Measurement of ^{26}Al(n,p) and ^{26}Al(n,α) Reaction Rates in Supernova Temperatures

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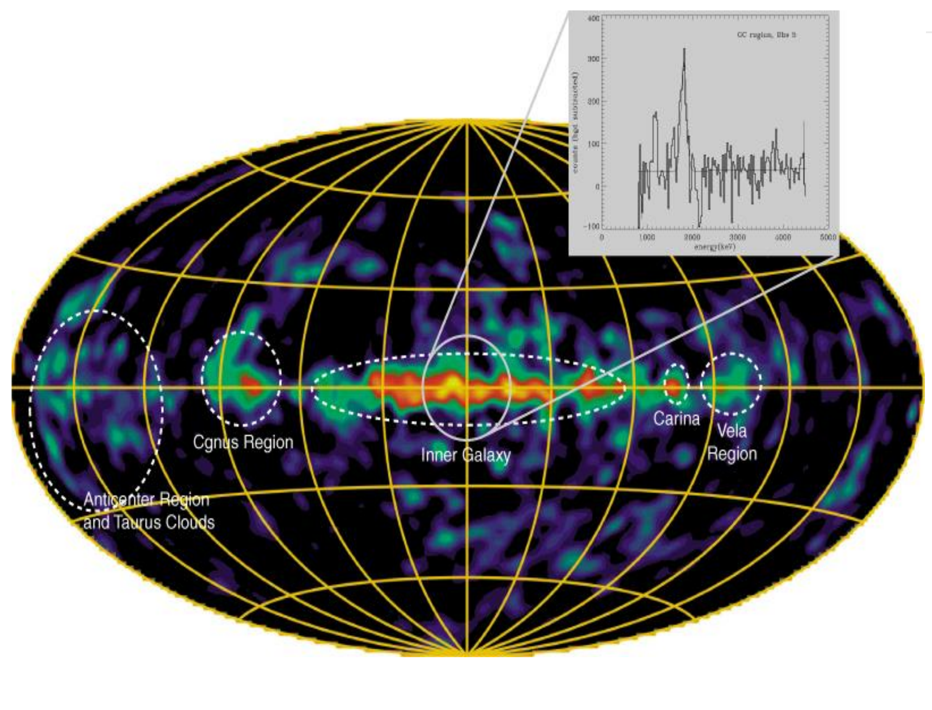
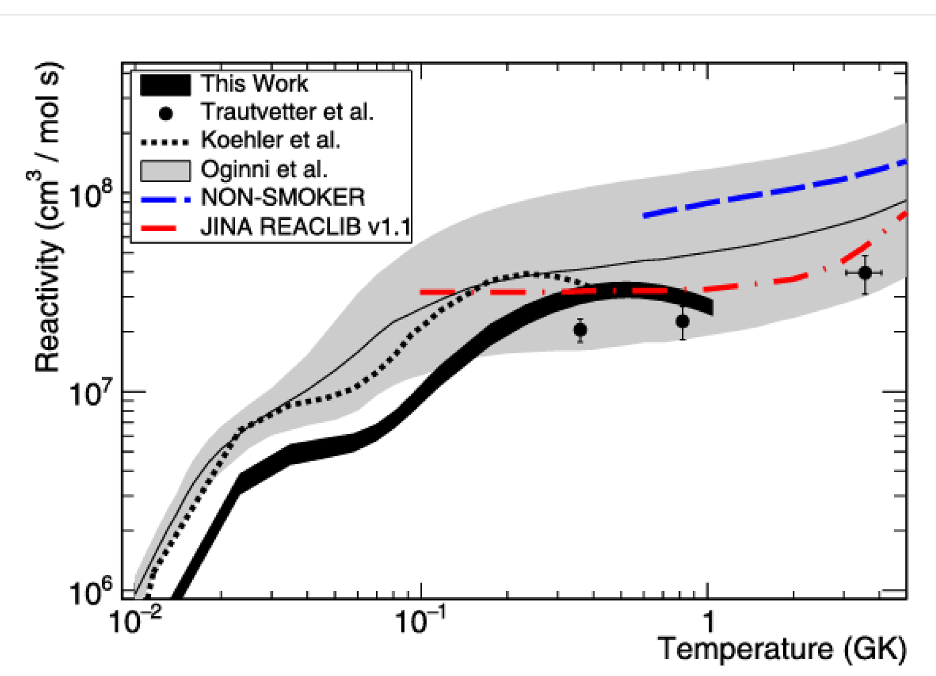
Introduction

The radioisotope ^{26}Al is crucial for understanding cosmic nucleosynthesis, with its 1809-keV γ-ray line providing direct evidence of element formation in the universe[1]. However, there is a lack of experimental data for the ^{26}Al(n,p) and ^{26}Al(n,α) reaction rates at high temperatures between 1.5-3.5 GK[2]. Our research addresses this gap by using a high-intensity neutron source generated by a thick ^{7}Li target and a proton beam, enabling precise measurement of these reaction rates. Our measurements will be conducted with a Micromegas-based gaseous detector, facilitating accurate detection of outgoing protons and reducing uncertainties in ^{26}Al abundance predictions.



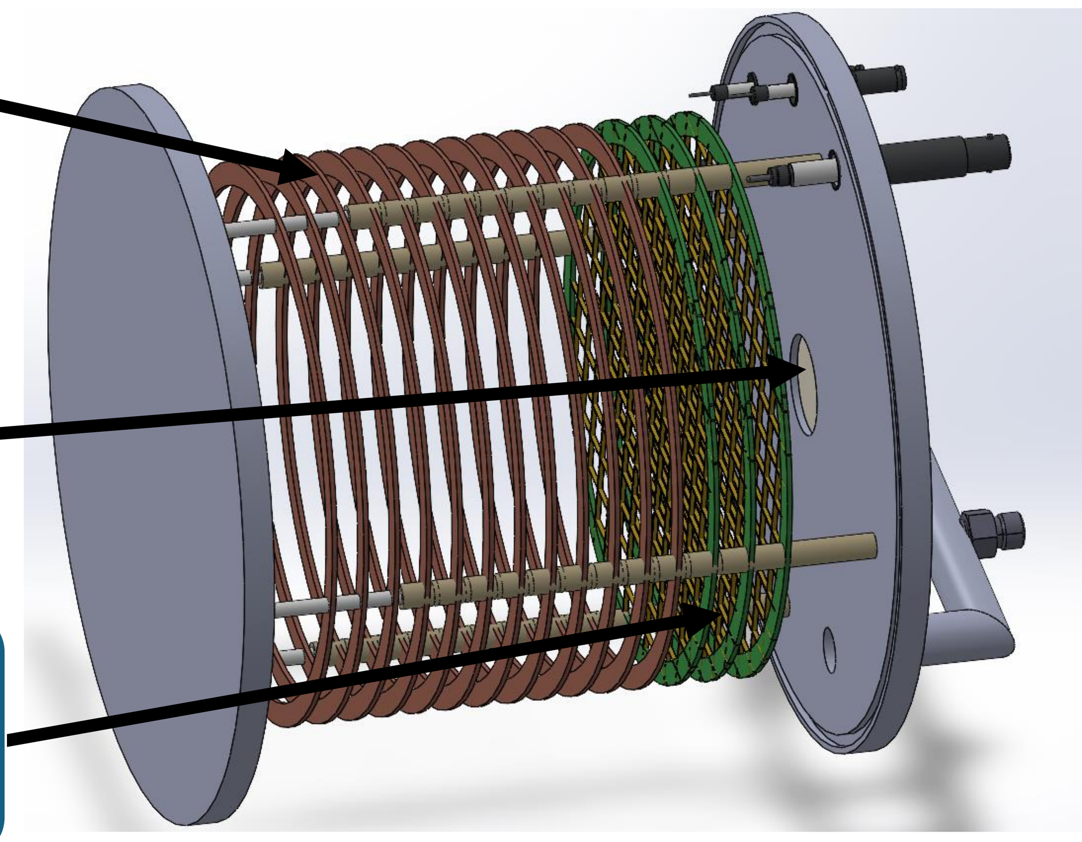
The distribution of 26Al in Milky Way
Comptel Collaboration (MPE/SRON/UNH/NASA)

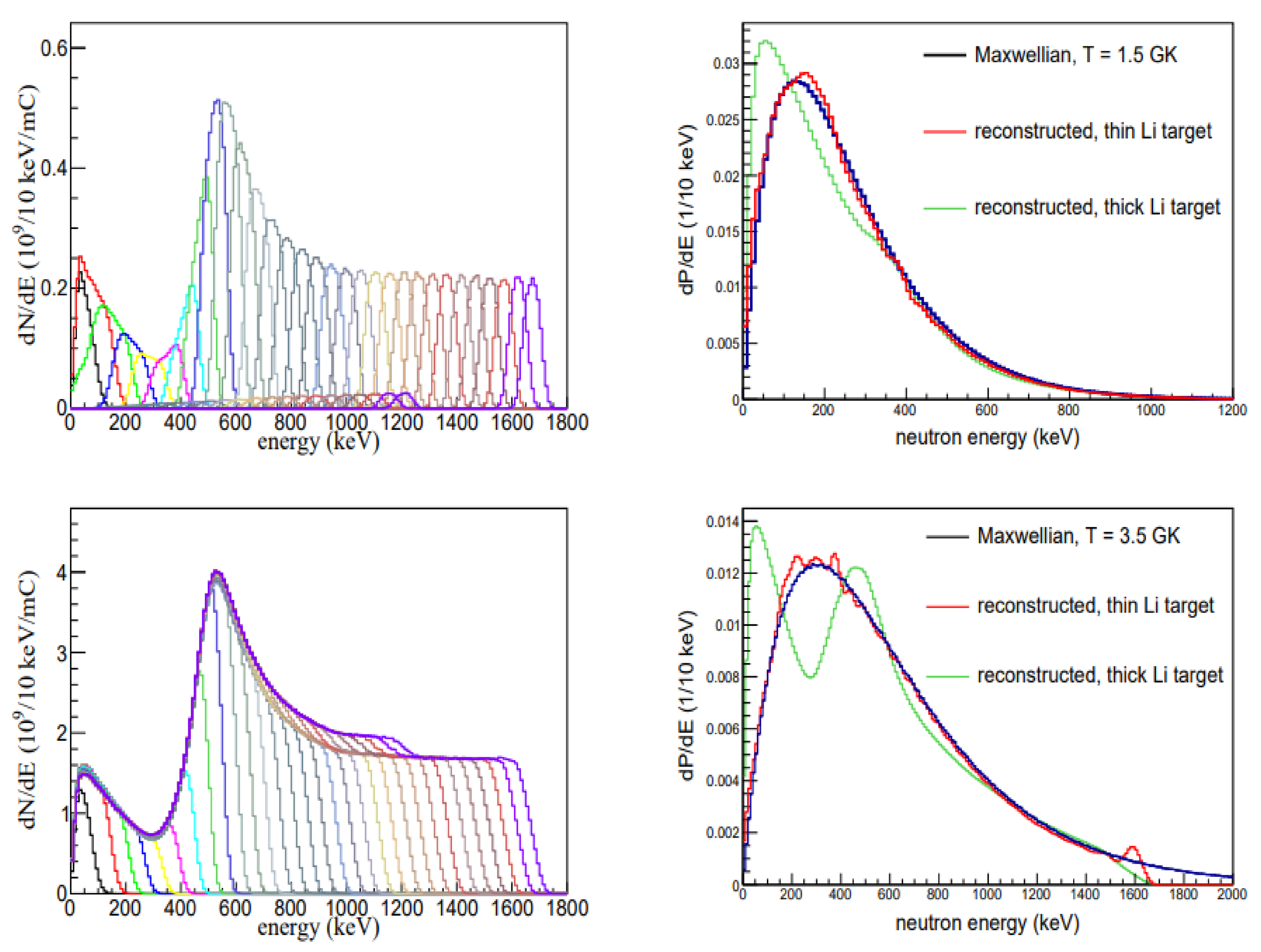


C. Lederer-Woods *et al.* (n_TOF Collaboration) Phys. Rev. C **104**, L022803 (2021).

Experimental Methods

- ^{7}Li(p,n) reaction as neutron source, placed 3 cm upstream of the ^{26}Al target.
- Varying proton beam energy between 1.9-3.6 MeV.
- Neutron intensity 10^9 n/s for a 10 μA proton beam.
- Gaseous detector to reduce the neutron and gamma background.
- Segmented Micromegas detector, where the central pad serves as a trigger, and outer pads as veto pads.





M. Friedman, Production of quasi-stellar neutron field at explosive stellar temperatures, Eur. Phys. J. 256 A. 56, 155 (2020).

For each proton energy, a corresponding neutron energy distribution ϕ^{i}_{exp} and a cross section σ^{i}_{exp} is extracted. We can then find a set of weights W_i that will satisfy:

$$\overline{\phi_{exp}} = \left(\frac{1}{\sum W^i}\right) \cdot \sum W^i \cdot \phi^i_{exp} = \phi_{MB}$$

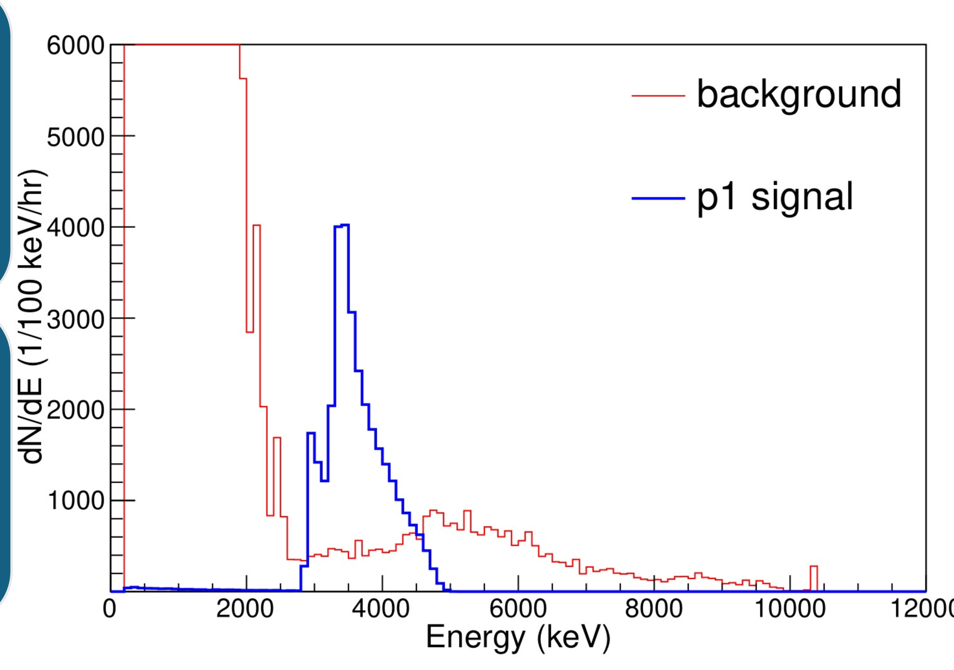
And subsequently obtain a weighted averaged experimental cross section[3]:

$$\overline{\sigma_{exp}} = \left(\frac{1}{\sum W^i}\right) \cdot \sum W^i \cdot \sigma^i_{exp} \propto MACS$$

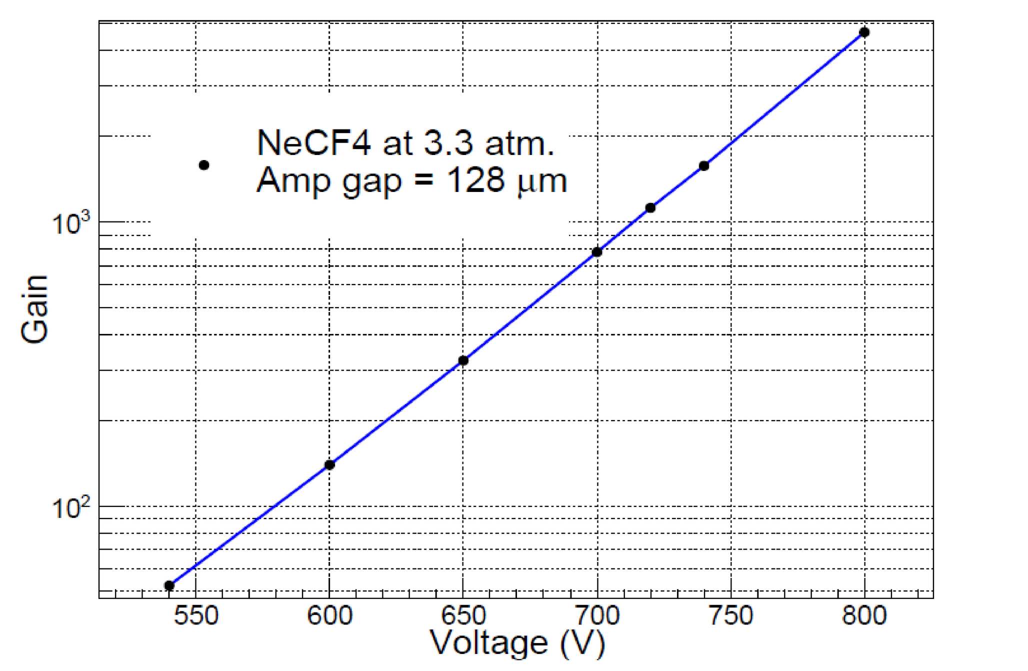
Geant4 Simulation

Expected yields from 1 hour of 10 μA proton beam at 3.6 MeV (highest expected background).

Calculated Efficiency of ≈ 33%



Average Gain



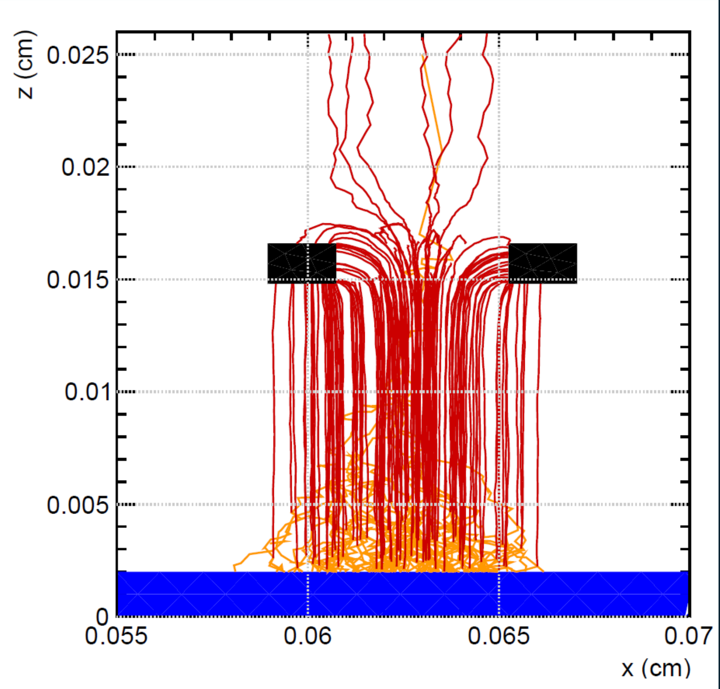
Average Gain in Amplification Region as Calculated by Garfield++.

Expected Impact

- Current uncertainties in these reactions are estimated to be a factor of 6 for the (n,p) and a factor of 3 for (n,α) reaction rates within 1.5–3.5 GK[5].
- A factor of two in the ^{26}Al(n,p) reaction rate changes the final ^{26}Al abundance by ~40%[6].
- A factor of 10 in the ^{26}Al(n,α) reaction rate changes the abundance by ~45%[6].
- **Our aim is to reduce these uncertainties to 25% or less across the full energy range.**

Ion Backflow

- **Ion Backflow (IBF):** IBF can cause a positive charge buildup in the drift region, distorting the electric field and negatively impacting detector performance.
- **IBF Proportionality**[4]**:** $IBF \propto \frac{1}{FR}\left(\frac{p}{\sigma_t}\right)^2$, where FR is the field ratio, p is the mesh pitch and $\sigma_t = D_t z$, where D_t is the transverse diffusion coefficient of the electron and z is the path traversed.
- **Active Region Design:** The active region design effectively reduces background ionization rates, minimizing the ion backflow effect.



References

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2. R. Diehl, M. Lugaro, A. Heger, et al., The radioactive nuclei 26Al and 60Fe in the cosmos and in the solar system, Publications of the Astronomical Society of Australia 38 (1) (12 2021).
3. M. Friedman, Production of Quasi-Stellar Neutron Field at Explosive Stellar Temperatures, Eur. Phys. J. A. 56, 155 (2020).
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