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
Project co-financed by the European Regional Development Fund

Photoneutron reaction studies at Extreme Light Infrastructure - Nuclear Physics (ELI-NP)

5th Workshop on Nuclear Level Density and Gamma Strength

Oslo 18-22 May 2015

D.M. Filipescu, H. Utsunomiya, F. Camera, V. Varlamov

eli Nuclear Physics

ELI-NP Milestones

2006 – ELI on ESFRI Roadmap

ELI-Beamlines (Czech Republic)

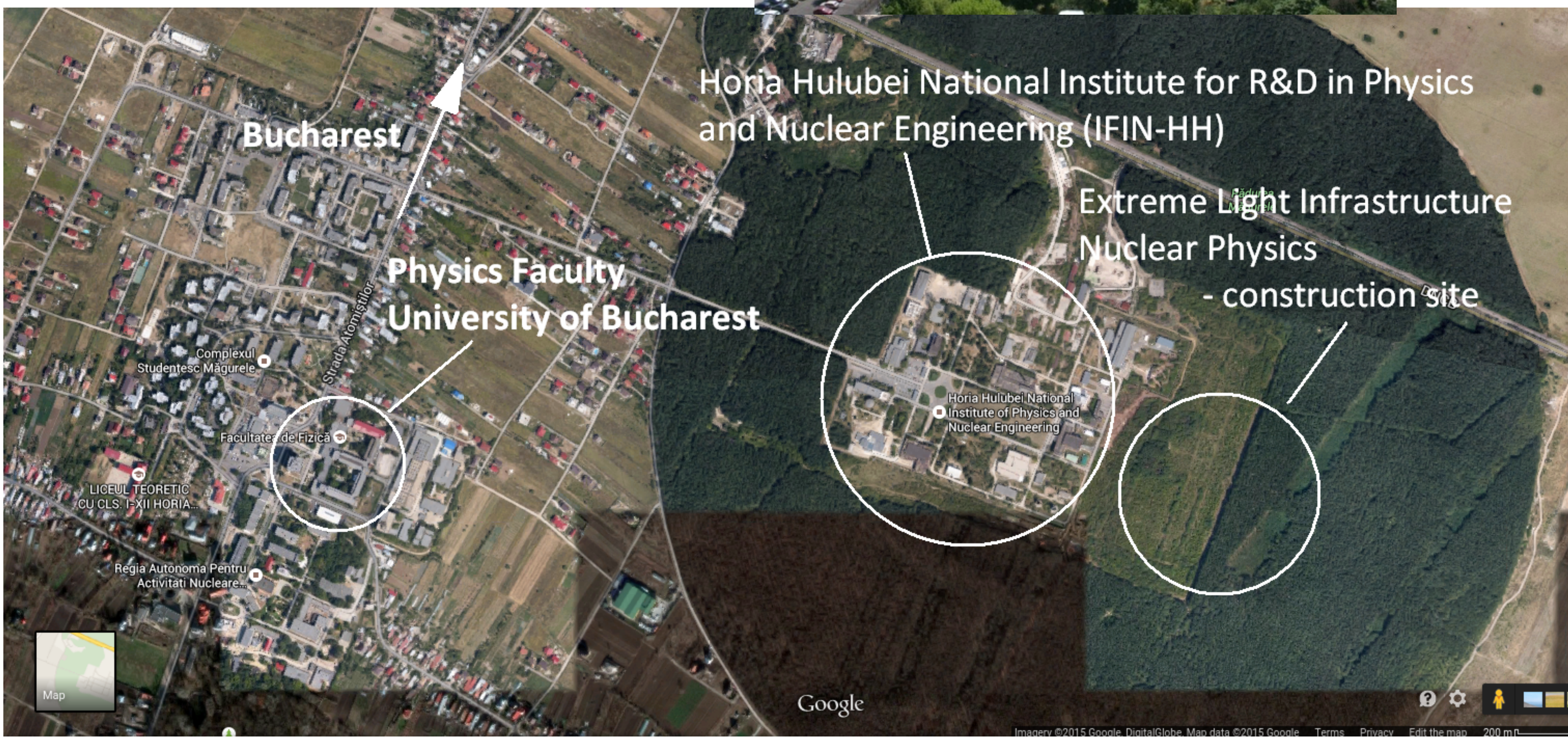
ELI-Attoseconds (Hungary)

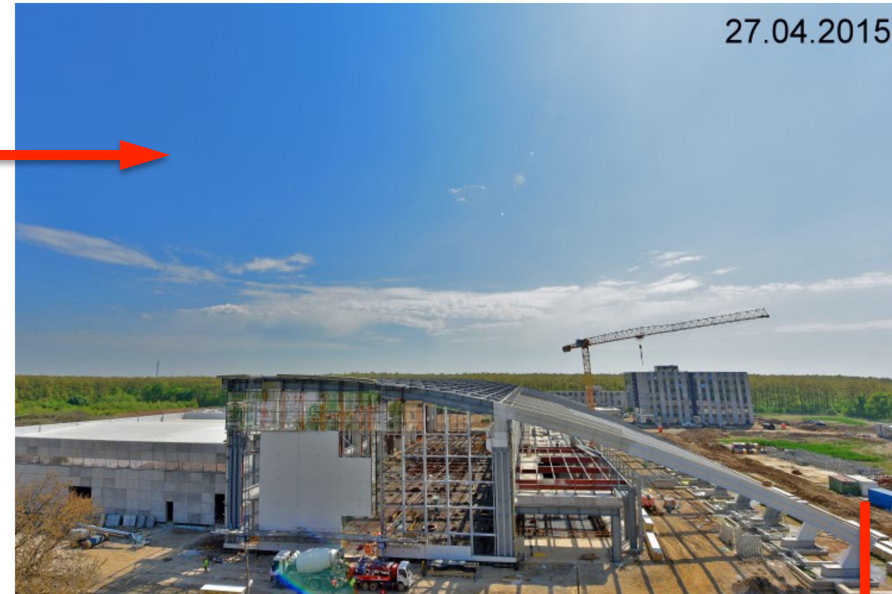
ELI-Nuclear Physics (Romania)

January 2012: Project submitted to the EC

- **July 2012: Romanian Government Decision**
  - **Construction of the New Research Infrastructure ELI-NP: 293 M€**
- **September 2012: EC Project Approval**
  - **European Regional Development Fund**
  - **Financial Support (83%) of the First phase (2012-2015) 180 M€**
- **December 2012: Contract with Romanian Managing Authority**

NUCLEAR
Tandem accelerators
Cyclotrons
γ – Irradiator
Advanced Detectors
Biophysics
Environmental Physics
Radioisotopes



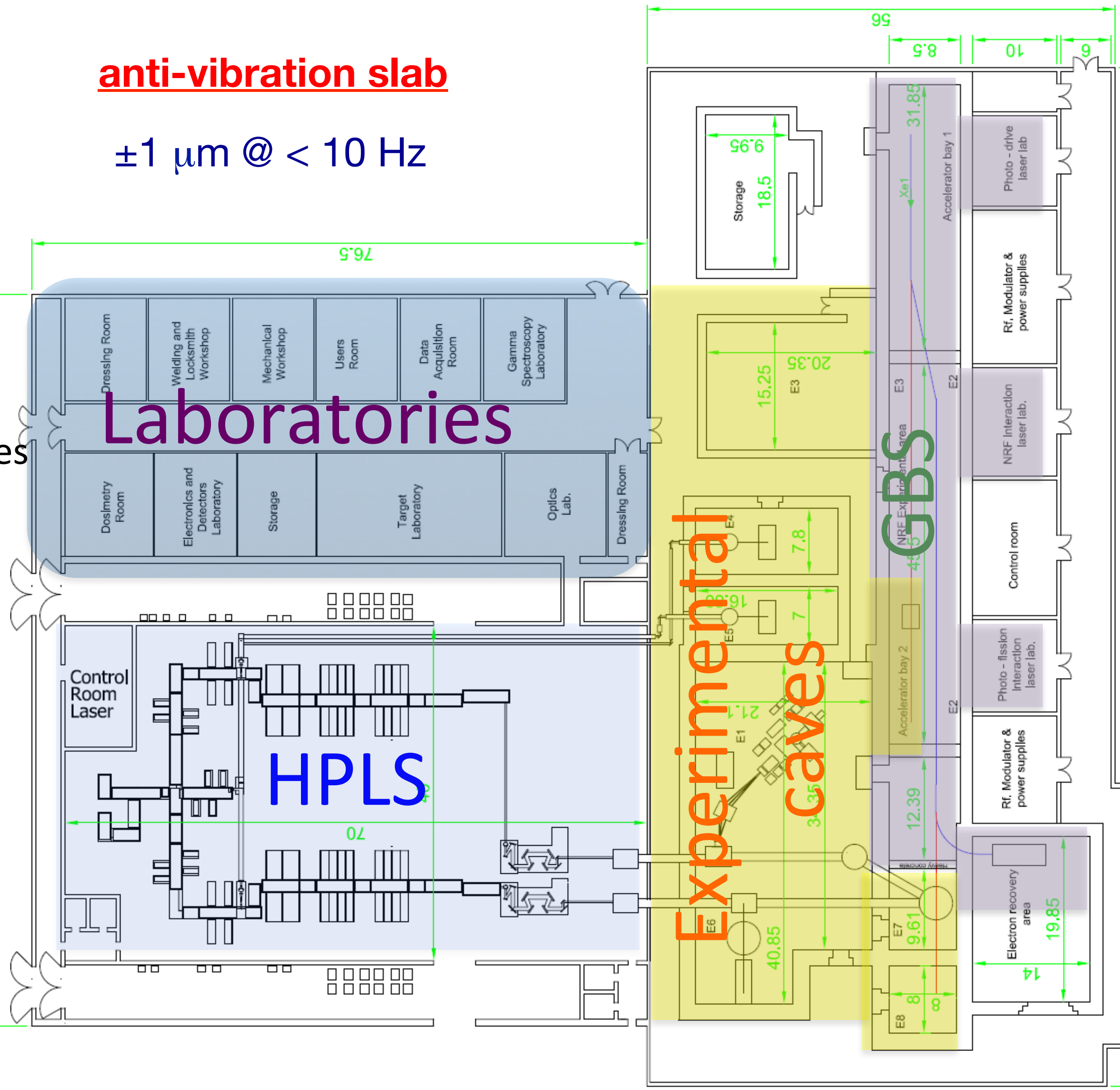


The construction will be finished in 2016.
The facility will deliver the first gamma ray beam in 2018.

ELI-NP – Laser and Gamma Beam systems

anti-vibration slab

±1 μm @ < 10 Hz



Laser beam system:

- 2 HPLS up to 10 PW – 6 output lines

2 x 0.1 PW
2 x 1 PW
2 x 10 PW

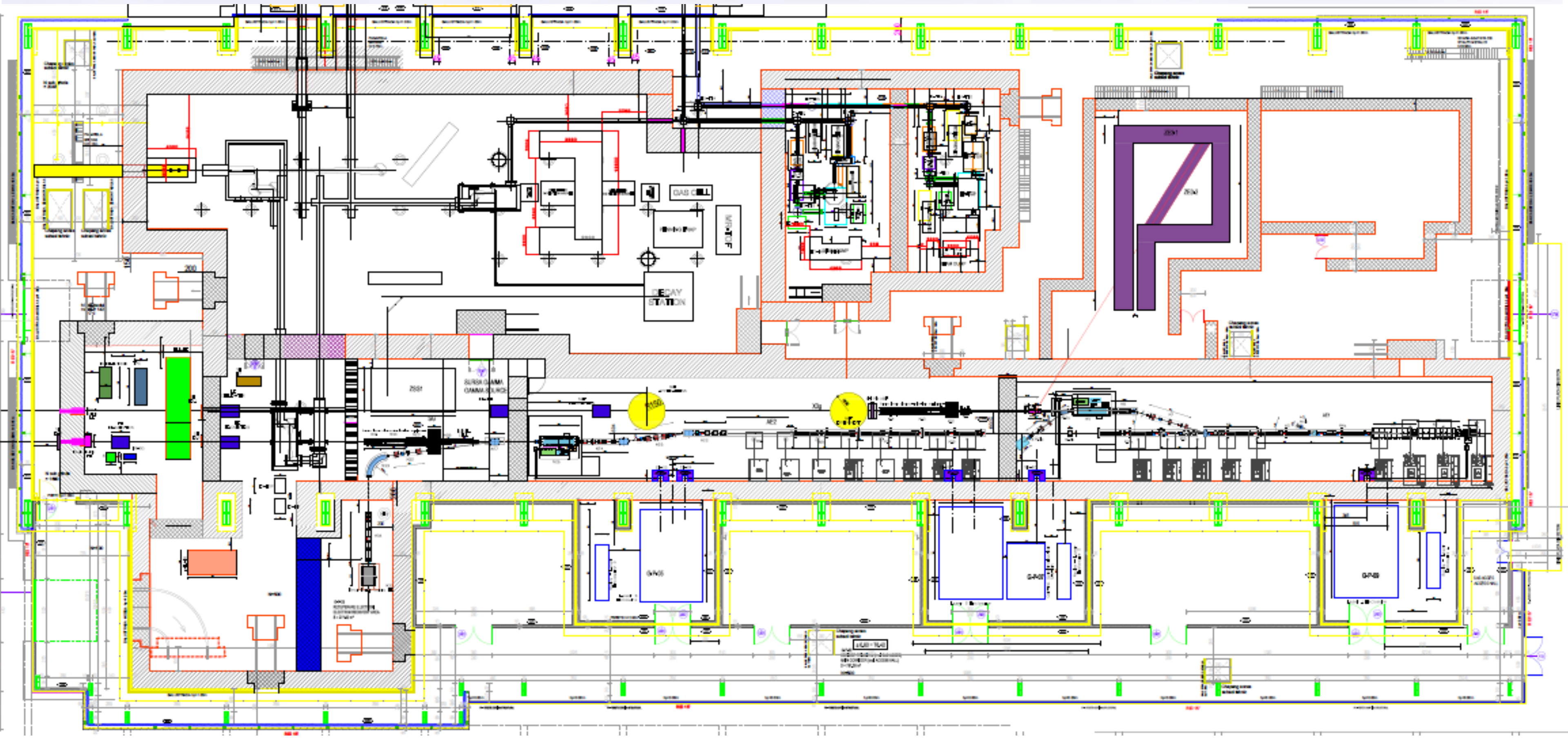
Gamma beam system

- High intensity
- High energy resolution

Experiments with:

- High power laser beams
- **Gamma ray beams**
- Laser + gamma ray beams

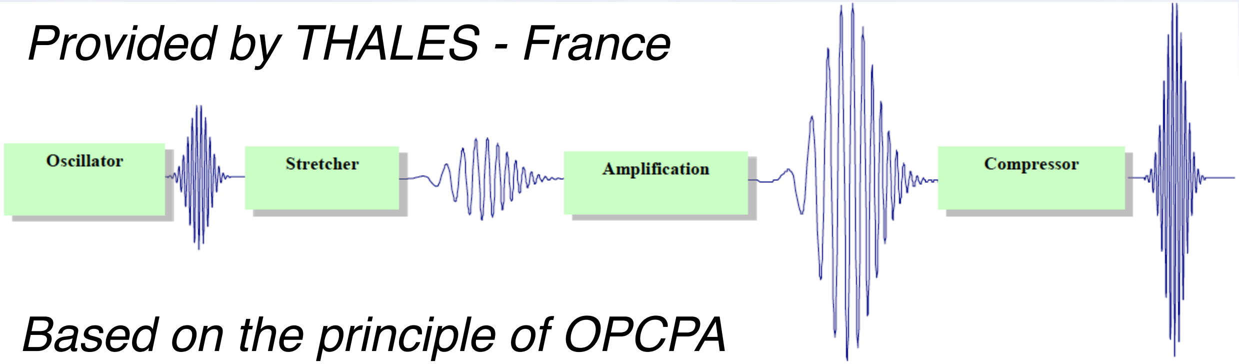
Gamma beam & Experimental halls layout



ELI–NP HPLS

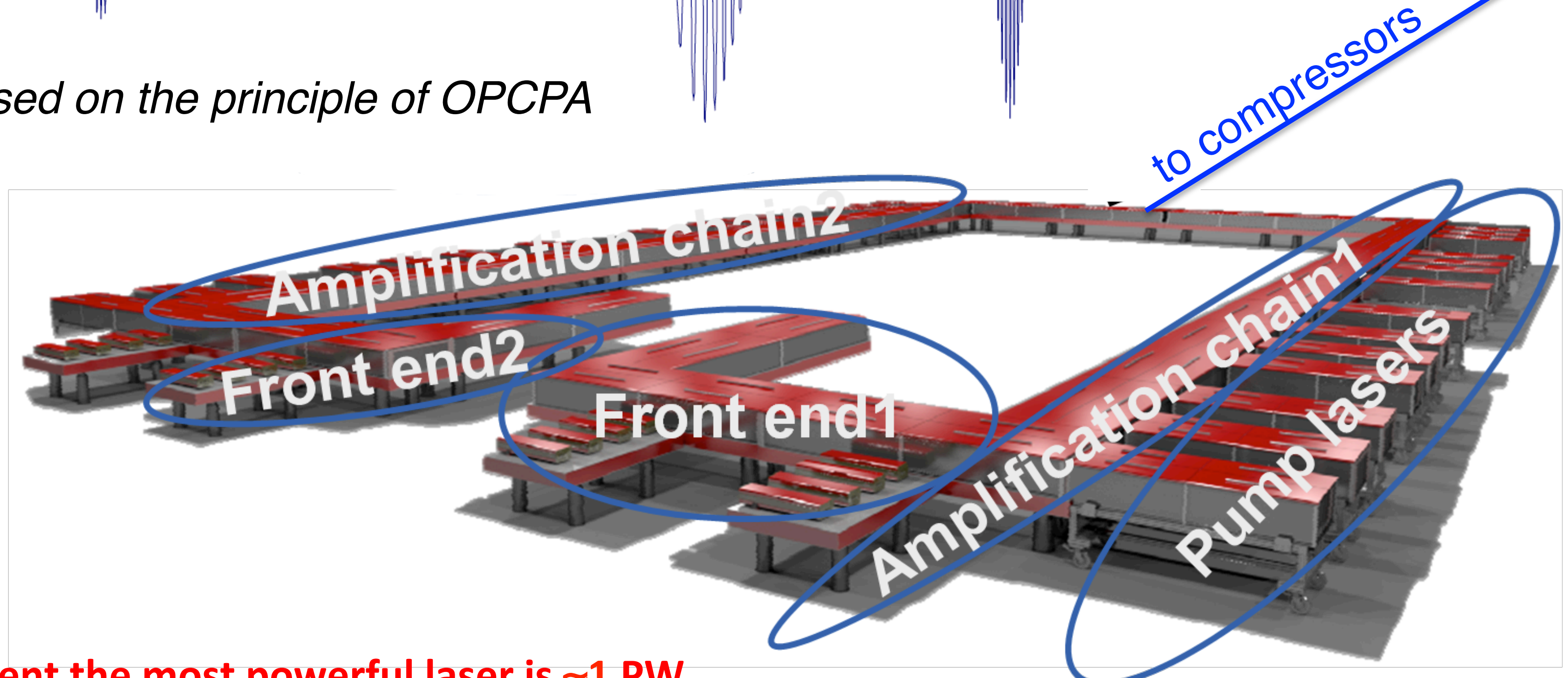
2 HPLS up to 10 PW – 6 output lines

Provided by THALES - France



2 x 0.1 PW
2 x 1 PW
2 x 10 PW

Based on the principle of OPCPA



at present the most powerful laser is ≈1 PW

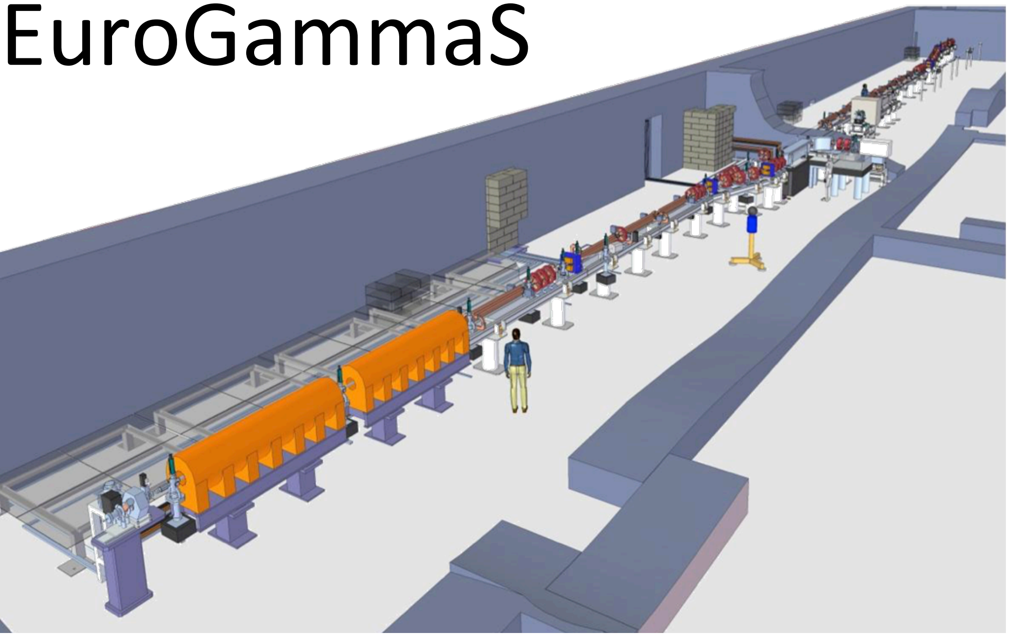
ELI-NP Gamma Beam System: the Italy-France-United Kingdom proposal

Nuclear Physics

SAPIENZA Università di Roma · INFN Istituto Nazionale di Fisica Nucleare · Science & Technology Facilities Council · cnrs IN2P3 Les deux infinis · Université Paris Sud Comprendre le monde, construire l'avenir

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

EuroGammaS



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 TDR Workgroups

- Workshops in June 2013, April 2014, February 2015, February 2015;

Gamma WGs:

- NRF and applications
- Photo fission (production and physics)
- **Gamma above Threshold**
- Charged particle array

+ Positron source for materials science WG

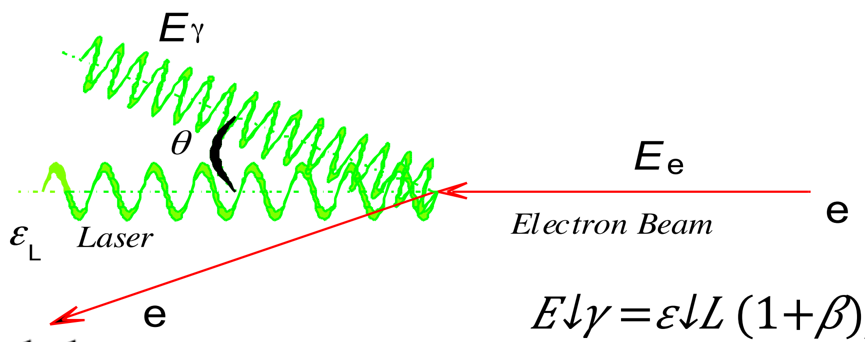
Laser WGs:

- Ion driven nuclear physics: fission-fusion
- Strong fields QED
- Towards High field (Laser +Gamma) and Plasma
- Applications

+ Transversal WGs: Beam delivery, Vacuum, Control Systems, Dosimetry

Laser Compton Scattering (LCS) gamma ray sources
Main concepts

The γ ray beams are produced by the inverse Compton scattering of laser photons from relativistic electrons.



$E_\gamma = \varepsilon_L (1+\beta)/1+\varepsilon_L/E_e - (\beta - \varepsilon_L/E$

$(small\ \theta) \approx 4\gamma^2 \varepsilon_L / 1+(\gamma\theta)^2 + 4\gamma^2 \varepsilon_L$

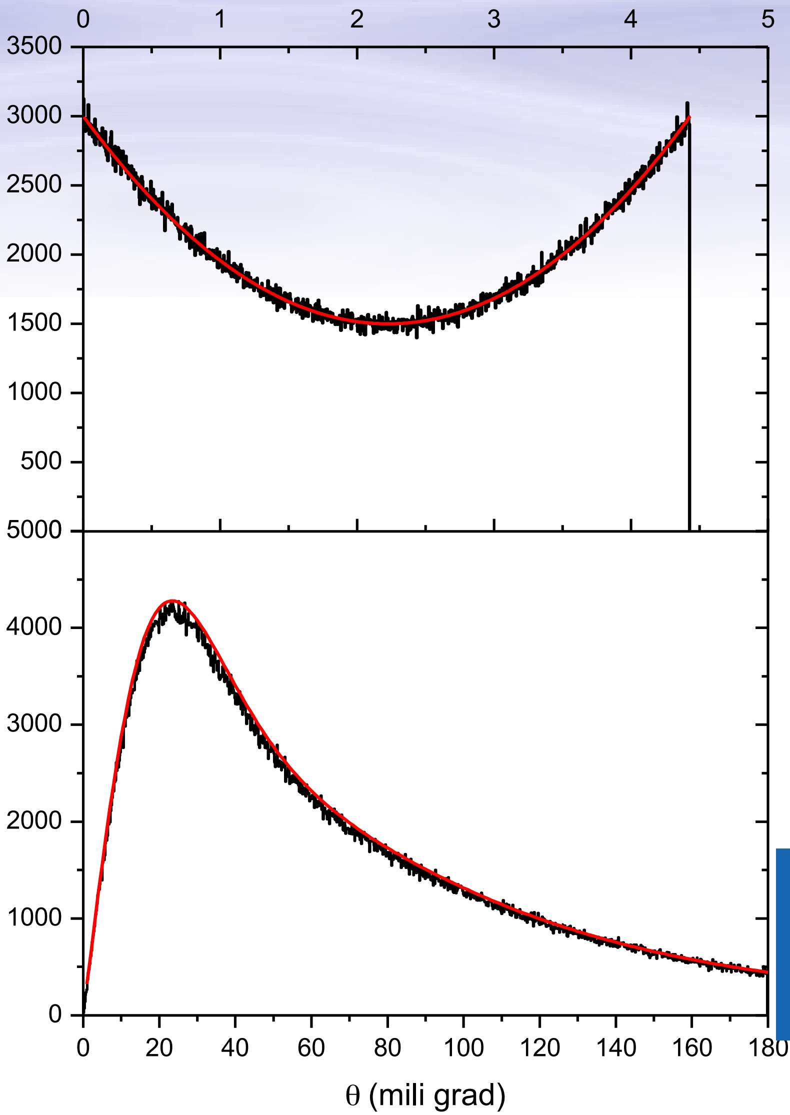
E_γ = energy of scattered photon
ε_L = energy of laser photon
E_e = total electron energy
θ = scattering angle of a laser photon with respect to the electron incident direction
mc^2 = rest energy of an electron

$\boldsymbol{E_\gamma \sim 4\gamma^2 \varepsilon_L}$

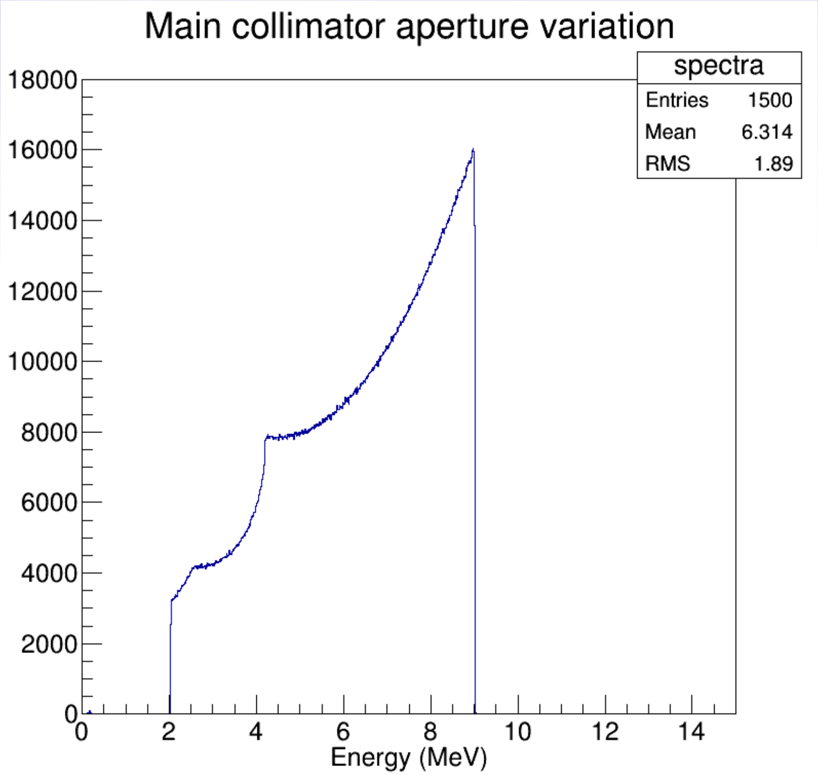
$\gamma = E_e / mc^2$

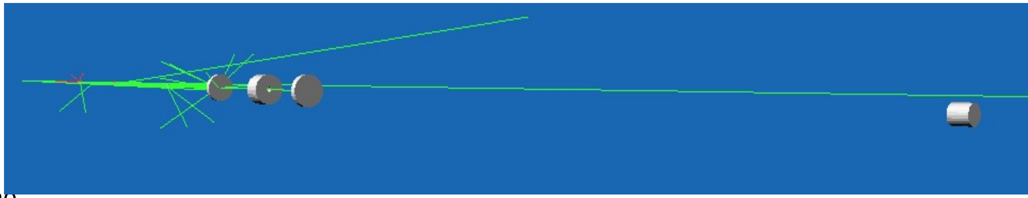
Continuous spectrum!

Laser Compton Scattering (LCS) gamma ray sources



Klein-Nishina C.S. theoretic vs. random generated



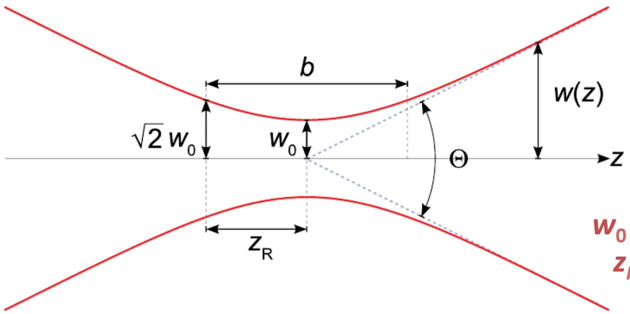


Collimation -> Quasi monochromatic spectrum

$E_e = 500 MeV \quad \lambda = 1064\ nm$

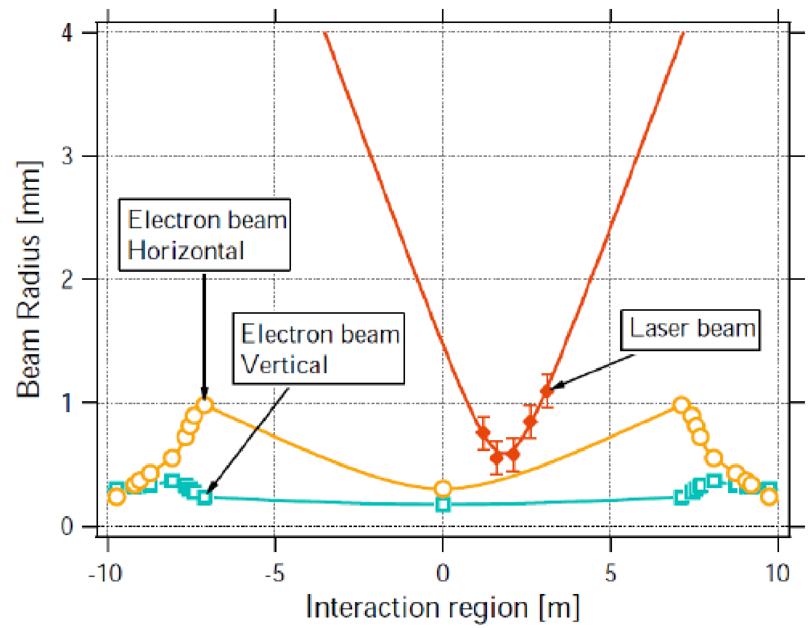
Unfortunately LCS gamma sources are produced by NOT-Ideal Electron & Laser beams

Laser modeling: hyperbolic dependence along the beam axis

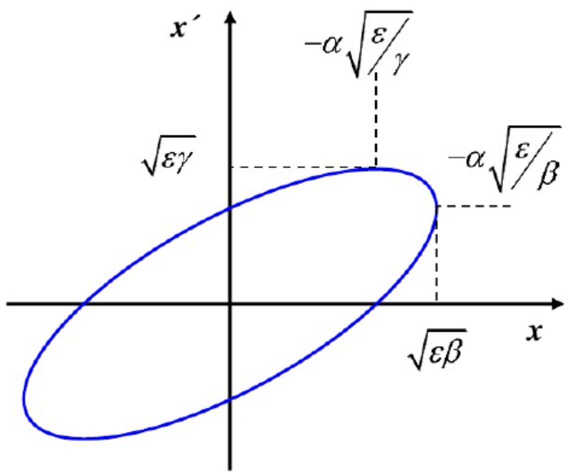


w_0 = beam size at focal point
$z_R = b/2$ = Rayleigh length

Example of electron and laser beam shape in the interaction region along straight beamline in the NewSUBARU e⁻ storage ring



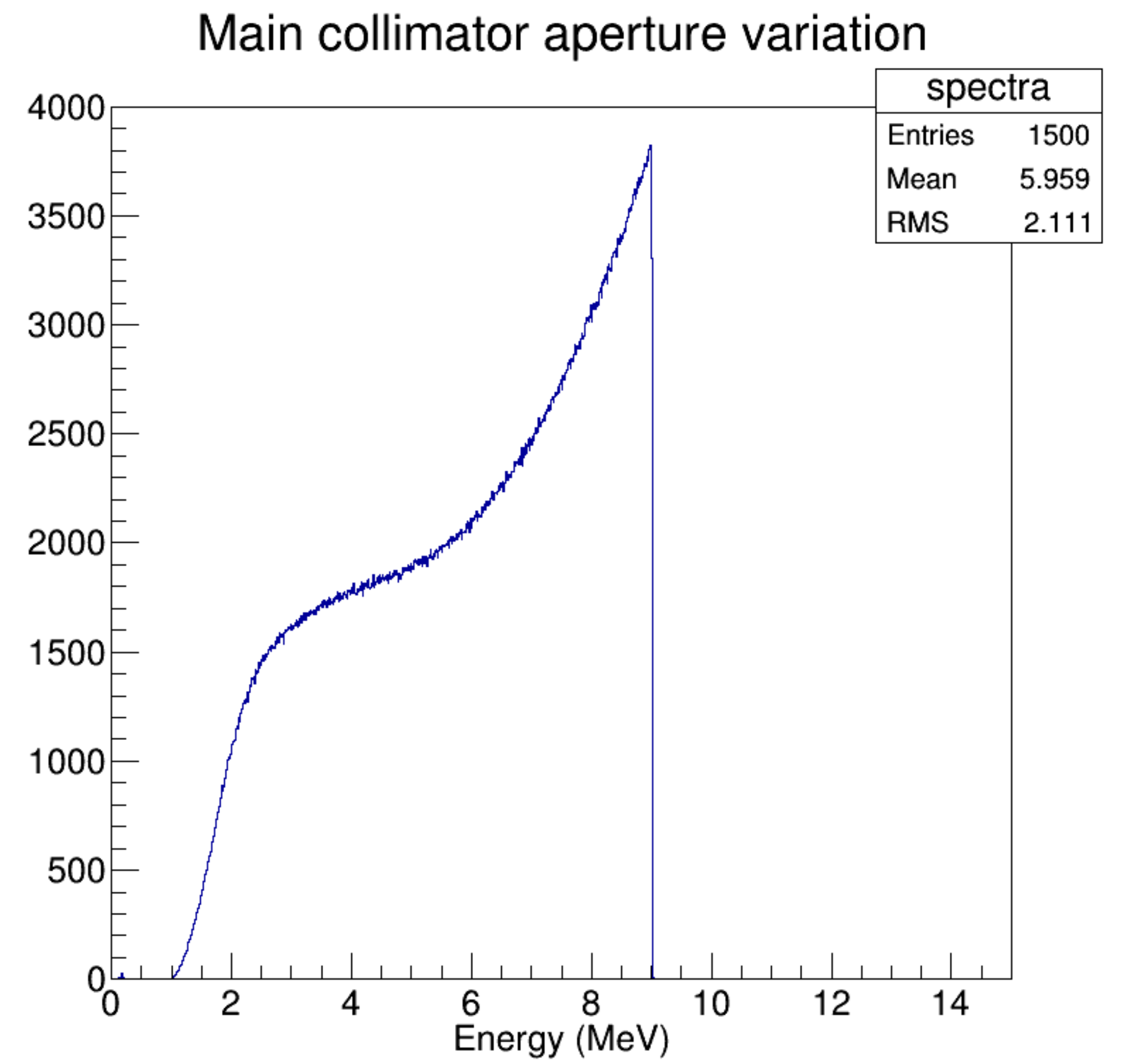
Drift space coordinates and Twiss parameters must be considered



Electron beam emittance:

$$\varepsilon_x = \gamma_x(z)\cdot x^2(z) + 2\alpha_x(z)\cdot x(z)x'(z) + \beta_x(z)\cdot x'^2(z)$$

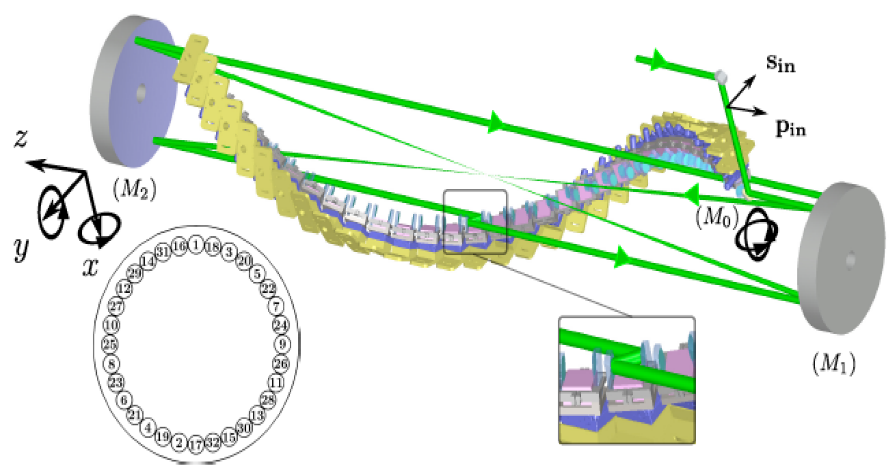
Real Electron & Laser beam parameters (non-head on collision)

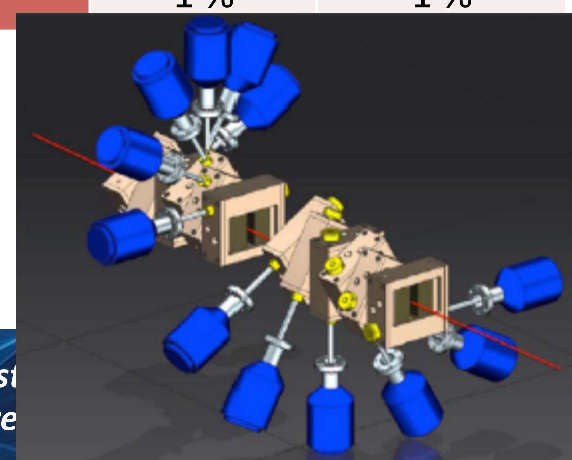


RF linac & pulsed laser source parameters

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

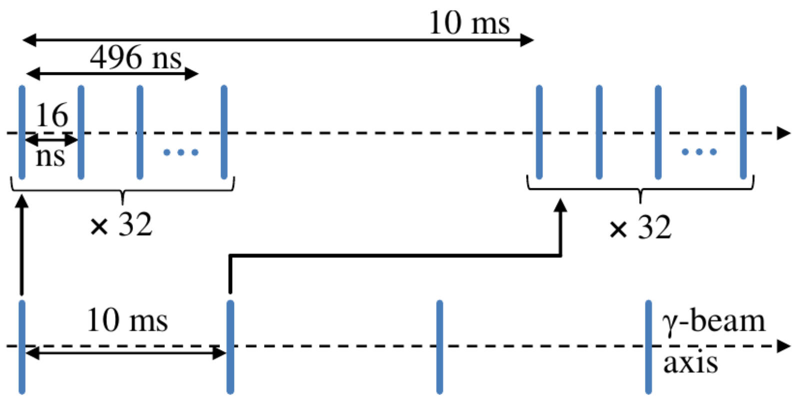
Yb:Yag Collision Laser	Low Energy Interaction	High Energy Interaction
Pulse energy (J)	0.2	0.5
Wavelength (eV)	2.4	2.4
FWHM pulse length (ps)	2-4	2-4
Repetition Rate (Hz)	100	100
M^2	≥ 1.2	≥ 1.2
Focal spot size w_0 (µm)	> 25	25
Bandwidth (rms)	0.05 %	0.05 %
Pointing Stability (µrad)	1	1
Sinchronization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

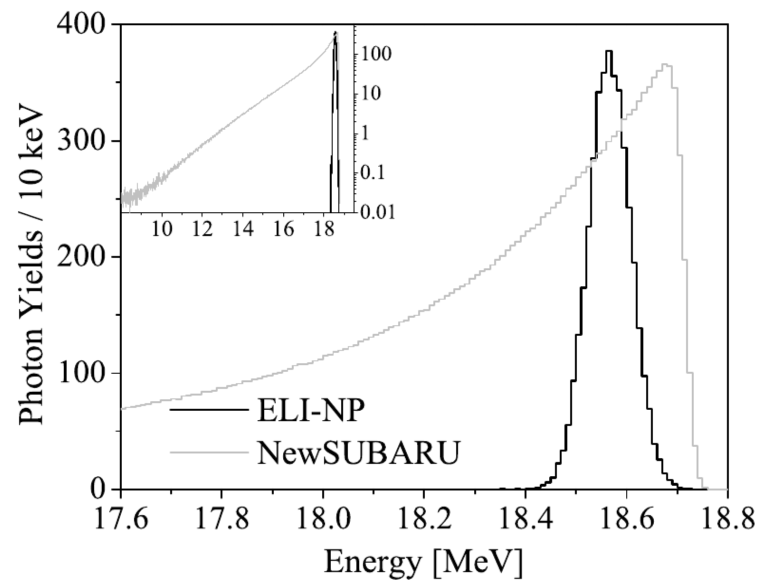




ELI-NP γ-ray beam expected parameters

	E_γ [MeV]	ΔE_γ [%]	I_γ^{bw} [ph/sec]
ELI-NP	0.2 - 19.5	< 0.5 (rms)	$8.3 \cdot 10^8$
NewSUBARU	0 - 76	> 1.2 (FWHM)	$\sim 10^5$
HIγS	0 - 100	0.8 - 10 (FWHM)	$\sim 10^7$



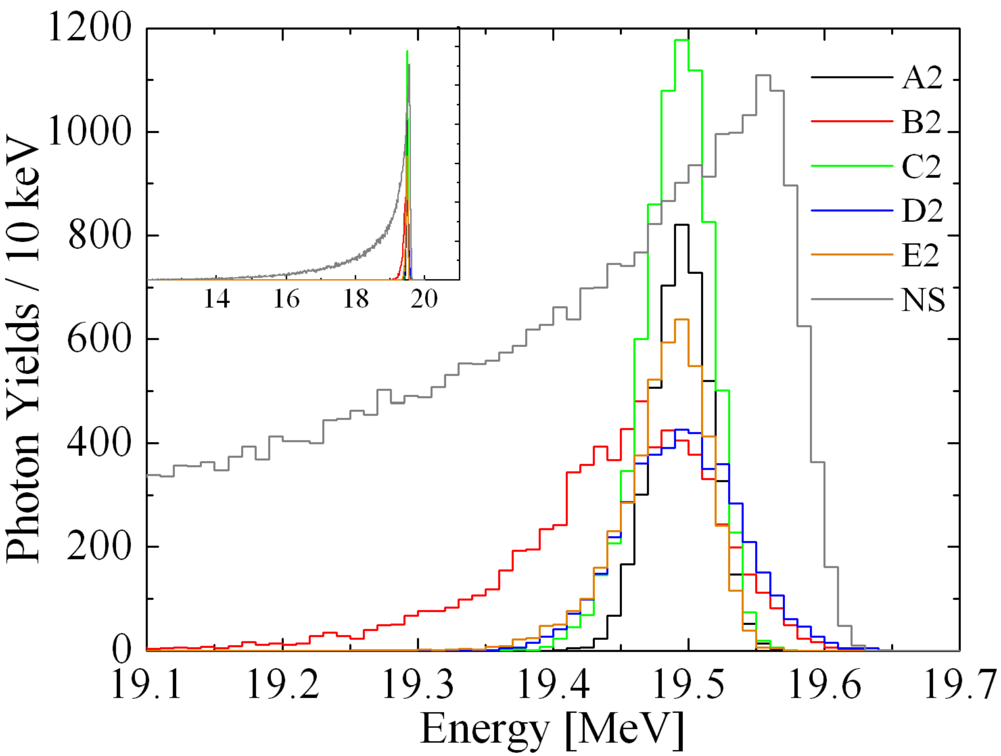


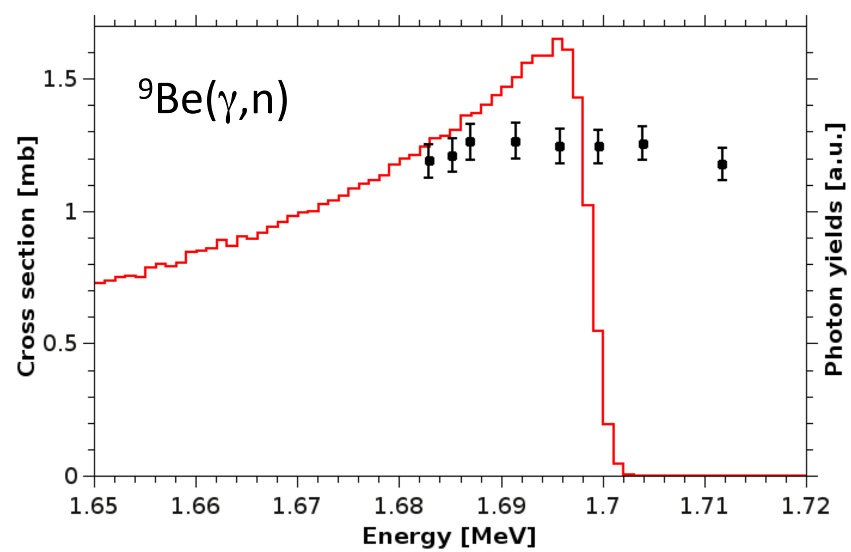
	Emittance [nm rad]	σ_{ele} [μm]	E_{ele} [MeV]	ΔE_{ele} [%]	λ_{laser} [nm]	θ_p [deg]	Collimator aperture	E_γ [MeV]	ΔE_γ^{FWHM}
ELI-NP	0.41	30	720	0.1	515	7.5	0.5 mm	18.55	0.5 % 9.3 keV
NewSUBARU	x: 40 y: 4	x: 300 y: 180	1056.56	0.04	1064	0.	C1: 3 mm C2: 1 mm	$E_\gamma^{max} = 18.68$ $E_\gamma^{avg} = 17.79$	2.2 % 41.1 keV

Laser Compton scattering simulation code

- Predictions for future ELI-NP γ-ray beam

		A2	B2	C2	D2	E2
ε_n	[mm×mrad]	0.2	0.6	0.2	0.2	0.6
ΔE	[%]	0.04	0.1	0.04	0.1	0.04
σ	[μm]	30	15	15	30	30





Nuclear Photonics

Electromagnetic dipole response of nuclei

Nuclear structure

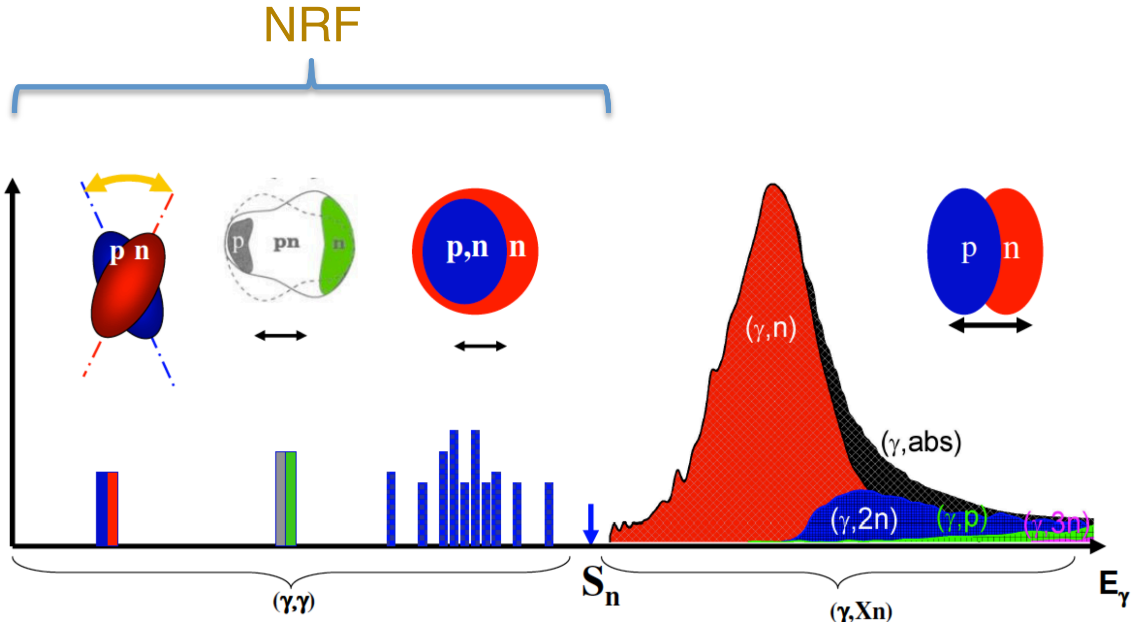
- Modes of excitation below the GDR

Impact on nucleosynthesis

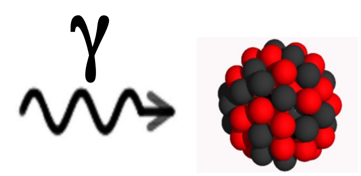
- Gamow window for photo–induced reactions in explosive stellar events

Understanding exotic nuclei

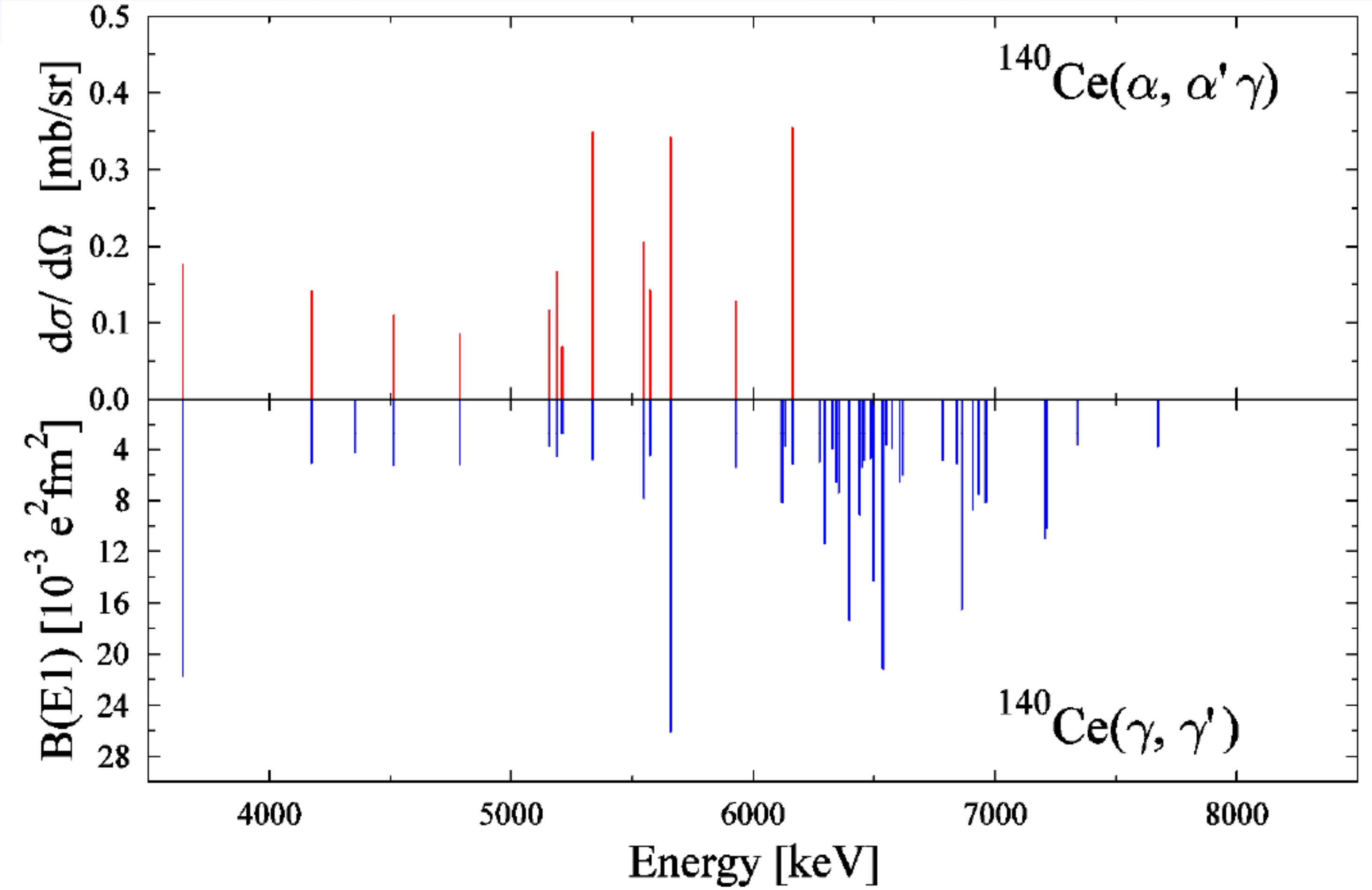
- E1 strength will be shifted to lower energies in neutron rich system



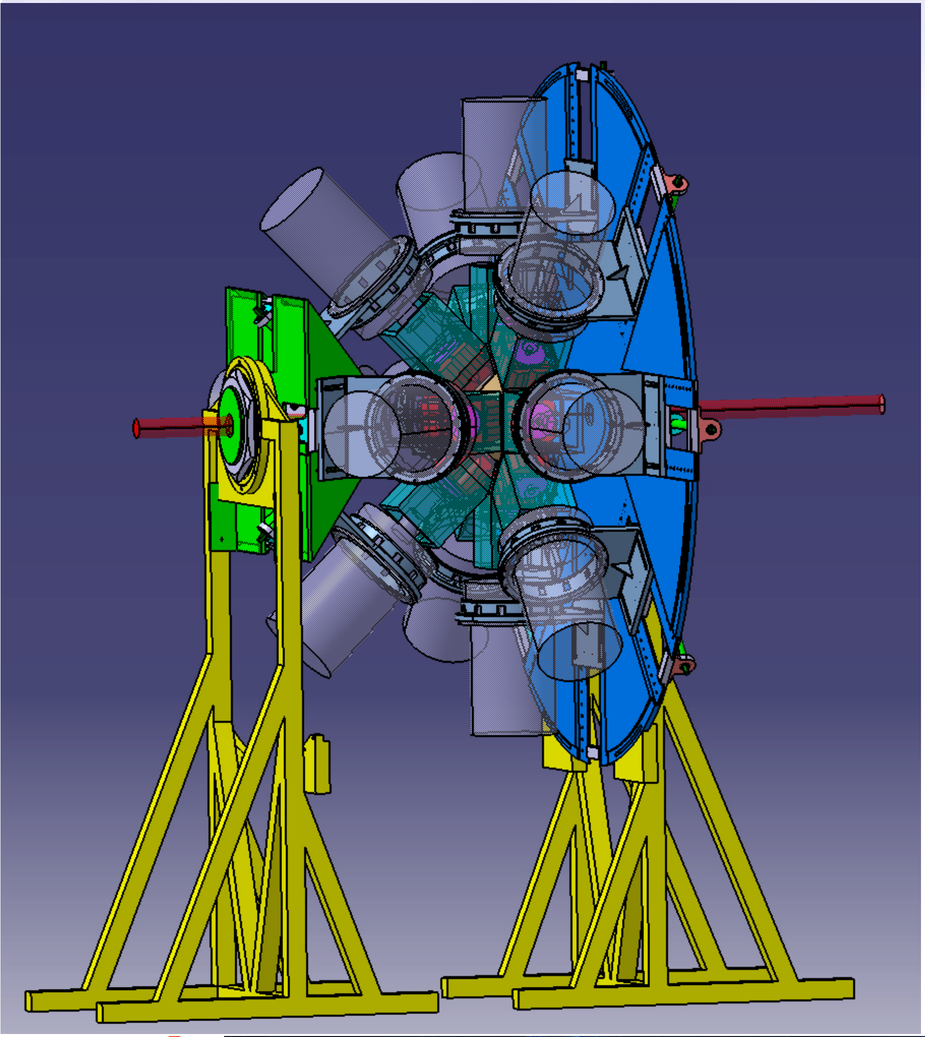
E1 strength distribution



Splitting of the E1 response of nuclei



TDR on Nuclear Resonance Fluorescence (NRF)



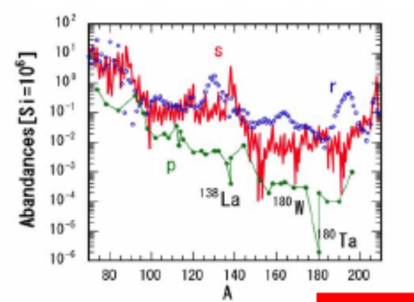
ELIADE – **ELI**–NP **A**rray of **De**tectors
8-12 Clover detector : 4 x crystals
60x90 cm (40% eff.) EXOGAM type
AC shield 2 configurations
4 3”x3” $LaBr_3$ det. @ 90 deg

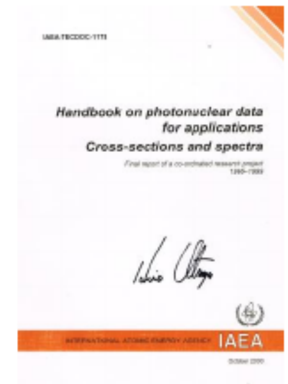
- Self-absorption measurements (Γ_0/Γ_i)
- Low-energy dipole response (e.g. Actinides)
- Dipole response and parity measurements for weakly-bound nuclei
- Investigation of the Pigmy Dipole Resonance
- Rotational 2^+ states of the scissor mode
- Parity violation in nuclear excitation: ^{20}Ne
- Constraints on the 0νββ-decay matrix elements of the scissors mode decay channel: ^{150}Sm

ELI-GANT workgroup:

- Conveners:
  - Prof. Dr. Hiroaki Utsunomiya
    - Konan University of Kobe, Japan
  - Prof. Dr. Franco Camera
    - University of Milano, Department of Physics, Italy
    - INFN section of Milano, Milano, Italy
- Collaborator:
  - Prof. Dr. Vladimir Varlamov
    - Physics Faculty, Lomonosov Moscow State University, Moscow, Russia
- Liason:
  - Dan Filipescu, ELI-NP

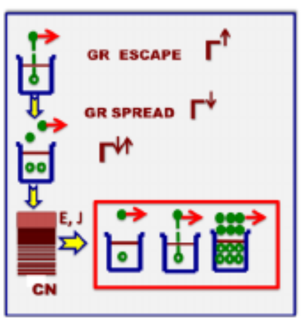
ELI-GANT – Physics program

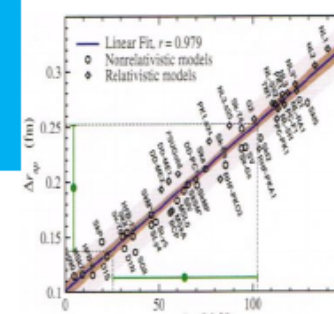




Four Physics Cases

P-process Nucleosynthesis	**New Compilation of (γ,xn) CS**
Nuclear Structure of GDR	**Nuclear Structure of PDR and MDR**





ELI-GANT – Physics program

Physics cases

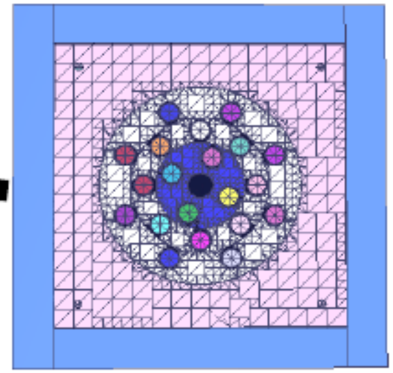
P-process

New Compilation

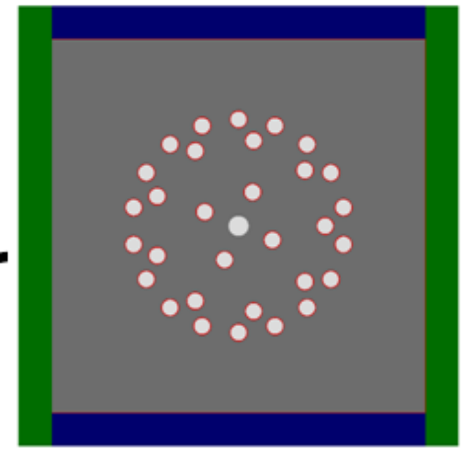
GDR

PDR and MDR

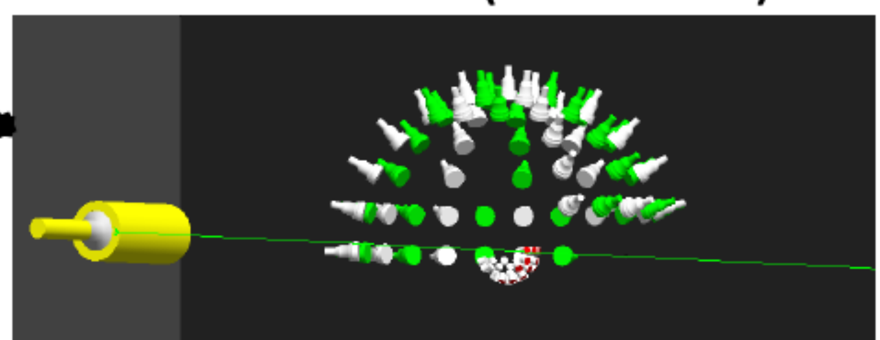
High-efficiency 4π neutron detector (ELIGANT-TNH)



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



Array of $LaBr_3$:Ce, Liquid, and Li glass scintillation detectors (ELIGANT-GN)

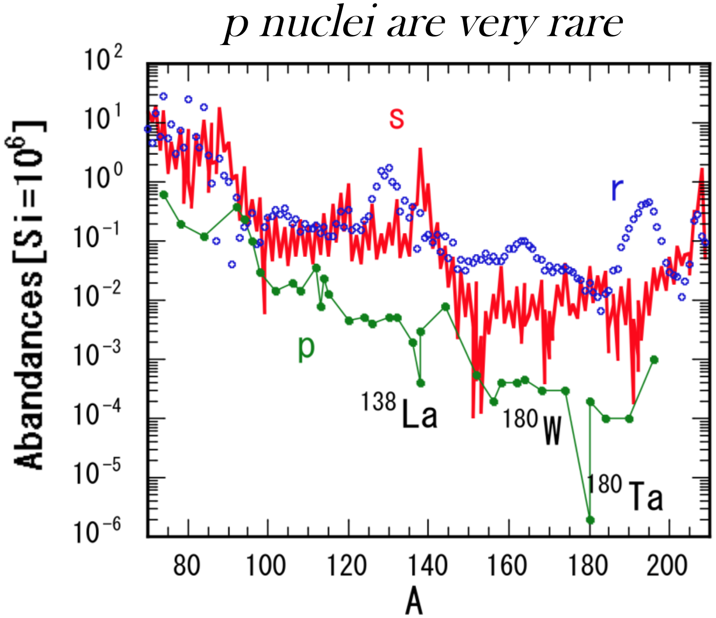


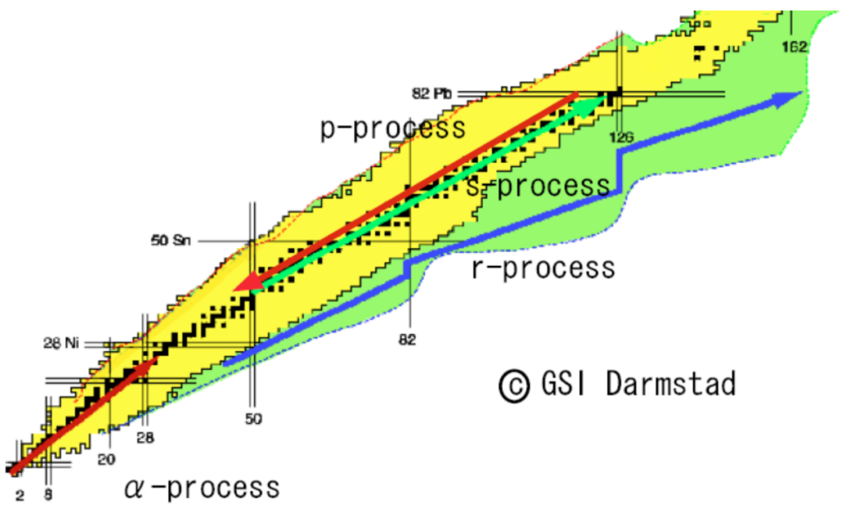
Photoneutron measurements

Nuclear astrophysics - the prediction of radiative neutron capture cross sections for short–lived radioactive nuclei that are difficult to measure can be obtained using inverse photoneutron reaction data near threshold

Abundances of 35 neutron deficient p–nuclides from 74Se to 196Hg not produced in neutron capture chains of s– or r–types could be explained using photonuclear reactions data

Rare isotope measurements for the p-process nucleosythesis



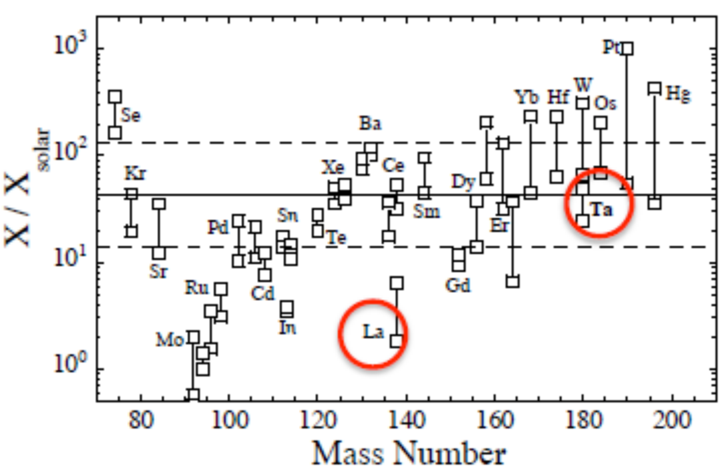


Rare isotopes to be studied ->

- Highest intensity and extremely monochromatic γ-ray beam
- 1 mg samples of rare isotopes
- Day 1 experiment

35 p-nuclei neutron-deficient isotopes

Production	vs	Destruction
$^{181}Ta(\gamma,n)\underline{^{180}Ta}$		$^{180}Ta(\gamma,n)\underline{^{179}Ta}$
$^{139}La(\gamma,n)\underline{^{138}La}$		$^{138}La(\gamma,n)\underline{^{137}La}$
measured!		Not so ever

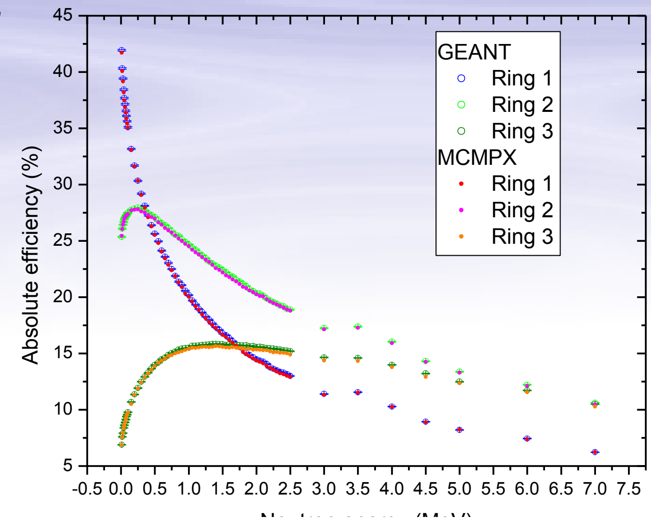


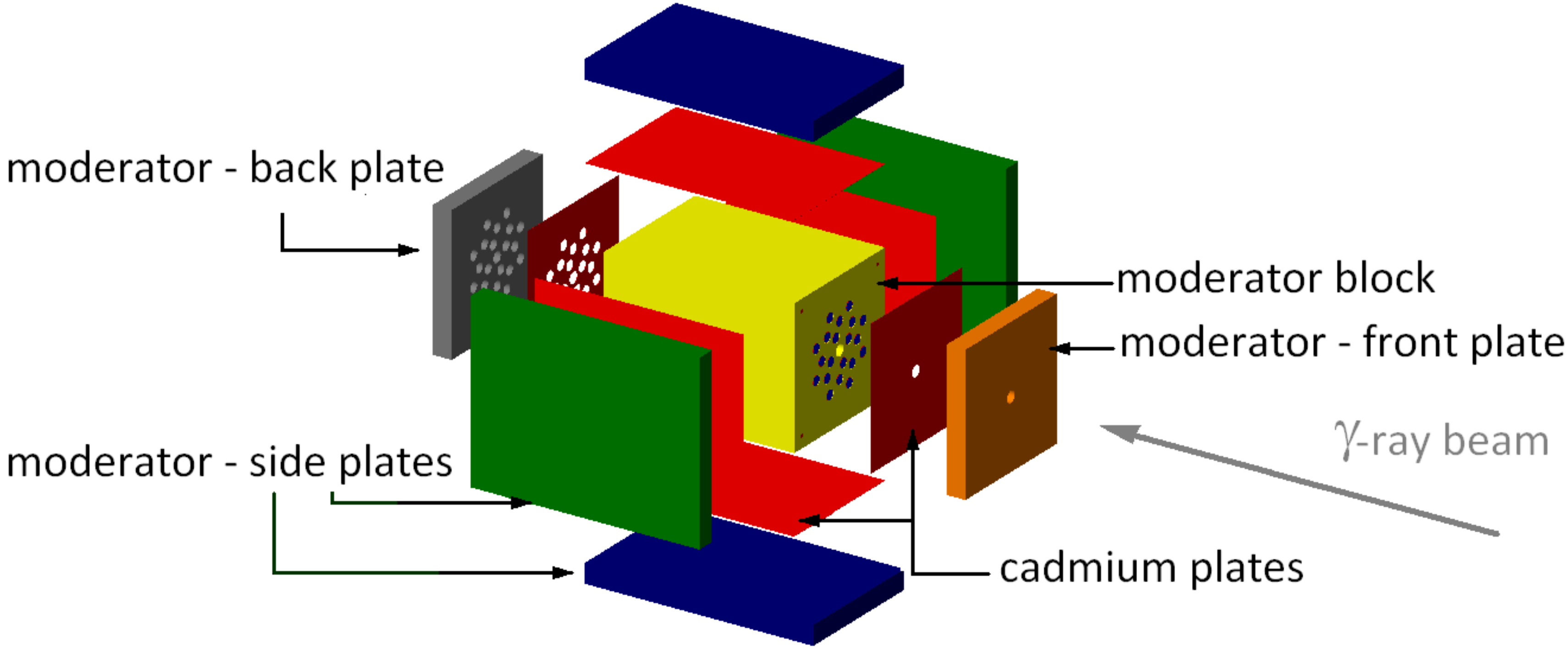
H. Utsunomiya et al., PRC67, 015807 (2003)

Nucleus	Natural abundance (%)	Abundance (10^6 Si) Anders&Grevesse
180Ta	0.012	2.48E-06
190Pt	0.014	0.00017
184Os	0.02	0.000122
156Dy	0.06	0.000221
120Te	0.09	0.0043
124Xe	0.09	0.00571
126Xe	0.09	0.00509
138La	0.09	0.000409
158Dy	0.1	0.000378
132Ba	0.101	0.00453
130Ba	0.106	0.00476
180W	0.12	0.000173
168Yb	0.13	0.000322
162Er	0.14	0.000351
196Hg	0.15	0.00048
174Hf	0.16	0.000249
136Ce	0.185	0.00216
152Gd	0.2	0.00066
138Ce	0.251	0.00284
115Sn	0.34	0.0129
78Kr	0.35	0.153
84Sr	0.56	0.132
114Sn	0.66	0.0252
74Se	0.89	0.55
108Cd	0.89	0.0143
112Sn	0.97	0.0372
102Pd	1.02	0.0142
106Cd	1.25	0.0201
164Er	1.61	0.00404
98Ru	1.87	0.035
144Sm	3.07	0.0008
113In	4.29	0.0079
96Ru	5.54	0.103
94Mo	9.25	0.236
92Mo	14.84	0.378

4π high efficiency neutron detector

- 20 ^{3}He proportional counters arranged in 3 concentric rings, embedded in a parallelepiped polyethylene moderator (36×36×50 cm) covered with polyethylene plates with cadmium sheets towards interior;
- Efficiency of neutron detector obtained with ring-ratio technique

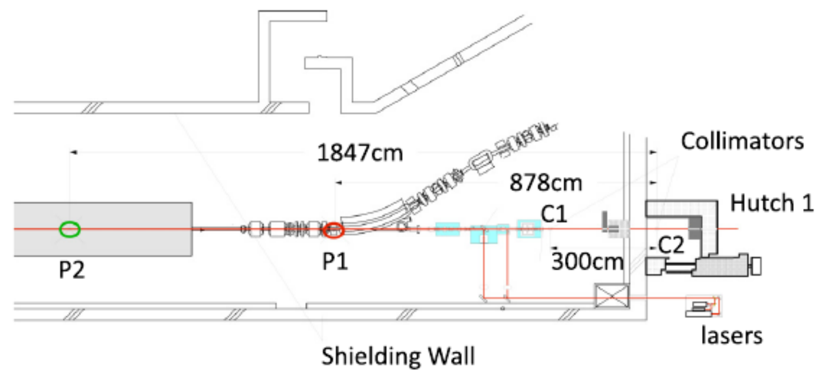


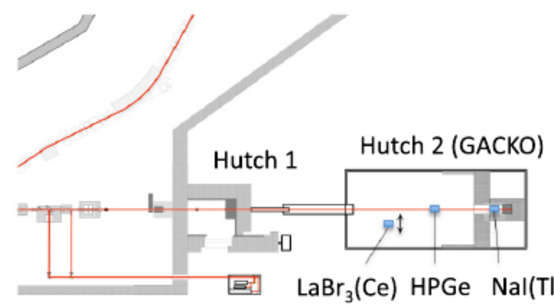


Preparatory experiment - Photoneutron measurements of Sm and Nd isotopes at NewSUBARU

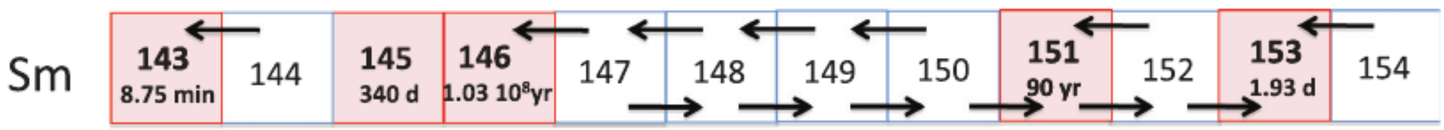
Participated to the measurements

- Electron energies between 573 and 850 MeV
- Q-switch Nd : YVO_4 laser INAZUMA
- 5.87 – 13 MeV γ-ray beams
- High efficiency 4π neutron detector
- LaBr3 detector for energy monitor
- 80% NaI-Tl detector flux monitor
- enriched samples of ^{144}Sm, ^{147}Sm, ^{148}Sm, ^{149}Sm, ^{150}Sm, ^{152}Sm, and ^{154}Sm in oxide form (Sm_2O_3)

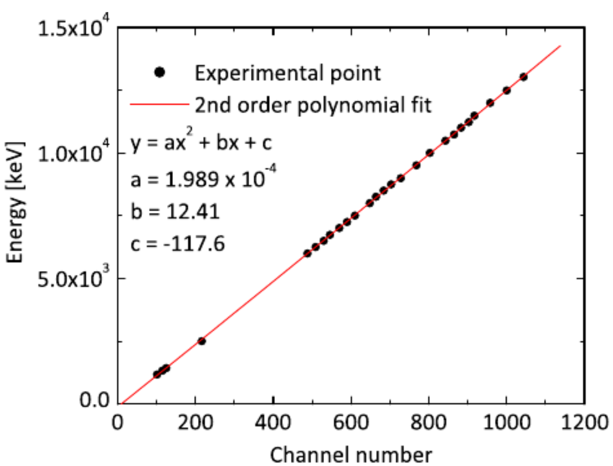




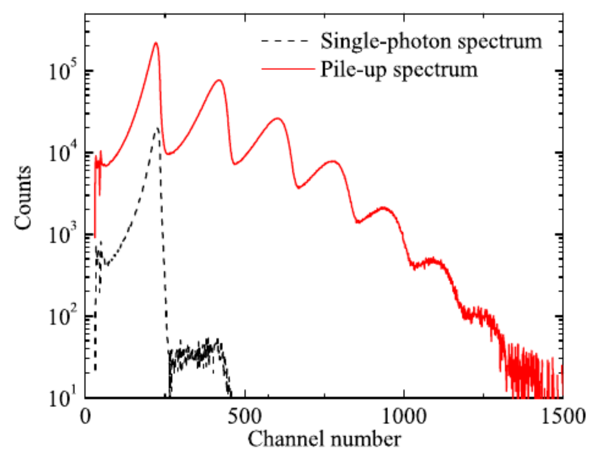
Preparatory experiment - Photoneutron measurements of Sm and Nd isotopes at NewSUBARU



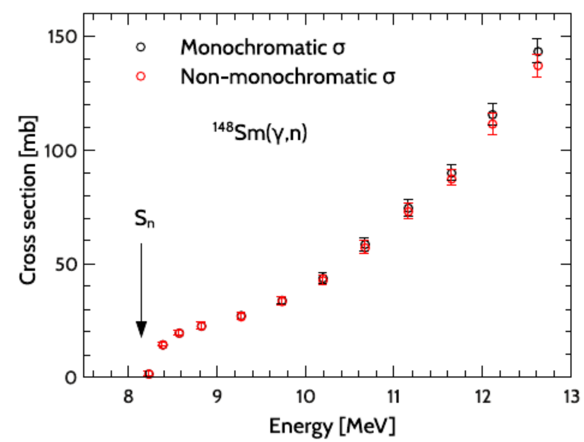
Analyzed the Sm data following the instructions and guidance of prof. Utsunomiya



Energy calibration of $LaBr_3$ detector



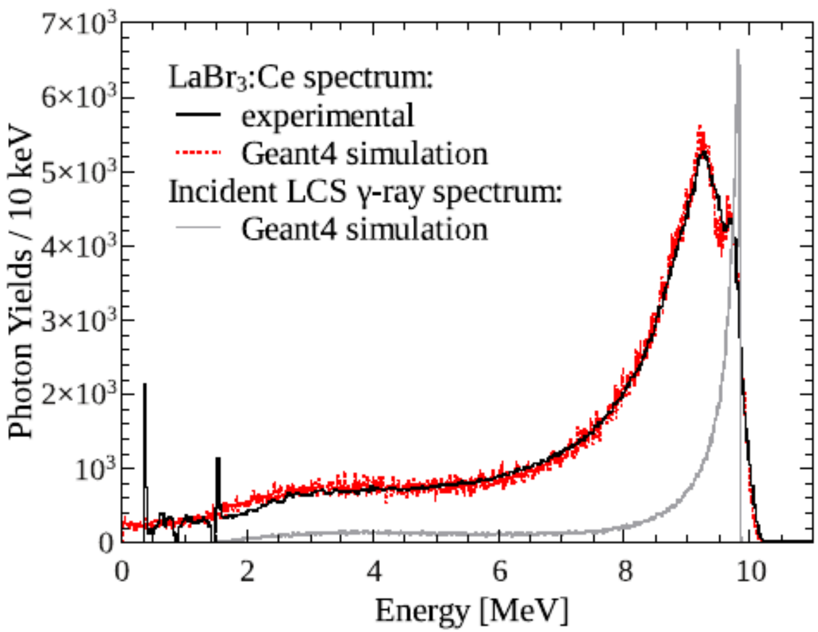
Pile-up and Single spectra of a 13.03 MeV LCS γ-ray beam recorded with the NaI-Tl detector

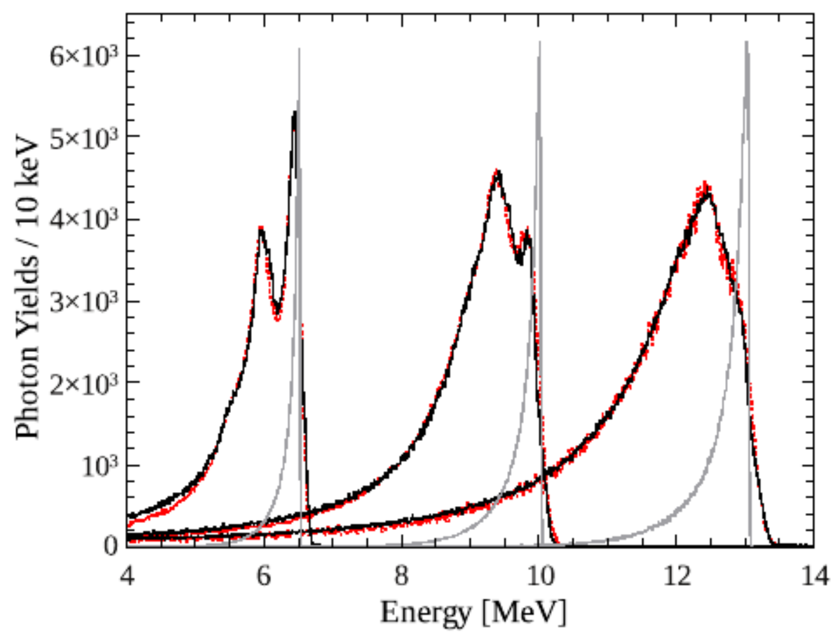


Final cs. - results of the Taylor expansion method

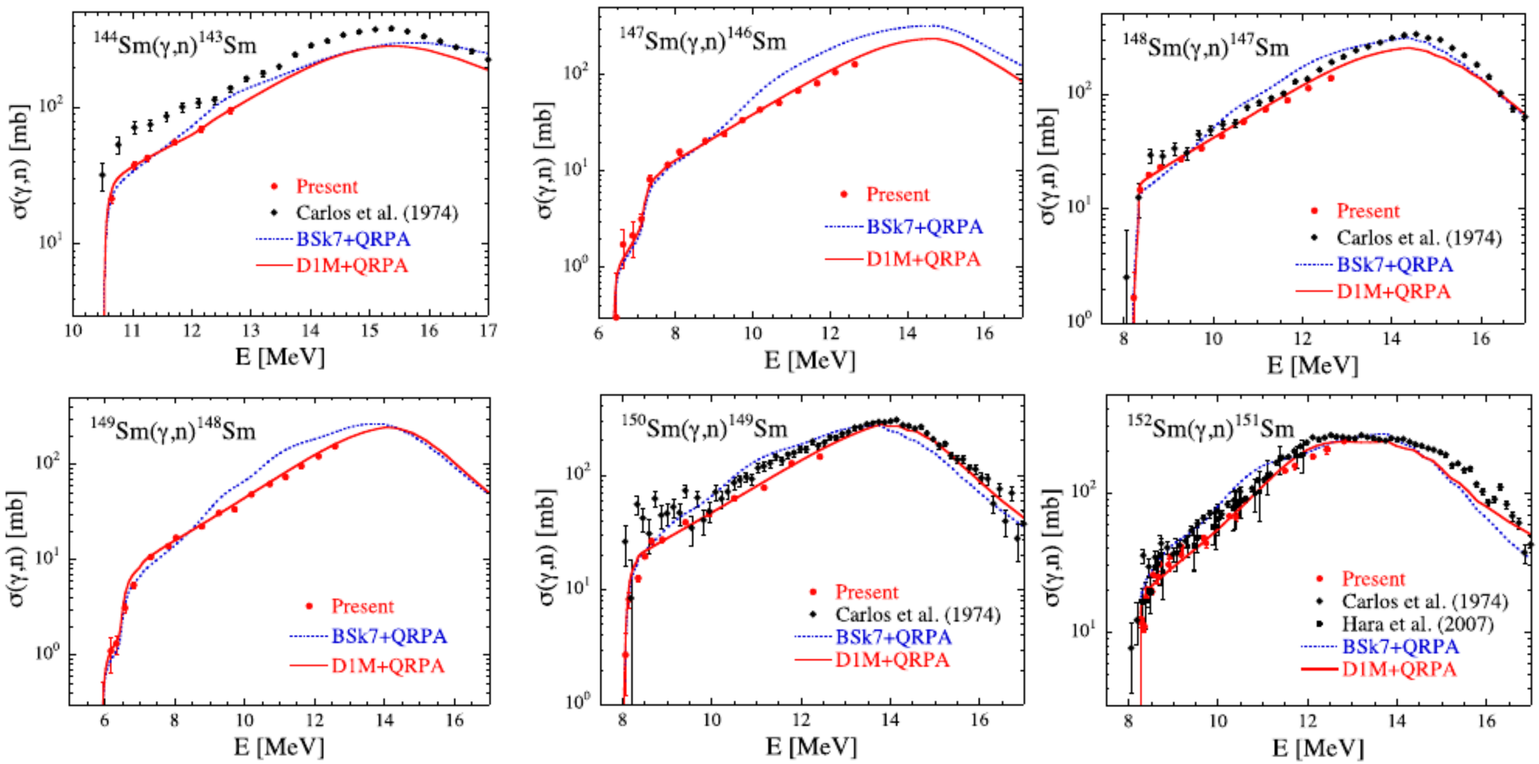
Preparatory experiment - Photoneutron measurements of Sm and Nd isotopes at NewSUBARU

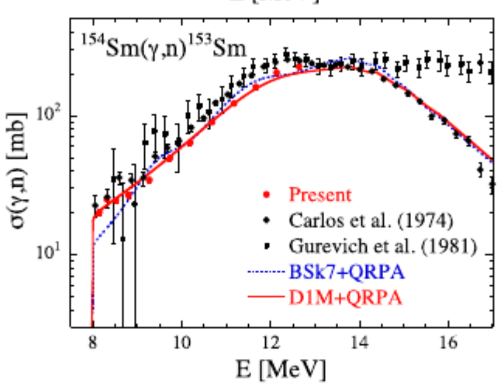
Development of a Laser Compton scattering simulation code currently used for reproduction of LCS γ-ray beam energy spectra and intensity at NewSUBARU and for predictions of the future ELI-NP beam





Preparatory experiment - Photoneutron measurements of Sm and Nd isotopes at NewSUBARU





Microscopic calculations performed by S. Goriely

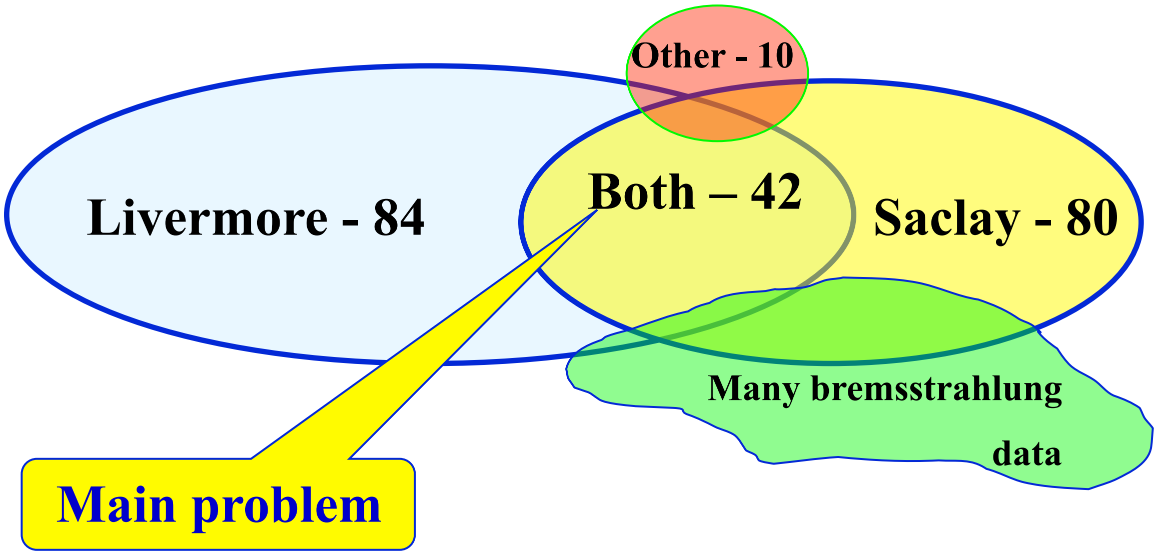
Photoneutron measurements

Systematics of experimental data:

many experimental data data for partial photonuclear reaction cross sections obtained in period 1962 - 1986 (the majority was obtained using quasi-monochromatic annihilation – QMA photons using positron in flight annihilation at Livermore (USA) and Saclay (France)), are published in

Atlas of Photoneutron cross sections obtained with monoenergetic photons (S.S.Dietrich, B.L.Berman. Atom. Data and Nucl. Data Tables, 38 (1988) 199)

Berman's EXFOR library - entries L0001 – L0059 (~ 174 nuclei sets)



For each nucleus – cross sections:

(γ, 3n)

(γ, 2n)

(γ, 1n)

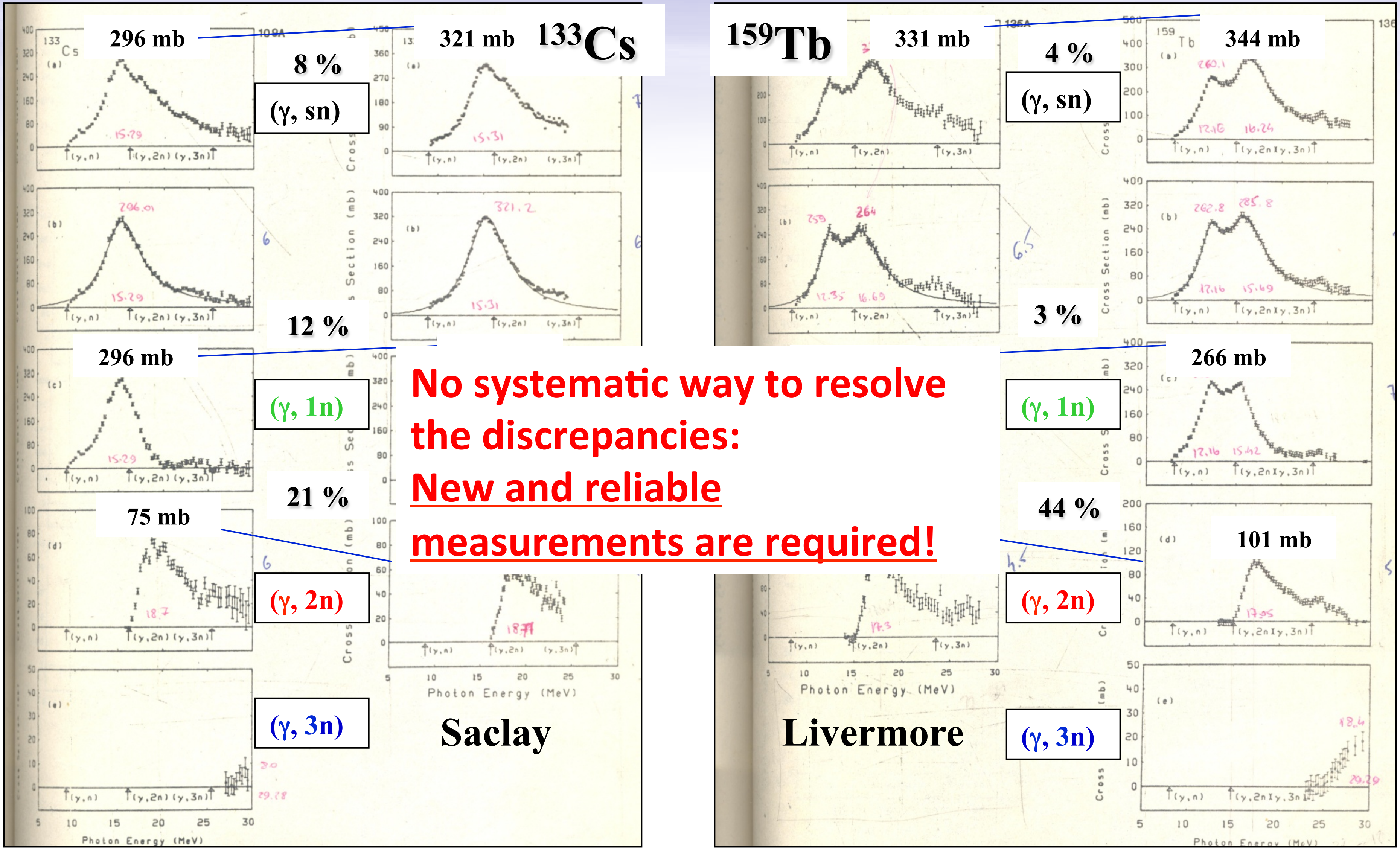
(γ, tot) = + (γ, 1n) + (γ, 2n) + (γ, 3n) +…

(γ, Sn) = + (γ, 1n) + 2(γ, 2n) + 3(γ, 3n) +…

Typical disagreements of data from two Labs:

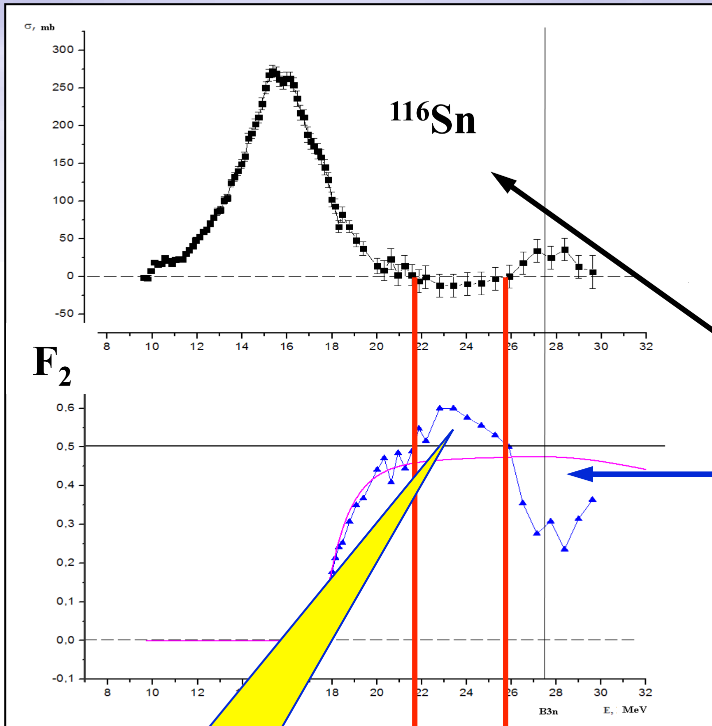
(γ, 1n) c.s. are generally noticeably larger at Saclay than at Livermore

(γ, 2n) c.s. are generally larger at Livermore than at Saclay.



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

Behavior of F_2 for many nuclei is quite different and do not satisfy the criteria proposed

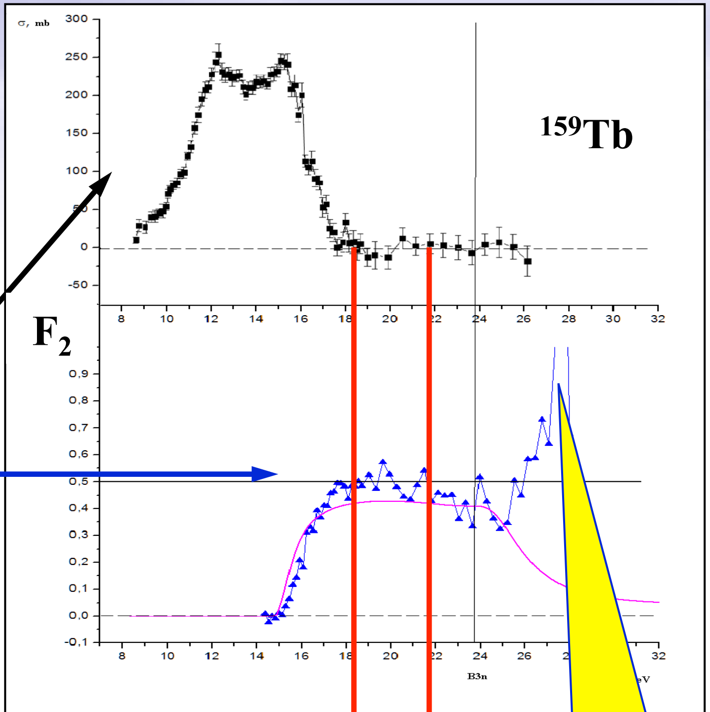


Livermore

data

$\sigma(\gamma, 1n)$

F_2



Significant disagreements: $F_2 > 0.6$!

$$F_2 = \frac{\sigma(\gamma, 2n)}{\sigma(\gamma, 1n) + 2\sigma(\gamma, 2n) + 3\sigma(\gamma, 3n) + \ldots} < 0.50\ (!)$$

Dramatic disagreements: $F_2 \approx 1.5 – 2.0$!

Physically not reliable negative cross section values are correlated with physically forbidden values $F_2 > 0.50$

Proposals for future measurements using The ELI-NP monoenergetic γ–quanta source with energies up to ~ 19 MeV.

The new measurements for isotopes for which we found out the most prominent disagreements between experimental and evaluated reaction cross sections are of great interest on the first stage.

1-st priority: ^{159}Tb (B2n = 14.9 MeV), ^{181}Ta (B2n = 14.2 MeV), ^{208}Pb (B2n = 14.1 MeV).

2-nd priority: ^{94}Zr (B2n = 14.9 MeV), ^{186,188,189,190,192}Os (B2n = 14.9,14.3,13.9,13.7,13.3 MeV).

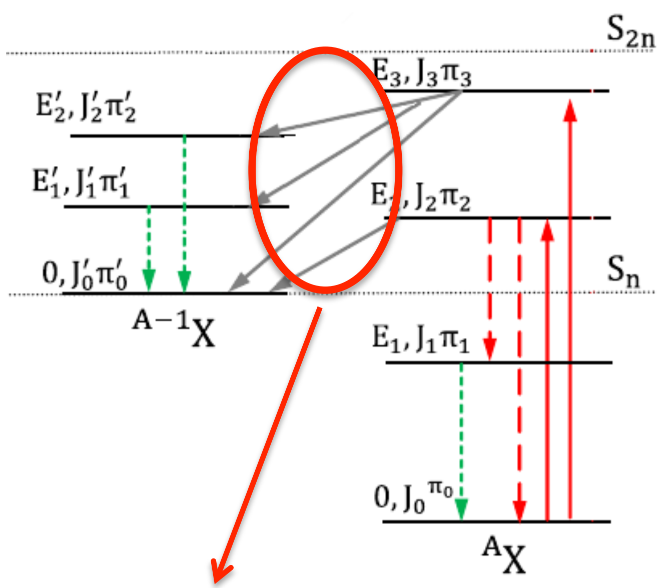
3-d priority (measurements would be possible for narrow energy range (~ 2 - 3 MeV)) ^{115}In (B2n = 16.3 MeV), ^{116}Sn (B2n = 17.1 MeV).

4-th priority new data will be evaluated further.

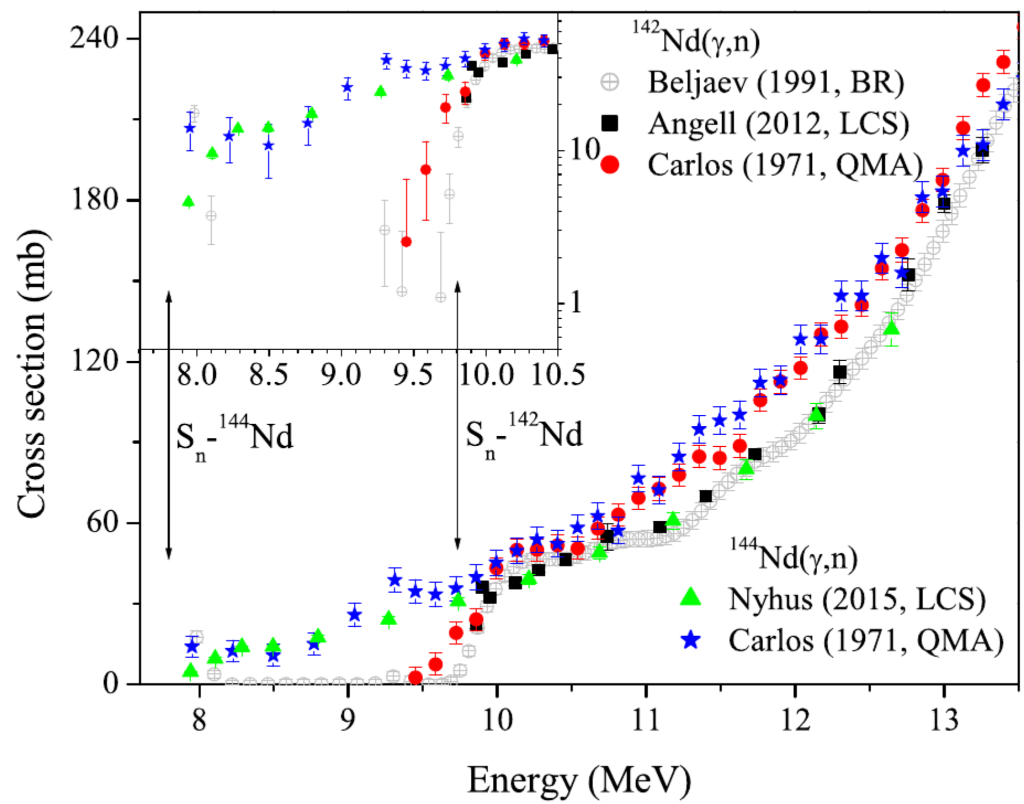
Because the correspondent final nuclei (^{157,158}Tb, ^{179}Ta, ^{206,207}Pb, ^{92,93}Zr, ^{184}Os, ^{113}In, ^{114,115}Sn) are not suitable candidates for activation measurements.

For (γ,1n) cross sections – measurements using LCS γ-ray beam and the high efficiency neutron detector developed at GACKO offer the required precision and reliability

$E_\gamma < S_{2n} \Rightarrow (\gamma,1n)$



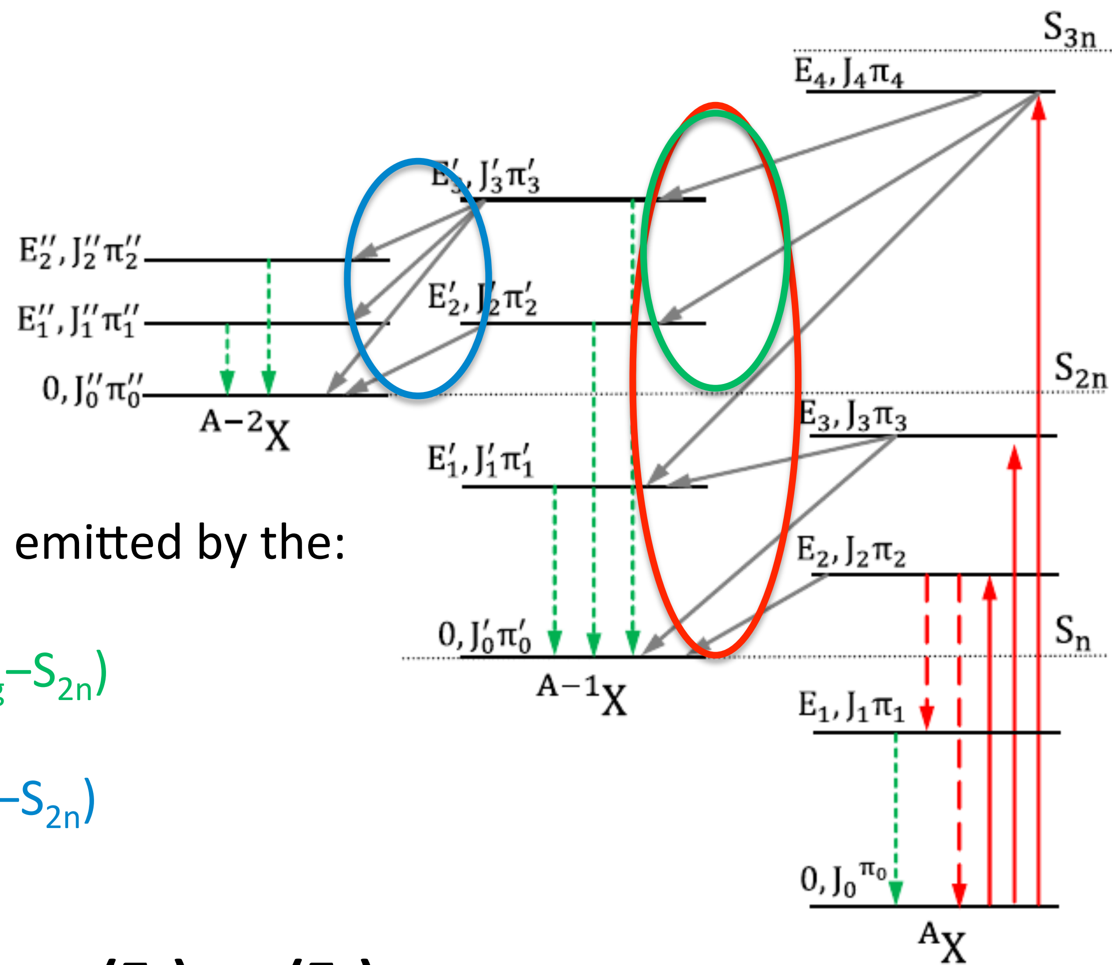
Average energy E_{avg} determined using the ring ratio method



For (γ,2n), (γ,3n), … cross sections

Example:

$$E_{\gamma} < S_{3n} \Rightarrow (\gamma,1n) + (\gamma,2n)$$



Neutrons from (g,1n) reactions
Average energy $\mathbf{E_1}$
Energy range: 0 to E_g-S_n

Neutrons from (g,2n) reactions emitted by the:

- ^{A}X nucleus
  - Energy range: ~(0 to E_g–S_{2n})
- ^{A-1}X nucleus
  - Energy range: ~(0 to E_g–S_{2n})

Average energy $\mathbf{E_2}$

$$E_1 \neq E_2 \Rightarrow \varepsilon(E_1) \neq \varepsilon(E_2)$$

Let us assume $E_\gamma < S_{4n} \Rightarrow (\gamma,1n), (\gamma,2n), (\gamma,3n)$ induced reactions

N_1, N_2, N_3 = number of (g,1n), (g,2n), (g,3n) induced reactions

E_1, E_2, E_3 = average energy of (g,1n), (g,2n), (g,3n) neutrons

N_s, N_d, N_t = number of single, double and triple neutron events

Adjust experimental conditions to have maximum one reaction per γ-ray beam pulse

Single neutron events:

$$N_s = N_1 \cdot \varepsilon(E_1) + N_2 \cdot {}_{2}C_{1} \cdot \varepsilon(E_2)(1-\varepsilon(E_2)) + N_3 \cdot {}_{3}C_{1} \cdot \varepsilon(E_3)(1-\varepsilon(E_3))^2$$

Double neutron events:

$$N_d = N_2 \cdot \varepsilon(E_2)^2 + N_3 \cdot {}_{3}C_{2} \cdot \varepsilon(E_3)^2 (1-\varepsilon(E_3))$$

Triple neutron events:

$$N_t = N_3 \cdot \varepsilon(E_3)^3$$

N_s, N_d, N_t - we measure directly

N_1, N_2, N_3 - we must determine to obtain the cross sections

E_1, E_2, E_3 - ? Can not be determined using the ring ratio method **PROBLEM**

A neutron multiplicity sorting technique with
a flat efficiency neutron detector is required!

Considering a flat efficiency neutron detector and $E_\gamma < S_{4n}$ we have:

Single neutron events:

$$N_s = N_1 \cdot \varepsilon + N_2 \cdot 2C_1 \cdot \varepsilon(1-\varepsilon) + N_3 \cdot 3C_1 \cdot \varepsilon(1-\varepsilon)^2$$

Double neutron events:

$$N_d = N_2 \cdot \varepsilon^2 + N_3 \cdot 3C_2 \cdot \varepsilon^2 (1-\varepsilon)$$

Triple neutron events:

$$N_t = N_3 \cdot \varepsilon^3$$

N_s, N_d, N_t - we measure directly

ε - known by direct measurement and by simulation

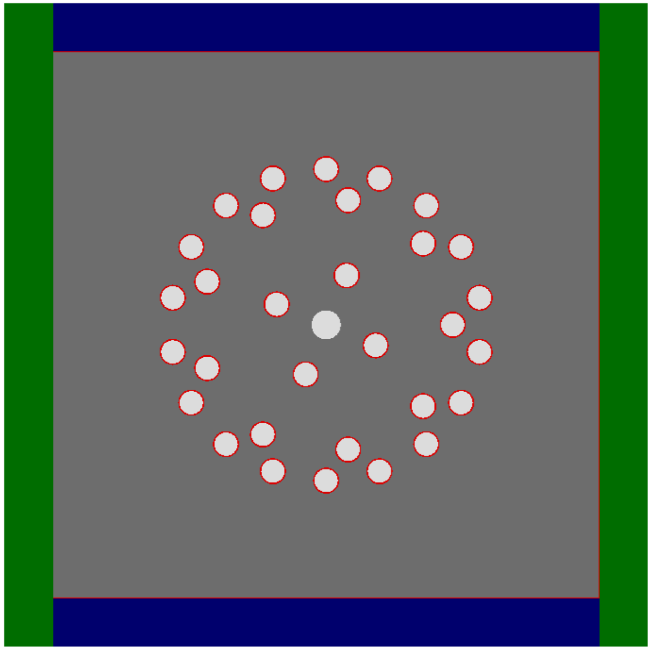
N_1, N_2, N_3 - we determine to obtain the

(γ,1n), (γ,2n), (γ,3n) cross sections

Neutron multiplicity sorting with a 4π neutron detector

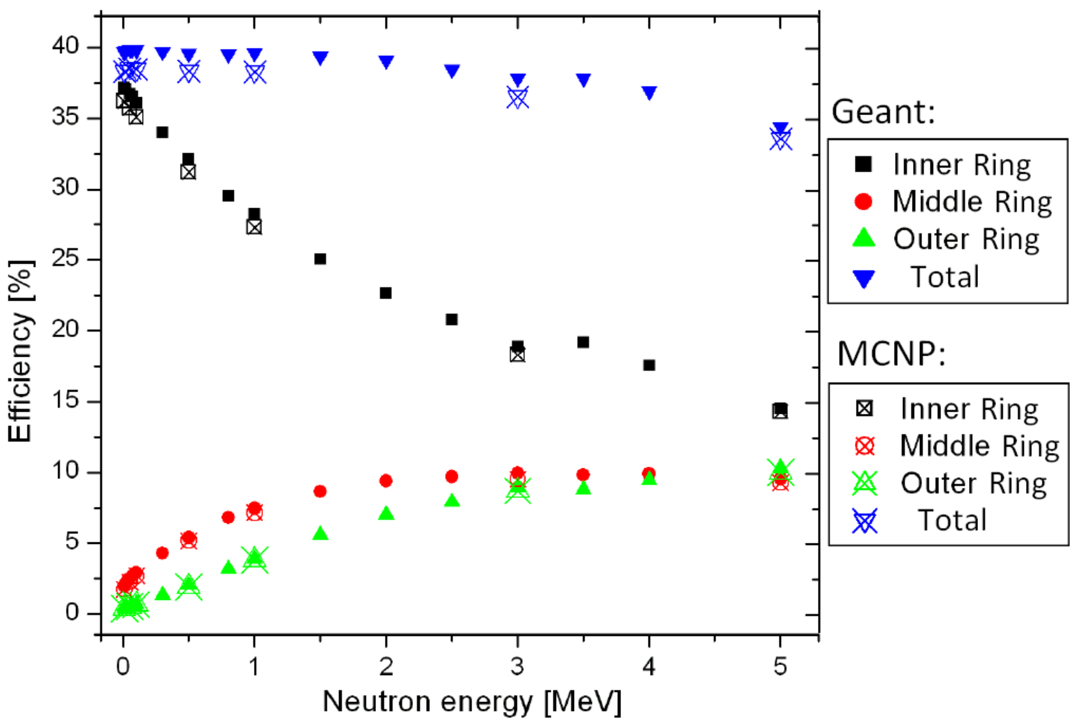
Flat-efficiency 4π neutron detector -> $\underline{\varepsilon(E_n) \text{ no longer depends on } E_n}$

Configuration	^{3}He counters	Distance
Inner ring	4	5.5 cm
Middle ring	9	13 cm
Outer ring	18	16 cm
Total	31	



Moderator size: 46 cm

Neutron multiplicity sorting with a 4π neutron detector



Detection efficiency:

<u>(γ,n) neutrons:</u>

$\varepsilon = 40\%$

<u>(γ,2n) neutrons:</u>

Both neutrons detected:

$\varepsilon^2 = 16\%$

Only one neutron detected:

$\varepsilon(1-\varepsilon) = 24\%$

<u>(γ,3n) neutrons:</u>

3 neutrons detected:

$\varepsilon^3 = 6.4\%$

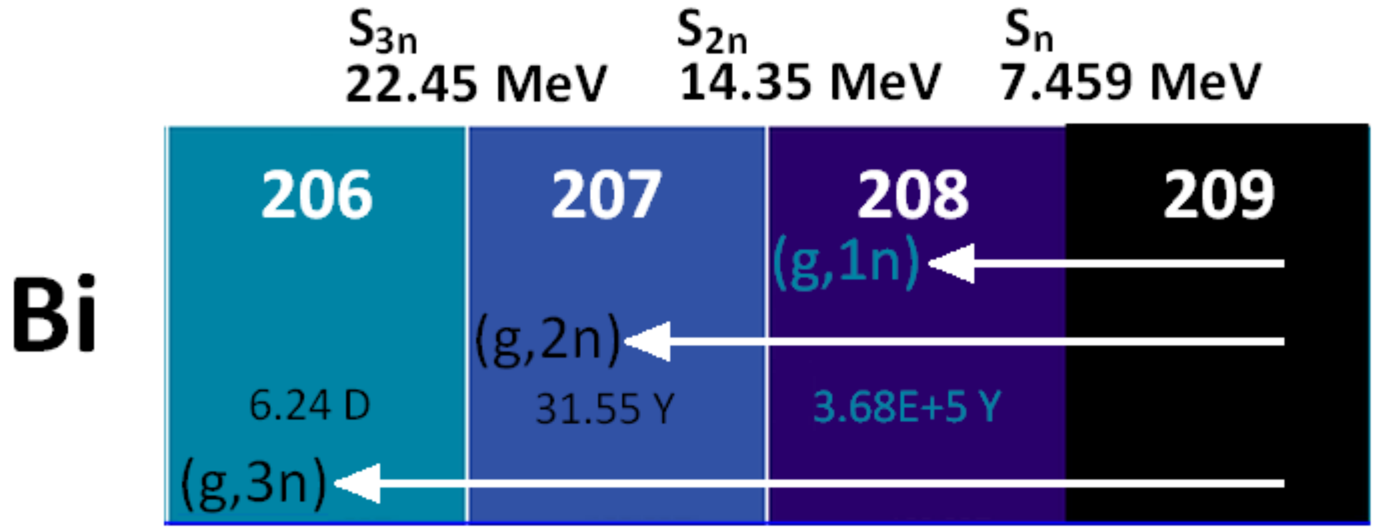
2 neutron detected:

$\varepsilon^2 (1-\varepsilon) = 9.6\%$

Only one neutron detected:

$\varepsilon(1-\varepsilon)^2 = 14.4\%$

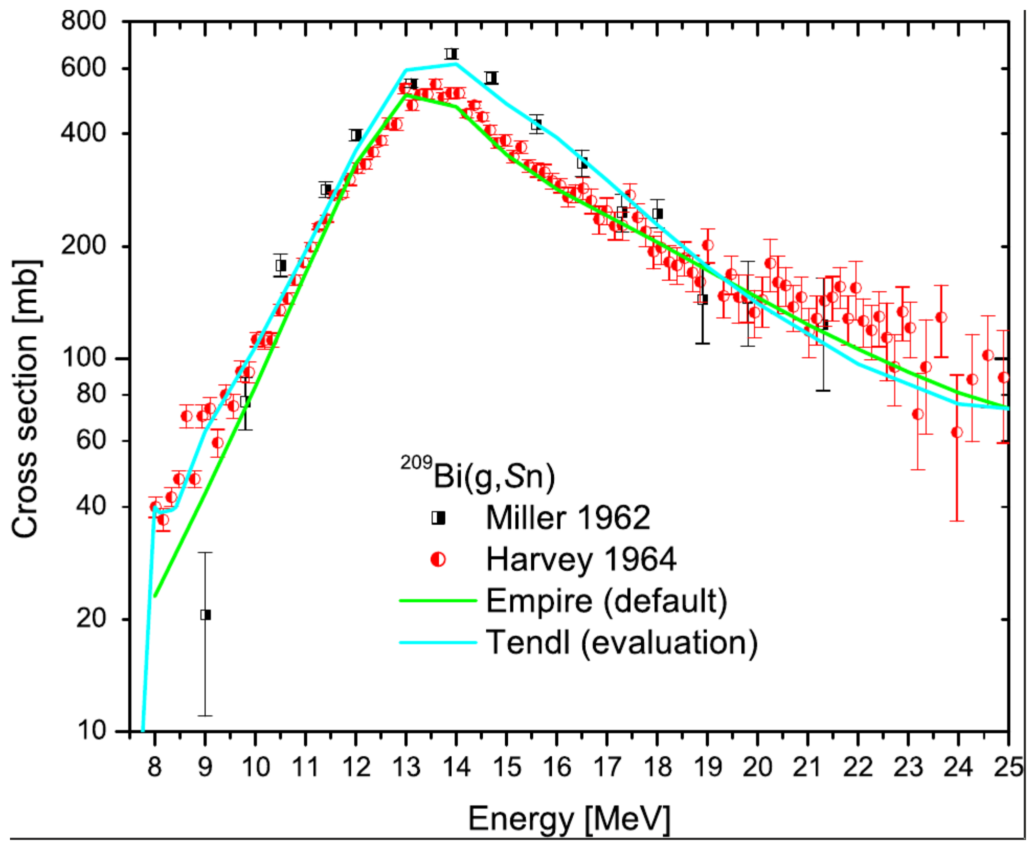
Measurements of partial and total photoneutron cross sections for ^{209}Bi



- Electron energies between 600 and 1250 MeV
- Q-switch Nd : YVO_4 laser INAZUMA
- 7.5 – 28 MeV γ-ray beams
- Flat efficiency 4π neutron detector
- $LaBr_3$ detector for energy monitor
- 100% NaI-Tl detector flux monitor
- Monoisotopic thick ^{209}Bi target

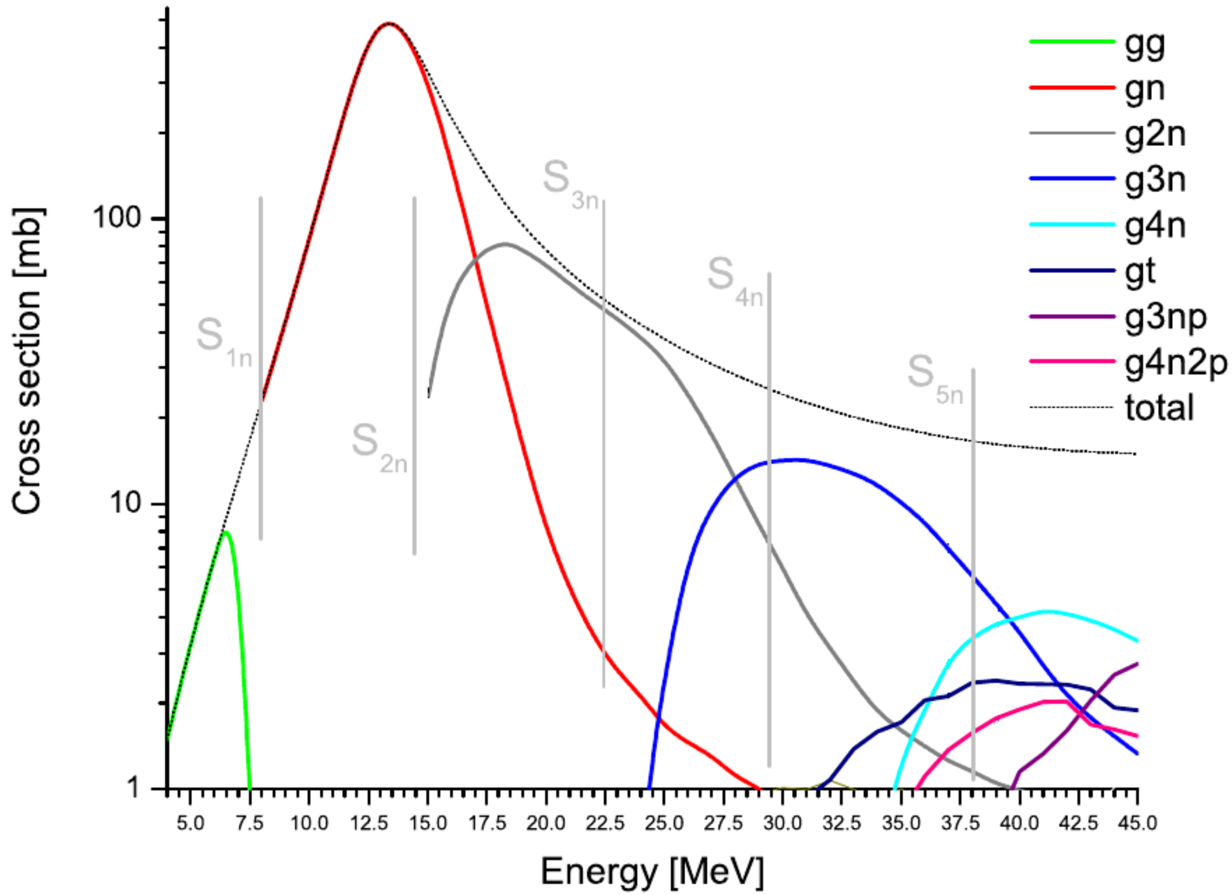
Calculations of ^{209}Bi(g,abs) cross section using the Empire code

Gamma strength function:
Modified Lorentzian 1 (MLO1) – taken from RIPL
GDR parameters - taken from RIPL
- first choice - deduced from experimental data
- second choice - **parametrizations**.



Default Level density - Enhanced Generalized Superfluid Model (EGSM) from RIPL.
Default optical potential for neutrons and protons is Koning-Delaroche regional potential.
Preequilibrium model - the exciton model implemented in PCROSS.

Calculations of ^{209}Bi(g,xn) cross section using the Empire code



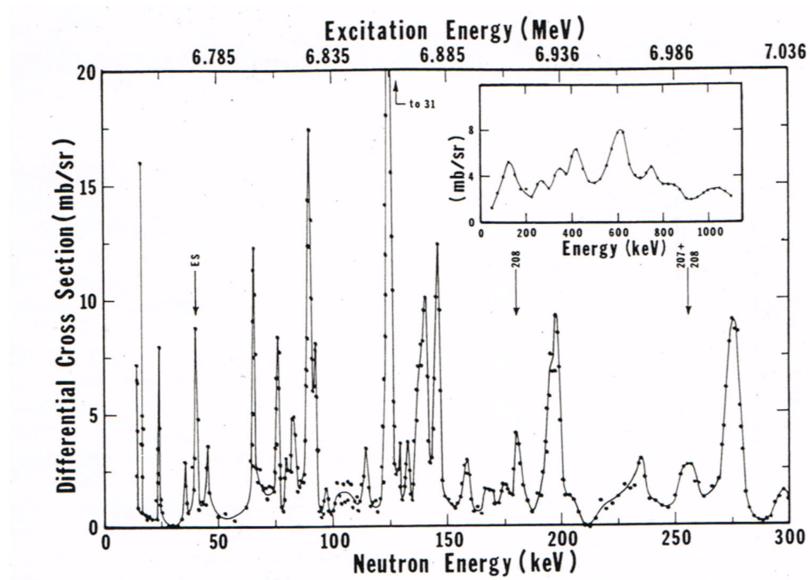
Research program in Japan during May – July 2015

- Reduce the minimum laser frequency of 20KHz to 1 kHz by using a Pockels Cell at NewSUBARU. The reduction of the frequency is necessary to record neutrons that are moderated in polyethylene event by event during the gamma-ray beam interval.
- Efficiency calibration of the flat-efficiency detector at NIMJ (National Institute of Metrology of Japan) in Tsukuba.
- Develop the new electronics and data acquisition system for event by event data format.
- A test of neutron-multiplicity sorting at GACKO of NewSUBARU.
- Experiment: ^{209}Bi(g,xn) cross sections.

PDR and spin-flip M1 resonance above Sn

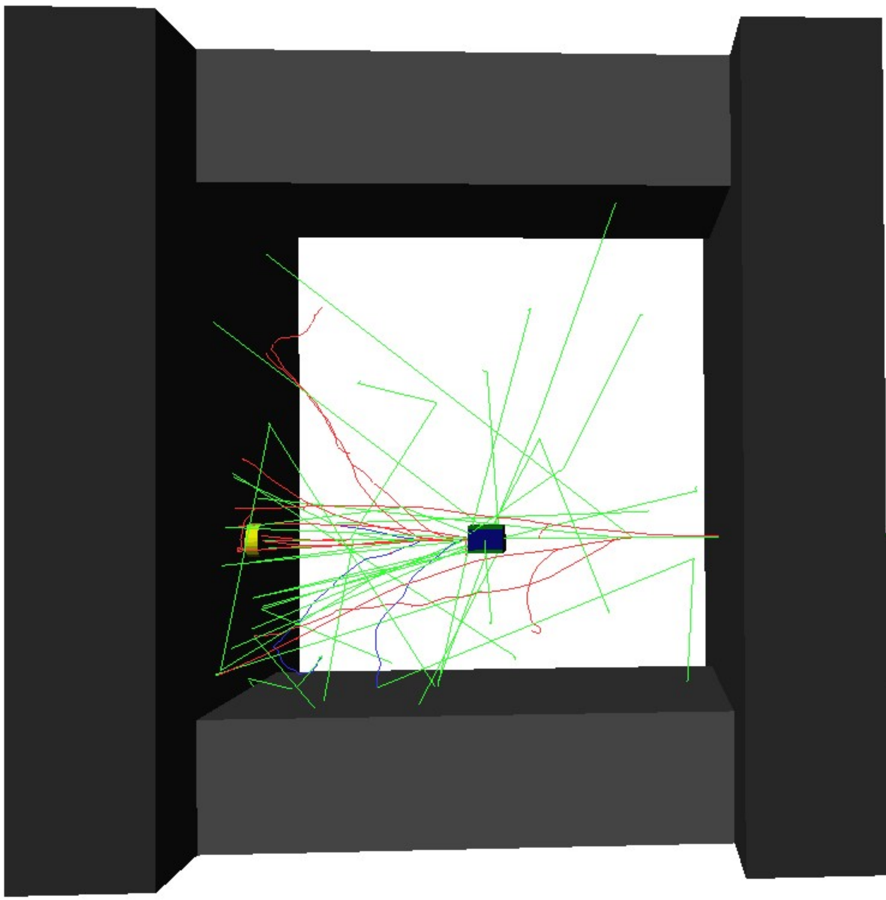
- Both PDR and spin-flip M1 resonance emerge near S_n
- Below S_n NRF experiments with 100% linear polarized γ-ray beams can separate E1 and M1 resonances in peak structure
- Recently, inelastic proton scattering at intermediate energies has revealed PDR and M1 resonance in ^{208}Pb and ^{90}Zr but the identification of E1 and M1 components by (p,p') reactions is indirect because PDR and M1 components are deduced by means of the multipole-decomposition analysis of the proton angular distribution

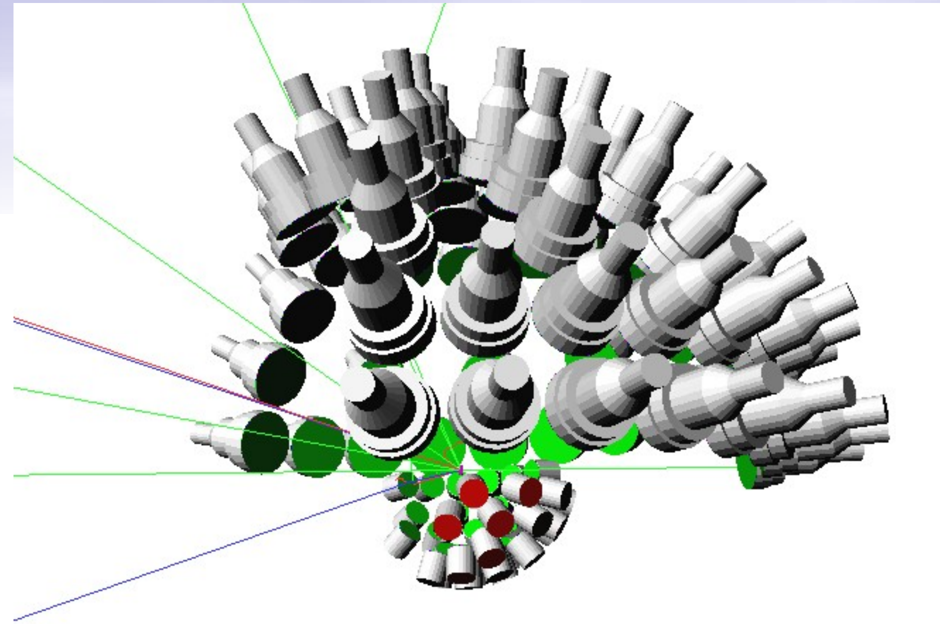
- We propose to investigate PDR and spin-flip M1 resonance with a mixed array consisting from LaBr3 + liquid scintillation neutron detector array

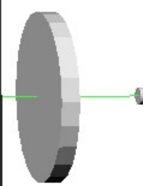


TDR on physics above the neutron threshold

Currently simulations are carried on in order to foresee the effect of pile-up and to test the ring ratio technique







31 n det. (20cm x 5cm NE213) +
31 n det (10cm x 2 cm 6Li-glass) +
34 $LaBr_3$ & CeBr3 det. (3 x 3 inch)

<u>Instrumentation:</u>

(i) $LaBr_3$(Ce) + CeBr3 array,

(ii) NE213 liquid scintillator + 6Li-glass detector array

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Structural Instruments 2007-2013

Sectoral Operational Programme "Increase of Economic Competitiveness"

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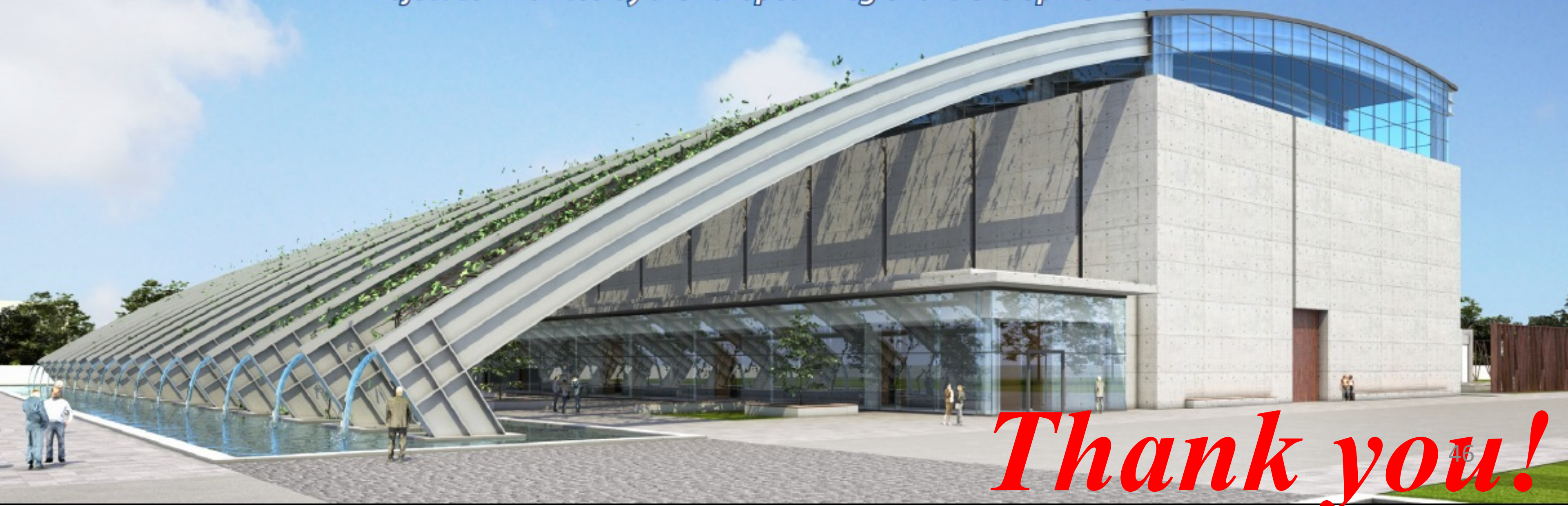

Thank you!