TRIUMF

The Impact of ^{17}O alpha captures on the weak s-process

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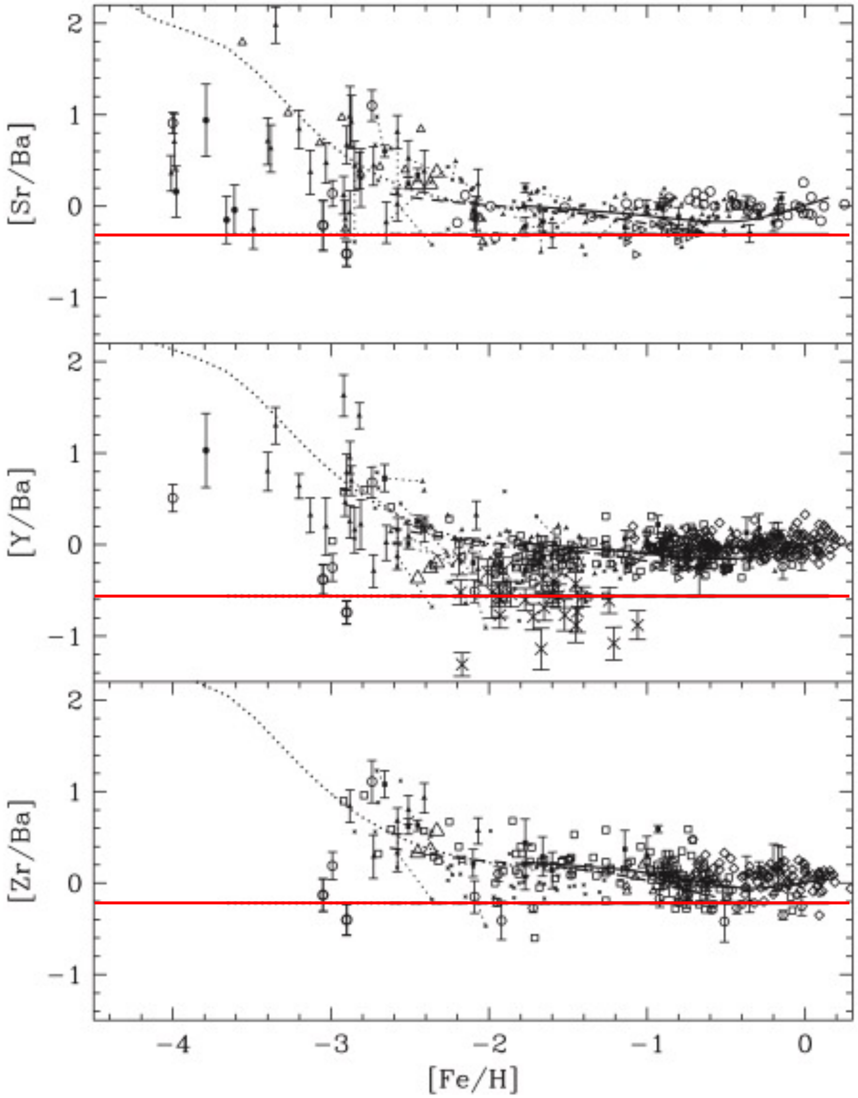
Astrophysical Motivation

- Comparing theoretical predictions to astronomical observations
- Ultra metal poor (UMP) stars are very old so can be used to test *r*-process models
- Generally, in agreement for heavy element abundances
- However, more elements with 26 < Z < 47 than expected!



C. Travaglio et al. (2004) ApJ. **601** 864

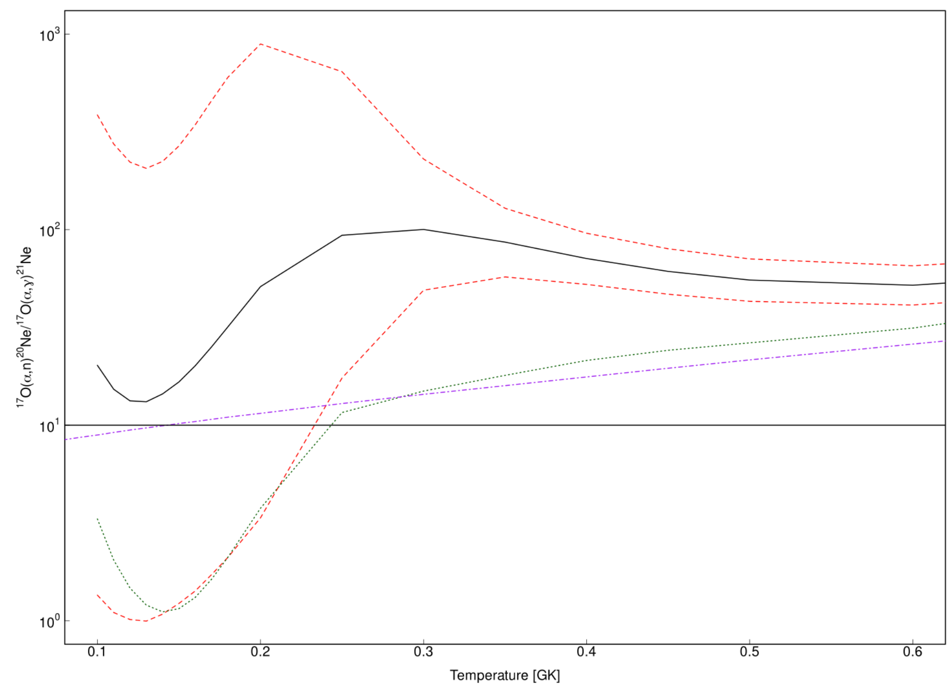
Rotating Metal-poor Stars

- *s*-process previously discounted
- ^{12}C produced in He core burning
- Rapid rotation mixes ^{12}C into H-burning shell stimulating ^{14}N production via CNO cycle
- ^{14}N engulfed by expanding He core increases production of ^{22}Ne via successive α captures
- ^{22}Ne(α,n)^{25}Mg – major source of neutrons for the *s*-process
- Potential to produce significant quantities of intermediate mass elements

Image Credit: HST, NASA and ESA

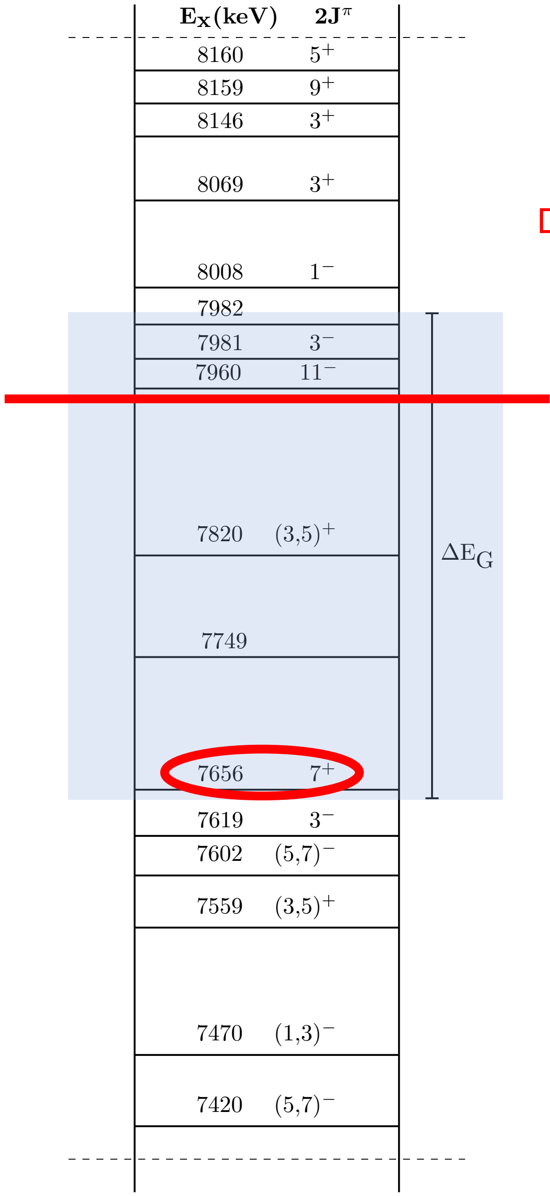
Neutron poisoning

- ^{16}O captures neutrons, reducing *s*-process rate
- Neutrons may be liberated again in subsequent $^{17}O(\alpha,n)^{20}Ne$ reaction
- Efficiency of the 'weak' *s*-process depends on $^{17}O(\alpha,n)^{20}Ne/^{17}O(\alpha,\gamma)^{21}Ne$ reaction rate ratio
- $0.2 \leq T\ [GK] \leq 0.3$



Energy levels of ^{21}Ne

- Reaction cross sections too low to measure directly
- Reaction rate dominated by narrow resonances in compound nucleus ^{21}Ne
- Several unknowns about important energy levels
  - Spin-parity, resonance strengths, neutron partial widths (Γ_n)…



Direct measurement at DRAGON

Williams et al. (2022) PRC.

Taggart et al. (2019) Phys. Let. B.

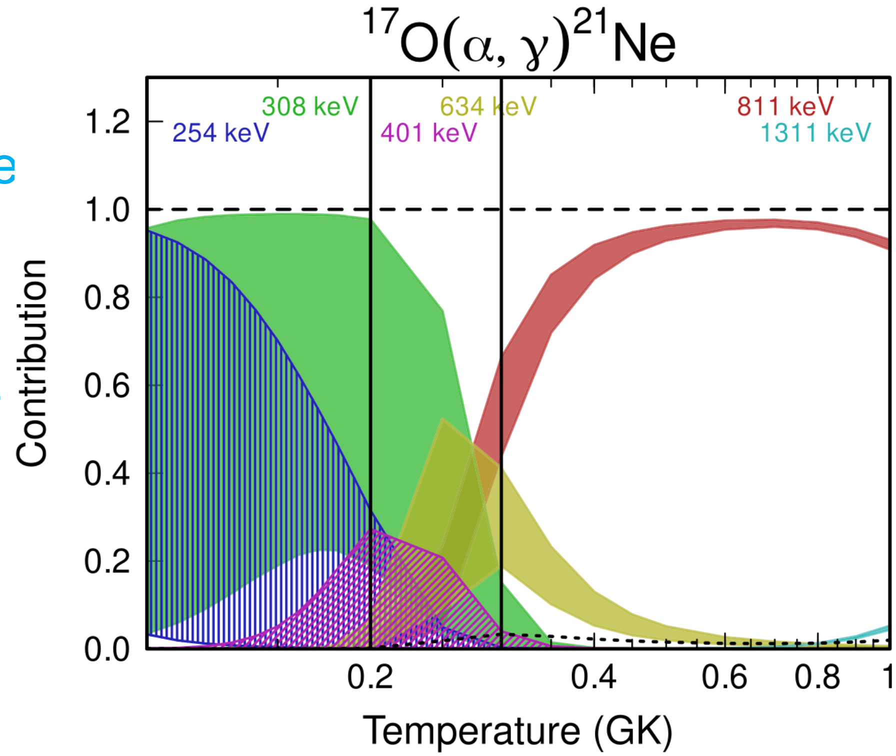
Experimental Studies

Facility	Aims
DRAGON, TRIUMF	$\omega\gamma_\gamma$
Enge Split-pole spectrometer, TUNL	E_x, J^π, Γ_n
HELIOS, ANL	J^π, Γ_n
Q3D, Munich	J^π, Γ_α
EMMA+TIGRESS, TRIUMF	J^π, Γ_α, B_γ

Slide adapted from: Prof. A. Laird

Experimental Aims

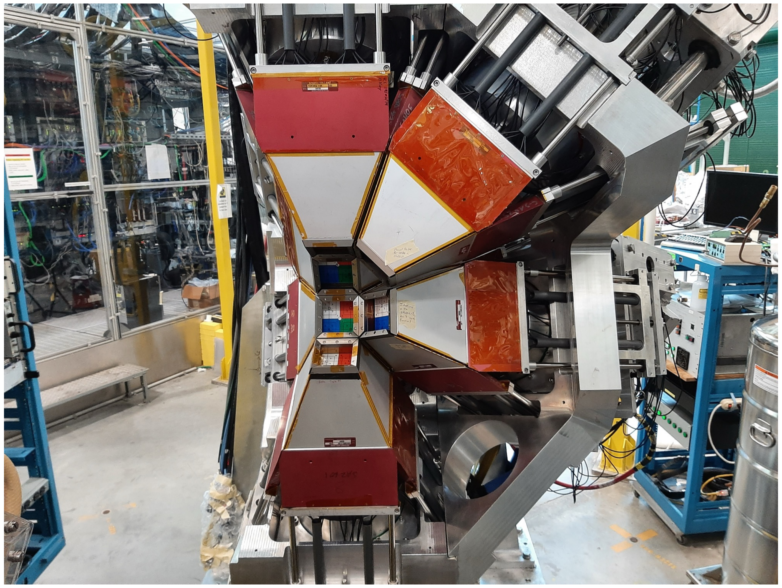
- Determine the resonances that significantly contribute to the $^{17}O(\alpha, \gamma)^{21}Ne$ reaction rate and measure their absolute resonance strengths
- Used $^{17}O(^{7}Li,t)^{21}Ne$ reaction to populate relevant energy levels
- 4.5 AMeV ^{17}O beam impinged on 100 $\mu g/cm^2$ LiF foil with a 30 $\mu g/cm^2$ carbon backing

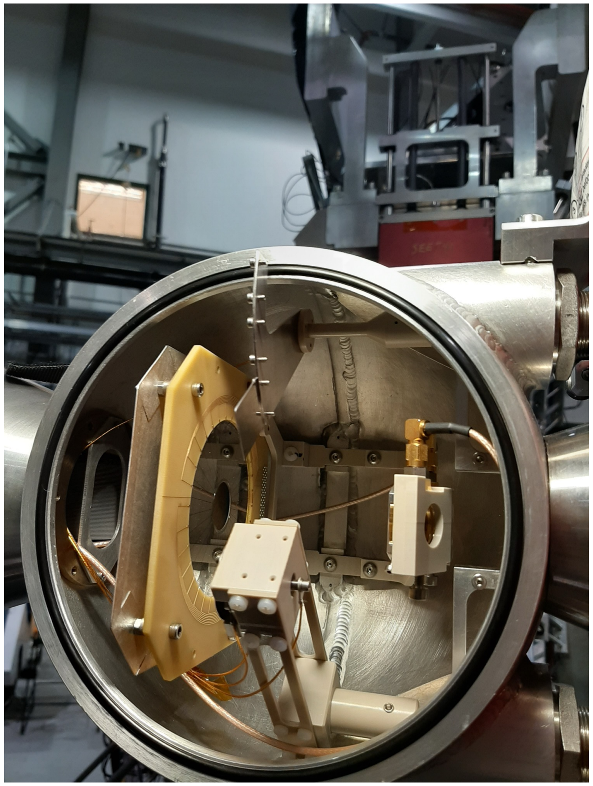


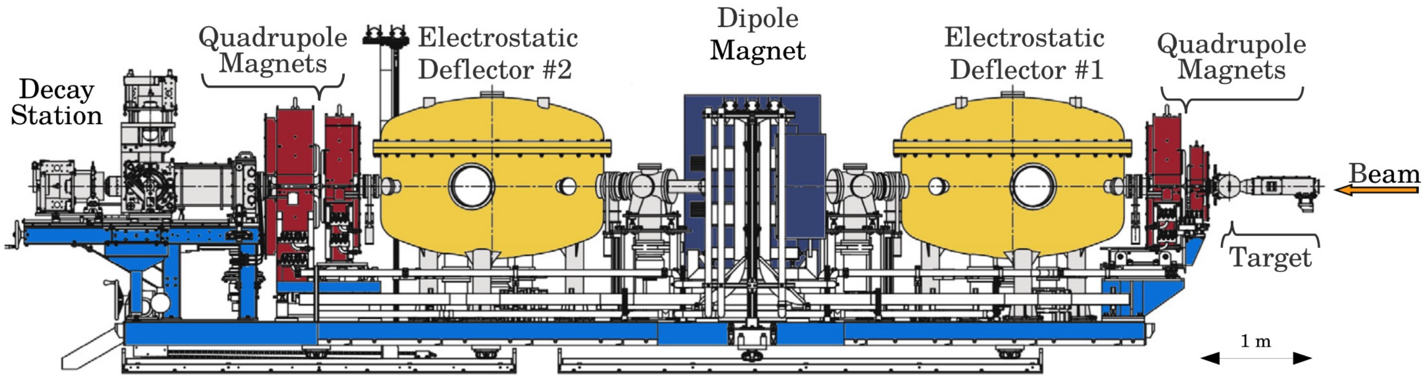
Frost-Schenck et al. (2022) MNRAS.

Experiment

- Dec 2019 & Nov 2020
- Electromagnetic Mass Analyzer (EMMA)
  - S3 annular detector in target chamber
- Triumf-ISAC Gamma-Ray Escape Suppressed Spectrometer (TIGRESS)



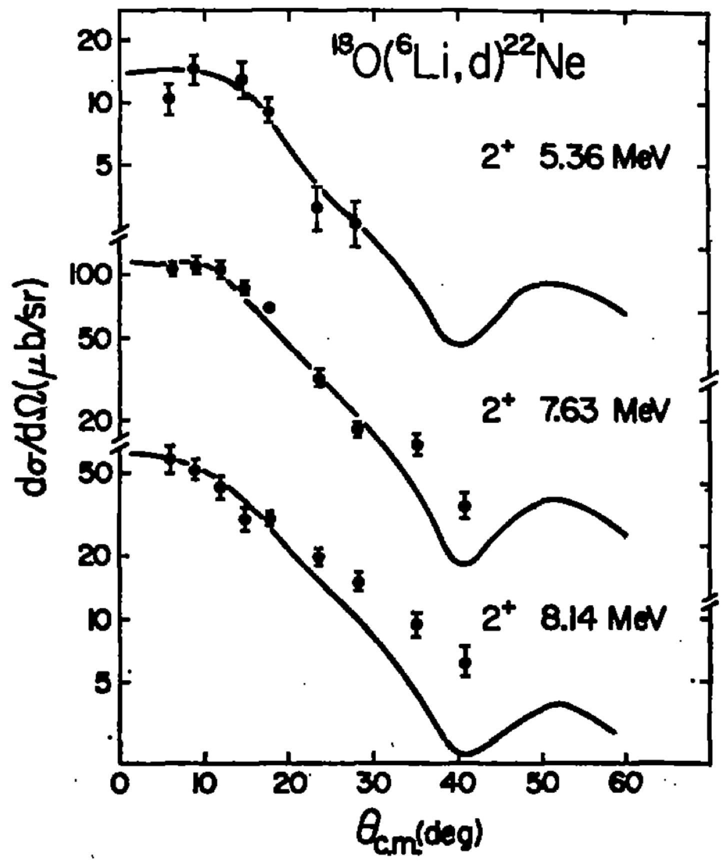




B. Davids et al. (2019) NIM. A. **930** 191-195

Experiment

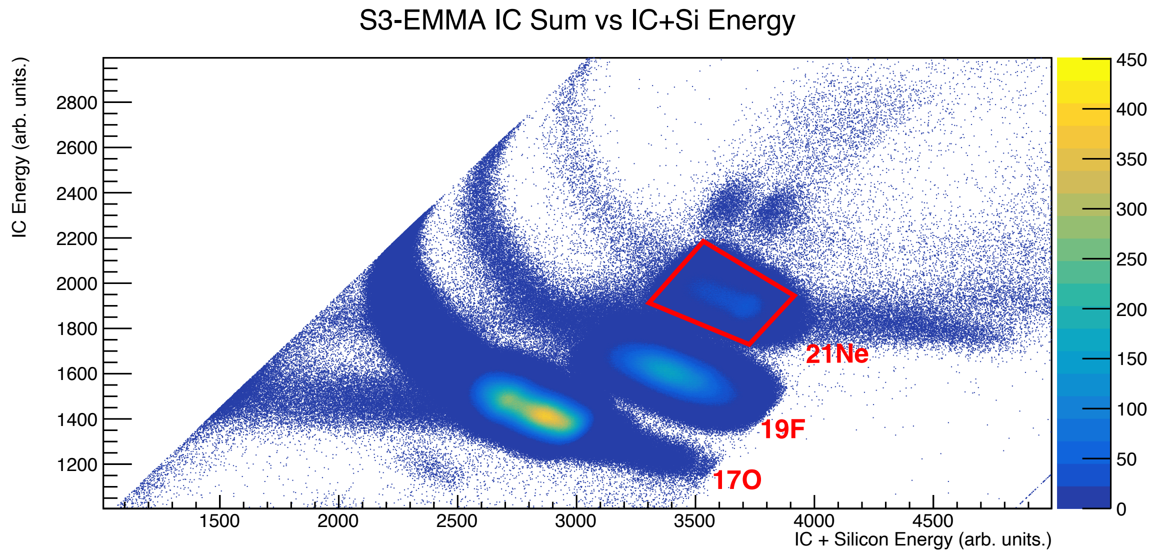
- S3 measured the tritons ejected from the reaction (16° – 37°)
- Compare Angular distribution to Distorted Wave Born Approximation (DWBA) predictions to determine spin-parity and alpha partial widths
- TIGRESS used to gate on gamma-rays associated with the de-excitation of specific energy levels
- EMMA used to detect ^{21}Ne recoils

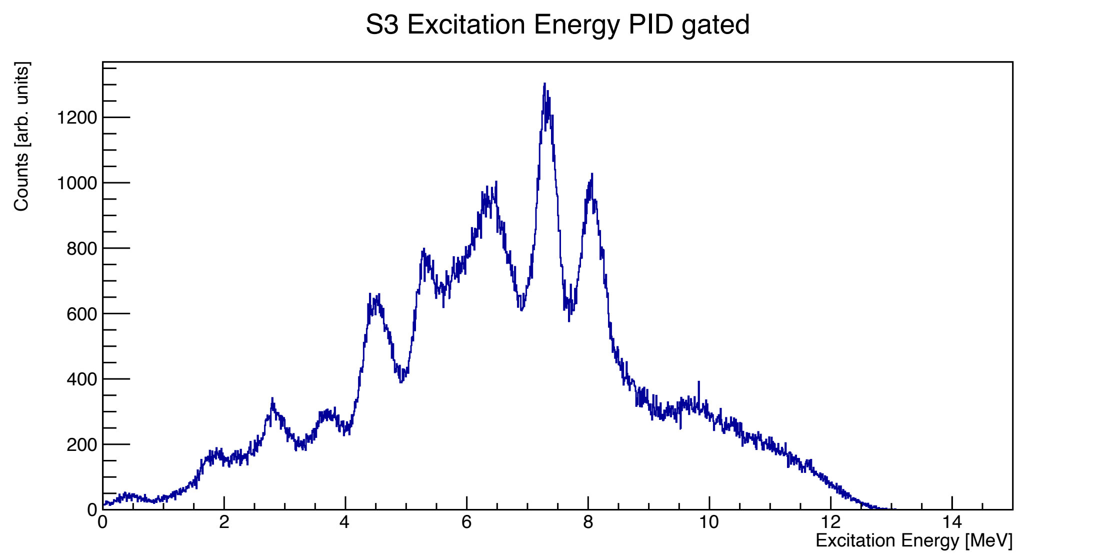


N. Anantaraman, H. E. Gove and J. P. Trentelman (1977) Nuclear Physics **A276** 119-129.

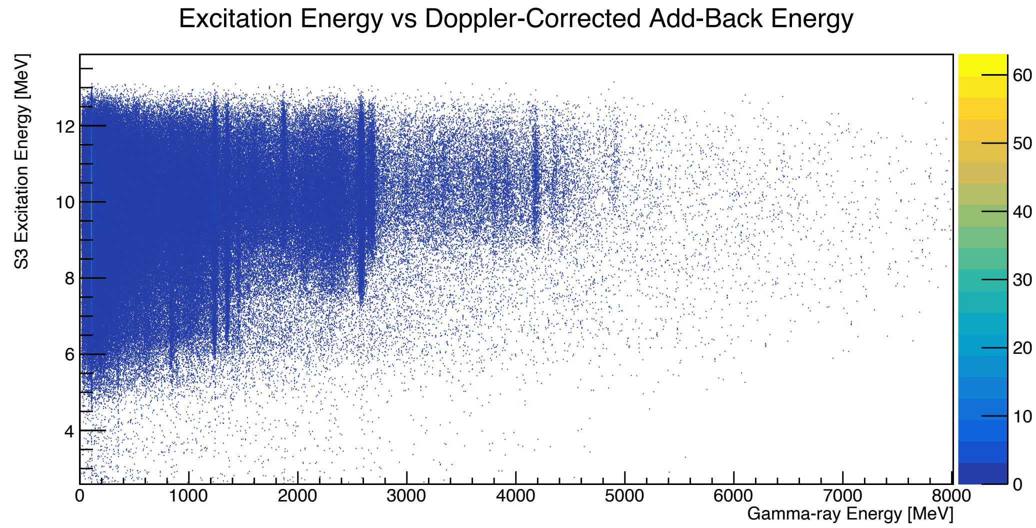
Analysis

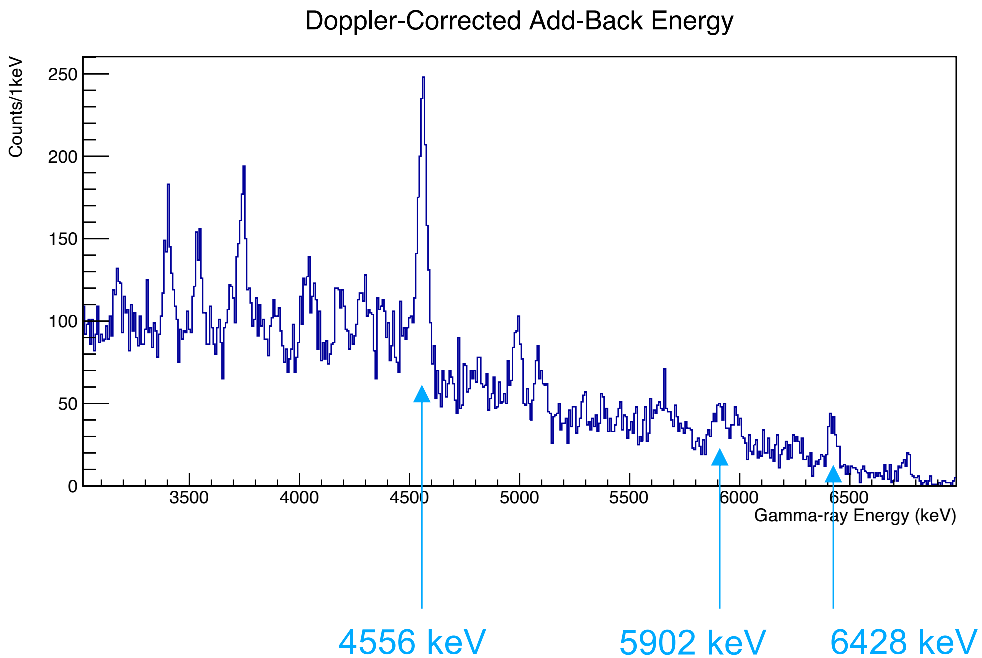
- Much analysis already conducted by Dr. M. Williams
- Gating on ^{21}Ne recoils identified from dE/E analysis
- Triton resolution in S3 makes analysis a bit tricky
- Need to isolate resonances using gamma-rays





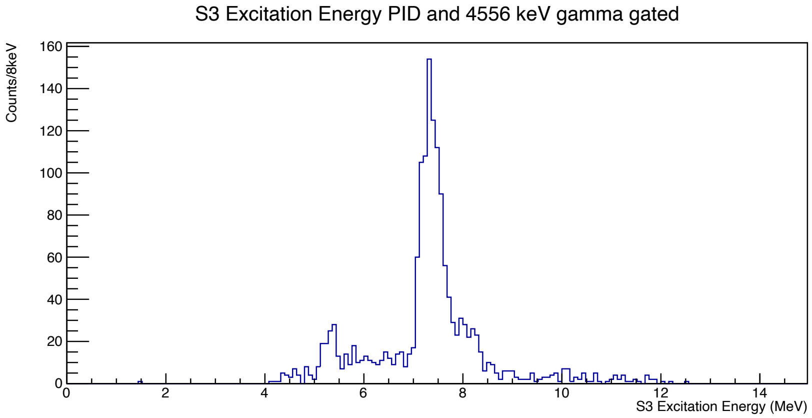
Analysis



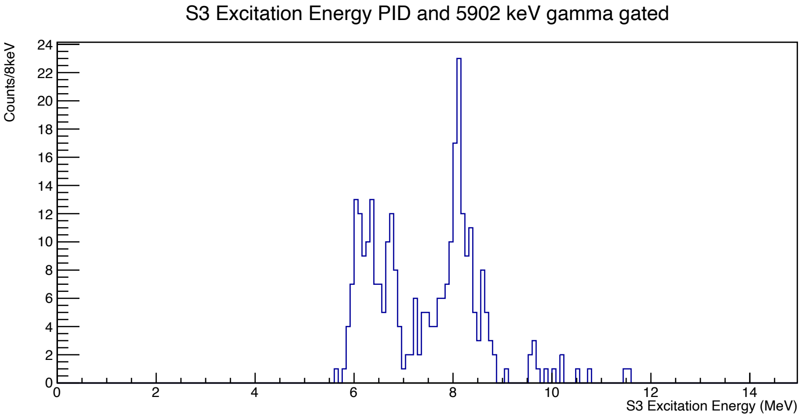


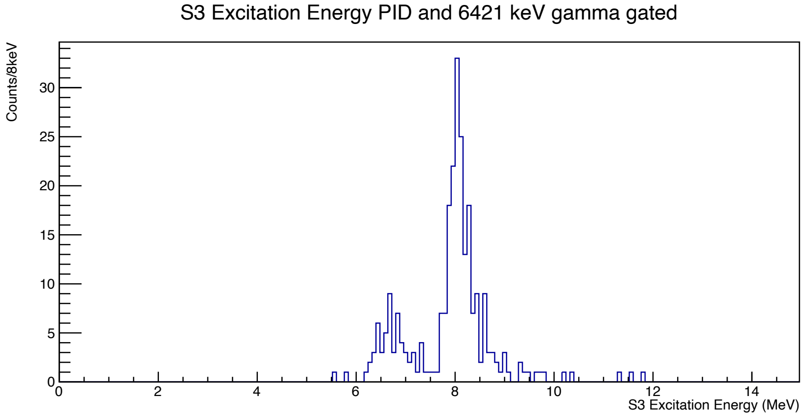
- 6428 keV gamma ray from the 8155 keV energy level
- 5902 keV gamma ray from the 7648 keV energy level
- 4556 keV gamma ray from the 7420 keV energy level

Analysis



- Next steps:
  - Use these Pid, gamma-ray gated S3 excitation energy spectra to extract angular distribution of ejected tritons
  - Fit DWBA predictions to extract spin-parity and alpha partial widths





Summary

- EMMA+TIGRESS has been used to measure the $^{17}O(^{7}Li,t)^{21}Ne$ reaction at TRIUMF-ISAC
- Motivation was to measure the strength of resonances that are the main source of uncertainty in the calculated rate of the $^{17}O(\alpha, \gamma)^{21}Ne$ reaction
- Needed to determine the effects of ^{16}O neutron poisoning of the weak s-process
- Weak s-process in rotating massive stars a possible site for early nucleosynthesis of intermediate mass elements
- Analysis ongoing…

Thank You for Listening!

And a big thank you to all my collaborators

M. Williams[1,2,4], A. M. Laird[1], B. Davids[2], C. Aa. Diget[1], S. Bhattacharjee[2], S. Gillespie[2], J. Williams[2], D. Yates[2,3], G. Hackman[2]

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