Update on Lambda Analysis using RG-E Datasets

CLAS Collaboration Meeting

November 18th, 2026

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Mississippi State University

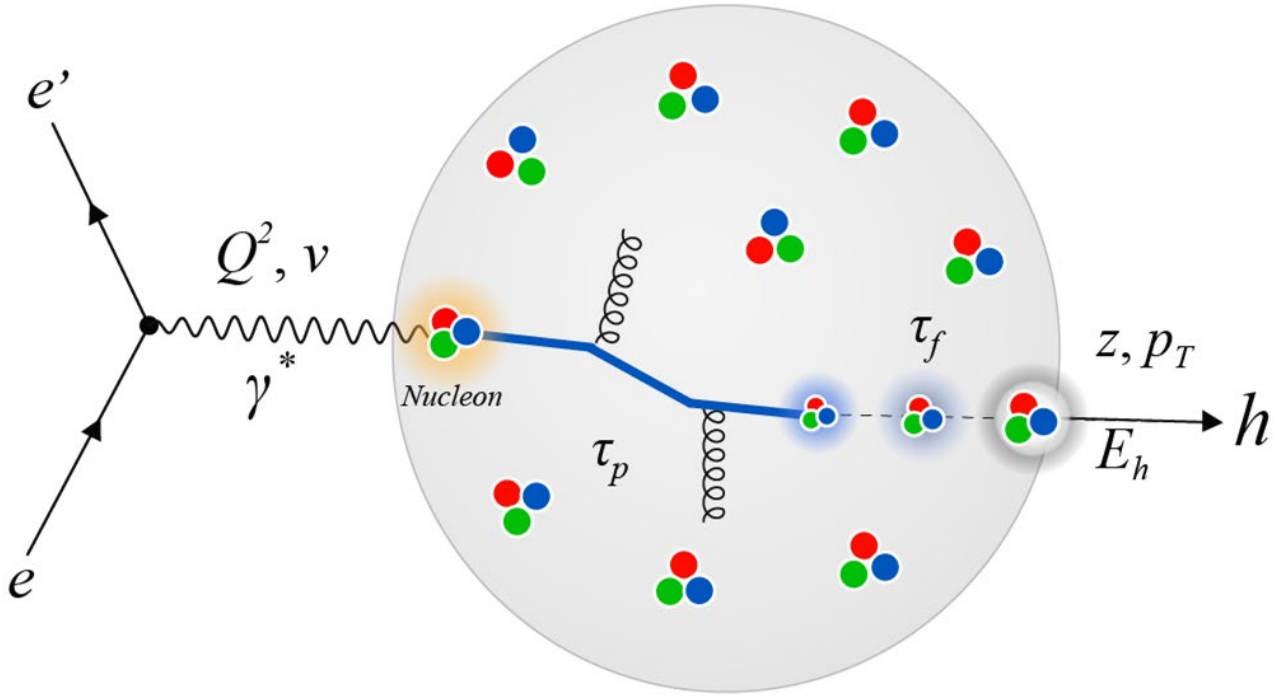
Outline

- SIDIS Production and Cuts
- Physics Observables
- Experimental Setup
- Fiducial Cuts
- Λ Production Channel
- Refining Particle Identification
- Vertex Cuts
- Refining the Λ Signal
- Event Mixing Background Studies
- Raw Multiplicity Ratios
- Raw p_T Broadening

Semi-Inclusive DIS Production

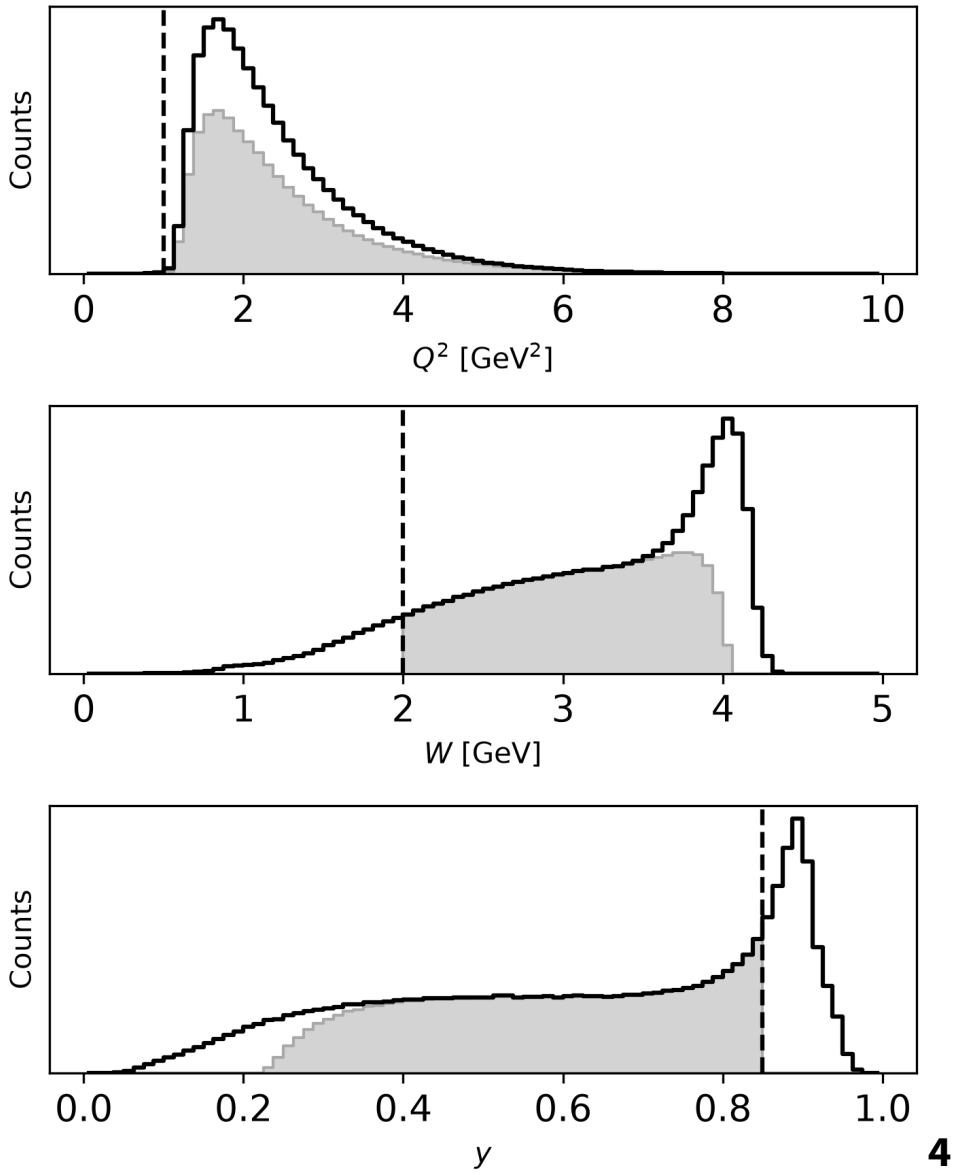
- Studying hadronization in Semi Inclusive Deep Inelastic Scattering (SIDIS) provides insight into quark confinement dynamics and the strong interaction as described by quantum chromodynamics (QCD)
- Hadronization process is characterized by two time-distance scales:
  - **Production time (τ_p):** Struck (di)quark propagation and color-neutralization to form a prehadron
  - **Formation time (τ_f):** Evolution of the color-neutral prehadron to a dressed hadron with its gluonic field

$$e + p \rightarrow e' + h + X$$



SIDIS Kinematics and Cuts

- The study of hadronization dynamics is probed in the SIDIS regime using this set of kinematics and cuts:
  - ν: electron energy loss or struck quark's initial energy
  - Q^2: four-momentum transferred squared
    - $Q^2 > 1\ \mathrm{GeV}^2$: to probe the intrinsic structure of nucleons
  - $y = {}^{\nu}/_{E_{beam}}$: electron energy fraction transferred to a struck quark
    - $y < 0.85$: to reduce radiative effects based on former HERMES studies
  - $W = \sqrt{M^2 + 2\nu M - Q^2}$: total mass of the hadronic final state, where M is the nucleon mass
    - $W > 2\ \mathrm{GeV}$: to avoid contamination from the resonance region
  - $z_h = {}^{E_h}/_{\nu}$: struck quark's initial energy fraction carried by the formed hadron
  - p_T: hadron transverse momentum measured relative to the virtual photon direction



Physics Observables

Multiplicity Ratio

$$R_A^h = \frac{N_{SIDIS}^{h\,(A)} / N_{DIS}^{e\,(A)}}{N_{SIDIS}^{h\,(D_2)} / N_{DIS}^{e\,(D_2)}}$$

R_A^h describes the attenuation of formed hadrons, h, in the medium

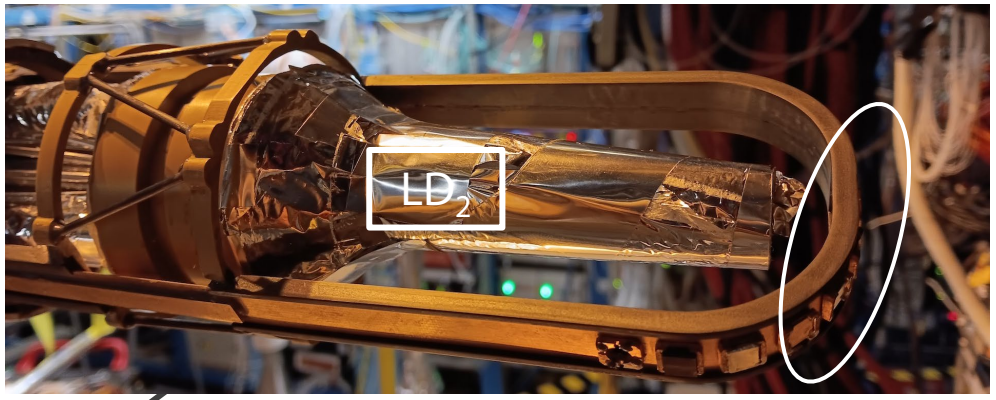
Transverse Momentum Broadening

$$\Delta p_T^2 = \langle p_T^2 \rangle_A - \langle p_T^2 \rangle_{D_2}$$

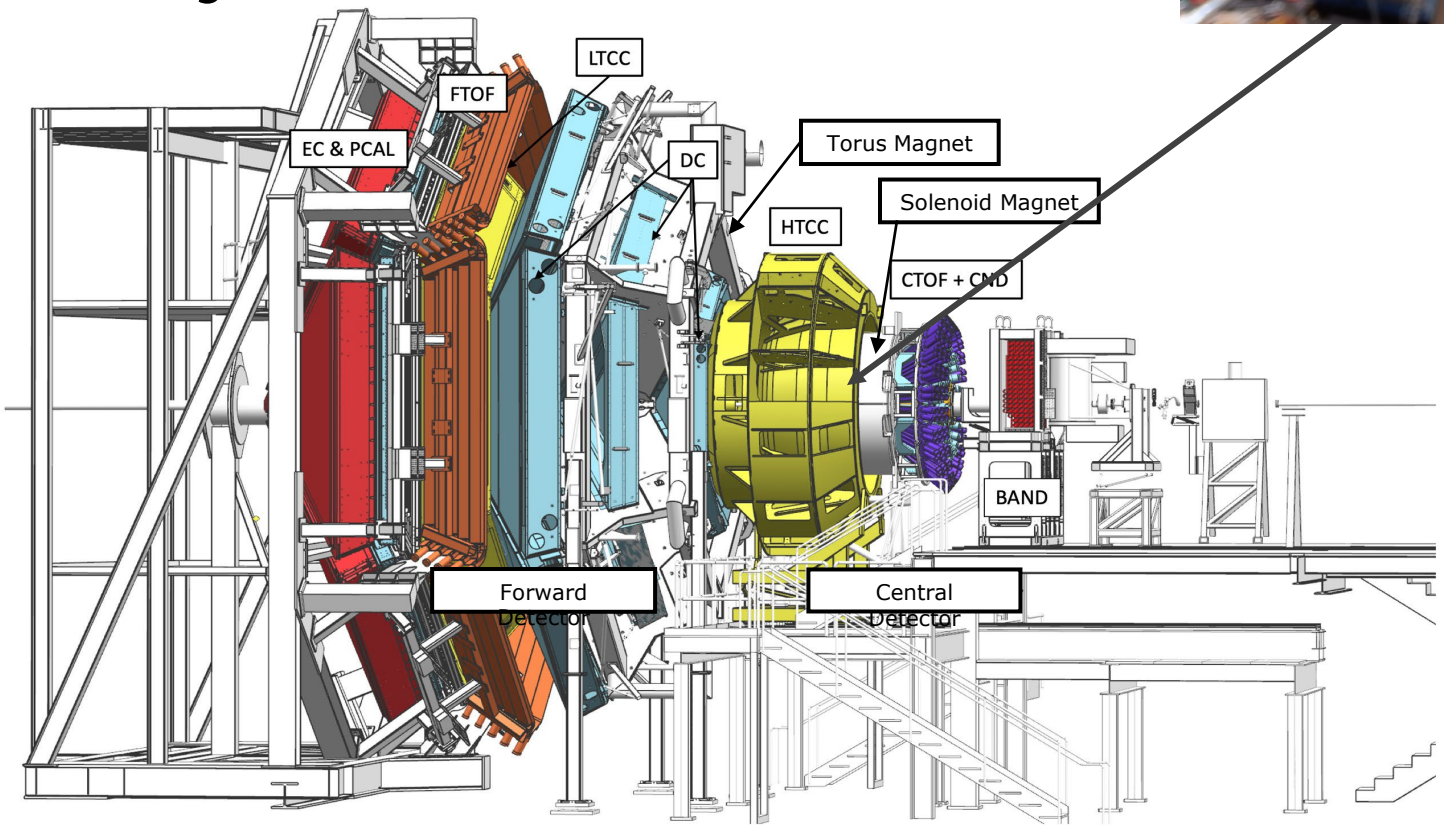
Δp_T^2 is due to the energy loss of the propagating struck (di-)quark(s) and/or the elastic and inelastic scattering of prehadrons and hadrons

Experimental Setup

- Run Group E (RG-E) experiments collected data in spring of 2024 using the CLAS12 detector housed in Hall B at Jefferson Lab
- A double target assembly consisting of liquid deuterium (LD_2) and solid foil targets was placed inside the solenoid magnet



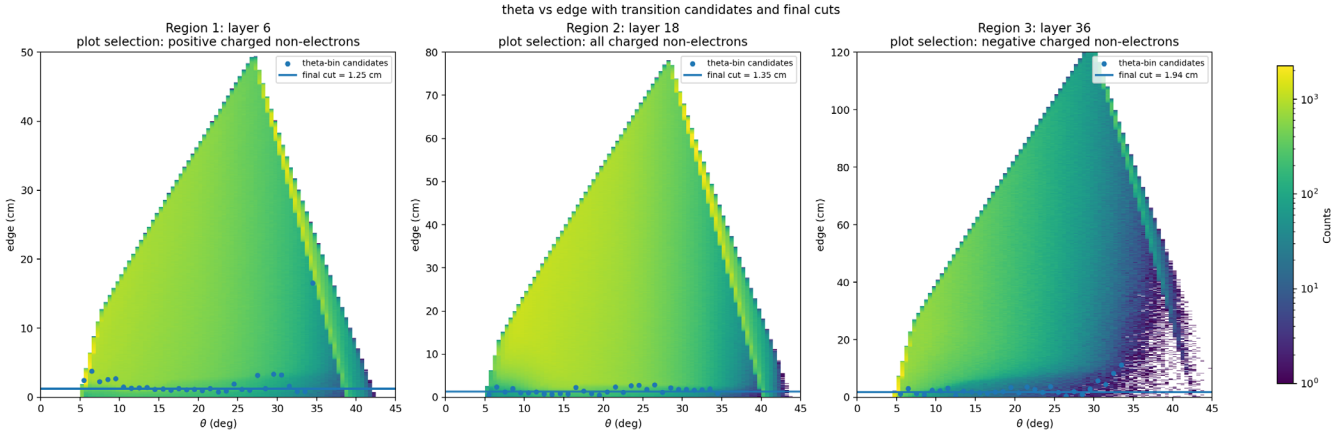
Solid foils
- C
- Al
- Cu
- Sn
- Pb

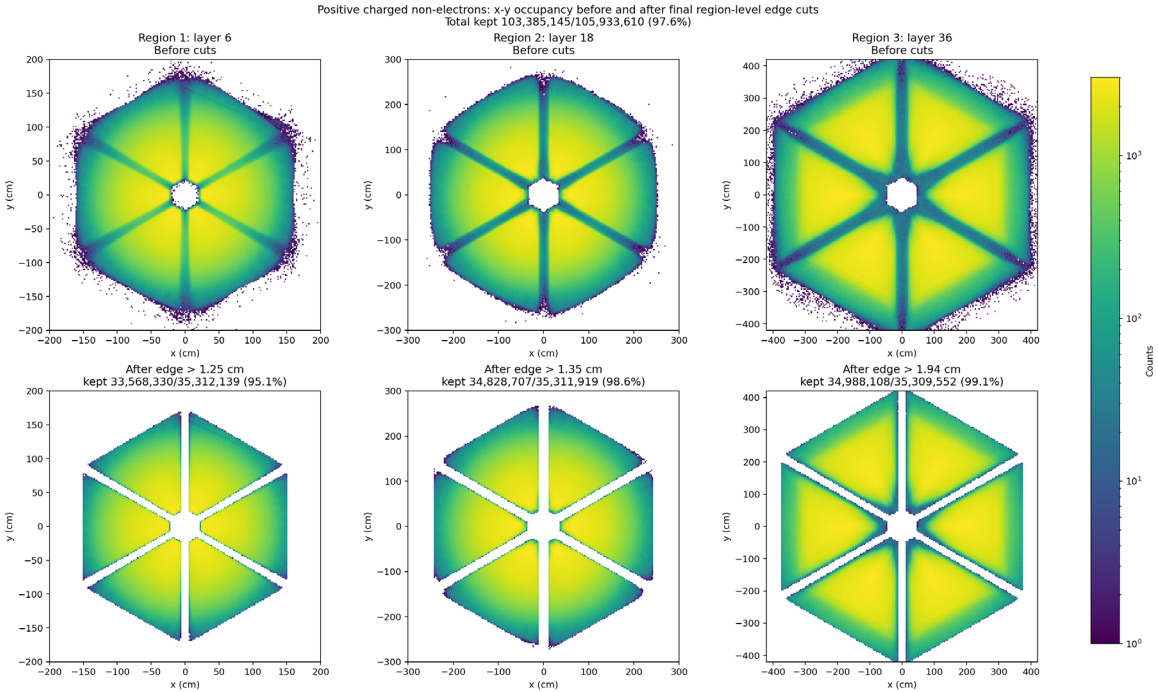


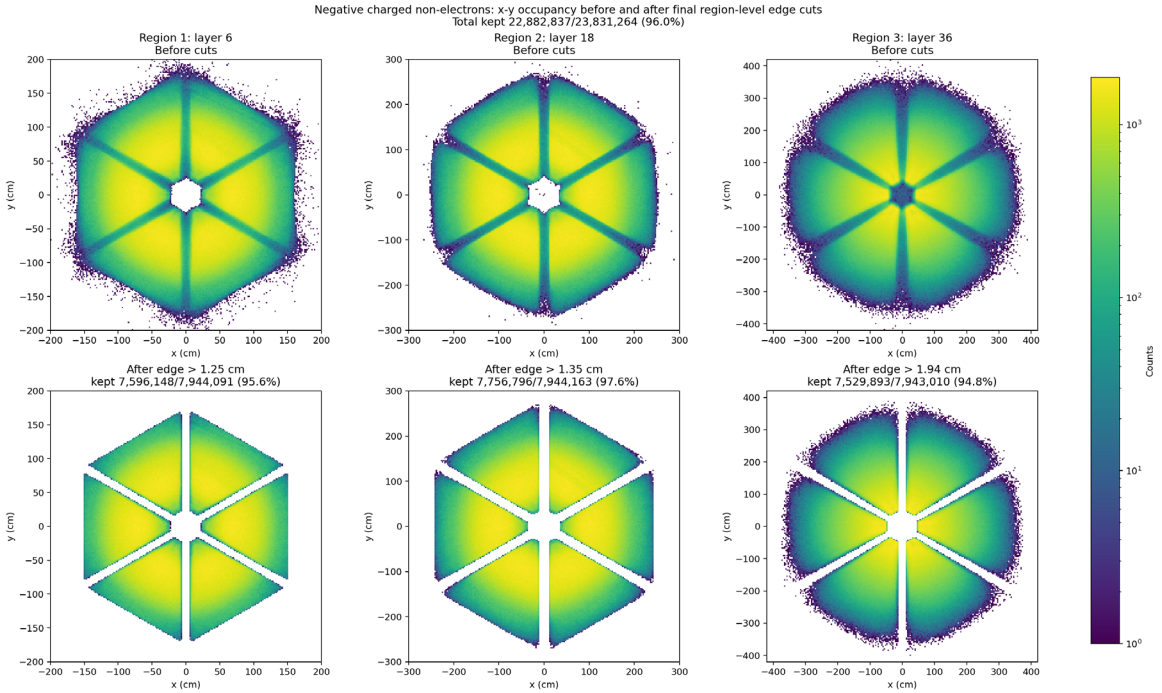
Electron Beam

Fiducial Cuts

- The Drift Chamber fiducial cuts were obtained by plotting yield vs edge in theta bins
- The cut limits were:
  - Region 1: 1.25 cm
  - Region 2: 1.35 cm
  - Region 3: 1.94 cm

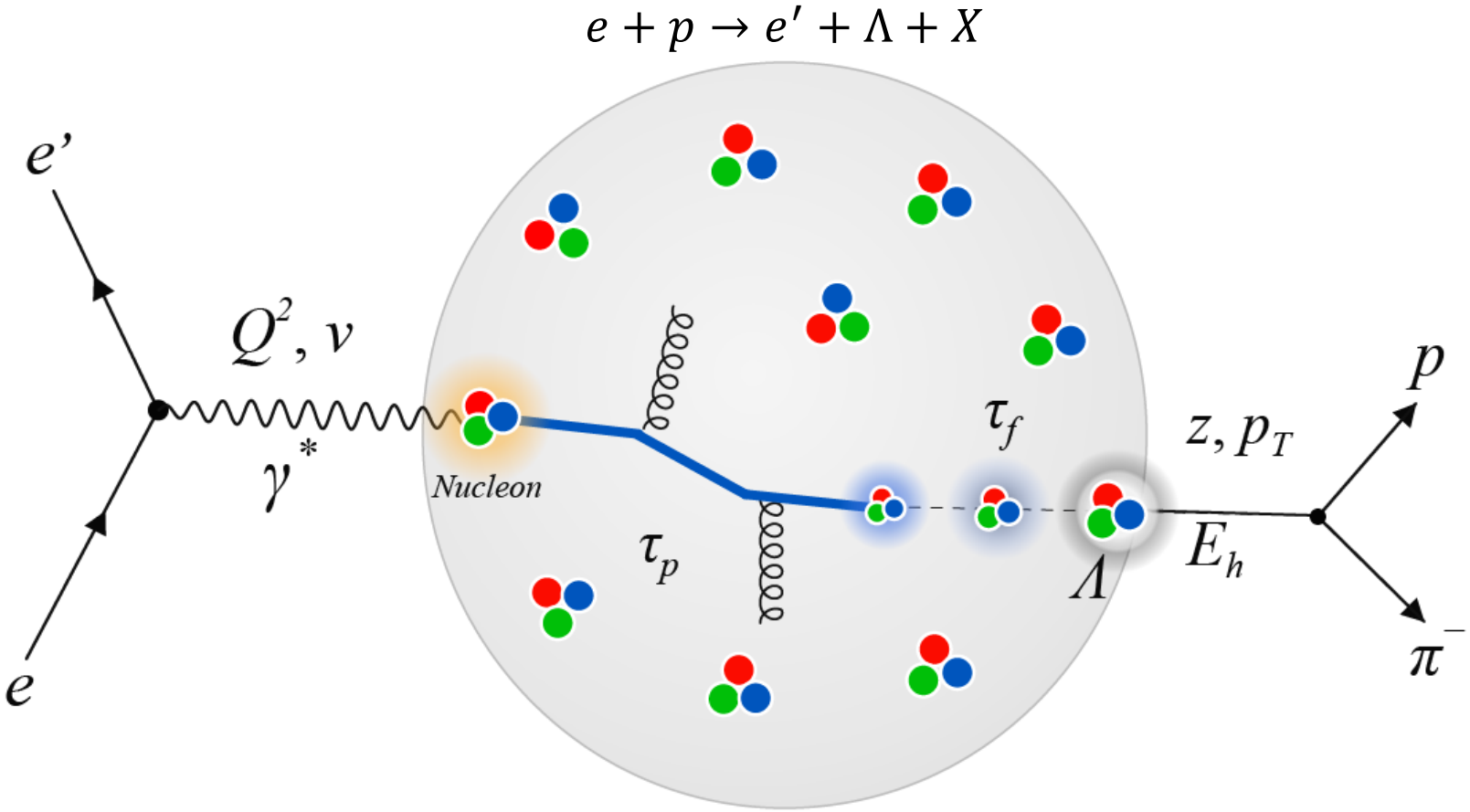






Λ Production Channel

- Our channel of interest is Λ SIDIS production off nuclei
- Λ is identified through its decay daughter particles, proton and π-, detected in coincidence with the scattered electron



Refining Particle Identification

Electron

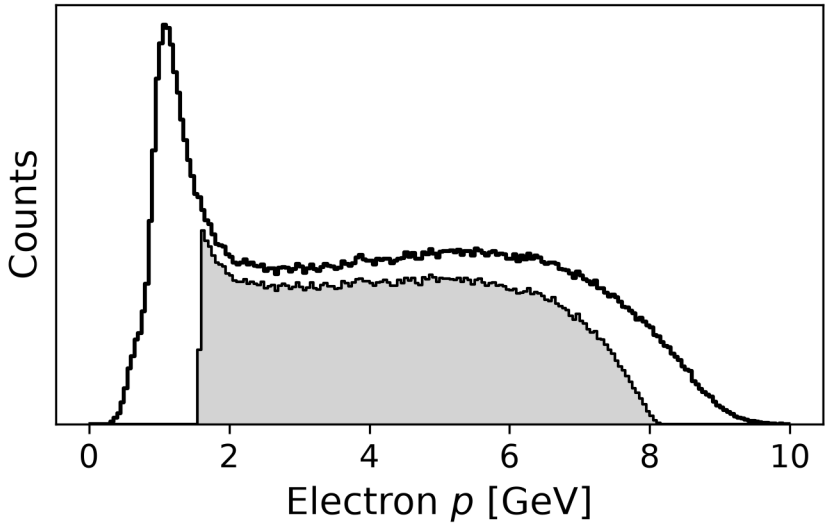
- Event Builder PID = 11
- Detected in the forward detector
- Drift chamber fiducial cuts
- Calorimeter local coordinates cuts
- Electron sampling fraction cuts
- DIS kinematics cuts

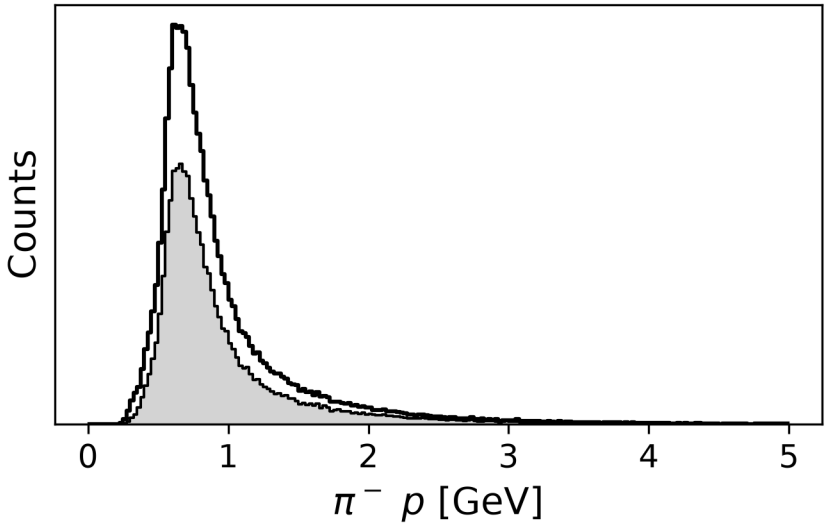
π^-

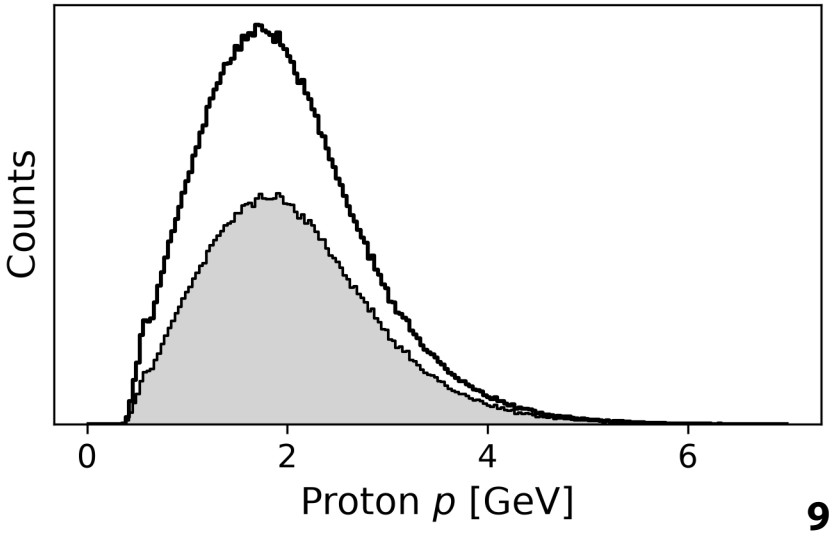
- Event Builder PID = -211
- Detected in the forward detector
- Drift chamber fiducial cuts
- Corrected time of flight matching cuts

Proton

- Event Builder PID = 2212
- Detected in the forward detector
- Drift chamber fiducial cuts
- Corrected time of flight matching cuts

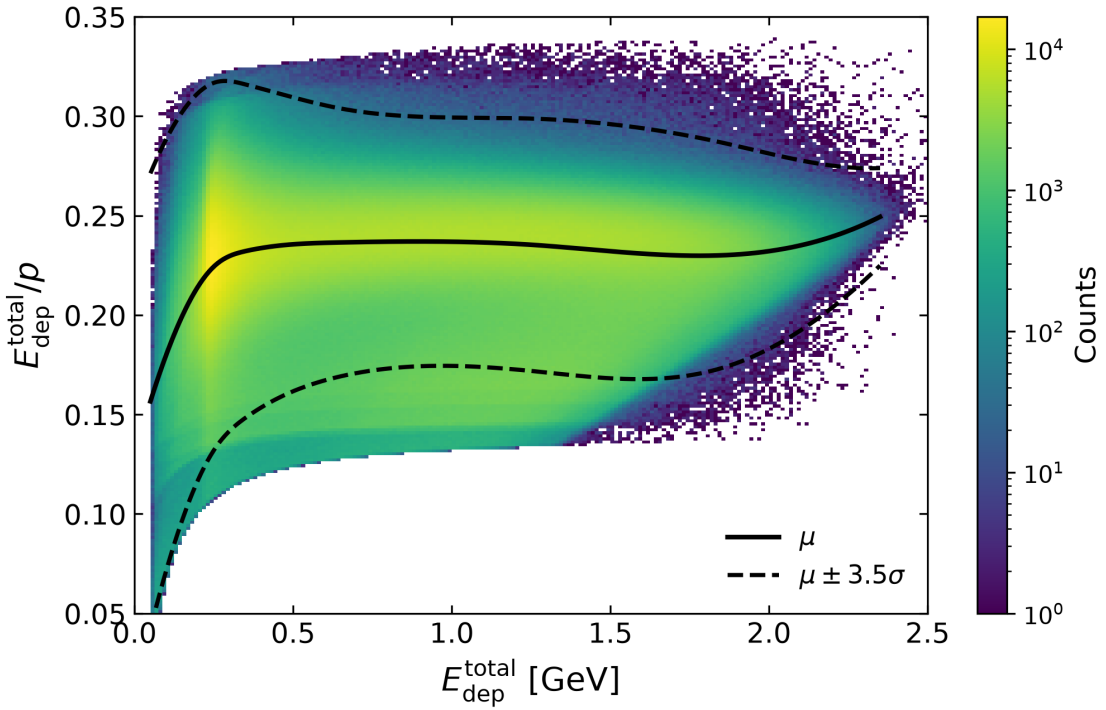


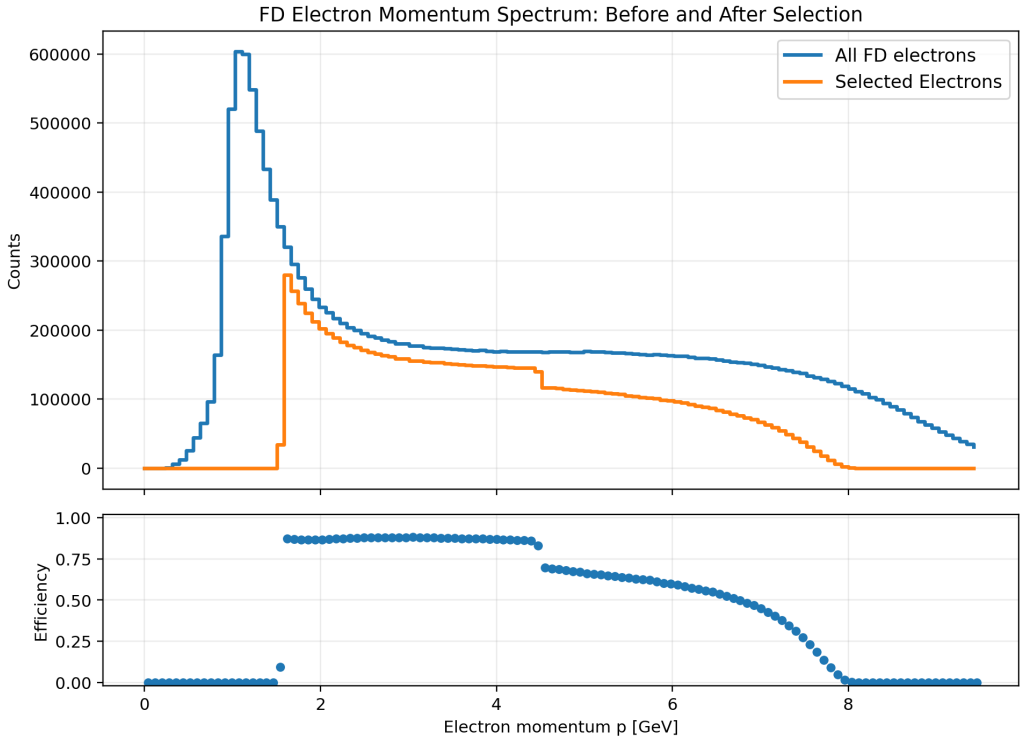




Refining Particle Identification: Electron

- Drift chamber fiducial cuts were used to remove tracks from the inefficient edges of the drift chamber
- PCAL local coordinate cuts were used to ensure that showers deposit charge across at least two adjacent strips
- Sampling fraction vs. energy deposition was used to further refine the electron PID

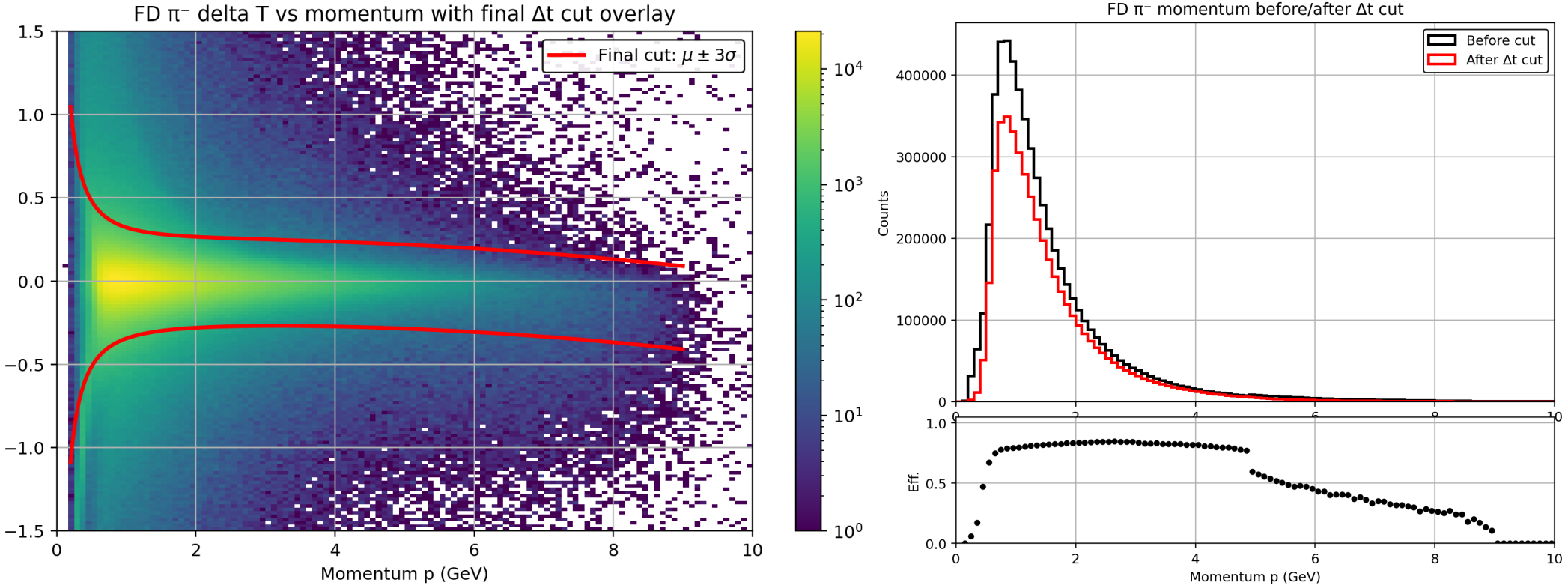




Refining Particle Identification: π^-

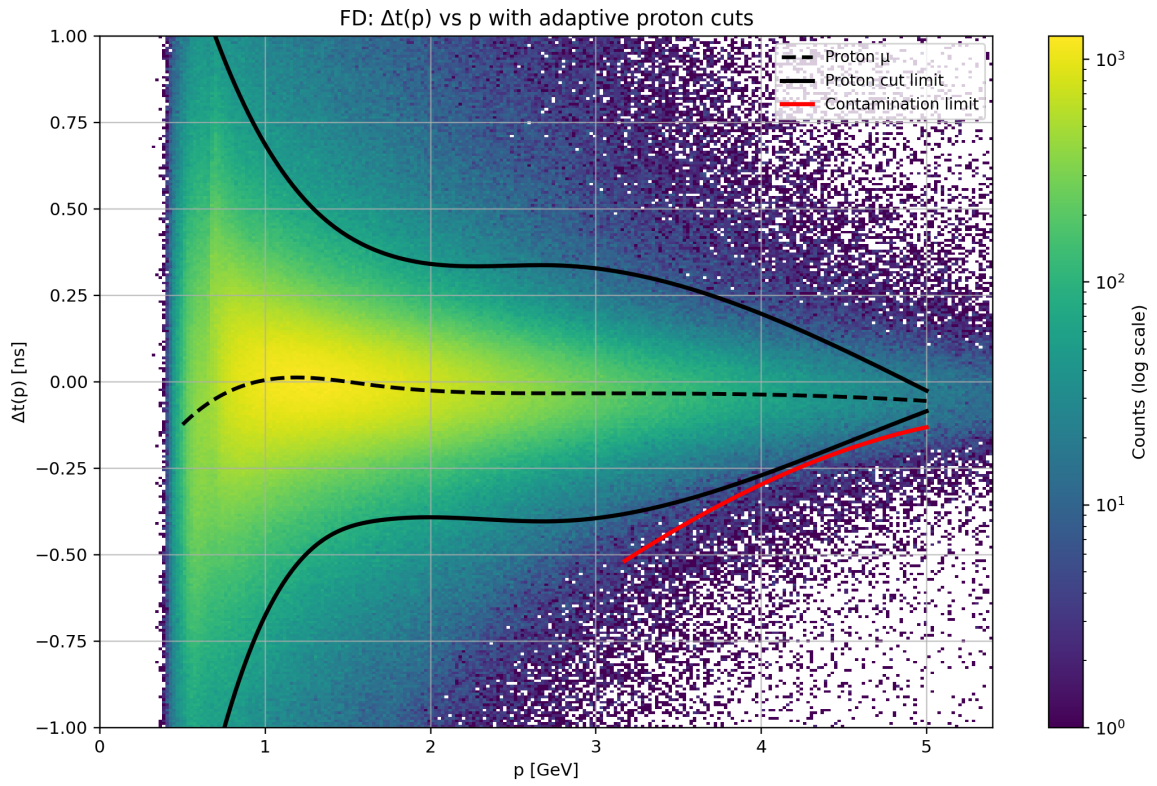
- The ΔT vs. momentum distribution was divided into 50 MeV momentum slices from 0–10 GeV
- In each slice, a Gaussian fit was performed to extract the π^- peak
- The resulting peak parameters were used to determine momentum-dependent PID cuts

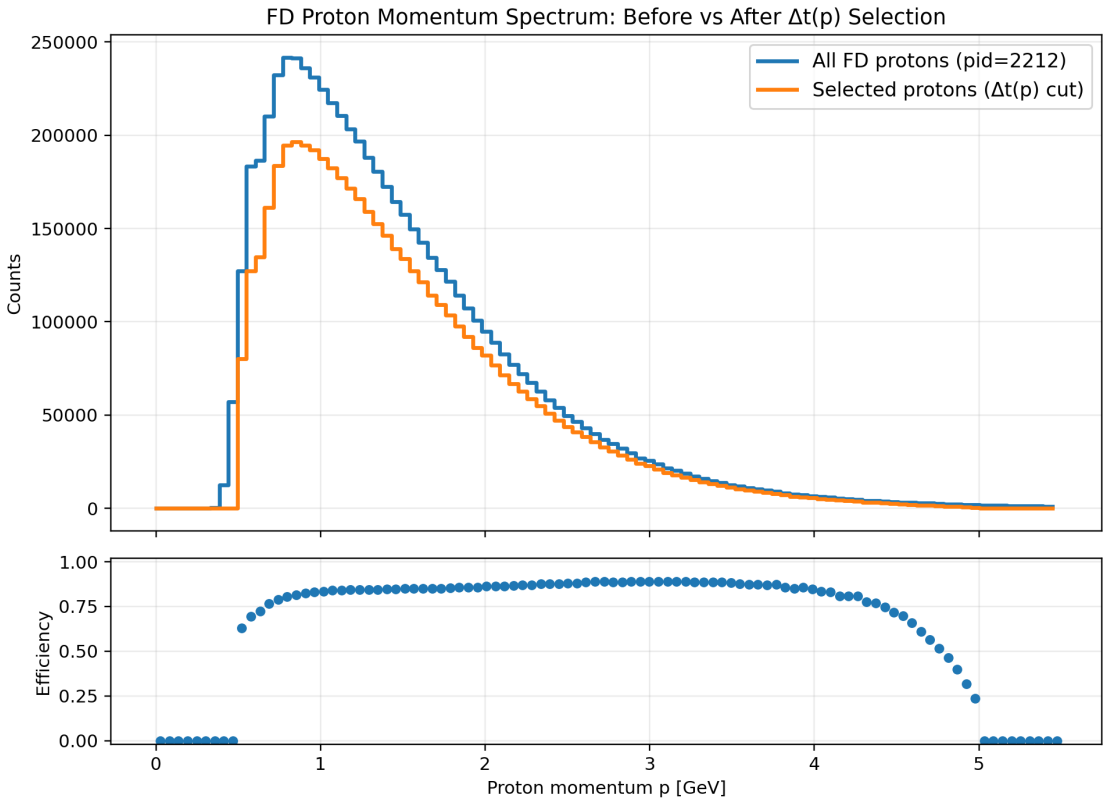
$$\Delta T = (t_{FTOF} - t_{start}) - \frac{l_{path}}{c \cdot \beta_{exp}}$$



Refining Particle Identification: Proton

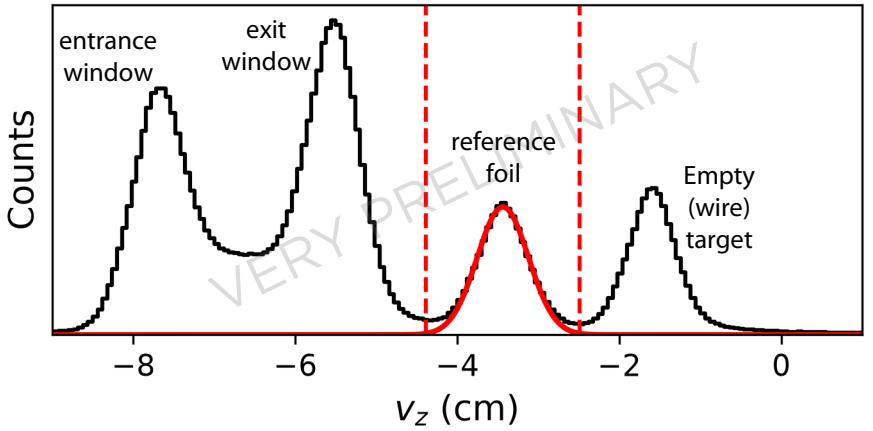
- The ΔT vs. momentum distribution was divided into 50 MeV momentum slices from 0–10 GeV
- In each slice, a Gaussian fit was performed to extract the π^- peak
- The resulting peak parameters were used to determine momentum-dependent PID cuts
- An adaptive cut was developed for the proton to avoid contamination from K^+

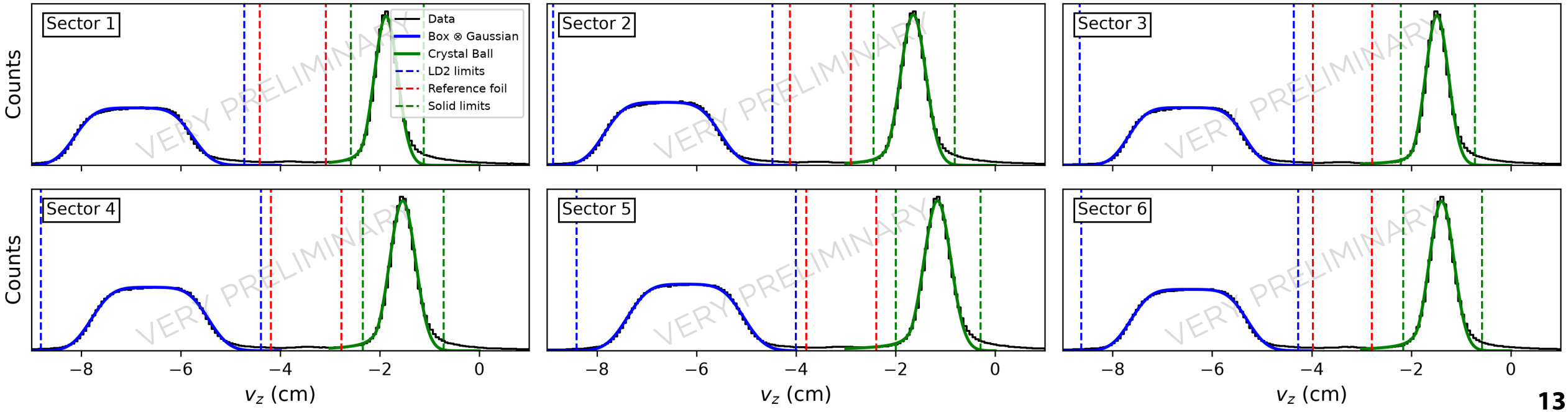




Vertex Studies

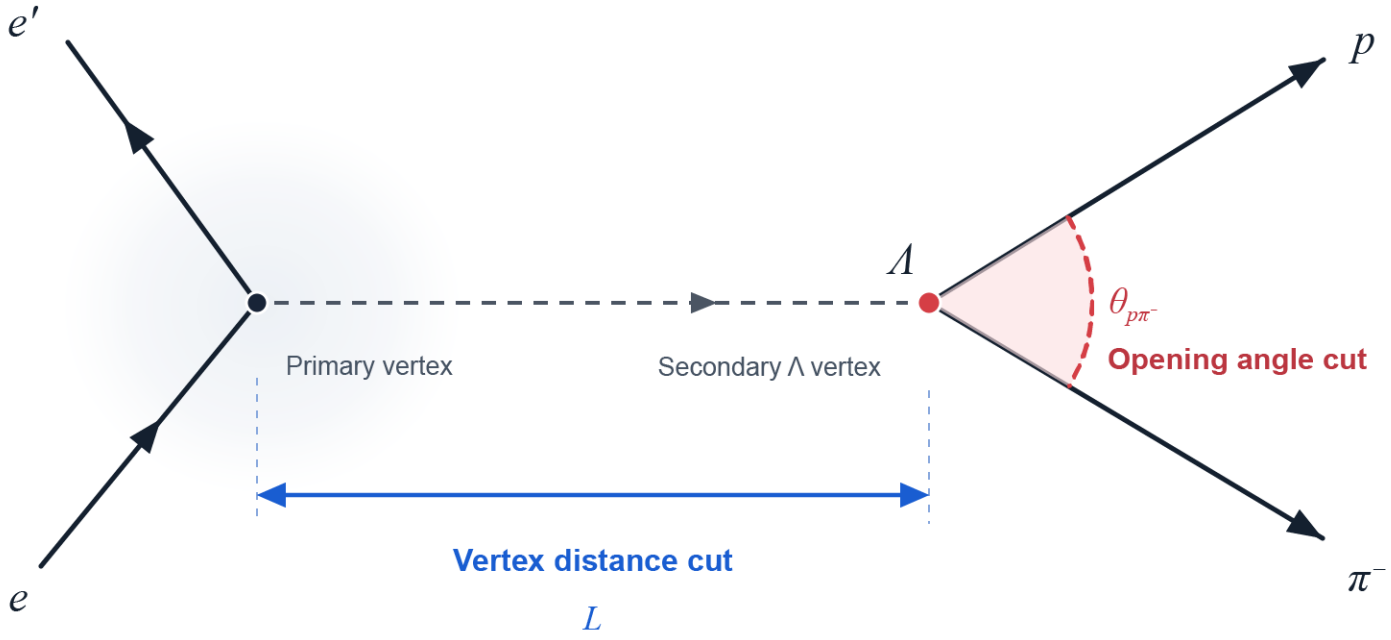
- Target separation is essential due to the dual-target configuration
- Electron v_z distributions were used to separate the target regions
- The reference-foil boundaries, determined from empty+wire data, constrained the target-selection limits
- For each configuration, fitted vertex distributions were used to define effective $\mu \pm 3\sigma$ cuts and assign events to their target of origin

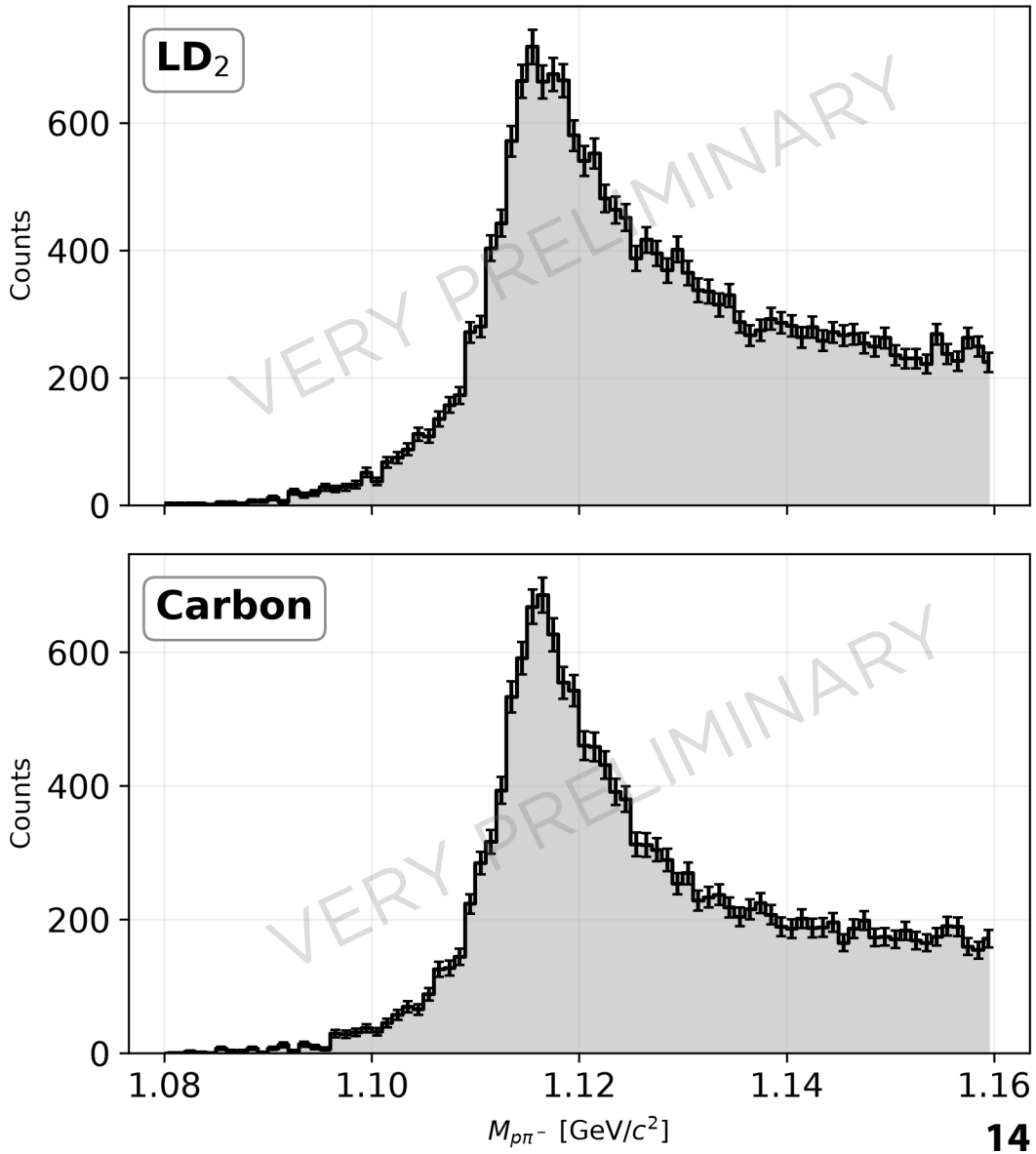




Refining the Λ Signal

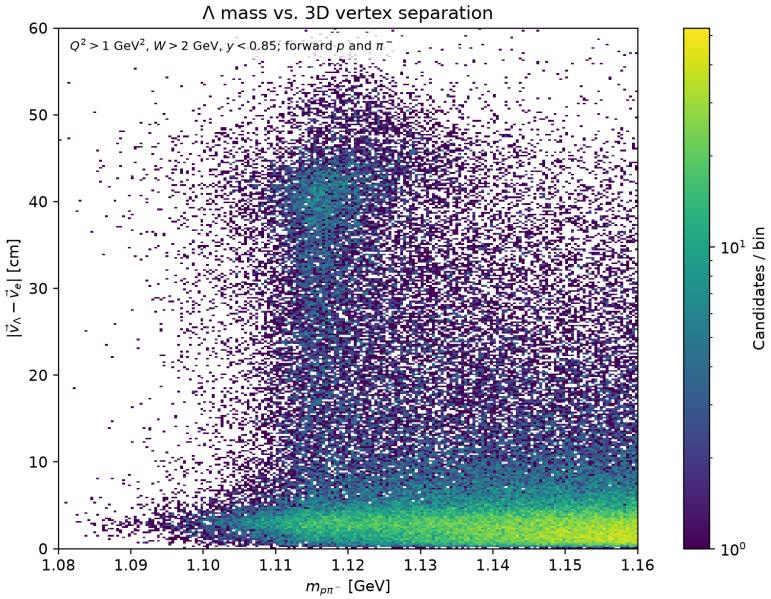
- Cuts applied on secondary vertex to refine the Λ signal
  - Distance between the electron and secondary Λ vertex
  - Opening angle between protons and π^-s

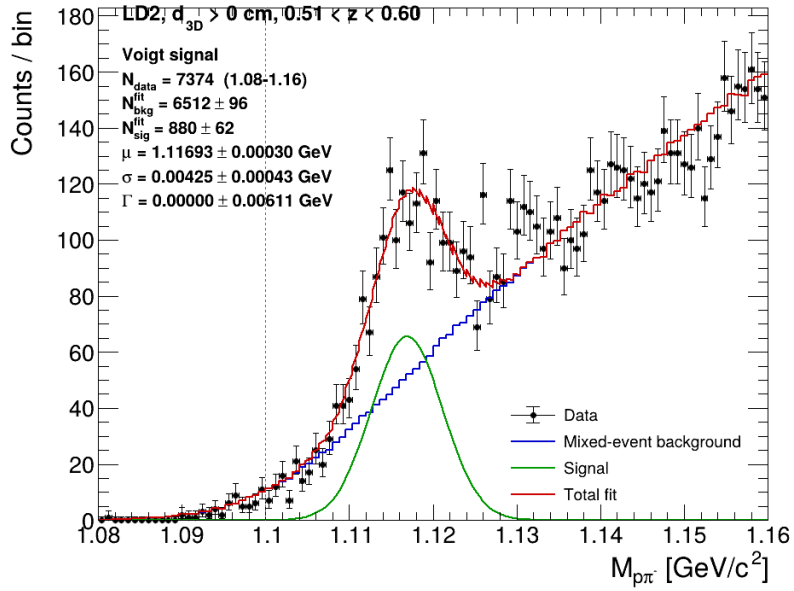


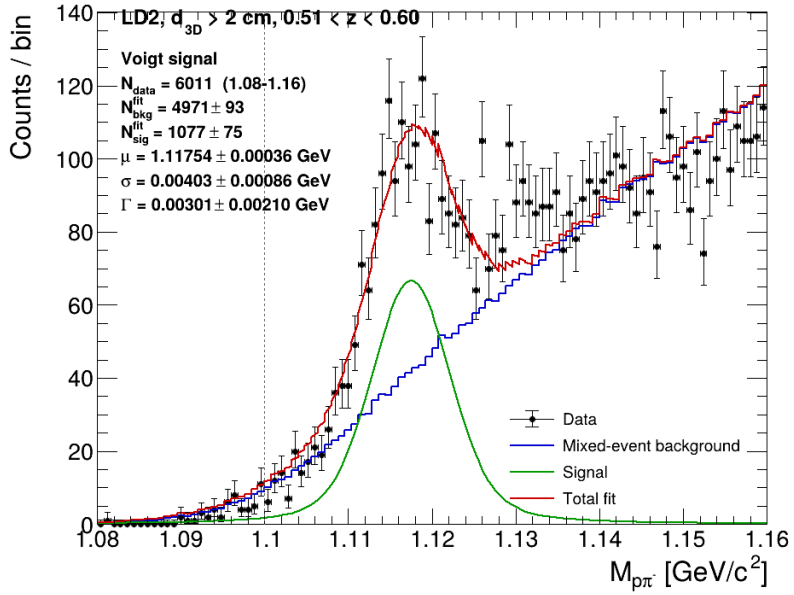


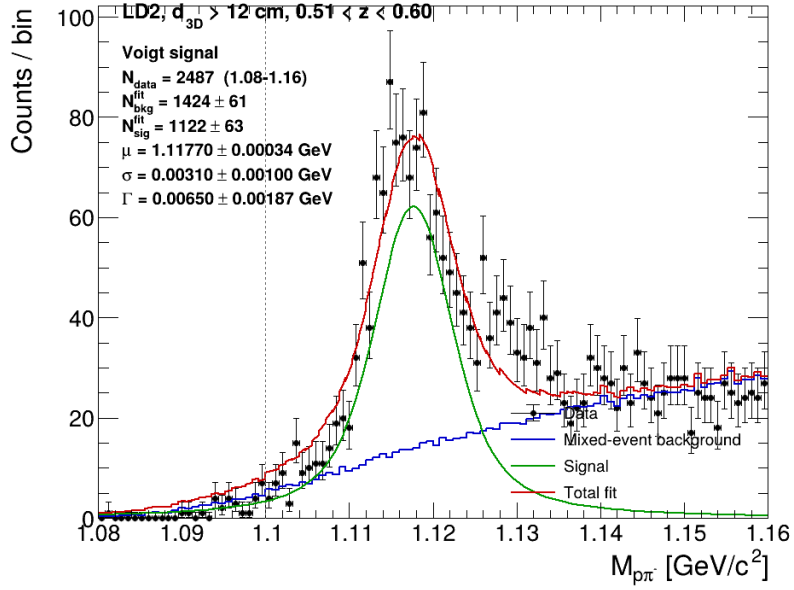
Refining the Λ Signal - Secondary Vertex Analysis

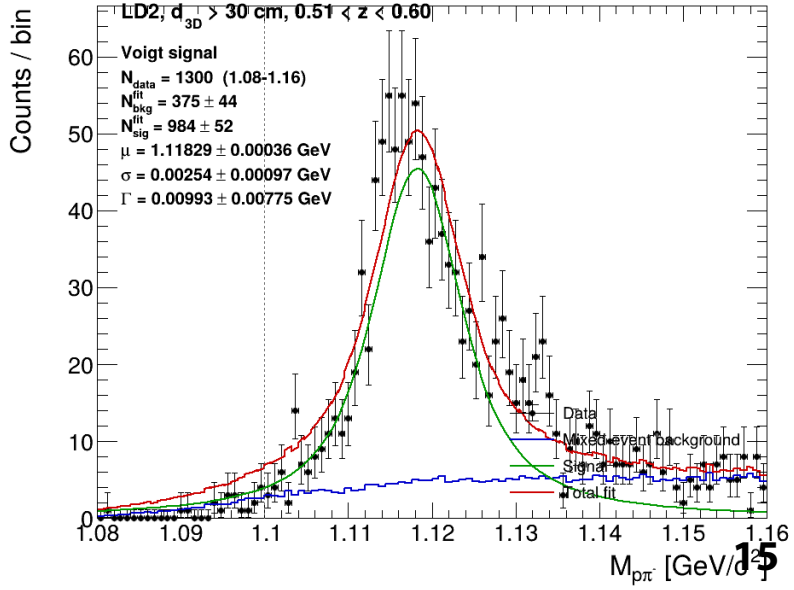
- The distance (d_{3D}) between the secondary Λ vertex and the primary electron vertex was plotted against the $p\pi^-$ invariant mass
- Two separate regions could be identified in this 2D histogram
- The reduction of the background was studied by varying the value of the cut on d_{3D}





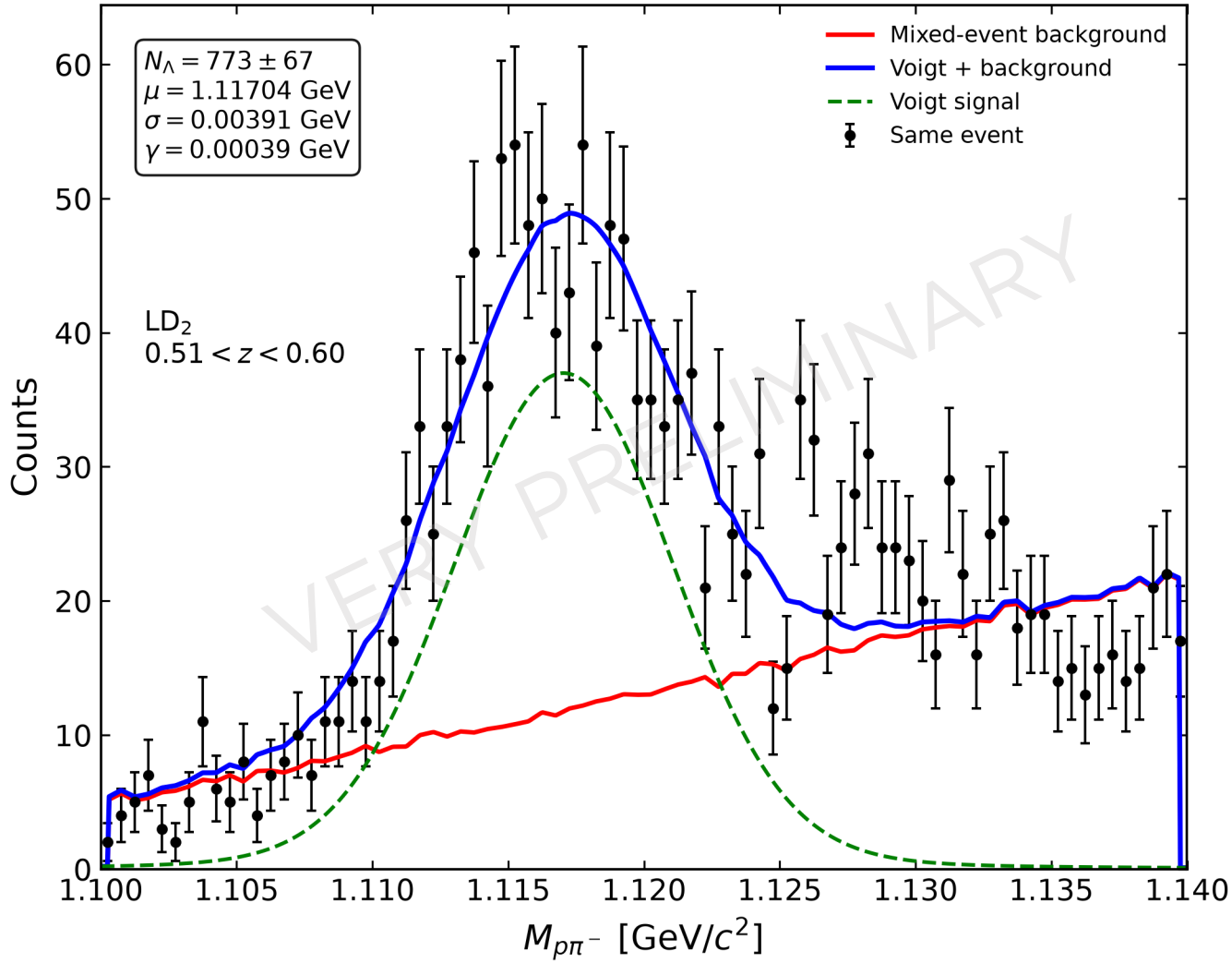






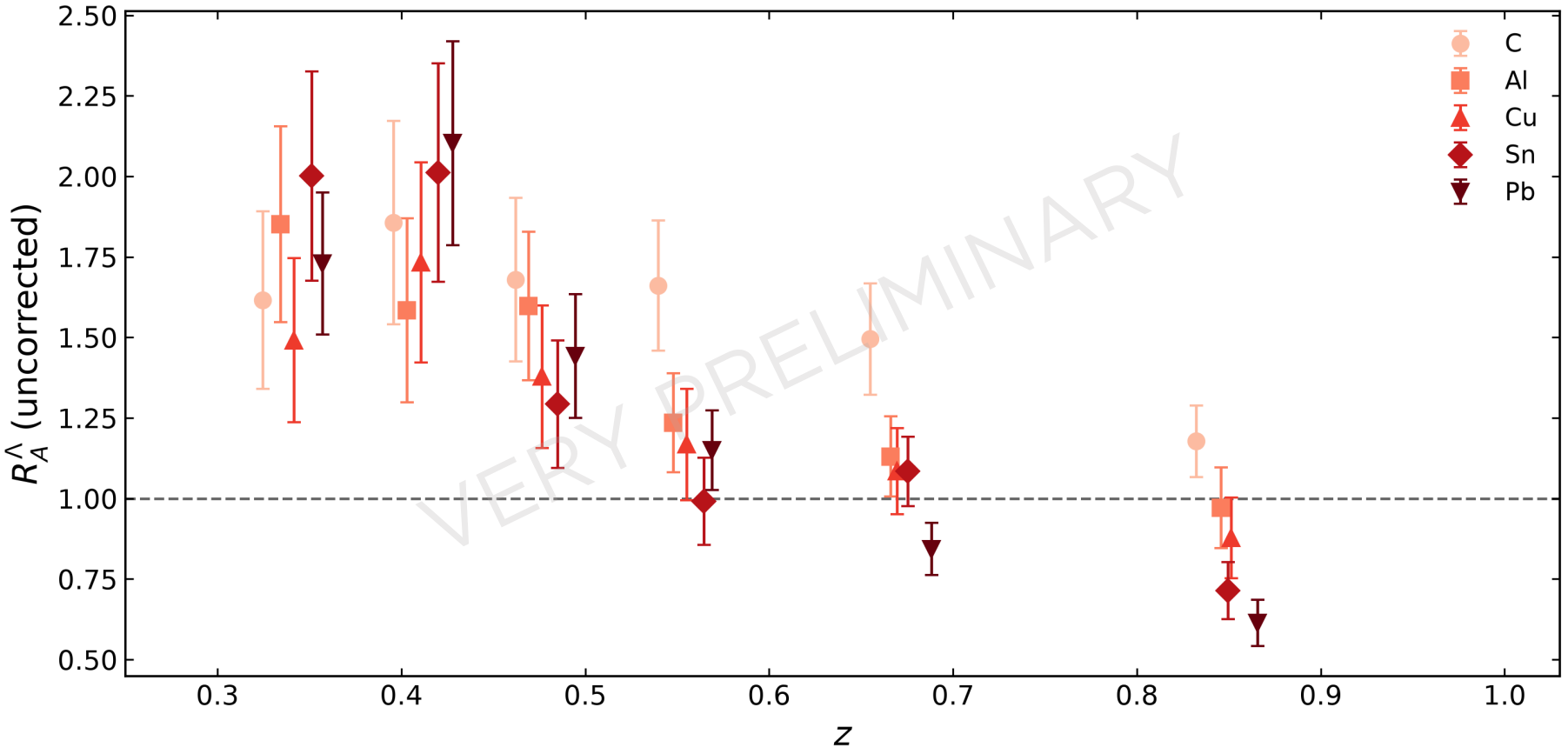
Event Mixing Background Studies

- Event mixing technique was successfully used in the 6 GeV Λ analysis
  - Each correlated protons and pions pairs are mixed, respectively, with pions and protons from uncorrelated events to model the combinatorial background underneath the Λ peak
- The RooFit library is used to fit the Λ invariant mass distribution with a Breit-Wigner convoluted with a Gaussian (Voigtian) for the signal and the event mixing background sample



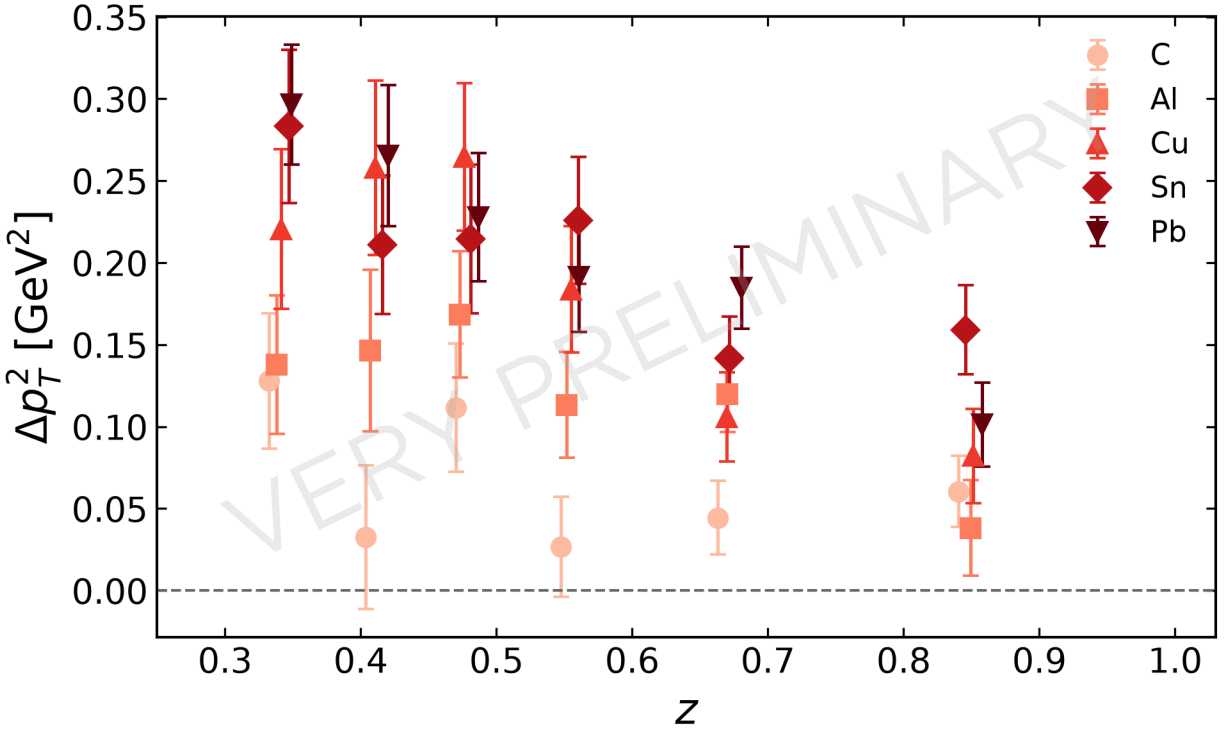
Raw Multiplicity Ratios

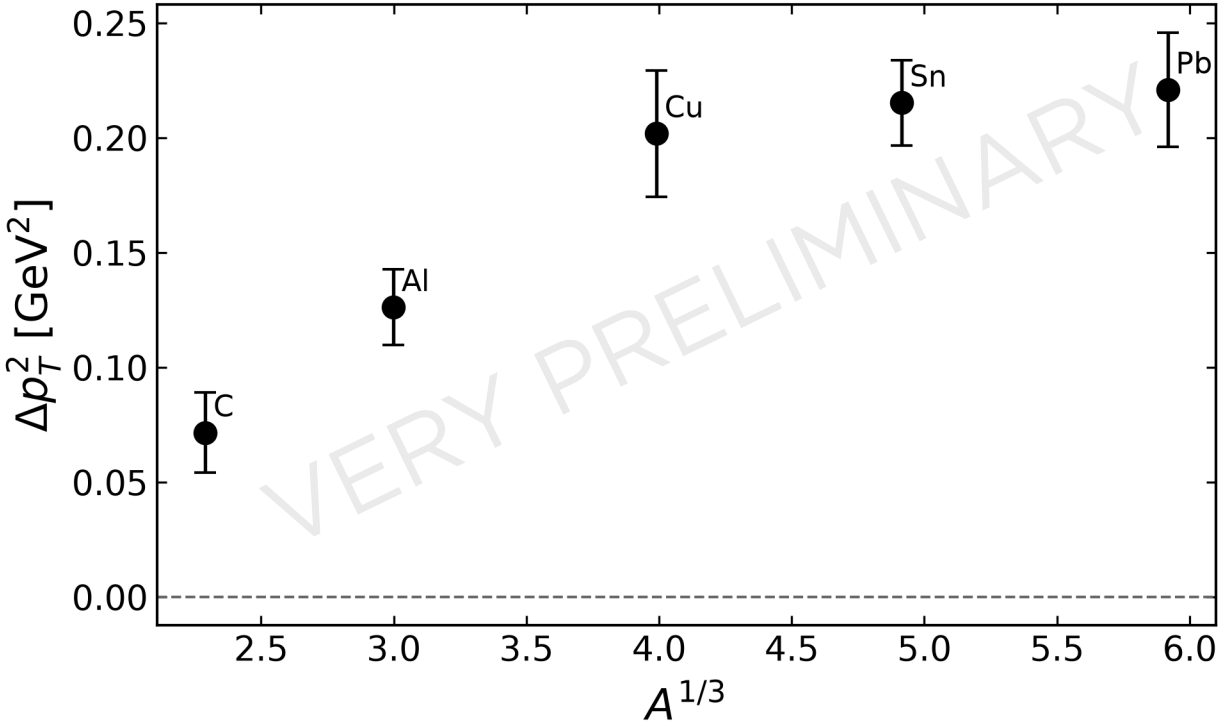
- Raw multiplicity ratios extracted before momentum, acceptance, LD_2 end-caps, and radiative corrections
- Pronounced suppression at high z with clear nuclear-mass (A) dependence
- Observed enhancement at low z, typical of target-remnant fragmentation



Raw p_T Broadening

- Raw p_T broadening extracted before momentum, acceptance, LD_2 end-caps, and radiative corrections
- Positive broadening is observed for all five nuclear targets
- Monotonic increase in magnitude with nuclear size (r)





Nuclear radius: $r = r_0 A^{1/3}$ where $r_0 = 1.2\ fm$

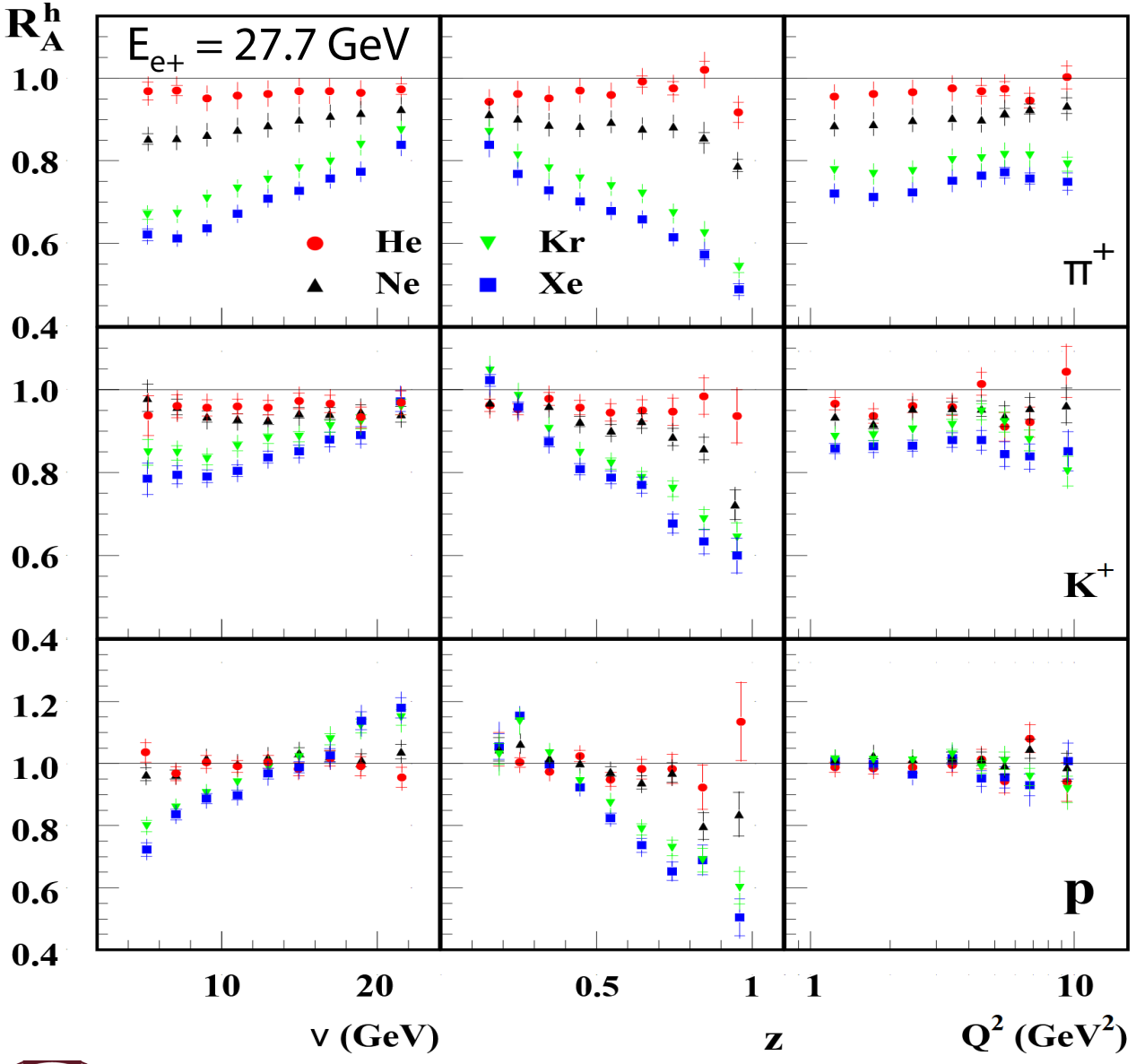
Summary and Outlook

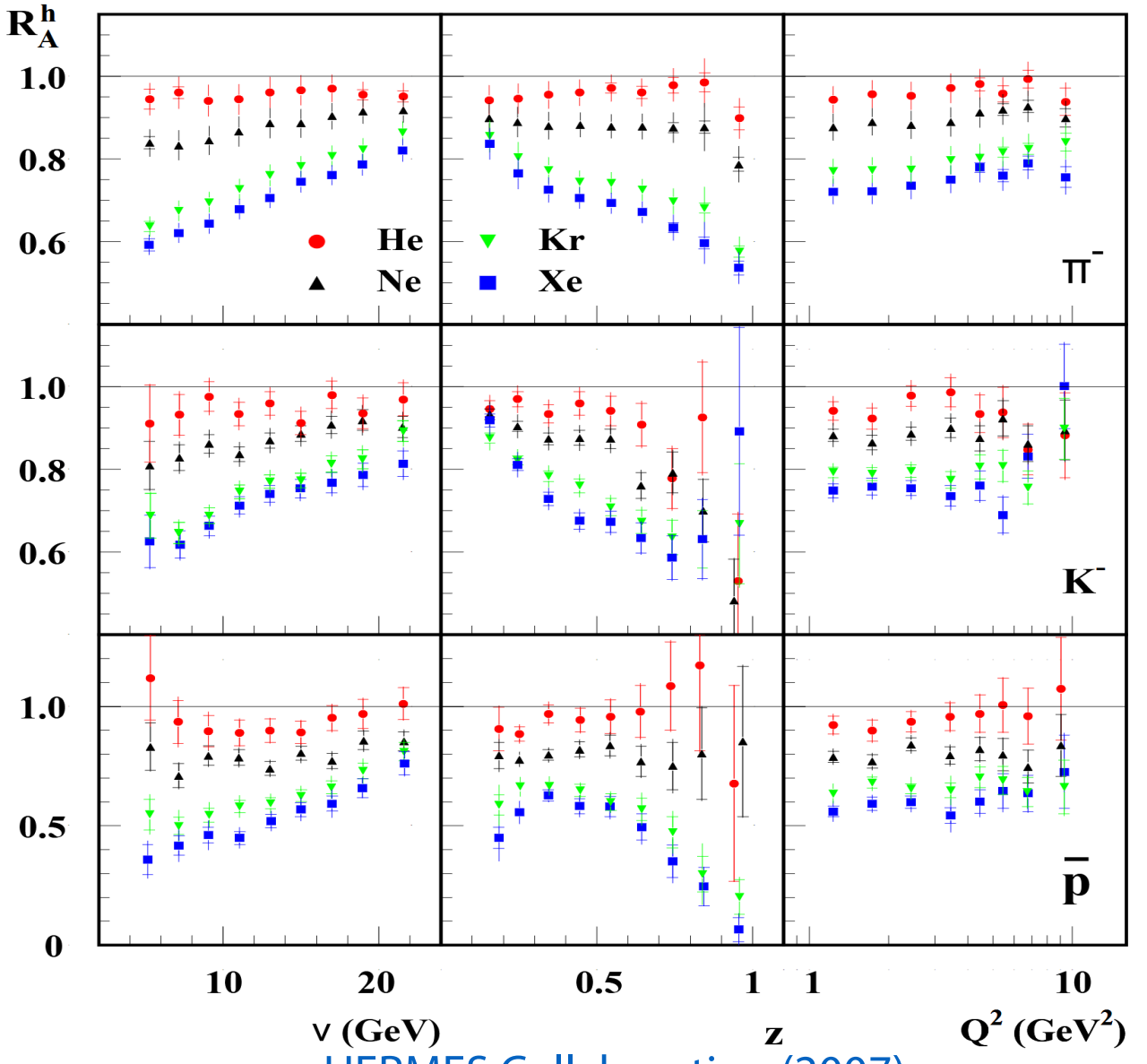
- The RG-E Spring 2024 dataset enables Λ SIDIS hadronization studies across LD_2, C, Al, Cu, Sn, and Pb targets
- Currently, analysis code has been developed for
  - PID refinement
  - Secondary vertex cuts
  - Target separation
  - Mixed-event background subtraction
- Work is in progress to implement:
  - Observable extraction
  - Momentum, acceptance, radiative, and target end-caps corrections
  - Systematic studies

Thank You!

Backup Slides

Previous Measurements – HERMES Multiplicity Ratios

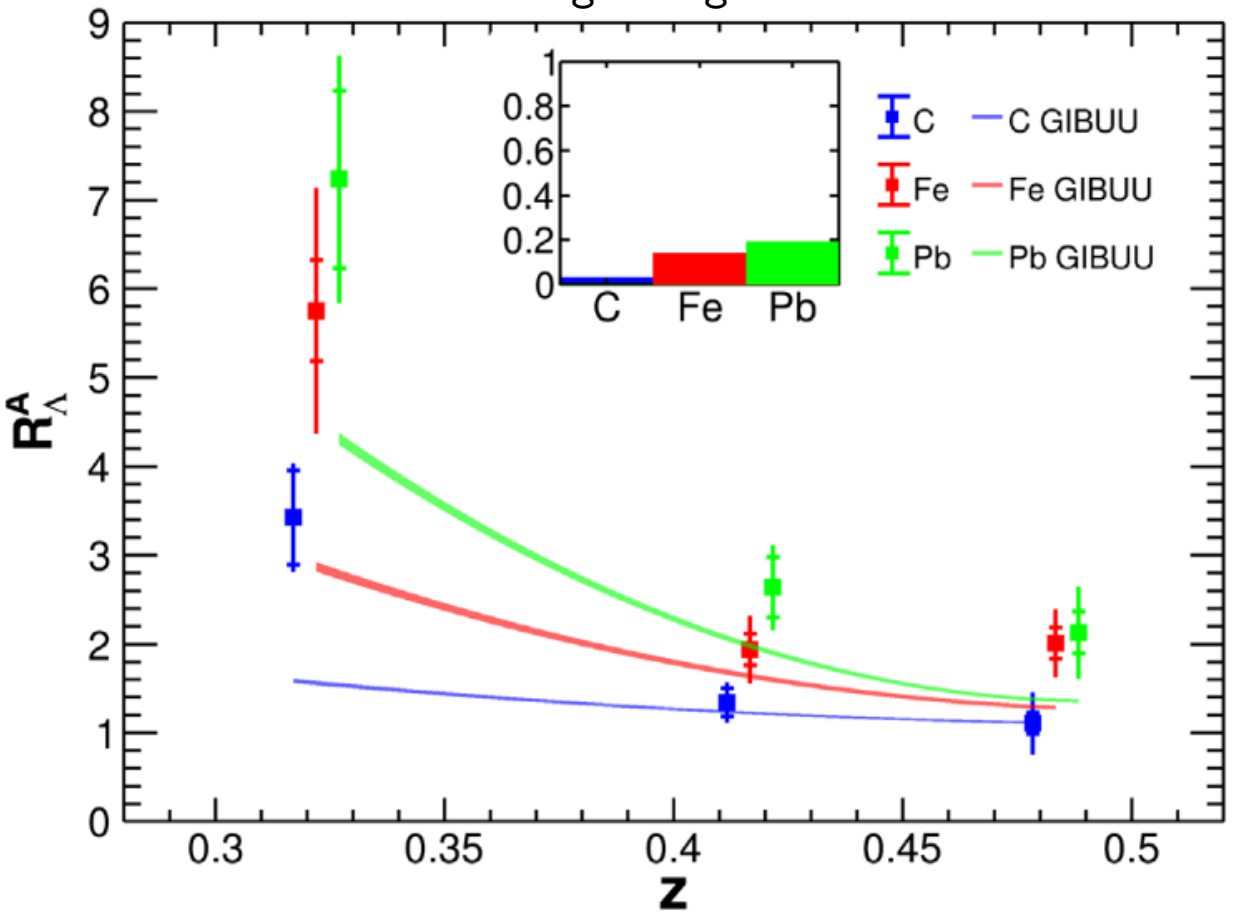




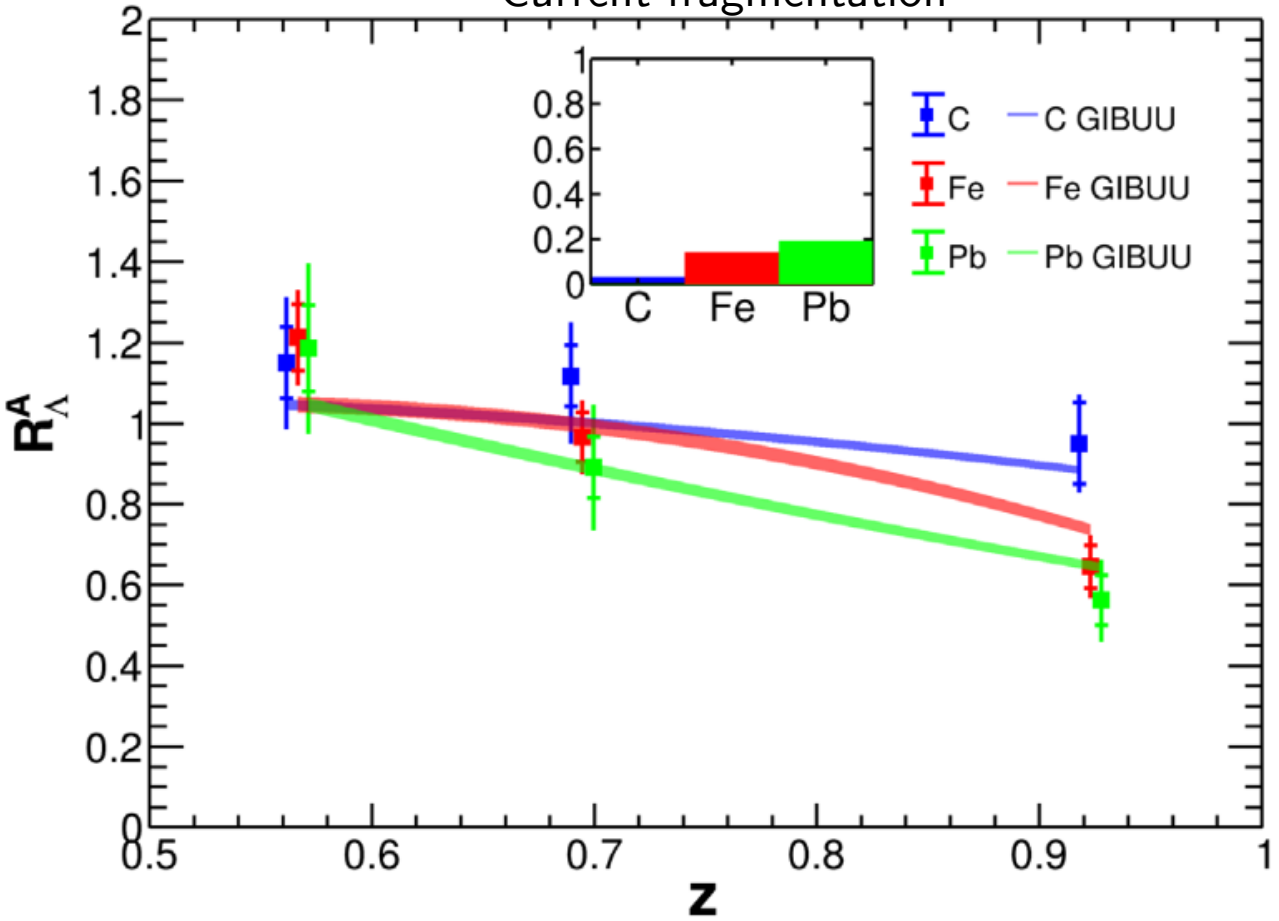
HERMES Collaboration (2007)

Previous Measurements – CLAS6 Λ

Target fragmentation

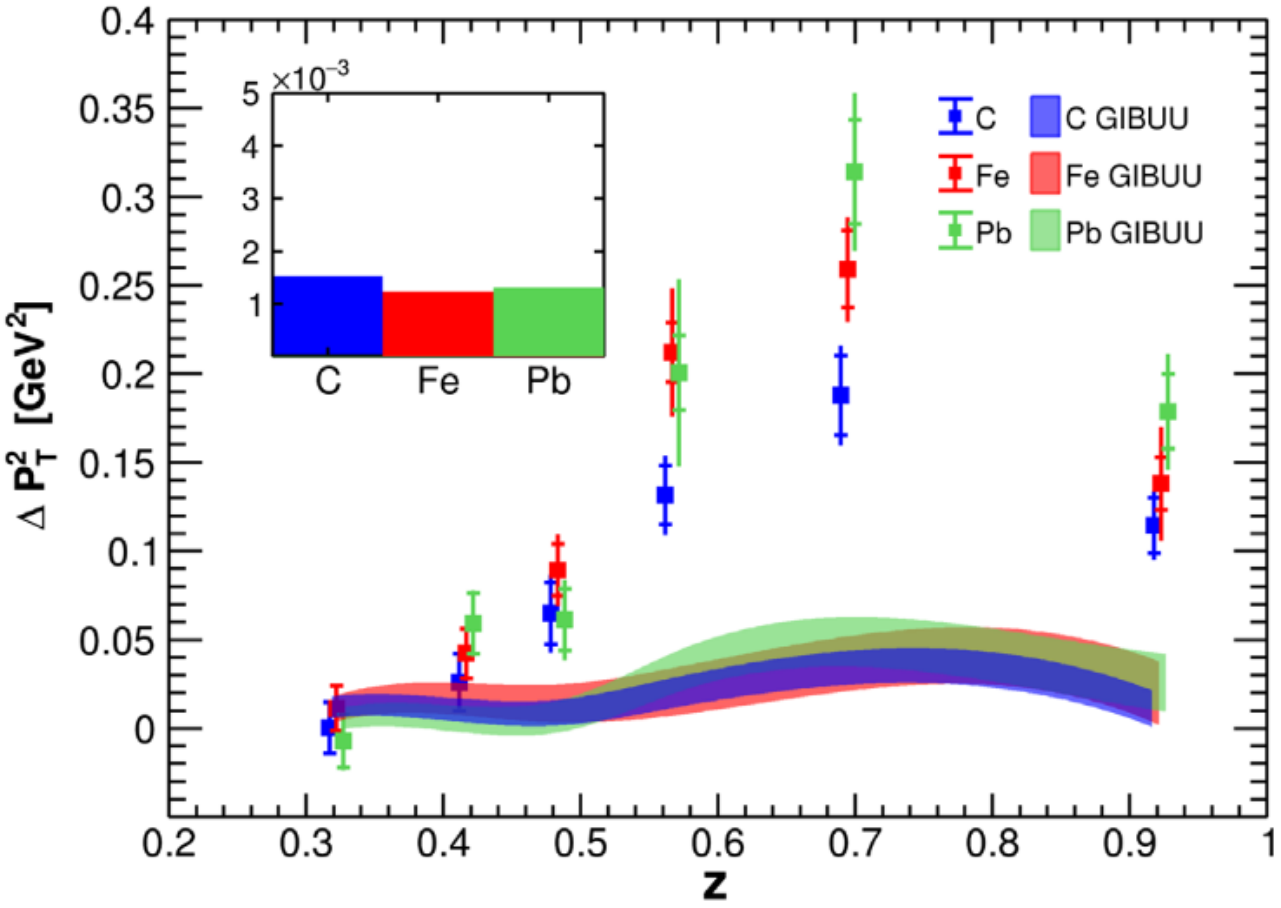


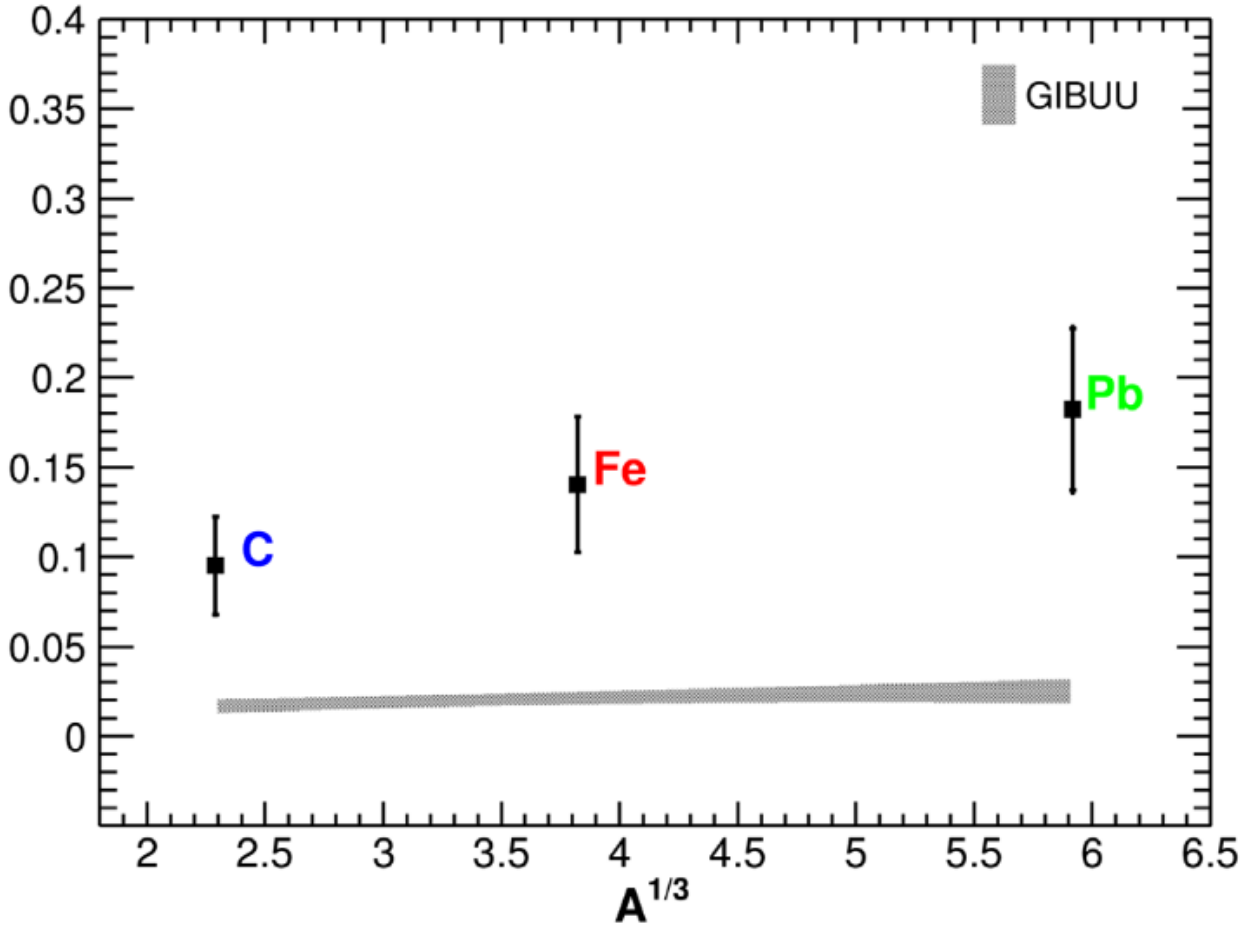
Current fragmentation



T. Chetry, L. El Fassi, CLAS Collaboration (2023)

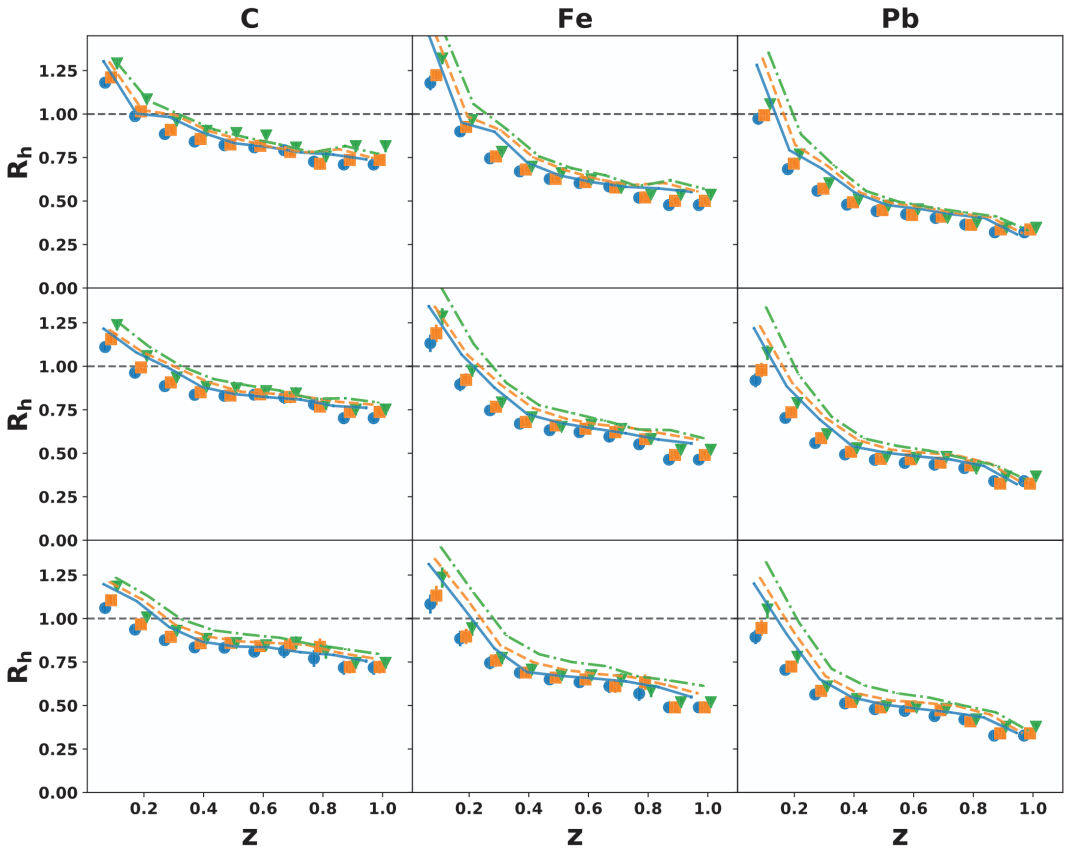
Previous Measurements – CLAS6 Λ

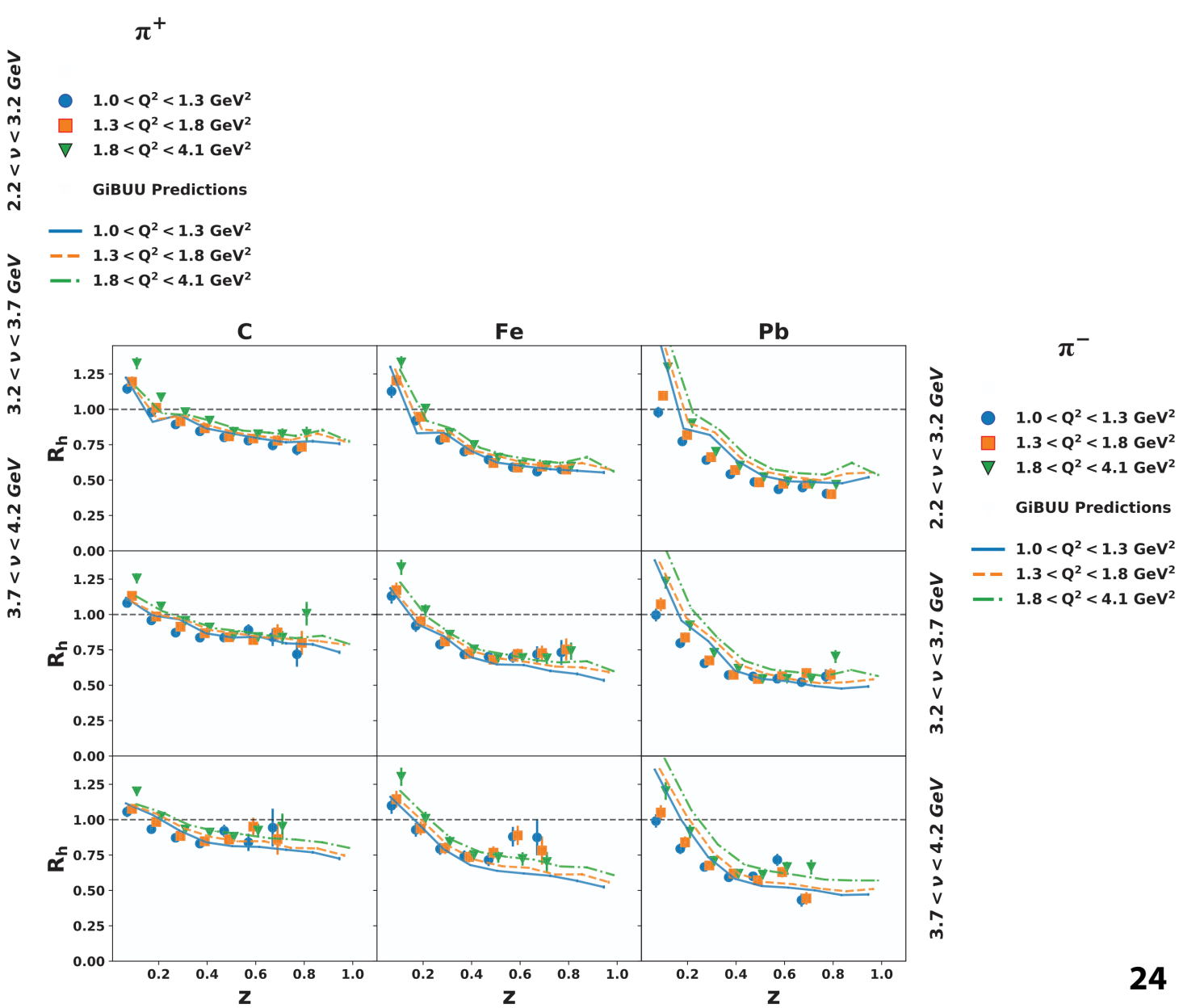




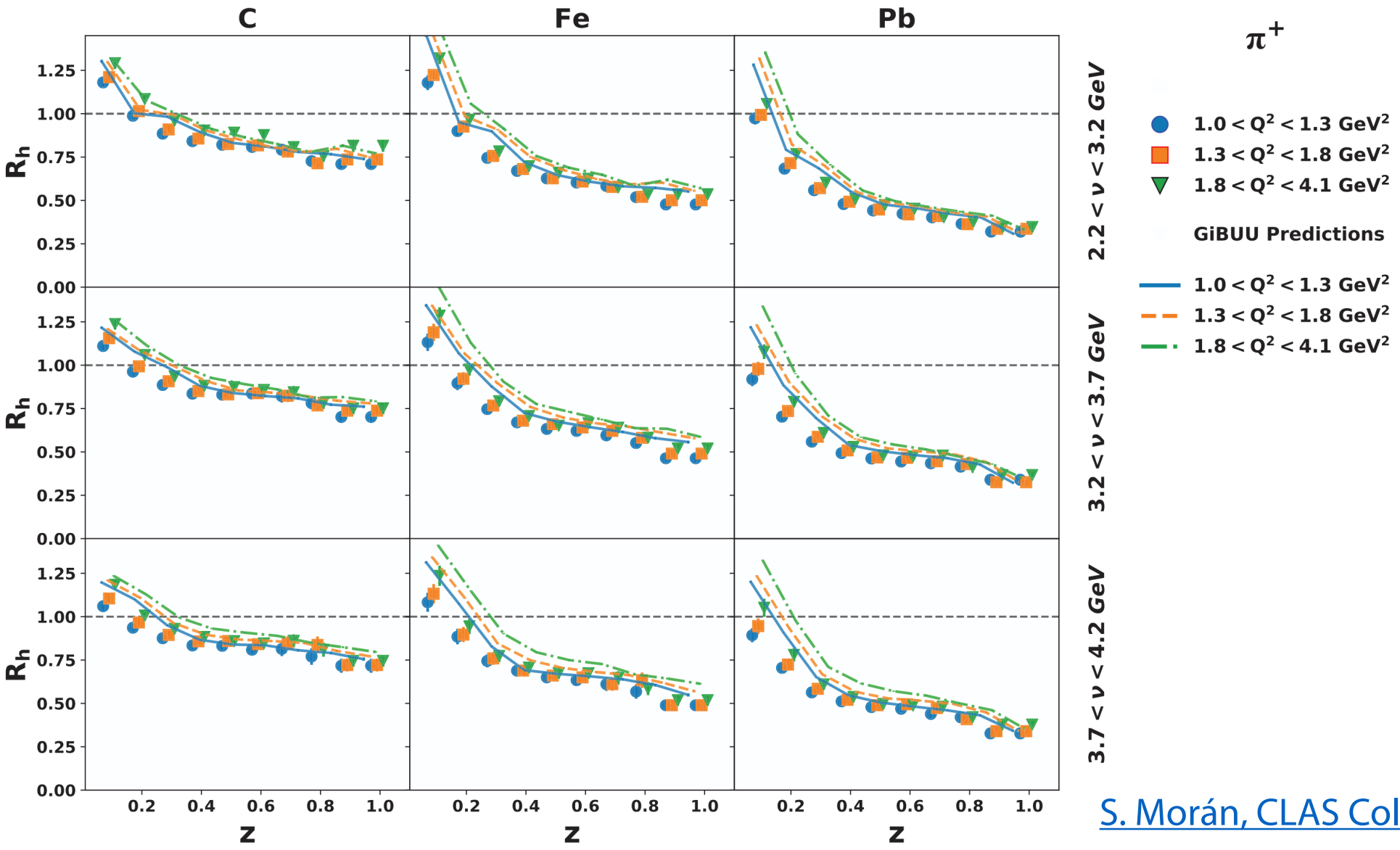
[T. Chetry, L. El Fassi, CLAS Collaboration (2023)]

Previous Measurements – CLAS6



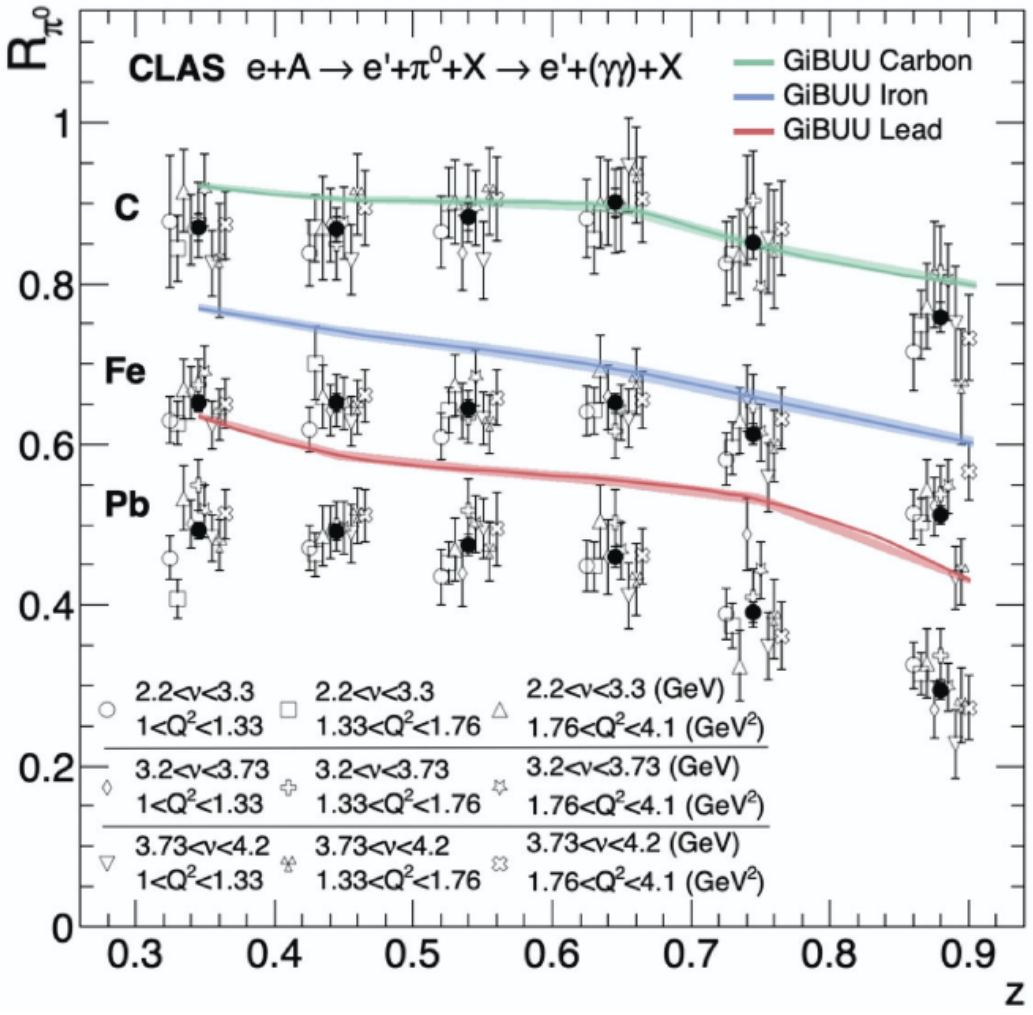


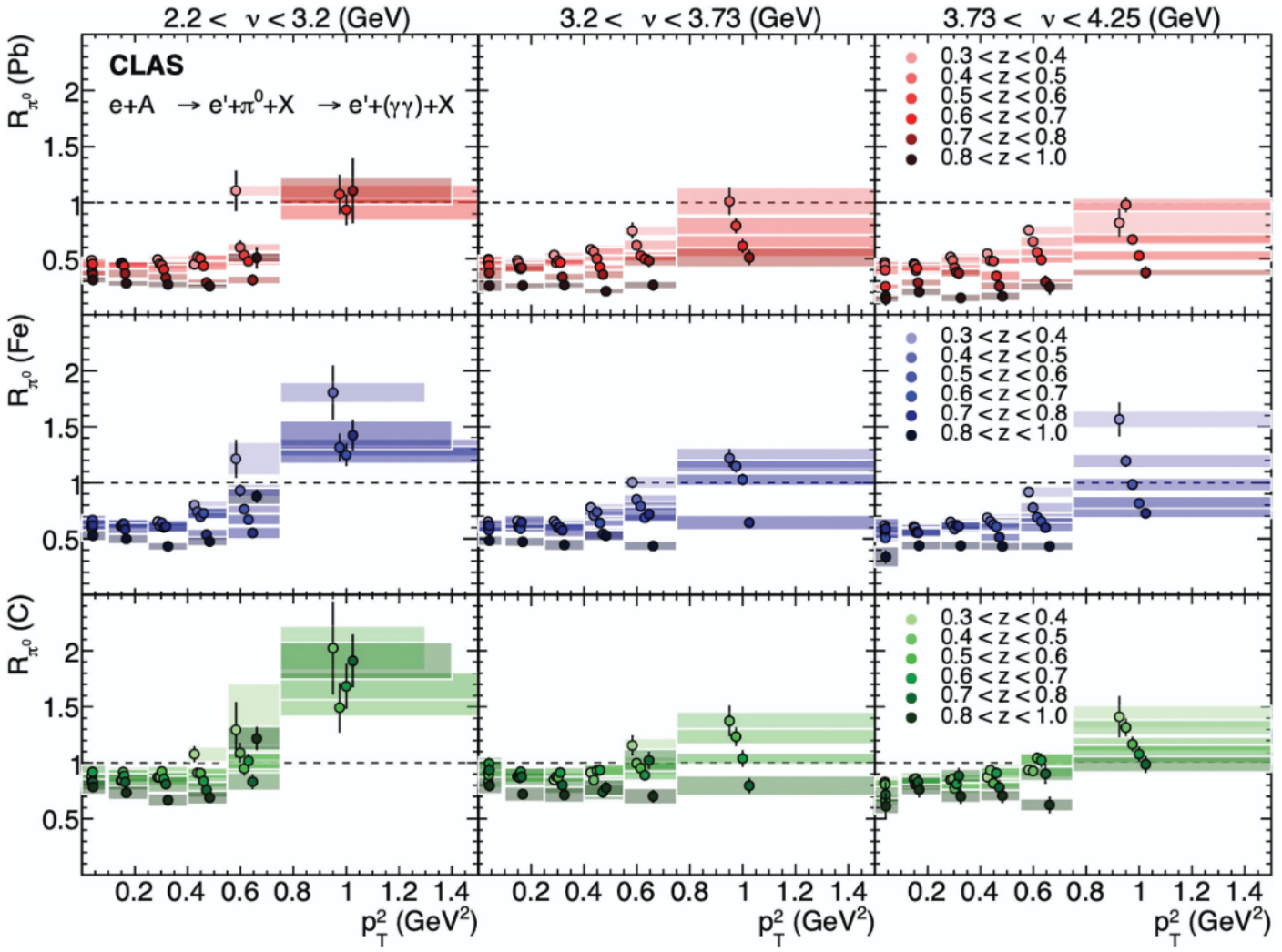
Previous Measurements – CLAS6 π^+



S. Morán, CLAS Collaboration (2022)

Previous Measurements – CLAS6 π^0

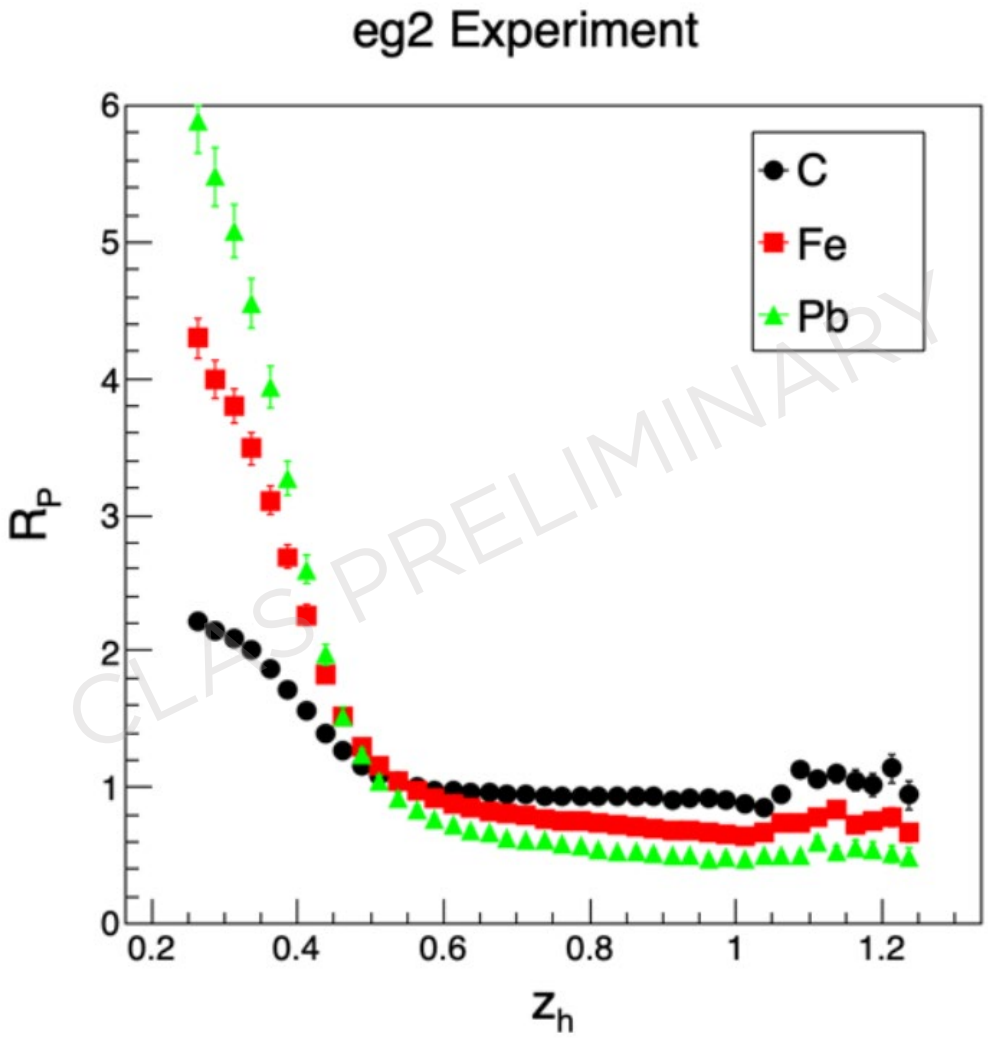


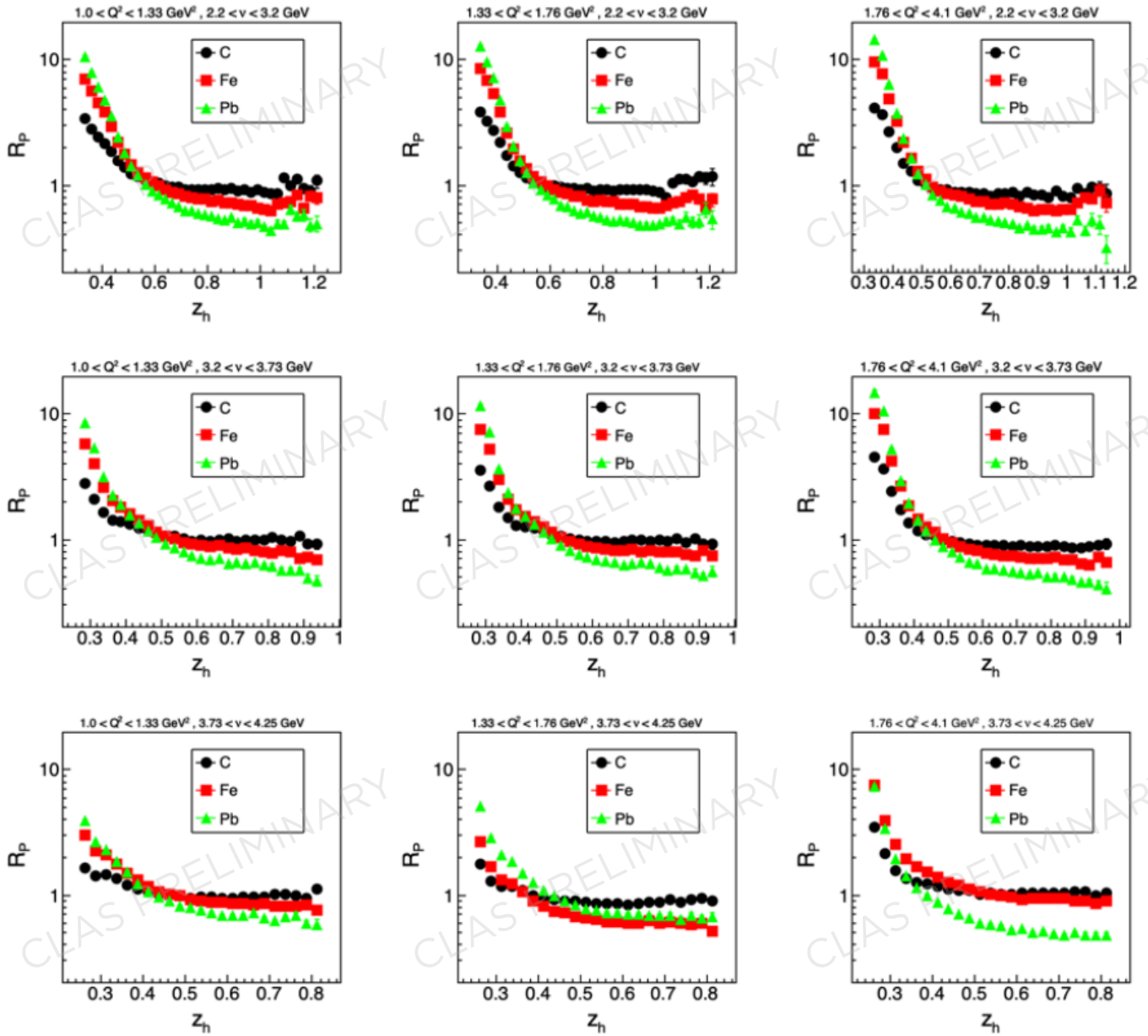


T. Mineeva, CLAS Collaboration (2025)

Previous Measurements – CLAS6 proton

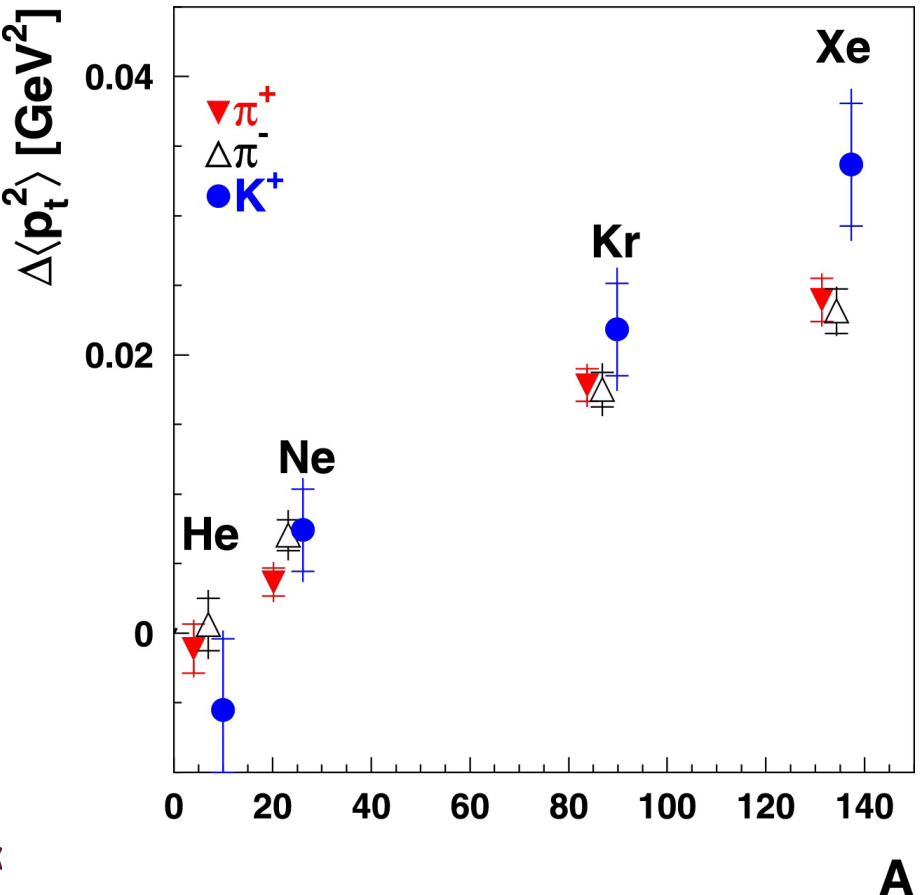
- Preliminary results by M. Wood undergoing internal analysis review

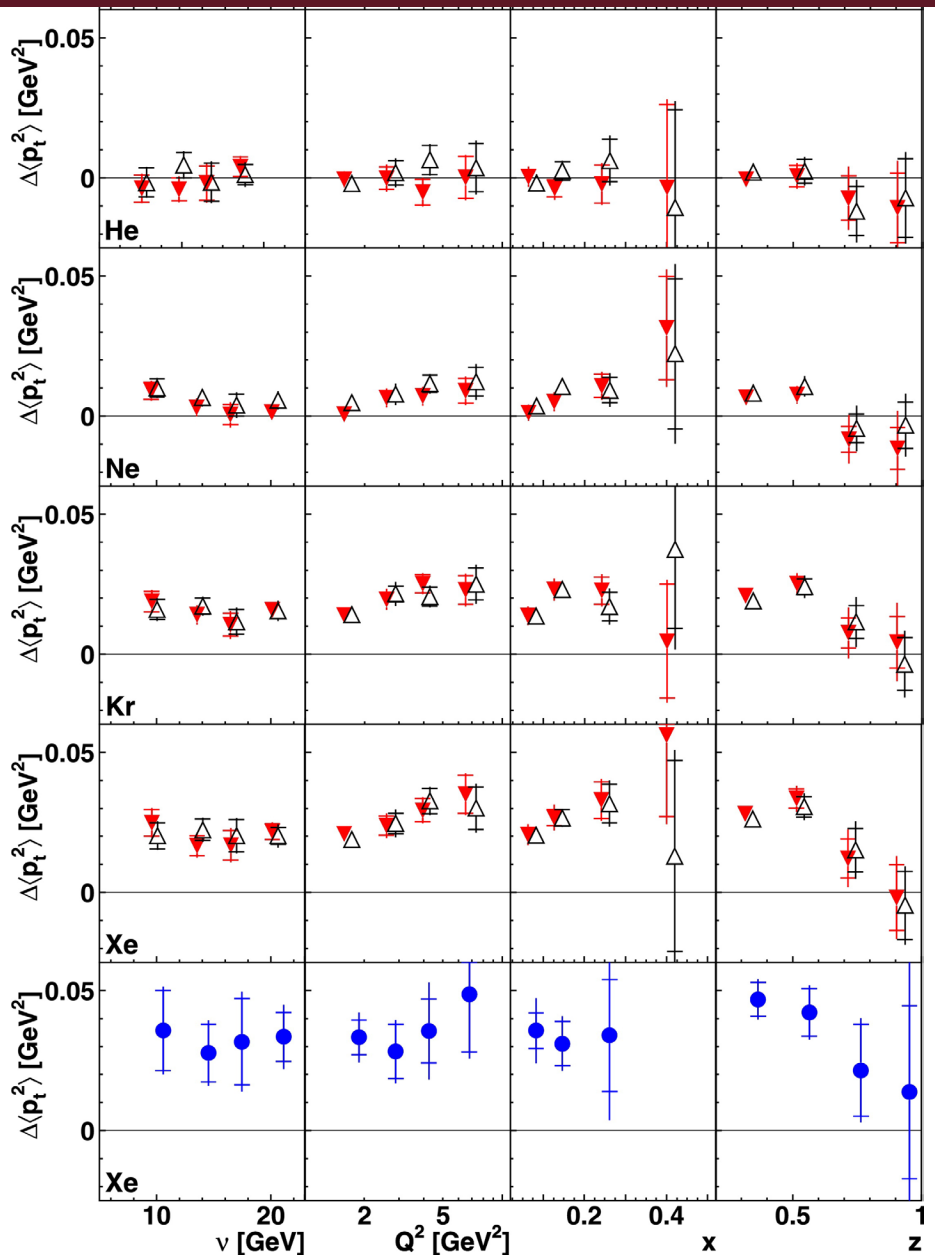




Previous Measurements – HERMES p_T Broadening

- CLAS6 observed substantially larger p_T broadening for Λ hyperons than the published HERMES meson measurements
- The difference was approximately an order of magnitude, motivating further study of baryon hadronization in nuclei





CLAS12 RG-E Proposed Channels

- CLAS12 provides access to a broad range of identified final-state hadrons, enabling comparative hadronization studies across mesons and baryons
- This analysis focuses on the Λ hyperon as a strange baryon probe of hadronization in nuclei

hadron	$c\tau$	mass (GeV)	flavor content	detection channel	Production rate per 1k DIS events
π^0	25 nm	0.13	$u\bar{u}d\bar{d}$	$\gamma\gamma$	1100
π^+	7.8 m	0.14	$u\bar{d}$	direct	1000
π^-	7.8 m	0.14	$d\bar{u}$	direct	1000
η	0.17 nm	0.55	$u\bar{u}d\bar{d}s\bar{s}$	$\gamma\gamma$	120
ω	23 fm	0.78	$u\bar{u}d\bar{d}s\bar{s}$	$\pi^+\pi^-\pi^0$	170
η'	0.98 pm	0.96	$u\bar{u}d\bar{d}s\bar{s}$	$\pi^+\pi^-\eta$	27
ϕ	44 fm	1.0	$u\bar{u}d\bar{d}s\bar{s}$	K^+K^-	0.8
$f1$	8 fm	1.3	$u\bar{u}d\bar{d}s\bar{s}$	$\pi\pi\pi\pi$	-
K^+	3.7 m	0.49	$u\bar{s}$	direct	75
K^-	3.7 m	0.49	$\bar{u}s$	direct	25
K^0	27 mm	0.50	$d\bar{s}$	$\pi^+\pi^-$	42
p	stable	0.94	ud	direct	530
$\bar{p}$	stable	0.94	$\bar{u}\bar{d}$	direct	3
Λ	79 mm	1.1	uds	$p\pi^-$	72
$\Lambda(1520)$	13 fm	1.5	uds	$p\pi^-$	-
Σ^+	24 mm	1.2	us	$p\pi^0$	6
Σ^0	22 pm	1.2	uds	$\Lambda\gamma$	11
Ξ^0	87 mm	1.3	us	$\Lambda\pi^0$	0.6
Ξ^-	49 mm	1.3	ds	$\Lambda\pi^-$	0.9