EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2007-2013

Photonuclear reactions with charged particles detection for nuclear astrophysics studies

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ISNS 2024, September 9-13, 2024

Outline

- nuclear astrophysics with γ-ray beams & charged particle detection
- $^{7}Li(\gamma,t)^{4}He$ reaction – Li-problem or theoretical conundrum
- $^{16}O(\gamma,\alpha)^{12}C$ reaction – the Holy Grail
- VEGA System – Variable Energy Gamma System

nuclear astrophysics with γ-ray beams

& charged particles detection

why use photonuclear reactions?

- the principle of detailed balance based on the notion of invariance under time reversal allows the calculation of the cross section $\sigma_{capture}$ for the capture processes to the ground state by measuring the cross section σ_γ for the inverse, photo-disintegration reaction:

$$A(x,\gamma)B \rightarrow B(\gamma,x)A$$

$$\sigma_{capture} = \frac{2(2j_B+1)k_\gamma^2}{(2j_A+1)(2j_x+1)k_x^2}\sigma_\gamma$$

- photo-disintegration cross section is enhanced by a factor of 50 or more compared to the direct radiative capture process

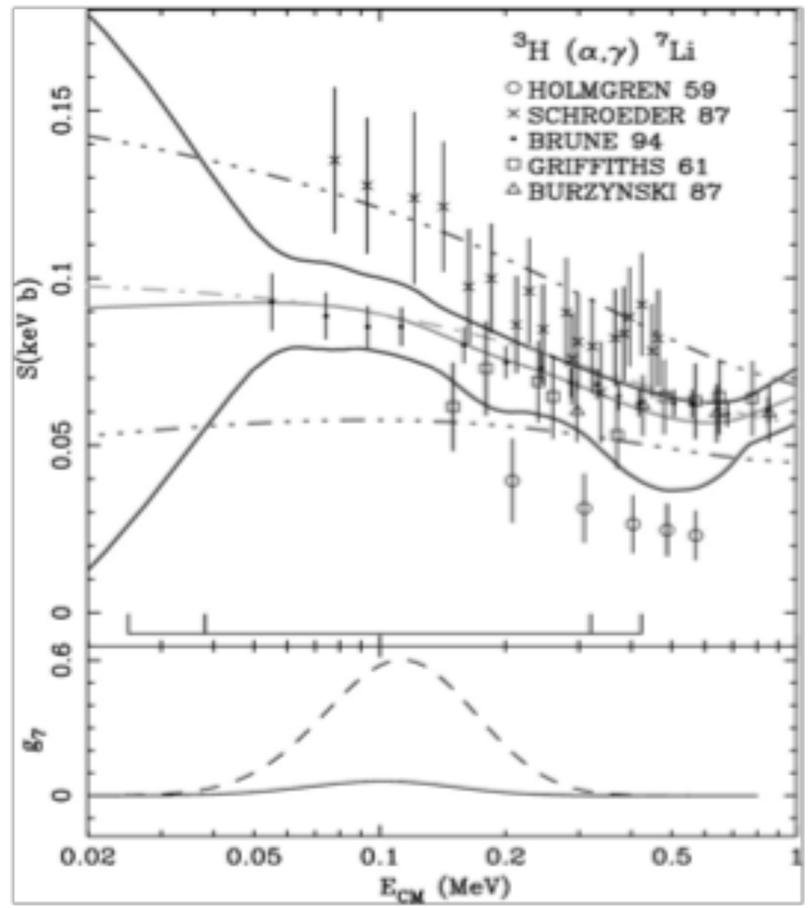
- gamma-ray beams do not experience electronic energy loss as they pass through the target material

why is $^{3}H(\alpha,\gamma)^{7}Li$ important?

- the study of the mirror alpha capture reactions $^{3}He(\alpha,\gamma)^{7}Be$ and $^{3}H(\alpha,\gamma)^{7}Li$ is needed to evaluate the primordial ^{7}Li abundance in the universe
- $^{3}H(\alpha,\gamma)^{7}Li$ could be responsible for ^{7}Li production under different value of the baryonic density

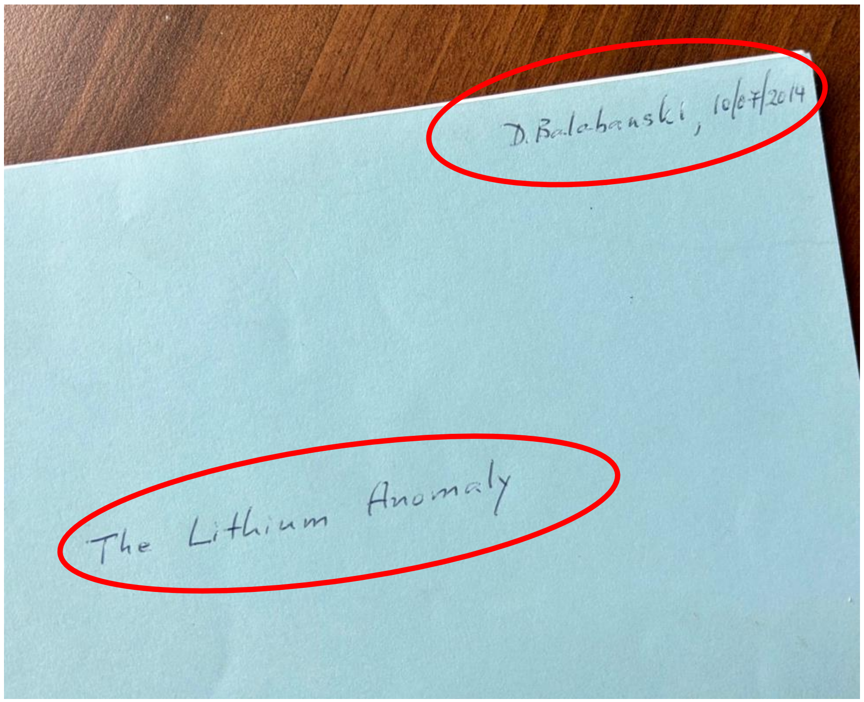
$^{3}H(\alpha,\gamma)^{7}Li$ experiments:

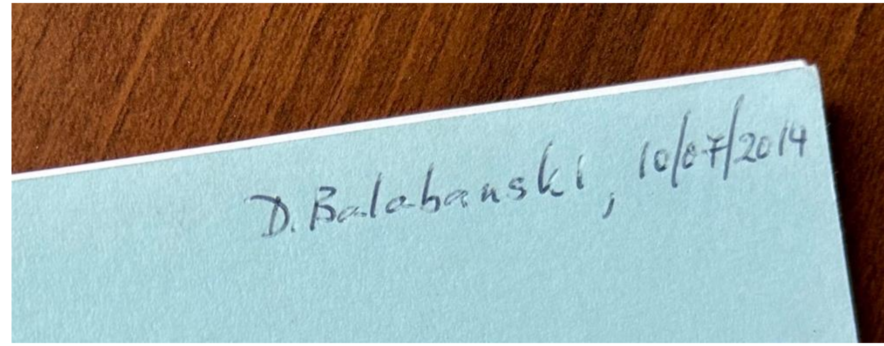
- conflicting results below 1 MeV
- lack of experimental data above 1.2 MeV
- most recent and complete data set by Brune et al in 1994
- measured angular distributions
- overall systematic uncertainty at 6%

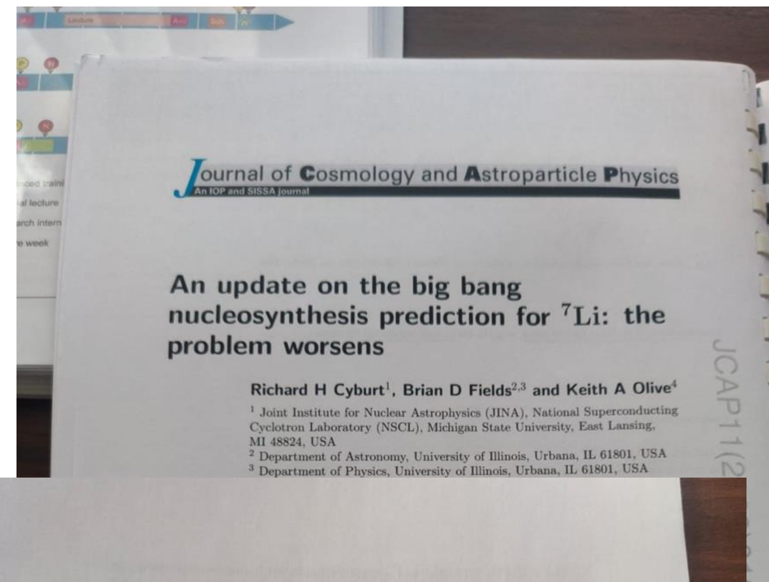


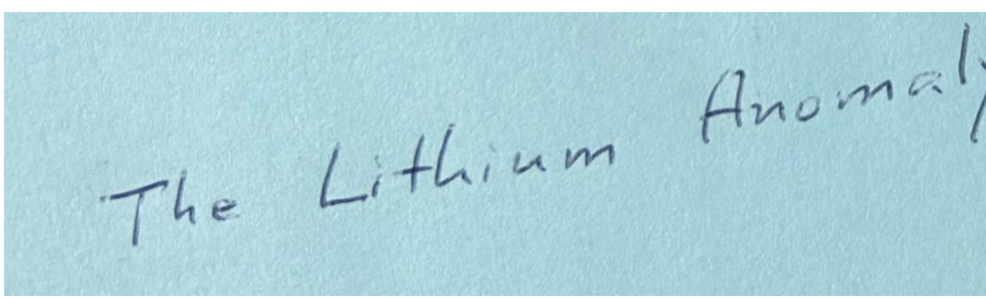
from Nollet et al, PRD 61, 123505 (2000)

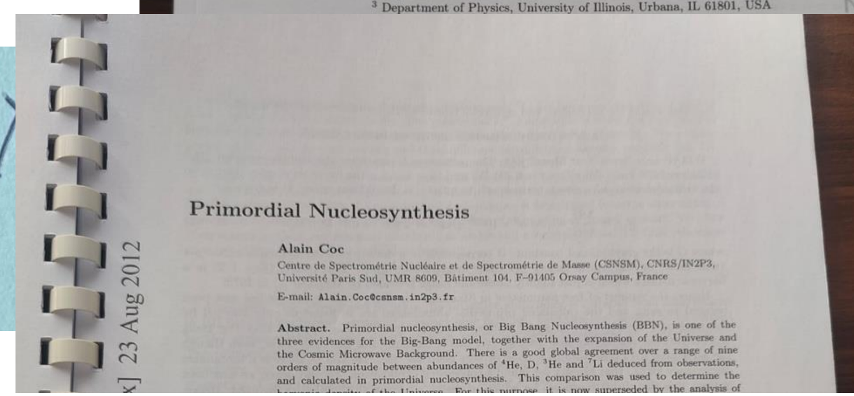
a bit of history on this project





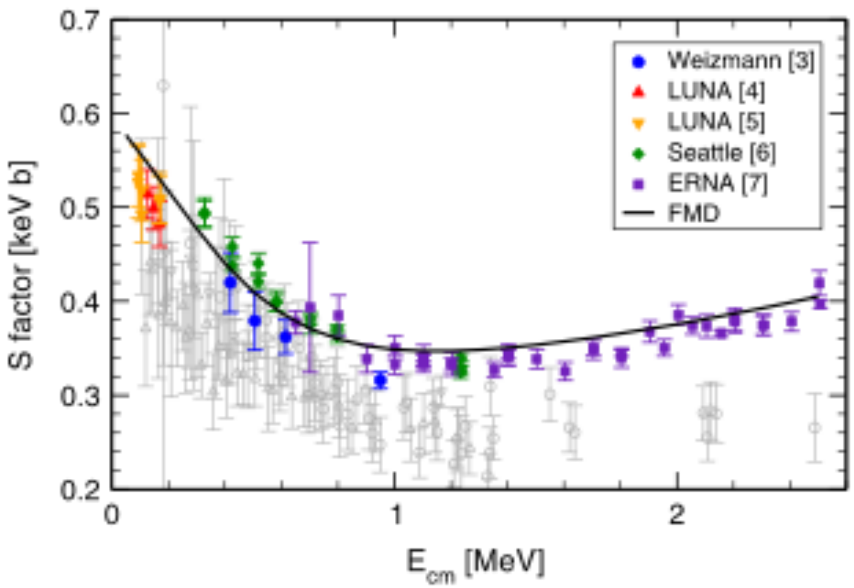


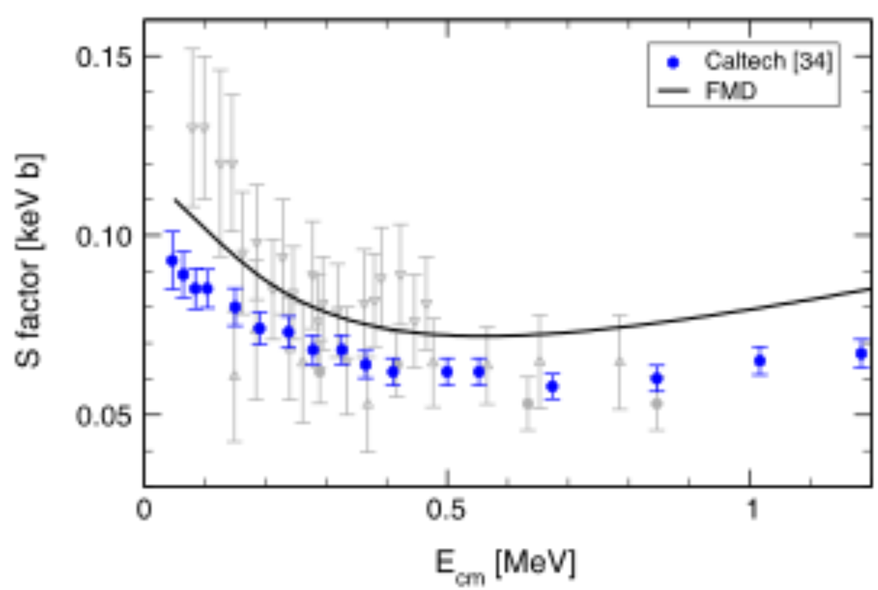




why is $^{3}H(\alpha,\gamma)^{7}Li$ important?

- the mirror alpha capture reactions $^{3}He(\alpha,\gamma)^{7}Be$ and $^{3}H(\alpha,\gamma)^{7}Li$ are receiving a lot of theoretical attention recently
- theoretical models could provide the the capture cross section at lower energies where experiments are not possible
- Neff et al. calculate the radiative capture cross section in the fully microscopic fermionic molecular dynamics approach using a realistic effective interaction
- good agreement with measurements of $^{3}He(\alpha,\gamma)^{7}Be$
- no agreement with measurements of Brune et al for $^{3}H(\alpha,\gamma)^{7}Li$



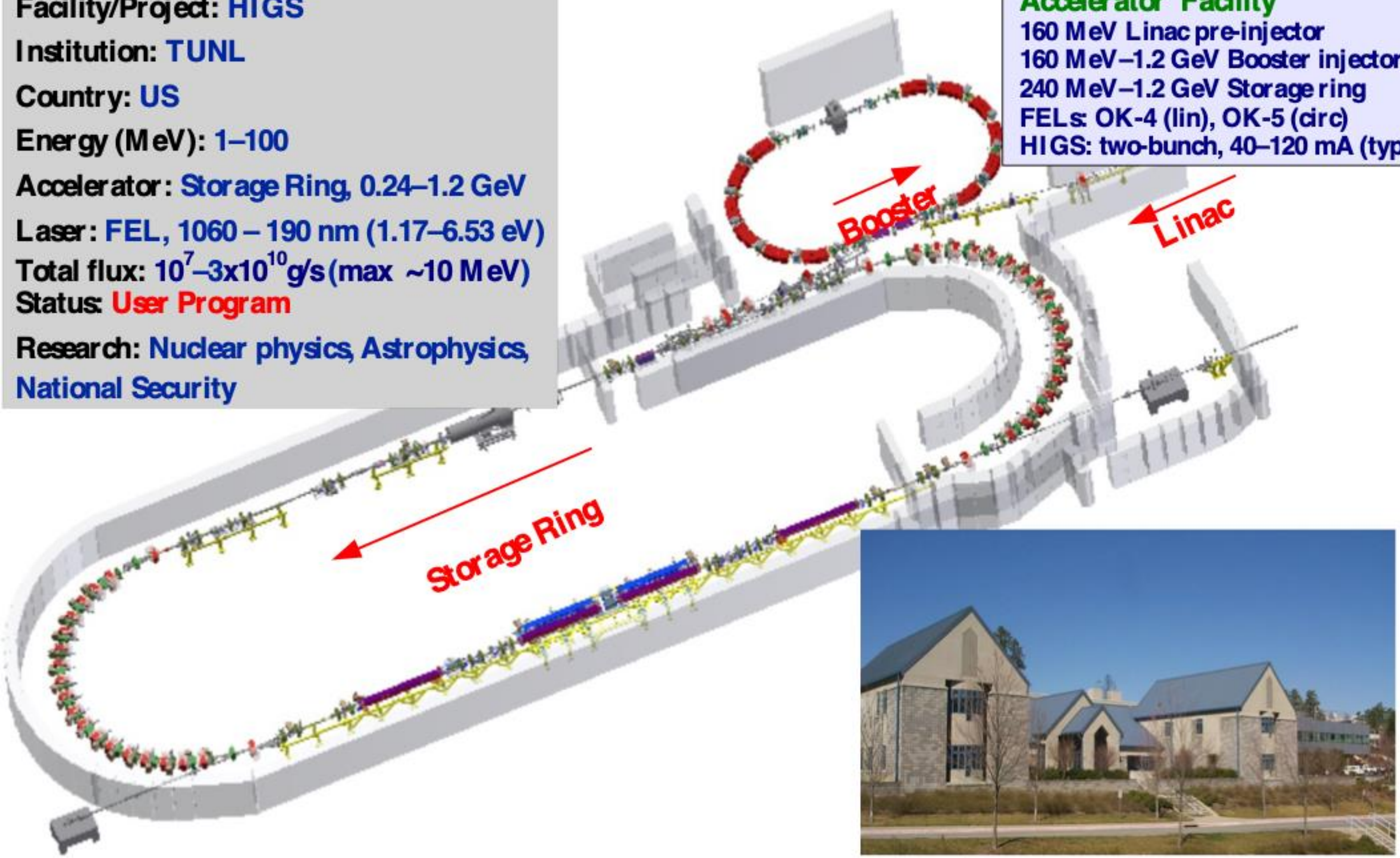


from Neff et al, PRL 106, 042502 (2011)

Laser-Compton Scattering (LCS)

Facility/Project: HIGS
Institution: TUNL
Country: US
Energy (MeV): 1–100
Accelerator: Storage Ring, 0.24–1.2 GeV
Laser: FEL, 1060 – 190 nm (1.17–6.53 eV)
Total flux: 10^7–3×10^{10} g/s (max ~10 MeV)
Status: User Program
Research: Nuclear physics, Astrophysics, National Security

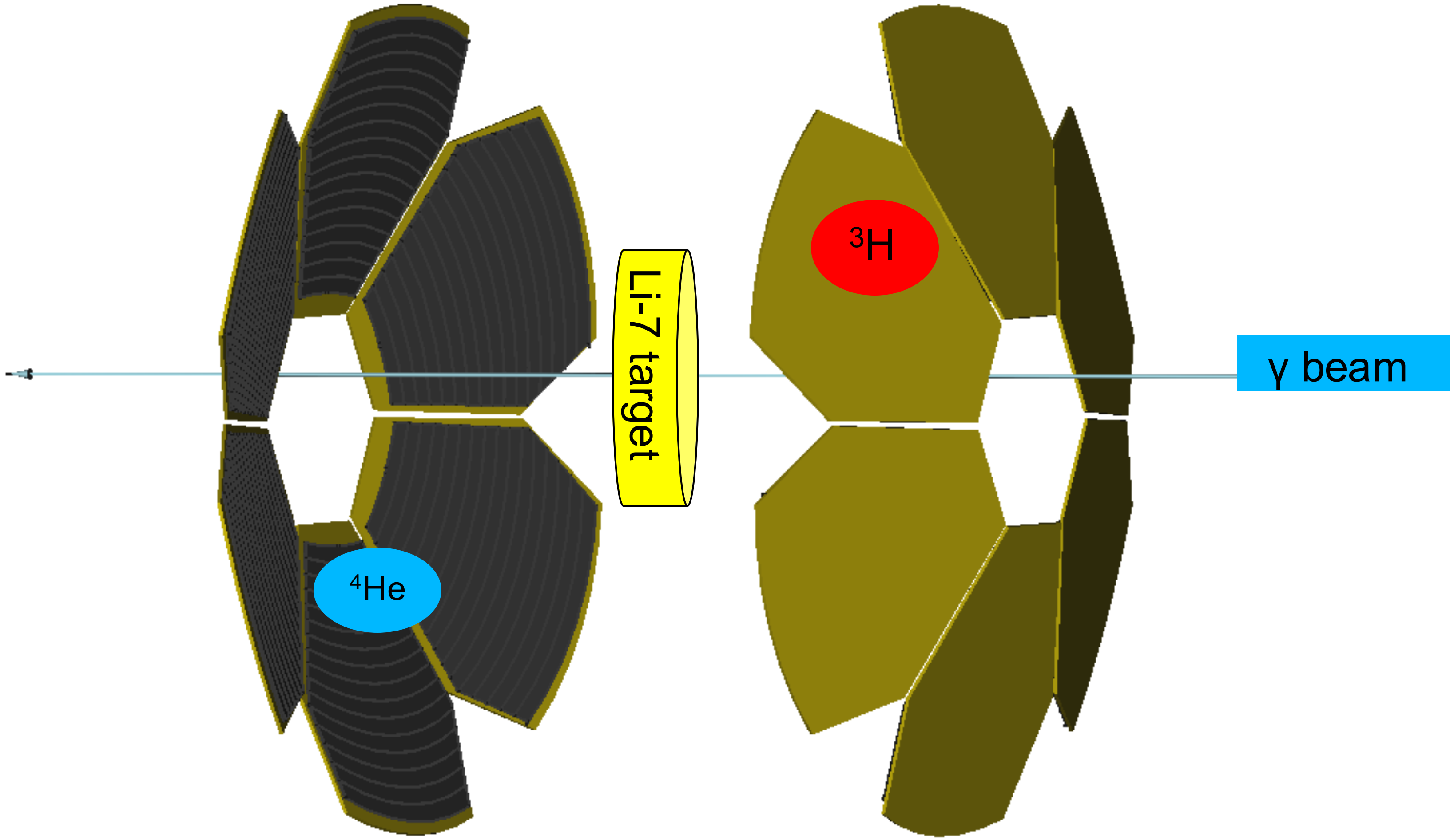
Accelerator Facility
160 MeV Linac pre-injector
160 MeV–1.2 GeV Booster injector
240 MeV–1.2 GeV Storage ring
FELs: OK-4 (lin), OK-5 (circ)
HIGS: two-bunch, 40–120 mA (typ)



from HIgS website

^{7}Li experiment @ HIGS

SIDAR array of YY1 detectors from ORNL

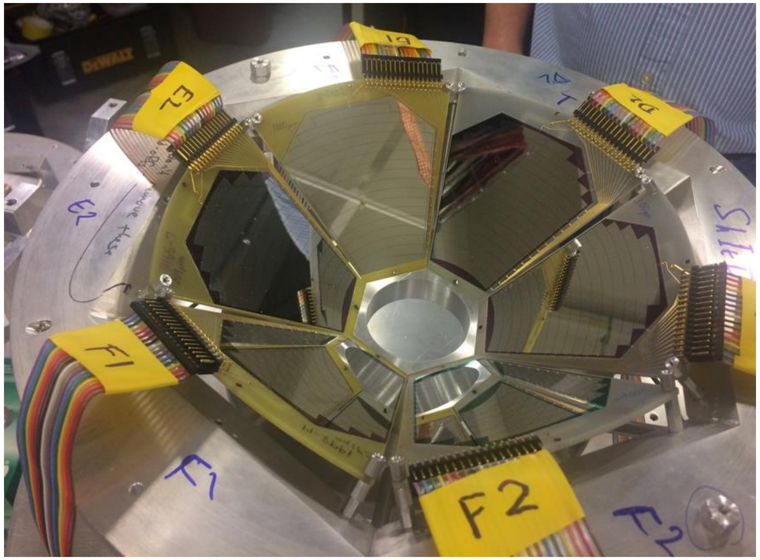


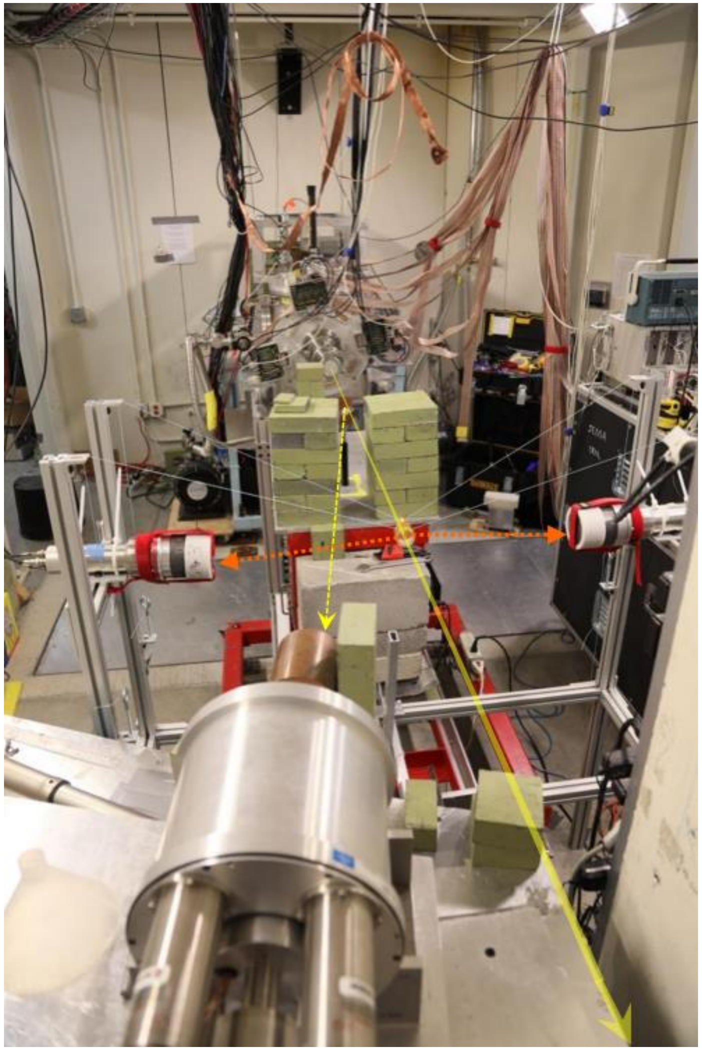
$^{7}Li + \gamma \rightarrow {}^{3}H + \alpha$

^{7}Li experiments @ HIgS

- $^{7}Li(g,t)^{4}He$ during March-April 2017
- $E_{\gamma} = 5 – 10$ MeV
- 70 hours of beam

- LiF target on mylar (300 μg/cm^2)
- SIDAR array (lamp-shade)
- 12 YY1 detectors (200 ch)



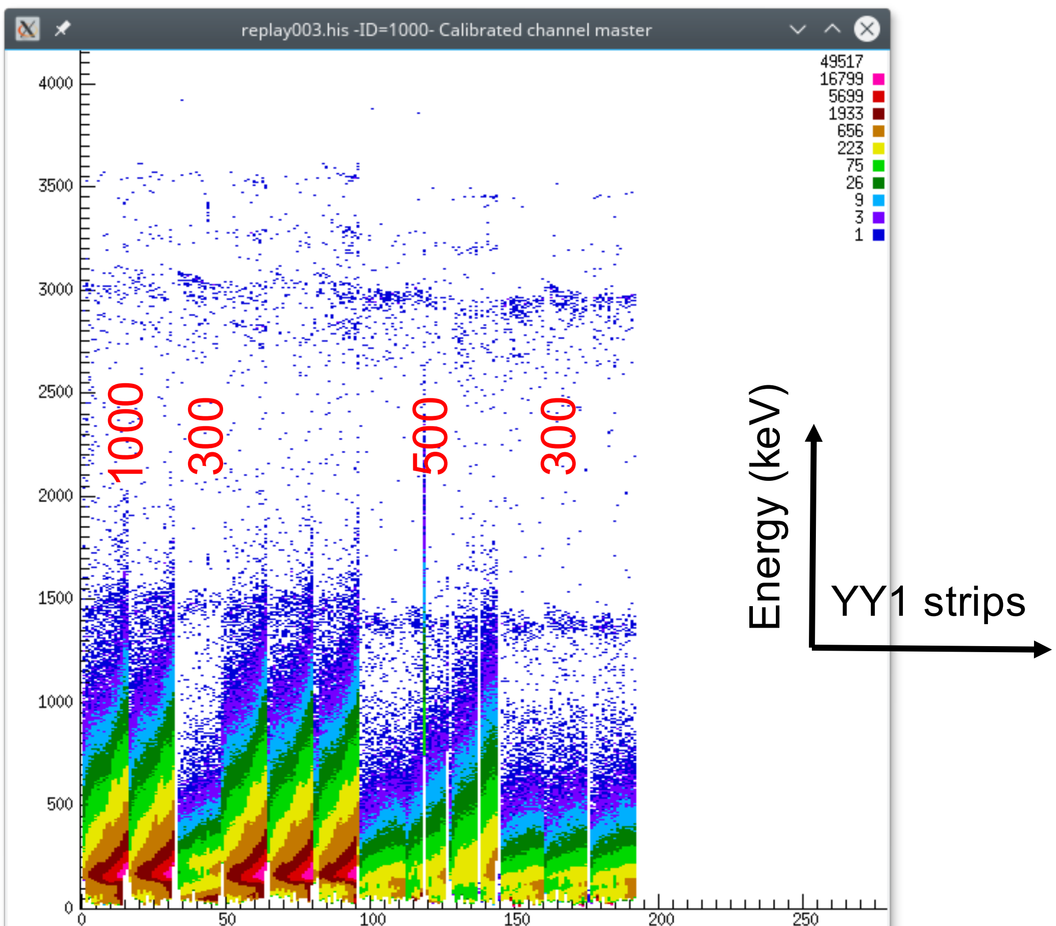


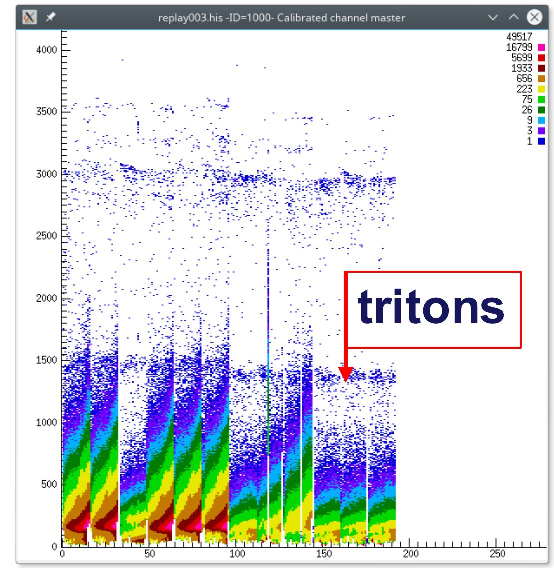
- large collaboration led by ELI-NP
- ORNL, Rutgers, UNC, York U, INFN-LNS, Aarhus U, SKKU, U Michigan

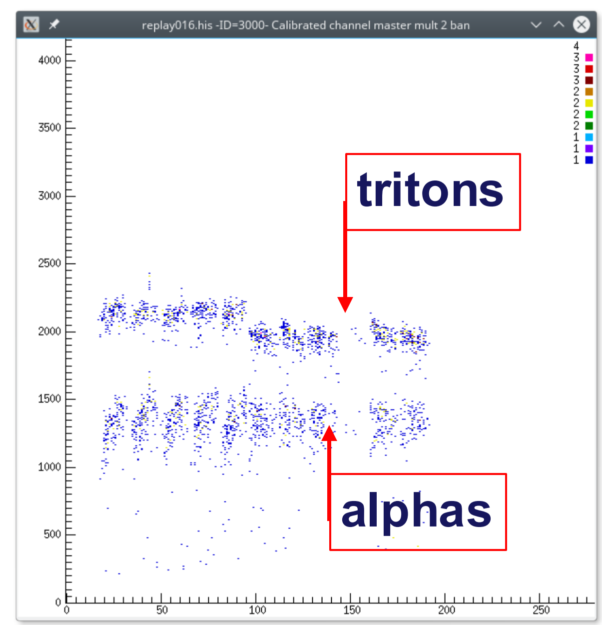
during the experiment in March 2017

^{7}Li(γ,t)α w/ SIDAR at HIgS

- using SIDAR array from ORNL
- two lamp-shades of YY1: 300, 500, 1000 μm
- background proportional to YY1 thickness
- clean alpha-triton coincidence above 6 MeV

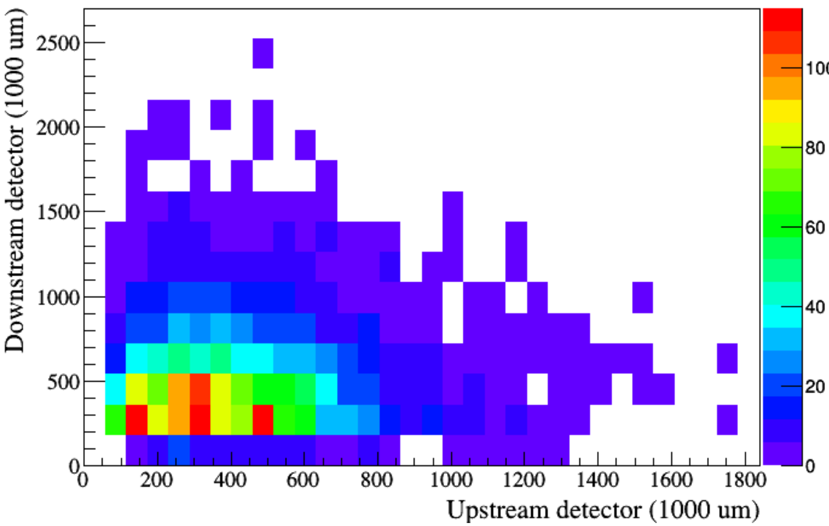




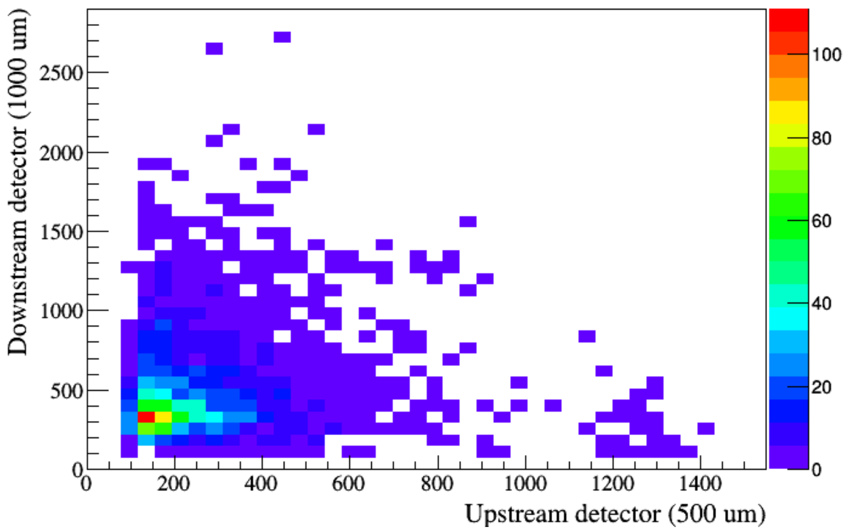


$^7Li(\gamma,t)\alpha$ w/ SIDAR below 6 MeV

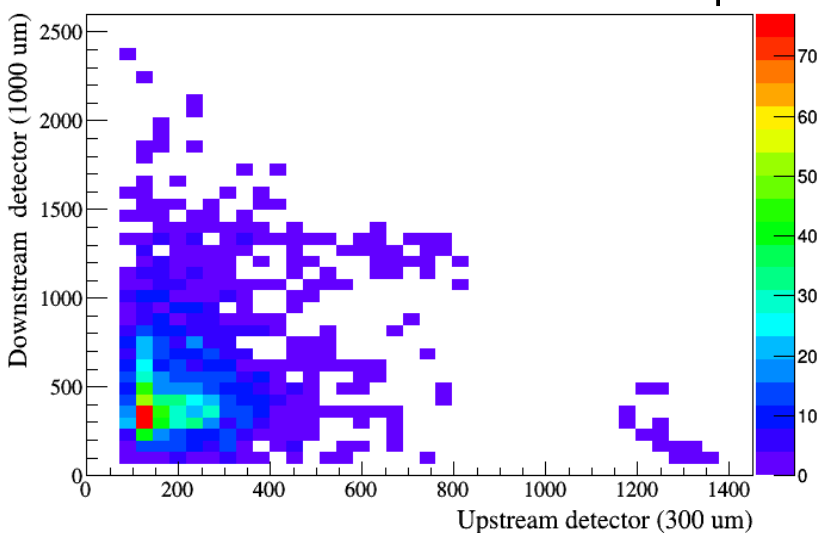
1000&1000 µm



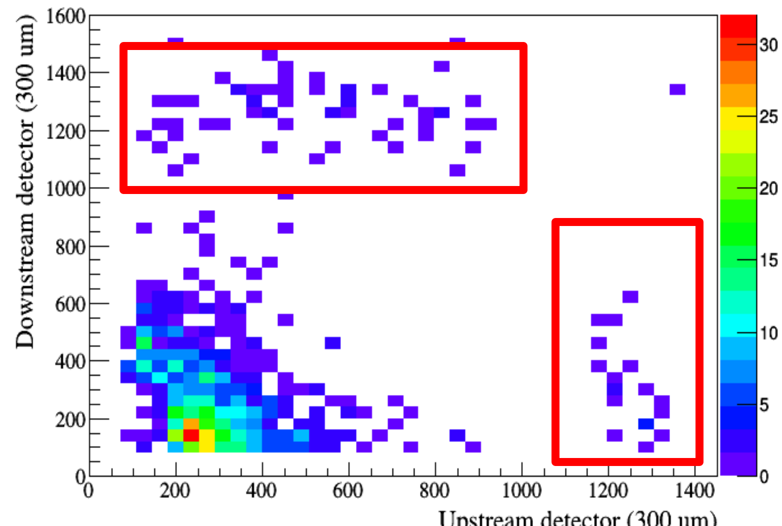
1000&500 µm



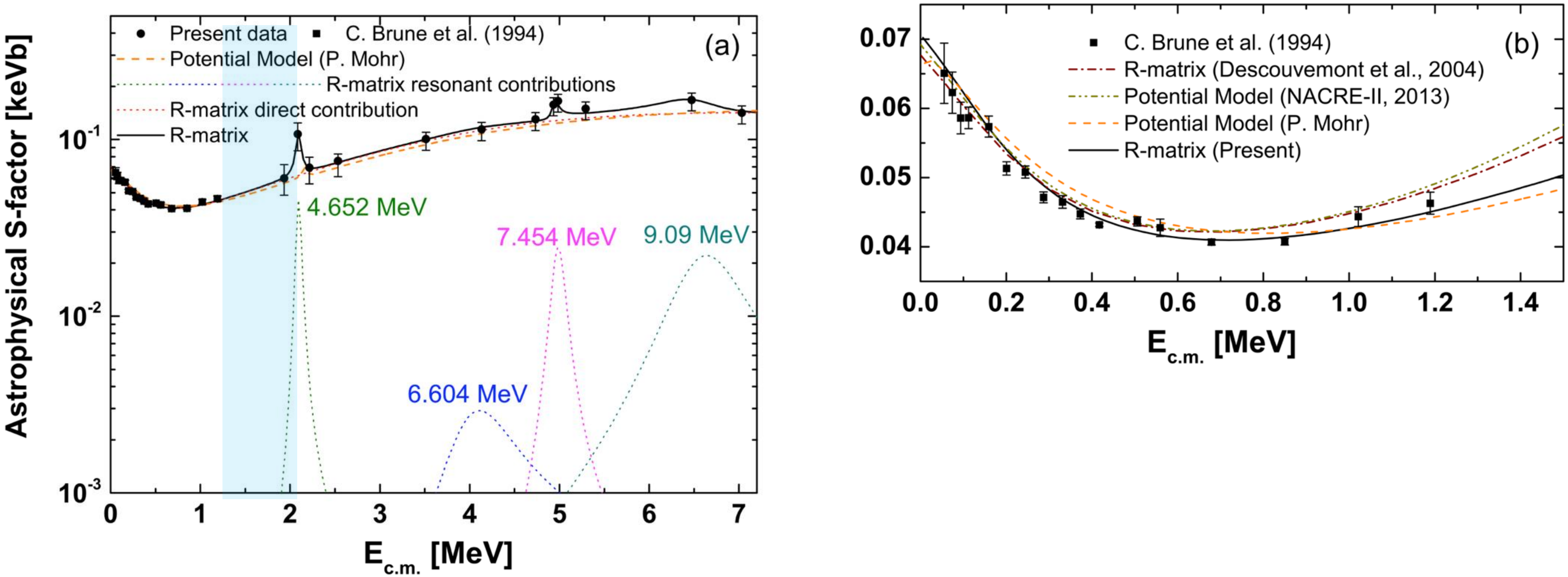
1000&300 µm



300&300 µm



$^{3}H(\alpha,\gamma)^{7}Li$ – S-factor



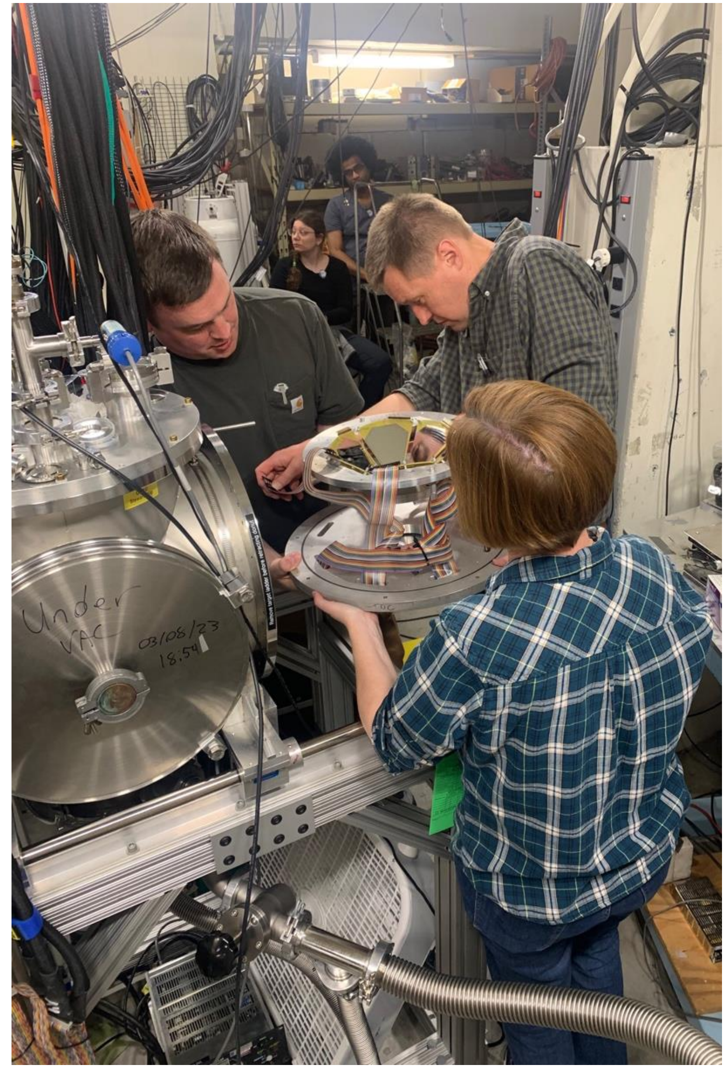
Measurement of the 7Li(γ,t)4He ground-state cross section between Eγ = 4.4 and 10 MeV, M. Munch, C. Matei, S.D. Pain, M.T. Febbraro, K.A. Chipps, H.J. Karwowski, C.Aa. Diget, A. Pappalardo, S. Chesnevskaya, G.L. Guardo, D. Walter, D.L. Balabanski, F.D. Becchetti, C.R. Brune, K.Y. Chae, J. Frost-Schenk, M.J. Kim, M.S. Kwag, M. La Cognata, D. Lattuada, R.G. Pizzone, G.G. Rapisarda, G.V. Turturica, C.A. Ur, and Y. Xu, **Phys. Rev. C 101, 055801 (2020)**

^{7}Li experiments @ HIgS

- ^{7}Li(g,t)^{4}He during April 2023
- E_{γ} = 3.7 – 6 MeV
- 70 hours of beam

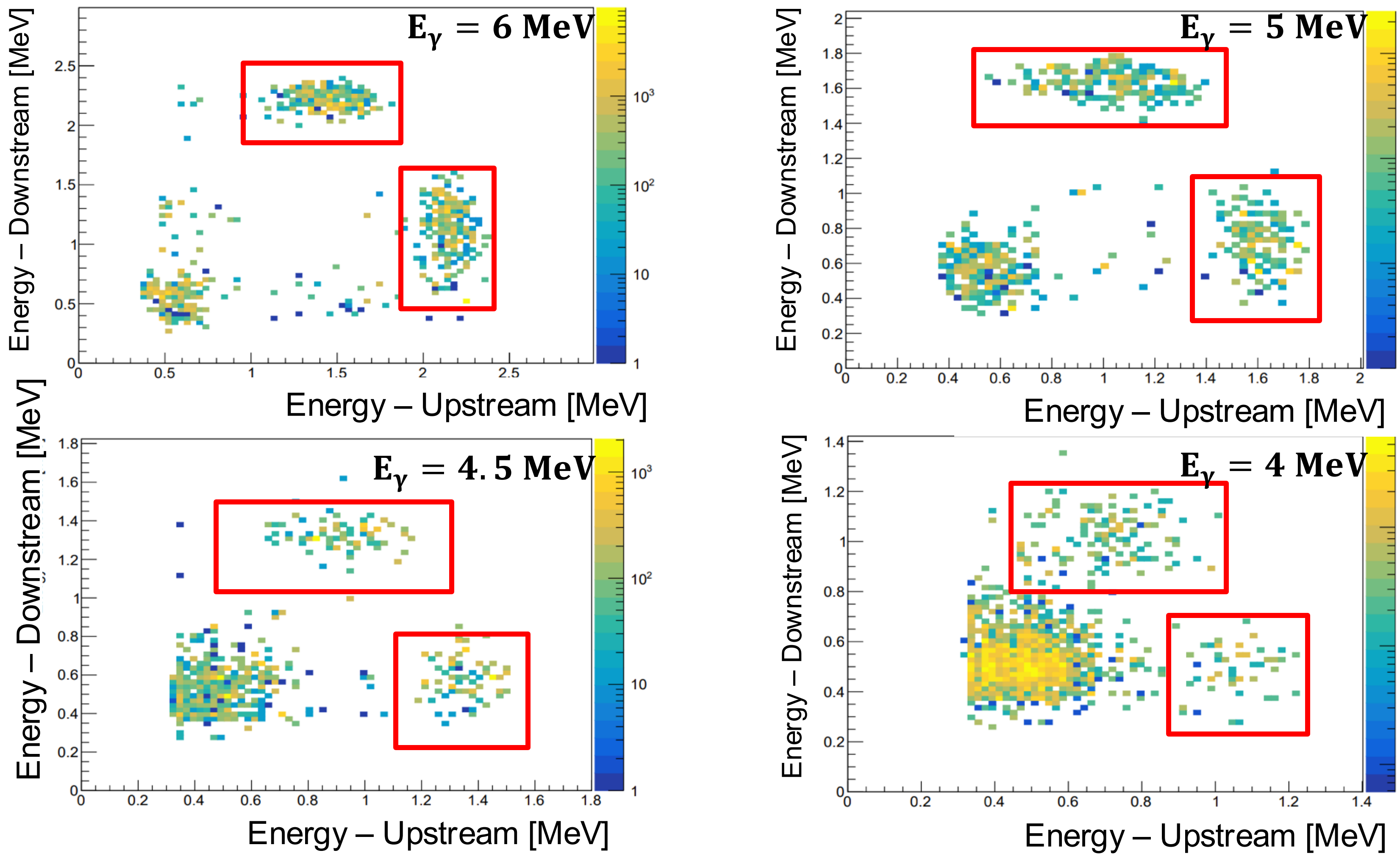
- LiF target on mylar (80 μg/cm^{2})
- SIDAR array (lamp-shade)
- 12 YY1 detectors (200 ch)
- 100 & 65 μm detectors

- additional steps to lower the beam-induced background:
  - thinner entry flange
  - entry flange farther away
  - longer vacuum pipe before interaction



- large collaboration led by ELI-NP
- ORNL, Rutgers, INFN-LNS, Ohio U, UNC, SHU, SKKU

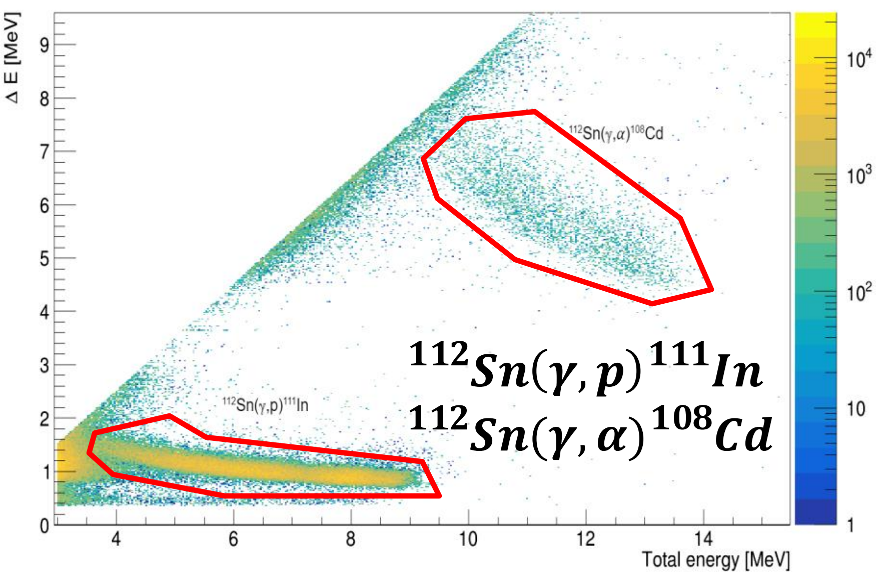
^{7}Li(γ,t)α w/ SIDAR in 2023

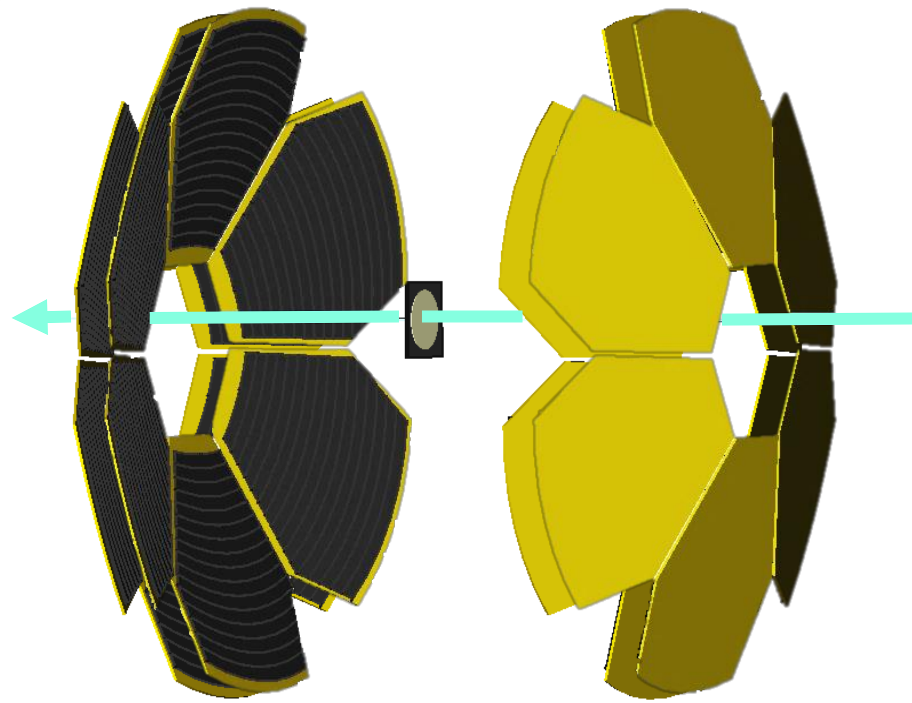


work of PhD student: Ioana Kuncser

p-process at HIgS in 2023

- ^{112}Sn and ^{102}Pd are accessible test cases to constrain OMP
- OMP variations – large effect on p-process abundances
- energy range 11-20 MeV
- P-17-19: D Lattuada (ELI-NP / INFN)
- P-15-19: K.A. Chipps (ORNL)
- carried out at HIgS for 200 hours during March 2023





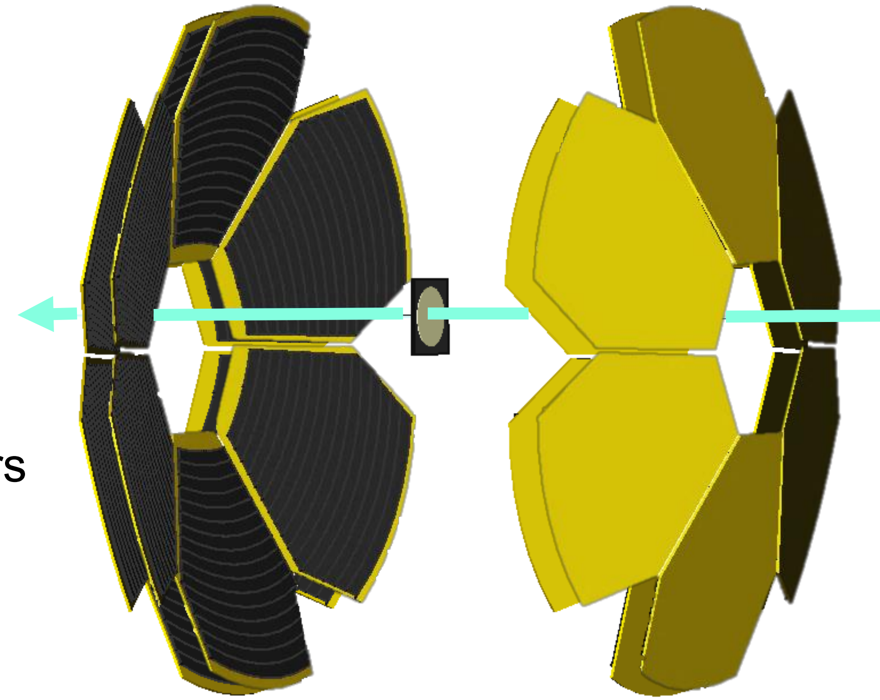
- SIDAR array (lamp-shade)
- 24 YY1 detectors (384 ch)
- 12 dE detectors: 65 & 100 μm
- 12 E detectors: 1000 μm

collaboration 2023

- Ioana Kuncser, T. Petruse, A. Pappalardo, H. Pai, Yi Xu, D. Balabanski (ELI-NP)
- Steve Pain, Kelly Chipps, T. King, M Febbraro (ORNL)
- M. Grinder, S. Balakrishnan, Heather Garland, Jolie Cizewski (Rutger U)
- H. Karwowski, R.V. Janssens, T. Psaltis, C. Marshall (UNC - Chapel Hill)
- G. Restifo, M. La Cognata, G.L. Guardo, S. Palmerini, L. Sergi, D. Lattuada, R.G. Pizzone, G. Rapisarda, A. Tumino (INFN-LNS)
- C.R. Brune, A. Voinov (Ohio U.)
- O. Tindle, C. Haverson, R. Smith (Shefield Hallam U, UK)
- K.Y. Chae, Gyoungmo GU (SungKyunKwan U)

more experiment approved at HIgS

- ^{116}Sn, ^{120}Sn as next targets for p-process program
- OMP variations – large effect on p-process abundances
- energy range 11-20 MeV
- P-10-23: K.A. Chipps (ORNL)
- approved at HIgS by PAC 2023 for 140 hours



- ^{24}Mg as next target for understanding silicon burning
- $^{24}Mg(\gamma,\alpha)^{20}Ne$ – determine reaction rate
- energy range 10-13 MeV
- P-09-24: G.L. Guardo (INFN-LNS
- approved at HIgS by PAC 2024 for 72 hours

how we end experiments at HIgS

summary

- successful experiments w/ SIDAR @ HIgS
  - 7Li(γ,t)4He analysis underway, new results coming soon
  - analysis underway for (γ,p) and (γ,α) on ^{112}Sn and ^{102}Pd
  - beam-induced background manageable w/ SSDs
  - beam diagnostics is challenging & can be improved
  - approved by 2023 HIgS PAC for additional 160 hours of beam time for p-process
- ELI-NP is currently the most important research project implemented in Romania. The facility is a user facility open to international users:
  - HPLS operational since 2020
  - VEGA will become operational in the future

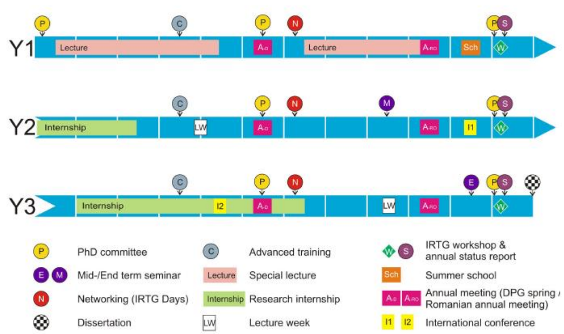
Nuclear Photonics Training Center

Spokesperson: N. Pietralla (TU Darmstadt), C.A. Ur (ELI-NP/UPB)

IGK 2891 Nuclear Photonics

Establishment Proposal

Funding Period:	01.10.2023 to 30.09.2028
Coordinating University:	Technische Universität Darmstadt
Designated Spokesperson (D):	Prof. Dr. Dr. h.c. mult. Norbert Pietralla
Designated Spokesperson (RO):	Dr. habil. Eng. Calin Alexandru Ur



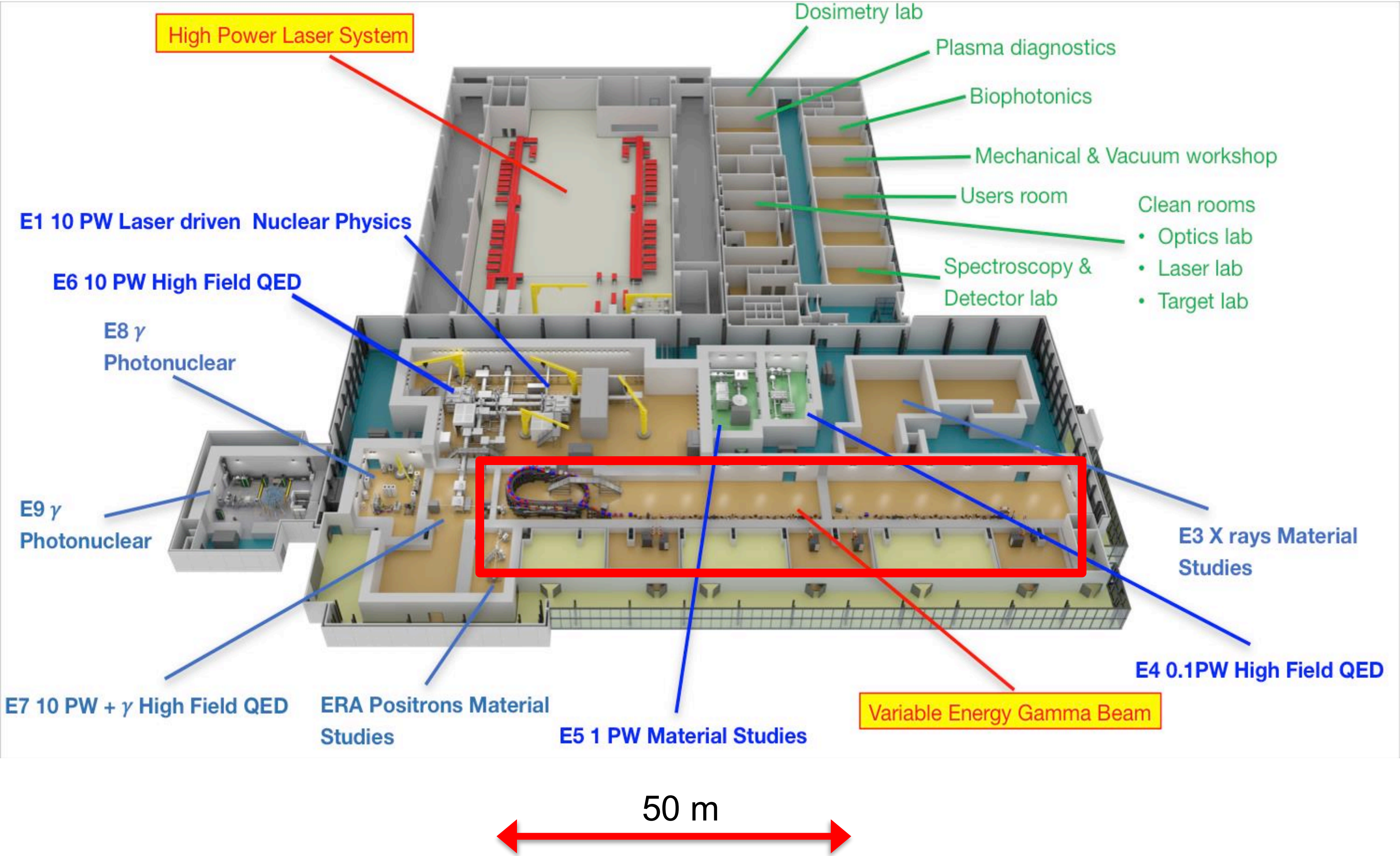
- joint project between TU Darmstadt and ELI-NP / University Politechnica Bucharest
- project approved in September 2023 by DFG & IFA
- supports 3 cohorts of 20 PhD students between 2023-2029
- open to international students for October 2024 admission
- topics in laser driven nuclear physics, accelerators, and photonuclear reactions

Overview of VEGA System

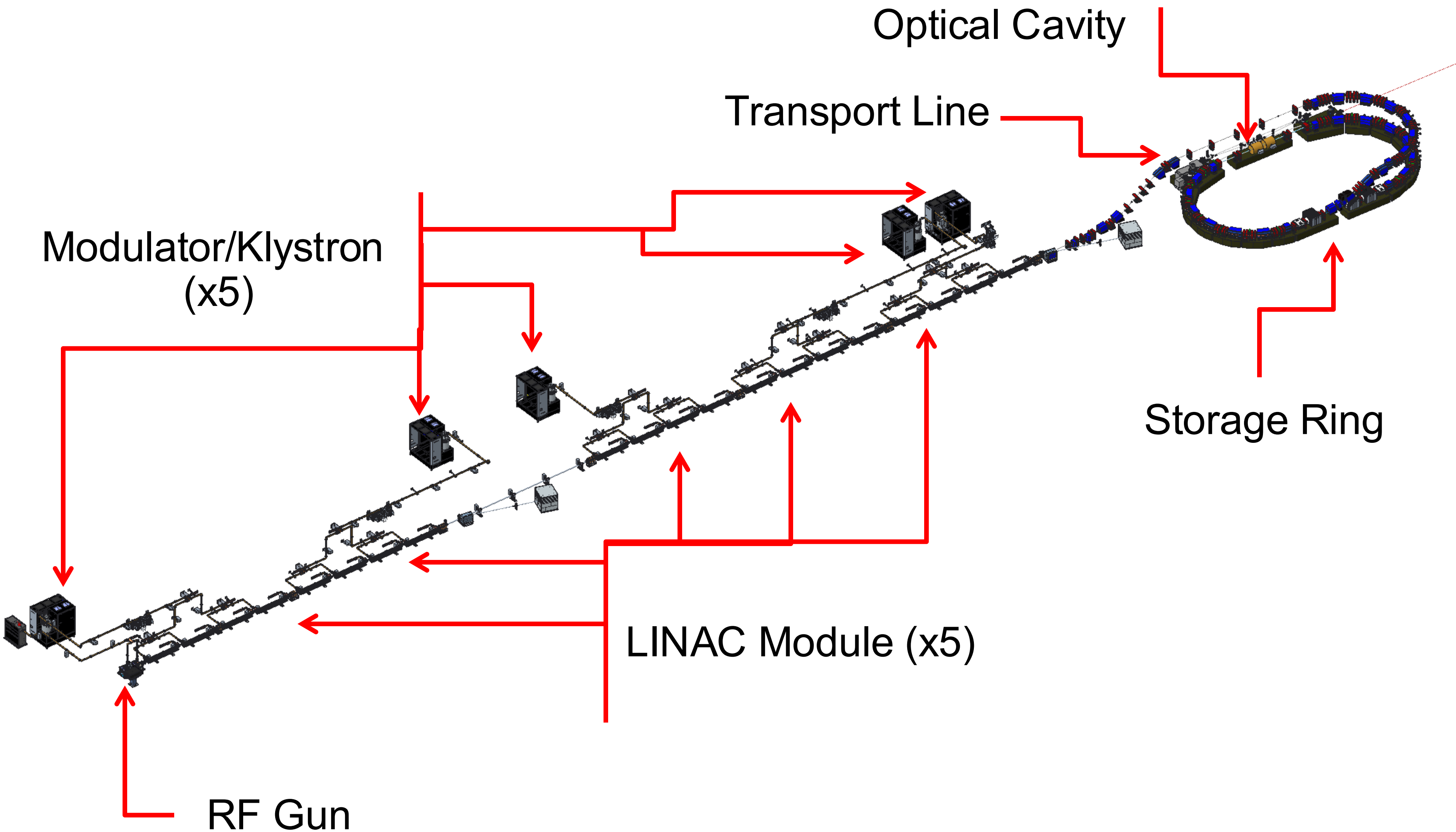
https://www.eli-np.ro/rd2.php

eli
nuclear physics

ELI-NP overview & layout



VEGA System - overview

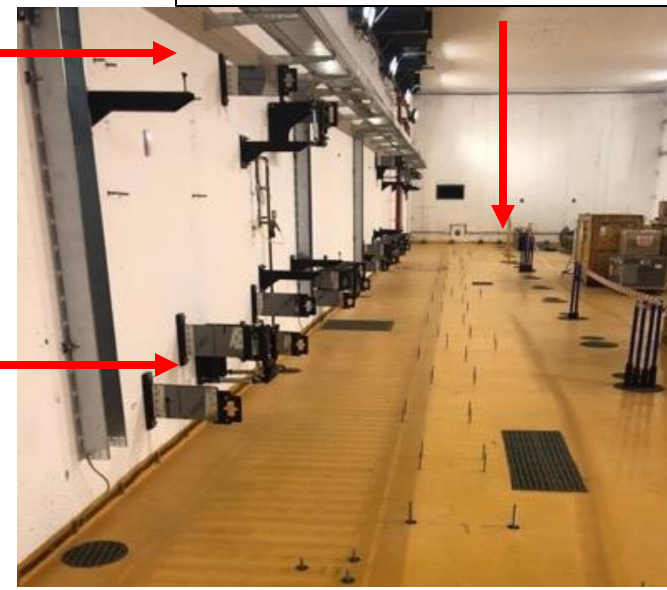


VEGA status – December 2022

installed water cooling infrastructure in the basement

cable trays in E-P-10

installed water cooling infrastructure in E-P-10



installed waveguide supports in E-P-10

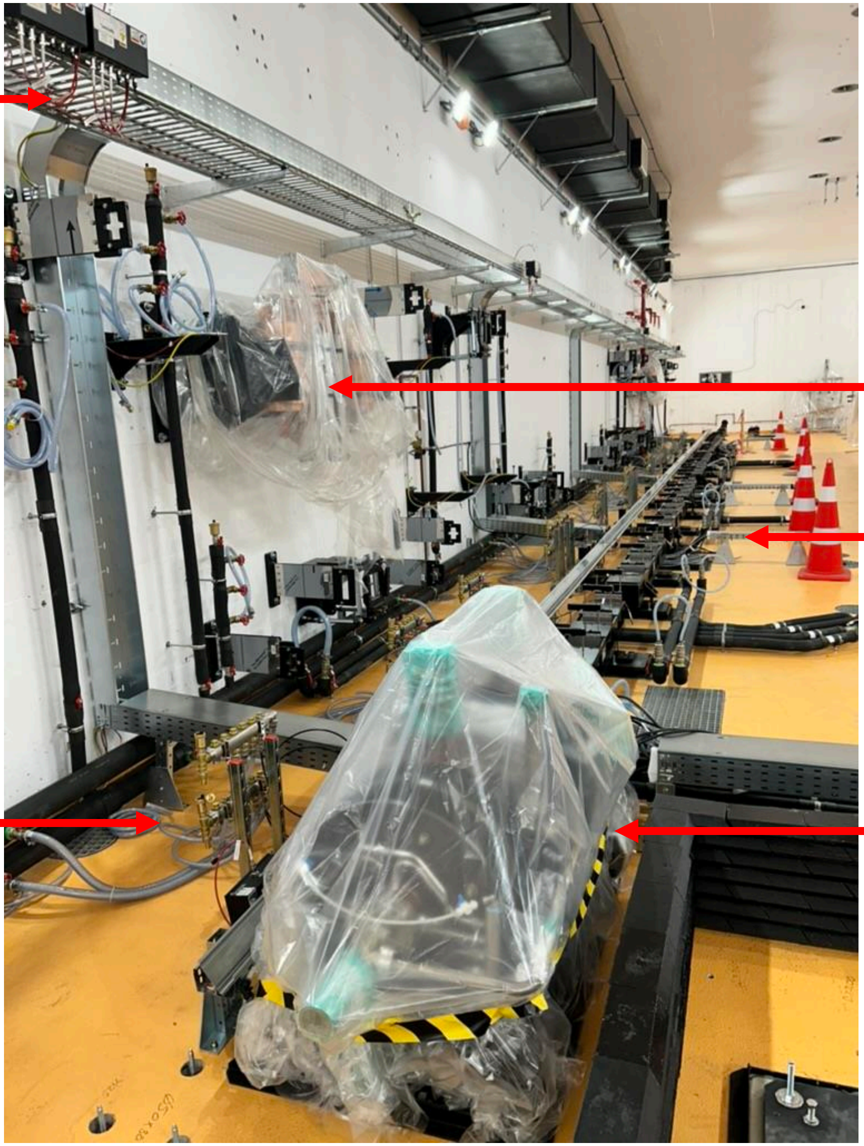
crated components

VEGA status – July 2024

all power & control for magnets / ion pumps / gate valves installed

ready for connecting accelerator structures to water cooling system

Accelerator Bay 1



all SLEDs installed

magnet power & signal cables installed

RF Gun on position

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  - analysis underway for (γ,p) and (γ,α) on ^{112}Sn and ^{102}Pd
  - beam-induced background manageable w/ SSDs
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  - HPLS operational since 2020
  - VEGA will become operational in the future

EXTRA

JOIN US

ELI-NP is building a team of dedicated, talented people willing to contribute to the operation and to perform laser-matter interaction experiments with the most powerful LASER in the world. If you are interested in working in an innovative, dynamic environment and share our passion for "pushing the limits", we would be thrilled to work with you.
ELI-NP offers researchers and engineers from various fields related to the activity of the new Research Center the opportunity to grow and reach their full potential in a multicultural and interdisciplinary environment. It aims to create an innovation a creativity lab for research and applications which benefit society at large. Our work ethic is based on respect, diversity, curiosity and integrity. We offer outstanding working conditions and competitive salaries and benefits.

We are very proud of our project and the team we have brought together. Our employees are our most valuable asset and the key means by which we can achieve our goals. For queries and further information: human.resources@eli-np.ro

ELI-NP Open positions

RESEARCH & TECH. DEVELOPMENT

29 open positions

ENGINEERING & TECHNICAL

52 open positions

ADMINISTRATIVE & SUPPORT

2 open positions

Senior Researchers

Junior Researchers

Post-Doctoral Research Assistants

Doctoral Research Assistants (PhD Students)

Engineers

Technicians

IT Specialists

Cybersecurity

Support