Photodissociation experiments

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on behalf of the AsFiN group

INFN
LNS

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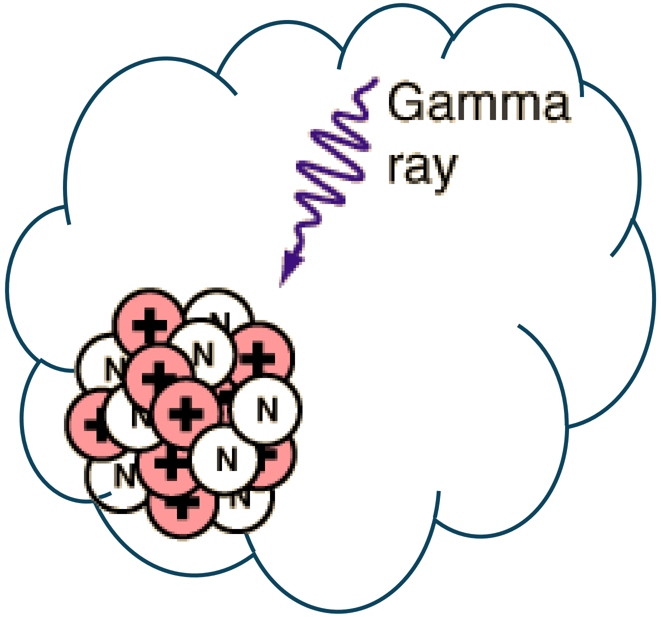
Photodissociation processes in astrophysics

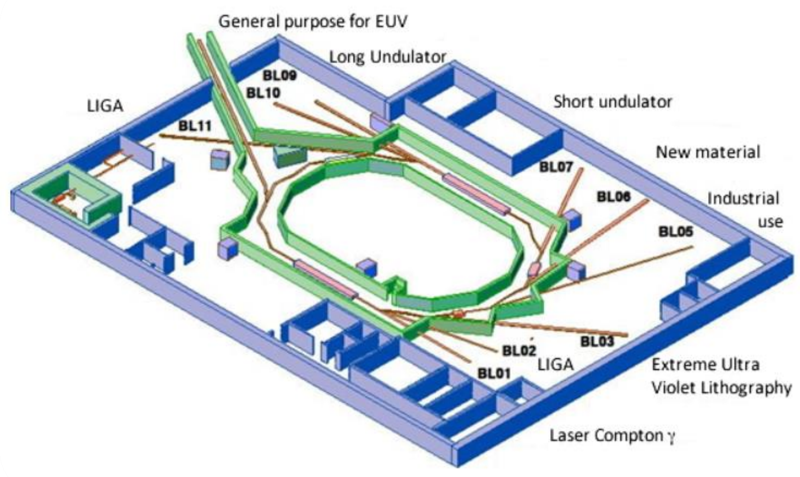
In evolved stars, high photon densities are present, making it possible to dissociate stable seed nuclei the photon energies being as large as many MeV.

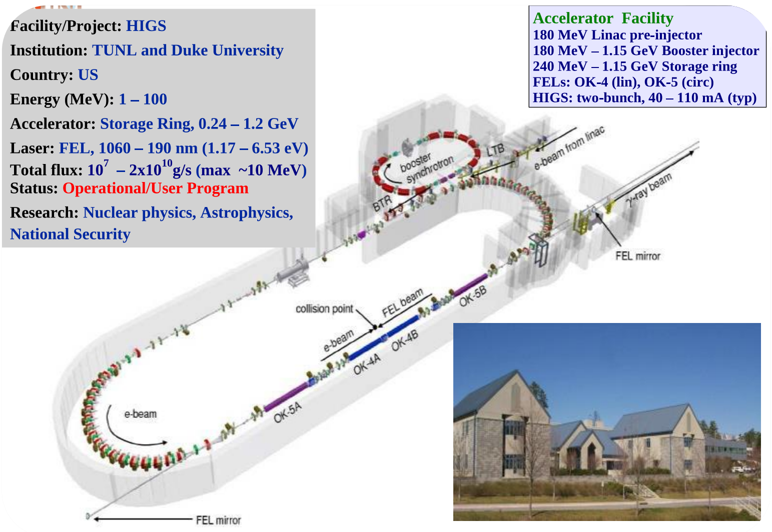
For the first time high intensity ($3 \cdot 10^8$ γ/s) high resolution ($<10^{-3}$) will be available, making it possible to measure photodissociation reactions of astrophysics importance (HIGS, NEW SUBARU, ELI-NP??)

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



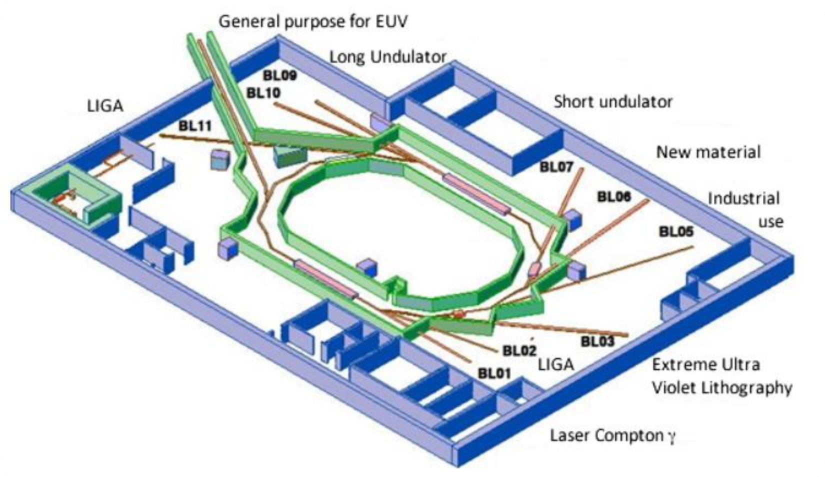
New facilities for gamma beams

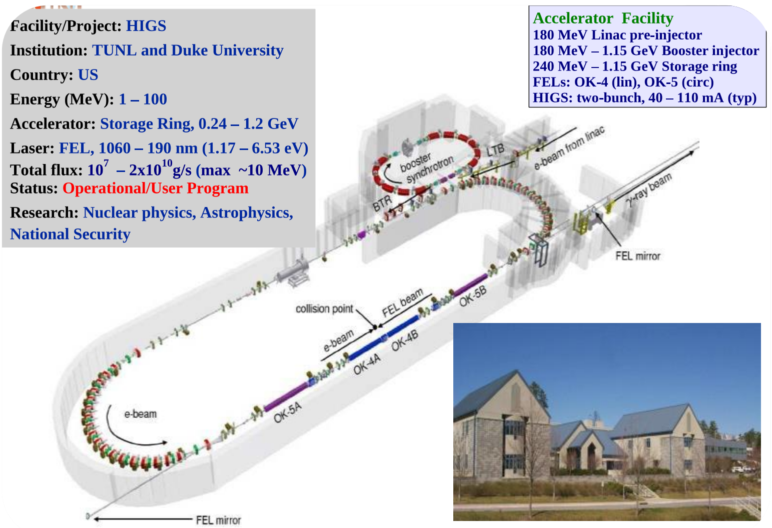




Location	Durham USA	Okazaki Japan	Shanghai China	Xi'an China	Magurele Romania
E_e (MeV)	240–1200	750	3500	120–360	234–742
λ_L (nm)	190–1060	1940/10600	10640	800	515/1030
$\langle I \rangle$ (mA)	10–120	300	100–300	N/A	non-disclosed
E_γ (MeV)	1–100	1–5.4	0.4–20	0.1–3	1–19.5
$\Delta E_\gamma / E_\gamma$ (FWHM)	0.8%–10%	2.9% ($\phi = 2$ mm)	<5% ($\phi = 2$ mm)	1.2%–10%	<0.5%
f_{rep} (MHz)	5.58	90	347	pulsed, 10 Hz	71.4
Polarization	lin, circ	lin, circ	lin, circ	lin, circ	lin
$N_{\gamma,total}$ (γ/s)	10^6-$3 \cdot 10^{10}$	10^7	10^6 - 10^8	10^8 - 10^9	10^{11}
$N_{\gamma,on-target}$ (γ/s)	10^3 - $3 \cdot 10^9$	$4 \cdot 10^5$	10^5 - 10^7	10^6 - 10^8	$\sim 10^8$

New facilities for gamma beams





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The $^7Li(\gamma,t)^4He$ reaction

Results

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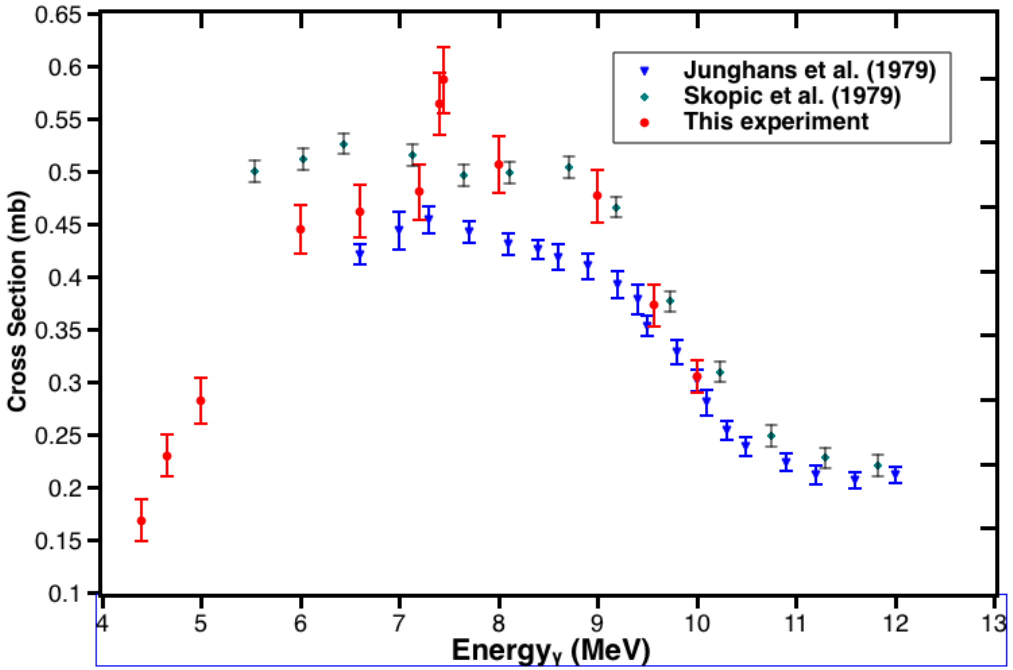
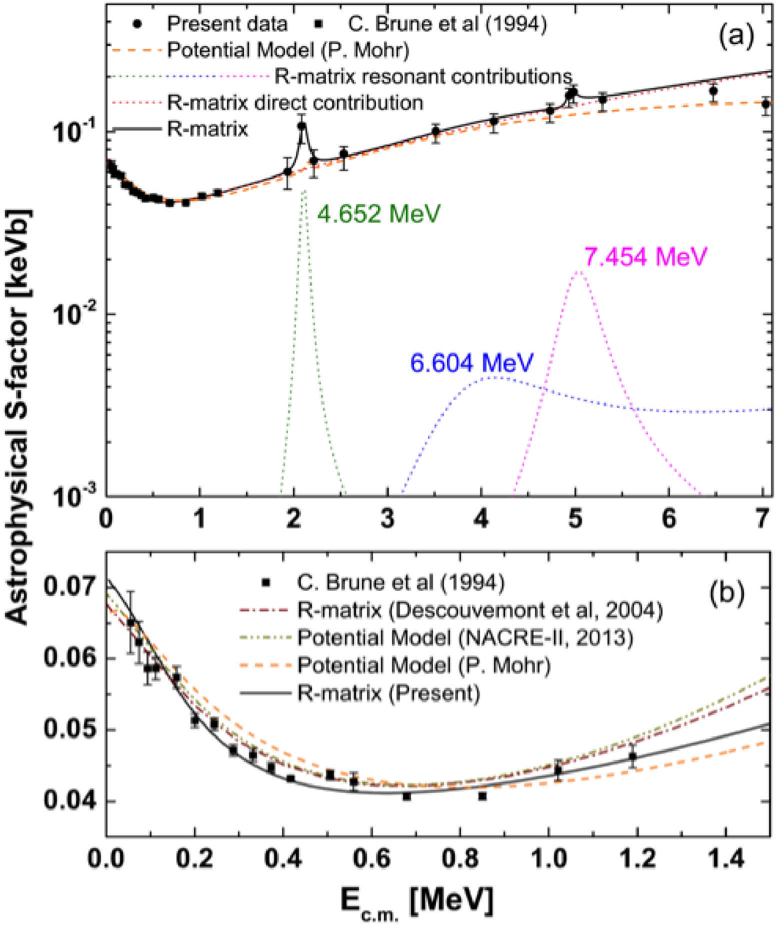
Measurement of the $^7Li(\gamma,t)^4He$ ground-state cross section between $E_\gamma = 4.4$ and 10 MeV

M. Munch,[1,2] C. Matei,[3,*] S. D. Pain,[4] M. T. Febbraro,[4] K. A. Chipps,[4] H. J. Karwowski,[5,6] C. Aa. Diget,[2] A. Pappalardo,[3] S. Chesnevskaya,[3] G. L. Guardo,[3,7] D. Walter,[8] D. L. Balabanski,[3] F. D. Becchetti,[9] C. R. Brune,[10] K. Y. Chae,[11] J. Frost-Schenk,[2] M. J. Kim,[11] M. S. Kwag,[11] M. La Cognata,[7] D. Lattuada,[3] R. G. Pizzone,[7] G. G. Rapisarda,[7] G. V. Turturica,[3] C. A. Ur,[3] and Y. Xu[3]

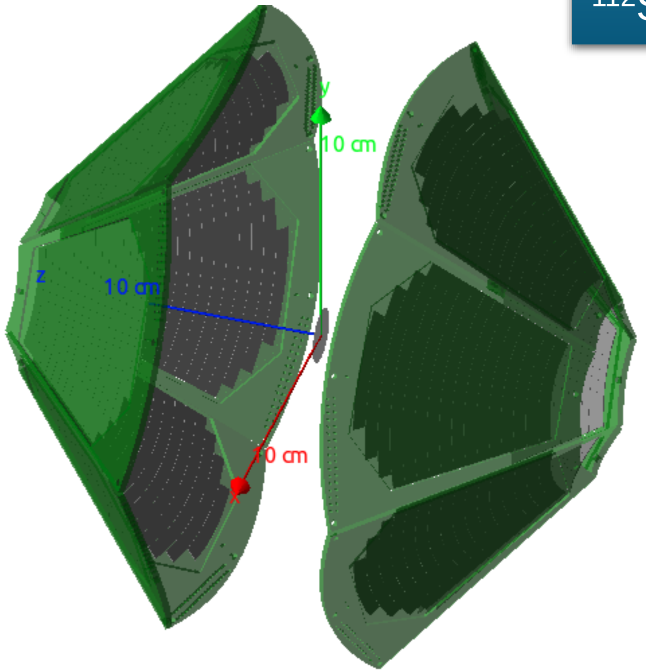




The p-process campaign

Direct measurement of photodissociation reactions of interest for p-process and BBN

Long campaign with measurements on ^{112}Sn(γ,p), ^{112}Sn(γ,α), ^{102}Pd (γ,p), ^{102}Pd (γ,α) and ^{7}Li (γ,p)



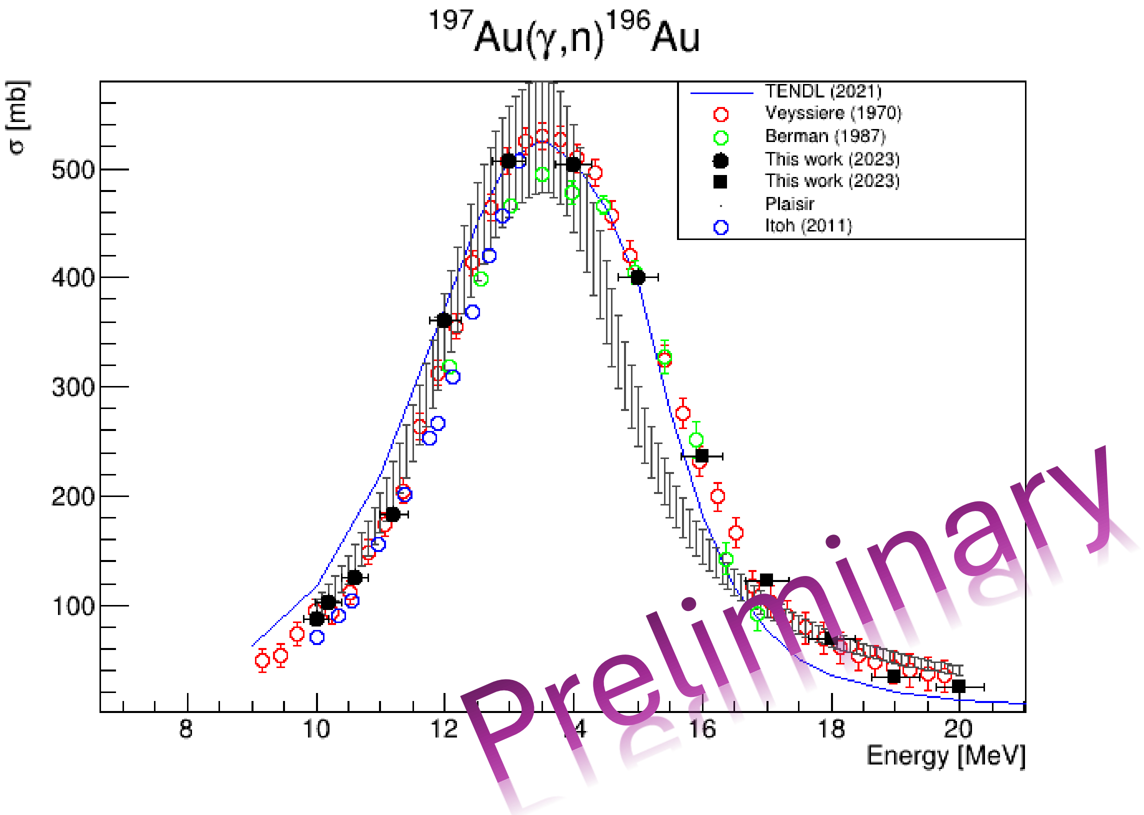
SIDAR array consisting of 2 lamp-shade SSD (12 YY1)

^{112}Sn(γ,α)^{108}Cd

^{112}Sn(γ,p)^{111}In

E_γ [MeV]	10-20
Total Time	106 h
DE-E Det	YY1
# channels	256

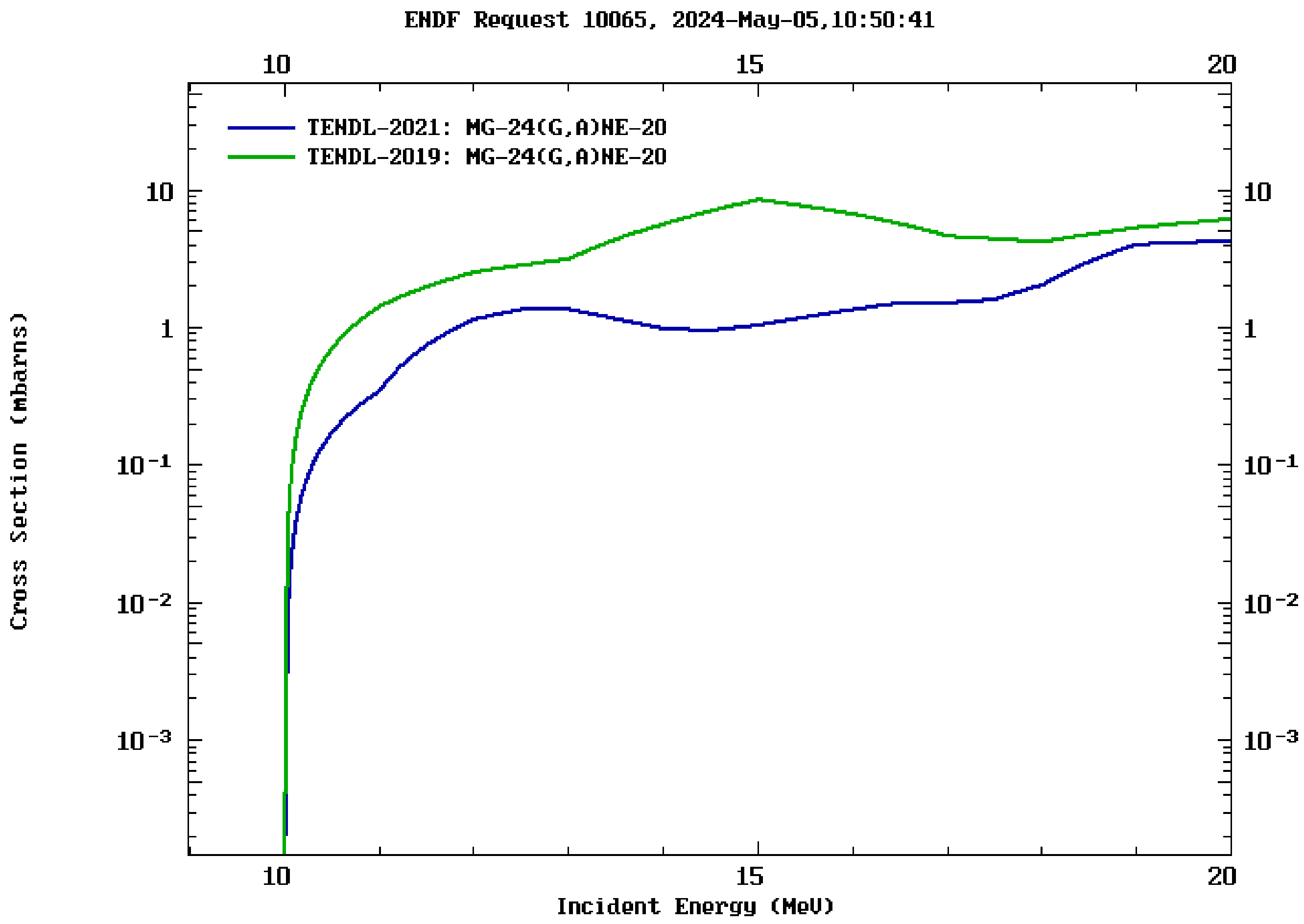
Beam flux measurement using Activation method ➔ Restifo's Master thesis



The $^{24}Mg(\gamma,\alpha)^{20}Ne$ reaction

In Si-burning, preceding the core-collapse supernova stage, fusion reactions such as $^{28}Si+^{28}Si$ or $^{28}Si+^{32}S$ are too unlikely to occur owing to the Coulomb barrier.

The nucleosynthesis is governed by the slowest reaction in the network: **$^{24}Mg(\gamma,\alpha)^{20}Ne$**
Its cross section is calculated from the inverse reaction and is affected by a factor of 2 uncertainty.



A direct ^{24}Mg photodissociation measurement using gamma beams of energies 10.4 - 12 MeV will allow us to determine a much more accurate cross section

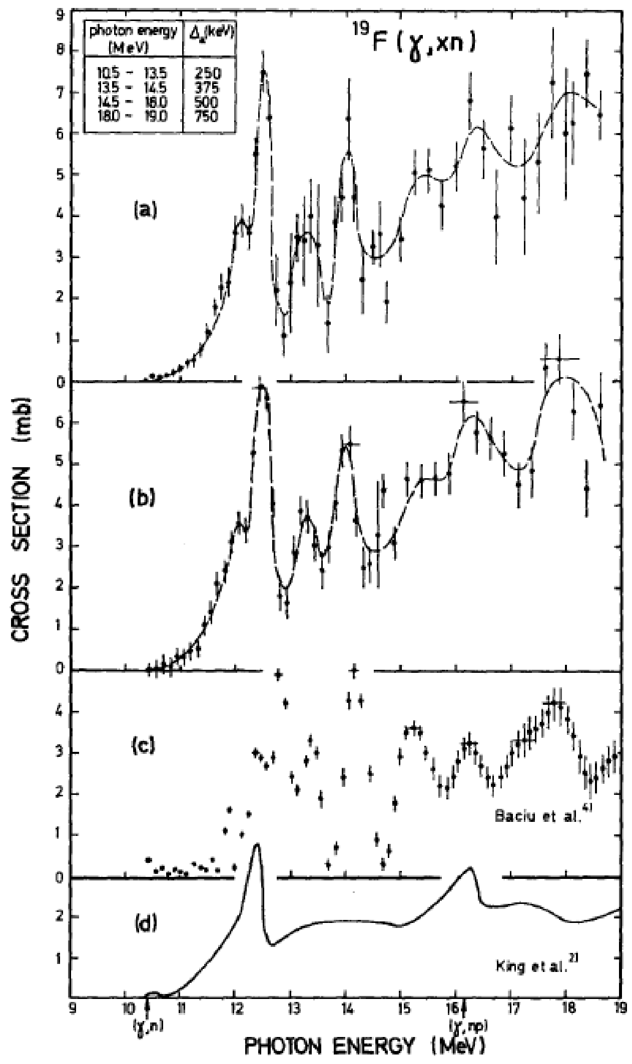
The $^{24}Mg(\gamma,\alpha)^{20}Ne$ reaction

- E_γ = 10-13 MeV provided by HIGS facility
- 1.2 cm collimator defines beam spot
- MgC target (200 μg/cm^2)
- LHASA array (lamp-shade)
- 12 YY1 detectors (or DSSSD)
- Standard electronic read-out

Eγ (MeV)	Total rate	Event/strip	Stat.Err.	Hours
10	15 ev/h	0.5	30%	72
10.5	100 ev/h	3	15%	12
11	100 ev/h	3	15%	12
11.5	100 ev/h	3	15%	12
12	100 ev/h	3	15%	12
12.5	100 ev/h	3	15%	12
13	100 ev/h	3	15%	12

Campaing measurement (Fall 2025)
(1) Robin Smith et al., Sheffield Univ., UK, P-21-19, 9Be(g,aa)
(2) Kelley Chipps et al., ORNL, P-10-23, Photodisintegraiton of p-process nuclei
(3) G. L. Guardo et al., INFN, Italy, P-09-24, 24Mg(g, a) cross-section measurements

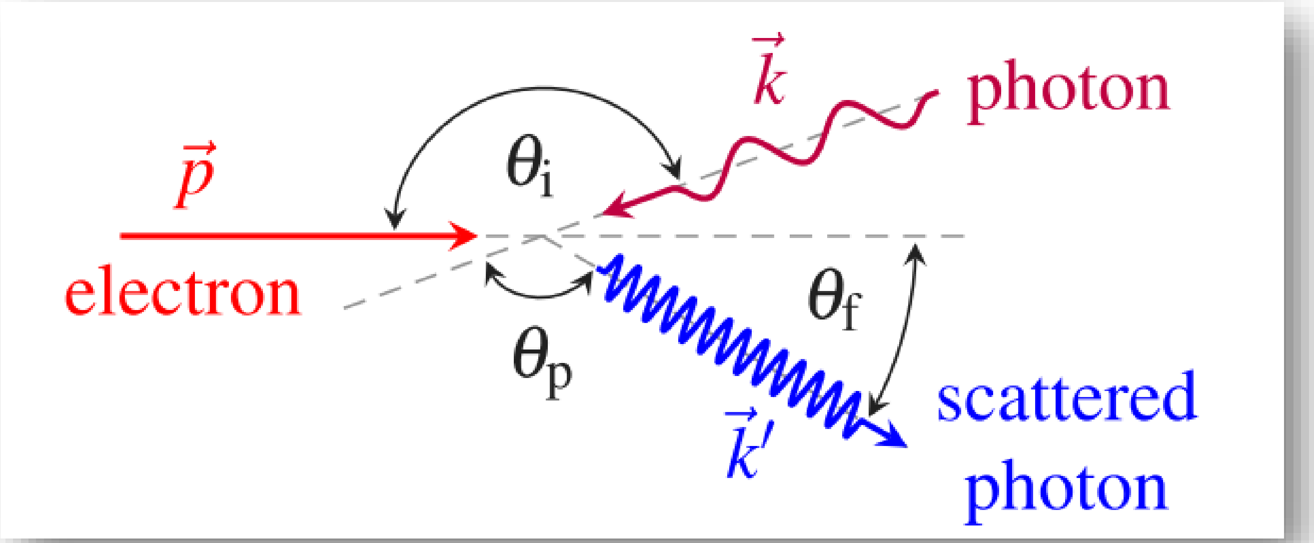
The $^{19}F(\gamma,n)^{18}F$ experiment



A high-precision measurement of the photo-neutron reaction cross sections for ^{19}F which can be used to determine the $^{18}F(n,\gamma)^{19}F$ reaction rate. Furthermore, the $^{18}F(p,\gamma)^{19}Ne$ reaction is an important reaction in the CNO cycle. The properties of $^{18}F(n,\gamma)^{19}F$ reaction can be used to constrain the reaction properties of $^{18}F(p,\gamma)^{19}Ne$ due to the fact that ^{19}F-^{19}Ne are mirror nuclei.

Project leader: Dimiter L. Balabanski
ELI-NP Team: P-A Söderström, A. Kusoglu, D. Testov and Y. Xu
University of South China: Wen Luo and his team
Beihang University: Sun Baohua
IIT Ropar: Deepika Choudhury
NPL, UK: Giuseppe Lorusso
INFN-LNS: G.L. Guardo, D. Lattuada, G. Rapisarda, M.L. Sergi

Laser Compton Backscattering



$$E_\gamma = \frac{(1+\beta)E_L}{(1-\beta\cos\theta_f)+(1+\cos\theta_f)E_L/E_e}$$

Laser photons are boosted into the MeV regime, which is the interesting range for nuclear physics experiments, when scattered off ultrarelativistic electrons with energies of several hundreds of MeV. By a proper collimation system, the scattered photons at very backward angles can be selected resulting in an almost monoenergetic photon beam, that can be tuned by varying the electron or laser photon energy.

EuPRAXIA Gamma Beam

Fascio di elettroni: da 500 MeV a 2 GeV, 100 pC single bunch a 400 Hz, energy spread 0.5%, emittanza rms norm. 0.5 mm.mrad, lunghezza bunch inferiore al psec, focalizzato a sigmax=15 micron al punto di interazione con il laser

Laser: 1.2 eV Yb:Yag (lambda=1030), 0.5 Joule di energia nell'impulso a 400 Hz, M2=1.2, bandwith=0.001, sigma-t=1.5 psec, focalizzato a W0=25 micron al punto di collisione

E-elettroni = 750 MeV, energia fotoni gamma 10. MeV
E-elettroni = 1000 MeV, energia fotoni gamma 18. MeV
E-elettroni = 2000 MeV, energia fotoni gamma 73. MeV

Numero fotoni gamma a 10 MeV al secondo compresi in una bandwidth di 0.5% = 1.7 * 10^8

Densità spettrale del fascio di fotoni gamma a 10 MeV = 3320. fotoni / (sec.eV)

Le prestazioni di ELI-NP come da TDR erano: densità spettrale a 10 MeV 5000.
Quindi siamo nel range, diciamo forse inferiori solo di un fattore 2, ma con la possibilità di arrivare a 2 GeV quindi con energia di fotoni molto maggiore di ELI-NP, la cui energia massima era 19.5 MeV.

Courtesy M. Ferrario & L. Serafini

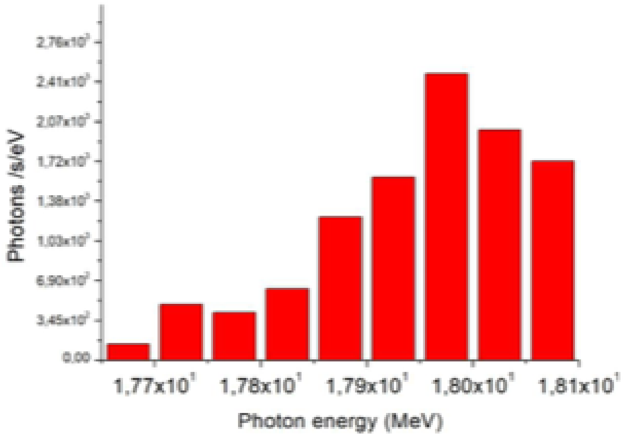
EuPRAXIA Gamma Beam

CAIN simulations for a Gamma source at EupraXia

Laser		
wavelength	micron	1.03
sigma	micron	20
Energy	J	0.5

Electrons	@EupraXia	
Charge	pC	100
Electron energy	GeV	1
Emittance	mm mrad	0.6
Energy spread	Per mill	0.4
igma_rms	micron	20

Radiation		
Photon energy	MeV	18
Photon number per shot	X 10^8	1.38
Rep rate		400
Bandwidth	Per mill	5
Collimation angle	microrad	450
Number of collimated photons per shot	X 10^6	1.34
Collimated photons/s	Number/s	5.33x 10^8
Spectral density in 1 eV	Number/s/ eV	2500



Courtesy M. Ferrario & L. Serafini

Thank you for your attention