Spectroscopy of ^{19}F and its impact on the production of ^{15}N in core-collapse SNe

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Astrophysical Background

- In some meteoritic grains, spatial correlation of ^{18}O and ^{15}N
  - Signature of core-collapse supernovae
  - Production by explosive helium burning during the shockwave
  - Excess of ^{15}N is a potential signature that the grain is of SN origin
- Sensitivity studies have found that the ^{18}F(n,p)^{18}O and ^{18}F(n,α)^{15}N reactions are important in the overall production of ^{15}N
  - PRC 89 025807, Bojazi and Meyer

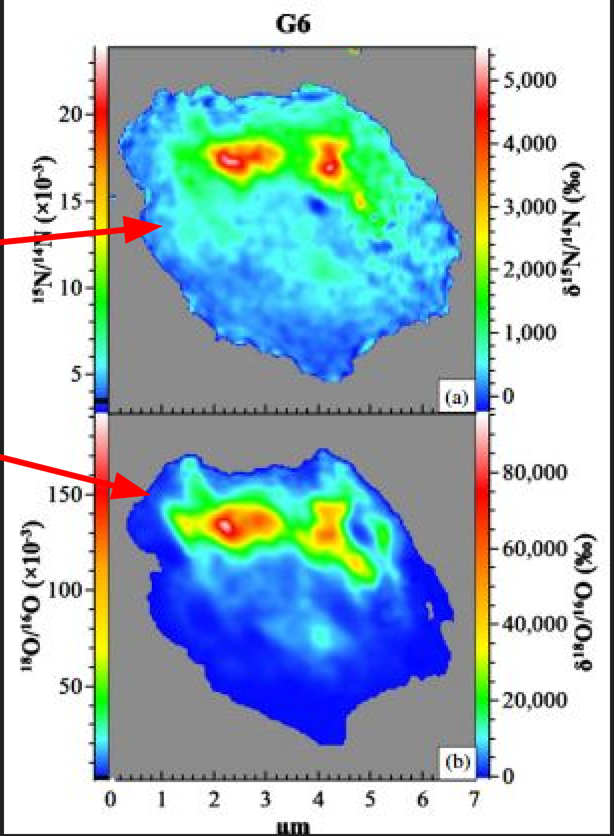
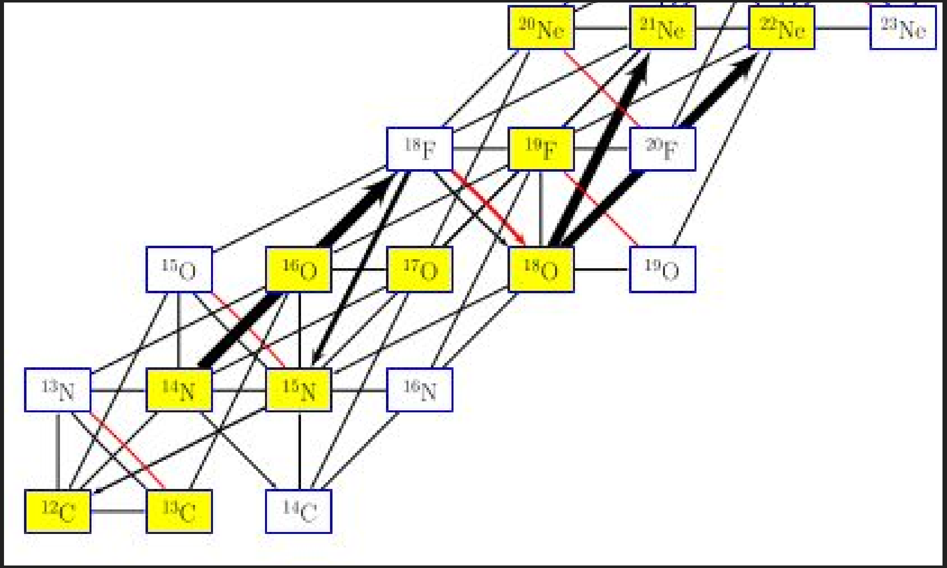


Fig 1 from Astro J Lett 754 L8

Astrophysical Background

Figure from PRC 89 025807, Bojazi and Meyer

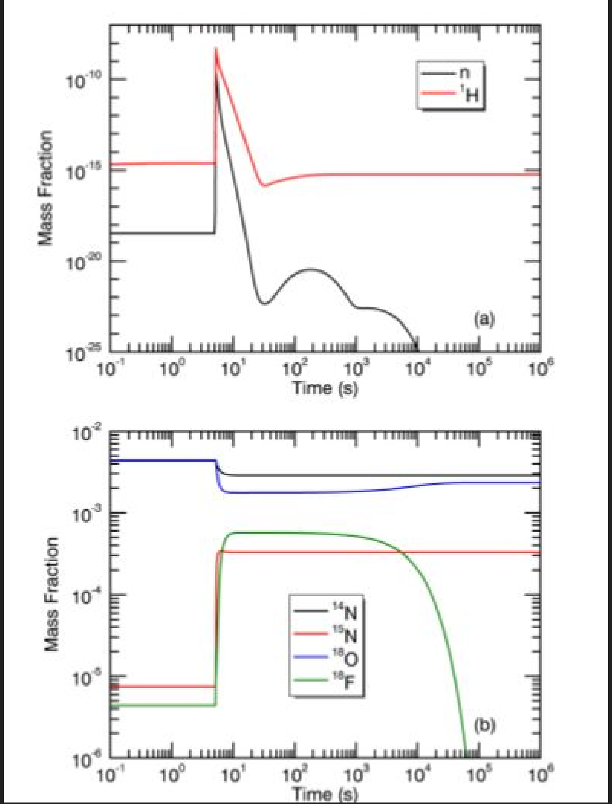
- Helium-burning shell
  - Hydrogen all consumed
  - He->C/O
  - Have ^{14}N(α,γ)^{18}F producing ^{18}F, decays into ^{18}O
- Stellar explosion -> shock in outer layers
  - Neutron production through ^{18}O(α,n) reactions
- Neutrons produced can start to react with ^{18}F



Astrophysical Background

Figure from PRC 89 025807, Bojazi and Meyer

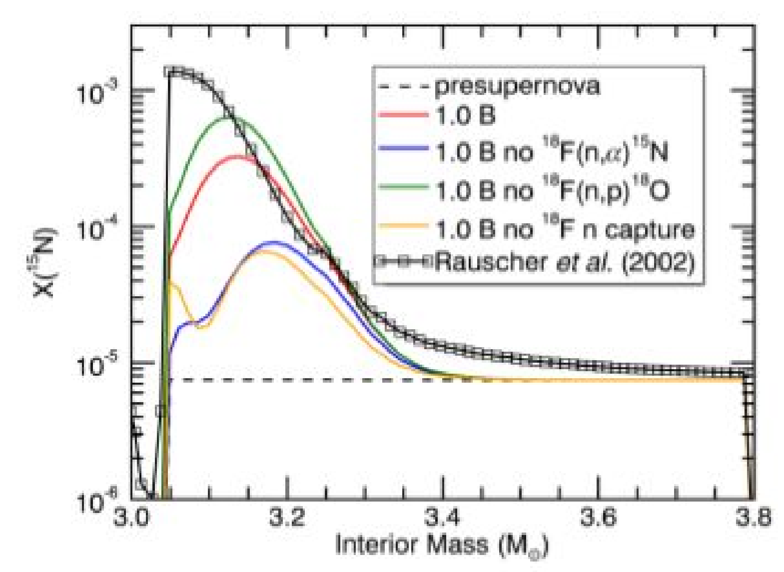
- Two possible reactions
  - ^{18}F(n,α)^{15}N - making the ^{15}N which is found in the grains
  - ^{18}F(n,p)^{18}O
- Second reaction is a proton source, produced protons can react again
  - ^{18}O(p,α)^{15}N - making more ^{15}N
  - ^{15}N(p,α)^{12}C - destroying ^{15}N
- Also have other possible reactions e.g. ^{14}N(n,p) producing protons, ^{15}N(α,γ) destroying ^{15}N



Astrophysical Background

Figure from PRC 89 025807, Bojazi and Meyer

- Suppressing the ^{18}F(n,α) reaction reduces the production of ^{15}N by a factor of 4
- If the ^{18}F(n,p) reaction isn't active, the production of ^{15}N *increases* by a factor of 2
    - Lower production from ^{18}O(p,α) but lower destruction via ^{15}N(p,α)
- Stronger ^{18}F(n,α) suppresses ^{18}F(n,p) and so not only produces more ^{15}N but also decreases the destruction by ^{15}N(p,α)

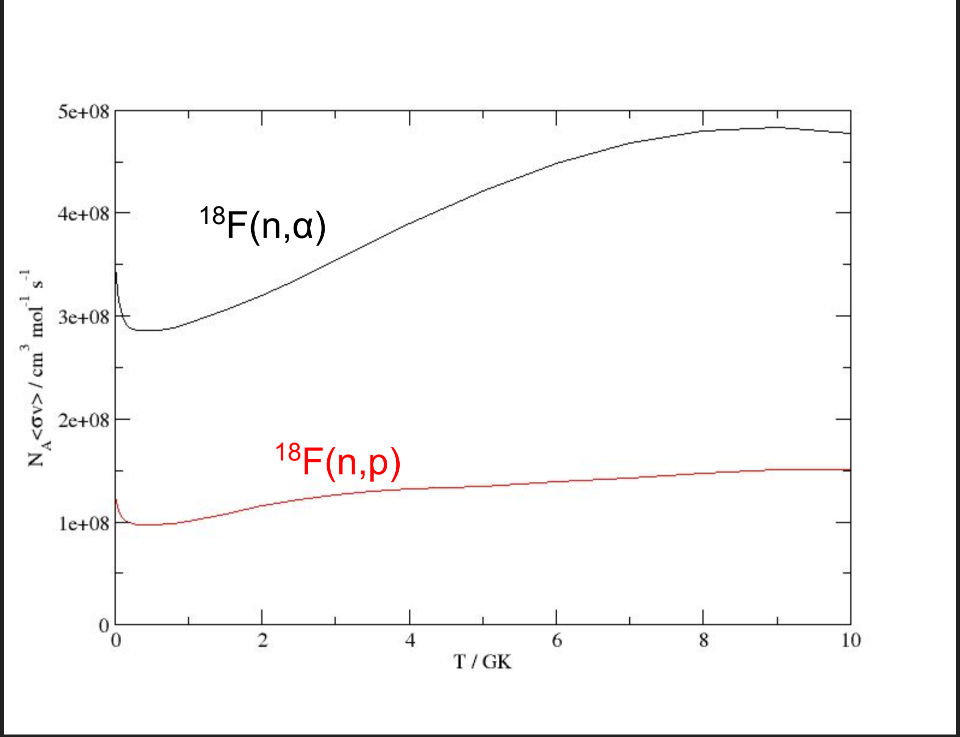


There's competition between the (n,α) and (n,p) channels! ^{18}F(n,p) can be suppressed because of strong ^{18}F(n,α)!

Astrophysical Background

- Need information on the strength of ^{18}F(n,α) and ^{18}F(n,p) reactions
  - Direct measurements of this are hard - can't make ^{18}F or neutron target easily (at all?)
  - Indirect information on proton and α-particle BRs can help to constrain the relative strengths (which is the most useful information)
- Previous rates from statistical models (which don't work very well in this region - α clustering in ^{19}F)

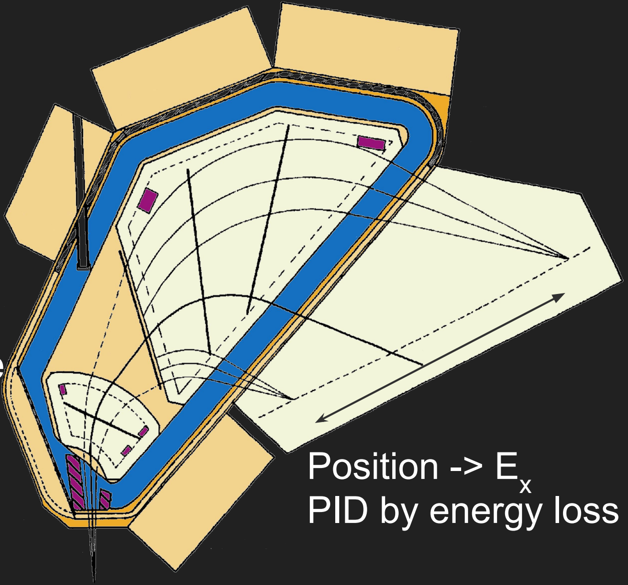
TALYS calculations of ^{18}F+n reactions



Experimental study of ^{19}F for $^{18}F+n$ reactions

The Experiment - ^{19}F(p,p')^{19}F

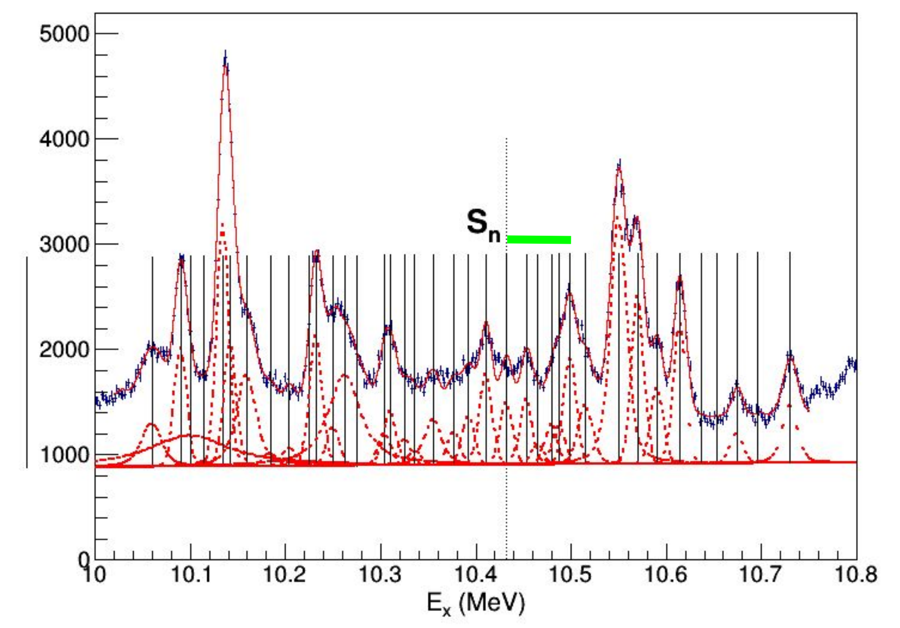
- Coincidence experiment - Enge spectrograph + silicon detectors
  - First, ^{19}F(p,p')^{19}F reaction - scattered proton into Enge
  - Using ^{nat}LiF target of 85 μg/cm^2 on nat carbon backing
  - Enge has resolving power of E/dE = 1000 -> 7 keV instrinsic resolution
  - Solid angle of 1.3 msr
  - Resulting resolution is ~16 keV FWHM - target thickness effect
  - Second, charged-particle decay of excited ^{19}F state observed in array of silicon detectors - Micron W1s - cover 14% of solid angle



Position -> E_x
PID by energy loss

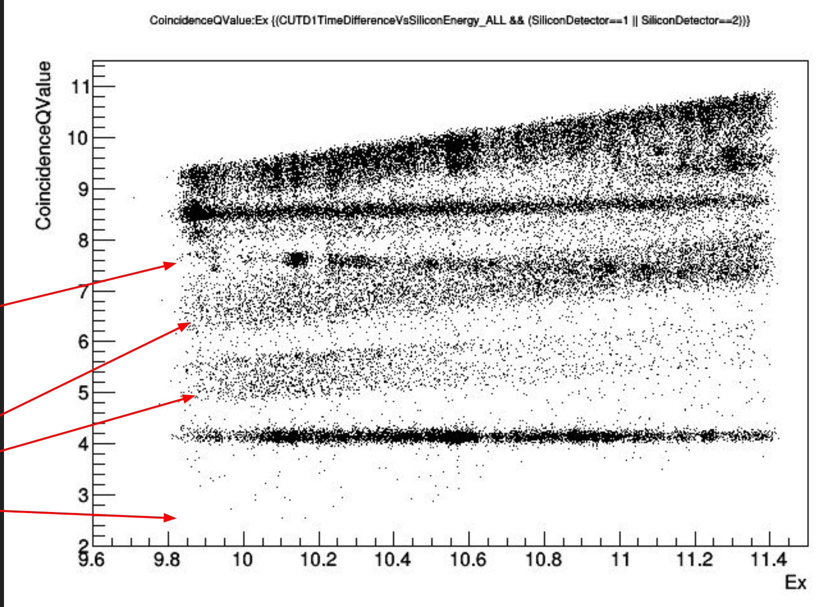
Results - Singles (Inclusive measurement)

- The problem with singles:
  - Very high background
  - Possibly instrumental
  - Possibly physical - could be a contribution from decay protons from ^{19}F excited states
- Whatever the source of the background, it makes analysis of the ^{19}F results difficult
- Coincidence results can assist in analysing the singles data
- Neutron separation energy = 10.432 MeV



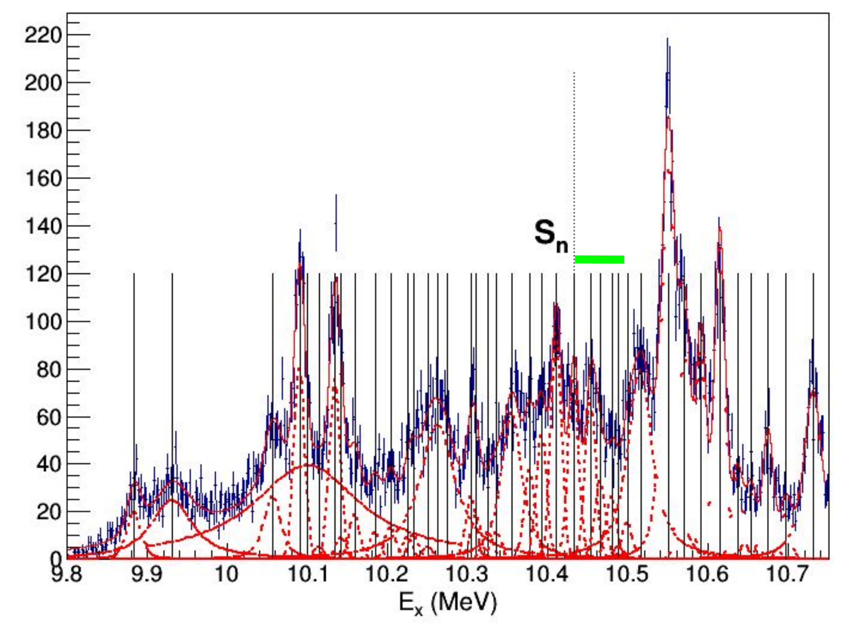
Results - Coincidence Spectra

- Coincidence 2D spectra generated from the calibrated focal plane (i.e. position -> Brho -> Ex) vs the silicon energy corrected for kinematics
  - Convert the system to the Q-value - identification of decay loci easier + contaminants obvious
- α_0 and p_0 loci are very clear but p_0 locus has an overlap with ^{12}C α-decay locus
  - Can distinguish with timing information



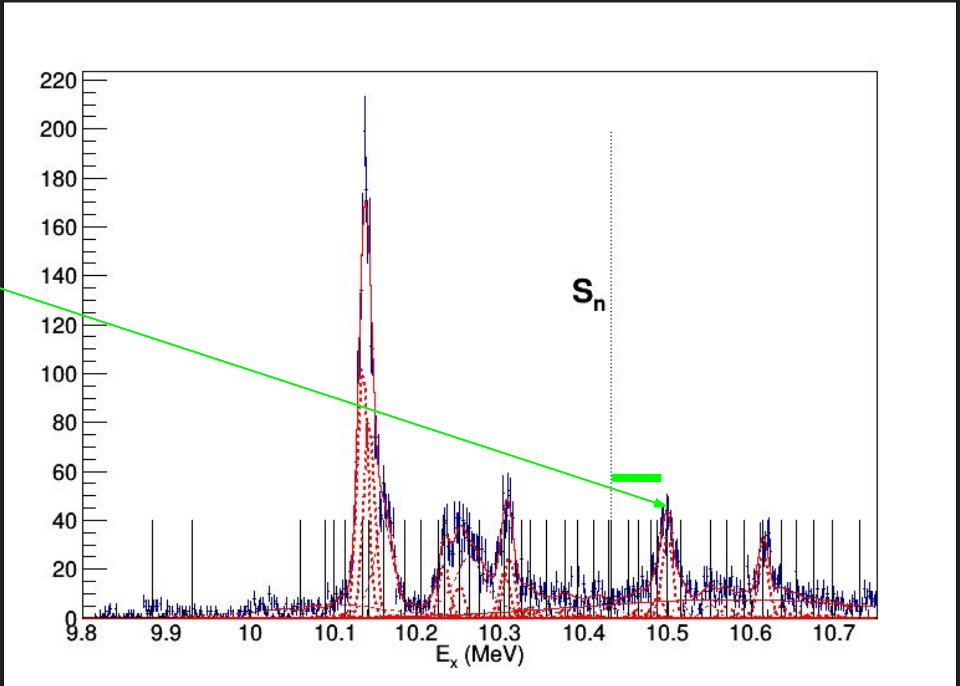
Results - alpha decay to ^{15}N ground state

- High level density
- There are inconsistencies in the literature which have made analysis difficult but now have relatively good consistency with *some* known states
- Alpha-particle decaying states exist close to the neutron threshold
  - Can have ^{18}F(n,α) reactions at lower temperatures



Results - proton decay to ^{18}O ground state

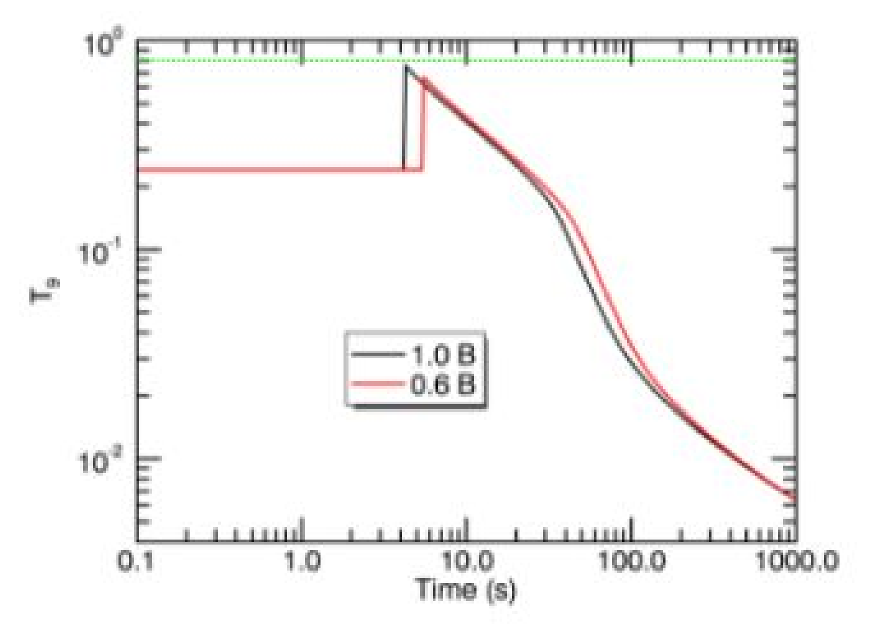
- A few strong states below threshold
- First strong proton-decaying state is at 10.5 MeV
  - ~68 keV above the neutron threshold
- There's a background in this spectrum from other decay channels which satisfy kinematic conditions but this is accounted for and doesn't change the lack of proton strength below this state



The important bit

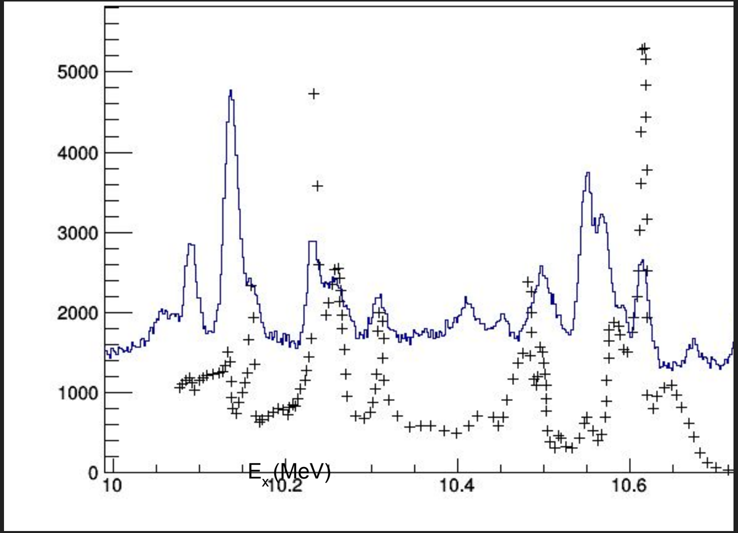
- The first significant state (above the neutron threshold) with a strong proton decay is 68 keV above the neutron threshold
  - kT = 68 keV -> ~0.8 GK
- The ^{18}F(n,p)^{18}O channel isn't strong at lower temperatures as it's suppressed by ^{18}F(n,α)
  - The production of ^{15}N is thus likely strongly enhanced over the current models due to changes in the reaction rates

Modified figure from PRC 89 025807, Bojazi and Meyer… green line is at 0.8 GK, approx energy of first strong ^{18}F(n,p) resonance



Summary and future prospects

- ^{18}F(n,p) reaction is much weaker than thought from statistical models
- Suggests that the production of ^{15}N is enhanced
    - Based on sensitivity study, could be twice the 'expected' yield just due to weakness of ^{18}F(n,p)
- Next step: match all of the resonances observed in previous measurements with those in the present study + collate the nuclear data
- Then use these data to calculate new rates for ^{18}F(n,p) and ^{18}F(n,α) + observe astrophysical impact



Comparison of ^{18}O(p,α_0) data at 90 degrees lab angle from Gorodetzky et al. Journal de Physique, 1963, 24 (11) with data from the present experiment

Collaborators

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Branching Ratios

- Can look at relative branchings to get information on the relative strength of the reactions
- The absolute branchings can constrain the reaction rate better
  - Can combine with available information on total (or partial widths) known for states from other measurements when available
  - Infer neutron width and calculate properties of resonances
  - Absolute branchings not corrected for all solid angle effects