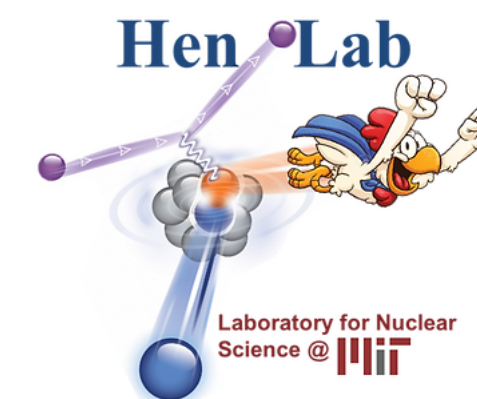


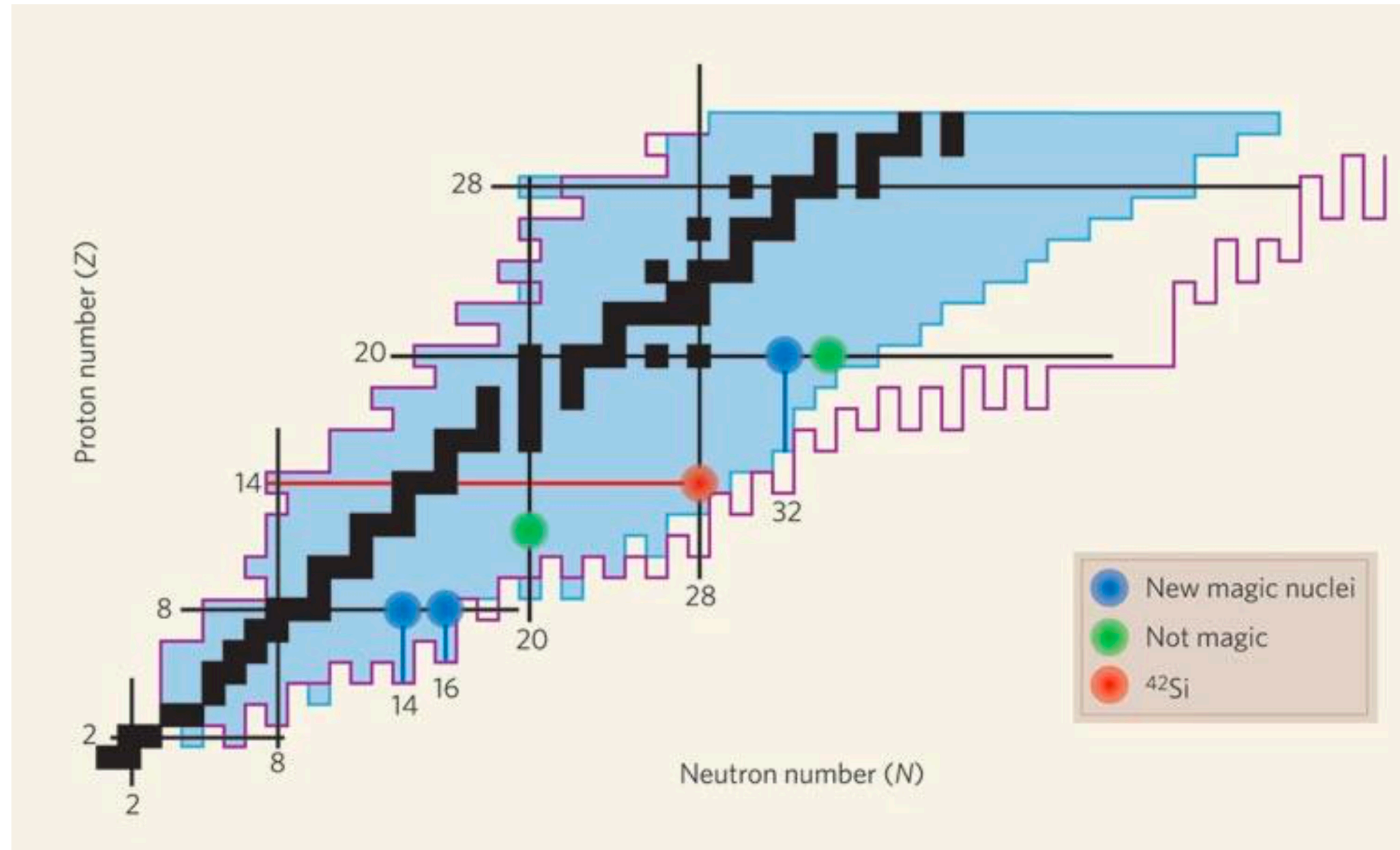
# Status update on SRC in radioactive nuclei

— study of  $^{16}\text{C}$  in inverse kinematics

Hang Qi, 08/2022



# Nuclear Structure changes with isospin asymmetry

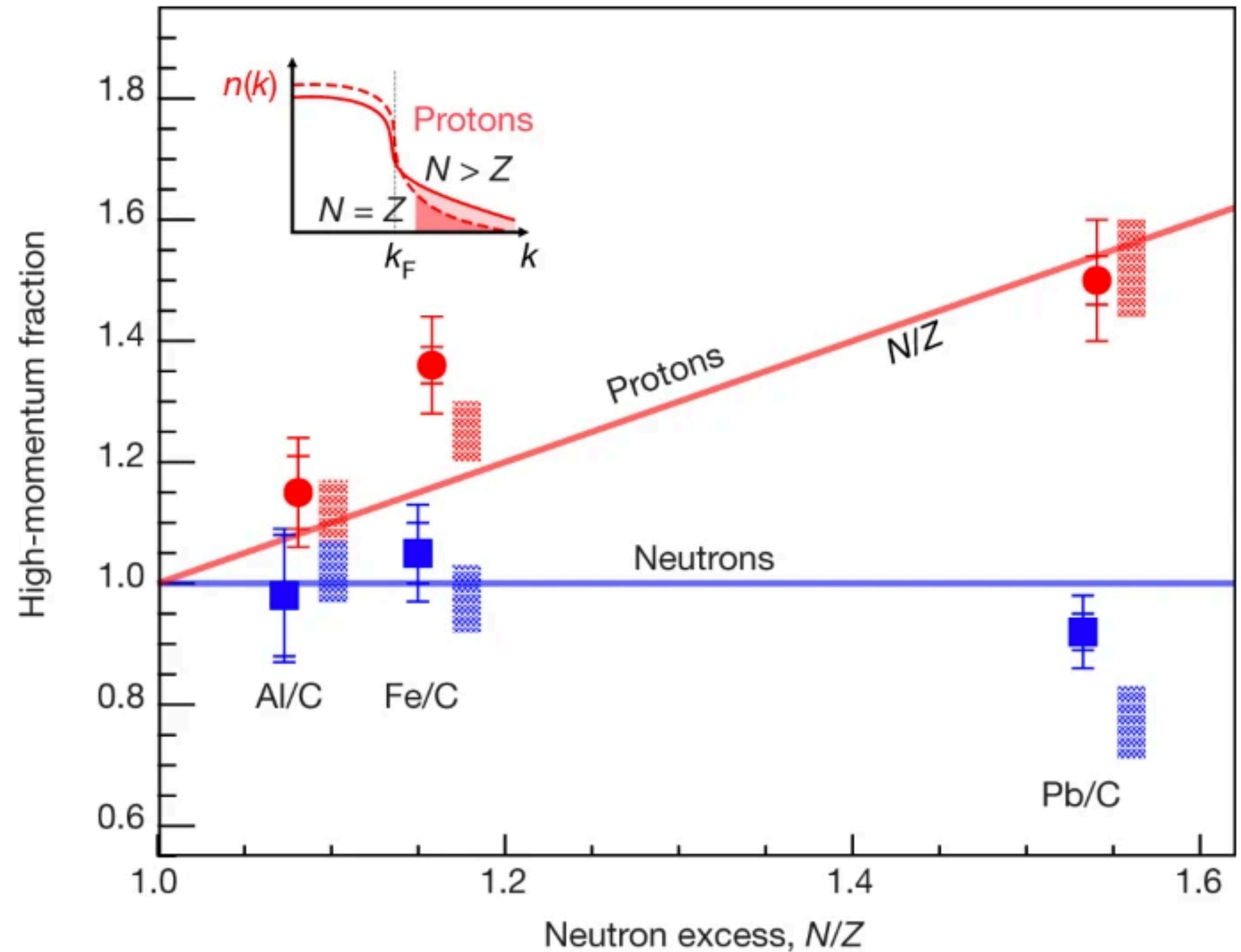


R. Janssens, Nature 2005.

# SRC study for neutron-rich nuclei

Limitations of this study:

- Inverse kinematics is the only way to study nuclei with asymmetry  $> 1.5$
- Results might be mass-dependent



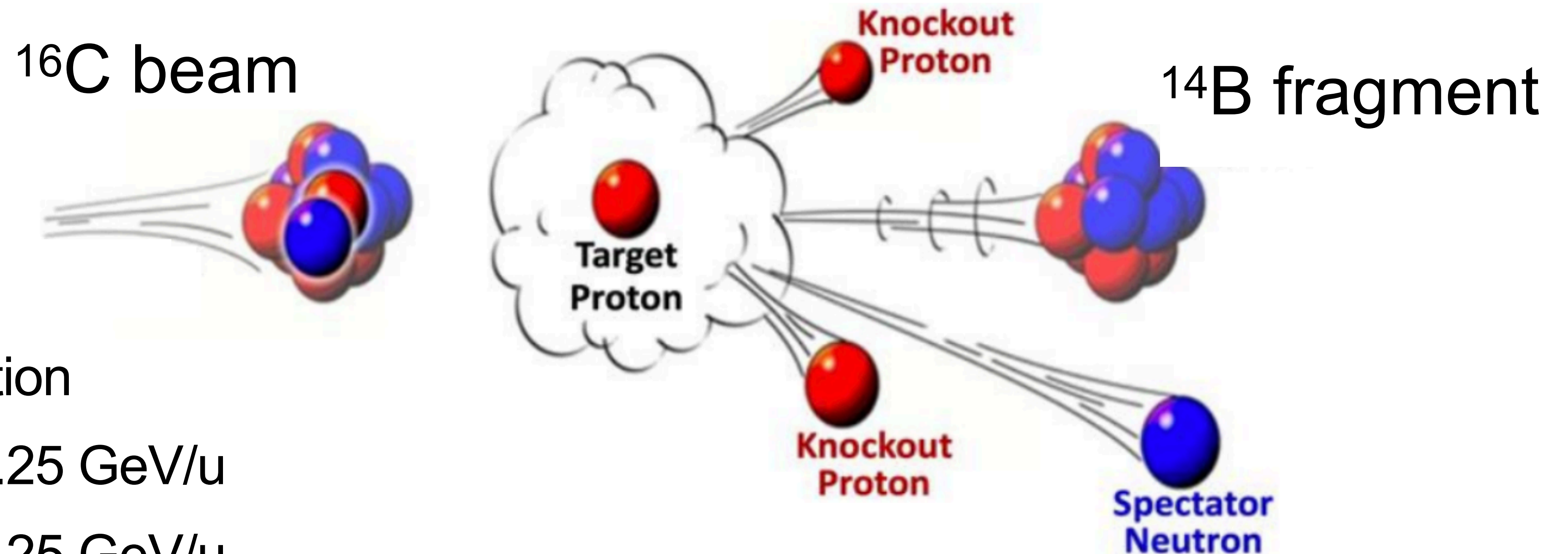
M. Duer et al. (CLAS), Nature 2018.

# Experimental Goals

- First look at SRC within radioactive nuclei ( $^{16}\text{C}$ )
- Inverse kinematics is the only way to study radioactive nuclei
- More direct and systematic access to SRC properties along the isotopic chain
- Kinematically complete measurements
  - Measure excitation energy of excited states
  - Recoil and fragment detection — fully exclusive SRC breakup



# Breakup of SRC in inverse kinematics



- Beam information
  - $^{16}\text{C}$  beam, 1.25 GeV/u
  - $^{12}\text{C}$  beam, 1.25 GeV/u
  - Intensity:  $1 \times 10^5$  pps
  - Expect  $\sim 1100$  fully-exclusive p-n SRC pairs in  $^{16}\text{C}$

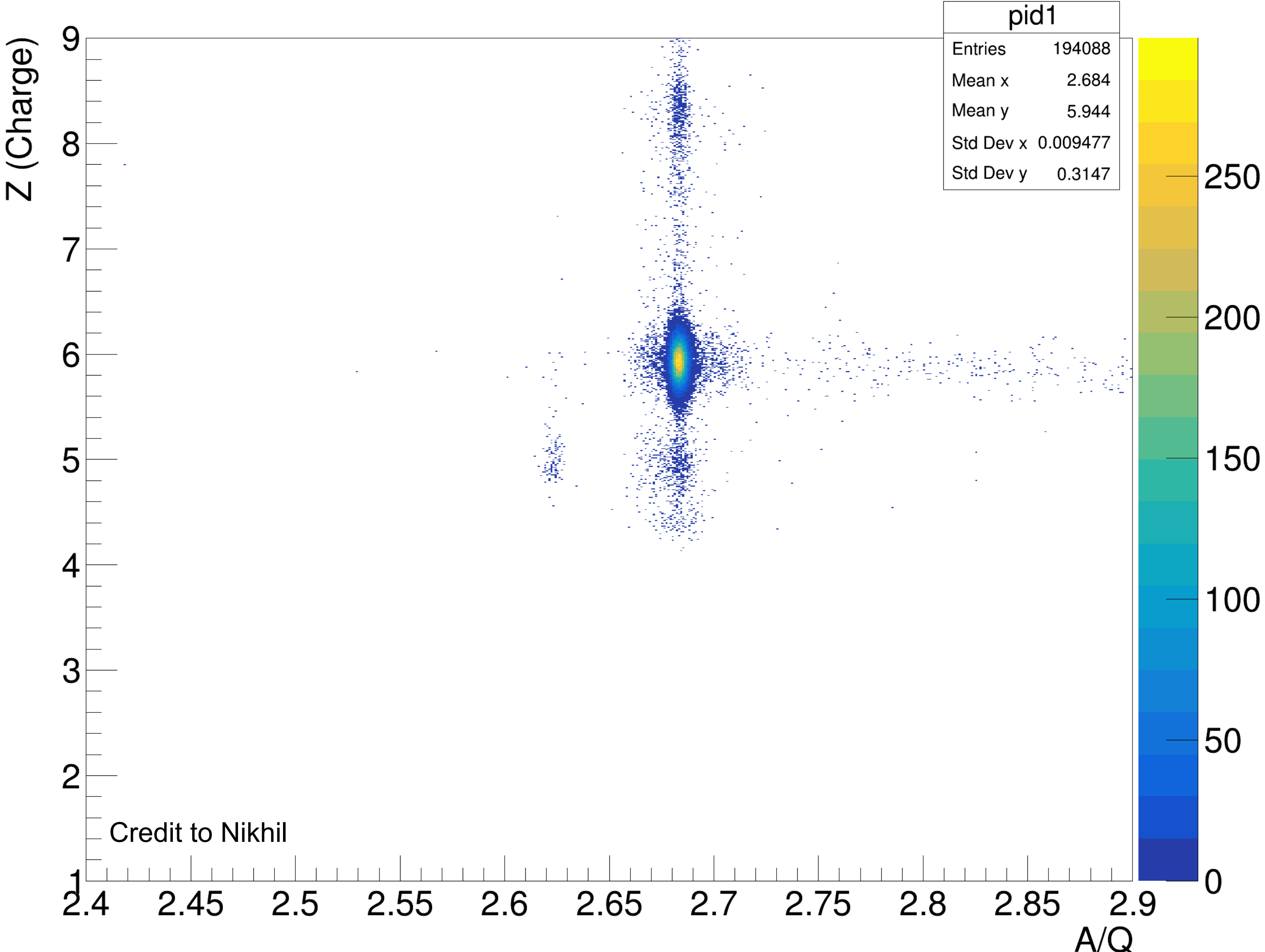
# Reaction channels

- Single Proton knockout:
  - $^{16}\text{C}(p,2p)^{15}\text{B}^*$
  - $^{12}\text{C}(p,2p)^{11}\text{B}^*$
- SRC channels
  - $^{16}\text{C}(p,2pn)^{14}\text{B}^*$ ,  $S_n=0.97$  MeV
  - $^{16}\text{C}(p,2pp)^{14}\text{Be}^*$ ,  $S_n=1.775$  MeV
  - $^{12}\text{C}(p,2pn)^{10}\text{B}^*$ ,  $S_n=8.437$  MeV
  - $^{12}\text{C}(p,2pp)^{10}\text{Be}^*$ ,  $S_n=6.812$  MeV

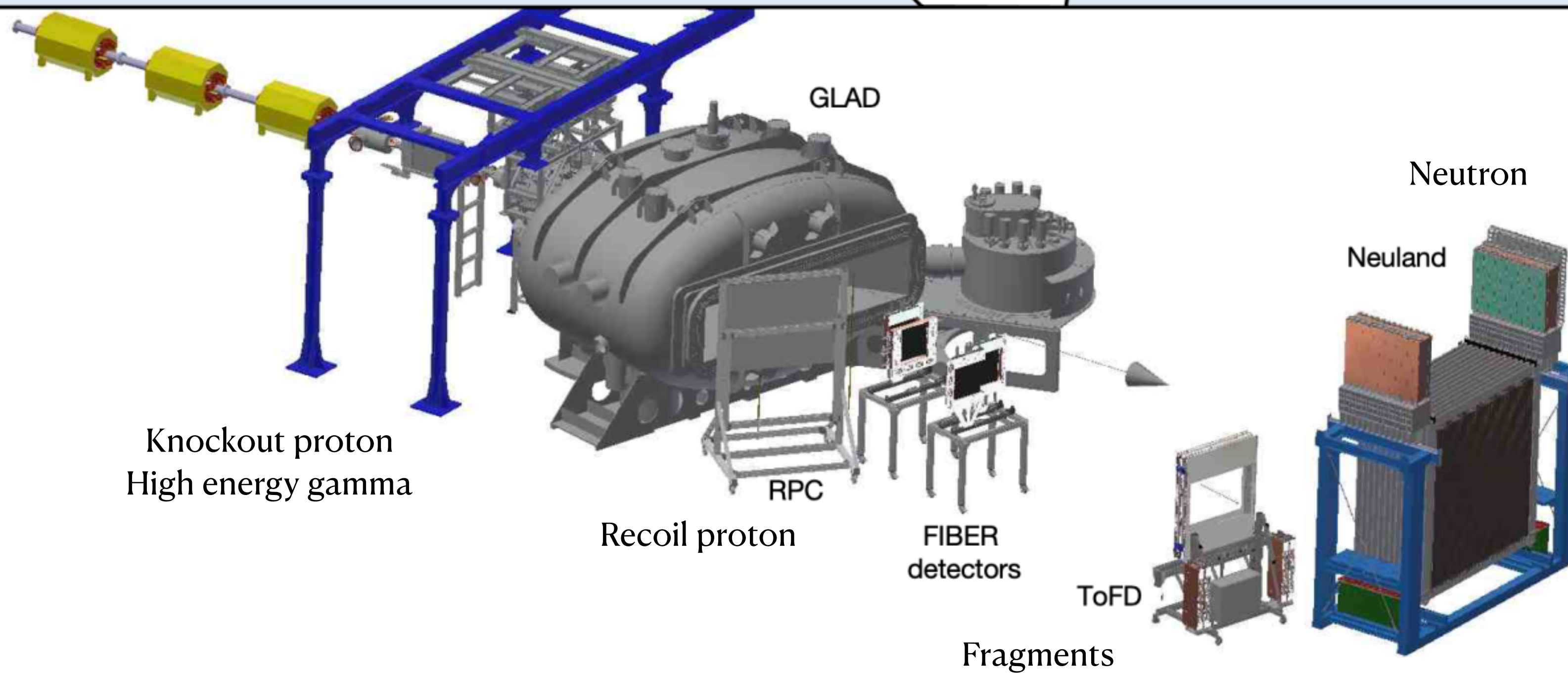
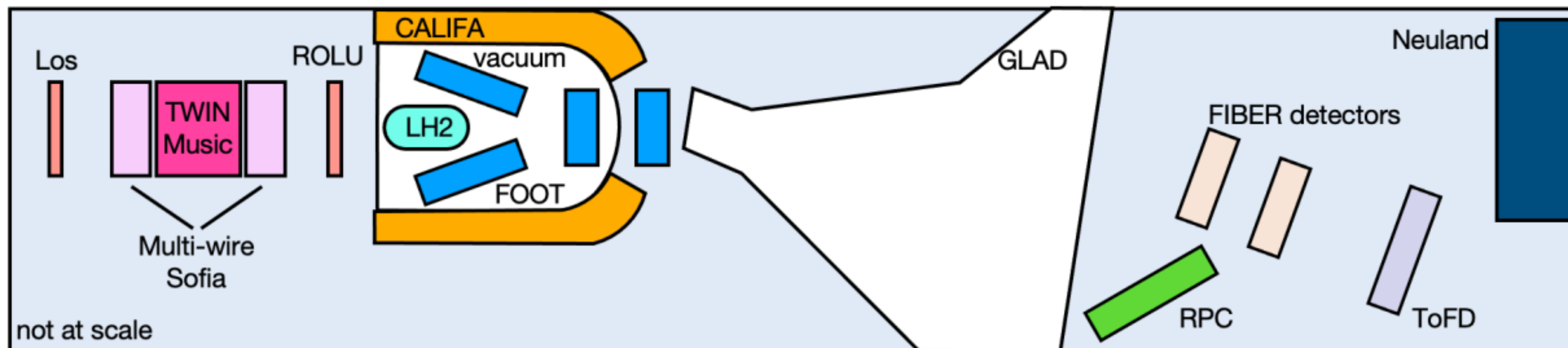
# Incoming beam ID

FRS: A/q vs q

$^{16}\text{C}$  beam  
Gas ionization chamber  
+ ToF measurement



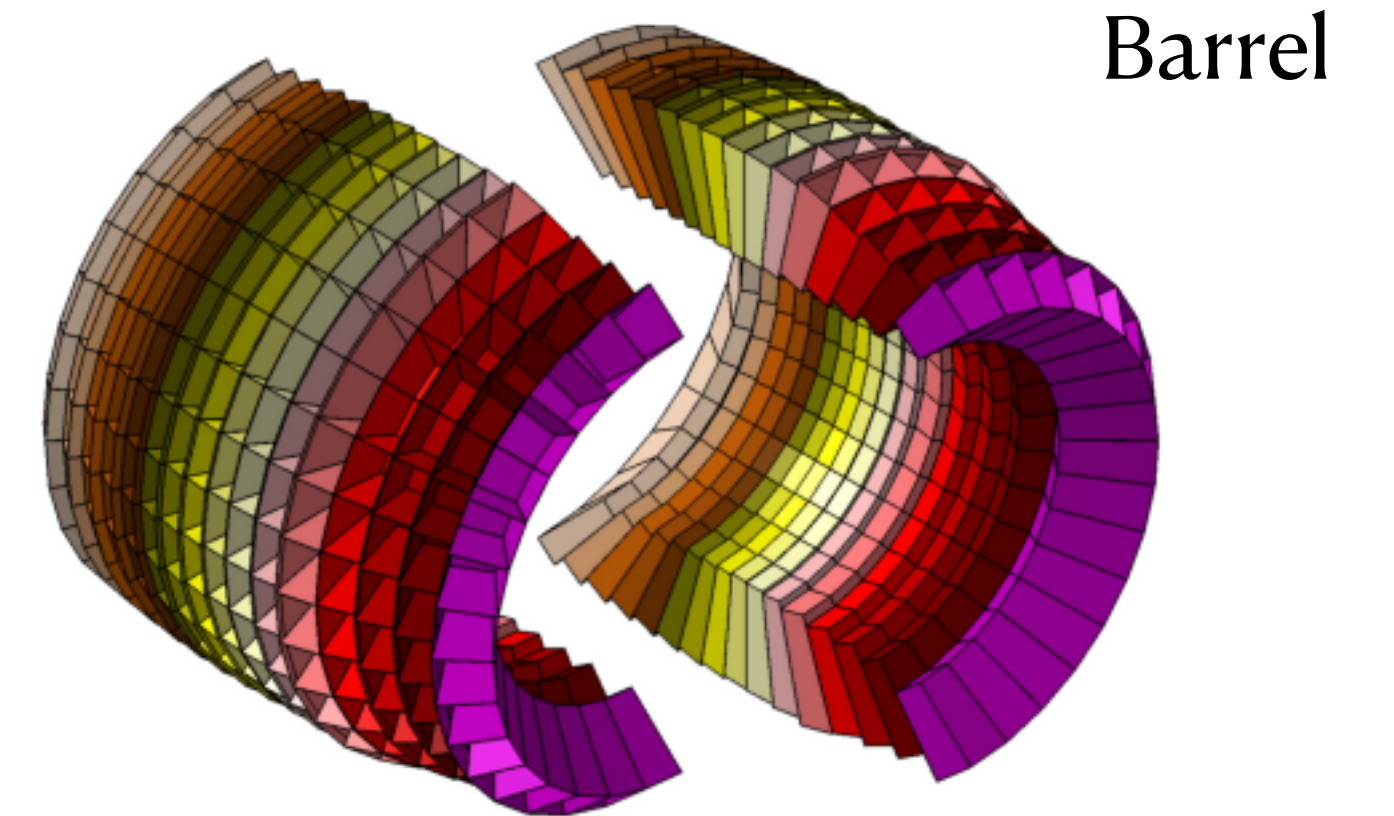
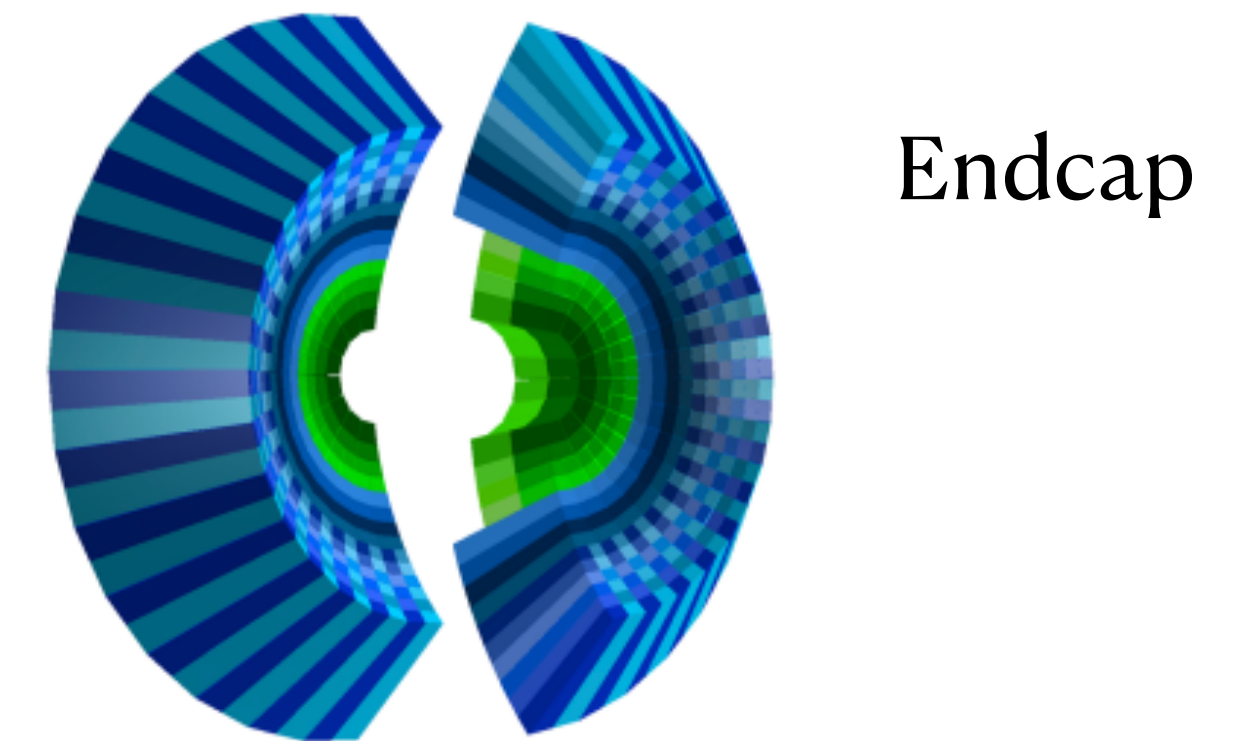
# R<sup>3</sup>B Setup





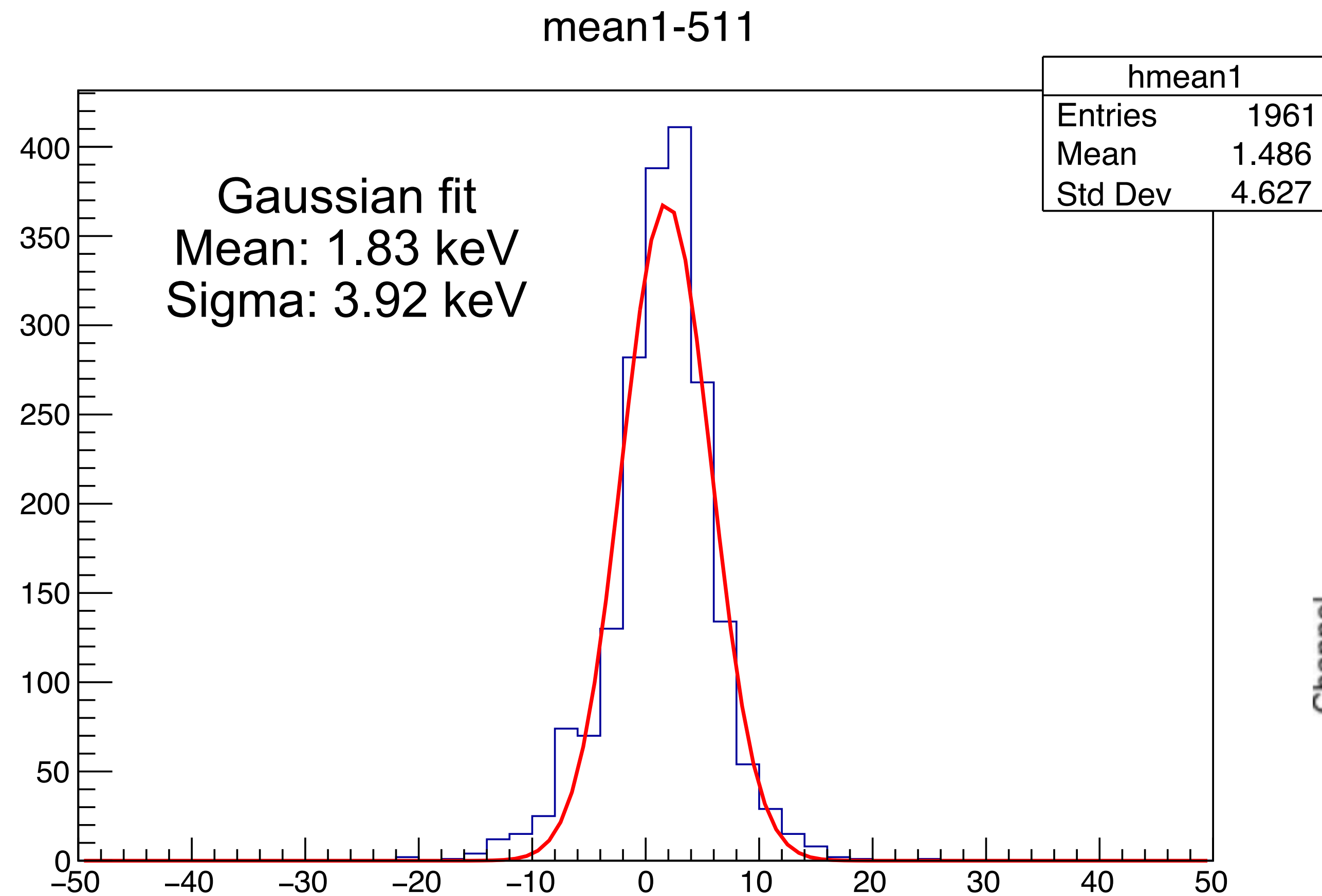
# p2p: Califa

- Calorimeter measures gamma rays energy and light charged particles
- Barrel: proton mode only, 1952 CsI crystals, 43 to 140 degrees
- IPhos: proton or gamma mode, 608 crystals, 19 to 43 degrees
- Stop protons up to 350 MeV
- APD readout

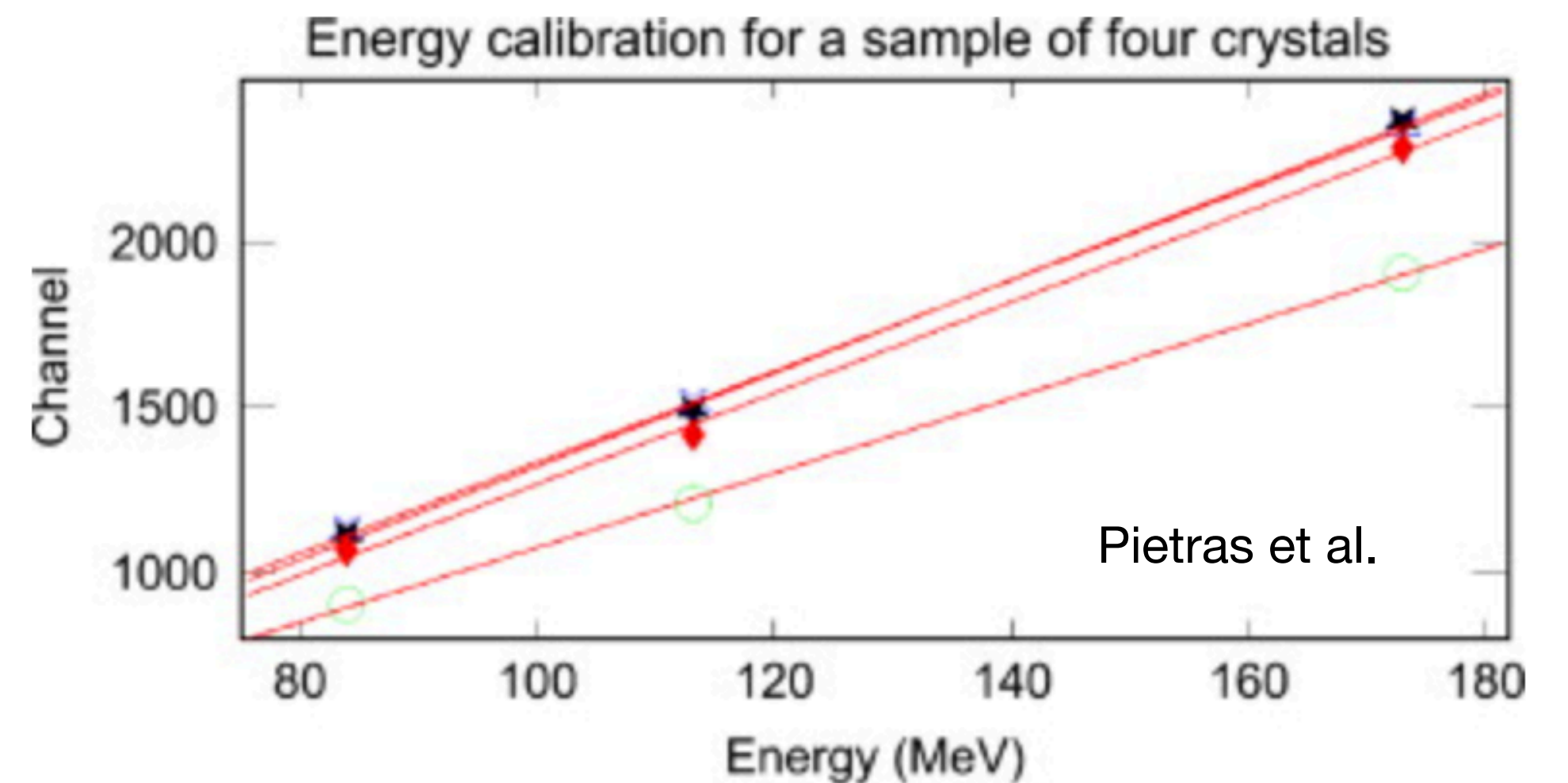


# Califa Calibration

Na 22 gamma source, 511 keV & 1274 keV peak energy



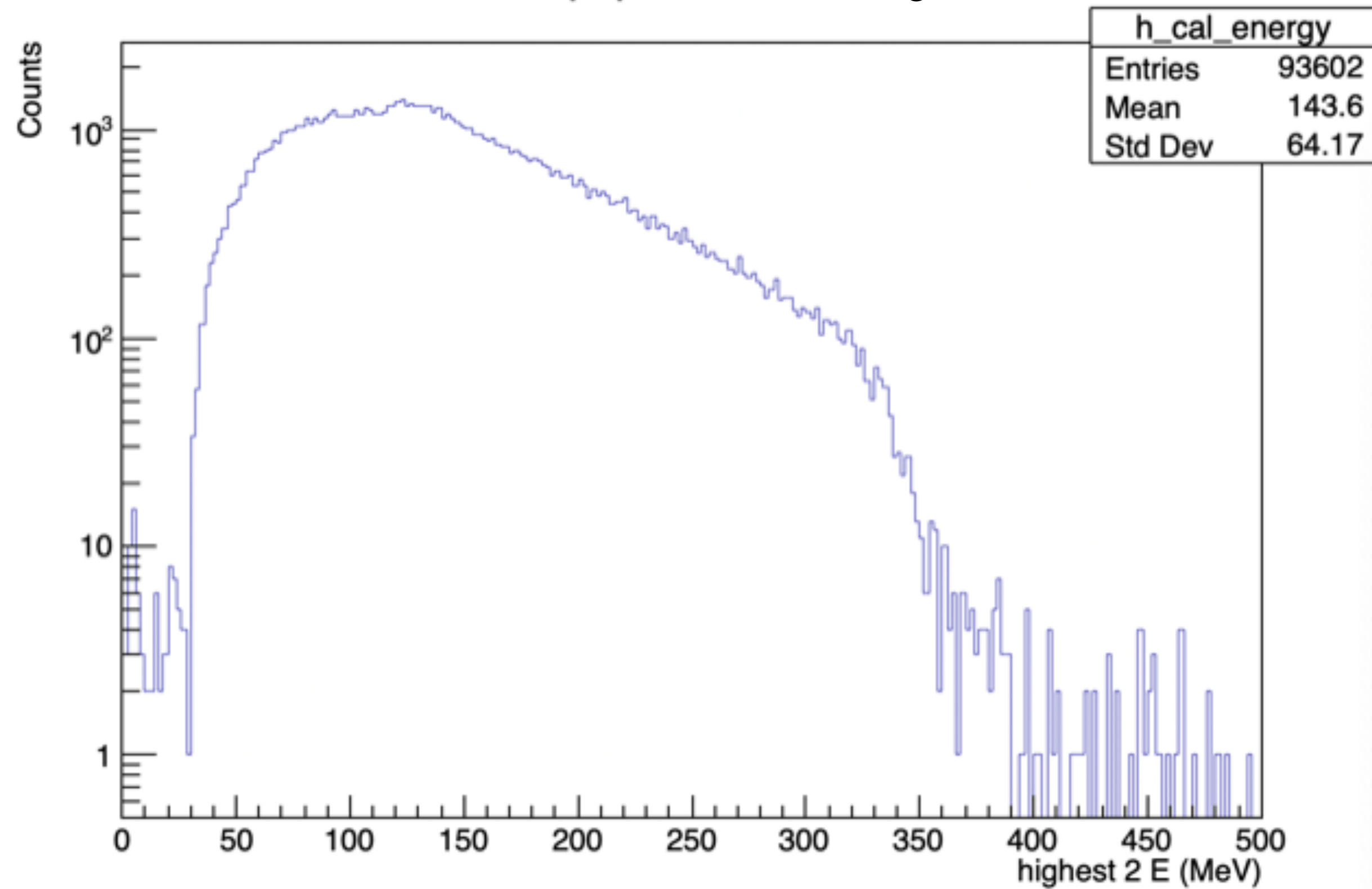
Next steps:  
AmBe source for 4.4 MeV  
Cosmic rays for higher energy  
calibration



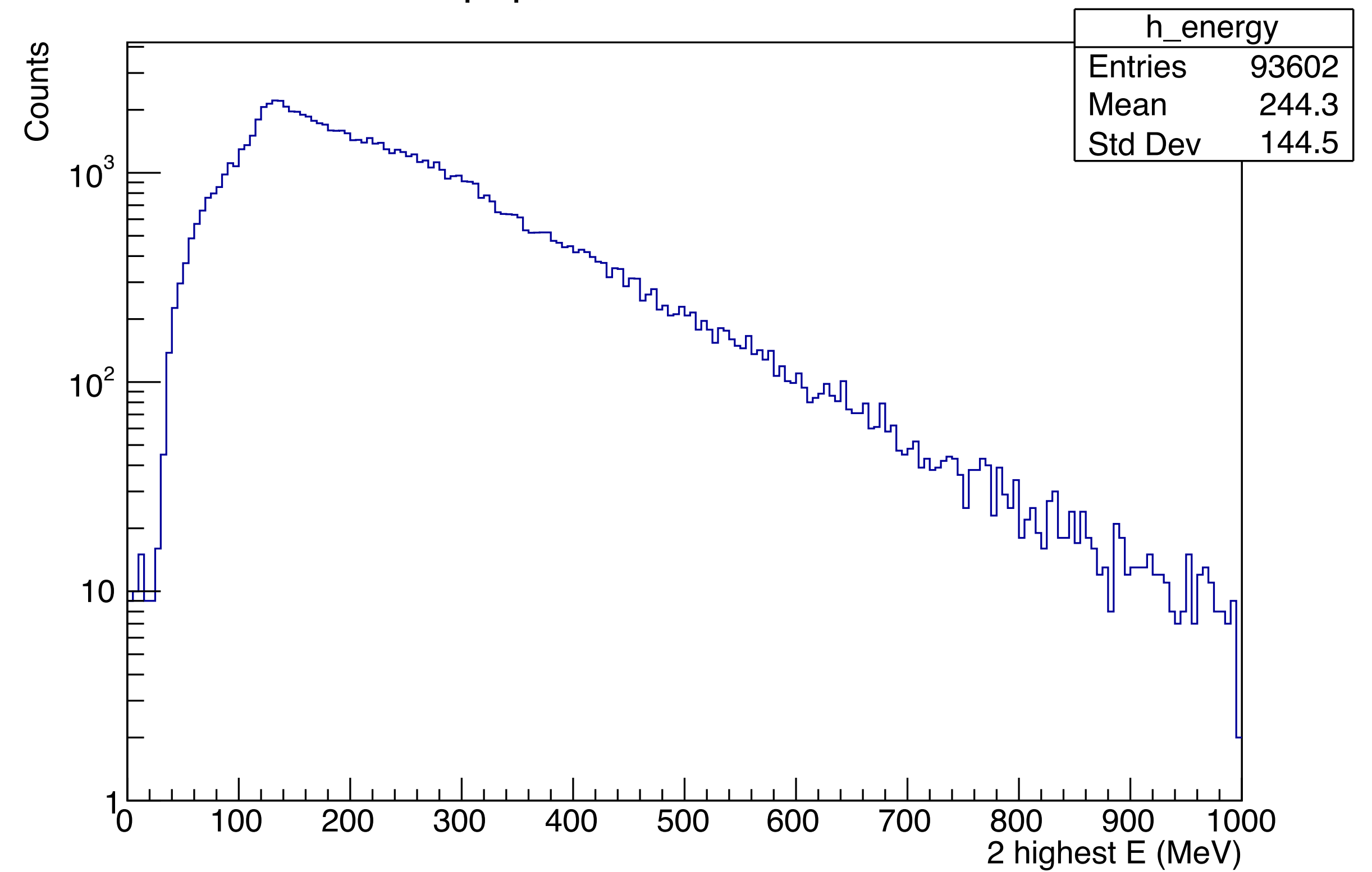
# p2p events

p2p reaction: at least two high energy hits (>20 MeV) on Califa hit level

p2p, cal level , single los hit

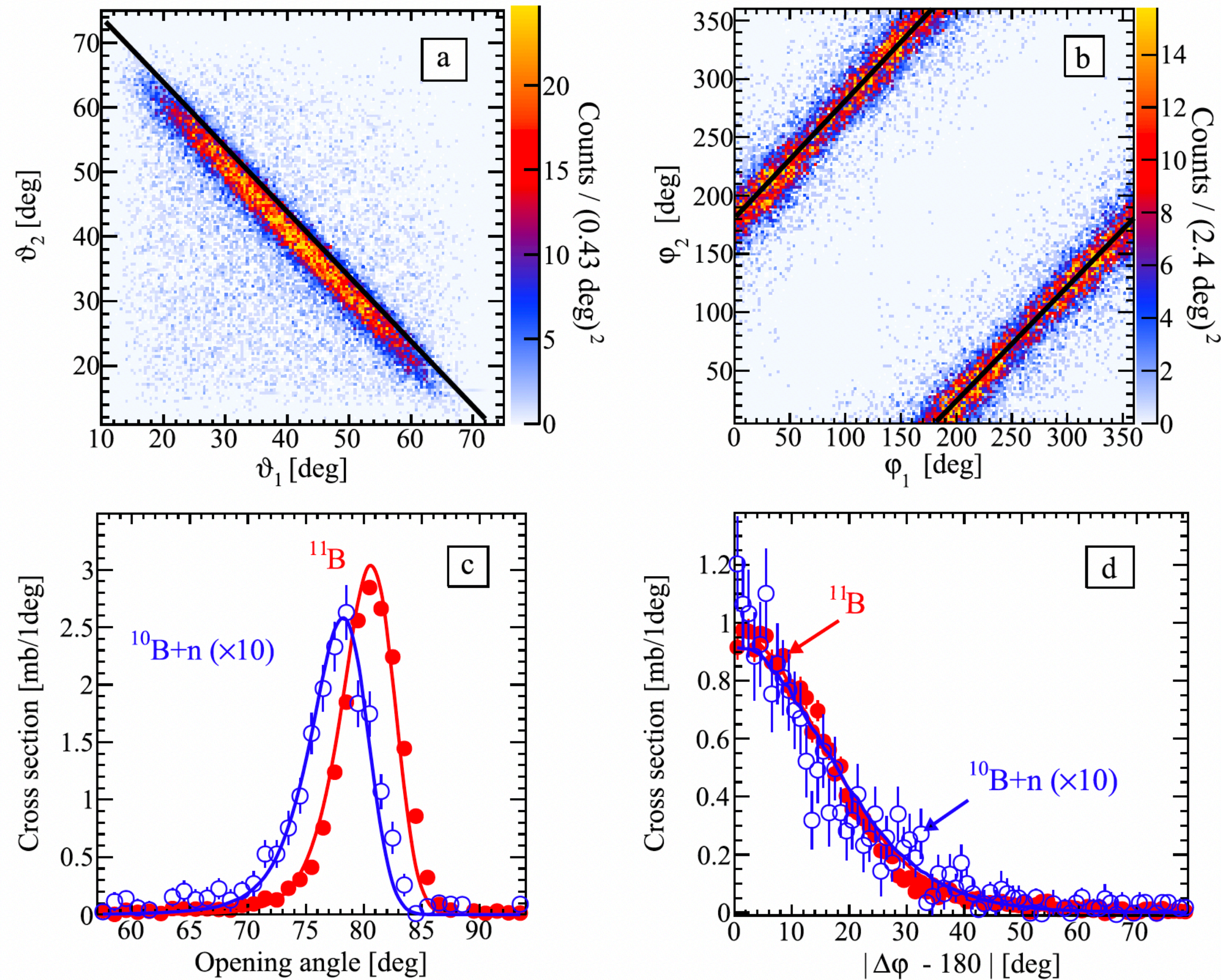


p2p, hit level, loshit==1





# $^{12}\text{C}$ mean field proton results

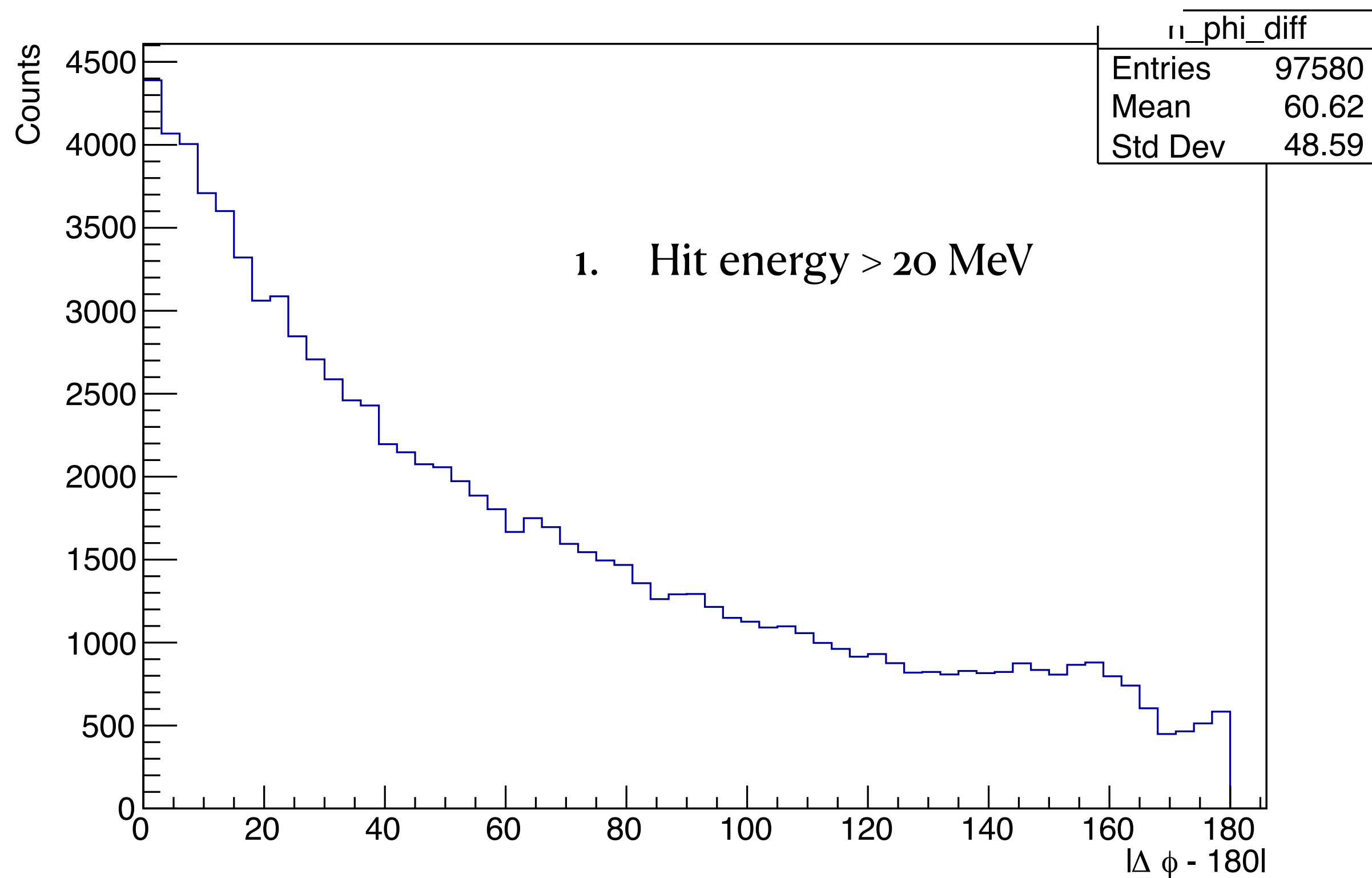


400 MeV/u beam

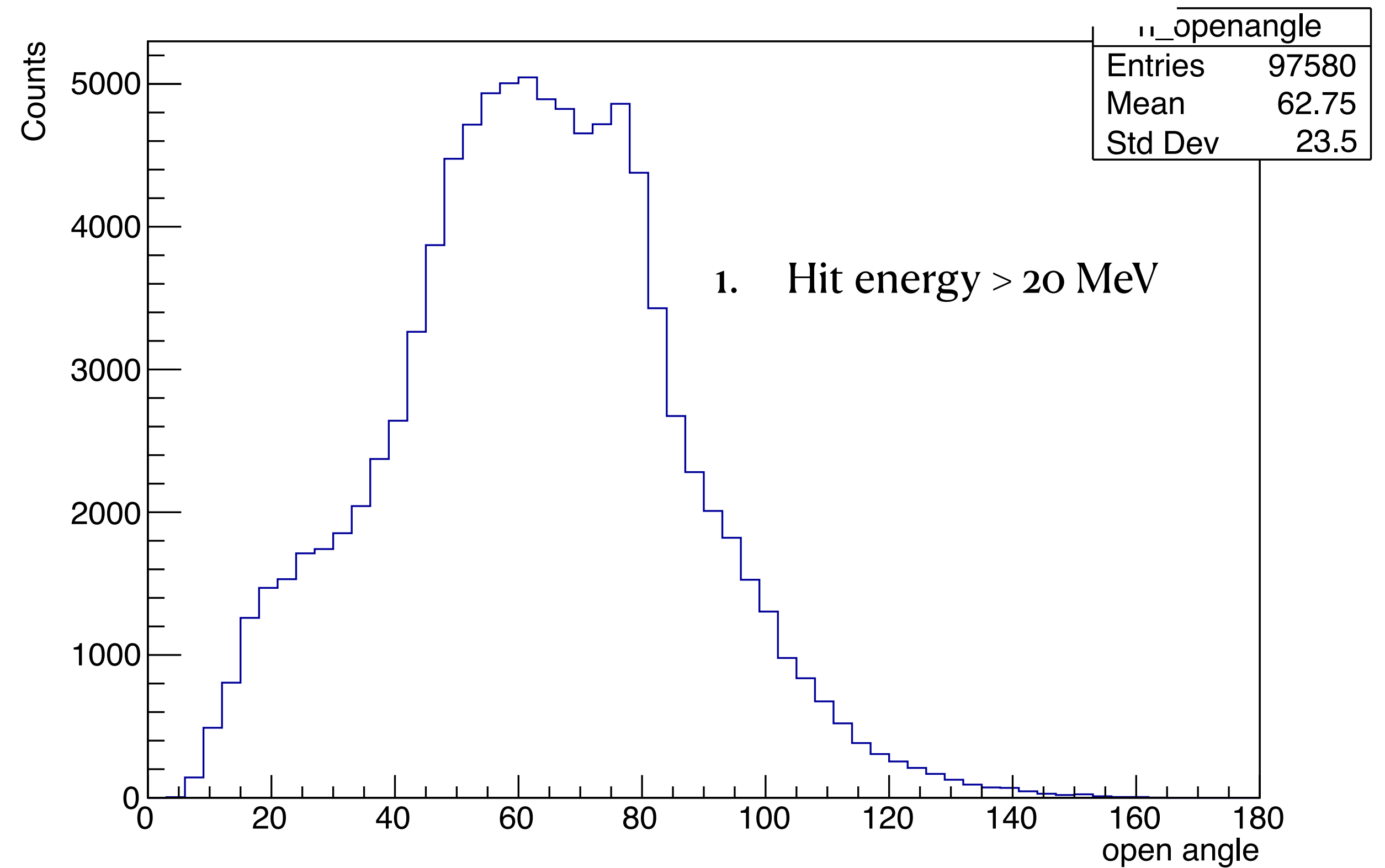


# p2p events: angular correlation

$||\phi_1 - \phi_2| - 180|$  (degree)



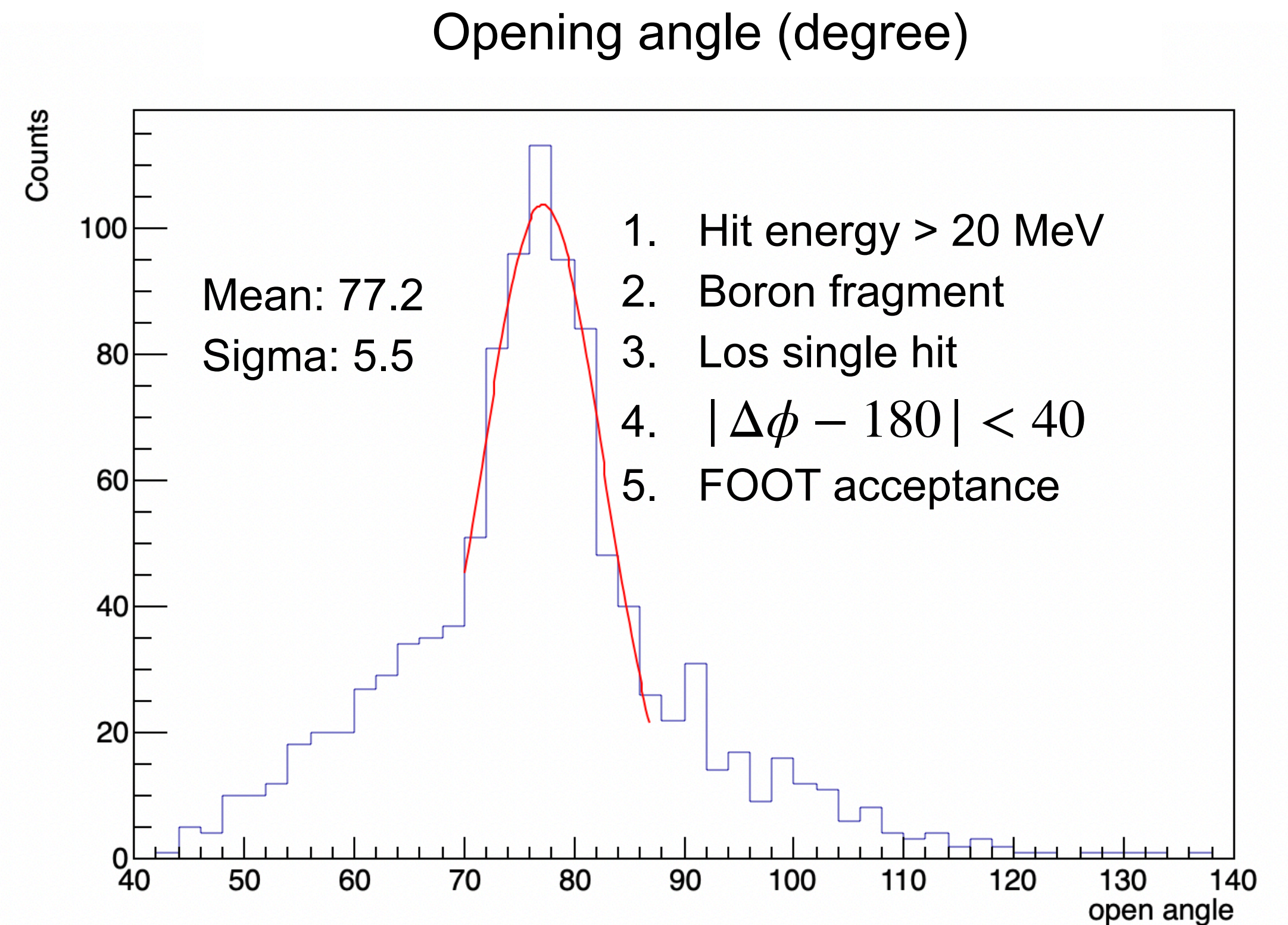
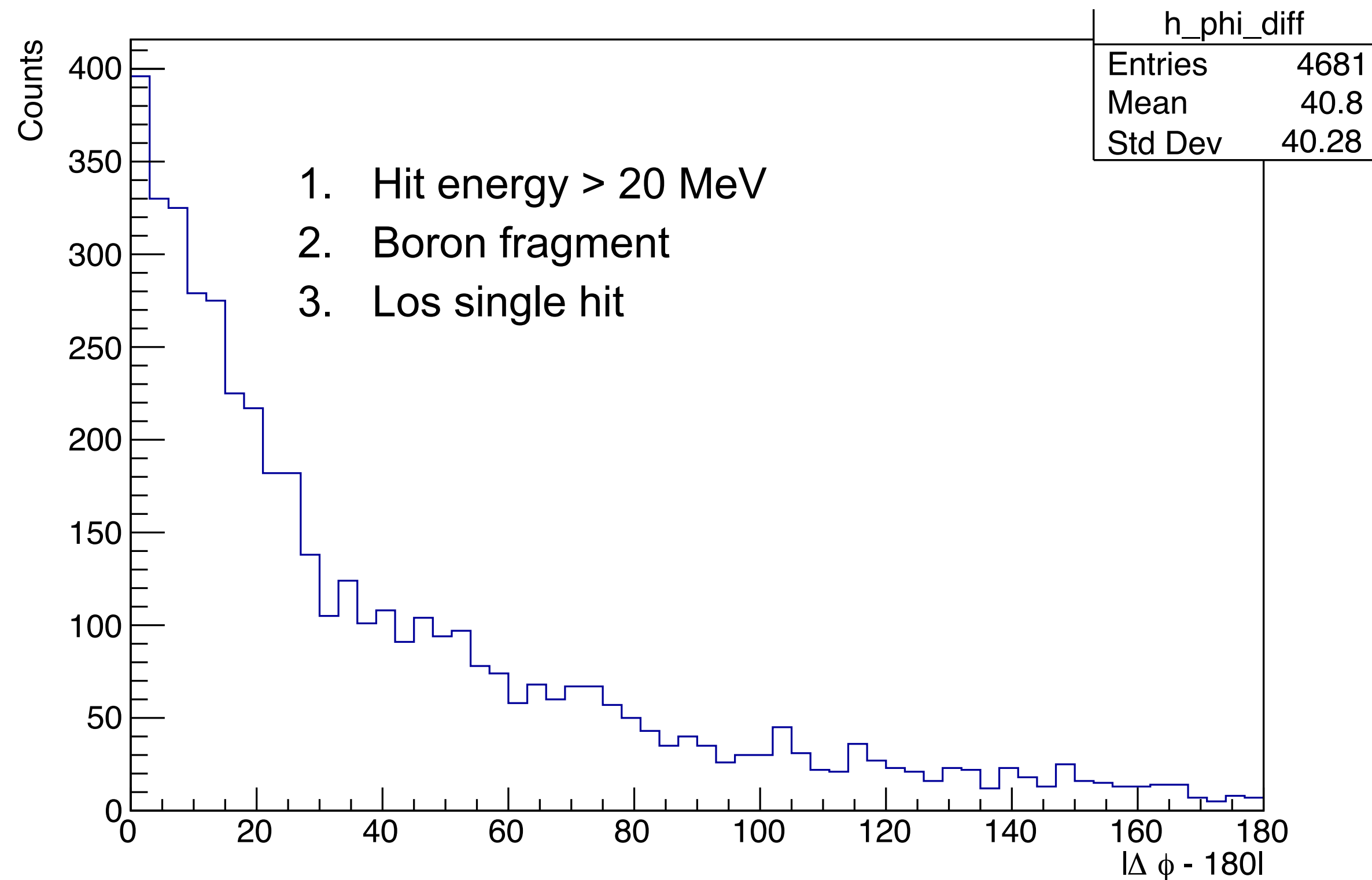
Opening angle (degree)



# p2p events: physical cuts

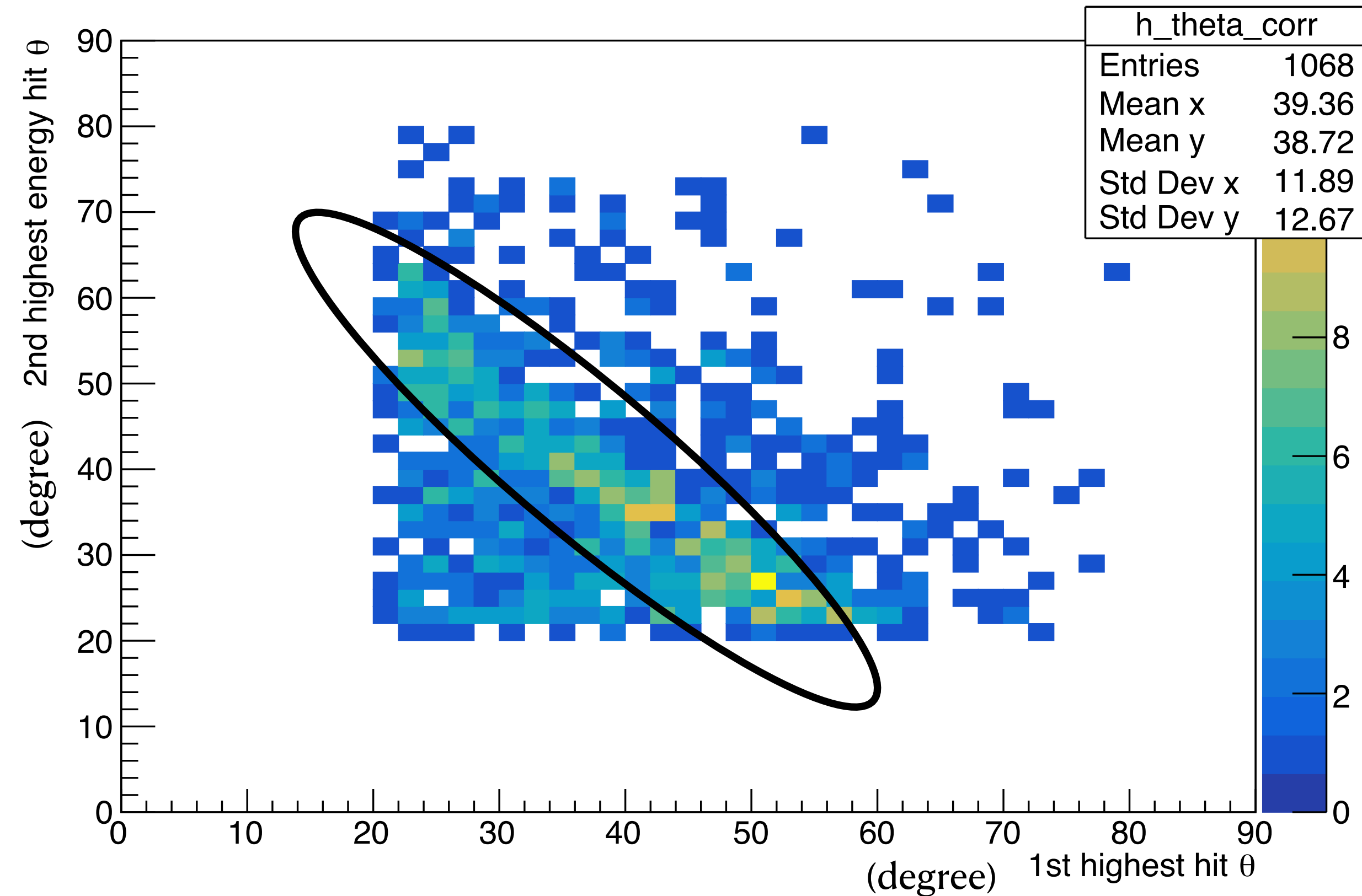
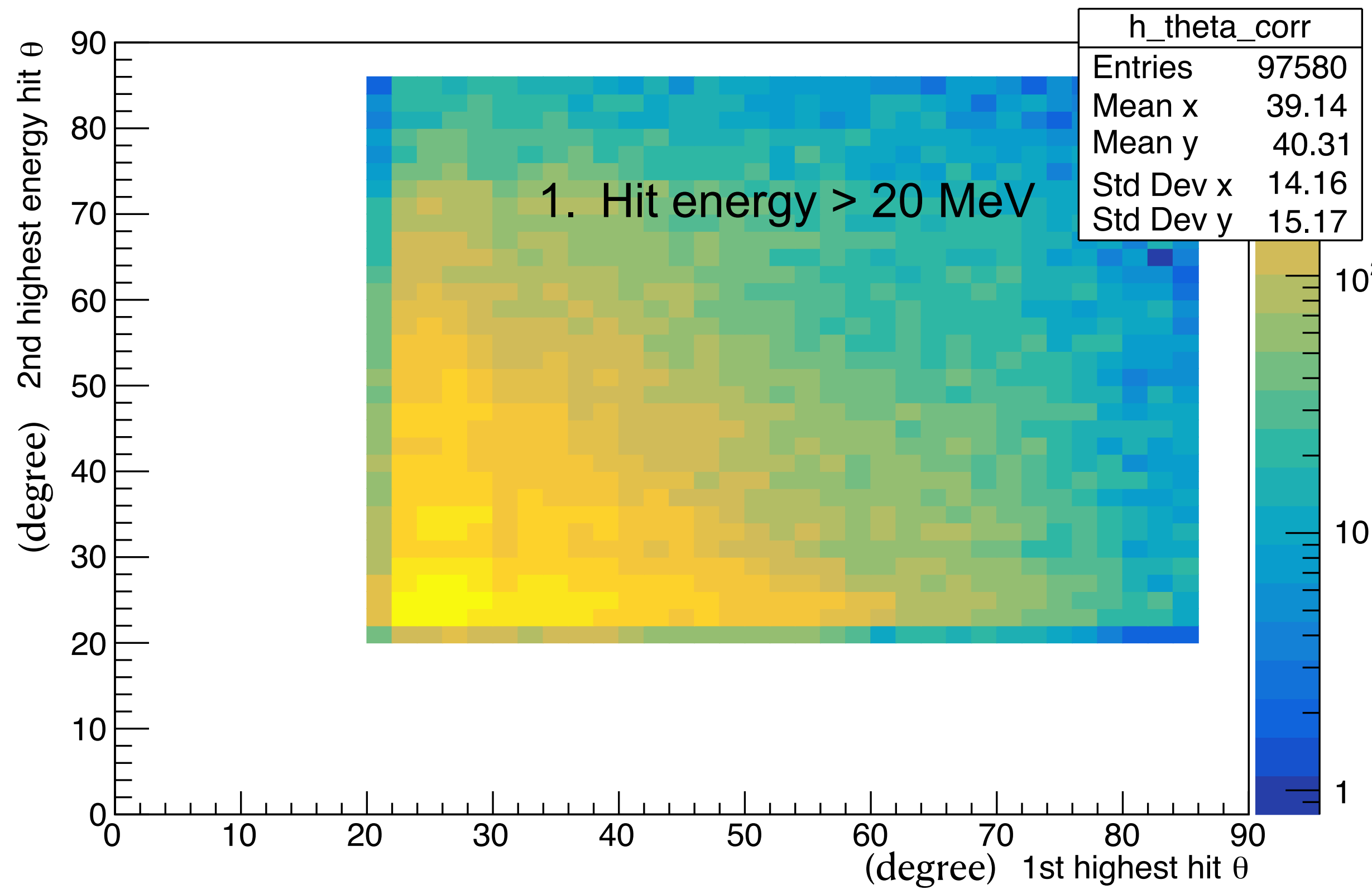
Expected: protons back-to-back in phi  
opening angle  $\sim 76$  degrees for 1.25 GeV/u beam

$$||\phi_1 - \phi_2| - 180| \text{ (degree)}$$



# p2p events: theta Correlation

1. Hit energy > 20 MeV
2. Boron fragment
3. Los single hit
4.  $|\Delta\phi - 180| < 40$
5. FOOT acceptance



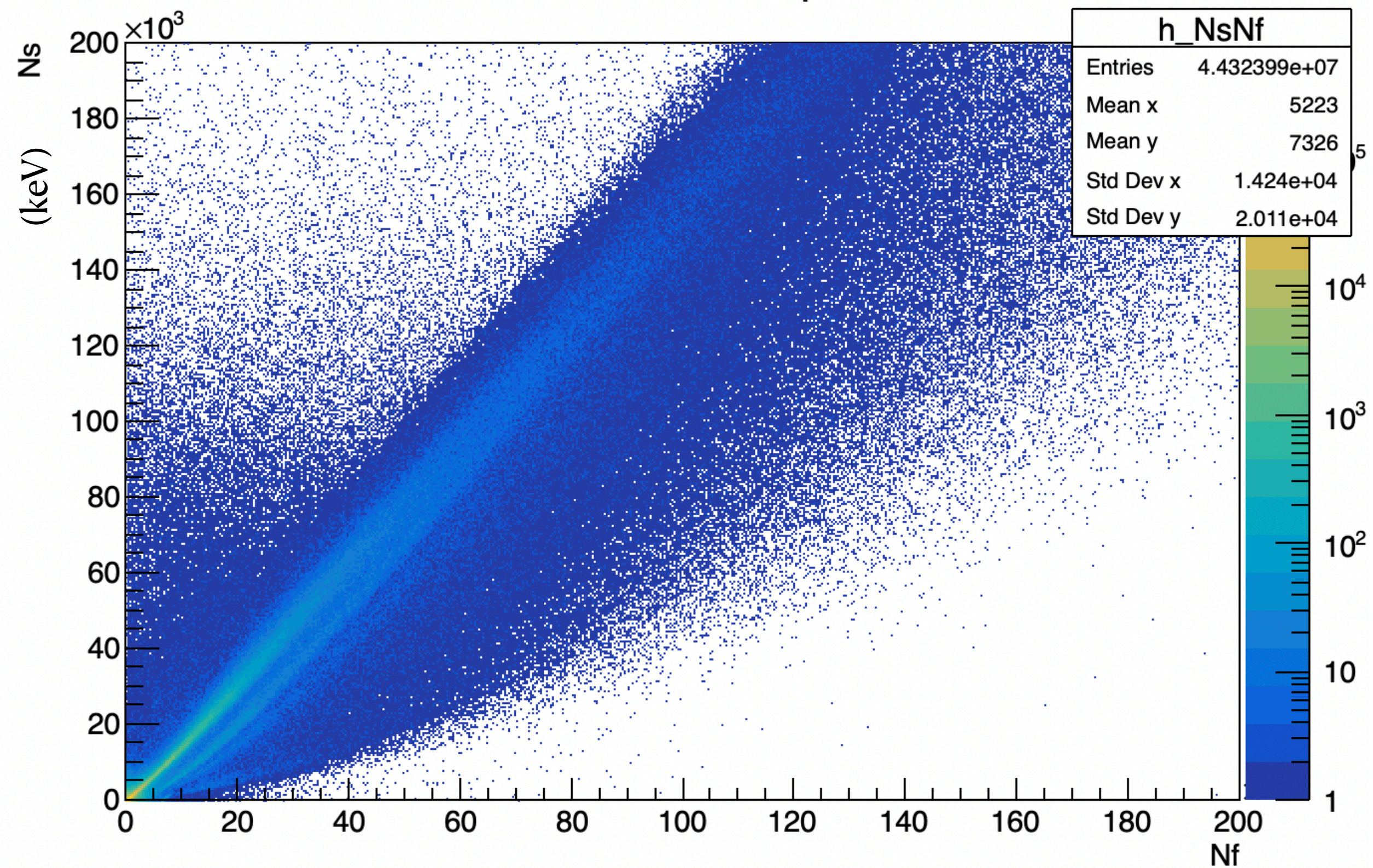


# Particle Identification

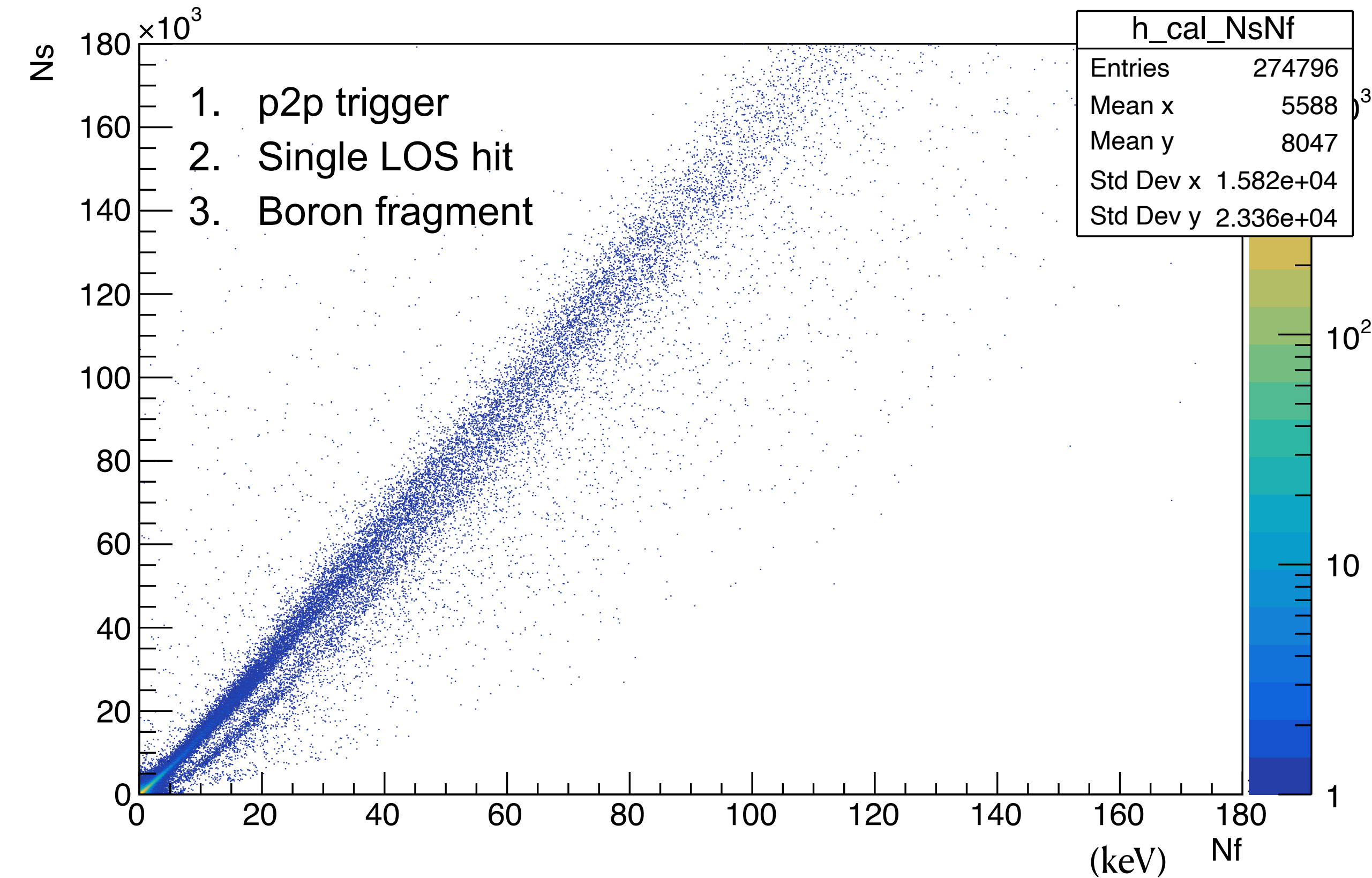
$$L(t) = \frac{N_f}{\tau_f} \exp(-t/\tau_f) + \frac{N_s}{\tau_s} \exp(-t/\tau_s) - \frac{N_r}{\tau_r} \exp(-t/\tau_r)$$

Fast (Nf) and slow (Ns) component from CsI response

Cal Level, Ns v. Nf



Cal Level, Ns v. Nf, with physical cuts





# Conclusion and Future Work

- Preliminary work without PID in Califa: expected patterns in angular correlations between high energy hits after physical cuts.
- Extend Califa calibration to higher energy
- Reconstruct missing momentum using Califa energy and FOOT tracking
- Add reaction channels with fragment ID
- Study SRC properties in radioactive nuclei  $^{16}\text{C}$
- Future systematic study along the isotopic chain

# **Thank you for listening**

**And a special thank you to the team at GSI for discussion  
and support**