DNP2020

Fall Meeting of the Division of Nuclear Physics of the American Physical Society

Oct. 29 – Nov. 1, 2020 *Now Virtual Meeting!*

~~Hyatt Regency Hotel, New Orleans, LA~~

APS physics

CLAS12 Charged Two-Pion Electroproduction Off the Proton

Krishna Neupane

Jefferson Lab

clas CEBAF Large Acceptance Spectrometer

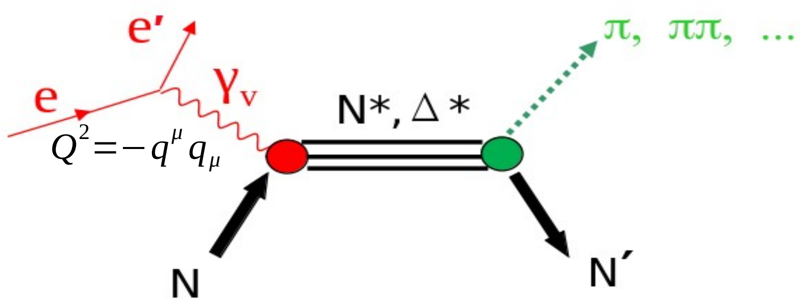
UNIVERSITY OF South Carolina

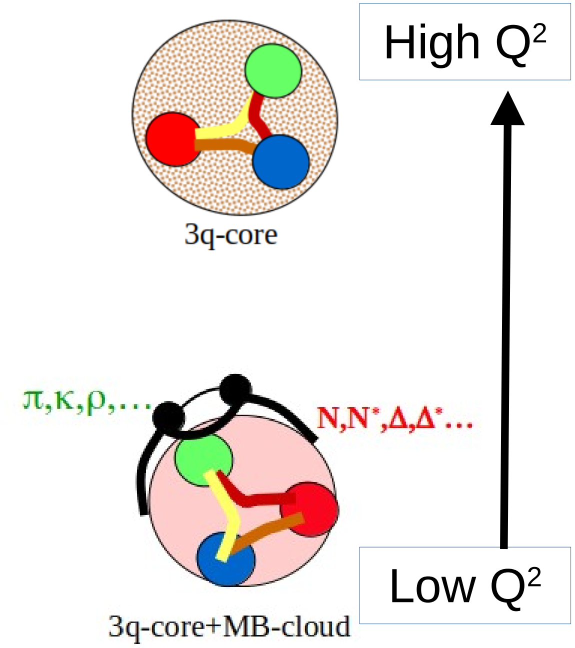
Overview

- **Physics Motivation**
- **Experimental Set up**
- **Physics Analysis**
- **Preliminary Results**
- **Conclusions**

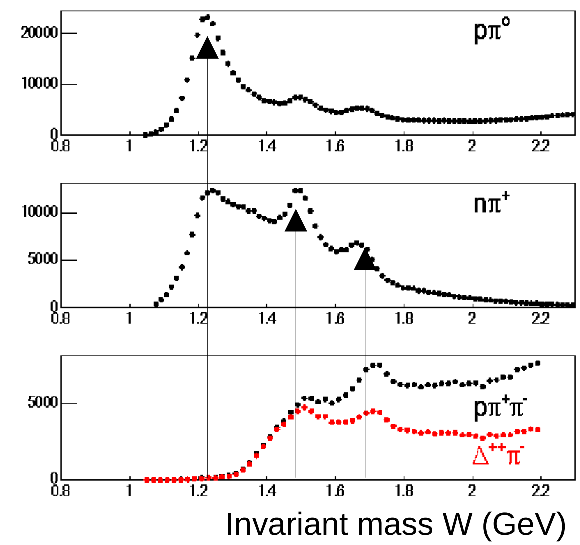
Physics Motivation

- CLAS12 is expected to provide the data that is capable of determining resonance electrocouplings for Q^2 up to 12 GeV^2, including the still almost uncharted range of $Q^2 > 5.0$ GeV^2
- Contribution from the 3-quark core is expected to dominate for $Q^2 > 5$ GeV^2, the experimental verification on this is crucial

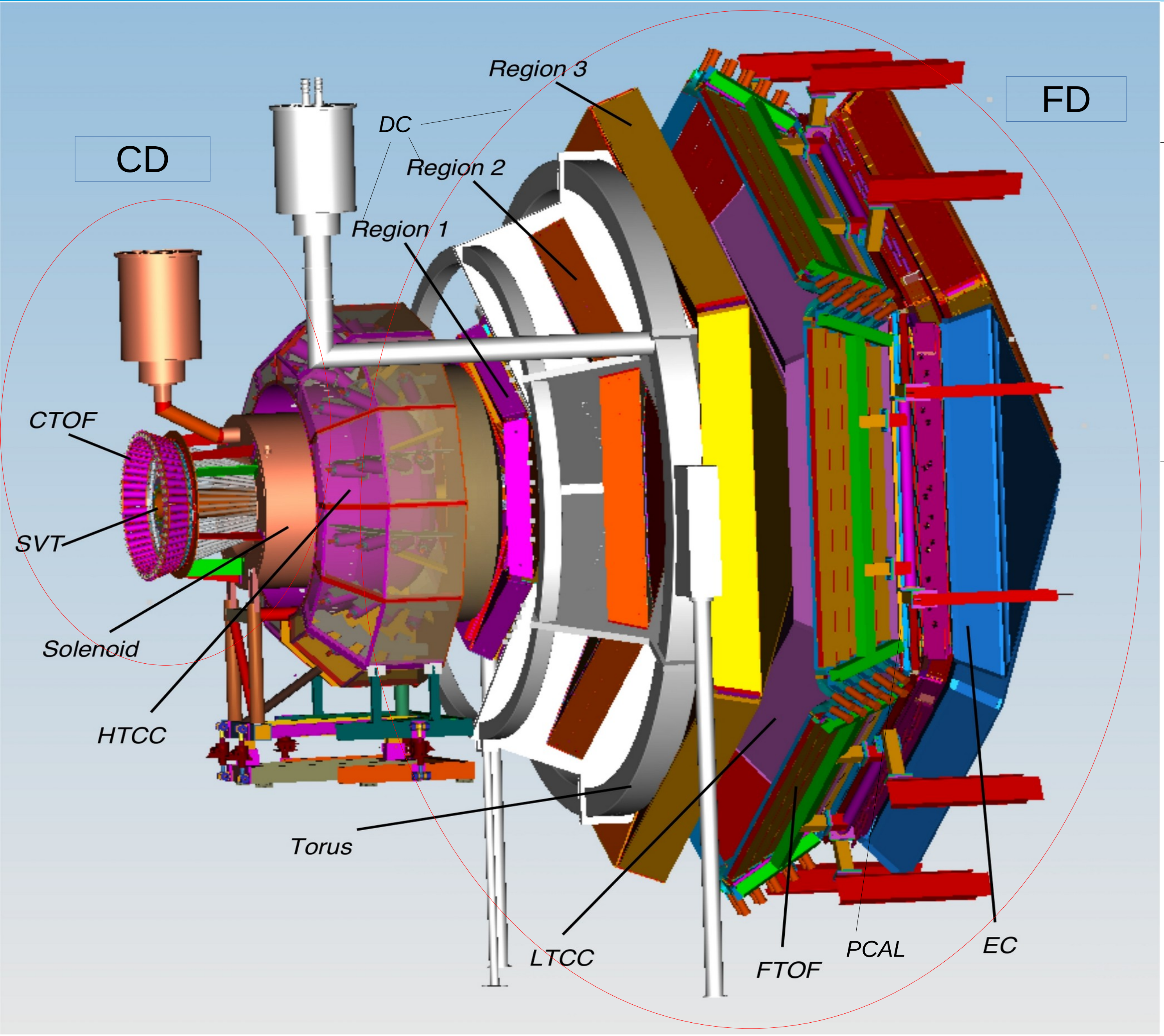




- Many final states (Nπ, Nππ, KY….) can be observed simultaneously in our experiment
- The two-pion channel is the major contributor to the information in the higher invariant mass W > 1.6 GeV range
- The goal of my analysis is to extract the differential cross-sections of the charged two-pion channel, which will serve as an input to reaction models (JM), that will extract reaction amplitudes



Experimental Set up : CLAS12 Detector



CLAS12 has multiple Detector systems

1) Central Detector (CD) system

CD system in a solenoid field up to 5T
(polar angle 35 ^{0} to 125 ^{0})

- *SOLENOID magnet*
- *Silicon Vertex Tracker*
- *Micromegas Vertex Tracker*
- *Central TOF system*
- *Central Neutron Detector*

2) Forward Detector (FD) system

FD system is around a toroidal field up to 3.6 T

(polar angle 5 ^{0} to 35 ^{0})

- *HT Cherenkov Counter*
- *TORUS magnet*
- *Drift Chamber system*
- *LT Cherenkov Counter*
- *Forward TOF system*
- *Pre-shower Calorimeter*
- *E.M. Calorimeter*

Physics Analysis

☞ **Particle Identification:**

- Electron pid cuts
- Hadron pid cuts

☞ **Event Selection**

☞ **Simulations**

☞ **Yield Extraction**

☞ **Acceptance Correction**

☞ **Holes Filling**

Particle Identification

Electron pid cuts:

- Electron must have negative charge -1
- Event-builder electron pid cut
- Momentum of electron > 1.5 GeV
- The electron is detected in forward detector
- Z component of the vertex position cut around target
- **Three sigma cut on Sampling Fraction**
- Preshower calorimeter fiducial cuts:

  (triangular and inner circular)
- Drift chambers fiducial cuts:

  (triangular and inner circular)

Simulations:

- TWOPEG event generator is used,
- All pid cuts and event selection process

  are same as that for the experimental data

Hadron pid cuts:

- Event-builder pid cuts for proton, π^+ and π^-
- **Delta t cut: |Δt ftof of particle| < 0.5 ns**
- Delta t cut: |Δt ctof of proton| < 0.4 ns
- Delta t cut: |Δt ctof of π^+| < 0.3 ns
- Delta t cut: |Δt ctof of π^-| < 0.5 ns

$$\Delta t = \frac{l_{SC}}{\beta.c} - t_{SC} + vertex\ time$$

where, $\beta = \sqrt{\frac{p^2}{m^2+p^2}}$,

$vertex\ time = t^e_{SC} - \frac{l^e_{SC}}{c}$,

l_{SC}, l^e_{SC} are length of path from vertex to SC for hadron, electron,

t_{SC}, t^e_{SC} are time measured by SC for hadron, electron,

c is the speed of light.

- Momentum of FTOF particle > 0.2 GeV
- Momentum of CTOF particle > 0.2 GeV
- Fiducial cuts : not done yet

Two-pion Event Selection:

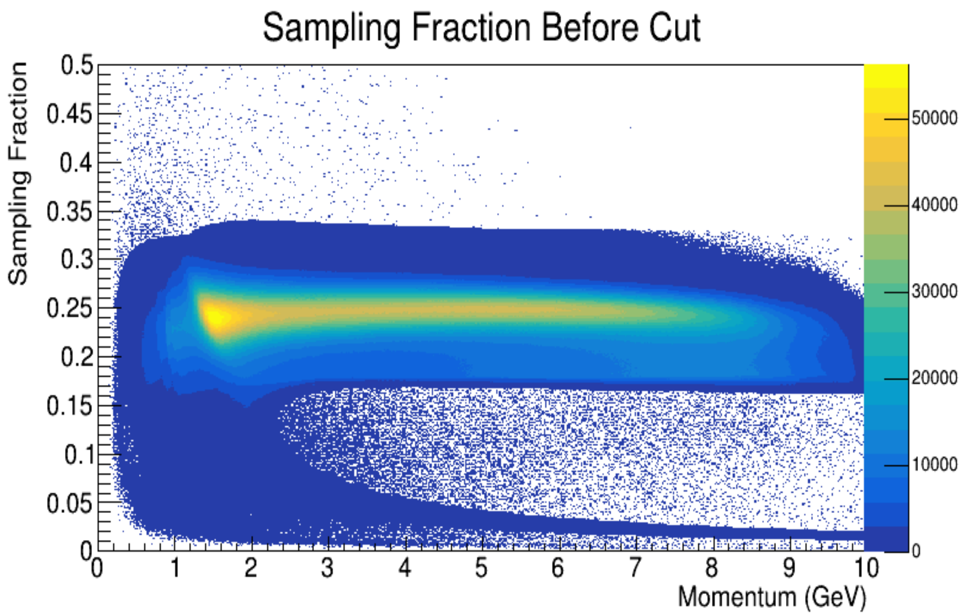
There are 4 different topologies in this reaction Channel:

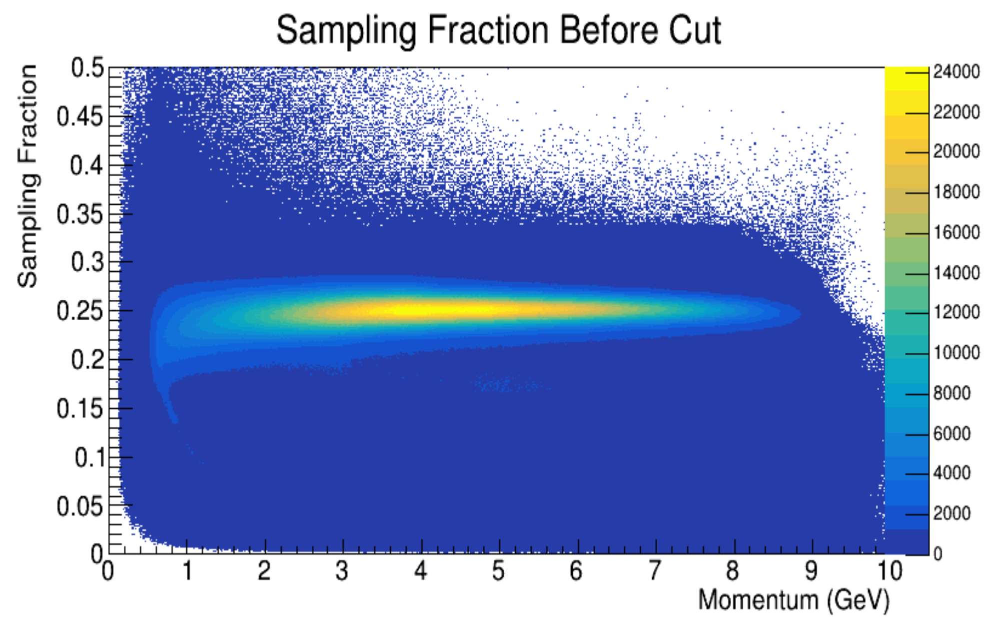
- e(p,p′π^+X)e′ (Missing π^-):
  - $\pi^{-\mu}$ reconstructed using the four vector of other particles
  - event must have electron, proton and π^+
  - **Missing Mass Square (MMSQ) cut :**

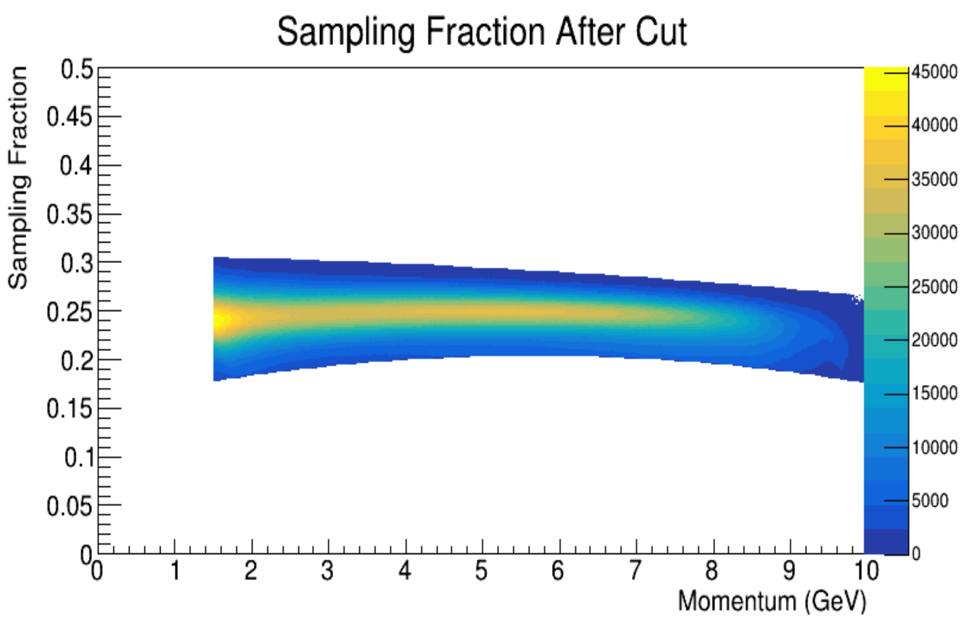
    $-0.06\ GeV^2 < MMSQ < 0.08\ GeV^2$

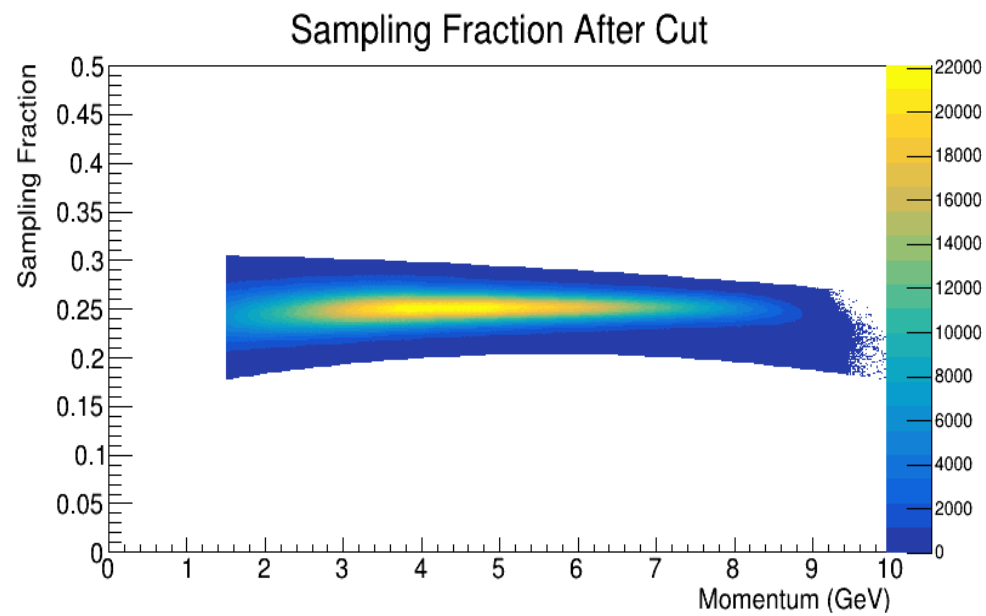
Particle Identification

Experimental Data	MC simulations Data



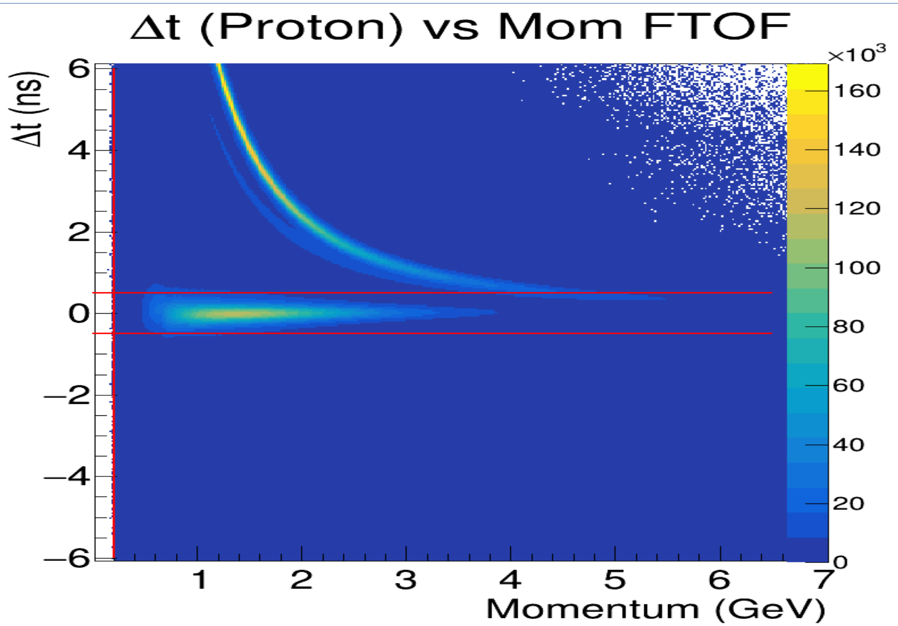


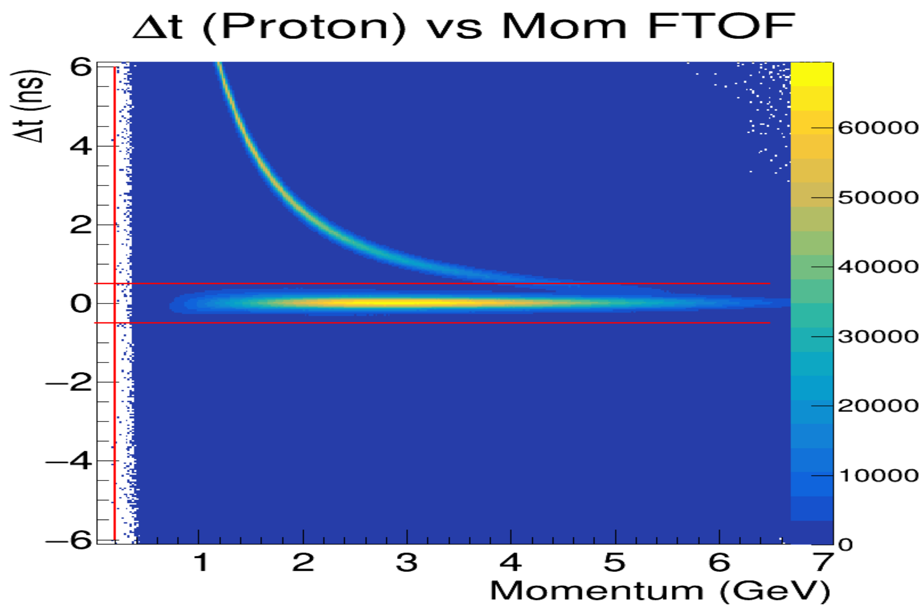


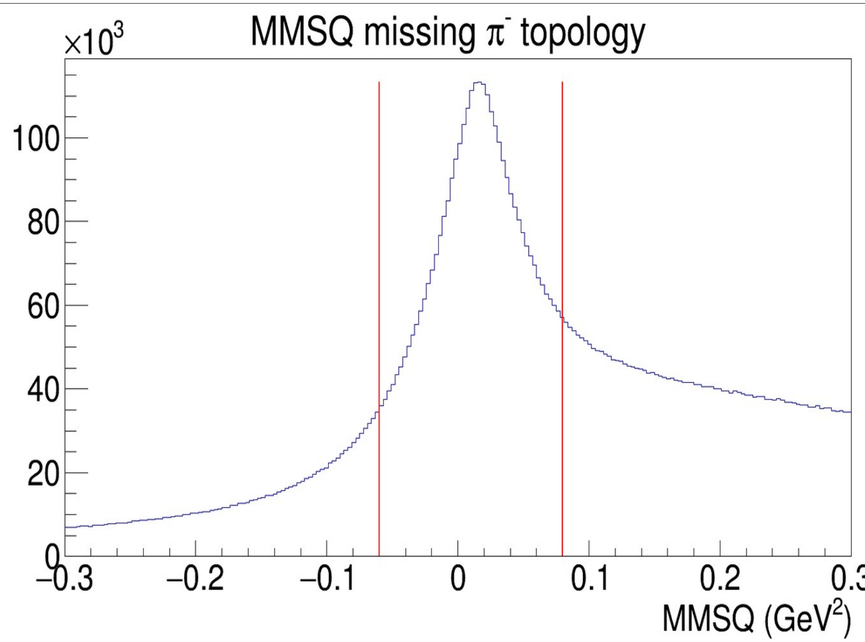


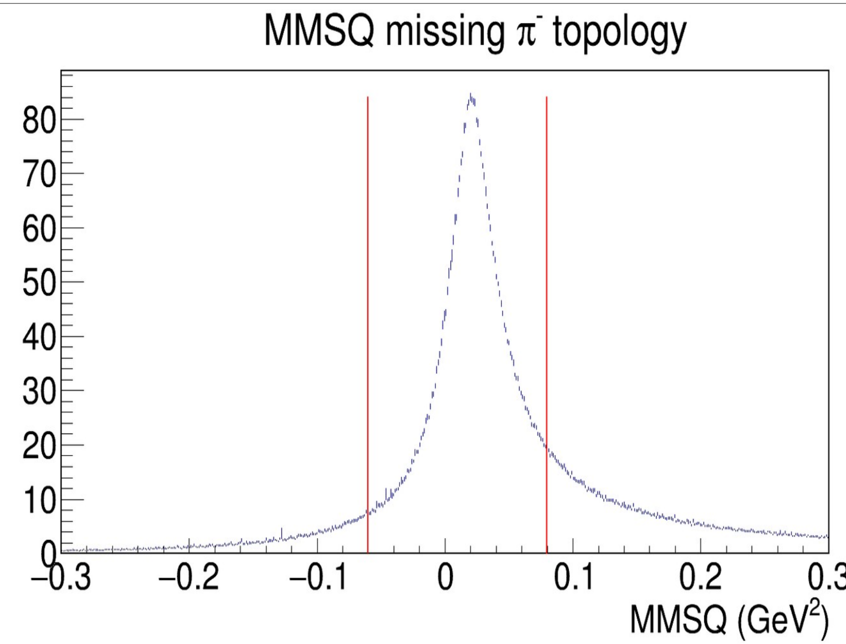
Particle Identification

Experimental Data	MC simulations Data







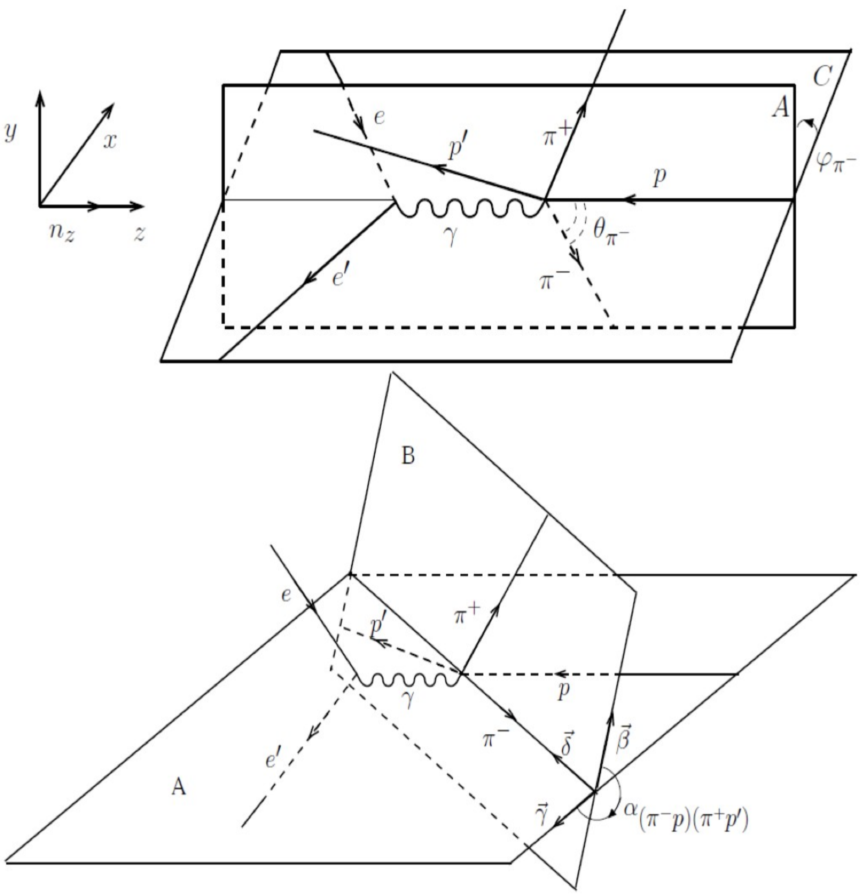


Two-Pion Channel Cross-Section

Seven-differential cross-section :

$$\frac{d^7\sigma}{dW\,dQ^2\,dM_{P\pi+}\,dM_{\pi+\pi-}\,d\Omega\,d\alpha_{\pi-}} = \frac{1}{F\,.\,R}\;\frac{\left(\frac{\Delta N_{full}}{Q_{full}} - \frac{\Delta N_{empty}}{Q_{empty}}\right)}{\Delta W\,\Delta Q^2\,\Delta\tau\,L}$$

Where, ΔN, Q are no of two pion events inside seven-differential bin and charge on faraday cup with full and empty target, F, R are correction factors, ΔW, ΔQ^2 are kinematical bins, L is luminosity, $\Delta\tau = \Delta M_{p\pi+}\,\Delta M_{\pi+\pi-}\,\Delta(-\cos(\theta_{\pi-}))\,\Delta\varphi_{\pi-}\,\Delta\alpha_{\pi-}$



1) $M_{\pi+p'}$, $M_{\pi+\pi-}$, $\theta_{\pi-}$, $\varphi_{\pi-}$ and $\alpha_{(p\pi-)(p'\pi+)}$ (ie. $\alpha_{\pi-}$)

2) $M_{p'\pi+}$, $M_{\pi+\pi-}$, $\theta_{p'}$, $\varphi_{p'}$ and $\alpha_{(pp')(\pi+\pi-)}$ (ie. $\alpha_{p'}$)

3) $M_{\pi+\pi-}$, $M_{\pi-p'}$, $\theta_{\pi+}$, $\varphi_{\pi+}$ and $\alpha_{(p\pi+)(p'\pi-)}$ (ie. $\alpha_{\pi+}$)

Binning:
- 50 MeV W bin and 1.0 GeV^2 Q^2 bin
- 12 bins for invariant masses
- 10 bins for θ
- 6 bins for φ
- 8 bins for α

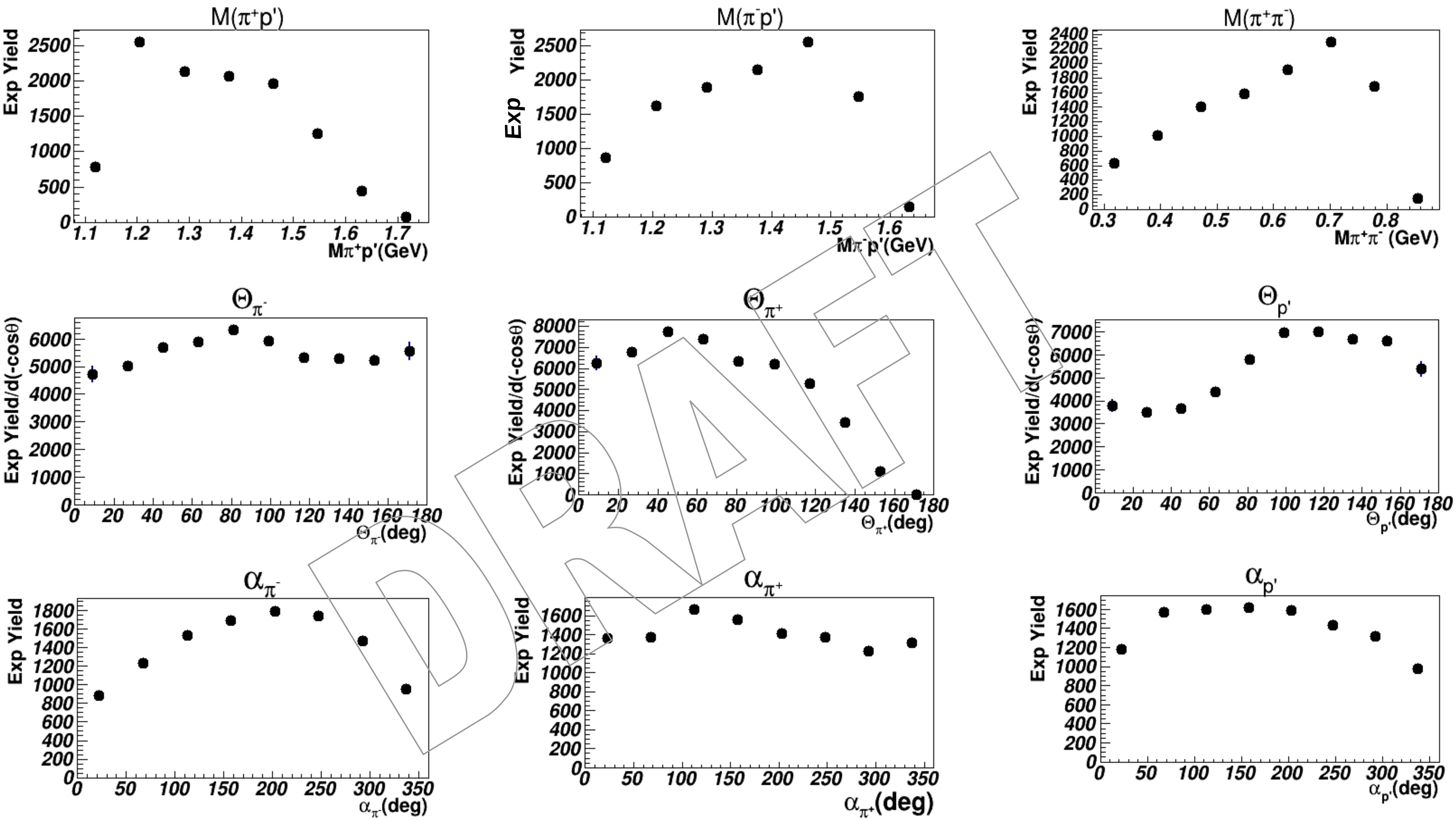
One-differential cross-sections:

$$\frac{d\sigma}{dM_{\pi^+\pi^-}} = \int \frac{d^5\sigma}{d^5\tau} d\tau^4_{M_{\pi^+\pi^-}}; \qquad d\tau^4_{M_{\pi^+\pi^-}} = dM_{\pi^+p}\,d\Omega_{\pi^-}\,d\alpha_{\pi^-}$$

with $d^5\tau = dM_{\pi^+\pi^-}dM_{\pi^+p}d\Omega_{\pi^-}d\alpha_{\pi^-}$

Nine 1-D Experimental Yields

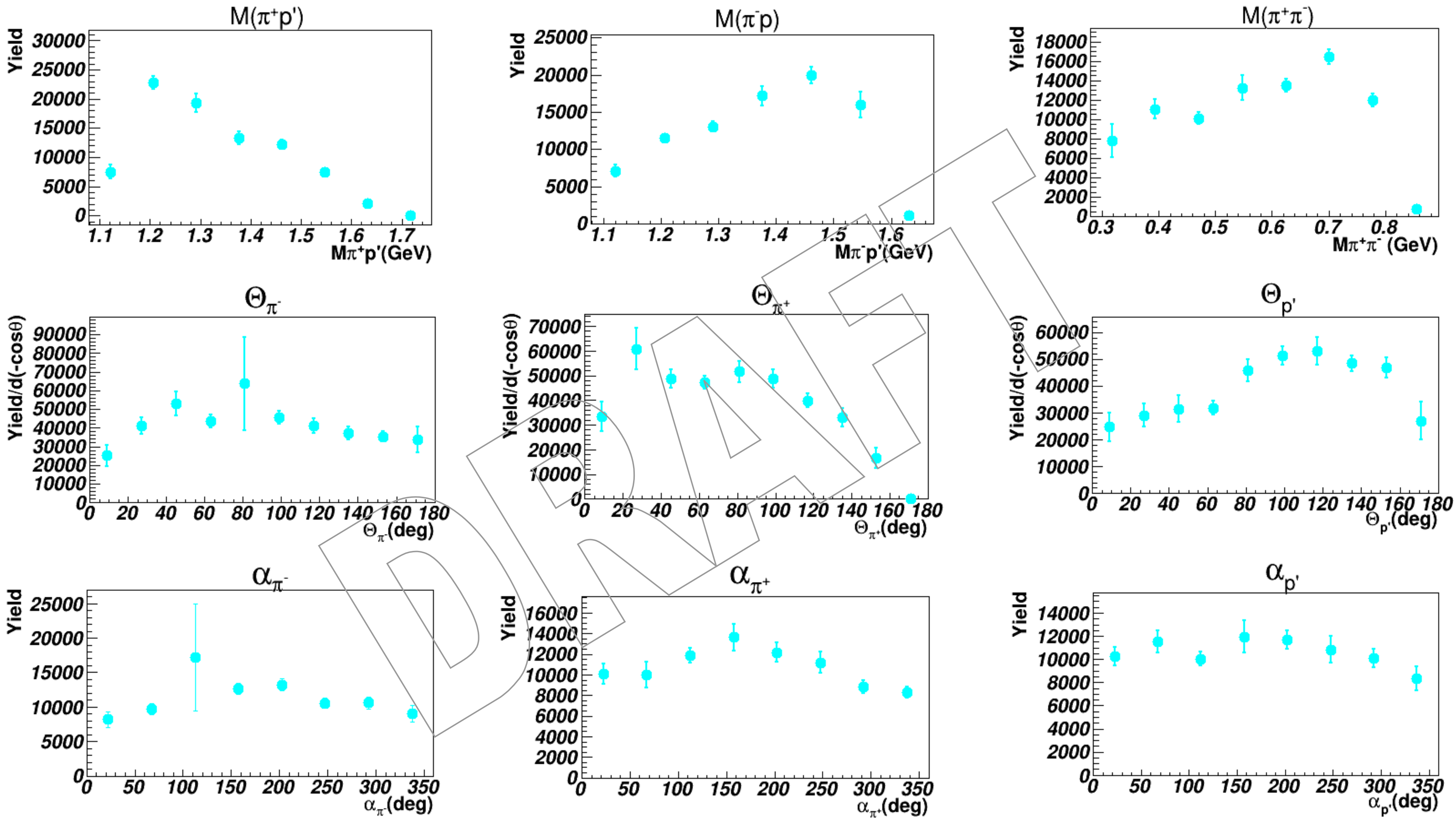
Using four vectors of the particles survived after all the cuts and event selection process



W-Q^2 bin for these yields: 1.75 GeV < W < 1.8 GeV, 4 GeV^2 < Q^2 < 5 GeV^2

Nine 1-D Acceptance Corrected Yields

$$Acceptance\ \ Corrected\ \ Yields\ =\ \frac{Experimental\ \ Yields}{Acceptance\ \ Factor\left(F\right)}\ ,\quad where\ \ F\ =\ \frac{Reconstructed\ \ Events}{Thrown\ \ Events}\ \approx 13-14\,\%$$



W-Q² bin for these yields: 1.75 GeV < W < 1.8 GeV, 4 GeV² < Q² < 5 GeV²

Holes Filling:

-CLAS12 detector does not fully cover 4π angular area

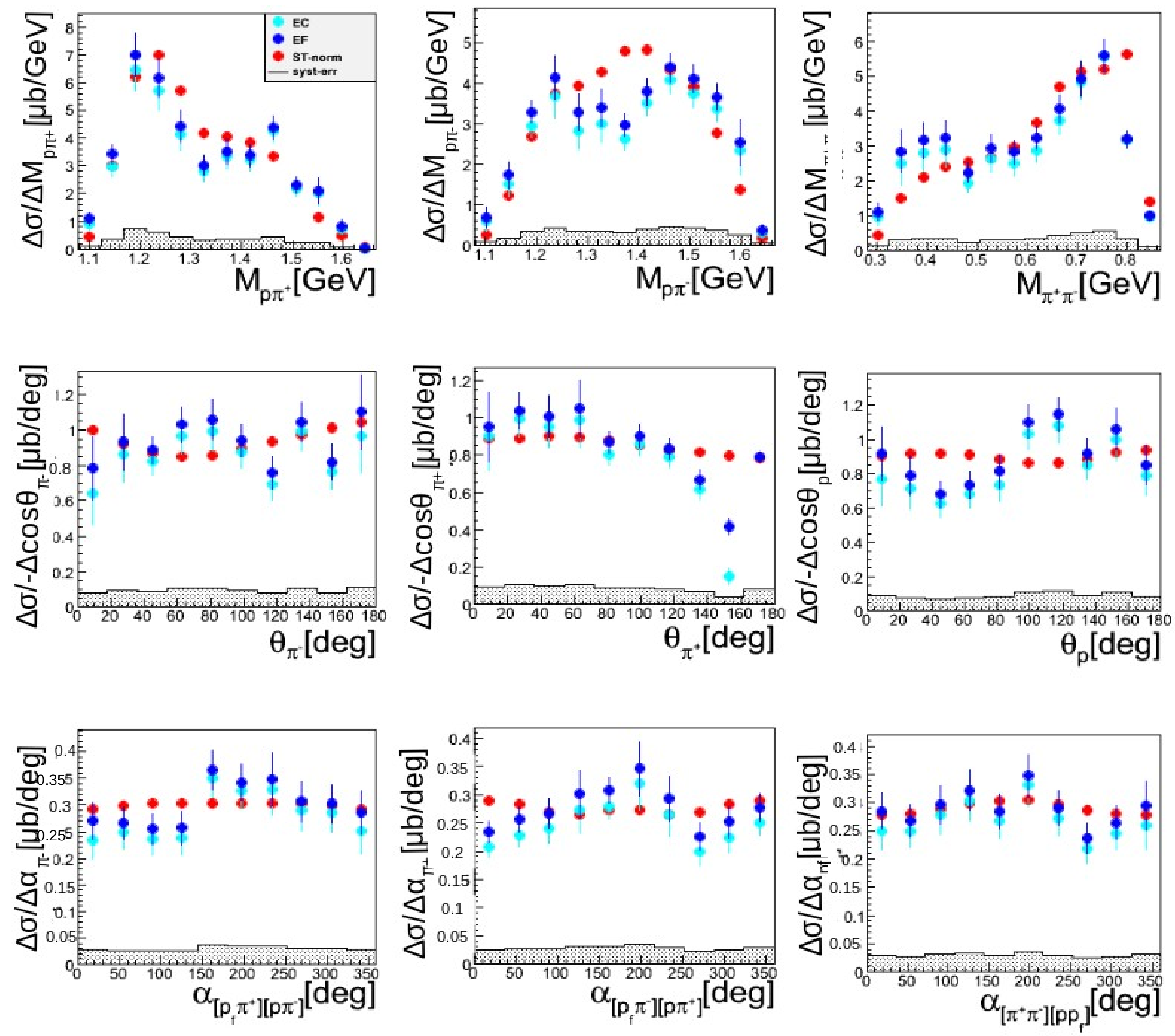
-Design constraint of detector system leads to some physical gaps called holes

-The acceptance factor on those holes is zero

-We have to fill those holes by using scaled generated yields

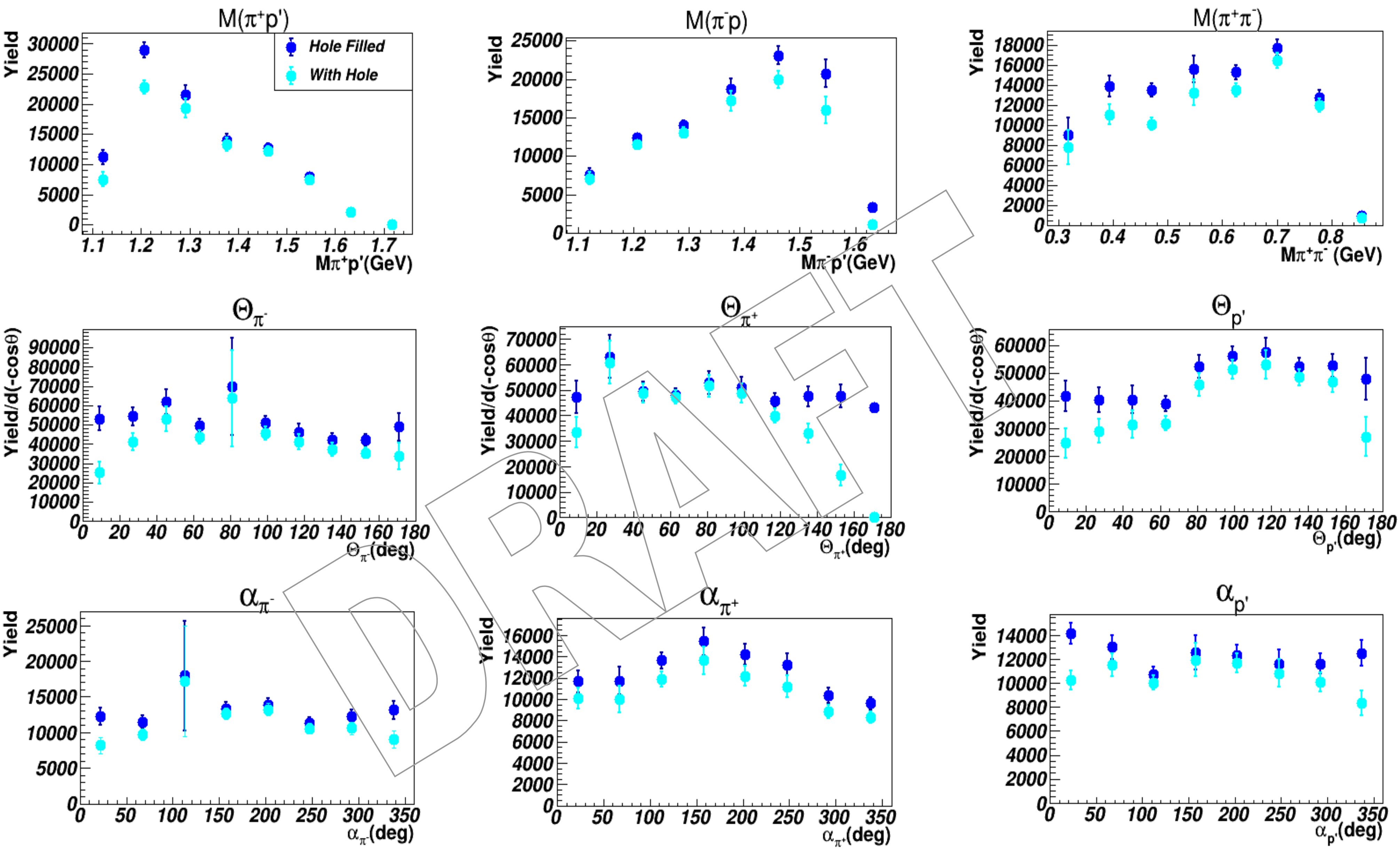
Source : Arjun Trivedi (CLAS e16 data)

Measurement of New Observables from the $\pi^+\pi^-$ Electroproduction off the Proton



W-Q^2 bin for these cross-sections: 1.775 GeV < W < 1.8 GeV, 4.2 GeV^2 < Q^2 < 5 GeV^2

Nine 1-D Hole Filled Yields



W-Q^2 bin for these yields: 1.75 GeV < W < 1.8 GeV, 4 GeV^2 < Q^2 < 5 GeV^2

Conclusions

- ☞ Particle identification cuts looks reasonable at the moment, will be refined accordingly
- ☞ Based on missing π^- topology, two-pion events are selected and experimental yields are extracted
- ☞ Using TWOPEG event generator, acceptance correction factor are applied and remaining holes are filled
- ☞ **More simulations are needed** to improve binning and hole filling process
- ☞ Energy/momentum correction, radiative effects corrections, background subtraction are needed to **extract actual cross-sections**

THANK YOU !

Backup Slide : Hole Filling Process

- In simulation:

1. h5-ST = Thrown yield
2. h5-SR = Thrown yield reconstructed in simulated detector.
3. h5-SA = Acceptance (h5-SA=h5-SR/h5-ST)
4. h5-SC = Acceptance corrected yield. (h5-SC=h5-SR/h5-SA)
5. h5-SH = Hole yield (h5-SH=h5-ST-h5-SC)
6. h5-SF = Yield in full (PS) (h5-SF=h5-SC+h5-SH)

- In experiment:

1. h5-ER = Natural yield reconstructed in actual detector.
2. h5-EC = Acceptance corrected yield (h5-EC=h5-ER/h5-SA)
3. h5-EH = Hole yield. (h5-EH='sf'xh5-SH)
4. h5-EF = Yield in full (PS) (h5-EF=h5-EC+h5-EH)

Obtain 'sf' as the ratio of total yield in h5-EC and total yield in h5-SC. Note that for both, the total yield is integrated over h5-SC's PS bins that are *filled* (i.e. their bin content > 0).

$$\text{sf} = \frac{\sum_{i=1}^{N} \text{h5-EC}_i}{\sum_{i=1}^{N} \text{h5-SC}_i}$$

where i=1,...,N are the *filled* PS bins filled in h5-SC.

Source: Arjun Trivedi (PhD Thesis)
Measurement of New Observables from the $\pi^+\pi^-$ Electroproduction off the Proton

Backup Slide: W Versus Q^2 Coverage

The invariant mass W of the virtual photon and initial nucleon system:

$$W = \sqrt{s} = \sqrt{(q^\mu + p^\mu)(q_\mu - p_\mu)}$$

where, s is the Mandelstam variable, q and p are their respective four momenta

Also the square four momentum transfer is given by: $Q^2 = -q^\mu q_\mu$ where, $q^\mu = e^\mu - e'^\mu$