Measurements of the Cosϕ and Cos2ϕ Moments of the Unpolarized SIDIS π^+ Cross-section at CLAS12

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CLAS Collaboration 2024

LinkedIn

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Motivation

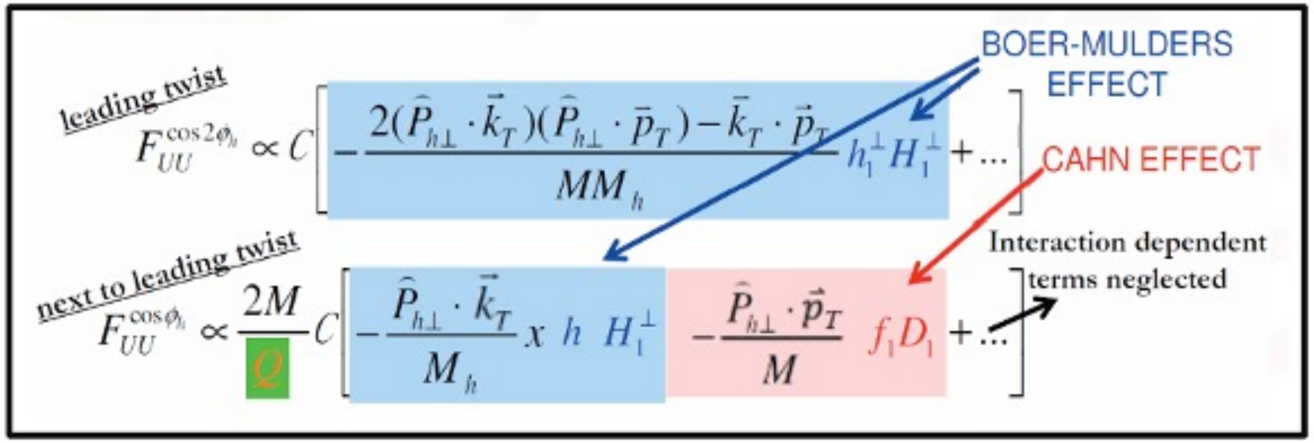
- Semi-Inclusive Deep Inelastic Scattering (SIDIS) experiments allow us to address questions about the 3D structure of nucleons
- Azimuthal modulations in unpolarized SIDIS cross-section for charged pion electroproduction can give access to the Cahn and Boer-Mulders effects
  - **Boer-Mulders Effect:** Sensitive to the correlation between the quark's transverse momentum and intrinsic transverse spin in an unpolarized nucleon
  - **Cahn Effect:** Sensitive to the transverse motion of quarks inside the nucleon
- A non-zero Boer-Mulders requires quark orbital angular momentum contributions to the proton spin (aspect of the proton missing spin puzzle)

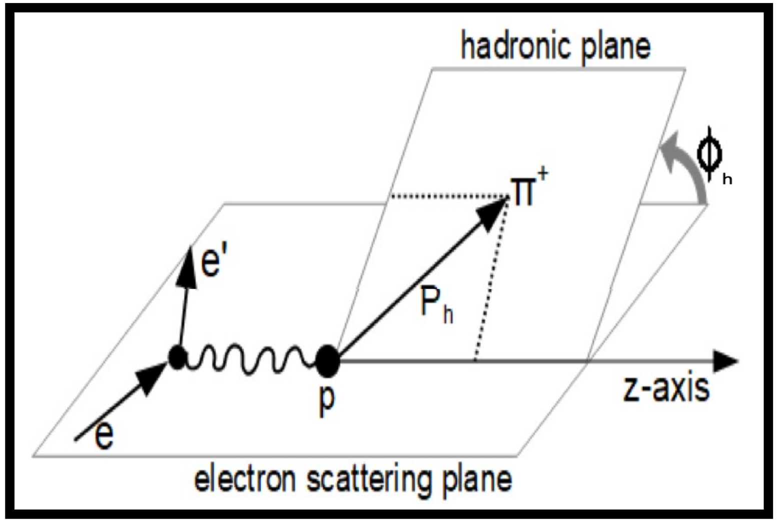
SIDIS Cross-Section and Boer-Mulders

The lepton-hadron Unpolarized SIDIS Cross-Section:

$$\frac{d^5\sigma}{dy\,dQ^2\,dz\,d\phi_h\,dP_{h\perp}^2} = \underbrace{\frac{x_B}{y}\frac{2\pi\alpha^2}{x_B y Q^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x_B}\right)(F_{UU,T}+\epsilon F_{UU,L})}_{A_0}\left\{1+\underbrace{\frac{\sqrt{2\epsilon(1+\epsilon)}F_{UU}^{\cos\phi_h}}{(F_{UU,T}+\epsilon F_{UU,L})}}_{A_{UU}^{\cos\phi_h}}\cos\phi_h+\underbrace{\frac{\epsilon F_{UU}^{\cos 2\phi_h}}{(F_{UU,T}+\epsilon F_{UU,L})}}_{A_{UU}^{\cos 2\phi_h}}\cos 2\phi_h\right\}$$

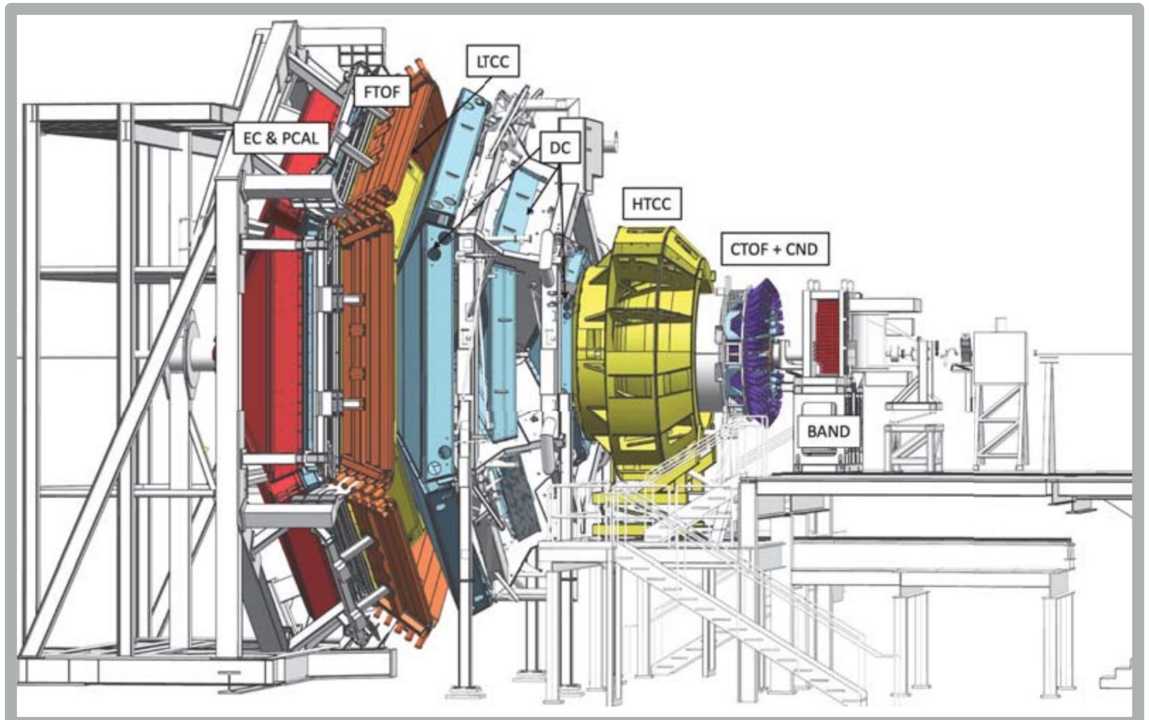
The Boer-Mulders and Cahn effects are present in the Structure Functions:





Reaction Studied: $ep \rightarrow e\pi^+(X)$

Data Collection



CLAS12 Detector

- CLAS12 detector in Hall B at Jefferson Lab
  - Upgrade from the CLAS detector
  - Enabled the higher energy and statistics for our experiments, not previously accessible
- Data from the Fall 2018 RG-A experiment
  - Used a 10.6 GeV polarized electron beam and unpolarized liquid hydrogen target
- Data presented uses forward tracking only

Event Selection

Particle ID (PID):

- **Electron ID:** Based on Electromagnetic Calorimeter (PCAL) and Cherenkov Counters (HTCC)
- **Hadron (π^+) ID:** Based on Time-Of-Flight Counters (TOF) and the correlation of velocity (ß) and momentum

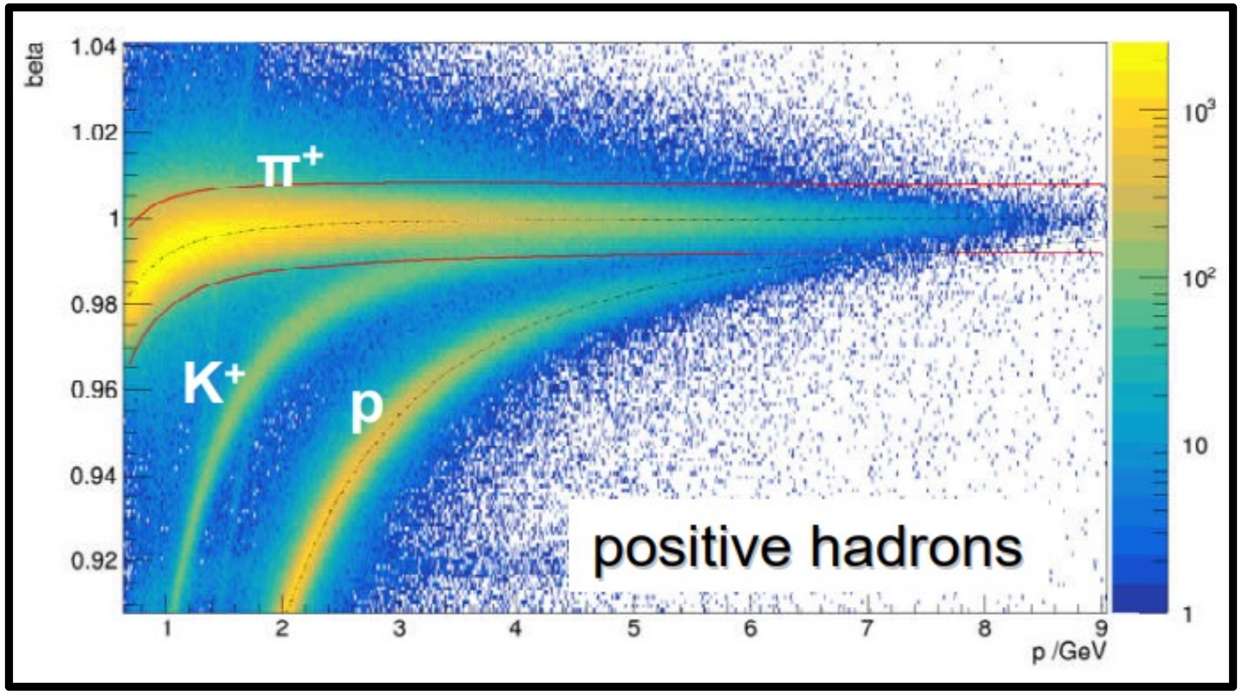


*Image provided by Stefan Diehl

π^+ Pion PID – ß vs p

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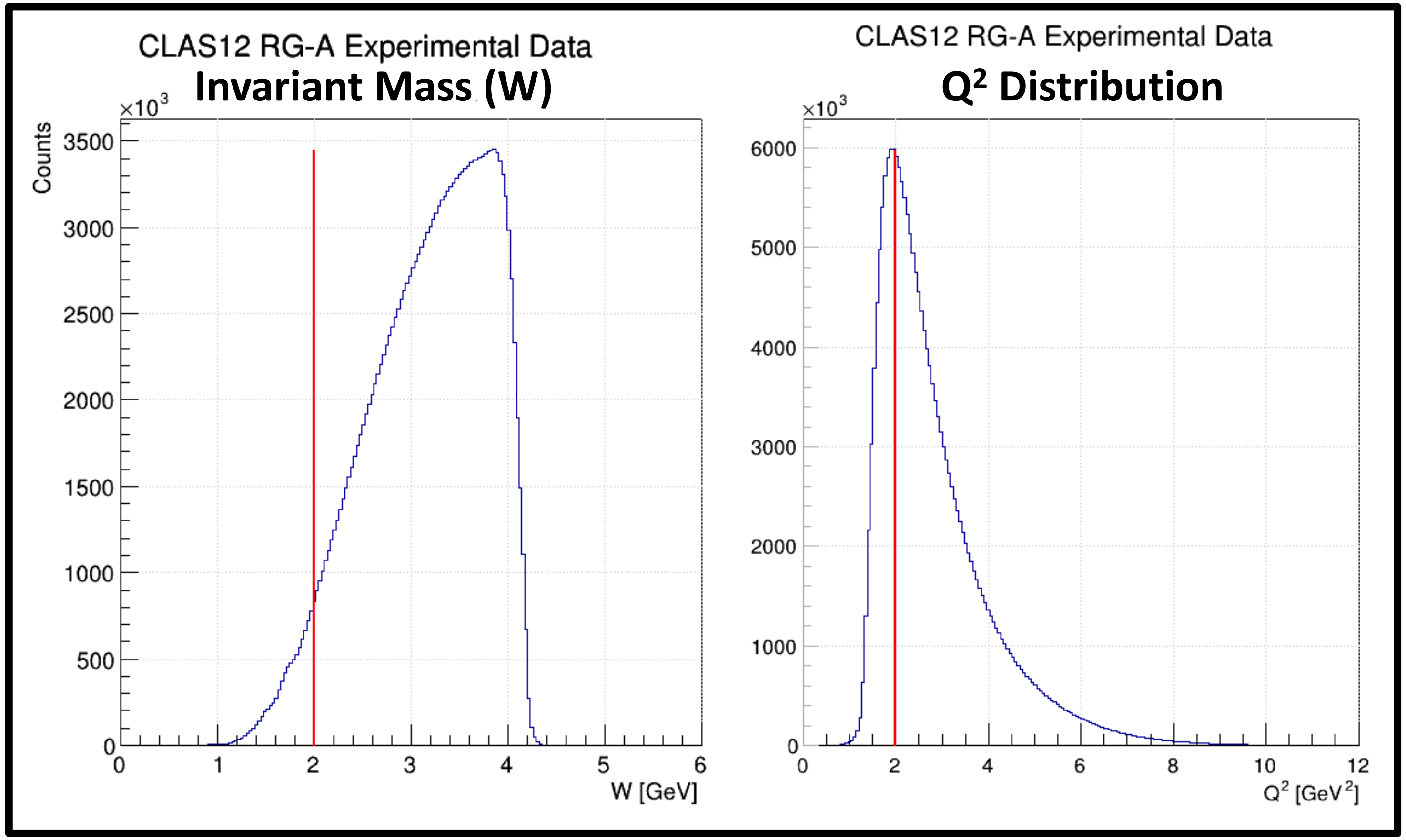
Analysis Cuts:

- **SIDIS Cuts**:
  - W > 2 GeV
  - $Q^2 > 2$ GeV^2



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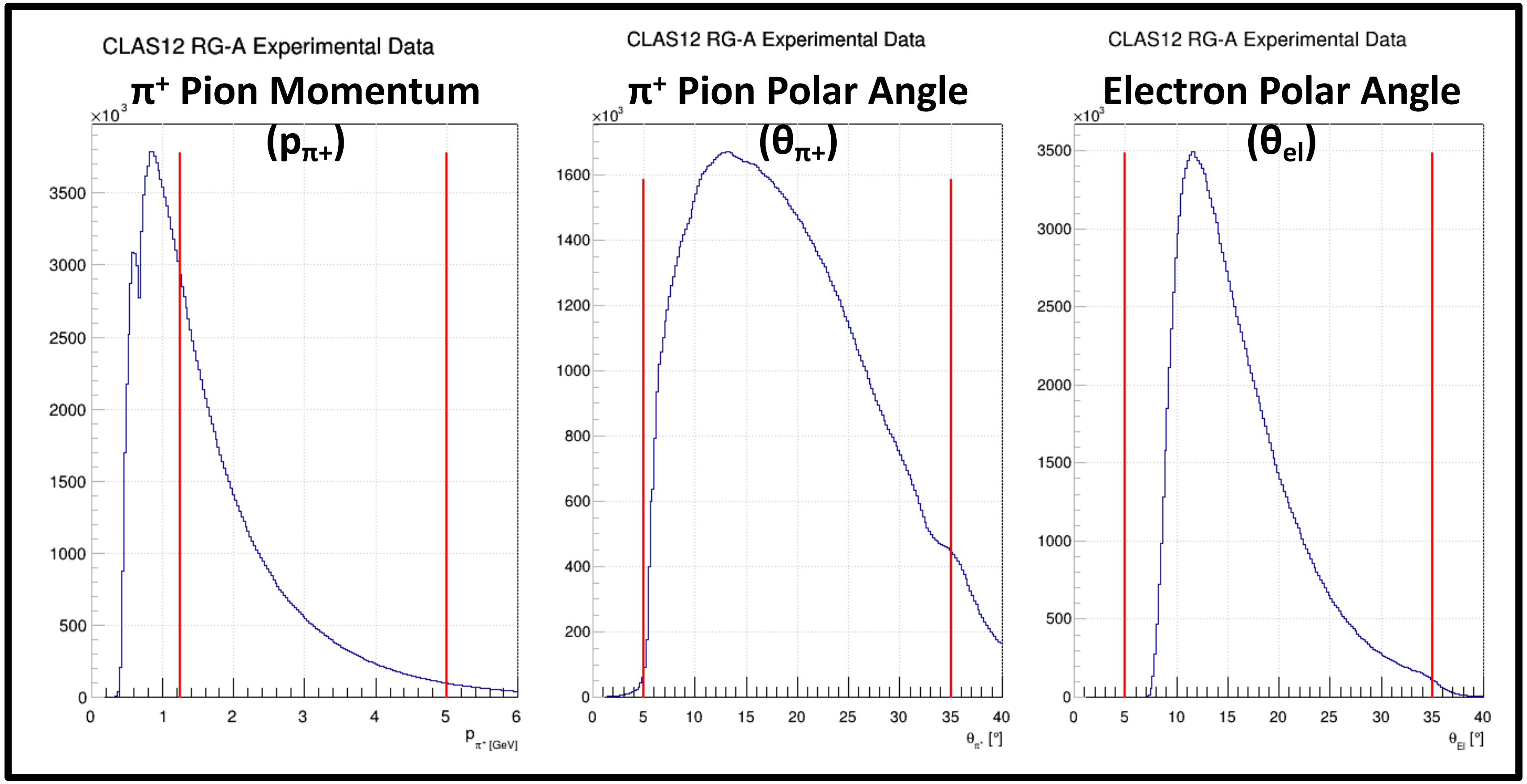
  - θ-angle Cut: 5° < $\theta_{particle}$ < 35°



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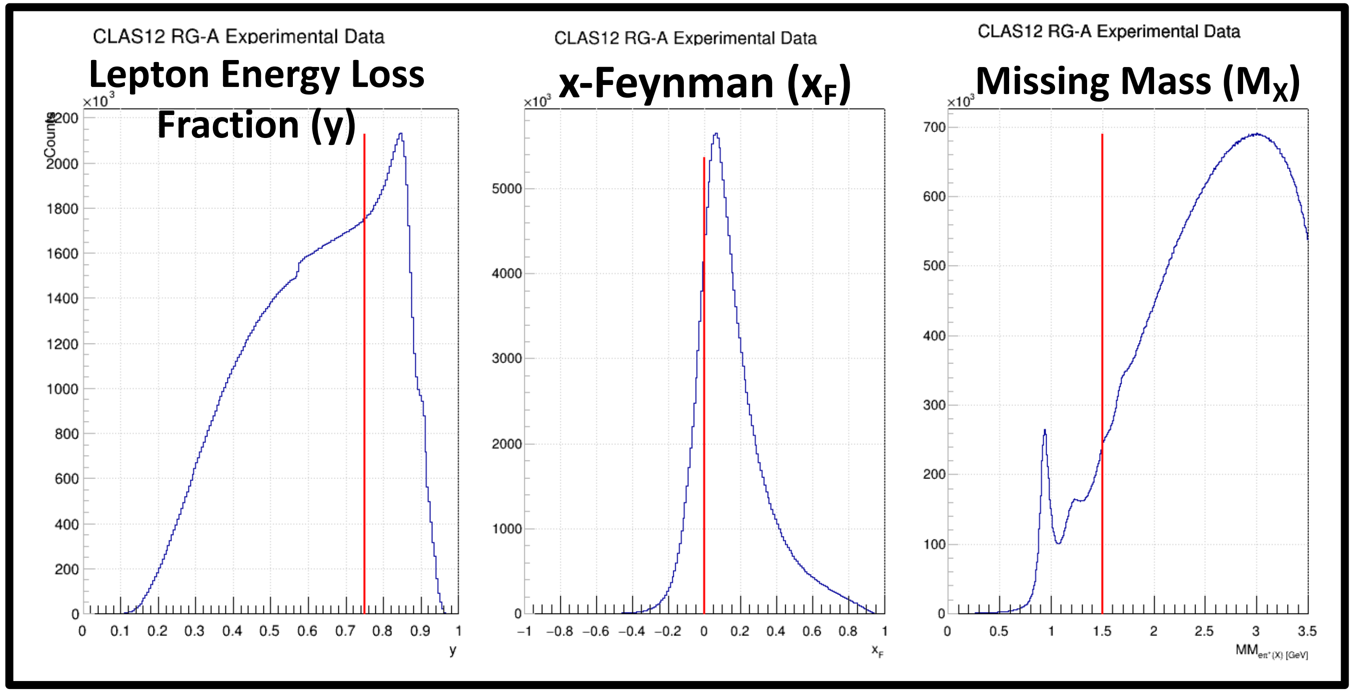
  - $x_F > 0$ (minimize contributions from target fragmentations)
  - Missing Mass Cut: $M_x > 1.5$ GeV (limits contributions from exclusive events)



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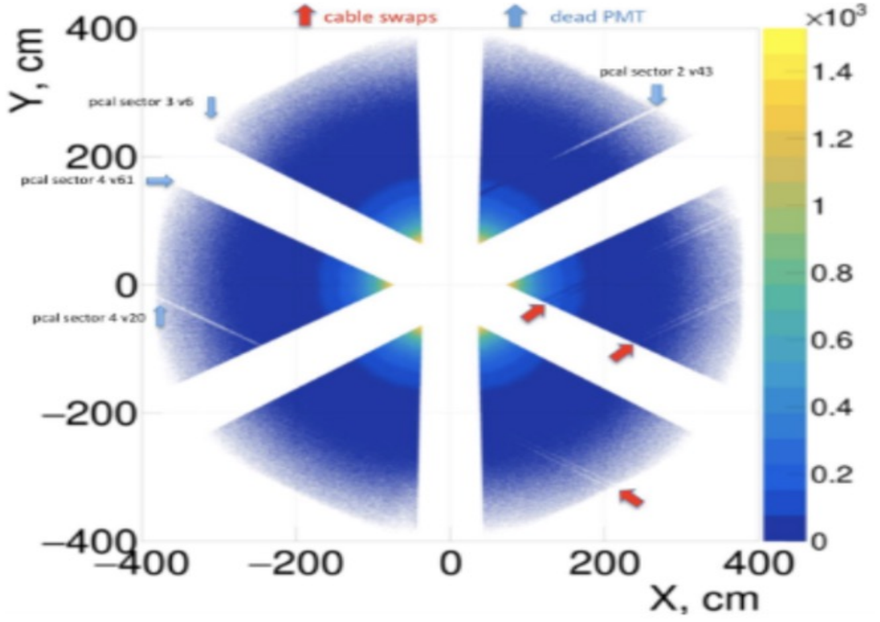
  - $x_F > 0$ (minimize contributions from target fragmentations)
  - Missing Mass Cut: $M_x > 1.5$ GeV (limits contributions from exclusive events)
  - Fiducial Cuts (e.g., accounts for bad channels present in data)

CLAS12 RG-A Experimental Data
PCAL



Analysis Procedure

Experimental extraction of cross-section

$$\frac{d^5\sigma}{dQ^2dydP_Tdzd\phi_h} = \frac{1}{\Gamma_\nu}\frac{1}{\Delta Q^2\Delta y\Delta P_T\Delta z\Delta\phi_h}\frac{N}{R\cdot BC\cdot\eta\cdot N_0}\frac{1}{(N_A\cdot\rho\cdot t/A_w)}$$

Bin Volume

Target Number Density

Where:

- R = Radiative Correction
- η = **Acceptance Correction** → **Requires Monte Carlo (MC) Simulation**
- N = Bin Yields
- N_0 = Life-time corrected incident electron flux
- BC = factor which evolves bin-averaged differential cross-section

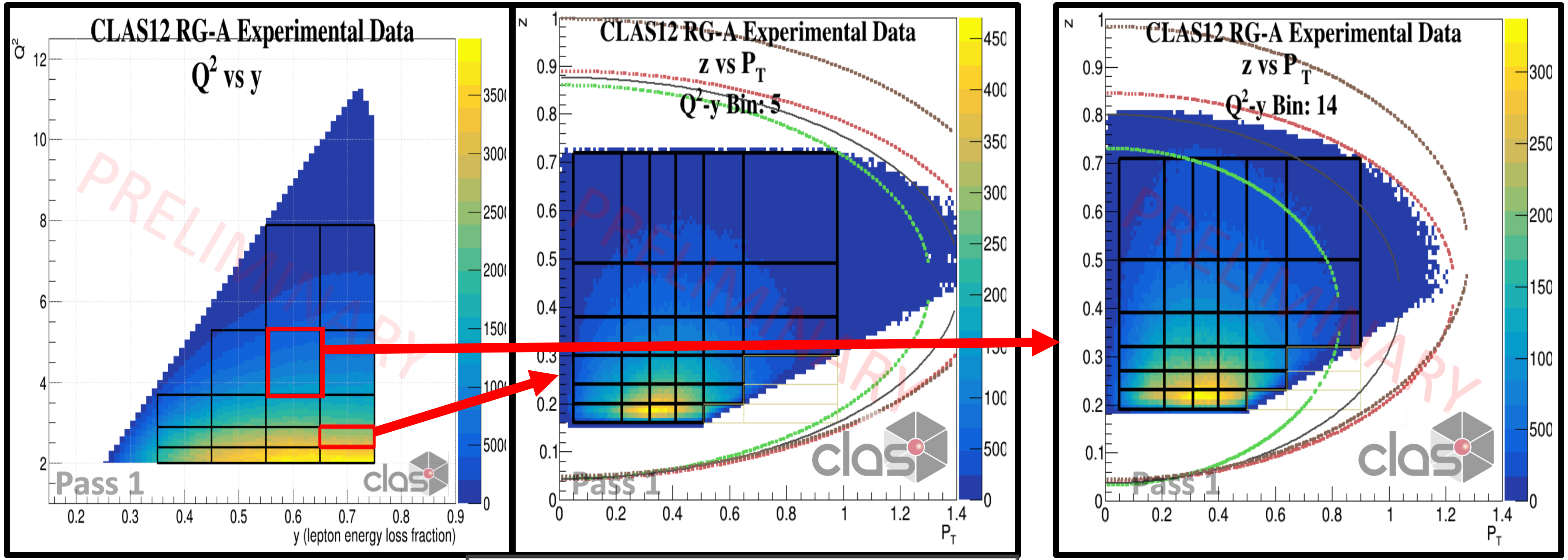
SIDIS MC are generated with LEPTO event generator

Multidimensional Analysis Procedures

Multidimensional Kinematic Binning (4 Dimensions)

17 Q^2-y Bins Total – 25-36 z-P_T Bins (per Q^2-y bin)

Examples of new binning scheme using Q^2, y, z, and P_T



Lines drawn here show regions affected by the Missing Mass Cut

Missing Mass Cut Lines:

Minimum MM Cut | Maximum MM Cut
Center MM Cut | Center (Neutron) MM Cut

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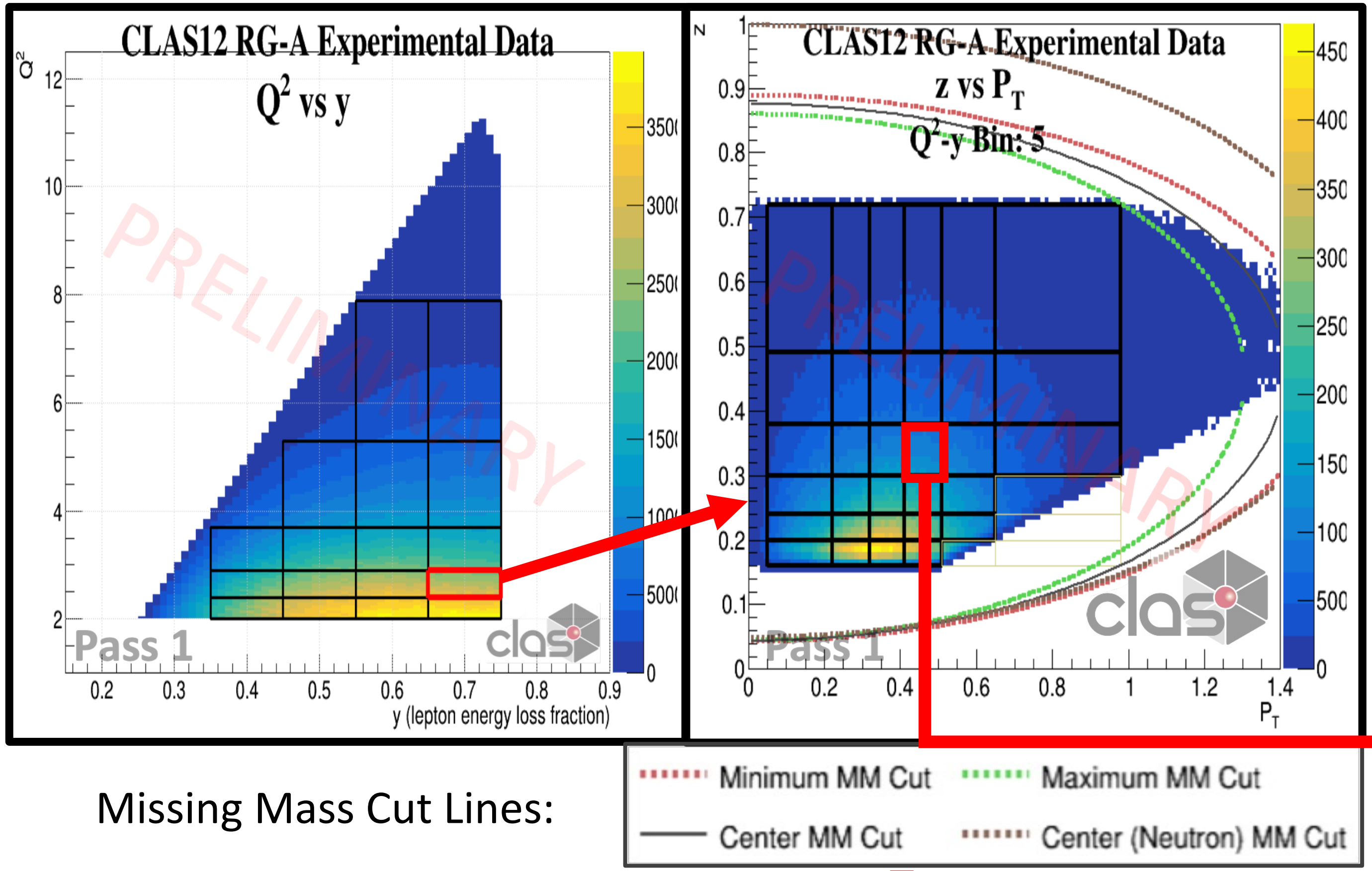
Multidimensional Analysis Procedures

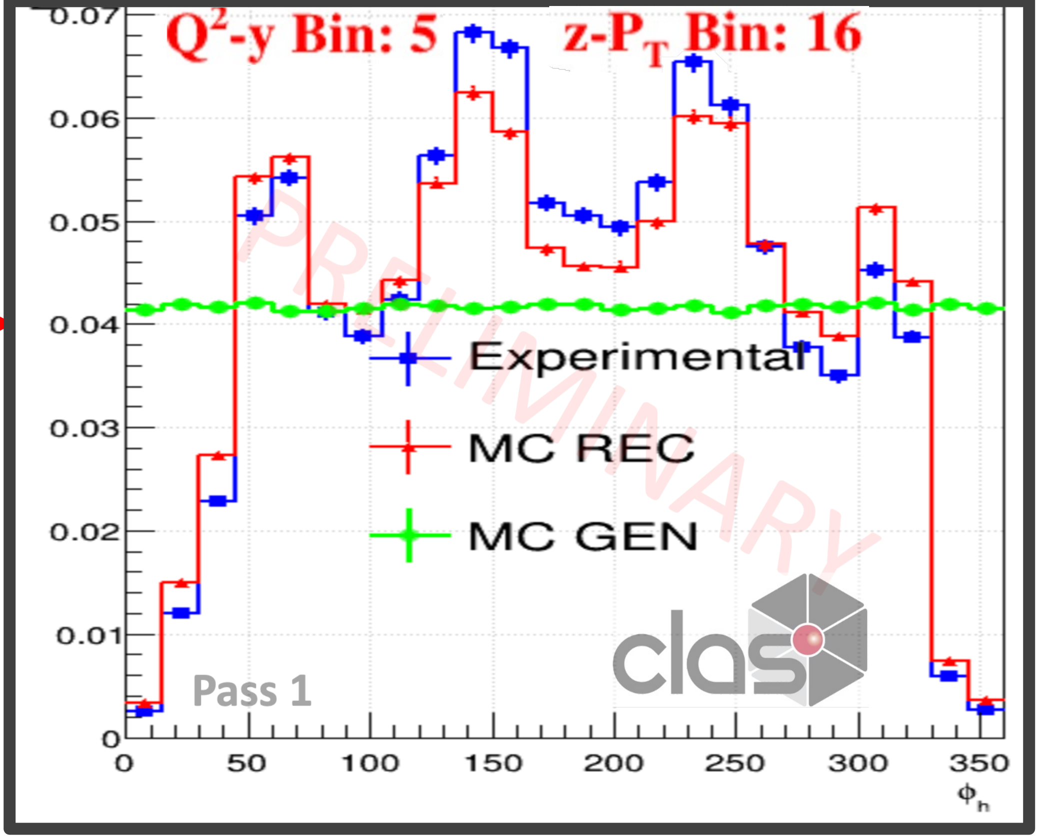
Multidimensional Kinematic Binning (5 Dimensions)

17 Q^2-y Bins Total – 25-36 z-P_T Bins (per Q^2-y bin)

ϕ_h distribution for the Q^2-y-z-P_T bin shown in red



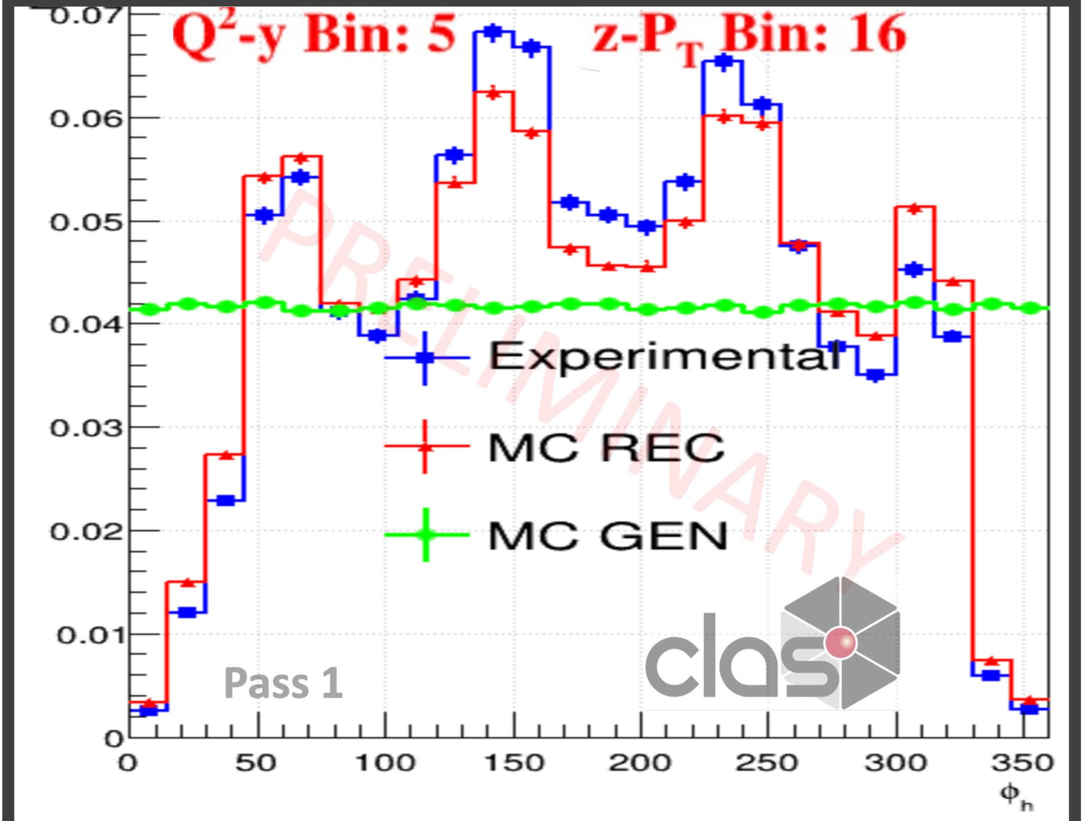
Missing Mass Cut Lines:



Multidimensional Analysis Procedures

Multidimensional Kinematic Binning (5 Dimensions)

Normalized Comparison of Data, Reconstructed, and Generated φ_h



Apply Multidimensional Acceptance Corrections and convert to a cross-section measurement

ϕ_h fit for every bin

$$A(1 + B\cos(\phi_h) + C\cos(2\phi_h))$$

Where the parameters A, B, C give the cross-section moments

$$A_{UU}^{\cos\varphi_h} = B \quad A_{UU}^{\cos 2\varphi_h} = C$$

Methods used for Acceptance Corrections:

- **Bin-by-bin Correction**
  - Simple method which just needs the 1D plots shown here
- **Bayesian Unfolding**
  - Bayesian Unfolding Method uses Acceptance Matrices to correct the data

Acceptance Corrections and Bin Migration Study

- **Acceptance Matrix:** $A_{(i,\,j)}$ describes both Acceptance (including geometric acceptance and detector efficiency) and Bin Migration

- $$A_{(i,\,j)} = \frac{\text{Number of Events Generated in bin } j \text{ but Reconstructed in bin } i}{\text{Total Number of Events Generated in the } j\text{th bin}}$$

- Acceptance Unfolding: $Y_i = A_{(i,\,j)} X_j + \beta_i \Leftrightarrow X_j = A^{-1}_{(i,\,j)}(Y_i - \beta_i)$

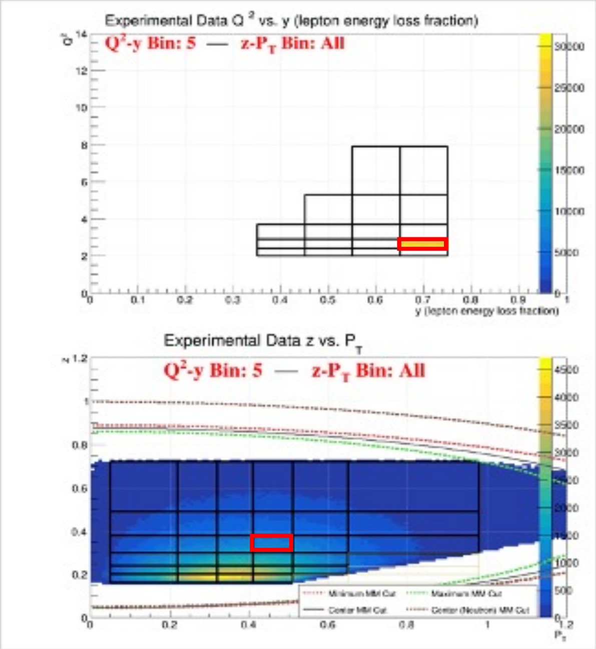
where:

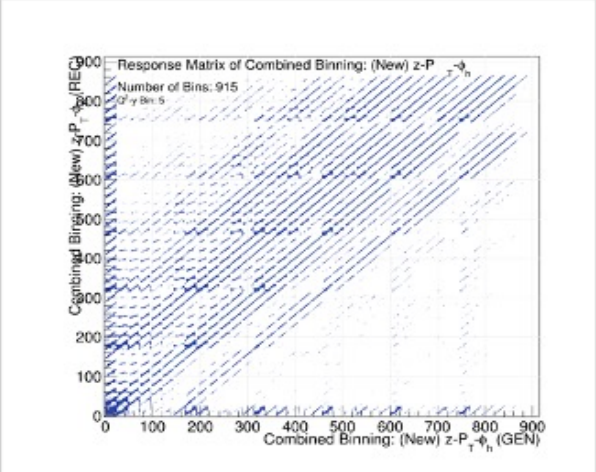
- Y_i = Number of events experimentally measured in the *i*-th bin
- X_j = Number of acceptance-corrected events in the *j*-th bin
- β_i = Number of events from outside the signal region measured in the *i*-th bin

Example of (3D) Unfolding Procedure

Using the Flattened z-P_T-ϕ_h Multidimensional Bins

Q^2-y Bin 5





Unfolded with Bayesian Method

Pass 1

PRELIMINARY

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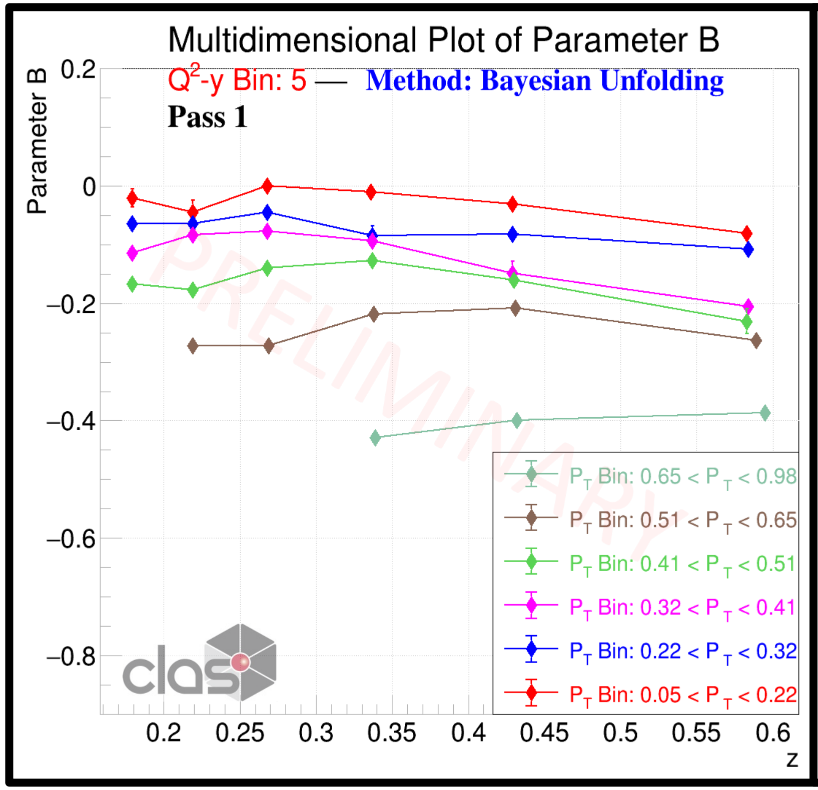
Cosine Moments as Functions of z – Pass 1

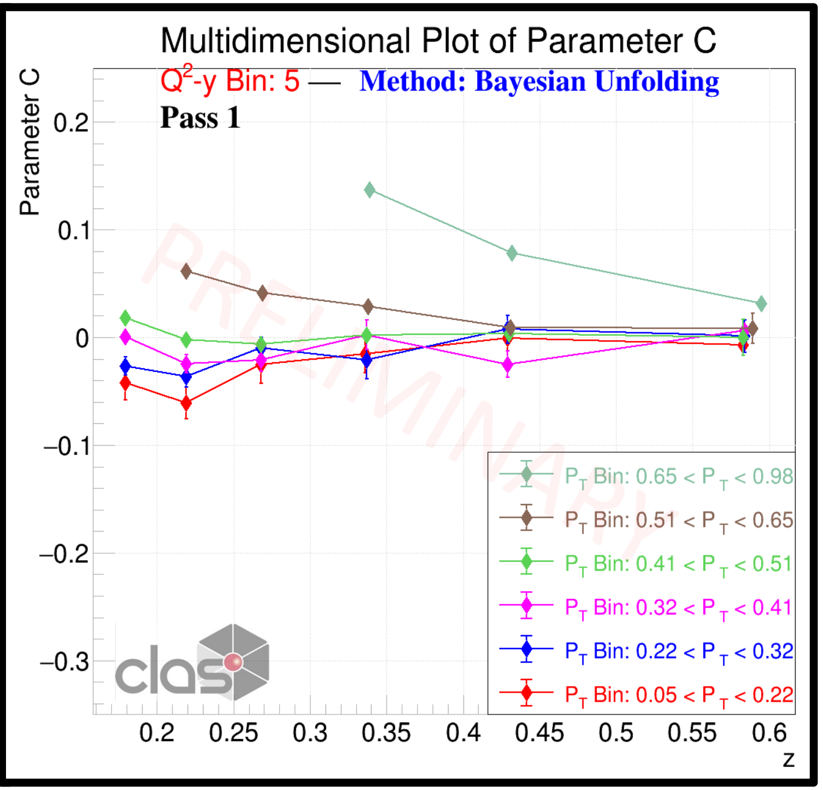
$B = A_{UU}^{\cos\varphi_h}$ $C = A_{UU}^{\cos 2\varphi_h}$

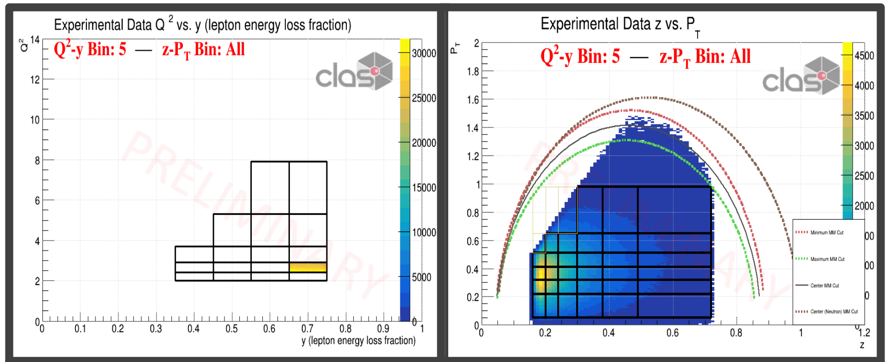
ϕ_h Plots were fitted with:
$A(1 + B\cos(\phi_h) + C\cos(2\phi_h))$

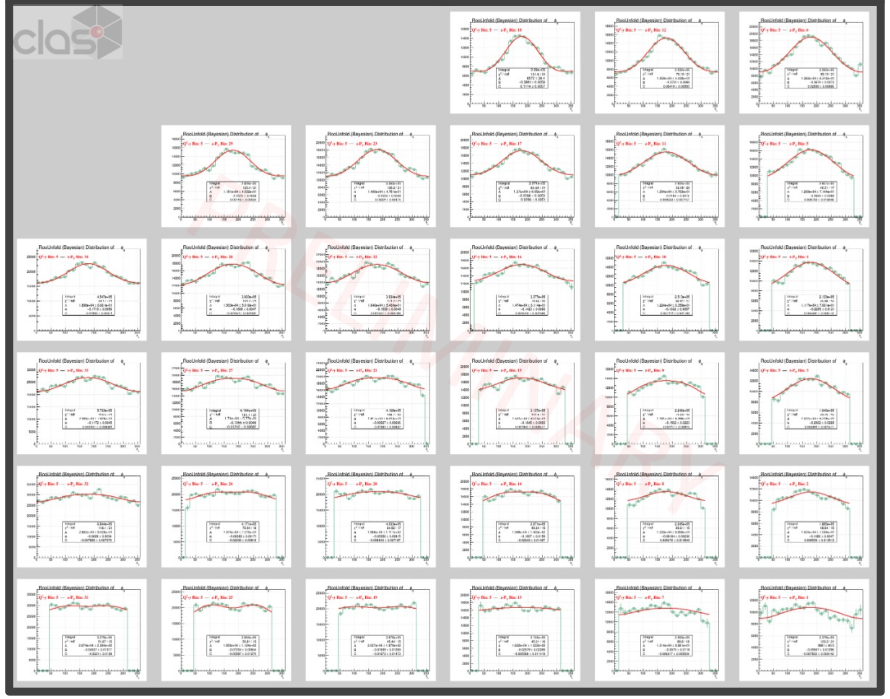
Unfolded with Bayesian Method

Q^2-y Bin 5









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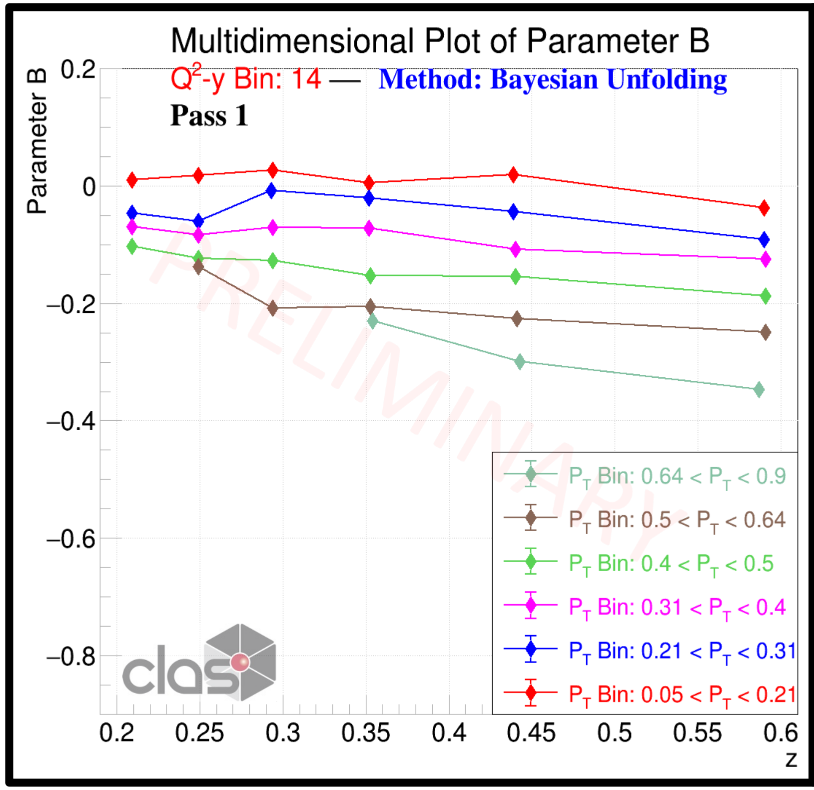
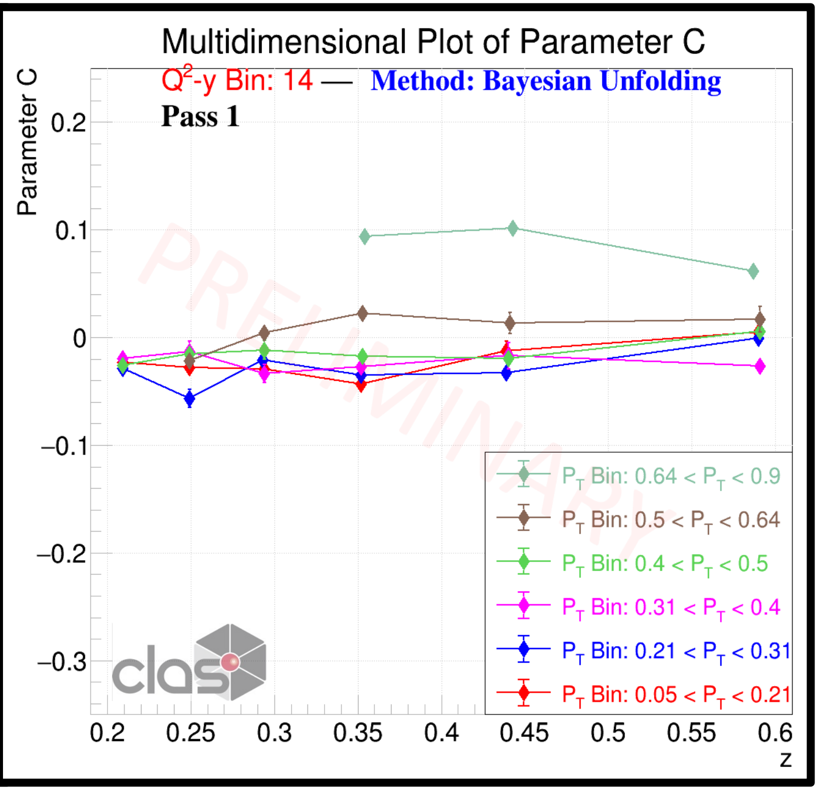
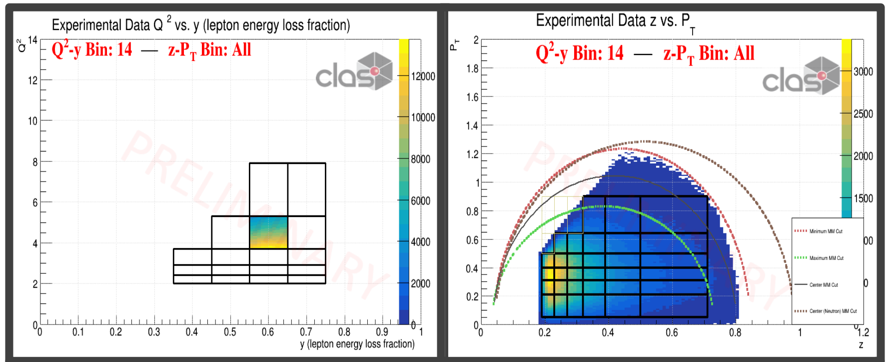
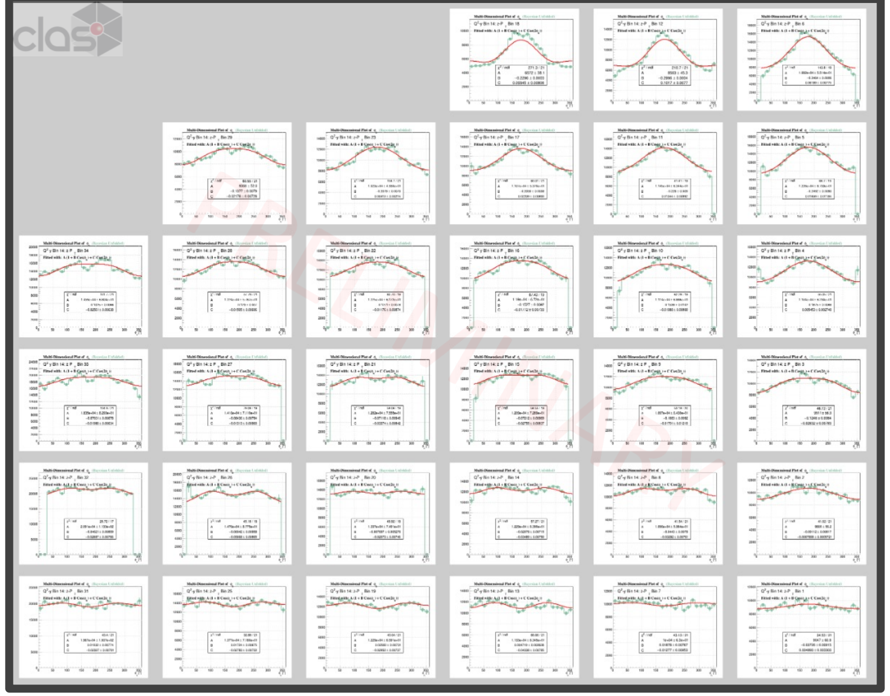
Unfolded with Bayesian Method

Q^2-y Bin 14









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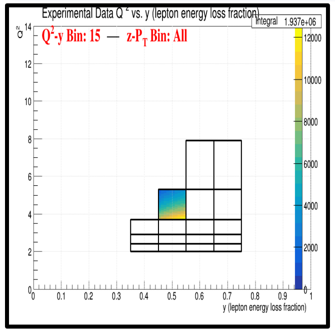
Pass 2 Conditions

- Monte Carlo statistics are low (using test sample)
- Have not applied Momentum/Energy Loss Corrections in Pass 2
  - Momentum Corrections have been developed for Pass 1 Data but not for Pass 2 yet
  - Momentum Smearing Corrections are also needed for the Pass 2 Monte Carlo
- Need to check/develop new fiducial cuts optimized for Pass 2
  - Sector dependences in the ϕ_h distributions may be improved by altering the cuts along the detector's edge

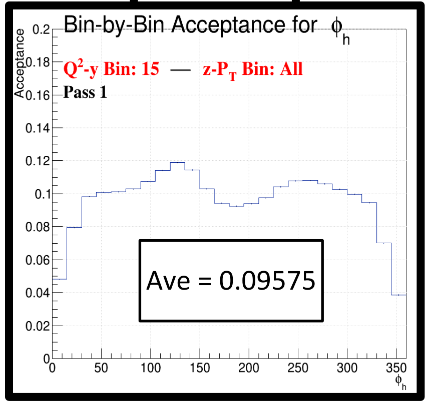
Pass 2 Comparisons - Acceptances



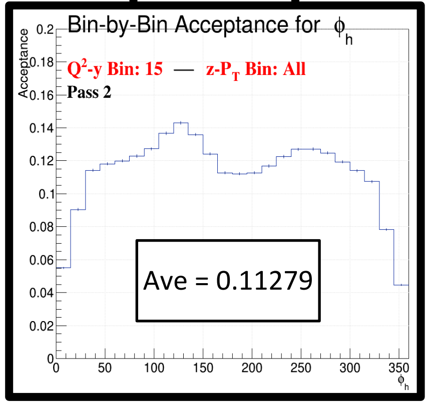
High Q^2
Low y

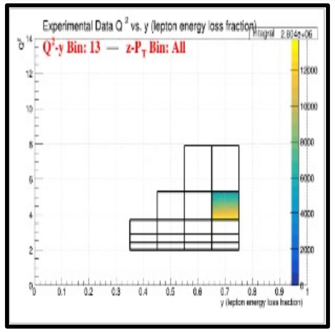
Δ Ave = +0.01704

Pass 1



Pass 2

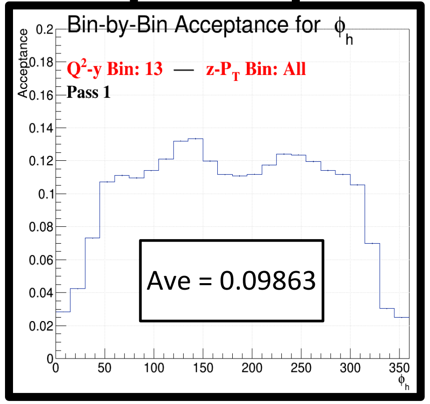




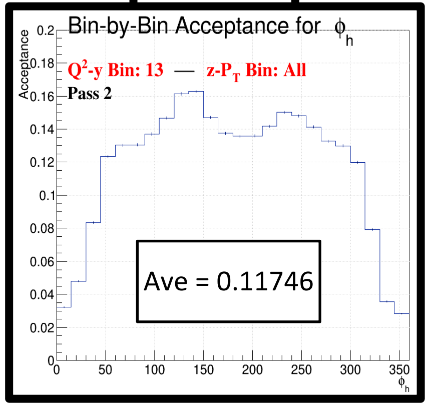
High Q^2
High y

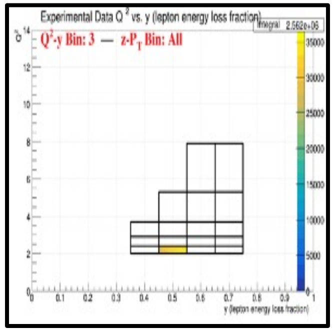
Δ Ave = +0.01883

Pass 1



Pass 2

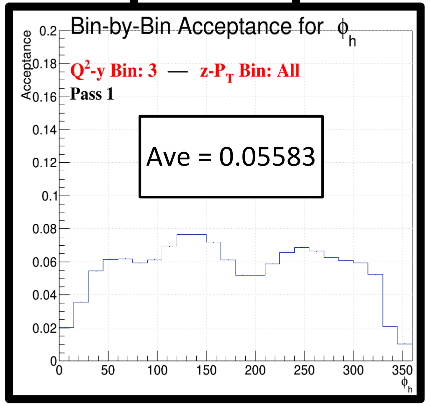




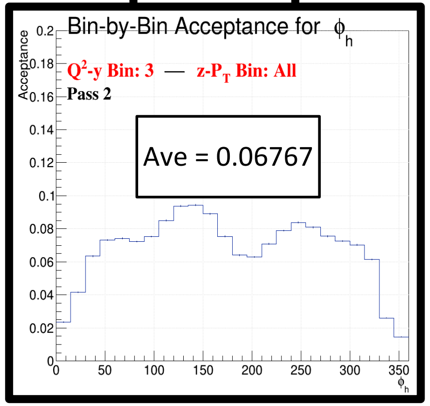
Low Q^2
Low y

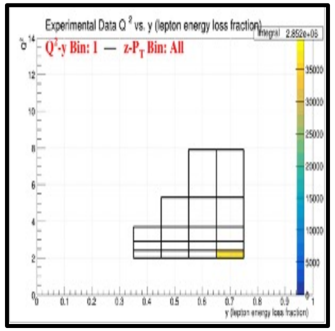
Δ Ave = +0.01184

Pass 1



Pass 2

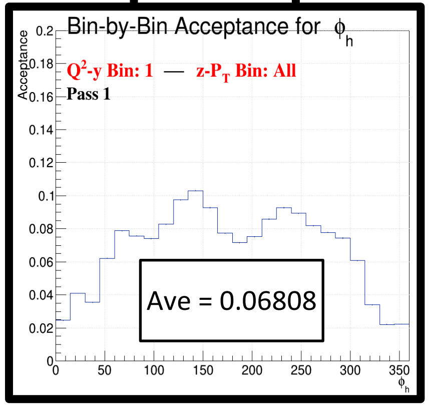




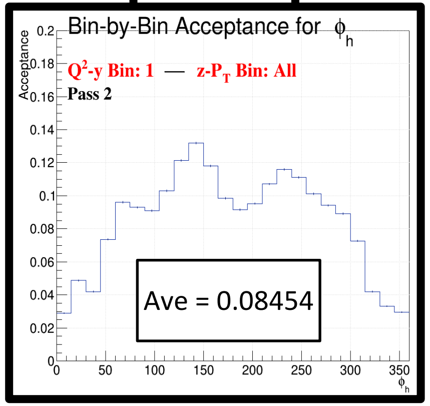
Low Q^2
High y

Δ Ave = +0.01646

Pass 1



Pass 2



Cos(ϕ$_h$) Moment as Functions of z - Pass 2 Comparison

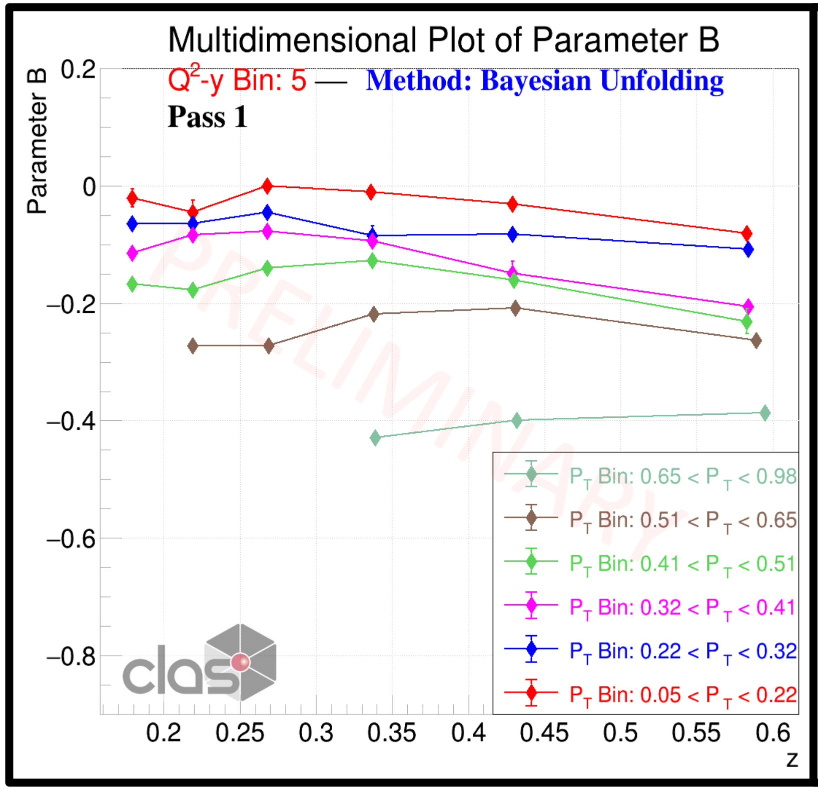
$$\mathbf{B} = A_{UU}^{\cos\varphi_h}$$

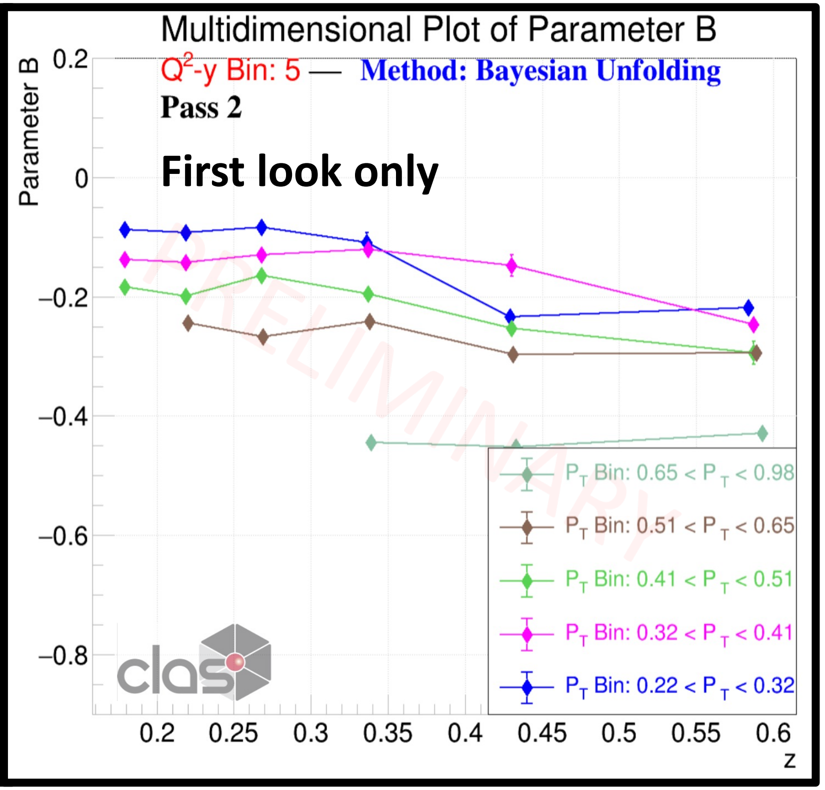
ϕ$_h$ Plots were fitted with:

$$A(1 + \mathbf{B}\cos(\phi_h) + C\cos(2\phi_h))$$

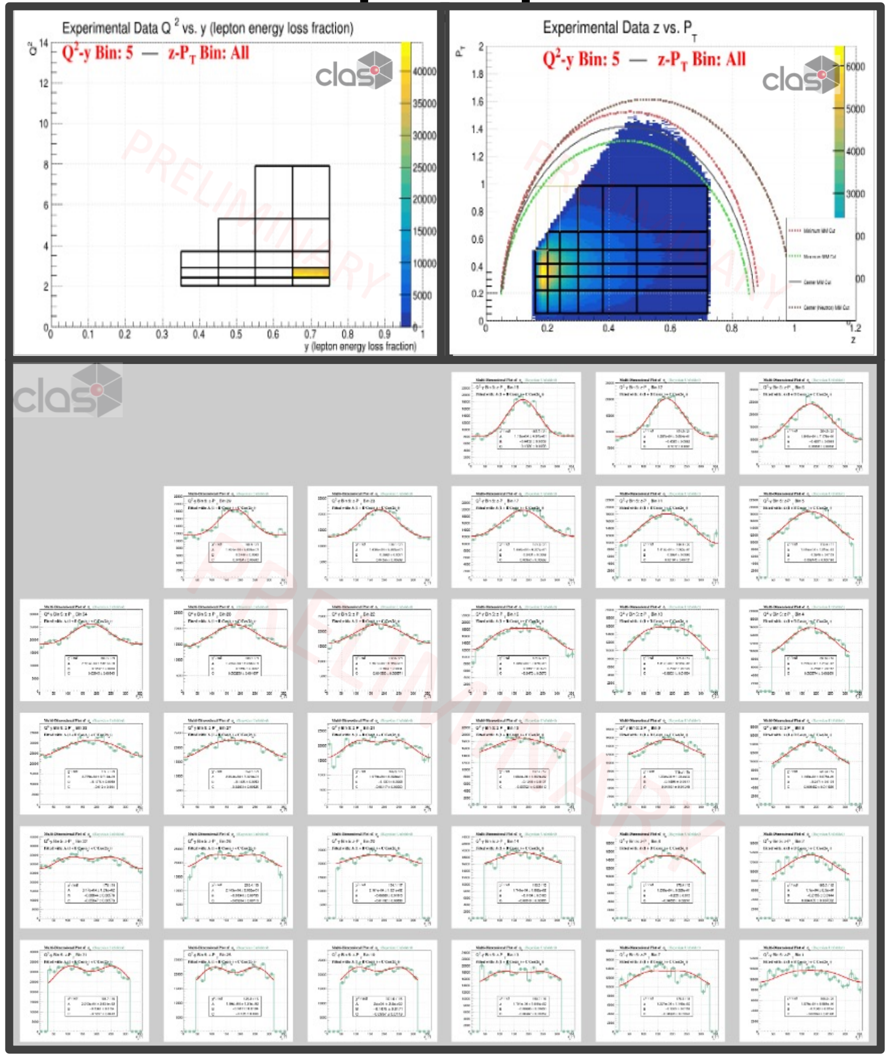
Unfolded with Bayesian Method

Q^2-y Bin 5





Pass 2



Cos(2ϕ_h) Moment as Functions of z - Pass 2 Comparison

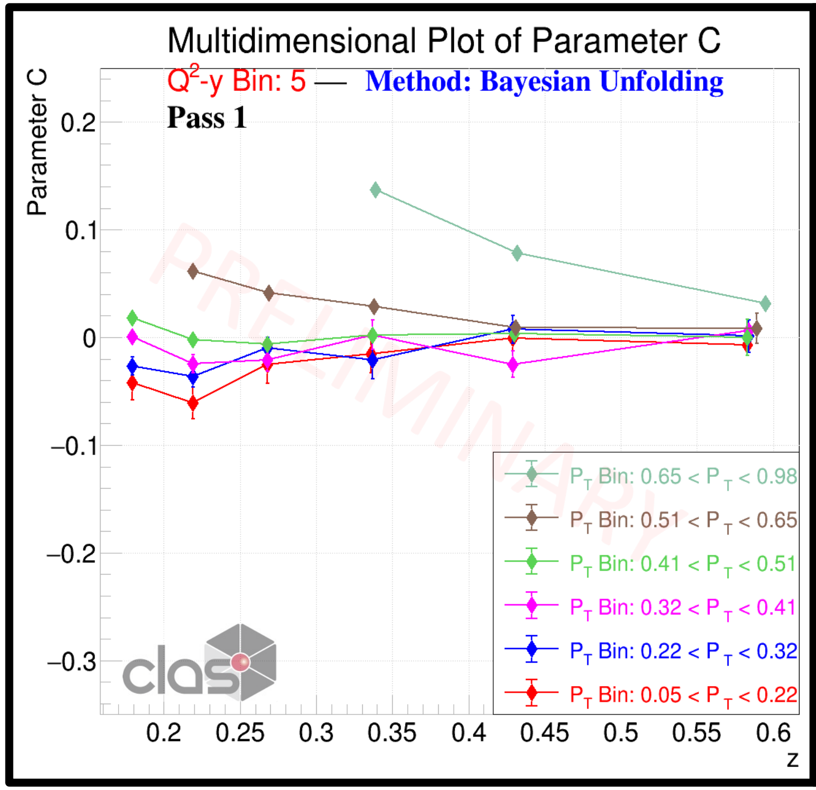
$$C = A_{UU}^{\cos 2\varphi_h}$$

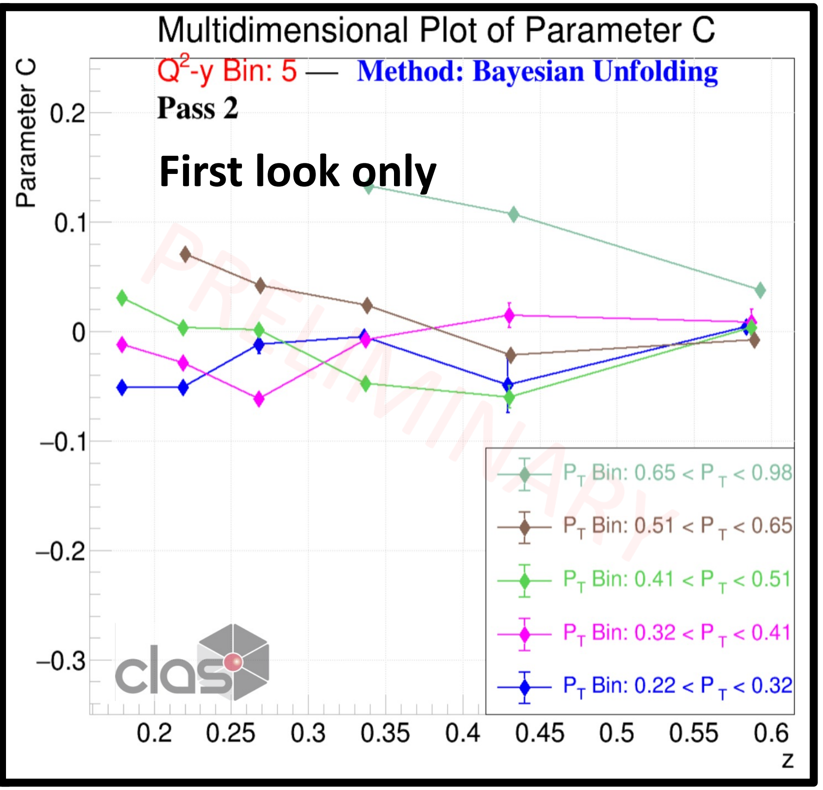
ϕ_h Plots were fitted with:

$$A(1 + B\cos(\phi_h) + \mathbf{C}\,\boldsymbol{cos(2\phi_h)})$$

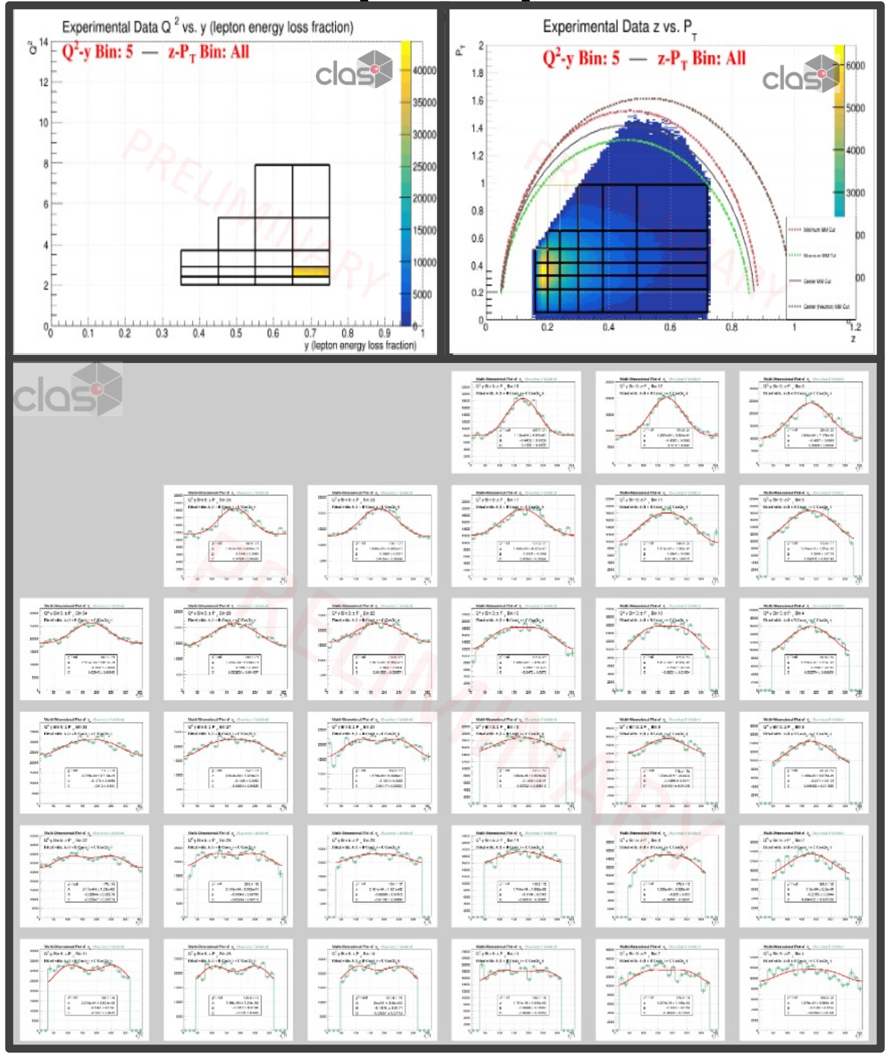
Unfolded with Bayesian Method

Q^2-y Bin 5





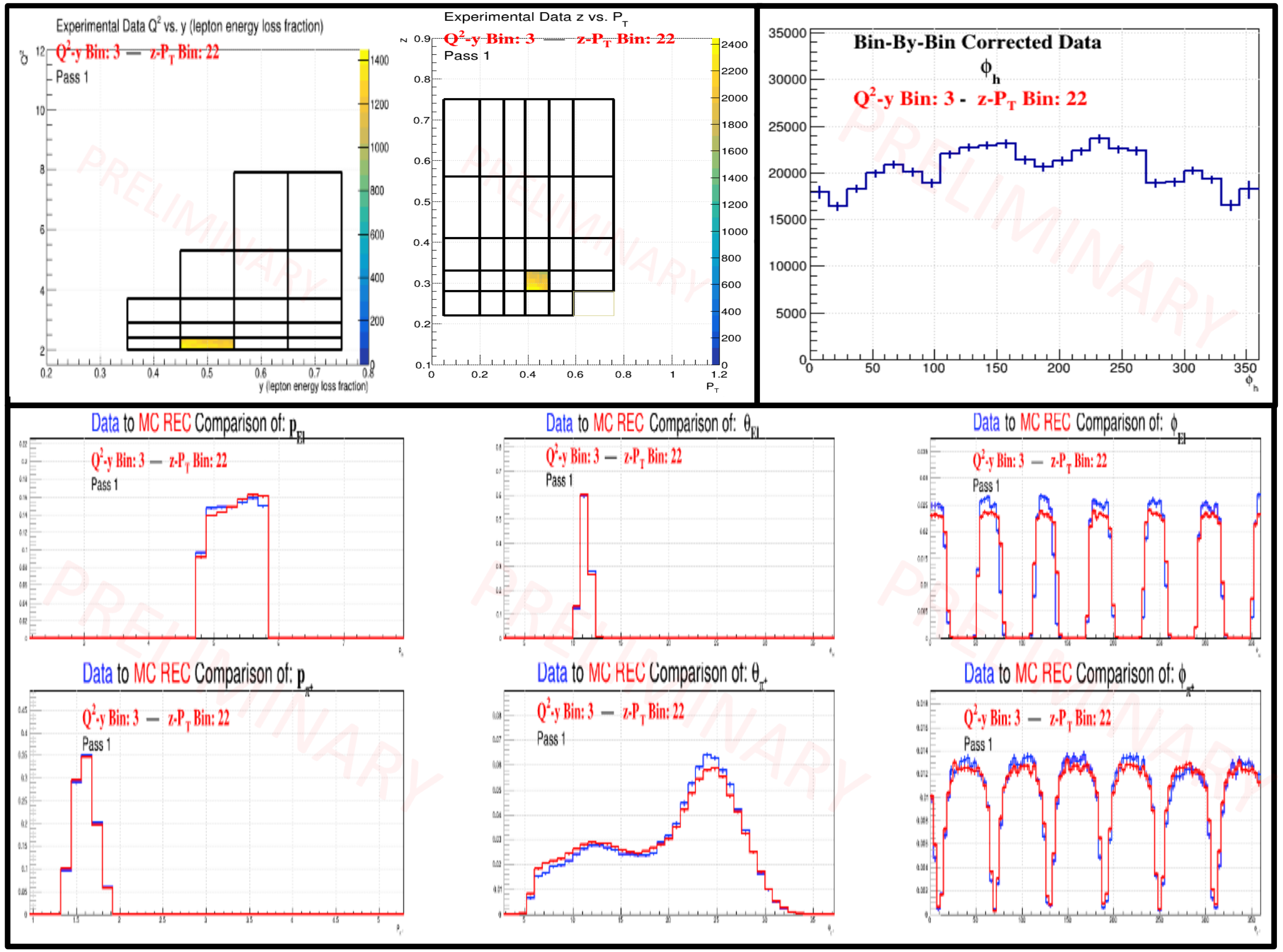
Pass 2



Outlook

- Working on Multidimensional Acceptance Corrections for the simultaneous unfolding of Q^2, y, z, P_T, and ϕ_h variables
  - Includes additional efforts towards more realistic MC simulations, both on the detector response description and physics process
  - Investigating Sector Description/Sector Dependence related to Acceptance Corrections
- Working on fully including Pass 2 Data
- Still need to include Radiative and BC Corrections in this analysis
- Ongoing Investigations of Vector Meson Contributions
- Cross-checking Analysis with T. Hayward

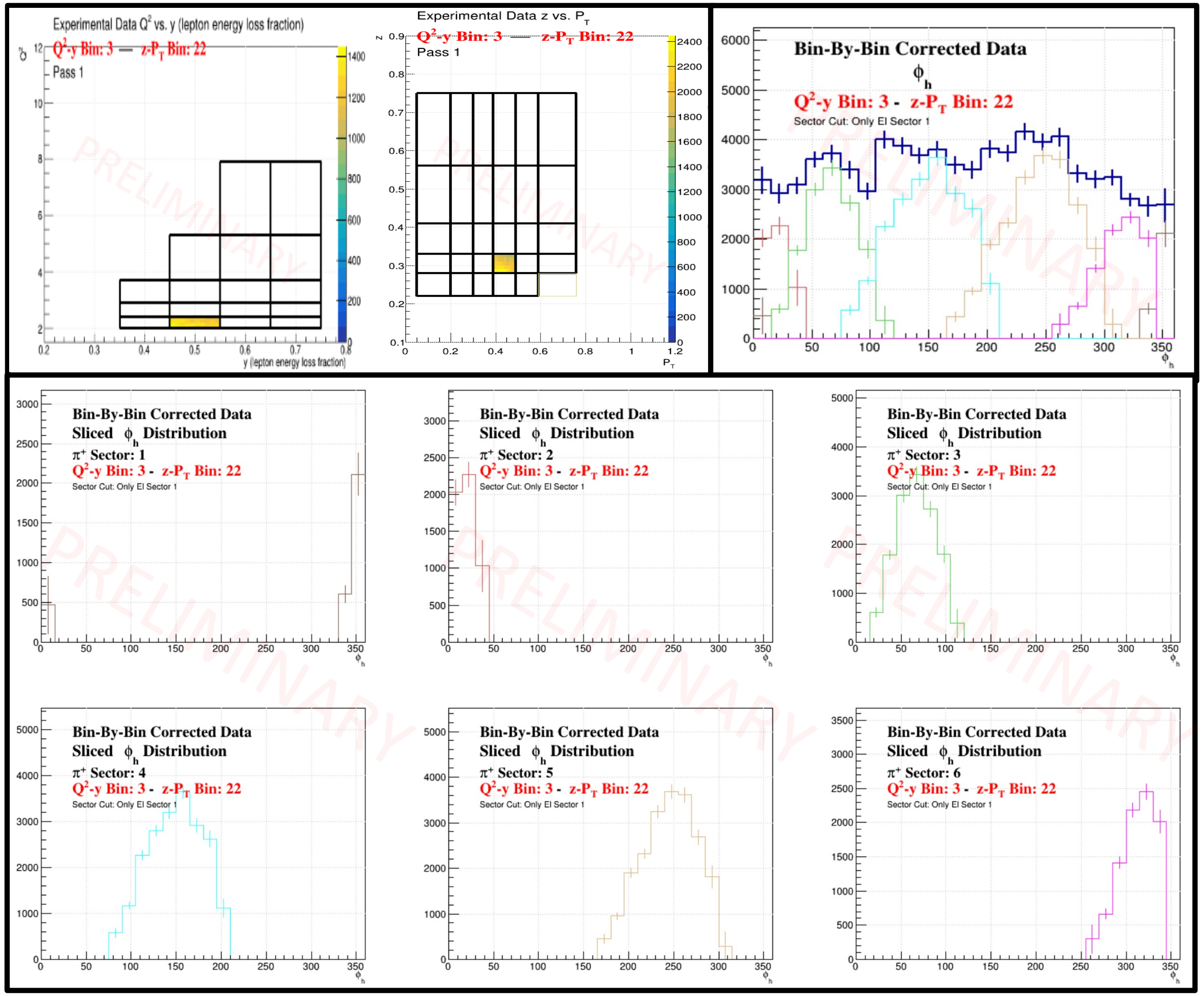
Sector Correlations with ϕ_h Distributions – Pass 1



<u>Issue</u>: Some bins seem to have additional modulations not explained by the Cos(ϕ) and Cos(2ϕ) moments

- The 6 peak structure could be related to the forward detector sectors
- Plots below show the lab angles and momentum of both particles within the given kinematic bin of Q^2, y, z, and P_T

Sector Correlations with ϕ_h Distributions – Pass 1



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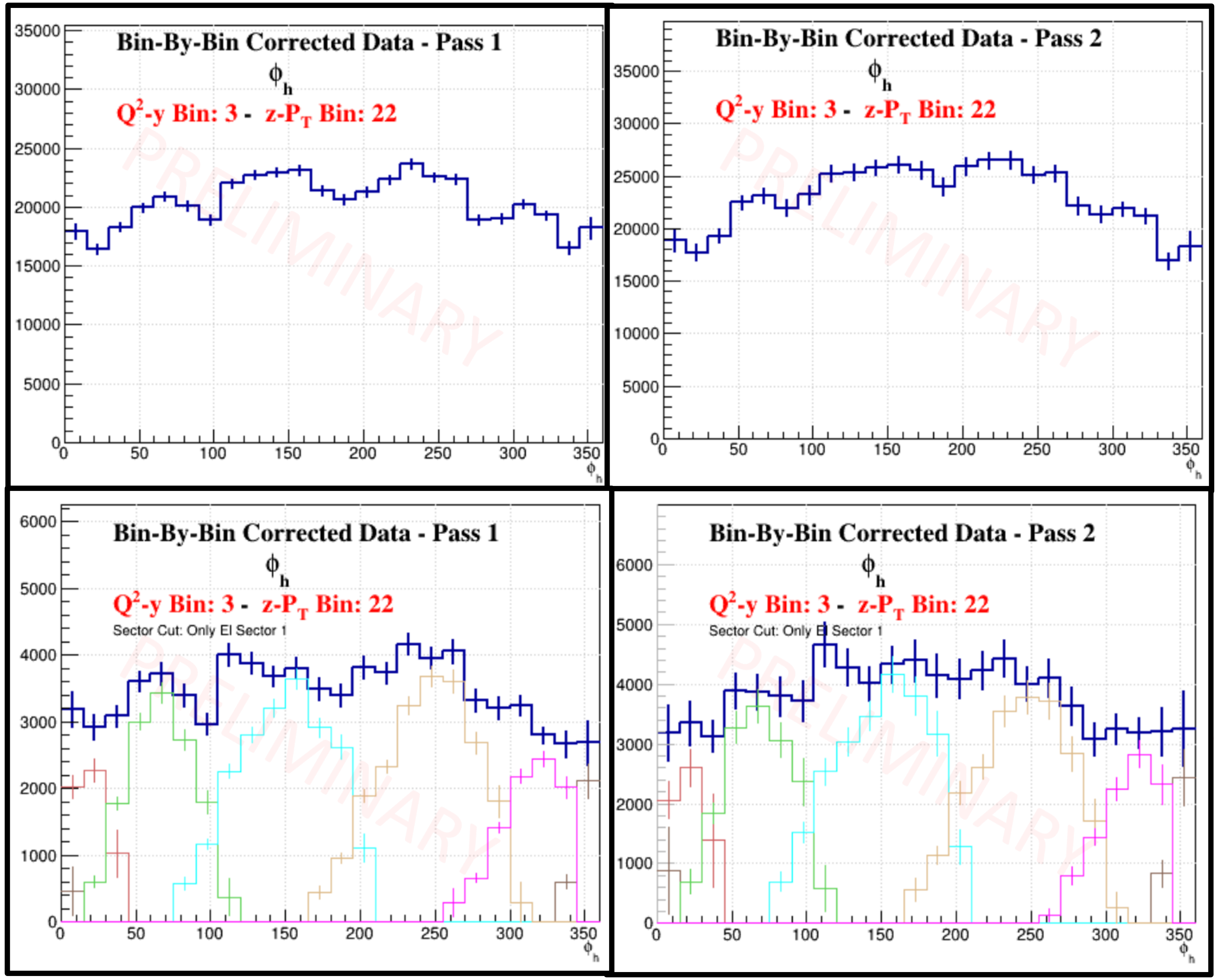
- The 6 peak structure could be related to the forward detector sectors
- Plots show the ϕ_h distributions separated based on which sector the π+ pion is detected
- Additional Requirement: Electron in Sector 1
- This suggests that the effect is related to mismatching in sector acceptance between Data and Monte Carlo

Sector Correlations with ϕ_h Distributions – Pass 2 Comparison



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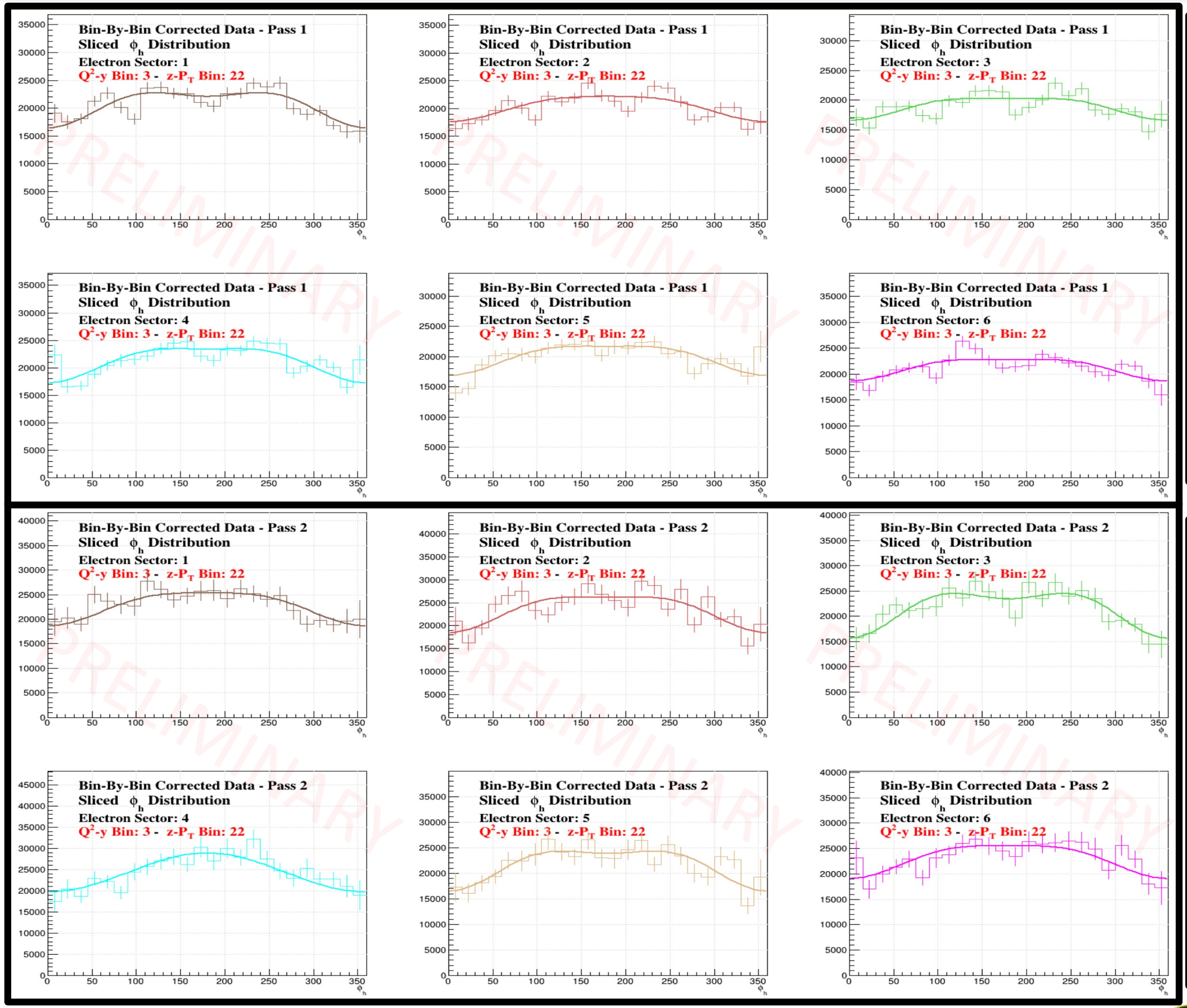
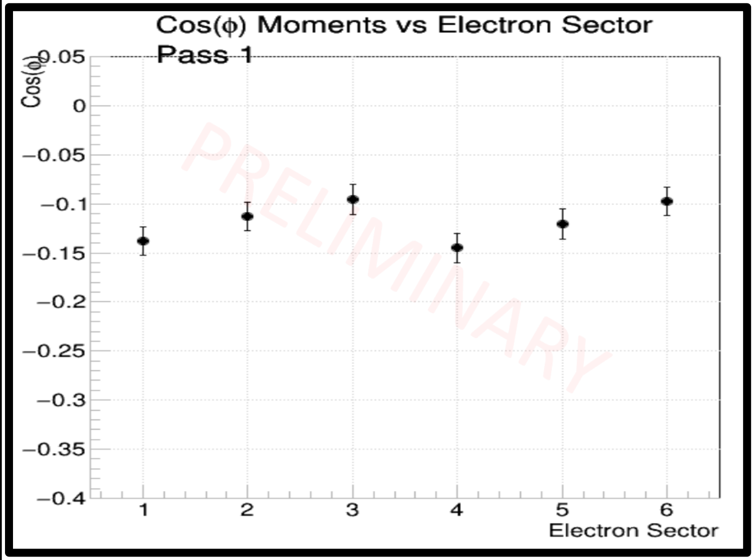
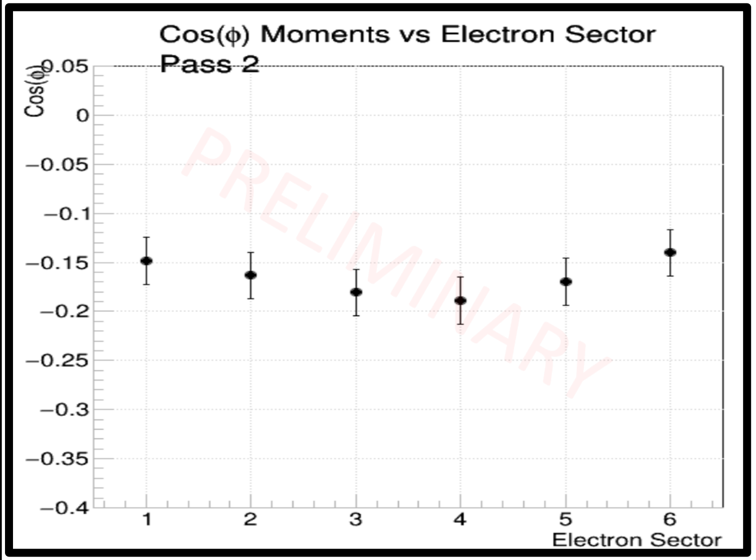
- Additional Requirement: Electron in Sector 1
- This suggests that the effect is related to mismatching in sector acceptance between Data and Monte Carlo
- **Also present in Pass 2**

Sector Correlations with Cos(ϕ) Measurements – Pass 1 and 2







Sectors can cause different modulations within the kinematic bins

These plots show those differences in Pass 1 (top row) and Pass 2 (bottom row)

Electron is restricted to being detected in a single sector

Plotting Cos(ϕ) Moments vs Electron Sector on the right

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Thank you

Questions?

Acknowledgments and Thanks

- Contributions made by other members of the CLAS Collaboration and researchers at Argonne National Lab
- This work is supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under contract number DE-AC02-06CH11357

Backup Slides

Cosine Moments as Functions of z - with Pass 2

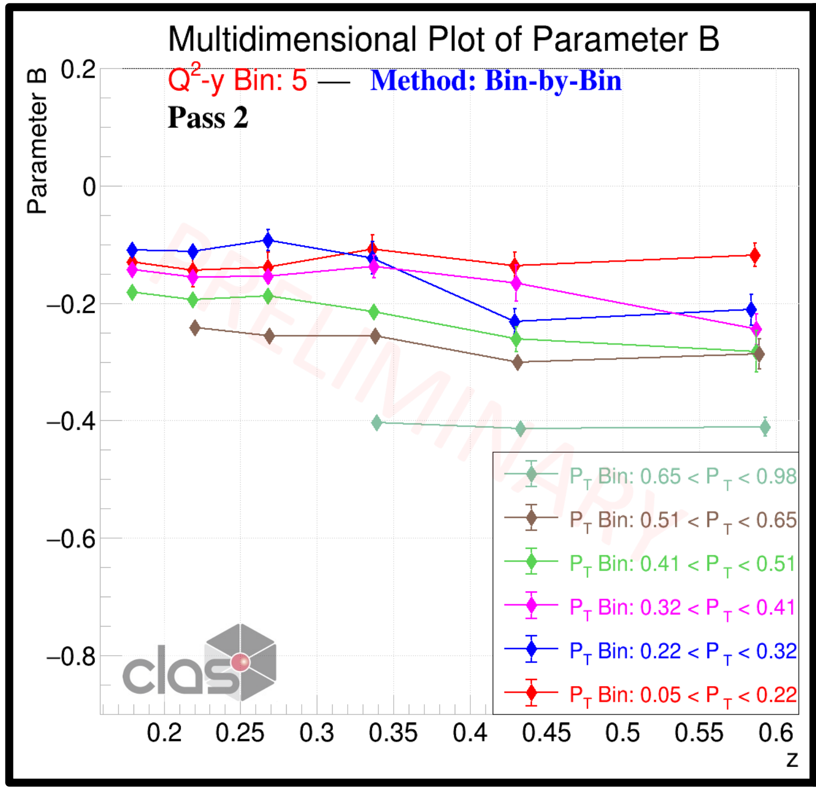
$$B = A_{UU}^{\cos\varphi_h} \qquad C = A_{UU}^{\cos 2\varphi_h}$$

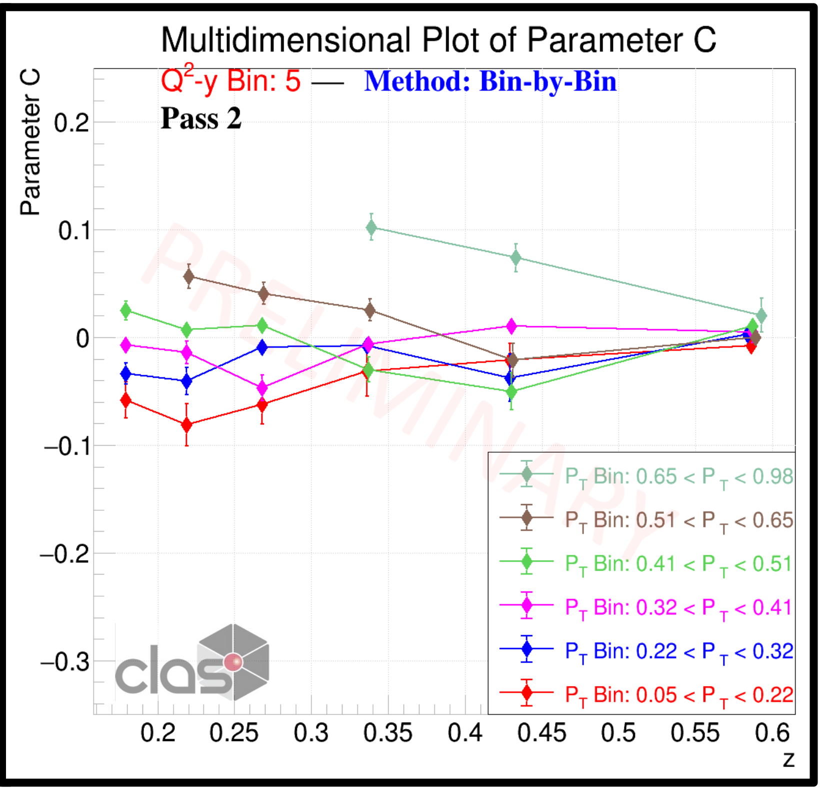
ϕ_h Plots were fitted with:

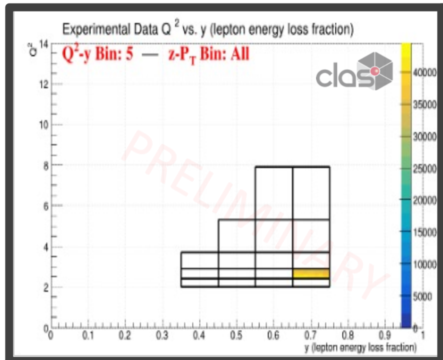
$$A(1 + B\cos(\phi_h) + C\cos(2\phi_h))$$

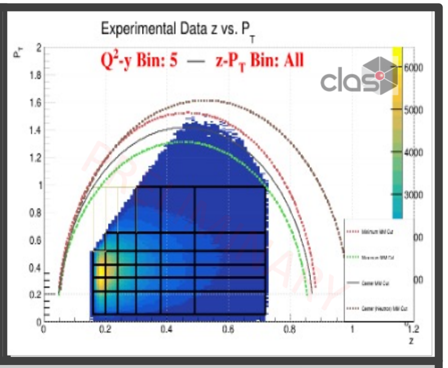
Corrected with Bin-by-bin Method

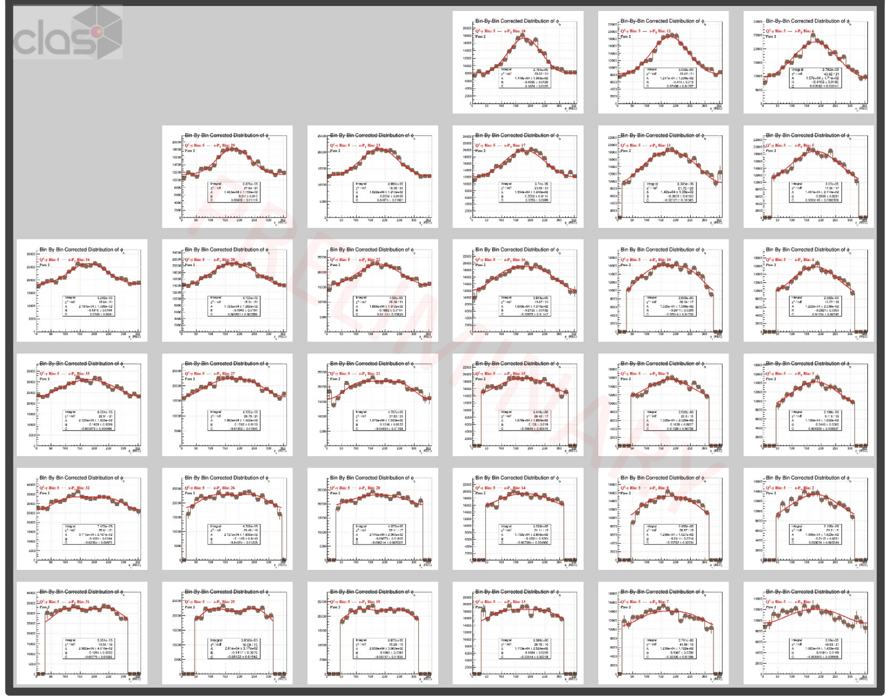
Q^2-y Bin 5











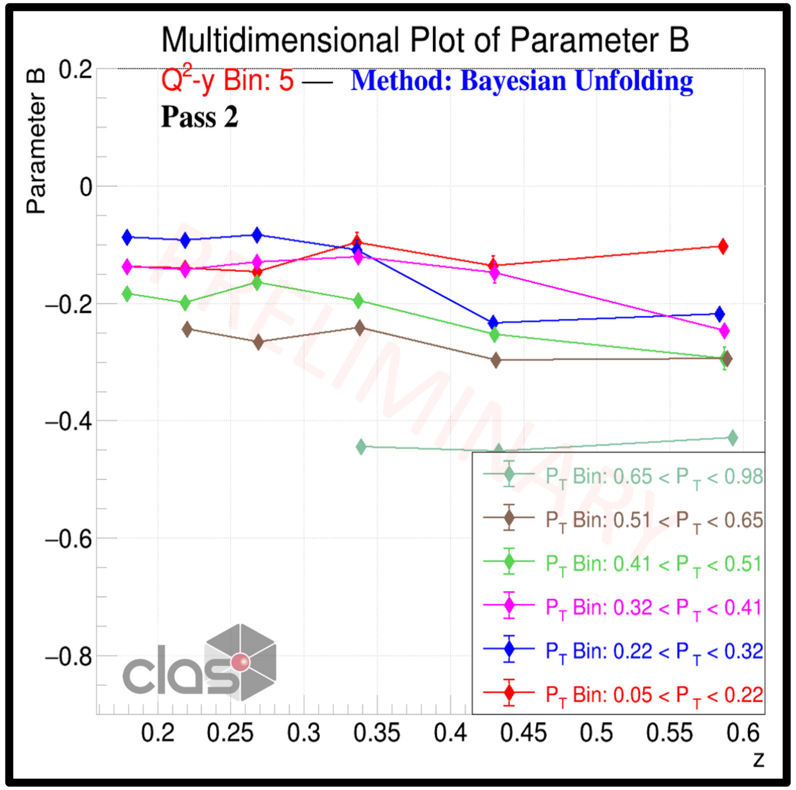
Cosine Moments as Functions of z - with Pass 2

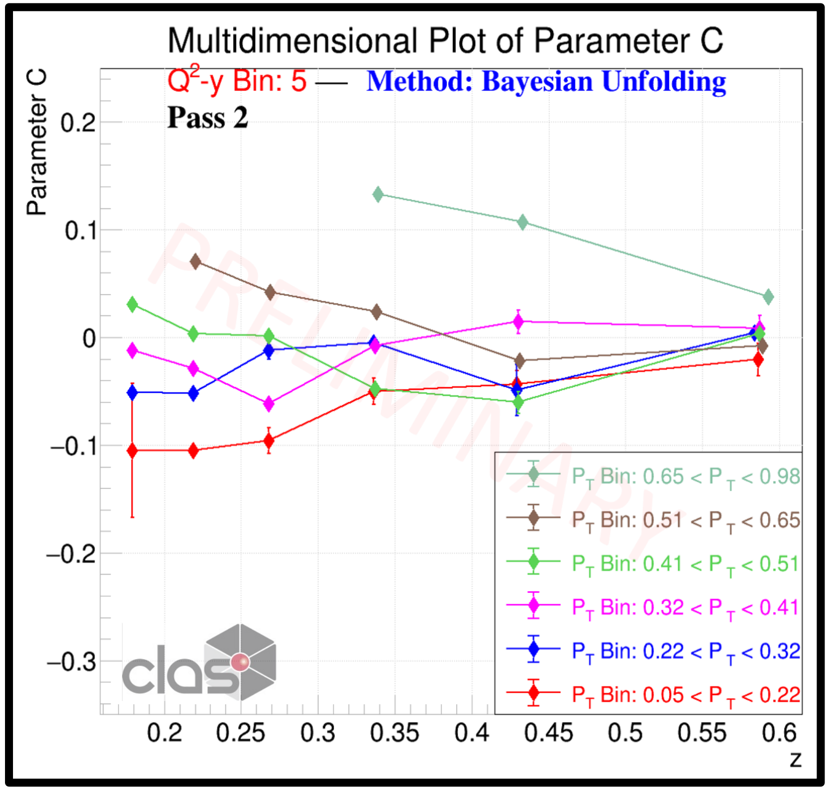
$B = A_{UU}^{\cos\varphi_h}$ $C = A_{UU}^{\cos 2\varphi_h}$

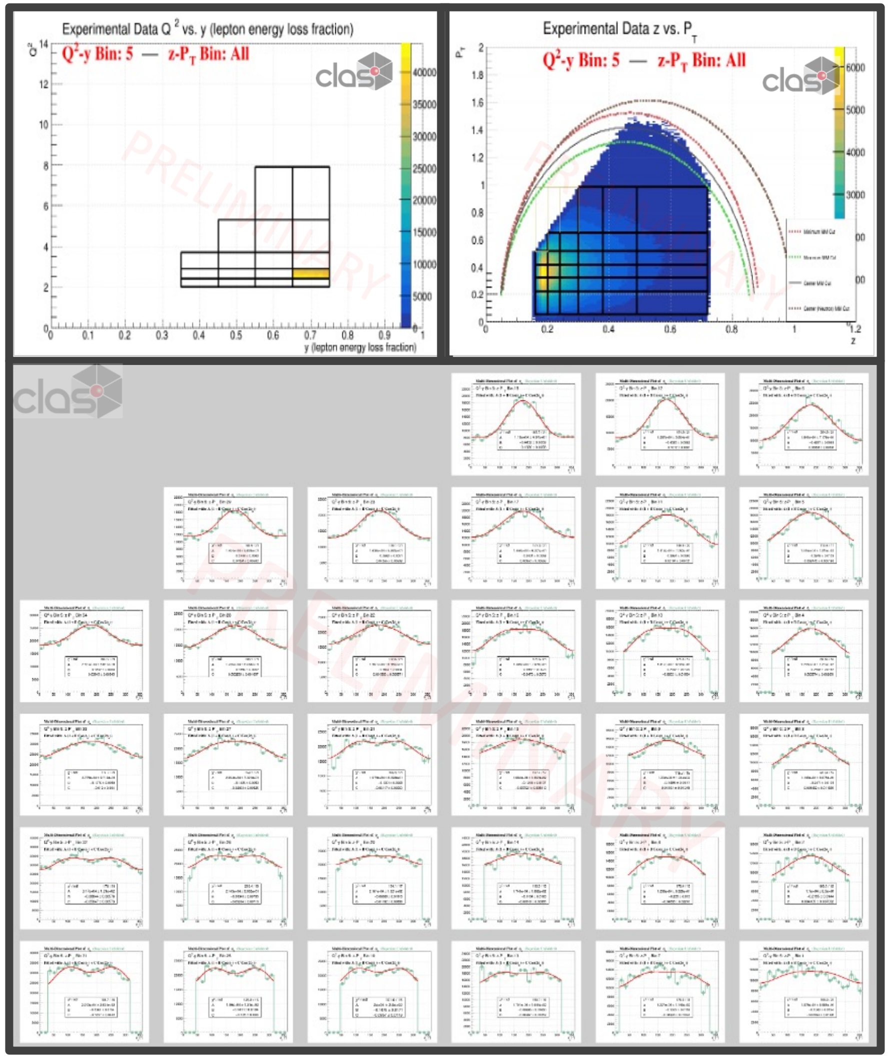
ϕ_h Plots were fitted with:
$A(1 + B\cos(\phi_h) + C\cos(2\phi_h))$

Unfolded with Bayesian Method

Q^2-y Bin 5







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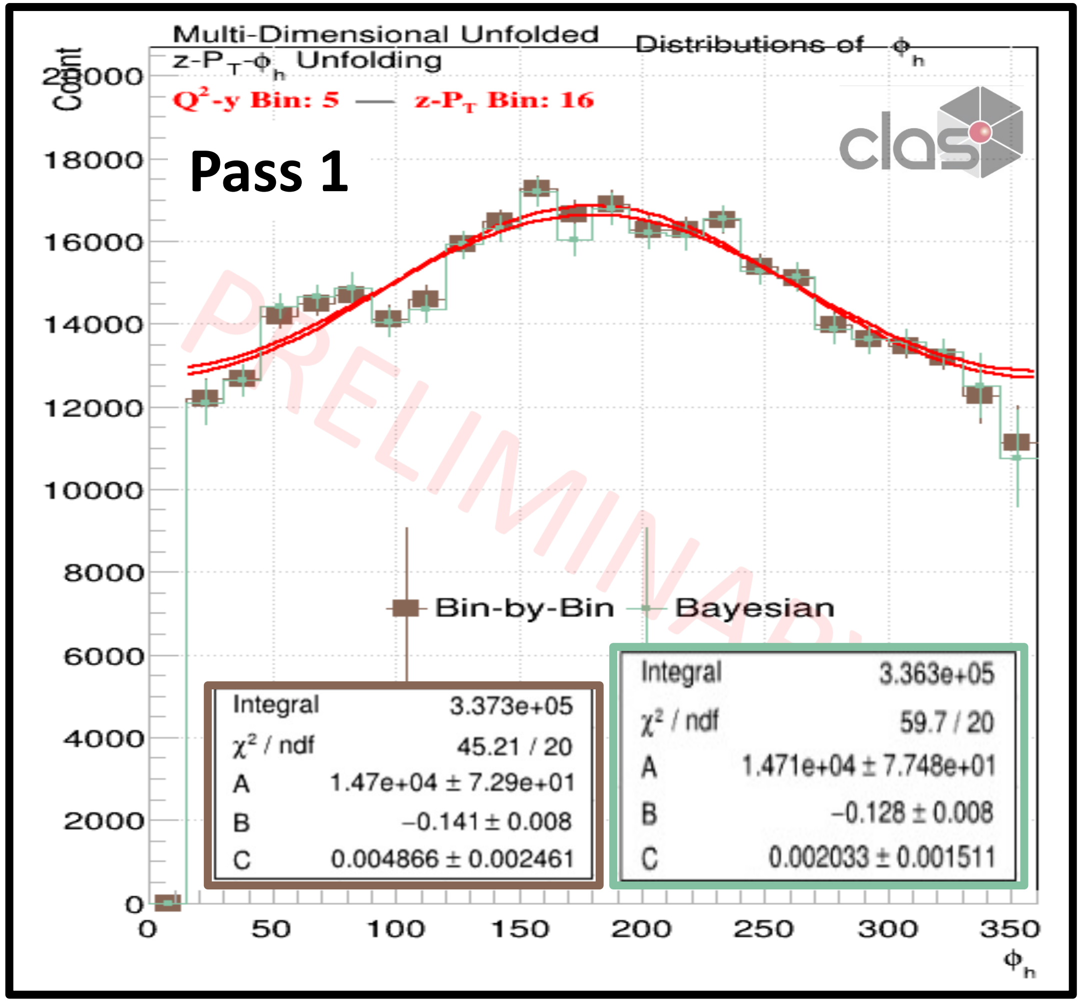
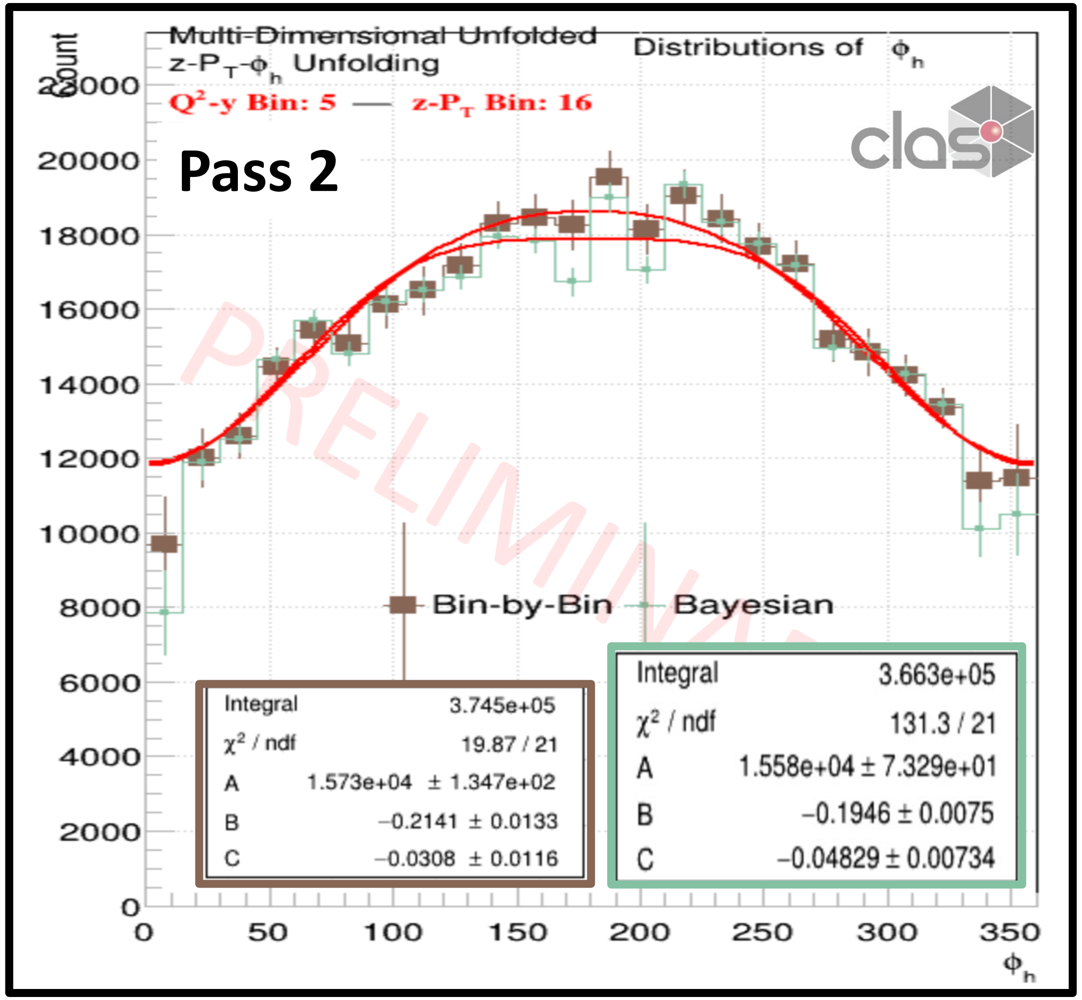
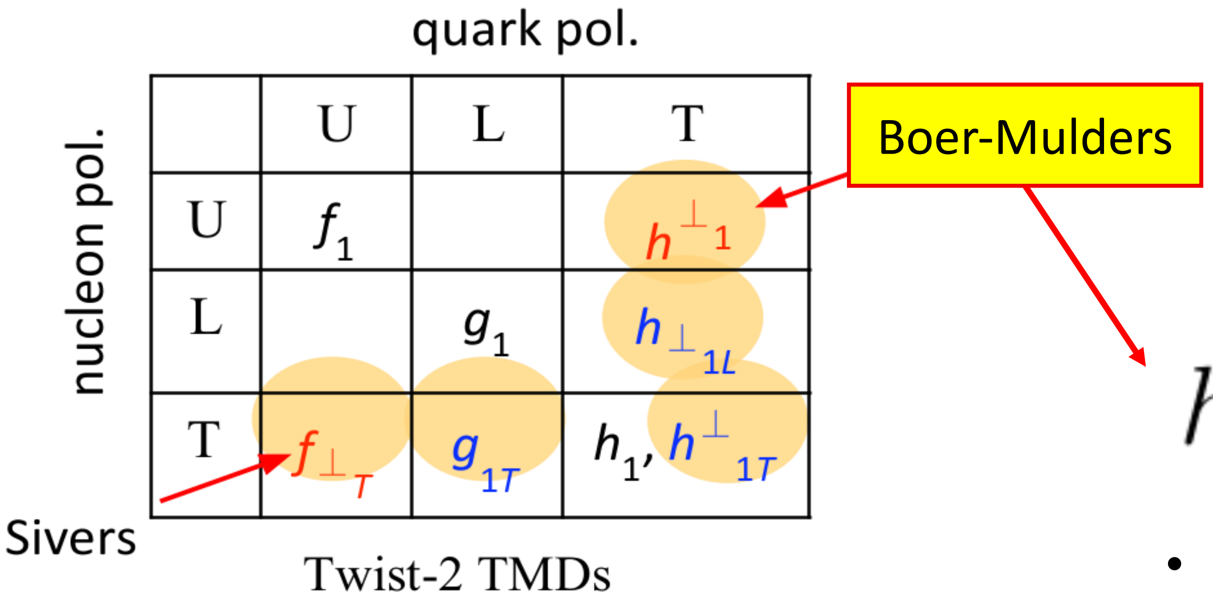
Comparisons of Pass 1 and Pass 2 Unfolding

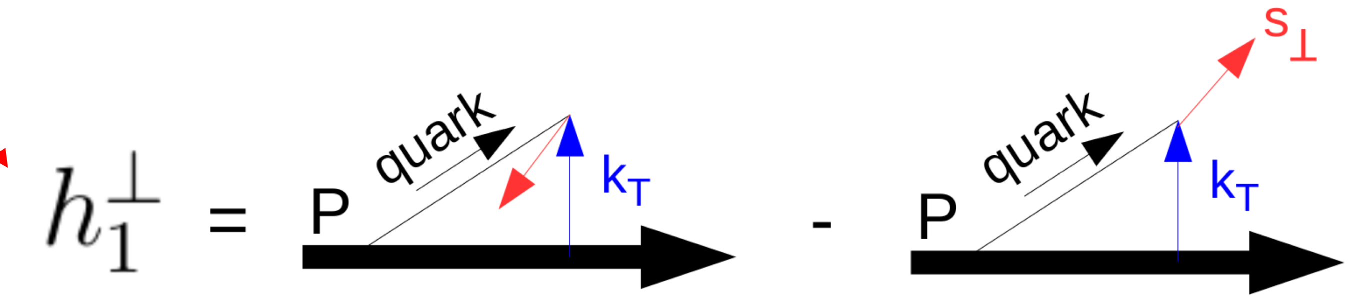
Using the Multidimensional Kinematic Bin from the prior example for this comparison





More on Boer-Mulders…





- **P** is the momentum of the proton
- $\mathbf{k_T}$ is the transverse momentum of the quark
- $\mathbf{s_{\perp}}$ is the transverse spin of the quark

If the Boer-Mulders term is non-zero, then there is a net transverse quark polarization inside of unpolarized protons

Event Selection (Full PID)

The RG-A Analysis Overview and Procedures note goes into detail about the common particle identification scheme used for RG-A

(See: https://clas12-docdb.jlab.org/DocDB/0009/000949/001/RGA_Analysis_Overview_and_Procedures-08172020.pdf)

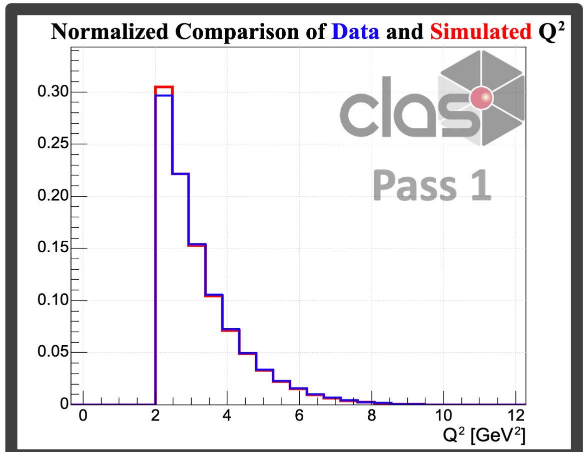
Electron PID Criteria:

- Detected in Forward Detector
- > 2 photoelectrons detected in the HTCC
- > 0.07 GeV energy deposited in the PCAL
- Sector dependent sampling fraction cut
- "Diagonal cut" for electrons above 4.5 GeV (HTCC threshold)
- y < 0.75, not strictly an "electron cut", but sets the min electron energy approximately > 2.4 GeV

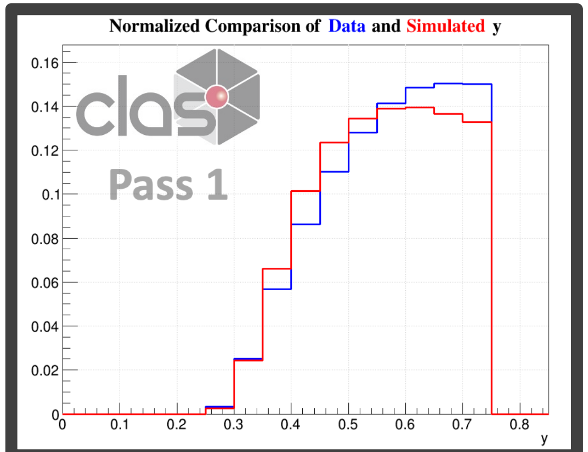
Pion PID Criteria:

- Detected in Forward Detector
- p > 1.25 GeV
- Refined chi2pid cuts

Data and Monte Carlo Comparison

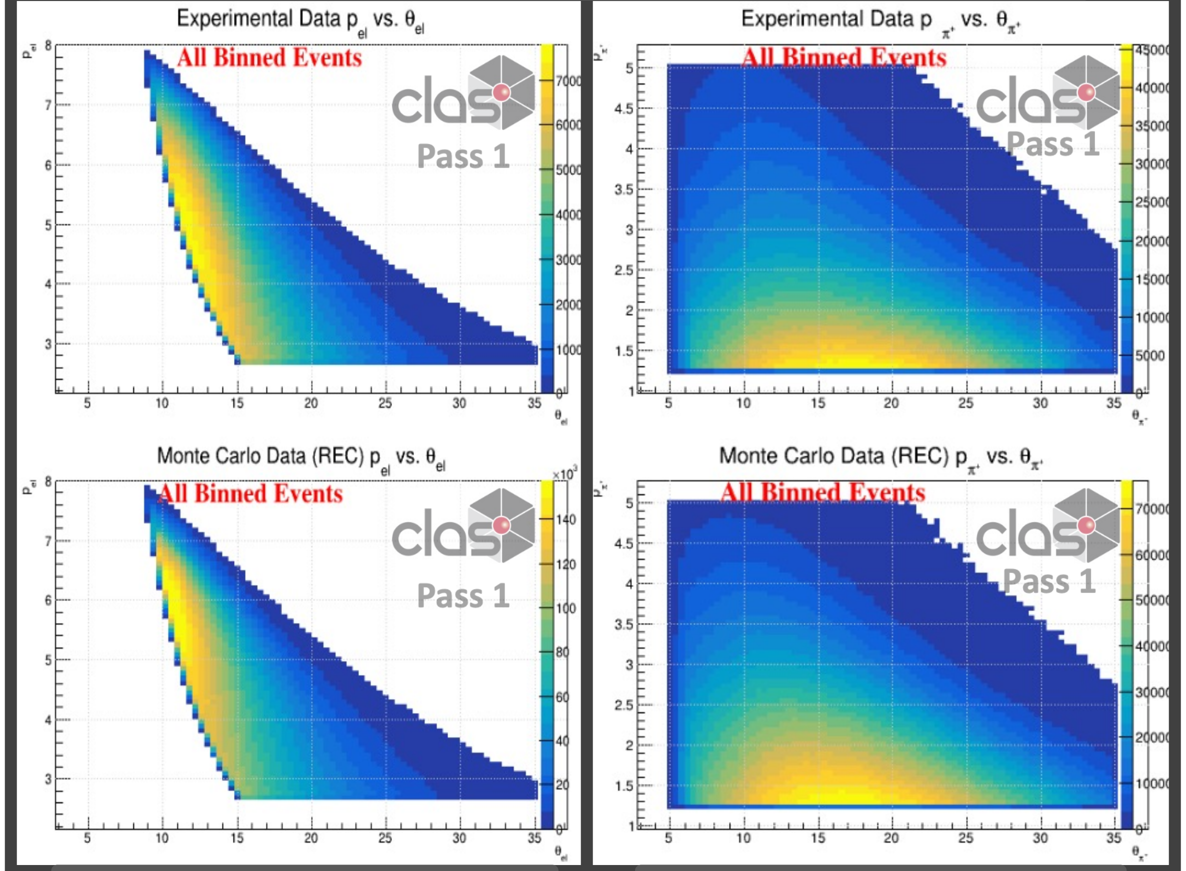


Q² Comparison



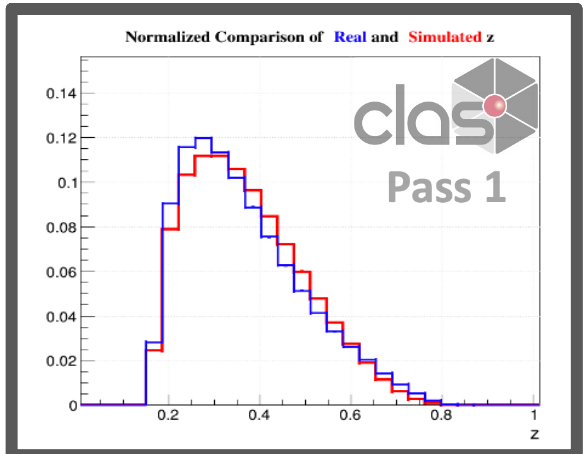
y Comparison

Momentum vs Polar Lab Angle Comparison

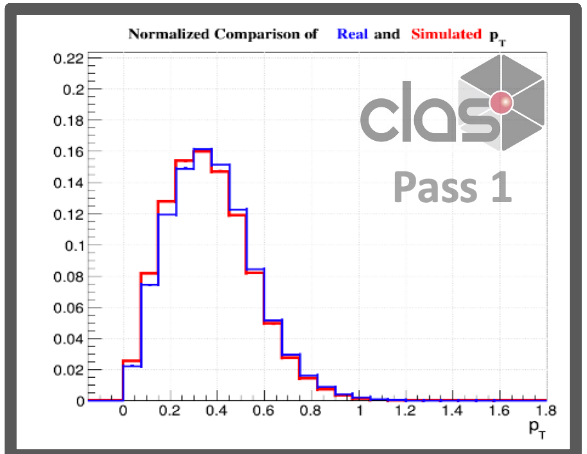


Electron Comparison

π^+ Pion Comparison



z Comparison



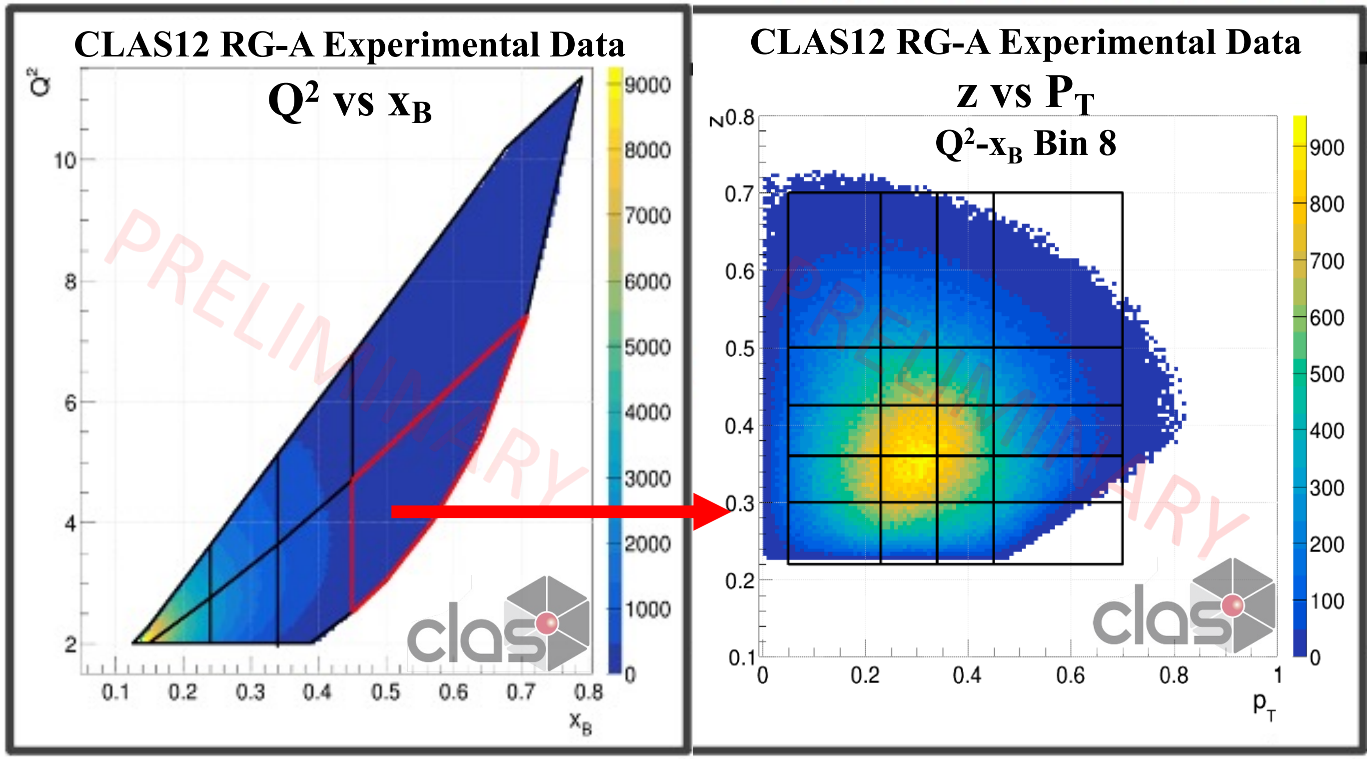
P_T Comparison

Multidimensional Analysis Procedures

Multidimensional Kinematic Binning (4 Dimensions)

8 Q^2-x_B Bins Total – 20-49 z-P_T Bins (per Q^2-x_B bin)

Example of old binning scheme using Q^2, x_B, z, and P_T



Main Issue was with the irregular shape of the Q^2-x_B Bins

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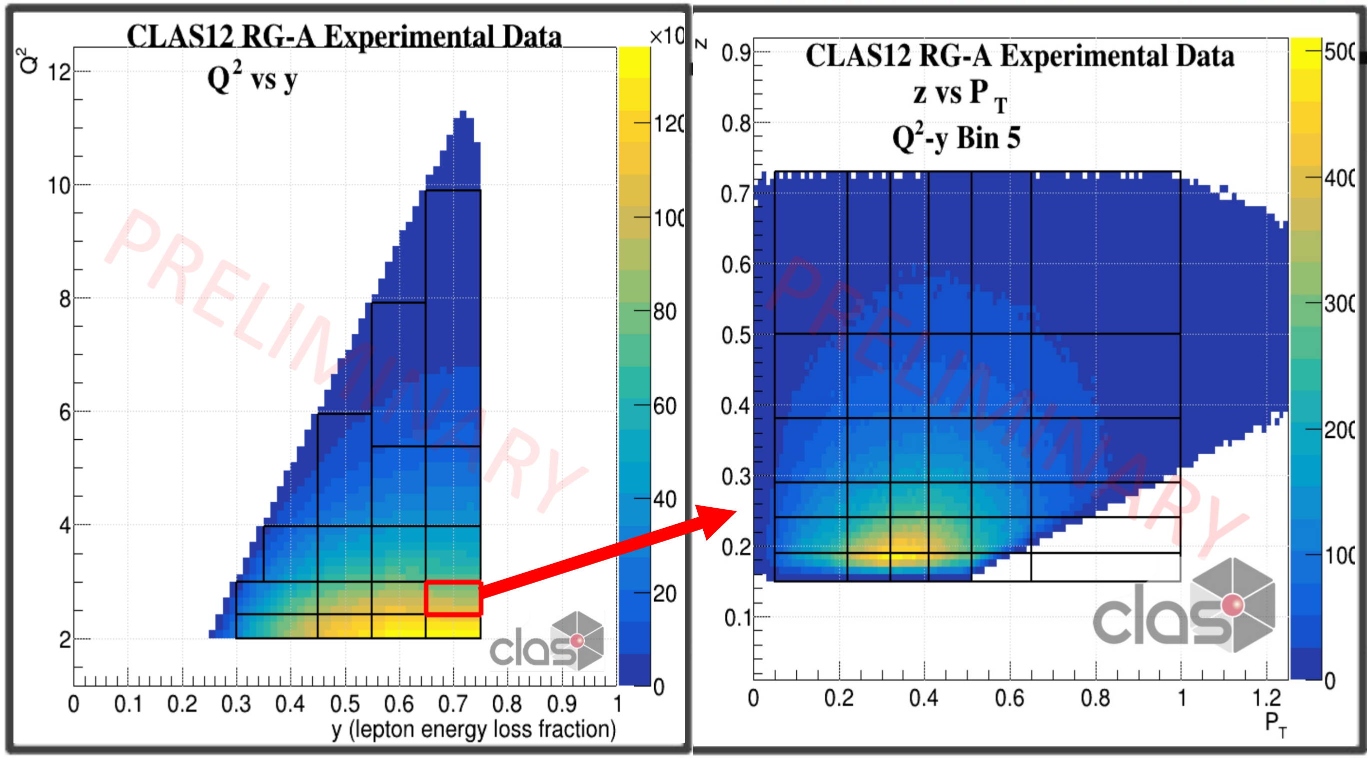
Multidimensional Analysis Procedures

Multidimensional Kinematic Binning (4 Dimensions)

17 Q^2-y Bins Total – 20-42 z-P_T Bins (per Q^2-y bin)

Example of prior binning scheme using Q^2, y, z, and P_T



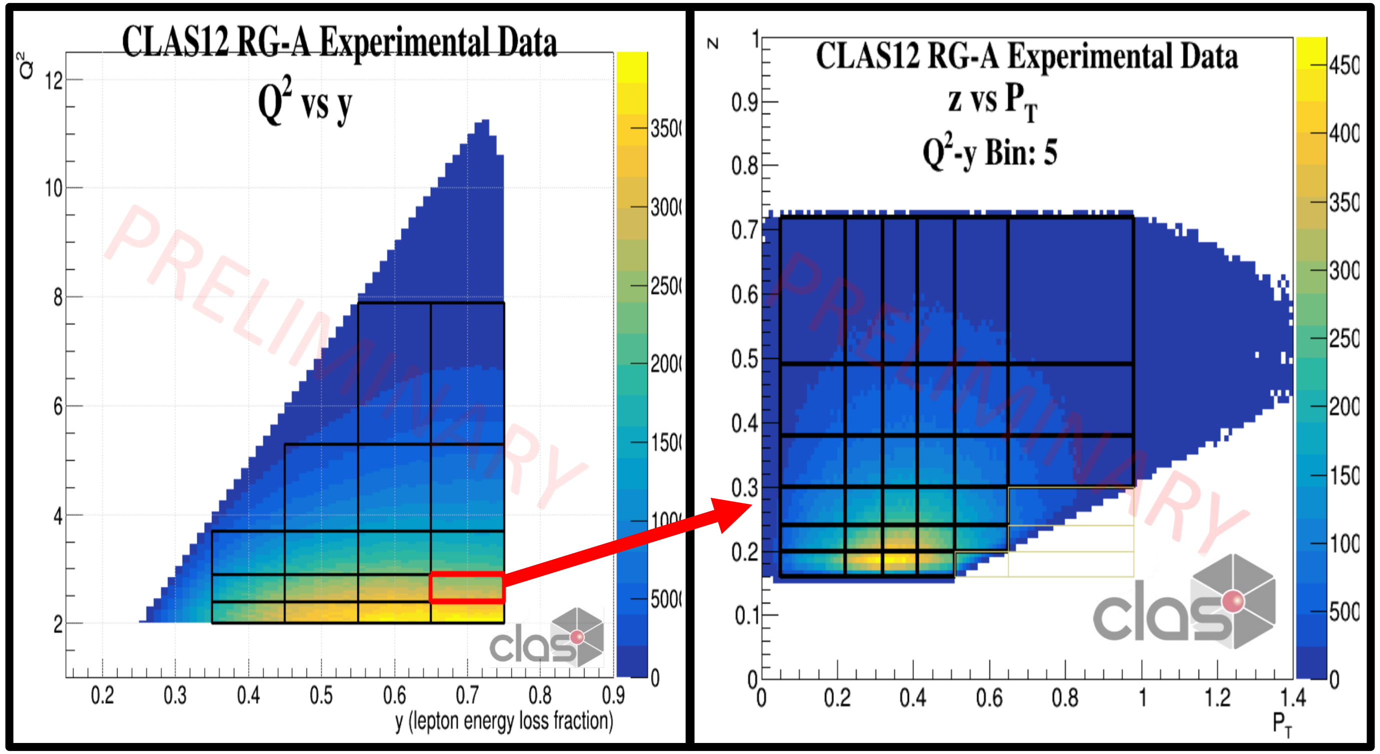
Both the Q^2-y and z-P_T bins are now rectangular, which makes the bins easier to work with

Multidimensional Analysis Procedures

Multidimensional Kinematic Binning (4 Dimensions)

17 Q^2-y Bins Total – 25-36 z-P_T Bins (per Q^2-y bin)

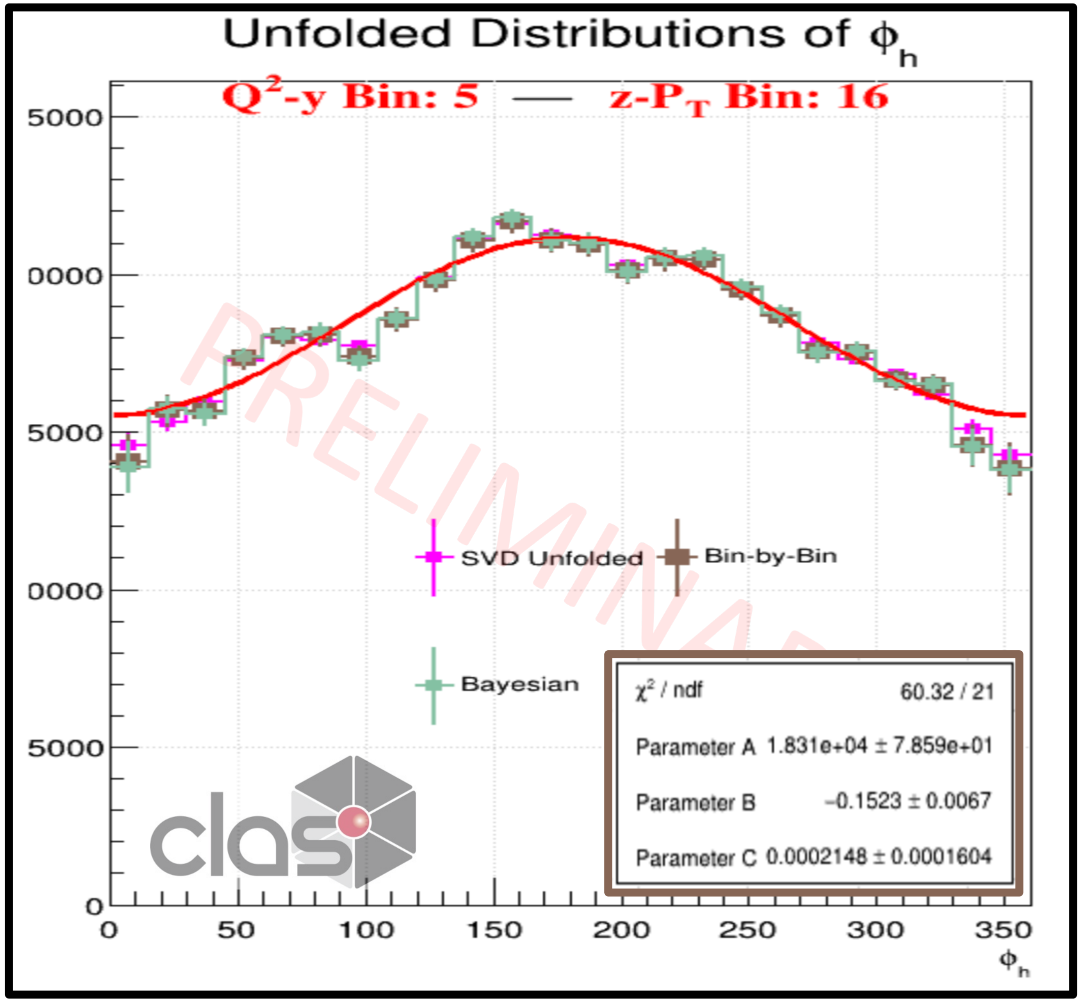
Example of the new binning scheme using Q^2, y, z, and P_T

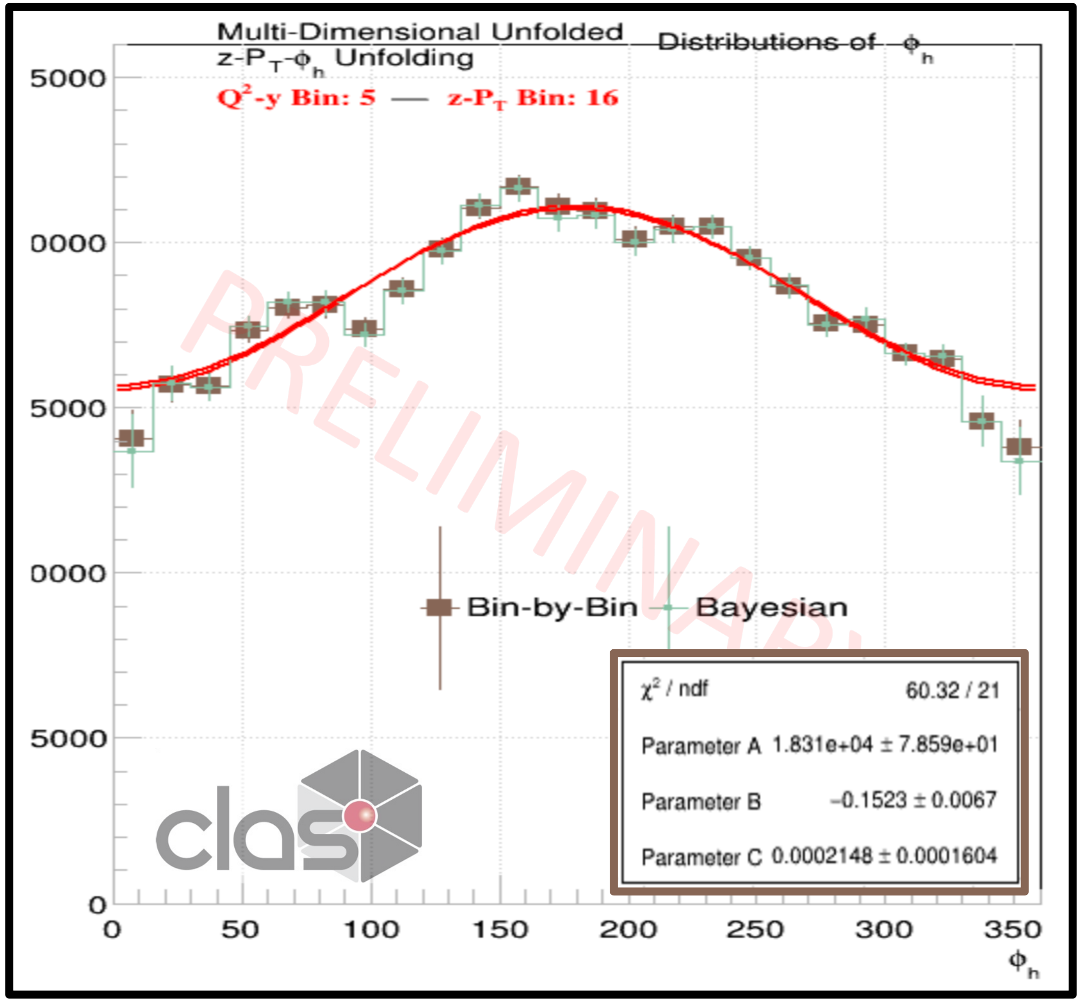


Optimized the binning for even distributions of event statistics and for consistent bin borders

Comparisons of 1D and 3D Unfolding Procedure

Using the Multidimensional Kinematic Bin from the prior example for this comparison





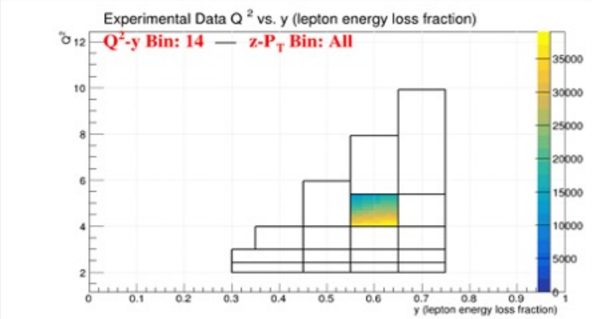
Bin-by-bin Acceptance Correction gives the exact same results

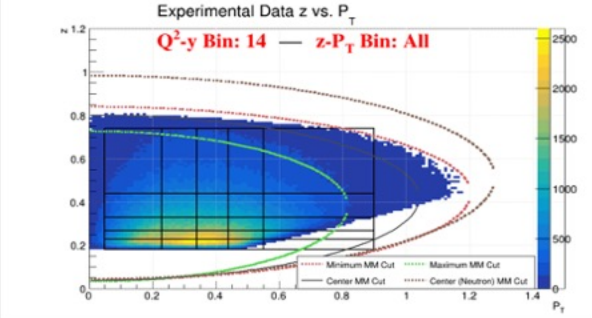
SVD Unfolding has not been able to work so far with the Multidimensional Unfolding procedures

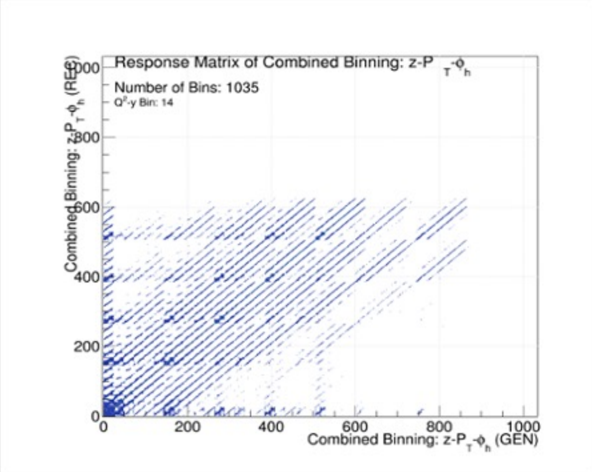
Extra Examples of (3D) Unfolding Procedure

Using the Flattened z-P_T-ϕ_h Multidimensional Bins

Q^2-y Bin 14







Unfolded with Bayesian Method

PRELIMINARY

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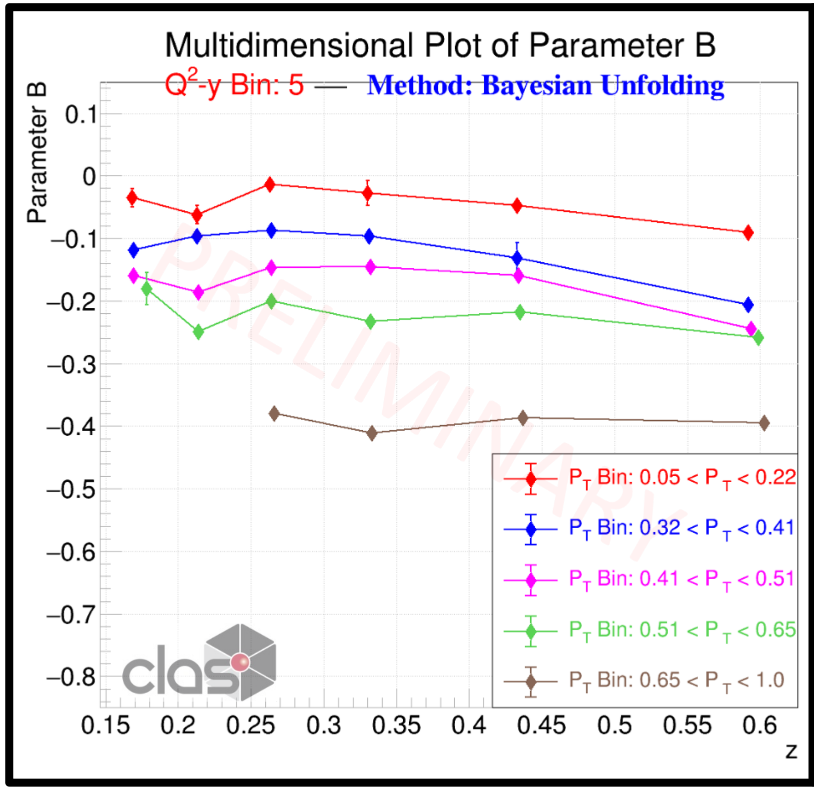
Cosine Moments as Functions of z – Old Bins

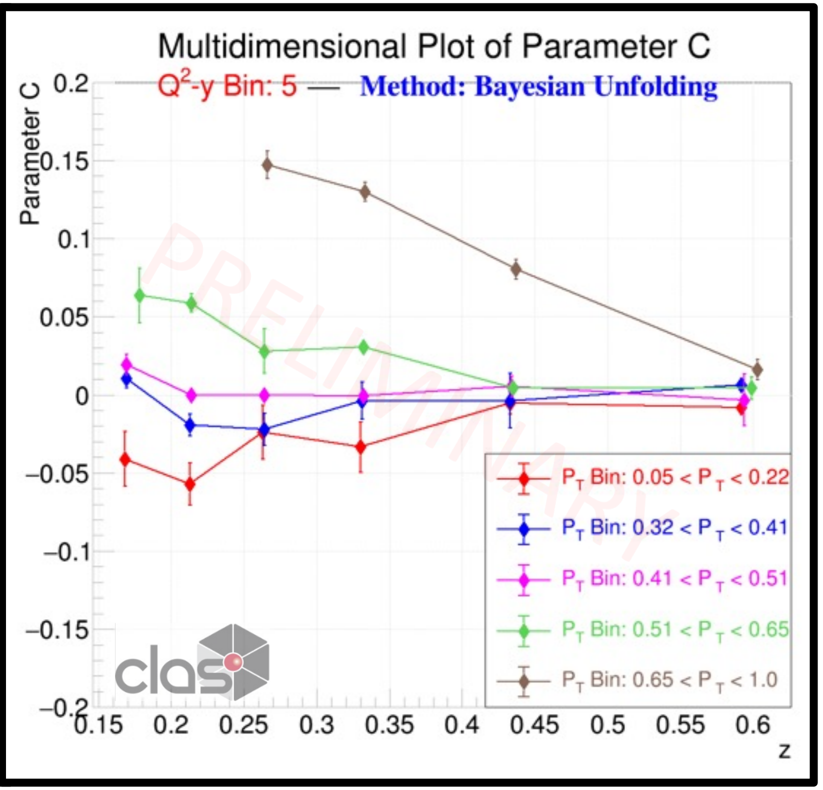
$B = A_{UU}^{\cos\varphi_h}$ $C = A_{UU}^{\cos 2\varphi_h}$

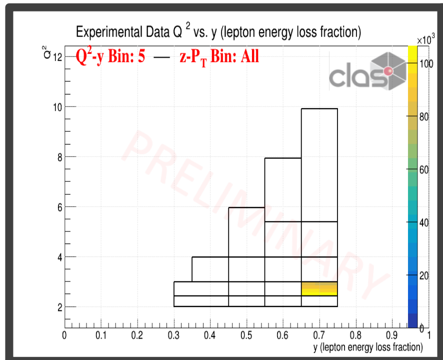
ϕ_h Plots were fitted with:
$A(1 + B\cos(\phi_h) + C\cos(2\phi_h))$

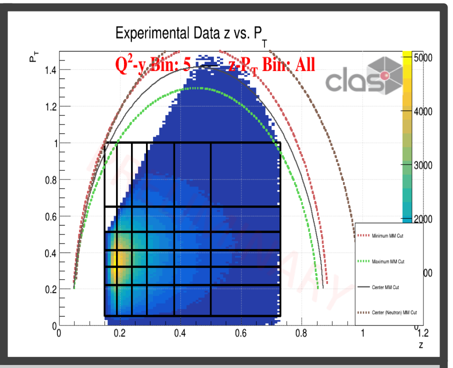
Unfolded with Bayesian Method

Q^2-y Bin 5









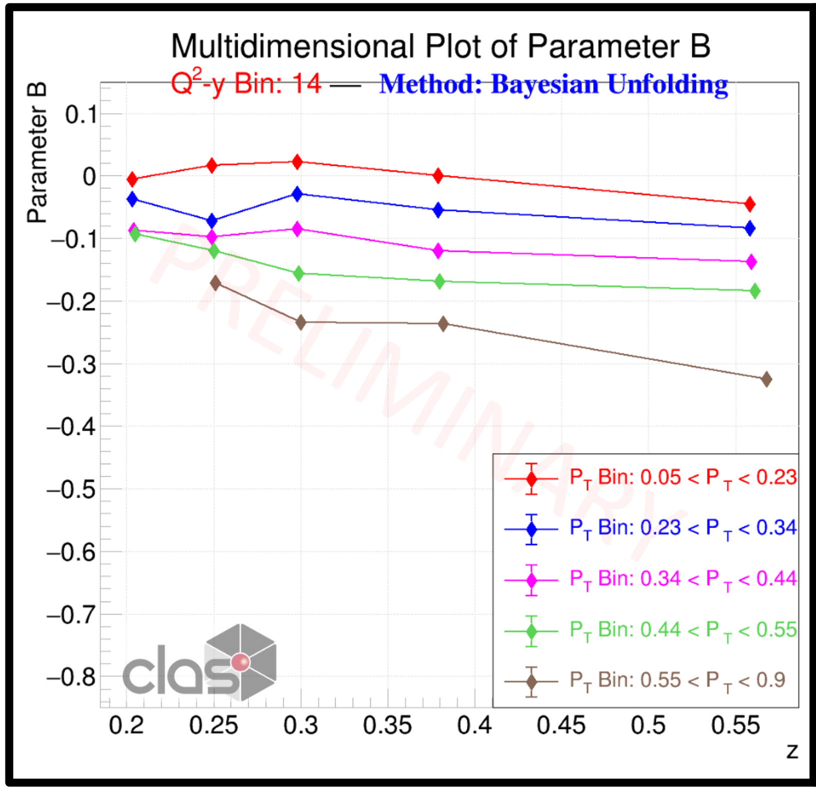
Cosine Moments as Functions of z – Old Bins

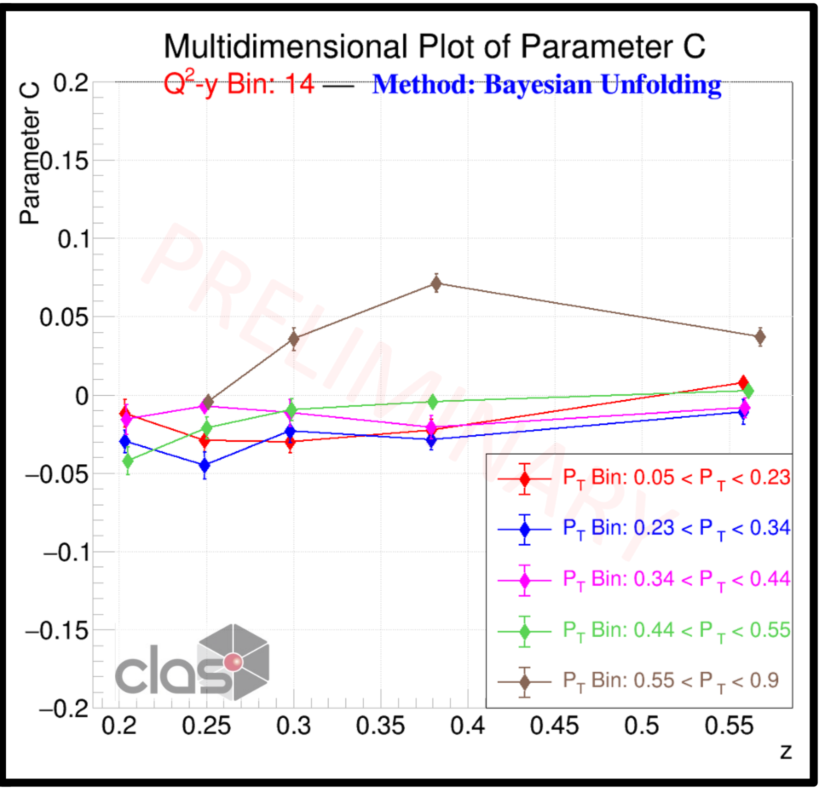
$B = A_{UU}^{\cos\varphi_h}$ $C = A_{UU}^{\cos 2\varphi_h}$

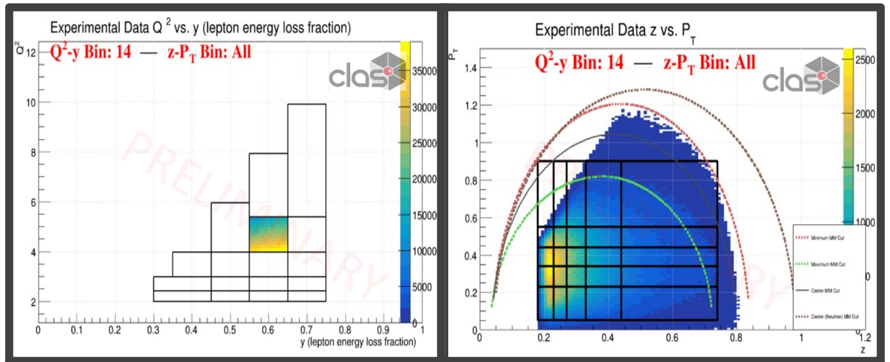
ϕ_h Plots were fitted with:
$A(1 + B\cos(\phi_h) + C\cos(2\phi_h))$

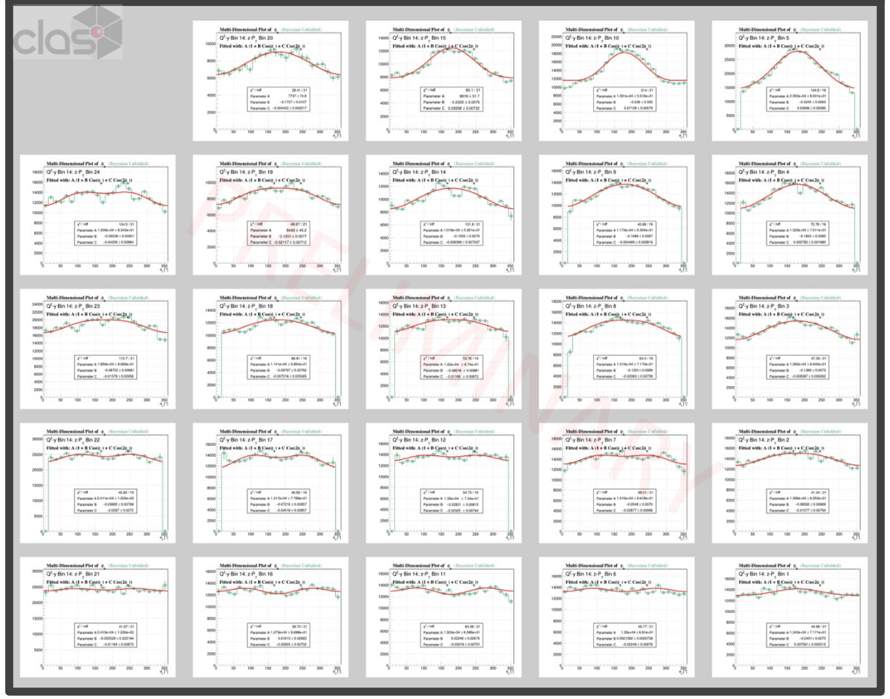
Unfolded with Bayesian Method

Q^2-y Bin 14









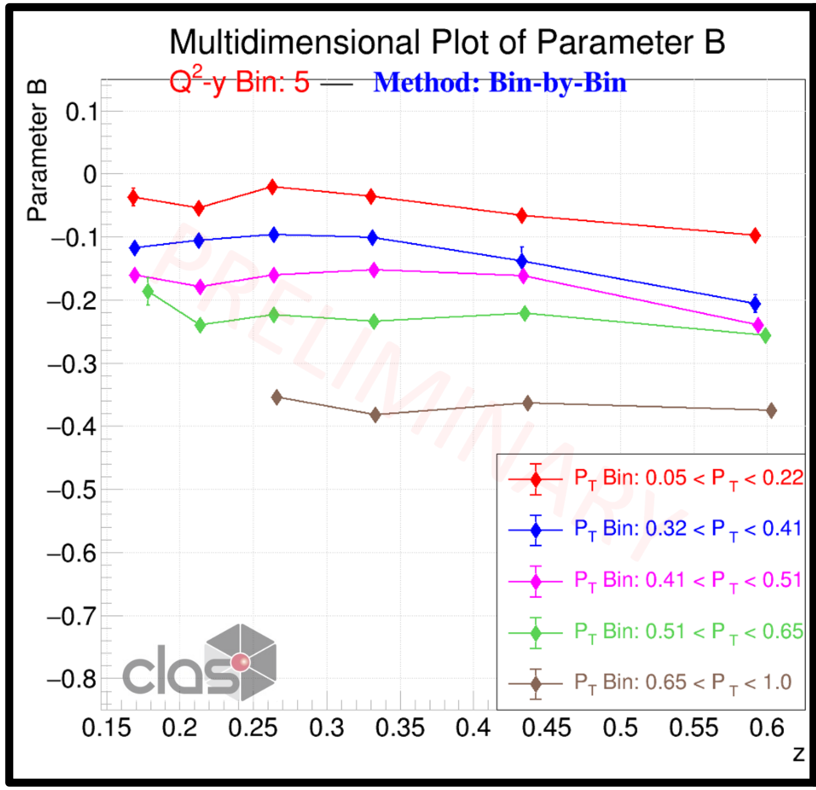
Cosine Moments as Functions of z – Old Bins

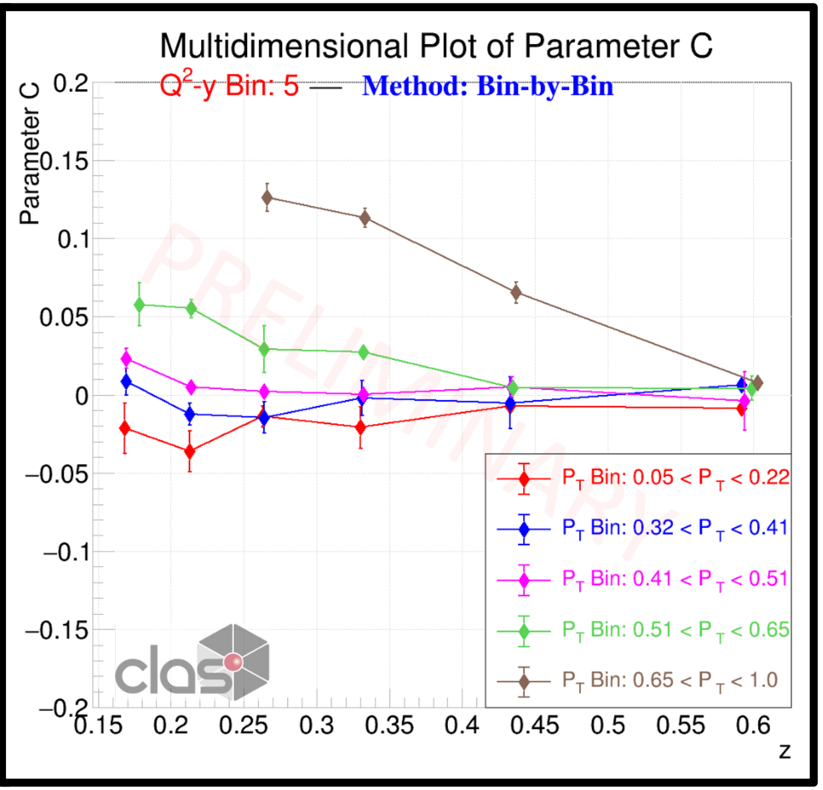
$B = A_{UU}^{\cos\varphi_h}$ $C = A_{UU}^{\cos 2\varphi_h}$

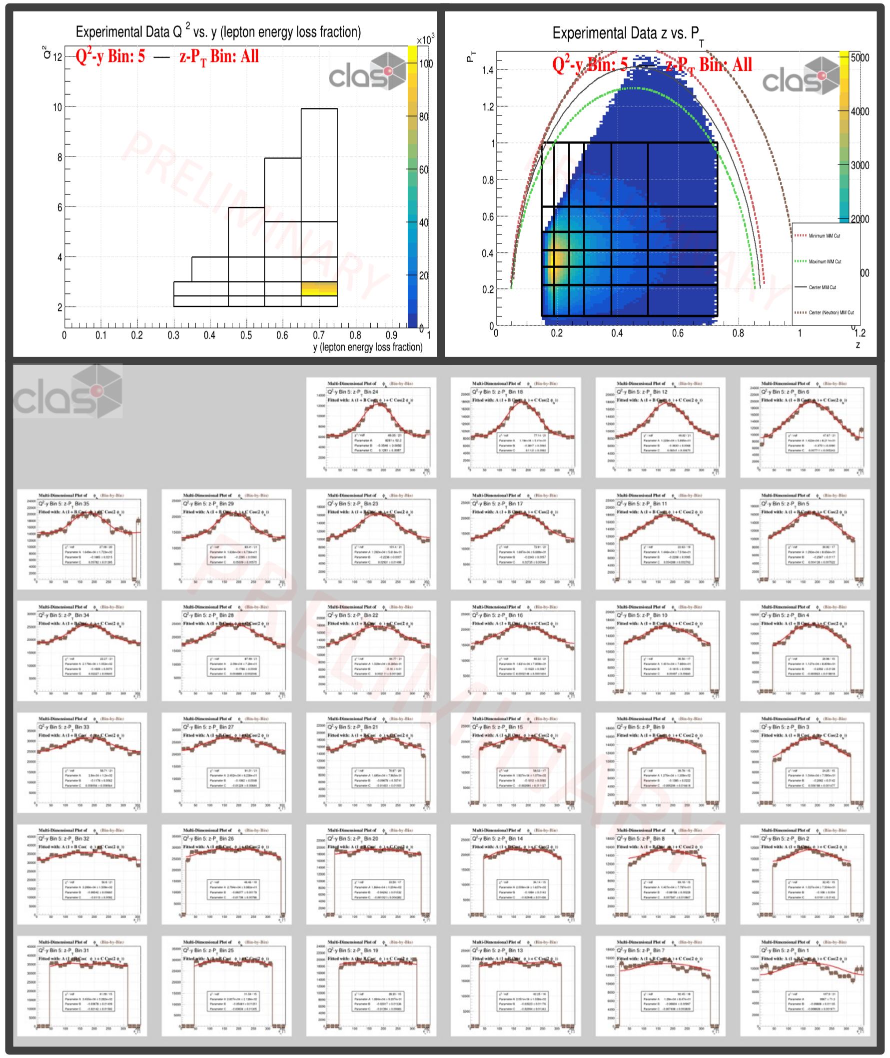
ϕ_h Plots were fitted with:
$A(1 + B\cos(\phi_h) + C\cos(2\phi_h))$

Corrected with Bin-by-bin Method

Q^2-y Bin 5







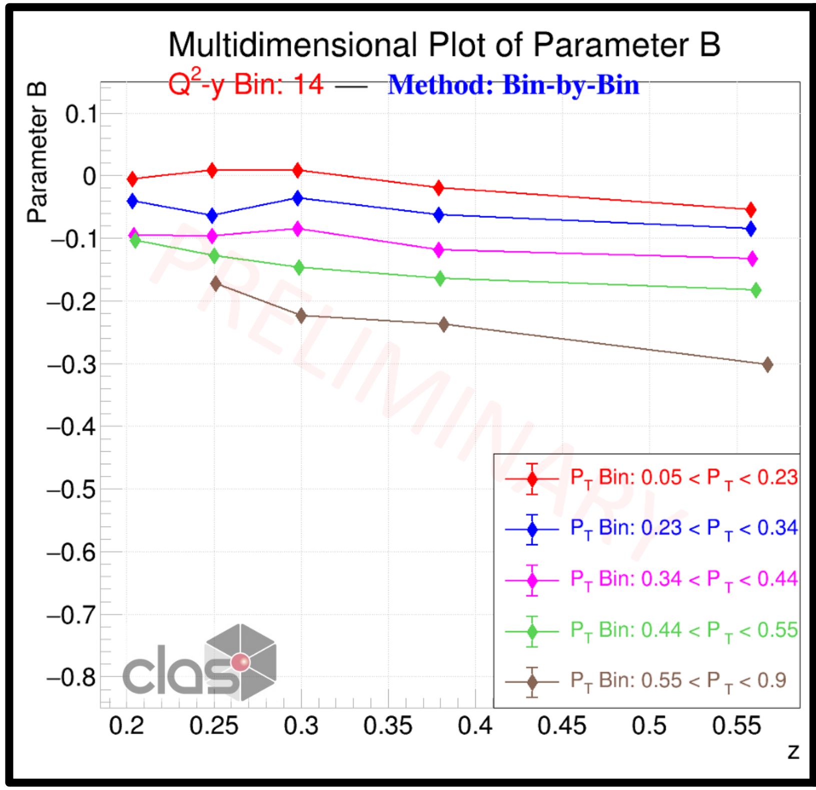
Cosine Moments as Functions of z – Old Bins

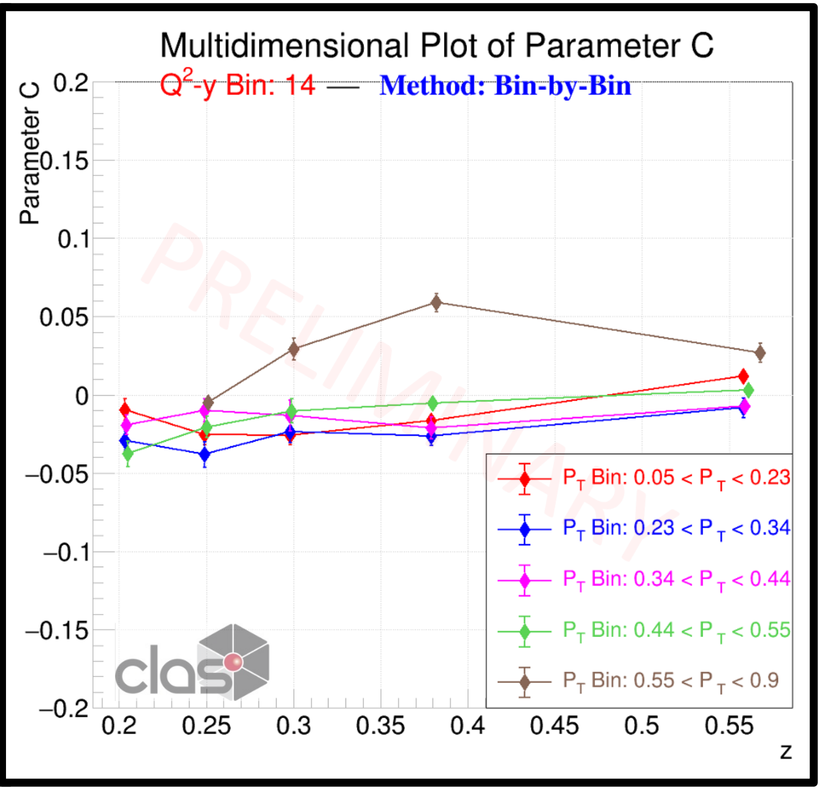
$B = A_{UU}^{\cos\varphi_h}$ $C = A_{UU}^{\cos 2\varphi_h}$

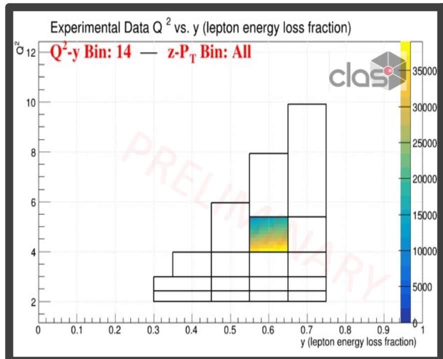
ϕ_h Plots were fitted with:
$A(1 + B\cos(\phi_h) + C\cos(2\phi_h))$

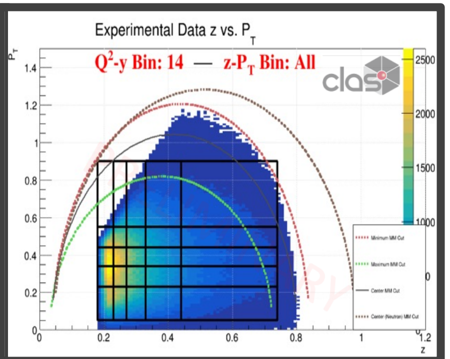
Corrected with Bin-by-bin Method

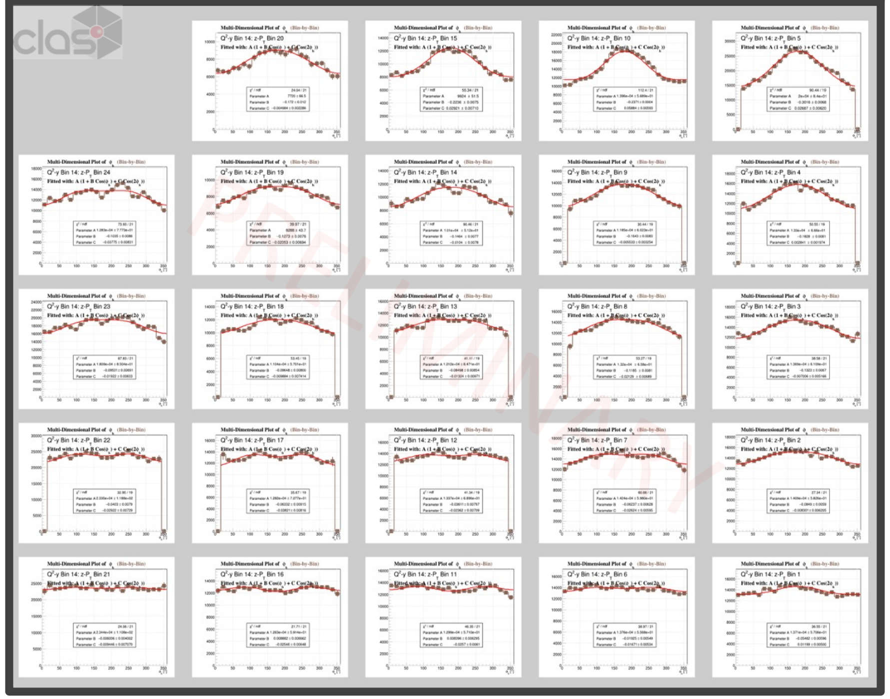
Q^2-y Bin 14





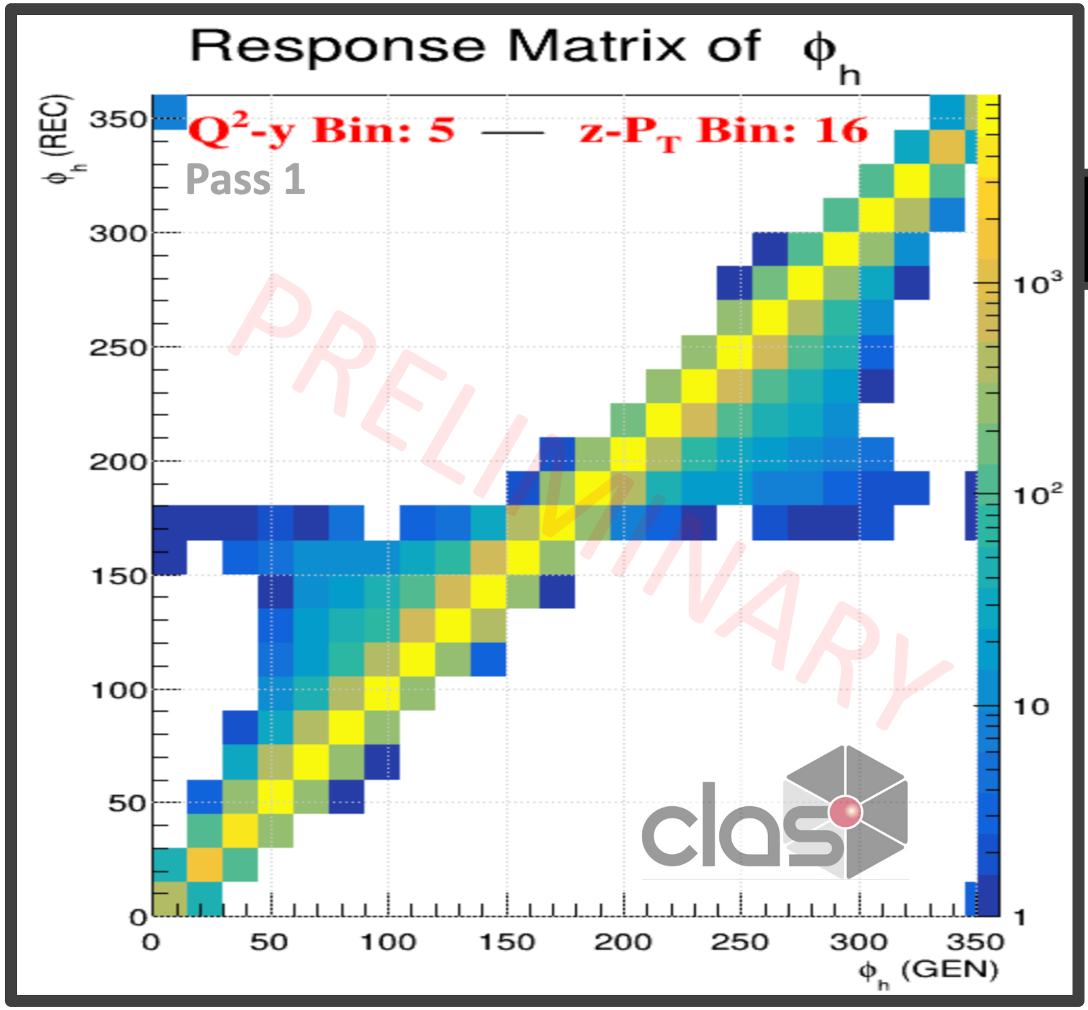




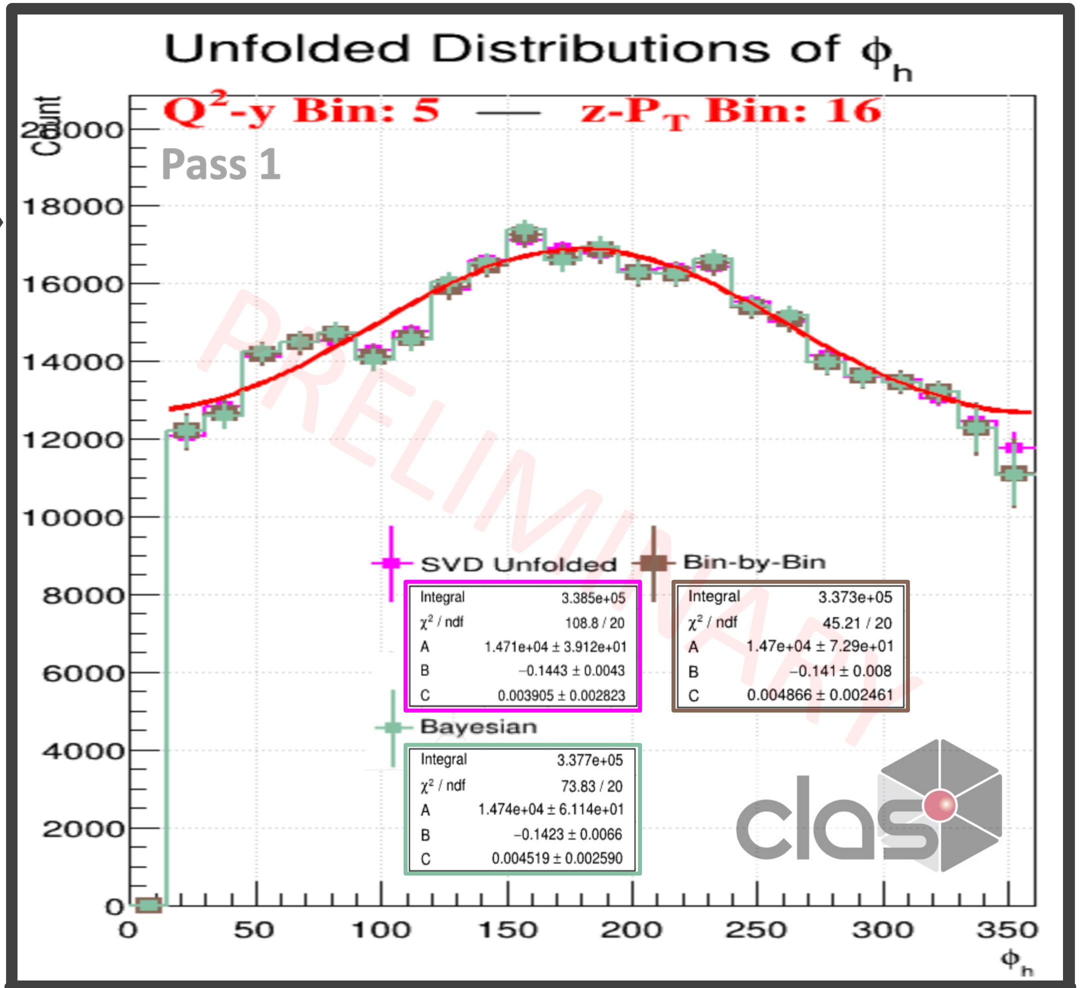


Example of (1D) Unfolding Procedure

Using the Multidimensional Kinematic Bin from prior example



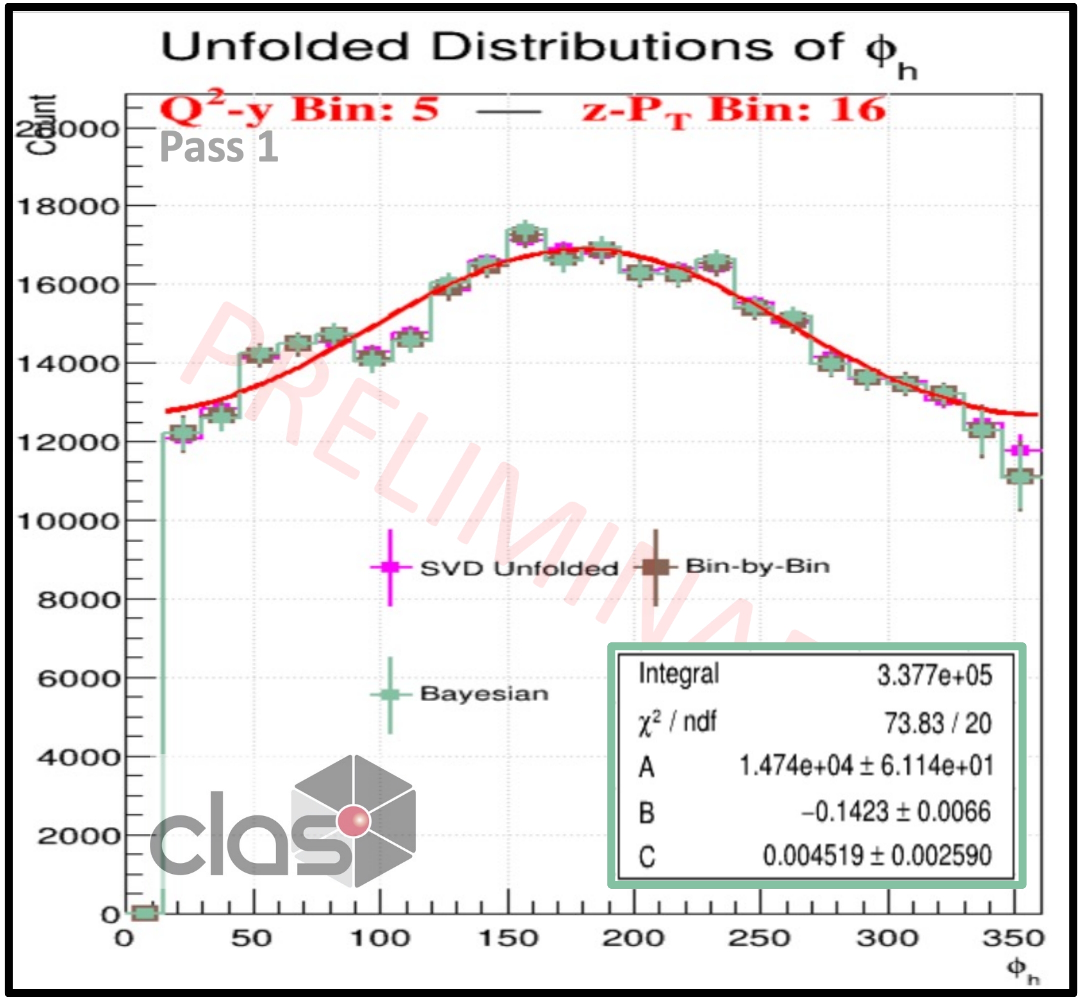
Unfolding Procedures

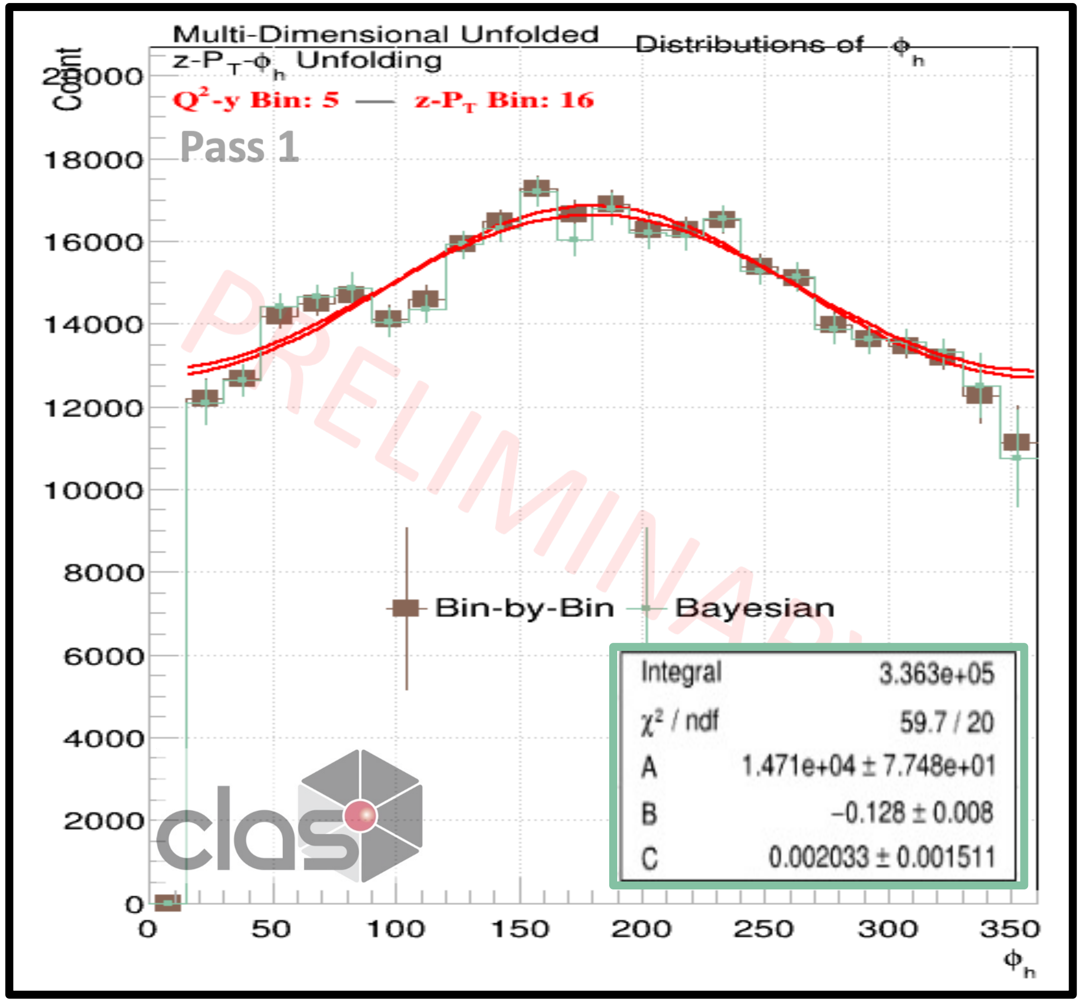


Parameters shown are from the fits previously described

Comparisons of 1D and 3D Unfolding Procedure

Using the Multidimensional Kinematic Bin from the prior example for this comparison



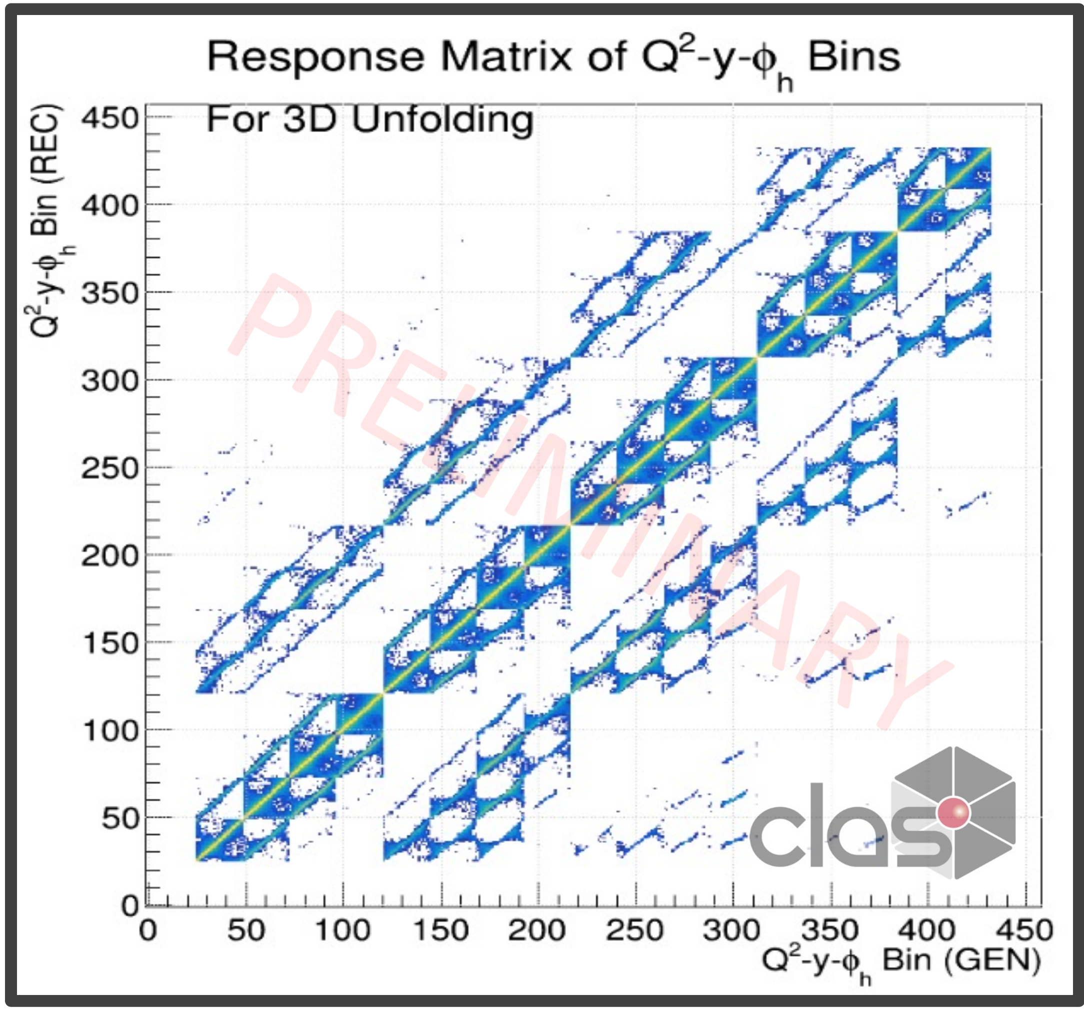


Bin-by-bin Acceptance Correction gives the exact same results

Bayesian Unfolding gives similar results

Example of (3D) Unfolding Procedure – Old Bins

Using Q^2-y-ϕ_h Multidimensional Bins



Unfolding Procedure

Unfolded with Bayesian Method

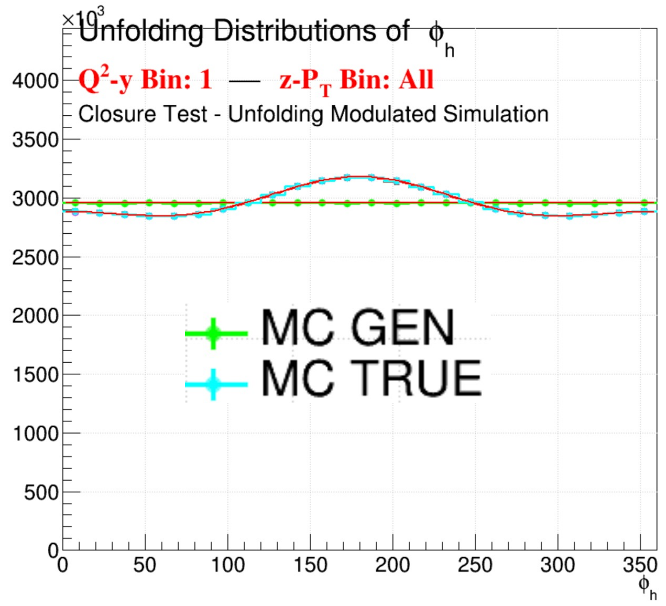
Modulated Unfolding Closure Tests

- Modulated the MC distributions using the formula:

$$Weight = 1 + B\cos(\phi_h) + C\cos(2\phi_h)$$

  - Gives the weight for each MC event based on generated ϕ_h
  - Parameter values currently being used in this image:
    - B = -0.05
    - C = 0.025

    (Same for every z-P_T bin)



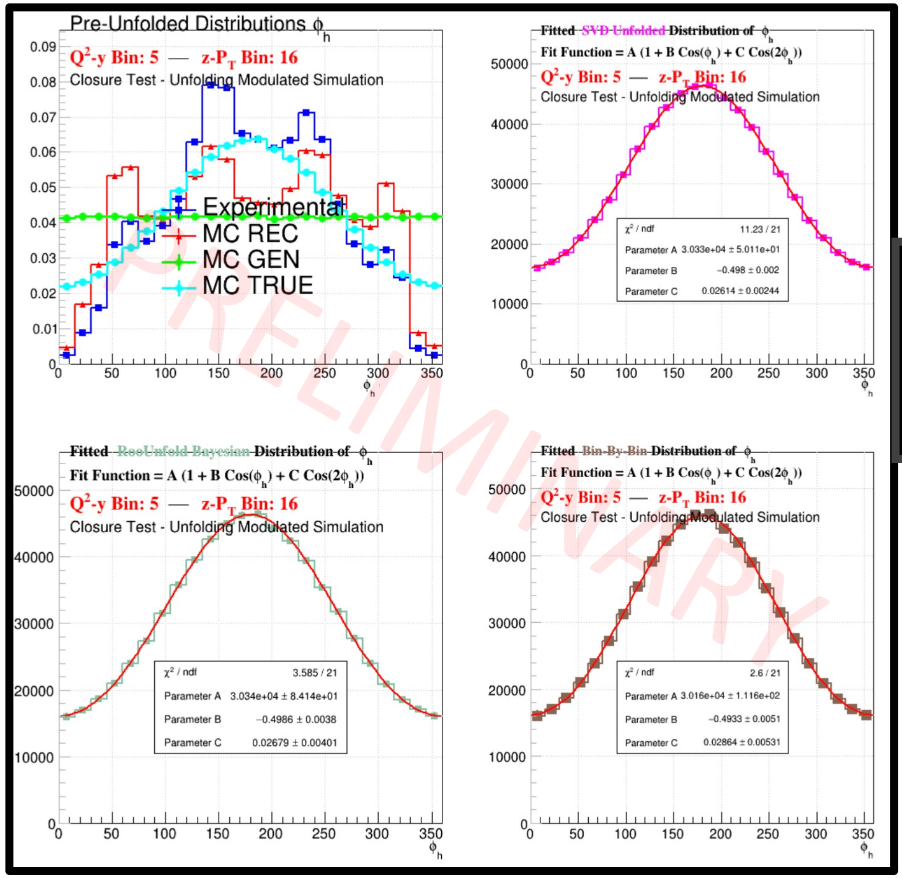
- Modulated MC REC is then unfolded using the un-modulated response matrix (in 1D and Multi-Dim examples) and compared with 'MC TRUE'
  - MC TRUE is the modulated MC GEN distribution
  - Also performed a closure test of unfolding the un-modulated MC REC distribution with the un-modulated response matrix to ensure the method was applied properly

Modulated Unfolding Closure Tests

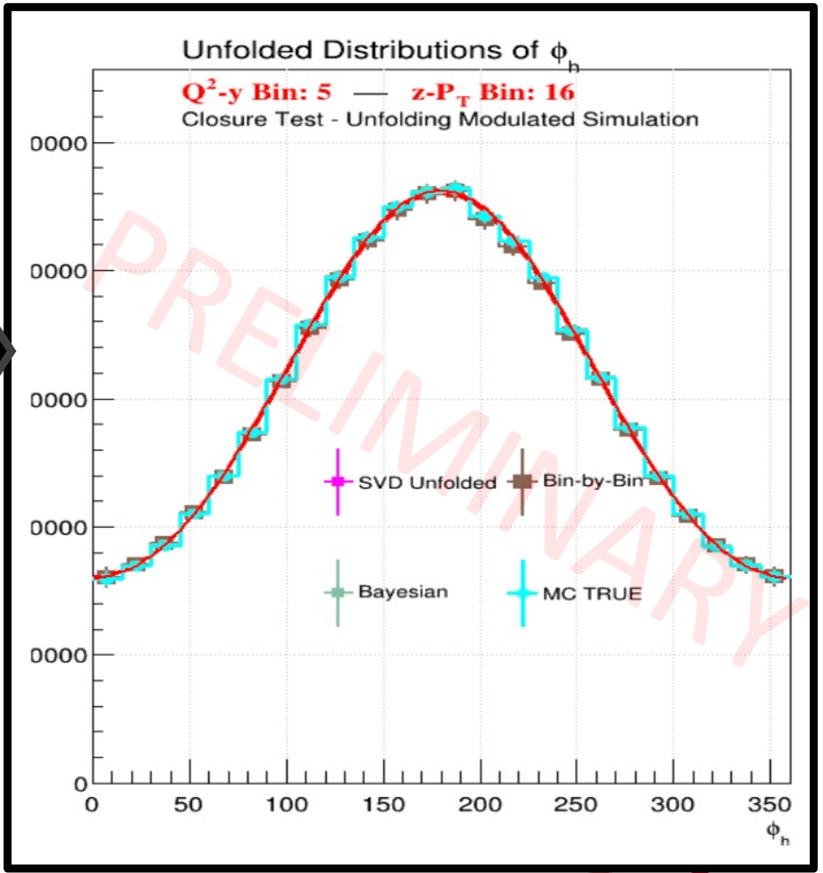
The parameters used for weighing modulations below are:

B = -0.5 and C = 0.025

Results show that an **unmodulated** Simulation can correct distributions **with modulations**



Checking that the corrected distributions match MC TRUE

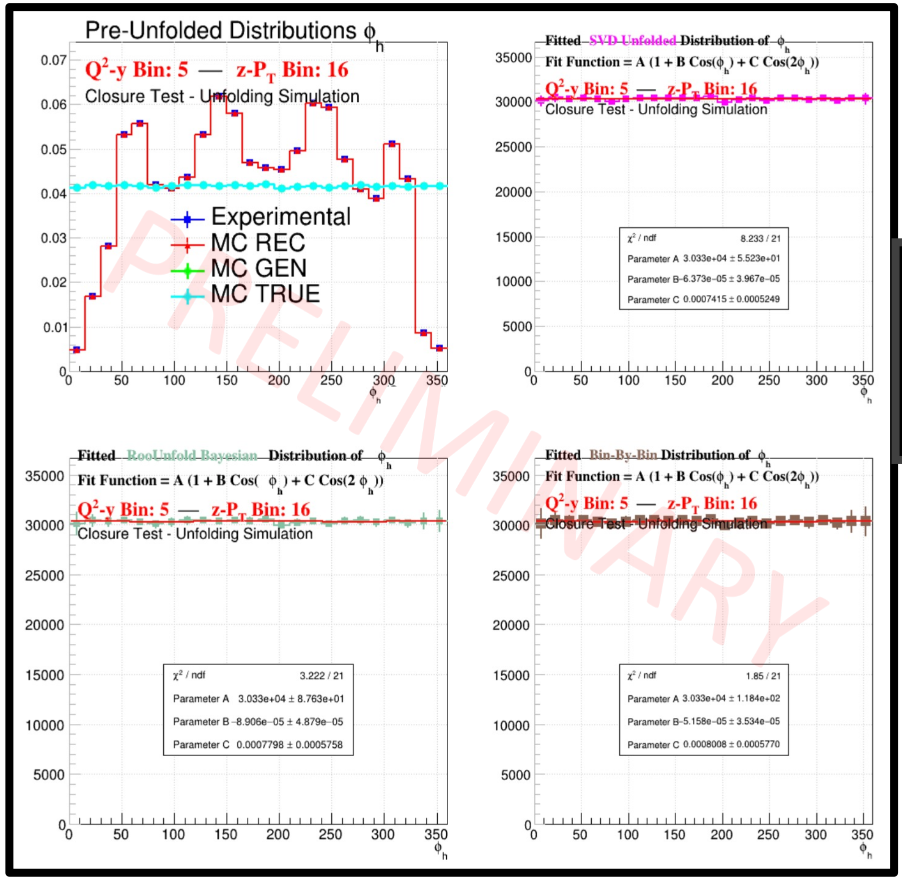


Fits are within the margin of error of the defined parameters

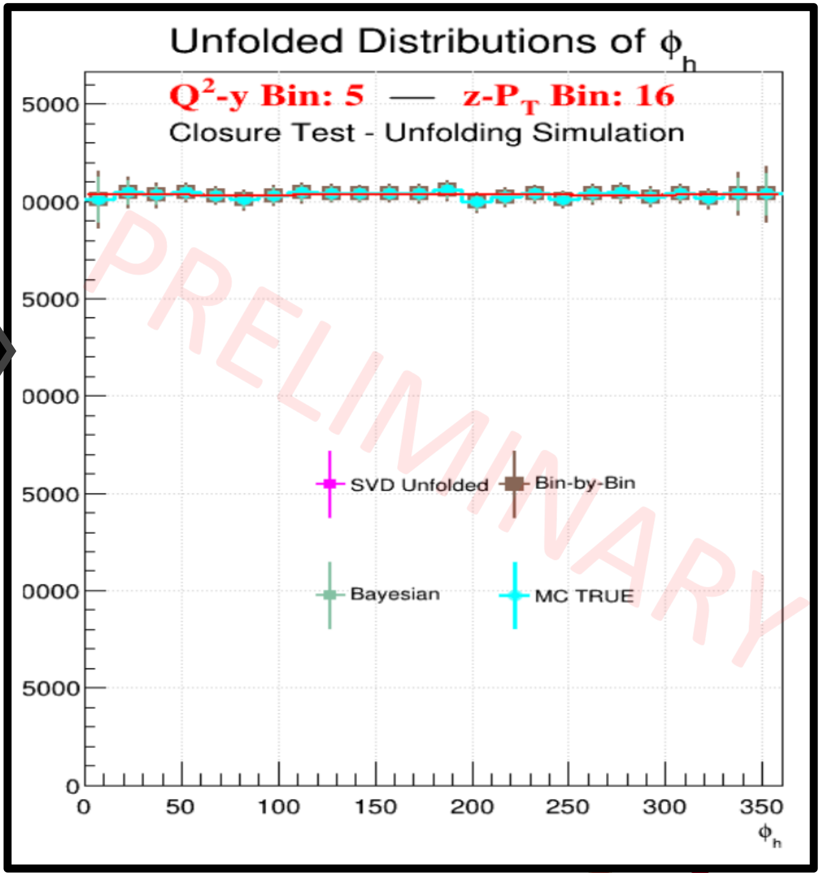
Other Unfolding Closure Tests

Other closure tests being used to check that Unfolding is done properly:

- Replace the experimental data with the reconstructed Monte Carlo (no modulations)
  - Should return the generated (i.e., MC TRUE) distribution



Checking that the corrected distributions match MC TRUE



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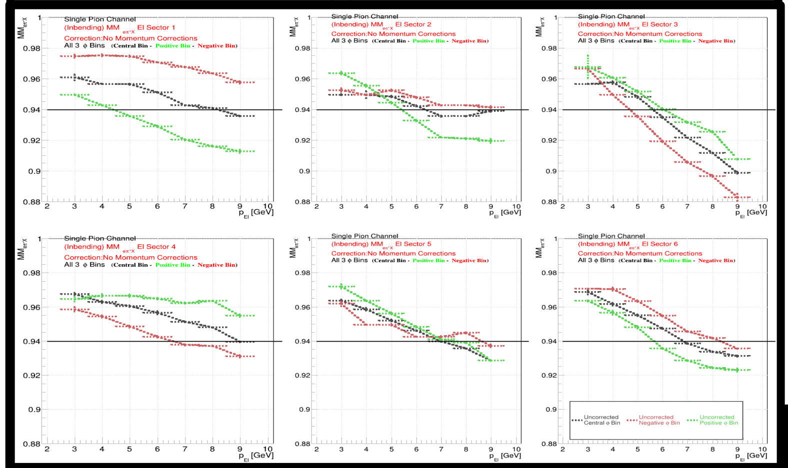
Momentum Corrections from Exclusive Events

- Momentum corrections are developed for the RG-A data being used in this analysis
- Designed to correct for kinematic-dependent reconstruction issues in the experimental data using well-understood reactions
- Use exclusive reactions to correct the particles’ momentum as sector-dependent functions of the particles’ measured azimuthal angle (ϕ_{lab}) and momentum
  - The primary reaction used for the electron and π^+ pion is $ep \rightarrow e'\pi^+(N)$
  - Elastic scattering process also used to help correct the electron momentum
- Developed from momentum 4-vector conservation to calculate the ideal momentum of a particle from exclusive reactions based on the kinematics of the other particle(s)
  - Correction is taken by plotting the difference between this calculation and the measured momentum as functions of the measured momentum and ϕ_{lab}

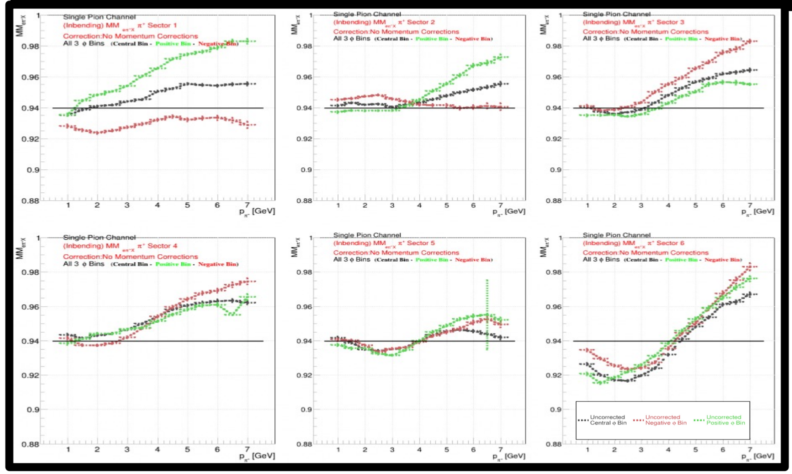
Momentum Corrections from Exclusive Events

These plots show Missing Mass vs. particle momentum in 3 ϕ bins for all 6 sectors of the detector before/after momentum corrections – **Corrections are quadratic functions of ϕ and momentum**

Missing Mass ($MM_{e\pi^+X}$) vs Electron Momentum

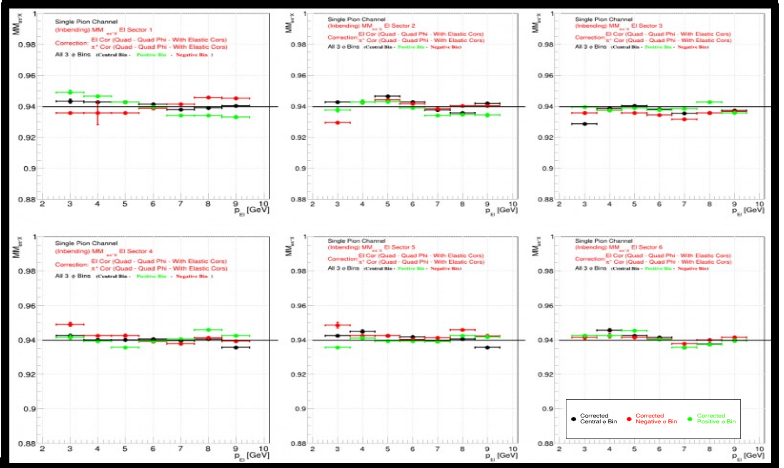


Missing Mass ($MM_{e\pi^+X}$) vs π⁺ Pion Momentum

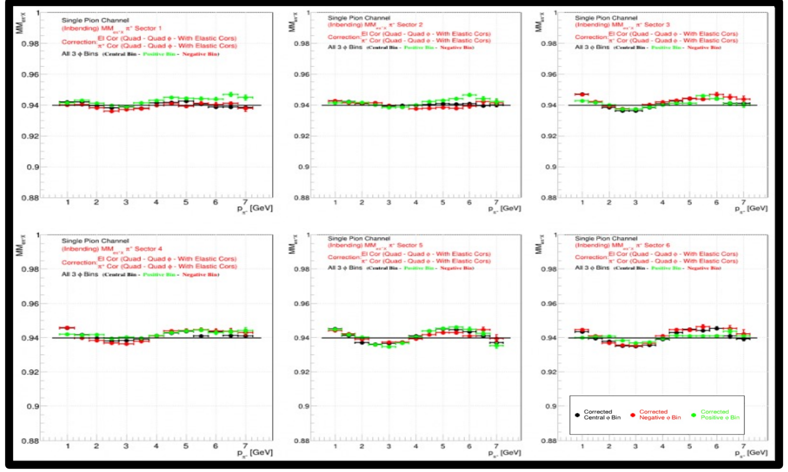


Apply Momentum Corrections

Missing Mass ($MM_{e\pi^+X}$) vs Electron Momentum

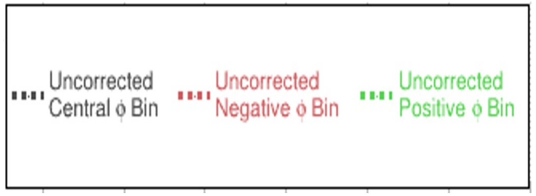


Missing Mass ($MM_{e\pi^+X}$) vs π⁺ Pion Momentum



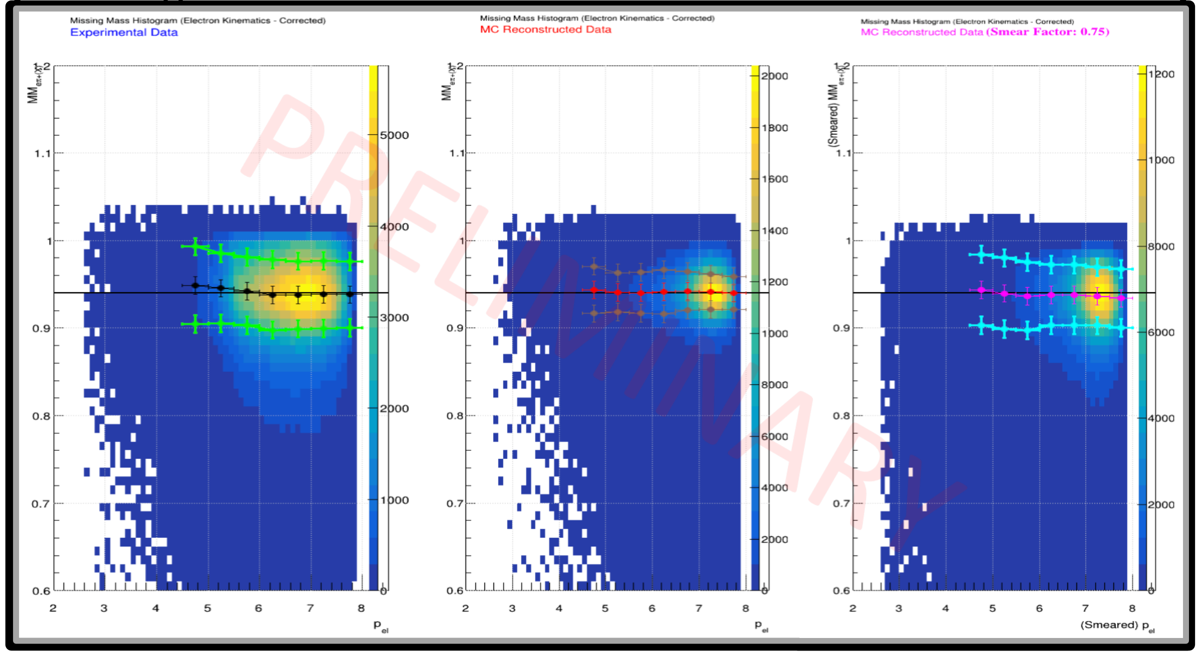
All Plots here are from Pass 1

(Pass 2 corrections are still in early development)

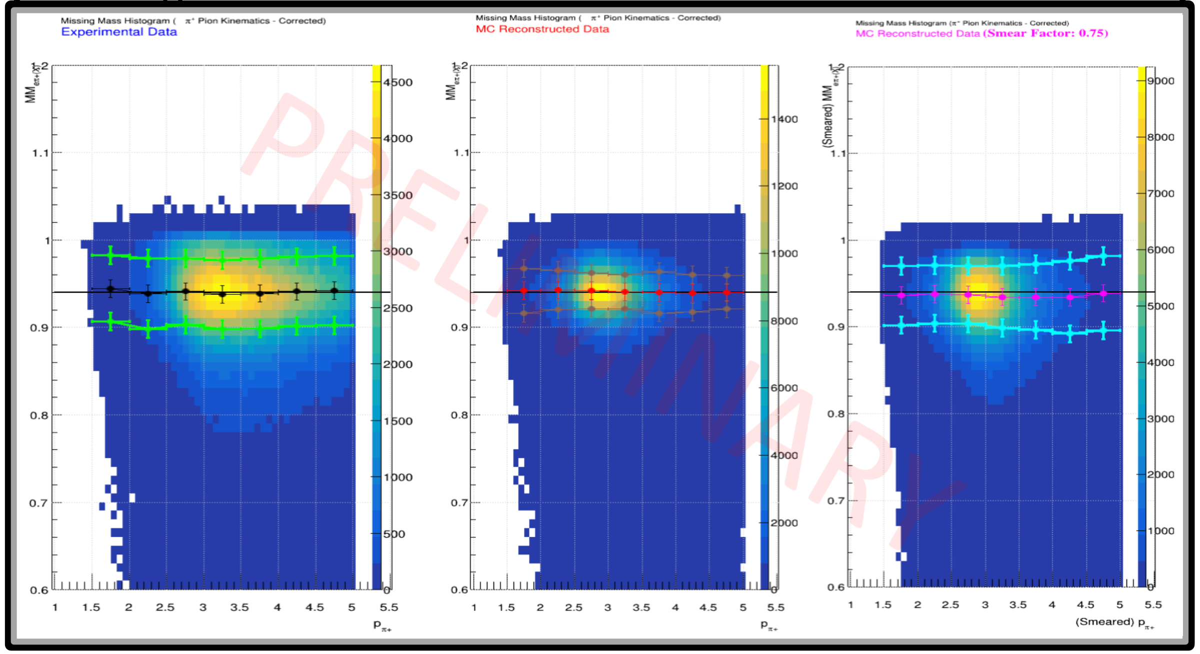


Momentum Smearing – Pass 1

Missing Mass vs Electron Momentum:



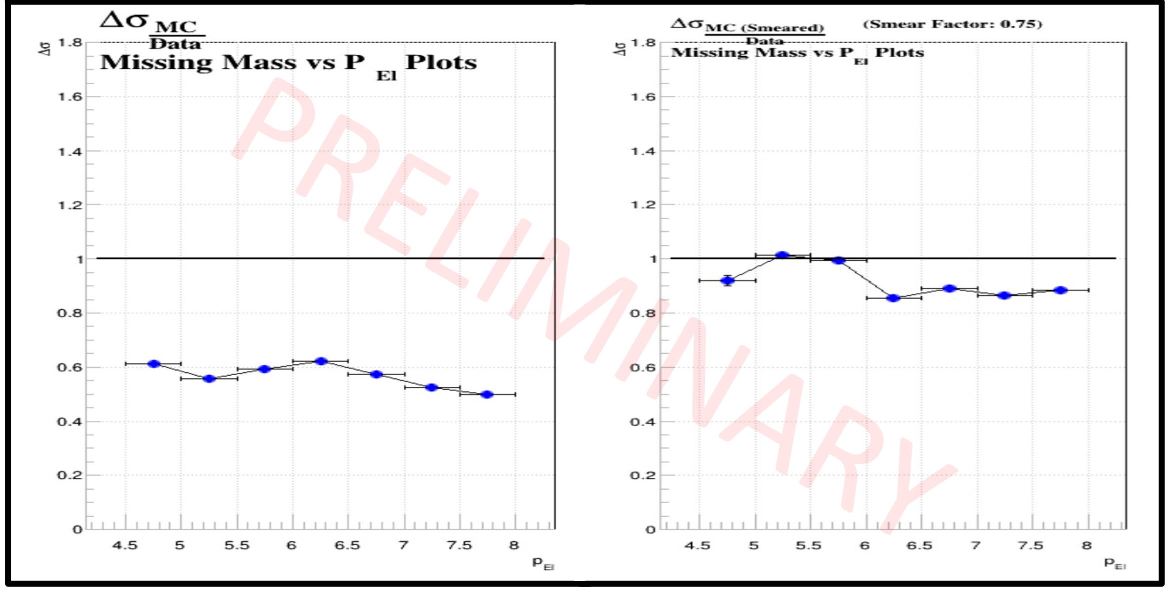
Missing Mass vs π^+ Pion Momentum:



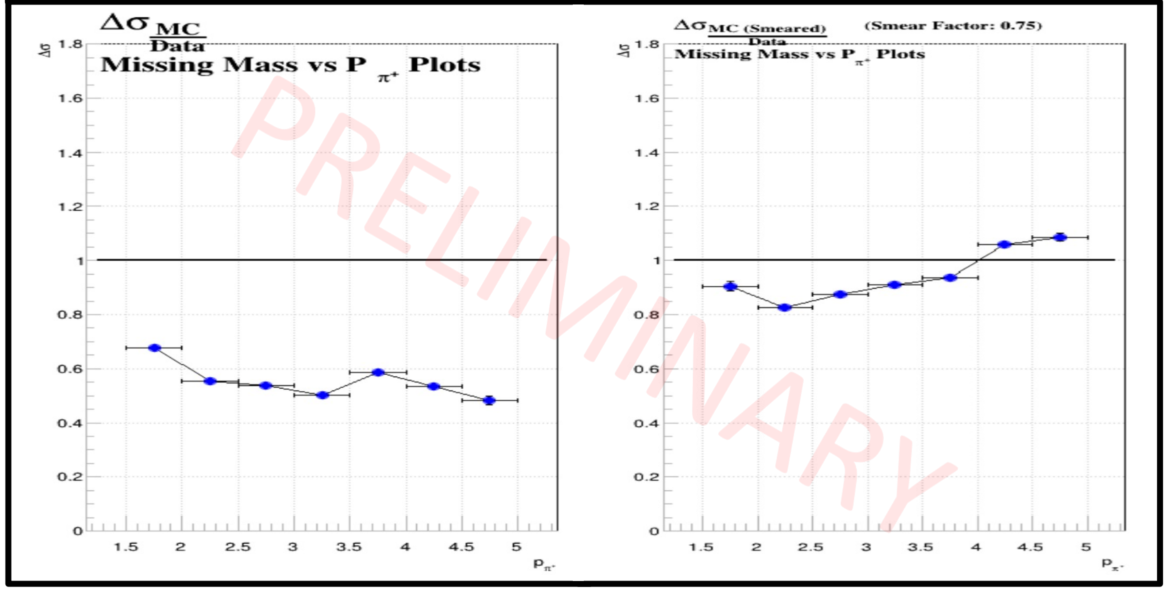
- **The momentums of the particles in these plots are <u>CORRECTED</u> (see Momentum Corrections from Exclusive Events)**
- Momentum Smearing is applied in addition to existing MC reconstruction processes
- The momentum smearing functions use 2D Missing Mass plots to check how it improves the MC
  - The widths of the peaks are shown in each plot above
- Momentum smearing is done with the equation: $\mathbf{P_{Smeared} = P_{Reconstructed} + SF*(P_{Reconstructed} - P_{Generated})}$
  - **SF** is the smear factor used to modify the simulated reconstructed momentum (currently equal to 0.75)
- A properly smeared MC distribution should have approximately the same width as the Experimental data

Momentum Corrections/Smearing – Pass 1

Ratio of Missing Mass Width vs Electron Momentum:



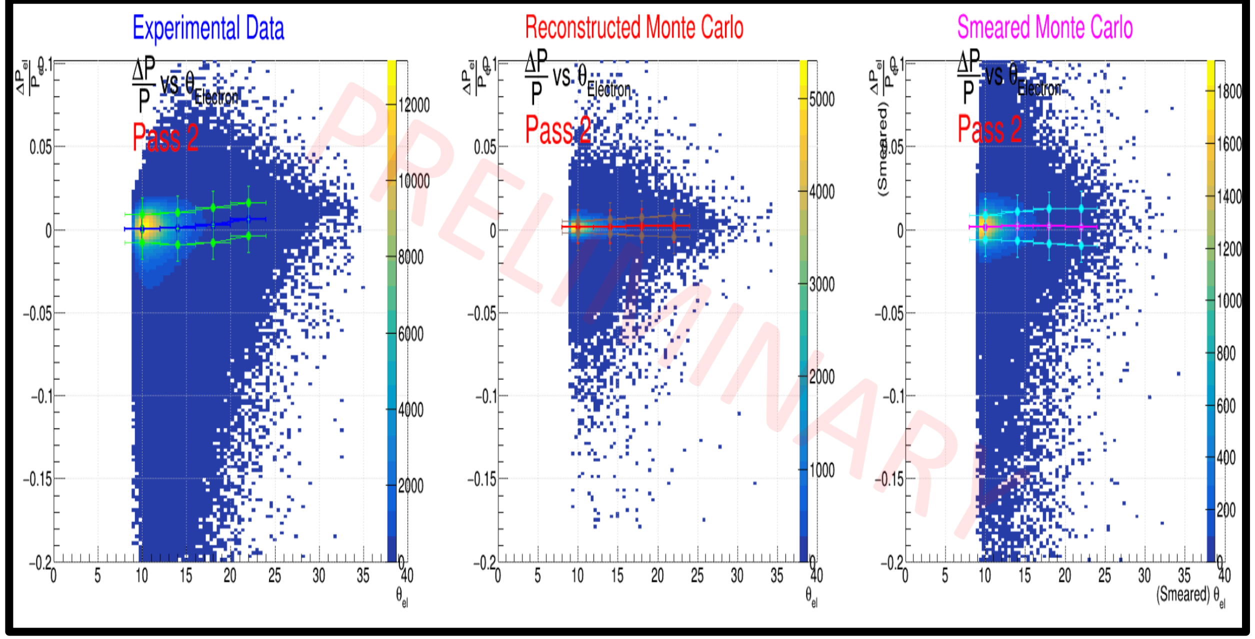
Ratio of Missing Mass Width vs π⁺ Pion Momentum:



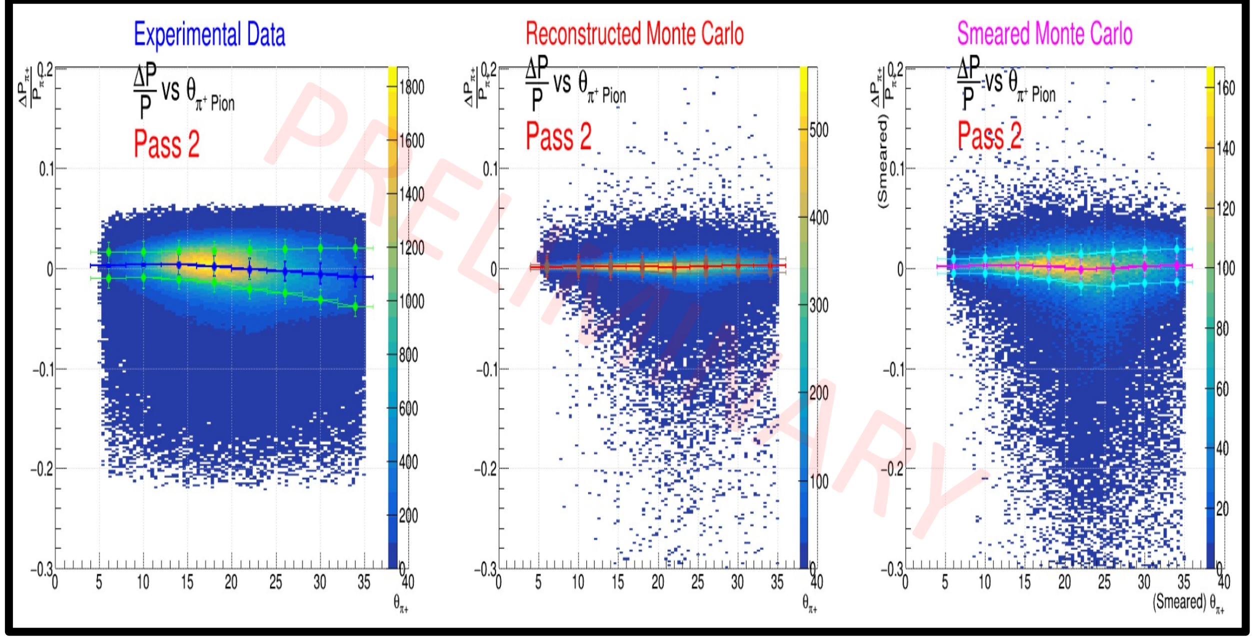
- **The ratio of the Monte Carlo and Experimental data's widths should go to 1 as smearing improves**
- Smearing the momentum also affects the widths of the Missing Mass vs azimuthal/polar angles of the particles
- Development of this correction calls for finding the best smearing parameter for all particle kinematics

Momentum Smearing – Pass 2

ΔP/P vs θ Plots for Electron Kinematics:



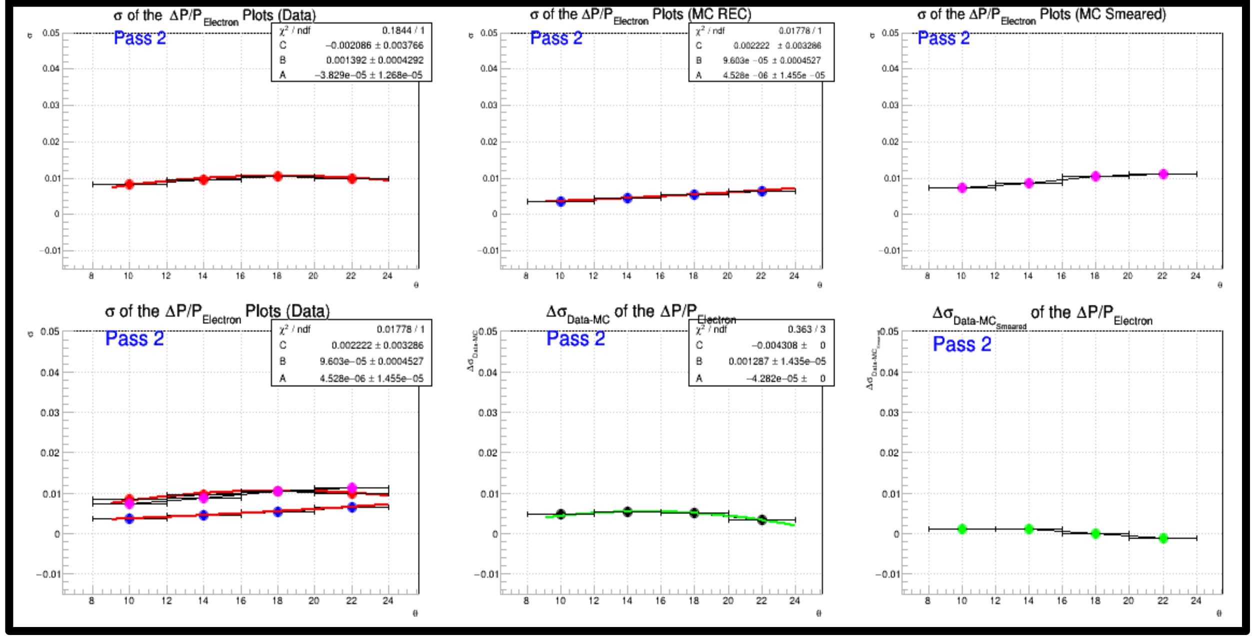
ΔP/P vs θ Plots for π^+ Pion Kinematics:



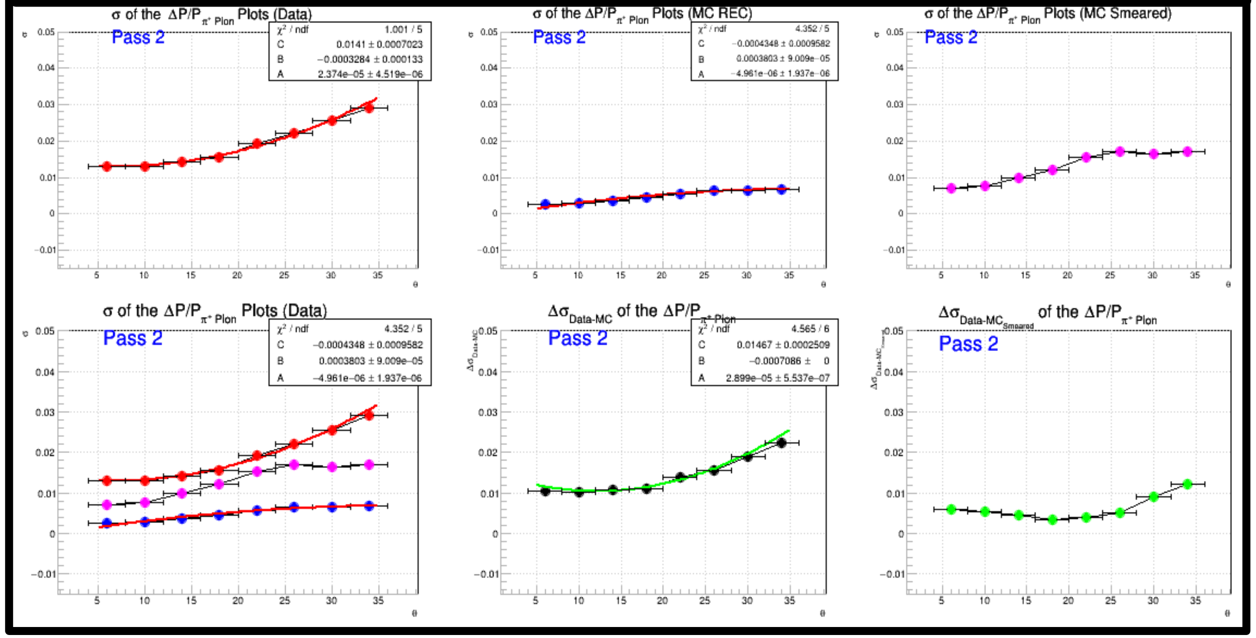
- **The momentums of the particles in these plots do NOT include Momentum Corrections from Exclusive Events**
- The momentum smearing procedure uses 2D ΔP/P vs θ plots to check the resolution matching between Data and MC
  - The resolution is defined as the widths of the peaks that are shown in each plot above
- Current Momentum smearing is done with the equation: $\mathbf{P_{Smeared} = P_{Reconstructed} + SF*(P_{Reconstructed} - P_{Generated})}$
  - **SF** is the smear factor used to modify the simulated reconstructed momentum (currently equal to 1.75)
- New (Ideal) form of Smearing Function (not yet applied) would be: $\mathbf{P_{Smeared} = P_{Reconstructed} + (P_{Reconstructed})*\sigma_{SF}(\theta)*SF*(gaus(0,1))}$
  - $\boldsymbol{\sigma_{SF}(\theta)}$ is the main smearing factor (function of θ) based on the fits of the ΔP/P vs θ plots above
  - The **gaus(0,1)** adds some randomness to the smearing while **SF** is still a static smear factor meant to help control the amplitude of smearing
- A properly smeared MC distribution should have approximately the same width as the Experimental data

Momentum Smearing – Comparison of Widths - Pass 2

Widths (σ) vs θ Plots for Electron Kinematics:

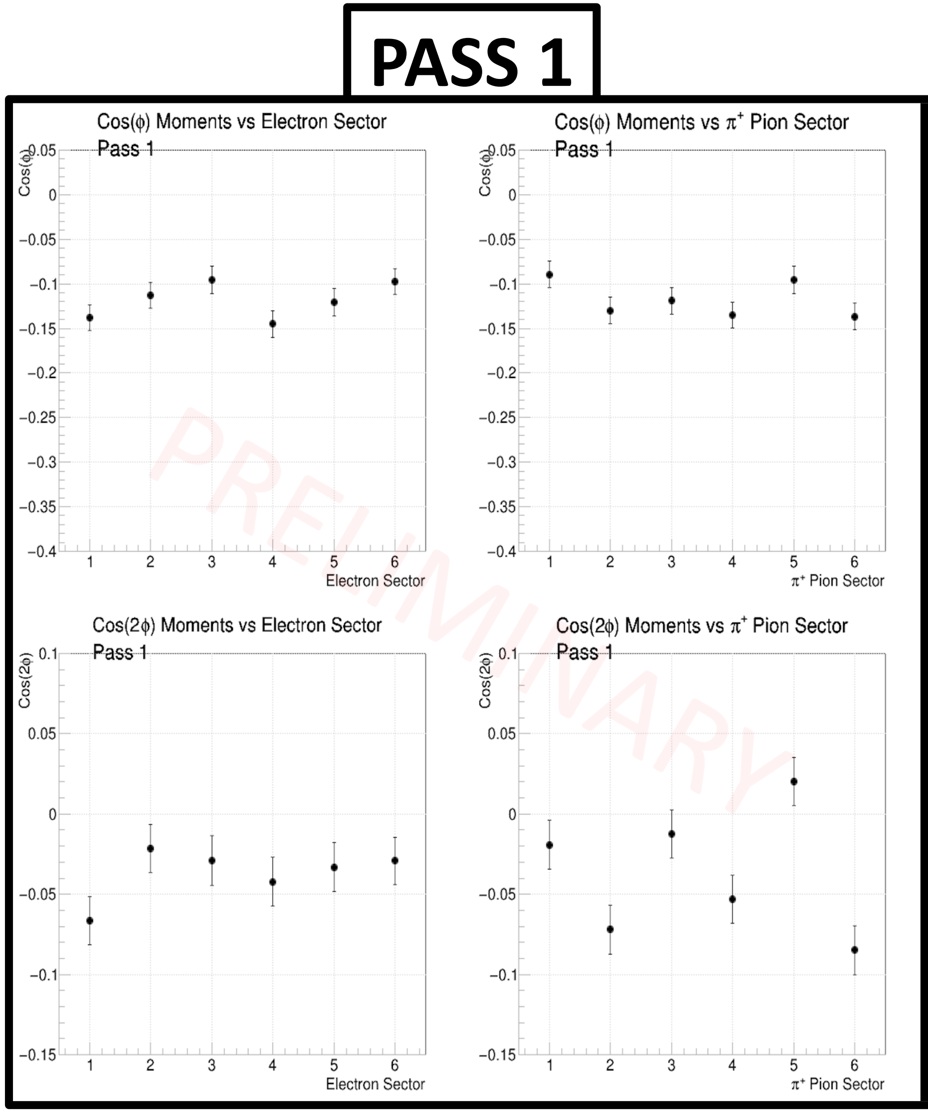


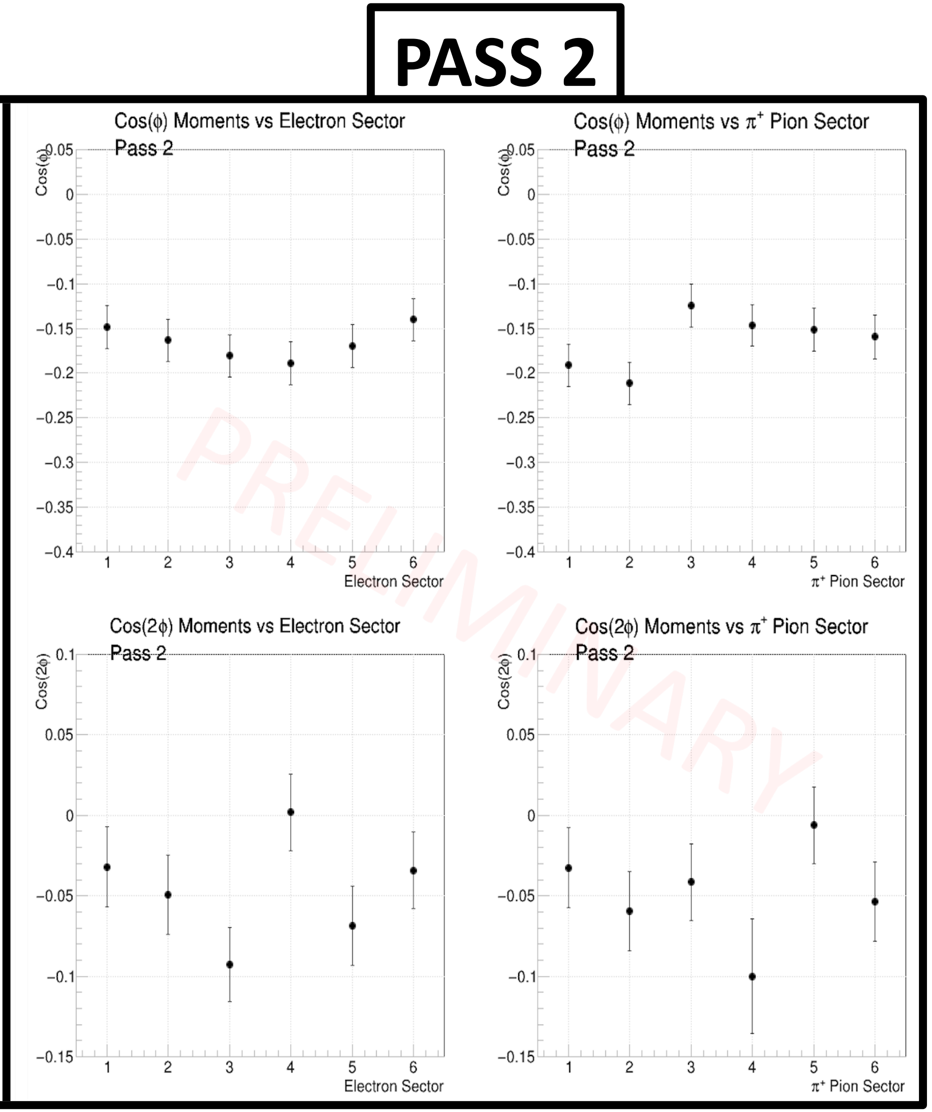
Widths (σ) vs θ Plots for π^+ Pion Kinematics:



- The **Bottom Center** and **Bottom Right** plots show the differences between the widths of **Data** and **unsmeared/smeared MC**
  - The difference should go to 0 as resolution becomes a better match
- $\boldsymbol{\sigma_{SF}(\theta)}$ can come from the **Bottom Center** plot to see how much more the MC Reconstructed momentum needs to be smeared to match the Experimental Data
  - Smeared plots here still use a static smearing factor instead of $\boldsymbol{\sigma_{SF}(\theta)}$

Sector Correlations with Cos(ϕ) and Cos(2ϕ) Measurements



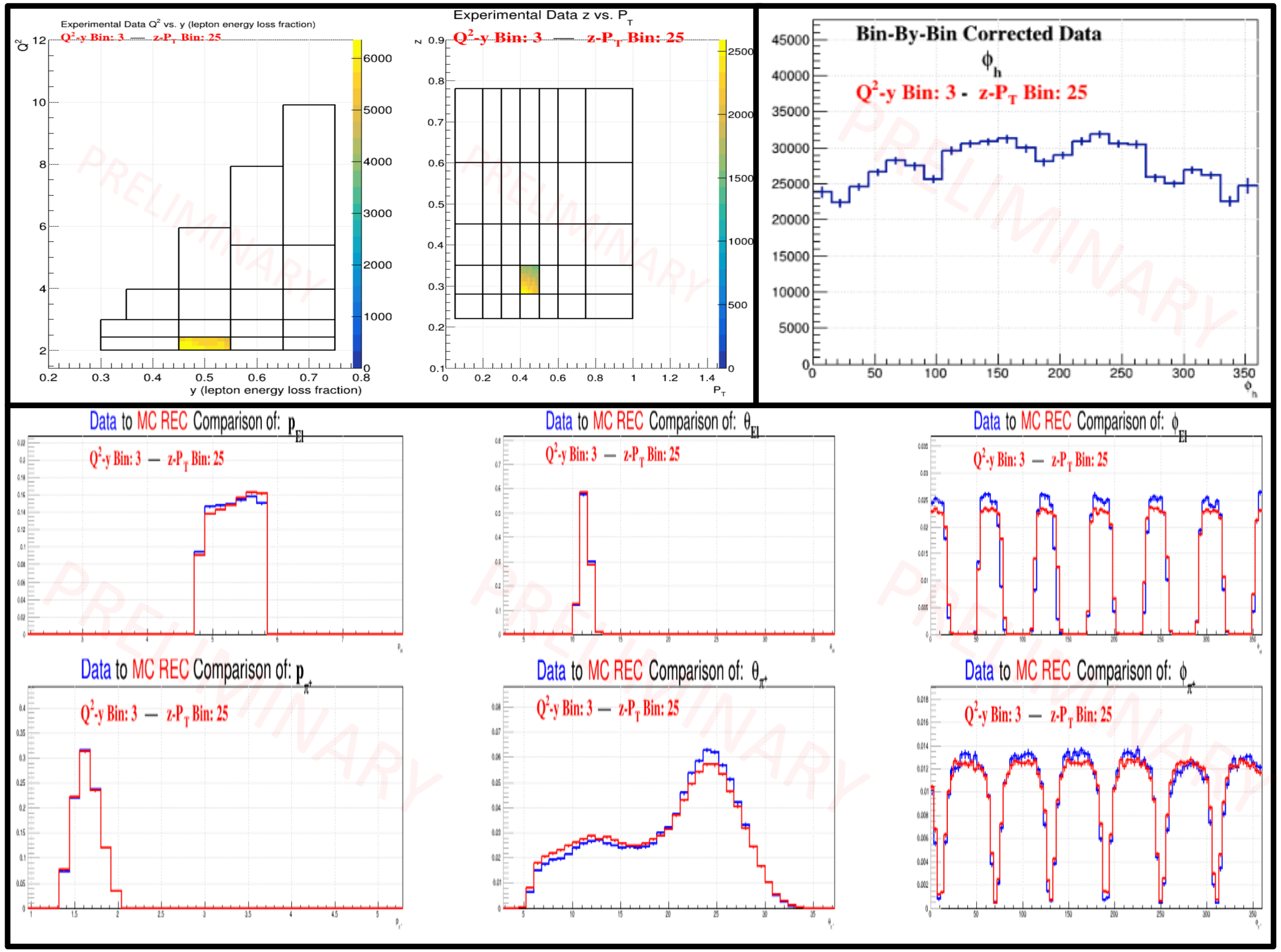


Showing the Cos(ϕ) and Cos(2ϕ) Moments as functions of the particle sector

These plots show those differences in Pass 1 and Pass 2 for when the Electron (left plots) or π^+ pion (right plots) are restricted to being detected in a single sector

Images are grouped on the left and right based on Pass version of the data being used

Sector Correlations with ϕ_h Distributions – Old Binning

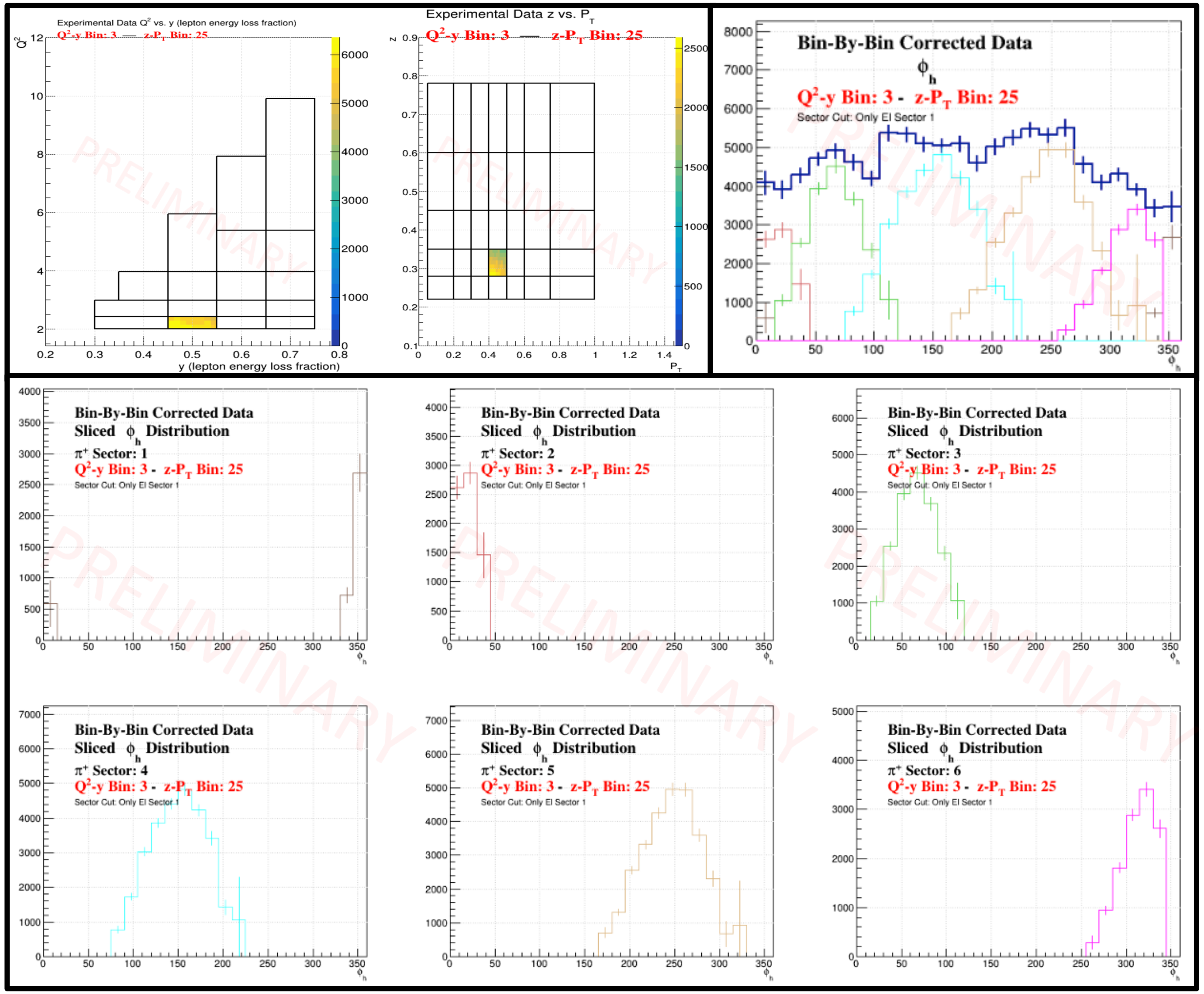


Issue: Some bins seem to have additional modulations not explained by the Cos(ϕ) and Cos(2ϕ) moments

- The 6 peak structure could be related to the forward detector sectors
- Plots below show the lab angles and momentum of both particles within the given kinematic bin of Q^2, y, z, and P_T

*Note: This example uses a slightly older version of the binning scheme and Pass 1 Data

Sector Correlations with ϕ_h Distributions – Old Binning



Issue: Some bins seem to have additional modulations not explained by the Cos(ϕ) and Cos(2ϕ) moments

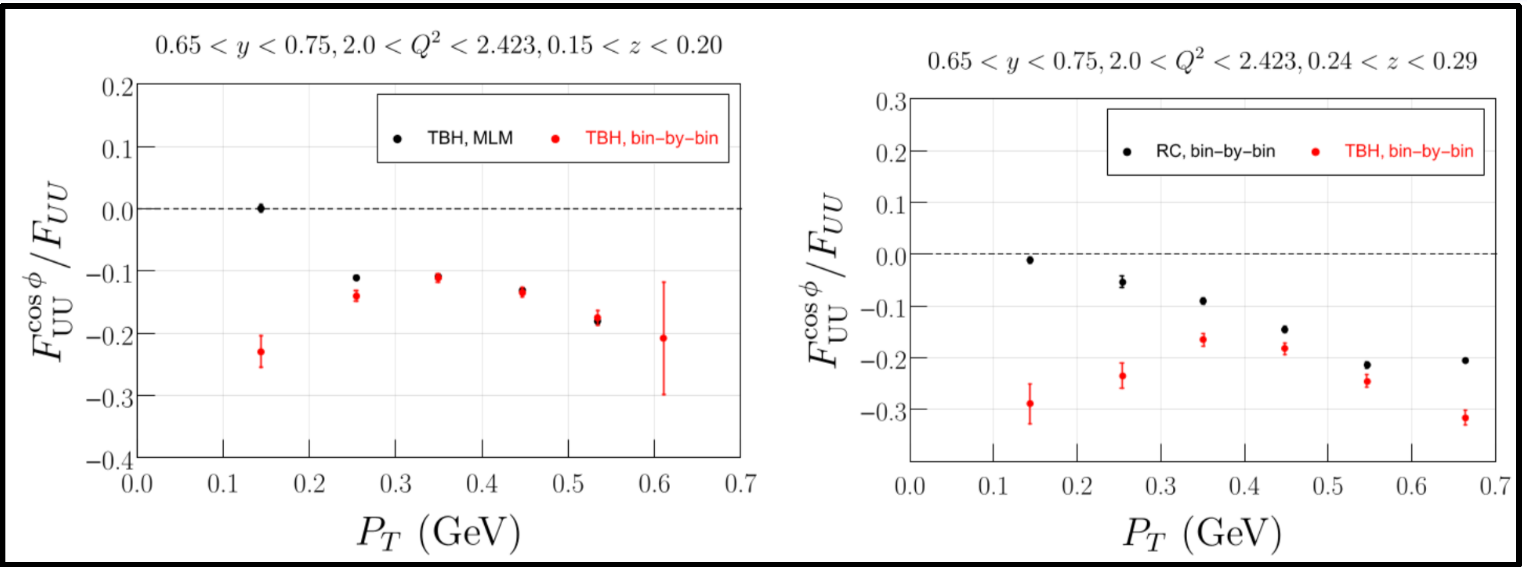
- The 6 peak structure could be related to the forward detector sectors
- Plots show the ϕ_h distributions separated based on which sector the π+ pion is detected
- Additional Requirement: Electron in Sector 1
- This suggests that the effect is related to mismatching in sector acceptance between Data and Monte Carlo

*Note: This example uses a slightly older version of the binning scheme and Pass 1 Data

Ongoing Cross-Checks with T. Hayward

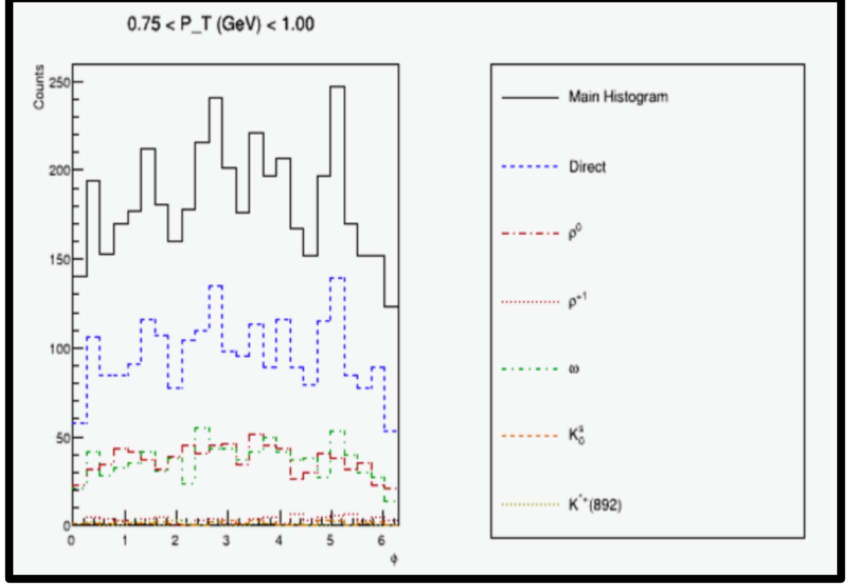
Comparisons between T. Hayward's measurements (TBH) of the Cos(ϕ_h) Moments and mine (RC)

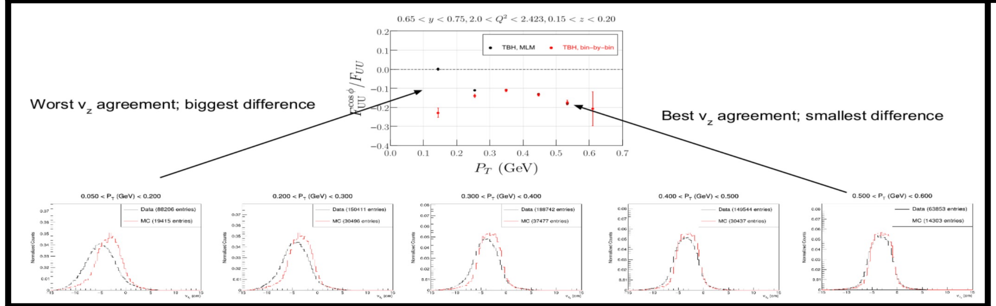
- Comparison is between different different fit methods
  - MLM → Maximum Likelihood Method
- TBH → Uses Pass 2 Data
- RC → Uses Pass 1 Data

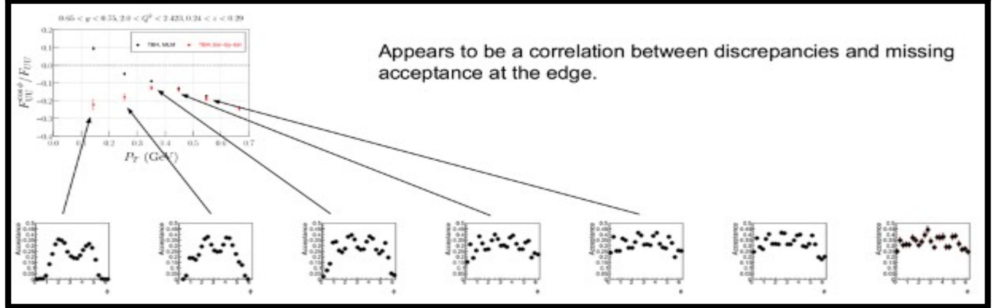


All images on this slide were created by T. Hayward

Vector Meson Contributions to ϕ_h Distributions







Investigations into discrepancies

← Suspicious Vertex Discrepancies between Data and MC

- Possibly coincidental based on other results in different kinematic regions

← Acceptance effects on the discrepancy

- Discrepancy is larger when acceptance vanishes along the edges of the ϕ_h Distributions

END

Link to more Images:

https://userweb.jlab.org/~richcap/Interactive_Webpage_SIDIS_richcap/Interactive_Unfolding_Page_Updated.html