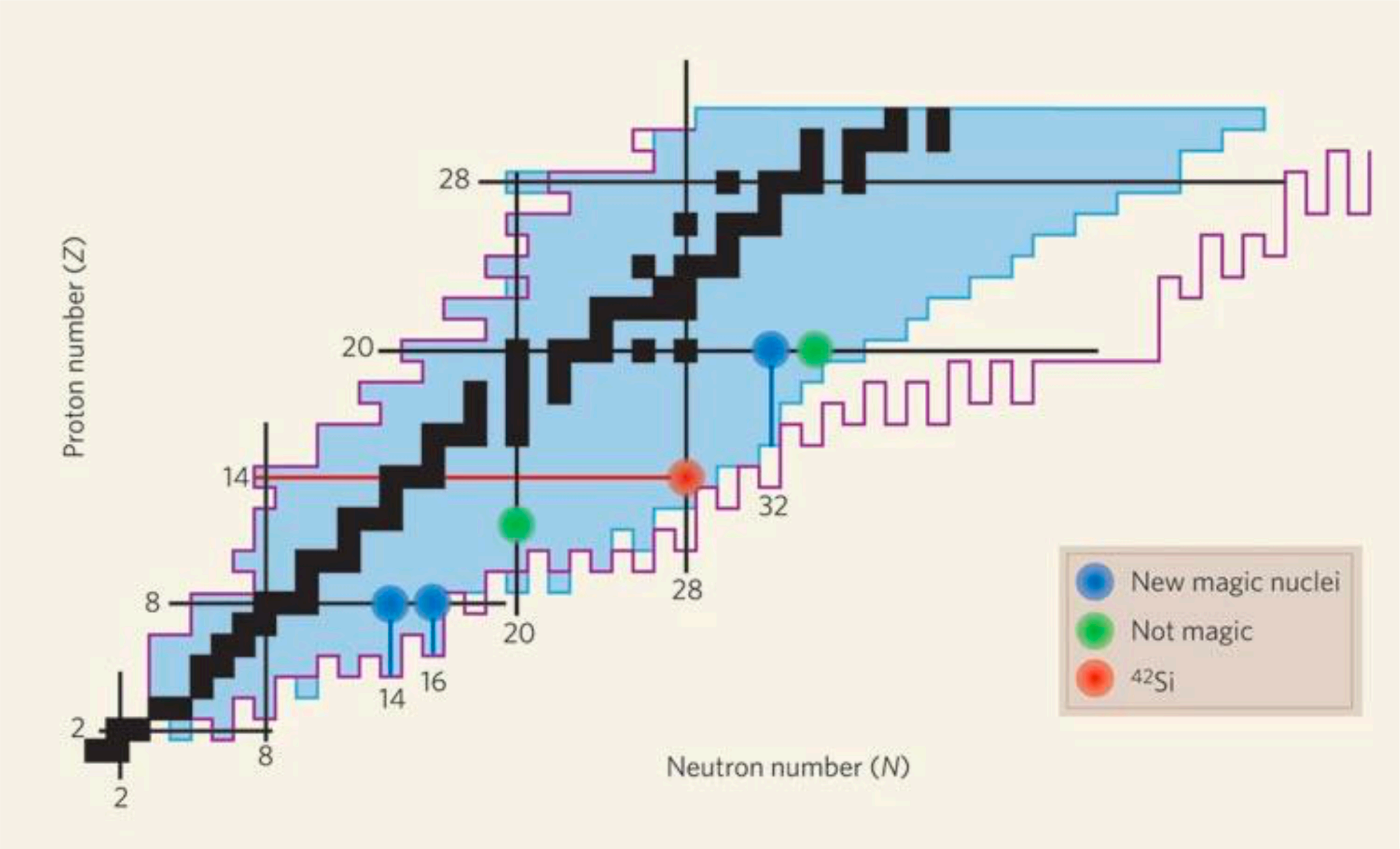
Status update on SRC in radioactive nuclei

— study of 16C in inverse kinematics

Hang Qi, 08/2022

Nuclear Structure changes with isospin asymmetry



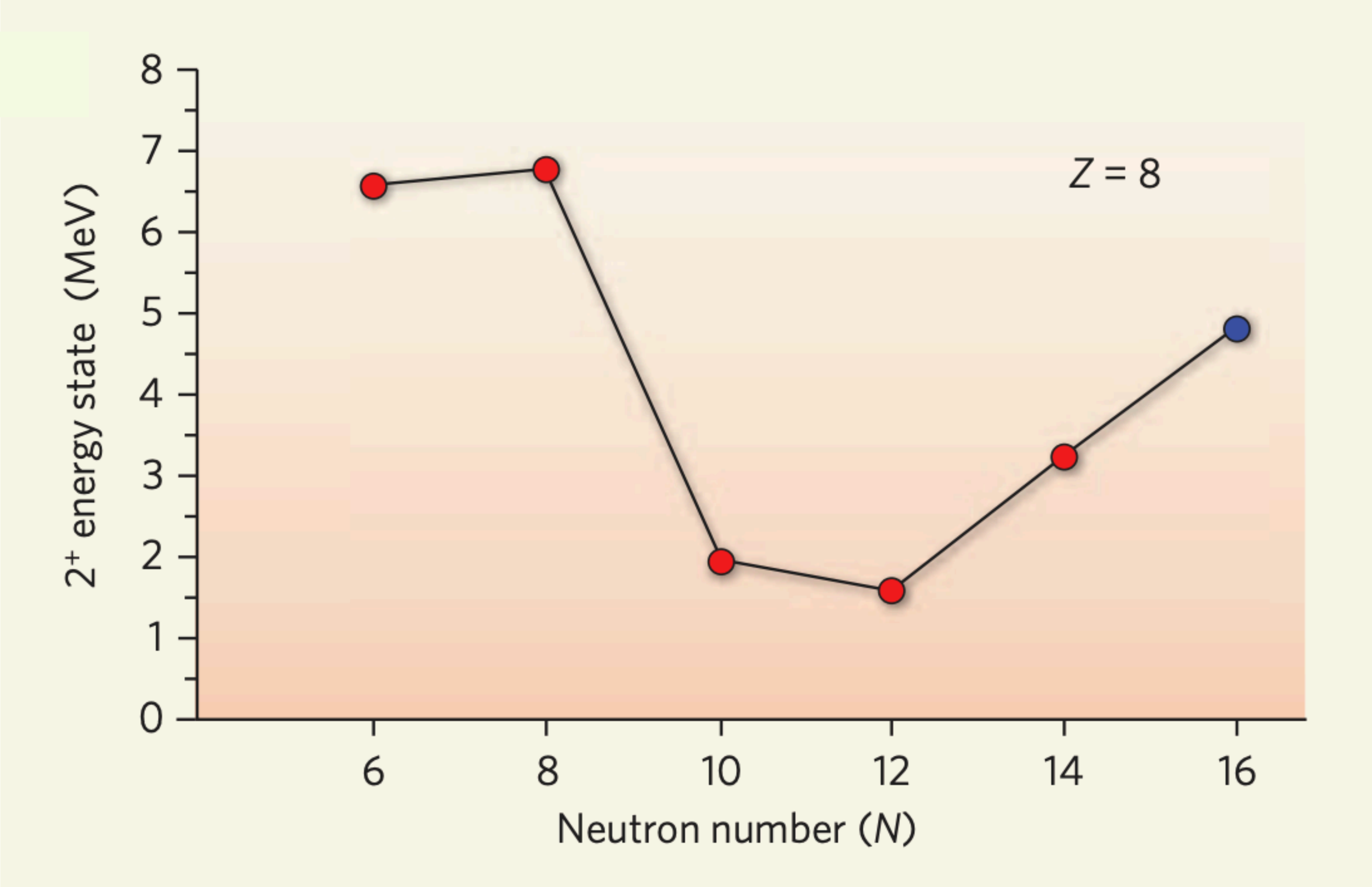
R. Janssens, Nature 2005.

Shell structure evolution

In isospin-asymmetric nuclei
some magic numbers disappear and new ones appear!

Oxygen isotopes, 14O to 24O

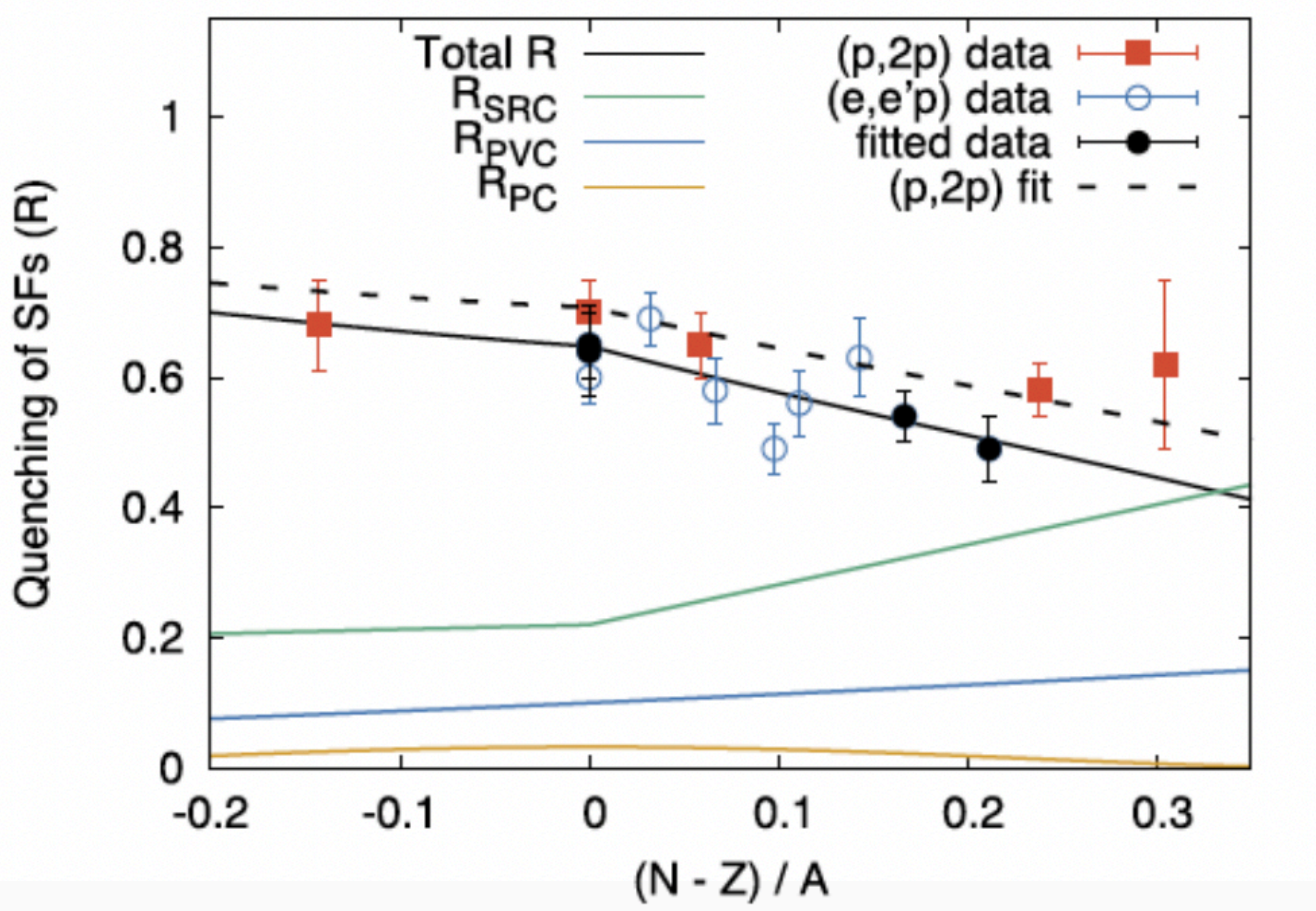
Doubly magic nuclei
N,Z values
2,8,20,28,50….



[Kanungo et al. PRL 102, 152501, 2009]
[Hoffman et al. PLB 672, 17-21, 2009]

Quenching of spectroscopic factor

Quenching associated with long-ranged and short-ranged correlations

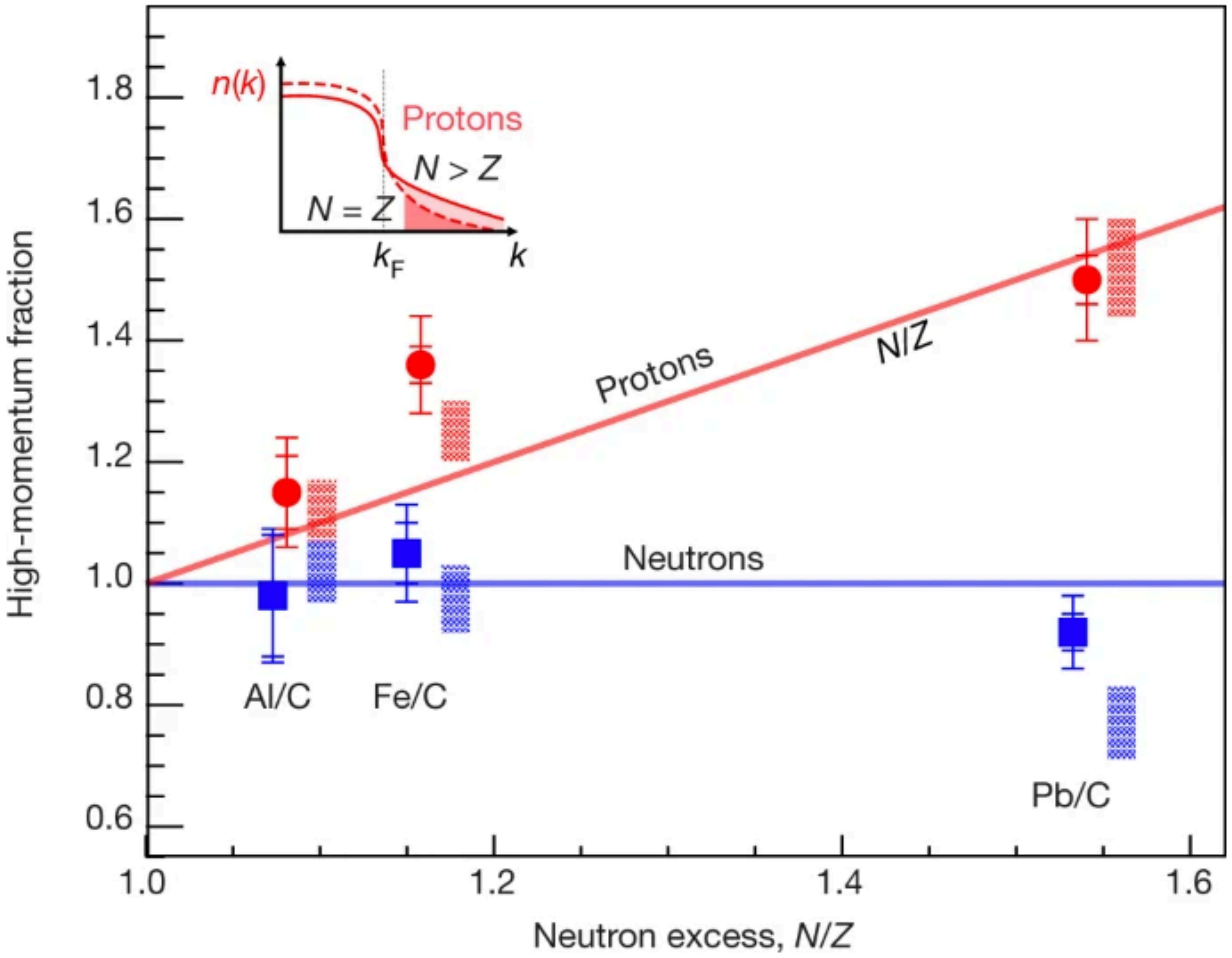


Paschalis et al., 2020, Phys. Lett. B 135110

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



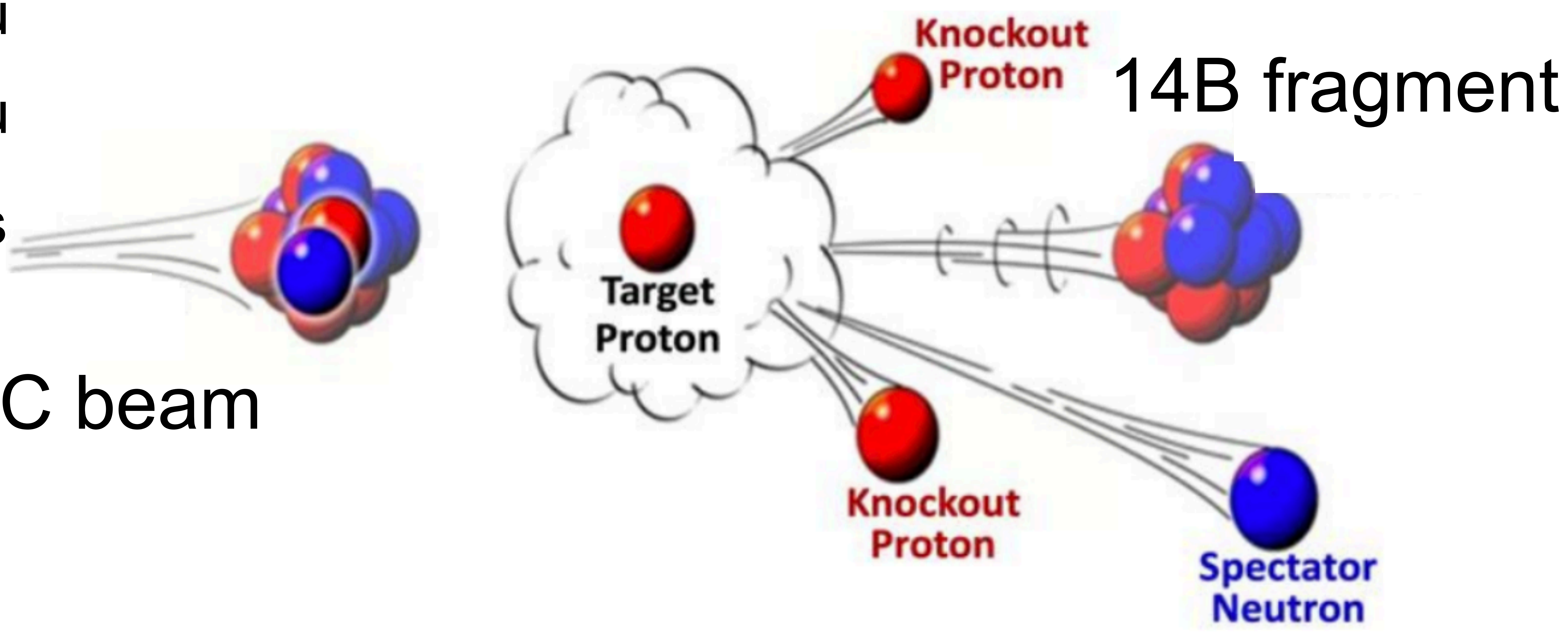
M. Duer et al. (CLAS), Nature 2018.

Experimental Goals

- First look at SRC within radioactive nuclei (16C)
  - 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}C beam, 1.25 GeV/u
  - ^{12}C beam, 1.25 GeV/u
  - Intensity: 1×10^5 pps



Reaction channels

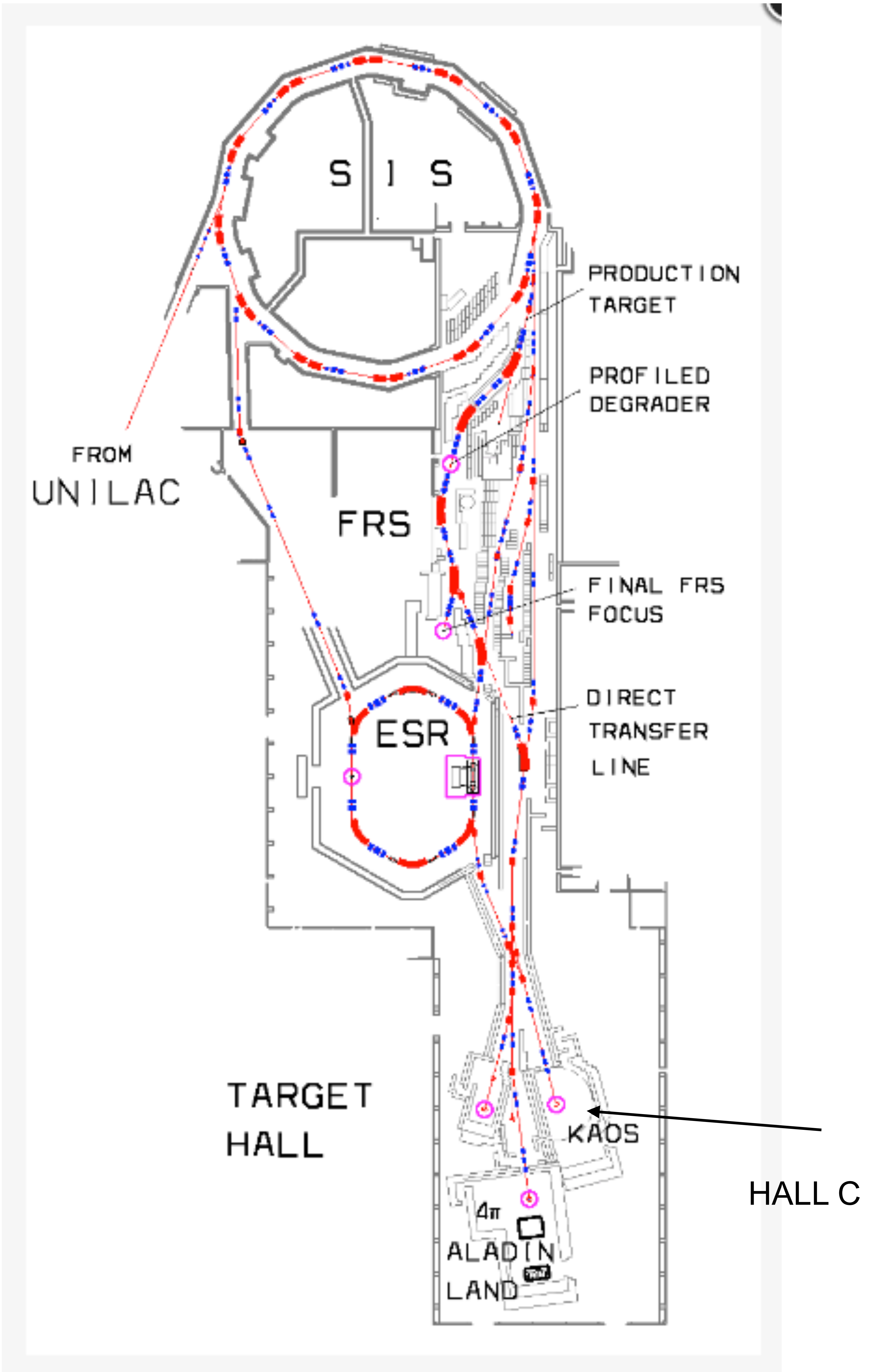
- Single Proton knockout:
  - $^{16}C(p,2p)^{15}B^*$
  - $^{12}C(p,2p)^{11}B^*$

- SRC channels
  - $^{16}C(p,2pn)^{14}B^*$, Sn=0.97 MeV
  - $^{16}C(p,2pp)^{14}Be^*$, Sn=1.775 MeV
  - $^{12}C(p,2pn)^{10}B^*$, Sn=8.437 MeV
  - $^{12}C(p,2pp)^{10}Be^*$, Sn=6.812 MeV

Incoming beam

FRS: Projectile fragment separator

- Production of neutron-rich nuclei via fragmentation (18O, beryllium target -> 16C)
- Separation and identification: magnetic rigidity -> P/Q, energy loss -> Q, time of flight

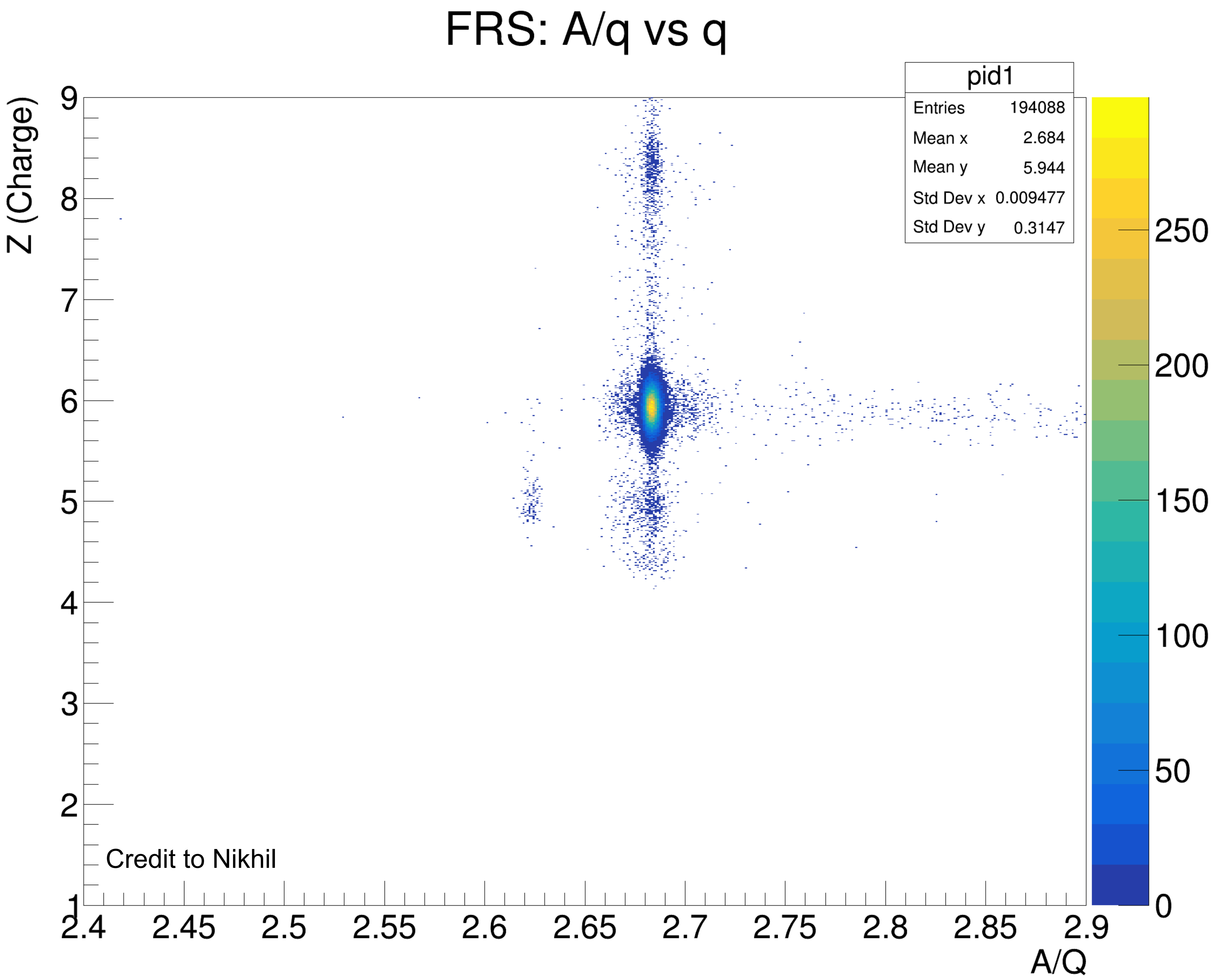


Incoming beam ID

^{16}C beam

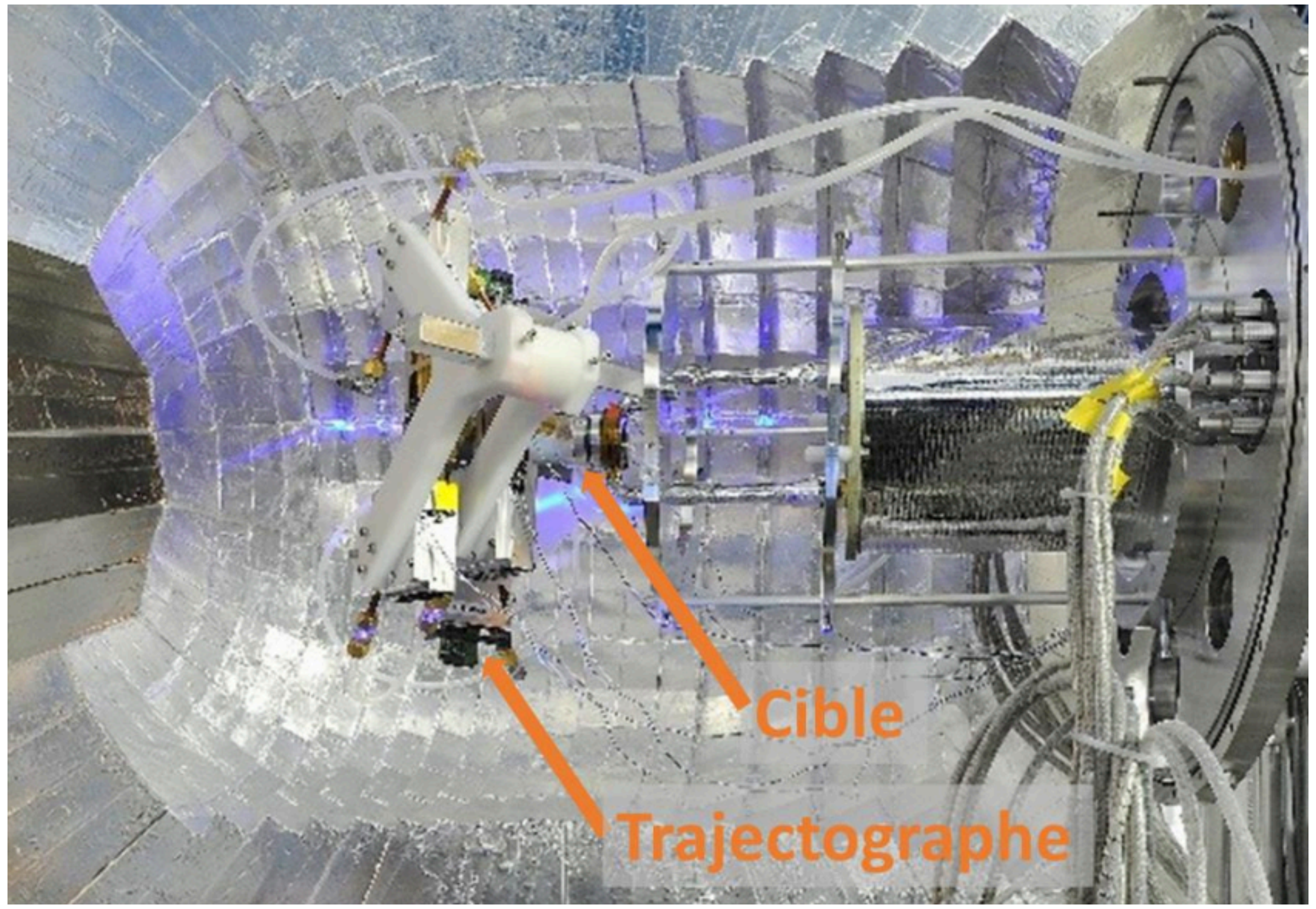
Gas ionization chamber

+ ToF measurement

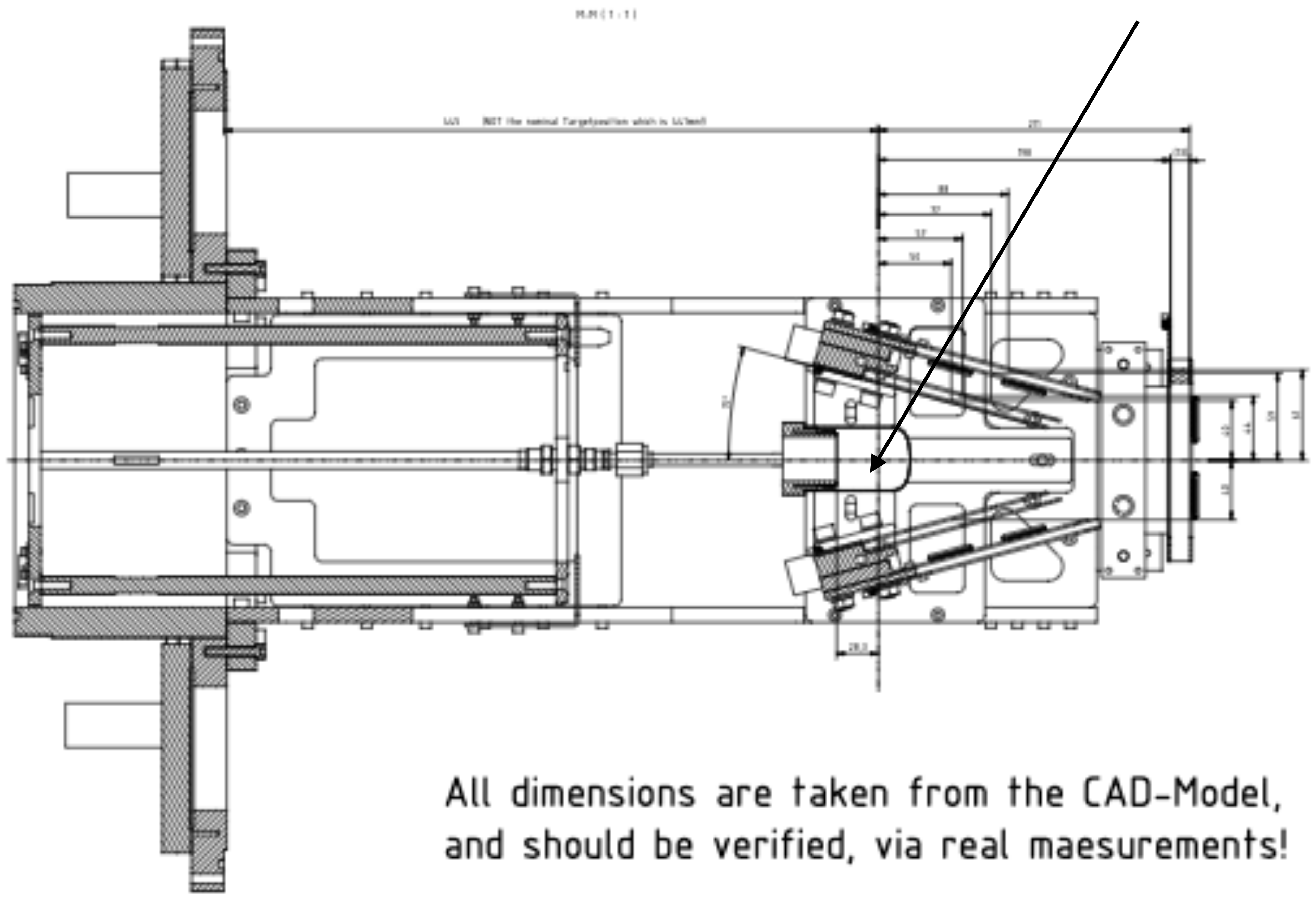


Liquid Hydrogen Target

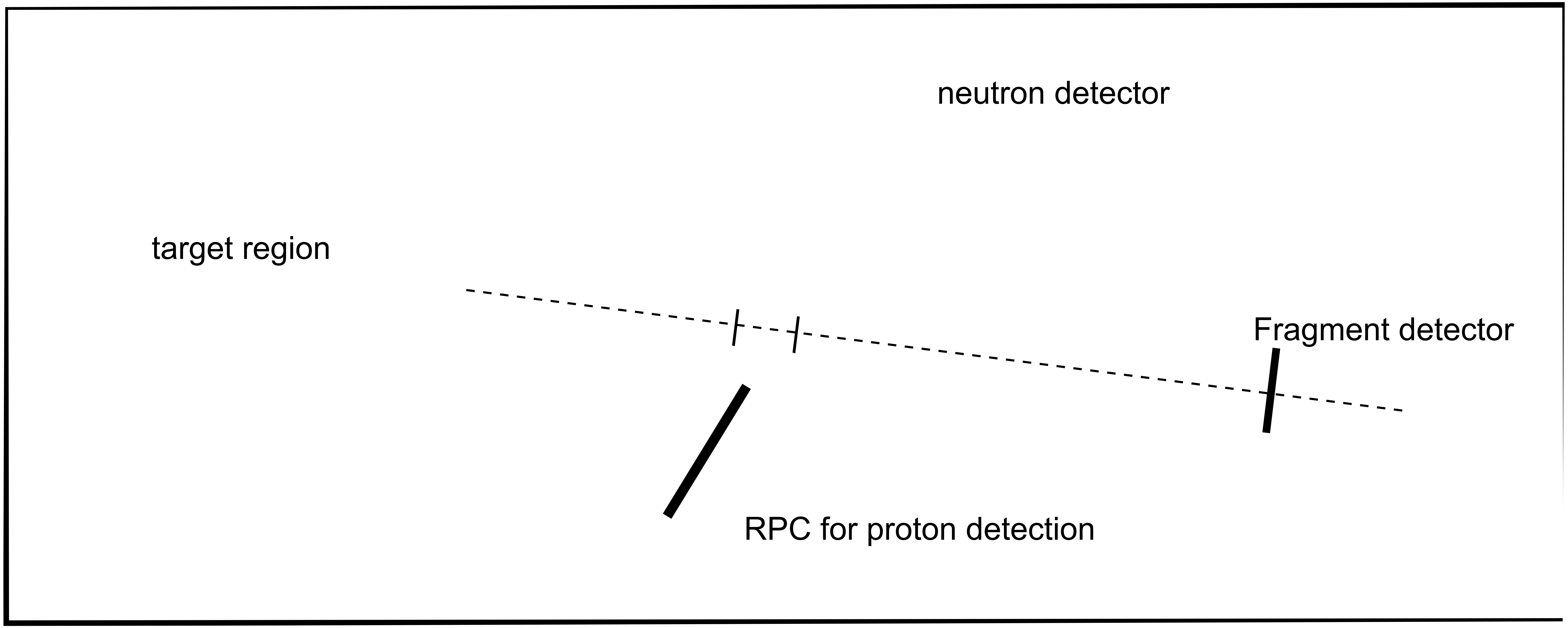
- 5cm liquid hydrogen target (LH2)



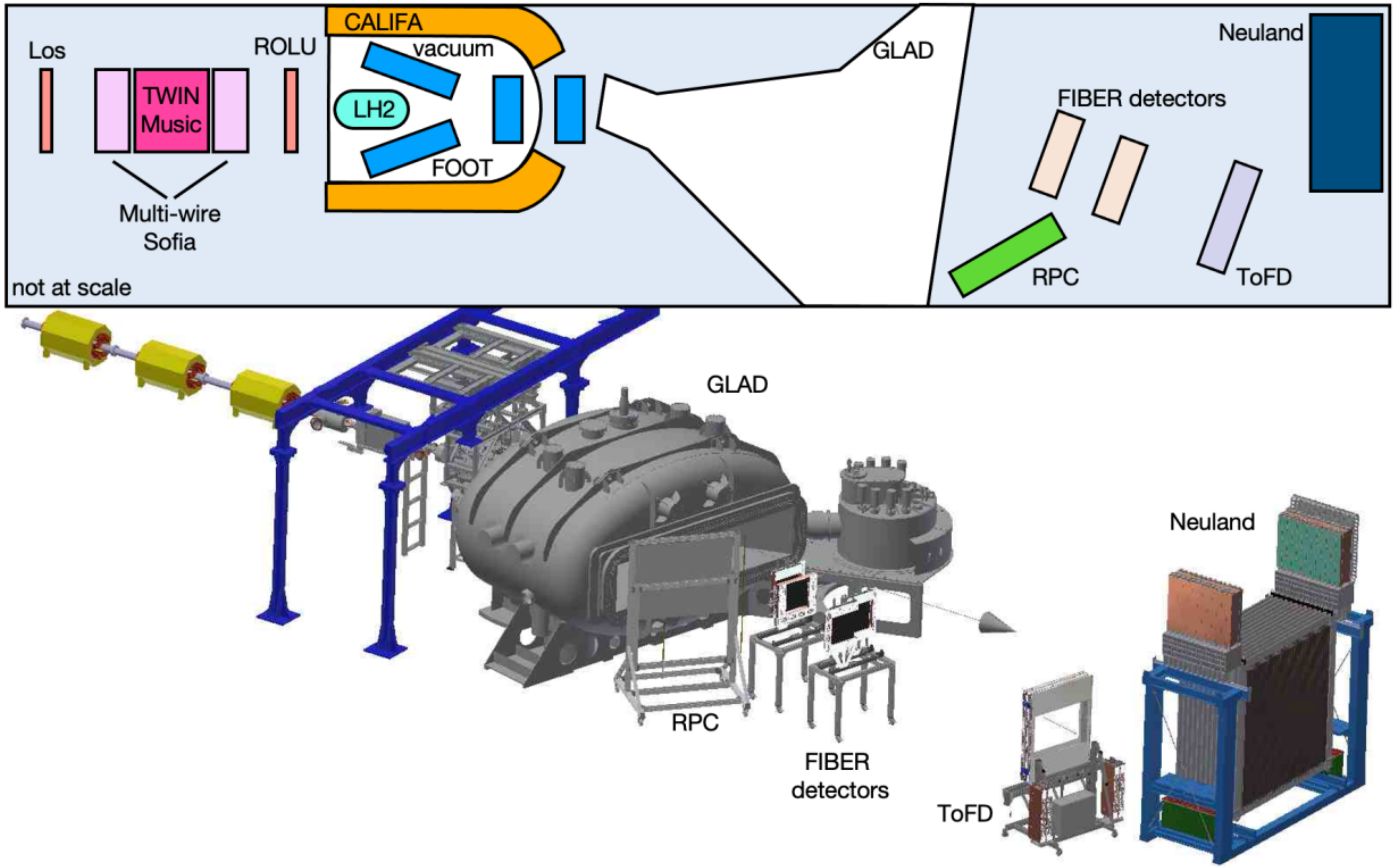
LH2 Target



Simulated trajectory



R^{3}B Setup

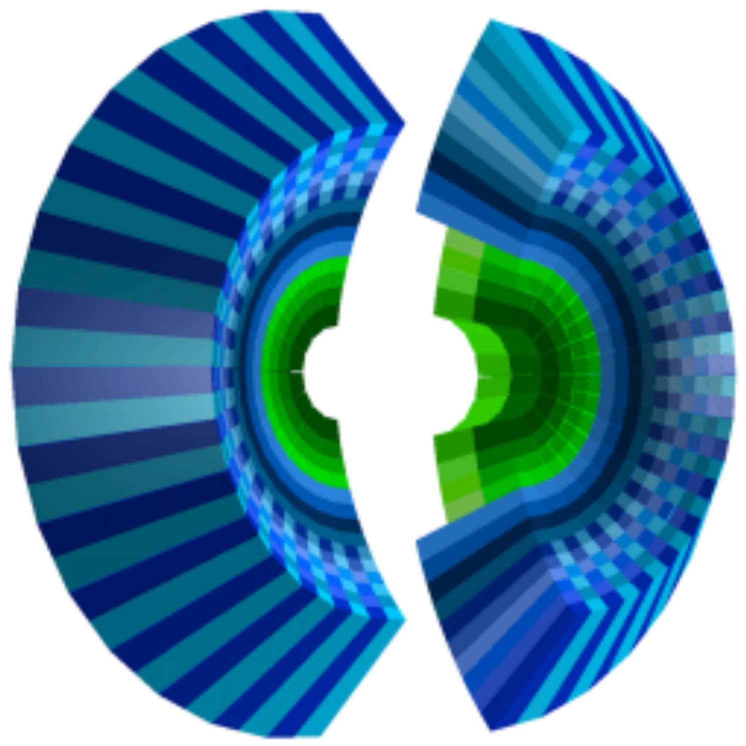


Los
ROLU
CALIFA
vacuum
TWIN
Music
LH2
FOOT
GLAD
Neuland
FIBER detectors
Multi-wire
Sofia
not at scale
RPC
ToFD
GLAD
Neuland
RPC
FIBER
detectors
ToFD

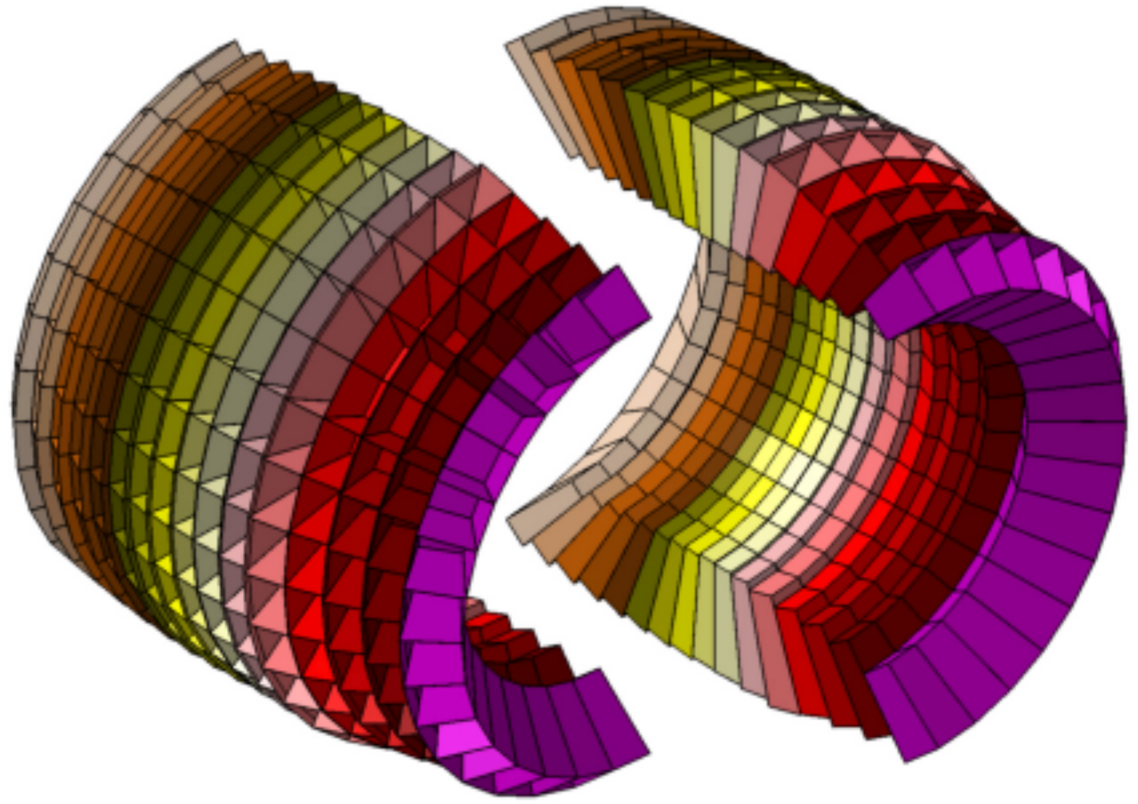
p2p: Califa

- 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

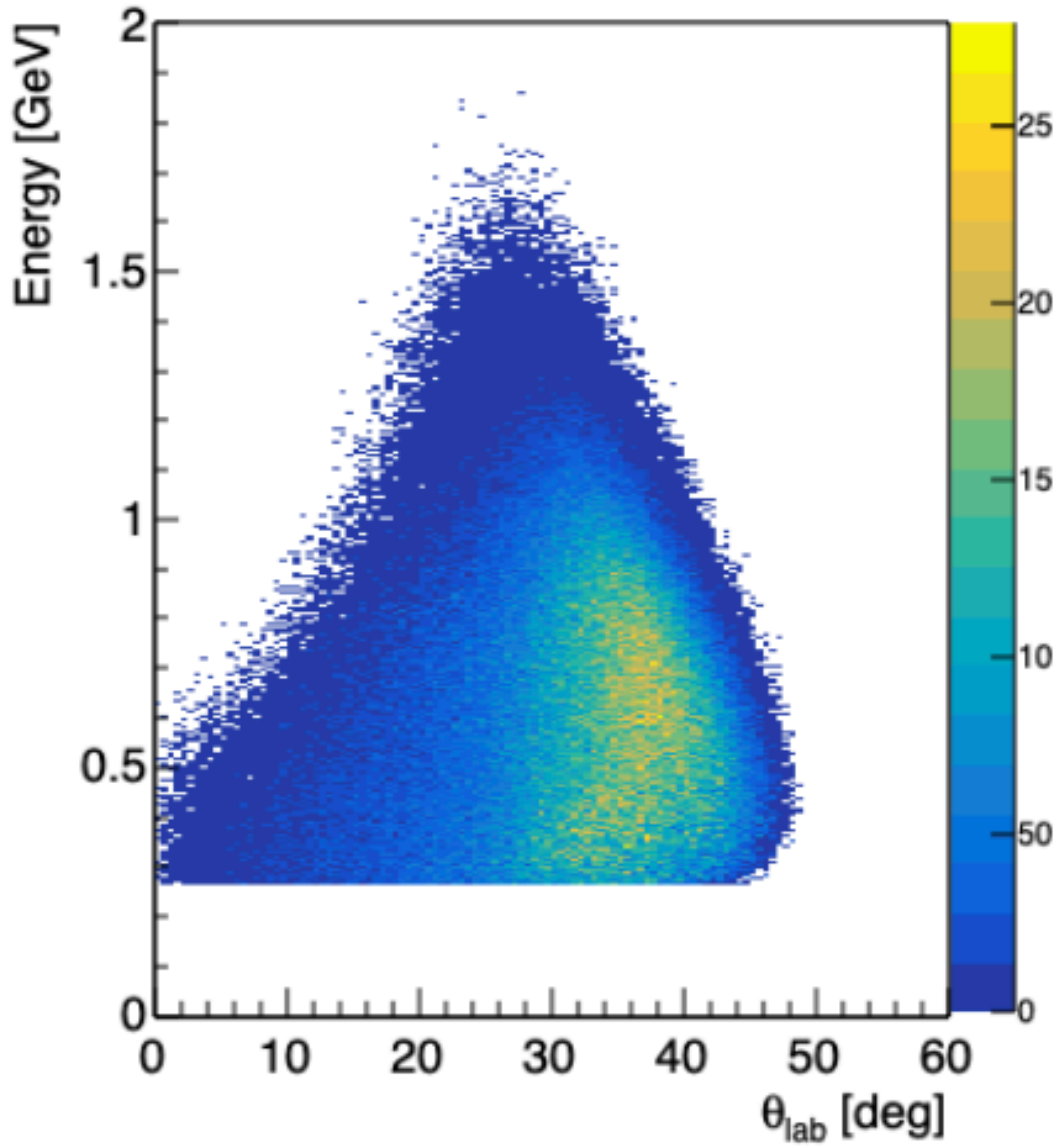
Endcap



Barrel



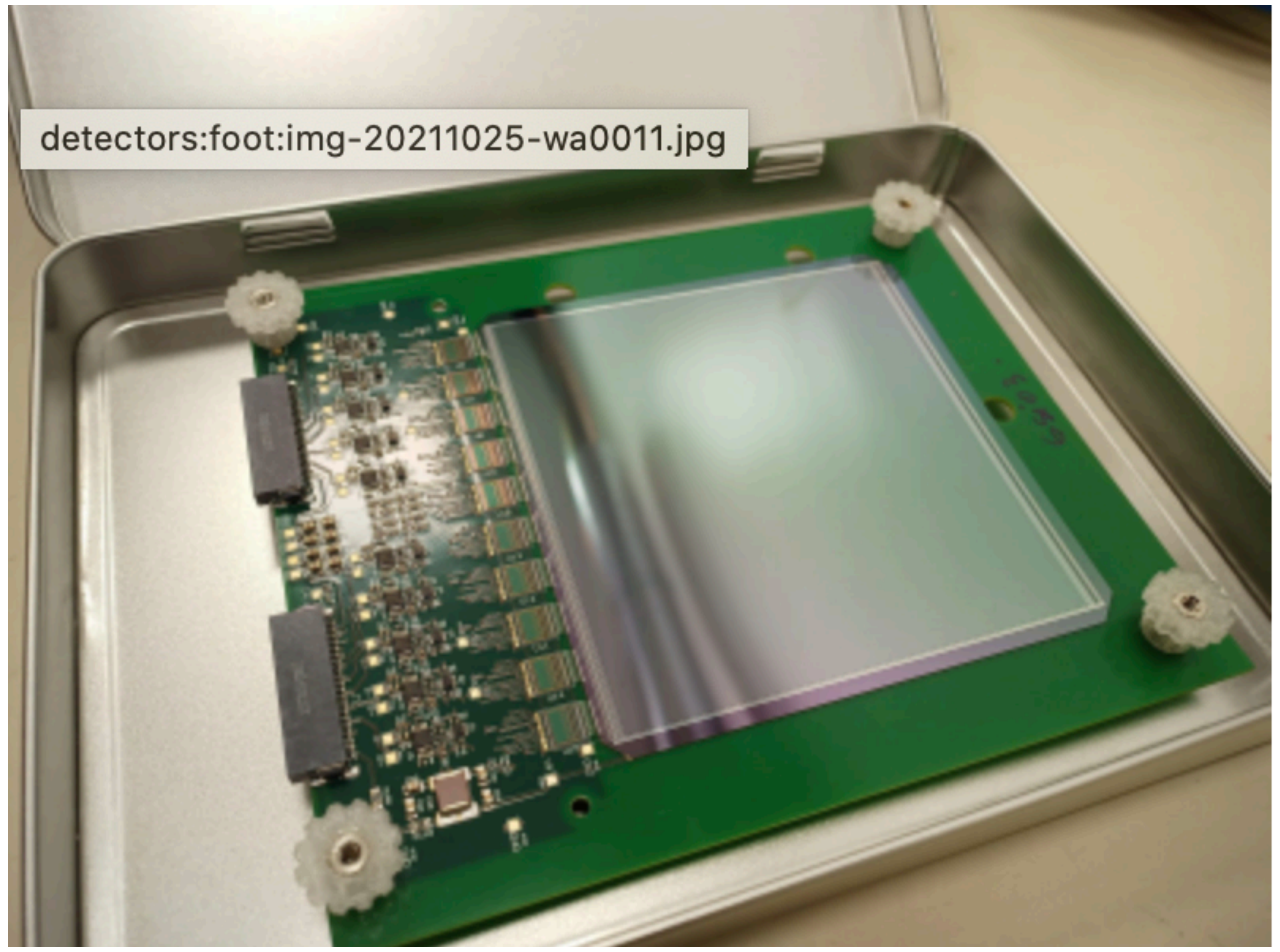
Simulate proton distribution
S522 proposal

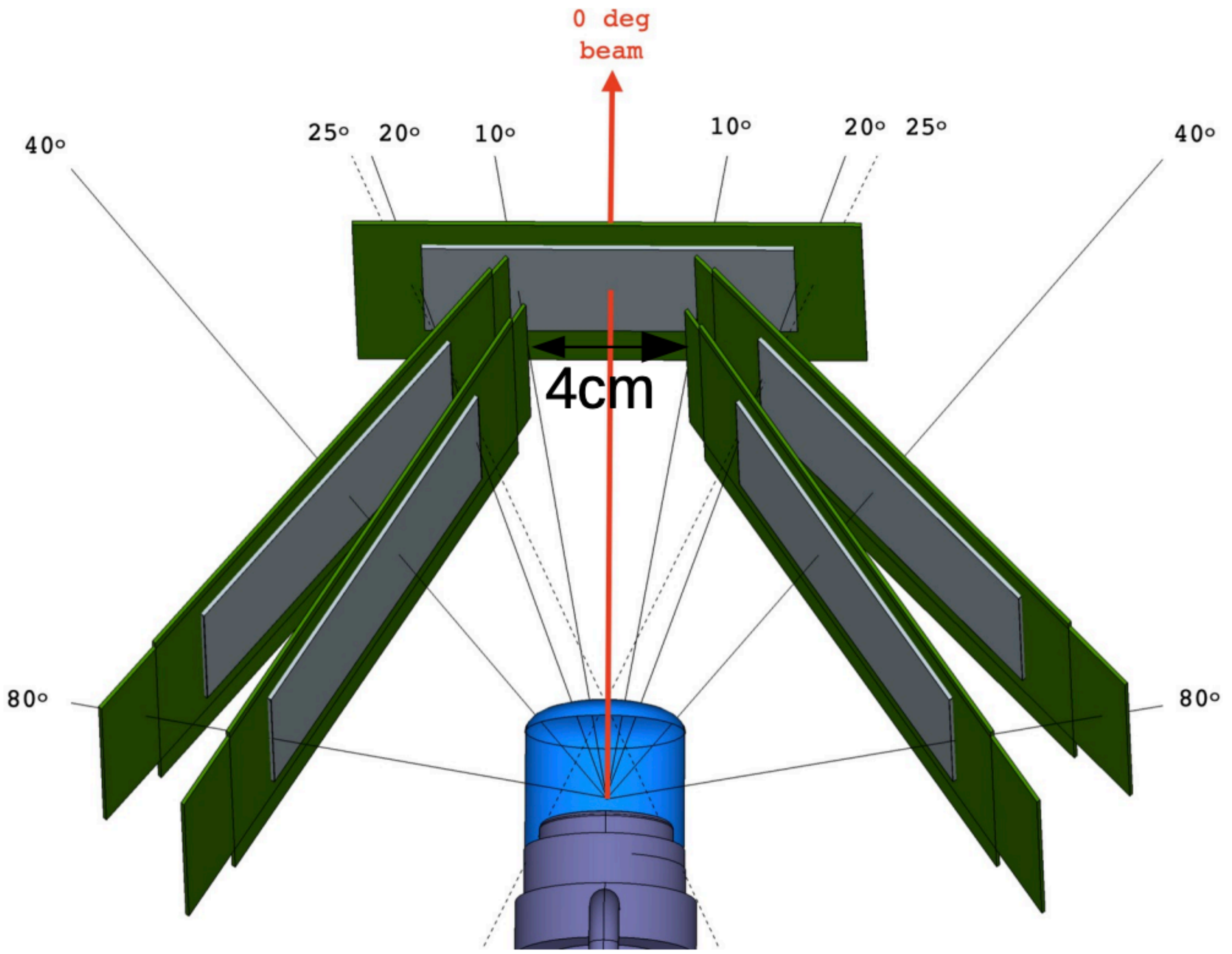


p2p: FOOT

Silicon tracking detectors, active area: 10cm x 10 cm

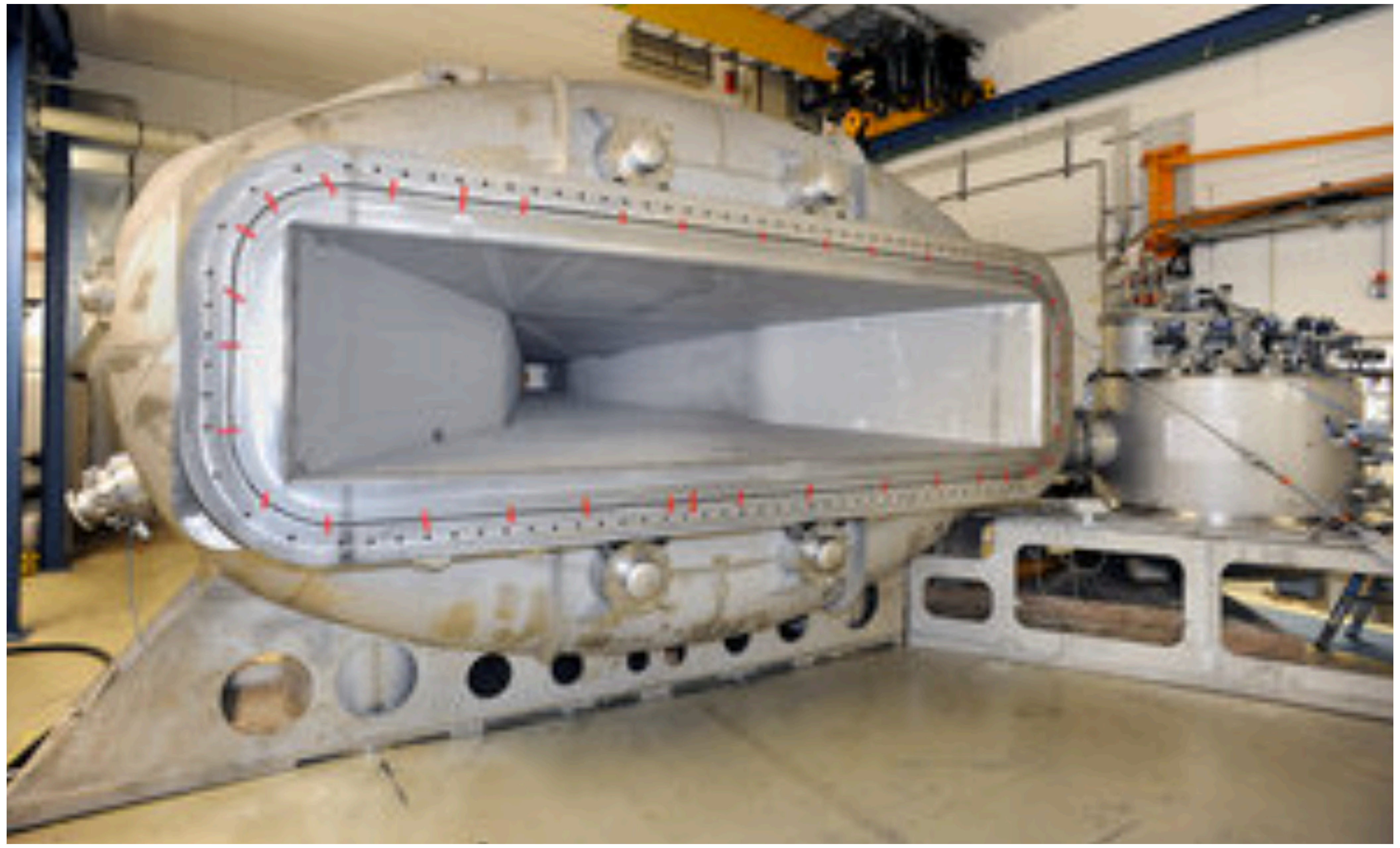
Effective strip pitch size 150 μm, 640 channels





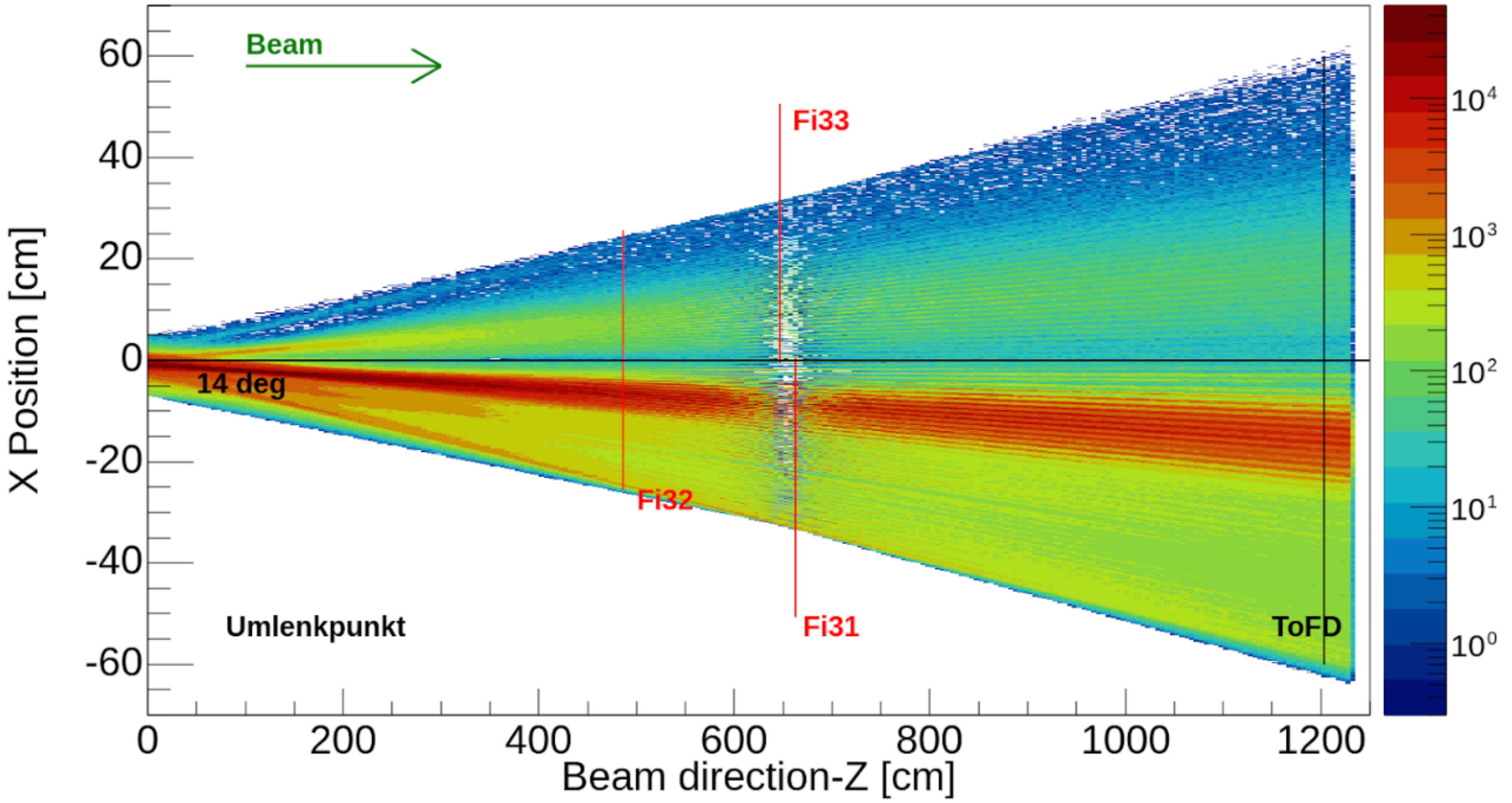
Fragment PID: GLAD magnet

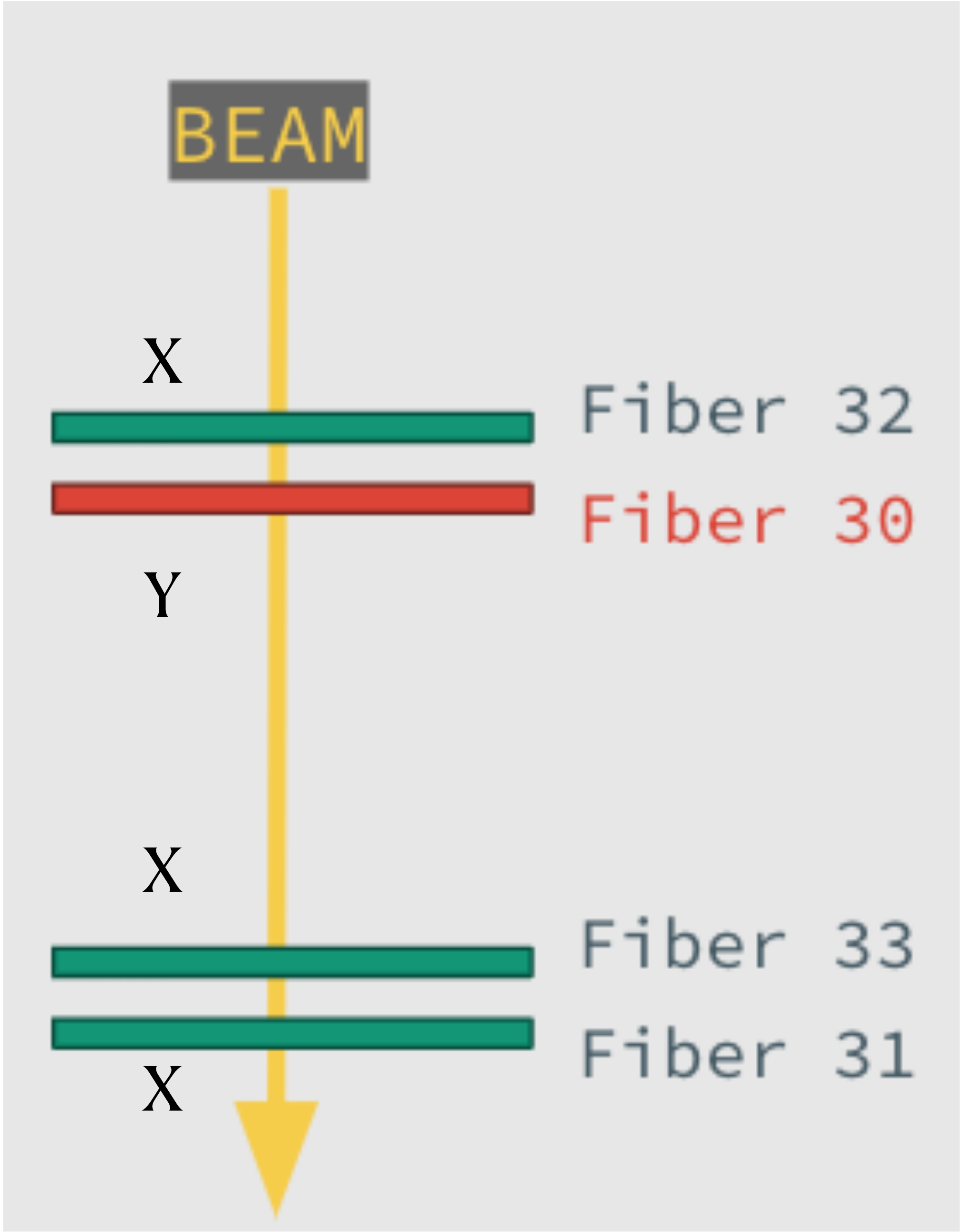
- GSI large acceptance dipole
- 4 superconducting coils
- Dimension: 3.5m x 7m x 4m
- Large vertical gap
- Magnetic field 2.7 T



Fragment PID: Fibers

- Tracking fragment after GLAD
- Position measurement with very high precision
- 1mm plastic scintillators, 512 channels
- Dimension: 50cm x 50 cm

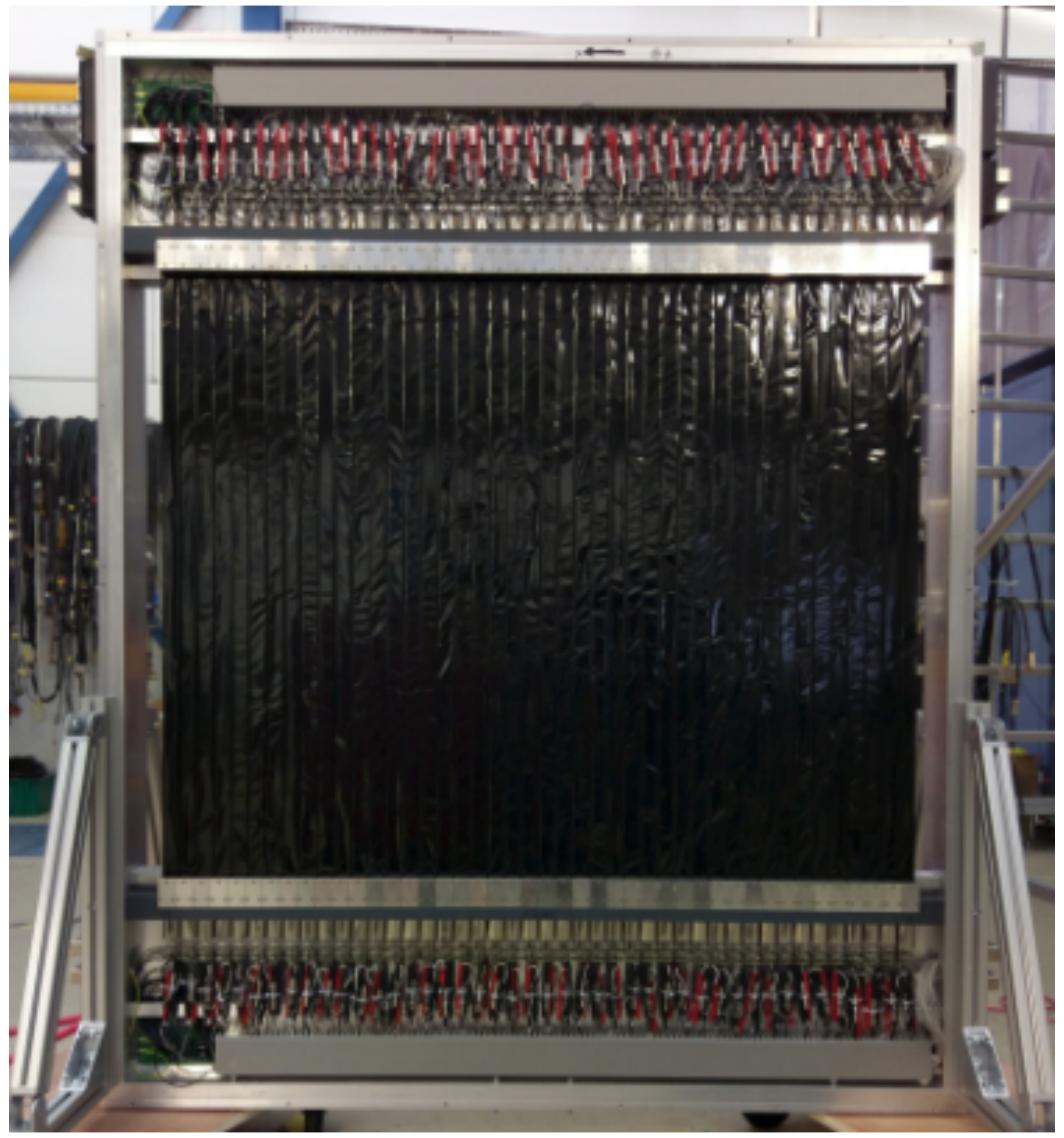


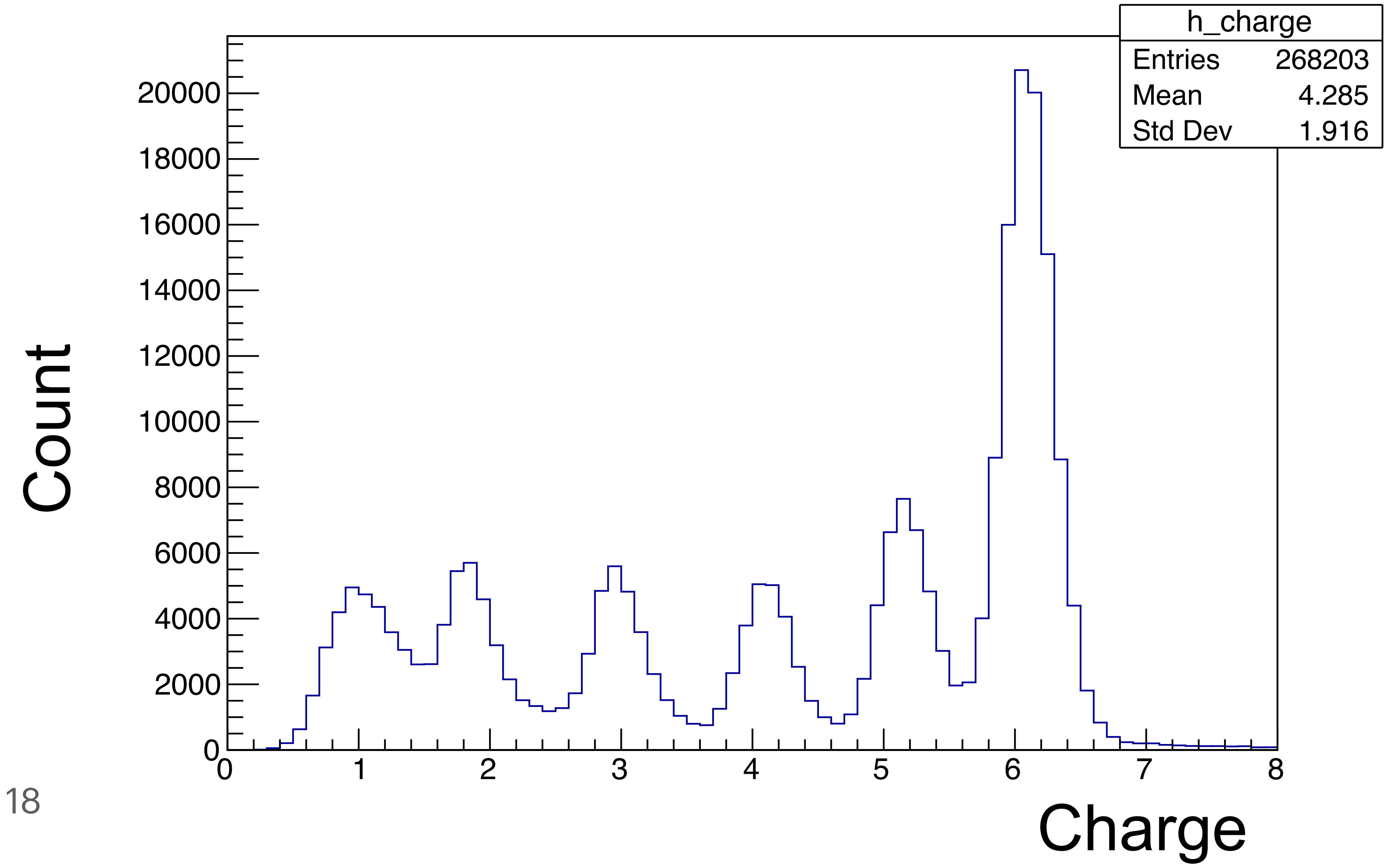


Credit to Enis Lorenz

Fragment PID: TofD

- Plastic scintillator array
- Measures ToF and energy loss of ion
- 4 planes with 44 scintillator bars (1m x 2.7cm x 5mm)
- PMT readout top and bottom





Recoil nucleons

RPC

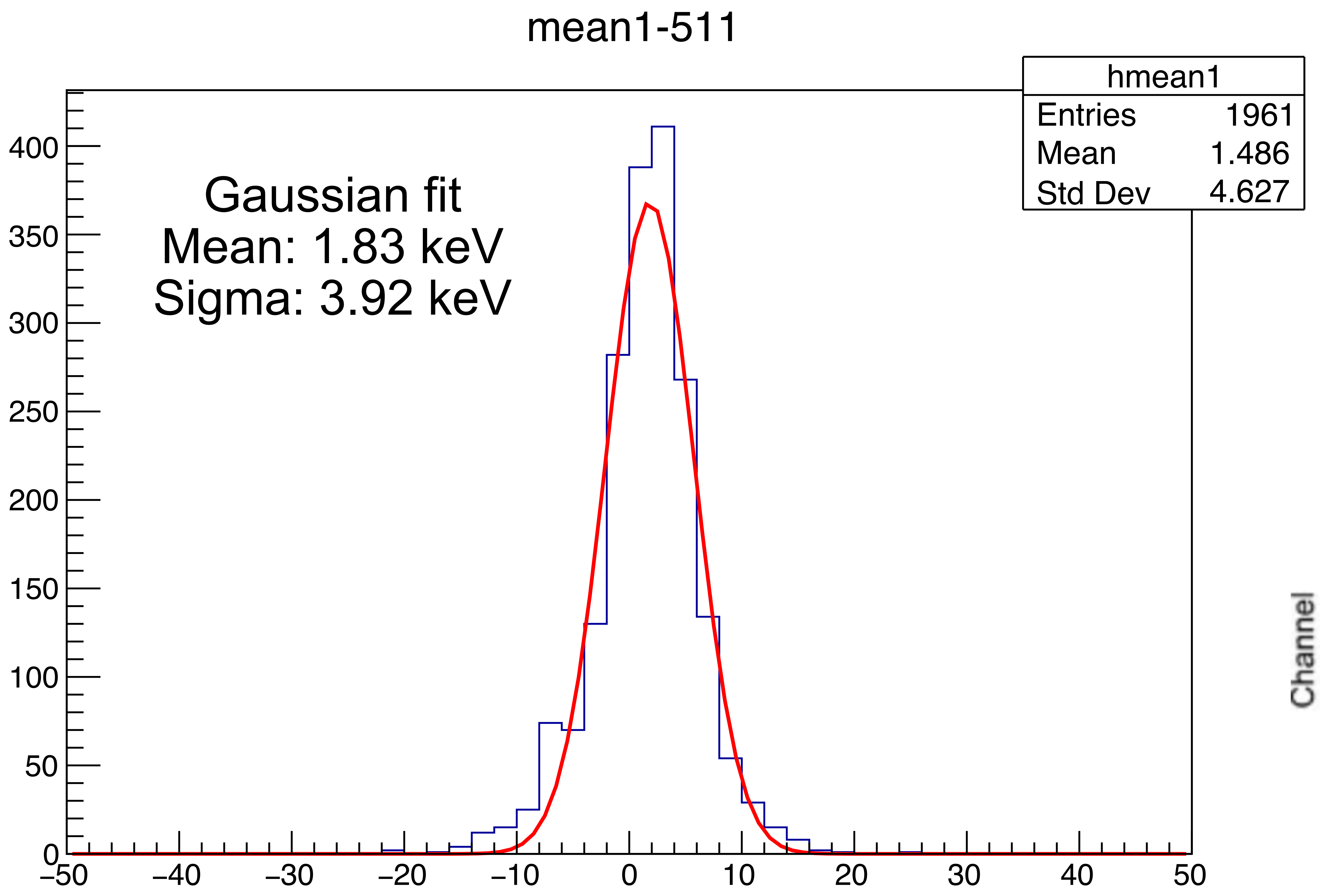
- Proton momentum measurement
- Time resolution ~ 50 ps, position resolution ~ 1cm in x-y plane

Neutron detector

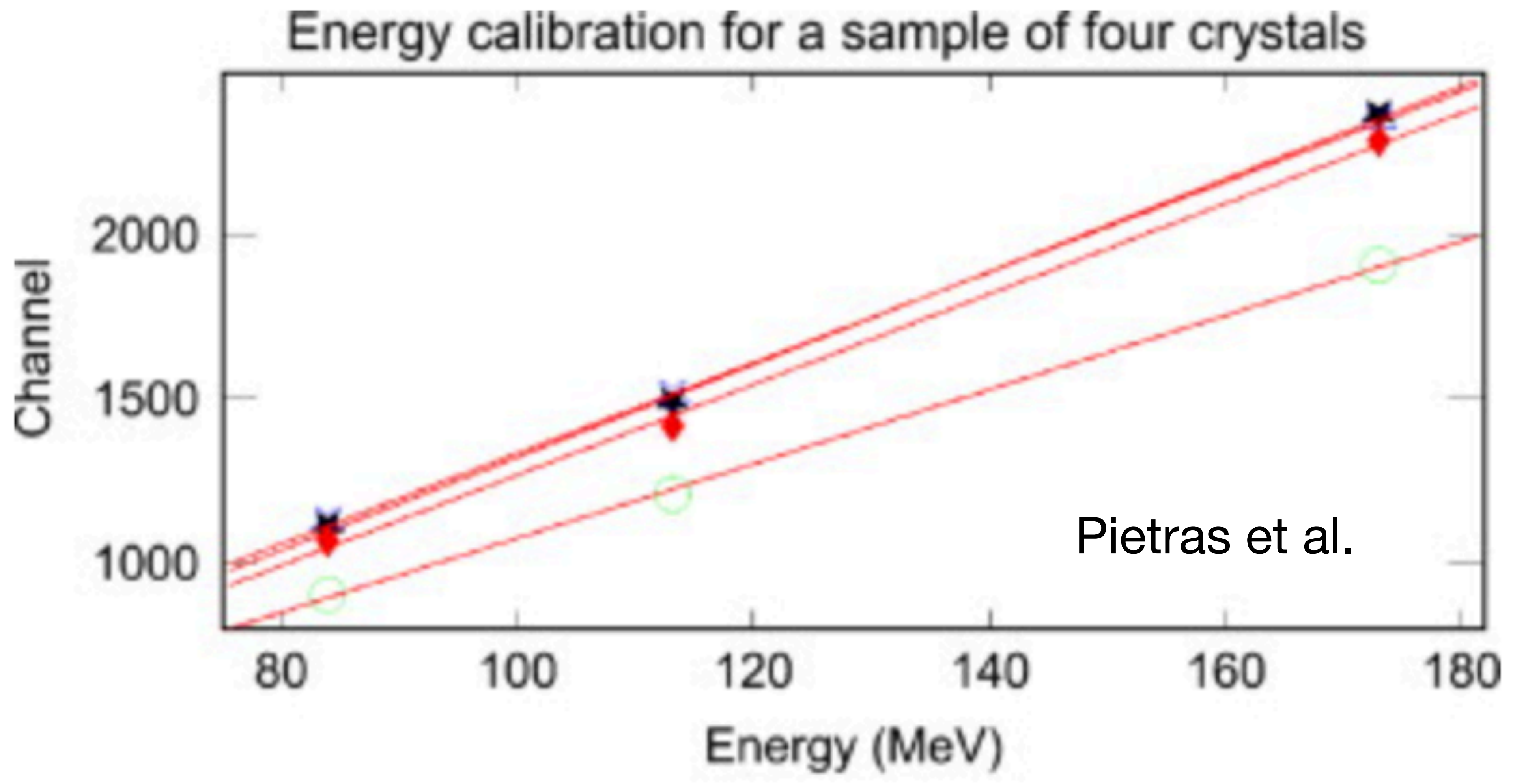
- Highly granular design of plastic scintillators
- 1300 submodules of size 5x5x250 cm^3

Califa Calibration

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

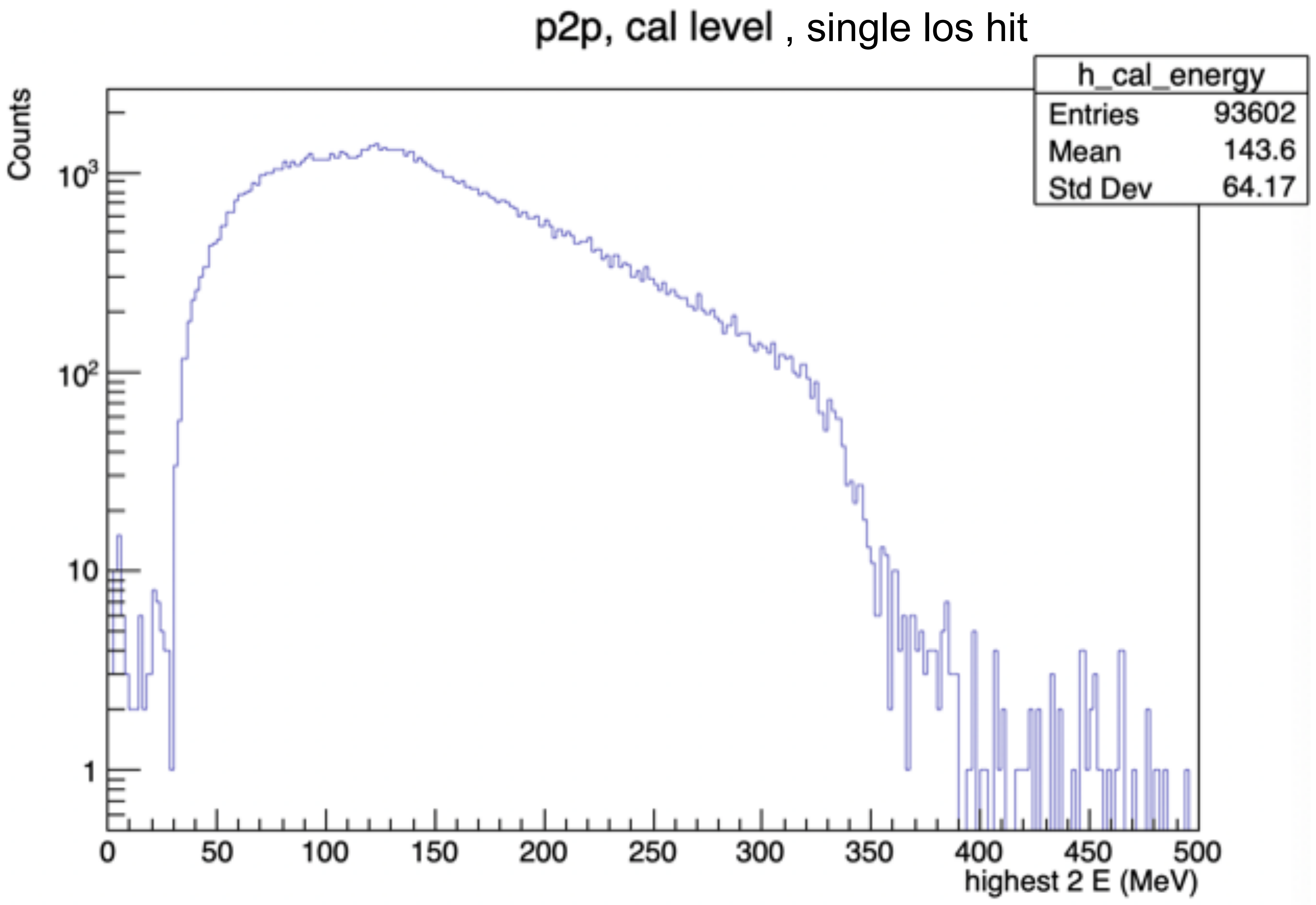


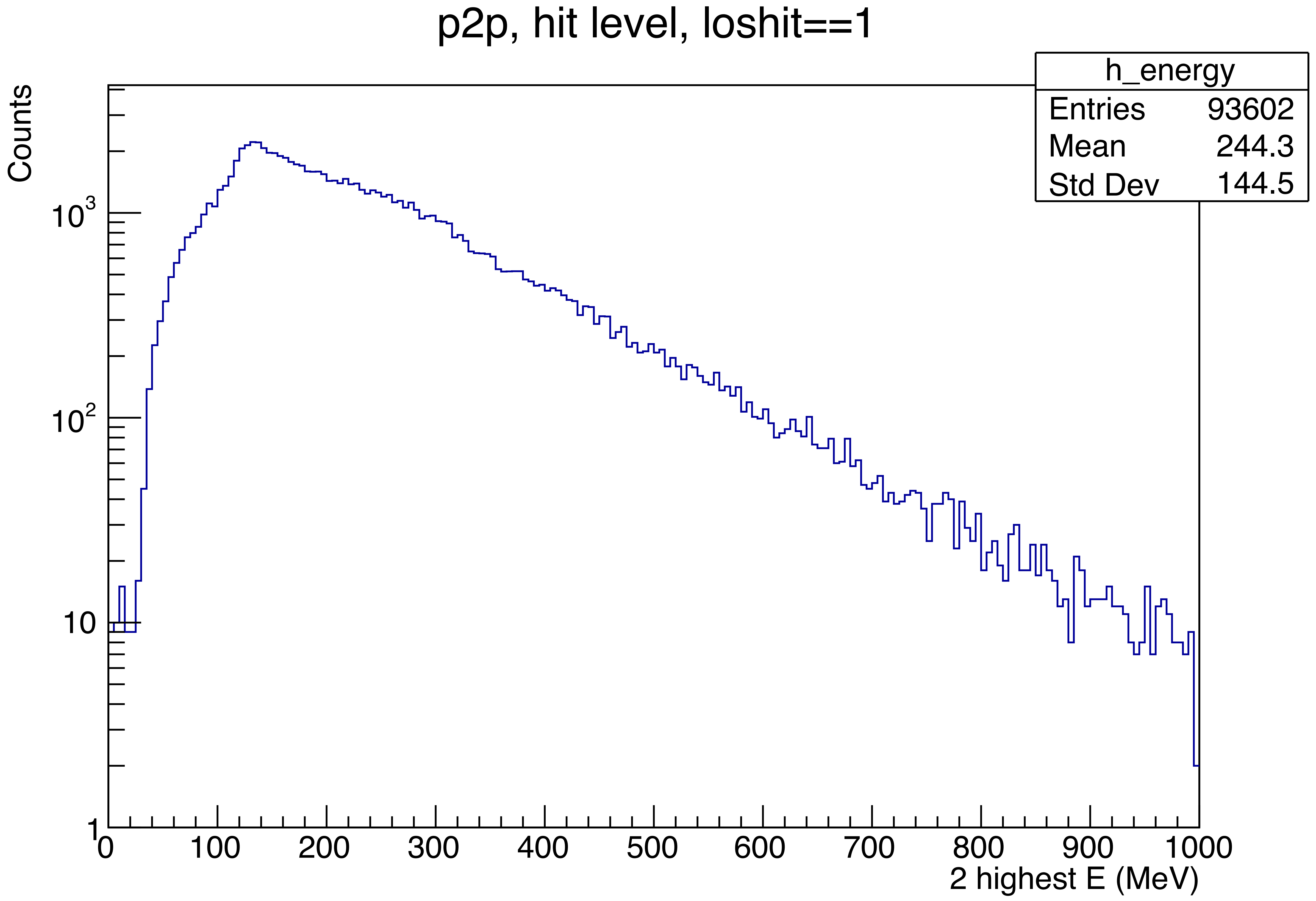
Next steps:
AmBe source for 4.4 MeV
Cosmic rays for higher energy calibration



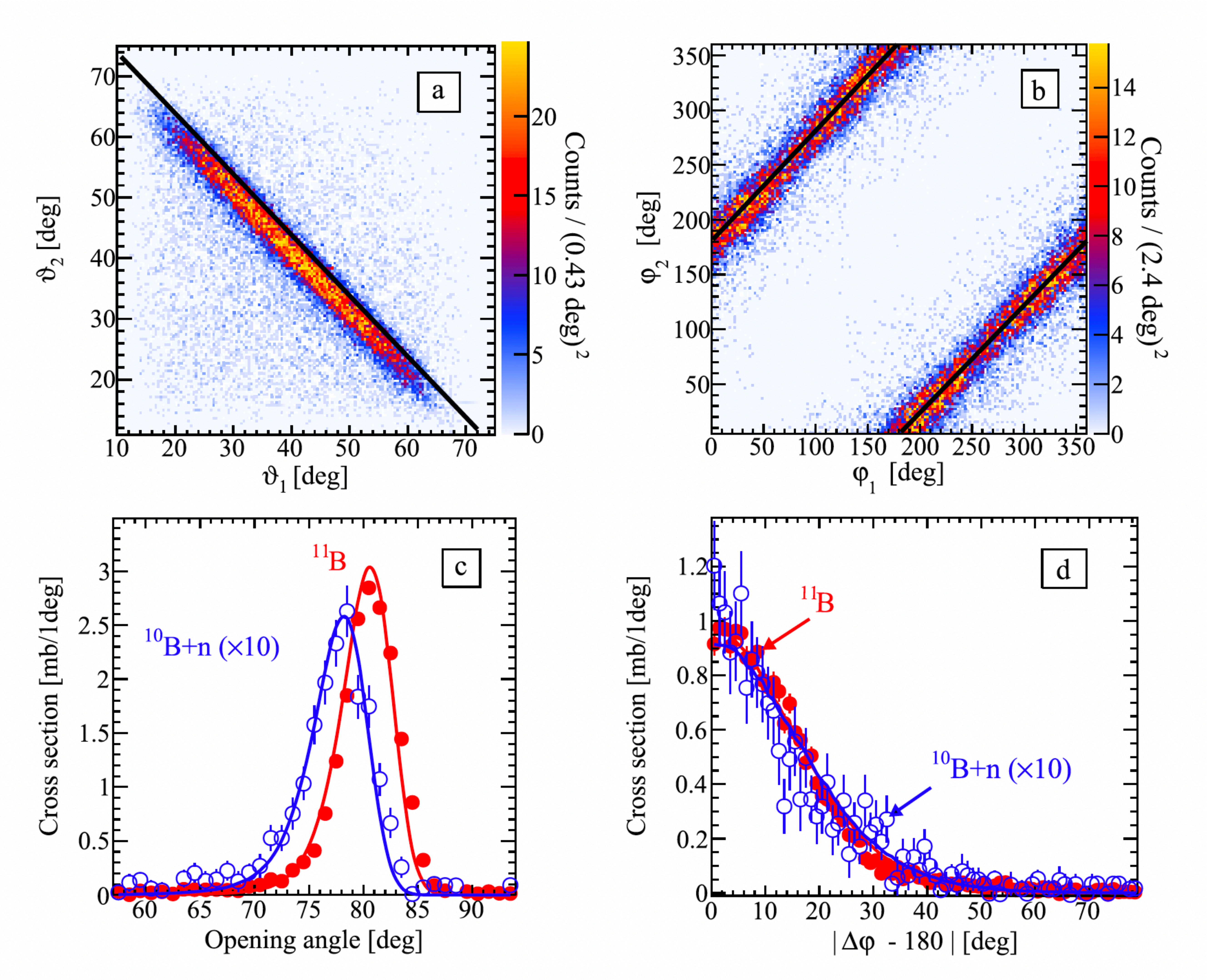
p2p events

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





^{12}C mean field proton results

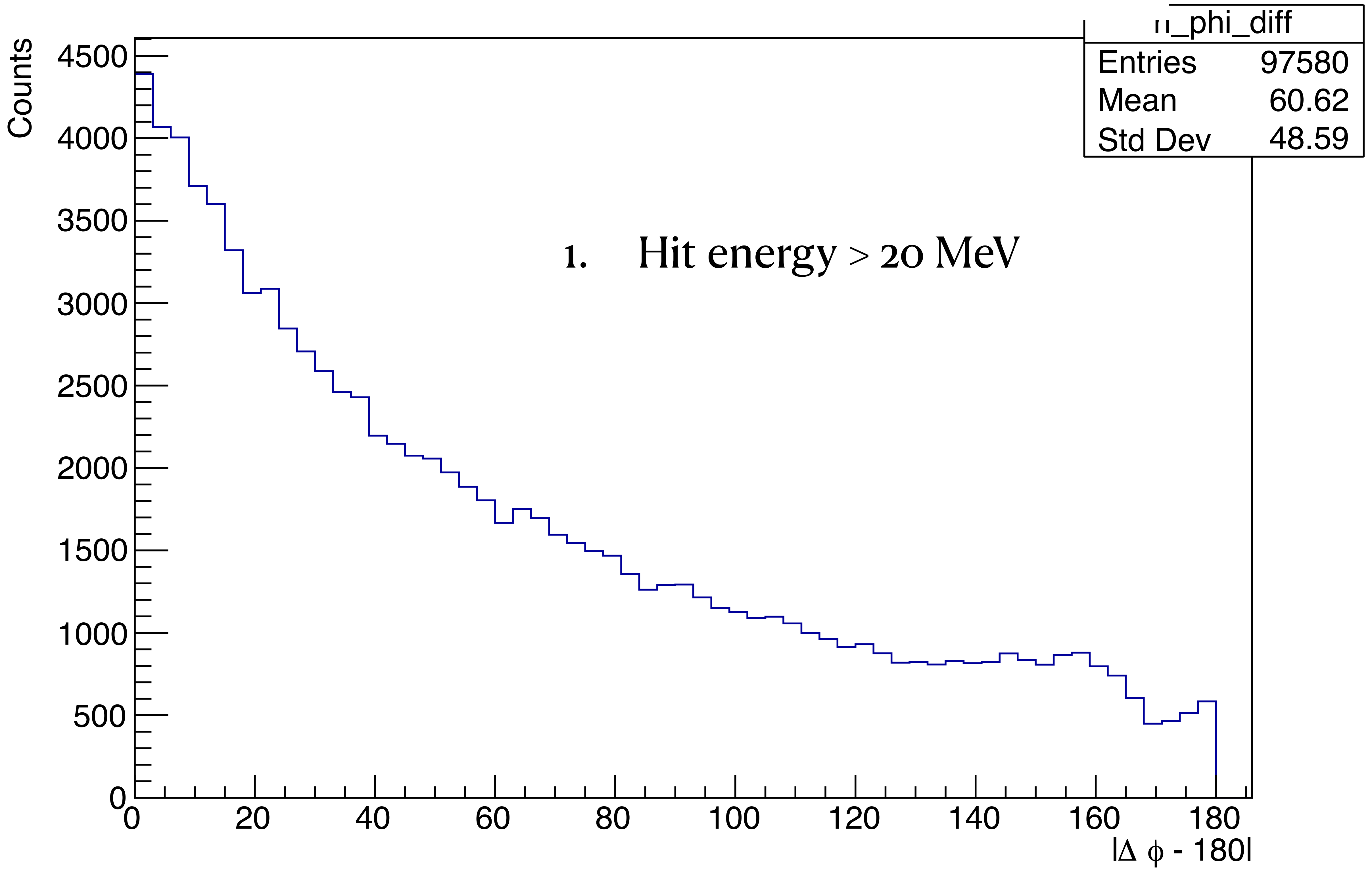


400 MeV/u beam

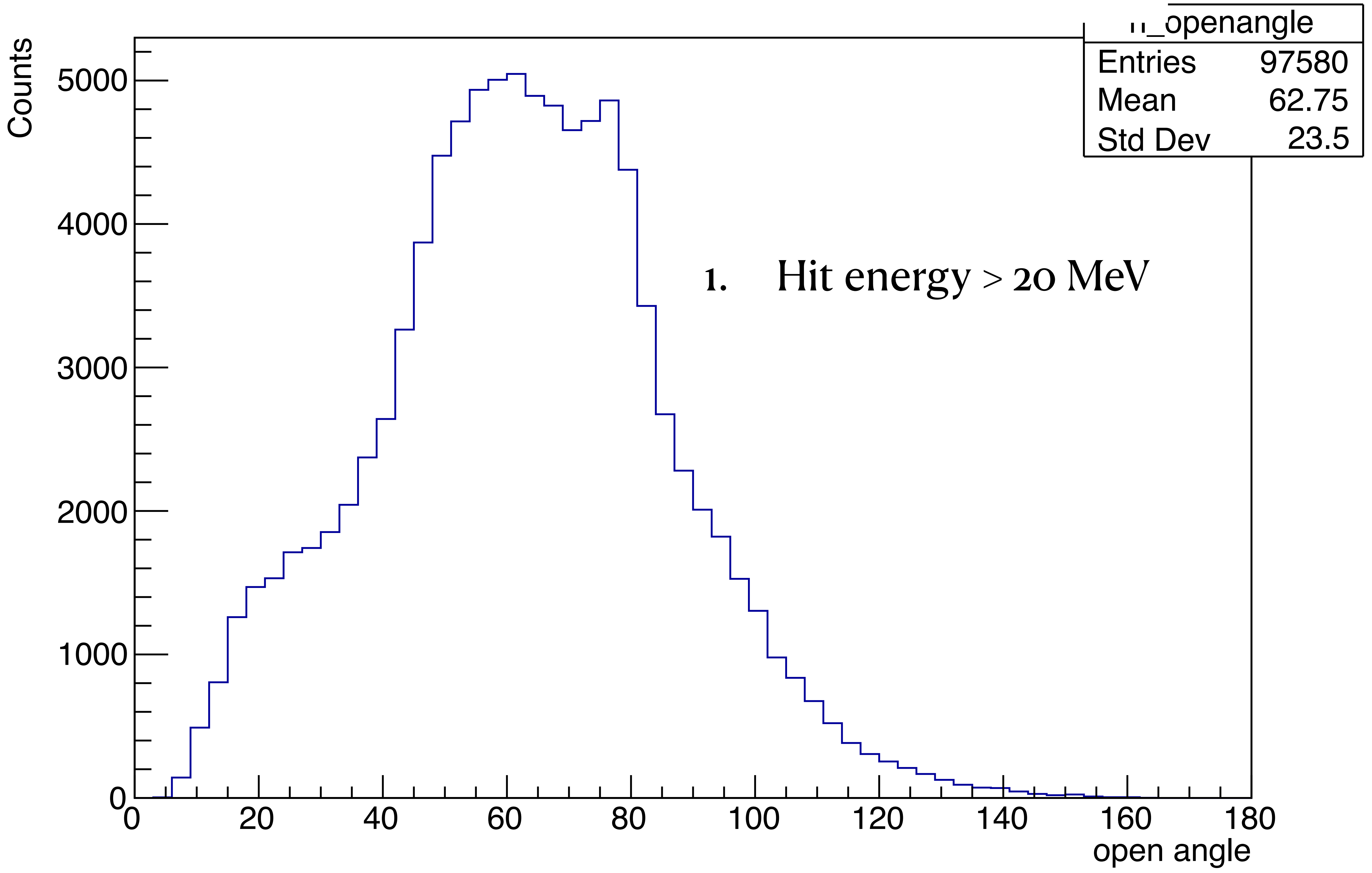
Panin et al., 2020, Phys. Lett. B753 (2016)

p2p events: angular correlation

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



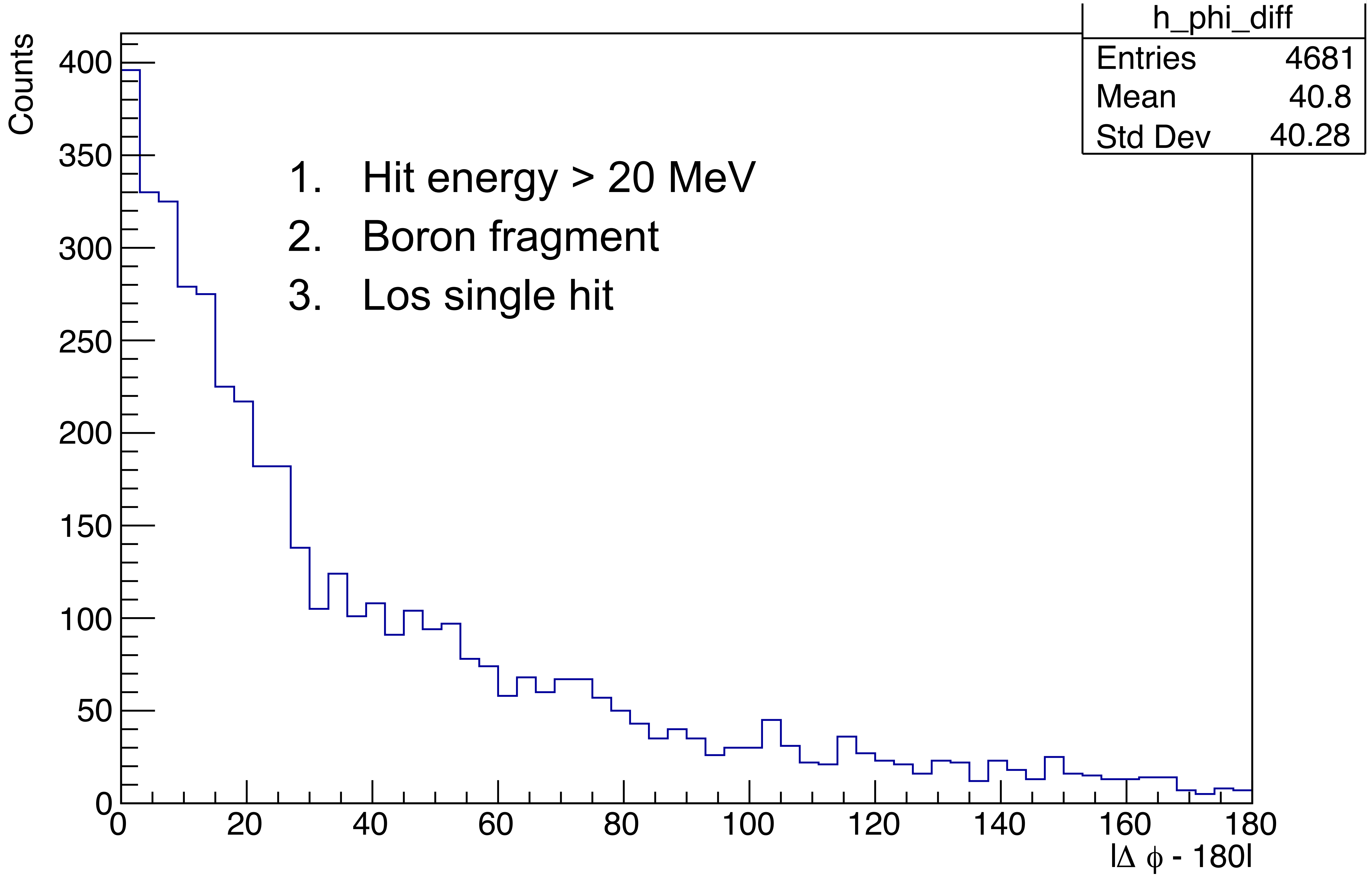
Opening angle (degree)



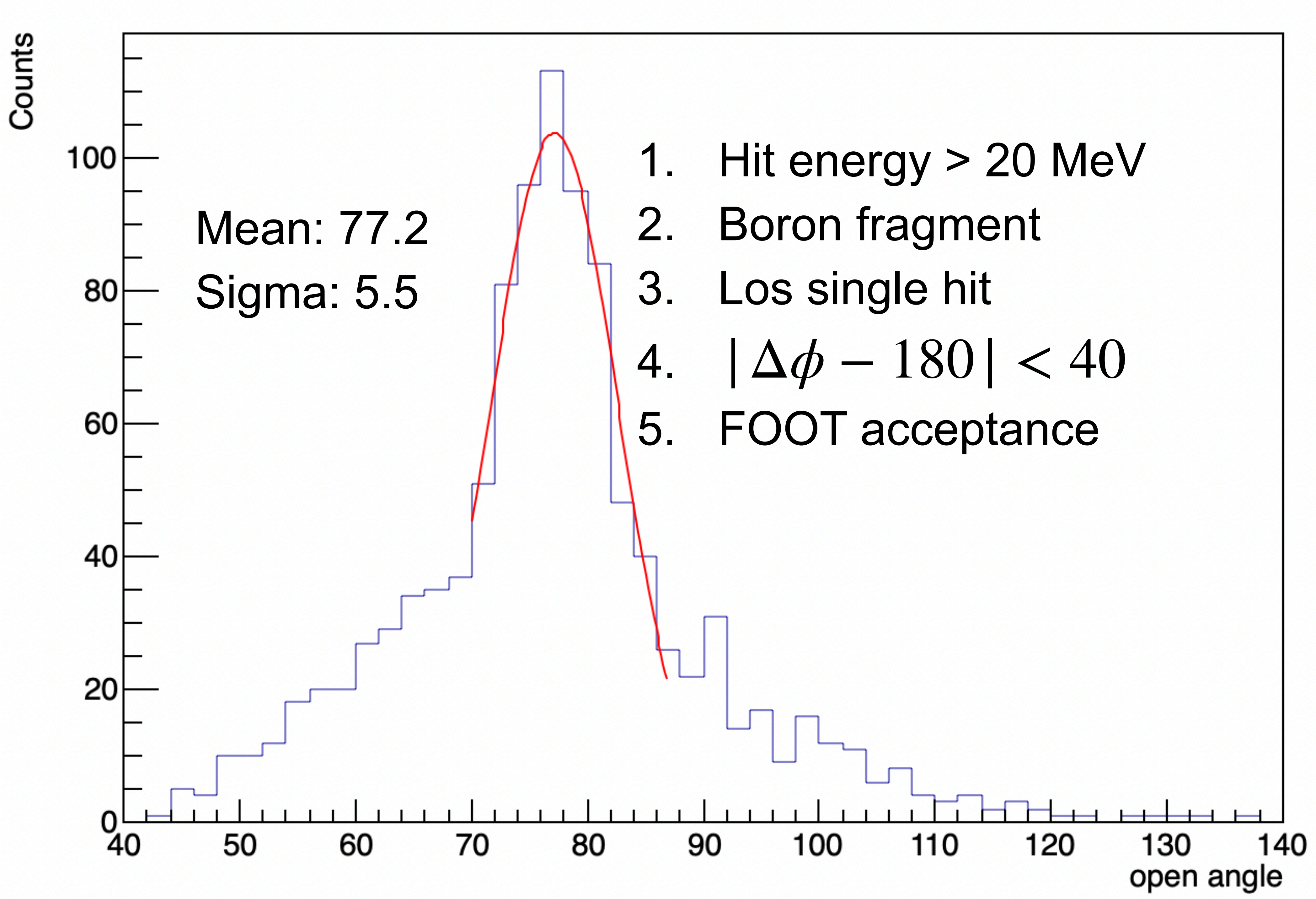
p2p events: physical cuts

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

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

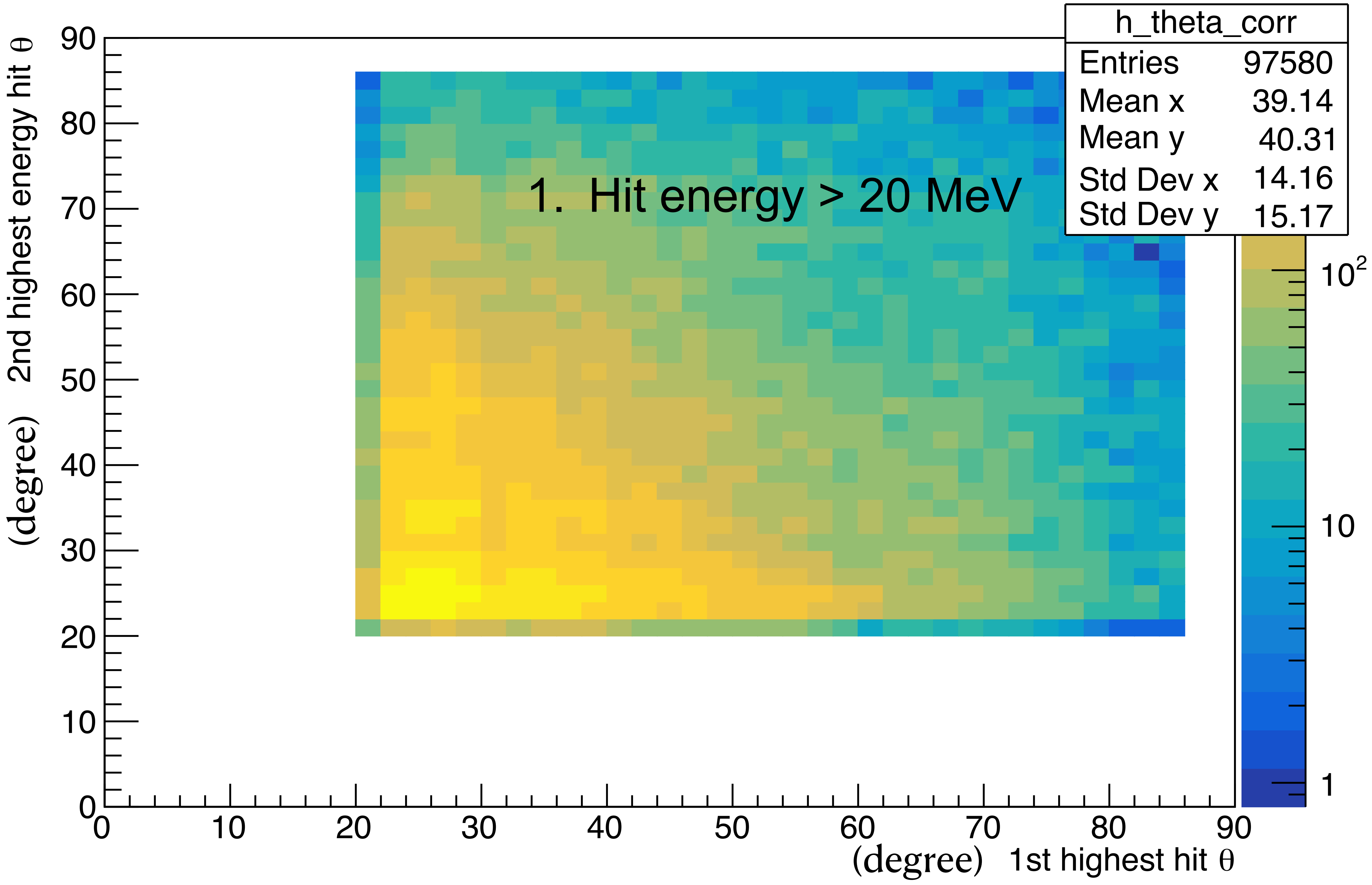


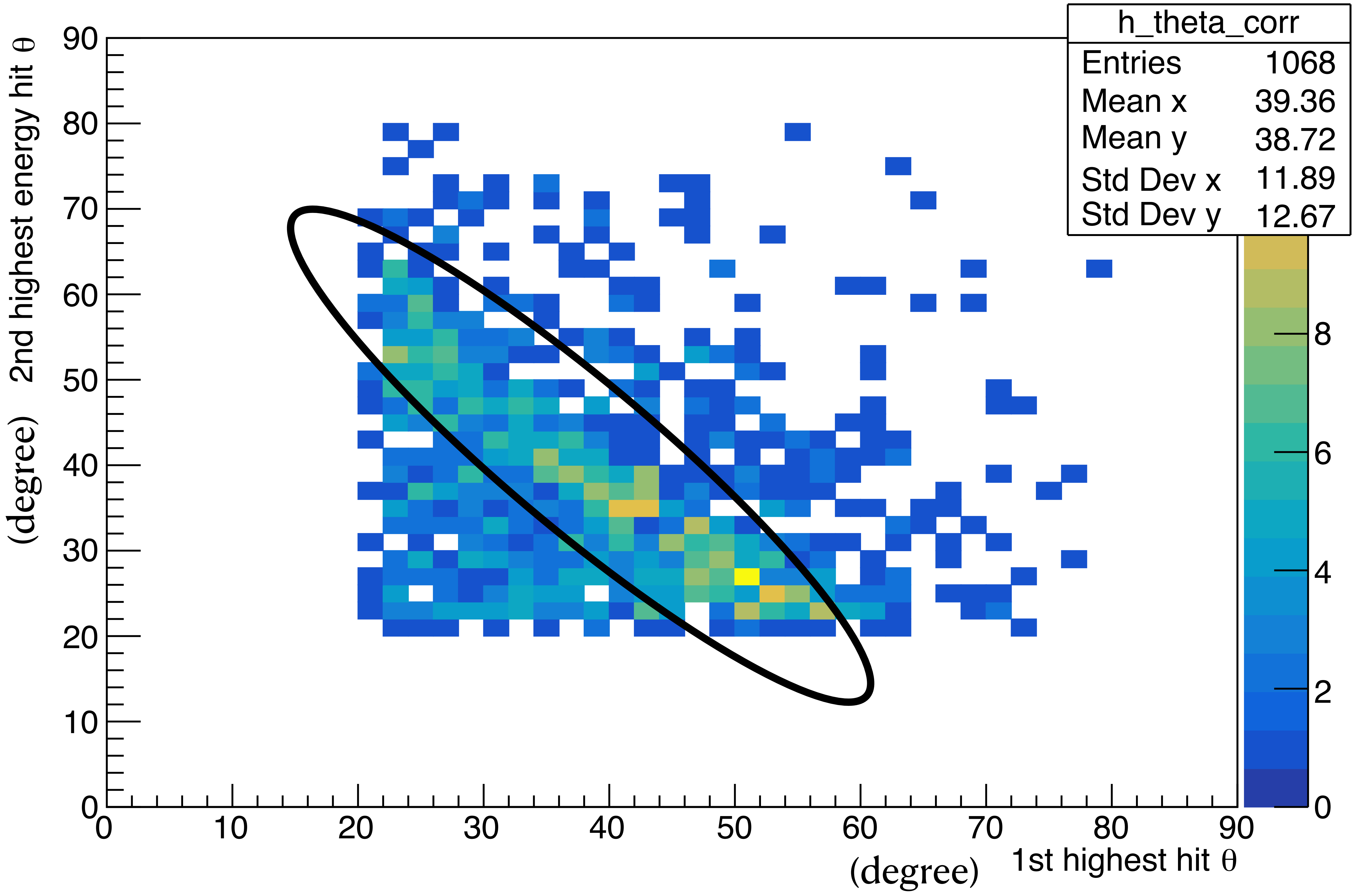
Opening angle (degree)



p2p events: theta Correlation

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



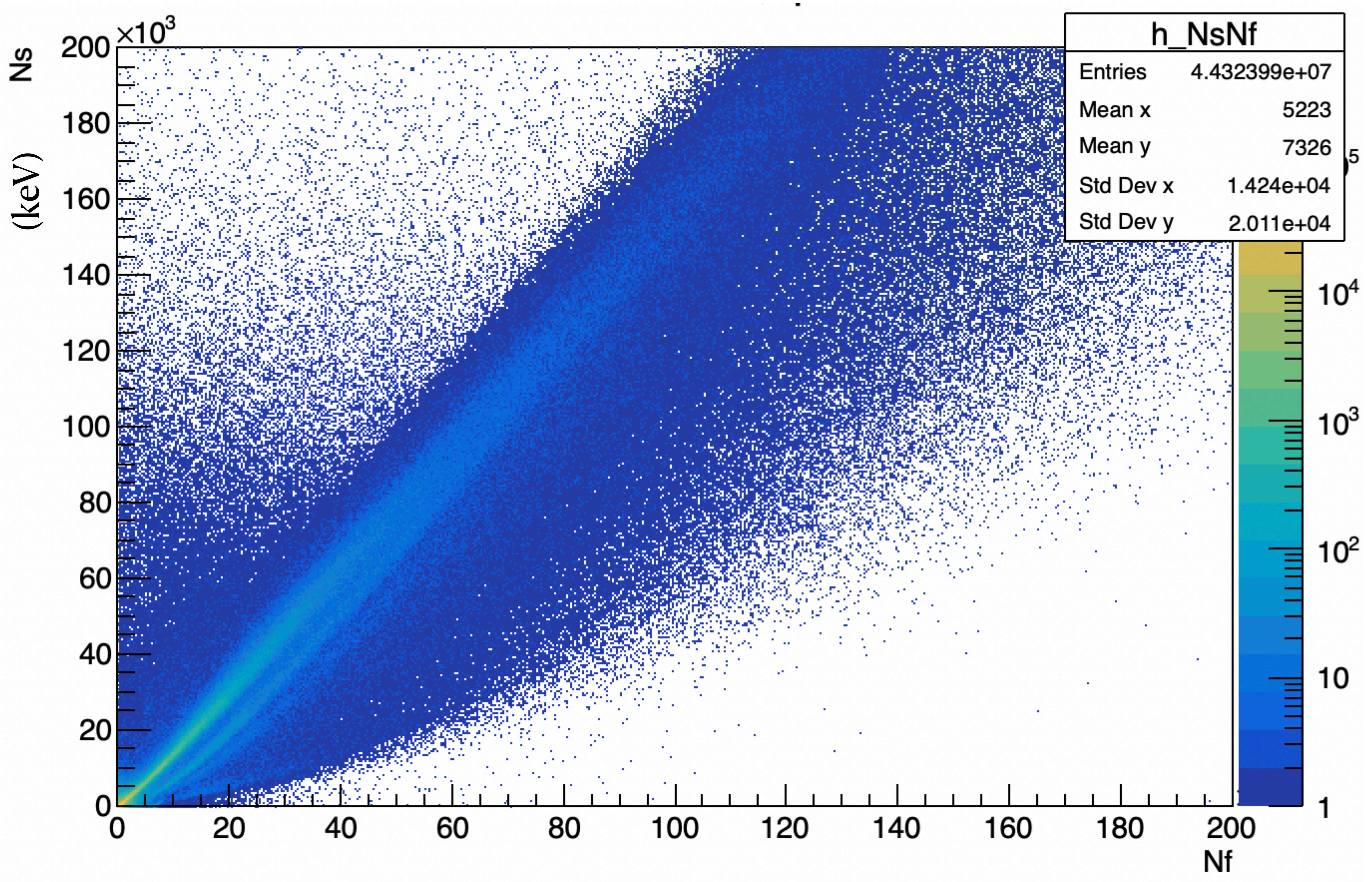


Particle Identification

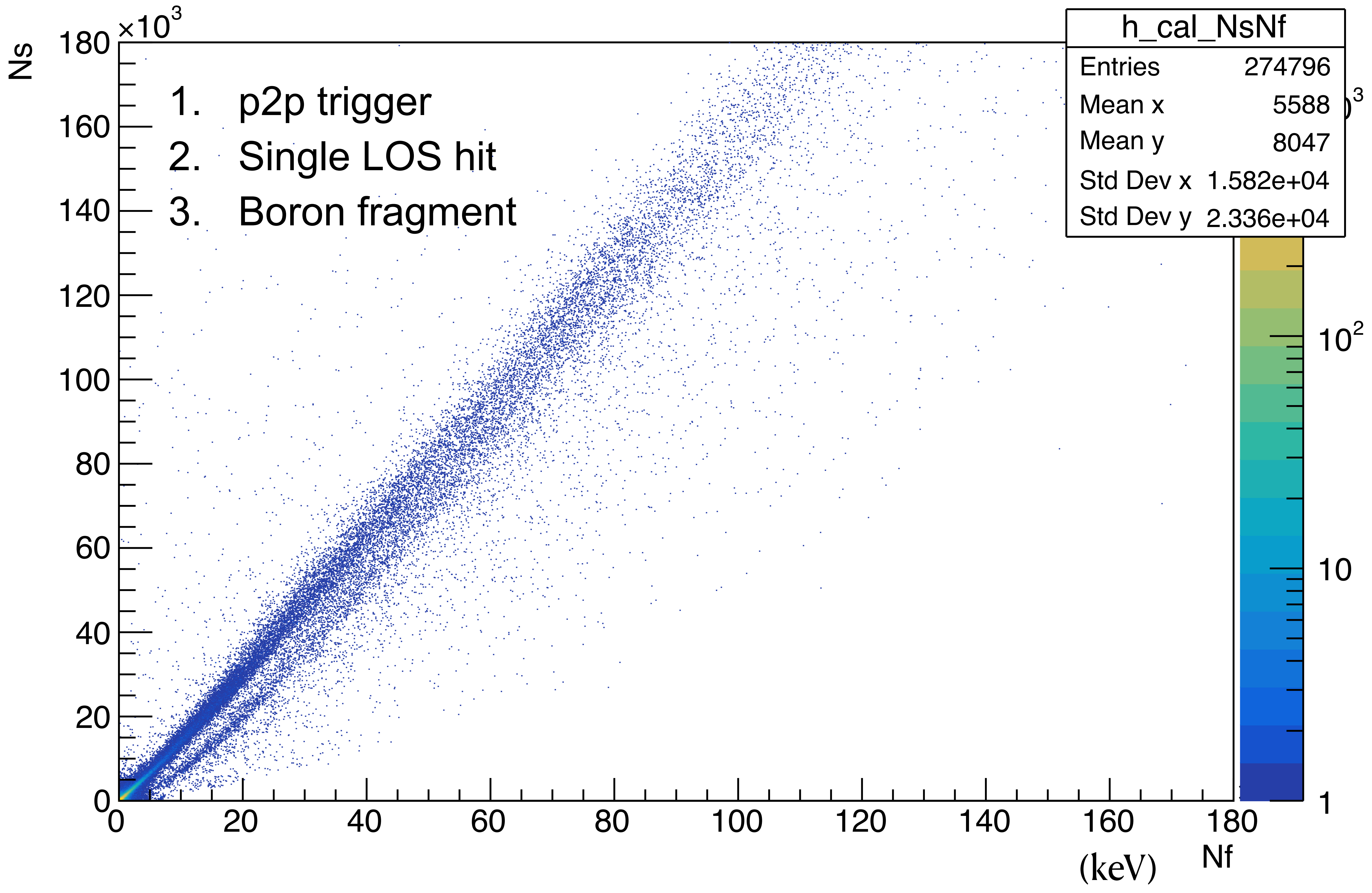
$$L(t) = \frac{N_f}{\tau_f}\exp(-t/\tau_f) + \frac{N_s}{\tau_s}\exp(-t/\tau_s) - \frac{N_r}{\tau_r}\exp(-t/\tau_r)$$

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}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