Radiative Decay of η' in CLAS

$$\gamma p \to p(\eta' \to \pi^+\pi^-\gamma)$$

Georgie Mbianda Njencheu

(LMD Group)

Old Dominion University

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Outline

- Theoretical Background
- CLAS Setup
- The g11 Experiment
- Current status of Analysis
- Preliminary Results

Axial Anomaly

- An anomaly arises when a classical symmetry is broken in QFT.
- The massless Dirac Lagrangian has a symmetry generated by the axial vector current

$$j_{5\mu} = \bar{\Psi}\gamma_\mu\gamma_5\Psi$$

- If Ψ satisfies $(i\gamma_\mu\partial^\mu - m)\Psi = 0$

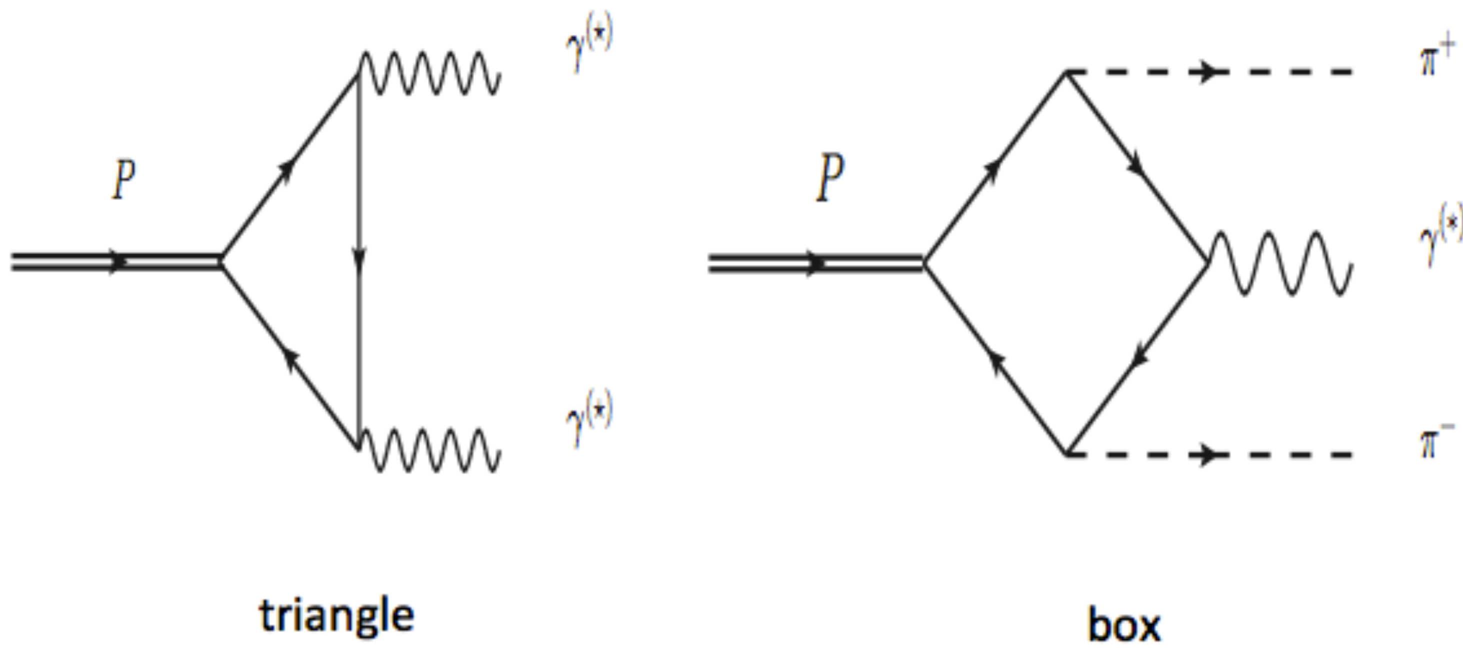
$$\begin{aligned}\partial^\mu j_{5\mu} &= (\partial^\mu\bar{\Psi})\gamma_\mu\gamma_5\Psi - \bar{\Psi}\gamma_5\gamma_\mu\partial^\mu\Psi \\ &= (im\bar{\Psi})\gamma_5\Psi - \bar{\Psi}\gamma_5(-im\Psi) = 2im\bar{\Psi}\gamma_5\Psi \\ &= 0(m=0)\end{aligned}$$

- However in QFT when gauge fields are present, the divergence of current is non-zero:

$$\partial^\mu j_{5\mu} = -\frac{e^2}{16\pi^2}\varepsilon^{\mu\nu\alpha\beta}F_{\mu\nu}F_{\alpha\beta}$$

- where $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$ is the EM field strength tensor.

Why is Radiative Decay Interesting?

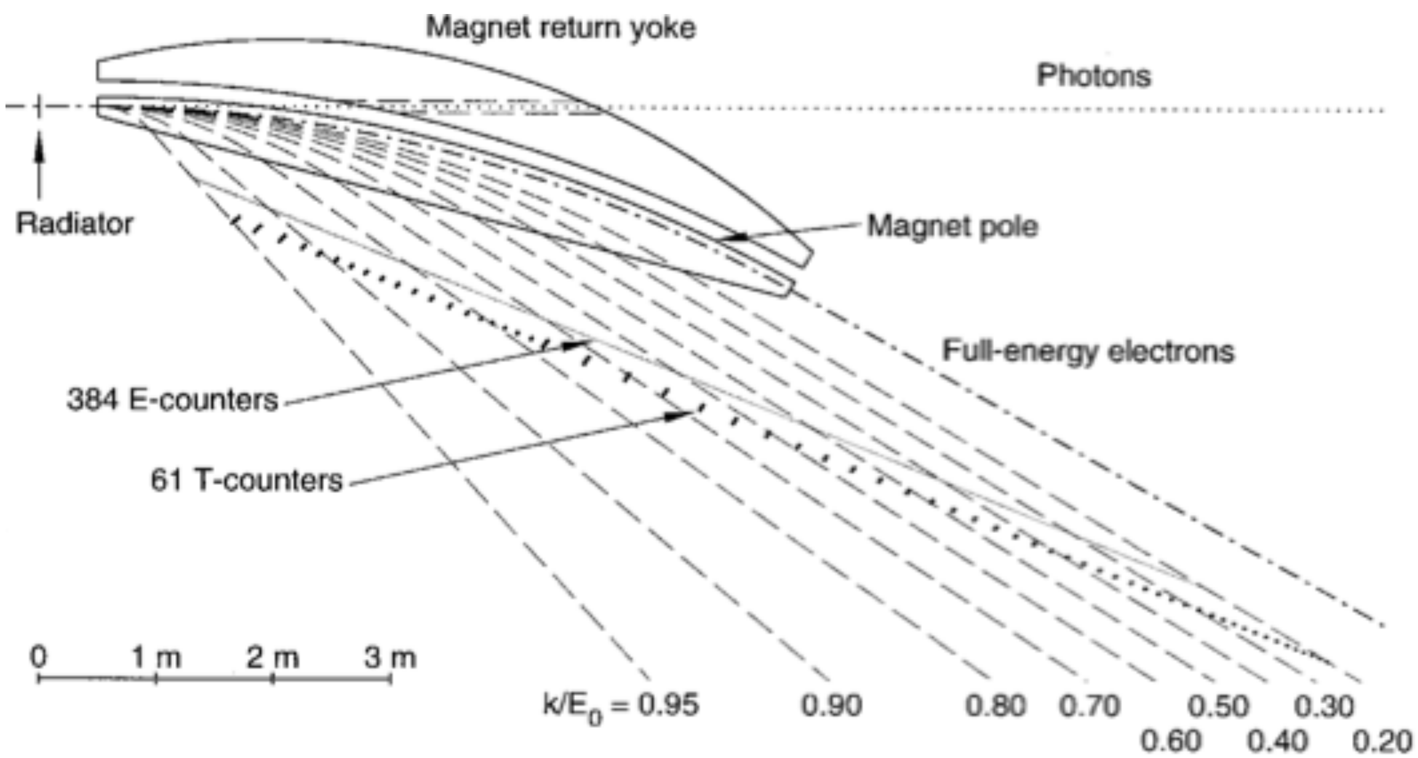


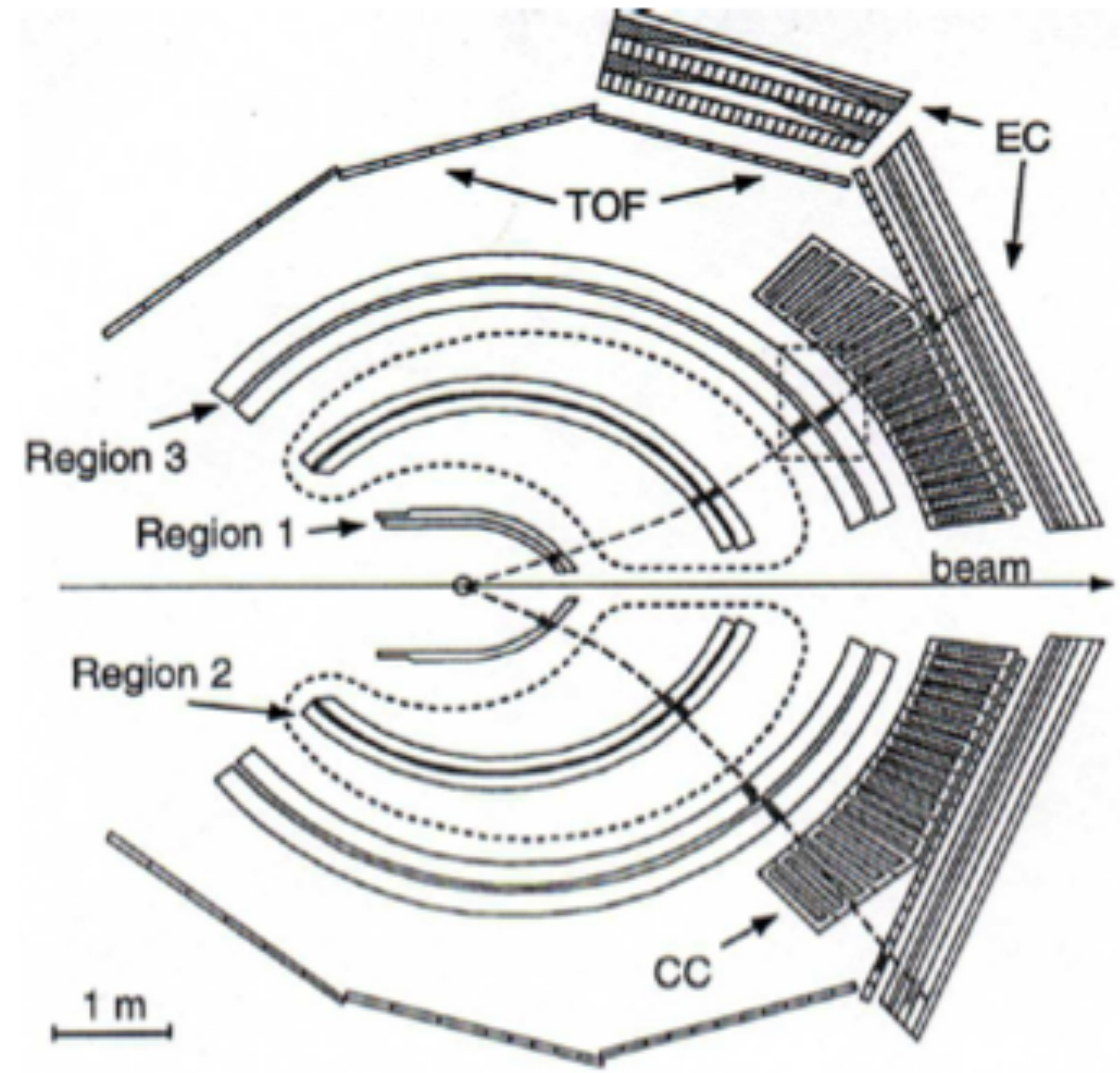
- Anomalies are encoded in some terms of the Wess-Zumino-Witten Langrangian.
- Radiative decays would provide access to box anomaly term of this Lagrangian
- The di-pion invariant mass for $\eta' \to \pi^+\pi^-\gamma$ could be described in a model-independent approach of two free parameters, α and β.

g11 Overview

- The g11 experiment ran in the summer of 2004
- Electron beam had the energy E=4GeV and average current of 60nA
- A gold radiator of 10^{-4} radiation length was used to create bremsstrahlung beam of photons
- Liquid H_2 target of 40cm long and 4cm diameter was used
- Trigger required at least two charged tracks in different sectors.
- 20 billion triggers stored as 21 TB of raw data.

Photon tagger and other subsystems of CLAS Detector





CLAS subsystems

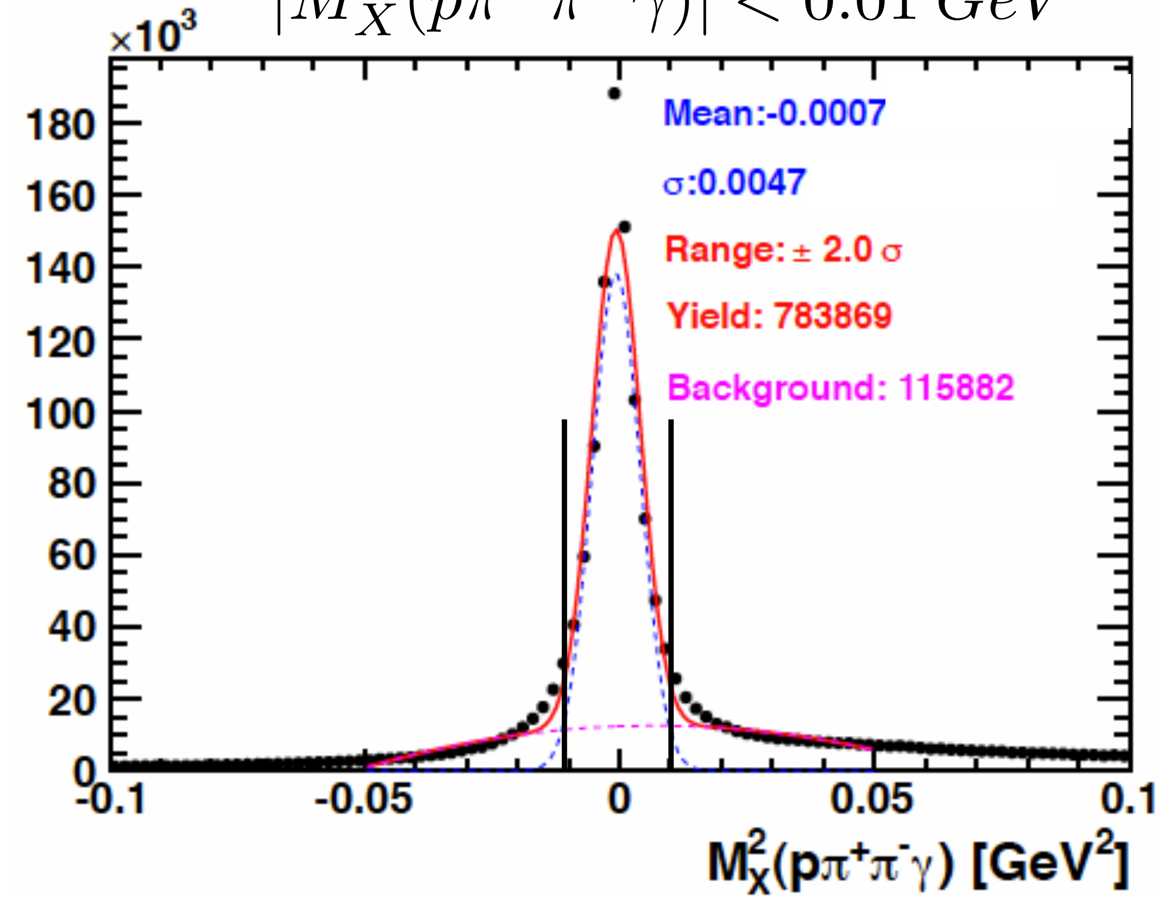
- The start counter surrounded the target and measured vertex time of particles in coincidence with the incoming photon.
- Tagger's E-plane measured energy of recoiling electrons from which photon energy is determined, $E_\gamma = E_0 - E_e$
- Tagger's T-plane made accurate timing measurements of recoiling electrons.
- The drift chambers measured the momentum of charged particles.
- TOF system measured time and position of each charged particle that hits it. Played important rule in trigger and particle ID.
- The EC used for detecting charged and neutral particles and discriminated between electrons and positrons from charged pions.

Event Selection and Particle Identification

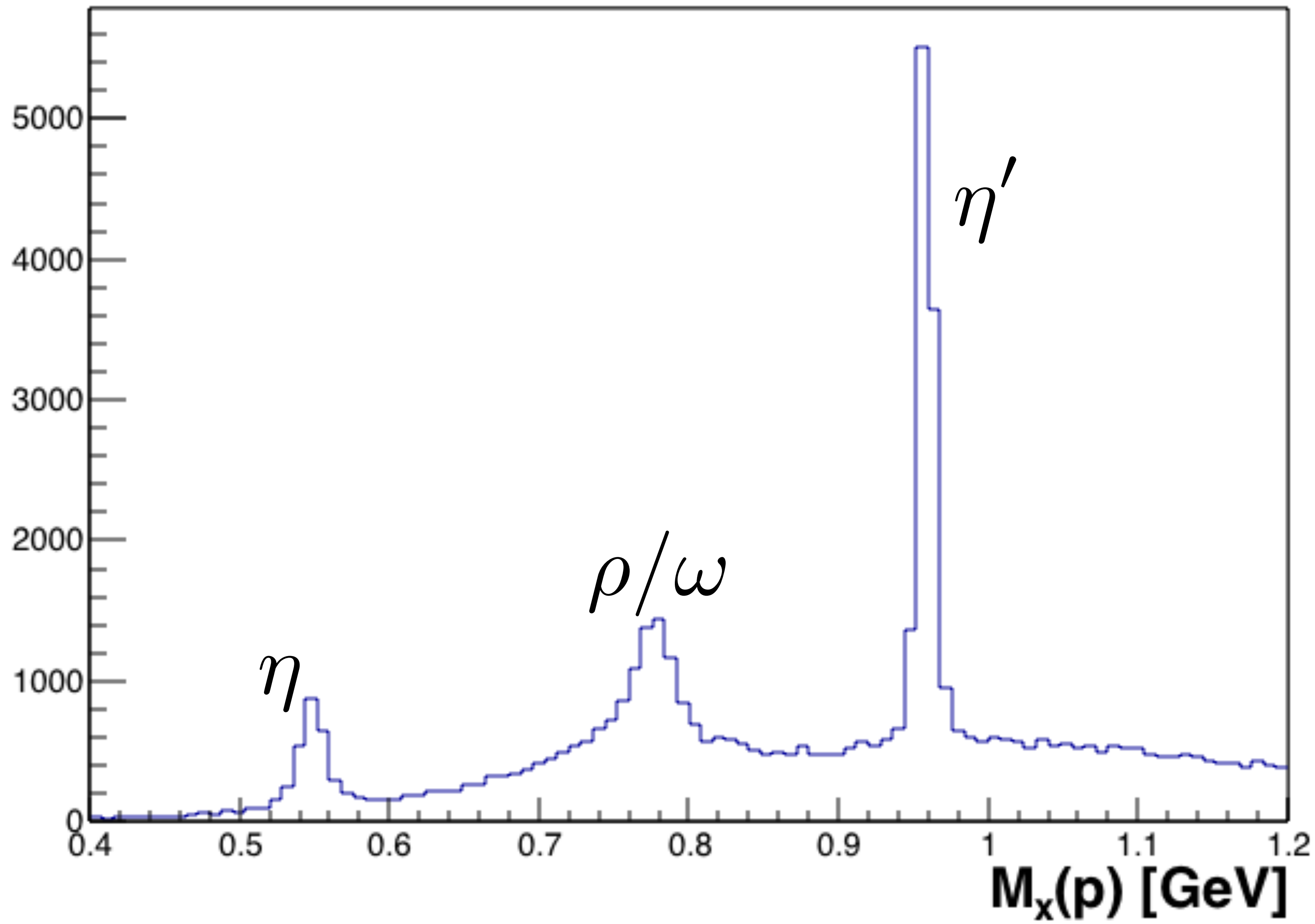
- Trigger required at least 2 charged track so we cannot detect events with mesons decaying into entirely neutral particles in the final state.
- Events with 3 charged tracks identified as proton, $\pi+$ and $\pi-$ and at least one photon were selected.
- TOF system was used for particle identification.

Squared missing mass of all detected particles

$$|M_X^2(p\pi^+\pi^-\gamma)| < 0.01\ GeV^2$$

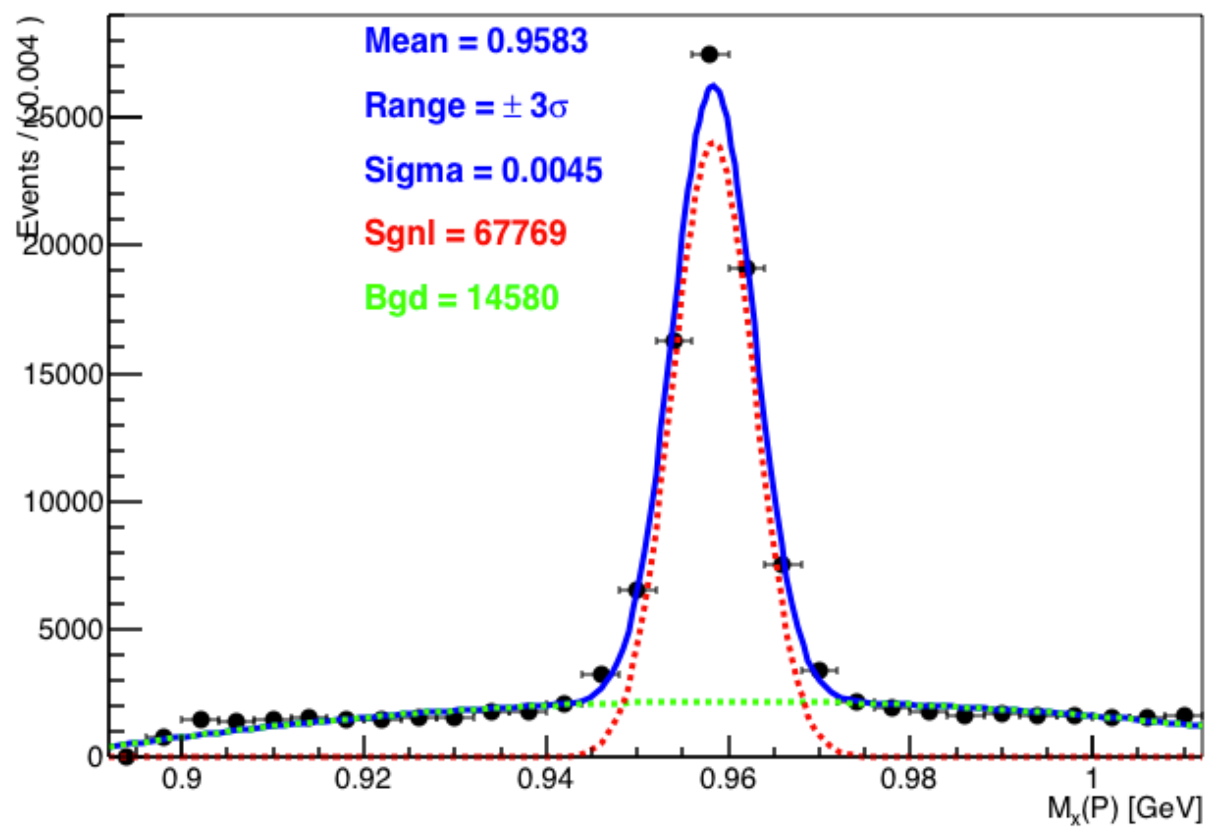


$M_X(p)$ *for selected data set*

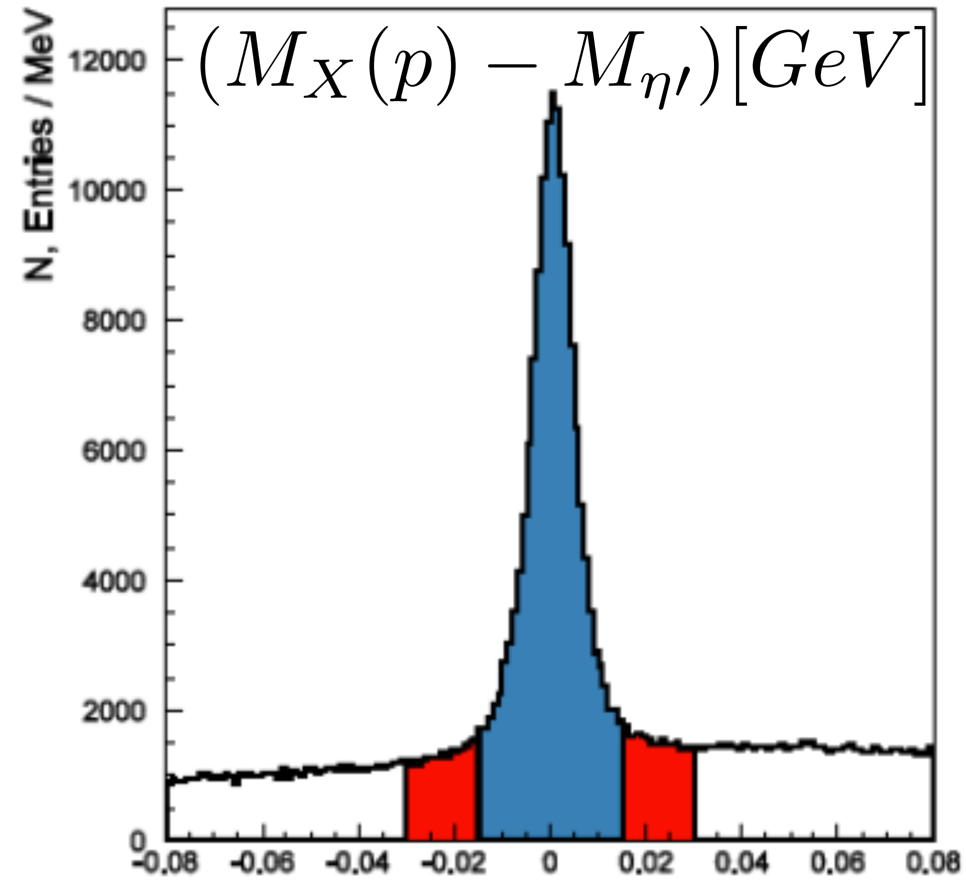


η' events and π^0 separation

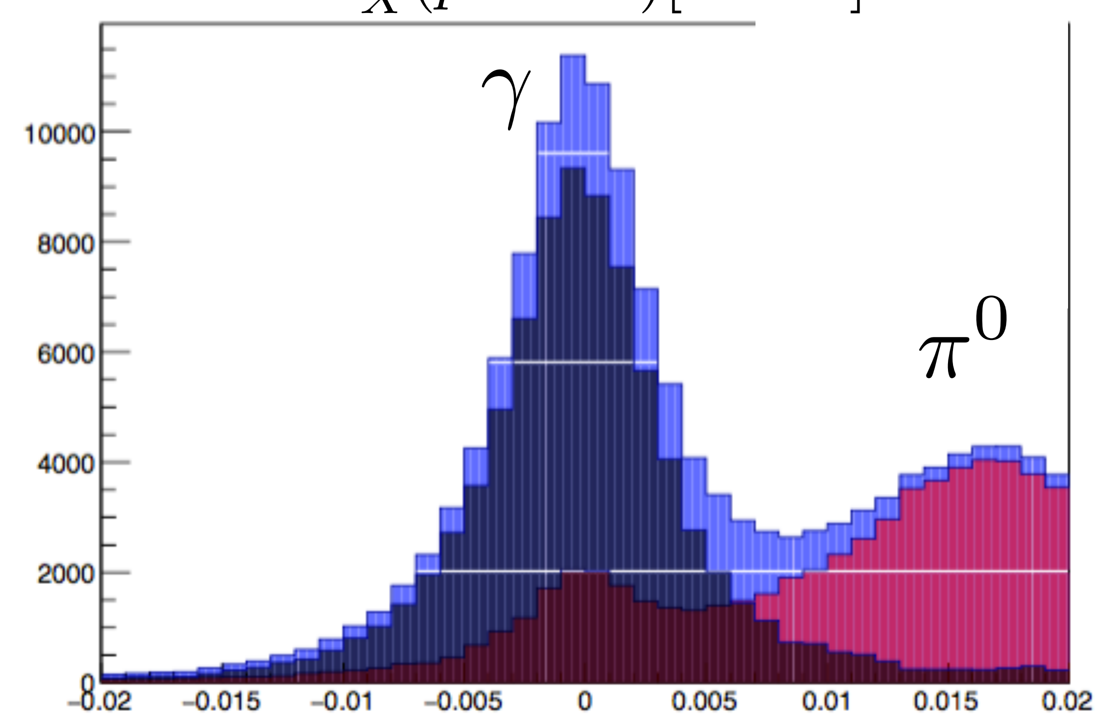
$M_X(p)[GeV]$



$(M_X(p) - M_{\eta'})[GeV]$



$M_X^2(p\pi^+\pi^-)[GeV^2]$

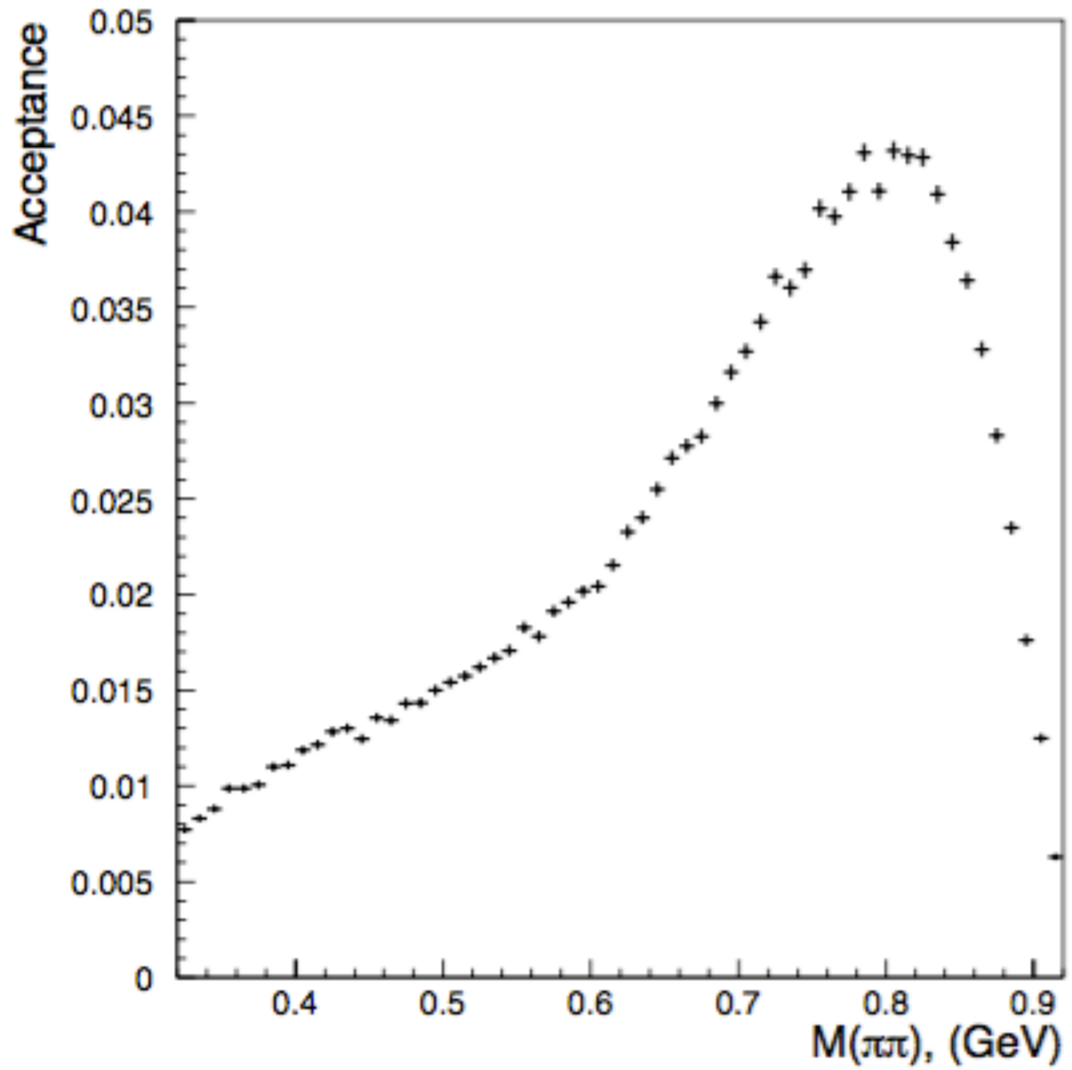


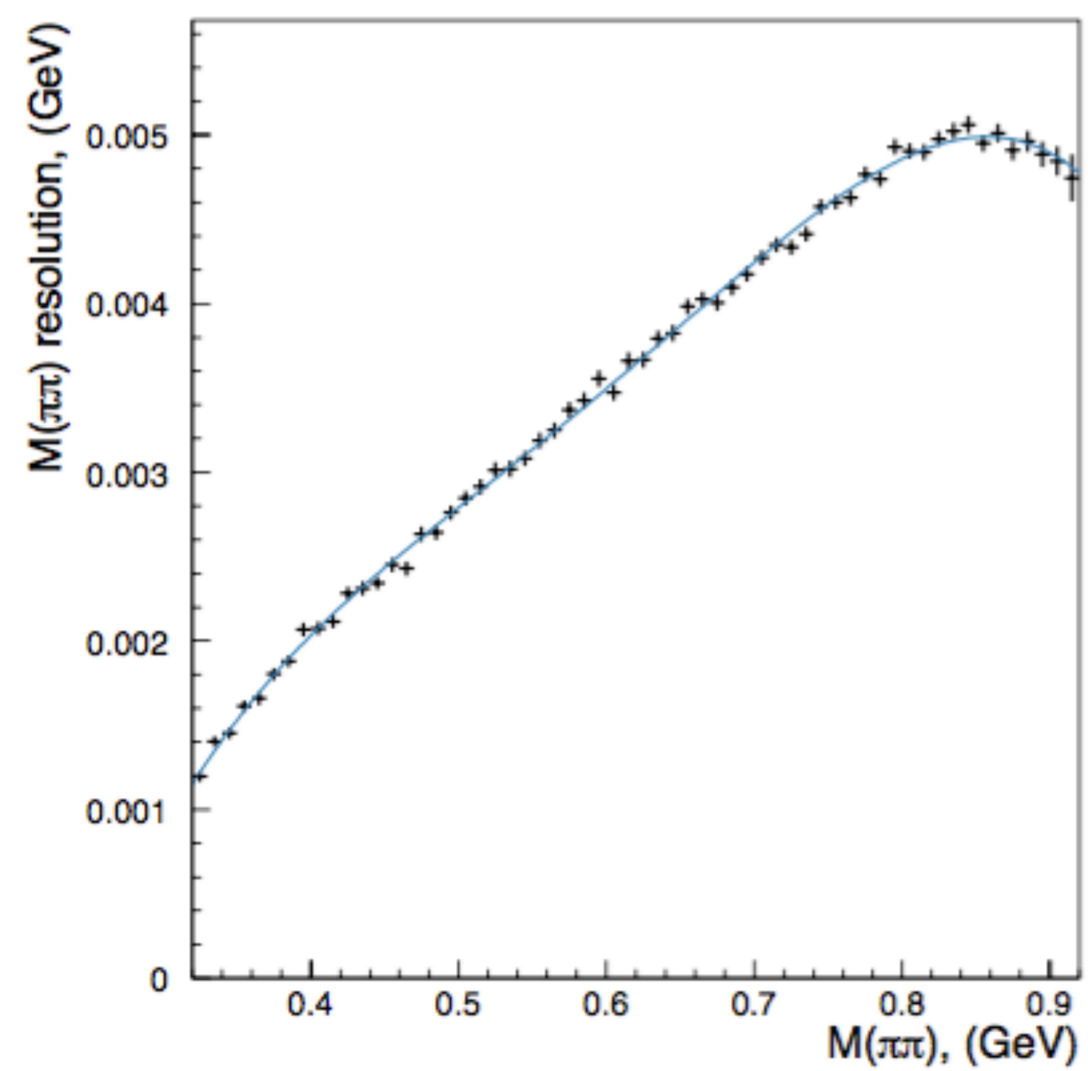
SIMULATION

- MC: Events are generated as per the cross section and beam flux
- GSIM: Generated events are passed through the Geant based simulation in CLAS that simulates-decay, energy loss & multiple scattering
- GPP: GSIM Post Processor for smearing detector signal to reflect actual resolution.
- RECSIS: Reconstruction program to analyze GSIM output in same manner as raw data

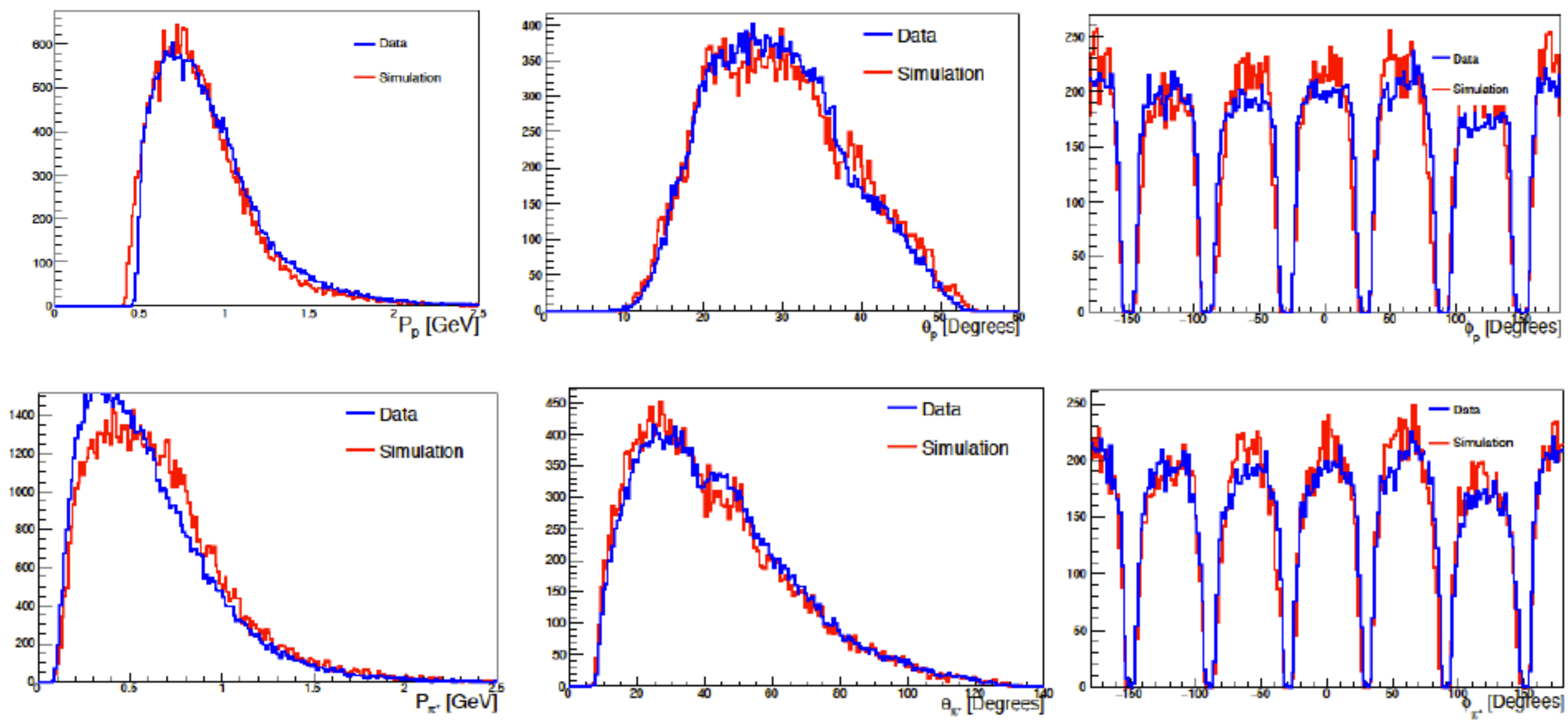
CLAS Acceptance & Resolution

- We used $M_{\pi\pi}$ mass range from 0.32 - 0.92 GeV split into 120 bins
- 10 million events were simulated for each $M_{\pi\pi}$ bin
- Acceptance and $M_{\pi\pi}$ resolution were obtained.





Data & MC Compared



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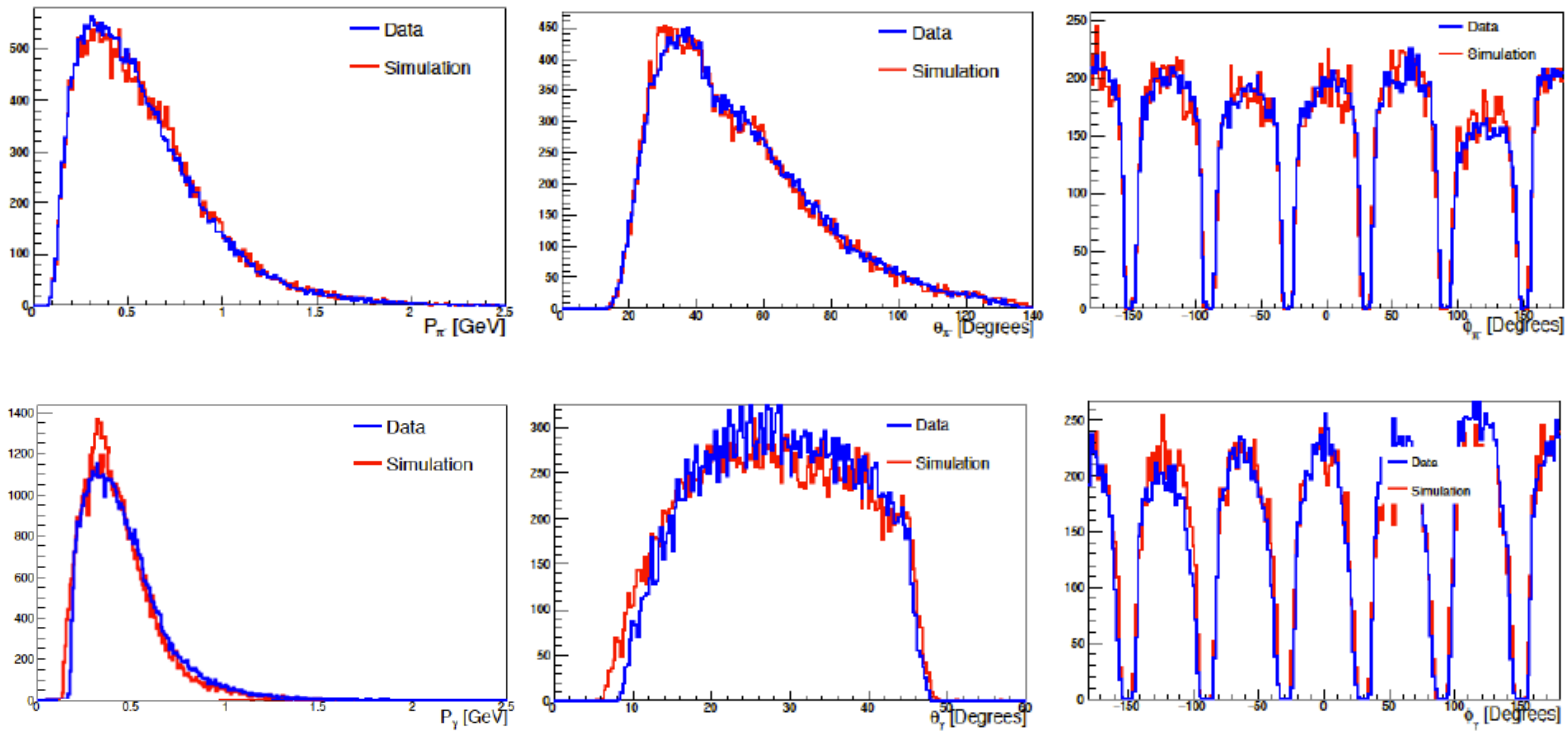
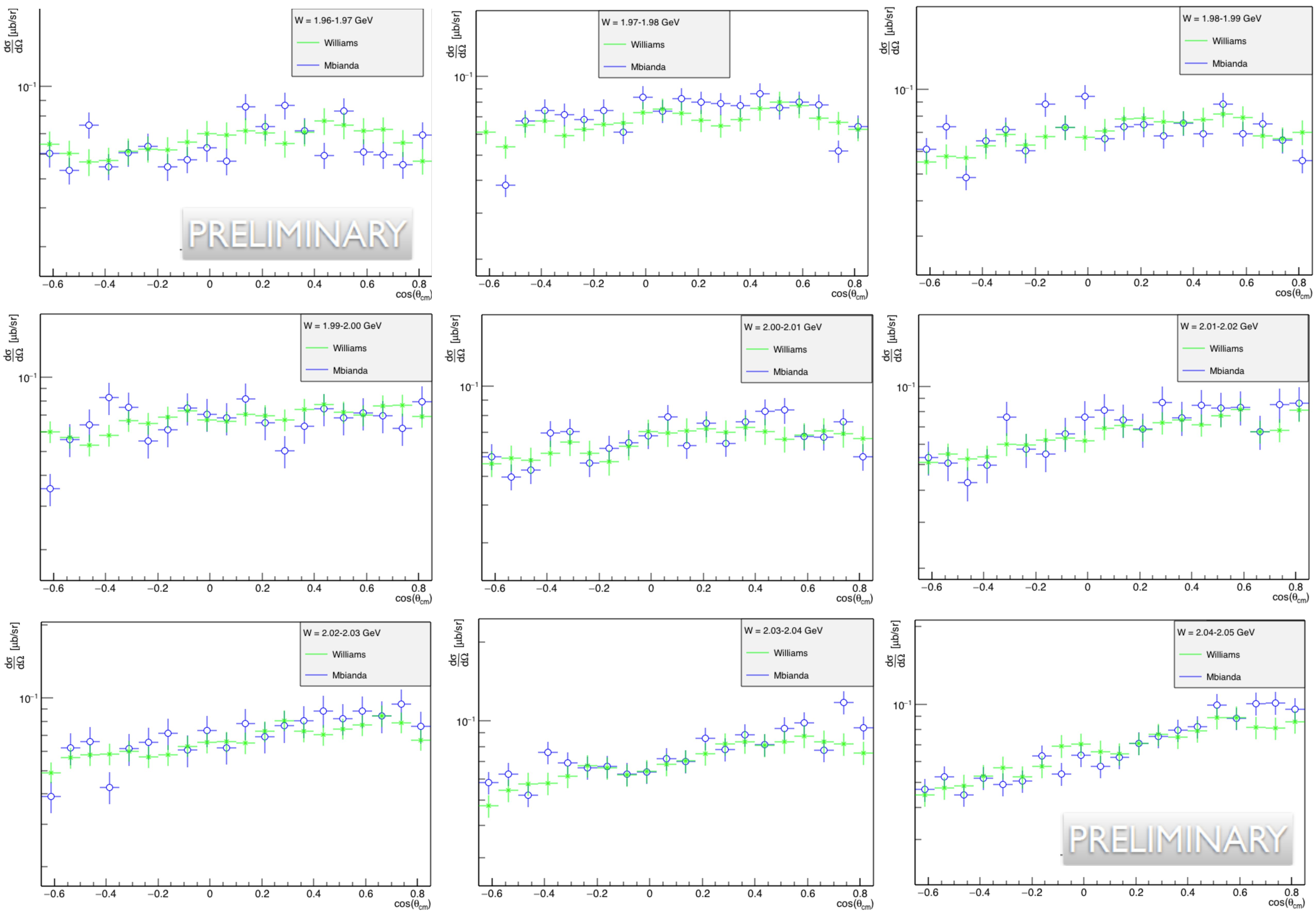
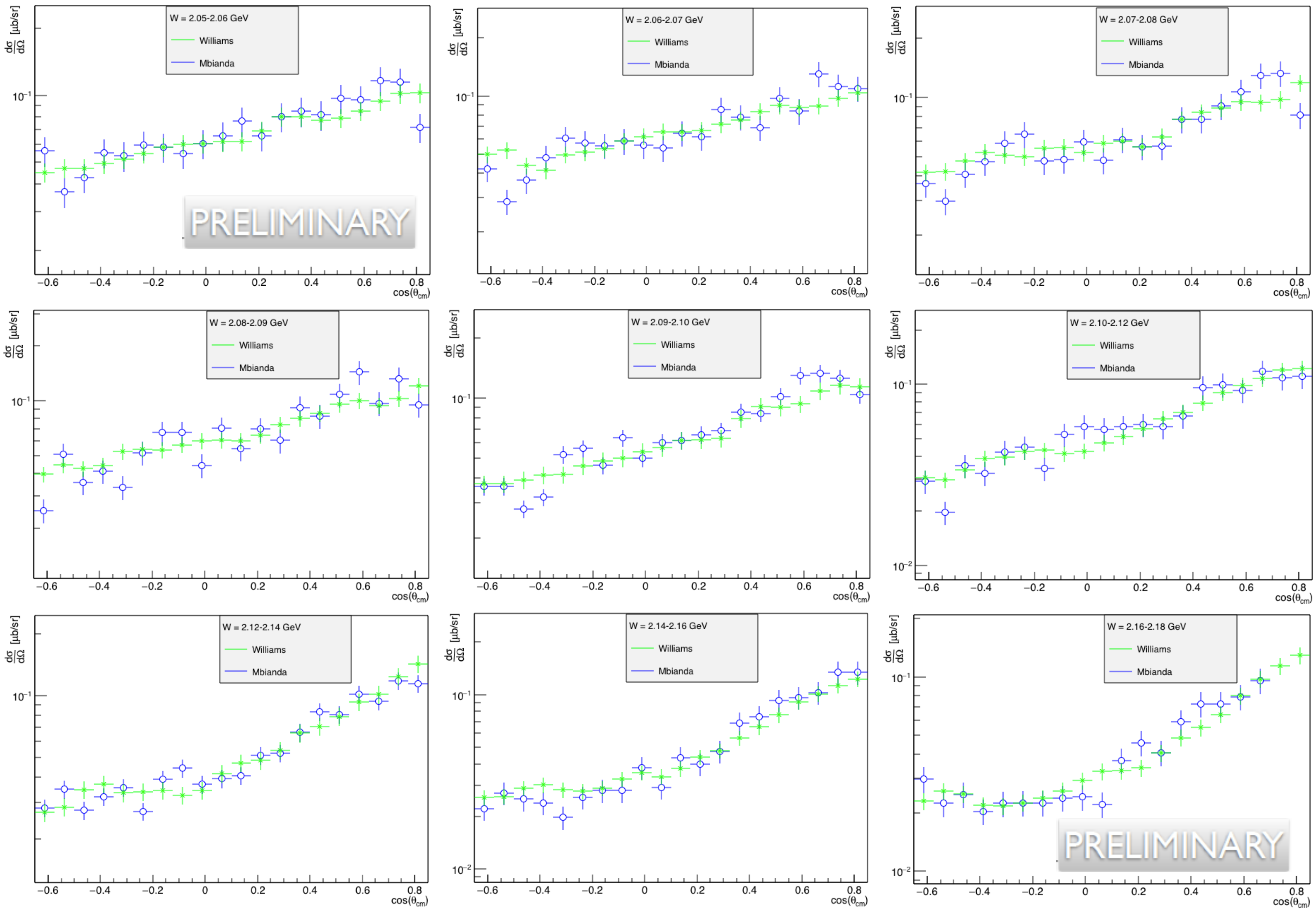


Differential cross section for $\gamma p \to p\eta'$ compared



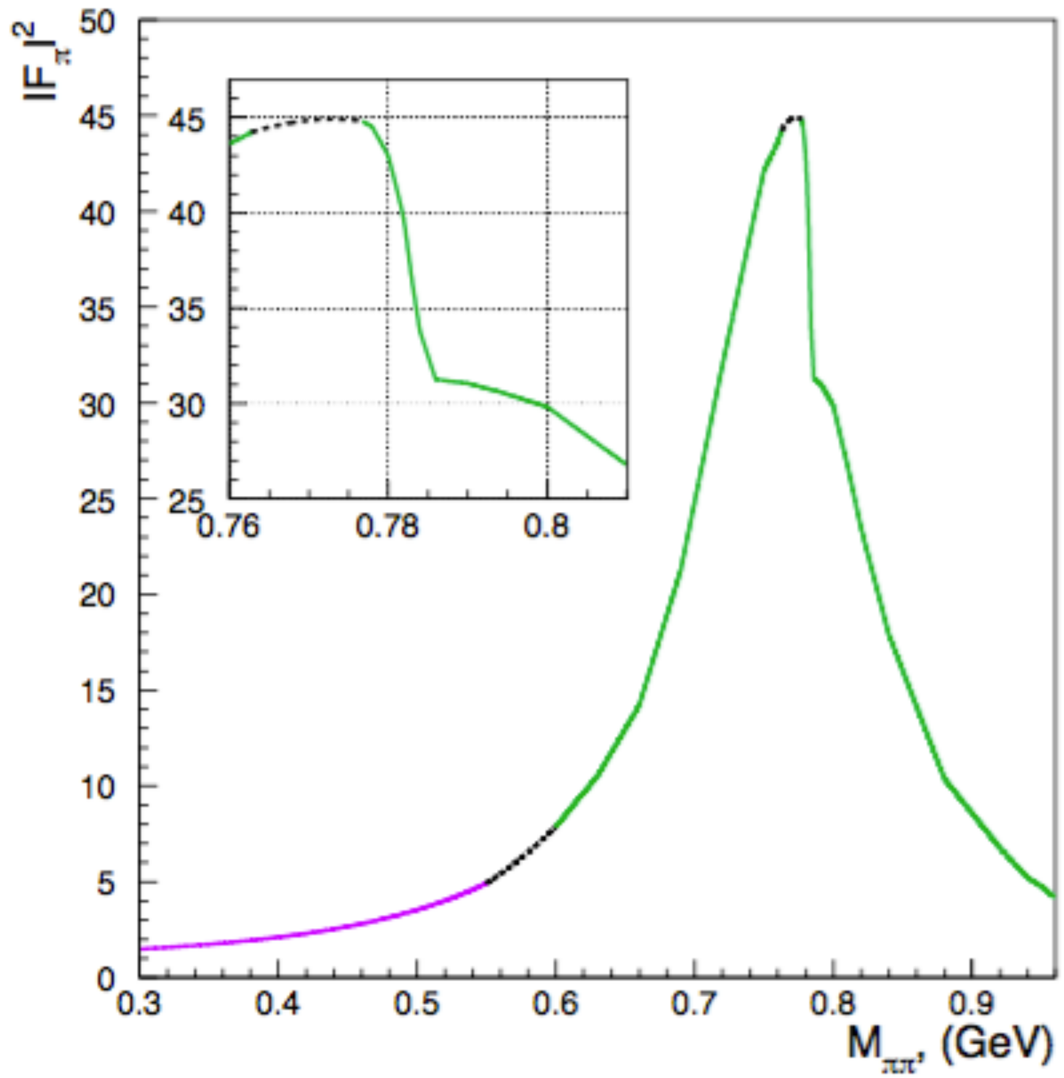
Differential cross section for $\gamma p \rightarrow p\eta'$ compared



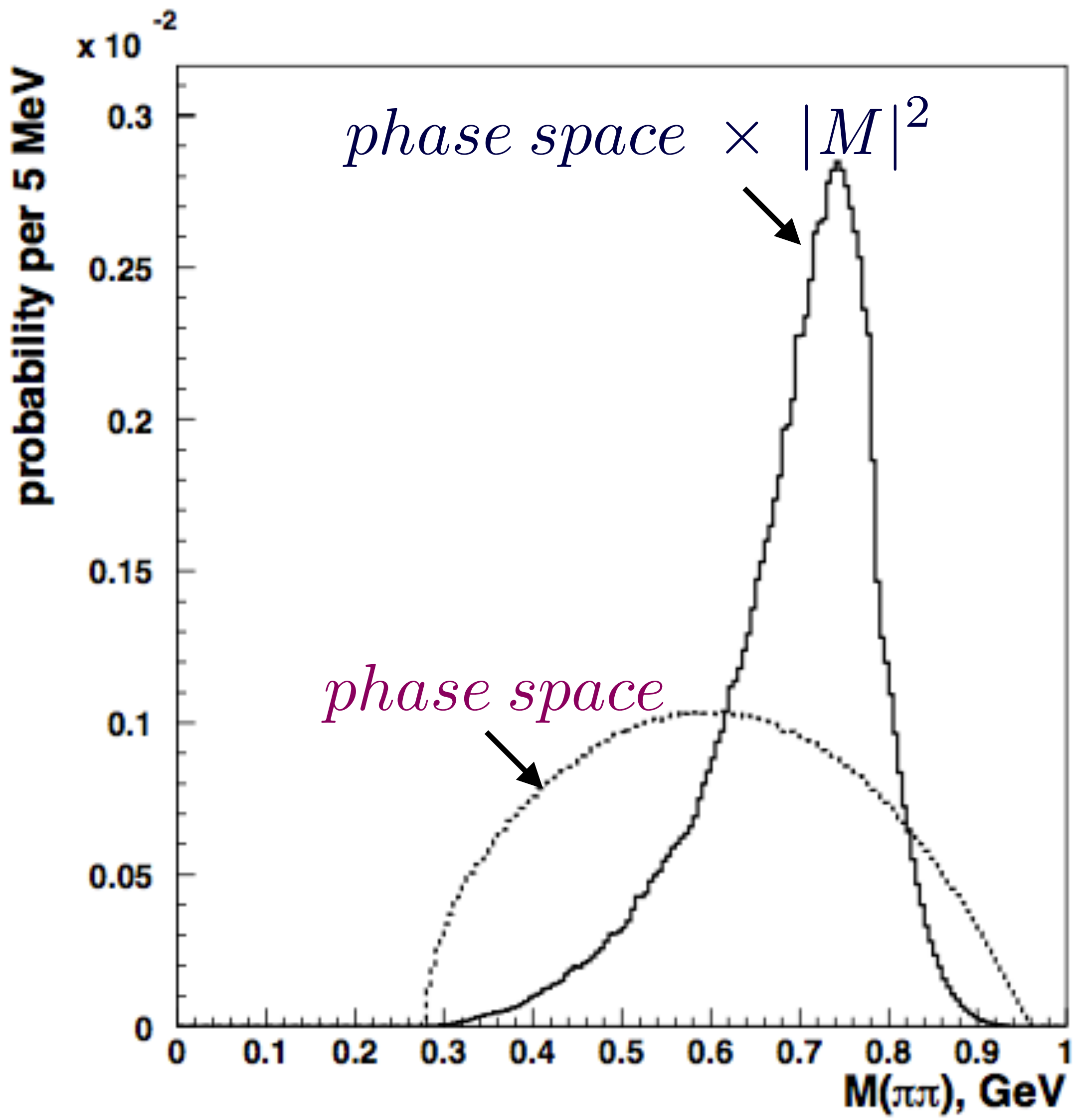
$Extracting\ parameters\ \alpha\ and\ \beta$

- The radiative decay matrix element can be written as:

$$|M|^2 \approx |F_V(m_{\pi\pi}^2)|^2(1+\alpha m_{\pi\pi}^2+\beta m_{\pi\pi}^4)^2 E_\gamma^2 q^2 sin^2(\theta)$$

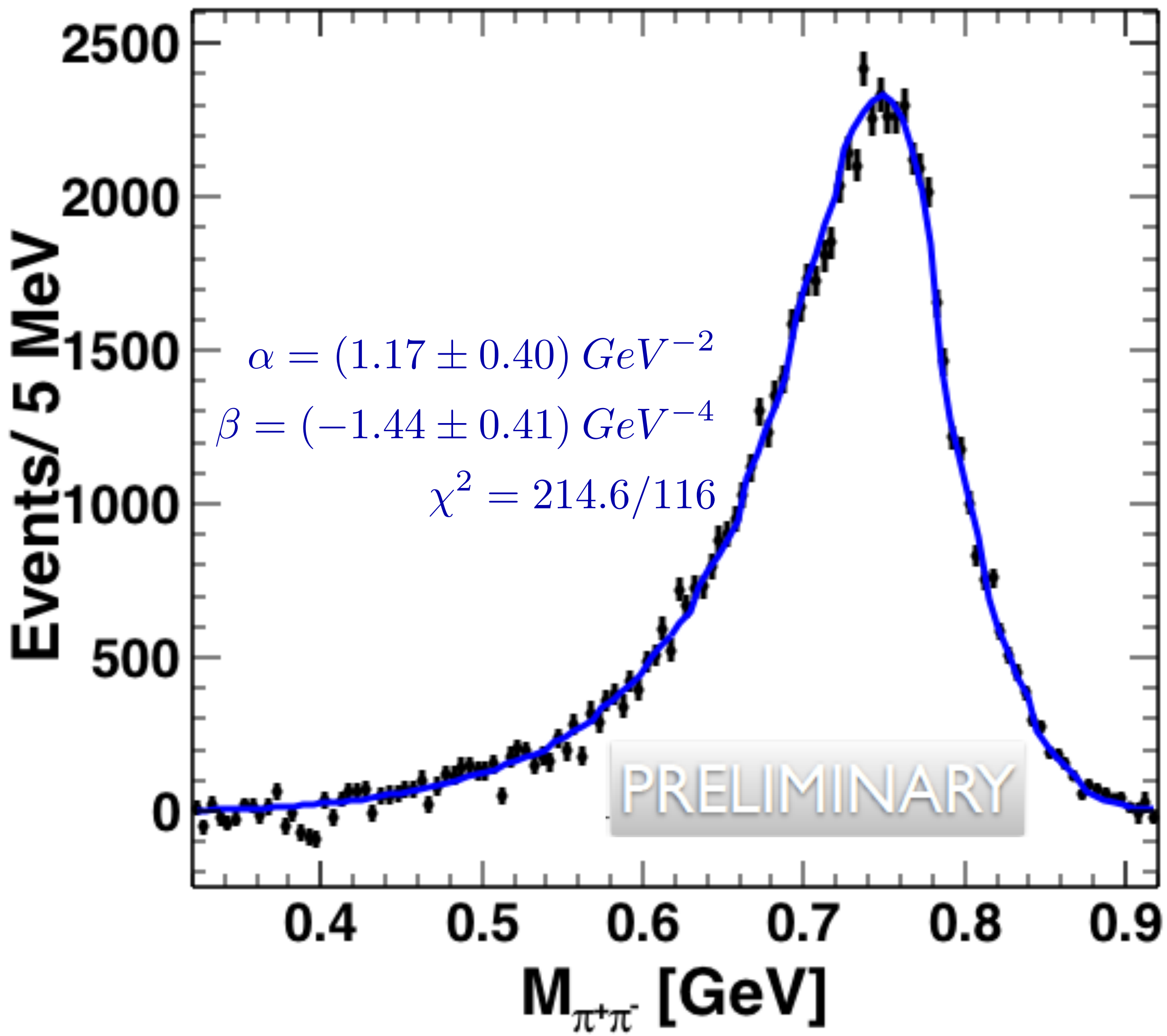


R.R. Akhmetshin et al. / Physics Letters B 527 (2002) 161–172



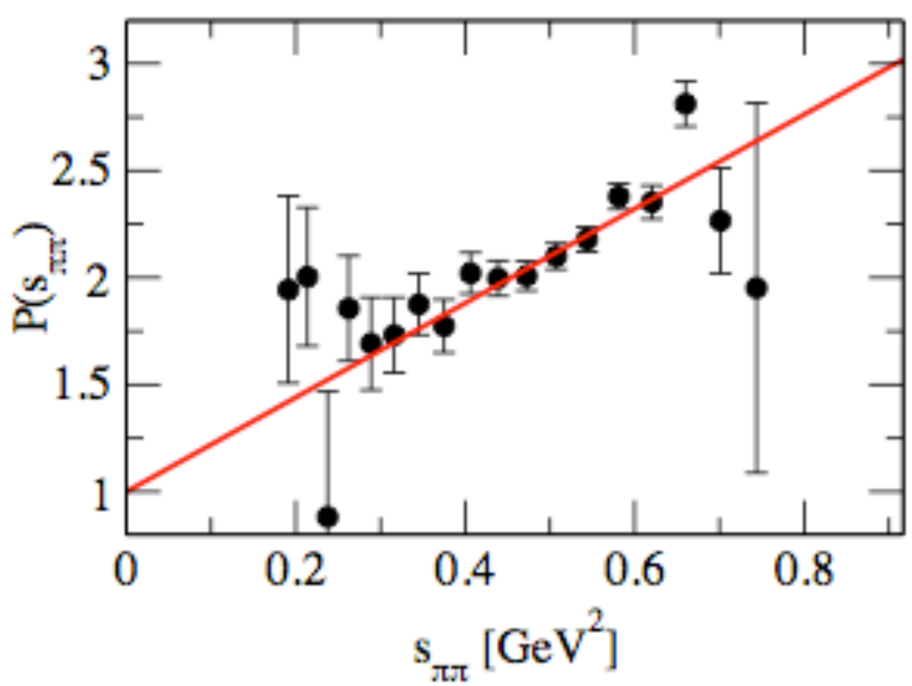
Preliminary Results

Theoretical $M_{\pi\pi}$ spectrum for given (α, β) was convoluted with acceptance and resolution to get observable $M_{\pi\pi}$



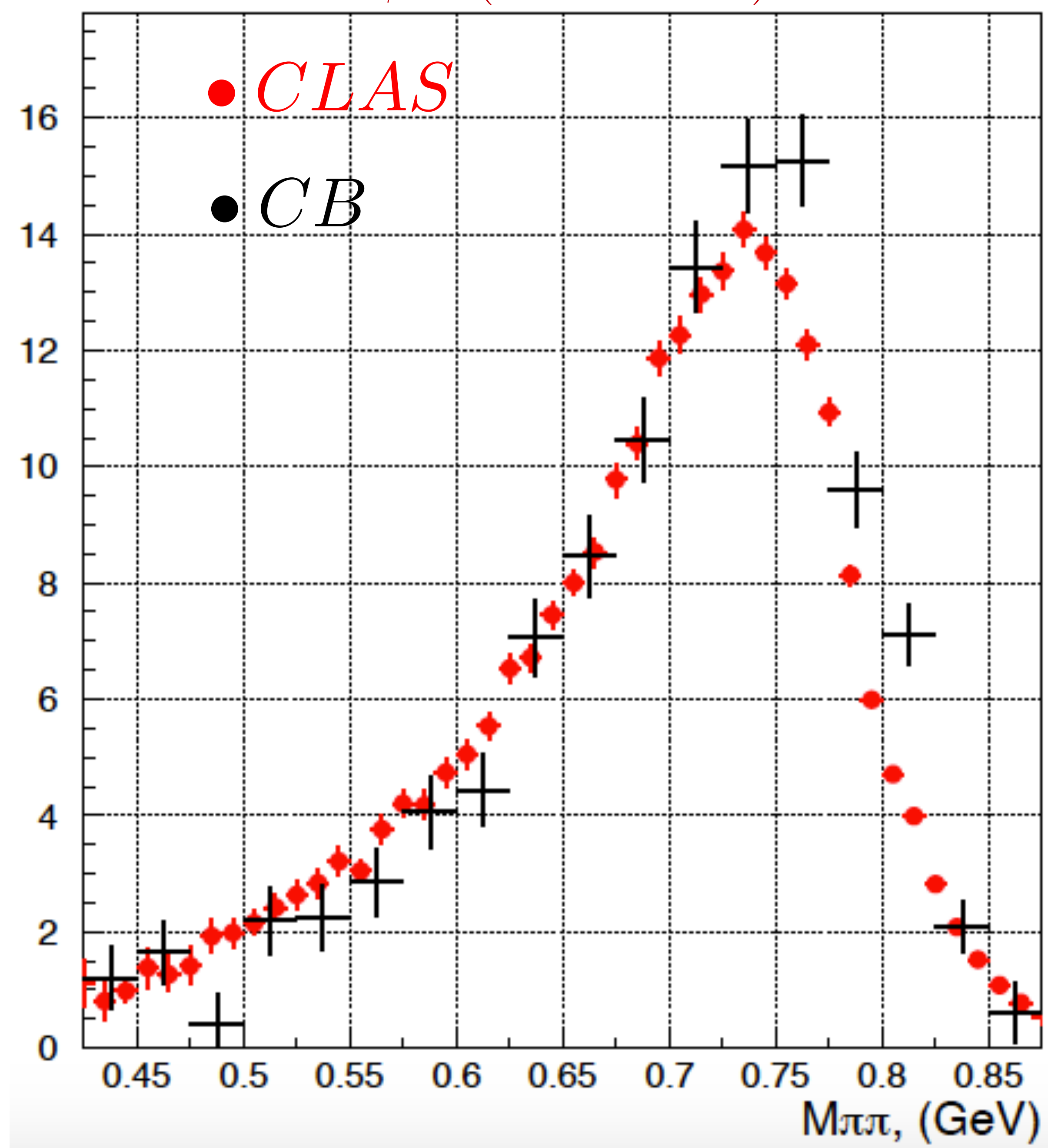
CLAS Preliminary results compared to CRYSTAL BARREL (1997)

$\alpha' = (1.80 \pm 0.49 \pm 0.04)\ \mathrm{GeV}^{-2}$ **(1997)**

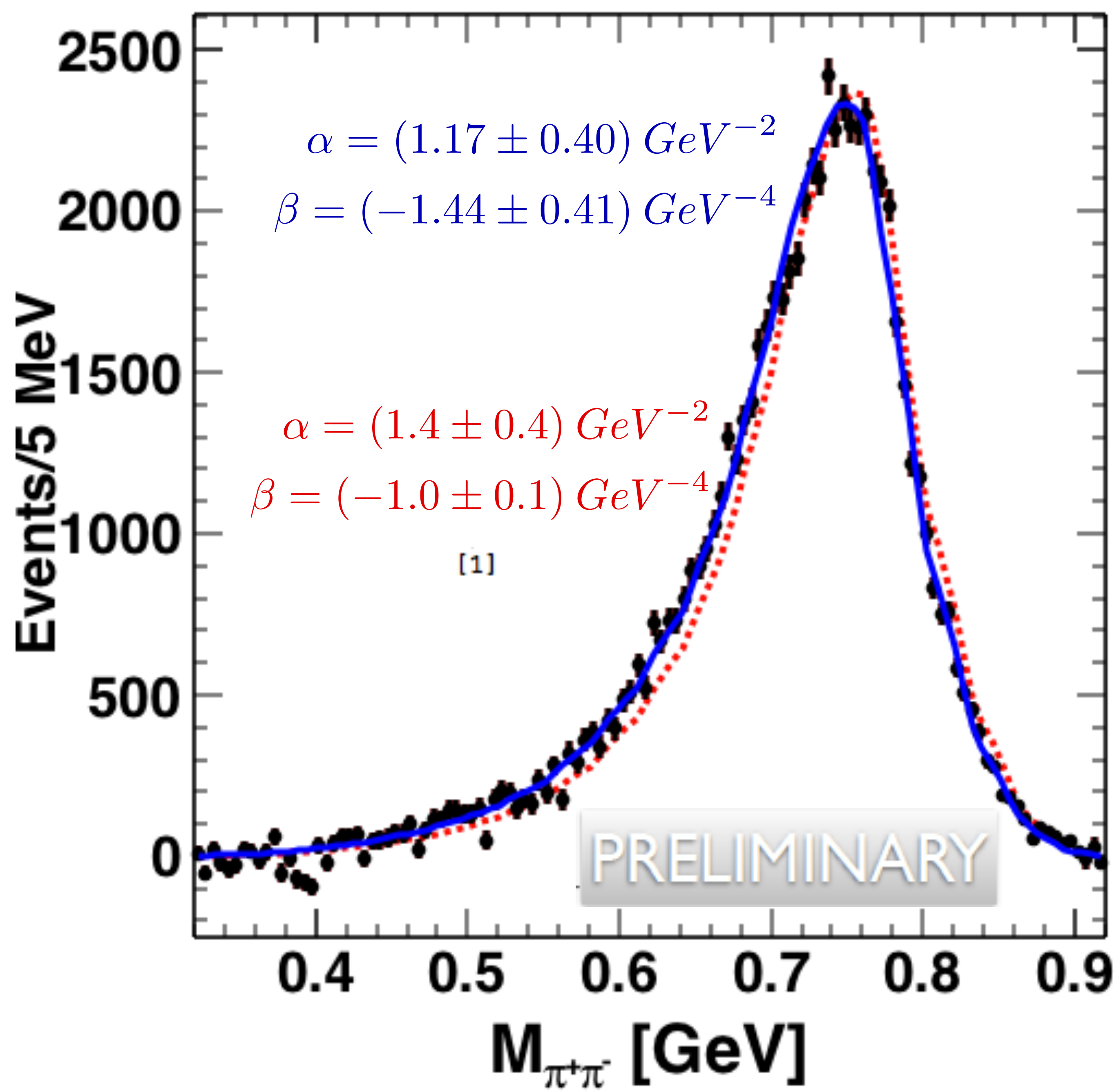


$\alpha = (1.17 \pm 0.40)\ GeV^{-2}$

$\beta = (-1.44 \pm 0.41)\ GeV^{-4}$



Comparison with Theoretical Prediction from Kubis et al. (2015)



[1] Kubis et al., Eur.Phys.J. C75 (2015) no.6, 283.

Systematic Uncertainties

- Estimated by varying each cut used in the event selection process
- The total systematic uncertainty was then obtained by adding the uncertainties from the different sources in quadrature
- The systematic uncertainty is $\approx 10\%$ for each parameter

Source	$\delta\alpha$	$\delta\beta$
$\lvert M_X(p\pi^+\pi^-\gamma)\rvert^2$	5.47×10^{-2}	7.74×10^{-2}
$\lvert M_E(p\pi^+\pi^-) - P_\gamma\rvert$	5.73×10^{-2}	6.43×10^{-2}
$M_E(p\pi^+\pi^-)$	2.70×10^{-2}	2.20×10^{-2}
P_γ	1.83×10^{-3}	1.21×10^{-3}
$\lvert M_X(p) - M(\eta')\rvert$	7.88×10^{-2}	9.33×10^{-2}
$\lvert M(\pi^+\pi^-\gamma) - M(\eta')\rvert$	1.84×10^{-3}	3.91×10^{-3}
$\cos\theta^{\eta'}_{CM}$	4.75×10^{-3}	4.68×10^{-3}
Total Systematic	1.15×10^{-1}	1.39×10^{-1}

Experiment	α [GeV^{-2}]	β [GeV^{-4}]
CRYTAL BARREL (1997)	$1.80 \pm 0.49 \pm 0.04$	$0.04 \pm 0.36 \pm 0.03$
GAMS-2000	2.7 ± 1.0	
CLAS(g11) Preliminary	$1.17 \pm 0.40 \pm 0.12$	$-1.44 \pm 0.41 \pm 0.14$
Theory		
Kubis (2015)	1.4 ± 0.4	-1.0 ± 0.1

Thank You