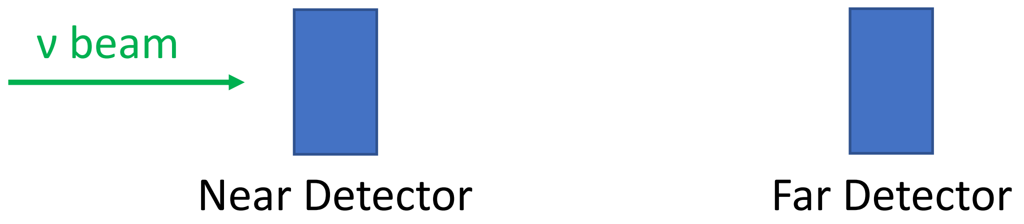
Measuring CLAS D(e,e'π) Cross Sections for e4ν

Caleb Fogler for the CLAS Collaboration

Neutrino Experiments

- Neutrino oscillations



Compare flux at near and far detectors

Neutrino Flux:

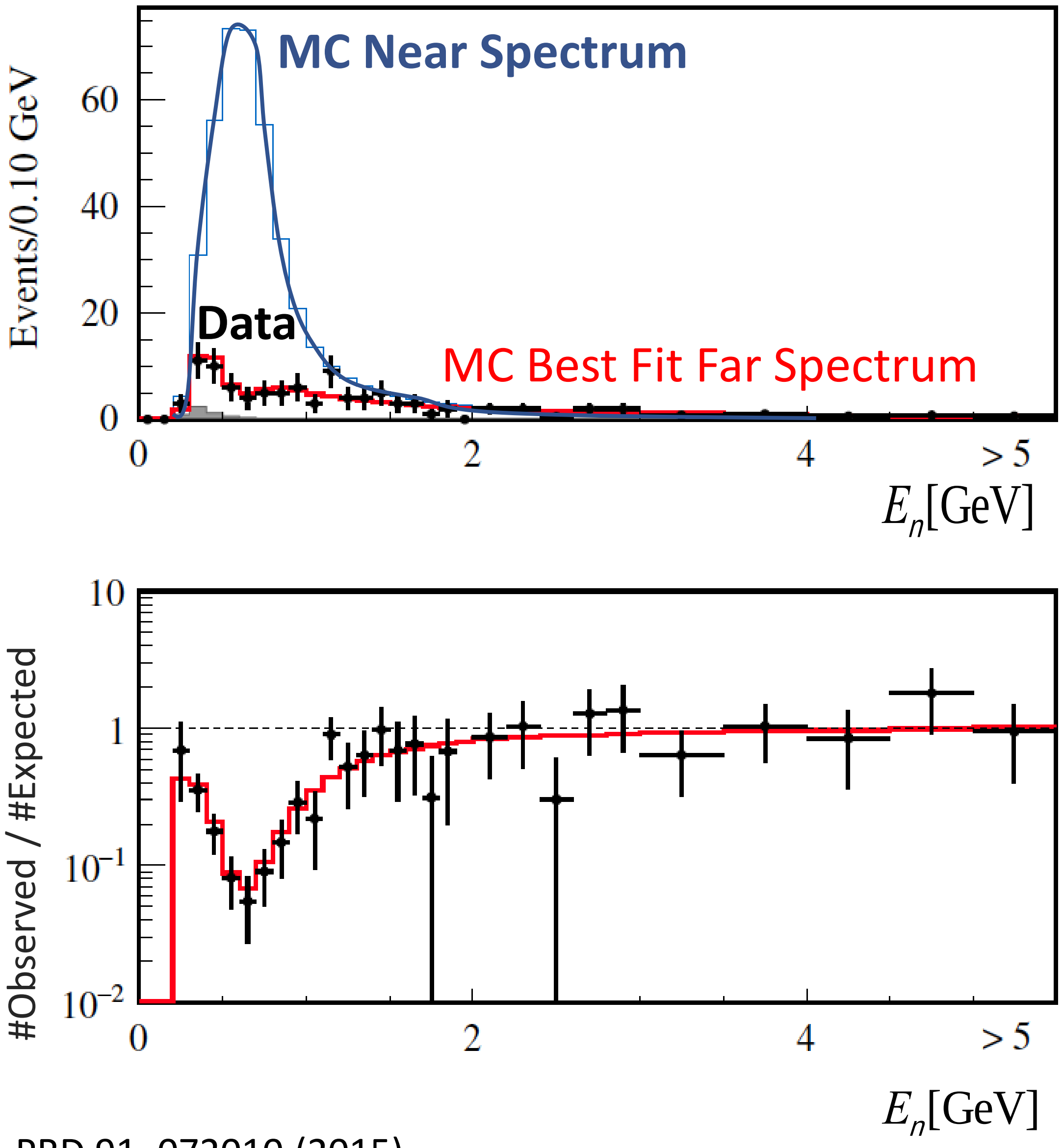
$$\Phi_\alpha(E,L) = \left[1 - P_{\nu_\alpha \to \nu_\beta}(E,L)\right] \Phi_\alpha(E,0)$$

Far   Near

$$N_\alpha(E_{rec},L) = \int \Phi_\alpha(E,L)\sigma(E) f_\sigma(E,E_{rec}) dE$$

Measured   Flux   Simulated

Need neutrino energy to get flux



PRD 91, 072010 (2015)

Neutrino Experiments

- Neutrino experiments are difficult
  - Large beam energy spread
  - Small cross sections
- Need to reconstruct incident beam flux from scattered particles

$$N_\alpha(E_{rec}, L) = \int \Phi_\alpha(E, L)\sigma(E)f_\sigma(E, E_{rec})dE$$

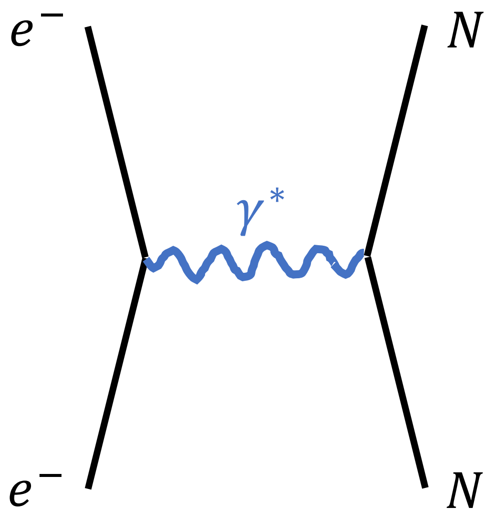
Measured Flux GENIE

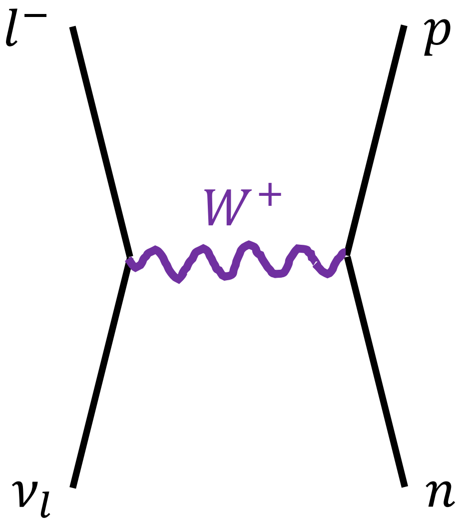
- Need event generators to extract the neutrino flux from data
  - GENIE = Generates Events for Neutrino Interaction Experiments
  - Simulates neutrino scattering events off of nuclear targets
  - For 1 MeV ≤ E_ν ≤ 1 PeV

How to validate GENIE?

Electrons vs. Neutrinos

- Monoenergetic
- Larger cross sections
- Similar interactions
  - Single boson exchange
  - Currents





EM Current:

$$j_\mu^{em} = \bar{u}\gamma^\mu u$$

Vector

Charge-Coupling Weak Current:

$$j_\mu^\pm = \bar{u}\frac{-ig_W}{2\sqrt{2}}(\gamma^\mu - \gamma^\mu\gamma^5)u$$

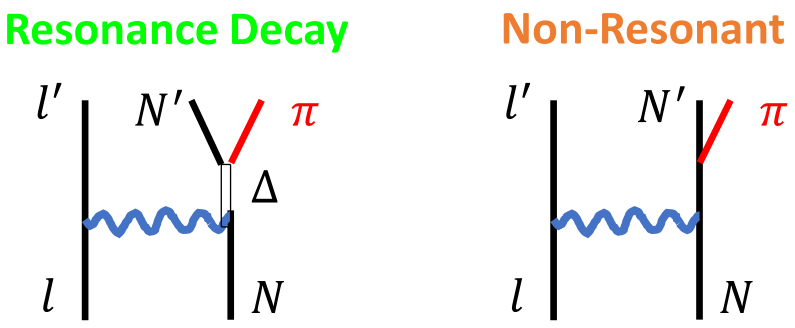
Vector Axial

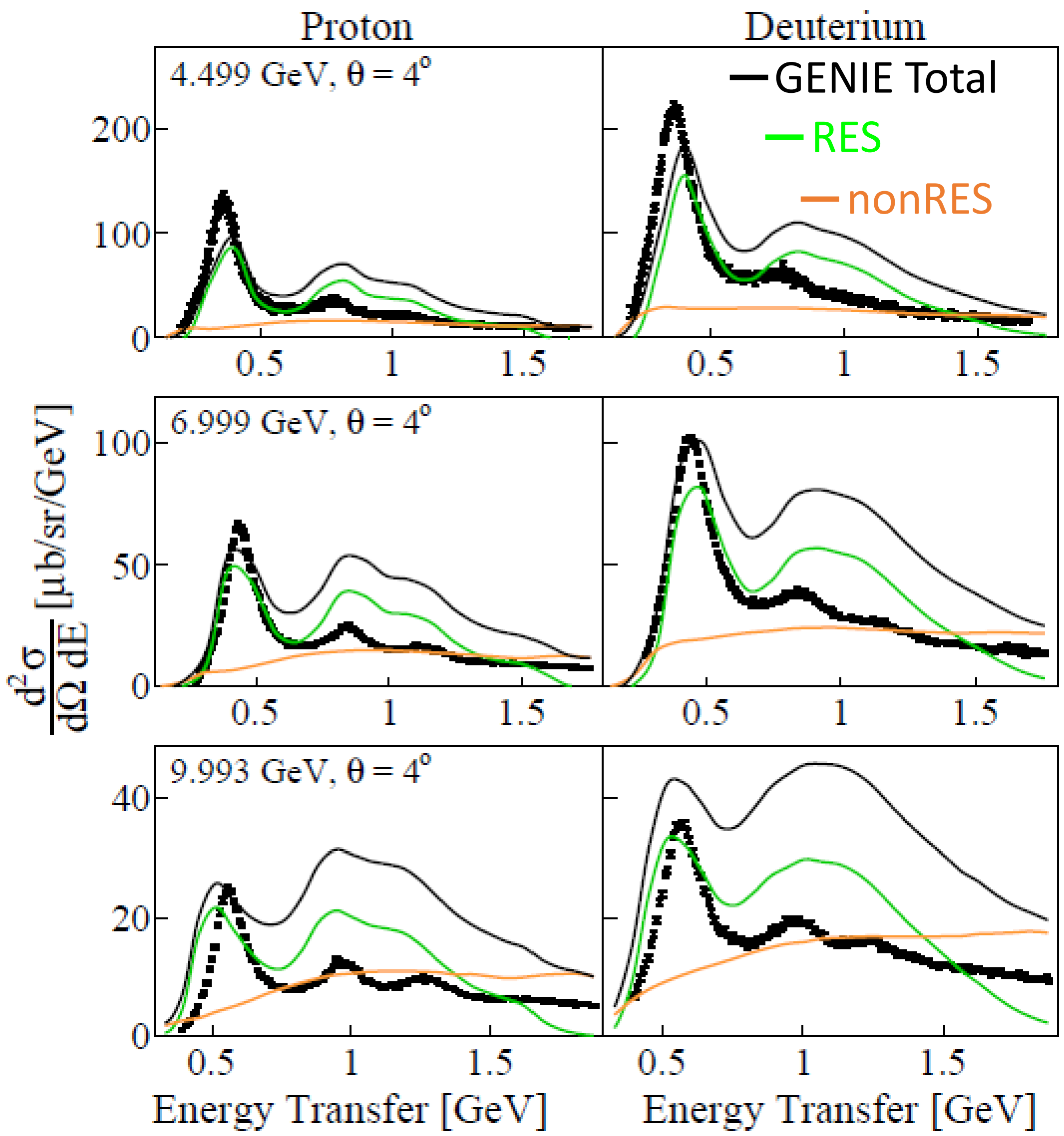
If GENIE can work with neutrinos, it can work with electrons

Motivation

- GENIE badly describes inclusive p(e,e') and D(e,e') scattering in pion production region
  - GENIE parameters are being tuned to better describe the data

- I will measure D(e,e'π) cross sections with CLAS12 to further improve GENIE



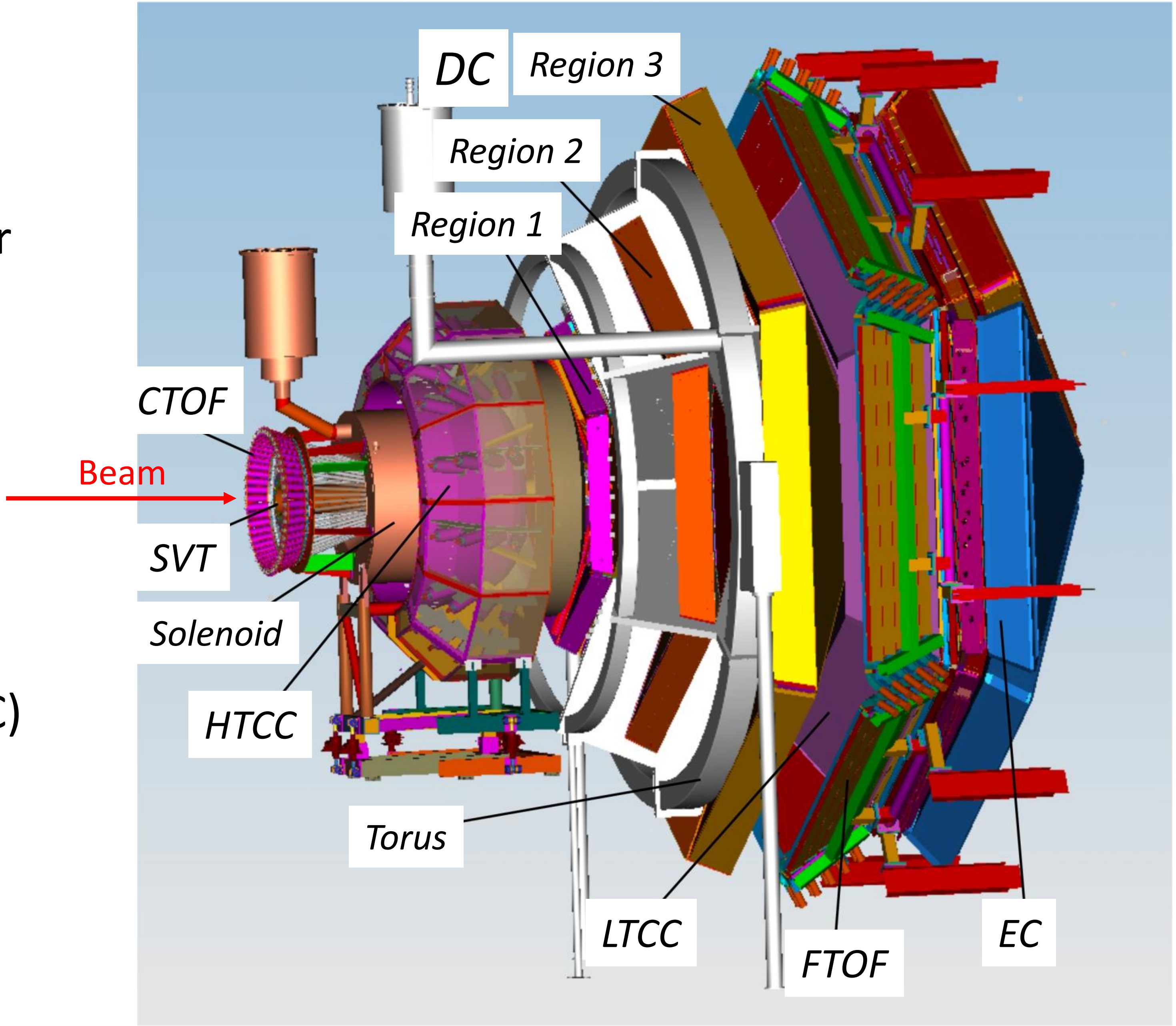


PRD 103, 113003 (2021)

CLAS12

- Forward Detector:
  - High Threshold Cerenkov Counter (HTCC) identifies scattered electrons
  - Drift Chambers (DC) measure charged particle momenta
  - Forward Time-of-Flight (FTOF) measures time-of-flight of charged particles
  - Electromagnetic Calorimeters (EC) identifies scattered electrons
    - Includes Pre-shower Calorimeter (PCAL)
- Central Detector:

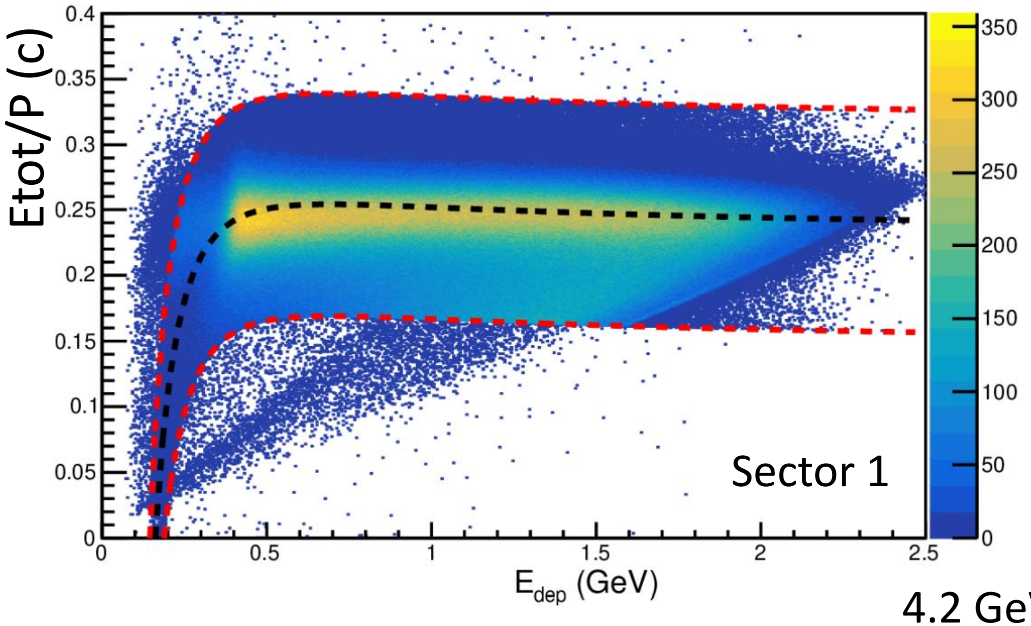
  Not used in this analysis



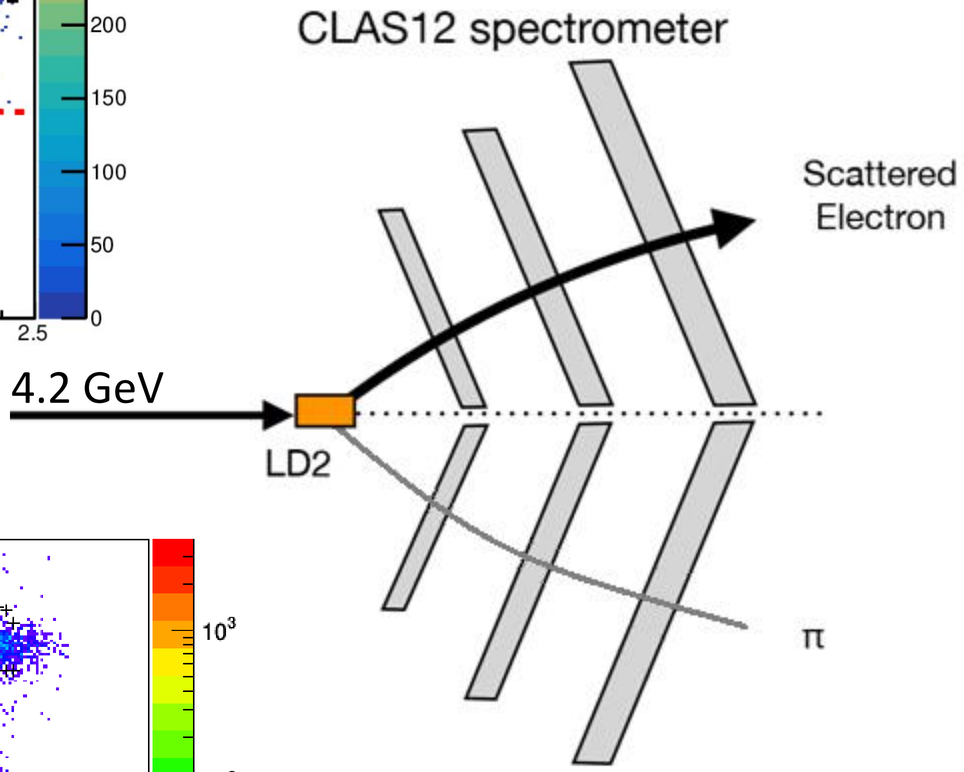
Particle Identification

Electron PID:
- Charge = -1
- HTCC photoelectrons > 2
- PCAL $E_{dep} > 0.06$ GeV
- EC sampling fraction cut < 5σ

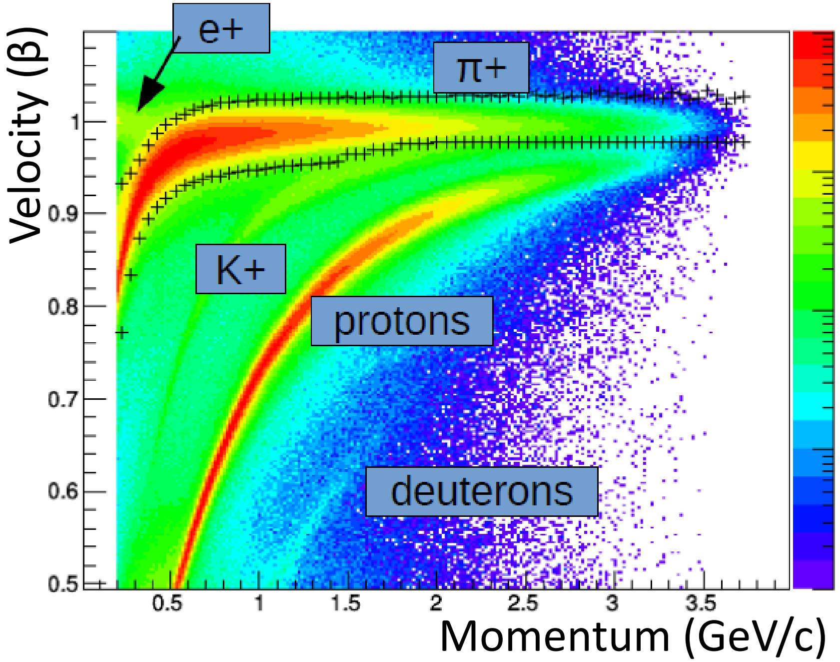
Hadron PID:
- FTOF time best fit



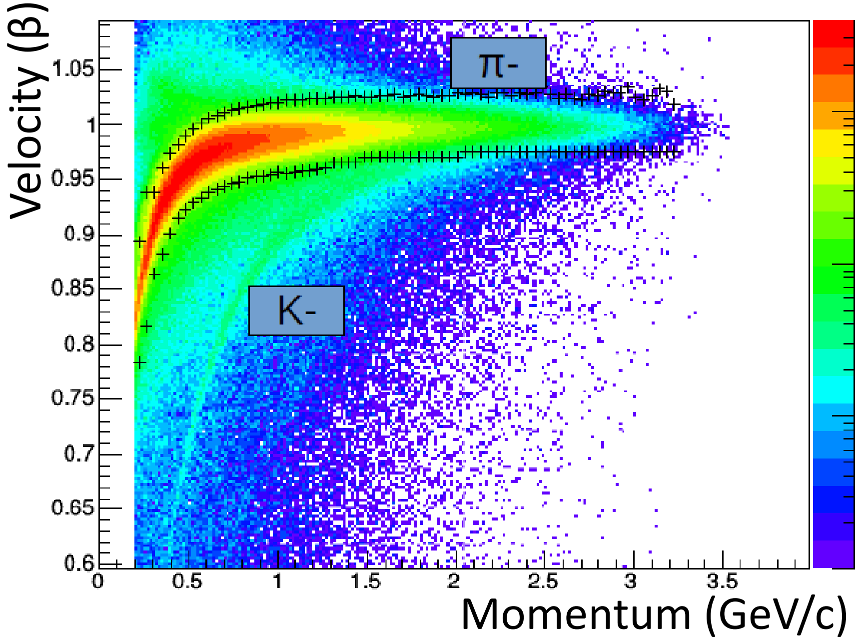
RG-A Analysis Note
October 8, 2020



Positive tracks



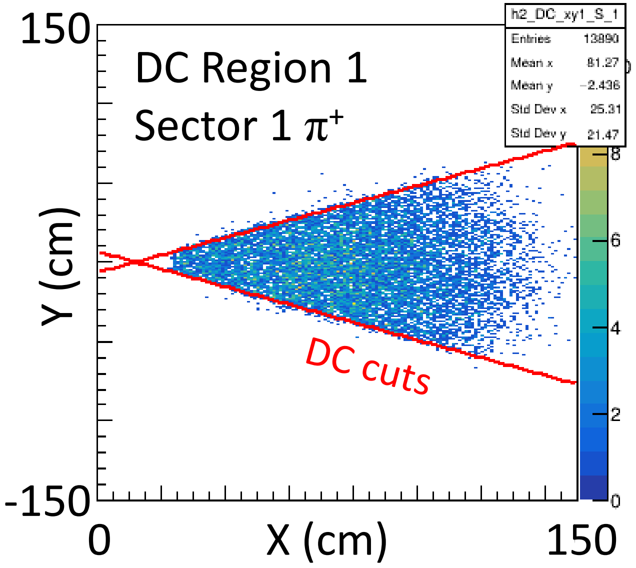
Negative tracks

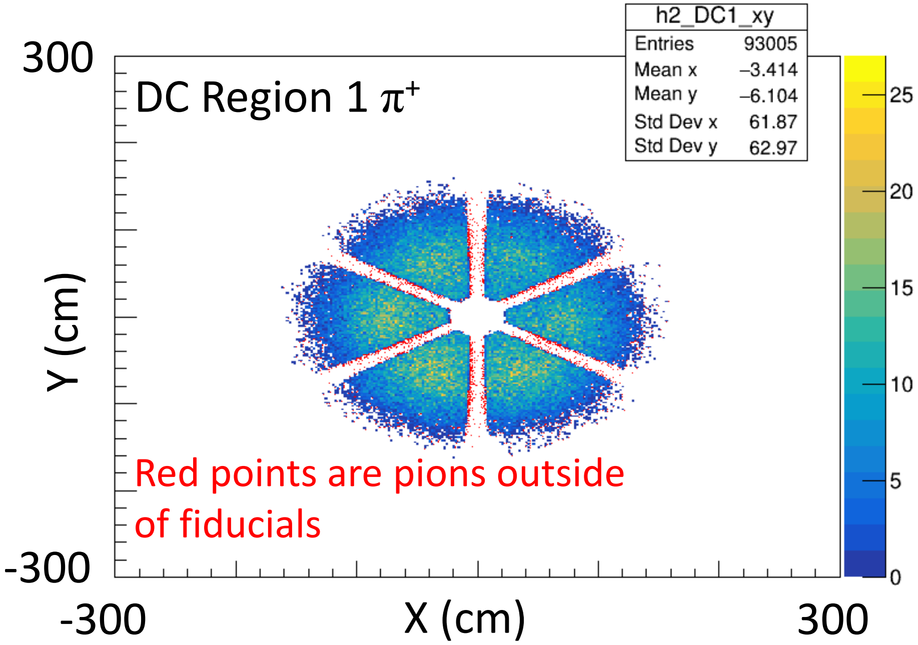


Data taken during RG-B (Fall 2019)

Nathan Harrison (UCONN)
CLAS Collaboration Meeting
February 26, 2016

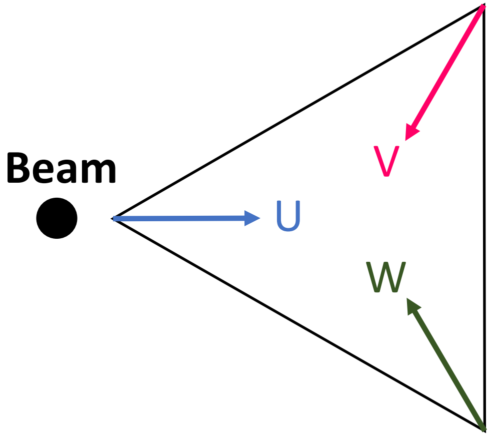
Fiducial Cuts

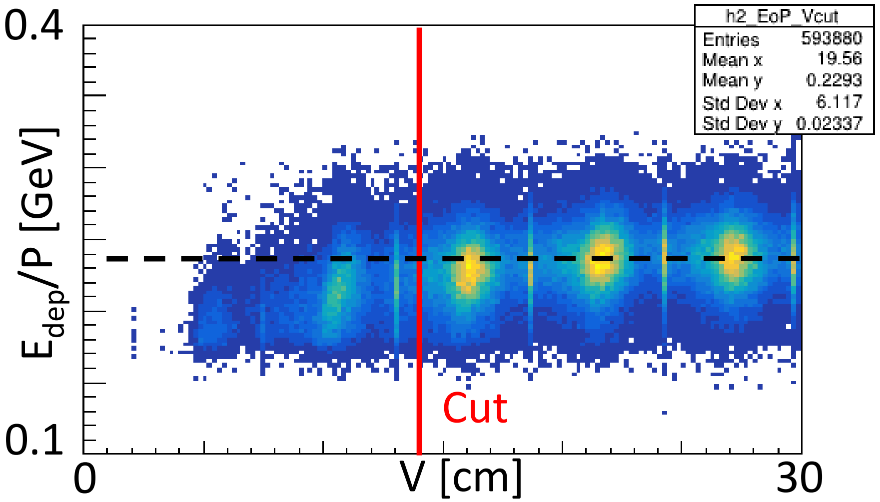


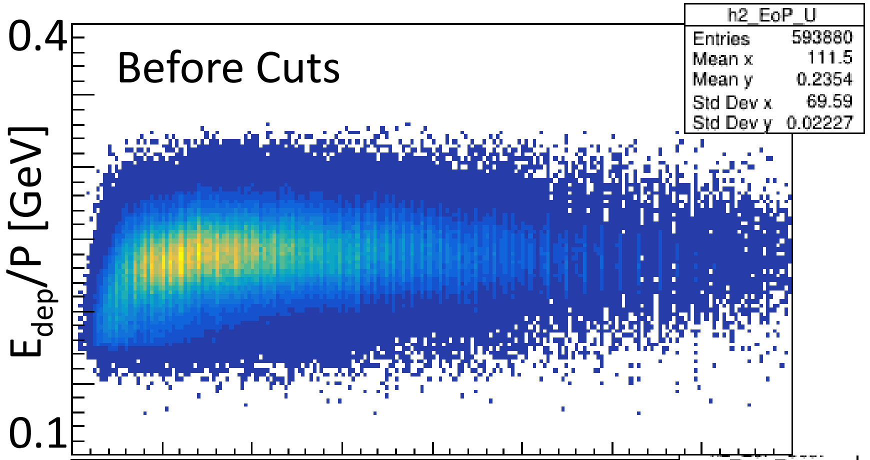


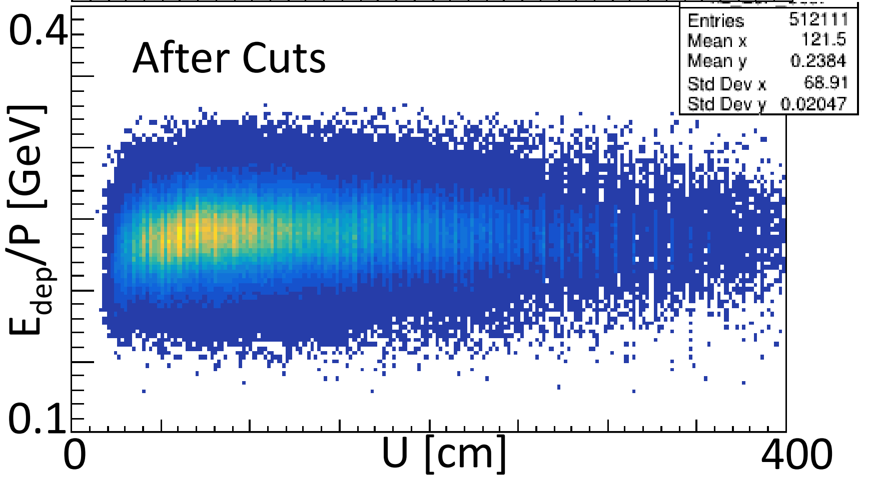
DC

EC

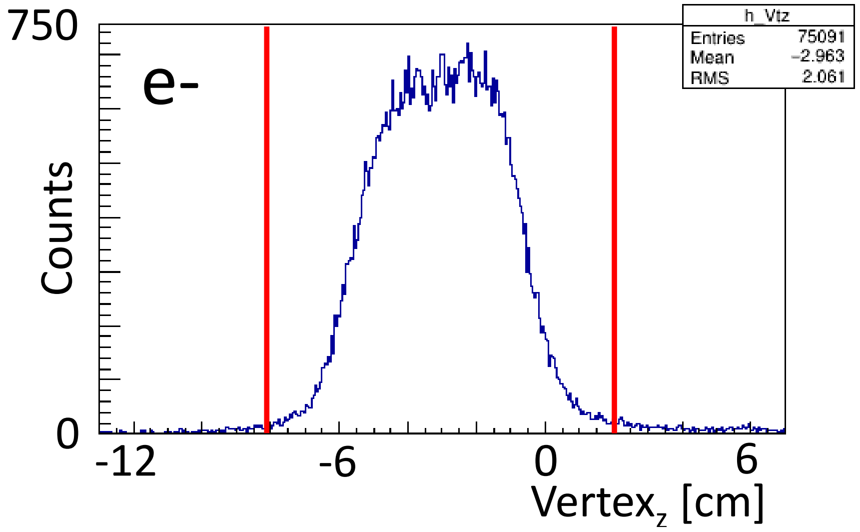




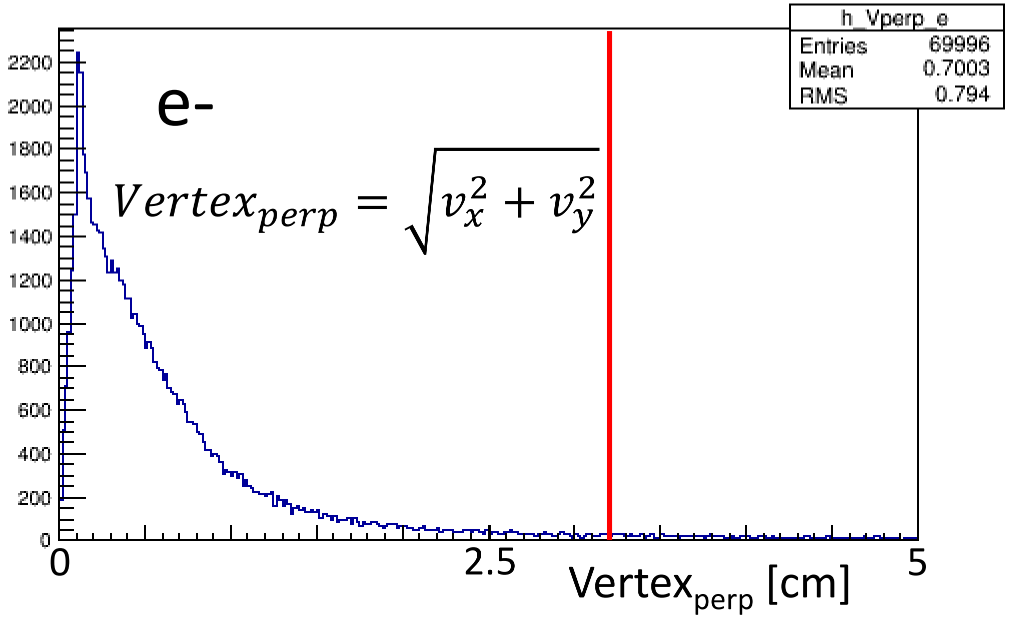




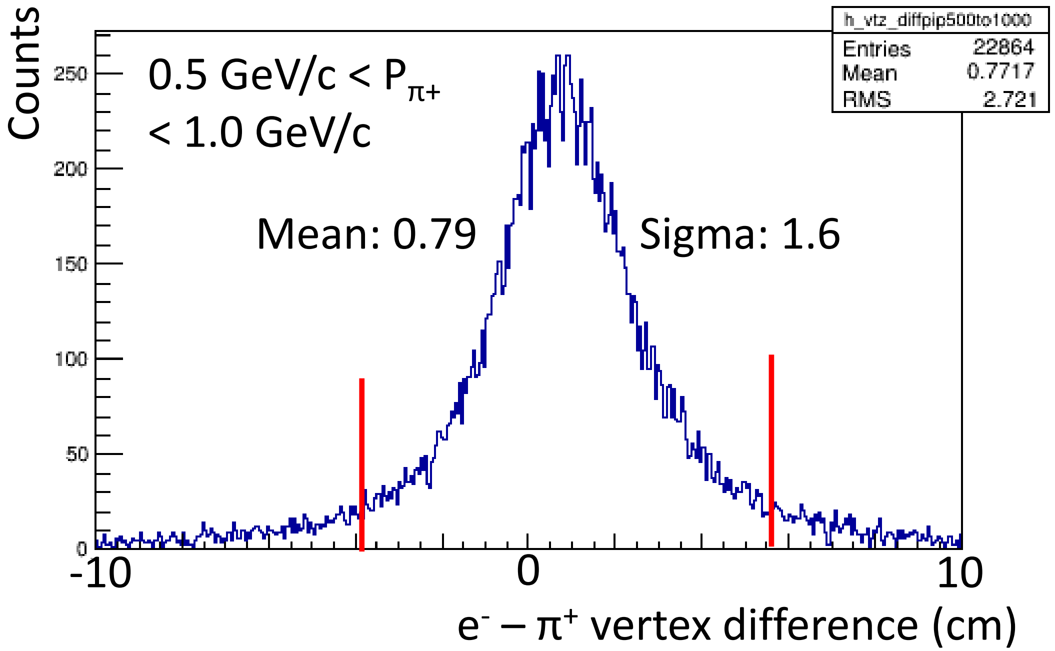
Vertex Cuts



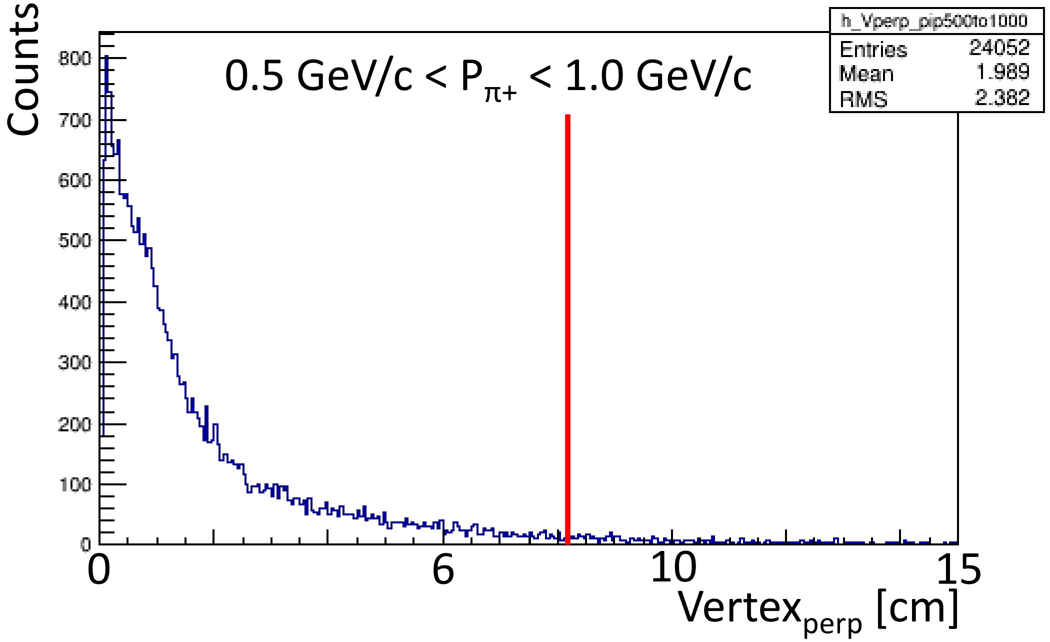
h_Vtz
Entries 75091
Mean -2.963
RMS 2.061
e-
750
0
Counts
-12
-6
0
6
Vertex$_z$ [cm]



h_Vperp_e
Entries 69996
Mean 0.7003
RMS 0.794
e-
$Vertex_{perp} = \sqrt{v_x^2 + v_y^2}$
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
2.5
5
Vertex$_{perp}$ [cm]



h_vtz_diffpip500to1000
Entries 22864
Mean 0.7717
RMS 2.721
Counts
0.5 GeV/c < $P_{\pi+}$ < 1.0 GeV/c
Mean: 0.79
Sigma: 1.6
250
200
150
100
50
0
-10
0
10
$e^- - \pi^+$ vertex difference (cm)



h_Vperp_pip500to1000
Entries 24052
Mean 1.989
RMS 2.382
Counts
0.5 GeV/c < $P_{\pi+}$ < 1.0 GeV/c
800
700
600
500
400
300
200
100
0
0
6
10
15
Vertex$_{perp}$ [cm]

Cross Sections vs. W

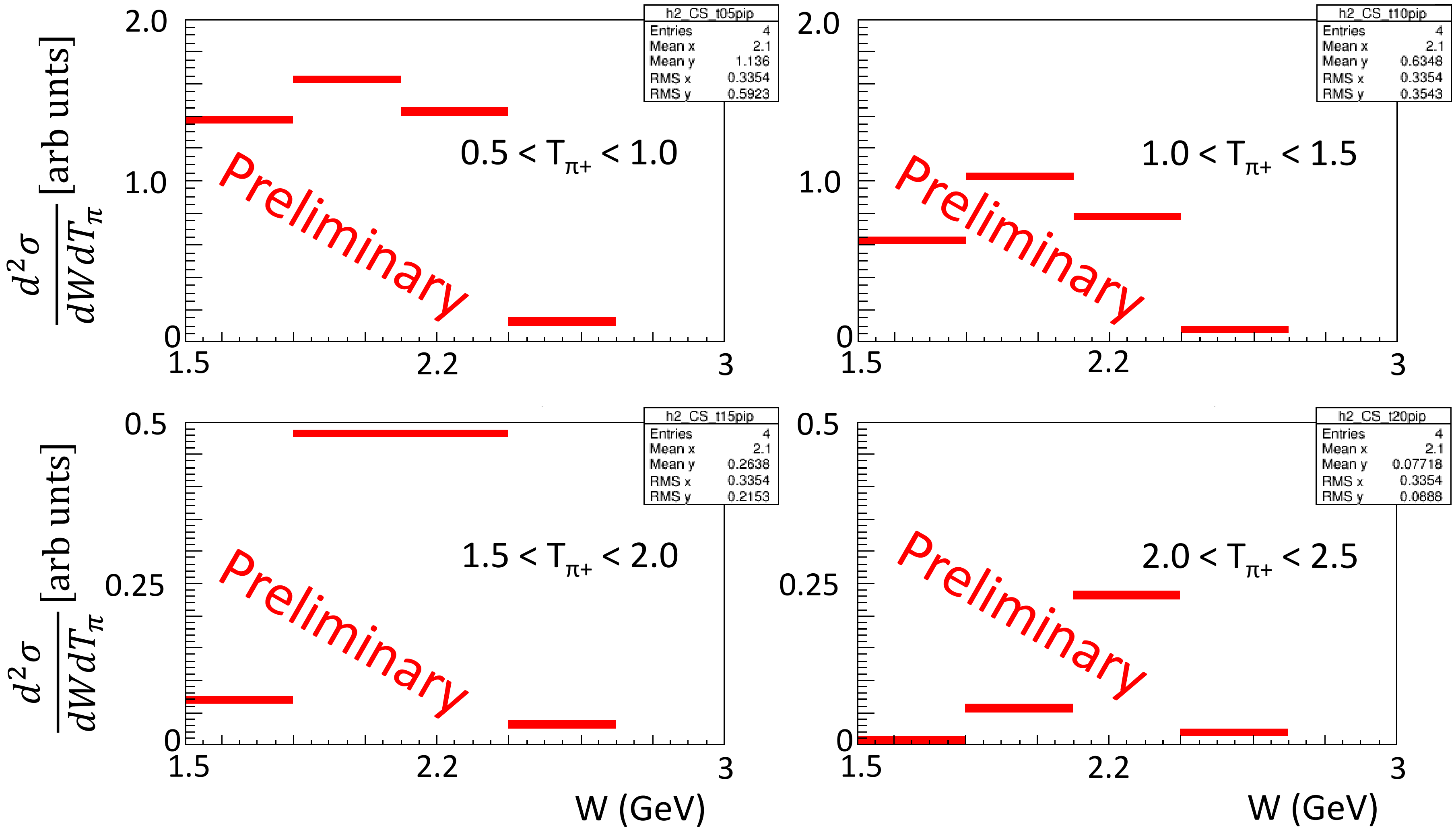
Run 11286

$$\frac{d^2\sigma}{dW dT_\pi} = \frac{N_{events}}{\Delta W \Delta T_\pi L}$$

Electron Cuts:
- Electron PID
- DC fiducial cuts
- ECAL fiducial cuts
- Vertex cuts

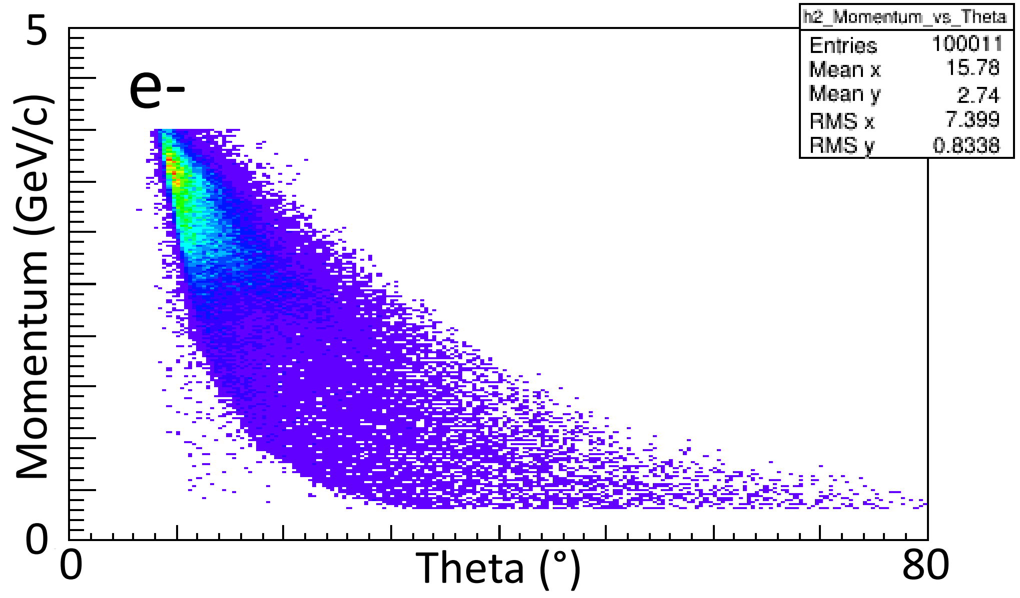
Pion Cuts:
- Pion PID
- DC fiducial cuts
- Vertex cuts

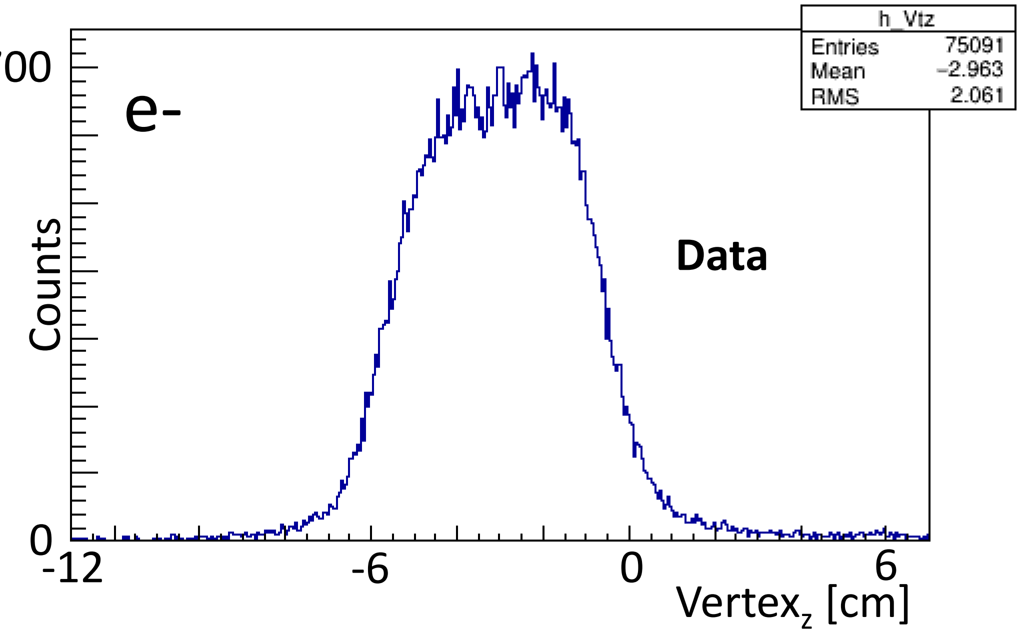
π+

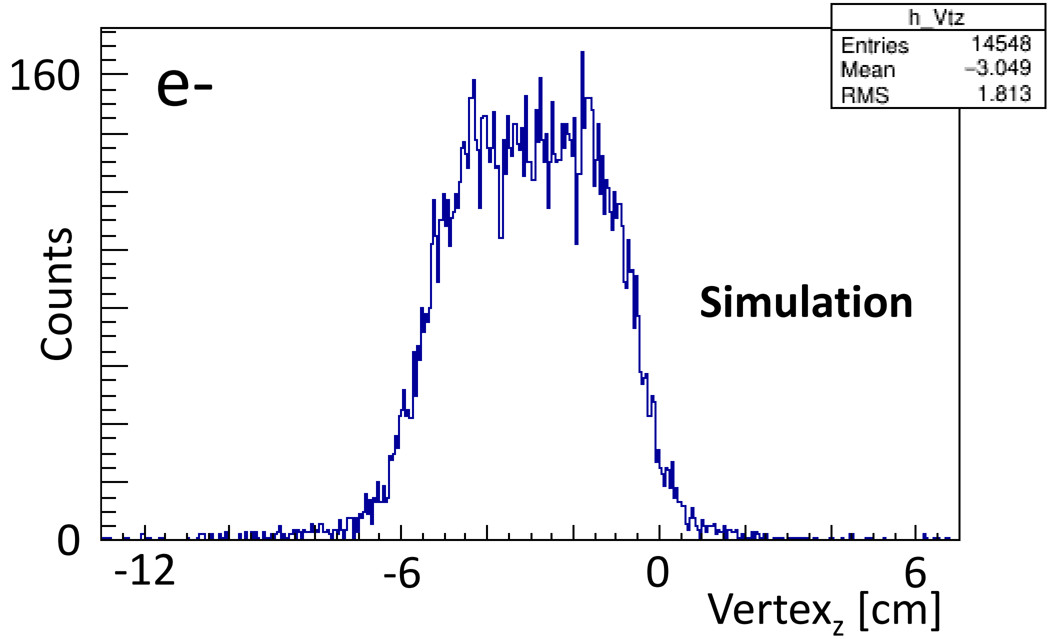


Future Work

- Correction Analysis with onepigen (MAID cross section models)
  - Radiative effects
  - Acceptance
  - Detector efficiency
  - Systematic uncertainty
- Compare measured cross sections to GENIE and onepigen

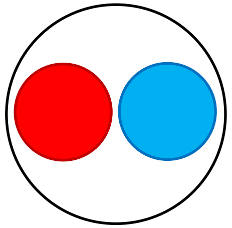






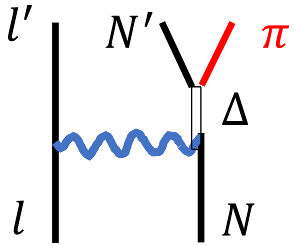
Backup Slides

Pion Physics

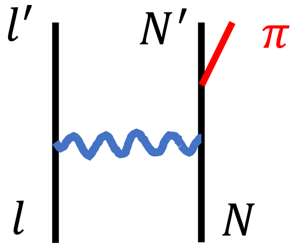


- Mesons consisting of combinations of u and d quarks and antiquarks
- Commonly produced in scattering experiments

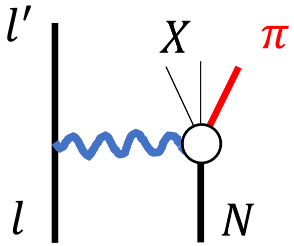
Resonance Decay Production

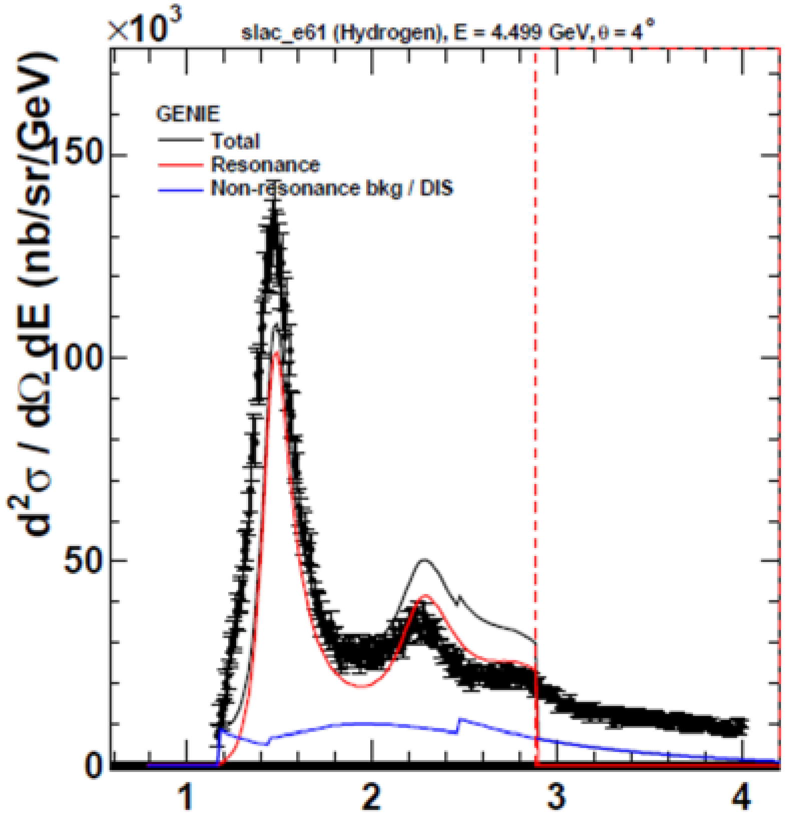


Non-Resonant Production



DIS Production

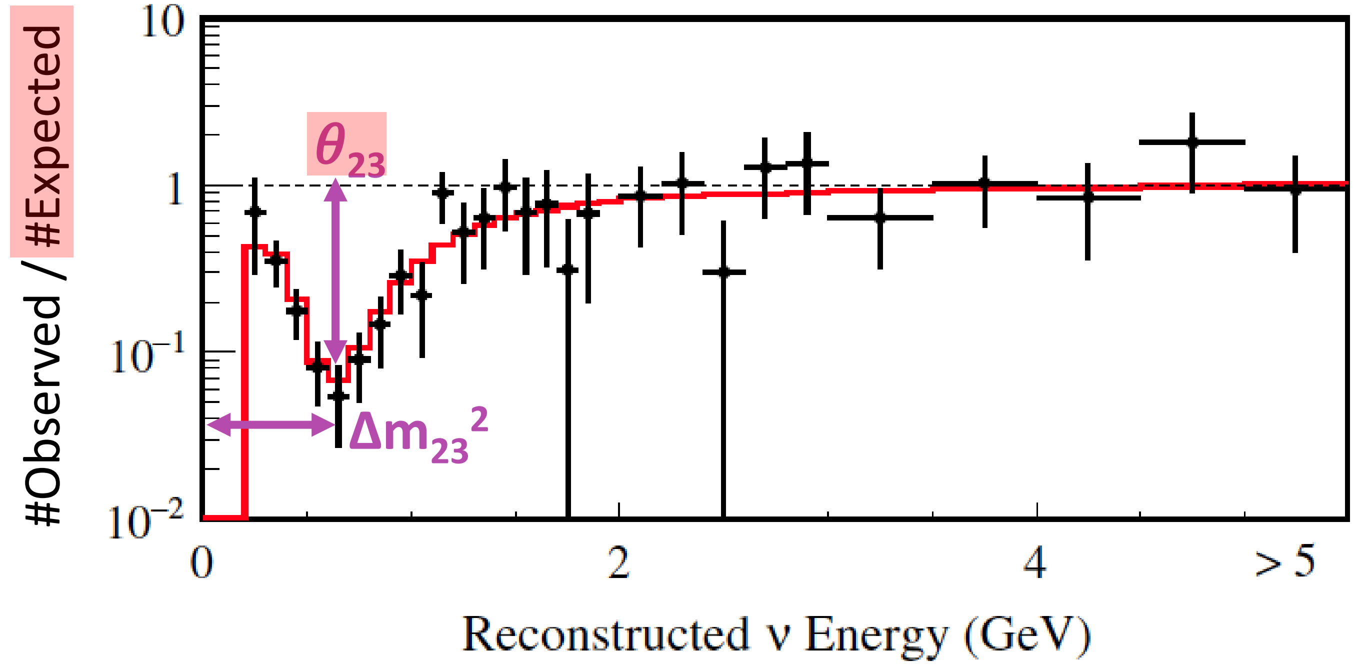




Steve Dytman (Univ. of Pittsburgh)
FUNFACT at JLab
May 15, 2015

Oscillation Probability

$$P(n_m \rightarrow n_m) = \sin^2(2q_{23}) \times \sin^2\left(\frac{Dm_{32}{}^2 L}{4E_n}\right)$$



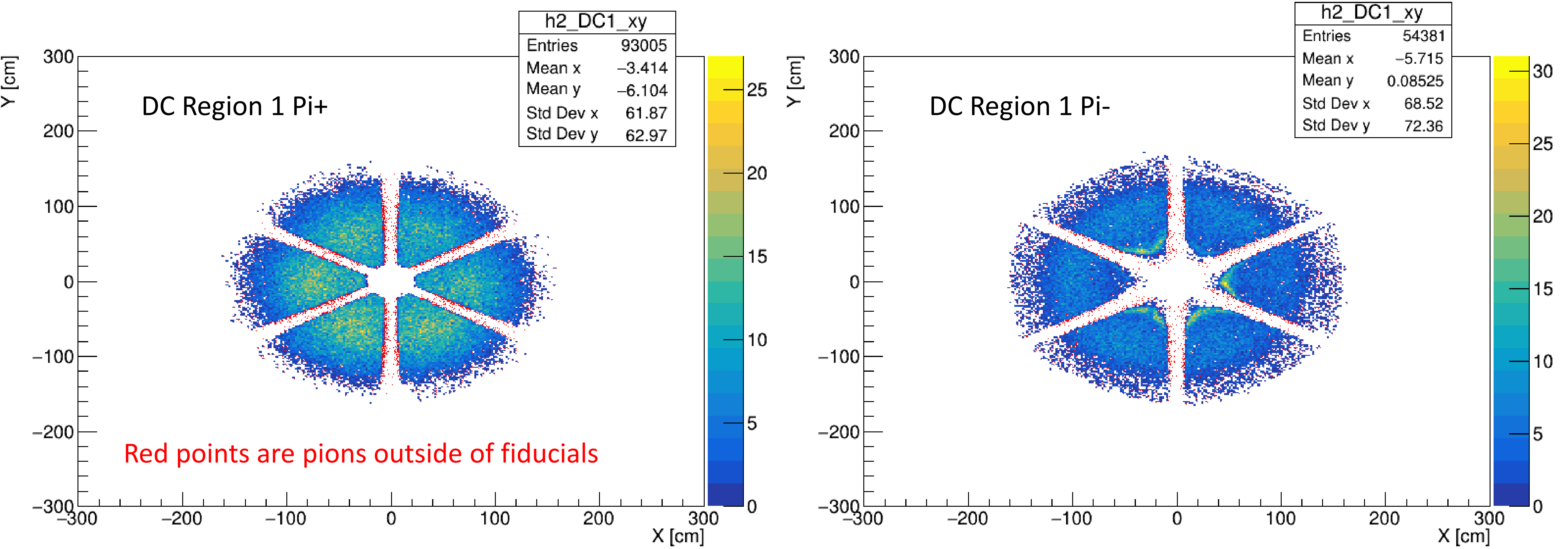
T2K PRD (2015)

FTOF Best Fit

$$\Delta t = t_{start\ time} - \left[t_{FTOF} - \frac{L}{\beta_h(p)} \right]; \beta_h(p) = \frac{p}{\sqrt{p^2 + m^2}}$$

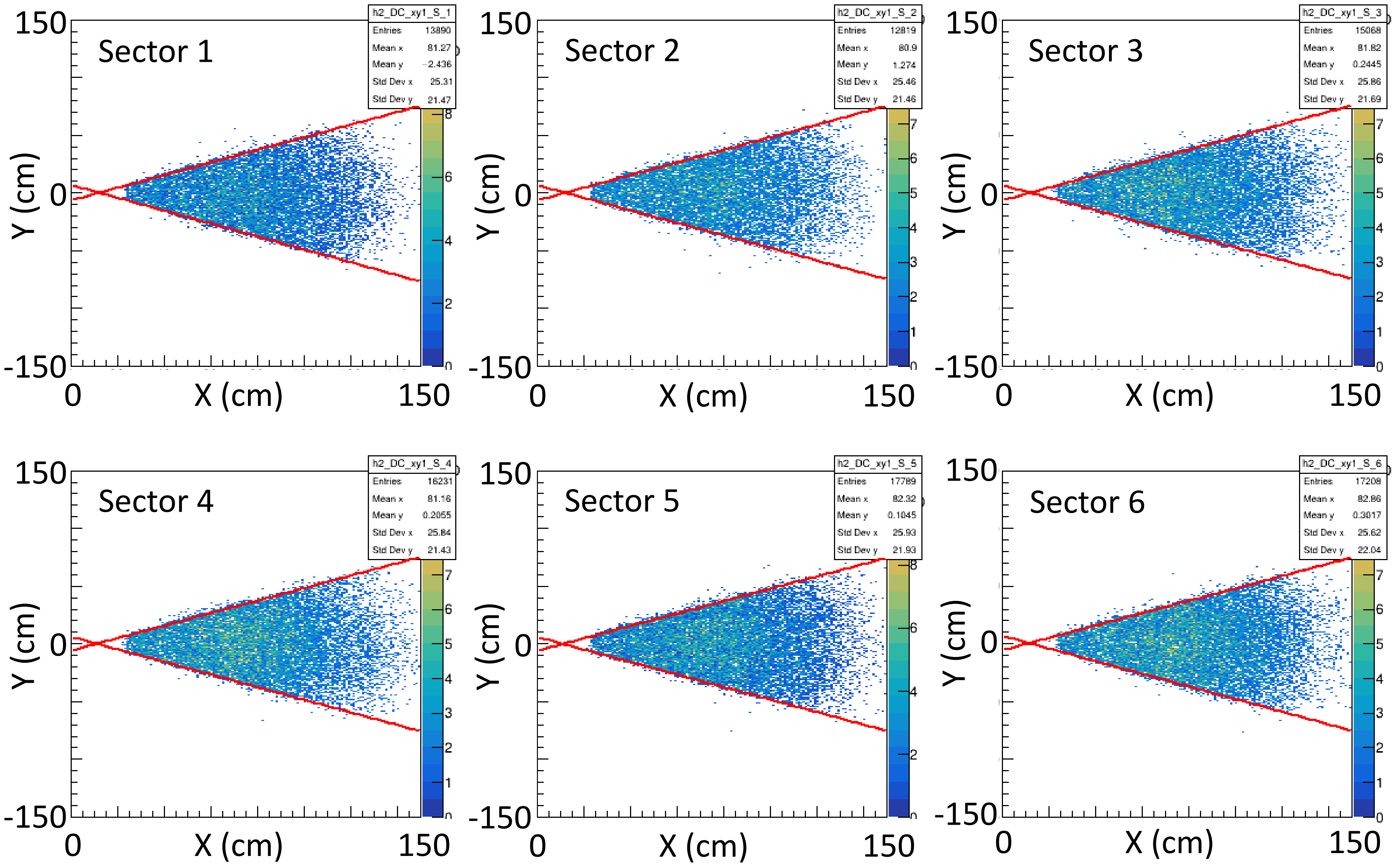
DC Fiducial Cuts

- Fiducial cuts select hits (or tracks) with near 100% efficiency



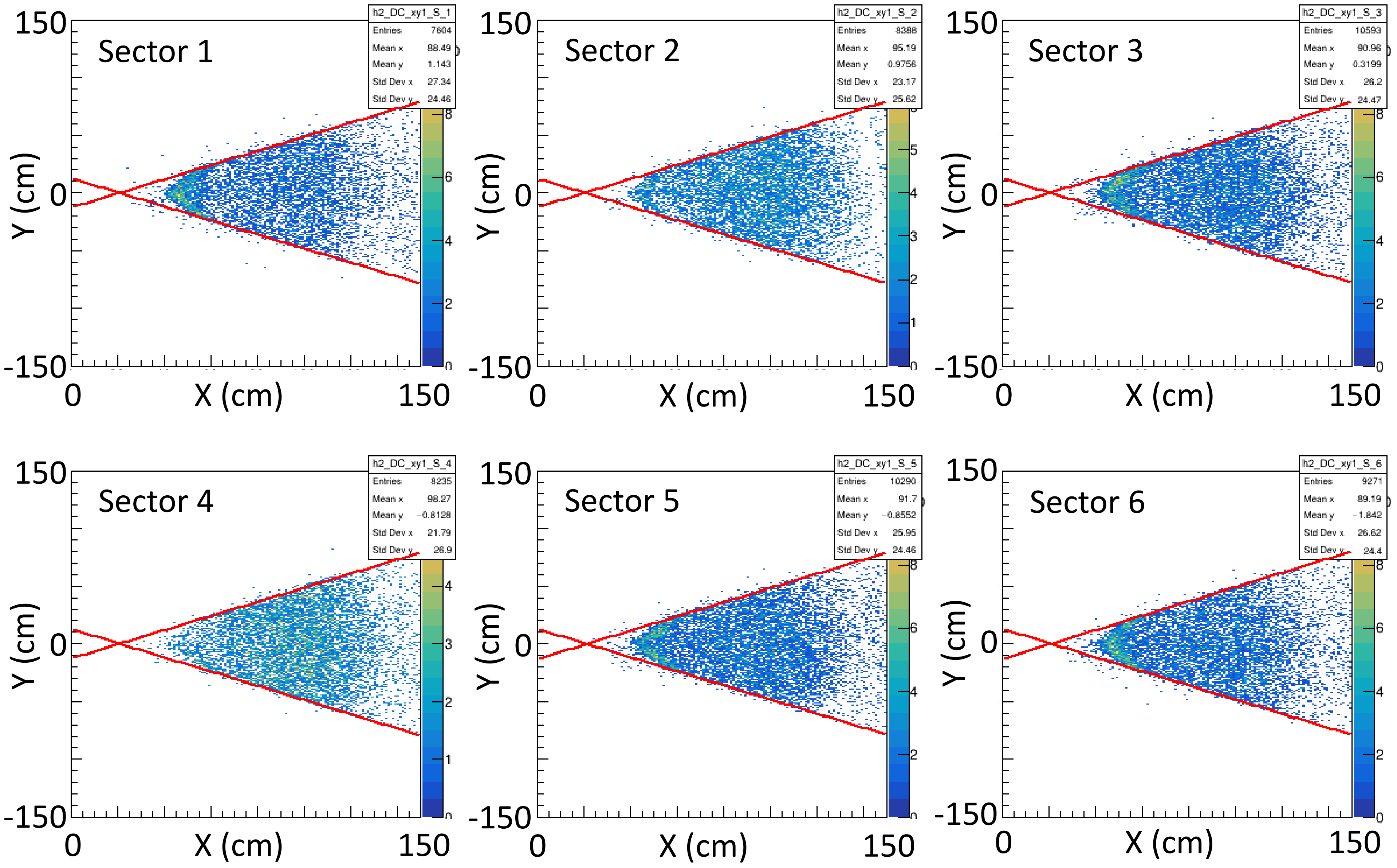
DC Fiducial Cuts

Region 1 (Pi+)

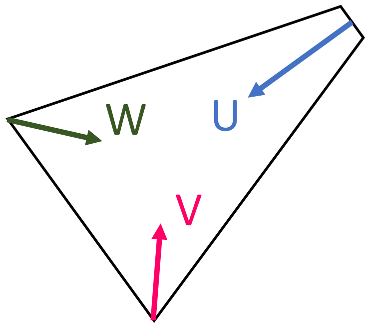


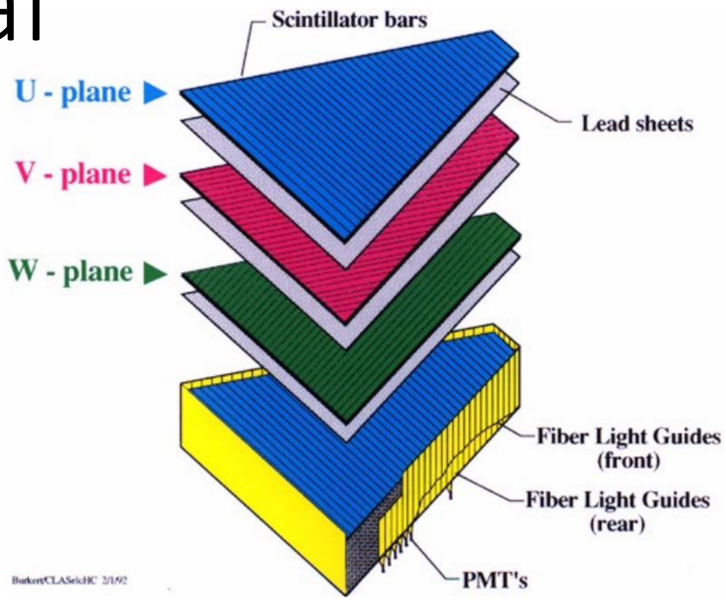
DC Fiducial Cuts

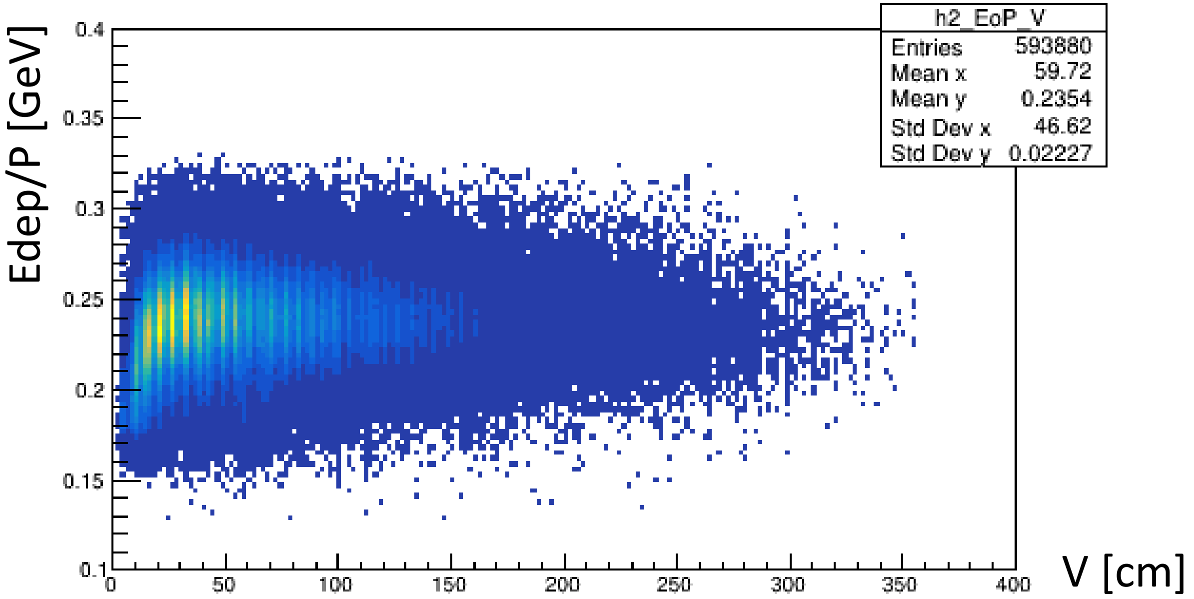
Region 1 (Pi-)

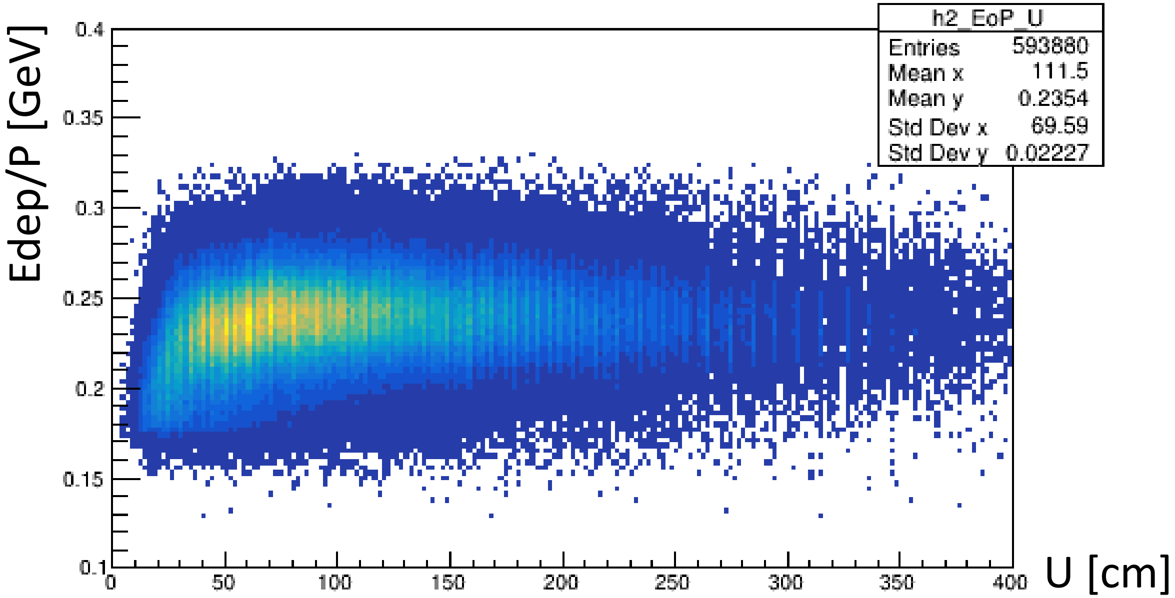


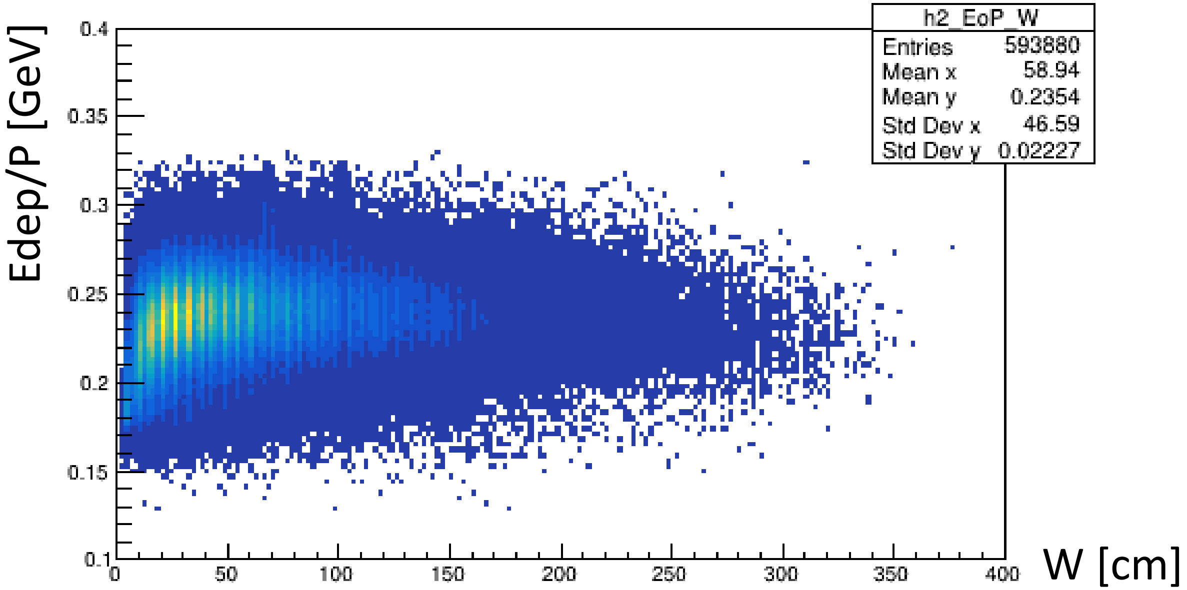
EC Fiducial Cuts





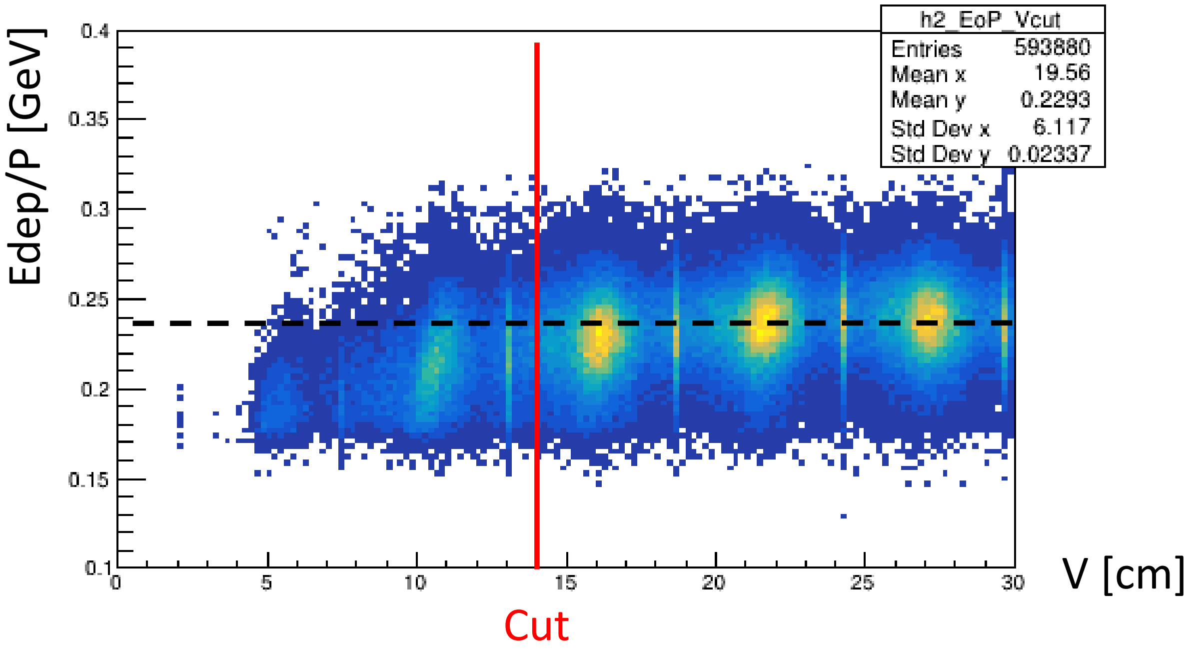


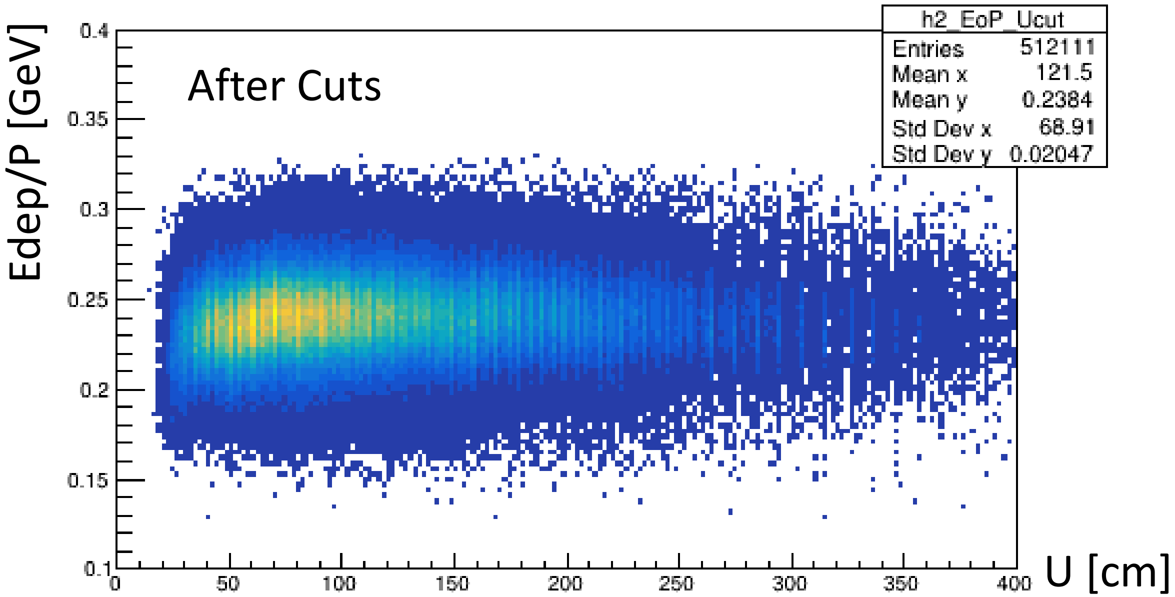


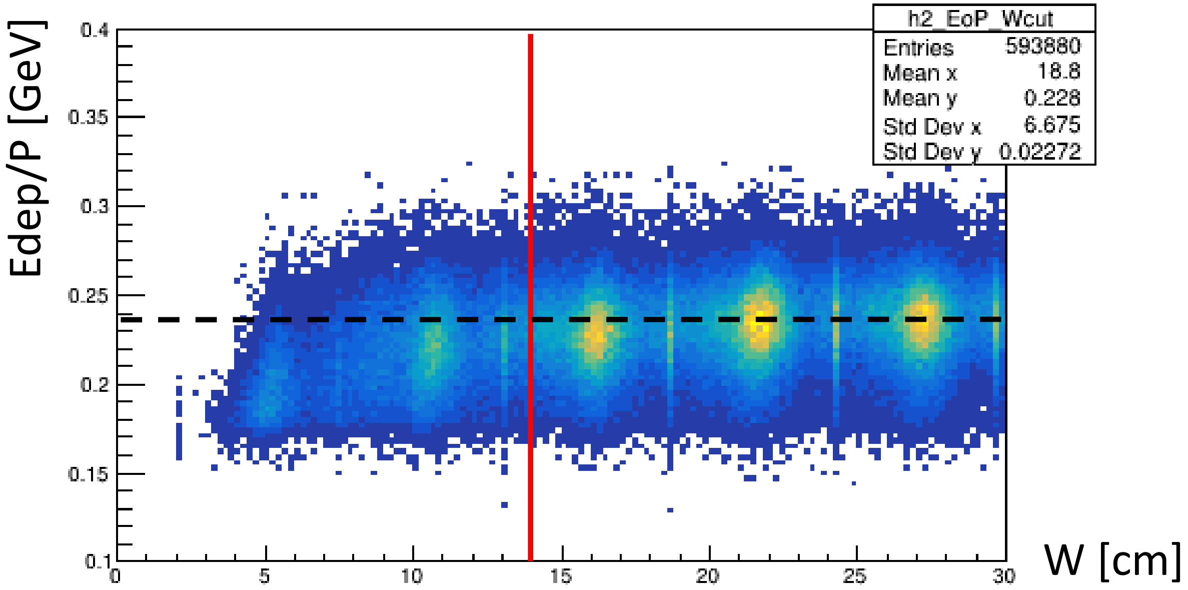


EC Fiducial Cuts

Required V, W > 14 cm (removed outer 2 bars)

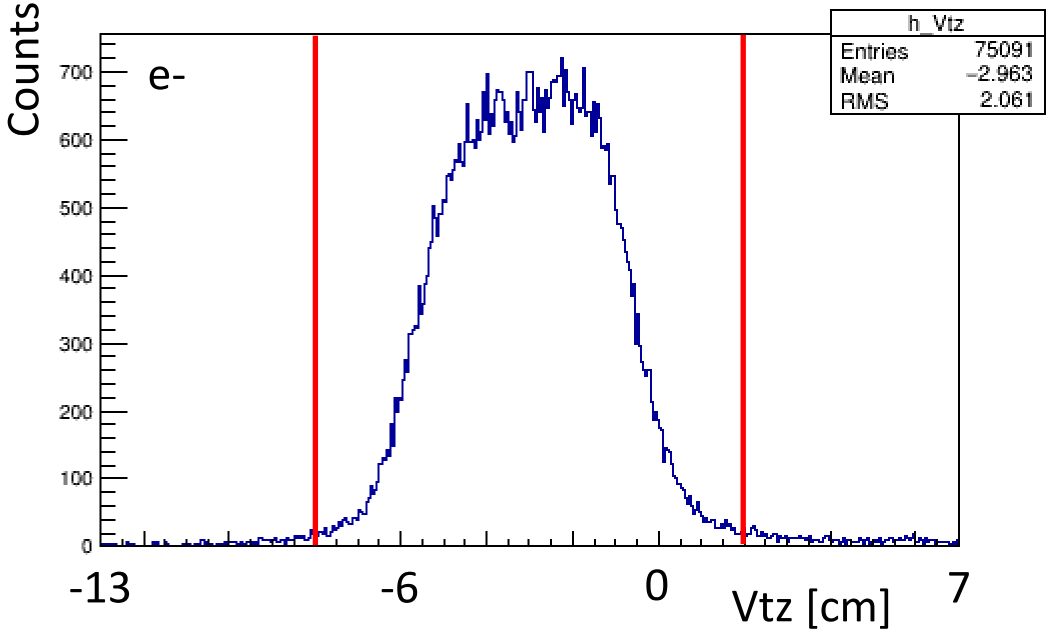


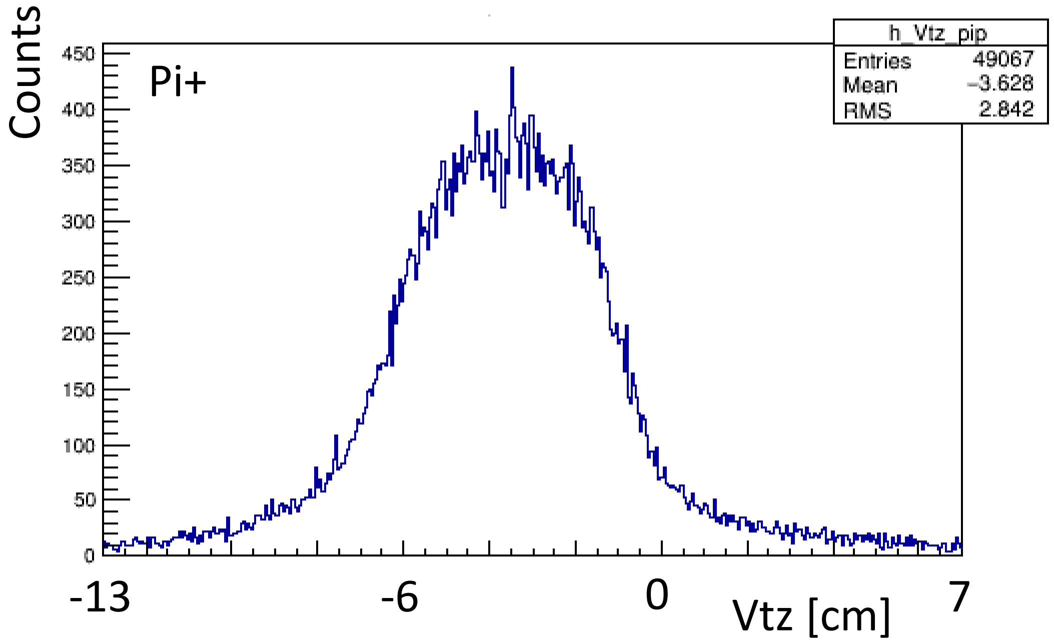


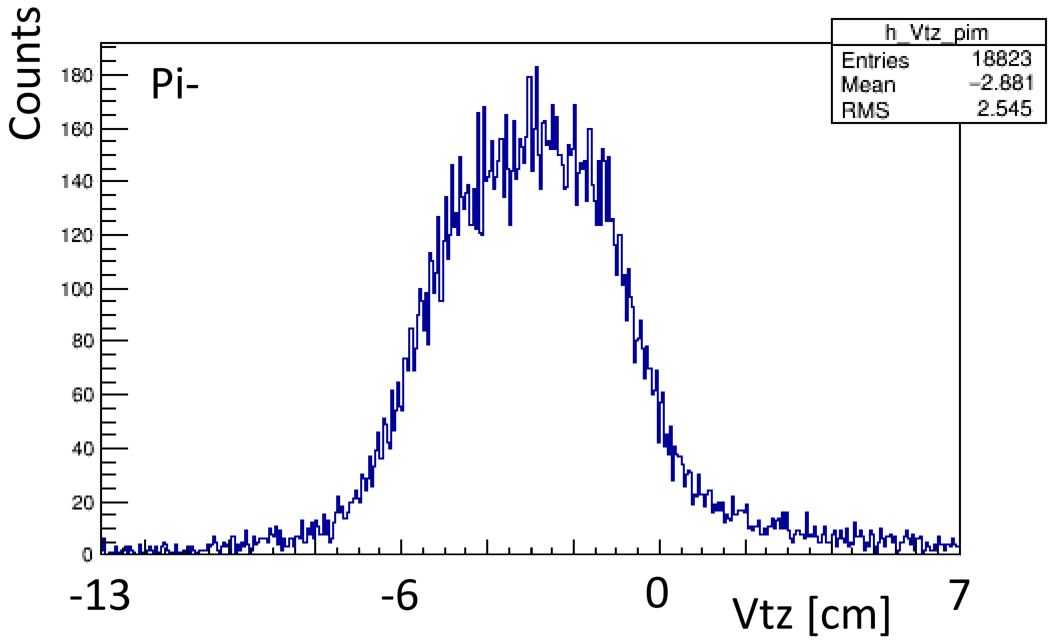


Electron and Pion z Vertices

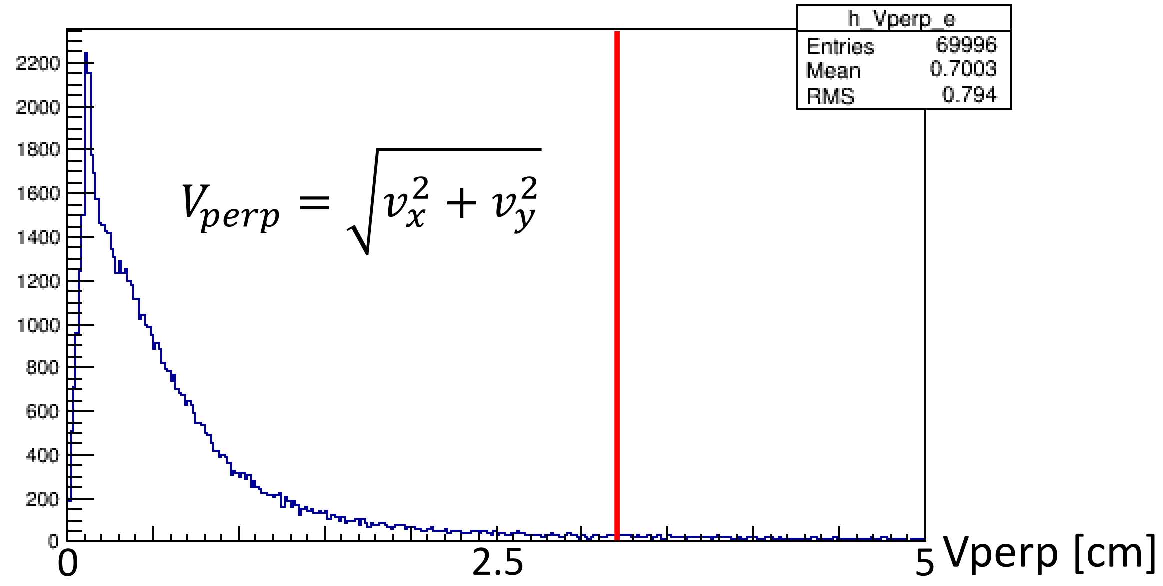
-8 cm < Vtz_e < 2 cm

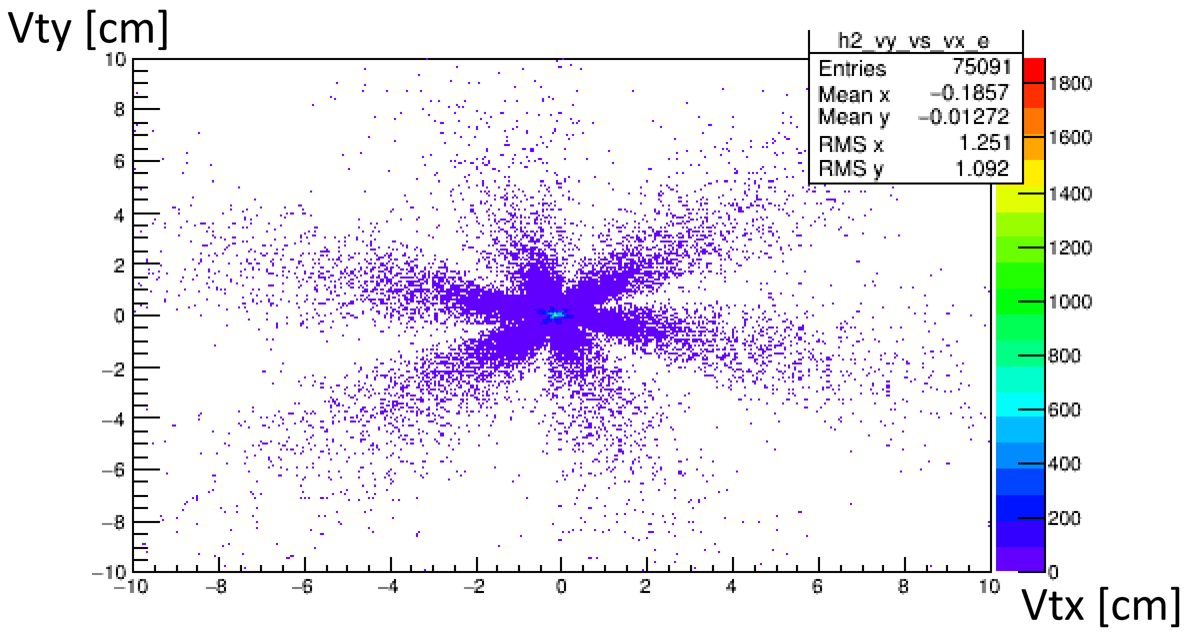


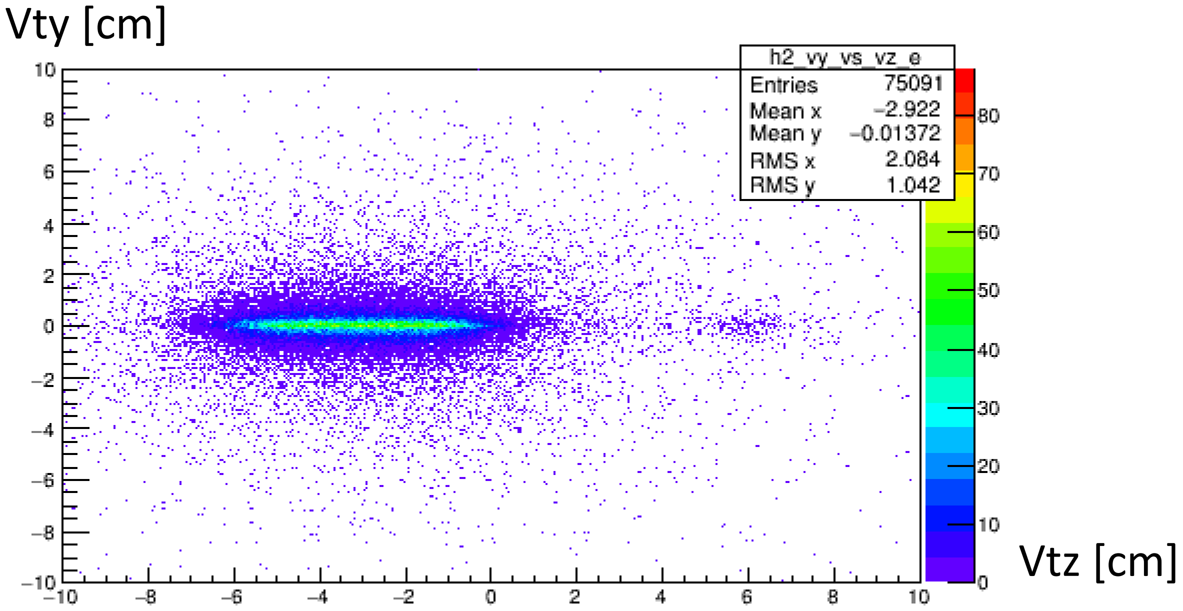


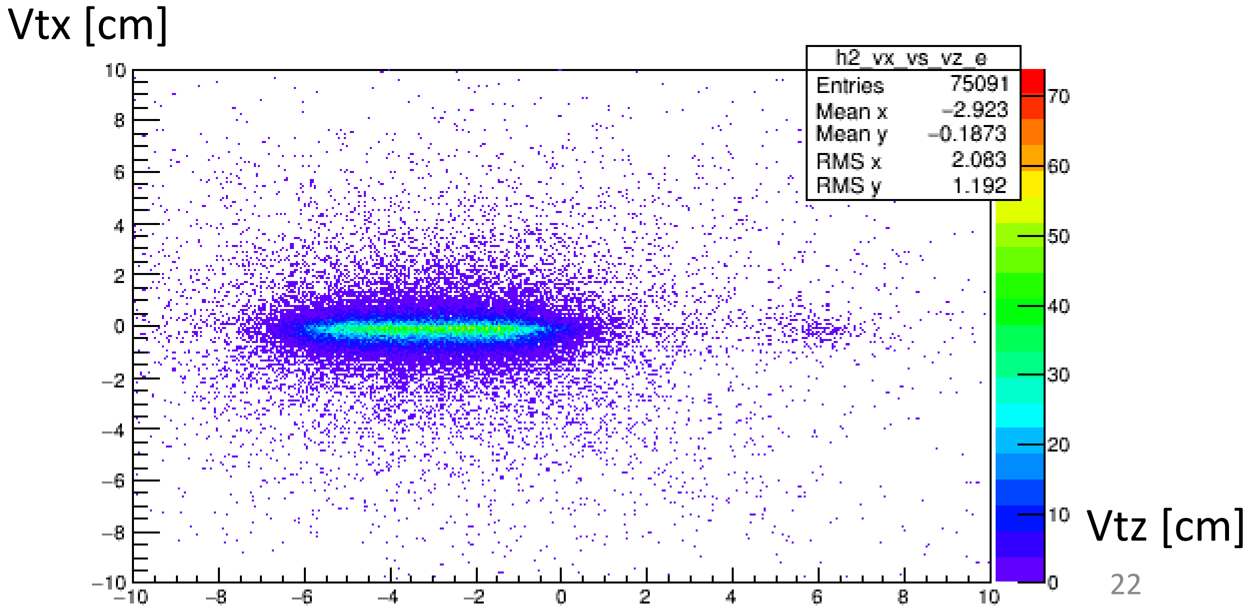


Electron Perpendicular Vertices

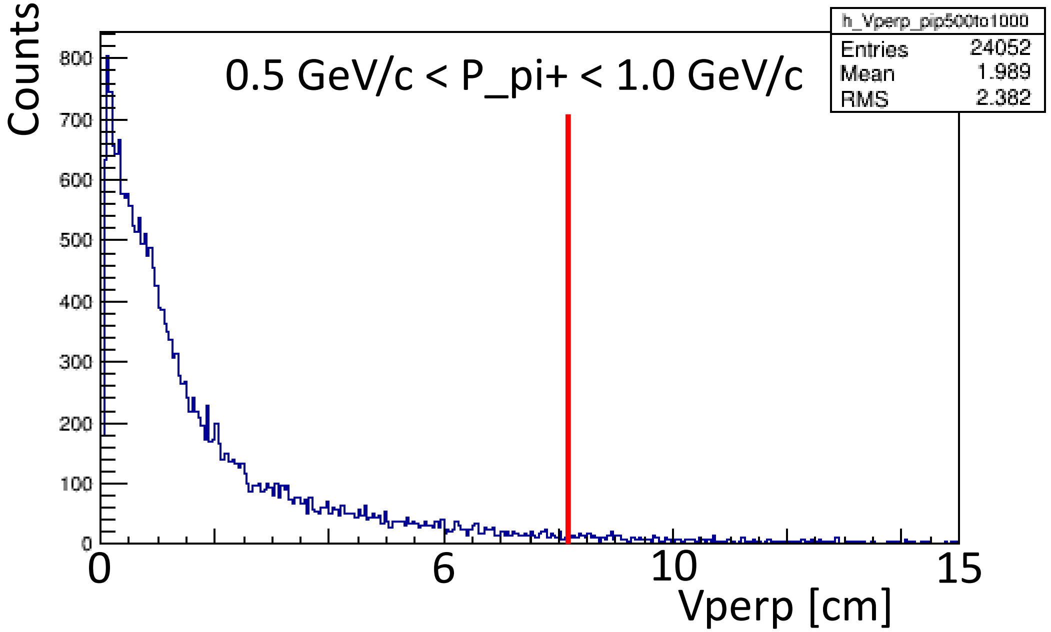


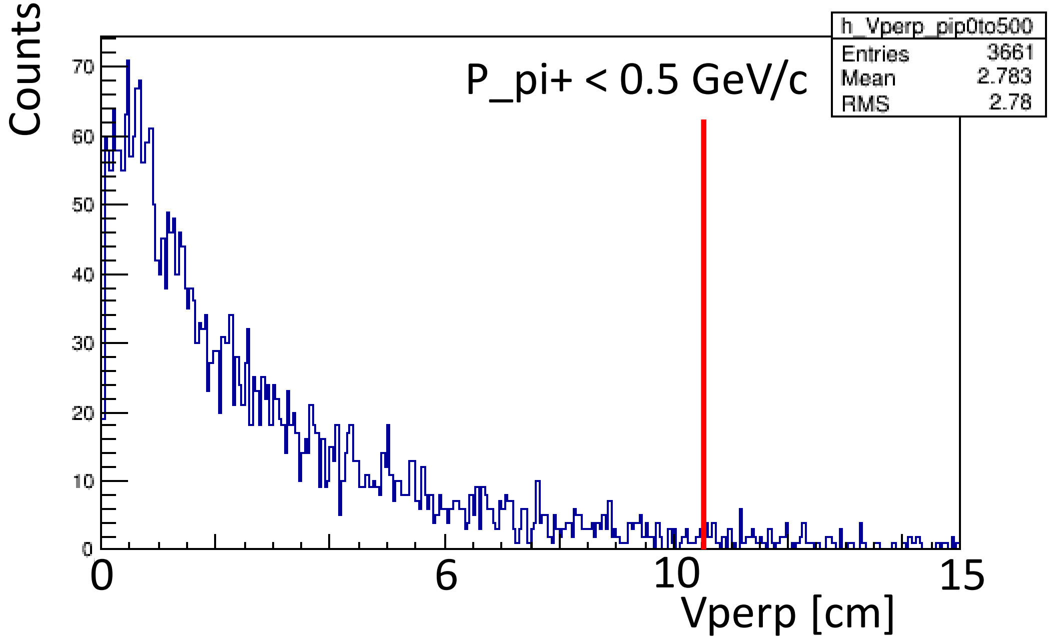


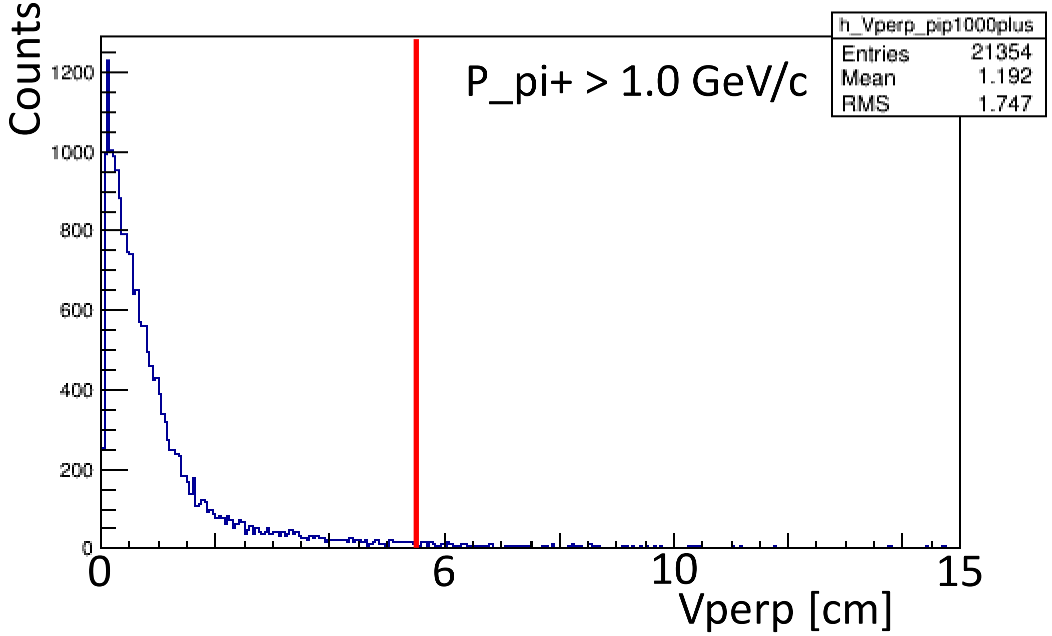




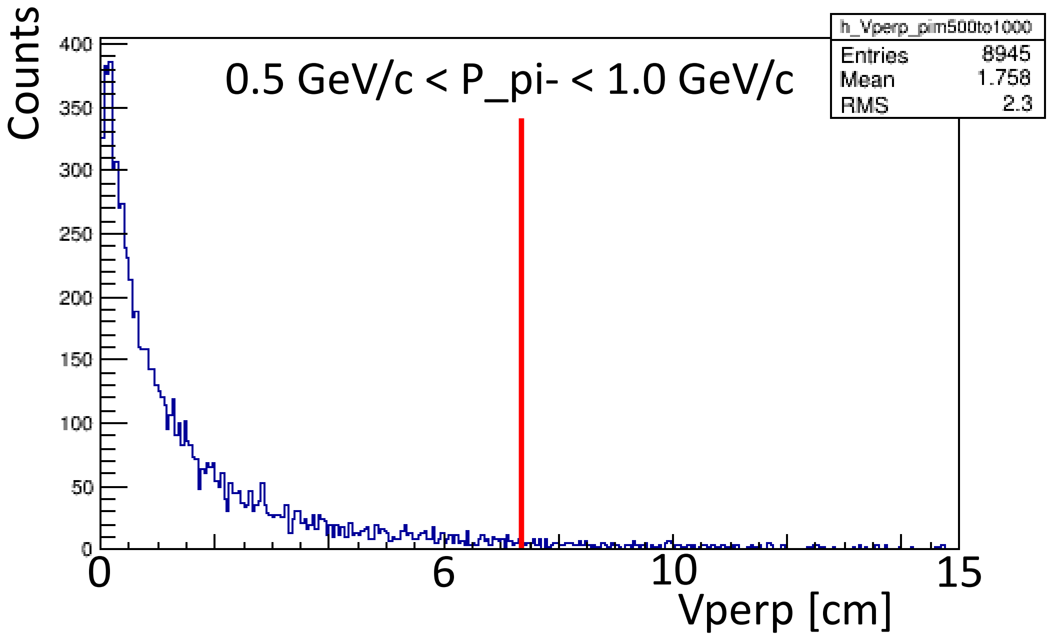
Pi+ Perpendicular Vertices

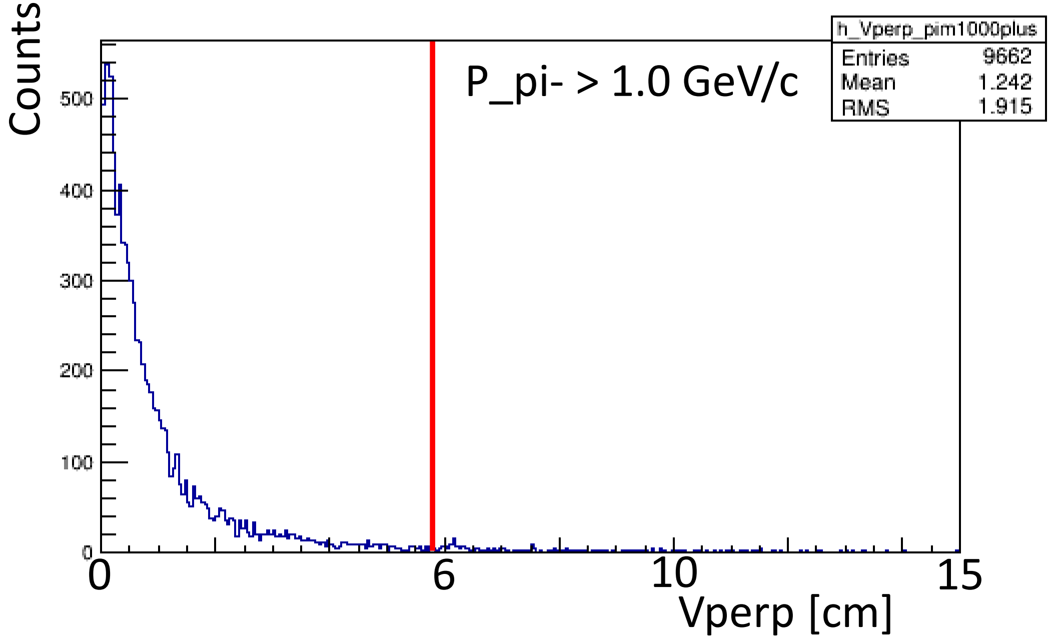






Pi- Perpendicular Vertices

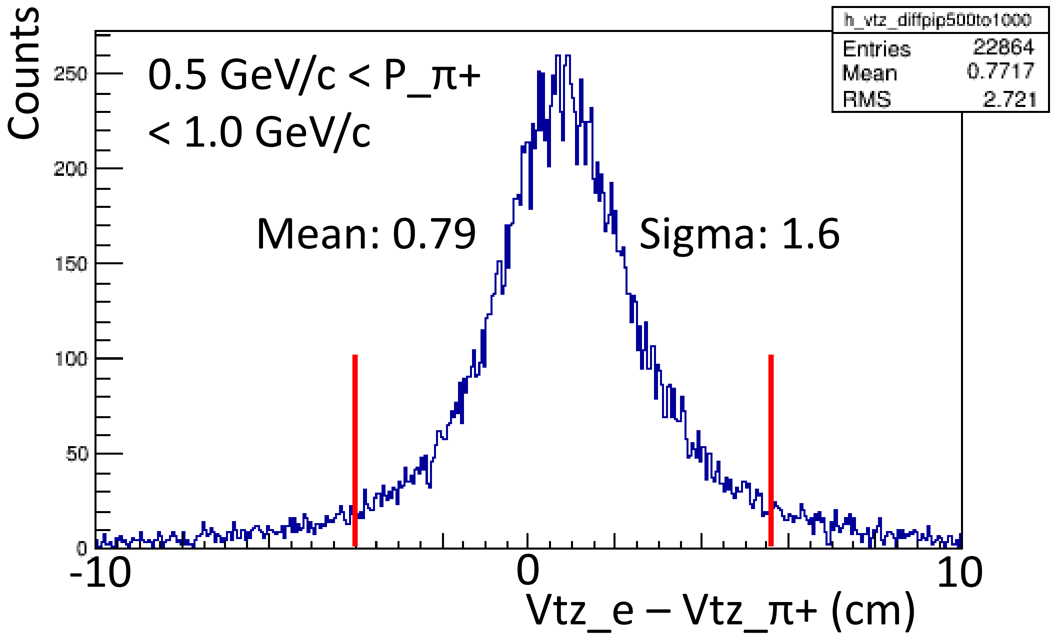


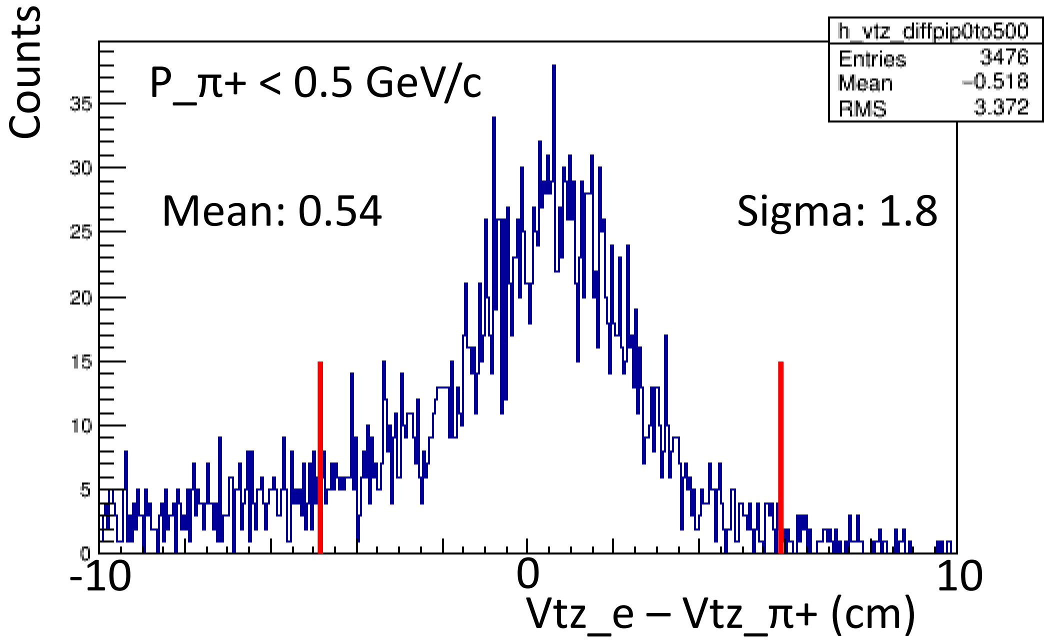


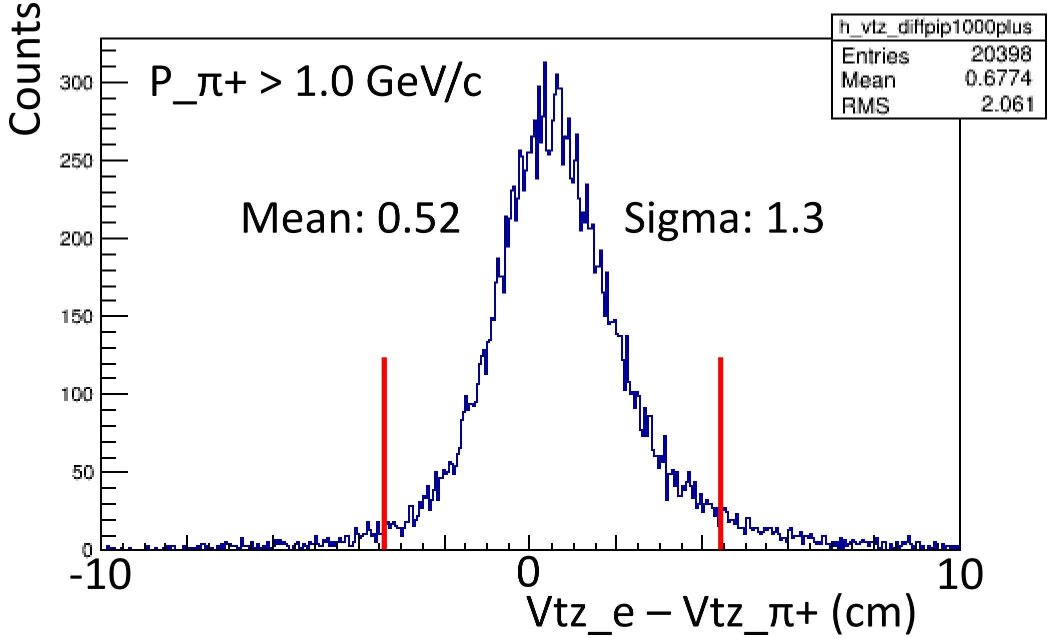
Vertex Z Difference (Electron – Pi+)

Fitted with gaussian

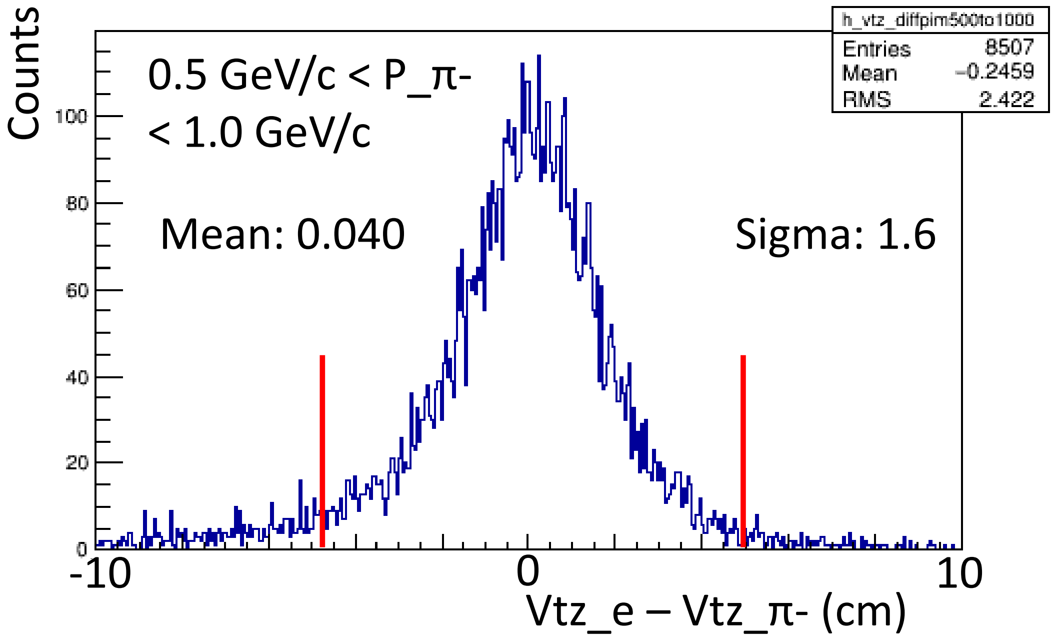
Cut = mean ± 3 * σ

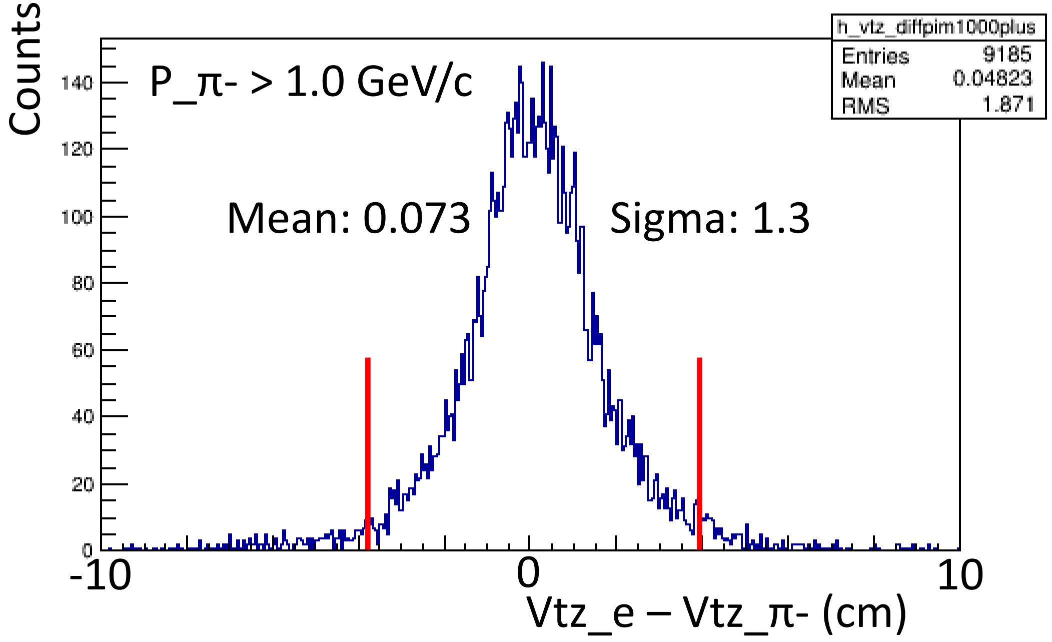






Vertex Z Difference (Electron – Pi-)

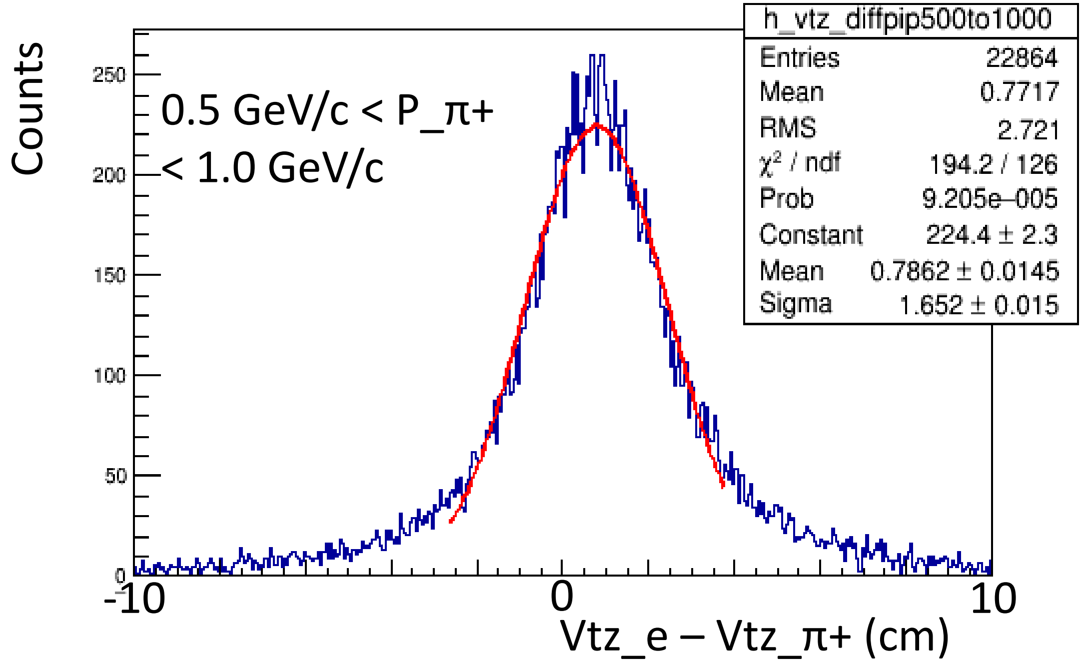


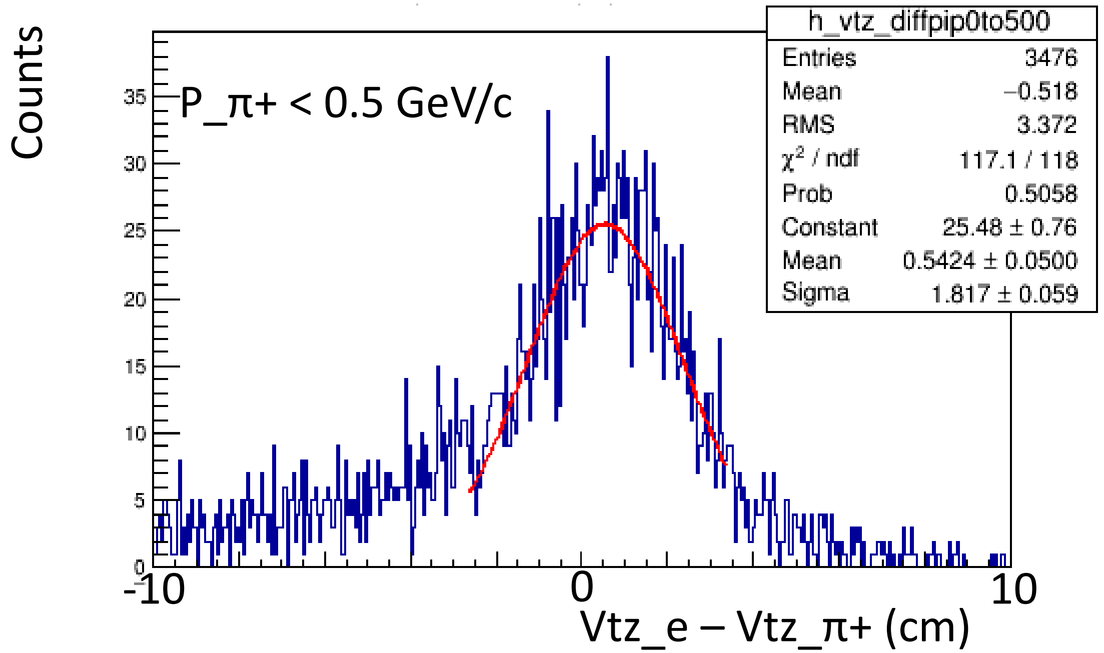


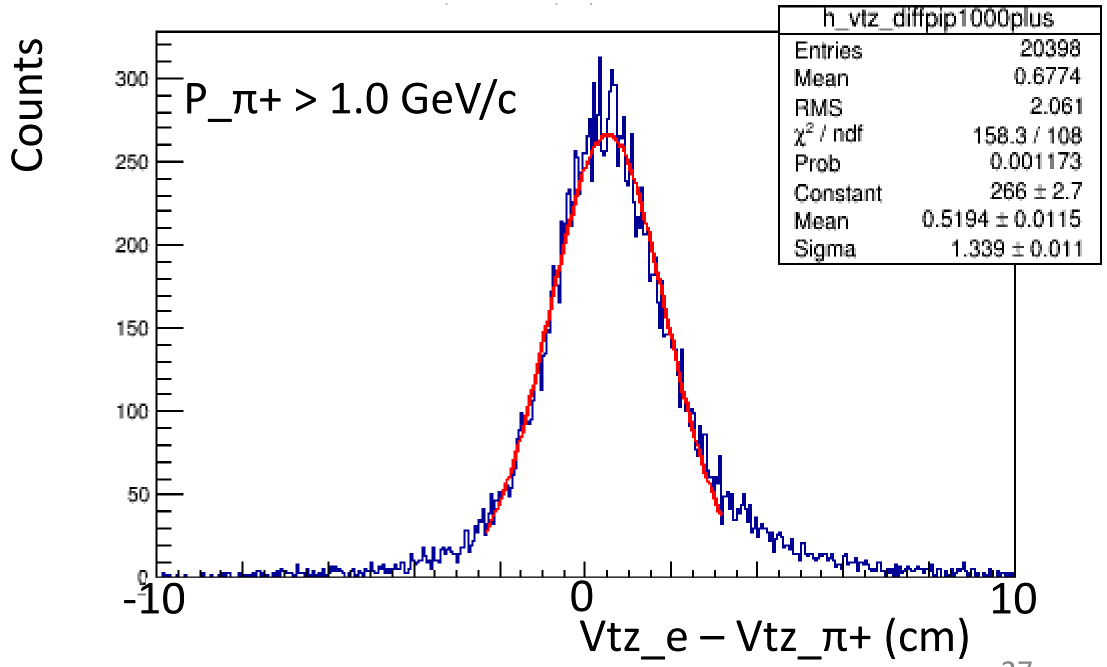
Vertex Z Difference (Electron – Pi+)

Fitted with gaussian

Cut = mean ± 3 * σ



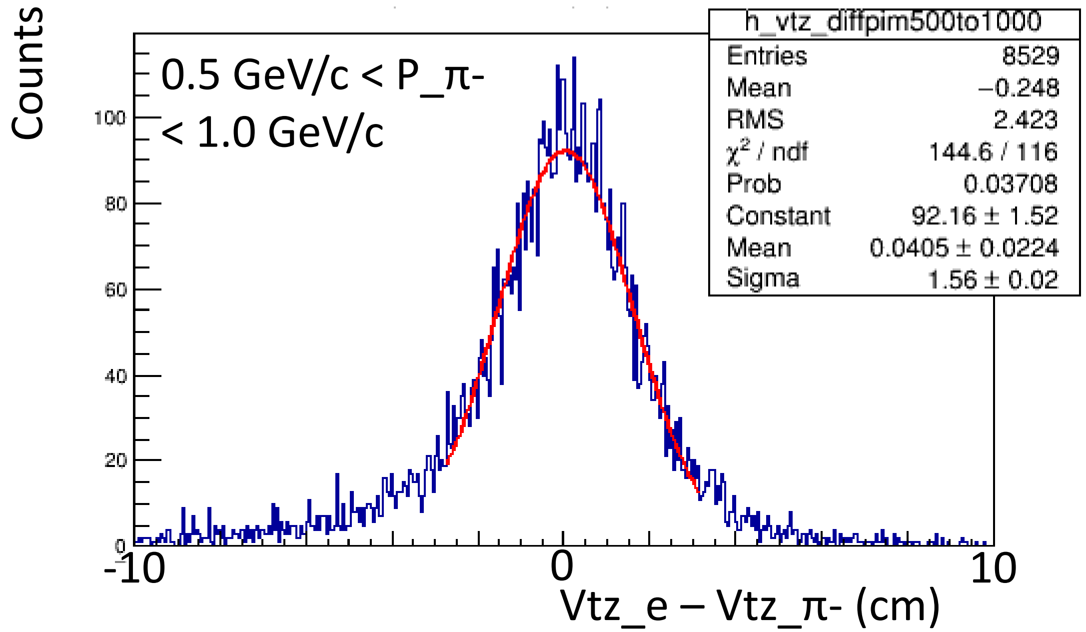


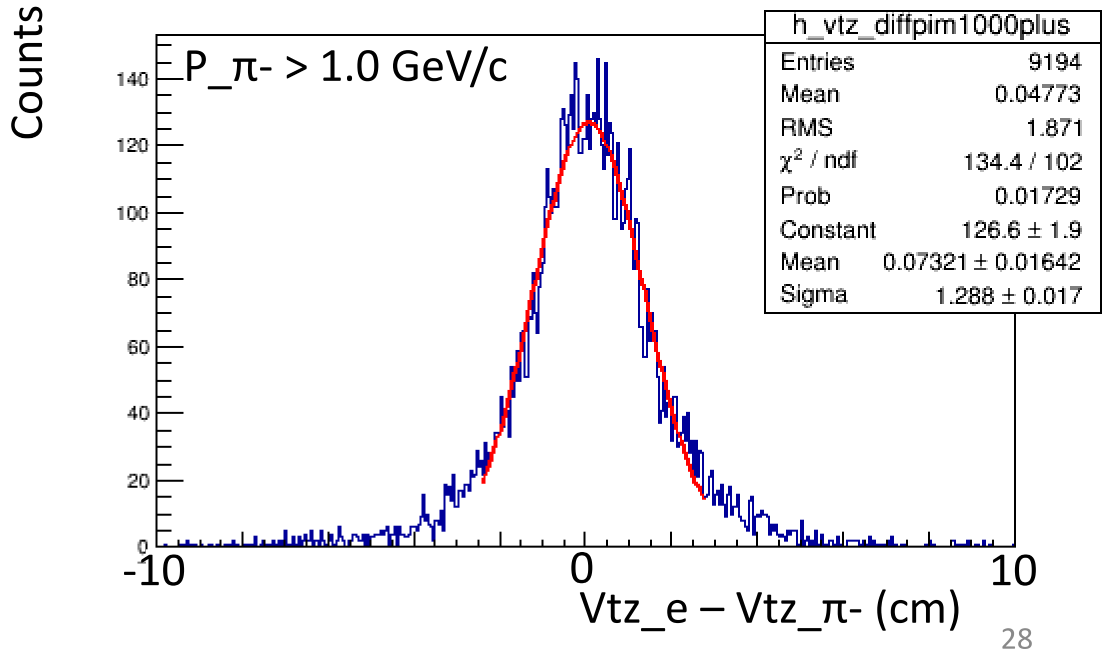


Vertex Z Difference (Electron – Pi-)

Fitted with gaussian

Cut = mean ± 3 * σ





D(e,e'pi) Cross Sections

$$N_{events} = \boxed{\frac{d^6\sigma}{d\Omega_E d\Omega_\pi dE' dT_\pi}} \Delta\Omega_E \Delta\Omega_\pi \Delta E' \Delta T_\pi * N_e t_{tgt} * correction\ factors$$

What we want

$$N_{events} = \frac{d^2\sigma}{dW dT_\pi} \Delta W \Delta T_\pi * N_e t_{tgt} * correction\ factors$$

$$\boxed{\frac{d^2\sigma}{d\omega dT_\pi} = \frac{N_{events}}{\Delta W \Delta T_\pi L} * corr.\ factors}$$

Our formula

$$L = N_e * t_{tgt} \qquad N_e = \frac{Q_{tot}}{q_e} \qquad t_{tgt} = \frac{\rho_{tgt} l_{tgt} N_A}{mol_{tgt}}$$