Lambda Hadronization Study using EG2 Dataset: Updates

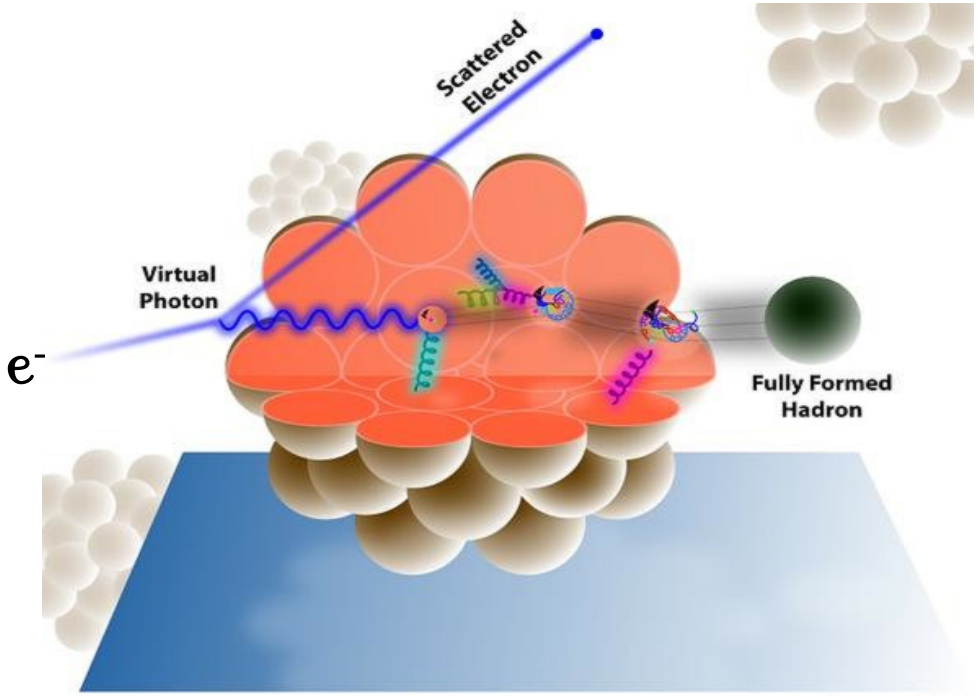
Taya Chetry
Mississippi State University

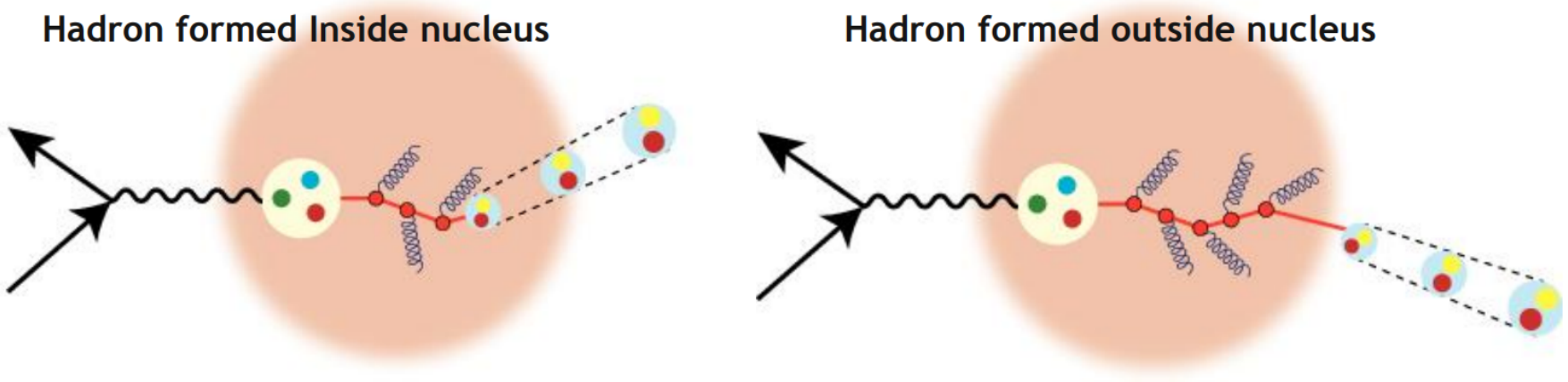
Contents
Hadronization
Overview of cuts/corrections
Results

CLAS Collaboration Meeting
11/12/2020

Probing QCD Dynamics

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

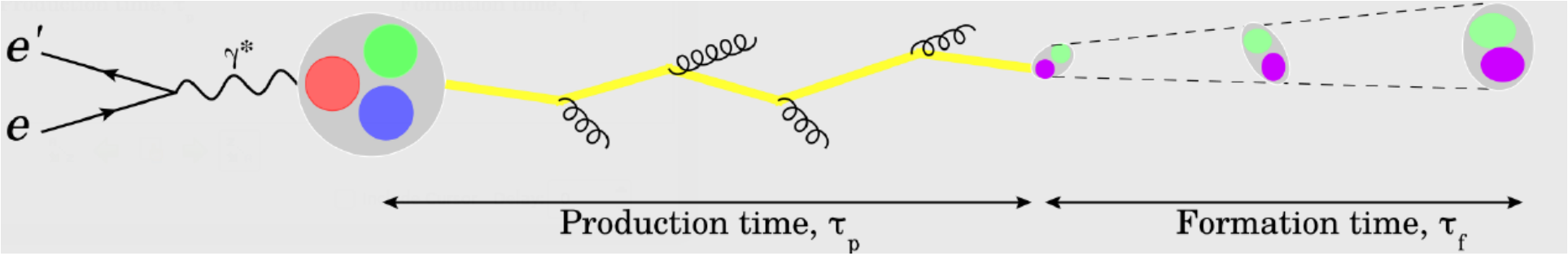




Depending on the size of nucleus, hadron formation can take place inside or outside the nucleus.

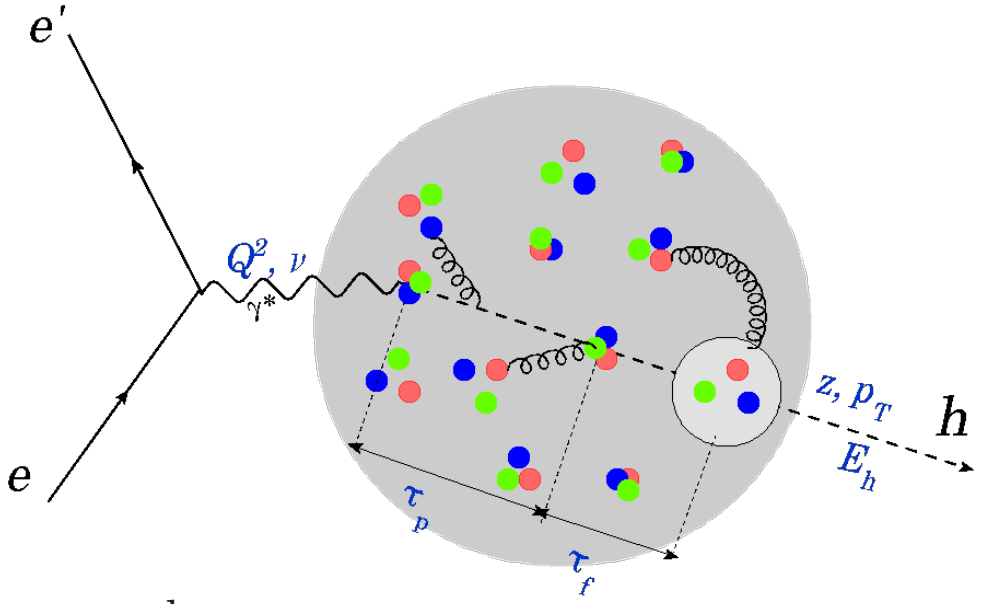
Probing QCD Dynamics

- **Hadronization Timescales:**
  - Production time: Time spent by a deconfined quark to neutralize its color charge.
  - Formation time: 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.

SIDIS Variables



- ν: E_e – $E_{e'}$; Electron energy loss.
- Q^2: Four-momentum transferred.
- y: ν/E_e, electron energy fraction transferred to the struck quark.
- W: Total center of mass energy.
- p_T: Hadron momentum transverse to the virtual photon direction.
- x_F: Feynman variable, $P_L^{CM}/P_L^{max,\,CM}$.
- z: E_h/ν; Fraction of the struck quark's initial energy carried by the formed hadron.

Experimental Observables

- **Multiplicity ratio:**

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

  - Initial state effects are reduced/cancelled due to the normalization with the electron DIS events.

- **Transverse momentum broadening (p_T broadening)**

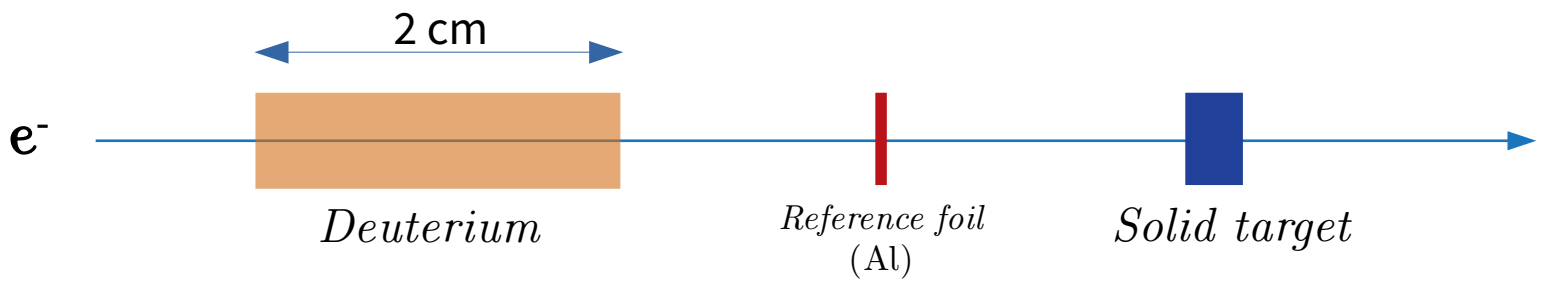
$$\Delta P_T^2 = \left\langle P_T^2 \right\rangle_A - \left\langle P_T^2 \right\rangle_D$$

D = Deuterium
A = C, Fe, Pb

- **These observables provide insights about**
  - 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).

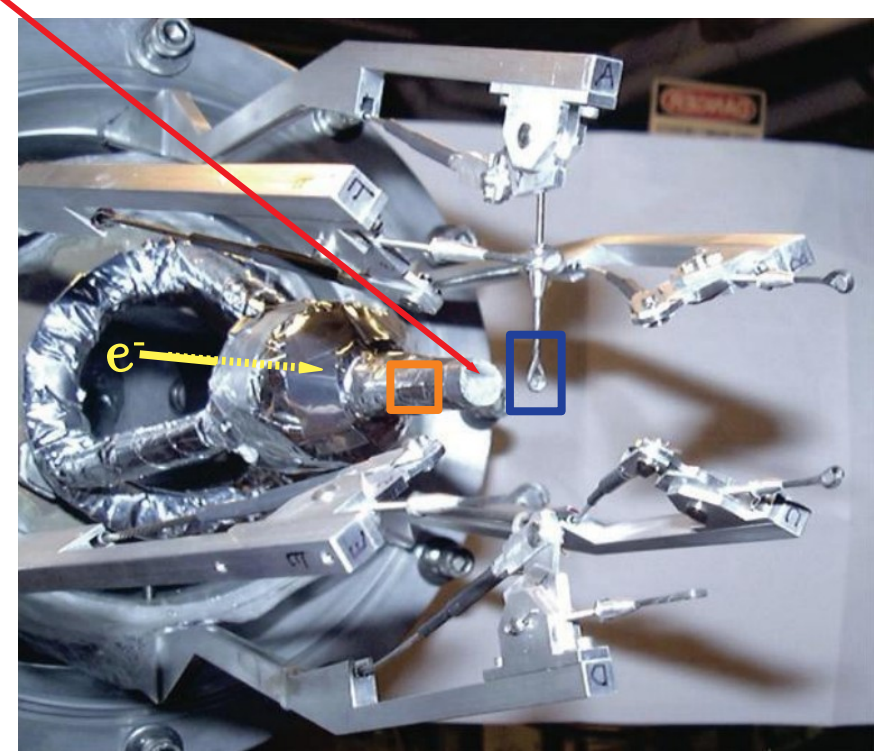
EG2 Run Conditions

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



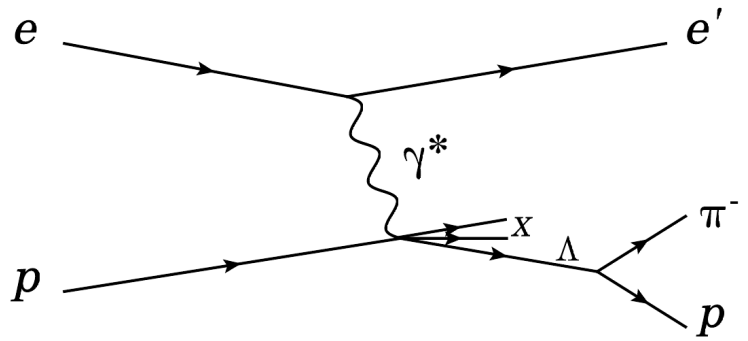
- Luminosity ~ 10^{34} s^{-1} cm^{-2}
- Beam energy: 5.014 GeV
- Target separation ~ 4 cm
- Solid Targets:

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

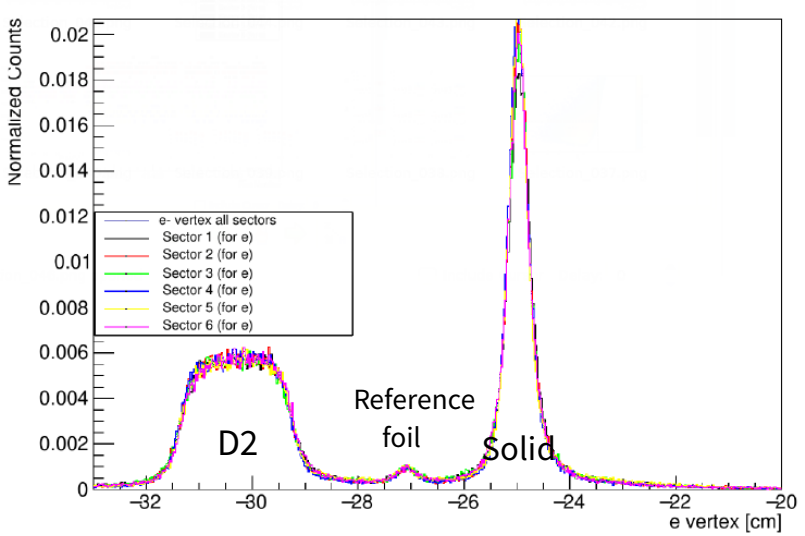


Cuts and Corrections

- Final state particles selected: one **e**; at least one π^- and one **p**. Proton and pion mixture constitutes Lambda events.



- Electron ID: Positive response in DC, CC, SC and EC.
- Pion ID: Matching signal in DC and SC.
- Proton ID: Momentum dependent time analysis using ROOT's TSpline method.
- Vertex corrections applied.
- SIDIS cuts: $W > 2$ GeV; $Q^2 > 1$ GeV^2; $y < 0.85$.
- Corrections: Proton energy loss, electron momentum corrections applied.
- CLAS acceptance corrections.
- Endcap corrections (for multiplicity ratios).



Corrected e^- vertex distributions for six sectors of CLAS6 detector.

Acceptance Corrections

Variable	Range	# of Bins	Bin width
W [GeV]	2.0 – 2.8	2	0.4
ν	2.25 – 4.25	3	$0.\overline{6}$
$\phi_{\pi^-}{}^*$ [deg]	0.0 – 360.0	2	180.0
$\phi_{e'\Lambda}$ [deg]	0.0 – 360.0	3	120.0
p_Λ [GeV/c]	0.1 – 4.25	3	$1.38\overline{3}$
z	0.28 – 1.0	6	variable*

Total Bins = 648

- P_Λ: Momentum of Lambda
- ϕ_{π^-}: Decay angle of π^- in Λ rest frame.
- $\phi_{e'\Lambda}$: Angle between leptonic and hadronic planes

- Generated 1B events using Pythia event generator for each target (Fe, C, Pb and D2).
- Six dimensional binning.
- *variable z-bining:

Bin #	1	2	3	4	5	6
z_{min}	0.28	0.38	0.44	0.51	0.60	0.75
z_{max}	0.38	0.44	0.51	0.60	0.75	1.00

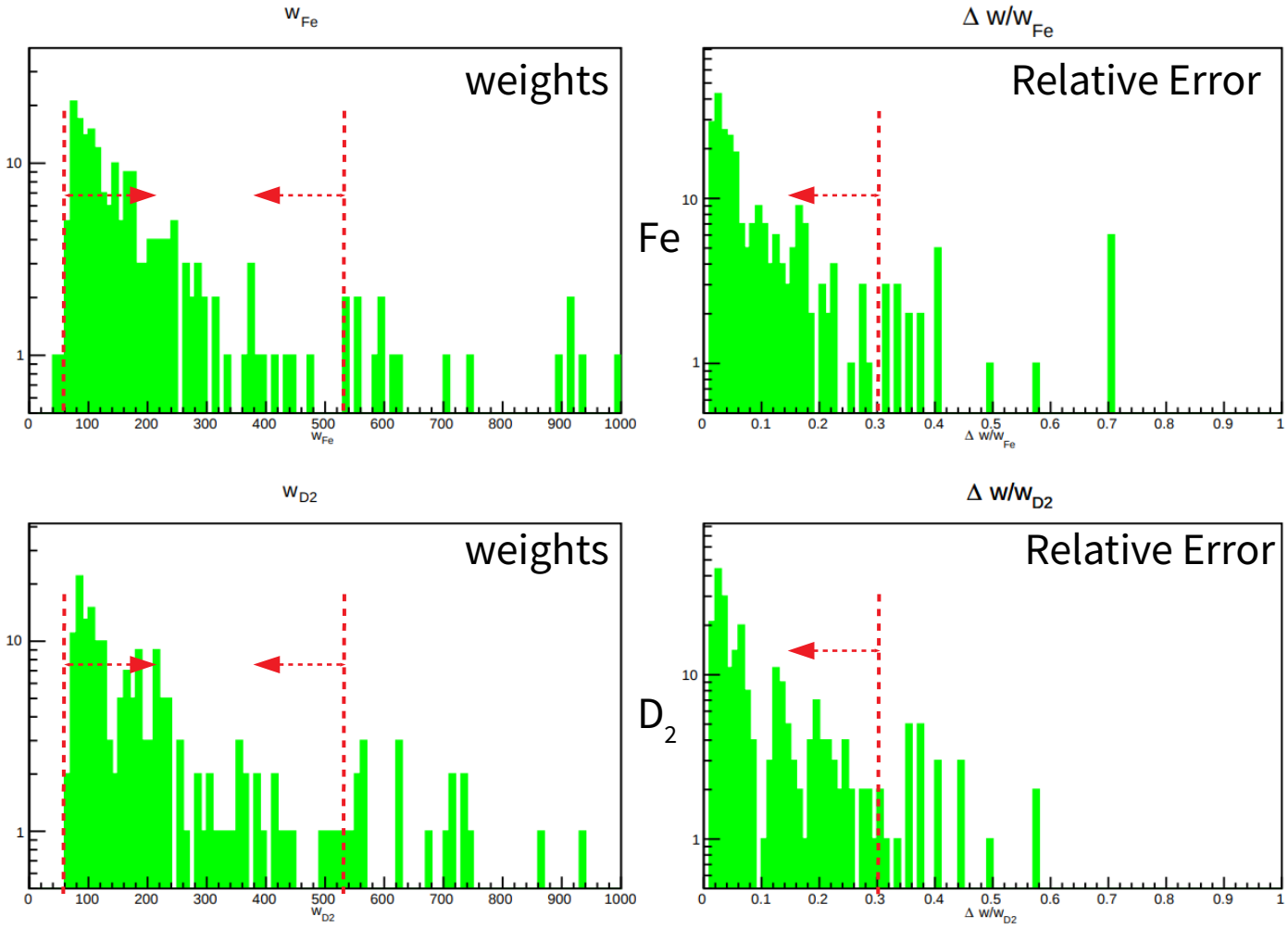
$$Bin,\quad k = (W, \nu, \theta^*_{\pi^-}, \phi^*_{\pi^-}, p_\Lambda, \Phi_{e'\Lambda}, z)$$

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

$$\text{Weight, } w_k = \frac{1}{eff_k}$$

* represents rest frame of Λ.

Cuts on the Weights and Relative Error



$$60 <= w < 530$$

$$0.0 < \Delta w/w < 0.3$$

Other targets: Backup slides

Effect on Λ Mass Distributions

Preliminary

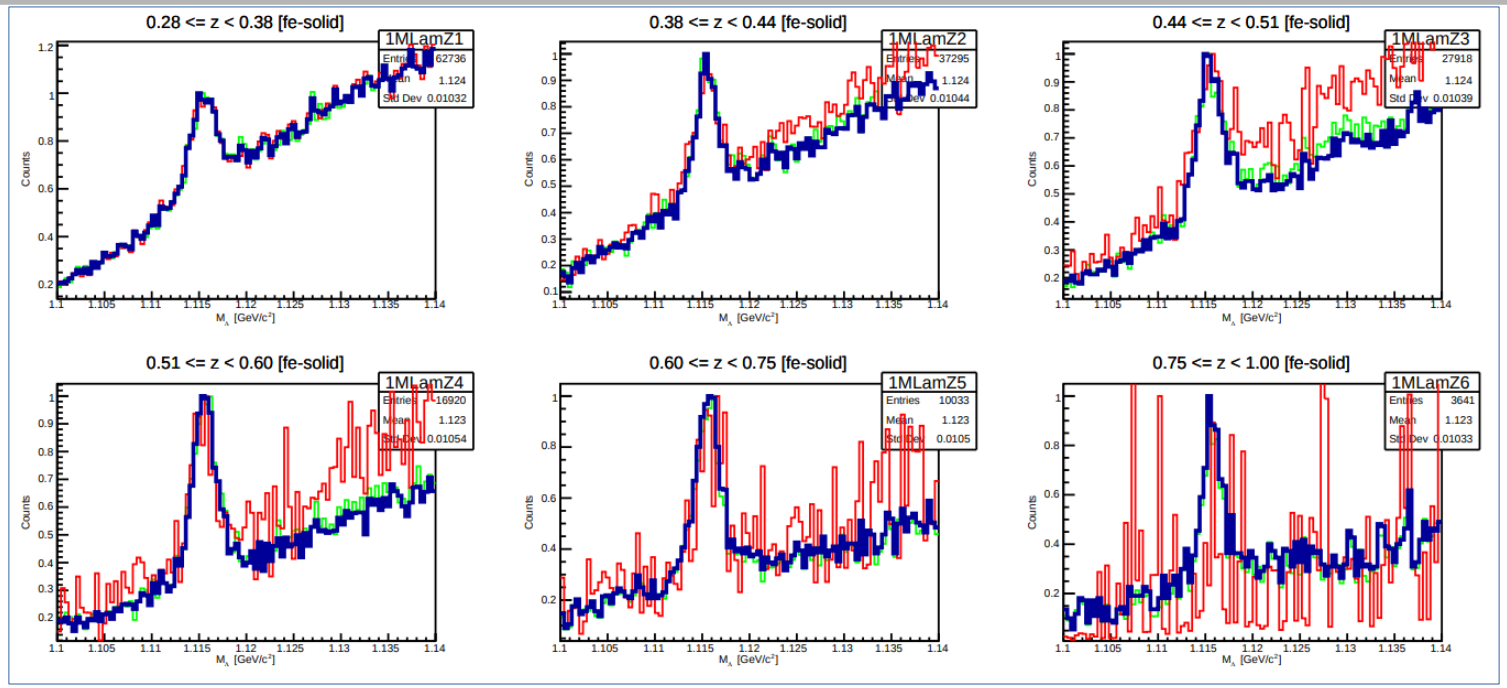
- Uncorrected.
- Correction applied without weight cuts.
- Corrections applied with weight cuts.

$$60 <= w < 530$$

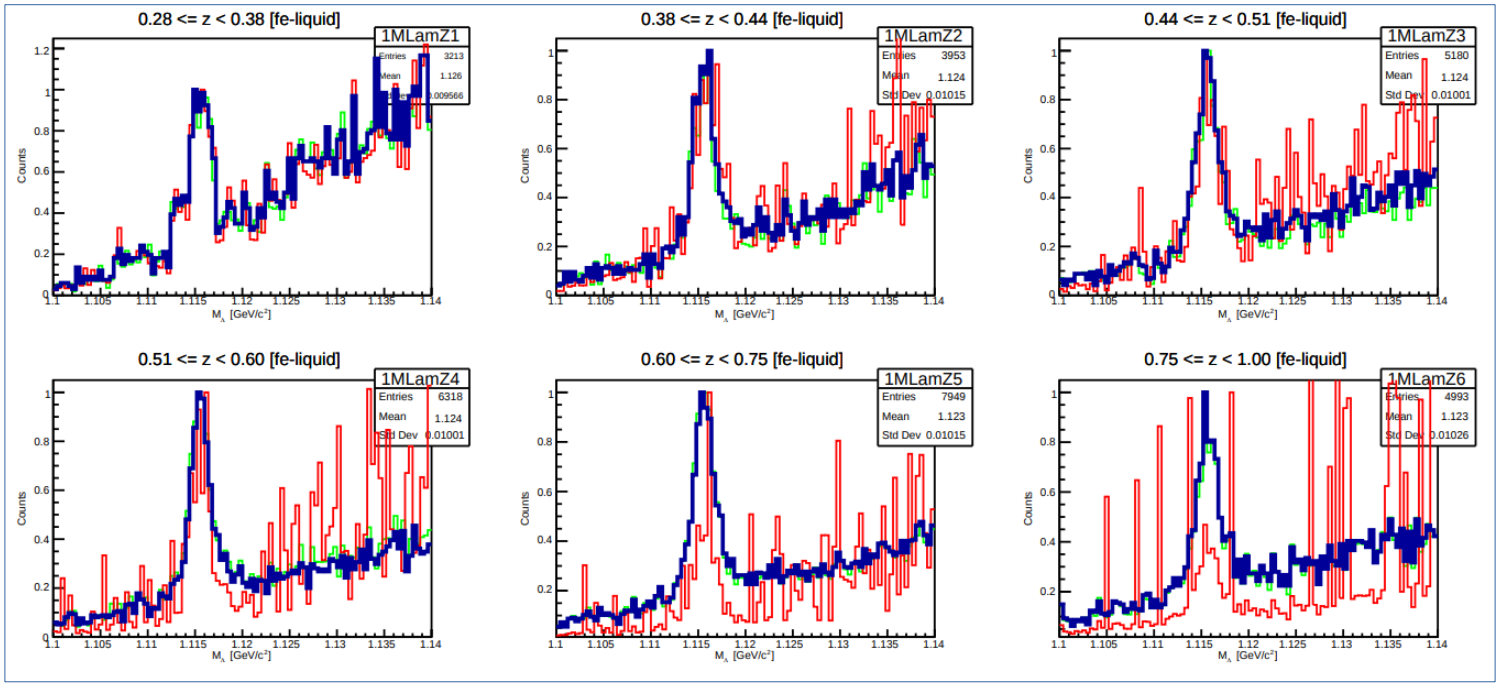
$$0.0 < \Delta w/w < 0.3$$

Other targets: Backup slides

D2Fe-Solid

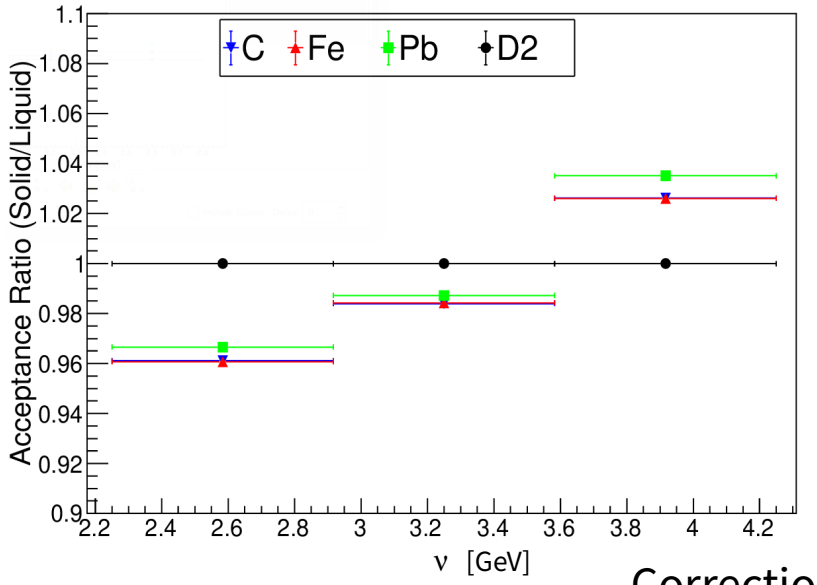


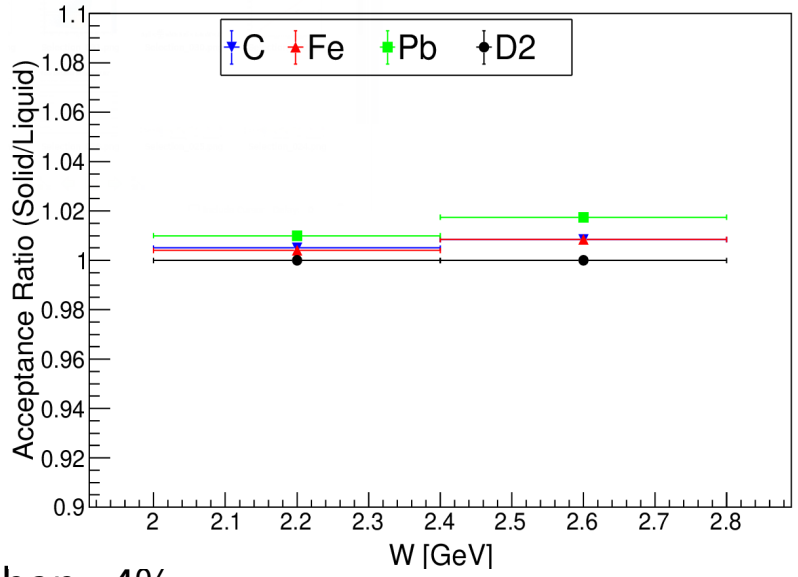
D2Fe-Liquid



Acceptance Corrections

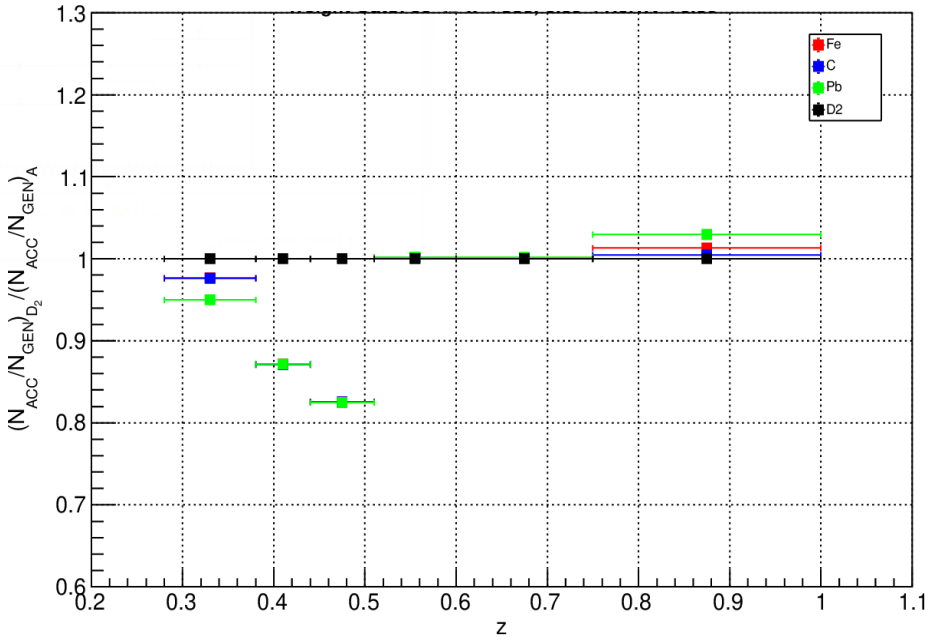
DIS electrons





Correction is less than ~4%

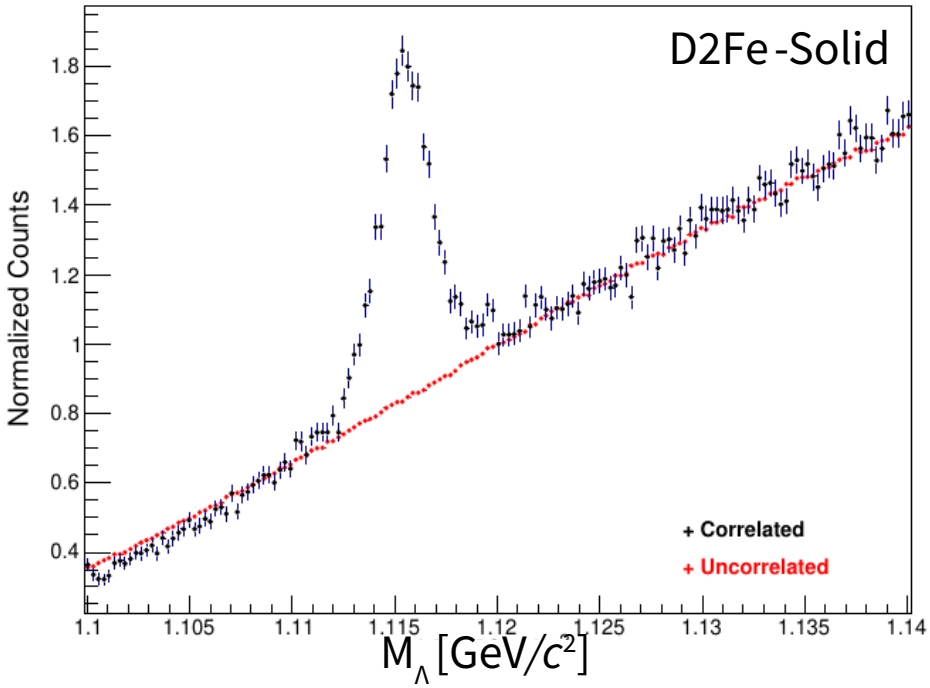
z-dependence

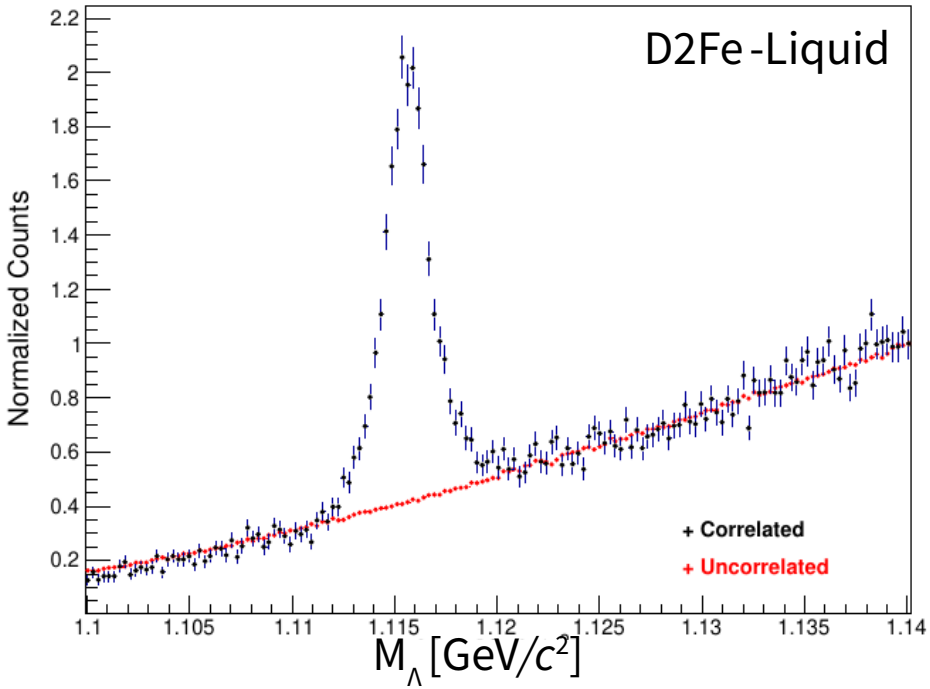


Global correction due to the weight cuts

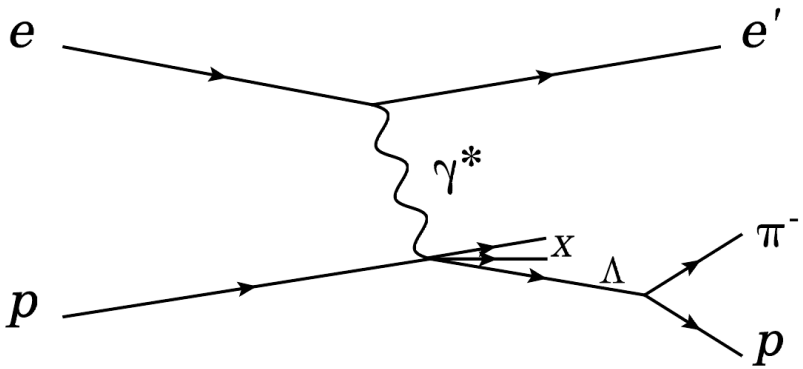
Combinatorial Background

Preliminary





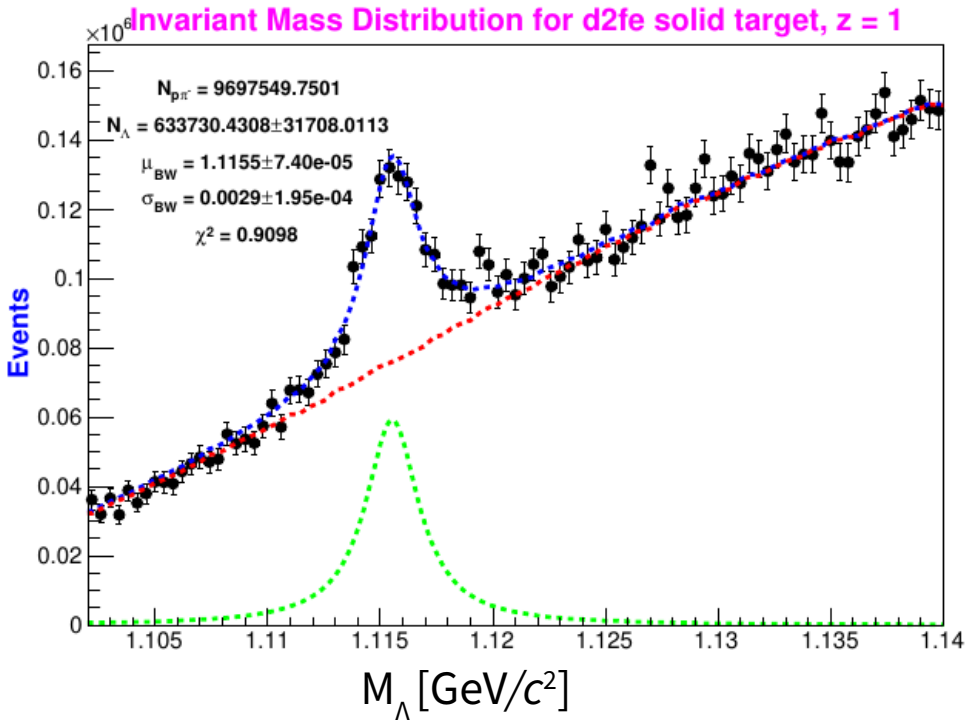
- Correlated protons and pions mixture constitutes the Λ events with a peak at ~1.1156 GeV.
- Uncorrelated protons and pions mixture describes the background.
- Using RooFit (ROOT's fitting toolkit), the background subtracted Lambda-yield is extracted.

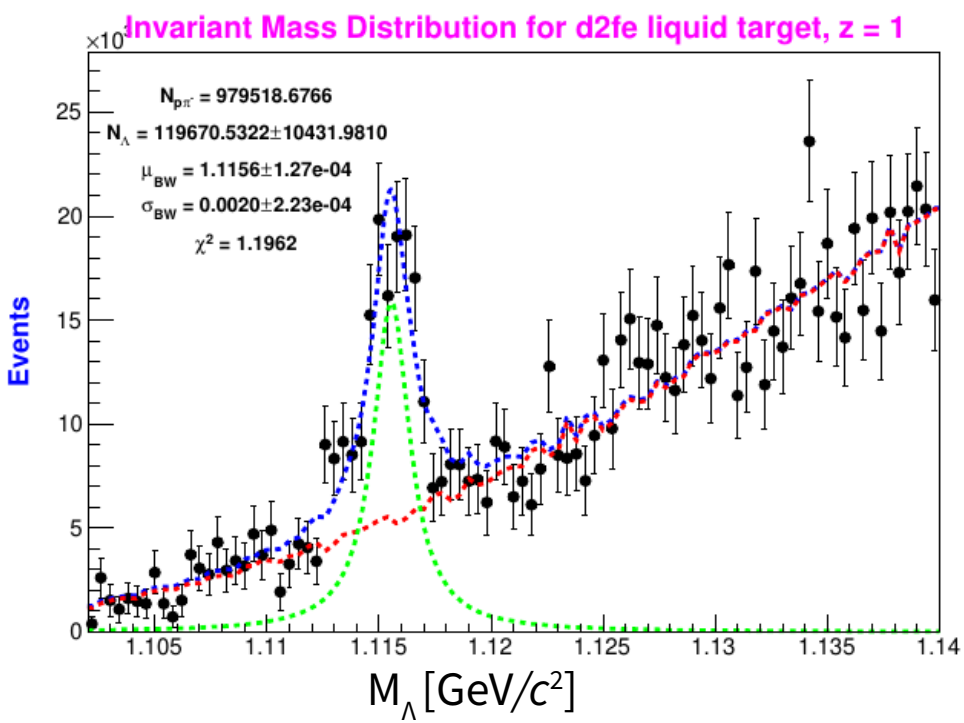


Yield Extraction: Acceptance Corrections Applied

Preliminary

- A sample z-bin: Λ invariant mass distribution after the background subtraction using RooFit minimization (Breit-Wigner + combinatoric background).



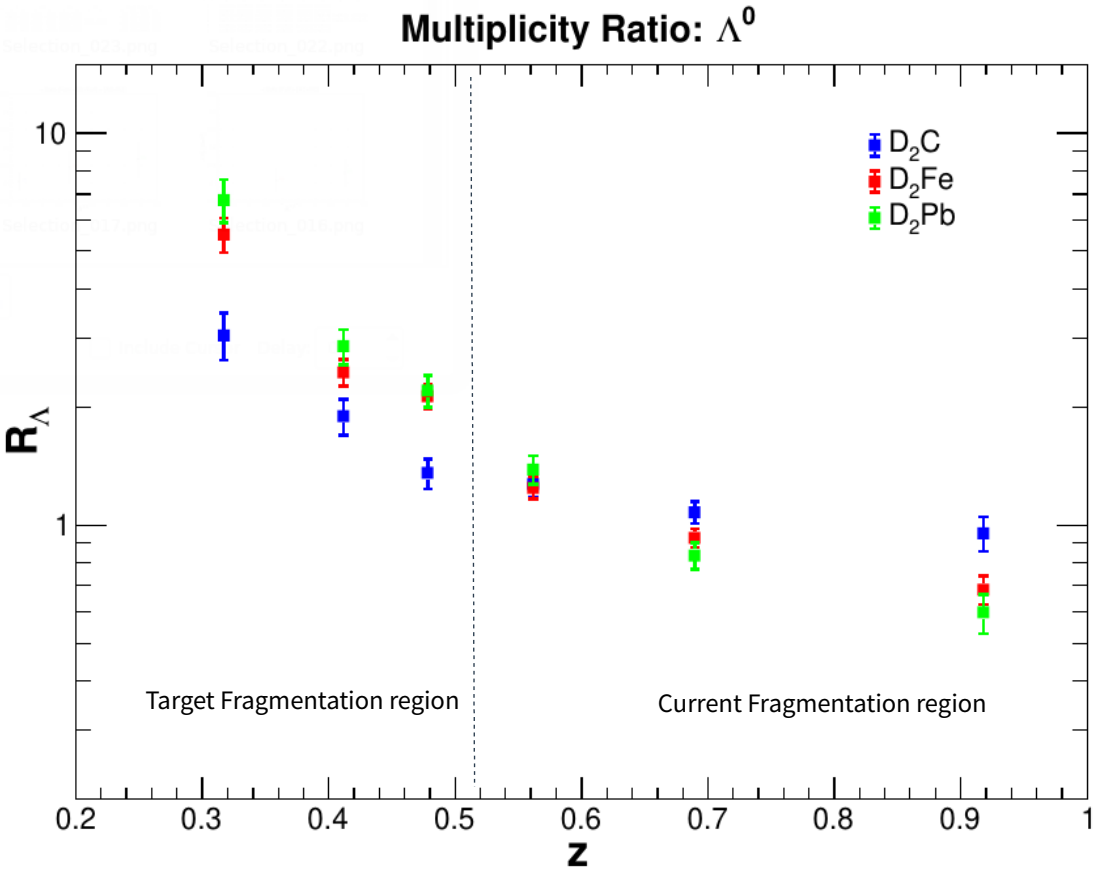


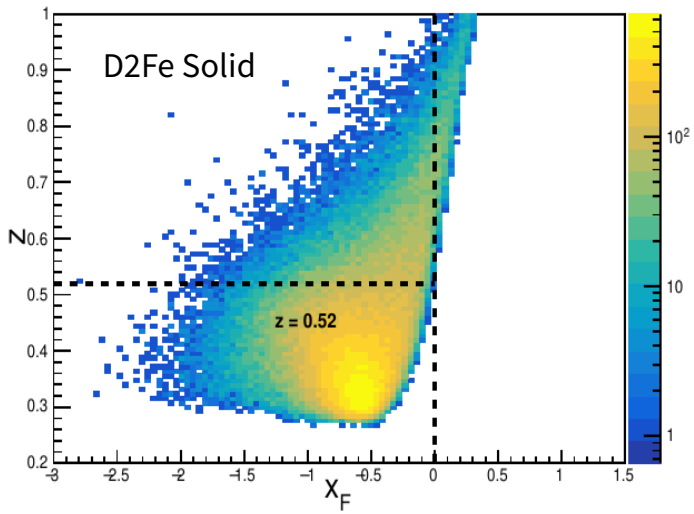
Bin #	1	2	3	4	5	6
z_{min}	0.28	0.38	0.44	0.51	0.60	0.75
z_{max}	0.38	0.44	0.51	0.60	0.75	1.00

Multiplicity Ratio

Preliminary
Acceptance+Radiative* Corrections Applied

* Radiative corrections provided by A. El Alaoui



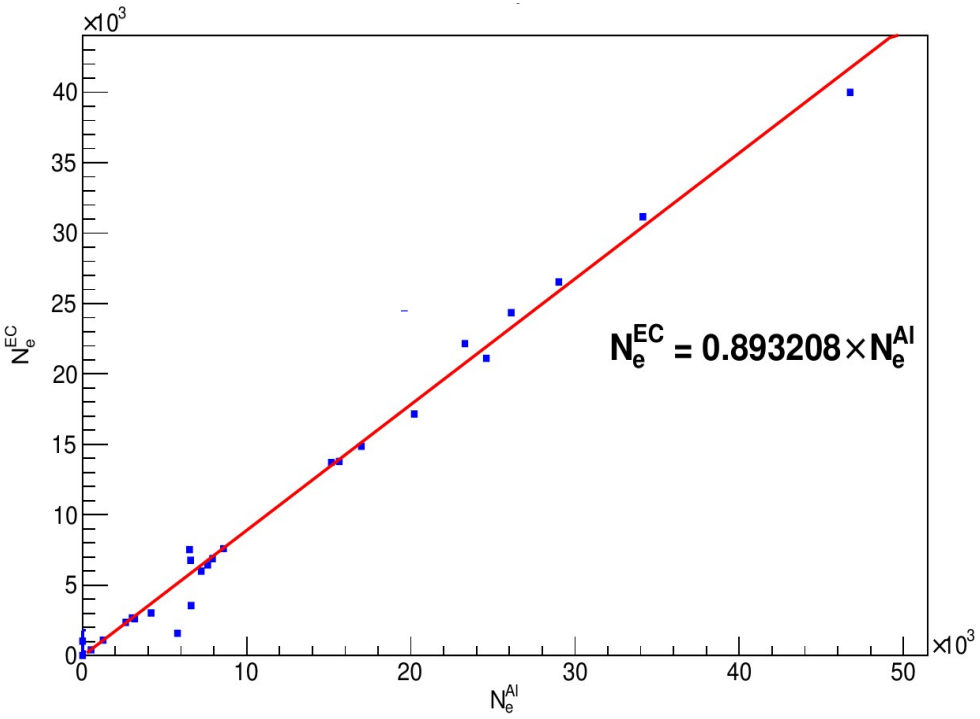


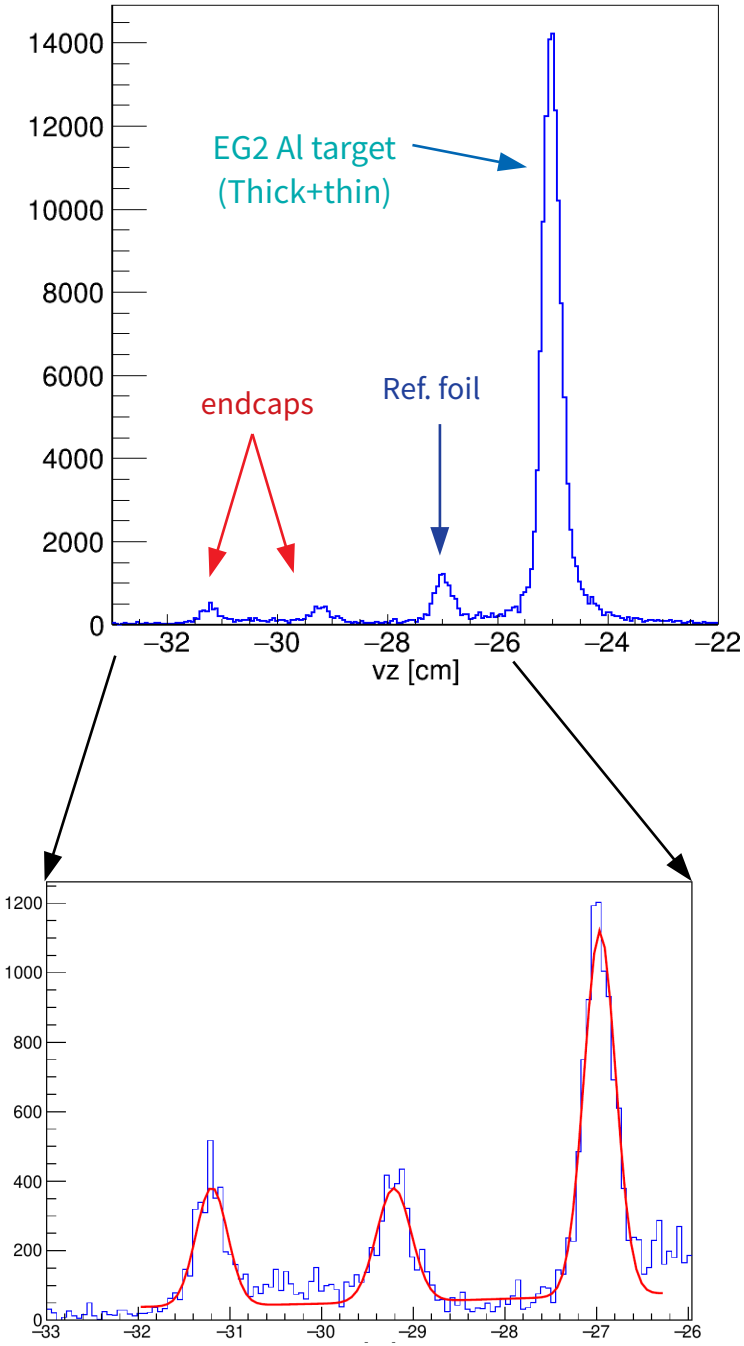
$$R_A^h(z) = \left.\frac{\frac{N_h(z)}{N_e|_{DIS}}}{\frac{N_h(z)}{N_e|_{DIS}}}\right|_A \Bigg|_{D_2}$$

- **Current fragmentation region**: struck quark initiates the hadronization process
- **Target fragmentation region**: The target remnant moves reciprocally with regard to the virtual photon direction undergoing a target fragmentation.
- An **attenuation flip** is observed at low z region for heavier nuclei.
- **First ever study of the hadronization process of Λ hyperon which probes the forward (current) and backward (target) fragmentation regions.**

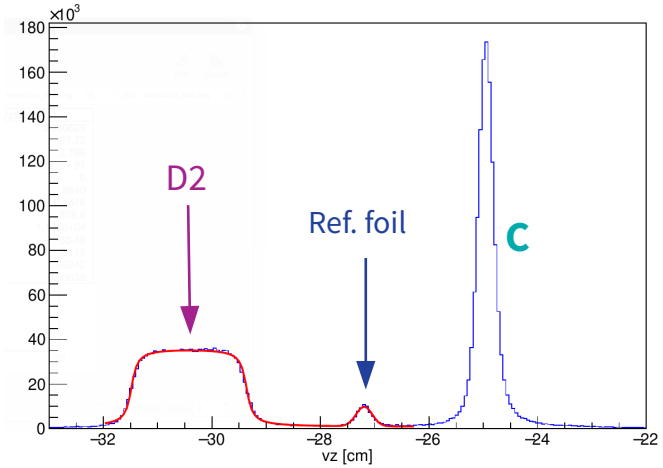
Endcap Corrections on the Multiplicity Ratios

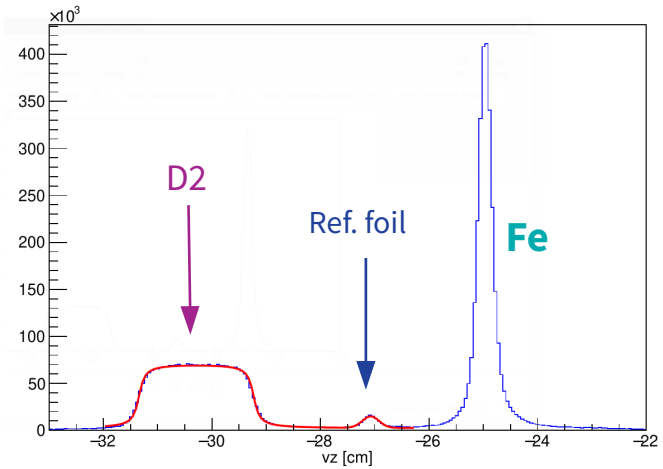
- **Six W** and **six ν** bins considered.
- Number of electrons originating from the endcaps (N_e^{EC}) and reference foil (N_e^{Al}) are estimated by fitting the z-vertex distribution in each bin.
- $N_e^{EC} = C \times N_e^{Al}$, $\quad C$ = constant

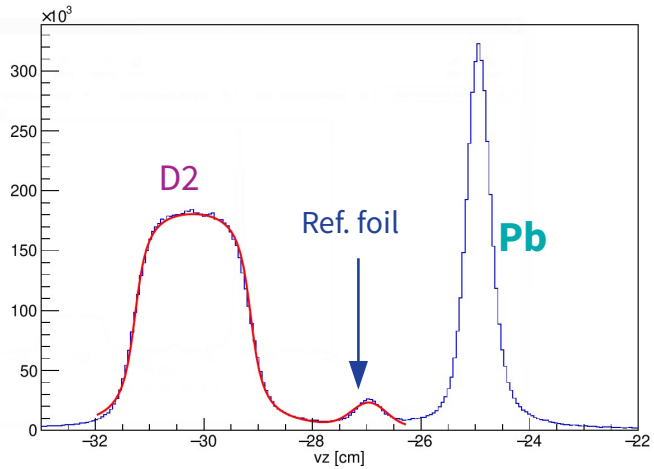




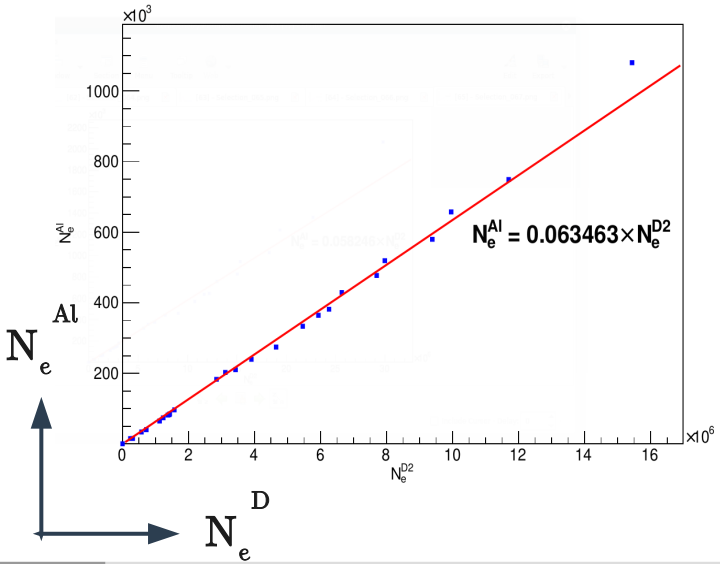
Endcap Corrections on the Multiplicity Ratios

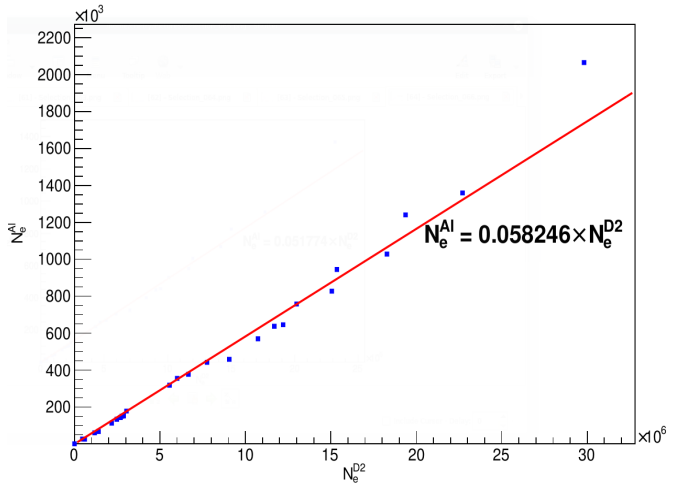


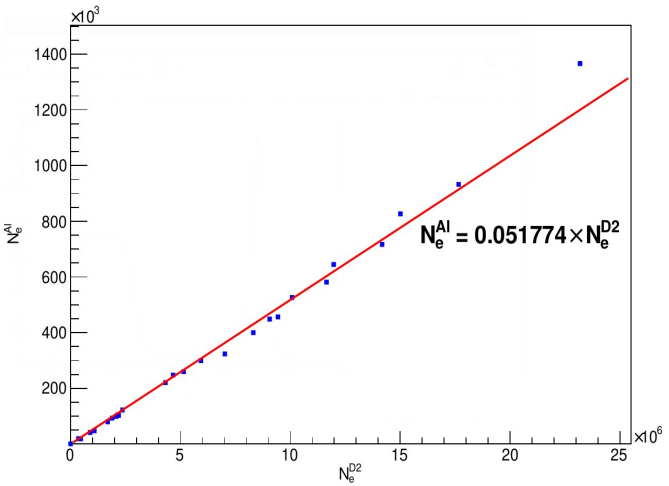




- Number of electrons originating from the liquid target including the endcaps (N_e^D) and the reference foil (N_e^{Al}) are estimated by fitting the z-vertex distribution in each bin.
- $N_e^{Al} = B_{Target} \times N_e^D$, B_{Target} = constant





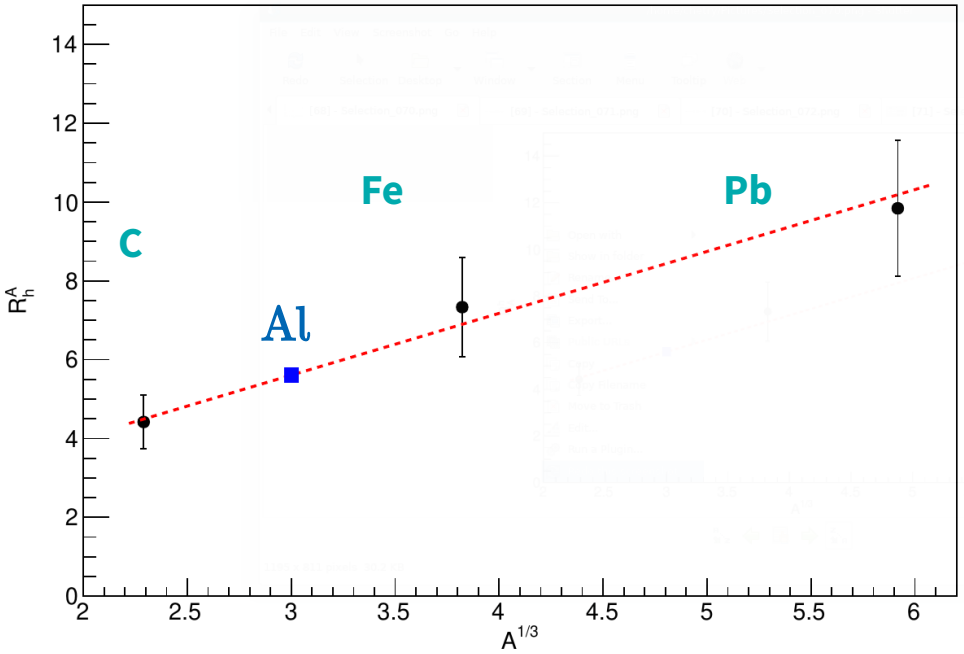


Endcap Corrections on the Multiplicity Ratios

- $N_e^{EC} = C \times N_e^{Al}$
- $N_e^{Al} = B_{Target} \times N_e^{D}$
- From the uncorrected R_h^A, the R_h^{Al} is estimated.

* $$R_h^A|_{corr} = \frac{N_h^A/N_e^A}{(N_h^D - N_h^{EC})/(N_e^D - N_e^{EC})},$$

* $$R_h^A|_{corr} = R_h^A \left(1 - \frac{N_e^{EC}}{N_e^D}\left(1 - R_h^{Al}\right)\right)$$

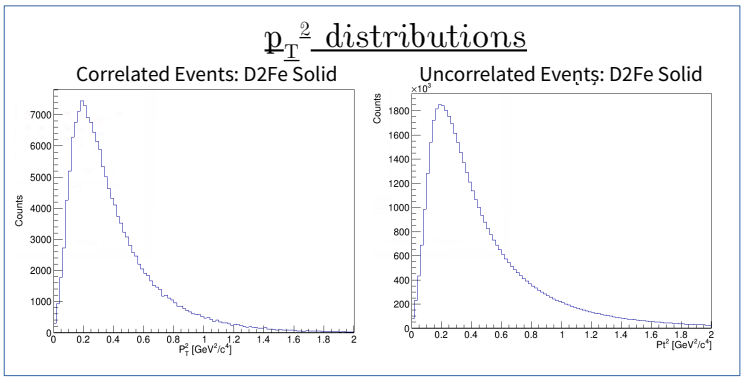


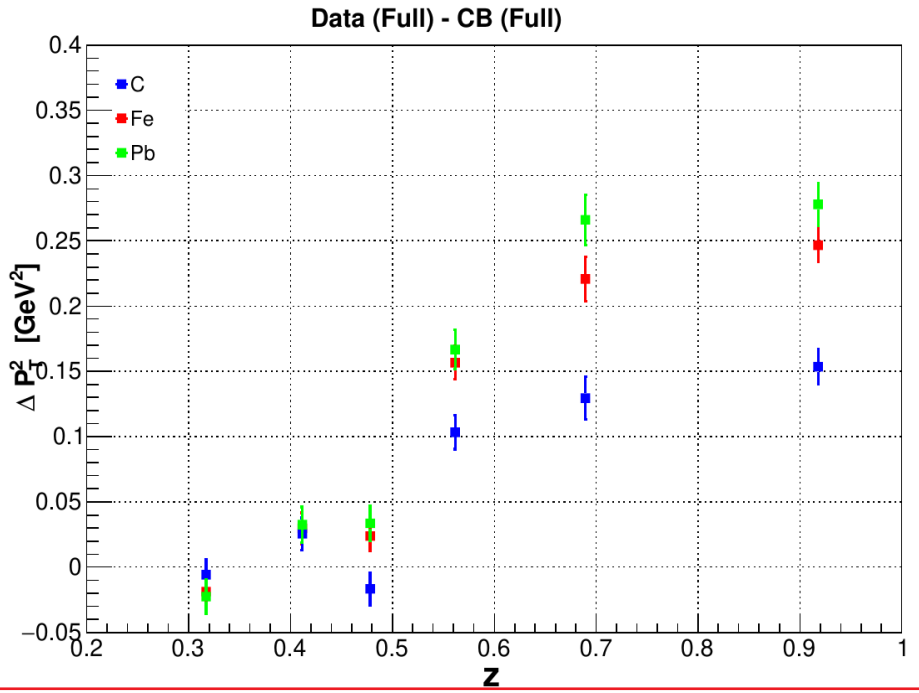
$$R_h^{Al} = 5.60747 \pm 1.61037$$

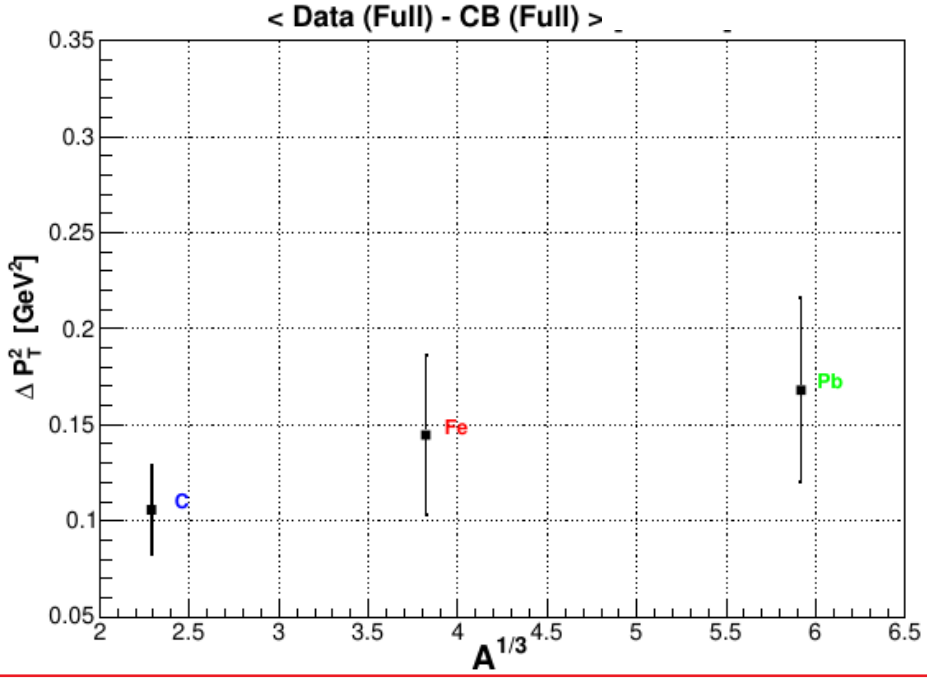
Target	$R_h^A\|_{corr}/R_h^A$
C	0.996804
Fe	0.997066
Pb	0.997391

* Neutral Pion Multiplicity Ratios from SIDIS Lepton-nuclear Scattering EG2 Analysis Note -T.Mineeva et. al.

- p_T^2 distributions recorded for Λ mass range: $1.1 <= M_\Lambda < 1.114$ GeV (**Full**).
- $\Delta P_T^2 = \langle P_T^2 \rangle_A - \langle P_T^2 \rangle_D$







- More broadening at high z.
- More broadening observed in heavier nuclei.

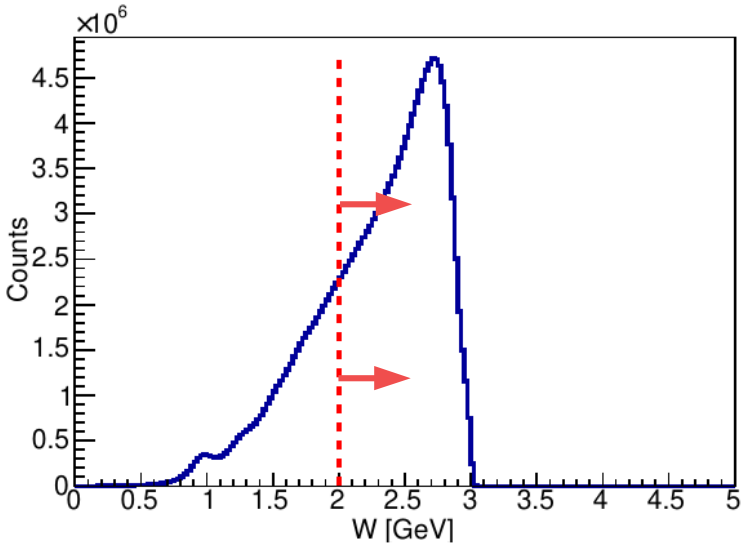
Summary and Outlook

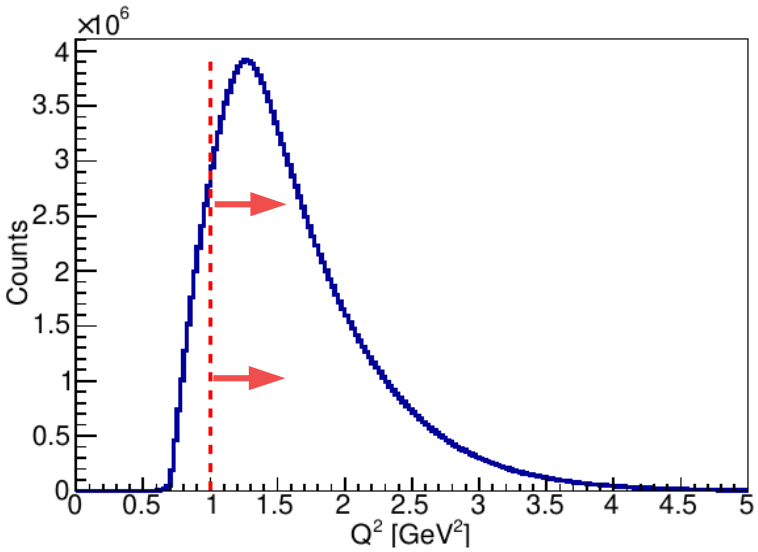
- First ever study of the hadronization process of Λ-hyperon probing the current- and target-fragmentation regions.
- Results from the baryon and meson channels using the same EG2 dataset are consistent.
- Next steps would include:
  - Submission of CLAS Analysis note.
  - Systematic studies.
  - Outlook: Study other dependencies of R_Λ on Q^2, ${P_T}^2$(Cronin effect).

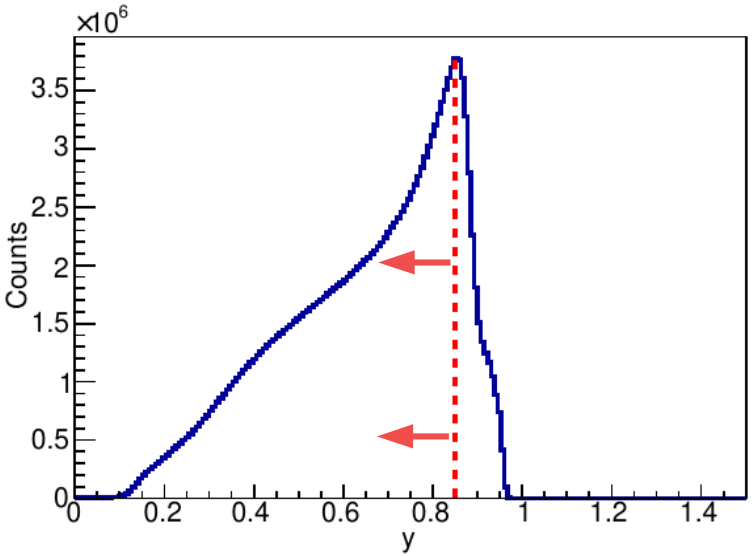
Thank you!

Extras

Selection of SIDIS Events: Kinematic Cuts







$W > 2$ GeV

→ to avoid contamination from resonance region.

$Q^2 > 1$ GeV^2

→ to probe nucleon substructure.

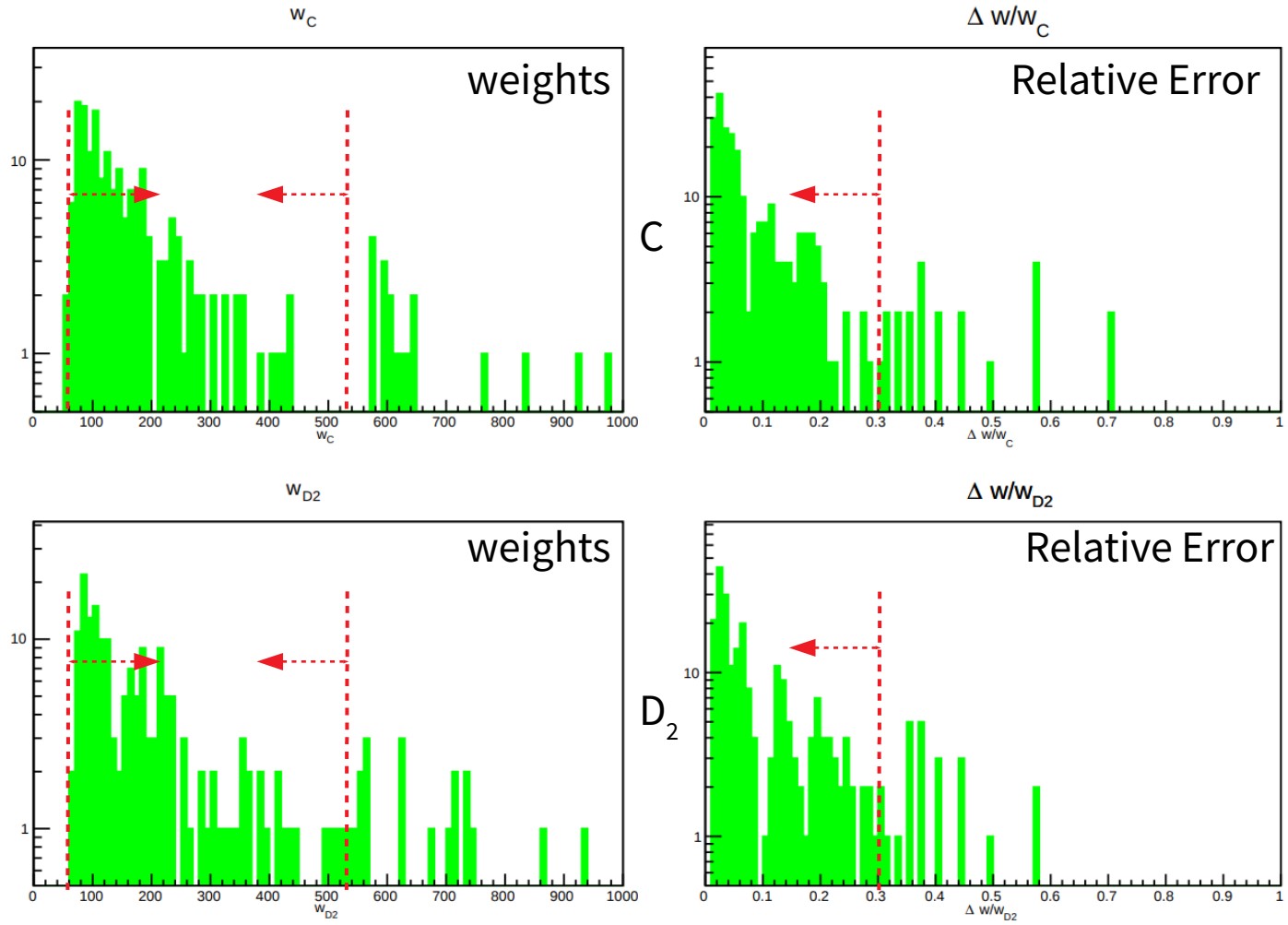
$y < 0.85$ (based on HERMES study)

→ to reduce the size of radiative effects.

Cuts on the Weights and Relative Error

$$60 <= w < 530$$

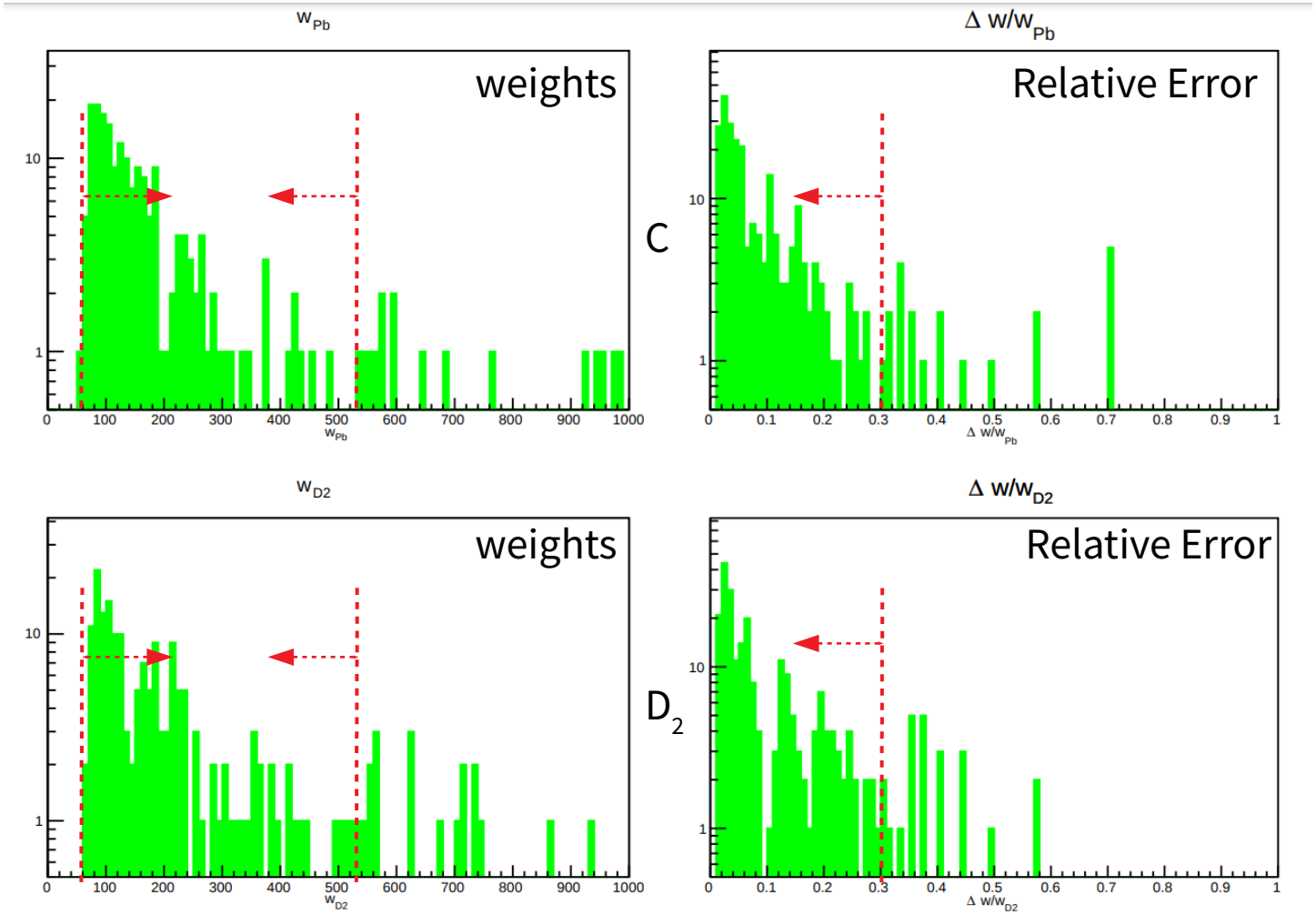
$$0.0 < \Delta w/w < 0.3$$



Cuts on the Weights and Relative Error

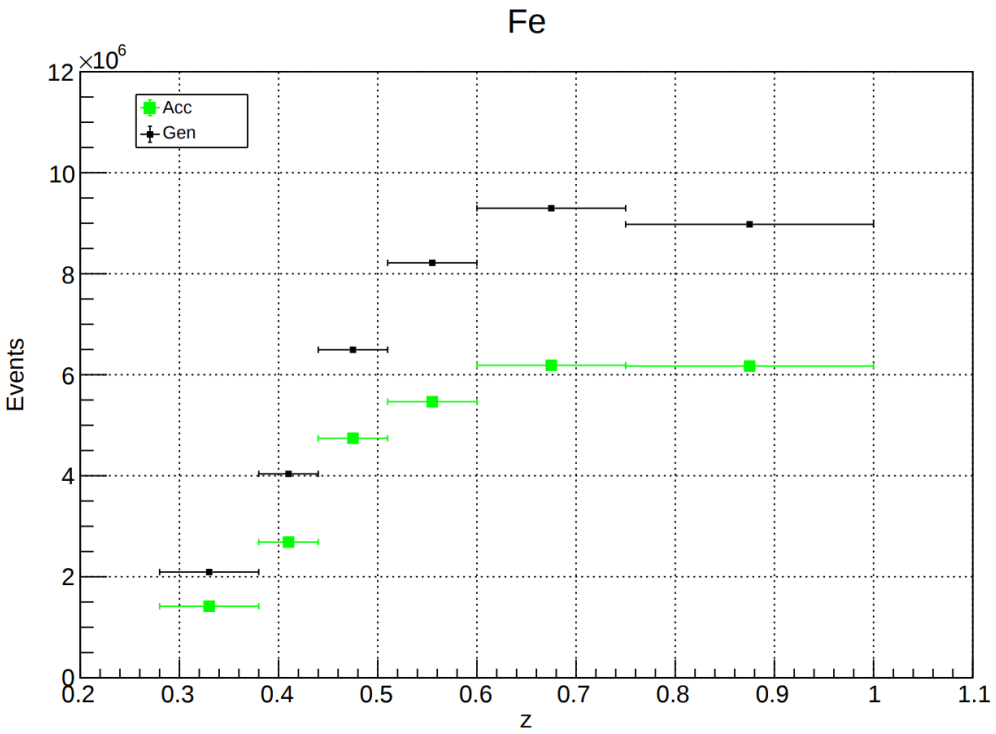
$$60 <= w < 530$$

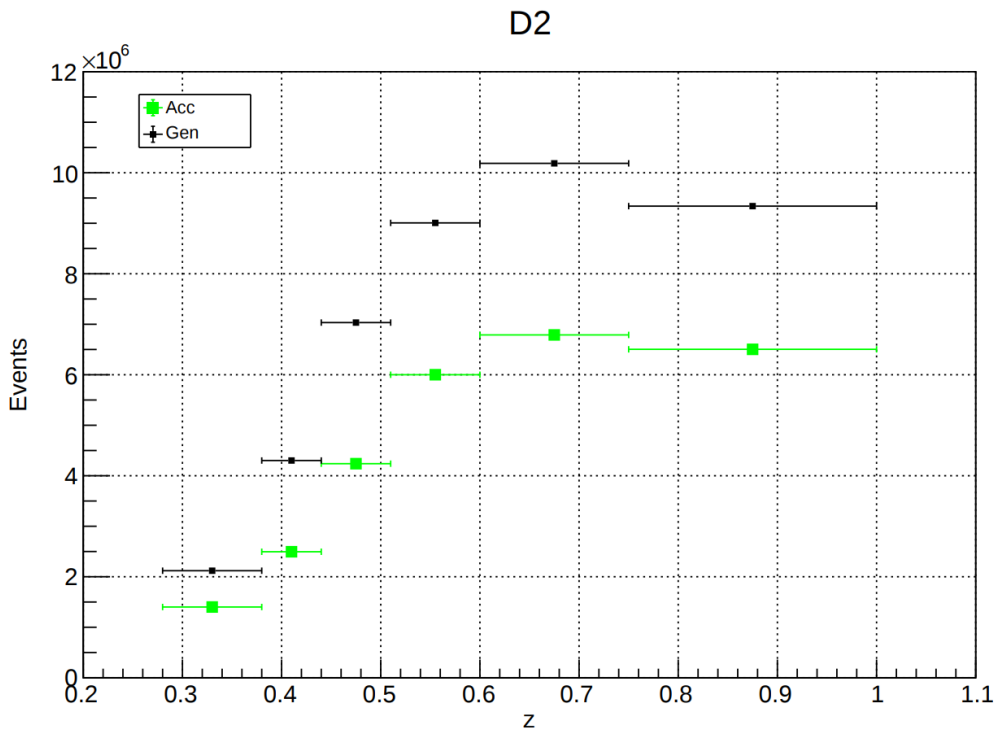
$$0.0 < \Delta w/w < 0.3$$



Effect of Weight Cuts on Number of Reconstructed Events

- Effect of the weight cuts on the number of reconstructed events.





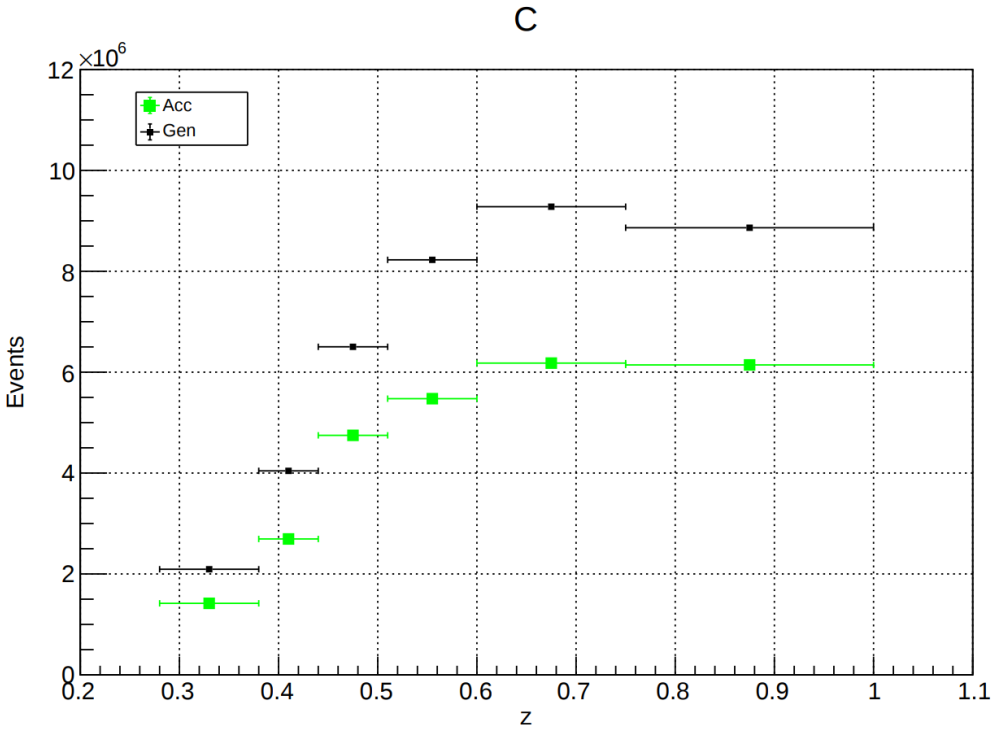
$$60 <= w < 530$$

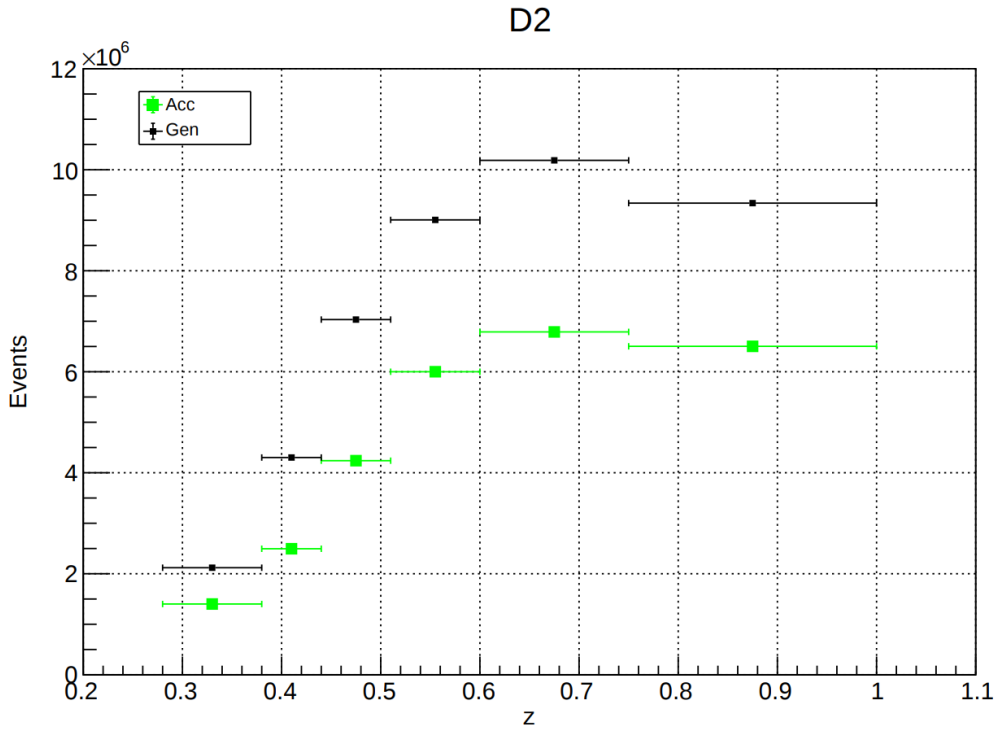
$$0.0 < \Delta w/w < 0.3$$

Other targets: Backup slides

Effect of Weight Cuts on Number of Reconstructed Events

- Number of events:
  - Effect of the weight cuts on the number of reconstructed (accepted) events.



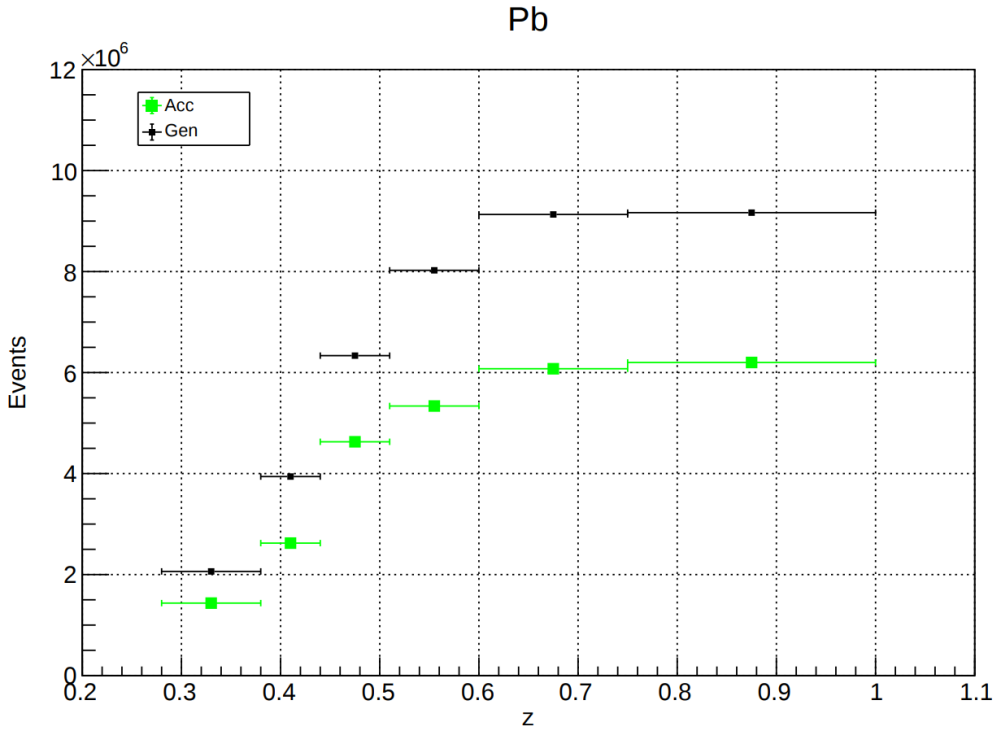


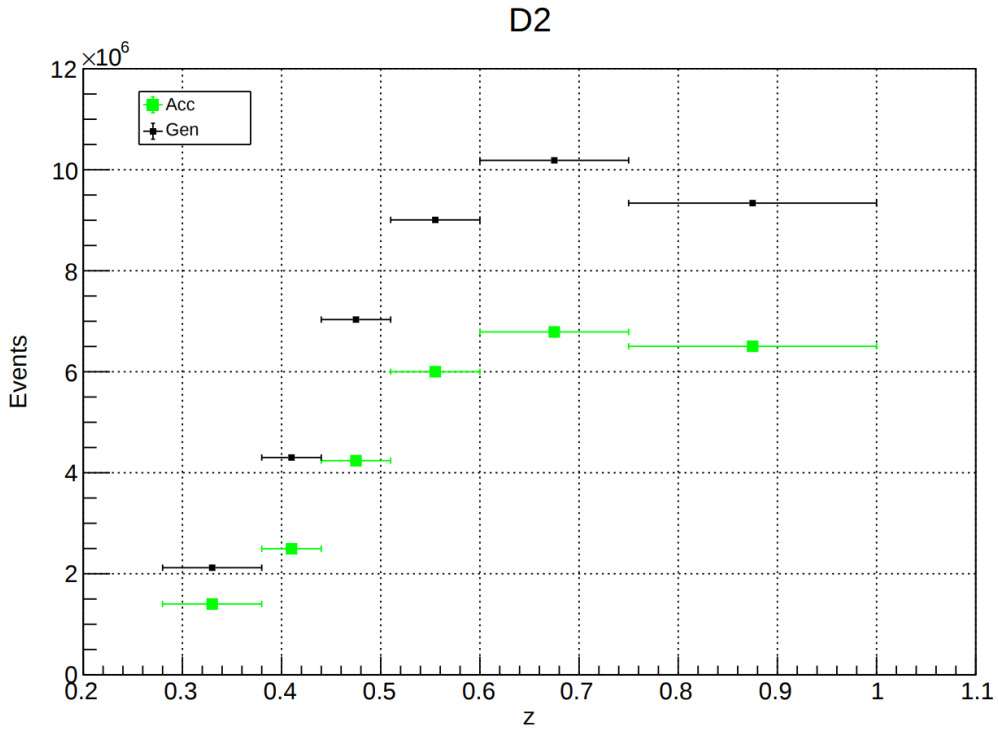
$$60 <= w < 530$$

$$0.0 < \Delta w/w < 0.3$$

Effect of Weight Cuts on Number of Reconstructed Events

- Number of events:
  - Effect of the weight cuts on the number of reconstructed (accepted) events.





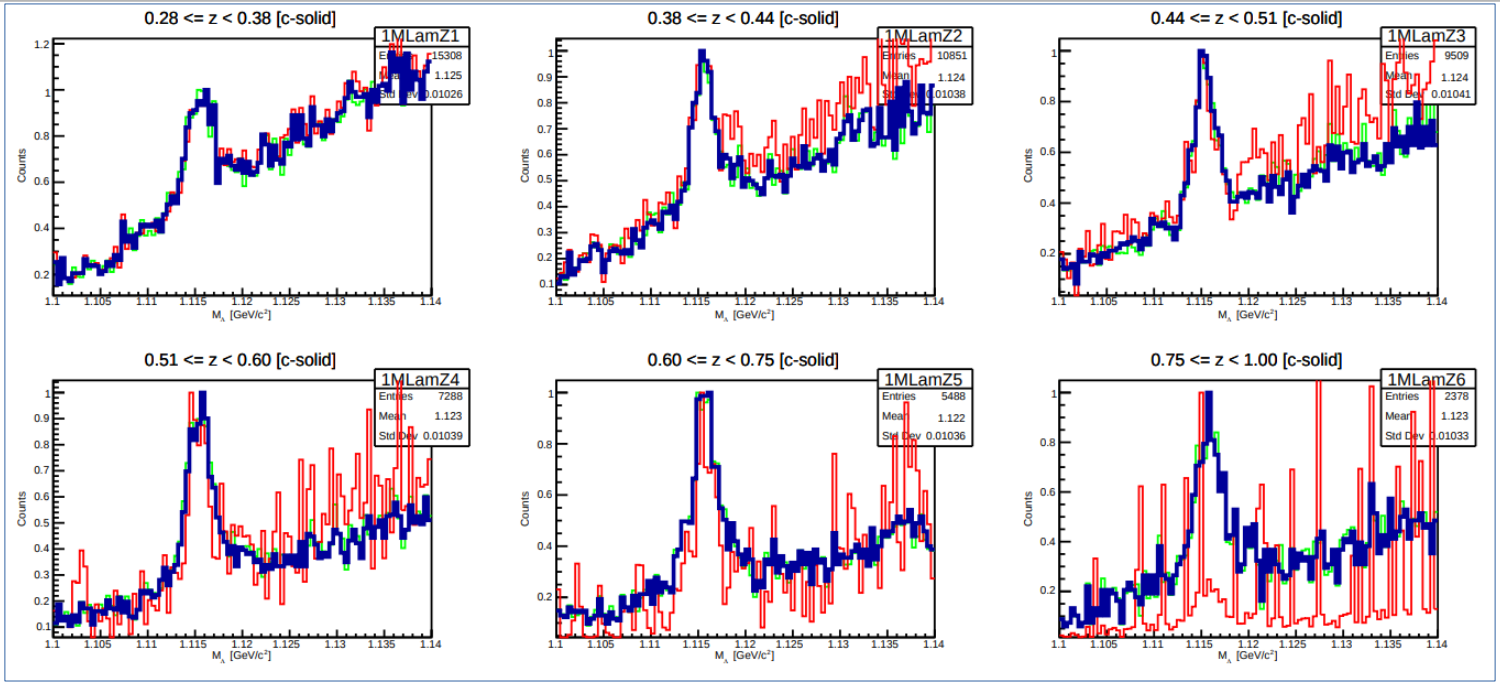
$$60 <= w < 530$$

$$0.0 < \Delta w/w < 0.3$$

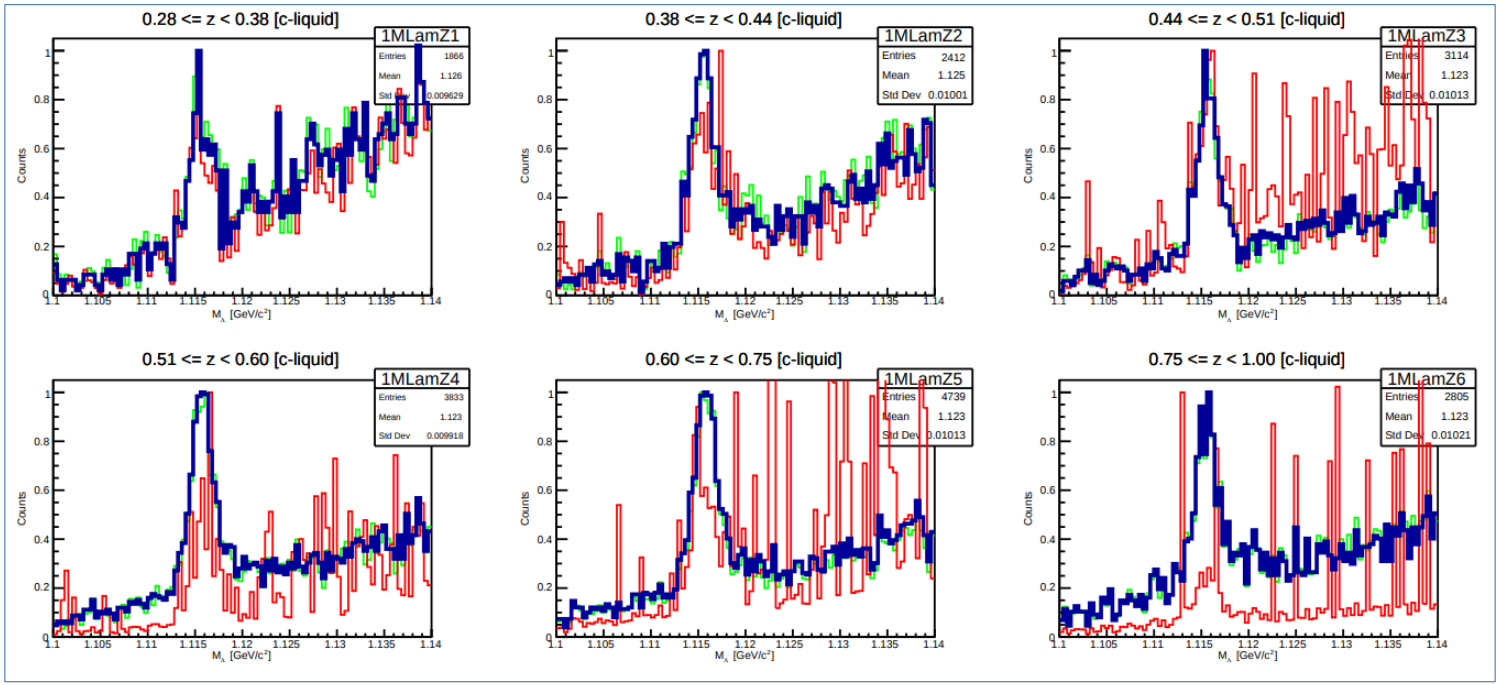
Effect of Weight Cuts on Λ Mass Distributions

- Uncorrected.
- Correction applied without weight cuts.
- Corrections applied with weight cuts.

D2C-Solid



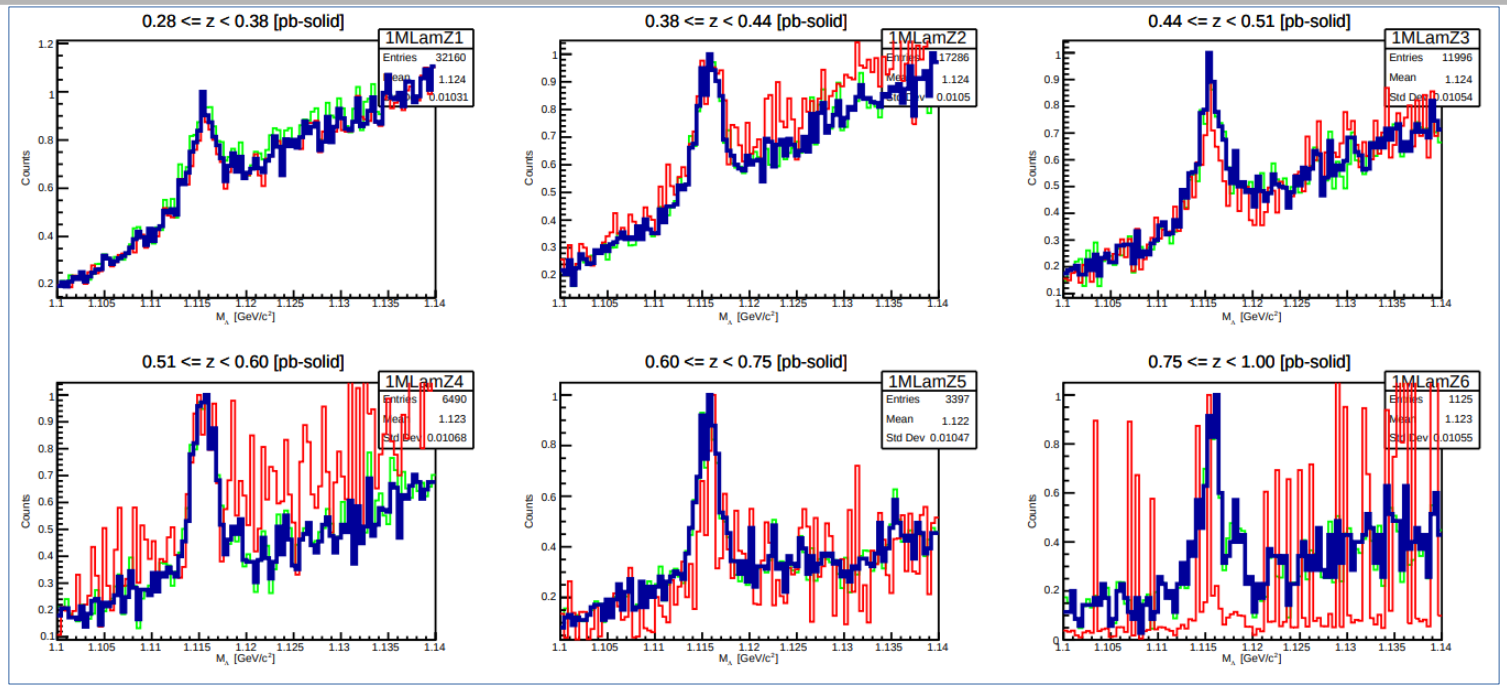
D2C-Liquid



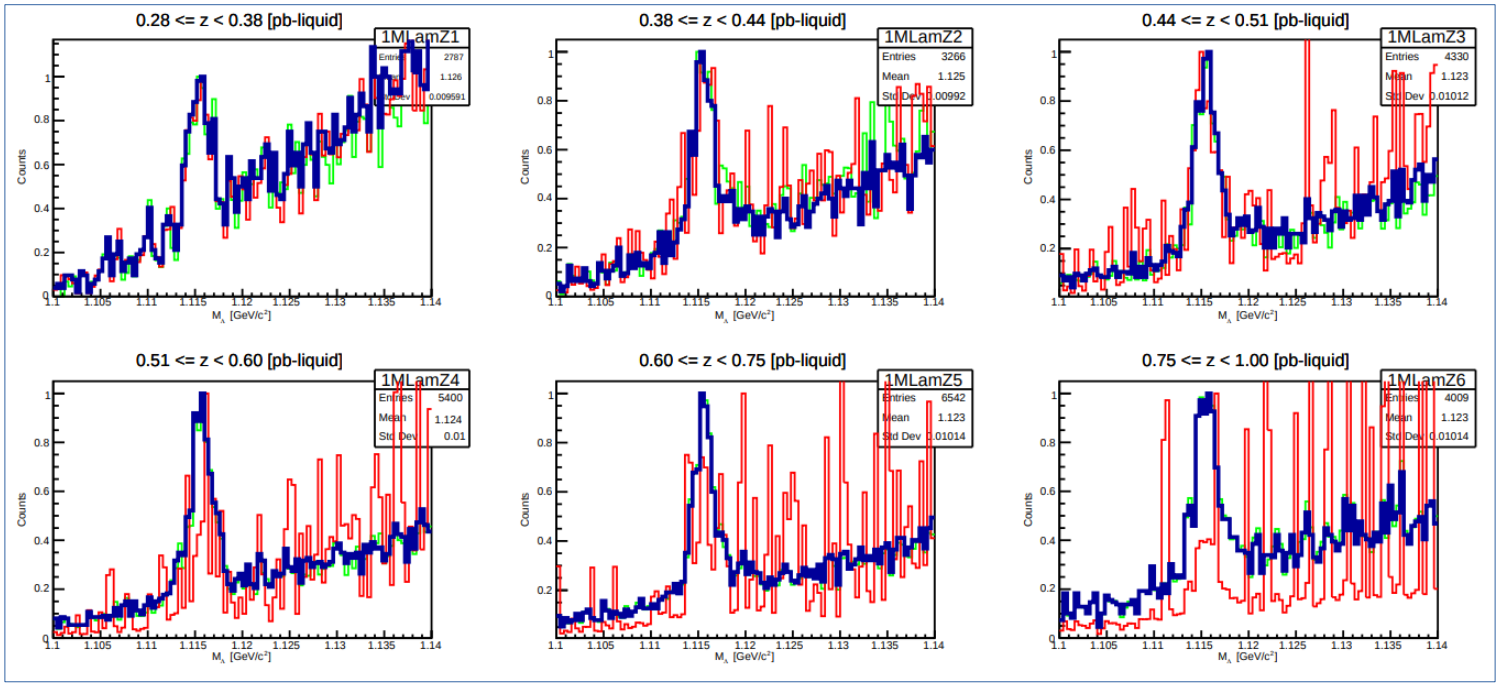
Effect of Weight Cuts on Λ Mass Distributions

- Uncorrected.
- Correction applied without weight cuts.
- Corrections applied with weight cuts.

D2Pb-Solid



D2Pb-Liquid

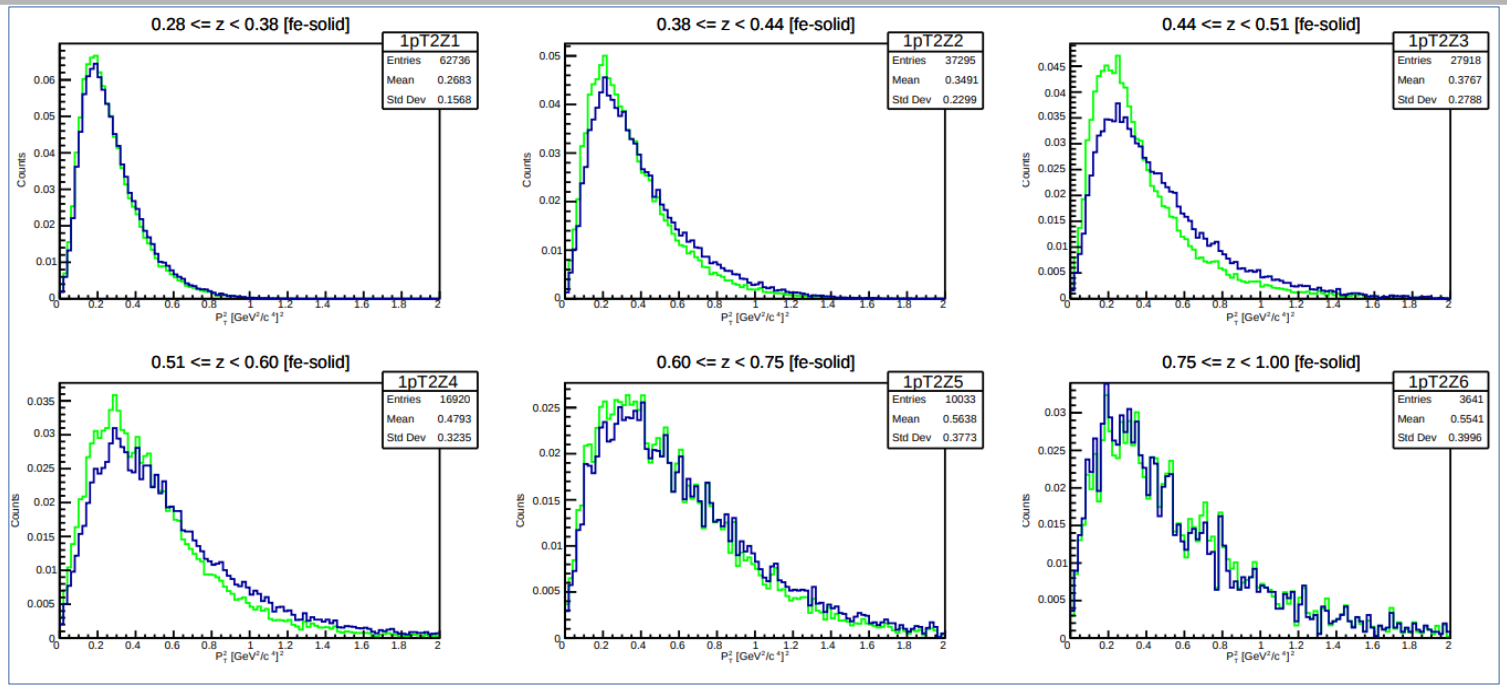


Effect of Weight Cuts on p_T^2 Distributions

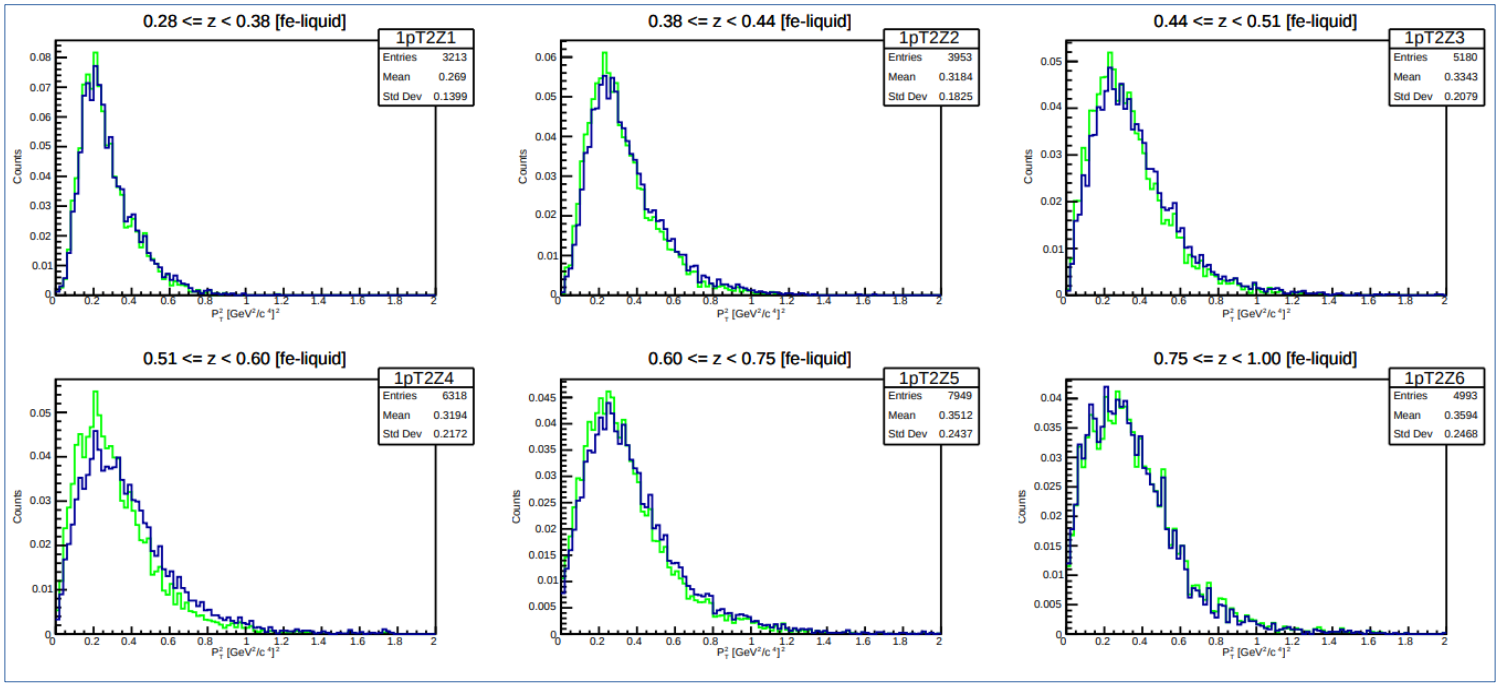
Preliminary

- Uncorrected.
- Corrections applied with weight cuts.

D2Fe-Solid



D2Fe-Liquid

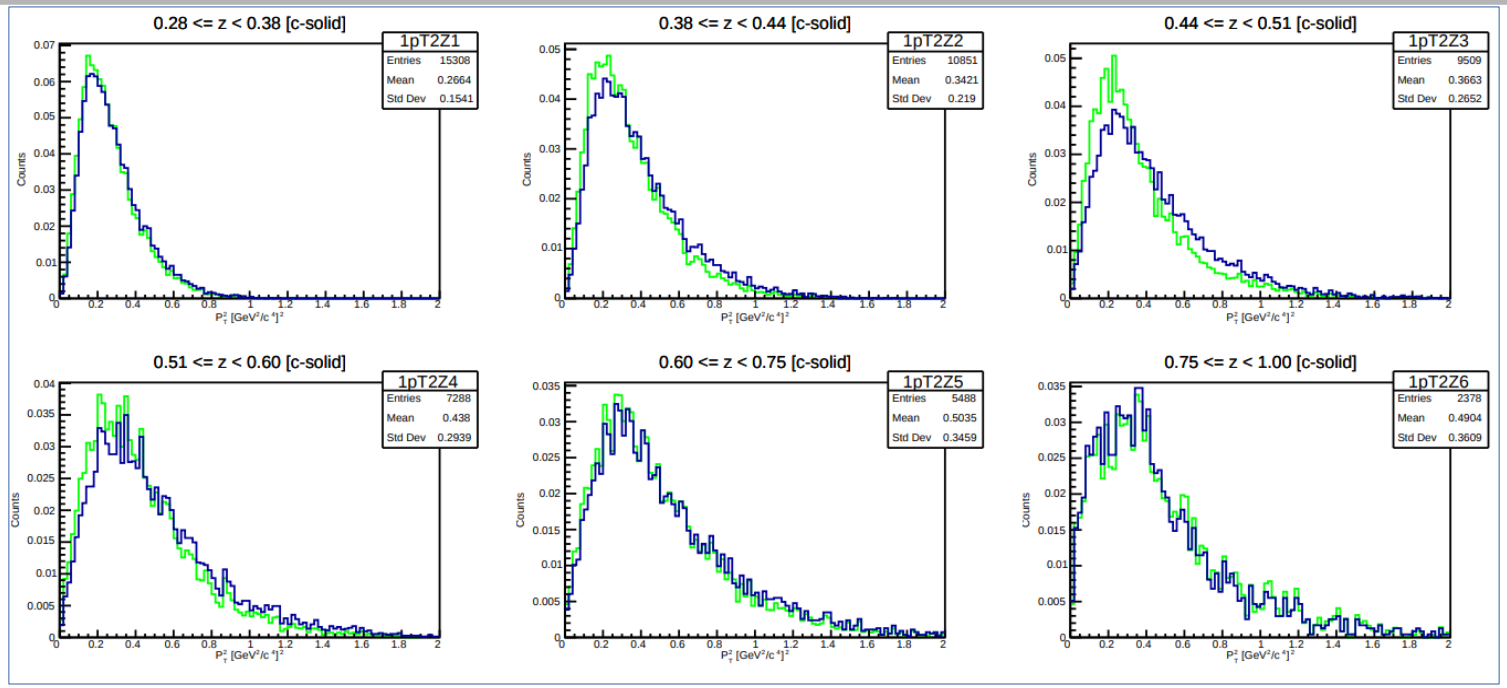


Effect of Weight Cuts on p_T^2 Distributions

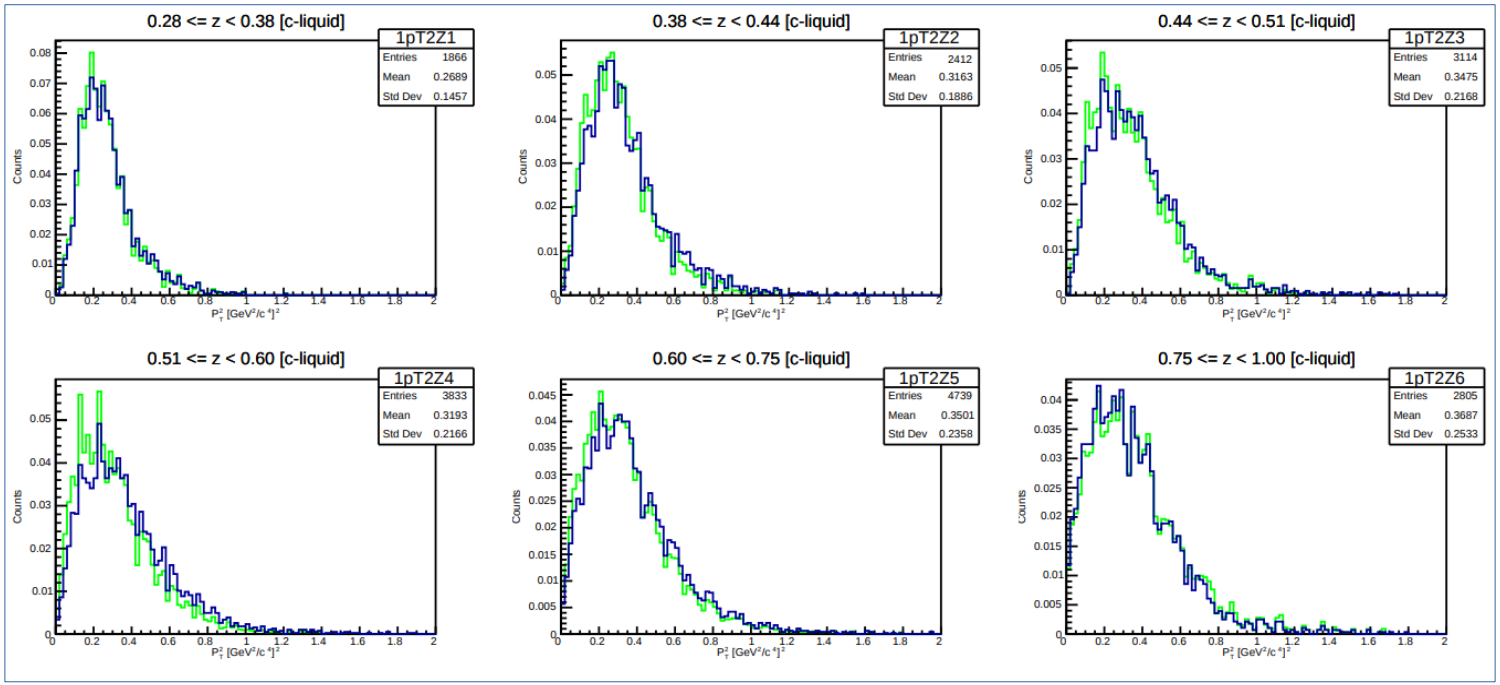
Preliminary

- Uncorrected.
- Corrections applied with weight cuts.

D2C-Solid



D2C-Liquid

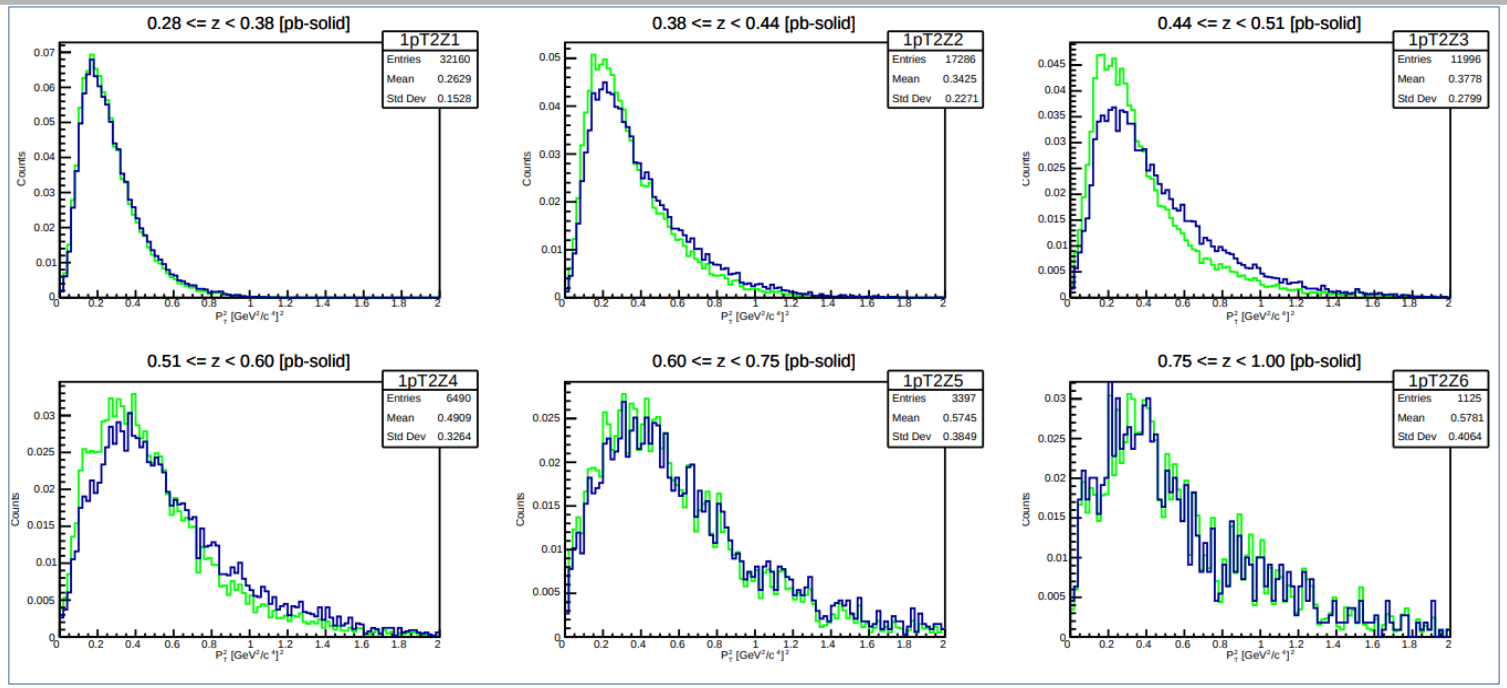


Effect of Weight Cuts on p_T^2 Distributions

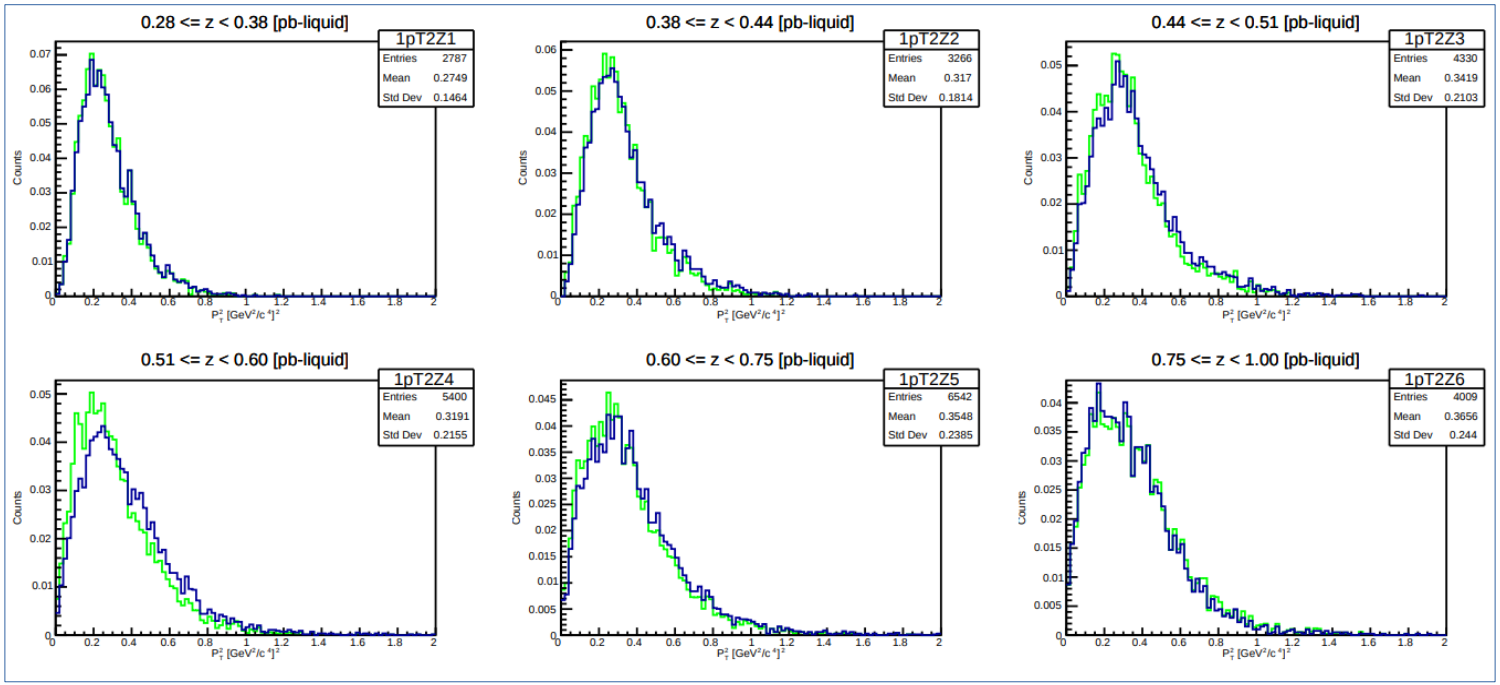
Preliminary

- Uncorrected.
- Corrections applied with weight cuts.

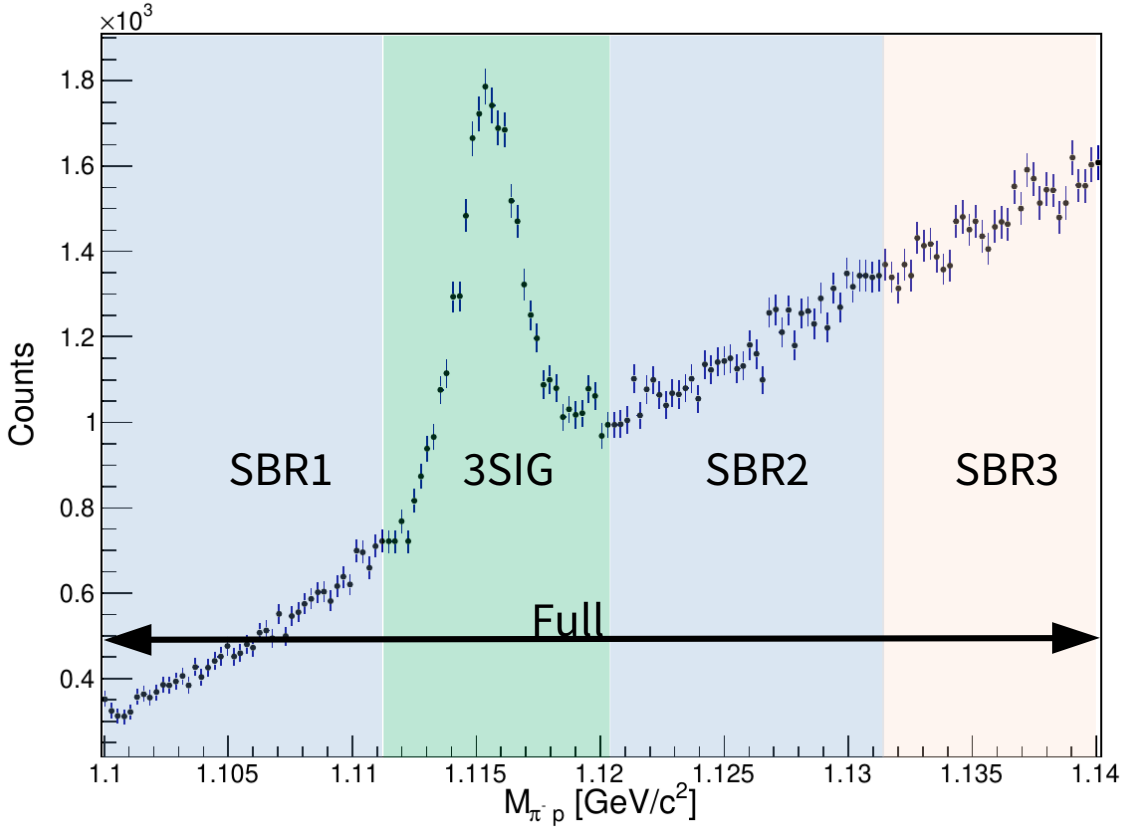
D2Pb-Solid



D2Pb-Liquid



Transverse Momentum Broadening (Acceptance Corrected with Weight Cuts)

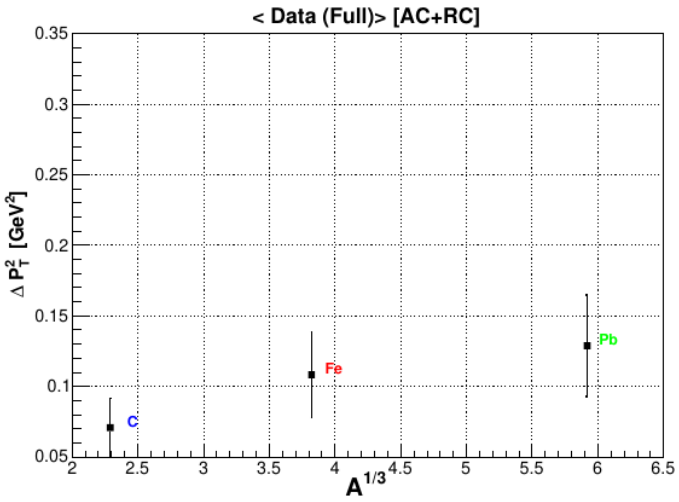


- **Full Range: 1.1 <= M_Λ < 1.14**
- SBR1: 1.1 <= M_Λ < μ − 3 σ
- 3SIG: μ − 3 σ <= M_Λ < μ + 3 σ
- SBR2: μ + 3 σ <= M_Λ < 2 μ − 1.1
- SBR3: 2 μ − 1.1 <= M_Λ < 1.14
- Widths of SBR1 and SBR2 are the same.

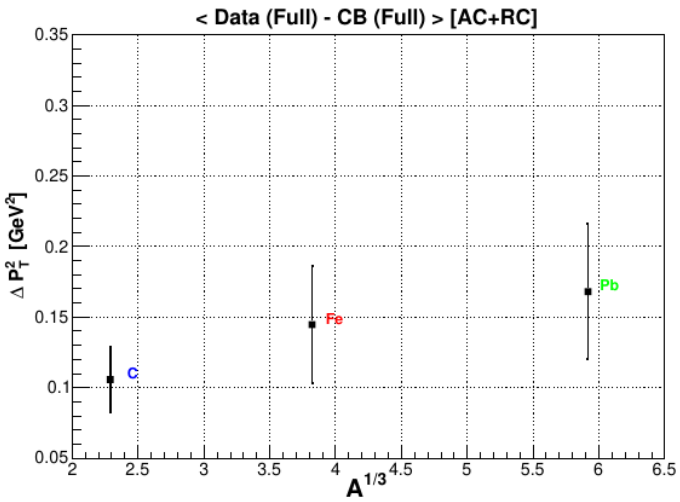
Transverse momentum distributions for each region are stored for **data** and **Combinatorial Backgrounds (CB)**.

Transverse Momentum Broadening (AC+RC)

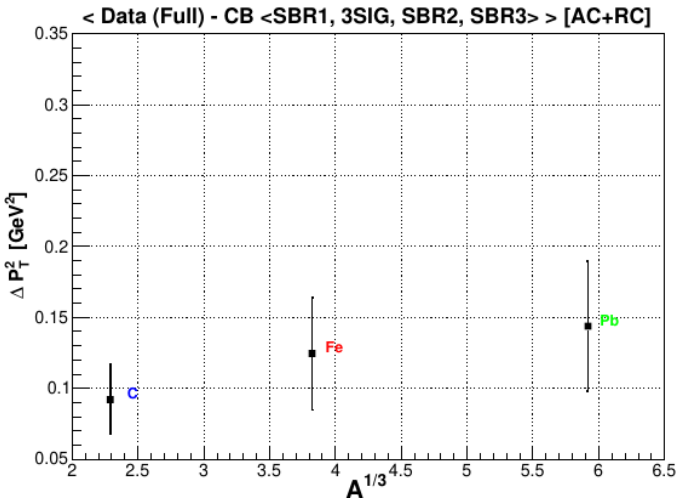
Result 1



Result 2

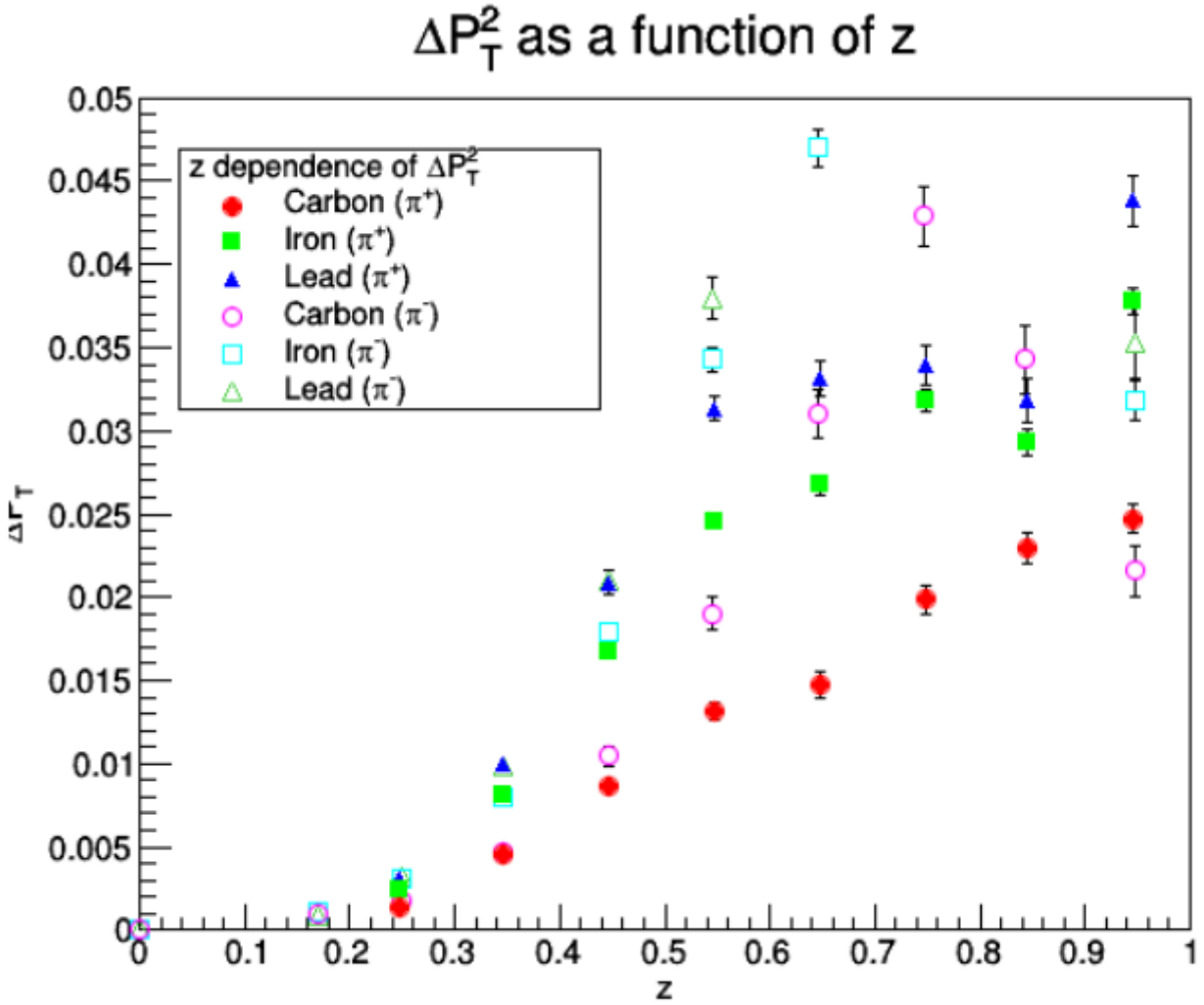


Result 3



- **Result 1:** Data (Full): No background subtraction
- **Result 2:** Data (Full) – CB (Full)
- **Result 3:** Data (Full) – CB (<SBR1, 3SIG, SBR2, SBR3>)

Transverse Momentum Broadening: Mesons



Study of the hadronization of charged pions
(Undergoing CLAS review)
-R. Dupre