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

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ASTRANUCAP WORKSHOP
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UNIVERSITÉ CAEN NORMANDIE

Outline

Abundance of ^{26}Al in the Galaxy

Nucleosynthesis of ^{26}Al

Motivation

The Experiment

Preliminary Results

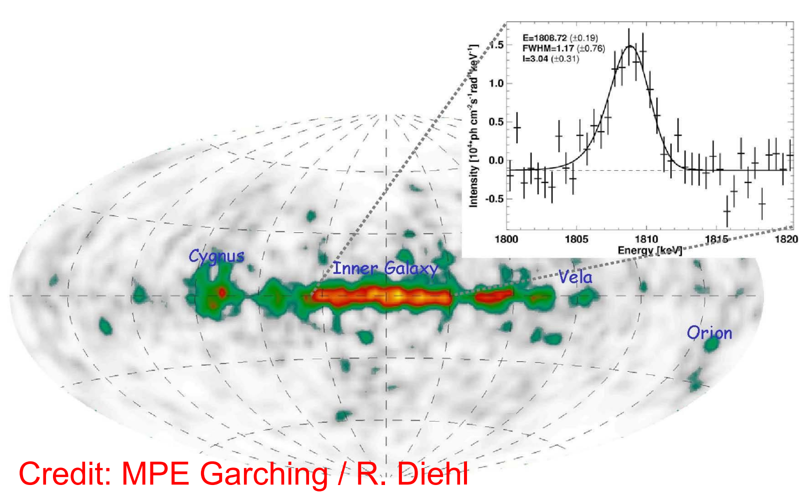
Outlook

^{26}Al Abundance in the Galaxy

γ-ray observations

1979-1980: Galactic center emission

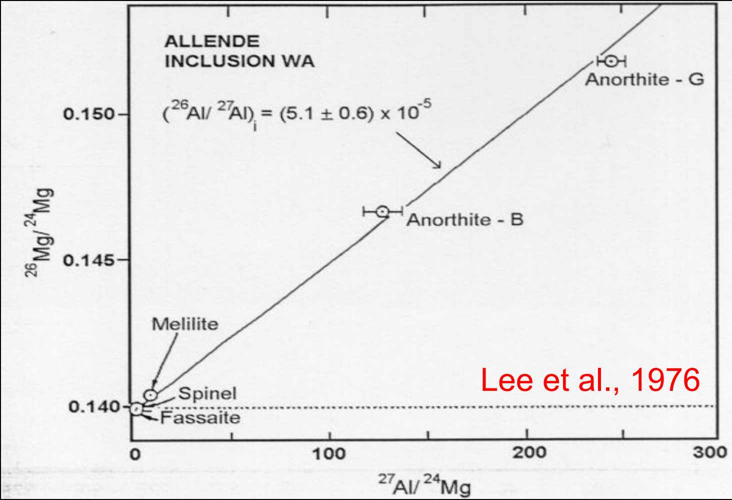
Mahoney et al. 1982



- 1.809 MeV γ-ray emission in the galactic plane
- Galactic abundance of ^{26}Al ~2.8$M_\odot$

Meteoritic observations

1976: Allende meteorite



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

$T_{1/2}$ (^{26}Al) << T_{Galaxy} ⇒ ^{26}Al is actively produced in the galaxy !!!

Source 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

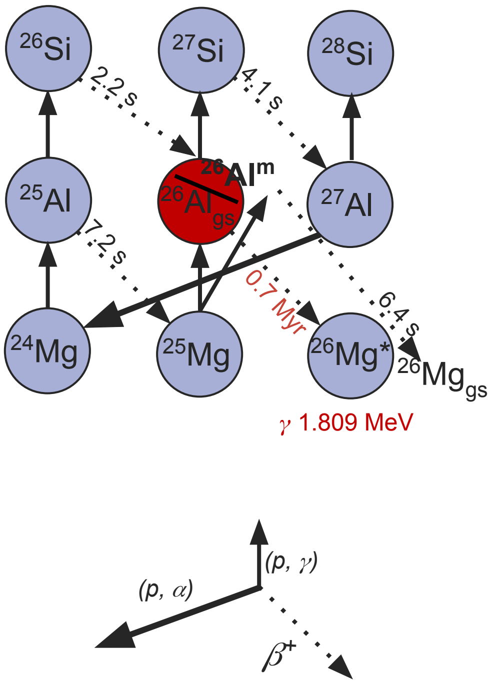
Core collapse supernova: The Crab nebula

Nova outbursts

These environments cover the temperature range 0.05 GK < T < 1.5 GK, relevant for the nucleosynthesis of ^{26}Al. **How much does each site contribute to the total galactic abundance???**

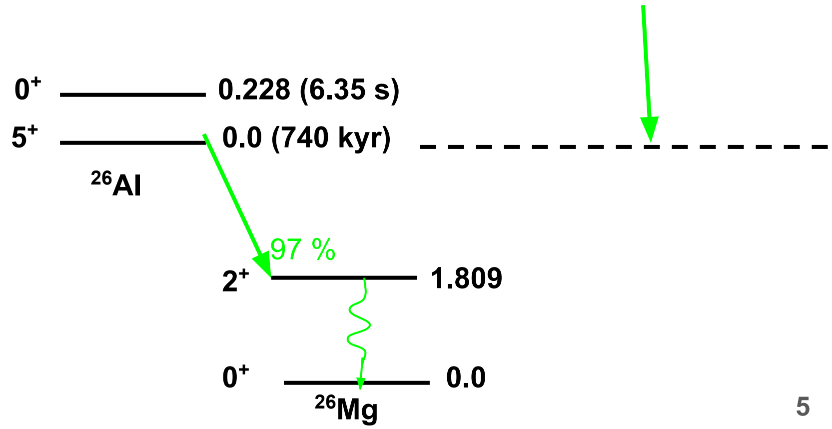
^{26}Al Nucleosynthesis in Novae Environments

In novae environment there are two important reactions networks:



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

$^{25}Mg(p,\gamma)^{26}Al^{gs}$



^{26}Al Nucleosynthesis in Novae Environments

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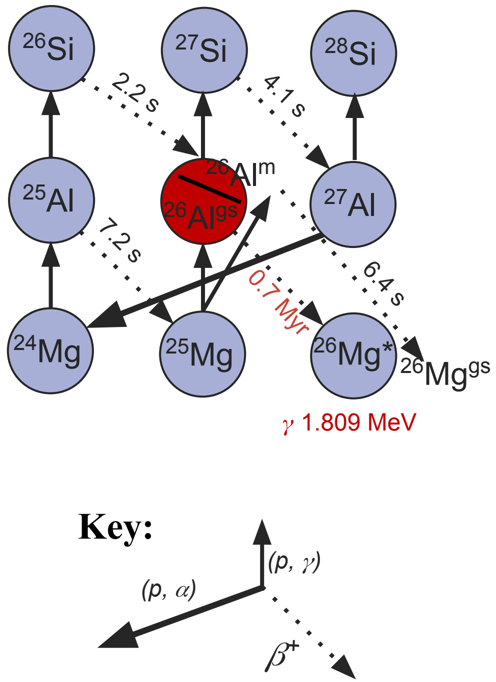
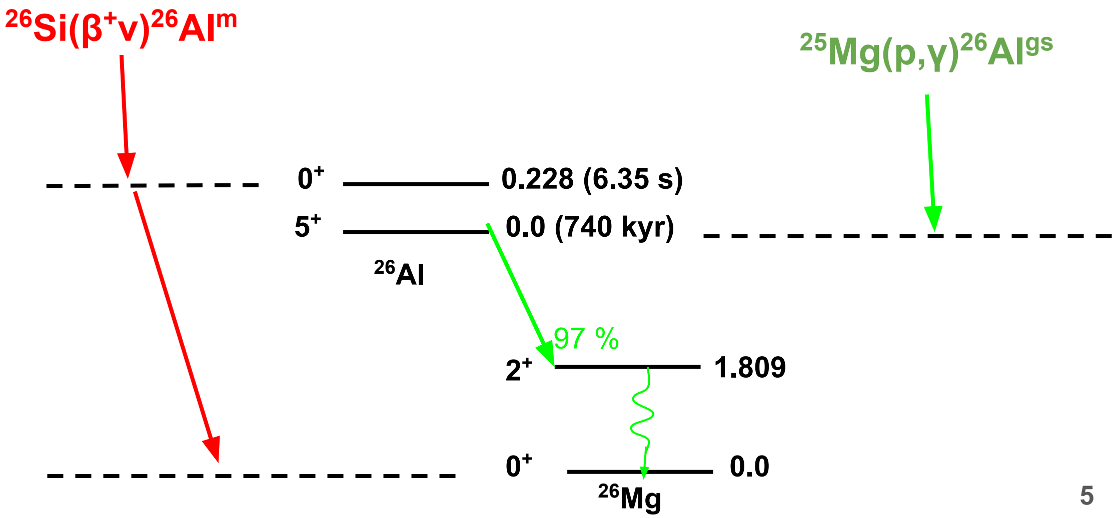


$^{25}Al(\beta^+ \nu)^{25}Mg(p,\gamma)^{26}Al^{gs}(\beta^+ \nu)^{26}Mg^*(\gamma)^{26}Mg^{gs}$: E_γ = 1.809 MeV

$^{25}Al(p,\gamma)\,^{26}Si(\beta^+ \nu)^{26}Al^{m}(\beta^+ \nu)^{26}Mg^{gs}$: no gamma-ray emission



Motivation

Reaction rates (narrow resonances case)

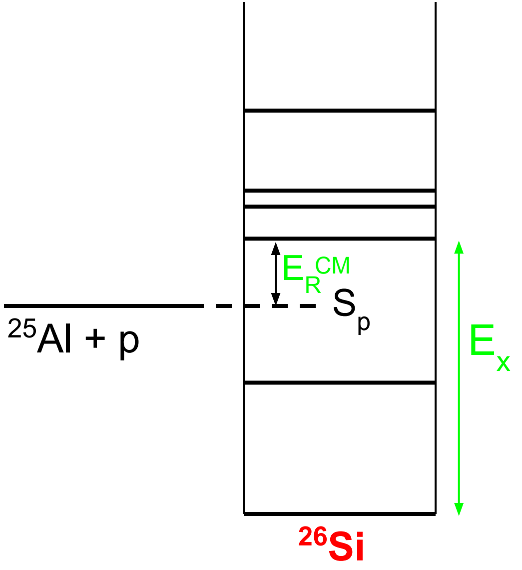
$$\langle \sigma \nu \rangle = \hbar^2 (\frac{2\pi}{\mu k T})^{3/2} \sum_i (\omega\gamma)_i \exp\left(\frac{-E_{R,i}^{CM}}{kT}\right)$$

with,

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

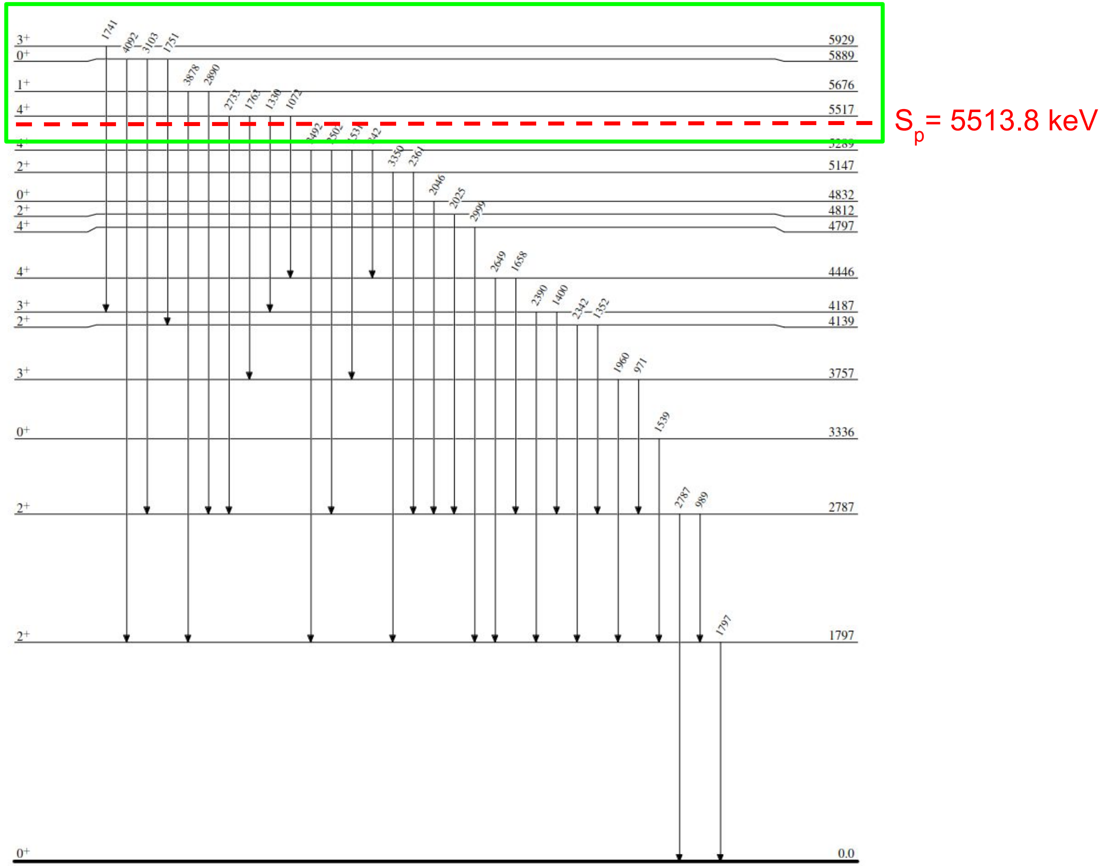
$$\mathbf{E_R^{CM} = E_x - S_p}$$

^{25}Al(p,γ) ^{26}Si(β$^+$ν)^{26}Al^m(β$^+$ν)^{26}Mg^{gs}



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



^{26}Si

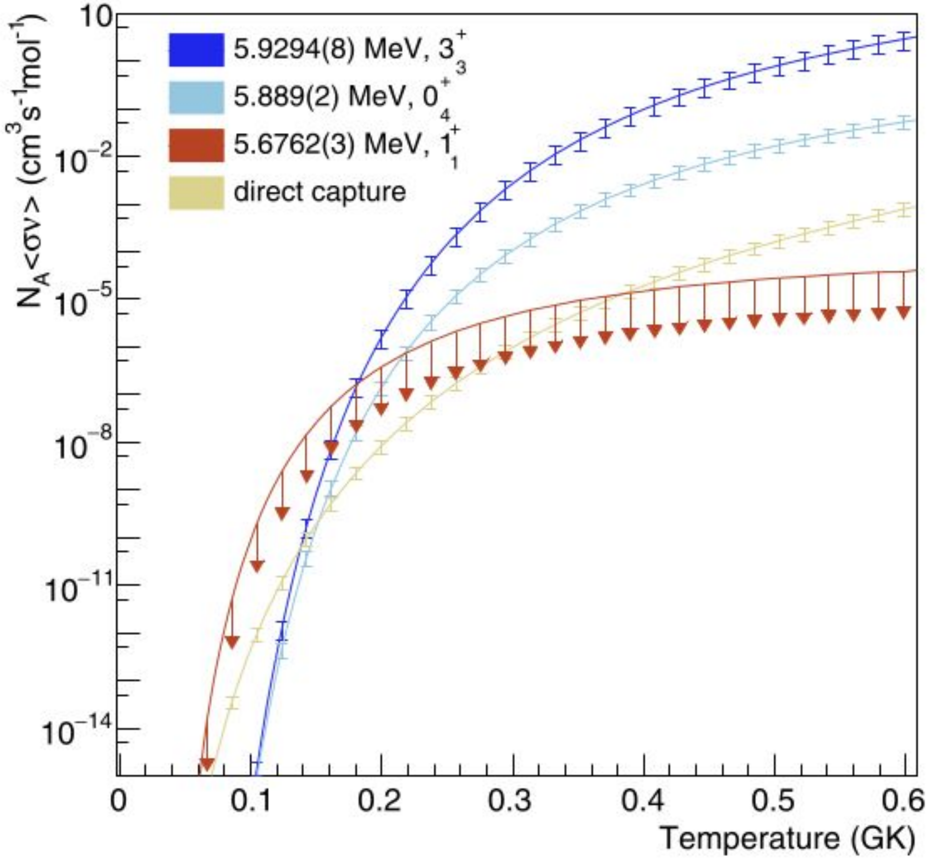
Resonance	E_{ex} (keV)	J^{π}	E_r (keV)
1	5517.3 ± 0.8	4_4^+	3.5 ± 0.9
2	5675.2 ± 1.4	1_1^+	161.4 ± 1.5
3	5890.0 ± 0.8	(0_4^+)	376.2 ± 1.0
4	5927.6 ± 1.0	3_3^+	413.8 ± 1.1
5 *	5949.7 ± 5.3	$(4_5^+, 0_4^+)$	435.9 ± 5.3

→ 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



Reaction rate for the ^{25}Al(p, γ) ^{26}Si reaction

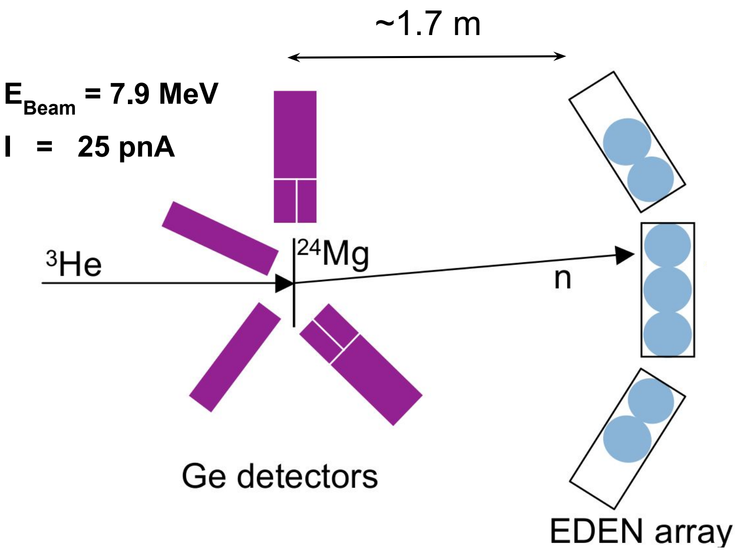
→ **States** above S_p **in ^{26}Si are critical to** the calculation of **the ^{25}Al(p, γ)^{26}Si reaction rate**.

→ **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



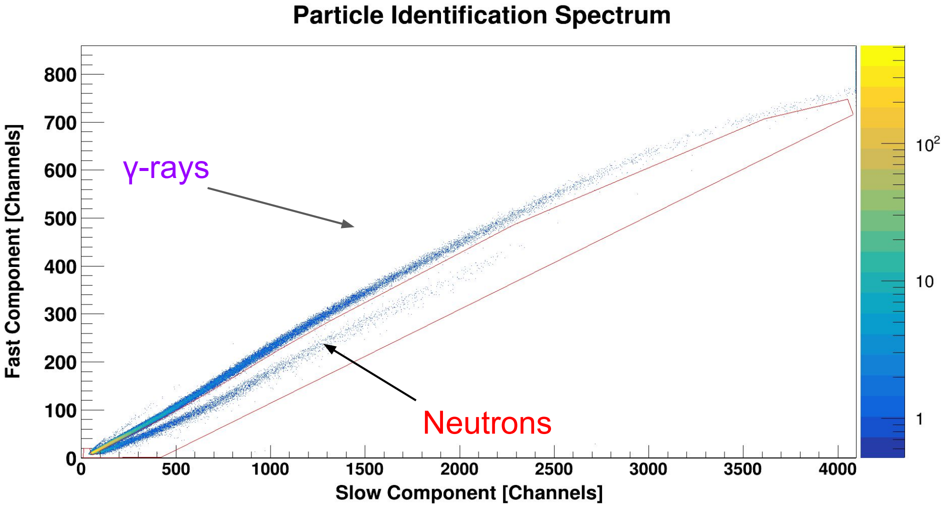
→ 99.85 % target purity
→ (150 μg/cm^{2} +250 μg/cm^{2}) ^{26}Mg target thickness
→ 0.2 mm Ta backing (beam stopped)

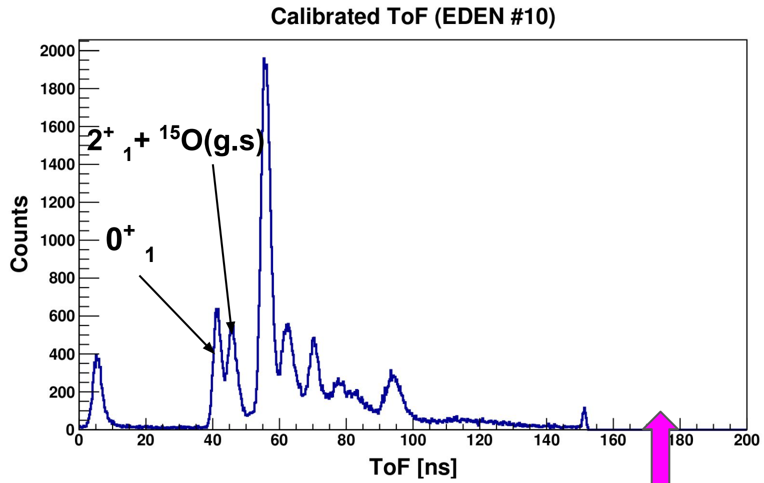
→ 2 clovers + 2 coaxials Ge detectors used for γ-rays

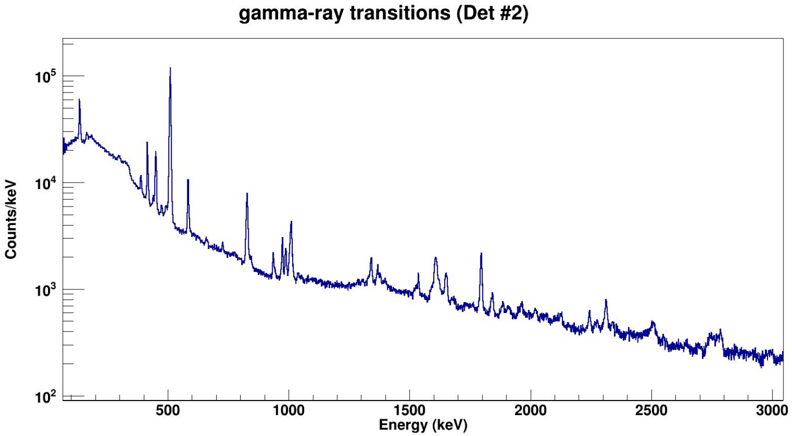
EDEN Array (neutrons)

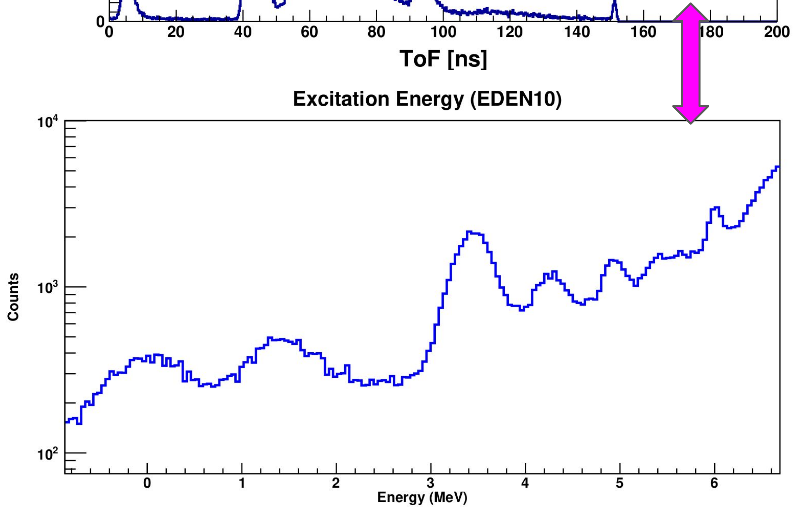
→ 36 NE213 (Φ 20 cm x L 5 cm) modules
→ ΔΩ = 350 msr
→ ε = 50% @ $E_{k,n}$ = 1 MeV & 30% @ $E_{k,n}$ = 6 MeV

Preliminary Results



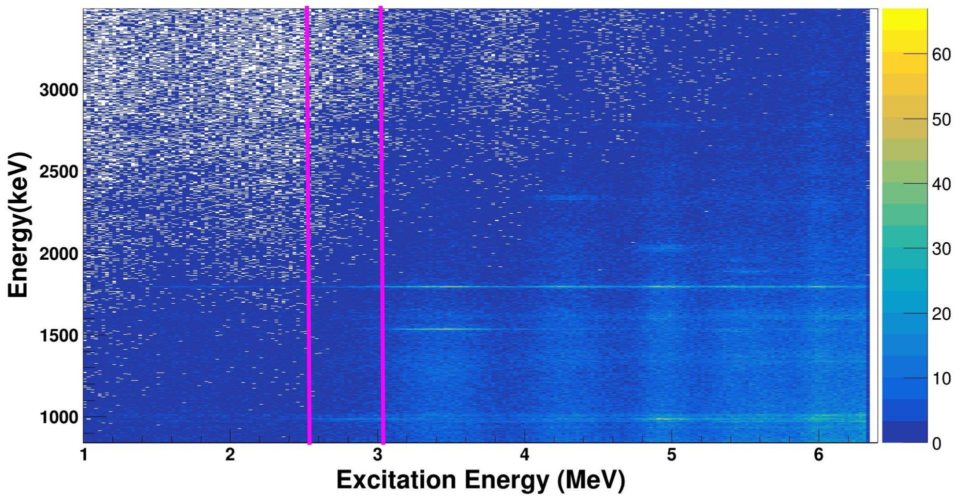


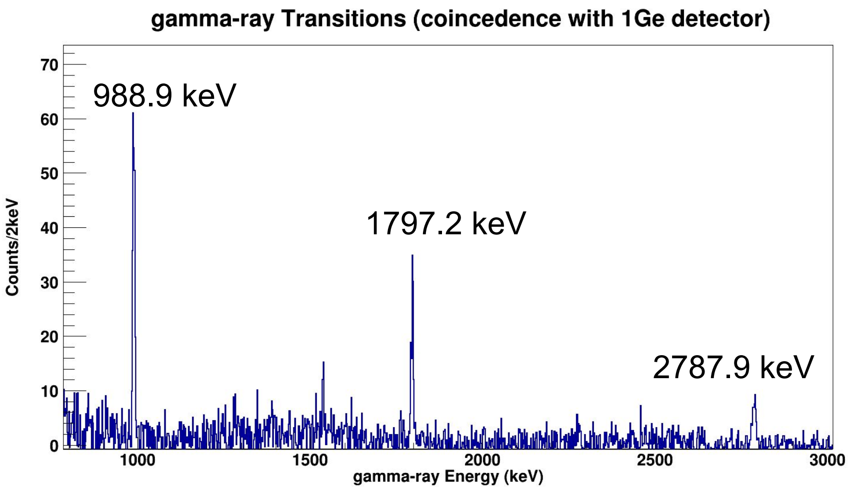


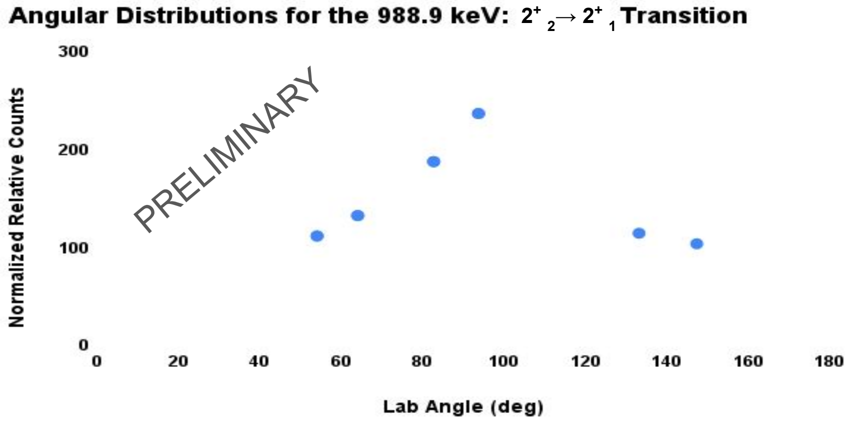


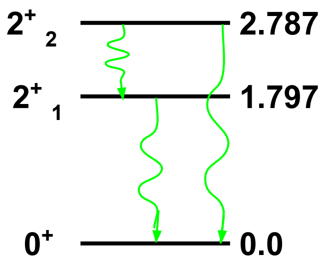
Many γ-ray transitions from known states in ^{26}Si were observed.

Preliminary Results









GATE: 2 – 3 MeV

Outlook

- ➔ Some known states in ^{26}Si have been confirmed.
- ➔ Search for new states and transitions in ^{26}Si is ongoing
- ➔ Angular distribution for the γ-ray transitions to determine spins
- ➔ Determine the **^{25}Al(p,γ) ^{26}Si** reaction rate
- ➔ Run astrophysical simulations with our new reaction rate

Thank you for your attention !!!!

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