New results on low energy $^{22}Ne(\alpha,n)^{25}Mg$ with SHADES at the LNGS Bellotti facility

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LUNA Laboratory for Underground Nuclear Astrophysics
INFN Istituto Nazionale di Fisica Nucleare
erc European Research Council Established by the European Commission
MUR Ministero dell'Università e della Ricerca

Astrophysical Motivation

$^{22}\mathrm{Ne}(\alpha, \mathrm{n})^{25}\mathrm{Mg}$ pivotal for:

- S-process nucleosynthesis
- Isotopic ratios of $^{24,25,26}\mathrm{Mg}$
- Nucleosynthesis of $^{60}\mathrm{Fe}$

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Weak component in massive stars:

T=0.36-0.37 GK,
density $N_n=10^{11\text{-}13}$ n/cm-3
$60 \leq A \leq 90$

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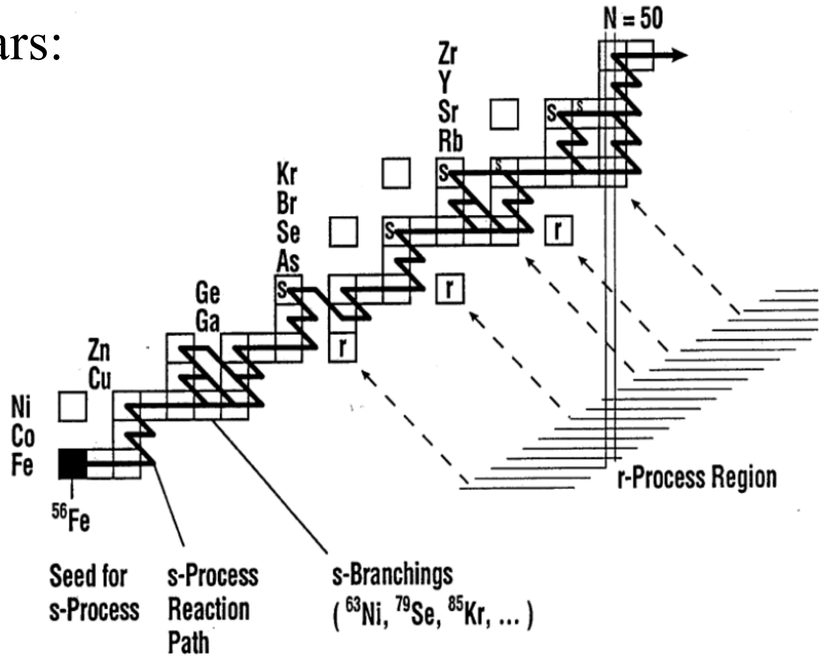

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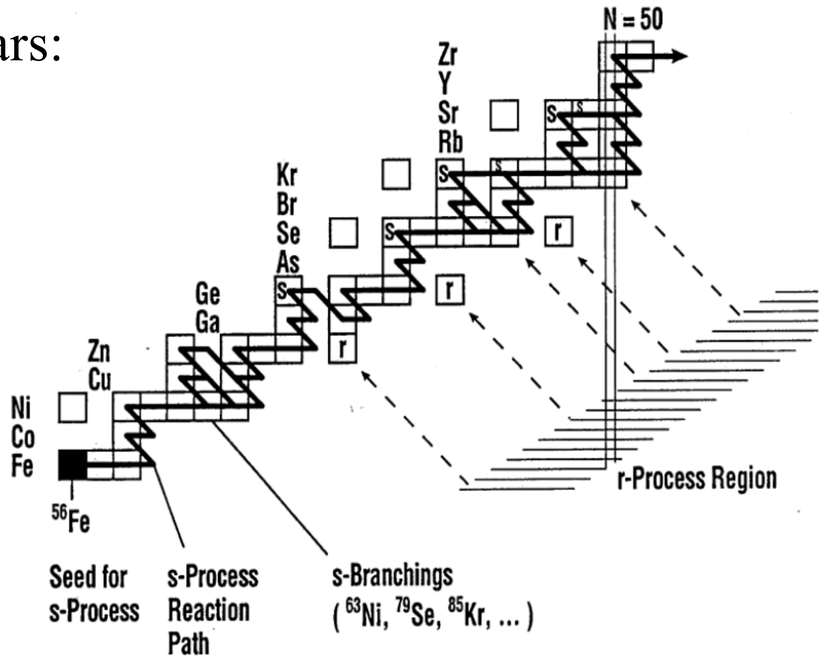

Stellar reaction rates for
$^{22}Ne(\boldsymbol{\alpha},\boldsymbol{n})^{25}Mg$ and $^{22}Ne(\boldsymbol{\alpha},\boldsymbol{\gamma})^{26}Mg$ required

State of the art

$$N_A < \sigma v > = \left(\frac{8}{\pi\mu}\right)^{\frac{1}{2}} \frac{N_A}{(k_B T)^{3/2}} \int_0^{\infty} \boldsymbol{\sigma}(\boldsymbol{E}) E e^{-E_r/k_B T} dE$$

Need to be known in the Gamow window
(E_α= 600 – 900 keV)

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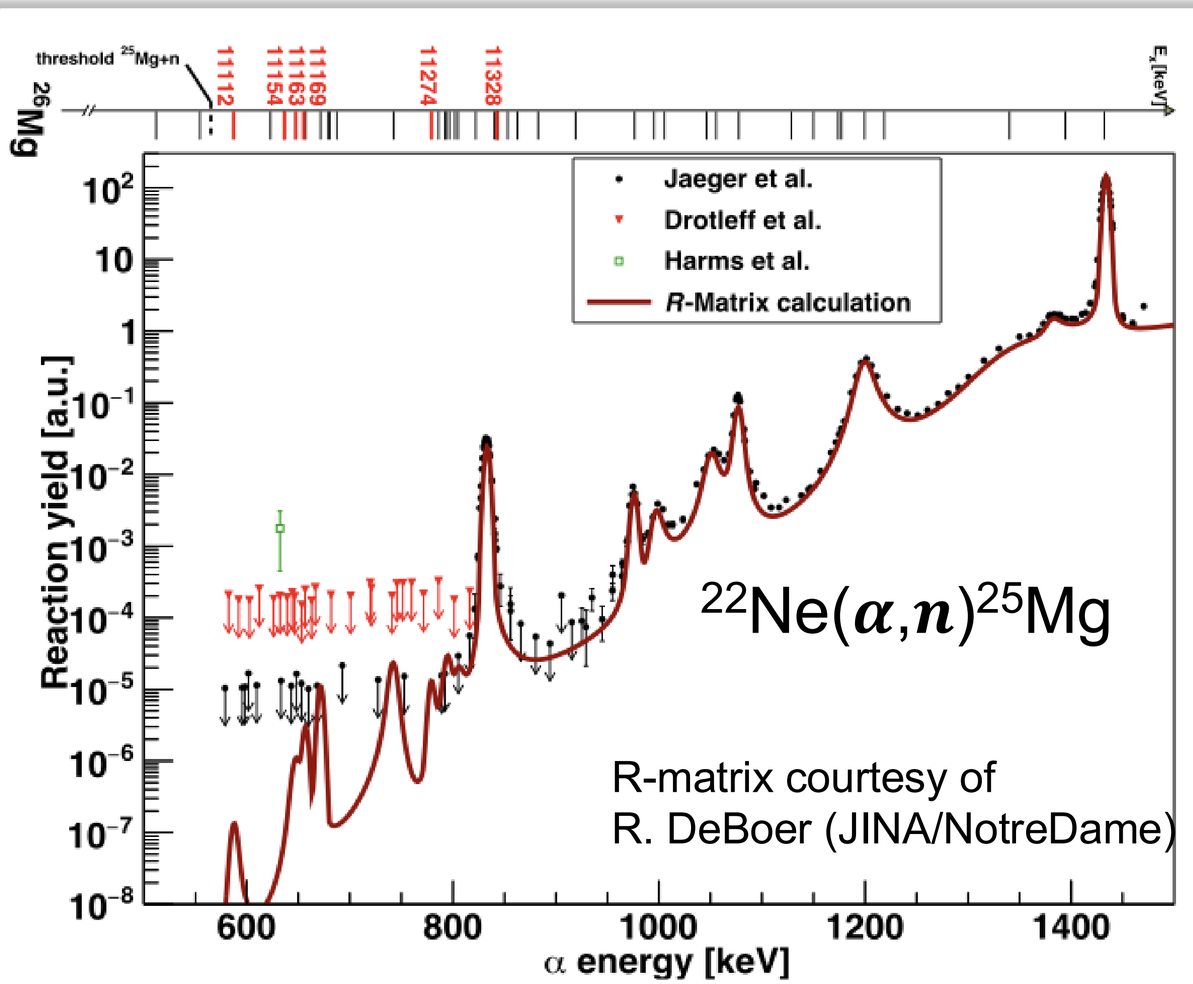

- Extremely low values (~ pb)
- High level density in ^{26}Mg

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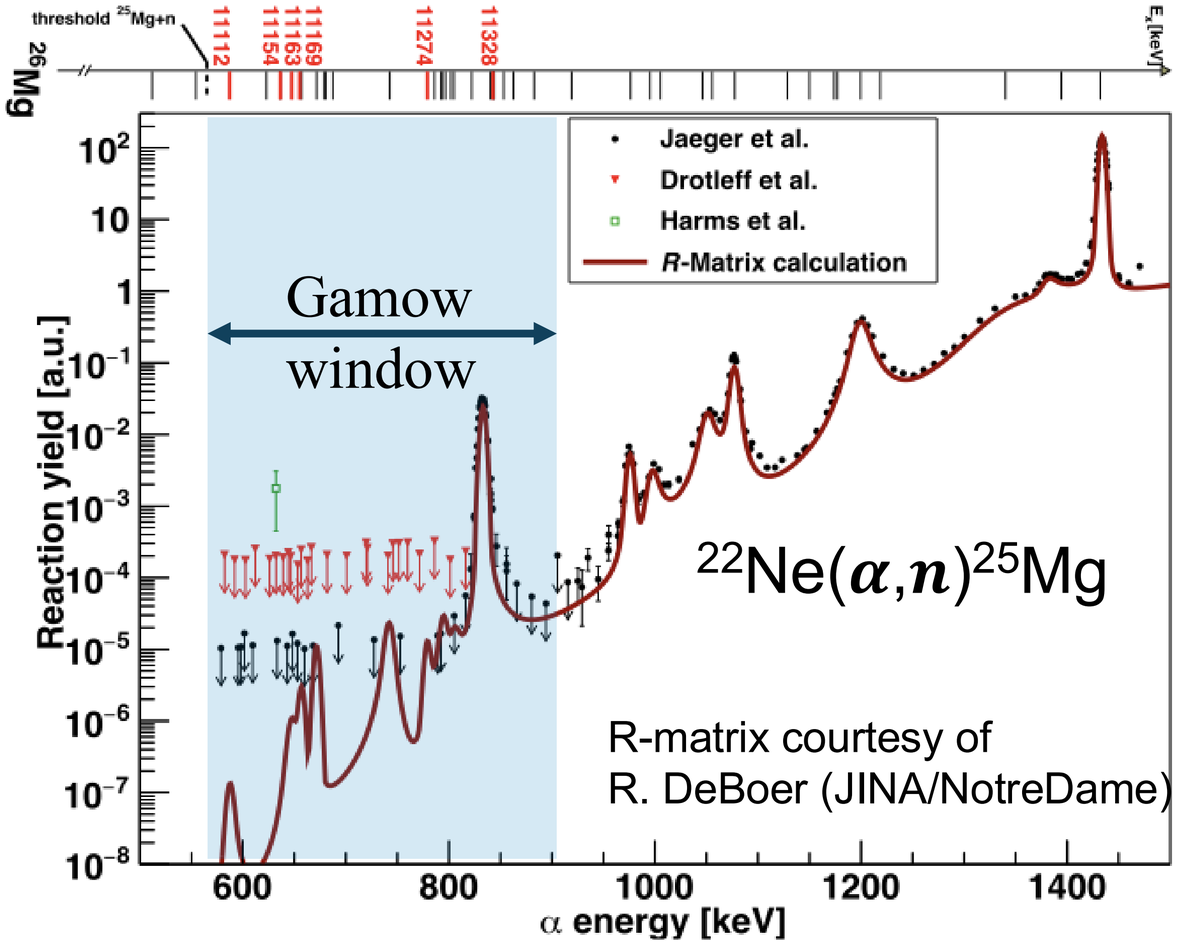

Direct measurement strongly hampered by **cosmogenic neutrons** (>100 counts/h)

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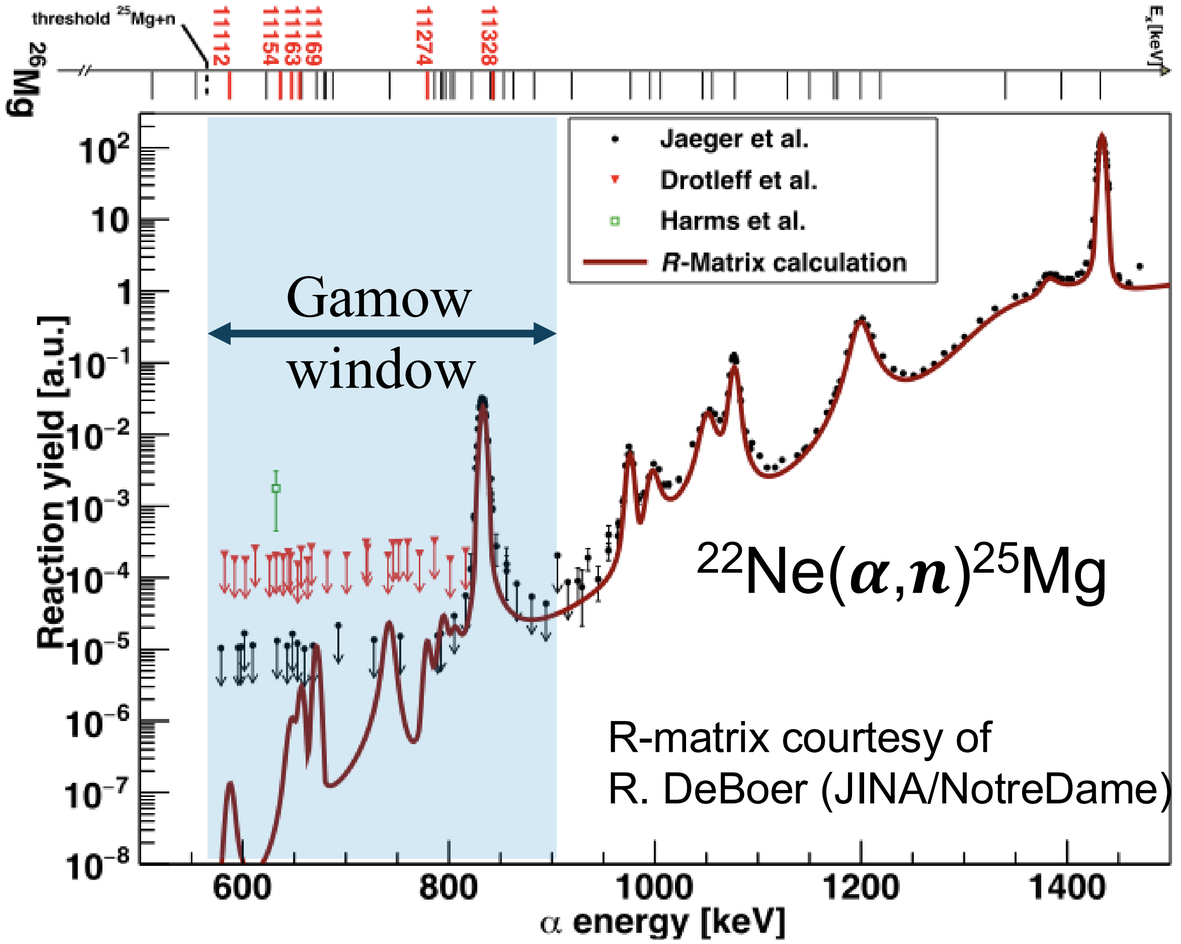

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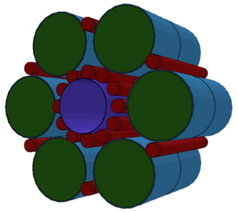
BEST, Andreas, et al. The ^{22}Ne(α, n)^{25}M reaction-state of the art, astrophysics, and perspectives. The European Physical Journal A, 2025, 61.5: 1-15.

SHADES Scientific Goal

First deep-underground direct measurement of the $^{22}Ne(\alpha,n)^{25}Mg$ cross-section in the range of astrophysical interest (E_α= 597-900 keV)



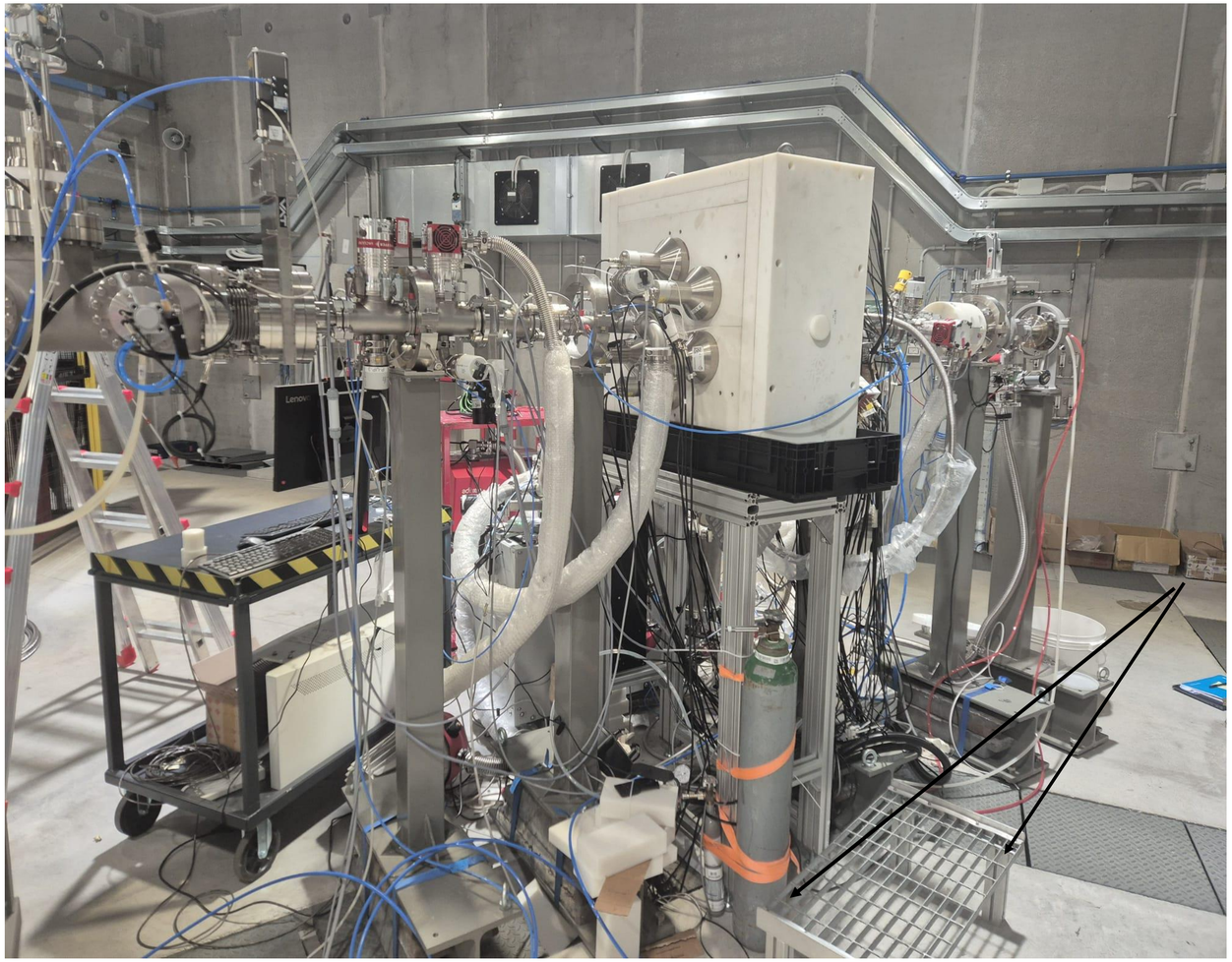
Hybrid array for neutron detection

Deep underground location at Bellotti IBF, LNGS

Beam-induced background reduction techniques

SHADES Experimental Setup

- >99% enriched ^{22}Ne windowless gas target
- He^{+} beam, I up to 500 μA



Gas target line of the Bellotti IBF

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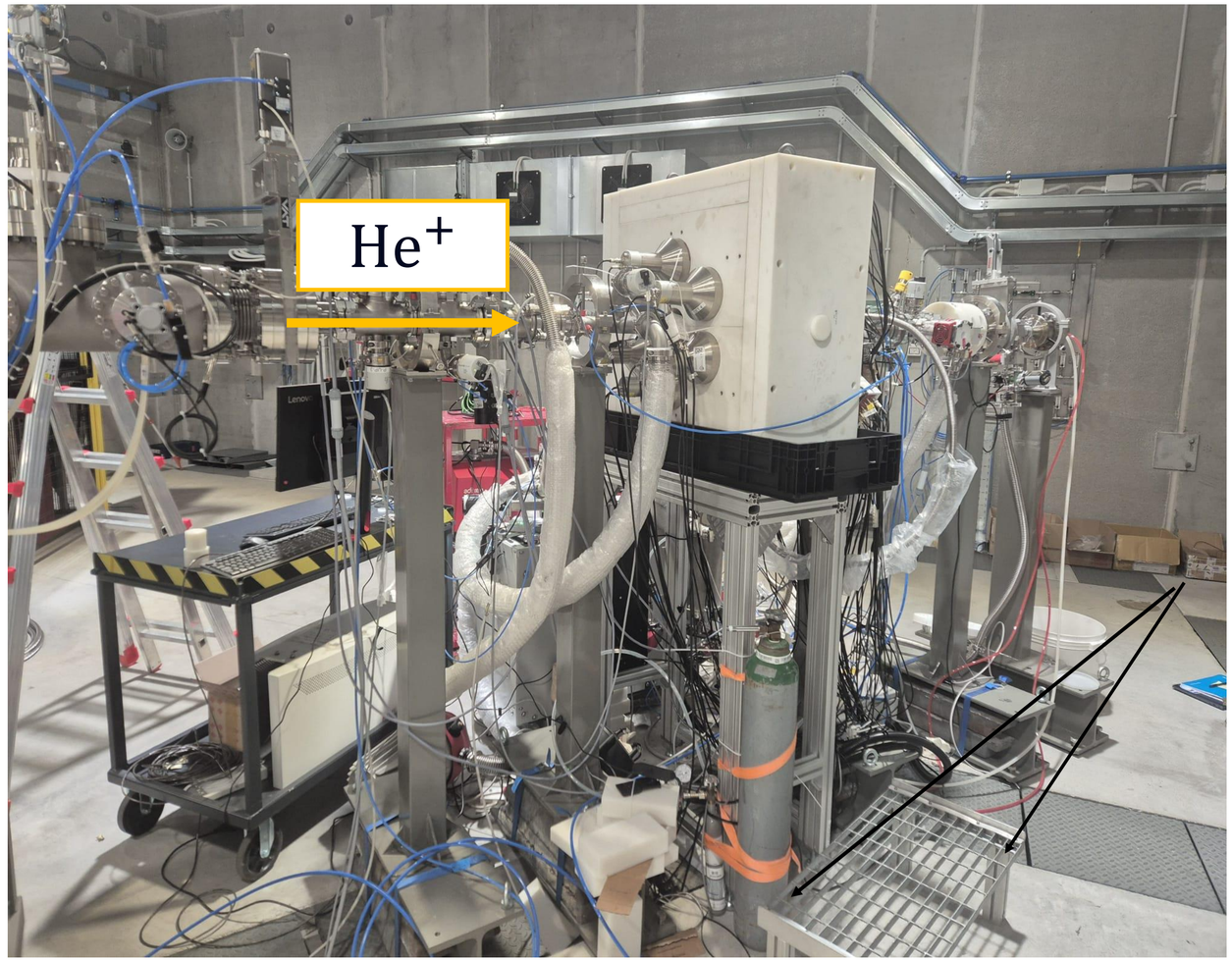

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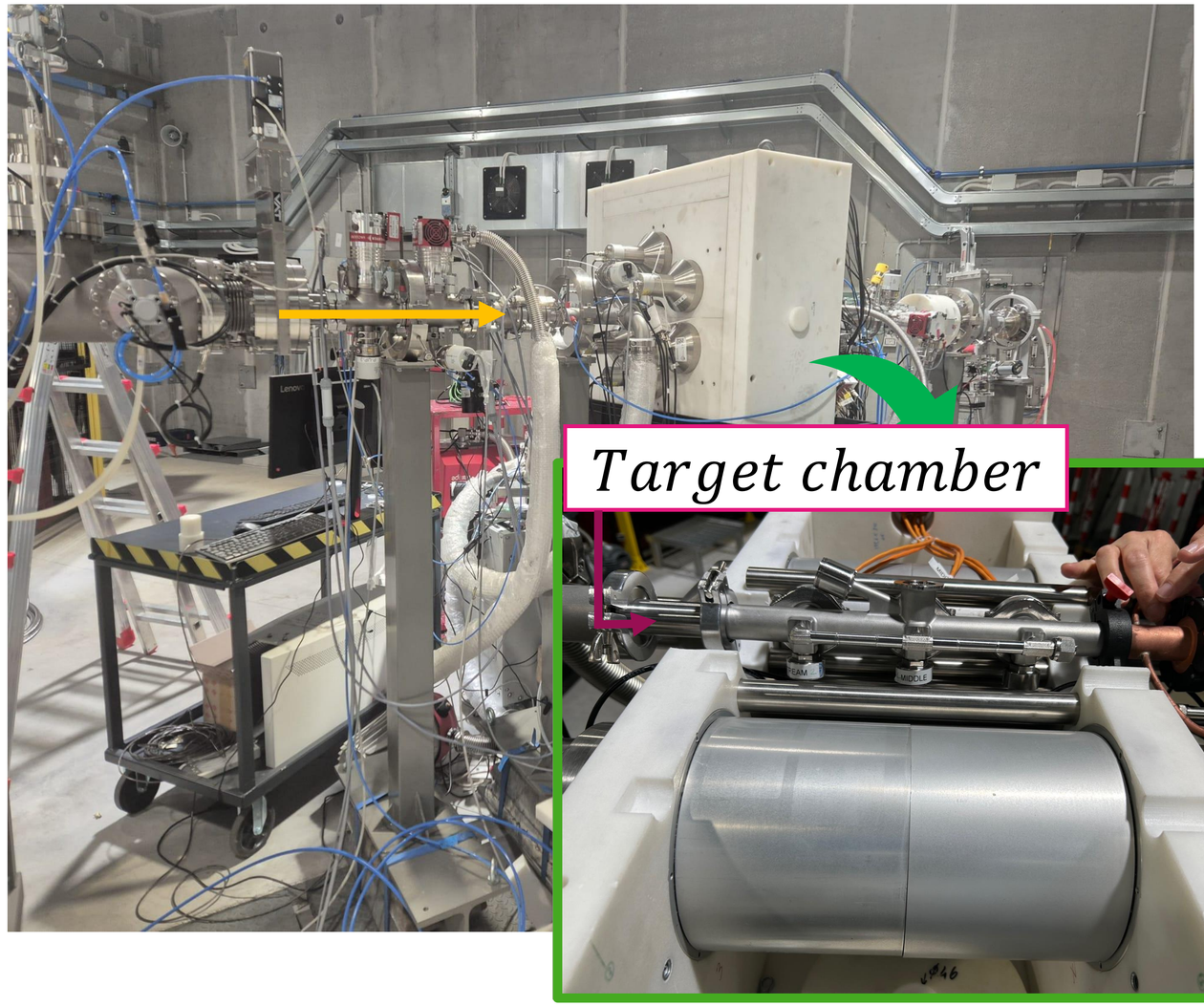

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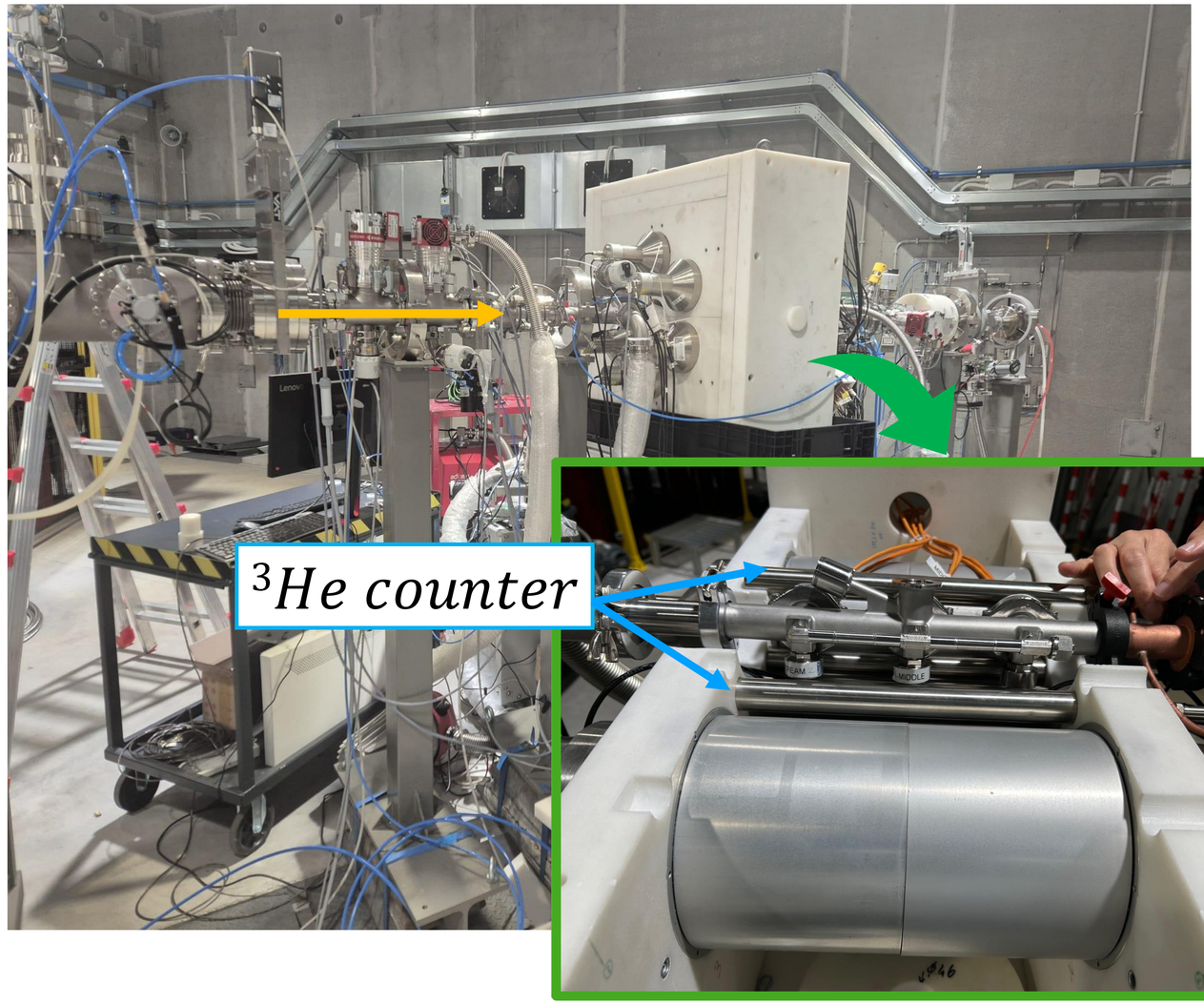

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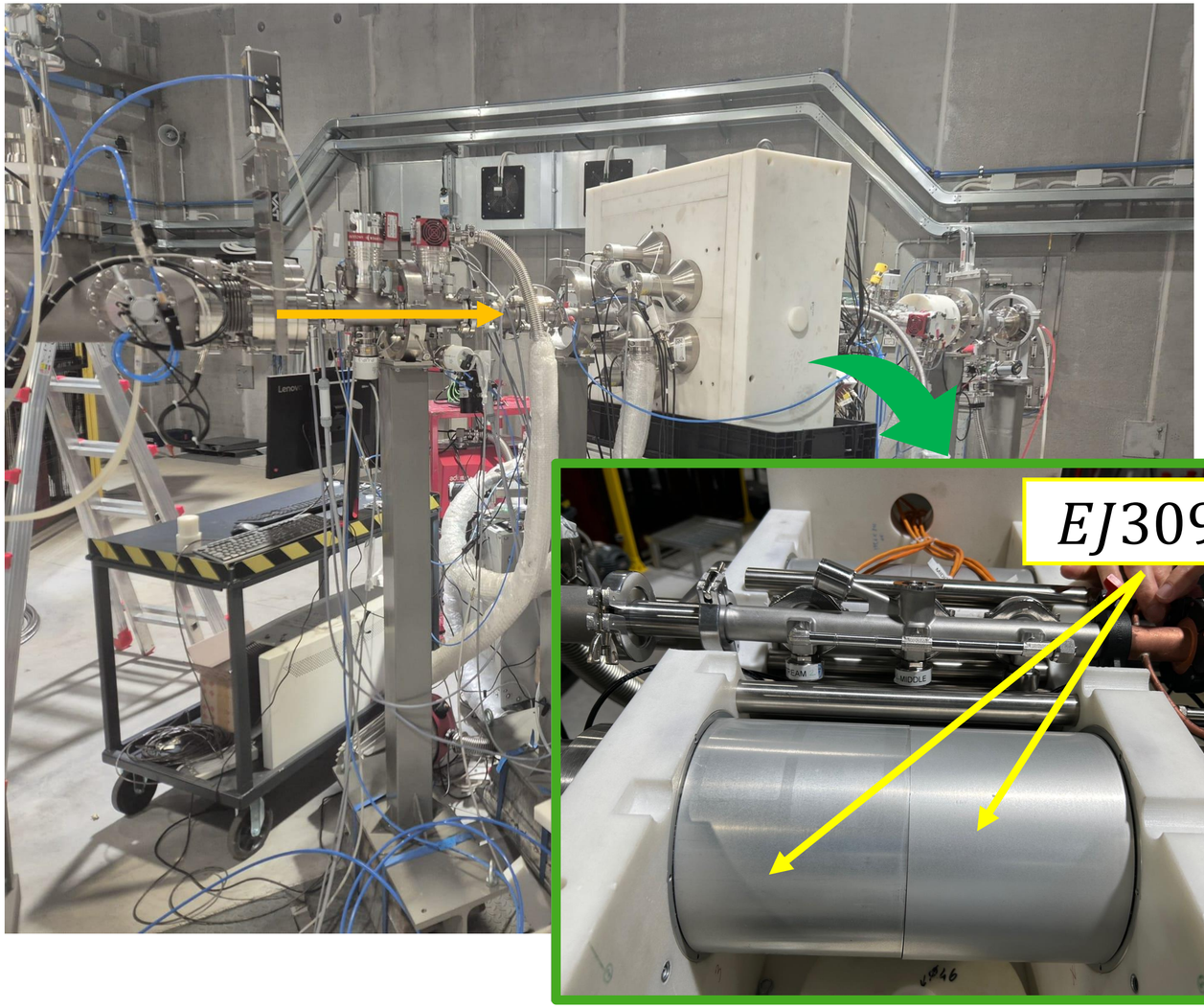
- 12 EJ309 liquid scintillators



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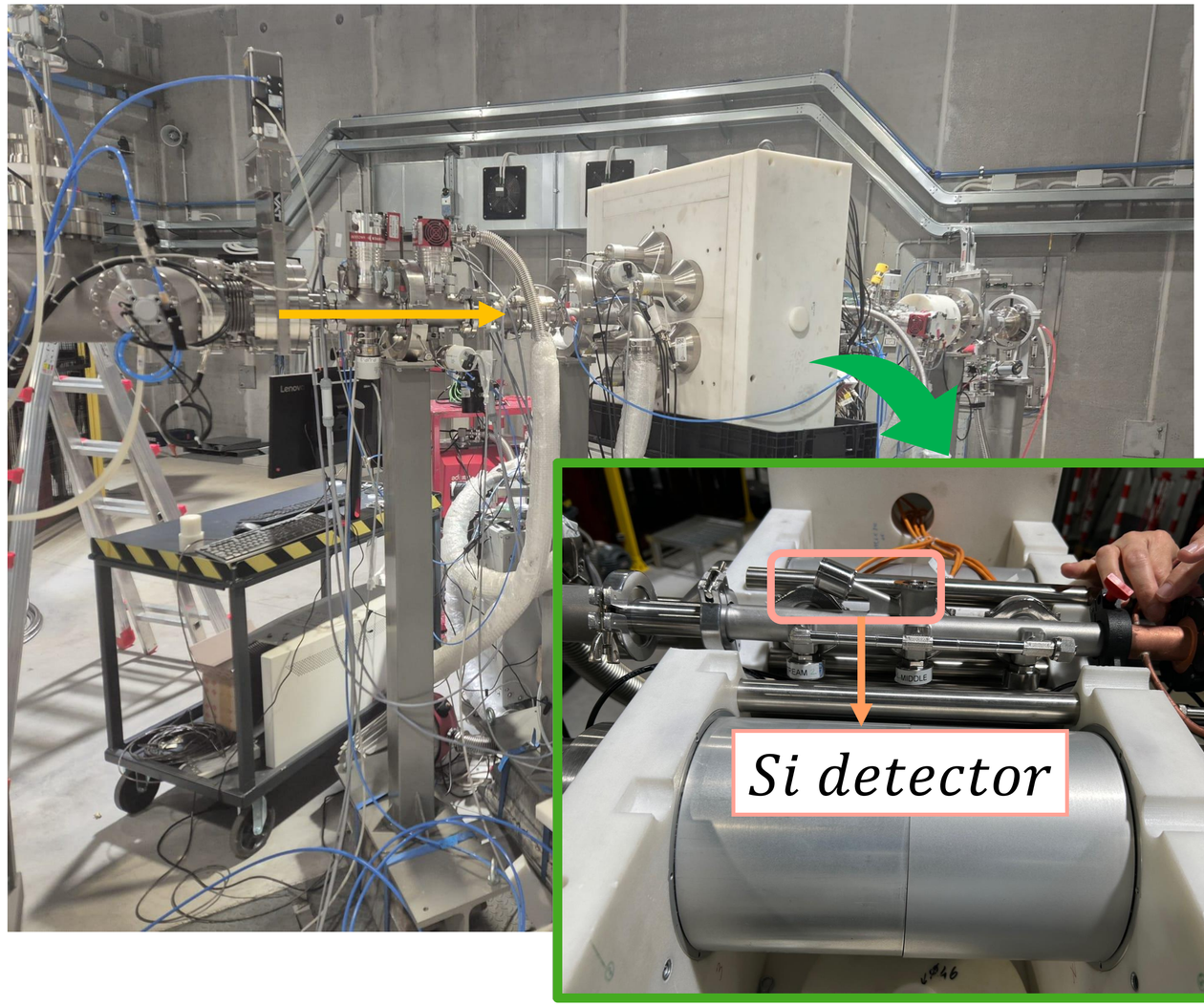

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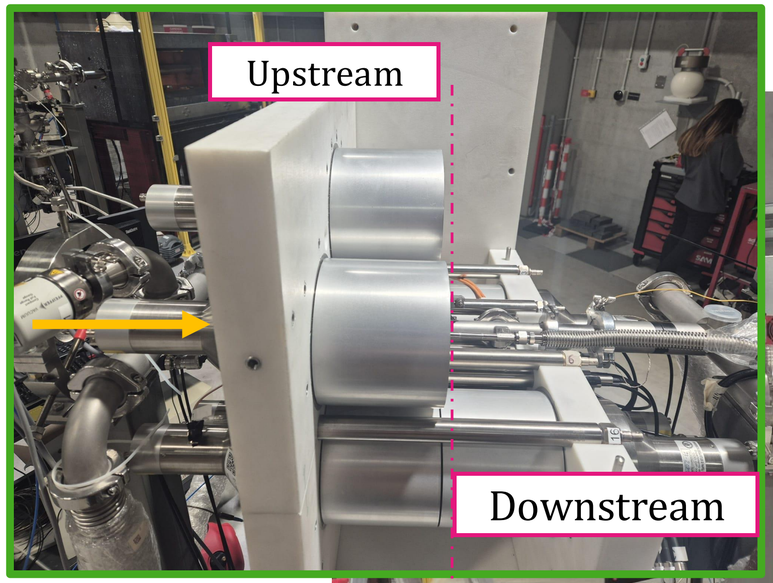

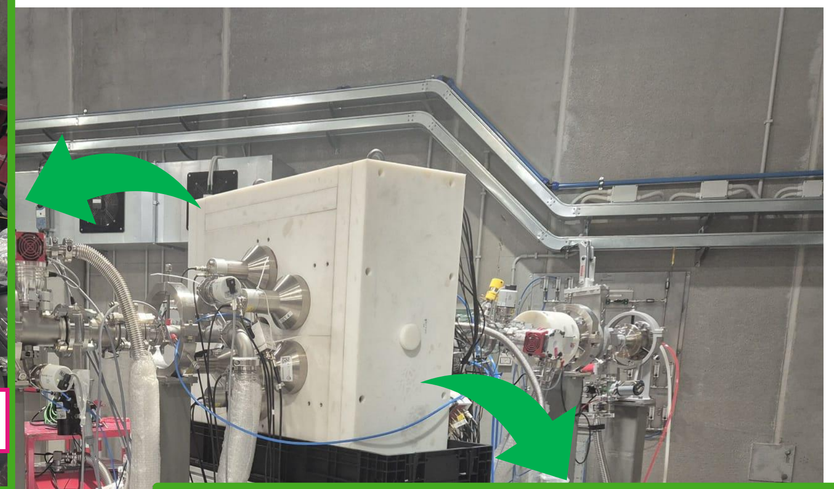

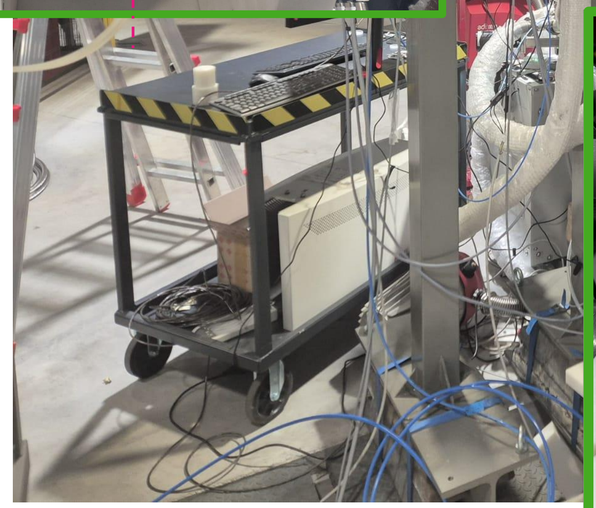

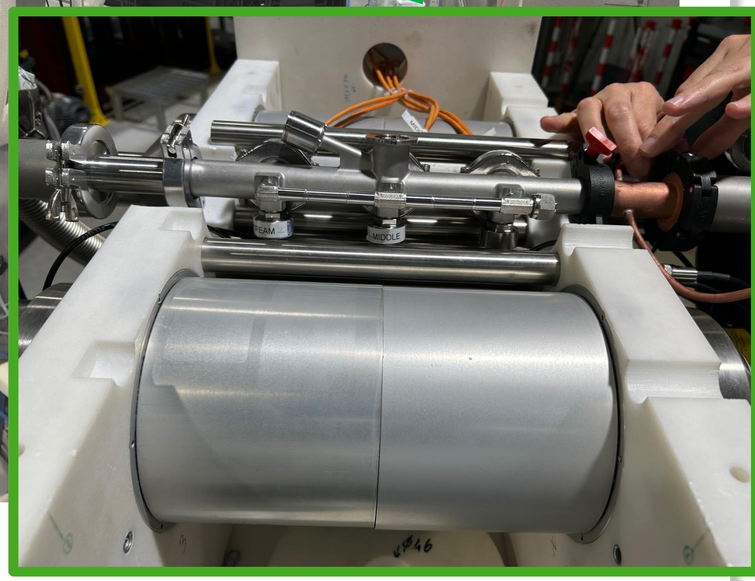

SHADES Background Problem

Surface measurements bkg > 100 counts/h

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Natural bkg = 0.00011 counts/s/counter
(~7 total counts/h)

SHADES Background Problem

Neutrons from α -induced reactions on impurities are **the main component** of background (**Beam Induced Background**)

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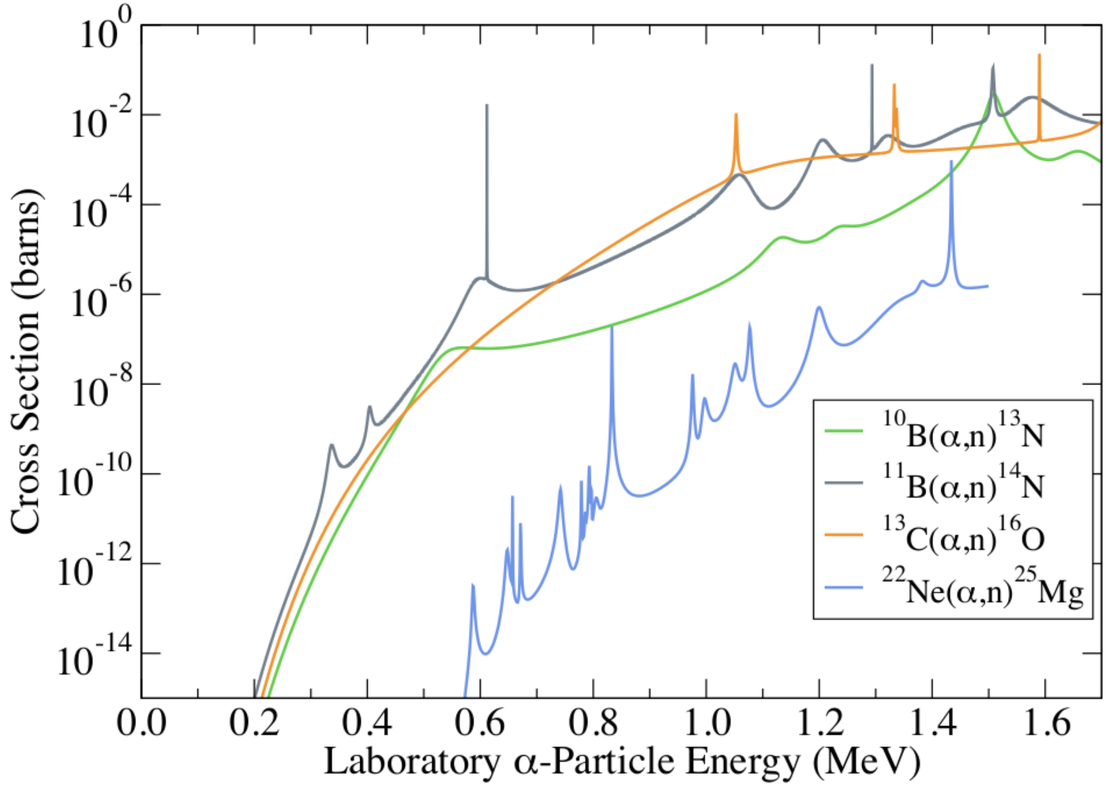

SHADES Status and Outlook

Setup characterization and optimization of BIB

Setup Characterization
BIB minimization

EJ309 liquid scintillators are **blind** to neutrons from $^{22}\mathrm{Ne}(\alpha, \mathrm{n})^{25}\mathrm{Mg}$ reactions

Neutrons coming from reactions on impurities have an $E_n > E_{threshold}$.

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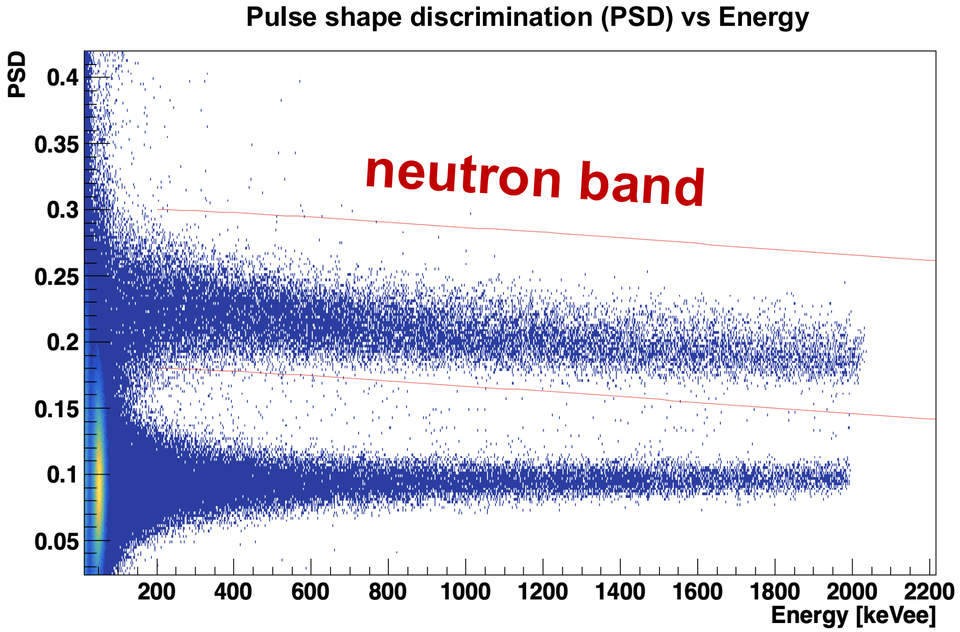
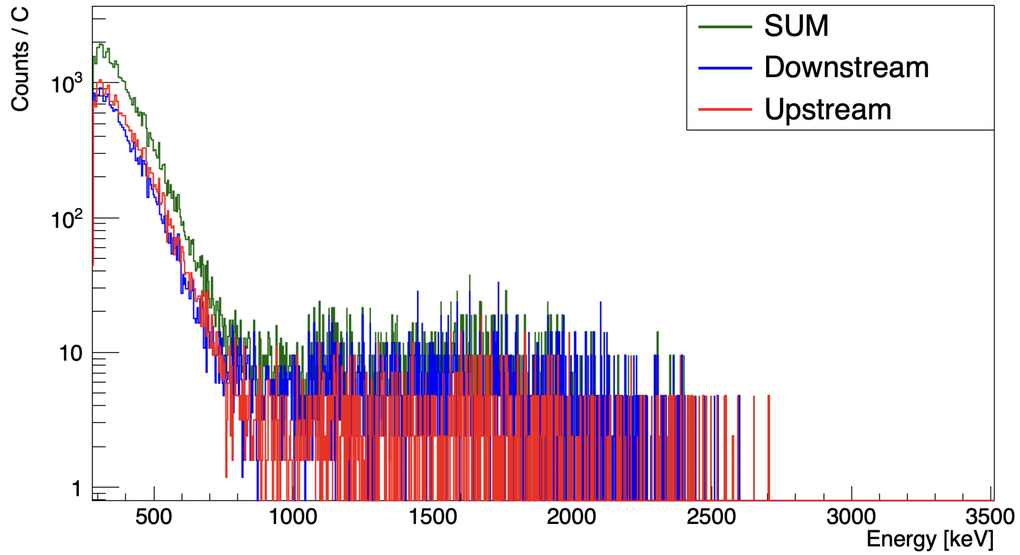


Identification of BIB achieved by looking at the EJ309 spectra:



- Energy information to identify BIB sources
- Information on the position of the BIB (upstream/downstream asymmetry)
- Anticoincidence ^{3}He-EJ309 (to be implemented)

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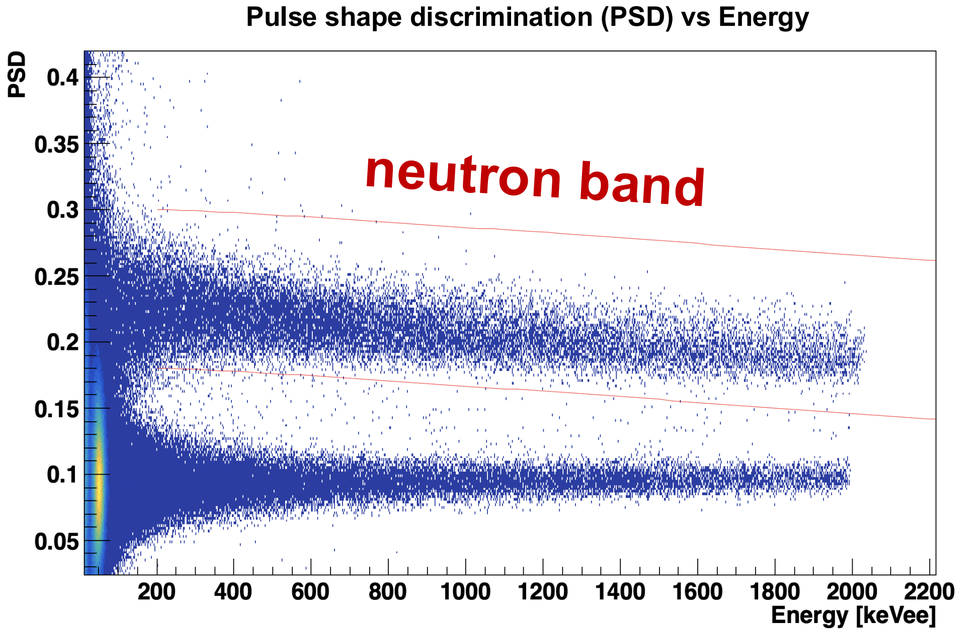

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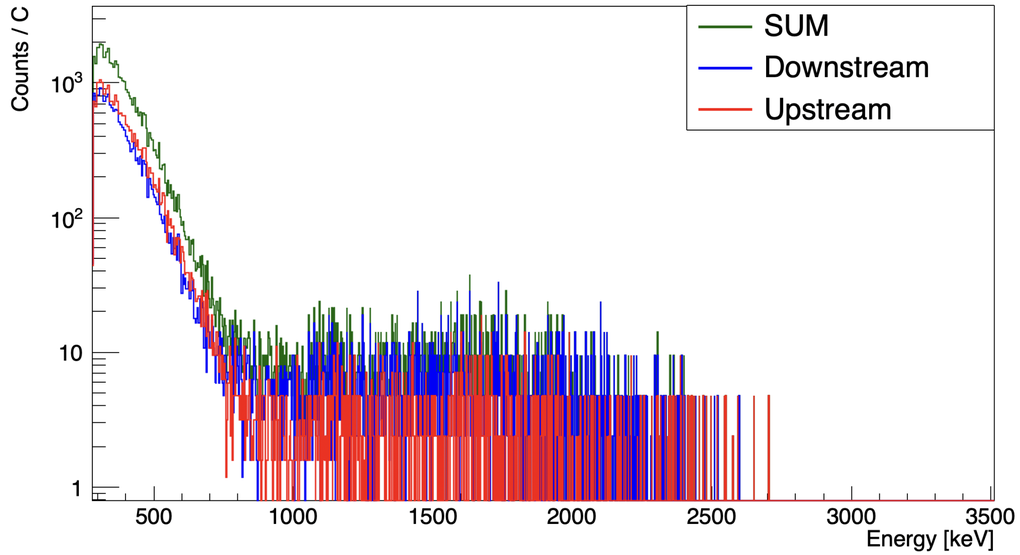

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Sensitivity level achieved is
~15 total counts/h

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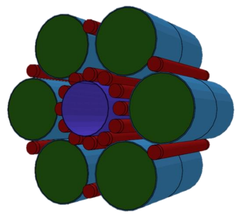
Efficiency measurements ^{51}V(p,n) at ATOMKI (April 2025)

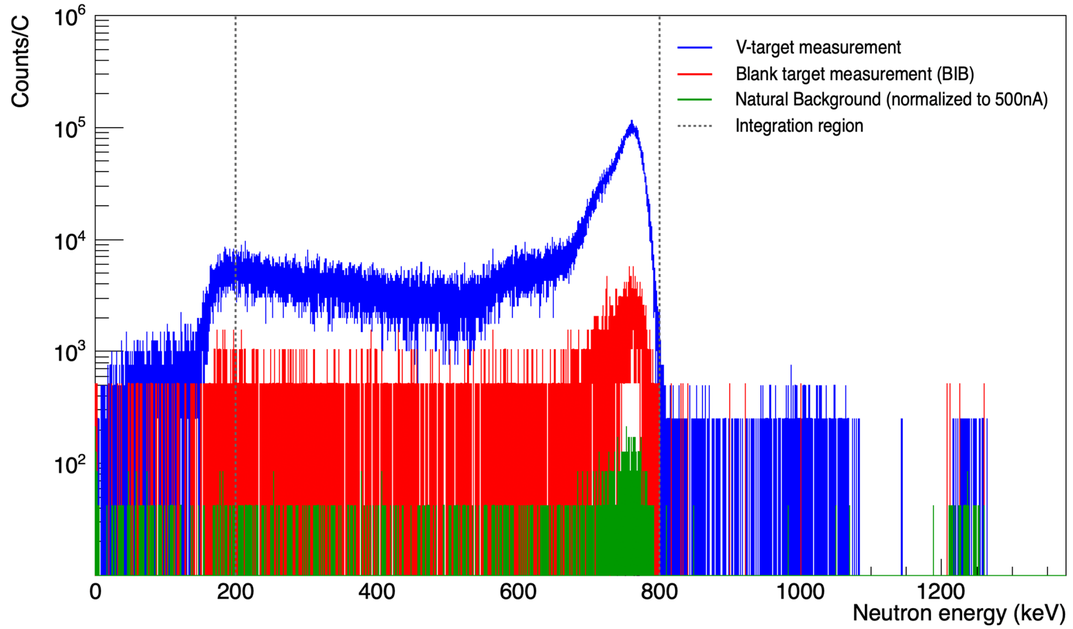


SHADES Preliminary Results

Efficiency calibration

Efficiency measurements using the standard $^{51}V(p,n)^{51}Cr$ reaction

$$\eta(E,x) = \frac{N_n}{N_R}$$

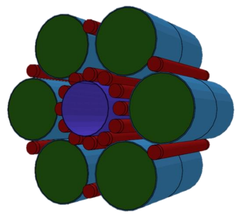


N_n ⟶ Irradiation measurement

N_R ⟶ Activation measurement

Van der Graaf Laboratory of Institute for Nuclear Reasearch ATOMKI, in Debrecen, Hungary

3rd -11th April 2025



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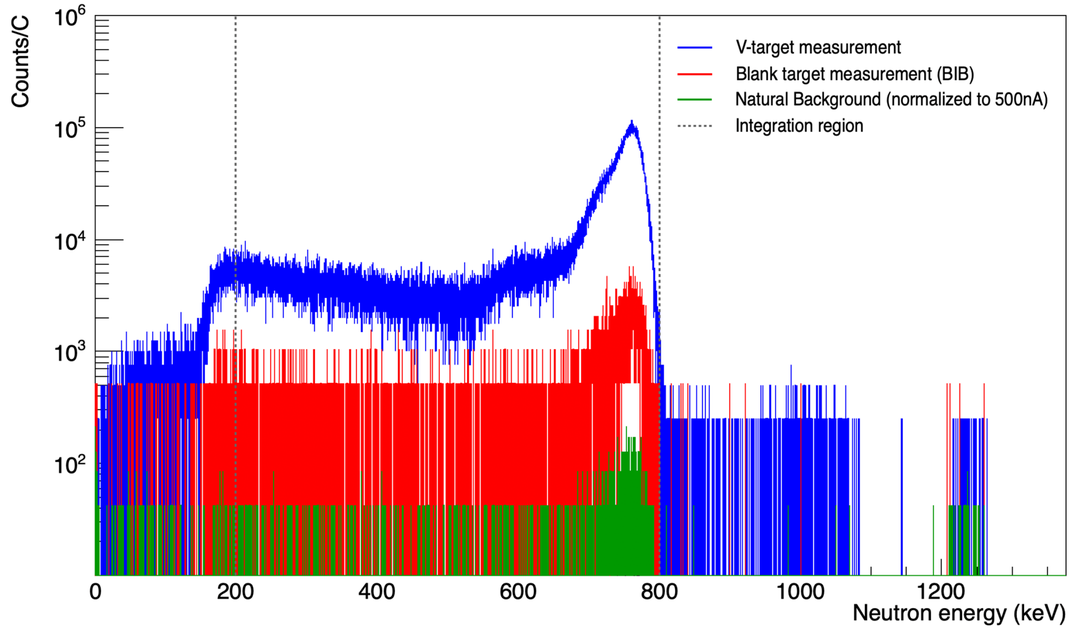

N_n ⟶ Irradiation measurement

N_R ⟶ Activation measurement

E_p [keV]	E_n range [keV]	η_{mes} %	η_{sim} %
1700	112-148	9.62 ± 0.13	11.4
1850	247-302	8.53 ± 0.11	10.2
2000	383-454	7.56 ± 0.09	9.62
2300	658-757	6.59 ± 0.06	8.25

SHADES Status and Outlook

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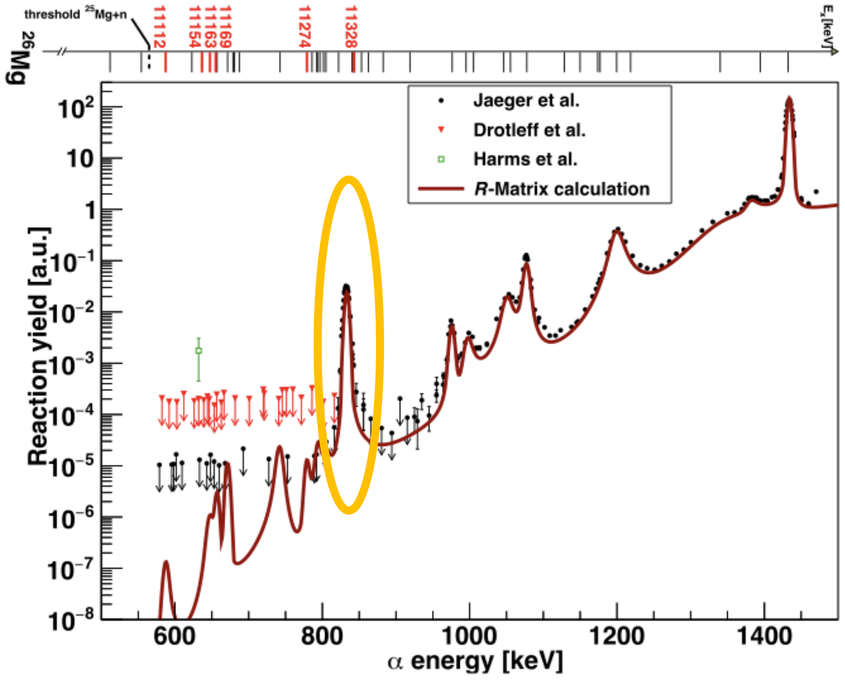
Efficiency measurements ^{51}V(p,n) at ATOMKI (April 2025)

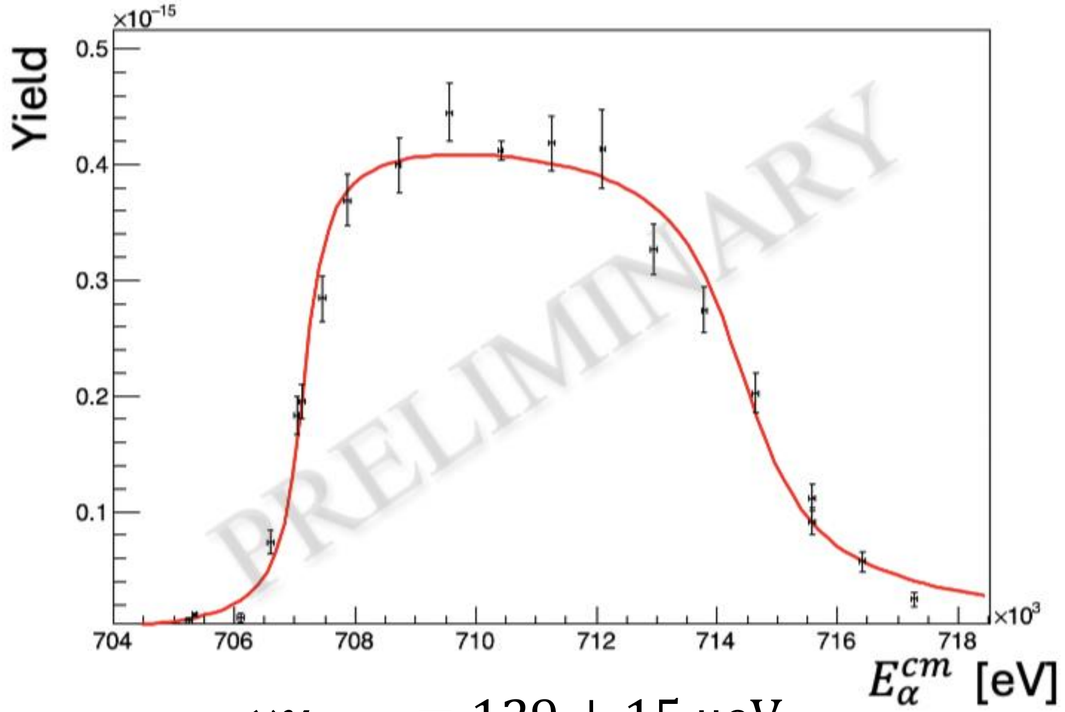
835 keV resonance measurement (November 2024 and March 2025)

SHADES Preliminary Results

E_x = 11329 keV (Er= 835 keV)



$$Y(E_0) = (\lambda_r^2\,\omega\gamma)\frac{1}{2\pi\epsilon_r}\left[\arctan\left(\frac{E_0 - E_r}{\frac{\Gamma}{2}}\right) - \arctan\left(\frac{E_0 - E_r - \Delta E}{\frac{\Gamma}{2}}\right)\right]$$

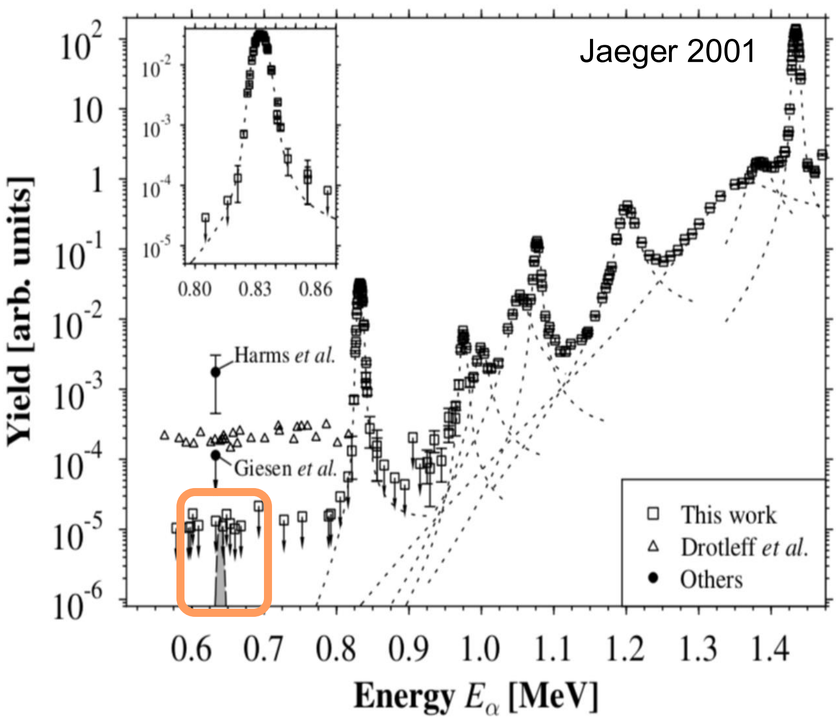


- Re-measure the resonance strenght $\omega\gamma$
- Identify its exact position in ^{26}Mg

$\omega\gamma_{prel} = 129 \pm 15$ μeV

$\omega\gamma_{Jaeger} = 118 \pm 11$ μeV

SHADES Status and Outlook



Setup characterization and optimization of BIB

Efficiency measurements ^{51}V(p,n) at ATOMKI (April 2025)

835 keV resonance measurement (November 2024 and March 2025)

Probing the 656 keV resonance (November-December 2025)

Conclusions and Takeaways

- $^{22}Ne(\alpha,n)$ pivotal in nuclear astrophysics, but its stellar reaction rate is highly uncertain
- Low energy investigations strongly hampered by natural background. State of the art dominated by UL of **100 counts/h** below the 835 keV resonance.
- SHADES takes the advantages of deep underground location (INFN-LNGS) to reduce natural background. Additional BIB minimization leads to an unprecented sensitivity of **15 counts/h**.
- 835 keV resonance scans performed : preliminary values of the $\omega\gamma$ in agreement with the literature.
- The enhancement in sensitivity opens the possibility to probe the lower-energy region to search for a possible resonance at 656 keV.

Thank you for the attention!