EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments
2007-2013

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

Extreme Light Infrastructure – Nuclear Physics (ELI-NP)

Project co-financed by the European Regional Development Fund

Developments for New Experiments with Intense Lasers and Brilliant Gamma Beams

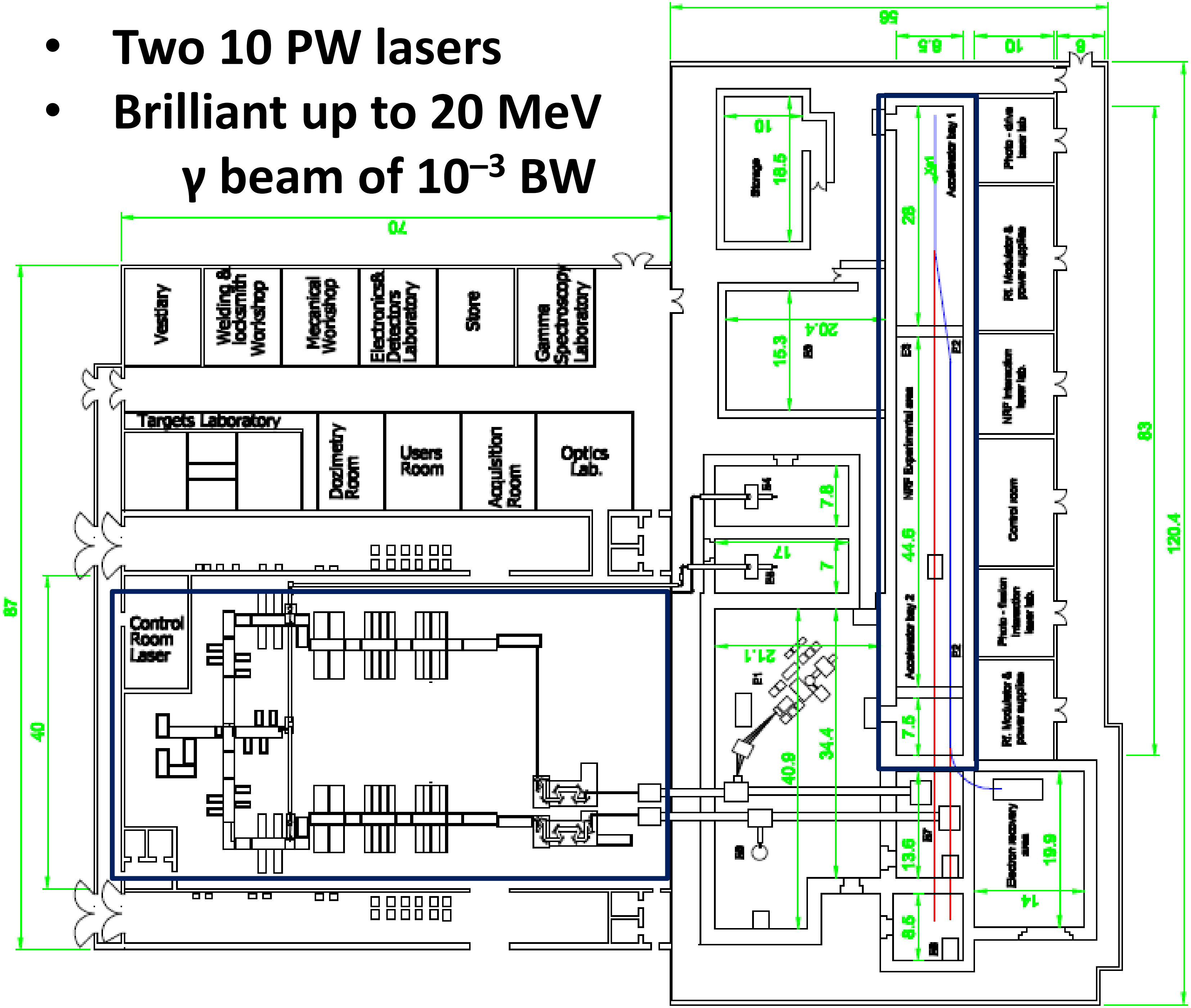
Dimiter L. Balabanski

NUSTAR Annual Meeting,
GSI, March 5th – 7th, 2014

eli Nuclear Physics

IFIN-HH

- **Two 10 PW lasers**
- **Brilliant up to 20 MeV γ beam of 10^{-3} BW**

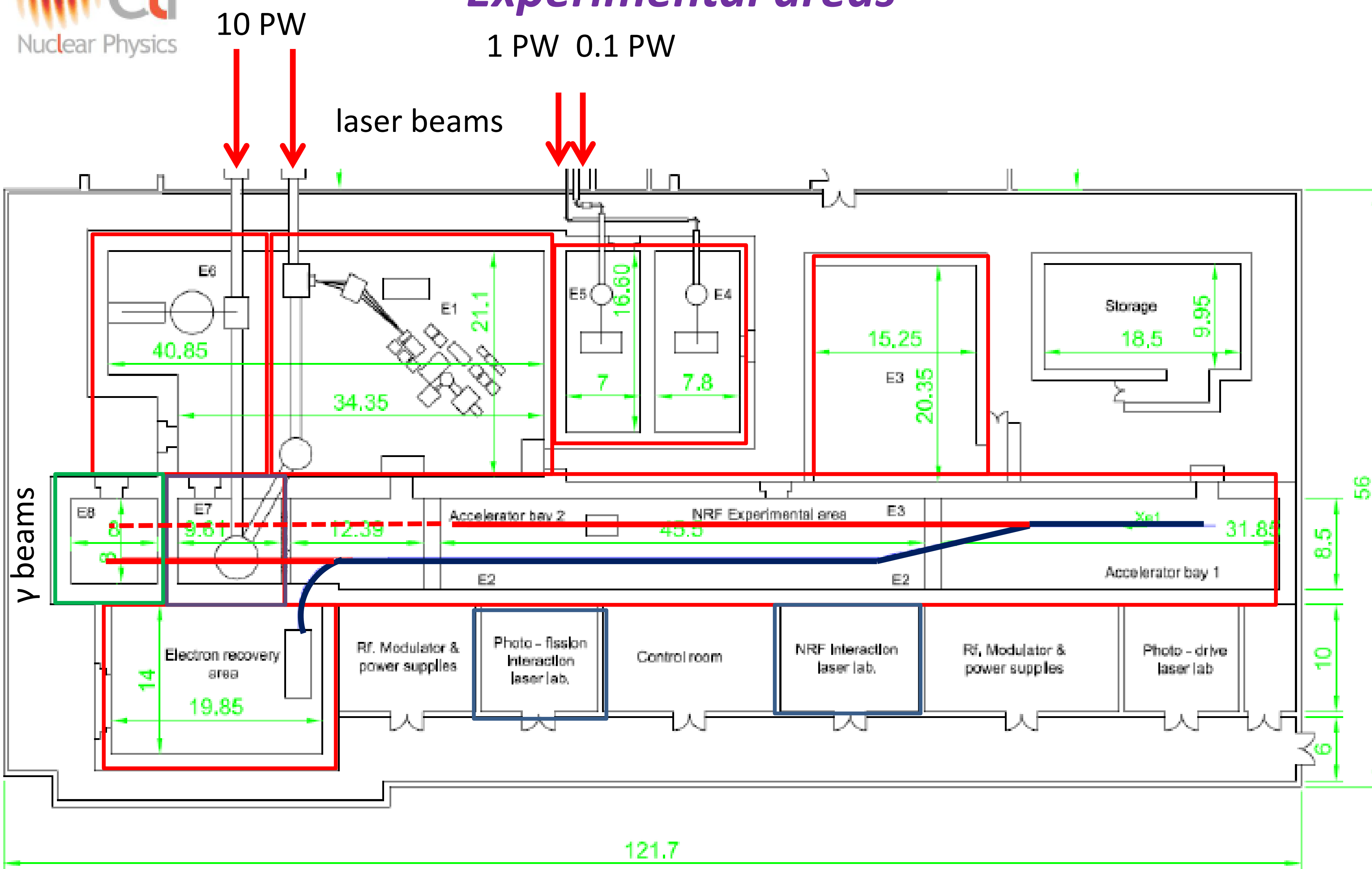



02.02.2014

High-power laser source

Parameter	Range
Available outputs power and repetition rate	Two outputs with 0.1PW at 10Hz two outputs with 1PW at 1 Hz two outputs with 10PW at 1shot/min
Pulse duration	<50 fs
Strehl Ratio	>0.7
Pointing stability	<0.2 microrad
Temporal contrast in the nanosecond range	10^{11}:1 for the 0.1PW outputs 10^{12}:1 extrapolated for the 10PW outputs
Temporal contrast in the picosecond range	10^{11}:1 for the 0.1PW outputs 10^{12}:1 extrapolated for the 10PW outputs
External clock synchronization jitter	<200fs

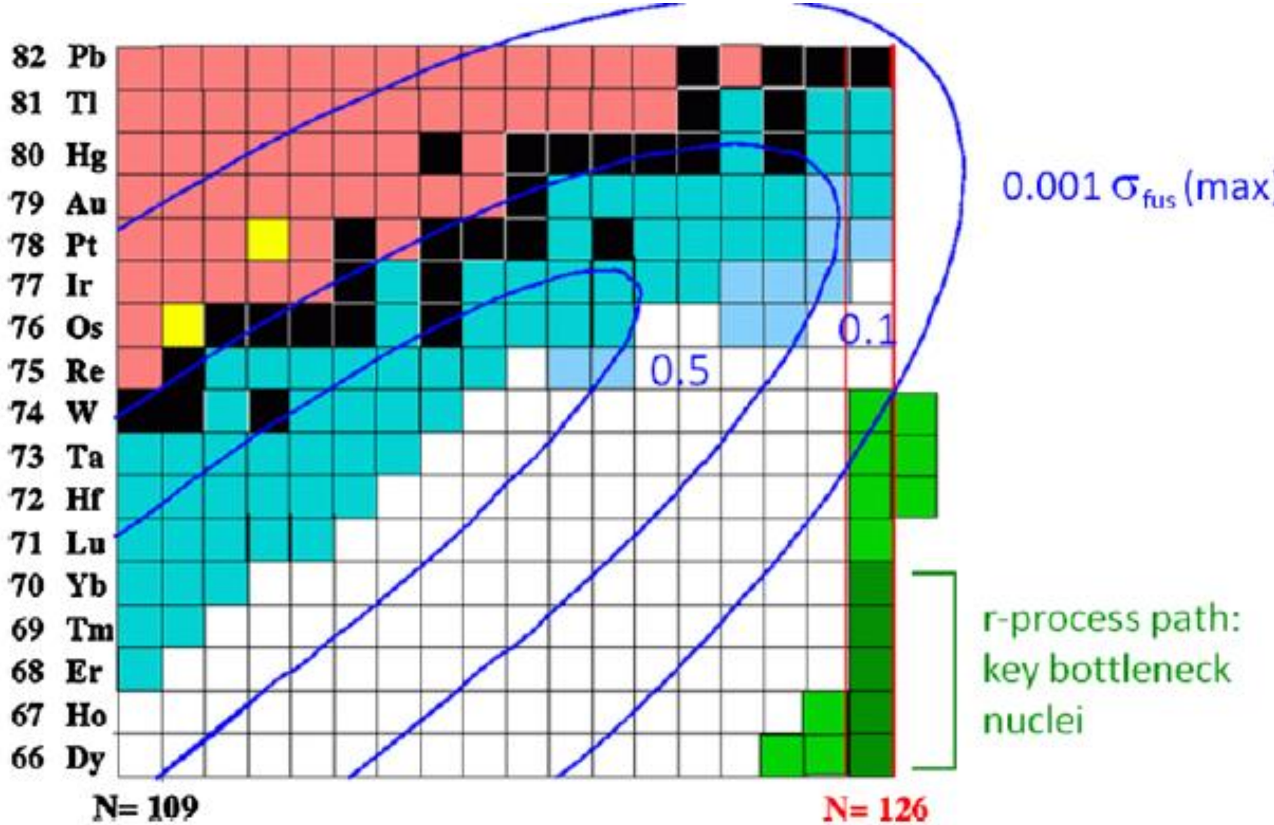
Experimental areas



Laser-

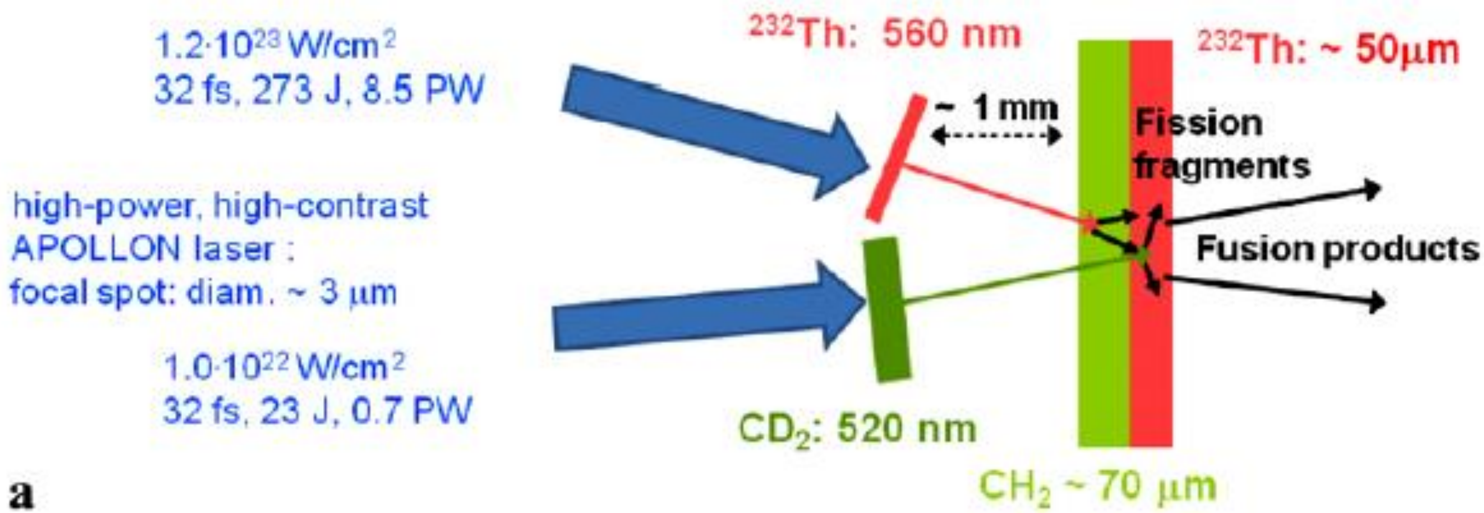
Appl Phys B (2011) 103: 471–484
DOI 10.1007/s00340-010-4261-x

$F_L + F_L \rightarrow \langle {}^{A}Z \rangle \approx {}^{192}Re$

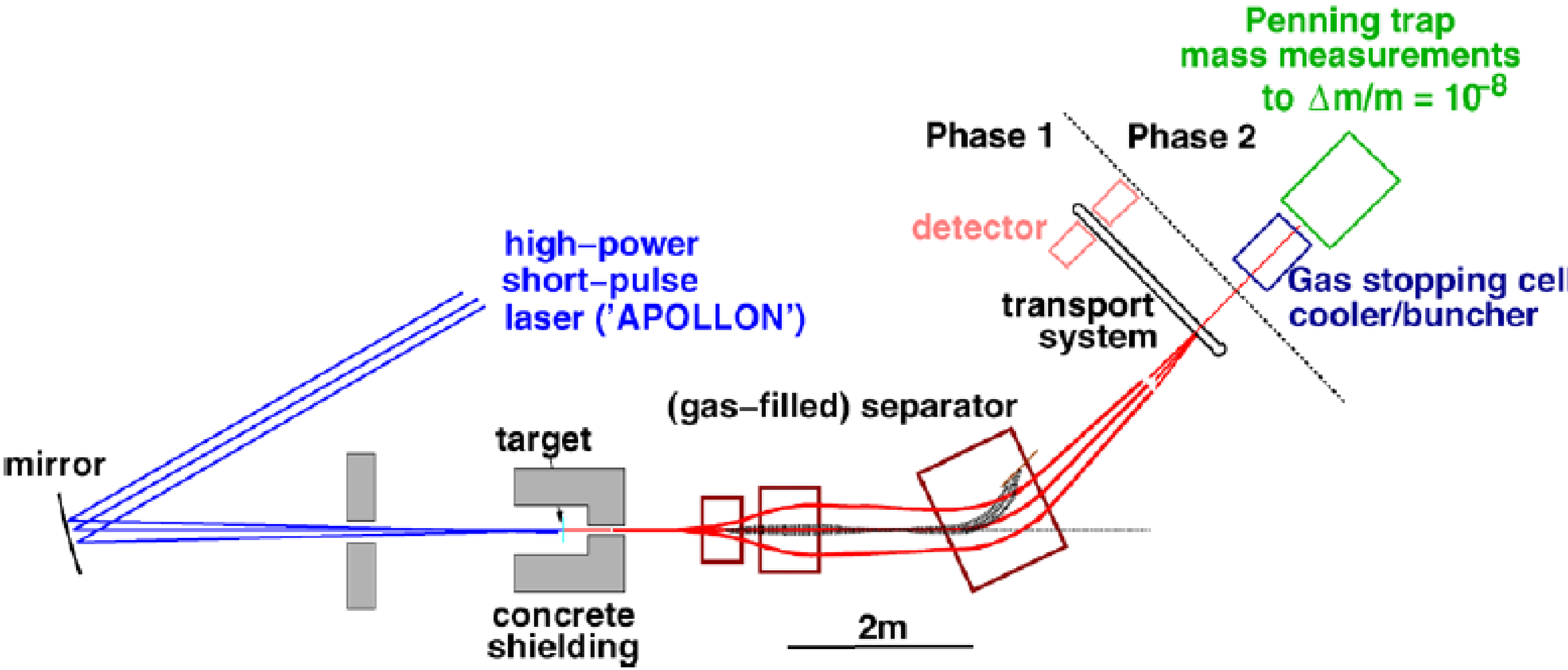


Introducing the fis
a laser-accelerated
towards the $N = 1$

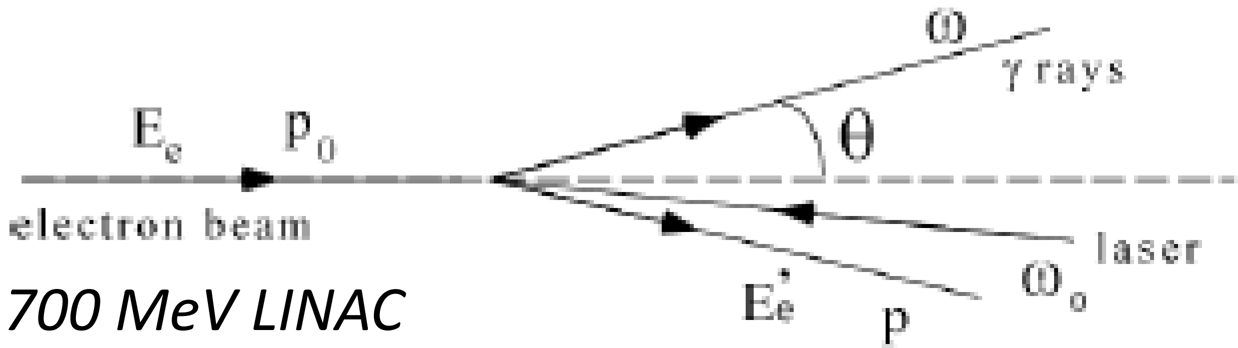
D. Habs · P.G. Thirolf · M. Gr
A. Henig · D. Kiefer · W. Ma ·



Experimental set-up @ ELI-NP



brilliant γ beam



700 MeV LINAC

Parameters of the gamma-beam

type	Units	Range
Photon energy	MeV	0.2 – 19.5
Divergence	Rad	$\leq 2.0 \times 10^{-4}$
Average Relative Bandwidth of Gamma-Ray Beam		$\leq 5.0 \times 10^{-3}$
Time-Average Spectral Density at Peak Energy	1/(s eV)	$\geq 5.0 \times 10^{3}$
Time-Average Brilliance at Peak Energy	$1/(s\ mm^2\ mrad^2\ 0.1\%\ \eta_{,\gamma})$	$\geq 1.0 \times 10^{11}$
Minimum Frequency of Gamma-Ray Macropulses	Hz	≥ 100

ELI-NP: the *F-I-UK* European proposal

European Collaboration for the proposal of a Gamma-Beam System to the ELI-NP Project

European Collaboration for the proposal of the gamma-ray source:

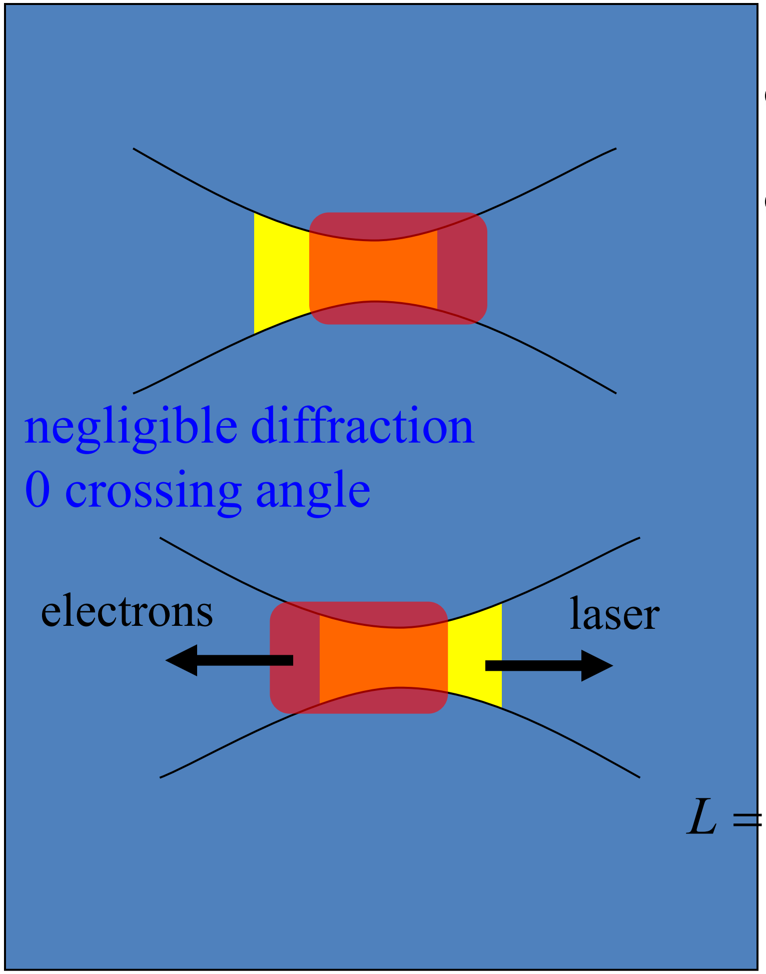
- ✓Italy: INFN,Sapienza
- ✓France: IN2P3, Univ. Paris Sud
- ✓UK: ASTeC/STFC

~ 80 collaborators elaborating the CDR/TDR

ELI-NP requirements:

State of the art + Compact = S-band Photoinjector + C-band linac

Thomson/Compton Sources are electron-photon Colliders, based on the concept of *Spectral Luminosity*, *i.e.* Luminosity per unit bandwidth



$$\sigma_T = 0.67 \cdot 10^{-24} cm^2 = 0.67 \ \ barn$$

- Scattered flux $\boxed{N_\gamma = \mathbf{L}\sigma_T}$ $\boxed{\sigma_T = \frac{8\pi}{3} r_e^2}$
- Luminosity as in HEP collisions
  - Many photons, electrons
  - Focus tightly
  - ELI-NP

$$\boxed{\mathbf{L} = \frac{N_L N_{e-}}{4\pi\sigma_x^2}} f$$

$$L = \frac{1.3 \cdot 10^{18} \cdot 1.6 \cdot 10^9}{4\pi (0.0015 cm)^2} 3200 (sec^{-1}) = 2.5 \cdot 10^{35} cm^{-2} sec^{-1}$$

cfr LHC 10^{34} SuperB-fac 10^{36}

A r.t. RF linac *vs* pulsed laser source

Electron beam parameter at IP	
Energy (MeV)	180-750
Bunch charge (pC) ≤	25-400
Bunch length (µm) ≤	100-400
$\varepsilon_{n-x,y}$ (mm-mrad)	0.2-0.6
Bunch Energy spread (%)	0.04-0.1
Focal spot size (µm)	15-30
# bunches in the train	□31
Bunch separation (nsec)	16
energy variation along the train	0.1 %
Energy jitter shot-to-shot	0.1 %
Emittance dilution due to beam breakup	< 10%
Time arrival jitter (psec)	< 0.5
Pointing jitter (µm)	1

Yb:Yag Collision Laser	Low Energy Interaction	High Energy Interaction
Pulse energy (J)	0.2	0.5
Wavelength (eV)	2.4	2.4
FWHM pulse length (ps)	2-4	2-4
Repetition Rate (Hz)	100	100
M^2	□1.2	□1.2
Focal spot size w_0 (µm)	> 25	> 25
Bandwidth (rms)	0.05 %	0.05 %
Pointing Stability (µrad)	1	1
Sinchronization to an ext. clock	< 1 psec	< 1 psec
Pulse energy stability	1 %	1 %

Accelerator and Equipments in ELI-NP Building ELI-NP-GS

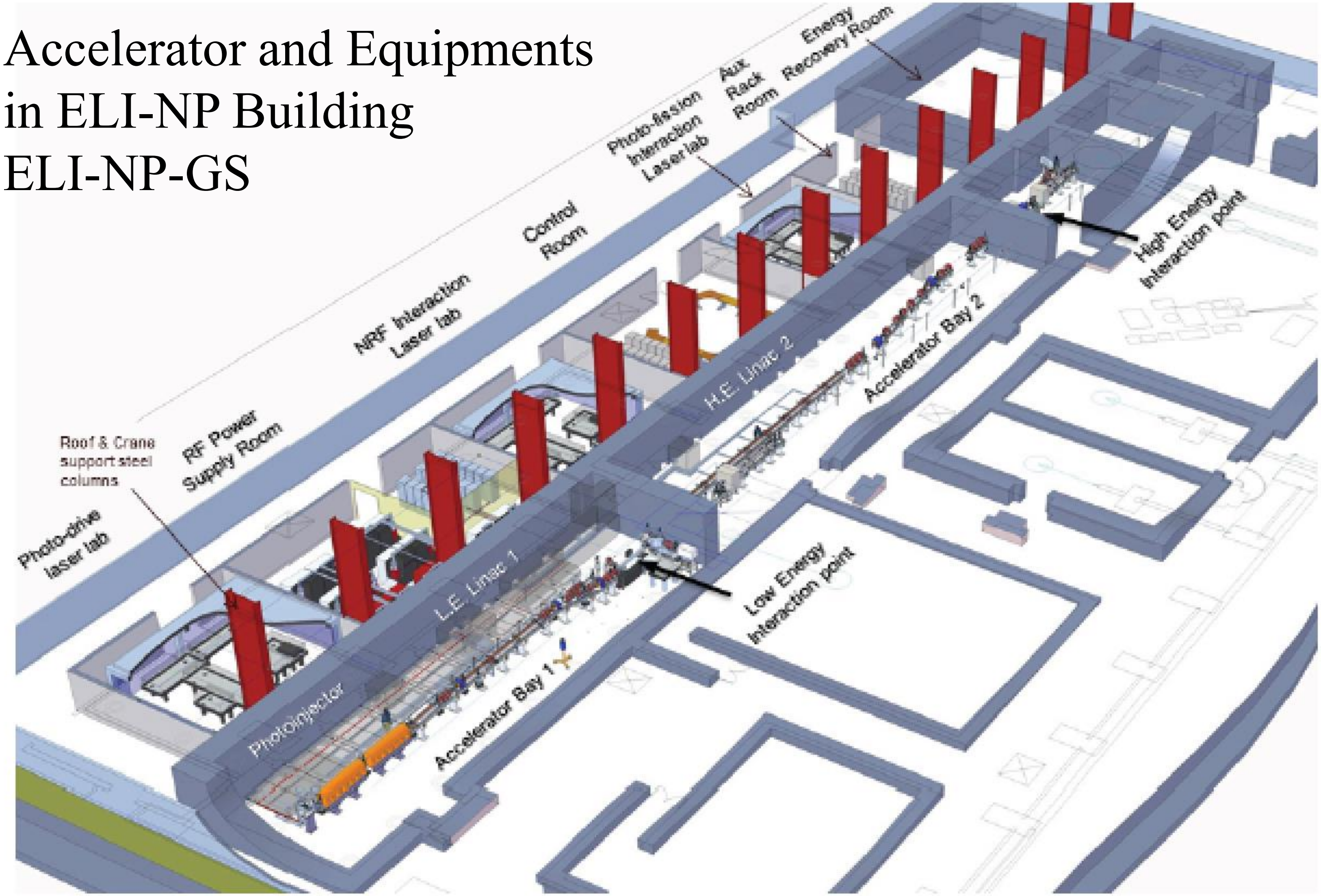


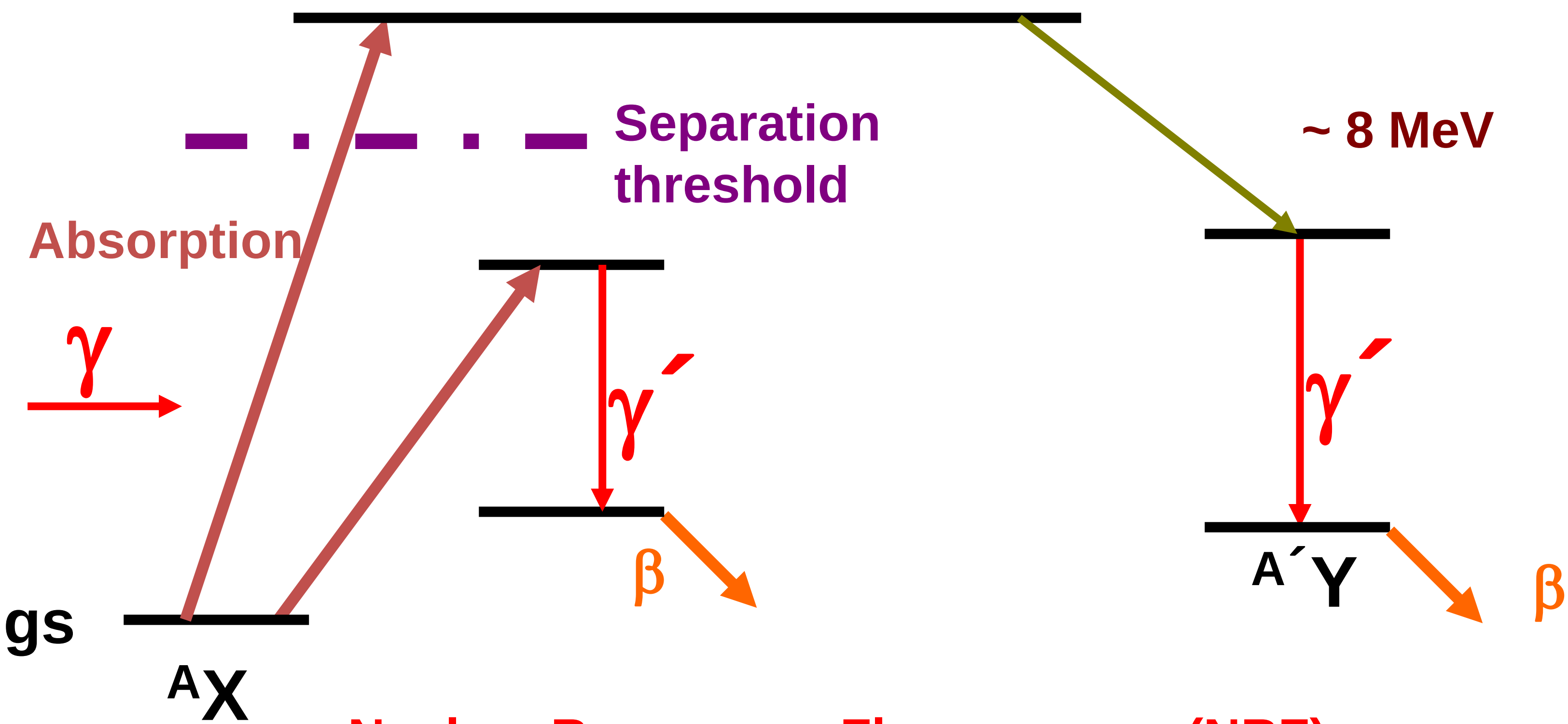
Fig. 197. Isometric 3D view of Building Layout of the Accelerator Hall & Experimental Areas

Main Parameter Tables of ELI-NP-GBS

Table 1: Summary of Gamma-ray beam Specifications

Photon energy	0.2-19.5 *MeV*
Spectral Density	0.8-4·10⁴ *ph/sec.eV*
Bandwidth (rms)	≤ 0.5%
# photons per shot within FWHM bdw.	≤ 2.6·10⁵
# photons/sec within FWHM bdw.	≤ 8.3·10⁸
Source rms size	10 - 30 *μm*
Source rms divergence	25 - 200 *μrad*
Peak Brilliance ($N_{ph}/sec \cdot mm^2 mrad^2 \cdot 0.1\%$)	10^{20} - 10^{23}
Radiation pulse length (rms, *psec*)	0.7 - 1.5
Linear Polarization	> 99 %
Macro rep. rate	100 *Hz*
# of pulses per macropulse	≤ 32
Pulse-to-pulse separation	16 *nsec*

Photonuclear Reactions



Nuclear Resonance Fluorescence (NRF)
Photoactivation
Photodesintegration (-activation)
Photofission

TDR working groups and instruments

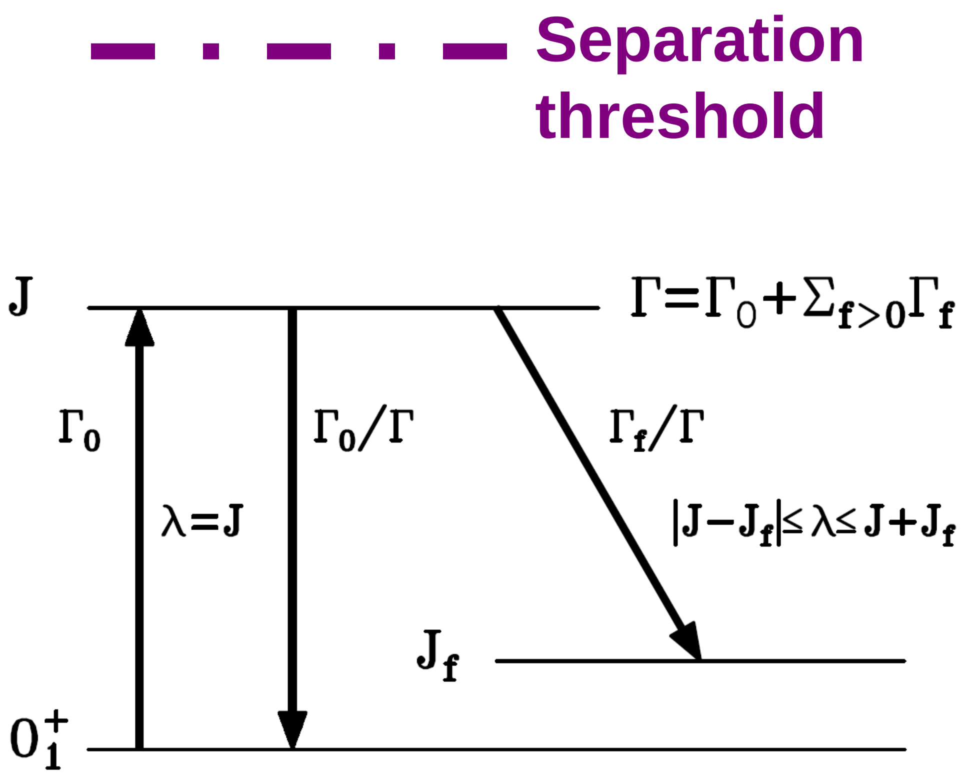
Gamma-beam TDR working groups

1. Excitations above the threshold (conveners: Hiroaki Utsunomiya, Franko Camera, ELI-NP liaison: Dan Filipescu)
2. Nuclear Resonance Fluorescence (convenor: Norbert Pietralla, liaison: Calin Ur)
3. Photo-fission (conveners: Fadi Ibrahim, Attila Krazsnahorkay, liaison: Dimiter Balabanski)
4. Charged-particle experiments (convener: Moshe Gai, liaison: Ovidiu Tesileanu)
5. Gamma-beam transport (ELI-NP liaision: Calin Ur)
6. Positron beams (ELI-NP liaision: Cristian Teorurescu)

Laser-beam TDR working groups

1. Laser-beam delivery (convener: Gilles Cheriaux, liaison: Daniel Ursescu)
2. Fission fusion experiments (convener: Markus Roth, liaison: Florin Negoita)
3. Strong-filed QED (conveners: Paul MacKenna, Dino Jaroszynski, liaison: Edmond Turku)
4. Combined laser-gamma experiments (convener: Kensuke Homma, liaison: Daniel Ursescu)
5. Laser control system (ELI-NP liaison: Mihai Cernaianu)

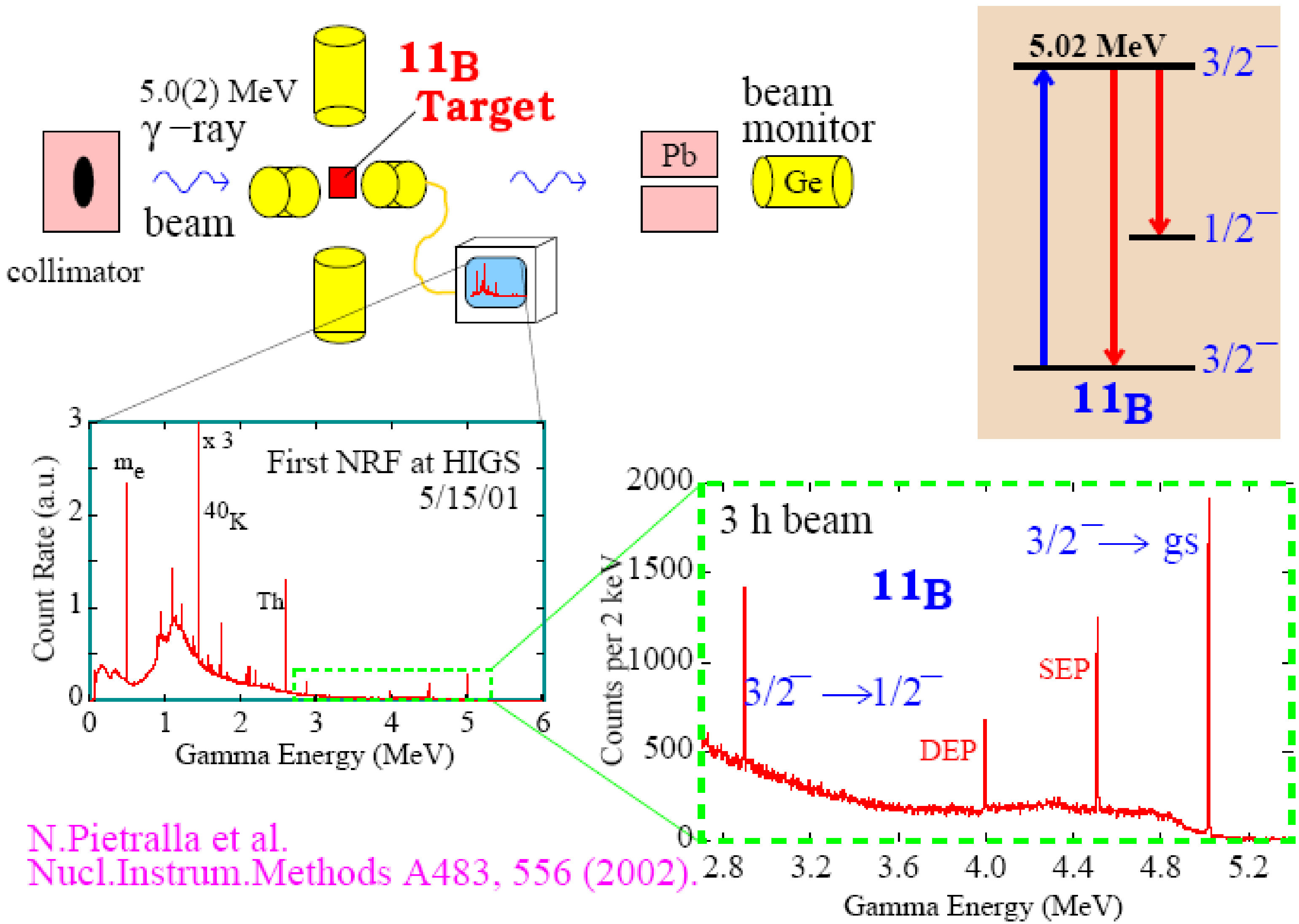
Nuclear Resonance Fluorescence



<u>Observables</u>

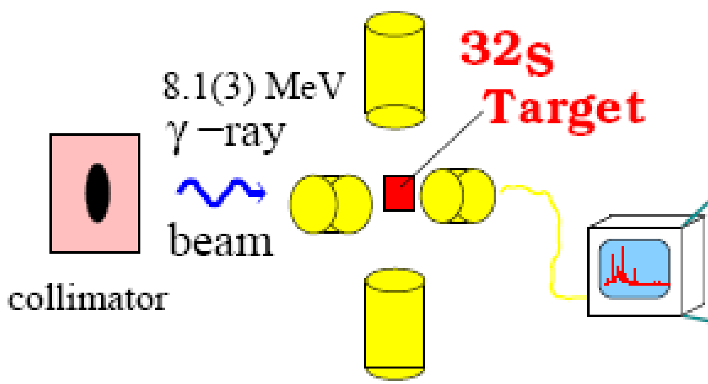
- Excitation Energy E_r
- Spin *J*
- Parity π
- Decay Energies E_γ
- Partial Widths Γ_i/Γ_0
- Multipole Mixing δ
- Decay Strengths $B(\pi\lambda)$
- Level Width Γ (eV)
- Lifetime τ (ps – as)

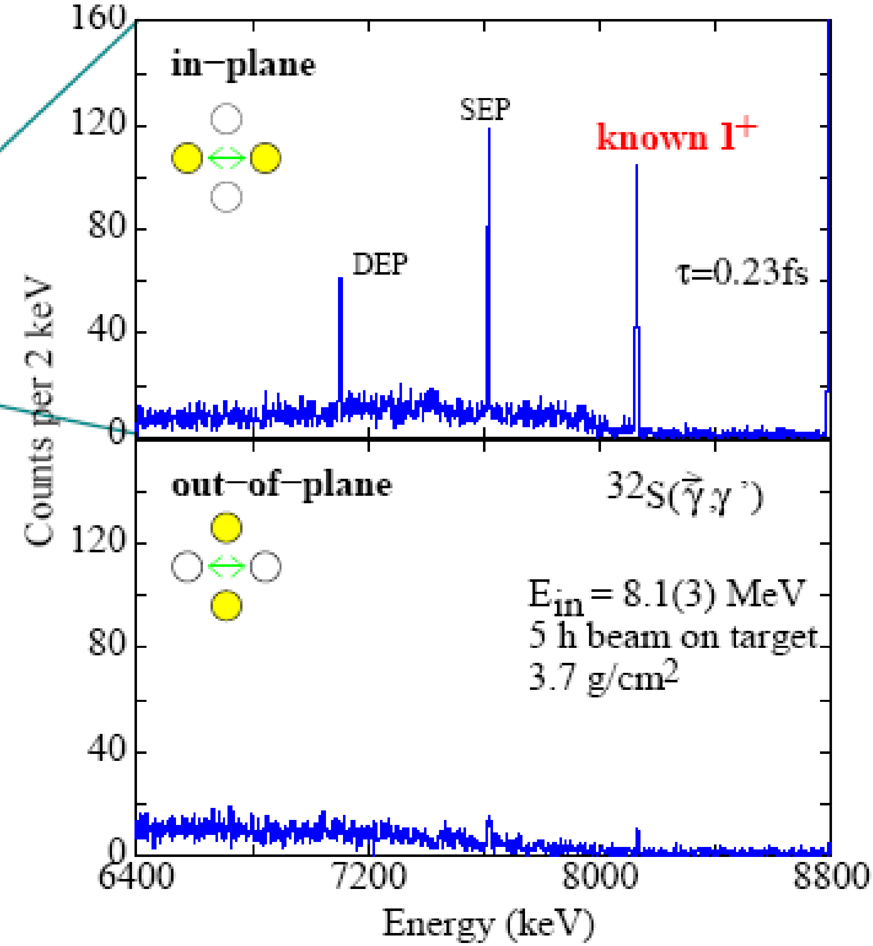
Sample NRF Spectra



N.Pietralla et al.
Nucl.Instrum.Methods A483, 556 (2002).

NRF Proof of Principle

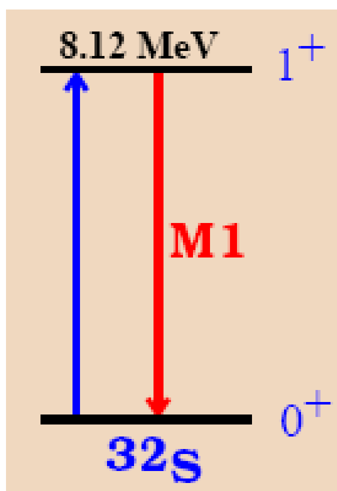




DFELL/TUNL polarimeter

Asymmetry

~ 80%



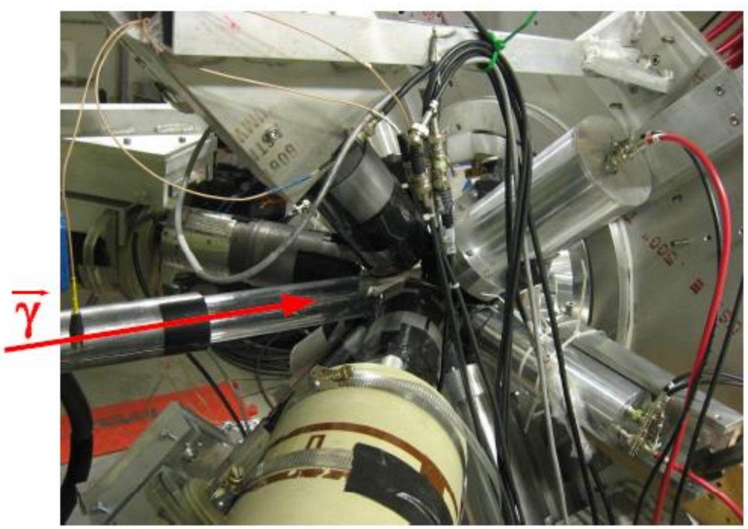
N.Pietralla et al., Nucl.Instrum.Methods A483, 556 (2002).

NRF Setup γ^3 @ HIγS

ELIADE array at ELI-NP (8-12 anti-Compton shielded Clover detectors)

The γ^3 setup installed @ HIγS in summer of 2012.

4 x 60% HPGe
4 x 3"x 3" $LaBr_3$
4 x 1.5" x 1.5" $LaBr_3$



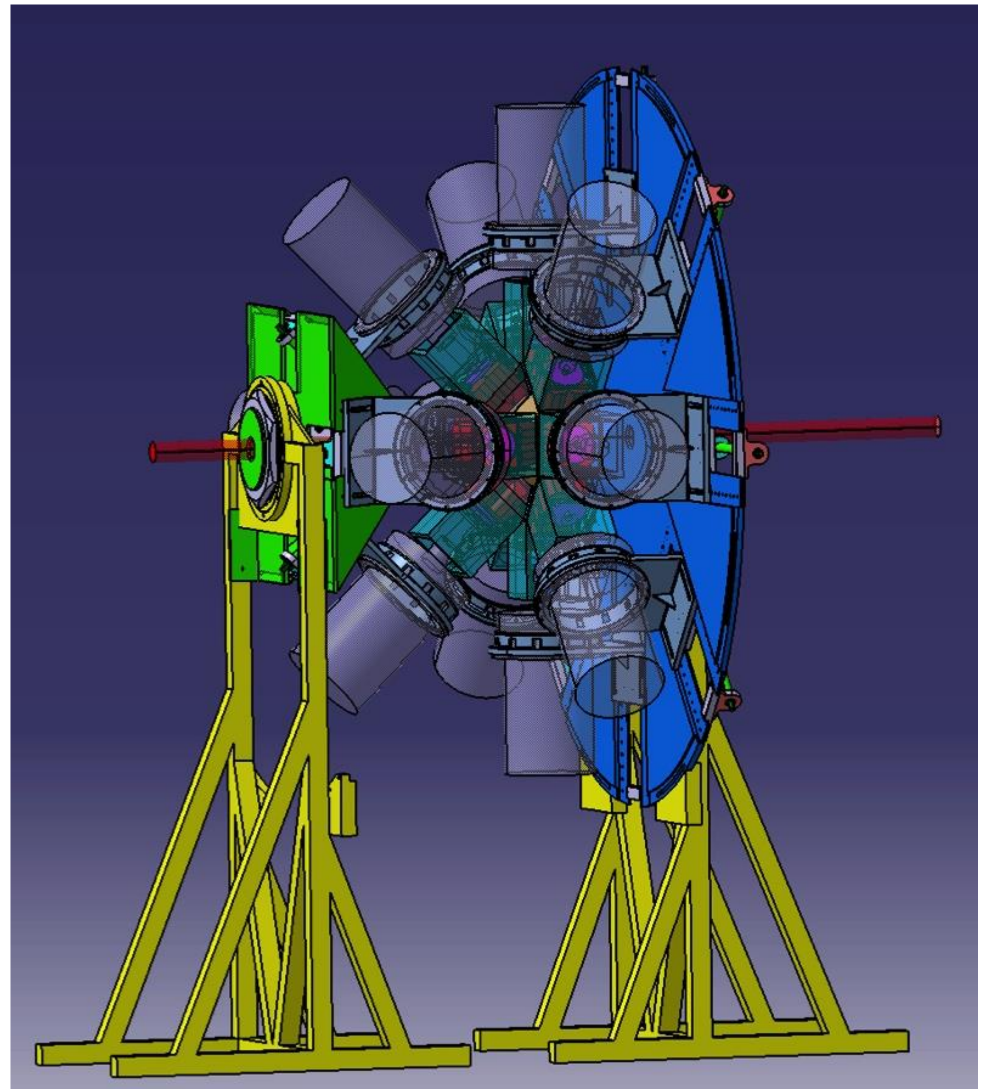


Photo-fission @ ELI-NP

Attila Krasznahorkay

Fadi Ibrahim

Dimiter L. Balabanski

EPJ Web of Conferences **38**, 08001 (2012)
DOI: 10.1051/epjconf/20123808001

Perspectives for photofission studies with highly brilliant, monochromatic γ-ray beams

P.G. Thirolf[1,a], L. Csige[1], D. Habs[1,2], M. Günther[2], M. Jentschel[3], A. Krasznahorkay[4], D. Filipescu[5], T. Glodariu[5], L. Stroe[5], O. Tesileanu[5], H. Karwowski[6], and G. Rich[6]

Photonuclear physics is a well-established field of research since decades [1]. Mostly bremsstrahlung has been used to excite nuclei or to induce fission in the actinides [2].

Table 1. Comparison of performance properties of existing and upcoming γ-beam facilities.

	HIγS	HIγS2	MEGa-Ray	ELI-NP
$E_\gamma [MeV]$	2-100	2-100	< 8	< 19
total flux [γ/s]	$\sim 10^9$	$5 \cdot 10^{12}$	10^{13}	10^{13}
$\Delta E/E$	$2\text{-}5 \cdot 10^{-2}$	$\leq 10^{-3}$	$\leq 10^{-3}$	$\leq 10^{-3}$
spectral density [γ/eVs]	10^2	10^4-10^6	10^4-10^6	10^4-10^6

Photo-fission experiments
Physics goals

- High-resolution photofission studies in actinides → investigation of 2nd, 3rd potential minima, angular and mass distribution measurements.

- measurements of absolute photofission cross sections:

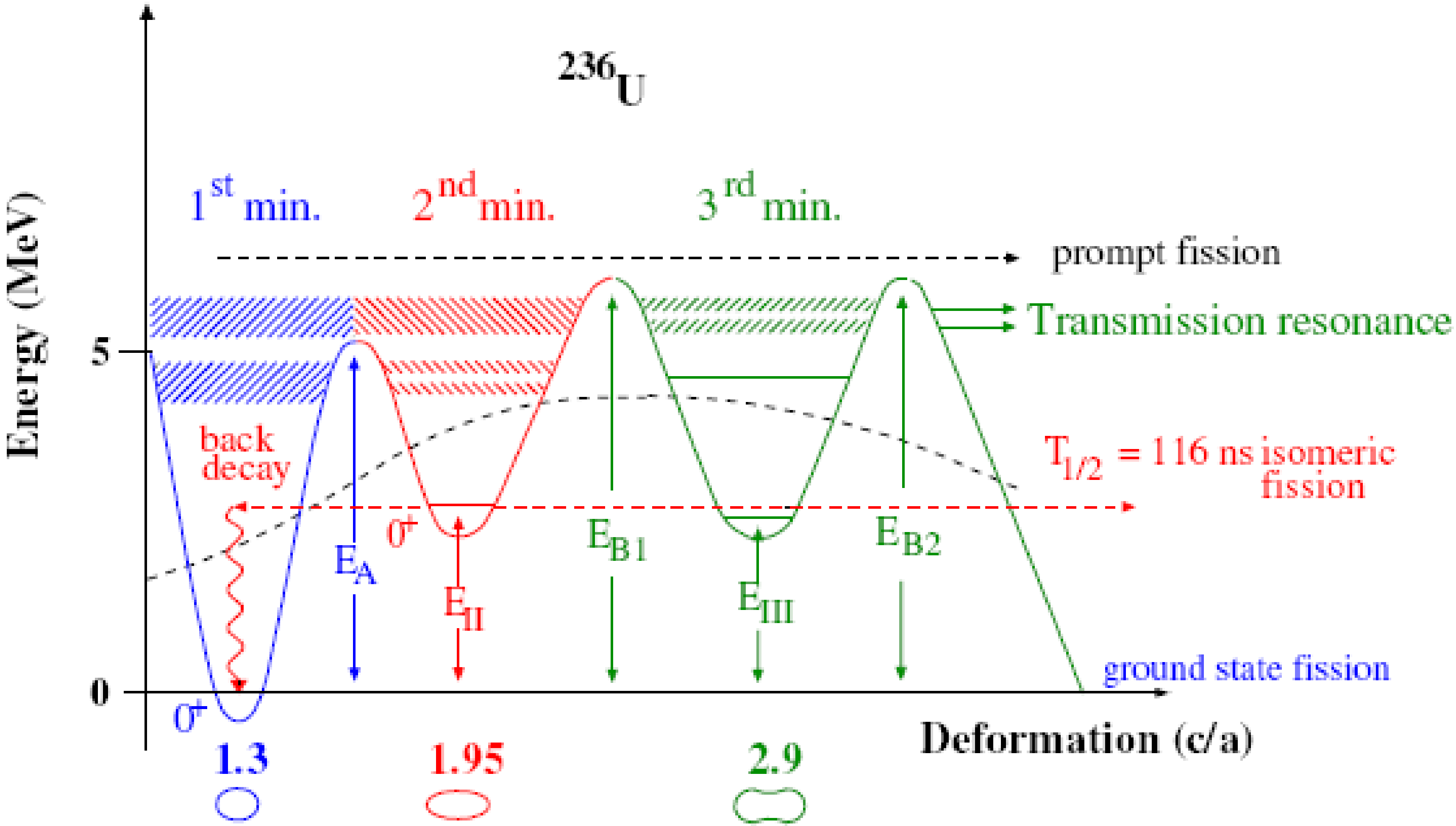
→ (monochromatic photons with variable energy required)

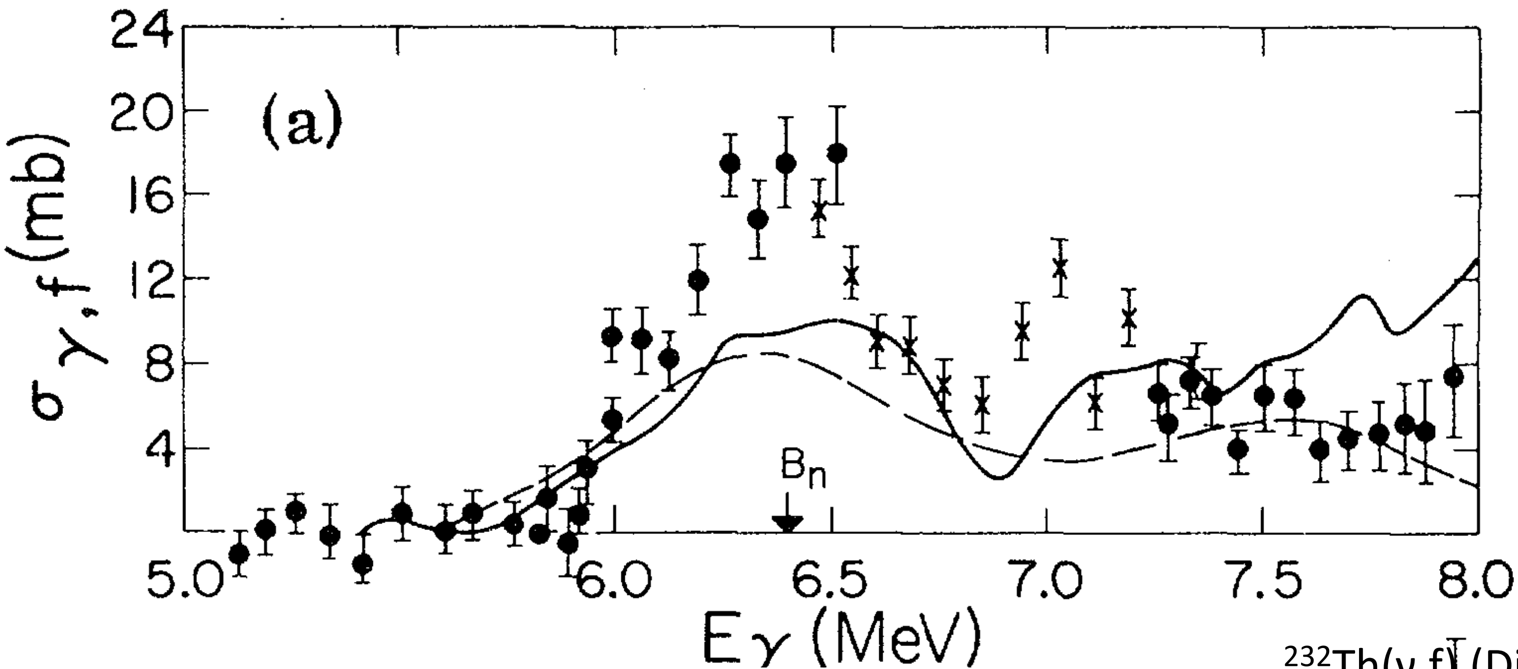
- limited photon source intensity:

→ target thickness limited by finite range of fission fragments (ca. 8 mg/cm^2 in uranium)

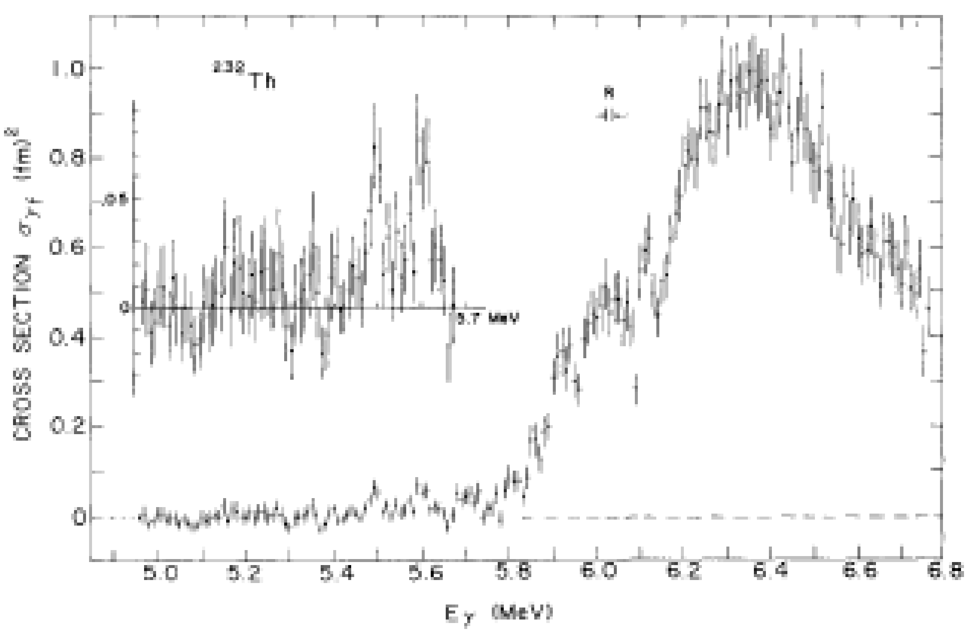
→ multiple target-detector arrays needed

Resonant tunneling through the triple humped fission barrier





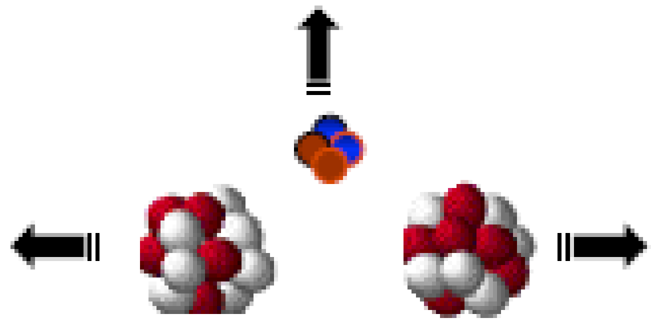
^{232}Th(γ,f) (Dickey 1975)



^{232}Th(γ,f) (Knowles 1982)
PLB 116B (1982) 315

Ternary fission studies with ELI-NP

Ternary Fission



The two heavy fragments are sometimes accompanied by a Light Charged Particle : Ternary fission

(roughly 2 to 4 times every thousand events depending on the mass of the fissioning nucleus)

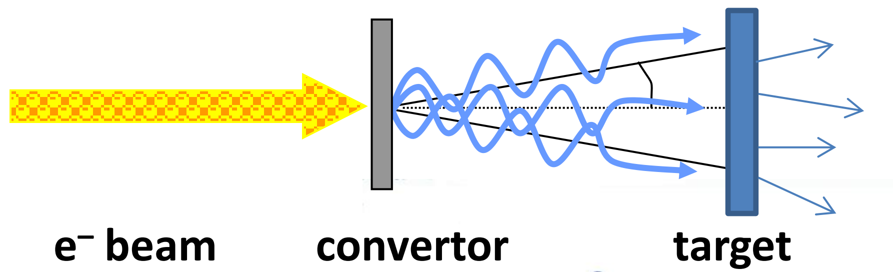
Let's see what else we can squeeze from photo-fission?

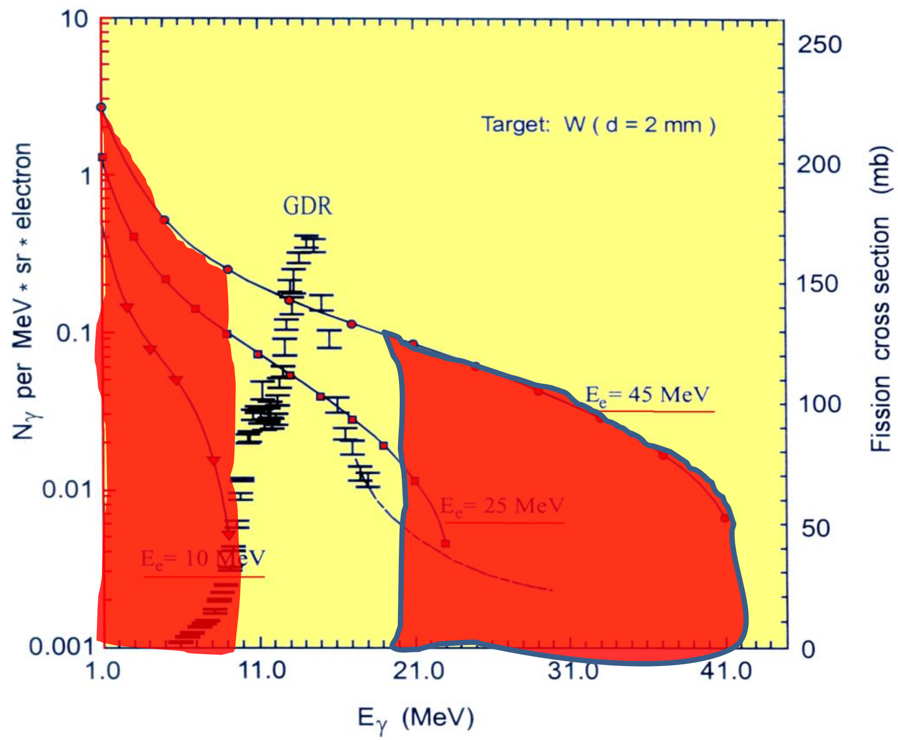
In fission fragments share about 200 MeV and have angular momentum of $20\hbar$. The nuclear spin ensemble has oblate orientation with respect to the beam axis. The ions are emitted in a charge state around 20^{+}.

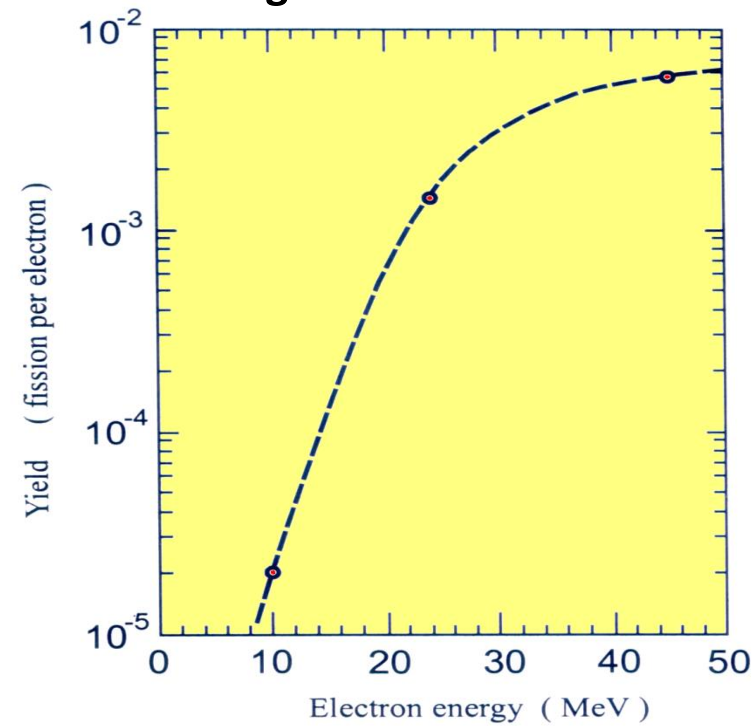
Optional experiments

- *ISOL studies of exotic nuclei*
- *High-spin physics of exotic nuclei*

Production of fission fragments by photo-fission ALTO

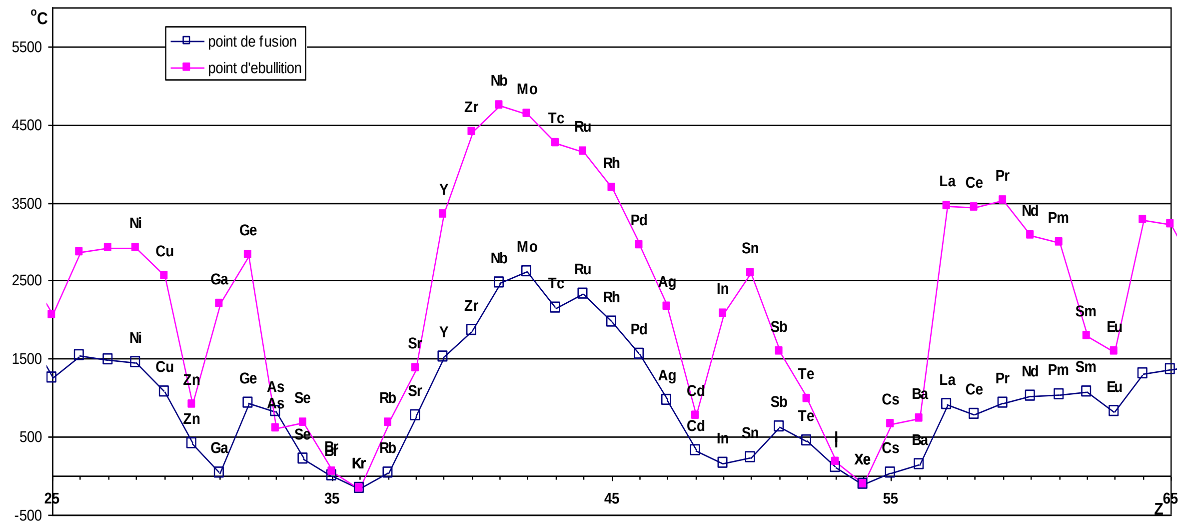




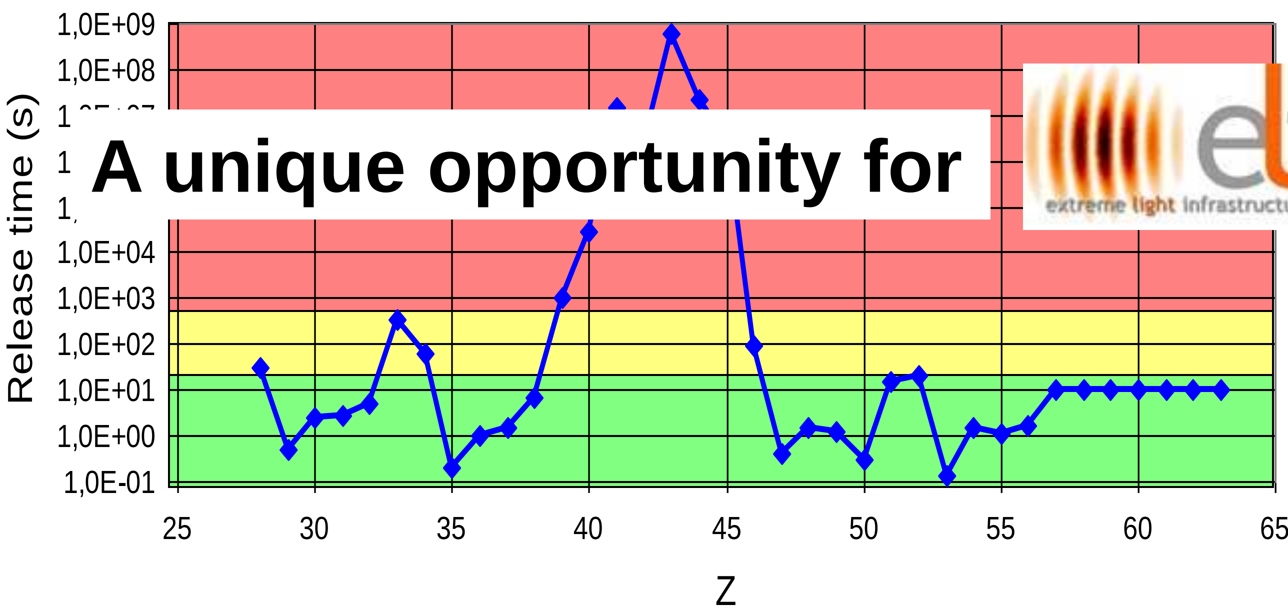


With 10 μA electrons at 50 MeV at ALTO they have 1.6 10^{13} γ at 15 MeV

What about the refractory elements ?



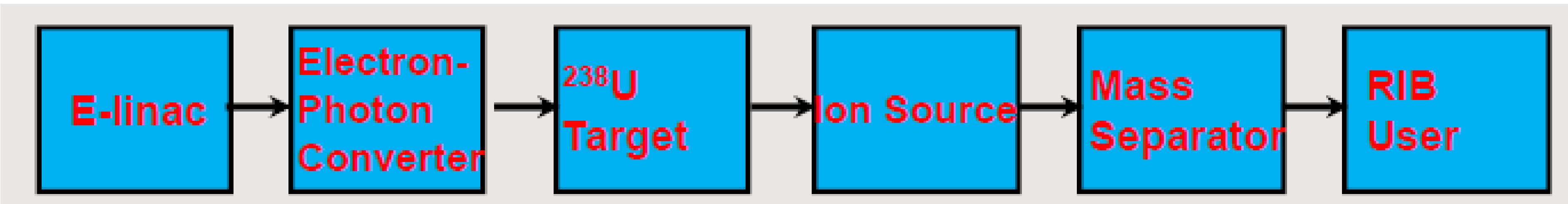
Boiling point & Melting point



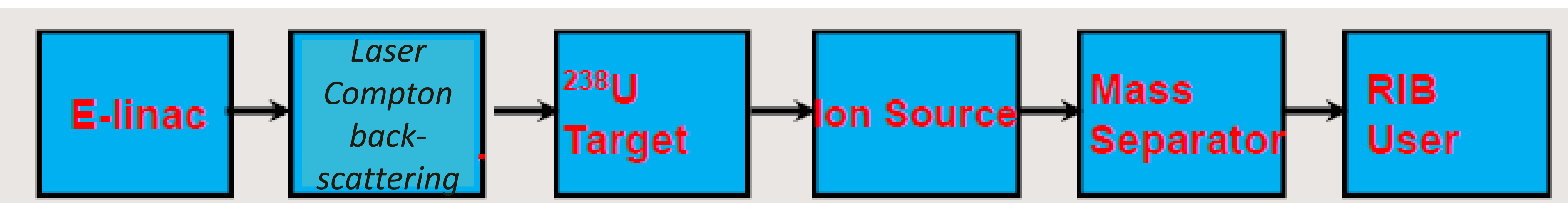
A unique opportunity for

Taken from PIAFE project Report based on Studsvik measurements

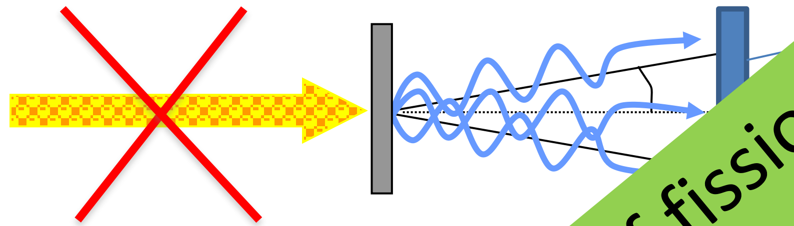
ALTO, ARIEL, etc.



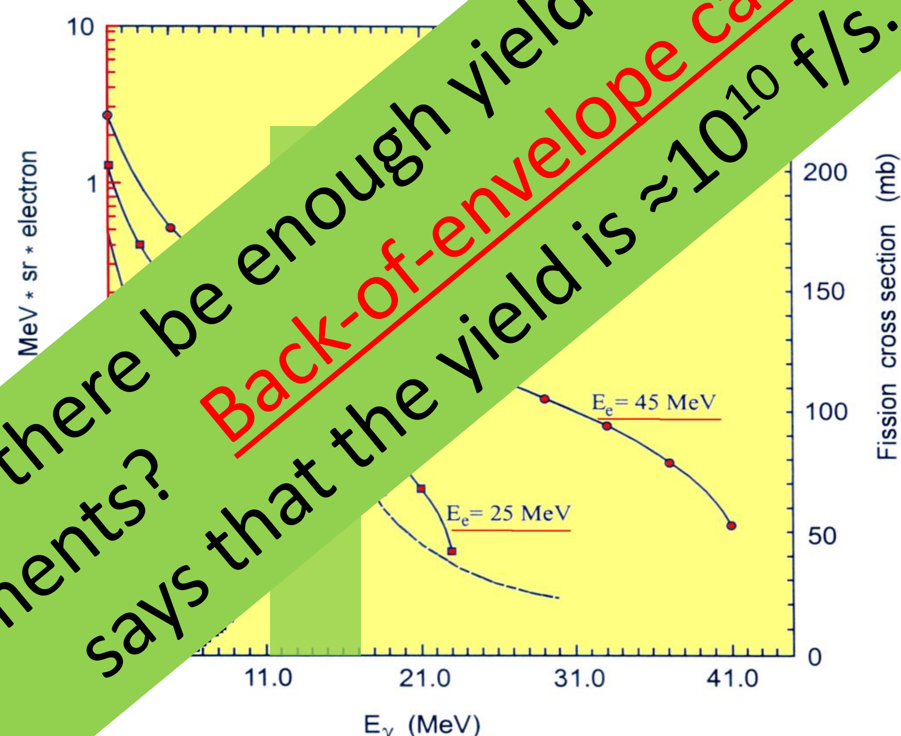
ELI-NP



Production of fission fragments by photo-fission at ELI



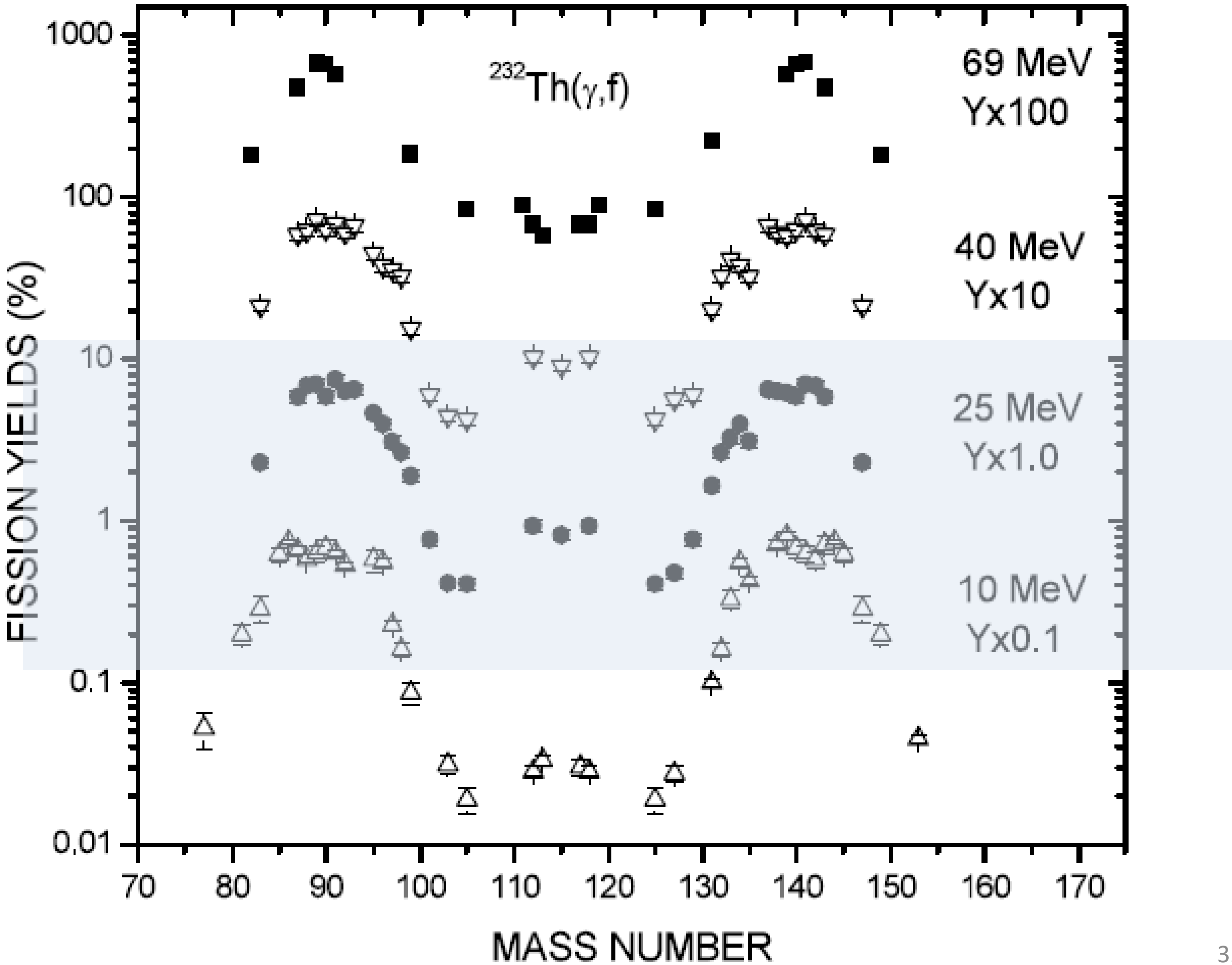
$\Phi = 1.4 \cdot 10^{12}$ γ/s



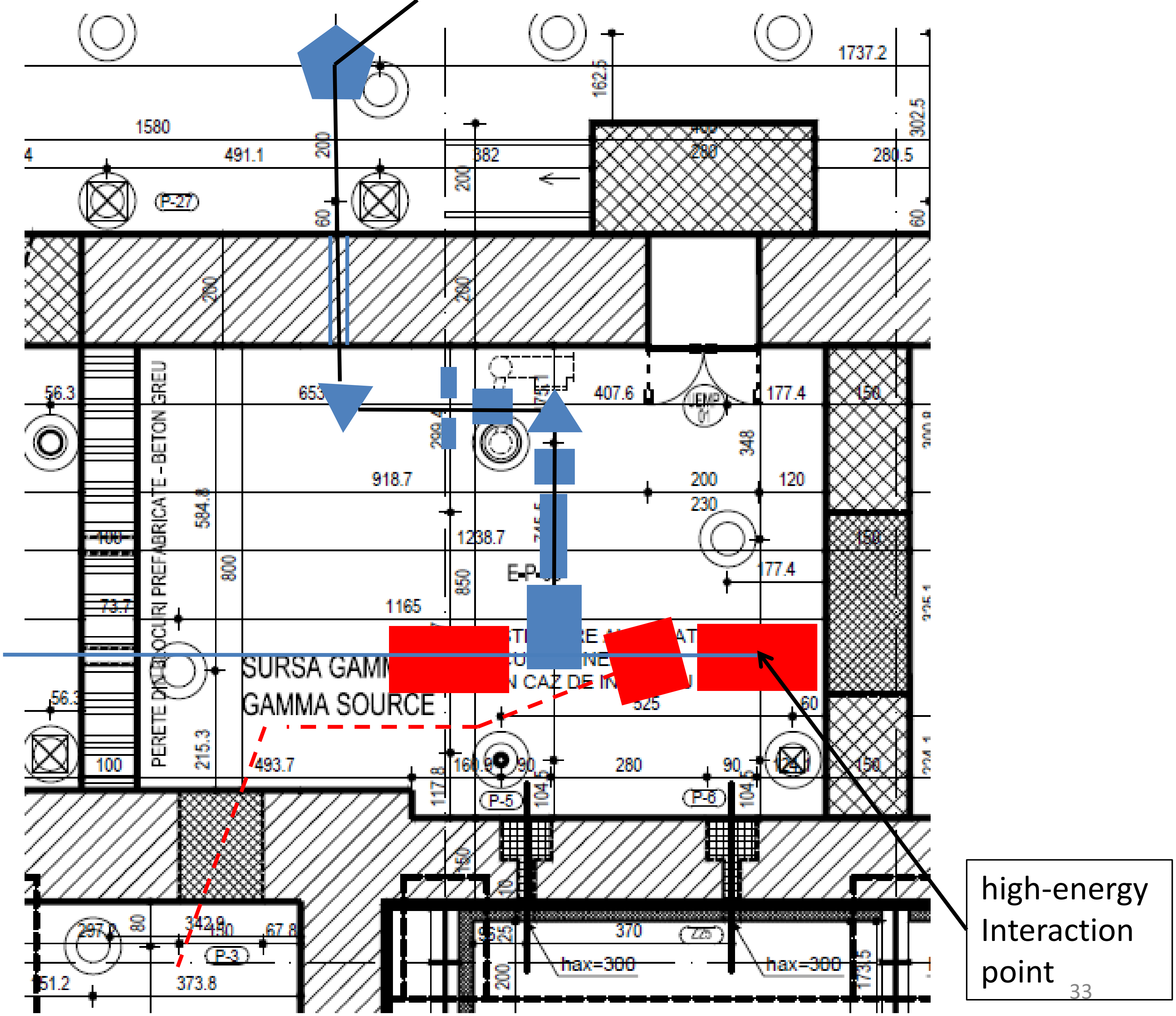
Will there be enough yield of fission fragments? Back-of-envelope calculation says that the yield is $\approx 10^{10}$ f/s.

Φ. s. N= Φ.6,4 10^{-3} f/s

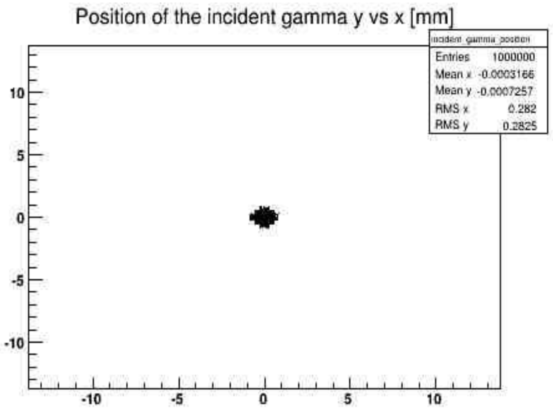
H. Naik et al. / Nuclear Physics A 853 (2011) 1–25

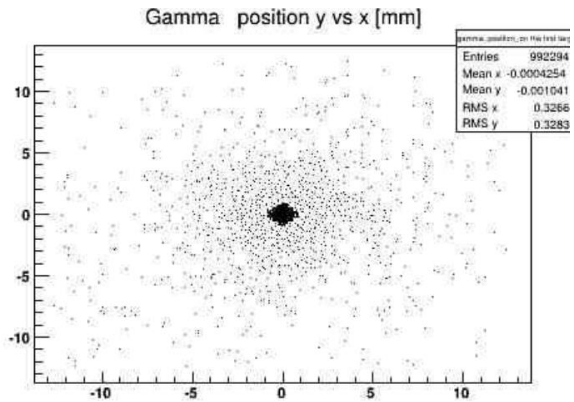


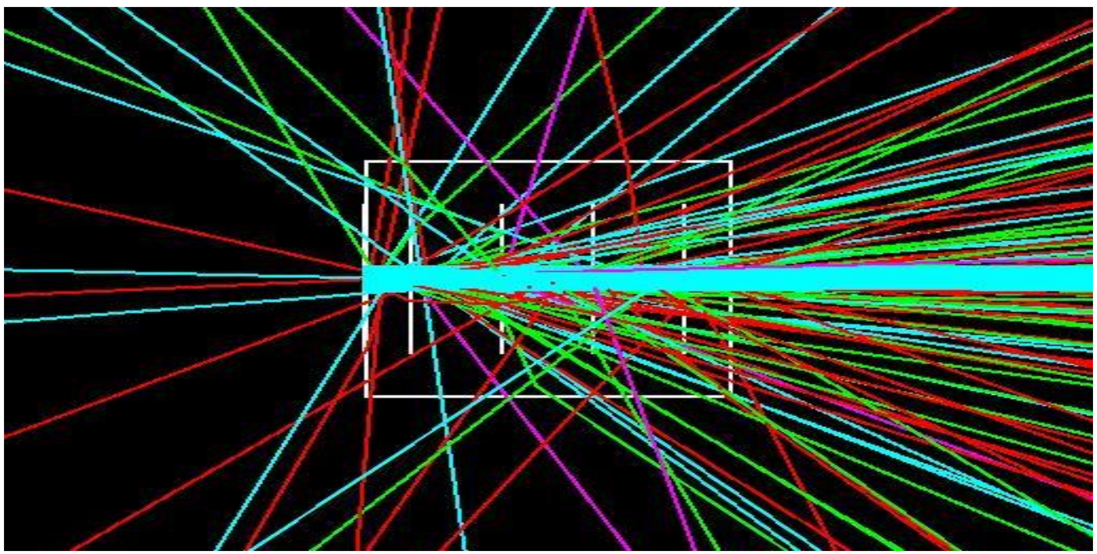
Phase 1


SURSA GAMM
GAMMA SOURCE
PERETE DIN BLOCURI PREFABRICATE - BETON GREU
high-energy Interaction point

Yield estimates





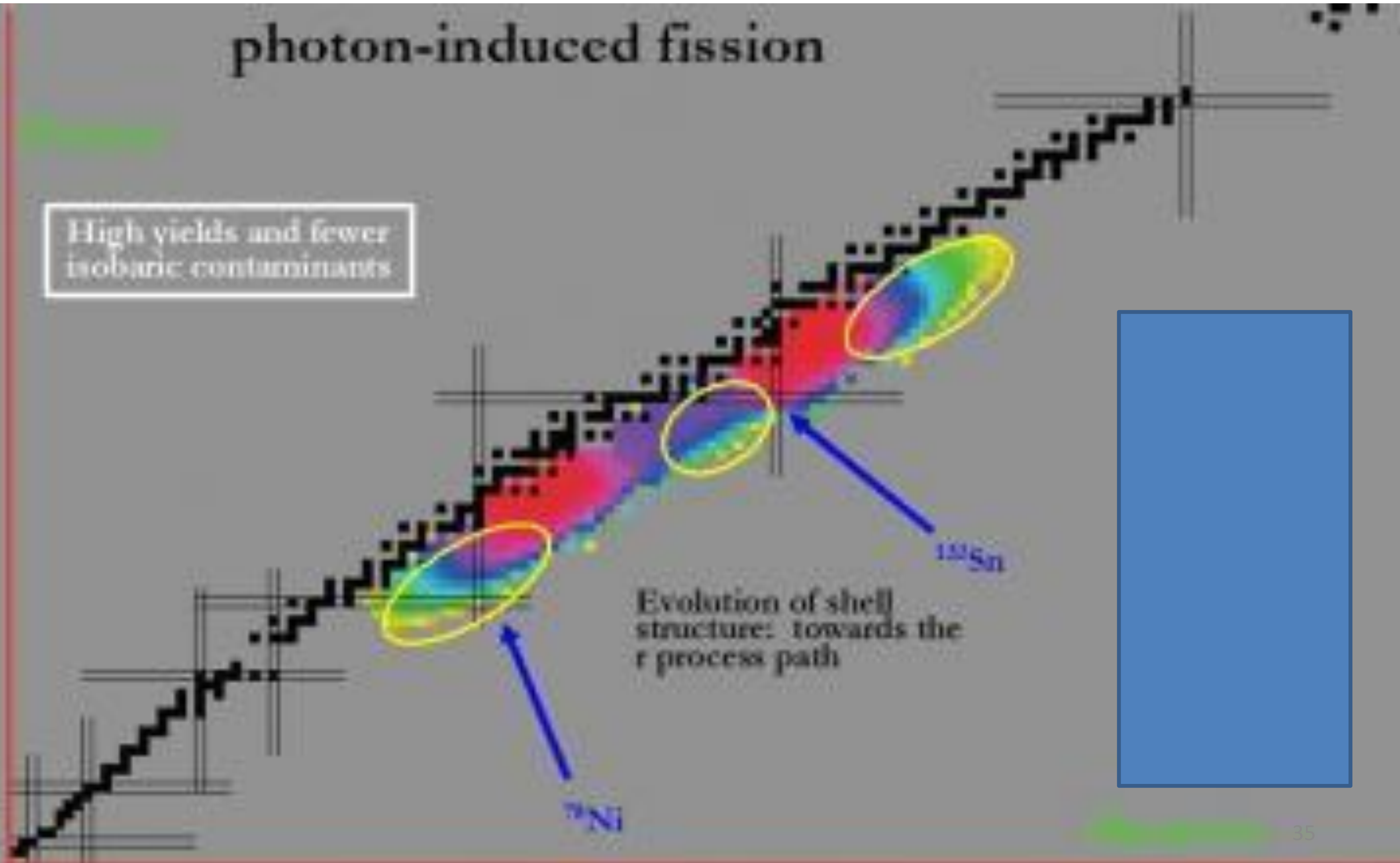


Yield: $6.2 \cdot 10^8$ f/s

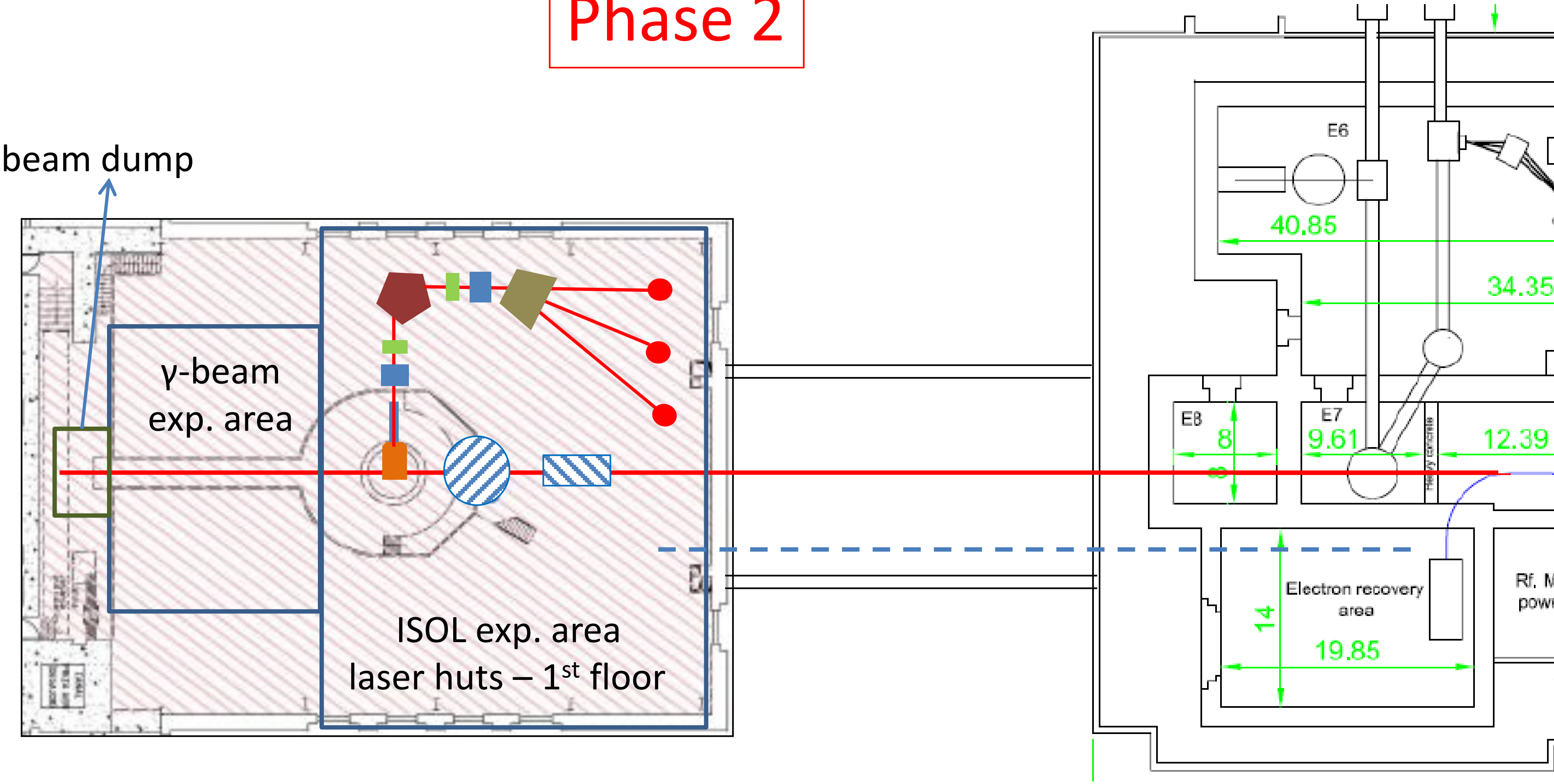
with a stack of targets:

$\approx 10^{10}$ f/s

Al window 19.17 mg/sm^2
^{238}U targets of 19.1 mg/sm^2


photon-induced fission
High yields and fewer isobaric contaminants
Evolution of shell structure: towards the r process path
Sn
Ni

Phase 2



Research Reactor
(end of decommissioning 2017)

ELI –NP (commissioning 2017)

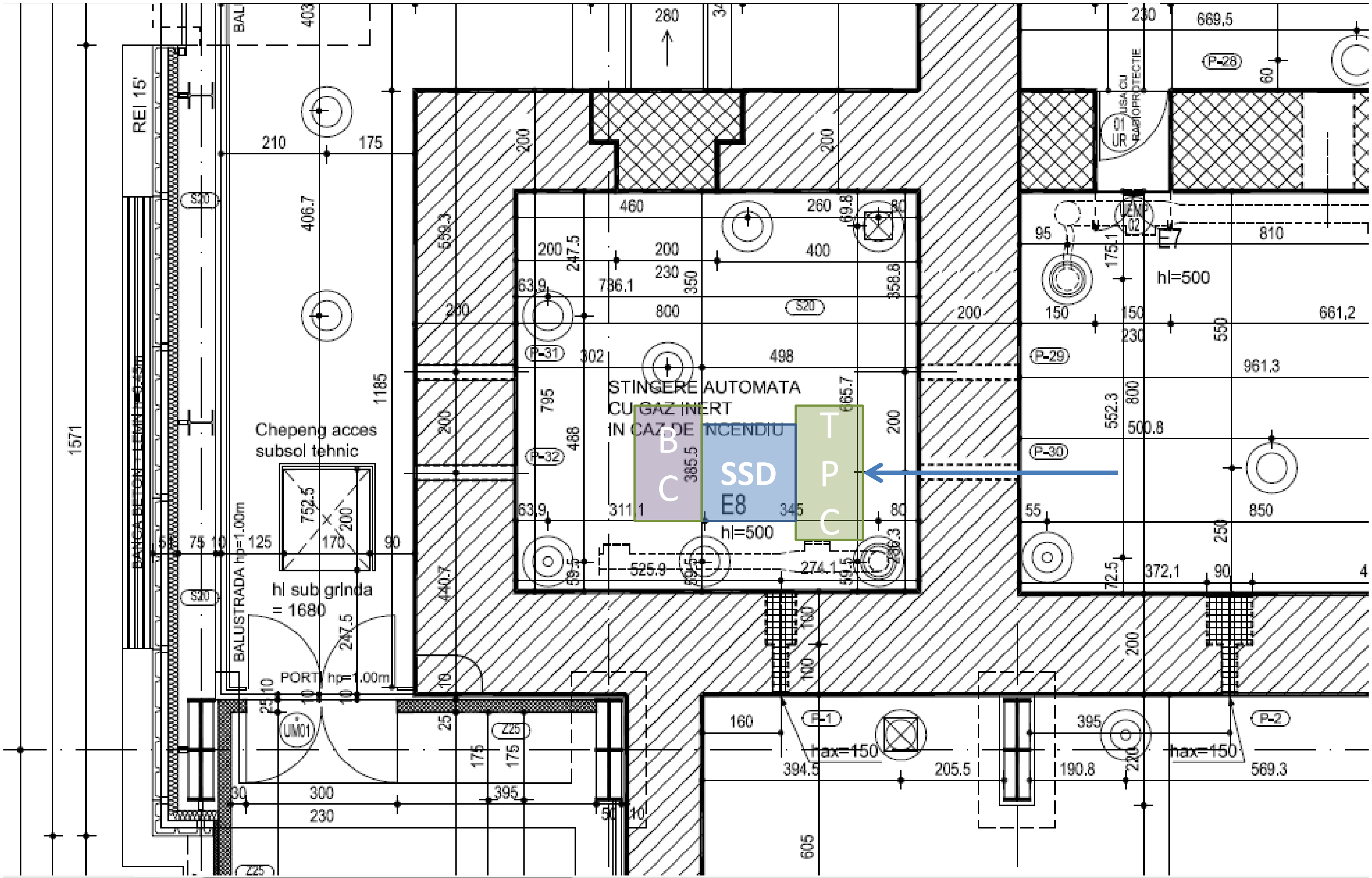
Nuclear Astrophysics at ELI-NP
Scope of the CPWG

- **Requirements for detection:**
  - Light Ions, A < 12, “0” – 10 MeV, up to a kHz.
  - Photofission product, high Z, <10 MeV/u
  - Total Energy ($\Delta E \sim 1\%$), Particle ID, Angle ($\Delta\Theta < 5°$)
  - Position sensitive
  - Tracking
  - Diagnosis system
  - 4π

Goal: e.g. $^{16}O(\gamma,\alpha)^{12}C$ at the threshold

- **Three options of detectors:**
  - **Bubble chamber**
  - **[O]-TPC**
  - **4π Silicon Strip Detector**

Footprint



Total: about 14 ± 4 m^2

Instrumentation (gamma beams)

NRF set-up (the ELIADE array)

- rings of segmented HPGe detectors (8-12 Ge Clovers)
- good timing detectors

Nuclear structure set-up: modular and very flexible

- high resolution neutron detection
- gamma-ray detection with medium resolution (20 $LaBr_3$ det.)
- high-resolution γ-ray detection (in some cases)

THGEM + DSSD detector set-up for cross section measurements

Gas-filled Bragg spectrometers

4π DSSSD detector set-up

Gas-filled TPC

Bubble chamber

Production of RIB with IGISOL-type technique

Tape station and Ge array for decay studies

Multi-reflection trap

Collinear laser spectroscopy beam line

Extreme Light Infrastructure – Nuclear Physics

Finally

1. There are many scientific and technical challenges ahead of us. However, time is short and we need to find solutions now.
2. ELI-NP is open for collaborations. We are building a user community. Formal collaborations to be established through MoUs.
3. Cooperation between nuclear and laser physicists needs to be established, e.g. first unify the language (!)

Job opportunities

The ELI-NP research teams will consist in **218 researchers, engineers and technicians** (25 heads of research and senior researchers, 107 junior researchers, 50 research assistants (PhD students), 36 engineers and technicians) from 2018 on. 31 MSc and PhD students are also expected to receive some trainings with the equipment at ELI-NP every year.

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

EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2007-2013

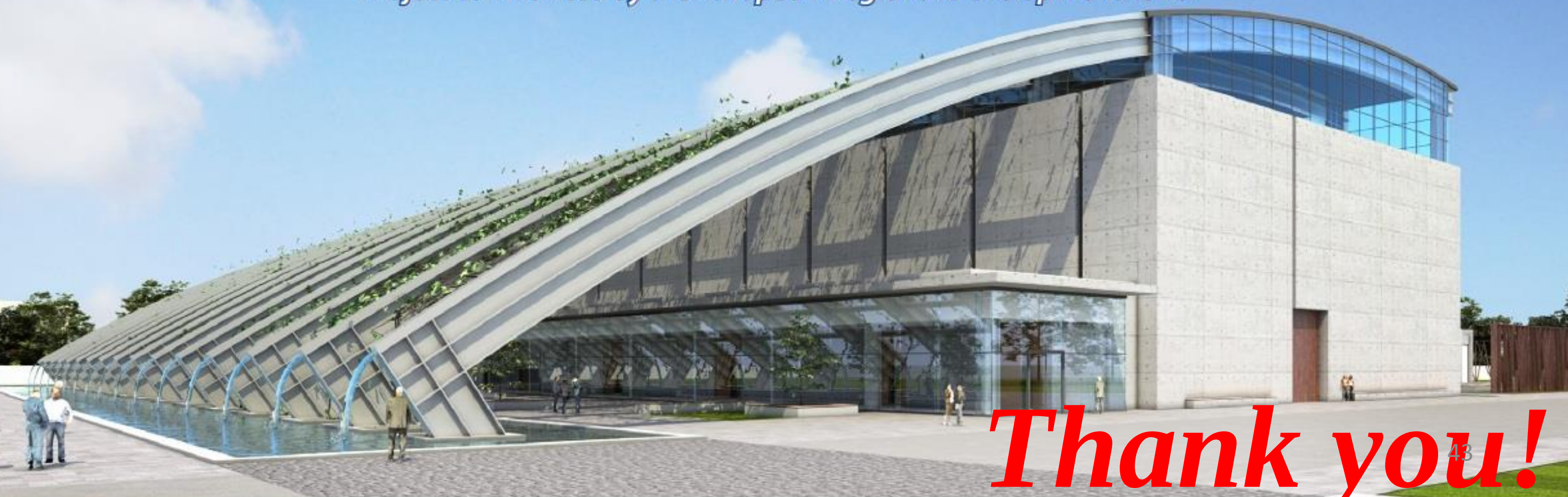
Sectoral Operational Programme "Increase of Economic Competitiveness"

"Investments for Your Future!"

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

www.eli-np.ro

Project co-financed by the European Regional Development Fund



Thank you!