Radiative Decay of η' in CLAS

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

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CLAS Collaboration Meeting

June 17 2016

Outline

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

Light Mesons in CLAS

Meson Decay	Physics Interest	Meson Decay	Physics Interest
$\pi^0 \to e^+e^-\gamma$	Heavy photon upper limit	$\eta' \to \pi^+\pi^-\gamma$	Box anomaly
$\eta' \to e^+e^-\gamma$	Transition form factor	$\omega \to \pi^+\pi^-\gamma$	Upper limit branching ratio
$\omega \to e^+e^-\pi^0$	Transition form factor	$\eta, \omega, \phi \to \pi^+\pi^-\pi^0$	Dalitz plot analysis
$\eta' \to e^+e^-\pi^0$	C violation	$\eta' \to \pi^+\pi^-\eta$	Dalitz plot analysis
$\eta' \to e^+e^-\pi^+\pi^-$	CP violation	$\phi \to \pi^+\pi^-\eta$	G-parity violation

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

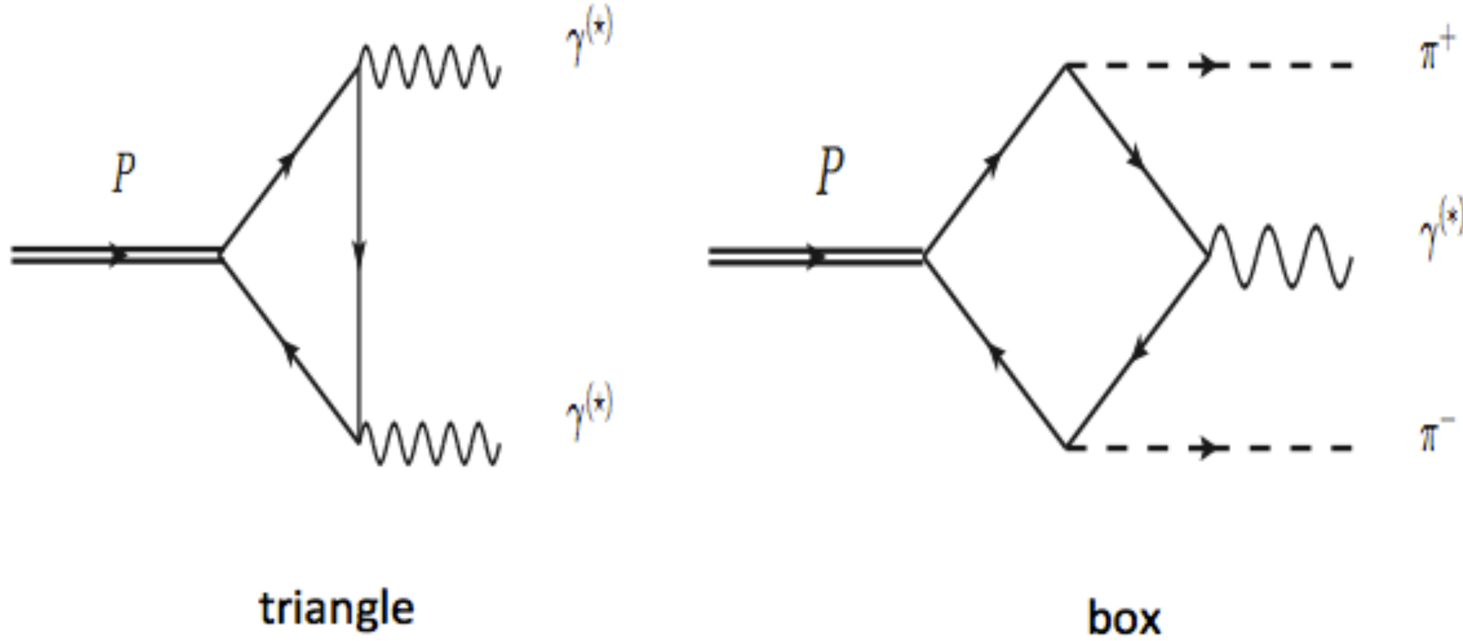
$$\begin{aligned} \partial^\mu j_{5\mu} &= (\partial^\mu\bar{\Psi})\gamma_\mu\gamma_5\Psi - \bar{\Psi}\gamma_5\gamma_\mu\partial^\mu\Psi \\ &= (im\bar{\Psi})\gamma_5\Psi - \bar{\Psi}\gamma_5(-im\Psi) = 2im\bar{\Psi}\gamma_5\Psi \\ &= 0(m=0) \end{aligned}$$

- 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 a single free parameter, α

Transition of type: $\gamma^*(q) \to P^+(p_1) P^0(p_2) P^-(p_3)$

- In the chiral limit ($m_\pi = 0$) and soft-point limit ($p_j = q = 0$), a reasonable approximation at low energies for pions, anomaly analysis predicts the theoretical amplitude to be exactly

$$A_\gamma^{3\pi} \equiv \lim_{m_\pi \to 0} F_\gamma^{3\pi}(p_1 = 0, p_2 = 0, p_3 = 0) = \frac{e\, N_c}{12\pi^2\, f_\pi^3}$$

- where the pion decay constant $f_\pi = (92.42 \pm 0.33)\mathrm{MeV}$ and $A_\gamma^{3\pi} = (9.72 \pm 0.09)\,\mathrm{GeV}^{-3}$

- Published experimental value for the form factor (extracted from cross-section measured at Serpukhov) of the Primakoff process $\pi^-\gamma^* \to \pi^0\pi^-$ is

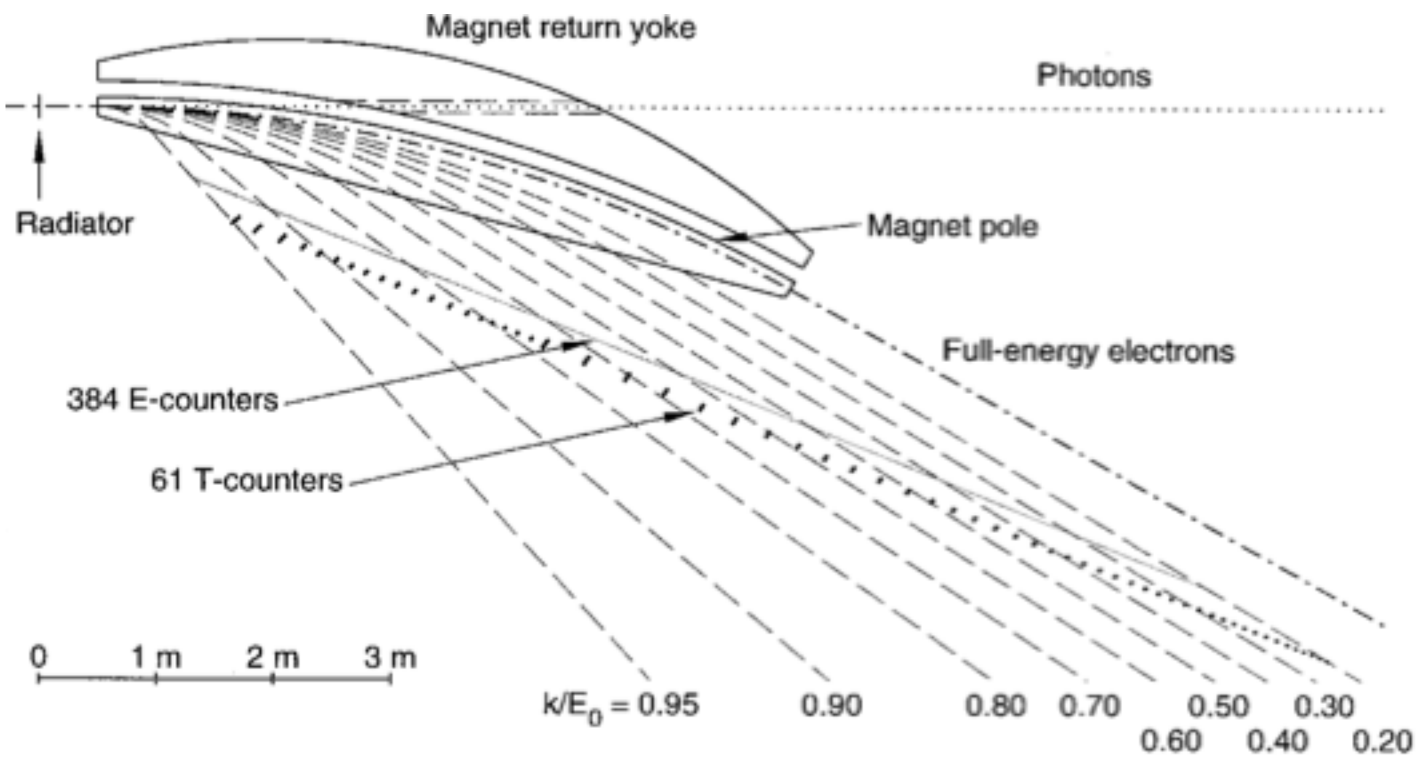
$$F_\gamma^{3\pi}(expt) = 12.9 \pm 0.9 \pm 0.5\,\mathrm{GeV}^{-3}$$

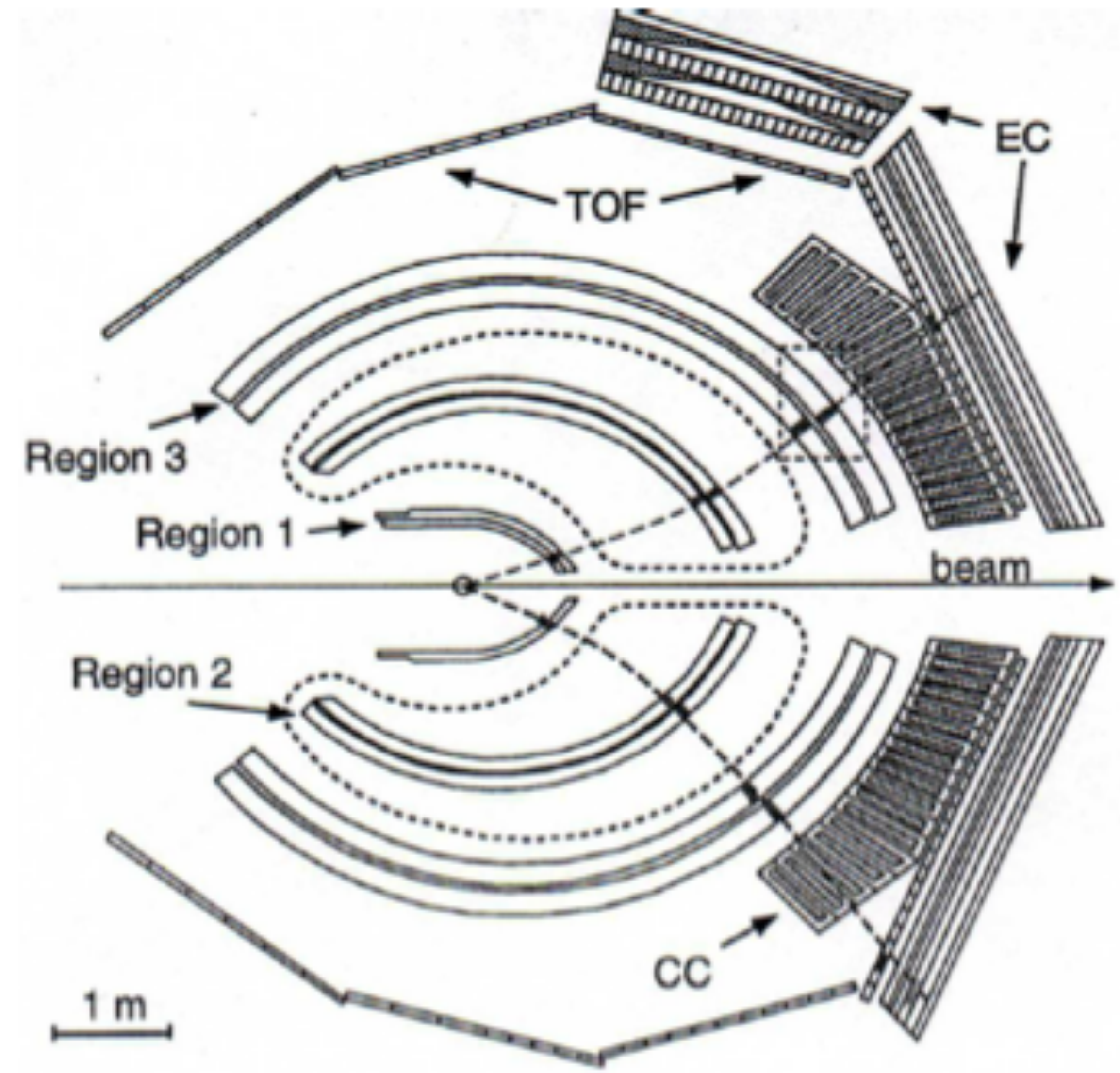
- Not in good agreement with theory. However high-statistics measurements from COMPASS and CLAS may provide a great improvement.

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

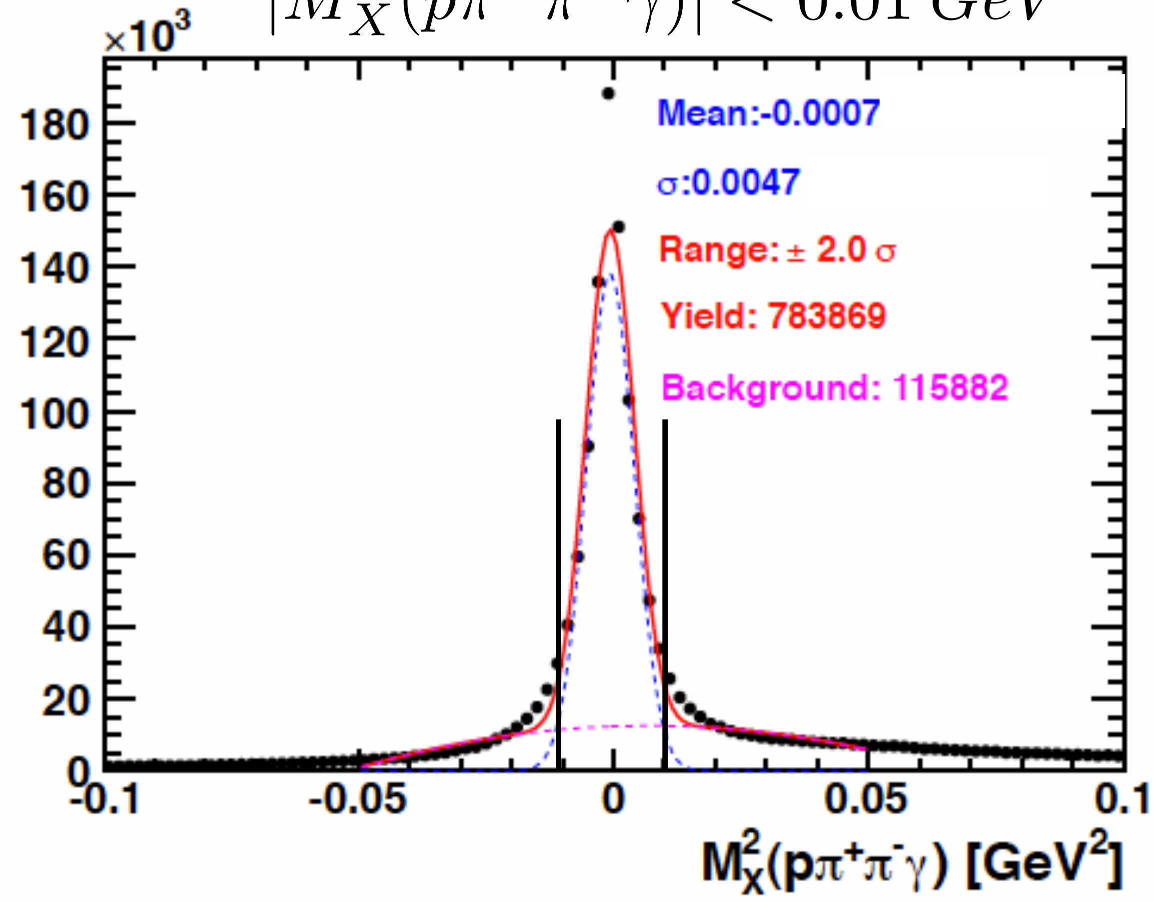
- The start counter surrounded the target and measured vertex time of particles in coincidence with the incoming photon.
- Tagger's E-plane measured energy of recoiling electrons from which photon energy is determined, $E_\gamma = E_0 - E_e$
- Tagger's T-plane made accurate timing measurements of recoiling 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

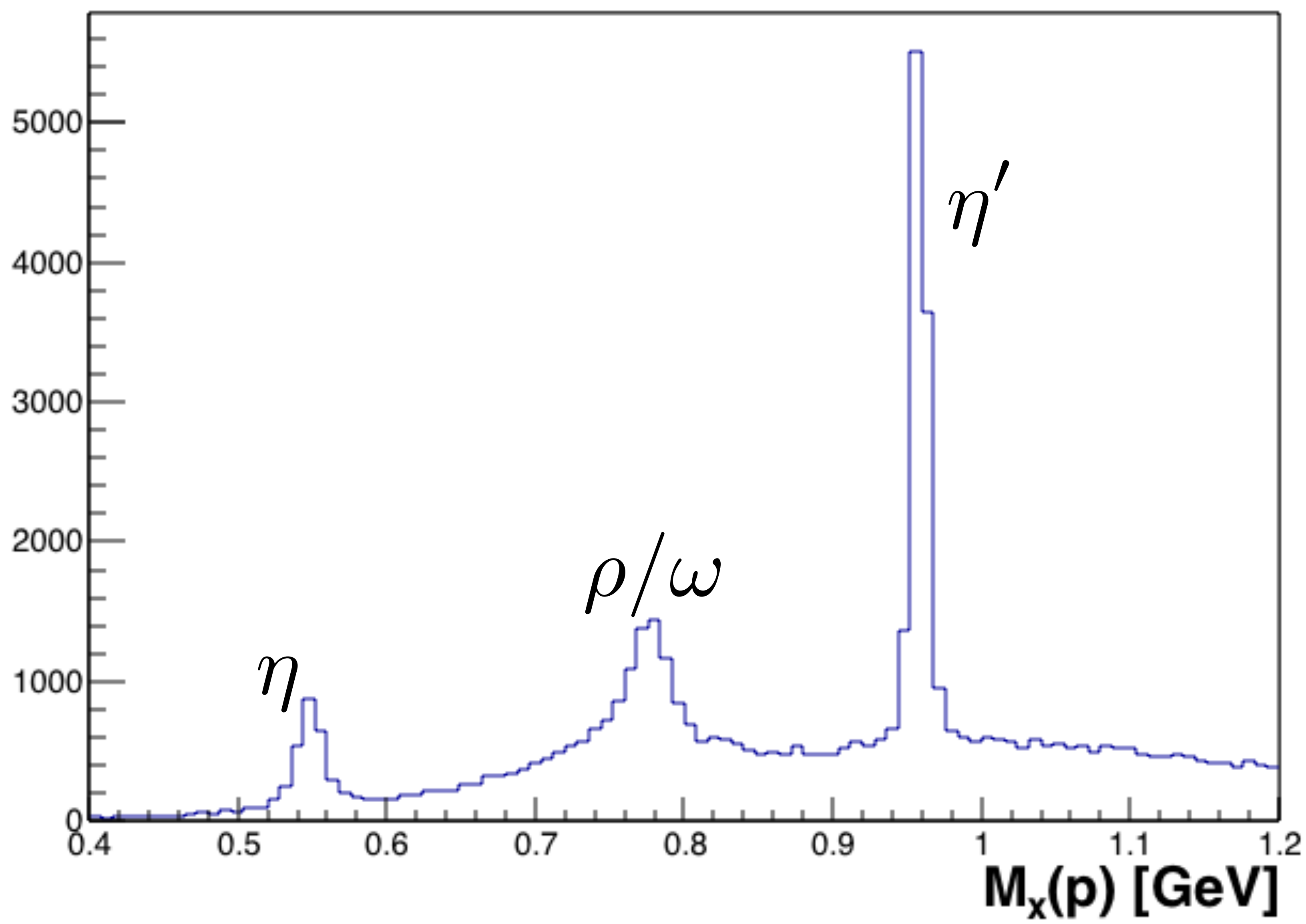
- Trigger required at least 2 charged track so we cannot detect events with mesons decaying into entirely neutral particles in the final state.
- Events with 3 charged tracks identified as proton, $\pi+$ and $\pi-$ and at least one photon were selected.
- TOF system was used for particle identification.

Squared missing mass of all detected particles

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

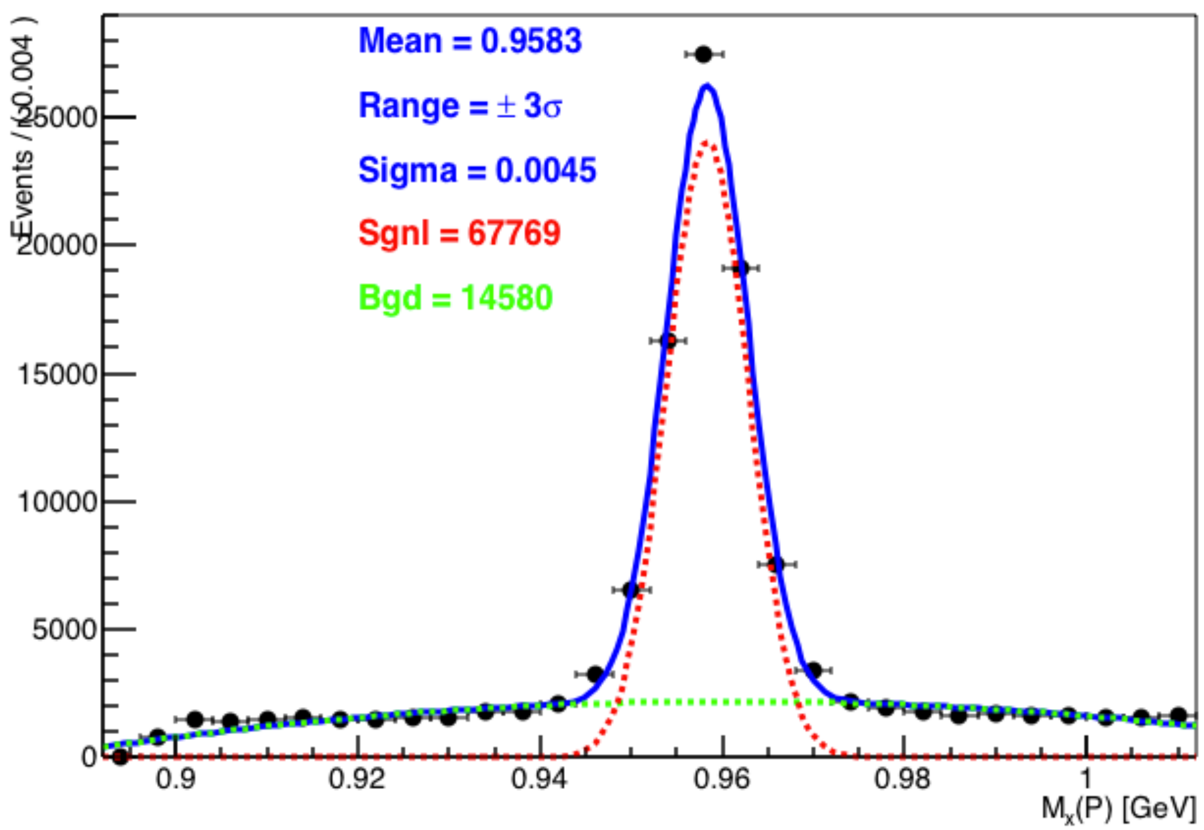


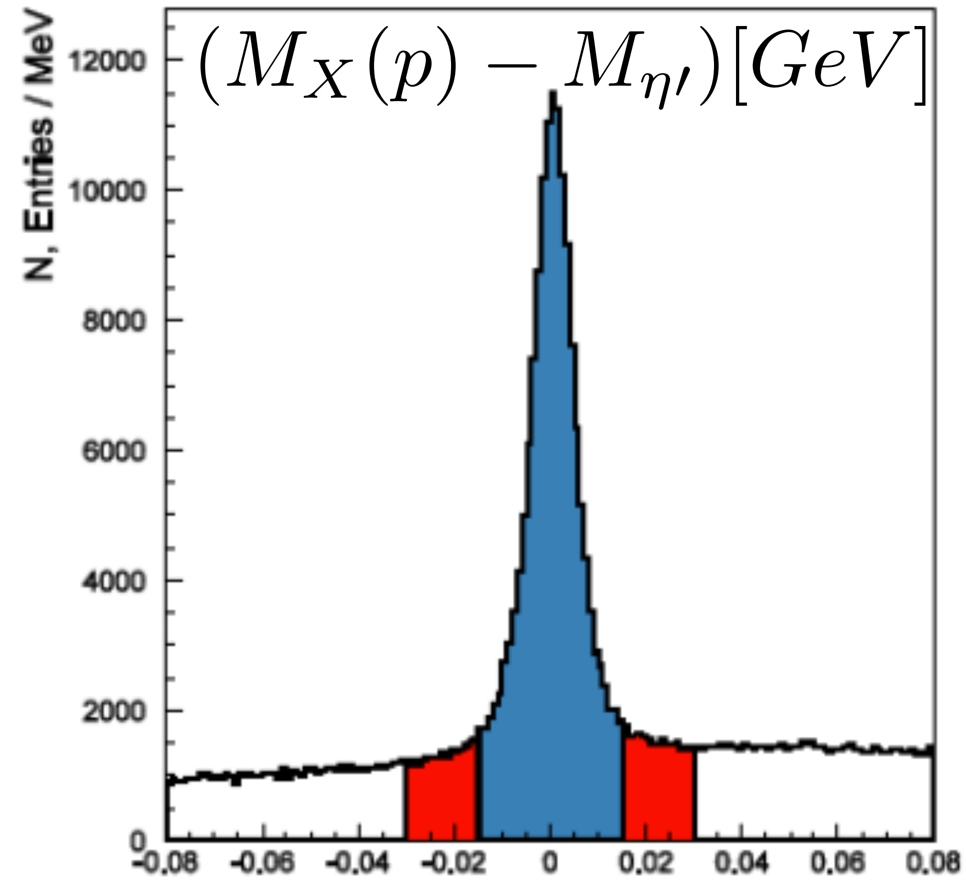
$M_X(p)$ $for\ selected\ data\ set$



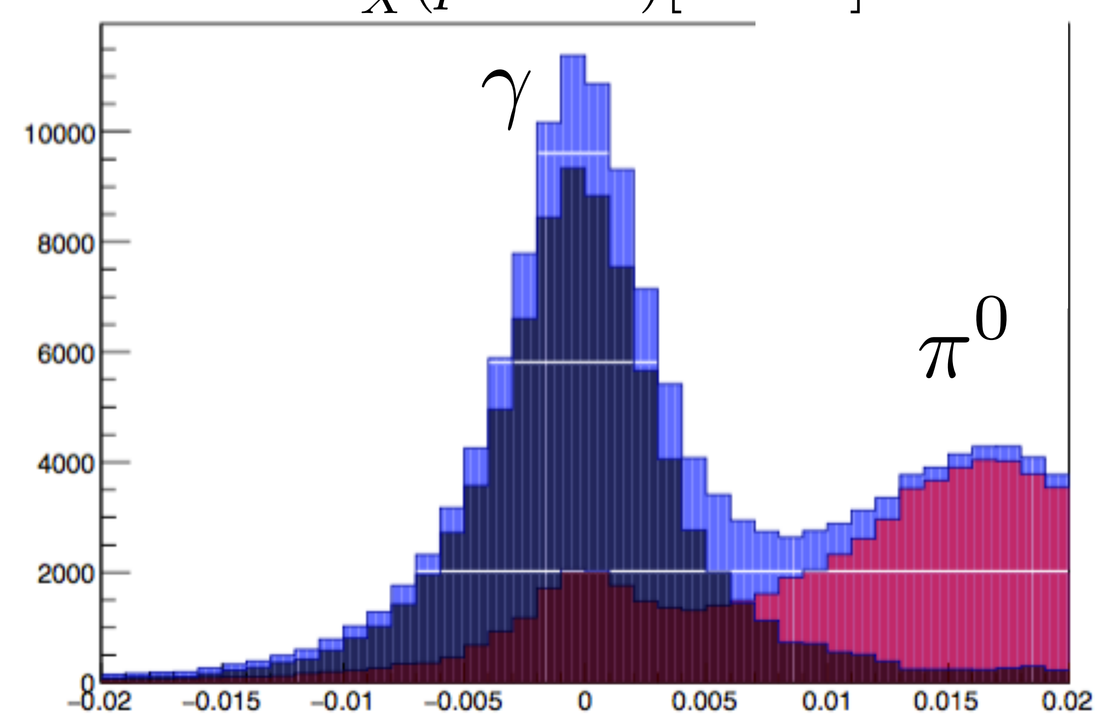
η' events and π^0 separation

$M_X(p)[GeV]$





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

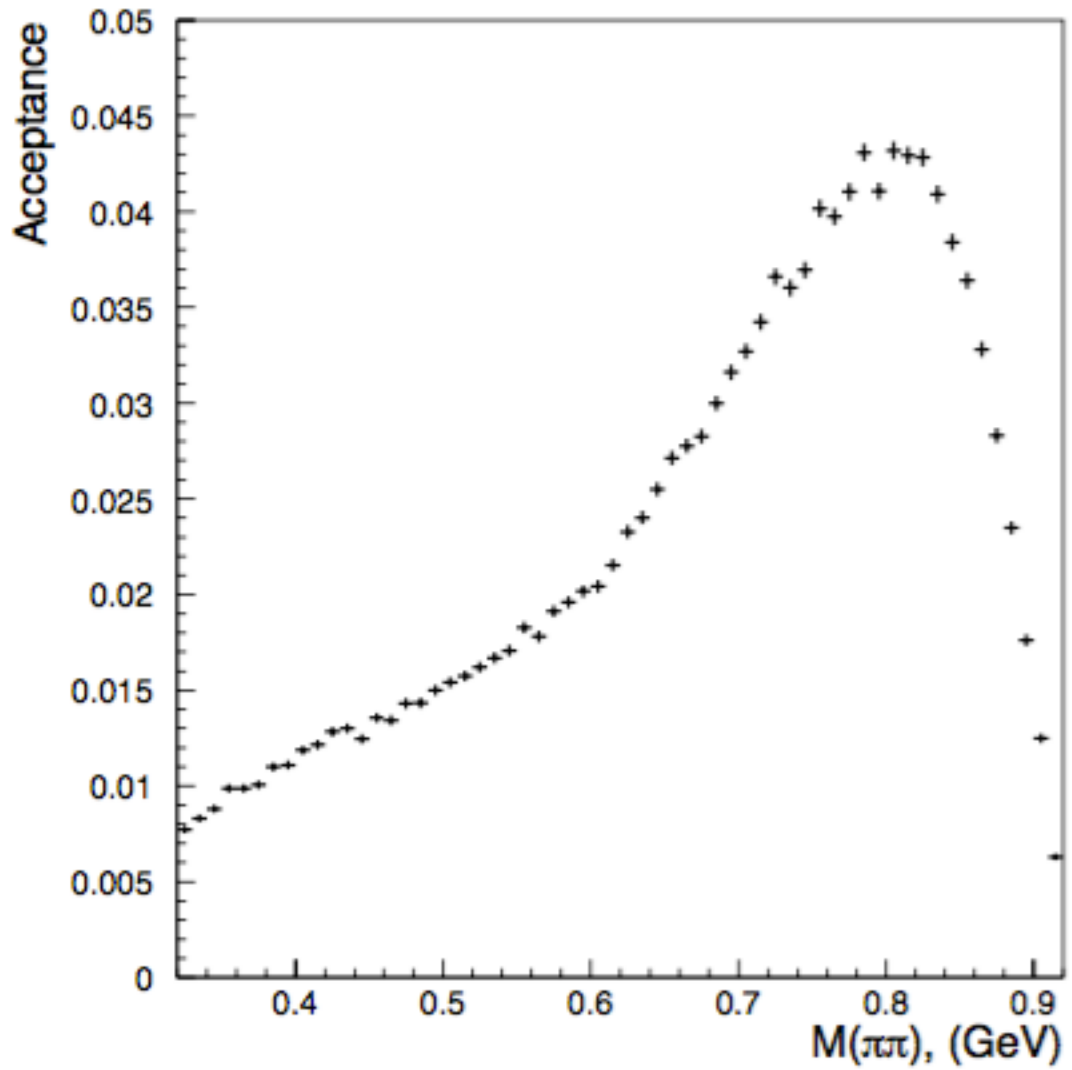


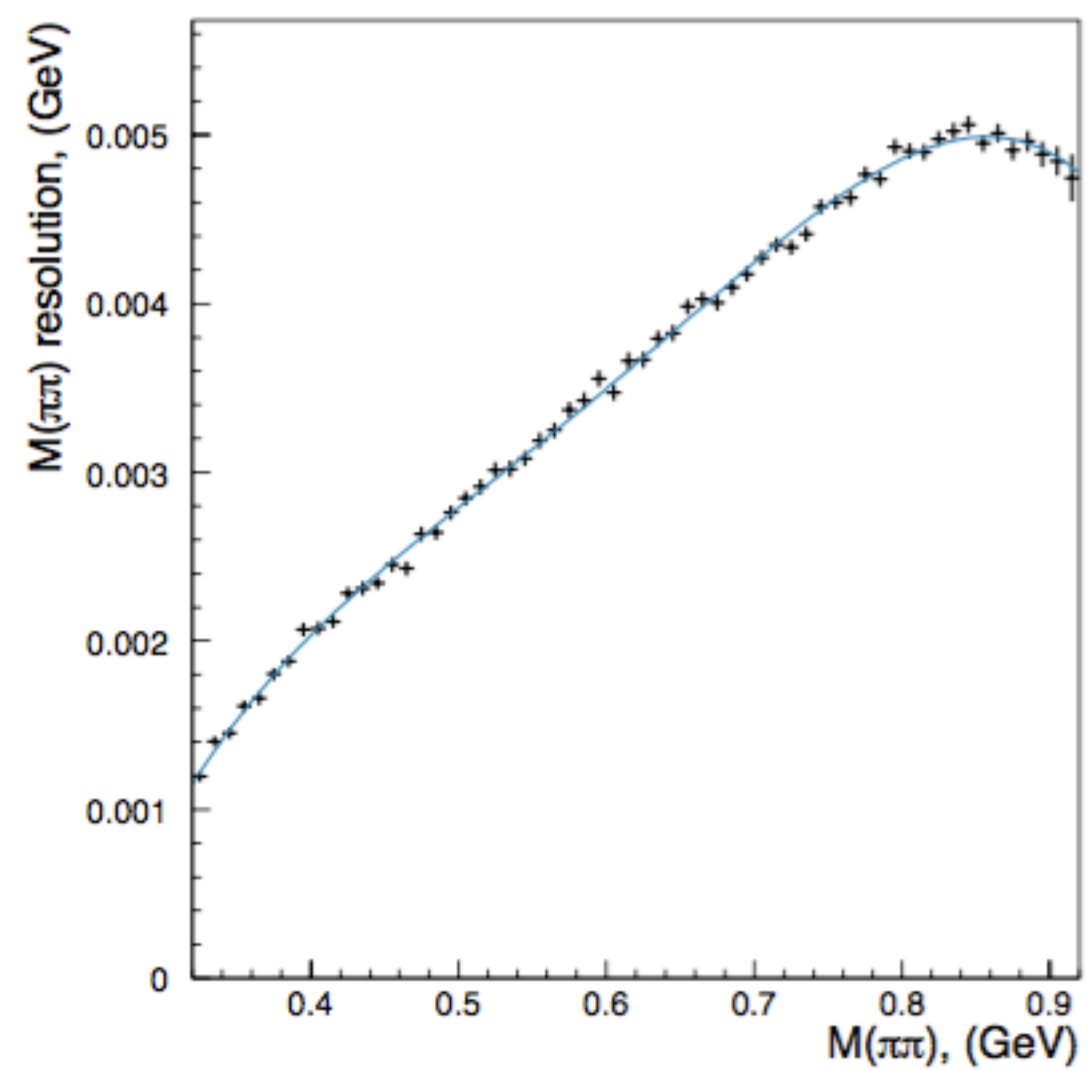
SIMULATION

- 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

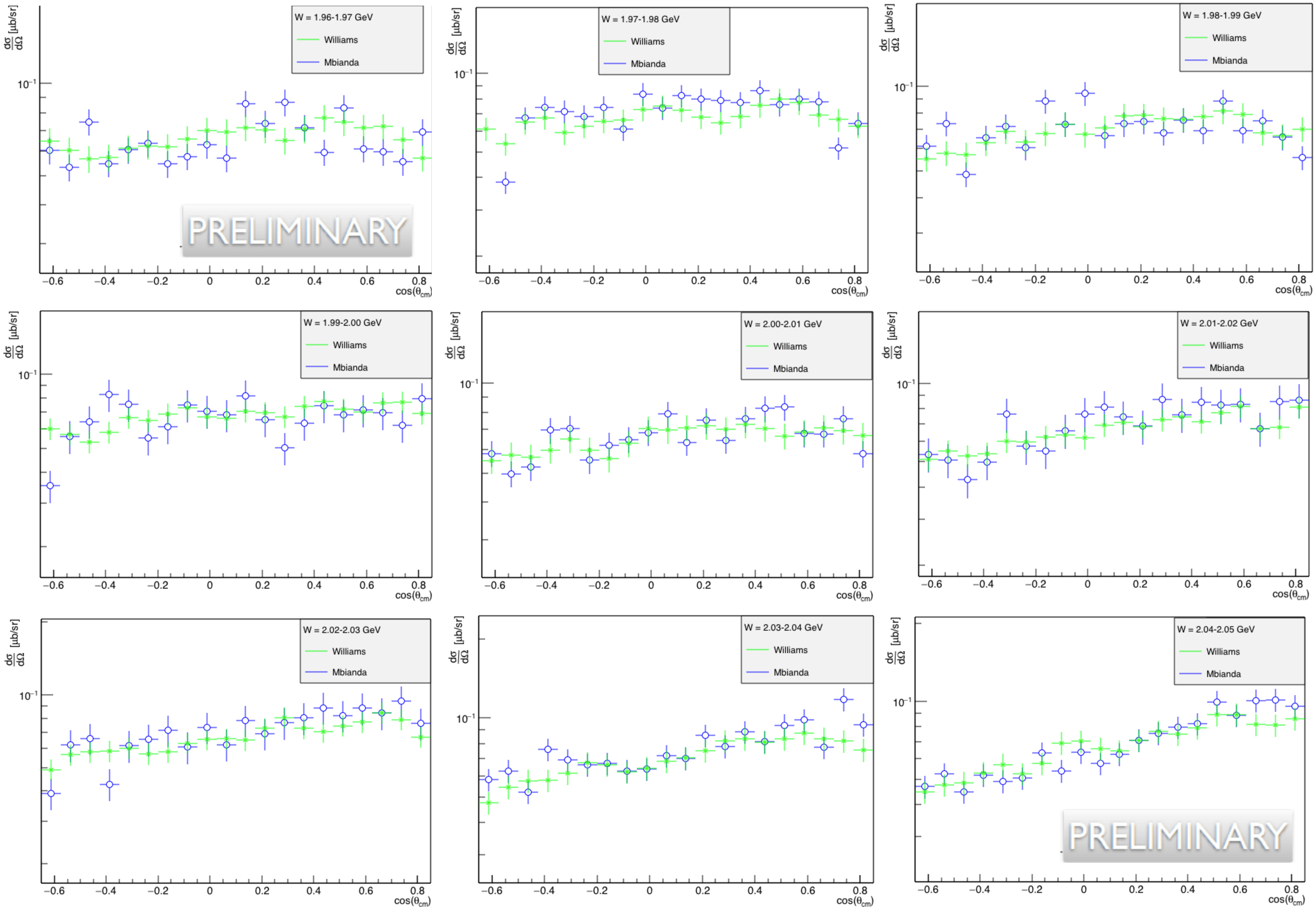
CLAS Acceptance & Resolution

- 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.





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



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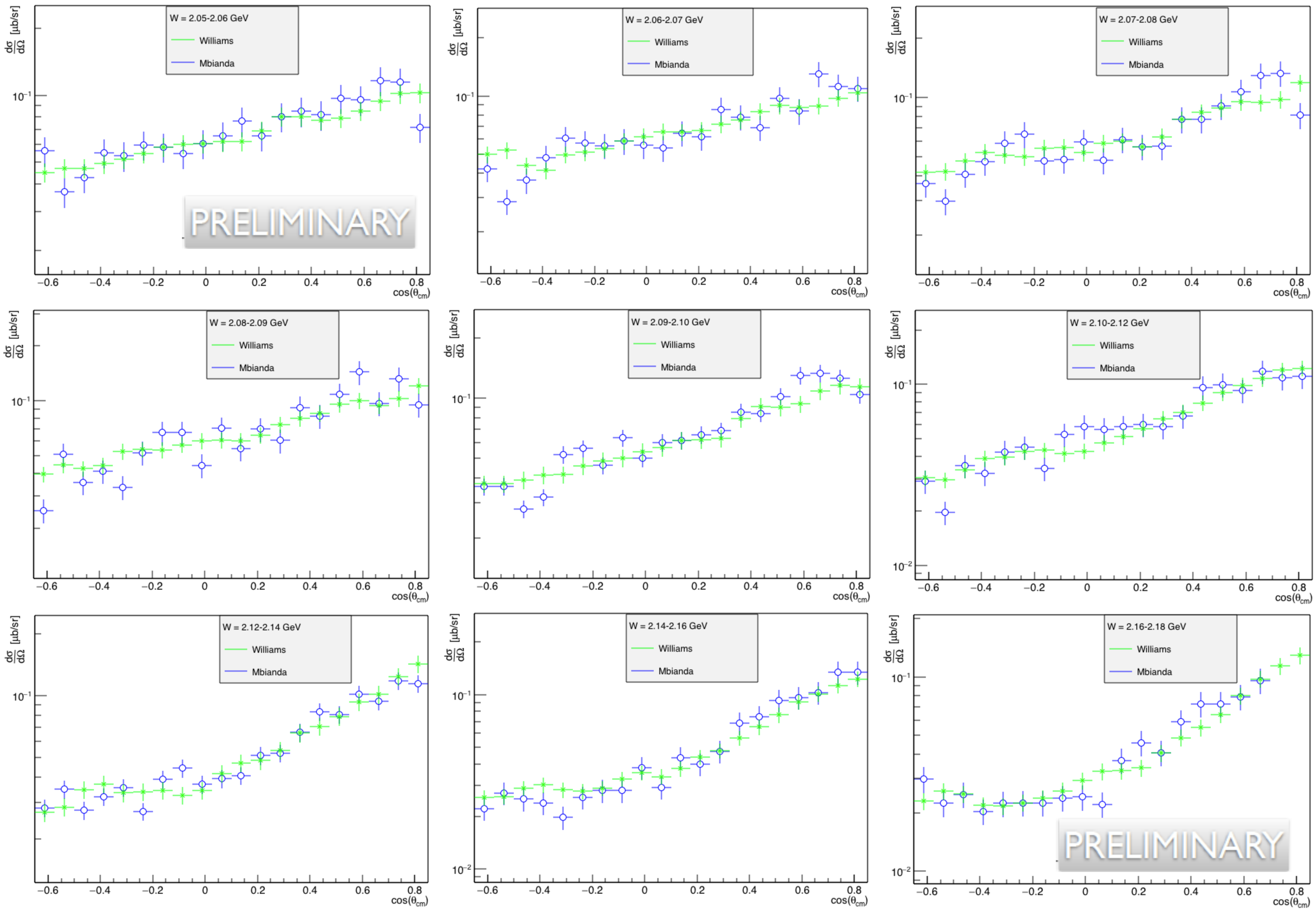
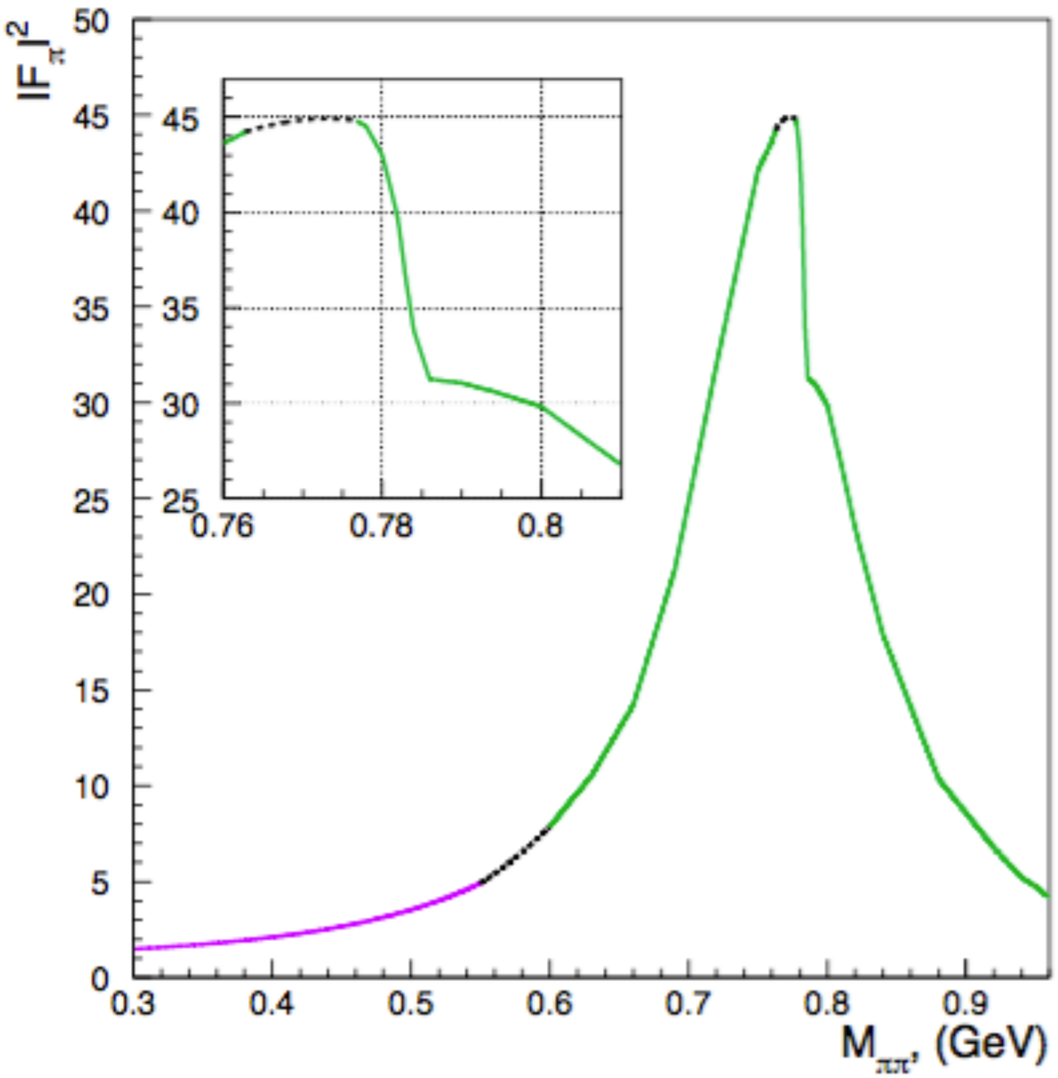


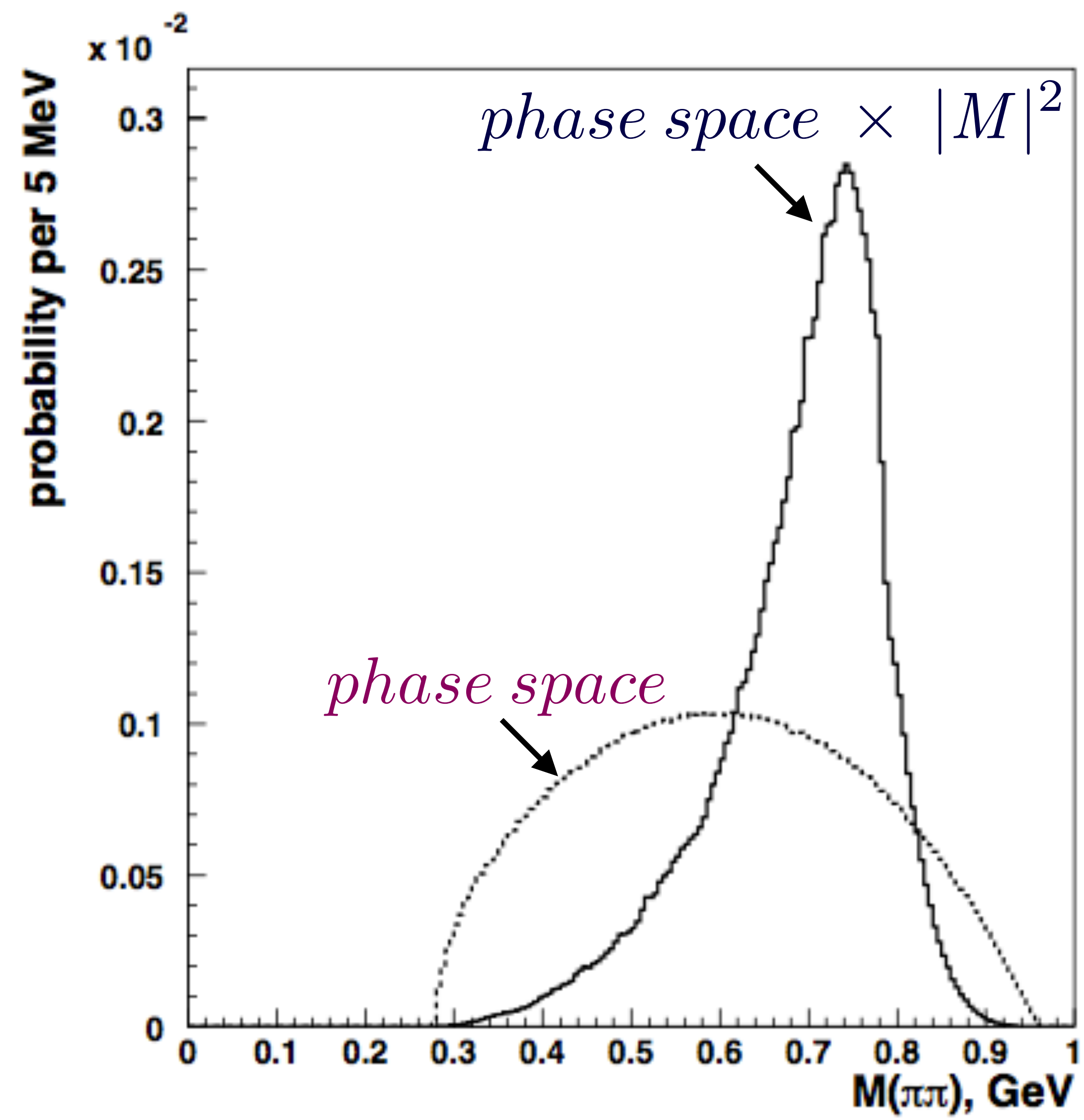
Extracting parameters α and β

- The radiative decay matrix element can be written as:

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

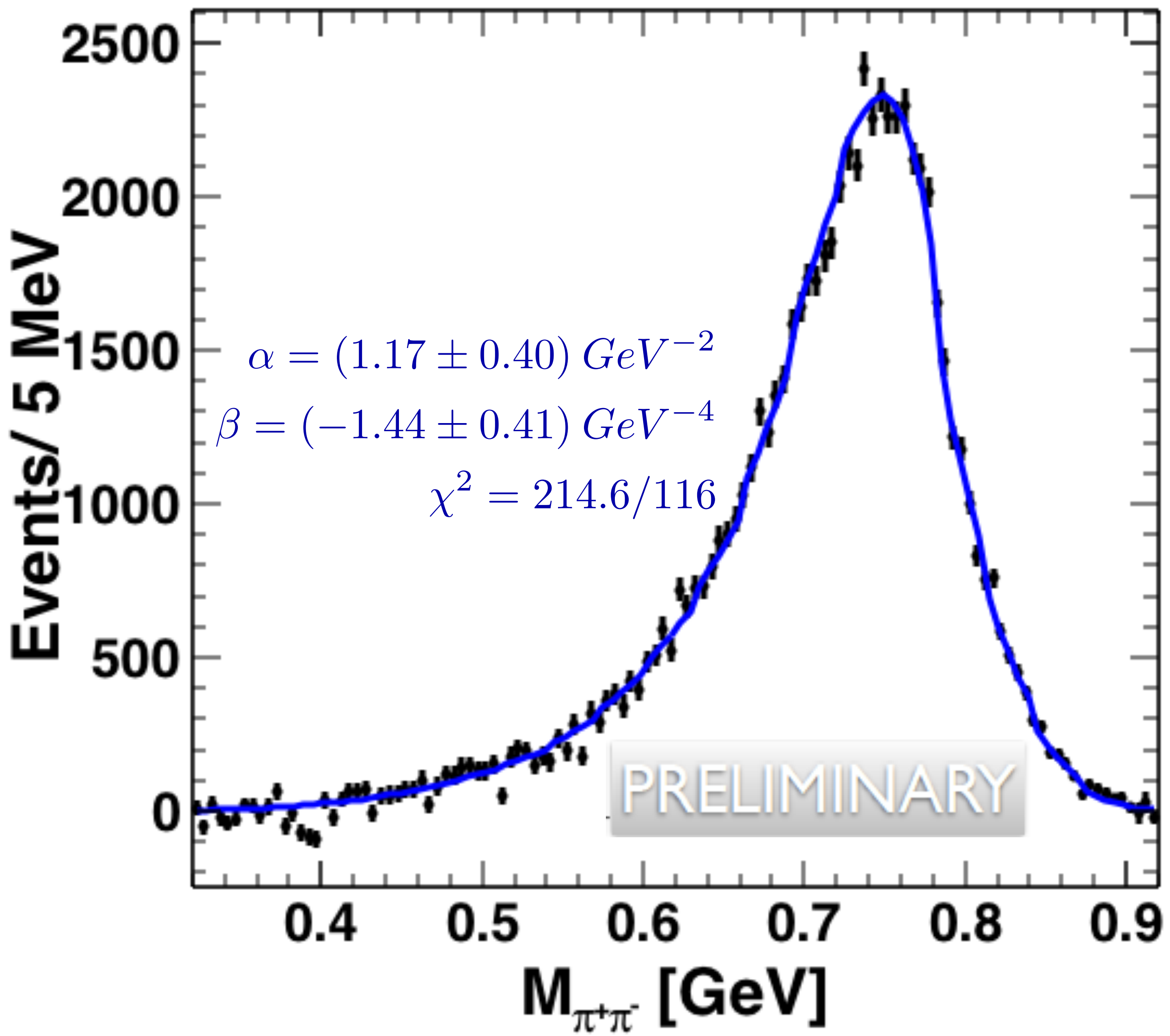


R.R. Akhmetshin et al. / Physics Letters B 527 (2002) 161–172



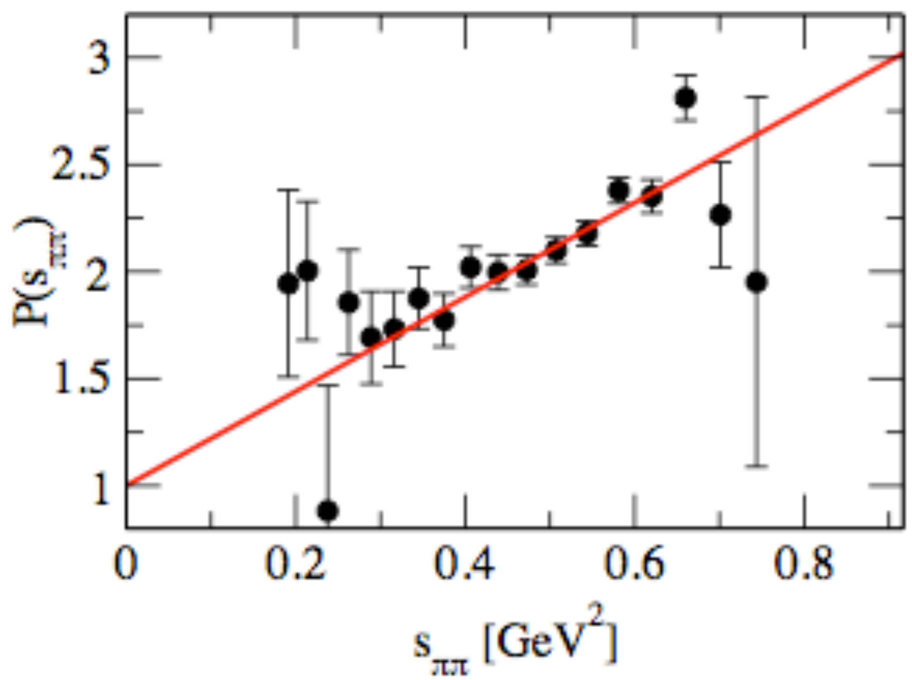
Preliminary Results

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



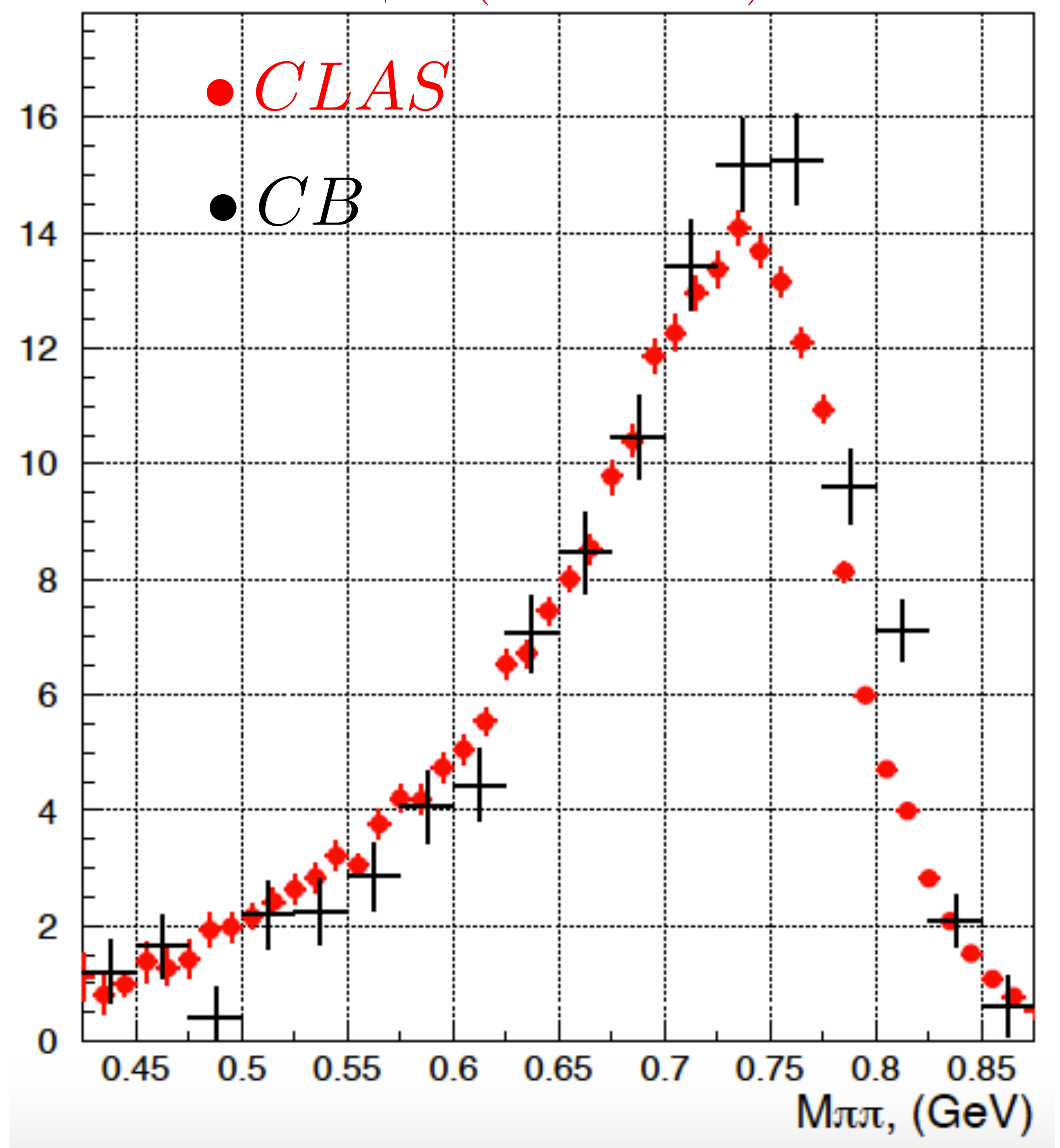
CLAS Preliminary results compared to CRYSTAL BARREL (1997)

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

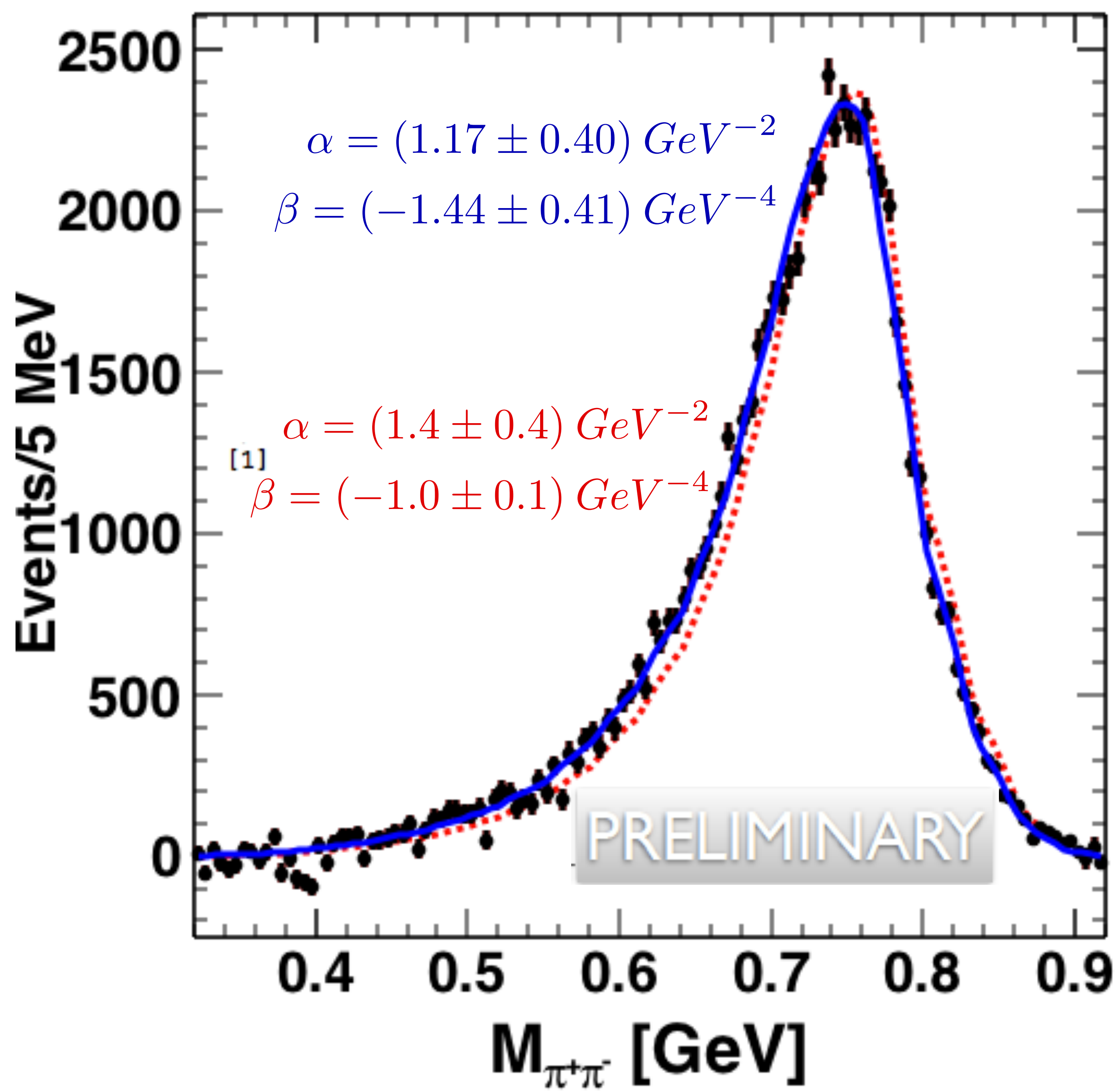


$\alpha = (1.17 \pm 0.40)\ GeV^{-2}$

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



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



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

Major Sources of Systematic Error

- Pion vector form factor
- Systematics due to MC simulation

- Estimation of systematic error in progress

Thank You