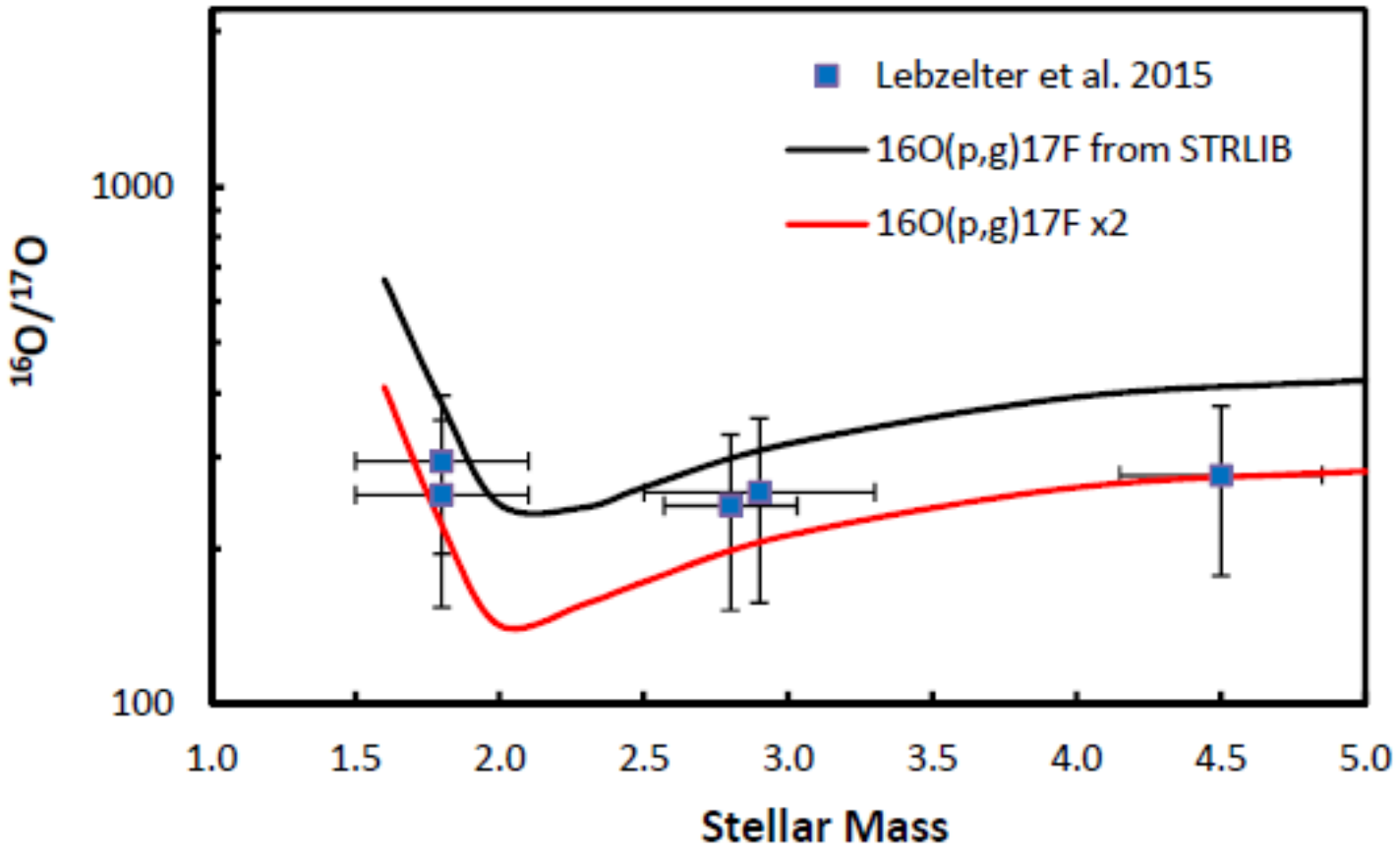
Underground Measurements of the $^{16}O(p,\gamma)^{17}F$ Reaction at LUNA

Laboratory for **U**nderground **N**uclear **A**strophysics

Astrophysical Motivation

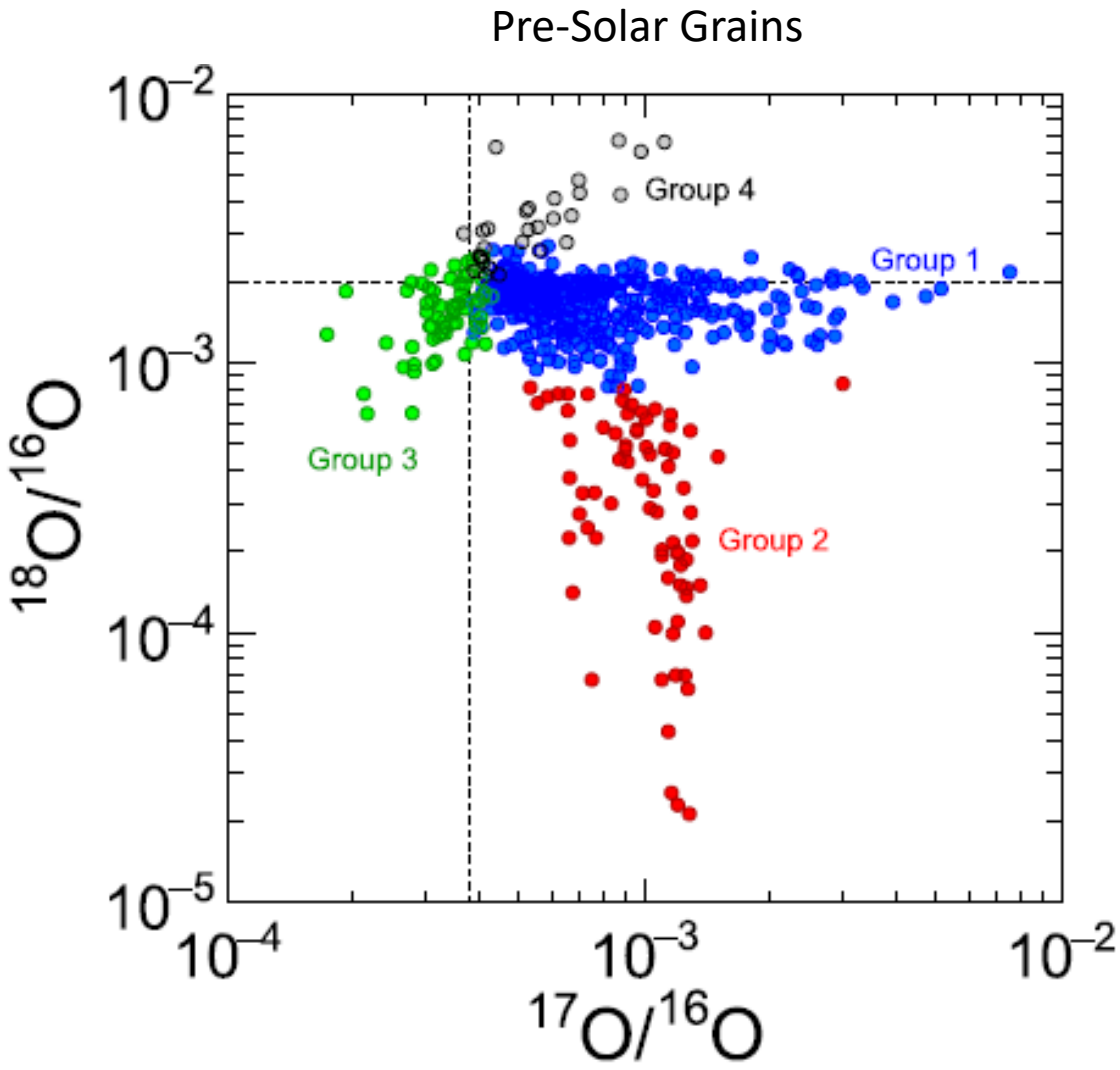
- Part of the CNO cycle
- Pure Direct Capture reaction – lowest energy resonance is at E_{CoM} = 2.6 MeV
- $^{16}O/^{17}O$ ratio in red giants depends on the $^{16}O(p,\gamma)$ rate

$^{16}O/^{17}O$ Ratio in Open Cluster Red Giant Stars



AGB Stars - Pre-Solar Grains and Hot Bottom Burning

- Group 2 pre-solar grains are predicted to have originated in AGB stars
- With the current $^{16}O(p,\gamma)$ rate models struggle to account for the observed $^{17}O/^{16}O$ ratios
- HBB is a suggested additional mixing mechanism. Its success depends sensitively on the $^{16}O(p,\gamma)$ rate



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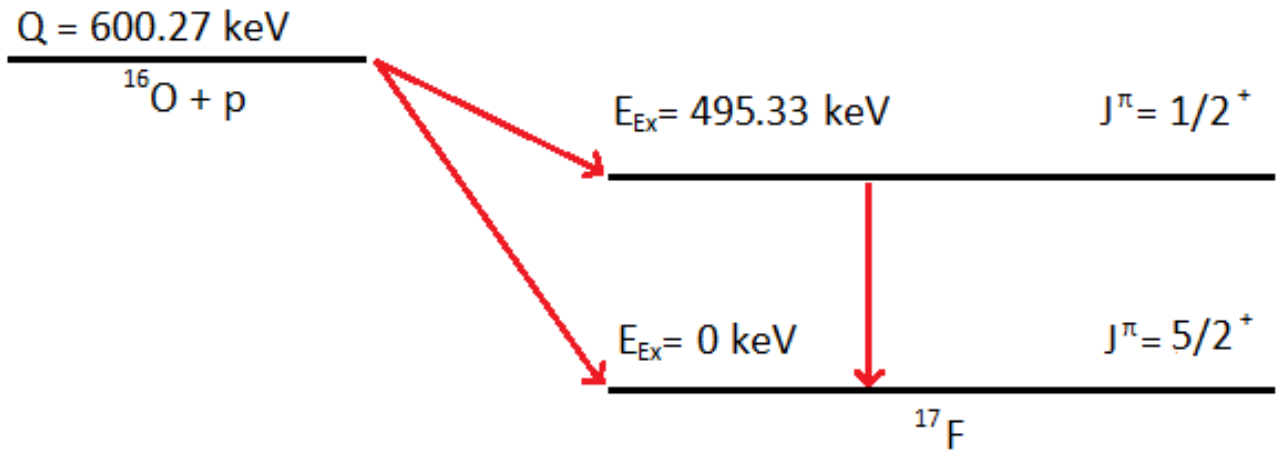
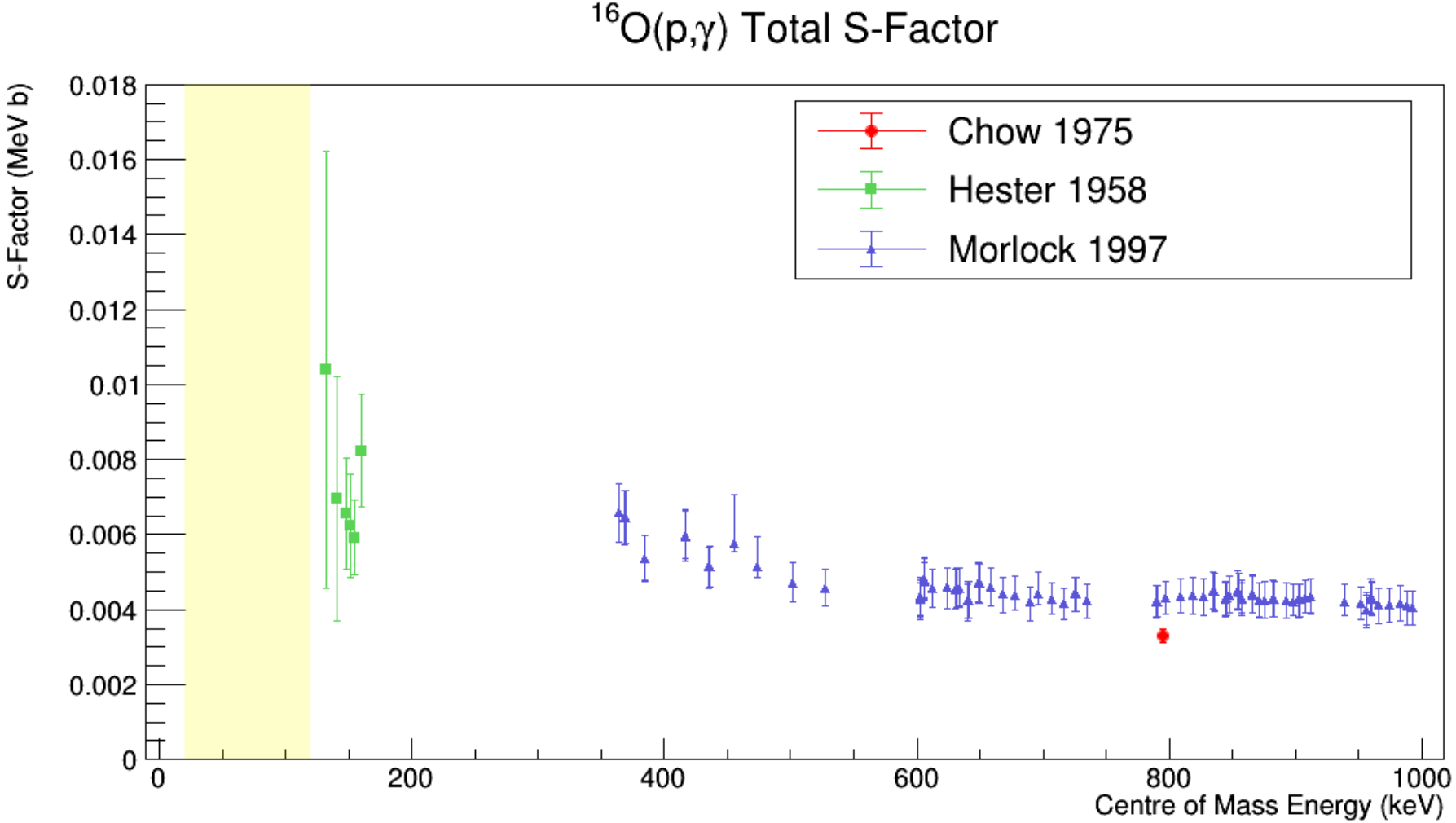
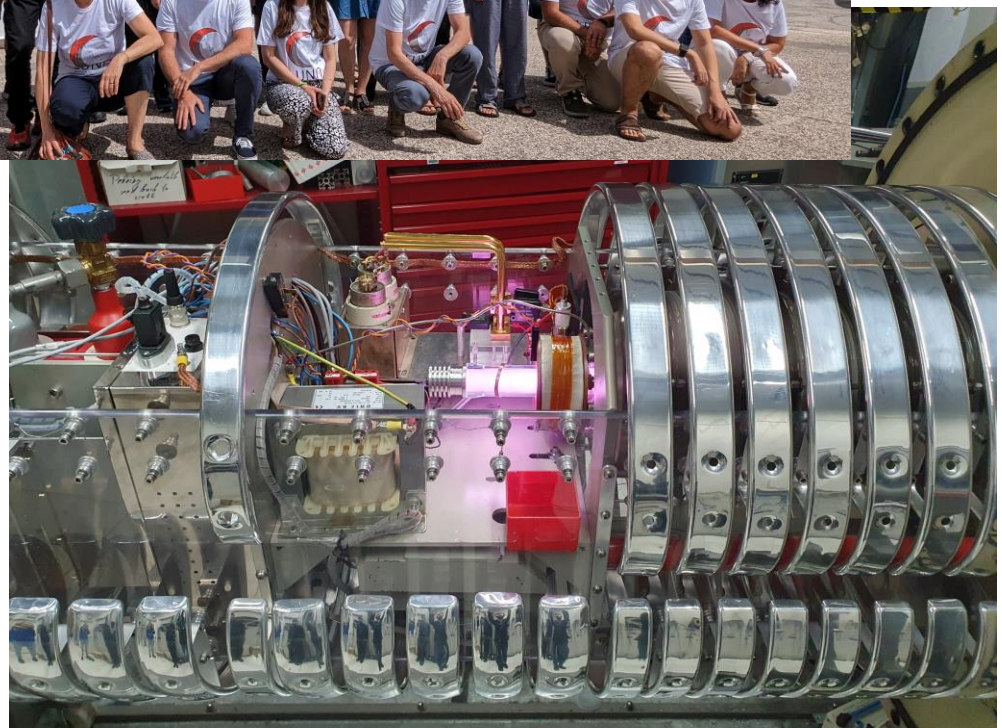
The $^{16}O(p,\gamma)^{17}F$ Reaction: State of the Art





LUNA Experiment

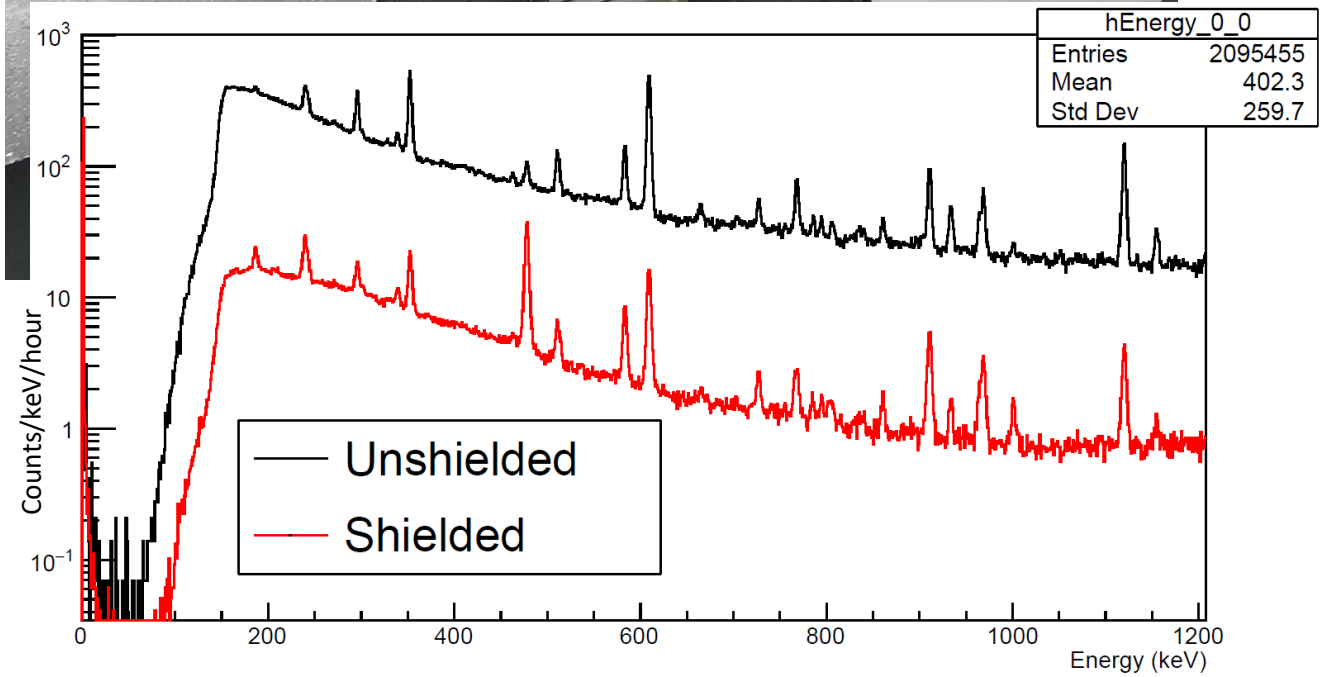
- 400 kV accelerator at Gran Sasso National Laboratory in Italy

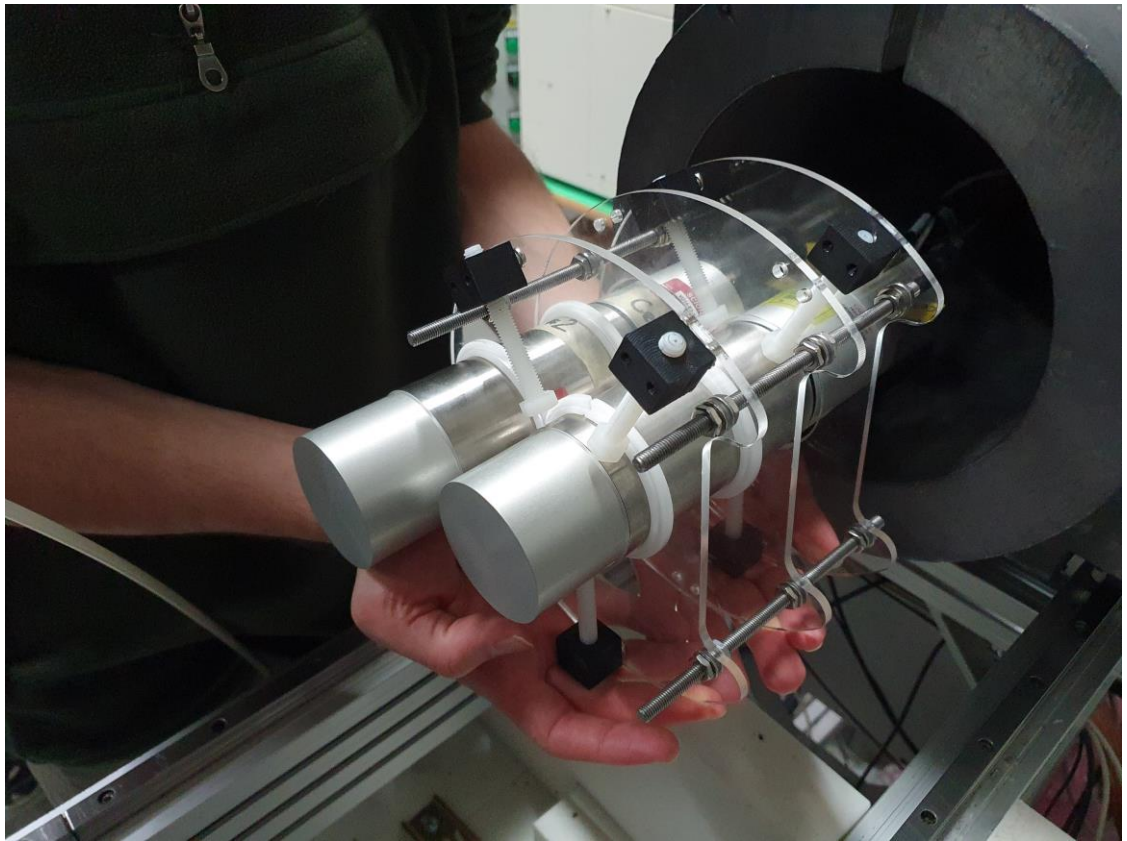


- Beneath more than 1 km of rock
- Cosmic radiation flux reduced by a factor of a million compared to the surface

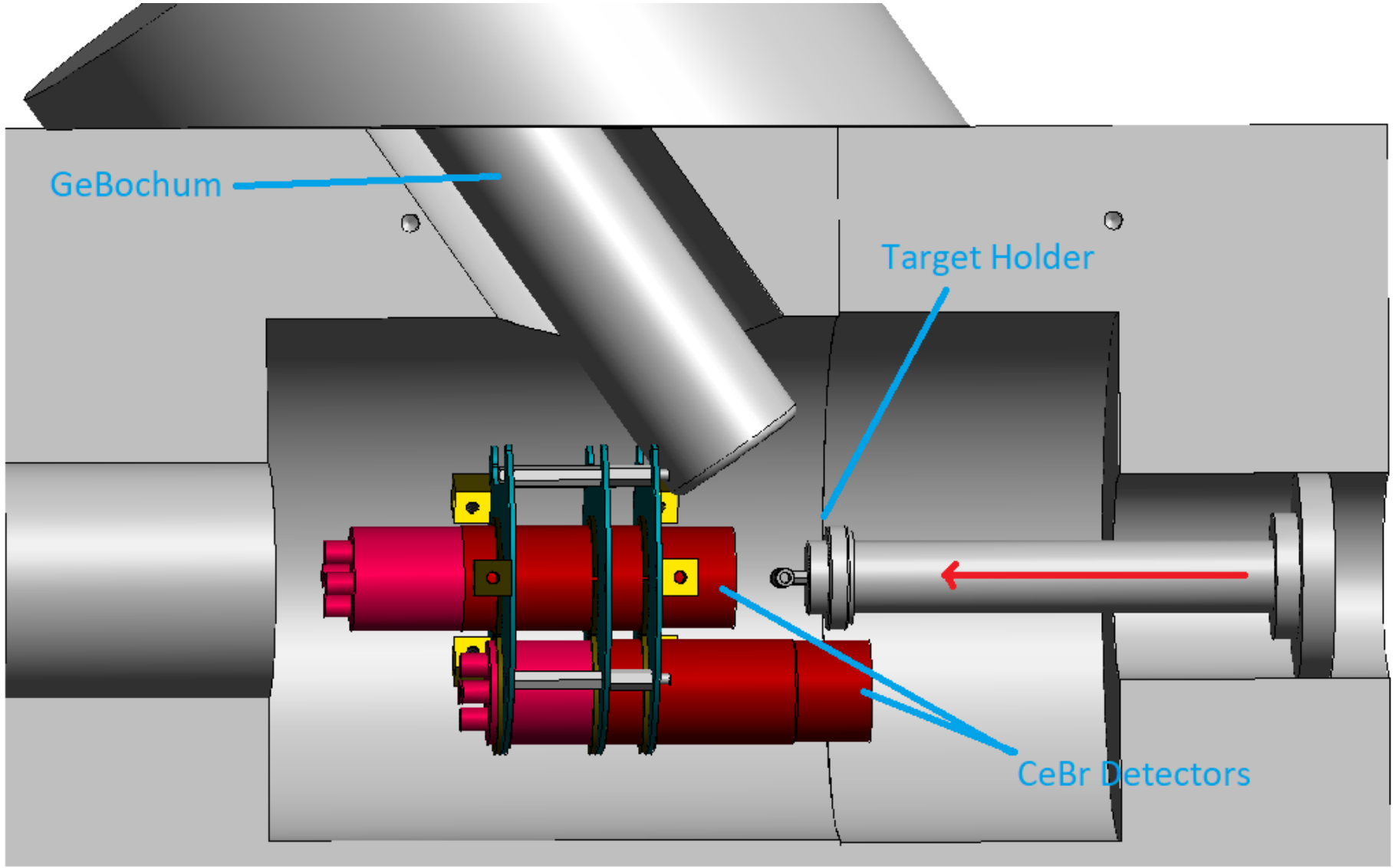
Experimental Setup

- One HPGe detector at 55°
- Two CeBr scintillators, one at 0° and one at 90°
- Solid tantalum oxide (Ta_2O_5) target
- All inside thick lead shield





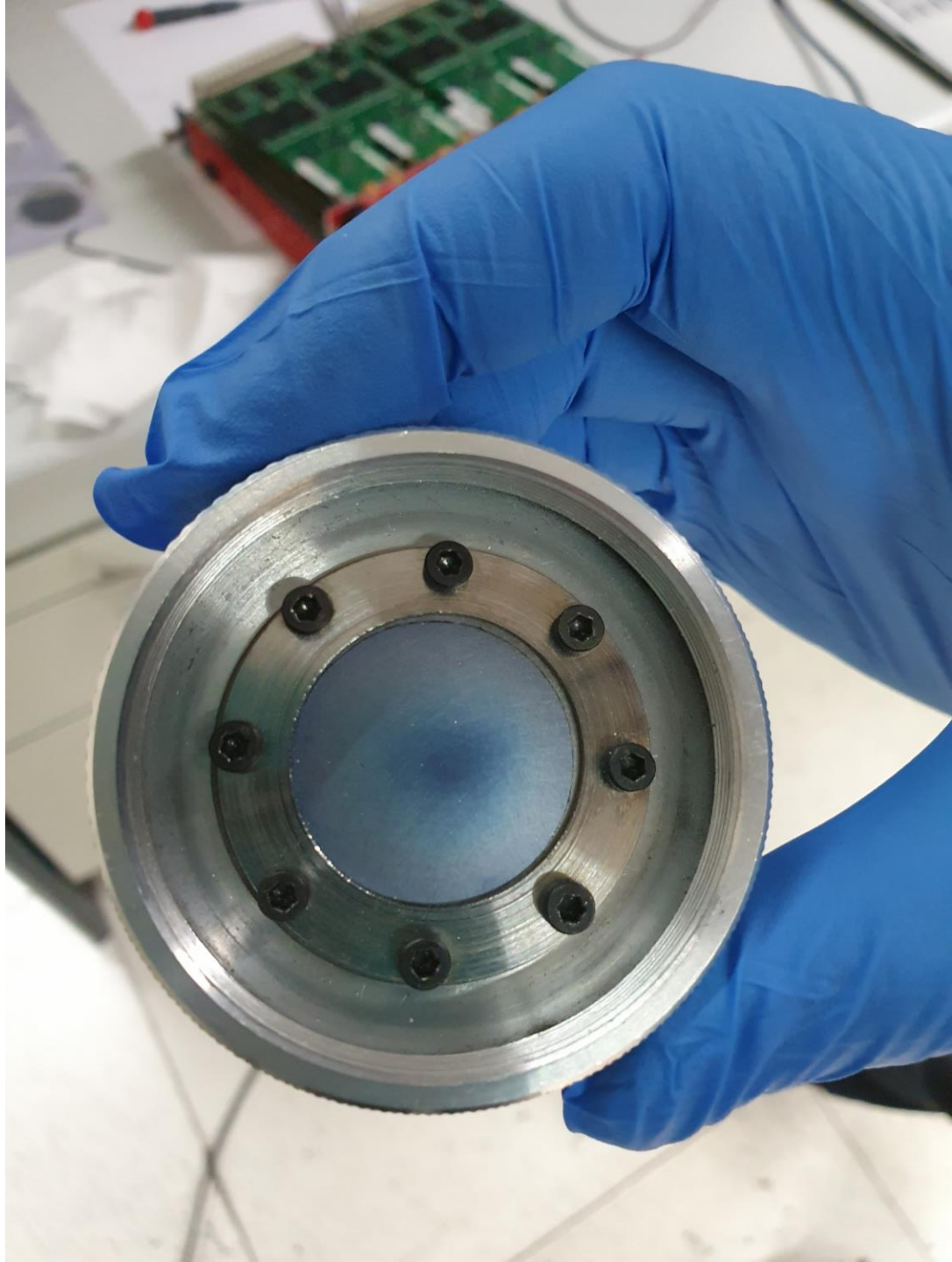
Experimental Setup



- Beam current during runs was around 150 – 250 µA
- Runs continued until 10 – 20 C of charge had been collected
- Later removed CeBr 0 degrees and moved HPGe closer to target

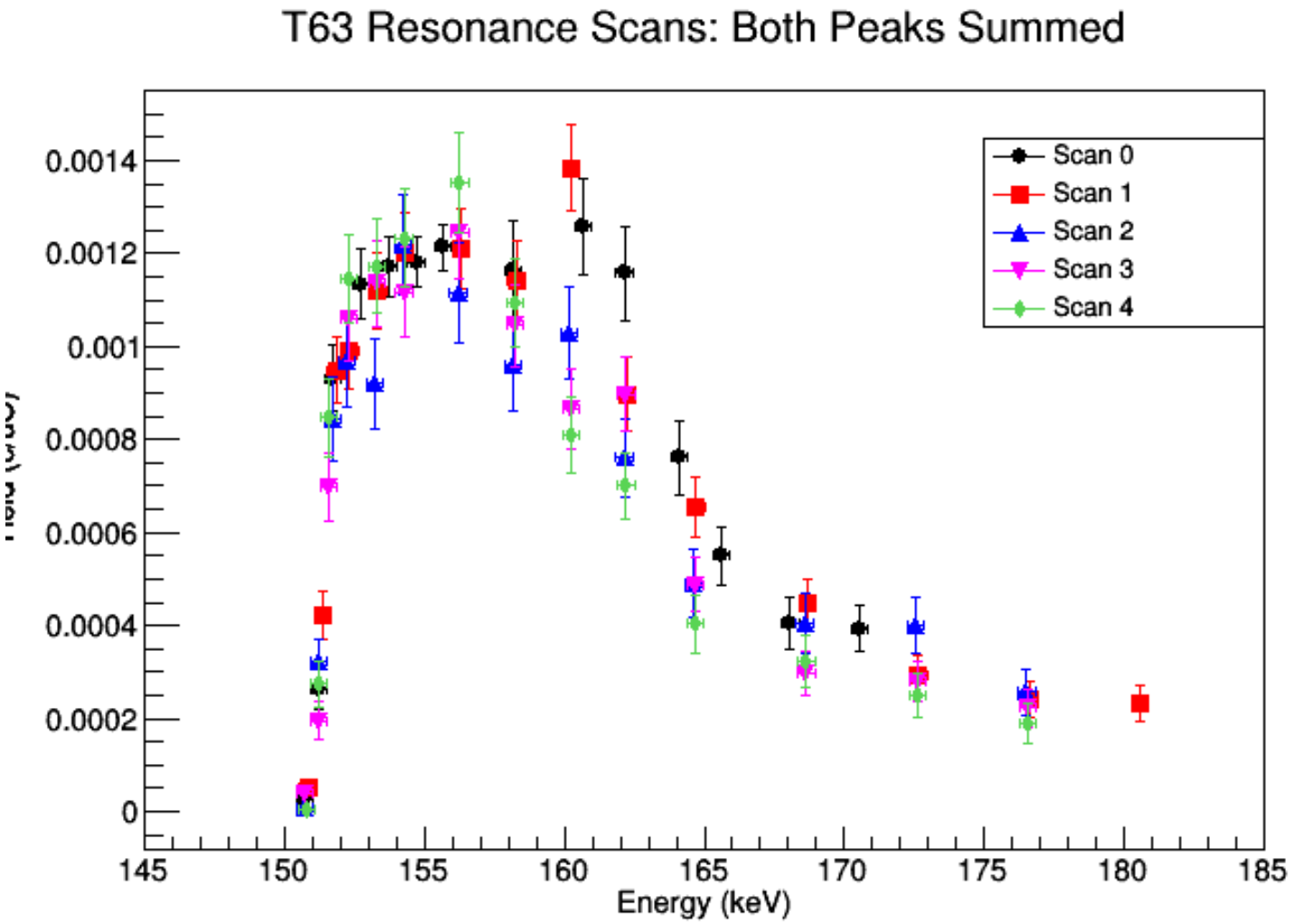
Targets

- Produced at LNGS by anodic oxidation of tantalum backings in water
- Water enriched in ^{18}O to 8% to allow Nuclear Resonant Reaction Analysis (NRRA)
- Use $^{18}O(p,\gamma)^{19}F$ resonance at E_p = 151 keV to determine target thickness



NRRA

- Two reaction peaks – at 3908 keV and 4230 keV
- Scan after each long run
- Fit each scan with below function: ΔE is the energy loss in the target
- Target stoichiometry is known, so can use stopping powers from SRIM to calculate target thickness

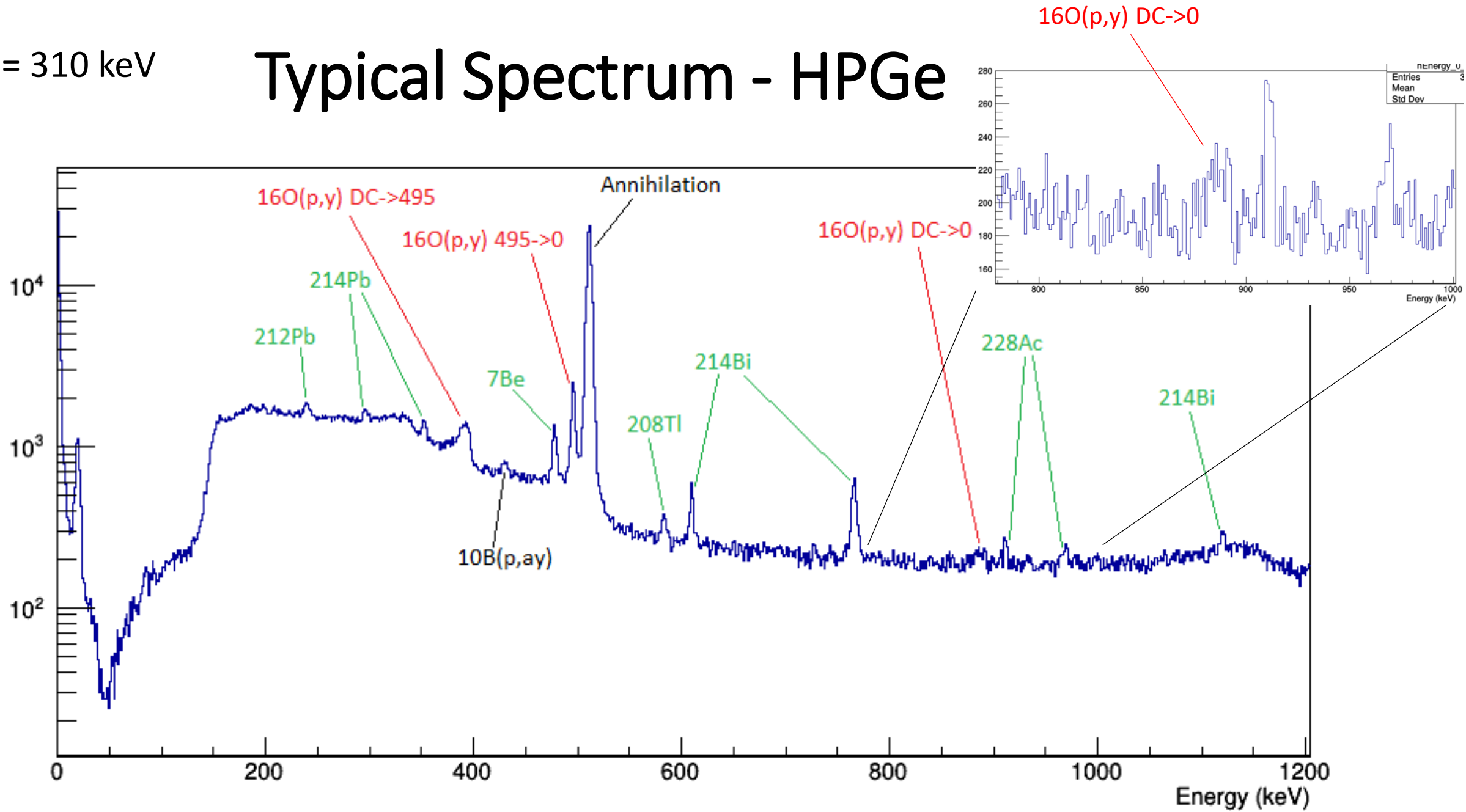


$$\frac{\lambda_r^2}{2\pi}\frac{\omega\gamma}{\varepsilon_r}\left[\arctan\left(\frac{E_0-E_r}{\Gamma/2}\right)-\arctan\left(\frac{E_0-E_r-\Delta E}{\Gamma/2}\right)\right]$$

C. Iliadis, Nuclear Physics of Stars

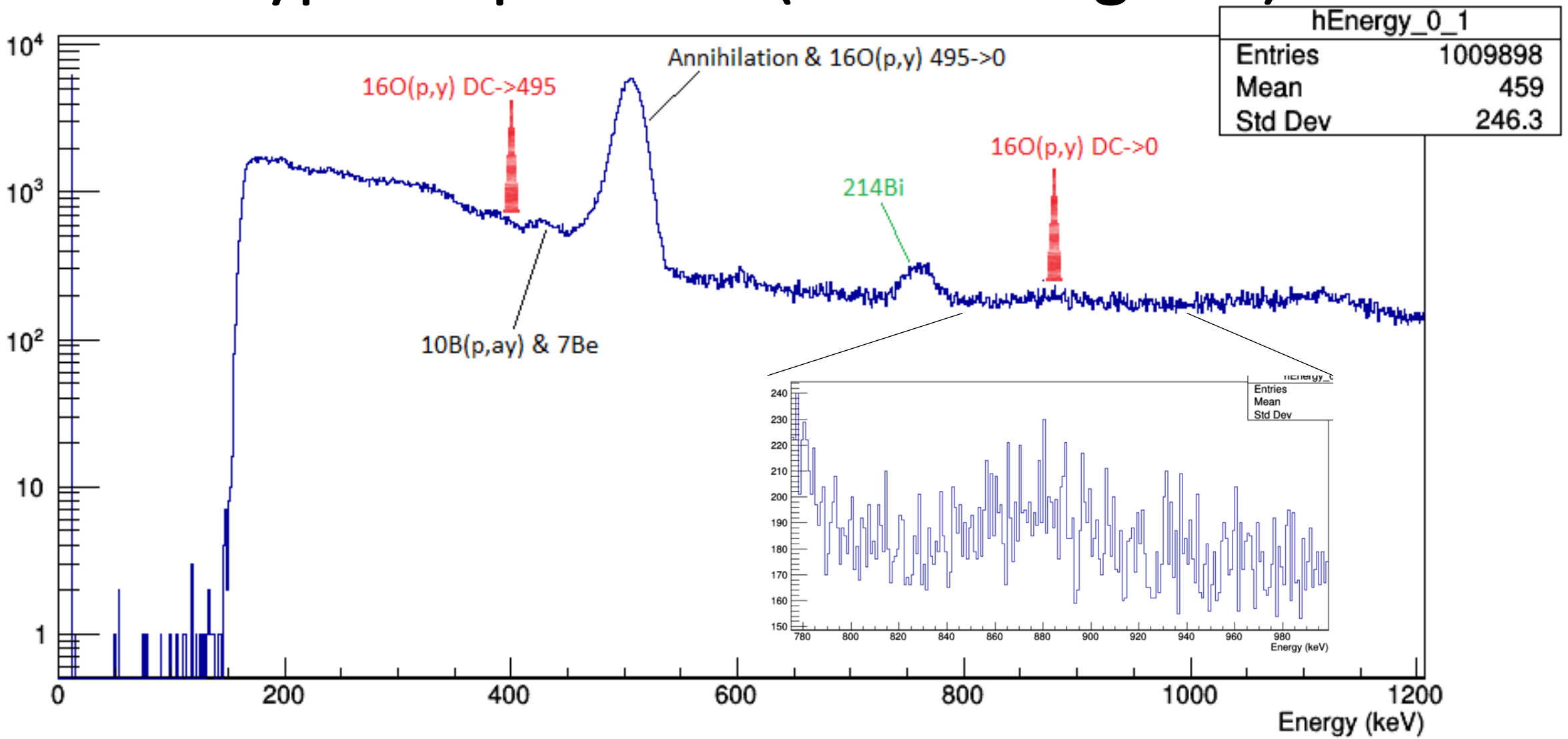
E_p = 310 keV

Typical Spectrum - HPGe



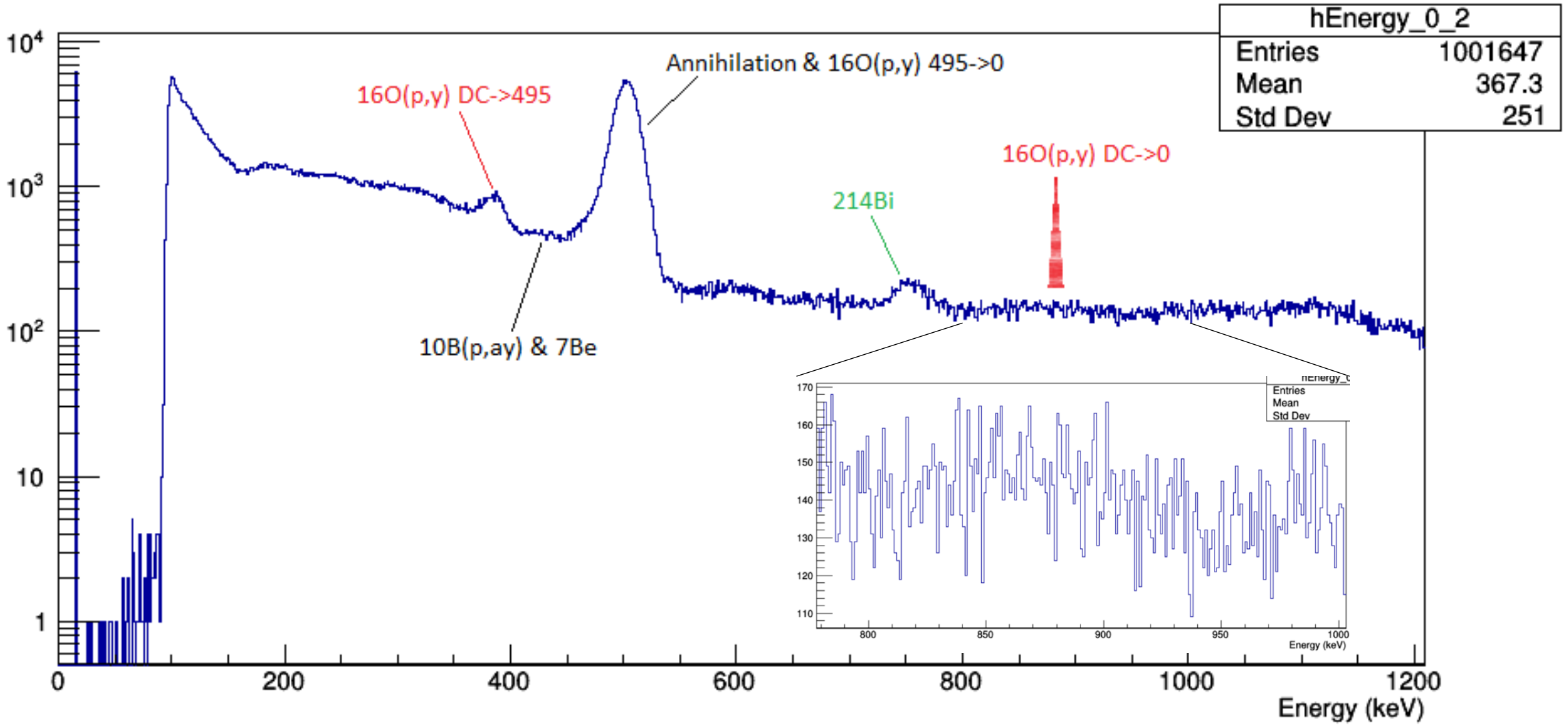
E_p = 310 keV

Typical Spectrum (CeBr 0 degrees)



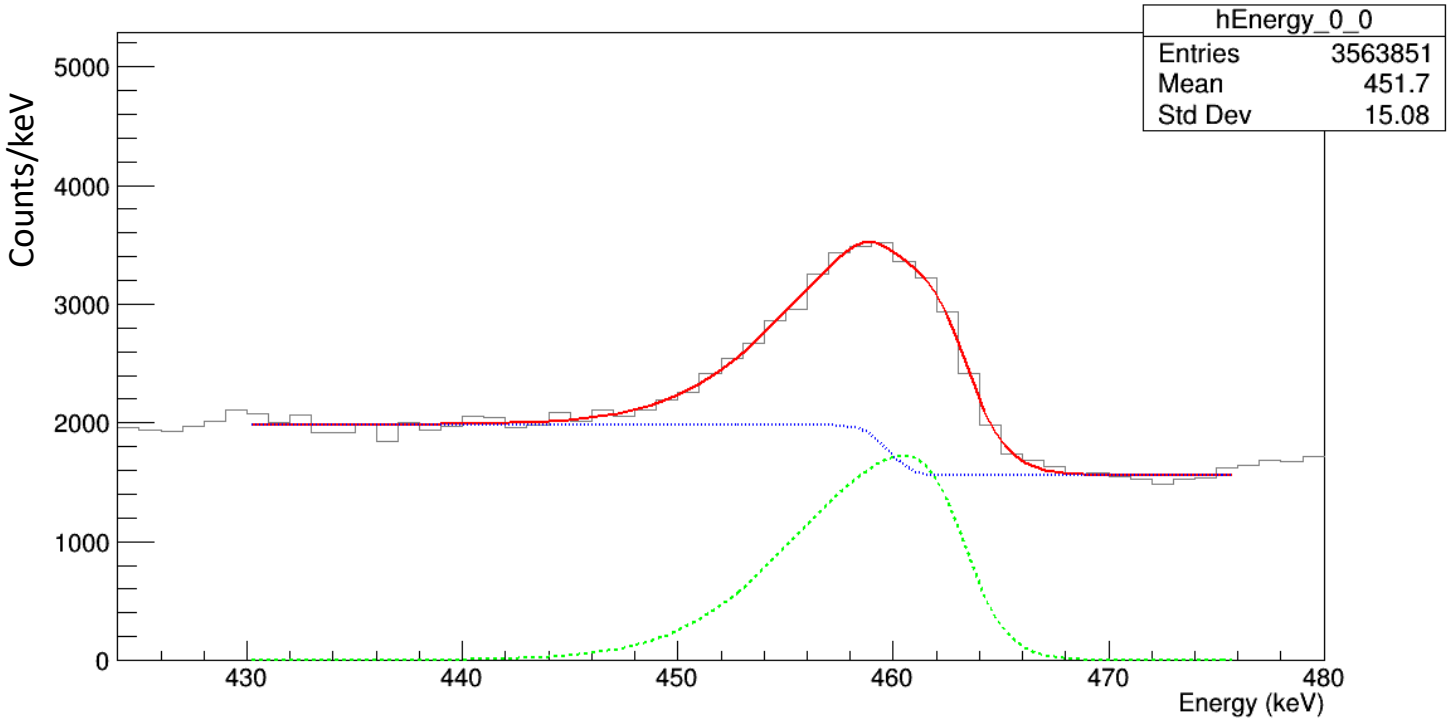
E_p = 310 keV

Typical Spectrum (CeBr 90 degrees)



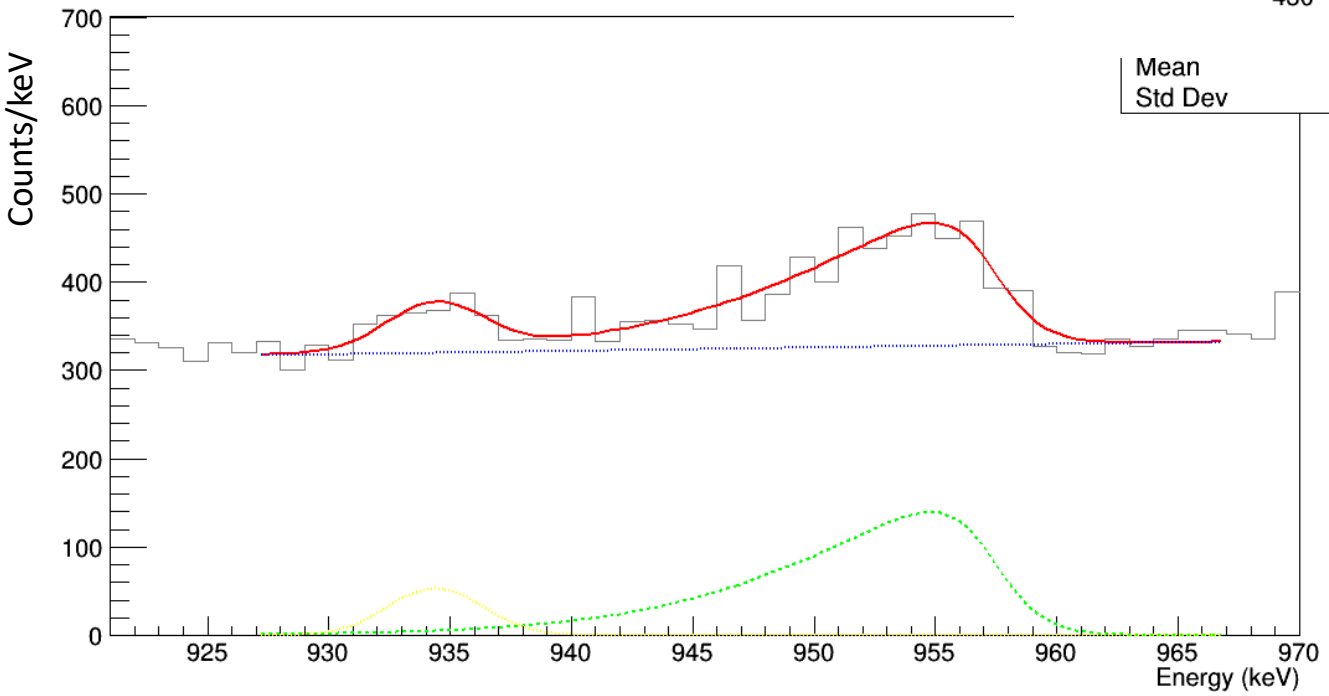
Example Peak Fits HPGe

E_p = 380 keV



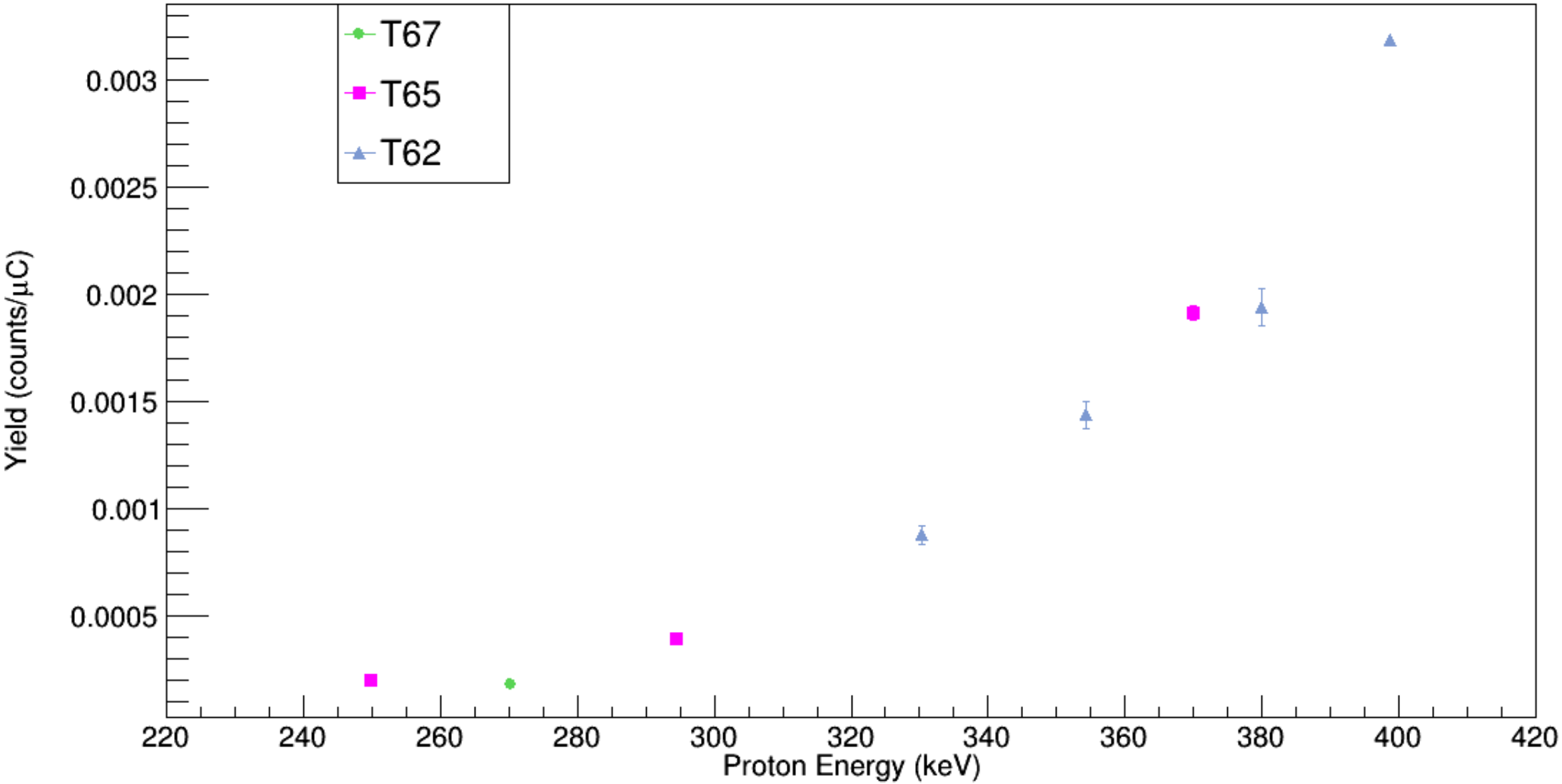
DC->1st

DC->Ground

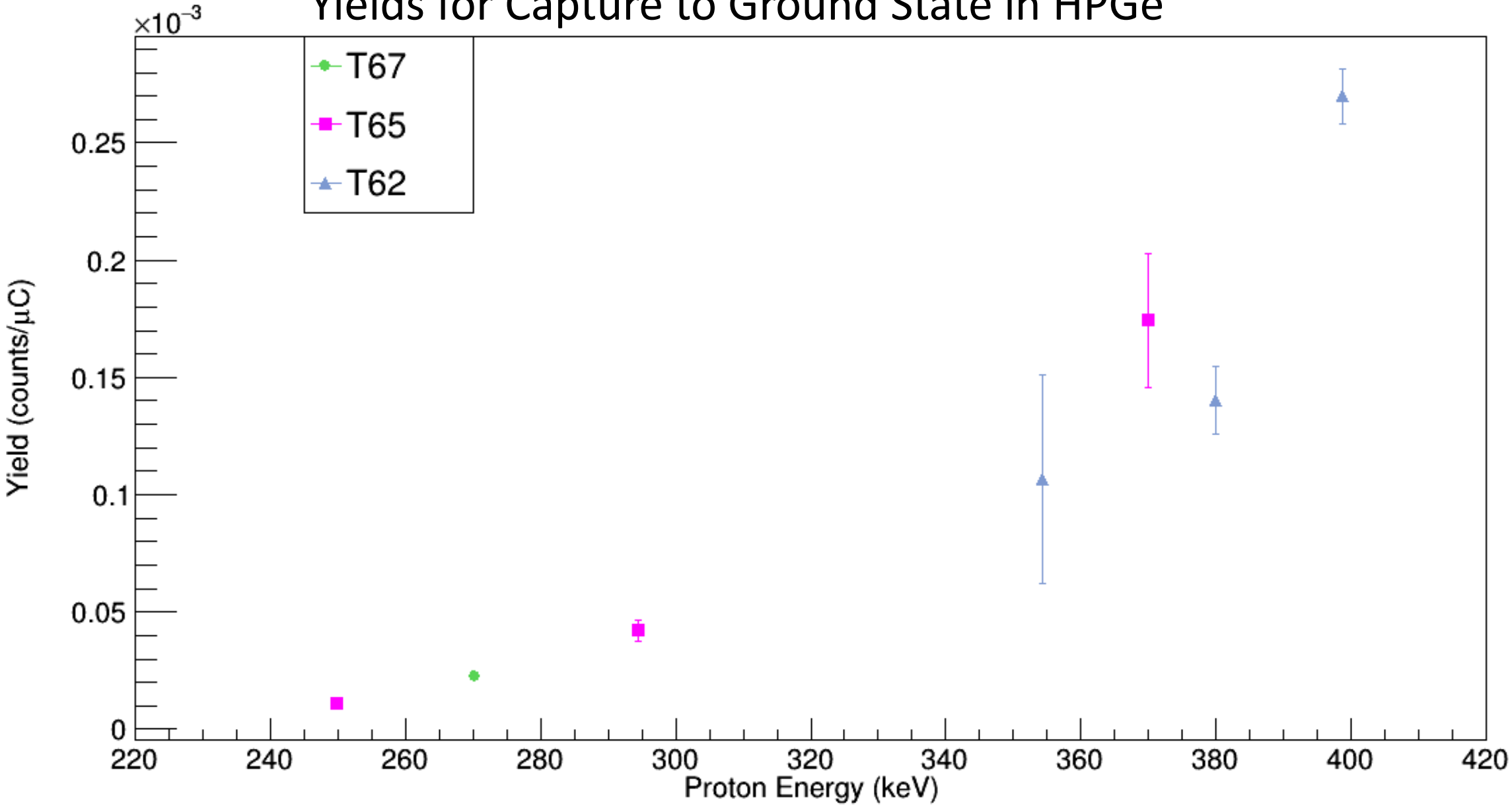


$$f(E_\gamma) = A\frac{1}{E_{\mathrm{cm}}}\exp\left(-2\pi\eta\right)P(E_\gamma)$$

Yields for Capture to First Excited State in HPGe



Yields for Capture to Ground State in HPGe



Next Steps

- Calculate efficiency including summing corrections from simulations
- Calculate angular distributions for both primary transitions
- Calculate cross sections and astrophysical S-factors
- Analyse activation data

THANK YOU!

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