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

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University of Connecticut

June CLAS Collaboration Meeting

Motivation

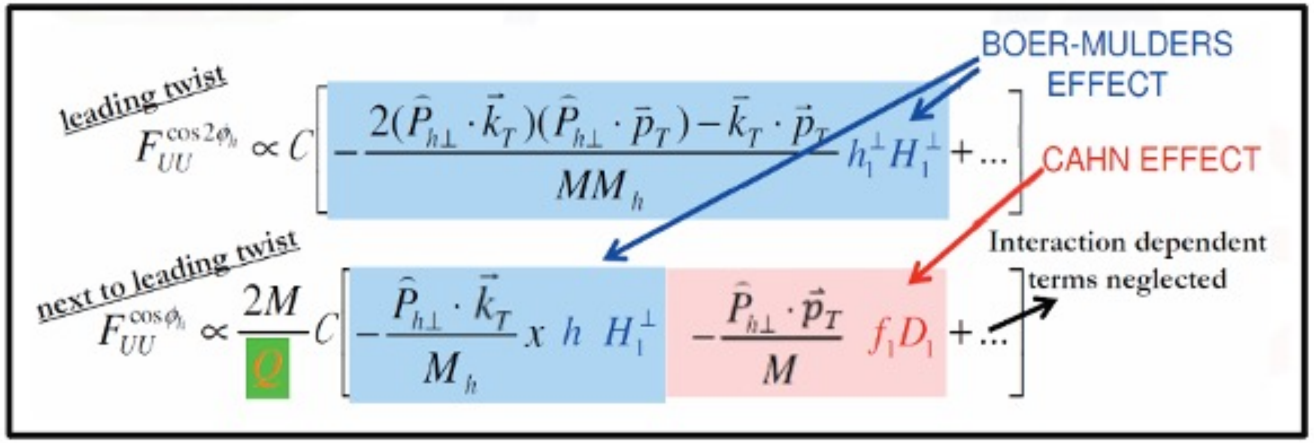
- Semi-Inclusive Deep Inelastic Scattering (SIDIS) experiments allow us to address questions about the 3D structure of nucleons
- Azimuthal modulations in unpolarized SIDIS cross-section for charged pion electroproduction can give access to the Cahn and Boer-Mulders effects
  - **Boer-Mulders Effect:** 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)

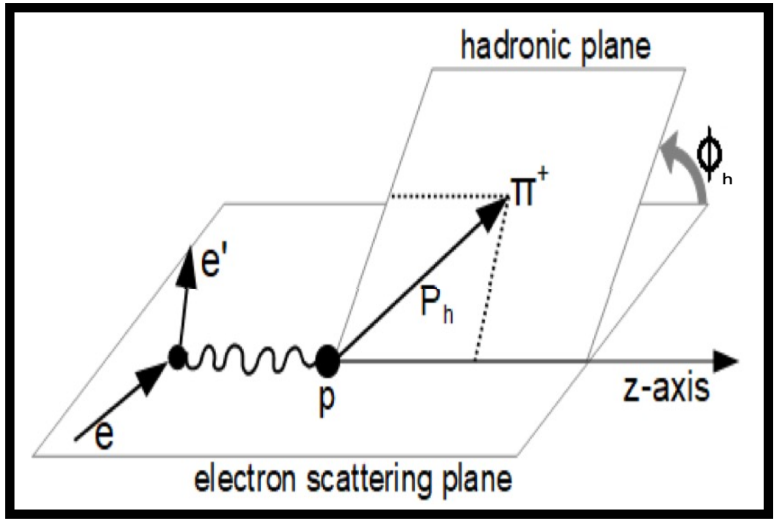
SIDIS Cross-Section and Boer-Mulders

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

Event Selection

Particle ID (PID):

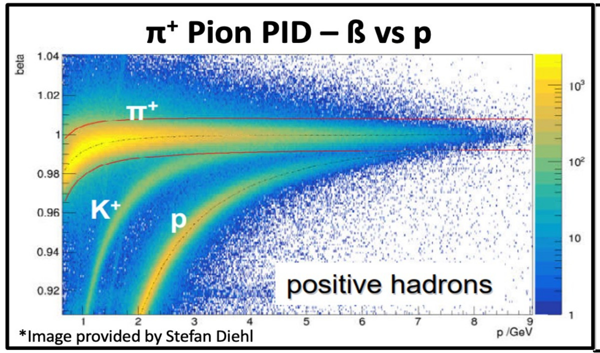
- **Electron ID:** Based on Electromagnetic Calorimeter (PCAL) and Cherenkov Counters (HTCC)
- **Hadron (π^+) ID:** Based on Time-Of-Flight Counters (TOF) and the correlation of velocity (ß) and momentum

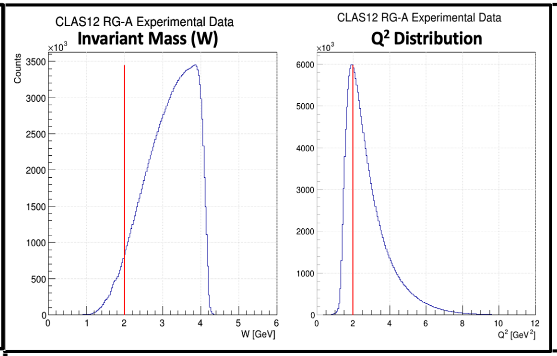
Using Data from RG-A Fall 2018

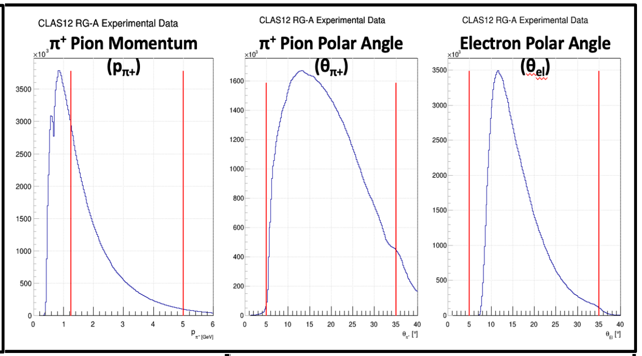
10.6 GeV Polarized Beam
Unpolarized Liquid Hydrogen Target
Inbending Forward Tracking Only

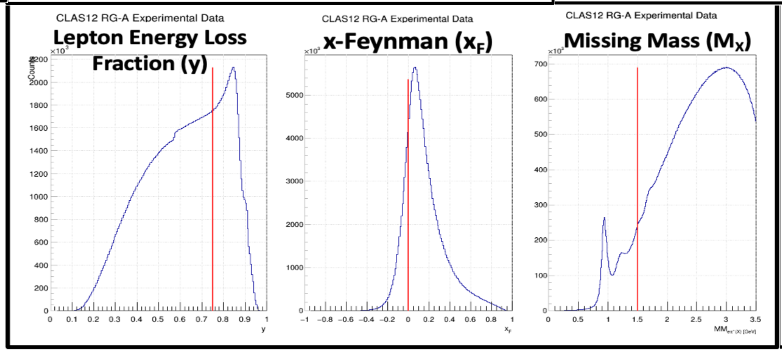
Analysis Cuts:

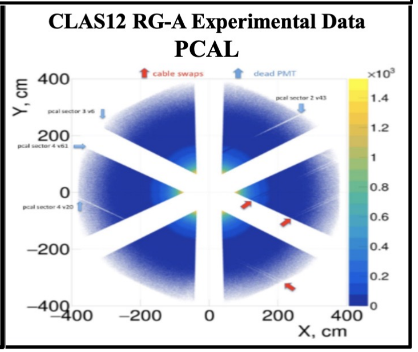
- **SIDIS Cuts**:
  - W > 2 GeV
  - $Q^2 > 2$ GeV^2
- **Other Analysis Cuts:**
  - $p_{\pi+}$ Cut: 1.25 GeV < $p_{\pi+}$ < 5 GeV
  - θ-angle Cut: 5° < $\theta_{particle}$ < 35°
  - y < 0.75 (minimize other background processes)
  - $x_F > 0$ (minimize contributions from target fragmentations)
  - Missing Mass Cut: M_x > 1.5 GeV (limit on exclusive events)
  - Fiducial Cuts (e.g., accounts for bad channels present in data)











Analysis Procedure

Experimental extraction of cross-section

$$\frac{d^5\sigma}{dQ^2 dy dP_T dz d\phi_h} = \frac{1}{\Gamma_\nu} \underbrace{\frac{1}{\Delta Q^2 \Delta y \Delta P_T \Delta z \Delta\phi_h}}_{\text{Bin Volume}} \frac{N}{R \cdot BC \cdot \eta \cdot N_0} \underbrace{\frac{1}{(N_A \cdot \rho \cdot t/A_w)}}_{\text{Target Number Density}}$$

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

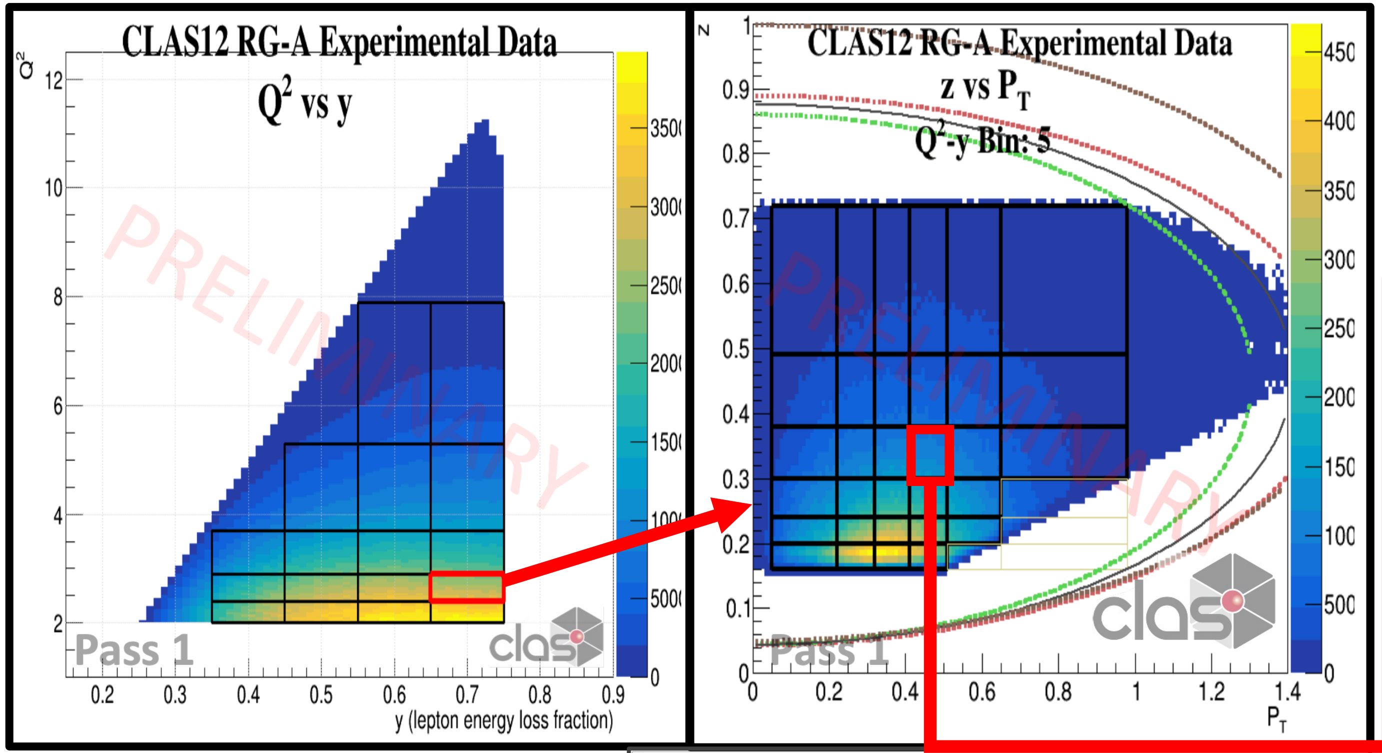
SIDIS MC are generated with LEPTO event generator

Multidimensional Analysis Procedures

Multidimensional Kinematic Binning (5 Dimensions)

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

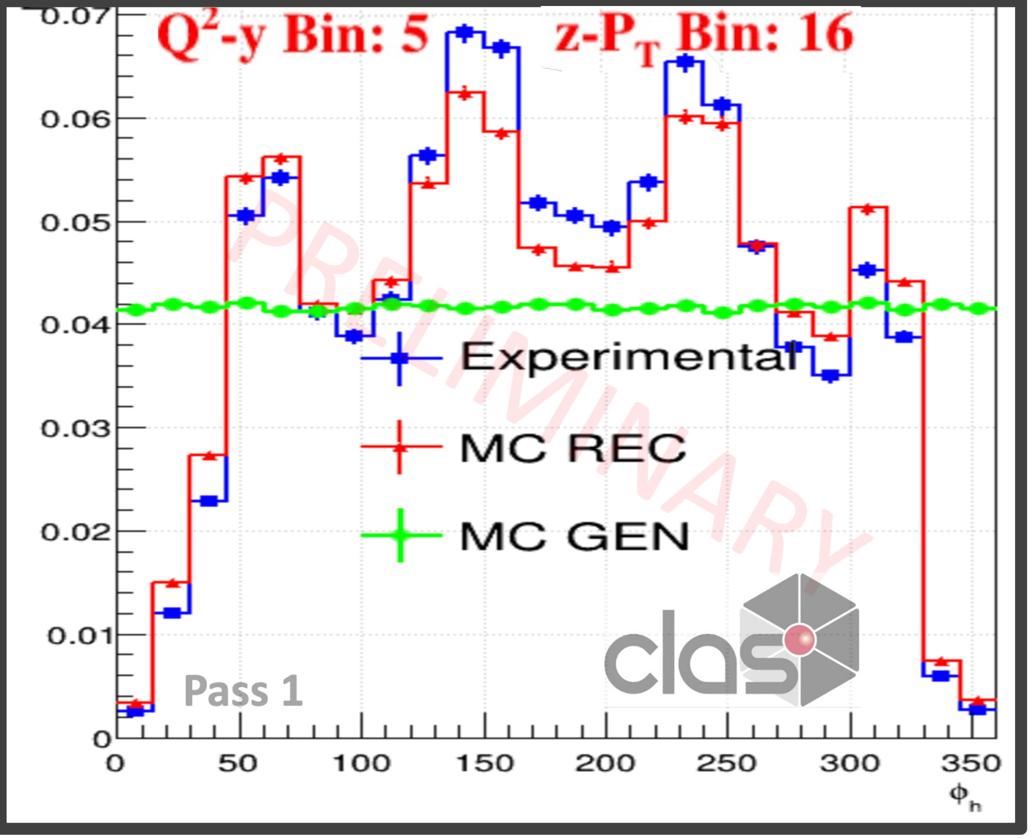
ϕ_h distribution for the Q^2-y-z-P_T bin shown in red



Missing Mass Cut Lines:

Minimum MM Cut	Maximum MM Cut
Center MM Cut	Exclusivity peak

Normalized Comparison of Data, Reconstructed, and Generated φ_h



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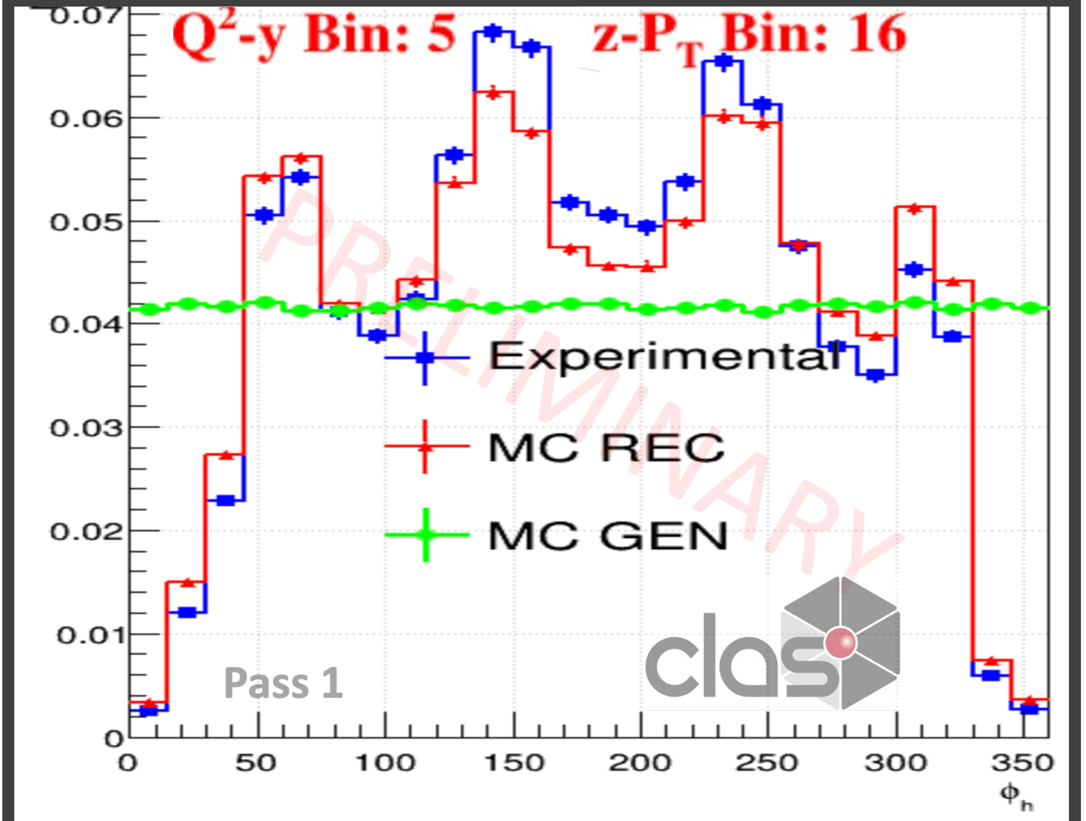


Apply Multidimensional Acceptance Corrections and convert to a cross-section measurement

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

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

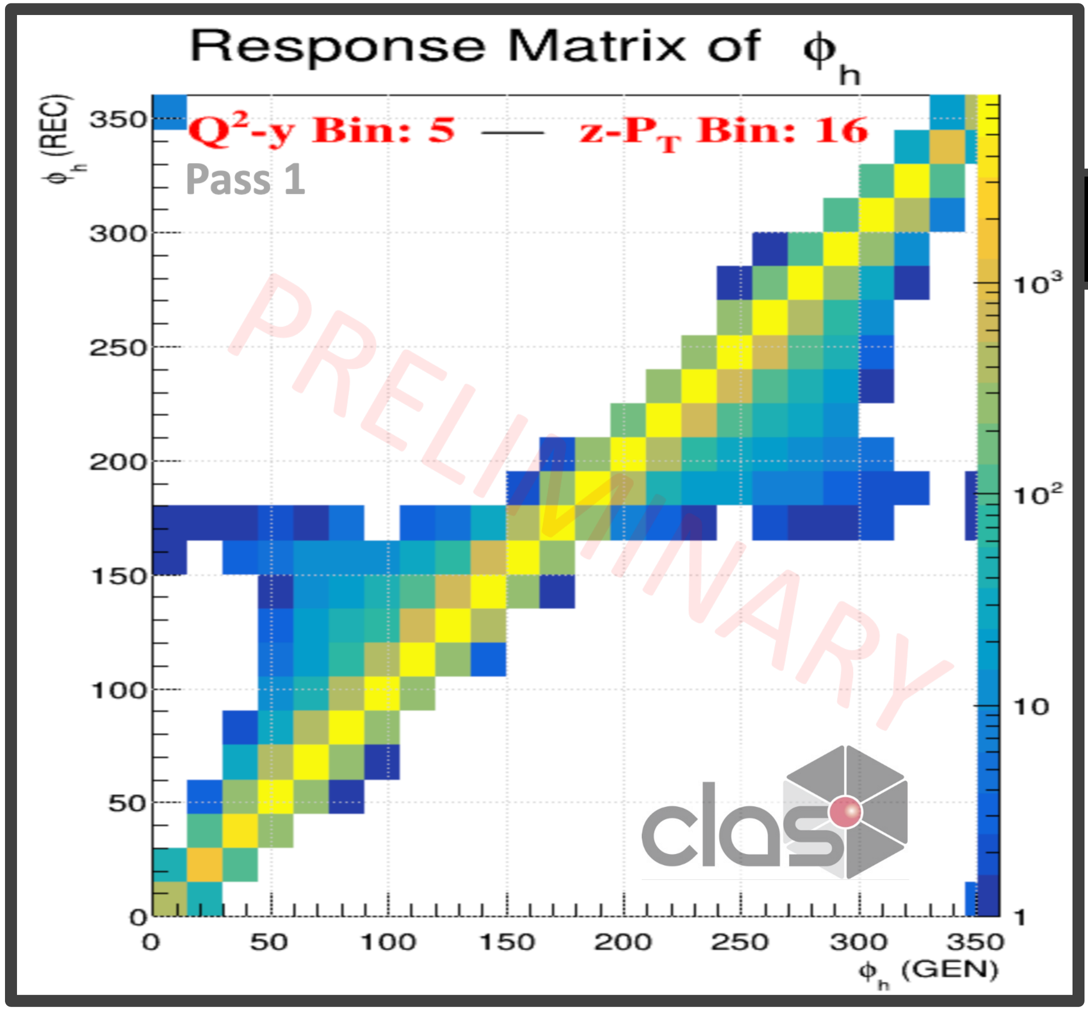
- Acceptance Unfolding: $Y_i = A_{(i,\,j)} X_j + \beta_i \Leftrightarrow X_j = A^{-1}_{(i,\,j)}(Y_i - \beta_i)$

where:

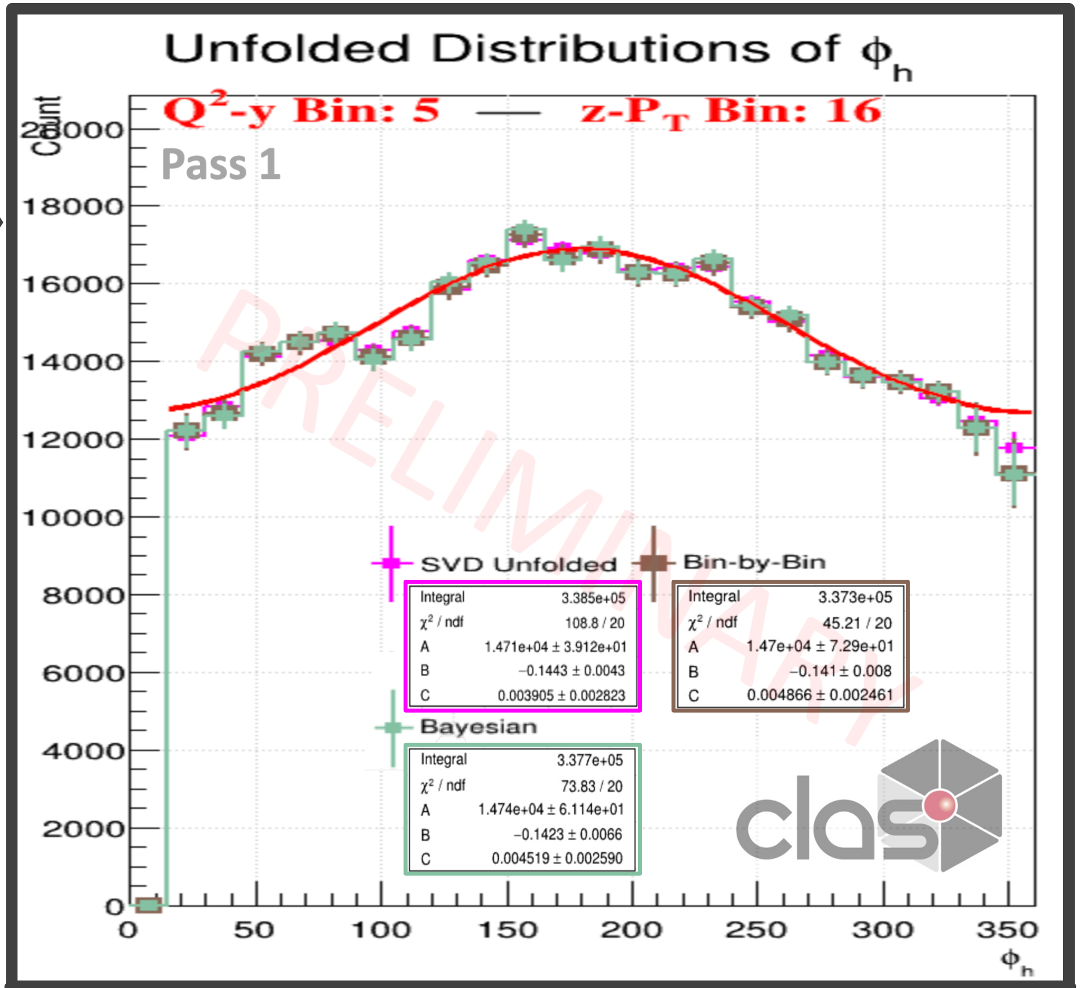
- Y_i = Number of events experimentally measured in the *i*-th bin
- X_j = Number of acceptance-corrected events in the *j*-th bin
- β_i = Number of events from outside the signal region measured in the *i*-th bin

1D Unfolding

Using the Multidimensional Kinematic Bin from prior example



Unfolding Procedures

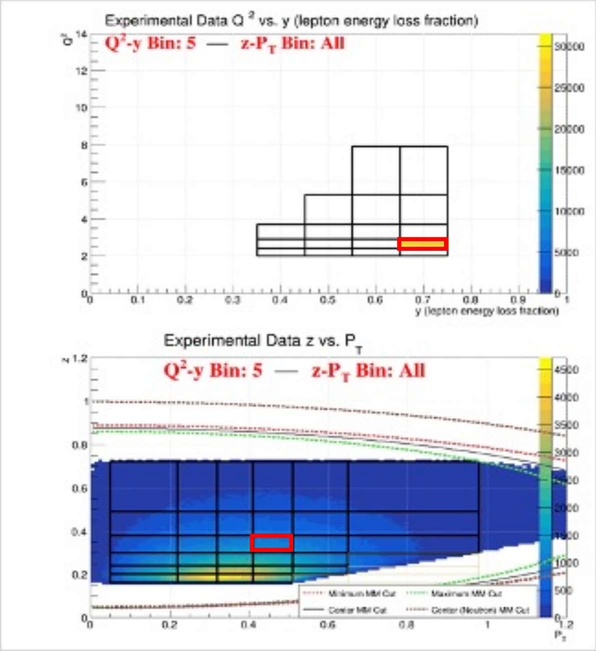


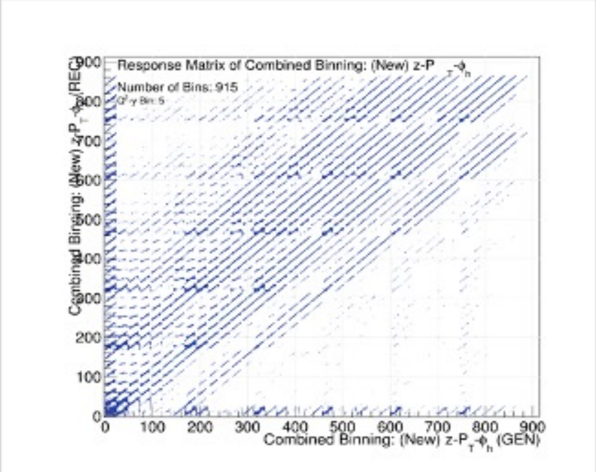
Parameters shown are from the fits previously described

3D Unfolding

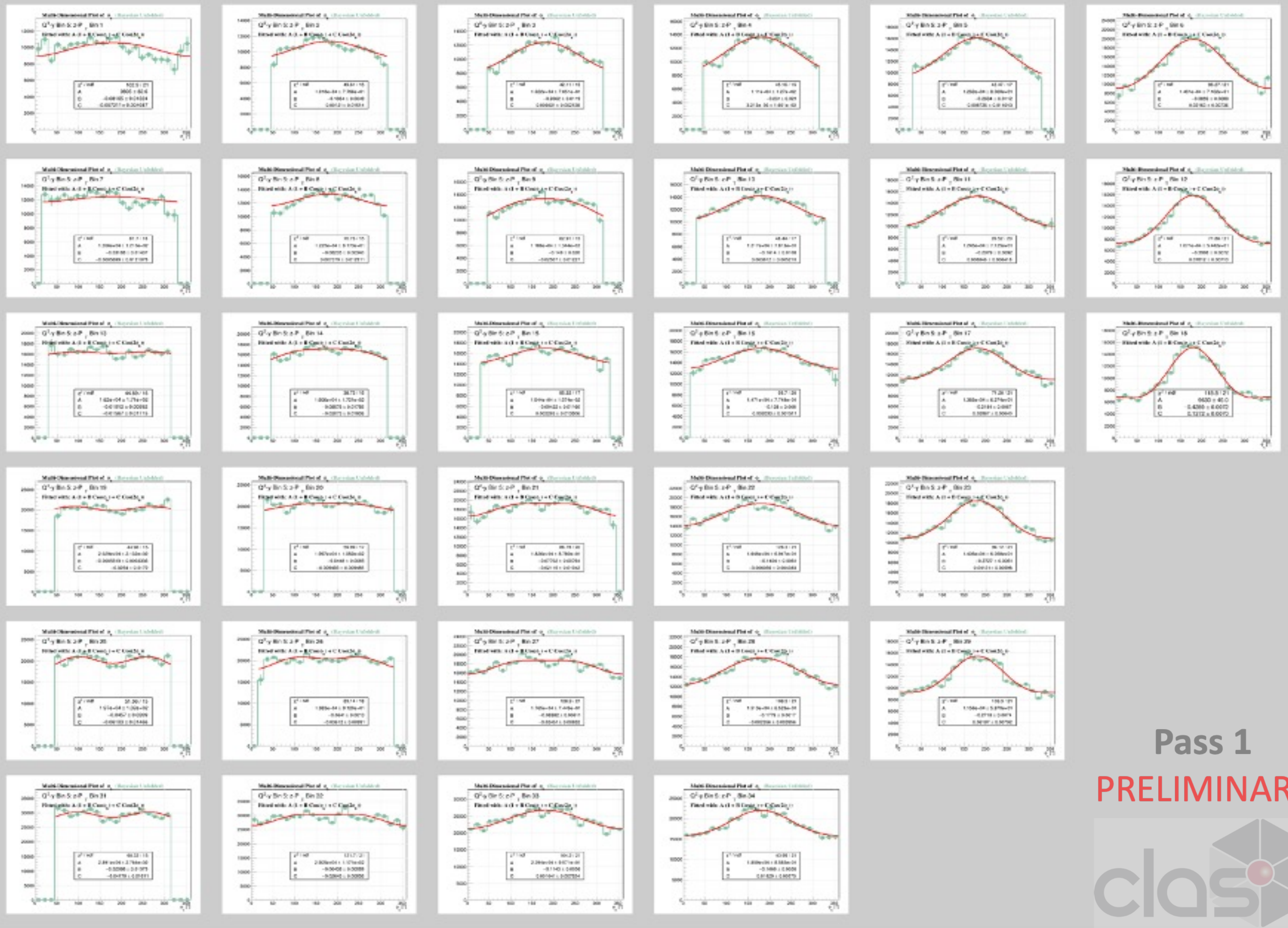
Using z-P_T-ϕ_h Multidimensional Bins

Q^2-y Bin 5





Unfolded with Bayesian Method



Pass 1

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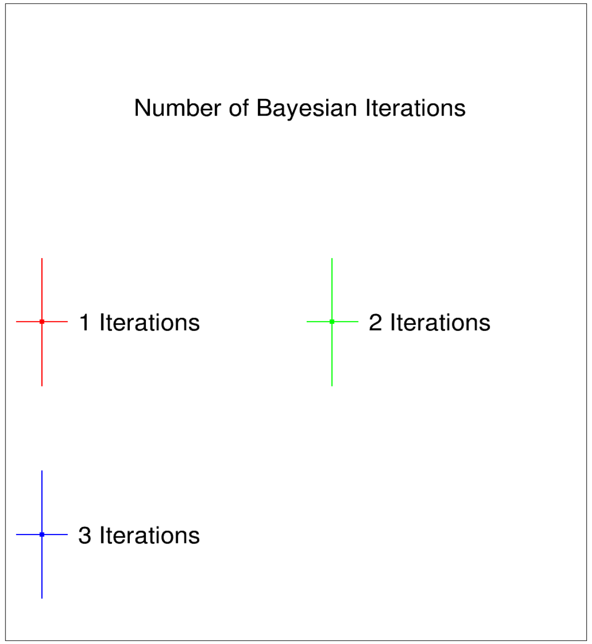
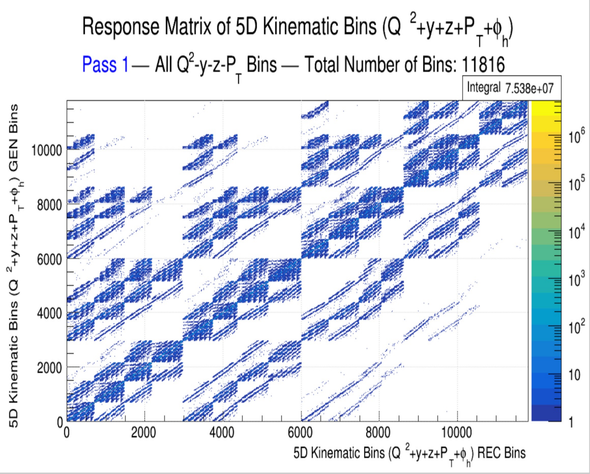
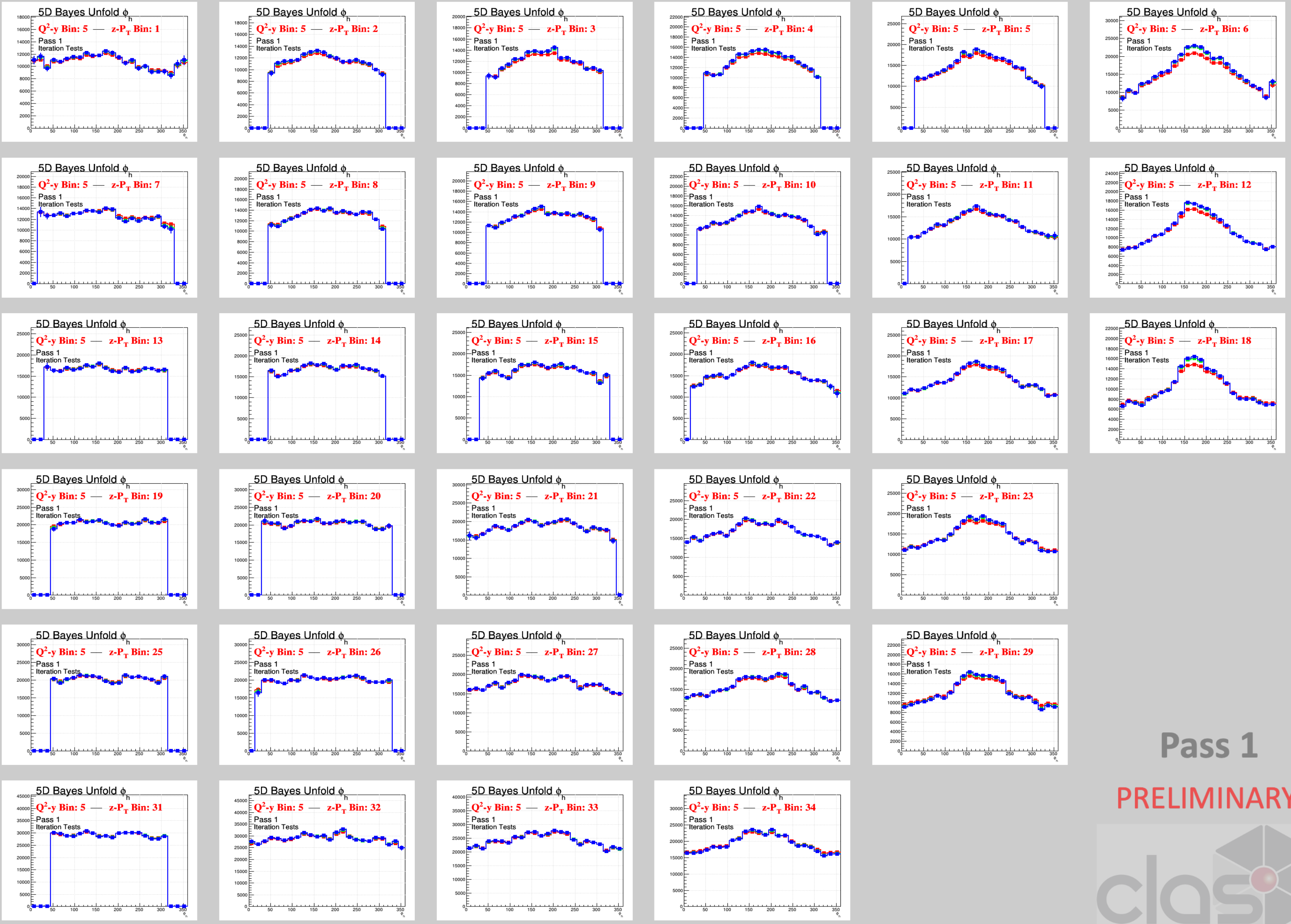
5D Unfolding – Iteration Test

Using Q^2-y-z-P_T-ϕ_h Multidimensional Bins

Q^2-y Bin 5







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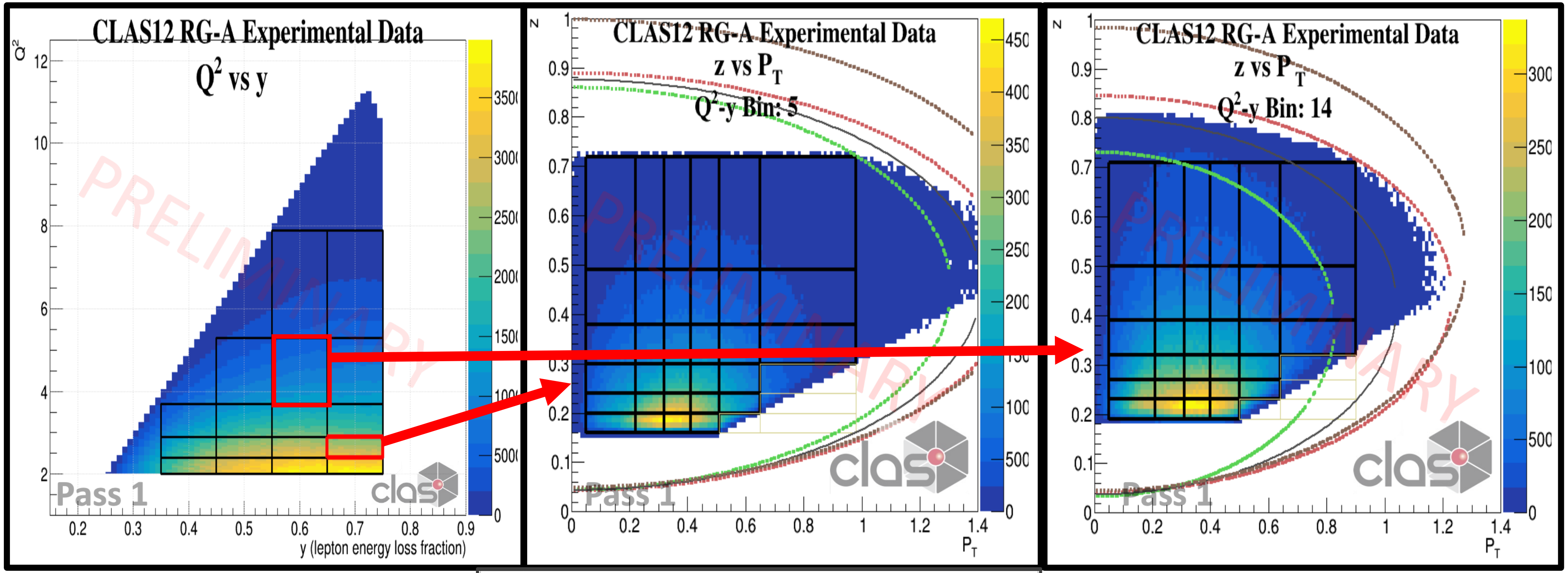
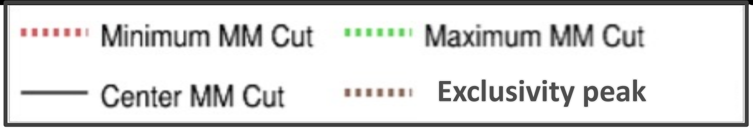
Migrations from Outside Kinematic Regions

Lines drawn here show Missing Mass Cuts in different Q^2-y bins

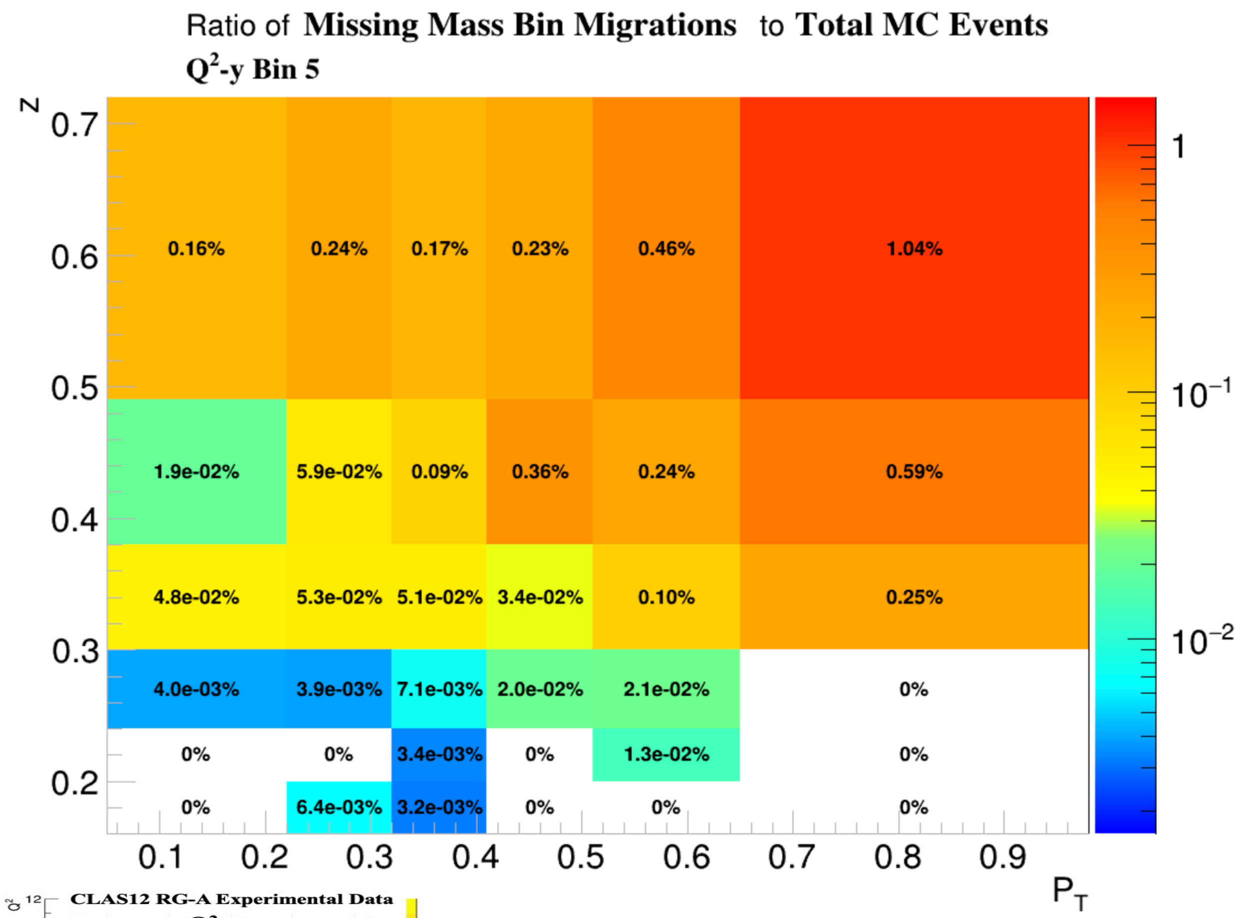


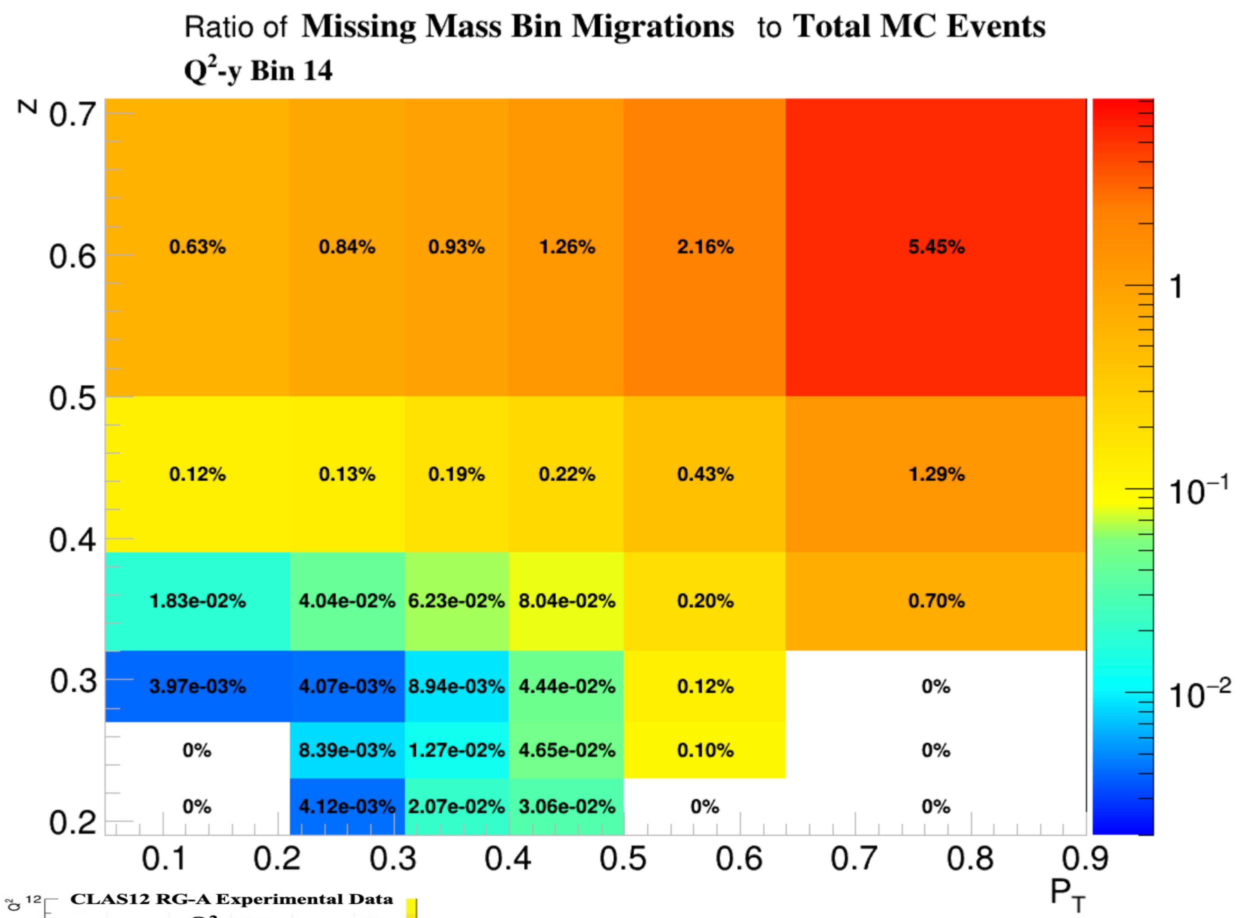
Events migrated from outside the borders of the signal region are removed with ß vector in the unfolding procedure

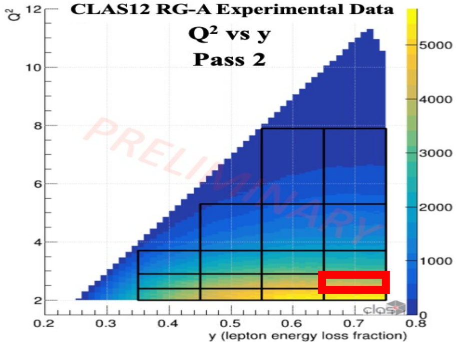
Missing Mass Cut Lines:



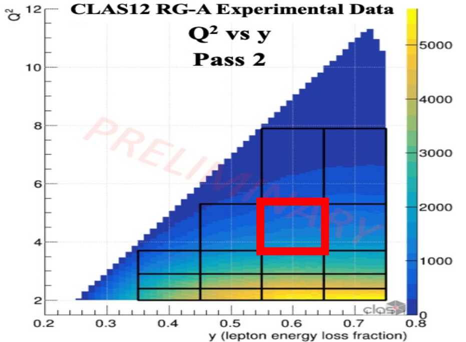
Missing Mass Migration Contributions (Per Q^2-y Bin)







Average Contribution to MC statistics from **Missing Mass Migrations** per z-P_T bin in this Q^2-y region is **0.74%**



Average Contribution to MC statistics from **Missing Mass Migrations** per z-P_T bin in this Q^2-y region is **3.29%**

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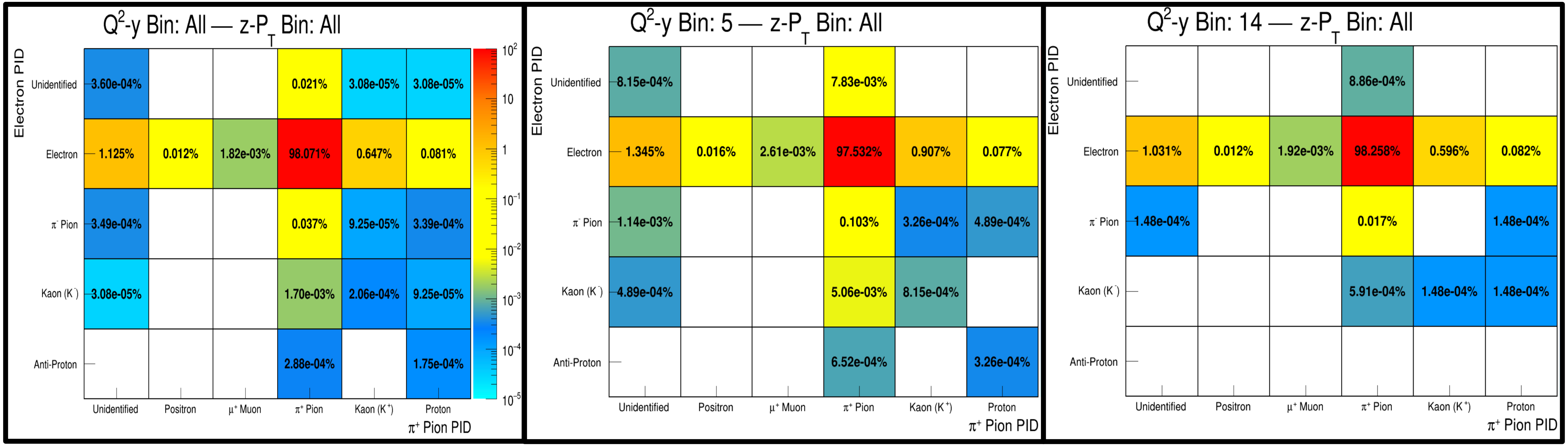
Particle Misidentification

True PID of the MC Events Reconstructed as Electrons/Pions



Meant to model remaining particle misidentification not caught by PID cuts

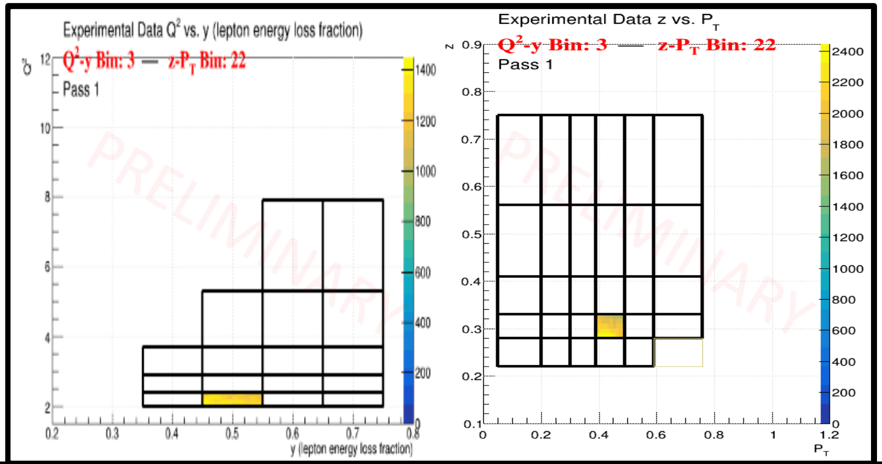
"Unidentified" Particles are those that had a reconstructed particle that could not be matched to a generated particle within the matching criteria used

Integrating over z-P_T: misidentification rate ranges from 1.5-2.5% (depending on Q^2-y bin), the average is ~1.8%

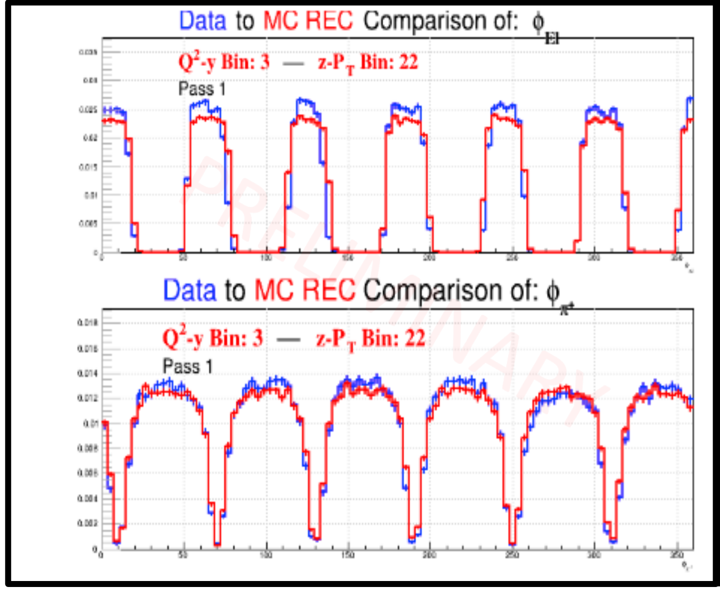
(About 58% of this is from Unidentified Particles on average)

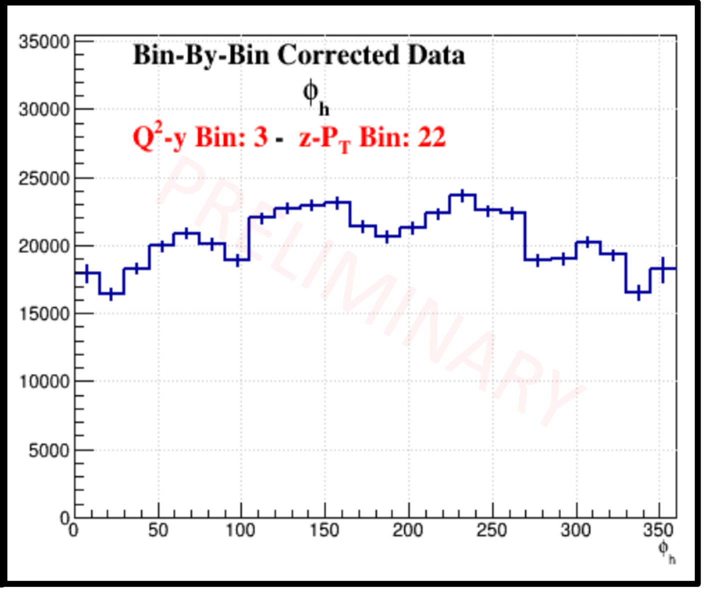
The misidentification rate within individual z-P_T Bins ranges from 0.8-6.5%

Sector Dependence of ϕ_h Distributions



Comparison of Lab ϕ angles of both particles for Data and MC
↓

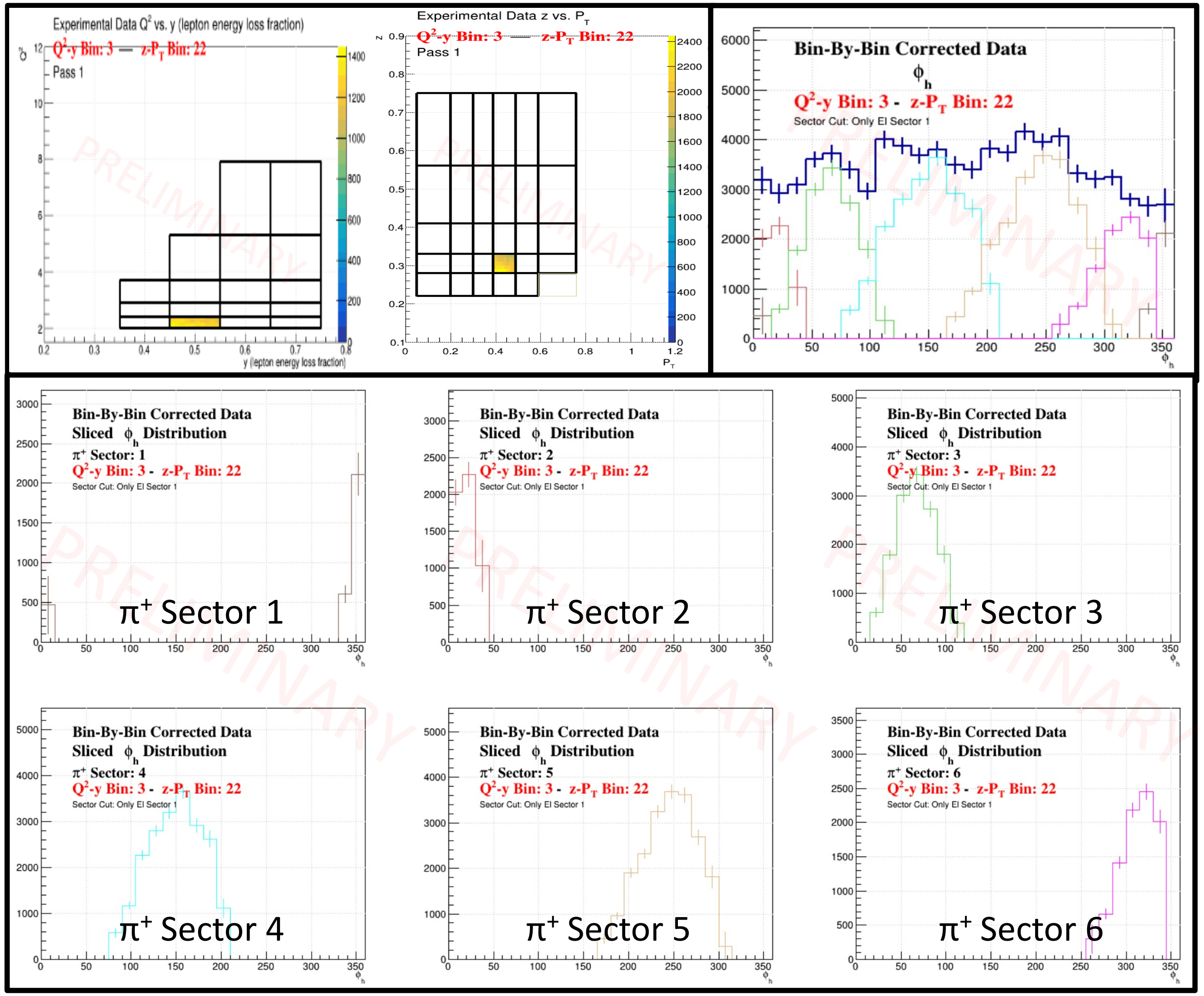




Issue: Some bins seem to have additional modulations AFTER Acceptance Corrections not explained by the Cos(ϕ) and Cos(2ϕ) moments

- The 6 peak structure is related to the forward detector sectors

Sector Dependence of ϕ_h Distributions



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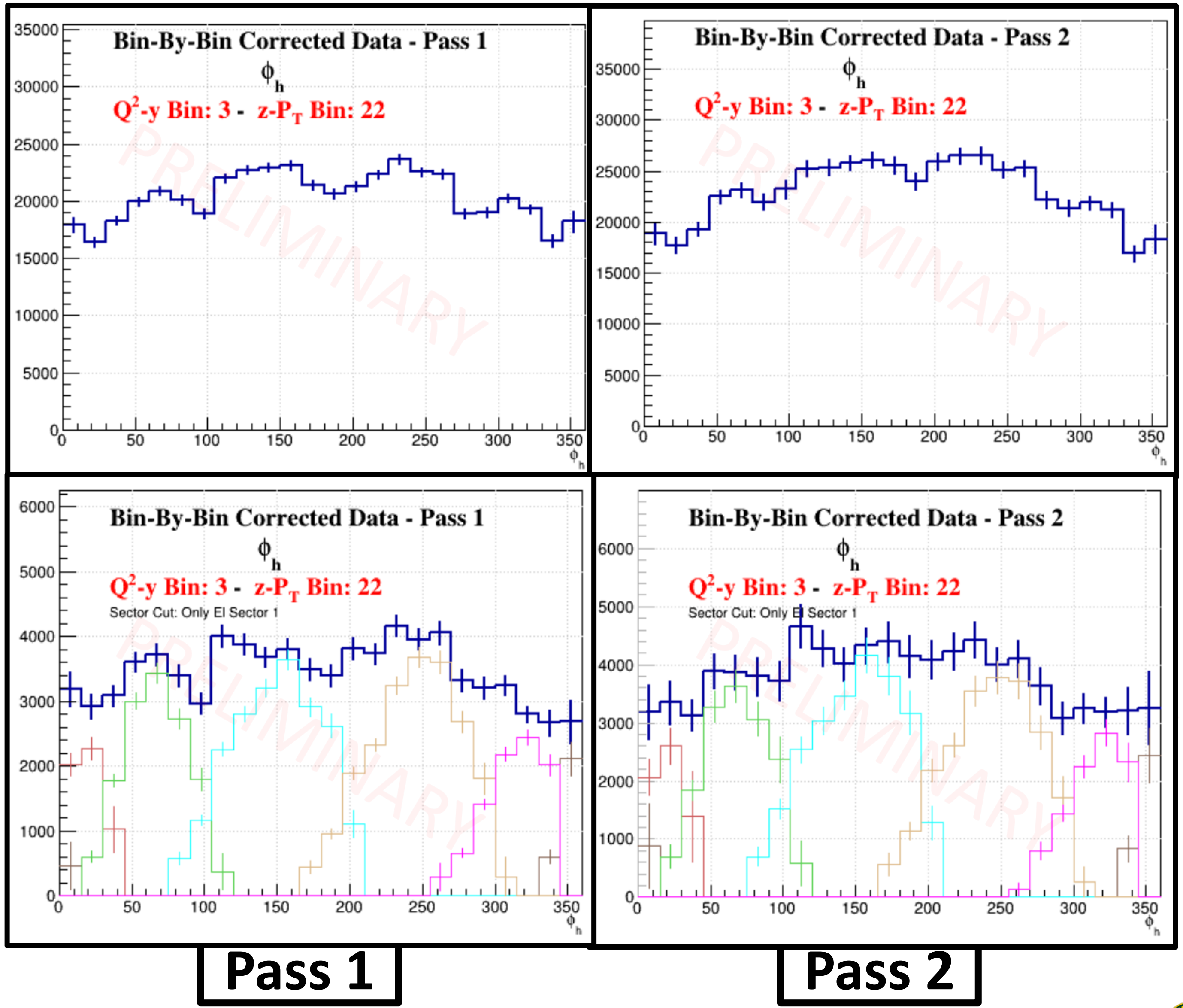
- The 6 peak structure is related to the forward detector sectors
- **Plots show the ϕ_h distributions separated based on which sector the π+ pion is detected**
- Additional Requirement: Electron in Sector 1
- This suggests that the effect is related to mismatching in sector acceptance between Data and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

Sector Dependence of ϕ_h Distributions – Pass 2 Comparison

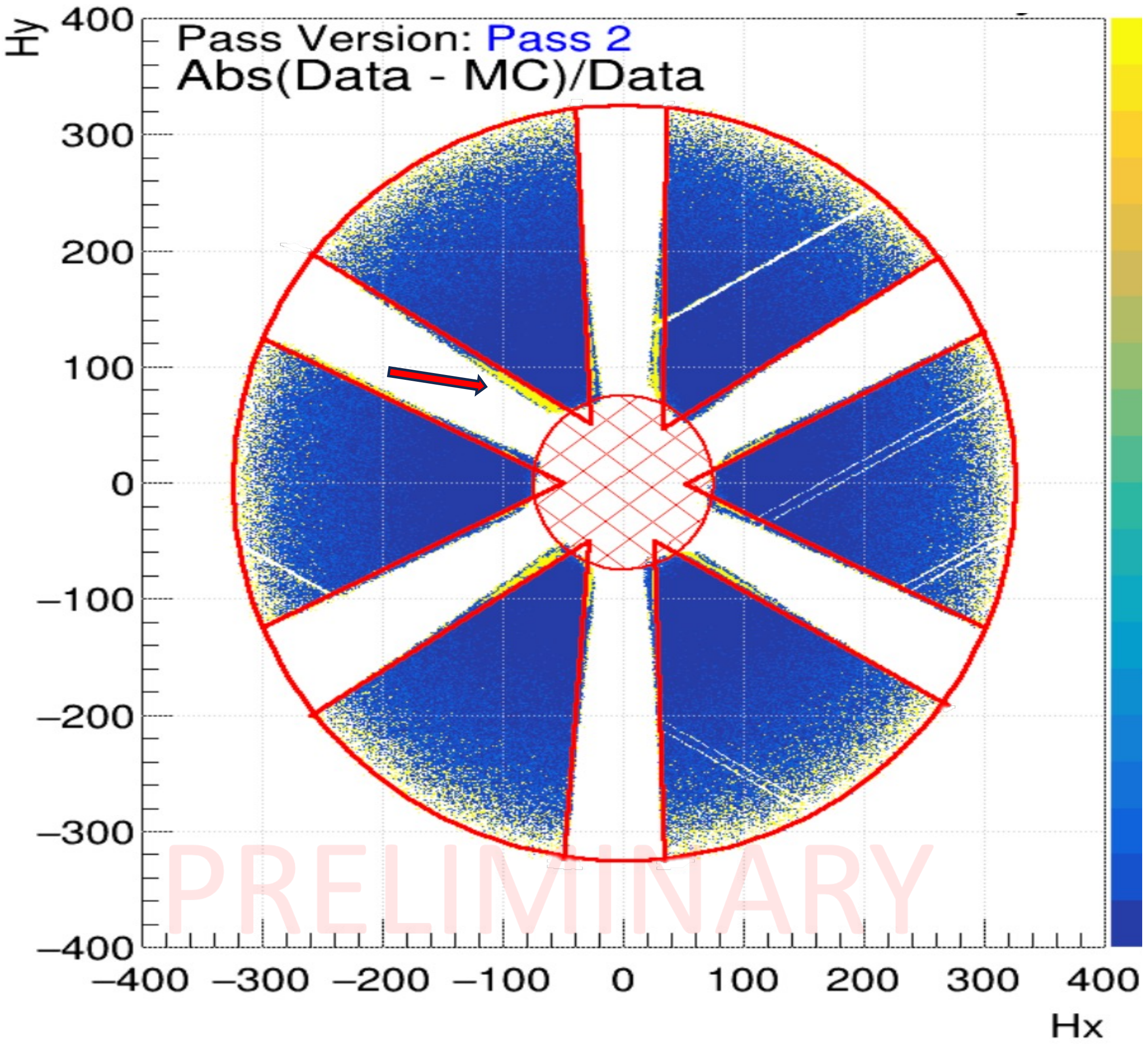


Issue: Some bins seem to have additional modulations AFTER Acceptance Corrections not explained by the Cos(ϕ) and Cos(2ϕ) moments

- The 6 peak structure is 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
- **Also present in Pass 2**

Refinement of Fiducial Cuts

Electron Hit Position Comparison

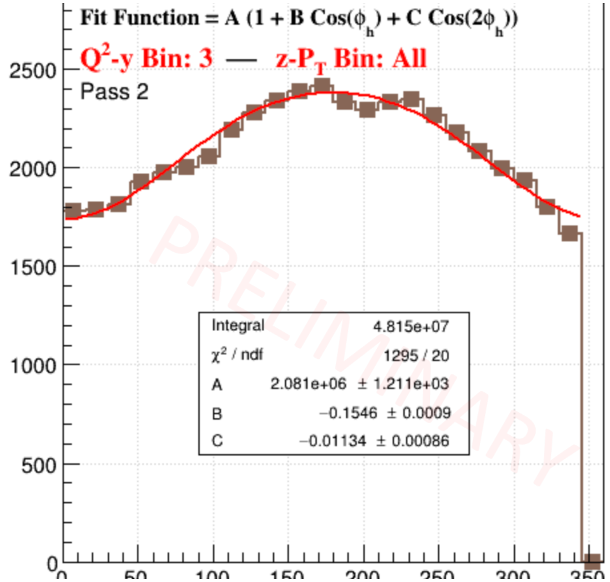


Shows the Percent Difference between the Normalized Data and Reconstructed MC For Electrons in the Particle Calorimeter

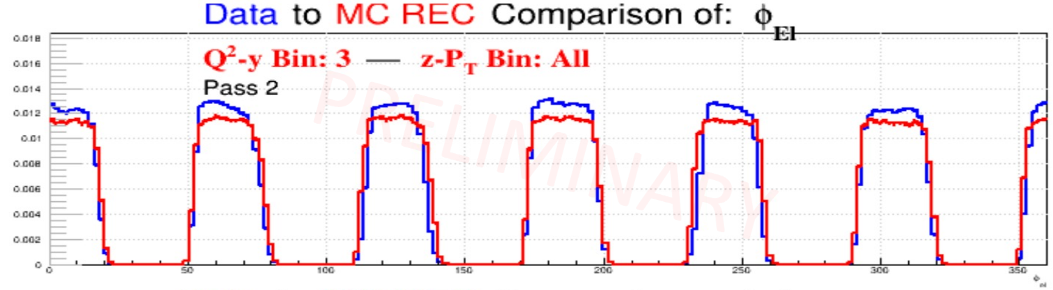
The highlighted regions show where the percent difference between Data and MC exceeds 100%

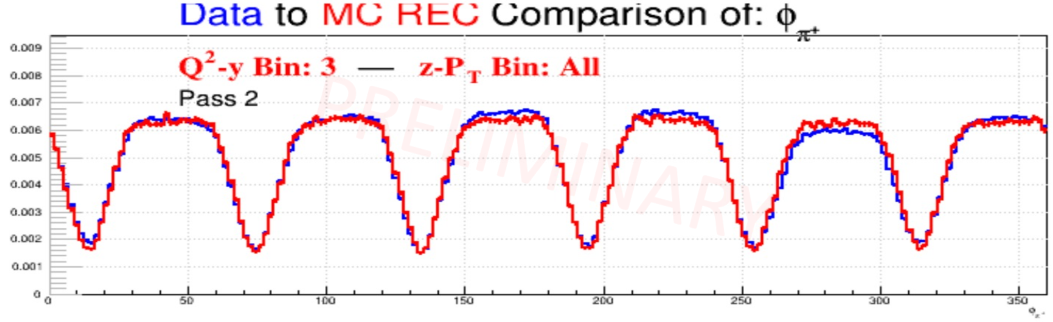
Red Lines show new (preliminary) fiducial cuts to be added

Impact of New Fiducial Cuts – Integrated z-P_T Bin

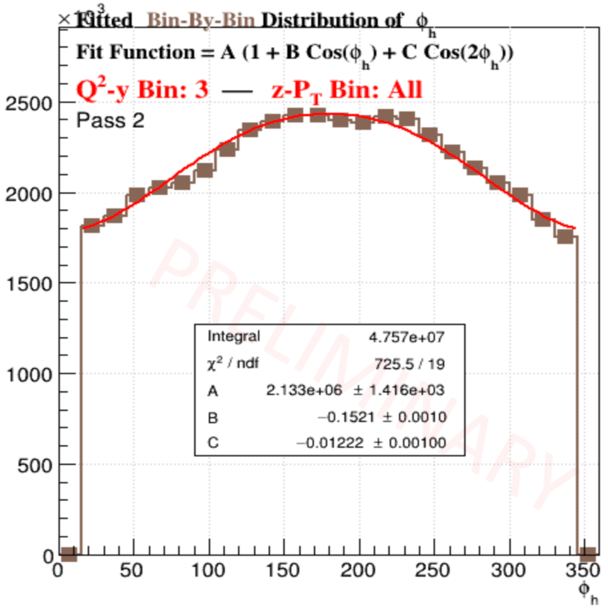


Before New Cuts



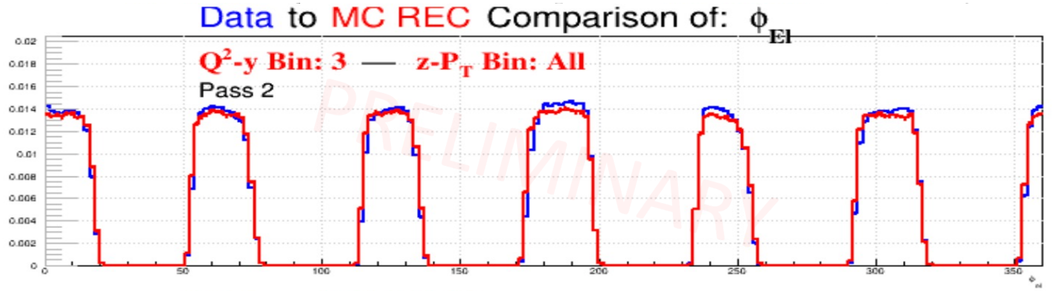


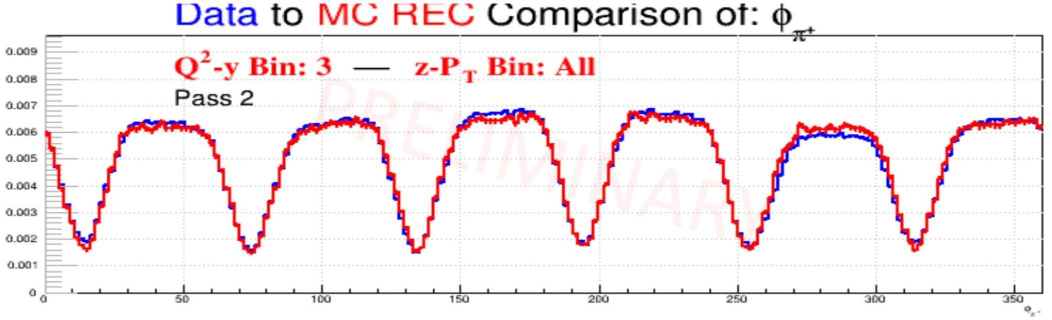
Discrepancies are more noticeable with integrated z-P_T bins



After New Cuts

← Much Better χ^2

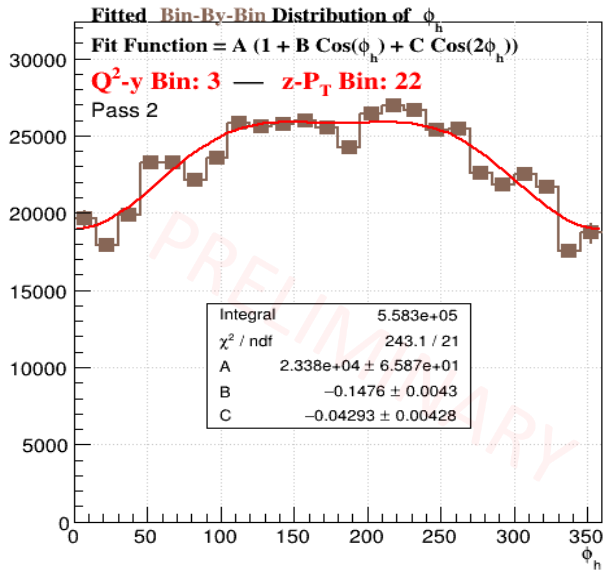




← Much better agreement between the lab angles of both particles

Cut starts to reduce (some) of the additional modulations for a smoother distribution of ϕ_h

Impact of New Fiducial Cuts – Individual z-P_T Bin



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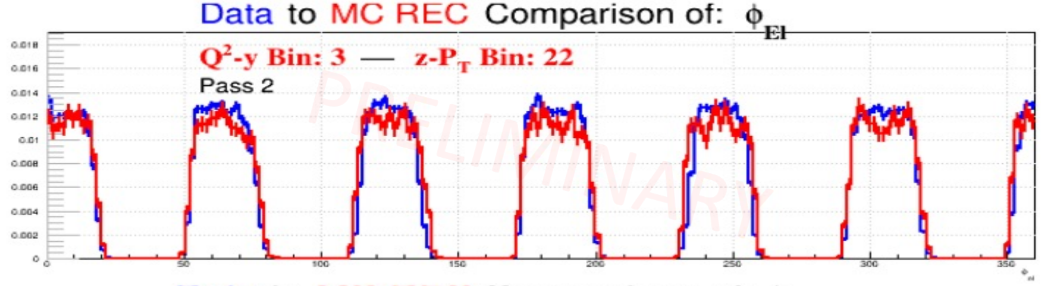

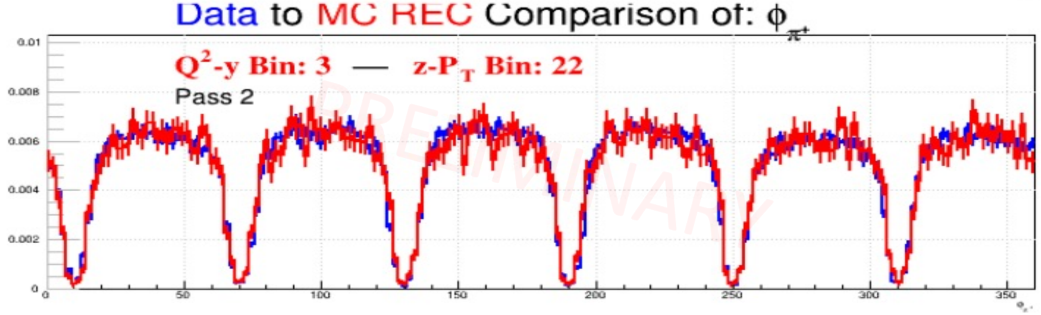

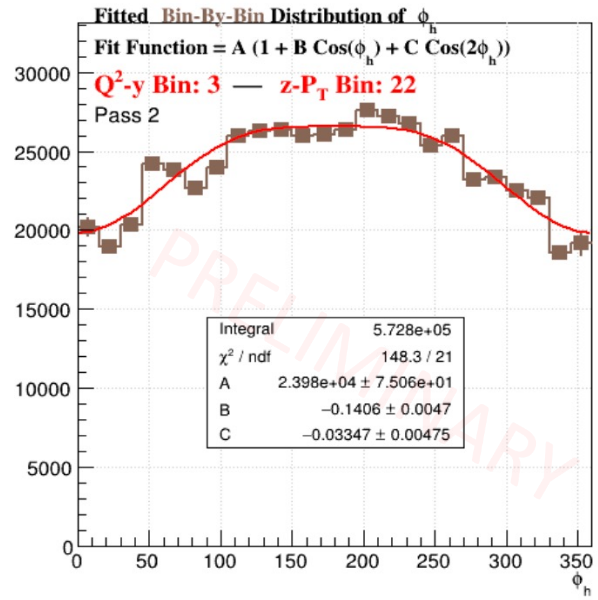

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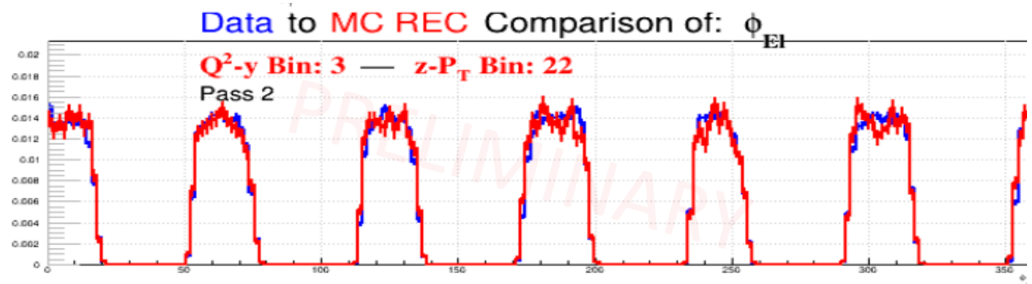

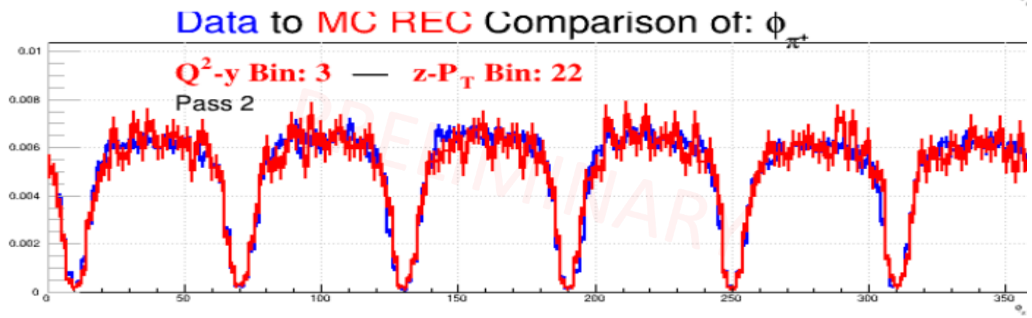

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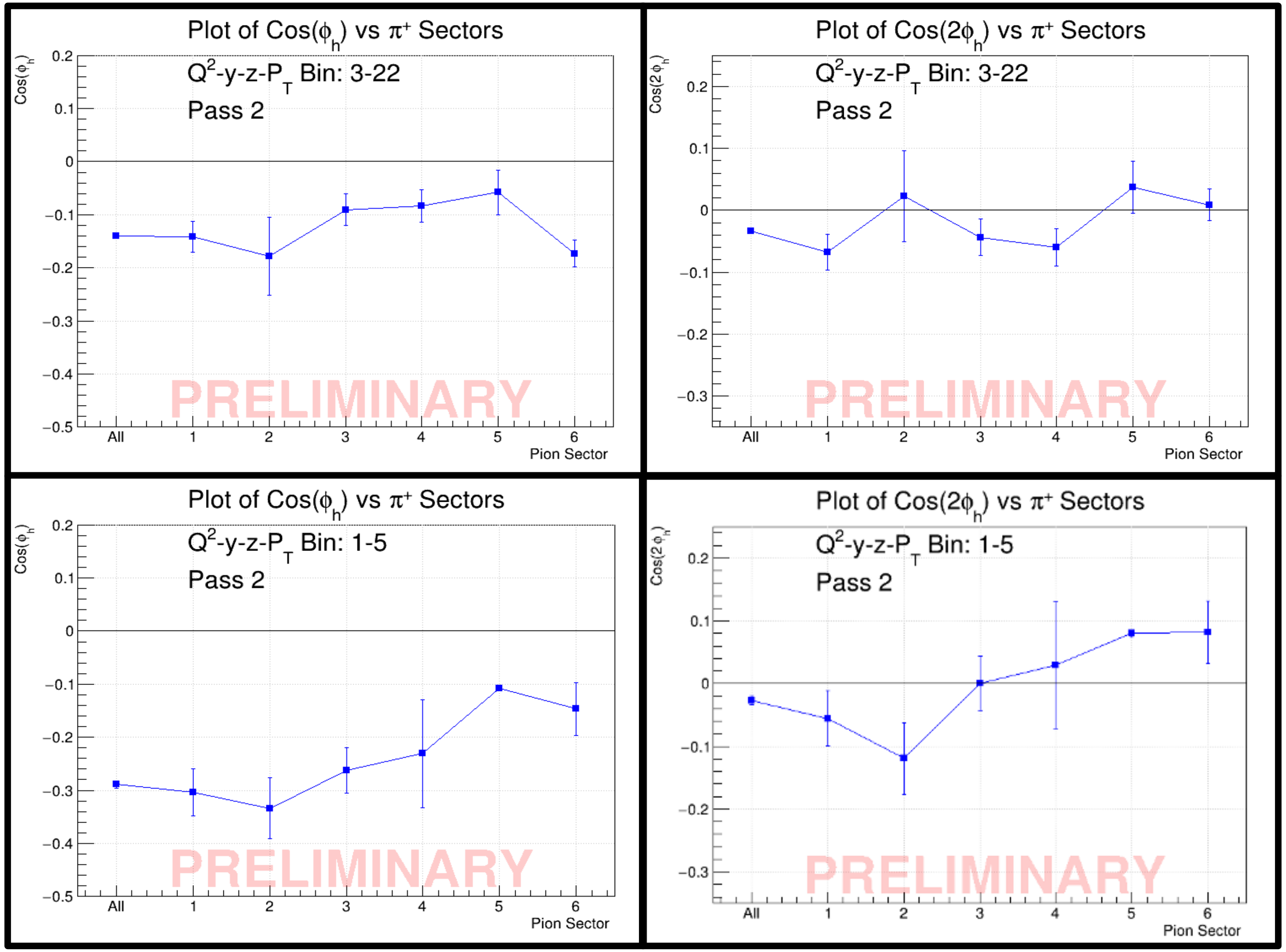
(Pion) Sector Correlations with Cos(ϕ) and Cos(2ϕ) Measurements



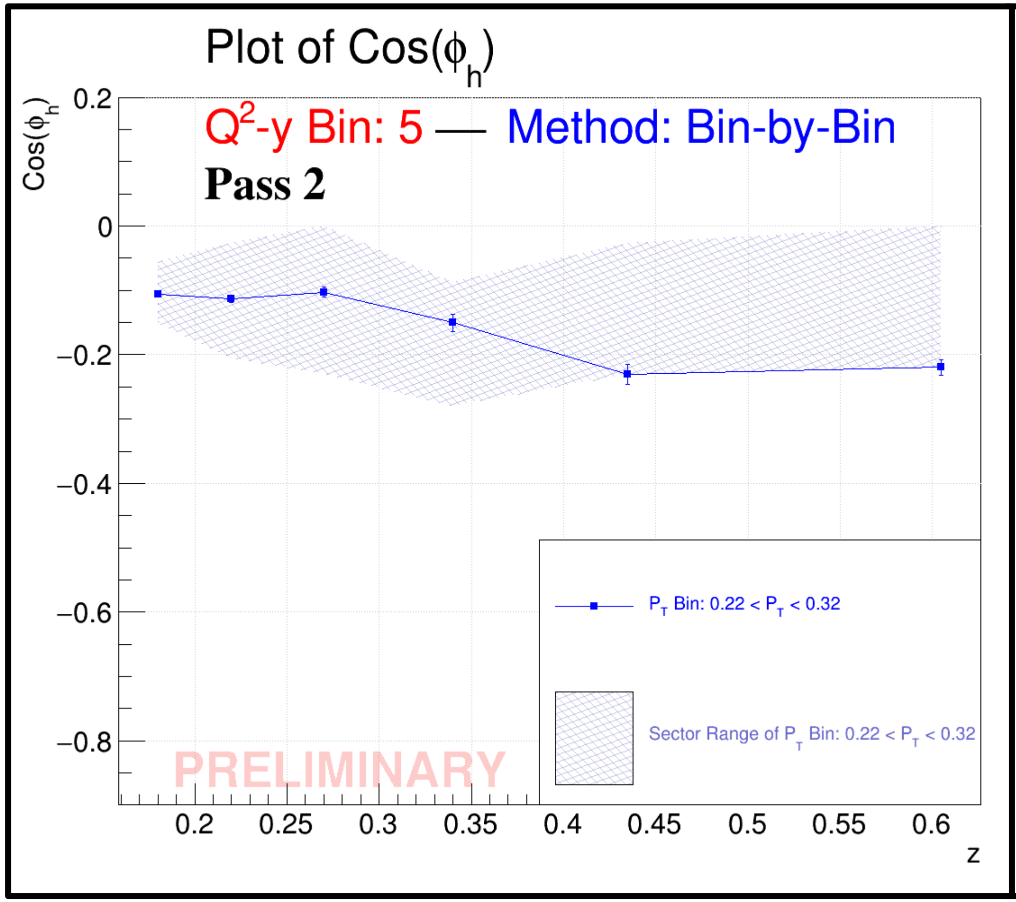
Some sector dependence remains despite the new cuts

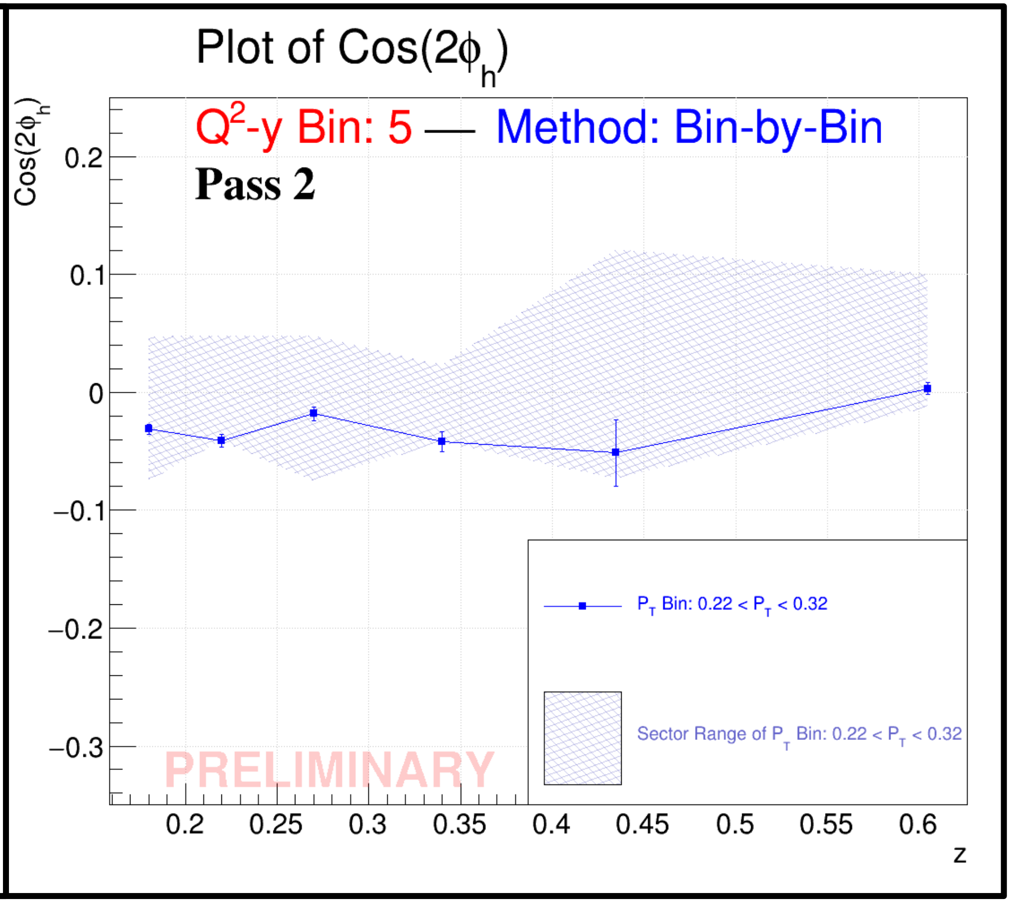
On average, the particle sector makes a noticeable difference about 50% of the time*
(i.e., the measurements of each sector do not agree with the measurement taken without sector dependence within the errors shown)

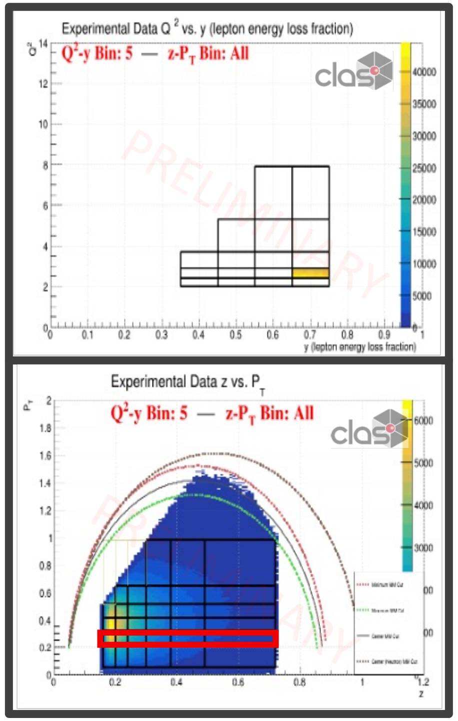
A sector dependences does seem to exist, but further investigation is still required

*Some of these discrepancies can be blamed on individual fits failing due to even worse acceptances that have not yet been individually addressed

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



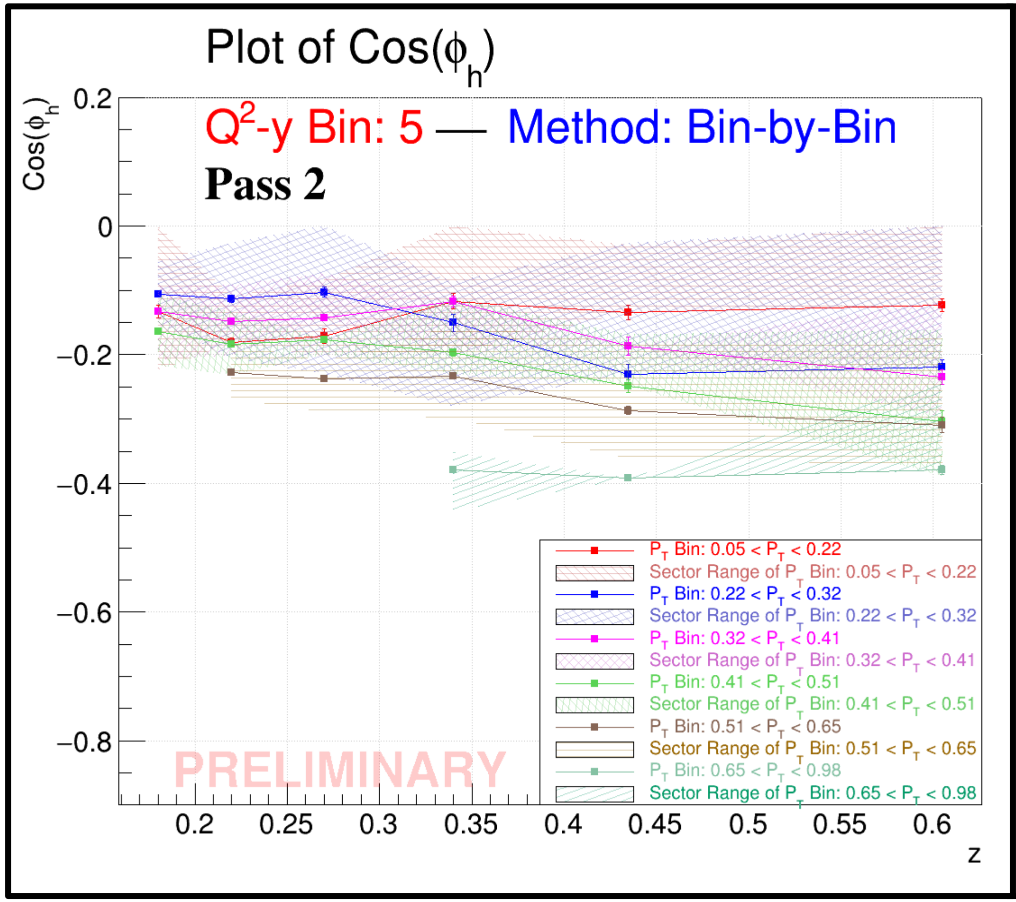


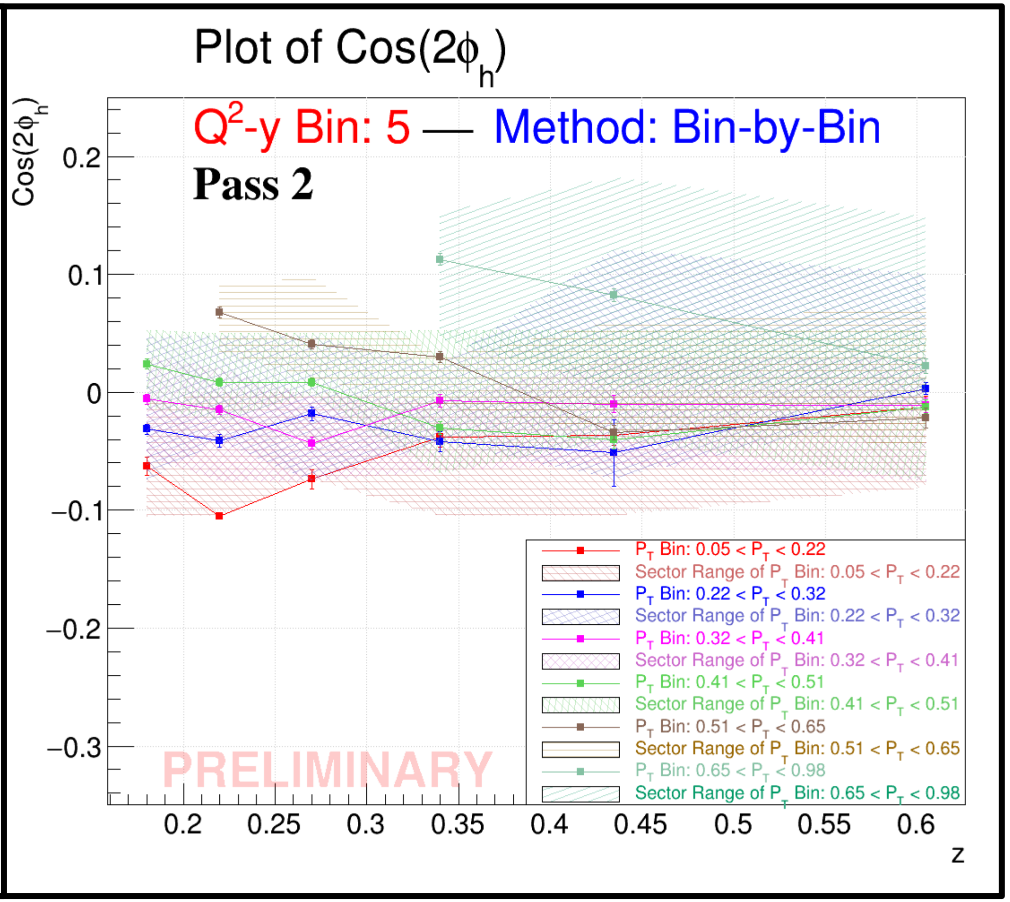


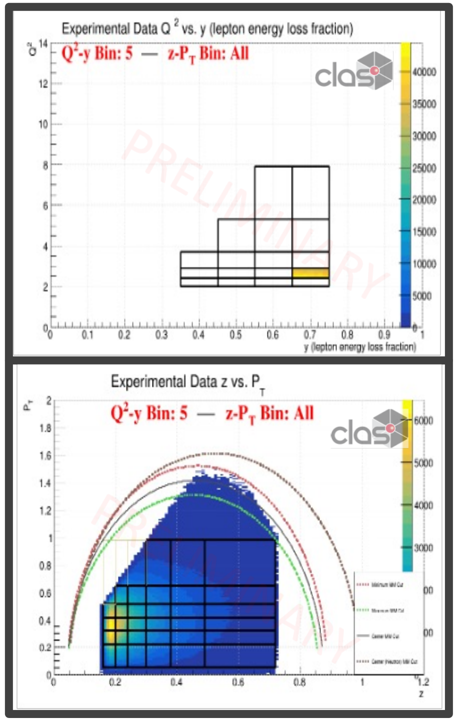
The shaded regions show the ranges of sector dependence on these measurements

Further refinements to limit this dependence are ongoing

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







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Monte Carlo Smearing

- Momentum Smearing Corrections are designed to match the resolution effects between MC and Experimental data
- Uses exclusive reactions to compare the widths of distributions from the exclusive reactions in both data sets
  - The primary reaction used for the electron and π^+ pion is **$ep \rightarrow e'\pi^+(N)$**
  - Follows a similar process as was used for developing Momentum Corrections for the experimental data
    - i.e., use momentum conservation calculations to derive a ΔP value between the predicted and measured momentums of a particle based on the kinematics of the other measured particle
    - Momentum smearing is focused on correcting the widths of the distributions instead of the peaks
  - Smearing functions are based on ΔP/P vs θ plots

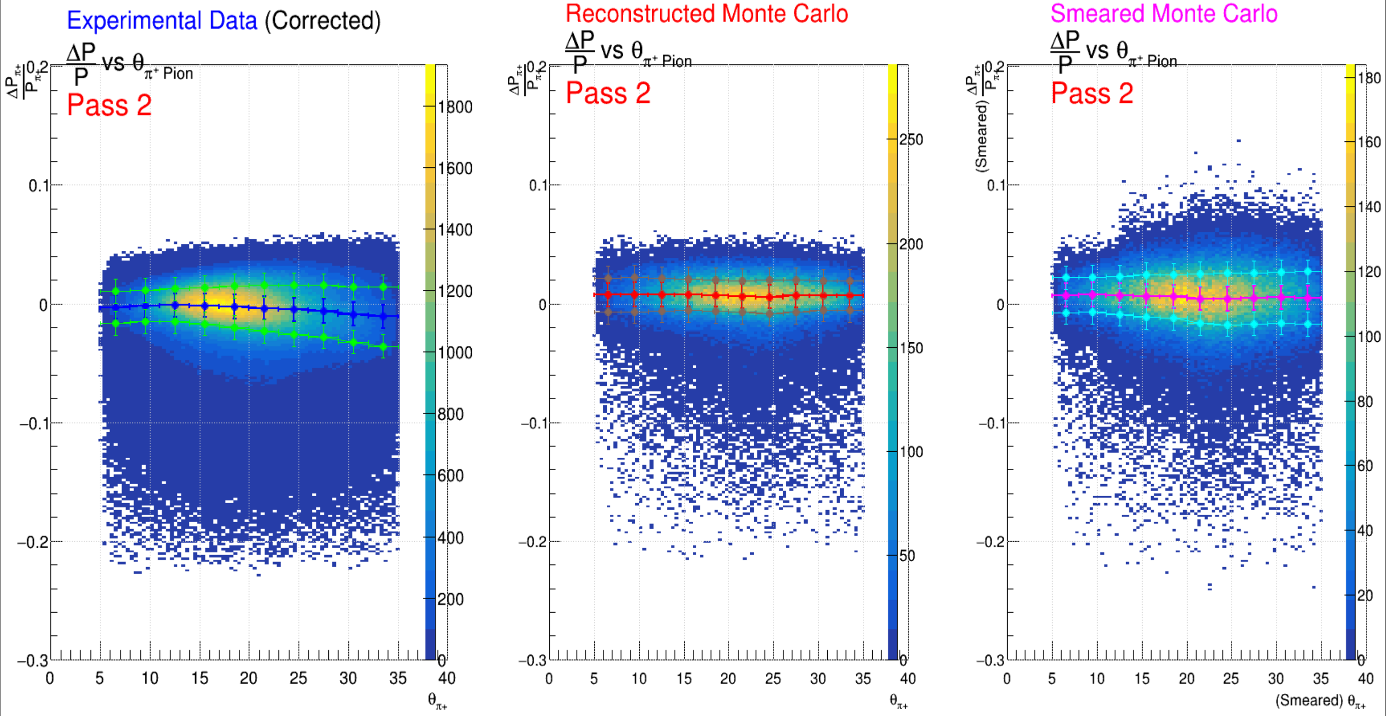
Data and Monte Carlo Comparison (Smearing)

Smearing for the π⁺ Pion

Form of Smearing Function:

$$P_{Smeared} = P_{REC} + gRandom \rightarrow Gaus(0, P_{REC} * \sigma(\theta) * SF)$$

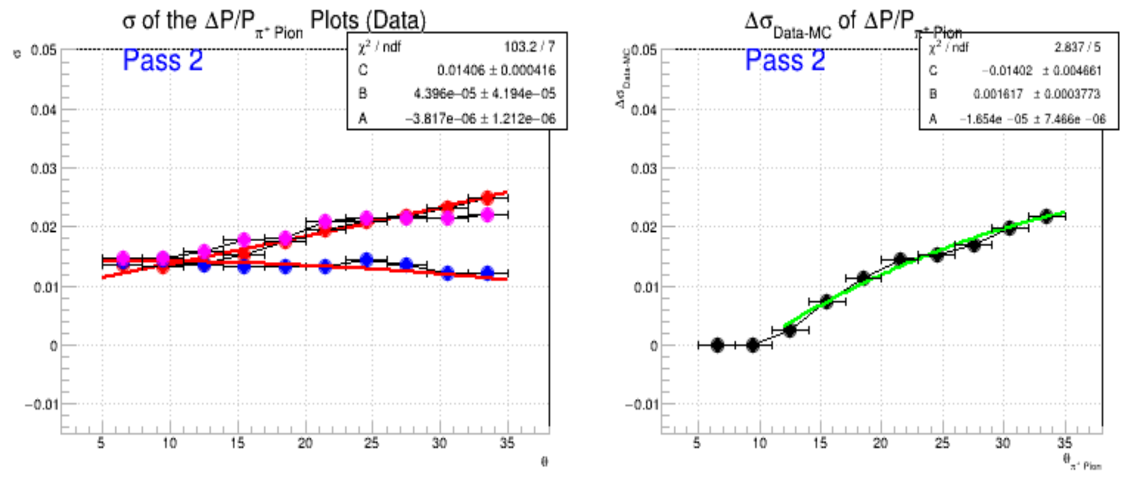
Plots of ΔP/P vs θ for Data, Unsmeared MC, and Smeared MC



Shown with the peak positions and widths of the fitted distributions

- $\sigma(\theta)$ is the difference in the widths of ΔP/P for the Unsmeared MC and Data plots
- *SF* is a constant factor that provides more control over the function's strength

Difference between widths of Smeared MC and Data



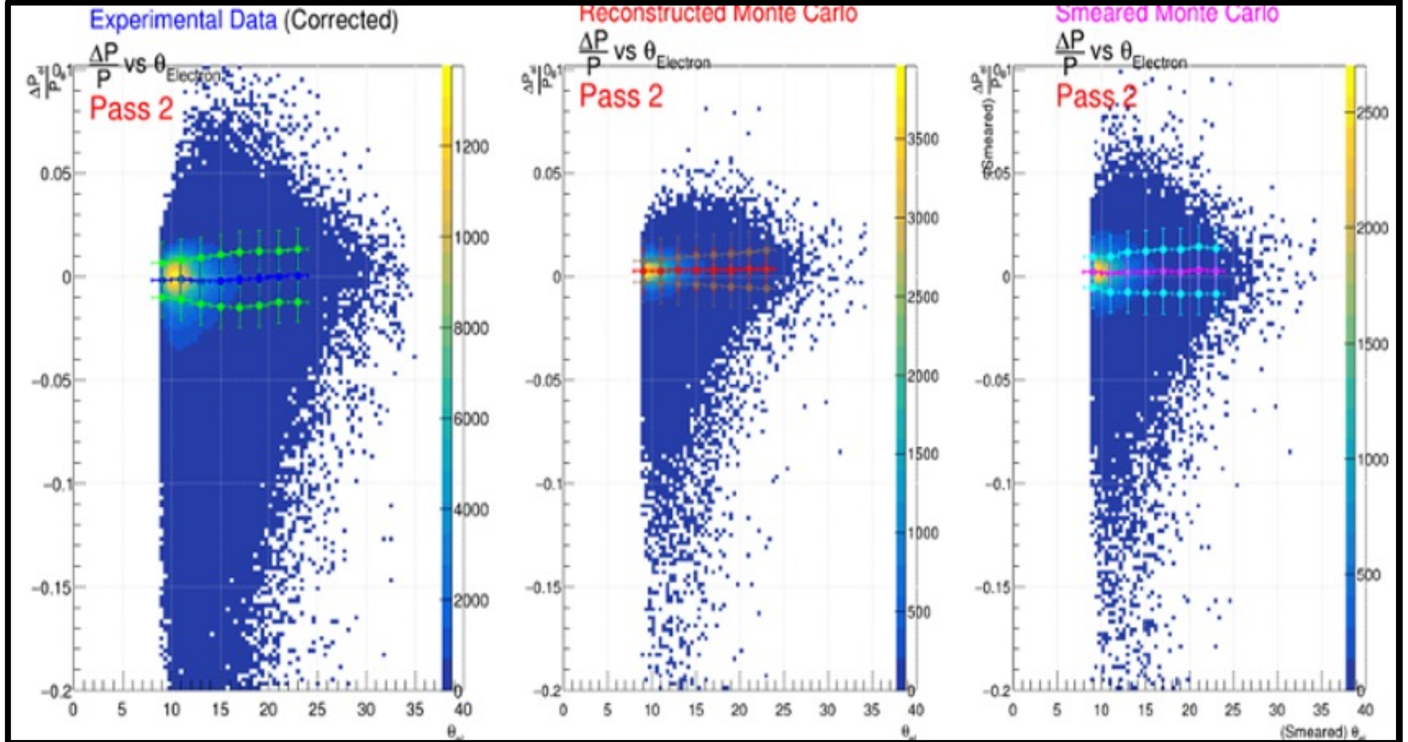
Data and Monte Carlo Comparison (Smearing)

Smearing for the **Electron**

Form of Smearing Function:

$$P_{Smeared} = P_{REC} + gRandom \rightarrow Gaus(0, P_{REC} * \sigma(\theta) * SF)$$

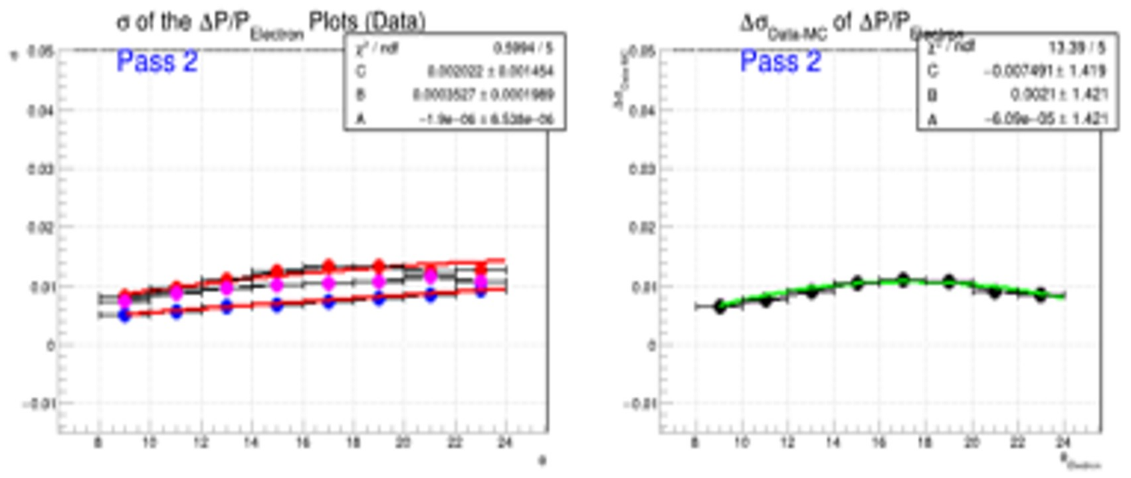
Plots of ΔP/P vs θ for Data, Unsmeared MC, and Smeared MC



Shown with the peak positions and widths of the fitted distributions

- $\sigma(\theta)$ is the difference in the widths of ΔP/P for the Unsmeared MC and Data plots
- *SF* is a constant factor that provides more control over the function's strength

Difference between widths of Smeared MC and Data



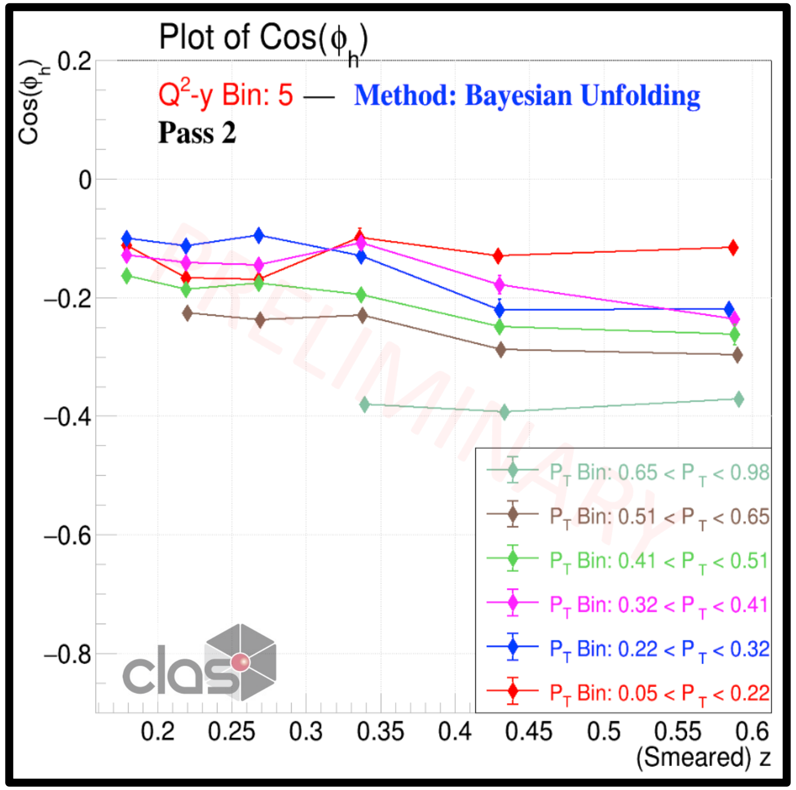
Cosine Moments as Functions of z

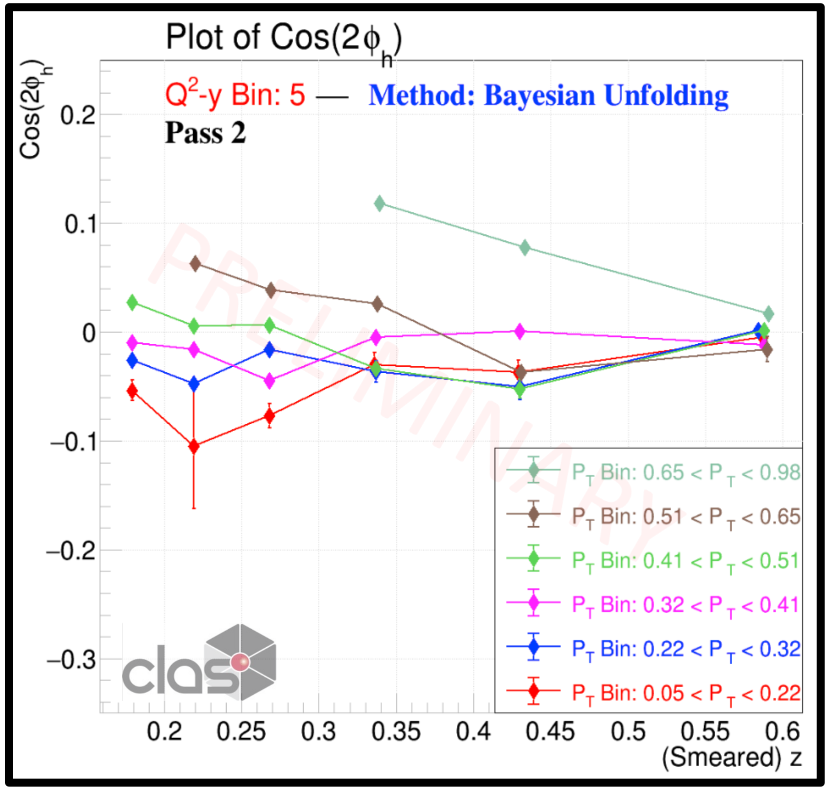
$B = A_{UU}^{\cos\varphi_h}$ $C = A_{UU}^{\cos 2\varphi_h}$

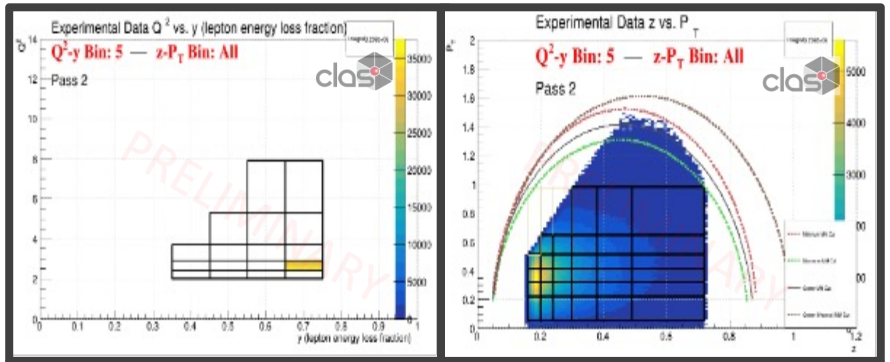
ϕ_h Plots were fitted with:
$A(1 + B\cos(\phi_h) + C\cos(2\phi_h))$

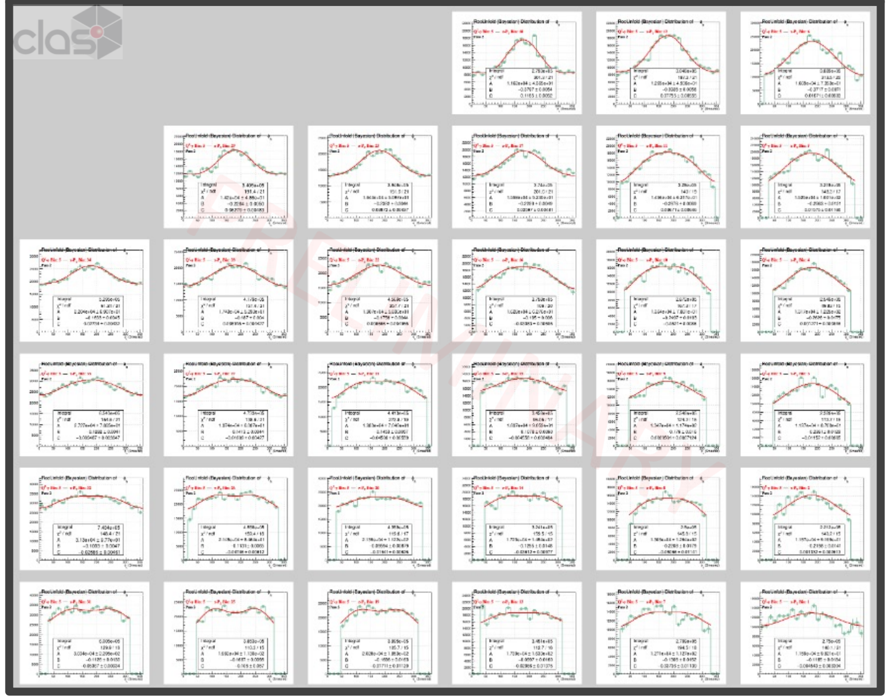
Unfolded with Bayesian Method

Q^2-y Bin 5









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

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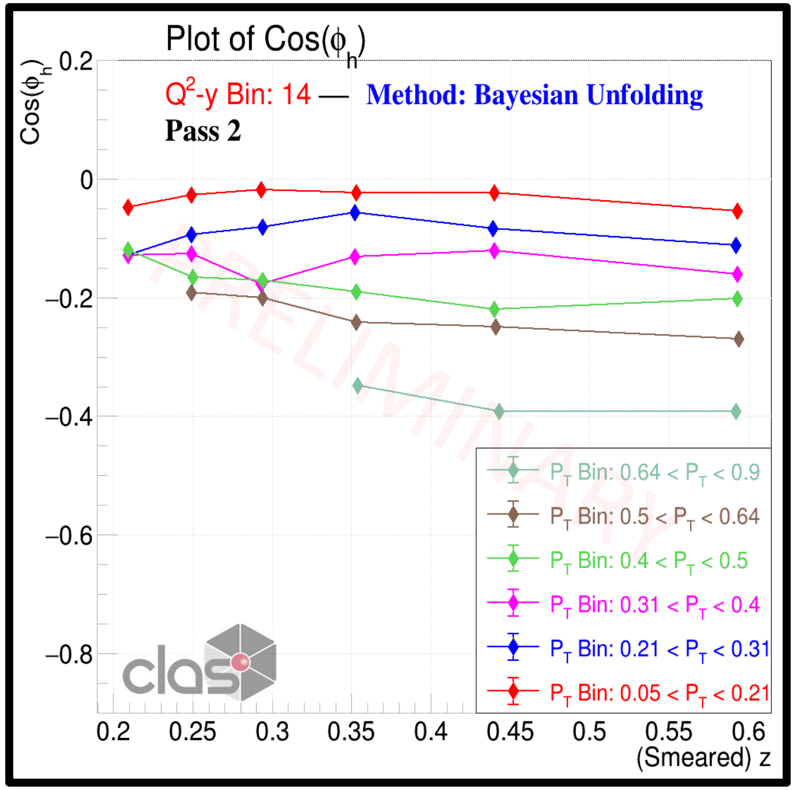
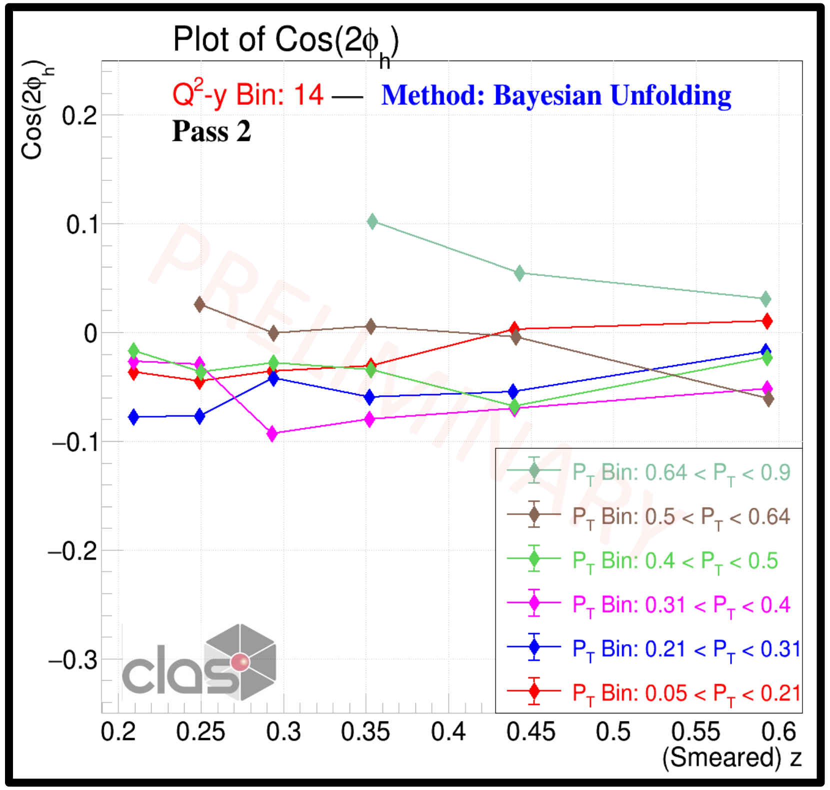
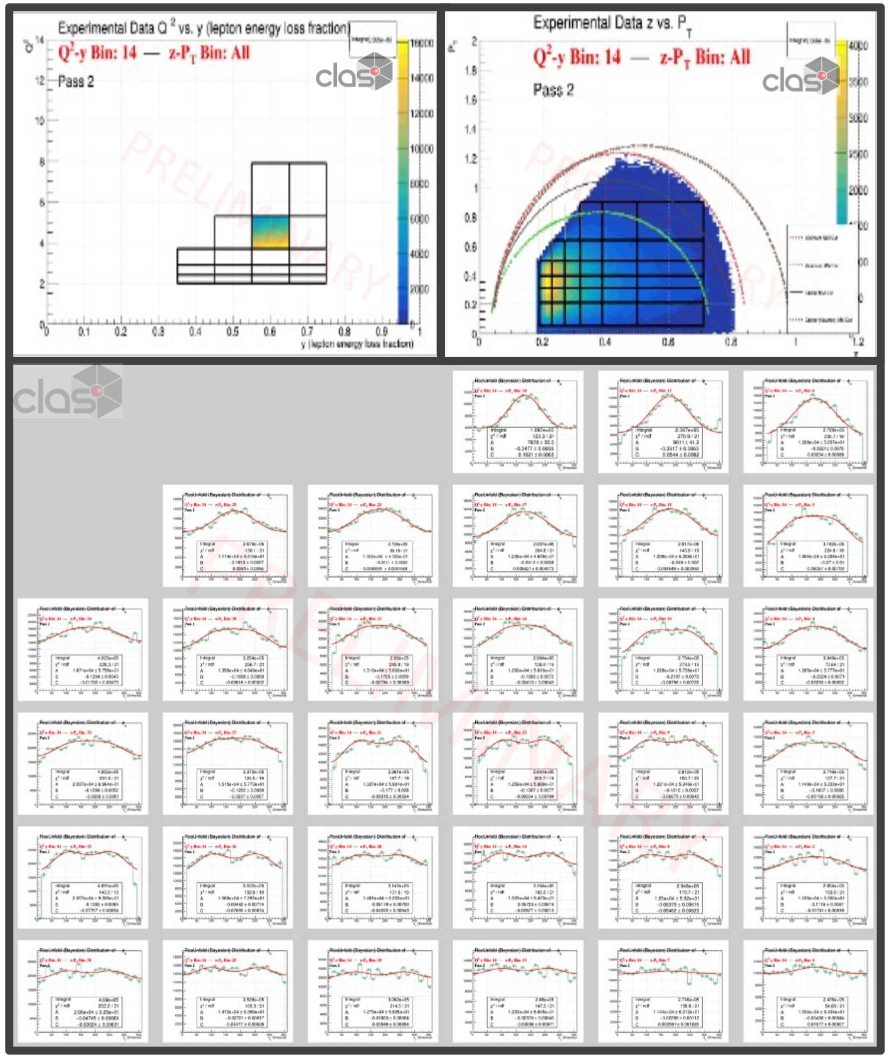
Unfolded with Bayesian Method

Q^2-y Bin 14







Summary

- Analysis switched to Pass 2 Data
- Finalizing tests for applying the Multidimensional (5D) Acceptance Corrections for the simultaneous unfolding of Q^2, y, z, P_T, and ϕ_h variables
  - Addressed migrations from outside the kinematic region
- Momentum Smearing Corrections applied to the Monte Carlo
- Began evaluation of systematic uncertainties related to sector dependence
- New Fiducial Cuts Added
  - Still optimizing

Outlook

- Further Investigations regarding Sector Dependences
- Working on adding more Pass 2 simulations
- Working on including Radiative Corrections in this analysis
- Ongoing Investigations of Vector Meson Contributions

Thank you

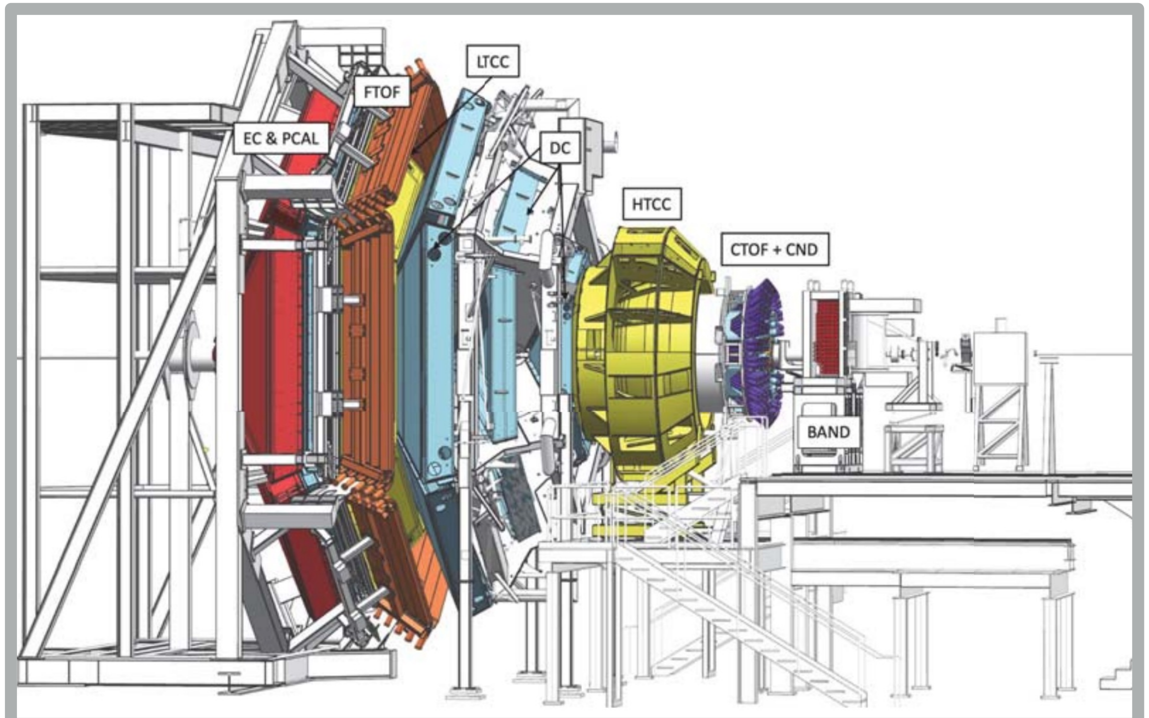
Questions?

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

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

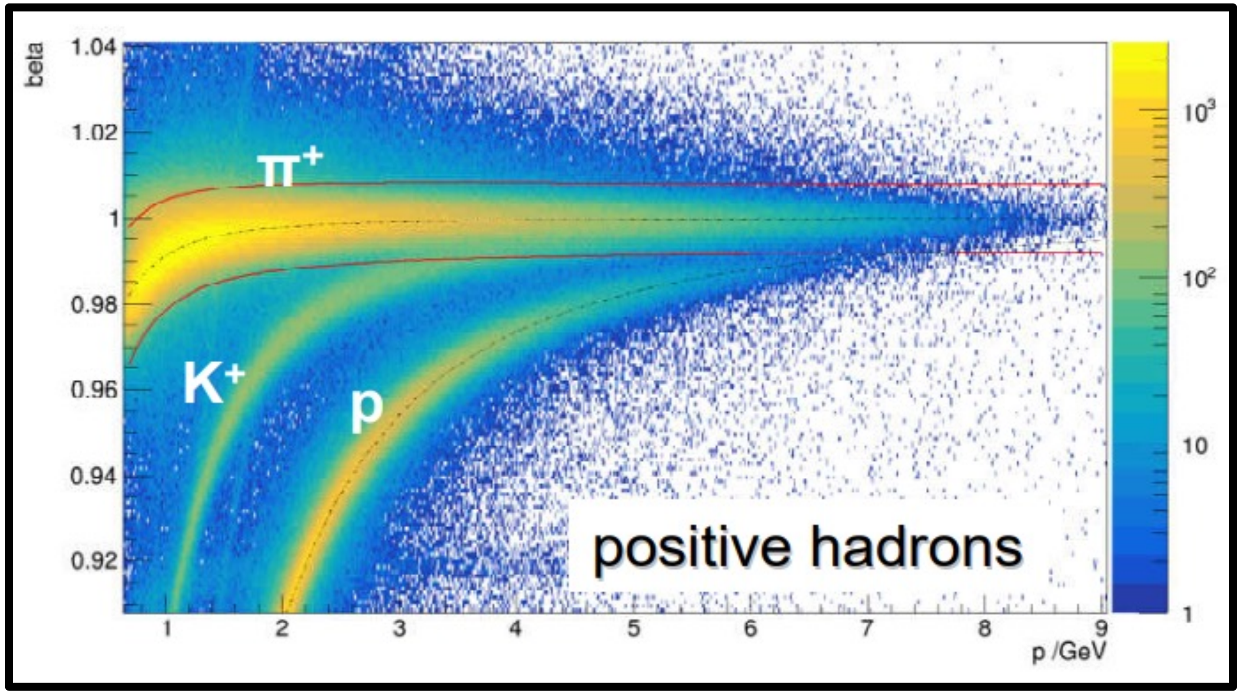


*Image provided by Stefan Diehl

π^+ Pion PID – ß vs p

Event Selection

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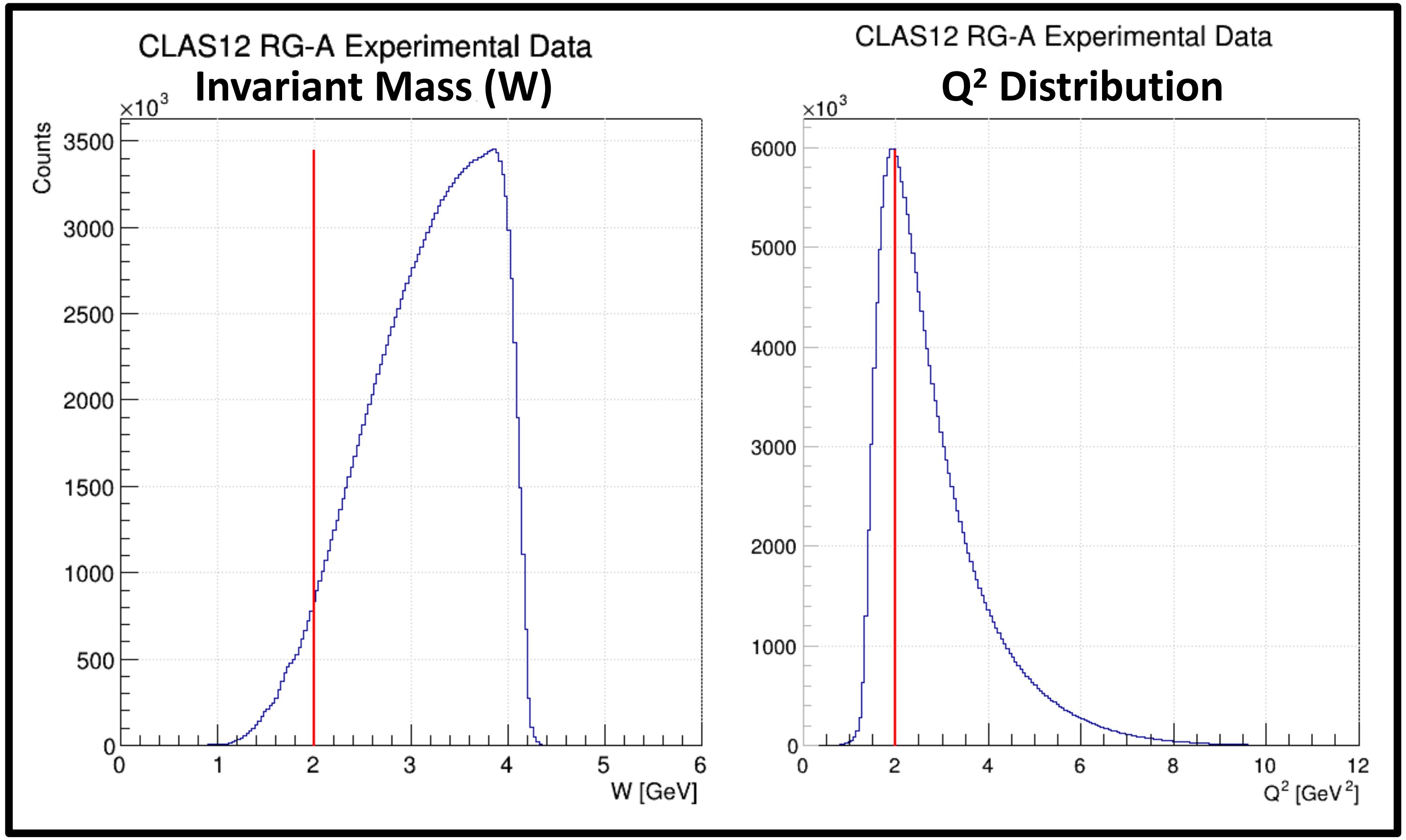
Analysis Cuts:

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



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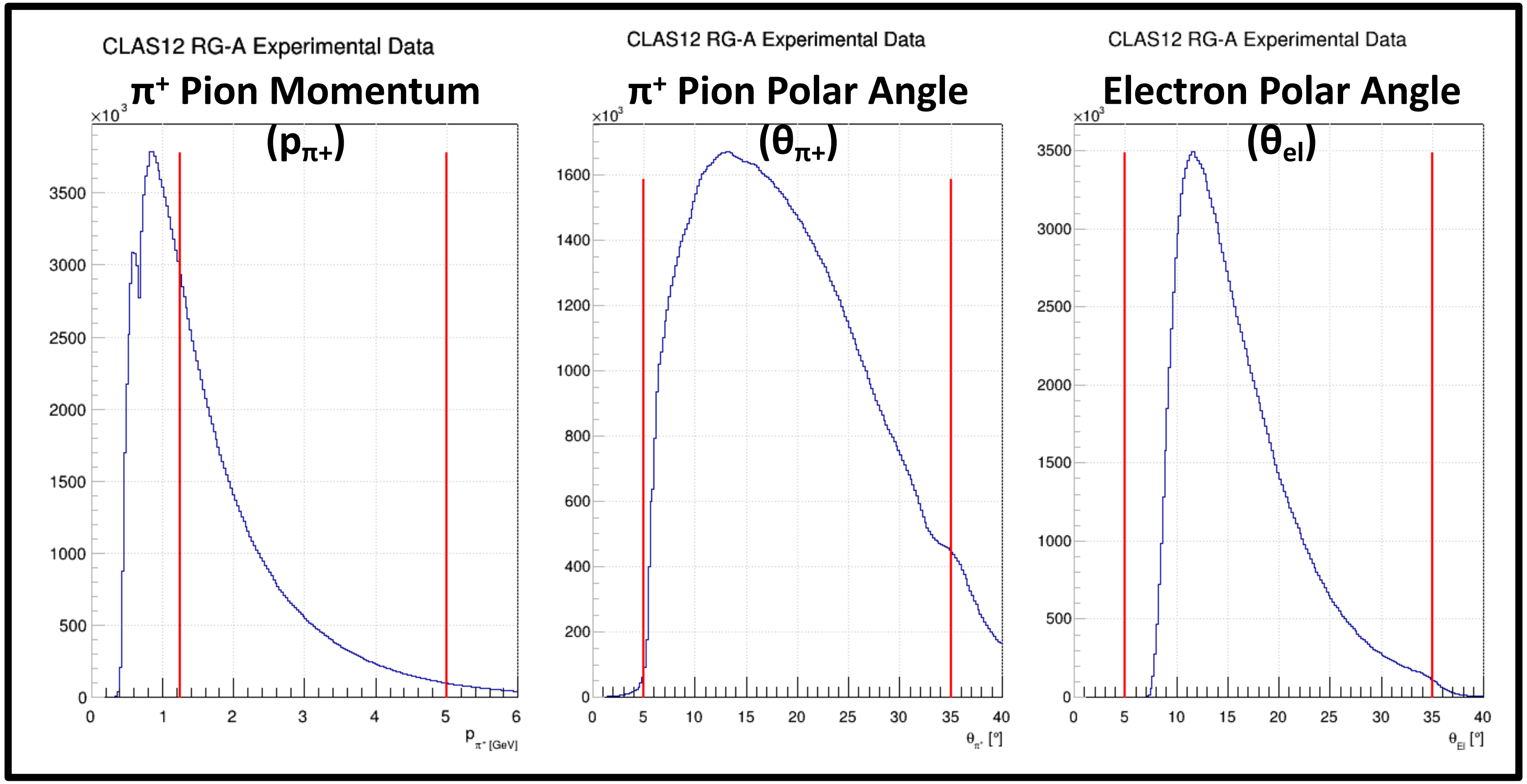
Analysis Cuts:

- **SIDIS Cuts**:
  - W > 2 GeV
  - $Q^2 > 2$ GeV^2
- **Other Analysis Cuts:**
  - $p_{\pi+}$ Cut: 1.25 GeV < $p_{\pi+}$ < 5 GeV
  - θ-angle Cut: 5° < $\theta_{particle}$ < 35°



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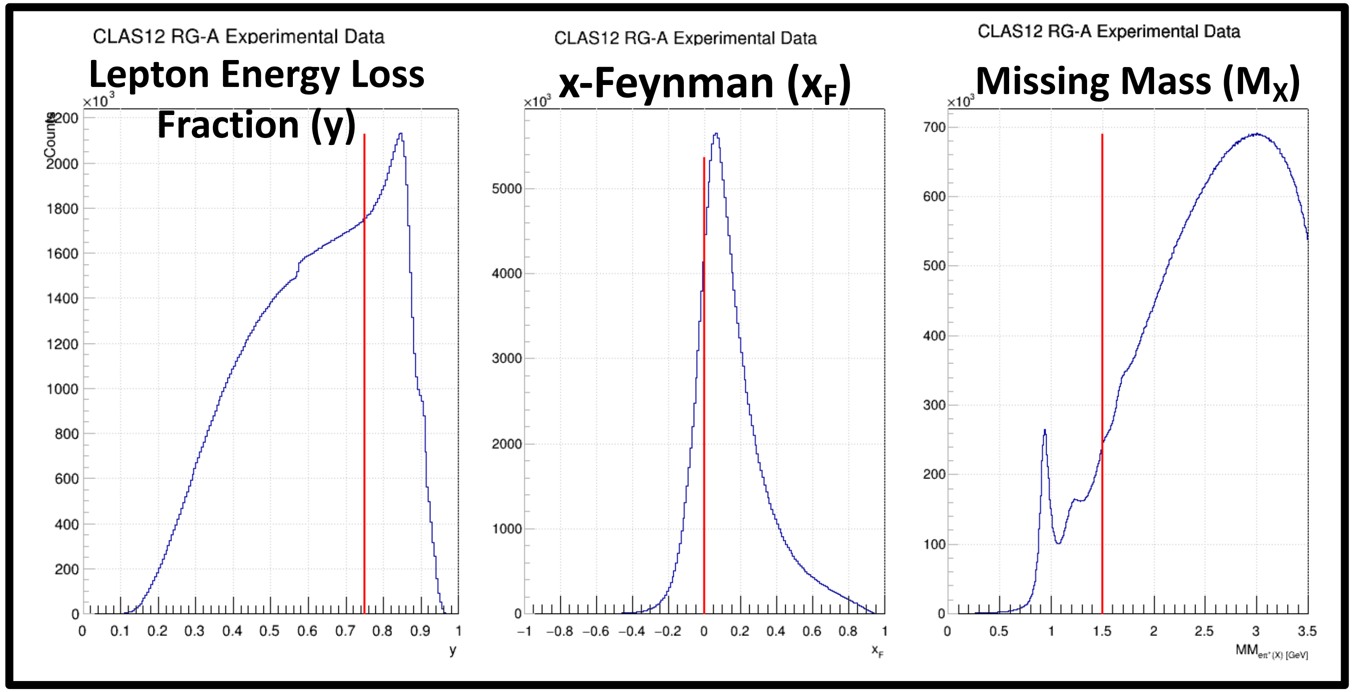
  - θ-angle Cut: 5° < $\theta_{particle}$ < 35°
  - y < 0.75 (minimize other background processes)
  - $x_F > 0$ (minimize contributions from target fragmentations)
  - Missing Mass Cut: M_x > 1.5 GeV (limits contributions from exclusive events)



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Analysis Cuts:

- **SIDIS Cuts**:
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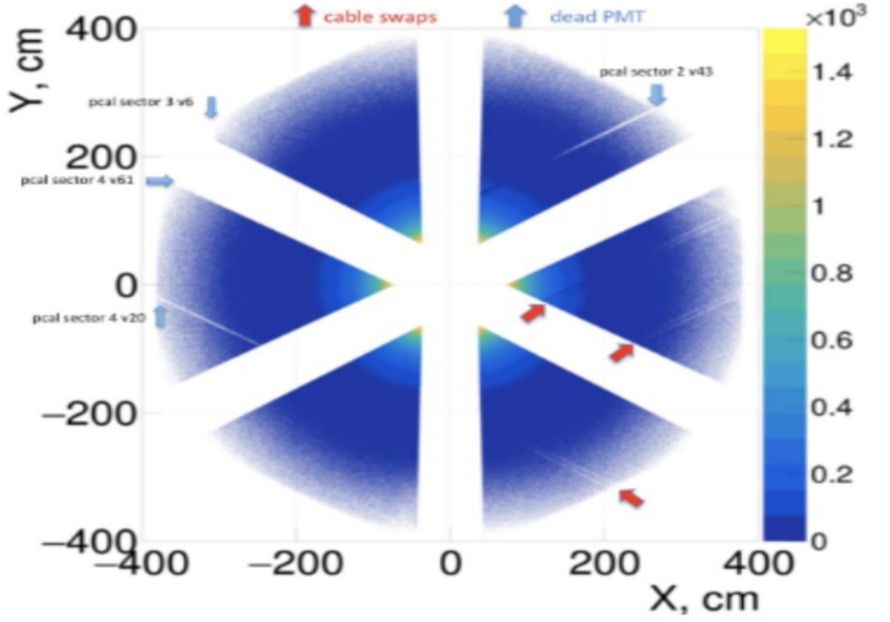
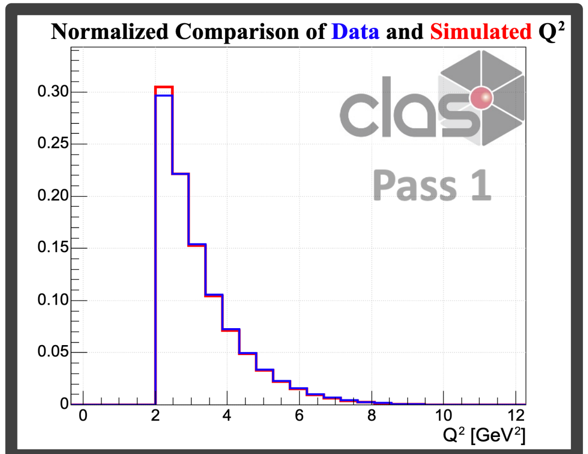
  - y < 0.75 (minimize other background processes)
  - $x_F > 0$ (minimize contributions from target fragmentations)
  - Missing Mass Cut: $M_x > 1.5$ GeV (limits contributions from exclusive events)
  - Fiducial Cuts (e.g., accounts for bad channels present in data)

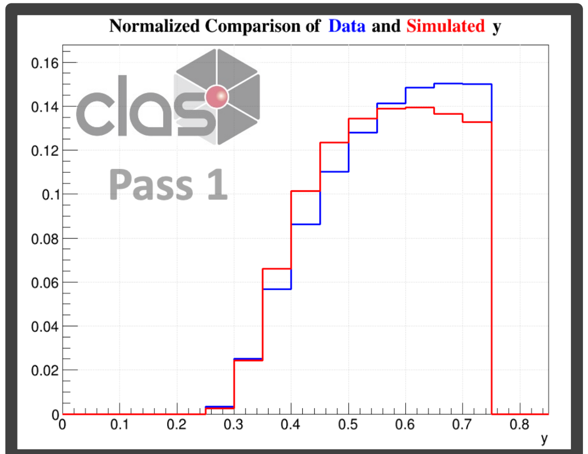
CLAS12 RG-A Experimental Data
PCAL



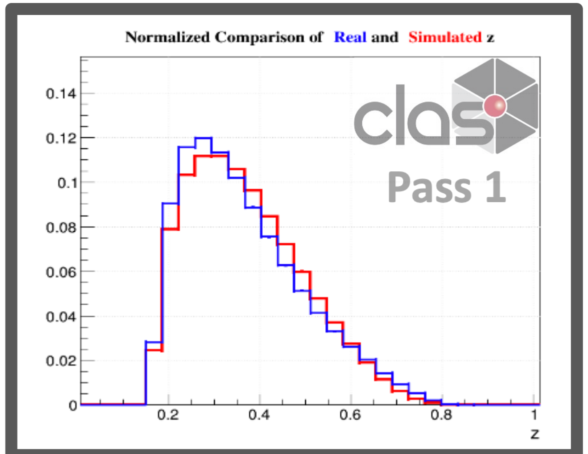
Data and Monte Carlo Comparison



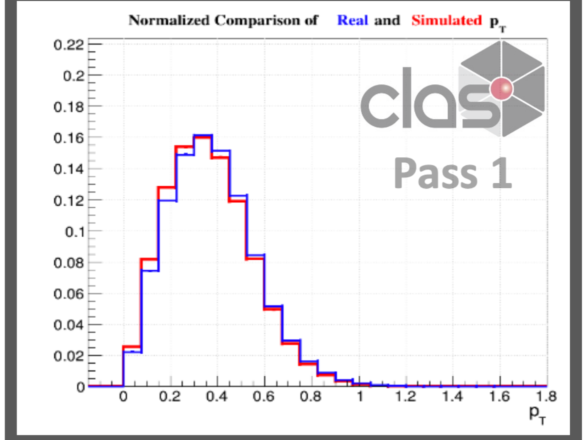
Q^2 Comparison



y Comparison

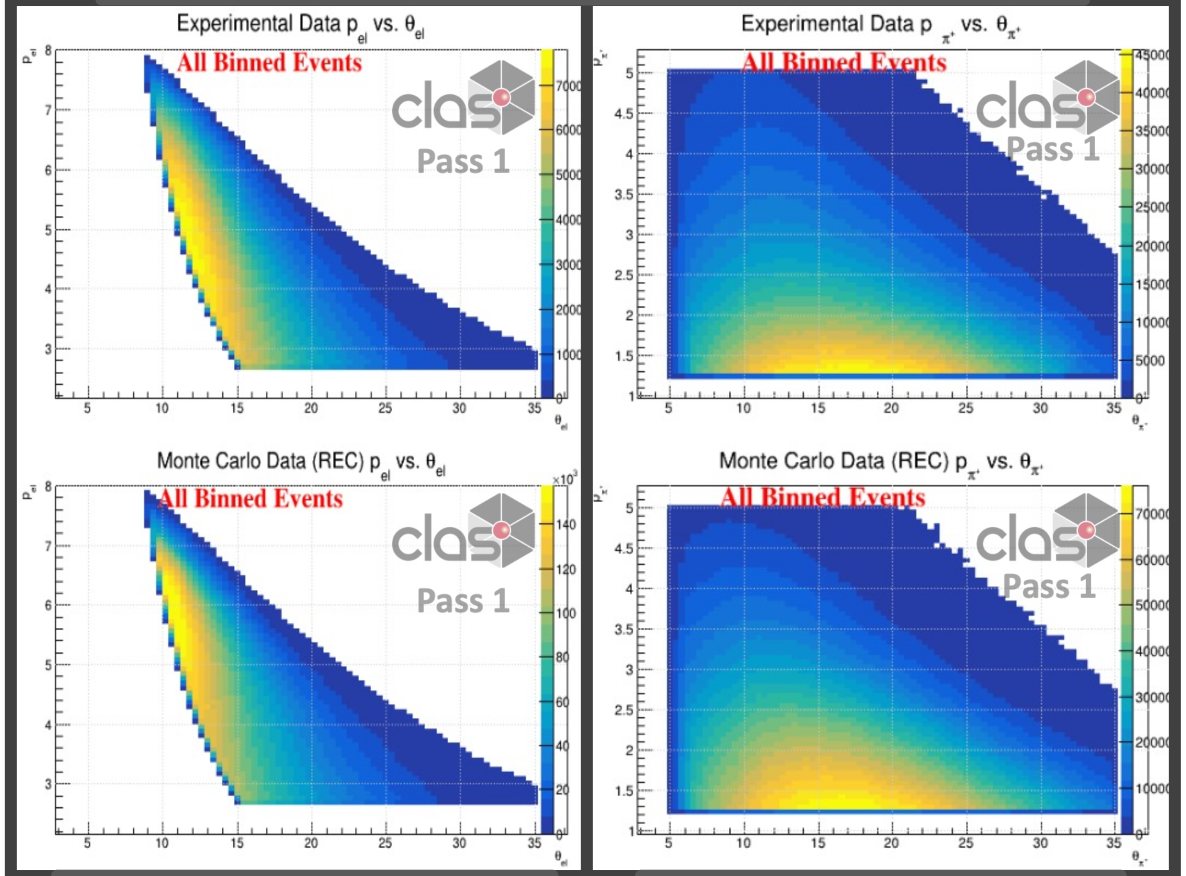


z Comparison



P$_T$ Comparison

Momentum vs Polar Lab Angle Comparison



Electron Comparison

π^+ Pion Comparison

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)

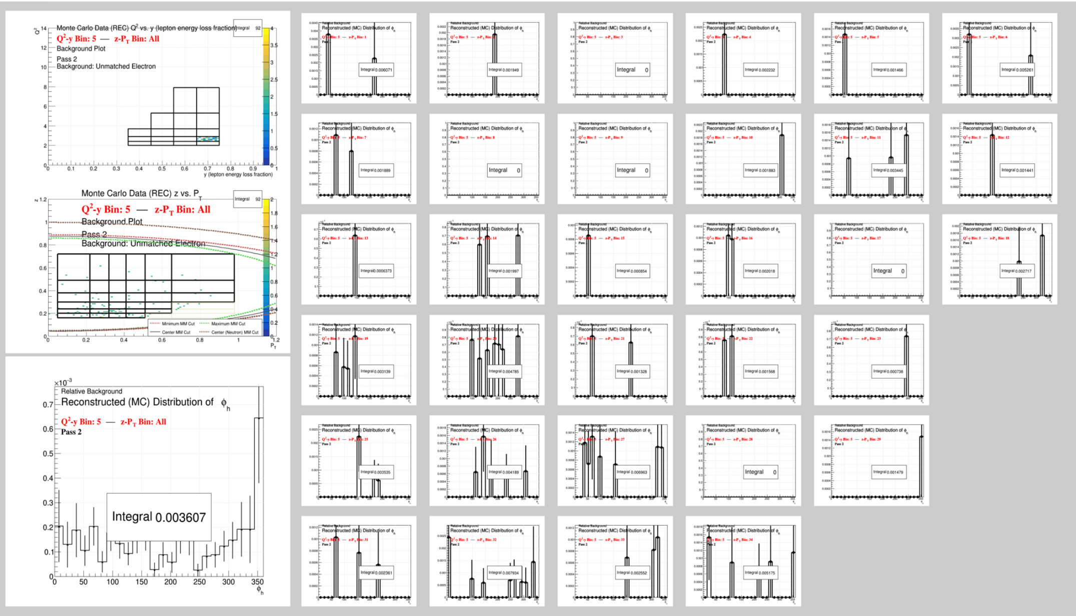
Electron PID Criteria:

- 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

Background (ß) Vector – Particle Mis-Identification (as functions of ϕ_h)

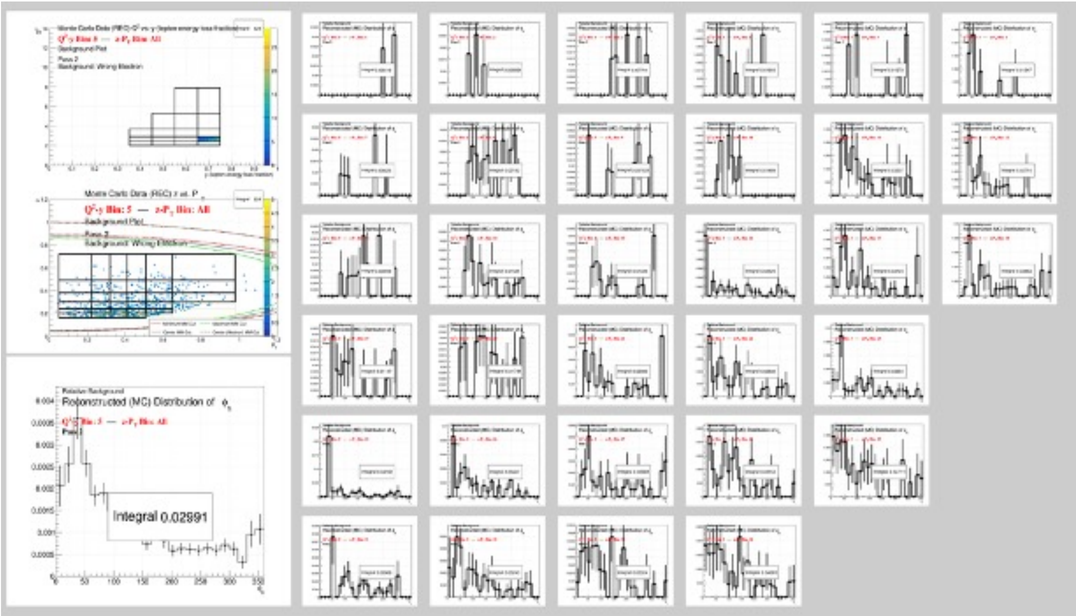


Unmatched

MC REC

Electron

←



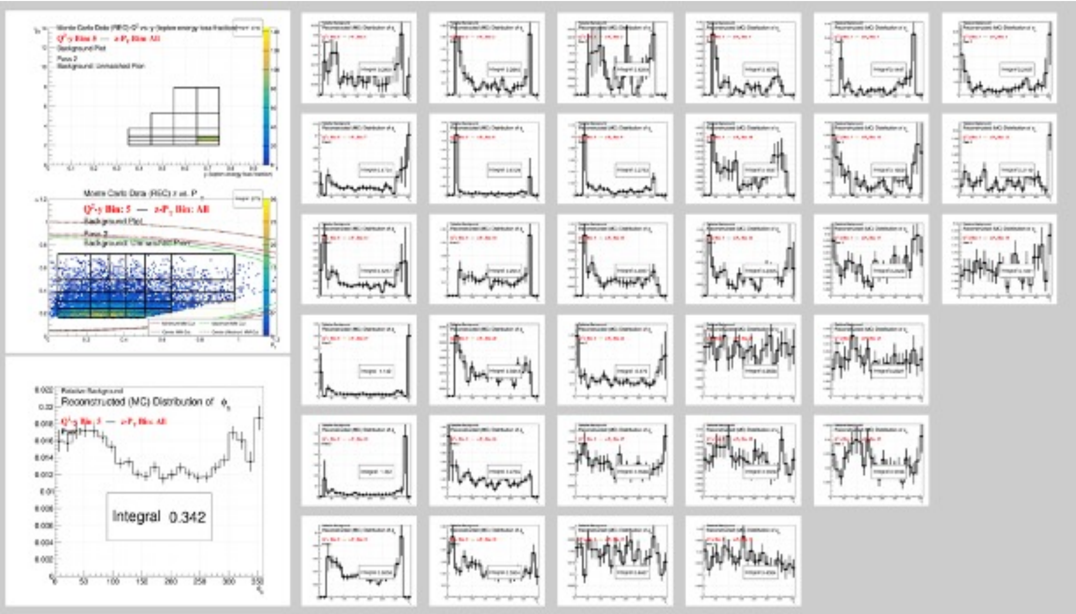
Incorrect

PID for

MC REC

Electron

←

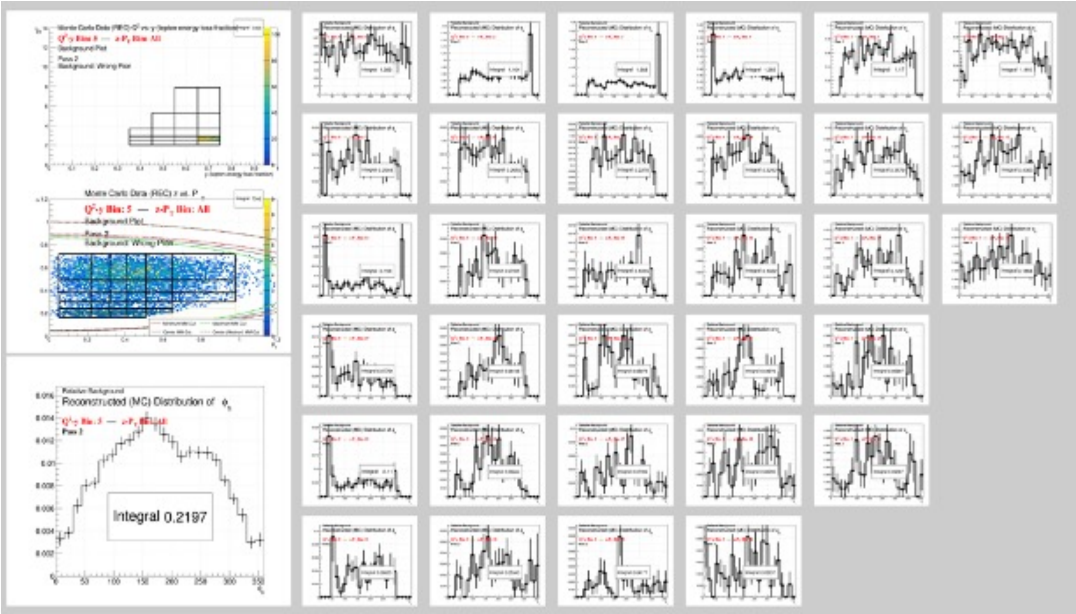


Unmatched

MC REC

π^+ Pion

←



Incorrect

PID for

MC REC

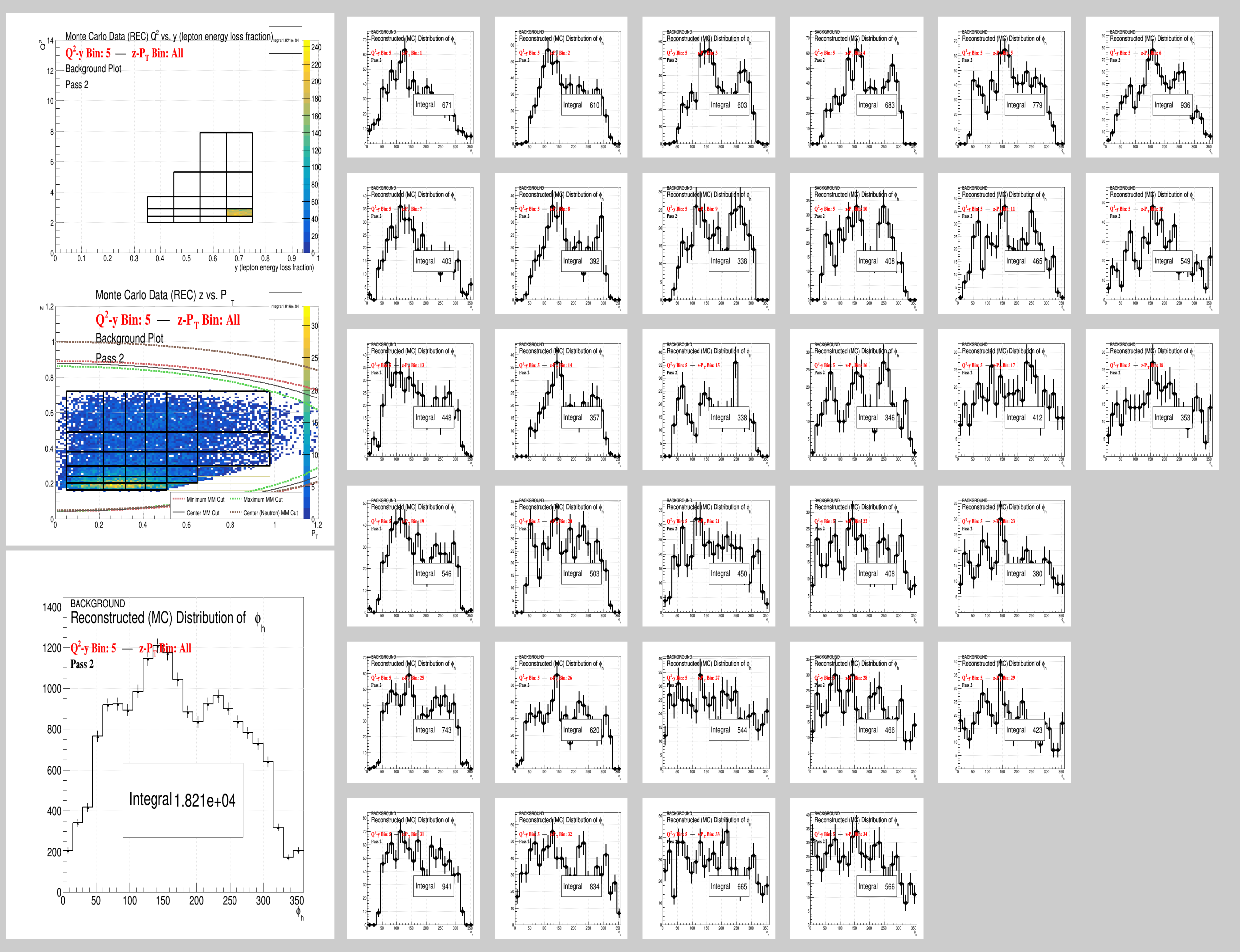
π^+ Pion

←

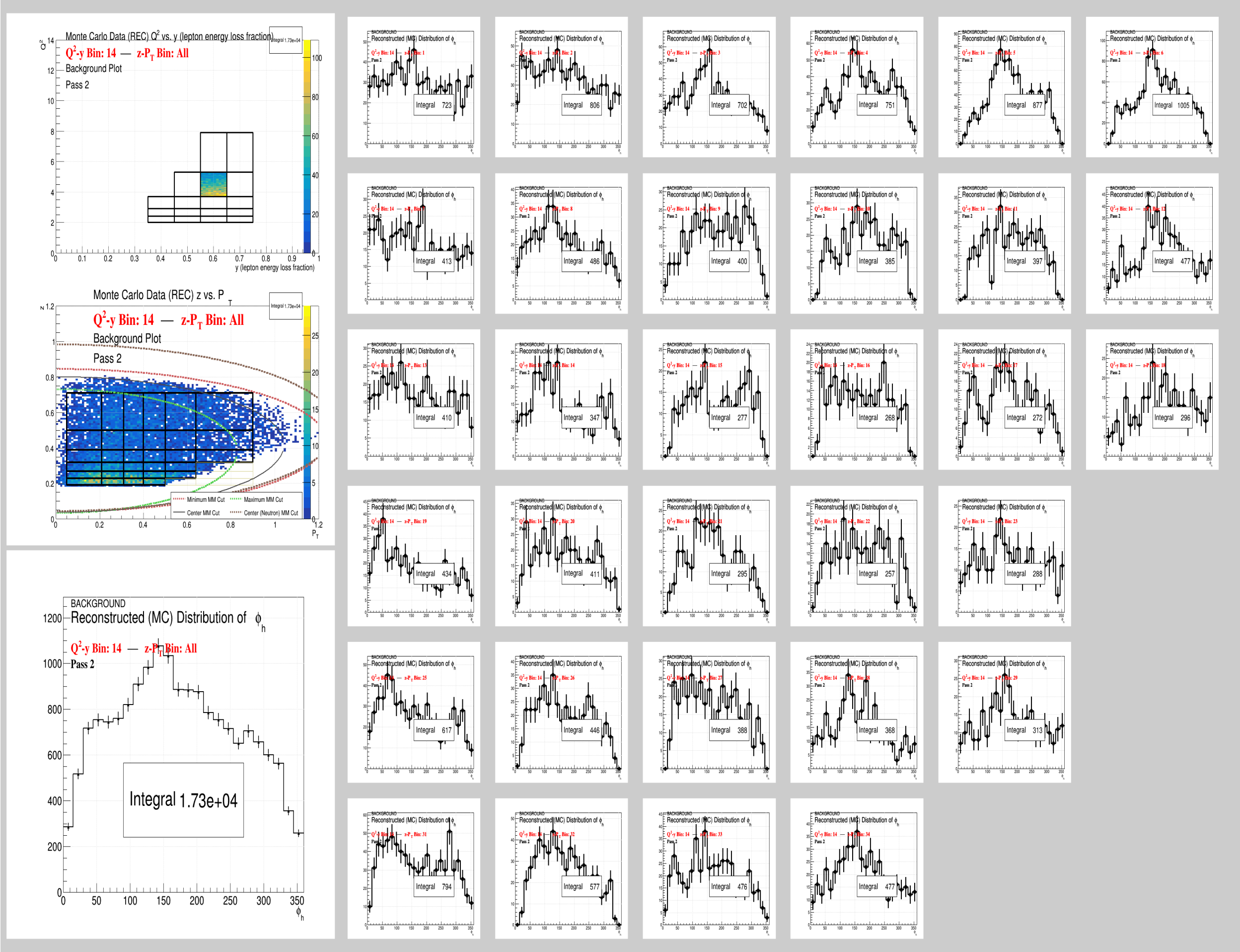
PASS 2

ß Vector – All Contributions (Per Q^2-y Bin)

Q^2-y Bin 5: Events from Generated Missing Mass Cuts make up about 0.87% of the 'Background' shown below

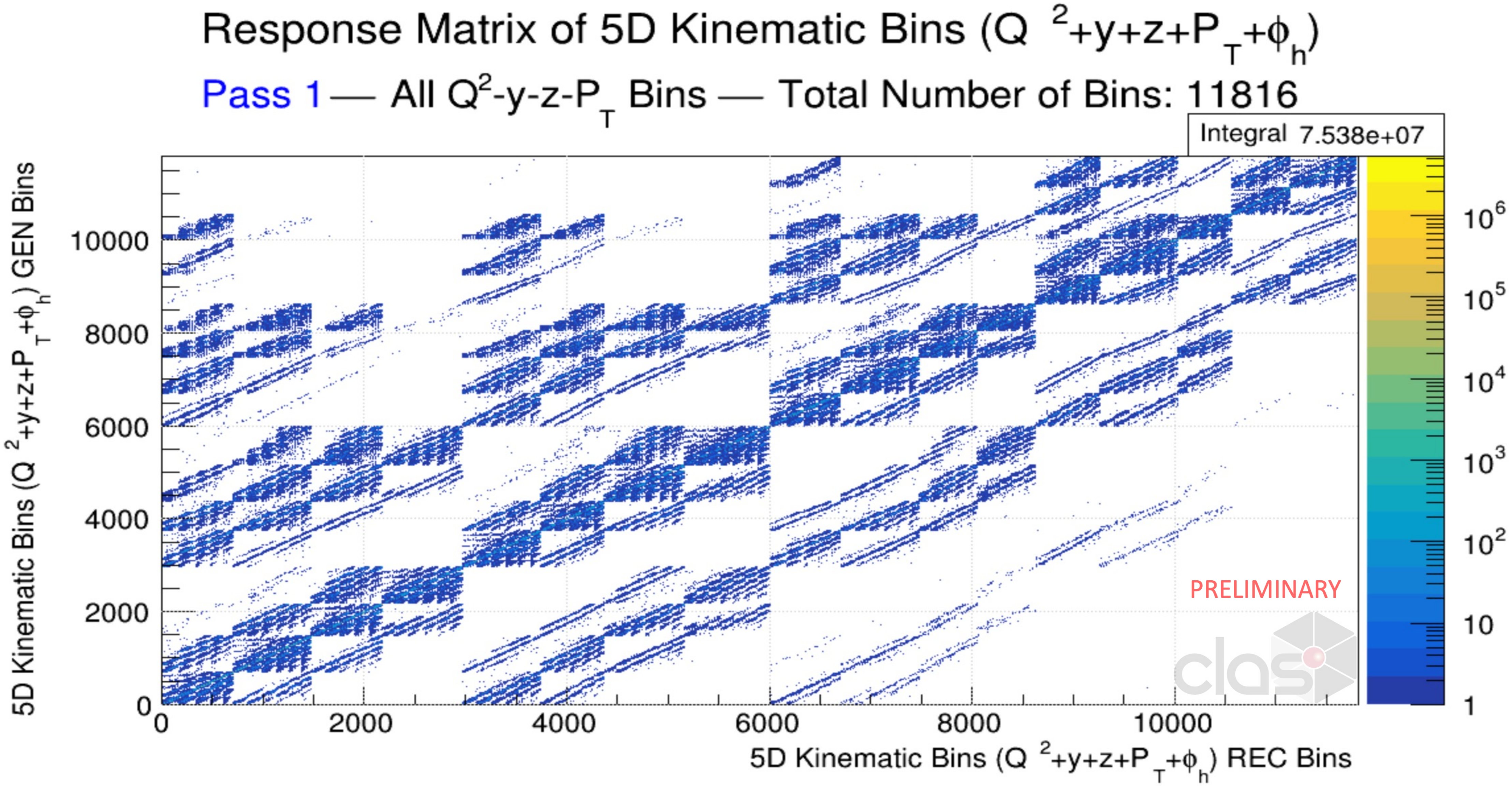


Q^2-y Bin 14: Events from Generated Missing Mass Cuts make up about 18.8% of the 'Background' shown below



Example of (5D) Unfolding Procedure

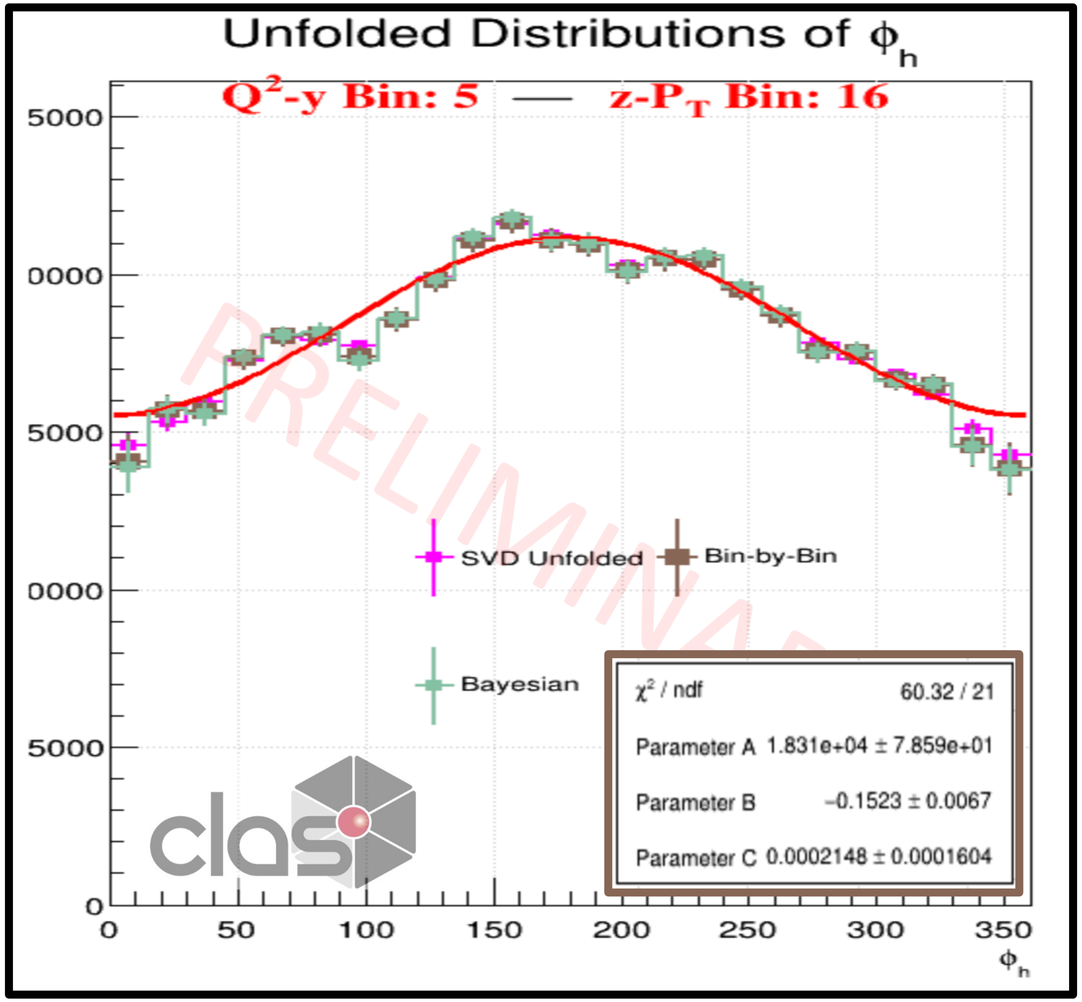
Using the Flattened Q^2-y-z-P_T-ϕ_h Multidimensional Bins

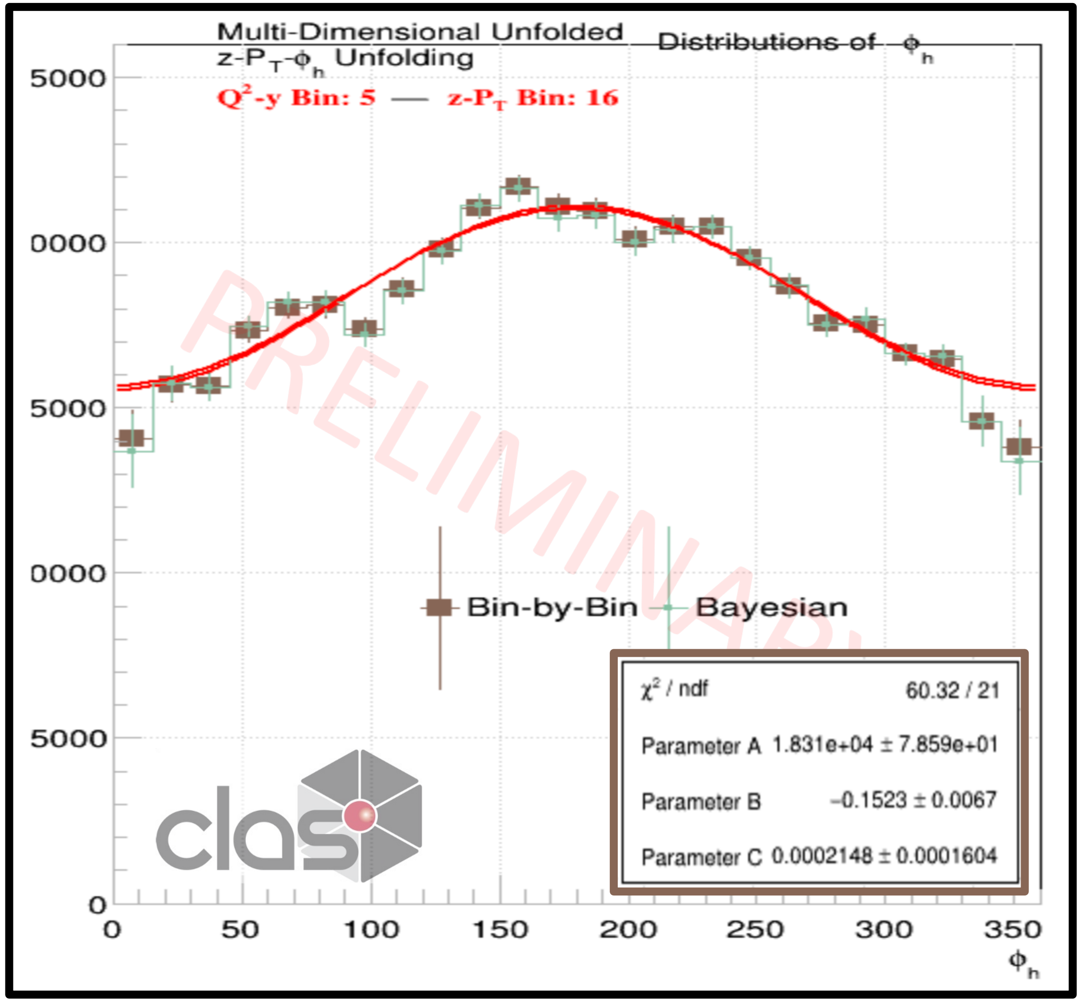


UCONN

Comparisons of 1D and 3D Unfolding Procedure

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



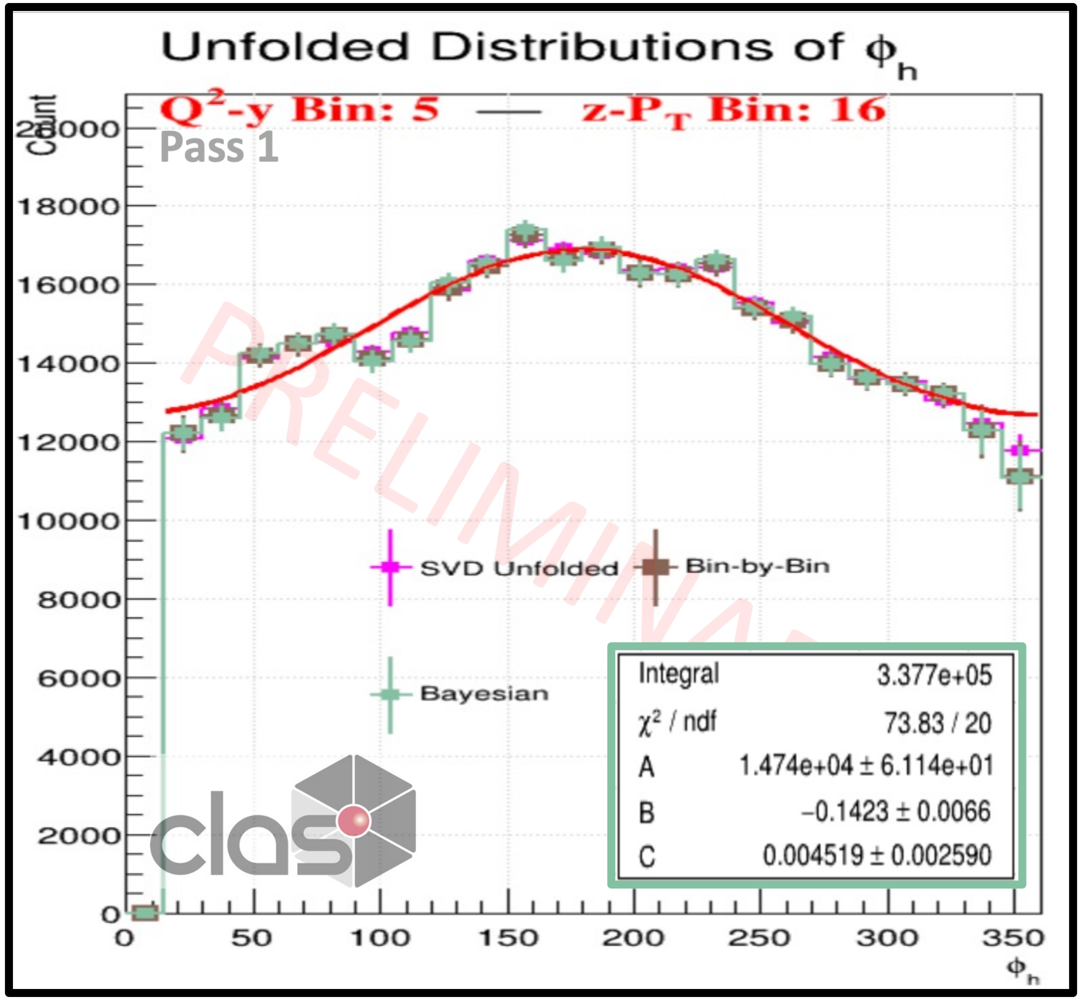


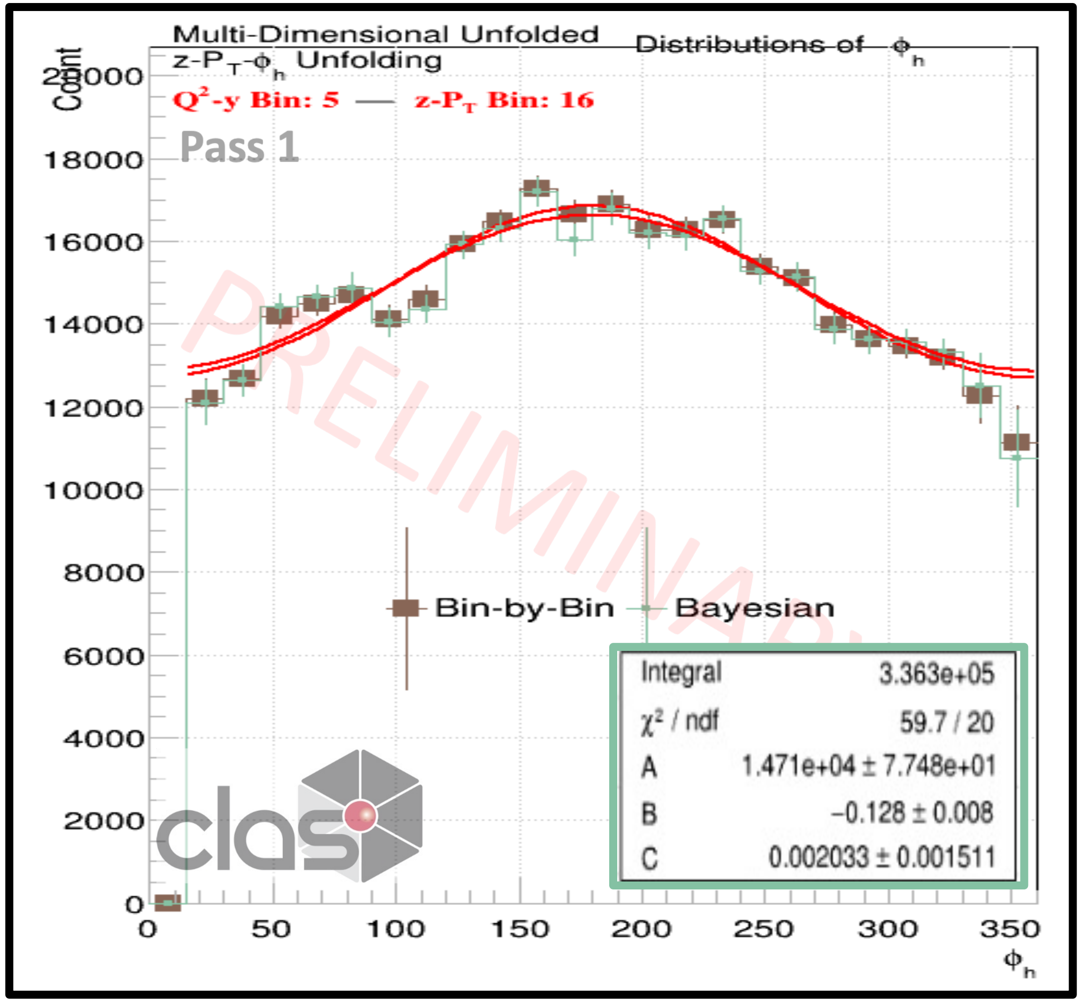
Bin-by-bin Acceptance Correction gives the exact same results

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

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

Cosine Moments as Functions of z – Pass 1

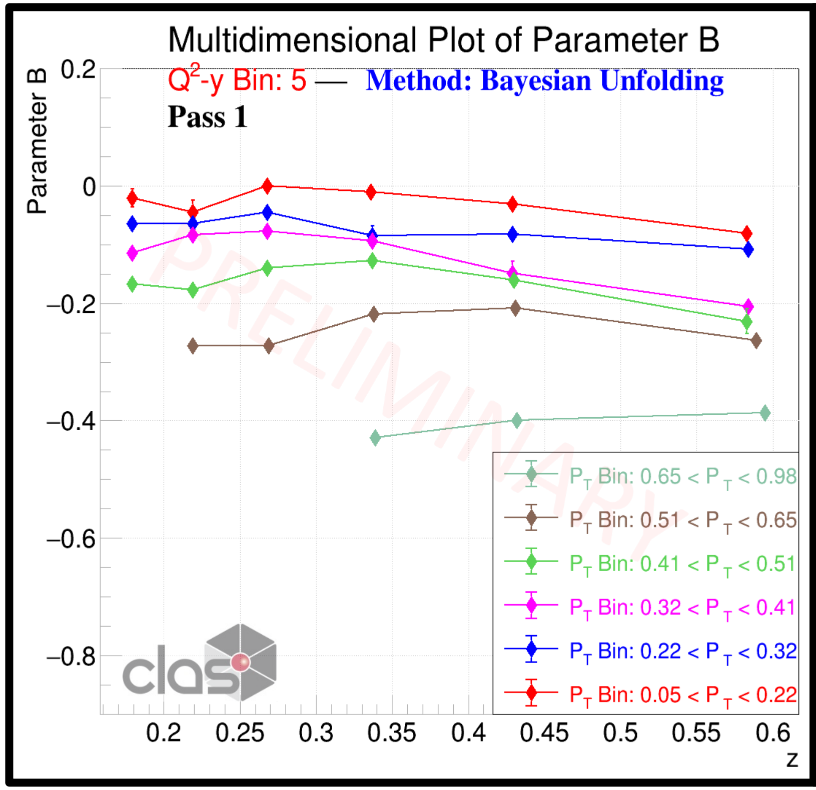
$$B = A_{UU}^{\cos\varphi_h} \quad C = A_{UU}^{\cos 2\varphi_h}$$

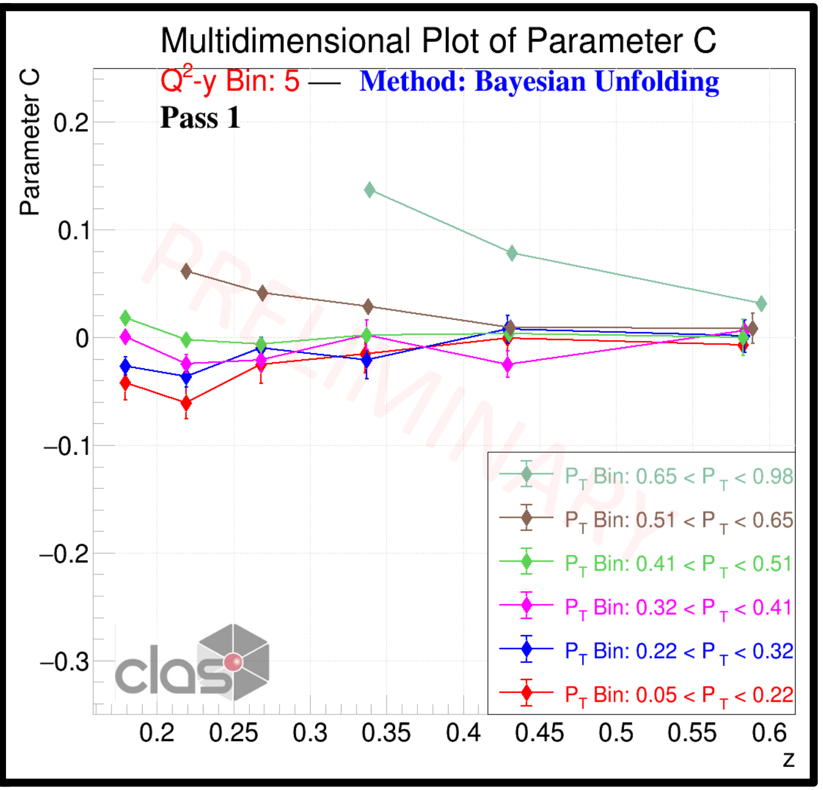
ϕ_h Plots were fitted with:

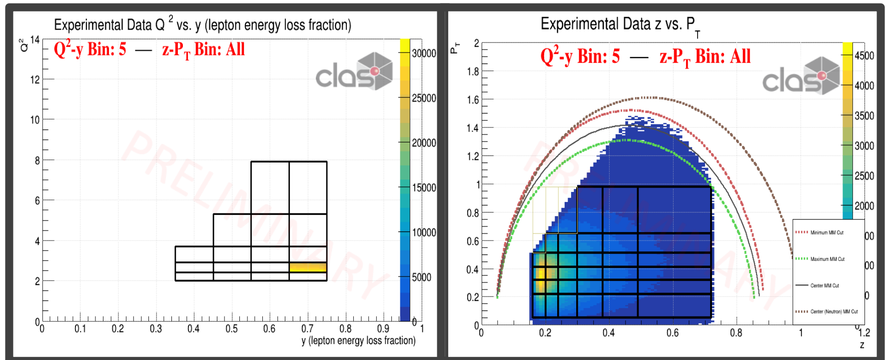
$$A(1 + B\cos(\phi_h) + C\cos(2\phi_h))$$

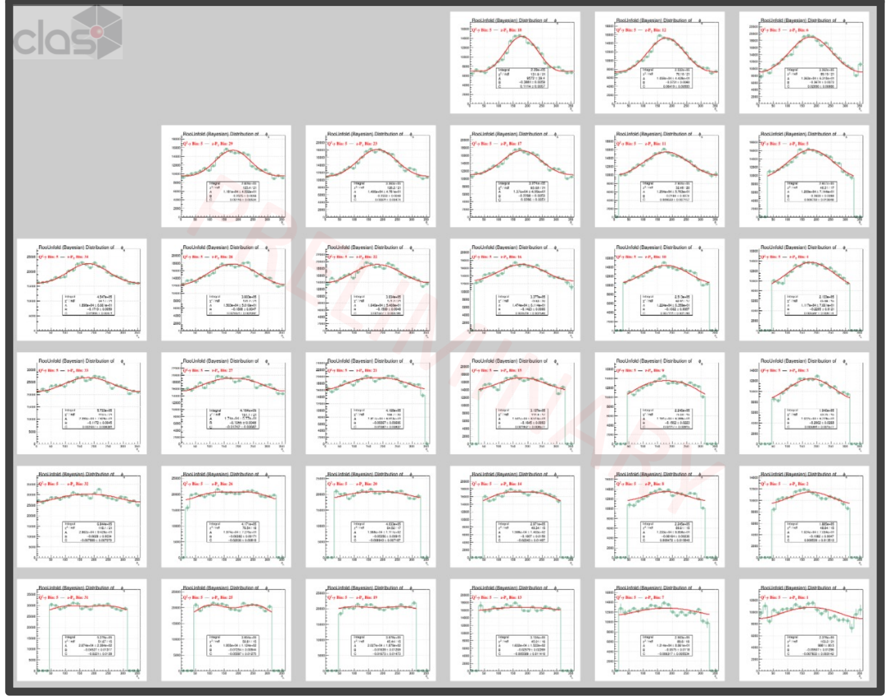
Unfolded with Bayesian Method

Q^2-y Bin 5









Cosine Moments as Functions of z – Pass 1

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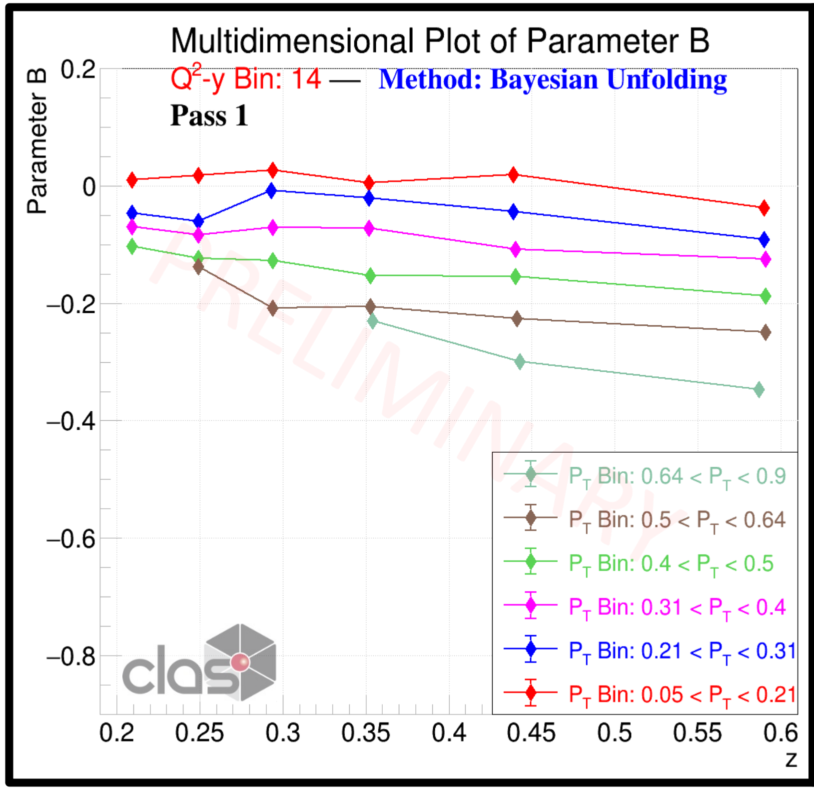
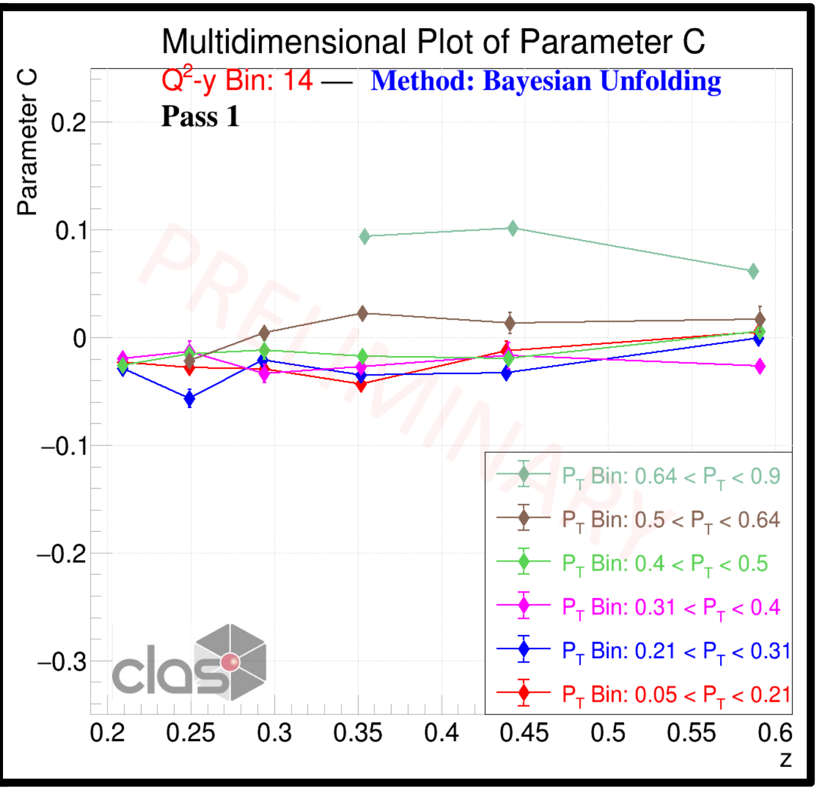
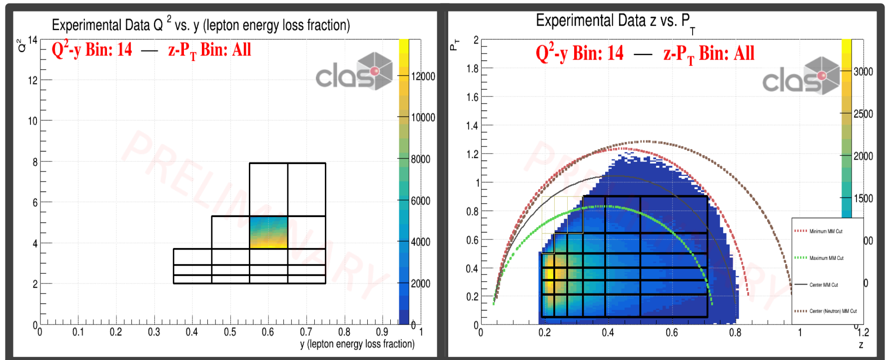
$A(1 + B\cos(\phi_h) + C\cos(2\phi_h))$

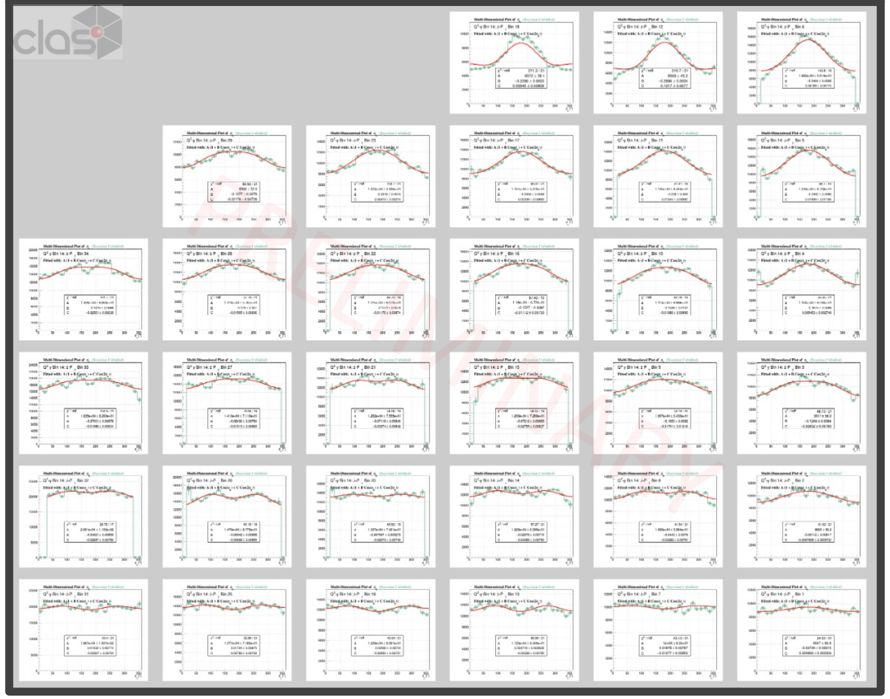
Unfolded with Bayesian Method

Q^2-y Bin 14









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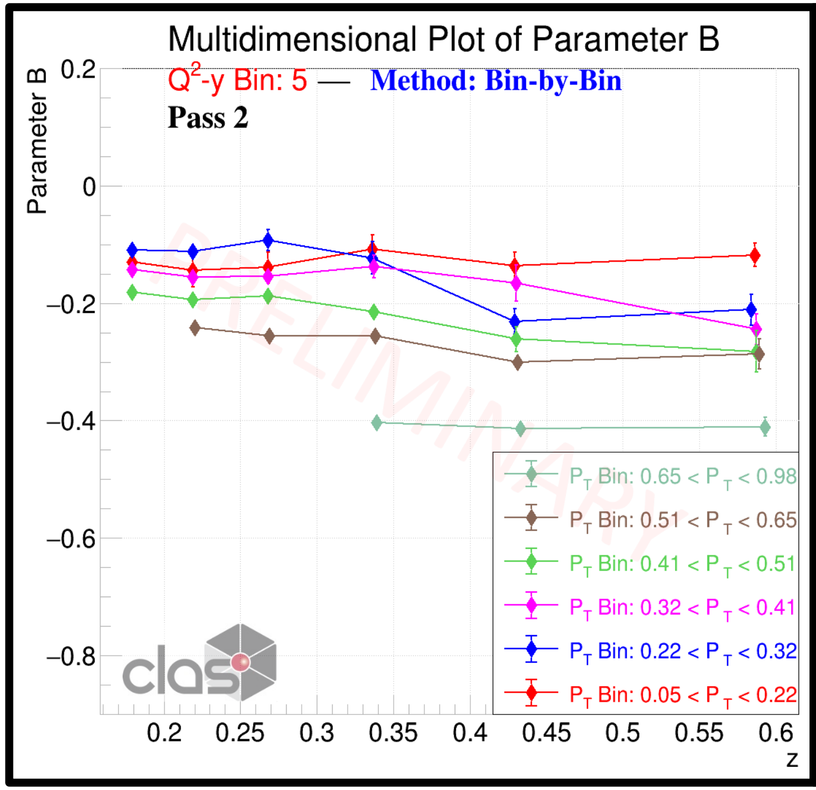
Cosine Moments as Functions of z - with Pass 2

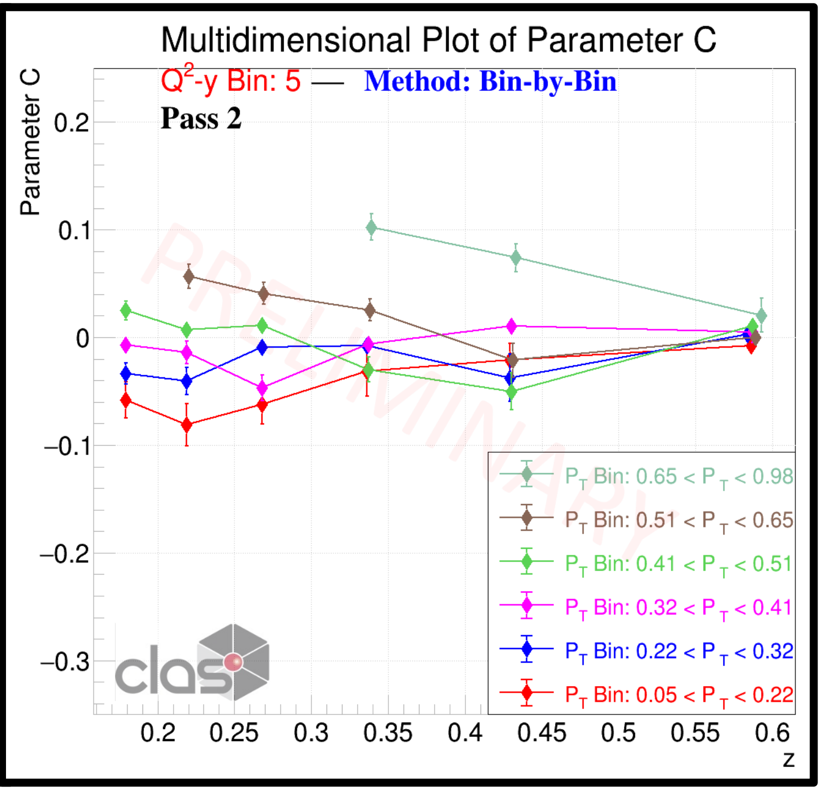
$$B = A_{UU}^{\cos\varphi_h} \quad C = A_{UU}^{\cos 2\varphi_h}$$

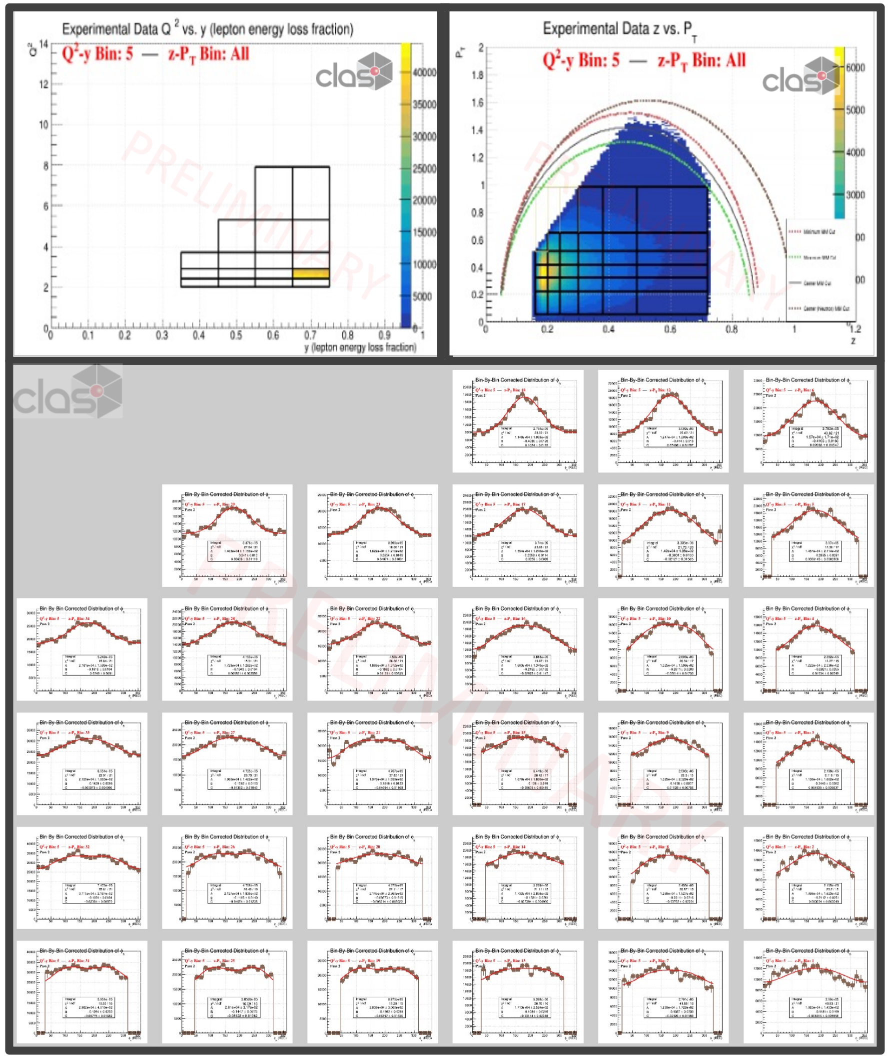
ϕ_h Plots were fitted with:
$$A(1 + B\cos(\phi_h) + C\cos(2\phi_h))$$

Corrected with Bin-by-bin Method

Q^2-y Bin 5







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Cosine Moments as Functions of z - with Pass 2

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ϕ_h Plots were fitted with:
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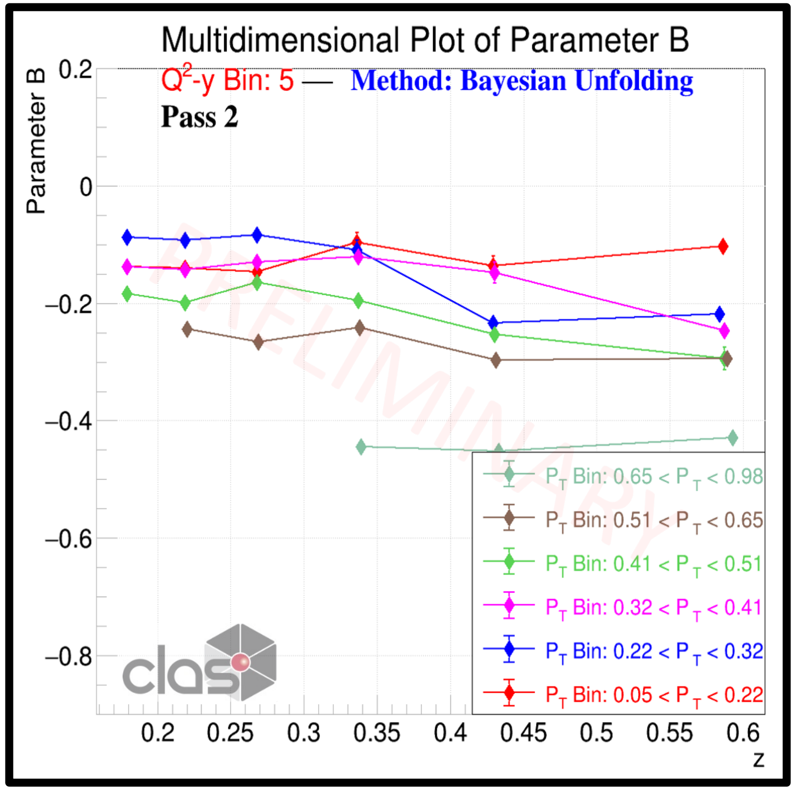
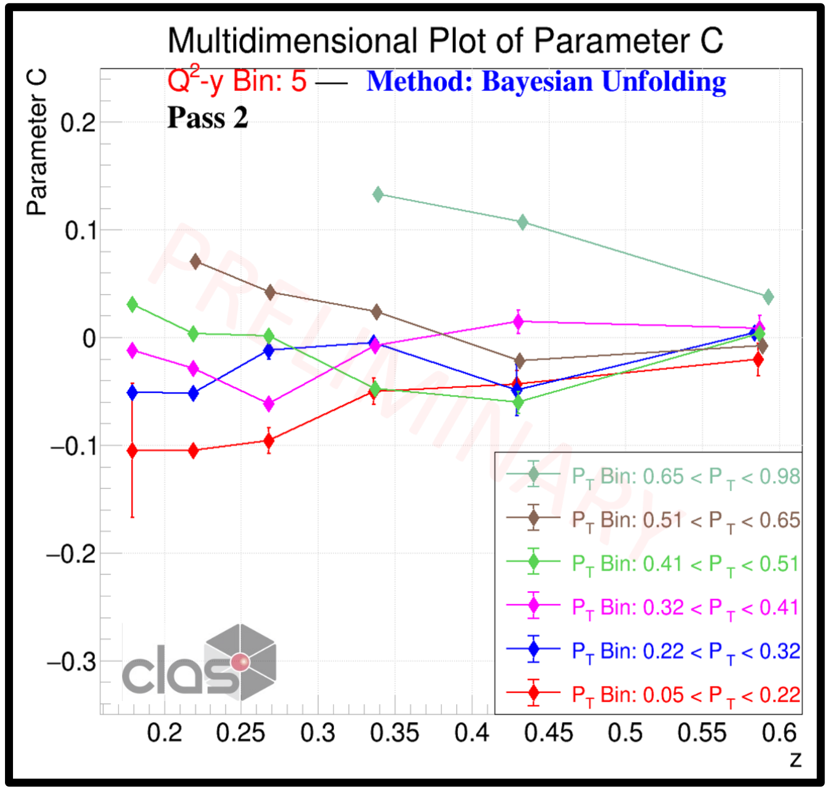
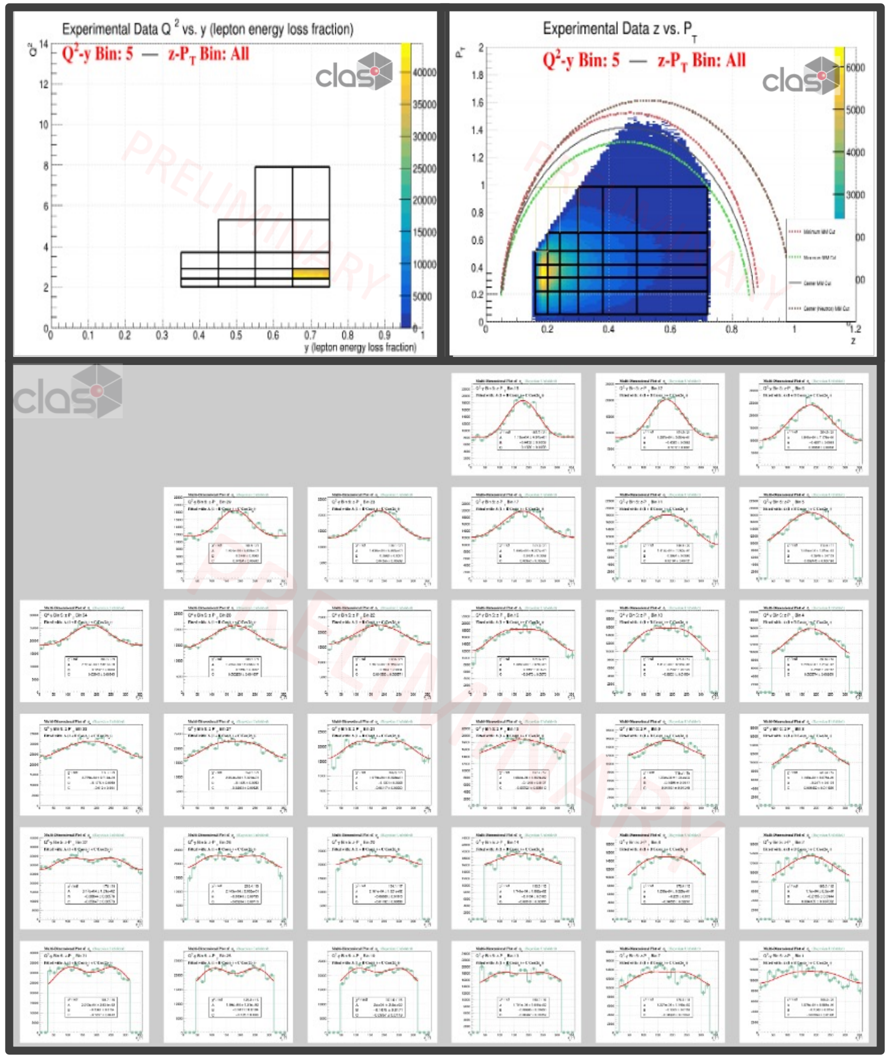
Unfolded with Bayesian Method

Q^2-y Bin 5







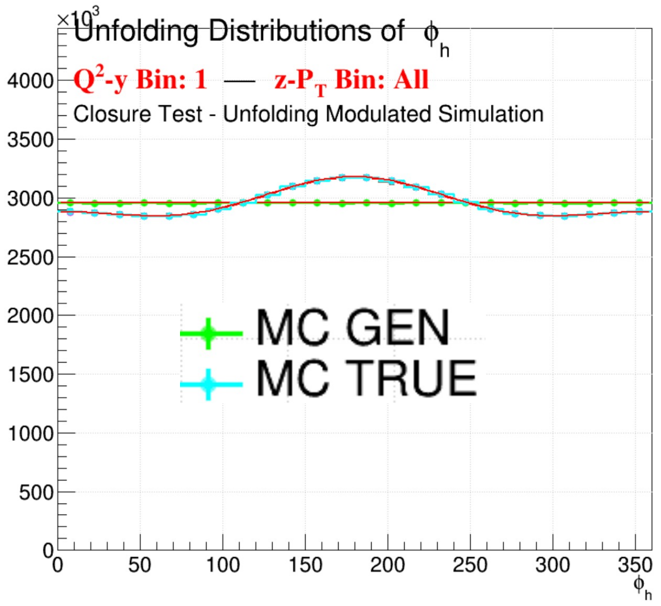
Modulated Unfolding Closure Tests

- 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)



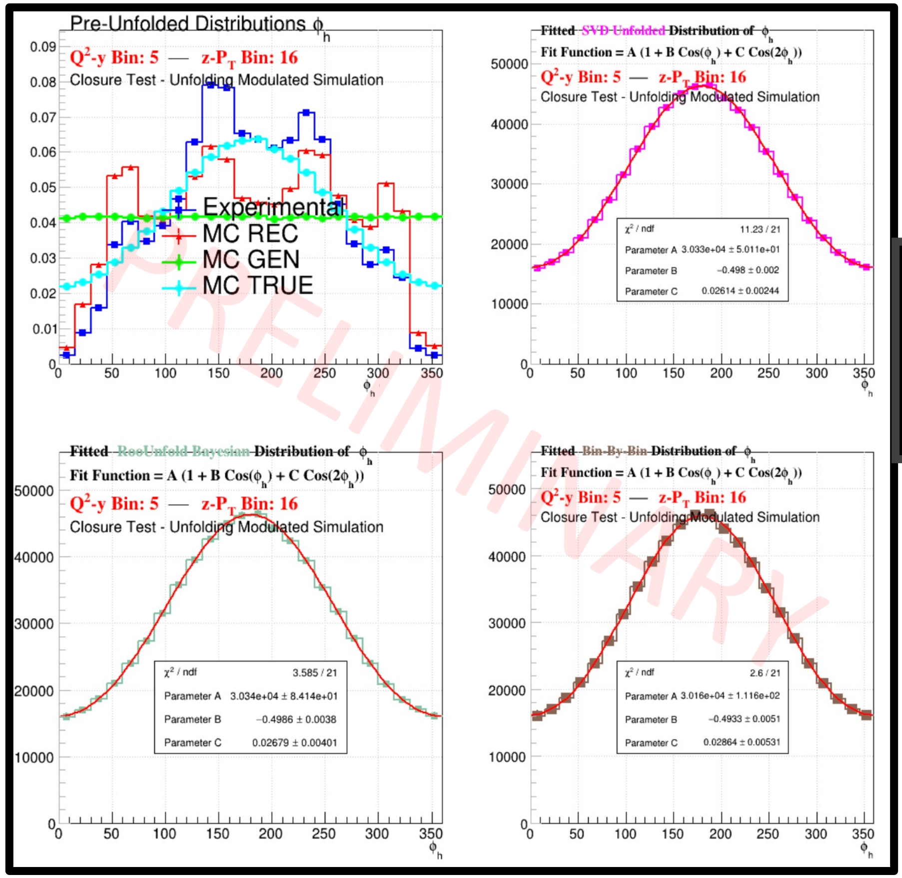
- Modulated MC REC is then unfolded using the un-modulated response matrix (in 1D and Multi-Dim examples) and compared with ‘MC TRUE’
  - MC TRUE is the modulated MC GEN distribution
  - Also performed a closure test of unfolding the un-modulated MC REC distribution with the un-modulated response matrix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

Modulated Unfolding Closure Tests

The parameters used for weighing modulations below are:

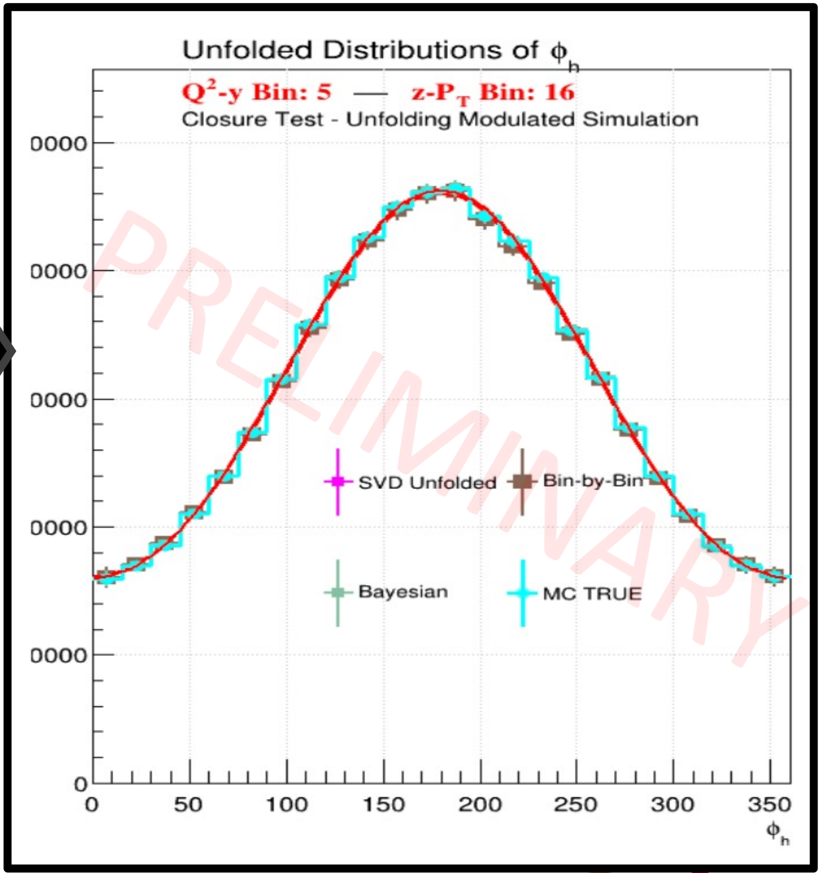
B = -0.5 and C = 0.025

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



Checking that the corrected distributions match MC TRUE

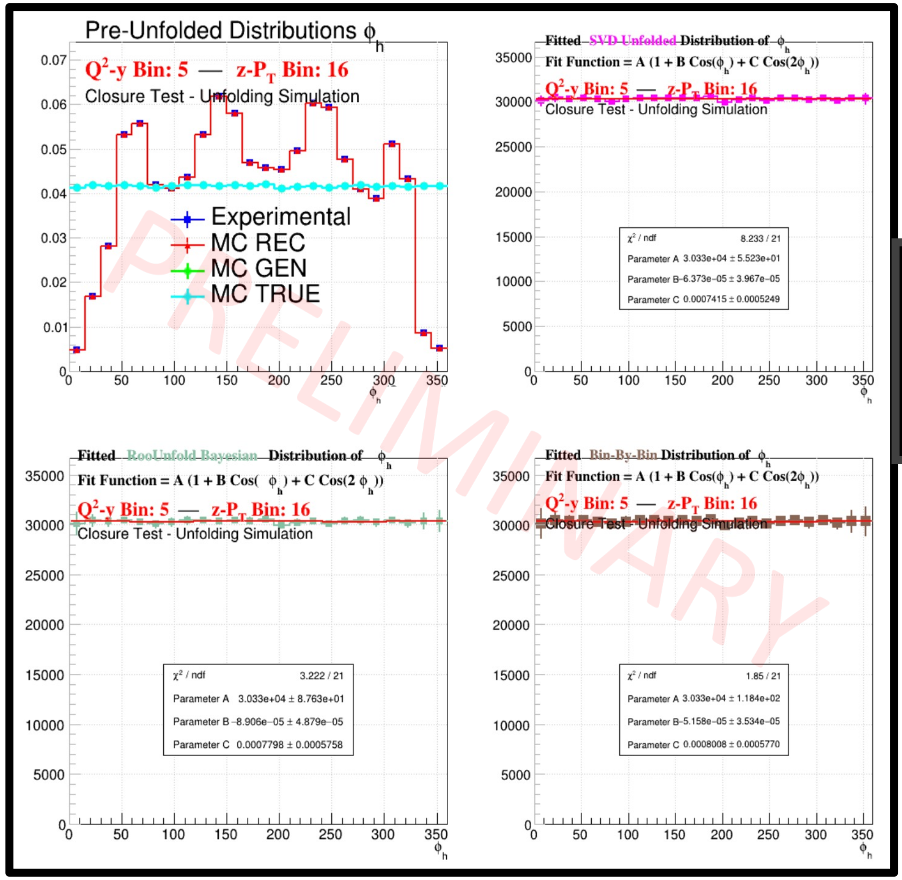
Fits are within the margin of error of the defined parameters



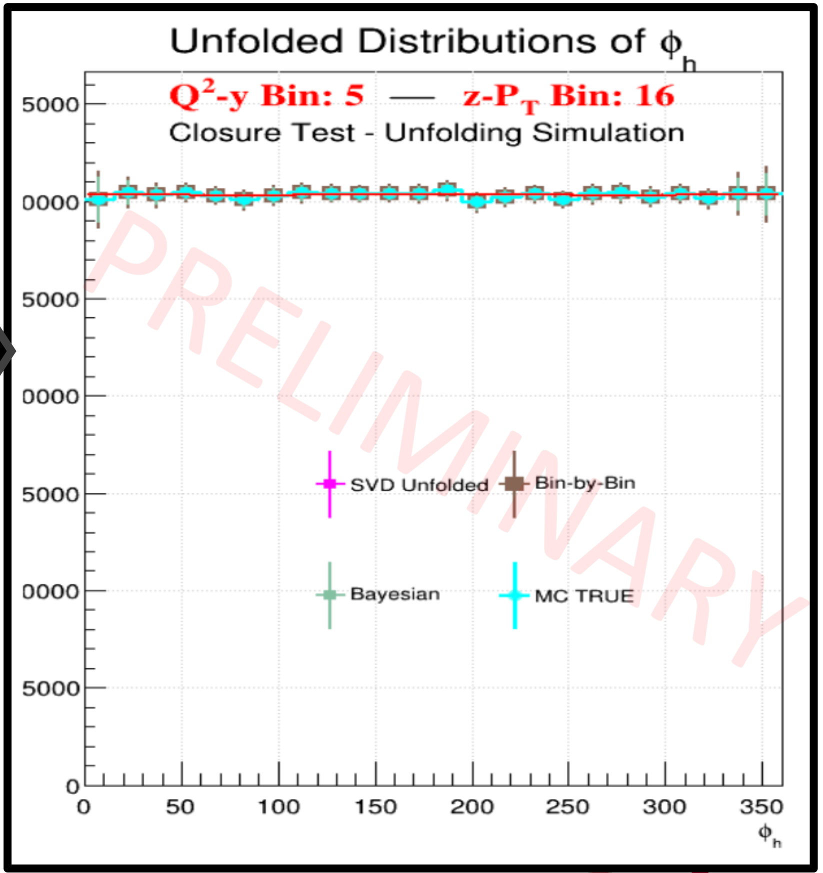
Other Unfolding Closure Tests

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



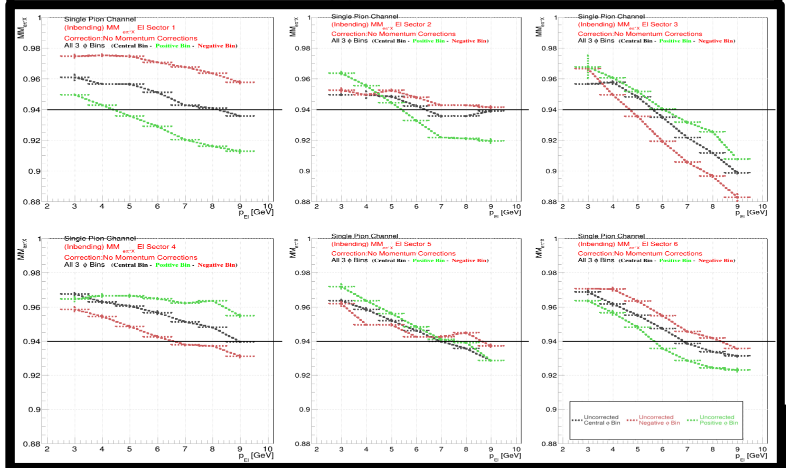
Momentum Corrections from Exclusive Events

- 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→e'π^+(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}

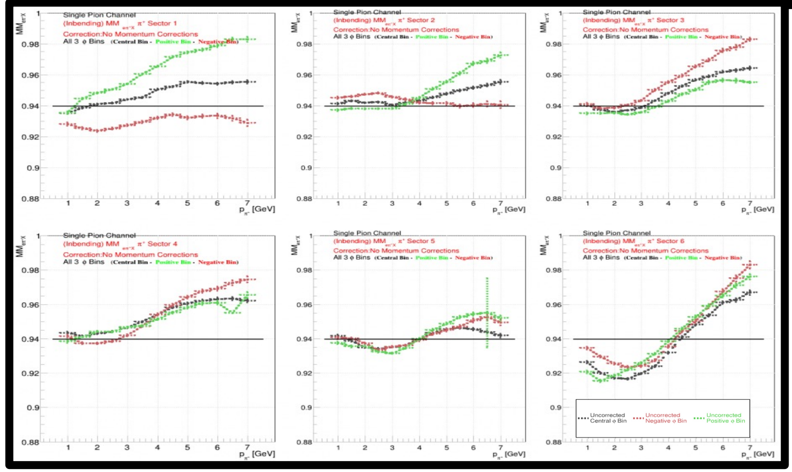
Momentum Corrections from Exclusive Events

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

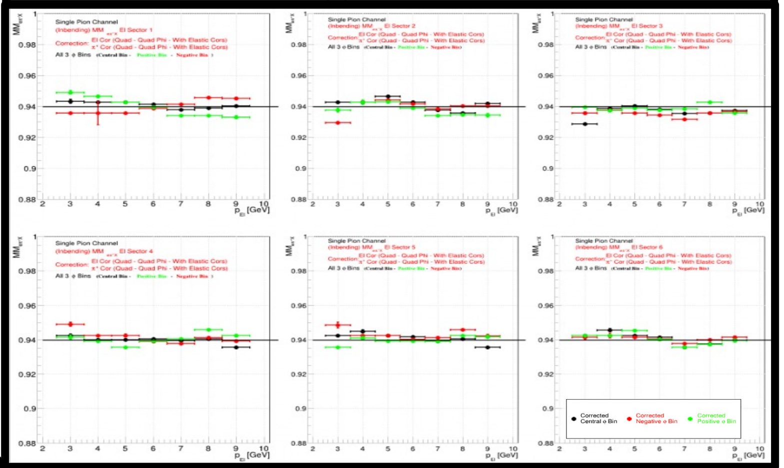


Missing Mass ($MM_{e\pi^+X}$) vs π⁺ Pion Momentum

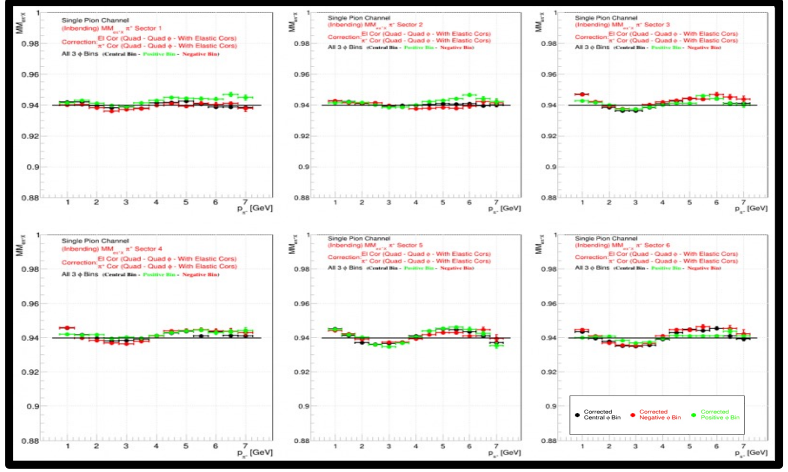


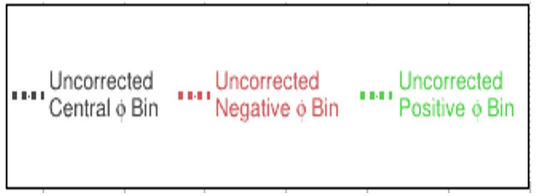
Apply Momentum Corrections

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

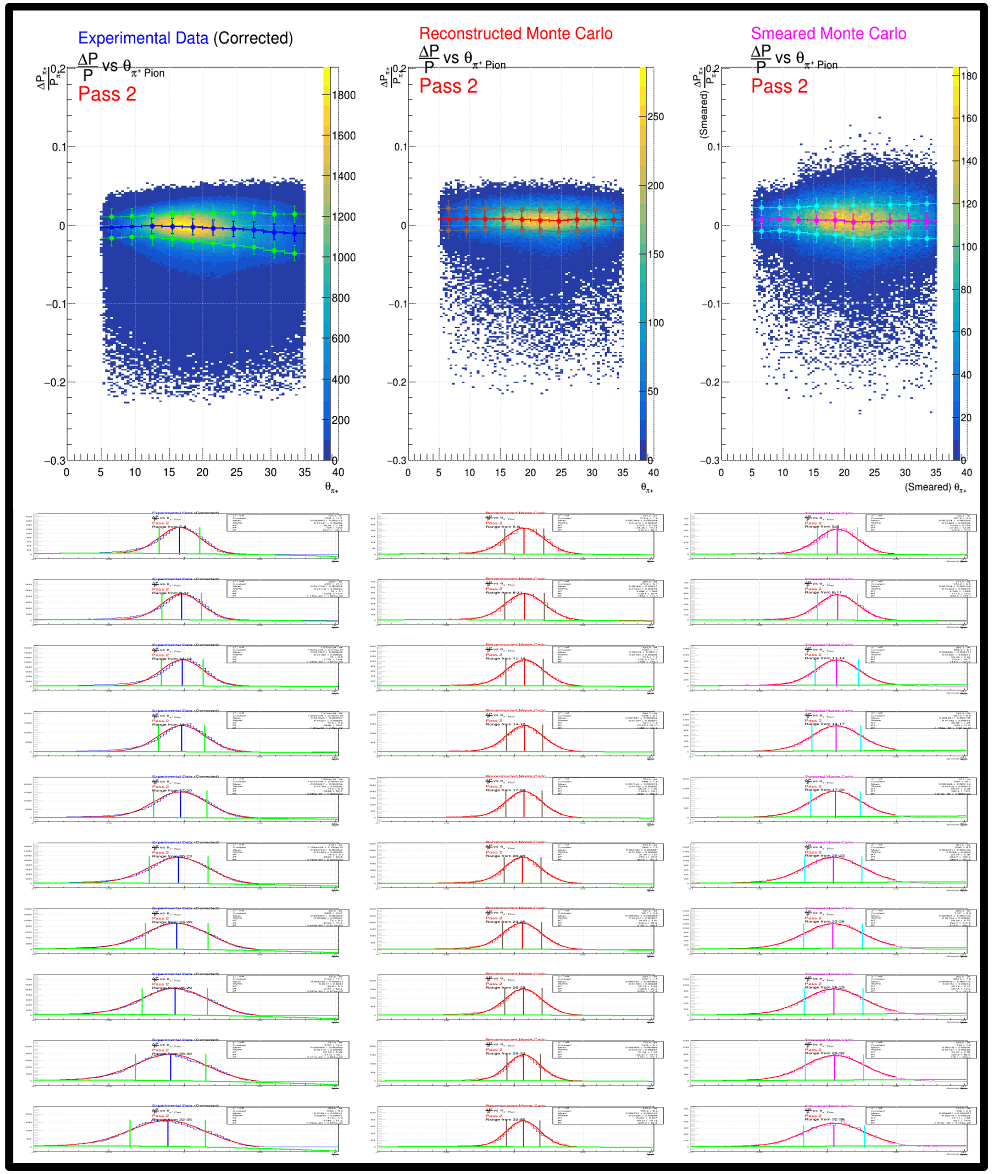


Missing Mass ($MM_{e\pi^+X}$) vs π⁺ Pion Momentum





Data and Monte Carlo Comparison (Smearing)

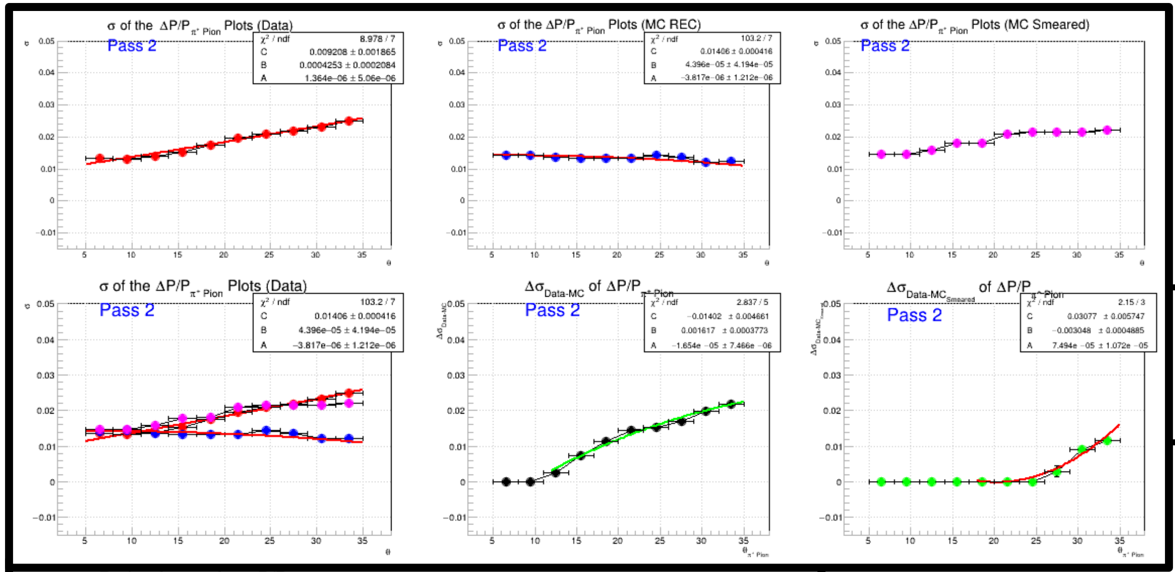


Form of Smearing Function:

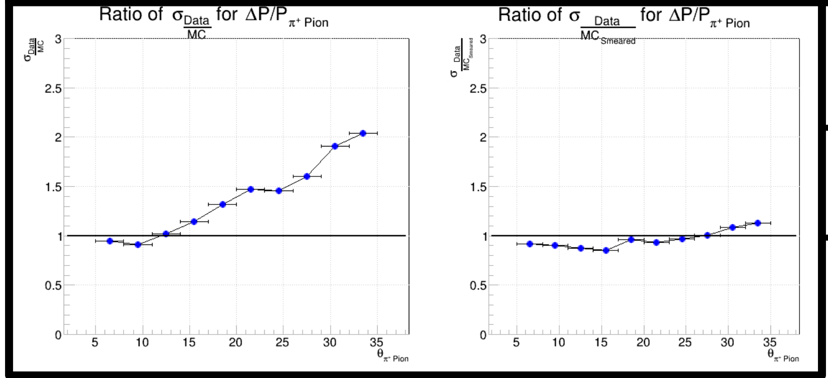
$$P_{Smeared} = P_{REC} + gRandom \rightarrow Gaus(0, P_{REC} * \sigma(\theta) * SF)$$

Where $\sigma(\theta)$ is the difference in the widths of ΔP/P for the Unsmeared MC and Data plots

SF is an additional constant smearing factor that gives me more control over the function



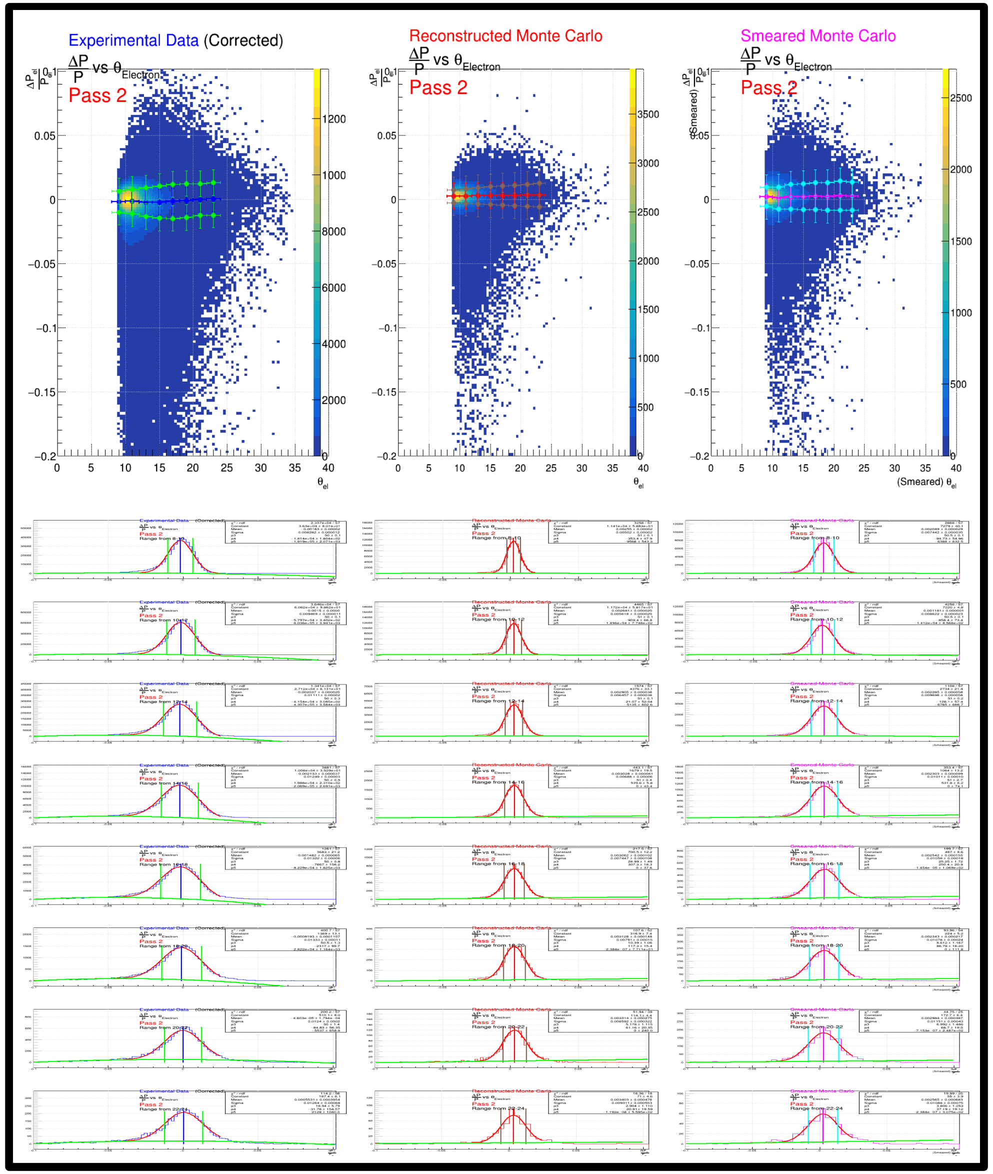
Difference between widths of Smeared MC and Data



Ratio of Peak Widths Before/After Smearing

Smearing for the π^+ Pion

Data and Monte Carlo Comparison (Smearing)



Form of Smearing Function:

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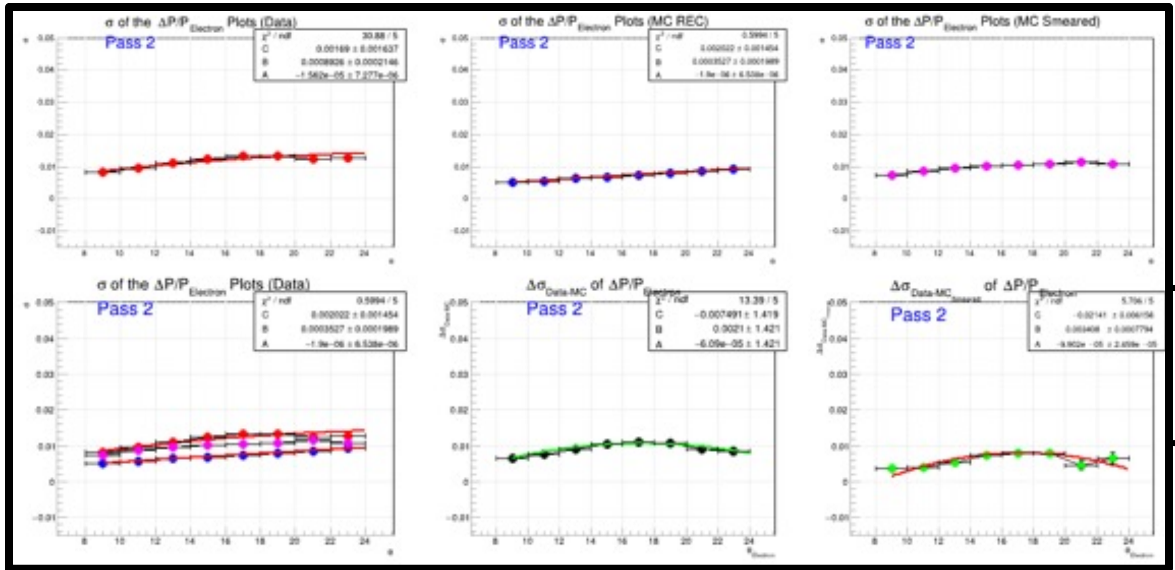
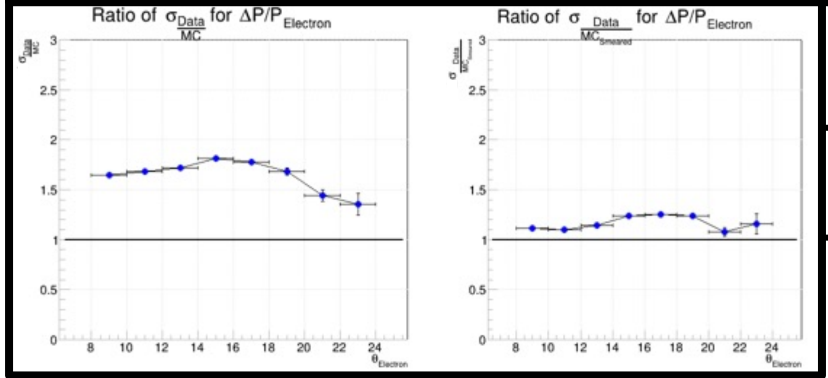
Where $\sigma(\theta)$ is the difference in the widths of ΔP/P for the Unsmeared MC and Data plots

SF is an additional constant smearing factor that gives me more control over the function



Difference between widths of Smeared MC and Data

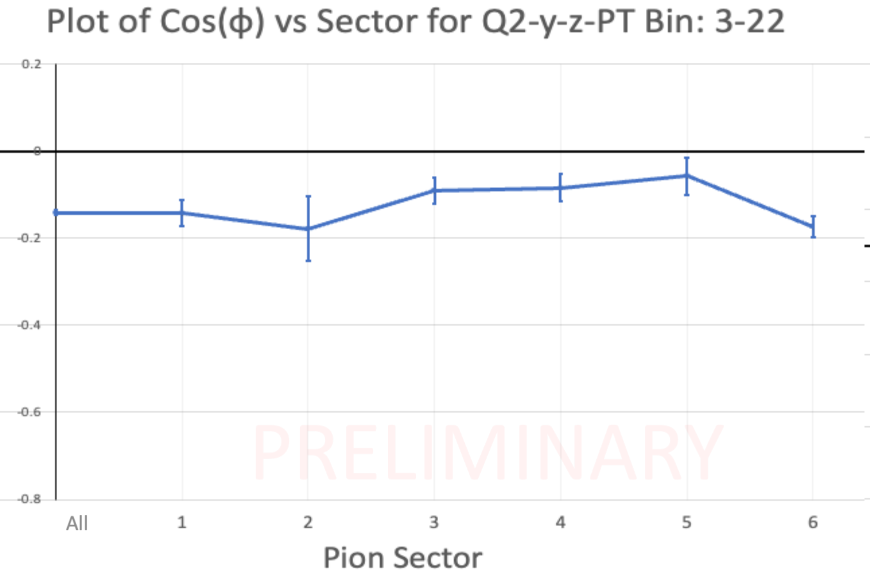


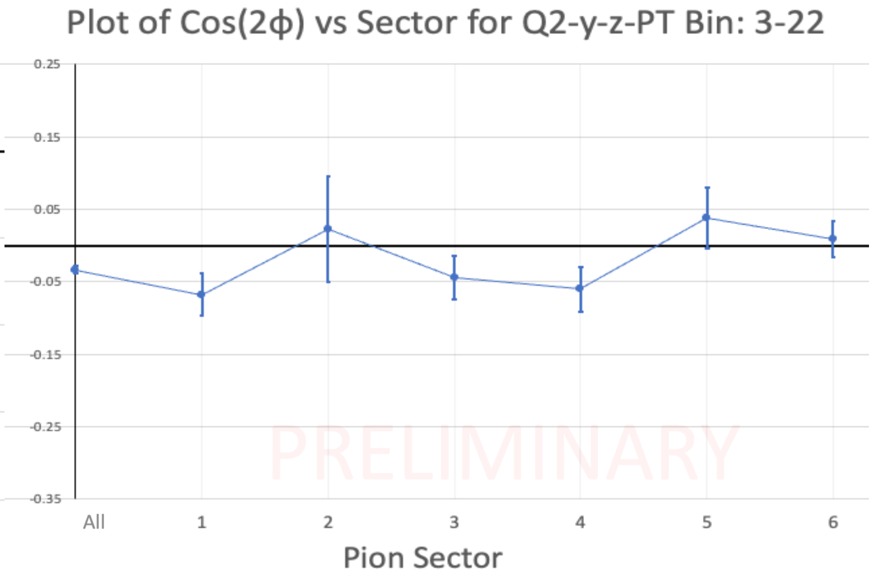
Ratio of Peak Widths Before/After Smearing

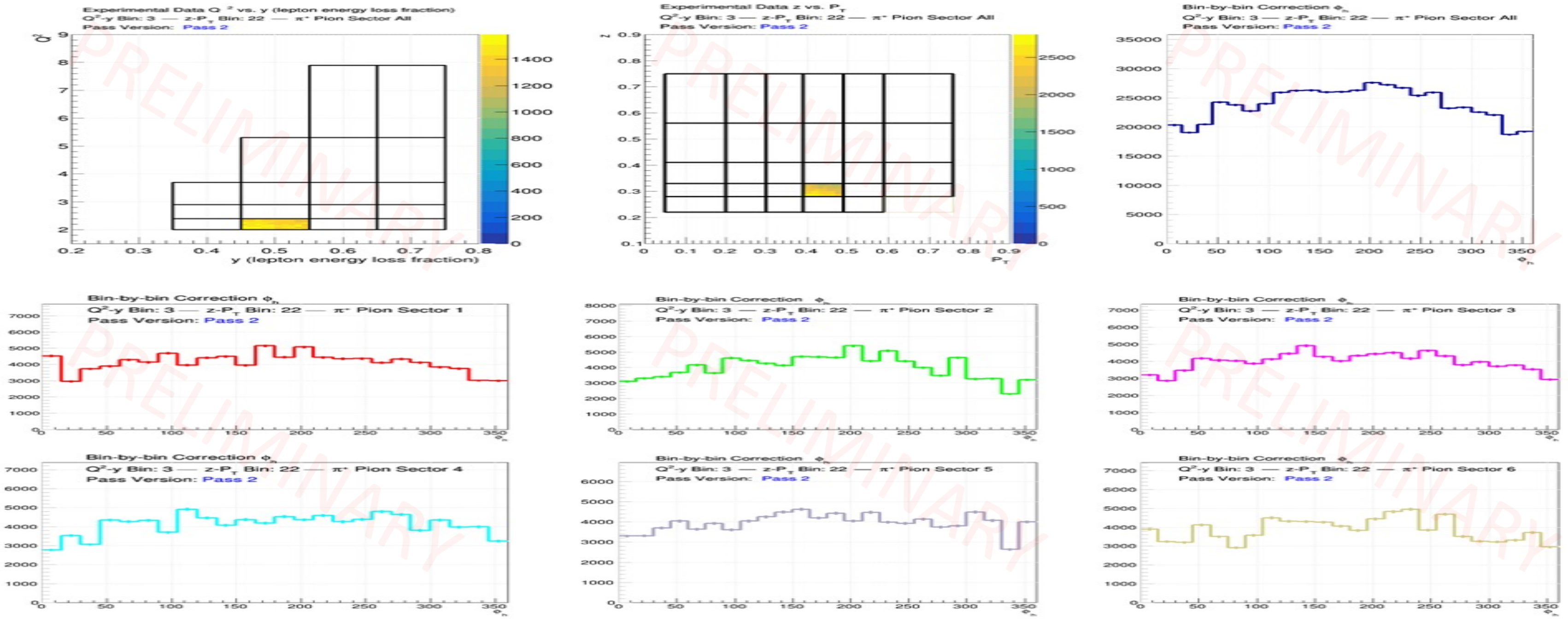
Smearing for the **Electron**

PASS 2

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







Some sector dependence remains despite the new cuts

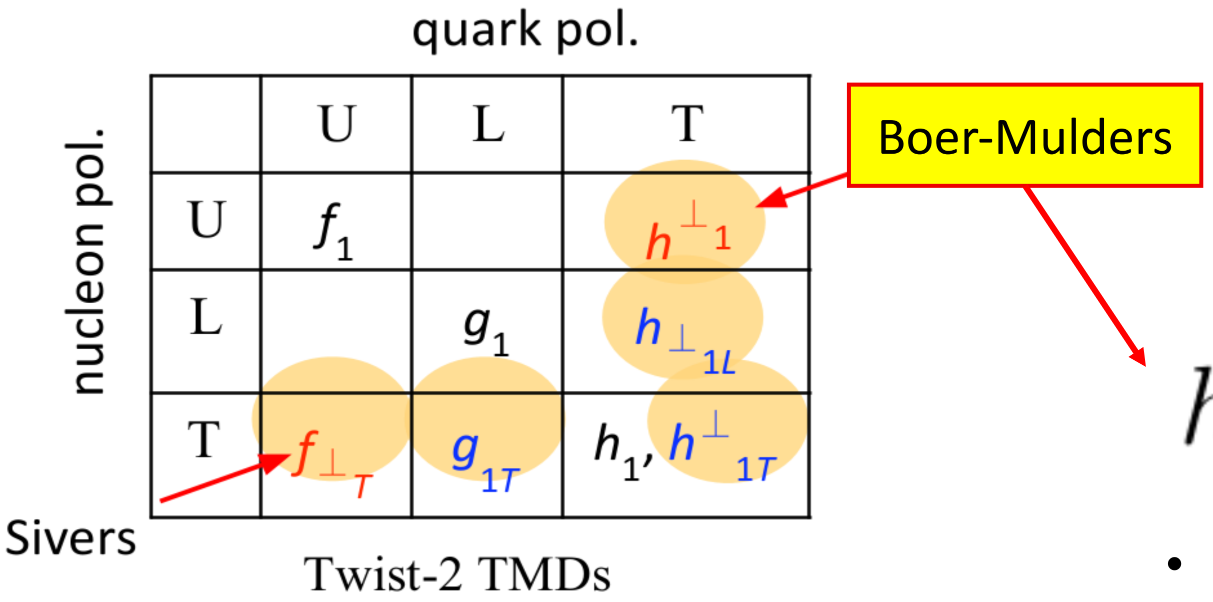
On average, the particle sector makes a noticeable difference about 50% of the time*

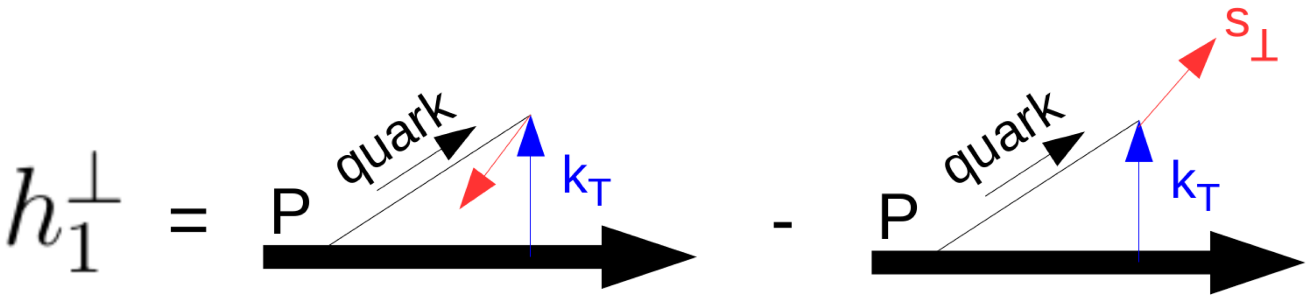
(i.e., the measurements of each sector do not agree with the measurement taken without sector dependence to within the errors shown)

A sector dependences does seem to exist, but further investigation is still required

*Some of these discrepancies can be blamed on individual fits failing due to even worse acceptances that have not yet been individually addressed

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

END

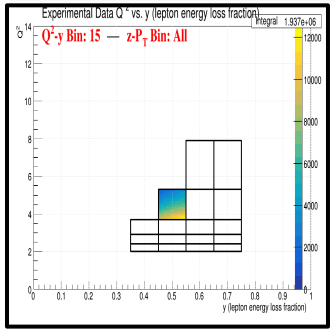
Link to more Images:

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

Pass 2 Condition

- Momentum/Energy Loss Corrections in Pass 2 have been implemented
- Monte Carlo statistics are still low (using test sample)
  - Planning to run more files soon
  - Also hope to run using RADGEN to start including radiative effects
  - Working side-by-side with Pass 1 in the meantime for better MC statistics

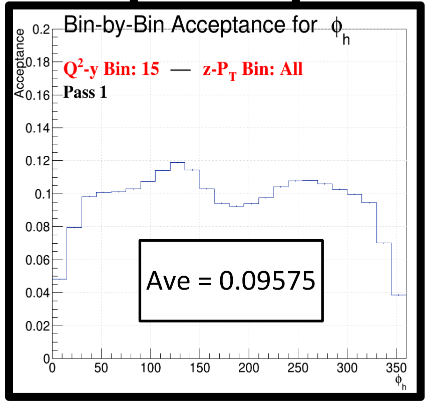
Pass 2 Comparisons - Acceptances



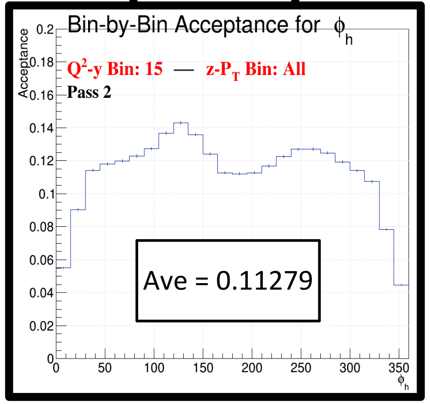
High Q^2
Low y

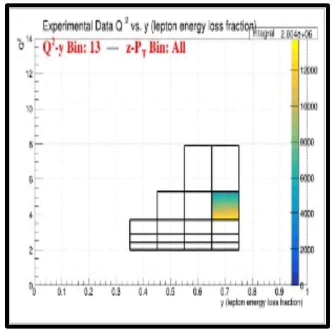
Δ Ave = +0.01704

Pass 1



Pass 2

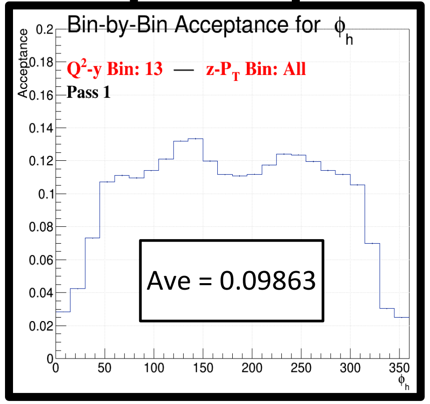




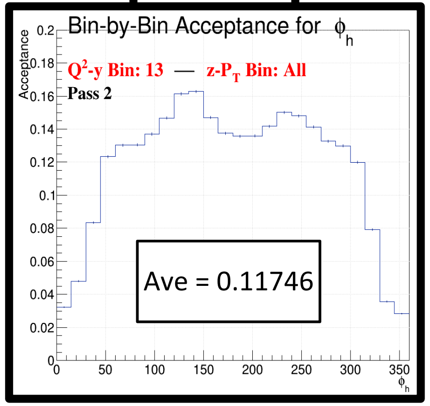
High Q^2
High y

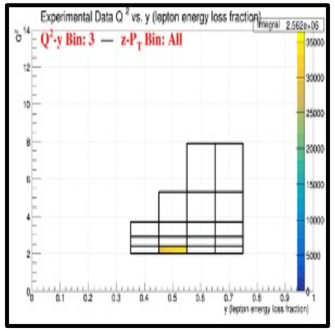
Δ Ave = +0.01883

Pass 1



Pass 2

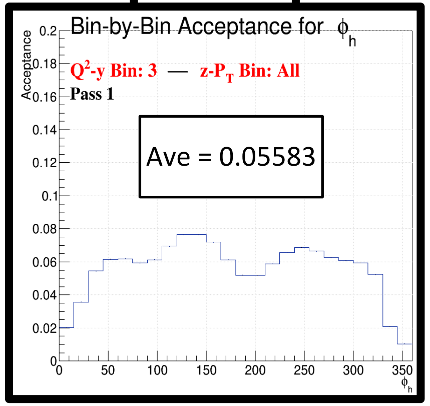




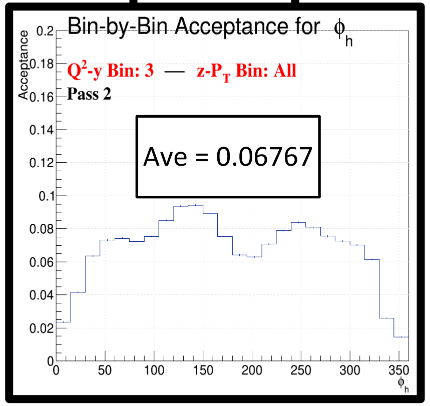
Low Q^2
Low y

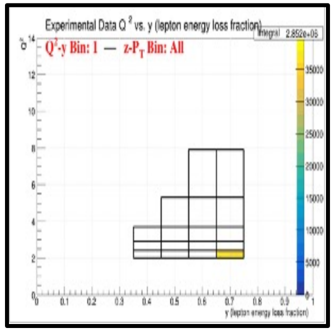
Δ Ave = +0.01184

Pass 1



Pass 2

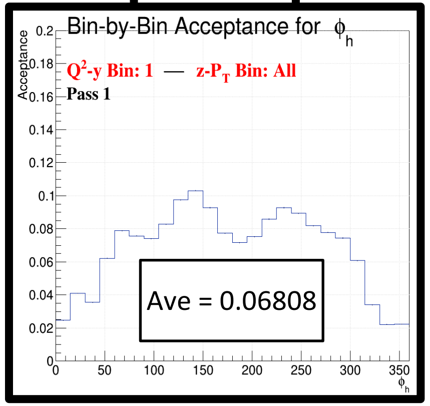




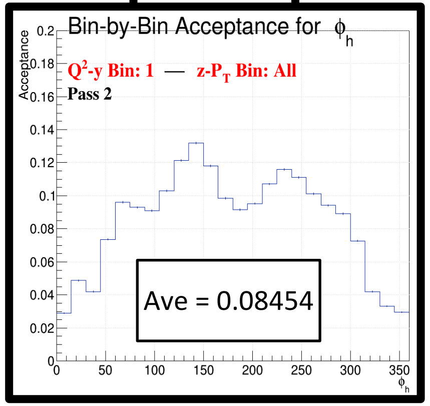
Low Q^2
High y

Δ Ave = +0.01646

Pass 1



Pass 2



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

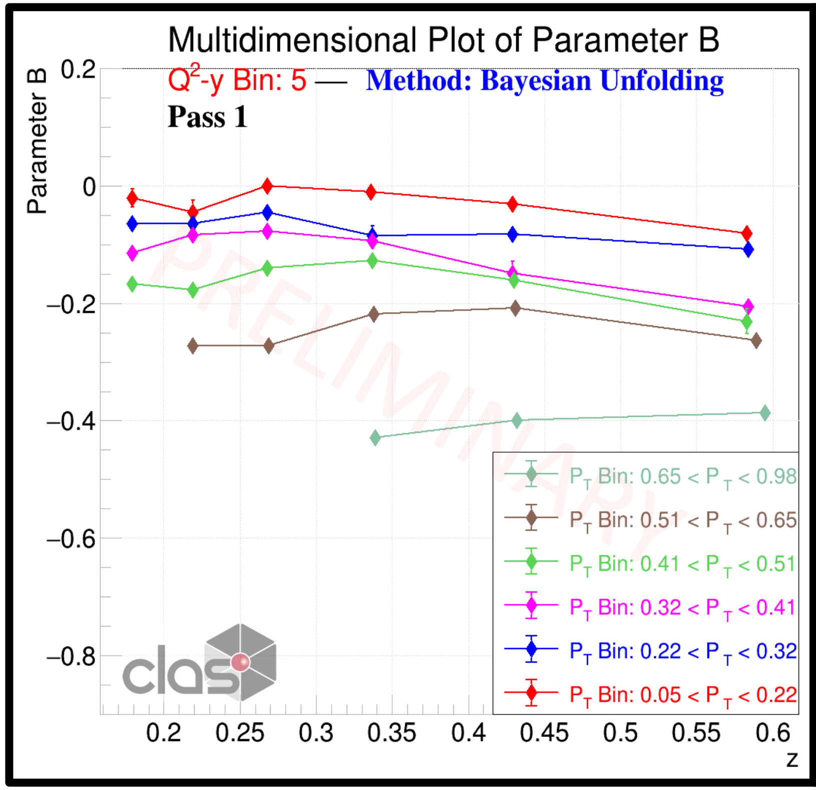
$$\mathbf{B} = A_{UU}^{\cos\varphi_h}$$

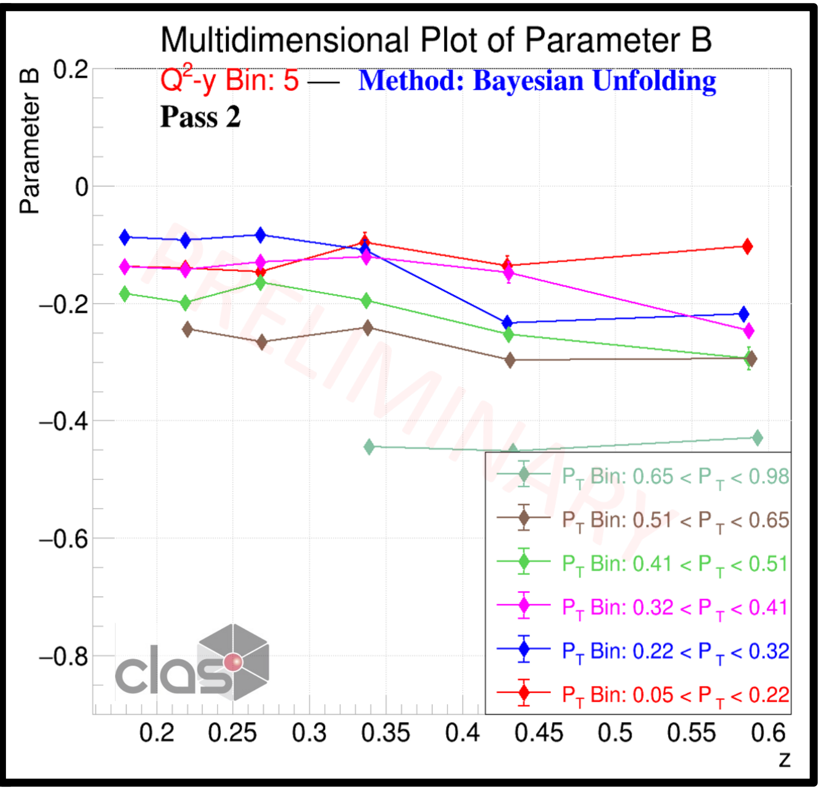
ϕ_h Plots were fitted with:

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

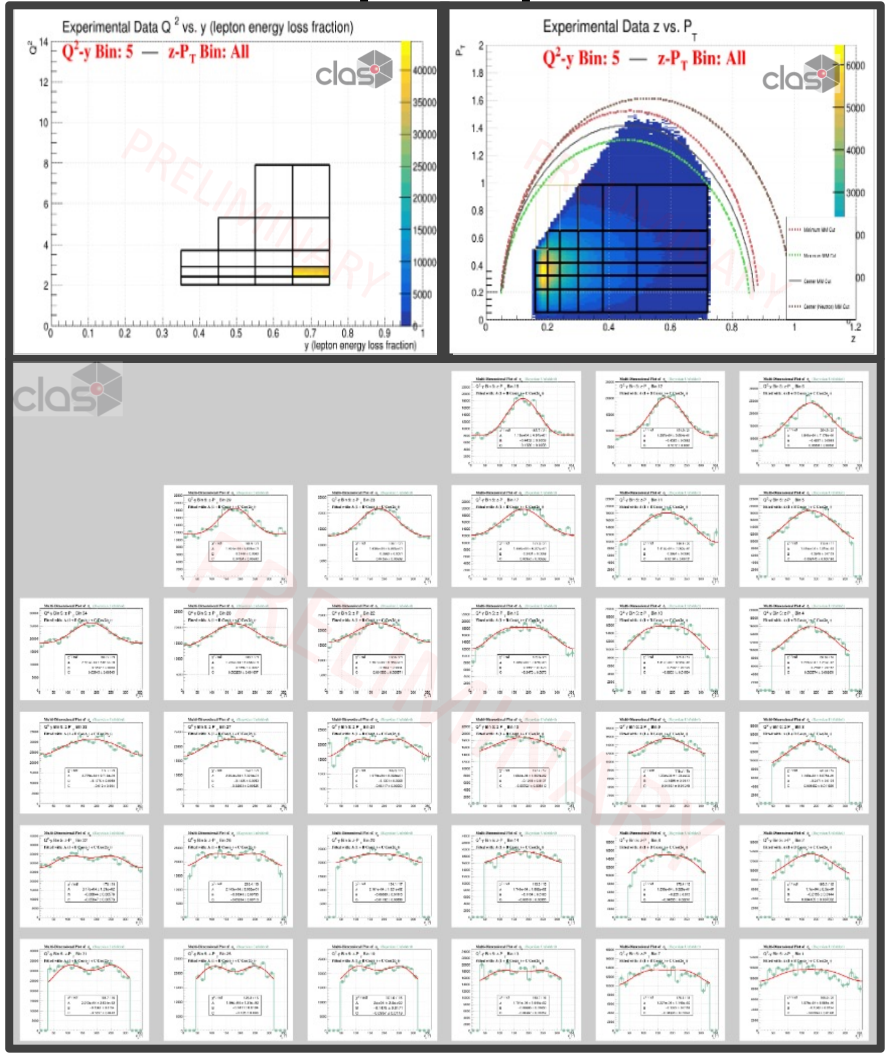
Unfolded with Bayesian Method

Q^2-y Bin 5





Pass 2



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

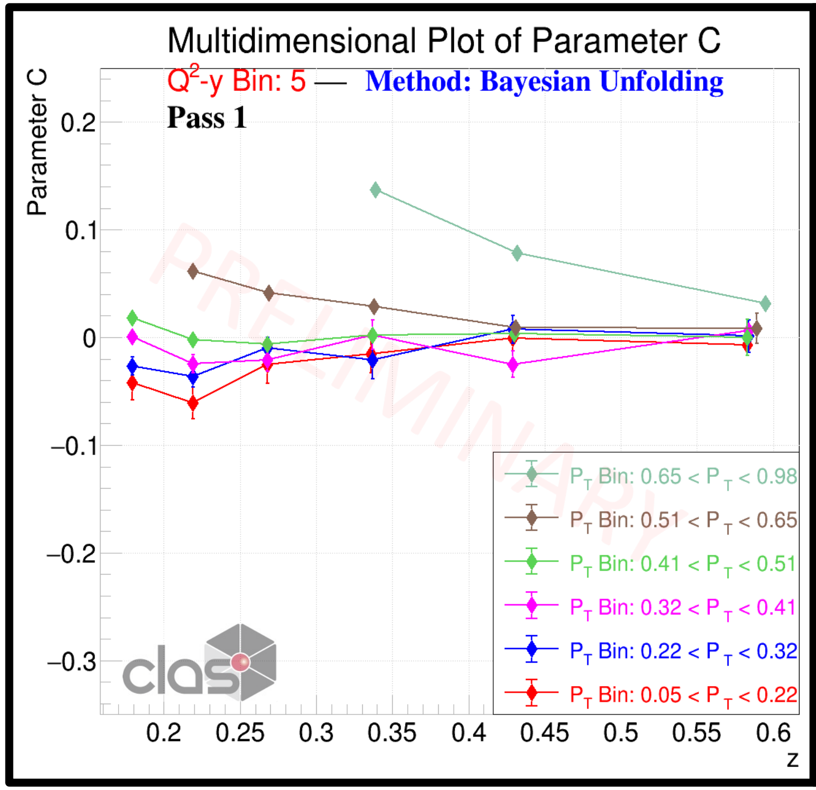
$$C = A_{UU}^{\cos 2\varphi_h}$$

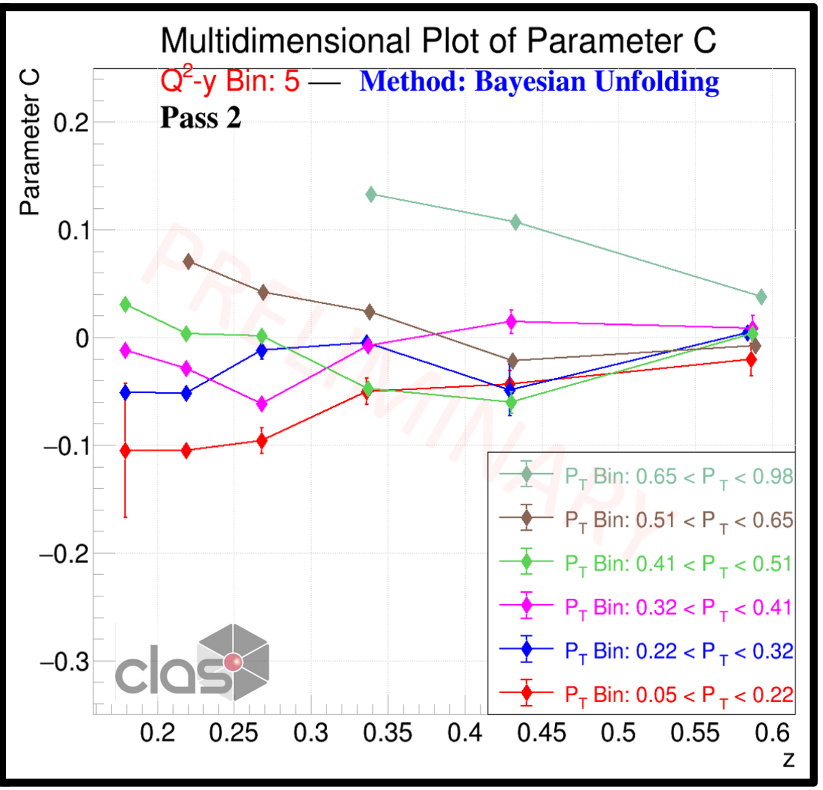
ϕ$_h$ Plots were fitted with:

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

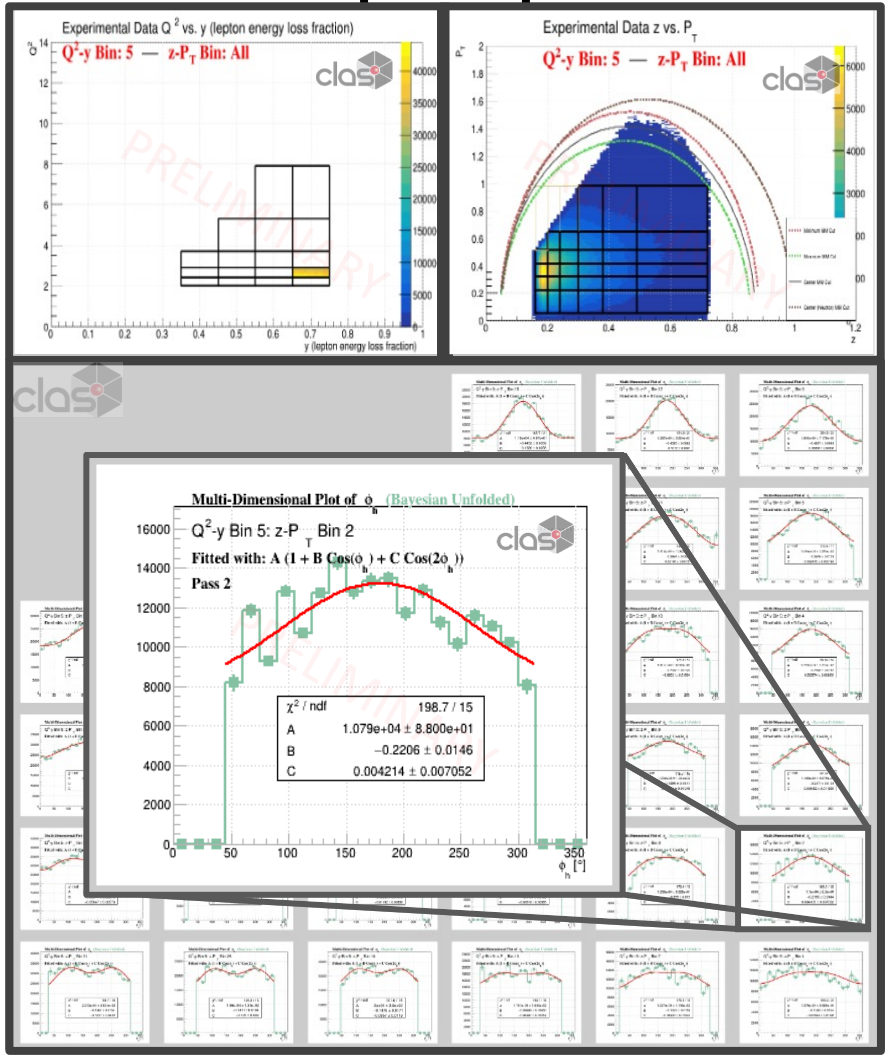
Unfolded with Bayesian Method

Q^2-y Bin 5





Pass 2



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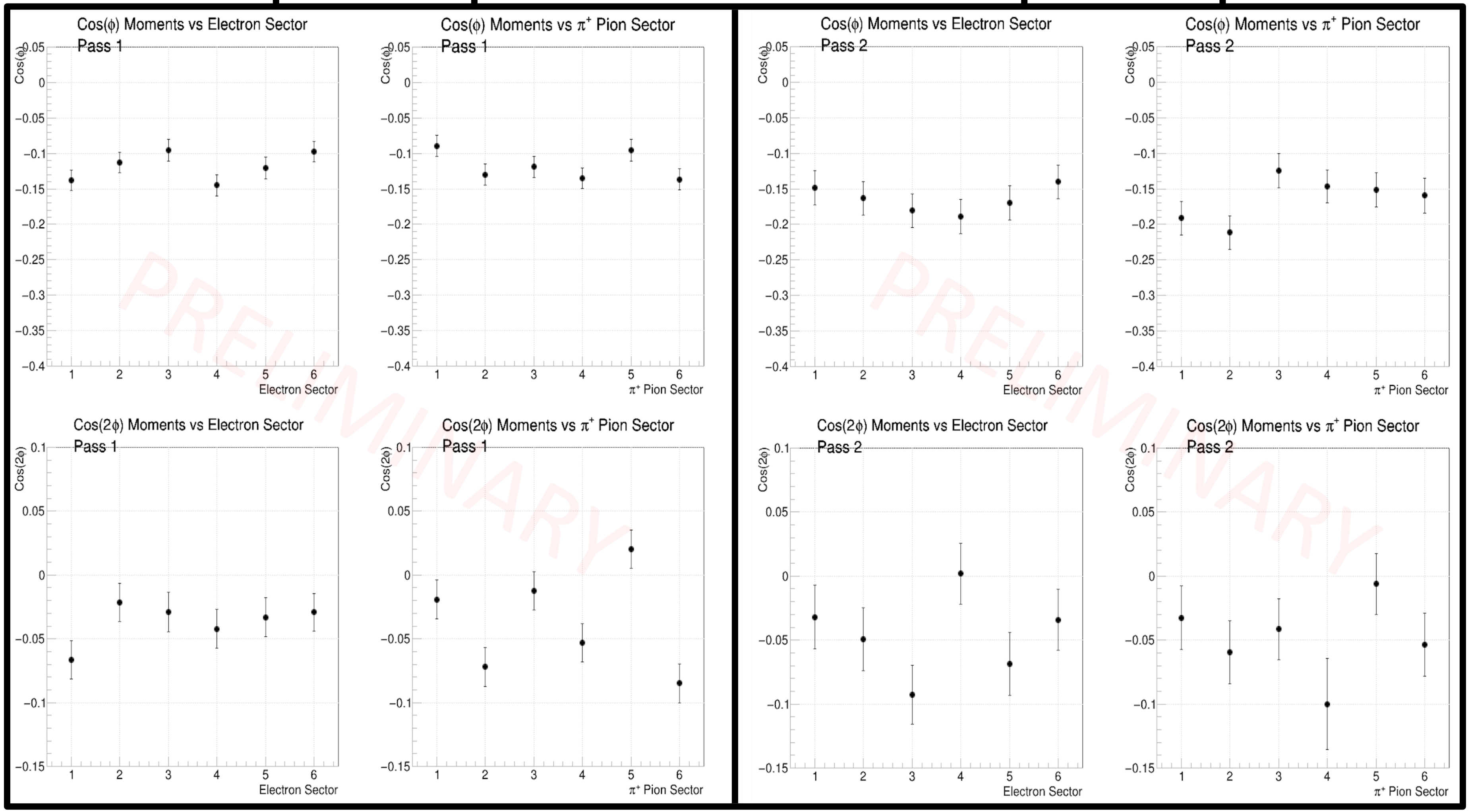
Sector Correlations with Cos(ϕ) and Cos(2ϕ) Measurements

PASS 1 **PASS 2**

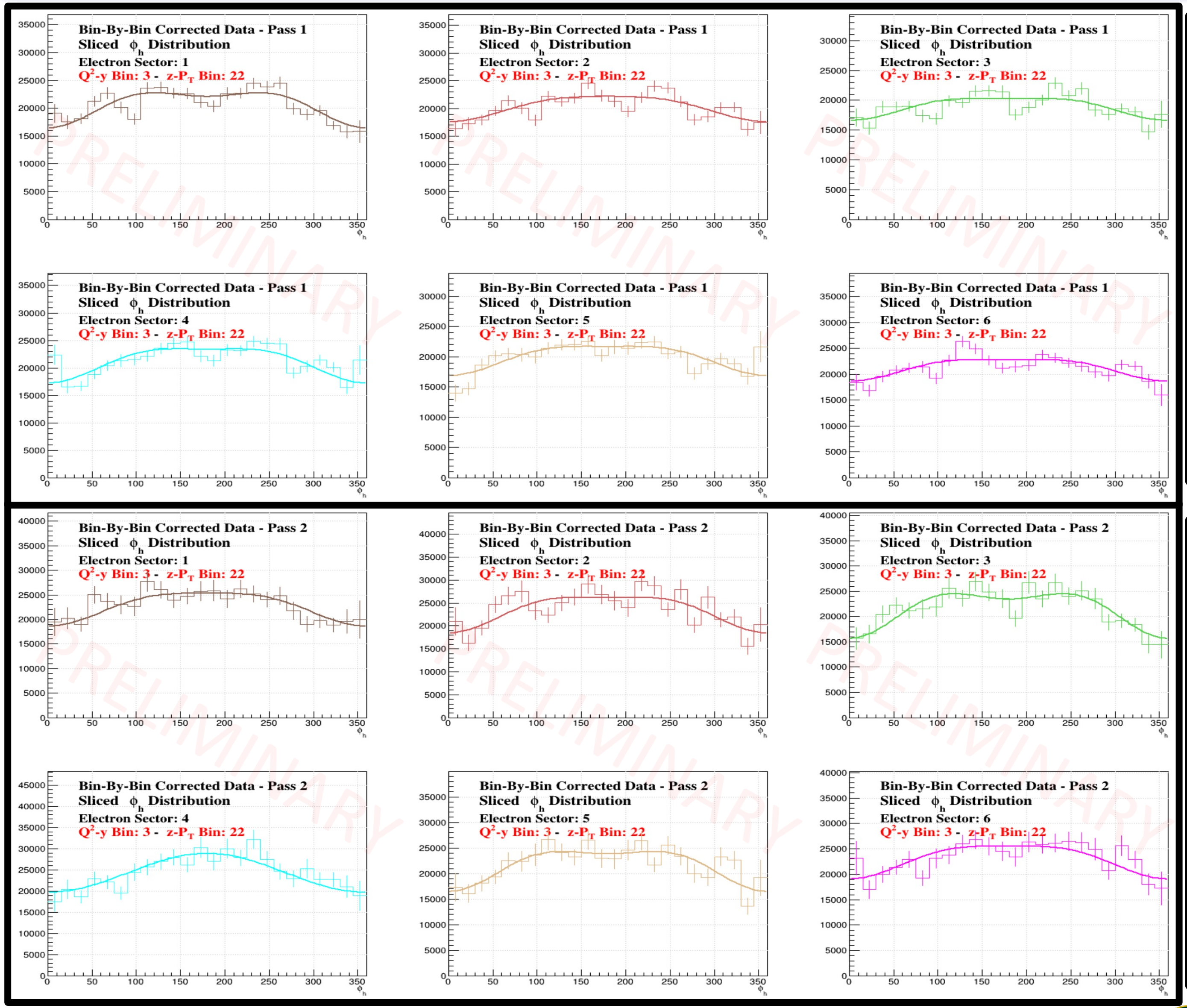


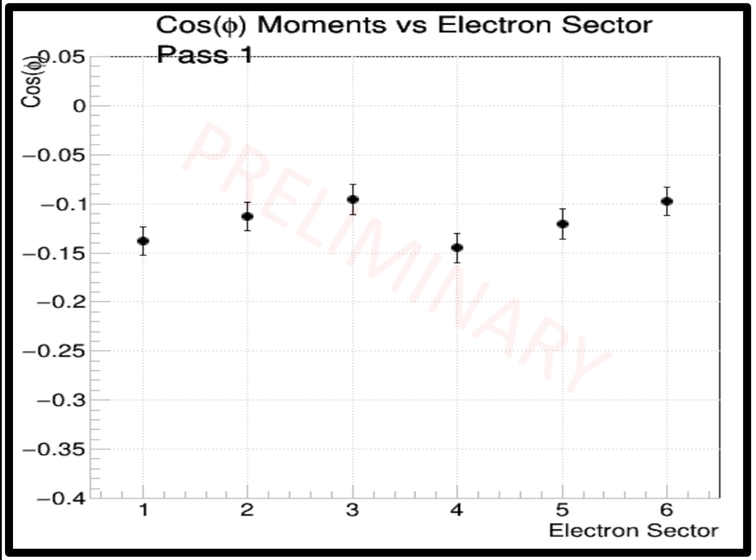
Showing the Cos(ϕ) and Cos(2ϕ) Moments as functions of the particle sector

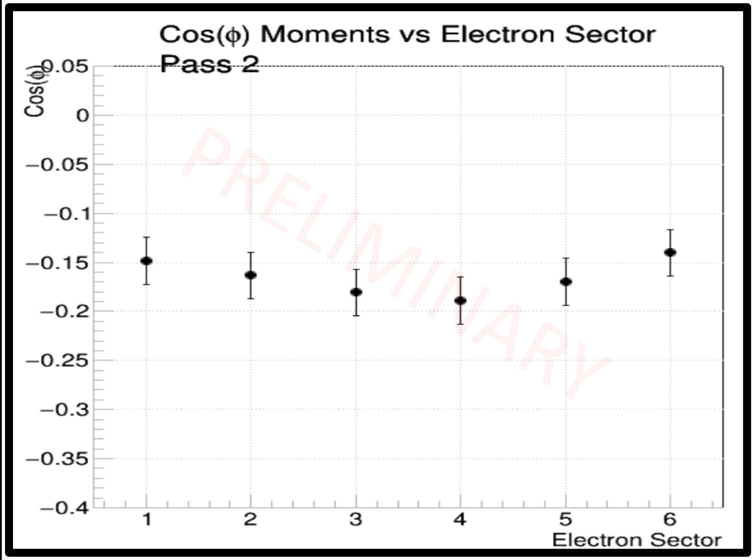
These plots show those differences in Pass 1 and Pass 2 for when the Electron (left plots) or π^+ pion (right plots) are restricted to being detected in a single sector

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

Sector Correlations with 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