EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2007-2013

γANT NRF PhF CPWG IndAppl Radioisotopes Positrons

Challenges for nuclear physics research at the Advanced Gamma Beam System of ELI–NP

eli Nuclear Physics

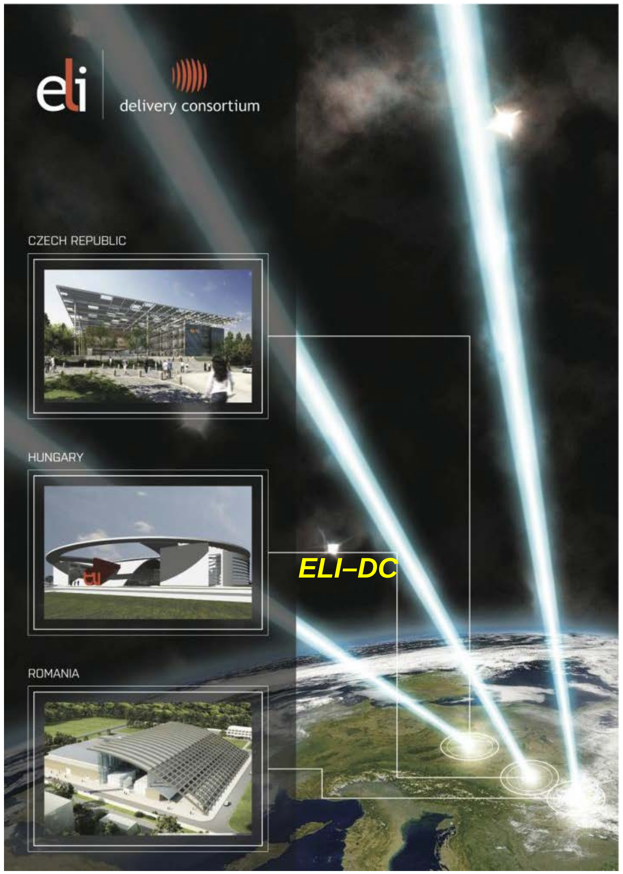
IFIN-HH

The 5th International Conference on "Collective Motion in Nuclei under Extreme Conditions" – COMEX5
September 14 – 18, 2015, Krakow, Poland

Călin A. Ur
for the ELI–NP Team

Extreme Light Infrastructure in a Nutshell

Nuclear Physics



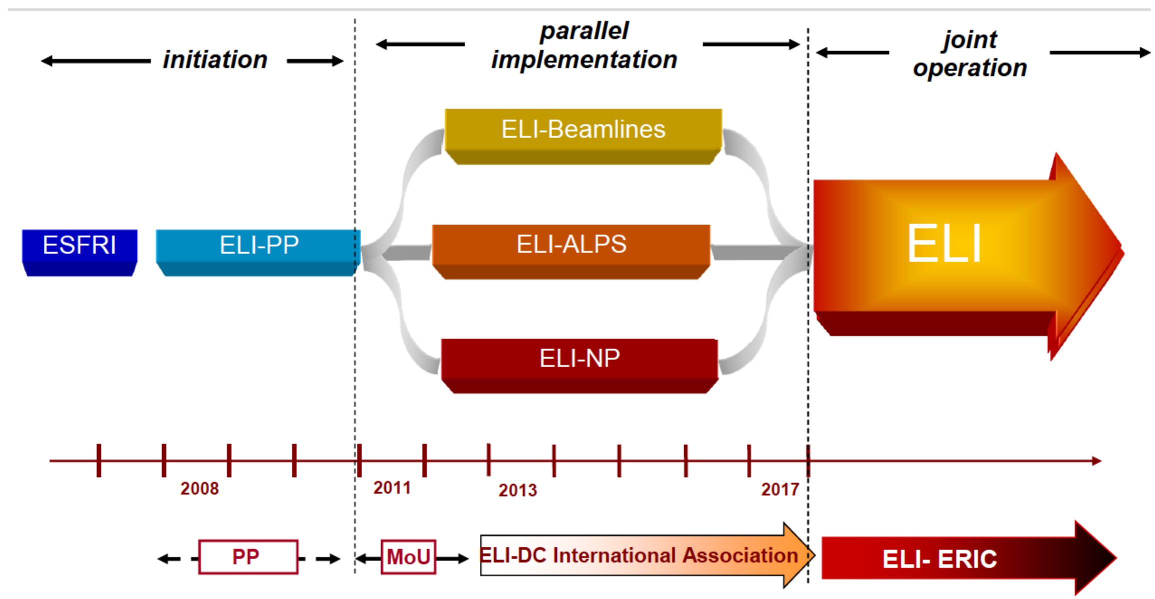
Extreme Light Infrastructure

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



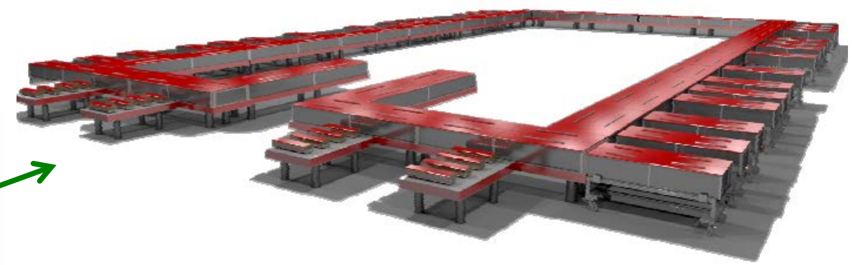
Extreme Light Infrastructure – Nuclear Physics

Nuclear Physics research with extreme electromagnetic fields

Host for two major systems

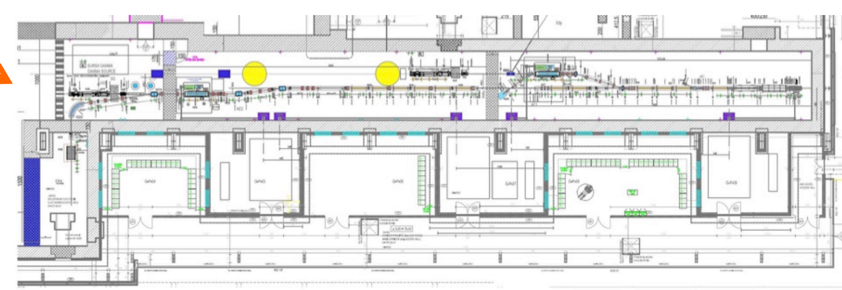
Based on the National Physics Platform in Magurele (Bucharest)

2 x 10 PW High–Power Lasers System



Thales Optronique

High Brilliance Gamma Beam System



EuroGammaS

Extreme Light Infrastructure – Nuclear Physics

- **Nuclear Physics**

  Nuclear Photonics

  Nuclear Resonance Fluorescence

  Photo–fission & Exotic Nuclei

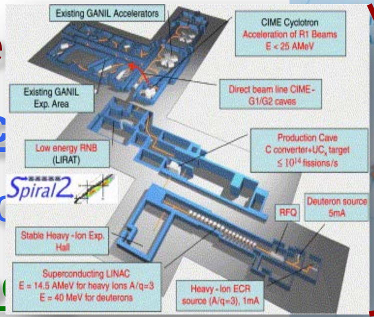
  Photo–disintegration and Nucle

  Laser Ion driven nuclear physic

  Laser–Target interaction charac

  Nuclear Physics diagnostics to

  Laser–Target interaction characteristics



- **Applications**

  based on high intensity laser and very brilliant ©

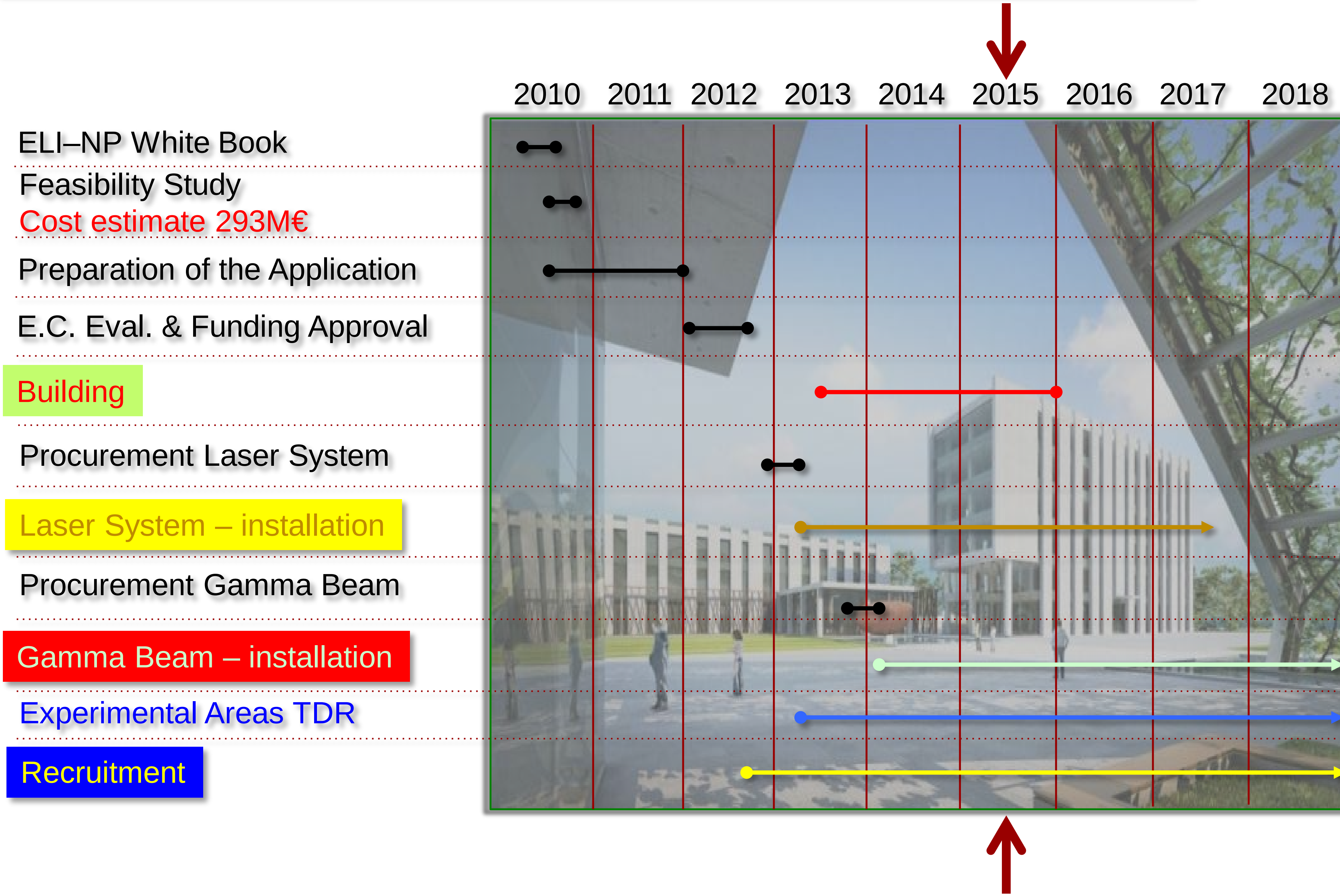
  beams complementary to the other ELI pillars

complementary to other ESFRI Large Scale

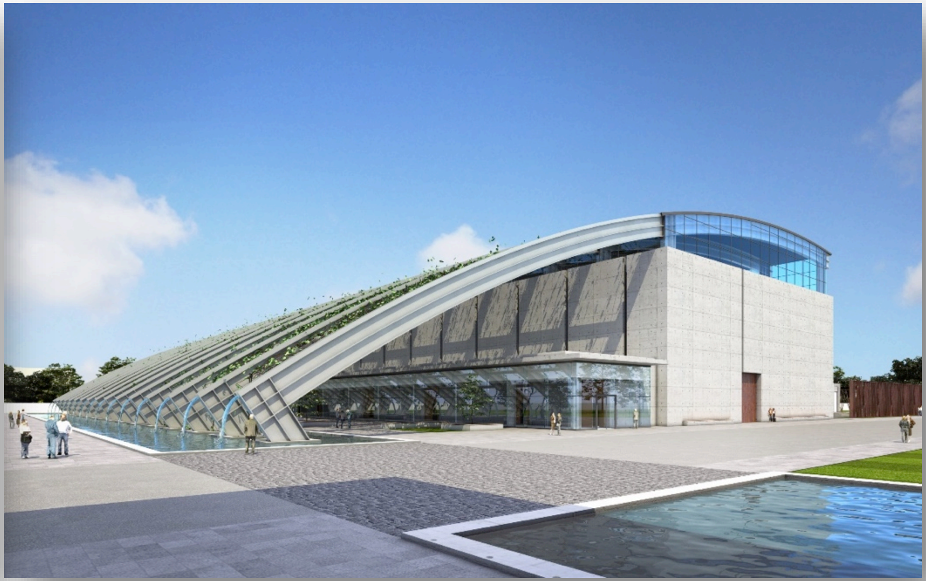
Nuclear Physics Facilities (FAIR, SPIRAL2)

ELI–NP Implementation Timeline

Nuclear Physics



ELI–NP –Building Status



ELI–NP Building the Experiments

White Book ⟹ Day–1 Experiments

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)

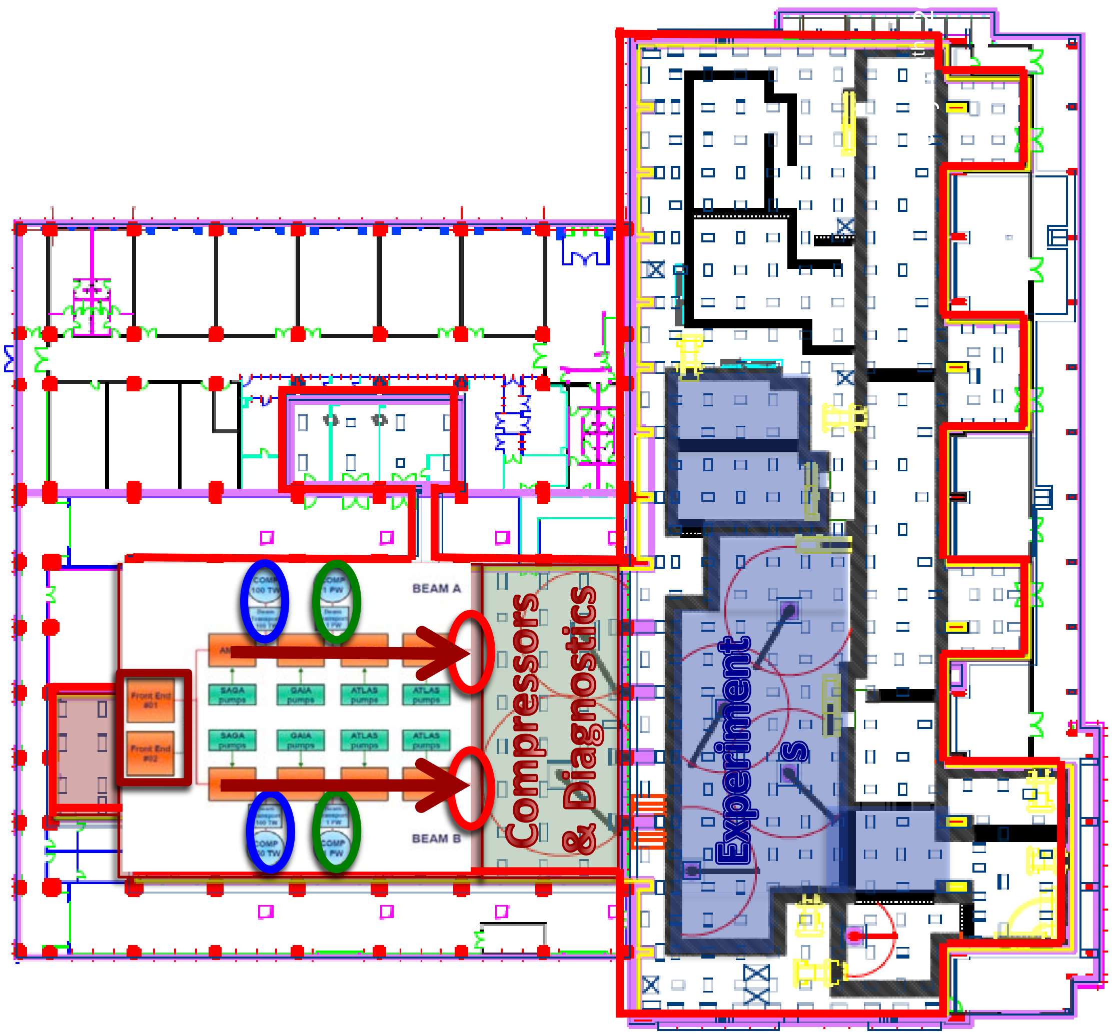
- ***added new working groups***
- ***applied physics***

ELI-NP Science Program and Instruments: Technical Design Reports
February 18-20, 2015 – Bucharest-Magurele (Romania)

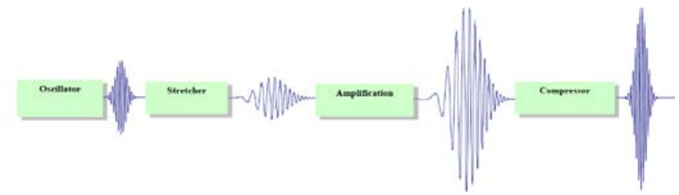
- ***final TDRs***
- ***definition of the experimental setups***

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

Nuclear Physics

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

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

~ 250 J

~ 25 fs

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

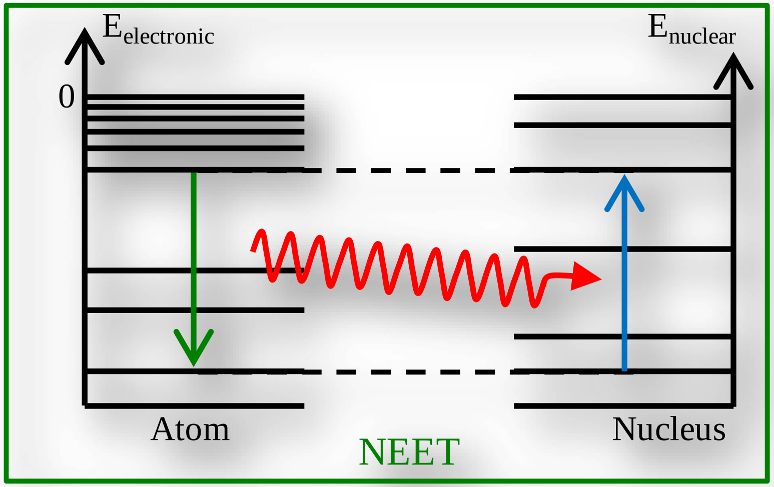
Topic Stellar photoreaction

GBS MeV γ → **$e + \gamma + A$ in E7** Production and photoexcitation of isomers ← LPA ~MeV e-

H.Utsunomiya (Konan U.) et al.

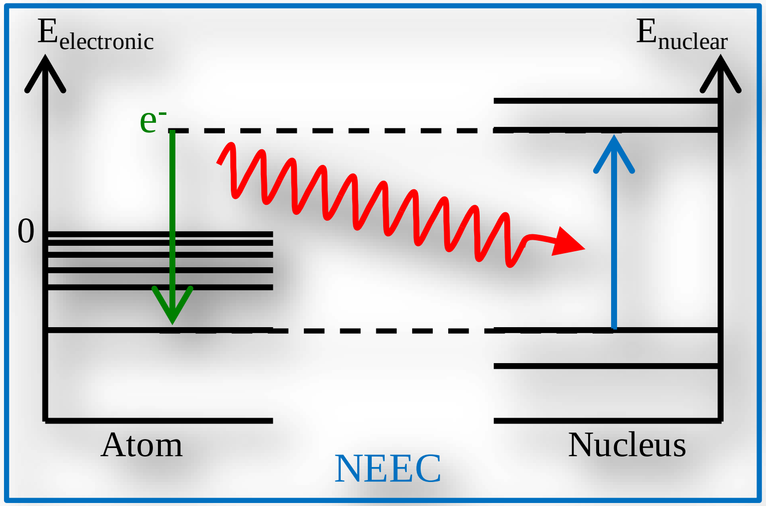
Laser Driven Nuclear Physics

Nuclear (de–)excitations in plasma

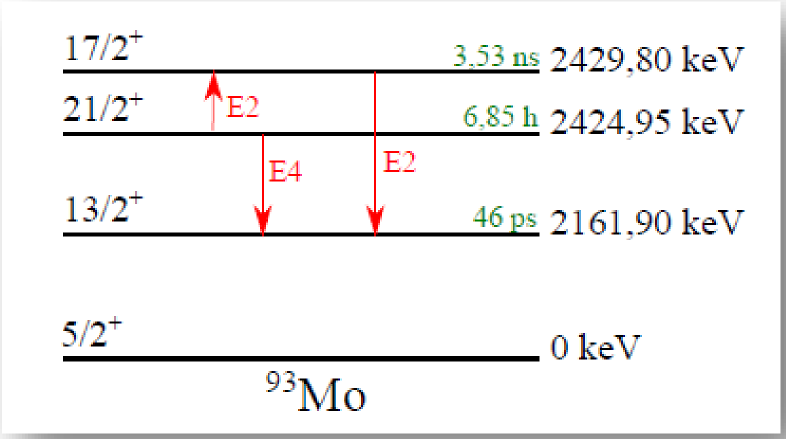


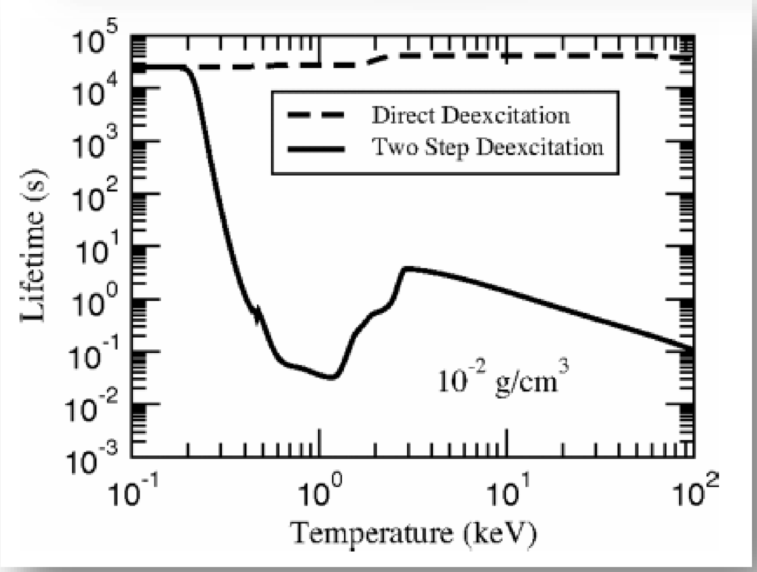
NEET observed in cold targets. Never observed in plasma.

NEEC was never observed



Significant changes in lifetimes are predicted in plasma conditions:

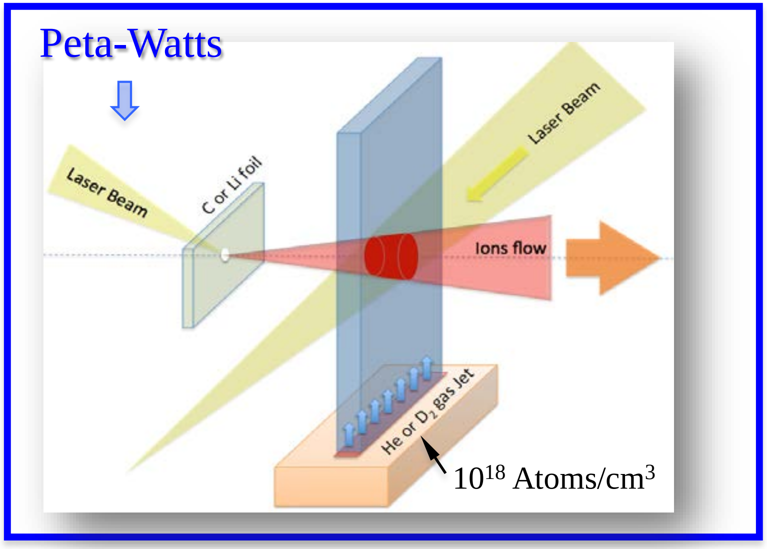


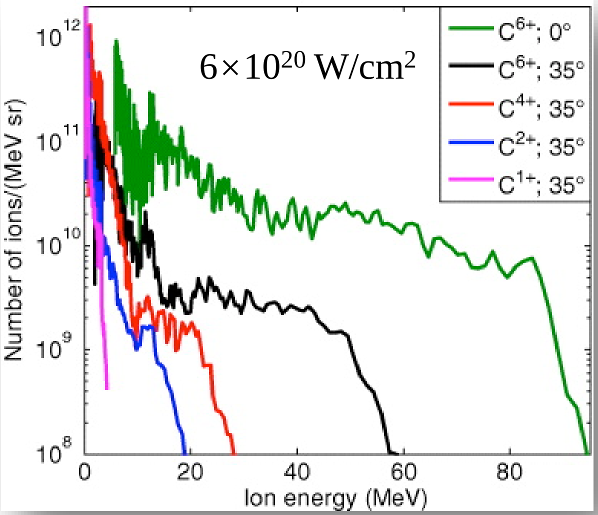


F. Hannachi (CENBG/IN2P3) et al.

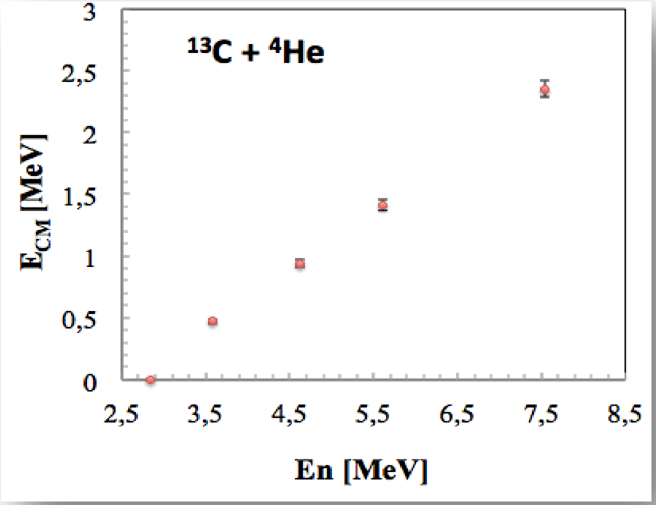
Laser Driven Nuclear Physics

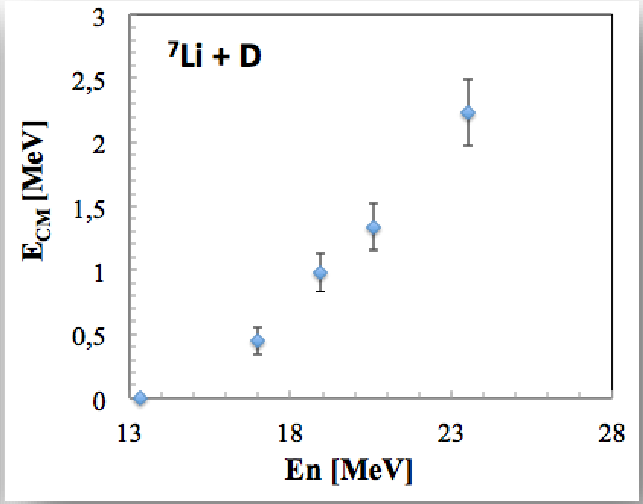
Astrophysics – Study of screening factor – The method and cases





D.C. Carrol et al., New J. of Phys. 12 (2010) 045020





The method requires measuring high energy neutrons

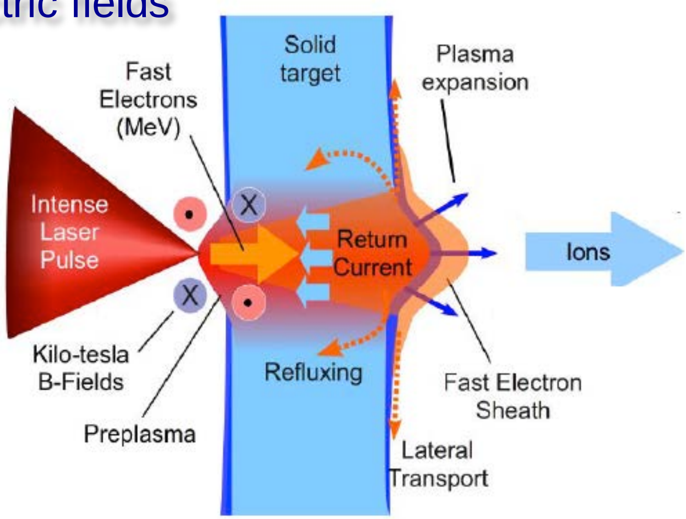
S. Tudisco (LNS/INFN) et al.

Laser Particle Acceleration – RPA

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

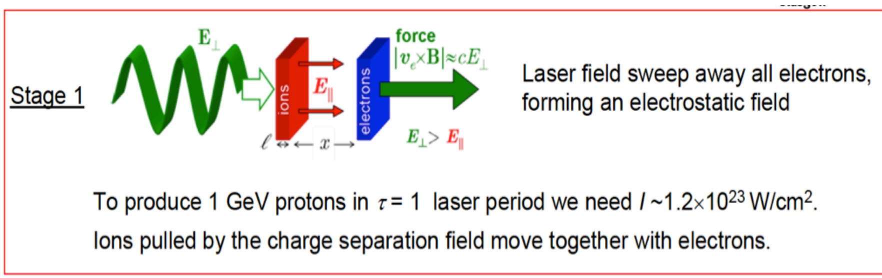
Target Normal Sheath Acceleration (TNSA)

- 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 Presure 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

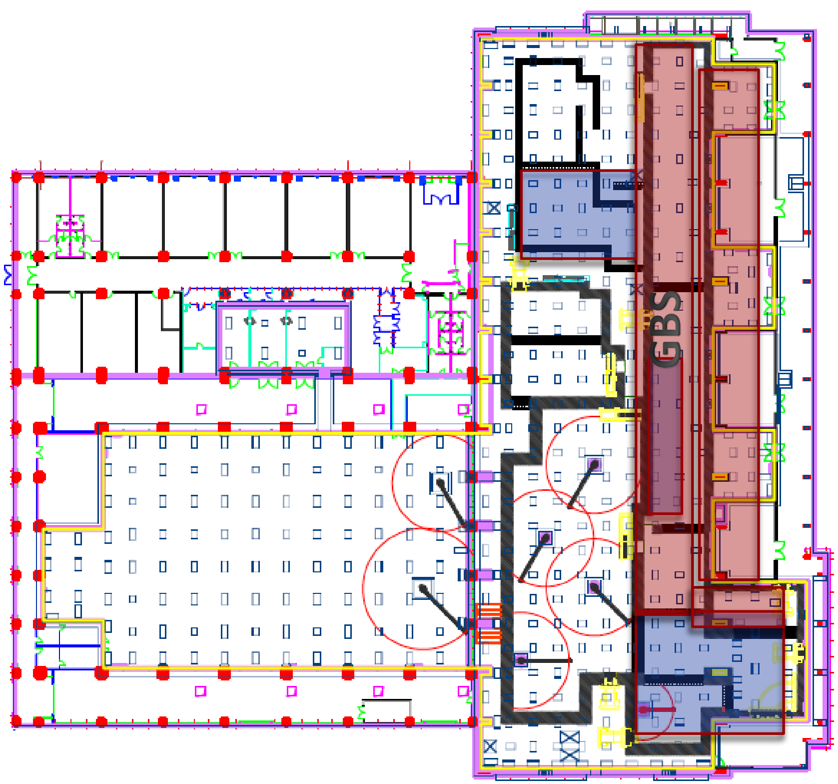


P.McKenna, CETAL Workshop, Bucharest, Nov. 19, 2013

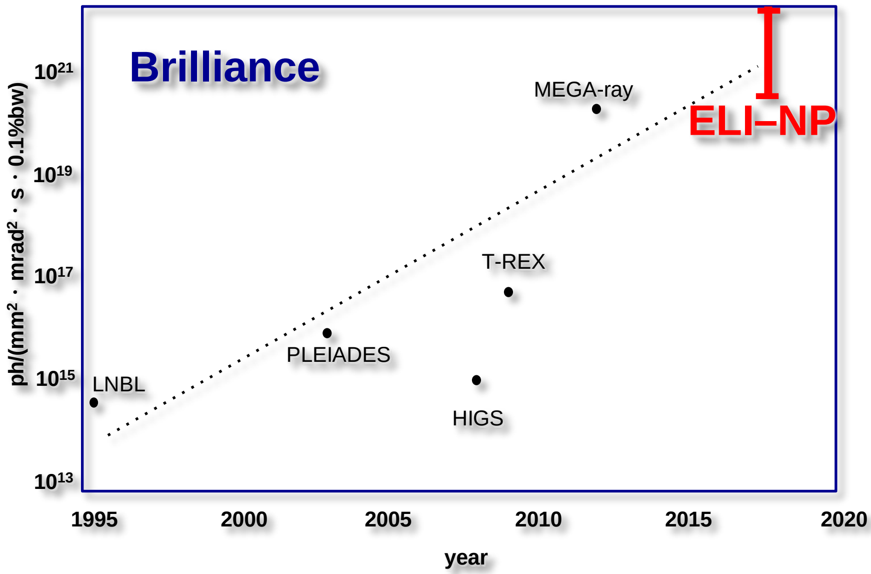
ELI–NP Gamma Beam System

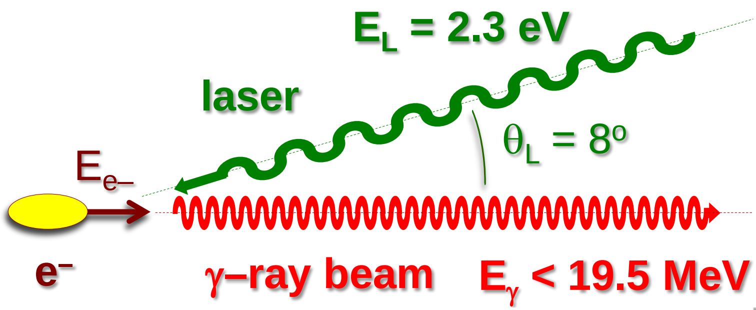
System with outstanding key features

high peak brilliance *(>10^{21} ph/s · mm^2 · $mrad^2$ · 0.1%bwd)*, **high spectral density** *(> 0.5 · 10^4 ph/s · eV)*, **tunable energy** *(0.2 – 19.5 MeV)*, **quasi–monochromatic** ***(relative bandwidth < 0.5%)***, **high degree of linear**



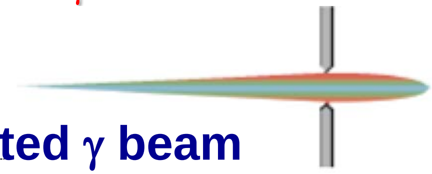
ELI–NP Gamma Beam System Concept

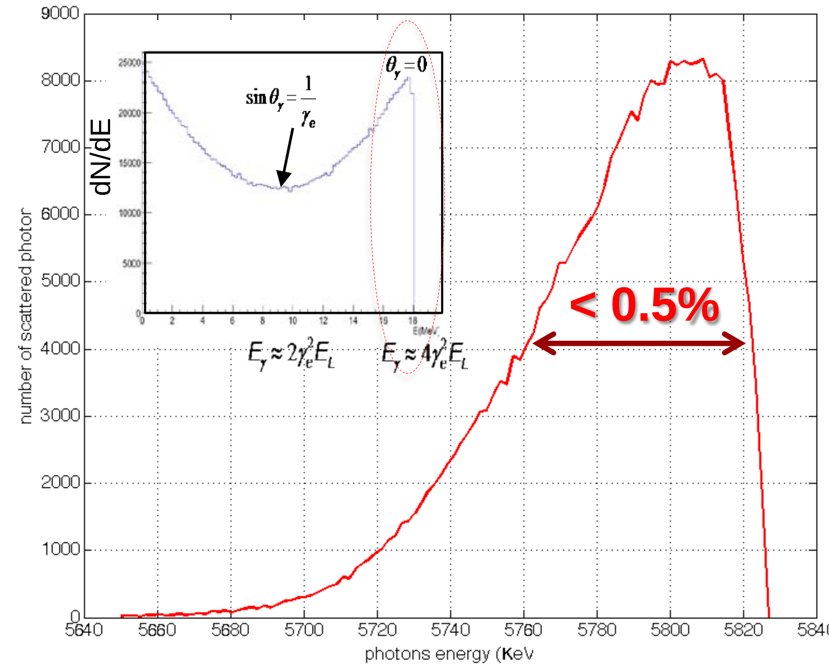




Good bandwidth

➞ Collimated γ beam





- **THE SOLUTION: Inverse Compton Scattering of laser pulses on relativistic electron pulses**
  - **high intensity / small emittance e⁻ beam from a warm LINAC**
  - **very brillant high rep./rate int. laser**
  - **small collision volume**

ELI–NP Gamma Beam System

Nuclear Physics

Provider – EuroGammaS Association

Academic Institutions
INFN (Italy), Sapienza University (Italy), CNRS (France)
Industrial Partners
ACP Systems (France), ALSYOM(France),
COMEB (Italy), ScandiNova Systems (Sweden)

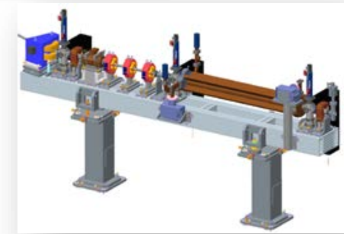
… and sub – contractors

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)

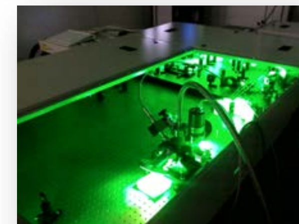
Main Components of the Gamma Beam System

1) *Warm electron RF Linac* (innovative techniques)



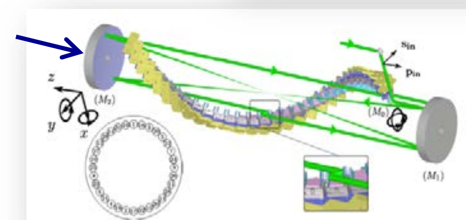
- multi–bunch photogun (32 e^- microbunches of 250 pC @100 Hz RF)
  - 2 x S–band (22 MV/m) and 12 x C–band (33 MV/m) acc. structures
  - low emittance 0.2 – 0.6 mm·mrad
  - two acceleration stages (300 MeV and 720 MeV)

2) *High average power, high quality J–class 100 Hz ps Collision Laser*



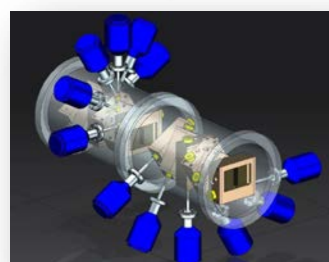
- state–of–the–art cryo–cooled Yb:YAG (200 mJ, 2.3 eV, 3.5 ps)
- two lasers (one for low–E_γ and both for high–E_γ)

3) *Laser circulation with μm and μrad and sub–ps alignment/synchronization*



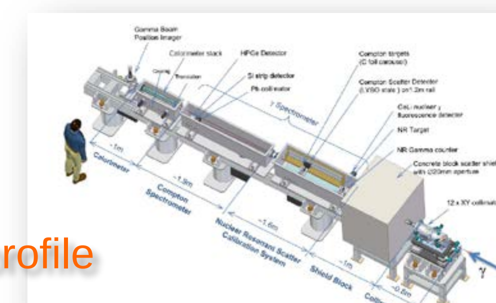
- complex opto/mechanical system
- two interaction points: E_γ < 3.5 MeV & E_γ < 19.5 MeV

4) *Gamma beam collimation system*



- complex array of dual slits
- relative bandwidths < 5 x 10^{-3}

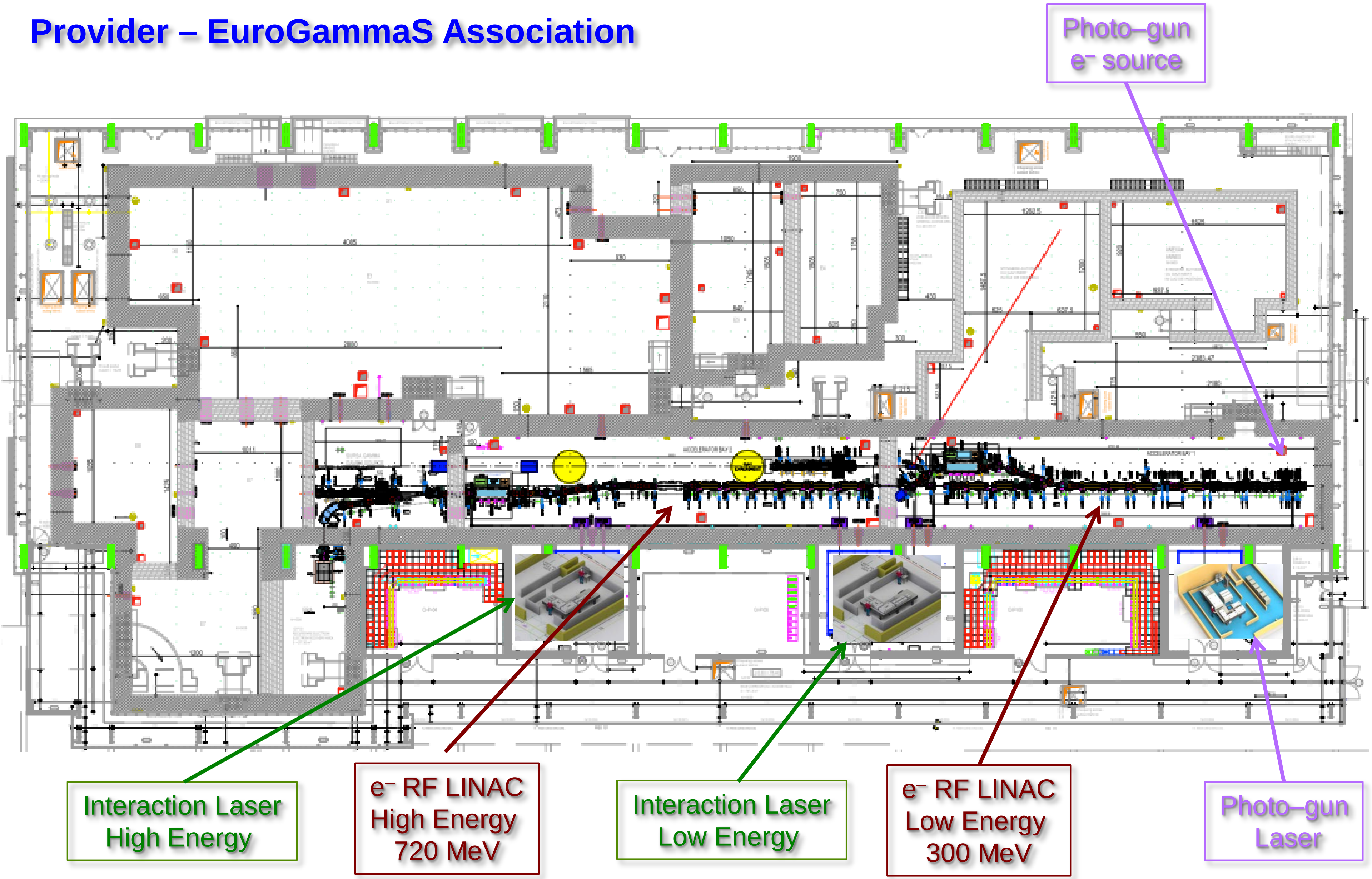
5) *Gamma beam diagnostic system*



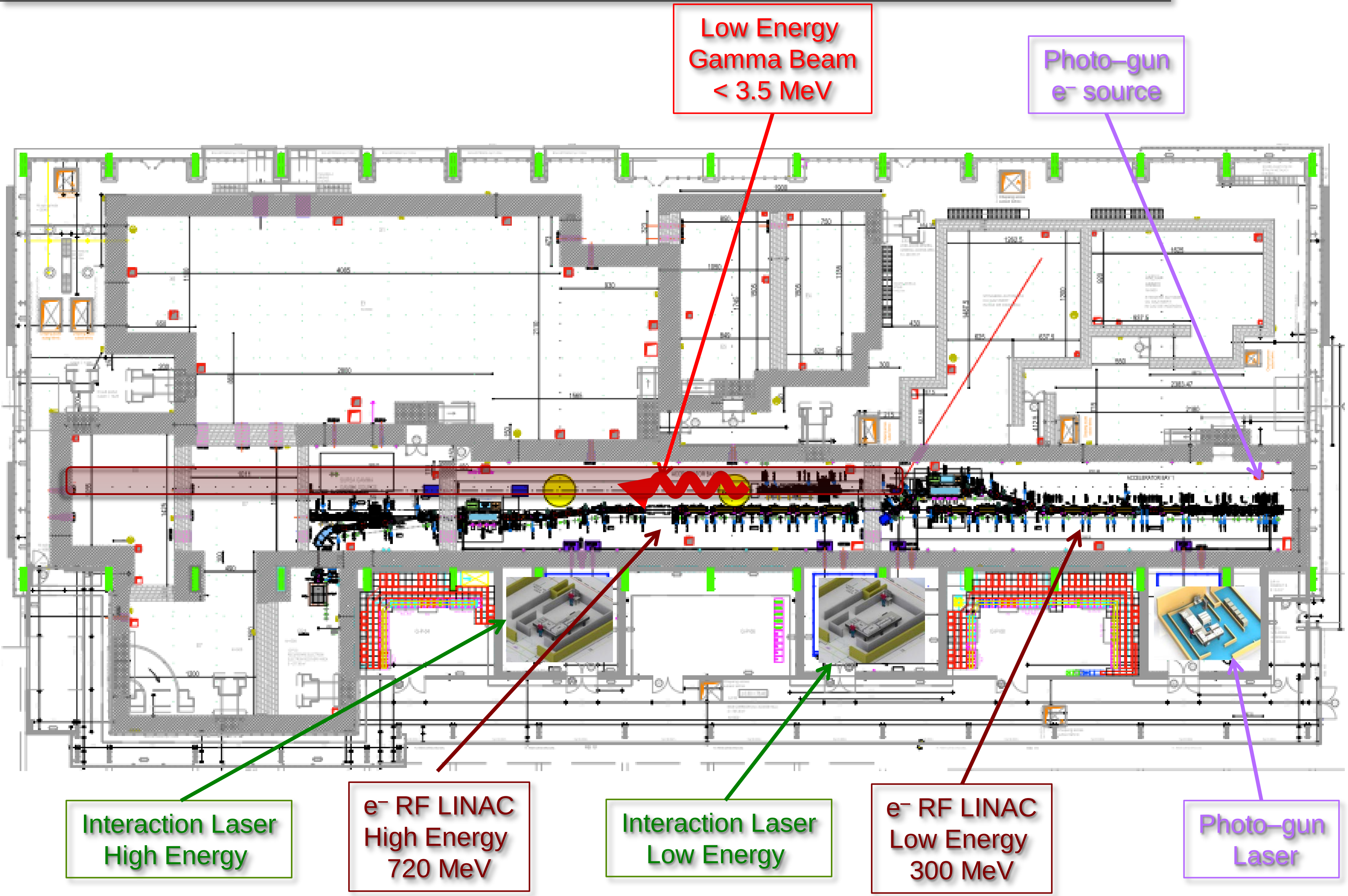
- beam optimization and characterization: energy, intensity, profile

Gamma Beam System Layout

Provider – EuroGammaS Association



Gamma Beam System Layout



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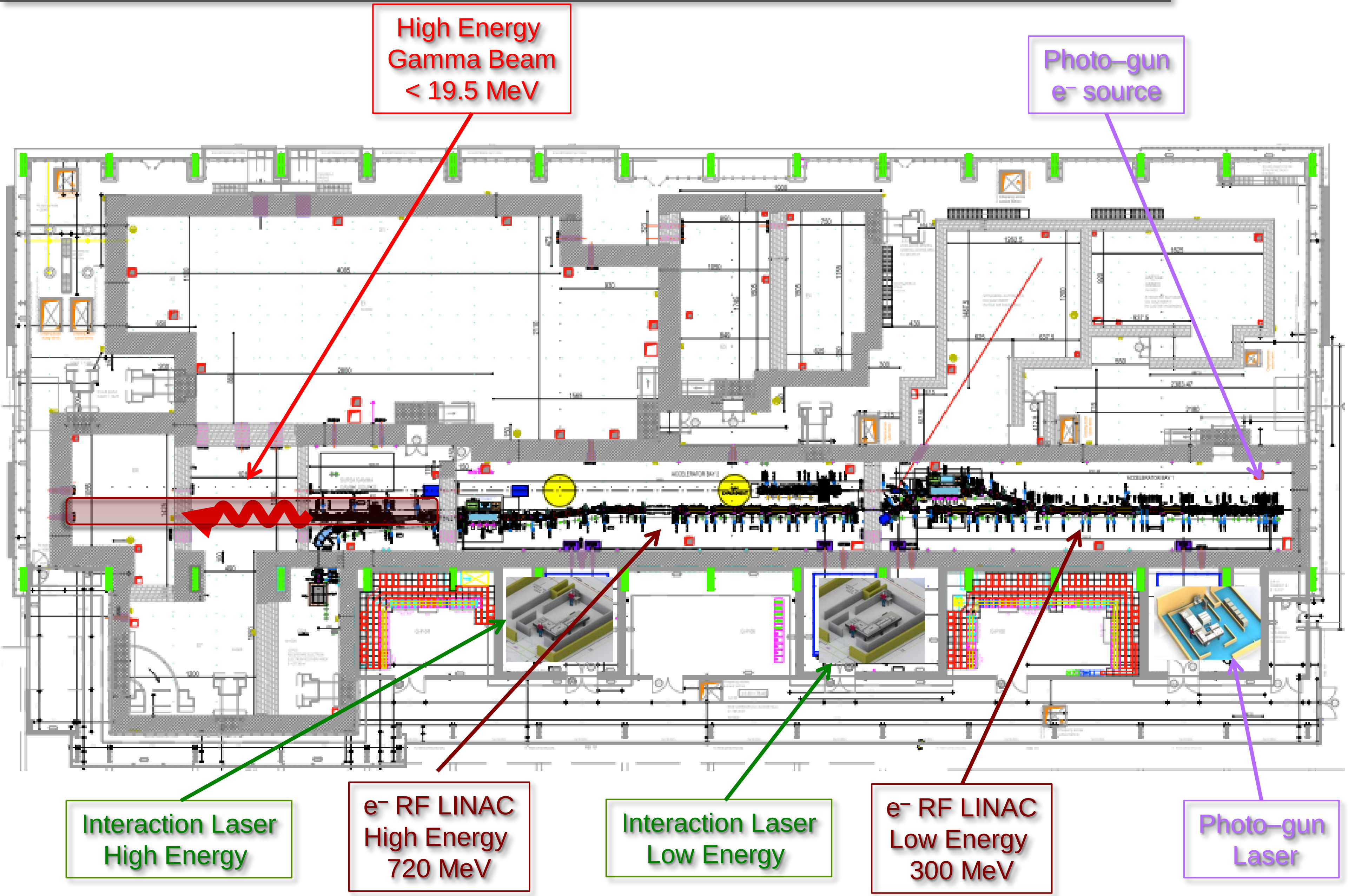


ELI–NP Gamma Beam Features

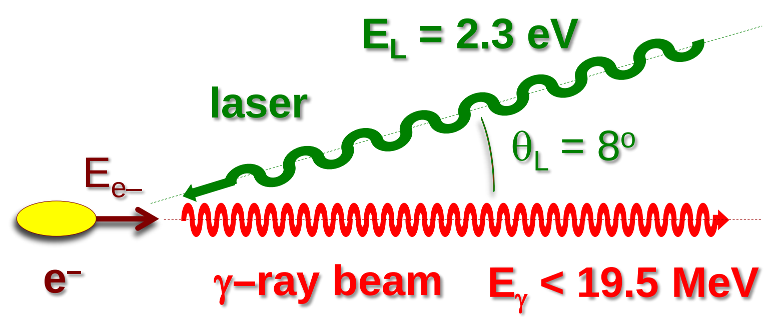
Nuclear Physics

Energy (MeV)	0.2 – 19.5
Spectral Density (ph/s·eV)	$> 0.5 \cdot 10^4$
Bandwidth rms (%)	≤ 0.5
# photons per pulse within FWHM bdw.	$\leq 2.6 \cdot 10^5$
# photons/s within FWHM bdw.	$\leq 8.3 \cdot 10^8$
Source rms size (μm)	10 – 30
Source rms divergence (μrad)	25 – 200
Peak brilliance (N_{ph}/sec·mm²·mrad²·0.1%)	$10^{20} – 10^{23}$
Radiation pulse length rms (ps)	0.7 – 1.5
Linear polarization (%)	> 95
Macro repetition rate (Hz)	100
# pulses per macropulse	32
Pulse–to–pulse separation (nsec)	16

Two stage system:

Low–energy stage: Eγ < 3.5 MeV
March 2017

High–energy stage: Eγ < 19.5 MeV
September 2018



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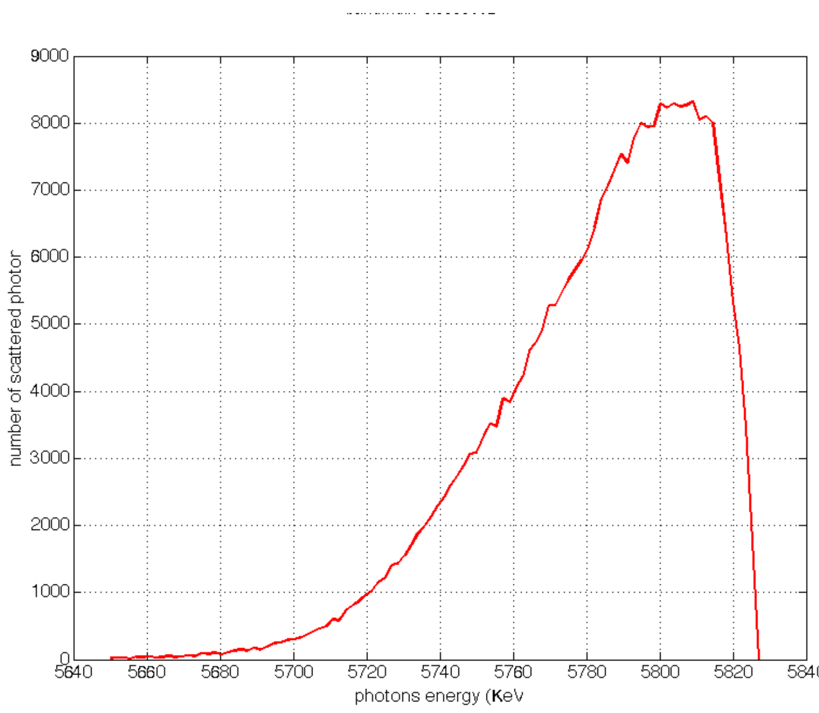

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Two stage system:

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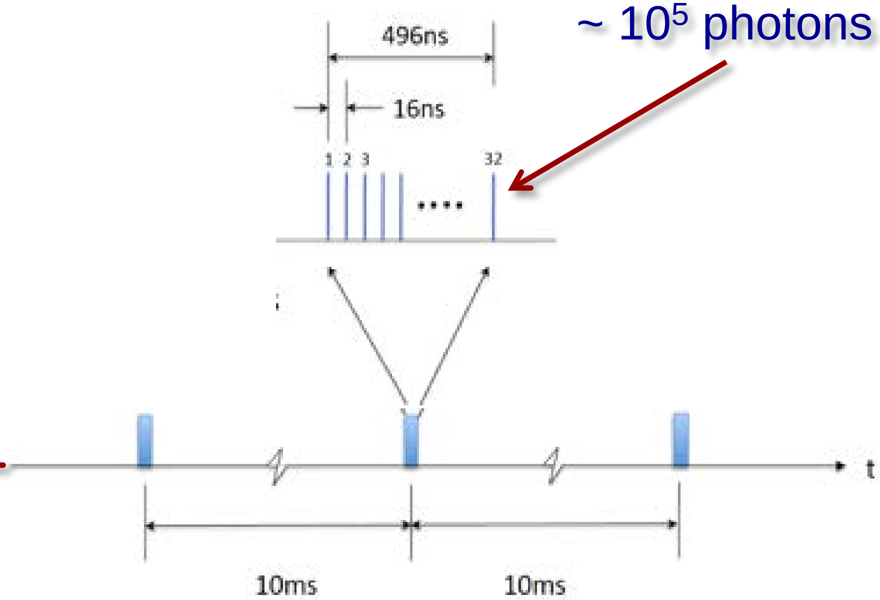
March 2017

High–energy stage: Eγ < 19.5 MeV
September 2018

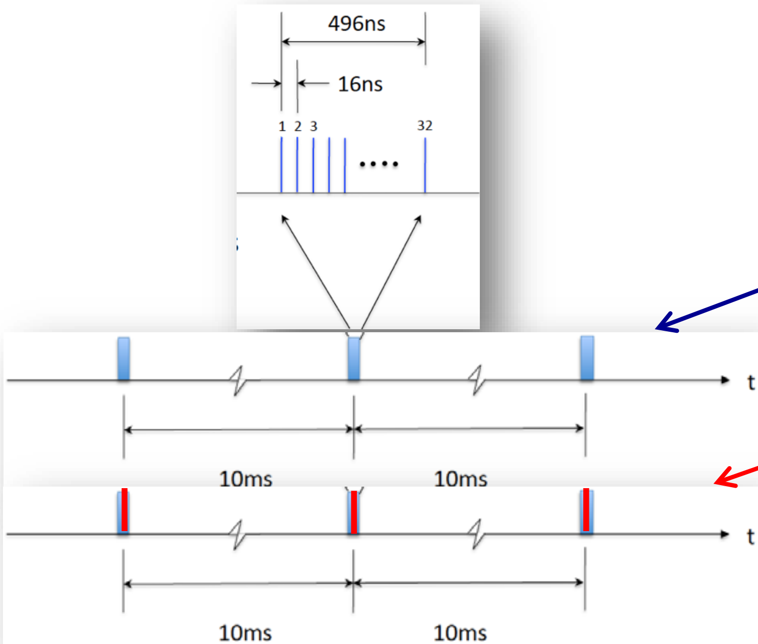
One pulse
~ 1 ps
~ 10^5 photons



Main Components of the Gamma Beam System

Nuclear Physics

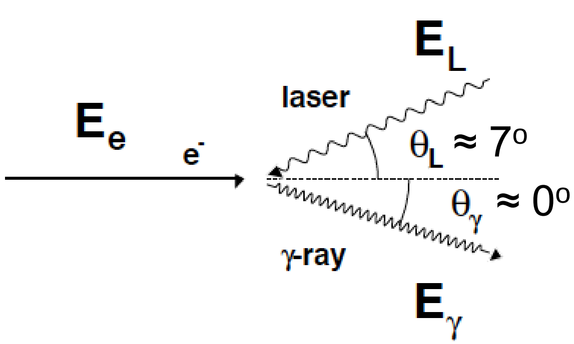
Designed by

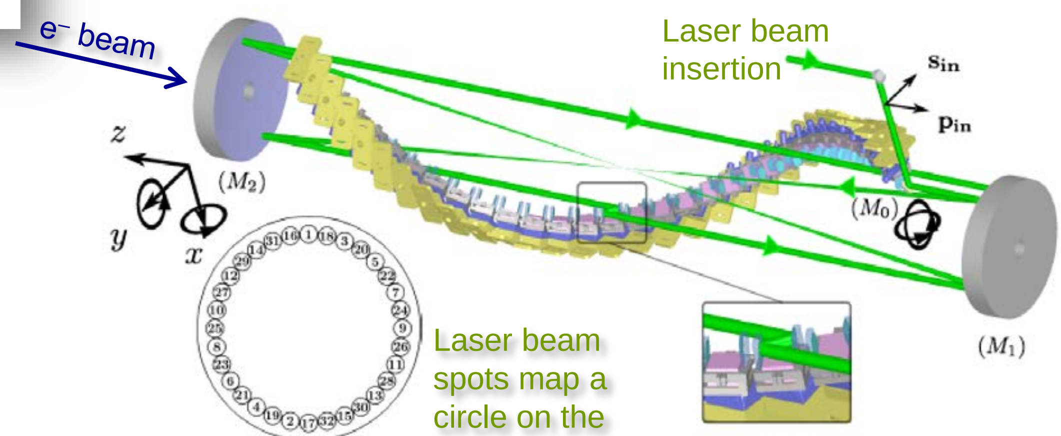


Electrons rep. rate –macropulses 100 Hz
32 micropulses @ 16 ns

Laser rep. rate – 100 Hz → ***laser recirculation***

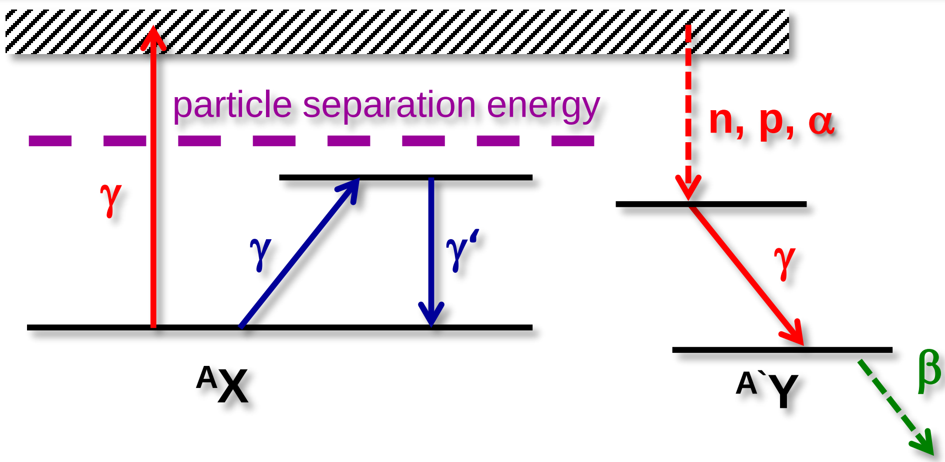
'*Dragon–shaped*' Laser Recirculation





K.Dupraz et al., Phys.Rev. STAB 17 (2014) 033501

Gamma Beam Experiments



Photonuclear Reactions

- Nuclear Resonance Fluorescence
- Photodisintegration, Photofission
- Photoactivation

Fundamental Research

- Nuclear Resonance Fluorescence (γ,γ□) (A.Zilges *U.Cologne*, C.A…
- Nuclear Astrophysics (γ,p) (γ,α) (M.Gai *U.Conn*, O.Tesile…
- Photonuclear Reactions (γ,n) (H.Utsunomiya *U.K*… …Filipescu)
- Photofission&Studies of Exotic Nuclei (A… …brahim *IPN Orsay*, D.L.Balabanski)

Applications

- Gamma I…
- Material … …schmidt *TU Munich*, N.Djourelov)
- Medical R… …c *IFIN-HH Bucharest*, M.Bobeica)

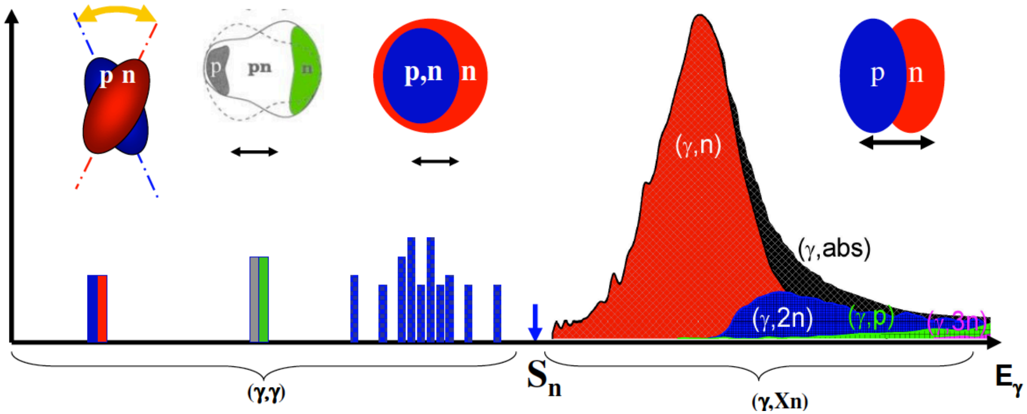
R&D Gamma … Diagnostics Detectors

- 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,
………

Nuclear Resonance Fluorescence

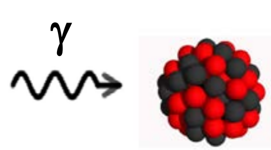
Electromagnetic dipole response of nuclei

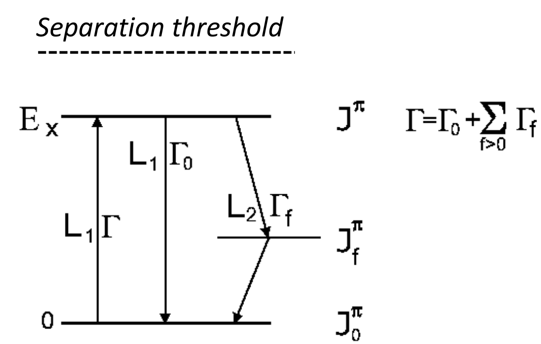


- Photoresponse of weakly abundant p–nuclei and actinides
- Rotational 2+ states of the nuclear scissor modes
- Pygmy Dipole Resonances
- Γ_0 and Γ/Γ_0 measurements

Access to nuclear observables – model independent

- Excitation Energy E_r
- Spin and parity J, π
- Decay Energies E_γ
- Partial Widths Γ_i/Γ_0
- Multipole Mixing δ
- Decay Strengths $B(\pi\lambda)$
- Level Width Γ (eV)

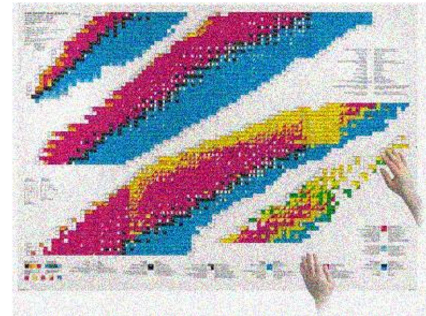




New Discovery Frontiers for NRF at ELI–NP

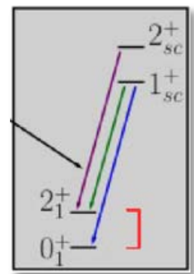
Availability frontier

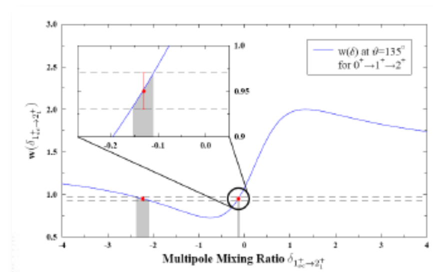
- access to rare isotopes
- photoresponse of weakly abundant p–nuclei and actinides



Sensitivity frontier

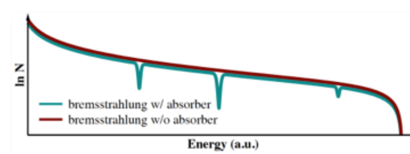
- weak channels
- rotational 2+ states of the nuclear scissor modes

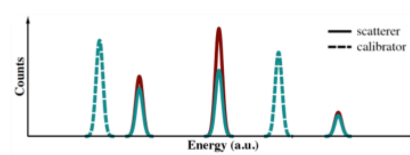




Precision frontier

- high statistics
- Γ_0 and Γ/Γ_0 measurements



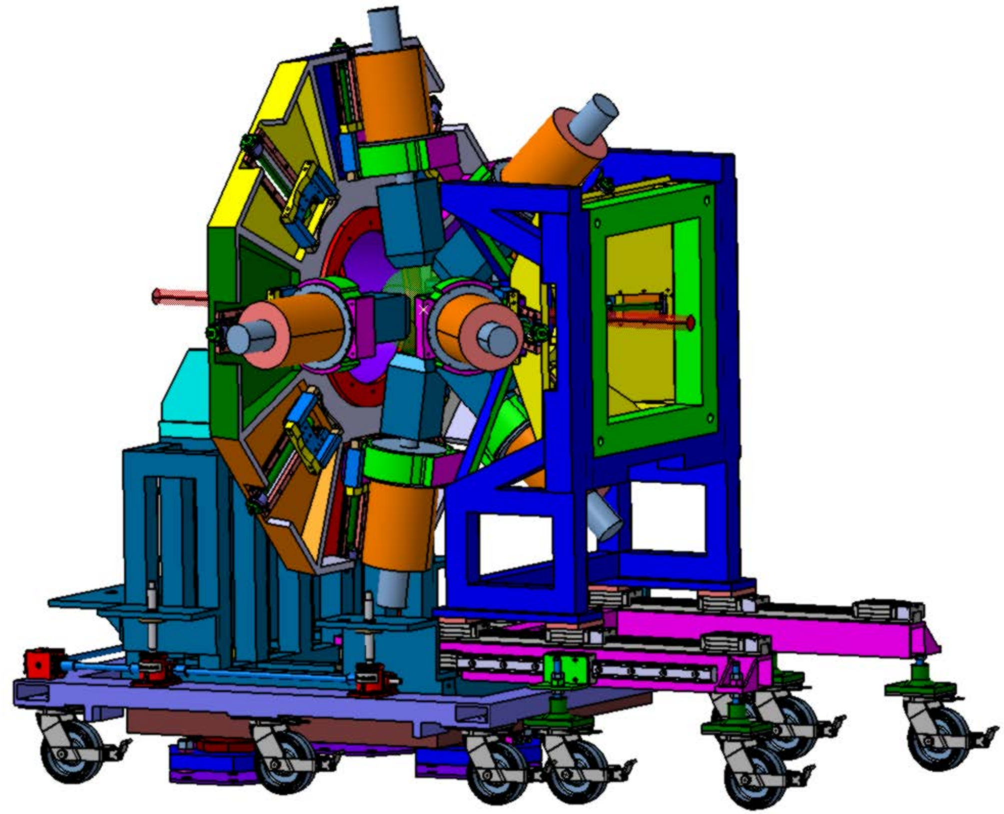


Nuclear Resonance Fluorescence

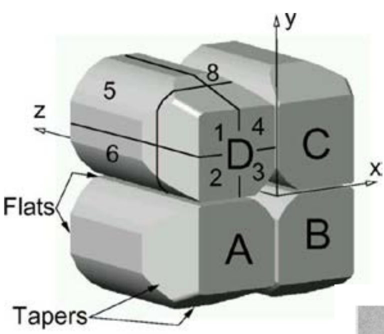
Instrumentation:

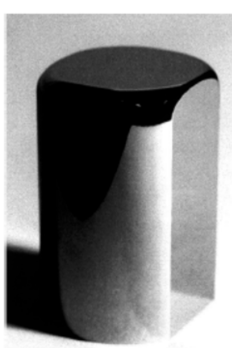
ELIADE = **ELI**–NP **A**rray of **DE**tectors

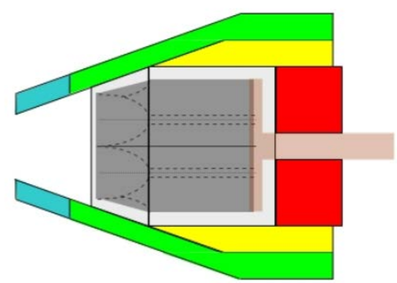
- 8 x TIGRESS – type Clover detector (*segmented*) with back–catcher (ε_{ph} ~ 6%)
- 4 x 3”x3” $LaBr_3$(Ce) detectors
- Digital DAQ



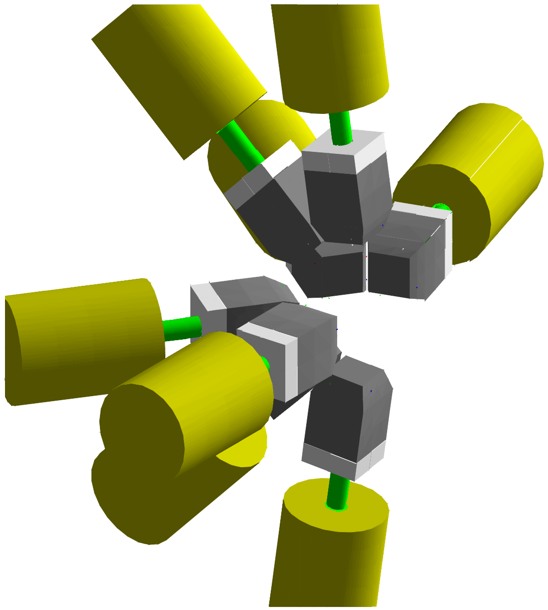
CAD : C.Petcu and E.Udup







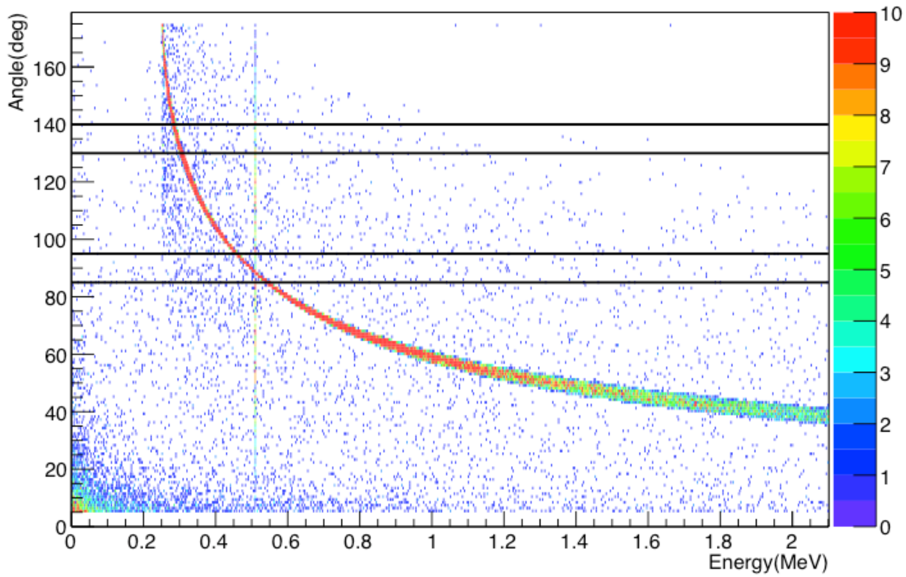
The ELIADE Array – Background Reduction



GEANT4: G.Suliman

Background radiation in the detectors

- **Compton scattering of the beam**



- **511 keV from positrons annihilation**

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

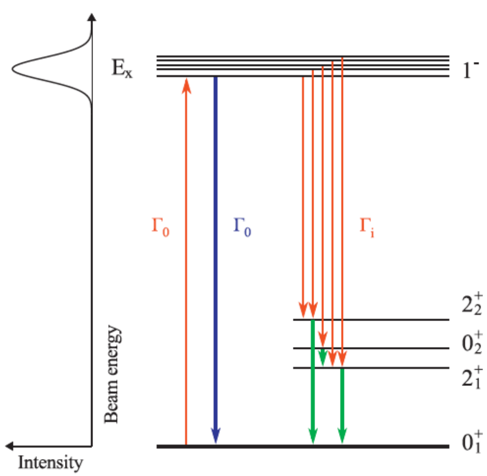
HIγS @ Duke U.

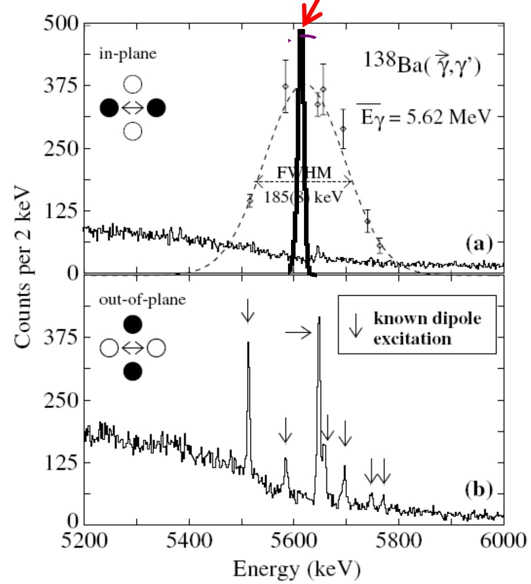
- Relative bandwidth ~ few percent
- Spectral density ~ 10^2 ph/s/eV

ELI–NP @ Magurele

- Relative bandwidth ~ few per mille
- Spectral density ~ 10^4 ph/s/eV

ELI–NP
/1000





N.Pietralla et al.

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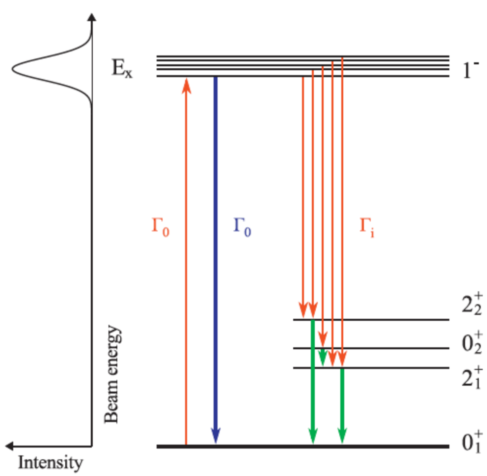

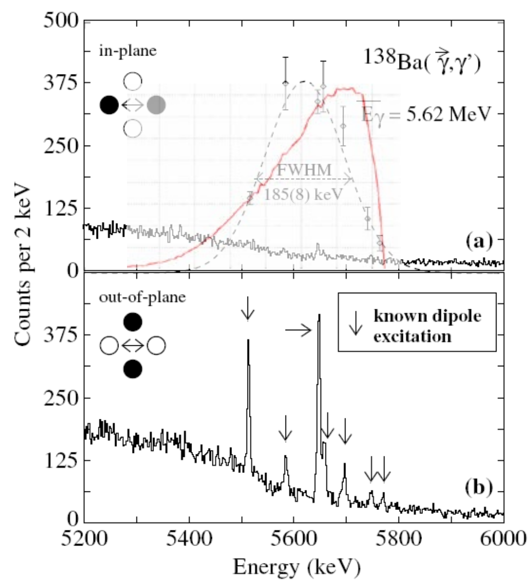

N.Pietralla et al.

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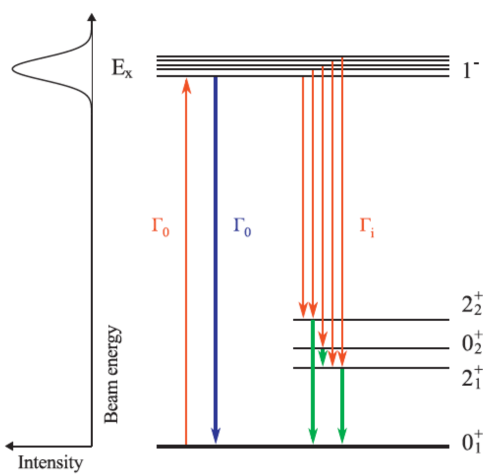
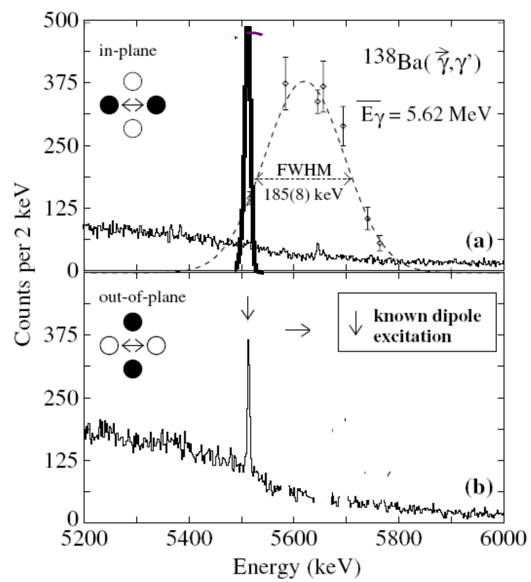


N.Pietralla et al.



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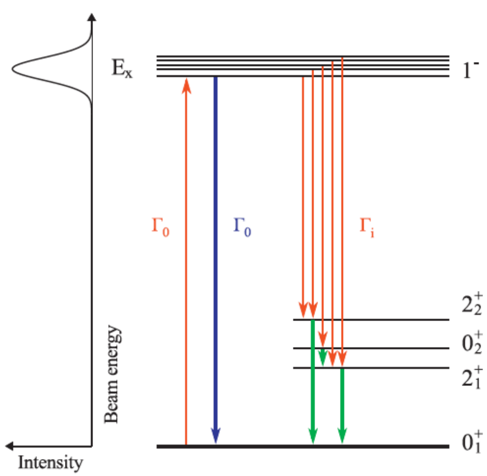

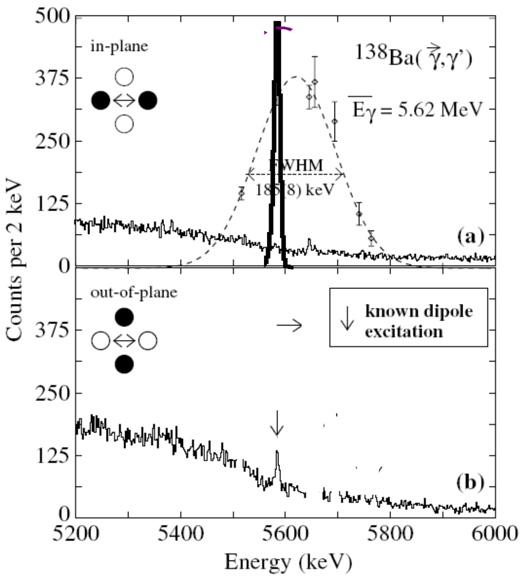

N.Pietralla et al.

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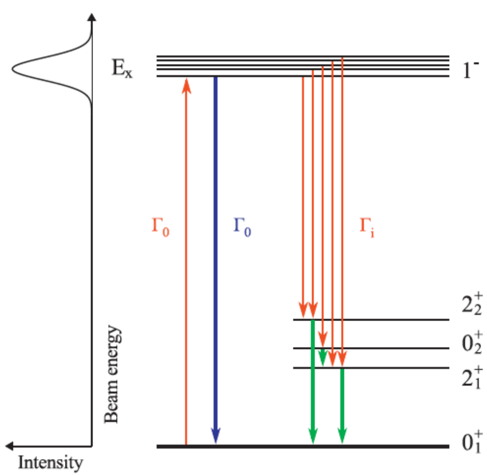

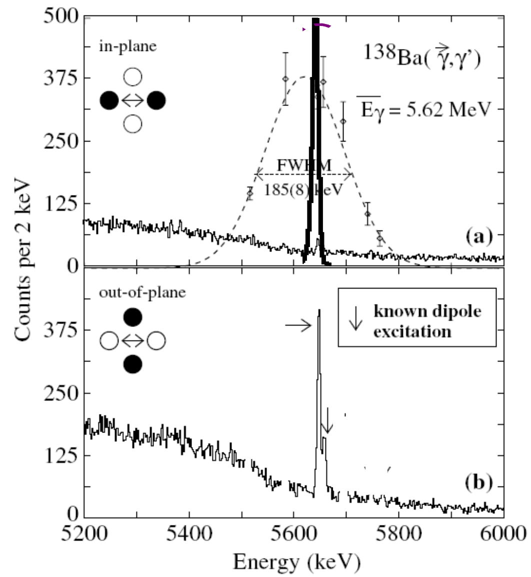

N.Pietralla et al.

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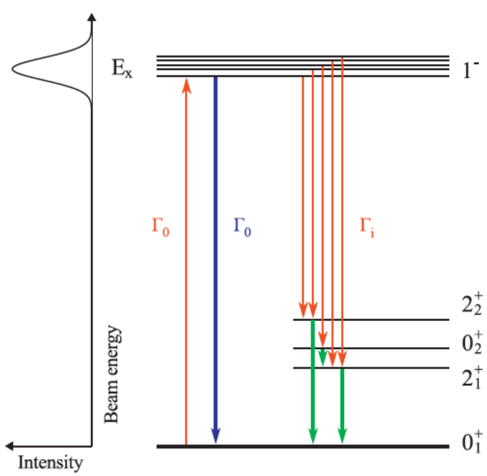

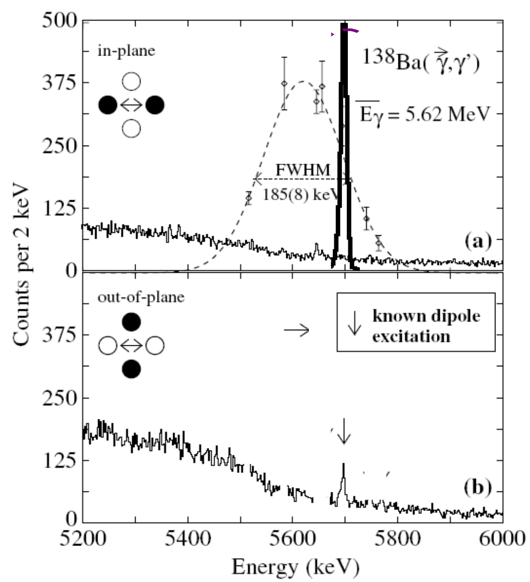

N.Pietralla et al.

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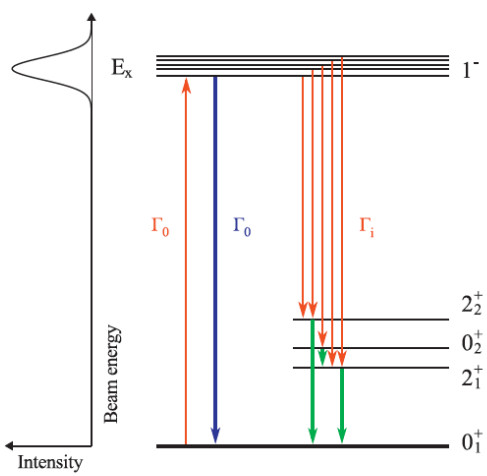
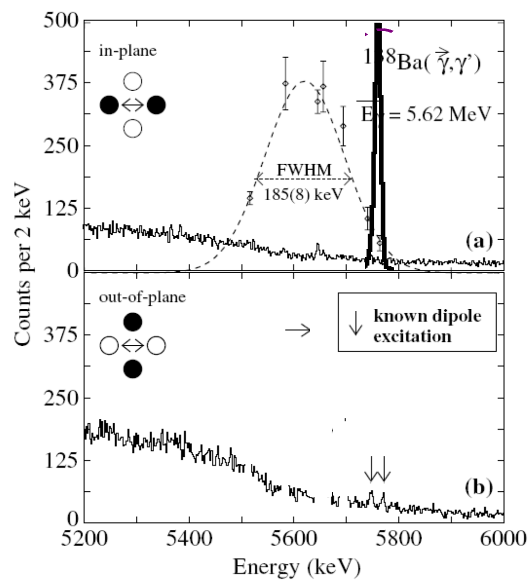


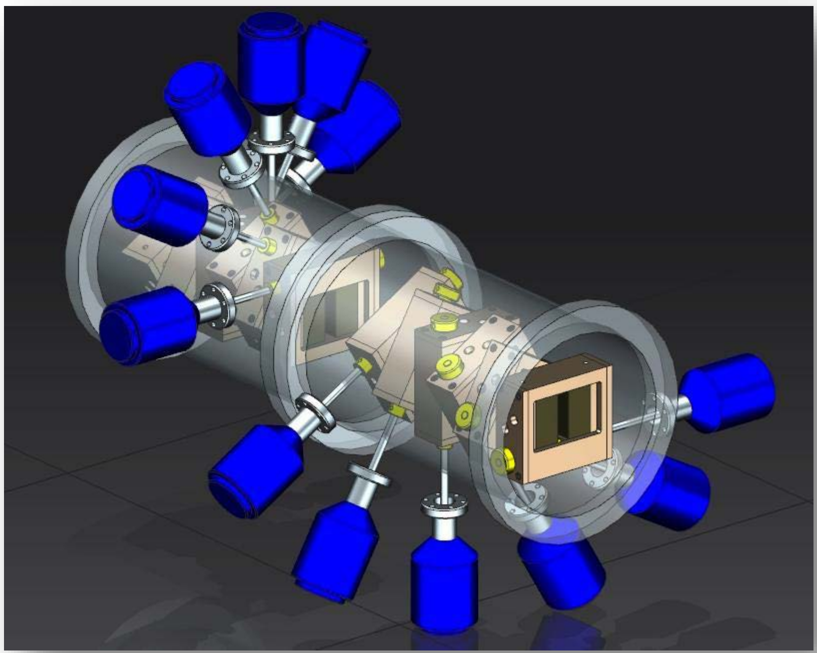


N.Pietralla et al.

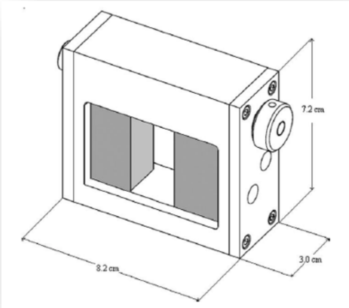
Gamma Beam Collimator System

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

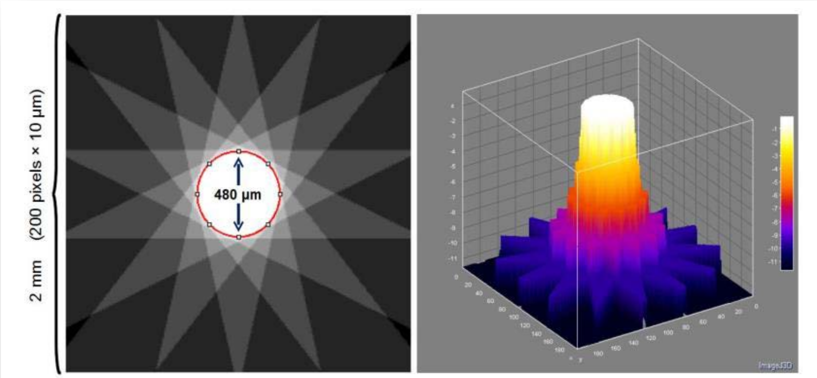


Collimation aperture varies from 20 mm to less than 1 mm, depending on the beam energy



Tungsten slits – 20 mm thick

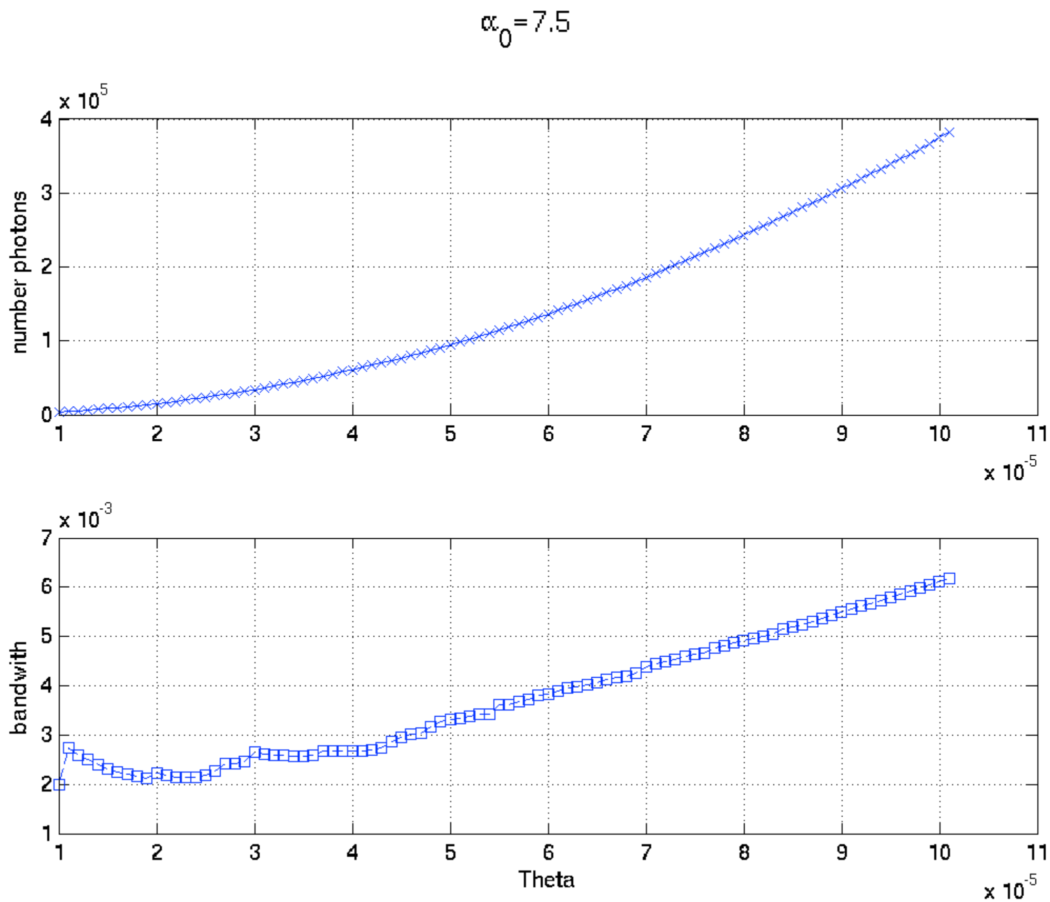
14 independent slits with 25.7º relative angle

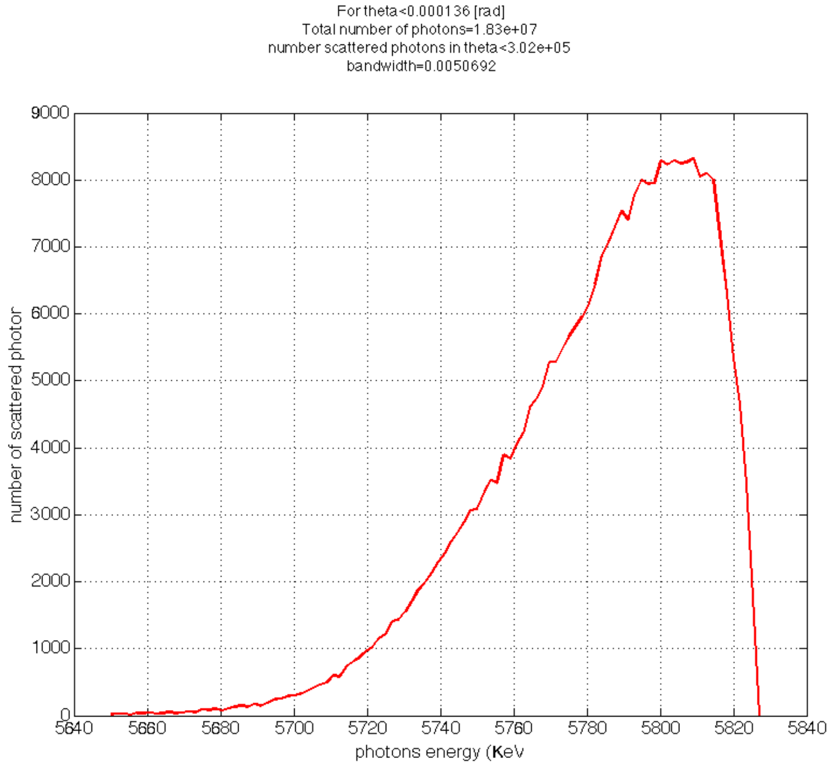


Simulated radiography of the collimator assembly ($\log_{10}$ pixel values)

3D plot

Gamma Beam Collimator System



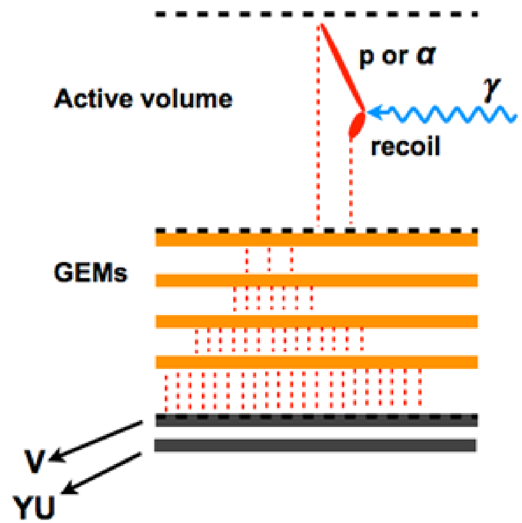


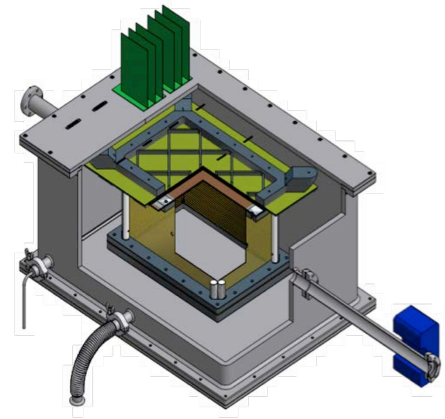
CAIN code for ICS

L.Serafini, I.Drebot

Nuclear Astrophysics

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



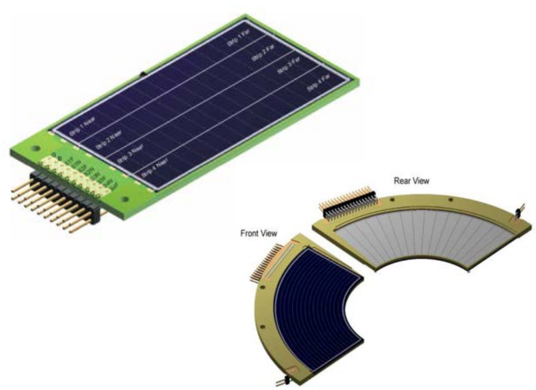


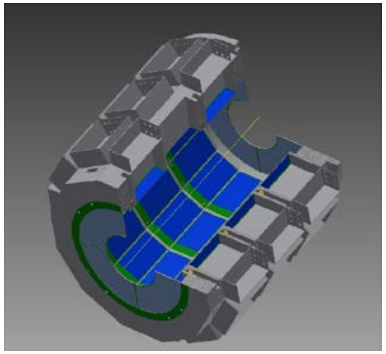
U.Warsaw

C.Mazzocchi – yesterday talk

Instrumentation:

- eTPC (35x20x20 cm^3)
- Large–area Si DSSD array

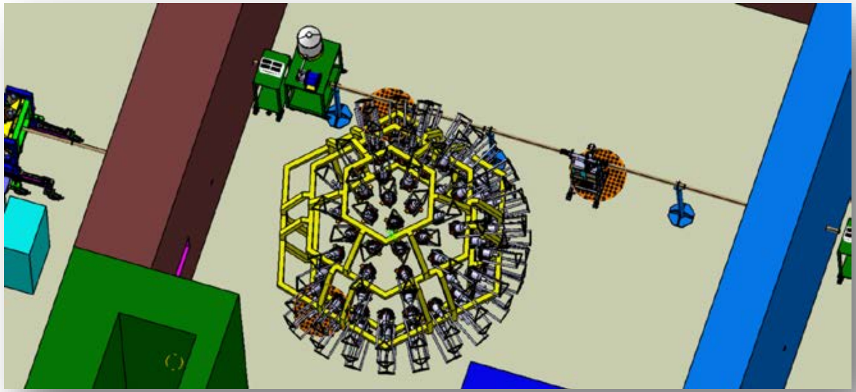


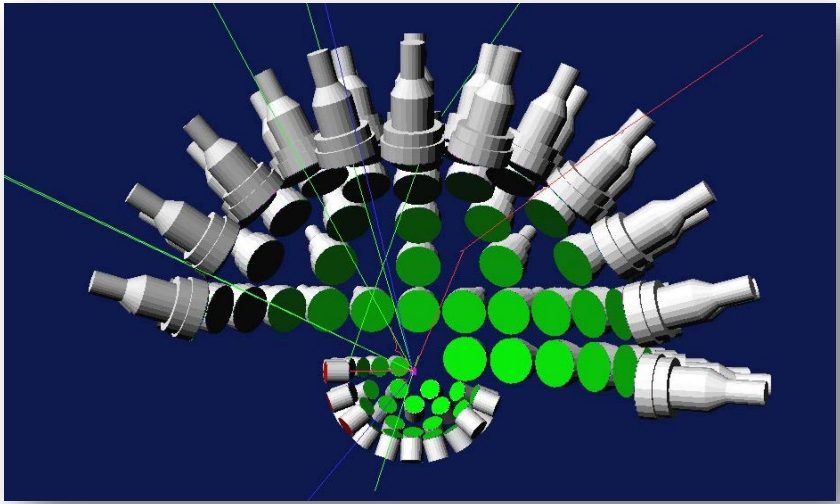


INFN LNS Catania

Gamma Above n Threshold

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





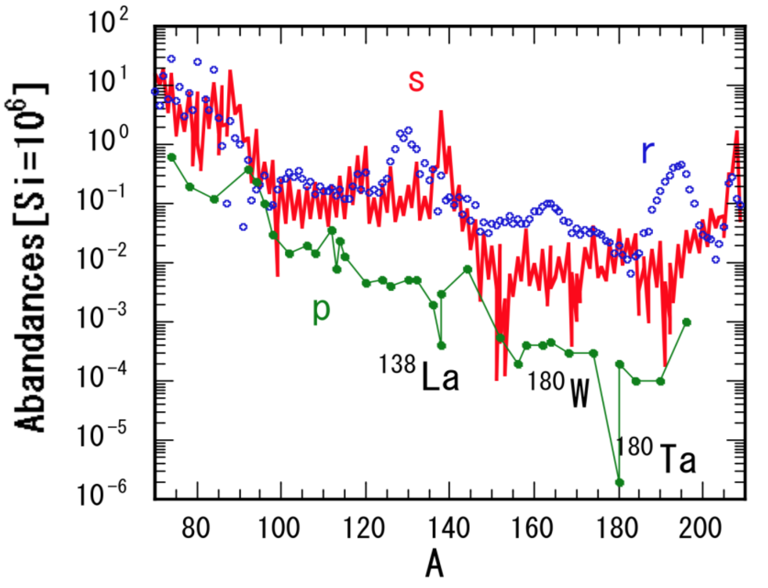
<u>Instrumentation:</u>

- $LaBr_3$(Ce) / $CeBr_3$ array (34 or 68))
  – high–energy gamma rays
- ^{6}Li–glass detectors and NE213 liquid scintillator array (34)
  – neutrons

INFN and U. Milano

Gamma Above n Threshold

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



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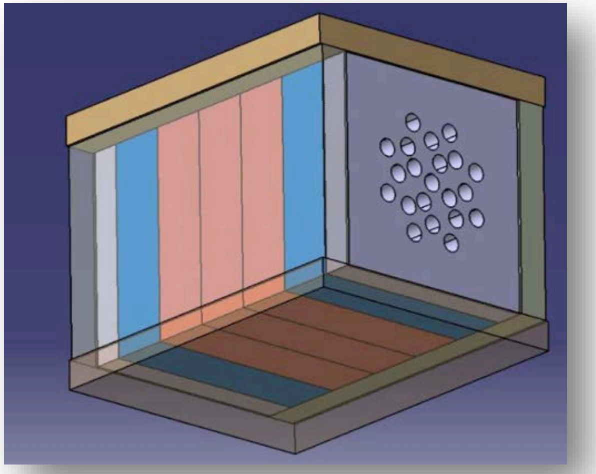
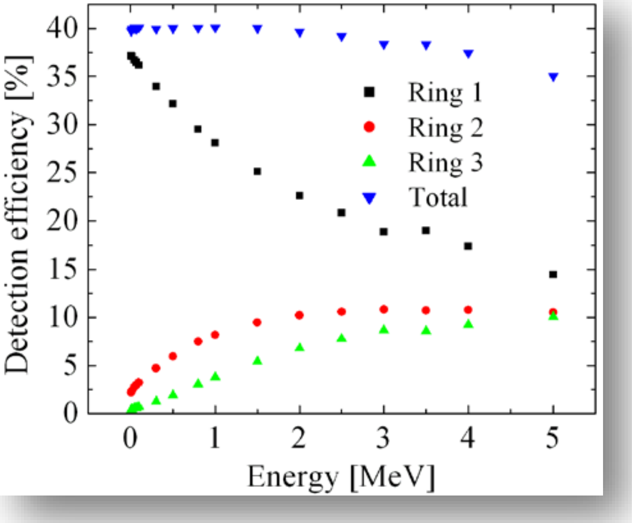




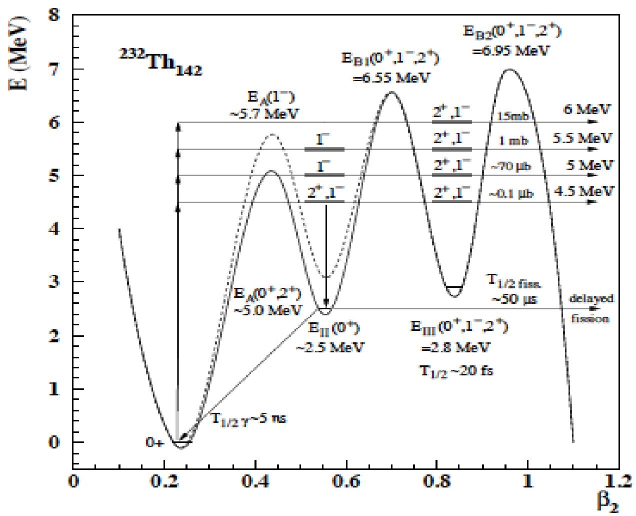
Instrumentation:

- ^{3}He neutron counter array
  - Embedded in polyethylene
  - 3 rings ➛ 'flat' efficiency response

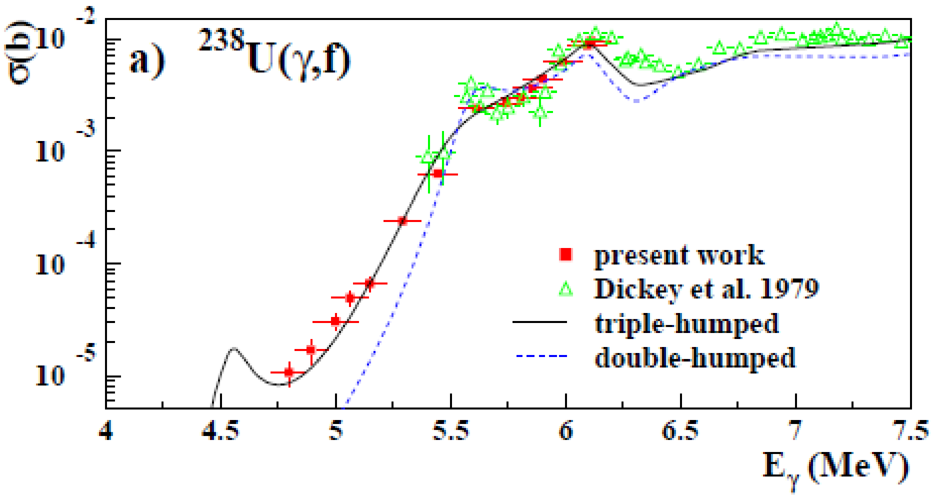
Konan U.

Photofission

- Studies in the 2nd and 3rd 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



P.G.Thirolf and D.Habs, Prog. Part. Nucl. Phys. 49, 245 (2002)



(γ,f) experiment at HIγS: Csige et al., Phys. Rev. C 87, 044321 (2013)

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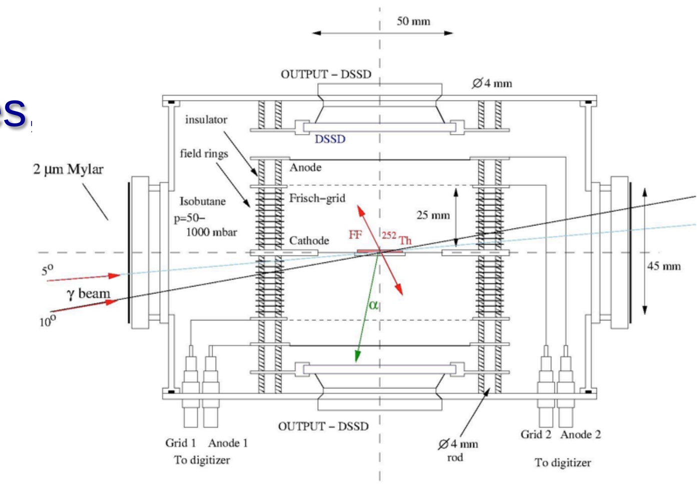
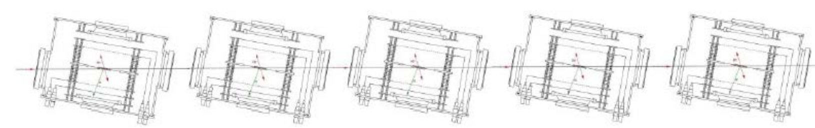


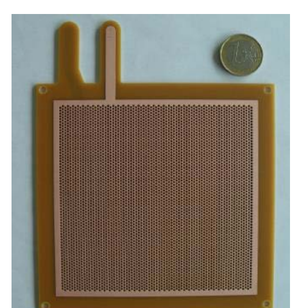


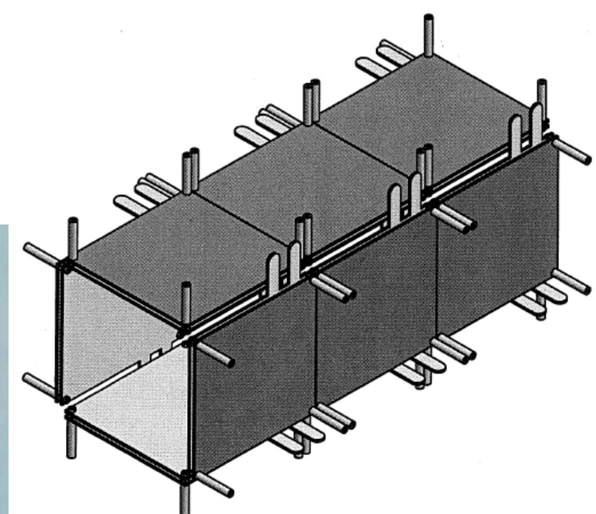
Instrumentation:

➢ System of multi–target Frisch–gridded twin ionization chambers and DSSD detectors

➢ Array of 12 x THGEM detectors

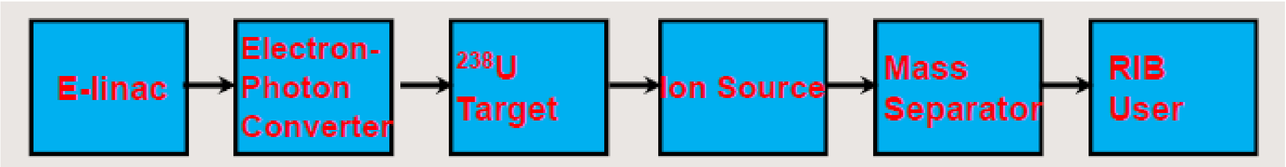
ATOMKI, Debrecen





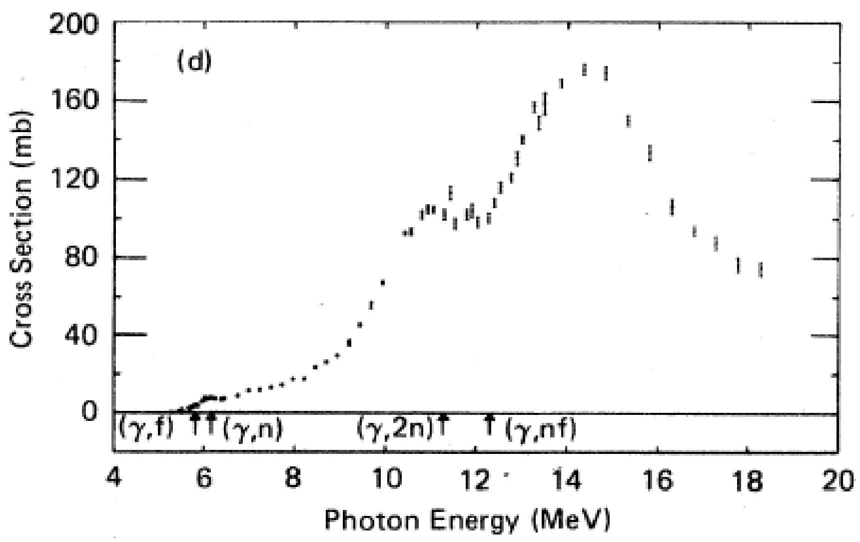
Photofission and Exotic Nuclei

ALTO, ARIEL, etc.



Photofission cross section for ^{238}U

Caldwell et al., Phys. Rev. C 21 (1980) 1215



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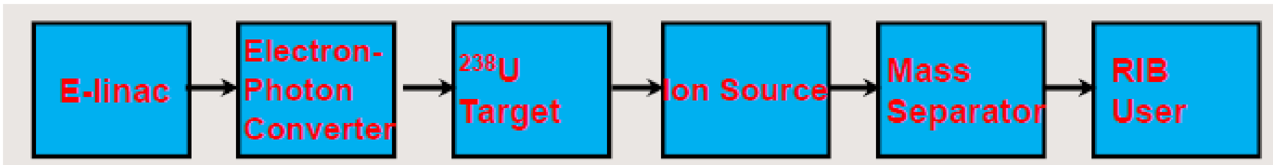
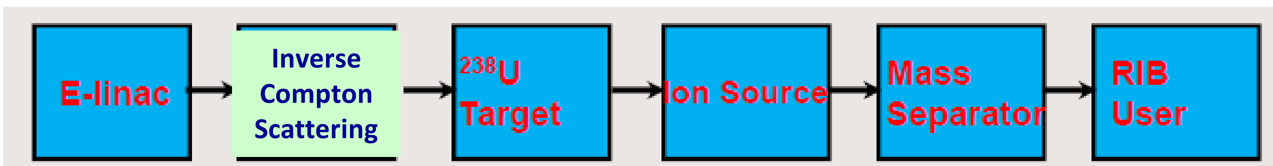


ELI-NP



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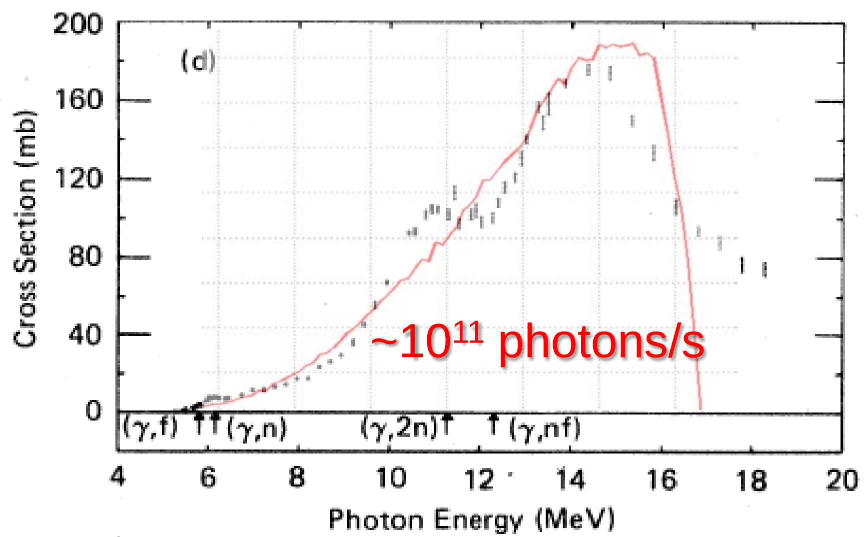
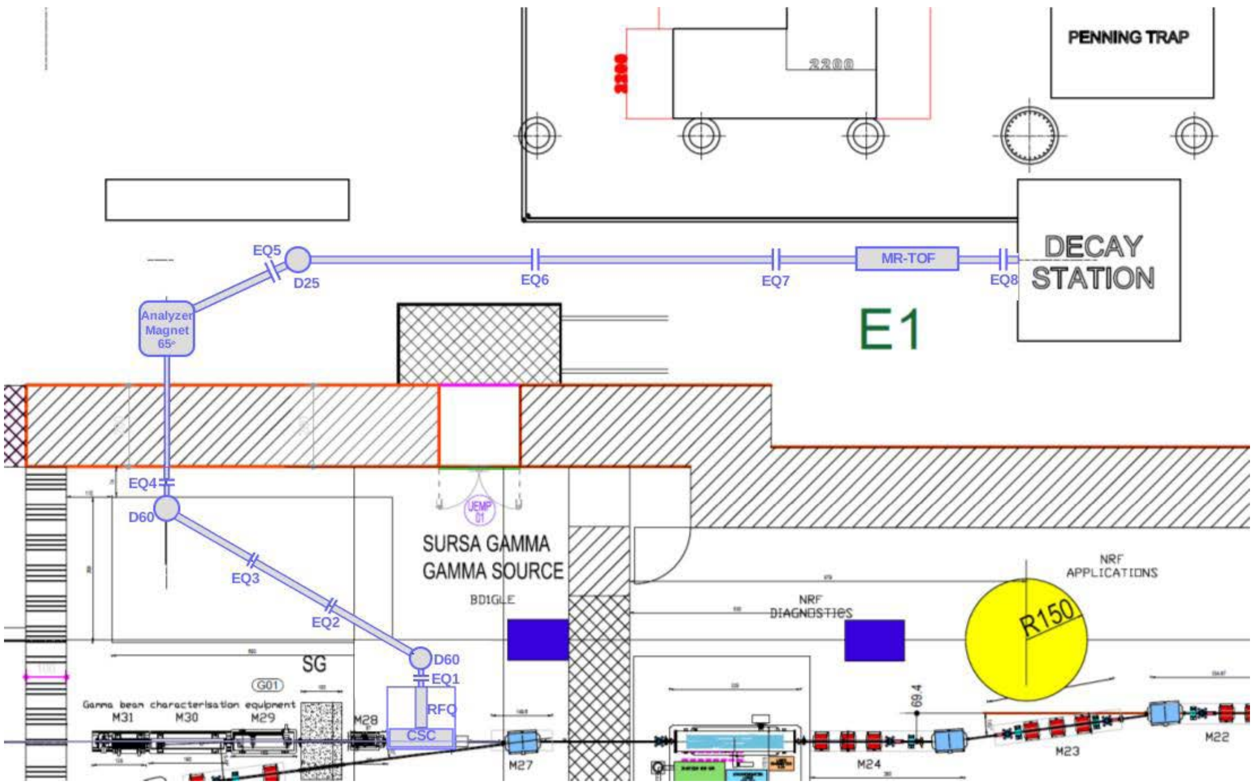


IGISOL Setup

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}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

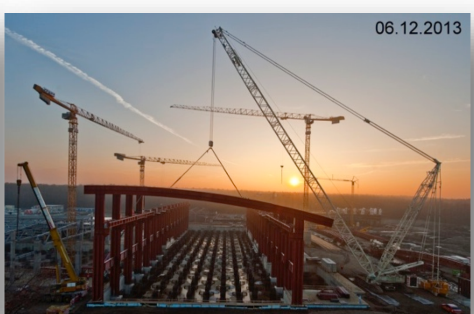
- a new nuclear physics research facility is being constructed at Bucharest
  - systems with features beyond state–of–the–art : **HPLS and GBS**

➞ 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
    - http://www.eli-np.ro/jobs.php



EUROPEAN UNION

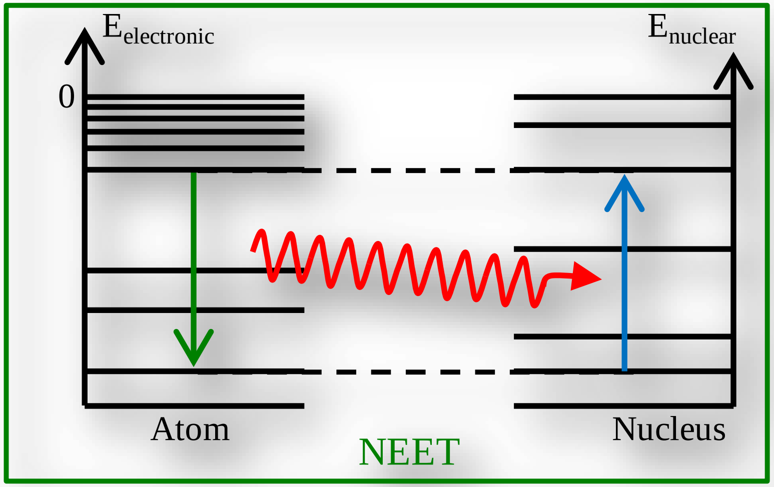
GOVERNMENT OF ROMANIA

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

Project co-financed by the European Regional Development Fund

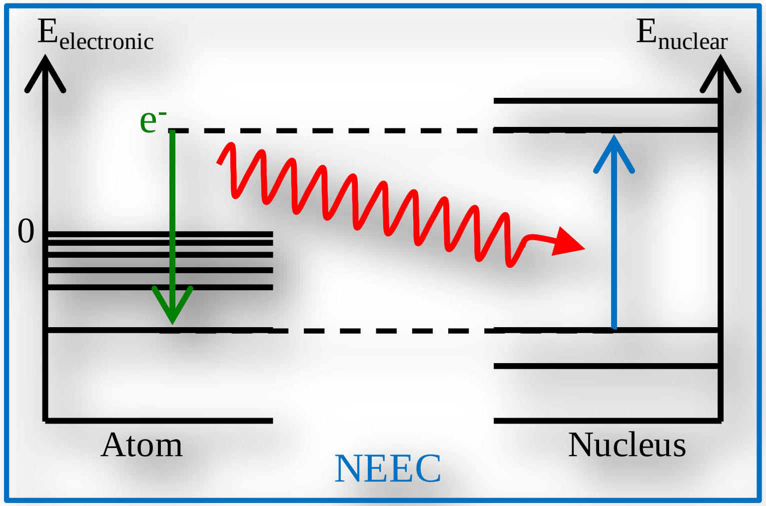
Laser Driven Nuclear Physics

Nuclear (de–)excitations in plasma

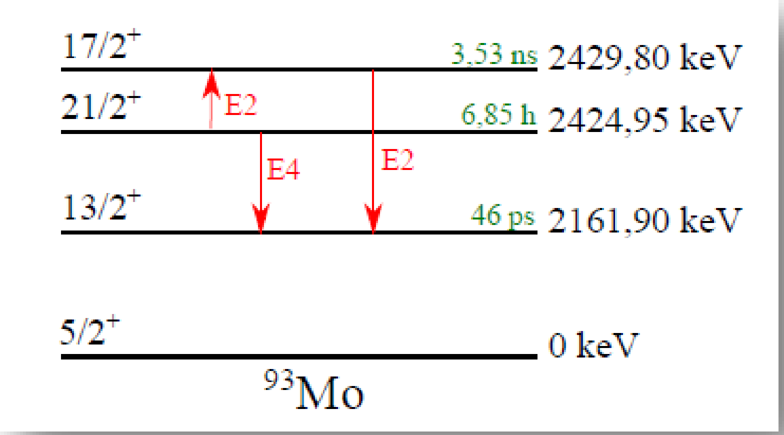


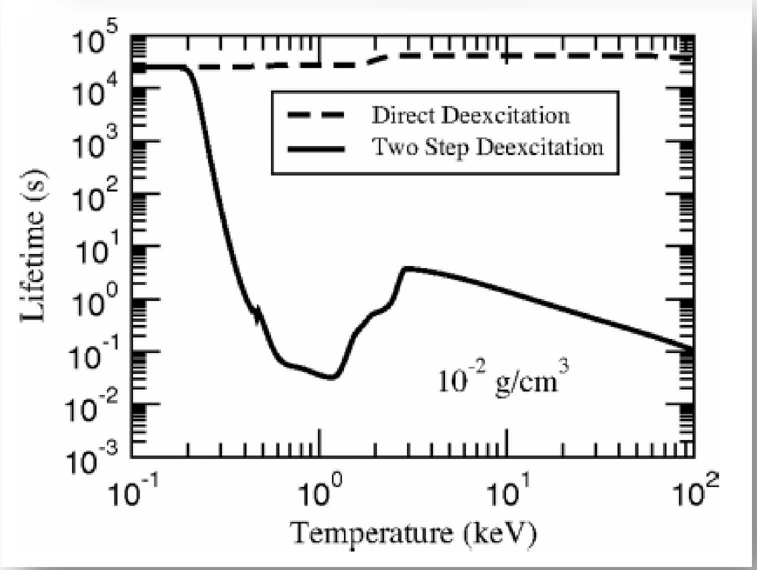
NEET observed in cold targets. Never observed in plasma.

NEEC was never observed



Significant changes in lifetimes are predicted in plasma conditions:

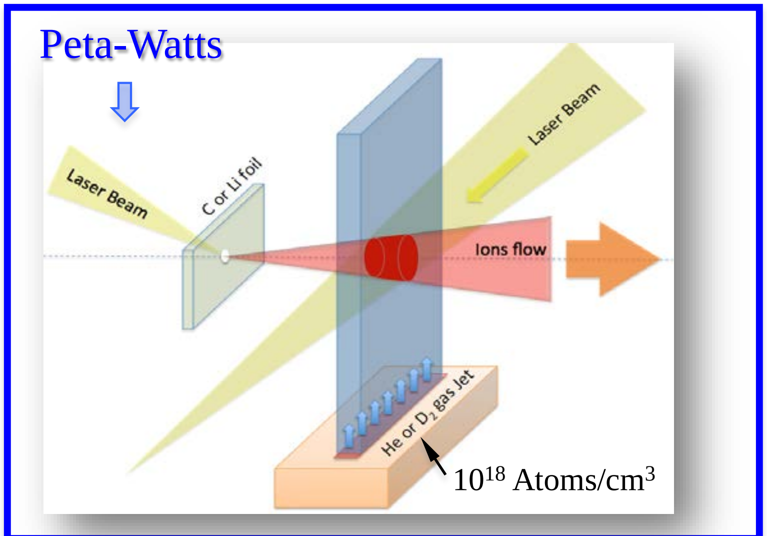


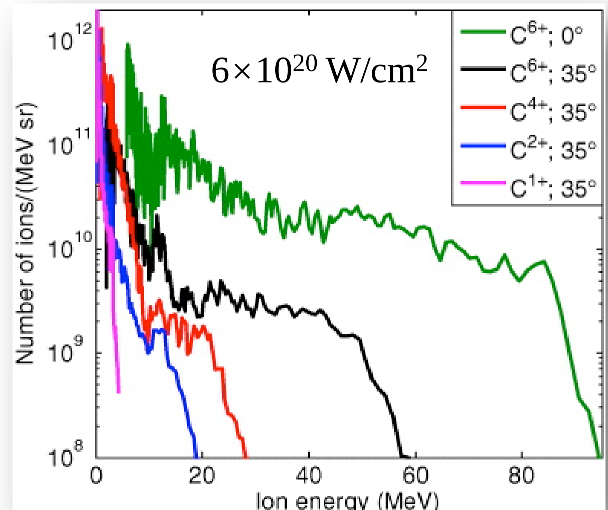


F. Hannachi (CENBG/IN2P3) et al.

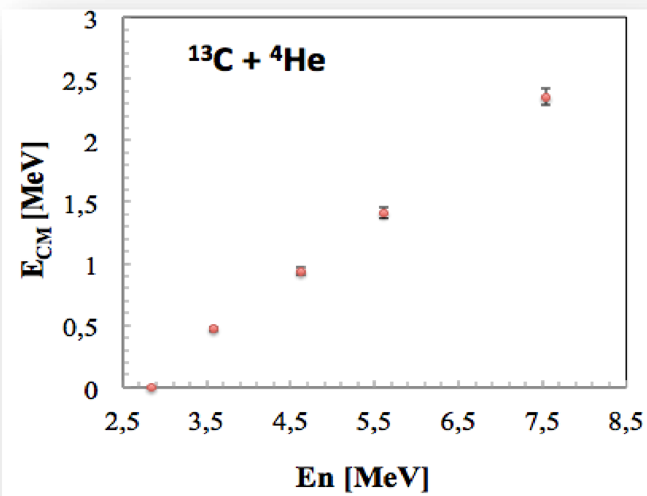
Laser Driven Nuclear Physics

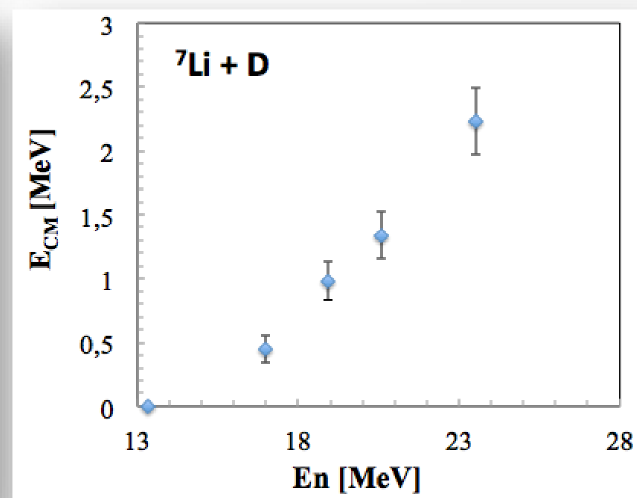
Study of screening factor – The method and cases





D.C. Carrol et al., New J. of Phys. 12 (2010) 045020





The method requires measuring high energy neutrons

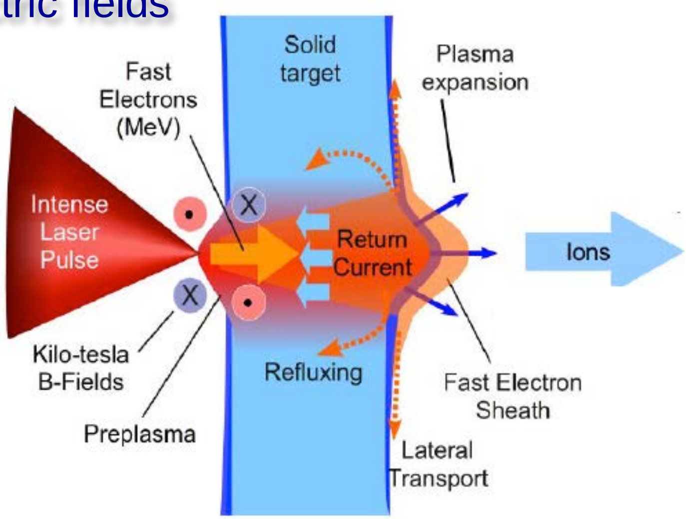
S. Tudisco (LNS/INFN) et al.

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)

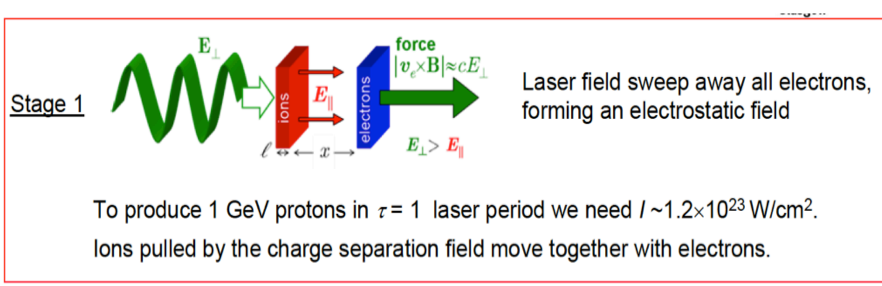
- Conversion of laser radiation into kinetic energy of relativistic electrons in μm thick targets
- Electrons move and recirculate through the solid target and appear at the surfaces where give rise to intense longitudinal electric fields



Radiation Presure 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



P.McKenna, CETAL Workshop, Bucharest, Nov. 19, 2013

Materials in Extreme Environments

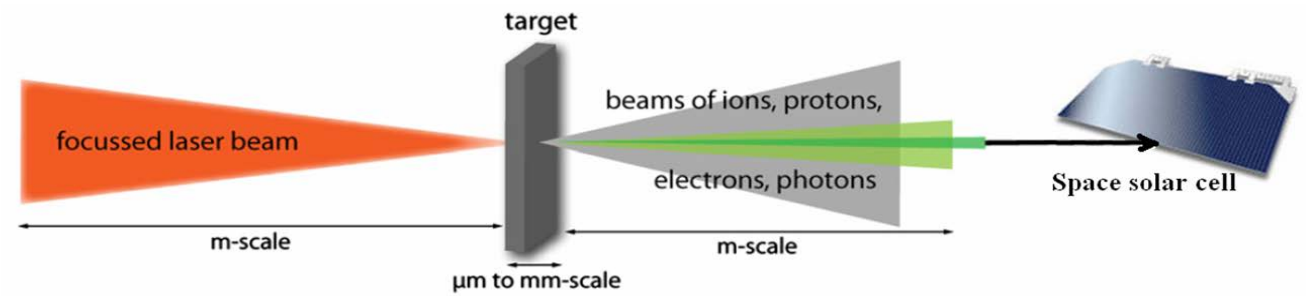
Convener: Marilena Tomut (GSI) *ELI-NP Liaison T. Asavei*

* 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



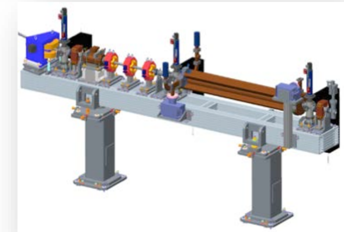
* Biological science research

- radiation effects on bio-molecules & cells

* Testing and developments of detectors

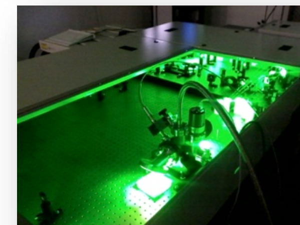
* Irradiated optical components testing, Materials for fusion energy systems

Main Components of the Gamma Beam System



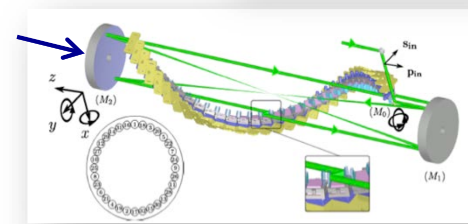
1) *Warm electron RF Linac* (innovative techniques)

- 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)



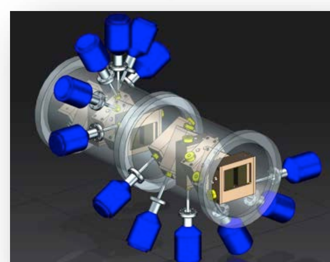
2) *High average power, high quality J–class 100 Hz ps Collision Laser*

  - state–of–the–art cryo–cooled Yb:YAG (200 mJ, 2.3 eV, 3.5 ps)
  - two lasers (one for low–E_γ and both for high–E_γ)



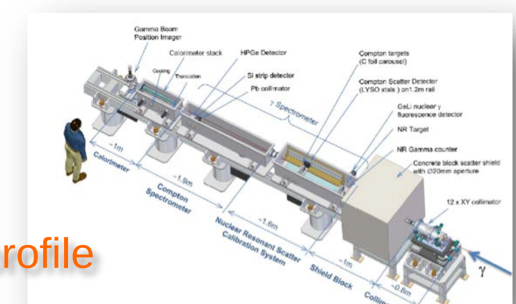
3) *Laser circulation with μm and μrad and sub–ps alignment/synchronization*

  - 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 $< 5 \times 10^{-3}$



5) *Gamma beam diagnostic system*

  - beam optimization and characterization: energy, intensity, profile

Photogun Laser

Photocathode Laser

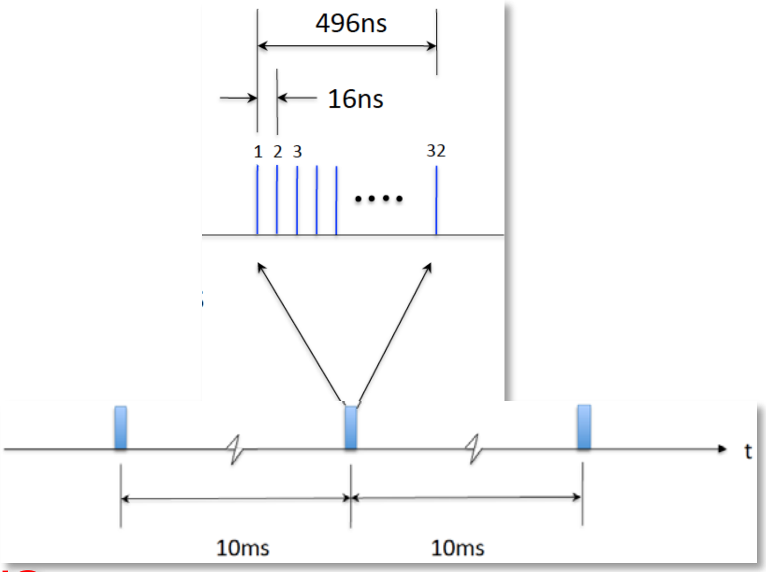
based on Ti:Sa amplifier
cryo–cooled
@ 100 Hz

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

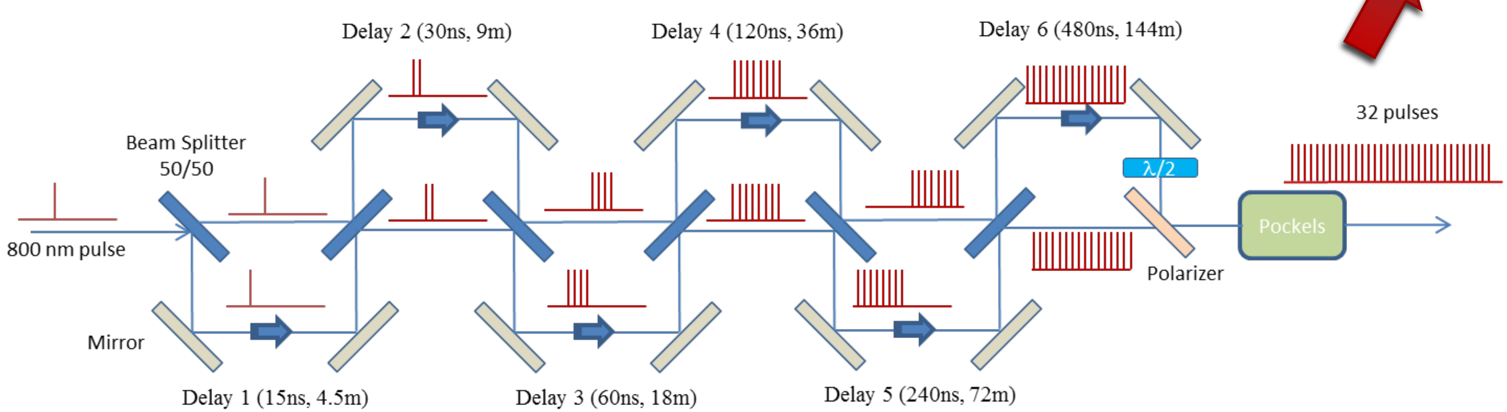
Output: UV (266 nm)
> 3 mJ , 32 pulses

producing 32 replica (before the last amplifier)

Time structure of the electron beam



MULTIBUNCHING

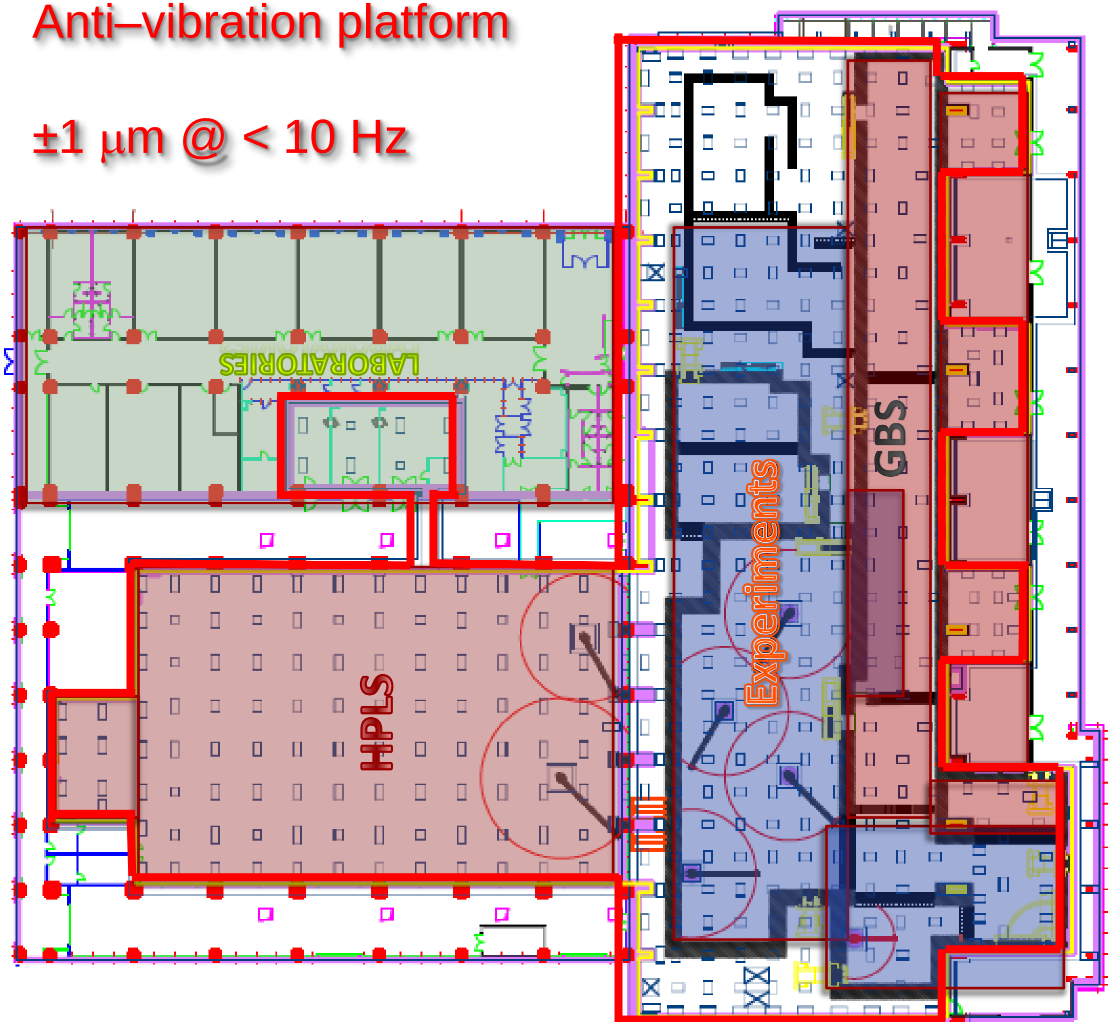


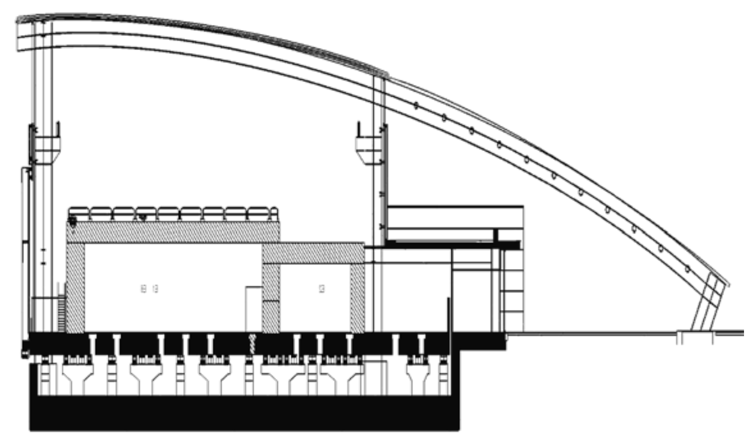
TDR – arXiv:1407.3669 [physics.acc-ph]

ELI–NP – Experimental Building Layout

Anti–vibration platform

±1 μm @ < 10 Hz

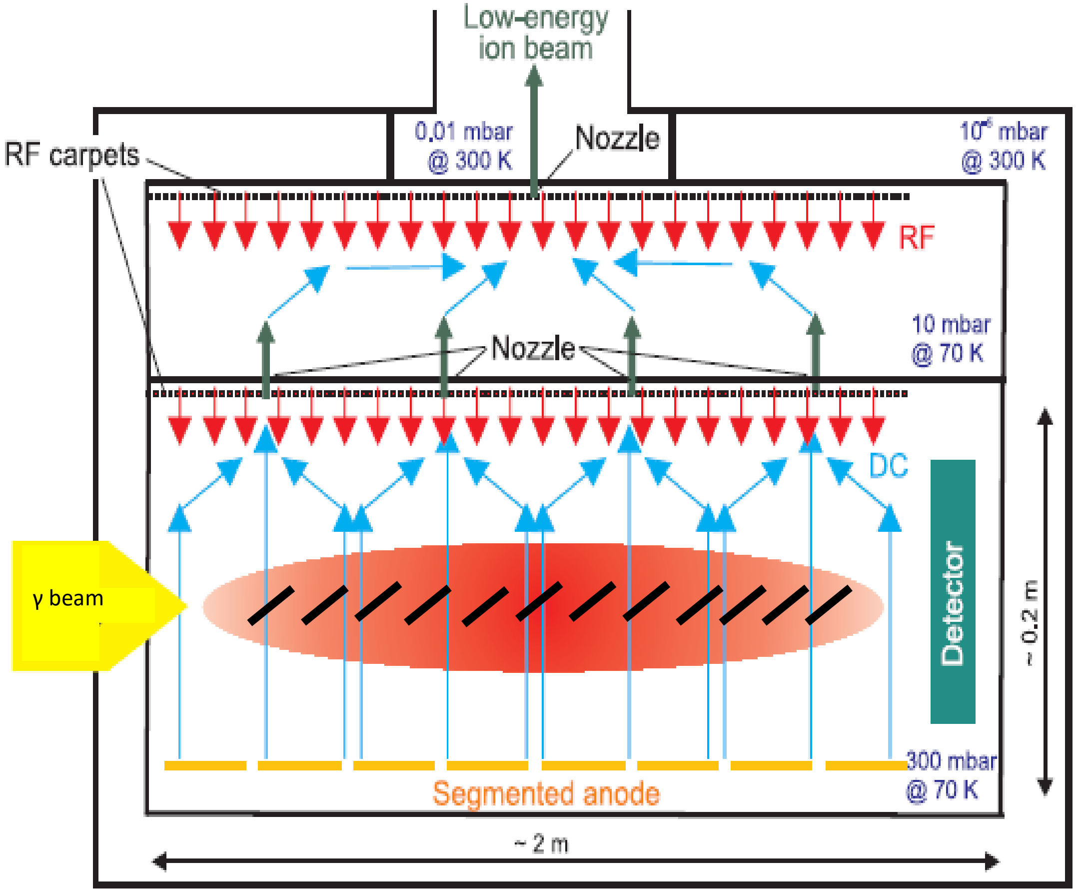




Platform supported on dampers

Cryogenic Stopping Cell

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

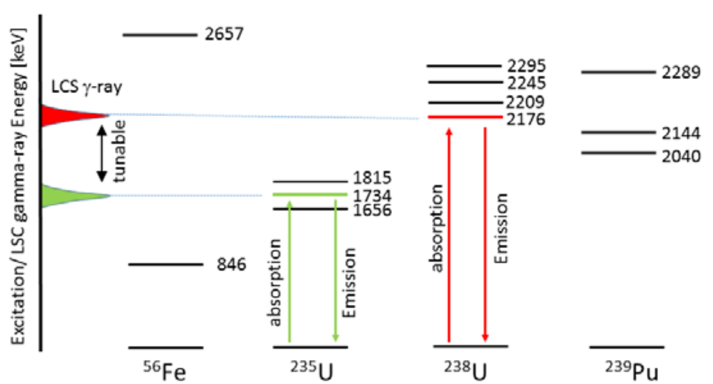
Non–destructive Inspection

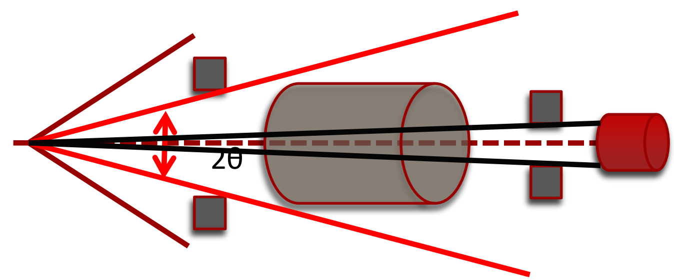
Active interrogation – Nuclear resonance fluorescence

- 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



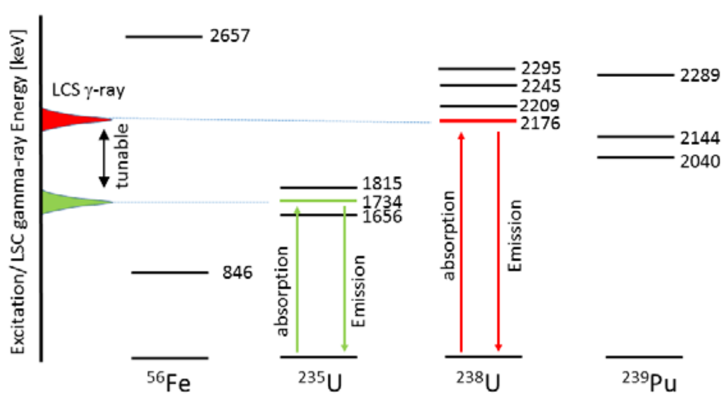


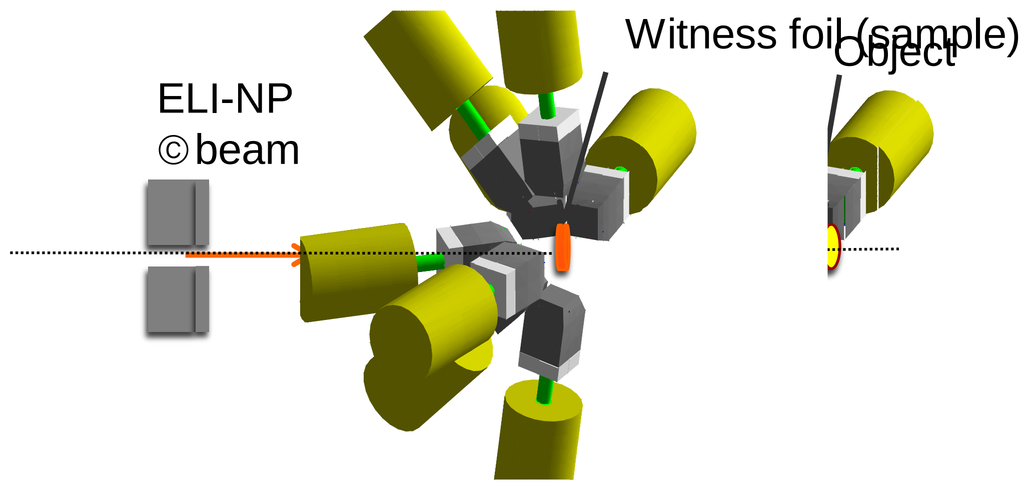
NRF + CT: Elemental/isotopic maps

Gamma Beam Industrial Applications

Active interrogation – Nuclear resonance fluorescence

- ✓ High intensity gamma beam and small bandwidth
- ✓ Tunable energy
- ✓ High efficiency detector array – ELIADE





Two experimental methods will be carried out:

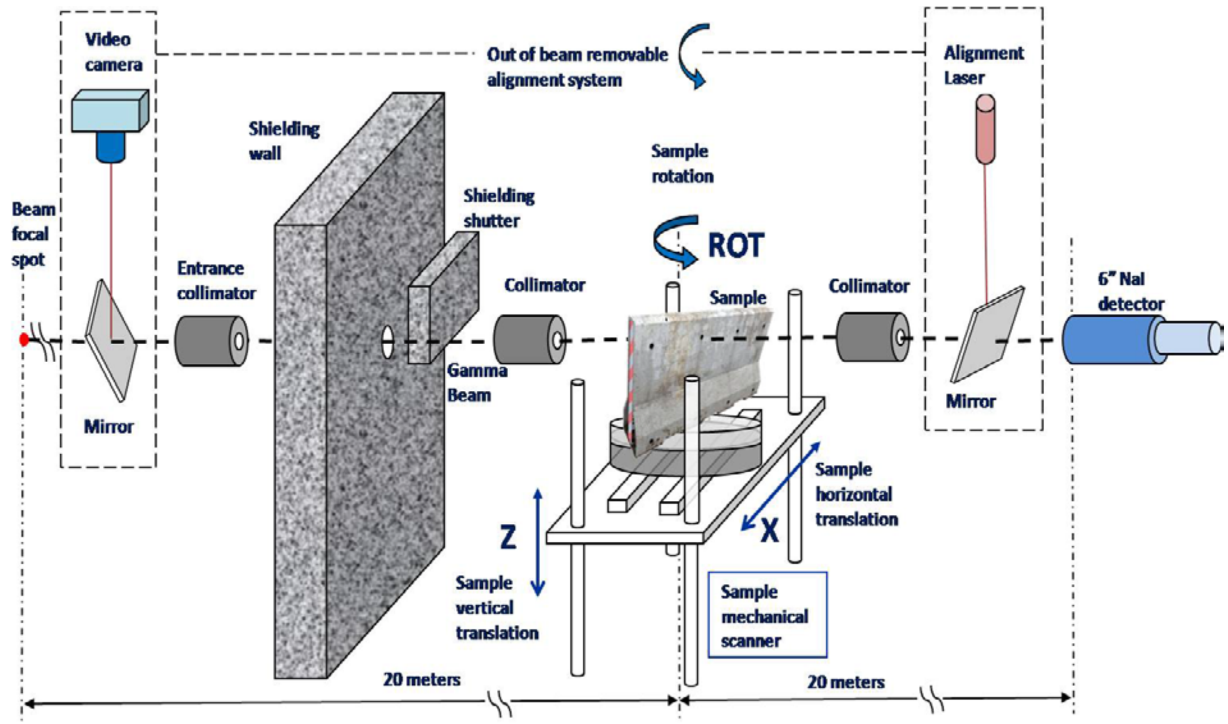
- **Scattering NRF –** Standard Method in Nuclear Physics Study
- **Self-absorption/Transmission NRF** (proposed by Bertozzi in 2005)

  Main interest in SNM control management

Gamma Beam Industrial Applications

Industrial Radiography and Tomography

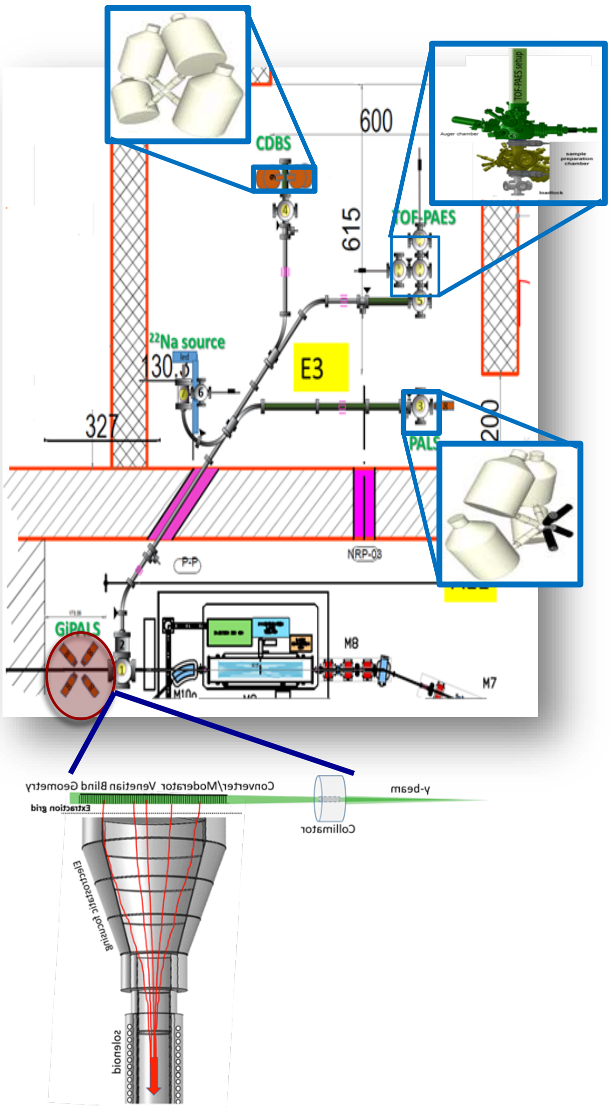
- **Two tomography tables with biaxial movement and rotation**
- Various collimators with collimation holes between 0.2 mm and 5 mm.
- **High volume detector for pencil-beam**
- 2D detector for cone-beam: CCD based gamma-ray camera or 2D flat panel



- **Implementation: 2015 -2017**
- **Operation: 2018**

Positrons for Material Sciences

The ELI-NP e^+ factory



Production method

- (γ, e^+e^-) reaction;
- circular polarized γ–beam
- $I_\gamma = 2.4\times10^{10}$ s^{-1}
- $E_\gamma < 3.5$ MeV
- W converter

Estimated e^+ beam parameters

- moderated e^+ intensity 1.9×10^6 s^{-1}
- degree of e^+ spin polarization 31%

Spectrometers

PALS – Positron Annihilation Lifetime Spectroscopy

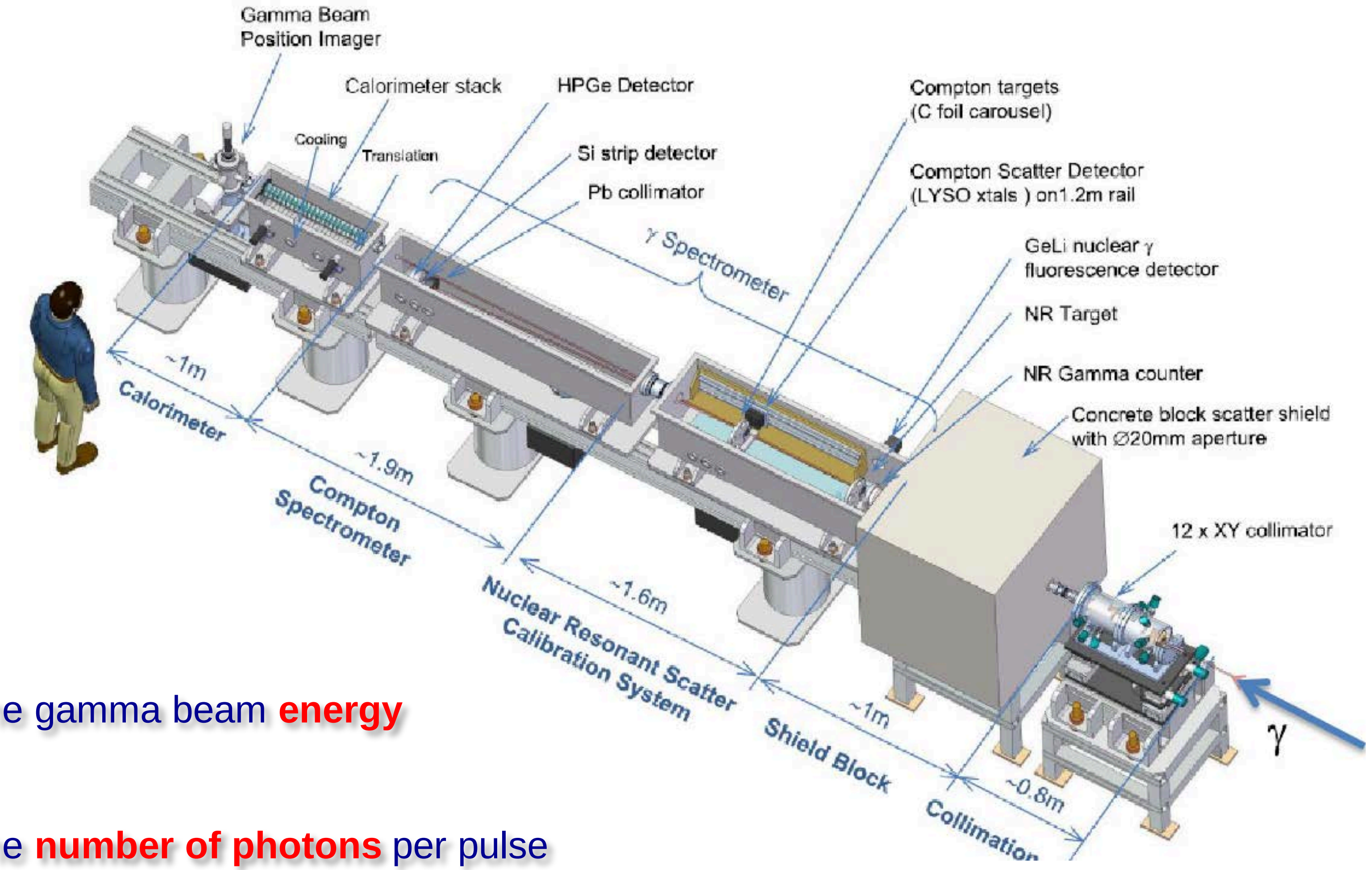
CDBS – Coincidence Doppler Broadening Spectroscopy

TOF–PAES – Positron annihilation initiated Auger Electron Spectroscopy

GiPALS – Gamma induced PALS

Gamma Beam Diagnostics

EuroGammaS



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

INFN Ferrara