Probing Hadronization Dynamics via Λ SIDIS Production off Nuclei

11th Workshop of the APS Topical Group on Hadronic Physics

March 14th, 2025

Uditha Weerasinghe

Mississippi State University

On behalf of the CLAS Collaboration

Outline

Semi-Inclusive Deep Inelastic Scattering Production

- SIDIS Kinematics and Cuts

Physics Observables

Results from Previous Experiments

- Hadronization: HERMES Results
- Lambda Production: CLAS6 Results

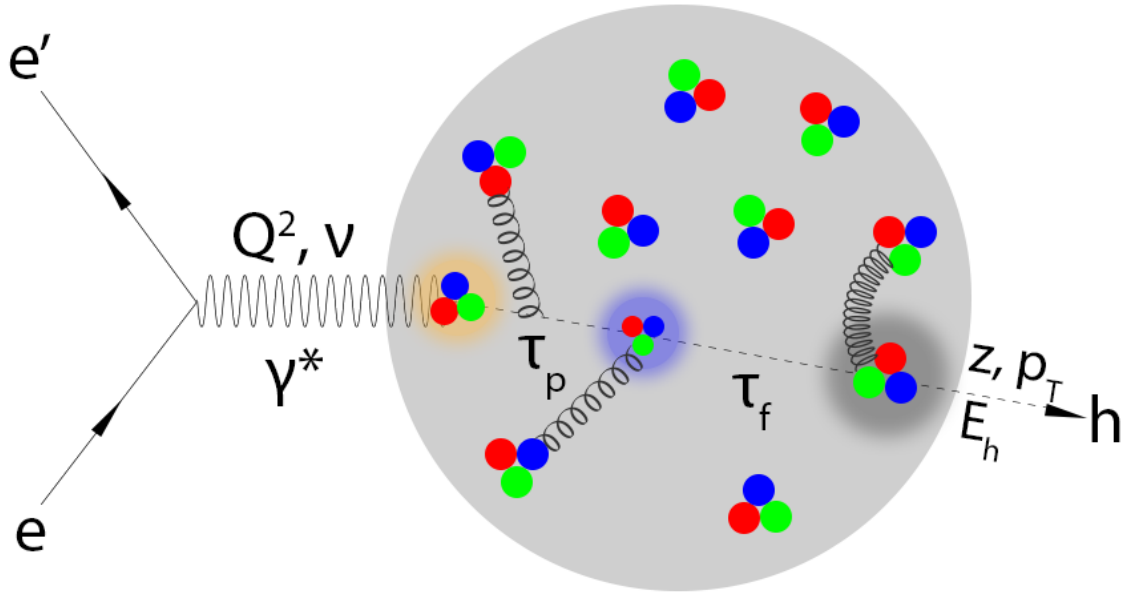
New CLAS12 Run Group E Experiments

- Online RG-E Multiplicity Ratios
- Particle Identification
- Vertex Distributions
- Lambda Production Channel
- Background Subtraction

Summary and Outlook

SIDIS Production

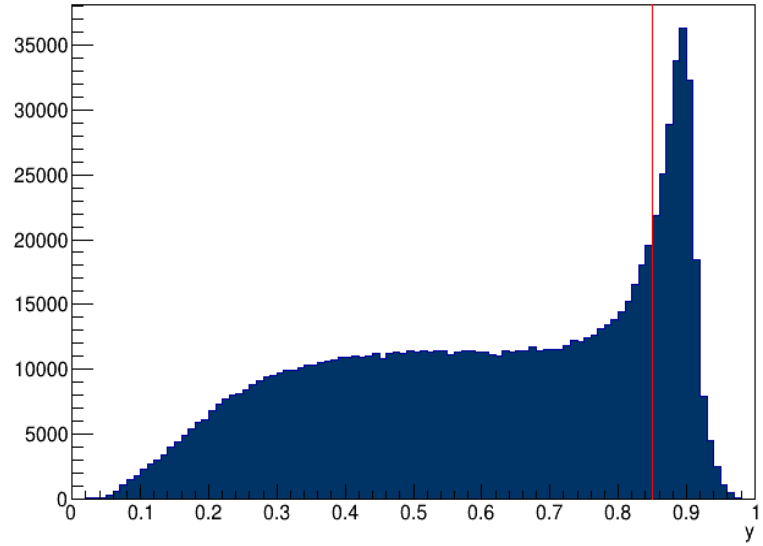
- Studying hadronization processes in SIDIS production helps improve our understanding of the strong interactions dynamics in terms of quarks and gluons, the building blocks of atomic nuclei
- Hadronization process is characterized by two time-distance scales
  - **Production time (τ_p):** Struck quark propagates as a colored object during the neutralization stage
  - **Formation time (τ_f):** Time needed for the color-neutral prehadron to evolve into a fully dressed hadron

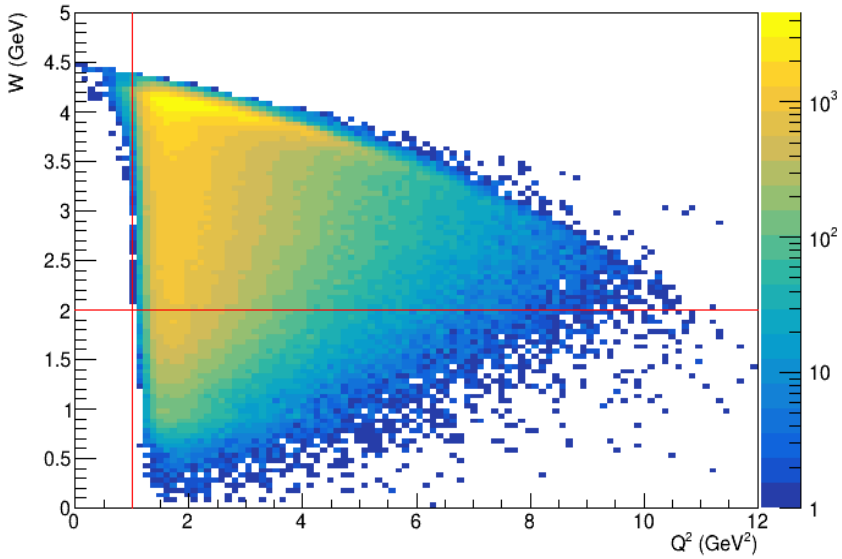


$$e + p \rightarrow e' + h + X$$

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 initial energy of a struck quark
  - 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
  - $W = \sqrt{M_n^2 + 2\nu M_n - Q^2}$: total mass of the hadronic final state, where $\mathrm{M_n}$ is the nucleon mass
    - $\mathrm{W} > 2\ \mathrm{GeV}$: 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 with regard to the virtual photon direction





Physics Observables

Multiplicity Ratio

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

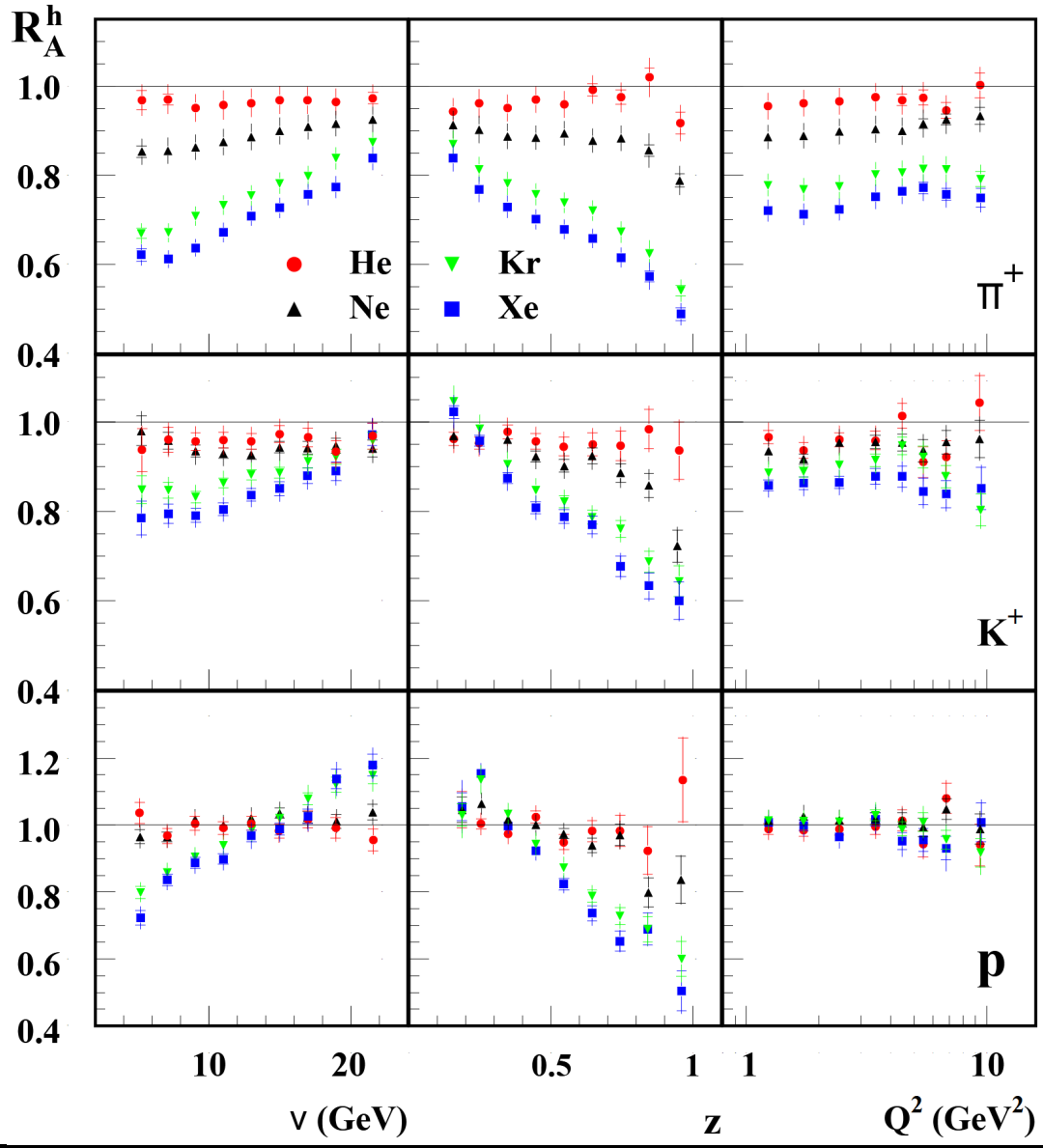
R_A describes the attenuation of formed hadrons in the medium

Transverse Momentum Broadening

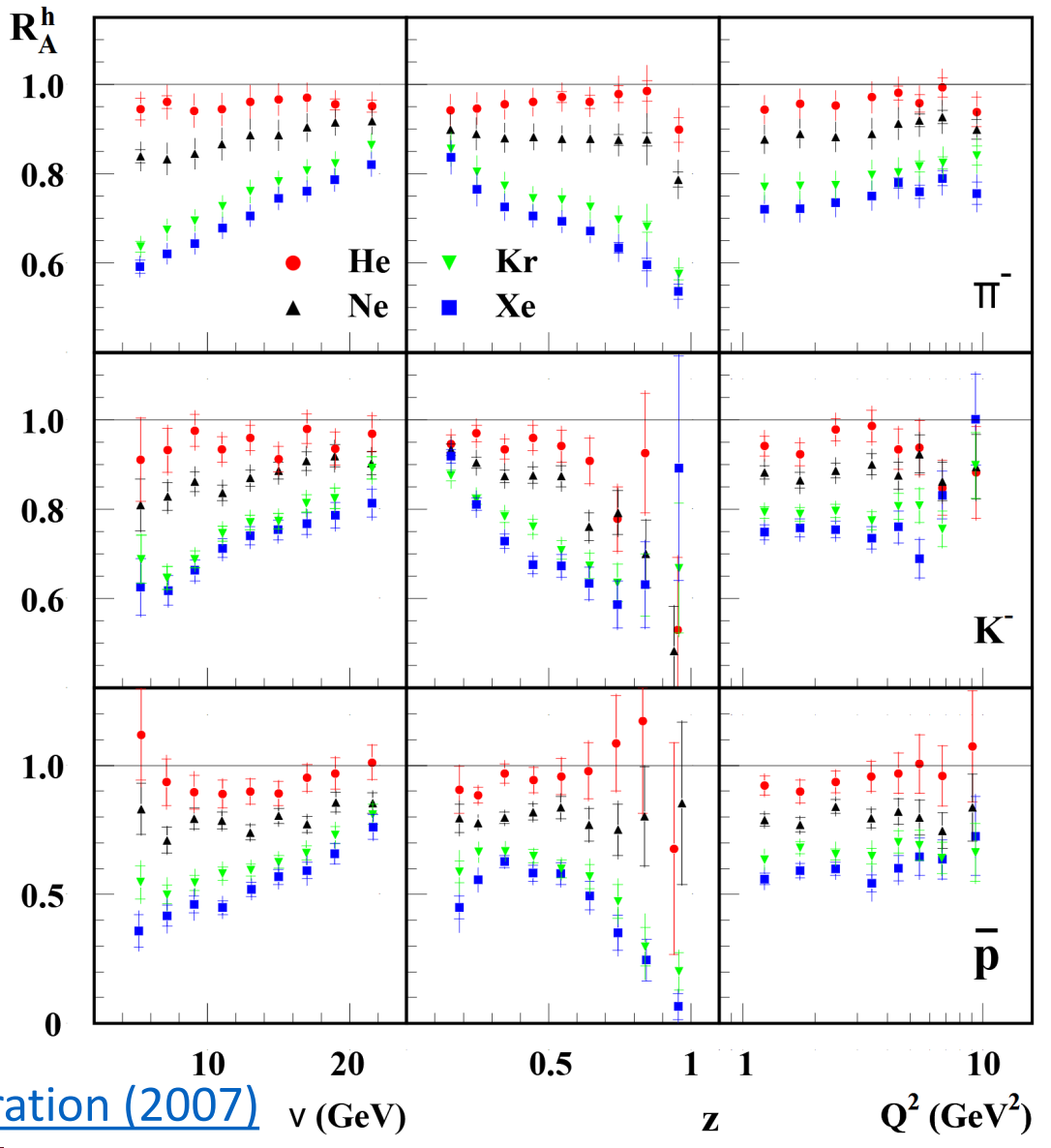
$$\Delta p_T^2 = \langle p_T^2 \rangle_A - \langle p_T^2 \rangle_{LD_2}$$

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

Hadronization: HERMES Results

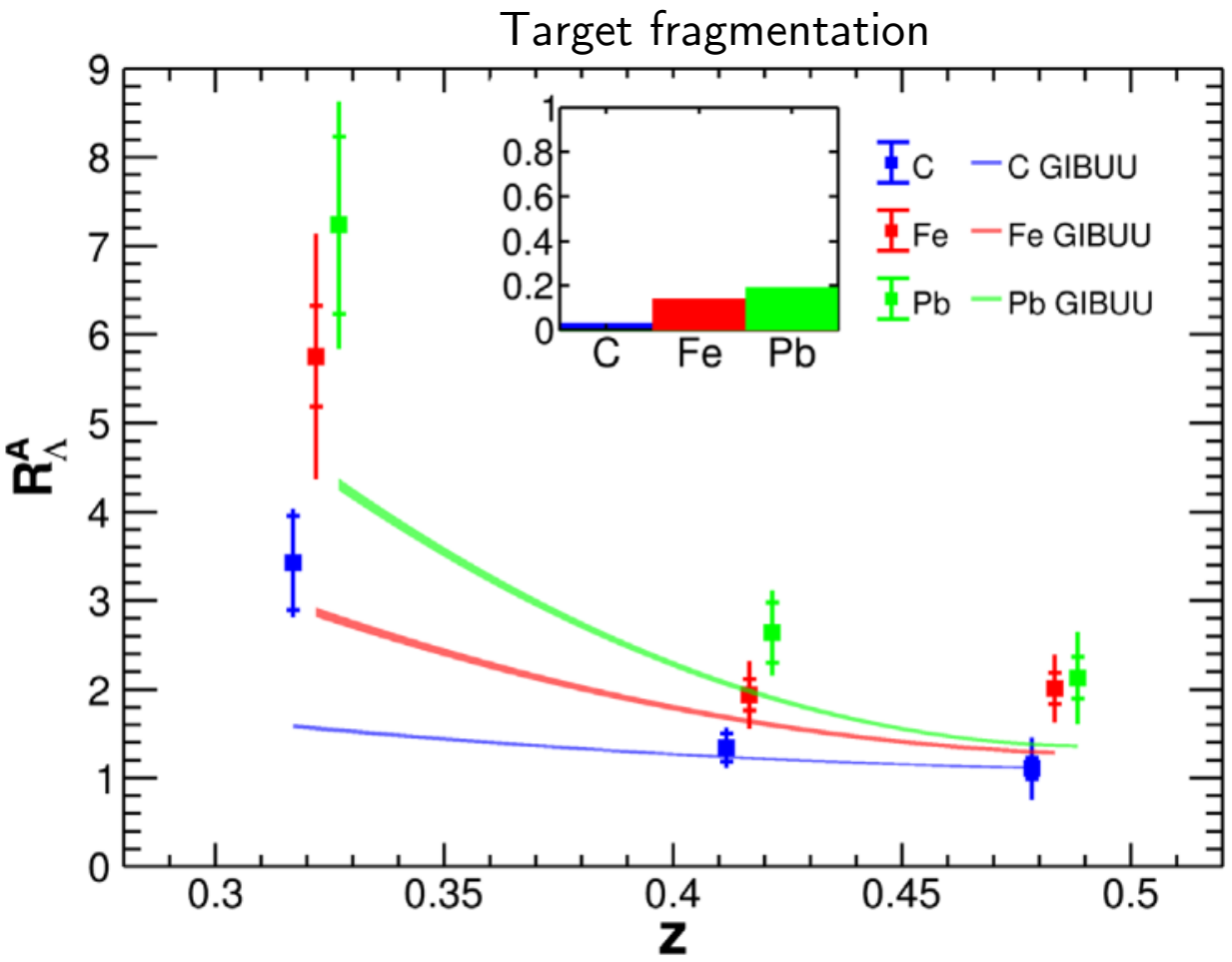


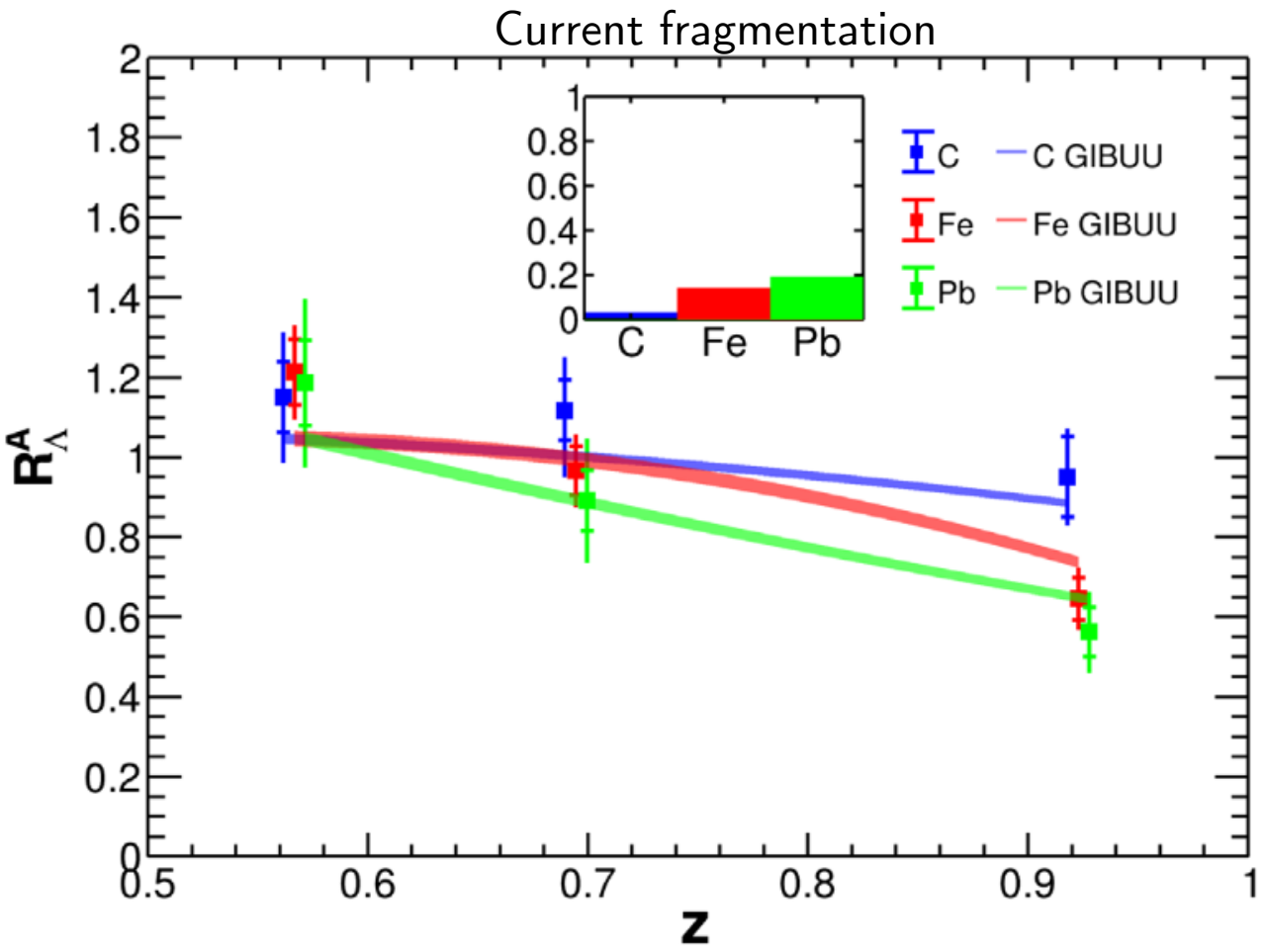
E_{e+} = 27.7 GeV



HERMES Collaboration (2007)

Lambda Production: CLAS6 Results

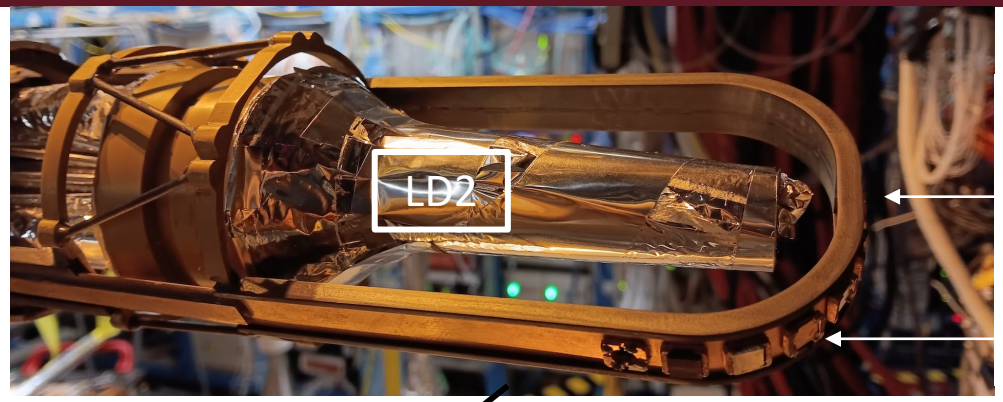




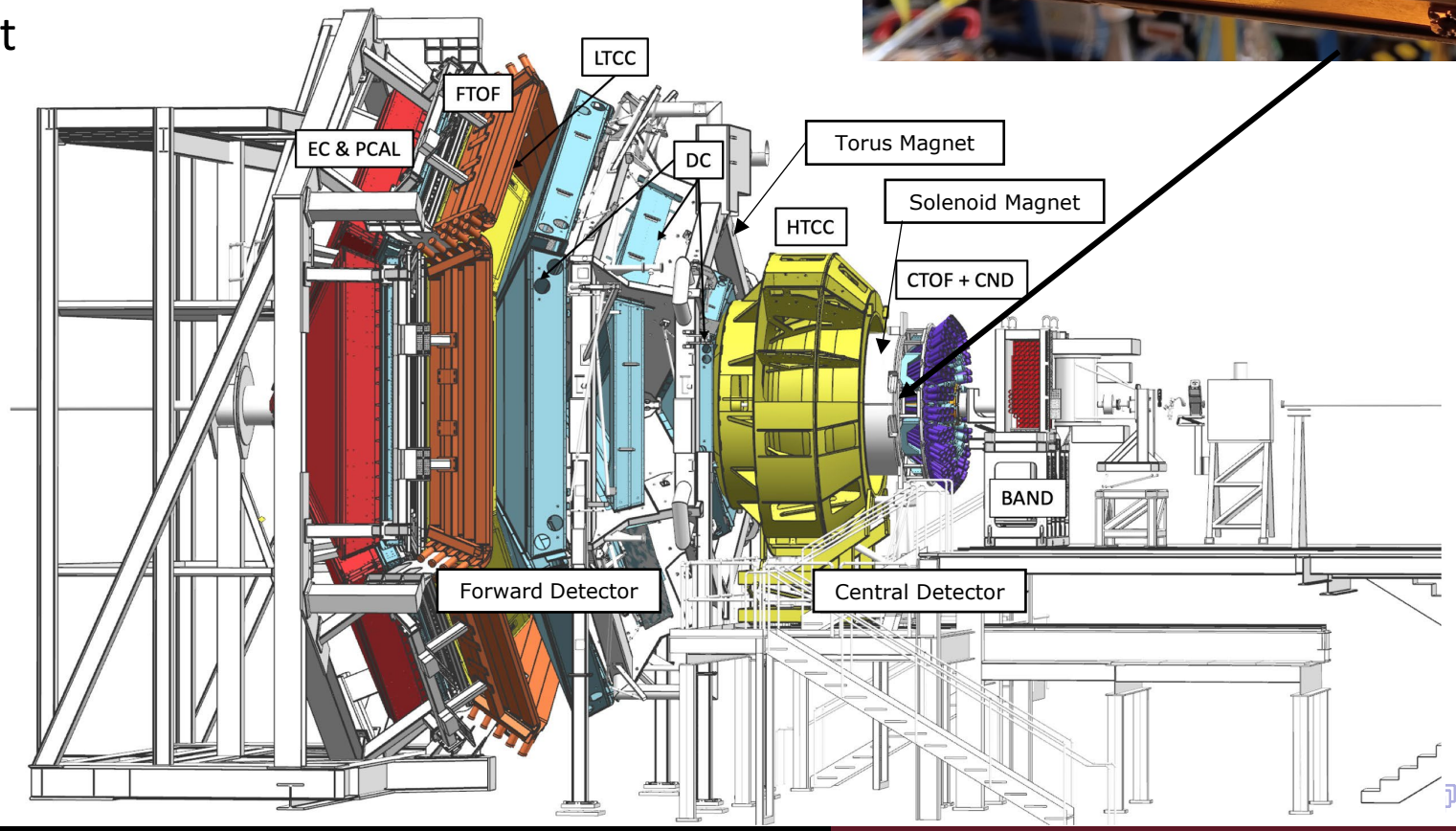
T. Chetry, L. El Fassi, CLAS Collaboration (2023)

New CLAS12 Run Group E Experiments

- 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 and solid foil targets was placed at the center of the solenoid magnet

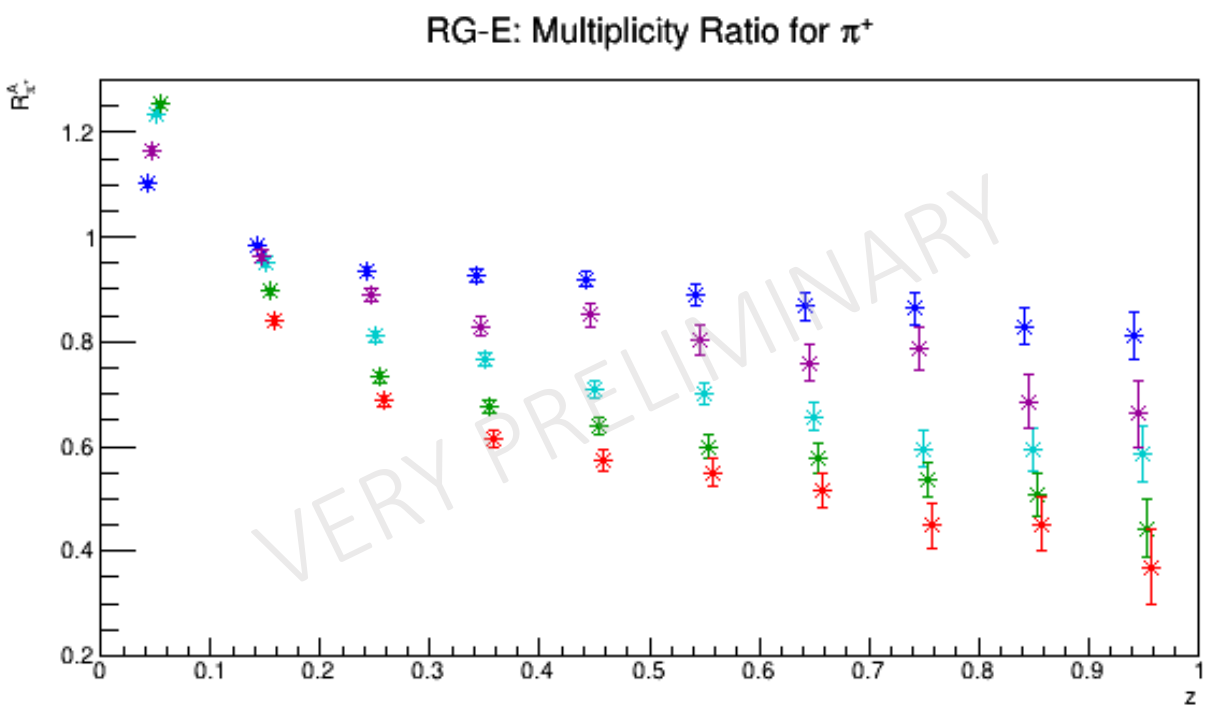


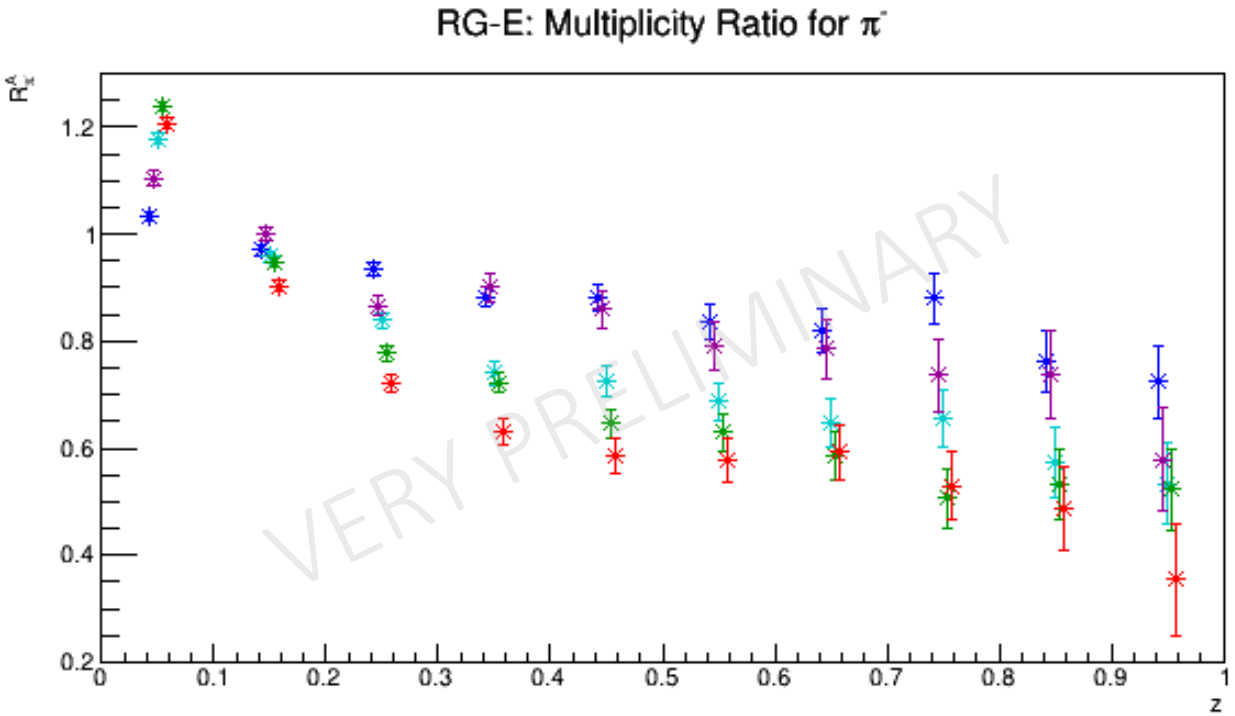
Solid foils:
- C
- Al
- Cu
- Sn
- Pb

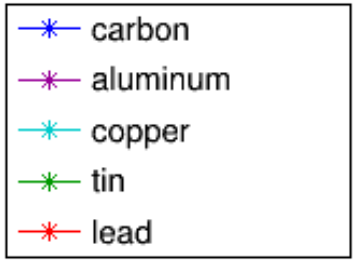


Electron Beam

Online RG-E Multiplicity Ratios



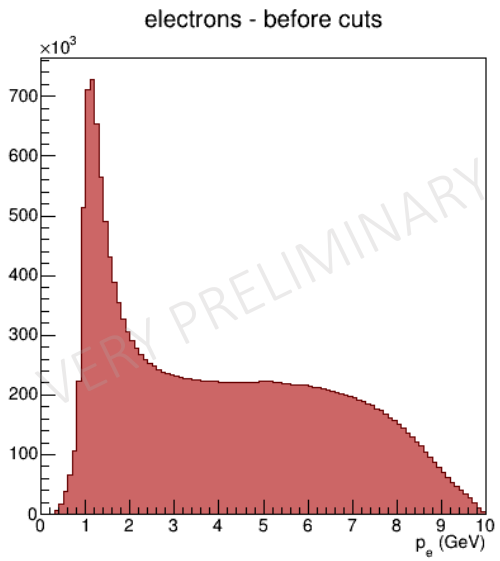


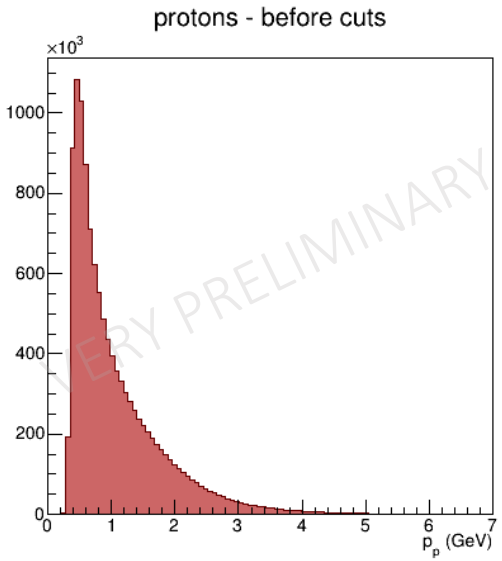


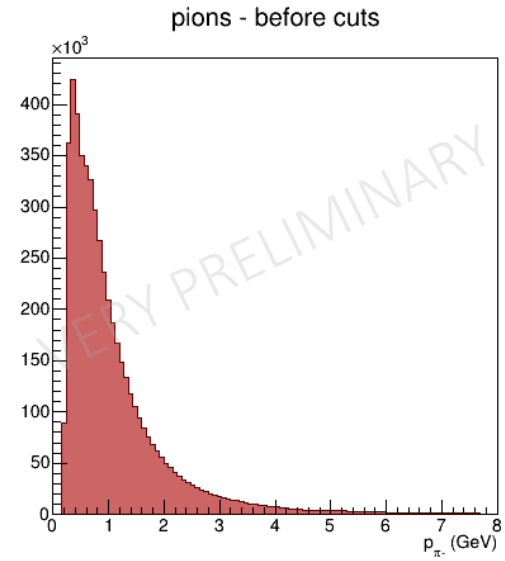
consistent with previously published CLAS6 charged pion multiplicity ratio results

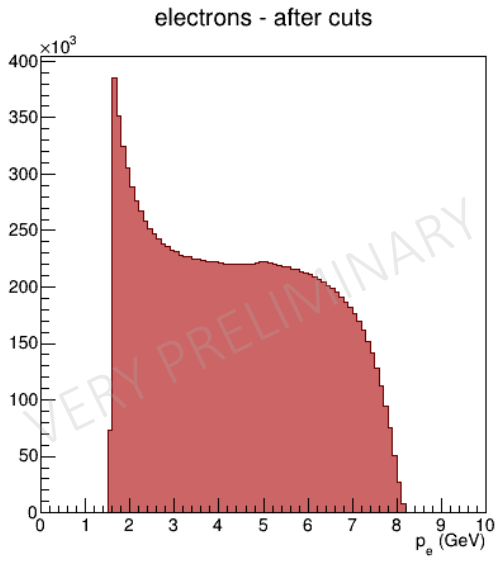
Particle Identification

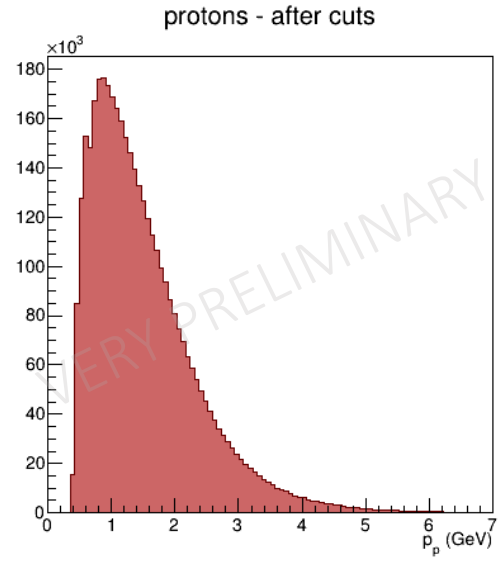
- Particle ID:
  - Electron: +11
  - (+/-) pions: (+/-) 211
  - Proton: +2212
- Detectors cuts:
  - Electron should be in the forward region
  - Pions and protons are either in the forward or central region
- Fit quality cut:
  - 3 σ cuts on the χ^2 of reconstructed tracks

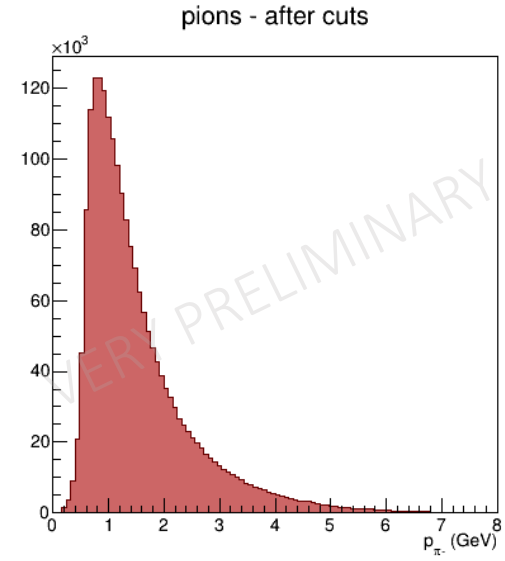






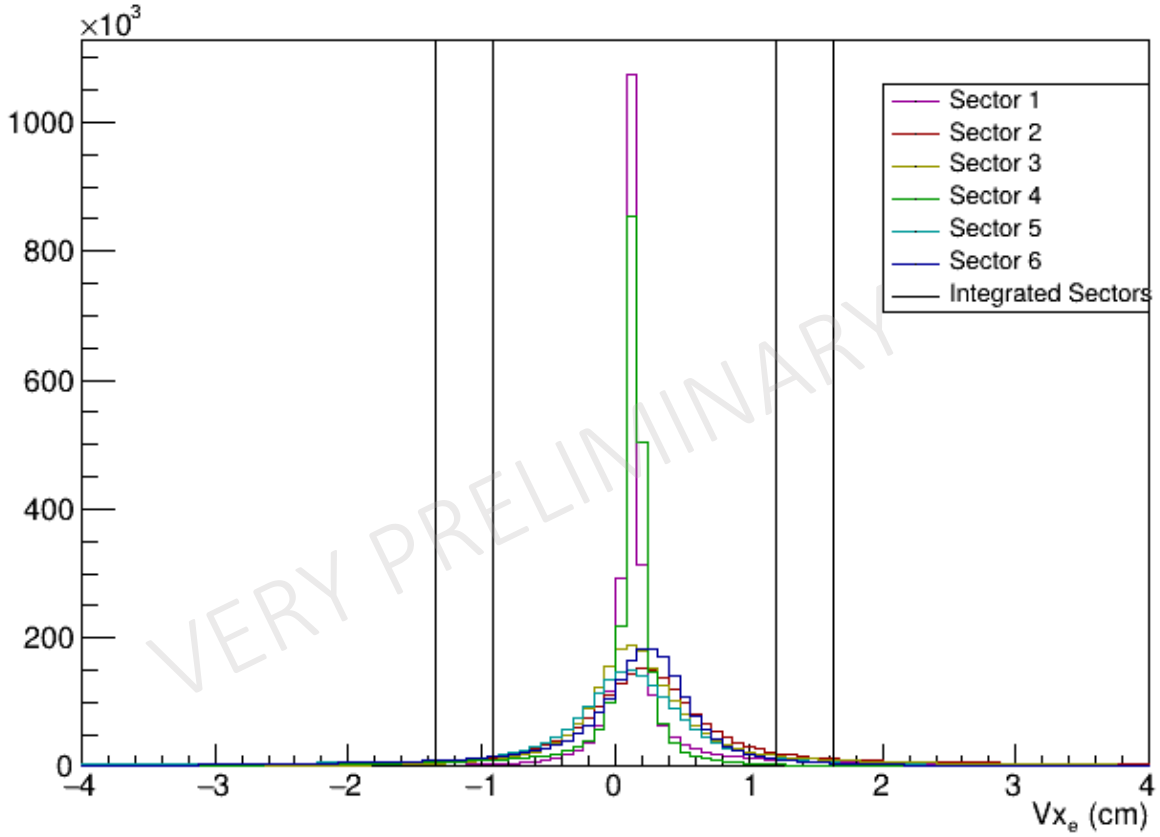


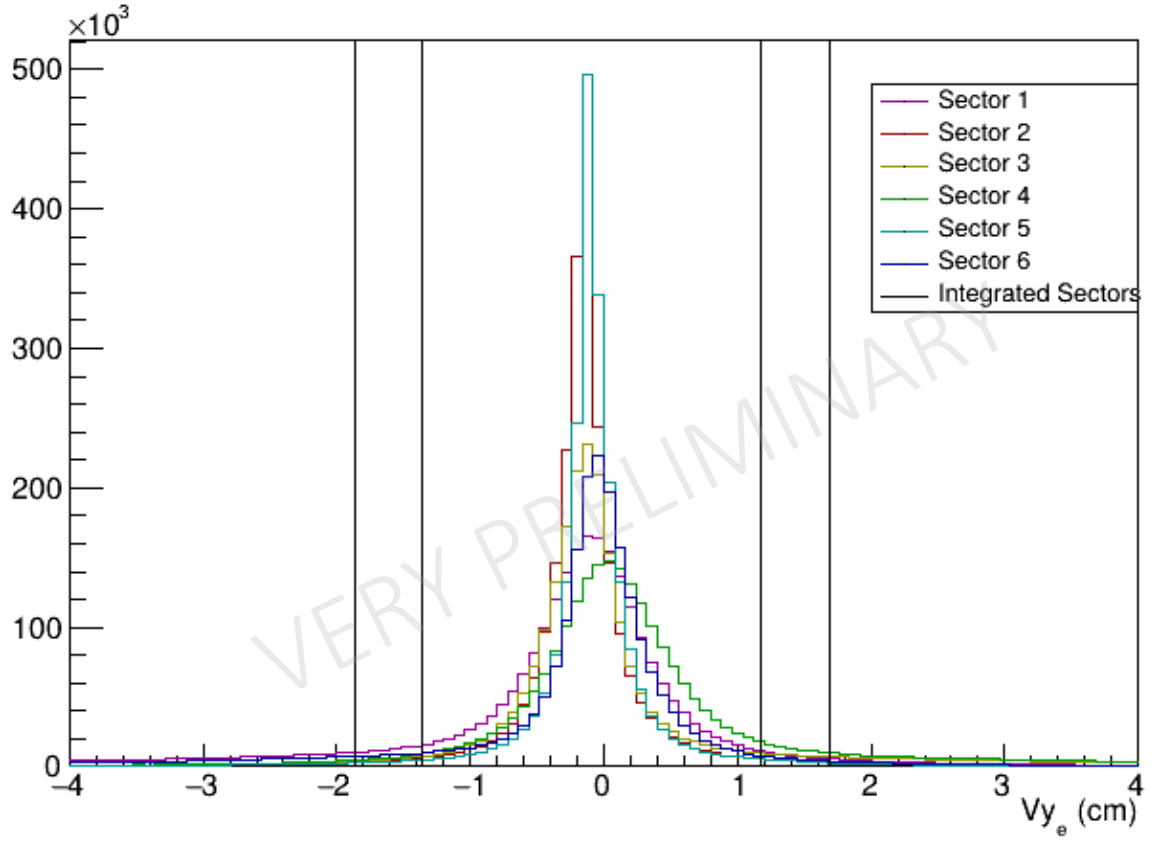




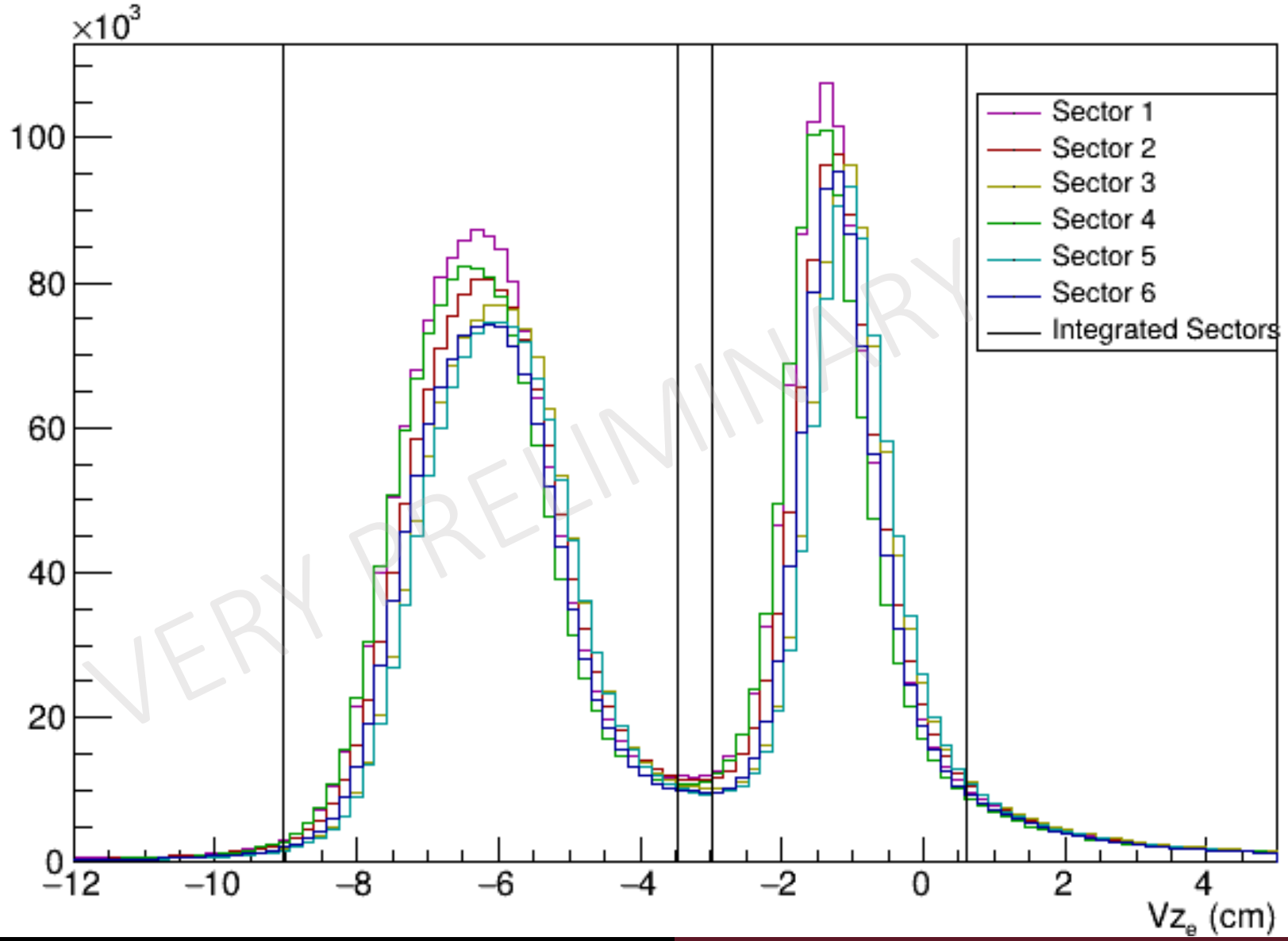
Electron Transverse Vertex Distributions

- Sector-independent vertex cuts are used to improve RG-E target separation after completing the alignment

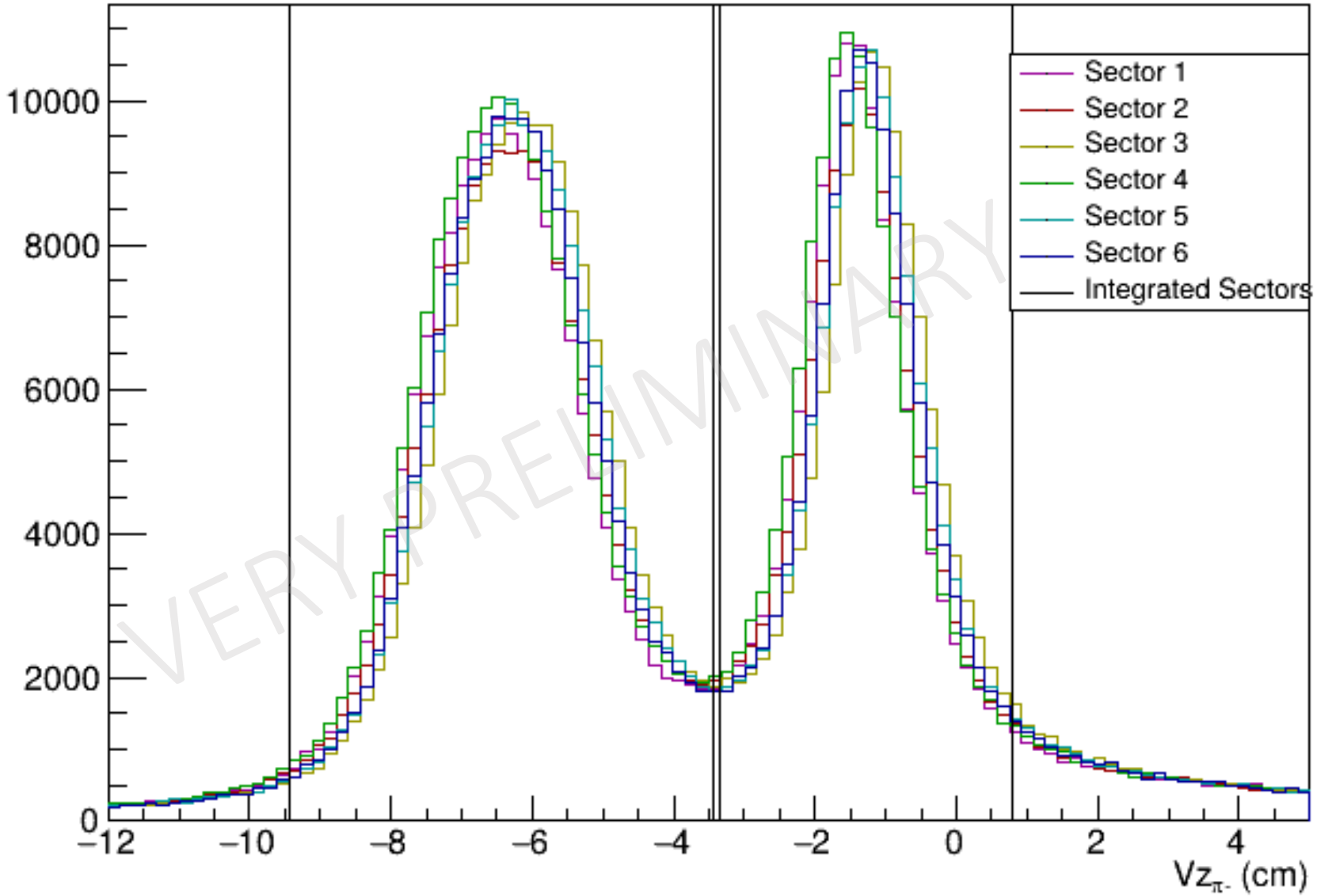




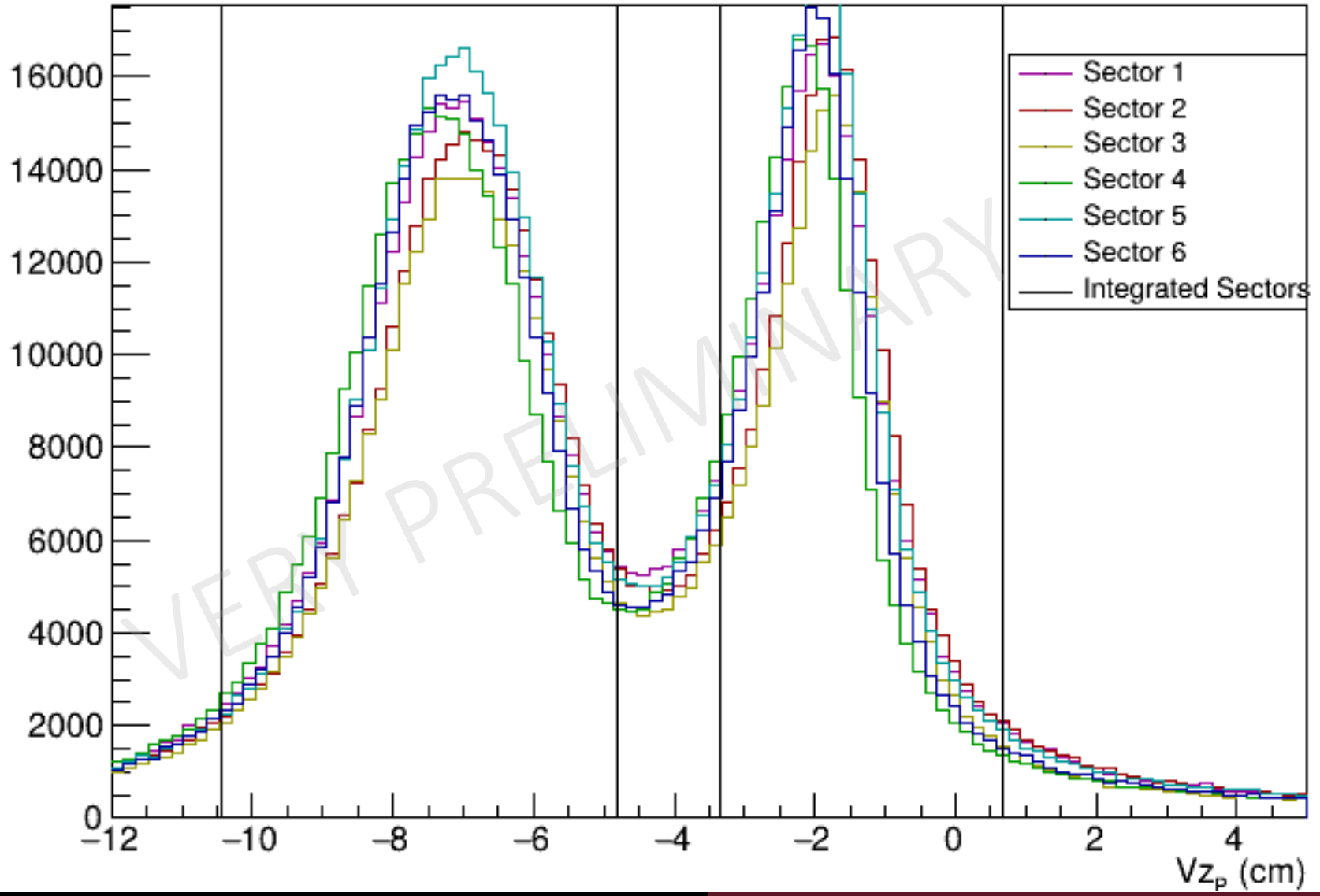
Electron z-Vertex Distribution



Pion z-Vertex Distribution

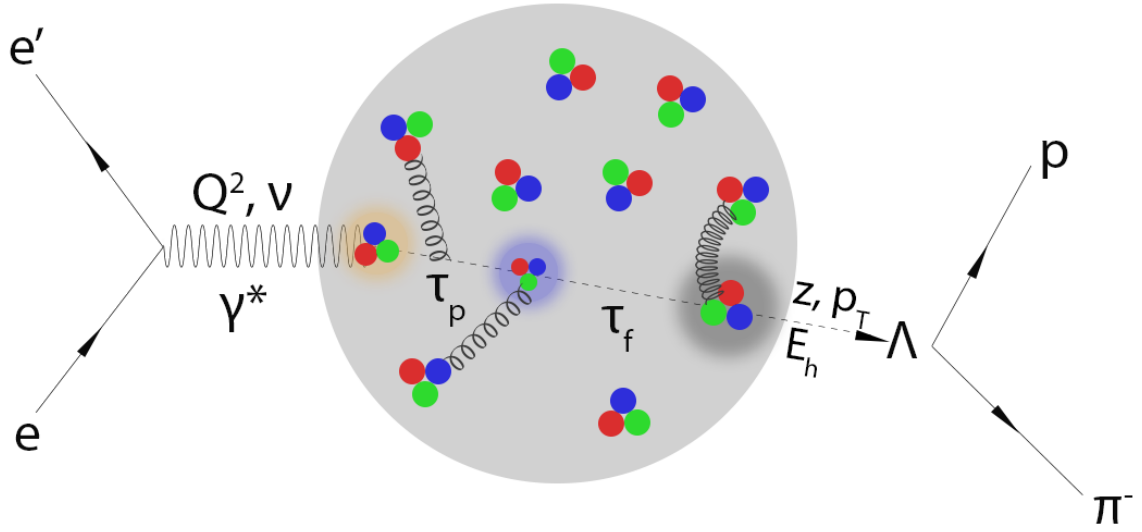


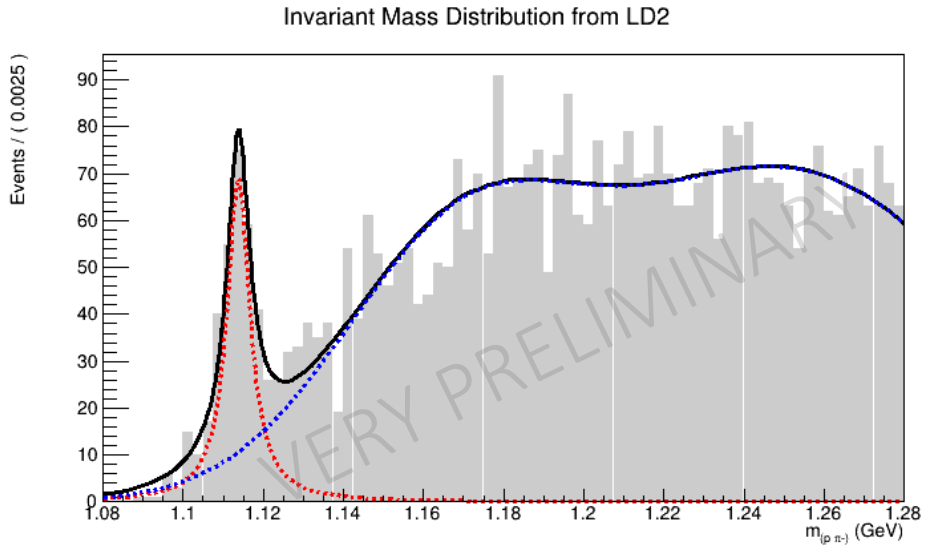
Proton z-Vertex Distribution

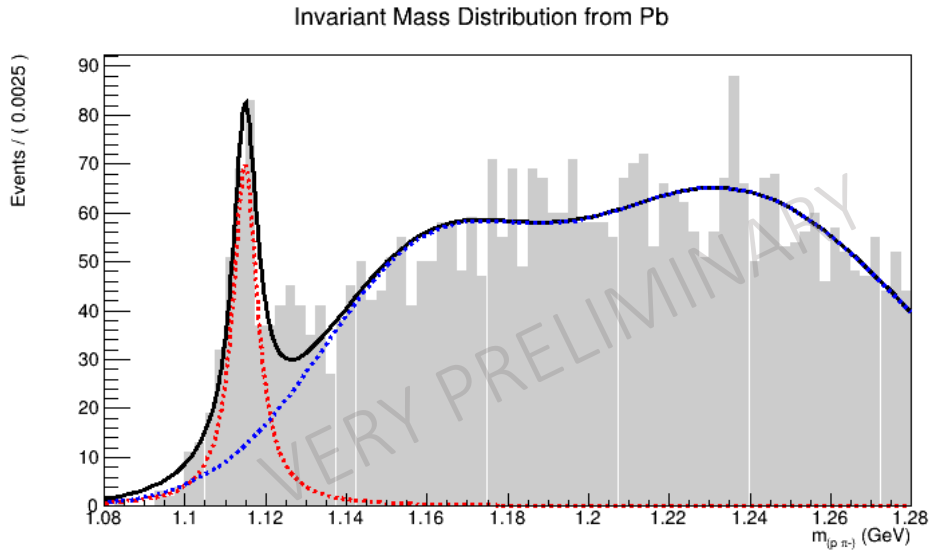


Lambda Production Channel

- Our channel of interest is Lambda SIDIS production off nuclei
- Lambda 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 Lambda signal
  - Distance between the electron and secondary Lambda vertex
  - Opening angle between protons and π-s
  - Studying cut on cos(α^*)

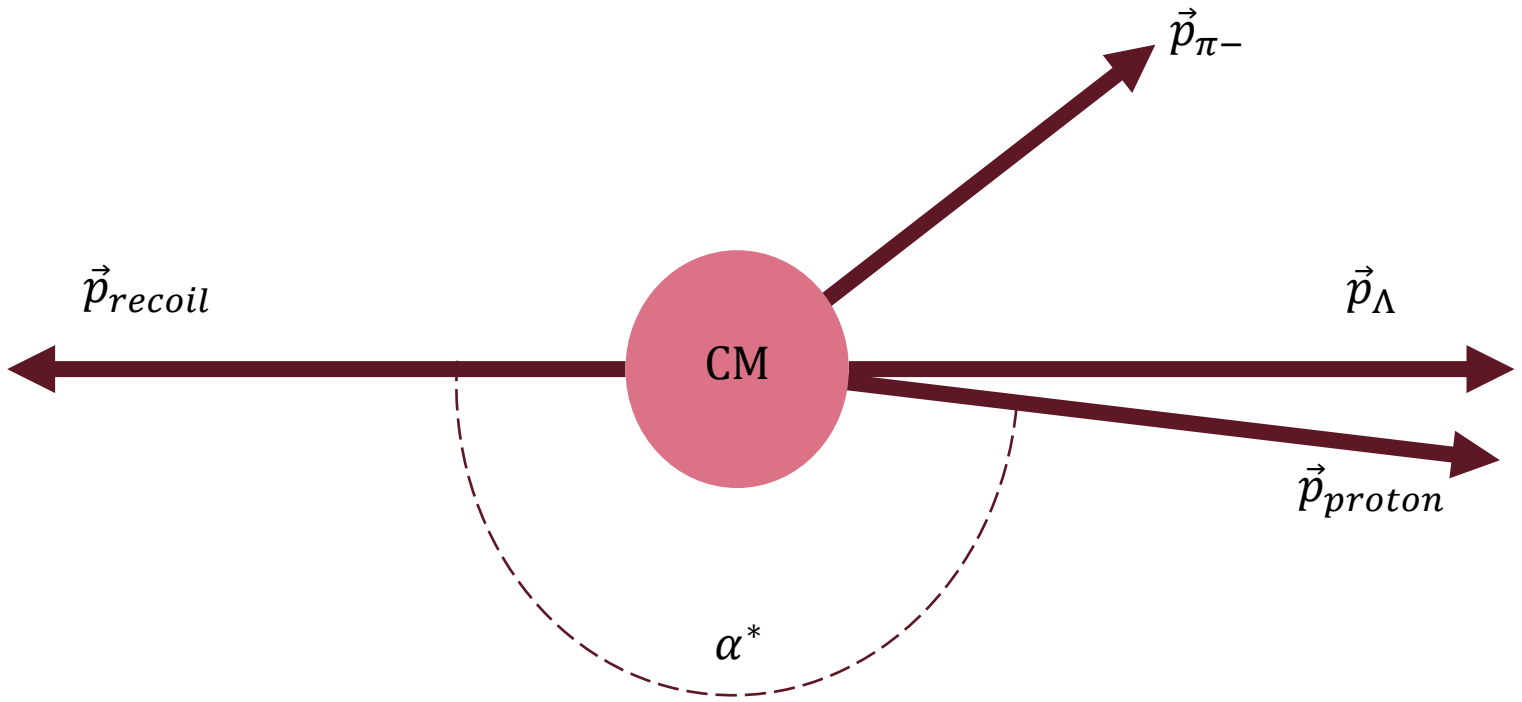


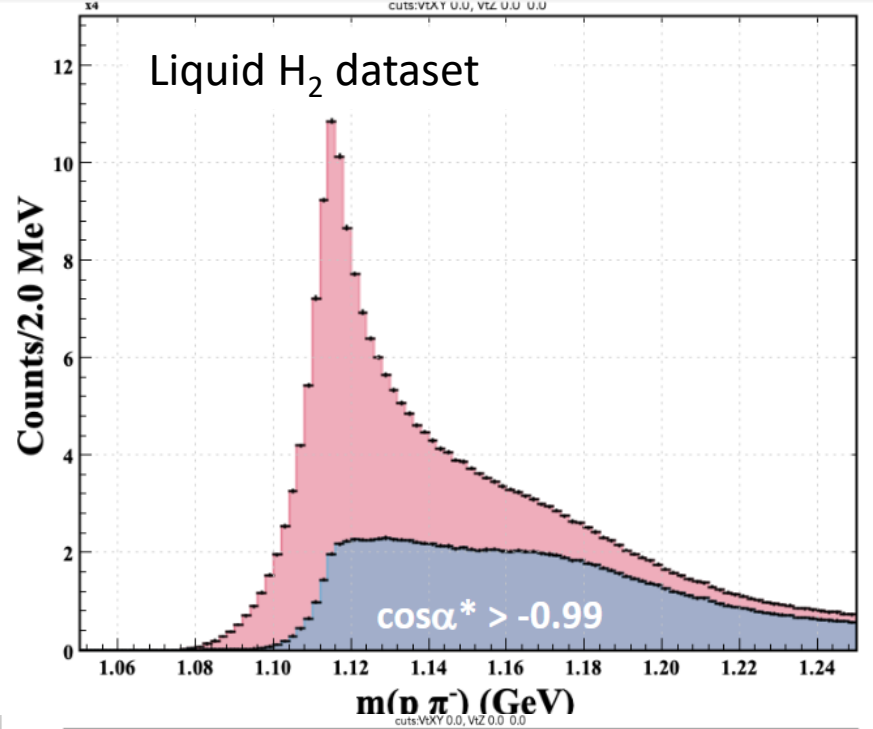


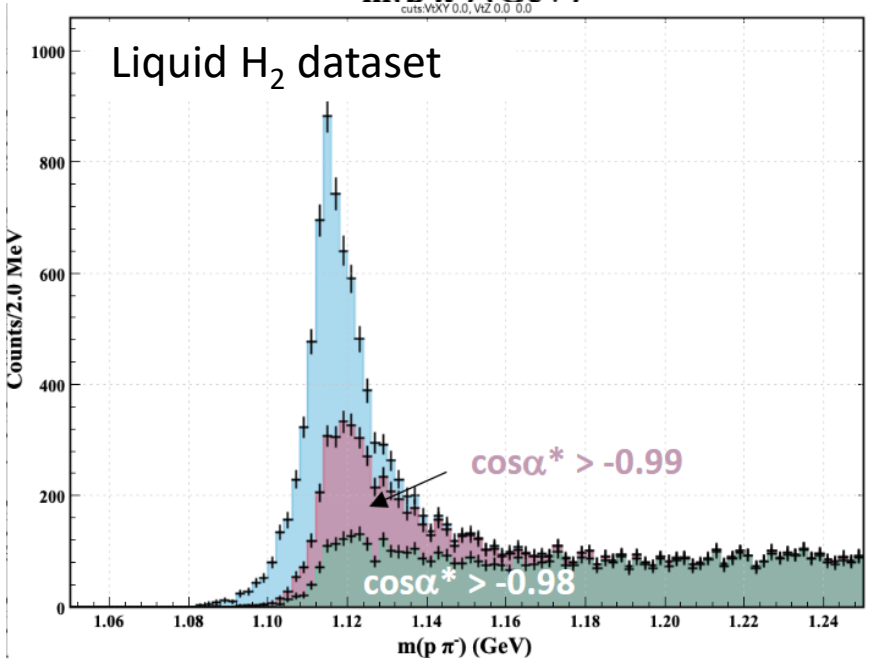


Ongoing cos(α^*) Cut Studies

- It is expected that the combinatorial background could be further fine-tuned by applying a cut on cos(α^*)

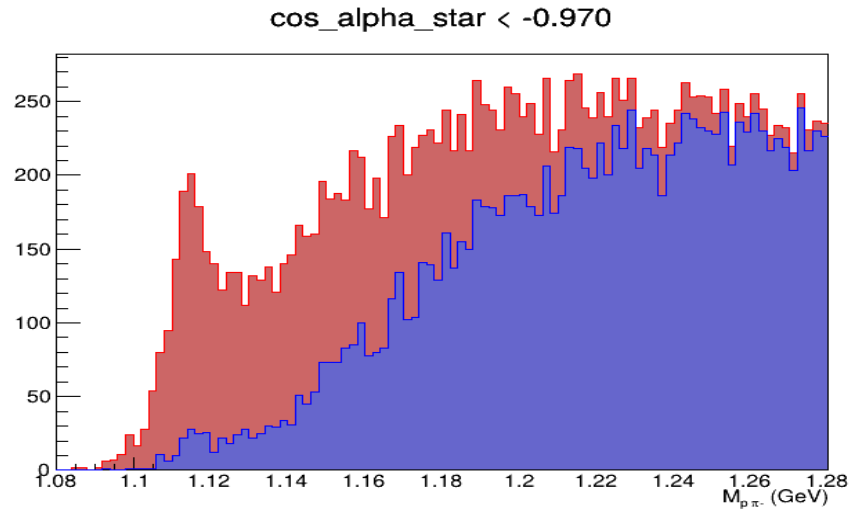


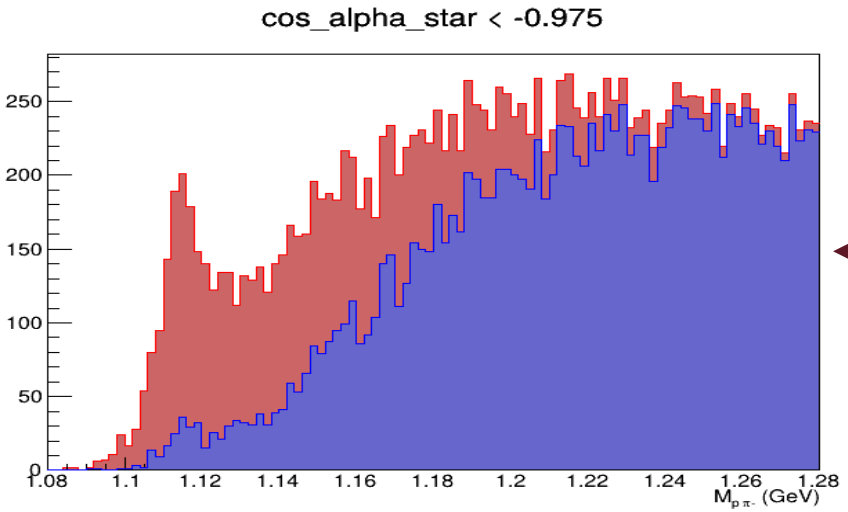


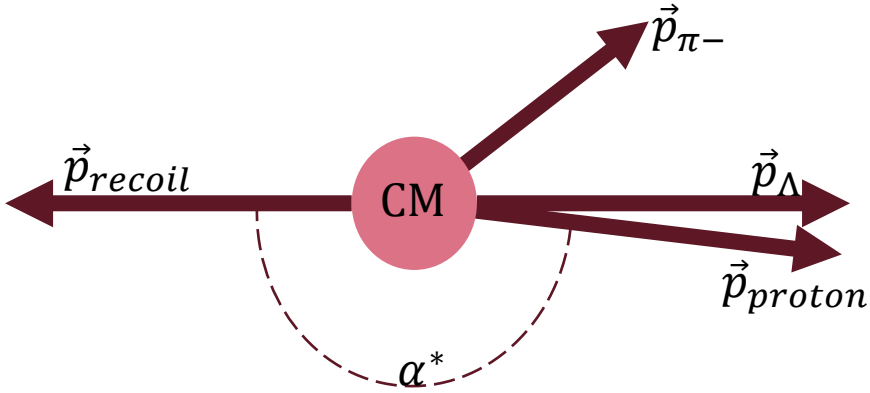


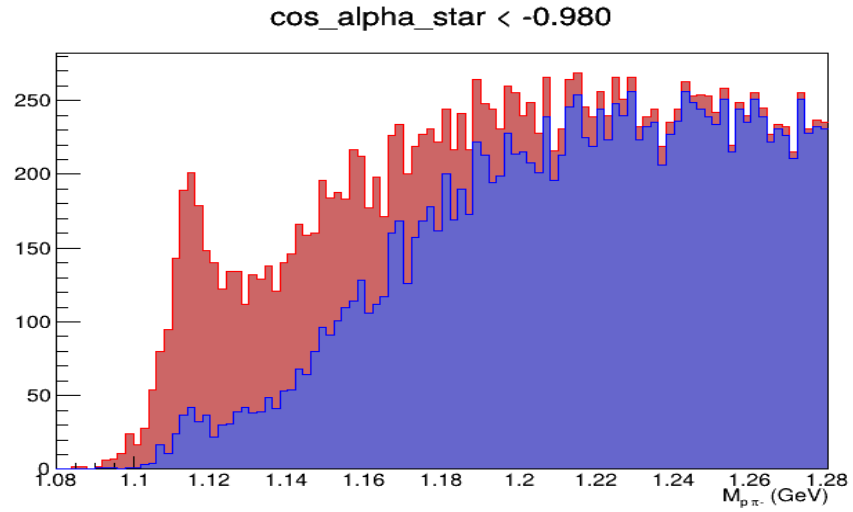
Ongoing cos(α^*) Cut Studies

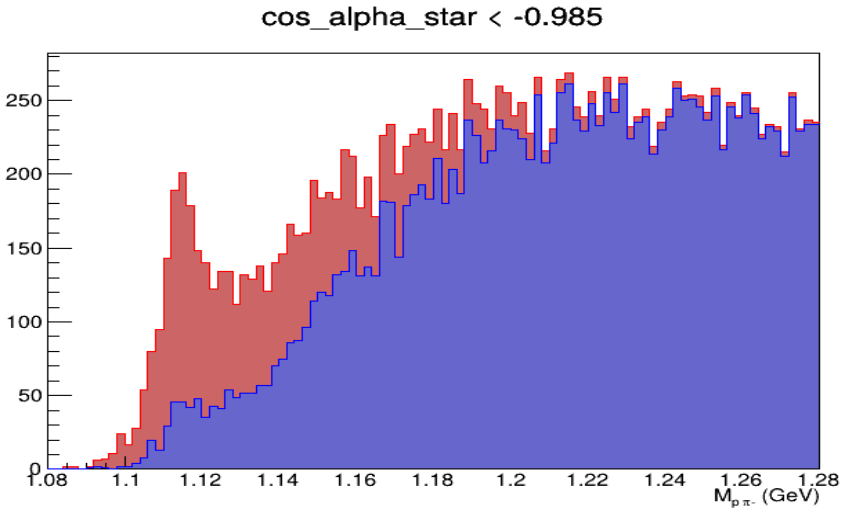
- It is expected that the combinatorial background could be further fine-tuned by applying a cut on cos(α^*)

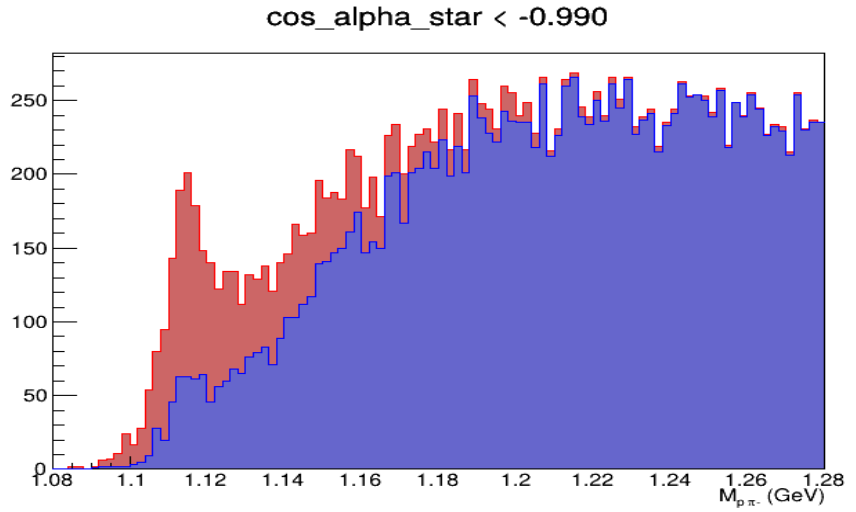




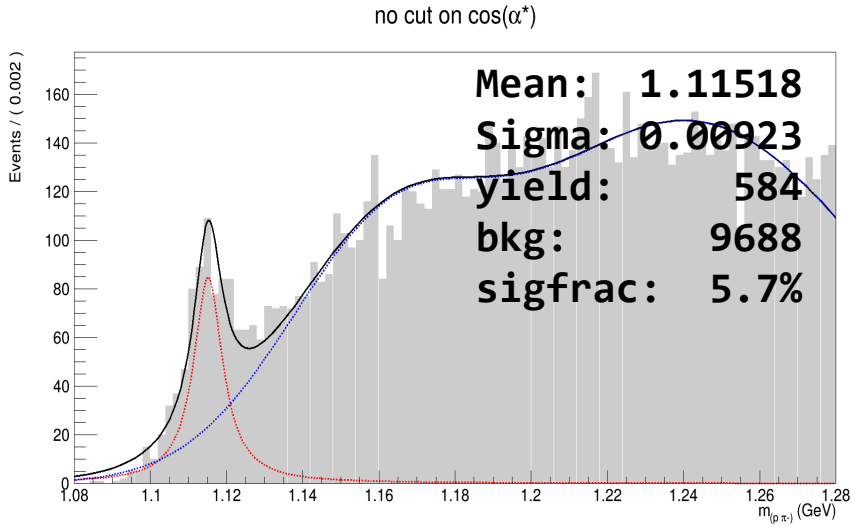


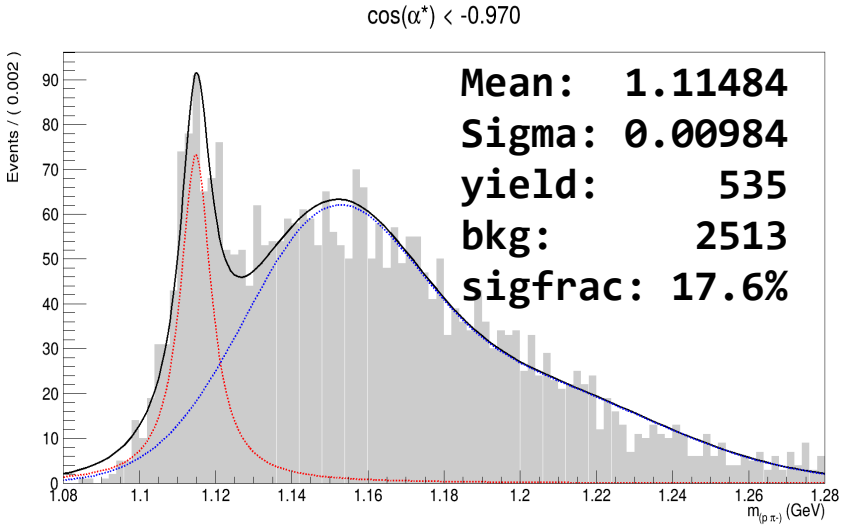


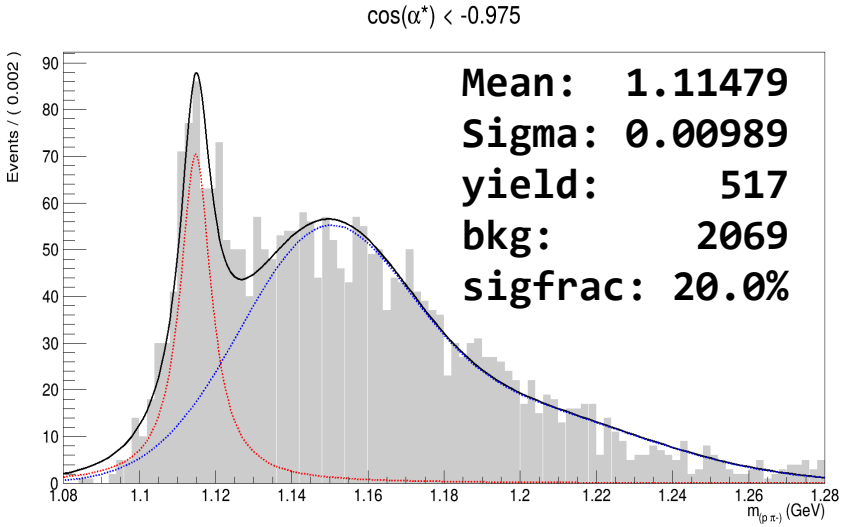


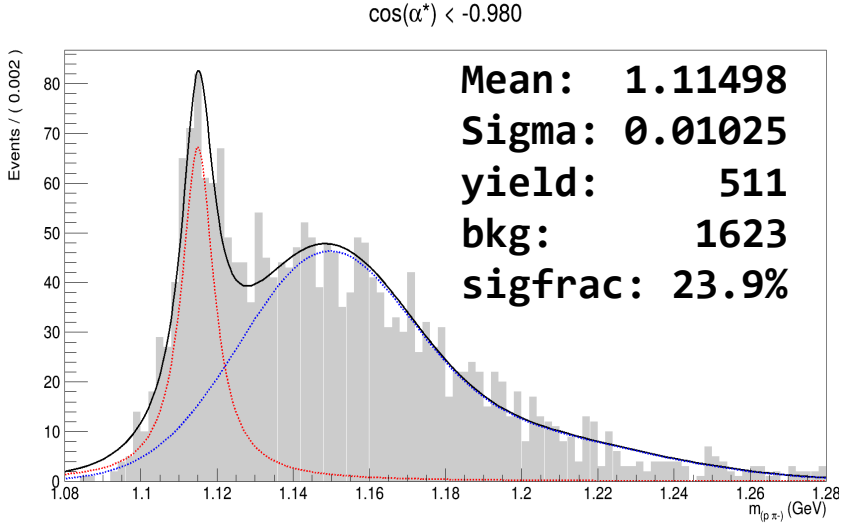


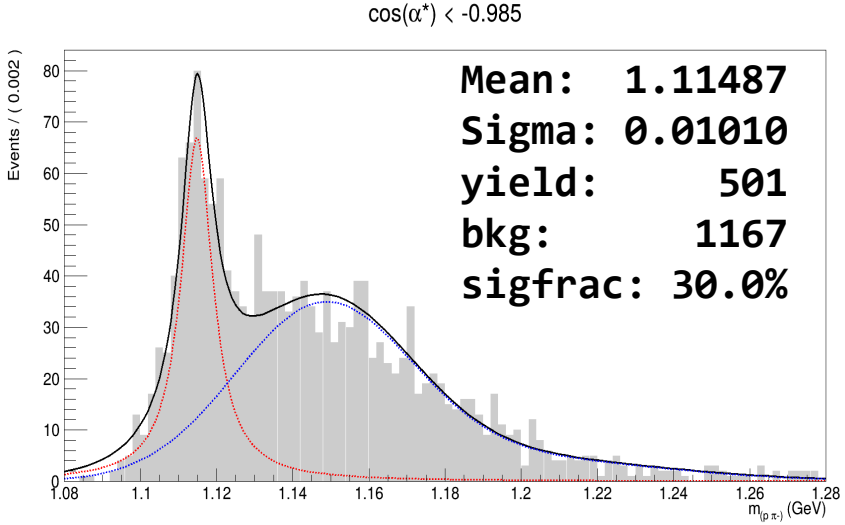
Ongoing cos(α^*) Cut Studies

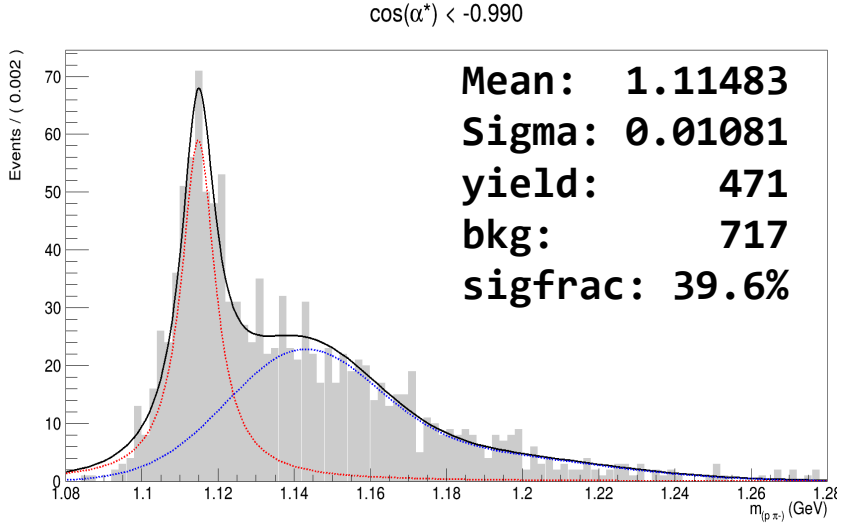






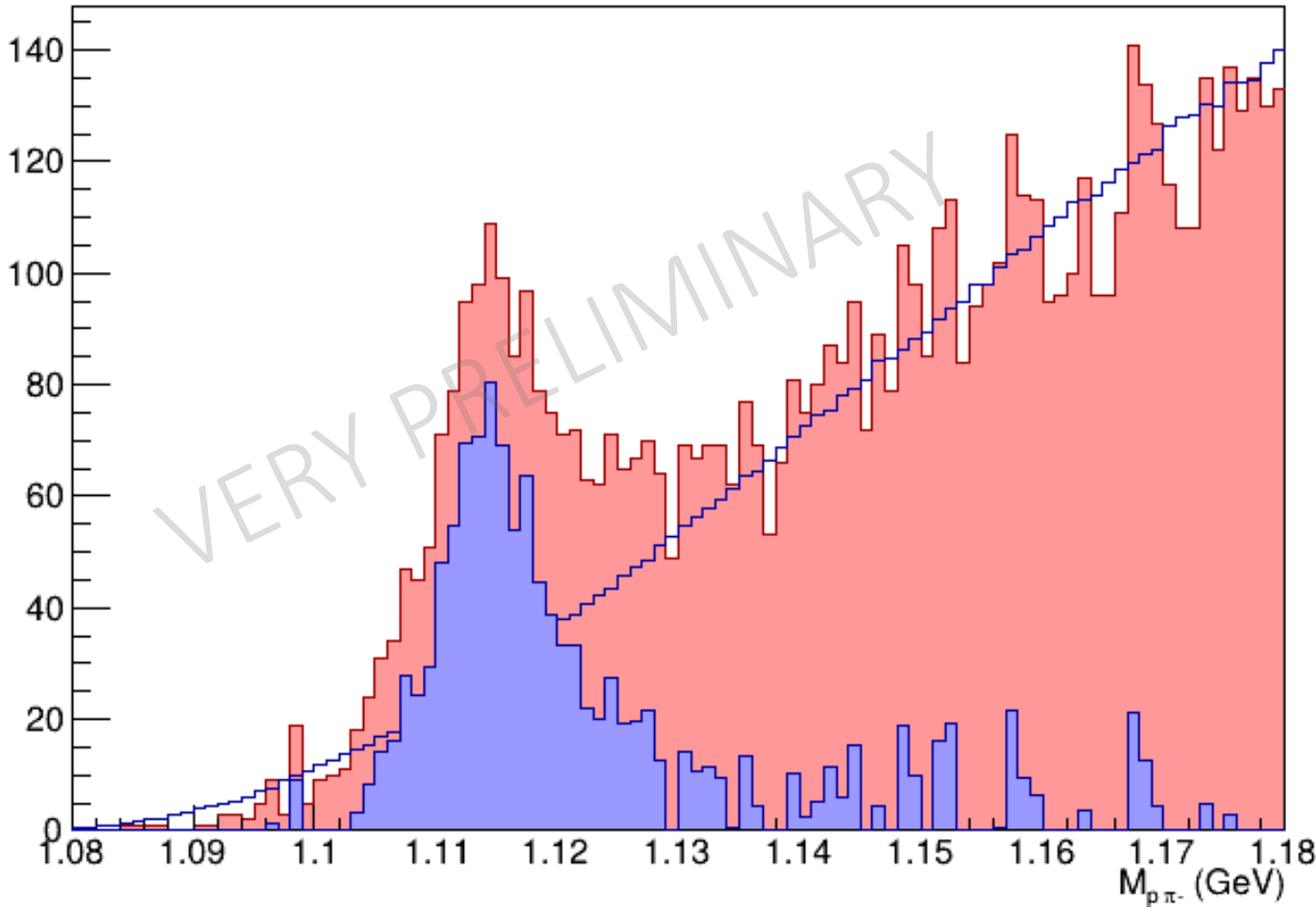






Event Mixing for Background Subtraction

- Event mixing technique proved to be effective in modelling 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



Summary and Outlook

- Efforts to calibrate the collected CLAS12 RG-E dataset are ongoing
- Analysis codes are under development to
  - improve particle identification, vertex cuts and corrections
  - polish the Lambda signal using secondary vertex cuts, and possible cuts on cos(α^*)
  - 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!

This work is supported in part by the U.S. DOE award #: DE-FG02-07ER41528