Improved Measurements of (α,p) Reactions with Digital ANASEN

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$(\alpha$,p) reactions in X-ray Bursts

- X-ray bursts are the most commonly observed stellar explosions in our Galaxy
- Difficult to compare simulations to observations due to uncertainties in nuclear physics inputs
- Sensitivity studies demonstrate importance of many (α,p) reactions, but most nuclear data comes from indirect studies
- ANASEN designed for direct (α,p) measurements — e.g. ^{18}Ne(α,p)^{21}Na

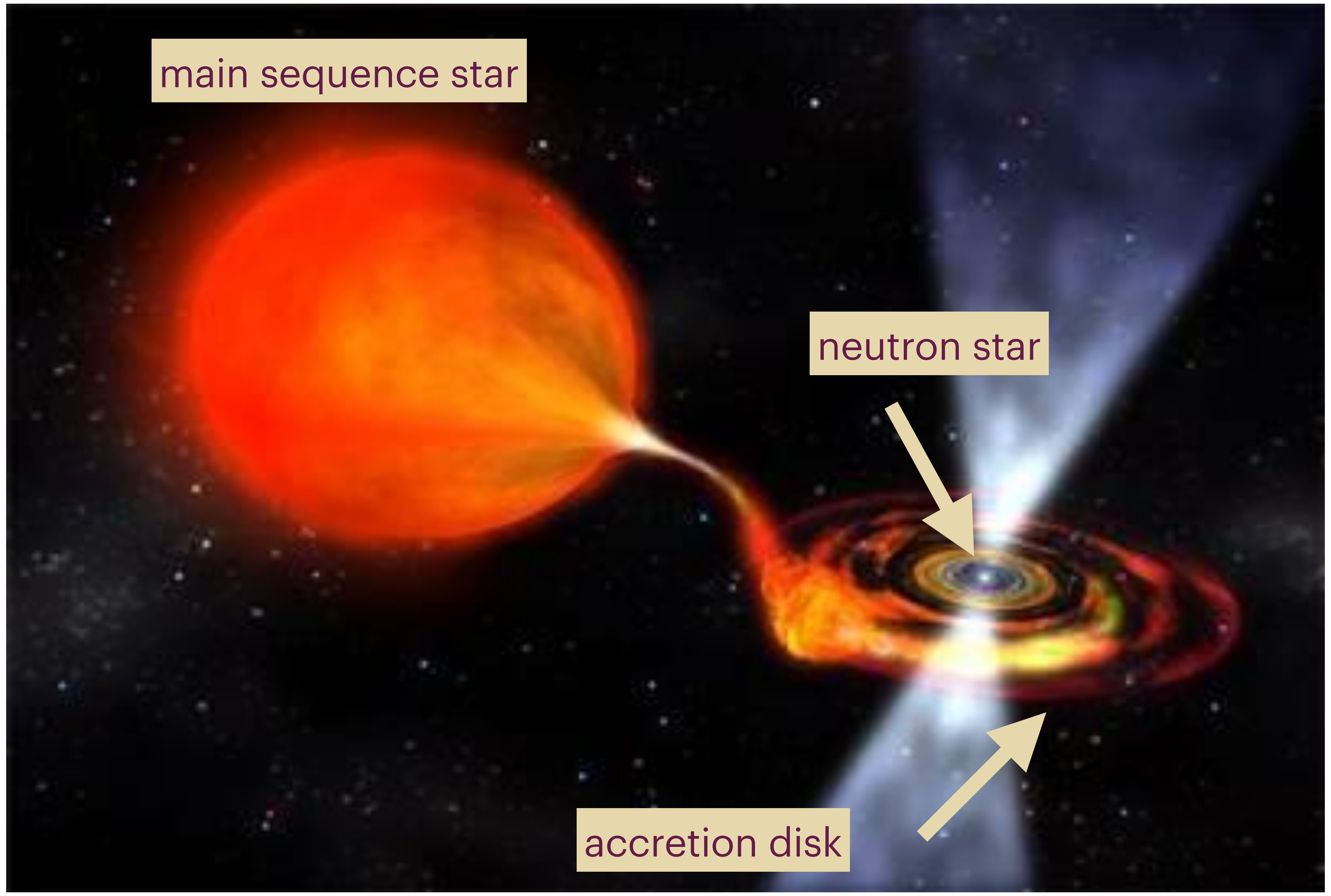

Table 2
Reactions that Impact the Burst Light Curve in the Multi-zone X-ray Burst Model

Rank	Reaction	Type[a]	Sensitivity[b]	Category
1	^{15}O(α, γ)^{19}Ne	D	16	1
2	^{56}Ni(α, p)^{59}Cu	U	6.4	1
3	^{59}Cu(p, γ)^{60}Zn	D	5.1	1
4	^{61}Ga(p, γ)^{62}Ge	D	3.7	1
5	^{22}Mg(α, p)^{25}Al	D	2.3	1
6	^{14}O(α, p)^{17}F	D	5.8	1
7	^{23}Al(p, γ)^{24}Si	D	4.6	1
8	^{18}Ne(α, p)^{21}Na	U	1.8	1
9	^{63}Ga(p, γ)^{64}Ge	D	1.4	2
10	^{19}F(p, α)^{16}O	U	1.3	2
11	^{12}C(α, γ)^{16}O	U	2.1	2

Cyburt et al., ApJ 830, 55 (2016)
Parikh et al., ApJS 178, 110 (2008)

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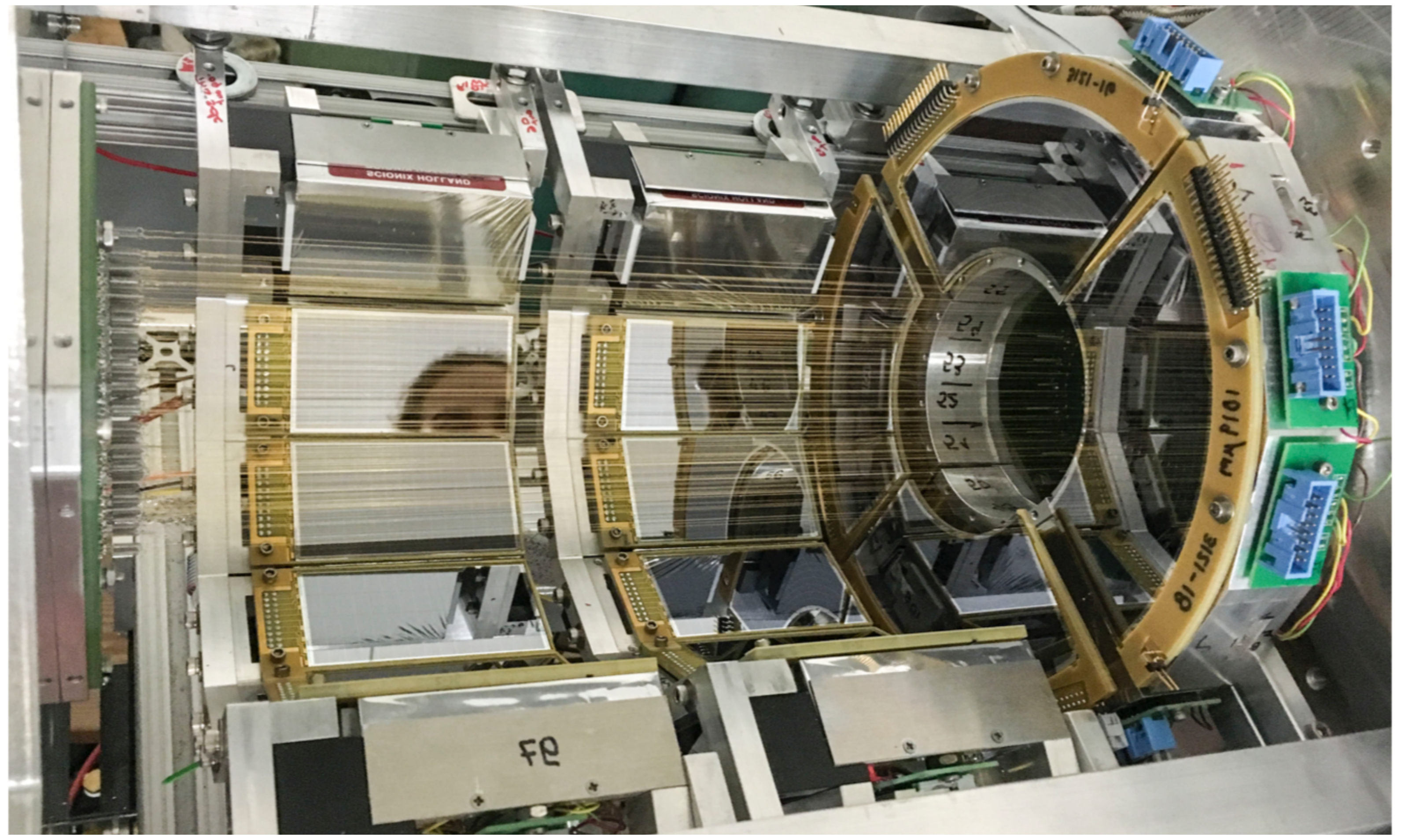
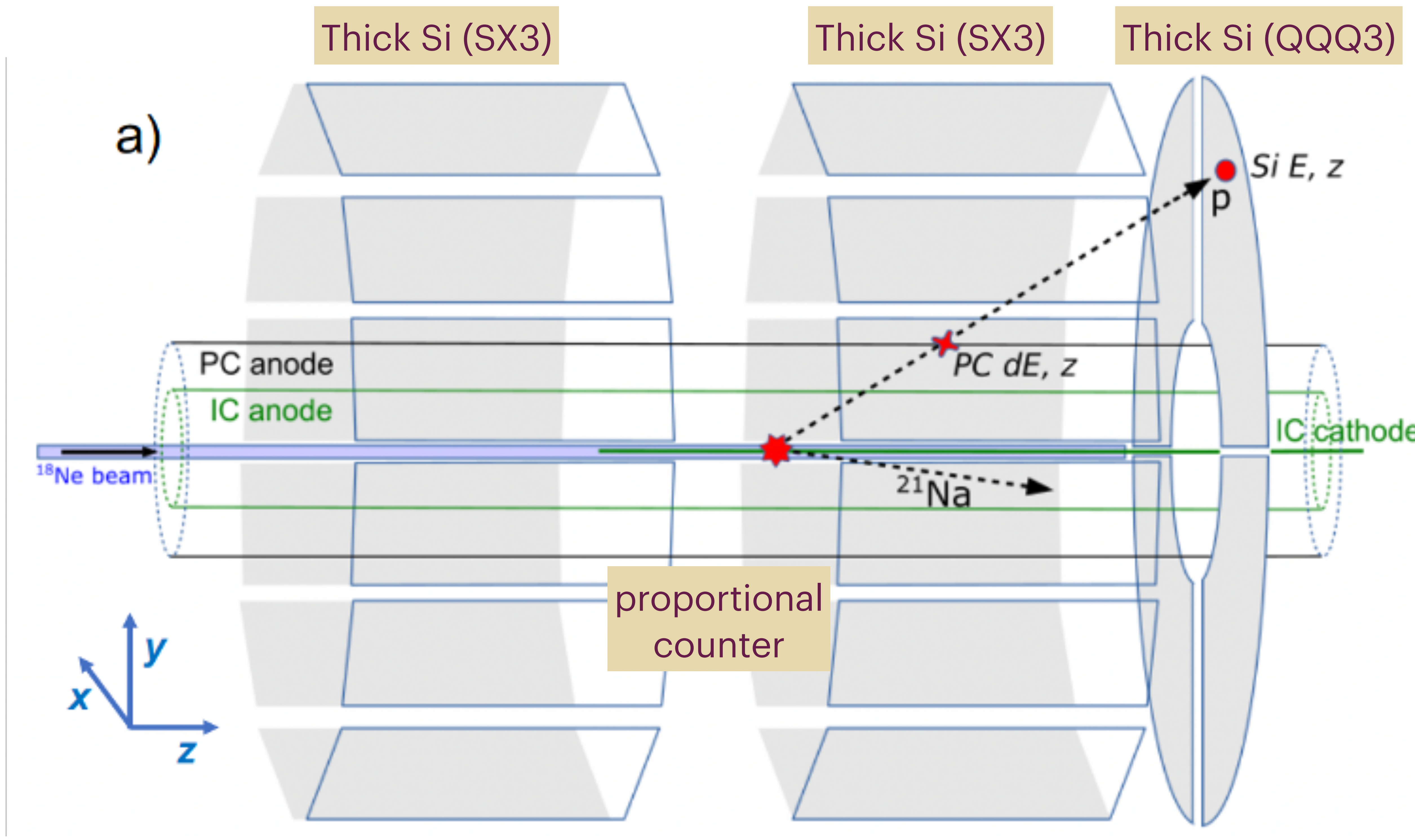
^{18}Ne(α,p)^{21}Na Cross Sections using ANASEN

Array for Nuclear Astrophysics and Structure with Exotic Nuclei

- Recently published direct measurement at Florida State University
- Active He-CO_2 gas target/detector
- Cylindrical proportional counter for ΔE
- Thick Si-strip detectors for residual E
- ^{18}Ne beam intensity 10^3 pps, scans $E_{cm} =$ 2.5–4.0 MeV simultaneously





Anastasiou et al., Phys Rev C 105, 055806 (2022)

$^{18}Ne(\alpha,p)^{21}Na$ Cross Sections using ANASEN

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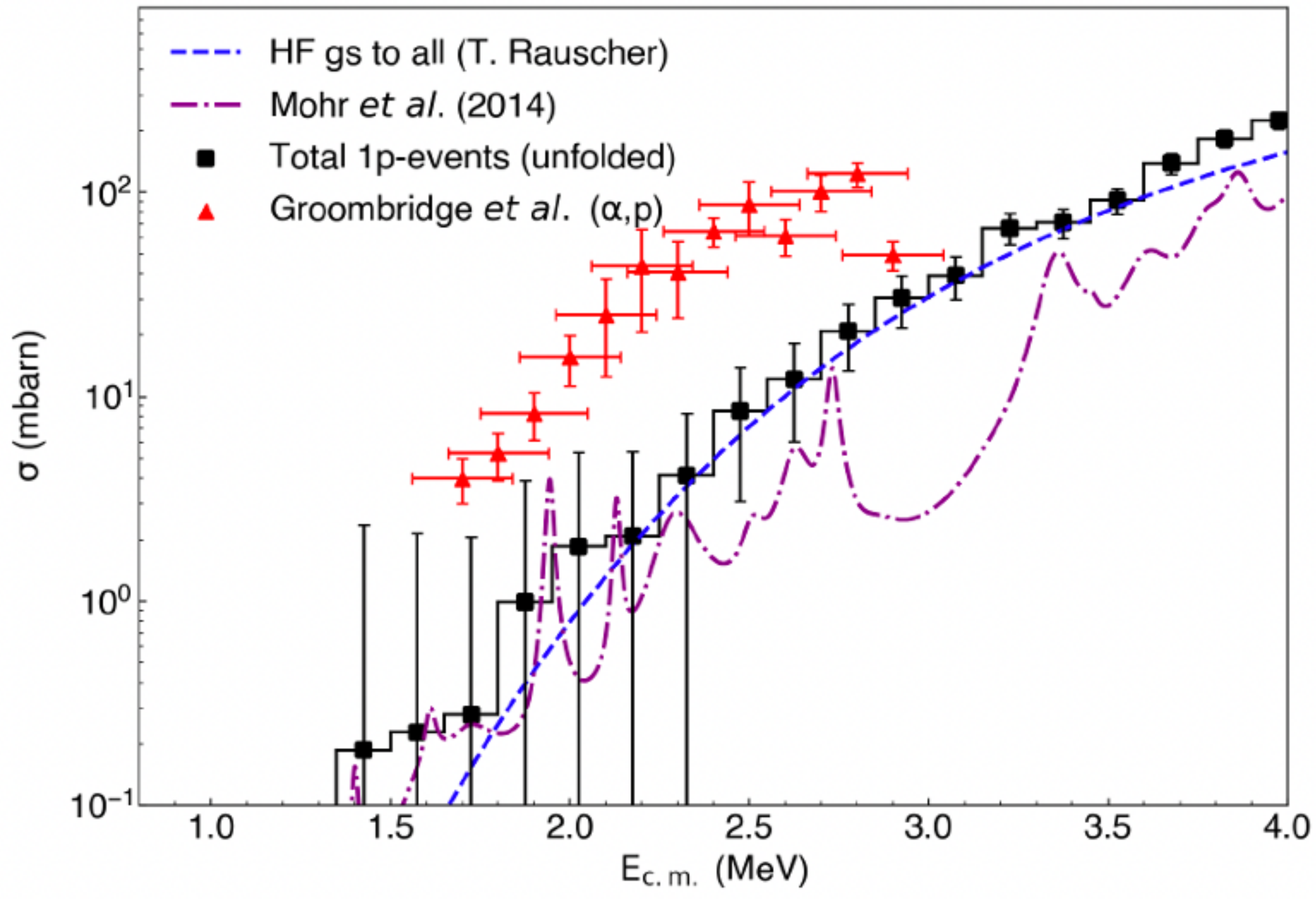
- ^{18}Ne beam intensity 10^3 pps, scans $E_{cm} =$ 2.5–4.0 MeV simultaneously
- Disentangled contributions from 2p-events
- Energy resolution $\delta E_{cm} \approx$ 1.5 MeV limited by position resolution
- Only upper limits for $E_{cm} <$ 2.4 MeV



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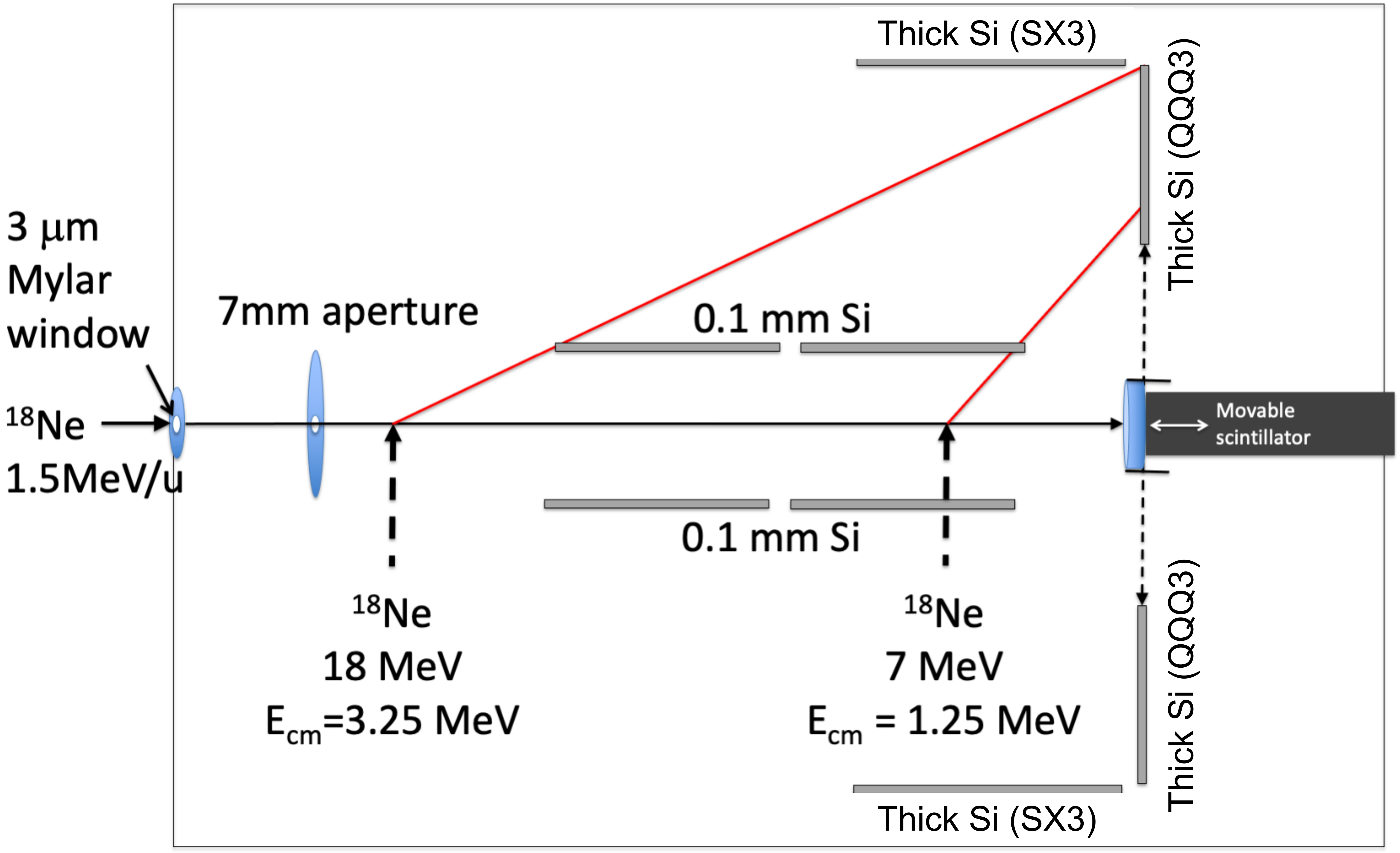
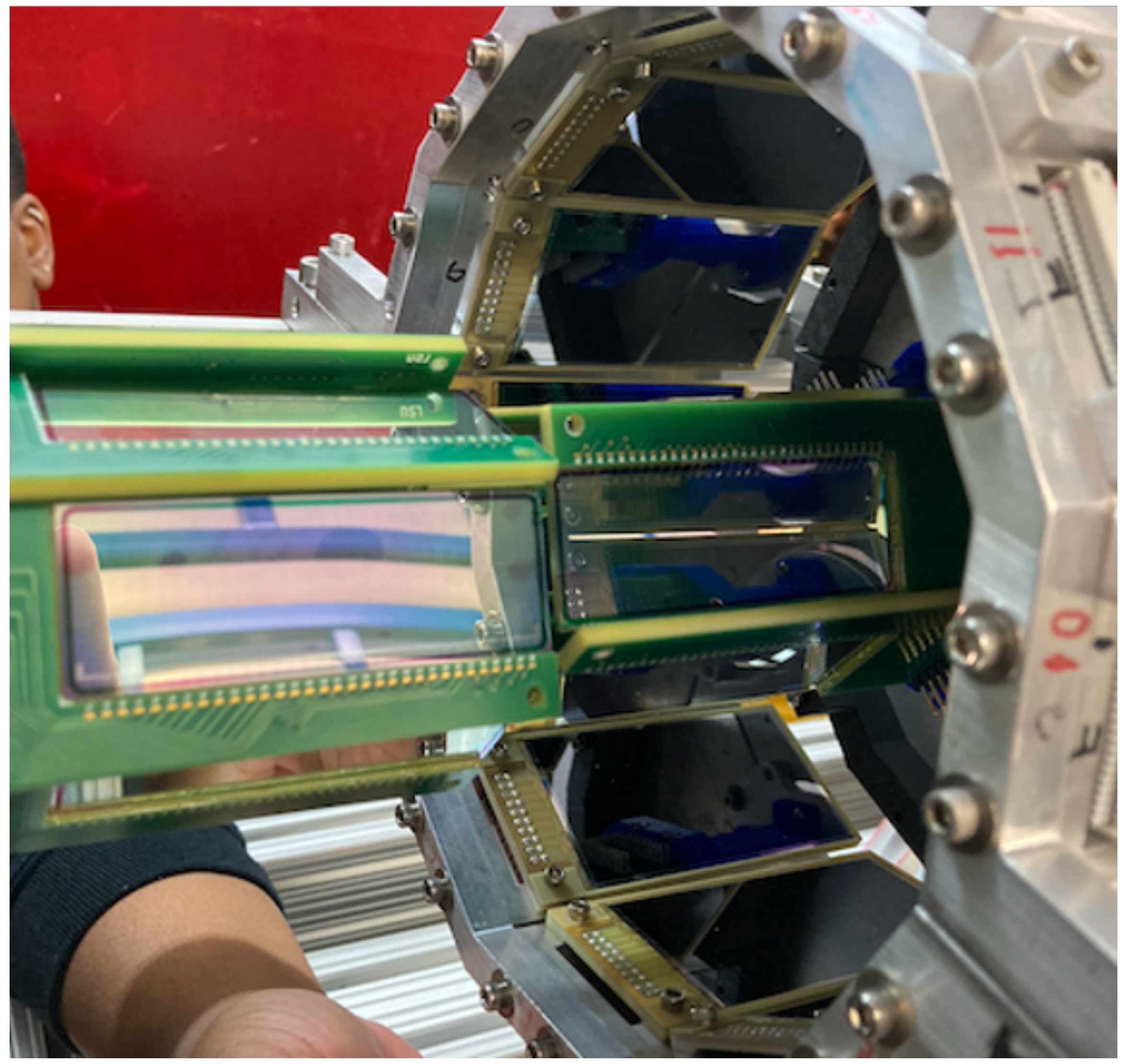
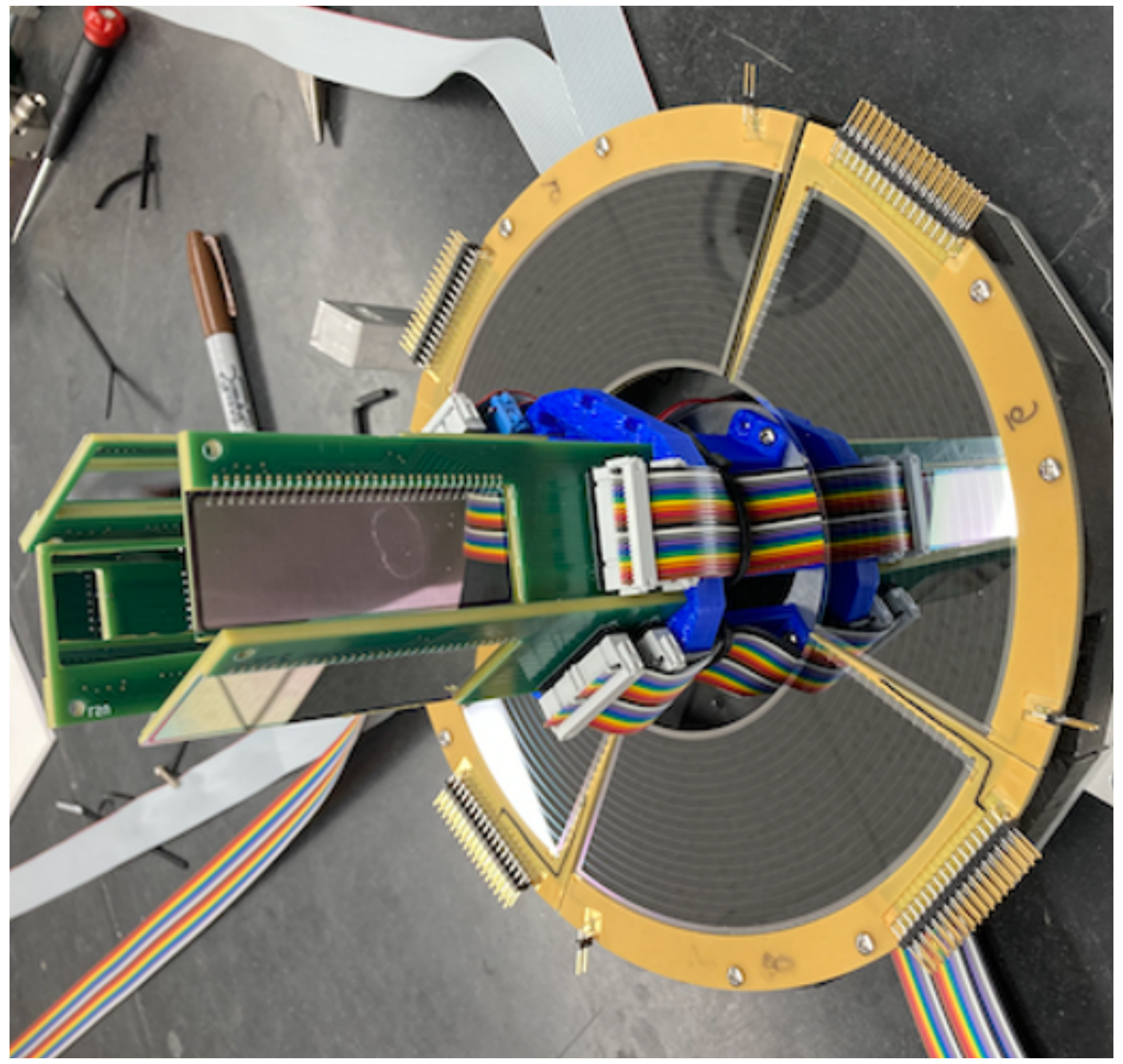
Upgrades for Improved Measurements

- Pure ^{4}He gas target
- 85-μm Si detectors, 2-mm strips for ΔE (CSIC-Barcelona)
- Thick Si-strip detectors for residual E (Micron)
- Sacrificed solid angle to focus on higher energy protons at forward angles
- Simulated $\delta E_{cm} \approx$ 150 keV, although energy- and angle-dependent







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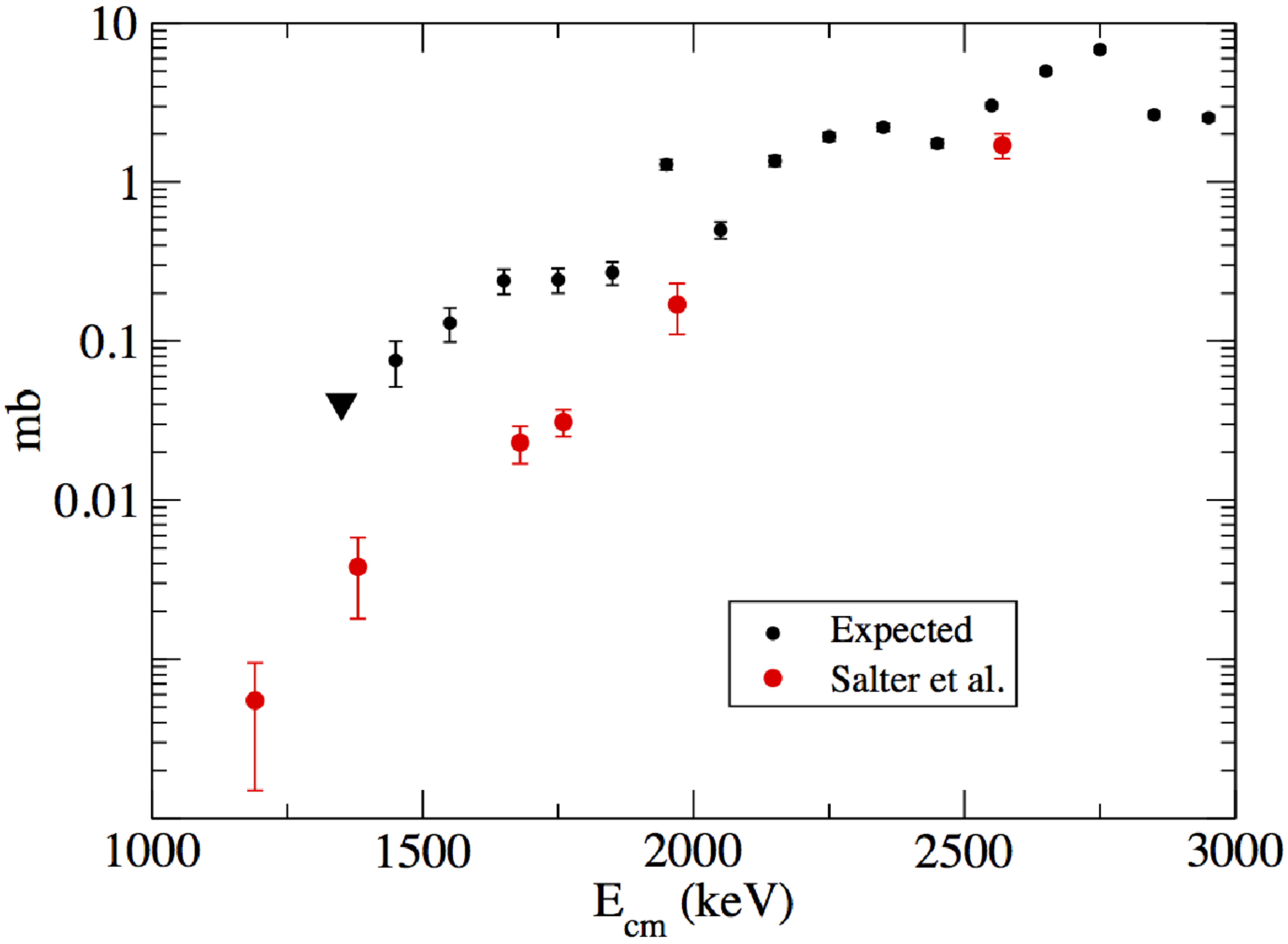
Predicted Excitation Function

- With >100x intensity at TRIUMF-ISAC I, ^{18}Ne beam scans E_{cm} = 1.25–3.25 MeV



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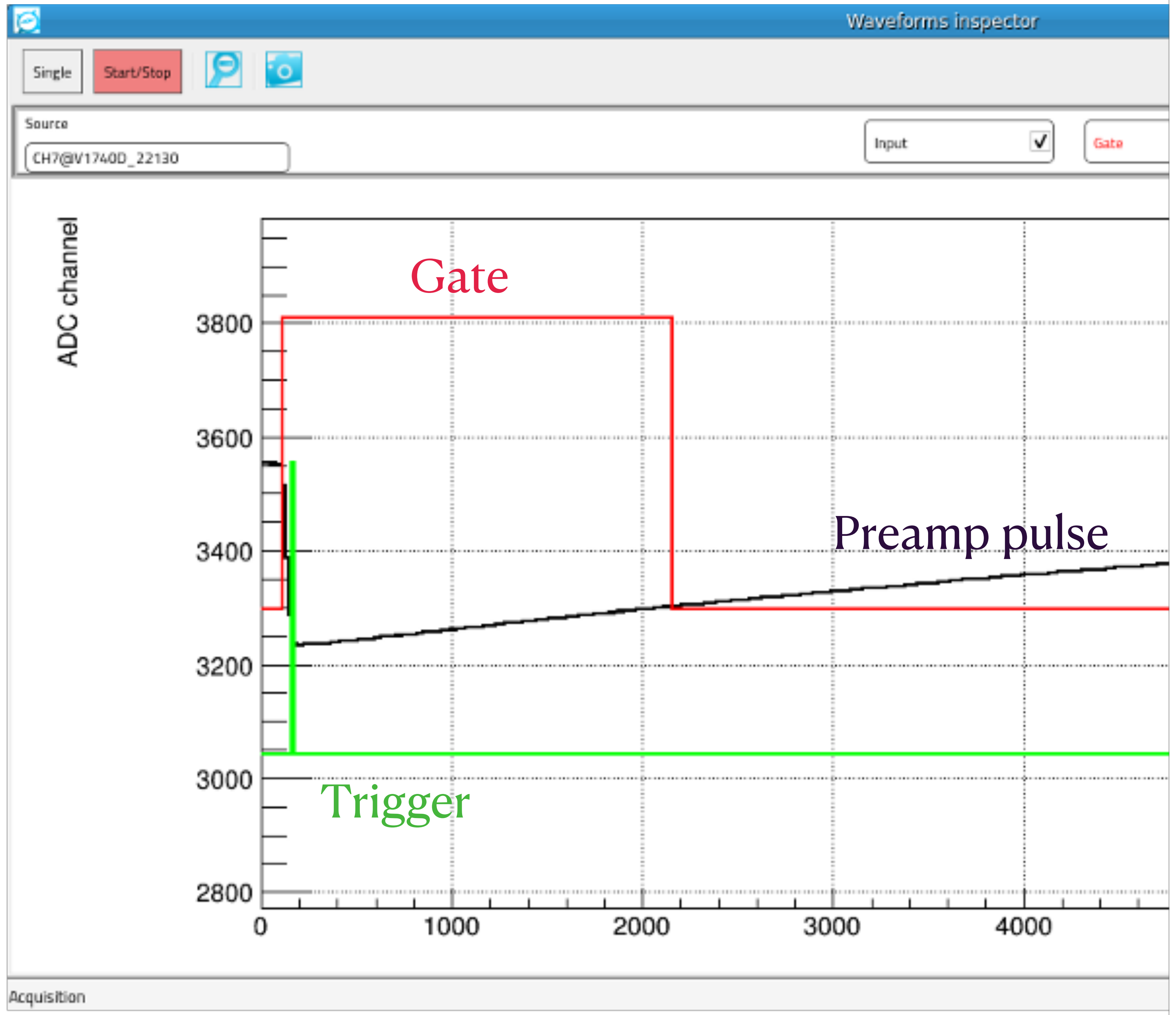
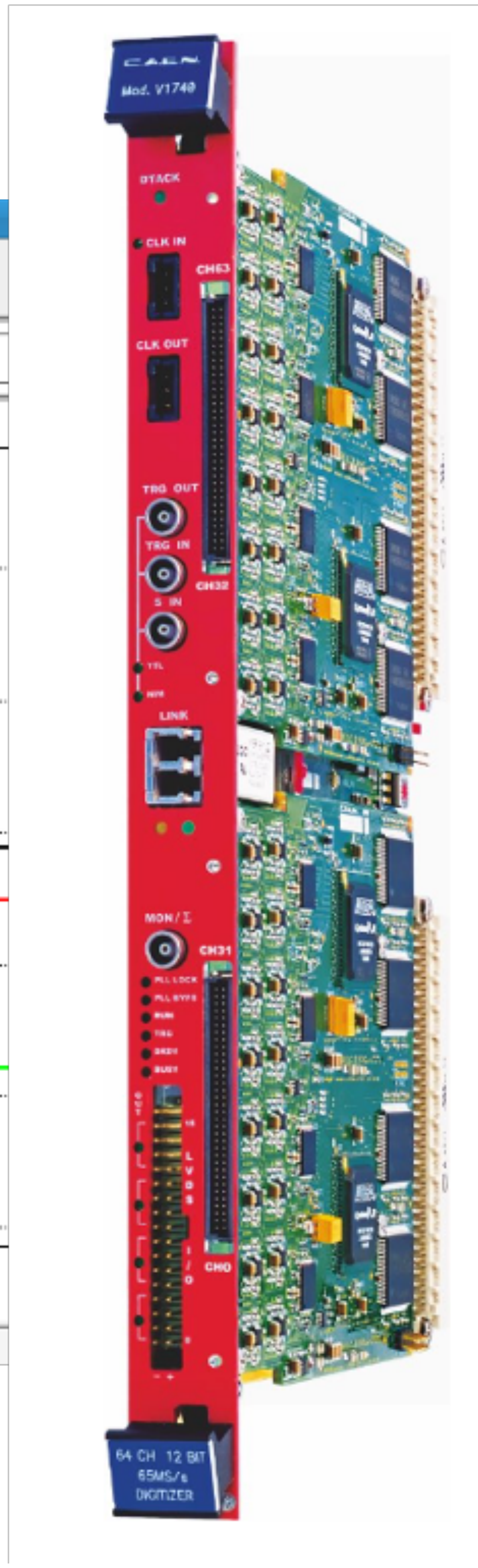
New Digital DAQ for ANASEN

- LSU 72-channel preamp box
- Caen 1740D digitizers (64 channels/ module, 12 bit, 62.5 MSamples/sec, ~$200/channel)
- Caen's CoMPASS software for data acquisition
- QDC firmware integrates preamp pulses
- ~1% energy resolution up to 1 kHz per channel rates
- Record all hits, coincidences analyzed in post-processing

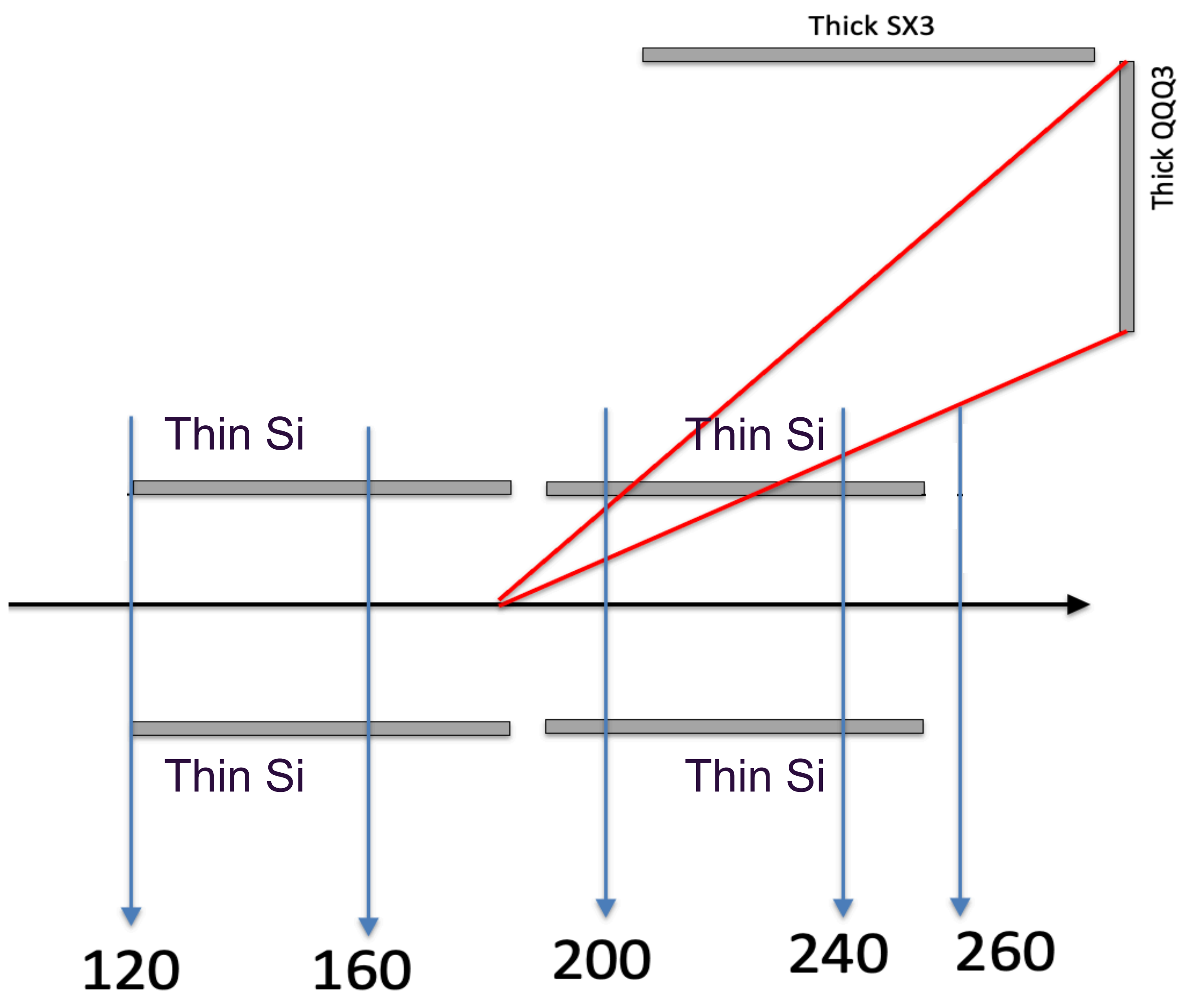




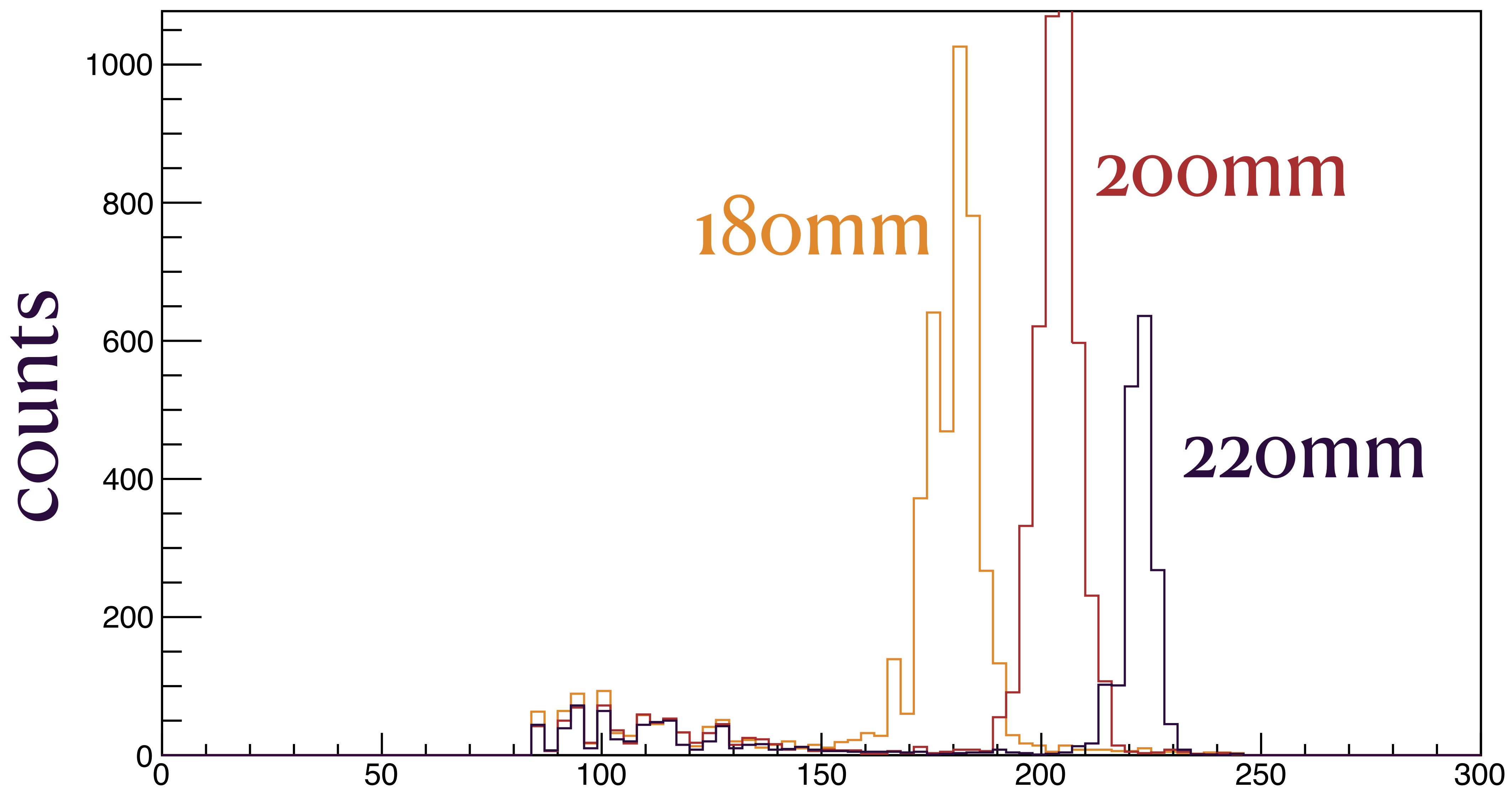
Proton Scattering with Solid ^{181}Ta Target

Position resolution improved to 1 cm FWHM

- 10 MeV protons
- Position resolution improved to 1 cm FWHM, or $\delta E_{cm} \approx$ 120 keV for ^{18}Ne
- Caveat: slightly optimistic case with high energy protons at larger angles



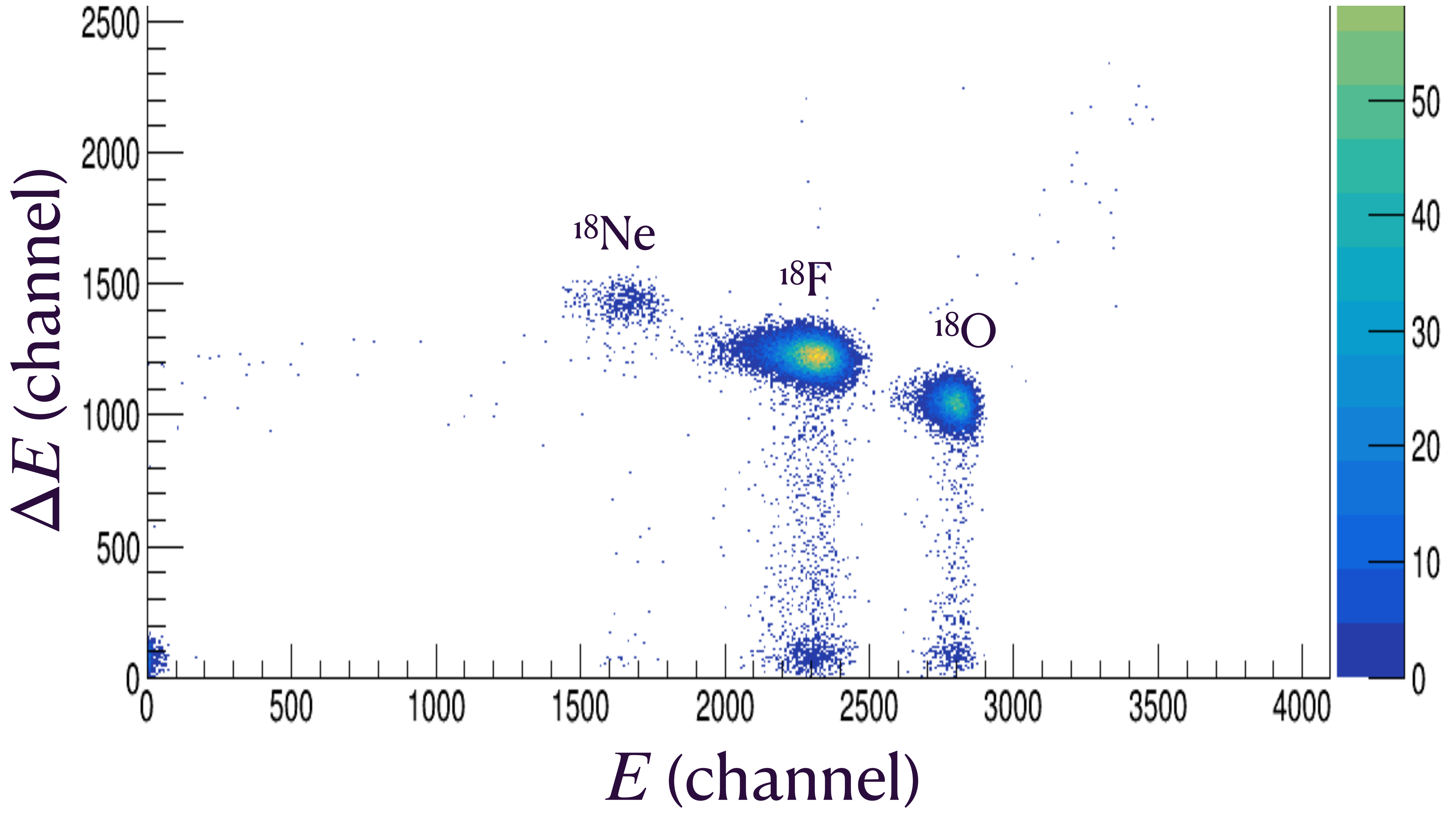
Target distance from window (mm)



Position (mm)

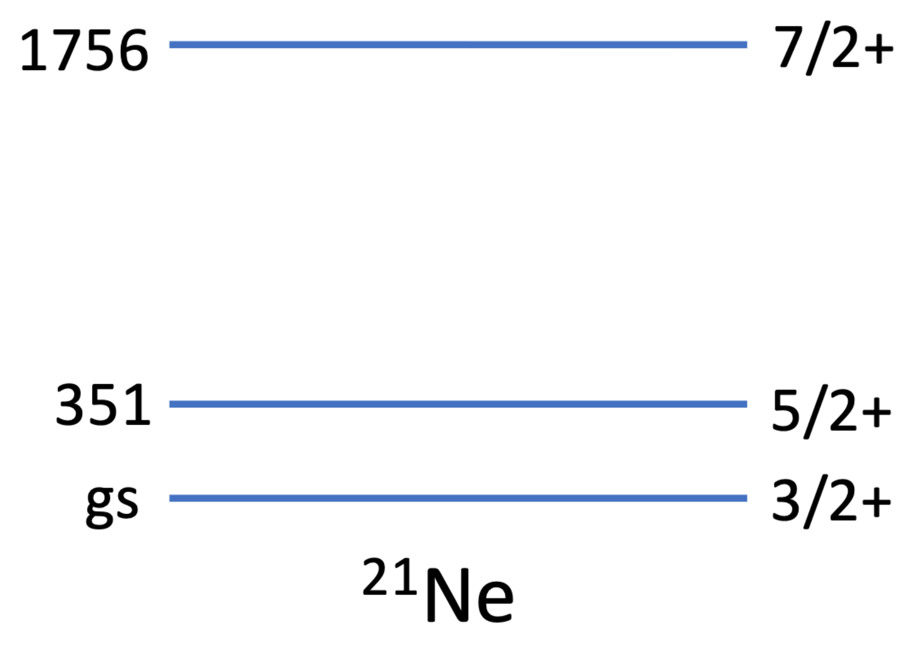
Radioactive Beam: ^{18}F

- Unable to achieve sufficient ^{18}Ne intensity due to technical difficulties
- $^{18}F(\alpha,p)$ is a potential proton source in AGB nucleosynthesis and accreting white dwarfs if rate closer to upper limit
- Need to measure $^{18}F(\alpha,p)$ for background in ^{18}Ne experiment
- Optimized ^{18}F beam with ~2:1 ratio ^{18}F:^{18}O with intensity ~10^5–10^6 pps
- Can ignore ^{18}O contamination due to $^{18}O(\alpha,p)$ Q-value

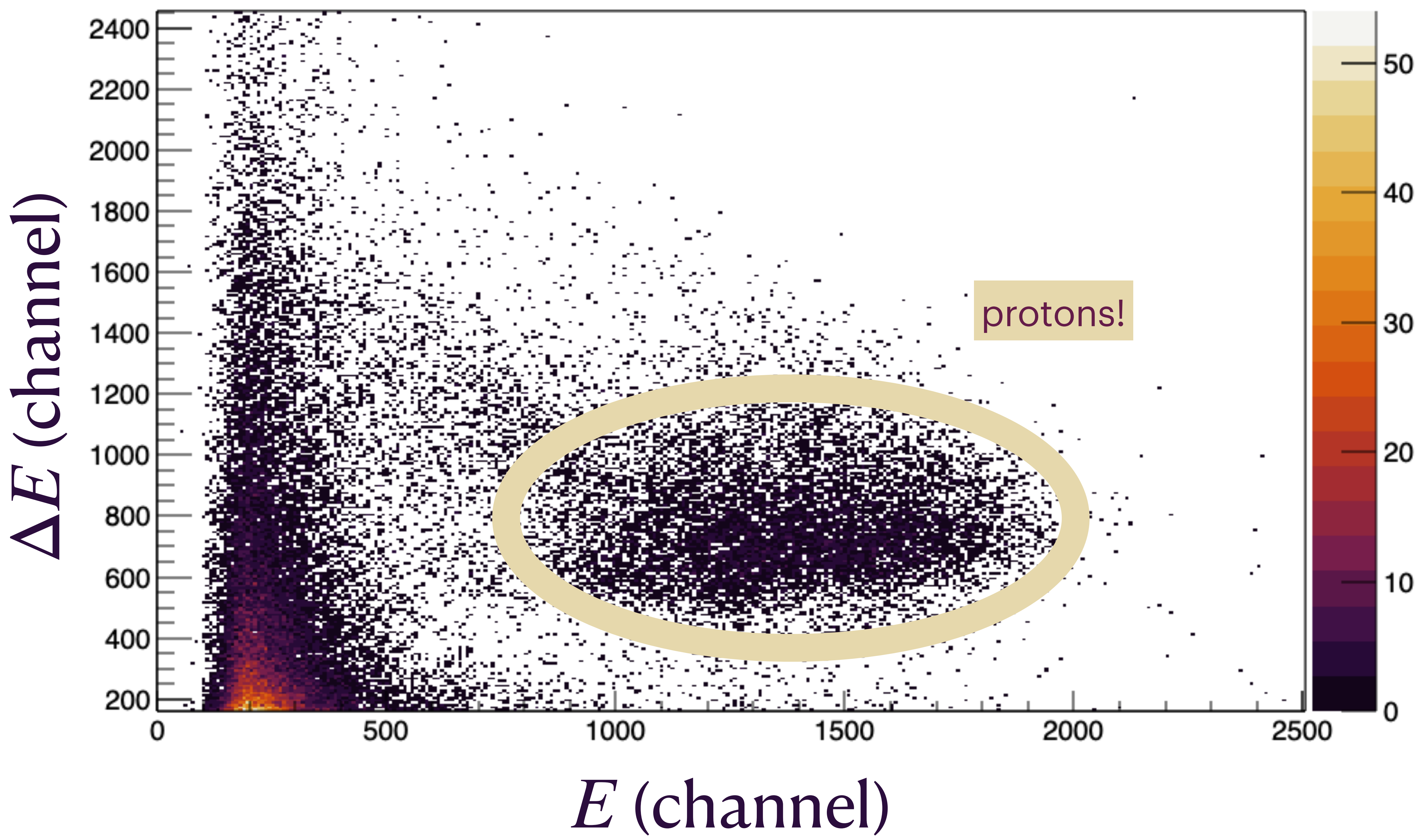


Karakas, Lee, Lugarto, ApJ 676 (2008)
Shen, Bildsten, ApJ 699 (2009)

Preliminary Results: $^{18}F(\alpha,p)$



- Protons clearly identified by ΔE–E
- Expect to populate ground and 1st excited states in ^{21}Ne



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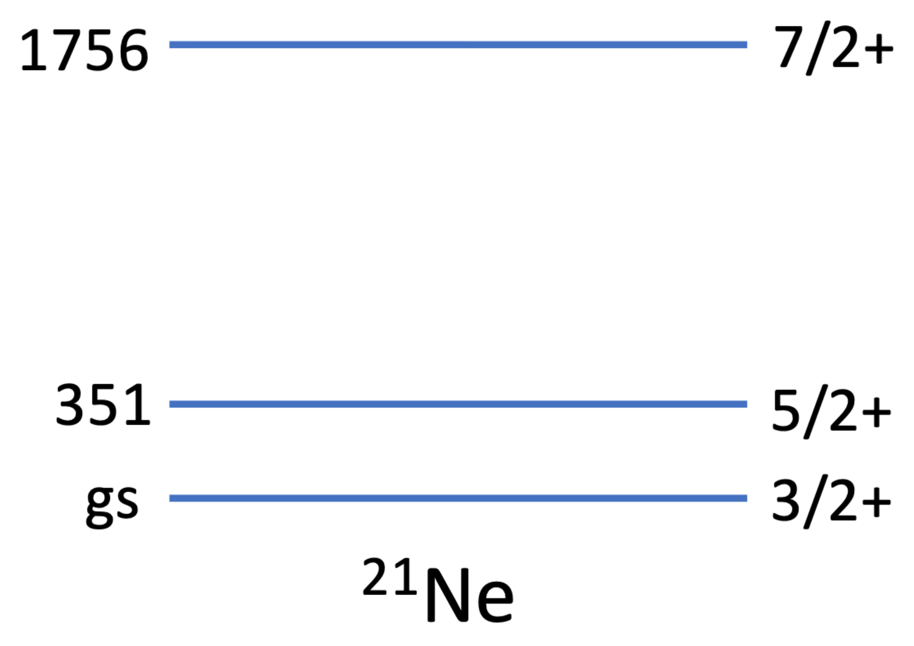

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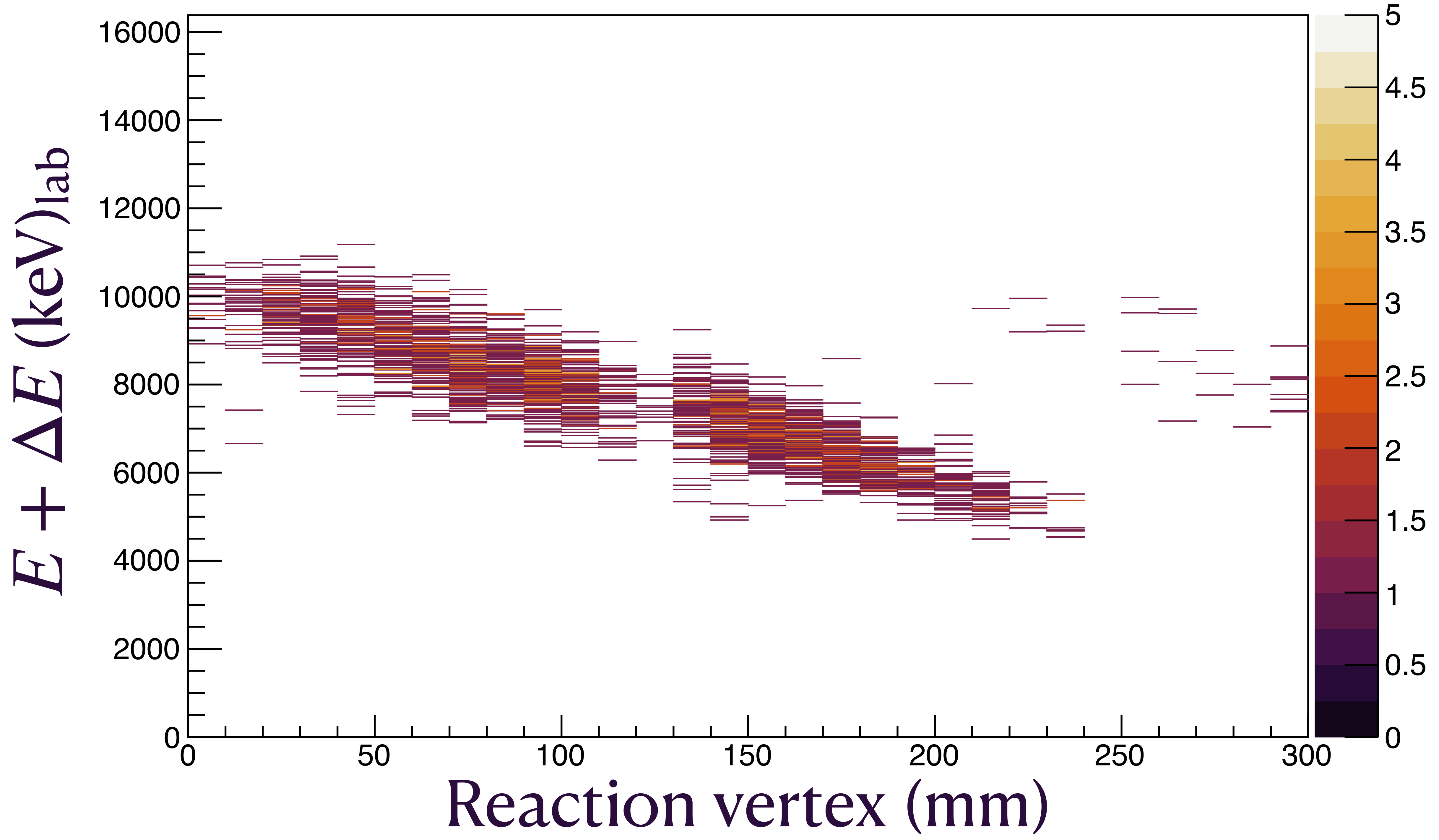

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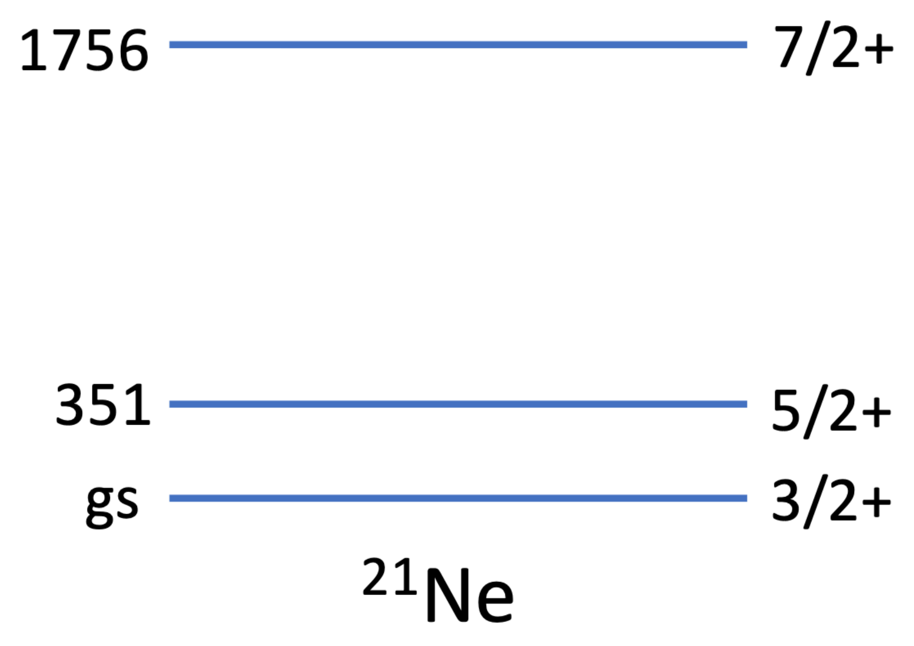
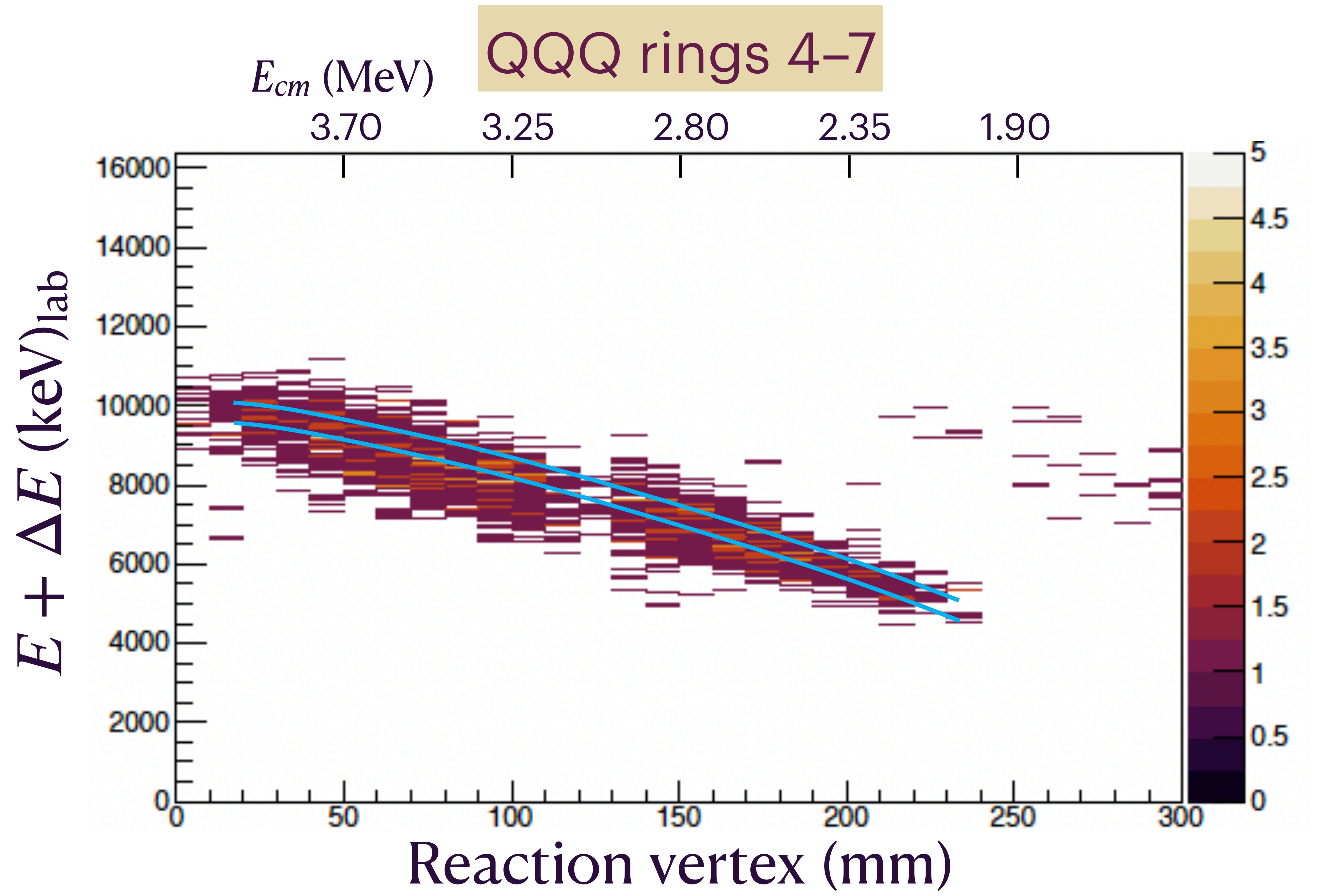
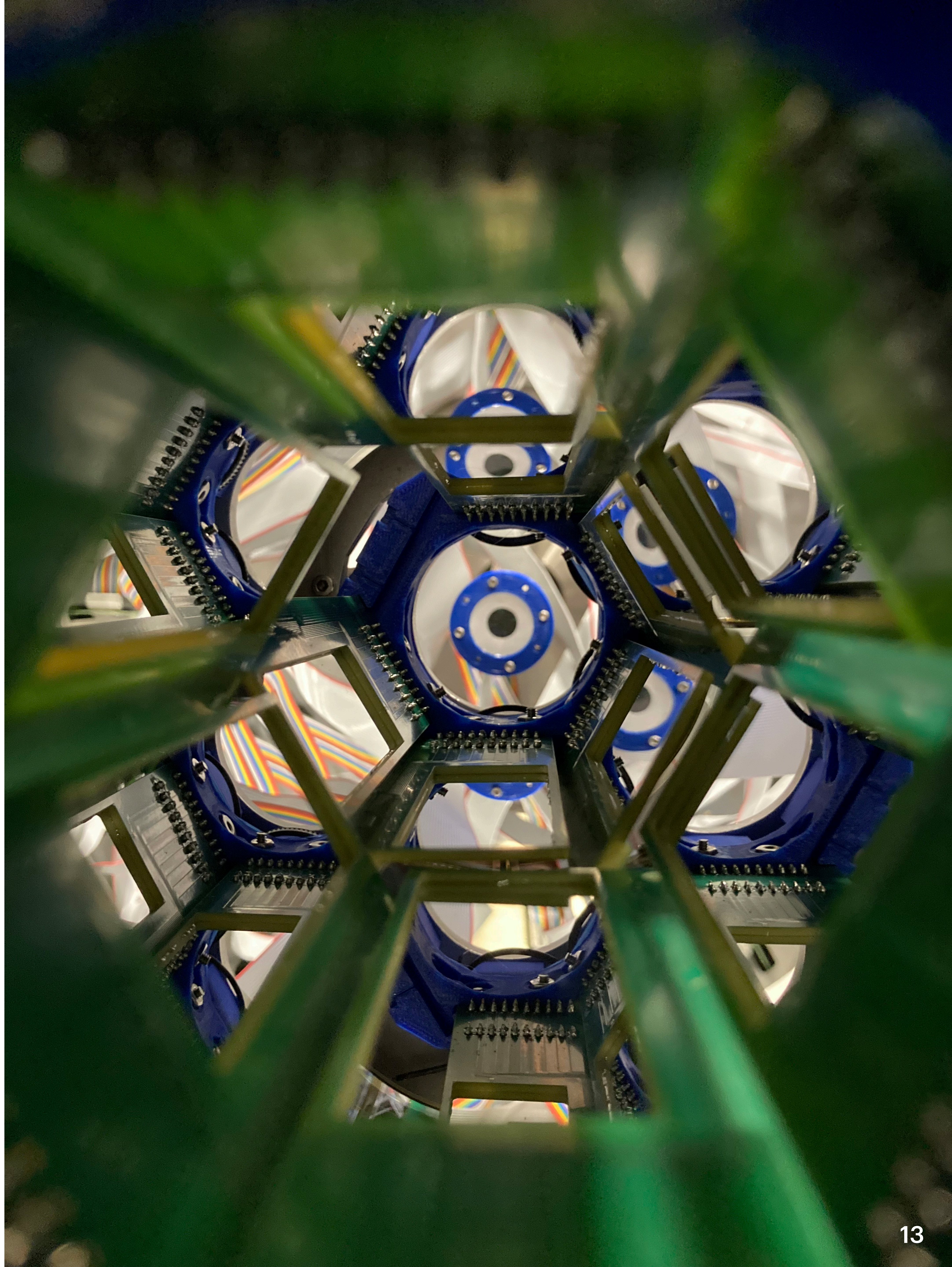


- Protons clearly identified by ΔE–E
- Expect to populate ground and 1st excited states in ^{21}Ne
- However, it's not clear that we can resolve these states
- Straggling in ΔE pushing our energy resolution closer to 500 keV
- In progress: analyzing SX3 data and extracting excitation function



Conclusions & Future Work

- Digital ANASEN marks an improvement for (α,p) direct measurements
- Straggling may be reduced with updated geometry
- Proposed measurements:
  - ^{14}O(α,p) at Florida State University (Fall 2023)
  - ^{18}Ne(α,p) at TRIUMF
  - ^{30}S(α,p) at FRIB



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