INSTITUTO GALEGO DE FÍSICA DE ALTAS ENERXÍAS

FRIB

Study of the full electric dipole strength of the double-halo nucleus ^{11}Li using proton inelastic scattering

Jose Manuel López González

26/05/25

USC

XUNTA DE GALICIA

Rede CIGUS
Centros de investigación do Sistema Universitario de Galicia

Cofinanciado pola Unión Europea

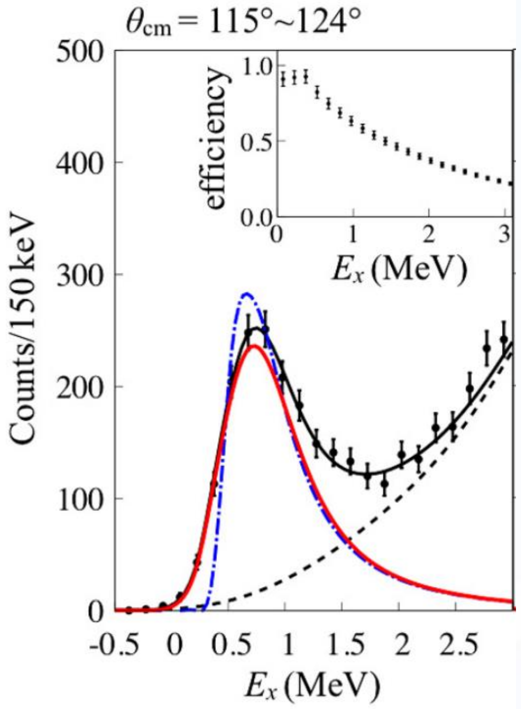
Fondos Europeos

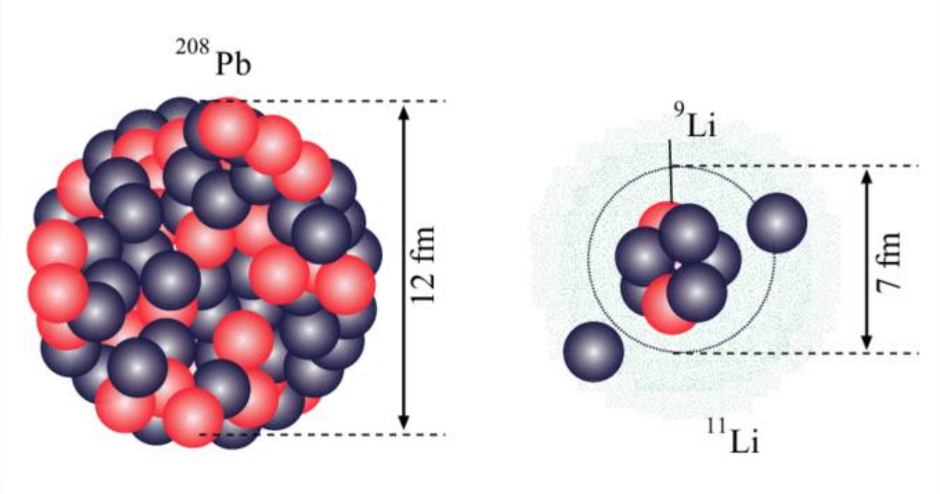
Physics case: Dipole response of ^{11}Li

The electric dipole polarizability of a nucleus is given by:

$$\alpha_D = \frac{8\pi}{9} \int \frac{dB(E1)}{\omega}$$

Only a small amount of the full E1 strength has been measured so far.





^{11}Li has a very weakly bound double-neutron halo:

$S_{2n} = 0.369$ MeV

It is a bound nuclei due to the pairing interaction between the 2 neutrons in its halo.

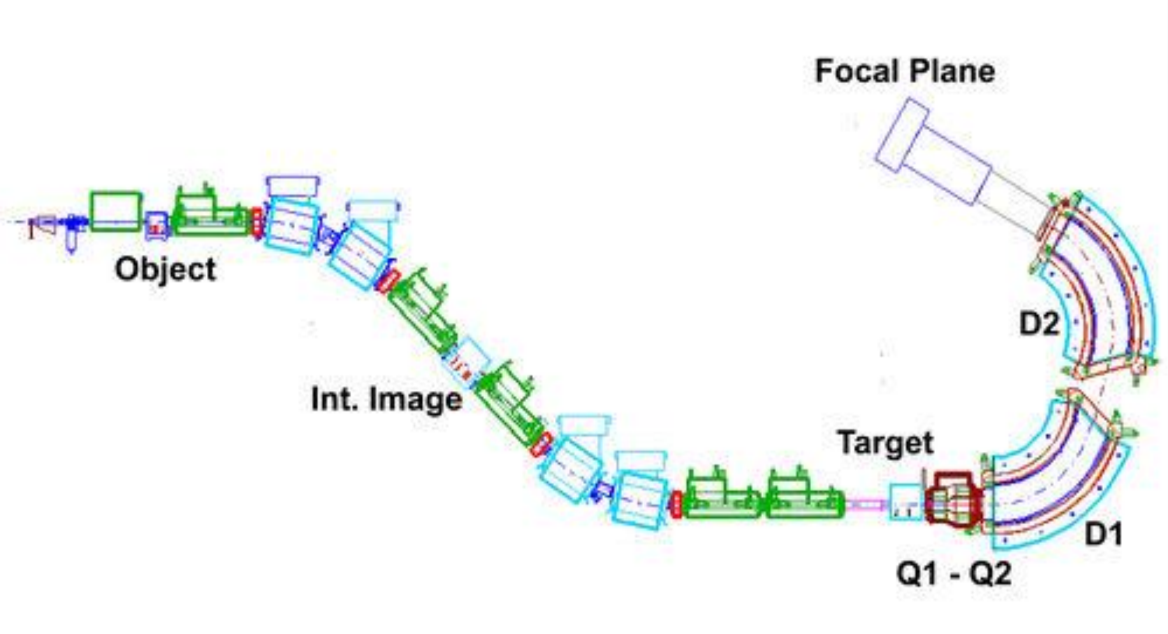
This makes 11Li a great test nucleus for the effect of the pairing interaction on the electric dipole properties of nuclei.

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

J. Tanaka et al Phys. Lett. B 774 (2017) 268–272

Experimental details

The S800 spectrograph beamline at FRIB [1]



Beam: 1E+4 pps, ~53.4 MeV/u, ^{11}Li beam

Target: AT-TPC filled with:

A) H_2@600Torr

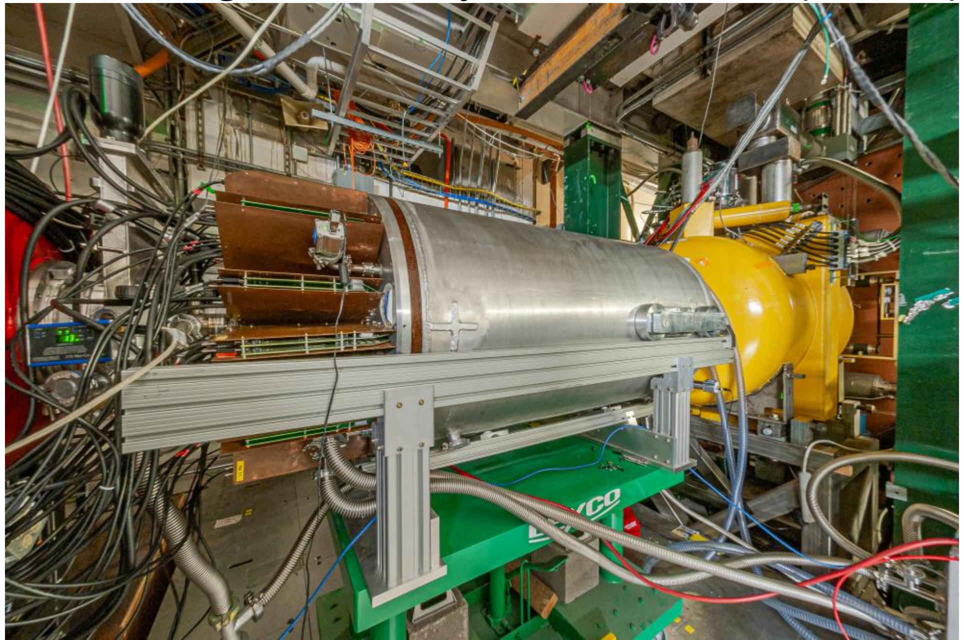
B) 90%H_2+10%CF_4@700Torr

Reaction to study: $^{11}Li + p \rightarrow {}^{11}Li^* + p' \rightarrow X + p'$

X could be:

- $^{9}Li + 2n$
- $^{8}Li + 3n$
- $^{7}Li + 4n$
- $^{4}He + 6n + p$

The Active Target Time Projection Chamber (AT-TPC) [2]

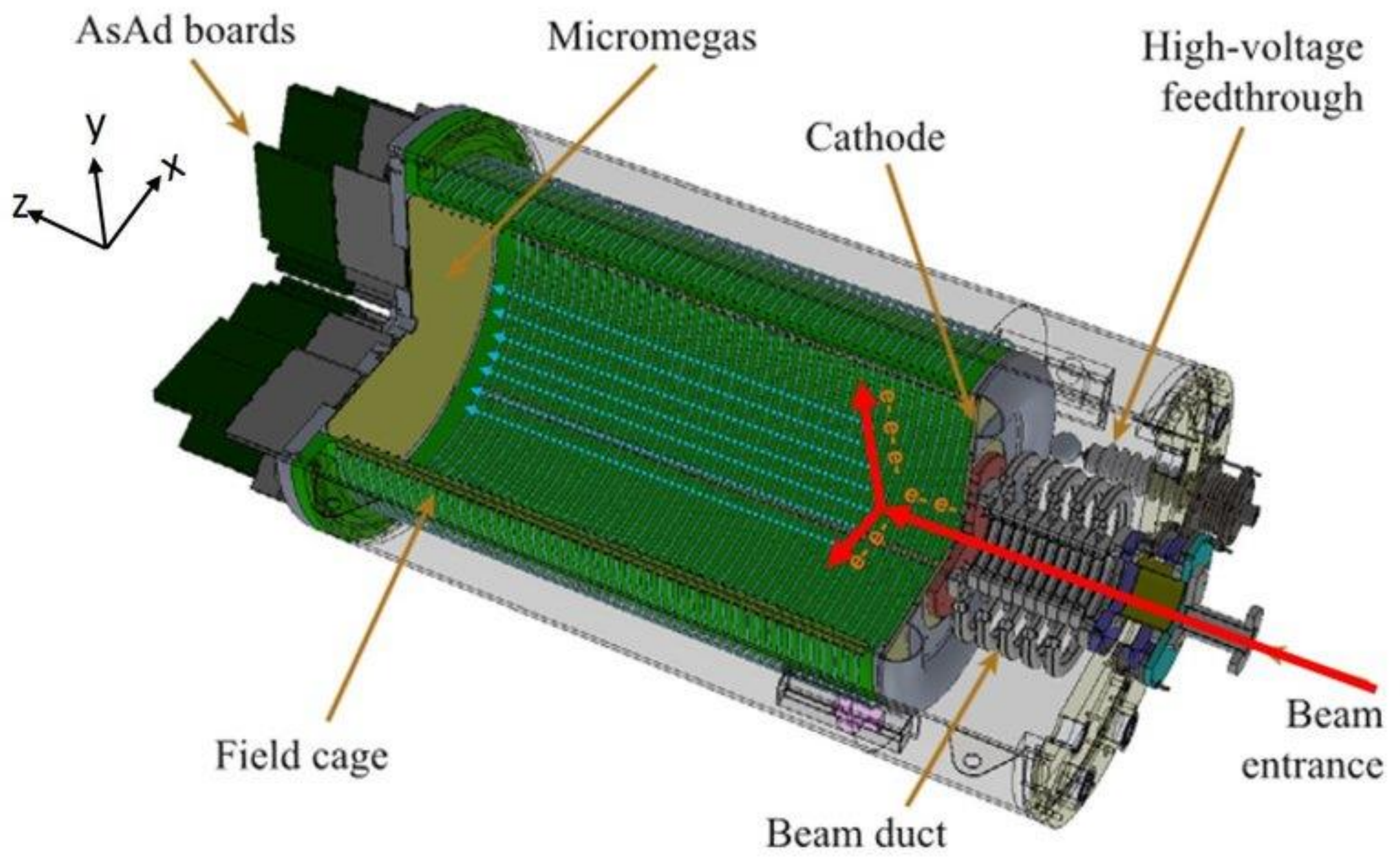


Sources: [1] https://wikihost.frib.msu.edu/S800Doc/doku.php

[2] https://people.frib.msu.edu/~noji/pictures

Experimental details: The AT-TPC

Reaction to study: $^{11}Li + p \rightarrow {}^{11}Li^* + p' \rightarrow X + p'$



The AT-TPC is used for the tracking of the scattered proton.

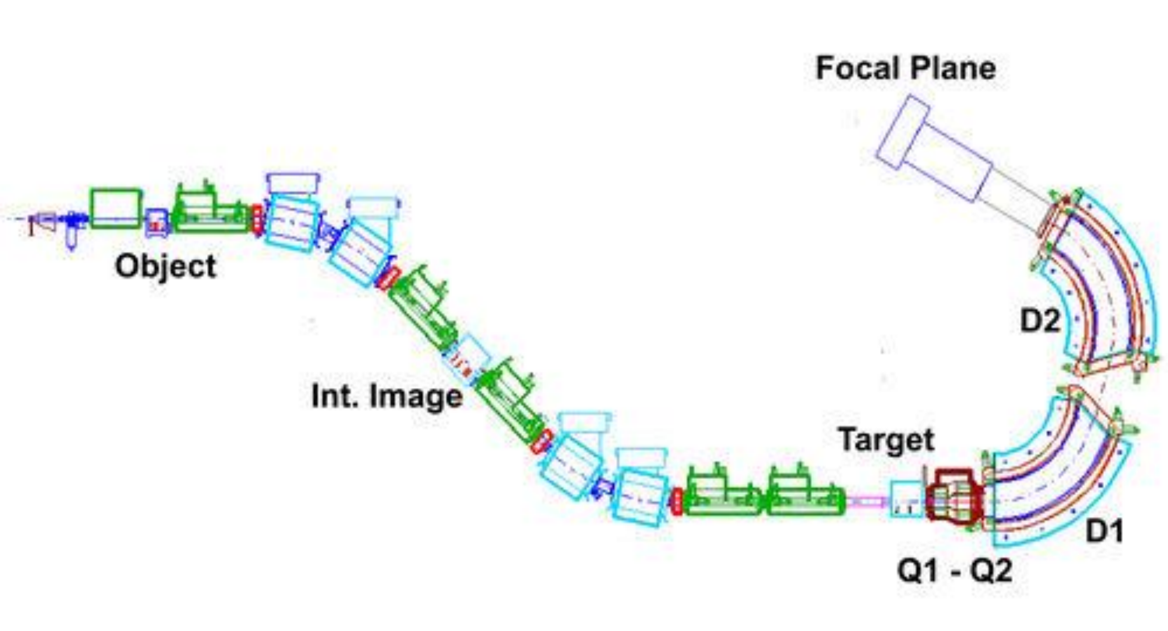
After AT-TPC analysis, the kinetic energy and scattering angle of the proton are obtained.

By using the missing mass technique, the excitation energy given to the 11Li nucleus is measured in inverse kinematics.

Source: J.S. Randhawa et al. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 948, 21 December 2019, 162830

Experimental details: The S800 spectrograph

The S800 spectrograph beamline at FRIB



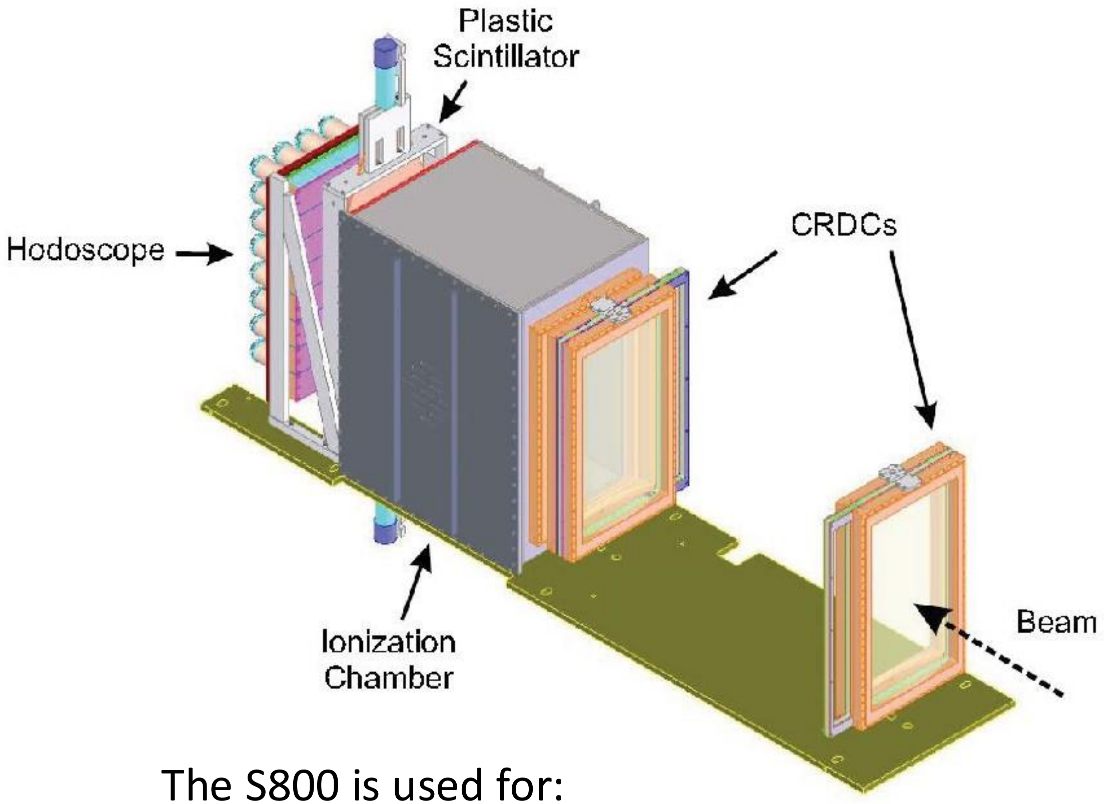
Different Bρ settings:

Bρ = 3.21060 Tm for ^{9}Li   Bρ = 2.84723 Tm for ^{8}Li

Bρ = 2.49012 Tm for ^{7}Li   Bρ = 2.11285 Tm for ^{4}He

Source: https://wikihost.frib.msu.edu/S800Doc/doku.php

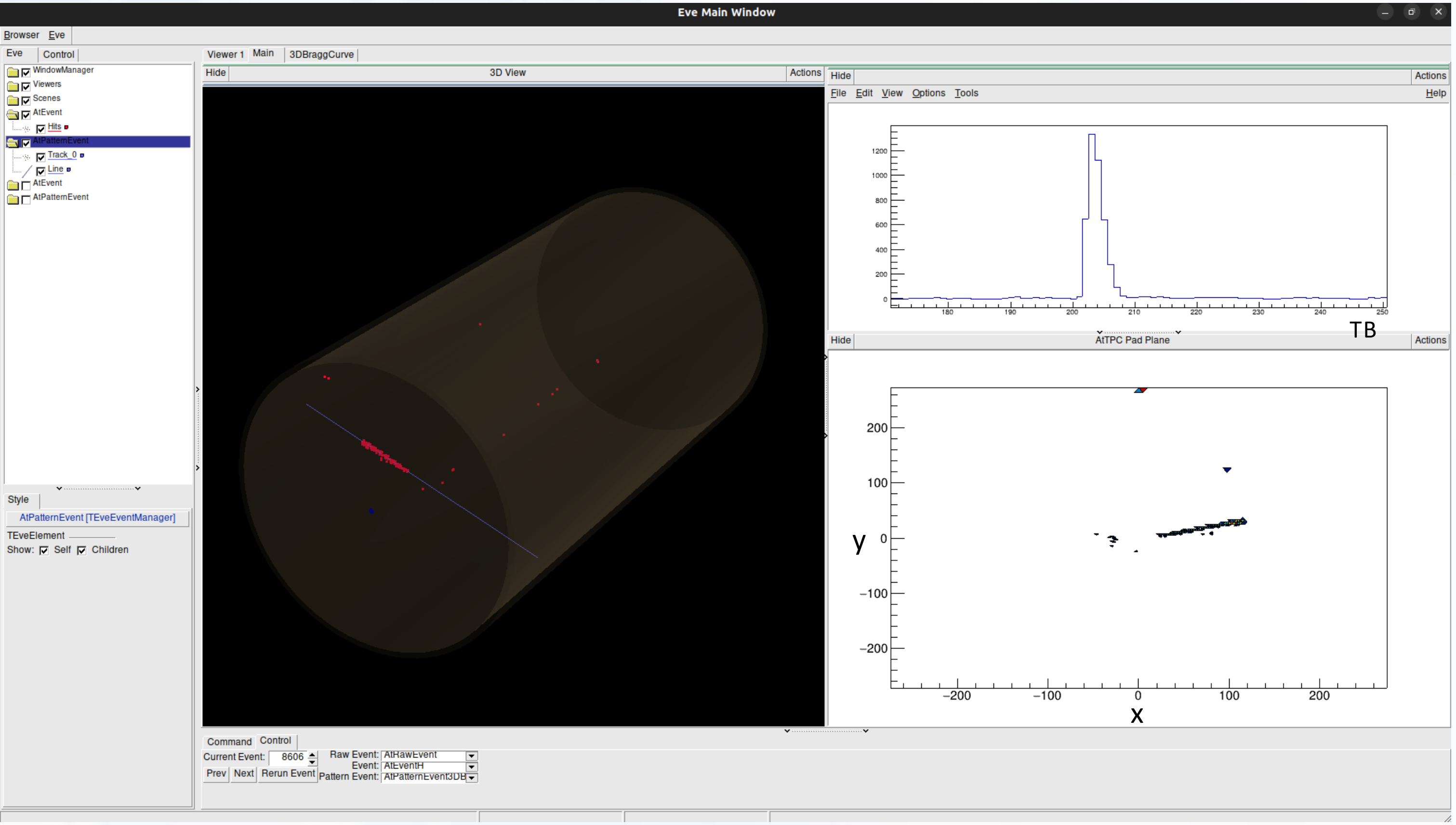
Reaction to study: ^{11}Li + p → ^{11}Li* + p' → X + p'



The S800 is used for:

1. Trigger
2. Beam PID
3. ^{11}Li* decay product PID

Analysis: ATTPCROOTv2



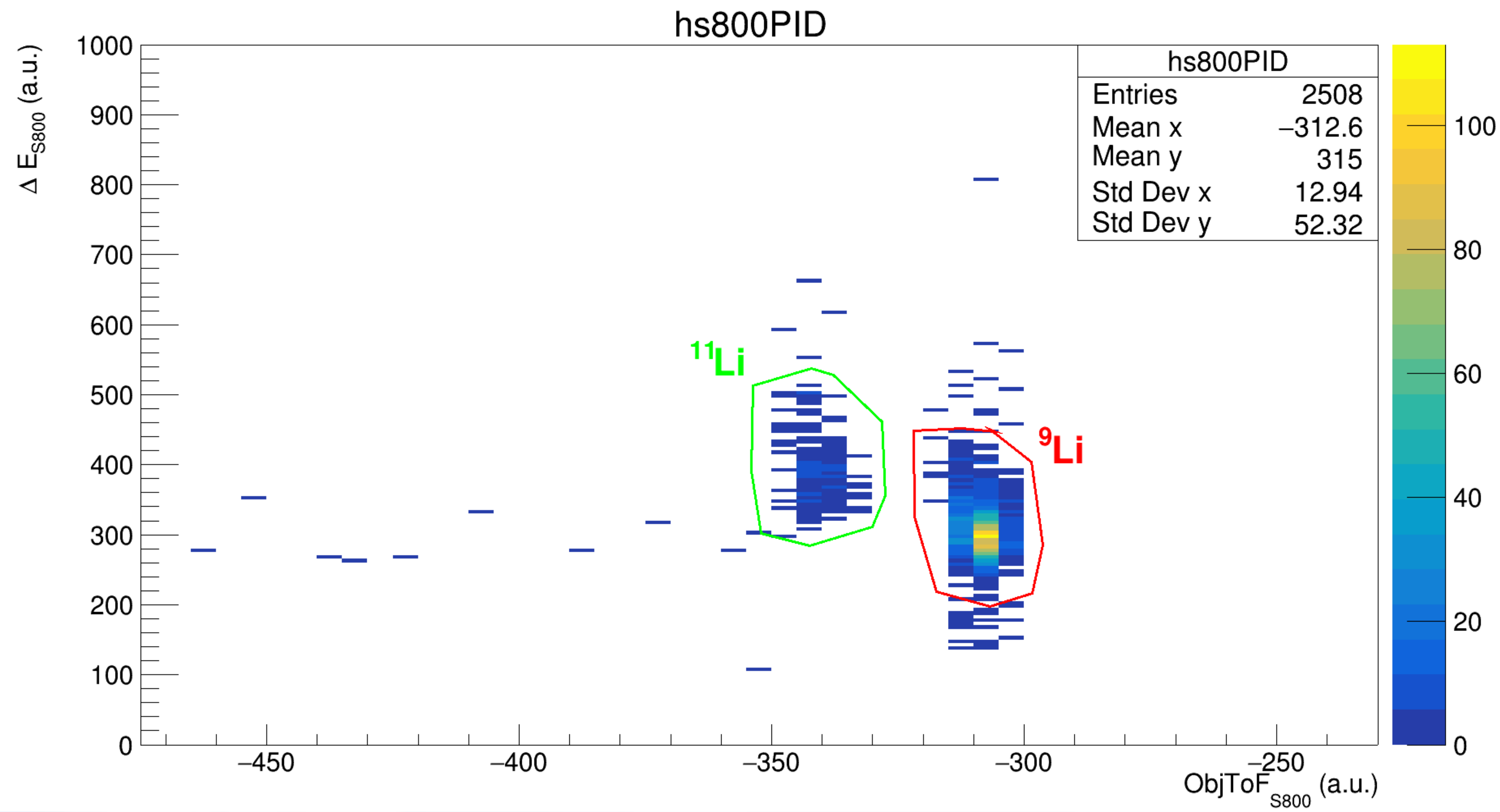
<u>Analysis phases</u>:

1. Unpacking of AT-TPC data.
2. Merging of S800 and AT-TPC data.
3. Pulse Shape Analysis (PSA).
4. Random Sample Consensus (RANSAC).
5. Use of SRIM energy loss tables to obtain the proton kinetic energy.

Source: Adam Anthony, Yassid Ayyad et al (2025). ATTPCROOTv2. Zenodo. https://doi.org/10.5281/zenodo.10113377

Preliminary results: ^{11}Li Pygmy Dipole Resonance

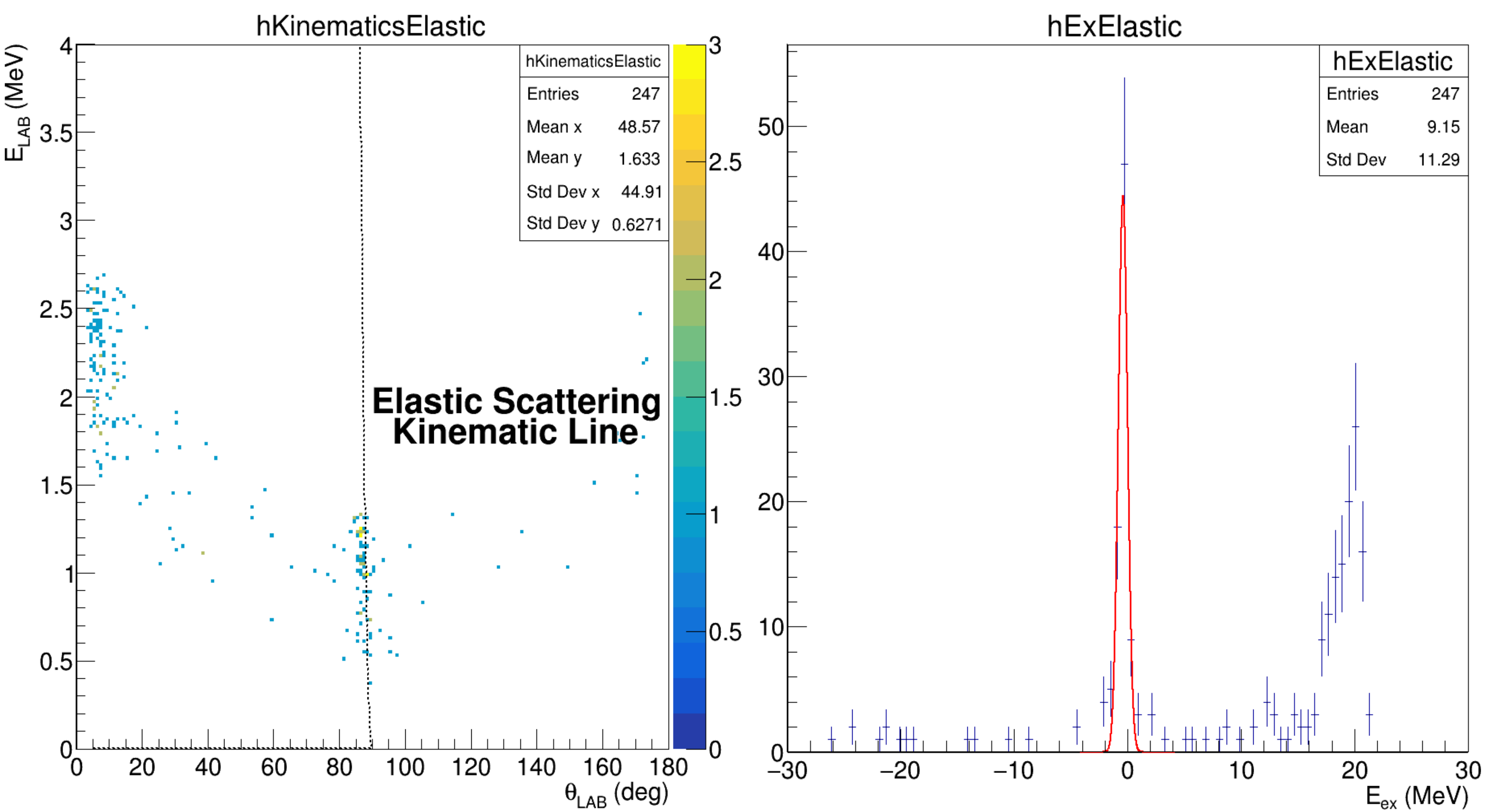
S800 centered on ^{9}Li. AT-TPC filled with H_2@600Torr



Preliminary results: ^{11}Li Pygmy Dipole Resonance

S800 centered on ^{9}Li. AT-TPC filled with H_2@600Torr

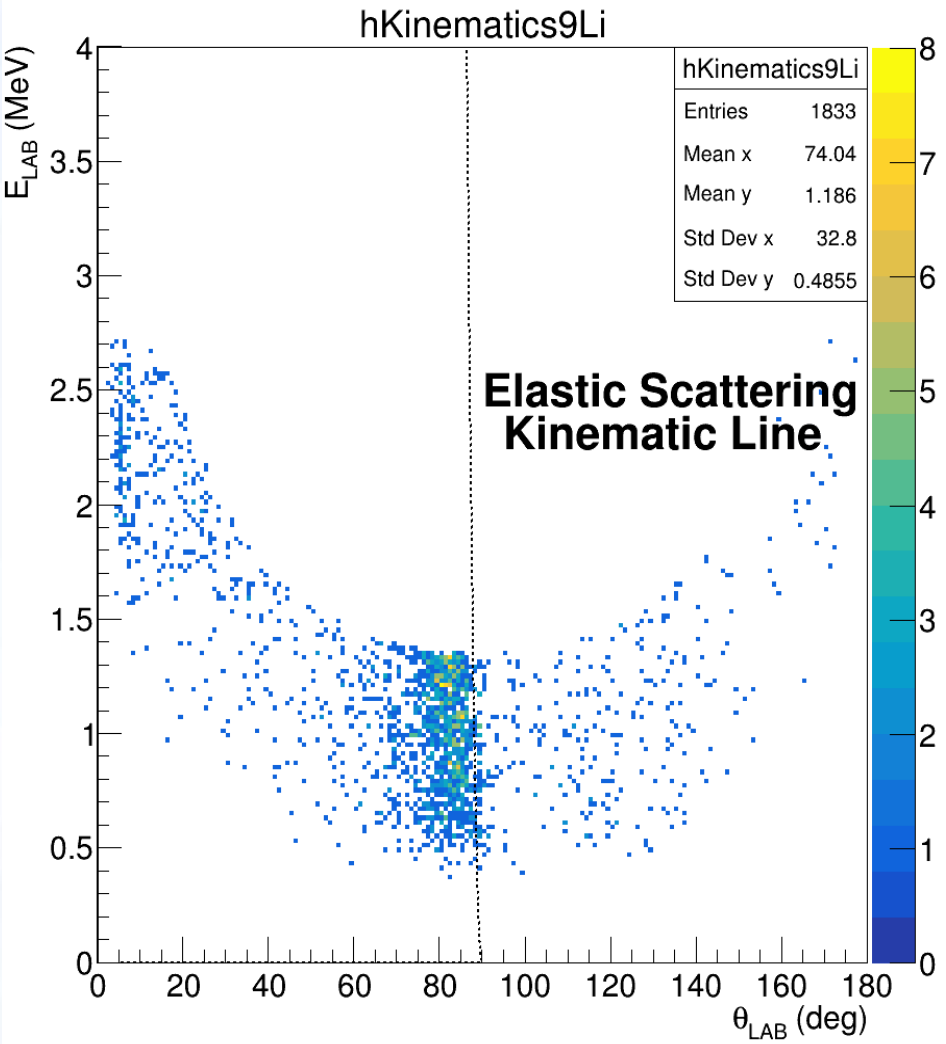
$^{11}Li + p \rightarrow {}^{11}Li + p$

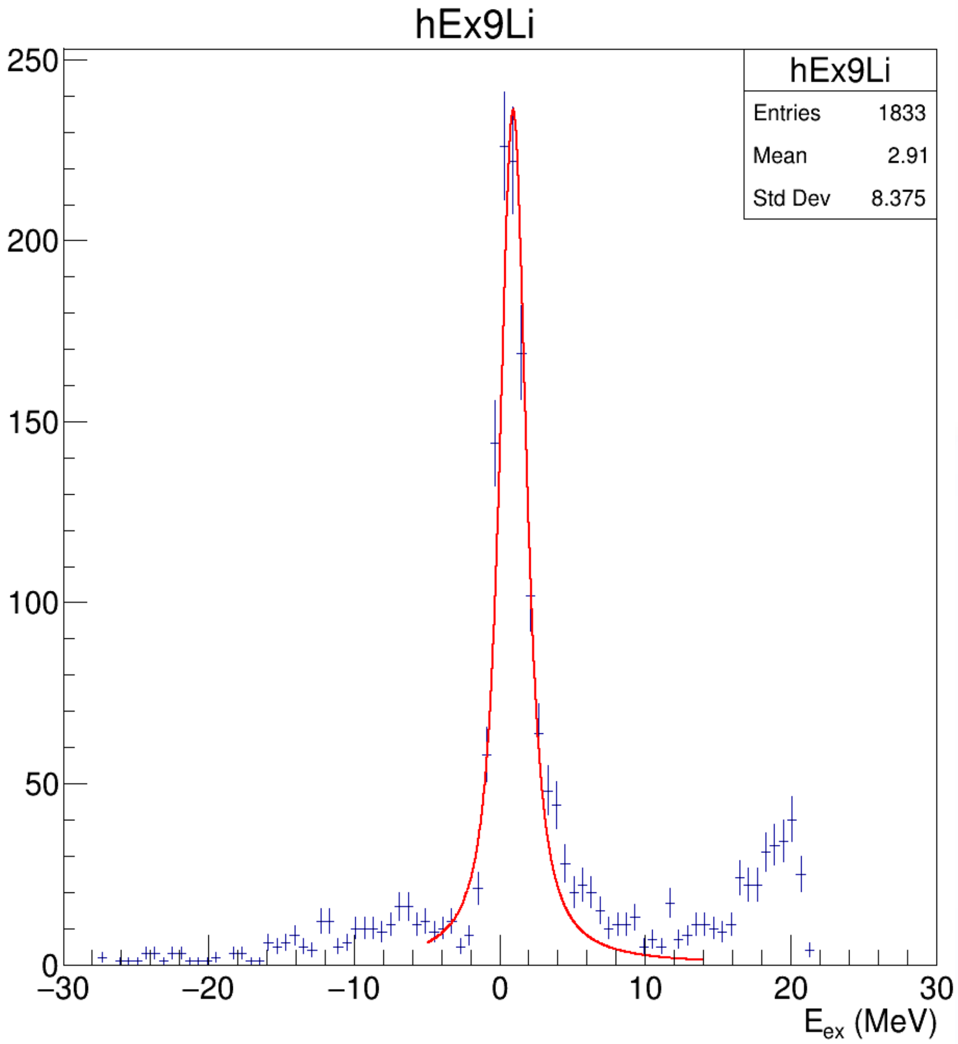


Preliminary results: ^{11}Li Pygmy Dipole Resonance

S800 centered on ^{9}Li. AT-TPC filled with H_2@600Torr

$^{11}Li + p \rightarrow {}^{11}Li^{*} + p' \rightarrow {}^{9}Li + 2n + p'$

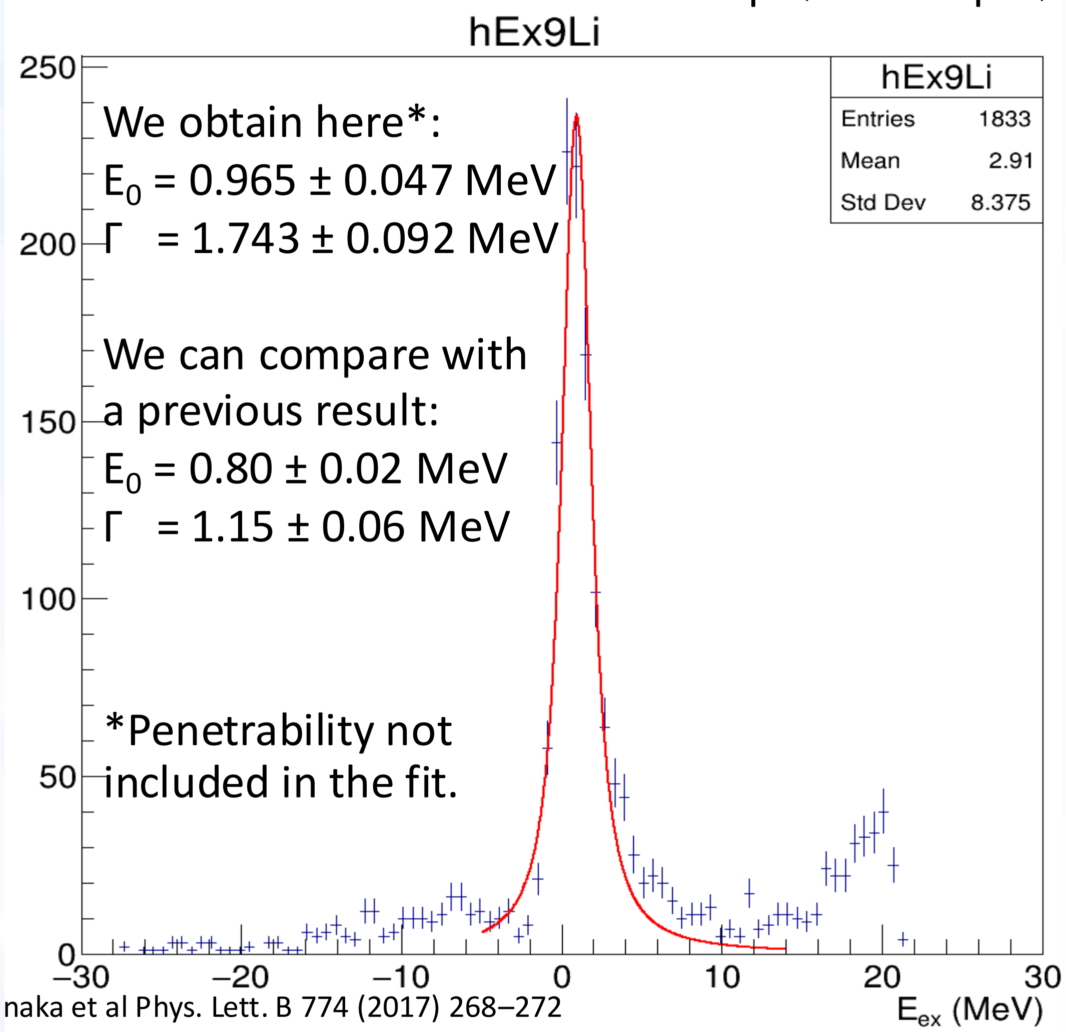


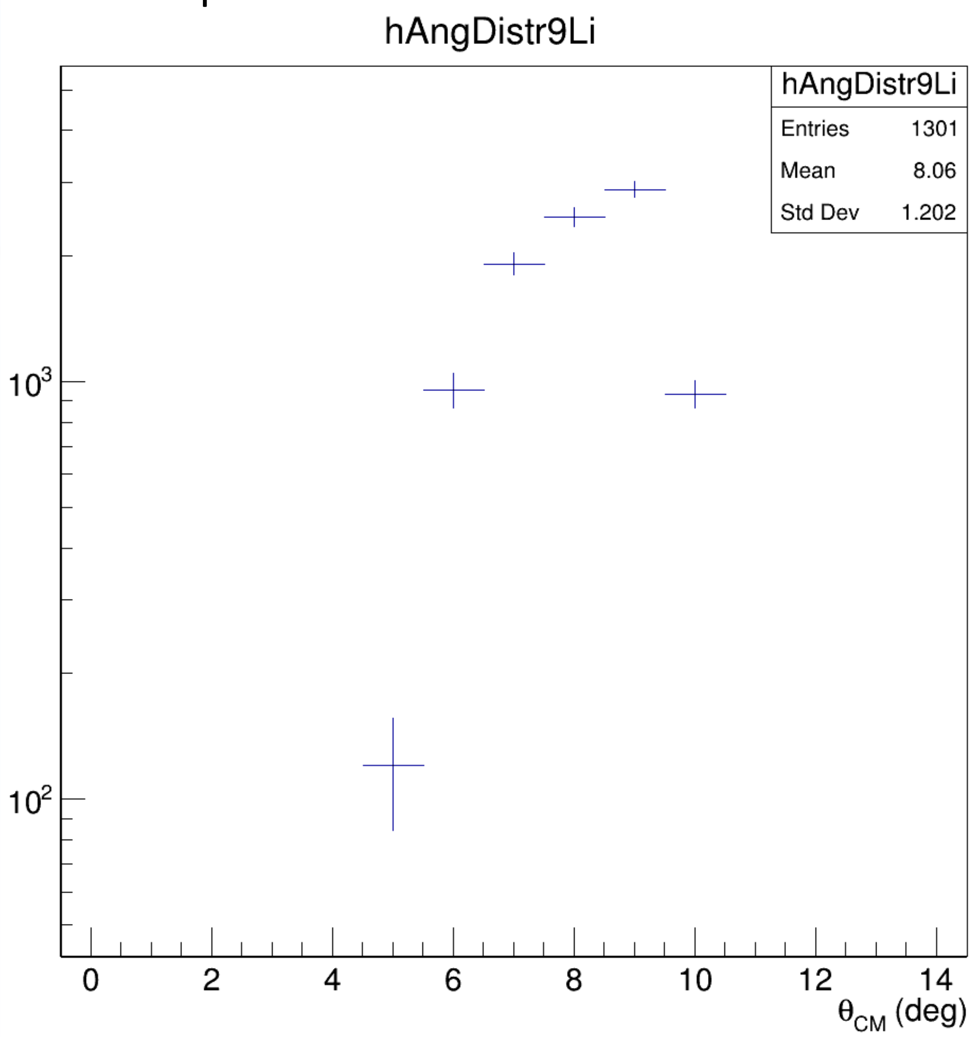


Preliminary results: ^{11}Li Pygmy Dipole Resonance

S800 centered on ^{9}Li. AT-TPC filled with H_2@600Torr

$^{11}Li + p \rightarrow {}^{11}Li^{*} + p' \rightarrow {}^{9}Li + 2n + p'$

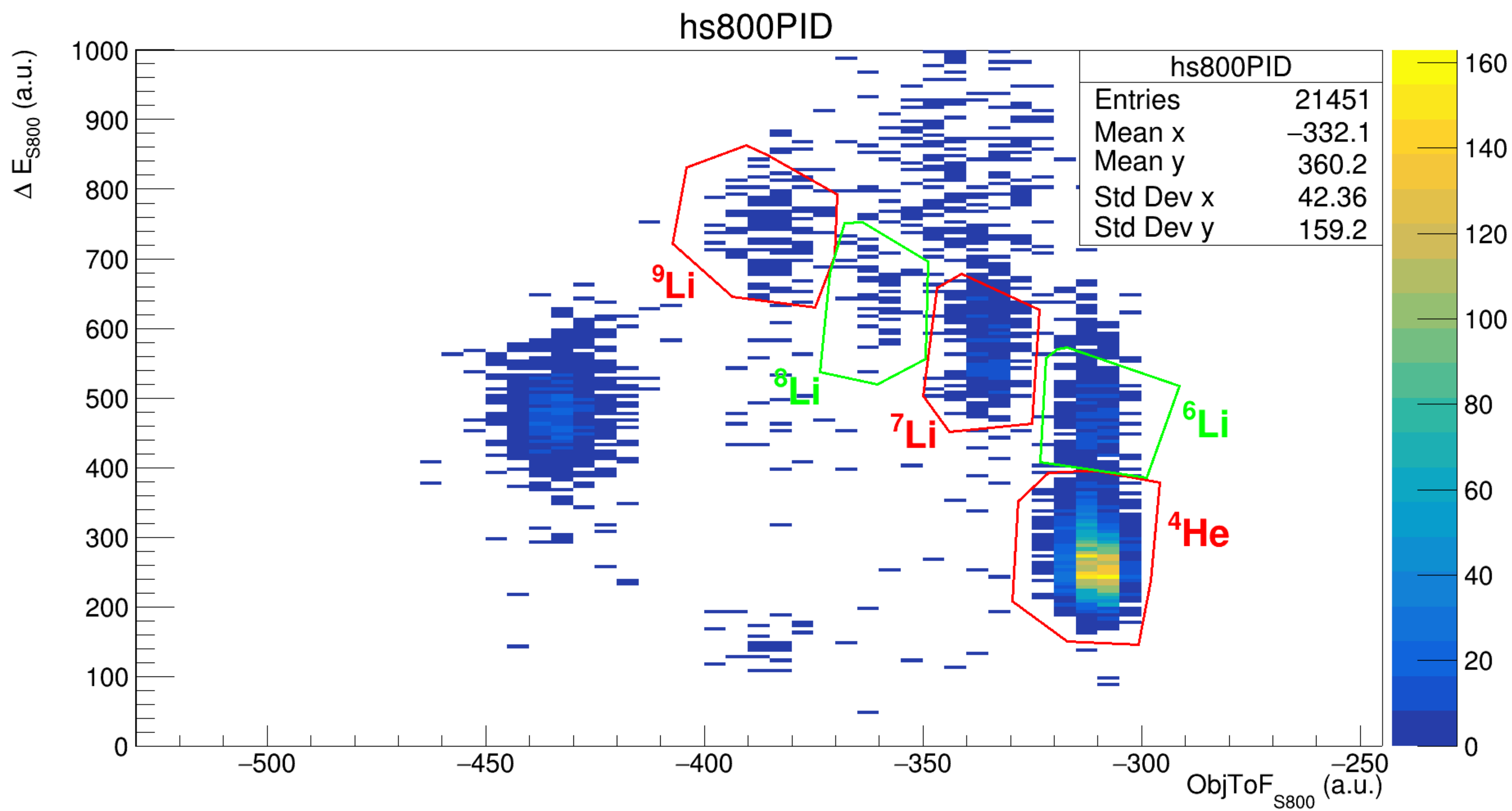




Source: J. Tanaka et al Phys. Lett. B 774 (2017) 268–272

Preliminary results: ^{11}Li Giant Resonance

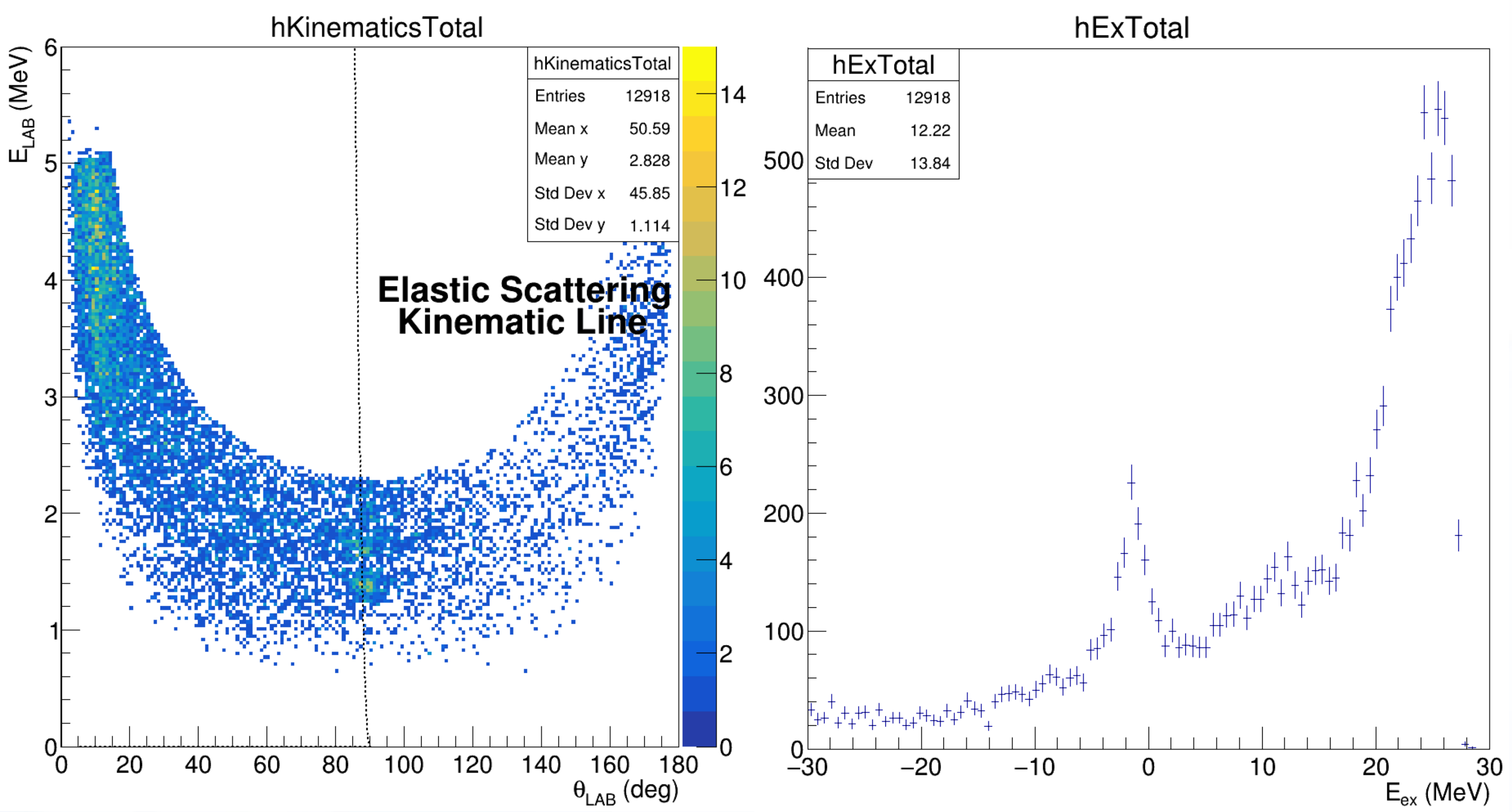
S800 centered on ^{4}He. AT-TPC filled with 90%H_2+10%CF_4@700Torr



Preliminary results: ^{11}Li Giant Resonance

S800 centered on ^{4}He. AT-TPC filled with 90%H_2+10%CF_4@700Torr

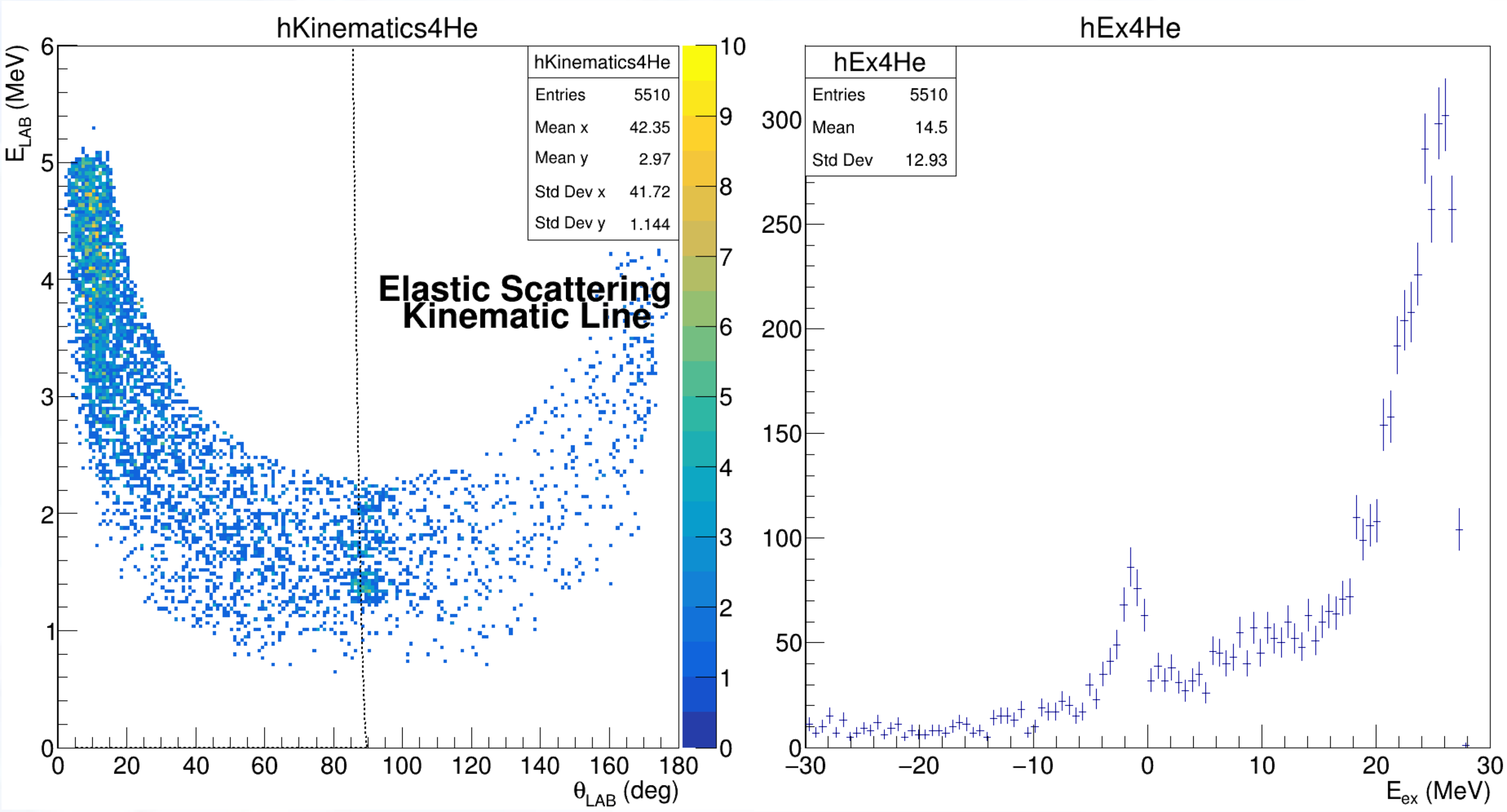
$$^{11}\text{Li} + p \rightarrow {}^{11}\text{Li}^* + p' \rightarrow X + p'$$



Preliminary results: ^{11}Li Giant Resonance

S800 centered on ^{4}He. AT-TPC filled with 90%H_2+10%CF_4@700Torr

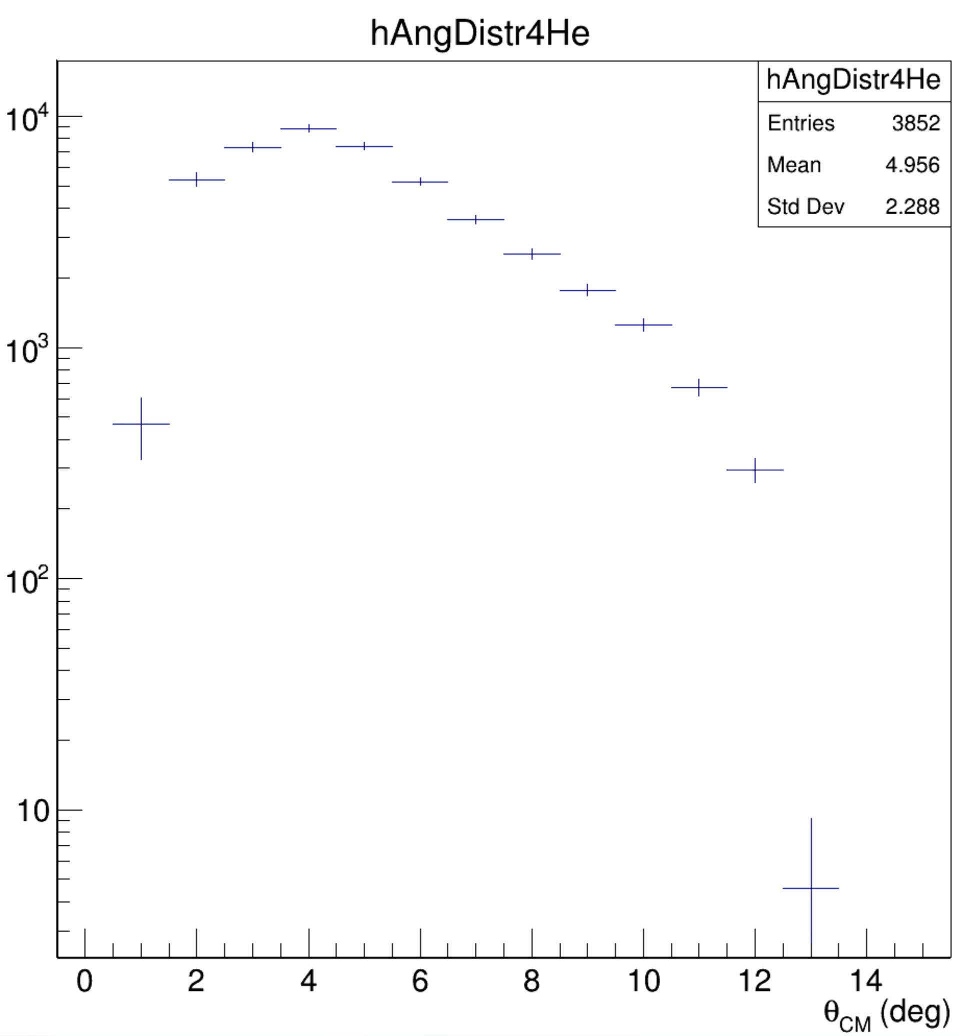
$^{11}Li + p \rightarrow {}^{11}Li^* + p' \rightarrow {}^4He + 6n + p + p'$

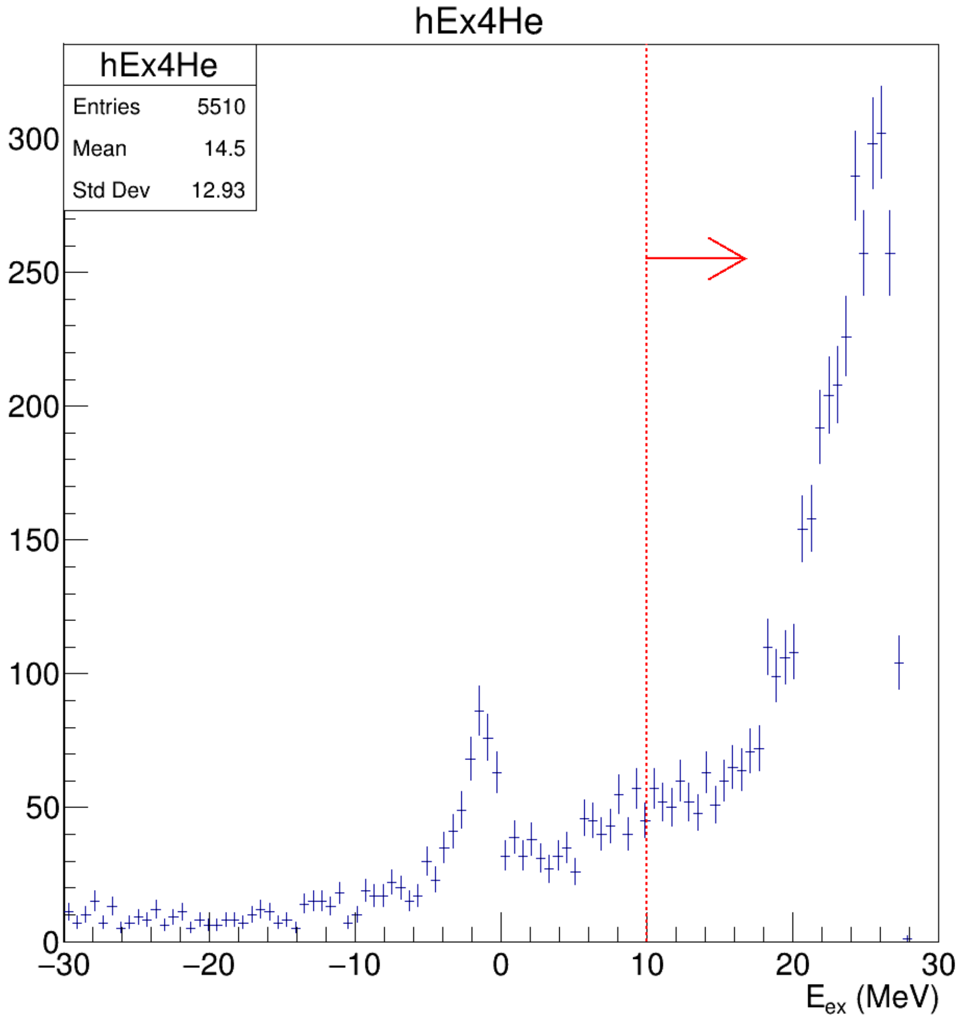


Preliminary results: ^{11}Li Giant Resonance

S800 centered on ^{4}He. AT-TPC filled with 90%H_2+10%CF_4@700Torr

$$^{11}Li + p \rightarrow {}^{11}Li^{*} + p' \rightarrow {}^{4}He + 6n + p + p'$$

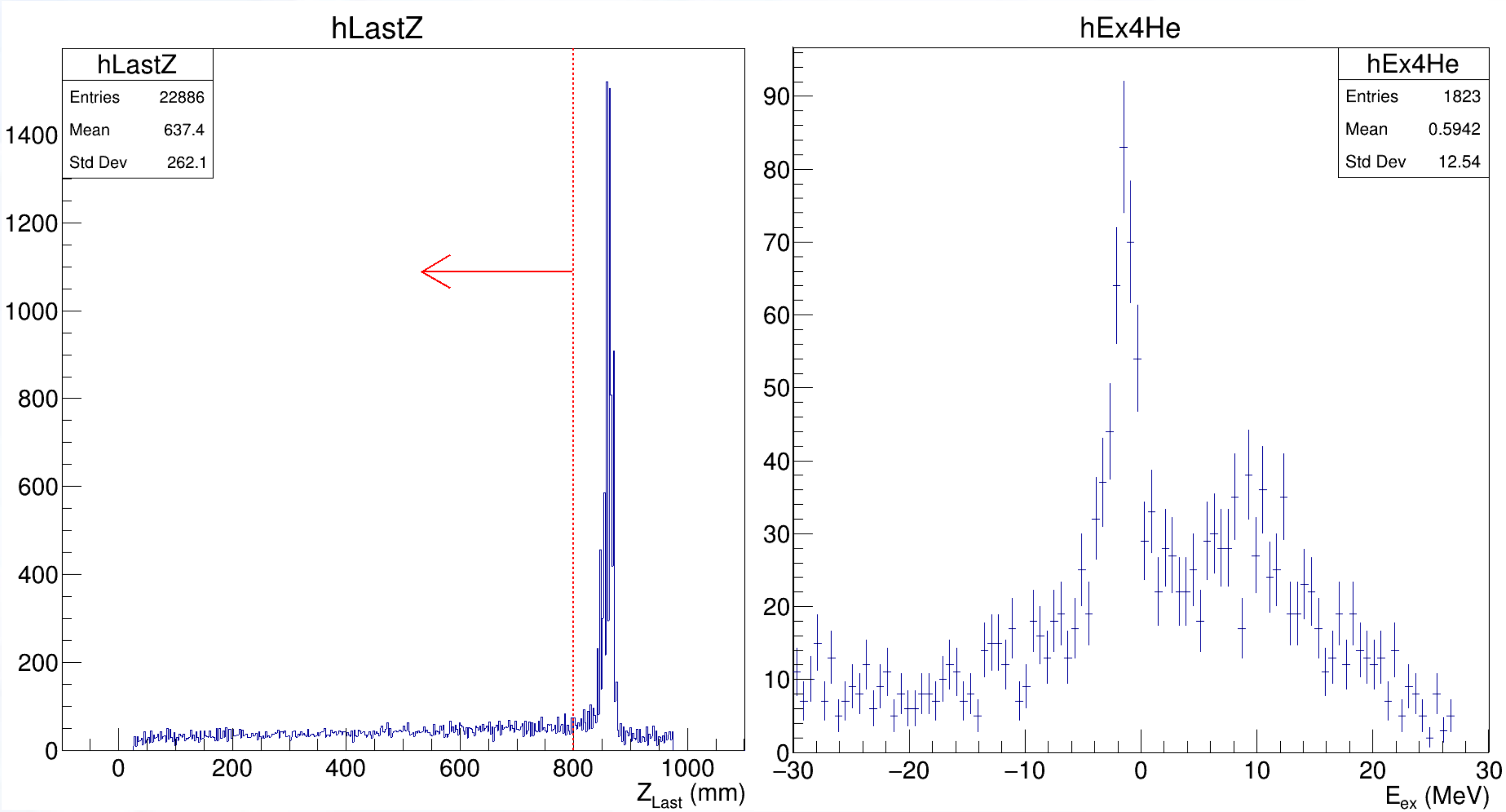




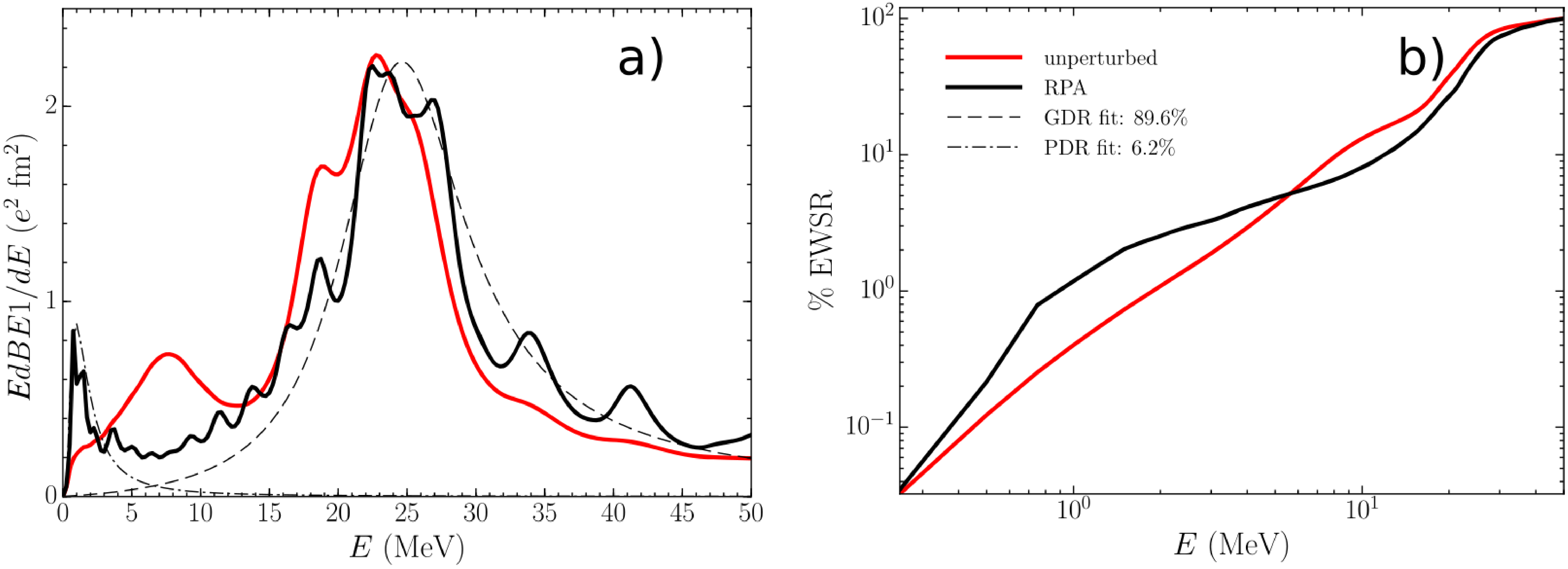
Preliminary results: ^{11}Li Giant Resonance

S800 centered on ^{4}He. AT-TPC filled with 90%H_2+10%CF_4@700Torr

$^{11}Li + p \rightarrow {}^{11}Li^{*} + p' \rightarrow {}^{4}He + 6n + p + p'$



The theory prediction



Source: R. A. Broglia *et al* 2019 *Phys. Scr.* **94** 114002

Preliminar conclusions for preliminar results

1. We observe an acumulation of cross section at lower energies that could be the previously measured Pygmy Dipole Resonance (PDR) in ^{11}Li.

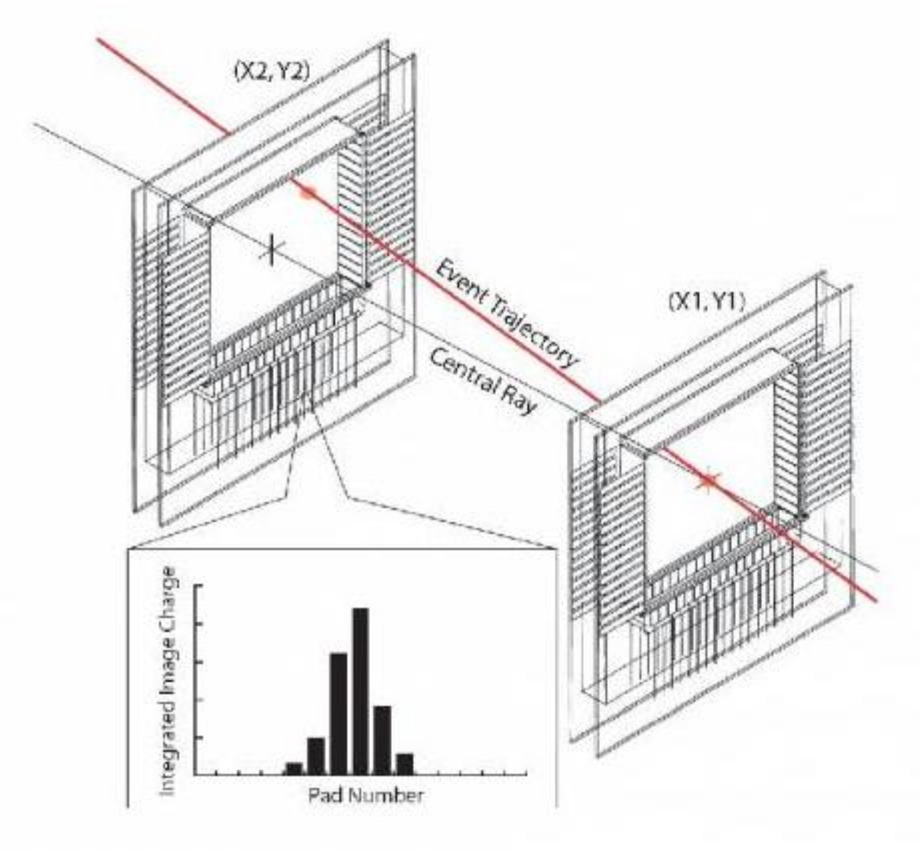
2. At higher energies, we observe a very big acumulation of cross section, which we initially thought it to be due to the presence of a Isovector Giant Dipole Resonance (IVGDR) in ^{11}Li. However, we can not conclude that an IVGDR is present, since the analysis needs to be carefully reviewed in order to understand what is really happening inside the AT-TPC.

3. As expected, it seems like the main decay mode of the PDR seems to be ^{9}Li.

4. The current preliminar fitting parameters for the PDR are not compatible with previous results, but this could change as we improve the analysis.

Questions?

Auxiliary 1: The S800 spectrograph CRDC detectors



$$xfp = x_{CRDC1}, \quad x\text{-position (dispersive) in the focal plane}$$

$$yfp = y_{CRDC1}, \quad y\text{-position (non-dispersive) in the focal plane}$$

$$afp = \text{atan}\left(\frac{x_{CRDC2} - x_{CRDC1}}{gap}\right), \quad \text{dispersive angle in the focal plane}$$

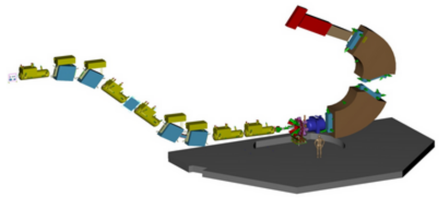
$$bfp = \text{atan}\left(\frac{y_{CRDC2} - y_{CRDC1}}{gap}\right), \quad \text{non-dispersive angle in the focal plane}$$

Sources: https://wikihost.frib.msu.edu/S800Doc/doku.php

Jaclyn Marie Schmitt's PhD thesis. Probing Spin-Isospin Excitations in Proton-Rich Nuclei via the $^{11}C(p,n)^{11}N$ Reaction. 2022

Auxiliary 2: The inverse map method

S800 Spectrograph Inverse Map Server



This page is intended to provide a mean to obtain inverse maps for the S800 Spectrograph from the recorded settings of the magnets. This calculation involves many steps performed by various programs and takes on the average 20 seconds. The result is in the form of a standard COSY map in ASCII format which can be directly used by the standard S800 SpecTcl program.

The data needed as input for the calculation are the currents in the 4 magnets of the S800 Spectrograph, the magnetic rigidity and the mass and charge of the particle of interest. The distance between the target of the pivot point is normally zero for the nominal target location. Upstream locations correspond to positive values of this parameter. The focal plane shift can be used to fine tune the calculations based on comparison with kinematics. It accounts for variations of effective lengths in the dipoles and/or discrepancies between the CAD distances and reality. Downstream locations correspond to positive values of this parameter.

Q1 or I256QA (old) or Q_D2566 (new) current (Amps):
Q2 or I258QB (old) or Q_D2572 (new) current (Amps):
D1 or I265DS (old) or DV_D2597 (new) current (Amps):
D2 or I269DS (old) or DV_D2648 (new) current (Amps):
Brho or Magnetic Rigidity (Tesla.Meter):
Mass number of particle of interest:
Charge number of particle of interest:
Distance between Target and Pivot Point (Meter): 0.0 (positive indicates upstream)
Focal Plane Shift (Meter): 0.0 (positive indicates downstream)
NSCL experiment number:
Your Name:
Email address:

Submit

Please click the Submit button only once and wait a few seconds until the server returns the calculated map!

If you have entered a valid Email address the map will be sent to you automatically

$$\begin{bmatrix} ata & yta & bta & dta \end{bmatrix} = S^{-1} \begin{bmatrix} xfp & afp & yfp & bfp \end{bmatrix}$$

$$dta = \frac{KE - KE_0}{KE_0} = \text{deviation from the central energy at the target}$$

$$yta = y\text{-position at the target}$$

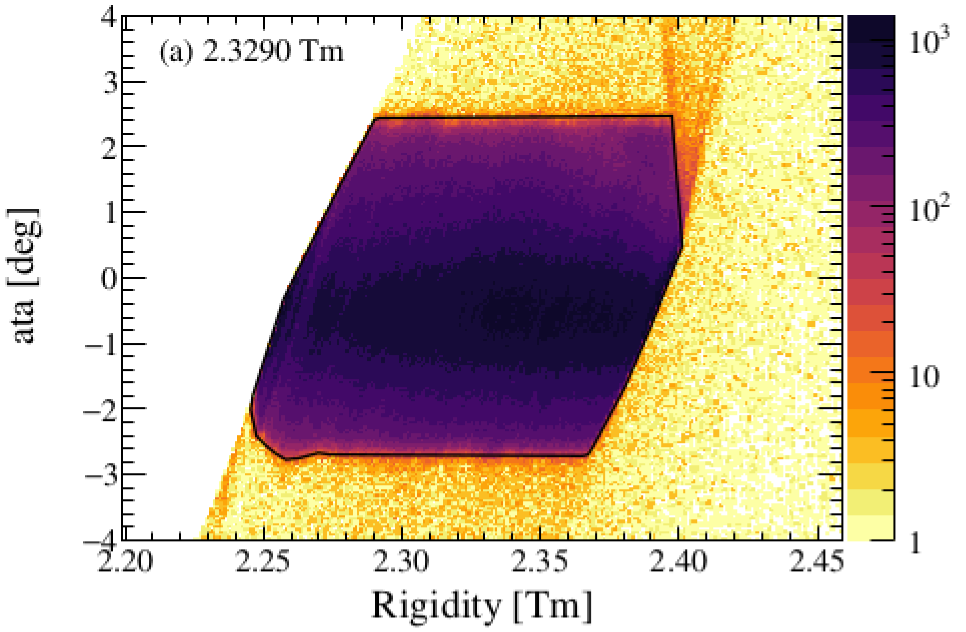
$$ata = \text{dispersive angle at the target}$$

$$bta = \text{non-dispersive angle at the target}$$

Sources: https://wikihost.frib.msu.edu/S800Doc/doku.php

Jaclyn Marie Schmitt's PhD thesis. Probing Spin-Isospin Excitations in Proton-Rich Nuclei via the $^{11}C(p,n)^{11}N$ Reaction. 2022

Auxiliary 2: The inverse map method 2



$$\begin{bmatrix} ata & yta & bta & dta \end{bmatrix} = S^{-1} \begin{bmatrix} xfp & afp & yfp & bfp \end{bmatrix}$$

$$dta = \frac{KE - KE_0}{KE_0} = \text{deviation from the central energy at the target}$$

$$yta = y\text{-position at the target}$$

$$ata = \text{ dispersive angle at the target}$$

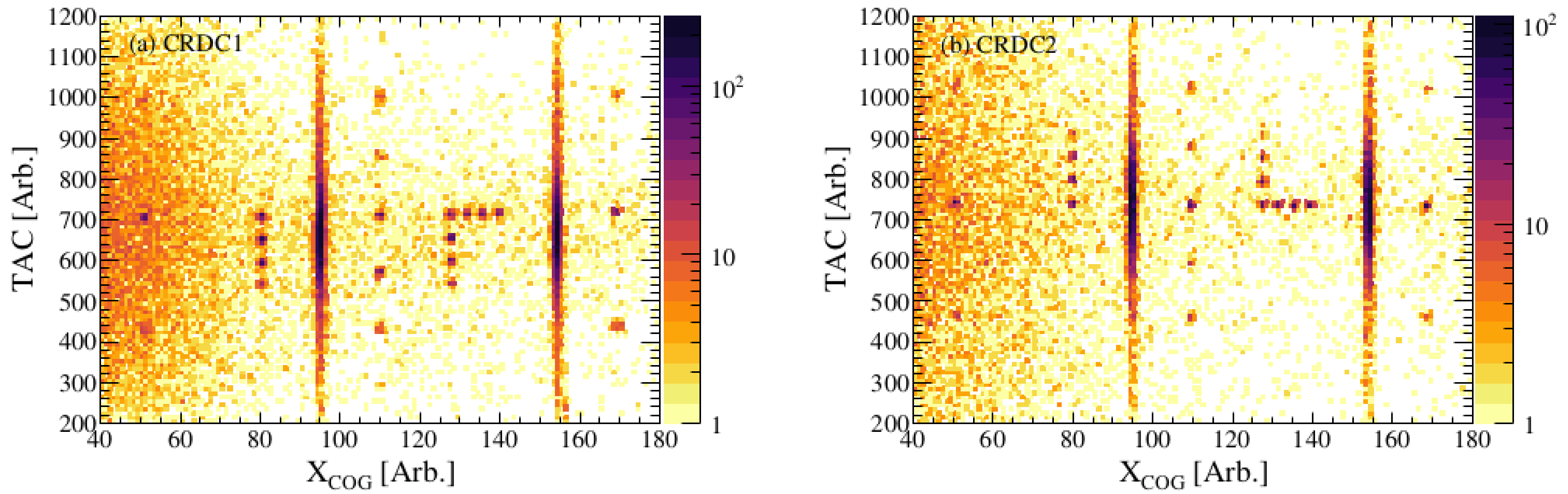
$$bta = \text{ non-dispersive angle at the target}$$

Source: Jaclyn Marie Schmitt's PhD thesis. Probing Spin-Isospin Excitations in Proton-Rich Nuclei via the $^{11}C(p,n)^{11}N$ Reaction. 2022

Auxiliary 3: The CRDCs calibration

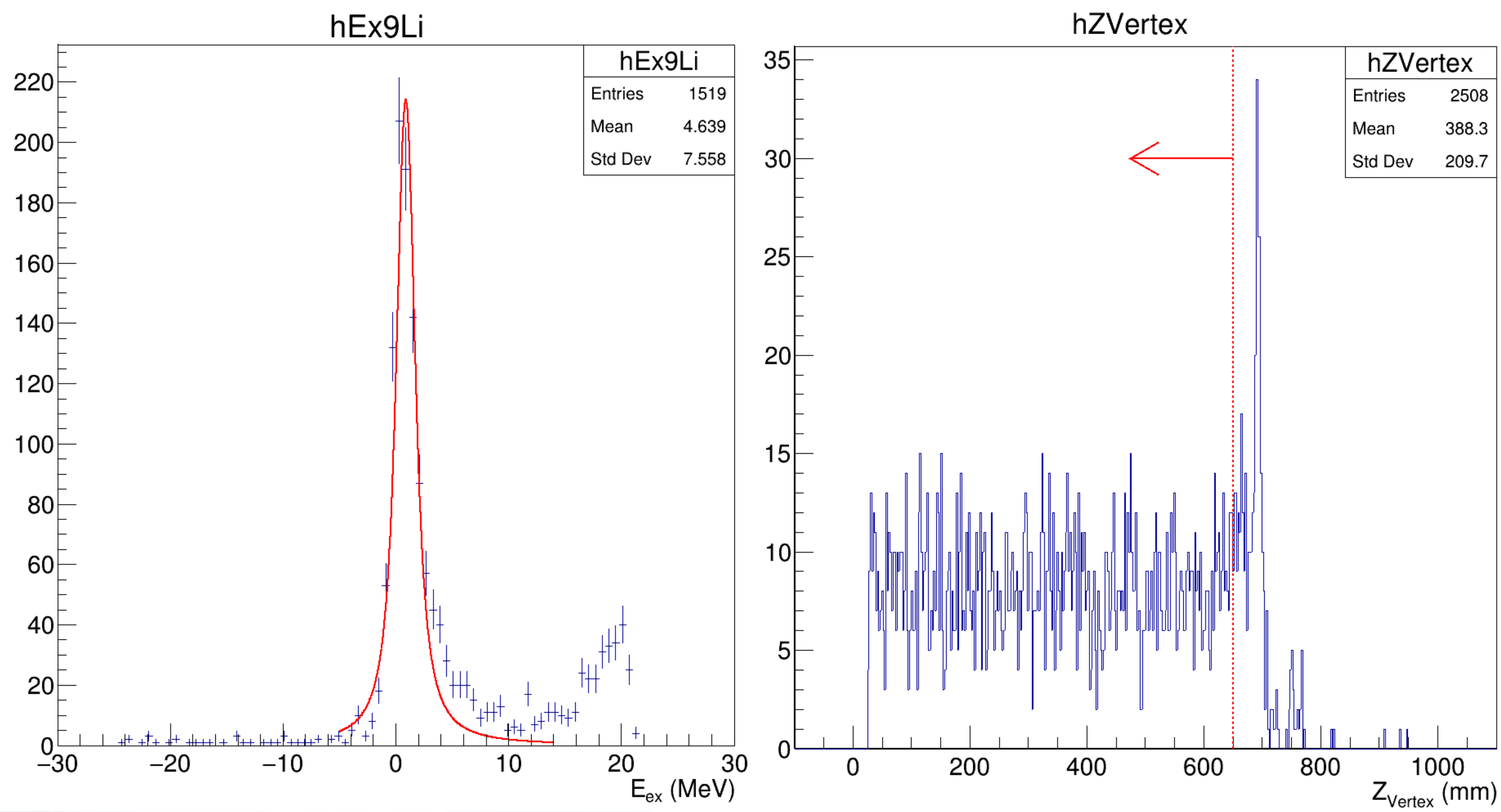
$$x_{CRDC}[\mathrm{mm}] = 2.54 \left[\frac{\mathrm{mm}}{\mathrm{pad}}\right] \times X_{COG}[\mathrm{pad}] + x_{offset}[\mathrm{mm}]$$

$$y_{CRDC}[\mathrm{mm}] = slope_y \left[\frac{\mathrm{mm}}{\mathrm{arb.\ time\ unit}}\right] \times TAC[\mathrm{arb.\ time\ unit}] + y_{offset}[\mathrm{mm}]$$

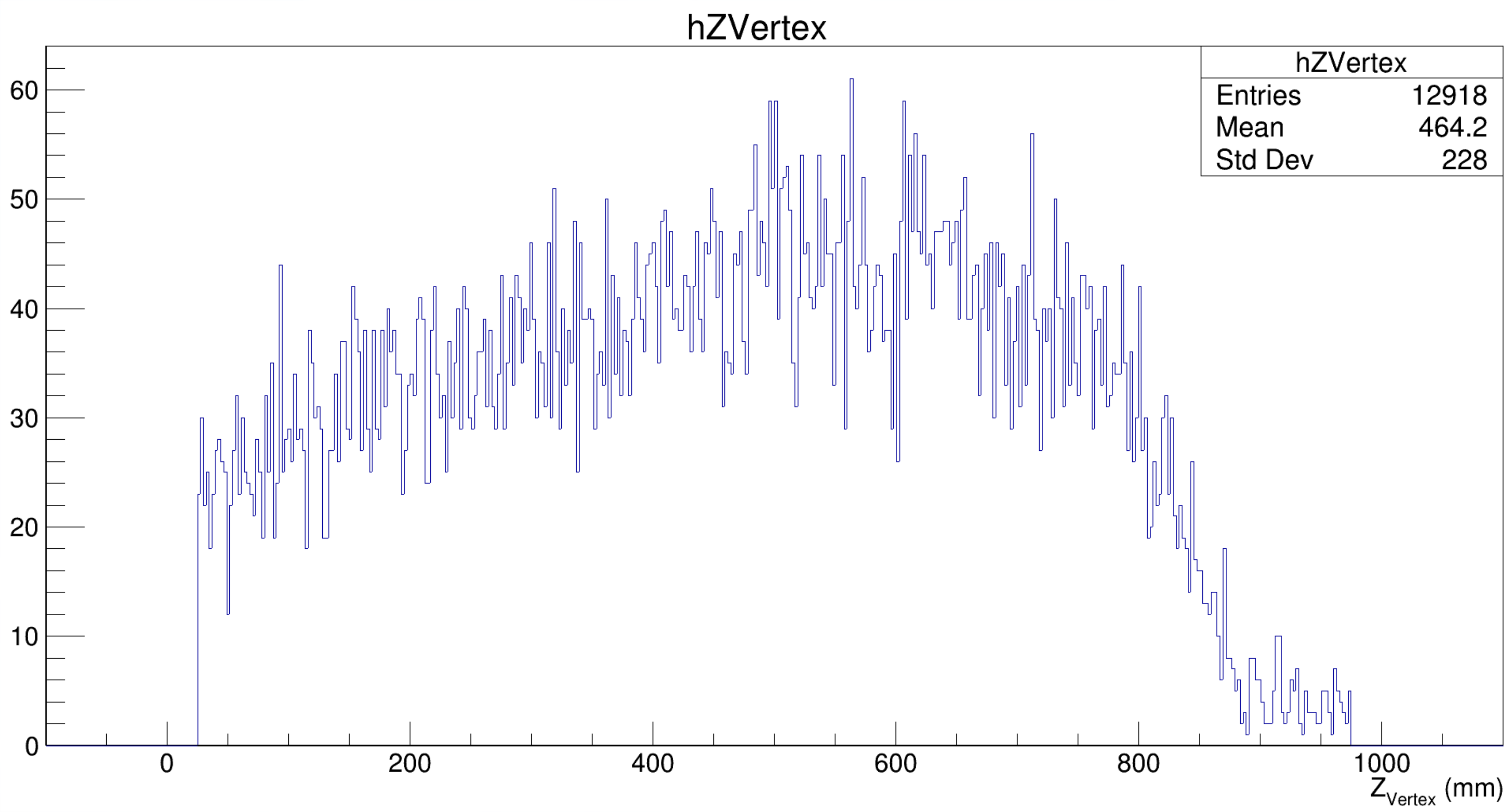


Source: Jaclyn Marie Schmitt's PhD thesis. Probing Spin-Isospin Excitations in Proton-Rich Nuclei via the $^{11}C(p,n)^{11}N$ Reaction. 2022

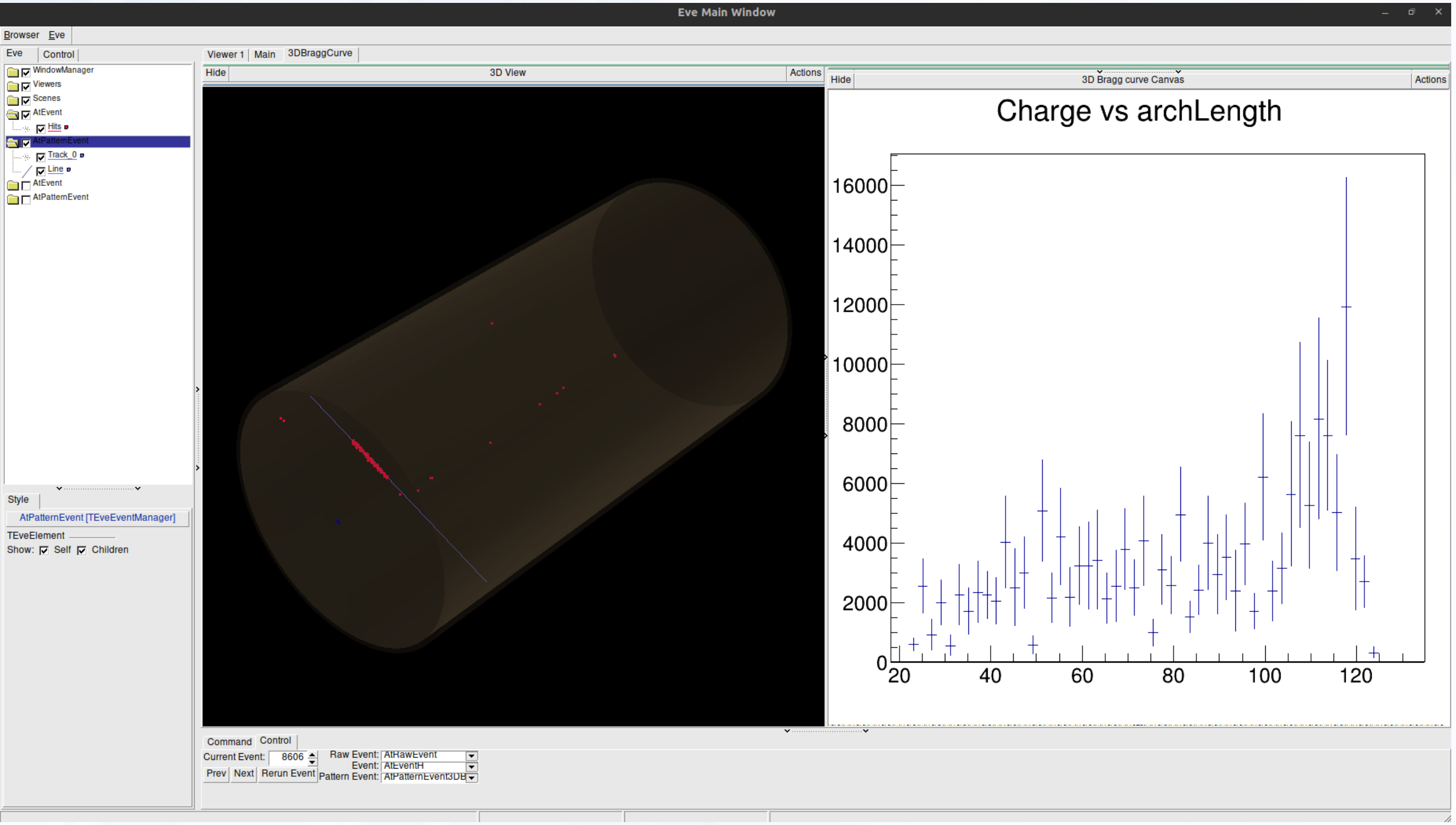
Auxiliary 4: Vertex Z distribution in ^{9}Li setting



Auxiliary 5: Vertex Z distribution in ^{4}He setting



Auxiliary 6: Bragg curve fitting



<u>Analysis phases</u>:

1. Unpacking of AT-TPC data.
2. Merging of S800 and AT-TPC data.
3. Pulse Shape Analysis (PSA).
4. Random Sample Consensus (RANSAC).
5. ~~Use of SRIM energy loss tables to obtain the proton kinetic energy.~~
6. Fit the 3D Bragg curve to obtain the proton kinetic energy.

Source: Adam Anthony, Yassid Ayyad et al (2025). ATTPCROOTv2. Zenodo. https://doi.org/10.5281/zenodo.10113377