Charged Two-Pion Electroproduction off the Proton for RGA Data

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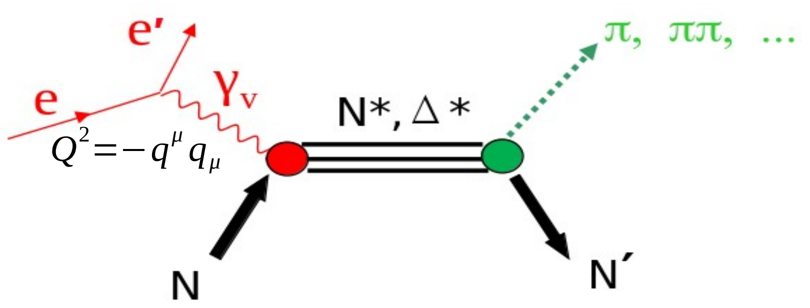
CEBAF Large Acceptance Spectrometer

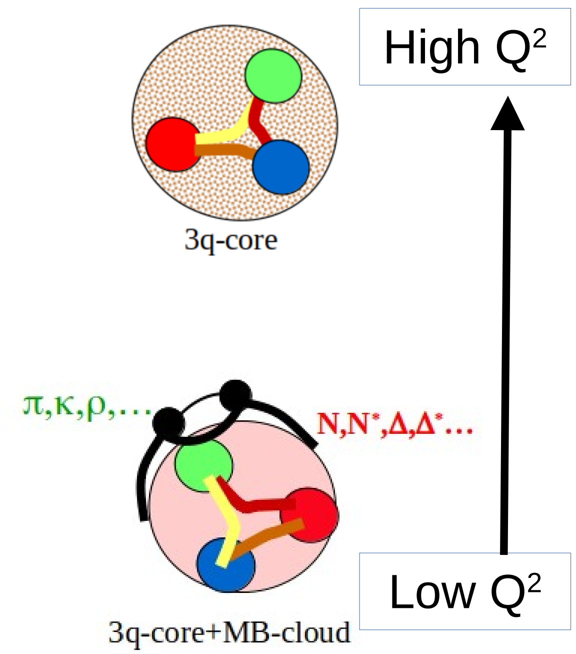
Overview

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

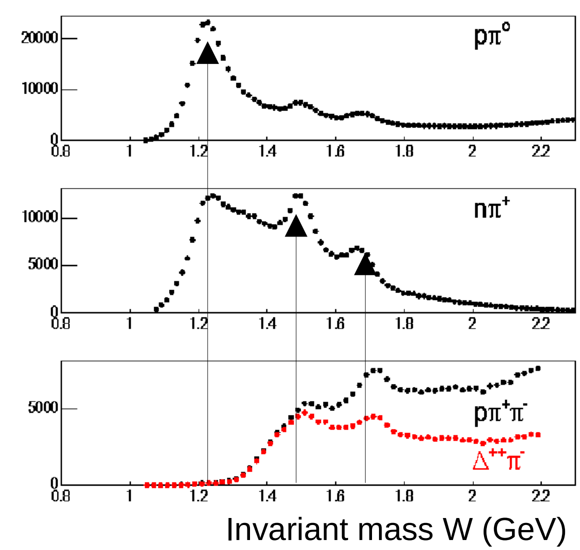
Physics Motivation

- 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
- Q^2 5-12 GeV^2 region is very important because of the transition from full dressed constituent quark to undressed current QCD quark

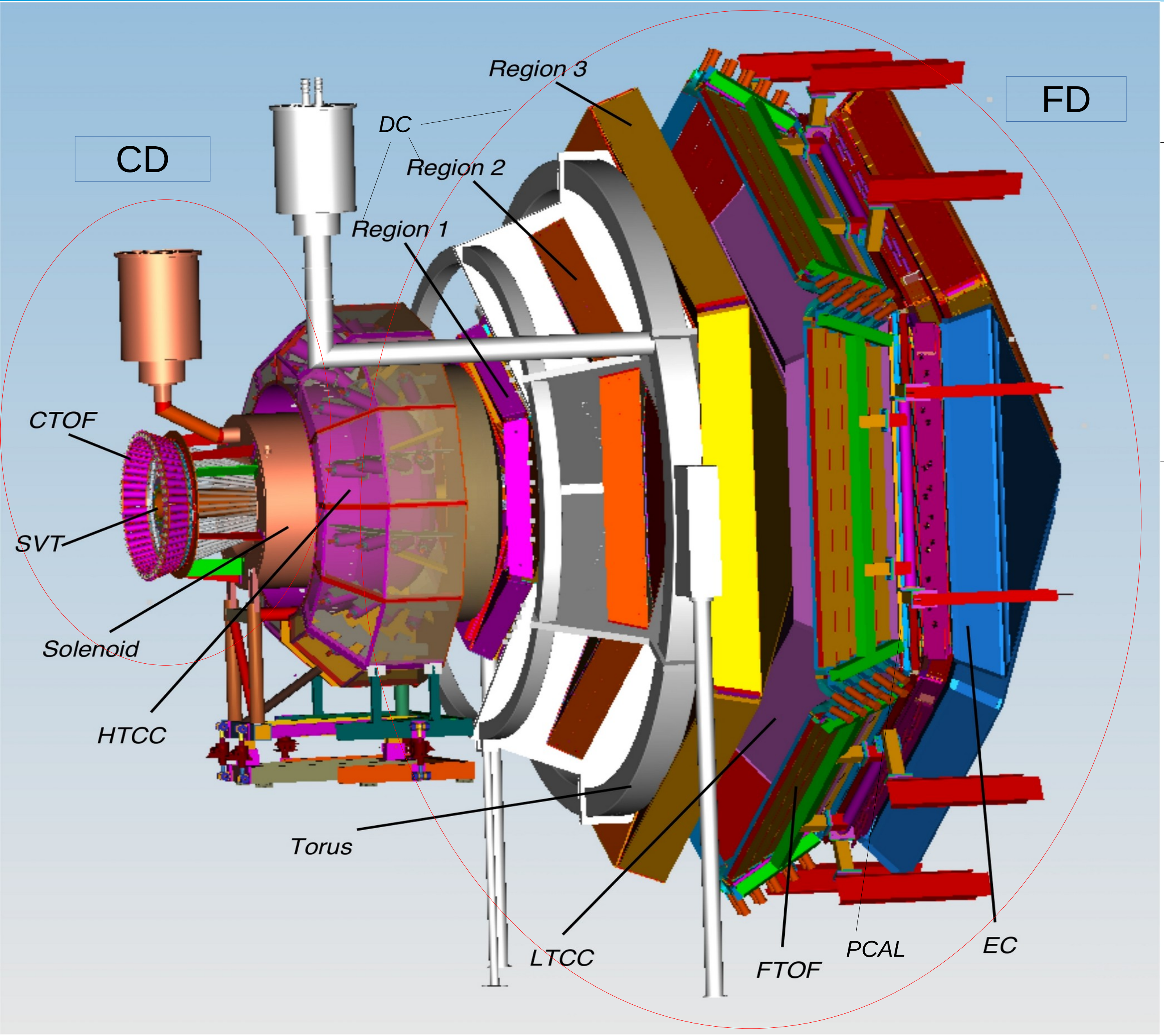




- Many final states (Nπ, Nππ, KY….) can be observed simultaneously in our experiment
- The two-pion channel is the major contributor to the information in the higher invariant mass W > 1.6 GeV range
- The goal of my analysis is to extract the differential cross-sections of the charged two-pion channel, 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**
- **Background and Efficiency Studies**

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)

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^+| < 0.4 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
- **Chi2pid Cuts for π^+ and π**

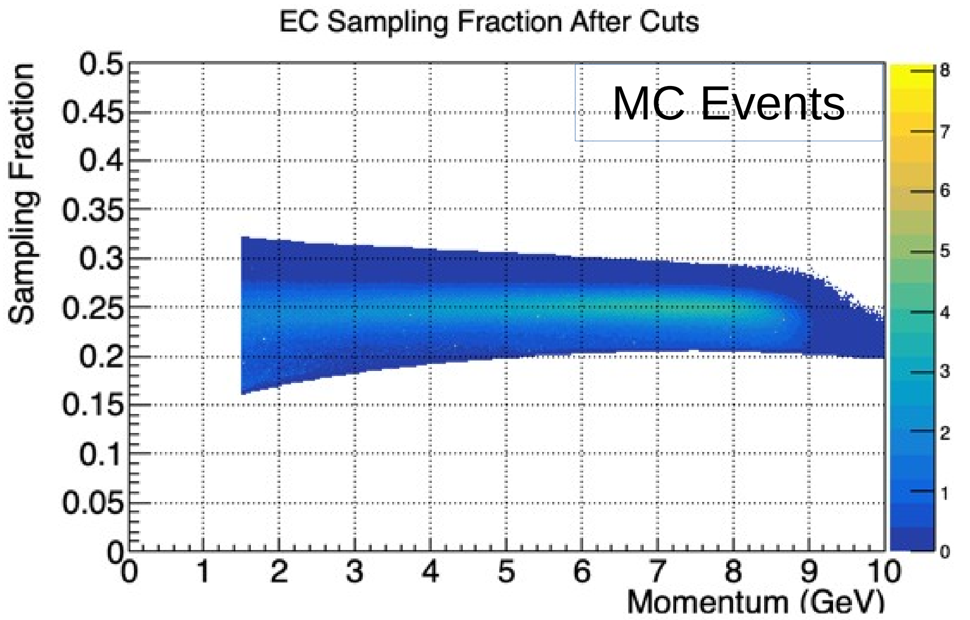
Experimental Data:

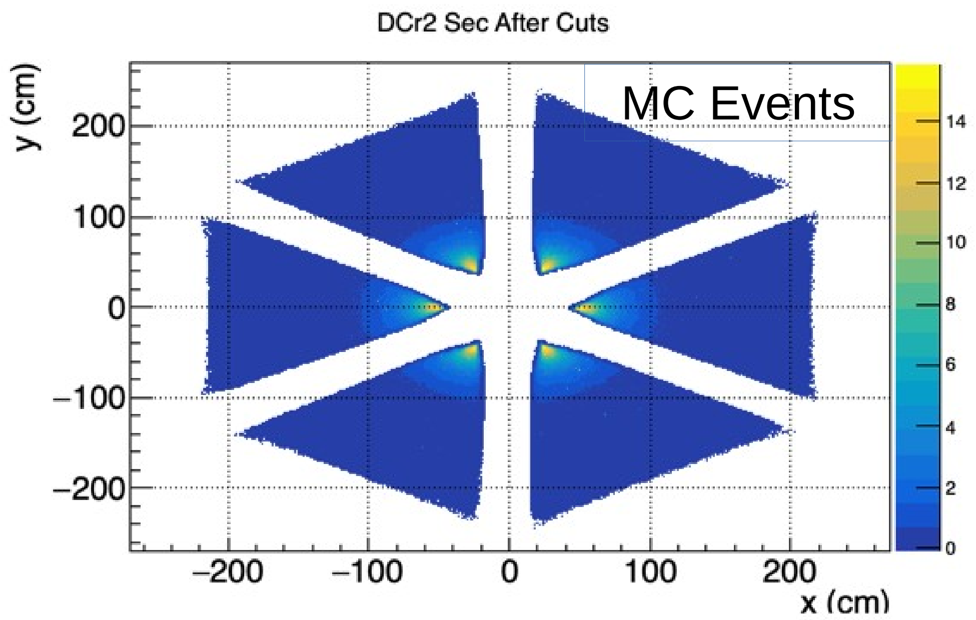
- **RGA Fall 2018 inbending (183 runs)**

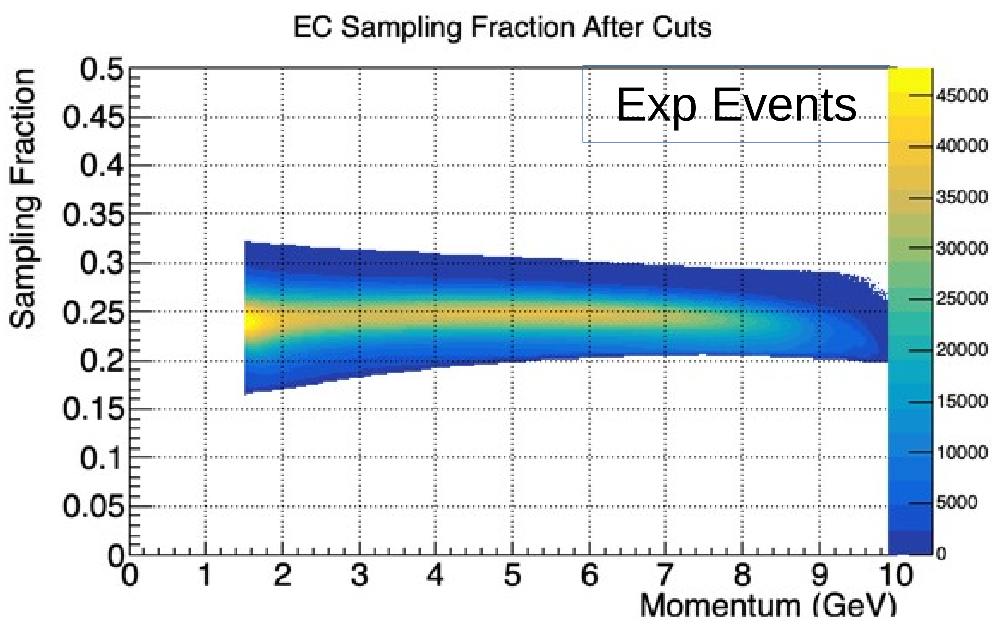
Simulations Data

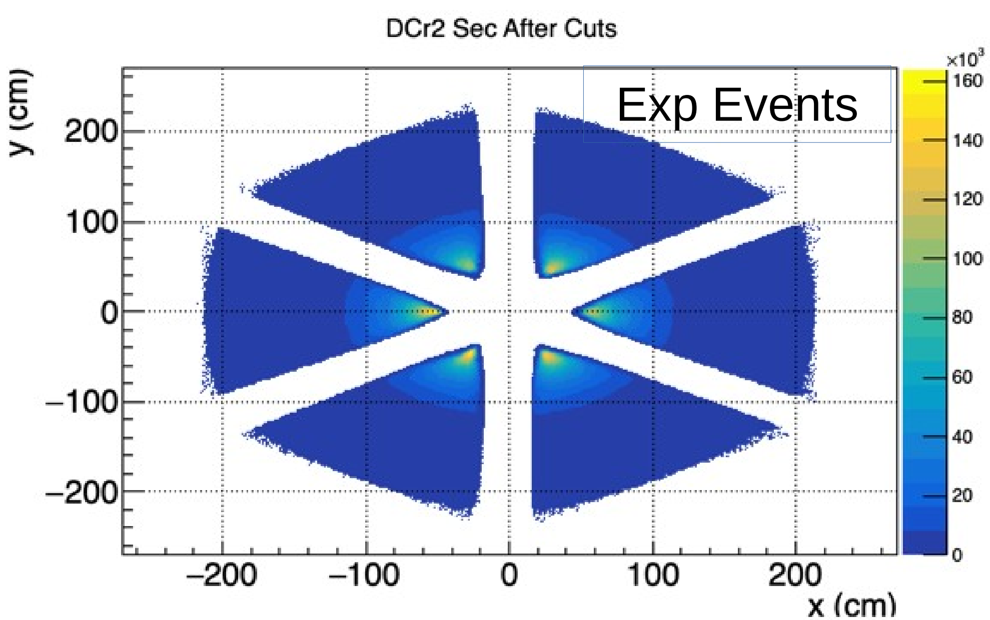
- **TWOPEG** event generator is used with GEMC version 4.4 and background files are merged, ~ 2.5 TB data are generated
- All pid cuts and event selection process are same as for the experimental data

Particle Identification: Electron Cuts

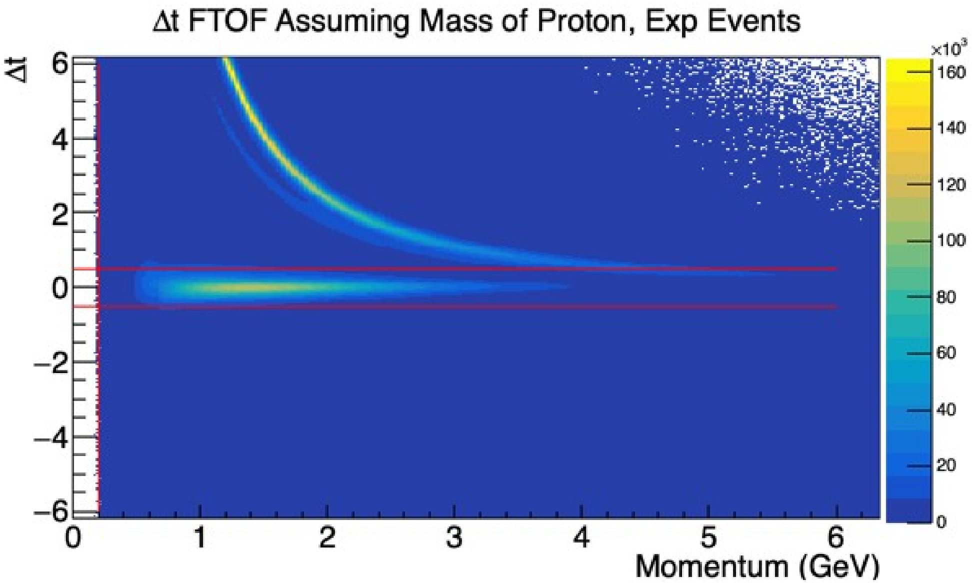


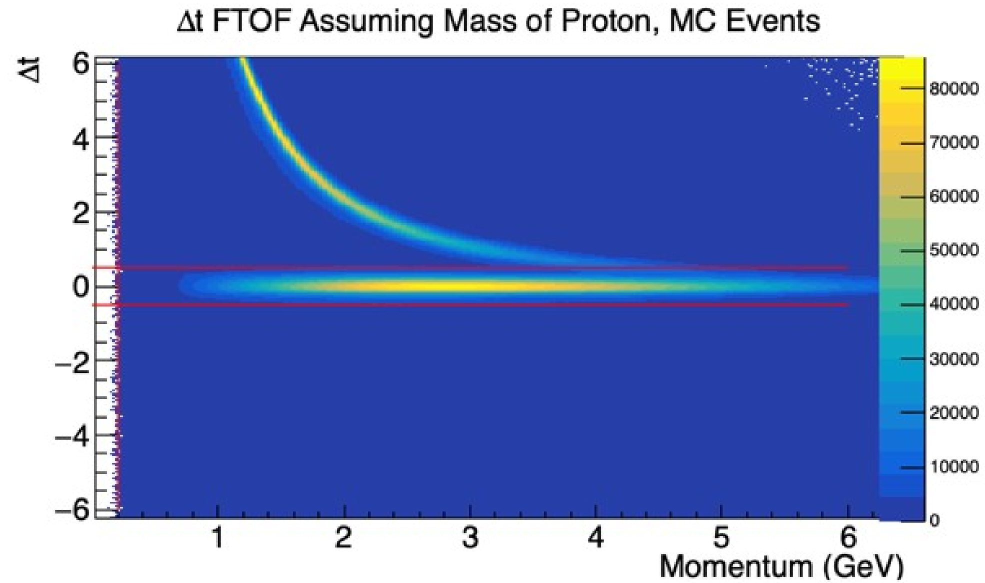


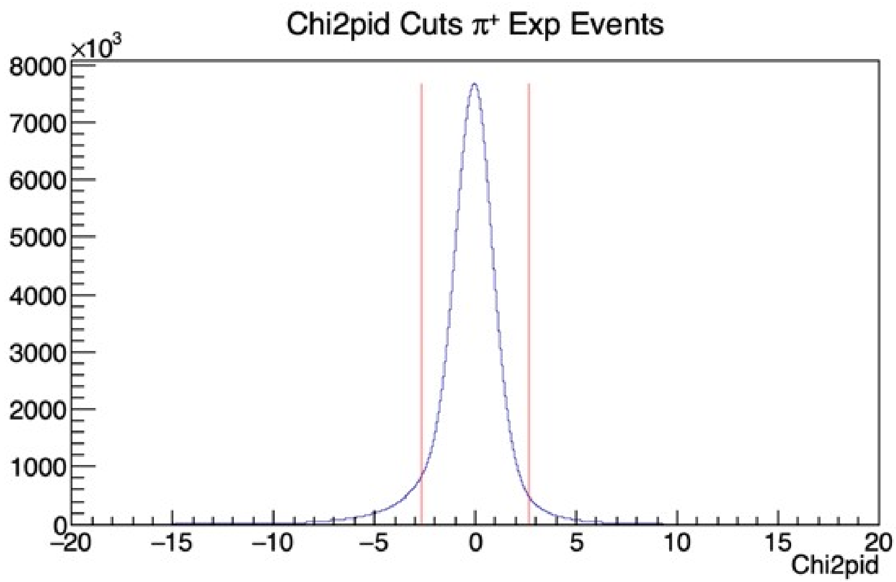


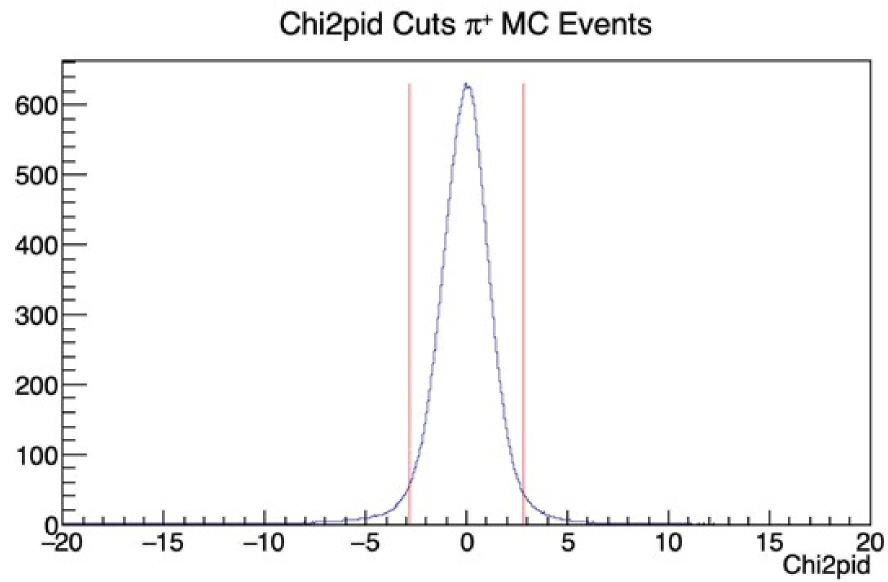


Particle Identification: Hadron Cuts









Two-Pion Event Selection

There are 4 different topologies in this reaction Channel:

- $e(p,p'\pi^+\pi^-X)e'$ (Exclusive):
  - event must have electron, proton, π^+ and π^-

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

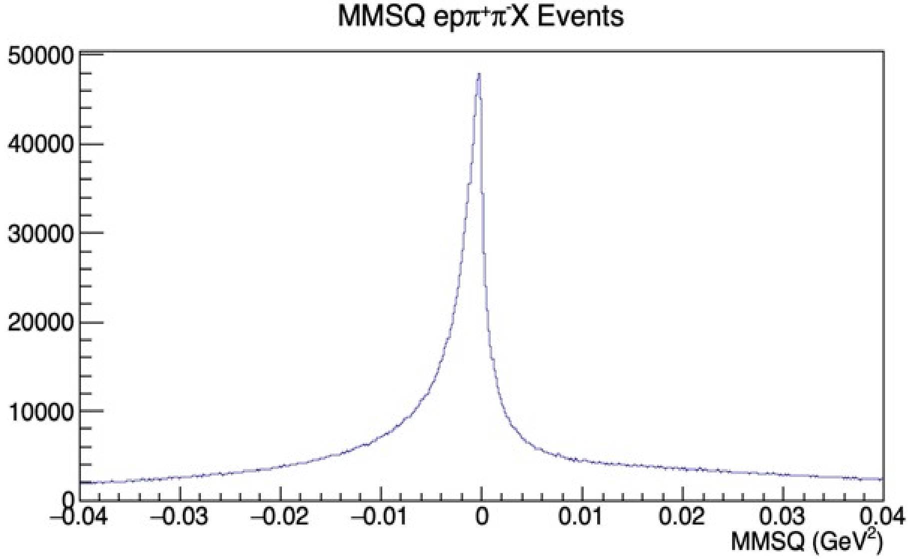
$$-0.06\ \mathrm{GeV}^2 < \mathrm{MMSQ} < 0.08\ \mathrm{GeV}^2$$

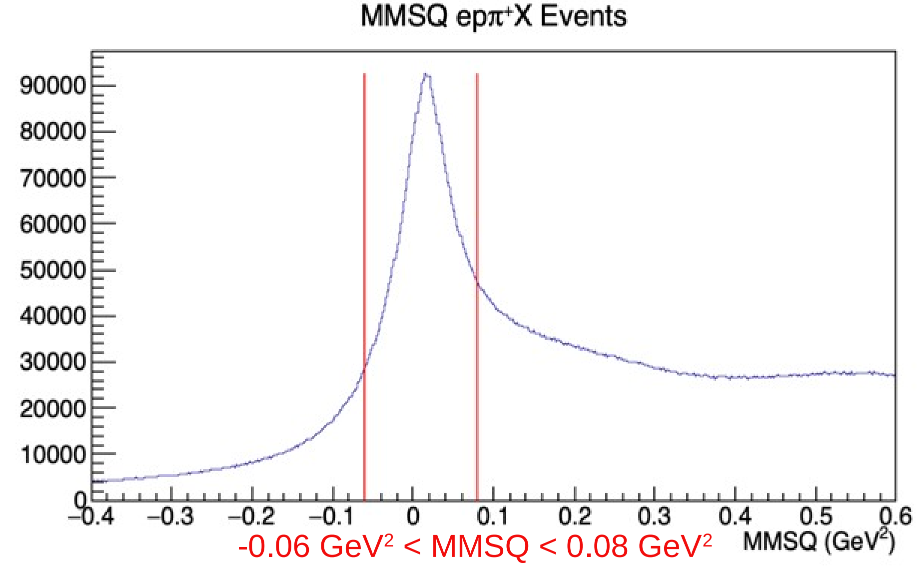
- $e(p,p'\pi^-X)e'$ (Missing π^+):
  - event must have electron, proton and π^-

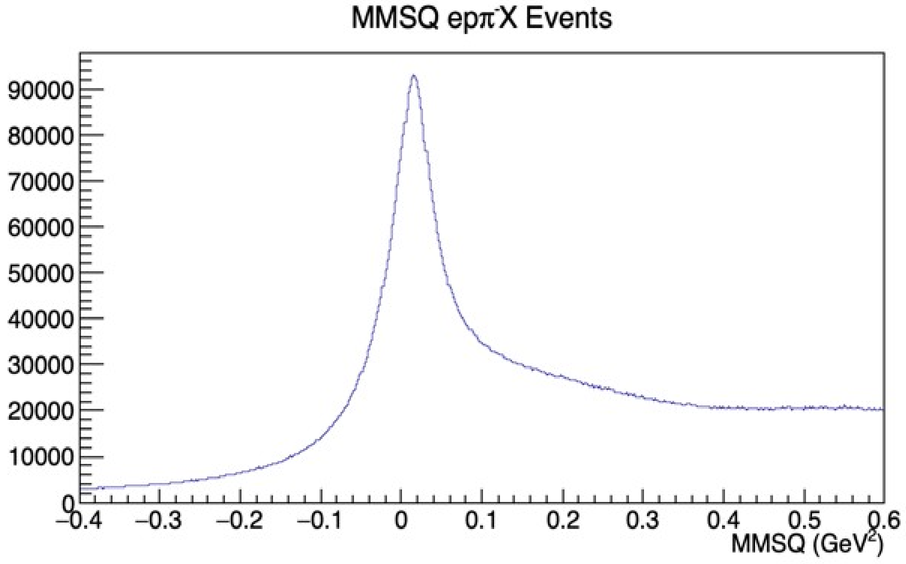
- $e(p,\pi^-\pi^+X)e'$ (Missing proton):
  - event must have electron, π^+ and π^-

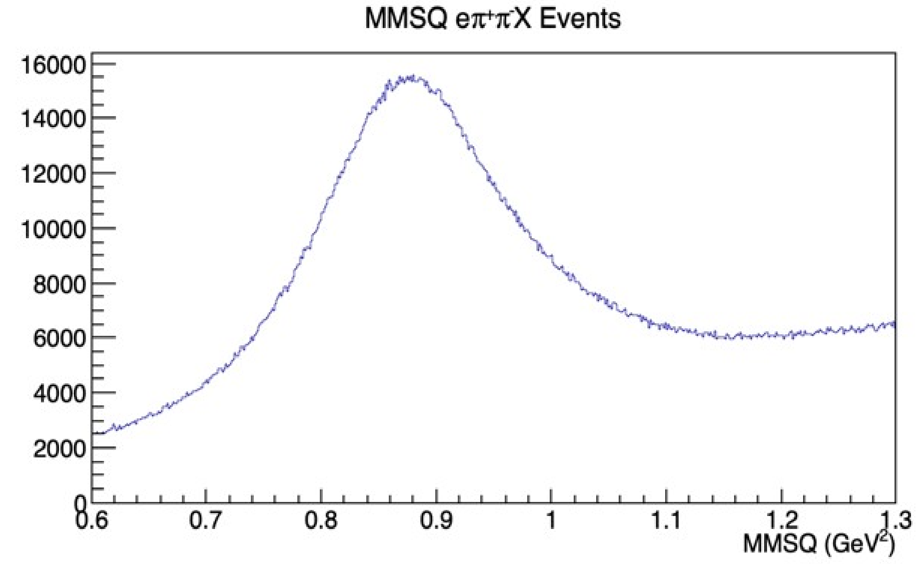
Missing Mass Square for Different Topologies Exp Events

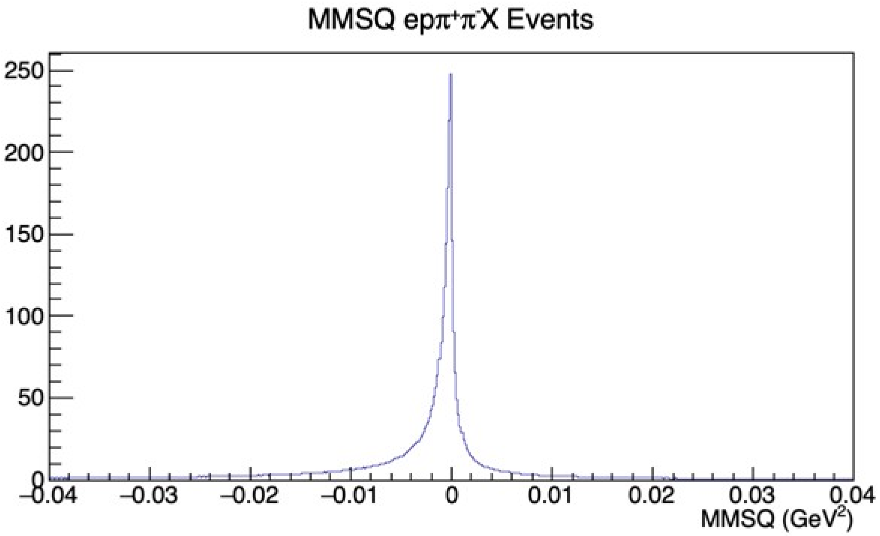
Based on those topologies, we are using the missing mass square technique to get the two-pion events



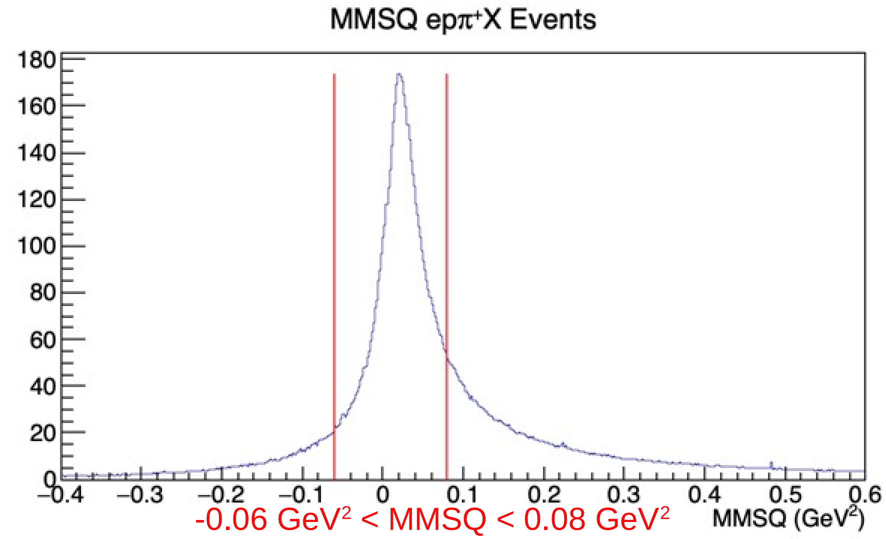




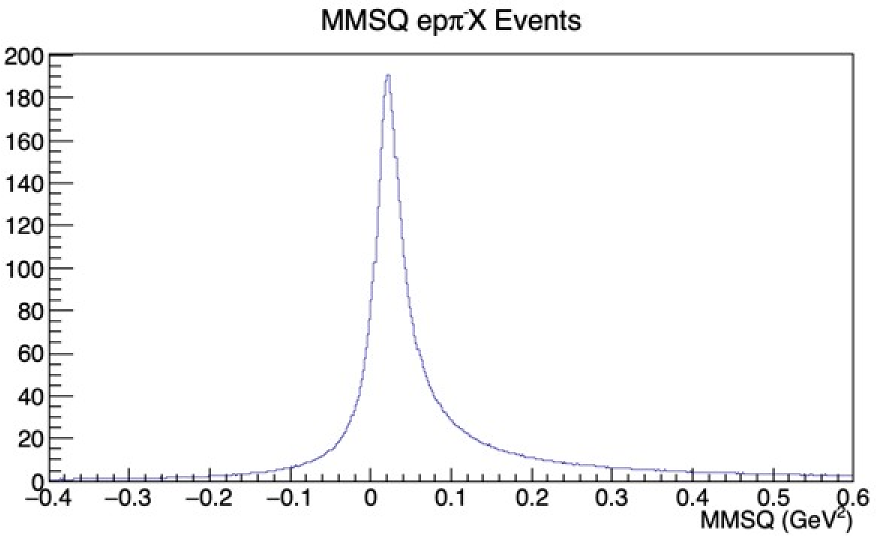




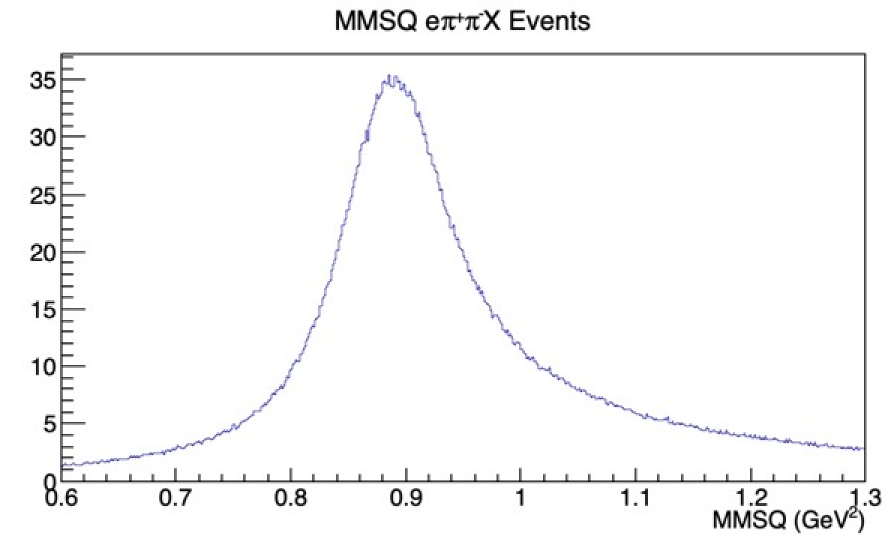
MMSQ epπ⁺π⁻X Events
MMSQ (GeV²)



MMSQ epπ⁺X Events
-0.06 GeV² < MMSQ < 0.08 GeV²
MMSQ (GeV²)



MMSQ epπ⁻X Events
MMSQ (GeV²)

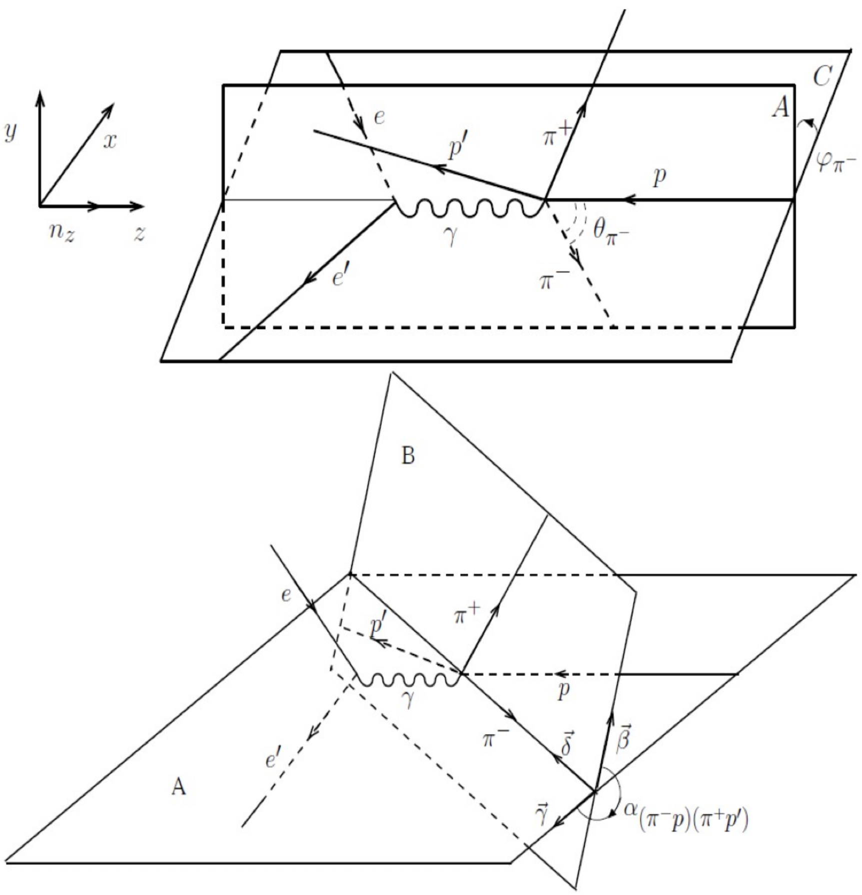


MMSQ eπ⁺π⁻X Events
MMSQ (GeV²)

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 $\alpha_{(p\pi-)(p'\pi+)}$ (i.e. $\alpha_{\pi-}$)

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

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

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

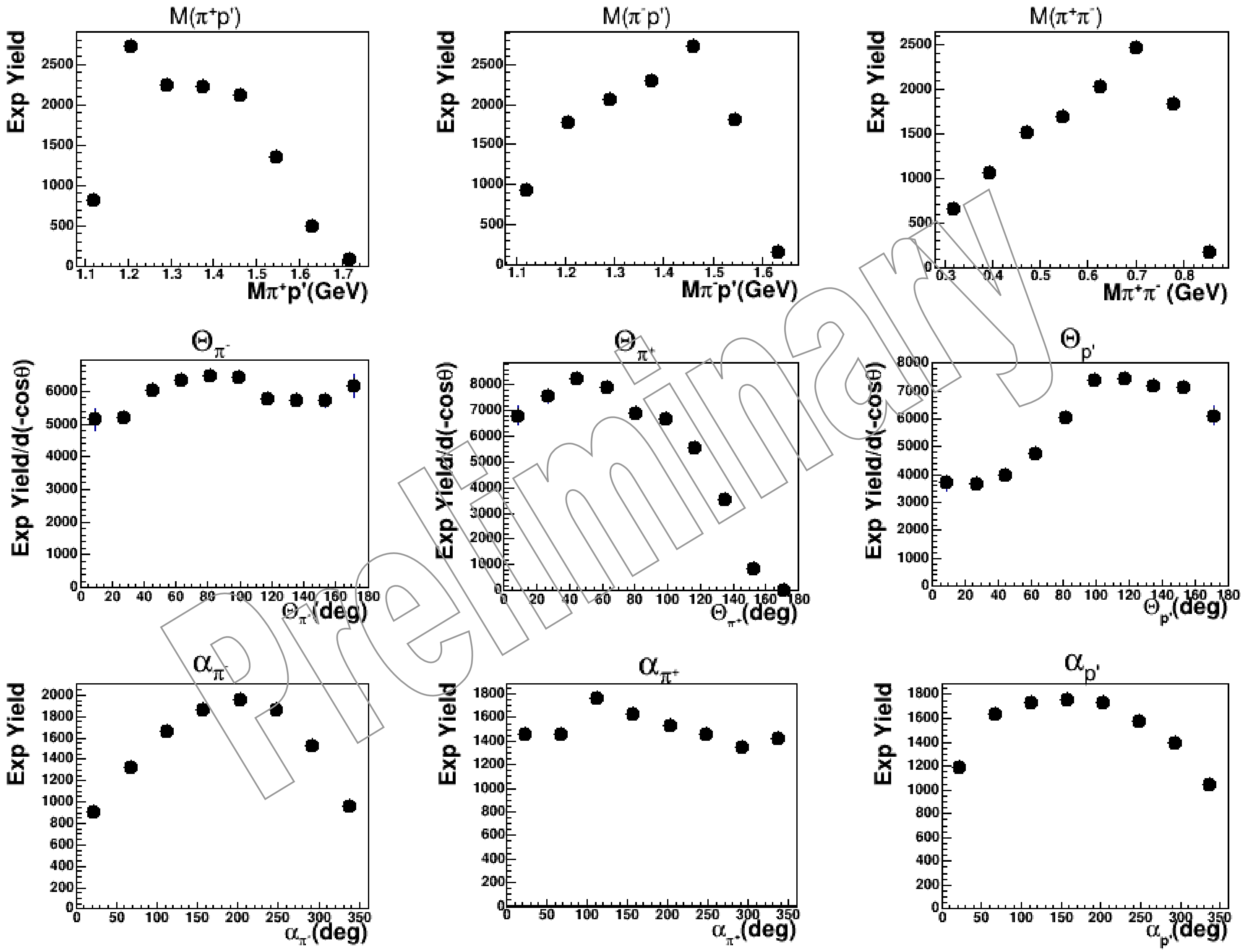
One-differential cross-sections:

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

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

Nine 1-D Experimental Yields

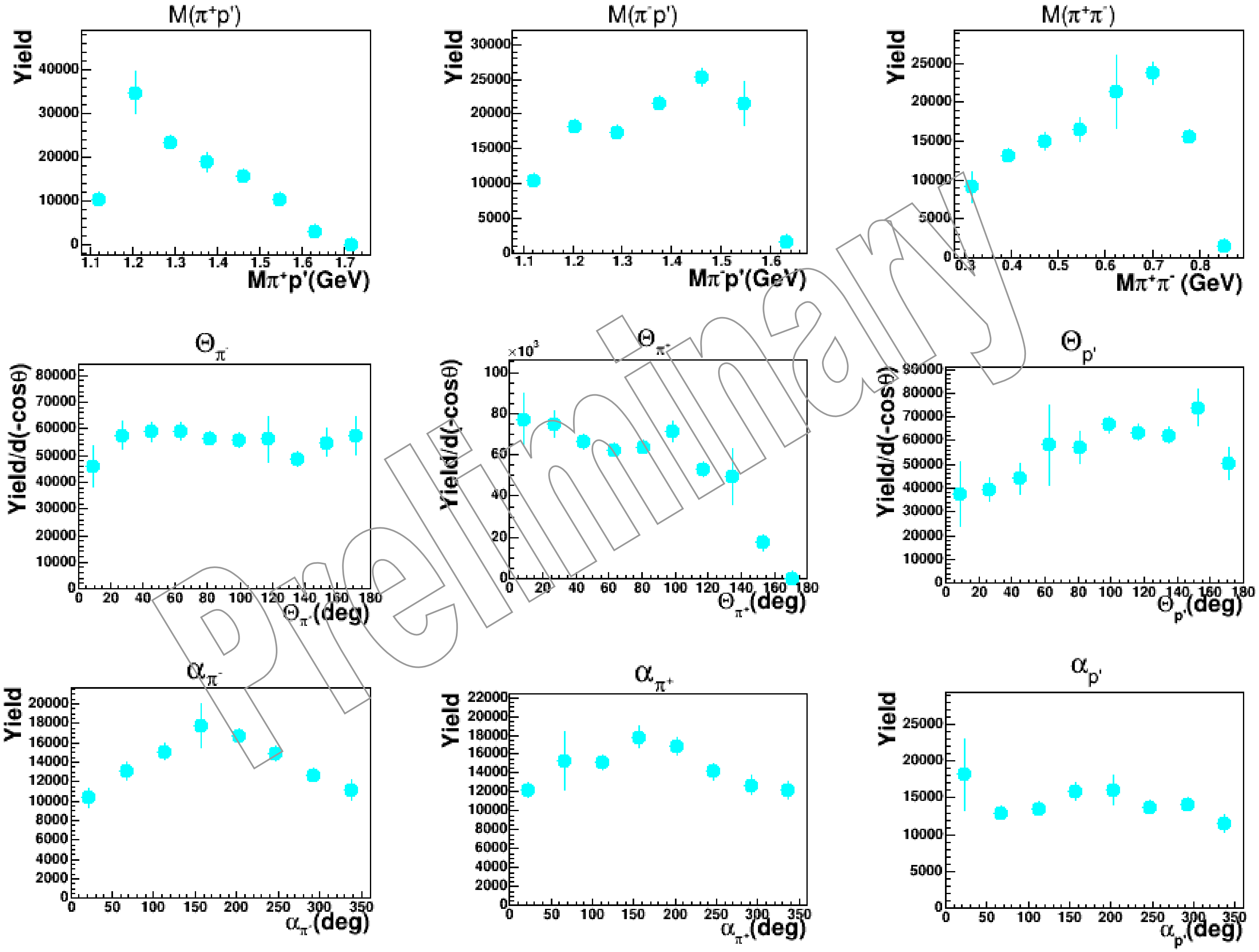
Using four vectors of the particles survived after all the cuts and event selection process



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

Nine 1-D Acceptance Corrected Yields

$$Acceptance\ \ Corrected\ \ Yields\ =\ \frac{Experimental\ \ Yields}{Acceptance\ \ Factor\,(F)}\ ,\quad where\ \ F\ =\ \frac{Reconstructed\ \ Events}{Thrown\ \ Events}$$



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

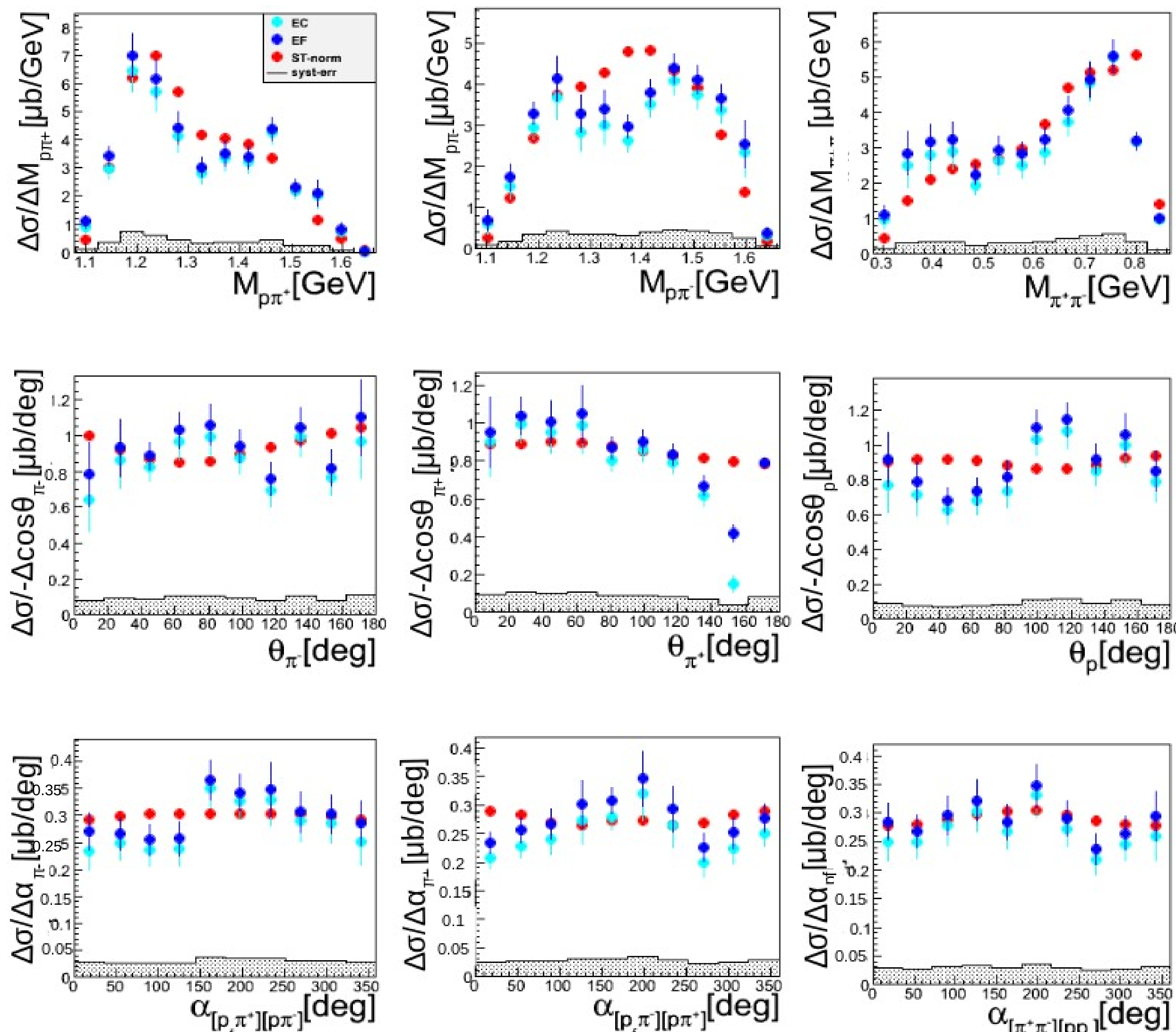
Nine 1-D Cross-Sections from CLAS E16

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

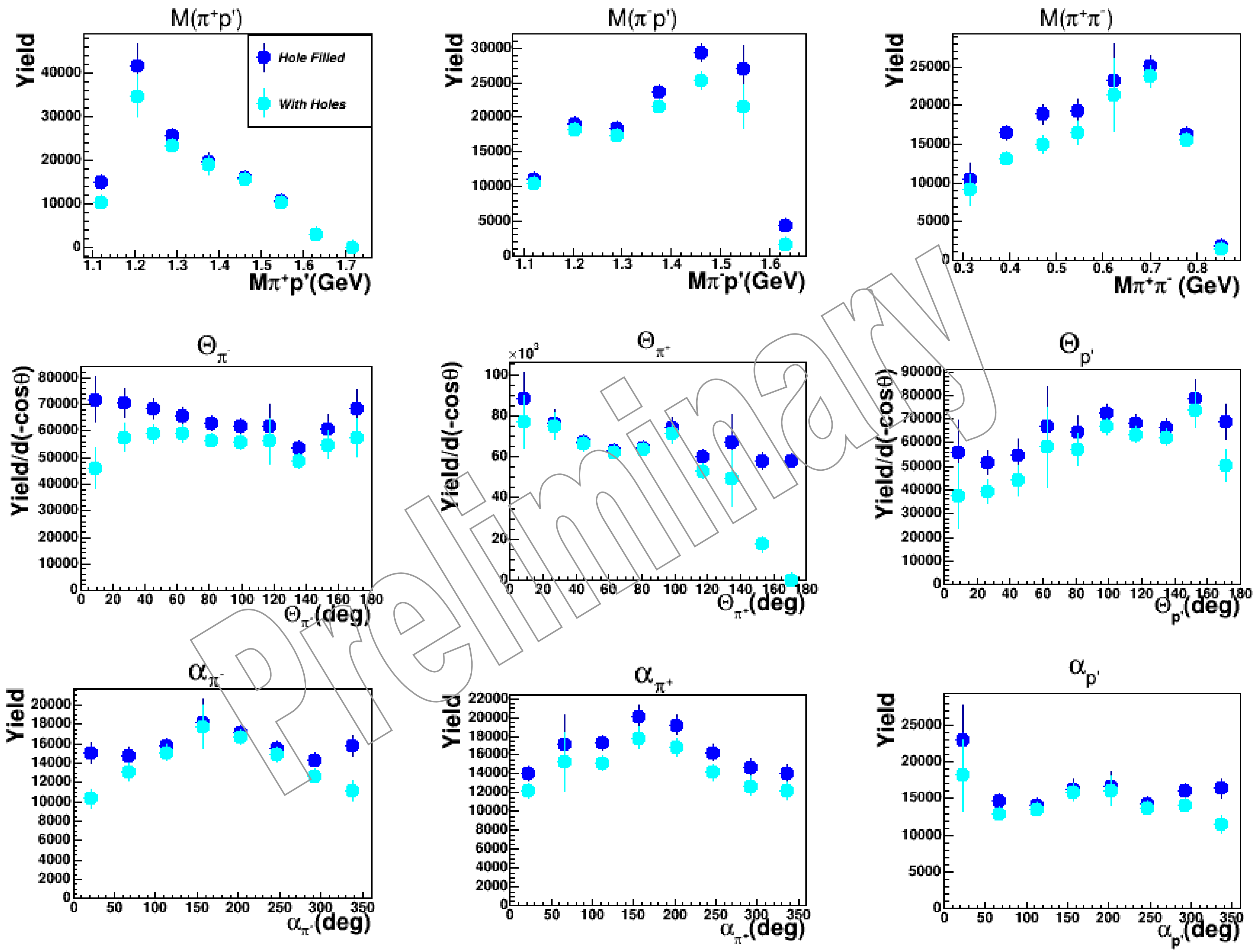
Source : Arjun Trivedi (CLAS e16 data)

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



W-Q² bins for these cross-sections: 1.775 GeV < W < 1.8 GeV, 4.2 GeV² < Q² < 5 GeV²

Nine 1-D Hole Filled Yields



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

Next Steps

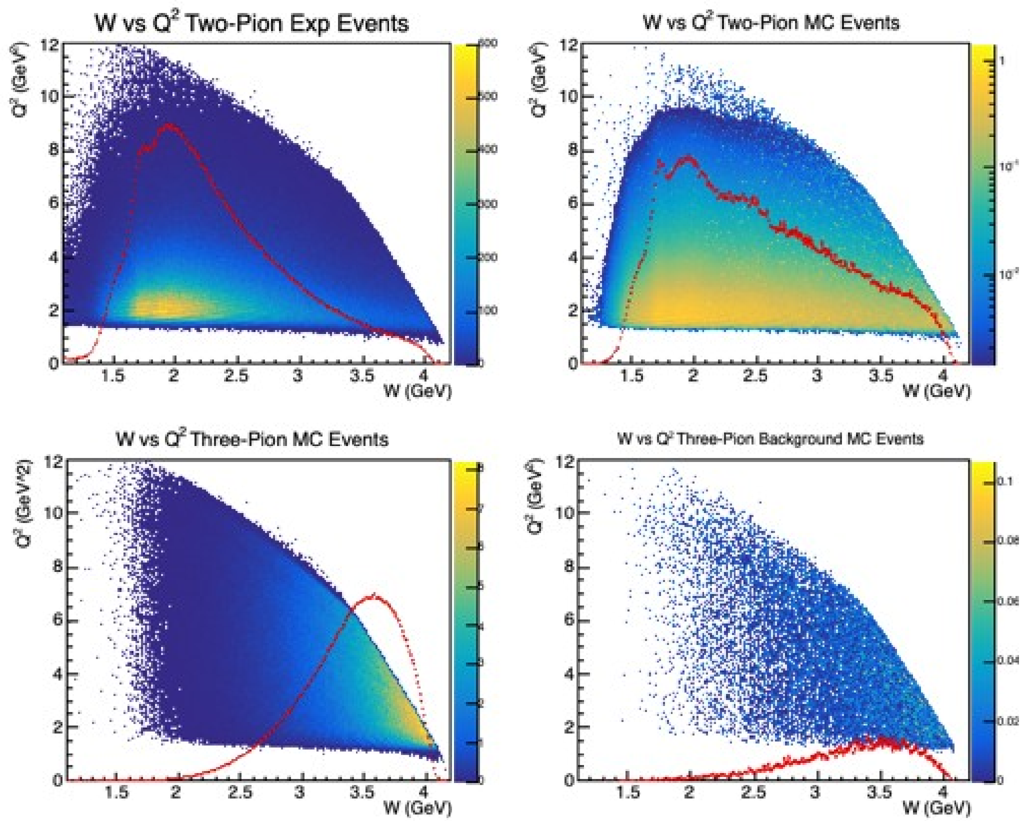
- Background and Efficiency Studies
- Energy/Momentum Corrections
- Radiative Effect Corrections
- Cross-Section Calculations
- Error Analysis

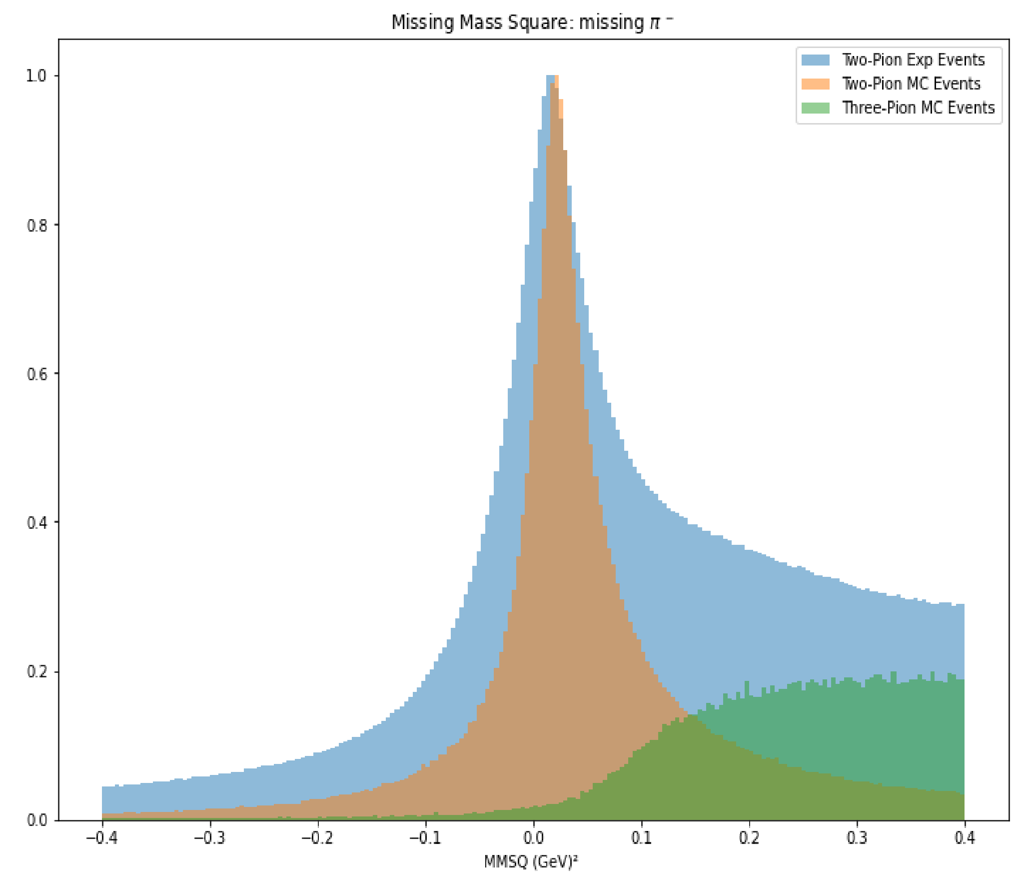
Background Studies: Three Pion Simulations

Phase space generator from N. Tyler is used to generate 3-pion: ep → e'p' $\pi^+\pi^-\pi^0$ events

TwoPion: ep → e'p'$\pi^+\pi^-$

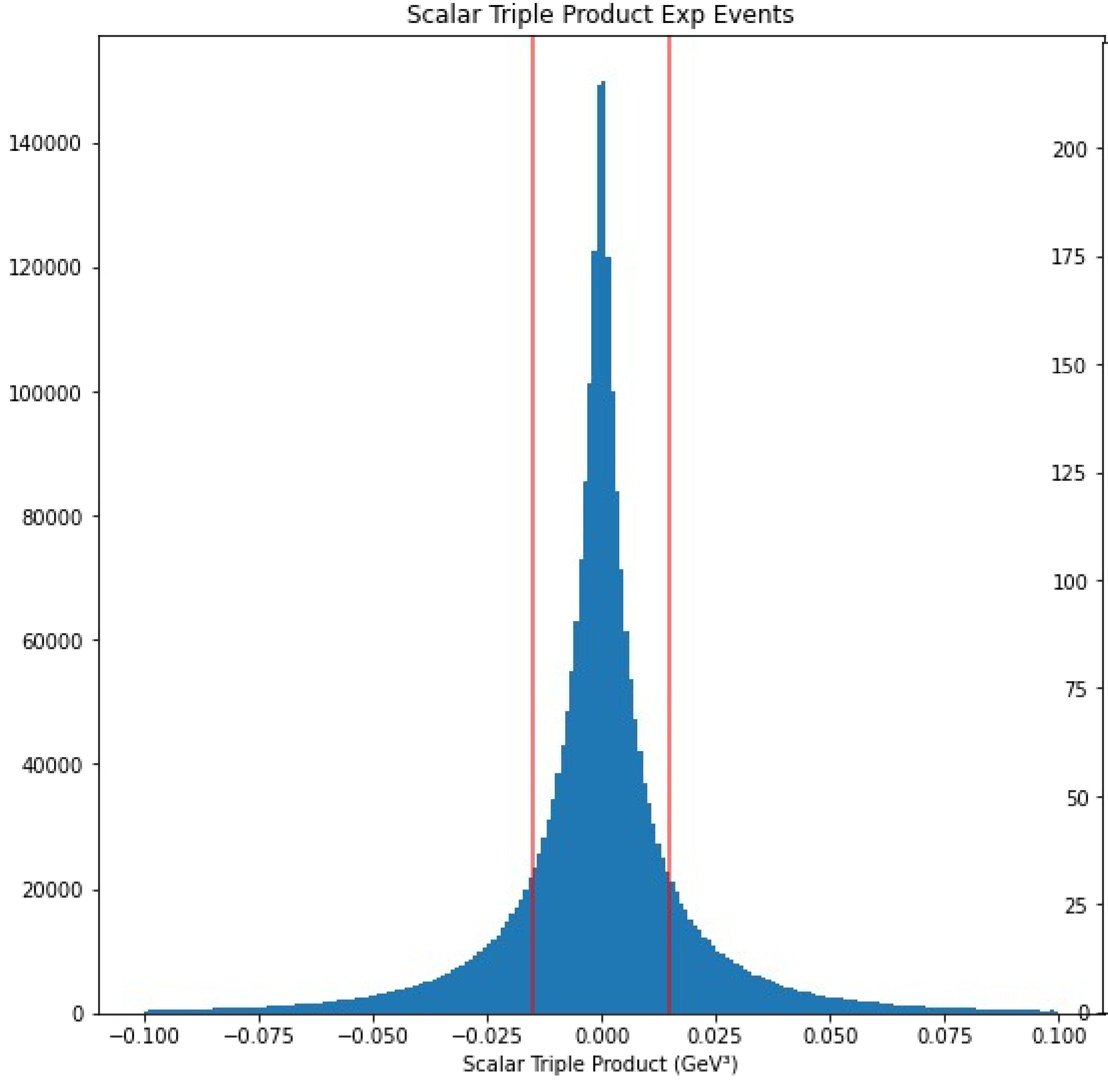
ThreePion : ep → e'p' $\pi^+\pi^-\pi^0$

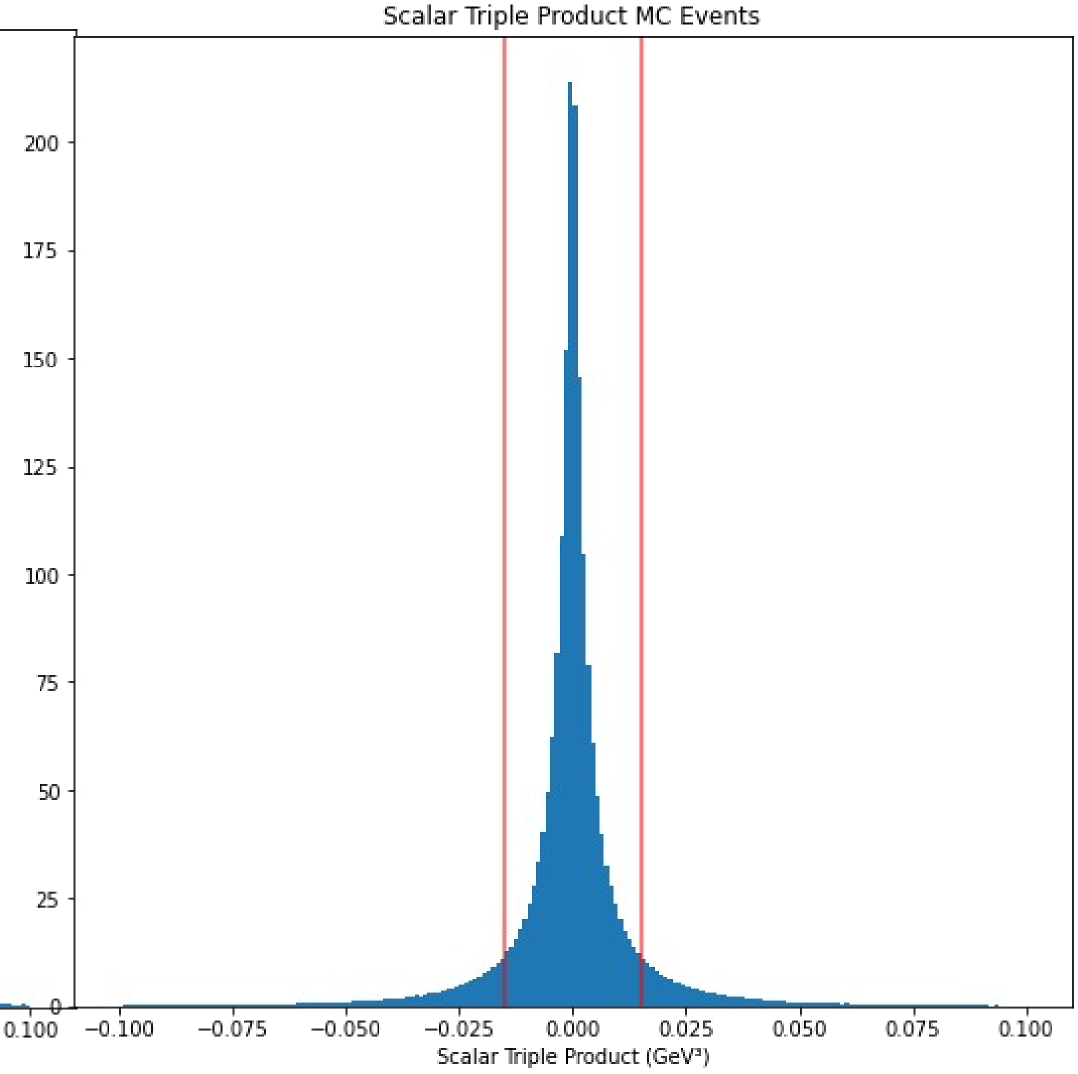




Coplanar-Cuts: $\vec{p} \cdot \left(\vec{\pi}^{+} \times \vec{\pi}^{-}\right) = 0$

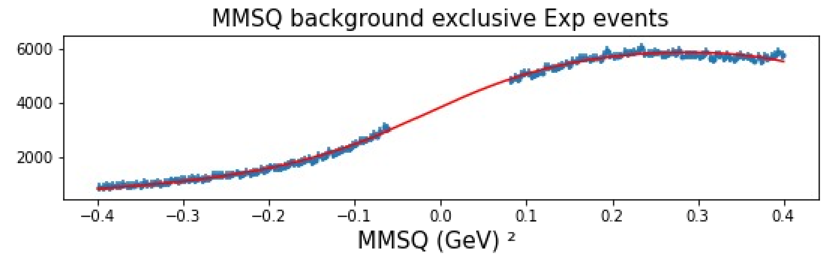
TwoPion: ep → $e'p'\pi^{+}\pi^{-}$ ← All final hadrons must be in one plane in CM frame

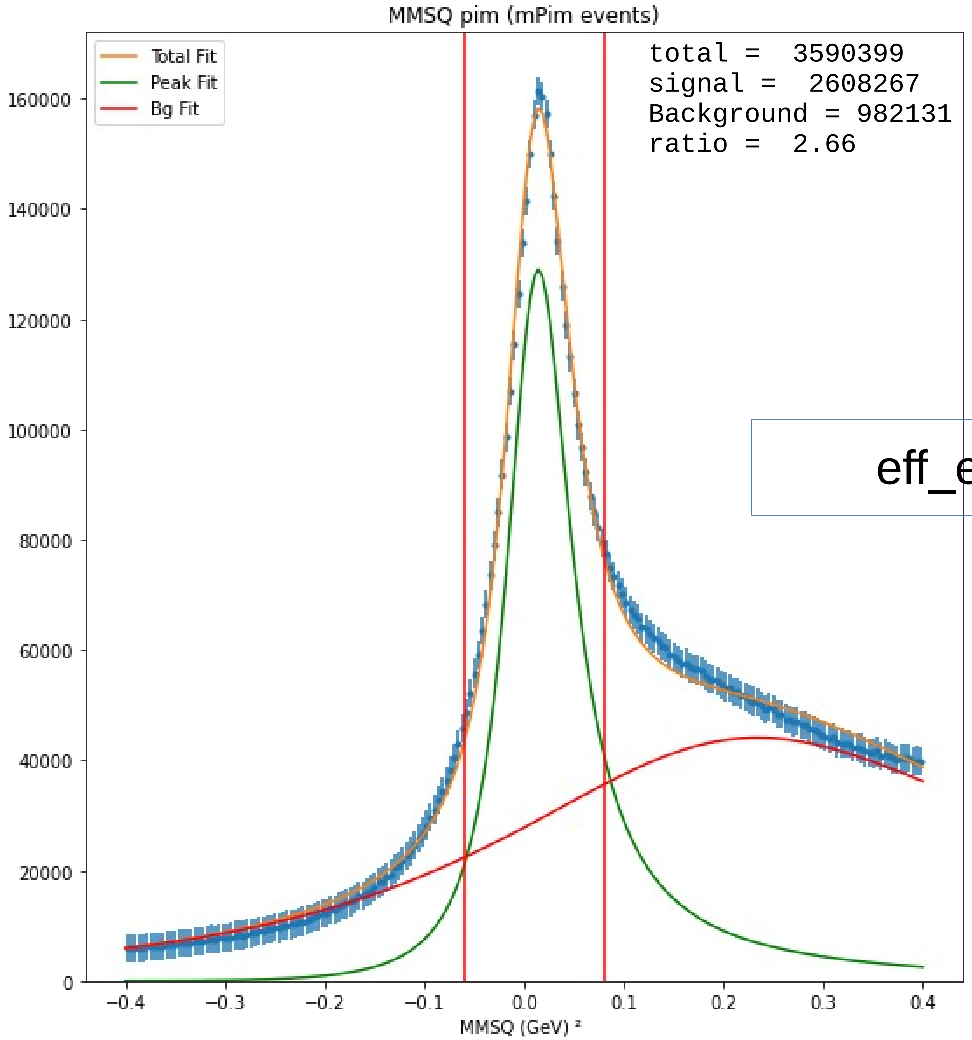




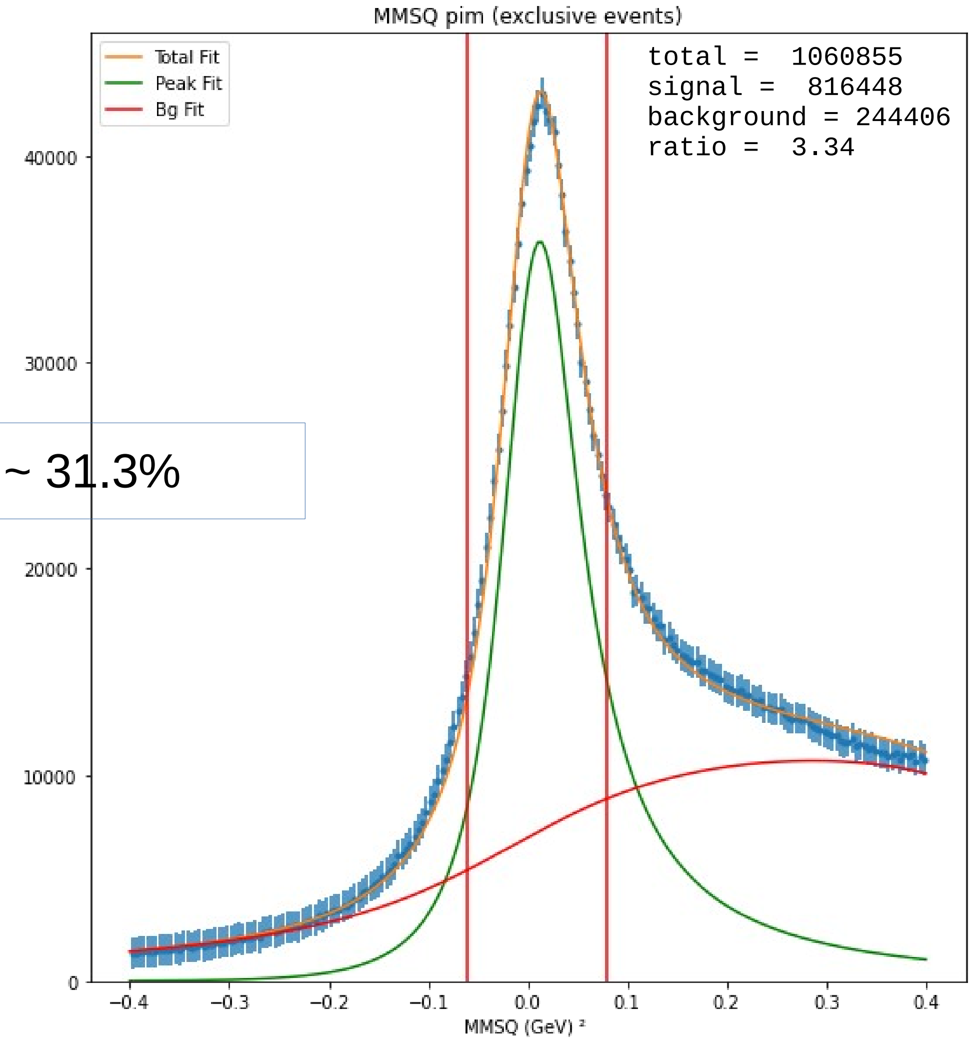
Background/Efficiency Studies Exp Events

Signal = SkewedVoigtModel
Background = RectangleModel
W < 3.0 GeV cut applied

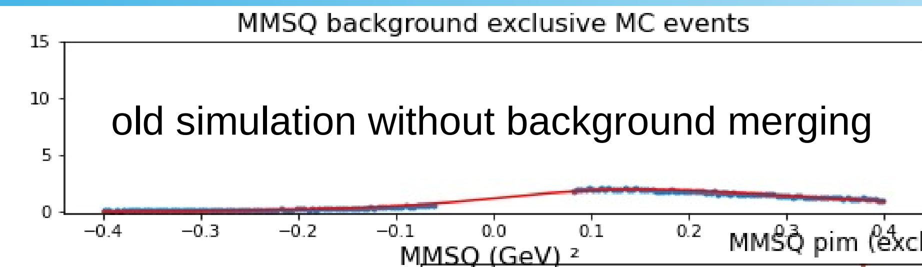




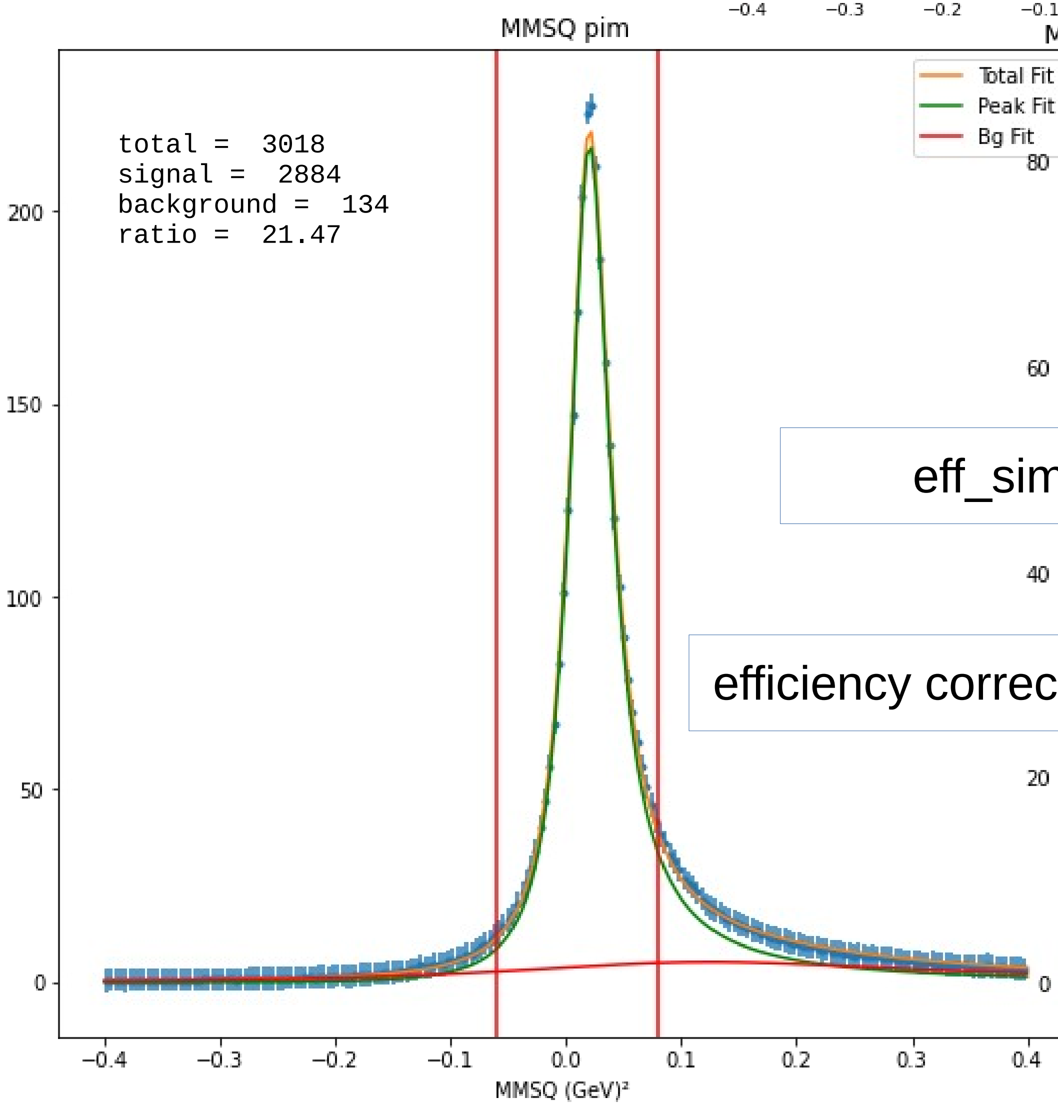
eff_exp ~ 31.3%

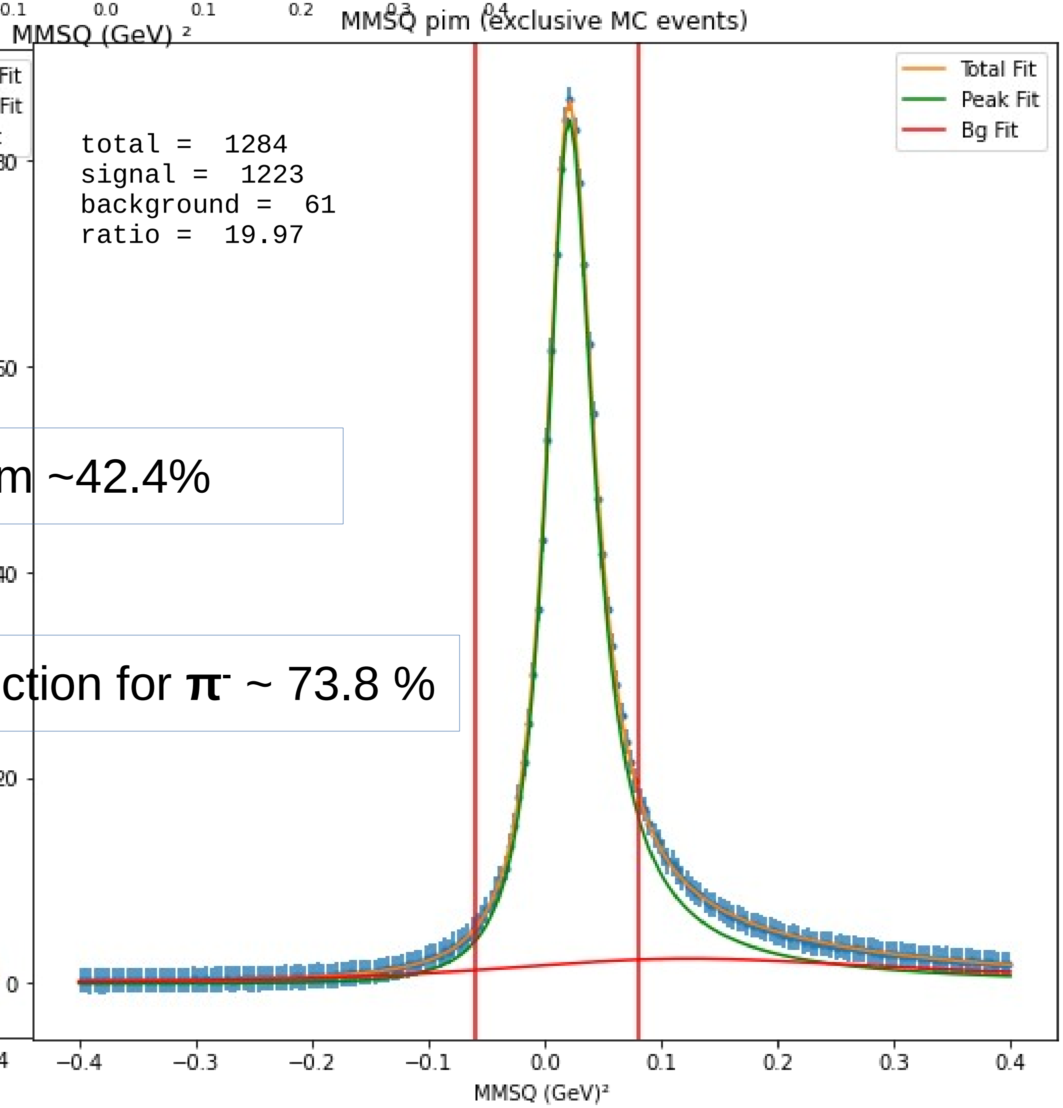


Background/Efficiency Studies MC Events



old simulation without background merging

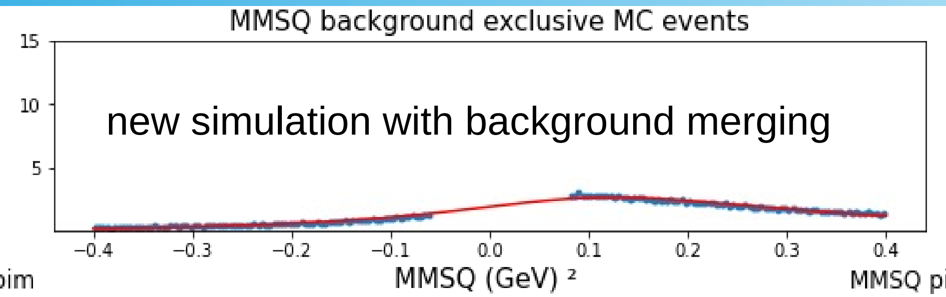




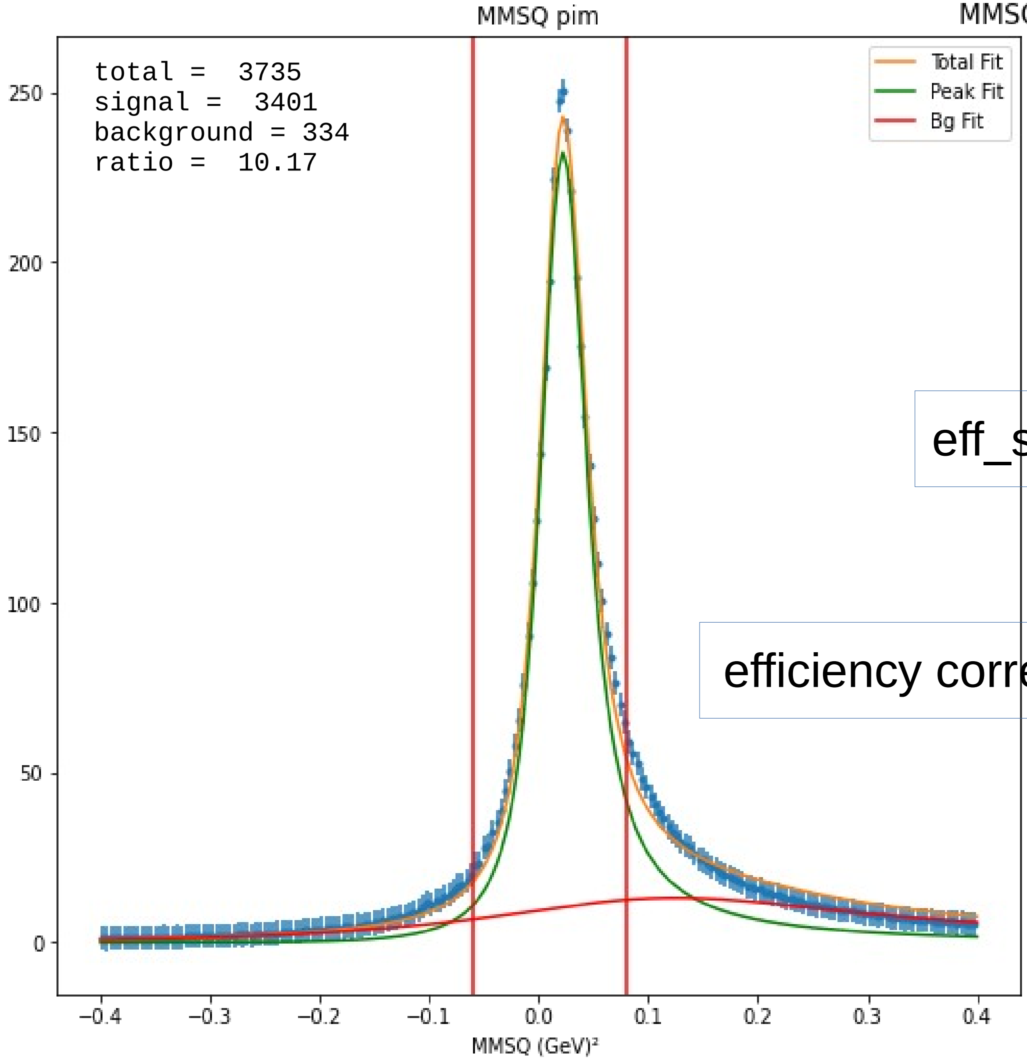
eff_sim ~42.4%

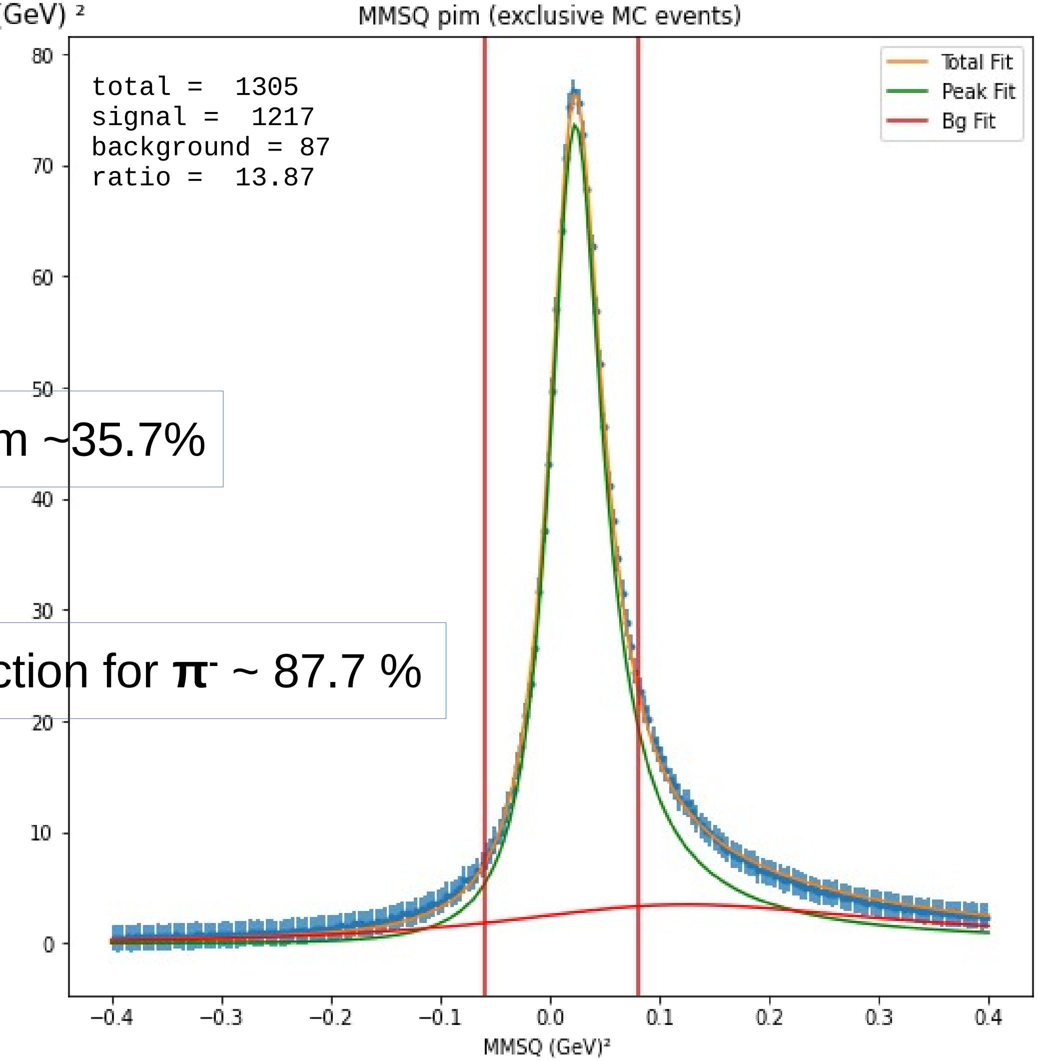
efficiency correction for $\boldsymbol{\pi}^-$ ~ 73.8 %

Background/Efficiency Studies MC Events



new simulation with background merging

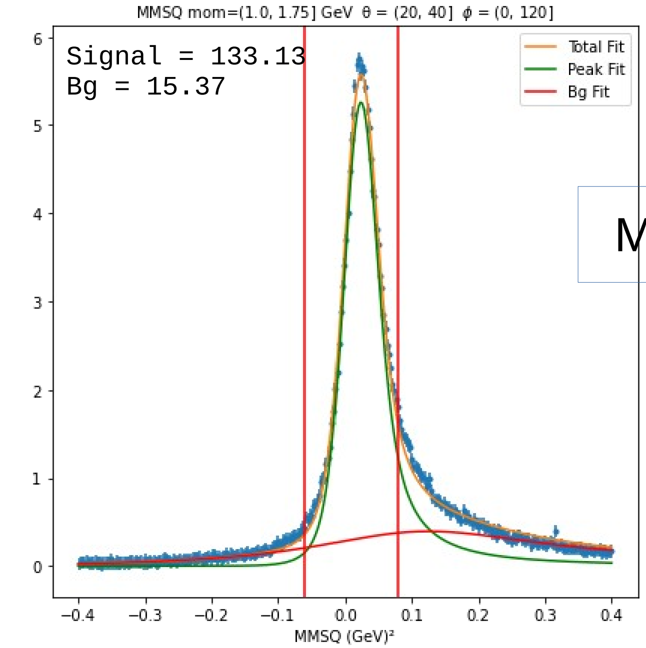


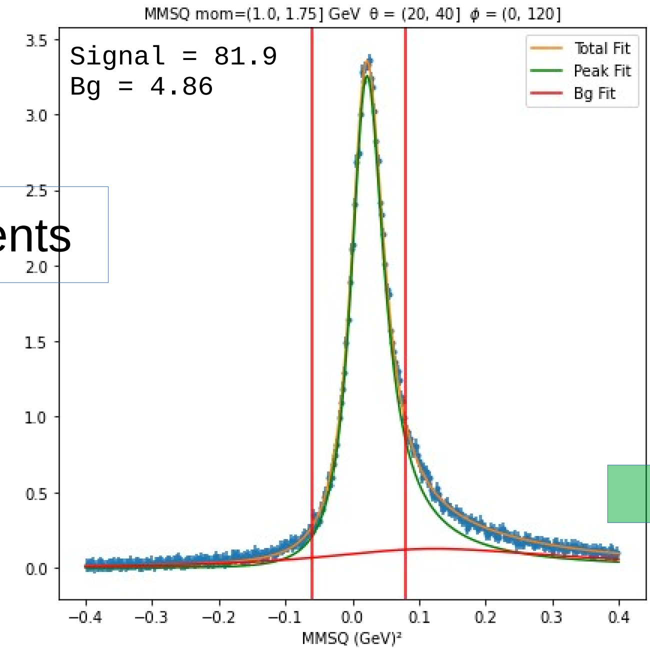


eff_sim ~35.7%

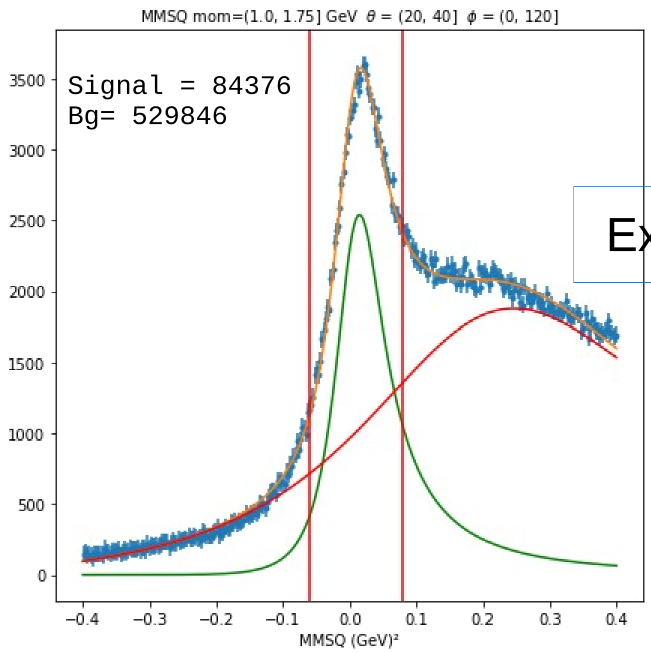
efficiency correction for $\boldsymbol{\pi^-}$ ~ 87.7 %

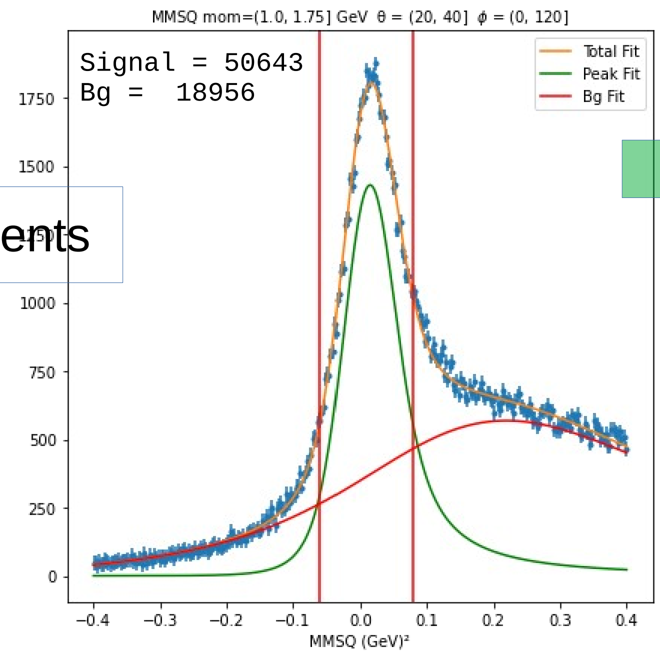
Background/Efficiency Studies 3-D bin





MC Events





Exp Events

π^- mom (4 bins)
$\theta_{\pi-}$ (3 bins)
$\varphi_{\pi-}$ (3 bins)

eff_sim = 61.1 %

eff_exp = 60.0 %

efficiency correction factor for π^- ~ 98.1 %

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 ongoing to improve binning and hole filling process
- ☞ Background and detector efficiency studies are in progress
- ☞ Energy/momentum correction, radiative effects corrections, and other normalization factors are needed to **extract actual cross-sections**

THANK YOU !

- The W < 3.0 GeV cut applied
- The efficiency presented here are only for $\boldsymbol{\pi^-}$
- The MMSQ distributions are fitted with signal function as SkewedVoigtModel and the background as RectangleModel
- SkewedVoigtModel is a skewed Voigt model (convolution of a Cauchy-Lorentz distribution and a Gaussian distribution), modified using a skewed normal distribution. It has Parameters amplitude (A), center (μ), sigma (σ), and gamma (γ), as usual for a Voigt distribution, and add a Parameter skew [1]
- RectangleModel is a model based on a Step-up and Step-down function. It has five parameters amplitude (A), center1 (μ1), center2 (μ), sigma1 (σ1), and sigma2 (σ2) [1]

signal

$$f(x; A, \mu, \sigma, \gamma, skew) = Voigt(x, A, \mu, \sigma, \gamma)[1 + erf[\frac{skew(x-\mu)}{\sigma\sqrt{2}}]]$$

background

$$f(x; A, \mu, \sigma, form='\mathrm{arctan}') = A[\arctan(\alpha_1) + \arctan(\alpha_2)]/\pi$$
$$where, \alpha_1 = (x-\mu_1)/\sigma_1, \quad \alpha_2 = -(x-\mu_2)/\sigma_2$$

Reference 1: https://lmfit.github.io/lmfit-py/builtin_models.html

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

Back Up: Invariant Mass Distribution in Two-Pion Channel