EUROPEAN UNION

GOVERNMENT OF ROMANIA

Sectoral Operational Programme "Increase of Economic Competitiveness"

"Investments for Your Future!"

Extreme Light Infrastructure - Nuclear Physics

(ELI-NP) - Phase I

Project co-financed by the European Regional Development Fund

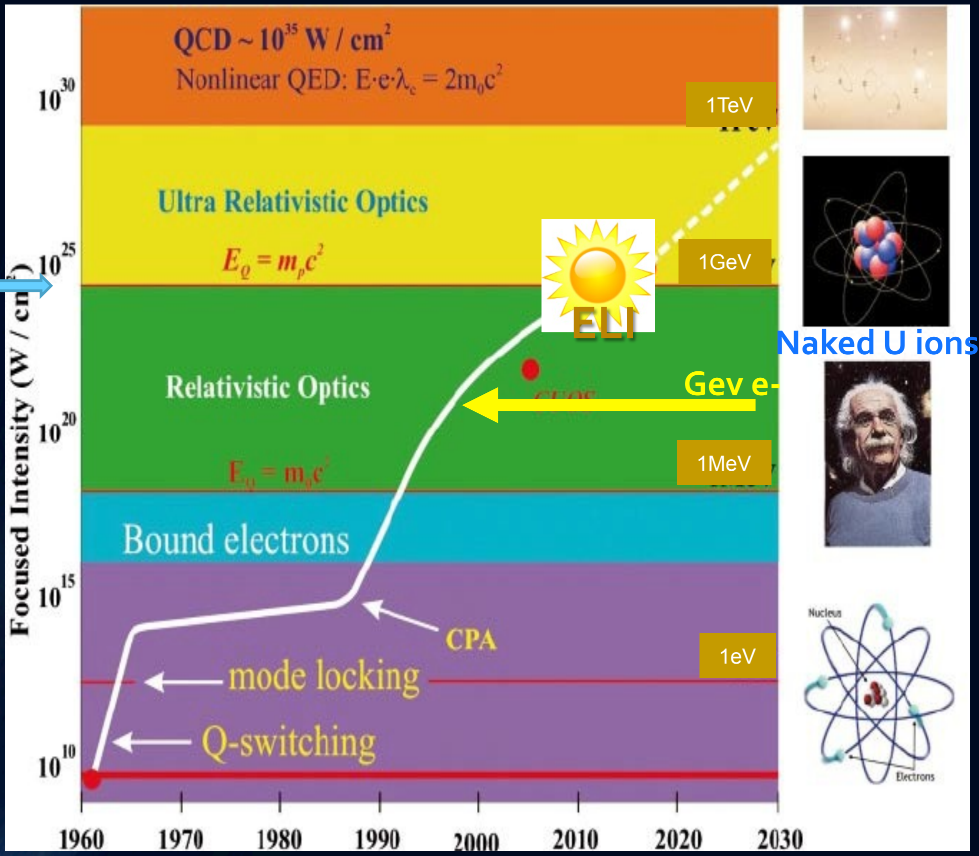
ELI–NP: New Frontiers in Nuclear Physics with High Power lasers and Brilliant Gamma Beams

S. Gales for the ELI-NP Team

INPC 2016-Adelaide –Sept 11th-16th

ELI: Extreme Light Infrastructure
World Roadmap for High Power Lasers

10^{25}W~
10%Solar
Power on
1cm2



At focal point of the laser(microns)
E= 9×10^6 MV/cm for an intensity of 10^{23}W/cm2

30 GeV e- acceleration within few mm

G. Mourou, T. Tajima, Science 331,41 (2011)

What is ELI?
Extreme Light Infrastructure

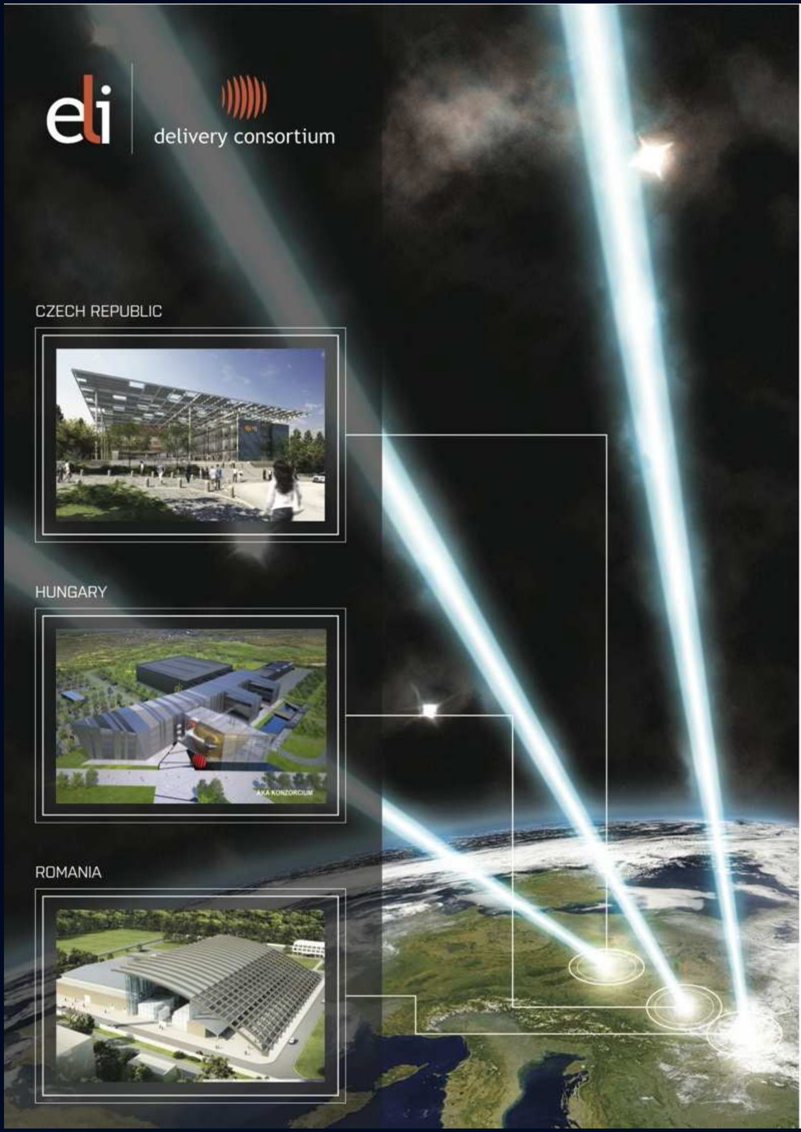
ELI will be

¤ The world's first international laser research infrastructure, providing unique science and research opportunities for international users

¤ A distributed research infrastructure based initially on 3 facilities in CZ, HU and RO

*The first ESFRI project to be implemented in the new EU Member States EU13

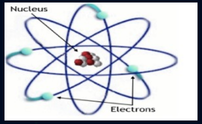
¤ Pioneering a novel funding model: combining structural funds (ERDF) for the implementation and member contributions to an ERIC for the operation

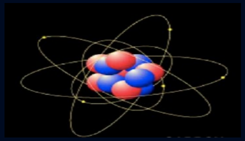


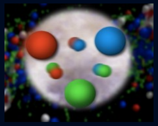
ELI-NP

Explore matter and its constituents : from atom to vacuum with new powerful probes at the frontiers of existing technologies

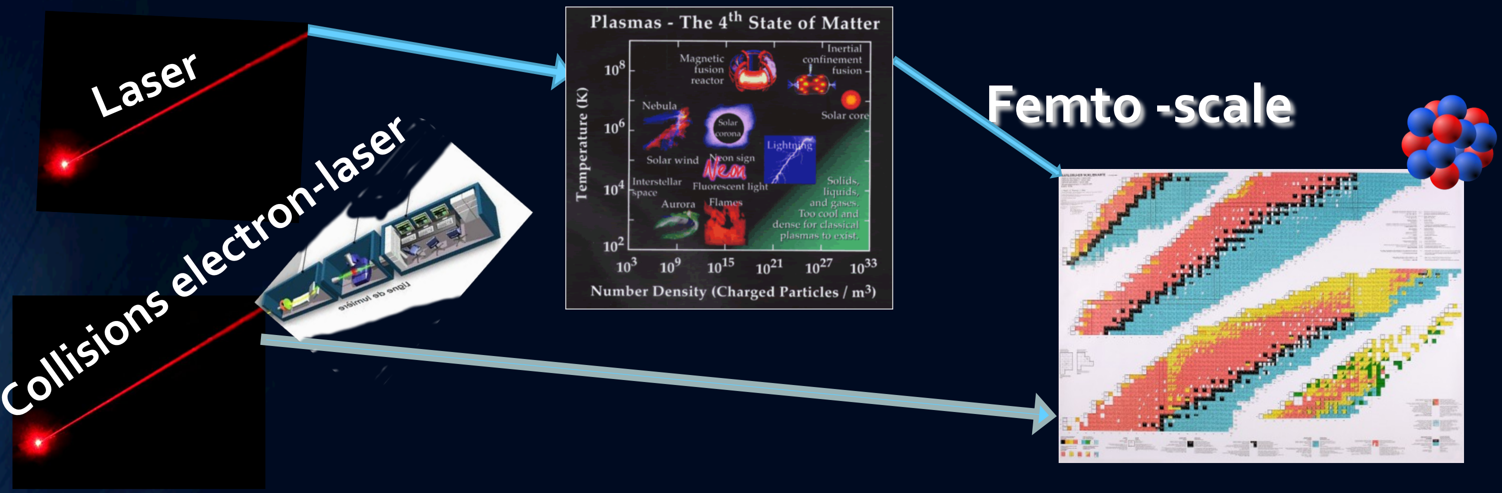
High Power lasers and High energy and brilliant gamma beams







1) Ultra-short High power laser pulse(25fs) 2 X1O PW, 1/mn



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2) GAMMA beams high flux , monochromatic, ~qqs10^{-3} , E= 0.2-19 MeV

Bucharest-Magurele

ELI Nuclear Physics in Romania

Nuclear Physics

Phase

Structural Funds approved in Sept. 2012
Start construction June 2013

Projected completion date: end of 2018-
Fully operation facility +1-2 years

Building under construction
(Completed June 2016)

Full budget approved in Dec 2015 by EU 300 M€
(23 Meuros for Expts)
Staff hiring in progress 2013- 15 members
To day about 130 ---- towards 240 in 2018

Management 6+ Support Staff 28 (legal, finance, HR, sec,....)
R&D (research,Eng,Tech) 104 ,e,g. Senior junior, postdocs, PhD, Engineers and Physicists, Technicians

Romania 65%, EU 15%, Asia,15%, USA,Can, others 5%

ELI-NP: Civil engineering completed

Buildings, 33000 m^2 total

- Building Lasers ,Linac and experiment halls
- Restaurant-Cafeteria
- Guest house

Physics building offices, meeting rooms ,…

Experiences – 7000 m^2

- ***8 expts halls for gamma, laser, and combined***
- ***gamma + laser research activities***

June 2016

High Power Laser System - HPLS

2013-2018

2 HPLS up to 10 PW – 6 outputs

World record in Laser power expected

Thales Optronique SA
& SC Thales System Romania

2 outputs 100 TW - 10 Hz
2 outputs 1 PW - 1 Hz
2 outputs 10 PW – 1/min

THALES

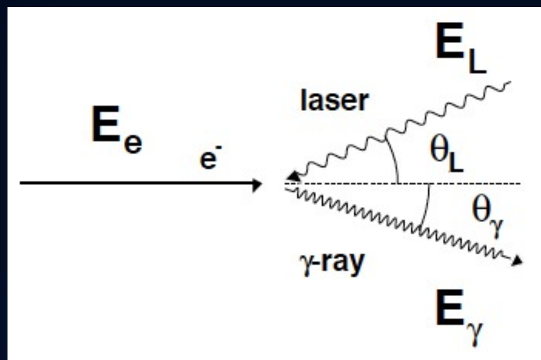
Achievements 9 Atlas 100J amplifiers out of 16 accepted

200mm TiSa crystal done (World premiere)

First stage of the HPLS completed 30 November 2015, Elancourt (Fr)

HPLS First arm 1,37PW , 21fs, 1Hz achieved

Gamma Beam System – Basic Concepts



Gamma–rays from Inverse Compton Scattering

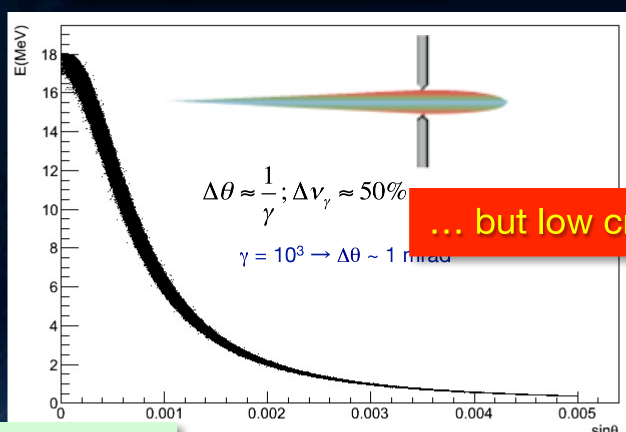
photon scattering on ultra relativistic electrons (g ≫ 1)

the most efficient frequency amplifier

'Photon accelerator'

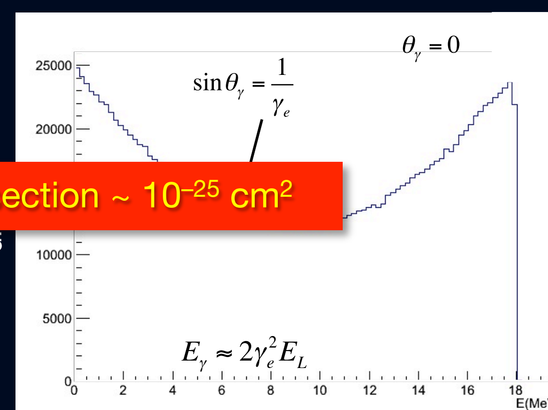
$$E_\gamma = 2\gamma_e^2 \cdot \frac{1+\cos\theta_L}{1+\left(\gamma_e\theta_\gamma\right)^2 + a_0^2 + \frac{4\gamma_e E_L}{mc^2}} \cdot E_L$$

Strong forward focusing



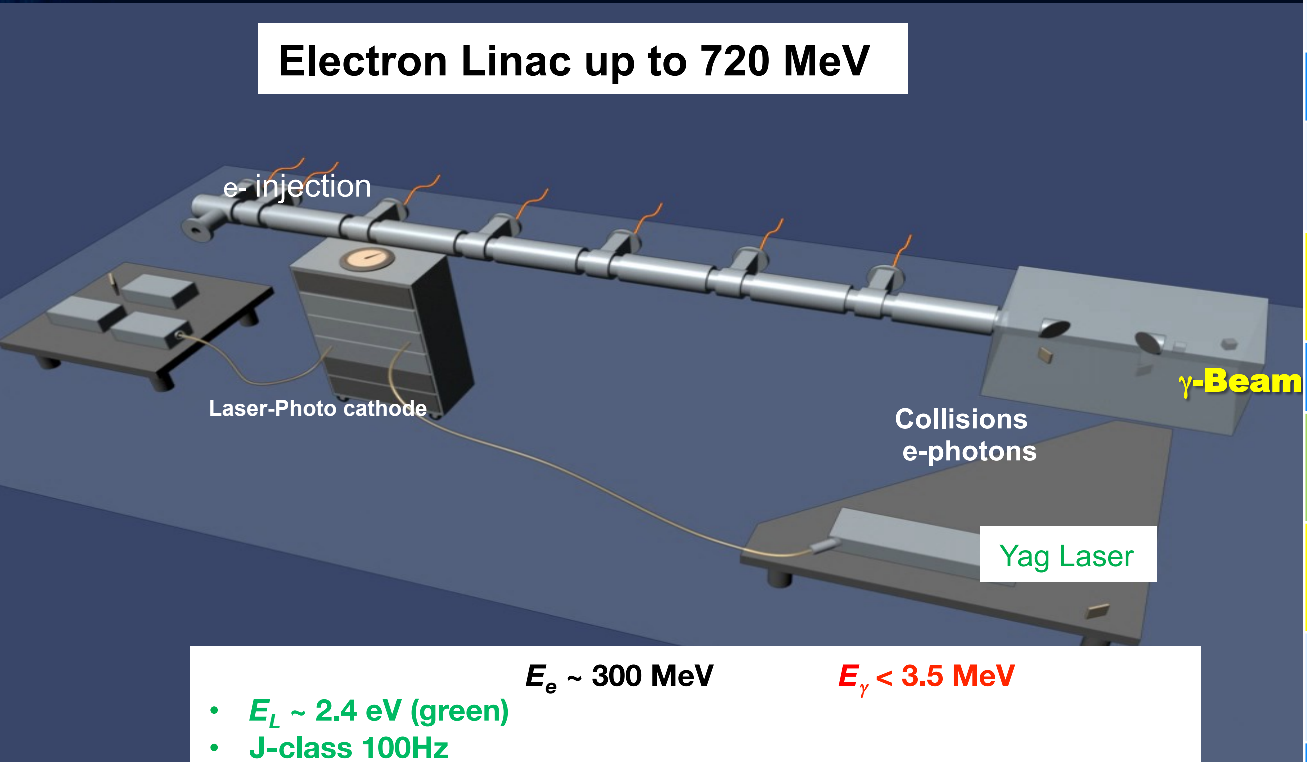
Angular dependence of the photon energy

… but low cross section ~ 10^{-25} cm^2



Compton edge

Gamma Beam Specifications (GBS)



- E_L ~ 2.4 eV (green)
- J-class 100Hz

E_e ~ 300 MeV — E_γ < 3.5 MeV

E_e ~ 720 MeV — E_γ < 20 MeV

Courtesy of C. Barty

Energy (MeV)	**0.2 – 19.5**
Spectral Density (ph/s·eV)	**0.8 – $4 \cdot 10^4$**
Bandwidth rms (%)	**≤ 0.5%**
# photons per shot within FWHM bdw.	**≤ $2.6 \cdot 10^5$**
# photons/sec within FWHM bdw.	**≤ $8.3 \cdot 10^8$**
Source rms size (mm)	**10 – 30**
Source rms divergence (mrad)	**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 (%)	**> 99**
Macro rep. rate (Hz)	**100**
# pulses per macro pulse	**32**
Pulse–to–pulse separation (nsec)	**16**

•ELI-NP, the Nuclear Physics Pillar of ELI, is building an advanced Compton Source (Gamma Beam System) aiming at making a substantial step forward in γ-ray beam performances

The Gamma Beam System at ELI–NP

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)

Phase 1: All components ready for 1MeV GBS

ELI–NP Science Program and Instruments

ELI-NP Physics and Engineering Team
Scientific Director

International Working groups
3 international workshops in 2013-2014 and 2015
(more than 150 part)

TDR's Gamma Beams System

1. **Gamma Beam Delivery & Diagnostics**
3. **NRF Experiments**
5. **Photo–fission experiments**
7. **Gamma Above Threshold**
8. **Charged Particle (g,p) (g,a)**
11. **Applications of Gamma beams**

Positron source ,NRF , Neutron Imaging and Tomography, Radio-Isotopes for Medicine

TDR's Convener local liaison

TDR's High–Power Laser System

1. **Laser Beam Transport System**
2. **Laser Driven Nuclear Physics**
3. **High Field Physics and QED**
5. **Combined Gamma+ Laser expts**
6. **Materials in Extreme Environments for Energy, Accelerators and Space**

TDR's Convener ↔ local liaison

>30 MoU's and about 20 research contracts with major Laser and NP labs and Institutions (EU and Worldwide)

Engineering office
Interface (building, safety RP ,Vacuum, C&C, labs, workshops)

All TDR's have been submitted to peer review and evaluated by an Int Scientific Advisory Board

ELI-NP Technical Design Reports

Published Romanian Reports in Physics Volume 68, Number 2, 2016

RA1: High-Power Laser System

RA1/TDR1: Laser Beam Delivery Systems

RA2: High-Brilliance Gamma Beam

RA2/TDR1: Gamma Beam Delivery and Diagnostics
RA2/TDR2: Positron Production by Gamma Beam
RA2/TDR3: Gamma Beam Industrial Applications

RA3: Nuclear Physics with High-Power Lasers

RA3/TDR1: Laser-driven Nuclear Physics
RA3/TDR2: High Field QED Experiments
RA3/TDR3: Materials in extreme environments for energy, accelerators and space applications

RA4: Nuclear Physics and Applications with high-brilliance Gamma Beams

RA4/TDR1: Nuclear Resonance Fluorescence Experiments
RA4/TDR2: Photofission Experiments
RA4/TDR3: Gamma above n threshold
RA4/TDR4: Charged Particles Detection
RA4/TDR5: Radioisotopes production for medical applications

RA5: Fundamental Physics with combined Laser and Gamma Beams

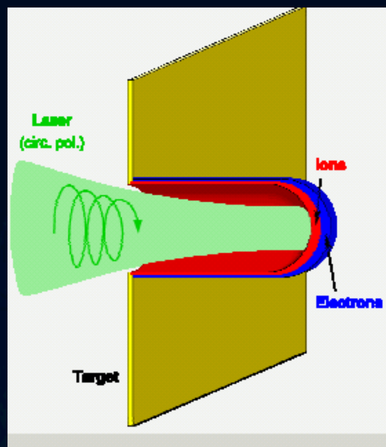
RA5/TDR1: Combined laser and gamma beams experiments

Transversal TDR's

Monitoring and Control Systems; Safety and Radiation Protection Dosimetry

Nuclear Physics with HP Lasers (D.Stutman& F. Negoita et al)

Interaction of High Power Laser (PW) with Matter will suffer this :



- field ~ TV/m
- E_e ~ GeV
- $E_{ion} \leq 150$ MeV/u
- charge ~ 10's of pC
- $\Delta E/E$ ~ 1-2% (e^-)
  ~ 10-20% (ion)
- $\varepsilon \sim 10^{-5}$ mm mrad

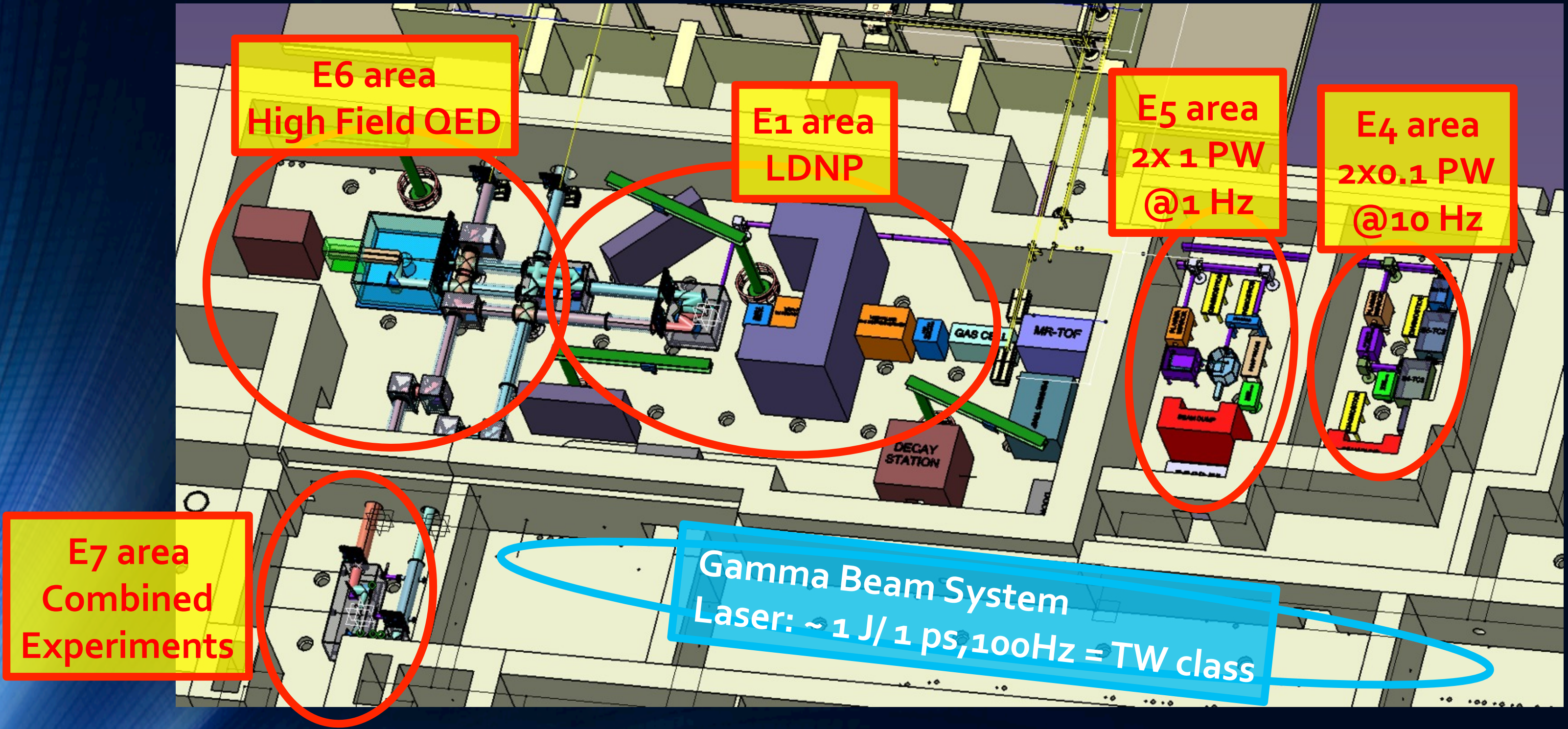
Electrons are expelled from the target due to the chock wave induced by the powerful laser .Heavy ions are accelerated in the field created by the electrons

Electrons and ions accelerated at solid state densities **10^{24}e cm^{-3} never reached before** (Classical beam densities 10^8e cm^{-3}) on very short distance (μm-mm) $E \sim I_{laser}$

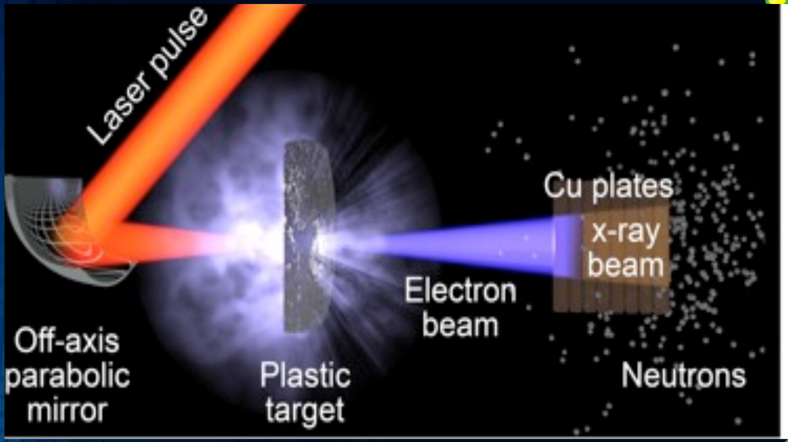
Experimental areas and Tools for High-Power Laser Experiment s (D.Ursescu et al)

Day-one expts Goals (2019-2020)

1) Demonstrate 10 PW power in E1 via Conversion of Laser light in Gamma radiations in dense He, H jet gas targets
2) Reach 200 MeV proton bunches in E5 and others heavy ion acceleration with 1PW laser to be demonstrated in E5. Then develop nuclear reaction studies
3) Production of very intense neutron flux



Nuclear reactions in Plasma (using Laser)



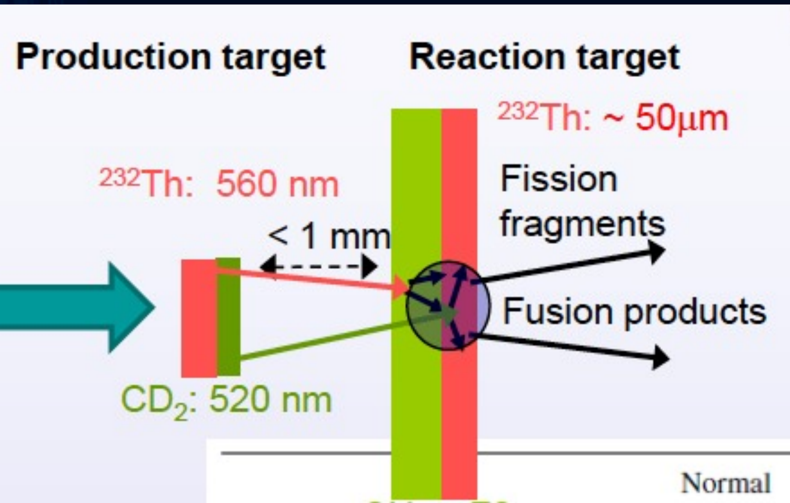
- interesting for astrophysics of light element nucleosynthesis (bare nuclei reactions as in stars)
- nucleosynthesis of heavy element
- lifetime changes (of isomer?) in the plasma and inverse electron capture

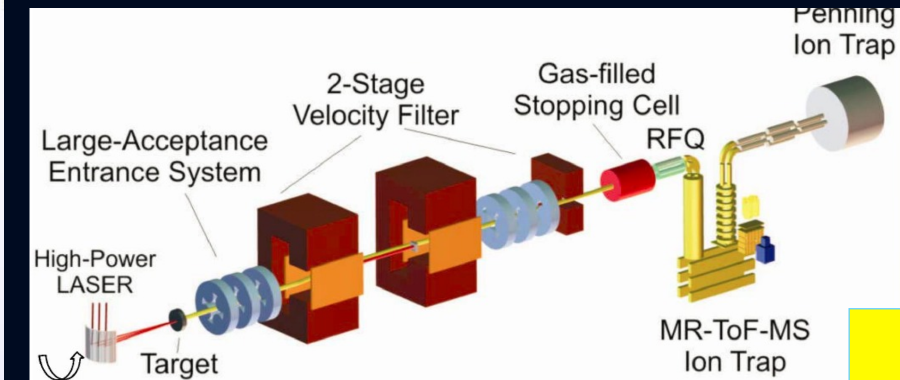
p an d beams created by LASER

Photonuclear neutron generation (I. Pomerantz)

Laser driven Fission-Fusion (Flagship expt)

P.Thirof ,F.Negoita et al





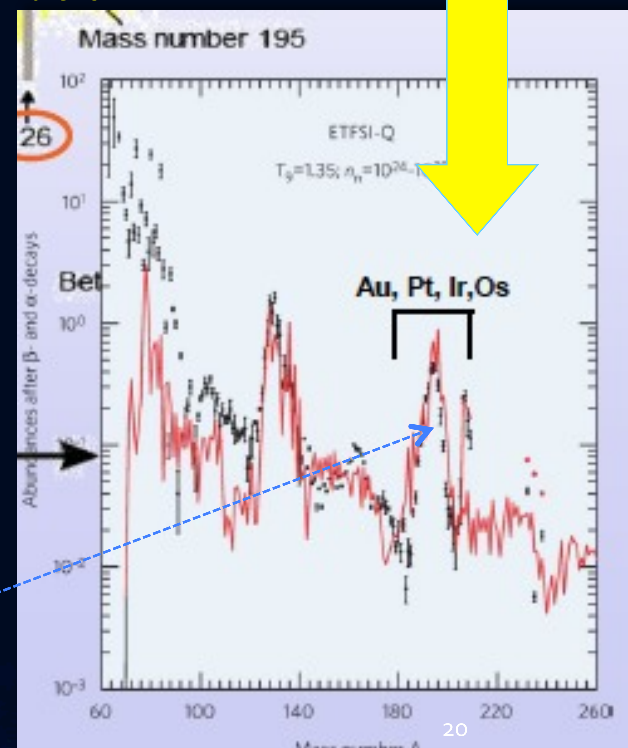
selection and separation

Difficult and challenging

It requires staging for solving several tecnical problems and safety issues

N= 126 waiting point bottleneck for nucleosyntheis of actinides

Last region of r-process



Electromagnetic excitation of nuclei by γ beams

Nuclear Physics

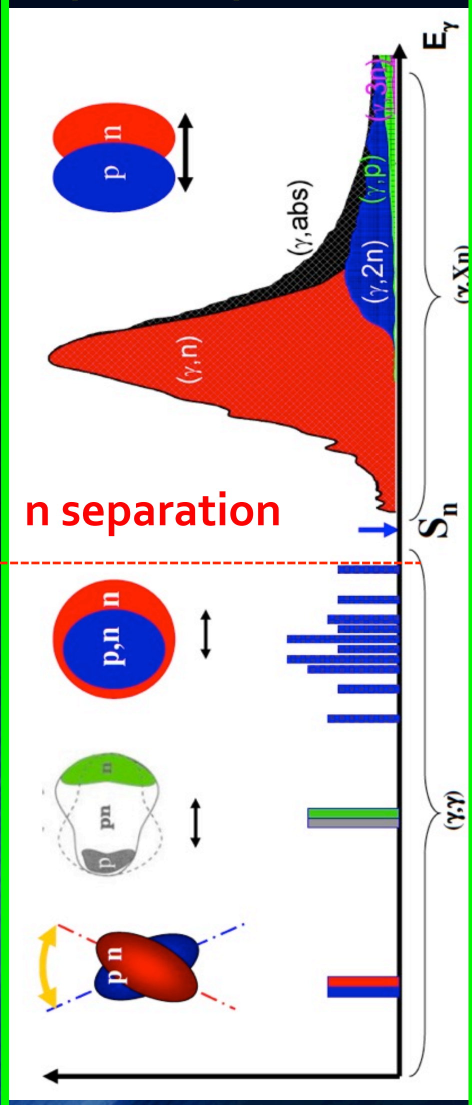
Dipole response

≈ 25

≈ 15

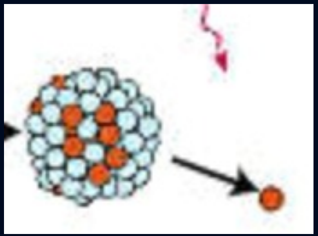
n separation

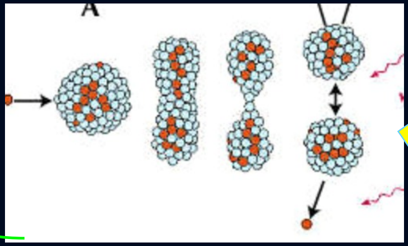
≈ 8



Gamma energy (MeV)

Evaporation of nucleons





- nuclear structure of collective modes- exclusive data
- Reaction rates for astrophysics
- Rare isotopes production

Nuclear Photonics

NRF and Detailed nuclear structure

- Nucleosyntheses r and s processes
- Fission barrier and high deformations

NRF Technical proposal

C.A Ur et al

- ***The gamma–ray detector array***

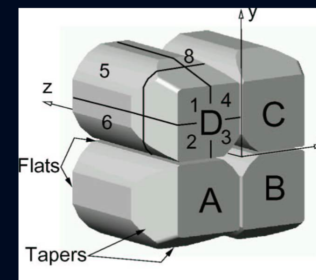
ELIADE = ELI–NP Array of DEtectors

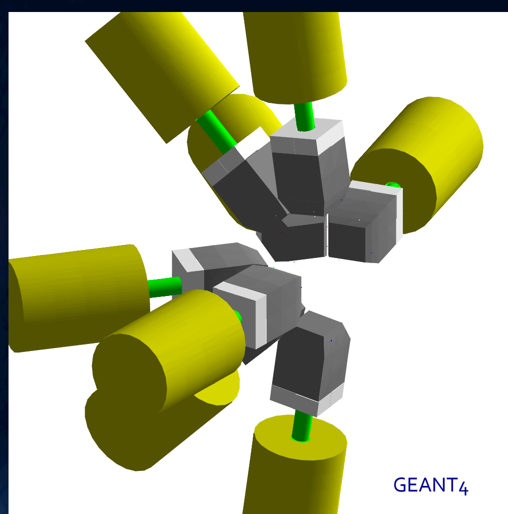
- use of composite Ge detectors HPGe :

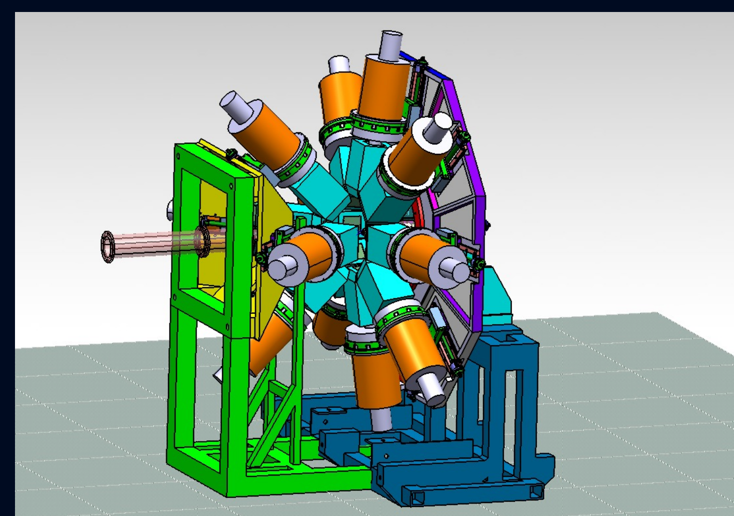
8 segmented Clover detectors : 4 x crystals 60x90 cm

every crystal segmented in 8

→ higher granularity – lower probability for multiple hits



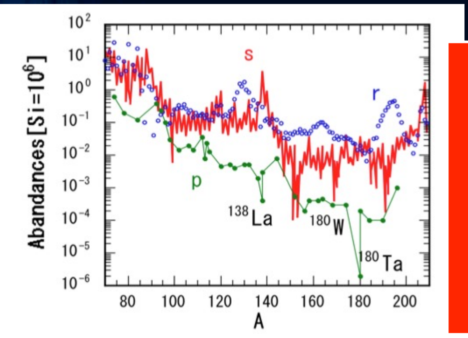




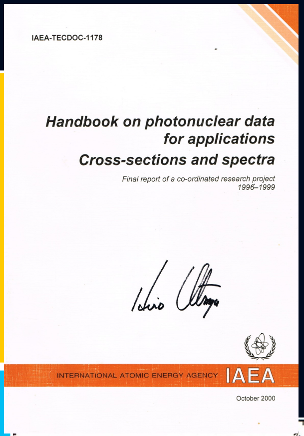
Group ELI-GANT
(Gamma Above Neutron Threshold)

F.Camera (INFN Milano) , H. Utsunomiya (Konan. University, D. Filipescu (ELI-NP)

PHYSICS CASES



p-process Nucleosynthesis	New Compilation of (γ,xn) Cross-Sect
Nuclear Structure of GDR&PDR	

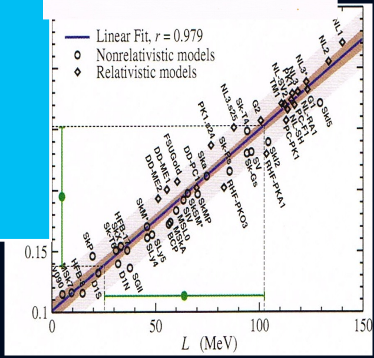

IAEA-TECDOC-1178

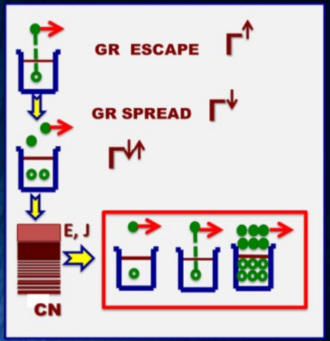
Handbook on photonuclear data for applications
Cross-sections and spectra

Final report of a co-ordinated research project 1996–1999

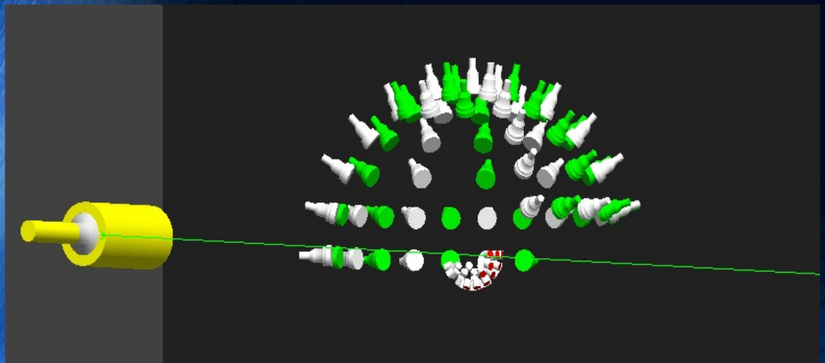
INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

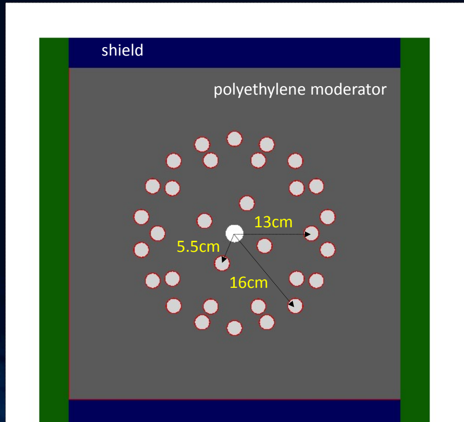
October 2000





Array of $LaBr_3$:Ce, Liquid, and Li glass scintillation detectors

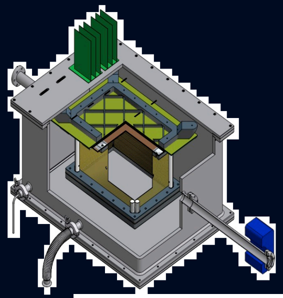


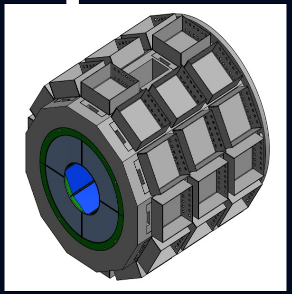


Flat-efficiency 4π neutron detector (ELIGANT-TNH)

The Charged Particles Working Group

Convener: Moshe Gai, Univ. of Connecticut & Yale Univ.
ELI-NP Liaison: Ovidiu Tesileanu

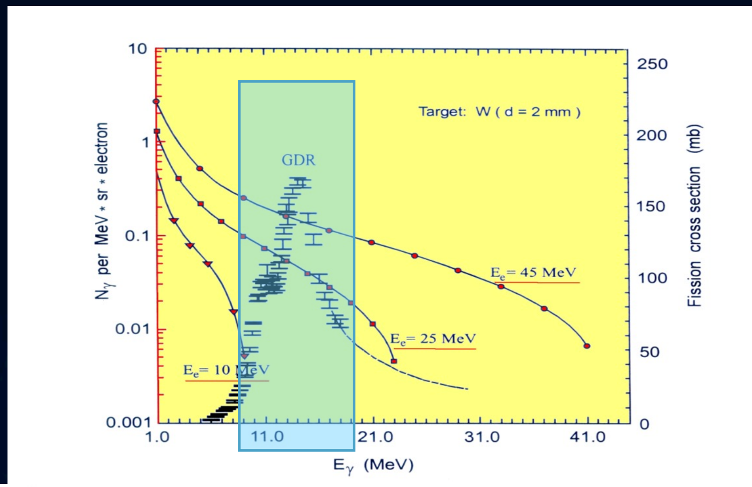


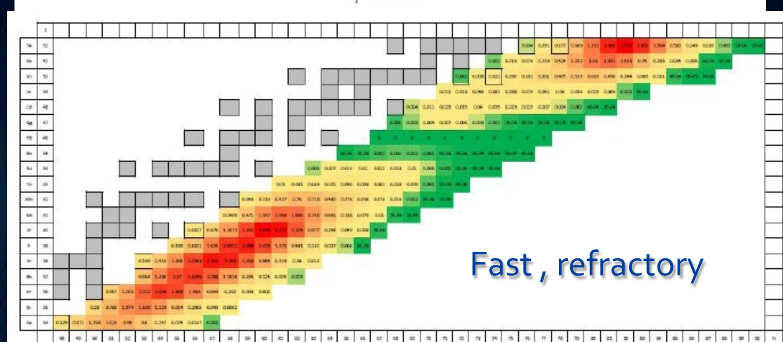


- **Scope: TDR for charged particles detection @ ELI-NP**
- Physics case:
  - Nuclear structure – clustering in light nuclei: ^{12}C, ^{16}O;
  - Nuclear astrophysics: **^{16}O(γ,α)^{12}C**, ^{22}Ne(γ,α)^{18}O, ^{19}F(γ,p)^{18}O,
  - the *p*-process (with the high energy γ beam in E8 experimental hall);
  - International collaboration: Italy (INFN-LNS), Poland (Univ. Warsaw), USA (U. Yale)&Connecticut), Romania…..

Photofission: Neutron-rich isotopes production

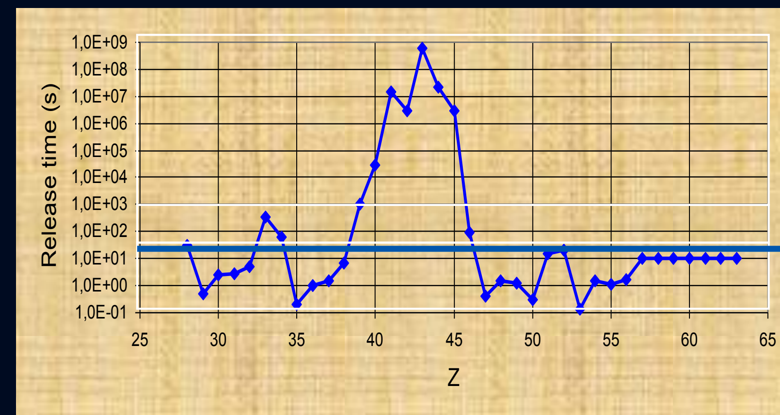
Convener F.Ibrahim(Orsay) - ELI-NP D. Balabanski





Production of fission fragments at ELI-NP

International Collaboration ALTO(IPNO) ,GSI,JYVL,KVI,....



IGISOL at ELI-NP

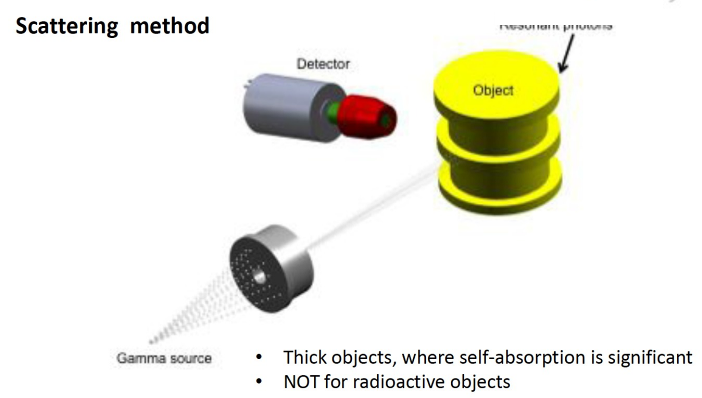
(Cryo Gas cell in coll with GSI-Mainz)

An unique niche!

Refractory elements

Short lifetime (<100ns)

Applications



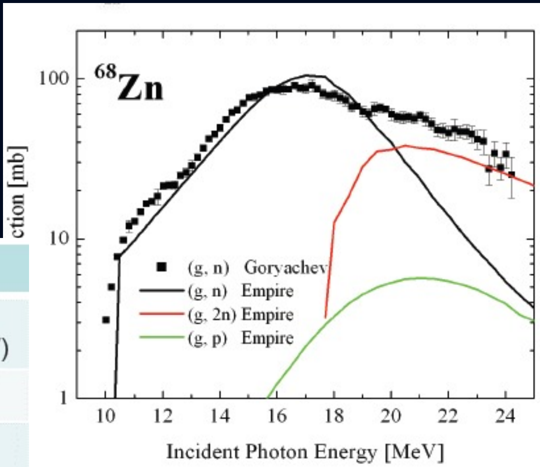
Industrial tomography

material inspection: nuclearwaste
food contaminations

Radio-isotope productions

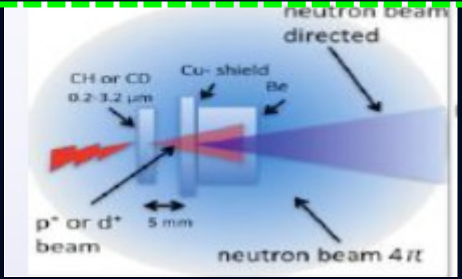
Diagnostic and radio theraphy
with electrons – alpha therapy

	Cross section (mb)
^{68}Zn(p,2p)^{67}Cu	6 (Ep=30-85 MeV) 24.8 (Ep=130-425 MeV)
^{70}Zn(p,α)^{67}Cu	15 (Ep= 16 MeV)
^{68}Zn(γ,p)^{67}Cu	11 (Eγ=22MeV)



Neutron production-

Positron production and
material studies with positrons



Outlook: Towards day one experiments

- *ELI-NP new research facility, open to the European and International community is in full implementation phase including building ,utilities, HPLS, GBS and LBTS , Laboratories, and workshops .*
- *Science program through TDR's and Day One expts Construction phase started for main instruments*

"Go East"

- *Young researchers are invited to join the fun!*

Very attractive science and large discovery potential at reach at the interface of High power laser , plasma , accelerator and nuclear physics

We are committed to build an open access "international user facility"

ELI: Extreme Light Infrastructure

EUROPEAN UNION

GOVERNMENT OF ROMANIA

Sectoral Operational Programme "Increase of Economic Competitiveness"

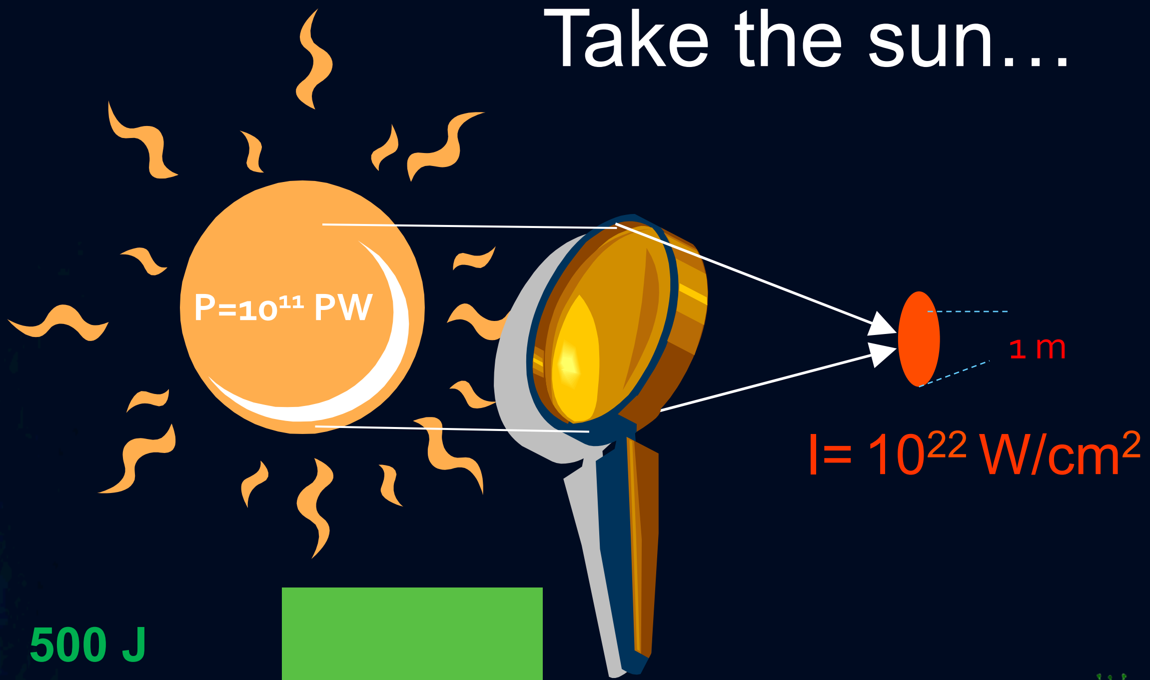
"Investments for Your Future!"

Thanks to ELI-NP team and Collaborators

Thank you for your patience

- END

Take the sun…

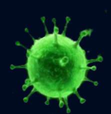


500 J

50 fs = **50x10⁻¹⁵s**

P= 10 PW

I > 10²² W/cm² ! 10micron



Taken from P.Martin

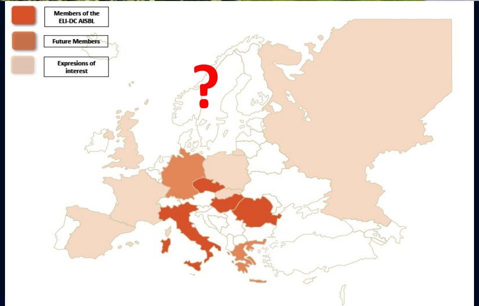
Complementary science, unique research opportunitites

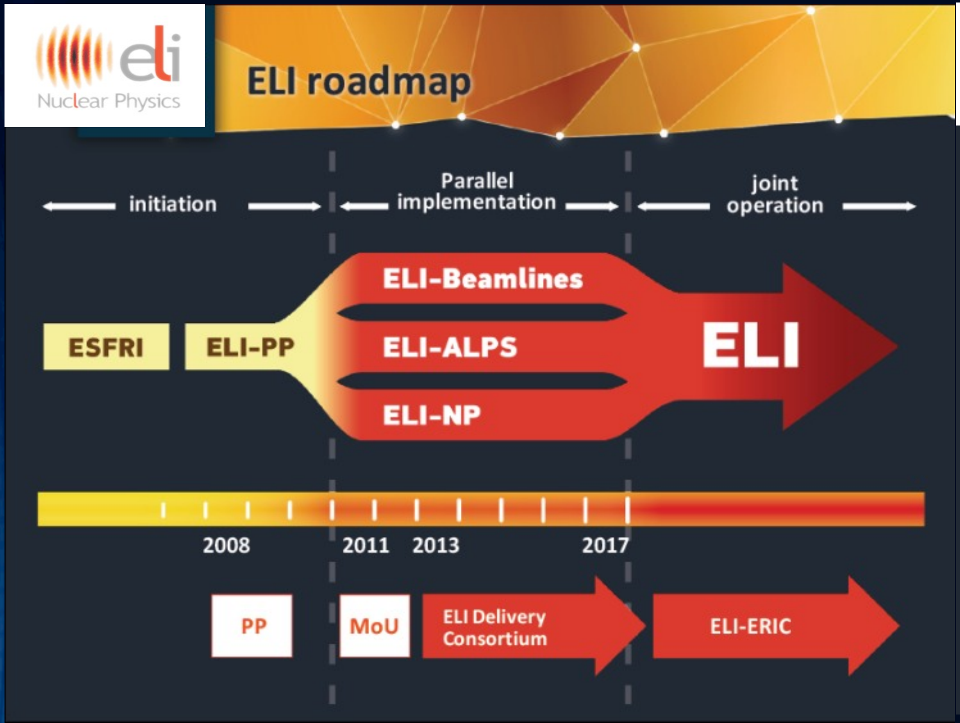
Attosecond Laser Science: new regimes of time resolution in broad spectral ranges (*ELI-ALPS*, Szeged, HU)

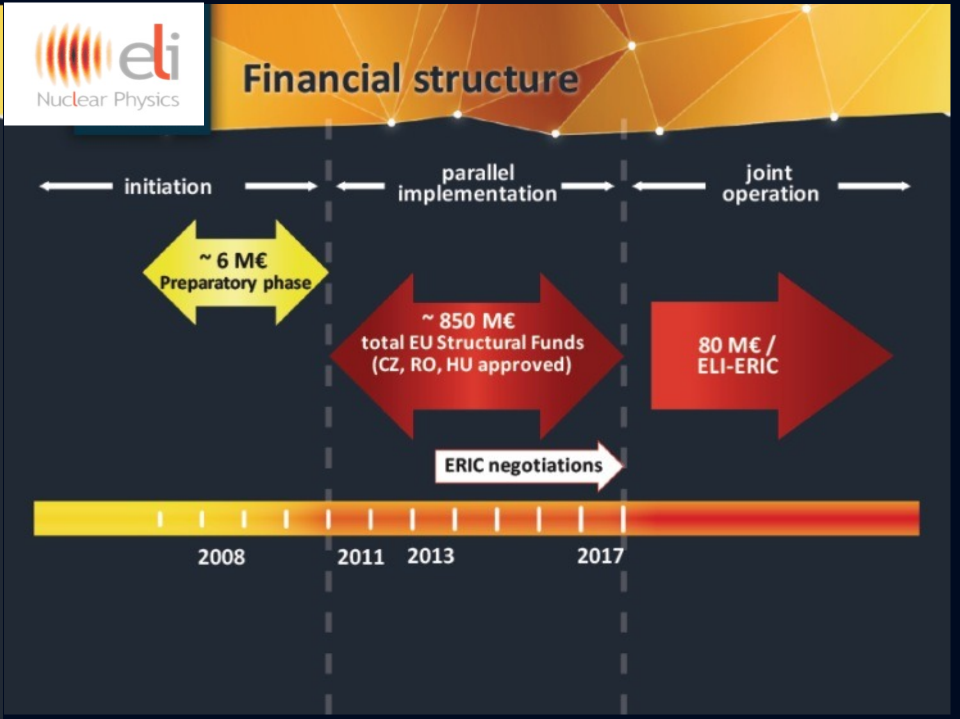
High-Energy Beam Facility: application of primary and secondary sources of high-energy radiation and particles (*ELI-Beamlines*, Prague, CZ)

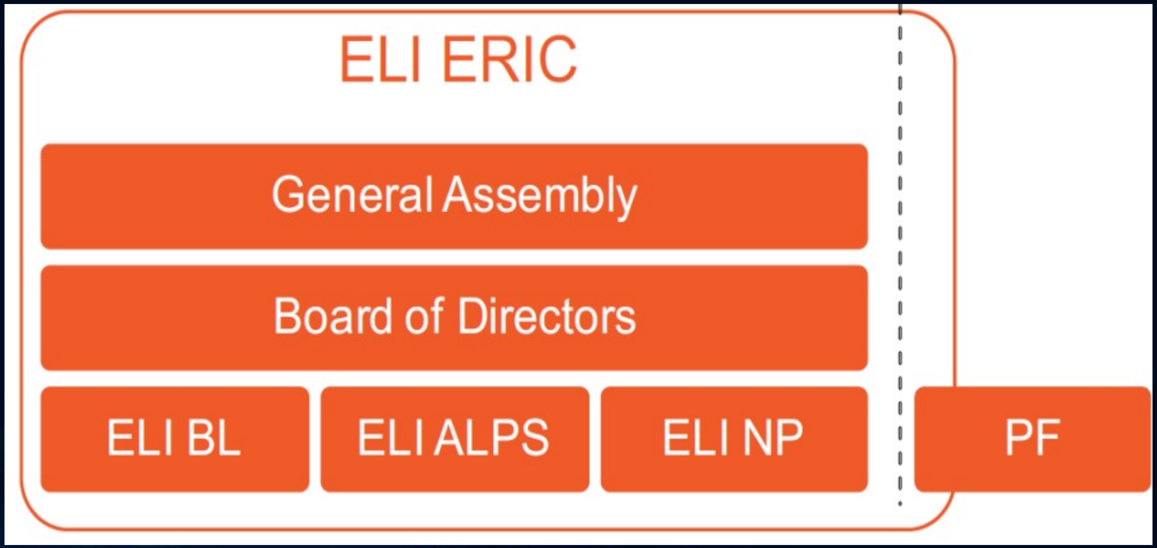
Nuclear Physics Facility: ultra-intense laser and brilliant gamma beams (up to 19 MeV) enabling novel nuclear and photonuclear studies (*ELI-NP*, Magurele, RO)

Ultra-High-Field Science: physics of unprecedented laser field strengths (*ELI 4*, to be implemented)

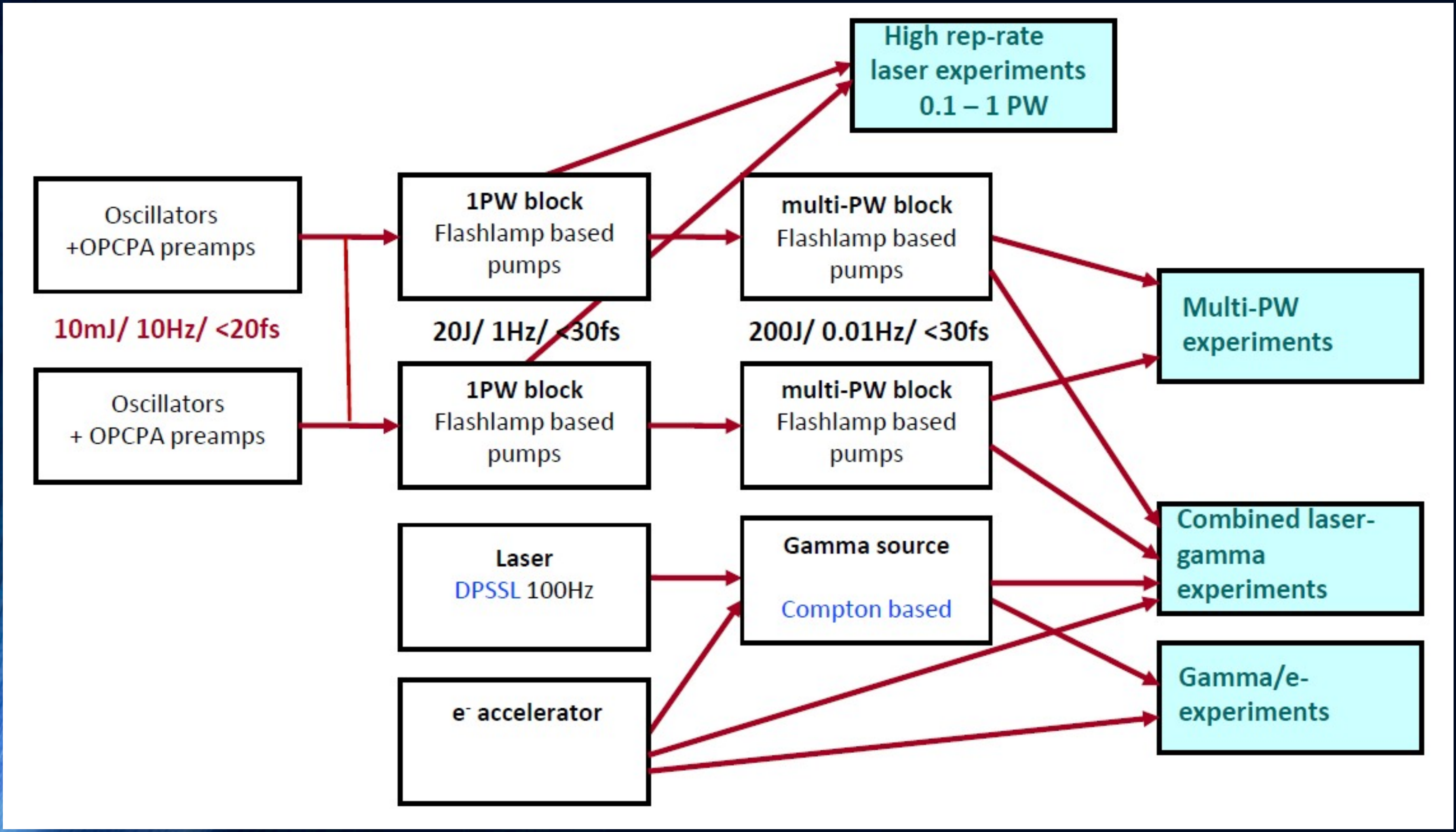



ELI roadmap
Nuclear Physics
initiation
Parallel implementation
joint operation
ESFRI
ELI-PP
ELI-Beamlines
ELI-ALPS
ELI-NP
ELI
2008
2011
2013
2017
PP
MoU
ELI Delivery Consortium
ELI-ERIC


Financial structure
Nuclear Physics
initiation
parallel implementation
joint operation
~ 6 M€
Preparatory phase
~ 850 M€
total EU Structural Funds
(CZ, RO, HU approved)
80 M€ /
ELI-ERIC
ERIC negotiations
2008
2011
2013
2017


ELI ERIC
General Assembly
Board of Directors
ELI BL
ELI ALPS
ELI NP
PF

High Power Laser System – HPLS
D. Ursescu et al

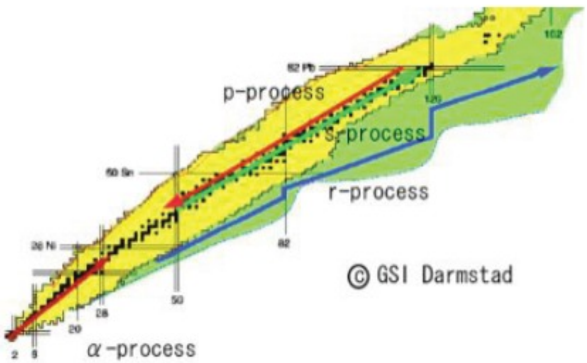


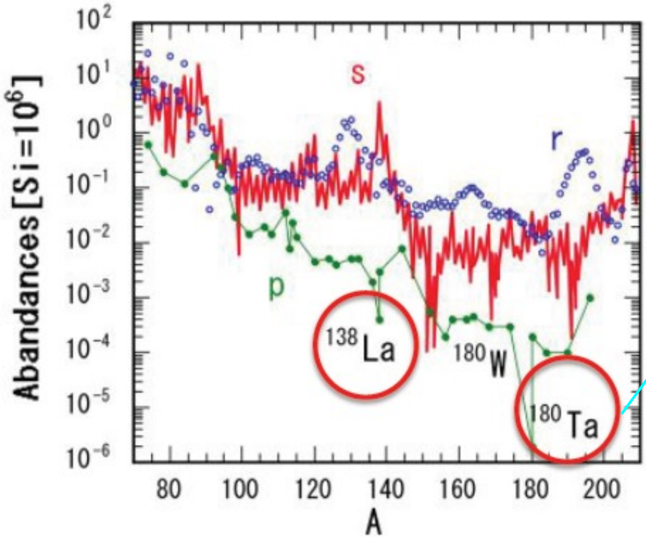
Nucleosynthesis of very rare isotopes

P-process nucleosynthesis

Photonuclear reactions play a major role.

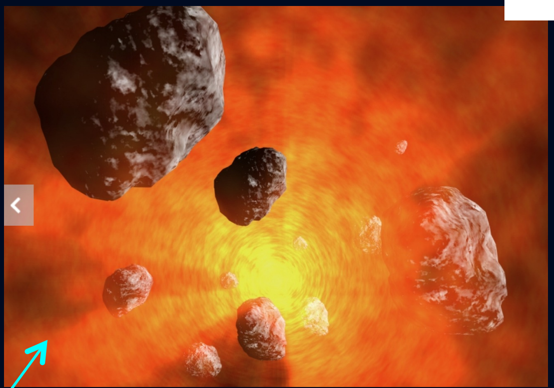
35 neutron-deficient rare isotopes



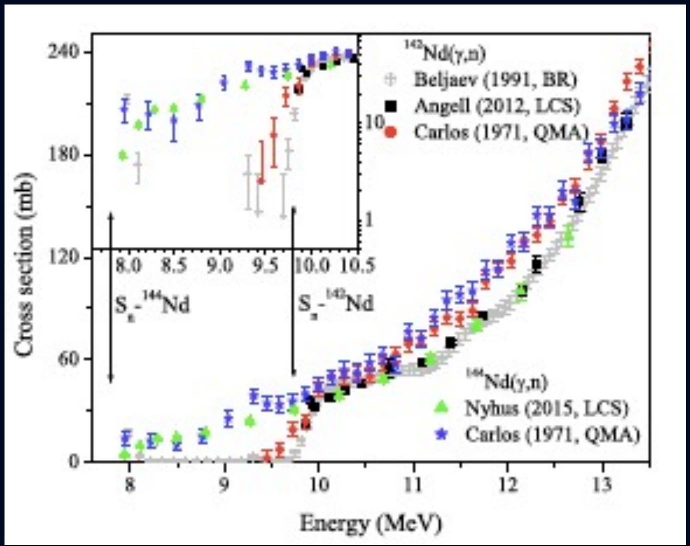


180Ta(γ,n)179Ta

138La(γ,n)137La



Abundances from meteorites presosal grain and geochemical analysis



The need is to measure accurately (γ,n) at threshold

High-Field QED Experiments

i) Controlled e-beams from gas target – 10 GeV beams for $\eta > 1$

ii) Collision of GeV e-beams with intense laser – Radiation reaction (RR),

iii) QED vacuum physics, pair production

Materials in extreme radiation environments

(i) Multi-beam irradiation effects on accelerator, fusion reactor, space materials (solar cells, crystals and other optics) and biological cells

Combined laser-gamma experiments O. Tesilneau

i) Production of isomers by irradiating nuclei with laser produced MeV gammas, followed by gamma beam photoexcitation

ii) Search for sub-eV Dark Matter candidates with two 0.1 PW lasers

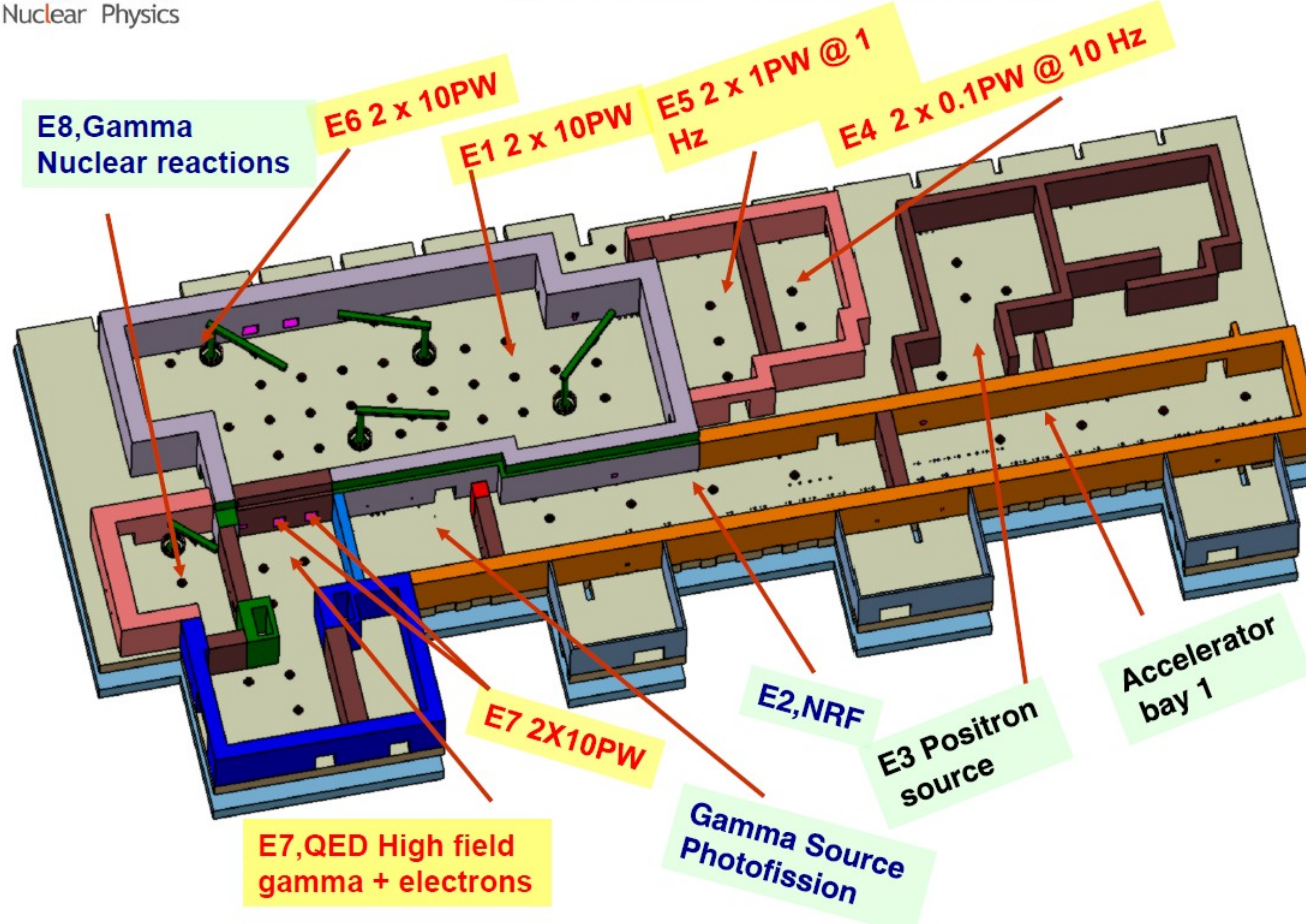
iii) Collision of 700 MeV linac e-beam with 10 PW laser

iv) Laser-gamma, gamma-gamma collisions, vacuum birefringence

Budget for Expts 23.3 M€

Nuclear Physics

8 experimental areas In Gamma Building



- $F_L + F_L$ → <^{A}Z> ≈ $^{182}75$: nuclei close to N=126 waiting point
- $F_L + F_H$ → ^{232}Th : original nuclei
- $F_H + F_H$ → unstable : (search for superheavy species ??)

- fusion-evaporation calculations (PACE4 code):

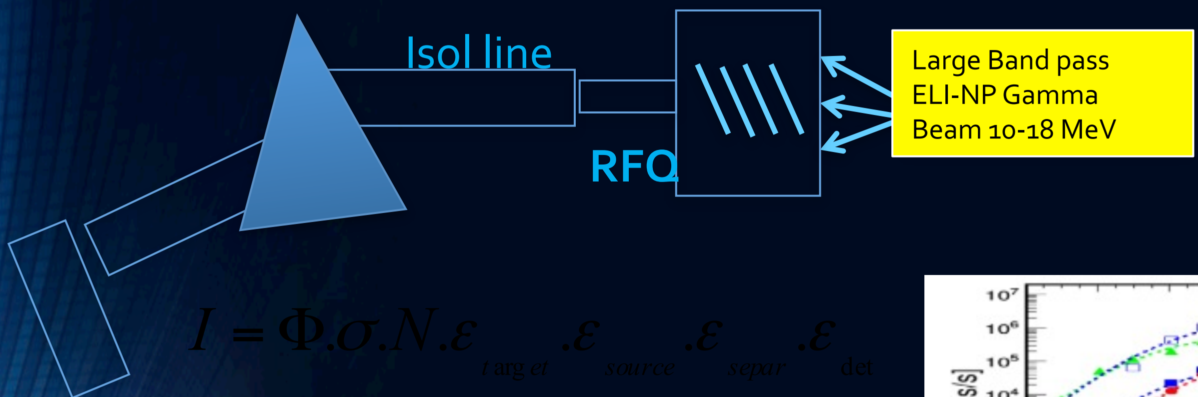
(Z=35,A=102) + (Z=35, A=102): E_{lab}= 270 MeV (E* = 65 MeV)

^{190}Yb (Z=70,N=126):	2.1	mb
^{189}Yb (N=125):	15.8	mb
^{188}Yb (N=124):	61.7	mb
^{187}Yb (N=123):	55.6	mb

laser acceleration (300 J, ε~10%):	normal stopping	reduced stopping
^{232}Th :	$1.2 \cdot 10^{11}$	$1.2 \cdot 10^{11}$
C :	$1.4 \cdot 10^{11}$	$1.4 \cdot 10^{11}$
protons :	$2.8 \cdot 10^{11}$	$2.8 \cdot 10^{11}$
beam-like light fragments	$3.7 \cdot 10^{8}$	$1.2 \cdot 10^{11}$
target-like light fragments	$3.2 \cdot 10^{6}$	$1.2 \cdot 10^{11}$
fusion probability F_L(beam) + F_L (target)	$1.8 \cdot 10^{-4}$	$1.8 \cdot 10^{-4}$
neutron-rich fusion products (A≈ 180-190)	1.5	$4 \cdot 10^{4}$

TDR on Photofission: Production and Separation of neutron-rich isotopes

$\varepsilon_{target} \geq 50\%$
$\varepsilon_{cell} \approx 50\%$ $\varepsilon_{RFQ} \geq 90\%$



$$I = \Phi.\sigma.N.\varepsilon_{target}.\varepsilon_{source}.\varepsilon_{separ}.\varepsilon_{det}$$

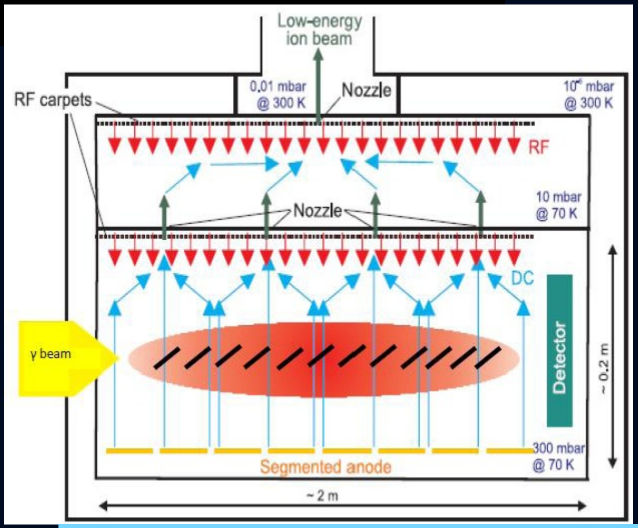
$\varepsilon_{ELI} \sim 3\ 10^{-3}$

$P_{extr}(^{78}Ni) = 5.6\ /s$ N=50 Z=28

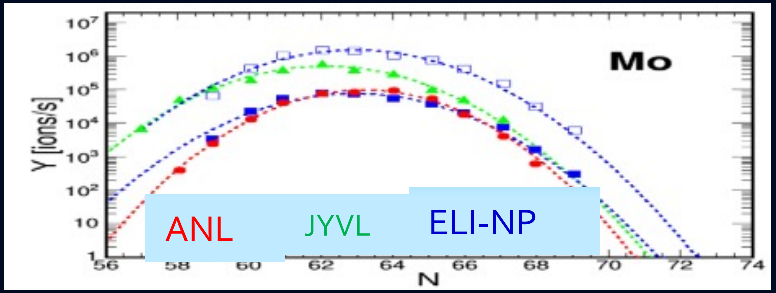
$P_{extr}(^{110}Zr) = 20\ /s$ N=70 Z=40

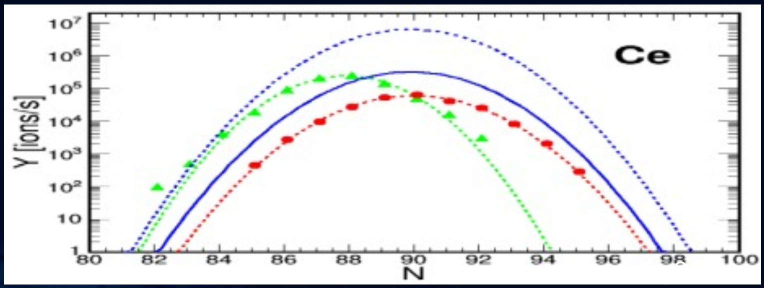
$P_{extr}(^{123}Rh) = 216\ /s$ N=78 Z=45

$P_{extr}(^{128}Pd) = 0.4\ /s$ N=82 Z=46



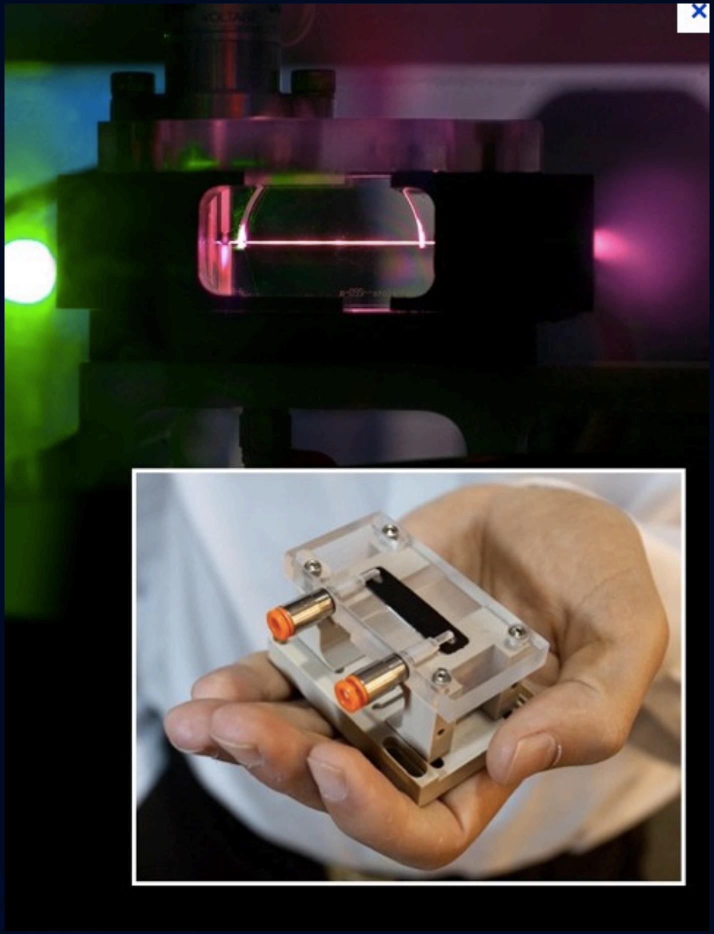
GSI design of CSC





Exciting Perspectives

Enormous reduction in scale



New Paradigm

Nuclear Physics

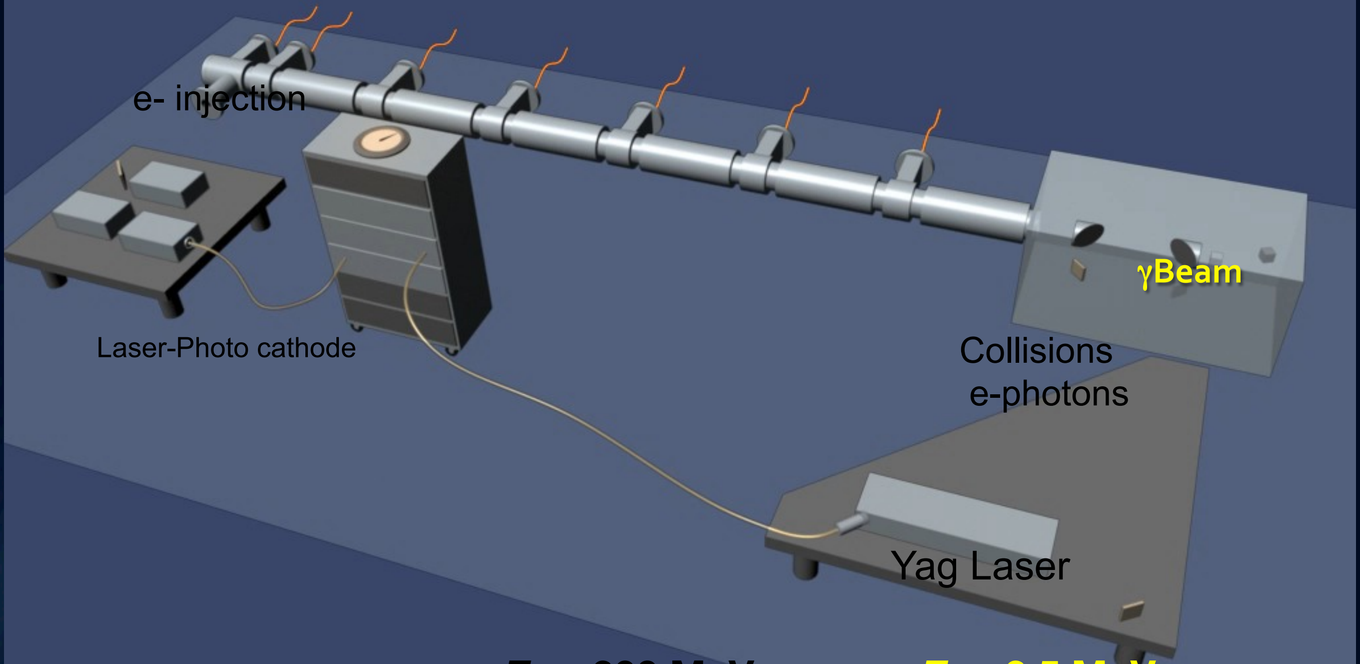
In the 20^th^ century Fundamental Research has been carried out and dominated by the Particle–based Paradigm: namely accelerator for Massive and Charged particles

The First example is the Extreme Light Infrastructure ELI

21st Century; the Photon Century
Could basic research be driven
by the massless and charge less Photons??

Large Scale Lasers: Could they become the Next Large Scale Fundamental Research Infrastructures?

Electron Linac



-
- E_L ~ 2.4 eV (green)

E_e ~ 300 MeV — E_γ < 3.5 MeV

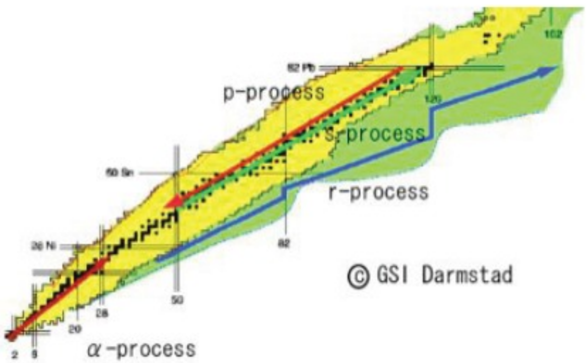
E_e ~ 720 MeV — E_γ < 20 MeV

The Electron LINAC &Gamma beams

Nucleosynthesis of very rare isotopes

P-process nucleosynthesis

Photonuclear reactions play a major role.



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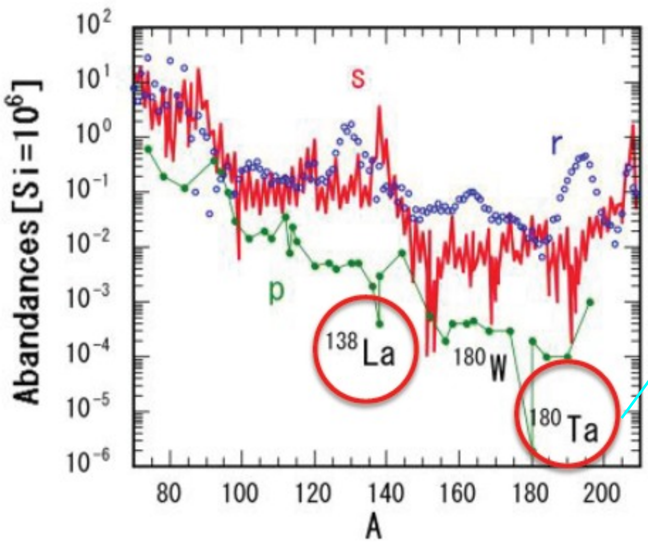

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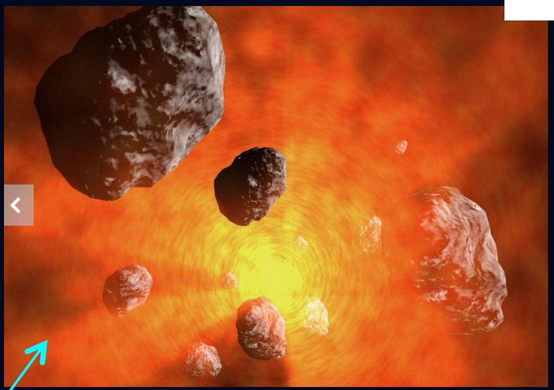

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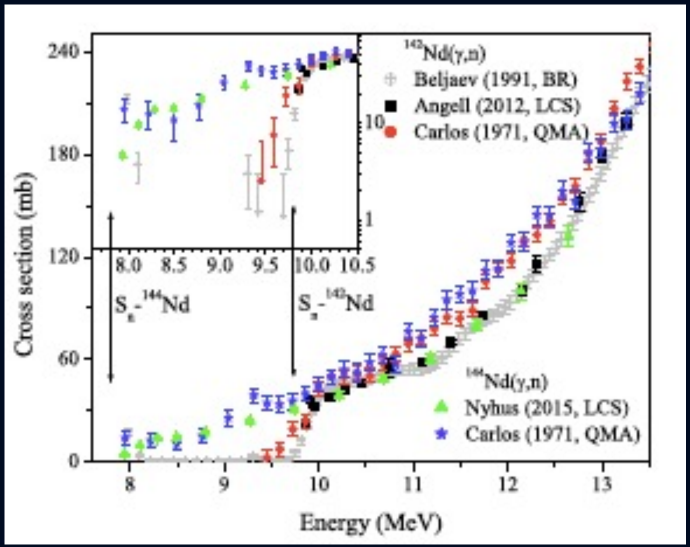
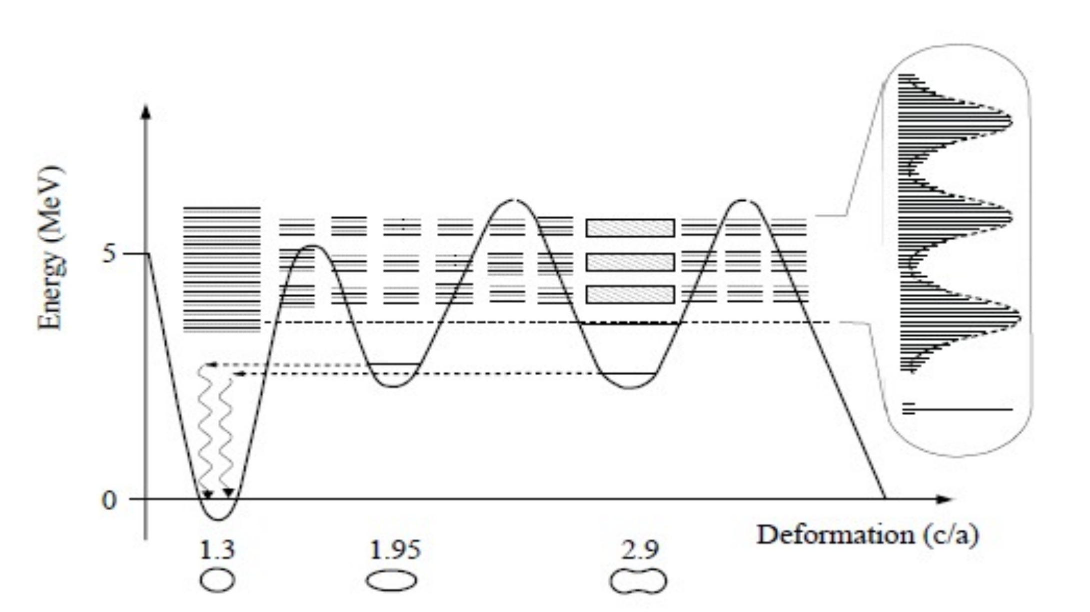


The need is to measure accurately (γ,n) at threshold

Photofission

Convener A. Krasznahorkay (Debrecen) - ELI-NP D. Balabanski

1. STUDIES IN THE 2ND AND 3RD MINIMUM OF THE FISSION BARRIER: TRANSMISSION RESONANCES
2. RARE FISSION MODES: TERNARY FISSION
3. STRUCTURE OF NEUTRON-RICH NUCLEI: THE RARE-EARTH NEUTRON-RICH DEFORMED REGION



P.G. Thirolf et al., EPJ Web of Conferences 38, 08001 (2012)

TDRs for Experiments

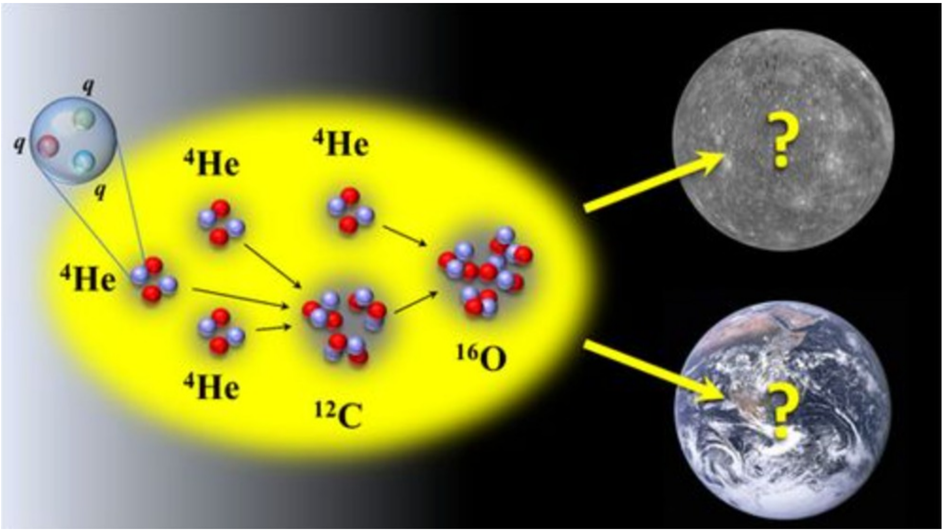
Technical Design Reports (TDRs):

33 MoUs (9 with Romanian institutions),
10 Research Contracts and Collaborative Agreements (17 Projects)

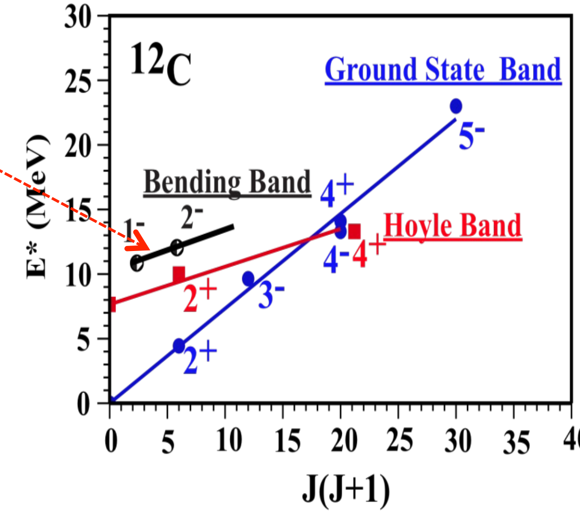
Workshops
June 25 – 28, 2013 - Towards TDRs of experiments at ELI-NP Workshop;
March 16 – 17 and April 2 - 3, 2014 – ELI-NP TDRs at midway;
February 18 – 20, 2015 – ELI-NP Science programme and instruments: TDRs
147 participants (76 Romanians) from 63 institutions, 16 countries

April – May 2015: Peer review of TDRs
June 2015 – ISAB: **TDR's evaluation , recommendations and priorities for Day one expts**

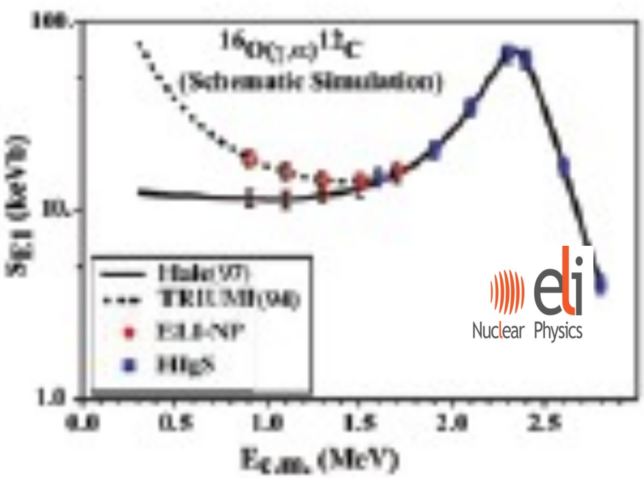
^{12}C : nuclear structure and nuclear astrophysics

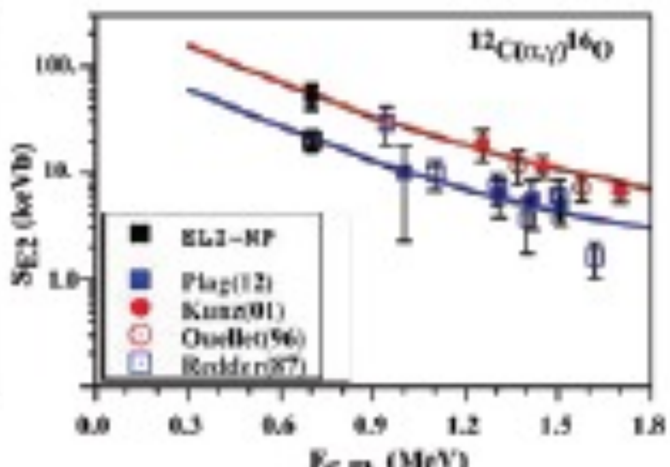


Rotational band on Hoyle states



ratio $^{12}C/^{16}O$ to be understood : use the $^{16}O(\gamma,\alpha)^{12}C$ reaction at ELI





Difficult to measure very low energy alpha partiles

TPC with optical reading