Nuclear AstroPhysics at ELI-NP: preliminary experiments with ELISSA detector

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ELI-NP facility

For the first time, a very high spectral density (10^4 γ/s/eV), brilliant γ beam, <0.5% bandwidth, with E_γ up to 19.5 MeV. This beam is obtained by incoherent Compton backscattering of a laser light off a very brilliant, intense, ultra-relativistic electron beam (E_e up to 720 MeV) produced by a warm LINAC.

Photon scattering on ultra relativistic electrons

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

Nuclear AstroPhysics at ELI-NP

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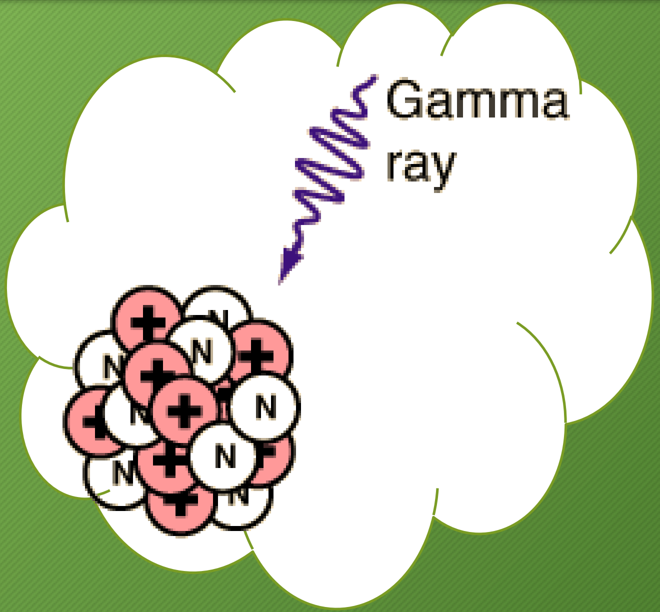
In evolved stars, high photon densities are present, making it possible to dissociate stable seed nuclei the photon energies being as large as many MeV.

For the first time high intensity ($3 \cdot 10^8$ γ/s) high resolution ($<10^{-2}$) will be available, making it possible to measure photodissociation reactions of astrophysics importance.

- Big Bang Nucleosinthesys and Li-problem
  $^{7}Li(\gamma,t)^{4}He$ reaction
- Si-burning in stars and presupernova phase
  $^{24}Mg(\gamma,\alpha)^{20}Ne$ reaction
  $^{28}Si(\gamma,p)^{27}Al$ reaction
- p-process (production of proton rich nuclei)
  $^{96}Ru(\gamma,\alpha)^{92}Mo$ reaction
  $^{74}Se(\gamma,p)^{73}As$ reaction



Extreme Light Infrastructure Silicon Strip Array

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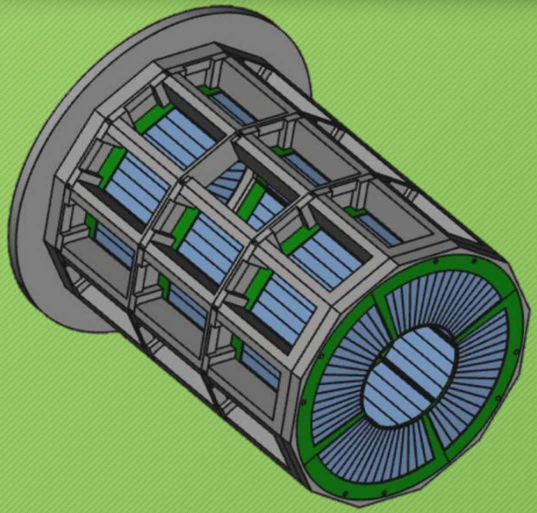

Barrel configuration:

- ✓ 3 rings of 12 position sensitive X3 silicon-strip detectors by Micron
- ✓ 2 end cap detectors made up of 4 QQQ3 DSSSD by Micron
- ✓ >550 channels readout with GET electronics/standard electronics

Characteristics:

- Wide angular range coverage
- Low energy threshold
- Compactness
- Angular resolution better than 0.5 cm
- Energy resolution better than 1%
- Kinematical identification of outgoing particle

Perfectly suited for nuclear astrophysical studies!!

G. L. Guardo et al. EPJ Web of Conf. 165, 01026 (2017)

MC Simulation: the GROOT code

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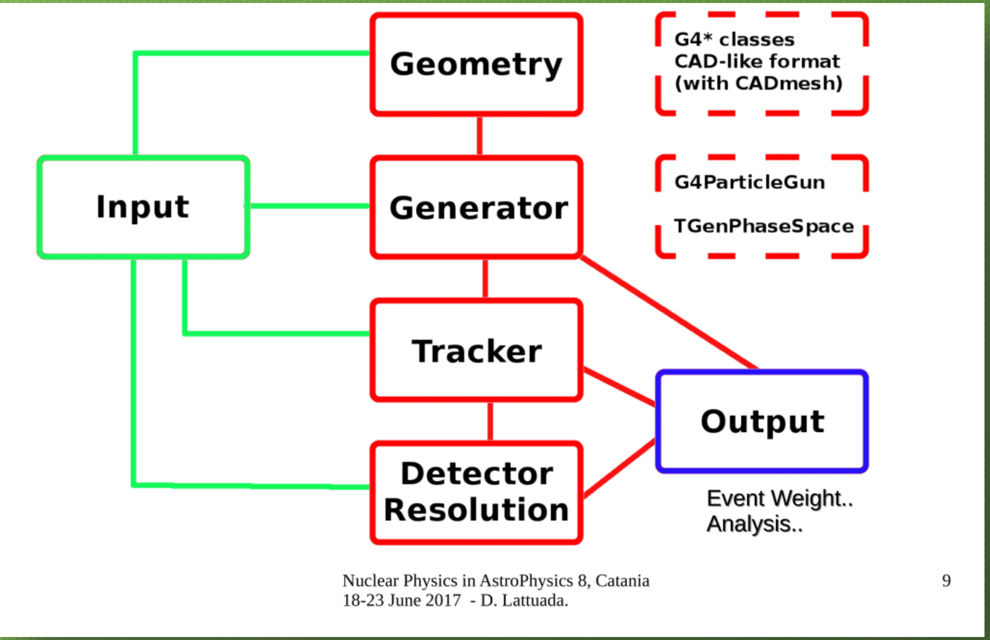
- ✓ Estimate the gamma-induced e.m. background
- ✓ Estimate the full background of photonuclear reactions and the detector’s resolution effect
- ✓ Optimization of the detector geometry
- ✓ Estimate the event rate (provided that we have reliable cross-section calculations) or calculate the minimum cross-section we can measure because of the background

Based on GEANT4 tracking + ROOT event generator engine



D. Lattuada et al. EPJ Web of Conf. 165, 01034 (2017)

ELISSA prototype @LNS

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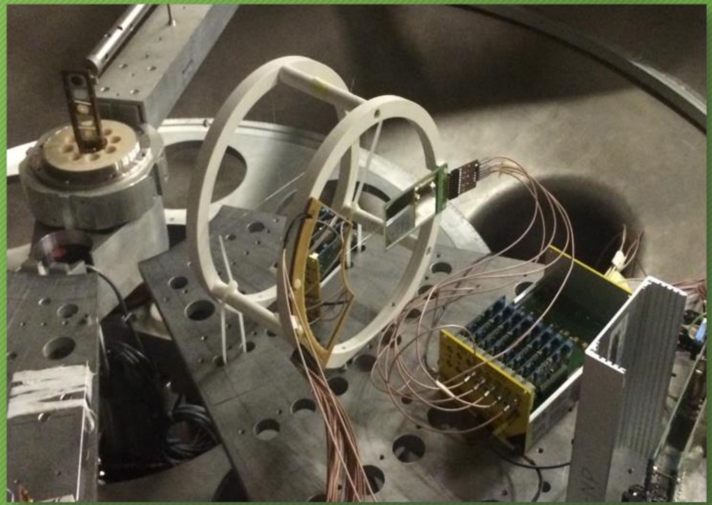
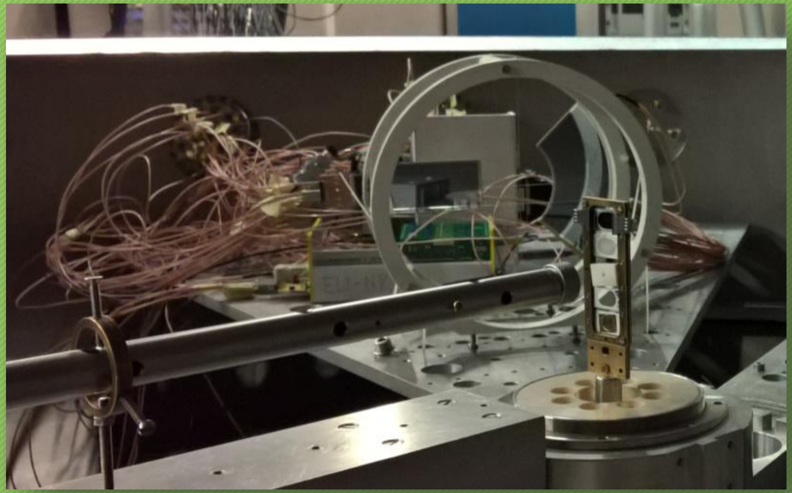
Design goal:
- ✓ Low threshold (few hundredes keV)
- ✓ Angular resolution better than 1 cm
- ✓ Energy resolution better than 1%



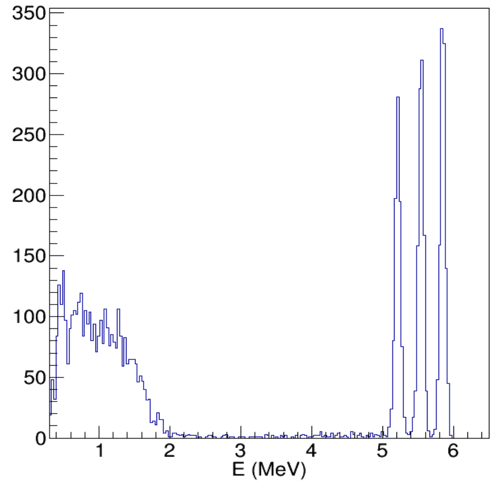
Experiments and tests:
- ➢ 3-peaks alpha sources
- ➢ ^{241}Am source and a 17μm Al foil
- ➢ 11 MeV ^{7}Li beam from the INFN-LNS tandem was delivered onto on Au (about 100 μg/cm^{2}) and ^{12}C (about 60 μg/cm^{2}) targets



Experimental setup:
- Grids with equally spaced slits of different sizes were used to estimate position resolution
- Collimation system of 1mm
- Distance from target 35cm
- 40° with respect the beam direction

Test results

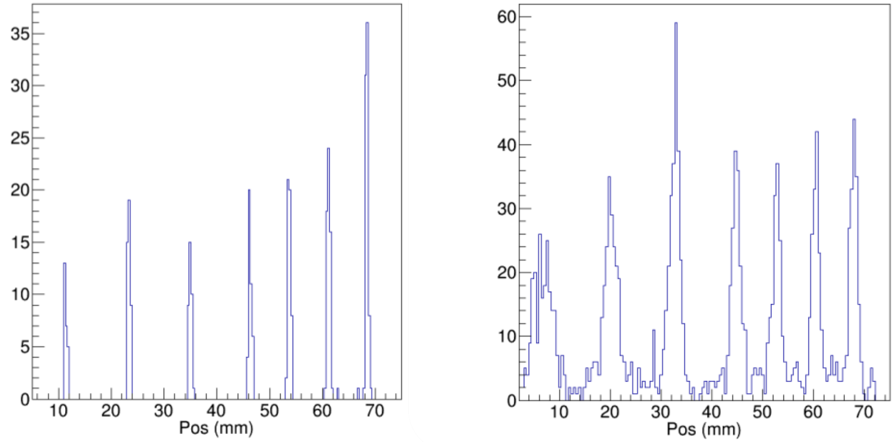
To measure the detection threshold, we have performed a run using a standard 3-peak alpha source and a americium source shielded by a 17 µm thick Al foil. This degrader shifts the energy peak to 1 MeV and, due to energy straggling, the energy range spanned reached zero.



→ 300 keV threshold achieved owing to a hot collimator close to detectors. Lower threshold achieved in other chambers.

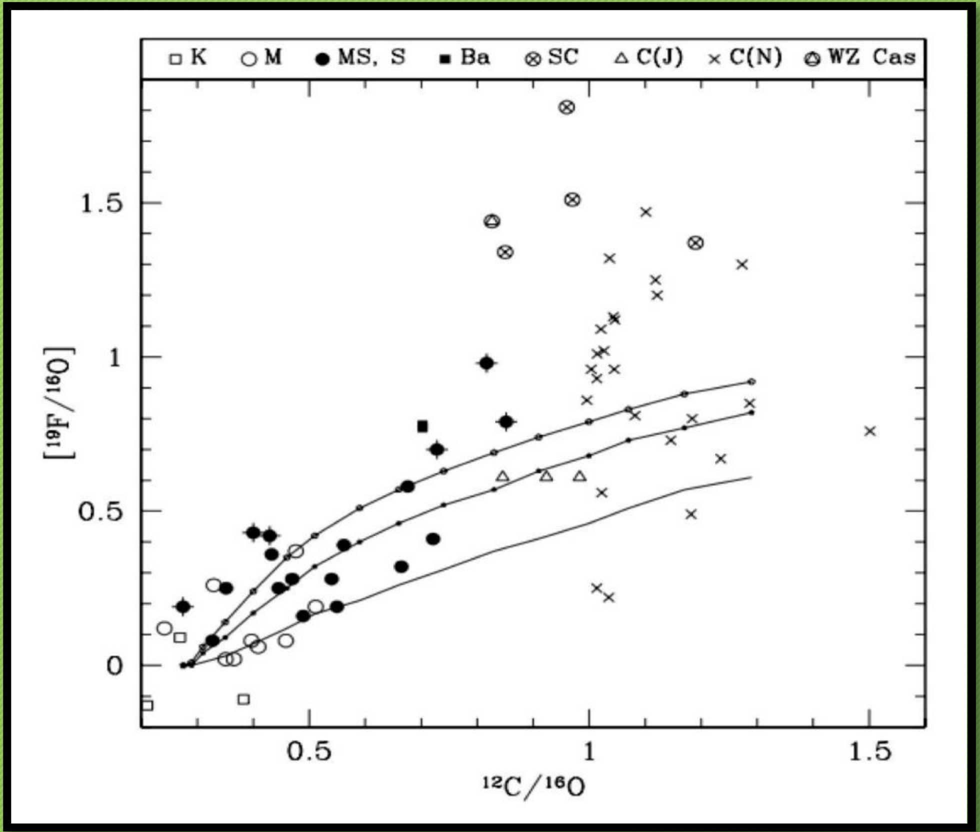
Position resolution at high energies (11 MeV, left panel) and low energies (1 MeV, right panel).

→ Resolution better than 1 mm at high energies and about 6 mm at low energies.



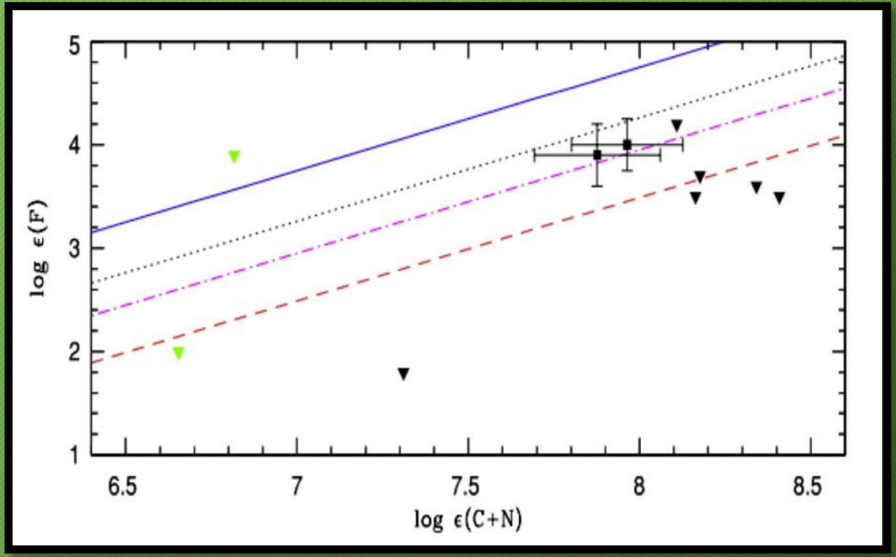
Upcoming experiment with ELISSA: the $^{19}F(p,\alpha_{\pi})^{16}O$ reaction

Astrophysical Motivation



^{19}F is a key isotope in astrophysics as it can be used to probe AGB star mixing phenomena and nucleosynthesis.

<u>But its production is still uncertain!!</u>



Upcoming experiment with ELISSA: the $^{19}F(p,\alpha_\pi)^{16}O$ reaction

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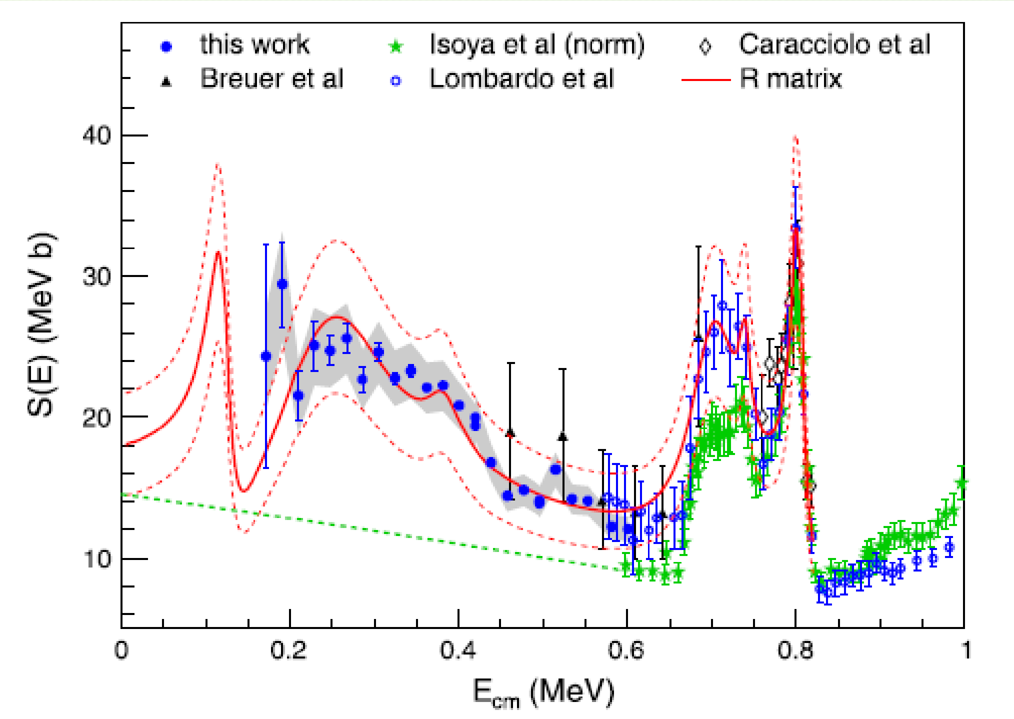
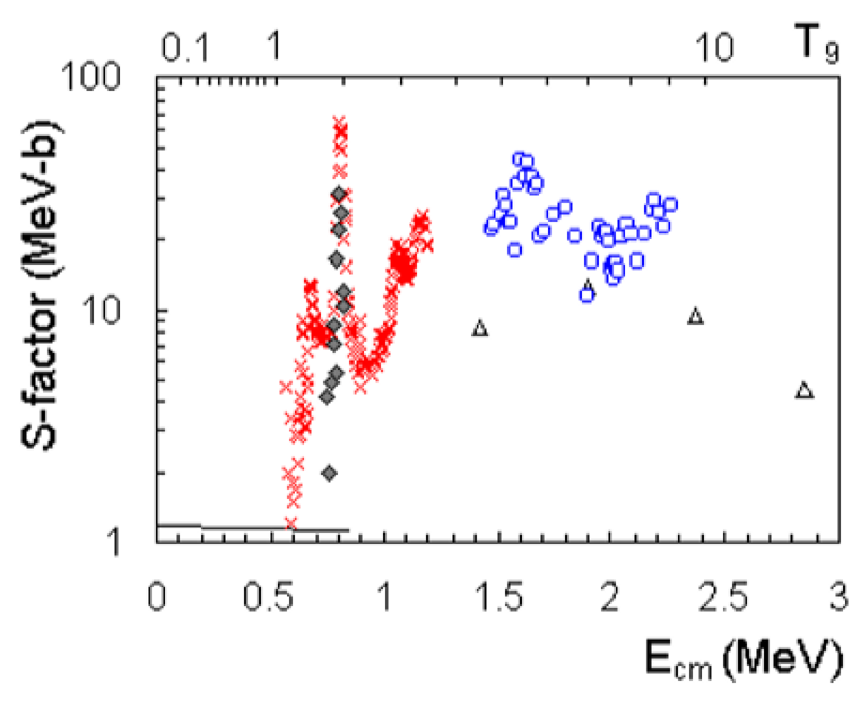
Status of the art of the different channels

$^{19}F(p,\alpha_0)^{16}O$

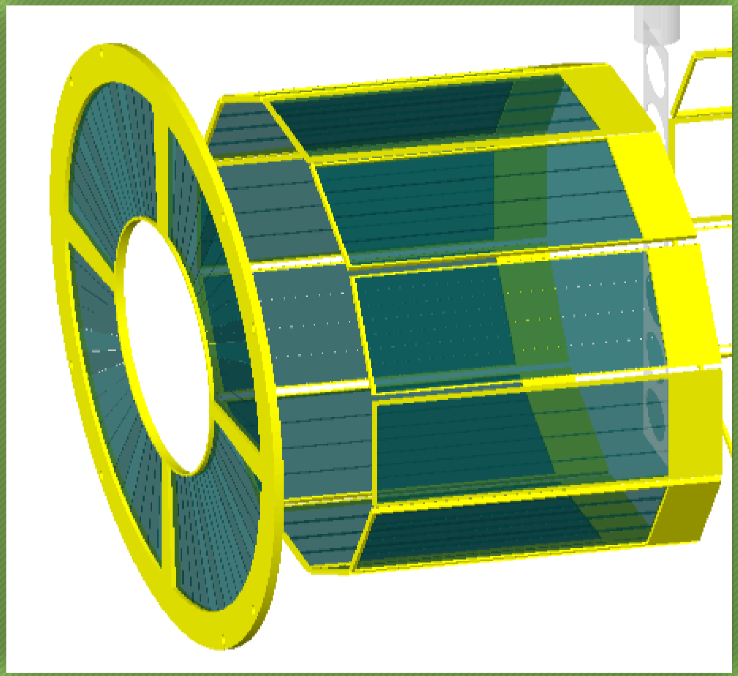


$^{19}F(p,\alpha_\pi)^{16}O$



Upcoming experiment with ELISSA: the $^{19}F(p,\alpha_{\pi})^{16}O$ reaction

Experimental setup



- ✓ One ring of 12 X3 position sensitive silicon detectors covering the angular range 40°-80°
- ✓ End cap made up of 4 QQQ3 silicon stip detectors covering the angular range 15°-35°
- ✓ Faraday cup for beam current measurement
- ✓ Point like telescope silicon detector act like a monitor for scattering measurement
- ✓ ^{19}F beam impinging on 100μg/cm² CH_2 target

Upcoming experiment with ELISSA: the $^{19}F(p,\alpha_\pi)^{16}O$ reaction

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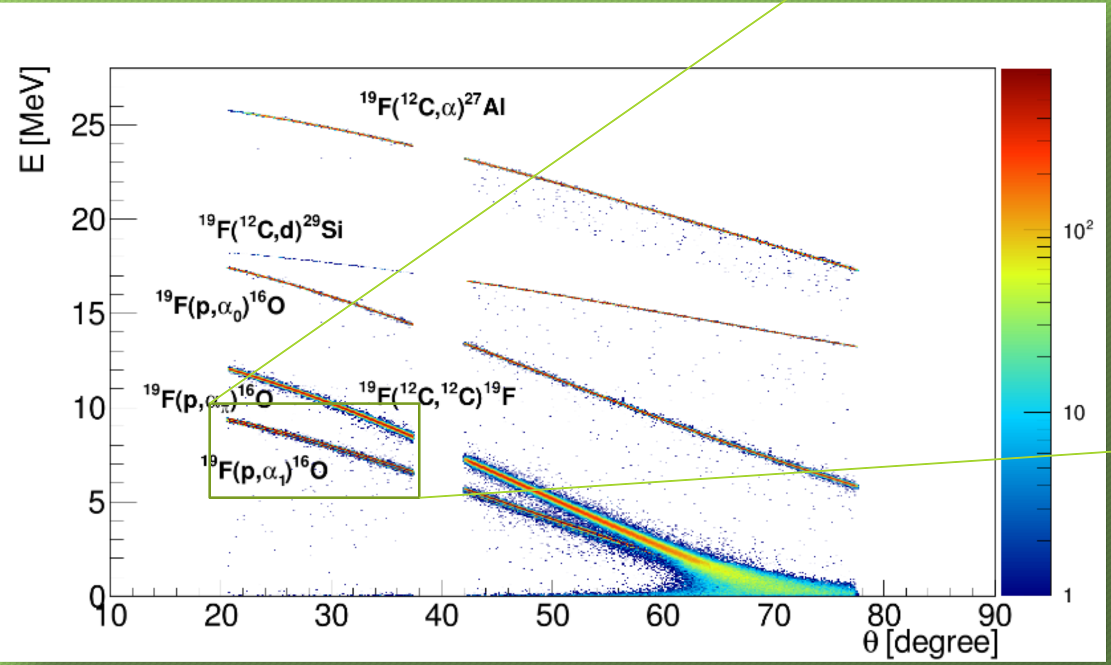
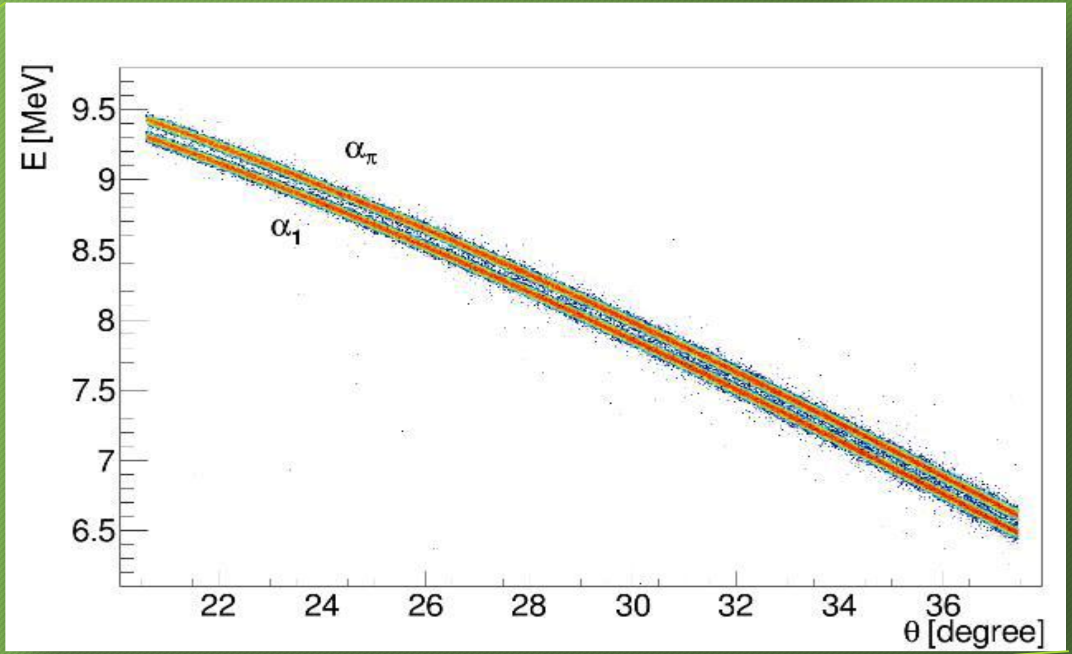
GROOT simulation





The simulation takes into account the energy and position resolution considering beam energy spread, target thickness and detector resolution.

γ beam experiment with silicon detectors: the $^{7}Li(\gamma,t)^{4}He$ reaction

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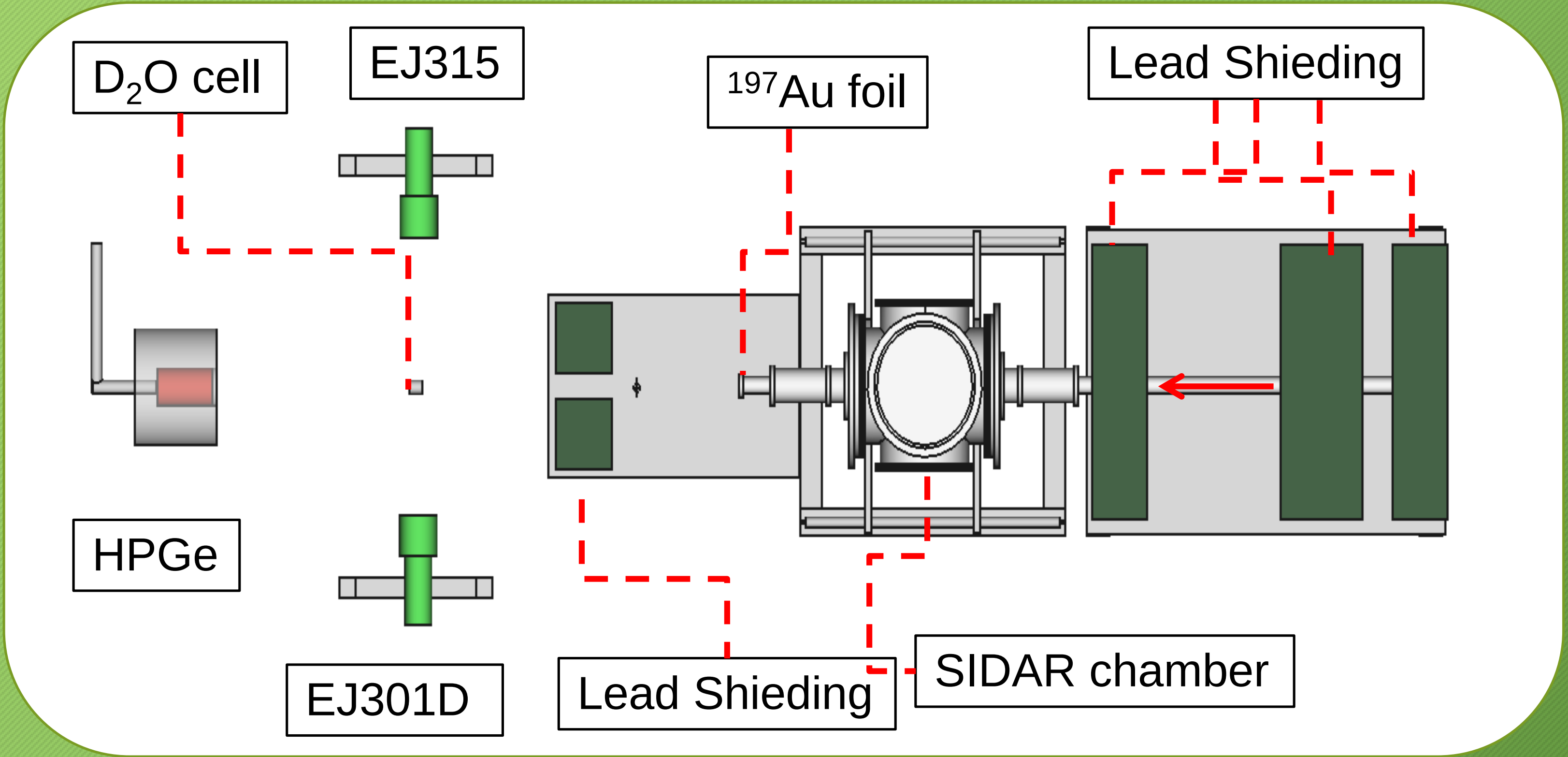
Experimental setup



- E_γ = 4.4 – 10 MeV
- 1.2 cm collimator defines beam spot
- LiF target on mylar (180 μg/cm²)
- SIDAR array from ORNL(lamp-shade)
- 12 YY1 detectors (200 ch)
- two lamp-shades of YY1: 300, 500, 1000 μm
- Standard electronic read-out (mesytec preamp + amp + caen adc)

γ beam experiment with silicon detectors: the $^{7}Li(\gamma,t)^{4}He$ reaction

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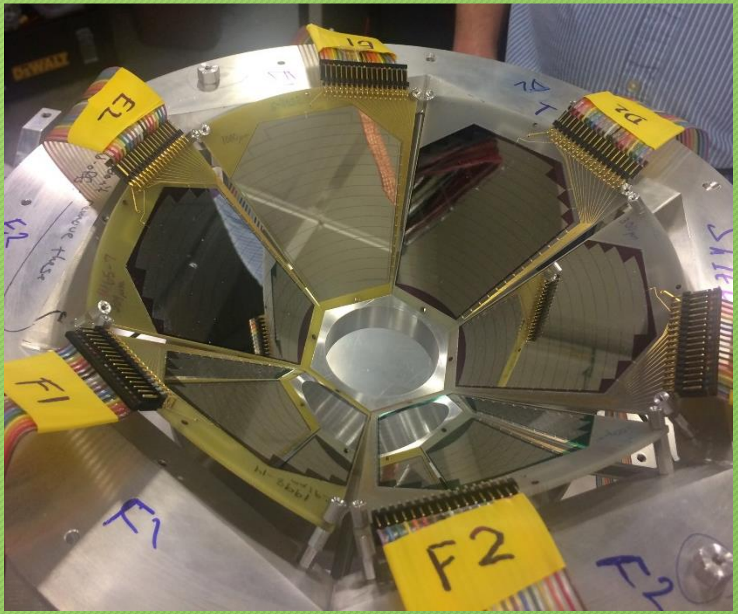
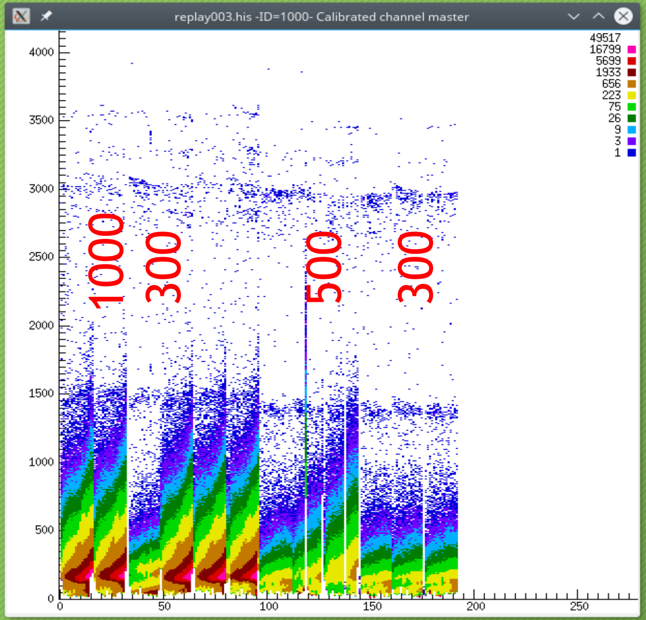
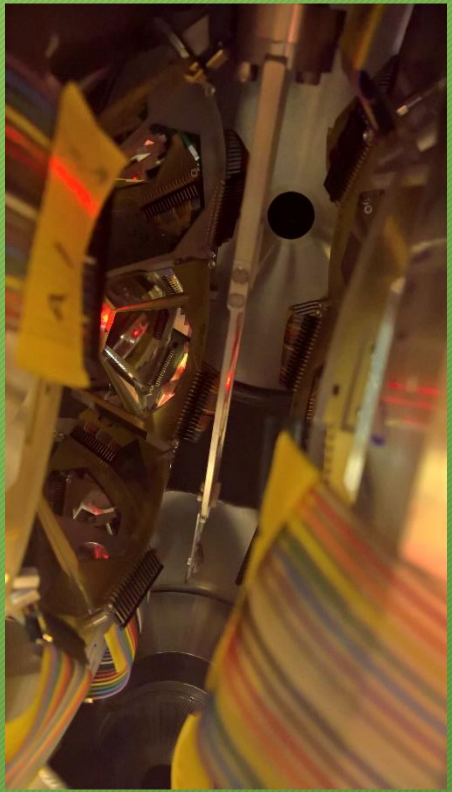
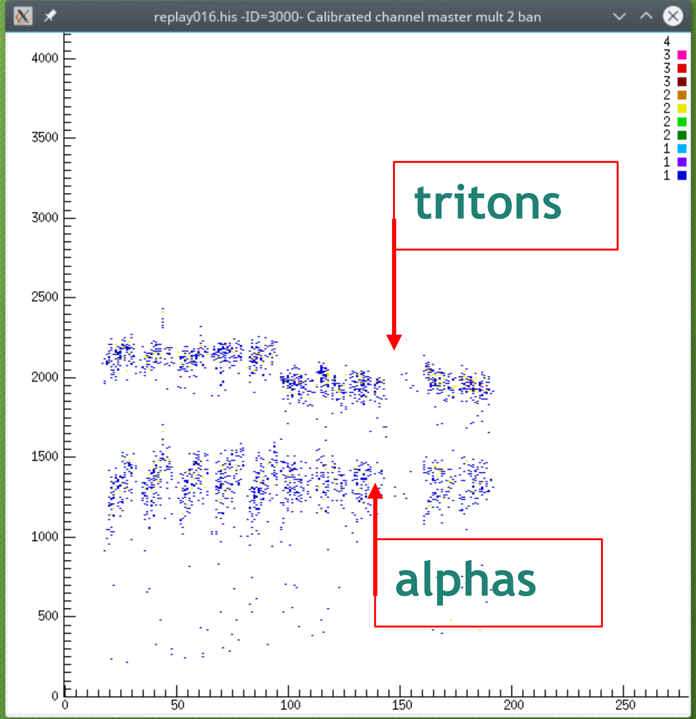
Data taking





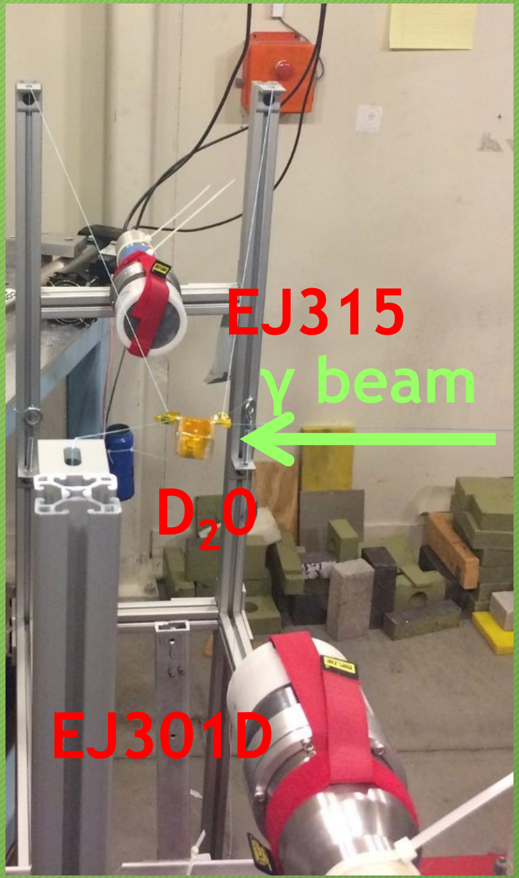


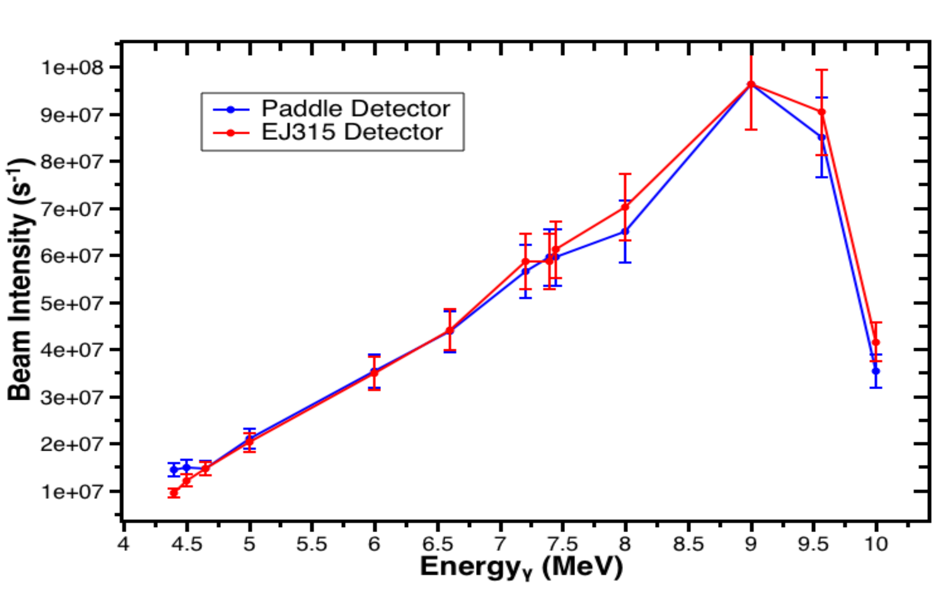


γ beam experiment with silicon detectors: the $^{7}Li(\gamma,t)^{4}He$ reaction

Beam intensity measurements

1) ^{197}Au activation above 8 MeV
2) d(γ,n)p w/ EJ301D & EJ315
3) HPGe & collimator for Compton

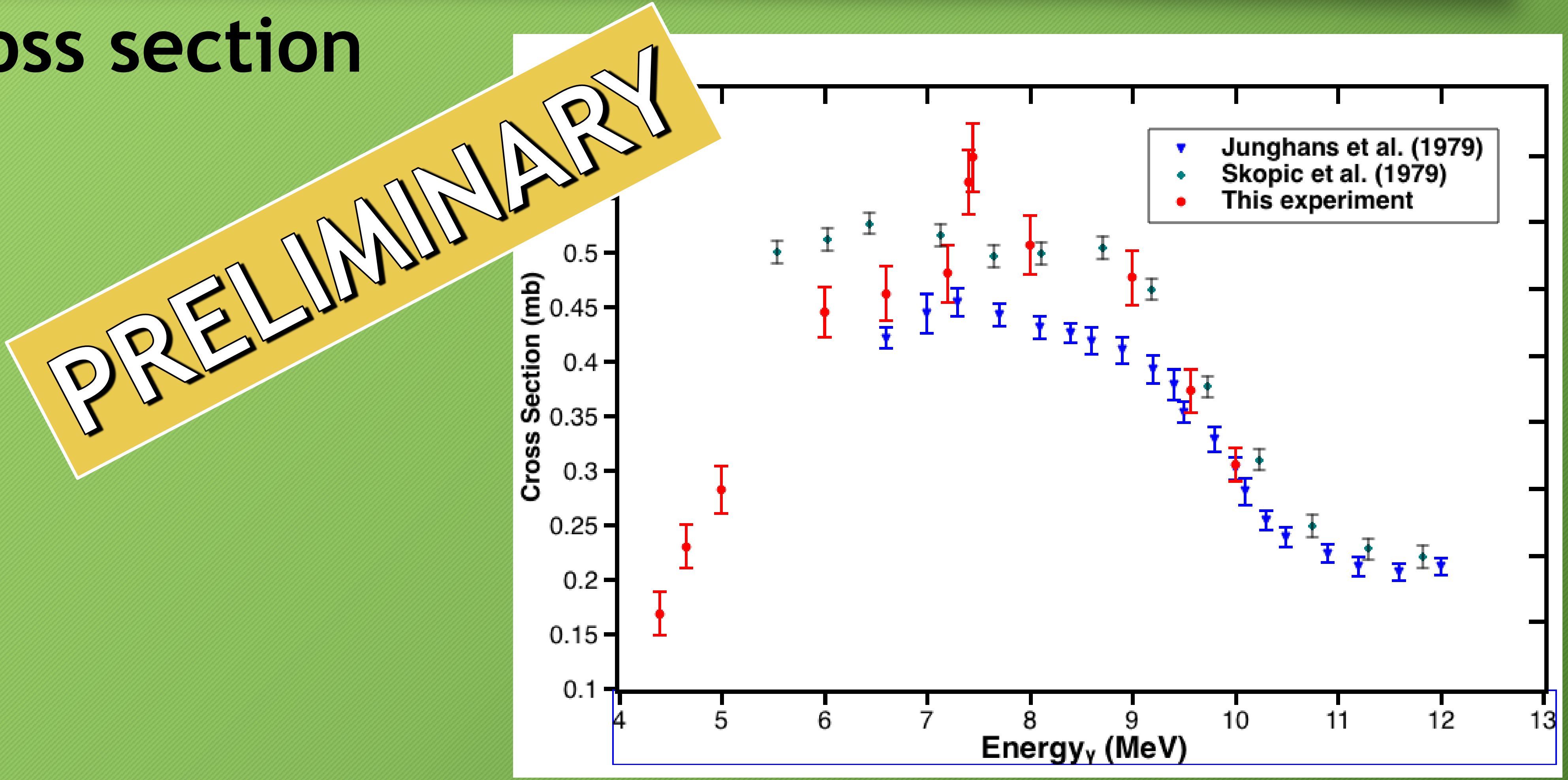




- beam intensity w/ EJ315
- beam intensity w/ paddle detector
- scaled to Au-197 activation
- good agreement 4.5-10 MeV

γ beam experiment with silicon detectors: the $^{7}Li(\gamma,t)^{4}He$ reaction

Cross section



Conclusions

- The advent of high-intensity & high resolution gamma-ray beam facilities is a great opportunity for nuclear physics and astrophysics, as a number of reaction of primary astrophysical importance can be measured for the first time

- In a typical nuclear astrophysics experiments, particles of energies as low as few hundreds keV are emitted, making it necessary a careful detector implementation showing up that a SSD array in barrel configuration (plus end cap detectors) turns out to be a very suited tool for nuclear astrophysics studies

- An ELISSA prototype was built and tested @LNS. We achieved a very good energy resolution (better than 1%) and very good position resolution, of the order of 1 mm with a threshold of 150 keV with no cooling

- Upcoming experimental campaign will confirm that the X3 detectors, as well the standard QQQ3 detectors, are perfectly suited for nuclear astrophysics studies with ELISSA.

- Meanwhile the good preliminary result obtained for the $^{7}Li(\gamma,t)^{4}He$ reaction make us confident for the feasibility of nuclear astrophysics experiment with silicon detectors and gamma beam.

Collaboration

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THANK YOU FOR YOUR ATTENTION