Lambda SIDIS Production on Nuclear Targets

CLAS Collaboration Meeting

March 11th, 2026

Uditha Weerasinghe

Mississippi State University

Outline

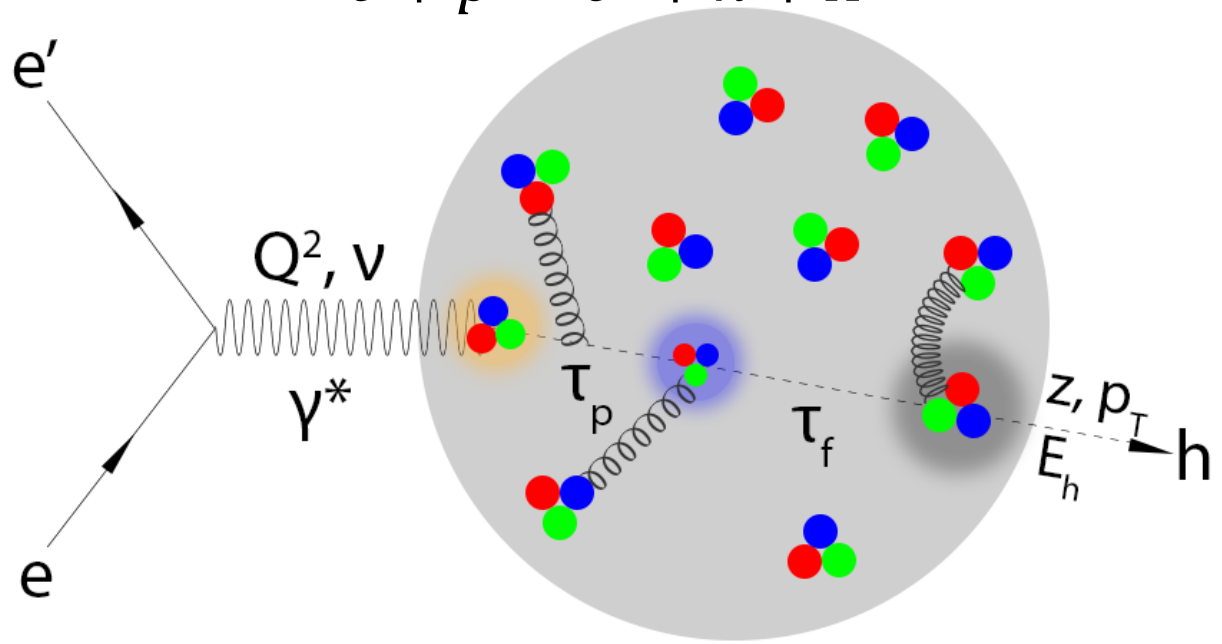
- Physics Motivation
- Kinematics Cuts
- Run Group E (RG-E) Experiment Setup
- Refining Particle Identification
  - Electron
  - π^-
  - Proton
- Vertex Cuts
- Λ Production Channel
- Event Mixing for Background Subtraction

Physics Motivation

- Studying hadronization processes in Semi Inclusive Deep Inelastic Scattering (SIDIS) production helps improve our understanding of the confinement dynamics, a fascinating feature of Quantum Chromodynamics, the fundamental theory of strong interactions between quarks and gluons

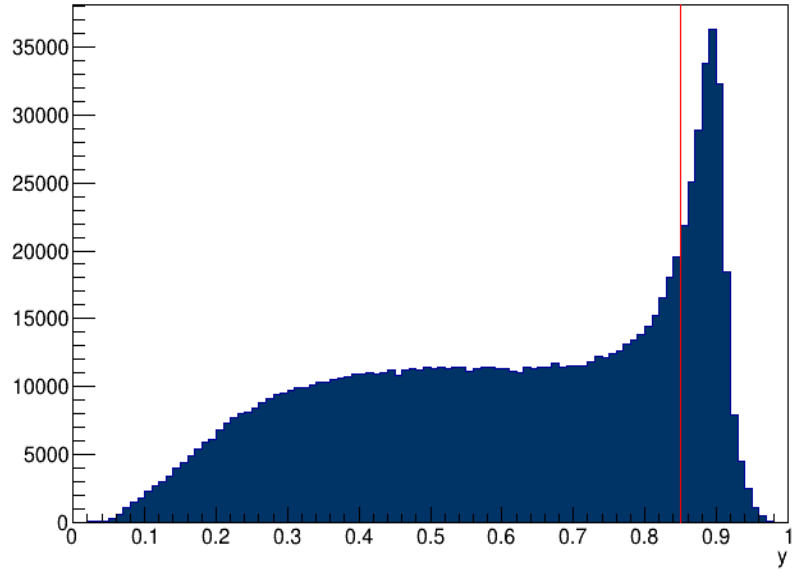
- Hadronization process is characterized by two time-distance scales:
  - **Production time (τ_p):** Struck quark propagates as a colored object during the color-neutralization stage
  - **Formation time (τ_f):** Time needed for the color-neutral prehadron to evolve into a fully dressed hadron with its gluonic field

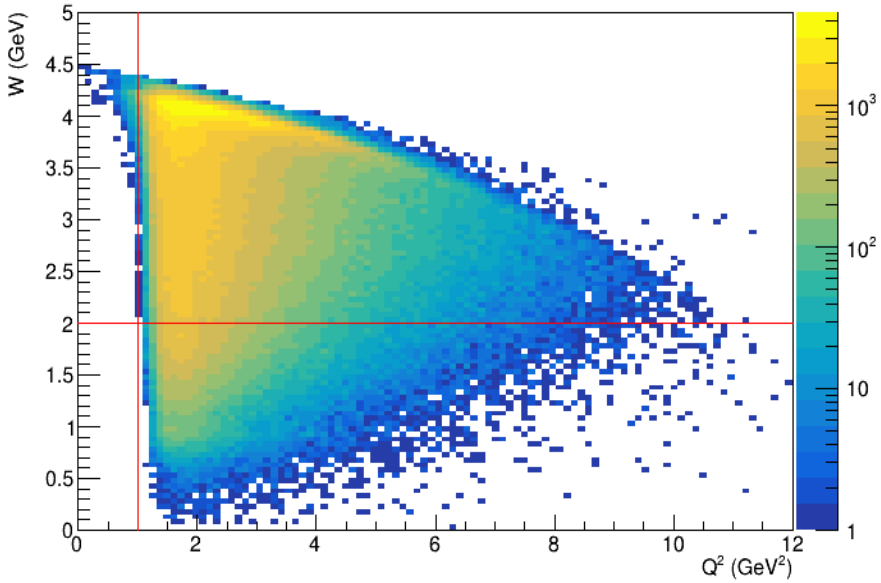
$$e + p \rightarrow e' + h + X$$



Kinematic Cuts

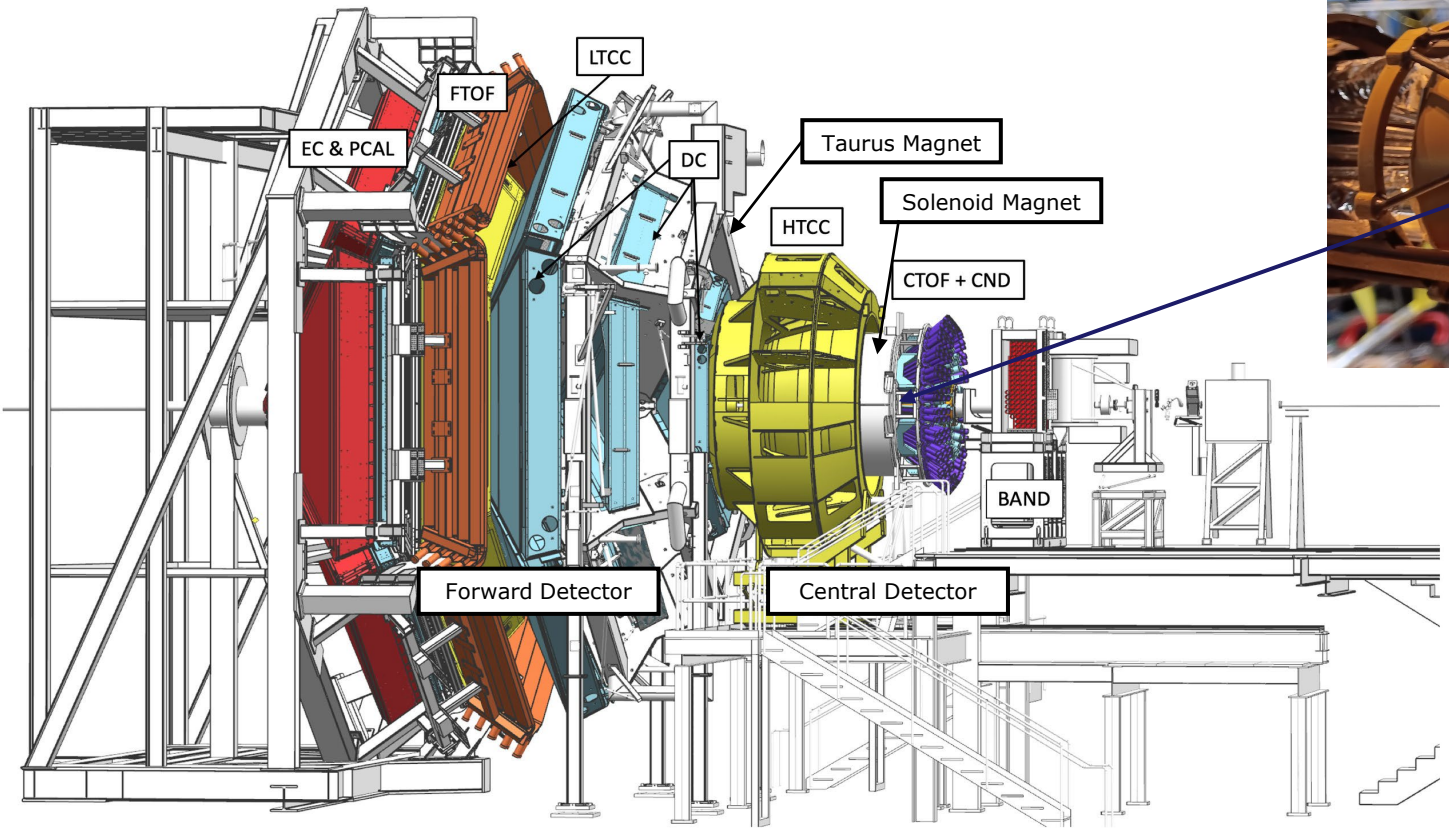
- The study of hadronization dynamics is probed in the SIDIS regime using this set of kinematics and cuts:
  - ν: electron energy loss or struck quark's initial energy
  - Q^2: four-momentum transferred squared
    - $\mathrm{Q}^2 > 1\ \mathrm{GeV}^2$: to probe the intrinsic structure of nucleons
  - $y = {}^{\nu}/_{E_{beam}}$: electron energy fraction transferred to a struck quark
    - $\mathrm{y} < 0.85$: 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





RG-E Experiment Setup

- RG-E experiments collected data during the spring of 2024 using the standard CLAS12 detectors with FT-OFF
- A double target assembly consisting of liquid deuterium (LD2) and solid foil targets placed inside the solenoid magnet

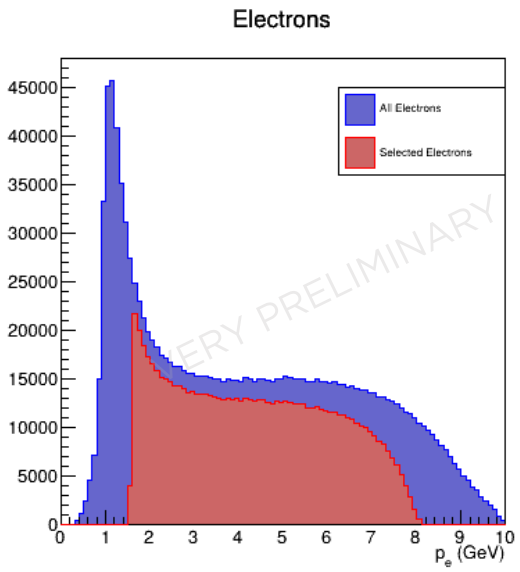


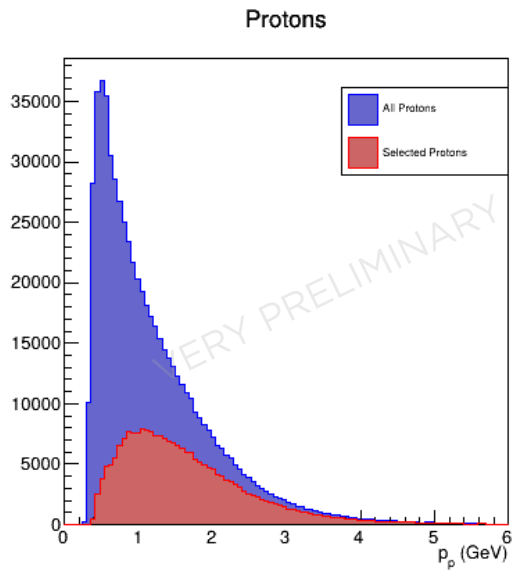
Solid foils:
- C
- Al
- Cu
- Sn
- Pb

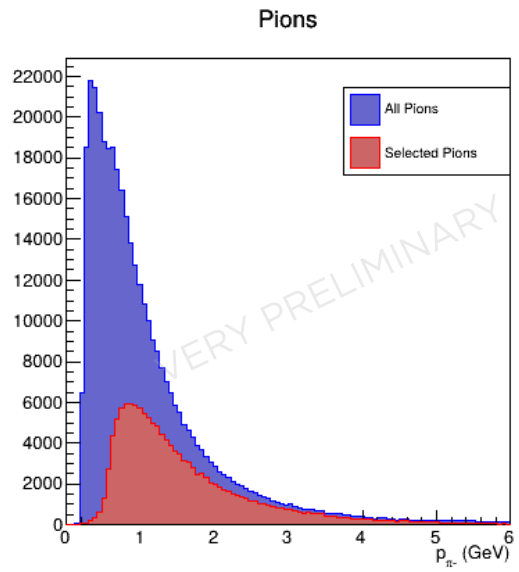
Electron Beam

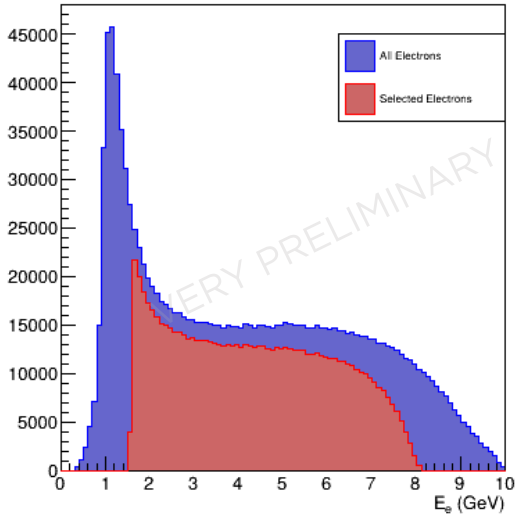
Refining Particle Identification

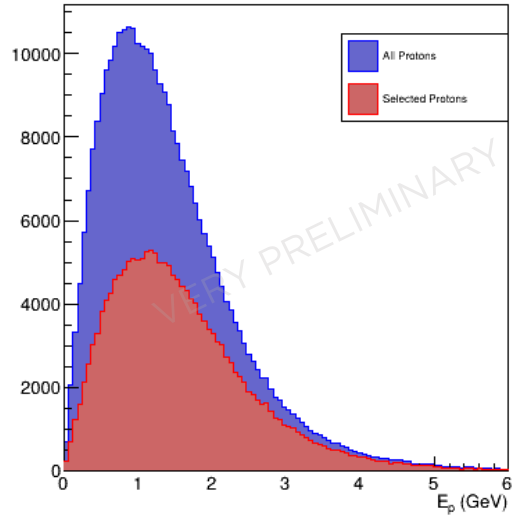
- Particle ID:
  - Electron: +11
  - (+/-) pions: (+/-) 211
  - Proton: +2212
- Detectors cuts:
  - Electron should be in the forward region
  - Pions and protons are either in the forward or central region
- Fit quality cut:
  - 3 σ cuts on the χ^2 of reconstructed tracks

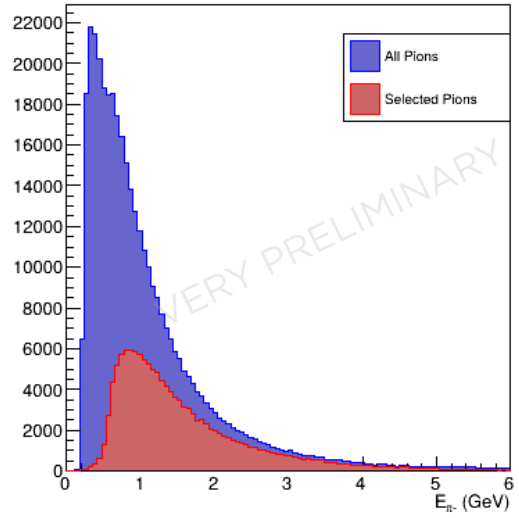








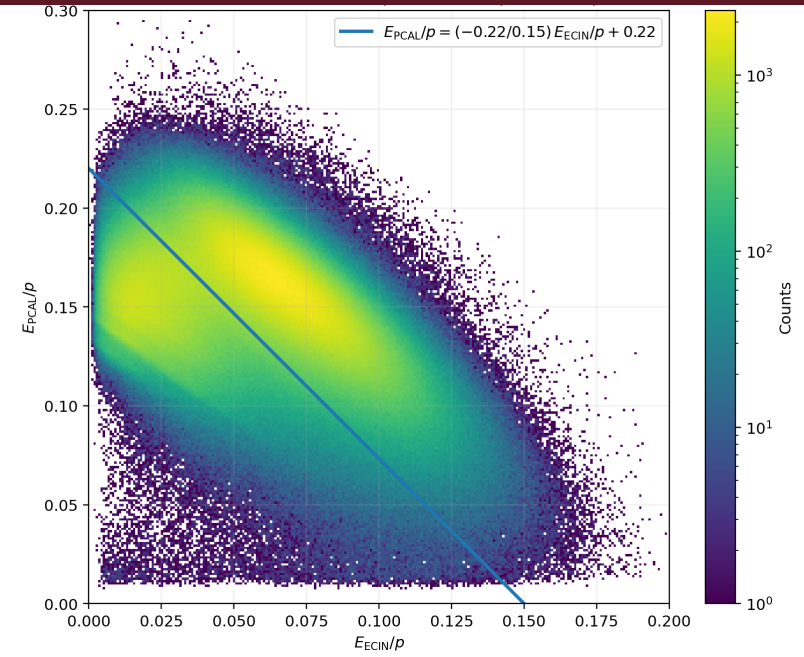


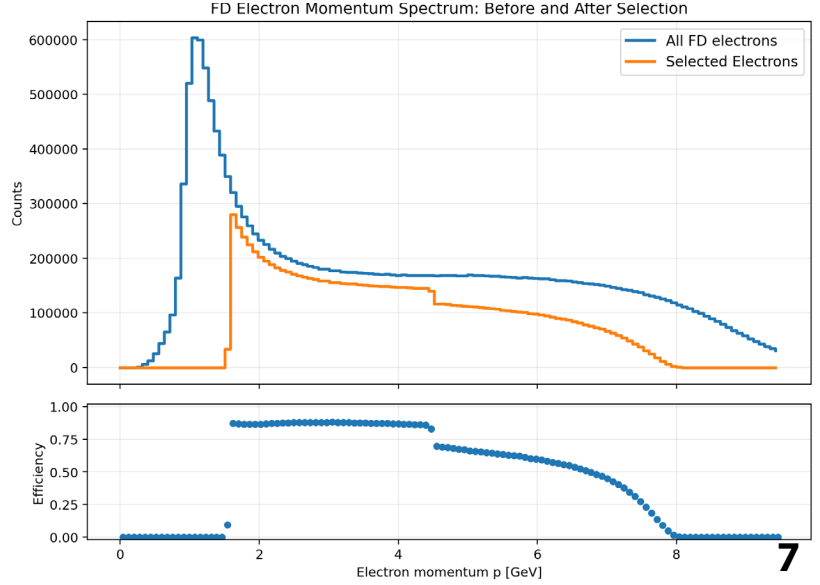


Refining Particle Identification: Electron

- **DC edge cuts** applied to remove tracks near drift chamber acceptance boundaries
  - Region 1: edge > **4.5 cm**
  - Region 2: edge > **3.5 cm**
  - Region 3: edge > **7.5 cm**
- Additional **partial sampling fraction cut** was used to remove pion contamination:
  - For electrons with $p > 4.5\ GeV$ (electrons with $p < 4.5\ GeV$ are vetoed by the Cherenkov)
  - Electrons were selected if they were above the line defined by

$$E_{PCAL}/p = \left(-\frac{0.22}{0.15}\right) * E_{PCAL}/p + 0.22$$





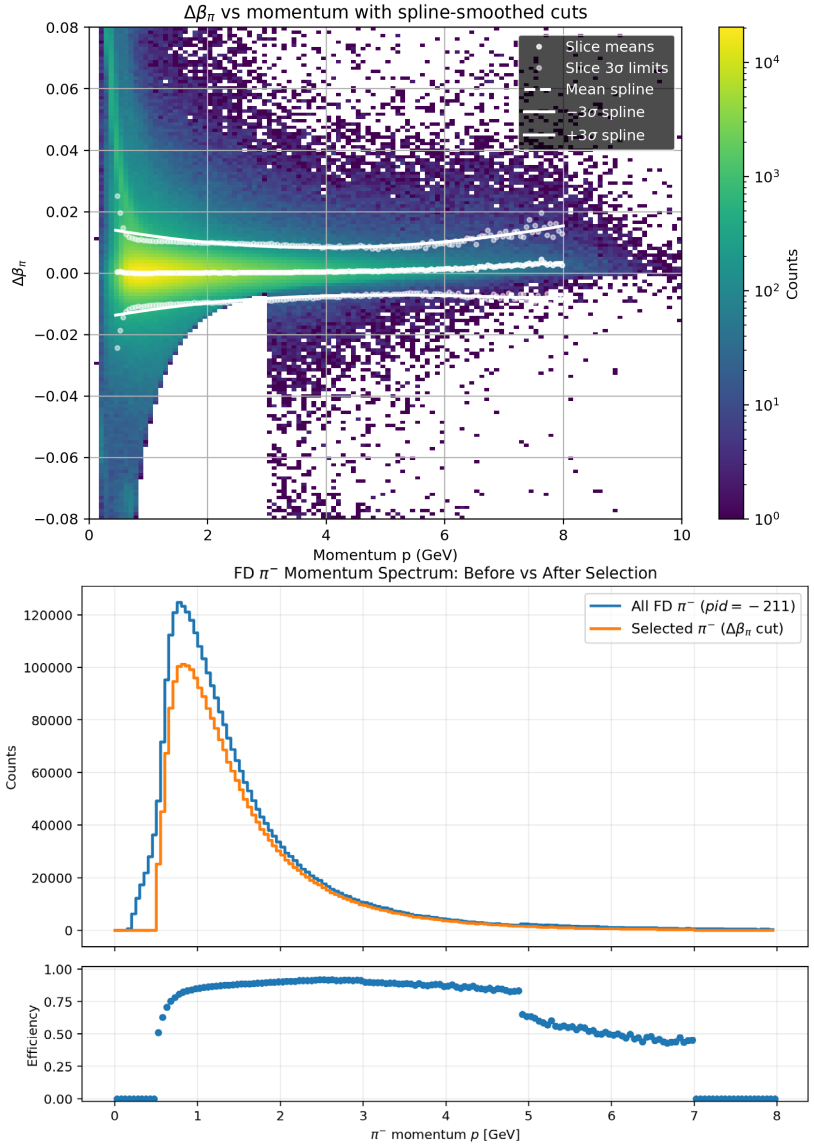
Refining Particle Identification: π^-

- A cut on Δβ was used to refine the selection of π^- where:

$$\Delta\beta_\pi = \beta_{meas} - \beta_{exp}^{(\pi)}$$

$$\text{where } \beta_{exp}^{(\pi)} = \frac{p}{\sqrt{p^2+m_\pi^2}}$$

- The plot of Δβ vs momentum was sliced into 50 MeV momentum bins and Gaussian fits were used to determine the limits
- The PID window was defined as $\mu_\pi \pm 3\sigma_\pi$ for each momentum slice
- The momentum-dependent cut was parameterized using a smoothed spline fit
- Work is still in progress on refining the pion identification



Refining Particle Identification: Proton

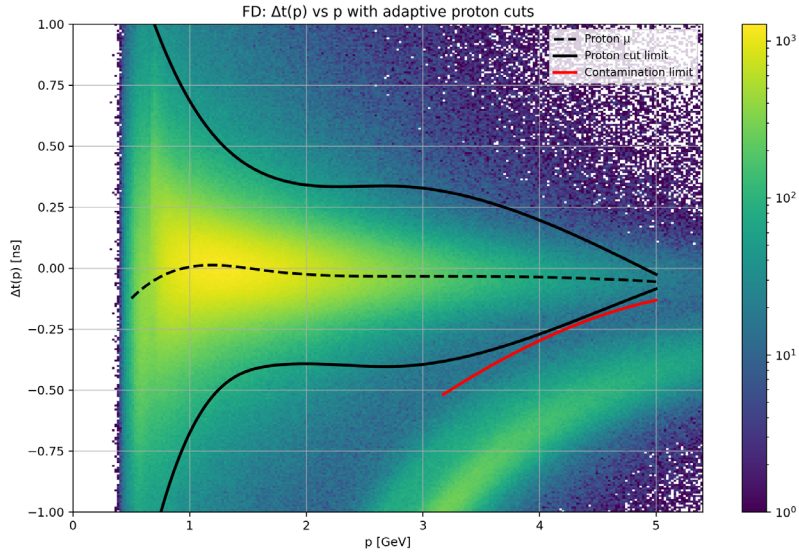
- A cut on ΔT was used to refine the selection of protons where:

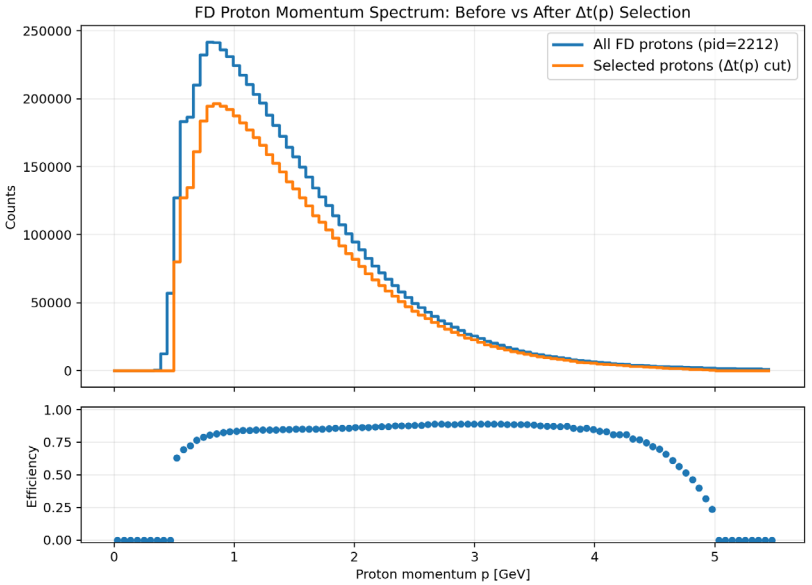
$$\Delta T(p) = (t_{meas} - t_0) - \frac{L}{c}\left(\frac{\sqrt{p^2 + m_p^2}}{p}\right)$$

- The plot of ΔT vs momentum was sliced into 50 MeV momentum bins and Gaussian fits were used to find the limits
- The initial PID window was defined as $\mu_p \pm 3\sigma_p$, applied up to the momentum where the contaminant distribution satisfied

$$\mu_{cont} + 3\sigma_{cont} \geq \mu_p - 3\sigma_p$$

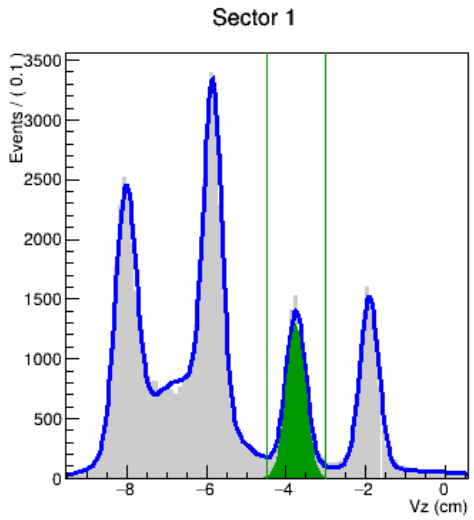
- Beyond this overlap point, the lower bound was progressively tightened in 0.5σ steps up to 5 GeV to mitigate increasing contamination
- The final momentum-dependent cut was parameterized using a smoothed spline fit

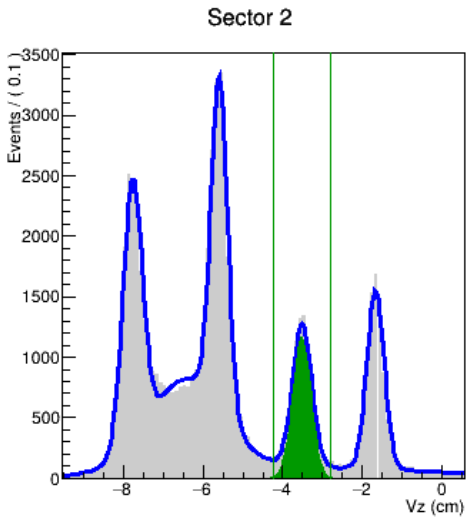


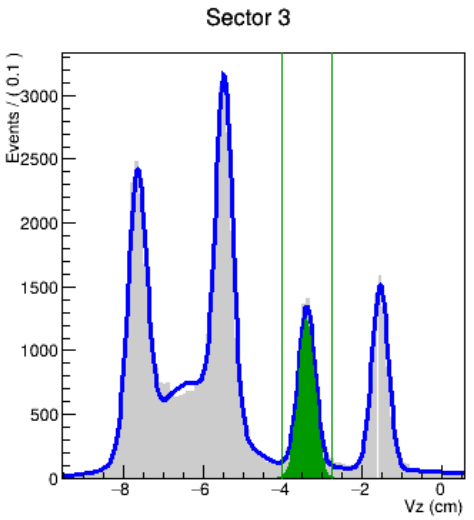


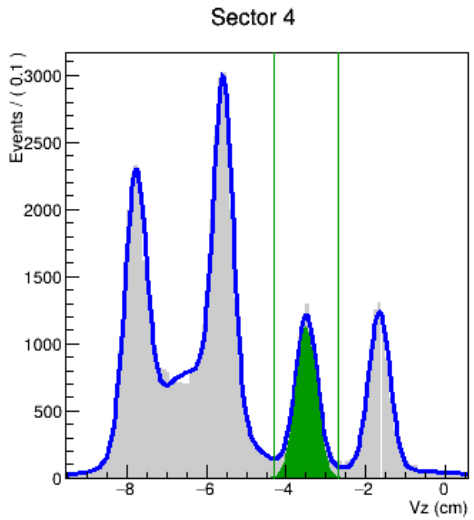
Vertex Cuts

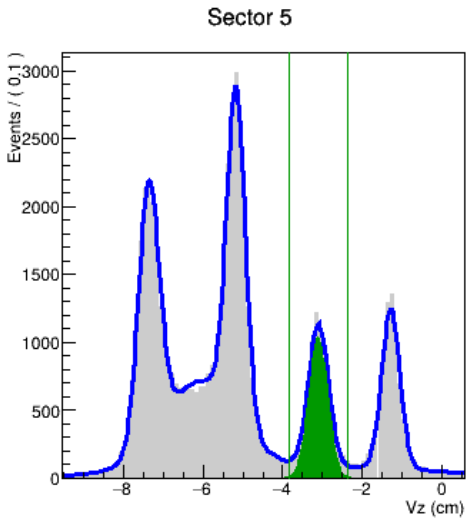
- Information from the FMT was used to improve the vertex resolution
  - Without the FMT, the Aluminum reference foil between the liquid target and the solid target could not be resolved
- The empty+wire target configuration was used to obtain the limits of the reference foil
- These limits were then used to set the upper limit of the LD2 target and the lower limit of the solid target

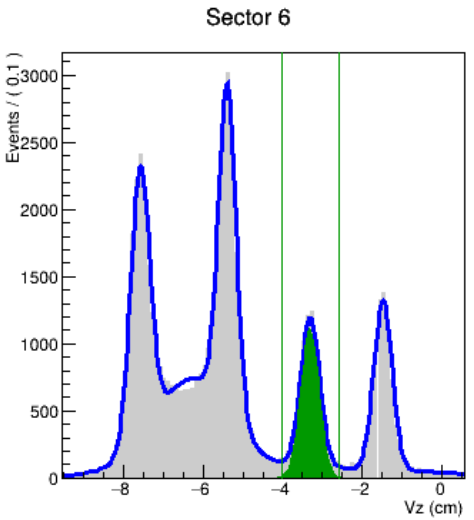




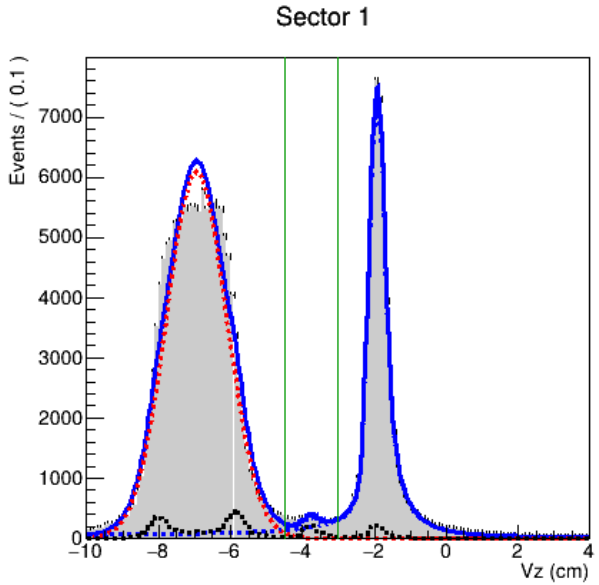


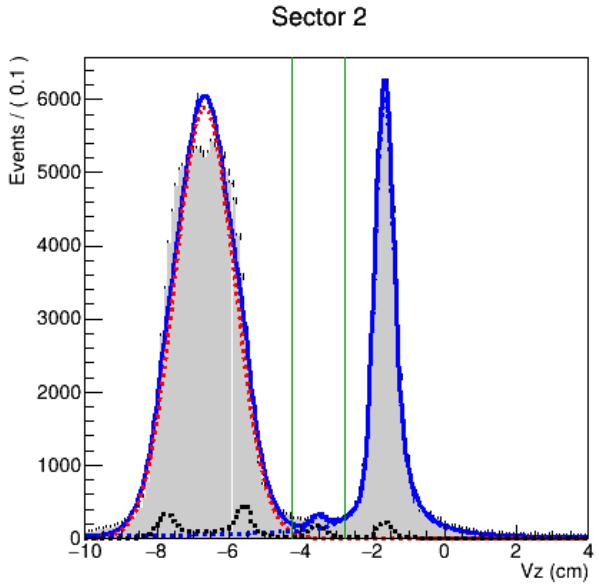


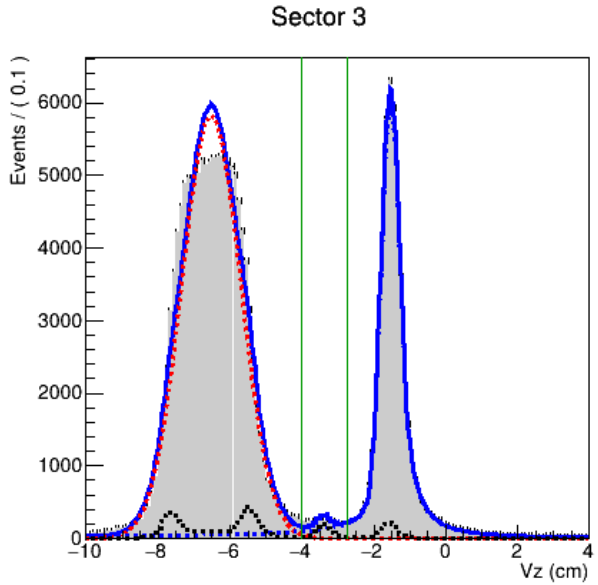


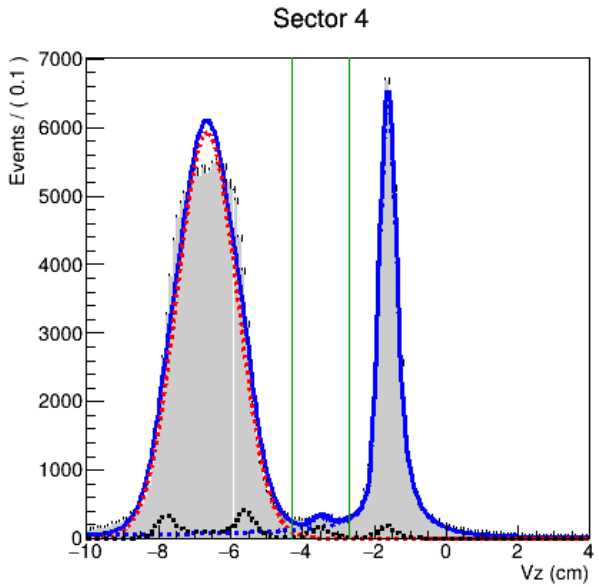


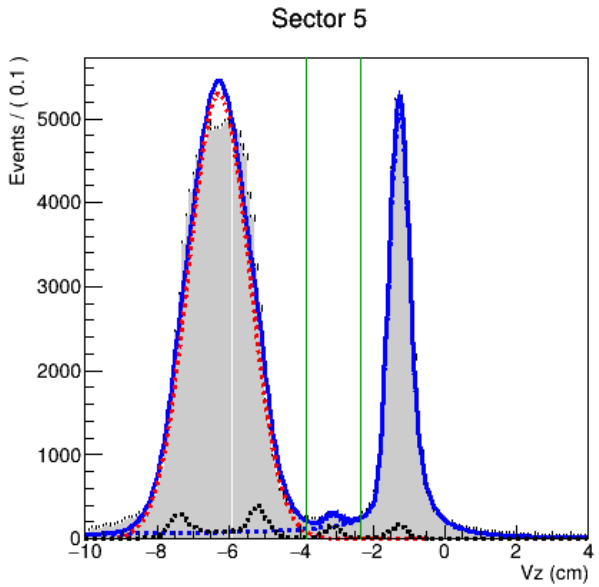
Vertex Cuts

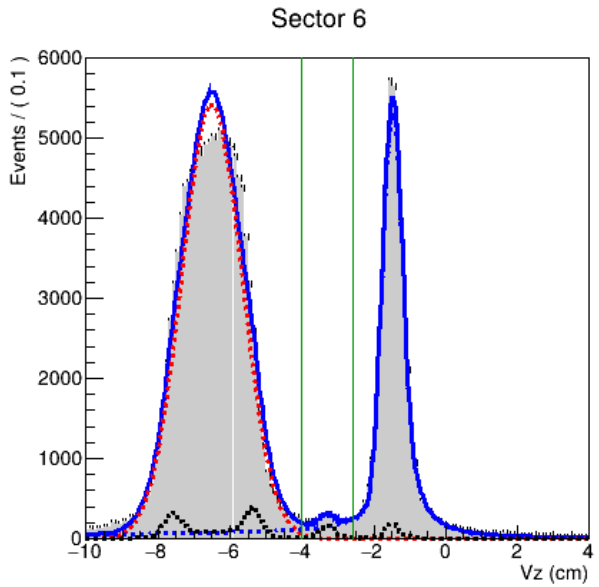

Sector 1
Events / (0.1)
Vz (cm)


Sector 2
Events / (0.1)
Vz (cm)


Sector 3
Events / (0.1)
Vz (cm)

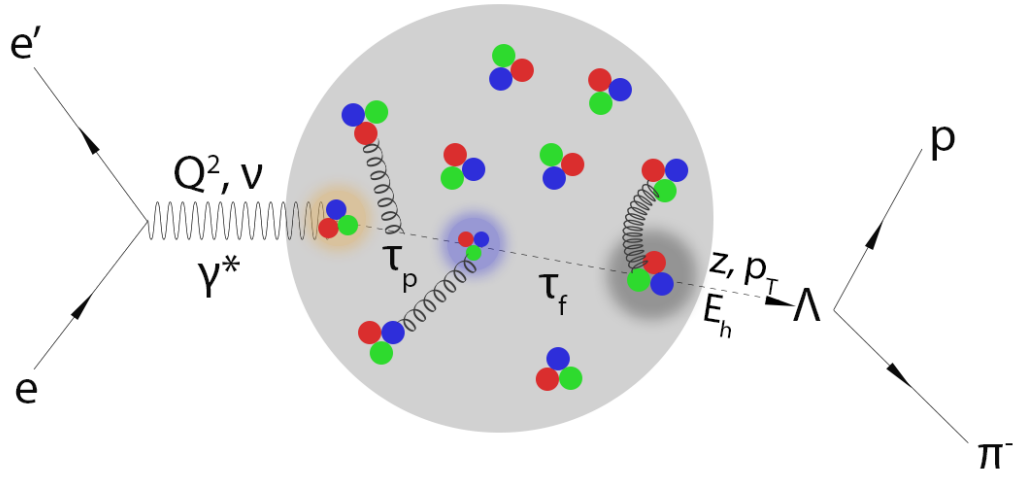

Sector 4
Events / (0.1)
Vz (cm)

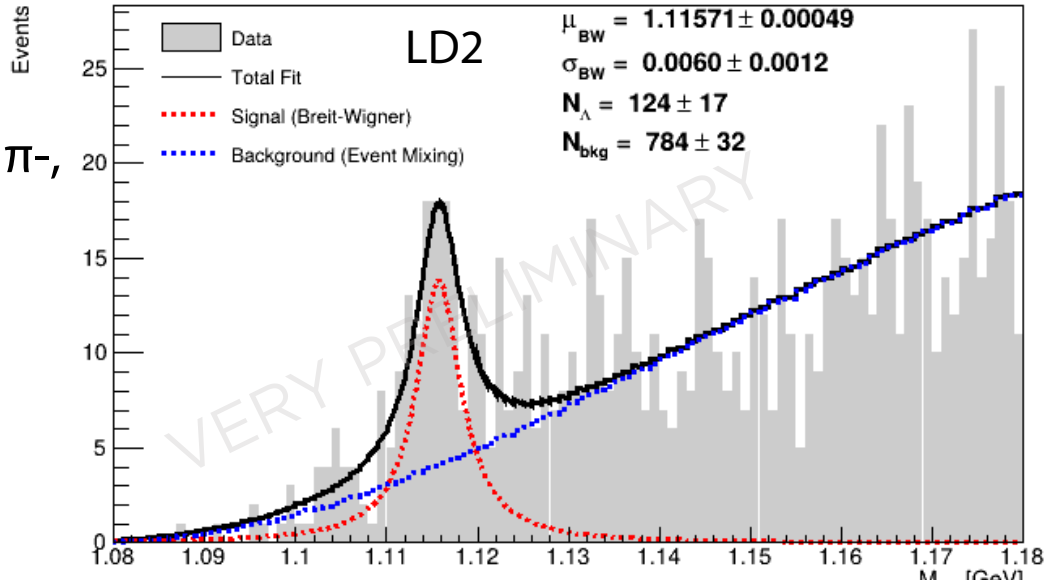

Sector 5
Events / (0.1)
Vz (cm)

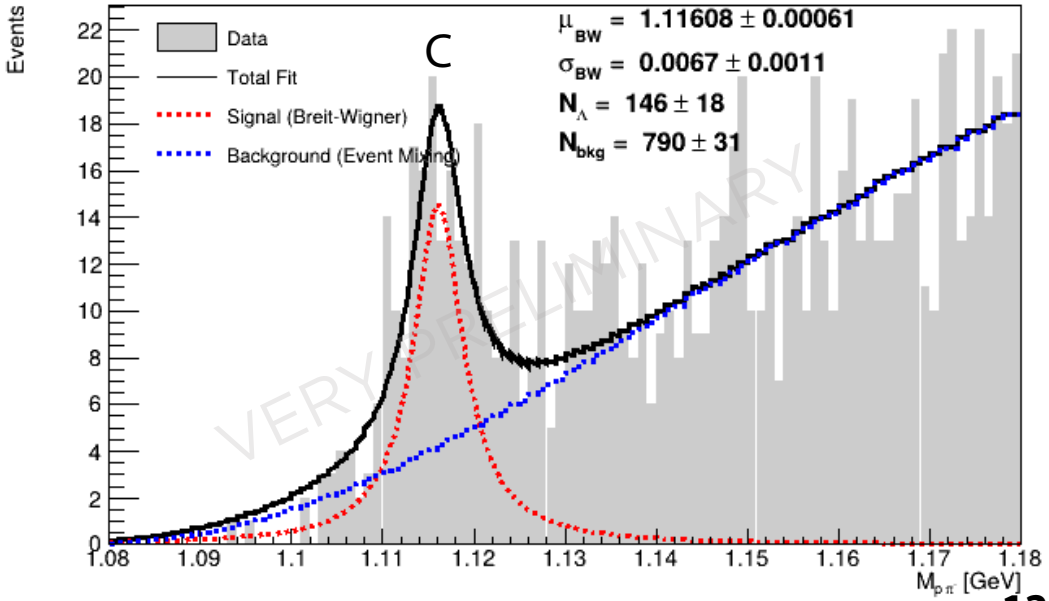

Sector 6
Events / (0.1)
Vz (cm)

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
- 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

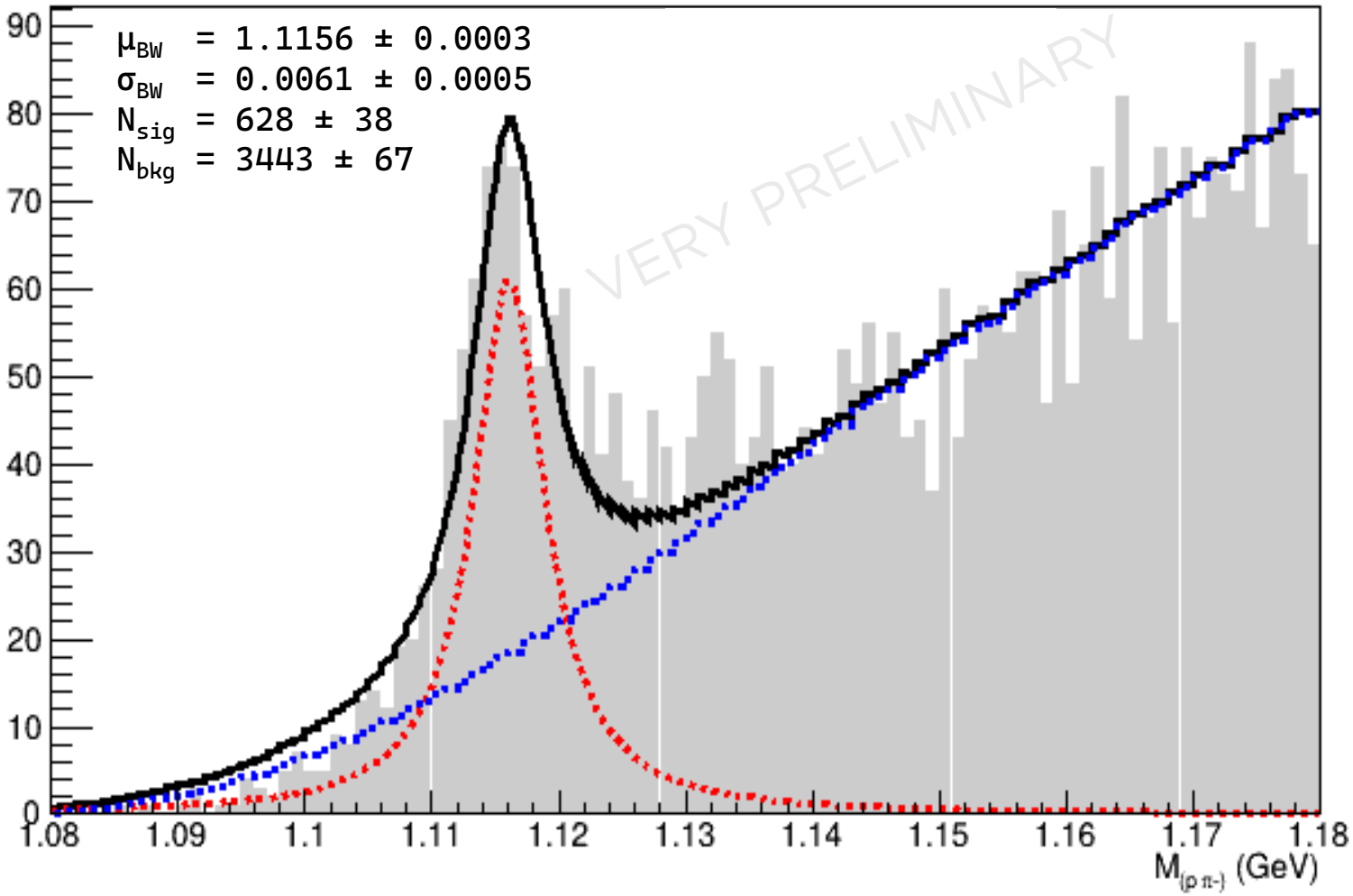






Event Mixing for Background Subtraction

- Event mixing technique proved to be effective in modeling the background in the Λ invariant mass for CLAS6 EG2 data
- Each correlated event 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 was used to assign probability distribution functions- Breit-Wigner for the signal and the mixed events sample for the background, to fit the invariant mass distribution and obtain the Λ yield



Summary and Outlook

- The CLAS12 RG-E dataset is calibrated and is awaiting permission to be cooked
- Analysis codes are under development to
  - improve particle identification, vertex cuts and corrections
  - polish the Lambda signal using secondary vertex cuts
  - improve the event mixing algorithm for the background subtraction underneath the Lambda peak
  - extract the Lambda preliminary results for multiplicity ratios and transverse momentum broadening

Thank You!

Backup Slides

Physics Observables

Multiplicity Ratio

$$R_A^h = \frac{N_{SIDIS}^{h\,(A)} / N_{DIS}^{e\,(A)}}{N_{SIDIS}^{h\,(LD_2)} / N_{DIS}^{e\,(LD_2)}}$$

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

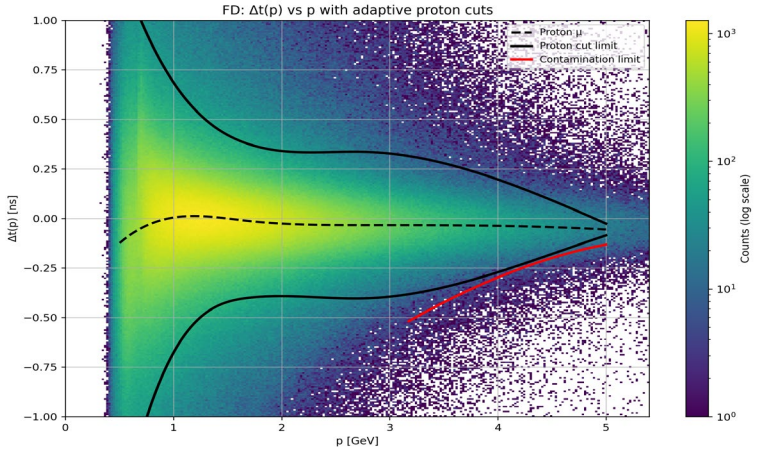
Transverse Momentum Broadening

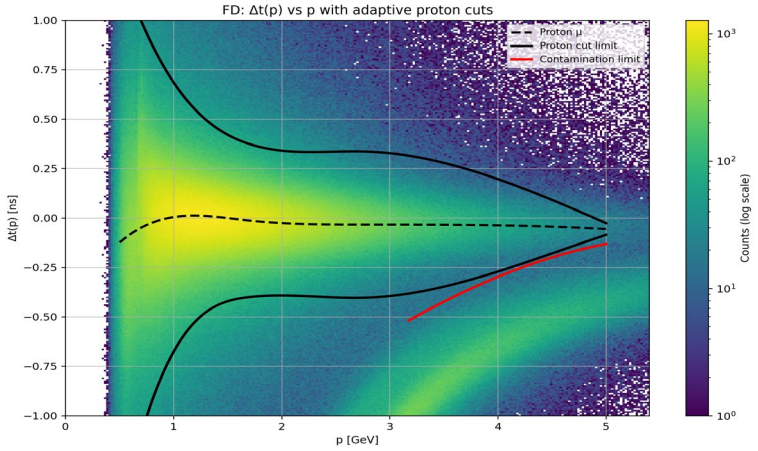
$$\Delta p_T^2 = \langle p_T^2 \rangle_A - \langle p_T^2 \rangle_{LD_2}$$

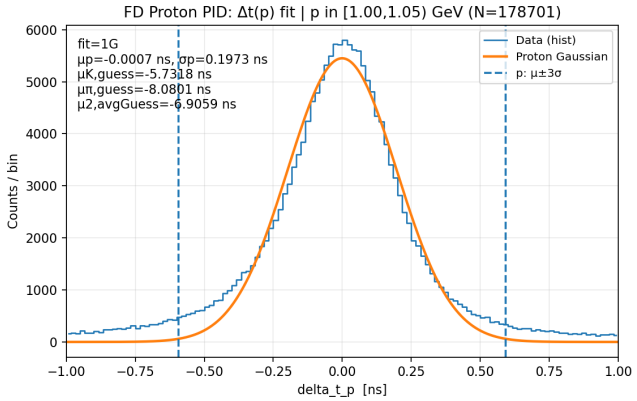
Δp_T^2 is due to the energy loss of the propagating struck quark(s) and/or the elastic and inelastic scattering of prehadrons and hadrons

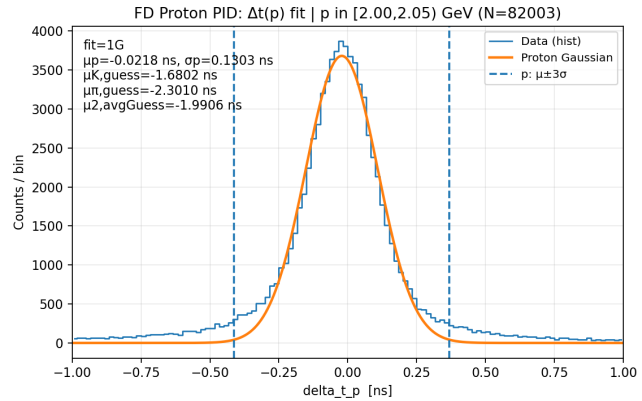
Proton Refinement – Contamination Study

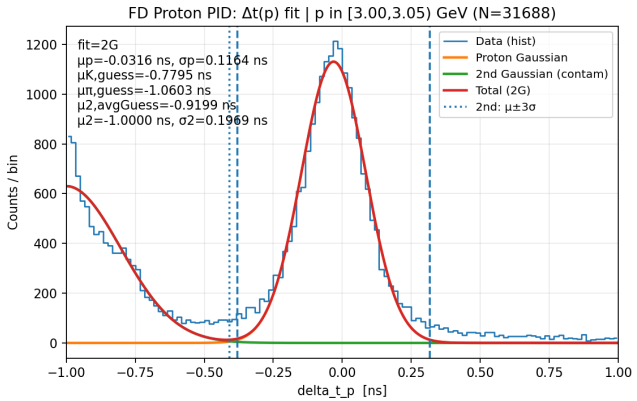
- Above a momentum of ~3 GeV, contamination from K^+ and later π^+ affect our selection of protons.
- Shown here are some of the Gaussian fits to the momentum slices used to construct the Δ T cut.

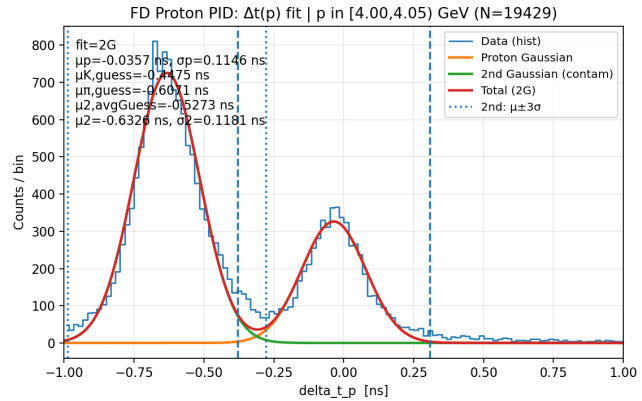


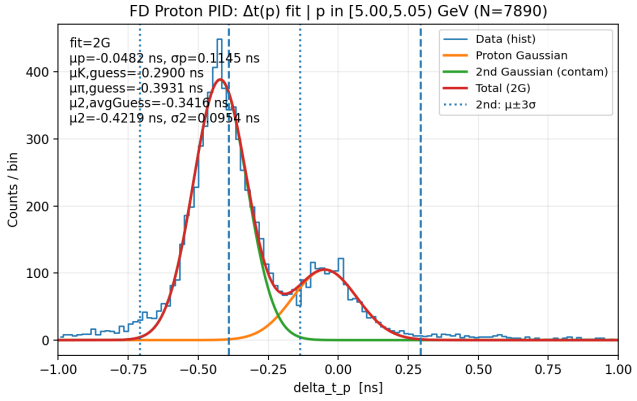


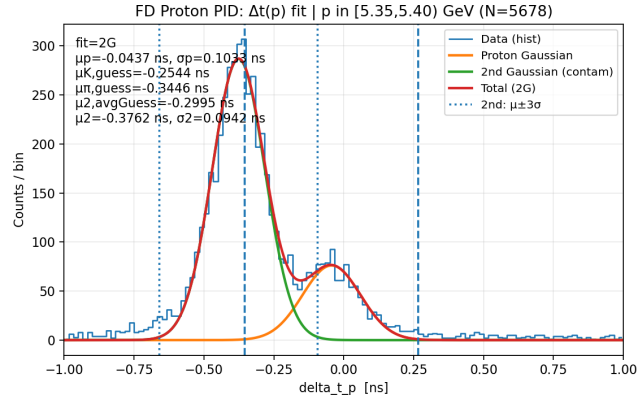




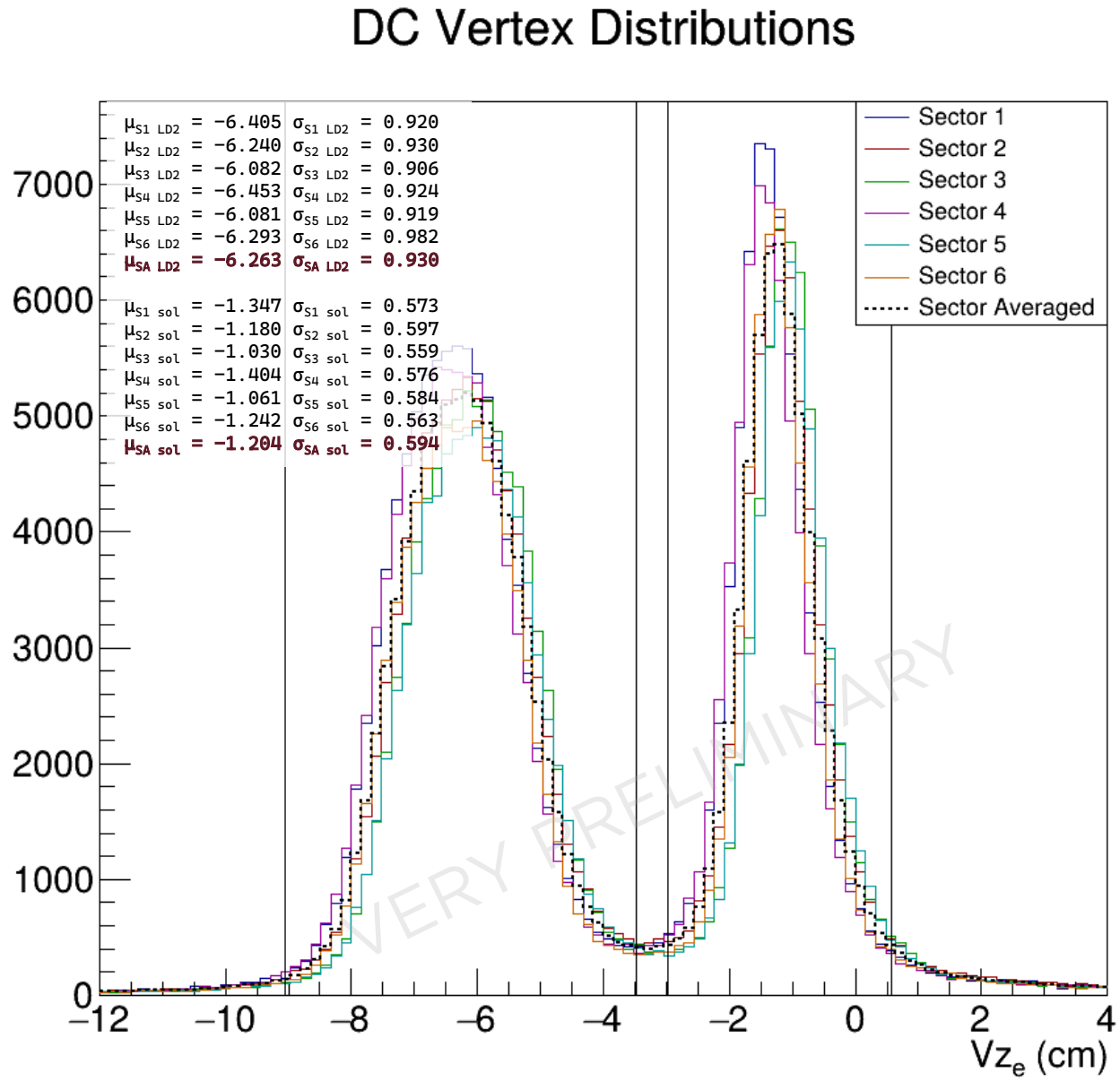


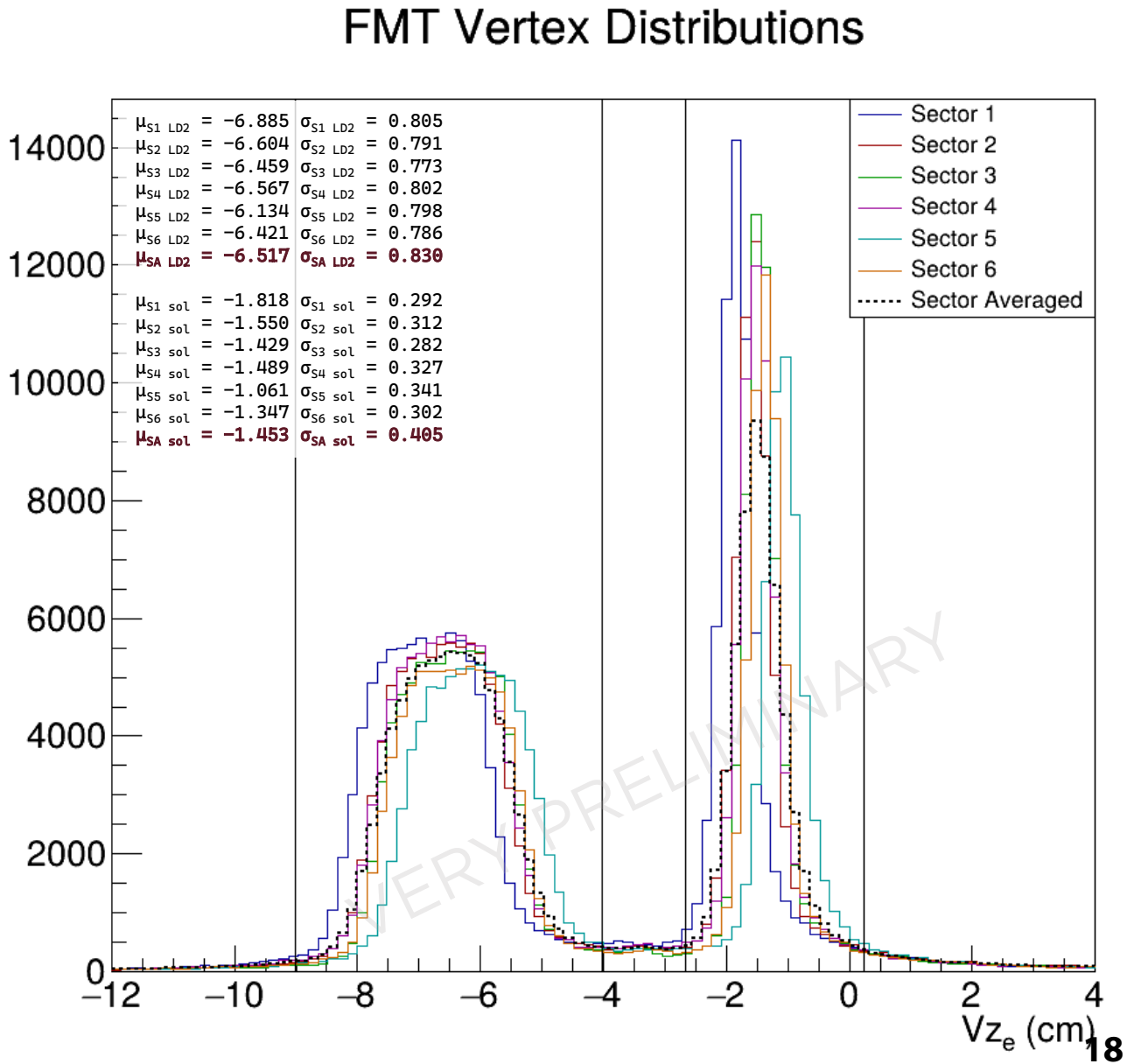






Vertex Cuts – Comparison of DC vs FMT





Λ Invariant Mass with all PID refinement cuts

- Applying the complete set of PID refinement cuts results in a significant reduction in available statistics for the invariant mass distributions.
- Further optimization of the PID refinement strategy is therefore needed.
- The results shown in the main talk include only the proton PID refinement.
- The invariant mass distributions shown here include all PID cuts described in this work.