diagnostic system**
   - beam optimization and characterization: energy, intensity, profile
Gamma Beam System Layout

Provider – EuroGammaS Association

- Photo-gun e⁻ source
- e⁻ RF LINAC High Energy 720 MeV
- Interaction Laser High Energy
- Interaction Laser Low Energy
- e⁻ RF LINAC Low Energy 300 MeV
- Photo-gun Laser
Gamma Beam System Layout

- Low Energy Gamma Beam < 3.5 MeV
- Photo-gun e⁻ source
- Interaction Laser
  - High Energy
  - e⁻ RF LINAC
    - High Energy 720 MeV
- Interaction Laser
  - Low Energy
- e⁻ RF LINAC
  - Low Energy 300 MeV
- Photo-gun Laser
Gamma Beam System Layout

High Energy Gamma Beam < 19.5 MeV

Interaction Laser
High Energy

e⁻ RF LINAC
High Energy 720 MeV

Interaction Laser
Low Energy

e⁻ RF LINAC
Low Energy 300 MeV

Photo-gun e⁻ source

Photo-gun Laser
**ELI–NP Gamma Beam Features**

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<td>Spectral Density (ph/s·eV)</td>
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<td>Bandwidth rms (%)</td>
<td>≤ 0.5</td>
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<tr>
<td># photons per pulse within FWHM bdw.</td>
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<tr>
<td>Source rms size (µm)</td>
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<td>Peak brilliance (N_ph/sec·mm²·mrad²·0.1%)</td>
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<td>Radiation pulse length rms (ps)</td>
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**Two stage system:**

- **Low–energy stage:** $E_\gamma < 3.5$ MeV  
  March 2017
- **High–energy stage:** $E_\gamma < 19.5$ MeV  
  September 2018

**Diagram:**

- Laser ($E_L = 2.3$ eV)
- Linear polarization ($\theta_L = 8^\circ$
- $E_\gamma < 19.5$ MeV
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#### Two stage system:

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  March 2017

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  September 2018

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One pulse  
~ 1 ps  
~ $10^5$ photons
Main Components of the Gamma Beam System

Electrons rep. rate – macropulses 100 Hz
32 micropulses @ 16 ns

Laser rep. rate – 100 Hz → laser recirculation

‘Dragon–shaped’ Laser Recirculation

Laser beam spots map a circle on the parabolic mirrors

**Gamma Beam Experiments**

**Photonuclear Reactions**
- Nuclear Resonance Fluorescence
- Photodisintegration, Photofission
- Photoactivation

**Fundamental Research**
- Nuclear Resonance Fluorescence ($\gamma,\gamma$) (A.Zilges U.Cologne, C.A.Ur)
- Nuclear Astrophysics ($\gamma,p$) ($\gamma,\alpha$) (M.Gai U.Conn, O.Tesileanu)
- Photonuclear Reactions ($\gamma,n$) (H.Utsunomiya U.Kyoto)
- Photofission&Studies of Exotic Nuclei ($\gamma,n$) (H.Utsunomiya U.Kyoto, D.L.Balabanski)

**Applications**
- Gamma Imaging ($\gamma$) (H.Ohgaki U.Kyoto, V.Iancu)
- Material Science with Positrons ($\gamma$) (C.Hugenschmidt TU Munich, N.Djourellov)
- Medical Radioisotopes ($\gamma$) (D.Niculae IFIN-HH Bucharest, M.Bobeica)

**R&D Gamma Beam Diagnostics Detectors**
- Gamma Beam Delivery and Diagnostics (H.Weller U.Duke, C.A.Ur)

**Broad International Collaboration**
- Germany, France, Italy, USA, Japan, Hungary, Poland, Vietnam, Switzerland, UK, Russia, Israel, India, Bulgaria, Turkey, Finland,

**Particle Separation Energy**
- $\gamma$ 
- $\gamma'$

**Diagram**
- $^A_X$ 
- $^A_Y$ 
- $\gamma$ 
- $n, p, \alpha$ 
- $\beta$
Electromagnetic dipole response of nuclei

- Photoresponse of weakly abundant p–nuclei and actinides
- Rotational 2+ states of the nuclear scissor modes
- Pygmy Dipole Resonances
- $\Gamma_0$ and $\Gamma/\Gamma_0$ measurements

Access to nuclear observables – model independent

- Excitation Energy $E_x$
- Spin and parity $J, \pi$
- Decay Energies $E_\gamma$
- Partial Widths $\Gamma_i/\Gamma_0$
- Multipole Mixing $\delta$
- Decay Strengths $B(\pi\lambda)$
- Level Width $\Gamma$ (eV)
New Discovery Frontiers for NRF at ELI–NP

Availability frontier
- access to rare isotopes
- photoresponse of weakly abundant p–nuclei and actinides

Sensitivity frontier
- weak channels
- rotational 2+ states of the nuclear scissor modes

Precision frontier
- high statistics
- \( \Gamma_0 \) and \( \Gamma/\Gamma_0 \) measurements
Nuclear Resonance Fluorescence

**Instrumentation:**

- **ELIADE** = ELI–NP Array of DETectors
- 8 x TIGRESS – type Clover detector (*segmented*) with back-catcher ($\varepsilon_{ph} \sim 6\%$)
- 4 x 3”x3” LaBr$_3$(Ce) detectors
- Digital DAQ
Background radiation in the detectors

- Compton scattering of the beam

Segmented Clover detectors + digital DAQ

- Reduce the 511 keV background
- Distinguish events from different pulses of gamma beam
- Eliminate pile-up events
Nuclear Resonance Fluorescence

HI\(\gamma\)S @ Duke U.
- Relative bandwidth ~ few percent
- Spectral density ~ \(10^2\) ph/s/eV

ELI–NP @ Magurele
- Relative bandwidth ~ few per mille
- Spectral density ~ \(10^4\) ph/s/eV

N. Pietralla et al.
Nuclear Resonance Fluorescence

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N.Pietralla et al.
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\[E_x\]

\[\Gamma_0\quad \Gamma_0\quad \Gamma_i\]

Counts per 2 keV

\[0\quad 250\quad 500\]

Energy (keV)

\[5200\quad 5400\quad 5600\quad 5800\quad 6000\]

N. Pietralla et al.
Main requirements are:

- **Low transmission of gamma photons** (high density and atomic number)
- **Continuously adjustable aperture** (to adjust the energy bandwidth in the entire energy range)
- **Avoid contamination of the primary beam** with production of secondary radiation

Collimation aperture varies from 20 mm to less than 1 mm, depending on the beam energy.

Tungsten slits – 20 mm thick

14 independent slits with 25.7° relative angle
Gamma Beam Collimator System

\[ \alpha_0 = 7.5 \]

CAIN code for ICS
Nuclear Astrophysics

- Molecular states and symmetries in light nuclei
- Astrophysics interest radiative capture reaction cross section measurements from photodisintegration reactions (advantage – minimizing systematic errors)
  - $^{16}\text{O}(\gamma,\alpha)^{12}\text{C}$, $^{24}\text{Mg}(\gamma,\alpha)^{20}\text{Ne}$,
  - $^{22}\text{Ne}(\gamma,\alpha)^{18}\text{O}$, $^{19}\text{F}(\gamma,\alpha)^{18}\text{O}$,
  - $^{21}\text{Ne}(\gamma,\alpha)^{17}\text{O}$

Instrumentation:

- eTPC (35x20x20 cm$^3$)
- Large–area Si DSSD array
Gamma Above n Threshold

- Studies of GDR and PDR decay \(^{90}\text{Zr}, ^{208}\text{Pb}\)
- Studies of spin–flip M1 resonances
  - combine with information from \((\gamma, \gamma')\)
    (e.g. polarization)
  - \(\gamma\) decay to g.s and ex. states as a function of excitation energy

Instrumentation:
- \(\text{LaBr}_3(\text{Ce}) / \text{CeBr}_3\) array (34 or 68)
  - high–energy gamma rays
- \(^6\text{Li}\)–glass detectors and NE213 liquid scintillator array (34)
  - neutrons

INFN and U. Milano
Gamma Above n Threshold

- Absolute $(\gamma,n)$ cross section measurements, e.g. p-process nucleosynthesis related measurements:
  - Production & Destruction of rare p–nuclei
    - $^{139}$La$(\gamma,n)^{138}$La & $^{138}$La$(\gamma,n)^{137}$La
    - $^{181}$Ta$(\gamma,n)^{180}$Ta & $^{180}$Ta$(\gamma,n)^{179}$Ta
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    - $^{181}\text{Ta}(\gamma,n)\ ^{180}\text{Ta}$ & $^{180}\text{Ta}_m(\gamma,n)\ ^{179}\text{Ta}$

**Instrumentation:**
- $^3\text{He}$ neutron counter array
- Embedded in polyethylene
- 3 rings → ‘flat’ efficiency response
Photofission

- Studies in the 2\textsuperscript{nd} and 3\textsuperscript{rd} minimum of the fission barrier: measurement of transmission resonances, angular and mass distributions of the fragments

- Rare fission modes: ternary fission

- Structure of neutron–rich nuclei: the rare–earth neutron–rich deformed region


Photofission

- Studies in the 2\textsuperscript{nd} and 3\textsuperscript{rd} minimum of the fission barrier: measurement of transmission resonances, angular and mass distributions of the fragments
- Rare fission modes: ternary fission
- Structure of neutron–rich nuclei: the rare–earth neutron–rich deformed region

**Instrumentation:**

- System of multi–target Frisch–gridded twin ionization chambers and DSSD detectors
- Array of 12 x THGEM detectors

ATOMKI, Debrecen
Photofission and Exotic Nuclei

ALTO, ARIEL, etc.

**Photofission cross section for $^{238}$U**

**β-decay studies at the IGISOL beam line:**

- Emphasis on refractory elements that can be separated with the IGISOL technique;

- Test of the SM around the doubly-magic $^{132}\text{Sn}$;

- Studies of the onset and fading away of deformation in the $A = 100$ Sr–Zr region;

- Studies of collective excitations in the $A = 150$ deformed region;

- Studies of octupole excitations in Sm-Nd nuclei.

GSI, IPNO, JYFL, …
Summary

- A new nuclear physics research facility is being constructed at Bucharest
  - Systems with features beyond state-of-the-art: HPLS and GBS
  - Many new research opportunities and challenges
  - Nuclear physics
    - Laser Driven Nuclear Physics
    - Combined laser–gamma
    - NRF, photofission, photodissociation
  - Job opportunities
    - Open positions: post-docs, junior researchers, senior researchers, engineers, PhD research assistants
Extreme Light Infrastructure - Nuclear Physics (ELI-NP) - Phase I

Project co-financed by the European Regional Development Fund

“The content of this document does not necessarily represent the official position of the European Union or of the Government of Romania”

For detailed information regarding the other programmes co-financed by the European Union please visit www.fonduri-ue.ro, www.ancs.ro, http://amposcce.minind.ro
Laser Driven Nuclear Physics

Nuclear (de-)excitations in plasma

**NEET** observed in cold targets. Never observed in plasma.

**NEEC** was never observed

Significant changes in lifetimes are predicted in plasma conditions:

- $^{17/2^+}$: 3.53 ns, 2429.80 keV
- $^{21/2^+}$: 6.85 h, 2424.95 keV
- $^{13/2^+}$: 46 ps, 2161.90 keV
- $^{5/2^+}$: 0 keV

F. Hannachi (CENBG/IN2P3) et al.
Laser Driven Nuclear Physics

Study of screening factor – The method and cases

The method requires measuring high energy neutrons

S. Tudisco (LNS/INFN) et al.

Short pulse high-power lasers → strong charge separation by laser–matter interaction
→ intense electric fields → ion acceleration

**Target Normal Sheath Acceleration (TNSA)**
- Conversion of laser radiation into kinetic energy of relativistic electrons in μm thick targets
- Electrons move and recirculate through the solid target and appear at the surfaces where give rise to intense longitudinal electric fields

**Radiation Pressure Acceleration (RPA)**
- Direct action of the ponderomotive force of the laser on the surface electrons
- Ultrathin targets (< 100–200 nm)
- Highly efficient energy conversion (> 60%)
- Ions and electrons accelerated as a neutral bunch → avoid Coulomb explosion
- Solid state beam density:
  \[10^{22} \text{ – } 10^{23} \text{ e/cm}^3\]

To produce 1 GeV protons in \(\tau = 1\) laser period we need \(I \sim 1.2 \times 10^{23} \text{ W/cm}^2\). Ions pulled by the charge separation field move together with electrons.
Materials in Extreme Environments

Convener: Marilena Tomut (GSI)  ELI-NP Liaison T. Asavei

* Testing of new materials for accelerator components
  - materials at fast energy deposition & mixed radiation fields
  - laser induced shock waves
  - laser modification of materials

* Evaluation of high energy ionizing radiation effects in materials
  Irradiation of components for space radiation studies

* Biological science research
  - radiation effects on bio-molecules & cells

* Testing and developments of detectors

* Irradiated optical components testing, Materials for fusion energy systems
Main Components of the Gamma Beam System

1) **Warm electron RF Linac** (innovative techniques)
   - multi–bunch photogun (32 e– microbunches of 250 pC @100 Hz RF)
     - 2 x S–band (22 MV/m) and 12 x C–band (33 MV/m) acc. structures
     - low emittance 0.2 – 0.6 mm⋅mrad
     - two acceleration stages (300 MeV and 720 MeV)

2) **High average power, high quality J–class 100 Hz ps Collision Laser**
   - state–of–the–art cryo–cooled Yb:YAG (200 mJ, 2.3 eV, 3.5 ps)
   - two lasers (one for low–E$_\gamma$ and both for high–E$_\gamma$)

3) **Laser circulation with µm and µrad and sub–ps alignment/synchronization**
   - complex opto/mechanical system
   - two interaction points: E$_\gamma$ < 3.5 MeV & E$_\gamma$ < 19.5 MeV

4) **Gamma beam collimation system**
   - complex array of dual slits
   - relative bandwidths < 5 x 10$^{-3}$

5) **Gamma beam diagnostic system**
   - beam optimization and characterization: energy, intensity, profile
Photogun Laser

Photocathode Laser

Based on Ti:Sa amplifier
cryo-cooled
@ 100 Hz

Photocathode = Copper
500 pC = max. charge
→ 250 µJ / pulse

Output: UV (266 nm)
> 3 mJ, 32 pulses

Producing 32 replica (before the last amplifier)

Time structure of the electron beam

MULTIBUNCHING

800 nm pulse
Beam Splitter 50/50
Mirror

Delay 1 (15ns, 4.5m)
Delay 2 (30ns, 9m)
Delay 3 (60ns, 18m)
Delay 4 (120ns, 36m)
Delay 5 (240ns, 72m)
Delay 6 (480ns, 144m)

Pockels
Polarizer
32 pulses

ELI–NP – Experimental Building Layout

Anti-vibration platform

±1 \mu m @ < 10 Hz

Platform supported on dampers
50% efficiency, 5 ms extraction time at a rate of ~ $10^7$ ions/s

Technical design at GSI, Darmstadt

He gas @ 70 K pressure 300 mb and 10 mb > 100 V/sm DC field RF carpet
Gamma Beam Industrial Applications

Non-destructive Inspection

Active interrogation – Nuclear resonance fluorescence
- Nuclear waste management
- Cargo screening/Material identification
- Origin of objects
- Metal count in food and in plants
- Density screening in ill tissues

High resolution imaging – Radiography and Tomography
- Test quality of industrial objects (engines faults, steel quality)
- Test strength of sinterization/welding
- Phase distribution
- Diffusion

NRF + CT: Elemental/isotopic maps
Two experimental methods will be carried out:

- **Scattering NRF** – Standard Method in Nuclear Physics Study
- **Self-absorption/Transmission NRF** (proposed by Bertozzi in 2005)

Main interest in SNM control management

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**Active interrogation – Nuclear resonance fluorescence**

- High intensity gamma beam and small bandwidth
- Tunable energy
- High efficiency detector array – ELIADE
Gamma Beam Industrial Applications

Industrial Radiography and Tomography

- Two tomography tables with biaxial movement and rotation
- Various collimators with collimation holes between 0.2 mm and 5 mm.
- High volume detector for pencil-beam
- 2D detector for cone-beam: CCD based gamma-ray camera or 2D flat panel

- Implementation: 2015 - 2017
- Operation: 2018
Positrons for Material Sciences

**The ELI-NP e\(^+\) factory**

### Production method
- \((\gamma, e^+e^-)\) reaction;
- circular polarized \(\gamma\)-beam
- \(I_\gamma = 2.4 \times 10^{10} \text{ s}^{-1}\)
- \(E_\gamma < 3.5 \text{ MeV}\)
- W converter

### Estimated e\(^+\) beam parameters
- moderated e\(^+\) intensity \(1.9 \times 10^6 \text{ s}^{-1}\)
- degree of e\(^+\) spin polarization 31%

### Spectrometers
- **PALS** – Positron Annihilation Lifetime Spectroscopy
- **CDBS** – Coincidence Doppler Broadening Spectroscopy
- **TOF–PAES** – Positron annihilation initiated Auger Electron Spectroscopy
- **GiPALS** – Gamma induced PALS
Measurement of the gamma beam **energy distribution**

Measurement of the **number of photons** per pulse

Measurement of the **size and spatial distribution** of the gamma beam