Study of Λ Fragmentation in Current and Target Regions using CLAS

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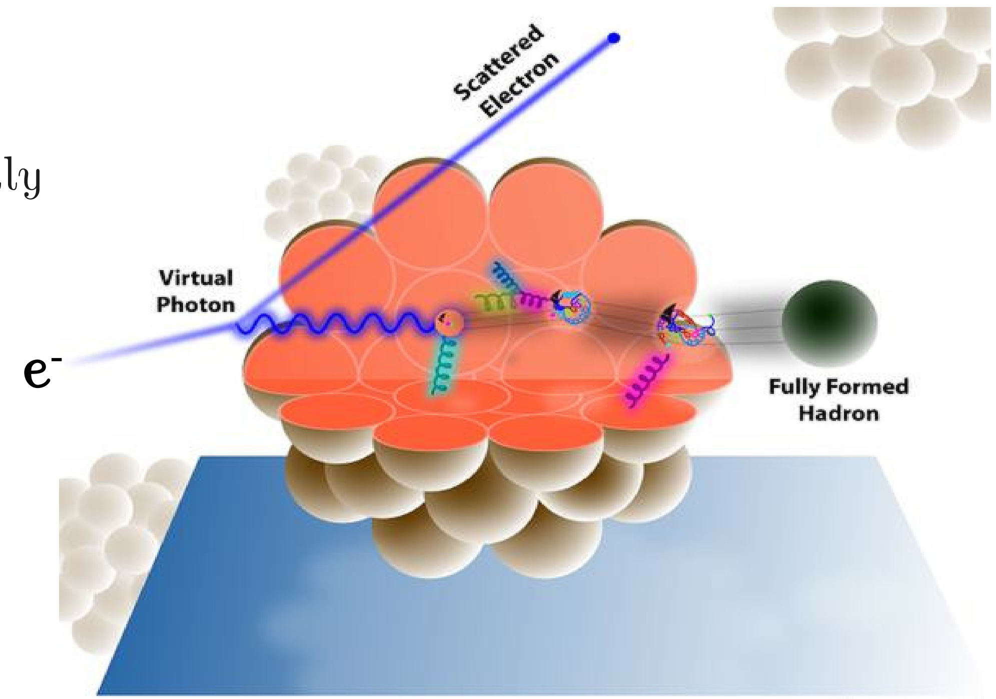
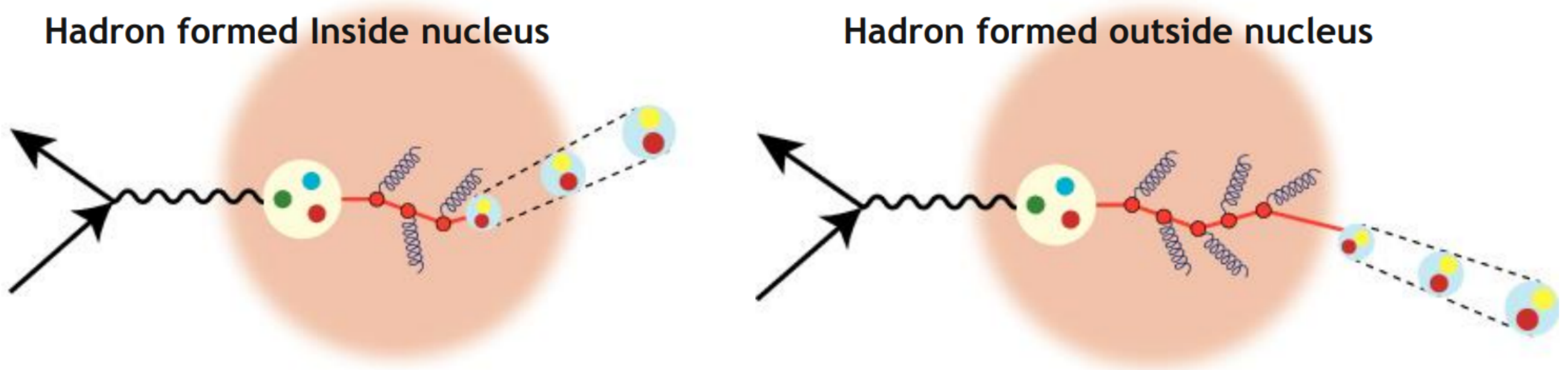
Outline

- *Hadronization*
  - *Previous measurements*
- *The EG2 experiment @ JLab*
- *Preliminary results*
- *Future directions*

Probing QCD Dynamics

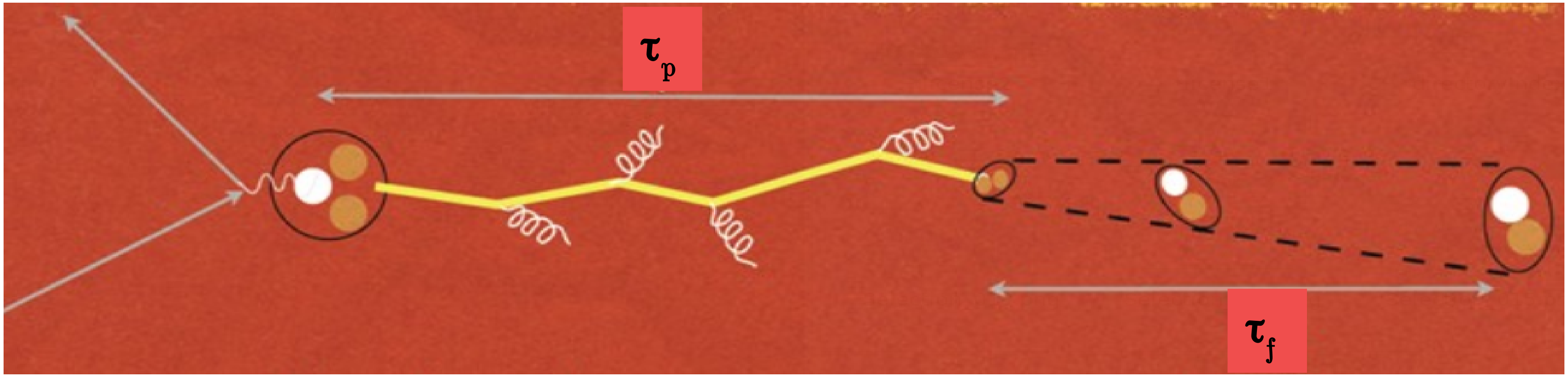
- **Hadronization process:**
  - Evolution of a colored bare quark into a fully dressed hadron.
  - A direct probe of the QCD confinement dynamics: quark propagation and fragmentation.





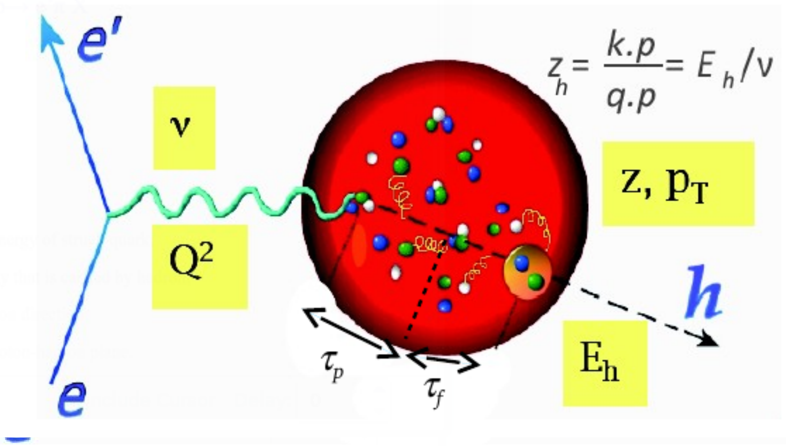
Depending on the size of nucleus, hadron formation can take place inside or outside the nucleus.

- **Hadronization Timescales:**
  - Production time, τ_p: Time spent by a deconfined quark to neutralize its color charge.
  - Formation time, τ_f: Time required to form a regular hadron.



- **Hadronization studies:**
  - Provide information on the dynamical scales of the process.
  - Constrain existing models that provide predictions of its time-characteristics.

Semi-Inclusive Deep Inelastic Scattering (SIDIS) is used to gain access to physical observables.



Kinematical variables:

- ν : Electron energy loss,
  - ≡ Initial energy of a struck quark
- Q^2: Four-momentum transferred,
  - ~ 1/(spatial resolution) of the probe
- y : ν/E_{beam}, Electron energy fraction transferred to a struck quark,
- $W : \sqrt{M_n^2 + 2\nu M_n - Q^2}$ *w/. M_n is a nucleon mass*, is the mass of the total hadronic final state,
- z_h: Fraction of the struck quark's initial energy carried by the formed hadron ($0 < z_h < 1$)
- p_T: Hadron momentum transverse to a virtual photon direction.
- x_F: $\frac{P_L}{P_L^{max}}$, *Feynman variable*, a fraction of the maximum longitudinal momentum carried by the observed hadron.

Experimental Observables

- **Multiplicity ratio:**

$$R_{\mathrm{A}}^{h}\left(\nu, Q^2, z, p_T, \phi\right) = \frac{\left.\frac{N_h(\nu,Q^2,z,p_T,\phi)}{N_e(\nu,Q^2)|_{\mathrm{DIS}}}\right|_{\mathrm{A}}}{\left.\frac{N_h(\nu,Q^2,z,p_T,\phi)}{N_e(\nu,Q^2)|_{\mathrm{DIS}}}\right|_{\mathrm{D}}}$$

  - Normalization with the electron DIS events that permits cancellation of the initial state effects.

- **Transverse momentum broadening:**

D = loosely bound nuclei
A = Heavy Nuclei

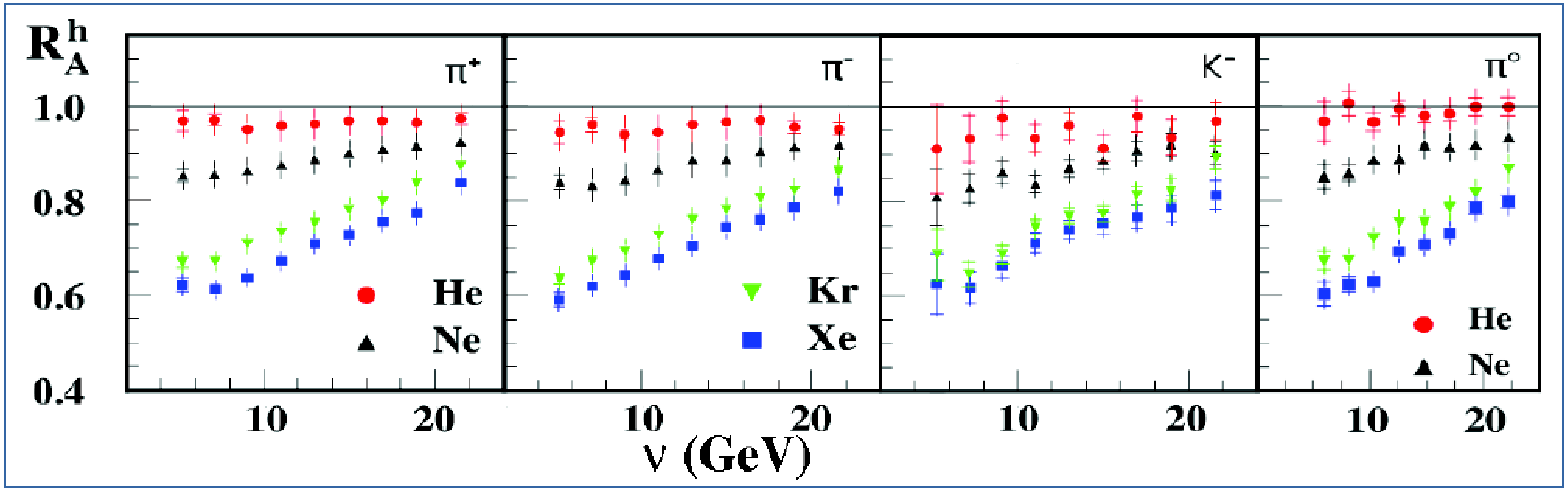
$$\Delta P_T^2 = \langle P_T^2 \rangle_A - \langle P_T^2 \rangle_D$$

- **These observables provide insight about**
  - Parton energy loss and hadron attenuation.
  - The hadronization timescales.
  - Hadronization with respect to nucleus size.

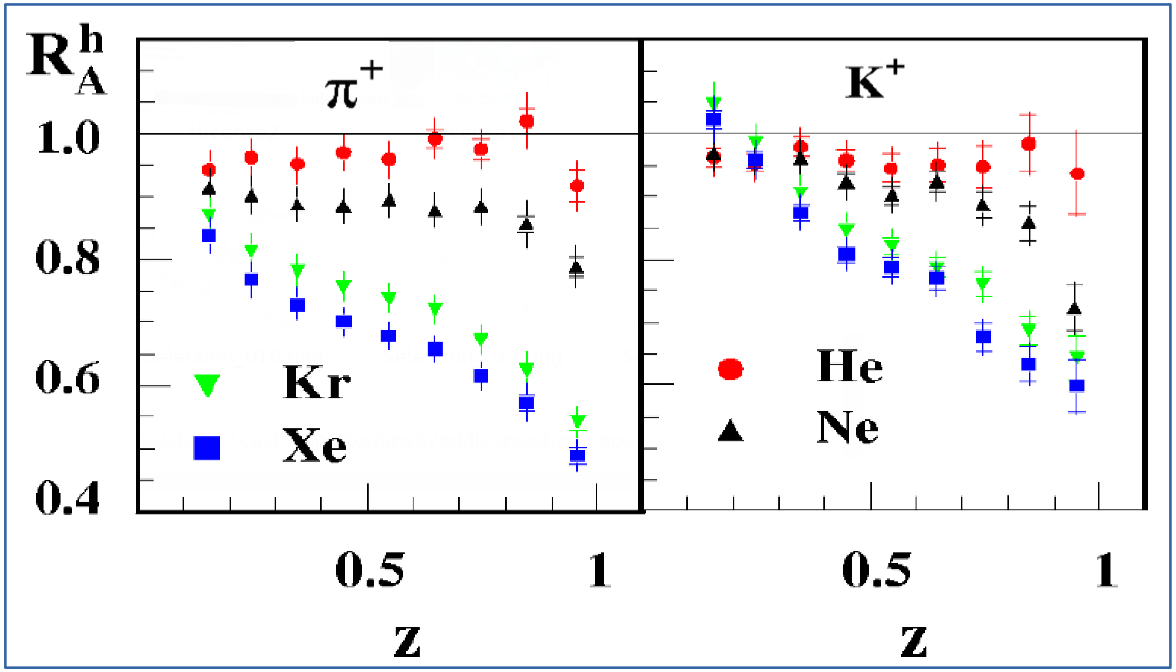
HERMES Multiplicity Ratios

Positron beam, E_{beam} = 27 GeV

A. Airapetian et al.
Phys.Lett., vol. B684, pages 114–118, 2010

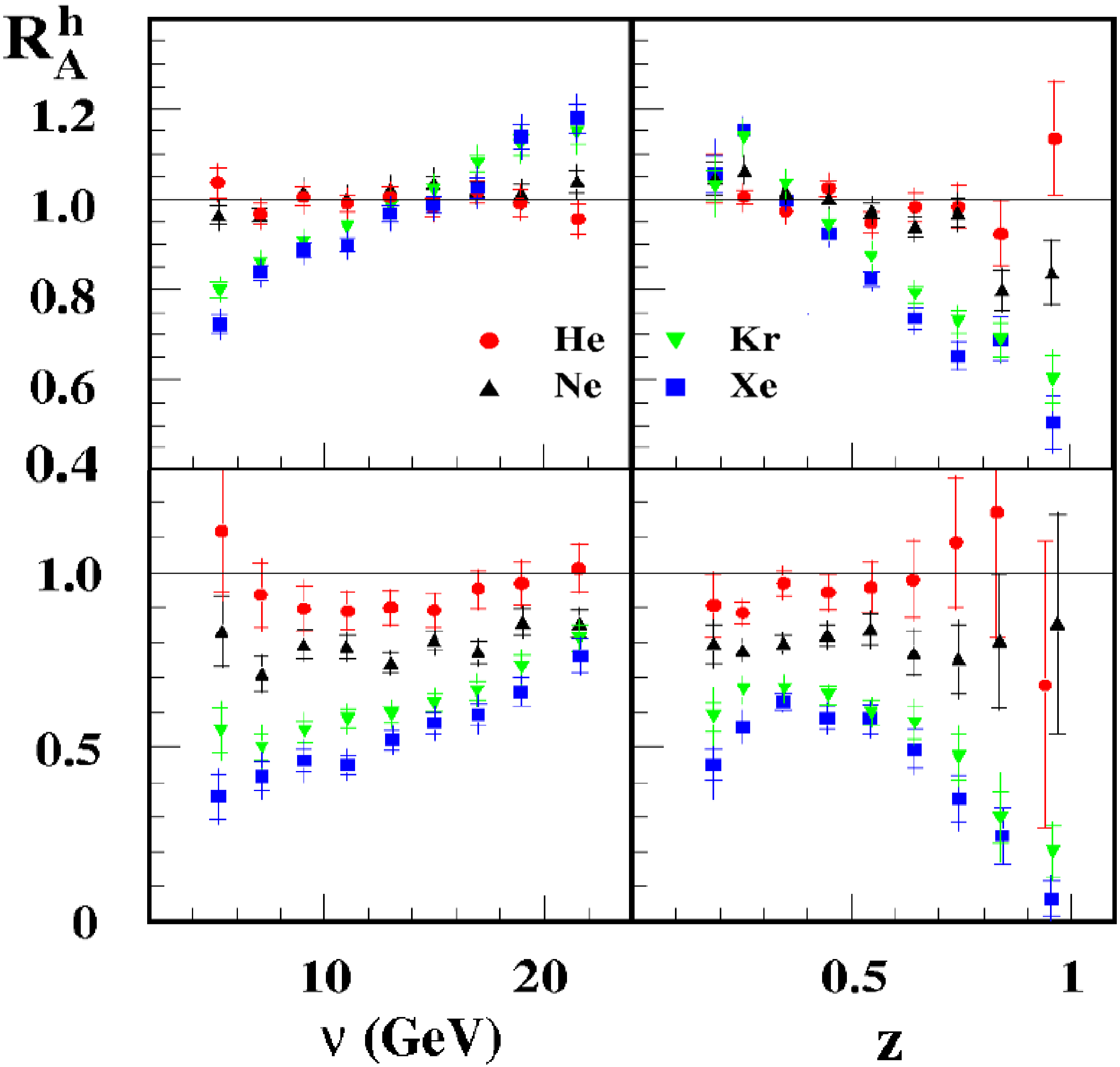


$$z \equiv \frac{E_{hadron}}{\nu}$$



- All pion flavors and K^- experience similar attenuation.
- K^+ is less attenuated compared to π^+ most likely due to a contamination from $\pi + p \rightarrow \Lambda + K$ (B. Kopeliovich *et al.*) from the target fragmentation.

HERMES Multiplicity Ratios



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proton

anti-proton

Positron beam, E_{beam} = 27 GeV

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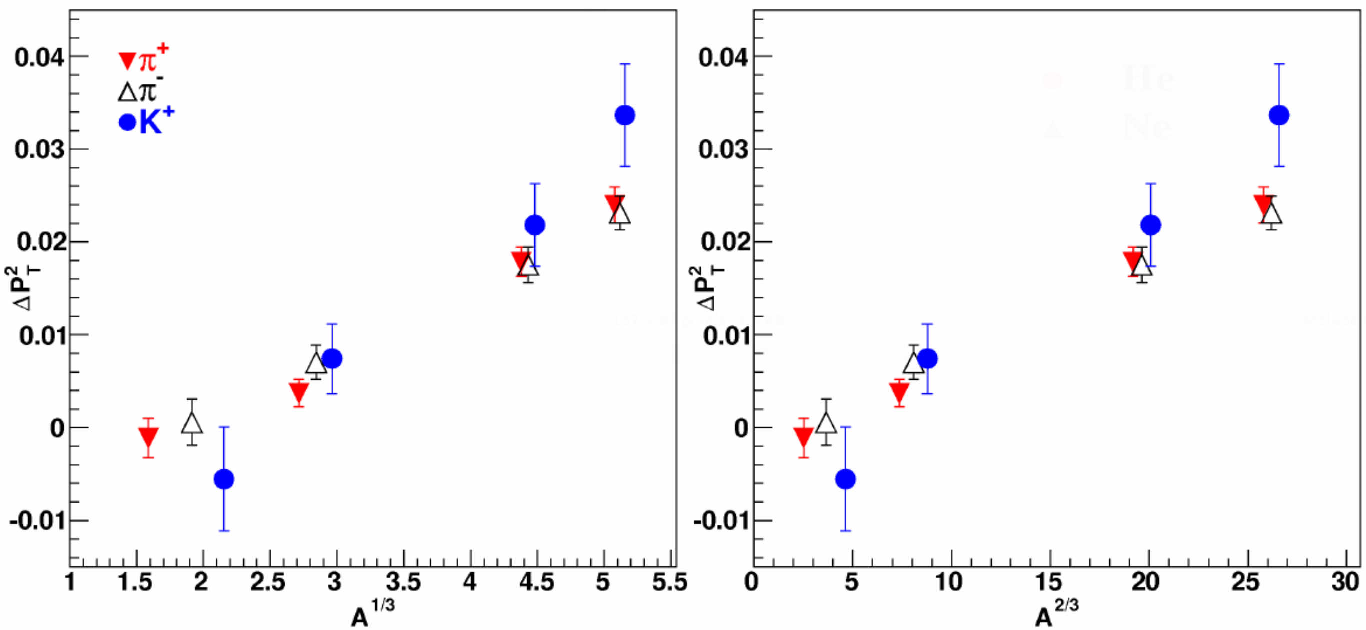
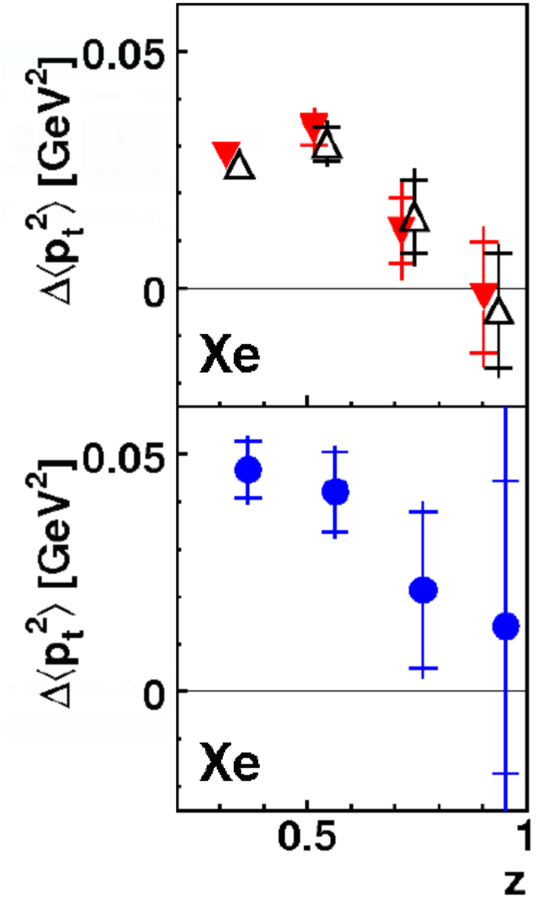
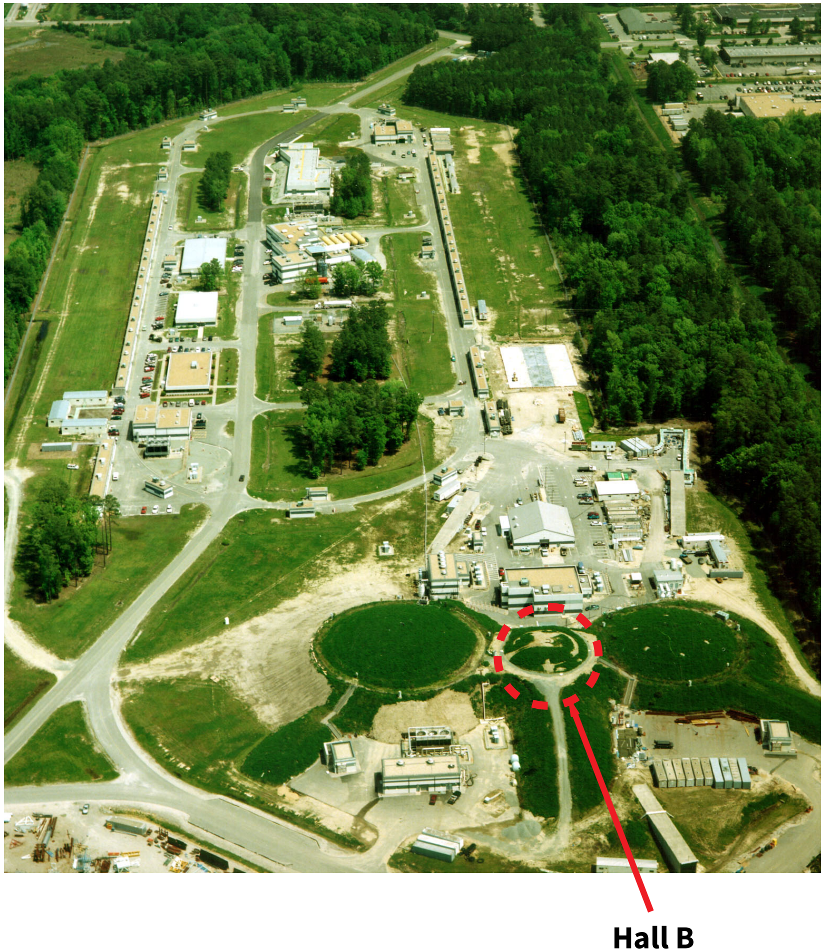


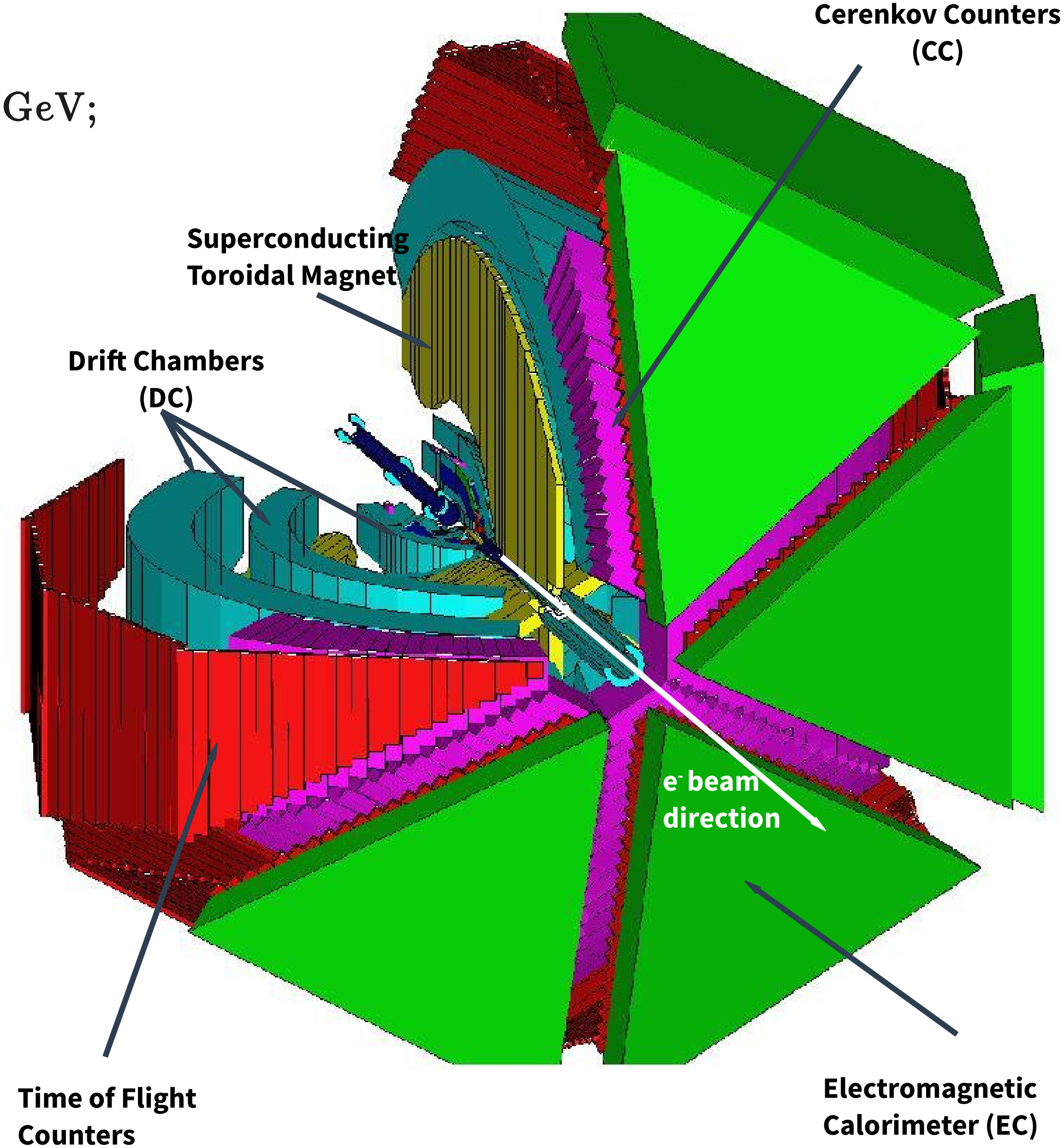


- Reduced broadening at high z favors no prehadron interaction.
- K^+ P_T broadening is different compared to that of the pions → Flavor dependence?
- Similar effect for nuclear size dependencies → Calls for more data?

CLAS @ JLab

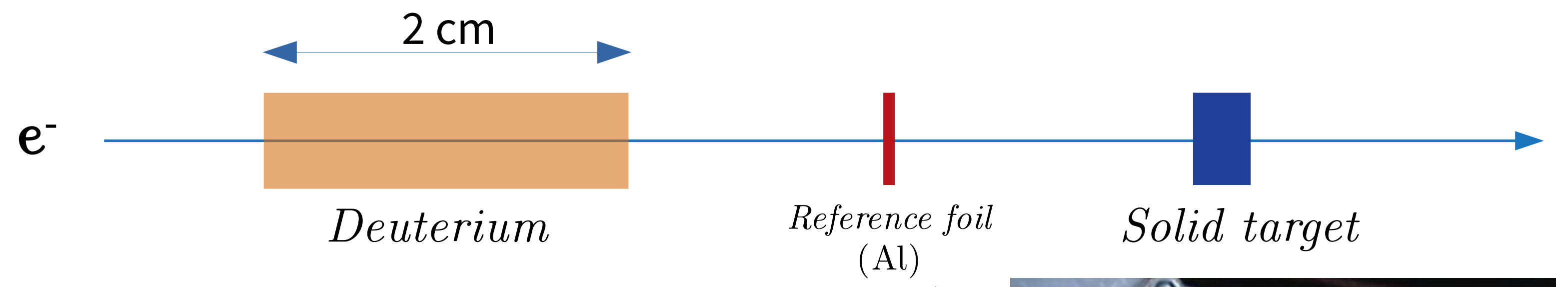
- Jefferson Lab: Newport News, VA;
- CEBAF: accelerated electrons up to 6 GeV;
- Experimental Halls: A, B, C
  (and D, 12 GeV upgrade);
- Hall B: electron or photon beam;

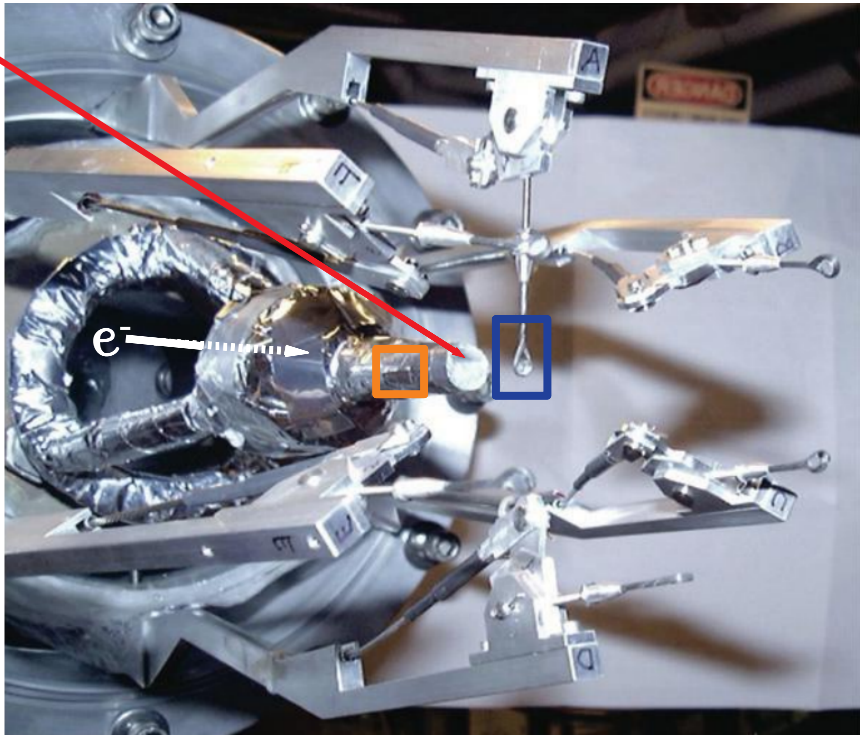




CLAS EG2 Dataset

- Targets: Deuterium, Carbon, Iron, Lead, Tin, Aluminum.
- Deuterium and solid target in beam simultaneously for improved systematics:



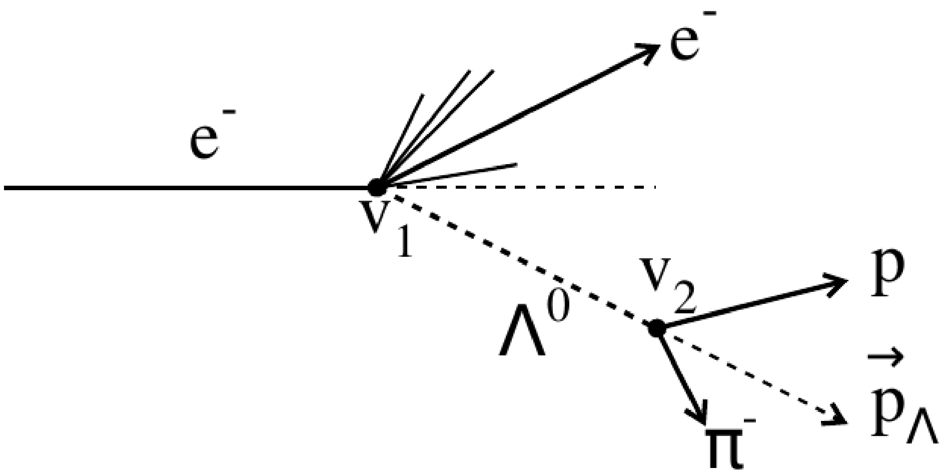


- Luminosity ~ 10^{34} s^{-1} cm^{-2}
- Beam energy: 5 GeV
- Target separation ~ 4 cm
- Solid Targets:

Targets	Fe	C	Al	Al	Pb	Sn
Radius (mm)	1.5	1.5	1.5	1.5	1.5	1.5
Thickness (mm)	0.4	1.72	0.58	1.5 E-03	0.14	0.3

Reaction Channel

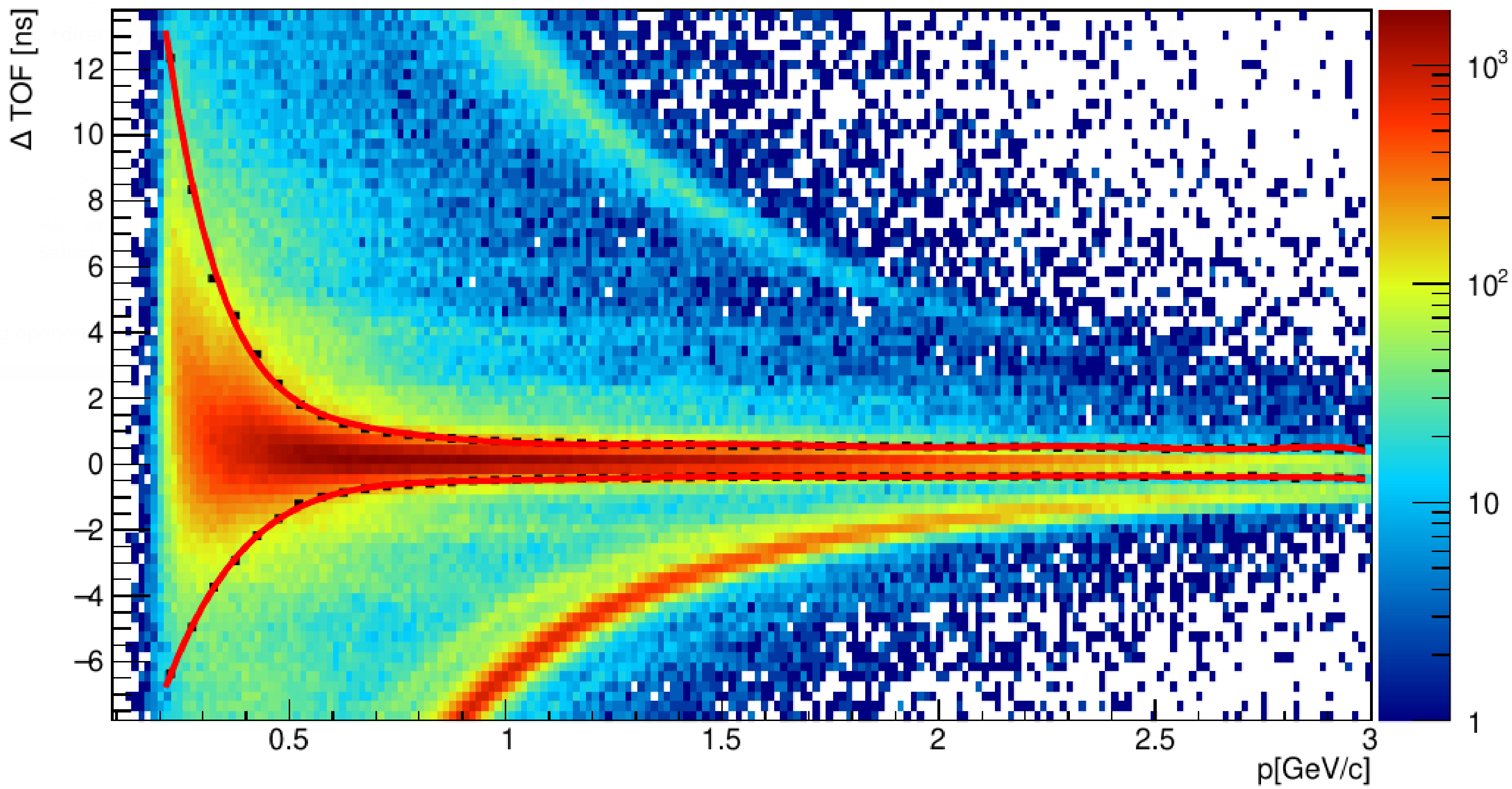
- SIDIS
  - $e + A \rightarrow e' + \Lambda$
  - Scattered electron and Lambda decay products detected.
- $\Lambda \rightarrow \pi^{-} + p$
  - ~64% branching ratio



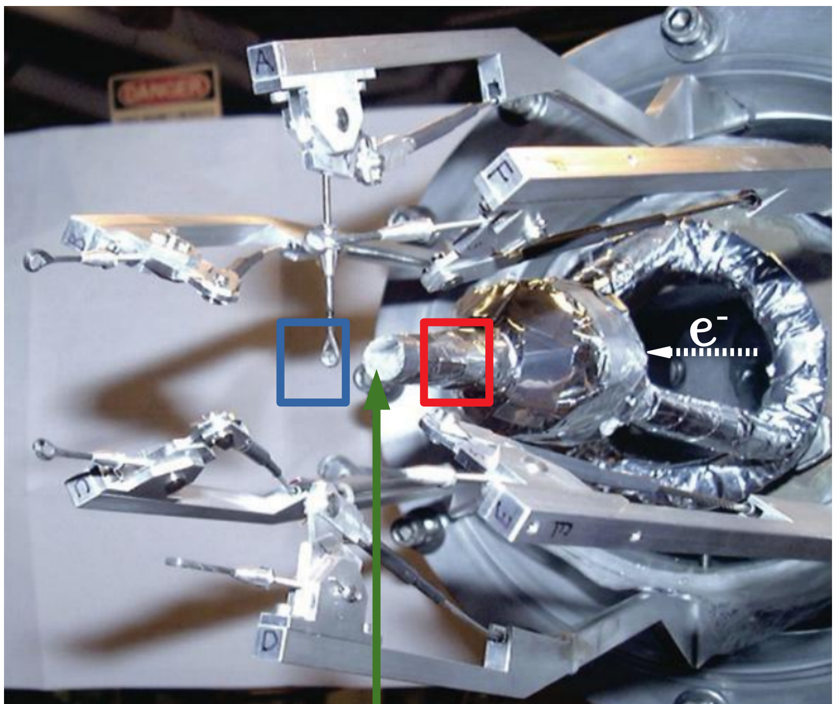
- e^{-} and π^{-} identification:
  - Method:
    L. El Fassi (CLAS Collaboration),
    Physics Letters B 712 (2012) 326–330.
  - e^{-} : Positive response in the four CLAS subsystems, i.e. DC, CC, SC and EC.
  - π^{-} : Matching signal in drift chambers (DC) and scintillator counters (SC).

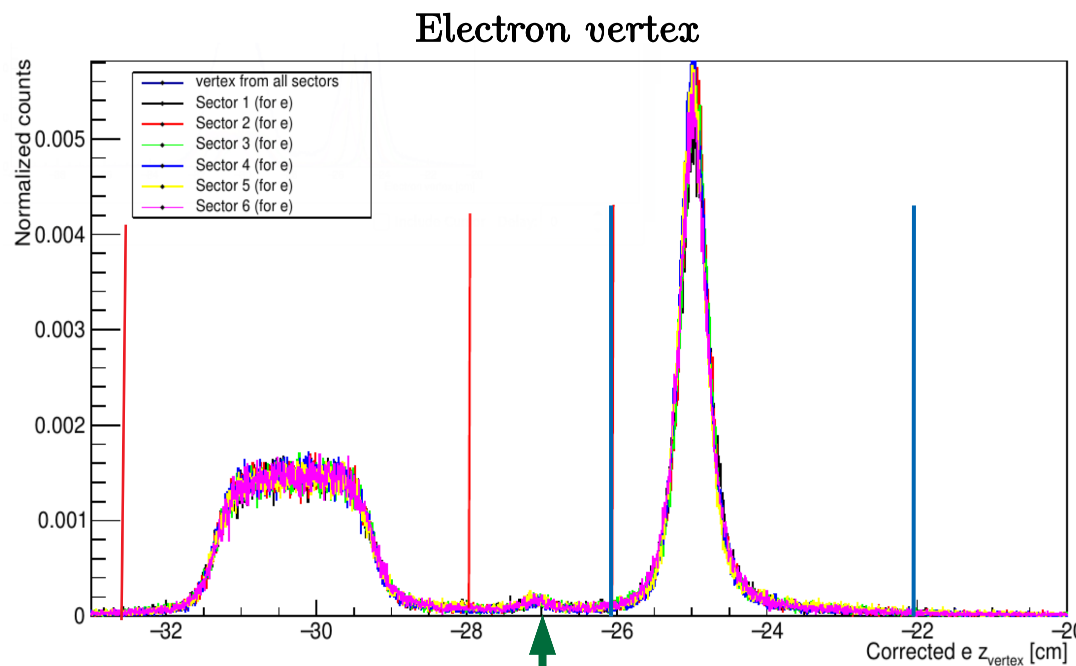
Proton Identification

- Matching signal in DC and SC.
- Timing versus momentum dependent study to select proton candidates.



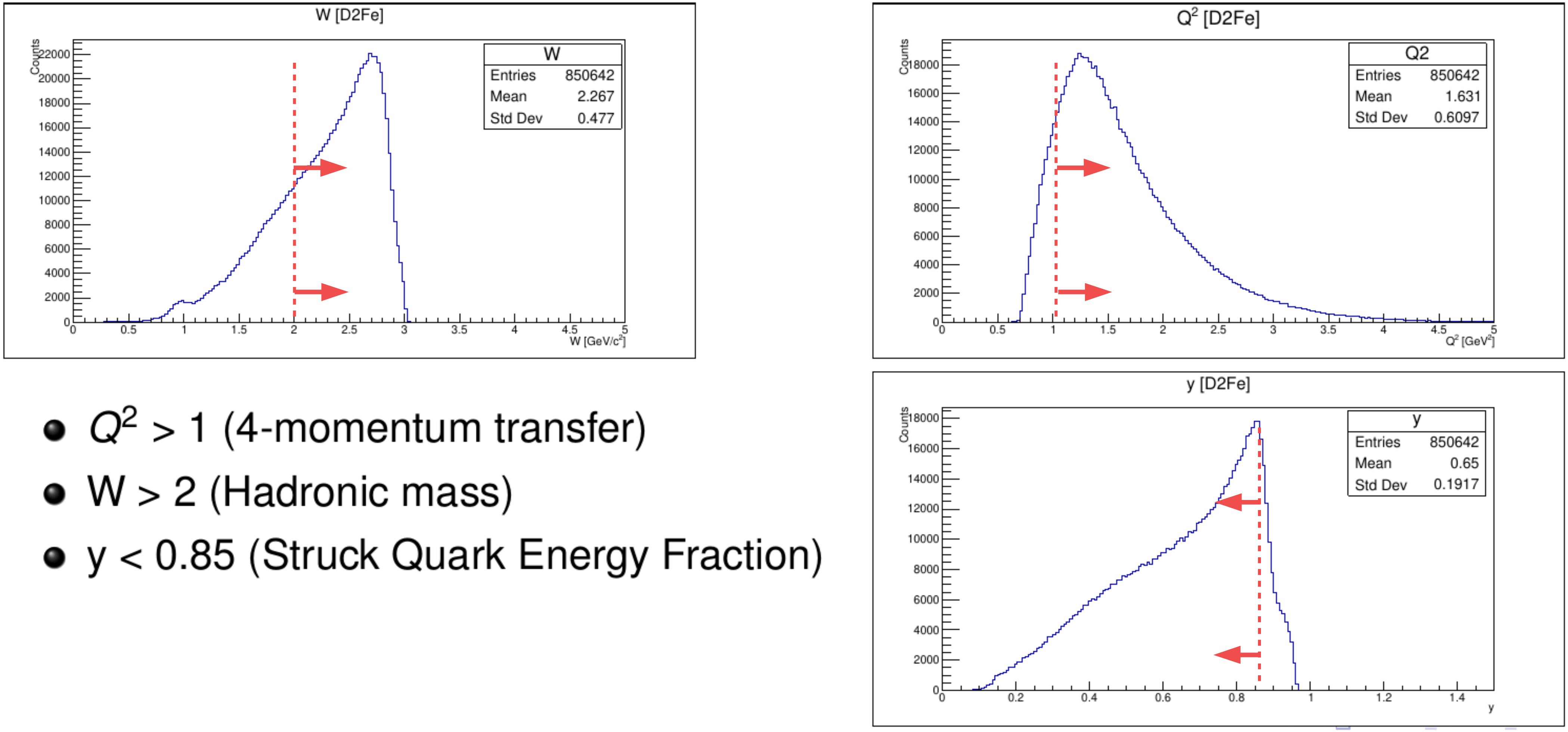
- Simultaneous targets: Necessary to correctly reconstruct the reaction vertex.





- All identified particles underwent the vertex correction.

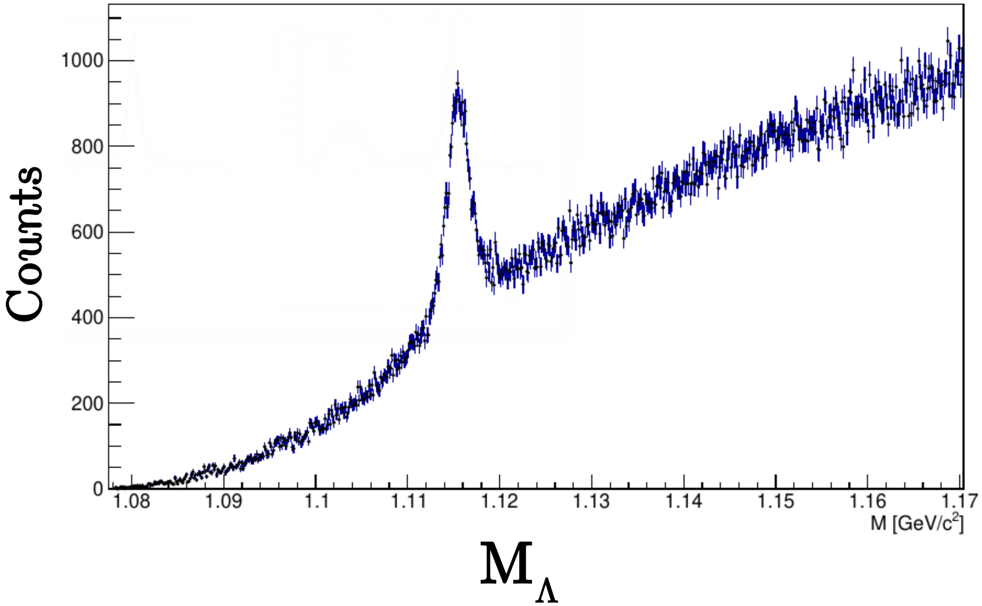
Selection of SIDIS Events: Kinematic Cuts

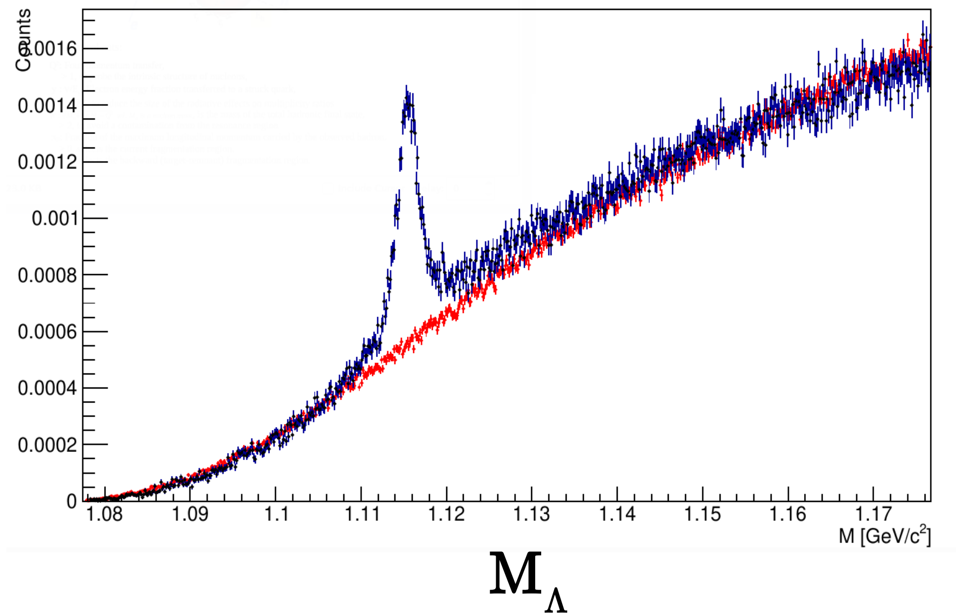


- $Q^2 > 1$ (4-momentum transfer)
- W > 2 (Hadronic mass)
- y < 0.85 (Struck Quark Energy Fraction)

Production Channel

- Reconstruct Λ via its decay products π^- and p.
- Perform various sanity checks of the background subtraction and yield extraction techniques.





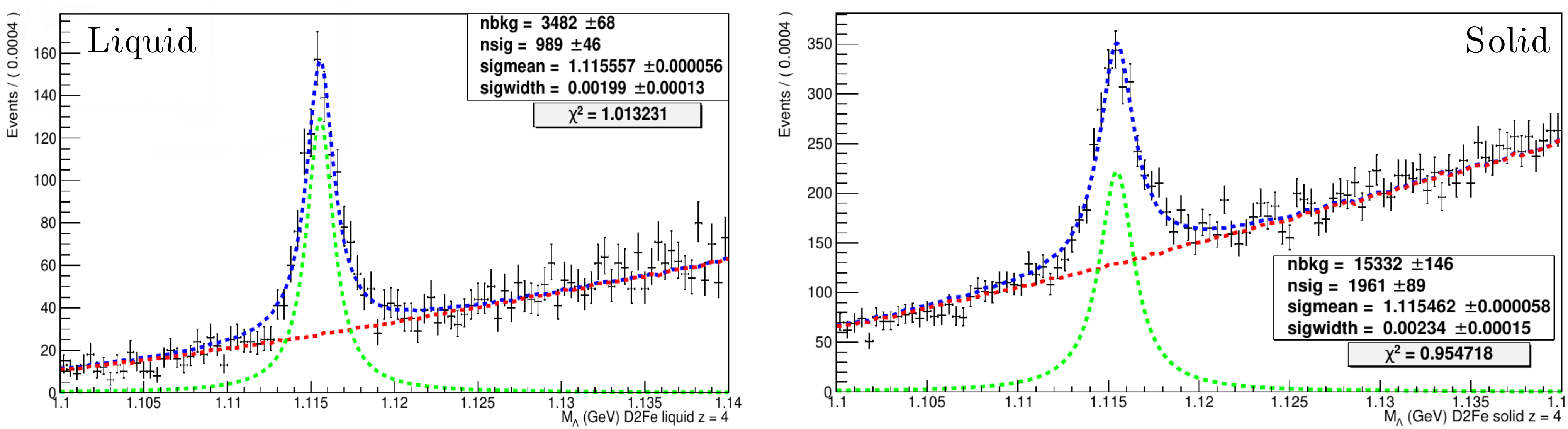
- First method: Polynomial (for background) + Breit-Wigner (for signal).
- Second method: Combinatorial background + Breit-Wigner using side-band normalization.
- Third method: Combinatorial background + Breit-Wigner based on MINUIT minimization (RooFit).

See also Sereres Johnston's talk:
04/11 @ 2:40 pm in Director's Row H

Λ Yield Extraction

- **A sample z-bin: Λ invariant mass distribution for the liquid (left) and solid (Fe)(right) using the third method.**
- **z**: fraction of the struck quark's initial energy carried by the formed hadron

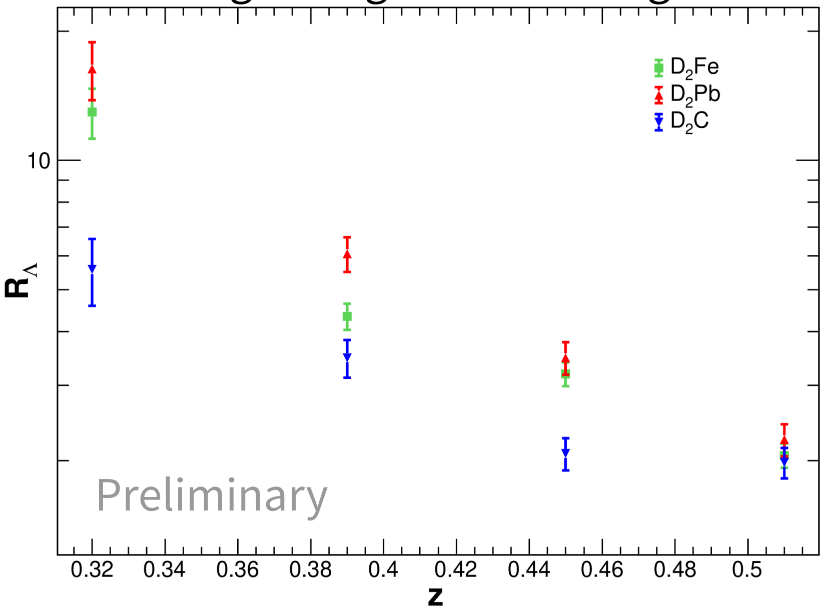
$z = [0.48, 0.54)$



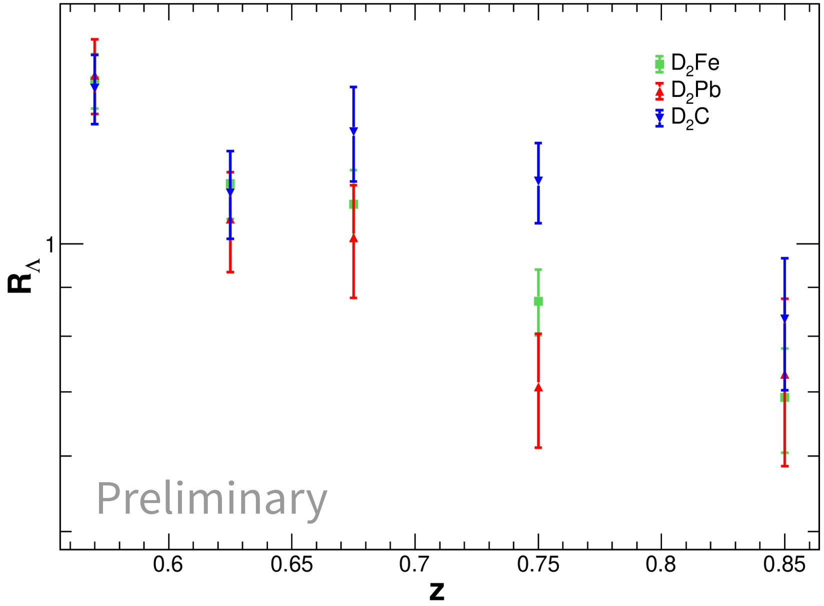
M_Λ M_Λ

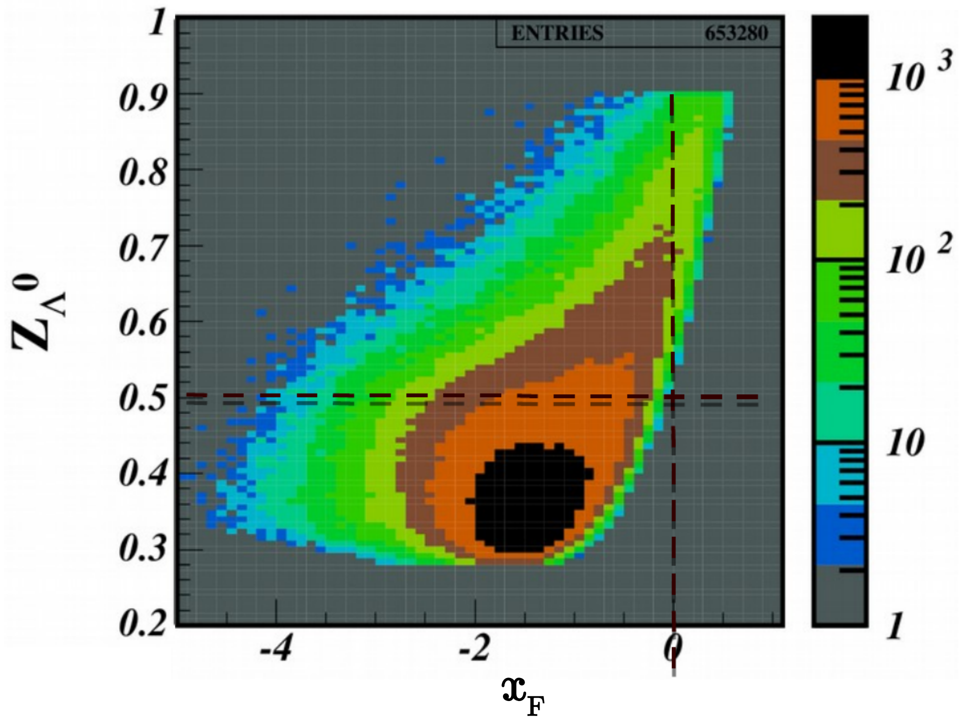
Multiplicity Ratio

Target Fragmentation region



Current Fragmentation region

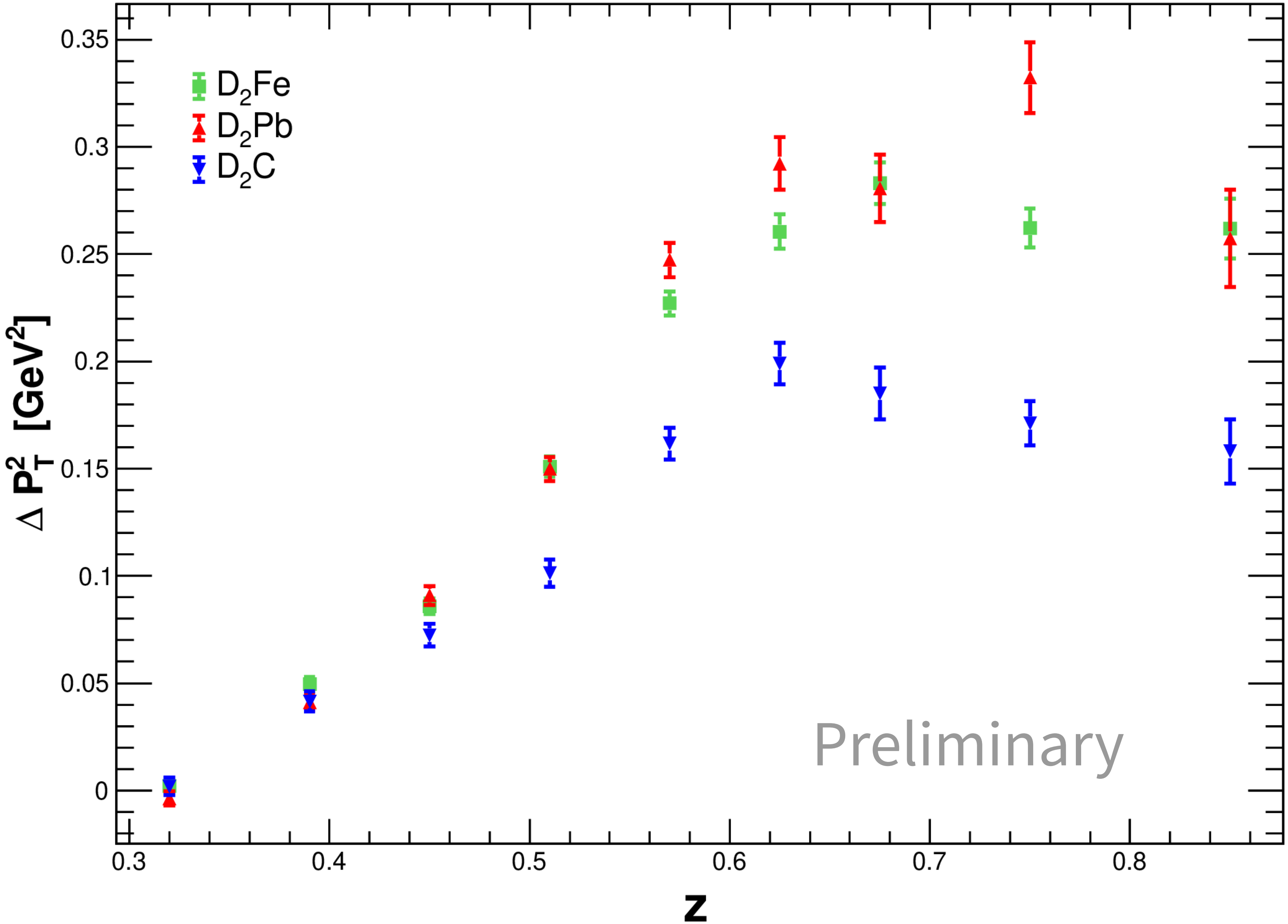




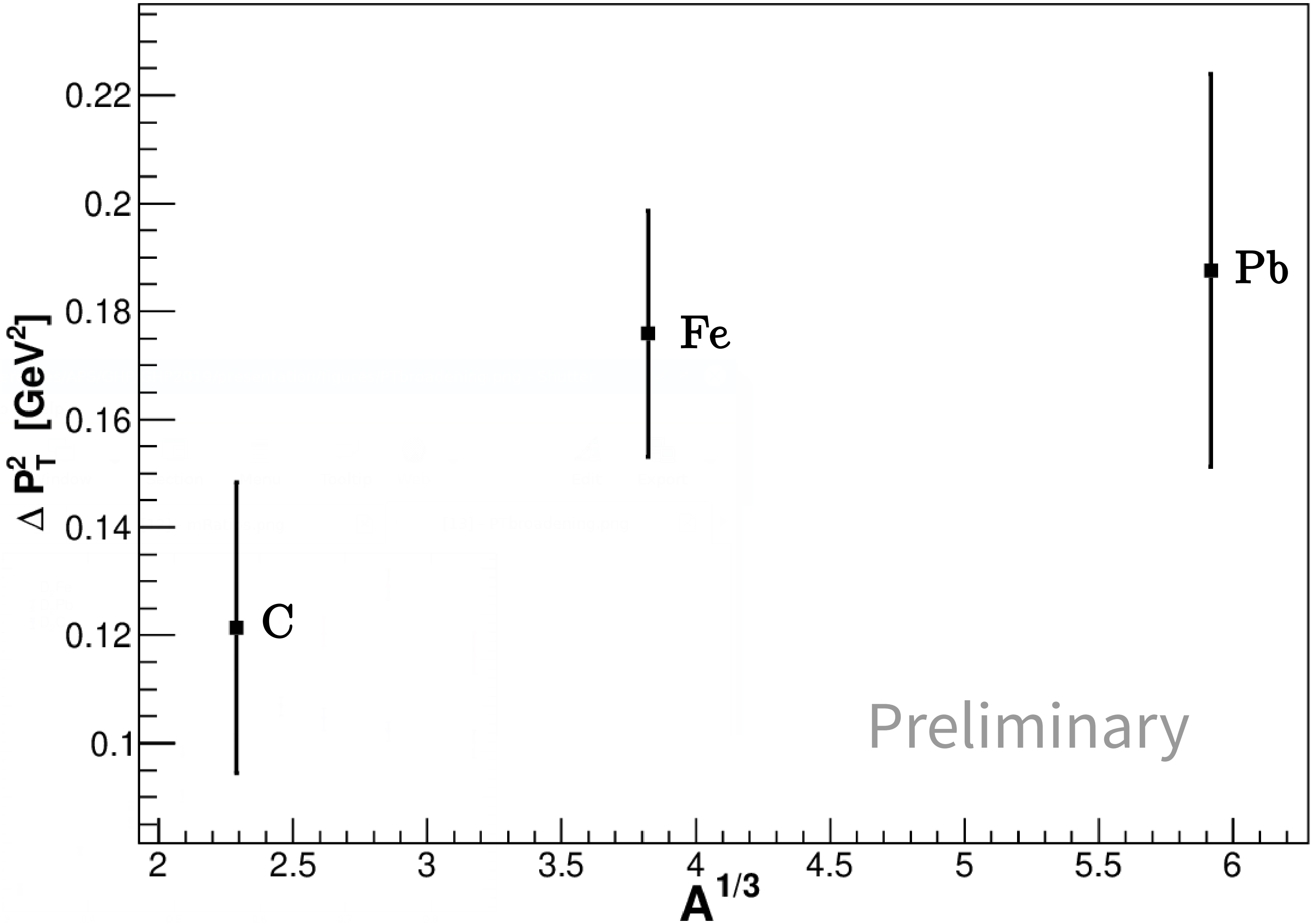
- $$R_A^h(z) = \frac{\left.\frac{N_h(z)}{N_e|_{DIS}}\right|_A}{\left.\frac{N_h(z)}{N_e|_{DIS}}\right|_D}$$

- First ever study of the hadronization process of Λ hyperon which probes the forward (current) and backward (target) fragmentation regions.

Transverse Momentum Broadening (z-dependence)

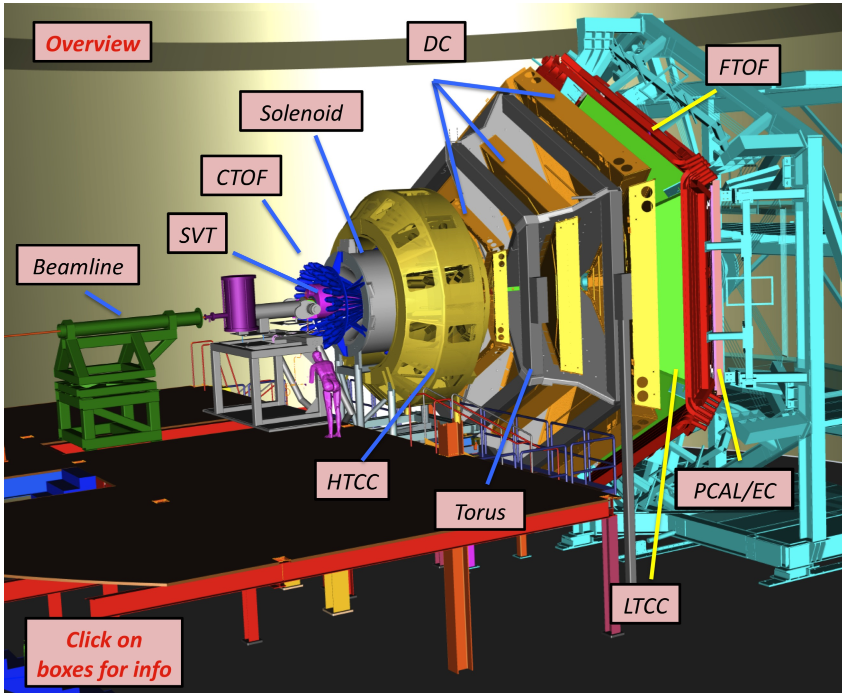


Transverse Momentum Broadening (A-dependence)



CLAS12 @ JLab

With 12 GeV upgrade of the CEBAF: accelerate electrons up to 11 GeV in Hall B.



Actively underway with existing 5 GeV data

meson	cτ	mass	flavor content	*baryon*	cτ	mass	flavor content
π^0	25 nm	0.13	$u\bar{u}d\bar{d}$	p	stable	0.94	ud
π^+, π^-	7.8 m	0.14	$u\bar{d}$, $d\bar{u}$	$\bar{p}$	stable	0.94	$\overline{ud}$
η	170 pm	0.55	$u\bar{u}d\bar{d}s\bar{s}$	Λ	79 mm	1.1	uds
ω	23 fm	0.78	$u\bar{u}d\bar{d}s\bar{s}$	$\Lambda(1520)$	13 fm	1.5	uds
η'	0.98 pm	0.96	$u\bar{u}d\bar{d}s\bar{s}$	Σ^+	24 mm	1.2	us
ϕ	44 fm	1.0	$u\bar{u}d\bar{d}s\bar{s}$	Σ^-	44 mm	1.2	ds
$f1$	8 fm	1.3	$u\bar{u}d\bar{d}s\bar{s}$	Σ^0	22 pm	1.2	uds
K^0	27 mm	0.50	$d\bar{s}$	Ξ^0	87 mm	1.3	us
K^+, K^-	3.7 m	0.49	$u\bar{s}$, $\bar{u}s$	Ξ^-	49 mm	1.3	ds

DIS channels: stable hadrons accessible with the CLAS12 detector

- Span a wider range of nuclei masses → Better understanding of A dependence;
- Study of various hadrons production → Improve our understanding of hadron's formation mechanism.
- Higher statistical precision → Multi-dimensional study of physics observables dependencies for a comprehensive extraction of the production and formation time scales.

Summary

- **Hadronization study is a direct probe of QCD confinement dynamics.**
- **Preliminary results for Multiplicity ratios for Fe, C and Pb targets.**
- **Preliminary Transverse Momentum Broadening.**
- **Next steps in current work would include:**
  - Acceptance corrections, Radiative corrections, Systematic Studies.
  - Study other dependencies of R_Λ, ${P_T}^2$, Cronin effect, etc.
- **A detailed comprehensive study of the hadronization mechanism with the upcoming CLAS12 experiment is crucial to constrain the competing theoretical models and extract the characteristic time scales.**

~ Acknowledgment ~

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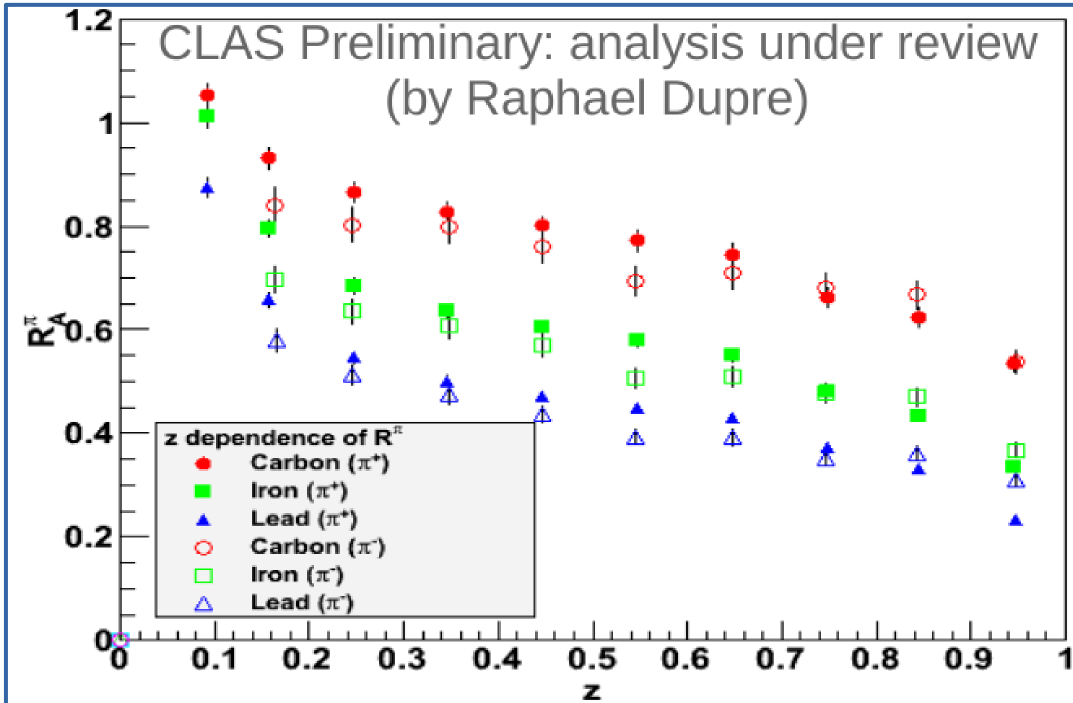
Thank you!!

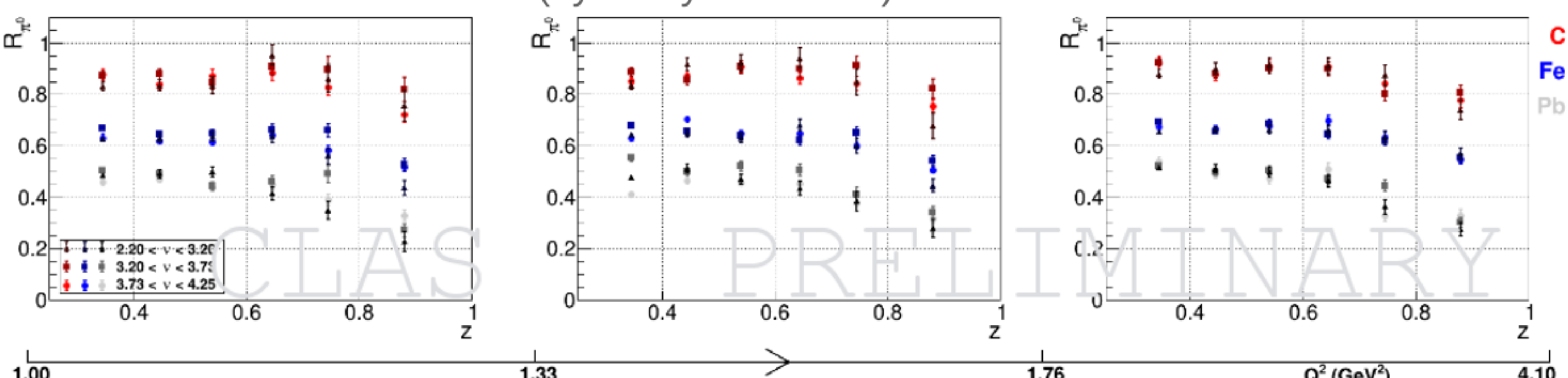
Extras

CLAS 6: Hadronization results on Meson channels

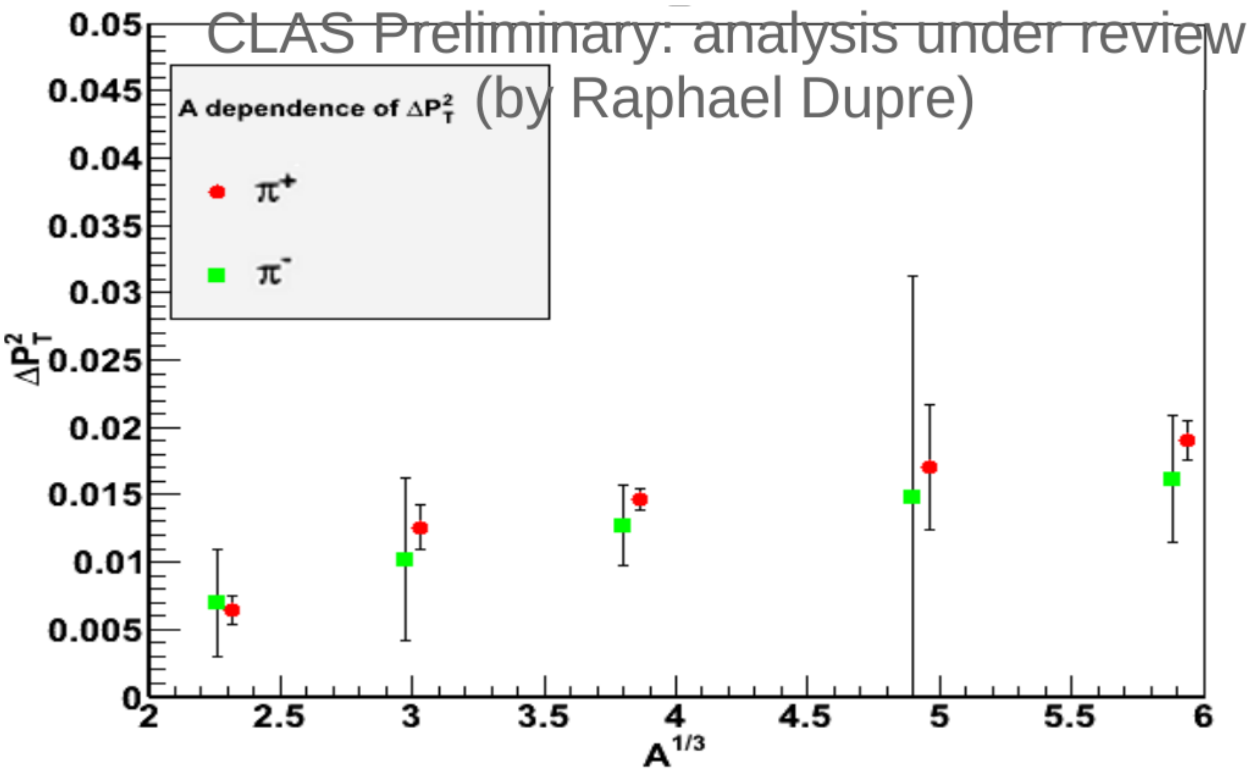


- 3-dimensional CLAS-6 multiplicity ratios in z x (Q^2, ν), fully corrected for radiative processes and acceptance, normalized to target thicknesses; C, Fe, Pb.
- Similar behavior for π^0 (Taisiya's thesis results; under review), π^+ (Hayk's thesis) and K^0 (A. Daniel, Ken Hicks *et al.*; published!)
- Consistent with Hermes results!

Example of 3-D π^0 multiplicity ratios
(by Taisiya Mineeva)

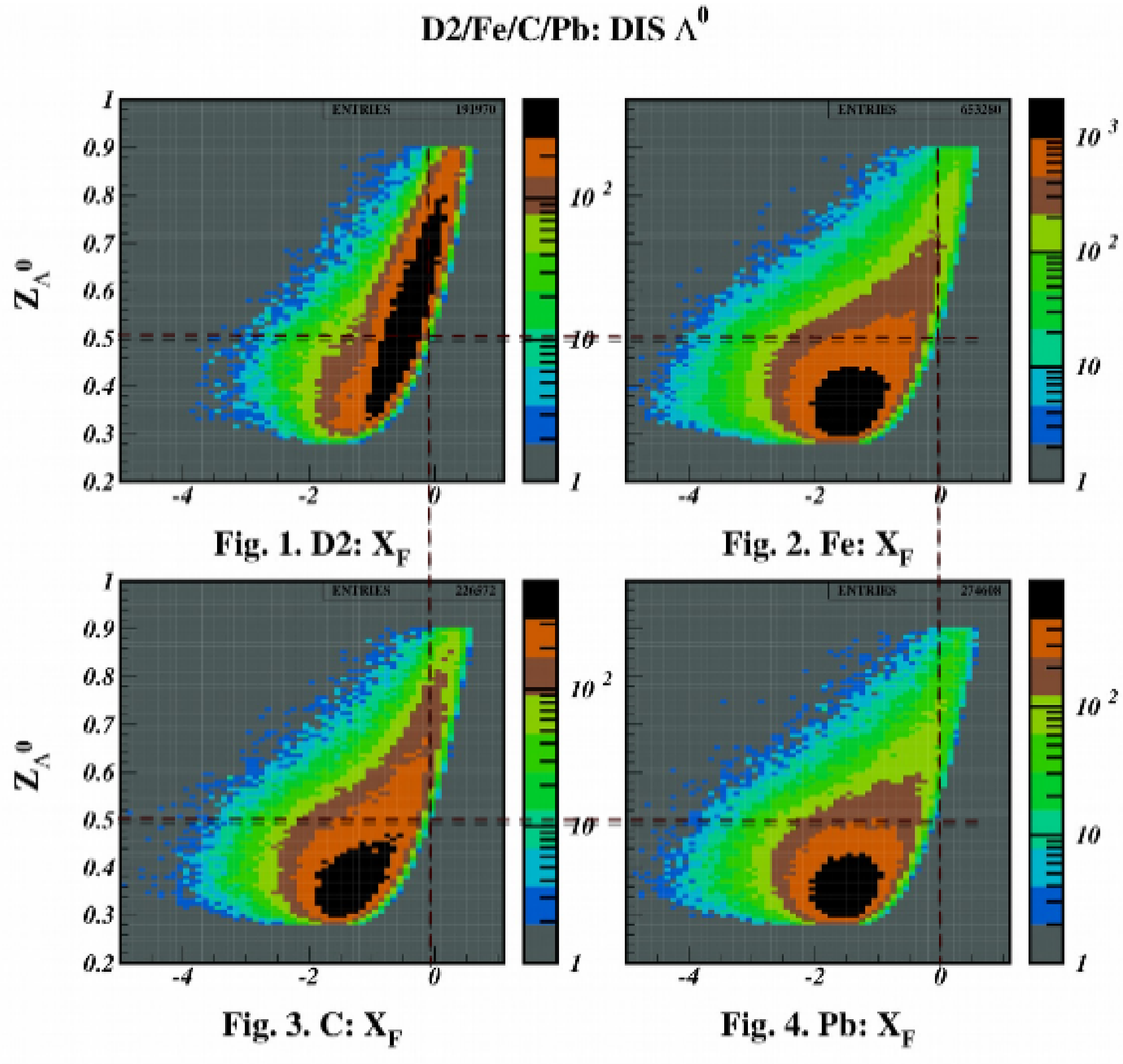


CLAS 6: Hadronization results on Meson channels



CLAS-6 transverse momentum broadening results for charged pions shows a similar behavior

- First time ever to study the hadronization process of Λ^0 hyperon and probe the forward (current) and backward (target) fragmentation regions.



P_t distribution