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

Photonuclear Reactions at Extreme Light Infrastructure - Nuclear Physics (ELI-NP)

P(ND)2-2 – Second International Workshop on Perspectives on Nuclear Data for the Next Decade

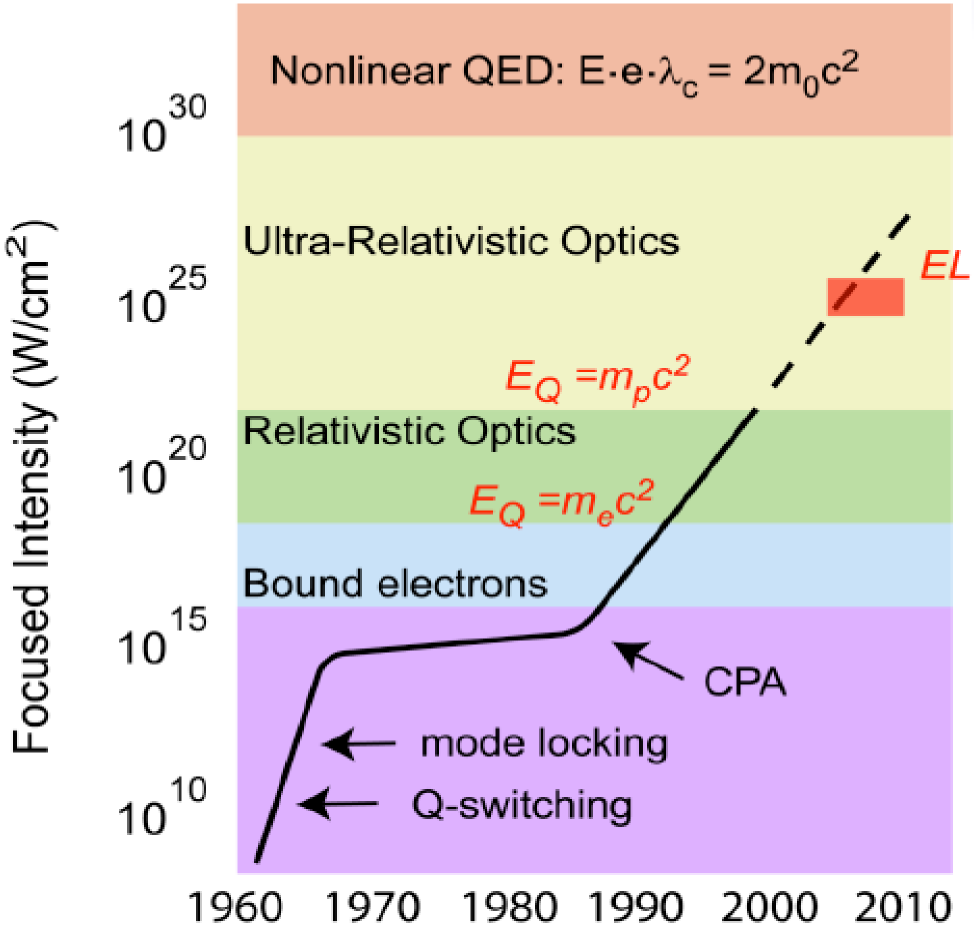
14-17 October 2014 Bruyères-le-Châtel, France 2014

N.V Zamfir, D.M. Filipescu

V. Varlamov, H. Utsunomiya, F. Camera, A. Krasznahorkay

Extreme Light Infrastructure

Gerard Mourou 1985: Chirped Pulse Amplification (CPA)



Extreme Light Infrastructure

2006 – ELI on ESFRI Roadmap

ELI-PP 2007-2010 (FP7)

ELI-Beamlines (Czech Republic)

ELI-Attoseconds (Hungary)

ELI-Nuclear Physics (Romania)

ELI-DC (Delivery Consortium): 2010

Legal entity: April 2013

Czech Republic, Hungary, Romania,

Italy, Germany, UK

ELI-NP Milestones

January 2012: Project submitted to the EC

July 2012: Romanian Government Decision

Construction of the New Research Infrastructure ELI-NP: 293 M€

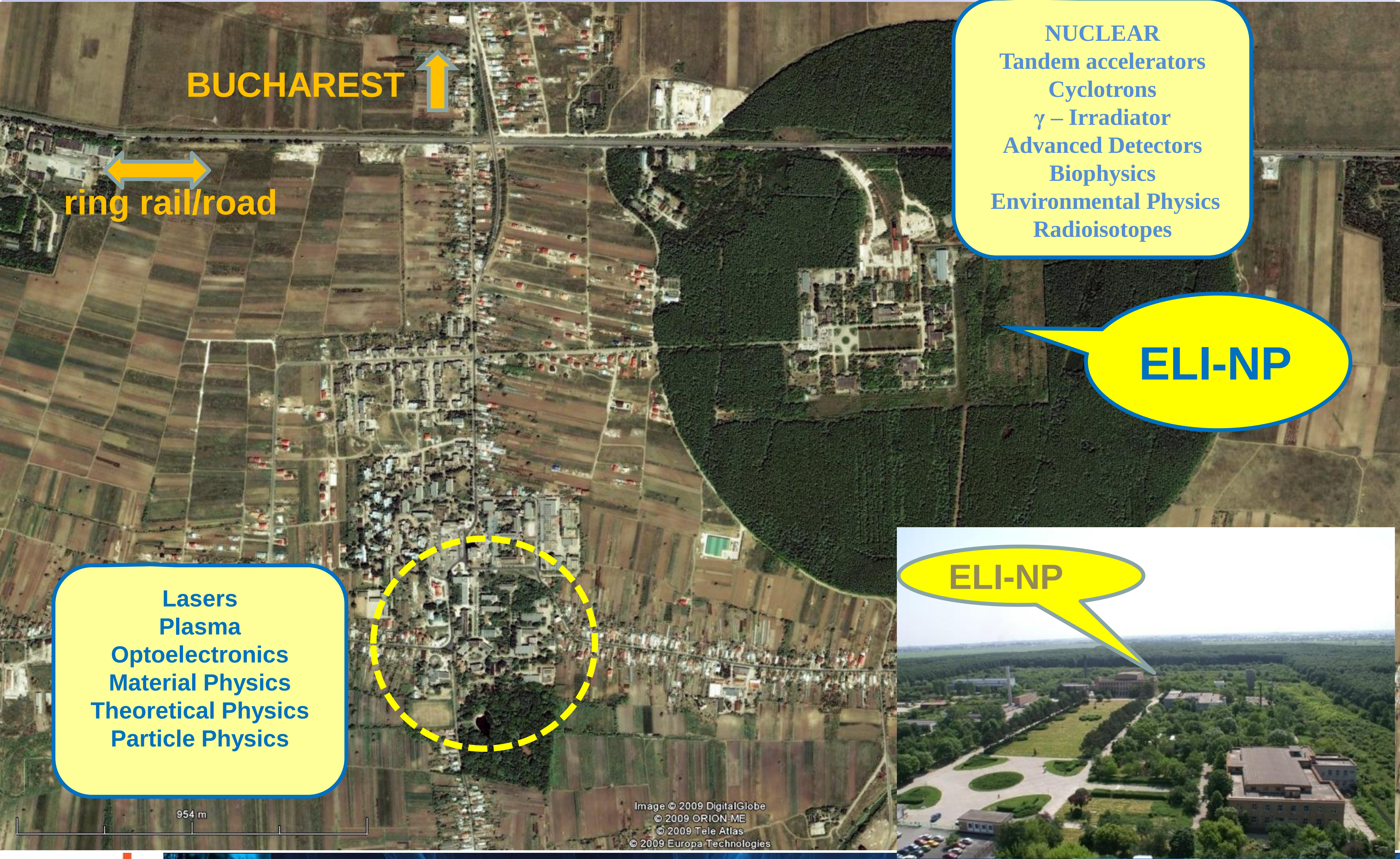
September 2012: EC Project Approval

European Regional Development Fund

Financial Support (83%) of the First phase (2012-2015) 180 M€

December 2012: Contract with Romanian Managing Authority

Bucharest-Magurele National Physics Institutes



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

Lasers
Plasma
Optoelectronics
Material Physics
Theoretical Physics
Particle Physics

Image © 2009 DigitalGlobe
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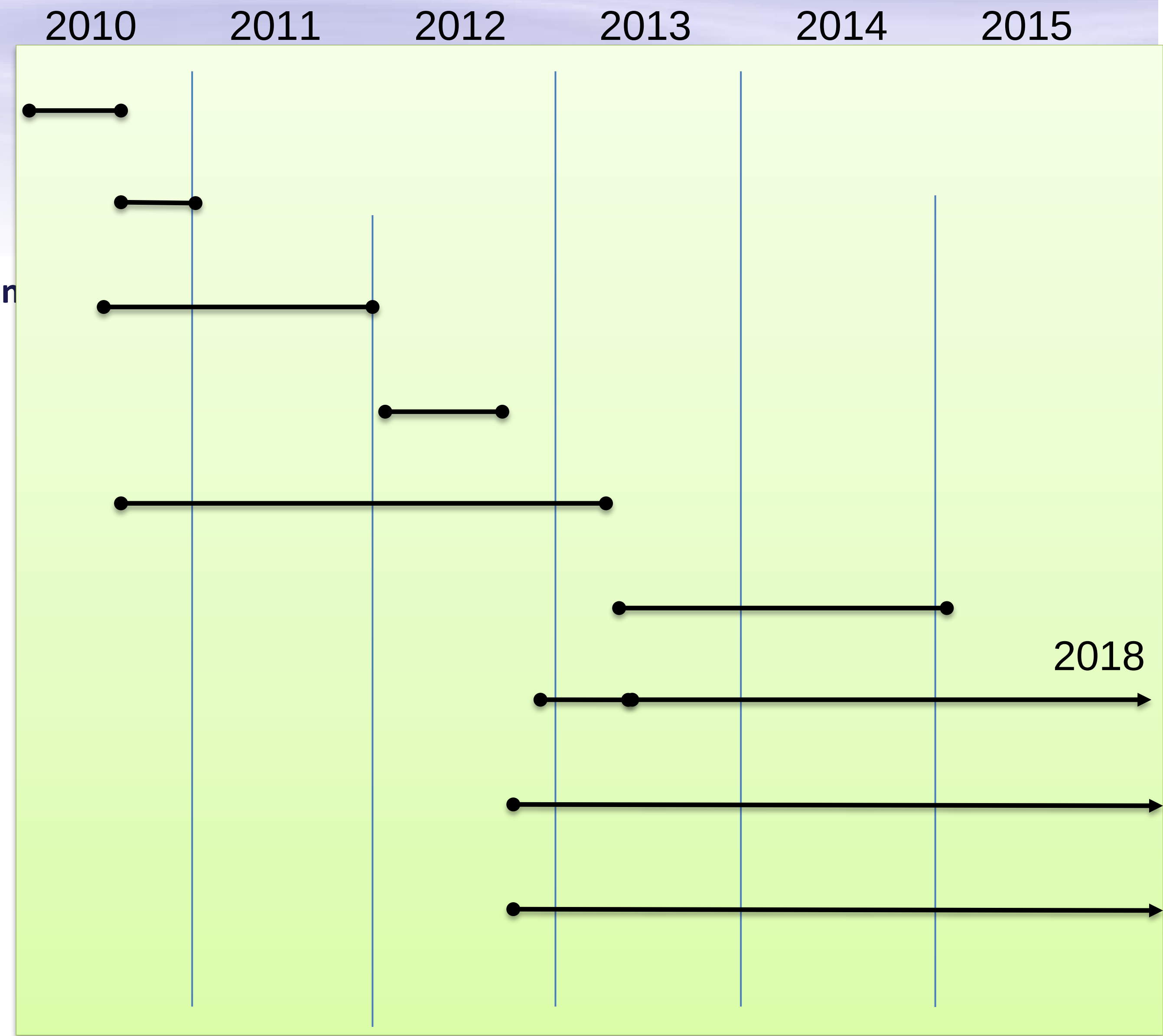
Project implementation



White Book (Scientific Case)

Feasibility Study 293M€

Preparation of the Application

E.C. Evaluation & Approval

Building - Preparation

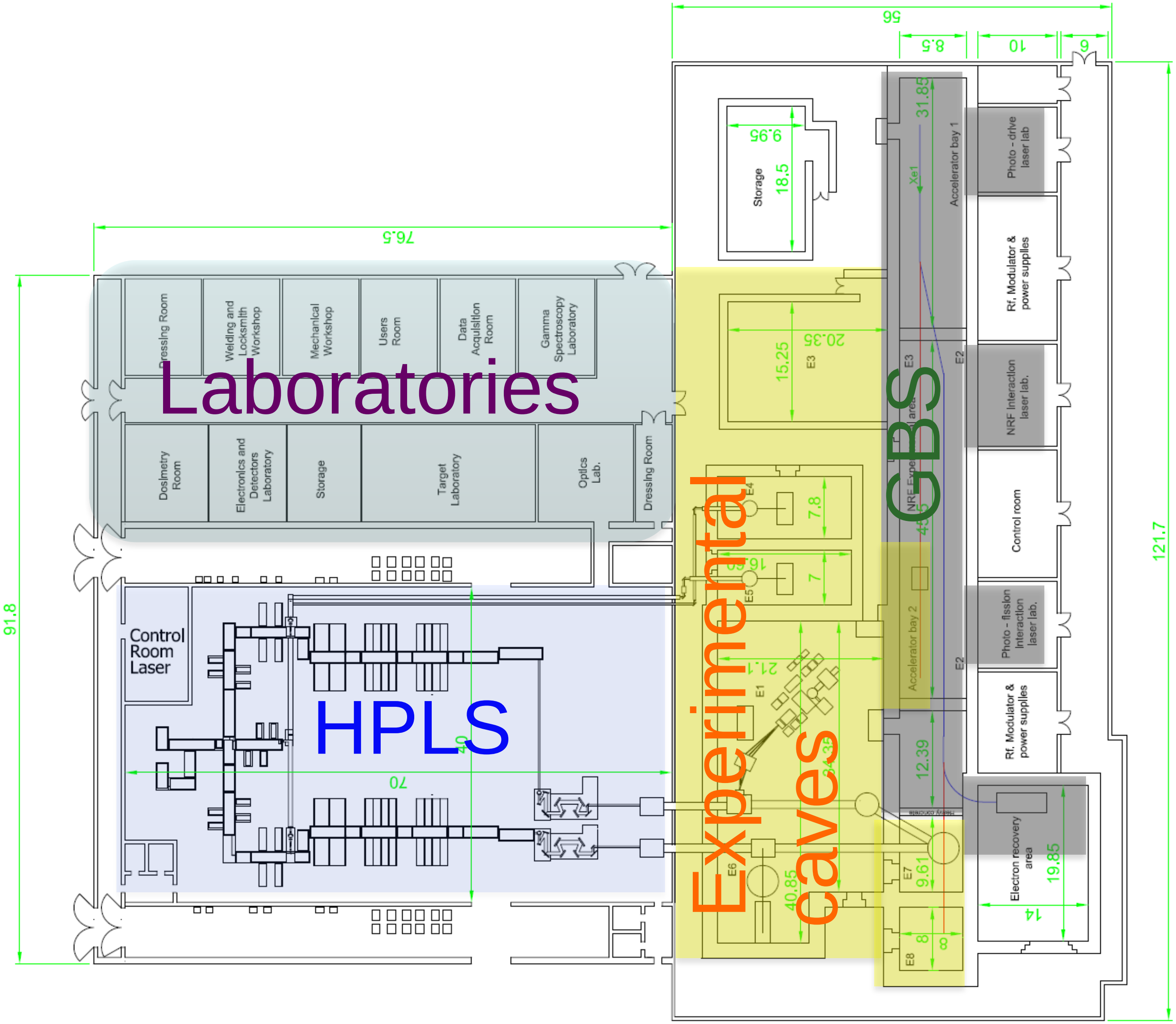
Building - Construction

Major Eqp.– Constr, Install

Experimental set-ups

Recruitment

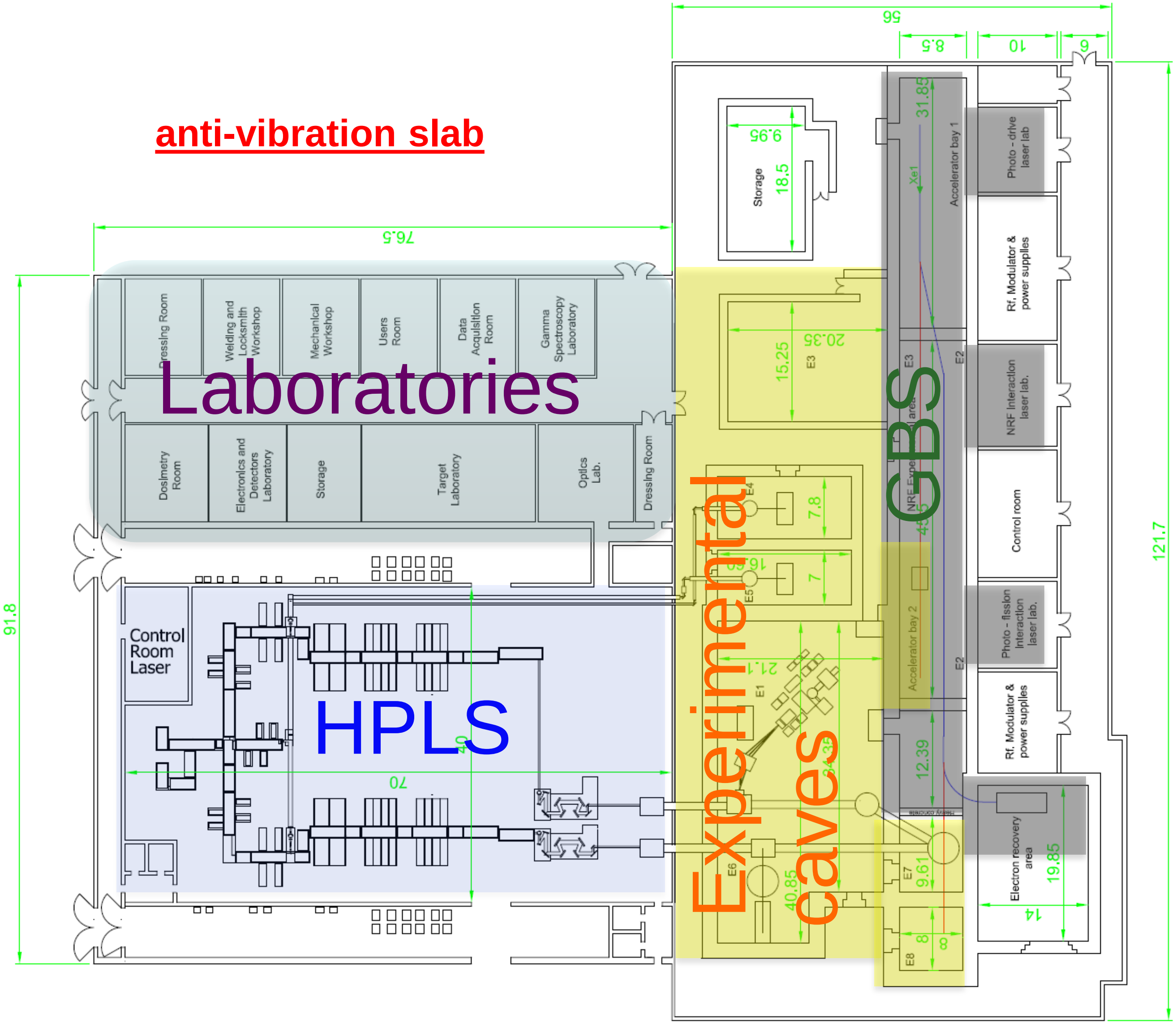
ELI–NP: Laboratory Building



ELI–NP: Laboratory Building

anti-vibration slab

±1 μm @ < 10 Hz



Buildings – STRABAG, 33000 m^2 total (~65M€)

- Experimental area building
- Office building
- Guest house
- Canteen

2x10PW Laser Contract

July 12th, 2013

Thales Optronique SAS and S.C. Thales System Romania SRL

2013-2017

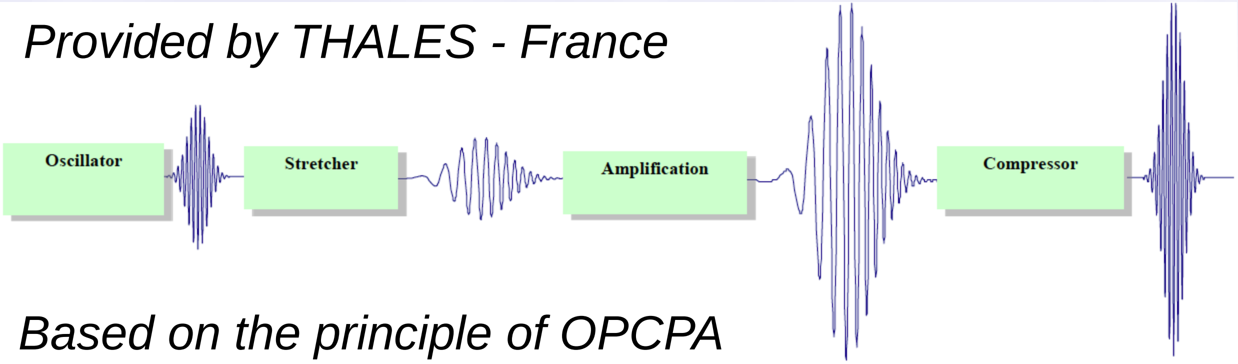
61.5 MEuro

ELI–NP HPLS

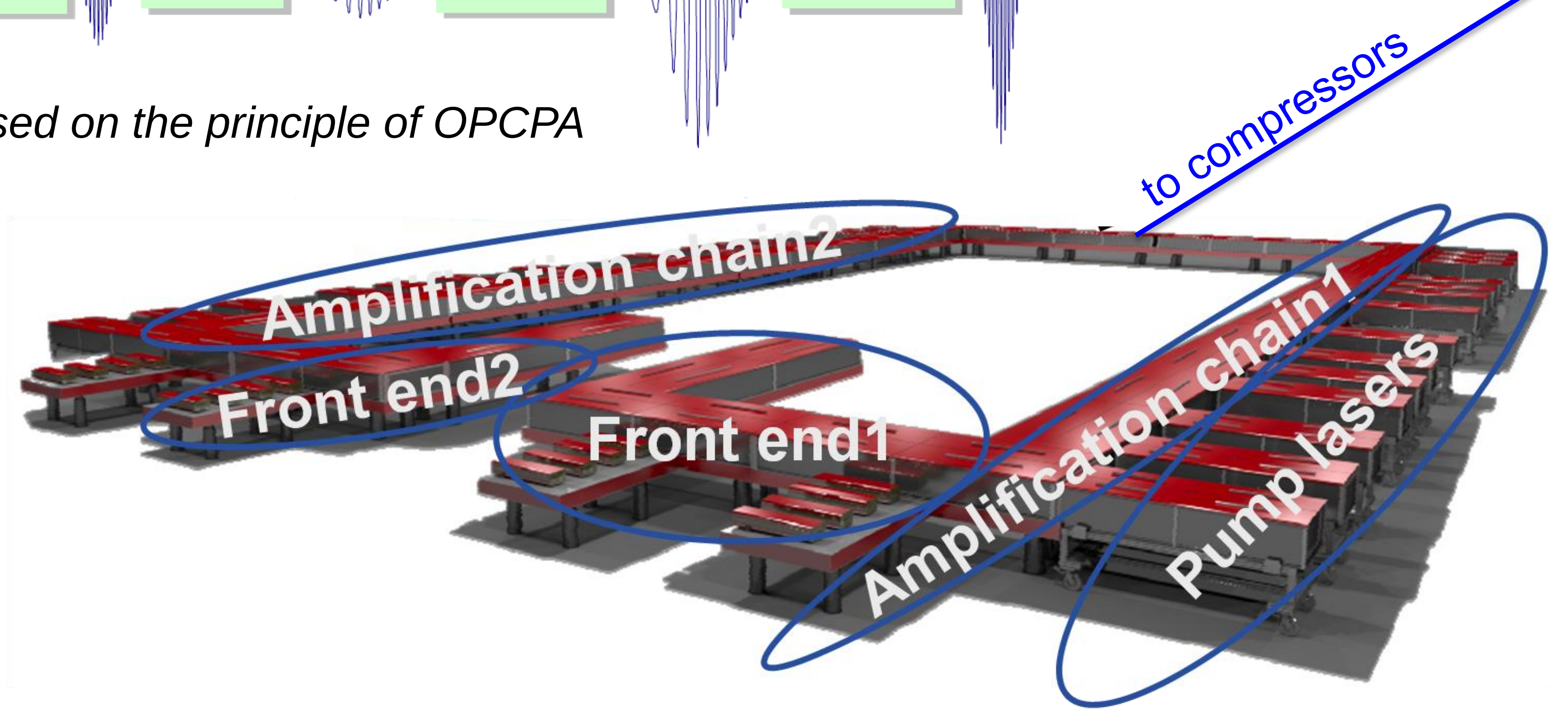
2 HPLS up to 10 PW – 6 output lines

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

Provided by THALES - France



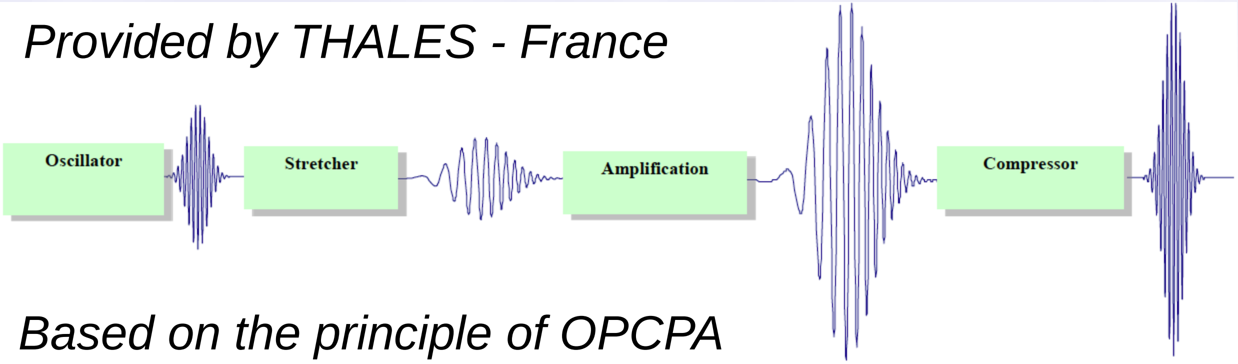
Based on the principle of OPCPA



ELI–NP HPLS

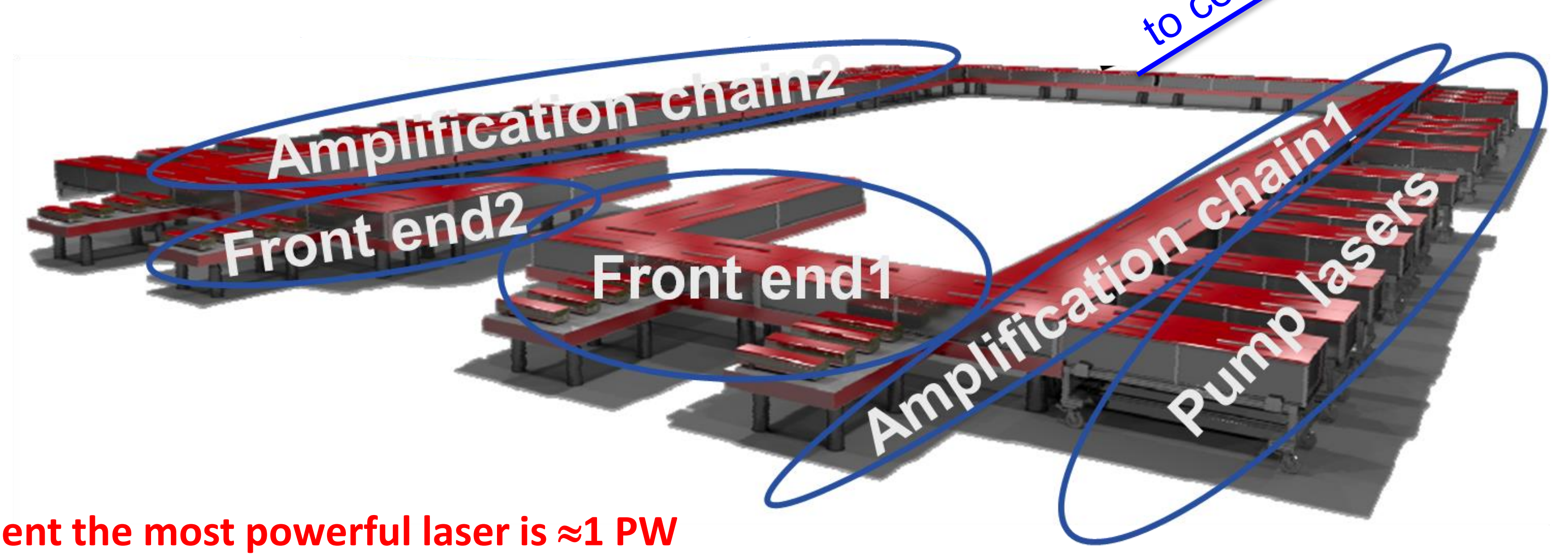
2 HPLS up to 10 PW – 6 output lines

Provided by THALES - France



Based on the principle of OPCPA

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



at present the most powerful laser is ≈1 PW

Gamma Beam System Contract

March 19th, 2019

EuroGammaS Consortium

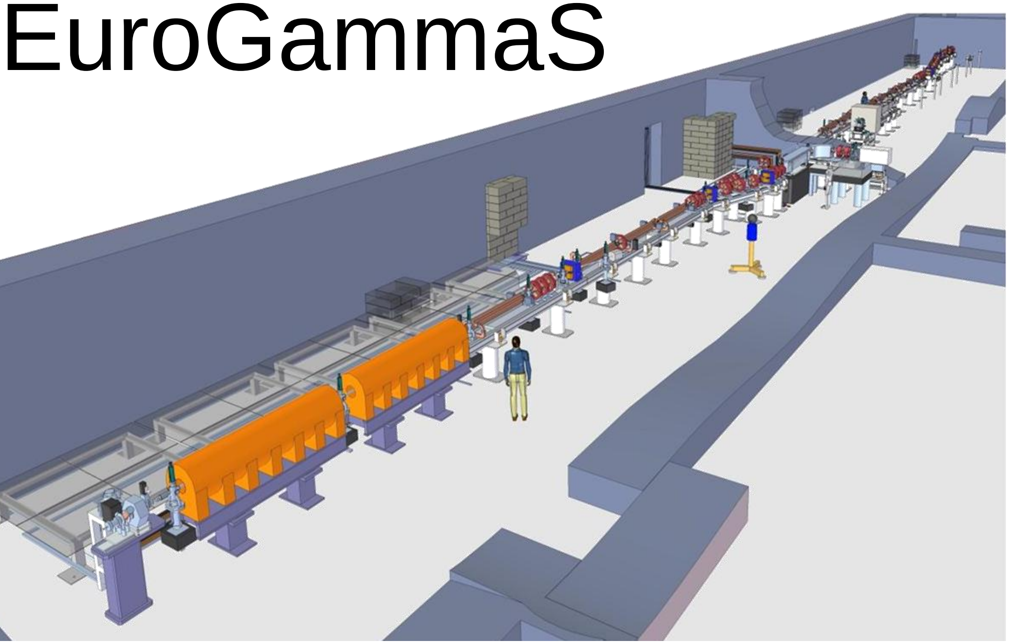
2014-2018

66.8 MEuro

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

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-Nuclear Physics

Scientific program:

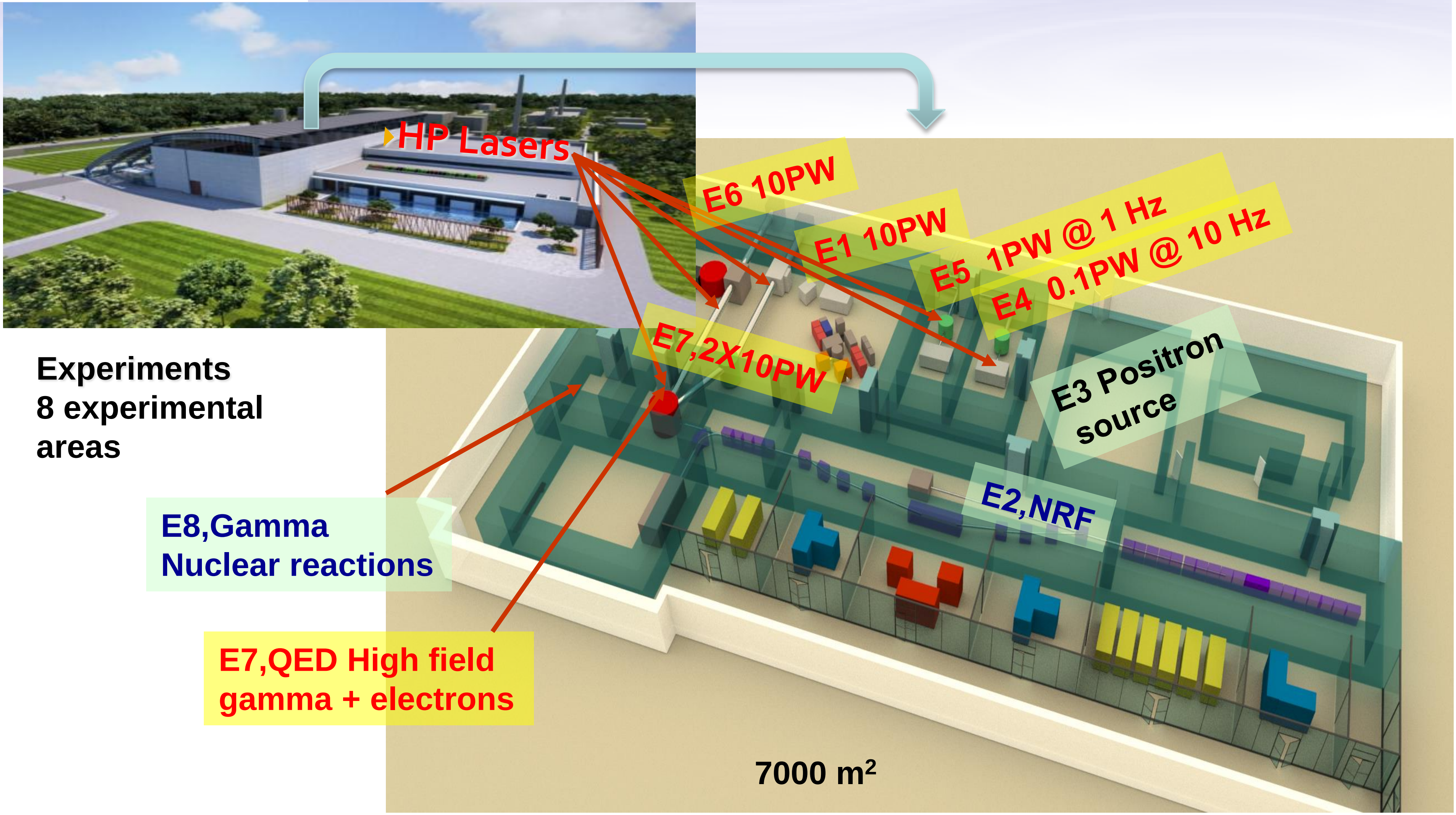
Nuclear Physics experiments to characterize laser – target int.

Photonuclear reactions

Exotic Nuclear Physics and astrophysics

Applied Research

ELI–NP Experiment Building



Experiments
8 experimental areas

E8,Gamma Nuclear reactions

E7,QED High field gamma + electrons

ELI-NP TDR Workgroups

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

Gamma WGs:

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

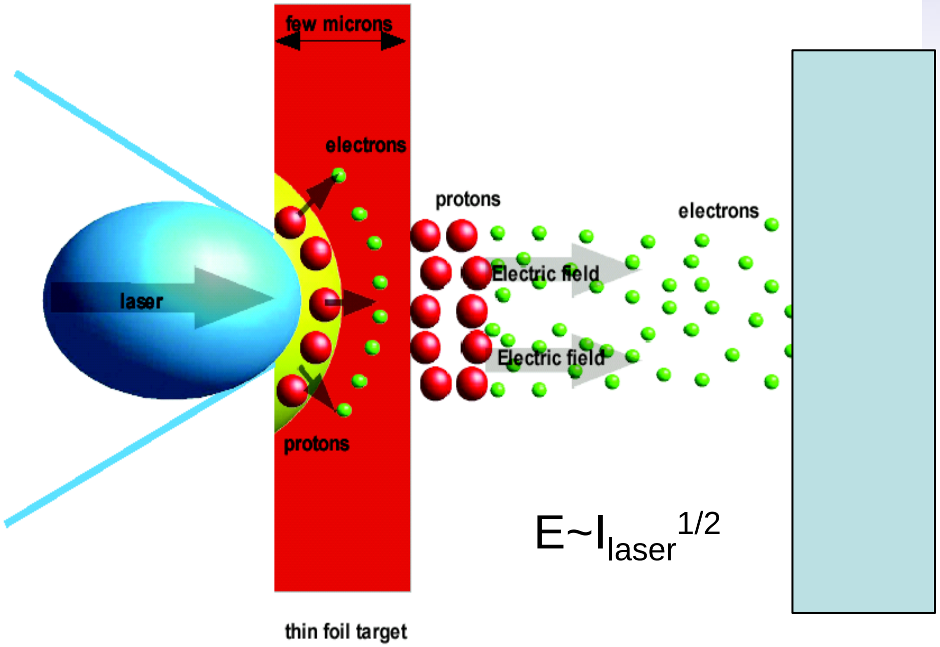
+ Positron source for materials science WG

Laser WGs:

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

+ Transversal WGs: Vacuum, Control Systems, Dosimetry

Target Normal Sheath Acceleration (TNSA)



Secondary
target

$E \sim I_{laser}^{1/2}$

Secondary radiations
- electrons bremsstrahlung
- gamma rays, neutrons

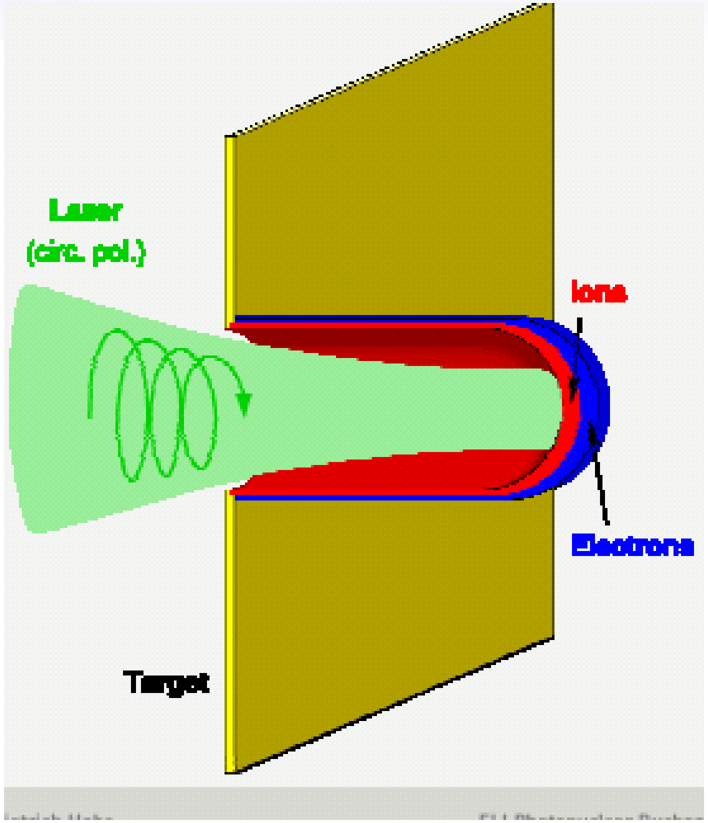
Primary radiations

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

S.C. Wilks et al., Phys. Plasmas **8**, 542 (2001).

Radiation Pressure Acceleration RPA



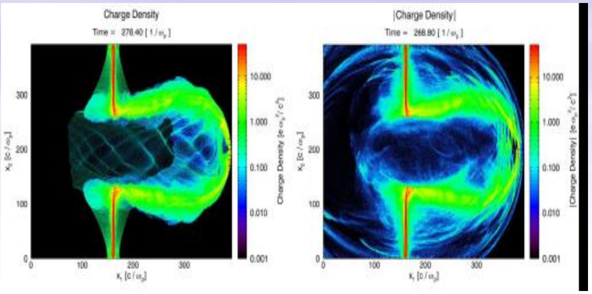
Electrons and ions accelerated
at solid state densities 10^{24}e cm^{-3}
(Classical beam densities 10^{8}e cm^{-3})
on very short distance (µm-mm)

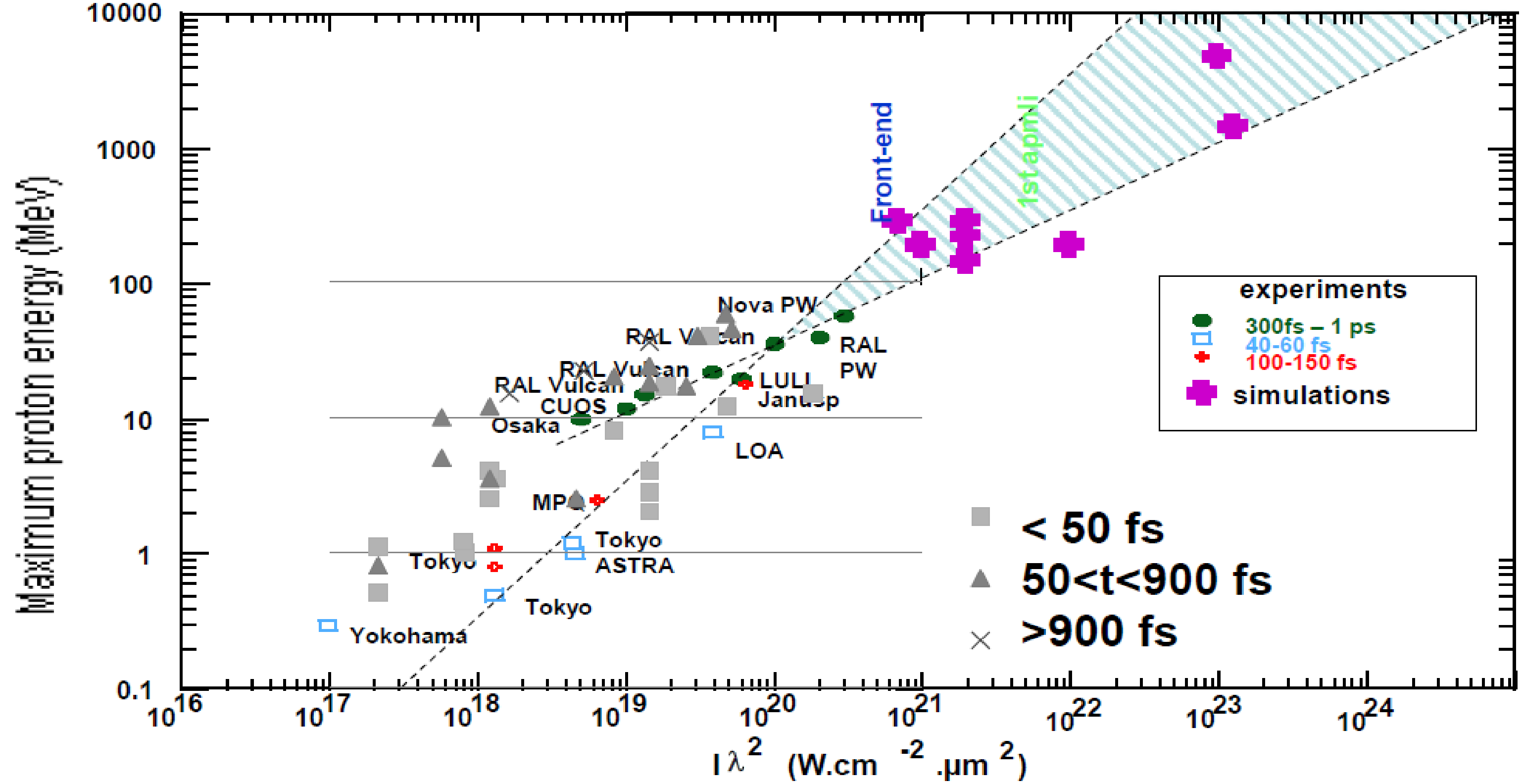
E~ I_{laser}

Energy reached equal to a 400m up-to-date accelerator (reduction of scale of 10^{9})

Proton acceleration

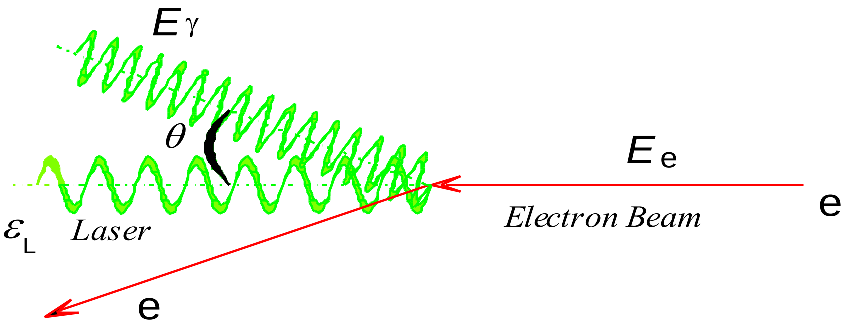
RPA simulations 10 23 W/cm2 ,15 fs





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_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

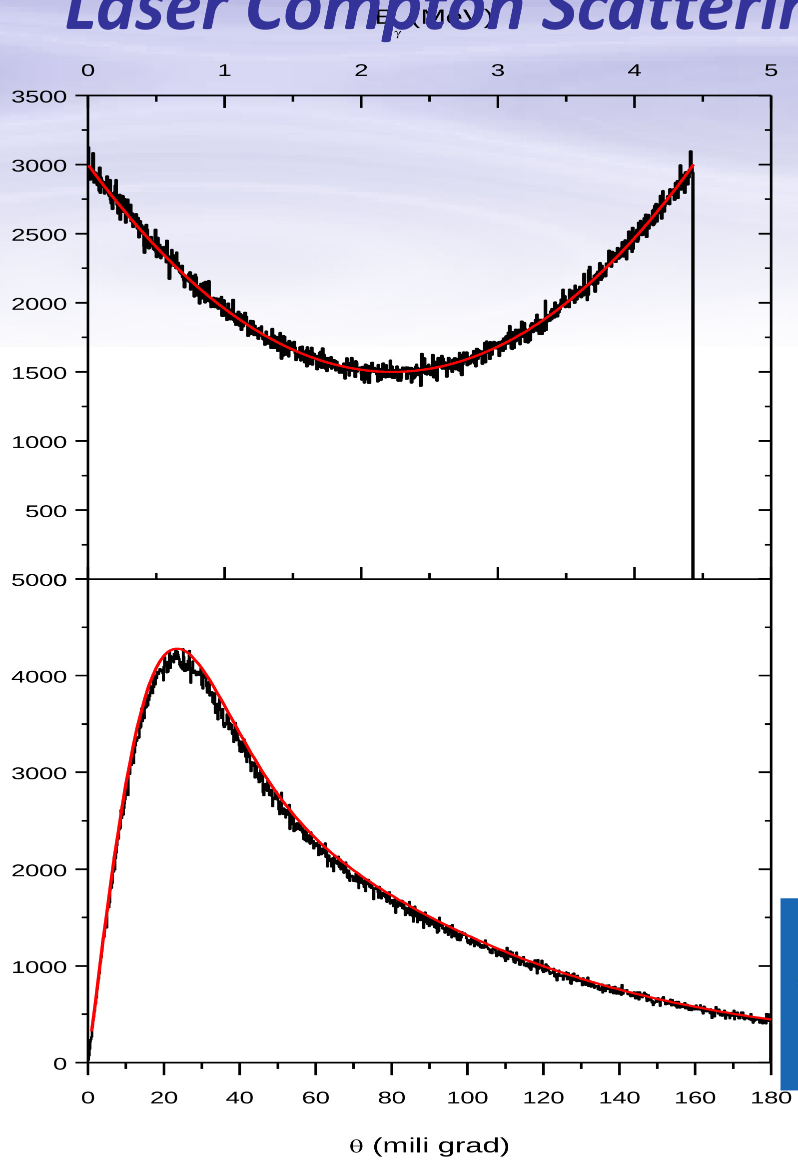
$$E_\gamma = \frac{\varepsilon_L(1+\beta)}{1+\varepsilon_L/E_e-(\beta-\varepsilon_L/E_e)\cdot\cos\theta}$$

$$(small\ \theta) \approx \frac{4\gamma^2\varepsilon_L}{1+(\gamma\theta)^2+4\gamma^2\varepsilon_L/(mc^2)}$$

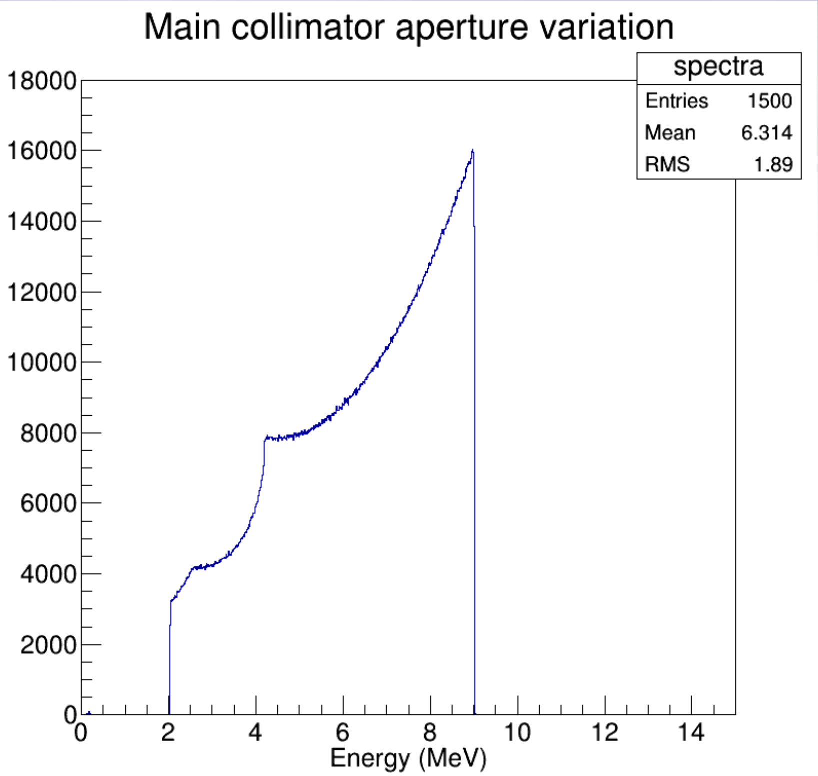
$$\boldsymbol{E_\gamma \sim 4\gamma^2\varepsilon_L} \qquad \gamma = E_e/mc^2$$

Continuous spectrum!

Laser Compton Scattering (LCS) gamma ray sources



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

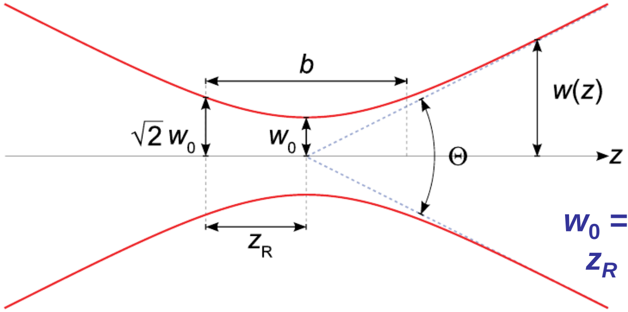


Collimation -> Quasi monochromatic spectrum

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

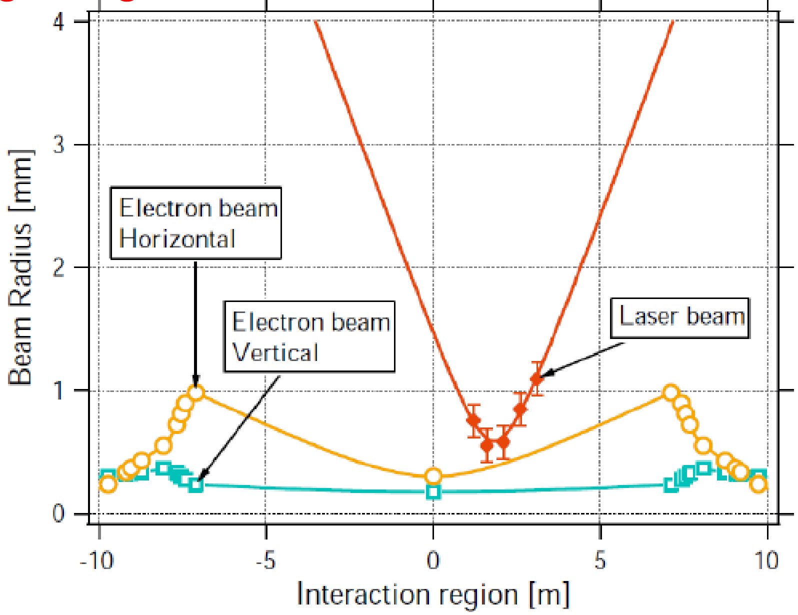
Unfortunately LCS gamma sources are produced by NOT-Ideal Electron & Laser beams

Laser modeling: hyperbolic dependence along the beam axis

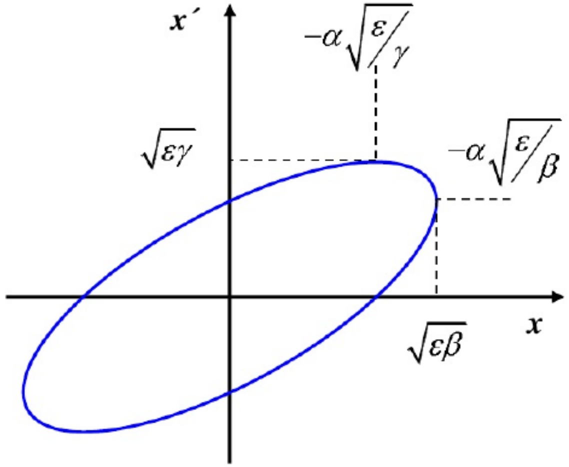


w_0 = beam size at focal point
z_R = $b/2$ = Rayleigh length

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



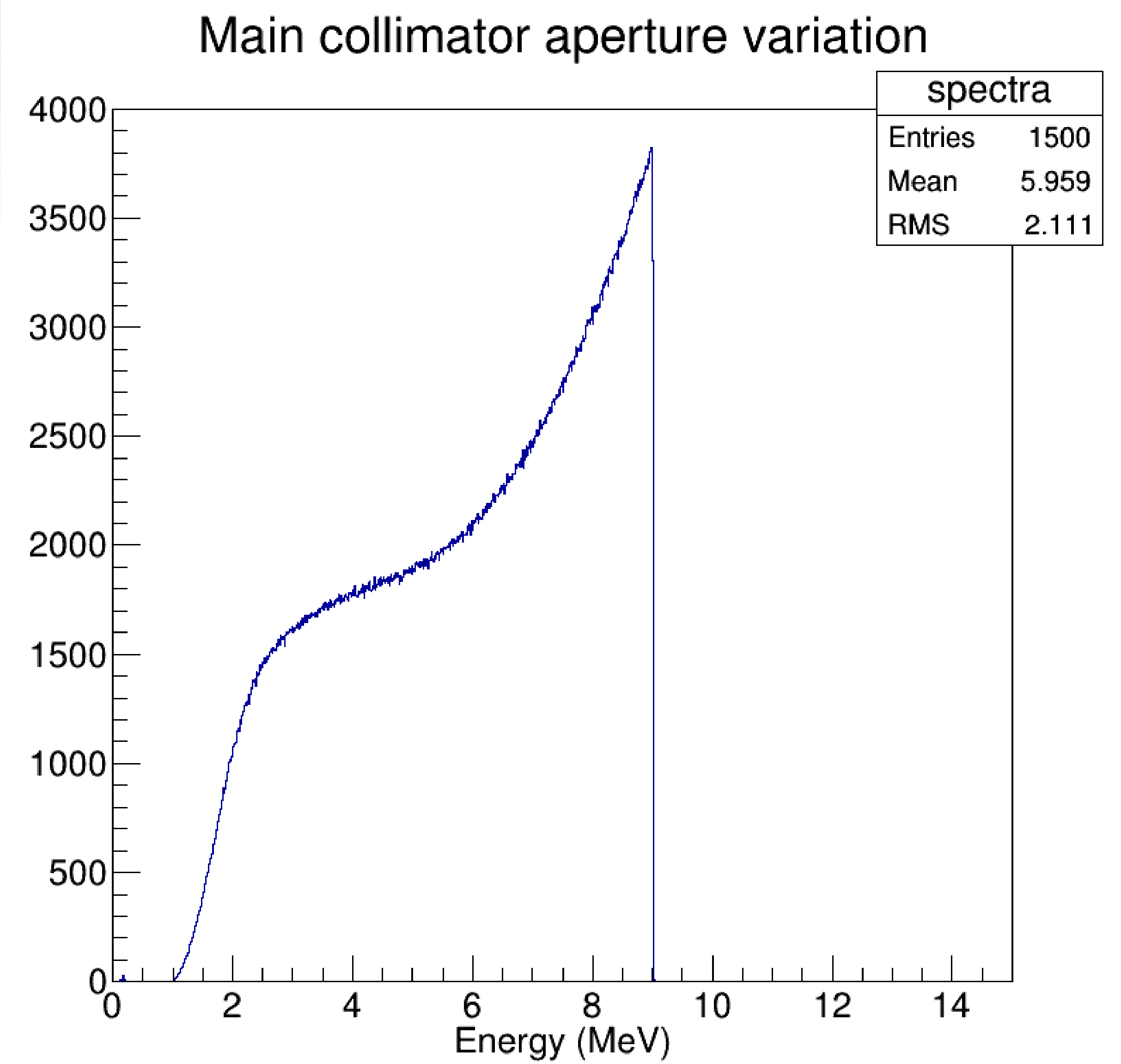
Drift space coordinates and Twiss parameters must be considered



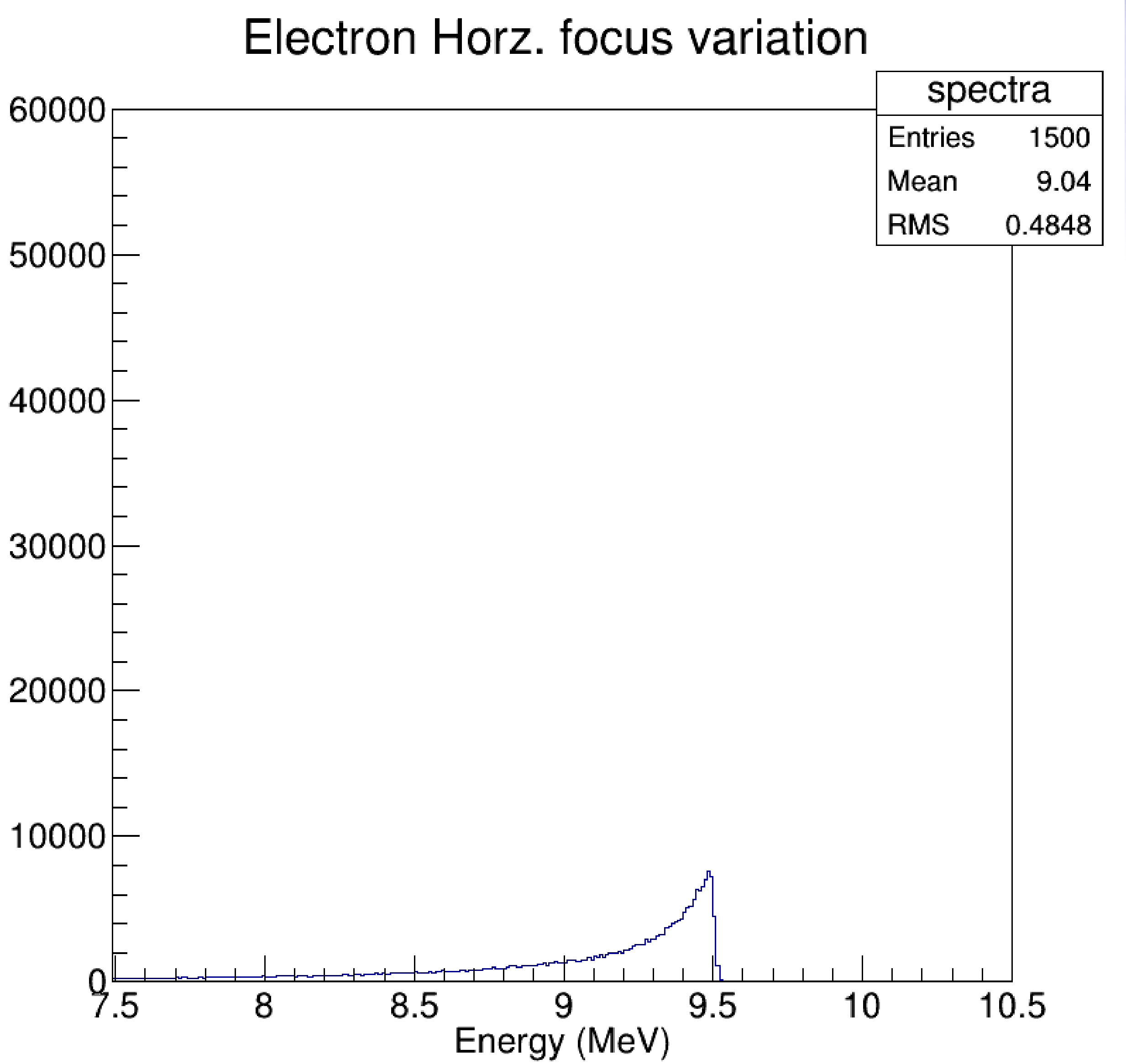
Electron beam emittance:

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

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



Real beam – dependence on the electron beam focus



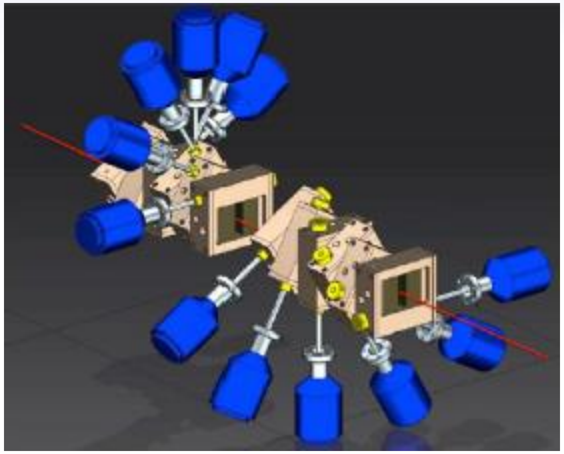
RF linac & pulsed laser source parameters

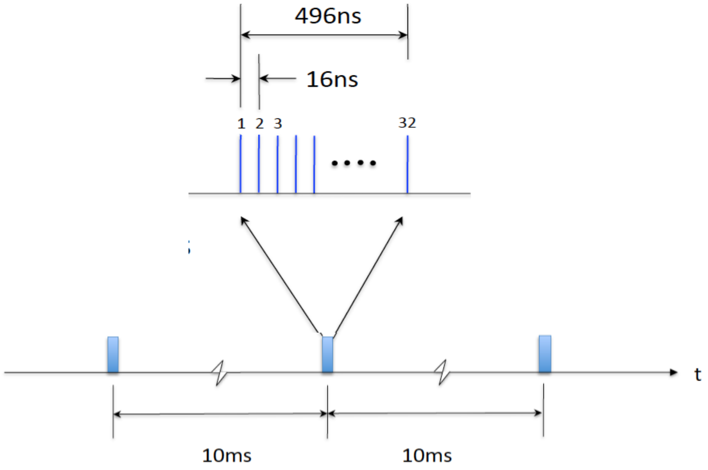
Electron beam parameter at IP	
Energy (MeV)	180-750
Bunch charge (pC)	25-400
Bunch length (µm)	100-400
$\varepsilon_{n\_x,y}$ (mm-mrad)	0.2-0.6
Bunch Energy spread (%)	0.04-0.1
Focal spot size (µm)	15-30
# bunches in the train	> 31
Bunch separation (nsec)	16
energy variation along the train	0.1 %
Energy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

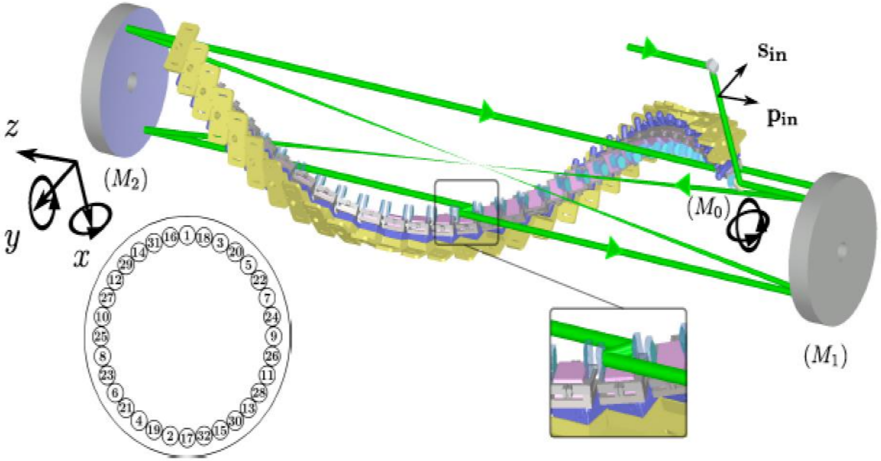
Yb:Yag Collision Laser	**Low Energy Interaction**	**High Energy Interaction**
Pulse energy (J)	0.2	0.5
Wavelength (eV)	2.4	2.4
FWHM pulse length (ps)	2-4	2-4
Repetition Rate (Hz)	100	100
M^2	≥ 1.2	≥ 1.2
Focal spot size w_0 (µm)	> 25	25
Bandwidth (rms)	0.05 %	0.05 %
Pointing Stability (µrad)	1	1
Sinchronization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

GBS – Gamma beam parameters

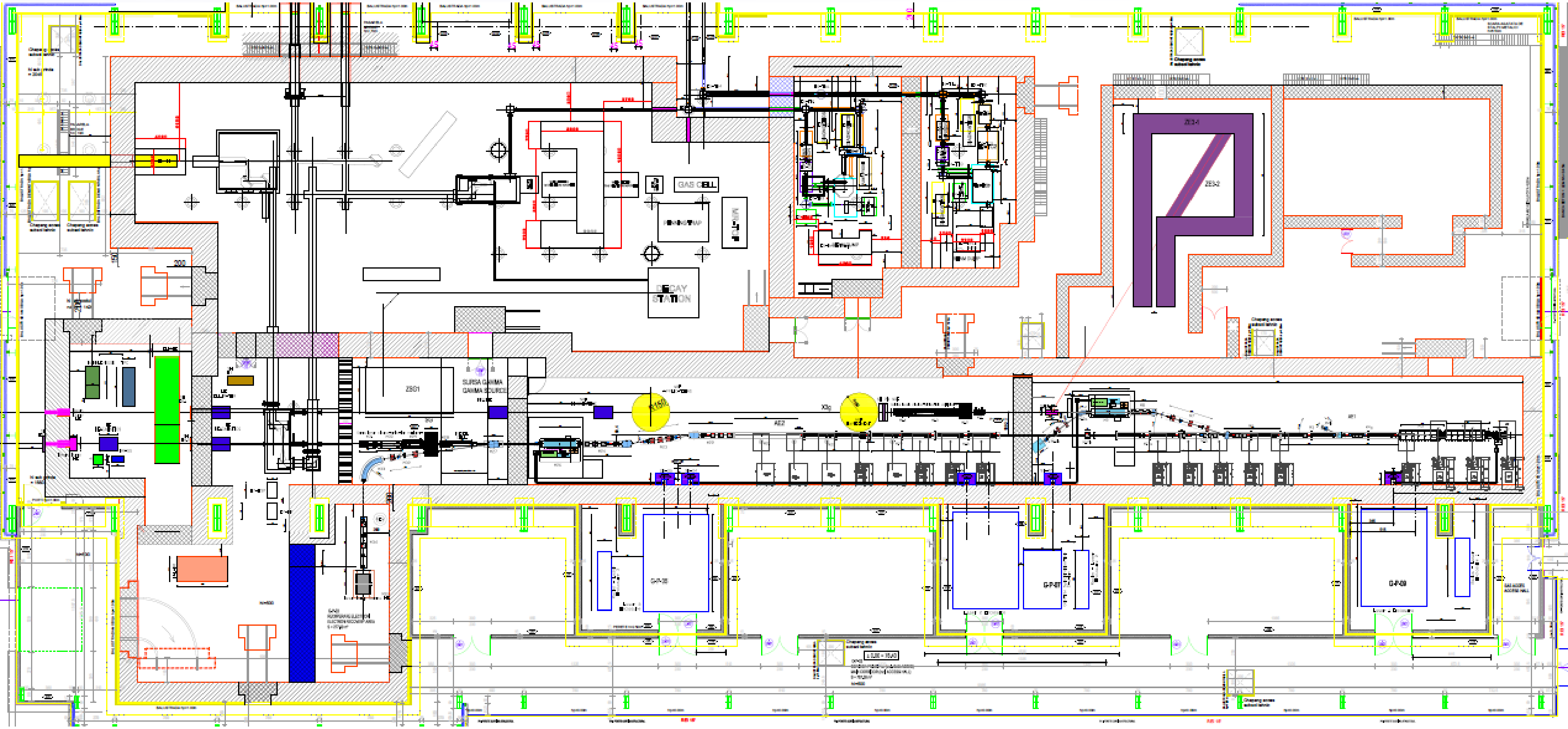
Photon energy	1-20 *MeV*
Spectral Density	> 10^4 *ph/sec.eV*
Bandwidth (rms)	<0.3%
# photons per shot within FWHM bdw.	$1.0\text{-}4.0 \cdot 10^5$
# photons/sec within FWHM bdw.	$2.0\text{-}8.0 \cdot 10^8$
Source rms size	10 - 30 *μm*
Source rms divergence	25-250 *μrad*
Peak Brilliance (N_{ph}/sec·mm²mrad²·0.1%)	10^{22} - 10^{24}
Radiation pulse length (rms, *psec*)	0.7-1.5
Linear Polarization	> 99 %
Macro rep. rate	100 *Hz*
# of pulses per macropulse	>31
Pulse-to-pulse separation	16 *nsec*







ELI-NP Gamma Beam System layout



Nuclear Photonics

Electromagnetic dipole response of nuclei

Nuclear structure

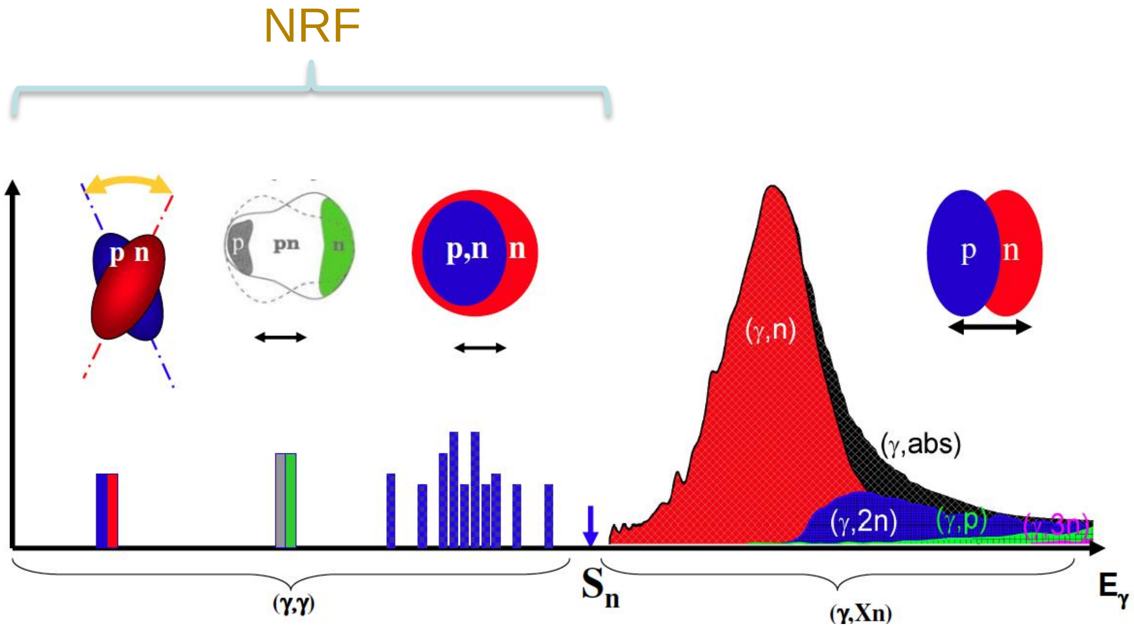
- Modes of excitation below the GDR

Impact on nucleosynthesis

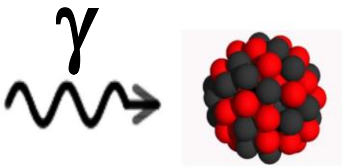
- Gamow window for photo–induced reactions in explosive stellar events

Understanding exotic nuclei

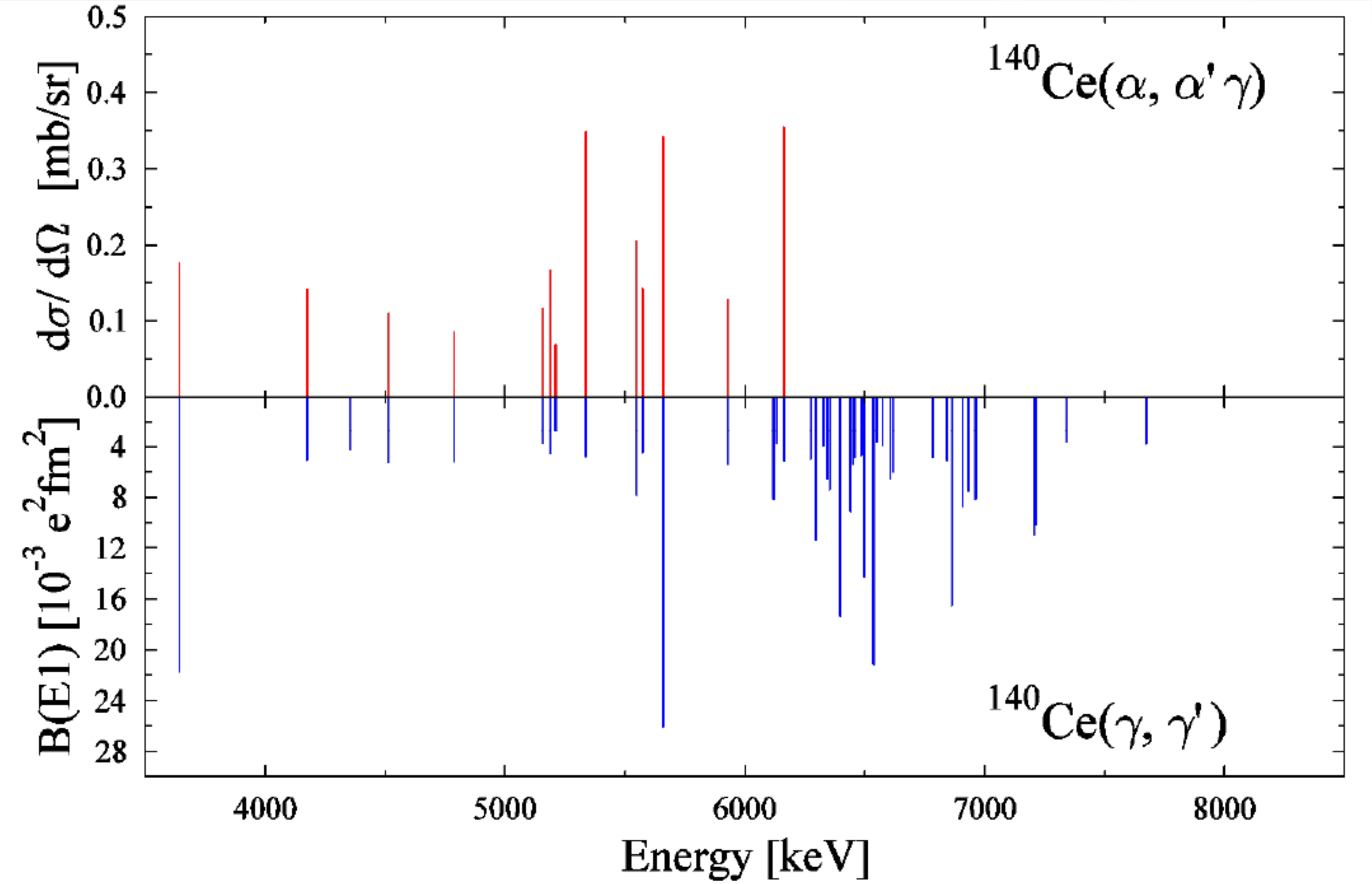
- E1 strength will be shifted to lower energies in neutron rich system



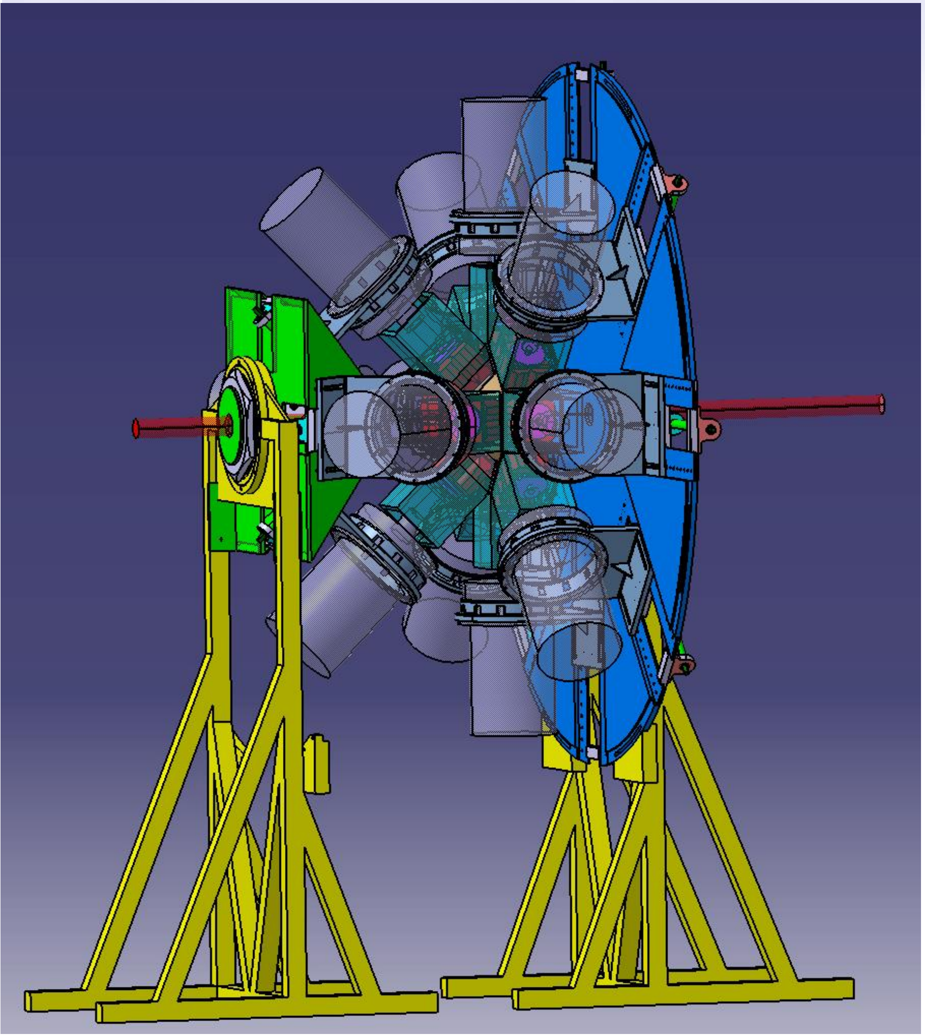
E1 strength distribution



Splitting of the PDR



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

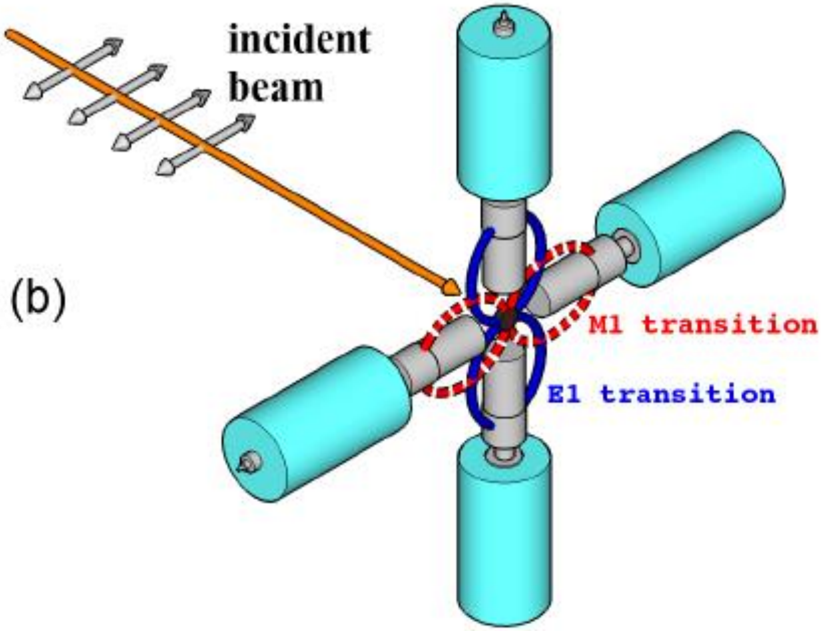
Additional level density information

- Presently most of the LD parameterizations rely on:

- low energy fully known level scheme;
- average $\langle \Gamma_{n0} \rangle$ $\langle D_0 \rangle$ of (n,γ) resonances at S_n

$$\rho(E,J,\pi) = \rho(E) \cdot \rho(J,\pi)$$

- Using high resolution, high intensity polarized γ-beam in conjunction with NRF -> produce additional information between the above mentioned energy limits
- Shed light on the region where low energy branch of $\rho(E)$ dominated by phenomenological forms is matched with high energy branch described usually by Fermi-gas models.



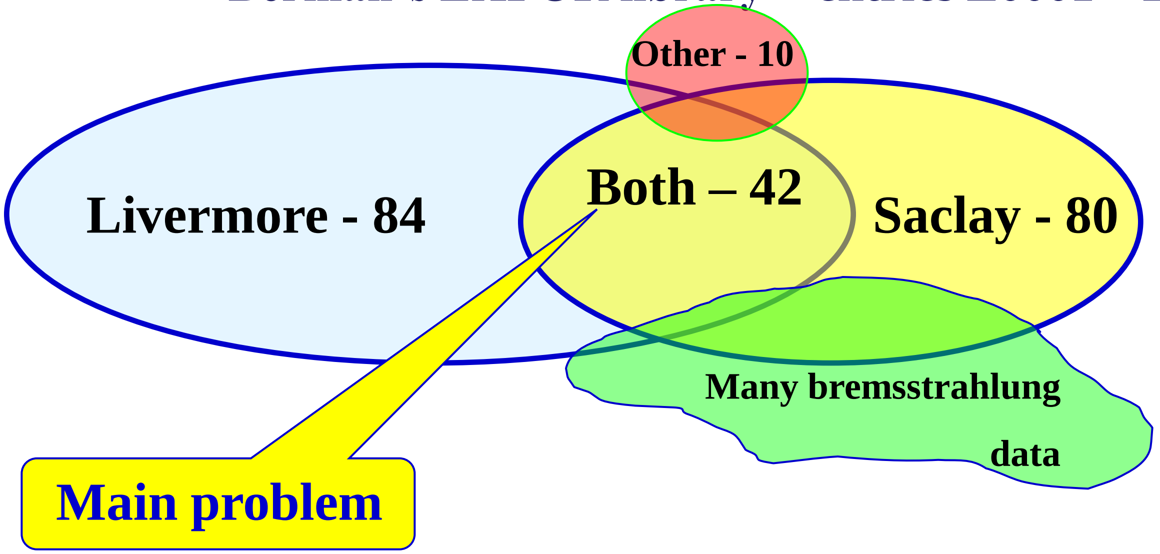
Photoneutron measurements

Systematics of experimental data:

many experimental data data for partial photonuclear reaction cross sections obtained in period 1962 - 1986 (the majority was obtained 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)



Other - 10

Livermore - 84

Both – 42

Saclay - 80

Many bremsstrahlung data

Main problem

For each nucleus – cross sections:

(γ, 3n)

(γ, 2n)

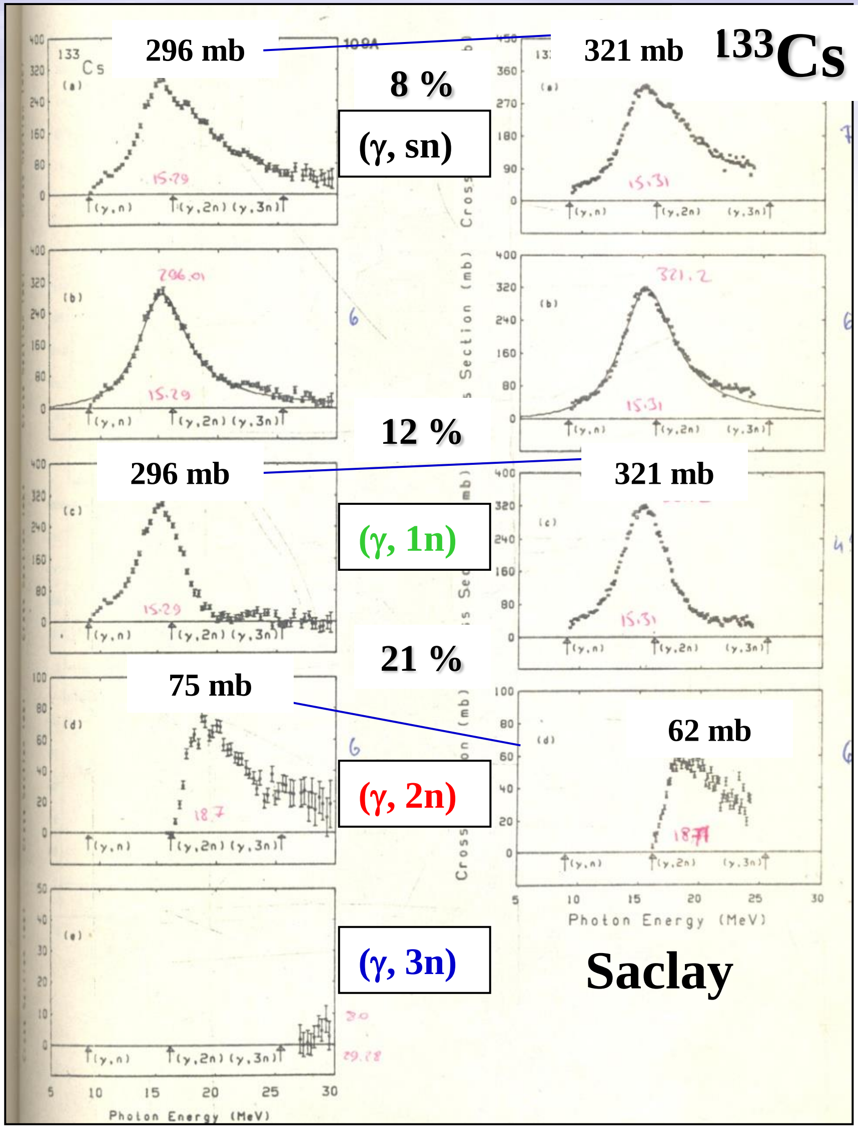
(γ, 1n)

(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:

cross sections of 1 neutron reactions are noticeably larger in Saclay but of 2 neutron – vice versa at Livermore



^{133}Cs

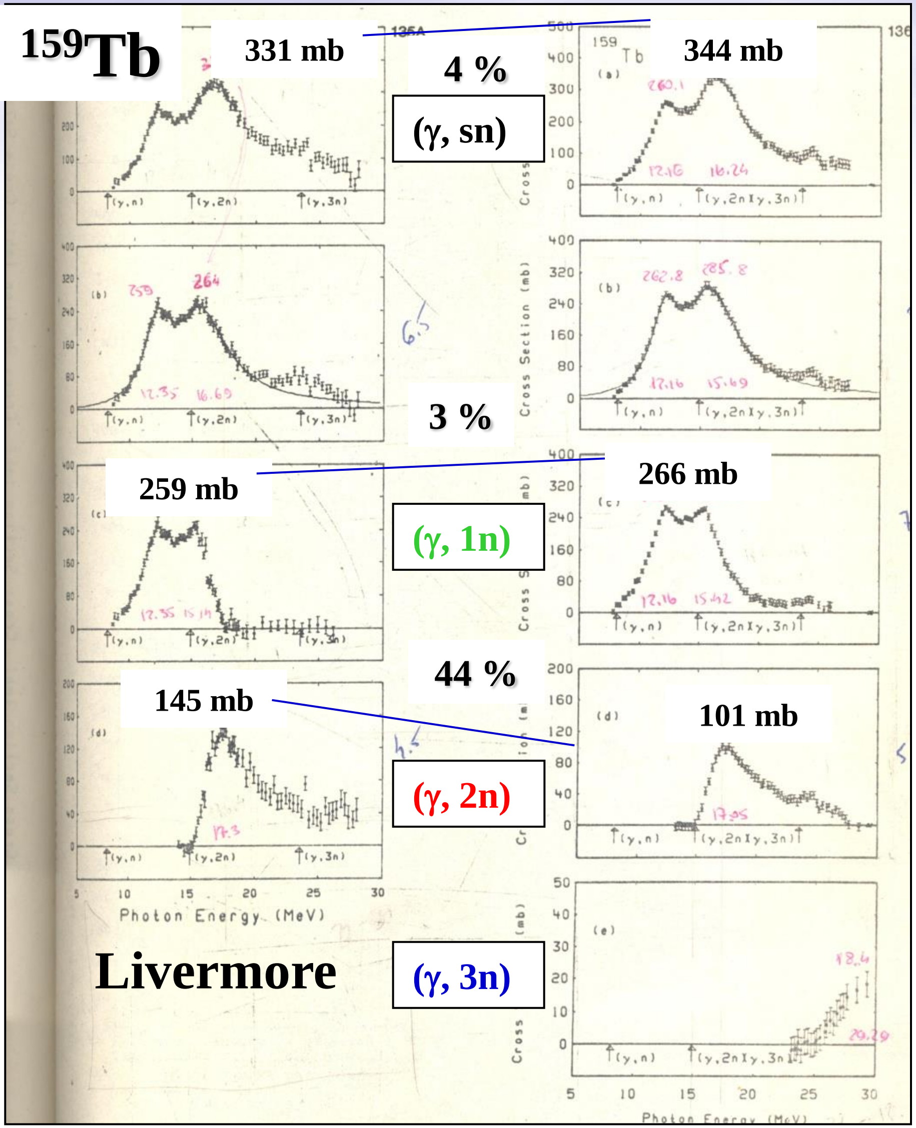
296 mb | 321 mb | 8 % | **(γ, sn)**

296 mb | 321 mb | 12 % | **(γ, 1n)**

75 mb | 62 mb | 21 % | **(γ, 2n)**

(γ, 3n)

Saclay



^{159}Tb

331 mb | 344 mb | 4 % | **(γ, sn)**

259 mb | 266 mb | 3 % | **(γ, 1n)**

145 mb | 101 mb | 44 % | **(γ, 2n)**

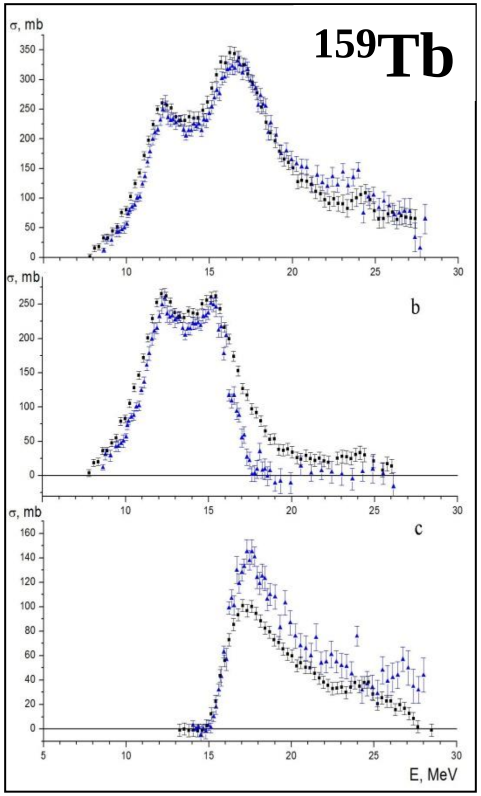
(γ, 3n)

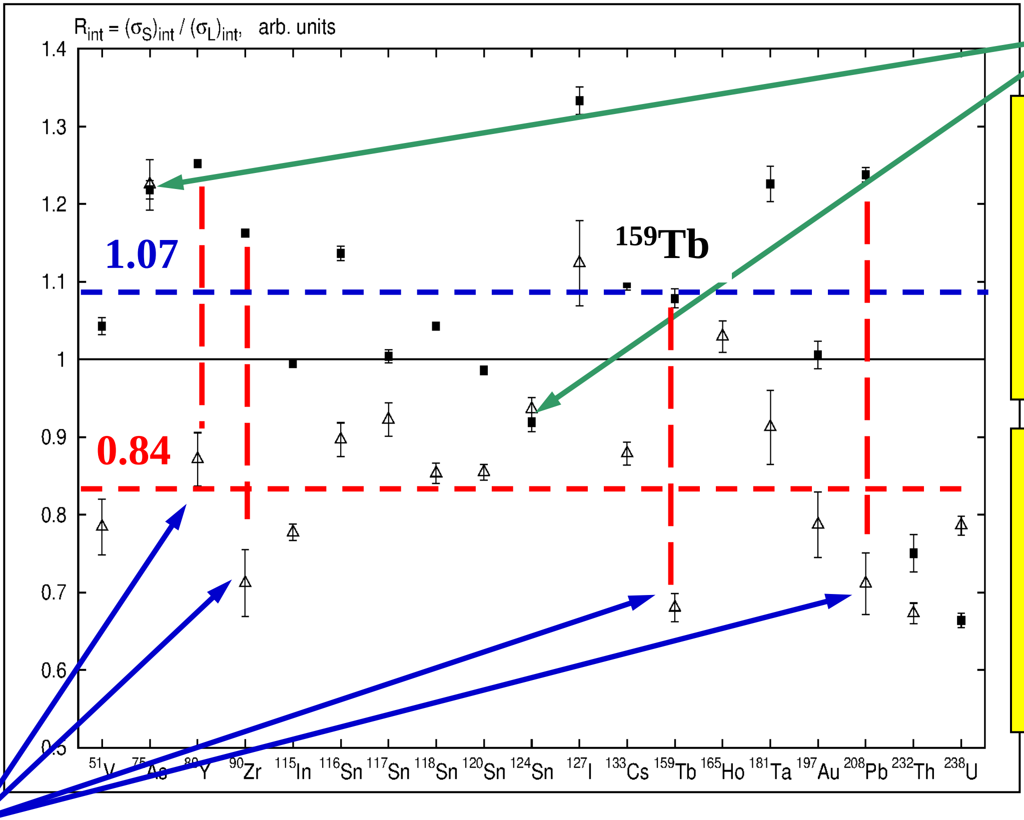
Livermore

Systematics of data for 20 nuclei investigated in both Labs:
For several nuclei disagreements are small but for majority are large.

V.V.Varlamov, et al. INDC(CCP)-440, IAEA NDS, Vienna, Austria, 2004, p. 37.

Ratios of integrated cross sections "S/L"





small

Squares - ■ - ratios for (γ, 1n) reactions – are larger than 1.0:

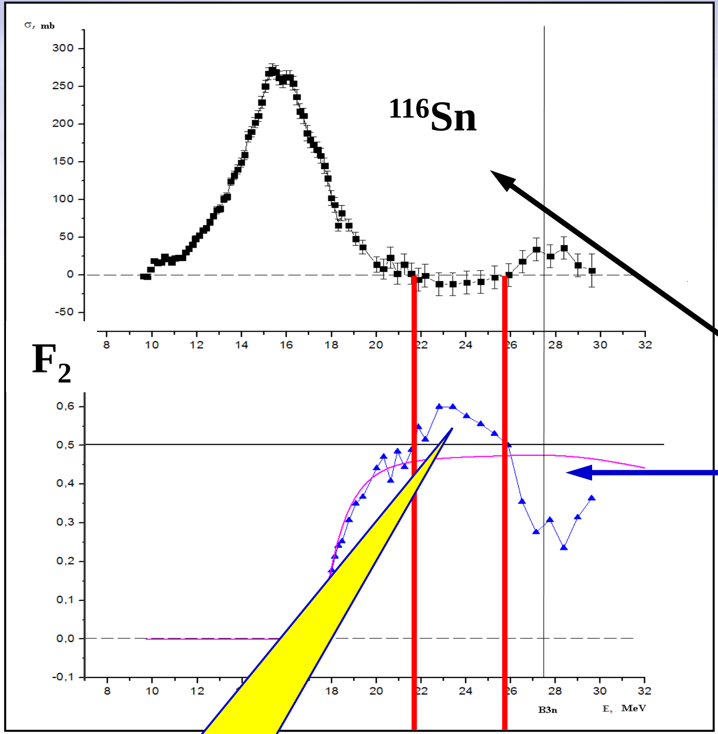
<R> ~ 1.2.

Triangles - △ - ratios for (γ, 2n) reactions – are smaller than 1.0:

<R> ~ 0.8.

very large

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

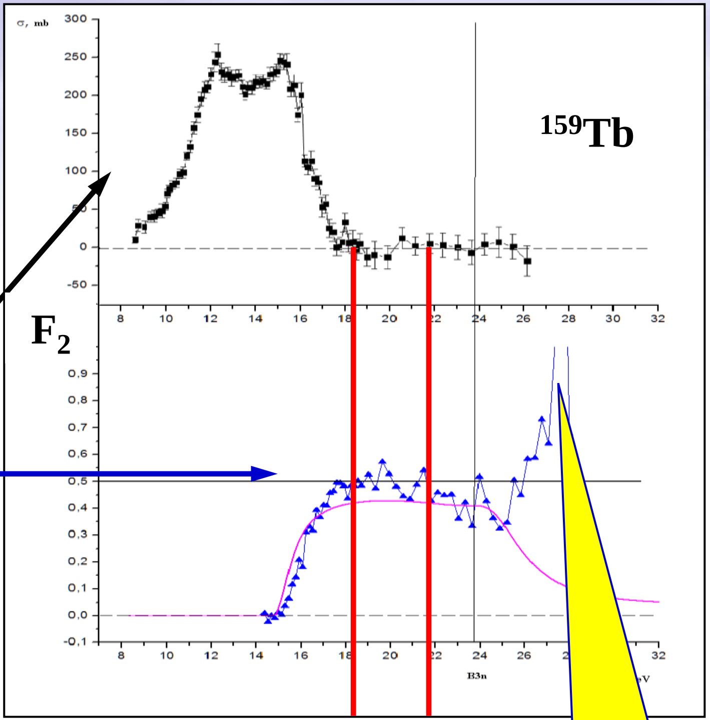


Livermore

data

σ(γ, 1n)

F_2



Significant disagreements: $F_2 > 0.6$!

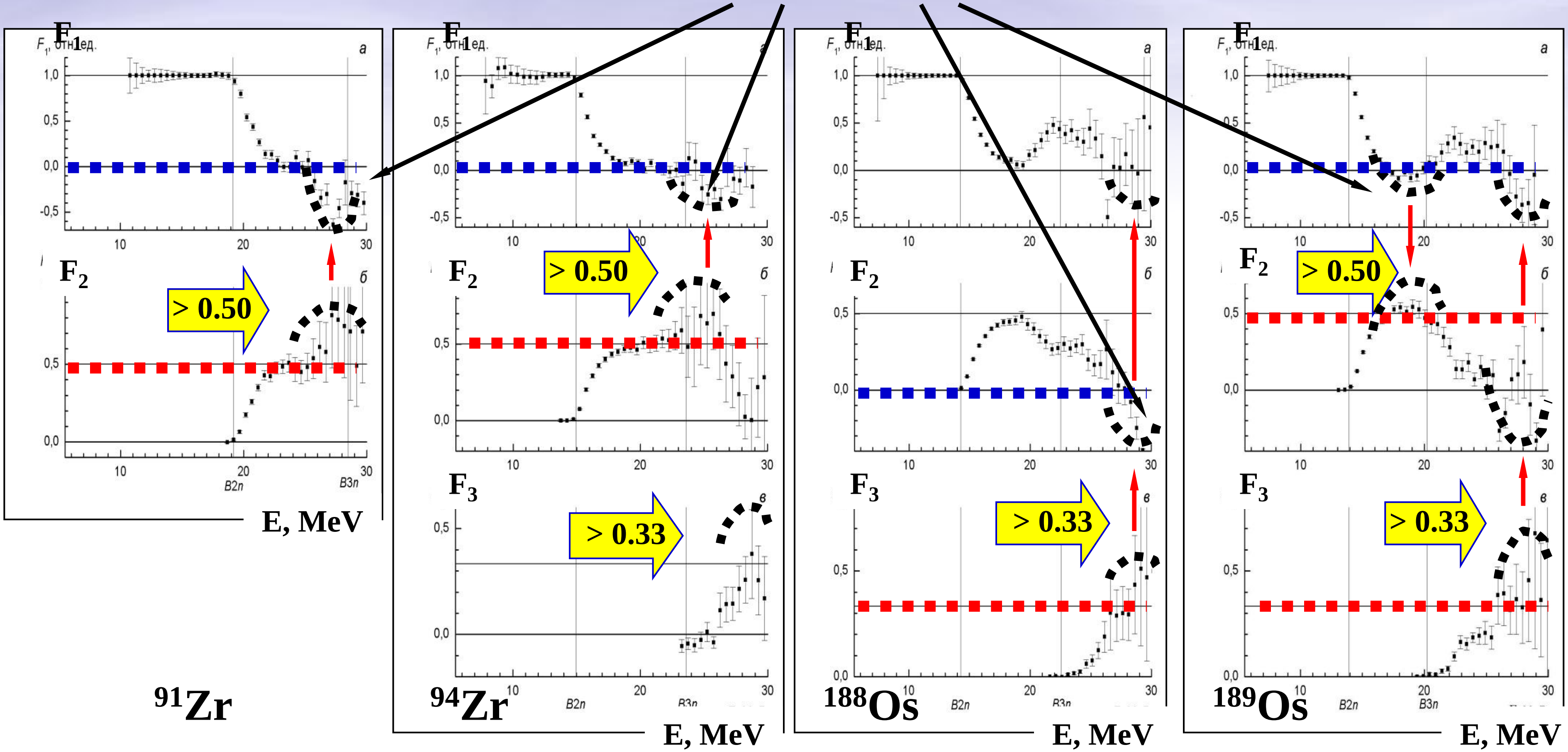
Dramatic disagreements: $F_2 \approx 1.5 – 2.0$!

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

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

Another examples:

physically forbidden negative values



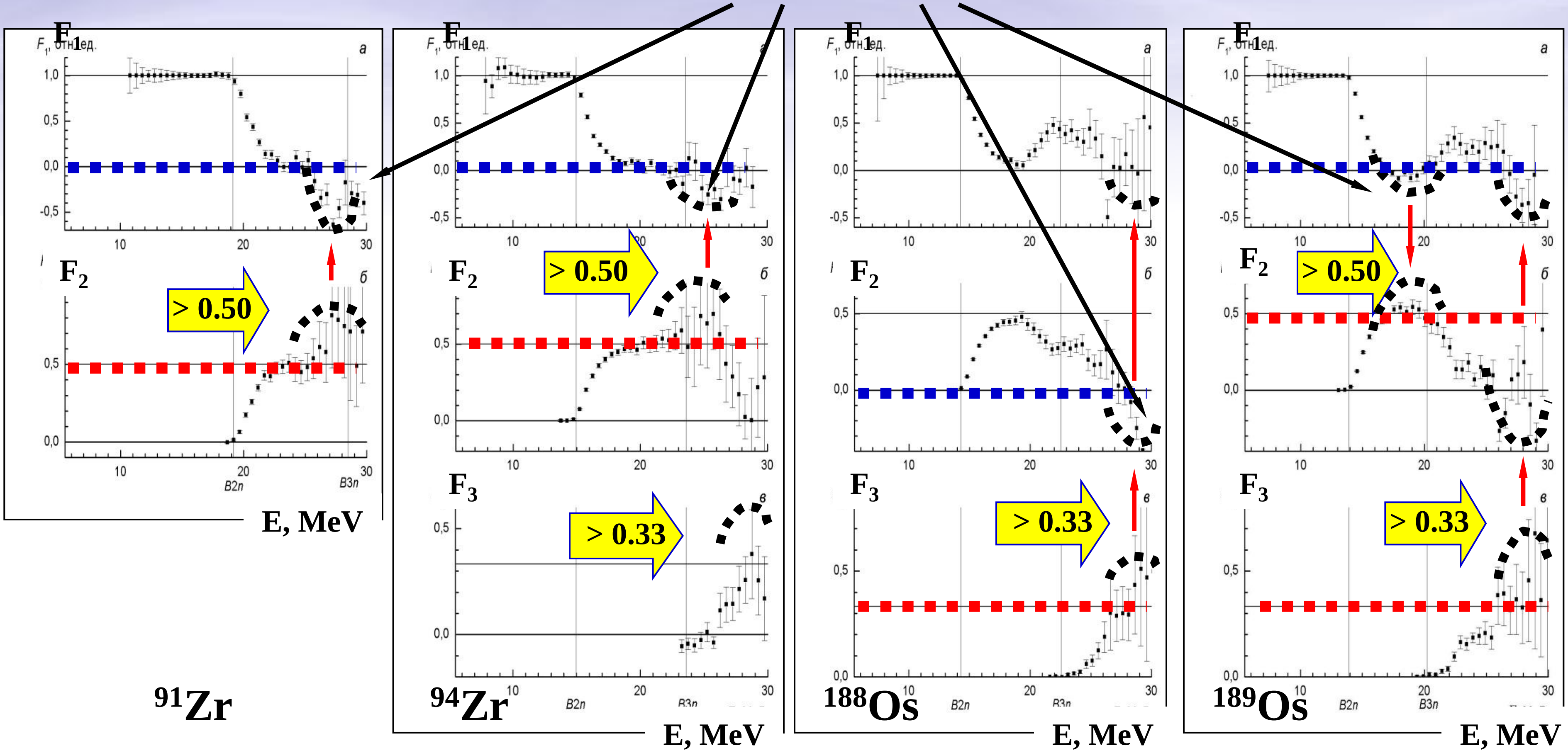
There are additional physically natural criteria:

$F_1 = \sigma(\gamma, 1n) \ / \ \sigma(\gamma, xn) < 1.00$

$F_3 = \sigma(\gamma, 3n) \ / \ \sigma(\gamma, xn) < \ 0.33$ etc.

Another examples:

physically forbidden negative values



The reliability of many data is doubtful.

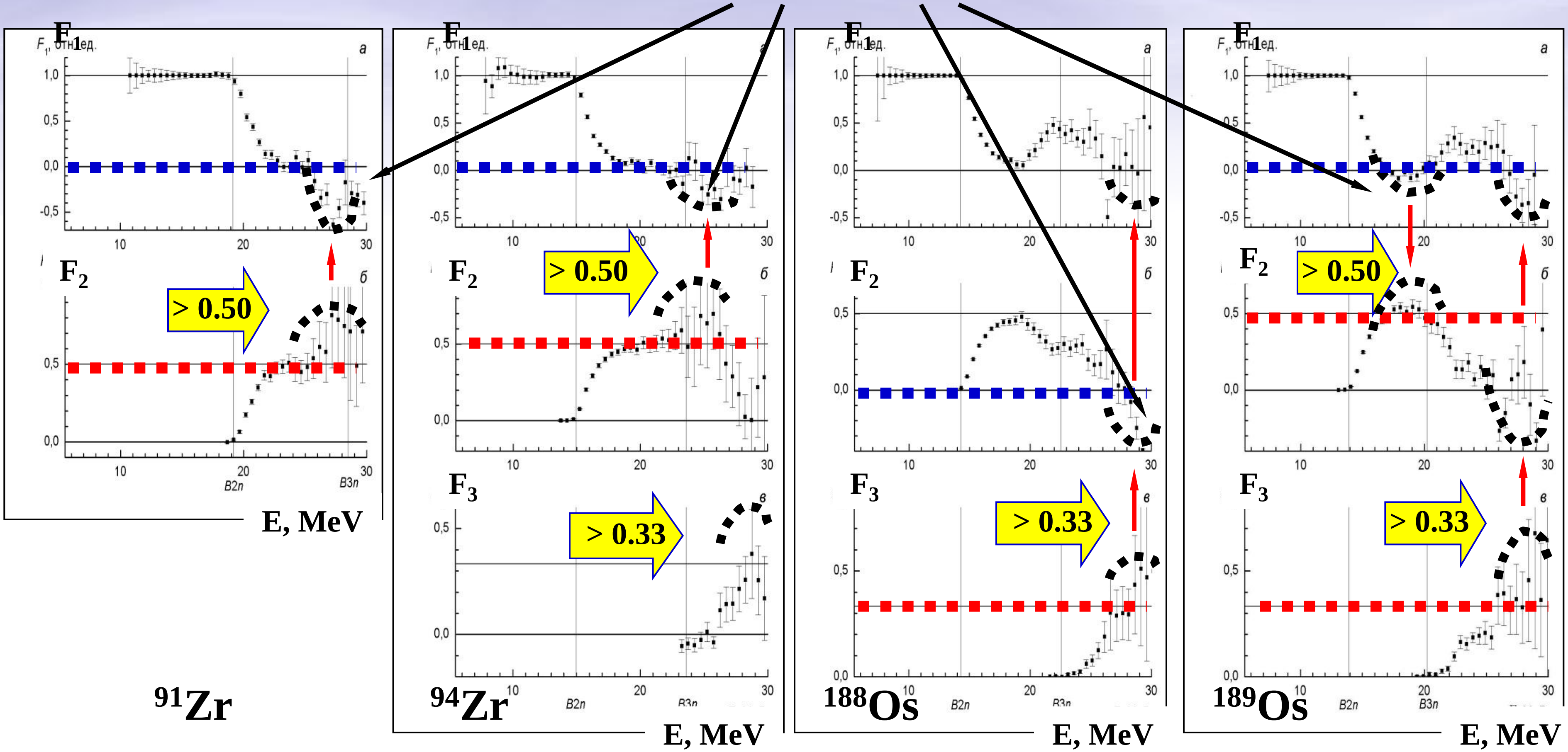
There are additional physically natural criteria:

$F_1 = \sigma(\gamma, 1n) \;/\; \sigma(\gamma, xn) < 1.00$

$F_3 = \sigma(\gamma, 3n) \;/\; \sigma(\gamma, xn) < 0.33$ etc.

Another examples:

physically forbidden negative values



The reliability of many data is doubtful. **Many data should be reanalyzed and reevaluated!**

There are additional physically natural criteria:

$F_1 = \sigma(\gamma, 1n) / \sigma(\gamma, xn) < 1.00$

$F_3 = \sigma(\gamma, 3n) / \sigma(\gamma, xn) < 0.33$ etc.

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.

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

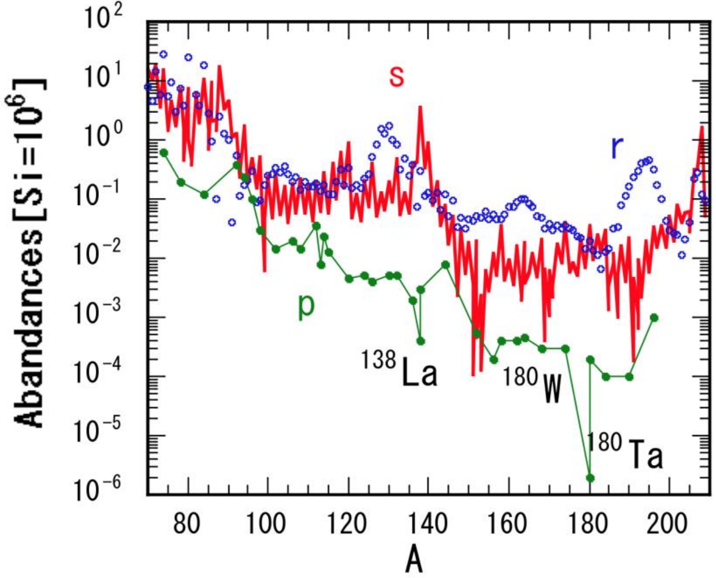
Photoneutron measurements

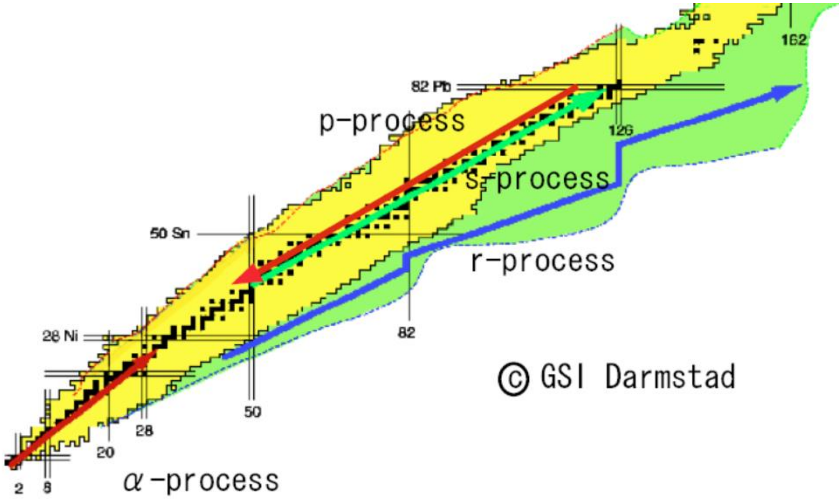
Nuclear astrophysics - the prediction of radiative neutron capture cross sections for short–lived radioactive nuclei that are difficult to measure can be obtained using inverse photoneutron reaction data near threshold

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

p nuclei are very rare





Rare isotopes to be studied ->

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

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

Production

$^{181}\mathrm{Ta}(\gamma,n)\underline{^{180}\mathrm{Ta}}$

$^{139}\mathrm{La}(\gamma,n)\underline{^{138}\mathrm{La}}$

measured!

vs

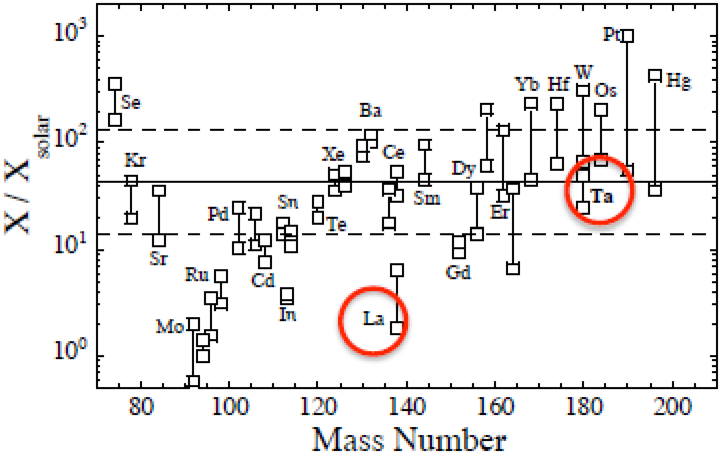
Destruction

$^{180}\mathrm{Ta}(\gamma,n)\underline{^{179}\mathrm{Ta}}$

$^{138}\mathrm{La}(\gamma,n)\underline{^{137}\mathrm{La}}$

Not so ever

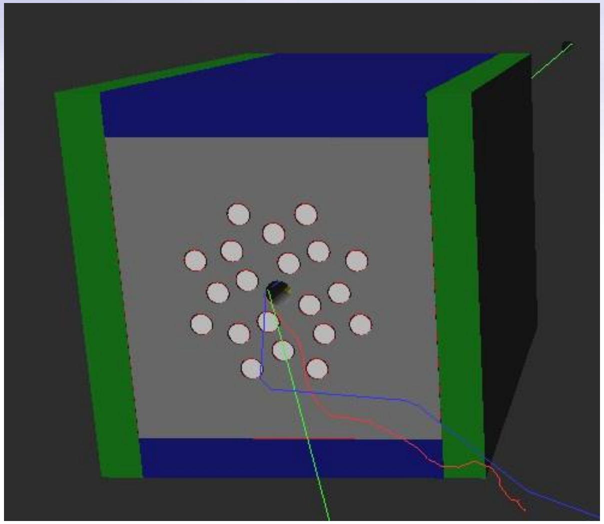
35 p-nuclei neutron-deficient isotopes

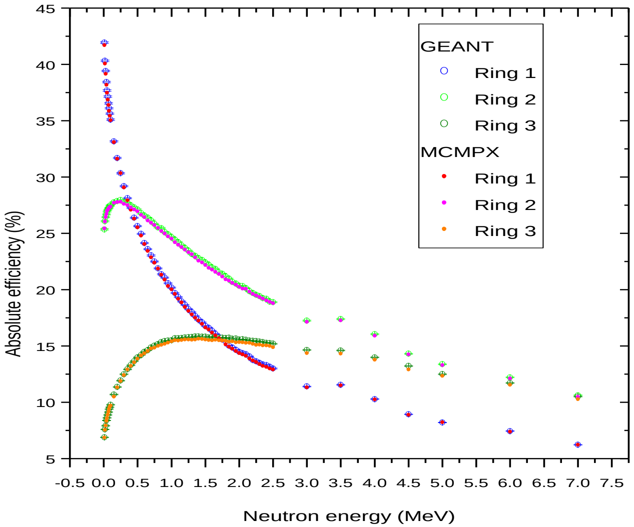


H. Utsunomiya et al., PRC67, 015807 (2003)

TDR on physics above the neutron threshold

- 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





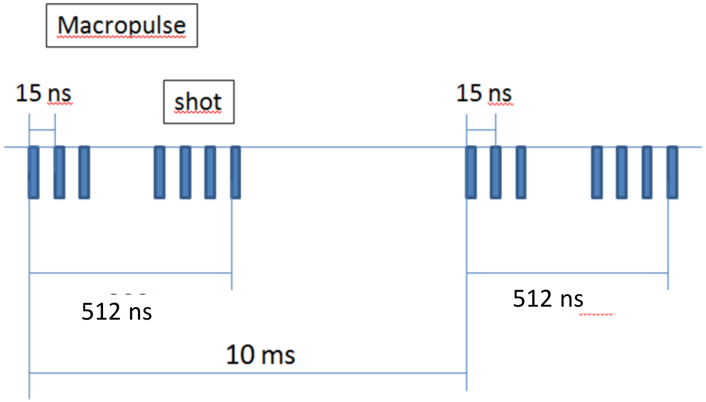
ELI-NP expected time structure of the gamma-ray beam

100Hz macropulses, 32 micropulses/macropulse macropulse width 512ns (32 x 16ns)

8 10^{8} ph/sec,

8 10^{6} ph/macropulse,

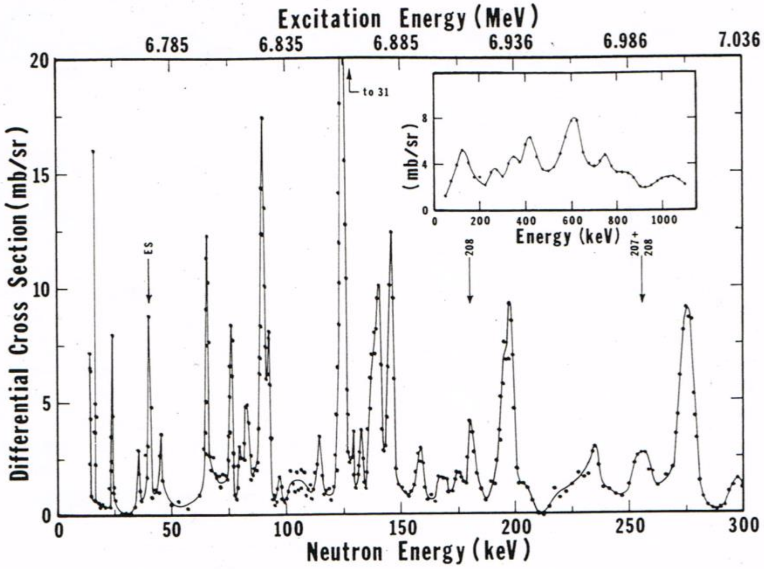
2.5 10^{5} ph/micropulse



PDR and spin-flip M1 resonance above Sn

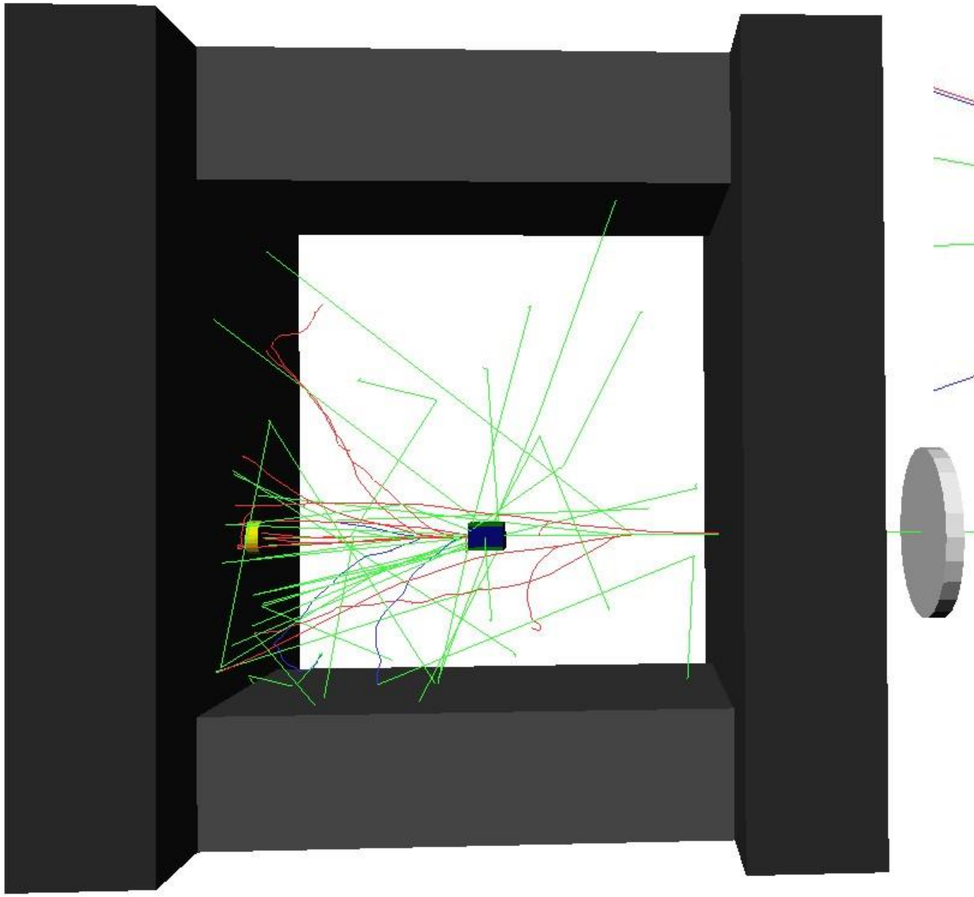
- Both PDR and spin-flip M1 resonance emerge near S_n
- Below S_n NRF experiments with 100% linear polarized γ-ray beams can separate E1 and M1 resonances in peak structure
- Recently, inelastic proton scattering at intermediate energies has revealed PDR and M1 resonance in ^{208}Pb and ^{90}Zr but the 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

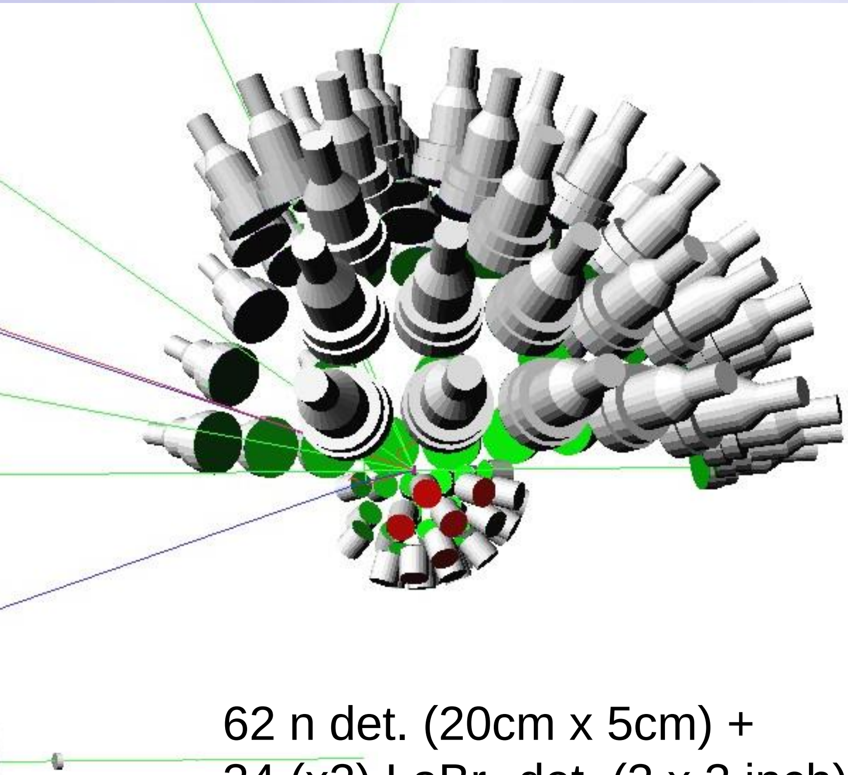
- This technique is limited to a narrow excitation energy range below the neutron threshold energy plus the first excited state in the residual nucleus
- We propose to investigate PDR and spin-flip M1 resonance with a mixed array consisting from LaBr3 + liquid scintillation neutron detector array



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



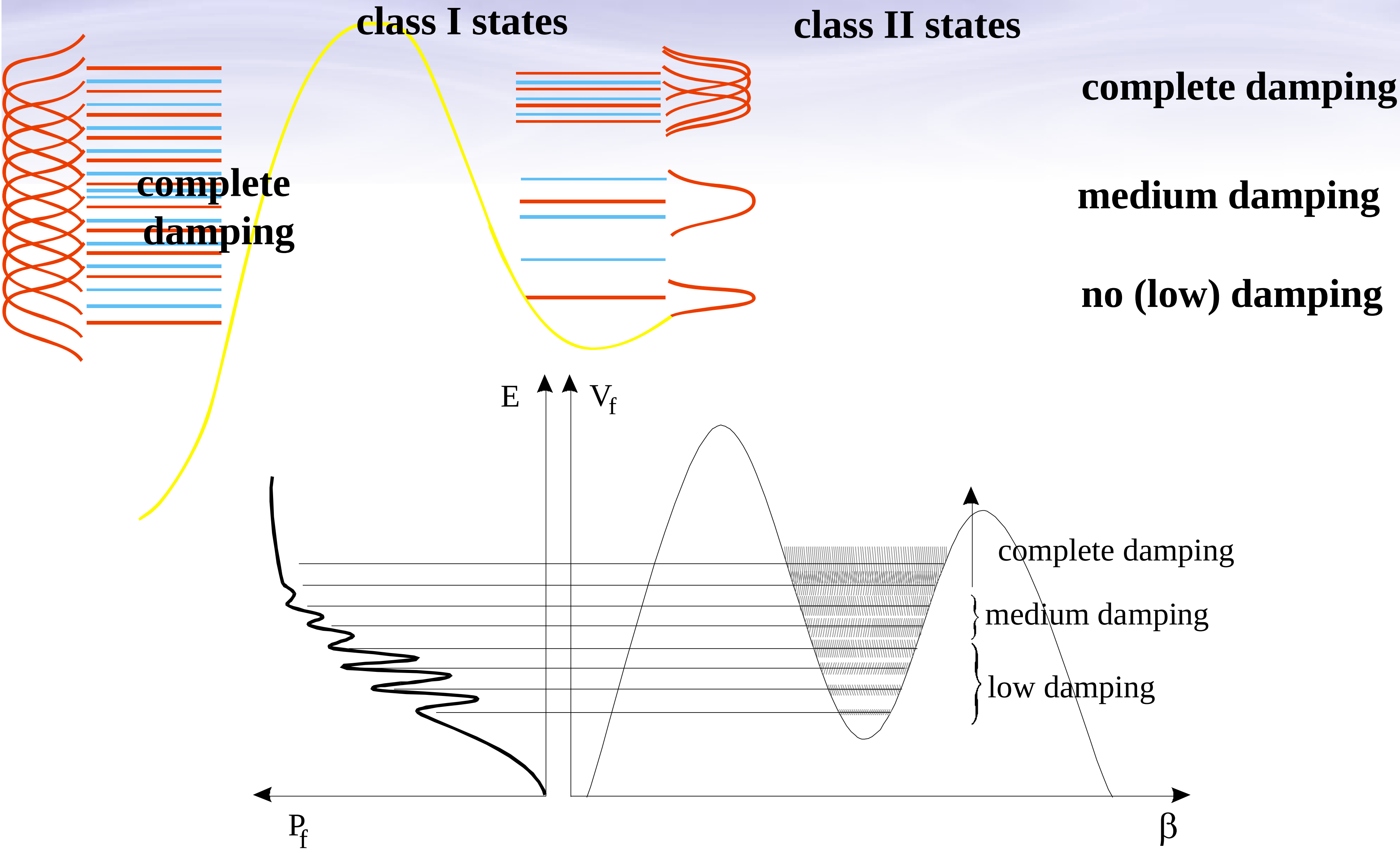


62 n det. (20cm x 5cm) +
34 (x2) $LaBr_3$ det. (3 x 3 inch)

Instrumentation:

(i) $LaBr_3$(Ce) array,
(ii) Fast-neutron detector array
(iii) NE213 liquid scintillator array

The study of fission process using gamma beams



class I states

class II states

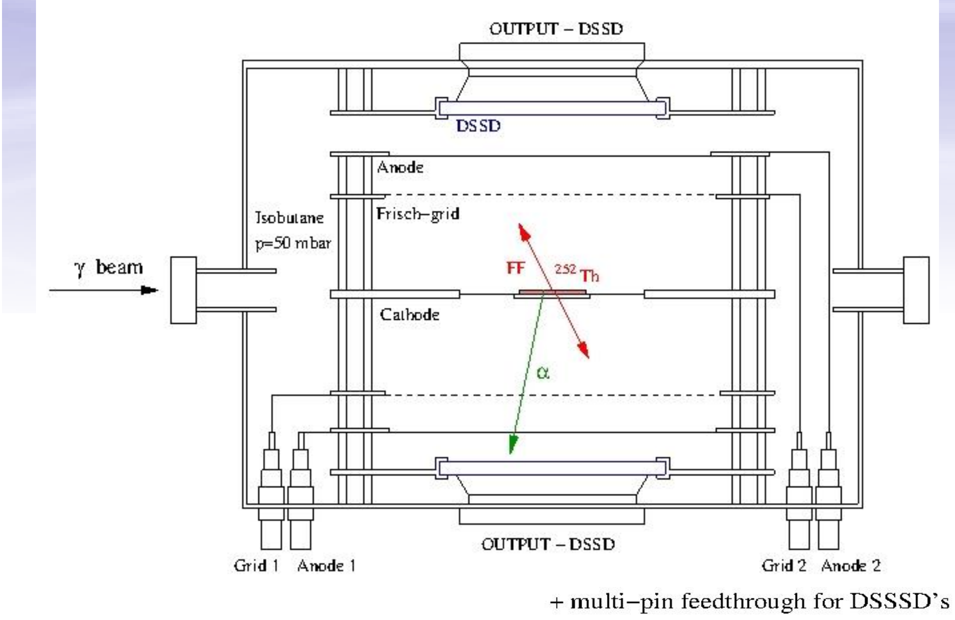
complete damping

complete damping

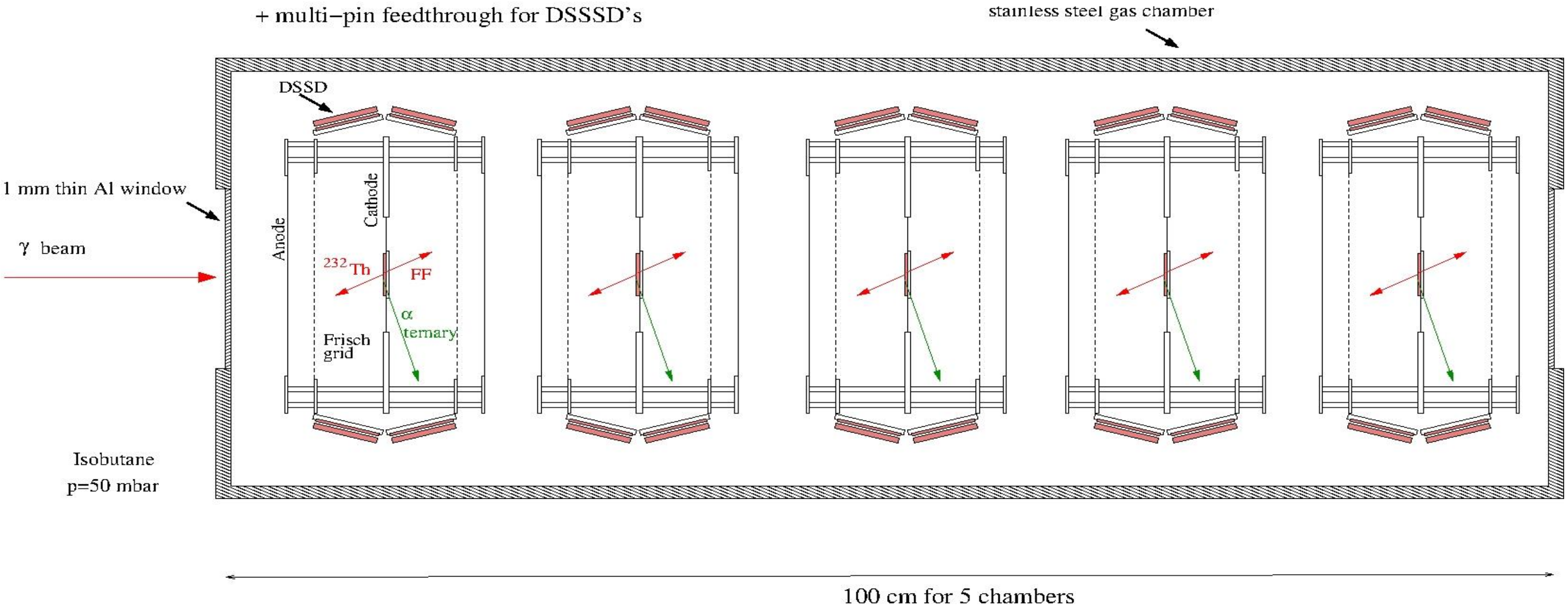
medium damping

no (low) damping

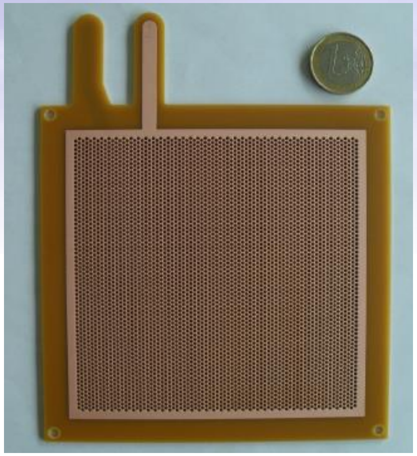
TDR on the study of photofission process

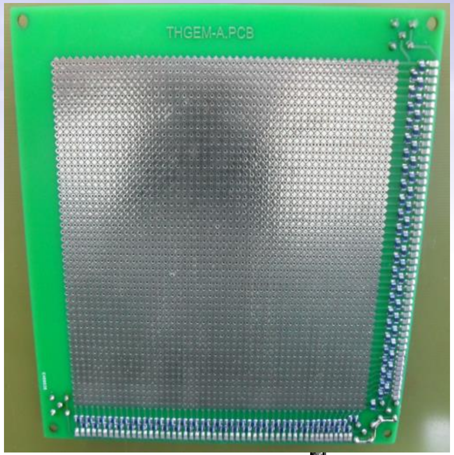


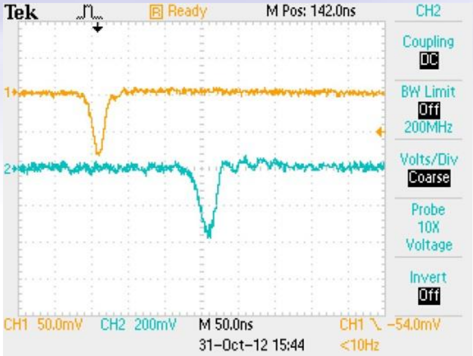
ATOMKI, Debrecen
Double-Bragg TPC



TDR on the study of photofission process







Tek Ready M Pos: 142.0ns

CH2

Coupling DC

BW Limit Off 200MHz

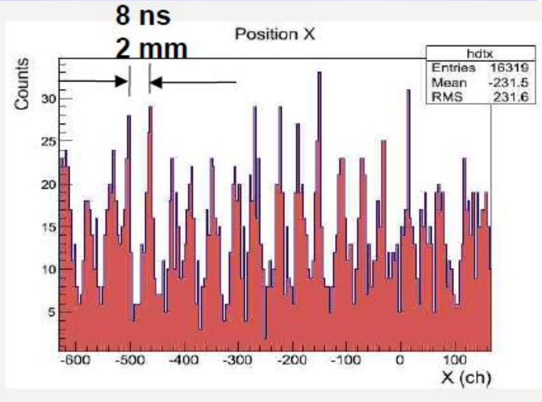
Volts/Div Coarse

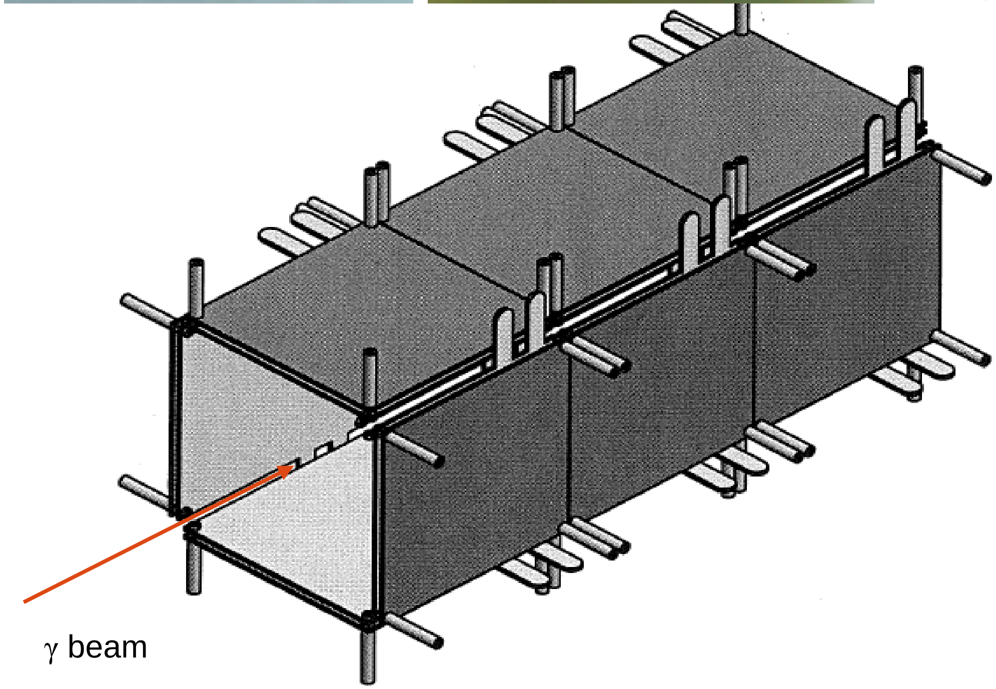
Probe 10X Voltage

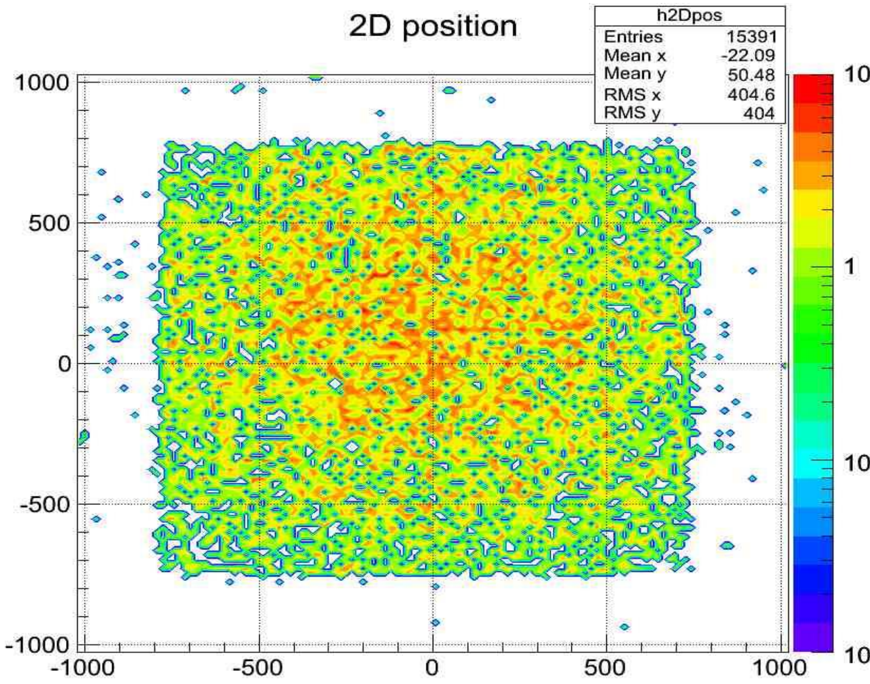
Invert Off

CH1 50.0mV CH2 200mV M 50.0ns CH1 ╲ −54.0mV

31-Oct-12 15:44 <10Hz





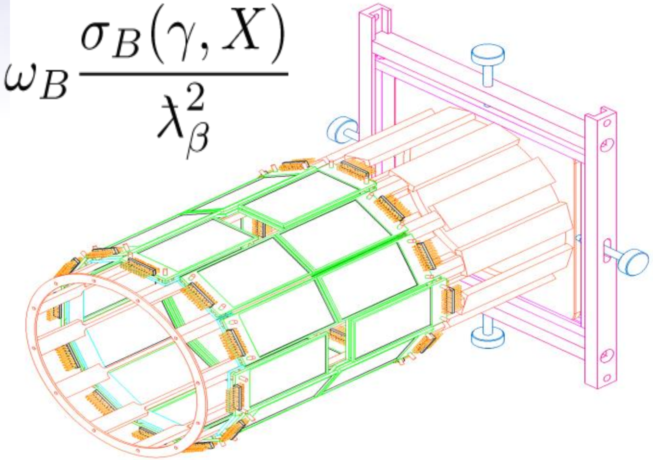


Photonuclear Reactions at Extreme Light Infrastructure – Nuclear Physics
P(ND)2-2 14-17 October 2014 Bruyères-le-Châtel, France

TDR on charged-particle physics

- Molecular states and symmetries in light nuclei
- The $^{16}O(\gamma,\alpha)^{12}C$ reaction
- The $^{24}Mg(\gamma,\alpha)^{20}Ne$ reaction
- The $^{22}Ne(\gamma,\alpha)^{18}O$ reaction
- The $^{19}F(\gamma,p)^{16}O$ reaction
- The $^{21}Ne(\gamma,\alpha)^{17}O$ reaction

$$\omega_A \frac{\sigma_A(X,\gamma)}{\lambda_\alpha^2} = \omega_B \frac{\sigma_B(\gamma,X)}{\lambda_\beta^2}$$

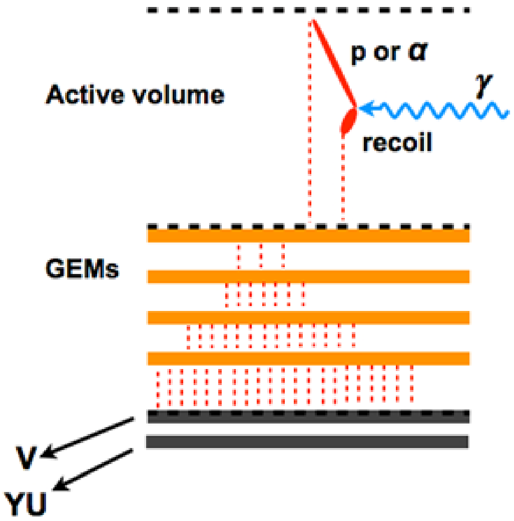


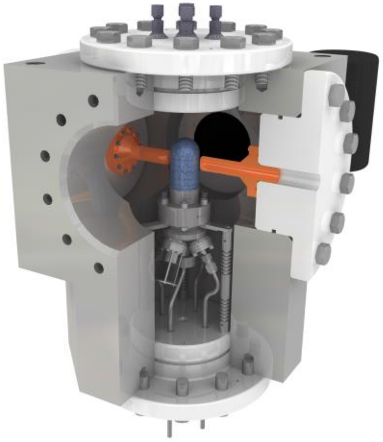
Instrumentation:

(i) Large-area Si DSSD array,

(ii) eTPC

(iii) Bubble-chamber detector

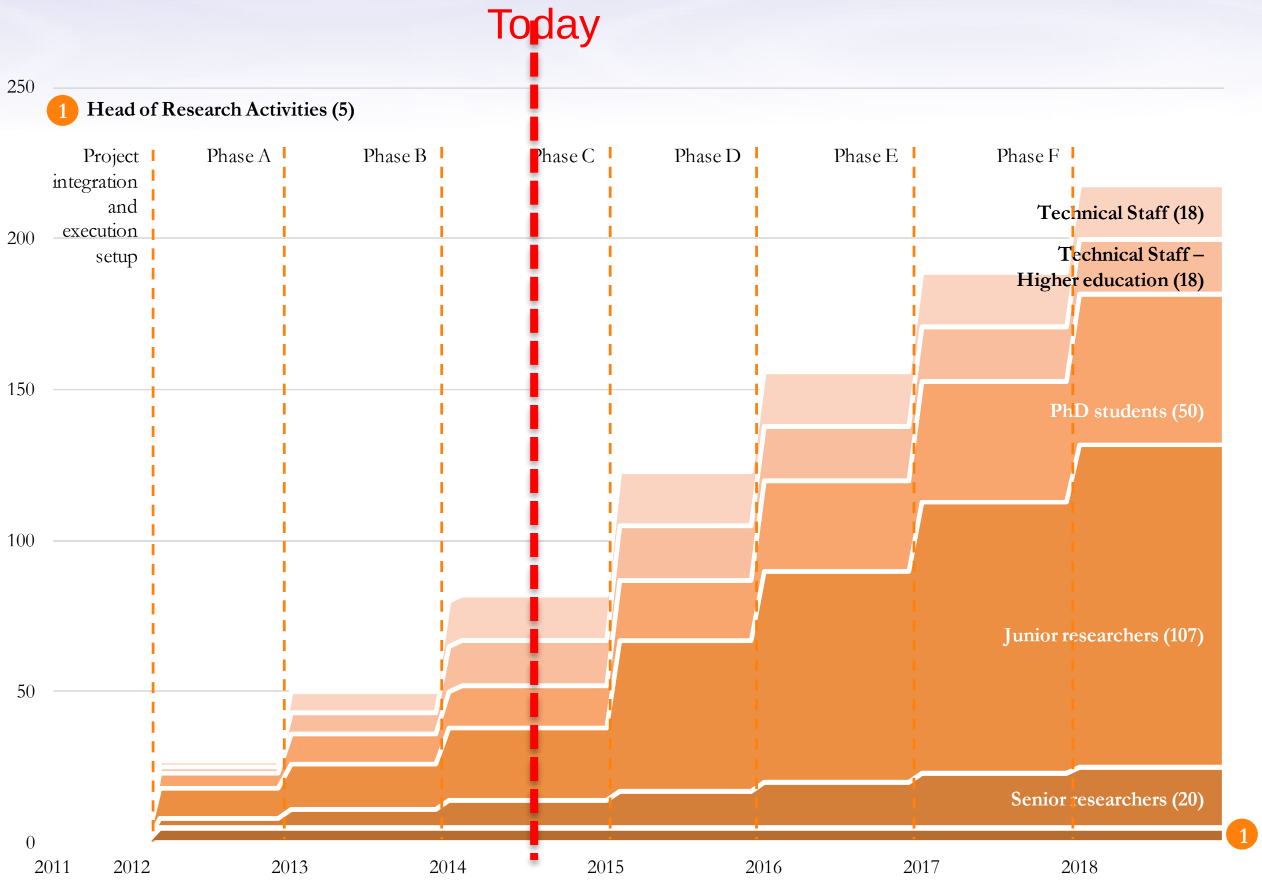




Human Resources

Attracting the best competencies:

- public announcements
- international recruitment
- Senior/junior researchers
- PhD students



EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments
2007-2013

Sectoral Operational Programme "Increase of Economic Competitiveness"

"Investments for Your Future!"

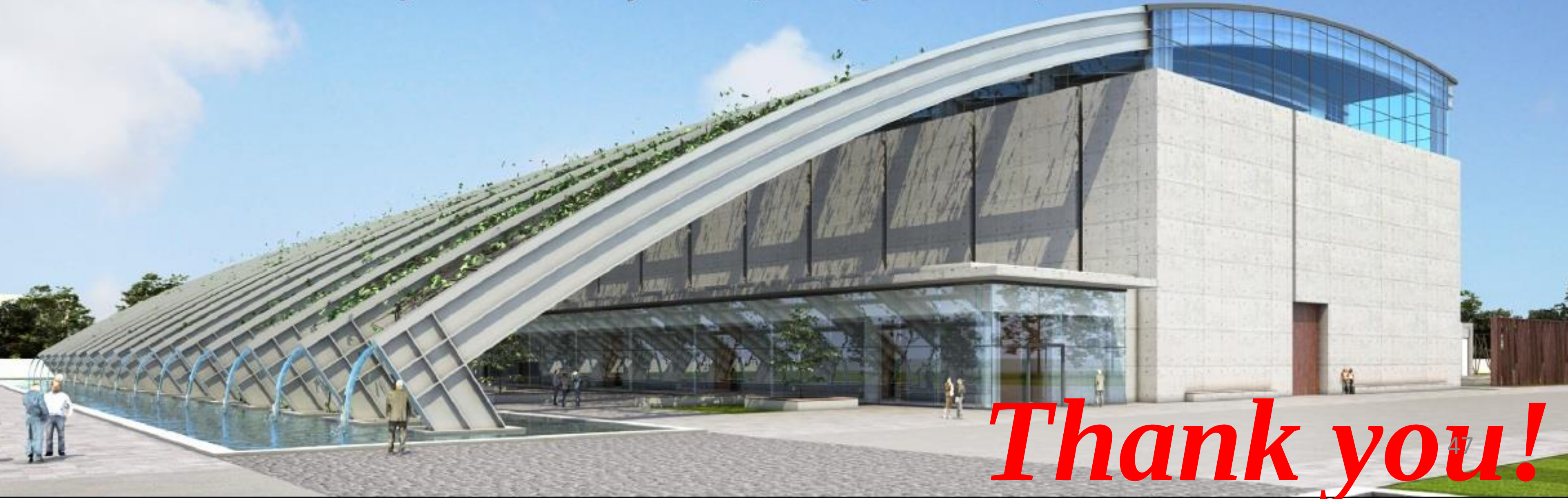
IFIN-HH

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

eli
Nuclear Physics

www.eli-np.ro

Project co-financed by the European Regional Development Fund



Thank you!