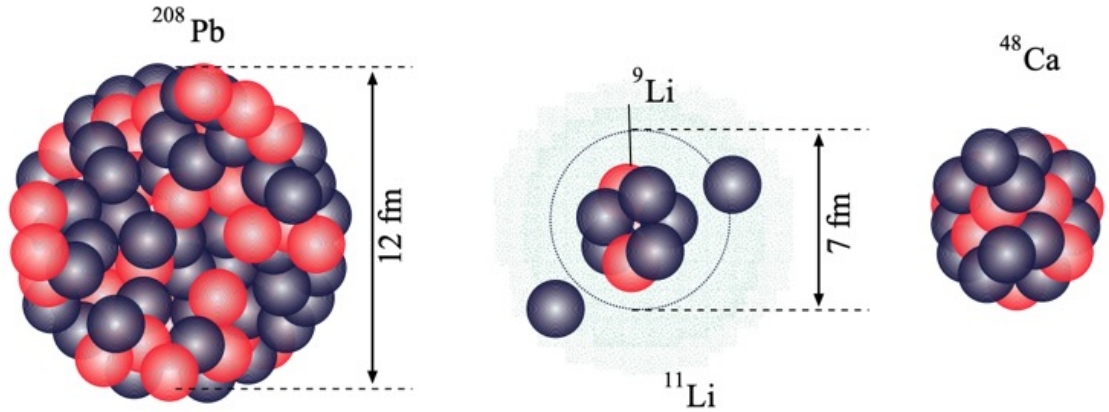
# TexAT-TPC and a Neutron Detector Array, TexNeut

*Dustin P. Scriven*

*May 18, 2023*

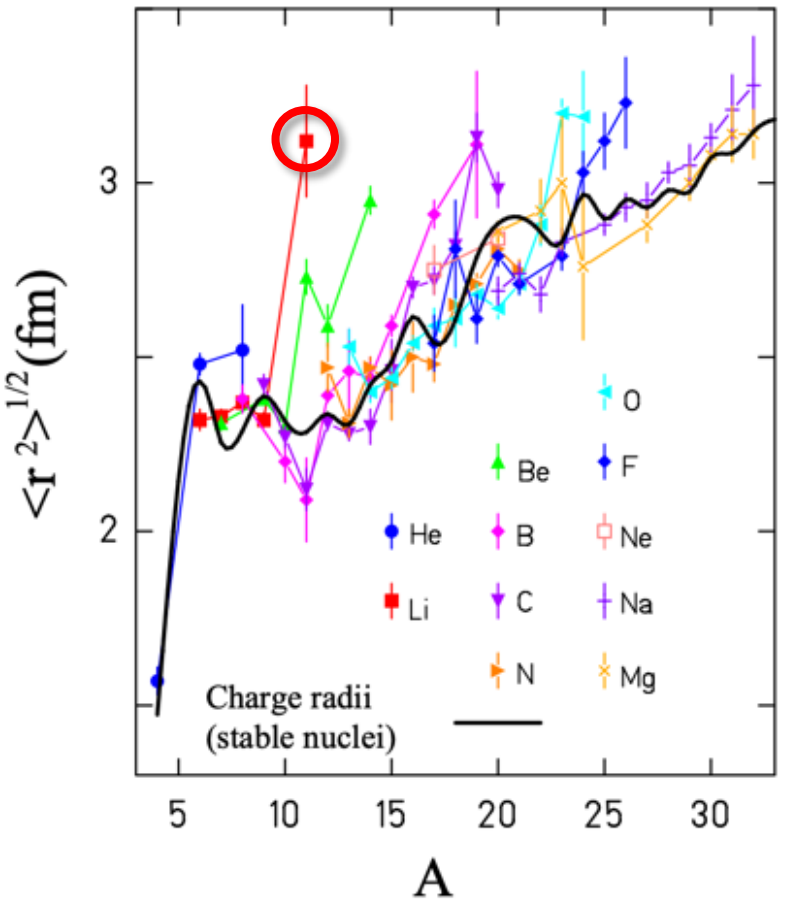
# Low-lying Resonances in $^{10}$Li

- $^{11}$Li first observed by I. Tanihata *et al*. at Berkley in 1985
- Nuclear radii predicted by $R = R_0 A^{\frac{1}{3}}$
  - Tanihata noted an RMS radius similar to $^{48}$Ca and valence neutron radius like $^{208}$Pb!
- $10^{17}$ s longer lifetime than $^{10}$Li due to pairing




B. Jonson, Phys. Rep. 389, 1 (2004).

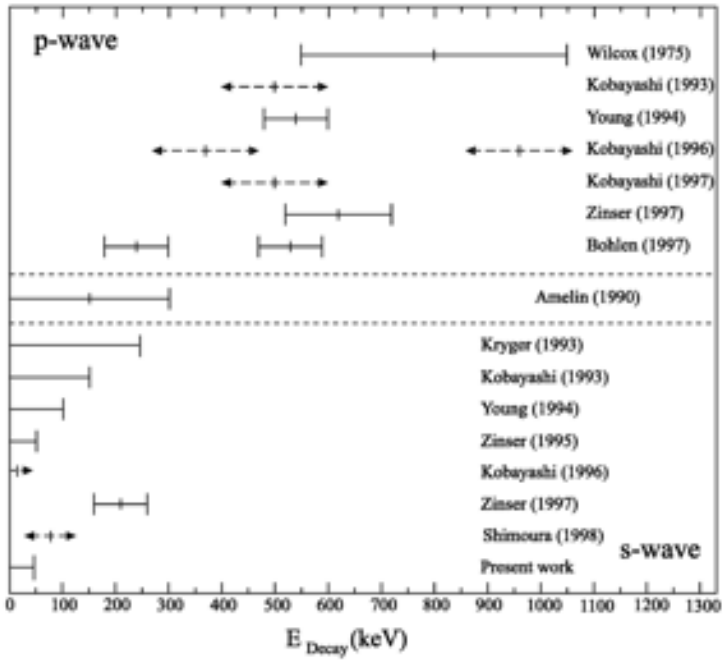
L.V. Chulkov, Nuovo Cimento 111A (1998) 791.



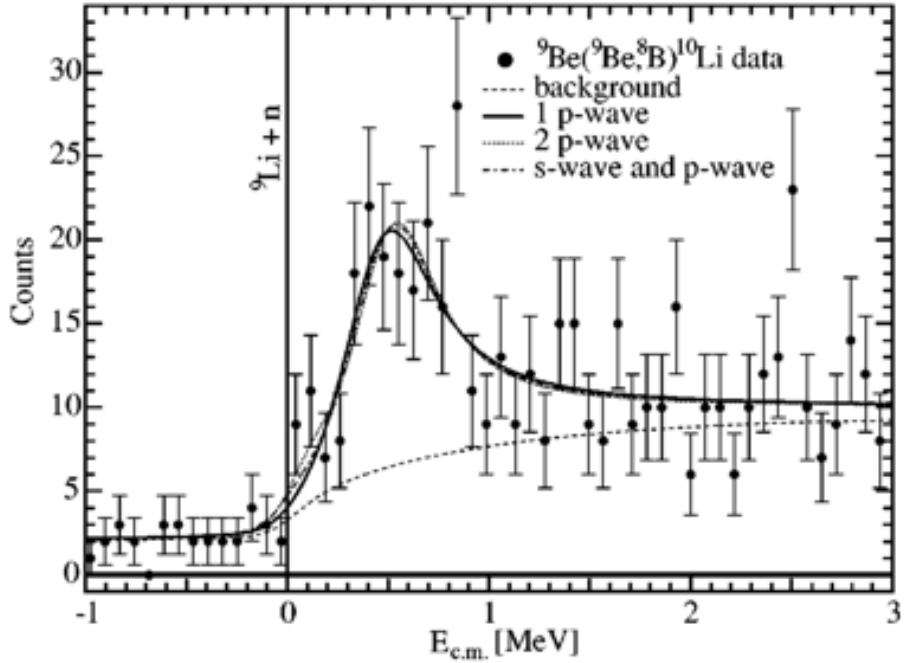
# Low-lying Resonances in $^{10}$Li

- To understand the $^{11}$Li system, we want to first know the details of the $^{9}$Li + *n* interaction
- $^{10}$Li is slightly more illusive – being neutron unbound
- The unbound G.S. $J^{\pi}$ assignment is not pinned down
- Suggested to have *s*-wave resonance with *p*-wave first excited state due to intrusion of $1s_{1/2}$ level
- Many studies have problems coming to a consensus on the *s/p*-wave resonance

M. Thoennessen et al., Phys. Rev. C 59 (1999)

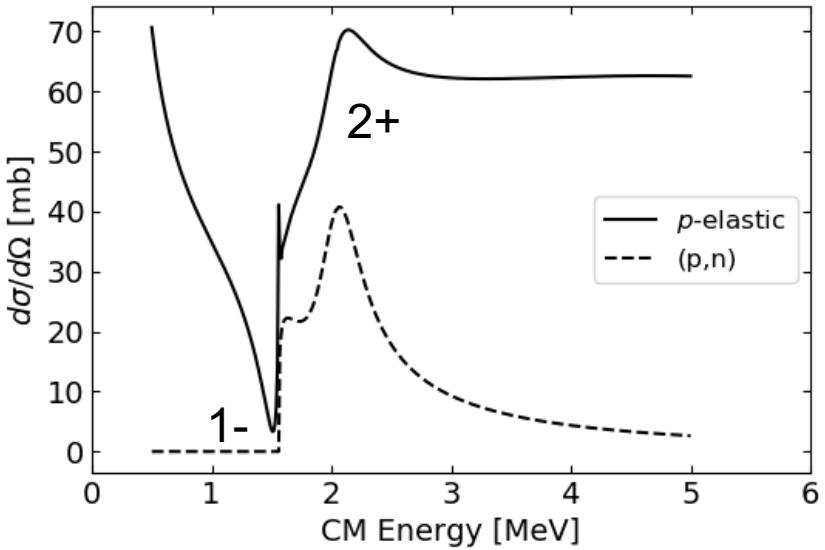


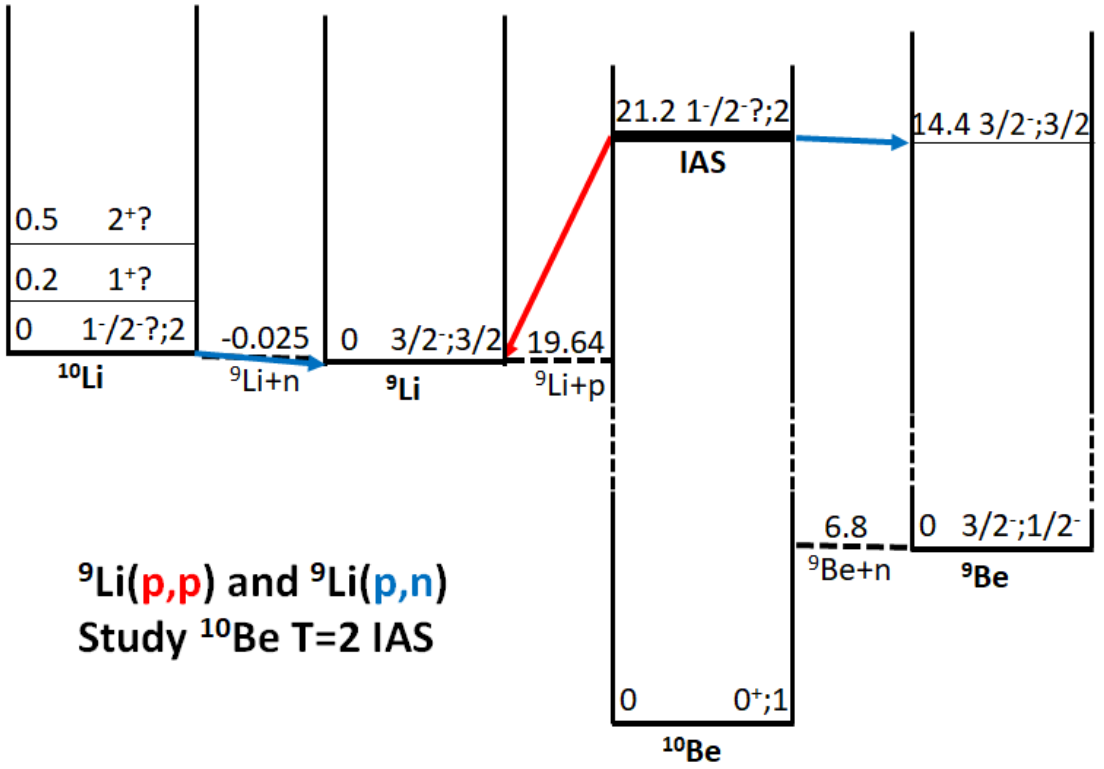

J. A. Caggiano et al., Phys. Rev. C. 60 (1999)



# Low-lying Resonances in $^{10}$Li

- Use TexAT to study broad resonances of $^{10}$Be T=2 IAS of $^{10}$Li with $^{9}$Li(p,p)
- R-matrix calculations show strong enhancement to XS in both channels
- Future - TexNeut array together to study broad resonances of $^{10}$Be T=2 IAS of $^{10}$Li with $^{9}$Li(p,p) and $^{9}$Li(p,n)

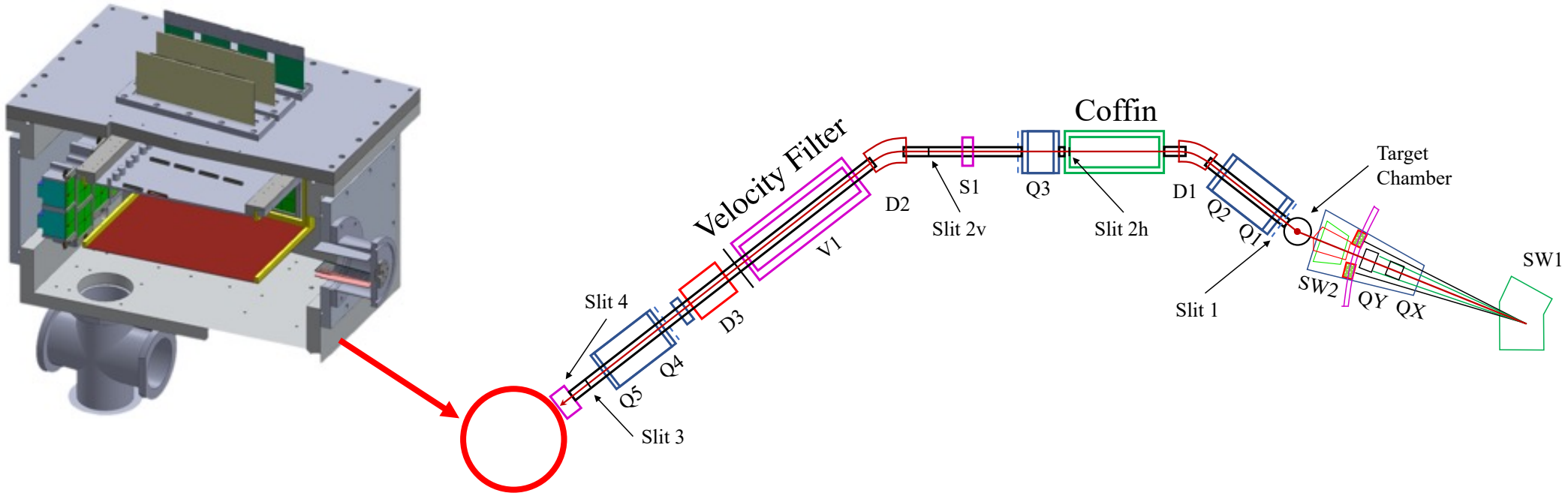


# Experimental Setup

A beam $^{7}$Li was delivered to MARS from the K150 Cyclotron

- Using a cryogenic $^{18}$O target the $^{7}$Li($^{18}$O,$^{16}$O)$^{9}$Li reaction was used to produce $^{9}$Li
- Reaction product were refocused and passed through a Wein ($E\times B$) filter and a dipole (D3)
- Remaining contaminants include the $^{m}/_{q}$ triplet – $^{9}$Li, $^{6}$He, and $^{3}$H at $B\rho$ 1.117 Tm



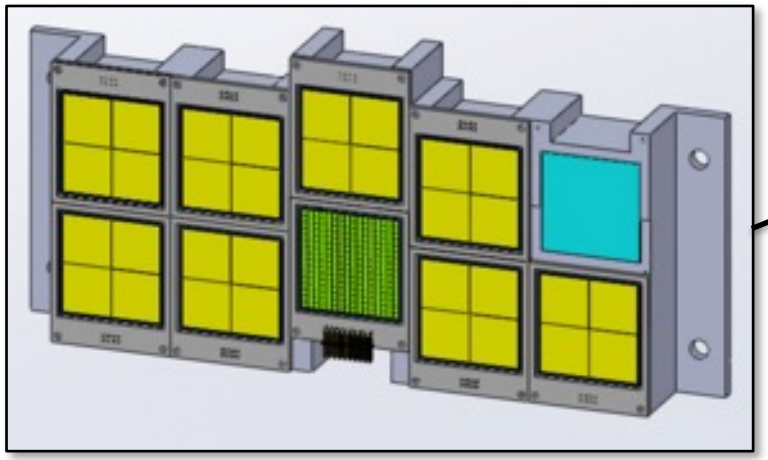

Momentum Achromat Recoil Separator [R.E. Tribble, et al., NIMA **185** (1989).]

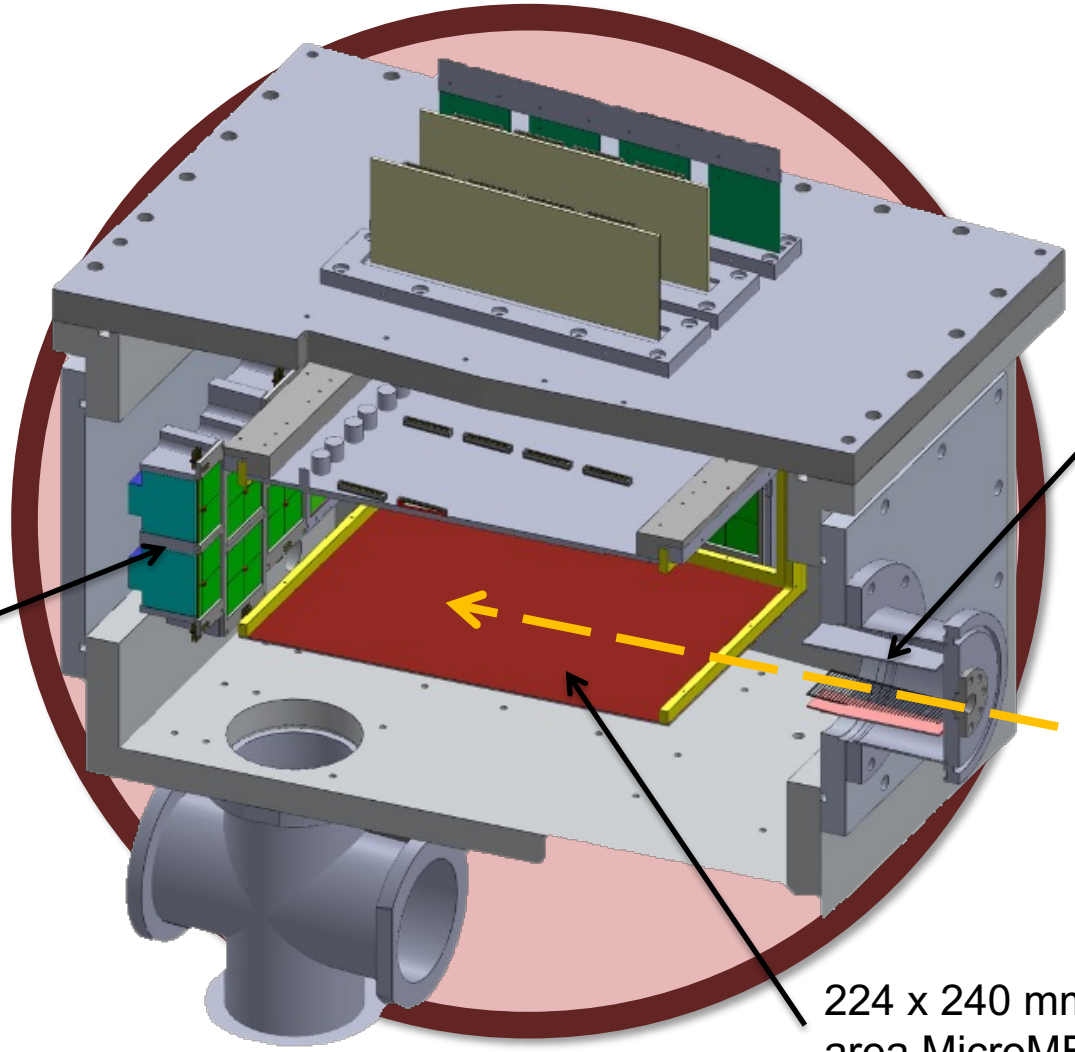
# TexAT-TPC

## Designed for TTIK with RIBs

- 260 Torr isobutane ($C_4H_{10}$) provides large proton target thickness Pressure tuned to stop 6.65 MeV/u $^9$Li in the active region

Segmented Si-CsI at forward lab angles



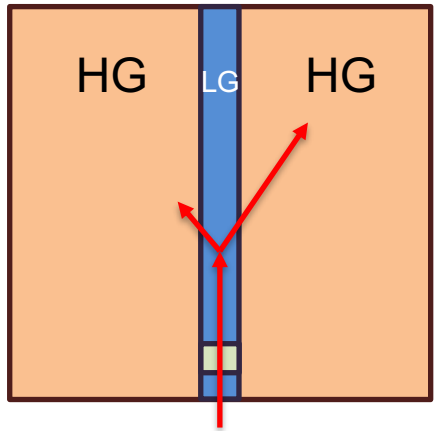


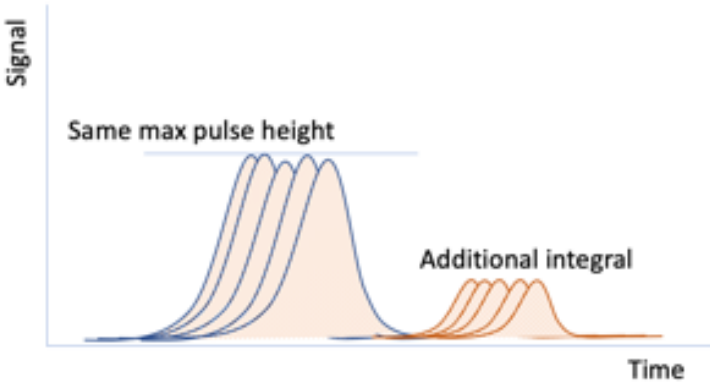

Texas Active Target Time Projection Chamber (TPC) [E. Koshchiy et al. NIMA **957**, 163398 (2020).]

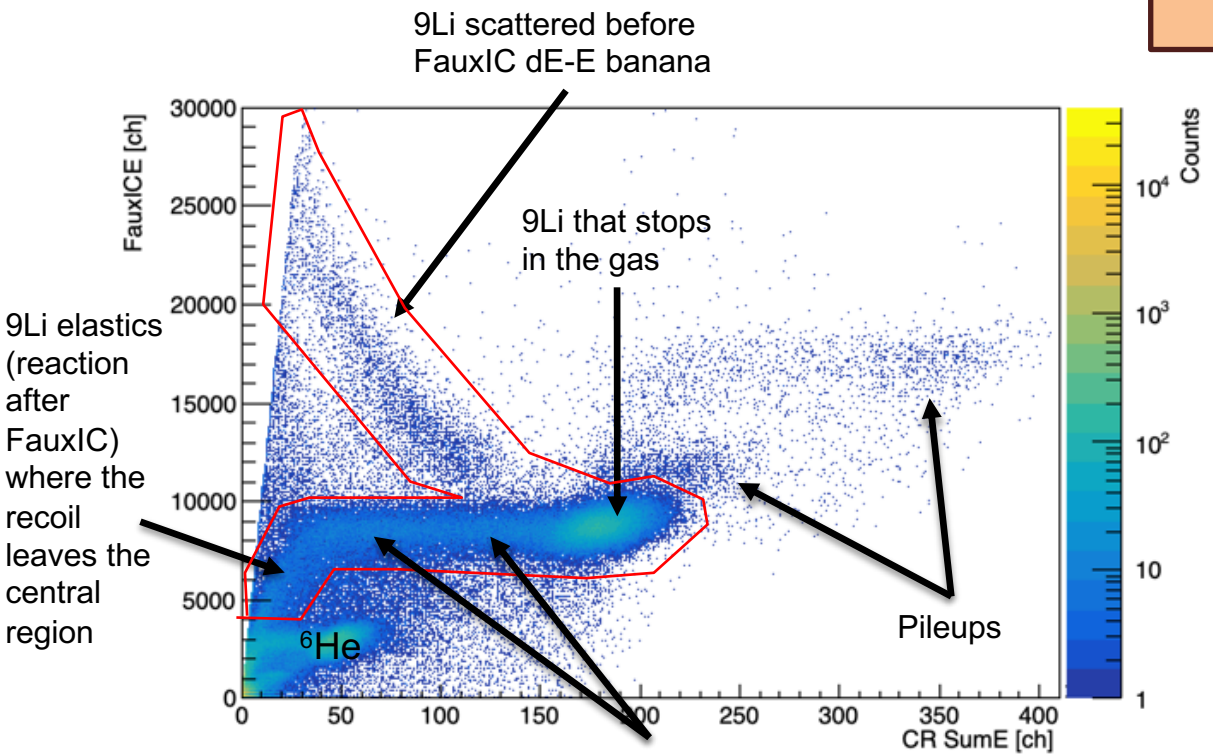
# Selection of $^{9}$Li Events

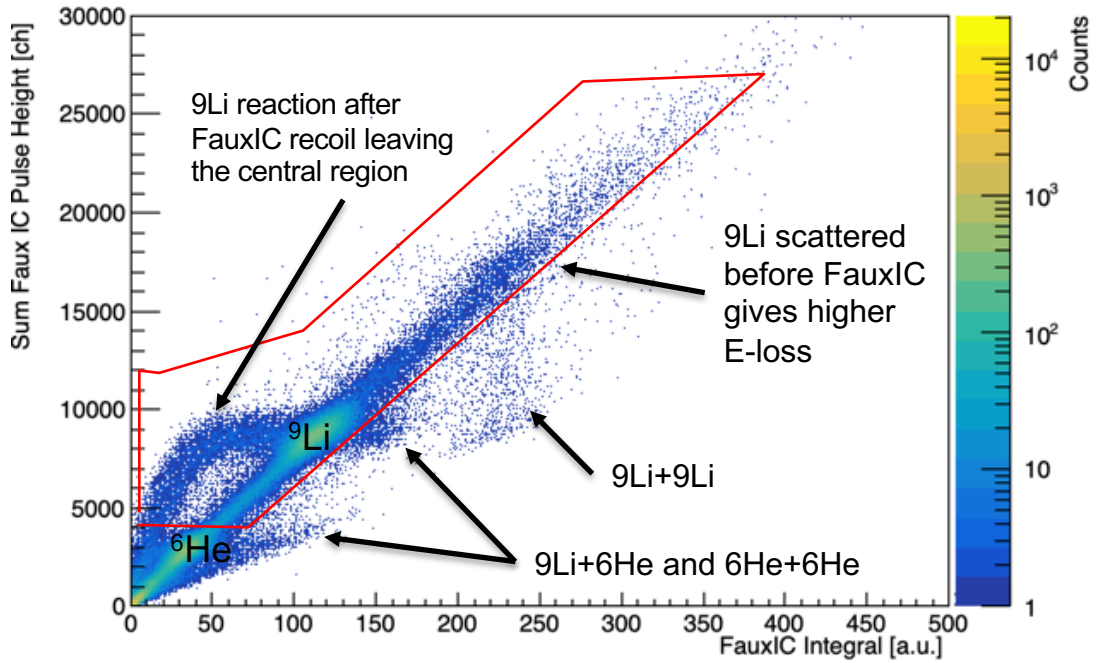
$^{3}$H and $^{6}$He beam contaminants and pileup were a major issue – NO IC

- Pulse height analysis is usable to remove the contaminants and pileups



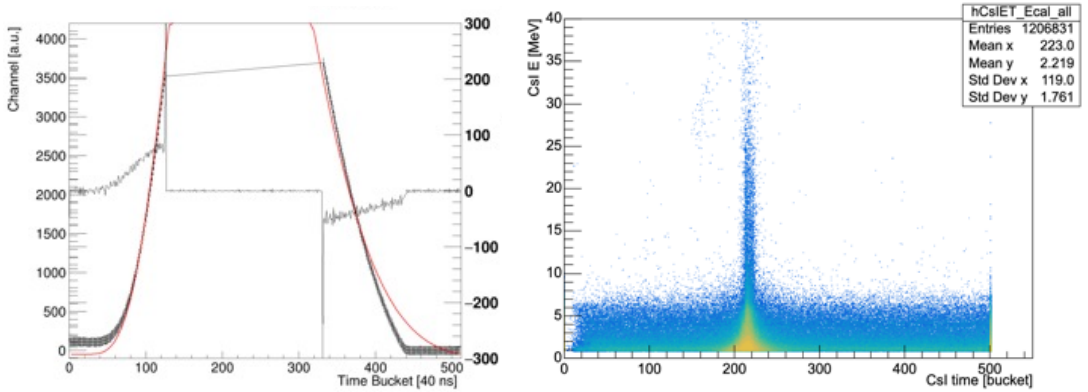



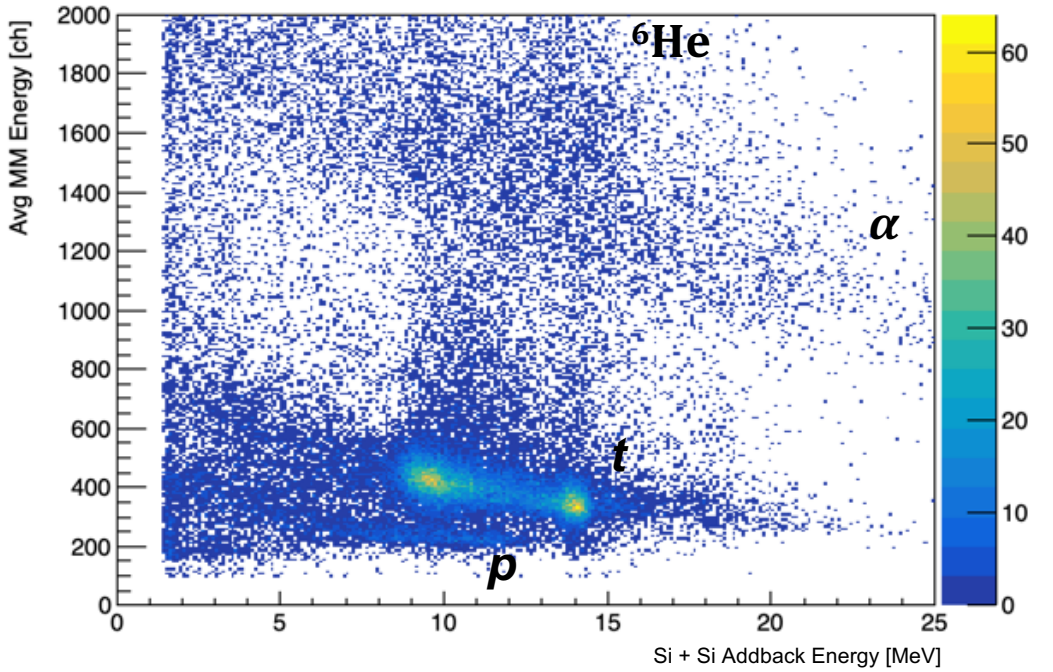

9Li elastics with recoil stopping in the central region

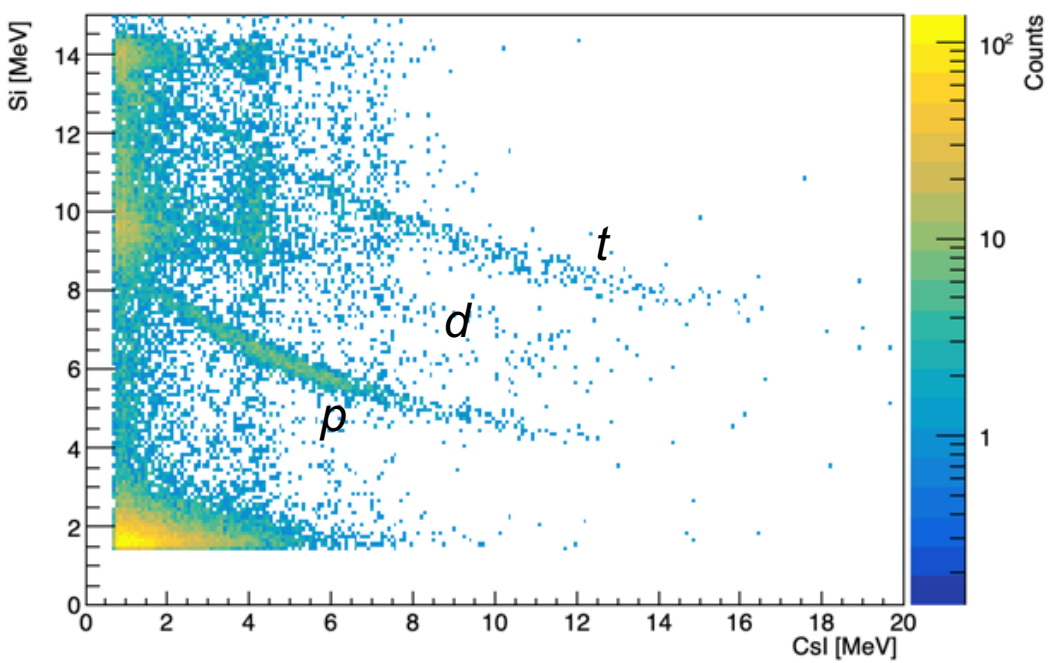
# Selection of Protons Events

Protons are selected in two energy regimes

- Low energy ID in MM-Si dE-E
- High energy ID in Si-CsI
  - CsI waveforms fit to increase dynamic range
  - Si-CsI events are time correlated



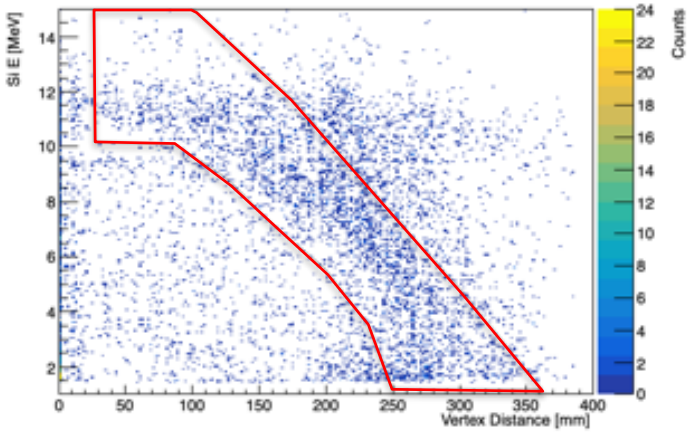
# Tracking

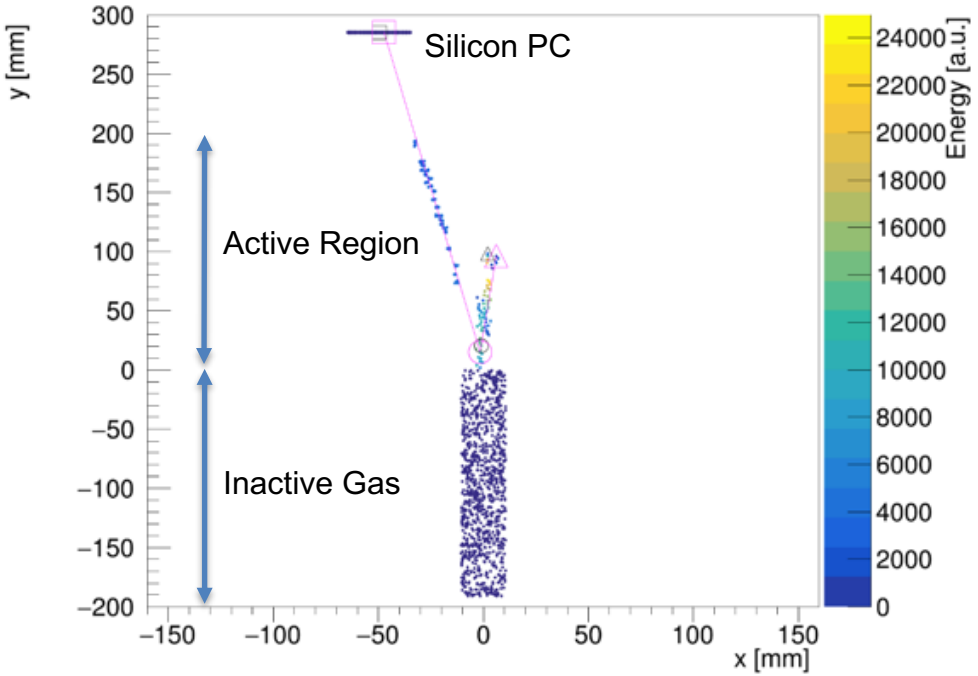
Tracking gives us E-loss COM reconstruction and E-loss

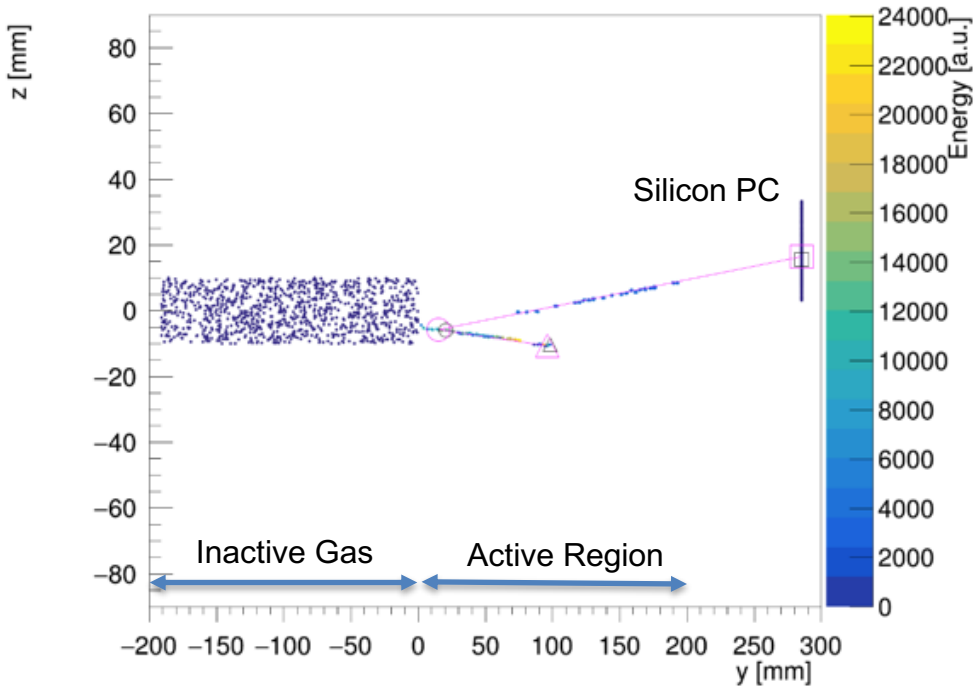
- $e^-$ drift velocity is calculated using `Garfield++` based code
- Vertex and $E_{Si}$ allow for identification of elastics

Employ the track fitting method *Random Sampling Consensus* - `RANSAC`

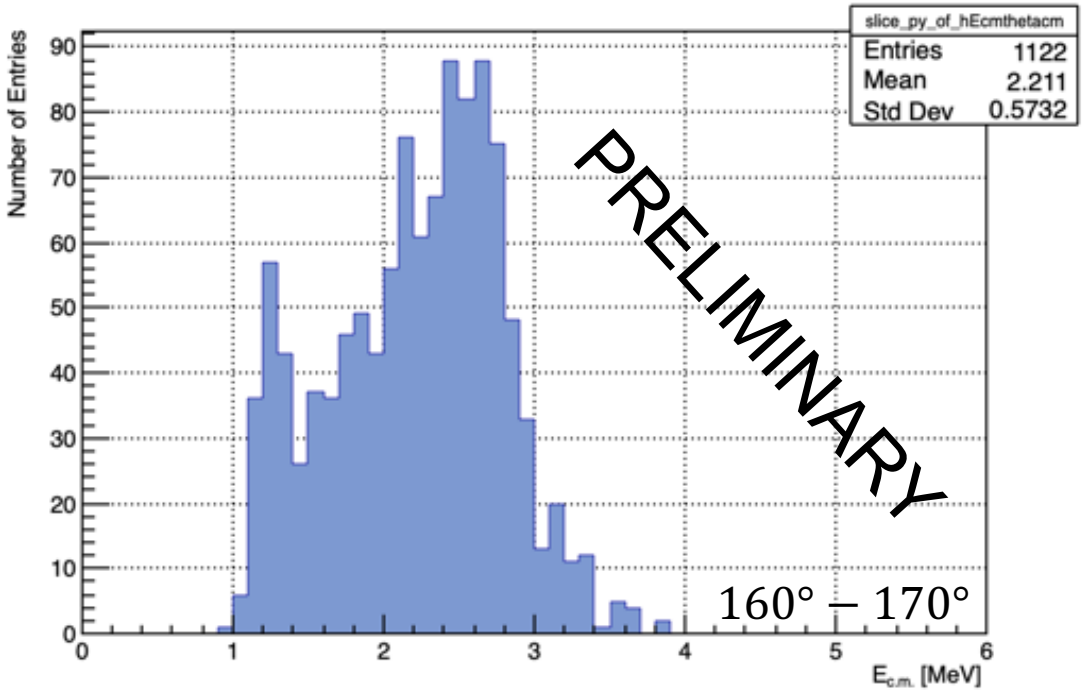
1. Iteratively selects random points & connects points with lines
2. Evaluates the connections by fitting the data and records a score

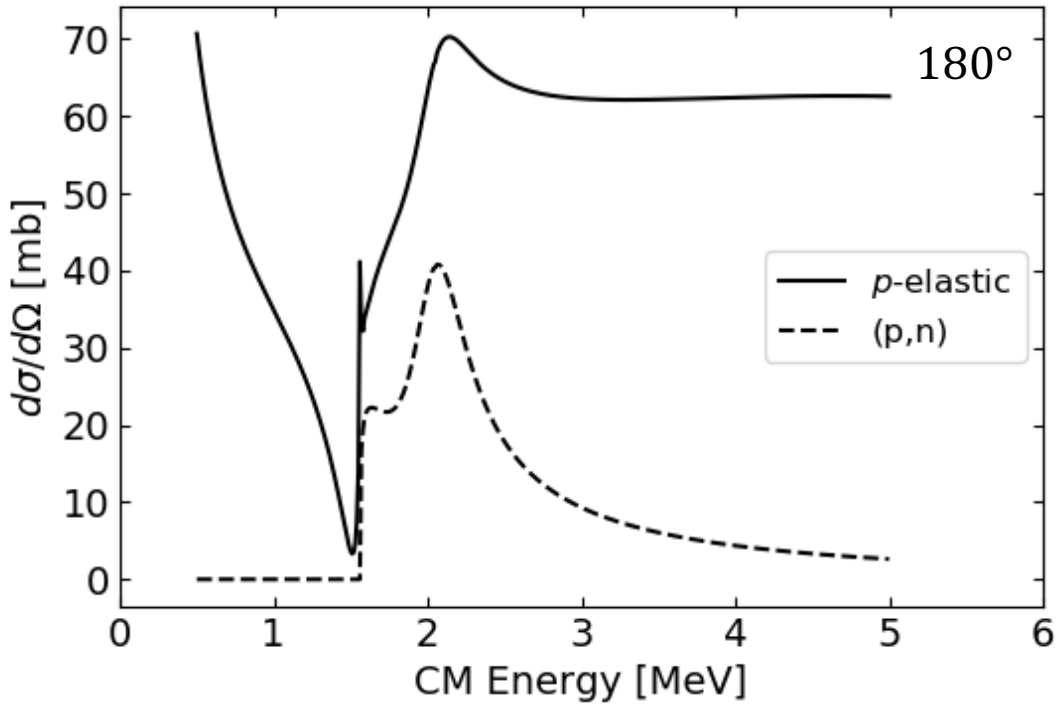


# Results


slice_py_of_hEcmthetacm
Entries 1122
Mean 2.211
Std Dev 0.5732
Number of Entries
$E_{c.m.}$ [MeV]
PRELIMINARY
160° – 170°


180°
p-elastic
(p,n)
dσ/dΩ [mb]
CM Energy [MeV]

# $^{9}$Li(p,p) Future

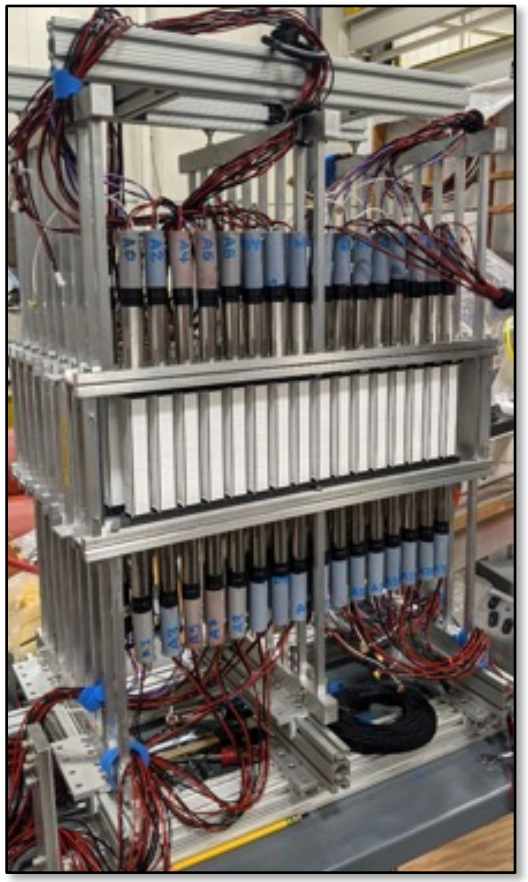
- Convert c.m. spectrum to Cross Section
- Fit and compare to *R*-matrix analysis

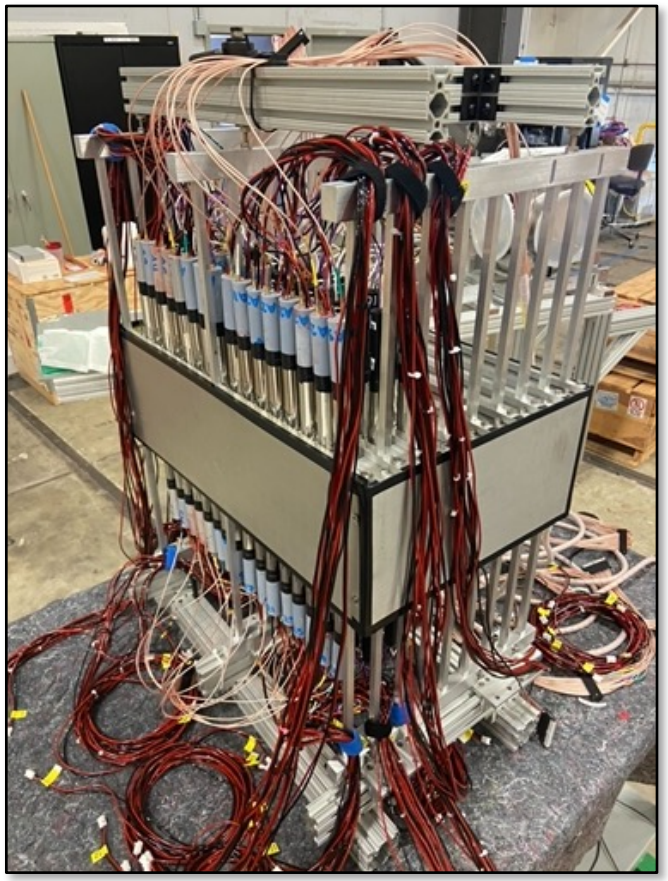
- Use TexNeut array with TexAT to study broad resonances of $^{10}$Be T=2 IAS of $^{10}$Li with $^{9}$Li(p,p) and $^{9}$Li(p,n)

The isospin decomposition:

$$|2\ 1\rangle = C_p^2 \left|{}^3/_2\ {}^3/_2\right\rangle \left|{}^1/_2\ {}^{-1}/_2\right\rangle + C_n^2 \left|{}^3/_2\ {}^1/_2\right\rangle \left|{}^1/_2\ {}^1/_2\right\rangle$$

$$\Gamma_s^2 = SC_s^2 \rightarrow \frac{\Gamma_p^2}{\Gamma_n^2} = \frac{C_p^2}{C_n^2} \rightarrow \Gamma_n^2 = 3\Gamma_p^2$$



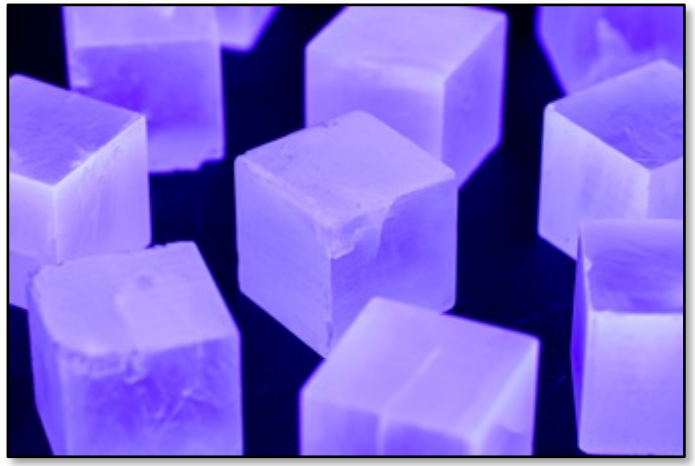


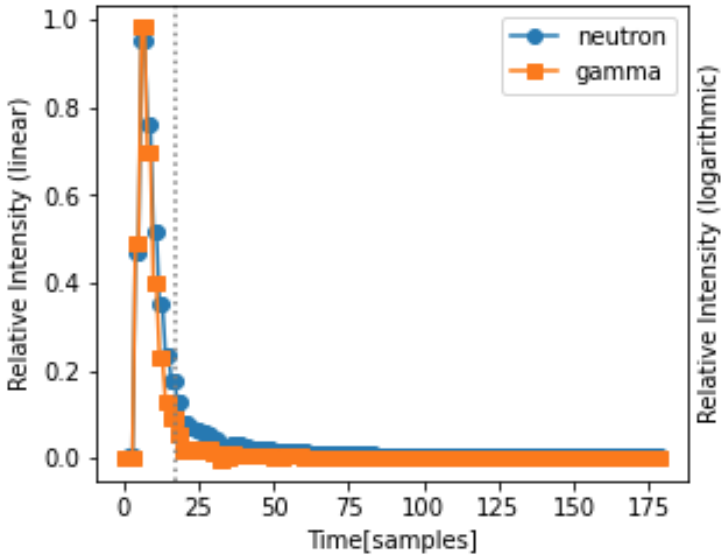
# *p*-Terphenyl

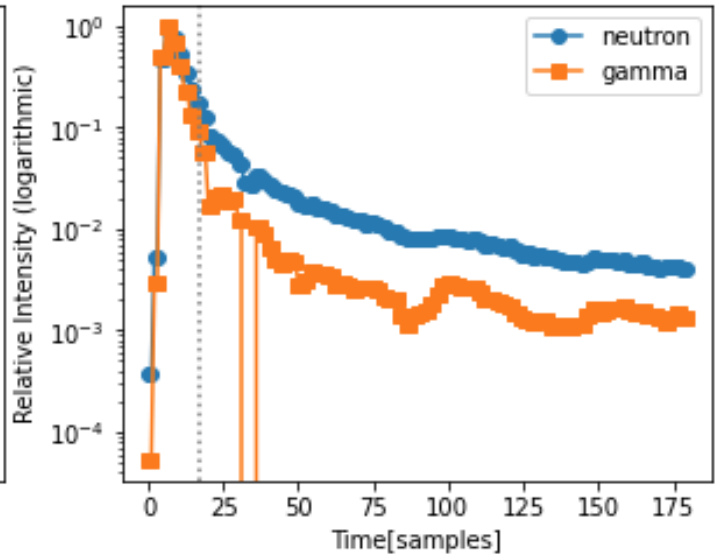
Solid organic crystal

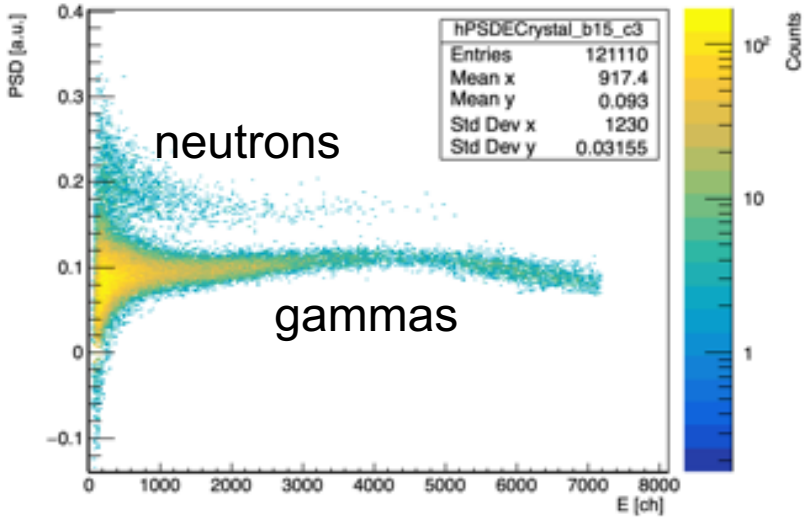
*Compared to other contemporary PSD organics*

- Extremely bright, fast, and exquisite *n*/*γ* PSD
- Not volatile, flammable, or toxic,
- Very bright - up to 35,000 γ/MeVee
- Exceptional PSD (comparable or better)





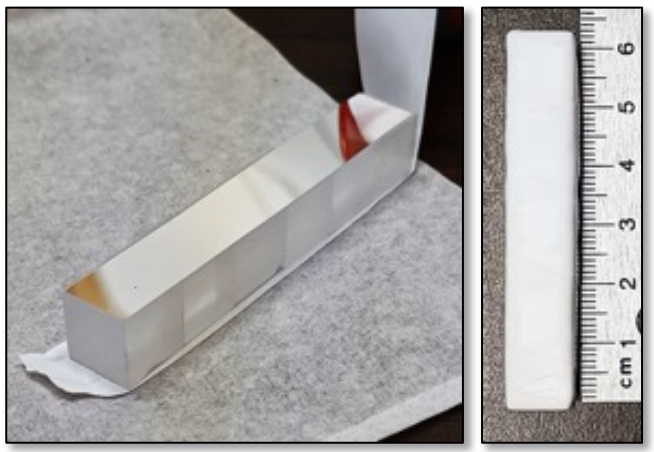



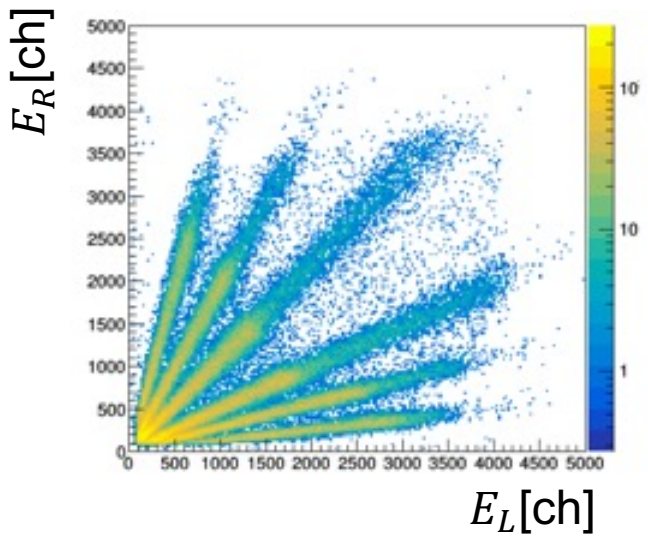
# 6-crystal Pseudo-bar

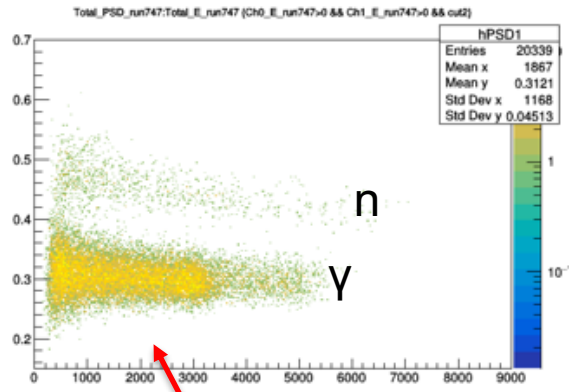
Crystals are optically coupled together (EJ-550 / EJ-560) to produce a position sensitive *pseudo-bar*

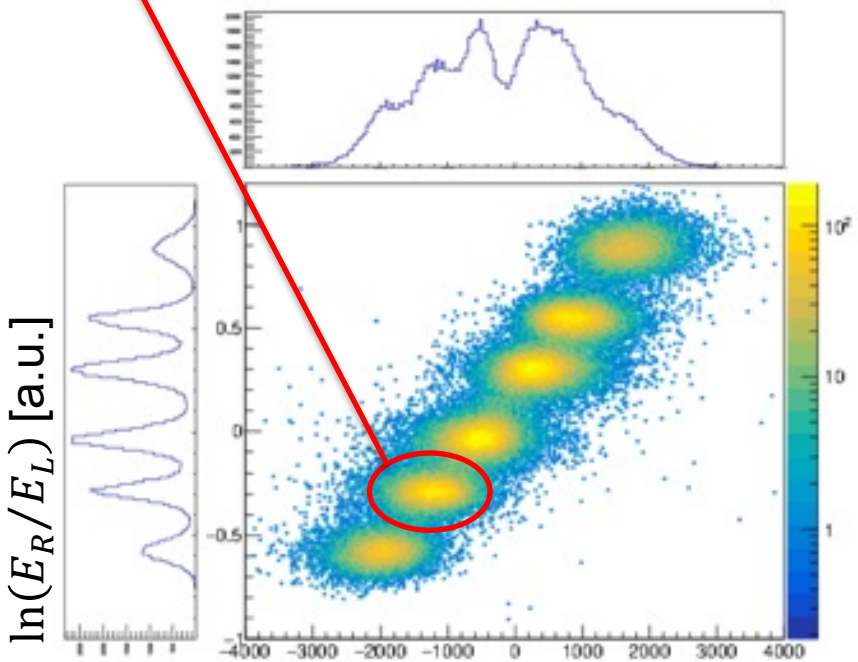
- Read out conventionally from both ends by PMTs
- Position given by $L + R$ energy and time
- Total energy is best reconstructed by $E_L + E_R$

Energies give **discrete position spectrum** shown by an uncollimated $^{207}$Bi source





# Detector Characterization

Analysis and characterization of position and PSD modules was performed on 6 x (2x2x2 $cm^3$) bar

- Energy calibrated with $^{137}Cs$ + $^{207}Bi$
- PSD evaluated using $^{252}Cf$
- CAEN 1730 500 MHz waveform digitizer

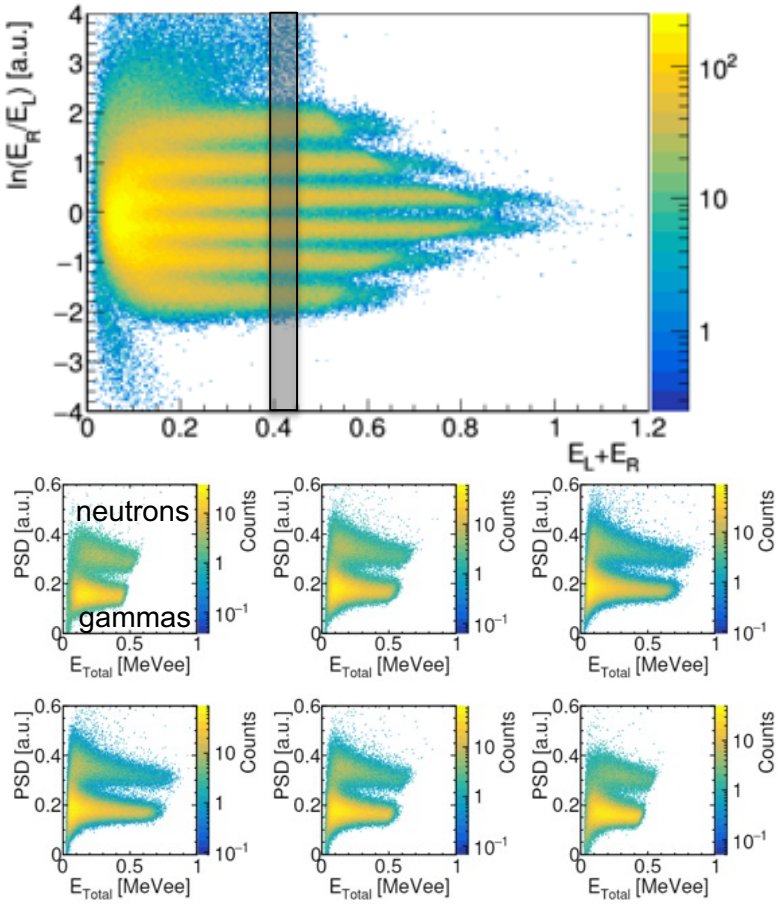
By stepping through increments of 50 keVee the PSD and position distributions are evaluated

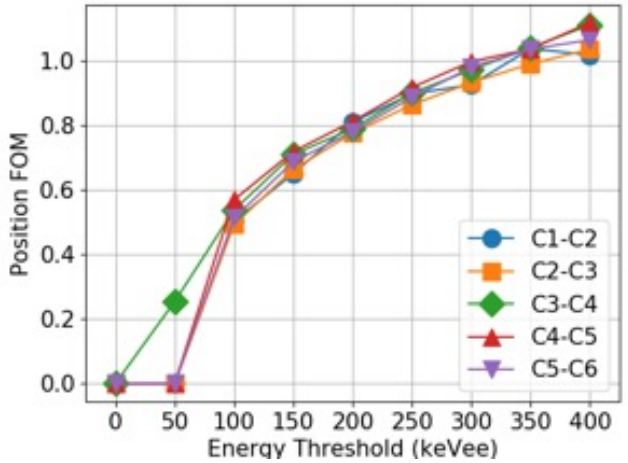
Position FOM evaluated by

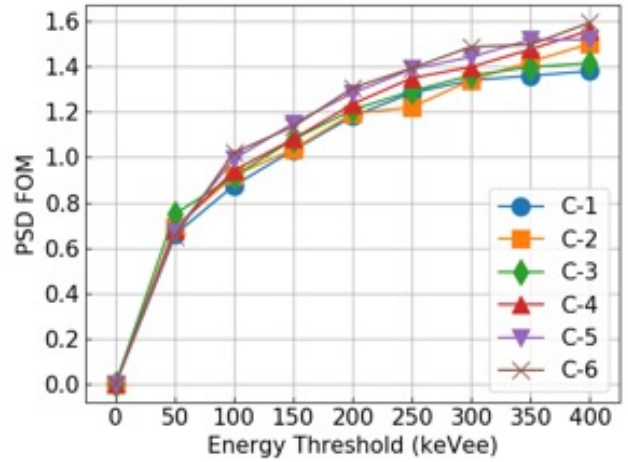
$$FOM_x = \frac{\mu_{i+1} - \mu_i}{2.355(\sigma_{i+1} + \sigma_i)}$$

PSD FOM evaluated by

$$FOM_{PSD} = \frac{\mu_n - \mu_\gamma}{2.355(\sigma_n + \sigma_\gamma)}$$



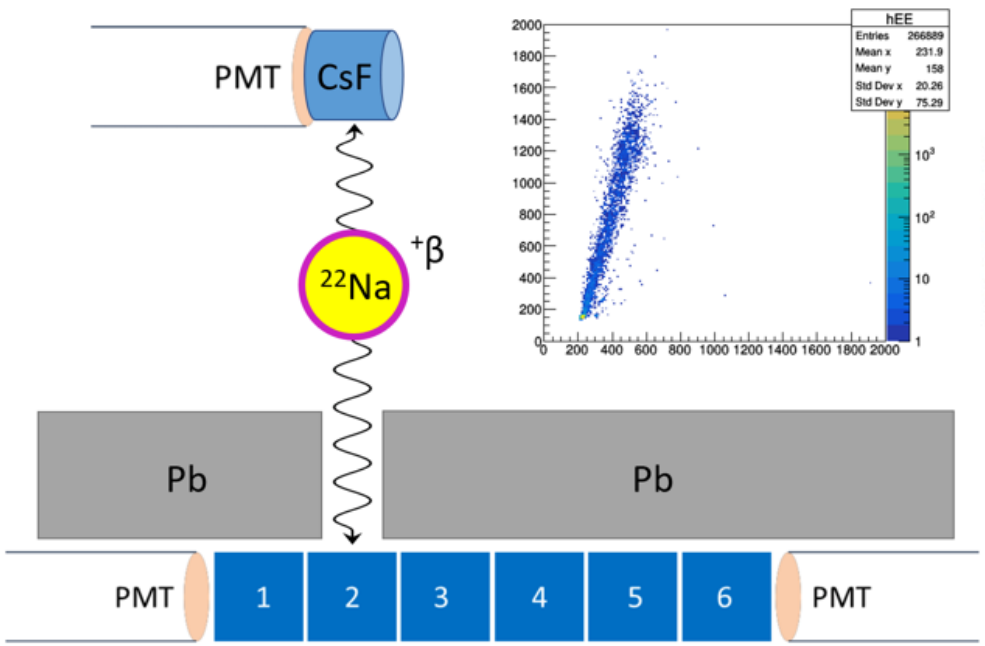
# Detector Characterization

Timing resolution is also important

- Detected coincident 511 keV $\gamma$-rays from $^{22}$Na with a fast CsF + pseudo-bar in both detector PMTs
- Analogue DAQ with QDC and TDC
- CsF timing resolution was determined simultaneously

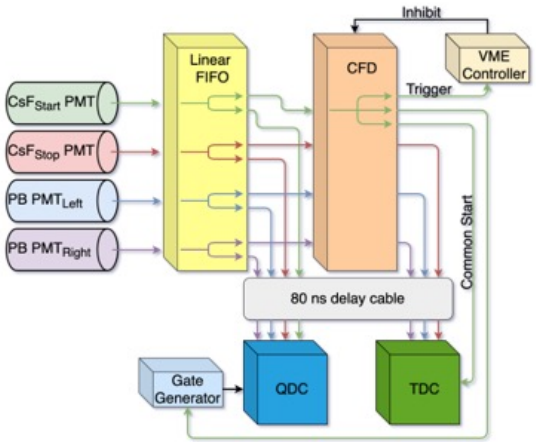
$$\sigma_{Avg} = (\Sigma_i w_i)^{-1/2} = \sqrt{\frac{\sigma_L^2 \sigma_R^2}{\sigma_L^2 + \sigma_R^2}}$$

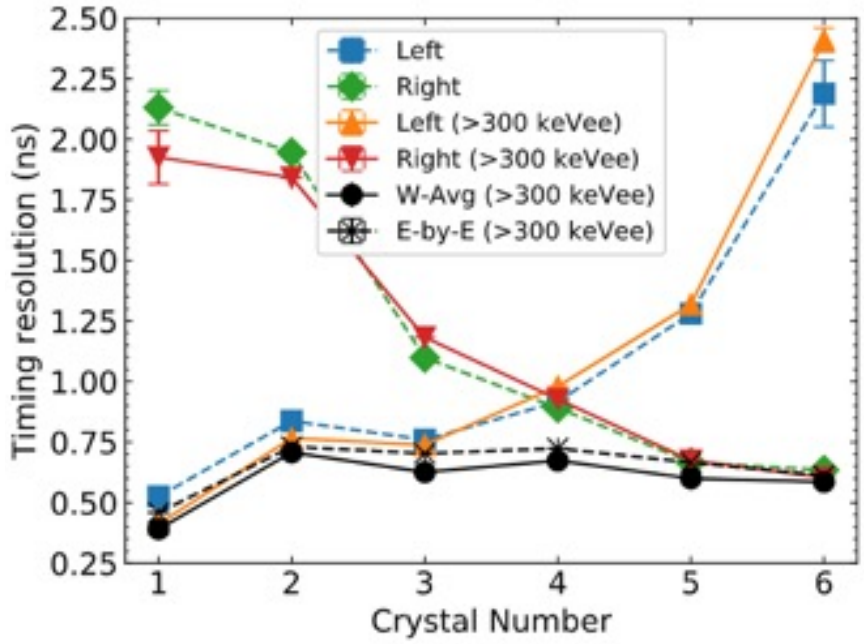
$$t_{E-by-E} = \frac{t_L \sigma_L^{-2} + t_R \sigma_R^{-2}}{\sigma_L^{-2} + \sigma_R^{-2}}$$



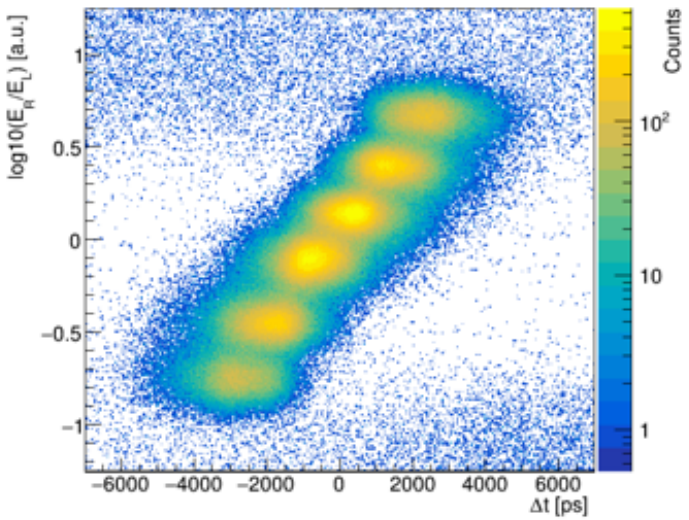


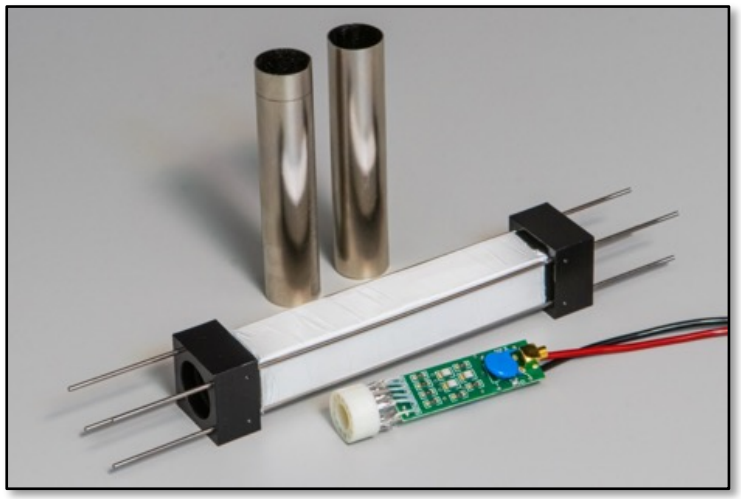


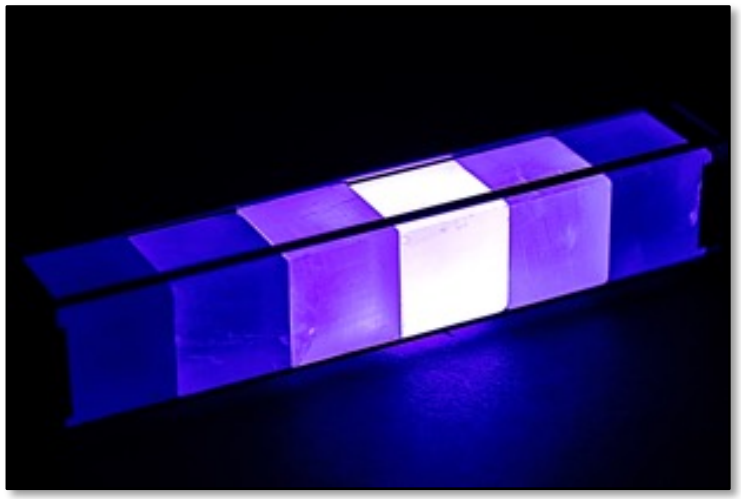


# 6-crystal Pseudo-bar



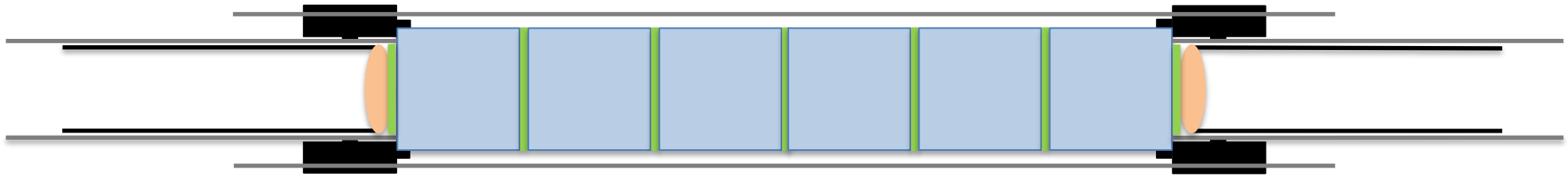





Characterization results were published in NIM

Pseudo-bar design was expanded upon…

- 2x2x2 $cm^3$ cubic crystals and EJ-550 -> EJ-560
- Modular construction with, $\mu$-metal shields,16-gauge hypodermic needle tubing truss rods, and Delrin endcaps

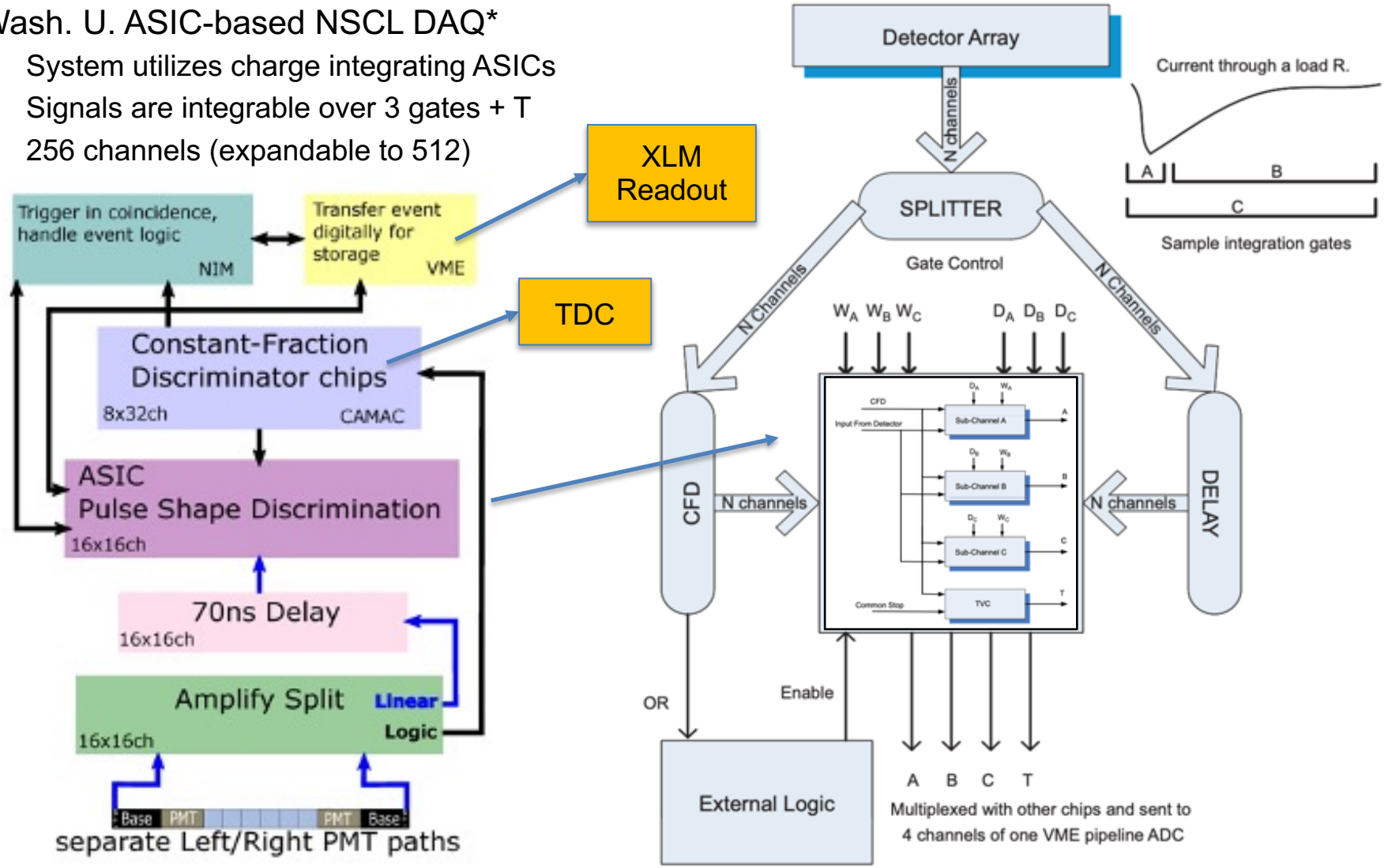


D.P. Scriven et al., Nucl. Instrum. Methods A 1010, 165492 (2021)

# Data Acquisition System

Wash. U. ASIC-based NSCL DAQ*

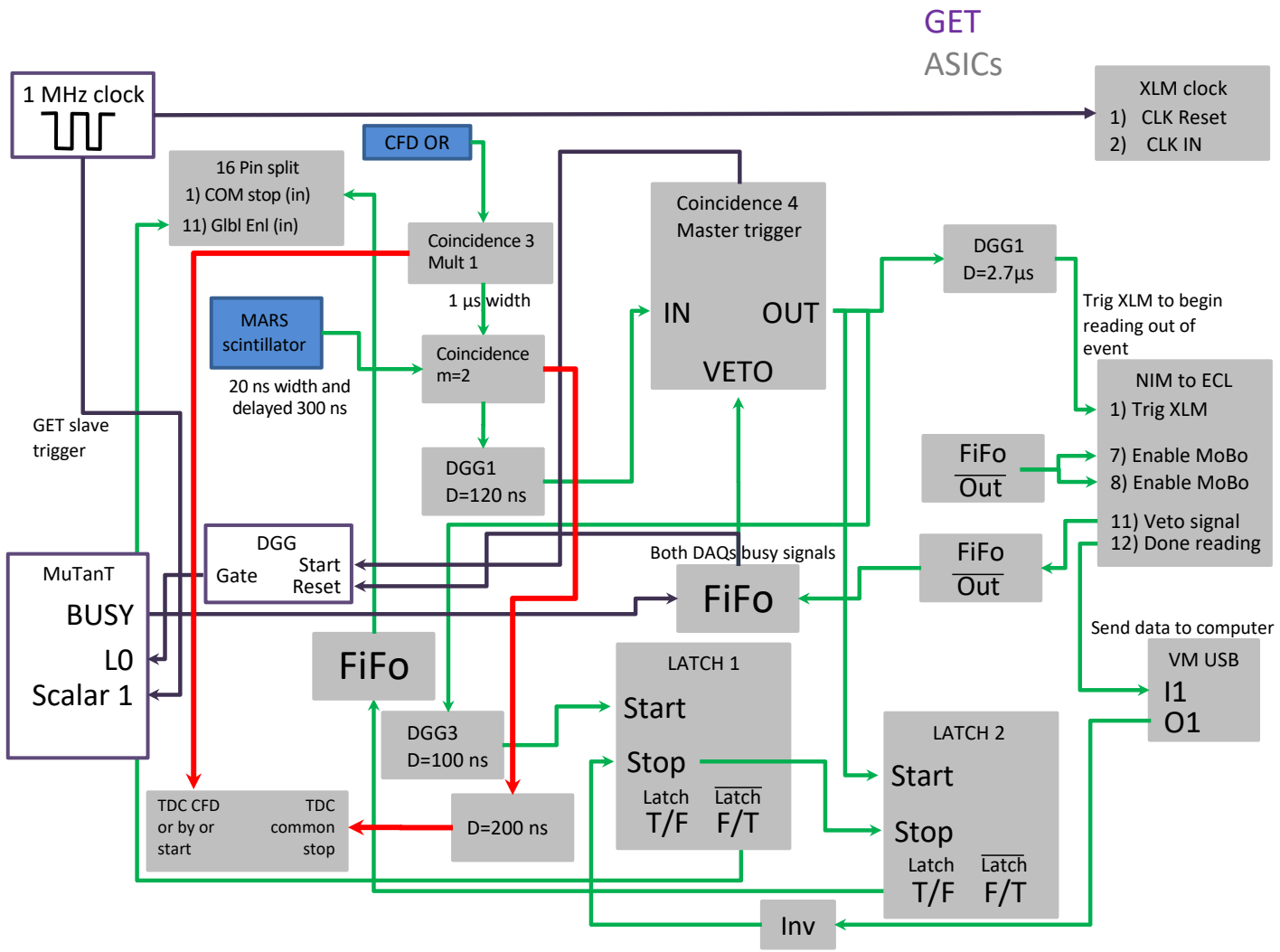
- System utilizes charge integrating ASICs
- Signals are integrable over 3 gates + T
- 256 channels (expandable to 512)



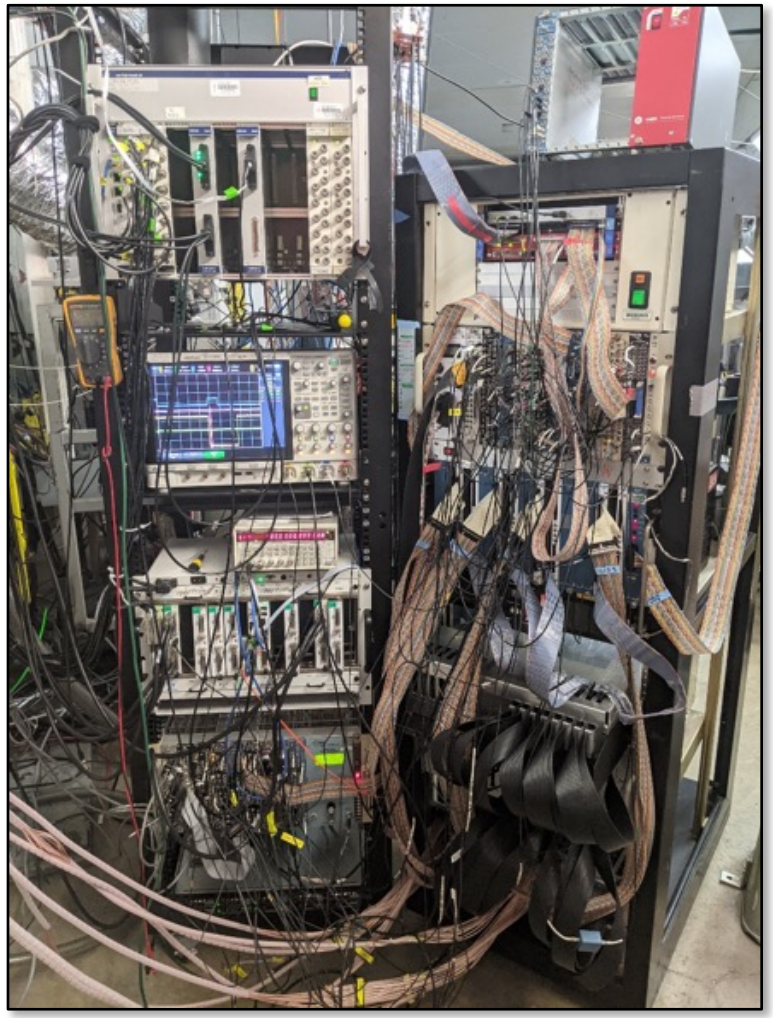



G.L. Engel et al, NIMA **612**, 161-170 (2009).

# Data Acquisition System



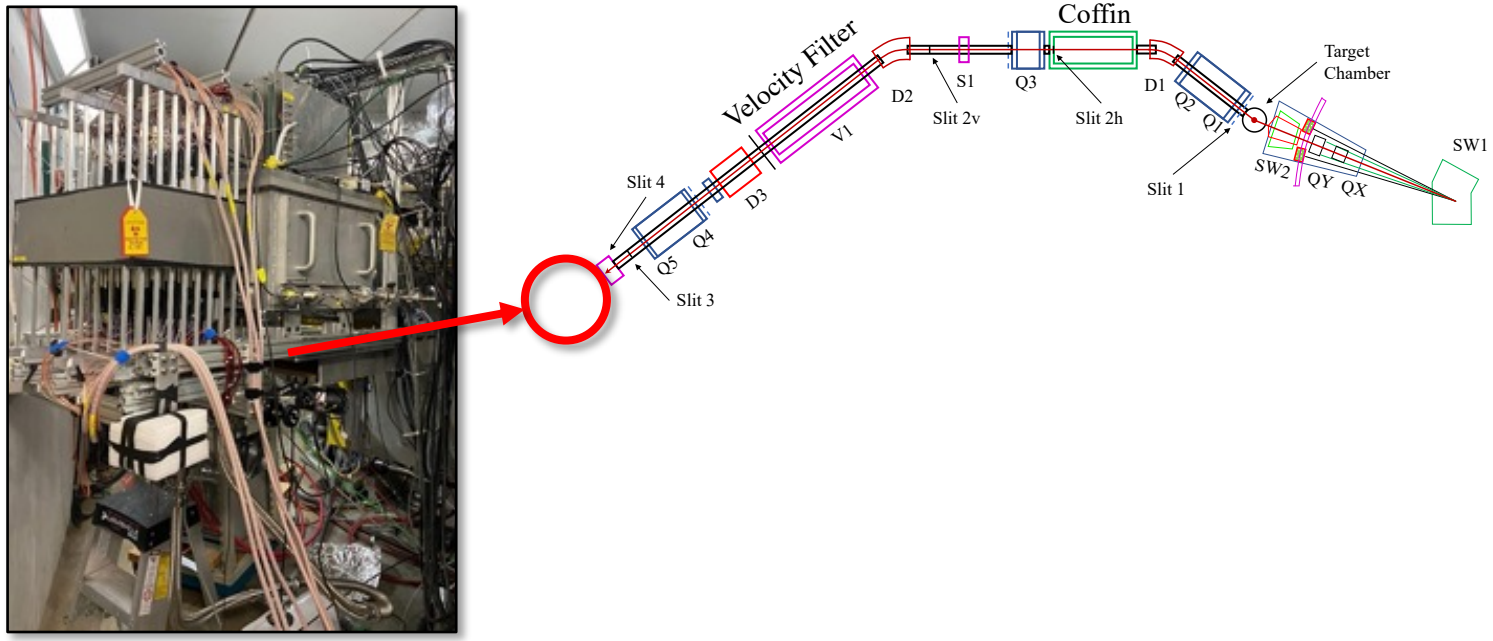

Successfully coupled the data streams for two separate DAQs

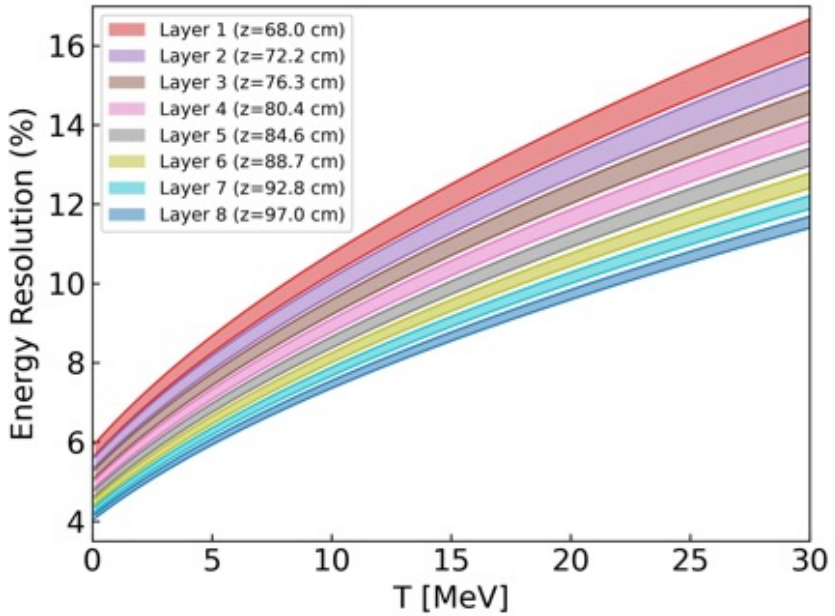


# Experiment

The same $^{7}$Li primary beam from the K150 allowed us to study the following reactions by changing the contents of TexAT and/or the MARS* production target:

- $^{7}$Li(p,n) on a thin solid $CH_2$ target and isobutane TTIK mode
- $^{6}$He(p,n) with isobutane in TTIK mode (future G.S.)
- $^{9}$Li(p,n) with both isobutane and $CO_2$ in TTIK mode (future G.S.)



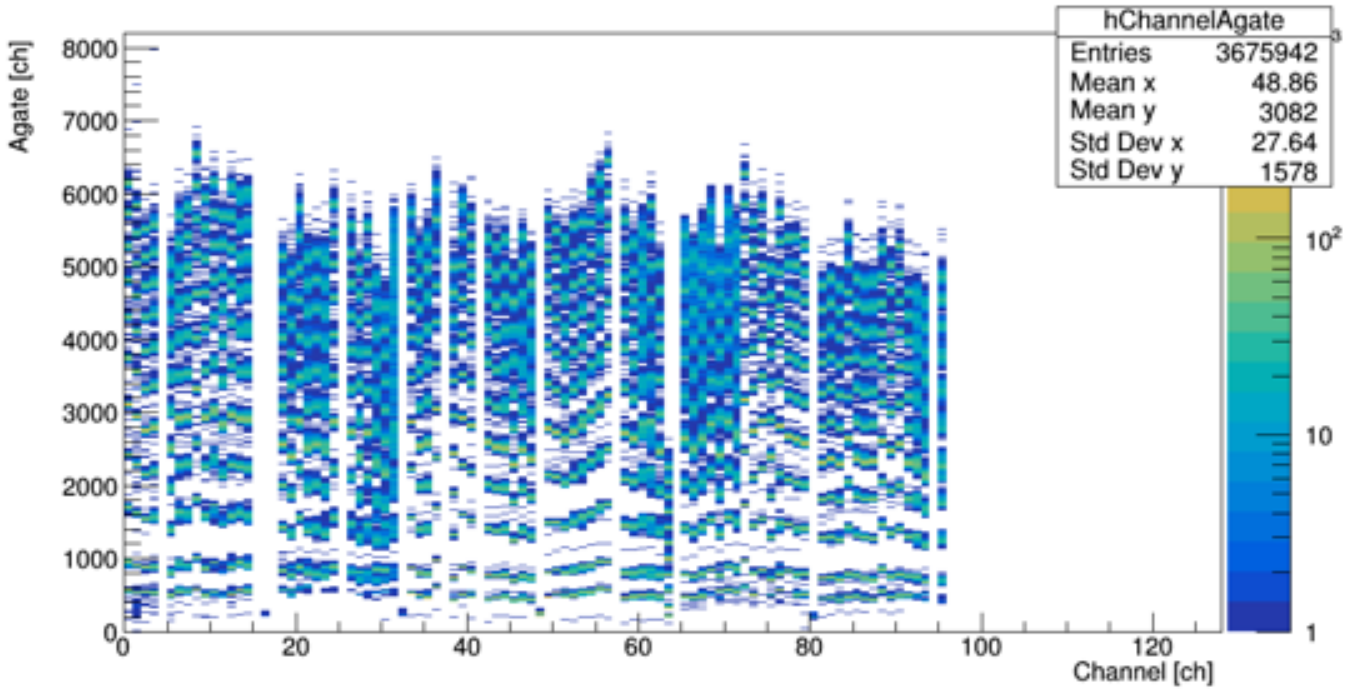



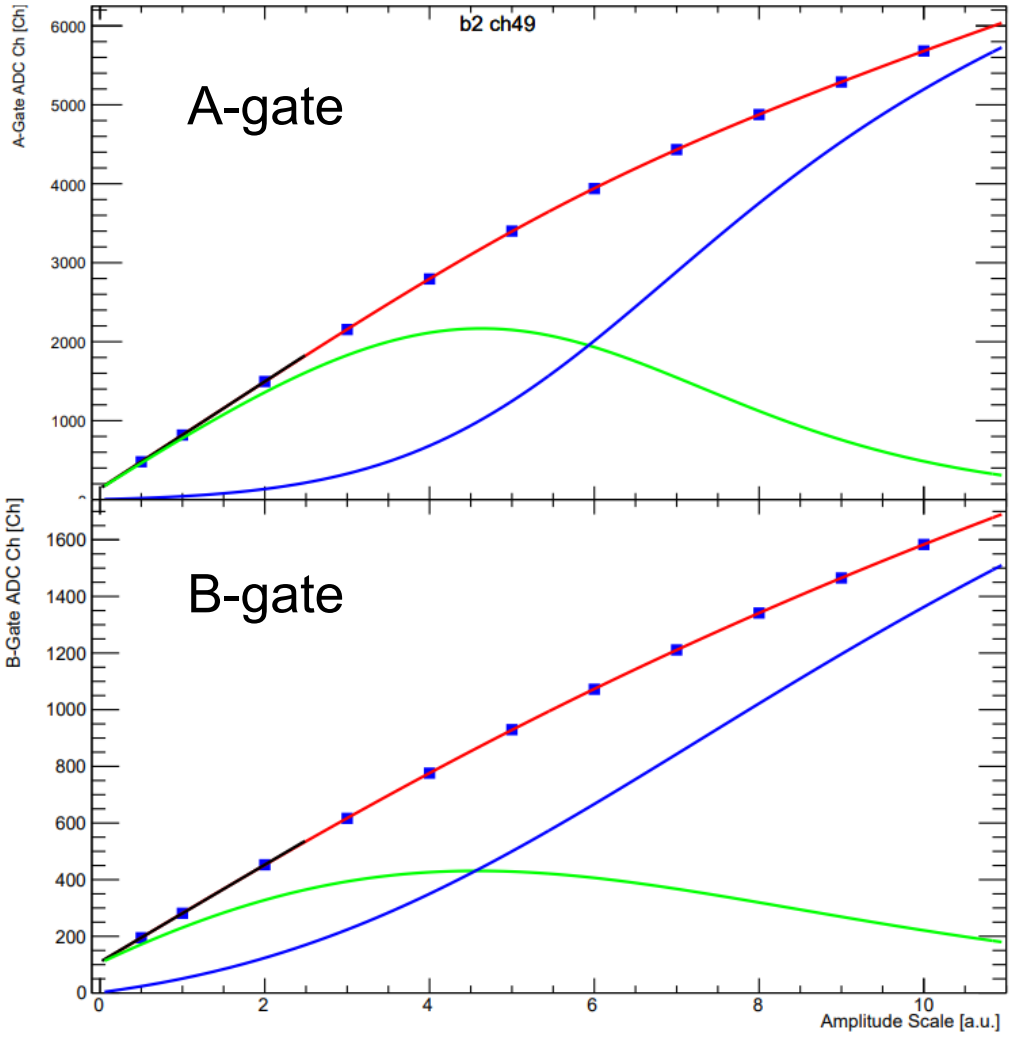

Momentum Achromat Recoil Separator
[R.E. Tribble, et al., NIMA **185** (1989).]

# Calibrations

DAQ characterization was performed using a pulser

- The ASIC chips exhibit a compressive non-linear response in A, B, C gates
- Response is near linear in the low range
- Used to set offsets for both integration gates



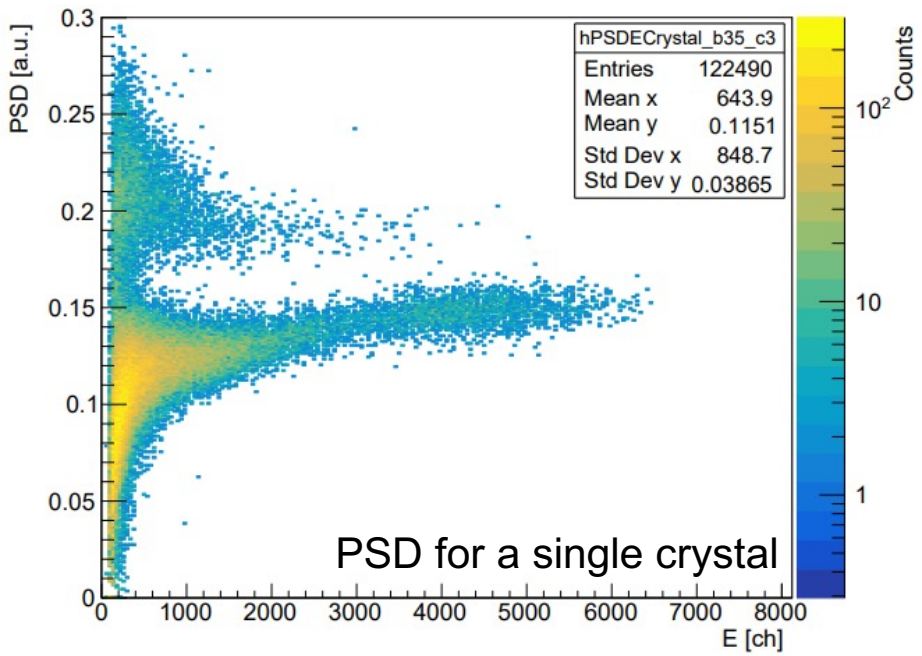



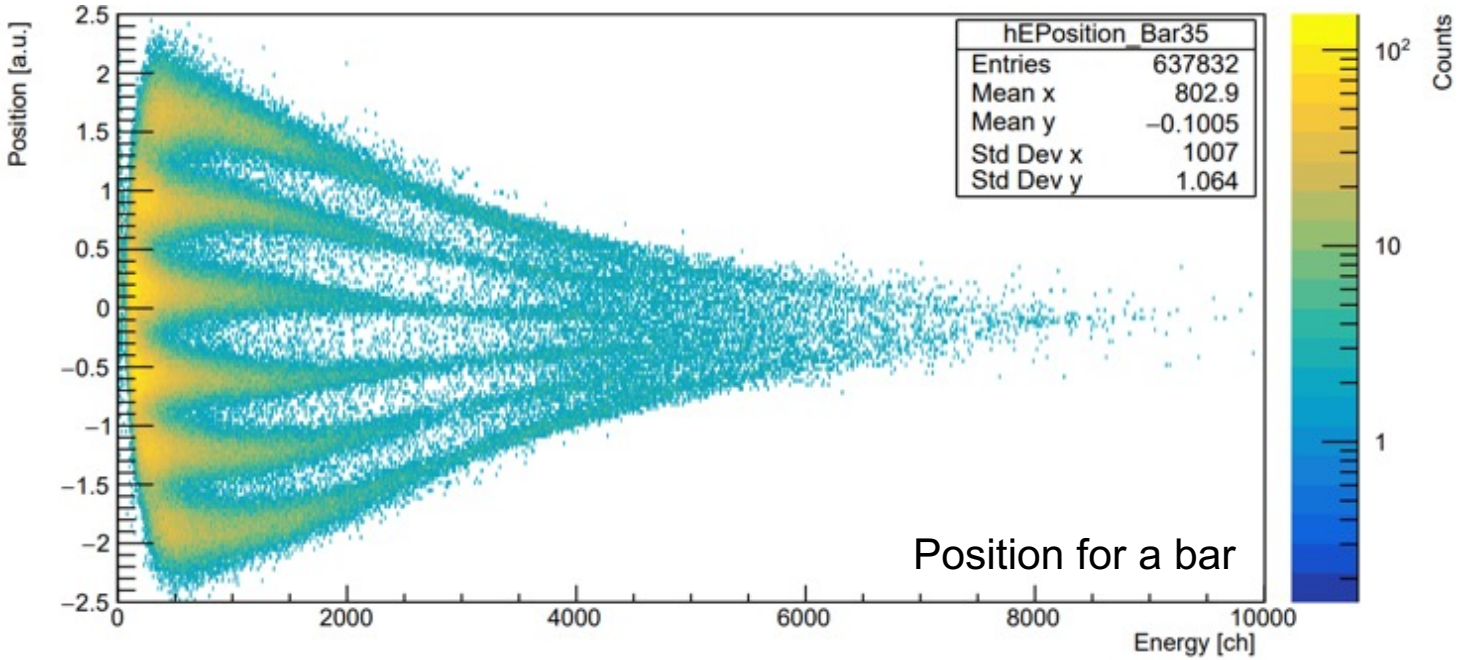
# Calibrations

$^{252}Cf$ used to verify the ASIC system and place position and PSD cuts

Position cuts are made on every bar

PSD cuts are made on every crystal

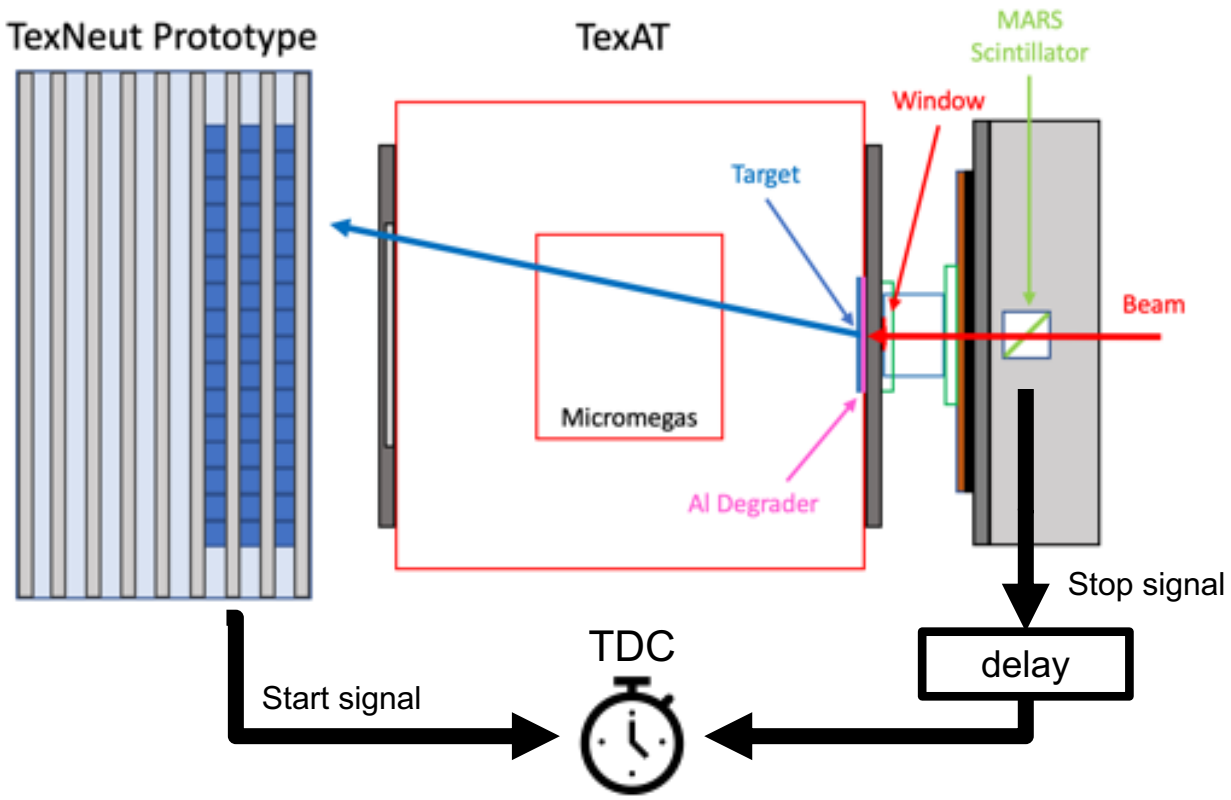


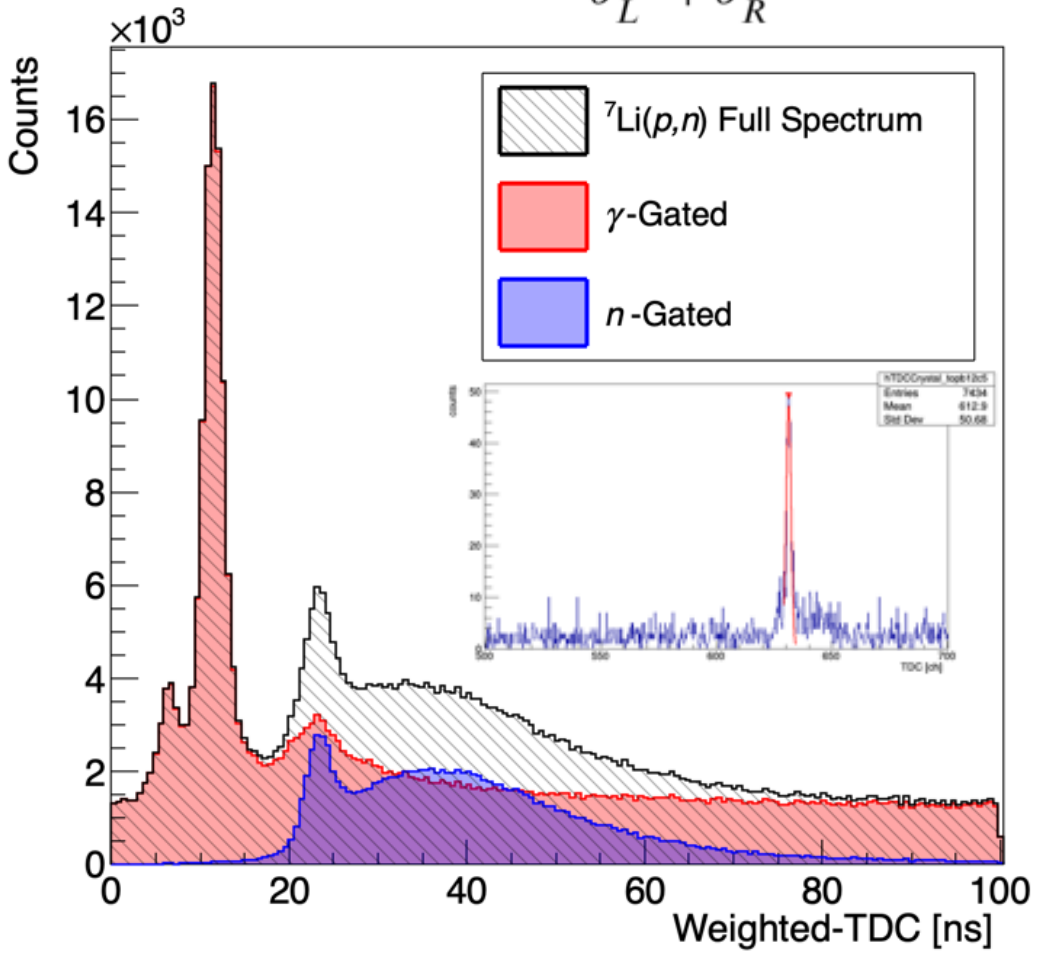
# Experiment

Time is calibrated for every crystal and PMT individually (576)

$$offset = d_{flange}/c - d_{scint-target}/v_{ion}$$




$$t_{E-by-E} = \frac{t_L\sigma_L^{-2} + t_R\sigma_R^{-2}}{\sigma_L^{-2} + \sigma_R^{-2}}$$

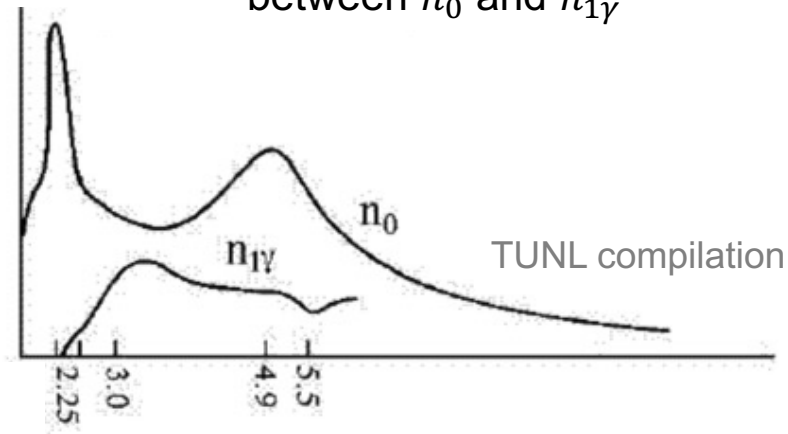


# Experiment

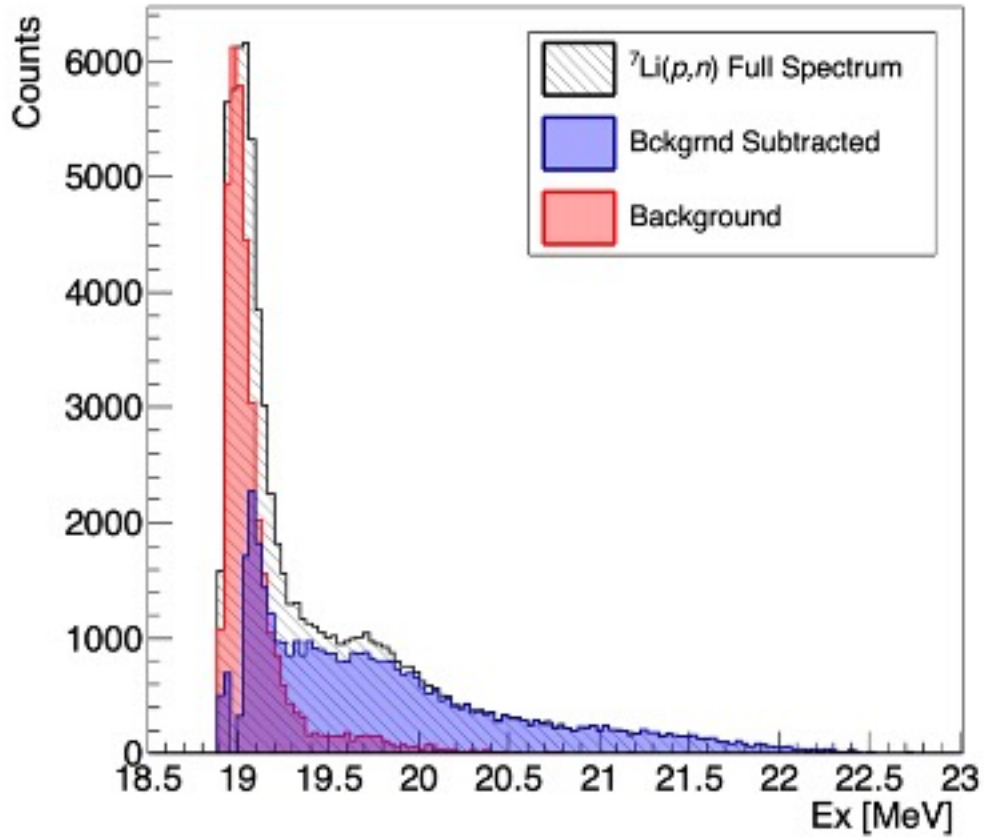
$$p_{beam} = \frac{8p_n^2 + 2m_{7Be} * 1.644\ MeV}{2p_n \cos(\theta_n)}$$

$$Ex = \frac{p_{beam}^2}{2m_{7Li}} * \frac{m_p}{m_{7Li} + m_p} + 17.2544\ MeV$$

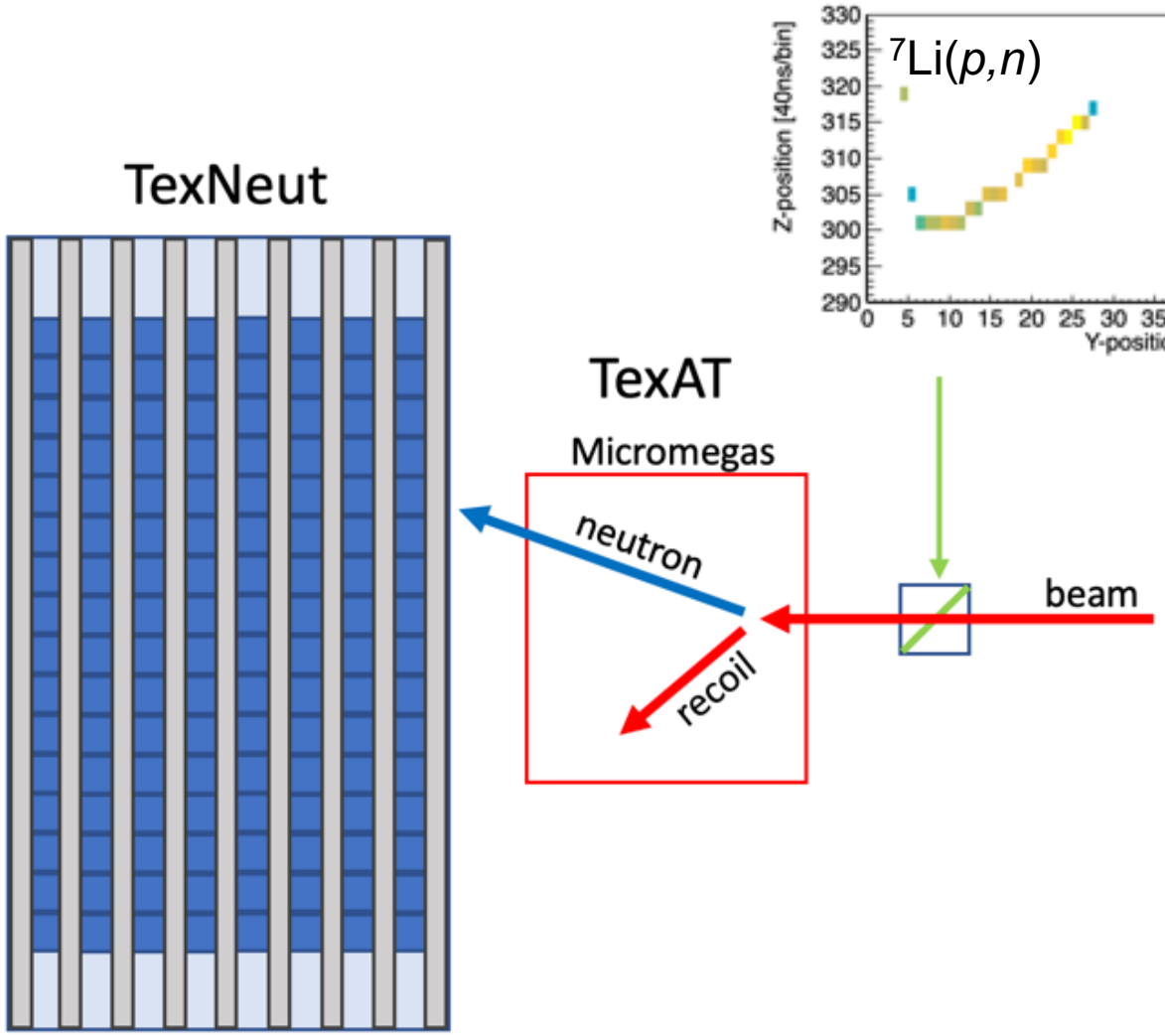
- We are not sensitive to selection between $n_0$ and $n_{1\gamma}$



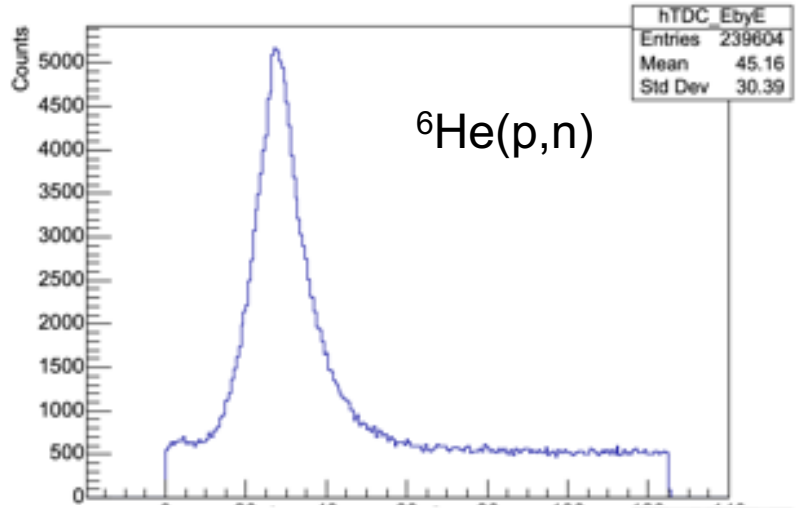

TUNL compilation for $^{8}$Be

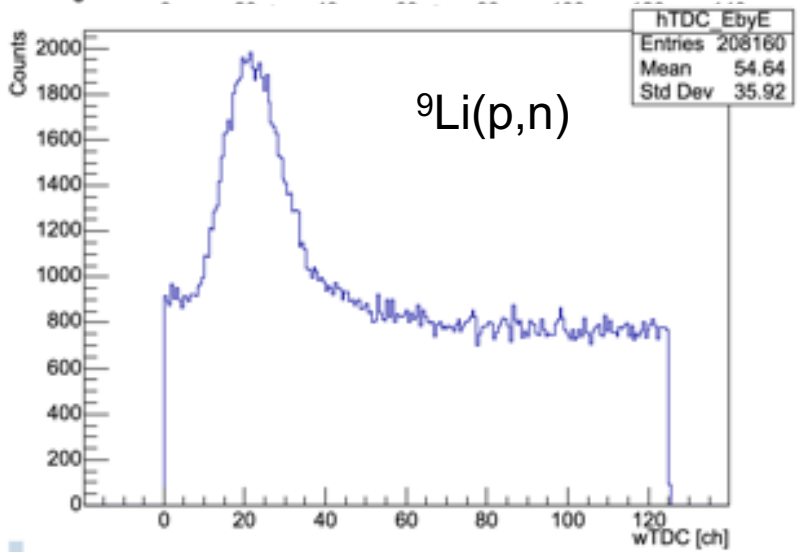


# Experiment


TexNeut
TexAT
Micromegas
neutron
recoil
beam


$^{7}$Li(p,n)
Z-position [40ns/bin]
Y-position [ch]
Energy [a.u.]


$^{6}$He(p,n)
hTDC_EbyE
Entries 239604
Mean 45.16
Std Dev 30.39
Counts

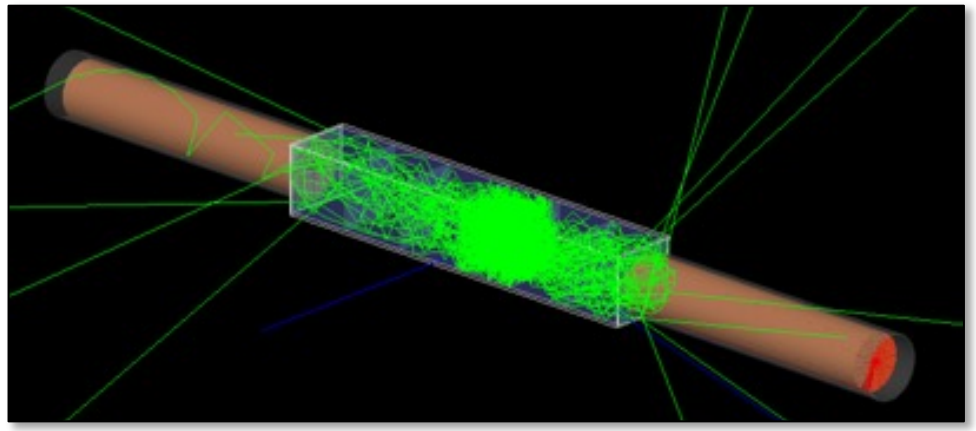

$^{9}$Li(p,n)
hTDC_EbyE
Entries 208160
Mean 54.64
Std Dev 35.92
Counts
wTDC [ch]

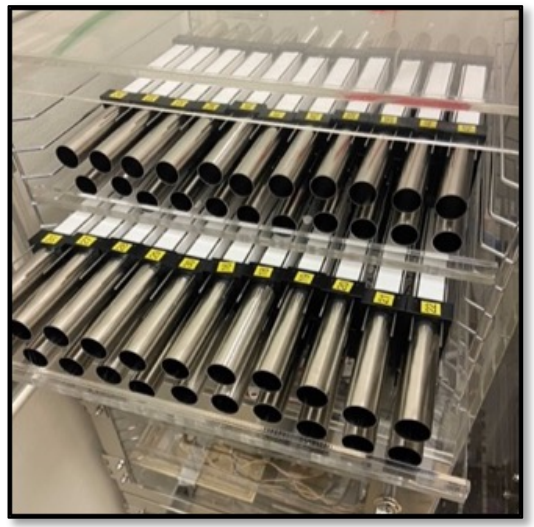
# TexNeut Future

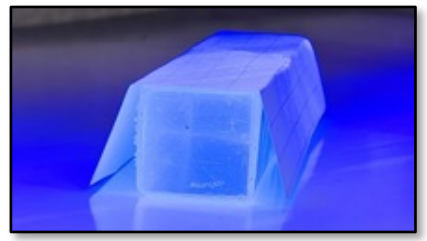
- Optimize optics/understanding of light partitioning w/ optical simulation
- Use ASIC PSD_T chip timing
- Add SiPMs to reduce position threshold
- Upgrade/Expand the system with *Organic Glass Scintillator* from Sandia after OGS characterization
- Si+Si telescope replacement in TexAT

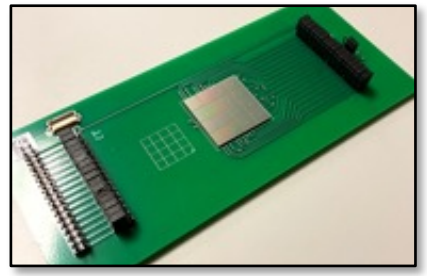
TexAT + TexNeut:

- Continue analysis of $^{6}$He(p,n) to benchmark
- $^{9}$Li(p,p), $^{9}$Li(p,n) – structure of $^{10}$Li through IAS in $^{10}$Be $^{12}$Be(p,n) (IAS of $^{13}$Be) to compliment previous $^{12}$Be(p,p) measurement









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- **Bryan Orabutt (GS)**
- Anthony Lloyd (UG→Sandia)
- Anthony Thomas

**CENTAUR-affiliated researchers**

# Thank you for your attention!

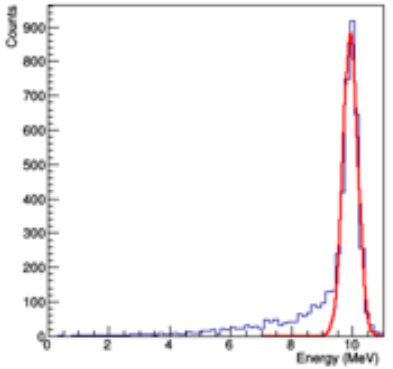
# Backup Slides

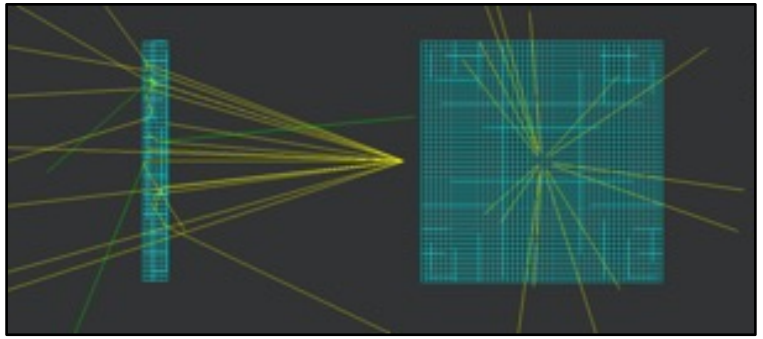
# Simulation

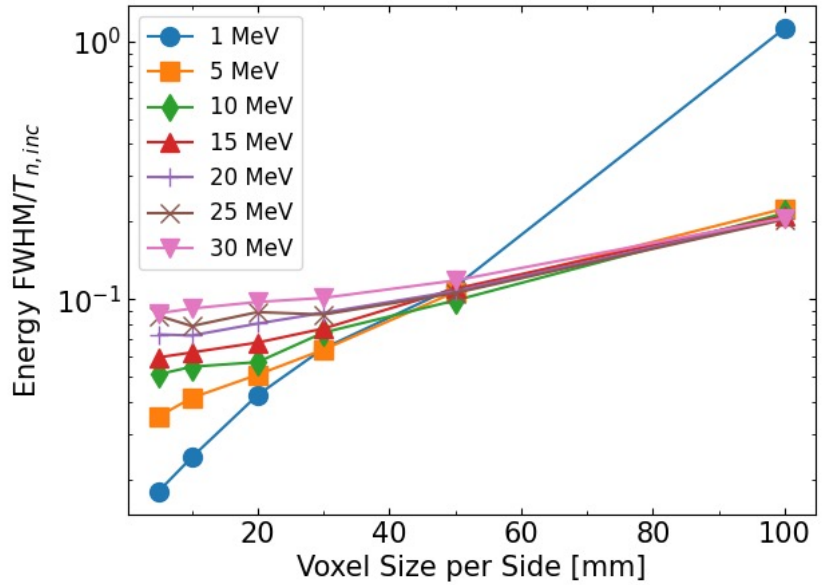
Simulated mono-energetic neutrons incident on 1x1x0.1 $m^3$ array in Geant4 with 1 m flight path

- Included `MENATE_R`* *n*-scattering cross sections
- Scintillator crystal size 5-100 mm
- Neutron energies 1-30 MeV
- Extracted FWHM and angular reconstruction

| $T_{n,initial}$ (MeV) | 1 | 5 | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|---|
| Voxel Size (mm) | 5 | 10 | 20 | 30 | 50 | 100 | |
| $1\sigma$ Timing (ps) | 0 | 100 | 200 | 500 | 1000 | | |






Results indicate that 2x2x2 $cm^3$ crystals yield good $T_n$ reconstruction

- resolution of ~100s keVs
- angular resolution less than 1°

*B. Roeder, EURISOL Design Study, Report: [10-25-2008-006-In-beamvalidations.pdf, pp 31-44] (2008).

# Readout Schemes

Wavelength shifting slabs

- To optically multiplex crystals using EJ-282 WLS
- Specular film + Teflon wrap
- Coupled to Hamamatsu R1450 PMTs