Direct low-energy measurement of the $^{25}Mg(\alpha,n)^{28}Si$ reaction via neutron spectroscopy

Shahina

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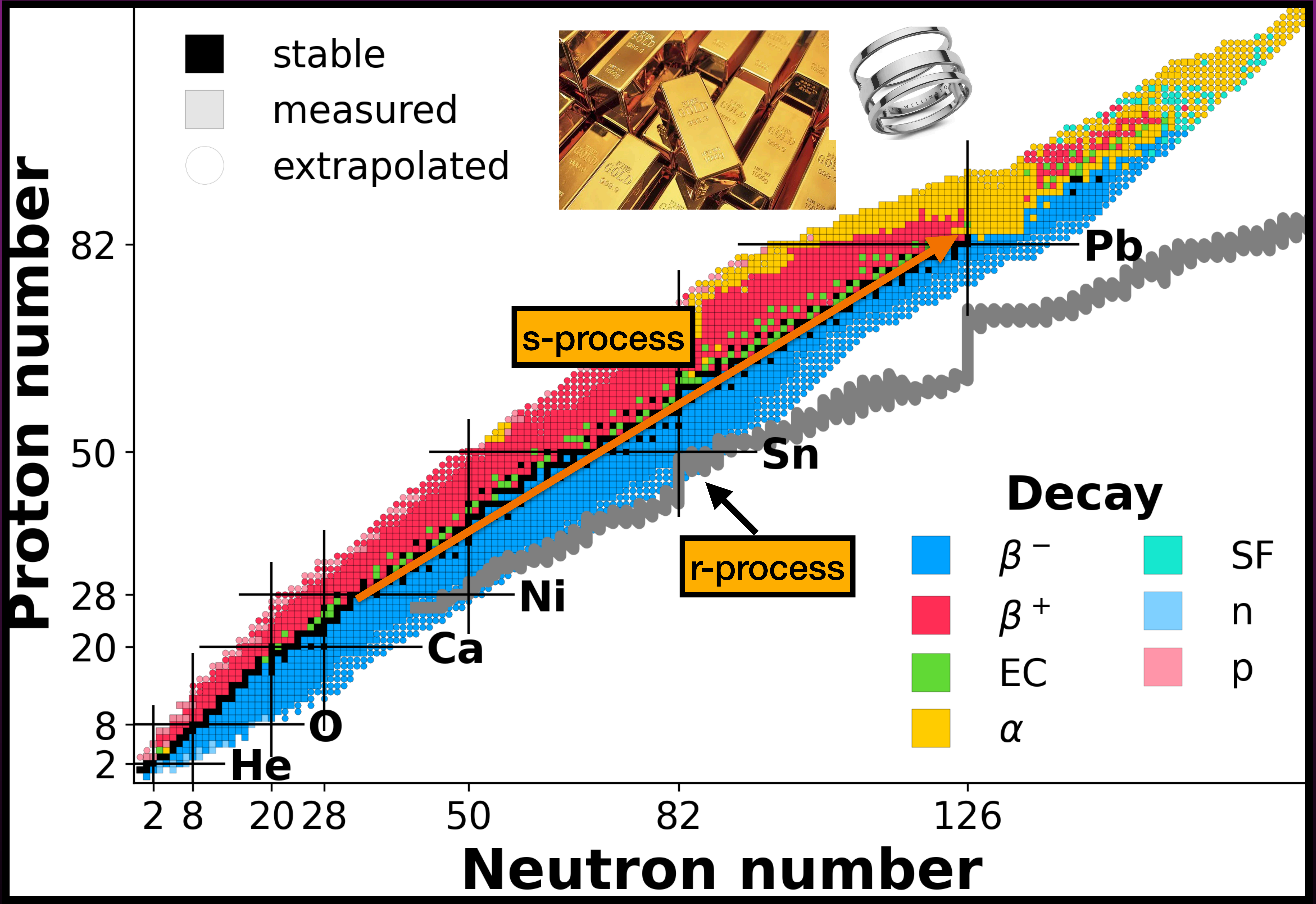
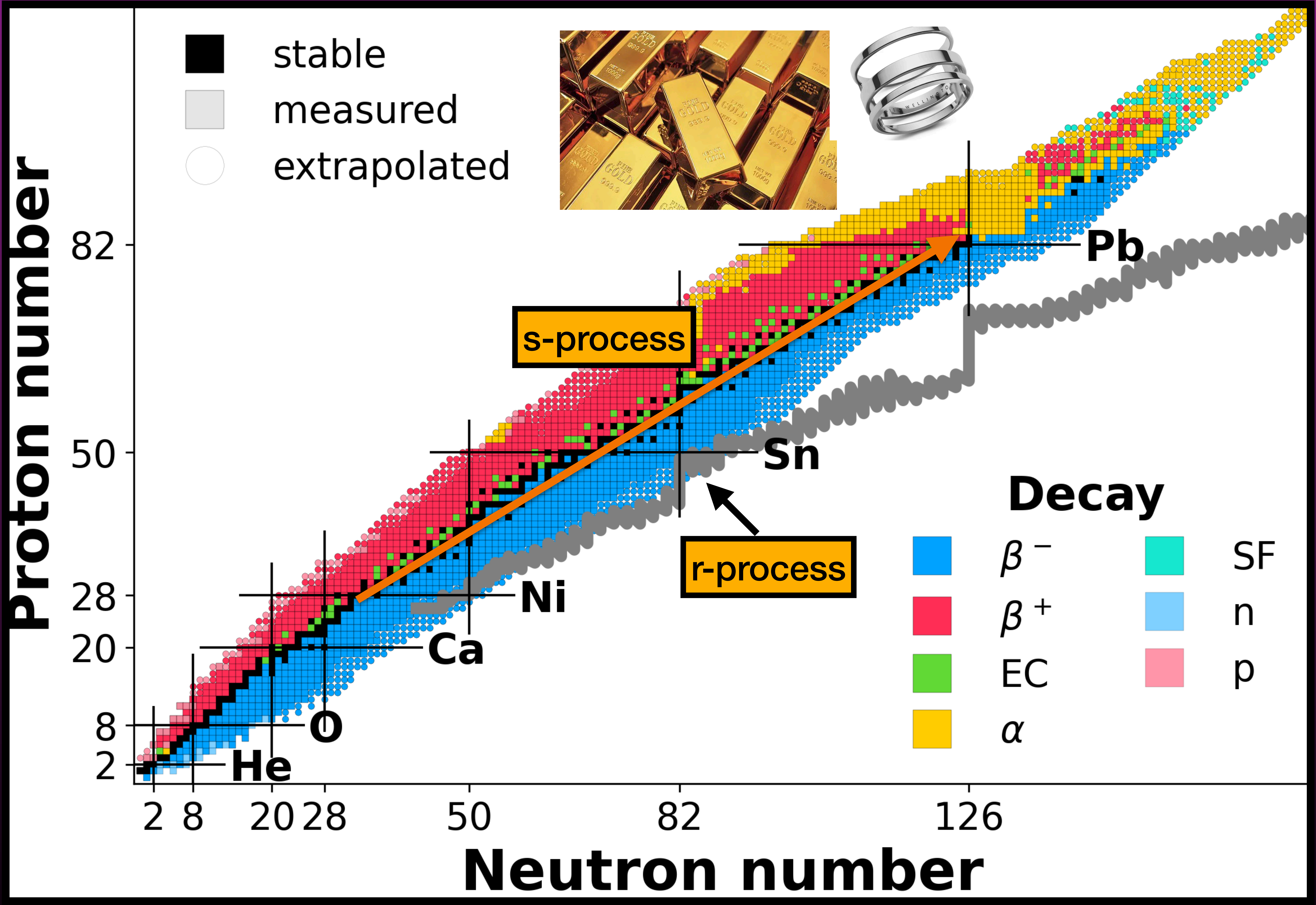
DNP 2024

How the heavy elements beyond Iron are produced?



How the heavy elements beyond Iron are produced?



Main s-process

A > ^{90}Sr

Site: Low mass AGB stars during thermal pulses

($1.3M_{\odot} < M < 8M_{\odot}$)

Weak s-process

^{60}Fe < A < ^{90}Sr

Site: Core He-burning and C-shell burning in massive stars

($M > 8M_{\odot}$)

Where do the neutrons come from?

Main s-process

$A > {}^{90}Sr$

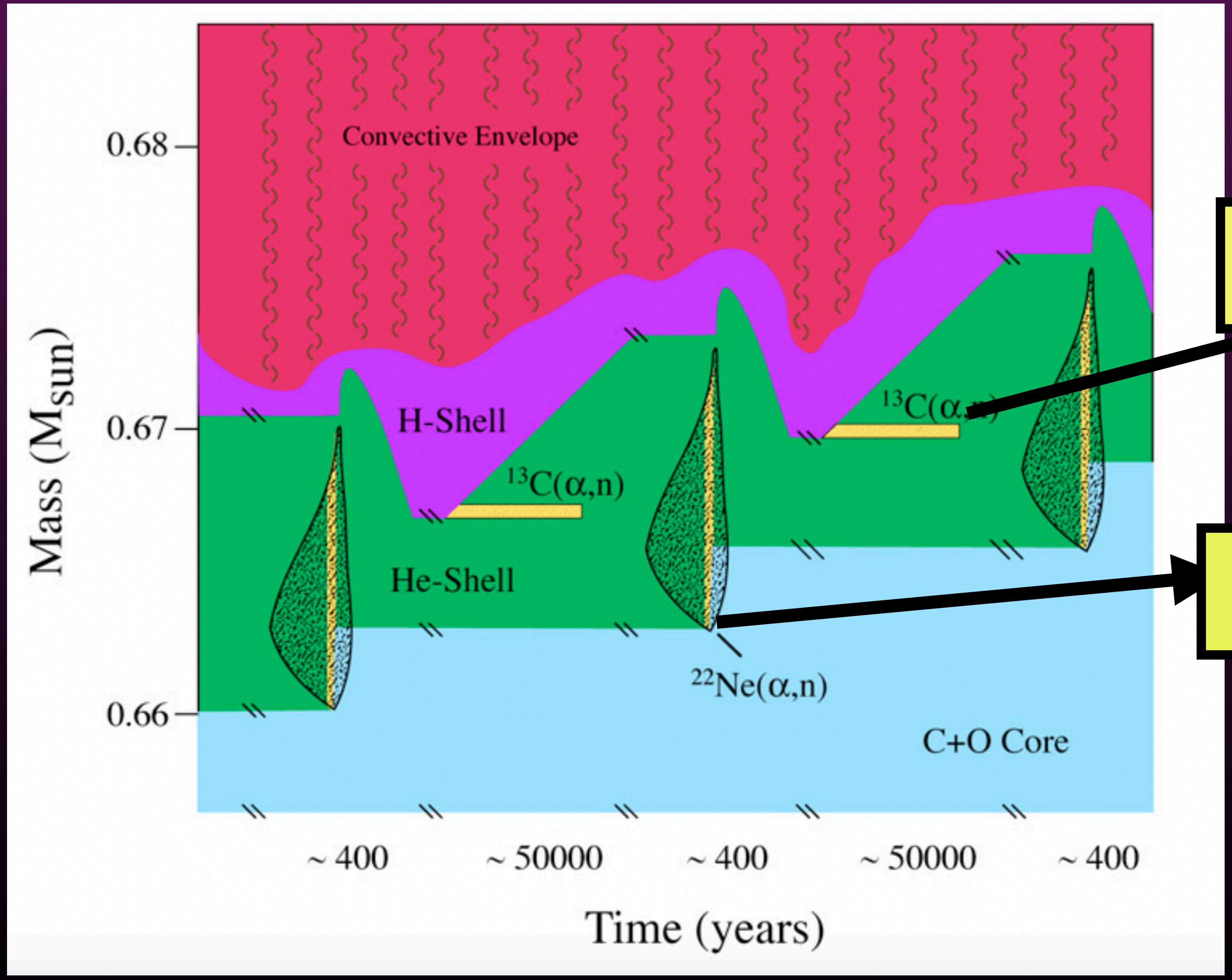
Weak s-process

${}^{60}Fe < A < {}^{90}Sr$

Neutron source: ${}^{13}C(\alpha,n){}^{16}O$

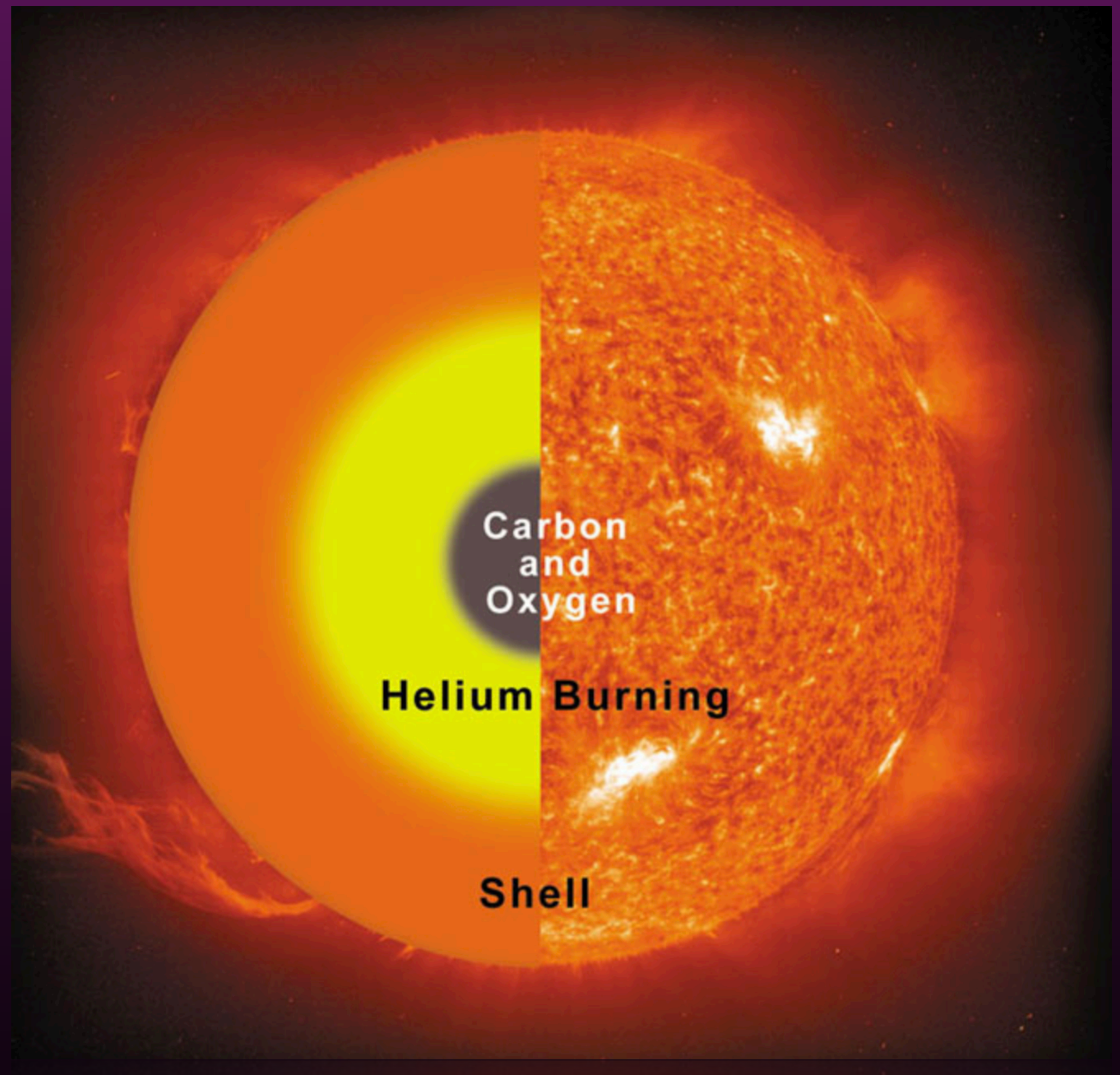
${}^{22}Ne(\alpha,n){}^{25}Mg$

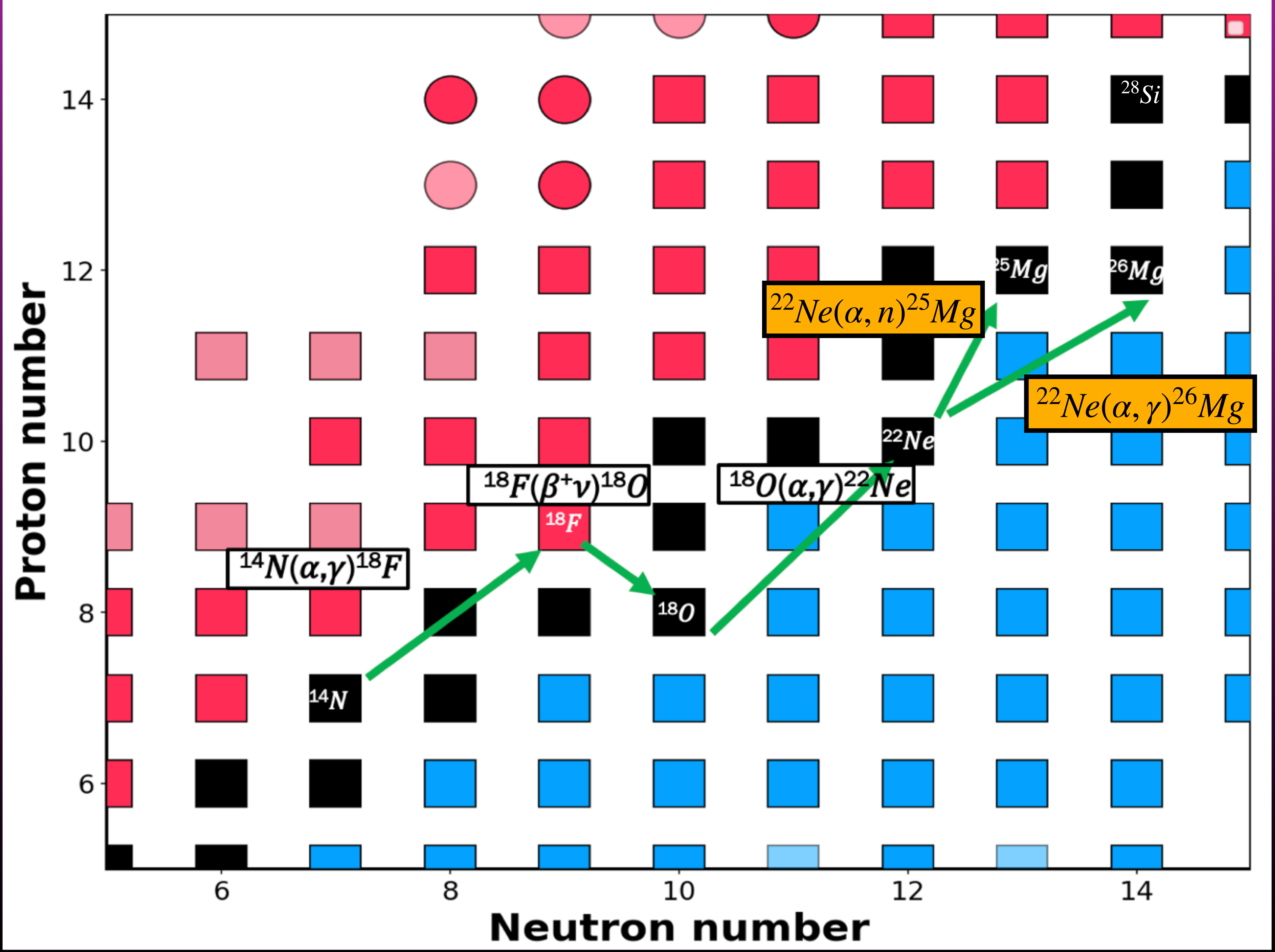
Neutron source: ${}^{22}Ne(\alpha,n){}^{25}Mg$



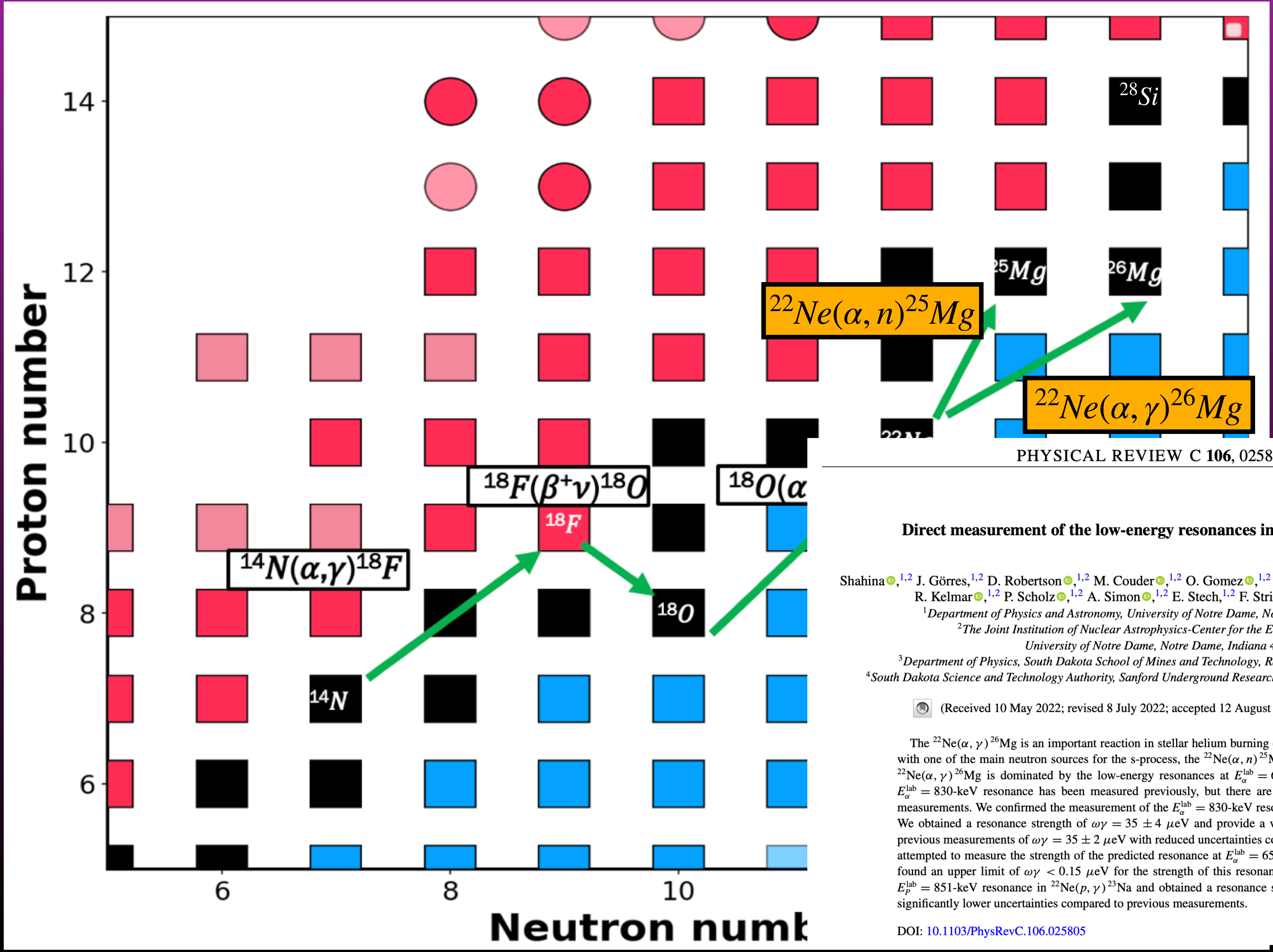
${}^{13}C(\alpha,n){}^{16}O$ (Dominant)

${}^{22}Ne(\alpha,n){}^{25}Mg$ (Sub-dominant)





^{28}Si
^{25}Mg
^{26}Mg
$^{22}Ne(\alpha,n)^{25}Mg$
$^{22}Ne(\alpha,\gamma)^{26}Mg$
^{22}Ne
$^{18}F(\beta^{+}\nu)^{18}O$
$^{18}O(\alpha,\gamma)^{22}Ne$
^{18}F
$^{14}N(\alpha,\gamma)^{18}F$
^{18}O
^{14}N
Proton number
Neutron number
6
8
10
12
14



PHYSICAL REVIEW C **106**, 025805 (2022)

Direct measurement of the low-energy resonances in ^{22}Ne(α, γ)^{26}Mg reaction

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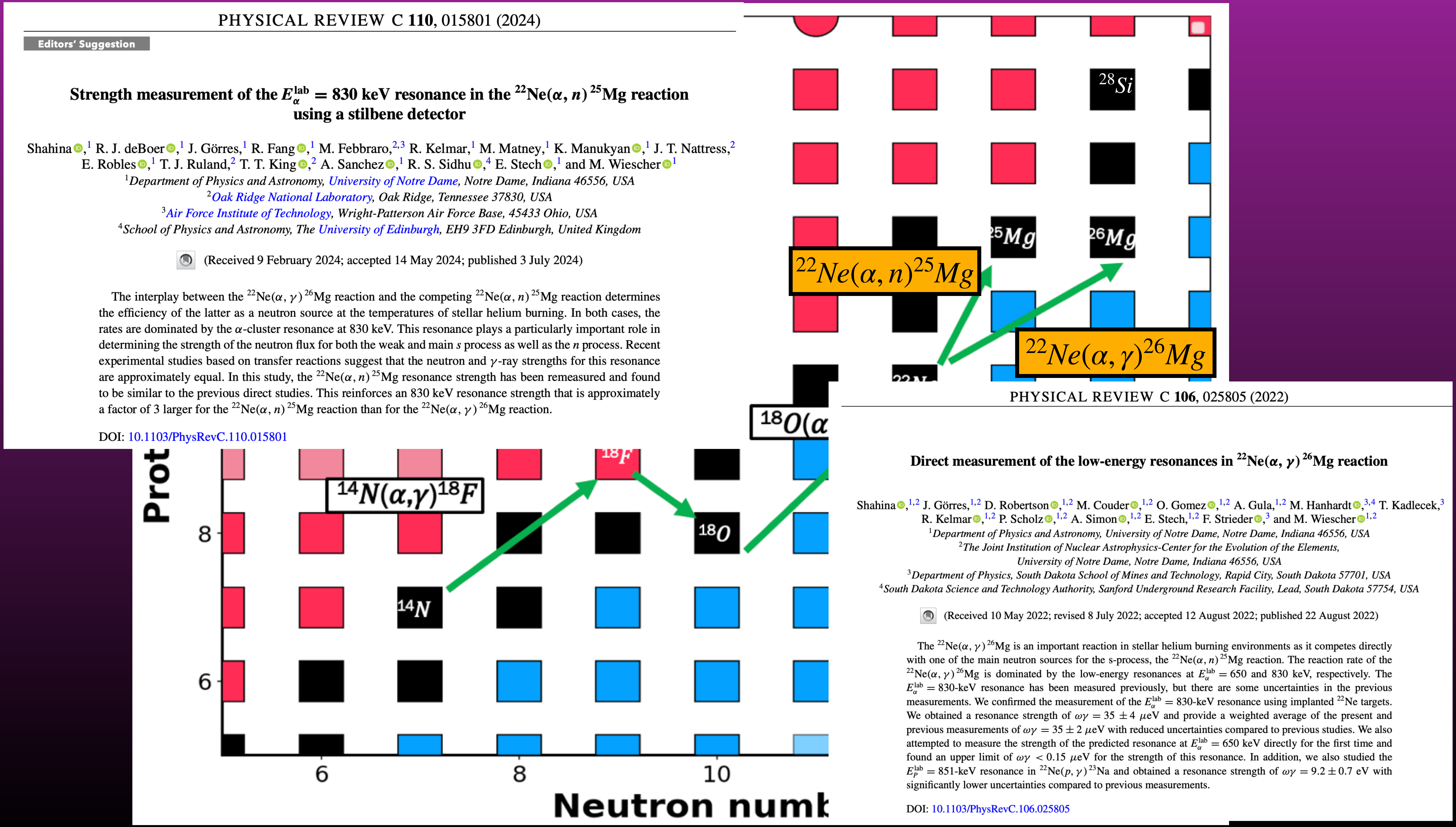
(Received 10 May 2022; revised 8 July 2022; accepted 12 August 2022; published 22 August 2022)

The ^{22}Ne(α,γ)^{26}Mg is an important reaction in stellar helium burning environments as it competes directly with one of the main neutron sources for the s-process, the ^{22}Ne(α,n)^{25}Mg reaction. The reaction rate of the ^{22}Ne(α,γ)^{26}Mg is dominated by the low-energy resonances at $E_\alpha^{\mathrm{lab}} = 650$ and 830 keV, respectively. The $E_\alpha^{\mathrm{lab}} = 830$-keV resonance has been measured previously, but there are some uncertainties in the previous measurements. We confirmed the measurement of the $E_\alpha^{\mathrm{lab}} = 830$-keV resonance using implanted ^{22}Ne targets. We obtained a resonance strength of $\omega\gamma = 35 \pm 4\ \mu$eV and provide a weighted average of the present and previous measurements of $\omega\gamma = 35 \pm 2\ \mu$eV with reduced uncertainties compared to previous studies. We also attempted to measure the strength of the predicted resonance at $E_\alpha^{\mathrm{lab}} = 650$ keV directly for the first time and found an upper limit of $\omega\gamma < 0.15\ \mu$eV for the strength of this resonance. In addition, we also studied the $E_p^{\mathrm{lab}} = 851$-keV resonance in ^{22}Ne(p,γ)^{23}Na and obtained a resonance strength of $\omega\gamma = 9.2 \pm 0.7$ eV with significantly lower uncertainties compared to previous measurements.

DOI: 10.1103/PhysRevC.106.025805



PHYSICAL REVIEW C **110**, 015801 (2024)

Editors' Suggestion

Strength measurement of the $E_\alpha^{lab} = 830$ keV resonance in the ^{22}Ne$(\alpha, n)^{25}$Mg reaction using a stilbene detector

Shahina,[1] R. J. deBoer,[1] J. Görres,[1] R. Fang,[1] M. Febbraro,[2,3] R. Kelmar,[1] M. Matney,[1] K. Manukyan,[1] J. T. Nattress,[2] E. Robles,[1] T. J. Ruland,[2] T. T. King,[2] A. Sanchez,[1] R. S. Sidhu,[4] E. Stech,[1] and M. Wiescher[1]

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The interplay between the ^{22}Ne$(\alpha, \gamma)^{26}$Mg reaction and the competing ^{22}Ne$(\alpha, n)^{25}$Mg reaction determines the efficiency of the latter as a neutron source at the temperatures of stellar helium burning. In both cases, the rates are dominated by the α-cluster resonance at 830 keV. This resonance plays a particularly important role in determining the strength of the neutron flux for both the weak and main *s* process as well as the *n* process. Recent experimental studies based on transfer reactions suggest that the neutron and γ-ray strengths for this resonance are approximately equal. In this study, the ^{22}Ne$(\alpha, n)^{25}$Mg resonance strength has been remeasured and found to be similar to the previous direct studies. This reinforces an 830 keV resonance strength that is approximately a factor of 3 larger for the ^{22}Ne$(\alpha, n)^{25}$Mg reaction than for the ^{22}Ne$(\alpha, \gamma)^{26}$Mg reaction.

DOI: 10.1103/PhysRevC.110.015801

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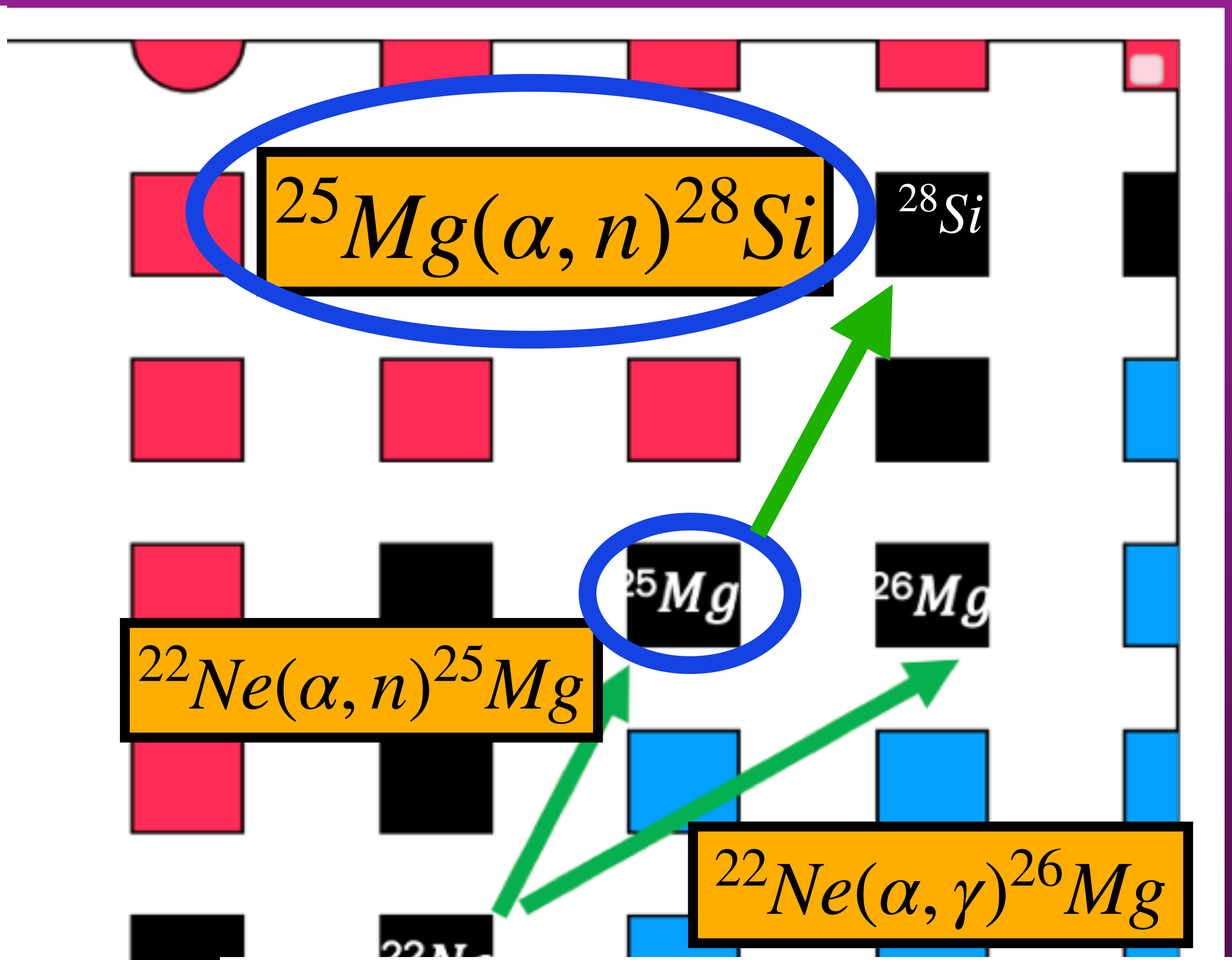

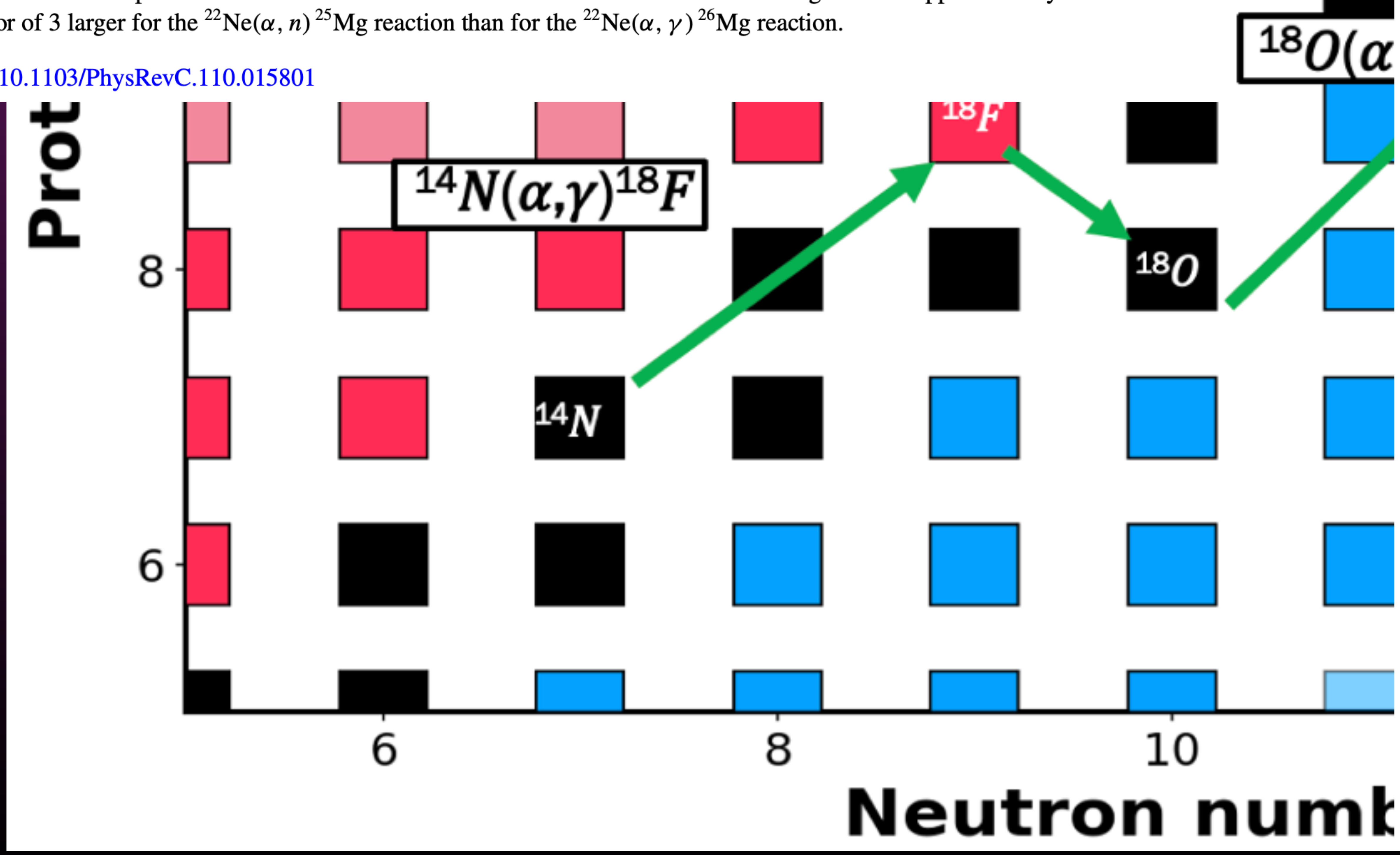

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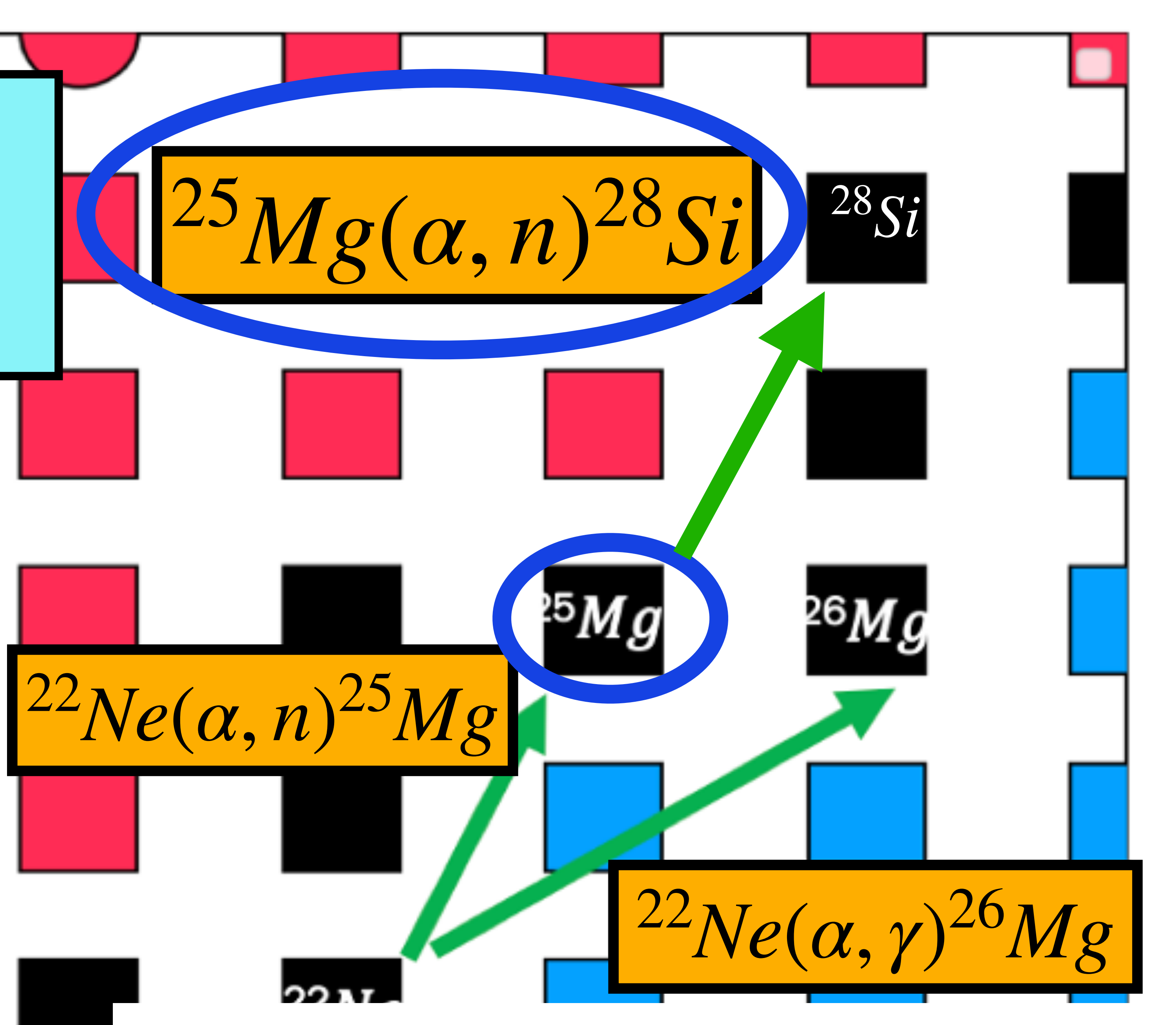
Influences neutron-production for the s-process



PHYSICAL REVIEW C **110**, 015801 (2024)

Editors' Suggestion

Strength me

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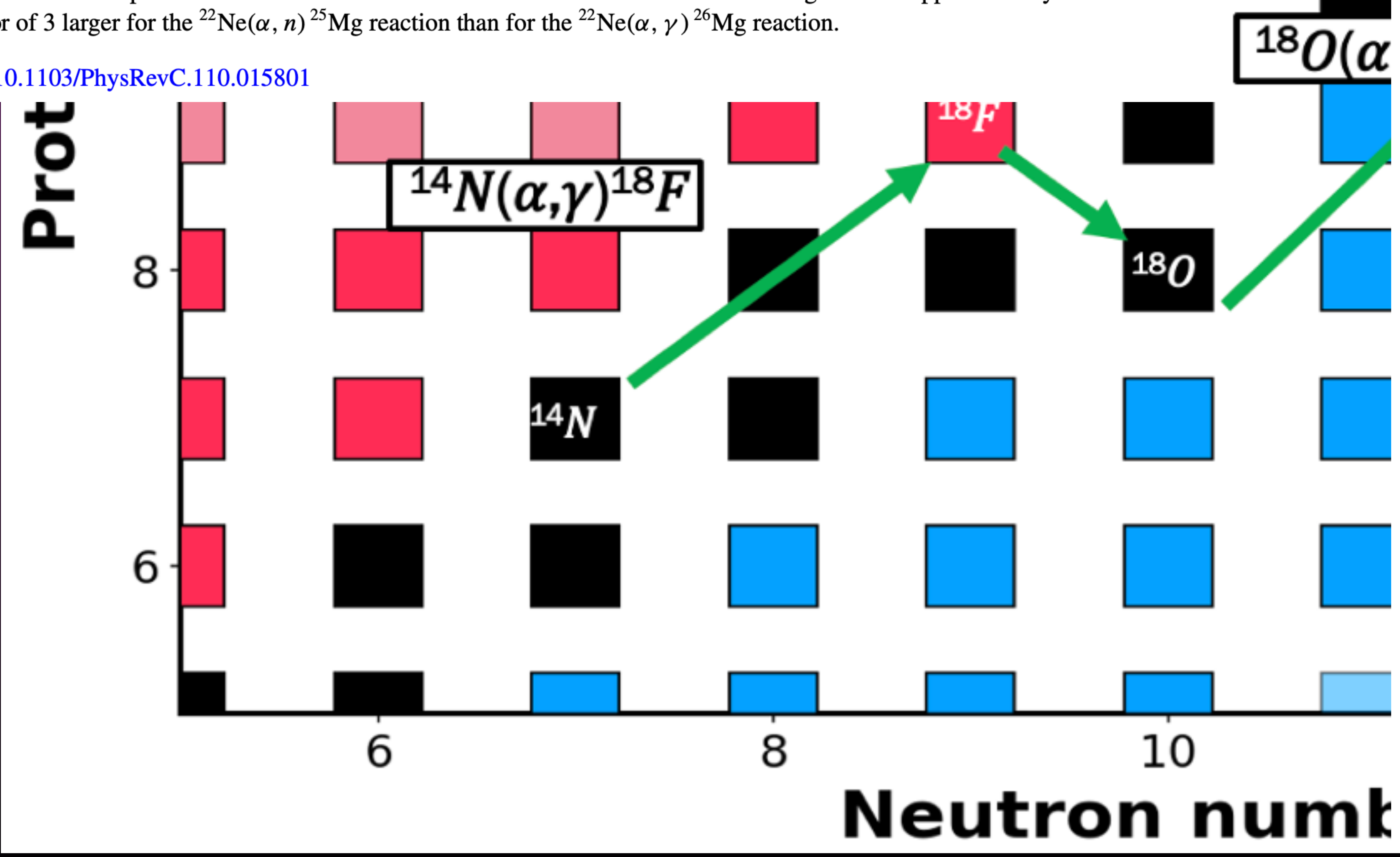

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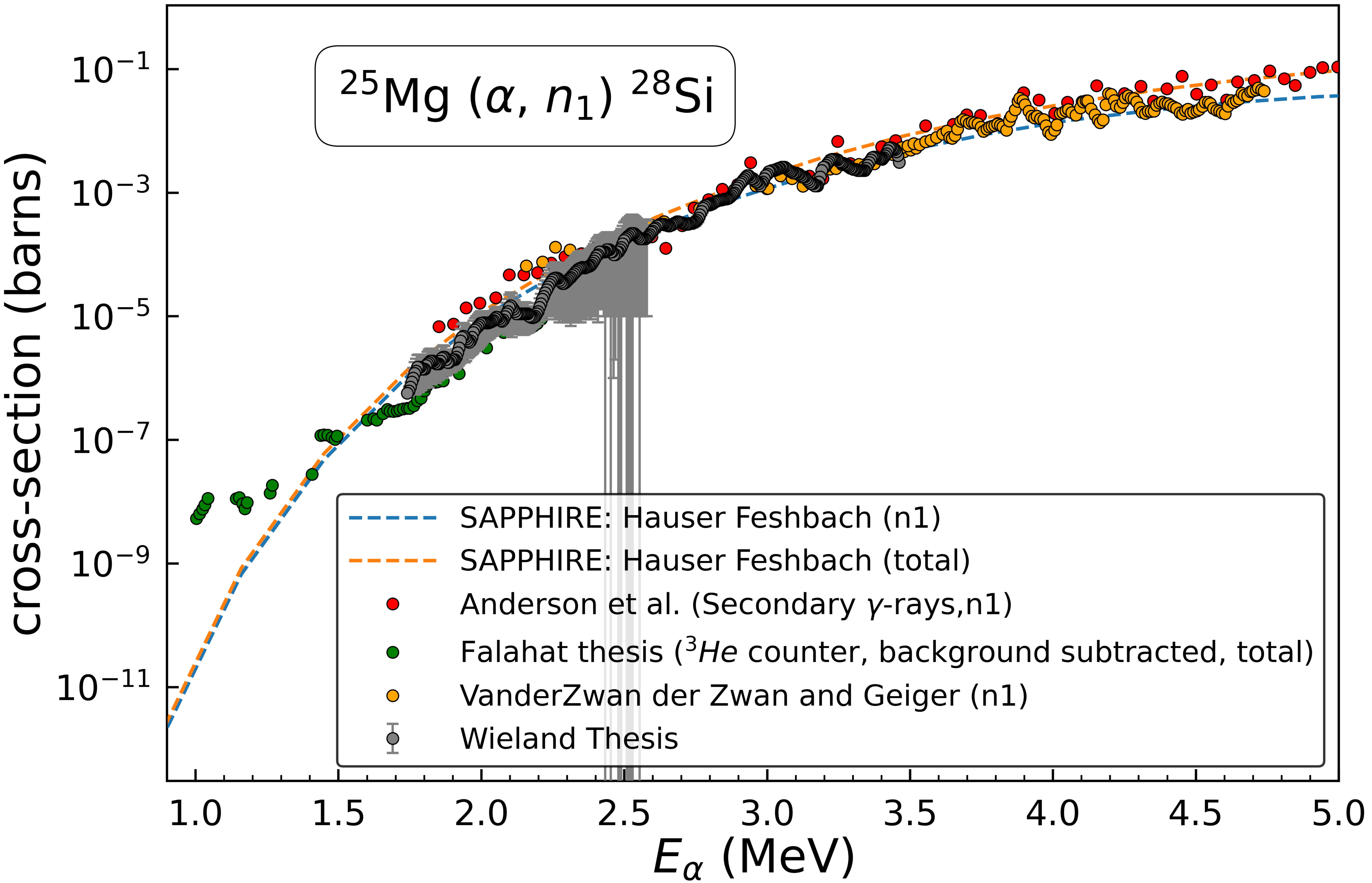
Previous Measurements of $^{25}Mg(\alpha, n)^{28}Si$



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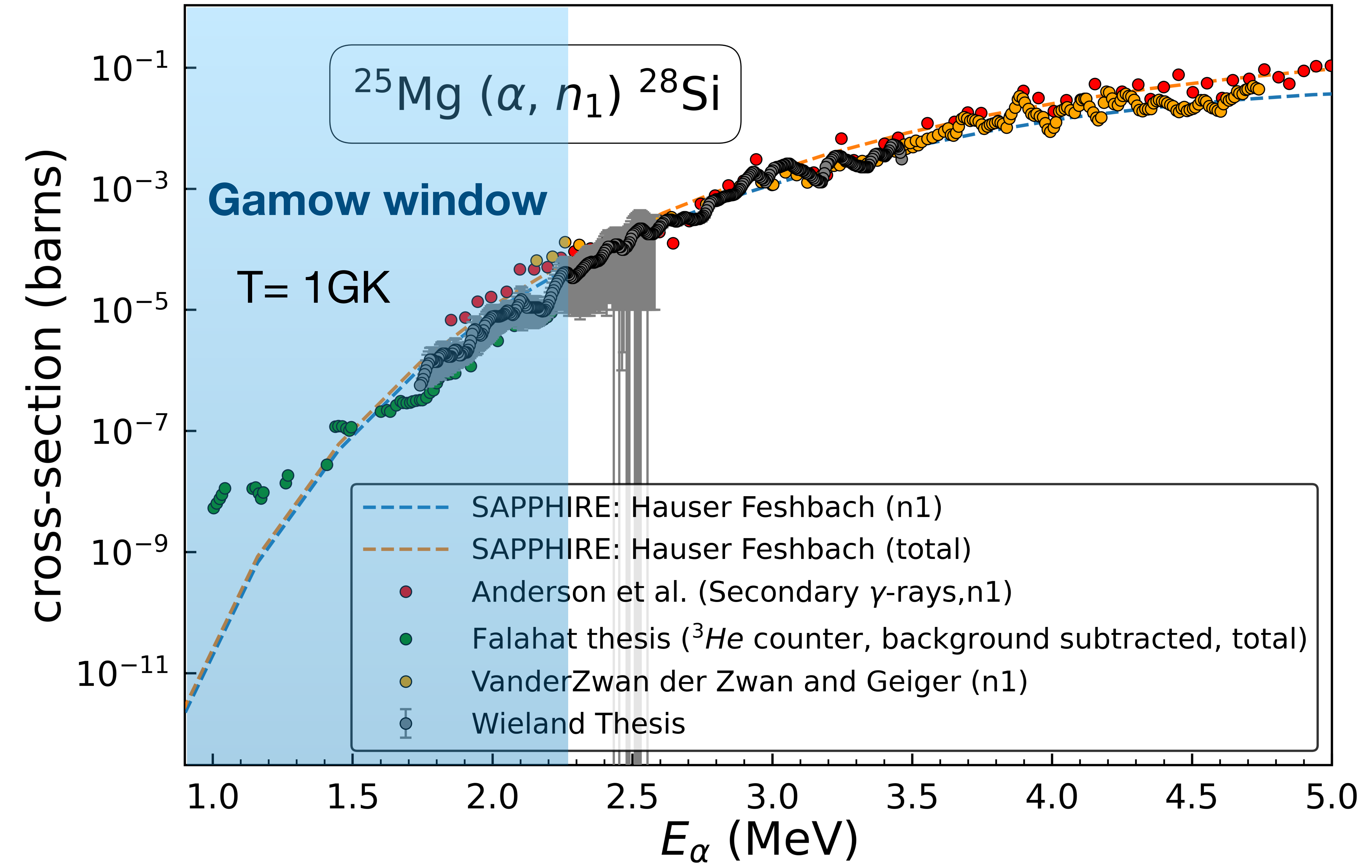

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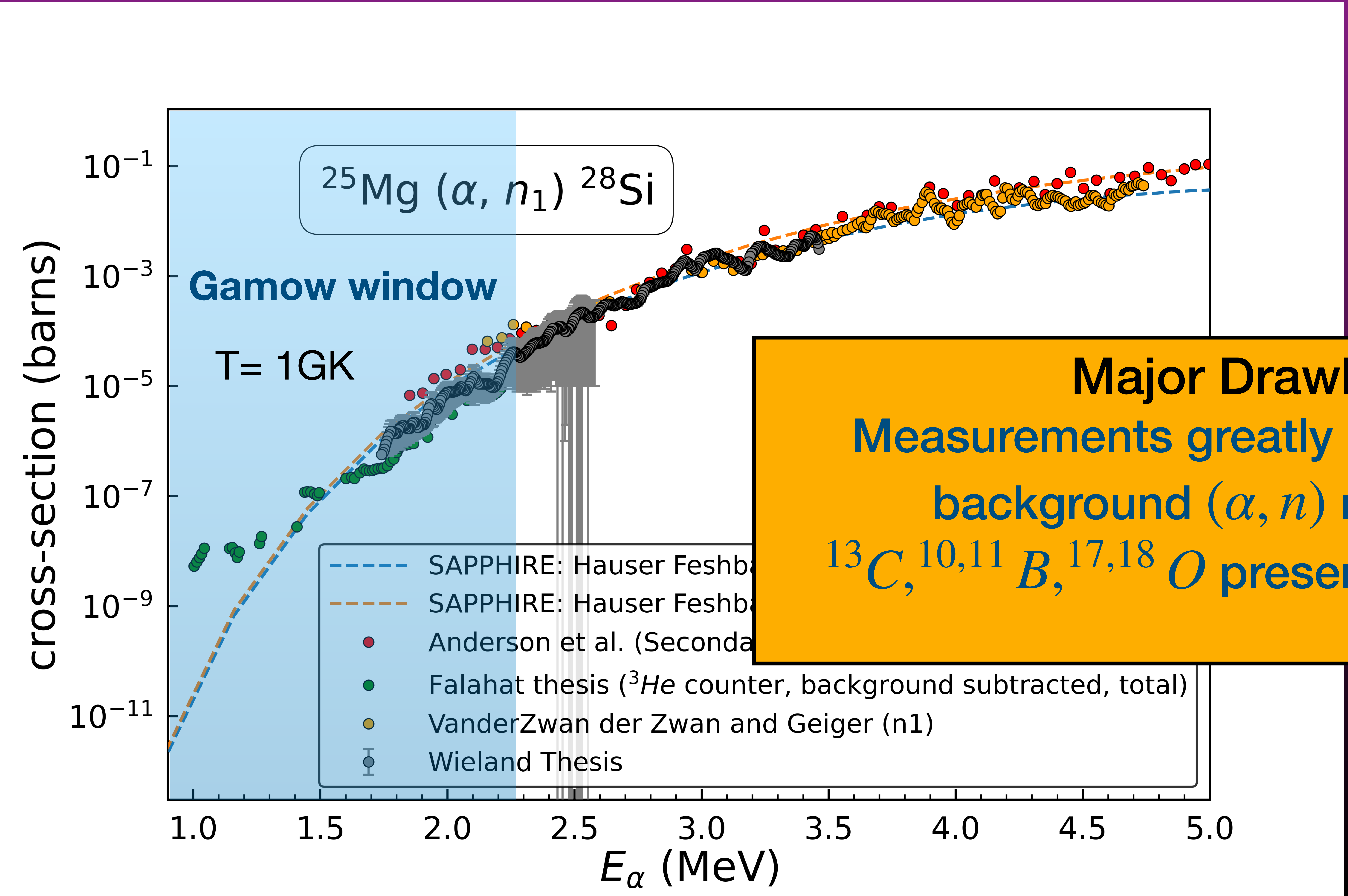
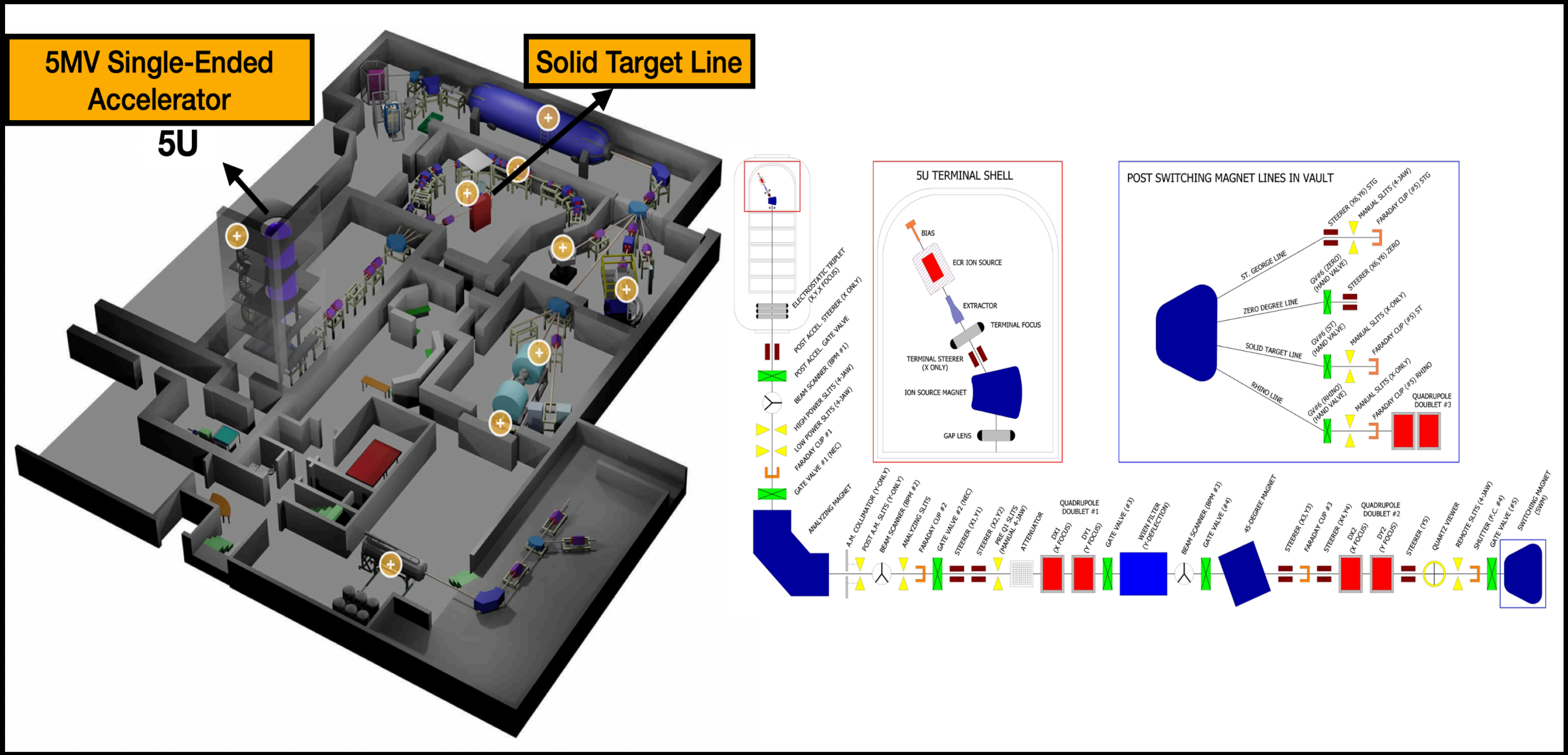


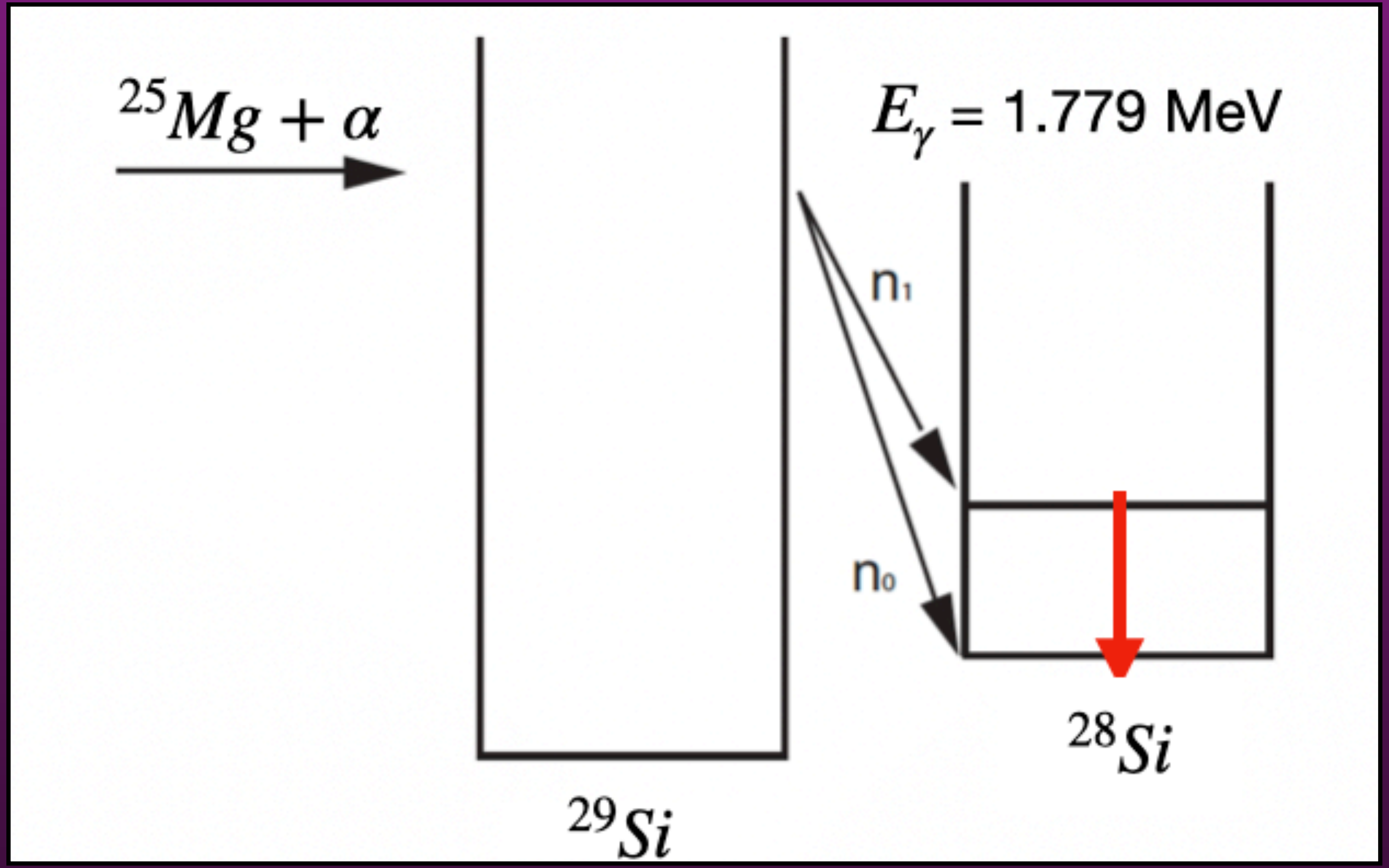
Major Drawback:

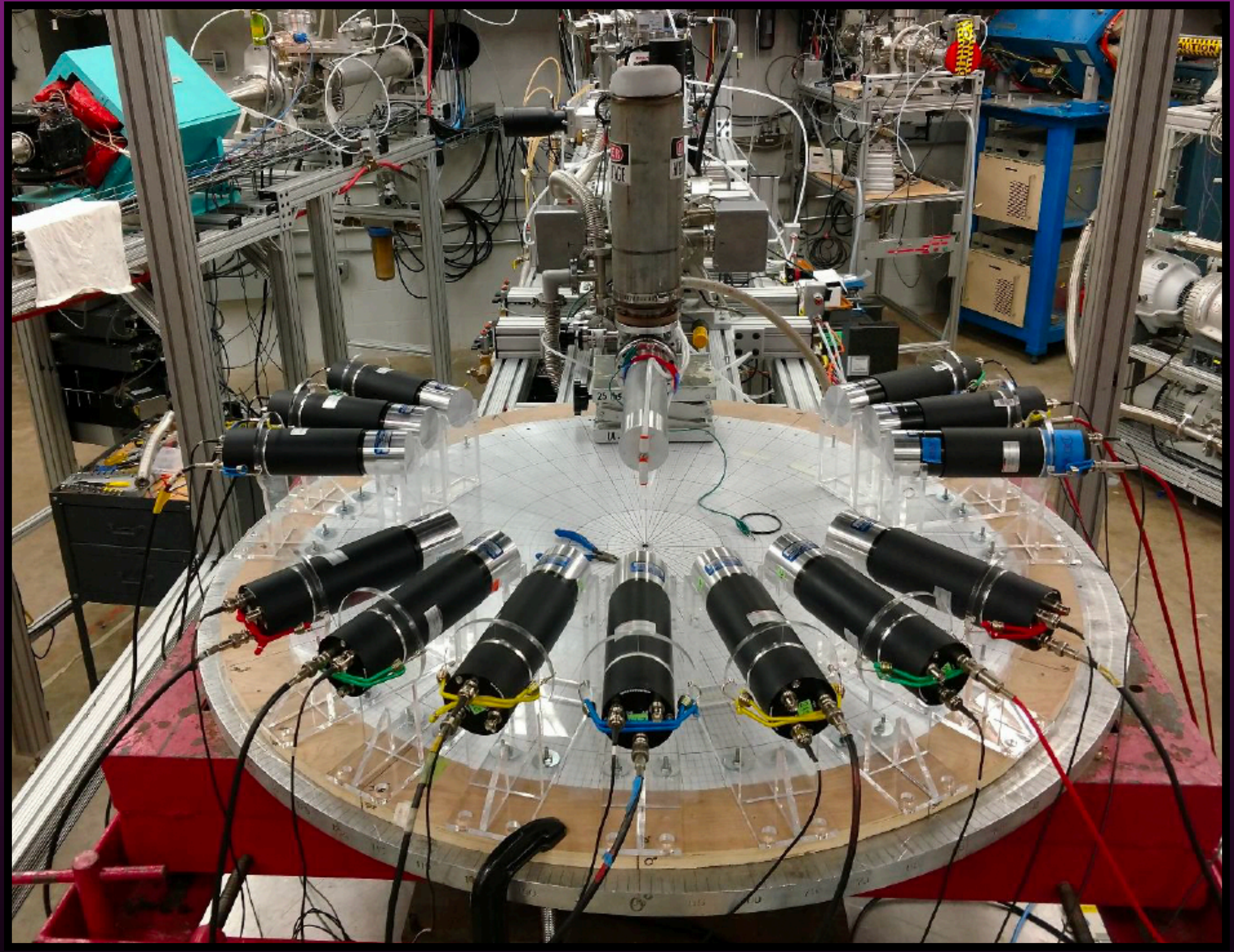
Measurements greatly hindered due to background (α, n) reactions on $^{13}C, ^{10,11}B, ^{17,18}O$ present in solid targets

Experimental Details



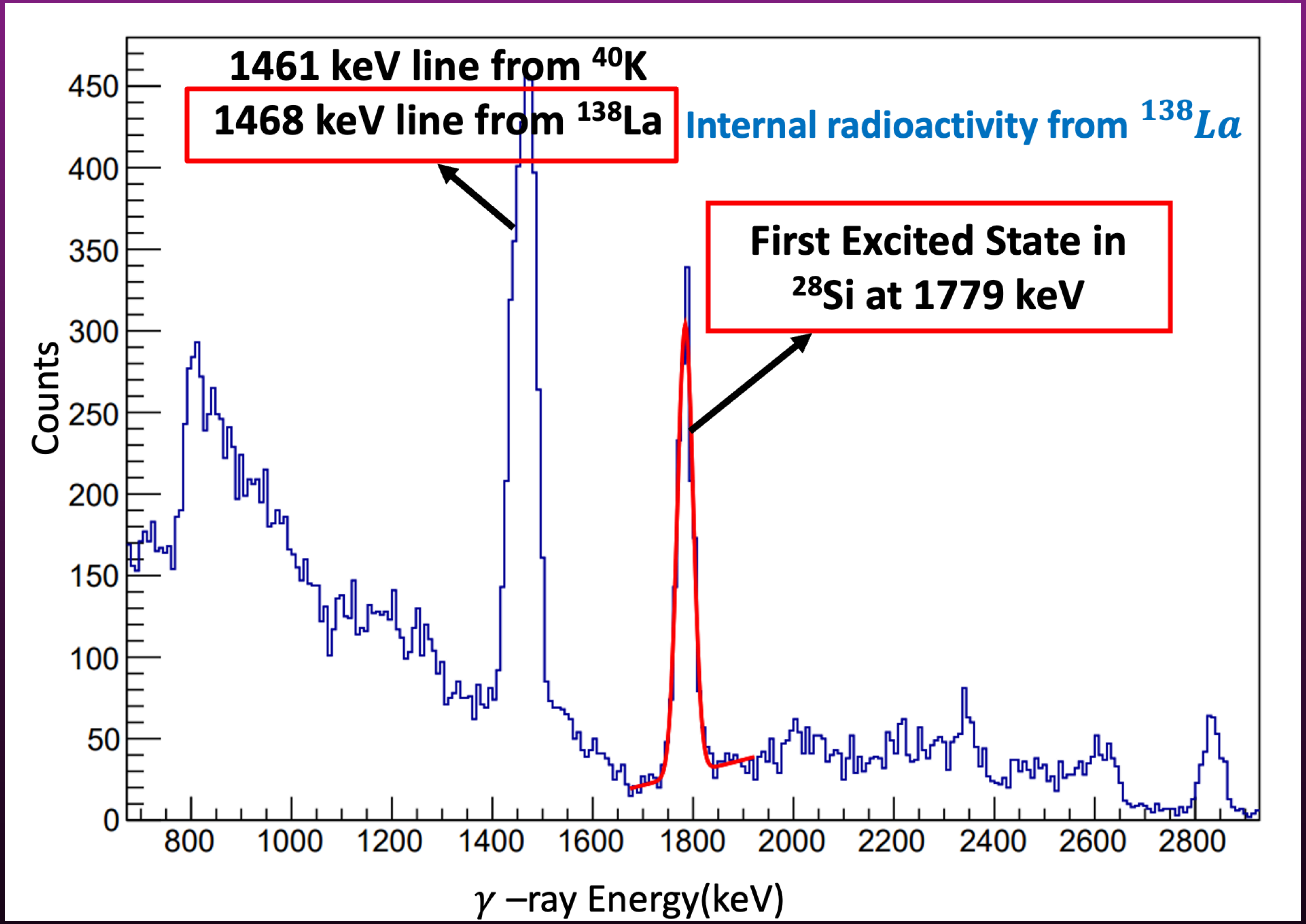
High Energy measurement: Secondary-γ-ray detection



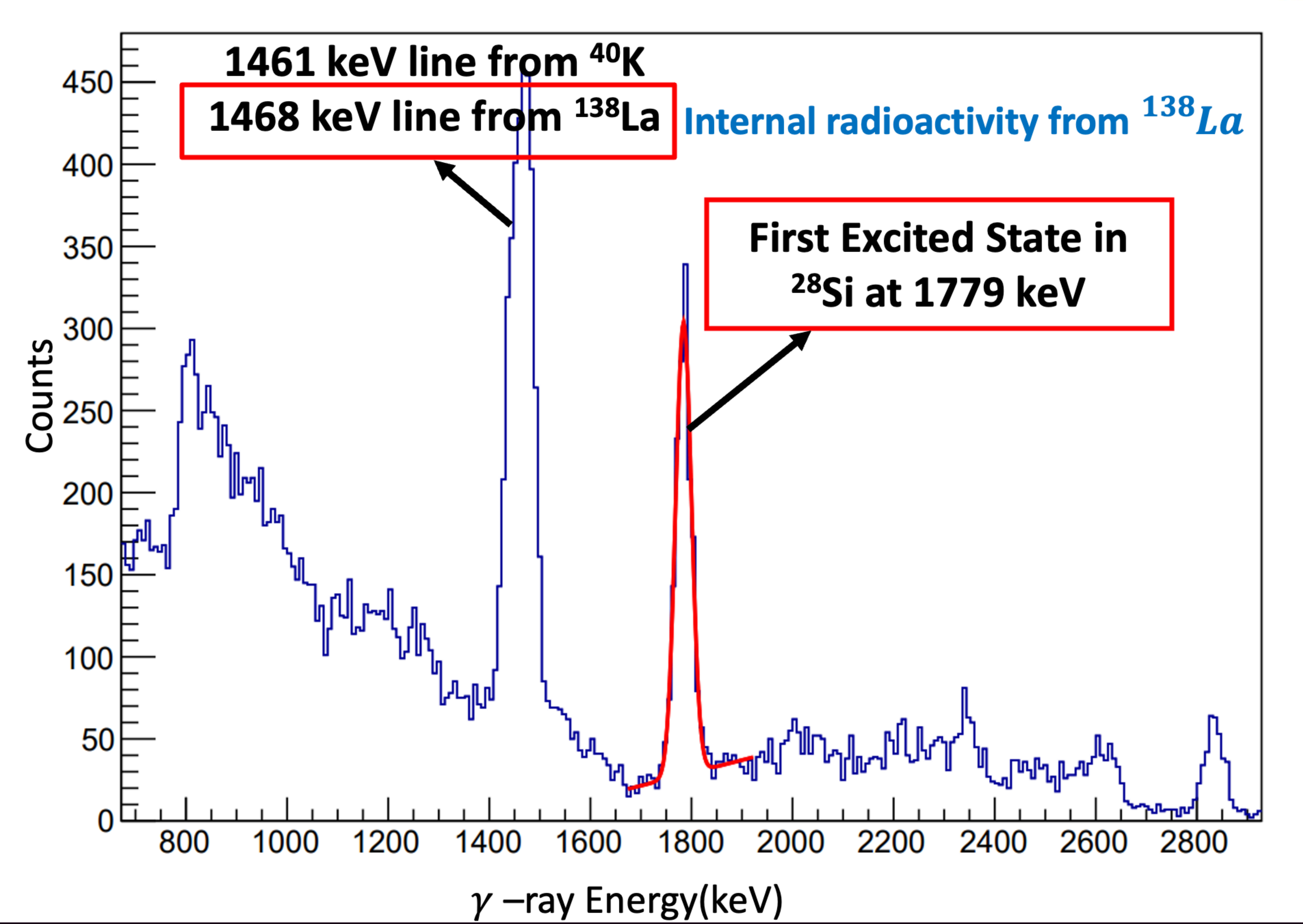


- 13 $LaBr_3$ detectors from the HAGRiD array provided by Kate Jones at UTK.
- For $2.35 < E_\alpha < 3.5$ γ-ray angular distribution was measured at 7 angles in far geometry every 20 keV.
- Angles symmetric about the beam direction

Secondary γ-ray Spectrum

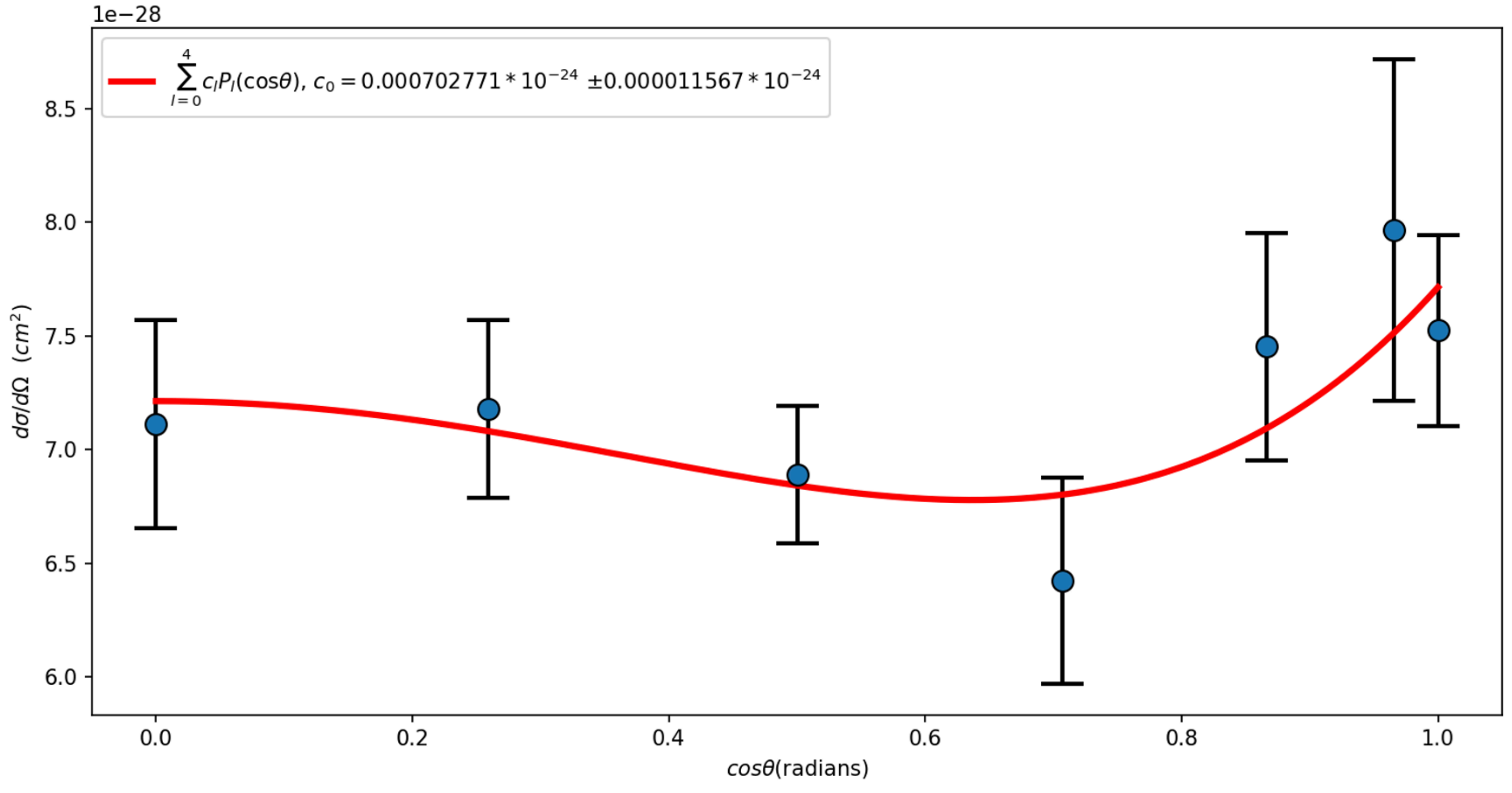


Secondary γ-ray Spectrum



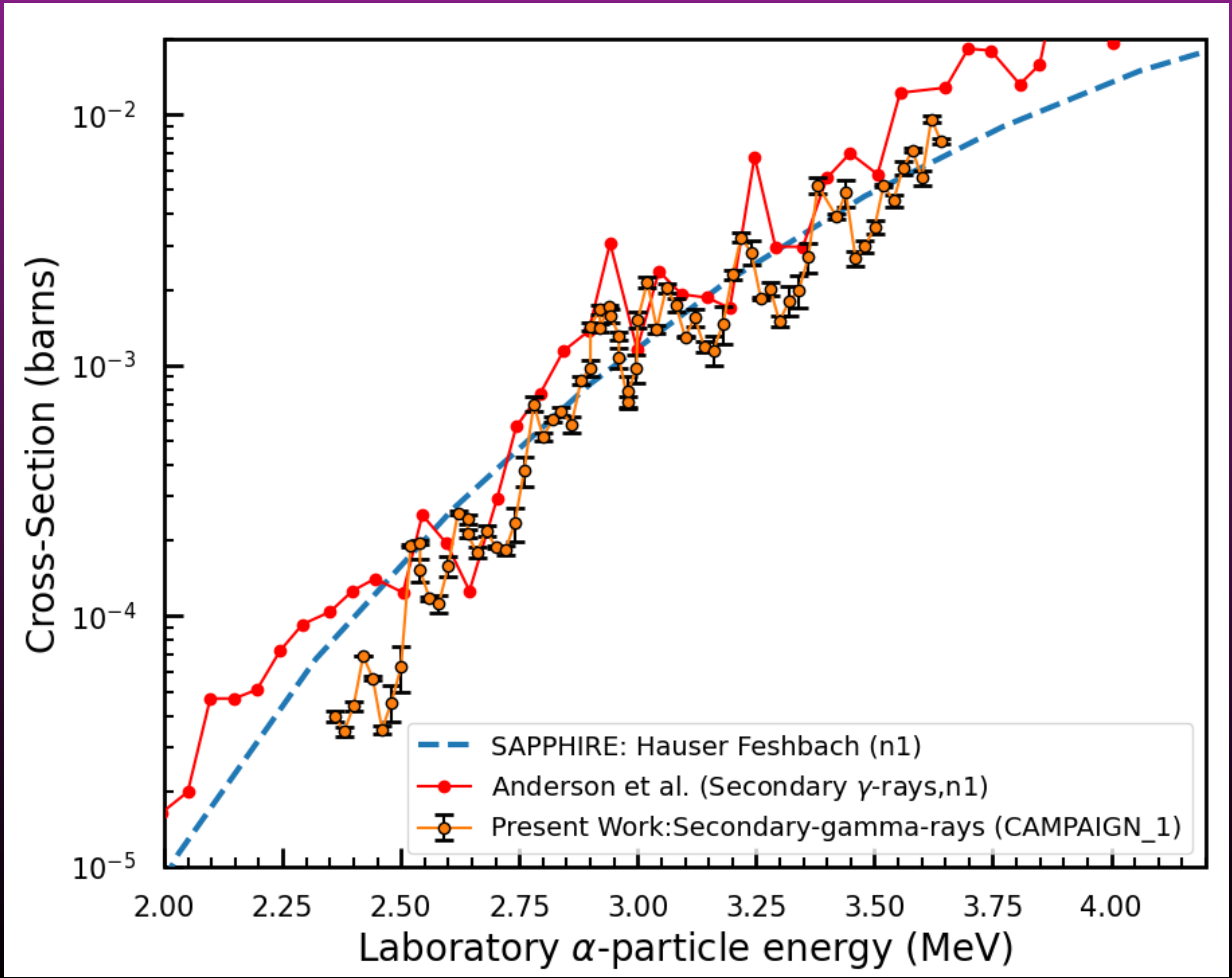
Angular distribution of γ-rays

$$\frac{d\sigma}{d\Omega} = \sum_n A_n P_n(\cos\theta)$$

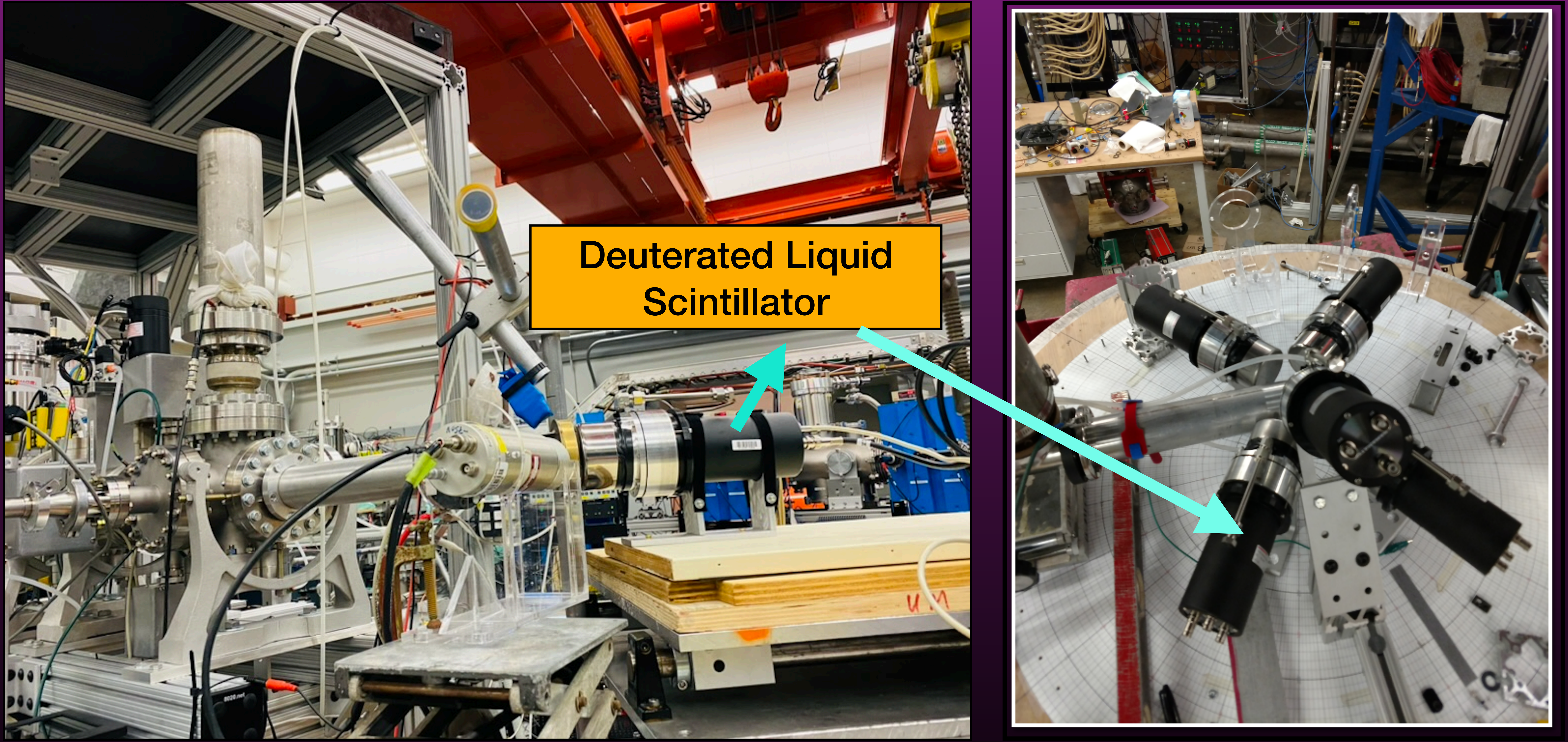


Angle intergrated cross-section = $4\pi a_0$

Cross-section from the high-energy measurement

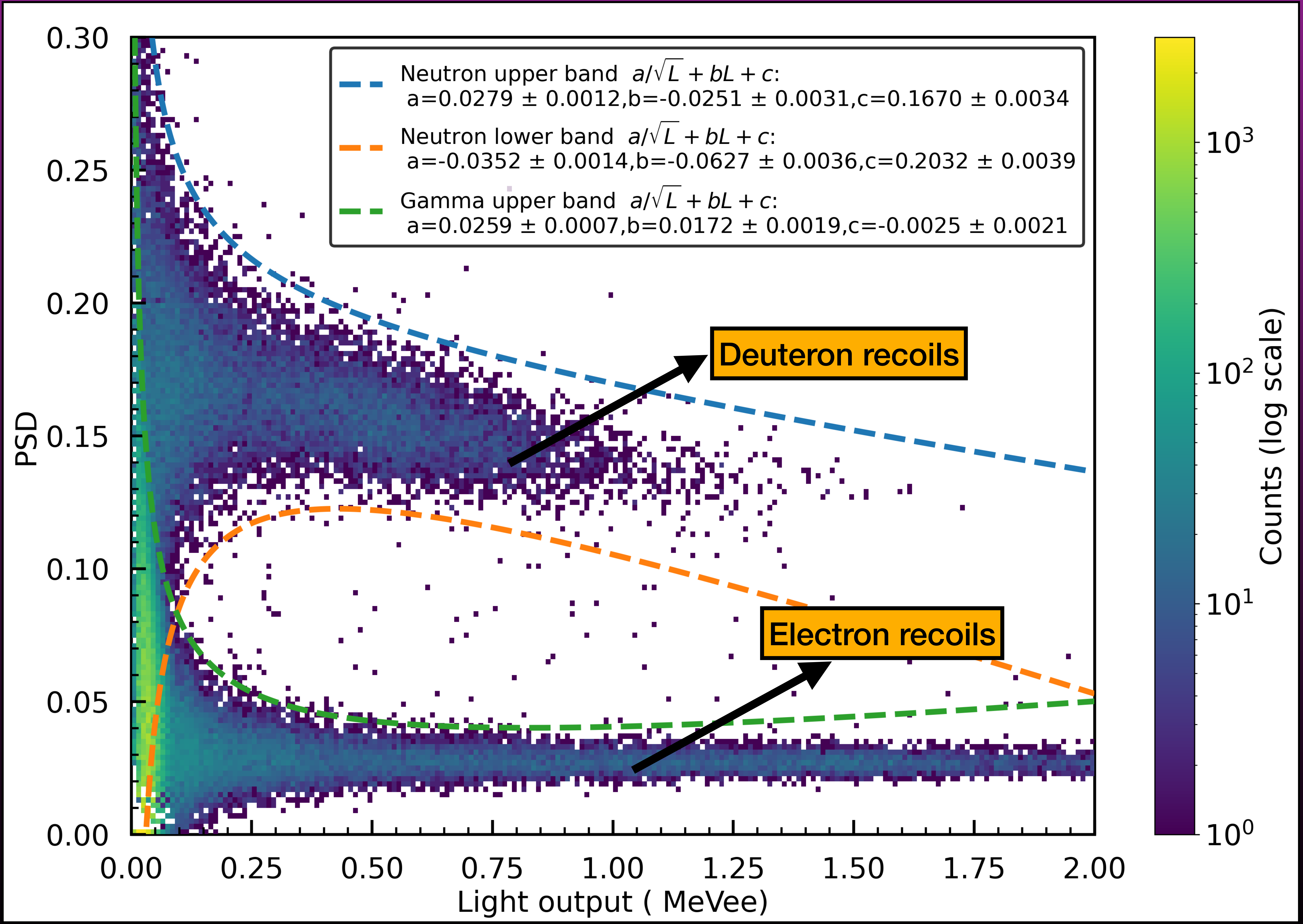


Neutron detection with ORNL Deuterated Spectroscopic Array - ODeSA



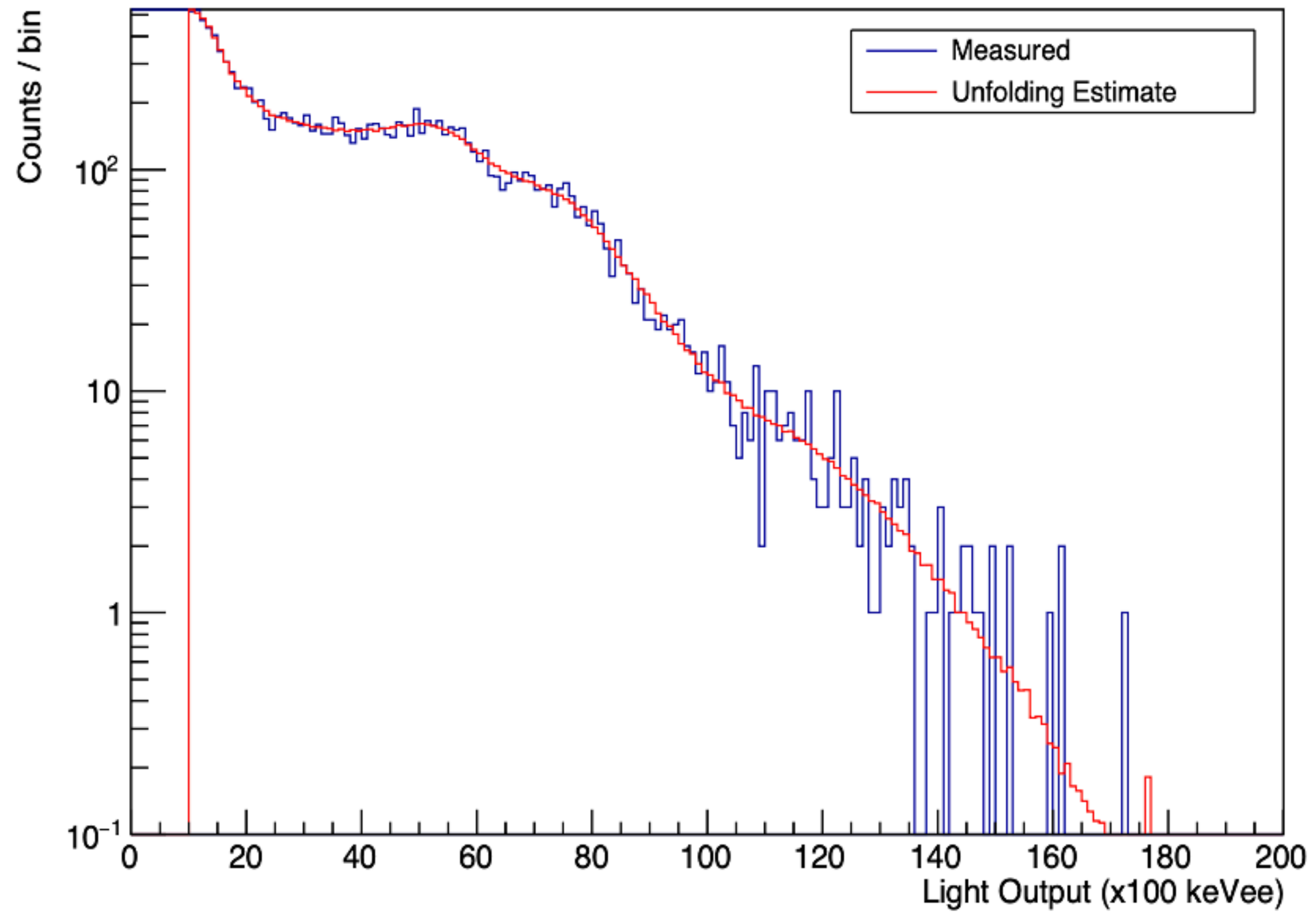
- Deuterated liquid scintillator detectors at 55°, 90° and two at 125° in close geometry to maximize efficiency.
- This low energy cross-section measurement covered $1.5 < E_{\alpha} < 3.5$ MeV

Pulse Shape Discrimination



Neutron Spectrum Unfolding using: MLEM
(Maximum-Likelihood Expectation Maximization)

Deuteron recoil-spectra



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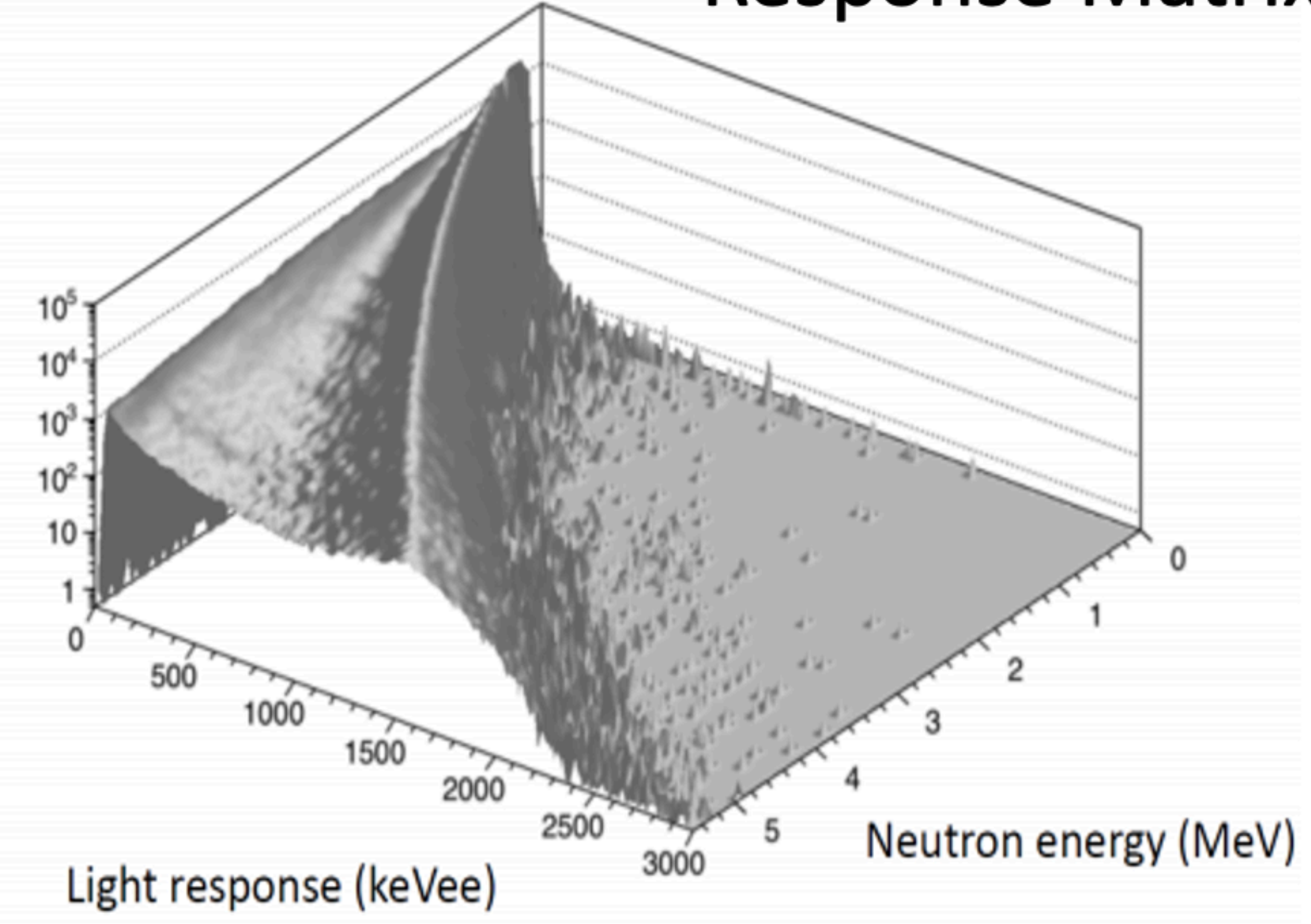
Response Matrix



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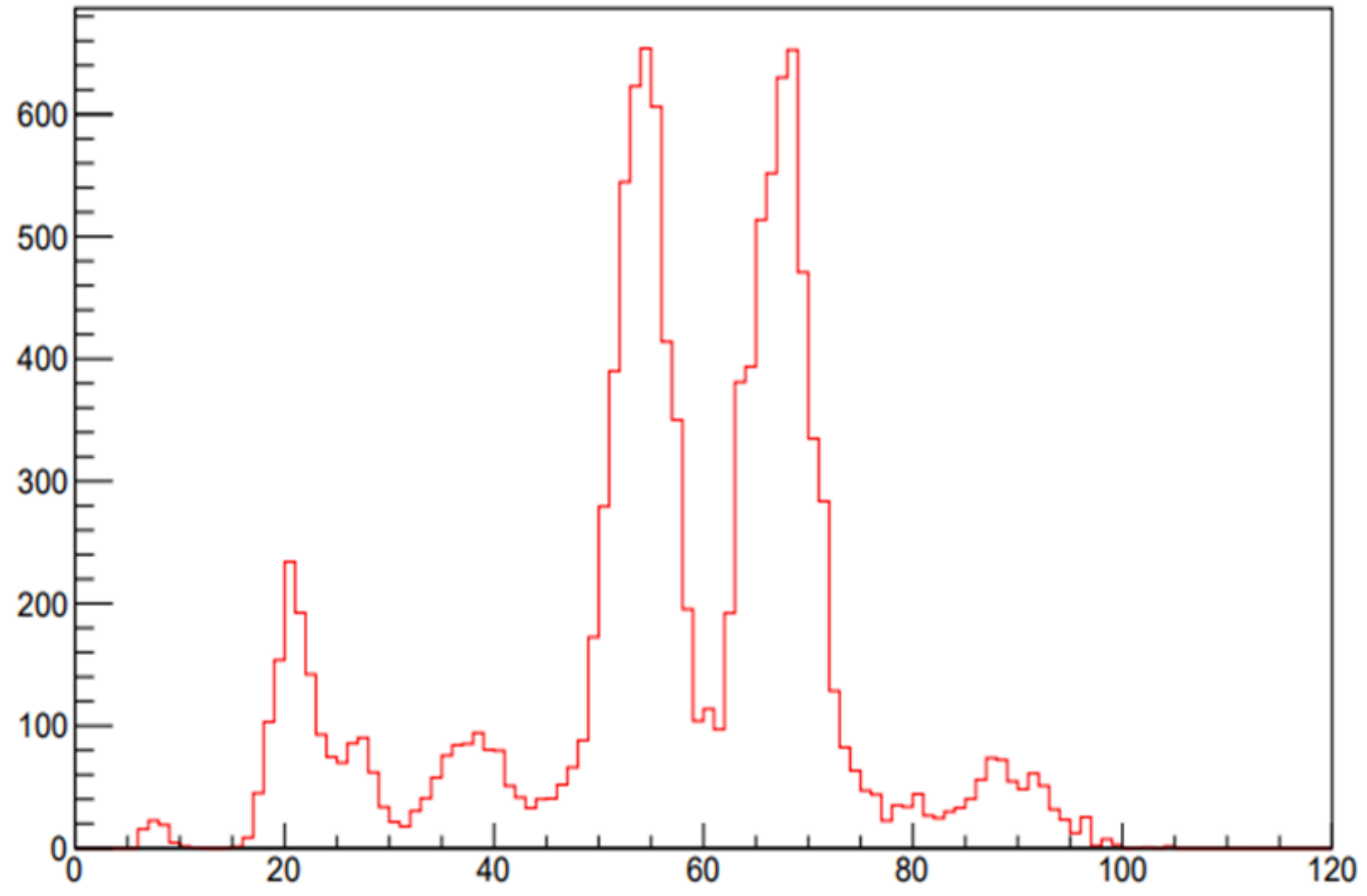
Unfolded neutron spectrum

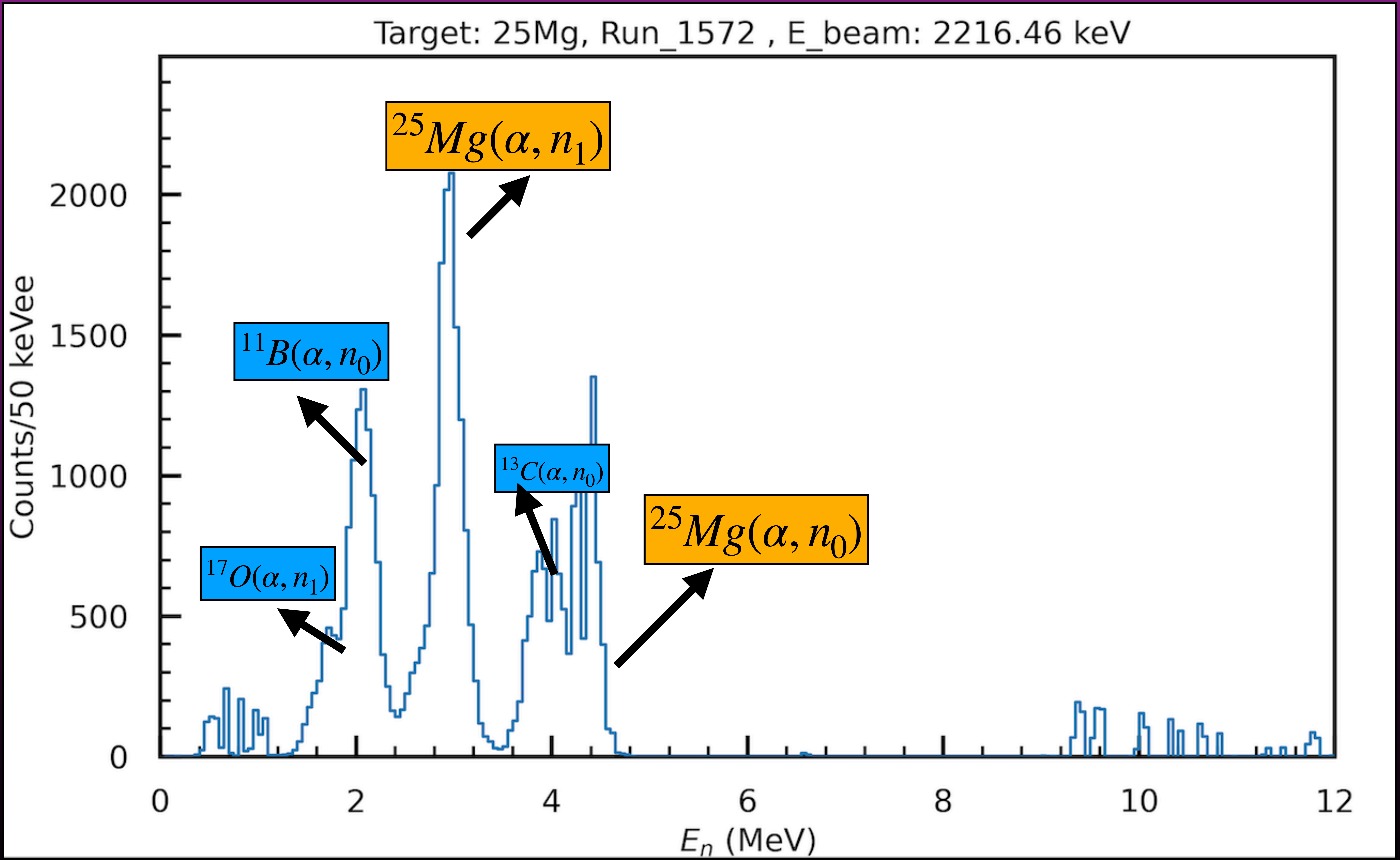


Mathematically,

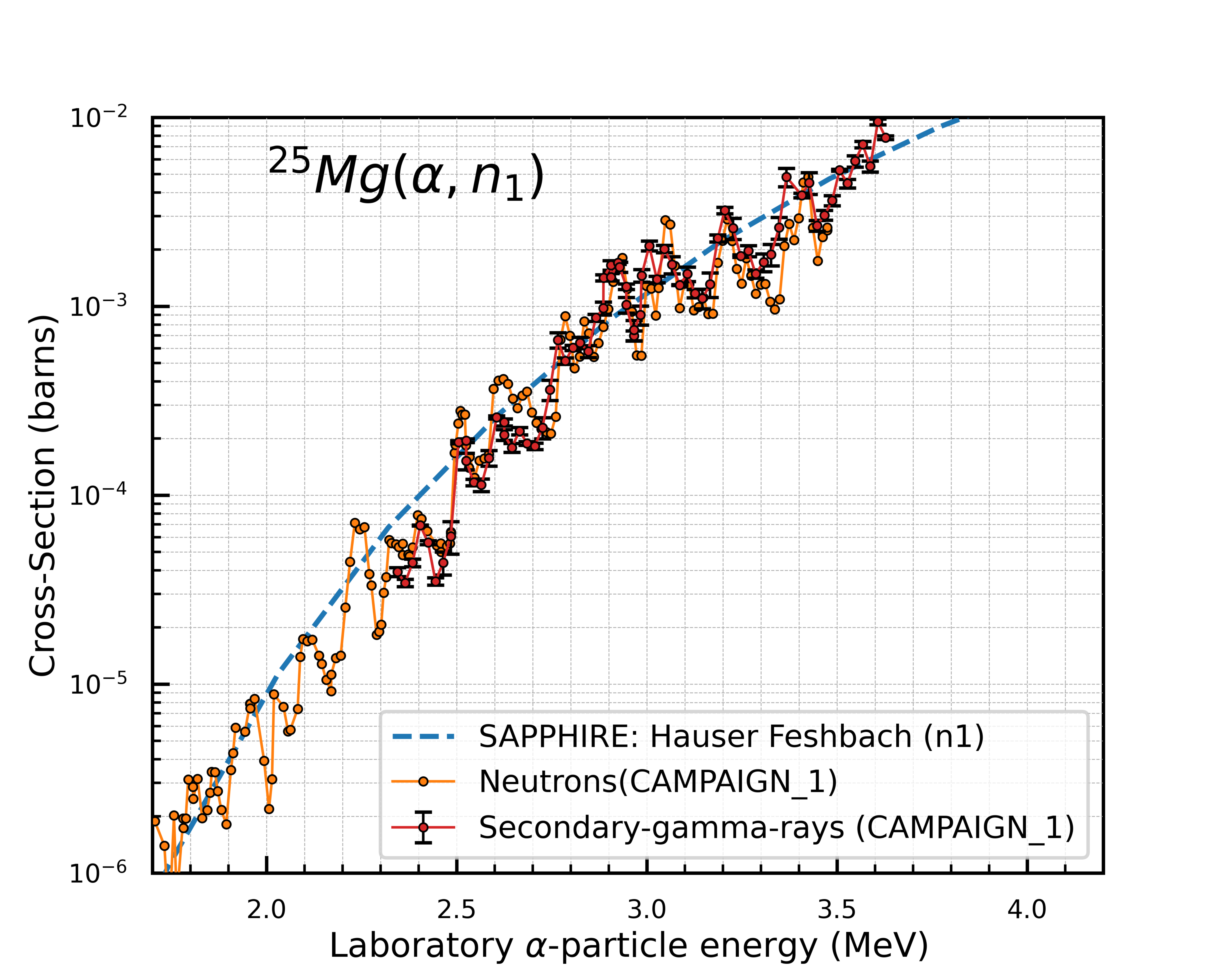
$$y_i = \sum_{j=1}^{J} r_{ij} x_j$$

y_i: No. of counts in the i^{th} bin of PHS
x_j: Incident neutron flux
r_{ij}: element of the response matrix of the detector

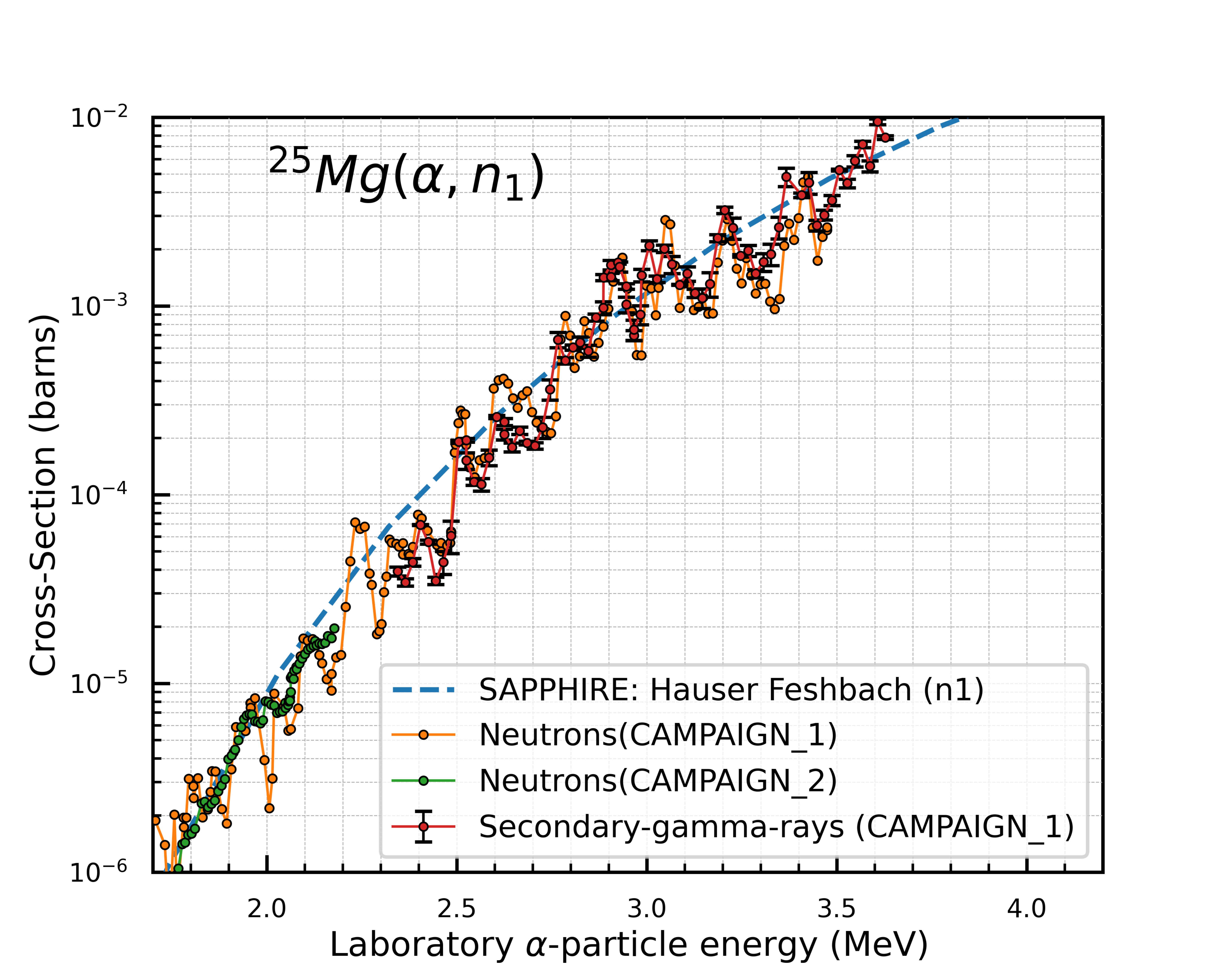
Unfolded Neutron Spectrum



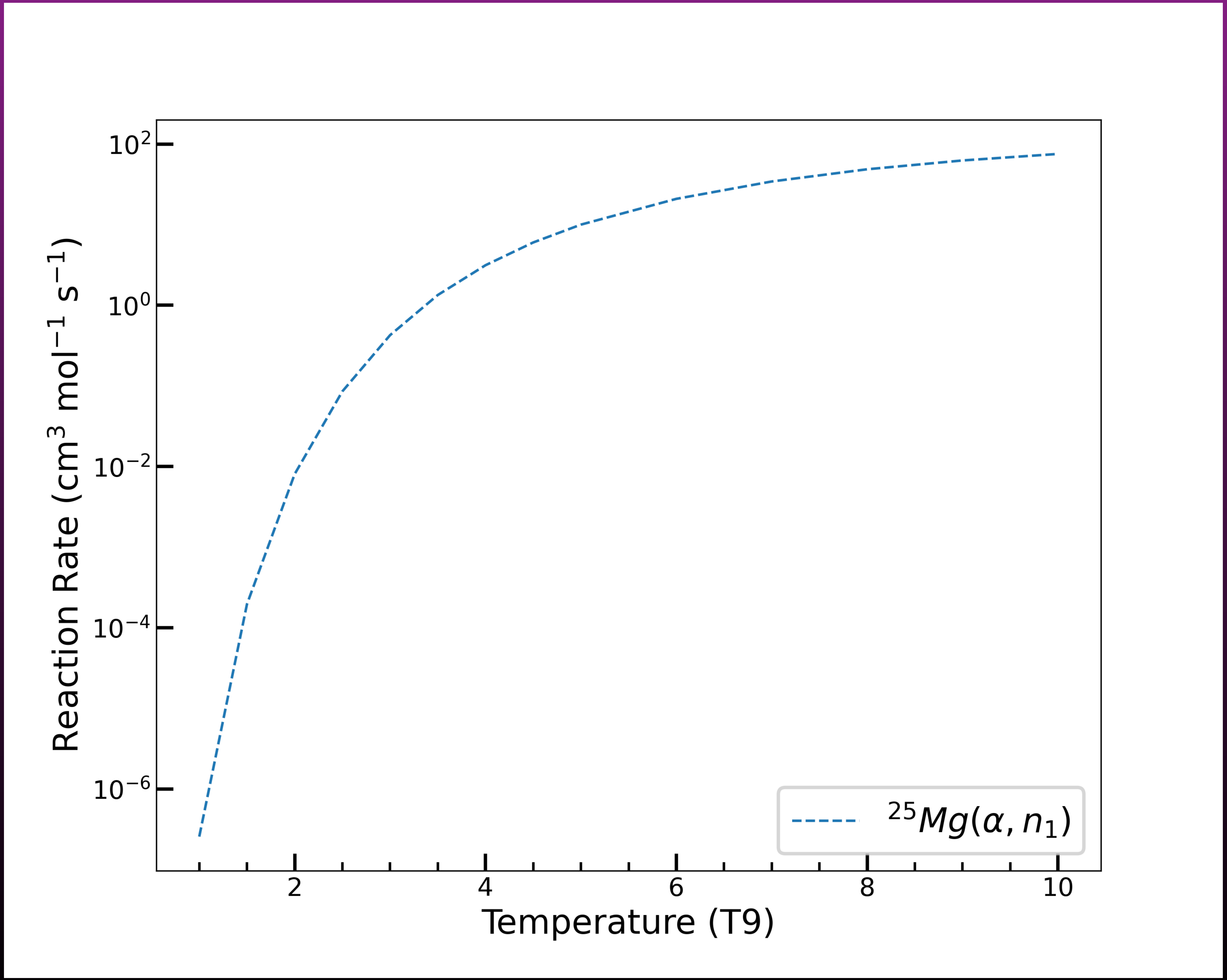
Cross-section from the low-energy measurement



Cross-section from the low-energy measurement



Preliminary reaction-rate



Summary

- New low energy-measurement of the $^{25}Mg(\alpha, n)^{28}Si$ cross-section have been performed over the energy range $1.5 < E_\alpha < 3.5$ MeV.
- Good agreement has been found with the previous data of Anderson et al. in the overlapping energy range.
- The cross-section agrees well with the Hauser-Feshbach calculations.
- Have identified different background contributions which hindered previous counter meaurements.
- The cross-section from the neutron measurement interpolated to get the preliminary reaction-rate.

Thanks!

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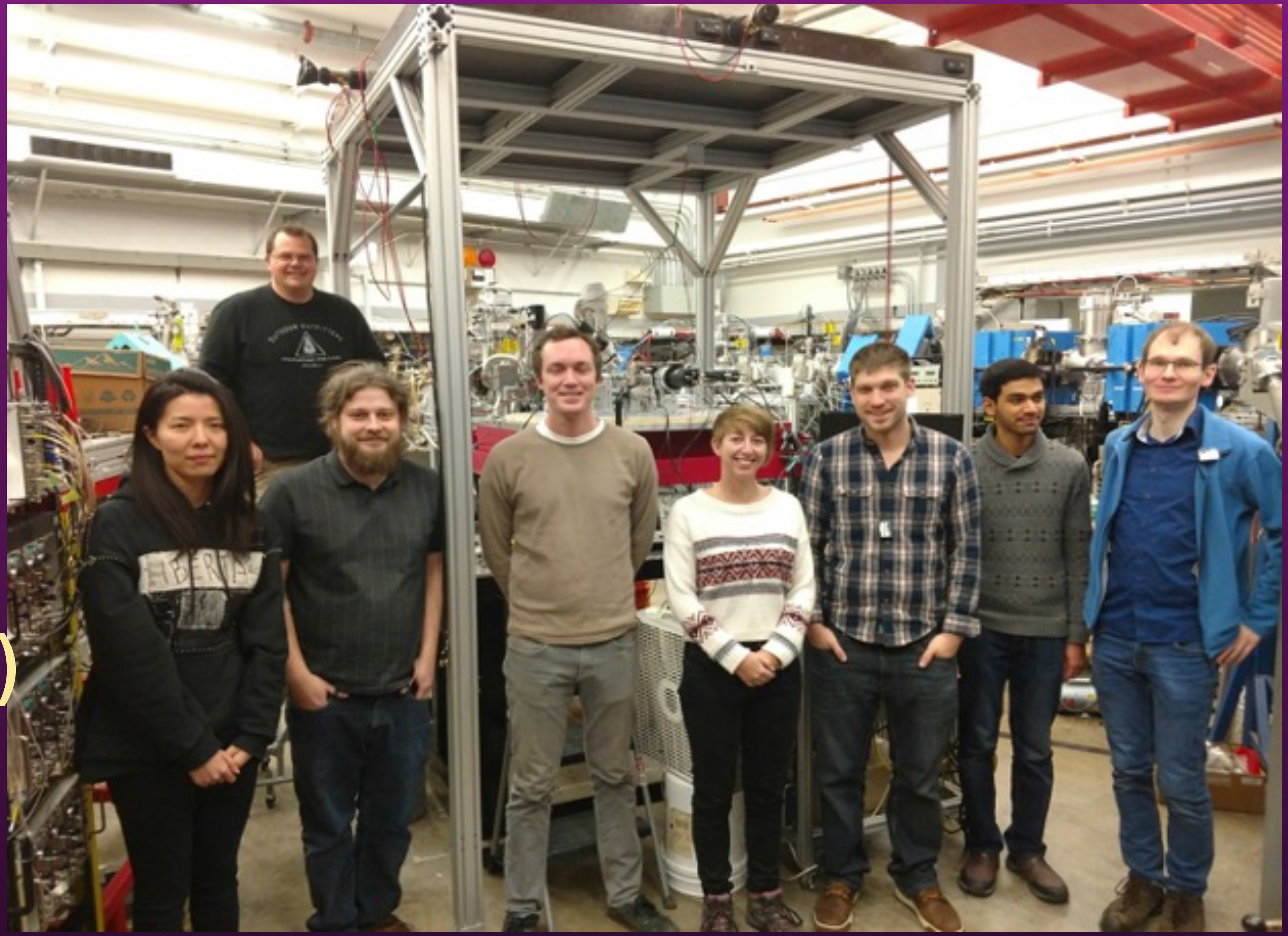

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