Photonuclear Astrophysics at ELI-NP

Nuclear Physics

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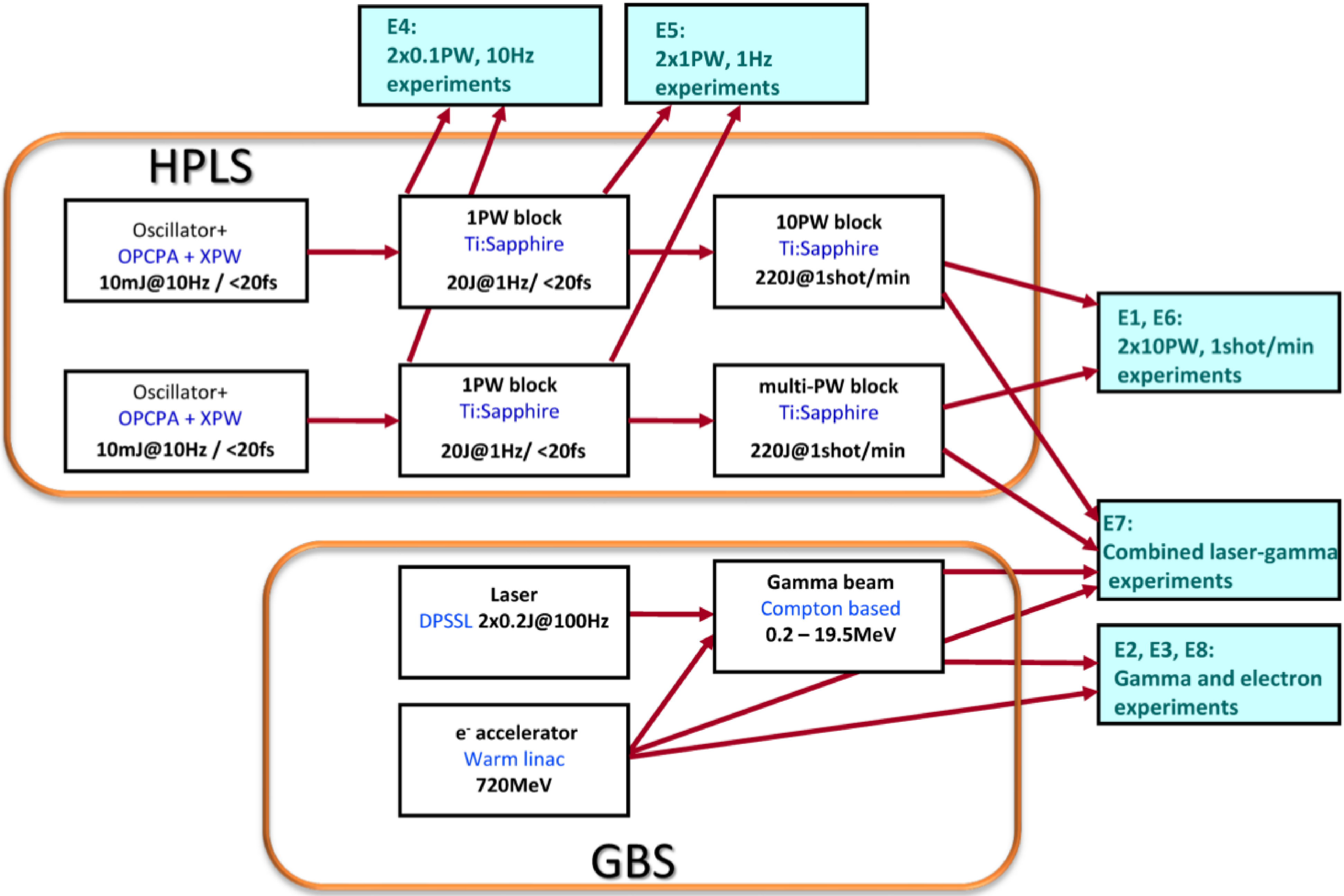
IFIN-HH/ELI-NP

OUTLINE

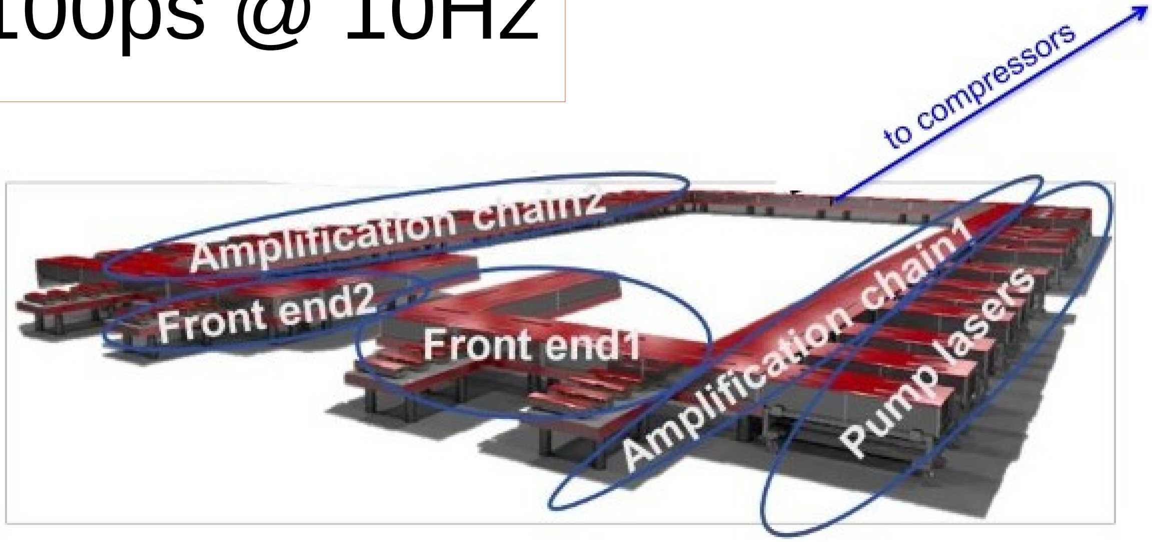
- ELI-NP
- HPLS & GBS
- GBS RA4 experiments
- Nuclear Astrophysics with ELISSA
- Monte Carlo simulations
- ..Conclusions..

Extreme Light Infrastructure - Nuclear Physics

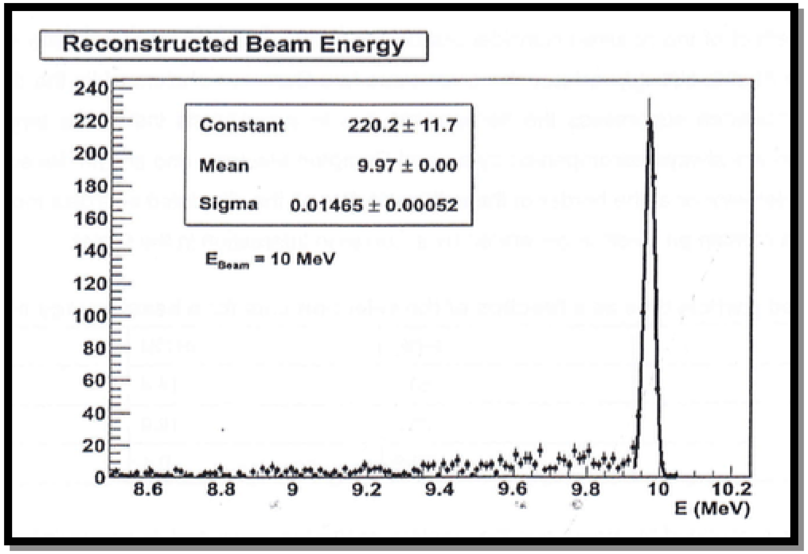

E4:
2x0.1PW, 10Hz
experiments
E5:
2x1PW, 1Hz
experiments
HPLS
Oscillator+
OPCPA + XPW
10mJ@10Hz / <20fs
1PW block
Ti:Sapphire
20J@1Hz/ <20fs
10PW block
Ti:Sapphire
220J@1shot/min
E1, E6:
2x10PW, 1shot/min
experiments
Oscillator+
OPCPA + XPW
10mJ@10Hz / <20fs
1PW block
Ti:Sapphire
20J@1Hz/ <20fs
multi-PW block
Ti:Sapphire
220J@1shot/min
E7:
Combined laser-gamma
experiments
Laser
DPSSL 2x0.2J@100Hz
Gamma beam
Compton based
0.2 – 19.5MeV
E2, E3, E8:
Gamma and electron
experiments
e- accelerator
Warm linac
720MeV
GBS

High Power Laser System (**HPLS**)

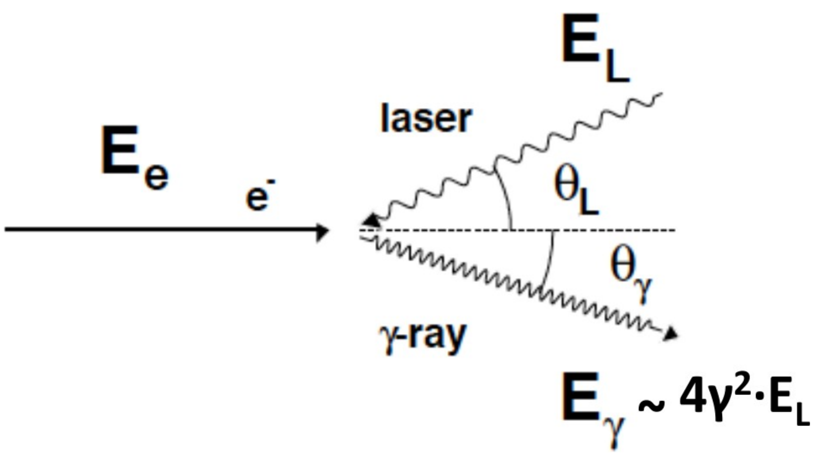
- 815nm
- 2x 10PW, 22fs @ 1/min
- 2x 1PW, 10ps @ 1Hz
- 2x 100TW, 100ps @ 10Hz



Gamma Beam System (**GBS**)

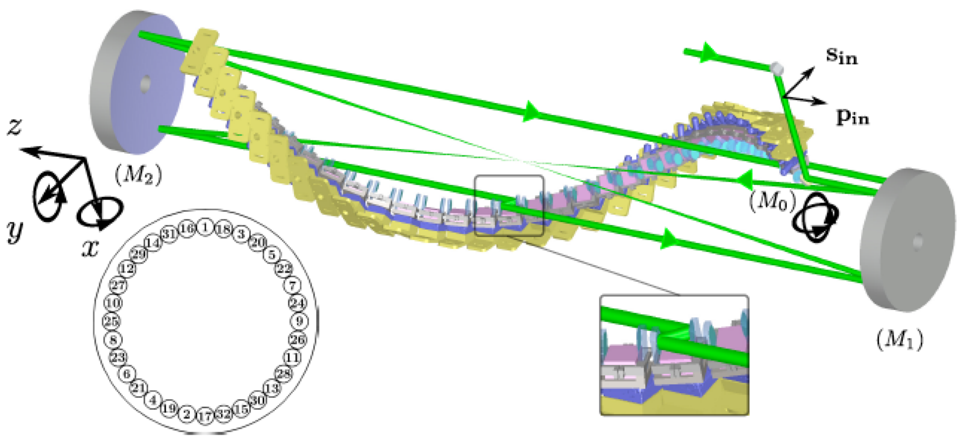


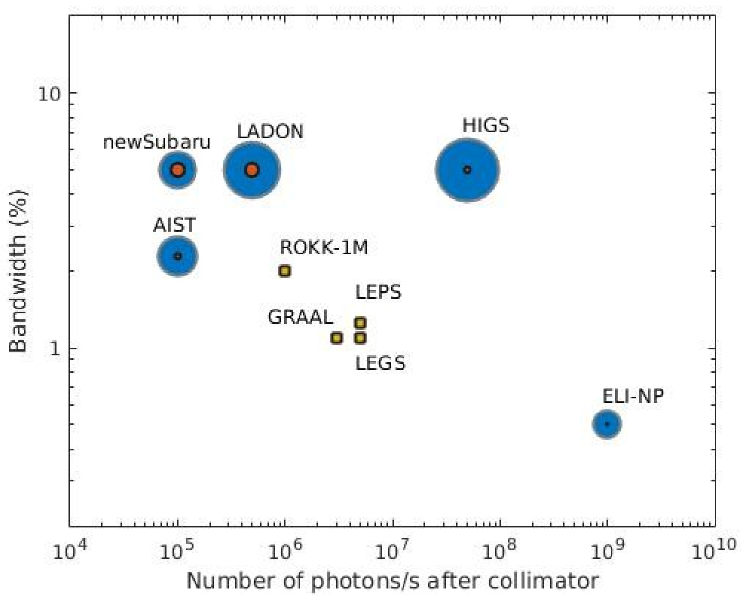
- Inverse Compton scattering
- 0.2–19.5MeV
- 0.5% bandwidth
- 10^4 photons/(eV·s)
- 99% P_γ



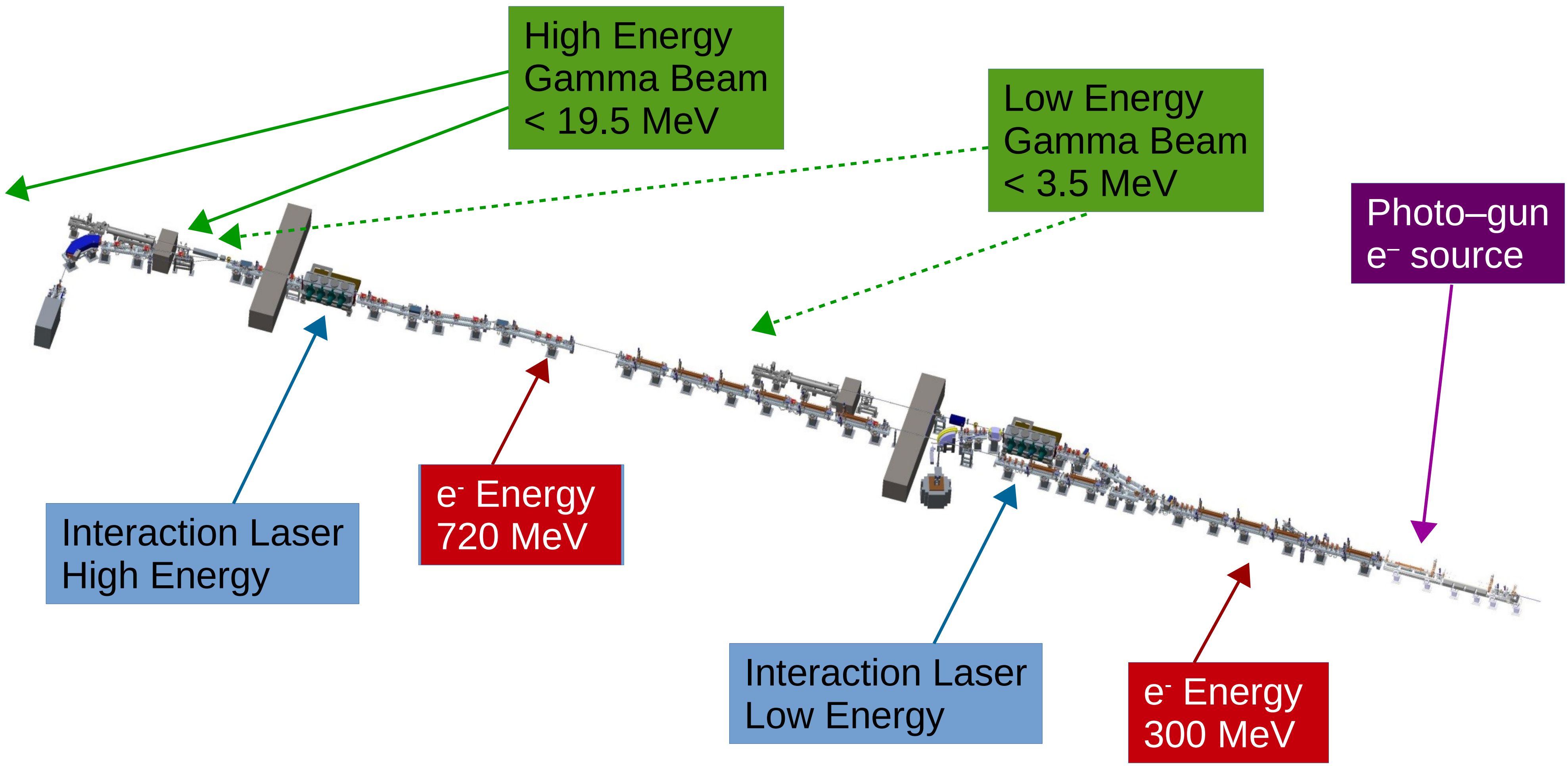
$$E_\gamma = 2\gamma_e^2 \cdot \frac{1+\cos\theta_L}{1+(\gamma_e\theta_\gamma)^2 + a_0^2 + \frac{4\gamma_e E_L}{mc^2}} \cdot E_L$$

Gamma Beam System Specs





Quantity	Symbol	Units	Specification
Minimum Photon Energy	E_γ	[MeV]	0.2
Maximum Photon Energy	E_γ	[MeV]	19.5
Tunability of the photon energy			Continuously variable
Linear polarization of the gamma ray beam	P_γ	[%]	≥ 99
Divergence	$\Delta\theta$	[rad]	(0.25 - 2.0) x 10^{-4}
Source rms diameter		[m]	(0.01 - 0.03) x 10^{-3}
Average diametral Full Width Half Maximum of beam spot	σ_r	[m]	≤ 1.0 x 10^{-3}
Average bandwidth of the gamma-ray beam	W		≤ 5.0 x 10^{-3}
Time-average spectral density at the peak energy	F	[1/(s eV)]	(0.8 - 4.0) x 10^4
Time-average brilliance at peak energy	B_{av}	[1/s mm^2 $mrad^2$ 0.1%W]	≥ 1.0 x 10^{13}
Peak-brilliance at peak energy	B	[1/s mm^2 $mrad^2$ 0.1%W]	10^{20} - 10^{23}
Average spectral off-peak gamma-ray background density	$\Phi_{\gamma,\mathrm{bkgr}}$	[1/(s eV)]	≤ 1.0 x 10^{-2}
Frequency of the gamma-ray macropulses	$\Omega_{\gamma,M}$	[Hz]	100
Number of gamma-ray micropulses per macropulse			32
Micropulse-to-micropulse separation		[ns]	16


High Energy Gamma Beam < 19.5 MeV
Low Energy Gamma Beam < 3.5 MeV
Photo–gun e⁻ source
Interaction Laser High Energy
e⁻ Energy 720 MeV
Interaction Laser Low Energy
e⁻ Energy 300 MeV

Research Activities

Fundamental Research

Nuclear Resonance Fluorescence (A.Zilges, C.A.Ur)

Nuclear Astrophysics (γ,p) (γ,a) (M.Gai, C. Matei, O.Tesileanu)

Photonuclear Reactions (γ,n) (H.Utsunomiya, F.Camera, D.Filipescu)

Photofission Studies of Exotic Nuclei (A.Krasznahorkay, F.Ibrahim, A. Oberstedt)

Applications

Gamma Imaging (H.Ohgaki, V.Iancu)

Material Science with Positrons (C.Hugenschmidt, N.Djourelov)

Medical Radioisotopes (D.Niculae, M.Bobeica)

R&D Diagnostics Detectors

Gamma Beam Delivery and Diagnostics (H.Weller, C.A.Ur)

RA4 Head: D. Balabanski.

Nuclear Astrophysics with GBS

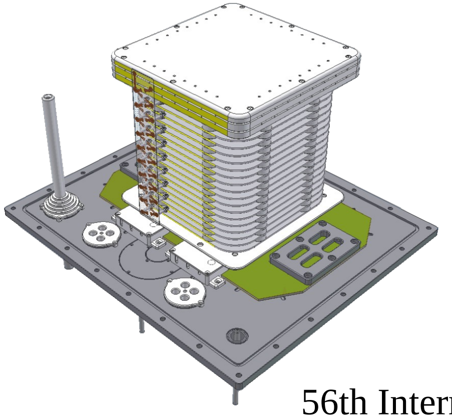
The Charged Particles Working Group (CPWG)

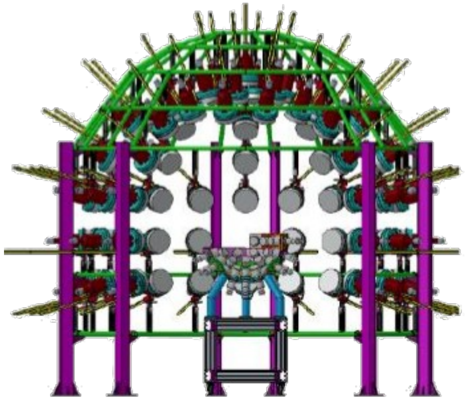
Time Projection Chamber: eTPC with electronic readout. Proposed reactions: $^{16}O(\gamma,\alpha)^{12}C$, $^{22}Ne(\gamma,\alpha)^{18}O$, $^{19}F(\gamma,p)^{18}O$

Silicon Strip Detectors Array: ELISSA allows for particle identification through kinematics. Proposed reactions: $^{24}Mg(\gamma,\alpha)^{20}Ne$ and p-process reactions

The Gamma above Neutron Threshold (GANT)

4π high-efficiency neutron detector. Proposed reactions: $^{181}Ta(\gamma,n)^{180}Ta$, $^{138}La(\gamma,n)^{137}La$





Nuclear Astrophysics with ELISSA

- to perform accurate measurements of (small) cross sections of nuclear reactions
- inverse photo-disintegration reactions with low background measurements
- different systematic uncertainties than charge-particle induced reactions at low energies of astrophysical interest

It is important to evaluate the expected background and event rate

Nuclear Astrophysics with ELISSA

Big Bang Nucleosinthesys and Li-problem

^{7}Li(γ,t)^{4}He reaction

Si-burning in stars and presupernova phase

^{24}Mg(γ,α)^{20}Ne reaction

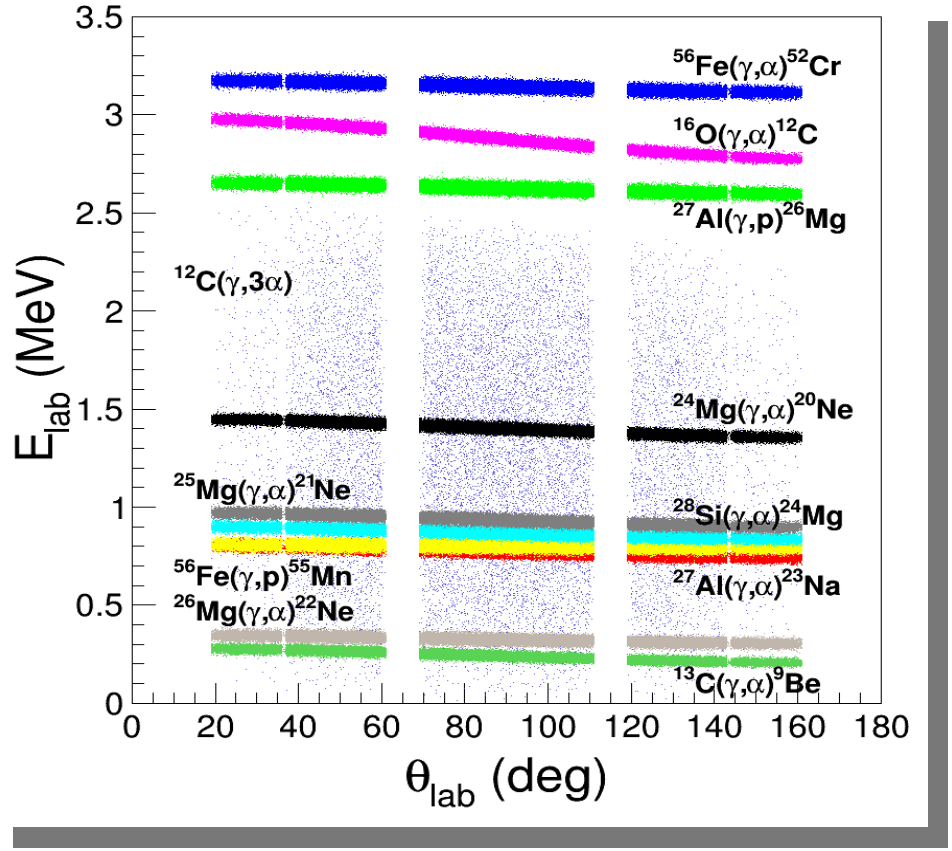
^{28}Si(γ,p)^{27}Al reaction

p-process (production of proton rich nuclei)

^{96}Ru(γ,α)^{92}Mo reaction

^{74}Se(γ,p)^{73}As reaction

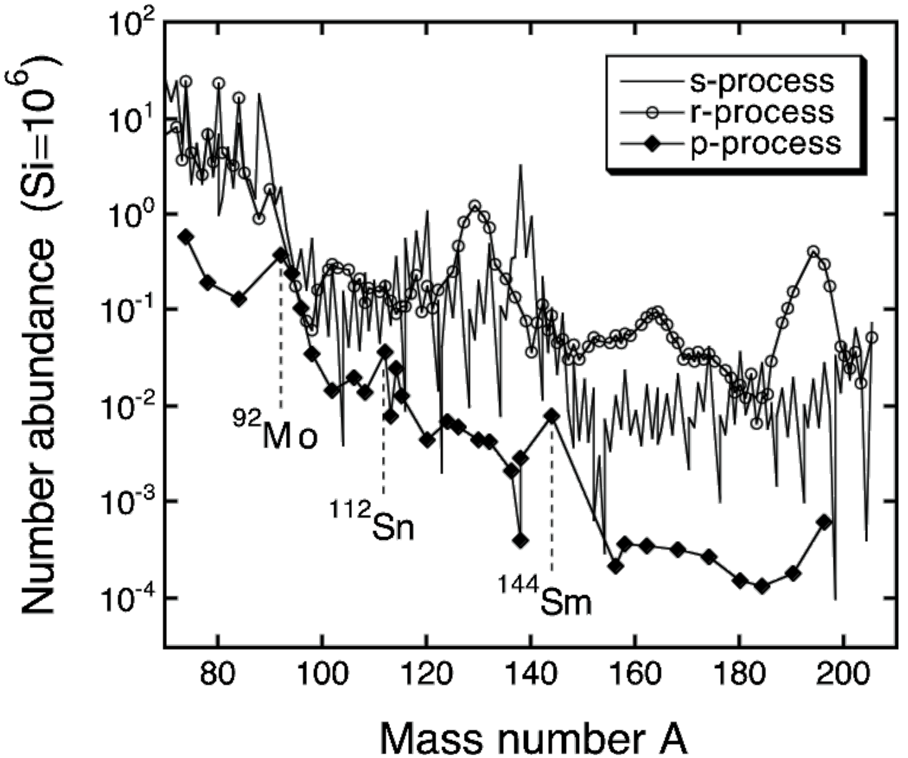
ToF, PSD & ΔE-E **difficult** → Kinematic ID → good energy and position resolutions needed

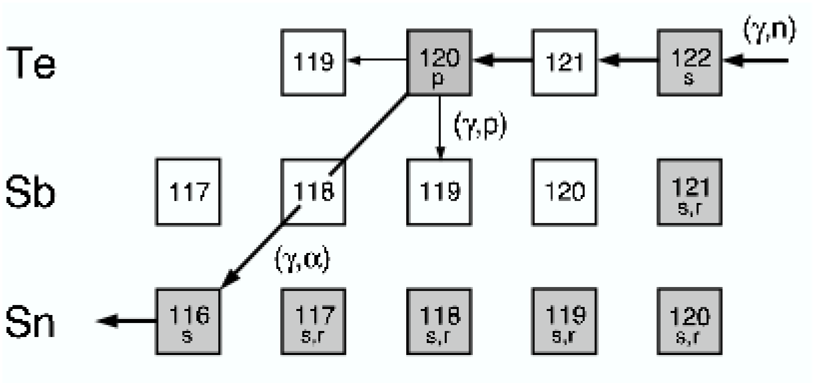


p-process

- proton-rich nuclei with A ≥ 74
- less abundant typically by factors of ten to one thousand than the other isotopes of the same element
- (p,γ) reactions inefficient
- s- and r-nuclei serve as seeds
- suggested to occur in type II supernovae when the shock wave passes through the O–Ne-rich layer of a massive star @ T≈2–3GK

ELISSA for studying reactions on nuclei intervening in the p-process
^{74}Se, ^{78}Kr, ^{84}Sr, ^{92}Mo, ^{96}Ru, ..

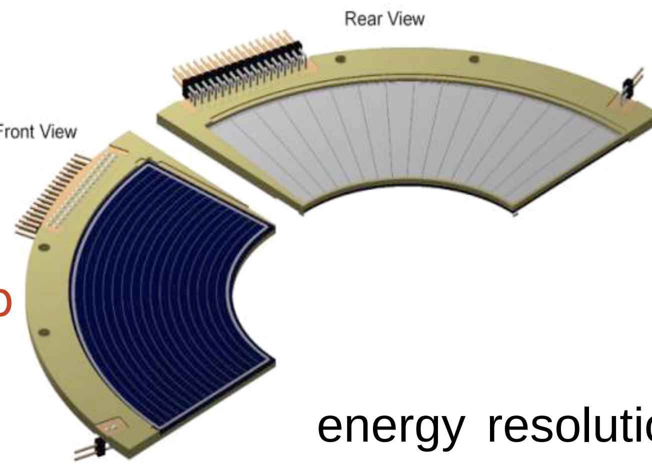


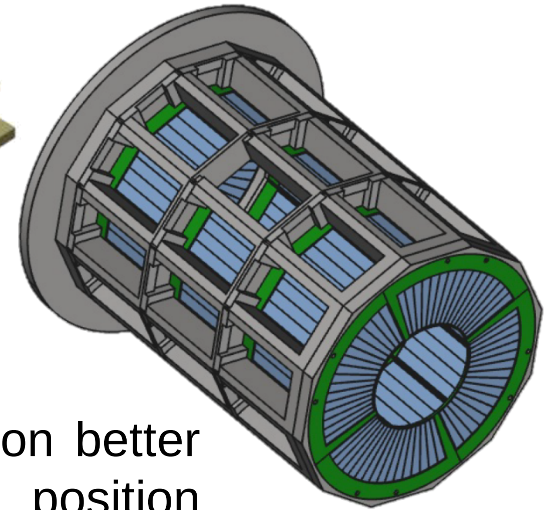


Extreme Light Infrastructure Silicon Strip Array

Barrel configuration:

- ✓ 3 rings of 12 position-sensitive X3 silicon-strip detectors by Micron
- ✓ 2 end cap detectors made up of 4 QQQ3 DSSSD by Micron
- ✓ ~ 500 channels readout with GET electronics

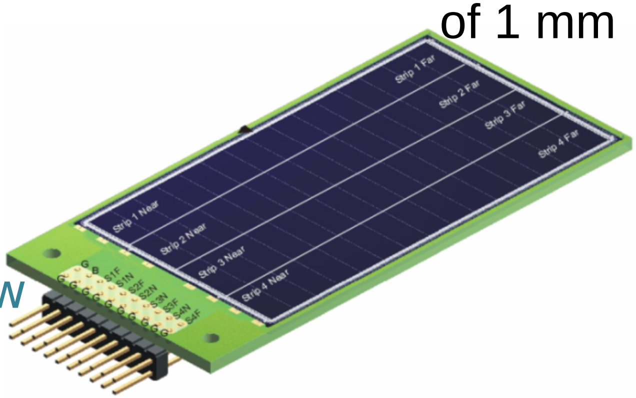


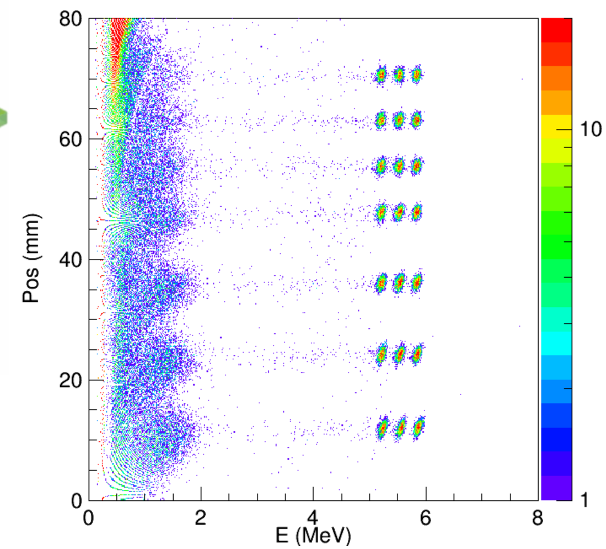


energy resolution better than 1% and position resolution of the order of 1 mm

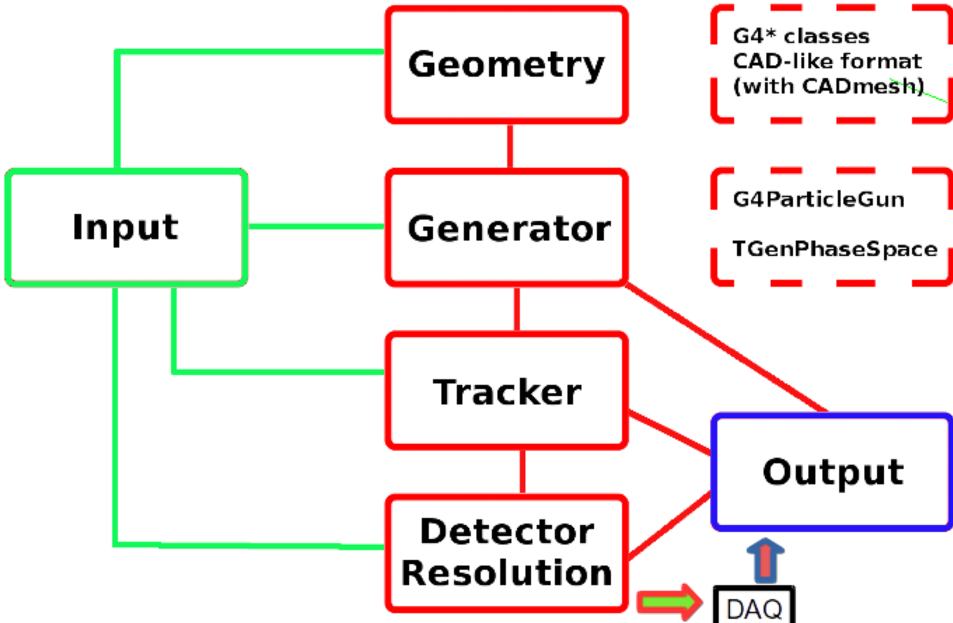
Characteristics:

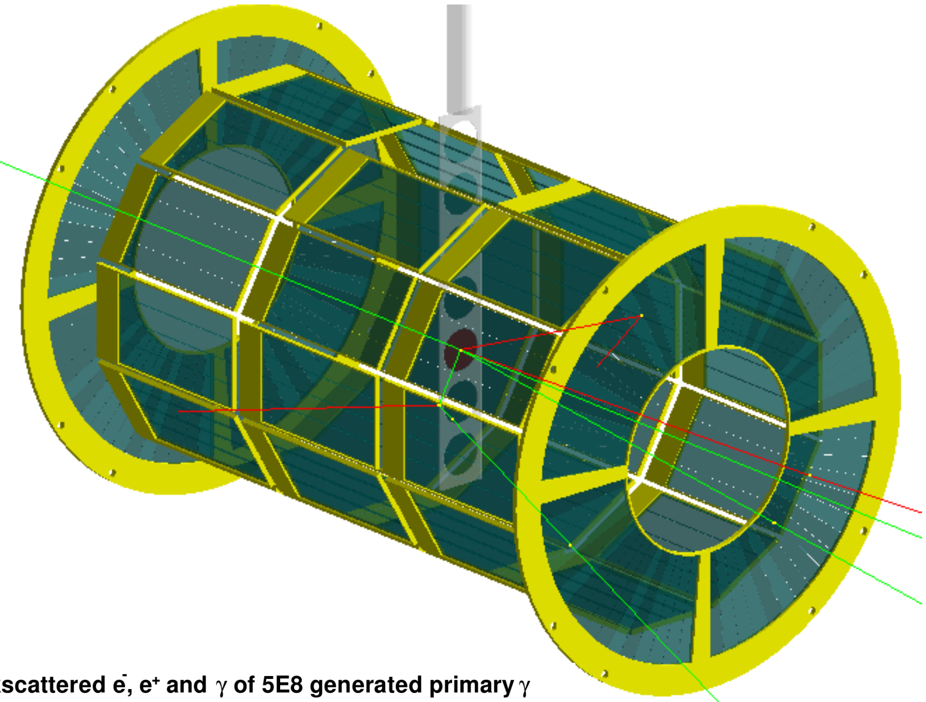
- ~80% geometrical coverage of 4π
- Negligible sensitivity to neutrons & photons
- No double hit effect (few particles in the exit channel)

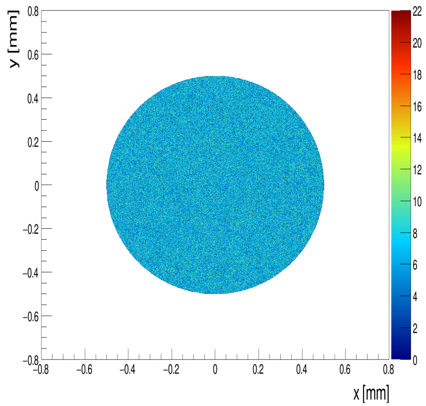


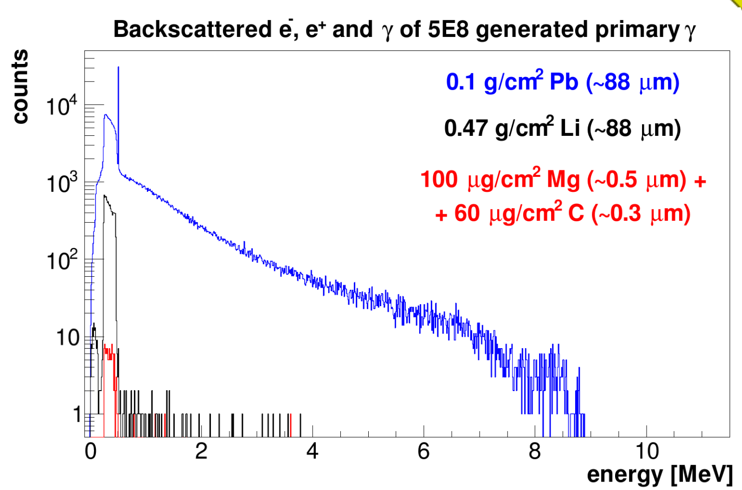


MC SIMULATIONS



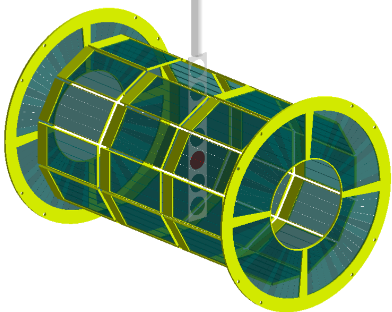


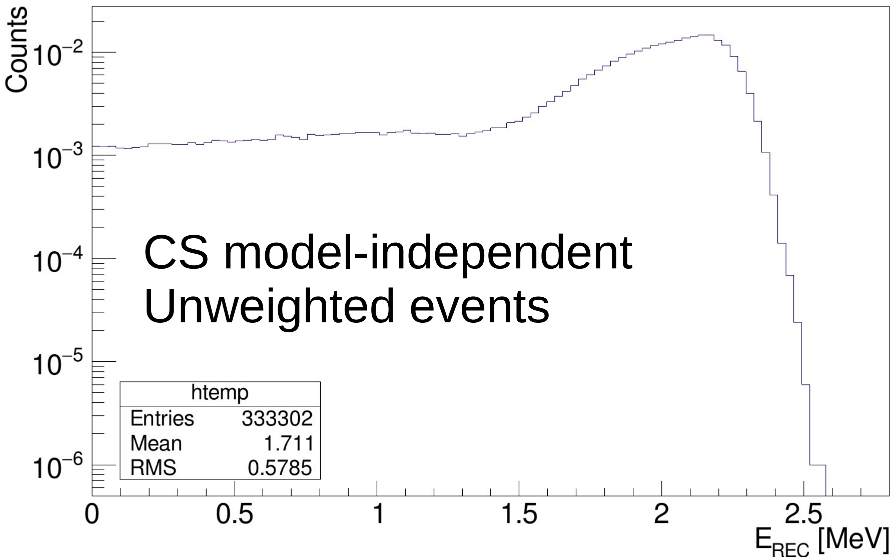


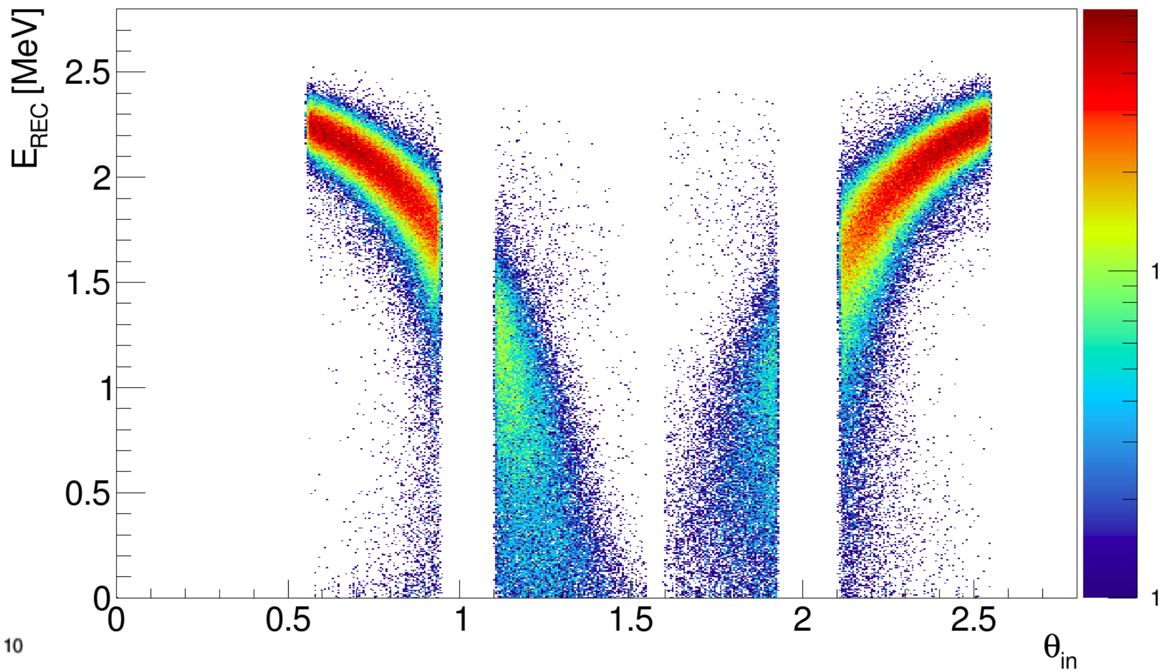


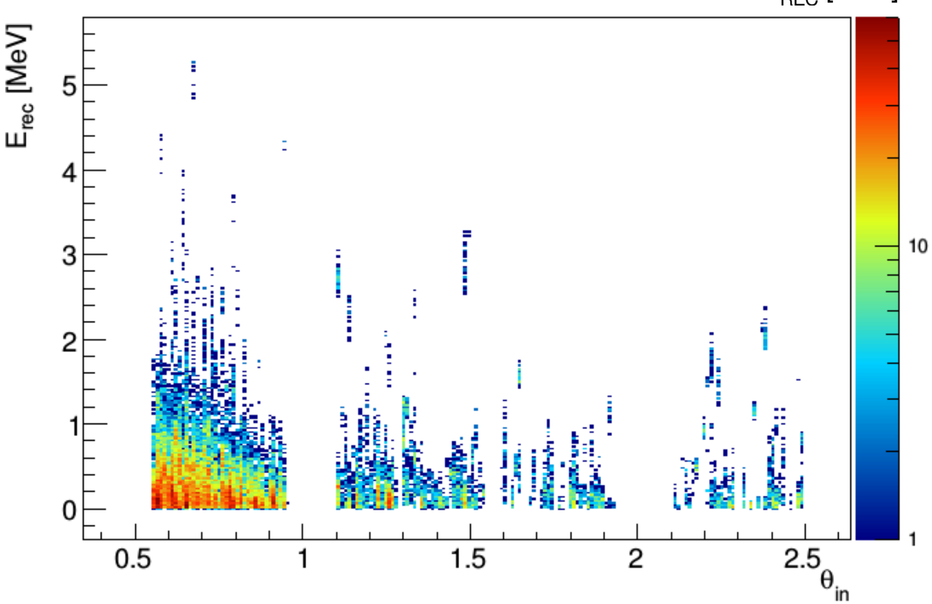
PRELIMINARY

$^{92}\mathrm{Mo}(\gamma,\alpha)^{88}\mathrm{Zr}$

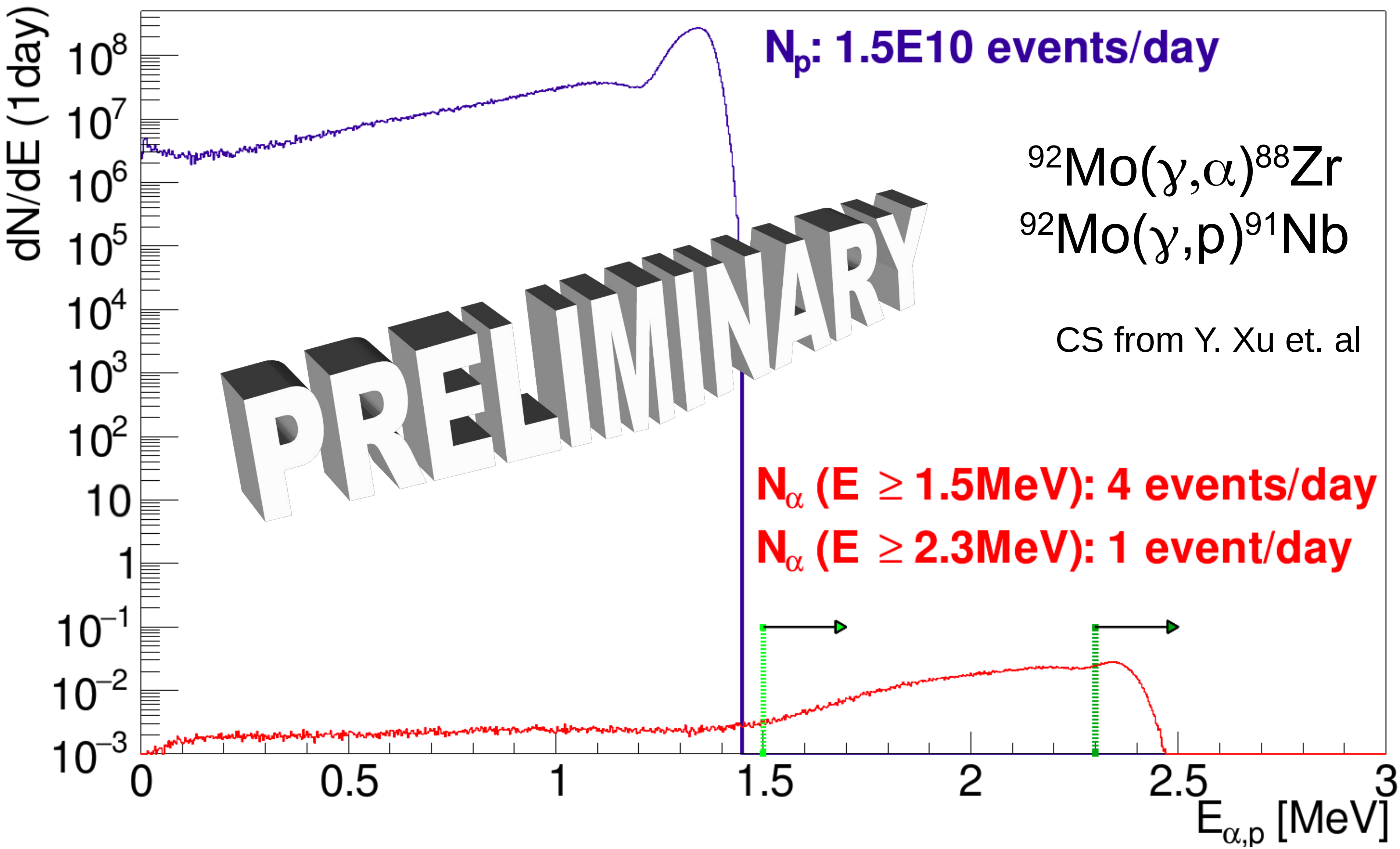








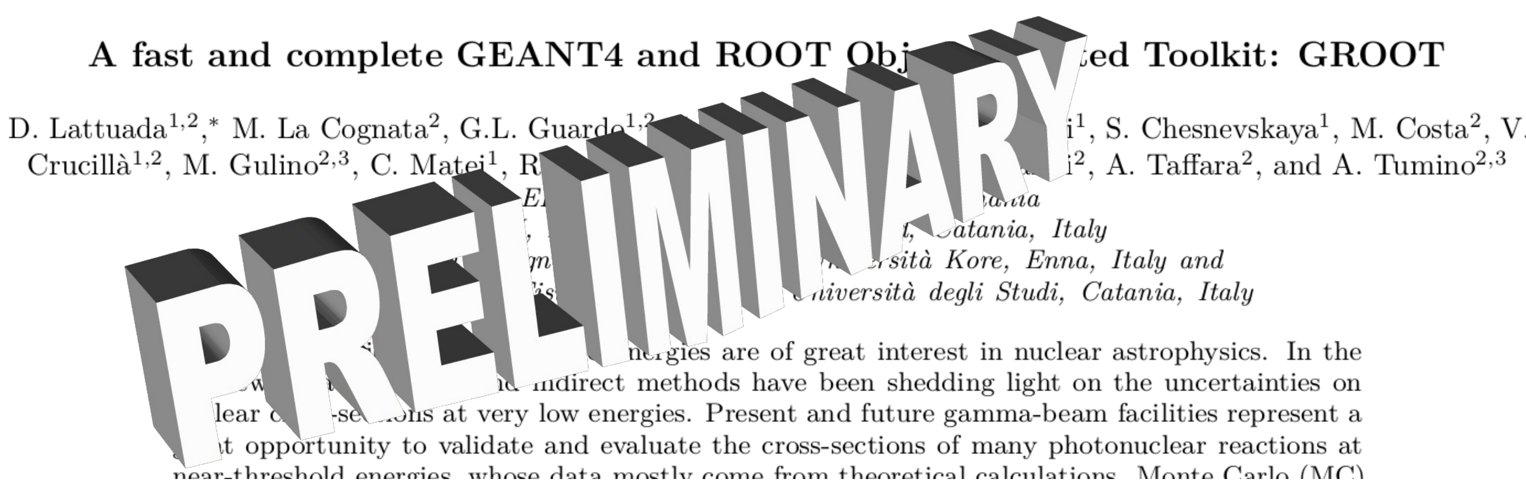
E_γ = 9 MeV I_γ = 1.E8 sec^{-1} ^{92}Mo (3 μm) on ^{12}C backing (0.5 μm)



Summary

- The ELI-NP gamma beam system will provide new exciting opportunities for nuclear-physics experiments
- The beam will enter the testing phase in late 2018 / early 2019
- Several experiments in which the international community is involved are under development at ELI-NP
- ELISSA is being finalized and it will be able to shed light on many astrophysical problems
- Electromagnetic background and reaction rates have been evaluated with MC simulations for many proposed experiments
- A GEANT4&ROOT-based tool for nuclear reaction is under development to be mainly used as reference software by users coming at ELI-NP facility.

Thank you


PRELIMINARY
A fast and complete GEANT4 and ROOT Obj... ...ed Toolkit: GROOT
D. Lattuada[1,2,*] M. La Cognata[2], G.L. Guardo[1,2] ... i[1], S. Chesnevskaya[1], M. Costa[2], V.
Crucillà[1,2], M. Gulino[2,3], C. Matei[1], R ... i[2], A. Taffara[2], and A. Tumino[2,3]
..., Catania, Italy
...rsità Kore, Enna, Italy and
...Università degli Studi, Catania, Italy
...nergies are of great interest in nuclear astrophysics. In the
...indirect methods have been shedding light on the uncertainties on
...lear c...-sections at very low energies. Present and future gamma-beam facilities represent a
...t opportunity to validate and evaluate the cross-sections of many photonuclear reactions at

EUROPEAN UNION

GOVERNMENT OF ROMANIA

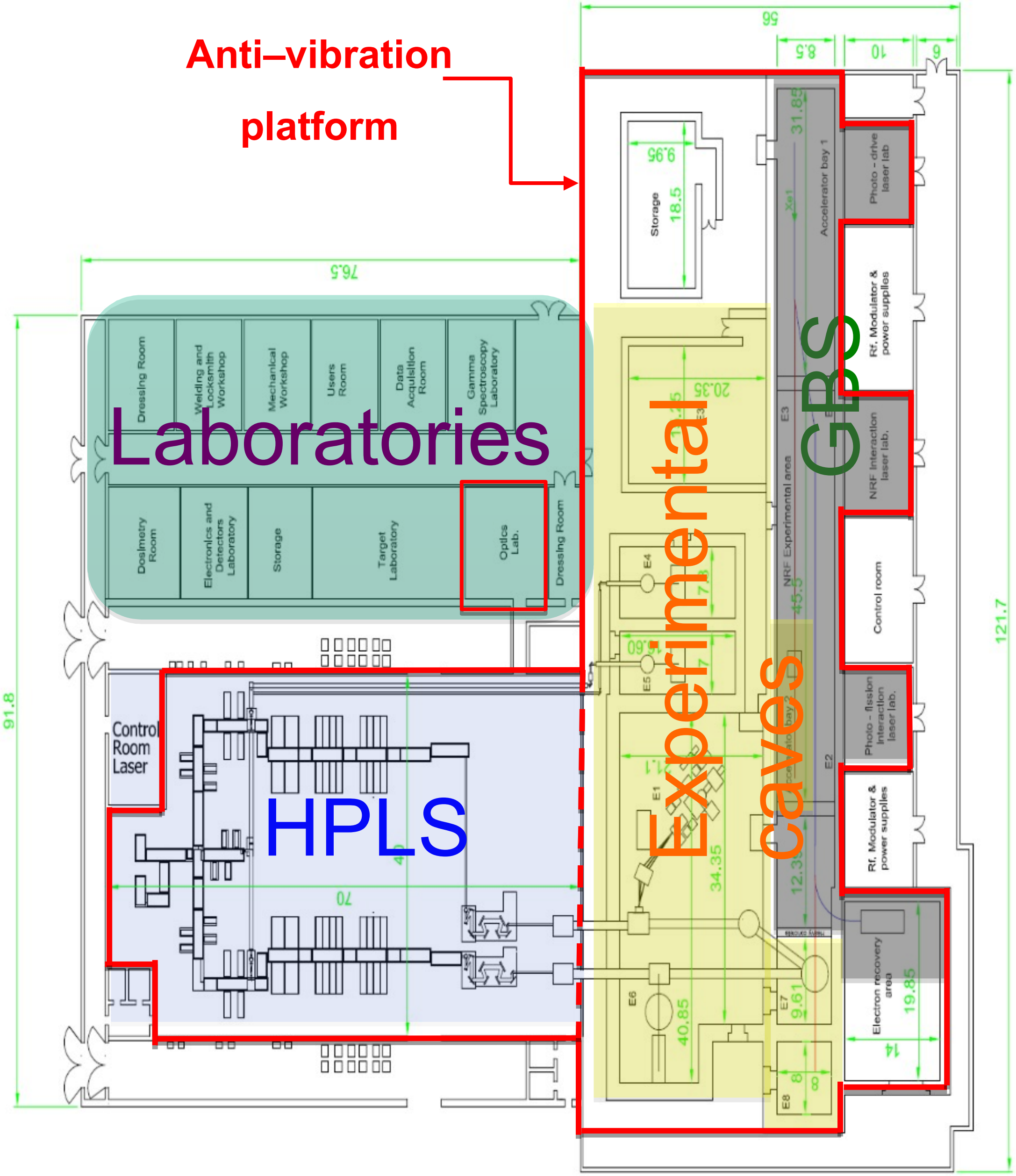
Structural Instruments
2007-2013

I would like to acknowledge the support from the Extreme Light Infrastructure Nuclear Physics (ELI-NP) Phase II, a project co-financed by the Romanian Government and the European Union through the European Regional Development Fund - the Competitiveness Operational Programme (1/07.07.2016, COP, ID 1334).
Thanks to my colleagues for their support, and to you for your attention.

eli Nuclear Physics

IFIN-HH

ELI-NP experimental areas

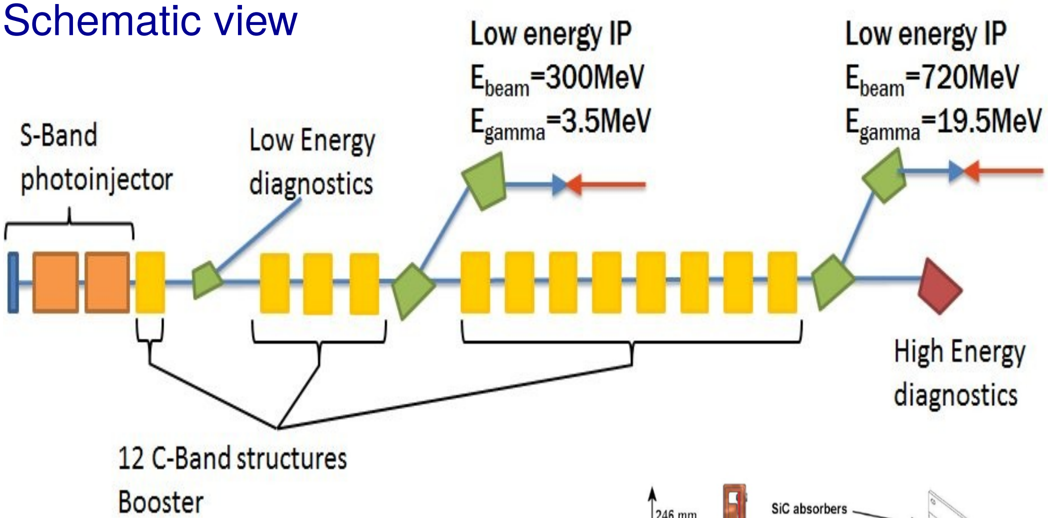


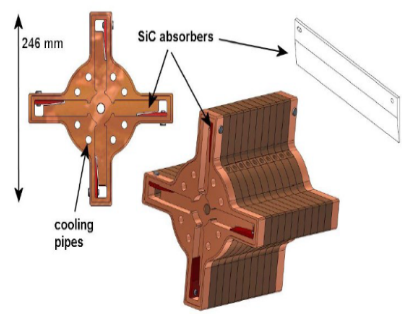
Platform vibrations

±1 μm @ < 10 Hz

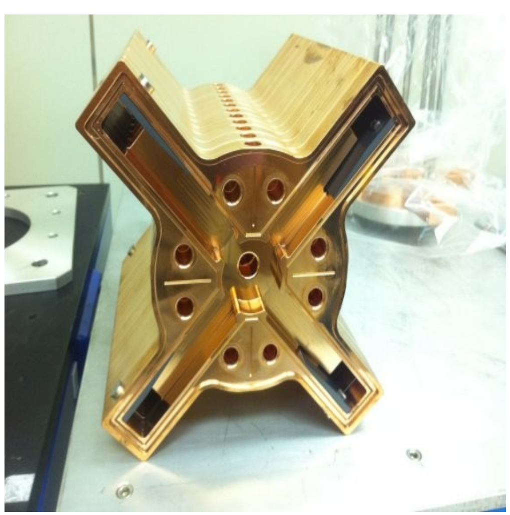
The electron LINAC

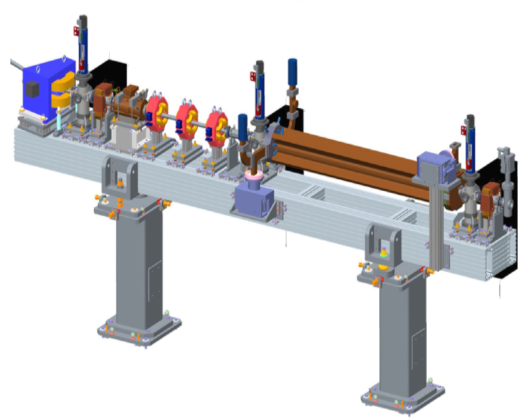
Schematic view





C–Band RF cavity



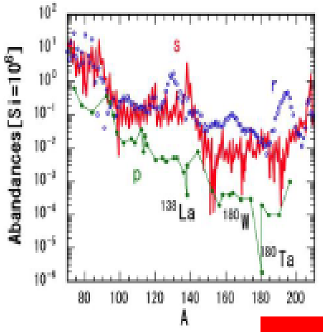


Energy	80 – 720 MeV
Bunch charge	25 – 500 pC
Number of bunches	32
Bunch distance	16 ns
C-band average accelerating gradient	33 MV/m
Norm. emittance	0.2-0.6 mm·mrad
Bunch length	100 – 400 μm
RF rep Rate	100 Hz
Focal spot size	> 15 μm
Bunch energy spread	0.04 – 0.1 %
Pointing jitter	1 μm

ELI-GANT experiment: overview

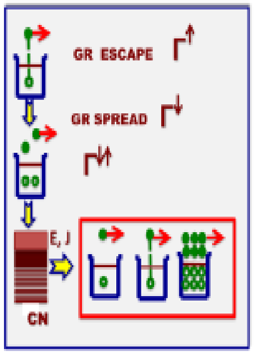
(Gamma Above Neutron Threshold)

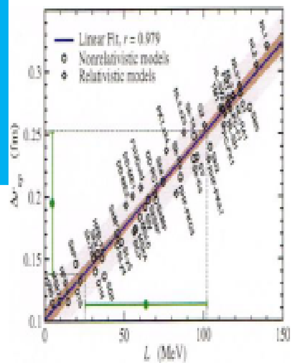
Franco Camera, Hiroaki Utsunomiya, Dan Filipescu



Four Physics Cases

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





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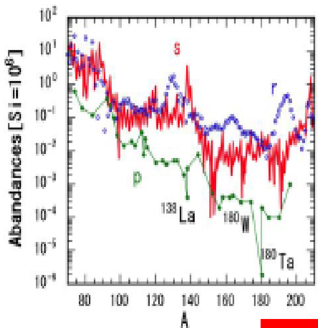

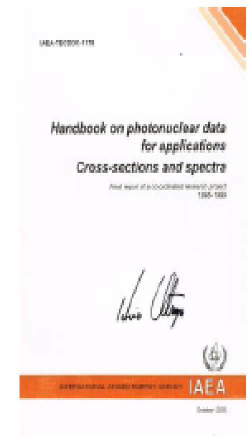

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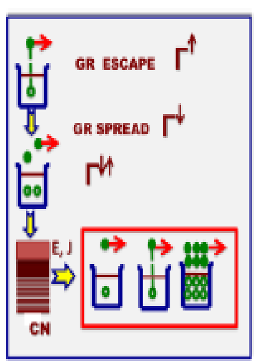
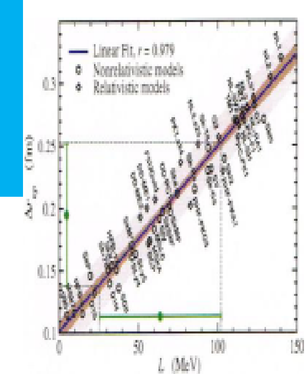
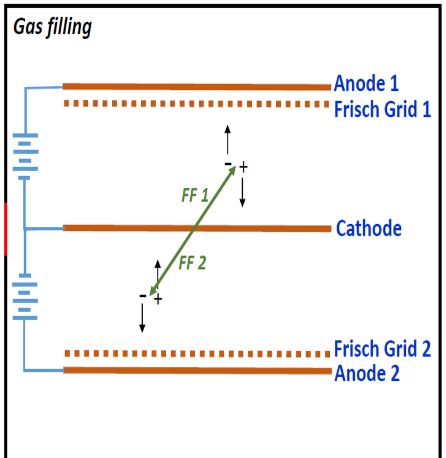




Photofission: ELI BIC (Bragg Ionization Chamber)



Highly efficient Frisch-gridded twin-ionization chambers

Measurement of mass, charge, kinetic energy distribution of the fission fragments

+

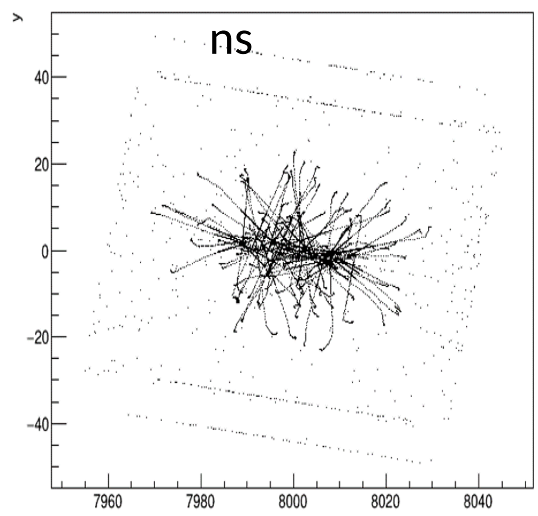
Array of 8 ΔE-E detectors

Identification of ternary fission

ΔE (gas detector)

DSSD

Simulations



P10 gas at 1 bar pressure