Measurement of Polarization Observables and Beam-Spin Asymmetry of Two Pion Electroproduction off the Proton with CLAS

Chris McLauchlin

University of South Carolina

Advisor: Dr. Ralf Gothe

Jefferson Lab

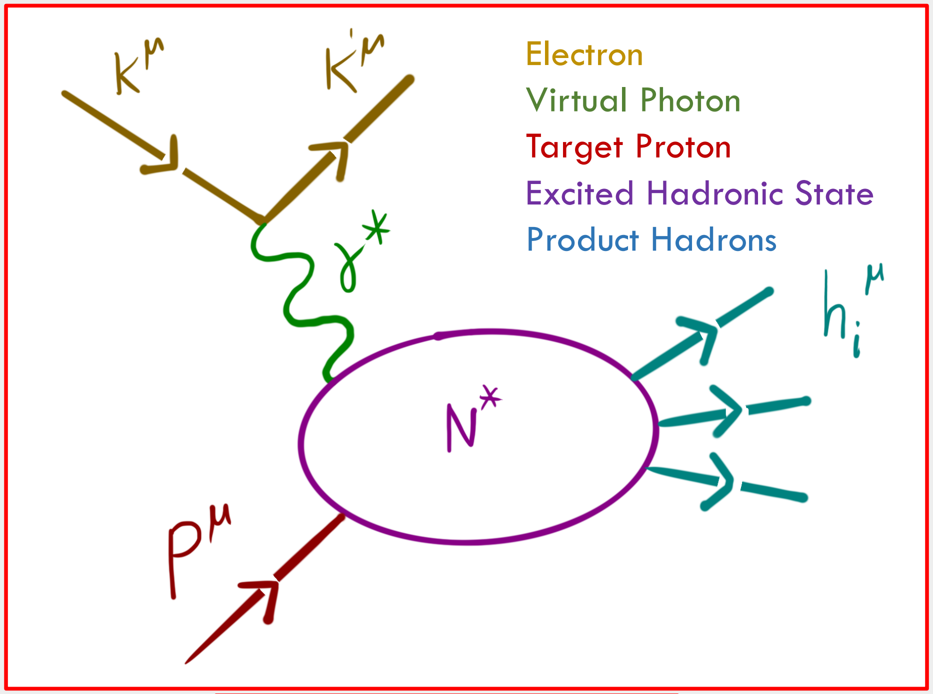
UNIVERSITY OF South Carolina

clas

Overview

- Reaction Channel
- Experimental Goals
- Experimental Setup
- Event Selection
  - Particle Identification
  - Topologies
- Observable Extraction
  - Simulation
  - Corrections
  - Final Extraction
- Summary

Reaction Channel



$$h_i = \{p, \pi^+, \pi^-\}$$

Double Charged Pion Electro-production off the Proton

$$W = \sqrt{(P^\mu + q^\mu)^2}$$

$$Q^2 = -q^\mu q_\mu$$

$$q^\mu = K^\mu - K'^\mu$$

$$M_i^2 = (K^\mu + P^\mu - K'^\mu - h_j^\mu - h_k^\mu)^2$$

$$i \neq j \neq k$$

Degrees of Freedom

Variable Sets

$\Delta^{++}: \underline{M_{p'\pi^+}}, M_{\pi^+\pi^-}, \theta_{\pi^-}, \phi_{\pi^-}, \alpha_{[p'\pi^+][p\pi^-]}$

$\Delta^{0}: M_{p'\pi^+}, \underline{M_{p'\pi^-}}, \theta_{\pi^+}, \phi_{\pi^+}, \alpha_{[p'\pi^-][p\pi^+]}$

$\rho^{0}: M_{p'\pi^+}, \underline{M_{\pi^+\pi^-}}, \theta_{p'}, \phi_{p'}, \alpha_{[\pi^+\pi^-][p'p]}$

Notation Note

$X_{ij} = \{M_i, \theta_i, \alpha_i\}$

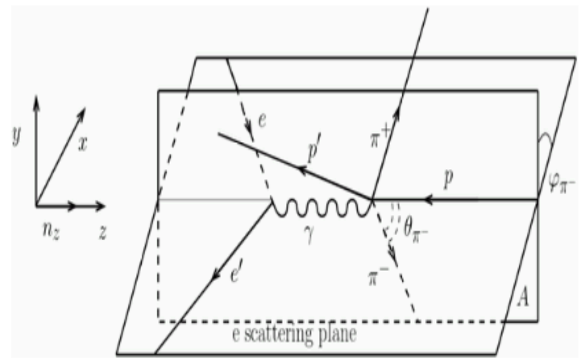


Figure 1.2: Illustration of the $\theta_{\pi^-}, \phi_{\pi^-}$ angular kinematics of variable set 1

Angular Definitions

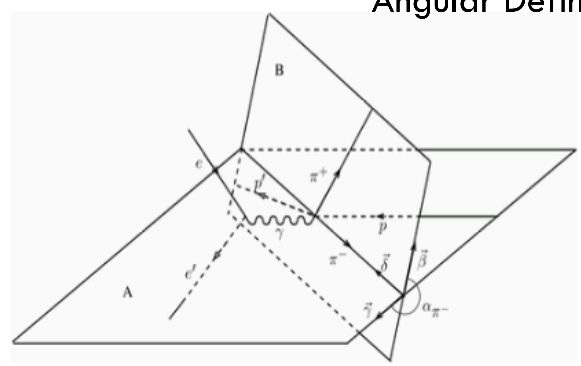
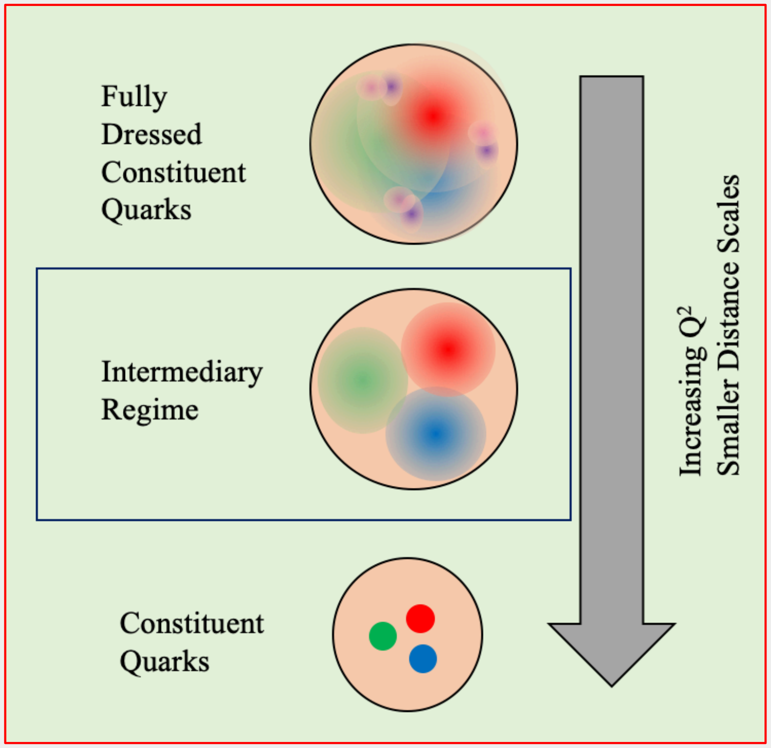


Figure 1.3: Illustration of the $\alpha_{[p'\pi^+][p\pi^-]}$ angular kinematics of variable set 1.

Experimental Goals

- Understand Proton Structure
  - Scale Dependence (Q^2)
  - Function of N* Mass (W)
  - Non-Perturbative Regime
  - Some Spin Structure
    - Polarization Observables
    - Beam-Spin Asymmetry



Extracted Observables

Polarization Observables

$$\frac{d^2\sigma^{v}}{dX_{ij}\,d\phi_i} = R2_{T\phi_i}^{X_{ij}} + R2_{L\phi_i}^{X_{ij}} + R2_{LT\phi_i}^{c,X_{ij}}\cos\phi_i + R2_{TT\phi_i}^{c,X_{ij}}\cos 2\phi_i + \delta_{X_{ij},\alpha_i}\left(R2_{LT\phi_i}^{s,X_{ij}}\sin\phi_i + R2_{TT\phi_i}^{s,X_{ij}}\sin 2\phi_i\right)$$

Photon Polarization dependent observables in the double charged meson electroproduction

Serve as input to the Jefferson Laboratory--Moscow State University (JM) Model for non-pQCD modeling

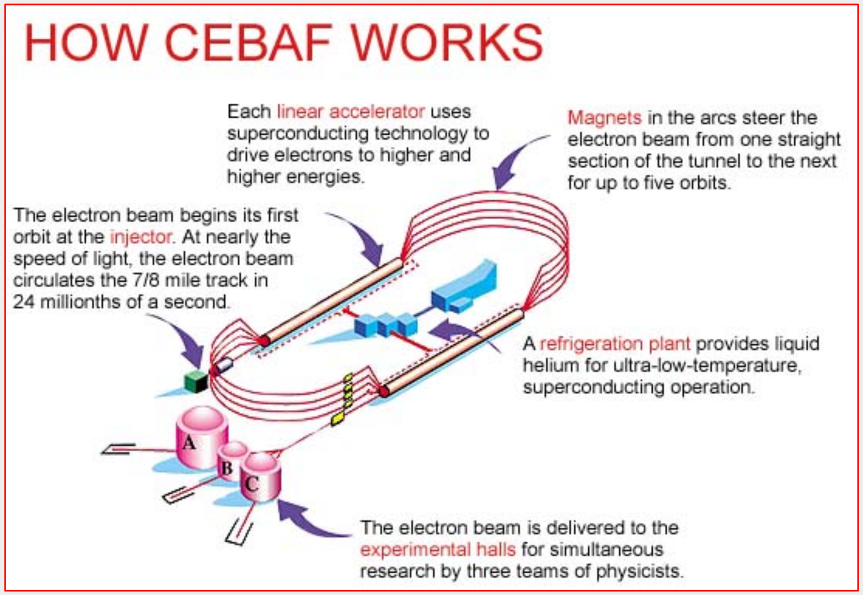
Beam-Spin Asymmetry

$$A_{LU} = A_{LU}^{0} + A_{LU}^{\sin\phi}\sin\phi = \frac{1}{P_B}\frac{N^{+}-N^{-}}{N^{+}+N^{-}}$$

Places relational constraints between Polarization Structure Functions

In addition to Single Differential Cross Sections

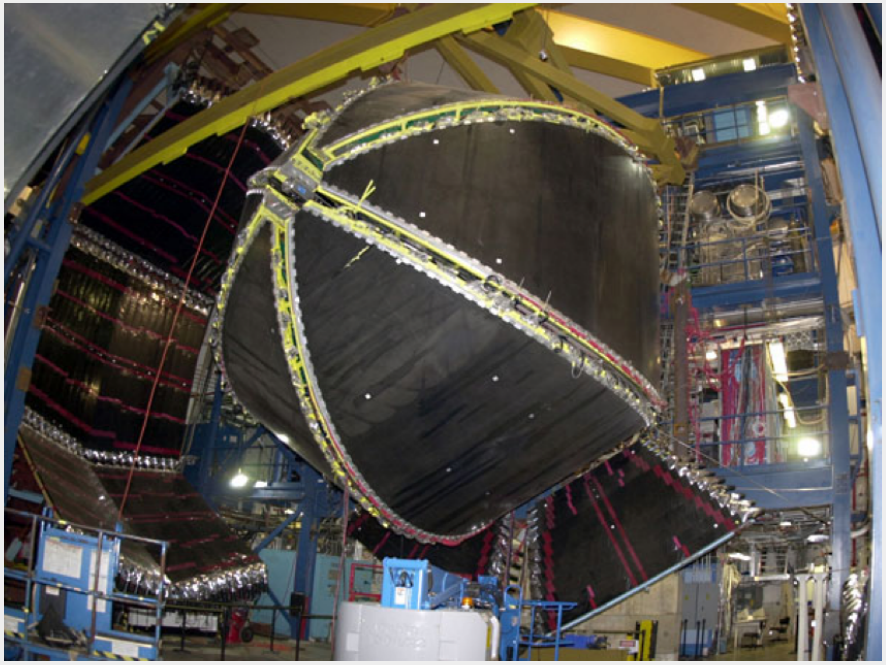
CEBAF at Jefferson Lab



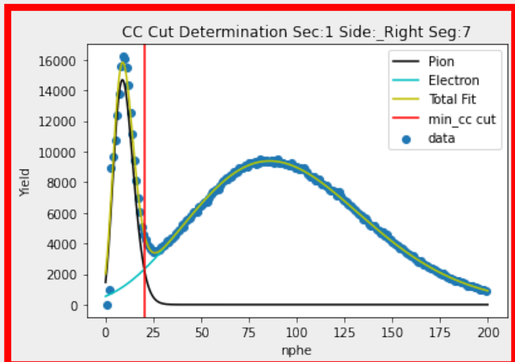
- Electron Accelerator
  - Polarized Electron Beam ~75%
- Run Group E1-6
  - 5.754 GeV
  - Unpolarized H_2 Target
  - Polarized Beam
- Run Group E1F
  - 5.498 GeV
  - Unpolarized H_2 Target
  - Polarized Beam

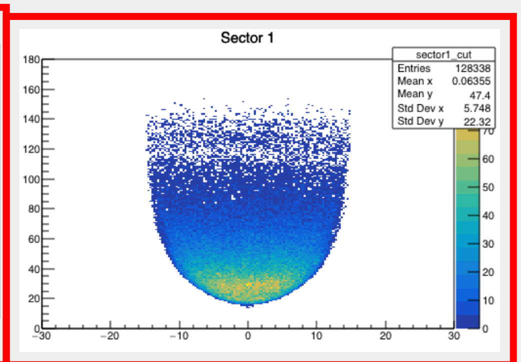
CLAS Detector

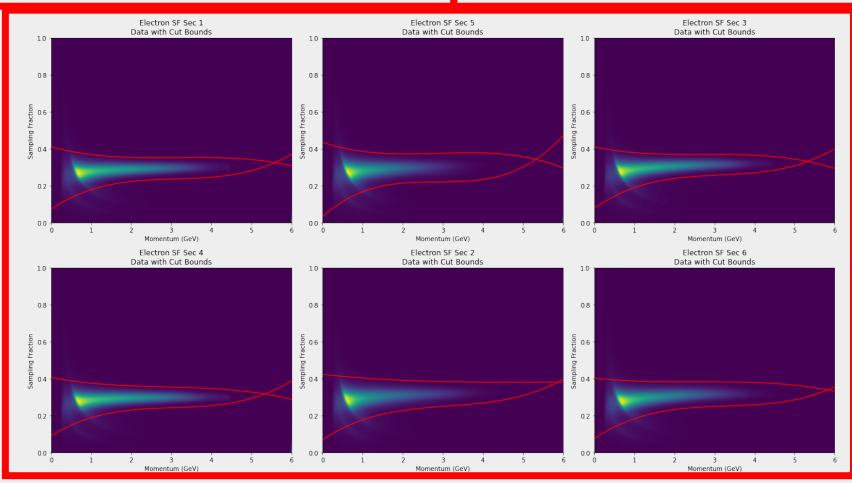
- Large Q^2 Coverage
  - Large angular acceptance
  - Explore scale dependence of hadron structure
- Particle Momentum and Tracking
  - Curvature through Drift Chambers (DC) in azimuthal magnetic field
- Electron/π^- Separation
  - Cherenkov Counters (CC)
  - Electromagnetic Calorimeter (EC)
- Hadron Identification
  - DC
  - Time of Flight from Scintillation Counters (SC)



Electron ID



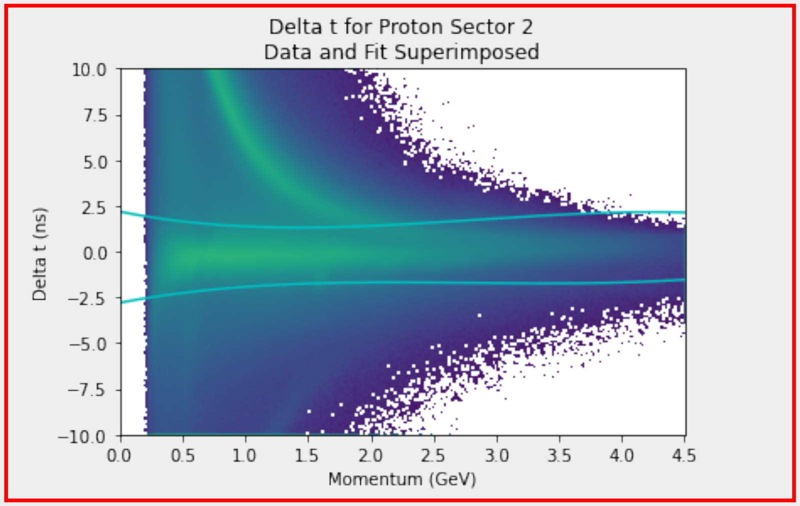


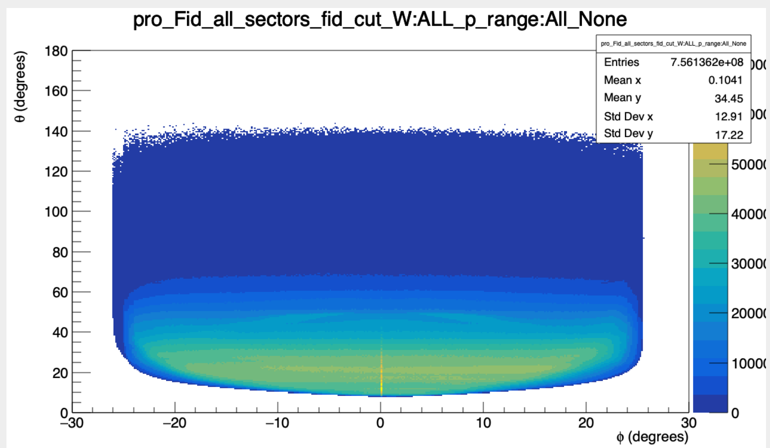


- Sanity Cuts
  - Did we hit all relevant detectors?
- Angular Fiducial Cuts
  - Cutting out clipping on detector edges
  - Momentum Dependent
- Minimum CC Cuts
  - Minimize Pion contamination
  - Not performed on Sim
- Sampling Fraction Cuts
  - Further separation from pions and other minimum ionizing particles

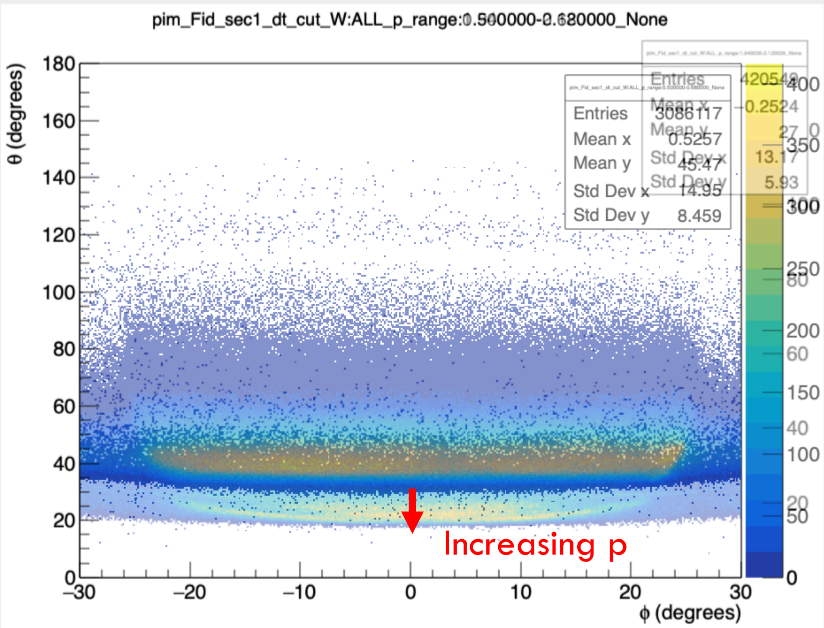
Proton and π^+ ID

- Sanity Cut
  - Hits in relevant detector systems
- Angular Fiducial Cut
  - Cut out detector clipping
- Delta T Cut
  - Comparison of traversal time from direct measurement and mass assumption



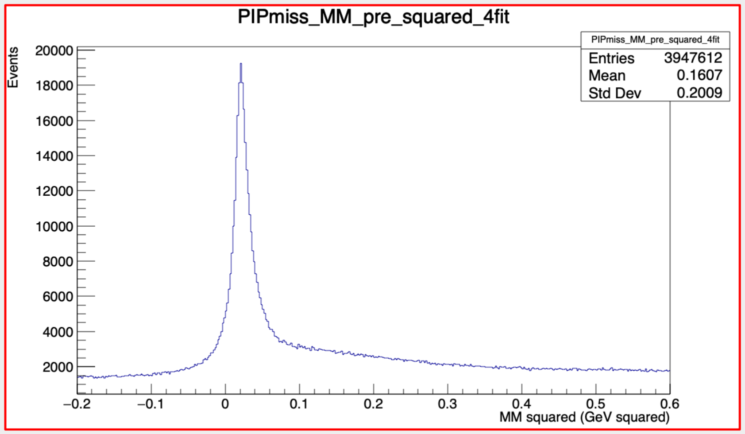


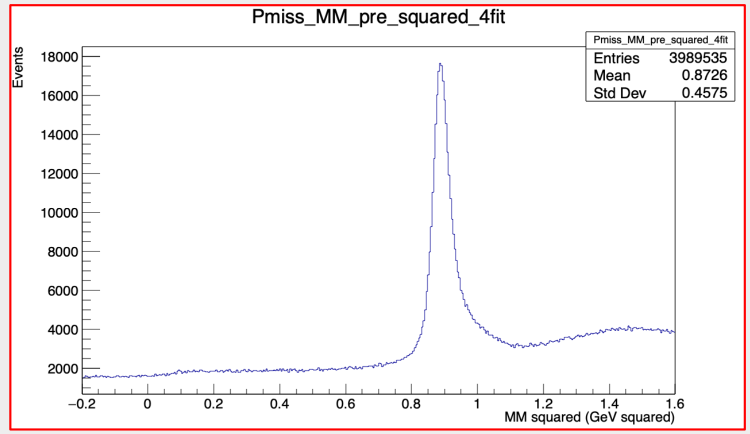
π^- ID

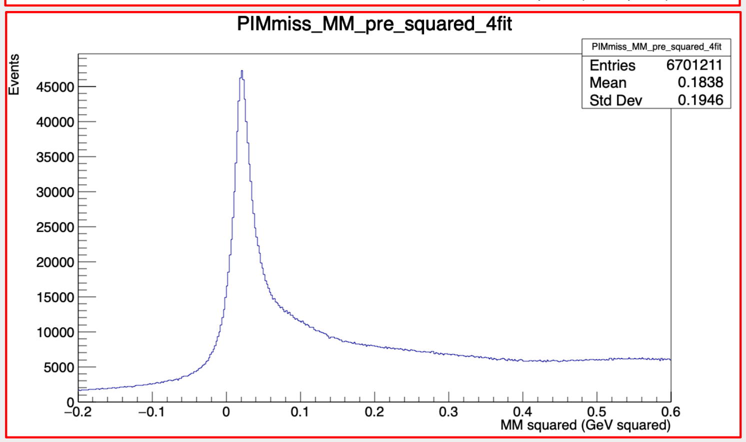


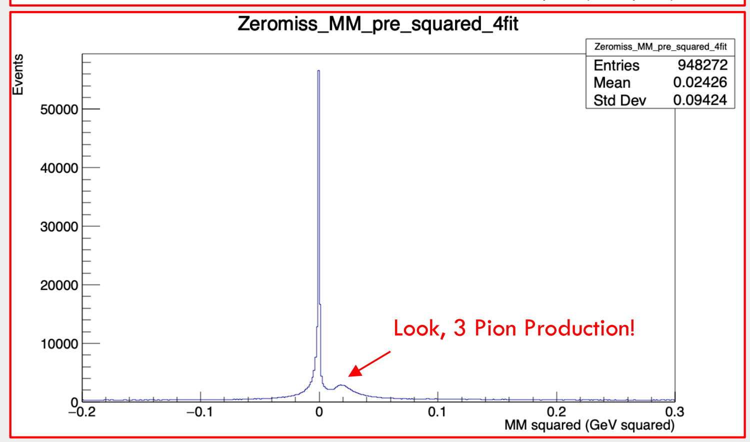
- Sanity Cut
  - Hits in relevant detector systems
- Angular Fiducial Cut
  - Cut out detector clipping
  - Momentum Dependent
- Delta t Cut
  - Comparison of traversal time from direct measurement and mass assumption

Topology Isolation

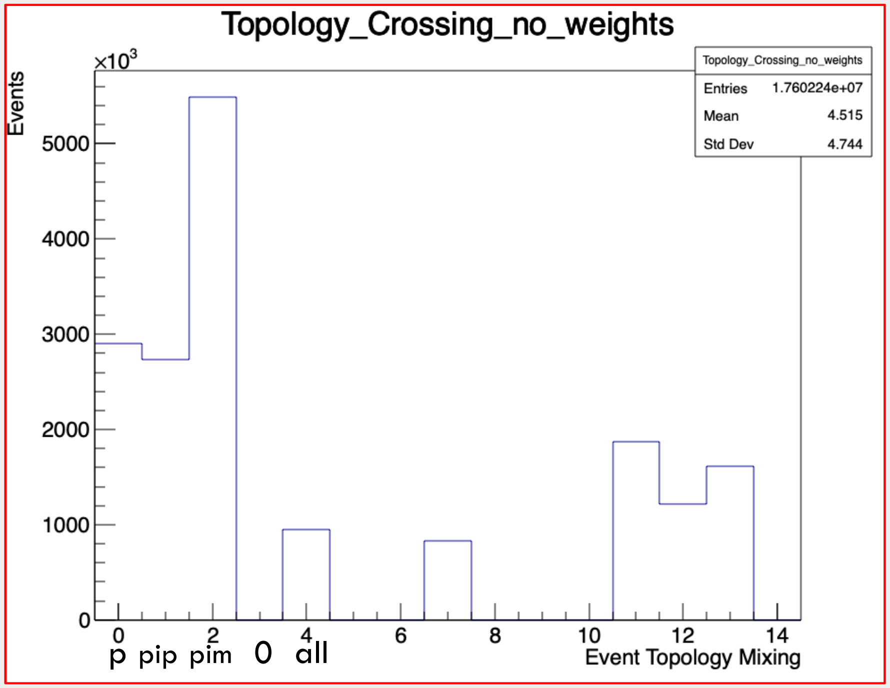








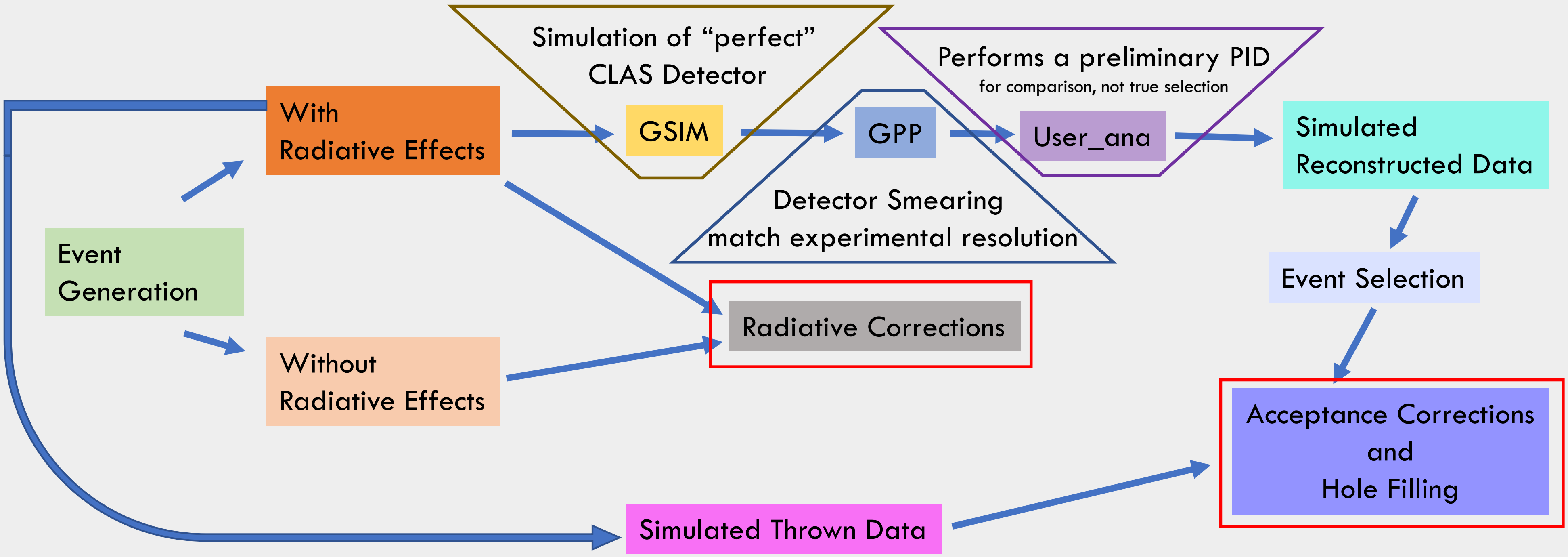
Topology Combination



x-axis referrs to different topology combinations

- Maximize Statistics
  - Combine multiple topologies
  - Increase yields ~20%
- Single events can fall under multiple topologies
  - How to categorize?
- Hierarchy
  - Fully Exclusive
  - PIM
  - Proton
  - PIP

Simulation

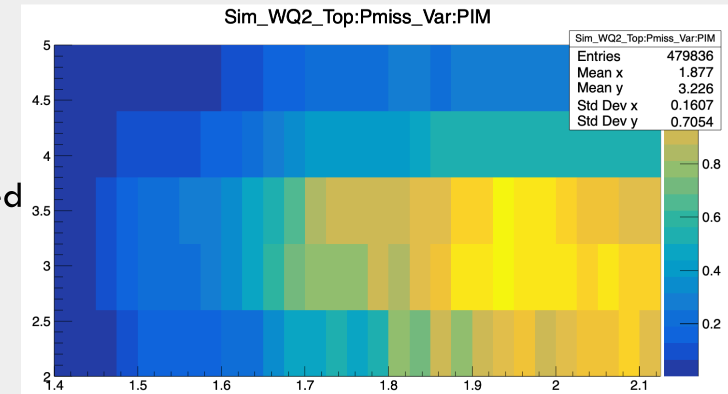

Simulation of "perfect"
CLAS Detector
GSIM
Performs a preliminary PID
for comparison, not true selection
With
Radiative Effects
GPP
User_ana
Simulated
Reconstructed Data
Detector Smearing
match experimental resolution
Event
Generation
Event Selection
Radiative Corrections
Without
Radiative Effects
Acceptance Corrections
and
Hole Filling
Simulated Thrown Data

Correction Factors

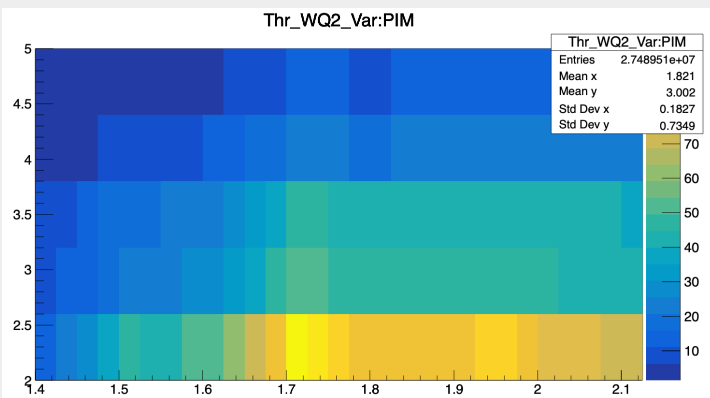
- Acceptance Correction
  - Detector Efficiencies
- Energy-Momentum Correction
  - Accounts for B-Field Irregularities and Subsequent Energy Loss
- Radiative Correction
  - Account for Radiated Photons
- CC Efficiency Correction
  - Account for CC Efficiencies
- Kinematic Hole Filling
  - Fill Kinematic Holes for Bin Integration
- Empty Target Subtraction
  - Isolate Events from Target

Need More Simulation

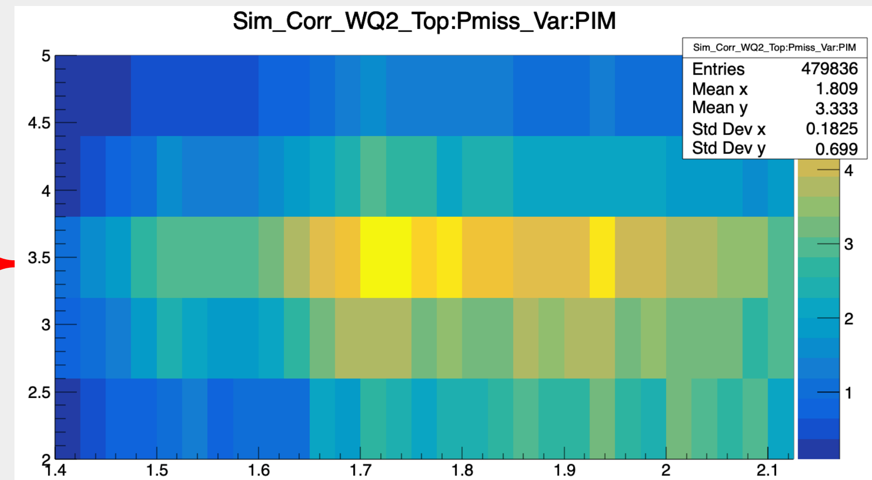
Reconstructed



Thrown



Acceptance Corrected Reconstruction



Should look similar to Thrown Distribution

Need far more statistics

Observable Extraction

Polarization Observables

$$\frac{d^2\sigma^v}{dX_{ij}\,d\phi_i} = R2_{T\phi_i}^{X_{ij}} + R2_{L\phi_i}^{X_{ij}} + R2_{LT\phi_i}^{c,X_{ij}}\cos\phi_i + R2_{TT\phi_i}^{c,X_{ij}}\cos 2\phi_i + \delta_{X_{ij},\alpha_i}\left(R2_{LT\phi_i}^{s,X_{ij}}\sin\phi_i + R2_{TT\phi_i}^{s,X_{ij}}\sin 2\phi_i\right)$$

$$\frac{\Delta^2\sigma^v}{\Delta X_{ij}\,\Delta\phi_i} = \frac{\Delta^4 N}{\Gamma^v L R\, \Delta W \Delta Q^2 \Delta X_{ij} \Delta\phi_i}$$

Single Differential

$$\frac{\Delta\sigma^v}{\Delta X_{ij}} = \frac{\Delta^3 N_{XEC} + \Delta^3 N_{XEH}}{\Gamma^v L R\, \Delta W \Delta Q^2 \Delta X_{ij}}$$

Beam-Spin Asymmetry

$$A_{LU} = A_{LU}^{0} + A_{LU}^{\sin\phi}\sin\phi = \frac{1}{P_B}\frac{N^+ - N^-}{N^+ + N^-}$$

Completed

- Particle ID Cuts
  - Methodology and Infrastructure
  - Single Iteration
- Topology Assignment and Combination
  - Methodology and Infrastructure
- Workflow for Simulation
- CC Efficiency
  - Methodology and Infrastructure
- Empty Target Subtraction
  - Methodology
- Energy-Momentum Correction
  - Methodology and Infrastructure
- Radiative Correction
  - Methodology
- Hole Filling
  - Methodology and Infrastructure

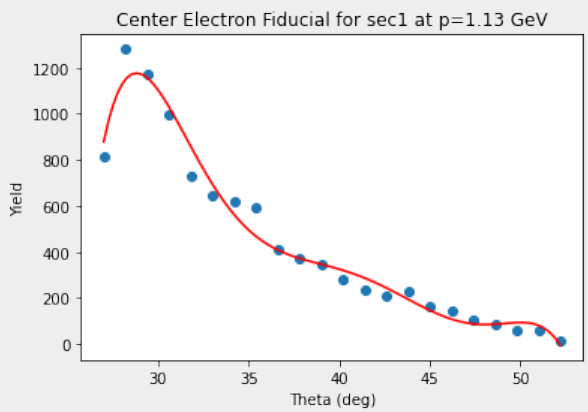
Current Work

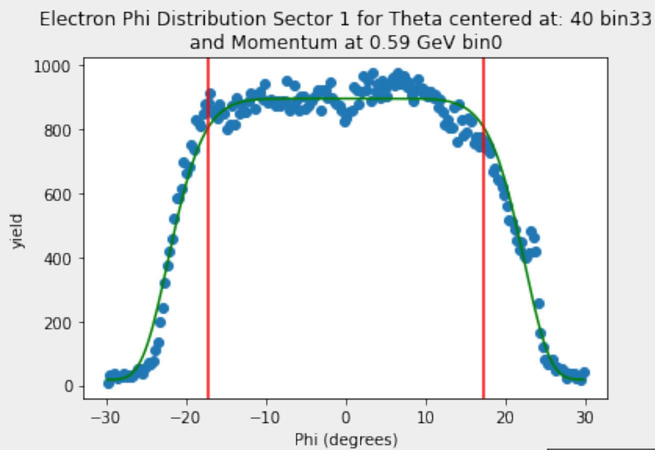
- Work Over Full Data Sets
- Reach Sufficient Statistics in Simulation
- Empty Target Subtraction
  - Infrastructure
- Additional Particle ID Cut Iterations
- Radiative Correction
  - Infrastructure
- Final Extraction
  - Infrastructure

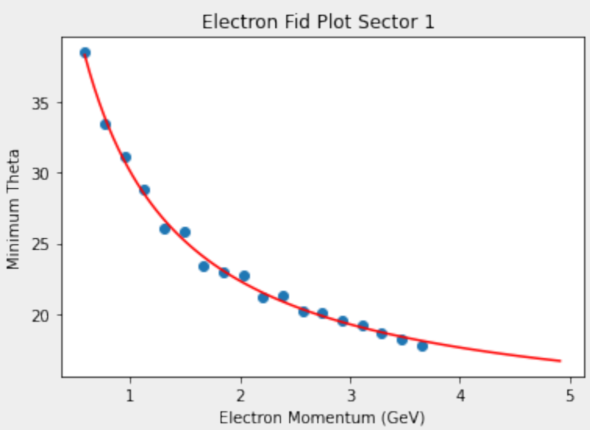
Thank you

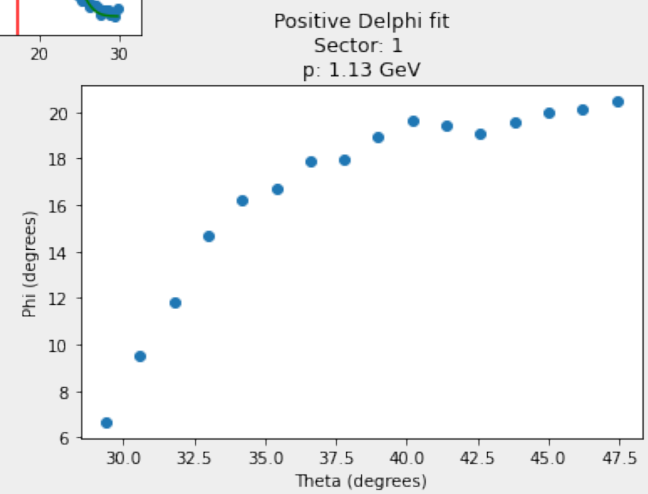
Any Questions?

Momentum Dependent Fiducial Cut









Delta t Cut

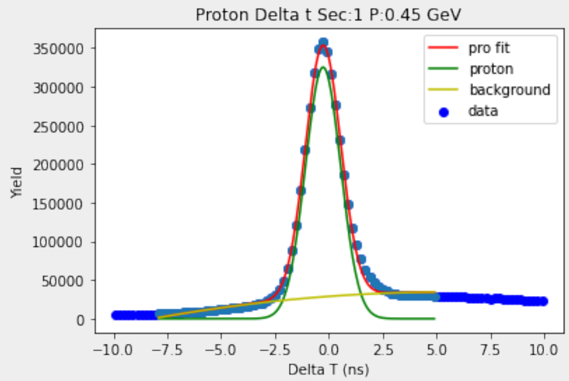
$$\Delta t = t_{SC} - t_{DC}$$

$$t_{DC} = \frac{r_{DC}}{c\sqrt{1+\frac{m^2}{p^2}}}$$

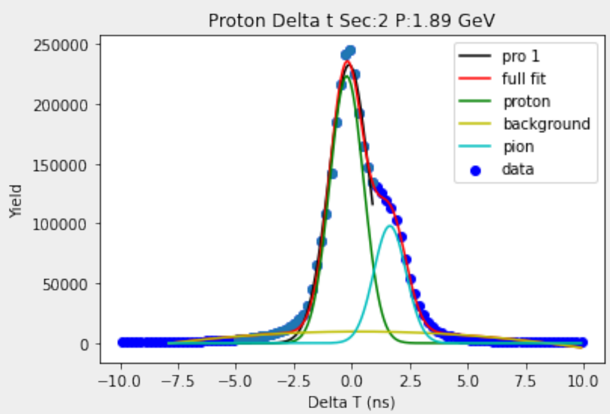
Gives the difference in traversal time between a direct measurement and one based on an assumed mass

More directly related to the detectors and allows for a nicer separation

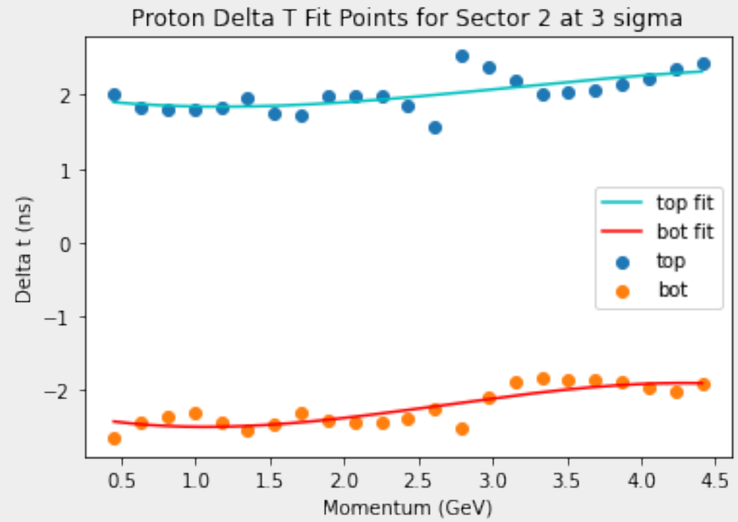
Delta t Cut



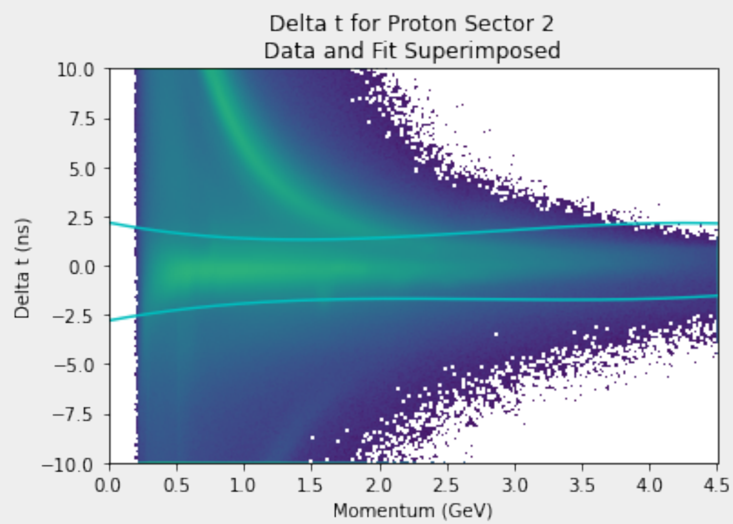
Proton Delta t Sec:1 P:0.45 GeV
pro fit
proton
background
data
Yield
Delta T (ns)



Proton Delta t Sec:2 P:1.89 GeV
pro 1
full fit
proton
background
pion
data
Yield
Delta T (ns)

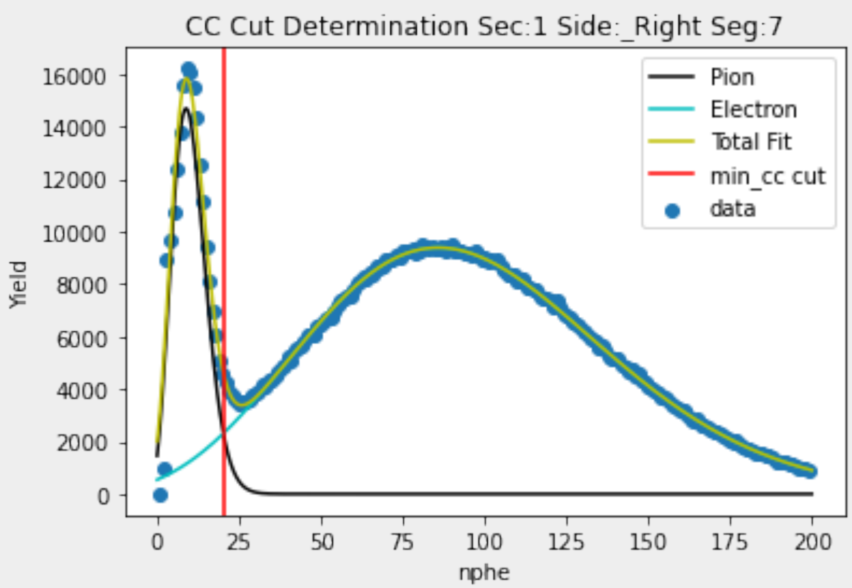


Proton Delta T Fit Points for Sector 2 at 3 sigma
top fit
bot fit
top
bot
Delta t (ns)
Momentum (GeV)

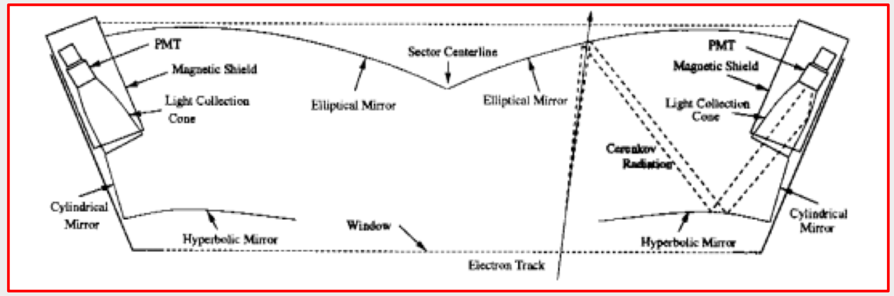


Delta t for Proton Sector 2
Data and Fit Superimposed
Delta t (ns)
Momentum (GeV)

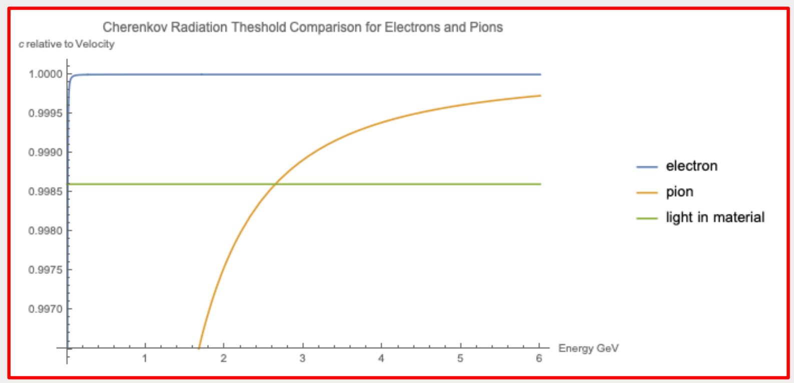
Min CC Cut



CC Cut Determination Sec:1 Side:_Right Seg:7
Pion
Electron
Total Fit
min_cc cut
data
Yield
nphe
16000
14000
12000
10000
8000
6000
4000
2000
0
0
25
50
75
100
125
150
175
200

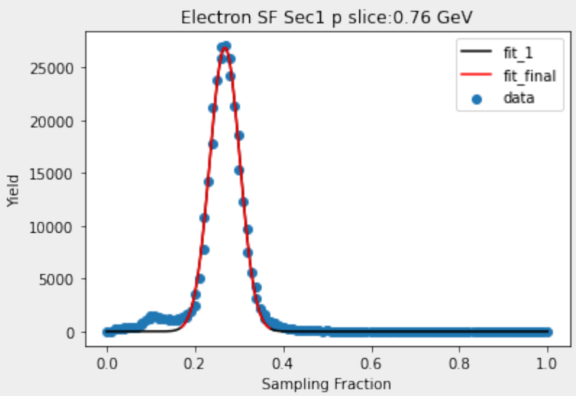


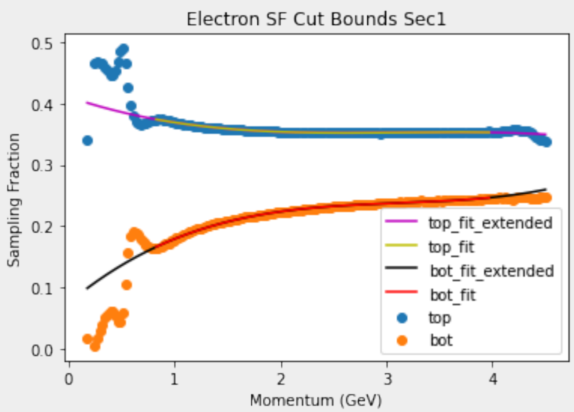
PMT
Magnetic Shield
Light Collection Cone
Elliptical Mirror
Sector Centerline
Elliptical Mirror
PMT
Magnetic Shield
Light Collection Cone
Cerenkov Radiation
Cylindrical Mirror
Hyperbolic Mirror
Window
Electron Track
Hyperbolic Mirror
Cylindrical Mirror

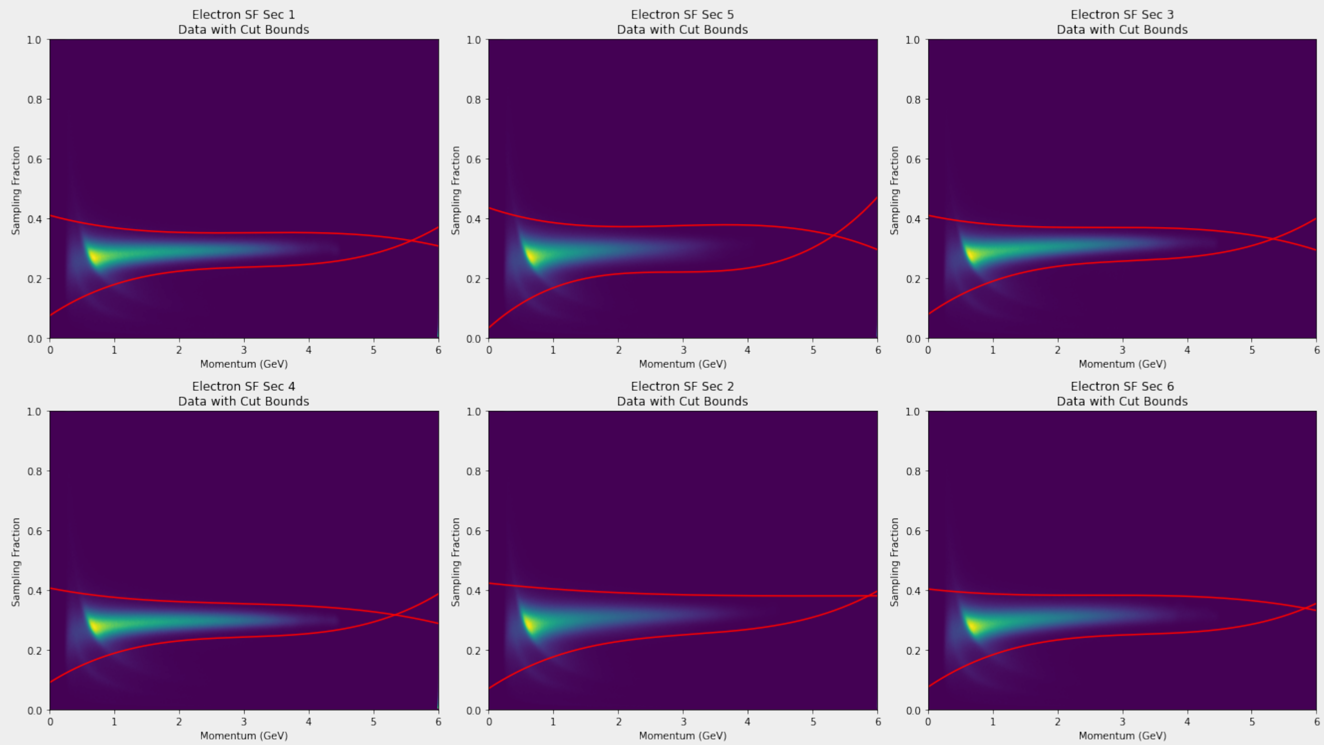


Cherenkov Radiation Theshold Comparison for Electrons and Pions
c relative to Velocity
1.0000
0.9995
0.9990
0.9985
0.9980
0.9975
0.9970
1
2
3
4
5
6
Energy GeV
electron
pion
light in material

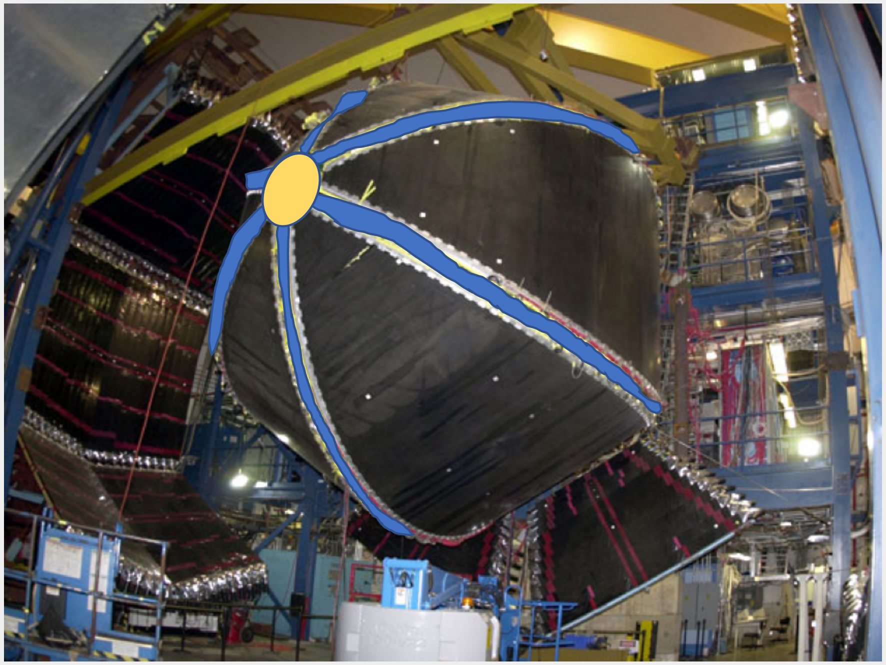
Sampling Fraction Cut







Kinematic Hole Filling



- HOLES
  - Physical holes in our kinematic coverage
  - Integration over bins for certain observables requires integration over artificially empty bins
  - Determined from simulation

Kinematic Hole Filling

$$\Delta^7 N_{XE} = \Delta^7 N_X - Q_r \Delta^7 N_E$$

$$\Delta^7 A = \frac{\Delta^7 N_R}{\Delta^7 N_T} \Rightarrow \quad \Delta^7 N_{RC} = \frac{\Delta^7 N_R}{\Delta^7 A}, \quad \Delta^7 N_{XEC} = \frac{\Delta^7 N_{XE}}{\Delta^7 A}$$

$$\Delta^7 N_{RH} = \Delta^7 N_T - \Delta^7 N_{RC} \qquad sf_7 = \frac{\int \Delta^7 N_{XEC}}{\int \Delta^7 N_{RC}}$$

$$\Delta^7 N_{XEH} = sf_7 \, \Delta^7 N_{RH}$$

$$\Rightarrow \Delta^7 N = \Delta^7 N_{XEC} + \Delta^7 N_{XEH}$$

Q_r – Integrated Faraday Cup Ratio
N – Yield
X – Experiment with Target
E – Experiment with Empty Target
R – Simulated Reconstruction
T – Simulated Thrown
A – Acceptance
C – Acceptance Corrected
sf – Scale Factor