Analysis Updates on the EG2 Λ Study

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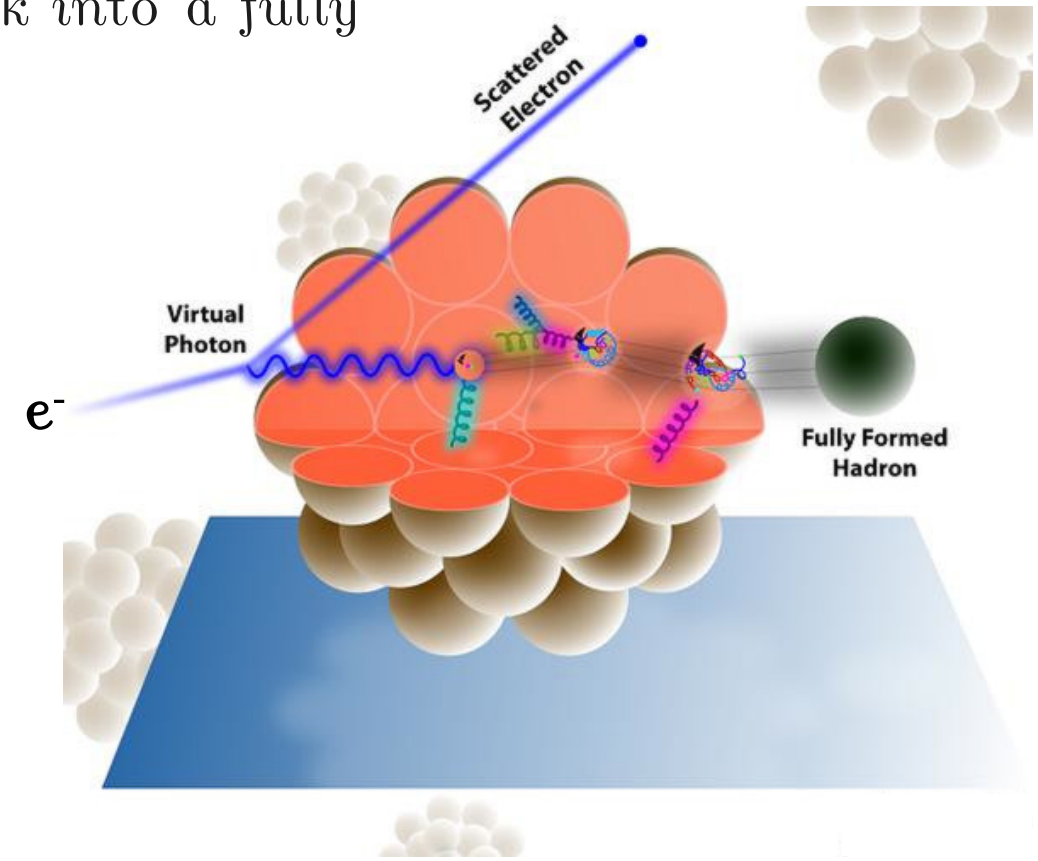
Outline

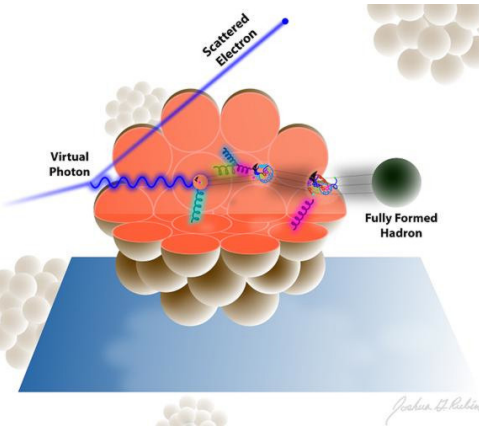
- *Introduction*
- *Particle Identification*
- *Vertex Correction*
- *Preliminary Results:*
  - *Multiplicity ratios*
  - *Transverse momentum broadening*
- *Validation of PYTHIA event generator*
- *Future directions*

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



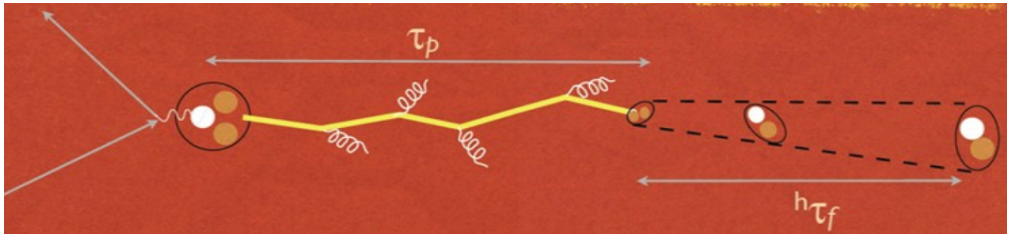
Probing QCD

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



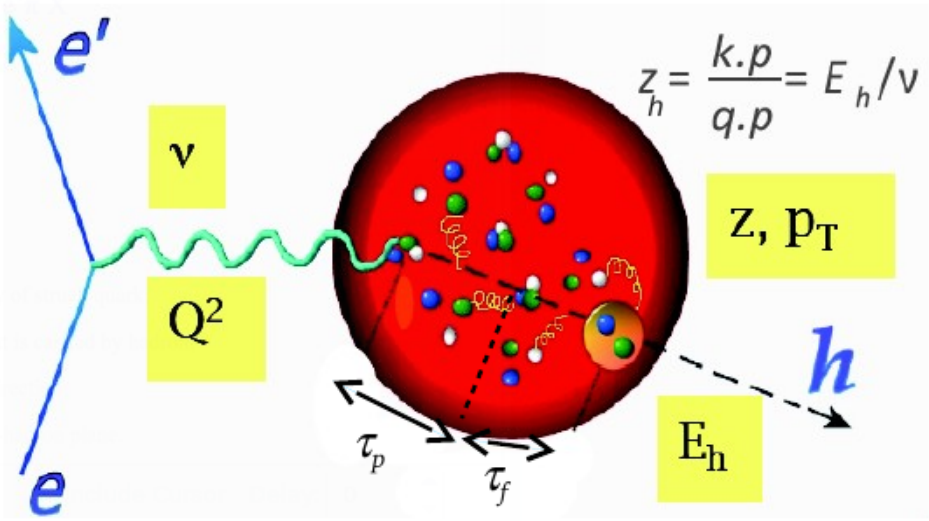
- **Hadronization Timescales:**
  - Production time, τ_p:

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



- **Use Semi-Inclusive Deep Inelastic Scattering (SIDIS) to gain access to physical observables.**

SIDIS



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.

Slide borrowed from Lamiaa, DNP18

Goal

- **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 number that permits cancellation of the initial state effects

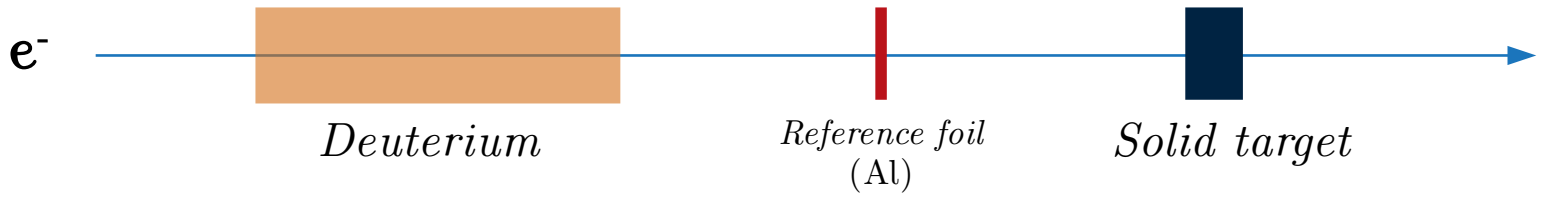
- **Transverse momentum broadening:**

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

D = loosely bound nuclei
A = Heavy Nuclei

CLAS EG2 dataset

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

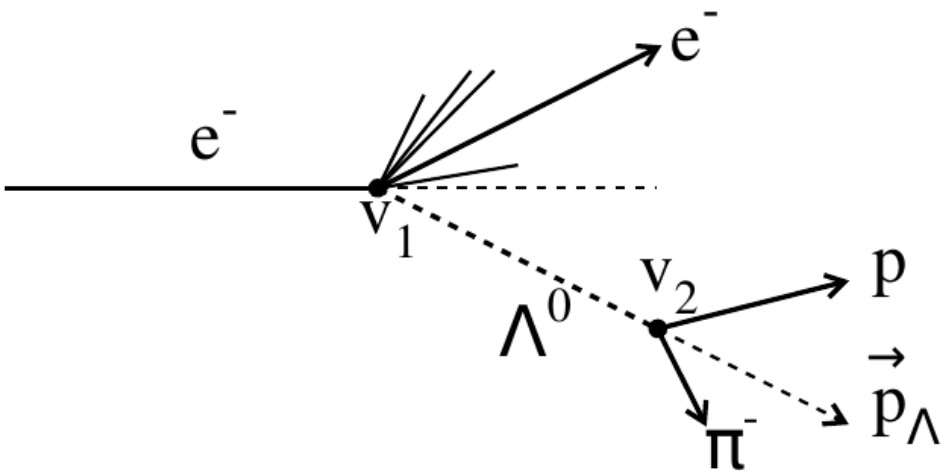


- Luminosity ~ 10^{34} s^{-1} cm^{-2}
- Beam energy: 5 GeV

Reaction Channel

- **SIDIS**
  - $e + A \rightarrow e' + \Lambda + X$
  - Scattered electron and Lambda decay products detected.

- **$\Lambda \rightarrow \pi^- + p$**
  - ~64% branching ratio



- **e^- and π^- identification:**
  - Method from approved Color Transparency analysis.

L. El Fassi *et al*, CLAS-NOTE 2012-001

Proton Identification

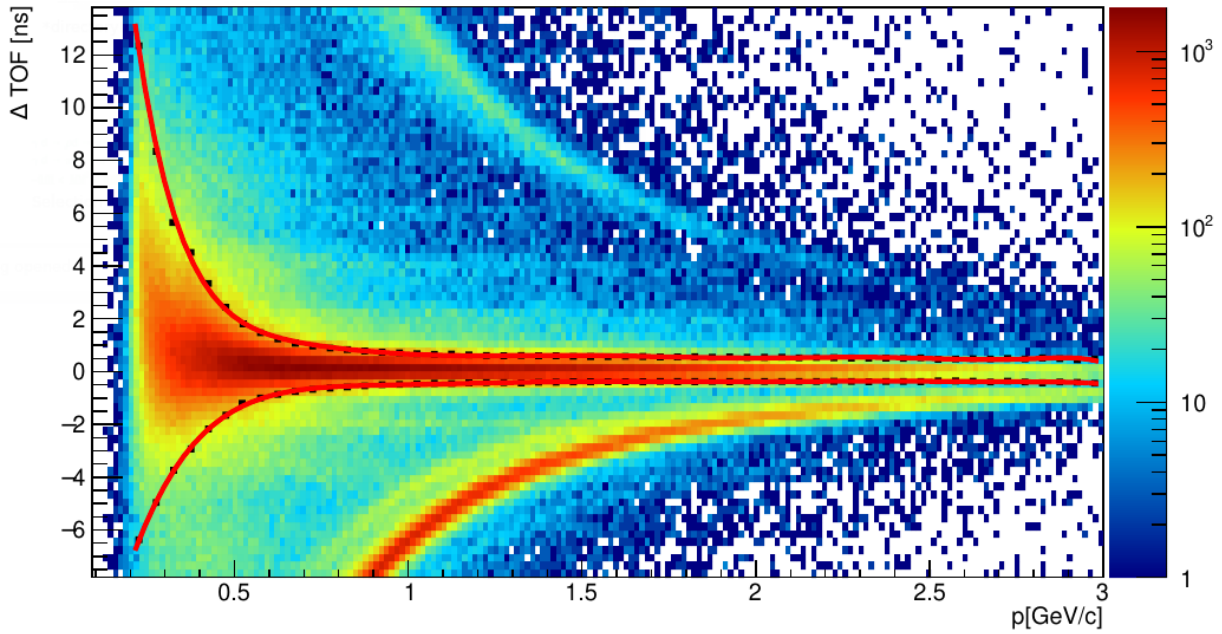
- **Proton track candidates:**
  - Not an electron or a positron.
  - +vely charged
  - Responses in both DC and SC with valid status flag.

- **TOF:**

$$T_{meas} = T^{p}_{sc} - T_{trig}$$

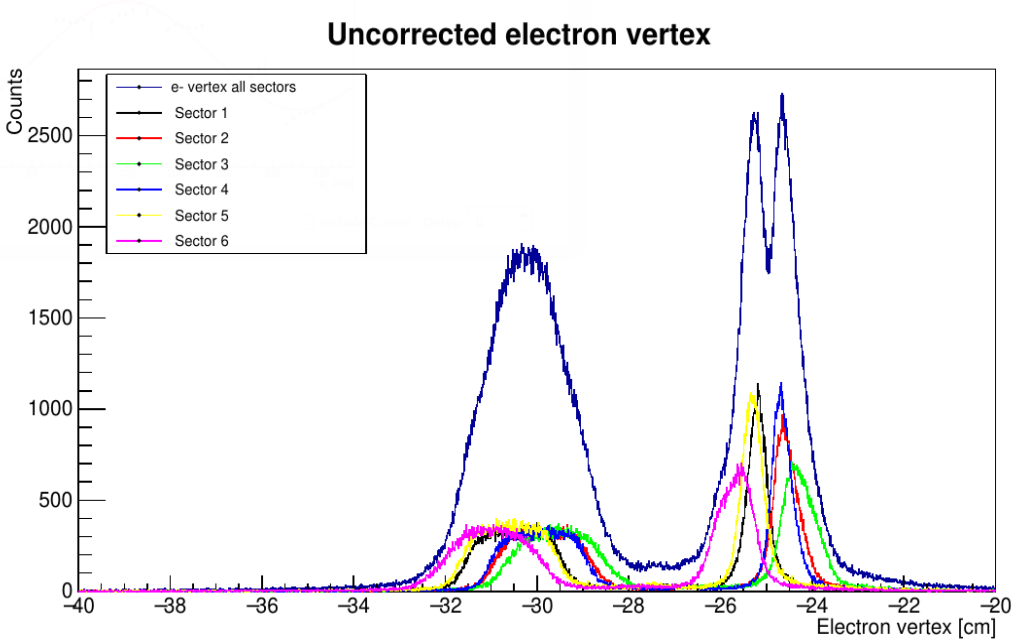
$$T_{calc} = \frac{R^{p}}{c} \frac{\sqrt{|\vec{p}^{2}| + m_{p}^{2}}}{|\vec{p}|}$$

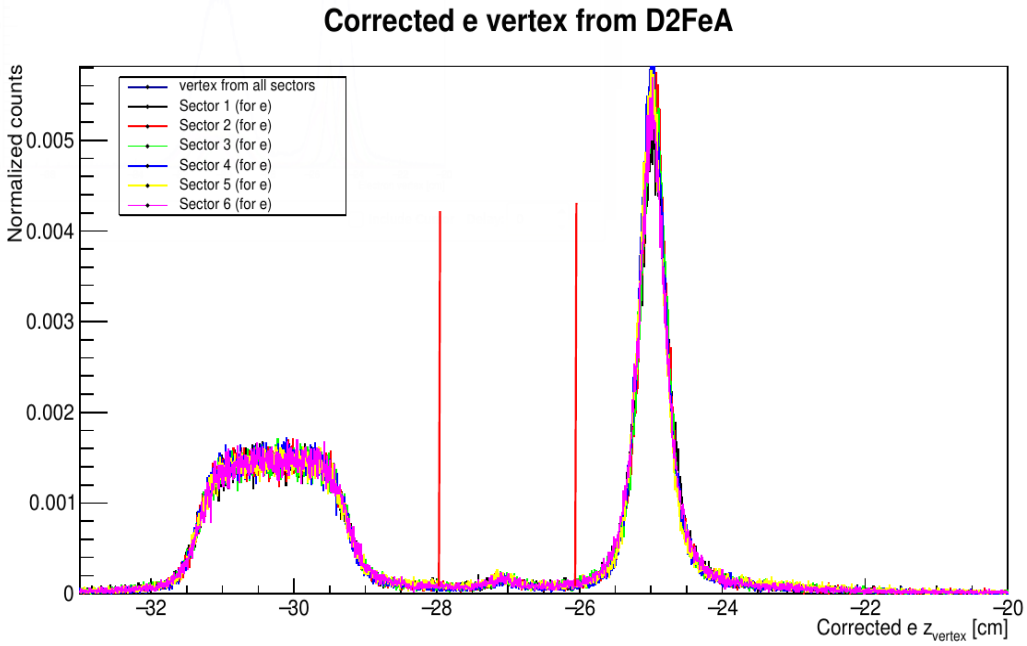
$$\Delta TOF = T_{meas} - T_{calc}$$



Reaction Vertex Correction

- Multiple targets: Necessary to correctly reconstruct reaction vertex
- Electron vertex correction:

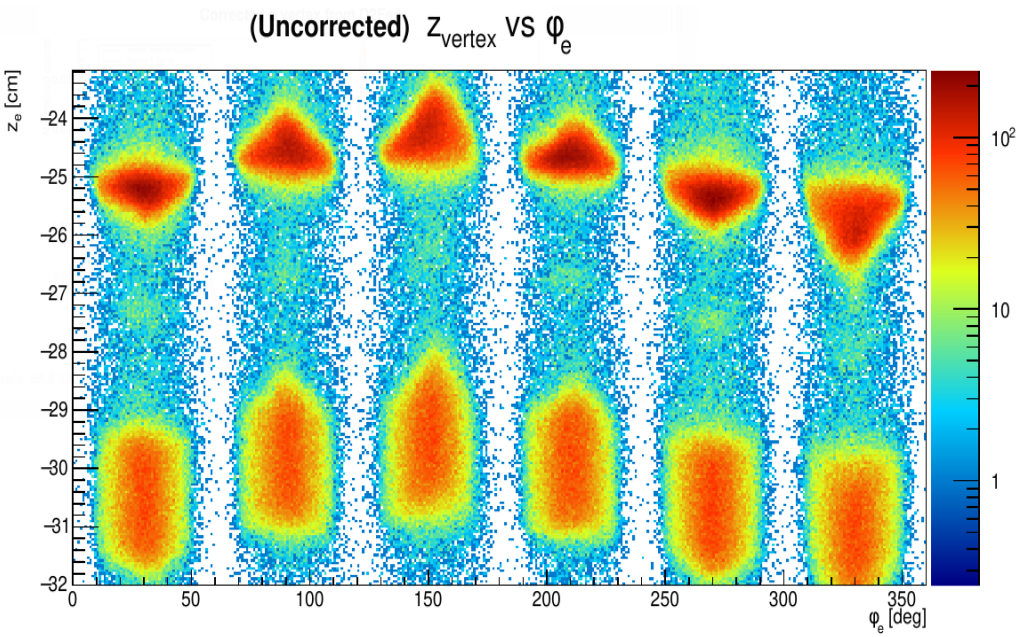


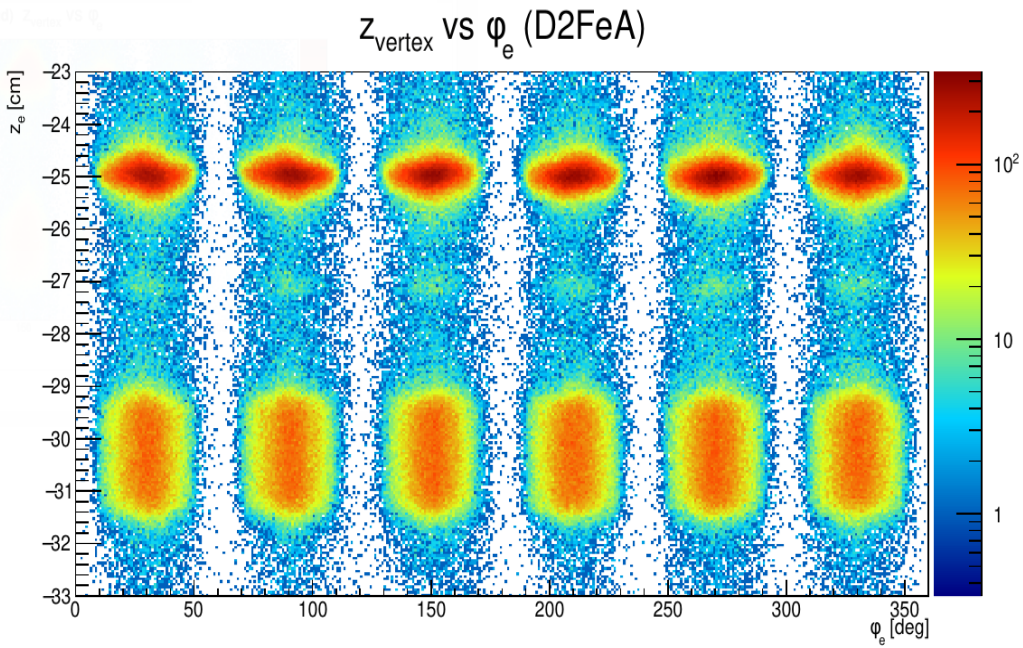


- The blue curve is for all sectors and other colors indicate different sectors.
- Both plots are using D_2Fe (A) dataset.

Reaction Vertex Correction

- Multiple targets: Necessary to correctly reconstruct reaction vertex
- Angular dependence: φ_e

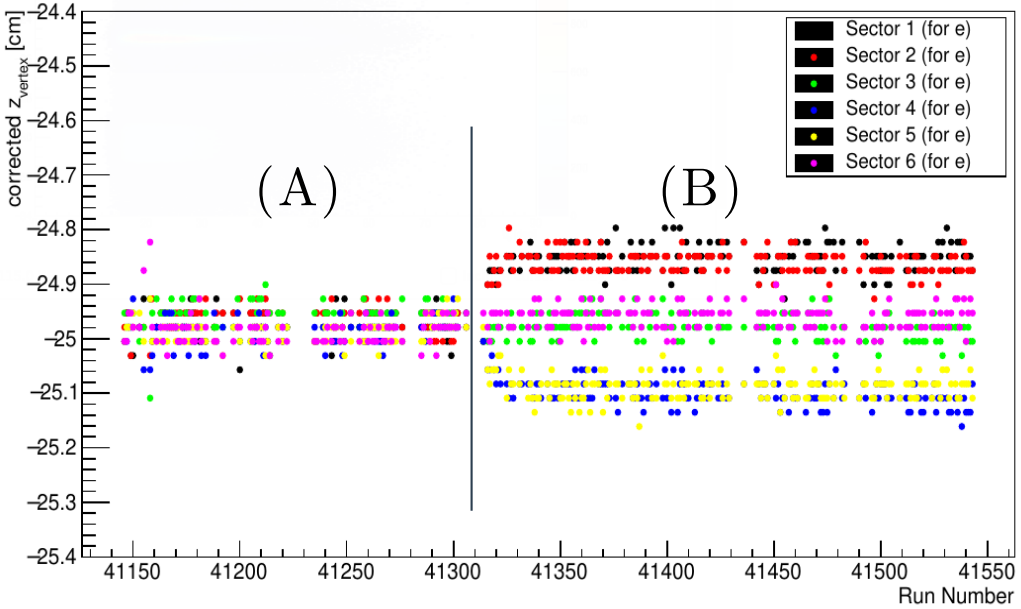


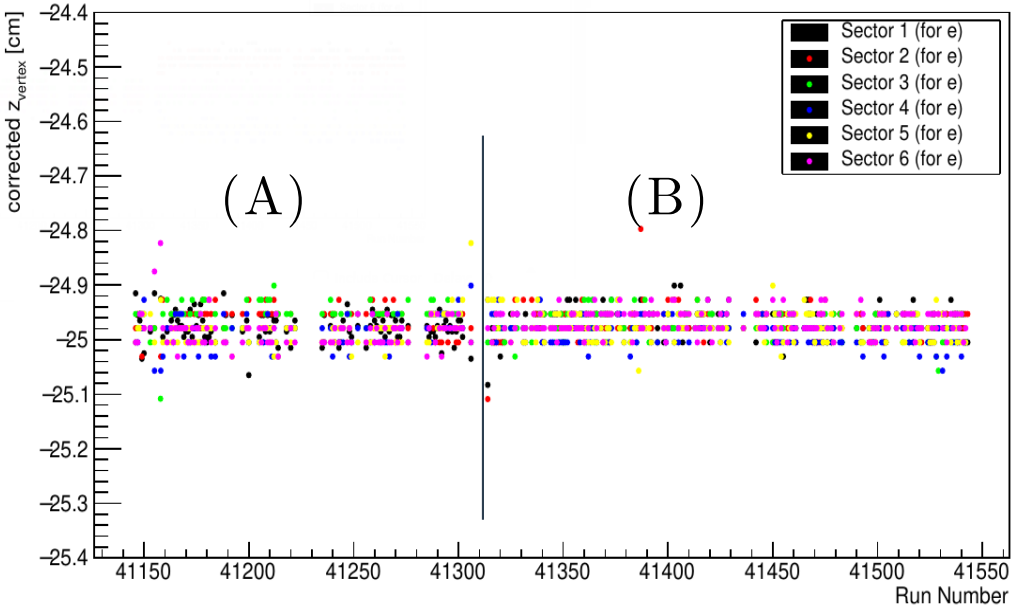


- Angular dependence of electron vertex without and with the correction applied.
- Both plots are using D_2Fe (A) dataset.

Reaction Vertex Correction

- Multiple targets: Necessary to correctly reconstruct reaction vertex
- Run Consistency

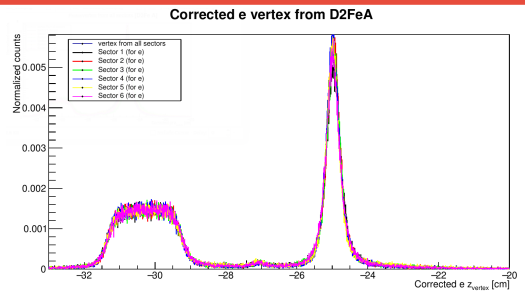


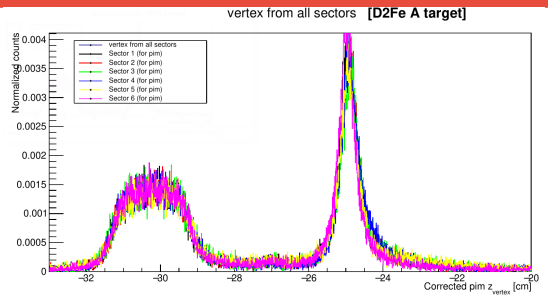


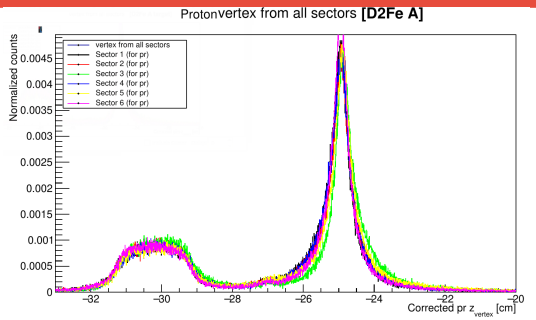
- To correct for possible beam misalignment during the run period, eg2 D_2Fe dataset was divided into two. Correction was applied separately (New vertex parameters for D_2Fe(B)).

Reaction Vertex Correction

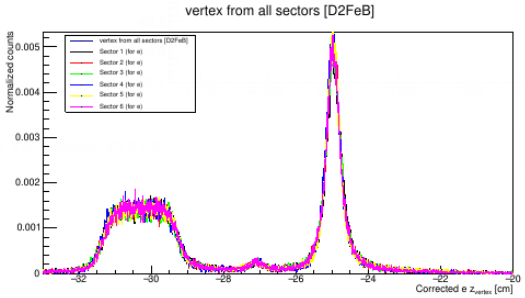
D_2Fe (A)

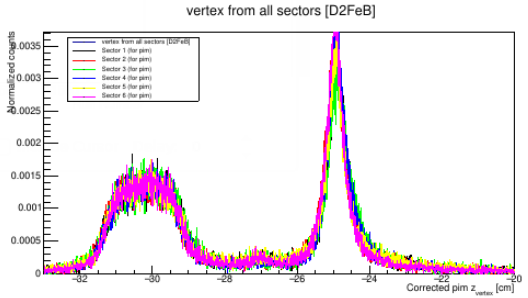


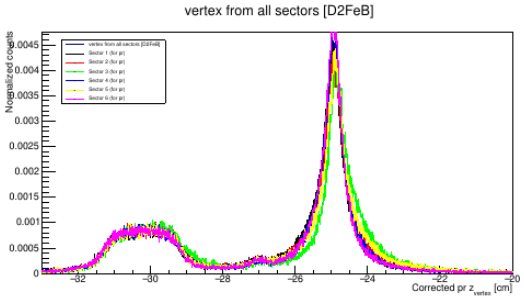




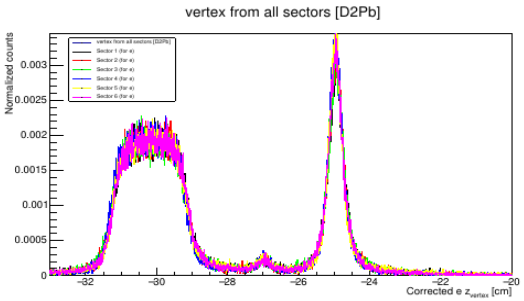
D_2Fe (B)

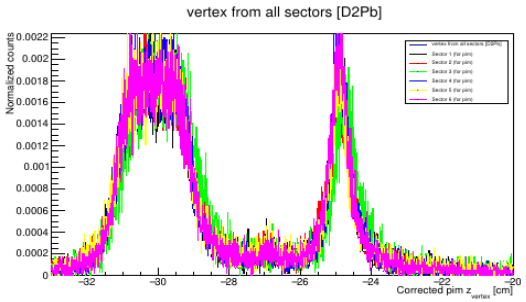


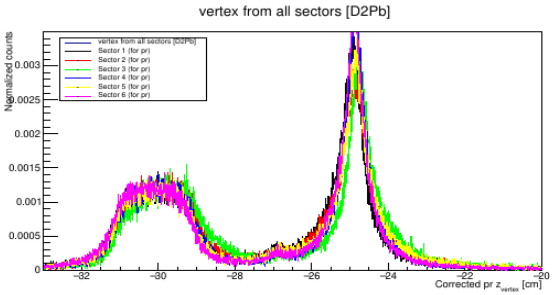




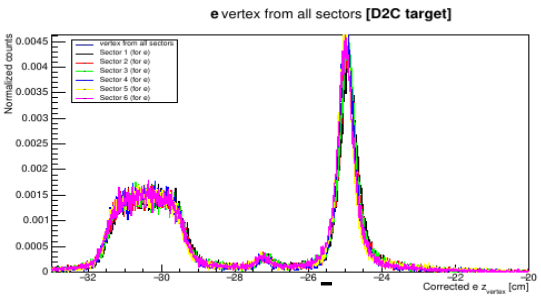
D_2Pb



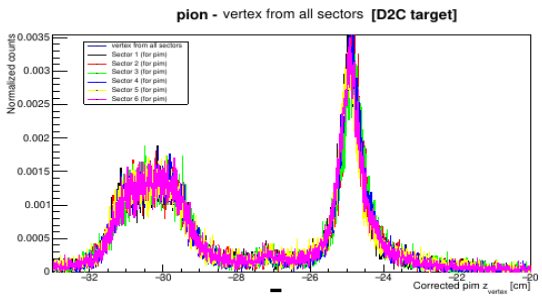




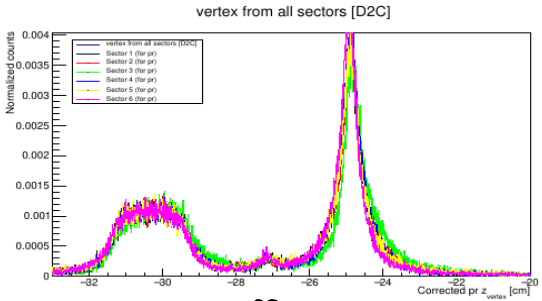
D_2C



e^-

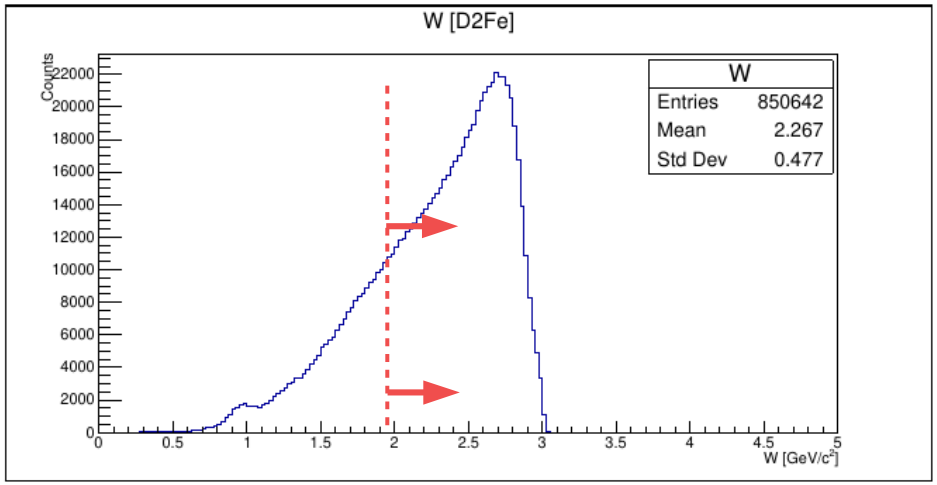


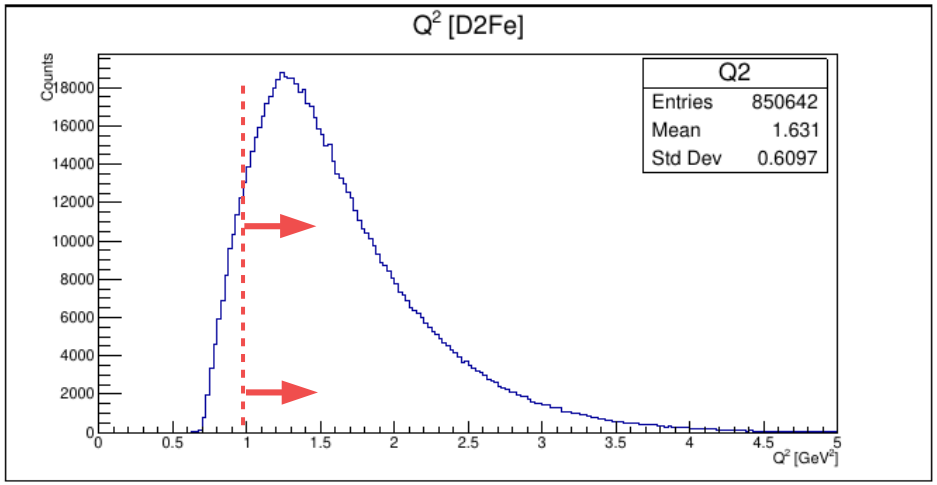
π^-

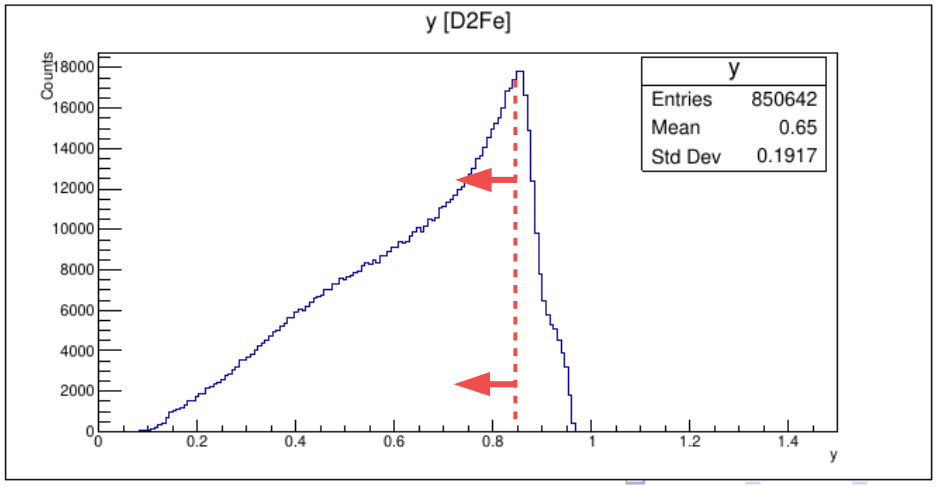


p

Selection of SIDIS Events: Kinematic Cuts



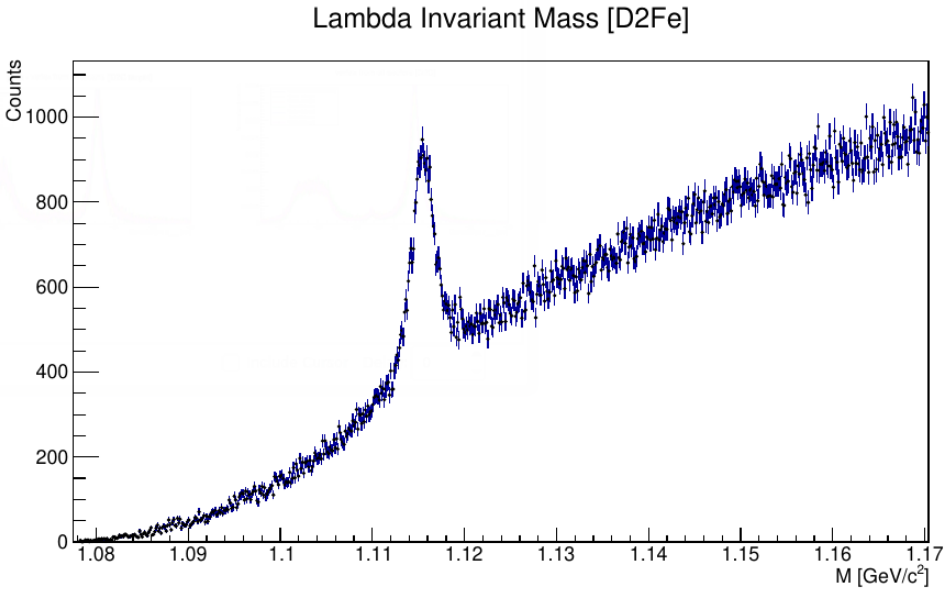


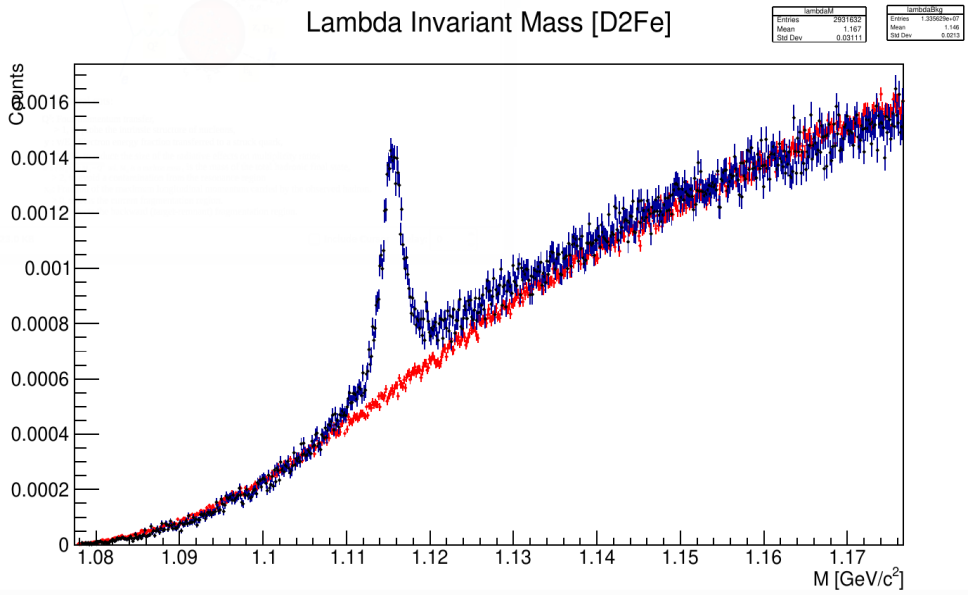


- $Q^2 > 1$ (4-momentum transfer)
- W > 2 (Hadronic mass)
- y < 0.85 (Struck Quark Energy Fraction)

Signal: Λ

- $\Lambda \rightarrow \pi^- + p$

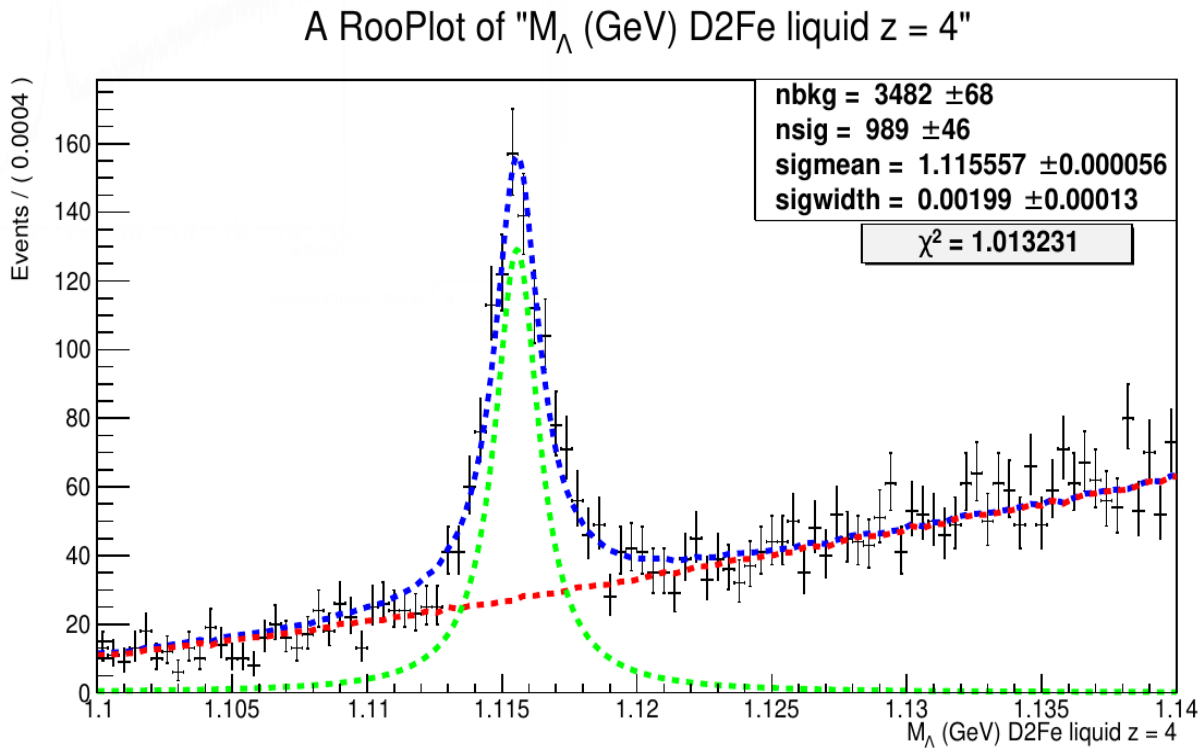




- Fit Polynomial (for background) + Breit-Wigner (for signal) or other similar combinations.
- **Event mixing/combinatorial background and Breit-Wigner combined using side matching.**
- Event mixing/combinatorial background and Breit-Wigner combined using χ^2 minimization (RooFit).

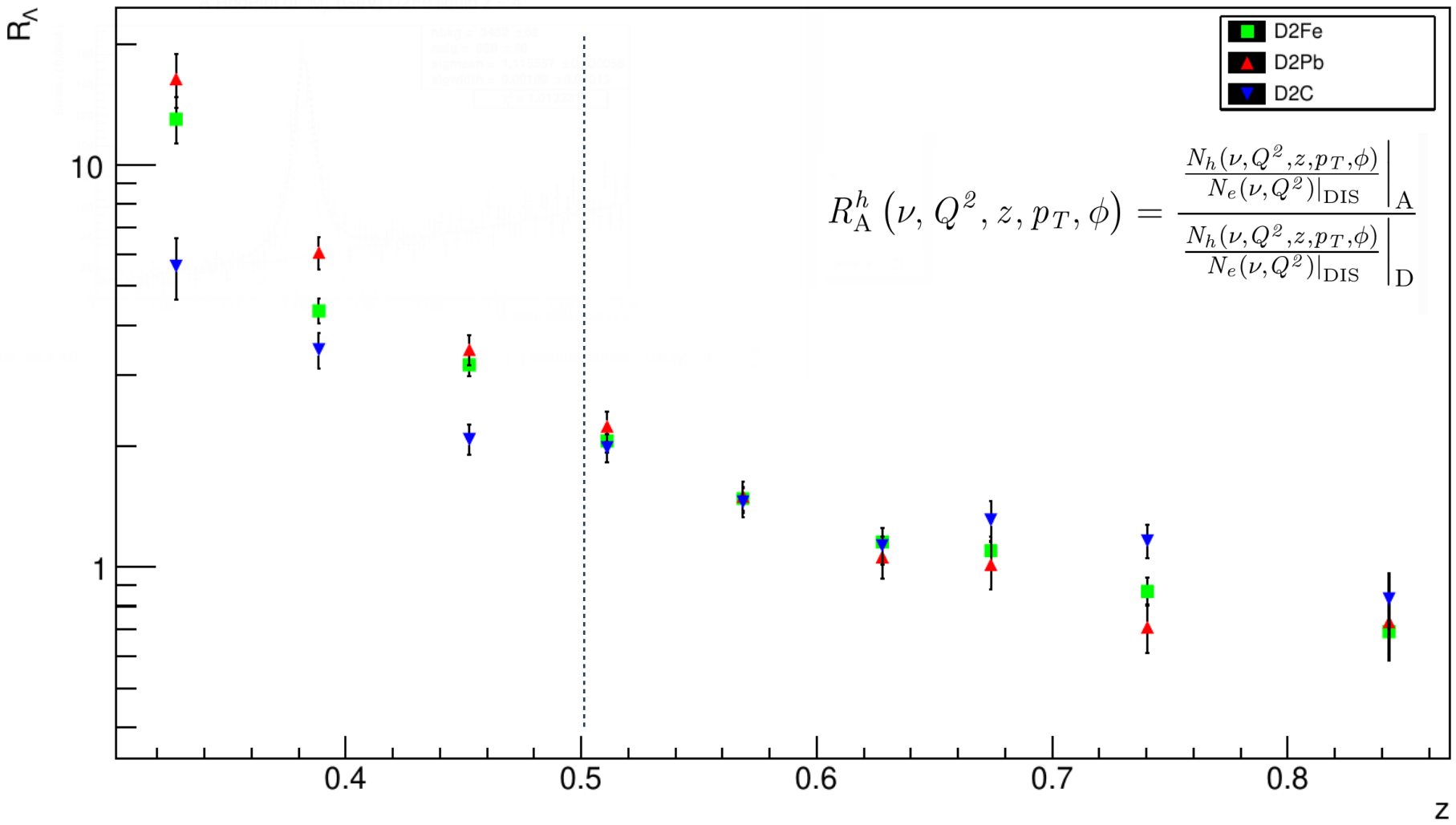
Signal Fitting: Λ

- $\Lambda \rightarrow \pi^- + p$



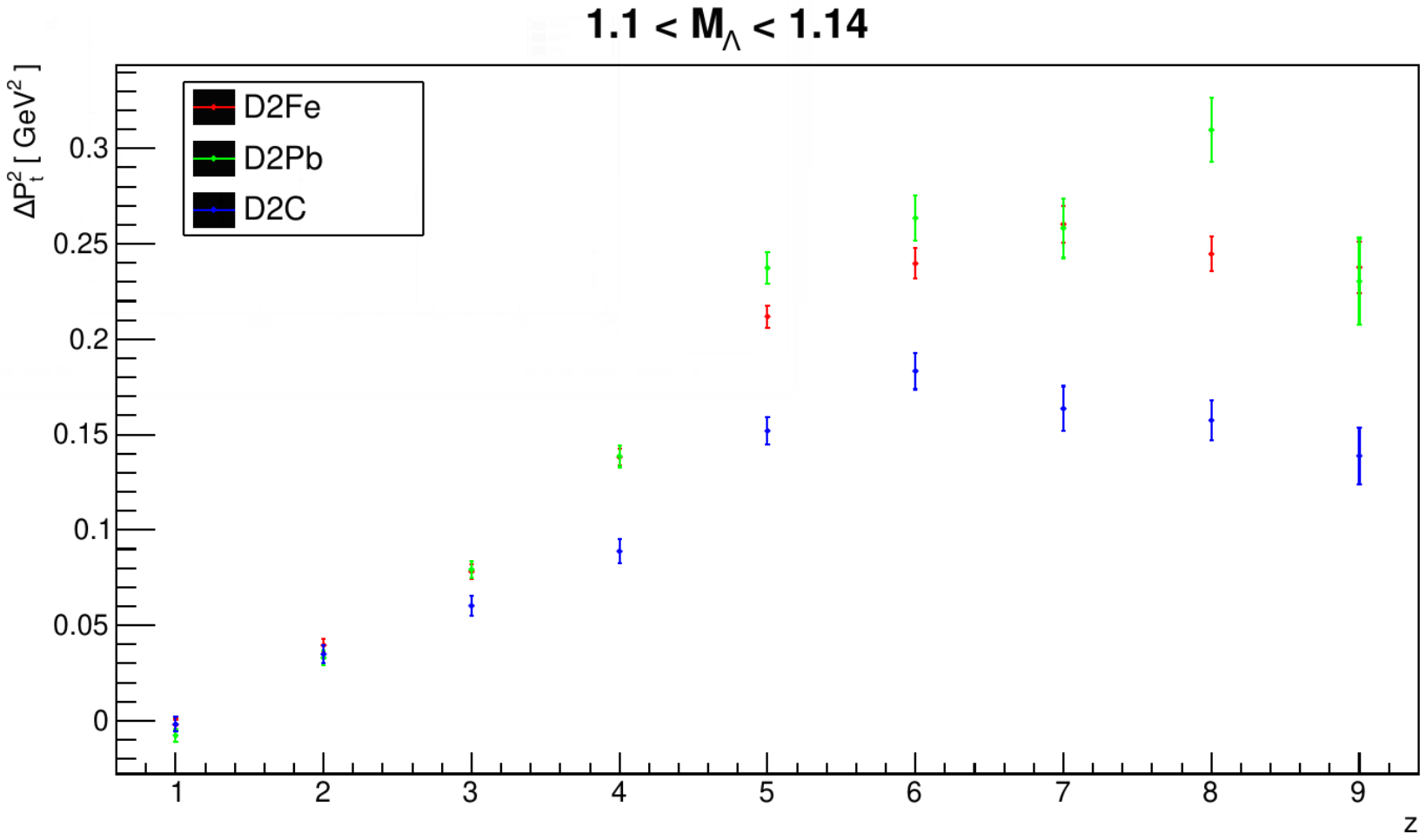
- Invariant mass distribution (+ + +) in z-bins. Sample bin shown for D_2 in dual target D_2Fe set up.
- Fit (- - -), Combinatorial background (- - -), Breit-Wigner (- - -)
- **Event mixing/combinatorial background and Breit-Wigner combined using χ^2 minimization (RooFit).**

- **Multiplicity ratio:**

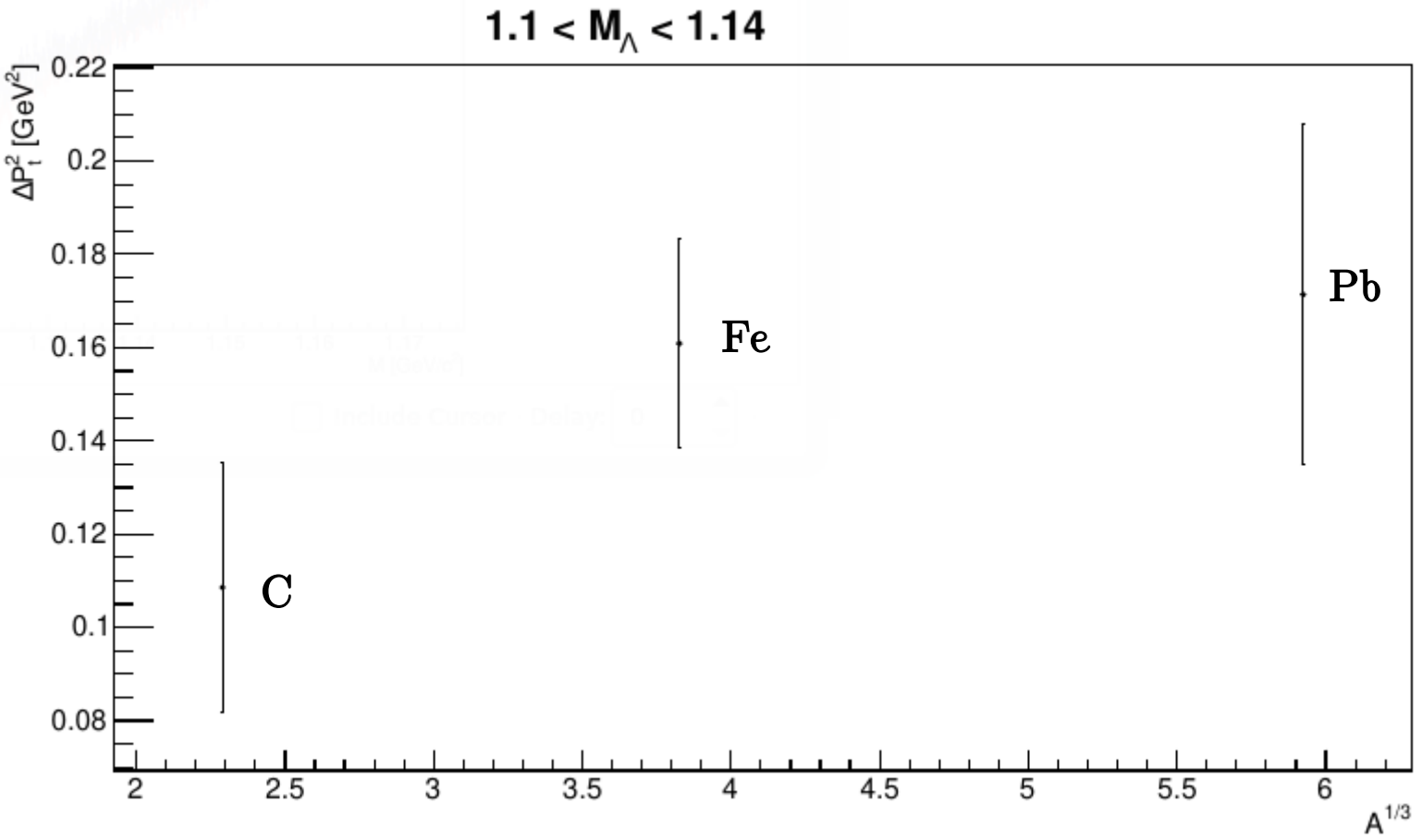


Target Fragmentation region current Fragmentation region

- Transverse Momentum Broadening:



- **$A^{1/3}$ dependence:**
  - Integrated transverse momentum broadening as a function of $A^{1/3}$.

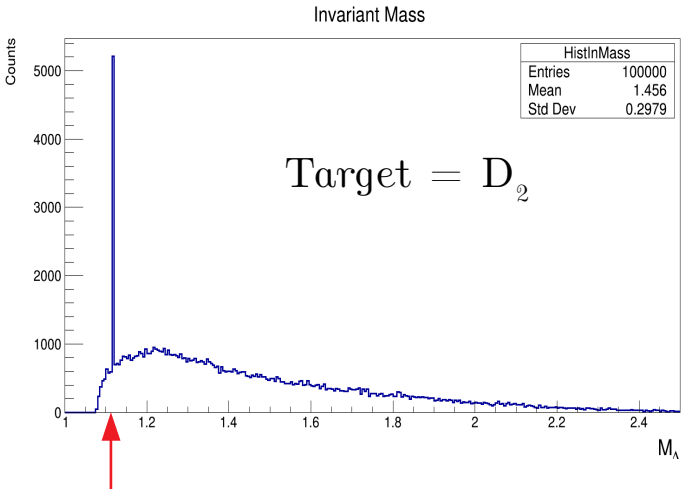


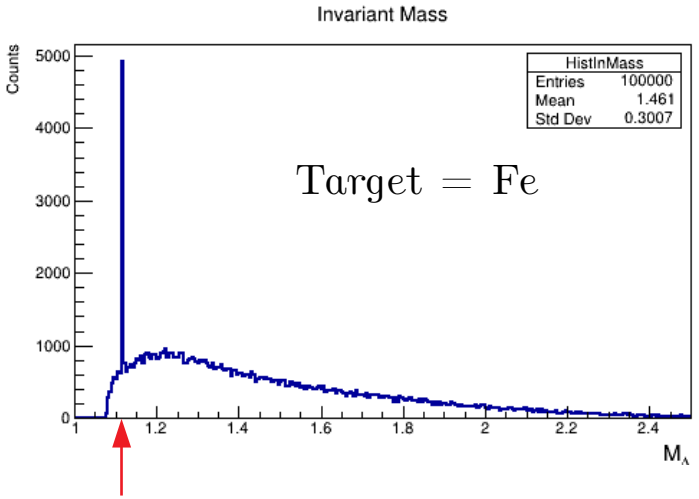
Validation of PYTHIA event generator

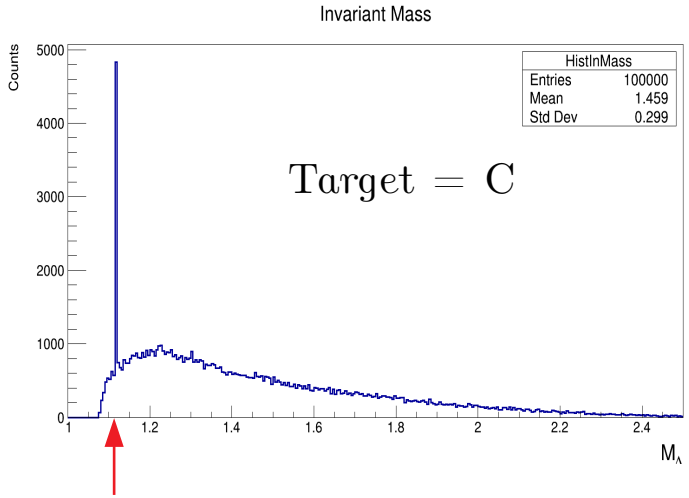
- Ebeam = 5.014 GeV
- Target options = D_2, Fe, C, Pb
- Fermi motion of nucleons included (LHAPDF)
- Generator provided by Ahmed El Alaoui.
- Current effort to reconstruct the Lambda invariant mass.

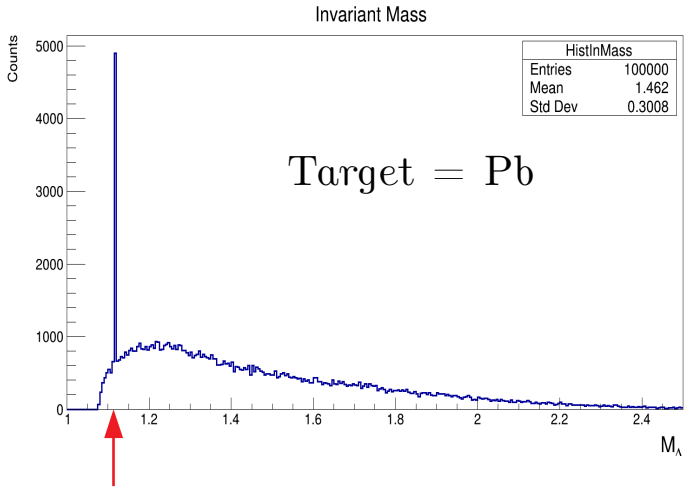
Validation of PYTHIA event generator

- Ebeam = 5.014 GeV









$M_\Lambda = 1.1156$ GeV

Summary

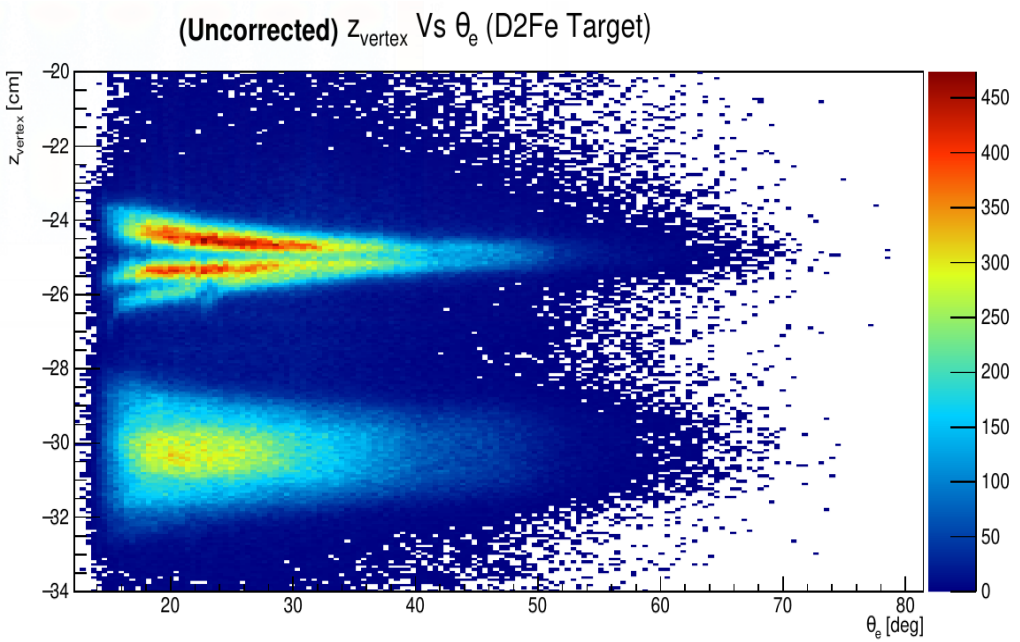
- **Hadronization study is a direct probe of QCD.**
- **EG2 data set: 'Gem' dataset for hadronization and many other studies.**
- **Updates on current analysis performed by previous MSU group member.**
- **Preliminary results for Multiplicity ratios for Fe, C and Pb targets.**
- **Preliminary Transverse Momentum Broadening.**
- **Next steps would include:**
  - Acceptance corrections: GSIM + GPP + RECSIS
    - Compare simulated to experimental data
  - Radiative corrections.
  - Systematic Studies: such as PID, etc.
  - Study other dependencies of R_A, P_T^2, Cronin effect, etc.

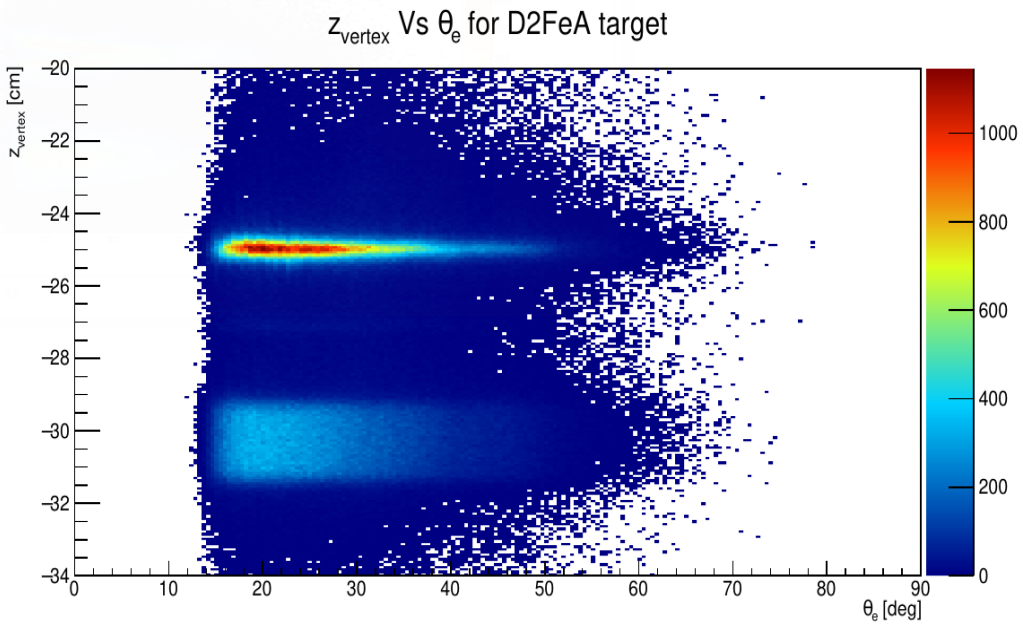
Thank you!!

Extras

Reaction Vertex Correction

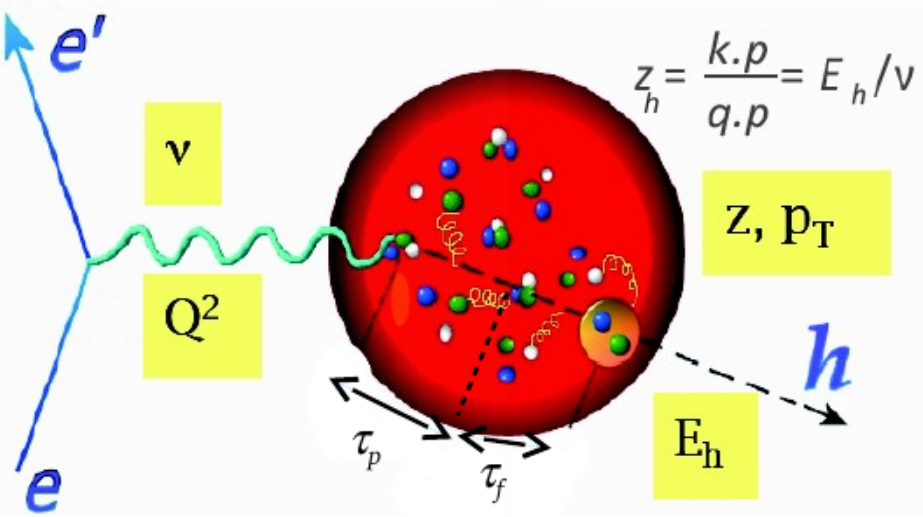
- Multiple targets: Necessary to correctly reconstruct reaction vertex
- Angular dependence: θ_e





- Angular dependence of electron vertex without and with the correction applied.
- Both plots are using D_2Fe dataset.

SIDIS



Kinematical cuts:

Q^2: Four-momentum transfer,
> 1, to probe the intrinsic structure of nucleons,

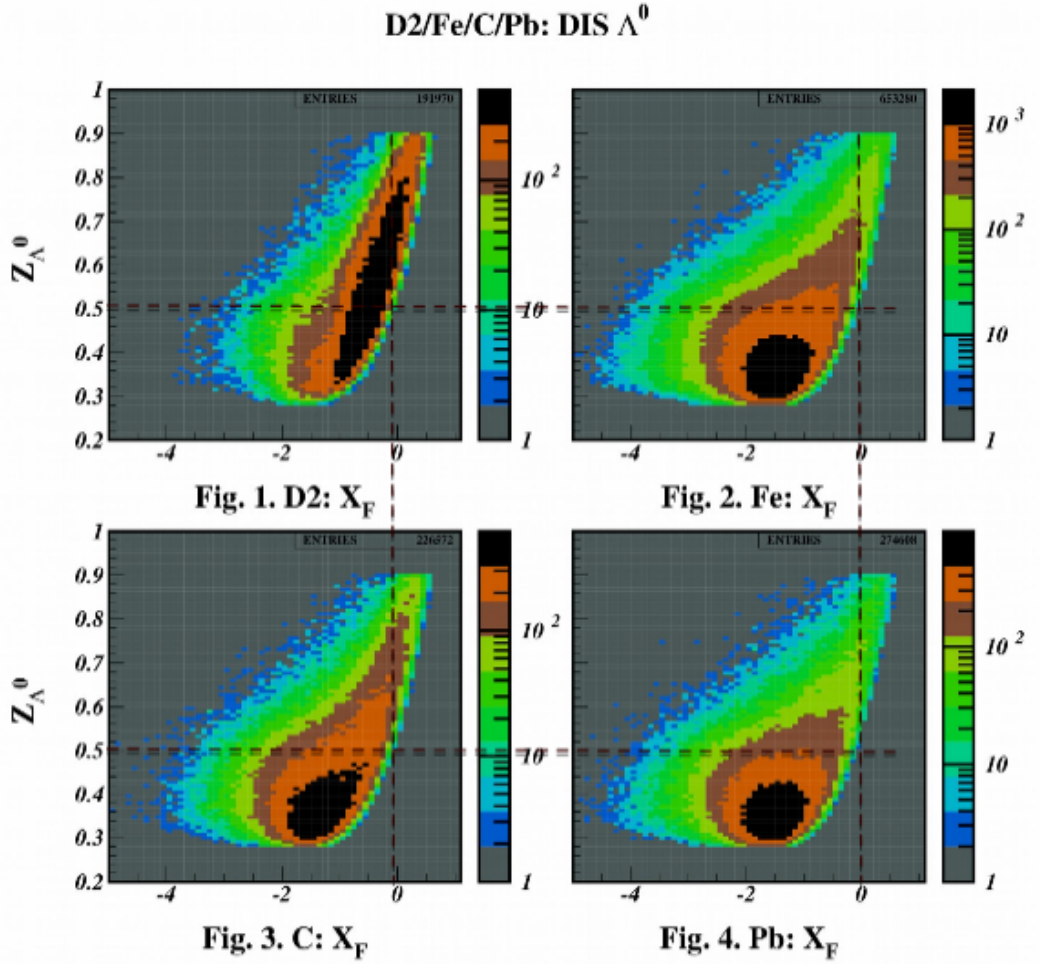
y : ν/E_h, Electron energy fraction transferred to a struck quark,
< 0.85, to reduce the size of the radiative effects on multiplicity ratios

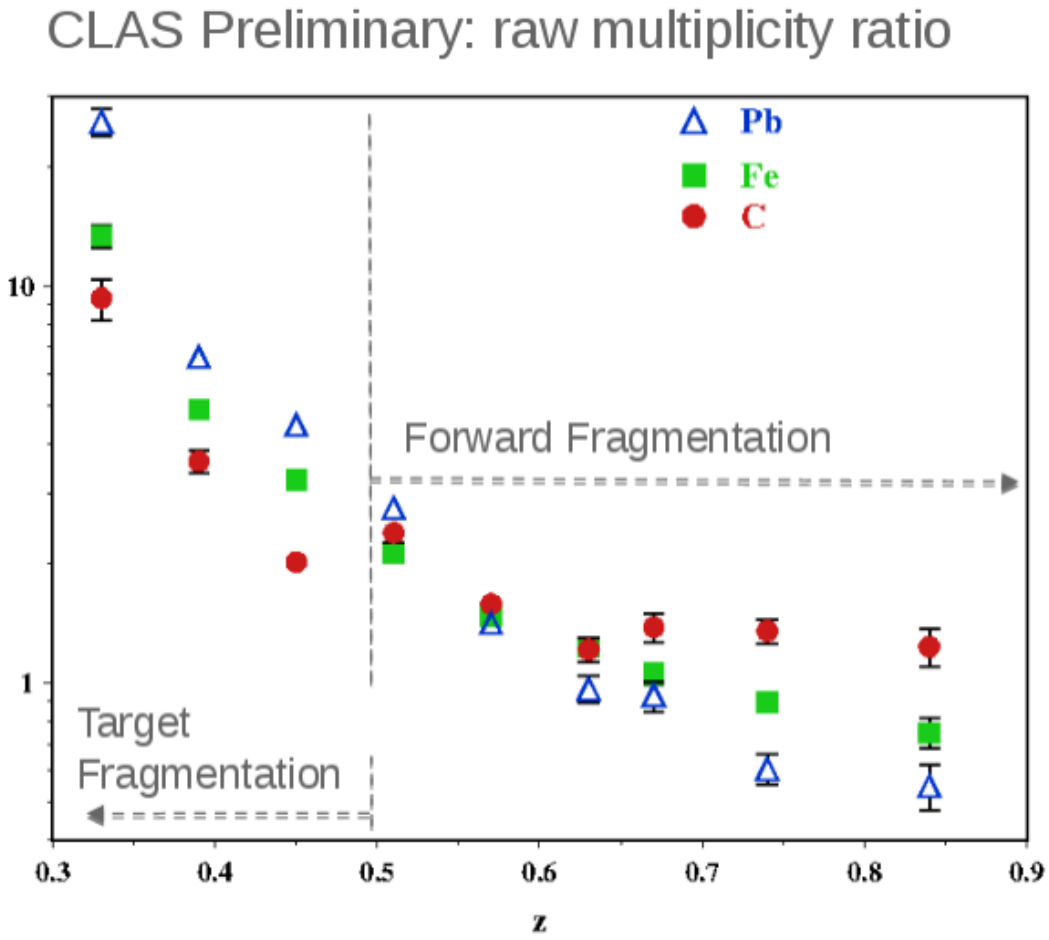
$W : \sqrt{M_n^2 + 2\nu M_n - Q^2}$ *w/.* M_n *is a nucleon mass*, is the mass of the total hadronic final state,
> 2, to avoid a contamination from the resonance region

x_F: Fraction of the maximum longitudinal momentum carried by the observed hadron.
> 0, selects the current fragmentation region.
< 0, selects the backward (target-remnant) fragmentation region.

Slide borrowed from Lamiaa, DNP18

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





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