Unfolding Λ Hadronization using CLAS EG2 Data: Updates and Outlook

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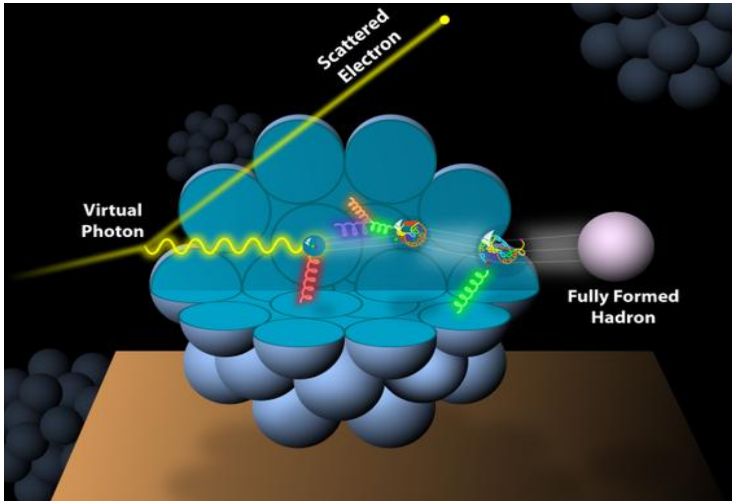
Physics Observables

- **Multiplicity ratio:**

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



Hadronization process

- **Transverse momentum broadening:**

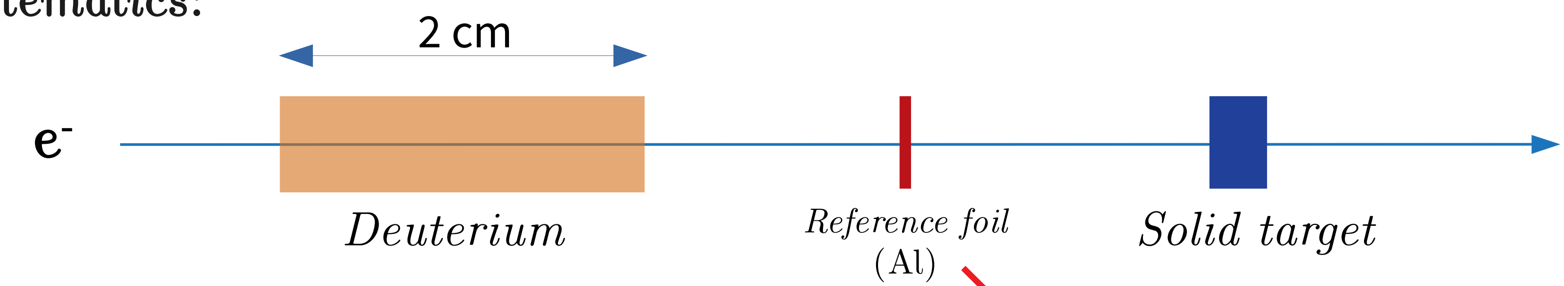
$$\Delta P_T^2 = \langle P_T^2 \rangle_A - \langle P_T^2 \rangle_D$$

D = Liquid Target Nuclei
A = Solid Target Nuclei

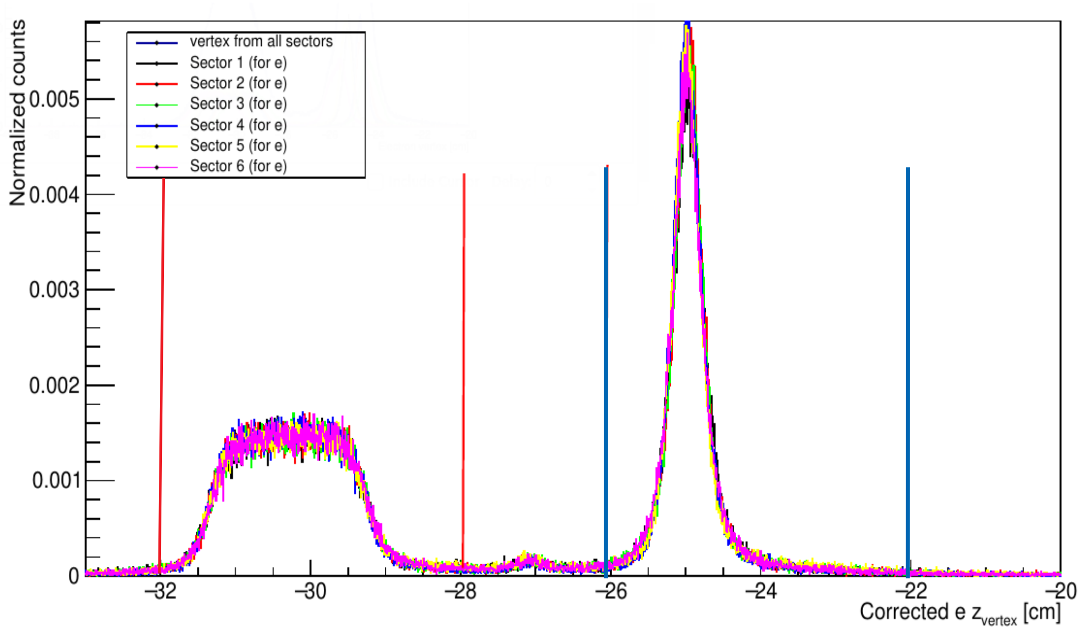
- **Why study them?**
  - The hadronization timescales, i.e., production and formation times.
  - Parton energy loss (related to the p_T broadening).
  - Hadron attenuation (related to $R_A{}^h$).

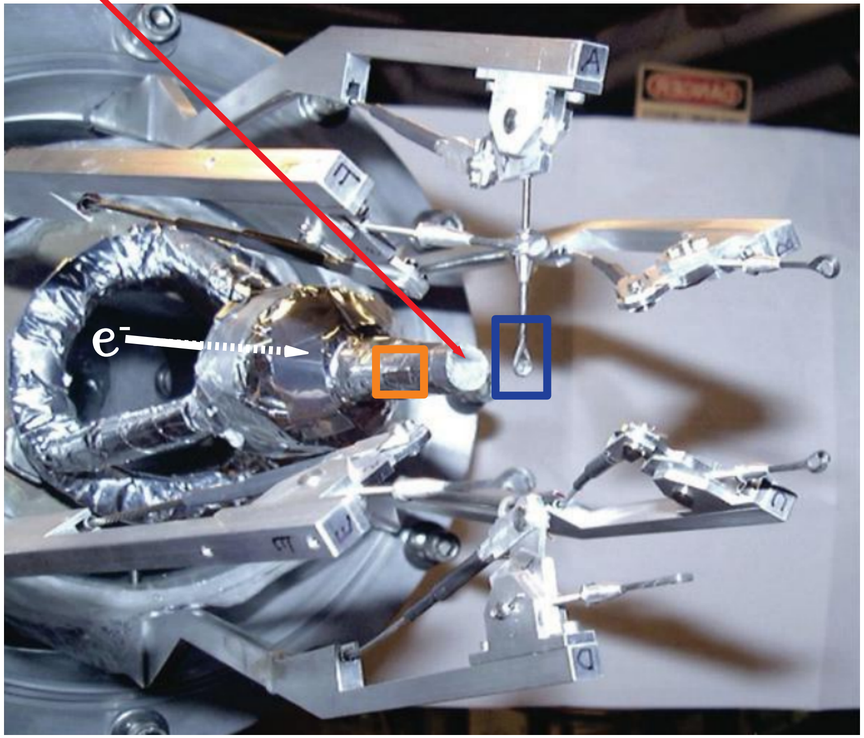
CLAS EG2 Dataset

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

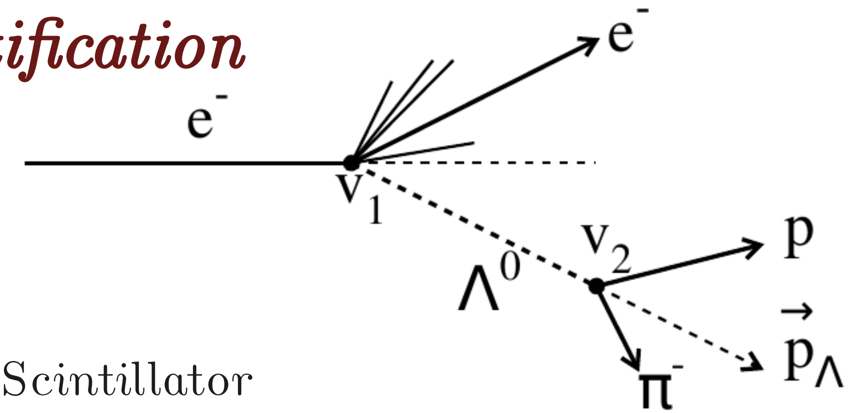


- Beam energy: 5.014 GeV

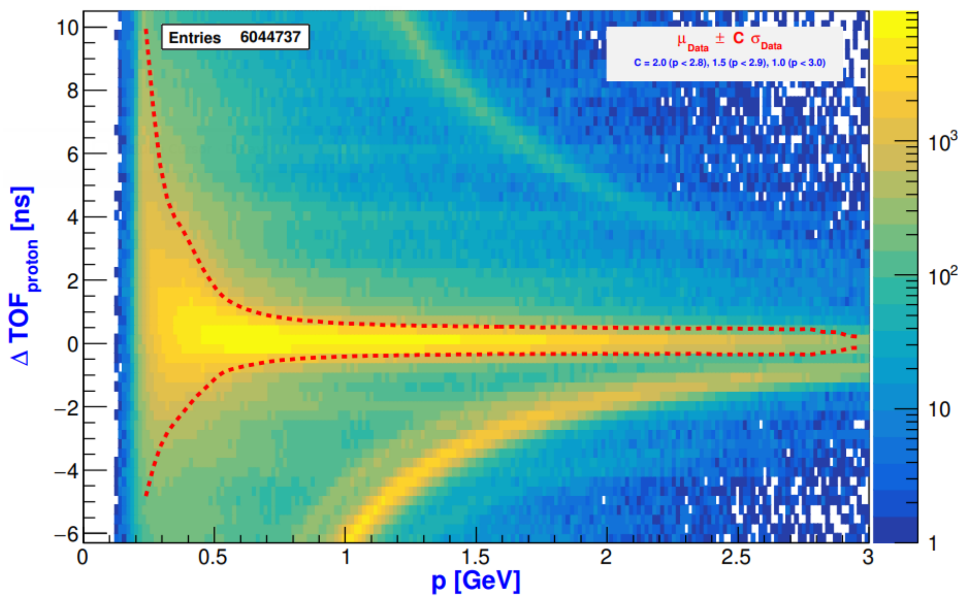




Reaction Channel and Particle Identification



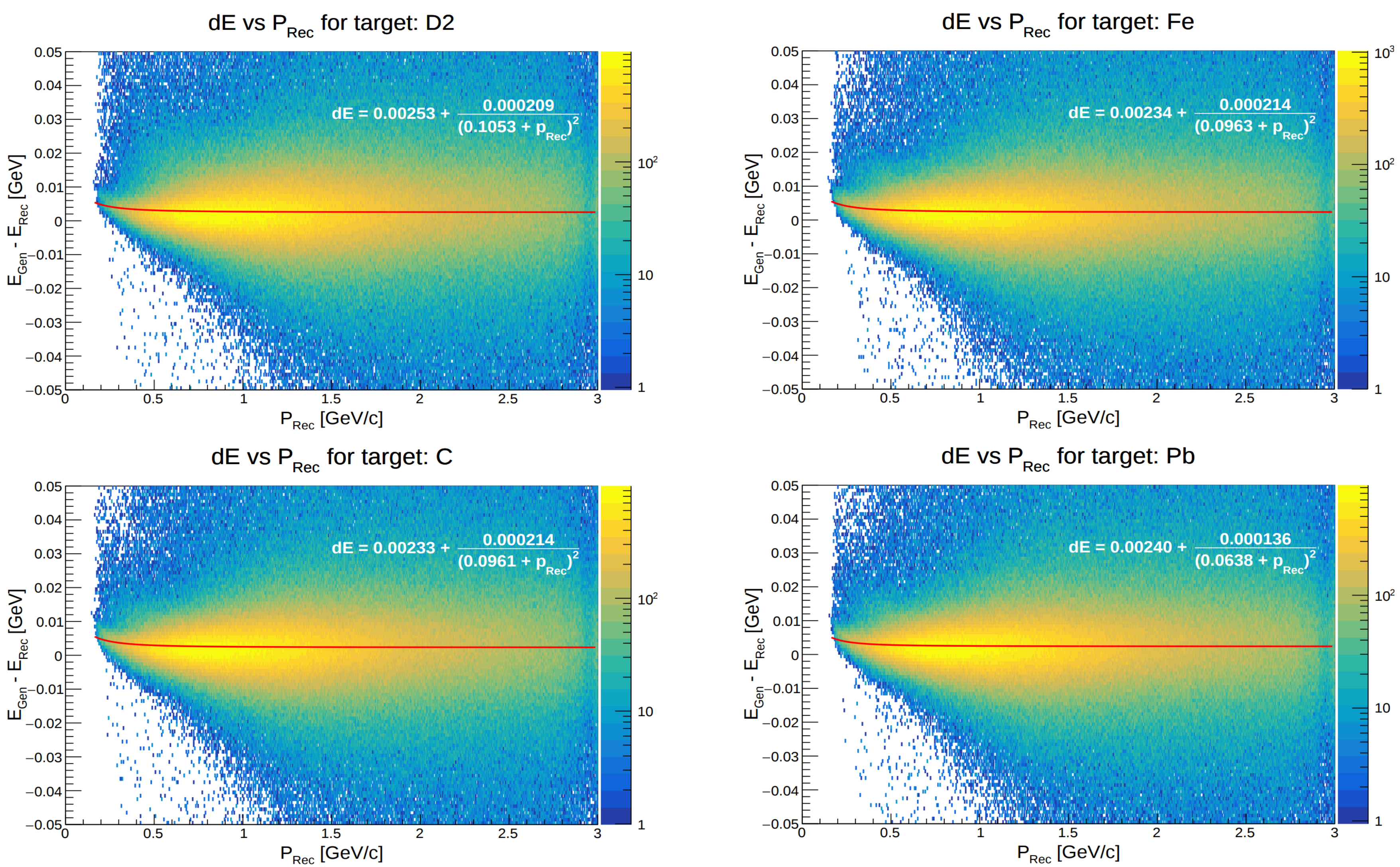
- $e + A \to e' + \Lambda$; where $\Lambda \to \pi^- + p$
  - e^-, π^- : (Method: CLAS-NOTE 2012-001)
  - p : Matching signal in Drift chamber and Scintillator Counters. Momentum dependent time-of-flight cut.



- Kinematic Cuts
  - $W > 2$ GeV $\to$ to avoid contamination from resonance region.
  - $Q^2 > 1$ GeV^2 $\to$ to probe nucleon substructure.
  - $y < 0.85$ (based on HERMES study) $\to$ to reduce the size of radiative effects.

Proton Ionization Energy Loss Correction

- Energy loss, $\mathbf{dE = E_{p,GEN} - E_{p,REC}}$
- A continuous parametrization for the energy loss correction has been developed/extracted as a function of proton momentum.



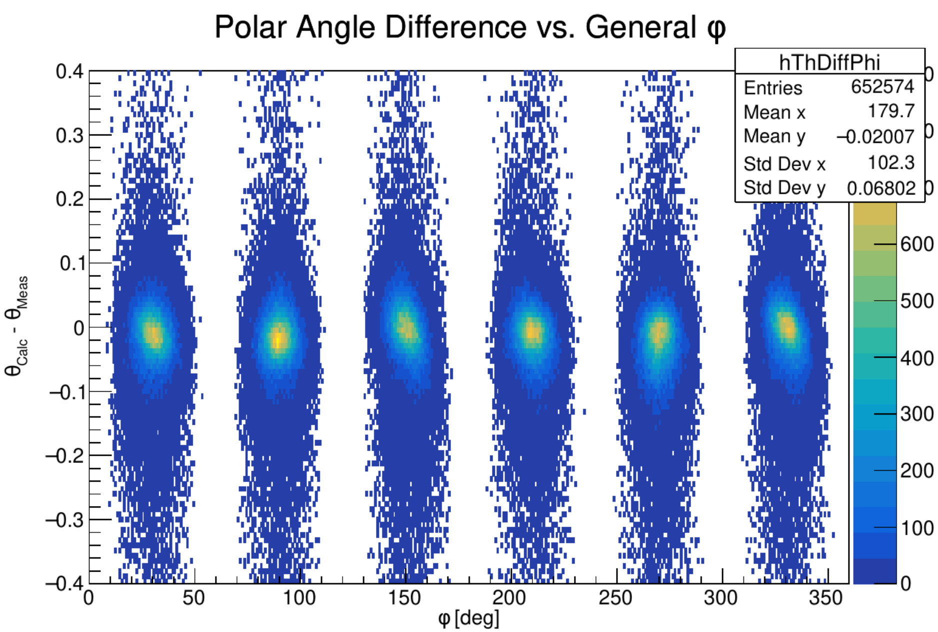
Beam Energy Correction *(using ep elastic reaction, H_2 Dataset)*

- Beam energy:

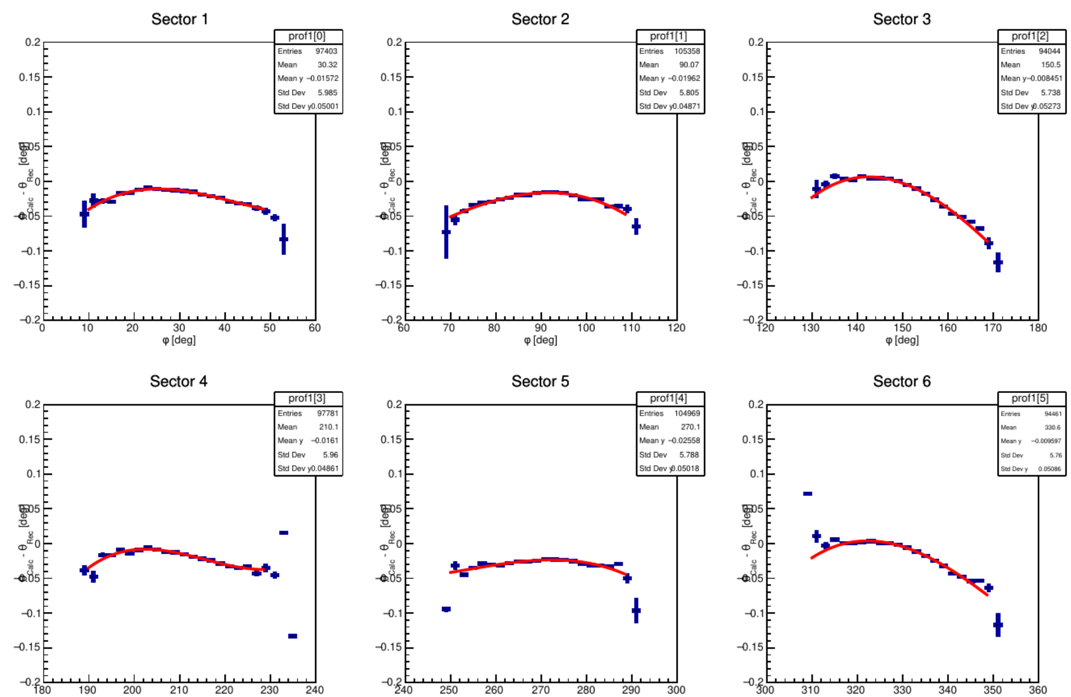
$$E_0 = \frac{M_p}{1-\cos\theta_e}\left(\cos\theta_e + \frac{\sin\theta_e}{\tan\theta_p} - 1\right)$$

where M_p is mass of proton and θ is the polar angle.

- Calculate θ_e assuming θ_p is correct. Compare with measured θ_e as a function of φ_{ep}.

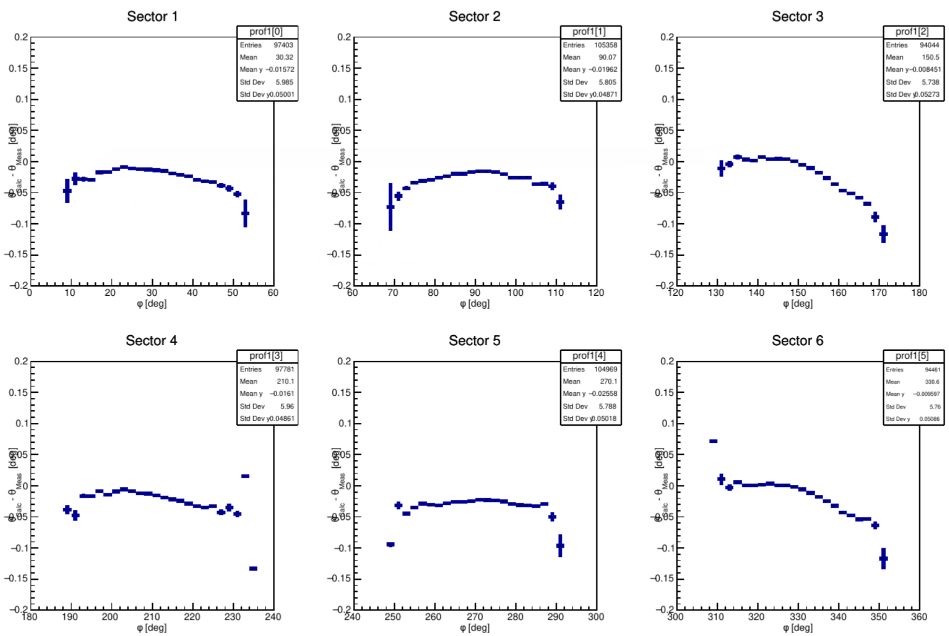


profiles

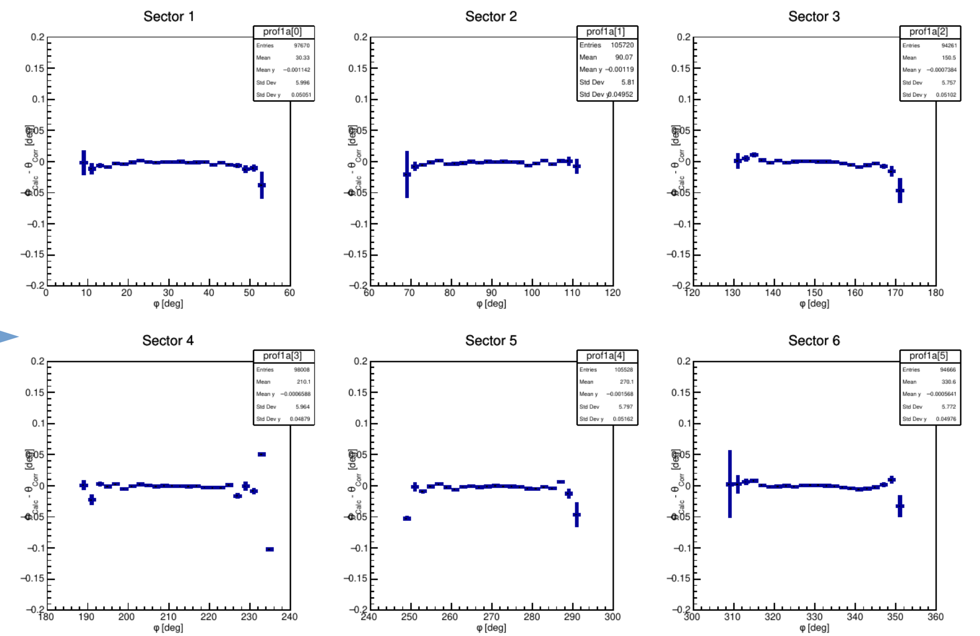


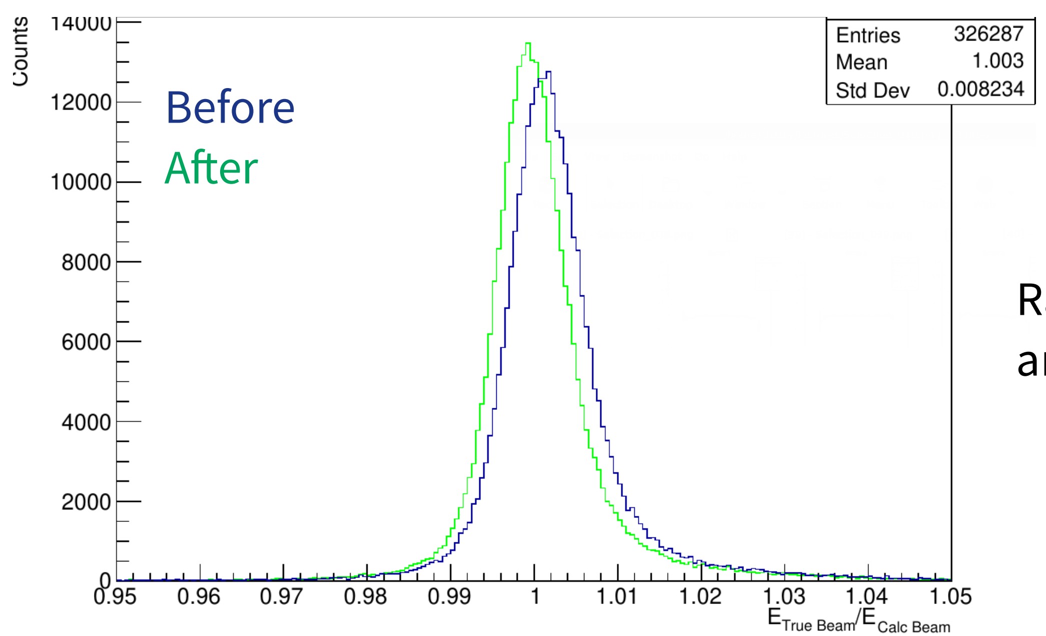
Beam Energy Correction *(using ep elastic reaction, H_2 Dataset)*

- Comparison



corrected





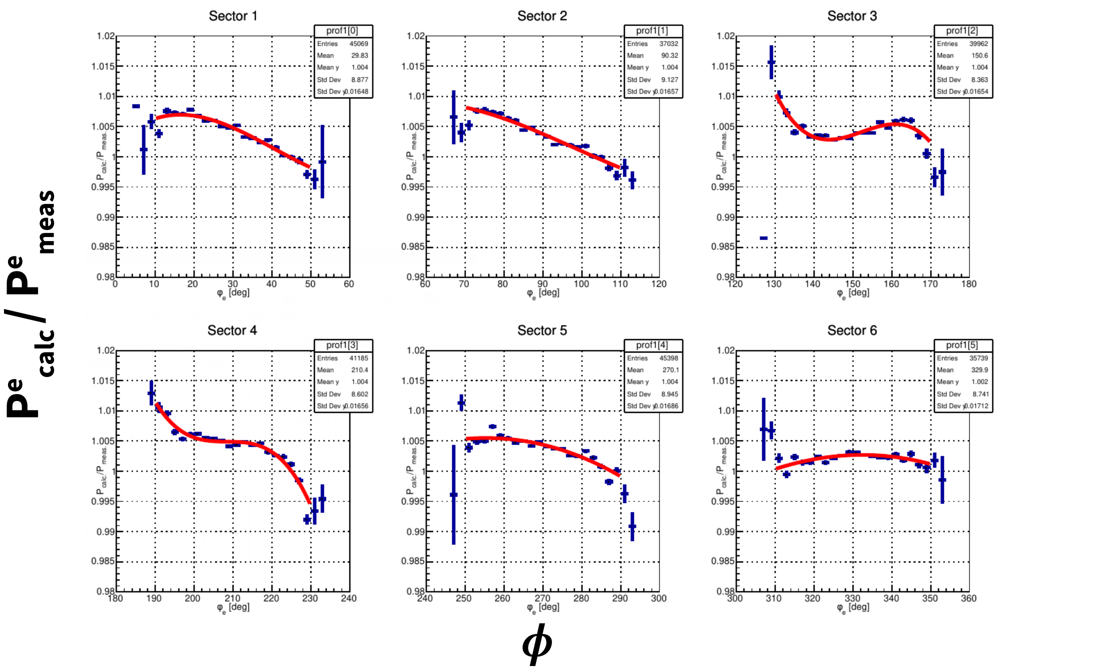
Ratio of beam energy (true) and calculated beam energy

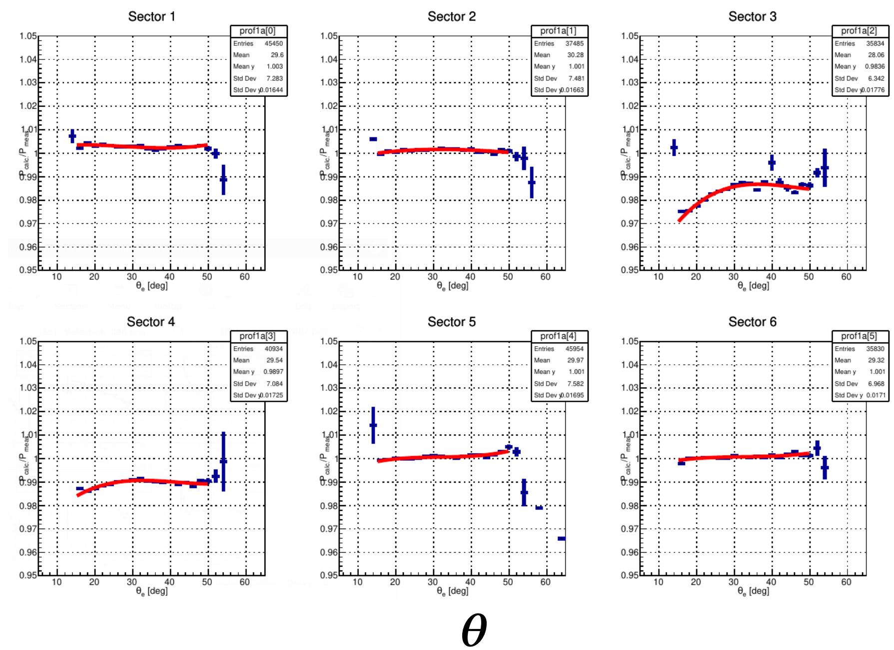
Electron Momentum Corrections

- Using elastic events from DIS events, coplanar **e-** and **p** are selected.
- Electron energy: $$E_f = \frac{E_i}{1 + E_i(1-\cos\theta_e)/M_p}$$

E_i is the beam energy calculated from corrected scattering angles.

- Extract f(ϕ_e) and g(θ_e): $$\frac{P_{e,calc}}{P_{e,meas}} = f(\phi) \times g(\theta)$$

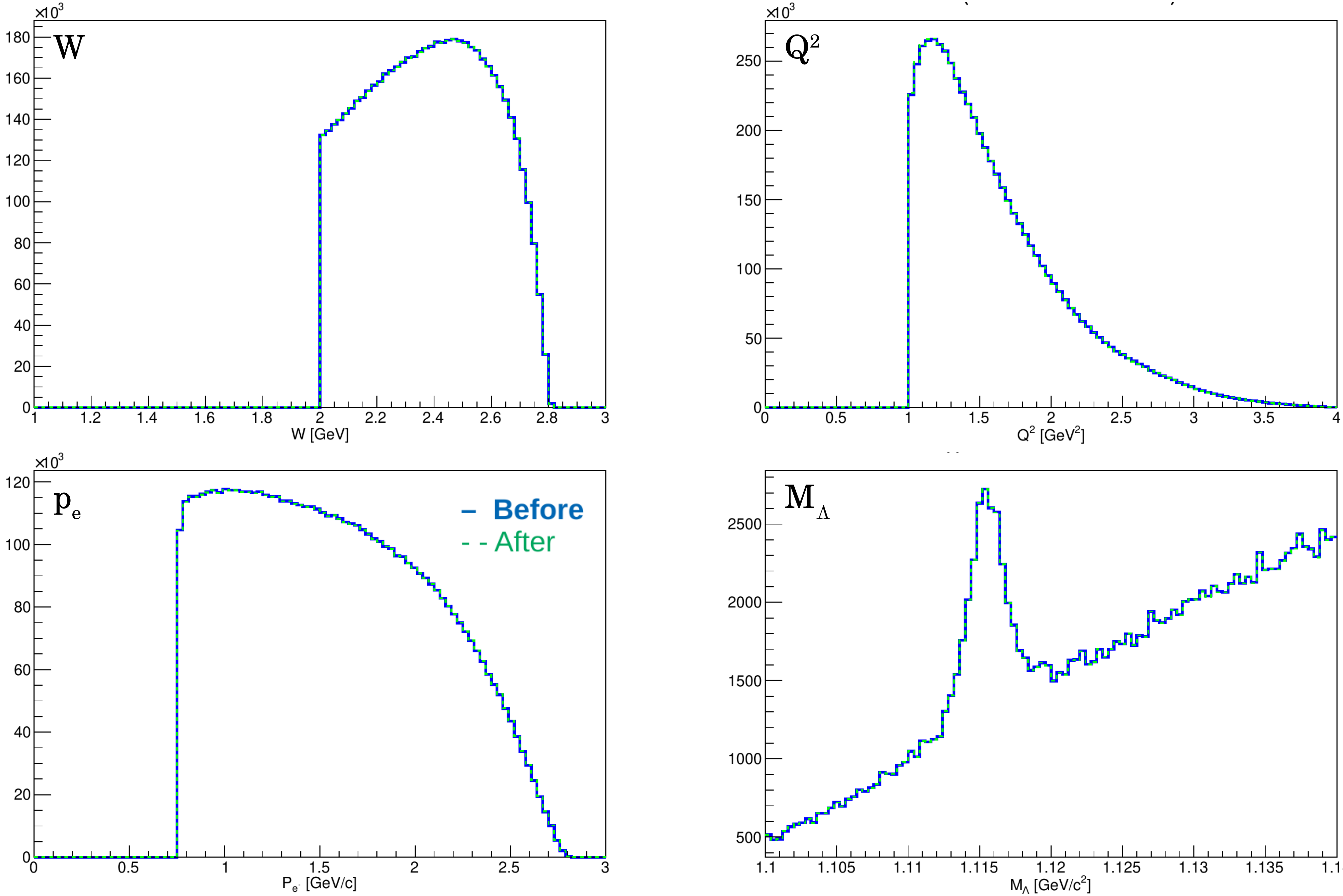




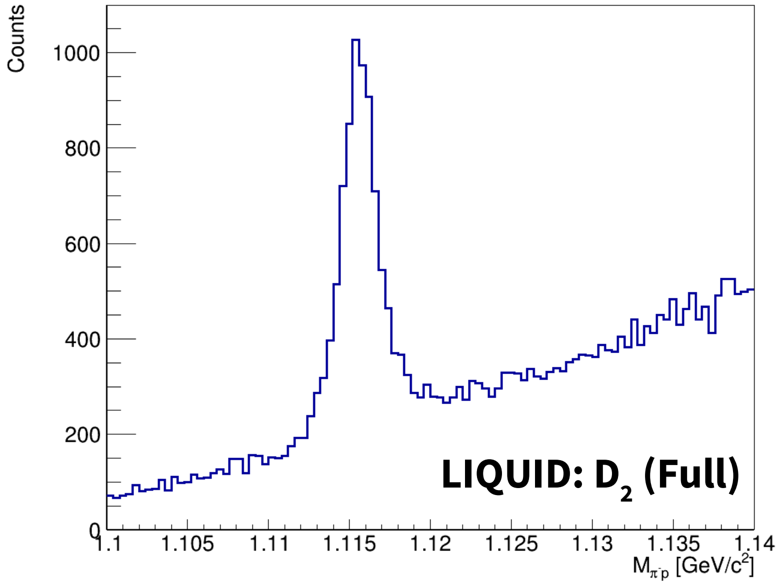
References:

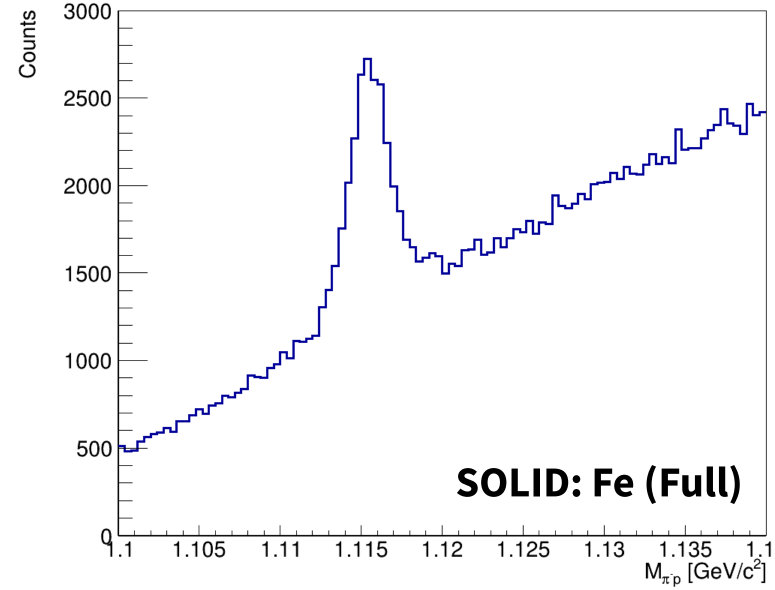
1. EG2 Data-Mining Analysis Note (B. Schmookler) 2018
2. Kinematic Corrections for CLAS (K. Park, V. Burkert, L. Elouadrhiri, W. Kim) 2003
3. Electron Momentum Corrections for CLAS at 4.4 GeV (D. Protopopescu, F.W. Hersman, M. Holtrop, S. Stepanyan) 2001

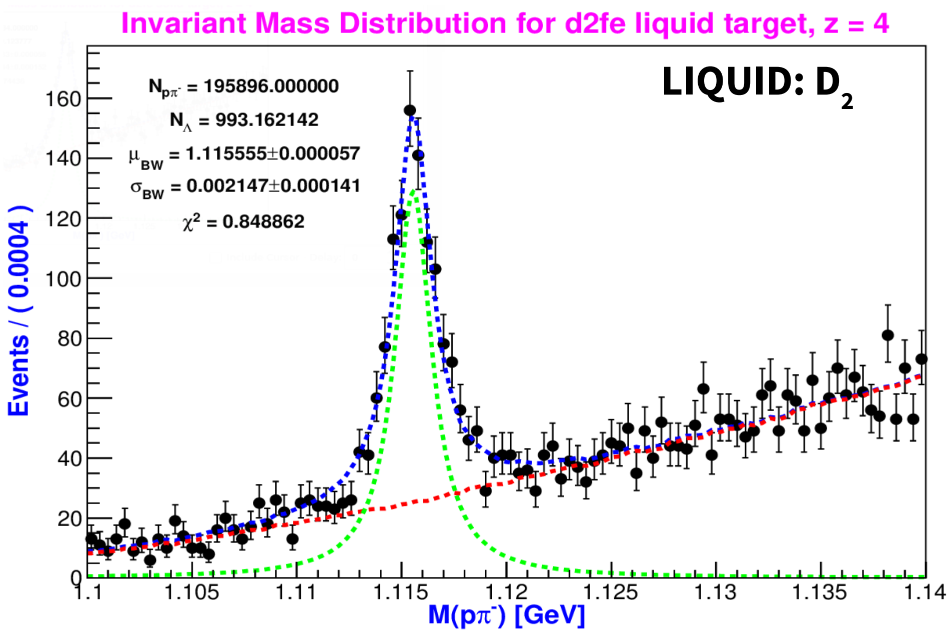
Electron Momentum Corrections $(p_{e,\ corrected} = p_{e,\ meas} * f * g)$

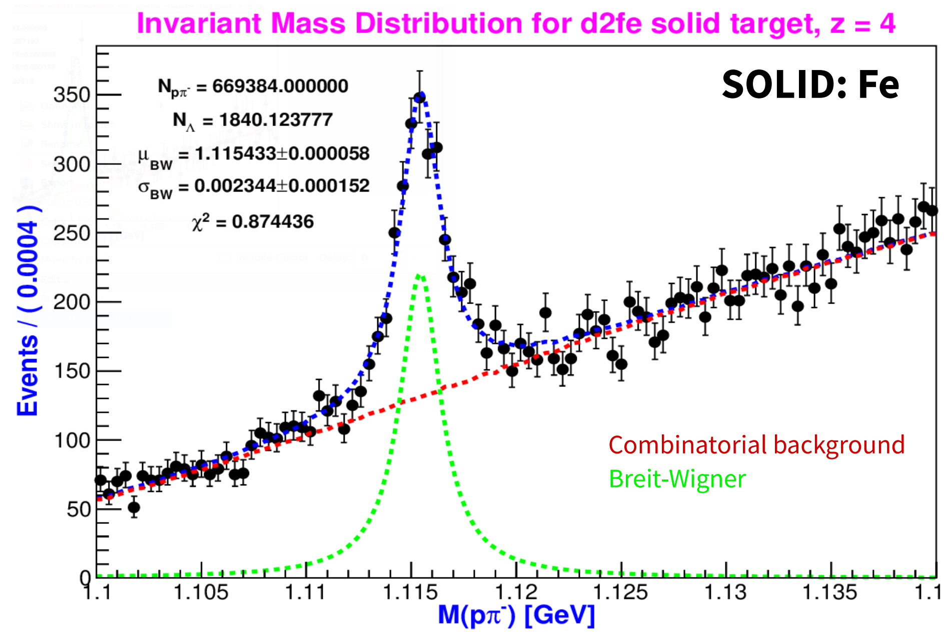


Signal and Background









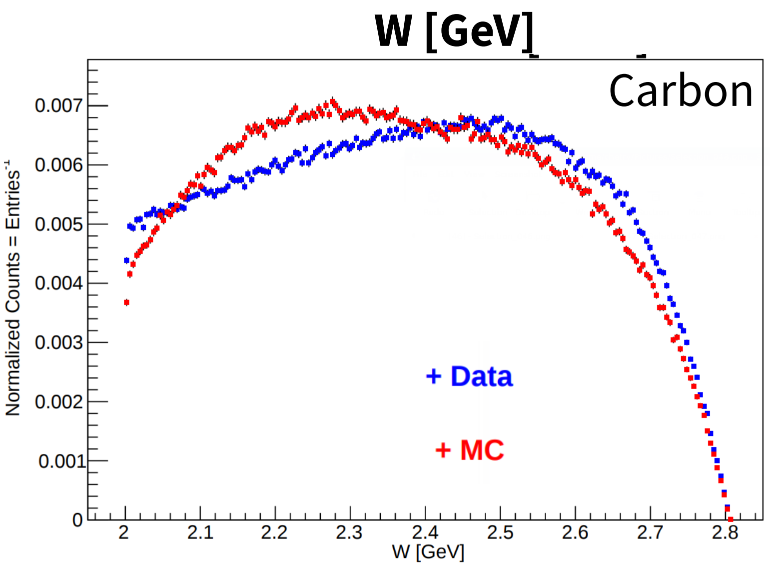
z-bin	1	2	3	4	5	6	7	8	9
Range	[0.28, 0.36)	[0.36, 0.42)	[0.42, 0.48)	[0.48, 0.54)	[0.54, 0.6)	[0.6, 0.65)	[0.65, 0.7)	[0.7, 0.8)	[0.8, 0.9)

Acceptance Corrections

- 500M events generated using Pythia Generator for each target (Fe, C, Pb and D_2).
- Accepted and generated simulated events binned:

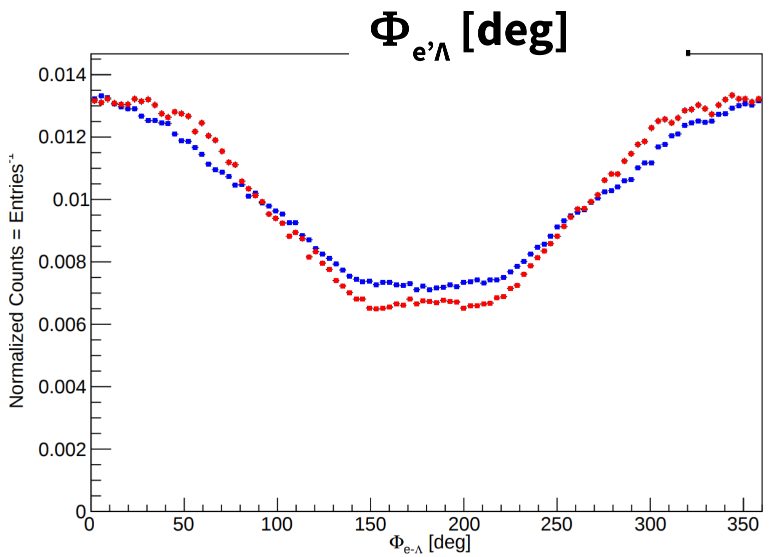
$$Bin, \quad k = (W, \nu, \theta^*_{\pi^-}, \phi^*_{\pi^-}, p_\Lambda, \Phi_{e'\Lambda}, z)$$

$*$ represents rest frame of Λ.



Variable	Range	# of Bins	Bin width
W [GeV]	2.0 – 2.8	3	variable
ν	2.25 – 4.25	4	0.5
$\theta_{\pi^-}^*$ [deg]	0.0 – 180.0	3	60.0
$\phi_{\pi^-}^*$ [deg]	0.0 – 360.0	3	120.0
$\phi_{e'\Lambda}$ [deg]	0.0 – 360.0	3	120.0
p_Λ [GeV/c]	0.2 – 3.5	5	0.66
z	0.28 – 0.9	9	variable

Total Bins = 14580

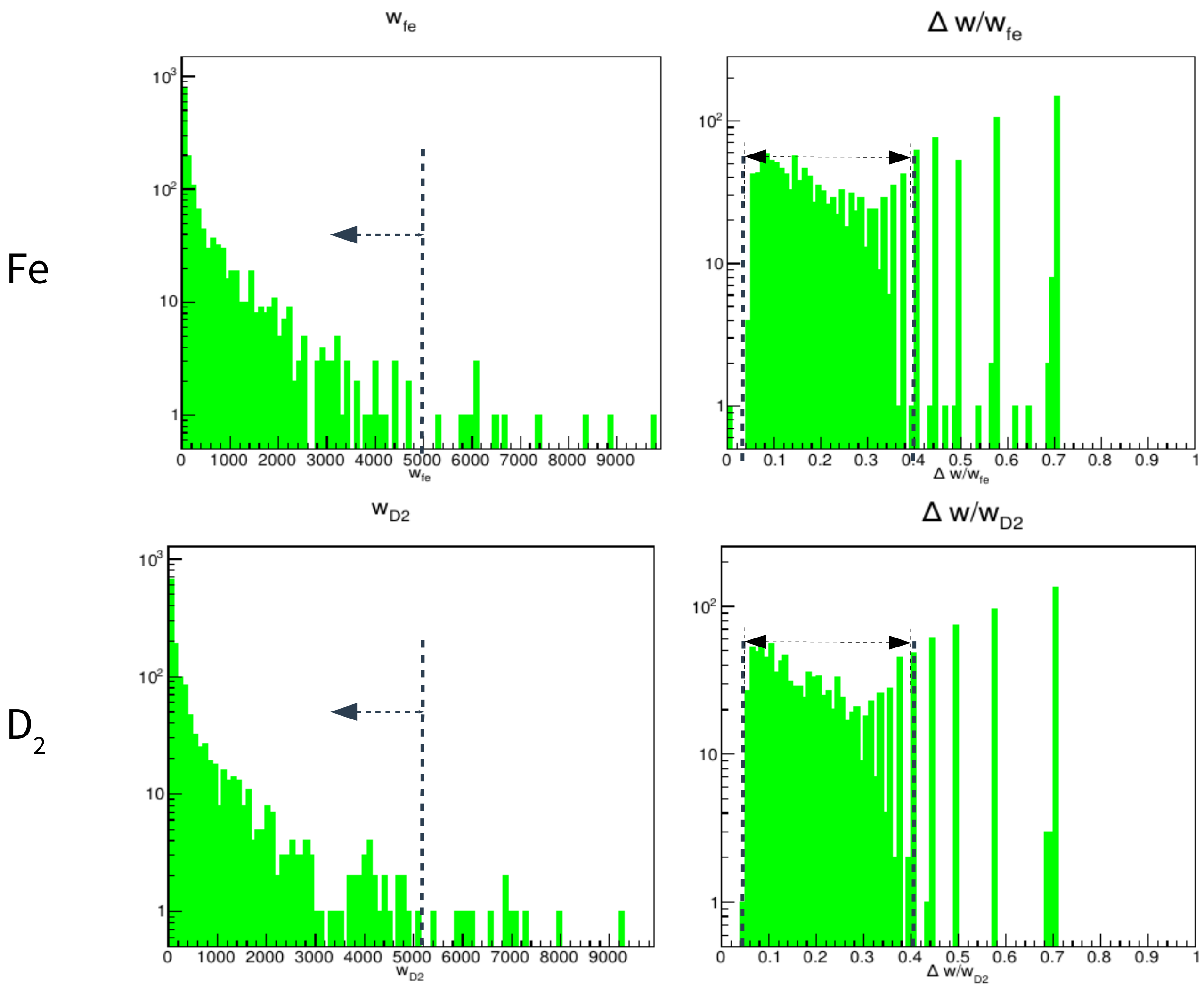


Acceptance Corrections

- Efficiency: $$eff_k = \frac{N_{acc}(W, \nu, \theta^*_{\pi^-}, \phi^*_{\pi^-}, p_\Lambda, \Phi_{e'\Lambda}, z)}{N_{gen}(W, \nu, \theta^*_{\pi^-}, \phi^*_{\pi^-}, p_\Lambda, \Phi_{e'\Lambda}, z)}$$ $$\Delta eff_k = \sqrt{\frac{eff_k(1 - eff_k)}{N_{gen}(W, \nu, \theta^*_{\pi^-}, \phi^*_{\pi^-}, p_\Lambda, \Phi_{e'\Lambda}, z)}}$$

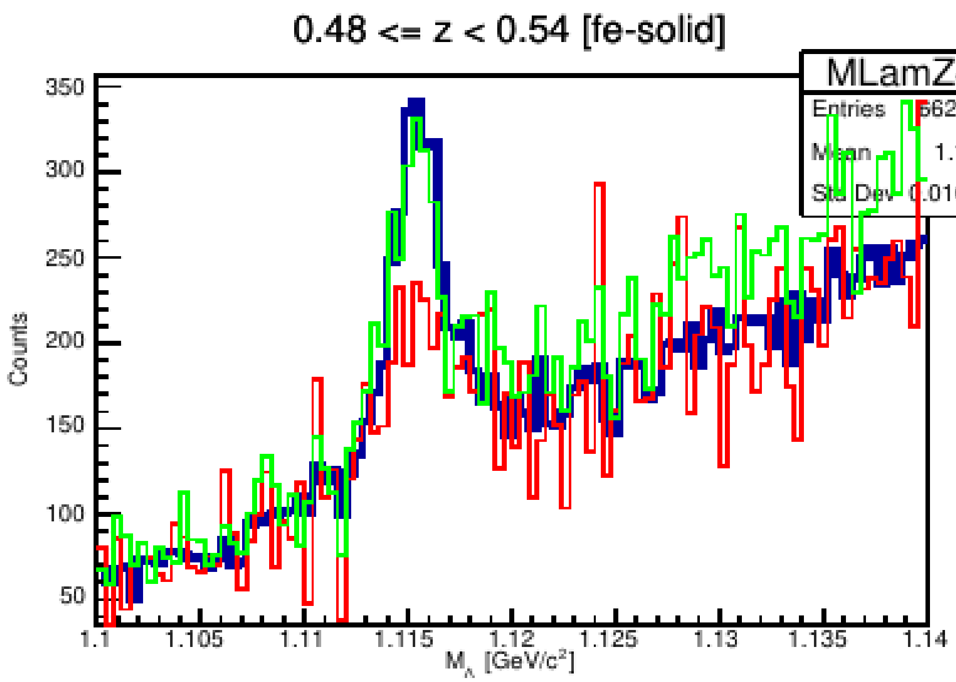
  * represents rest frame of Λ.

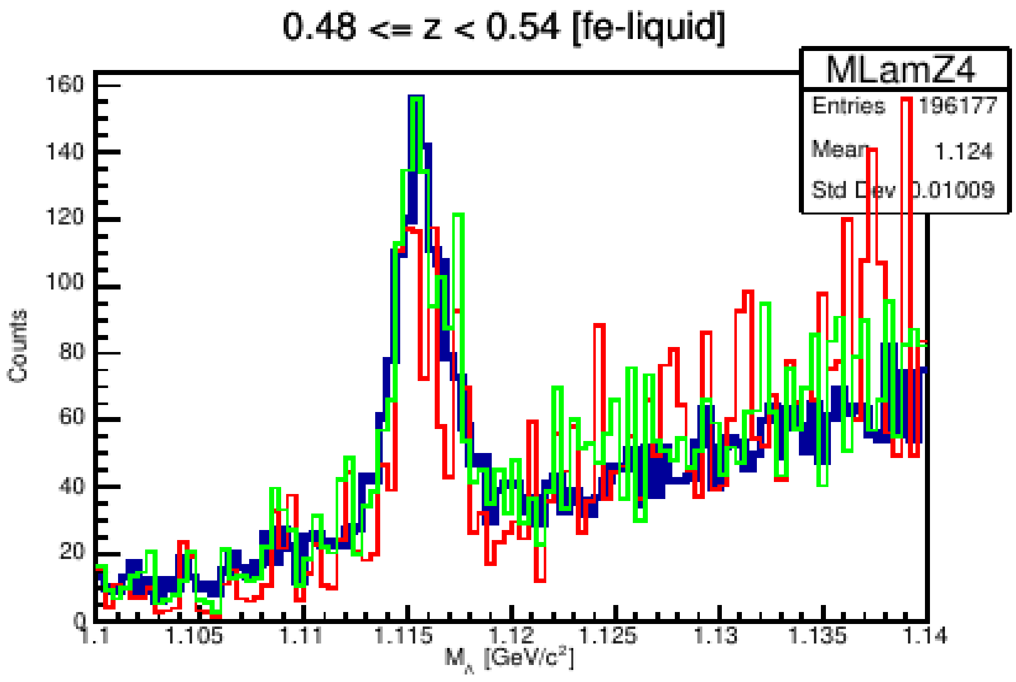
- Weights, $w = 1/\text{eff}$, are selected to reduce spikes in the corrected distributions.



Acceptance Corrections

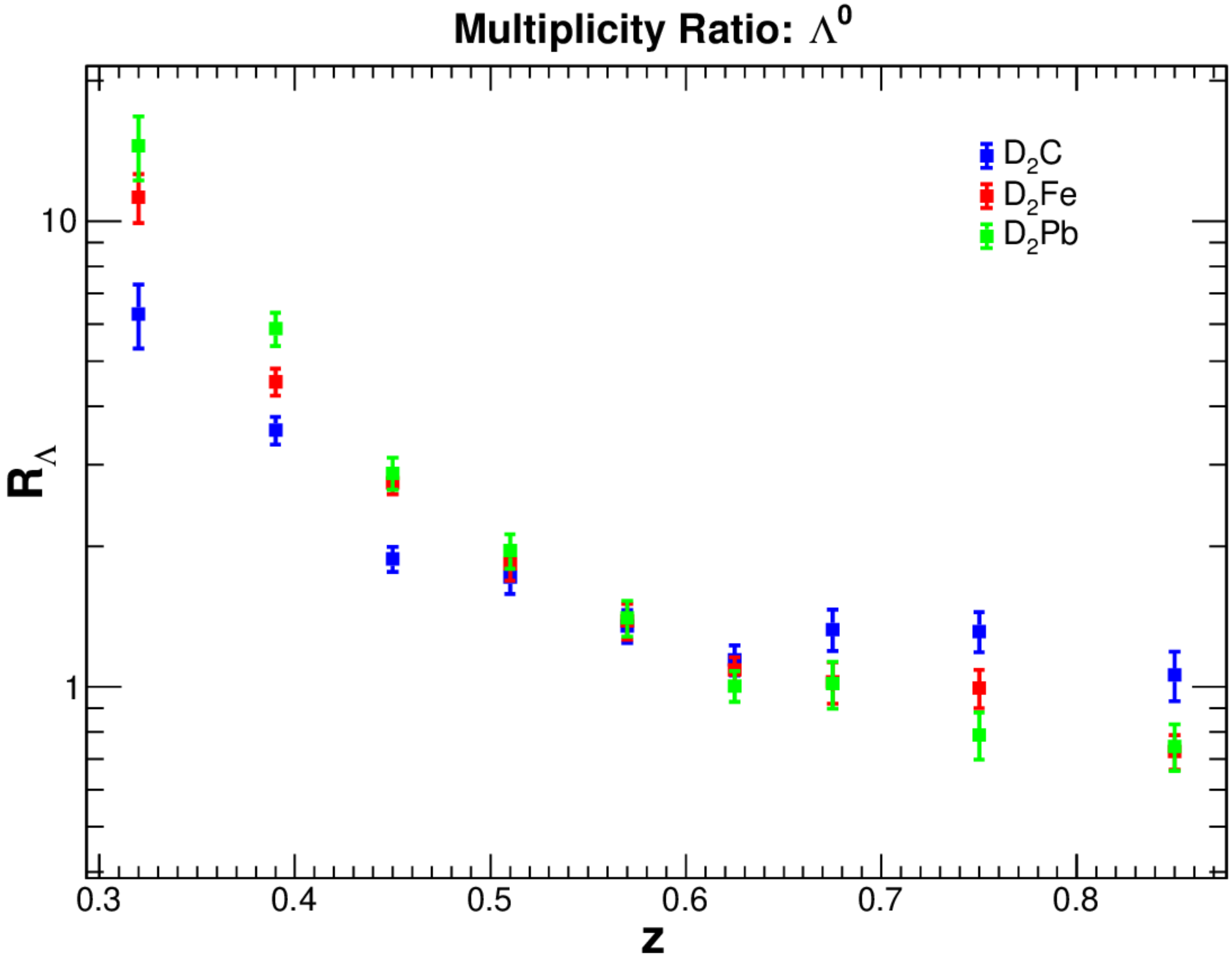
- Three cases: No correction, Correction applied (no weight cut) and Corrections applied (with weight cut: $0 < w < 5000$; $0.04 < \Delta w/w < 0.4$)





Multiplicity Ratio

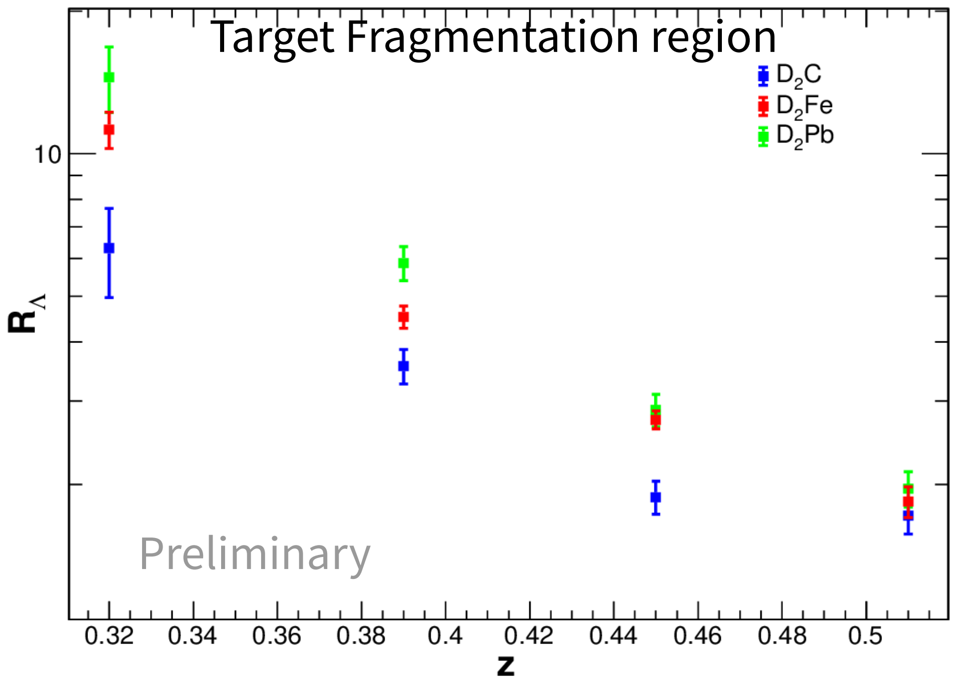
Preliminary
Acceptance corrected

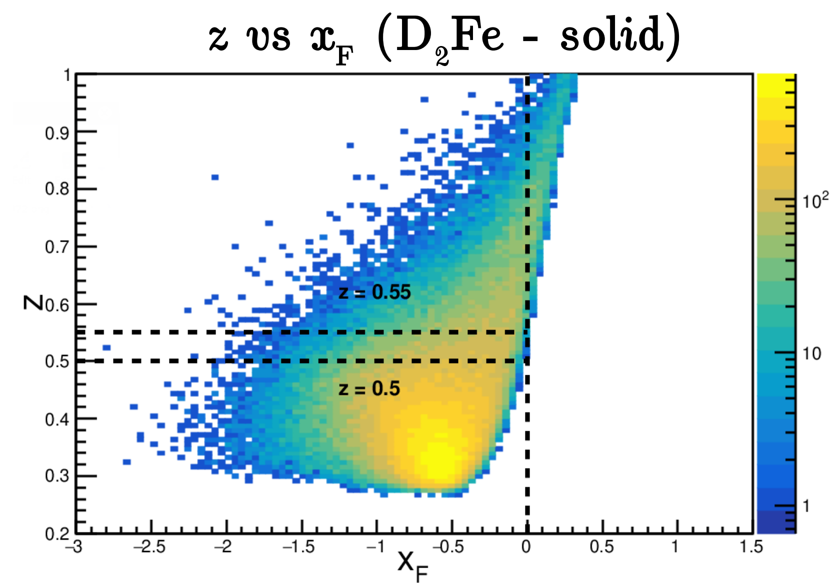


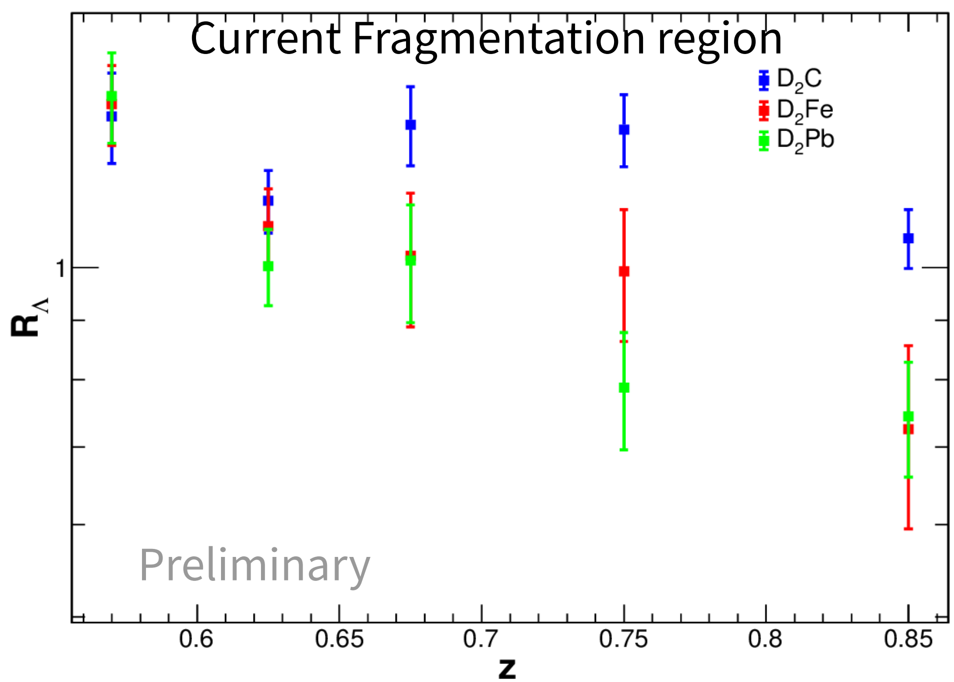
$$R_A^h(z) = \frac{\left.\frac{N_h(z)}{N_e|_{DIS}}\right|_A}{\left.\frac{N_h(z)}{N_e|_{DIS}}\right|_{D_2}} \times \frac{Eff(z)|_{D_2}}{Eff(z)|_A}$$

Multiplicity Ratio

Preliminary



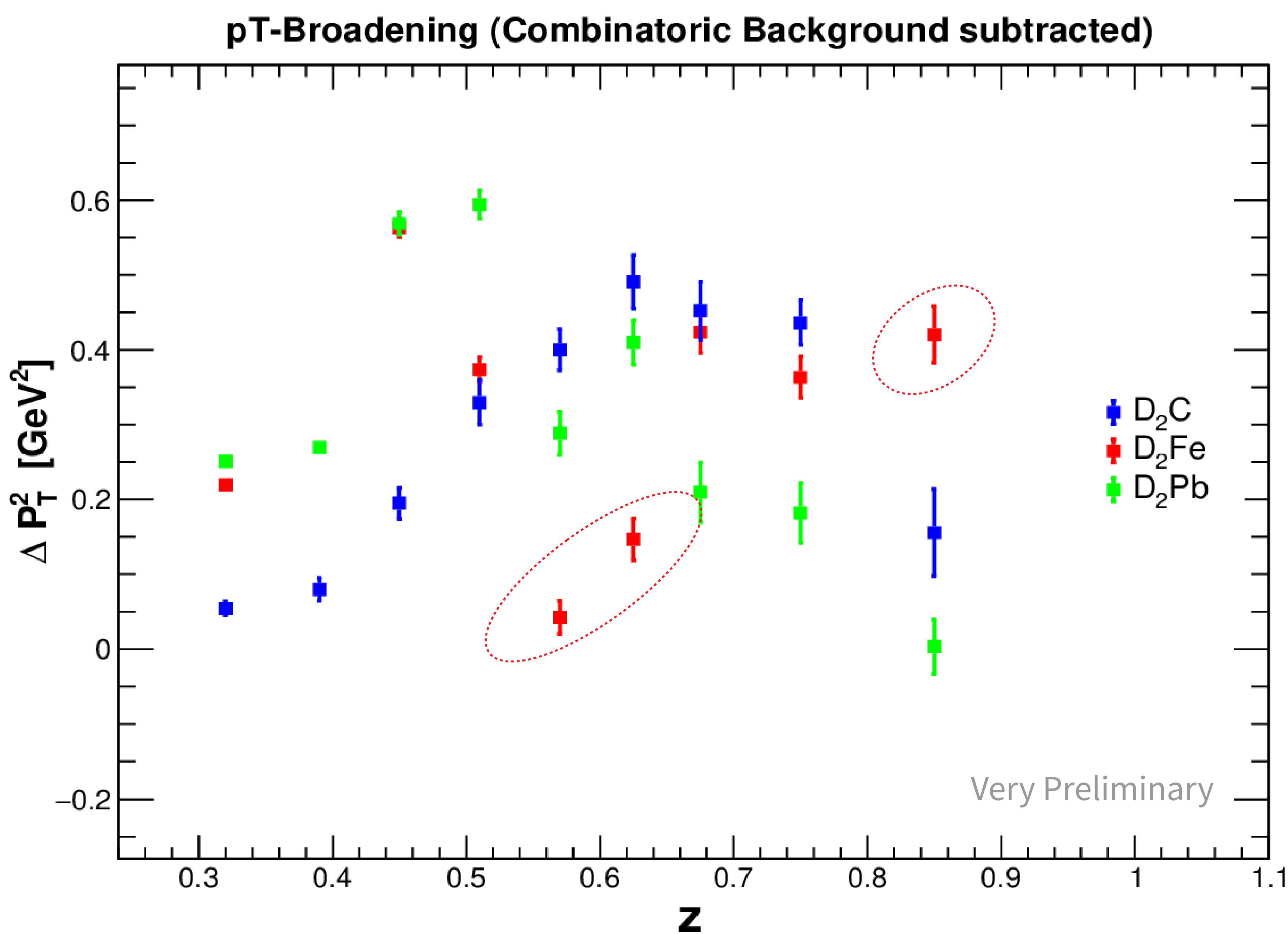




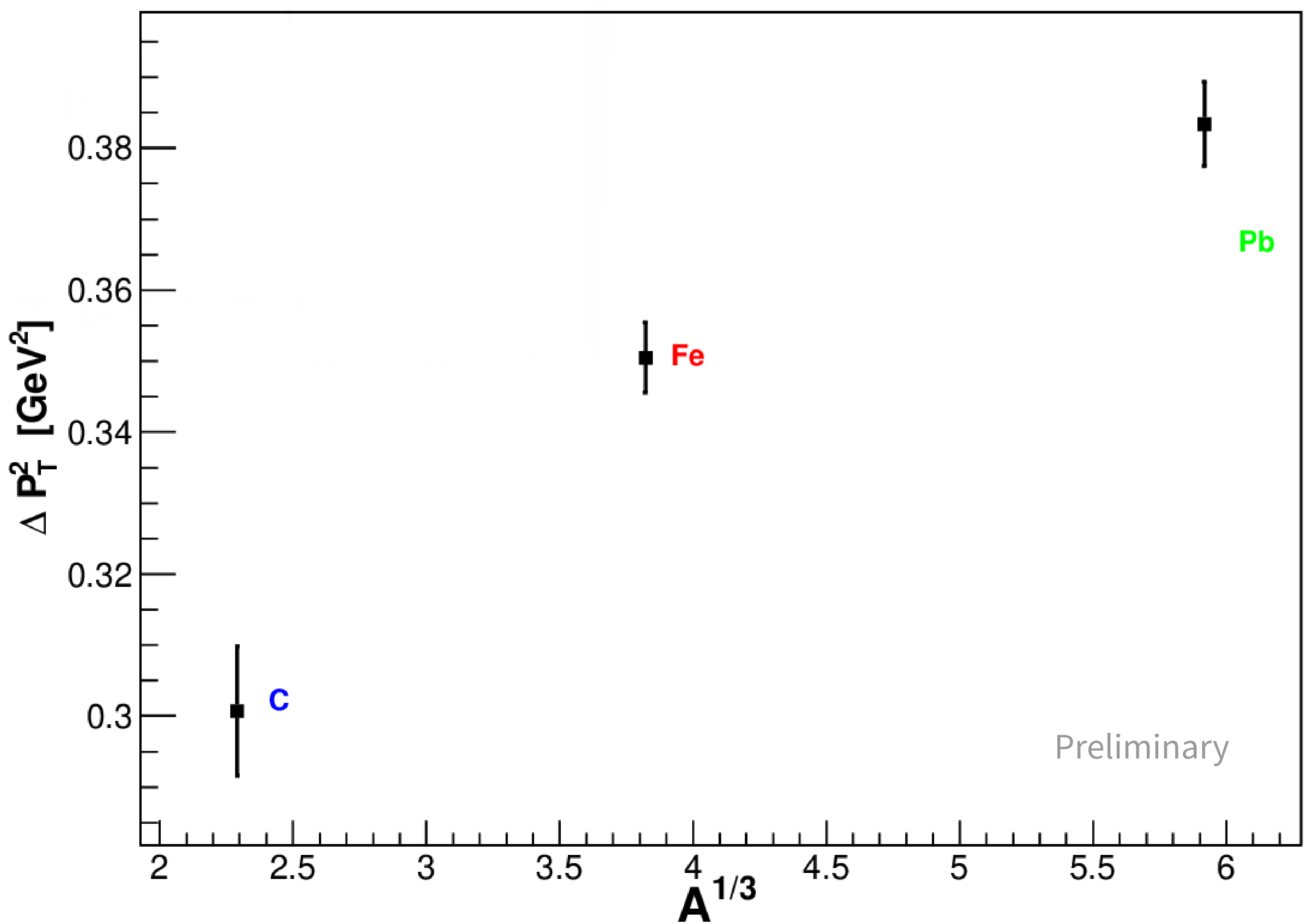
- $$R^h_A(z) = \frac{\left.\frac{N_h(z)}{N_e|_{DIS}}\right|_A}{\left.\frac{N_h(z)}{N_e|_{DIS}}\right|_{D_2}} \times \frac{Eff(z)|_{D_2}}{Eff(z)|_A}$$

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

Transverse Momentum Broadening (Acceptance corrected with weight cuts)



Transverse Momentum Broadening (A-Dependence)



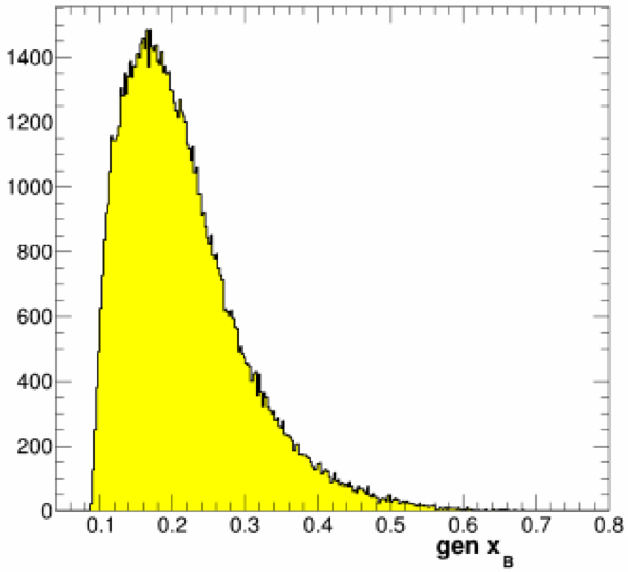
Summary and Outlook

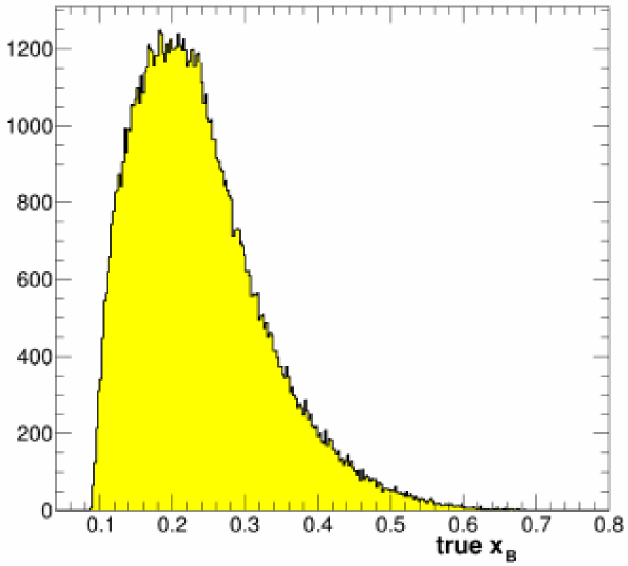
- **Kinematic corrections: extracted and applied.**
- **Acceptance corrections:**
  - Combinatoric background with corrections are being produced.
  - Optimization of binning and weight cuts: Iterative progress.
- **Preliminary results for Multiplicity ratio and Transerse Momentum Broadening are presented.**
- **Next steps would include:**
  - Systematic studies.
  - Radiative corrections (Software courtesy: Ahmed El Alaoui)
  - CLAS Analysis note.
  - Outlook: Study other dependencies of R_{Λ} on Q^2, P_T^2(Cronin effect).

Thank you for your attention!

Extras

x_{Bj} distribution





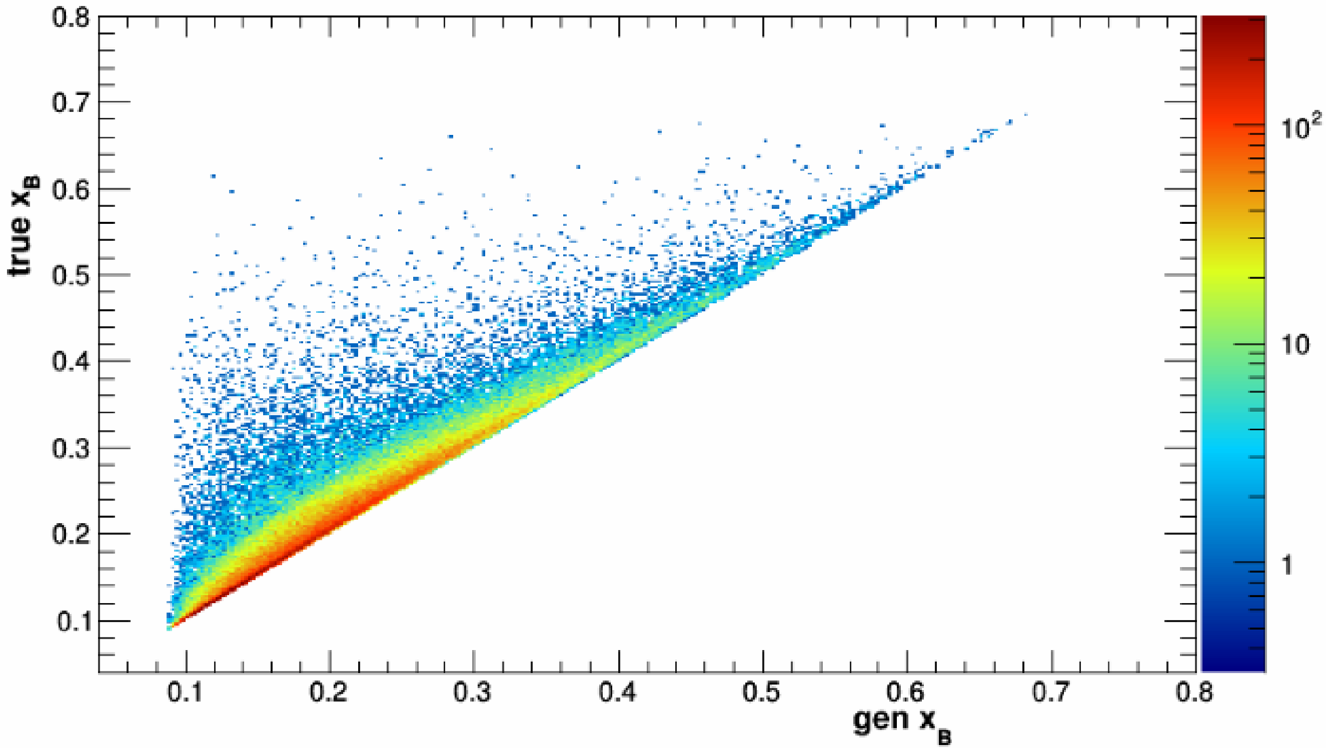
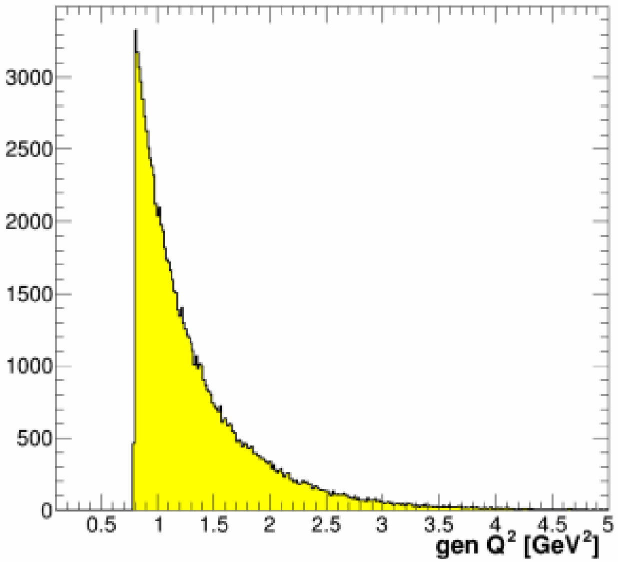
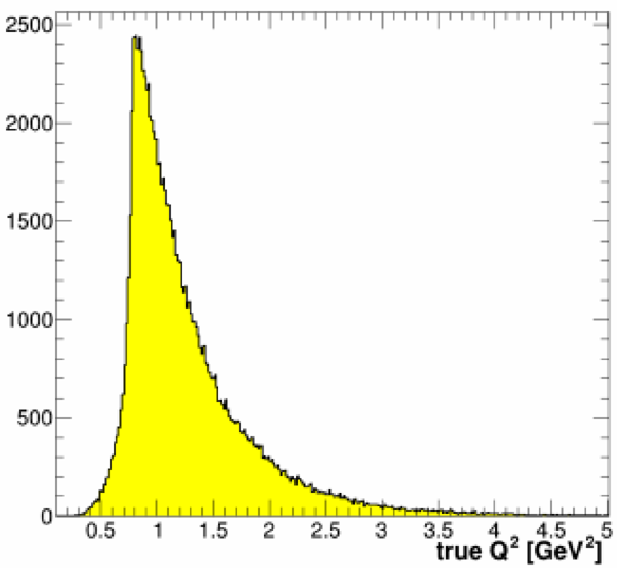


Fig courtesy: Ahmed El Alaoui





Q^2 distribution

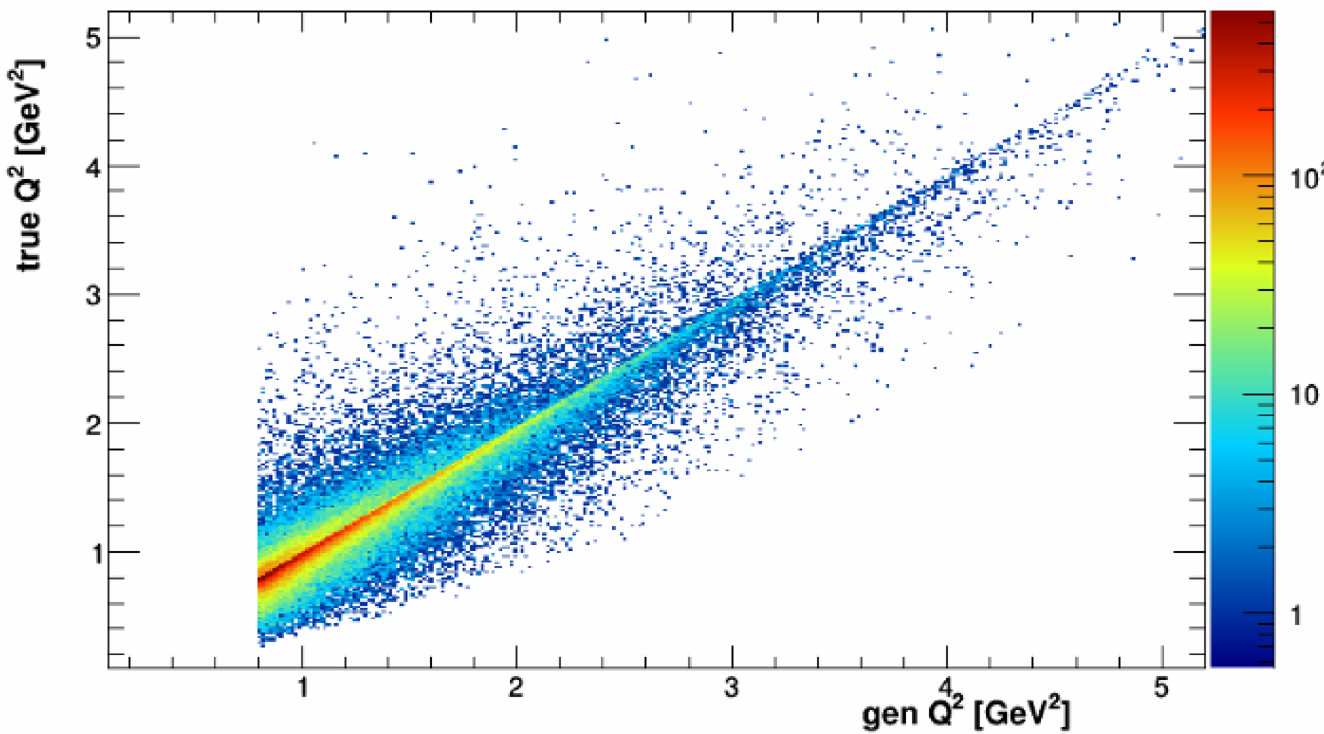


Fig courtesy: Ahmed El Alaoui

Feynman x, x_F

- Feynman x expressions:

Raphael

$$x_F = 2\frac{zM_p\upsilon^2 - zQ^2\upsilon - (M_p + \upsilon)P.q}{\sqrt{\upsilon^2 + Q^2}(W^2 - M_h^2)}$$

Hayk

$$x_F = 2\frac{(\upsilon + M_p)\sqrt{p^2 - p_T^2} - z\upsilon\sqrt{Q^2 + \upsilon^2}}{\sqrt{(W^2 - M_n^2 - M_\pi^2)^2 - 4M_\pi^2 W^2}}$$

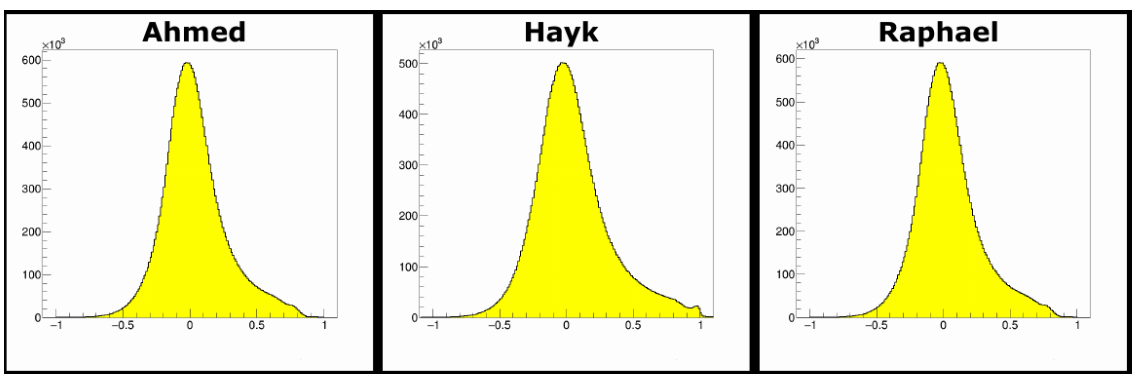
Ahmed

$$x_F = \frac{|\vec{p}_{||}|}{|\vec{q}|}$$

Expressed in the γ^*N CM frame

Modified expression (Hayk's)

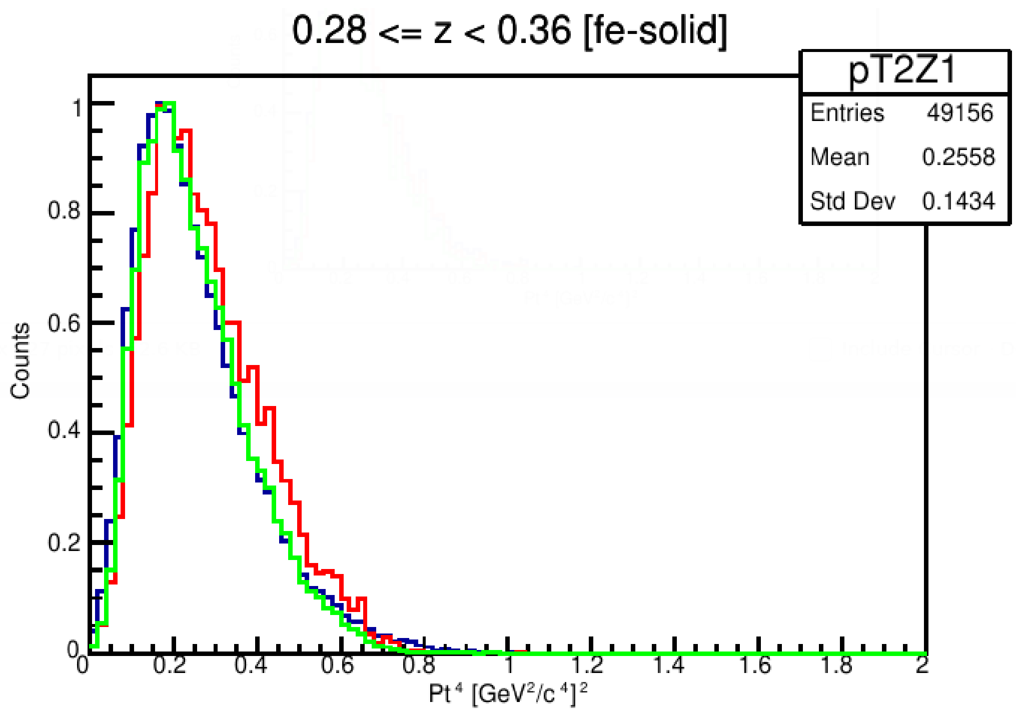
$$x_F = 2\frac{(\nu + M_p)\sqrt{p^2 - p_T^2} - z\nu\sqrt{Q^2 + \nu^2}}{\sqrt{(W^2 - M_K^2 - M_\Lambda^2)^2 - 4M_\Lambda^2 W^2}}$$

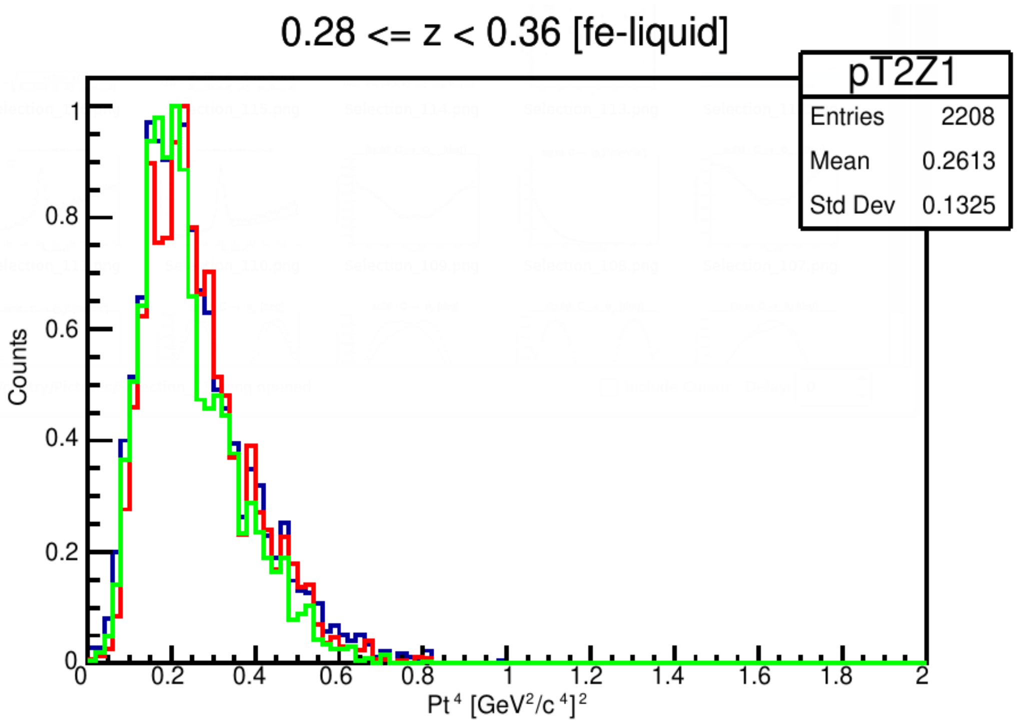


Plot courtesy: Ahmed

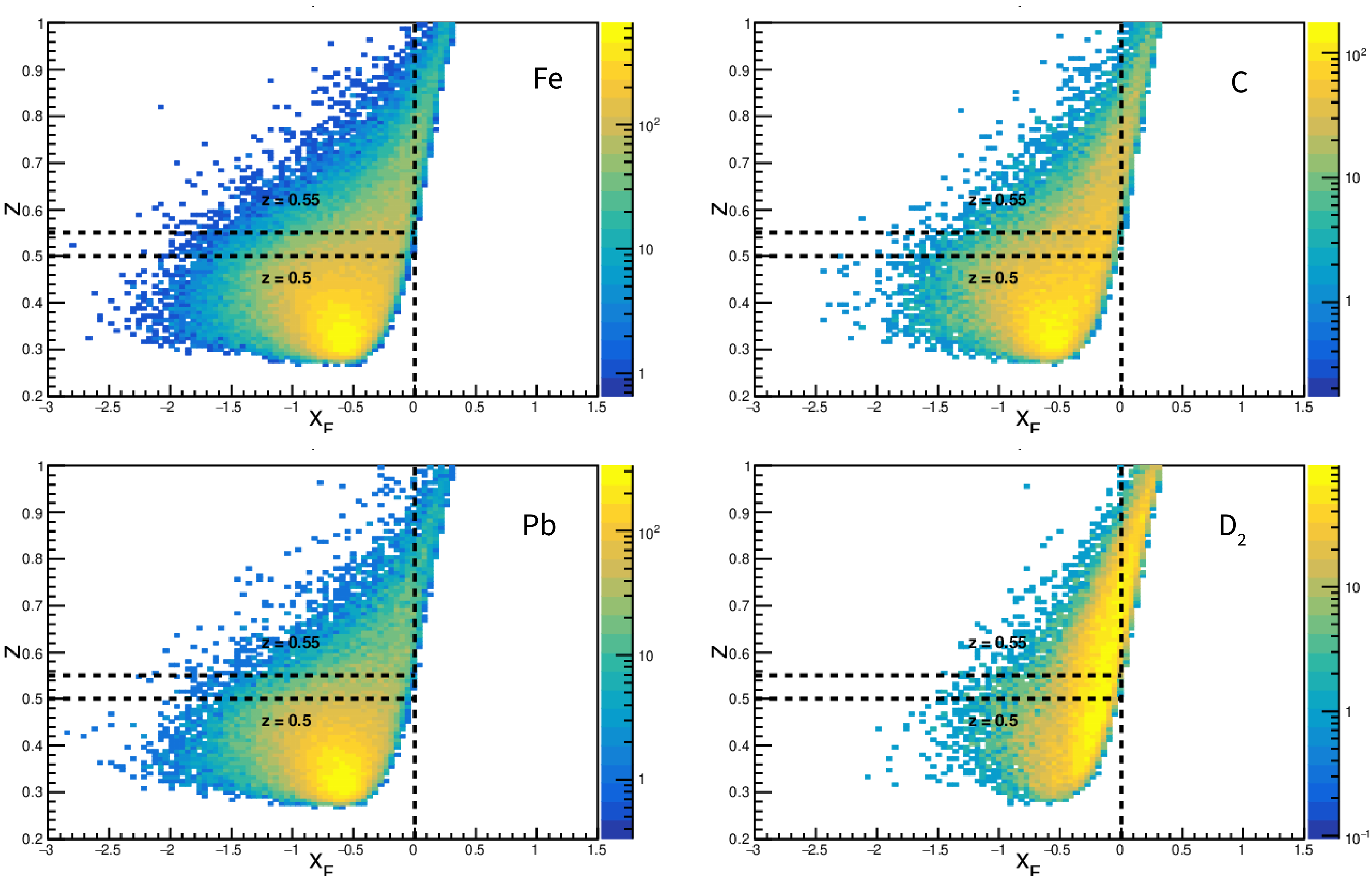
Acceptance corrections

- Distributions when corrections are applied
  - We compare here three cases: No correction, Correction applied (no weight cut) and Corrections applied (with weight cut: $0 < w < 5000$; $0.08 < \Delta w/w < 0.4$)
  - The corrections/cuts are preliminary. More events are being generated.

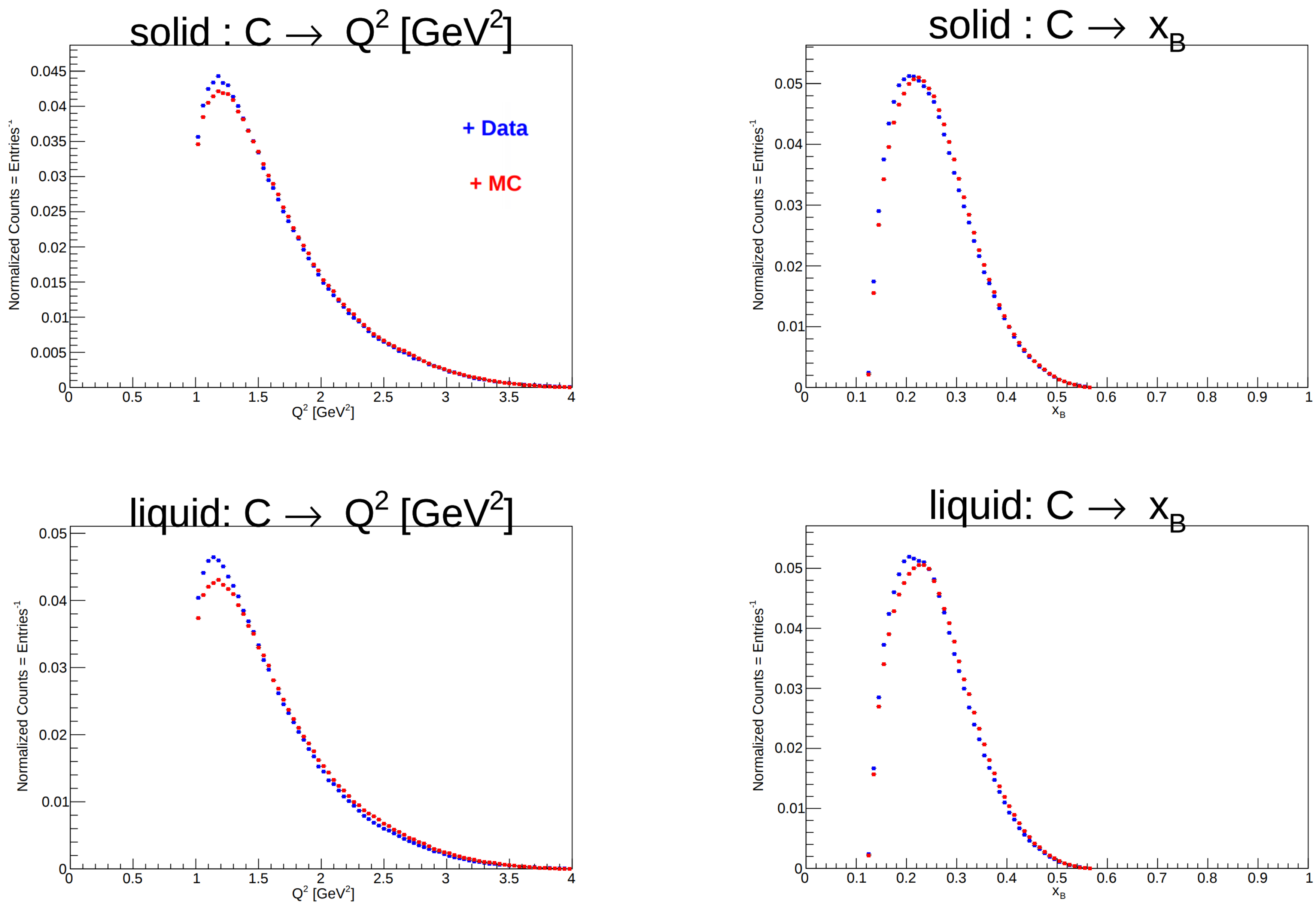




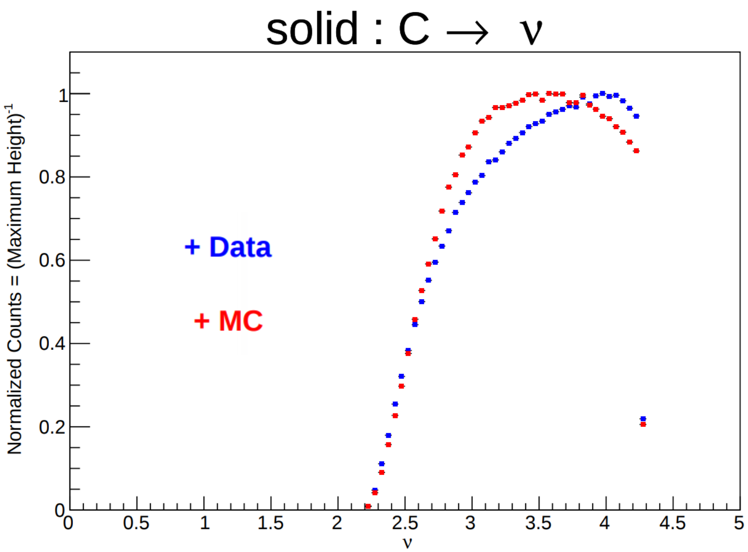
Plots: z vs x_F (Fe, C, Pb, D_2)

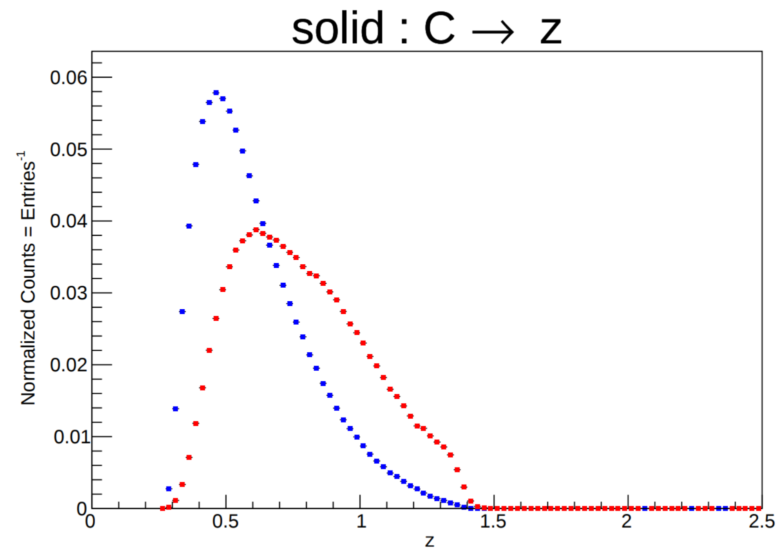


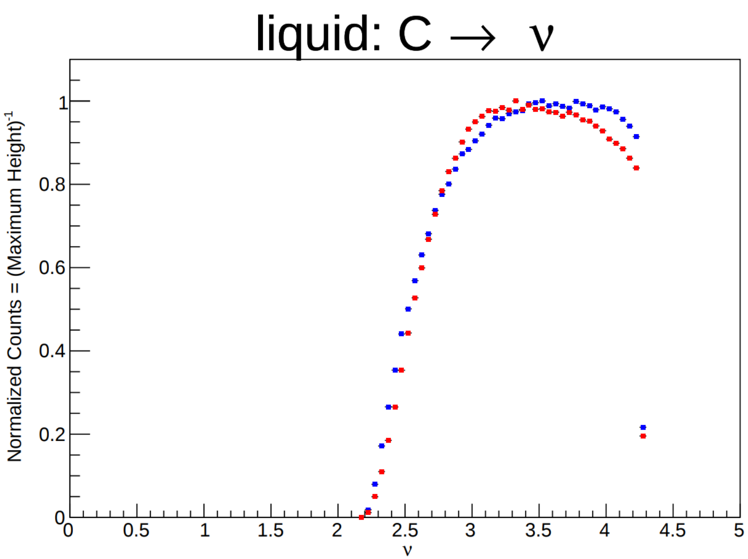
Acceptance corrections

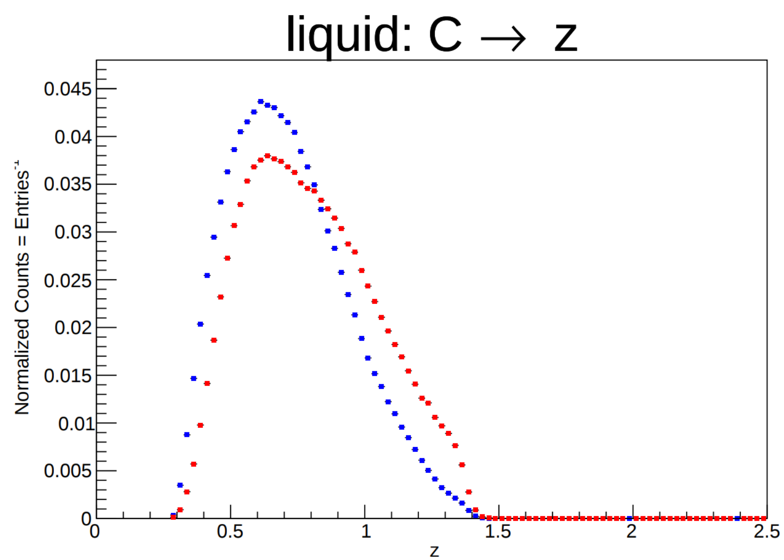


Acceptance corrections

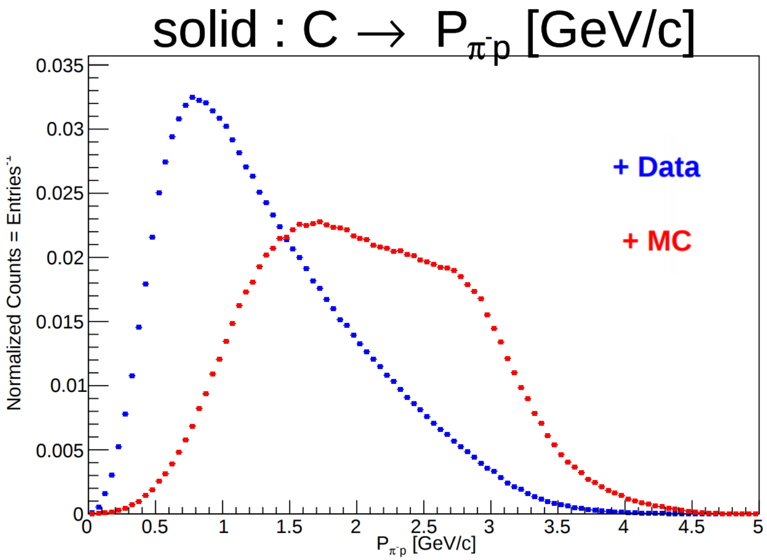


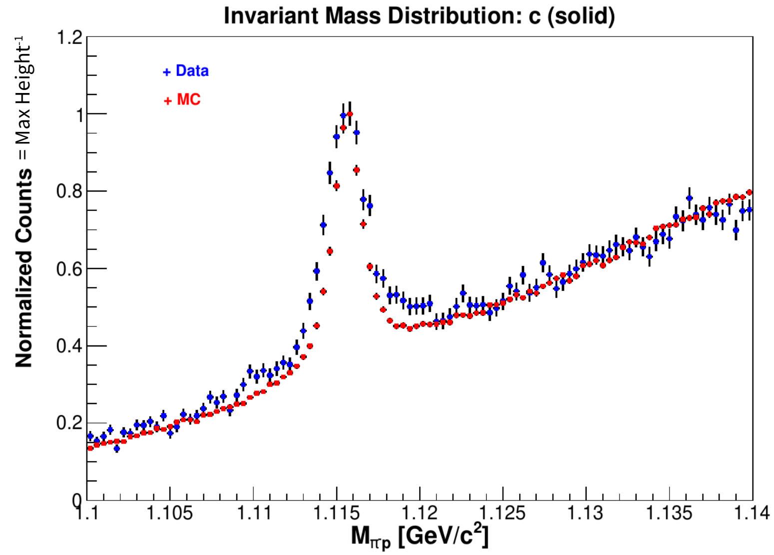


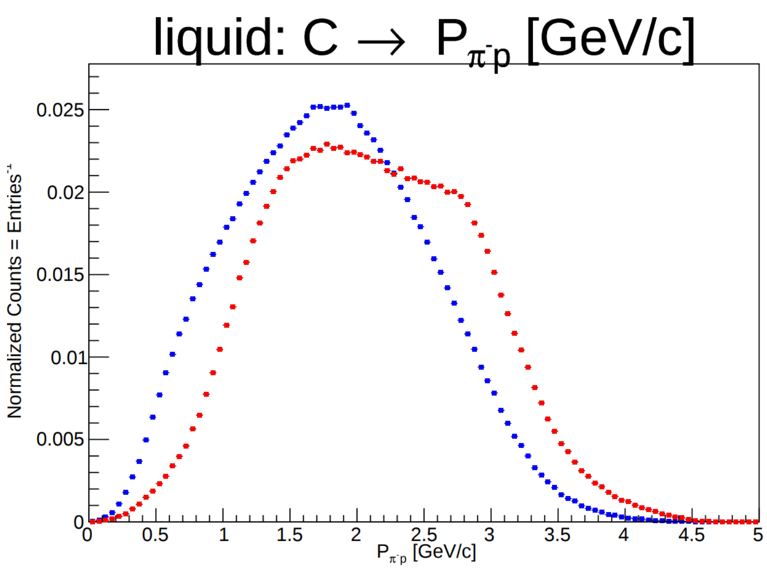


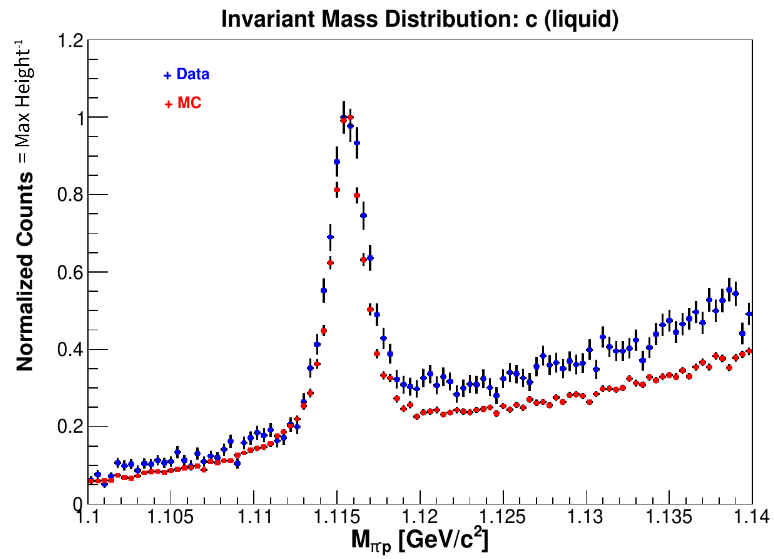


Acceptance corrections

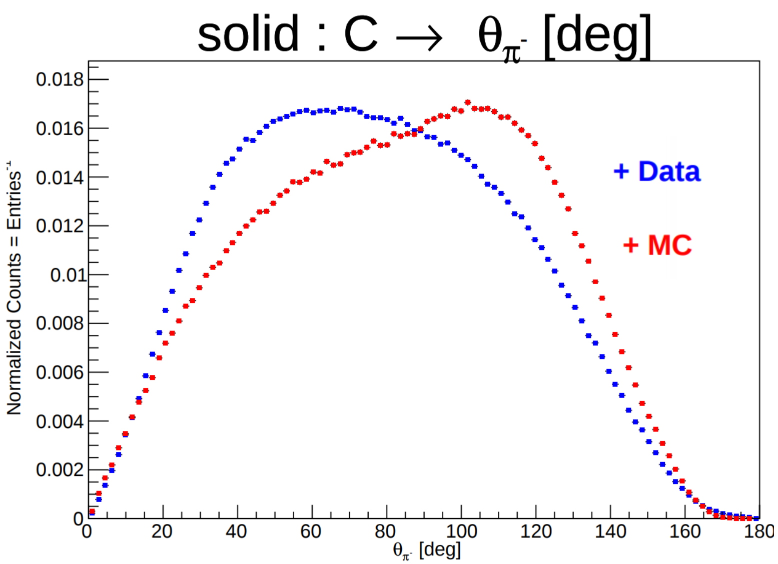


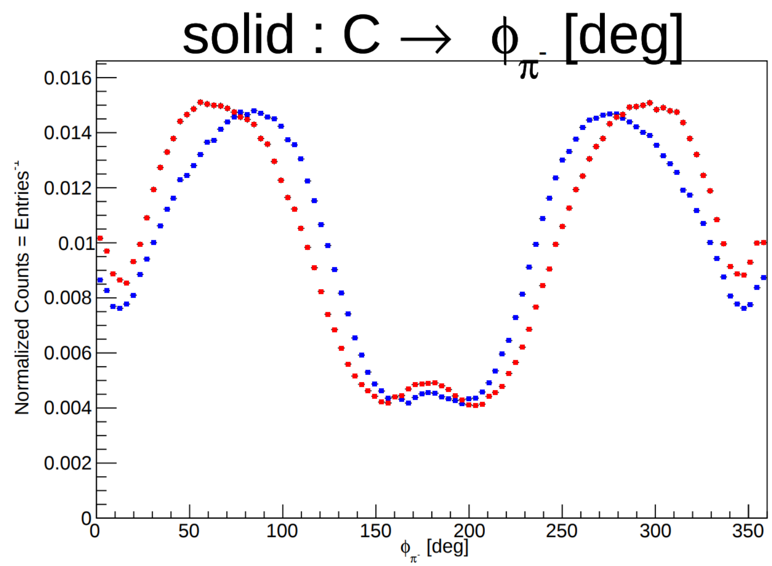


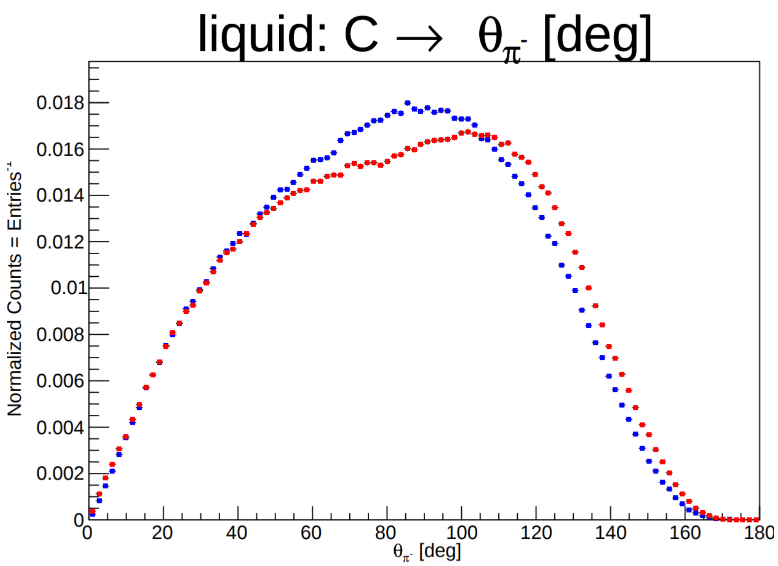


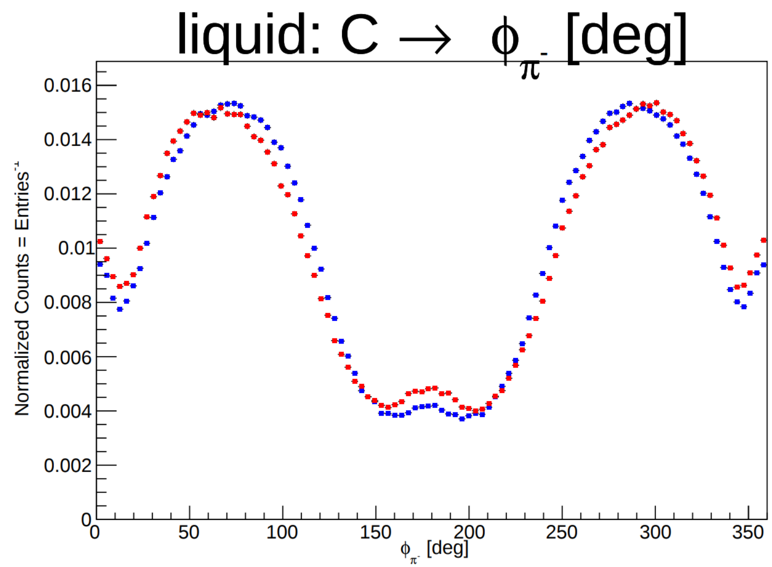


Acceptance corrections









Acceptance corrections