Understanding ^{26}Al Production in Classical Novae: Search for New States in ^{26}Si

Ignasio Wakudyanaye

Grand Accélérateur National d'ions Lourds

University of Caen Normandie, Caen, France

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laboratoire commun CEA/DRF CNRS/IN2P3

Outline

^{26}Al Nucleosynthesis & Abundance in the Galaxy

Motivation

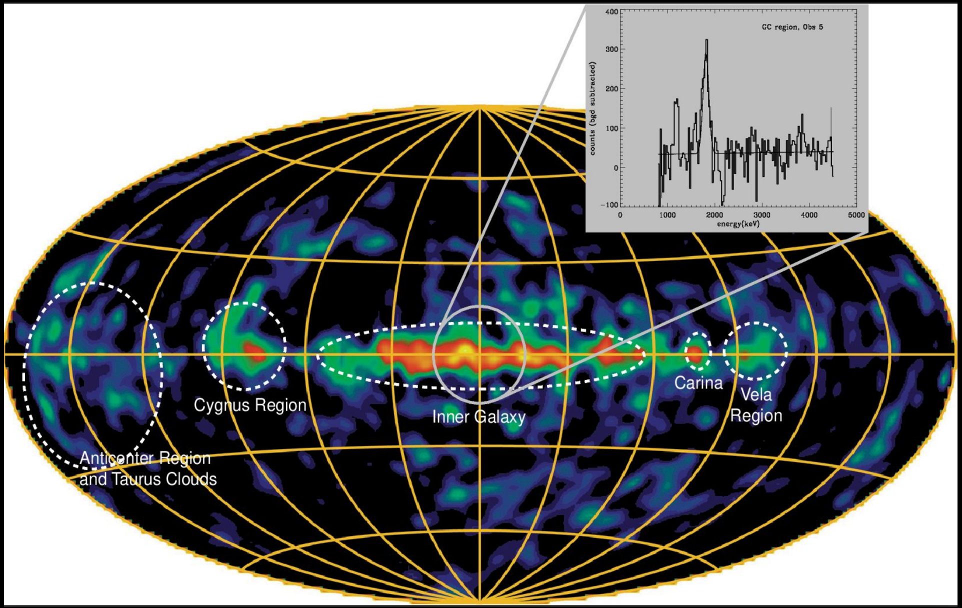
The Experiment

Data Analysis

Conclusions & Outlook

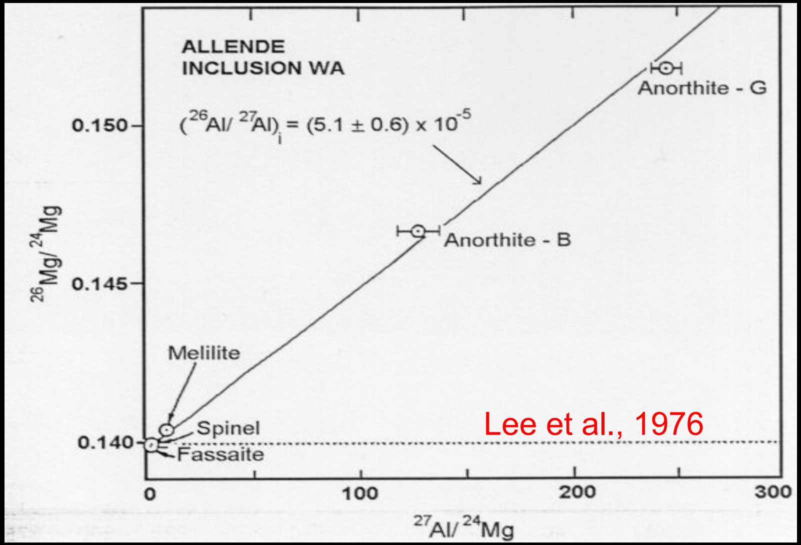
^{26}Al Abundance in the Galaxy

ISM γ-ray observations



Meteoritic observations

1976: Allende meteorite



Ratio $^{26}Al/^{27}Al = 5 \times 10^{-5}$ in Early SS

$T_{1/2}(^{26}Al) \sim 7 \times 10^5 << T_{Galaxy} \Rightarrow$ ^{26}Al active production!!!

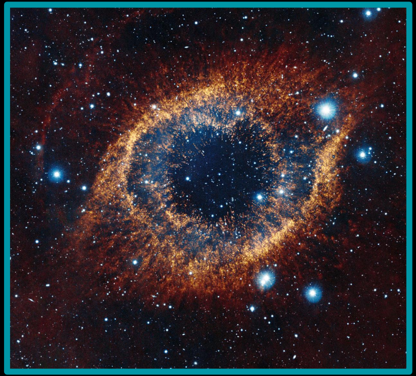
Production sites of ^{26}Al???

^{26}Al Nucleosynthesis

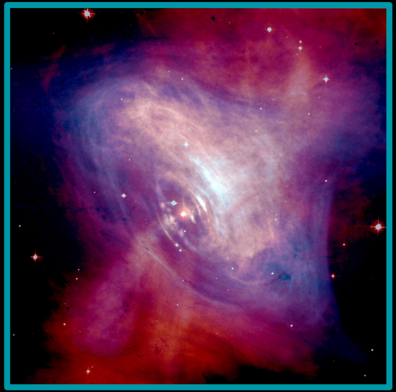
^{26}Al is produced in extreme astrophysical environments such as:

Wolf–Rayet stars

AGB Stars: The Helix Planetary Nebula



Core collapse supernova: The Crab nebula



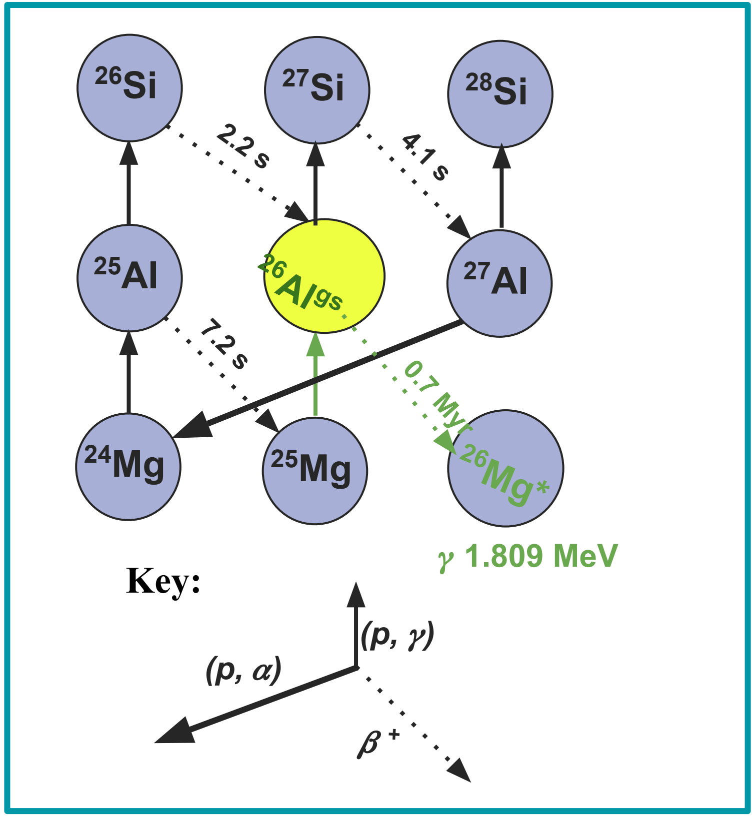
Nova outbursts

-Environments temperature range 0.05 GK < T < 1.5 GK, relevant for the nucleosynthesis of ^{26}Al.

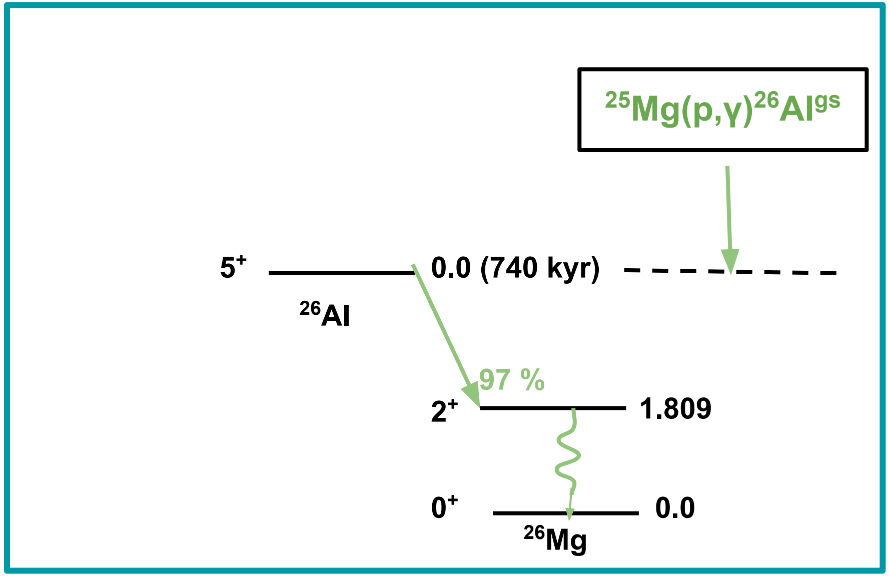
Site contribution to total Galactic abundance???

^{26}Al Nucleosynthesis in Novae Environments

Important reactions networks in novae environment:



$^{25}Al(\beta^+\nu)^{25}Mg(p,\gamma)^{26}Al^{gs}(\beta^+\nu)^{26}Mg^*(\gamma)^{26}Mg^{gs}$: E_γ = 1.809 MeV



^{26}Al Nucleosynthesis in Novae Environments

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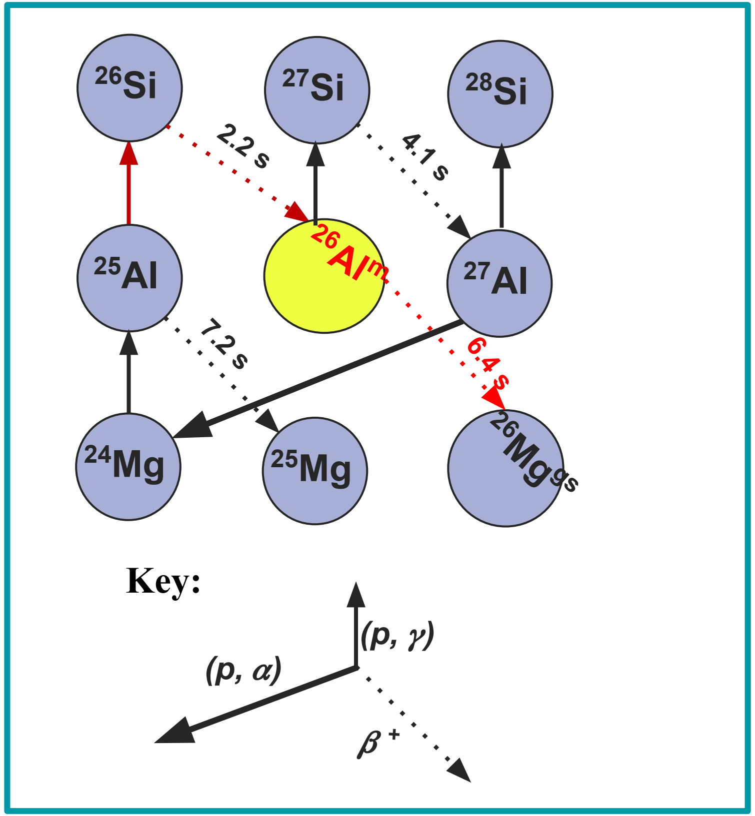
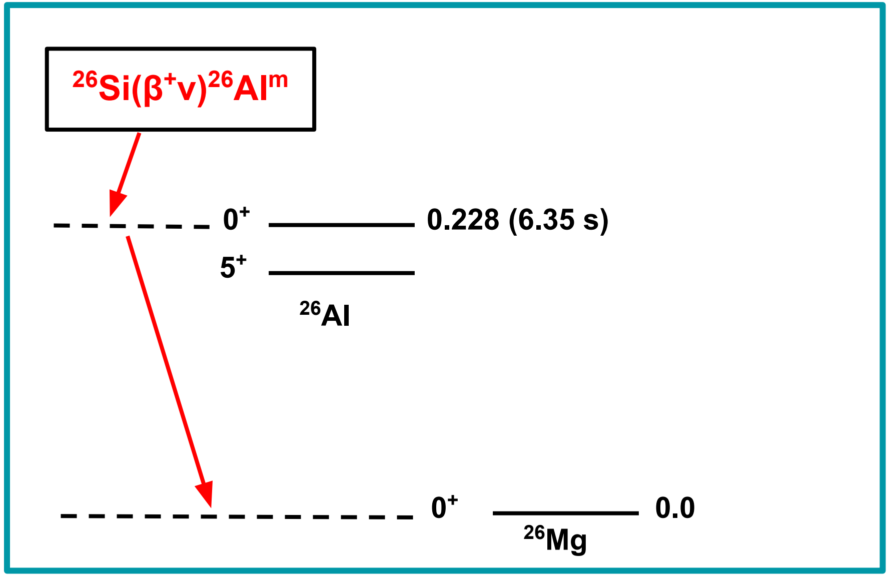


^{25}Al(p,γ) ^{26}Si(β^{+}v)^{26}Al^{m}(β^{+}v)^{26}Mg^{gs} : no γ-ray emission



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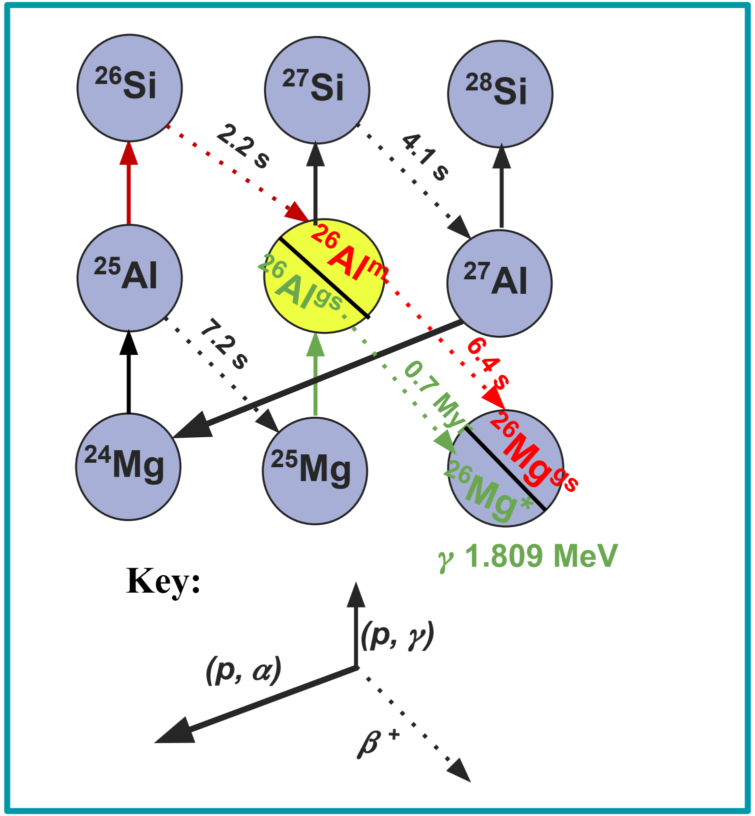

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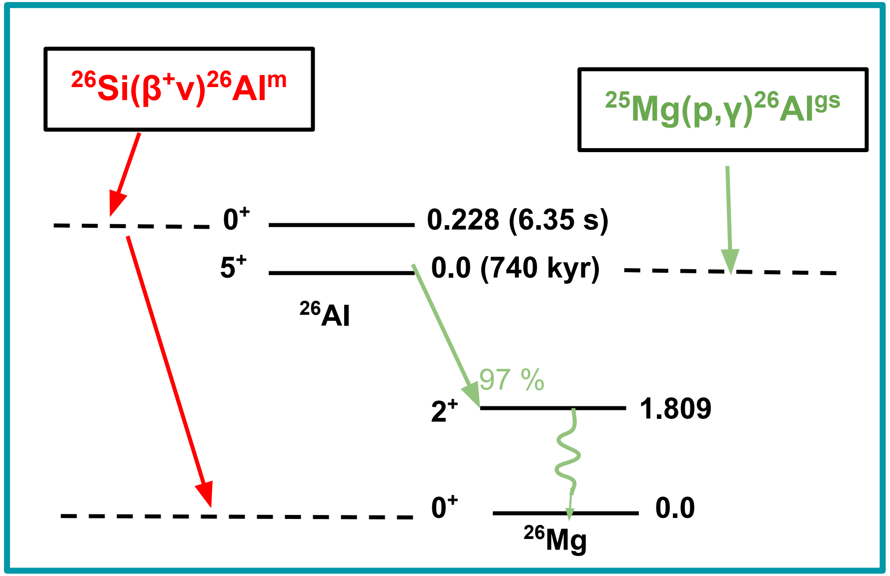

Motivation

Reaction rates (narrow resonances case)

$$\langle\sigma\nu\rangle = \hbar^2\left(\frac{2\pi}{\mu kT}\right)^{3/2}\sum_i(\omega\gamma)_i \exp\left(\frac{-E_{R,i}^{CM}}{kT}\right)$$

with,

$$\omega\gamma = \frac{(2J_r+1)}{(2J_p+1)(2J_T+1)}\left(\frac{\Gamma_p\Gamma_\gamma}{\Gamma_p+\Gamma_\gamma}\right)$$

$$E_R^{CM} = E_x - S_p$$

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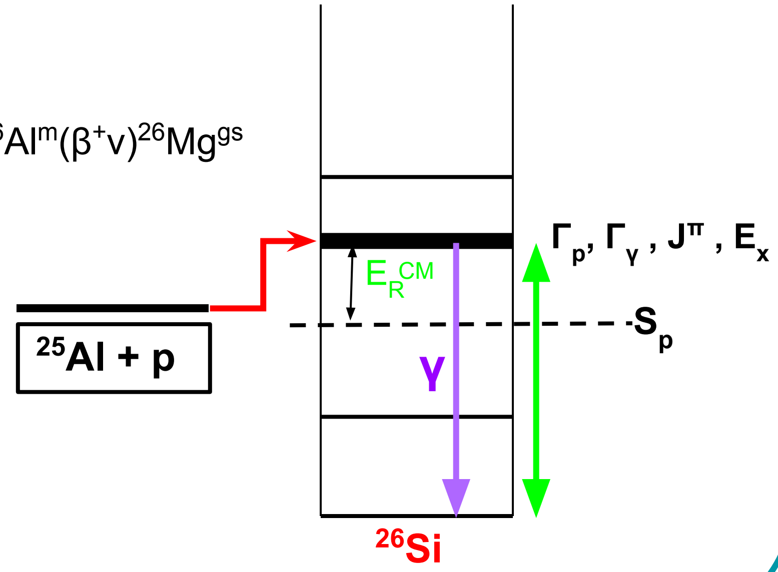

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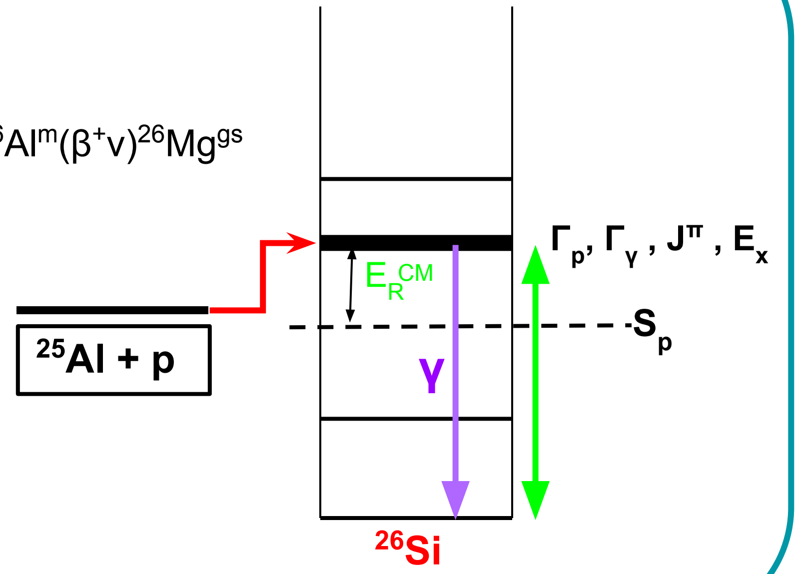
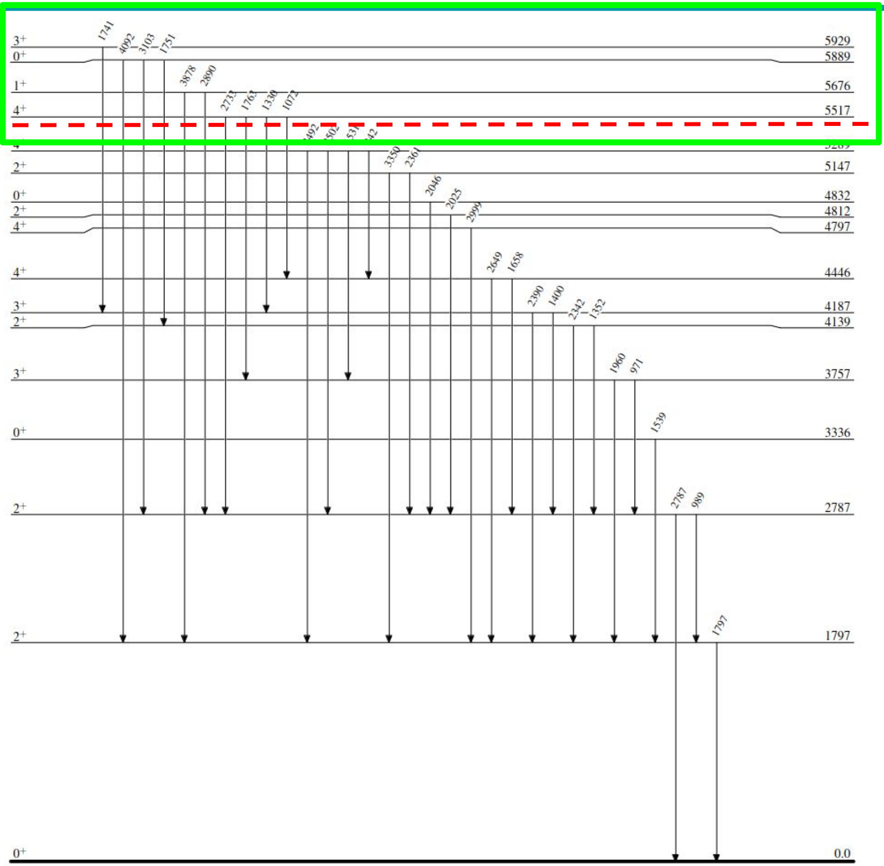


Precise information of nuclear physics observables **is required to accurately model the production of ^{26}Al** through the reaction ^{25}Al(p,γ) ^{26}Si.

Proton Resonance States in ^{26}Si



S_p = 5513.8 keV

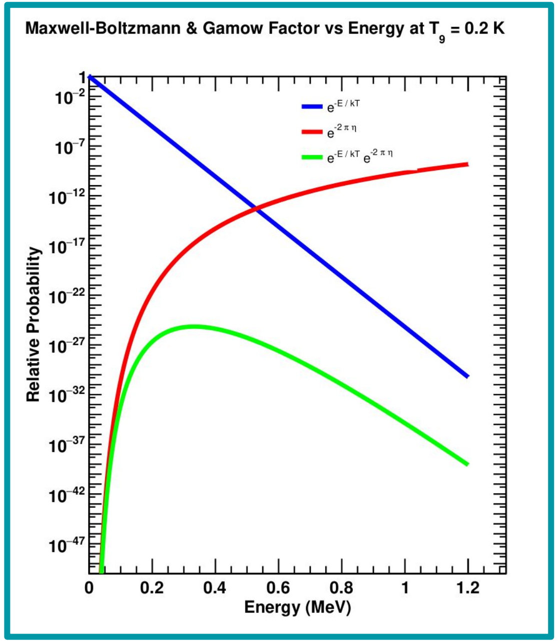
^{26}Si

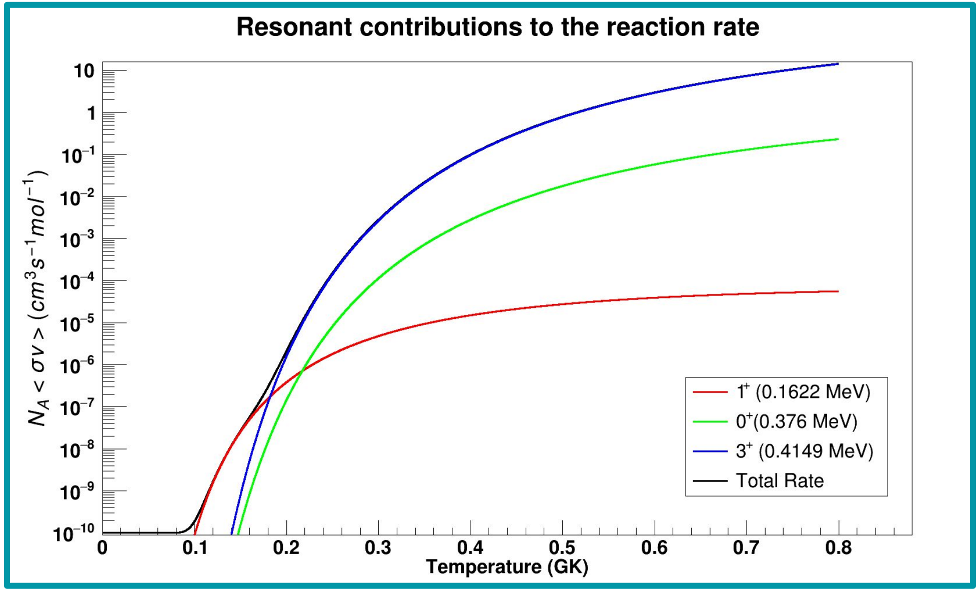
Resonance	E_{ex} (keV)	J^{π}	E_r (keV)
1	5517.3 ± 0.8	4_4^+	3.5 ± 0.9
2	5675.2 ± 1.4	1_1^+	161.4 ± 1.5
3	5890.0 ± 0.8	(0_4^+)	376.2 ± 1.0
4	5927.6 ± 1.0	3_3^+	413.8 ± 1.1
5 *	5949.7 ± 5.3	$(4_5^+, 0_4^+)$	435.9 ± 5.3

→ Uncertainties remain for some states above S_p (for instance, existence of the level @ *5.95 MeV)

→ **Are there any other resonances?**

Stellar Reaction Rates





→ **States** above S_p **in ^{26}Si are critical to** the calculation of **the ^{25}Al(p, γ)^{26}Si reaction rate**.

→ **J^{π} = 3^+ state dominates the total reaction rate** at temperatures above **0.2 GK**, owing to its **large resonance strength** (l = 0, no centrifugal barrier).

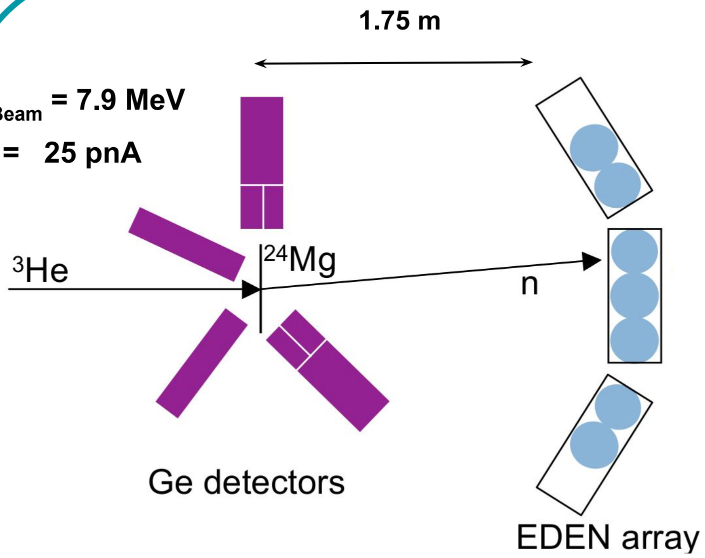
E. Temanson, et al. PHYSICAL REVIEW C 108, 065804 (2023)

Experimental Set-Up

^{24}Mg(^{3}He,nγ)^{26}Si reaction

E_{Beam} = 7.9 MeV

I = 25 pnA



→ 99.85 % target purity

→ (150 μg/cm^2 +250 μg/cm^2) ^{26}Mg target thickness

→ 0.2 mm Ta backing (beam stopped)

→ 2 clovers + 2 coaxials Ge detectors used for γ-rays

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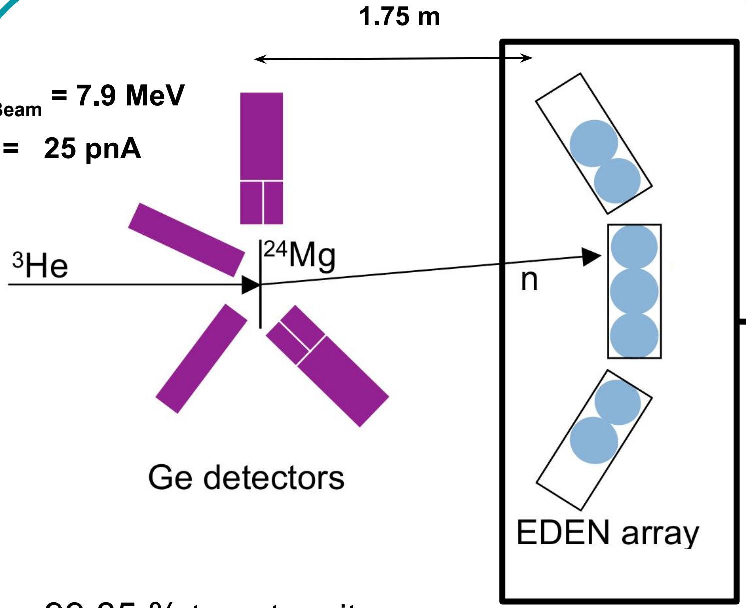

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→ 36 NE213 (Φ 20 cm x L 5 cm) modules

→ ΔΩ = 350 msr

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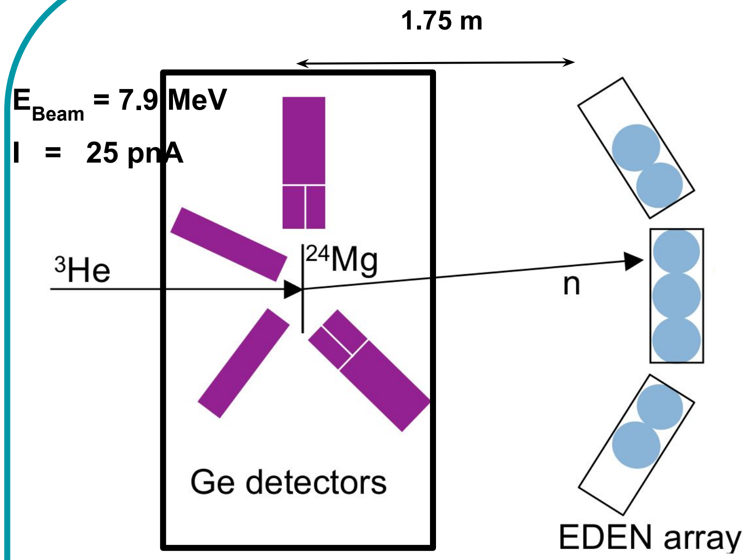

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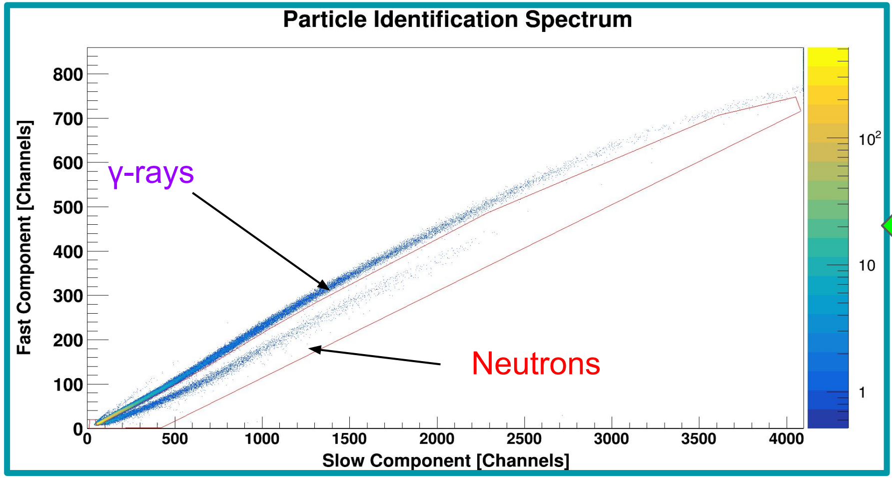
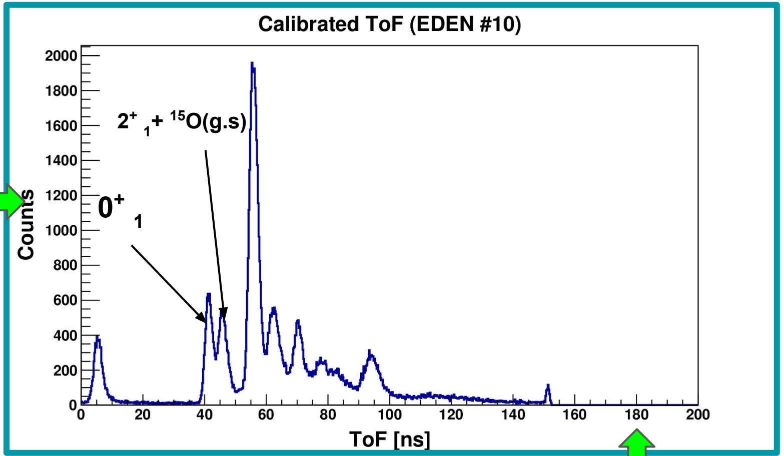
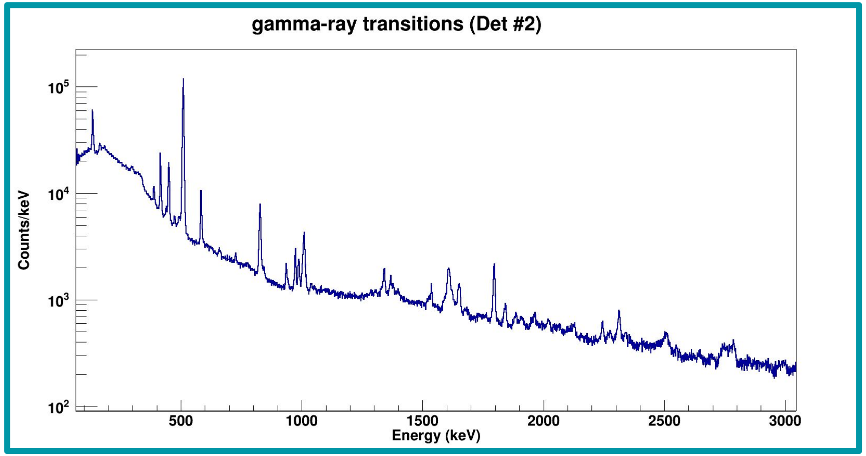
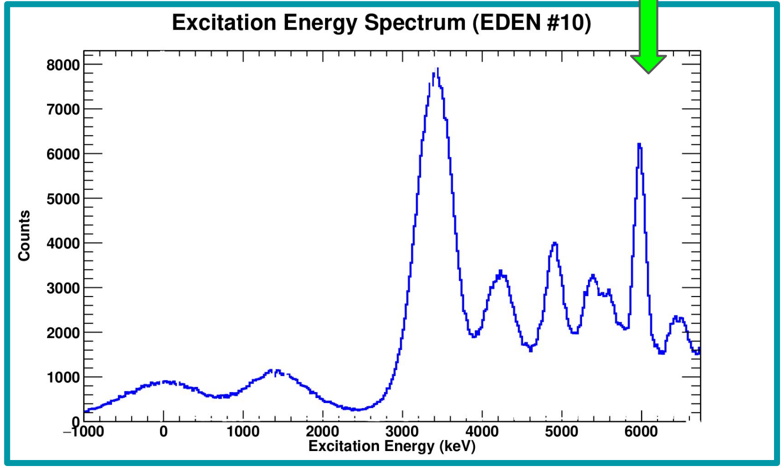
Preliminary Results



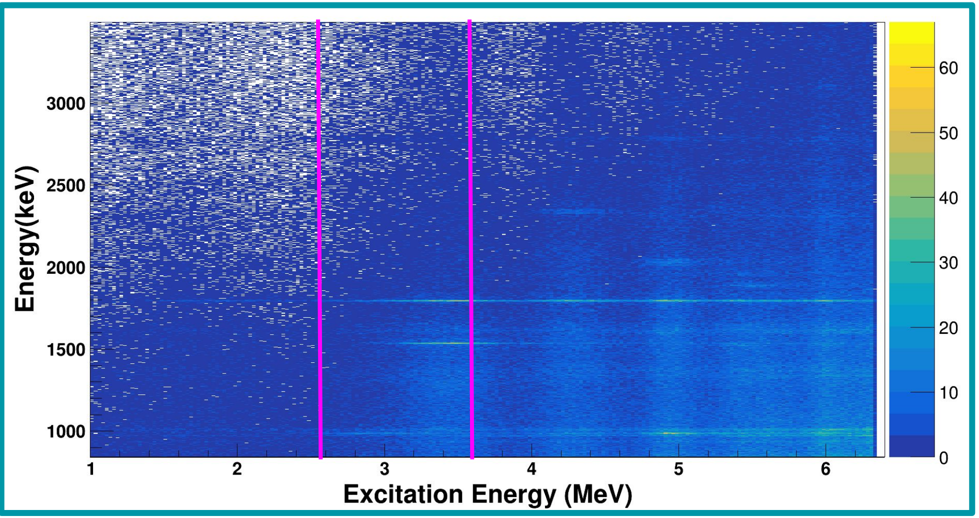


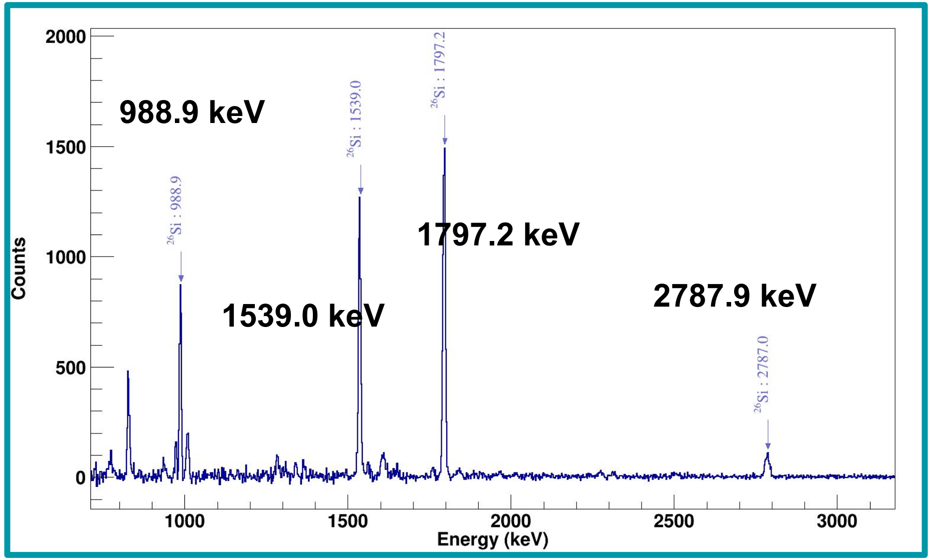




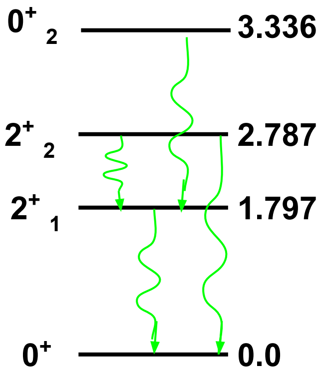
Many γ-ray transitions from known states in ^{26}Si were observed.

Preliminary Results





GATE: 2.5 – 3.5 MeV



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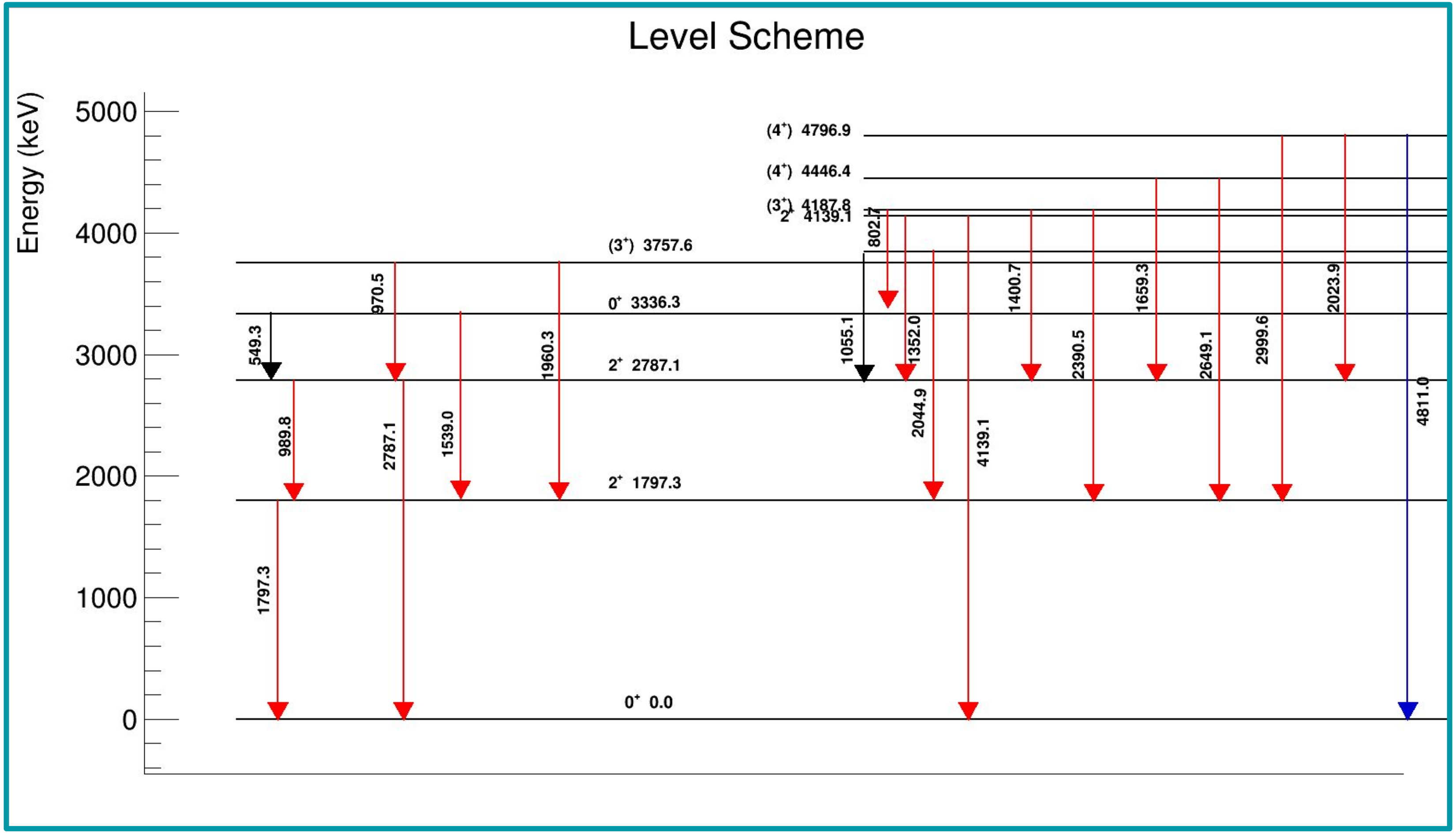
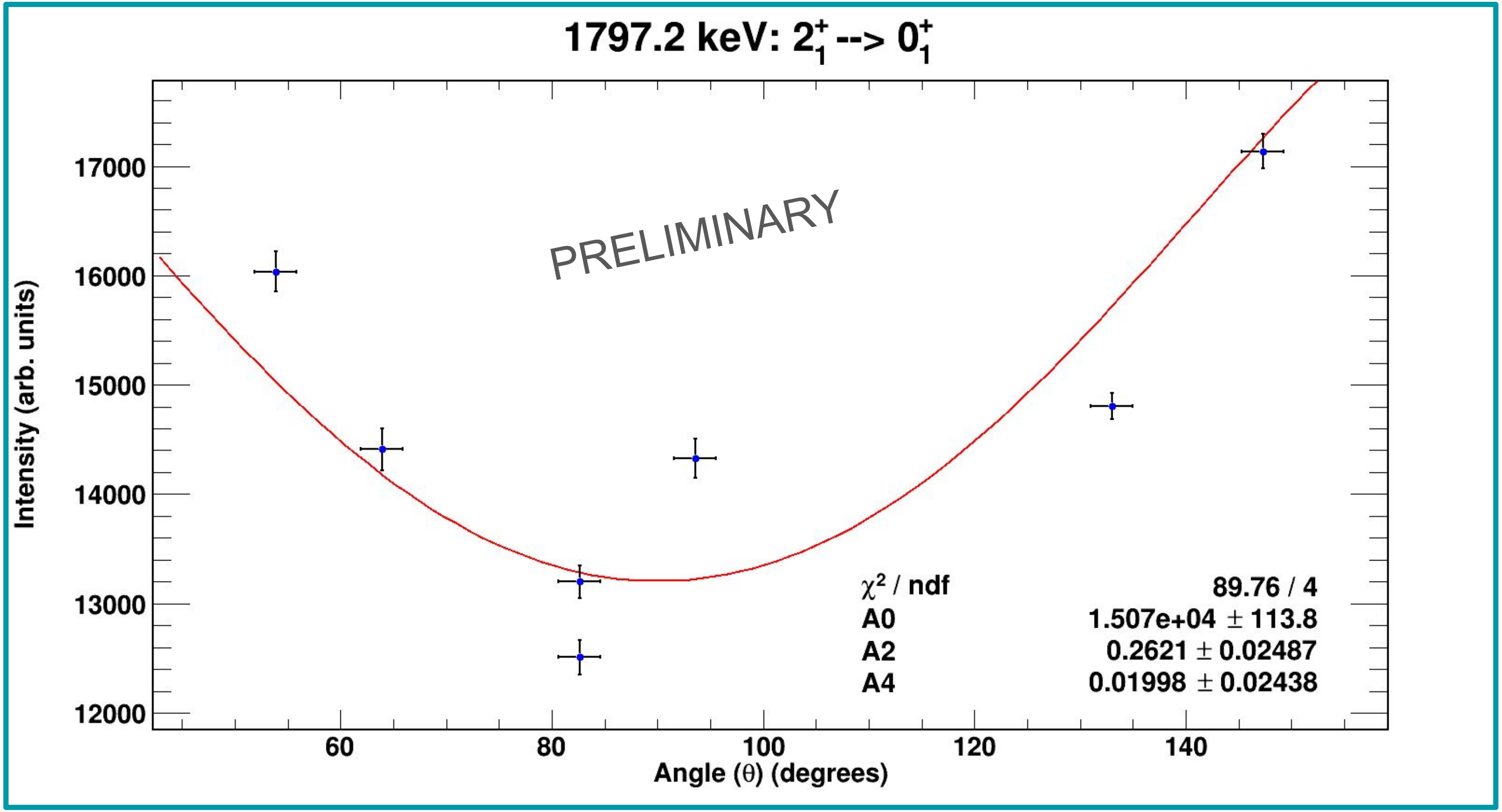
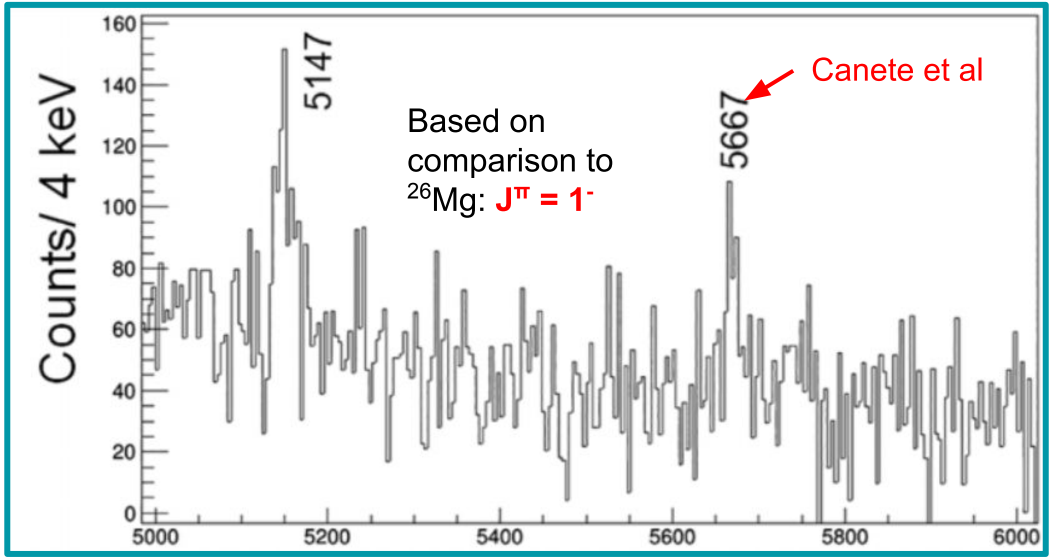


Level Scheme
Energy (keV)
5000
4000
3000
2000
1000
0
(4+) 4796.9
(4+) 4446.4
(3+) 4187.8
2+ 4139.1
(3+) 3757.6
0+ 3336.3
2+ 2787.1
2+ 1797.3
0+ 0.0
549.3
970.5
1960.3
989.8
2787.1
1539.0
1797.3
802.7
1055.1
1352.0
2044.9
4139.1
1400.7
2390.5
1659.3
2649.1
2999.6
2023.9
4811.0

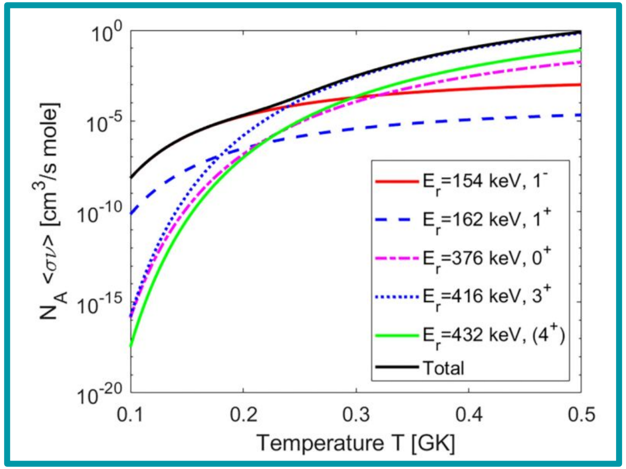
Angular Distribution Measurements



New State Close to Proton Threshold?



E_x [keV]	E_r [keV]	J^{π}	Γ_p [eV]	Γ_γ [eV]	$\omega\gamma$ [eV]
5668	154	1^-	3.1×10^{-7}	0.26[a]	7.8×10^{-8}
5676	162	1^+	$<8.9 \times 10^{-9}$	0.12[a]	$<2.2 \times 10^{-9}$
5890	376	0^+	0.004	0.009[a]	2.4×10^{-4}
5928	414	3^+	2.9	0.040	0.023
5946	432	(4^+)	0.007[b]	0.024[a]	0.004



L. CANETE et al. PHYSICAL REVIEW C 108, 035807 (2023)

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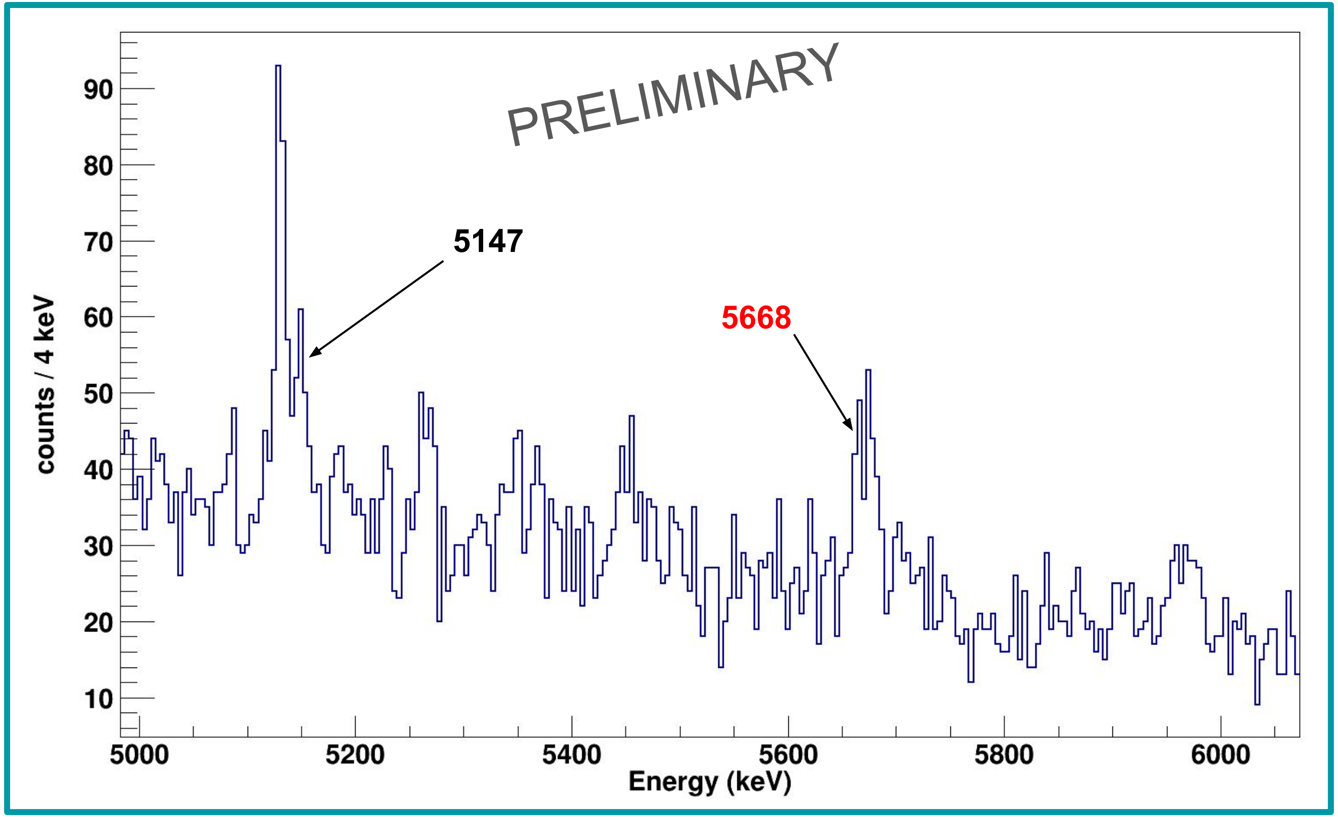
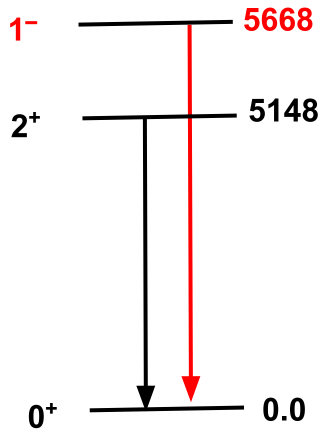
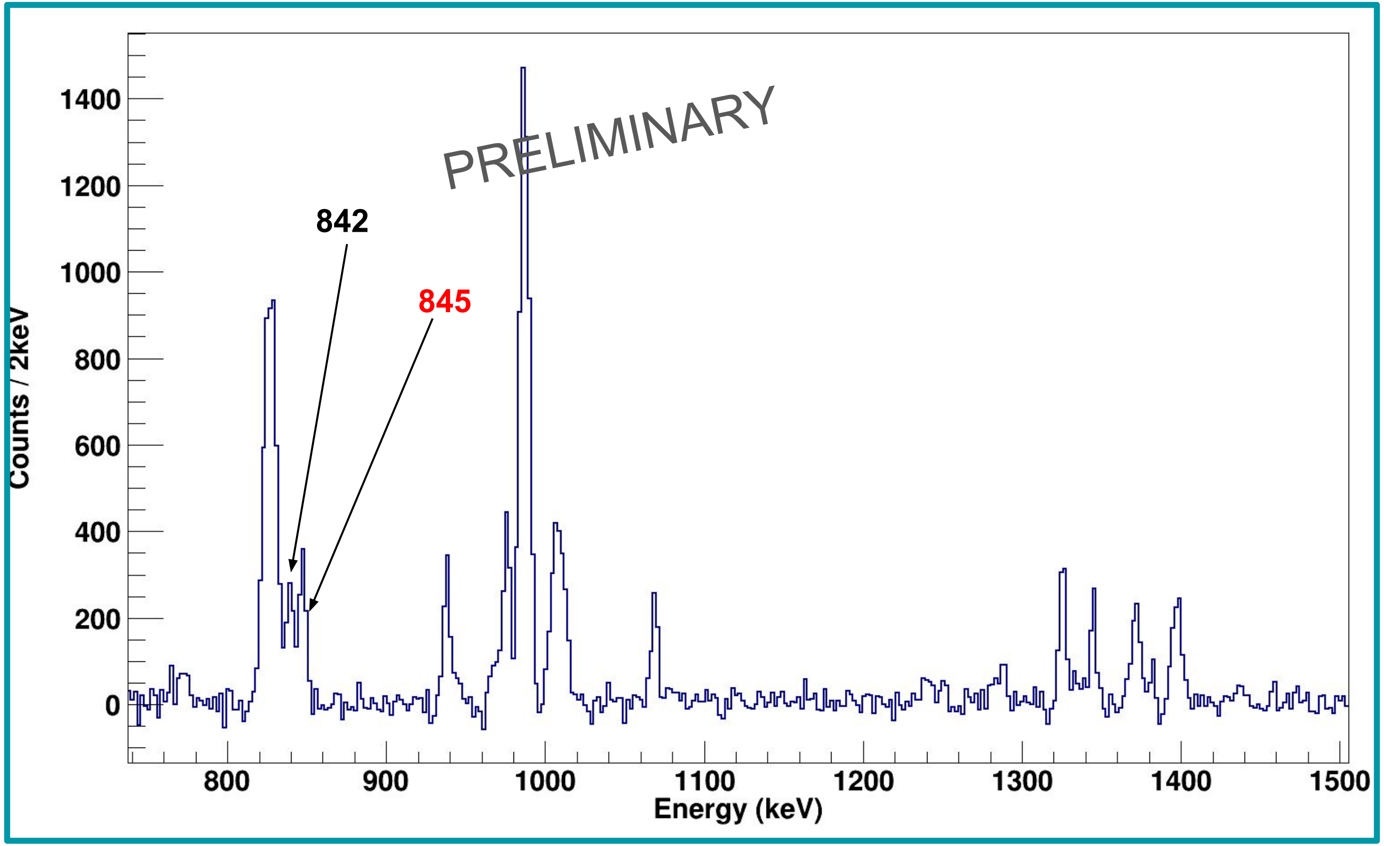
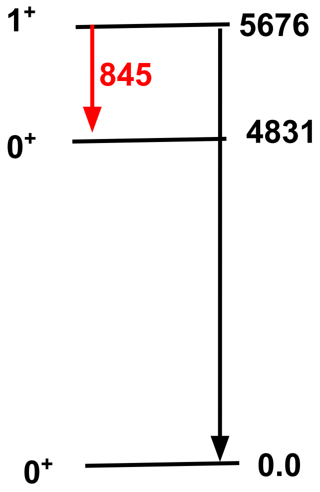




New ɣ-Ray Transition?





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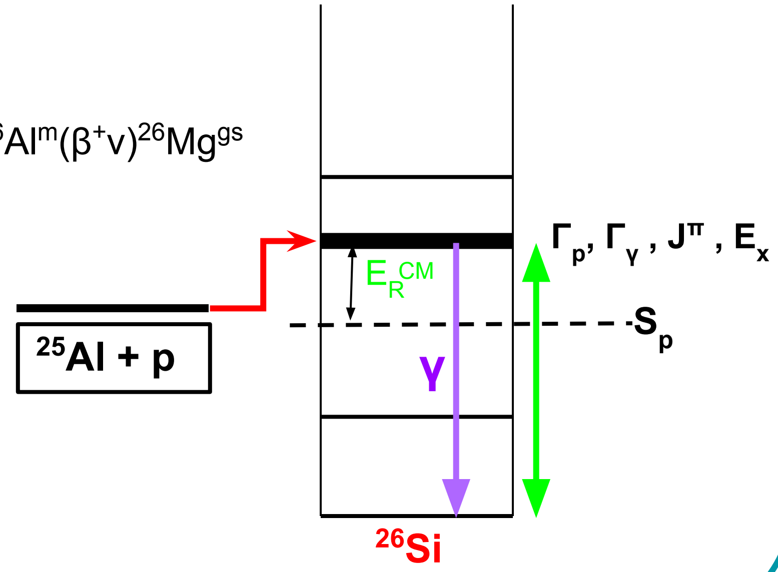

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Conclusions & Outlook

- ➔ ^{26}Si was populated through the $^{24}Mg(^{3}He,n\gamma)^{26}Si$ reaction.
- ➔ Most of the γ-ray transitions from low-lying levels in ^{26}Si have been confirmed.
- ➔ Ongoing search & confirmation for new states and γ-ray transitions in ^{26}Si
- ➔ Angular distribution measurements for the γ-ray transitions for J^{π} assignment
- ➔ Determine the $^{25}Al(p,\gamma)^{26}Si$ reaction rate (for all resonances)

Thank you for your attention !!!

PhD director:
De Oliveira, François (GANIL)
Encadrant:
Nicolas de Séréville (Orsay)