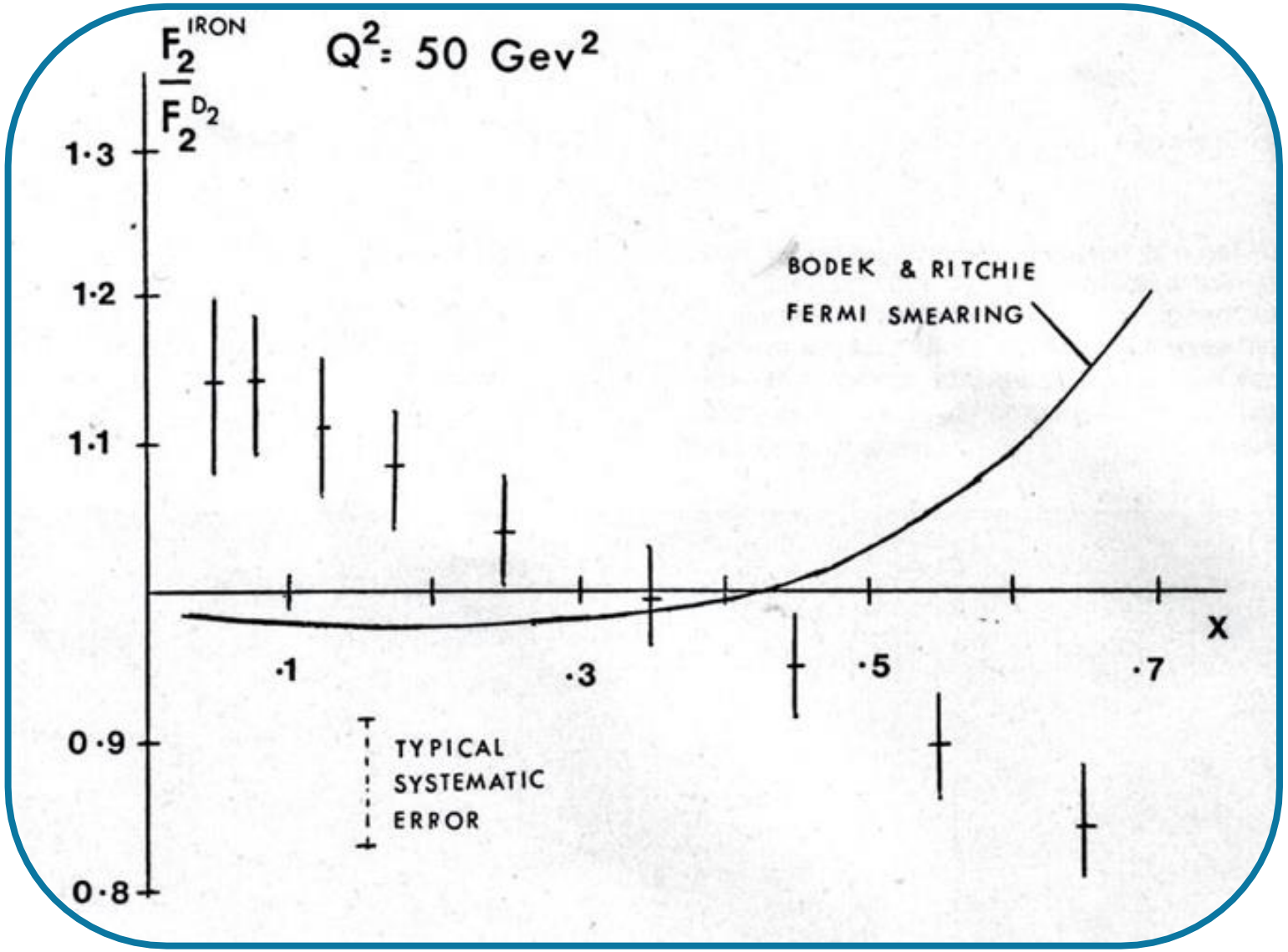
Measuring in-medium nucleon modification through spectator tagged DIS with the LAD experiment

Lucas Ehinger

On behalf of LAD Collaboration

The EMC Effect

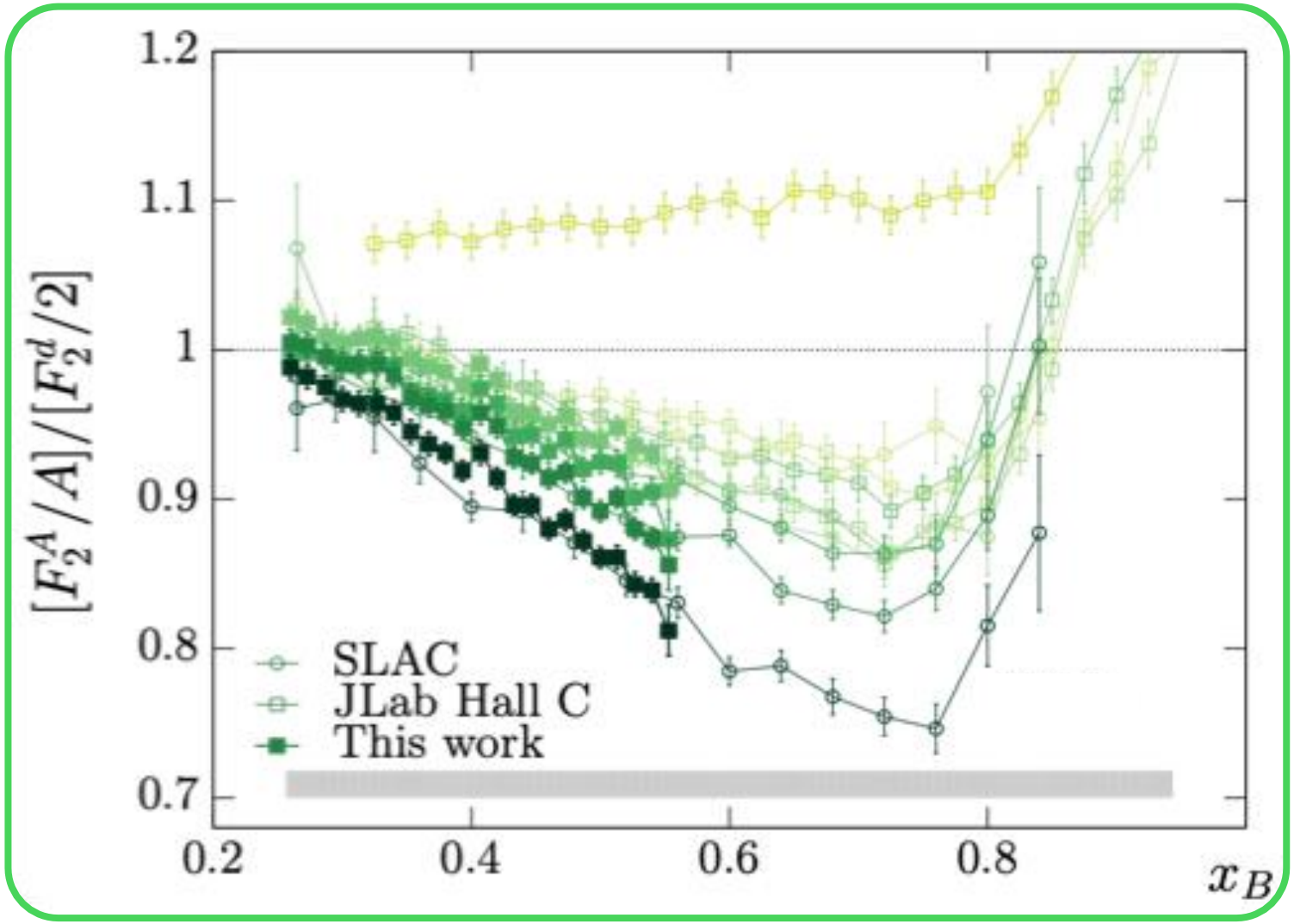
Aubert et al., PLB (1983)



The EMC Effect

- Bound nucleon ≠ free nucleon
- Present in all nuclei
- Discovered 1983
  - >40 years
  - >1,000 papers
  - **No accepted theoretical explanation**

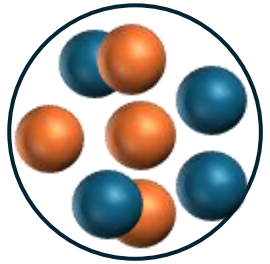
Schmookler et al., Nature (2019)



EMC Theories

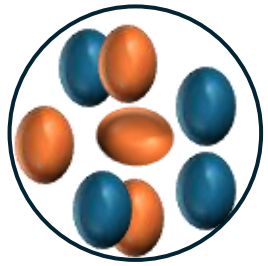
Traditional Nuclear Effects

- Fermi-motion
- Binding effects
- Meson exchange



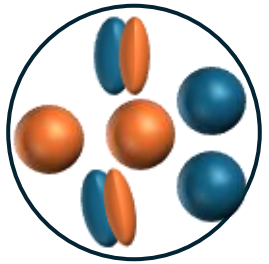
Mean-field Modification

- All nucleons modified equally
- Larger bound proton radius



SRC Modification

- Virtuality-dependent modification
  - SRCs are highly virtual



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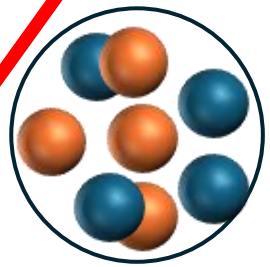

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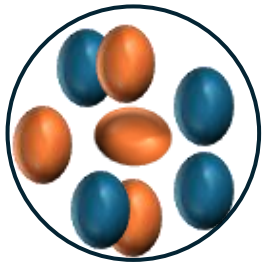

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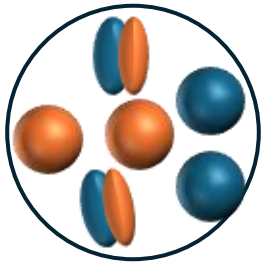

EMC Theories

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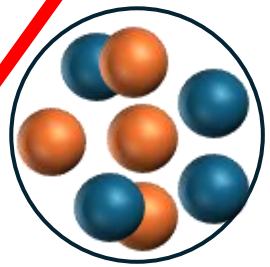

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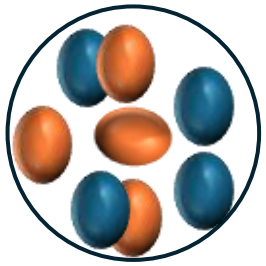

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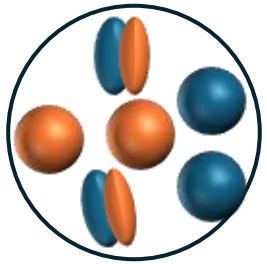
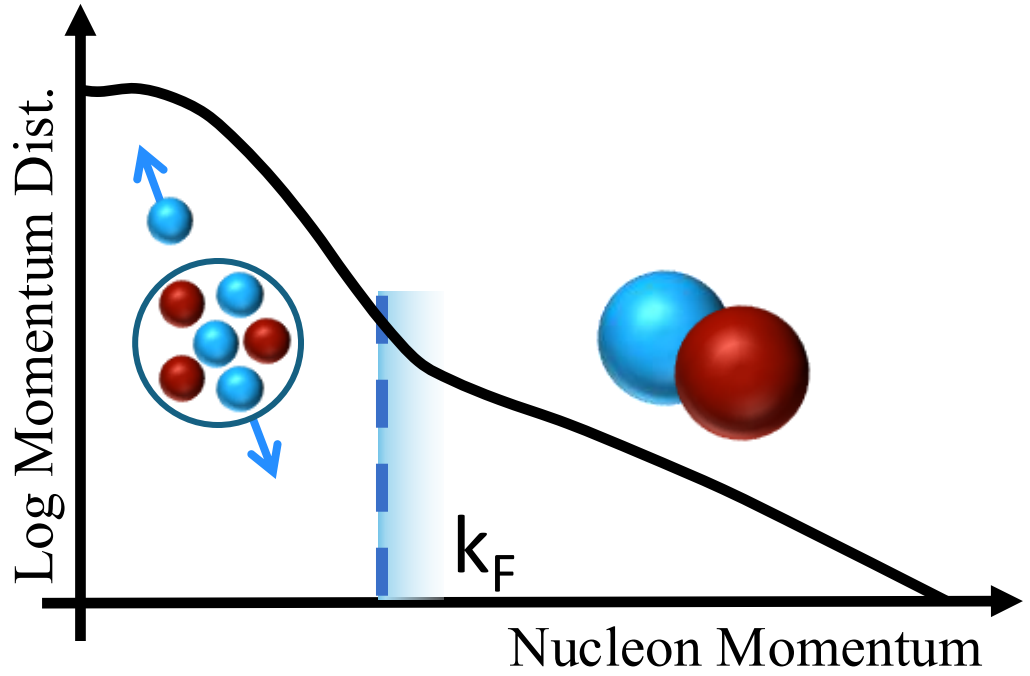


Short Range Correlations

- High Momentum States
  - ~20% of nucleons
- Back-to-back momentum
- Mostly np pairs
- Deuteron-like scaling



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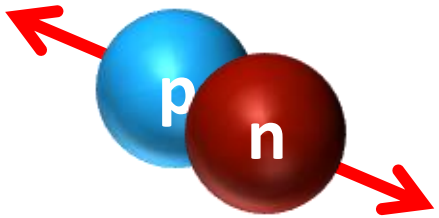

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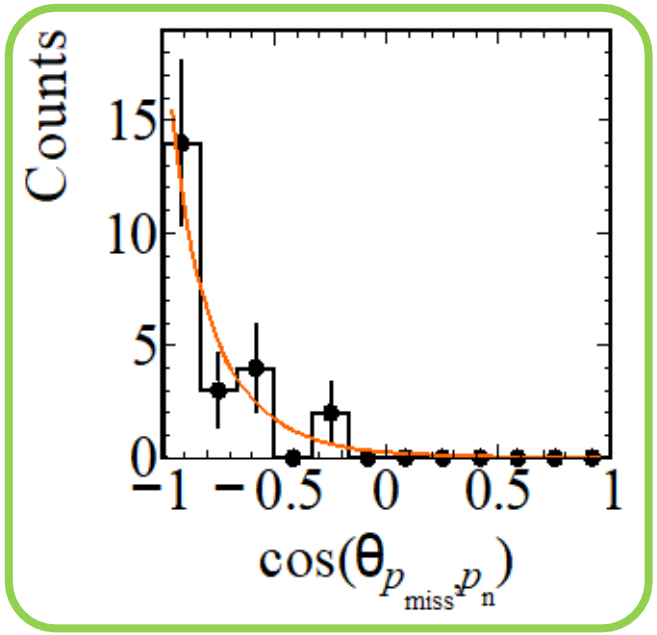
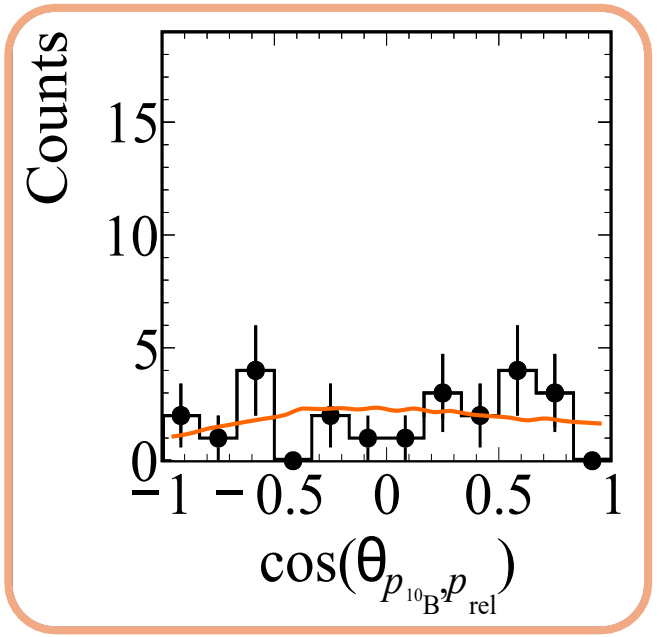
SRC's

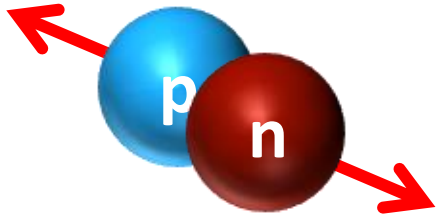


Mean Field



Patsyuk and Kahlbow et al., Nature Physics (2021)

Short Range Correlations



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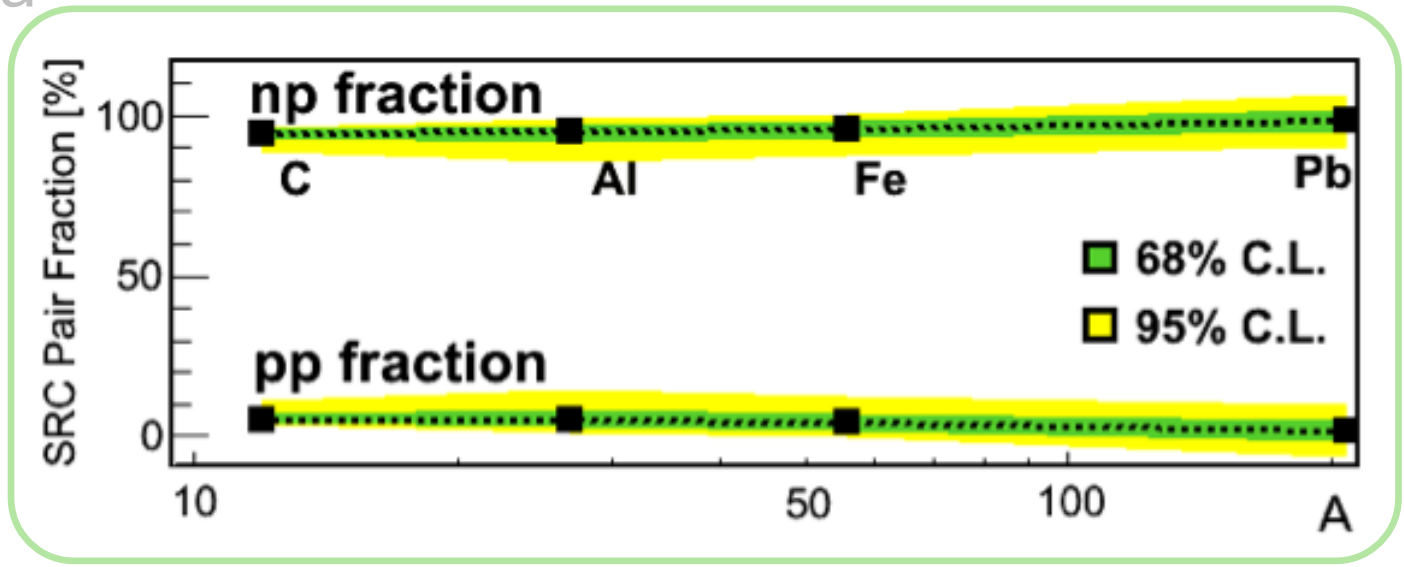

Hen et al., Science (2014)

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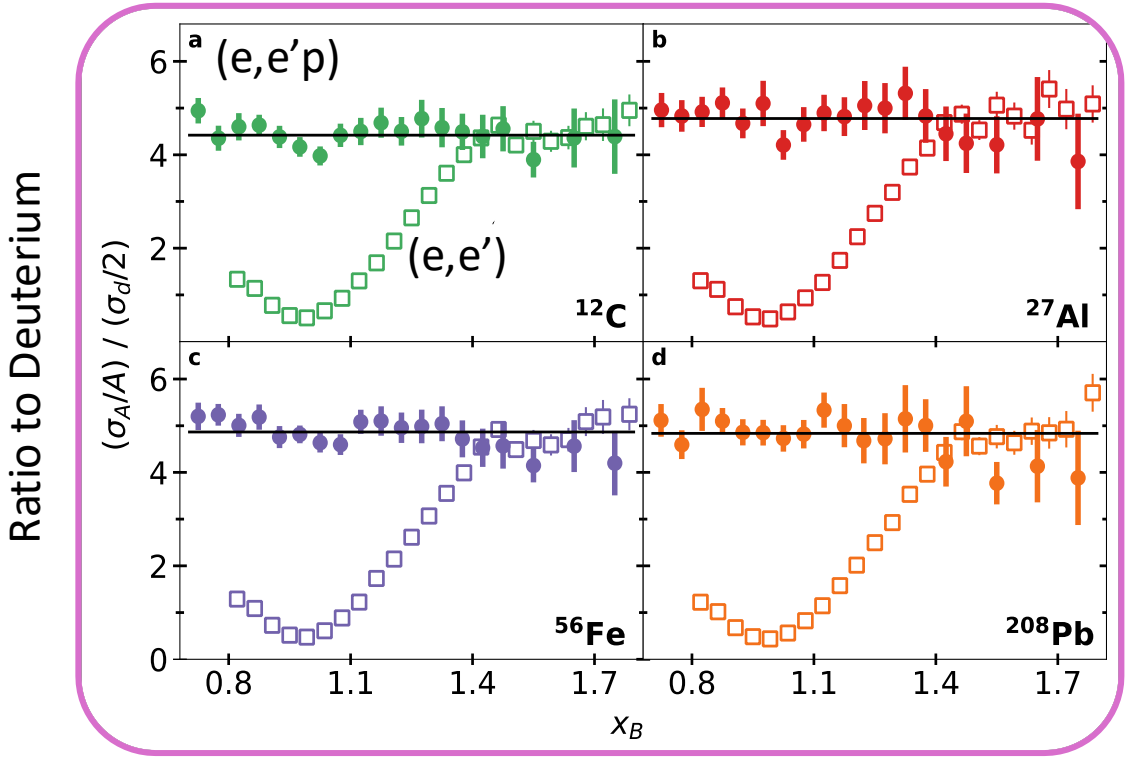
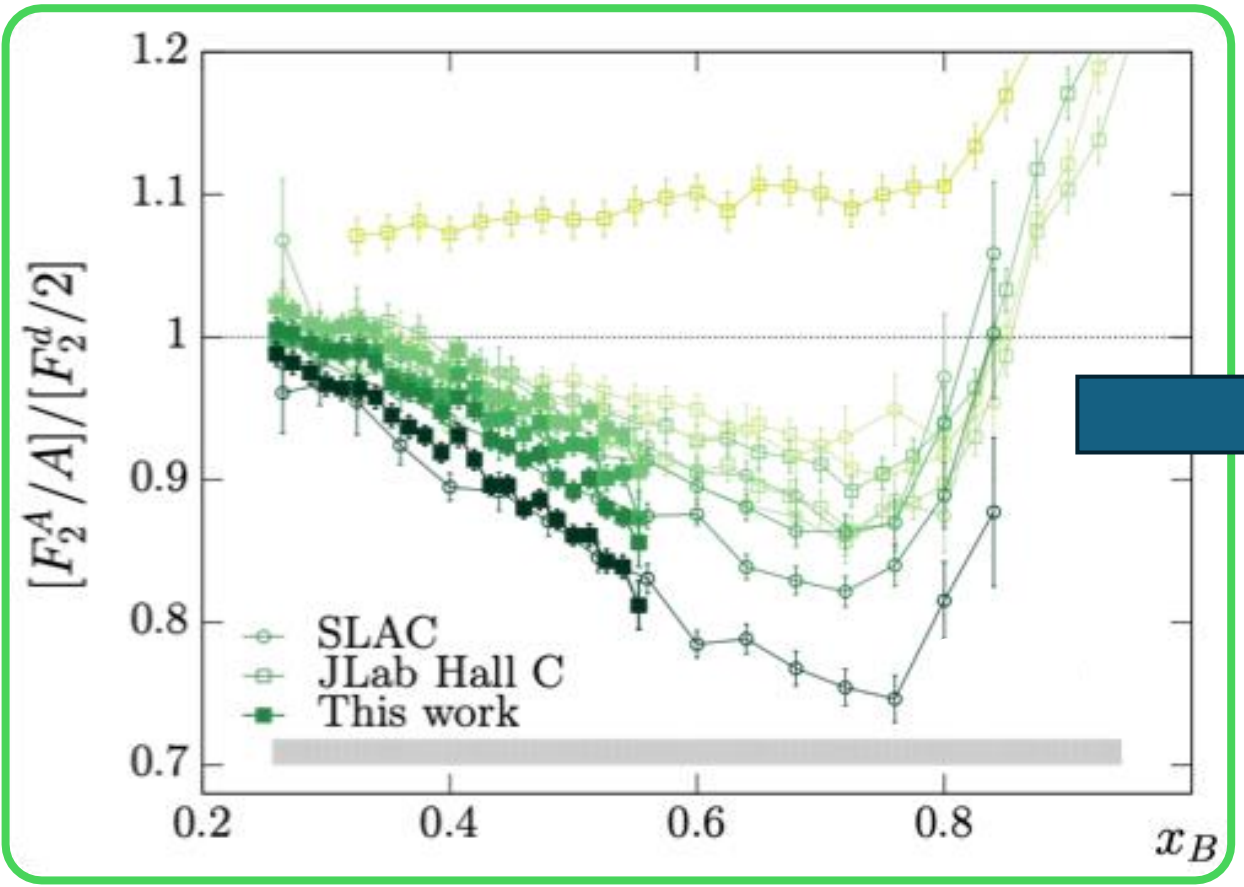


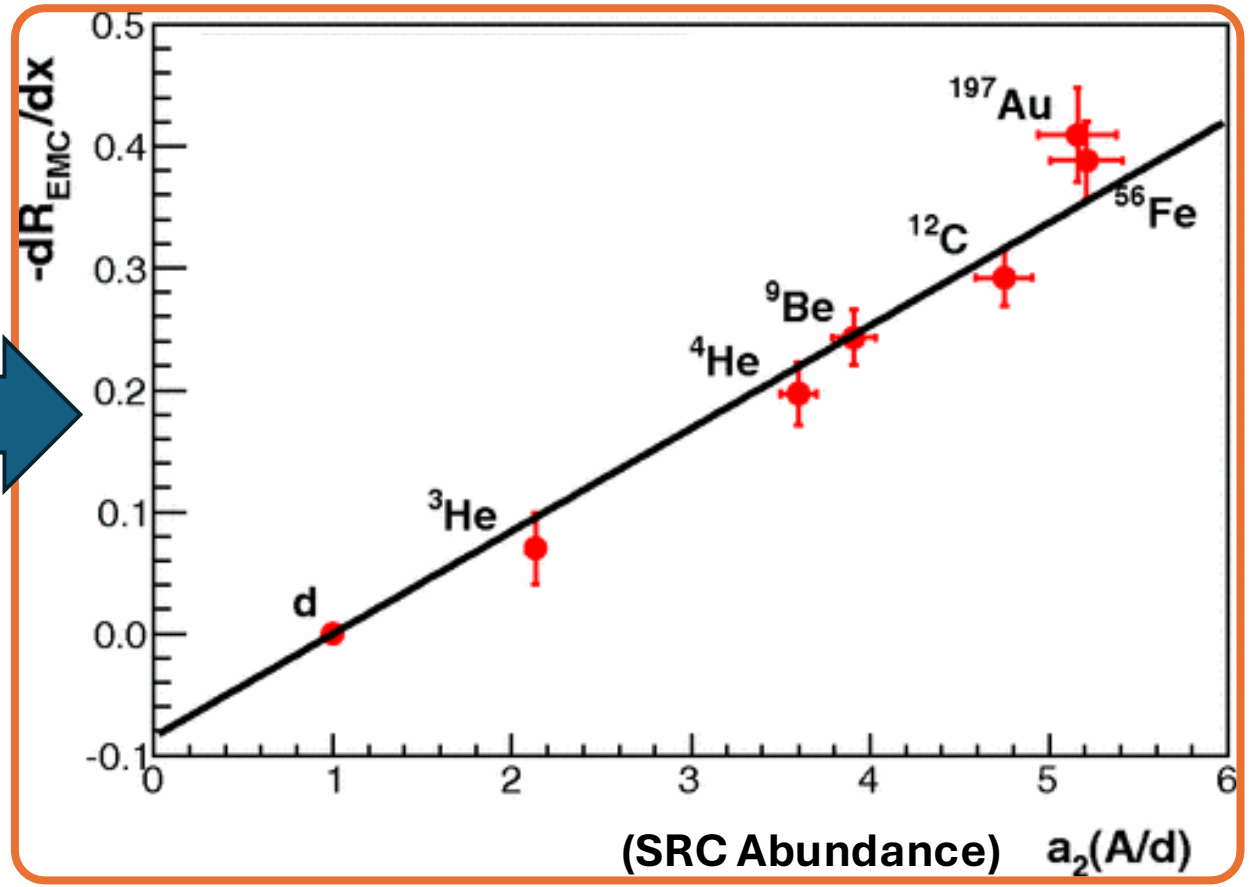
Korover and Denniston et al., PRC Lett. (2023)

SRC Modification is well supported

Schmookler et al., Nature (2019)

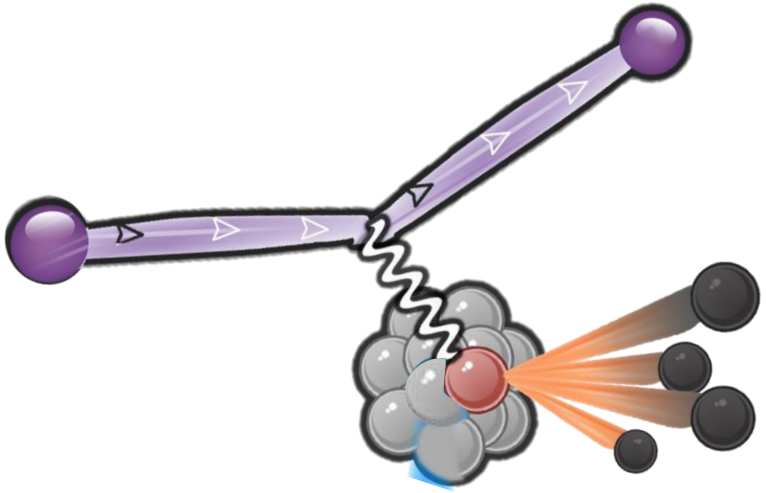


Weinstein et al., PRL (2011)



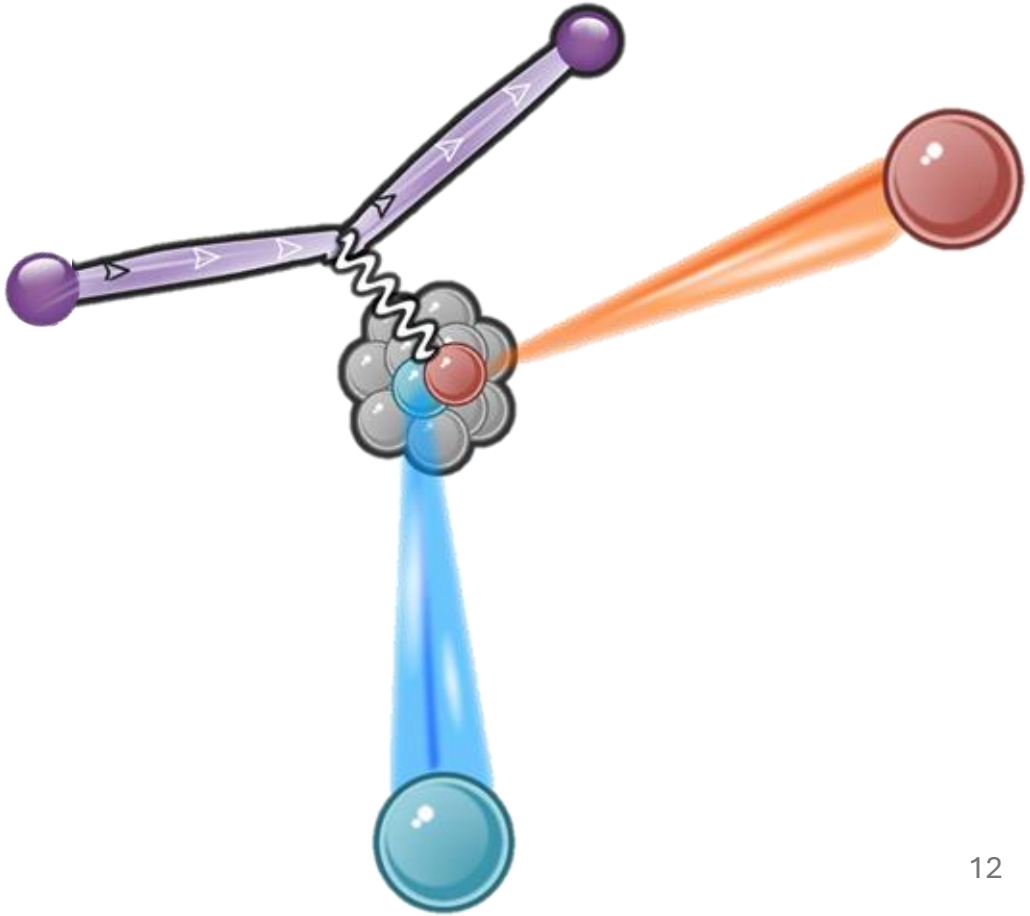
(Most) experiments measure

EMC Effect (inclusive DIS)

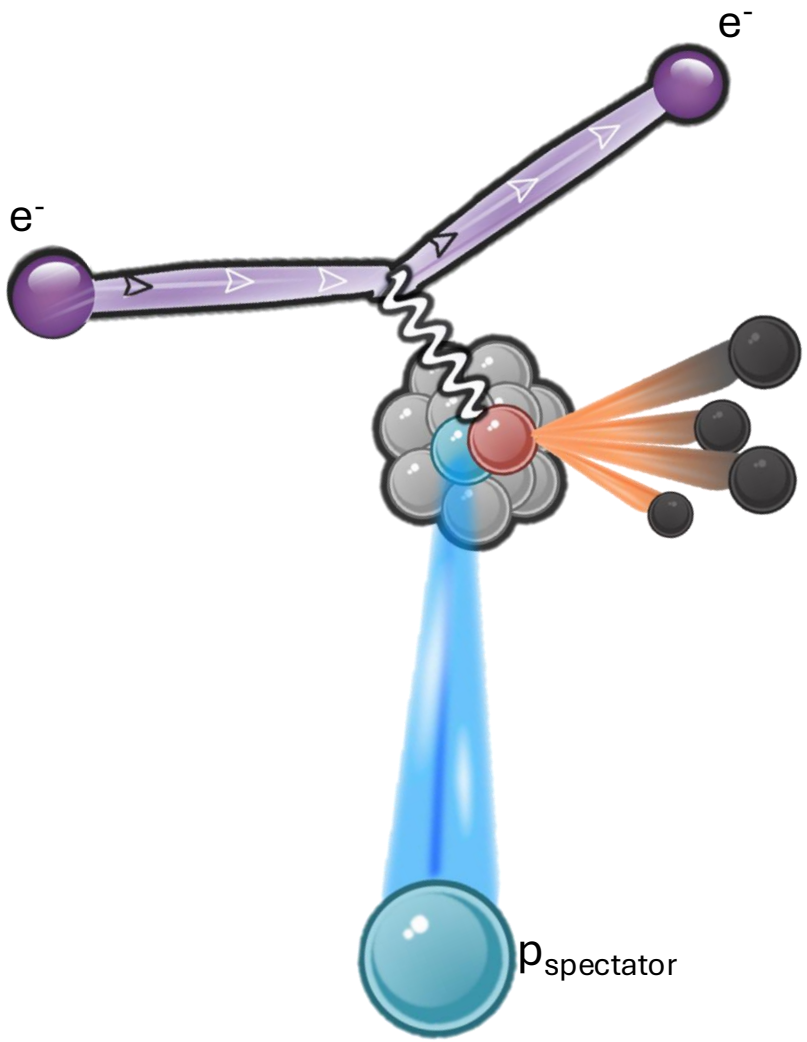


OR

SRC's (quasi-elastic)

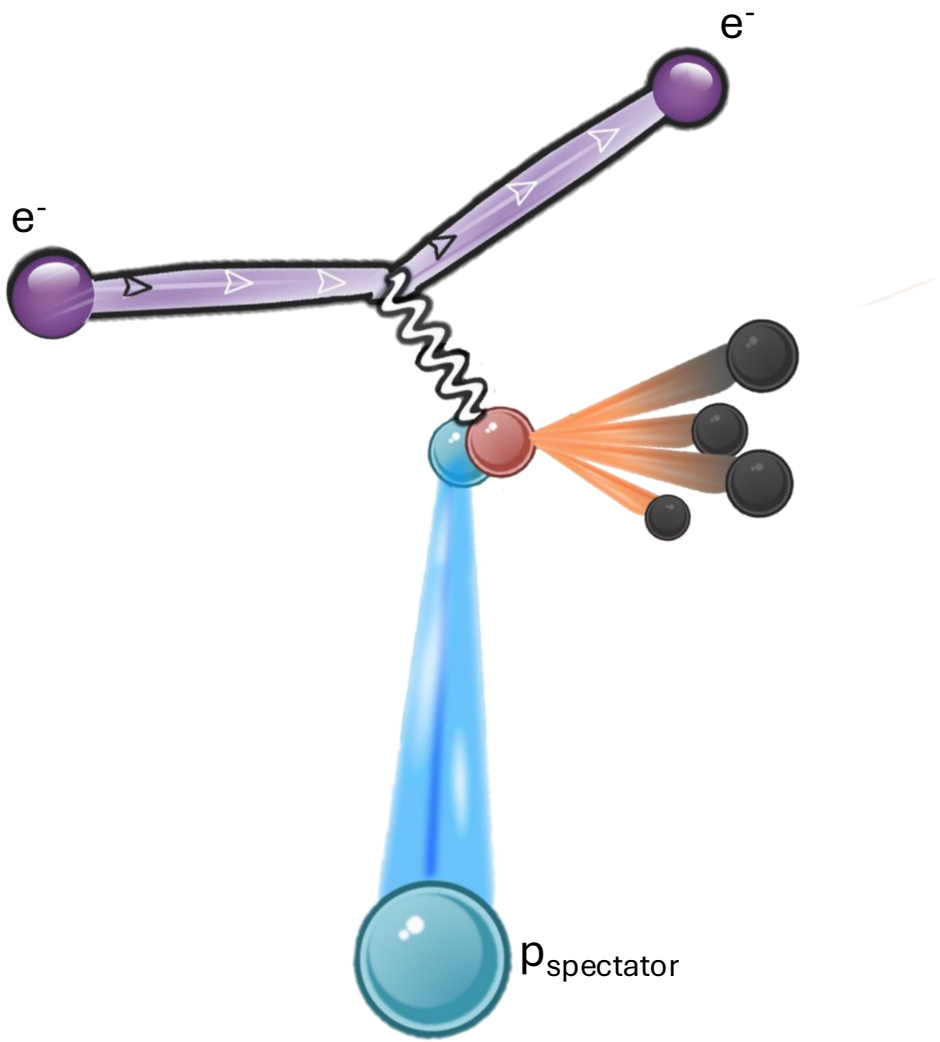


Spectator Tagged DIS



- Detect spectator nucleon
- Provides information on initial nucleon state
- (e,e’ p_s)

Spectator Tagged DIS



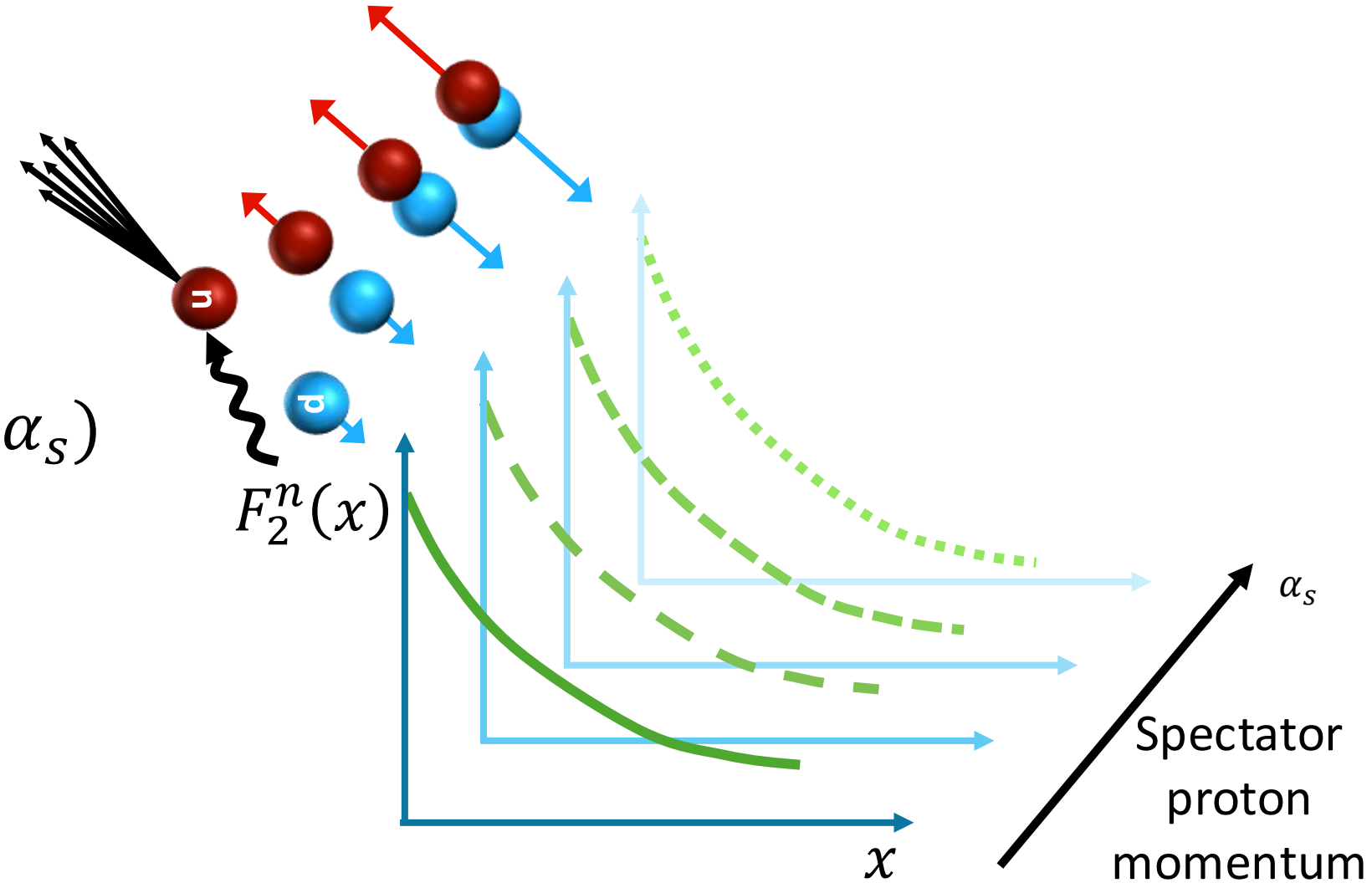
- Detect spectator nucleon
- Deuteron: Fully constrains initial nucleons

$$\vec{p}_{miss} \approx -\vec{p}_{recoil}$$

Spectator Tagged DIS

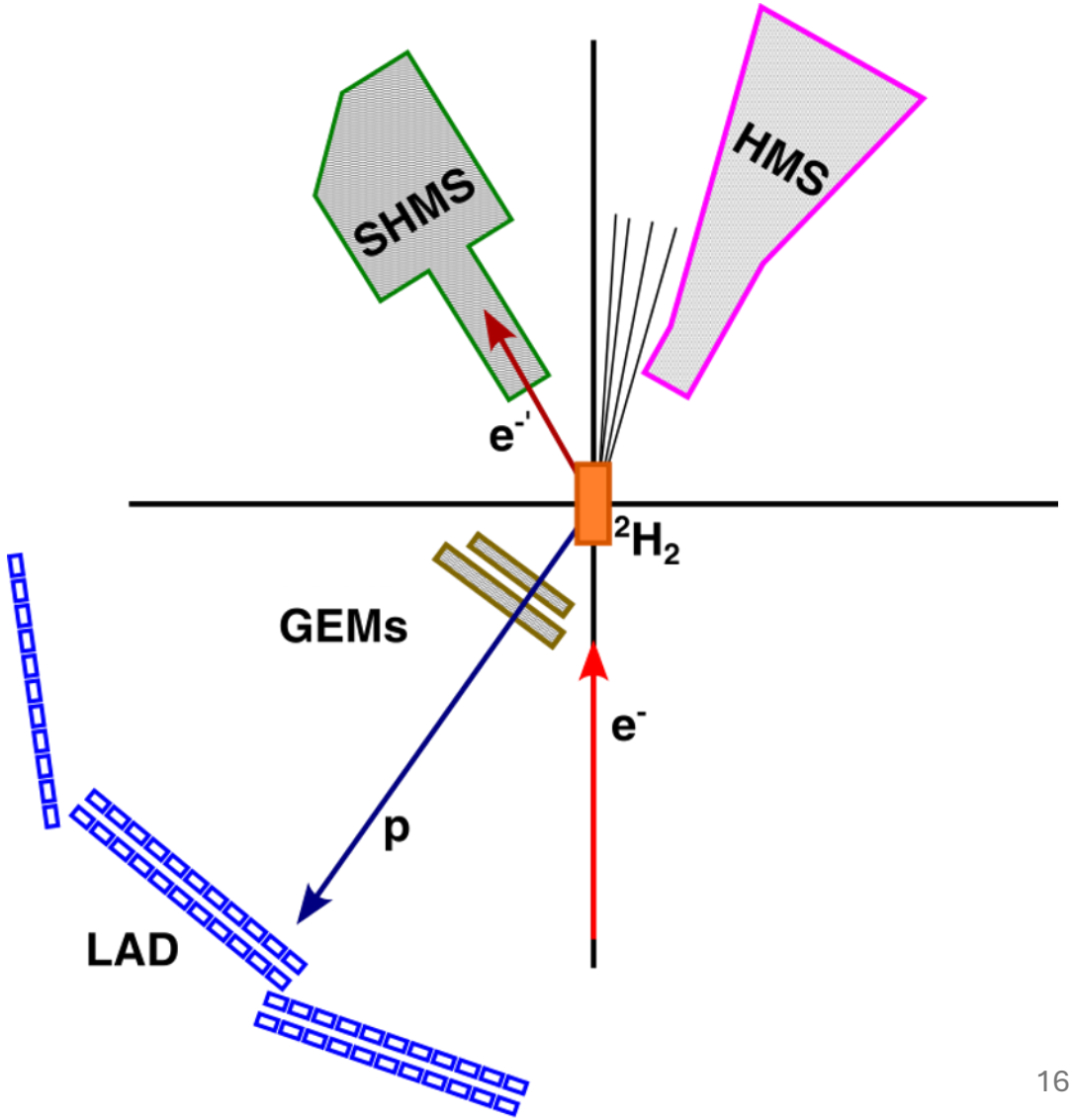
$$F_2(x, Q^2) -> \; F_2(x', Q^2, \alpha_s)$$

$$\alpha_s = \frac{E_s - p_s^z}{m_N}$$

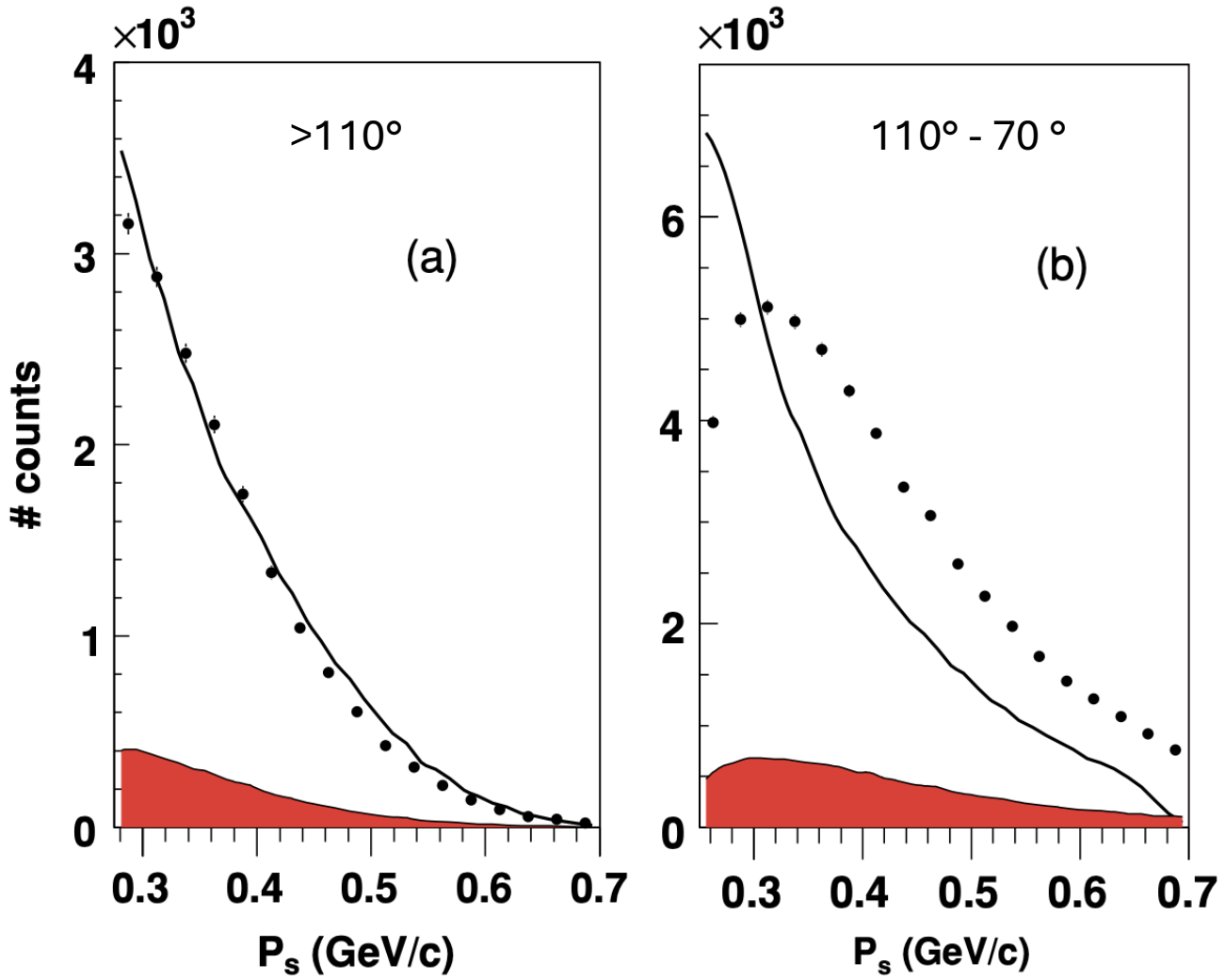


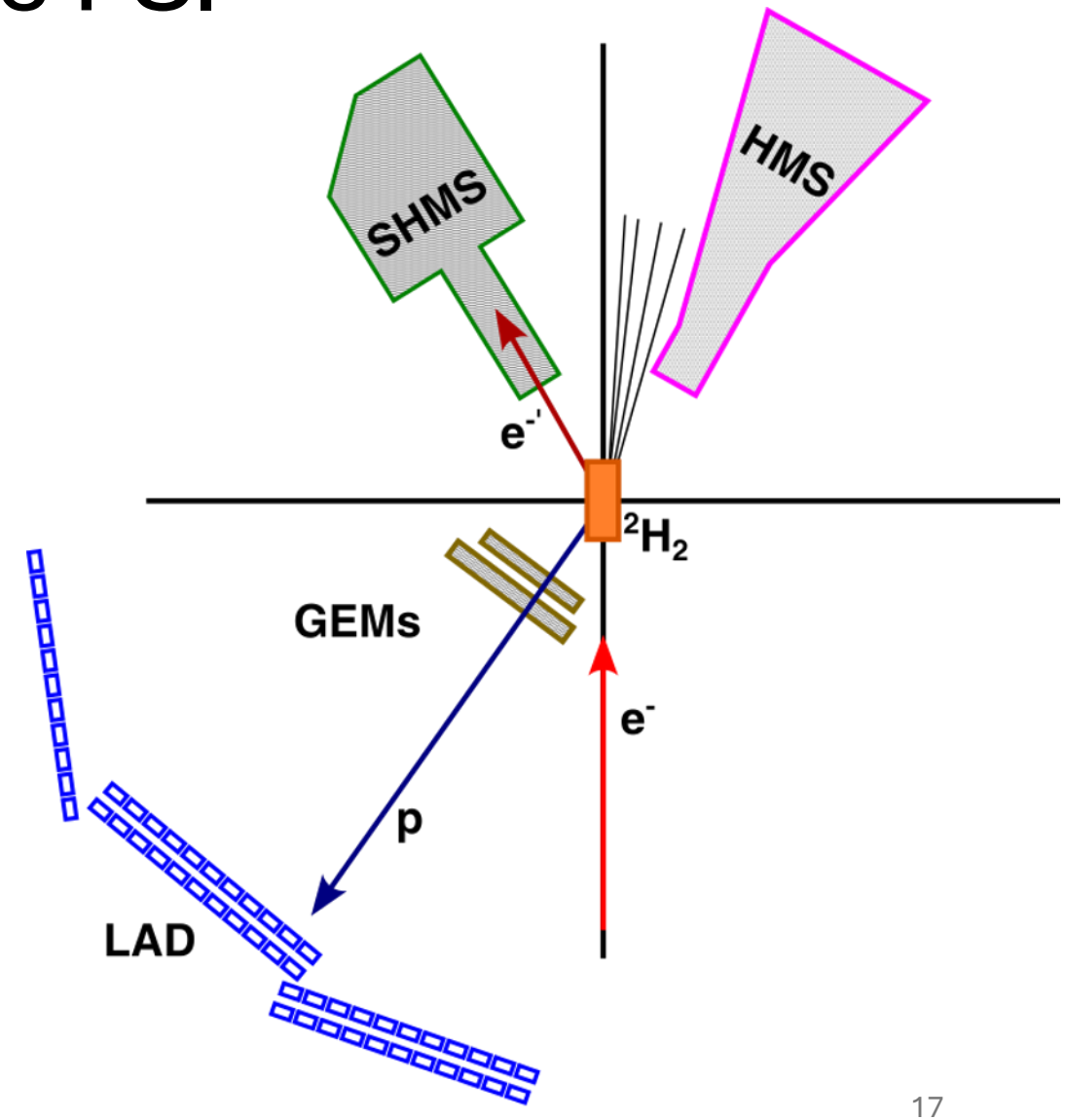
Large Acceptance Detector (LAD) Experiment

- D(e,e'p_s)
- HMS/SHMS for electron
- Install two new detectors
  - Scintillating bars
  - GEMs



Backward angles minimize FSI

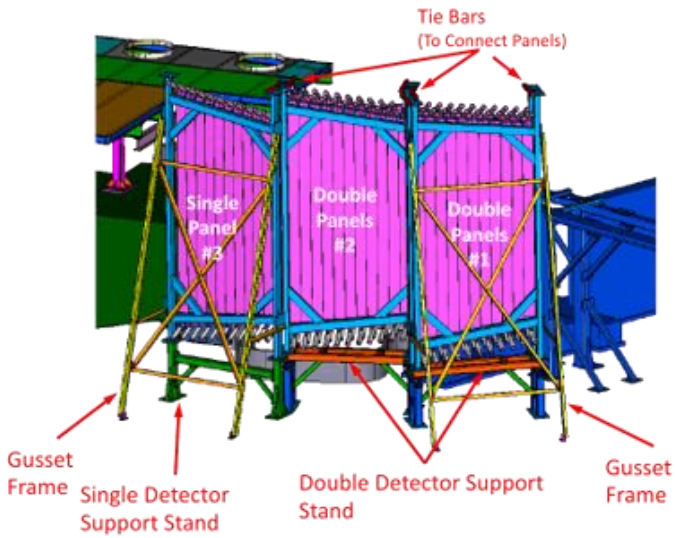


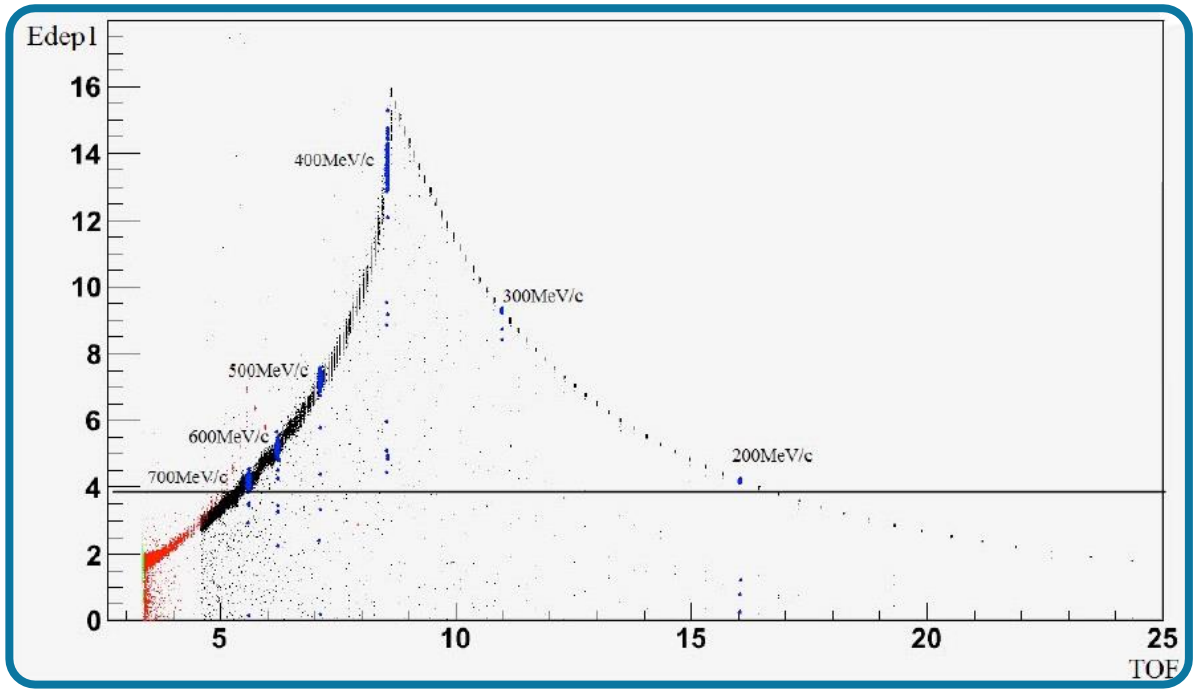


A. V. Klimenko et al., PRC (2006)

LAD: Scintillator Bars

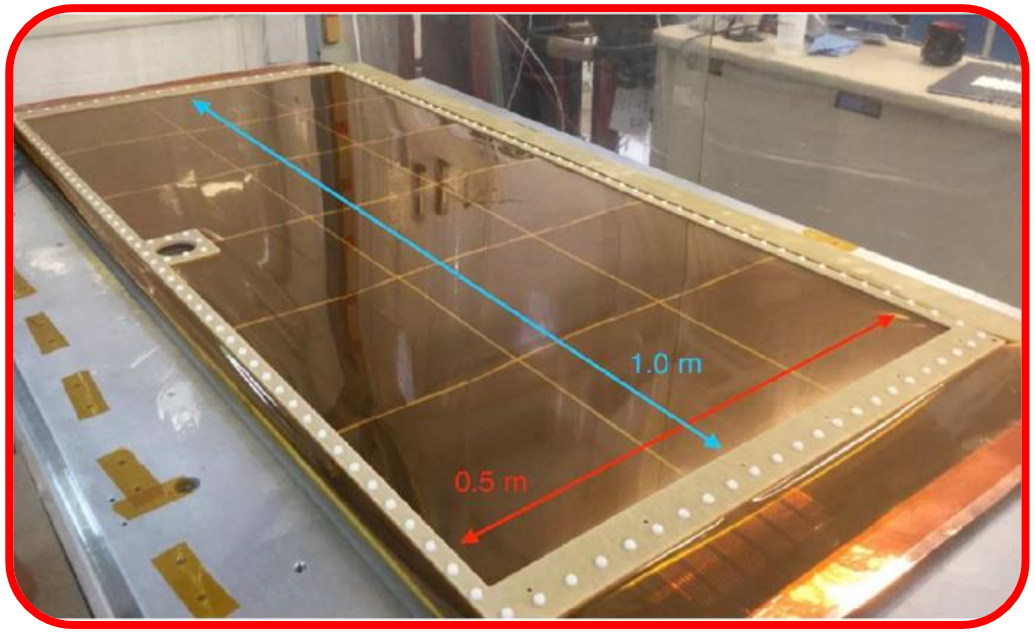
- Refurbished from CLAS-6 ToF
- 5 Panels
  - 2 double, 1 single plane
- PID through timing & energy
- Laser calibration

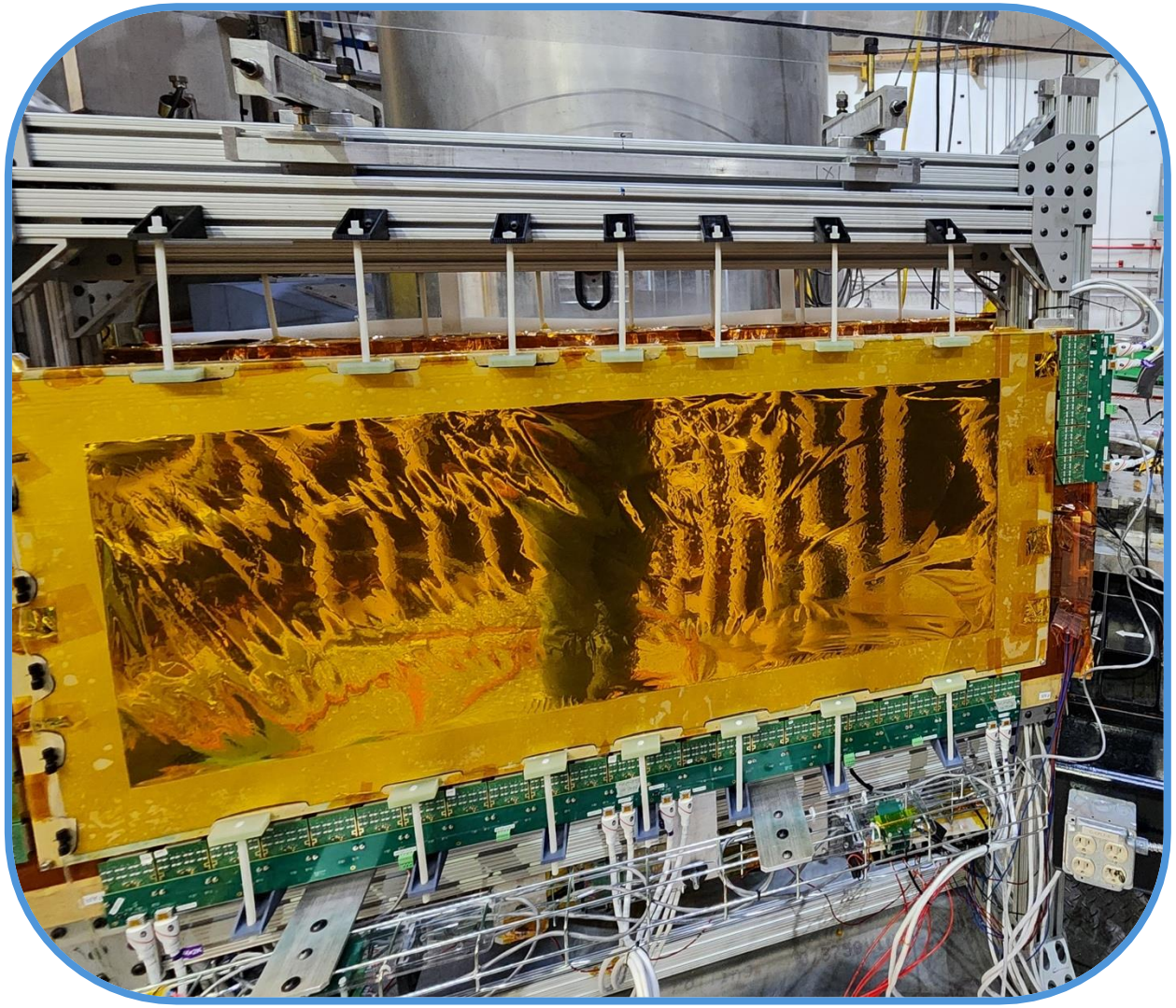




LAD: GEMs

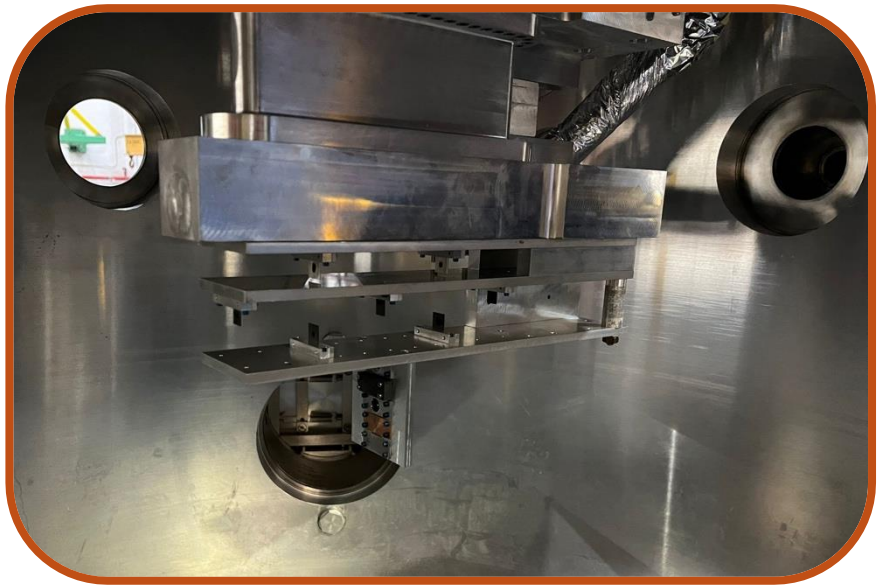
- Two layers
- Aid in vertexing
- Reused from PRAD



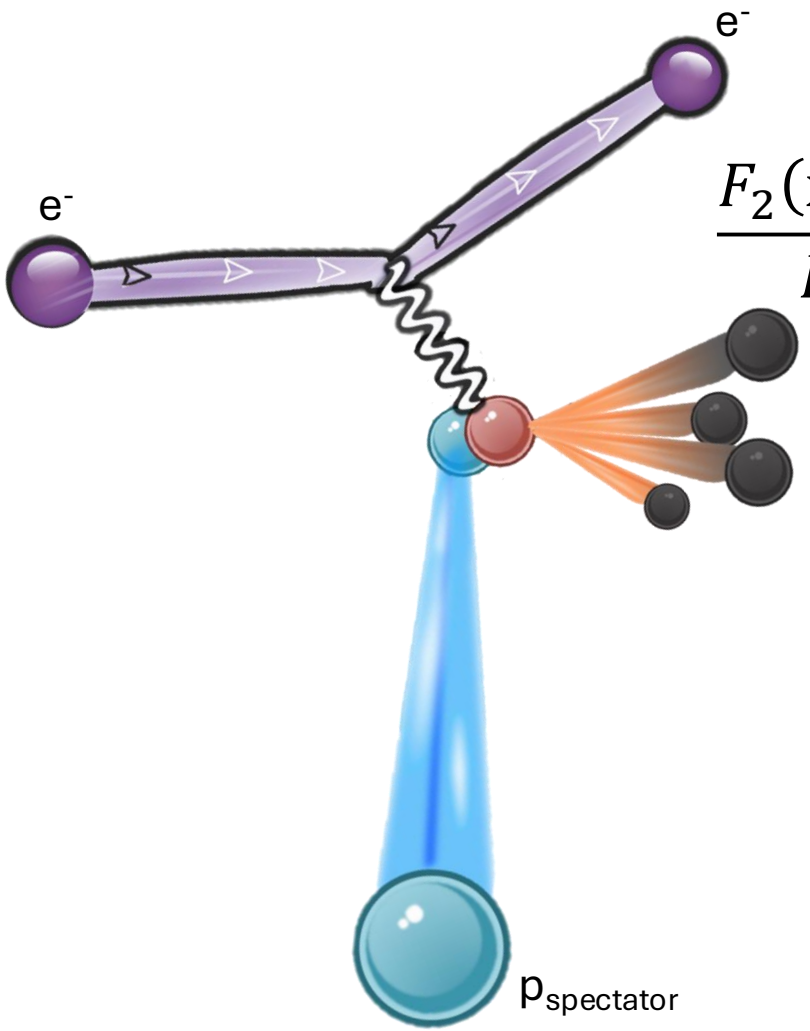


Experimental Run Conditions

- Jefferson Lab E12-11-107 (LAD)
- 34 PAC Days ~~(Feb 2025 – May 2025)~~
  (Mar 2025 – Jul 2025)
- Beam Energy: 11 GeV
- Current: ~~~1 μA~~ 0.3 μA
- Target: 20 cm liquid D2
- Luminosity: 1.2×10^{37} cm^{-2} s^{-1} per nucleon



Observables



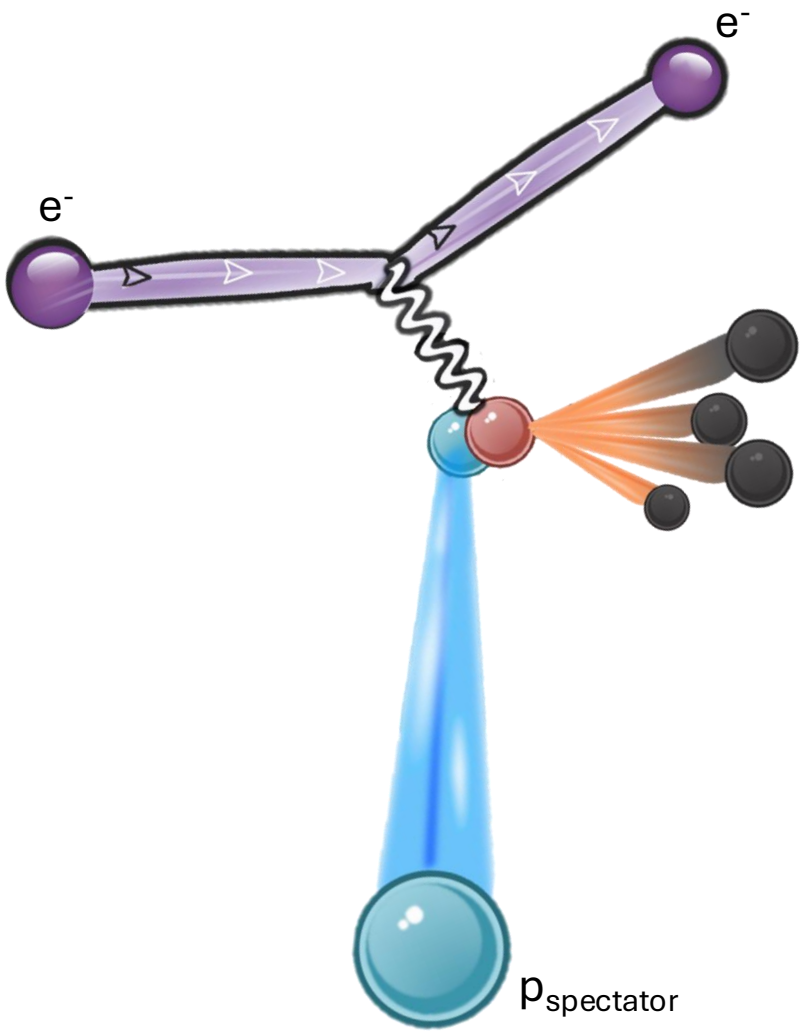
$$\frac{F_2(x', Q^2, \alpha_s)_{\text{bound}}}{F_2(x, Q^2)_{\text{free}}} = \frac{F_2^n(\alpha_s, x')_{\text{bound}}}{F_2^n(\alpha_s, x_0')_{\text{bound}}} \times \frac{F_2^n(\alpha_s, x_0')_{\text{free}}}{F_2^n(\alpha_s, x')_{\text{free}}} \times R_{\text{FSI}}$$

(Tagged DIS data) (Simulation)

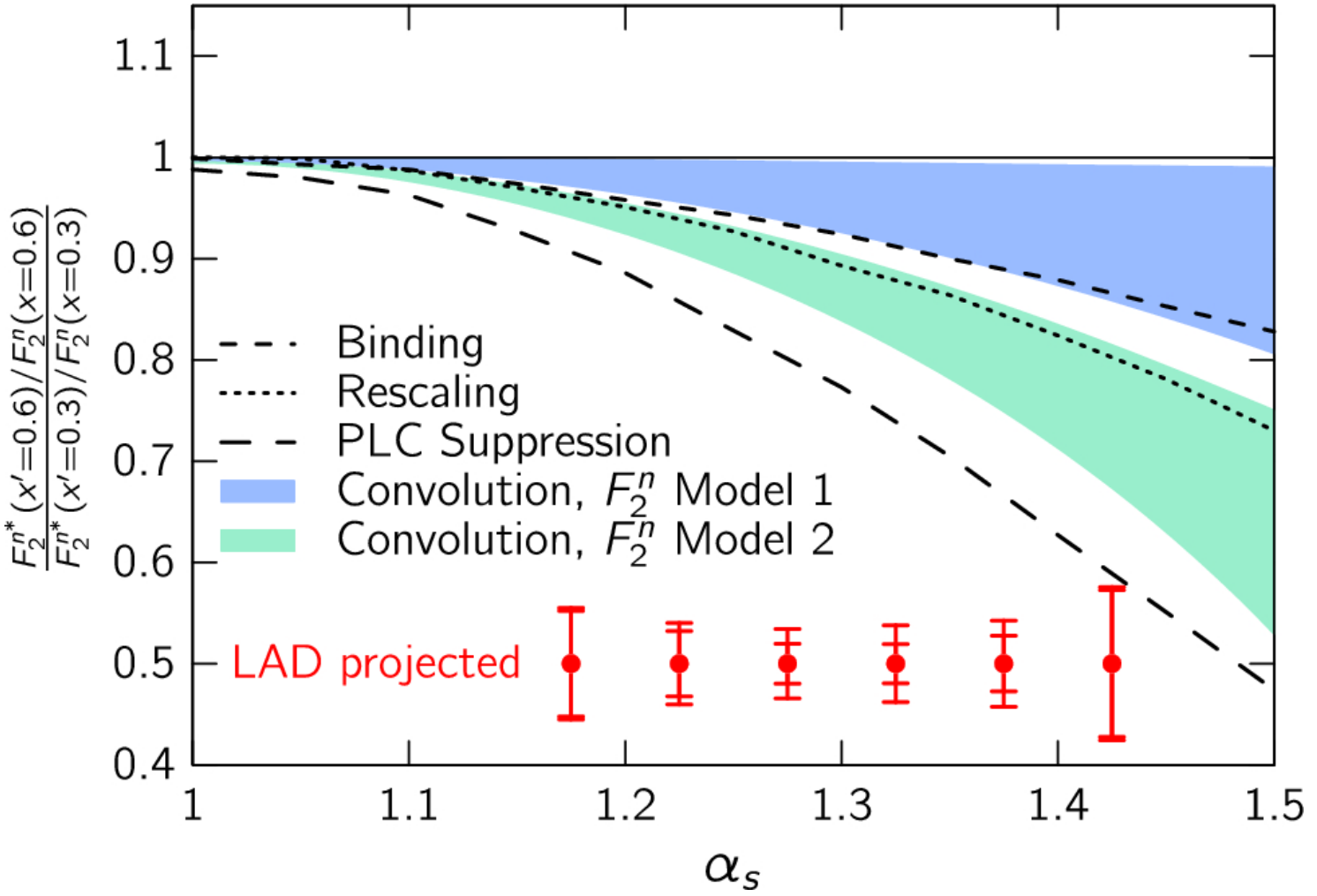
$$x_0' \approx 0.3$$

$$F_2^n(\alpha_s, x_0')_{\text{bound}} \approx F_2^n(\alpha_s, x_0')_{\text{free}}$$

Projected Sensitivity



Hauenstein et al., EPJA (2024)



Calibrations and Initial Results

Spectrometers

- Optics
- Individual detectors
- SHMS + HMS

GEMs

- Clustering
- Position
- Tracking

Hodoscopes

- Timing
- Energy
- Proton PID

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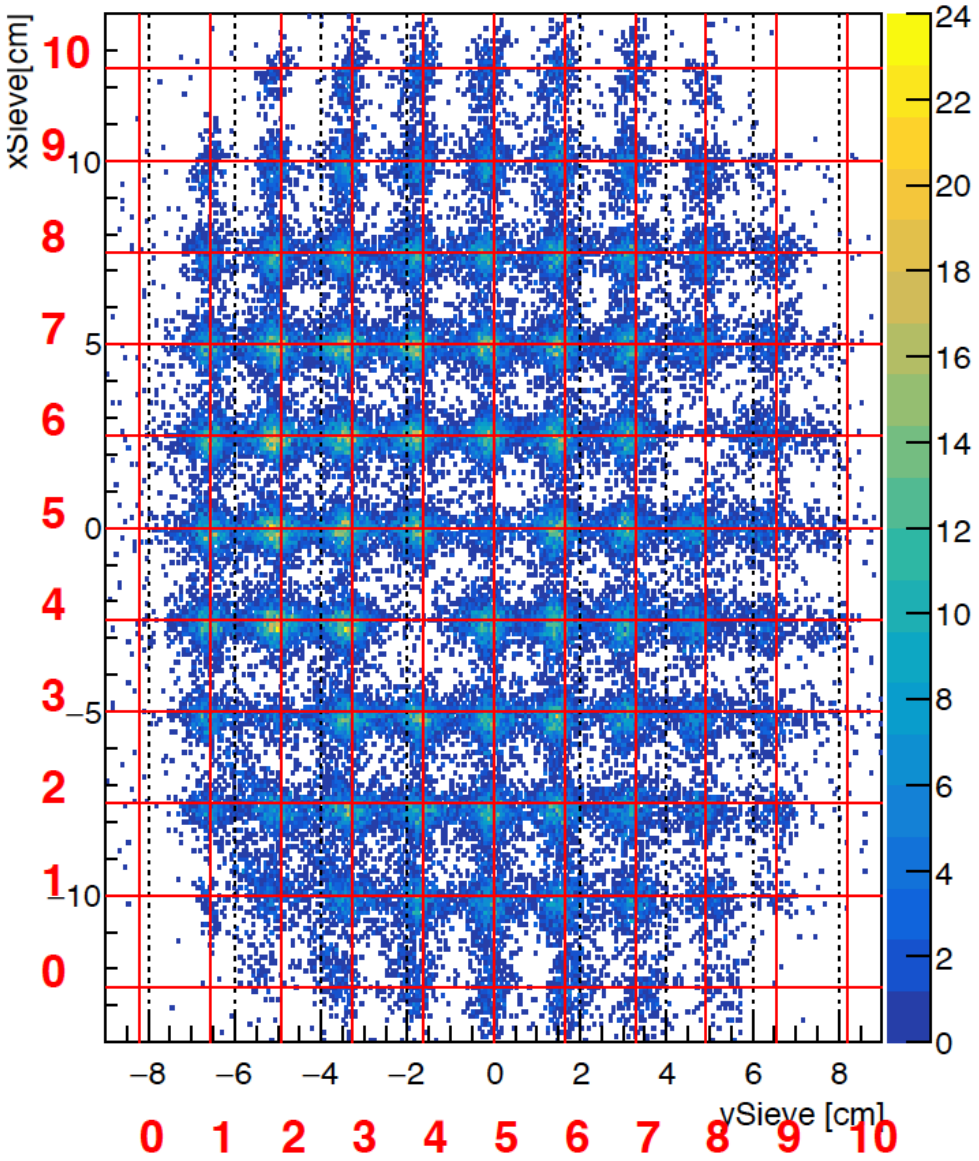
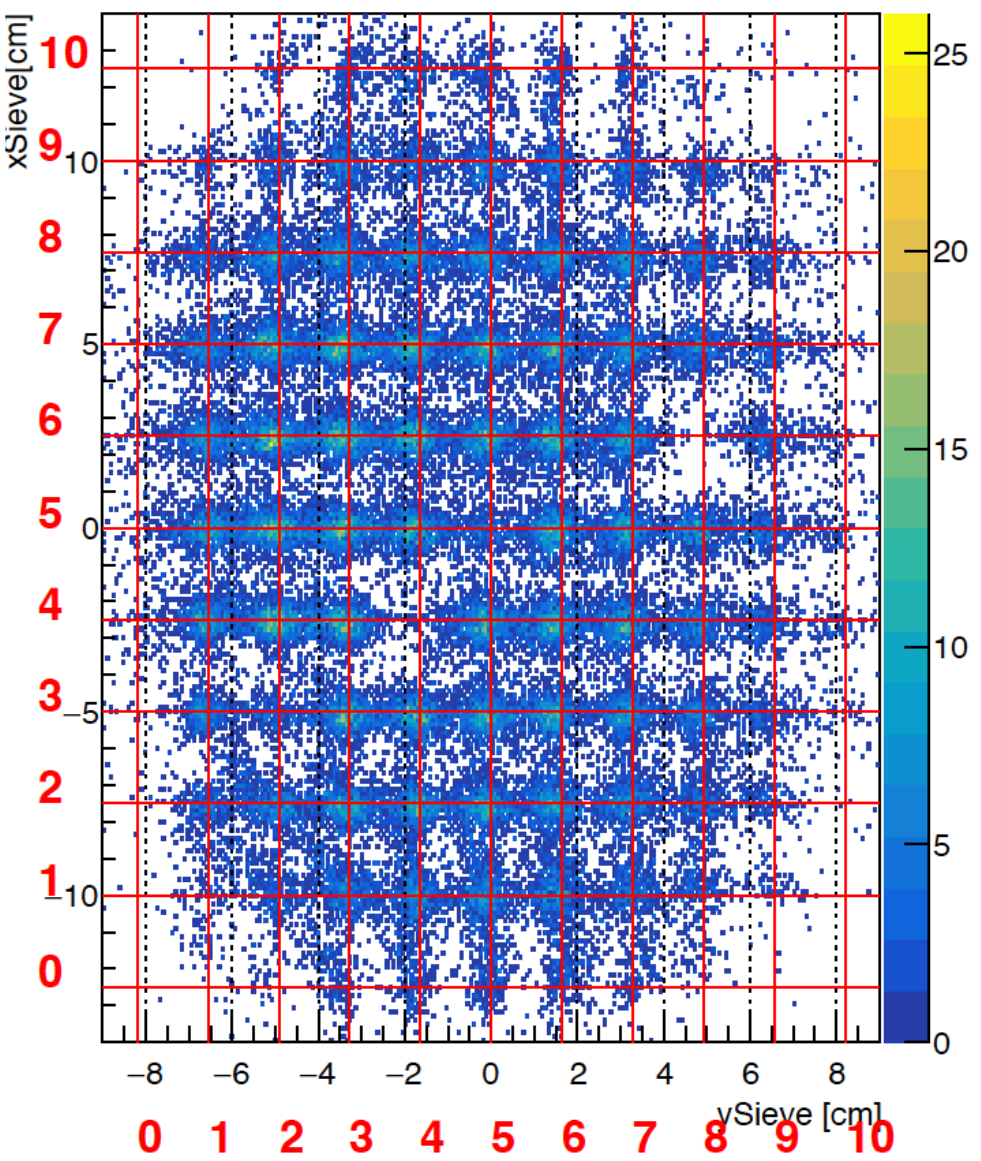
LAD SHMS Optics Status

A1n extended target matrix

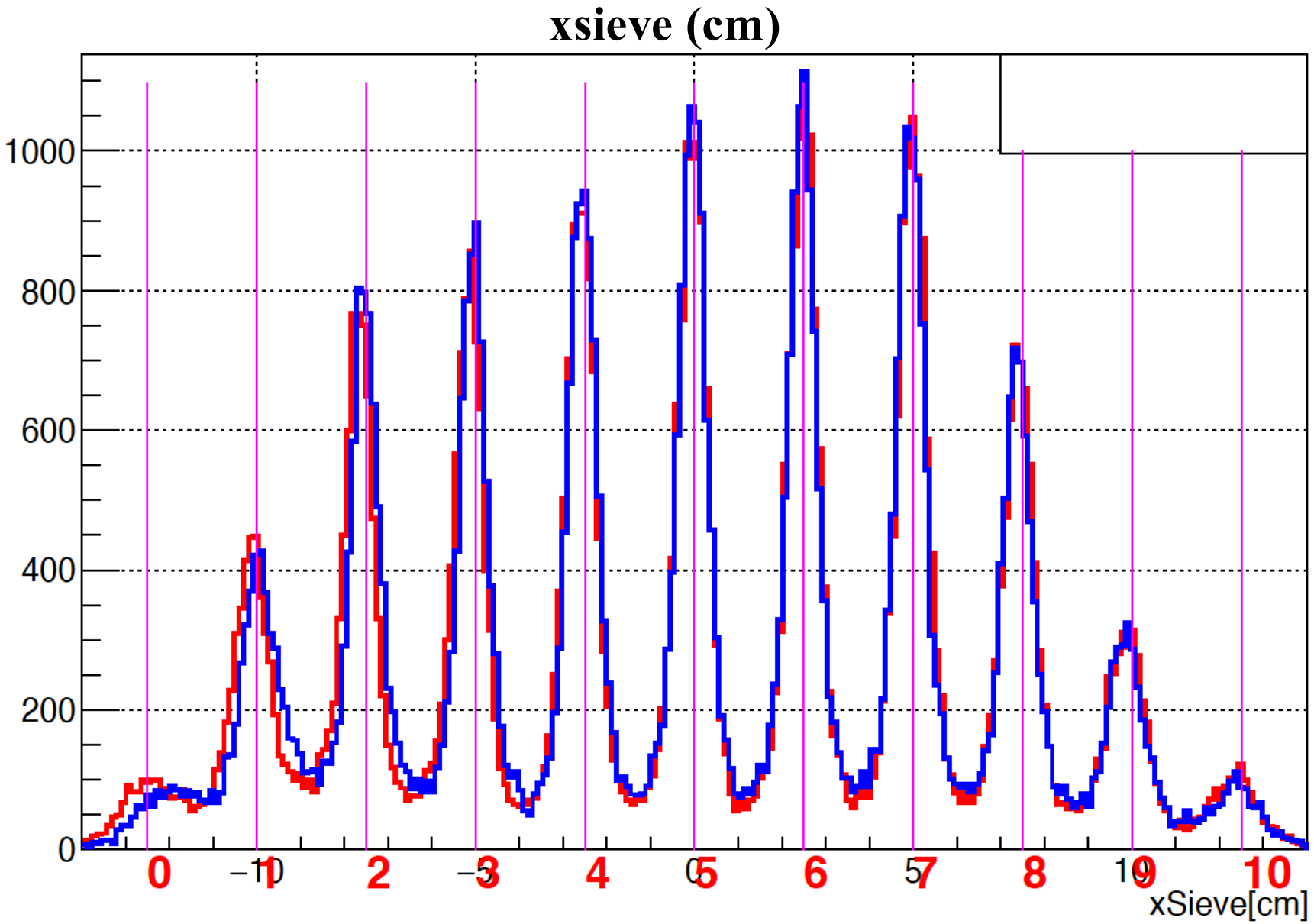


LAD optimized matrix



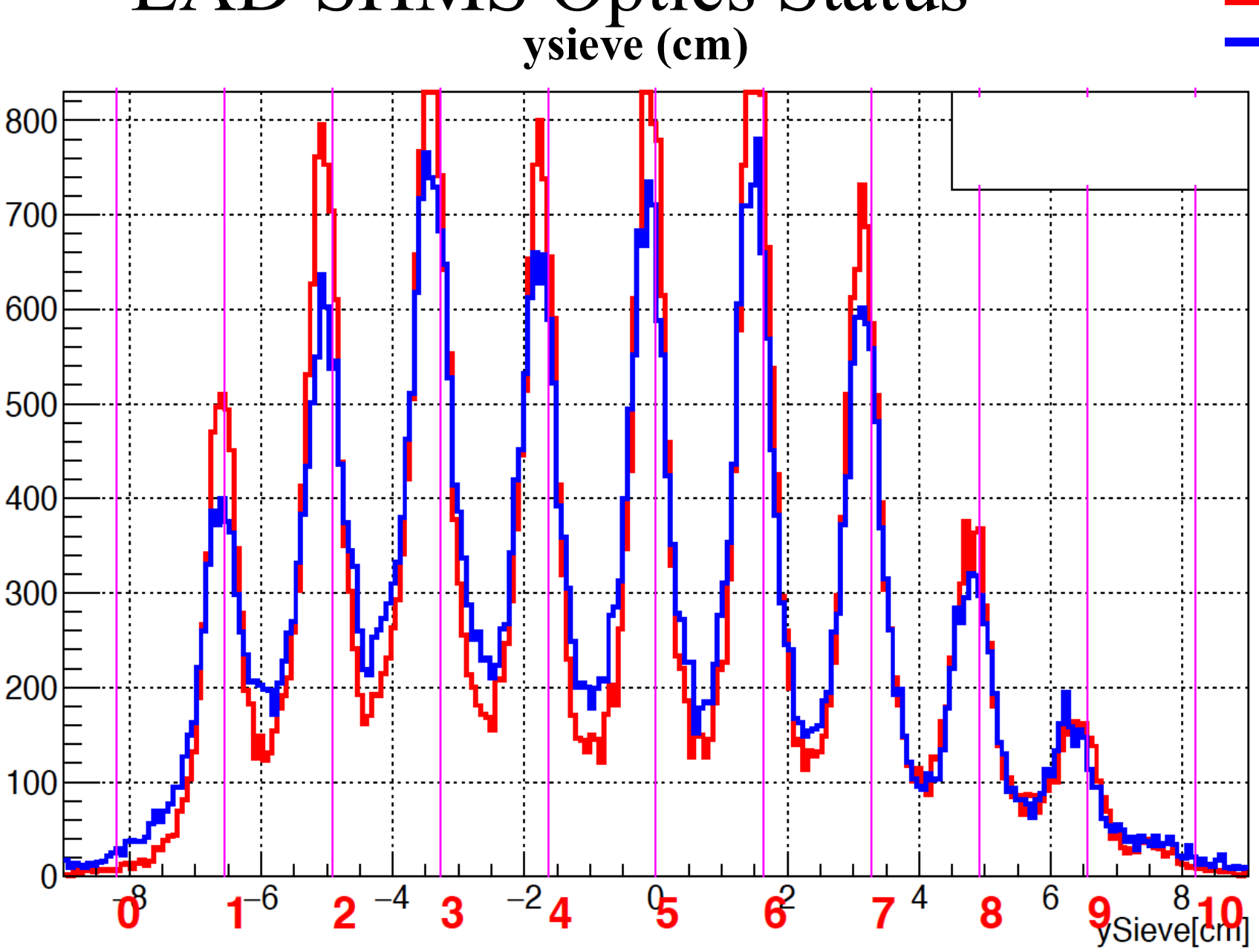
- Sieve pattern for LAD optimized matrix is slightly less distinct and does poorer on the edge regions.
- SHMS optics angle optimization is ongoing.

LAD SHMS Optics Status



- Xsieve pattern largely consistent
- LAD optimized matrix seems to do slightly worse on edge sieve holes

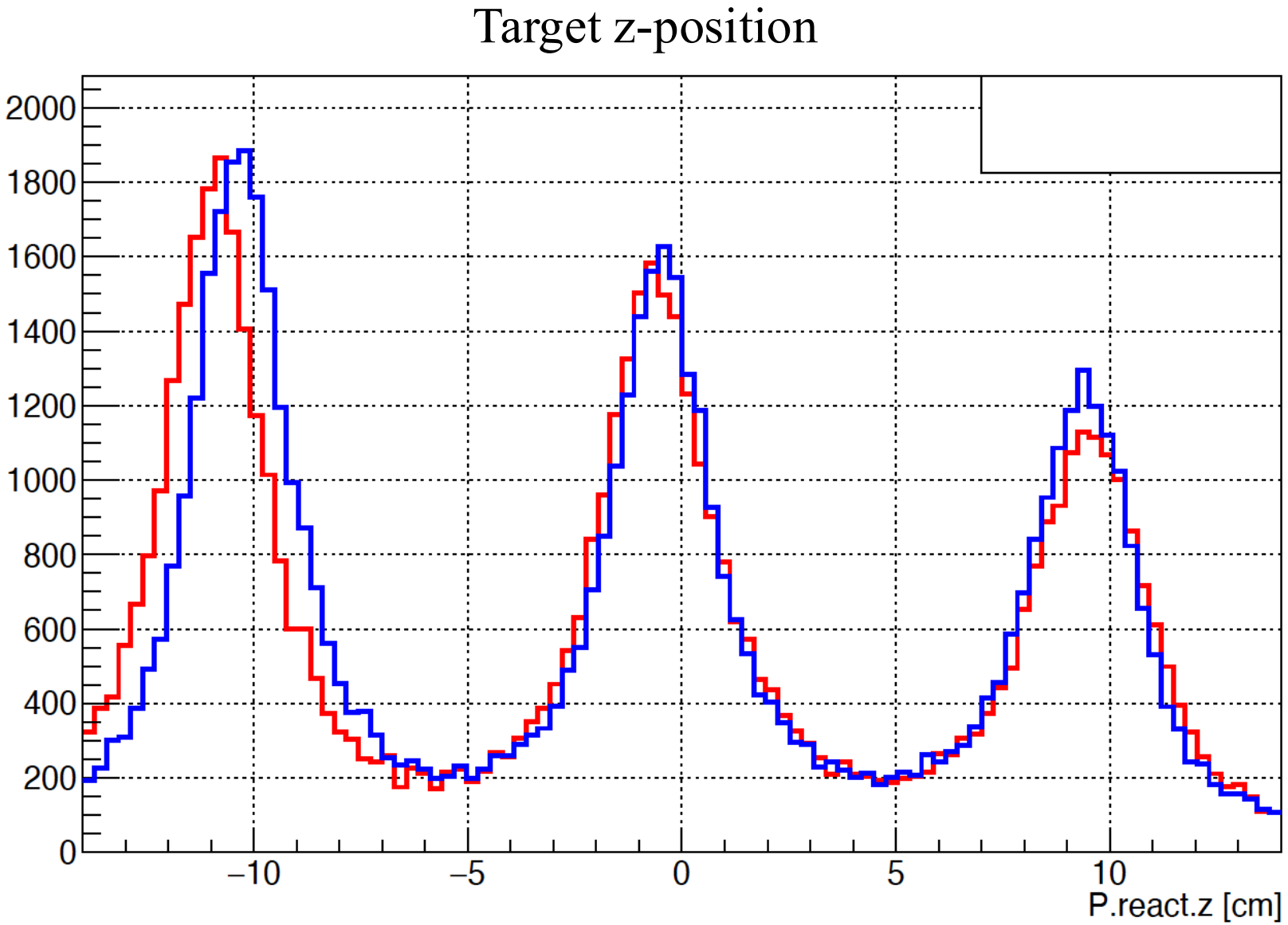
LAD SHMS Optics Status



- Ysieve pattern shows considerable differences between the two optics matrices
- Further study ongoing

LAD SHMS Optics Status

A1n extended target matrix
LAD optimized matrix



- Target z-position is clearly improved with LAD optimized matrix.

Calibrations and Initial Results

Spectrometers

- Optics
- Individual detectors
- SHMS + HMS

GEMs

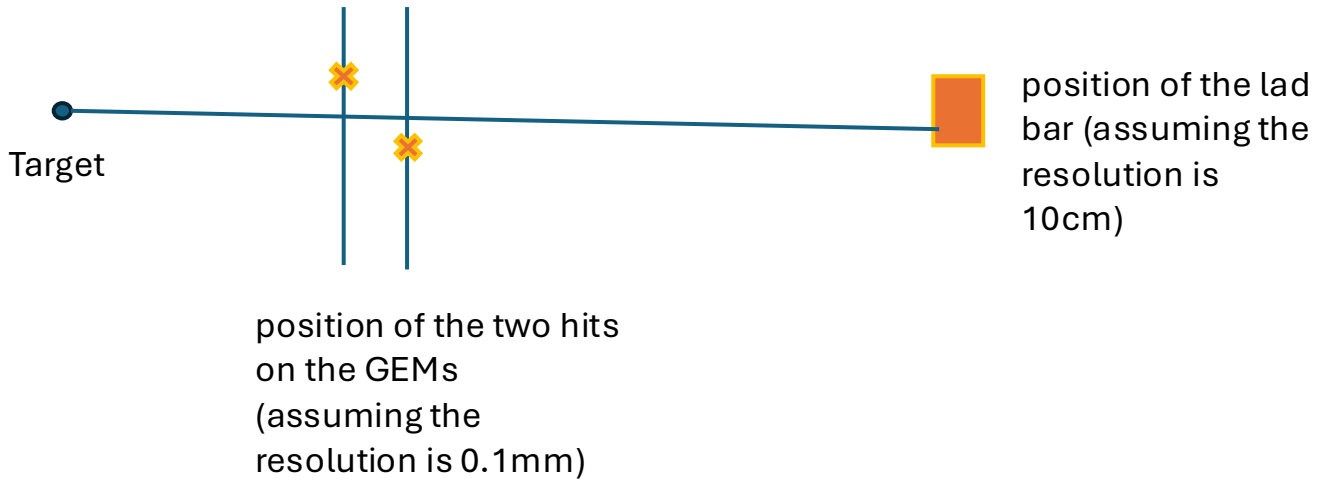
- Clustering
- Position
- Tracking

Hodoscopes

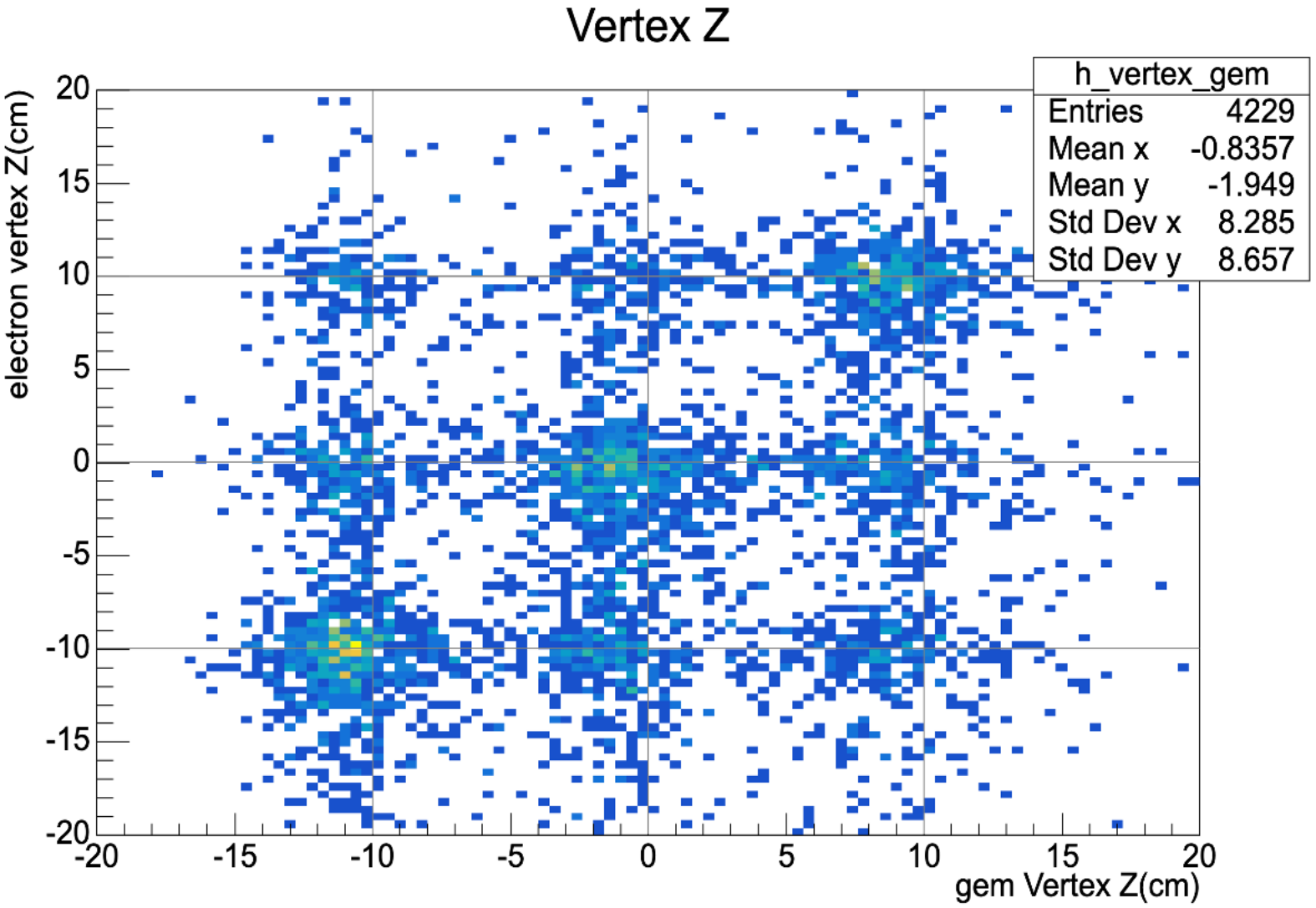
- Timing
- Energy
- Proton PID

Aligning the detectors

- Assume the track must go through one of the foils,
- Fit the track trough the two GEM hits and the hodoscope bars
- Minimize the average χ^2

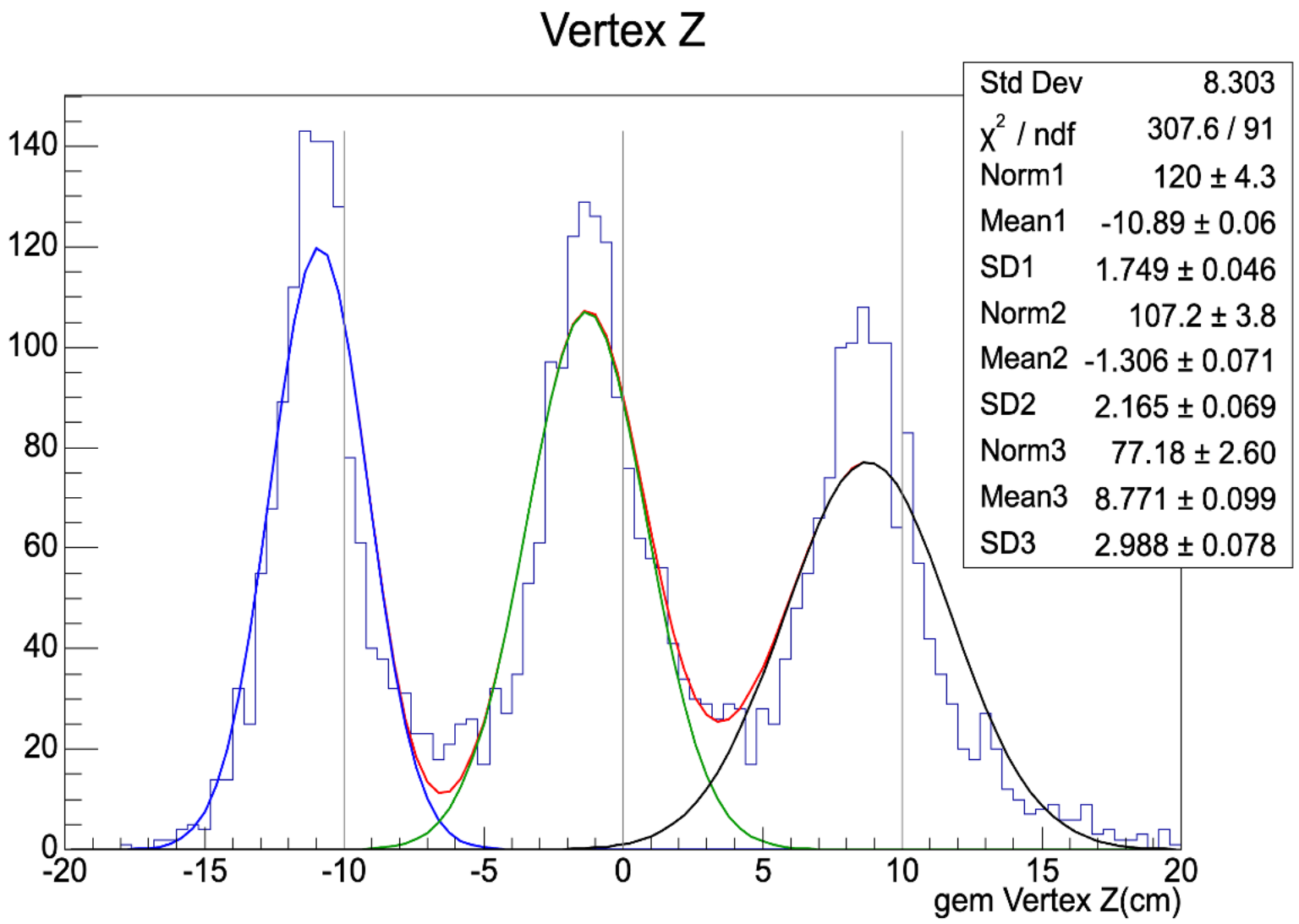


After 1st alignment



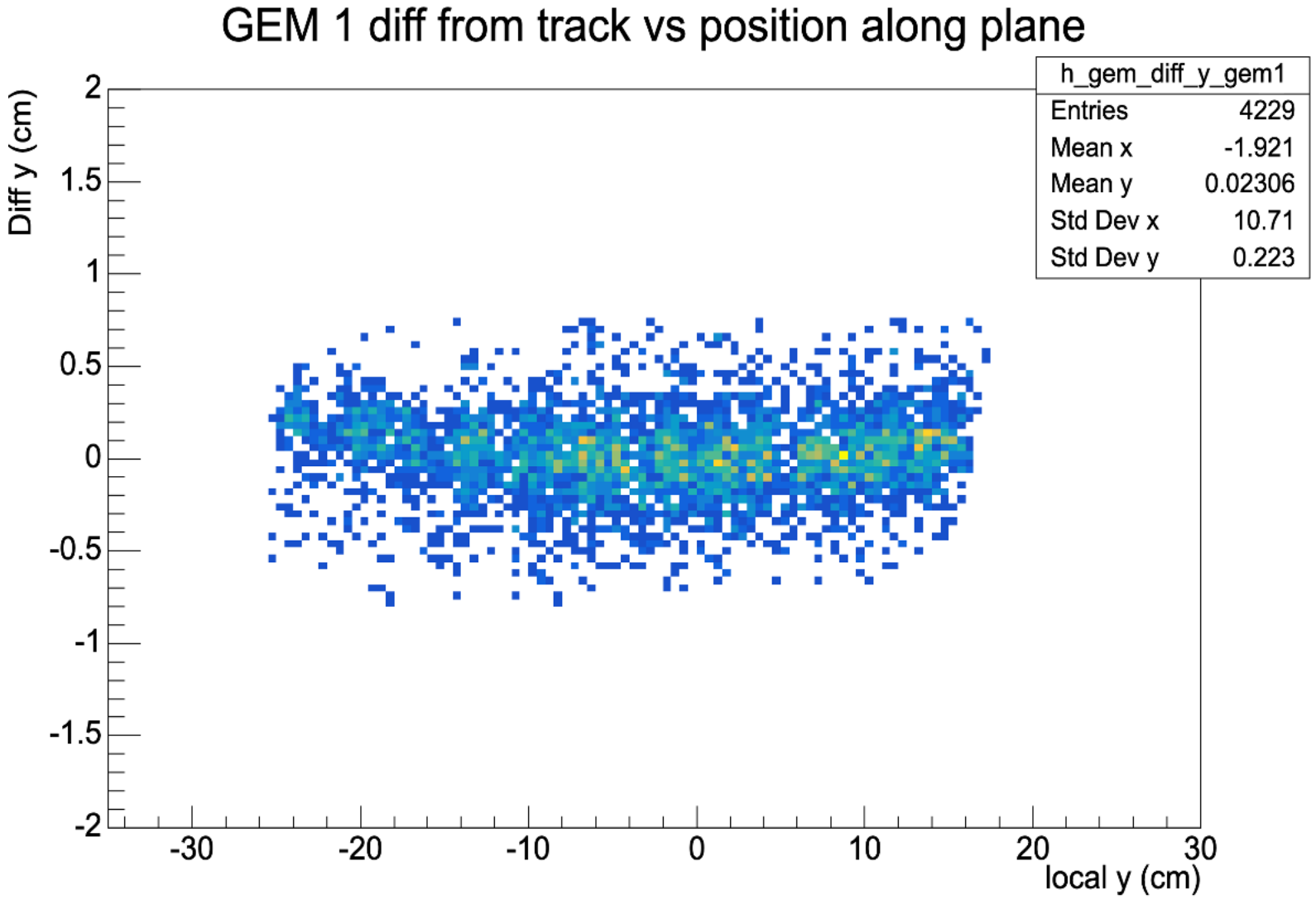
- All three foils can be resolved
- Clear electron-GEM correlation

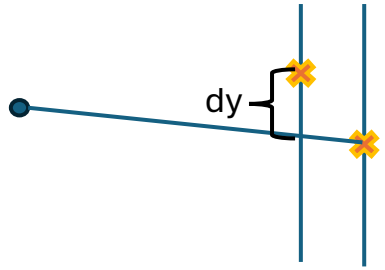
After 1st alignment



- Good foil resolution
- Systematic shift in foil centers

After 1st alignment





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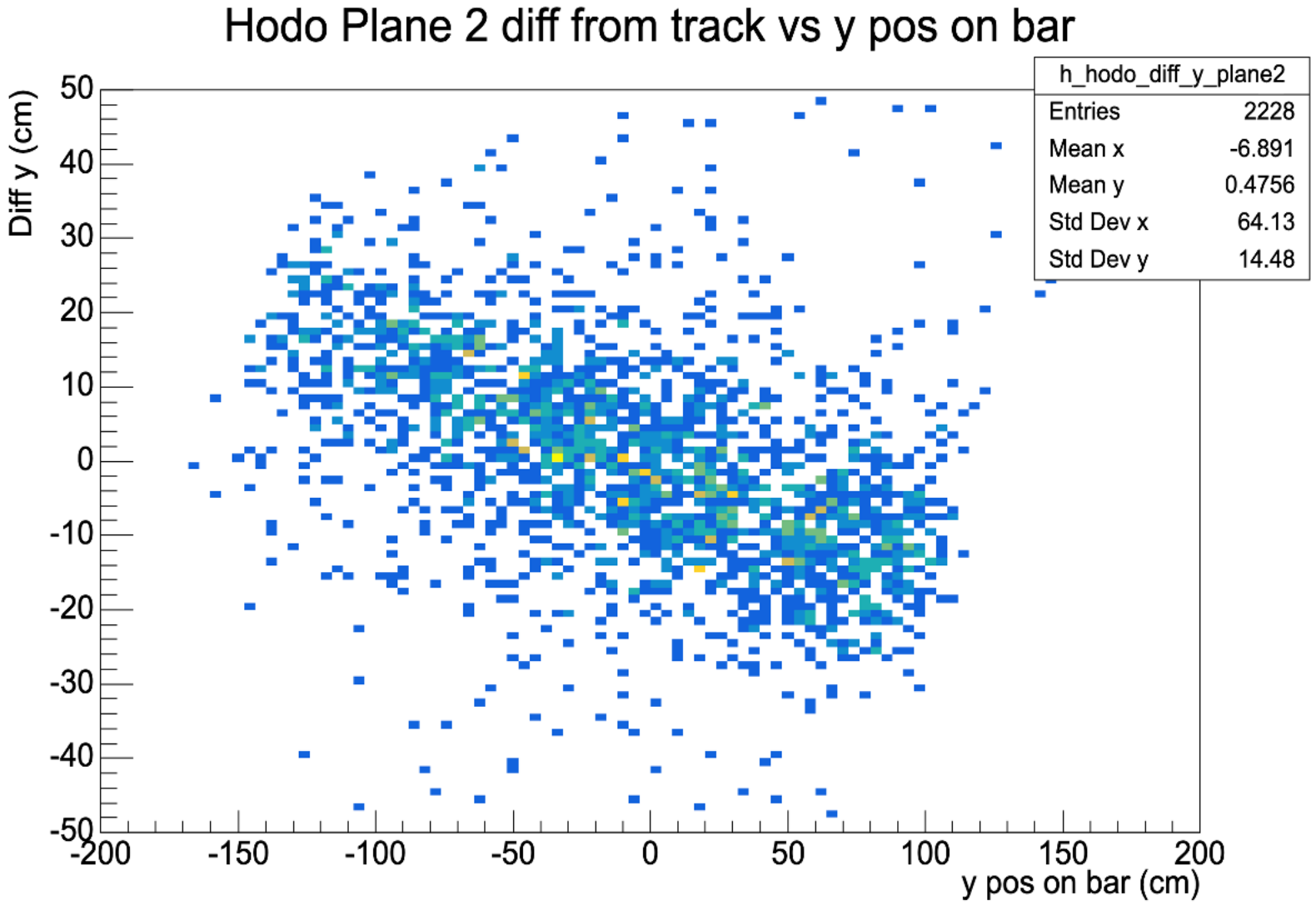
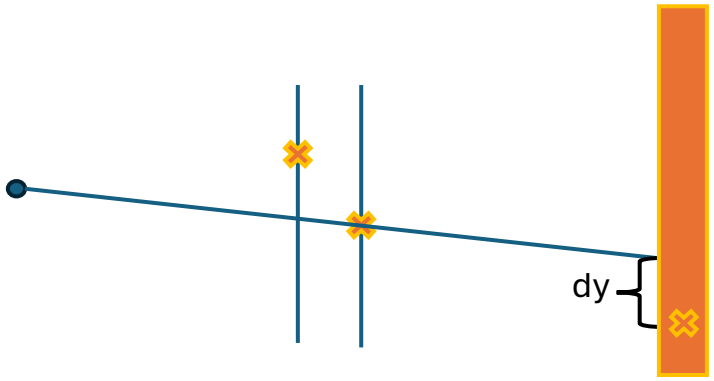
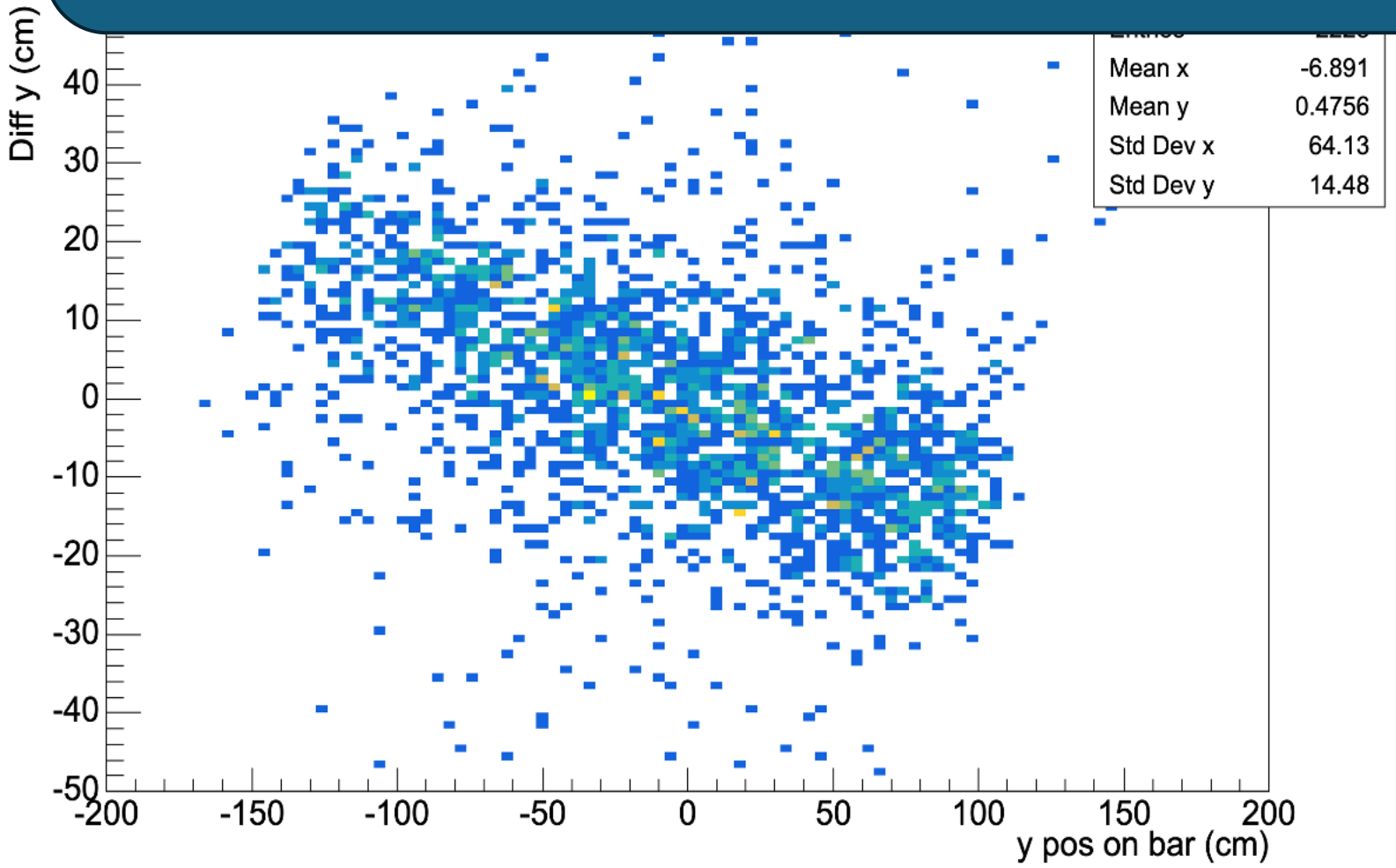
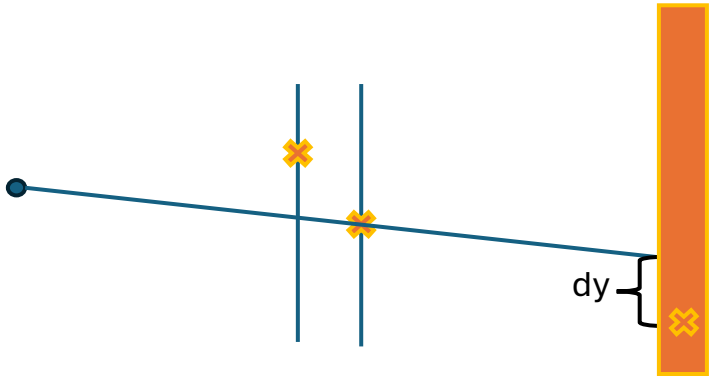




Able to diagnose a 10% shift in hodoscope propagation velocity!!

(Currently being corrected)





Calibrations and Initial Results

Spectrometers

- Optics
- Individual detectors
- SHMS + HMS

GEMs

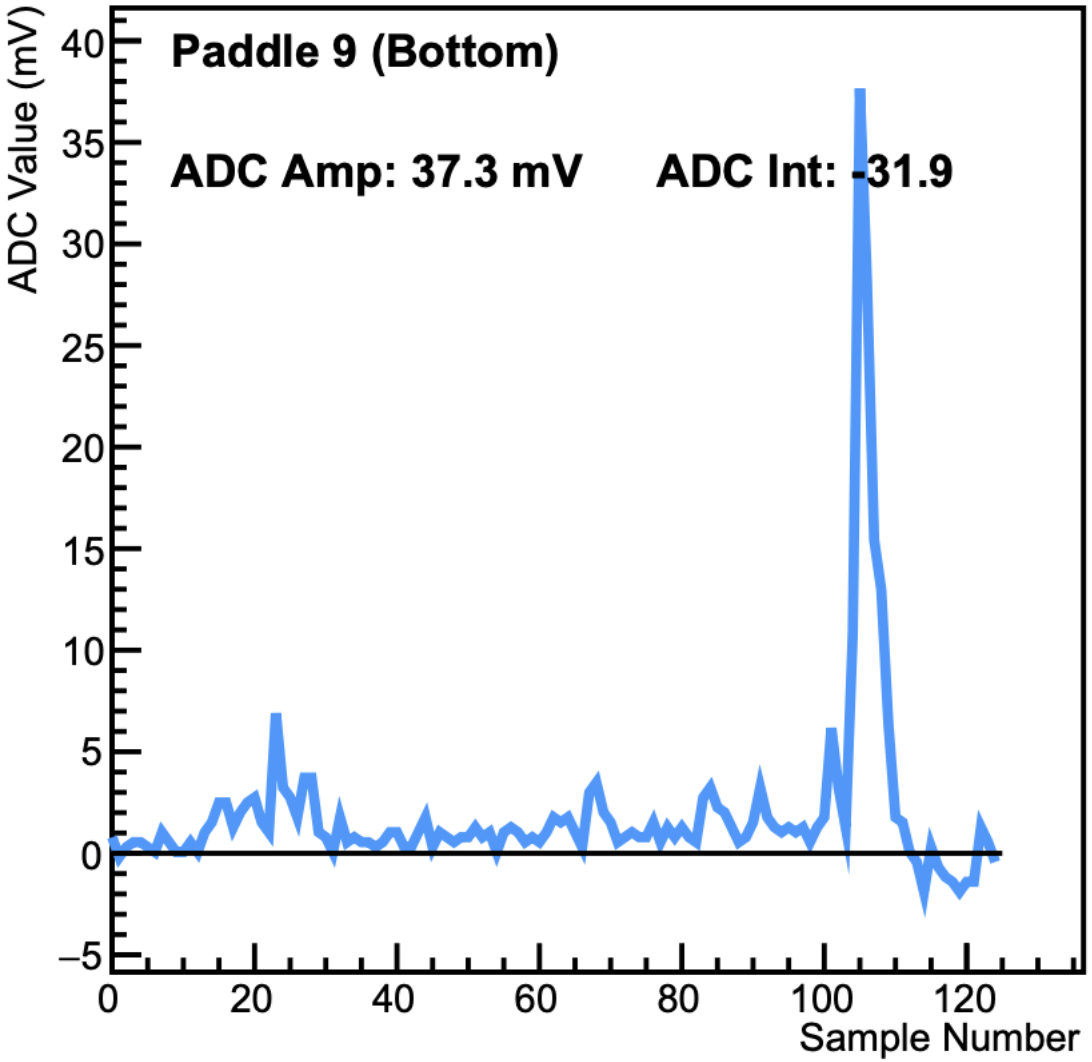
- Clustering
- Position
- Tracking

Hodoscopes

- Timing
- Energy
- Proton PID

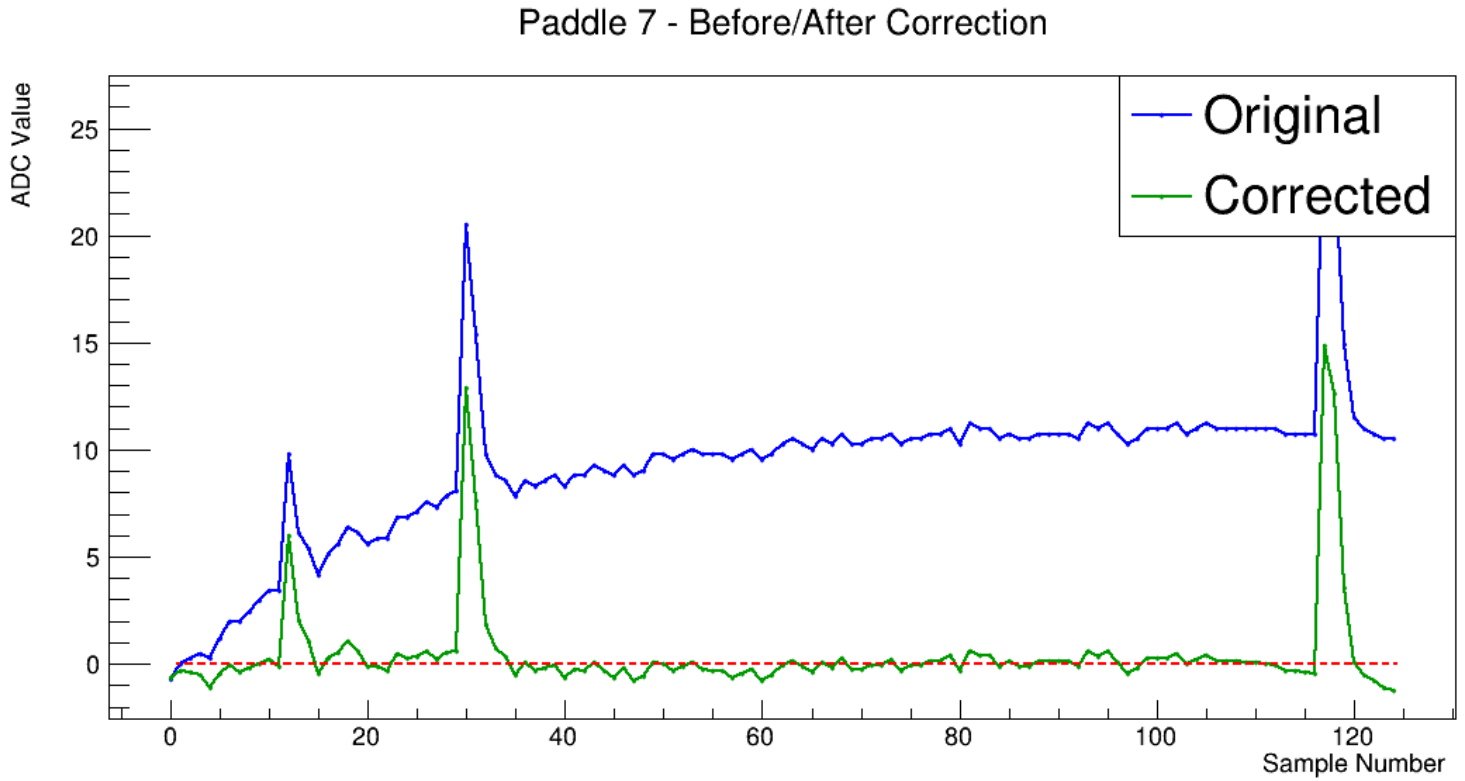
PMT Oddities

- Negative integral, positive amplitude



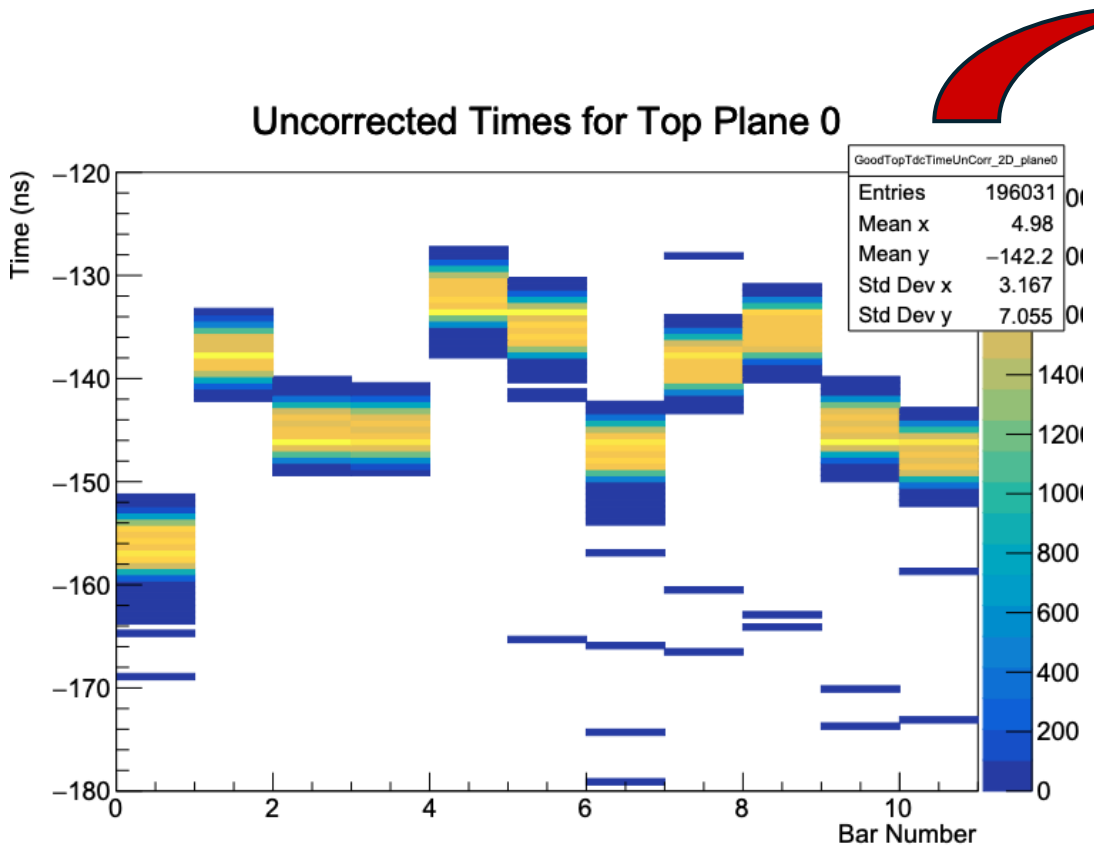
PMT Oddities

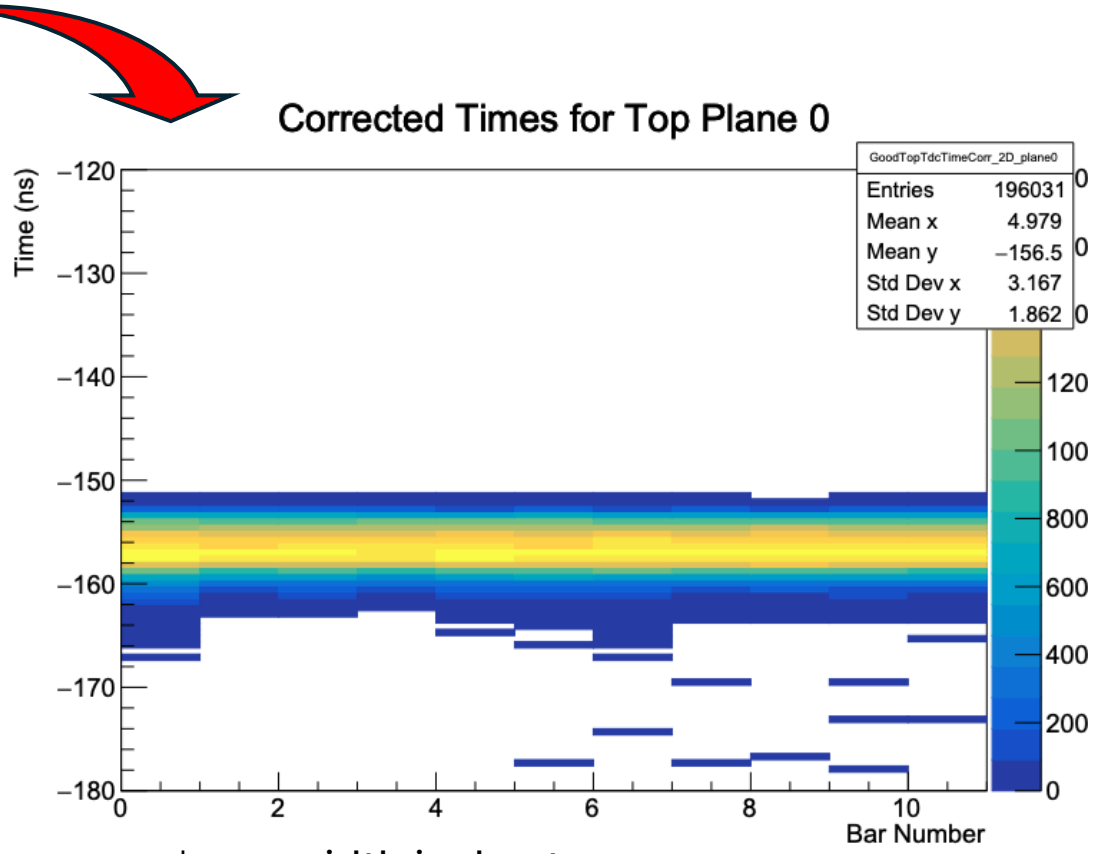
- Negative integral, positive amplitude
- Shaped baseline
  - Diagnosing magnitude of problem
  - Implementing fix



Hodoscopes: Bar-to-bar timing w/ laser

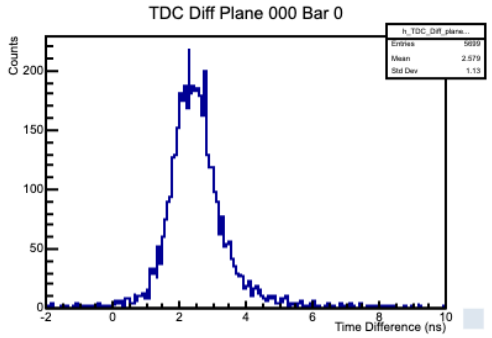
- Know: hit position (center) and time from laser

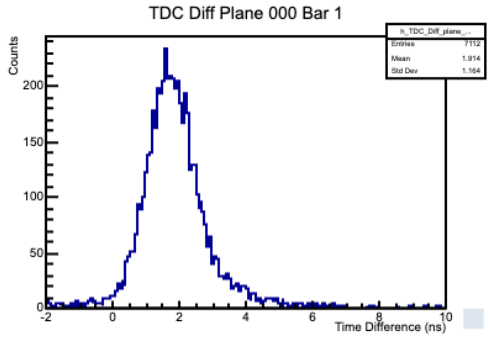


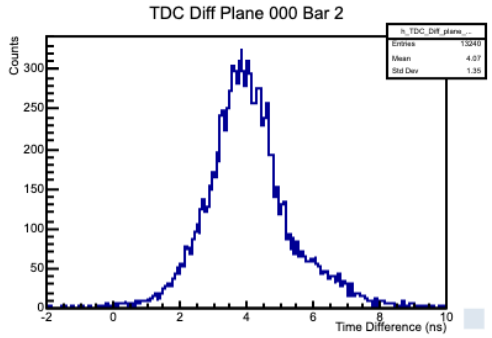


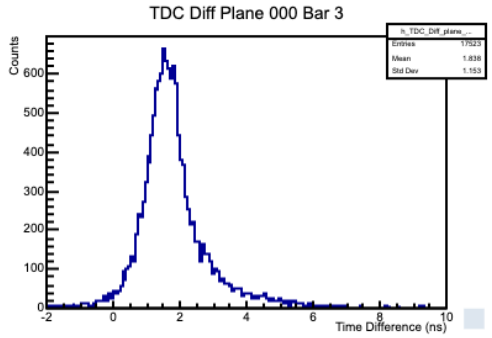
* ~ns width is due to uncorrected trigger jitter

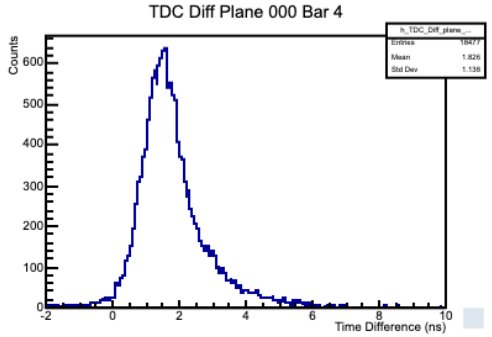
Cross-check: Back – Front Hodoscope times

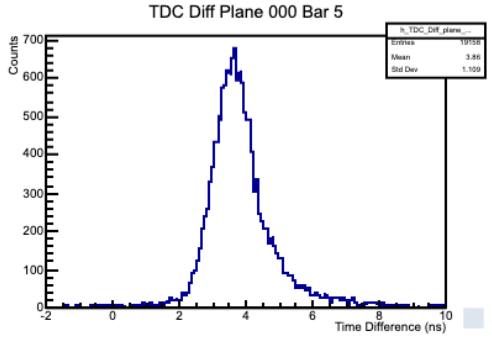


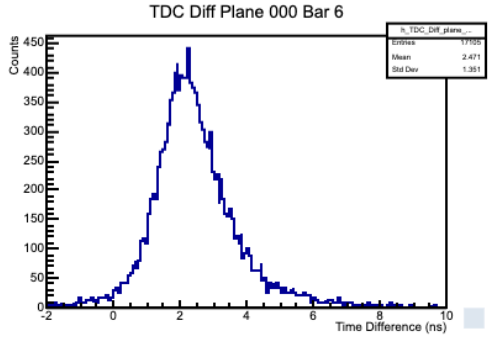


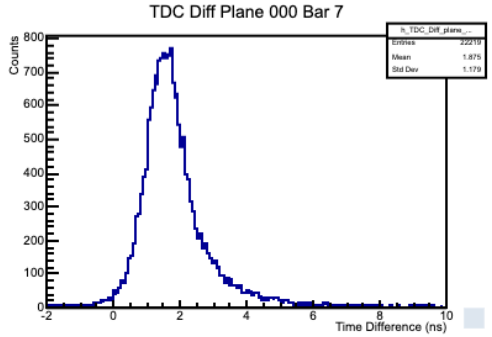


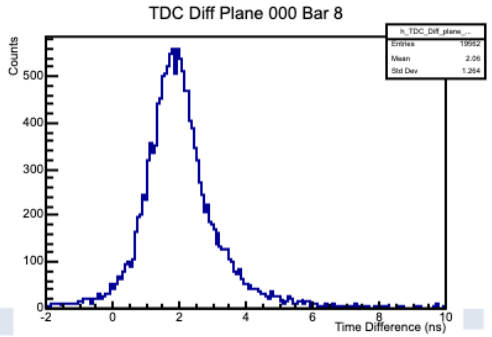


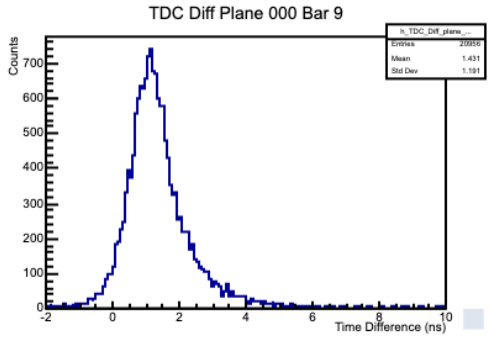


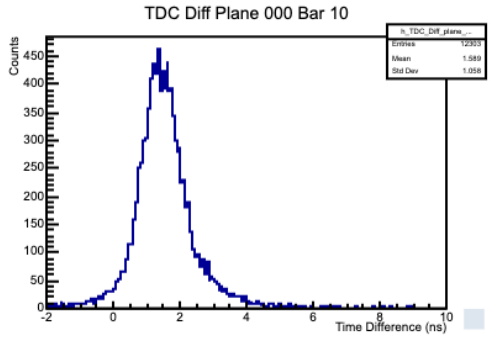






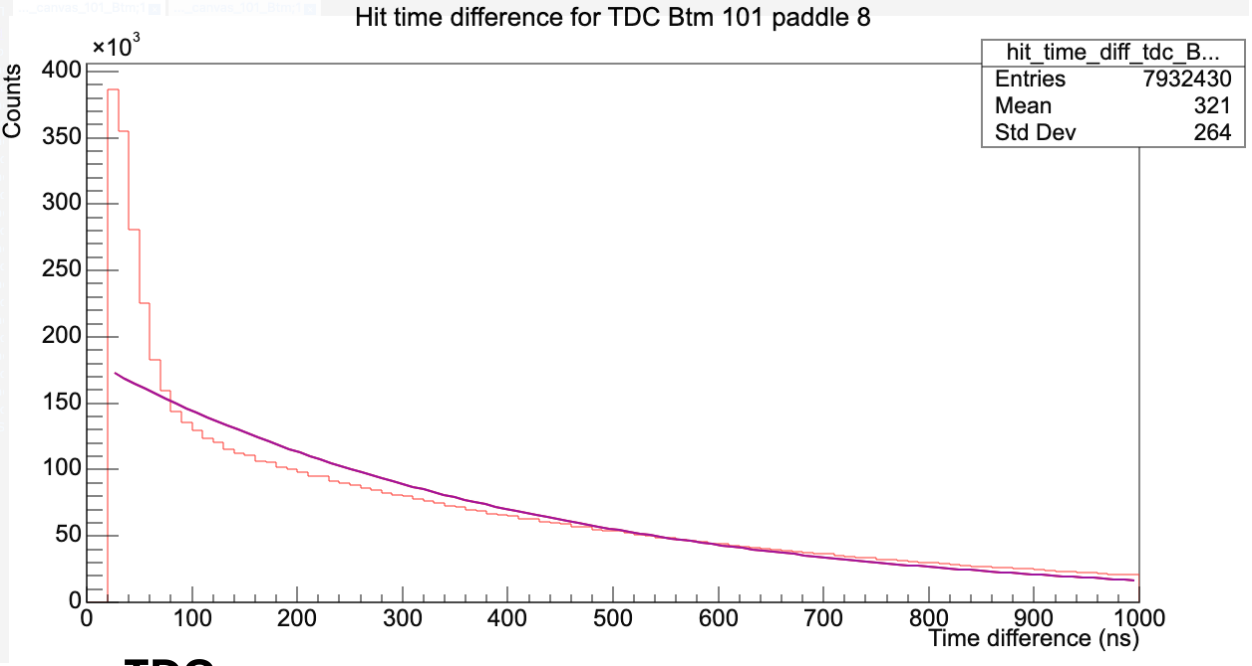




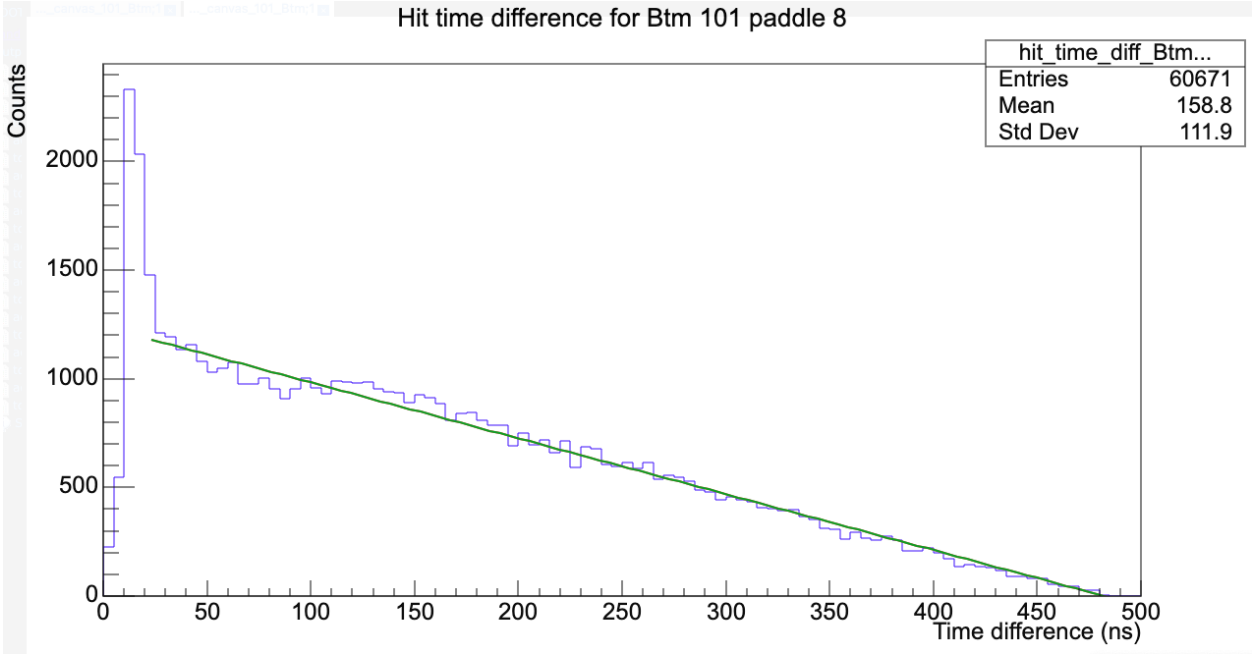


Still off by ~1ns!

ADC-TDC hit matching disrupted by after-pulses



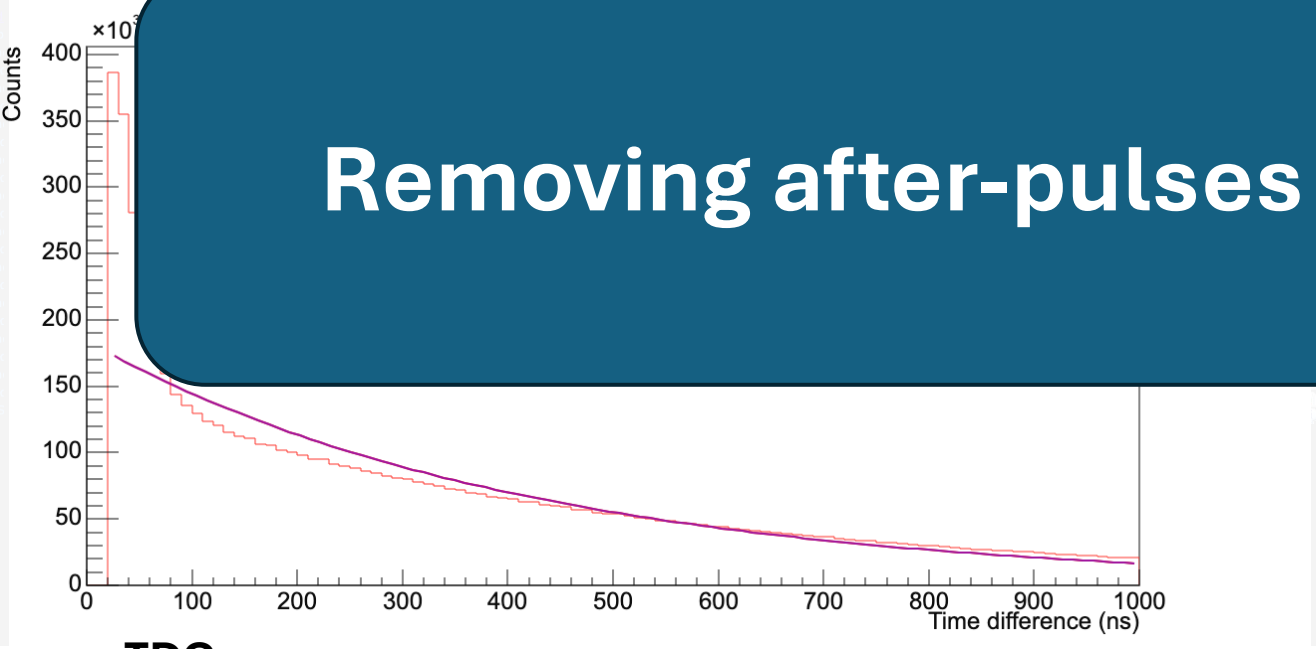
TDC



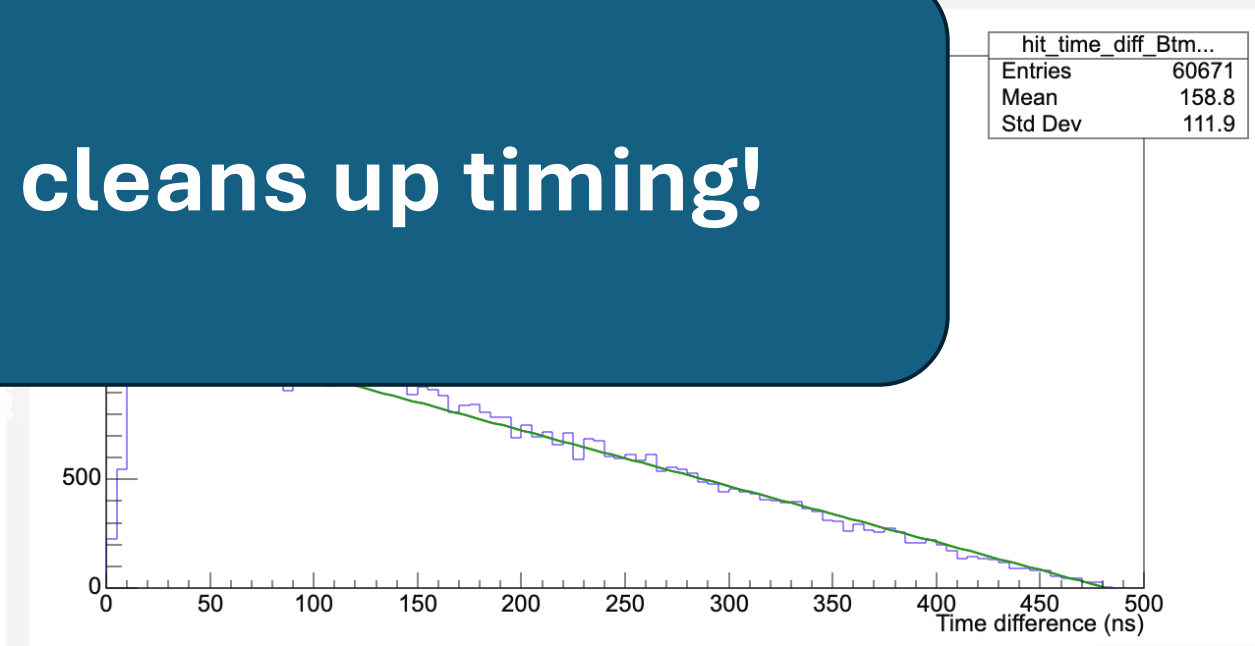
ADC

ADC-TDC hit matching disrupted by after-pulses

Removing after-pulses cleans up timing!

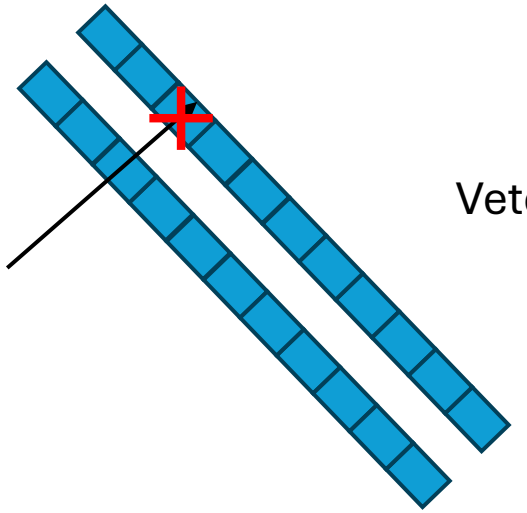


TDC

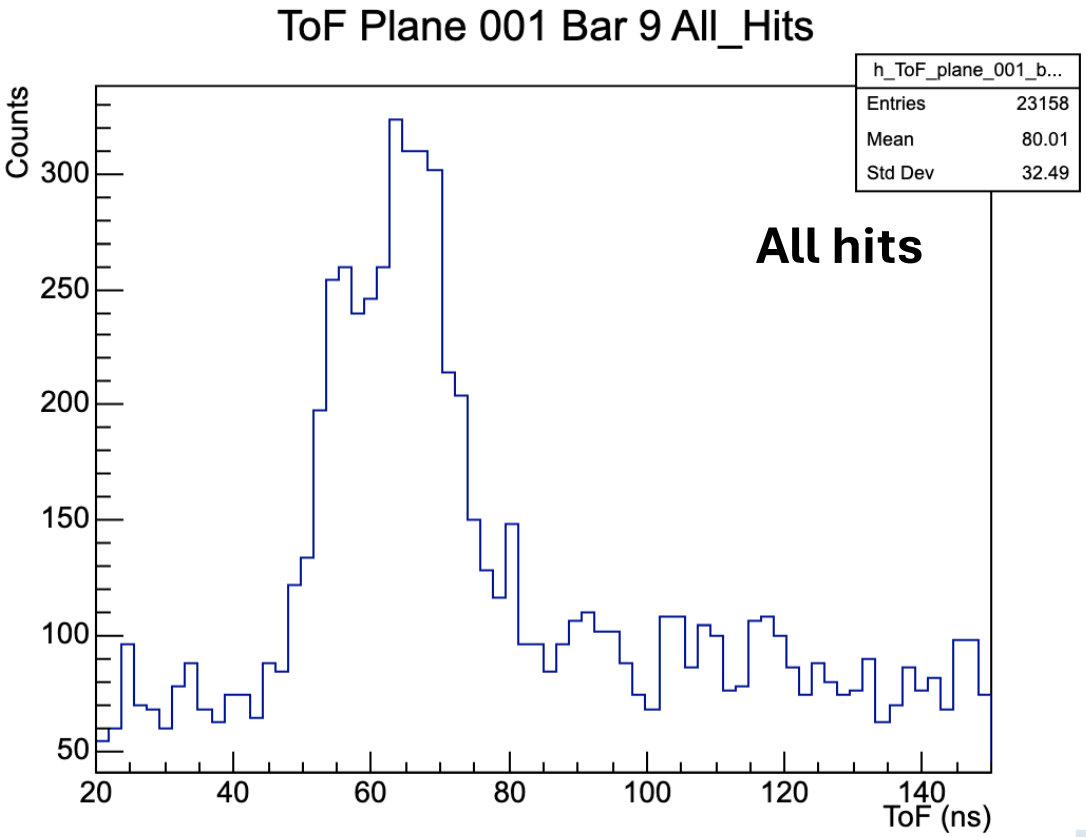


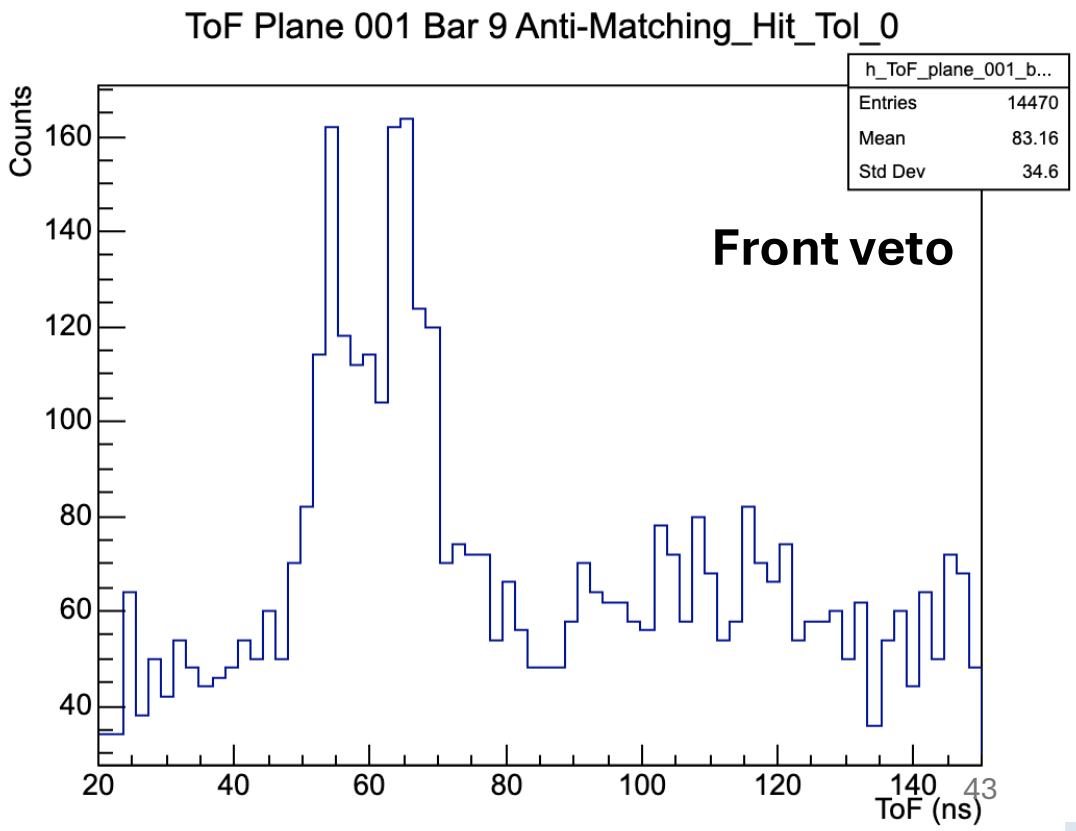
ADC

Absolute timing (Photon Flash)



Veto on front layer





Thank You & Questions!