Radiative Decay of η' in CLAS
$\gamma p \rightarrow p\{\eta' \rightarrow \pi^+ \pi^- \gamma\}$

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Outline

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

Light Mesons in CLAS

Meson Decay	Physics Interest	Meson Decay	Physics Interest
$\pi^0 \to e^+e^-\gamma$	Heavy photon upper limit	$\boxed{\eta' \to \pi^+\pi^-\gamma}$	$\boxed{\text{Box anomaly}}$
$\eta' \to e^+e^-\gamma$	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

- The EM gauge U(1) and the SU(3) color symmetry in QCD are exact symmetries
- 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 $(i\gamma_\mu\partial^\mu - m)\Psi = 0$

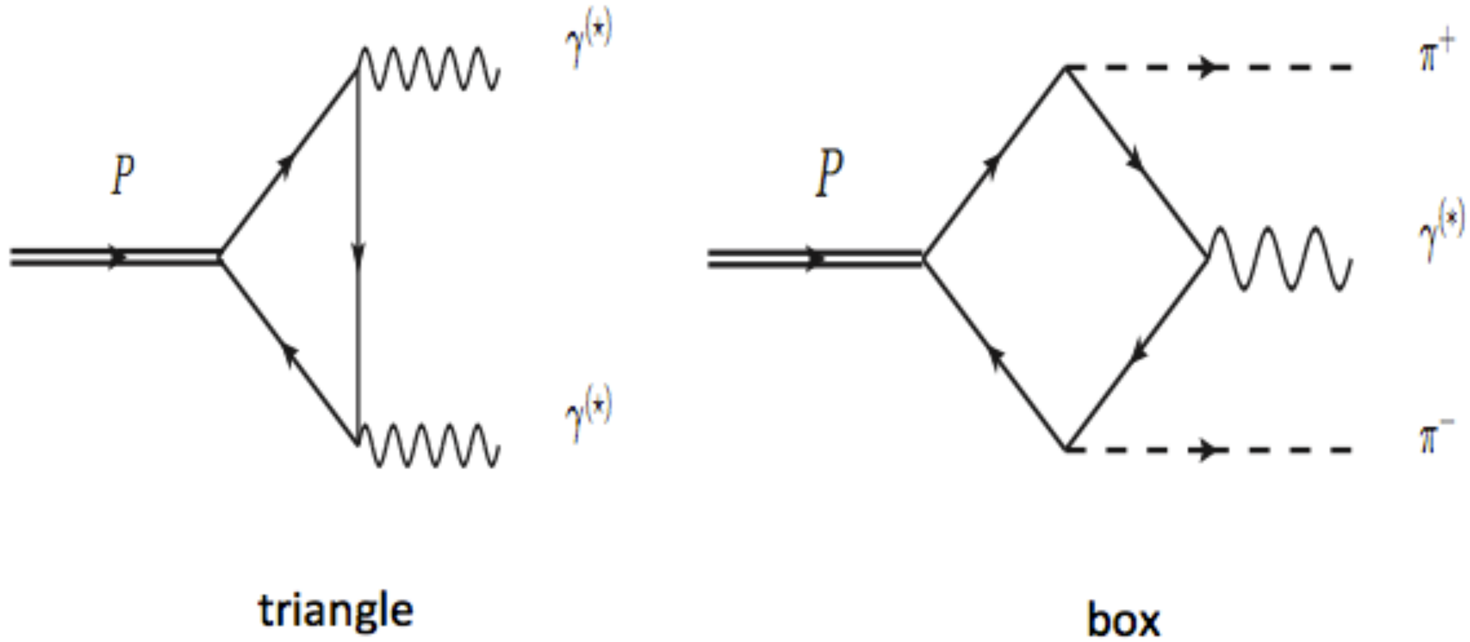
$$\begin{aligned}\partial^\mu j_{5\mu} &= (\partial^\mu\bar{\Psi})\gamma_\mu\gamma_5\Psi - \bar{\Psi}\gamma_5\gamma_\mu\partial^\mu\Psi \\ &= (im\bar{\Psi})\gamma_5\Psi - \bar{\Psi}\gamma_5(-im\Psi) = 2im\bar{\Psi}\gamma_5\Psi \\ &= 0 \quad (m=0)\end{aligned}$$

- 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?



- In the case of low energy ChPT with a limit of vanishing quark masses, the effects of the axial anomaly 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 $\eta(\eta') \to \pi^+\pi^-\gamma$ can be described in a model-independent approach by a single free parameter, $\alpha(\alpha')$.

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

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

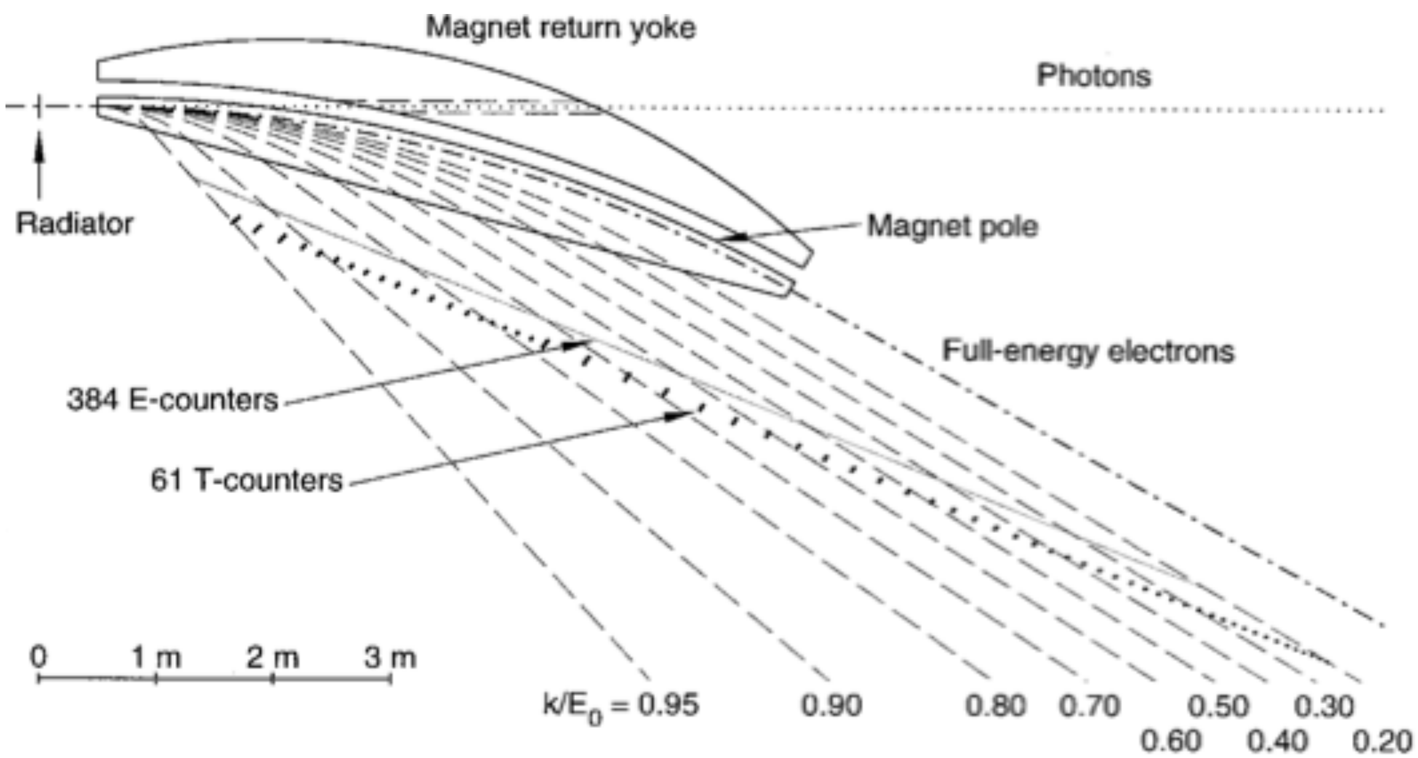
- where the pion decay constant $f_\pi = (92.42 \pm 0.33)\mathrm{MeV}$ and $A_\gamma^{3\pi} = (9.72 \pm 0.09)\,\mathrm{GeV}^{-3}$

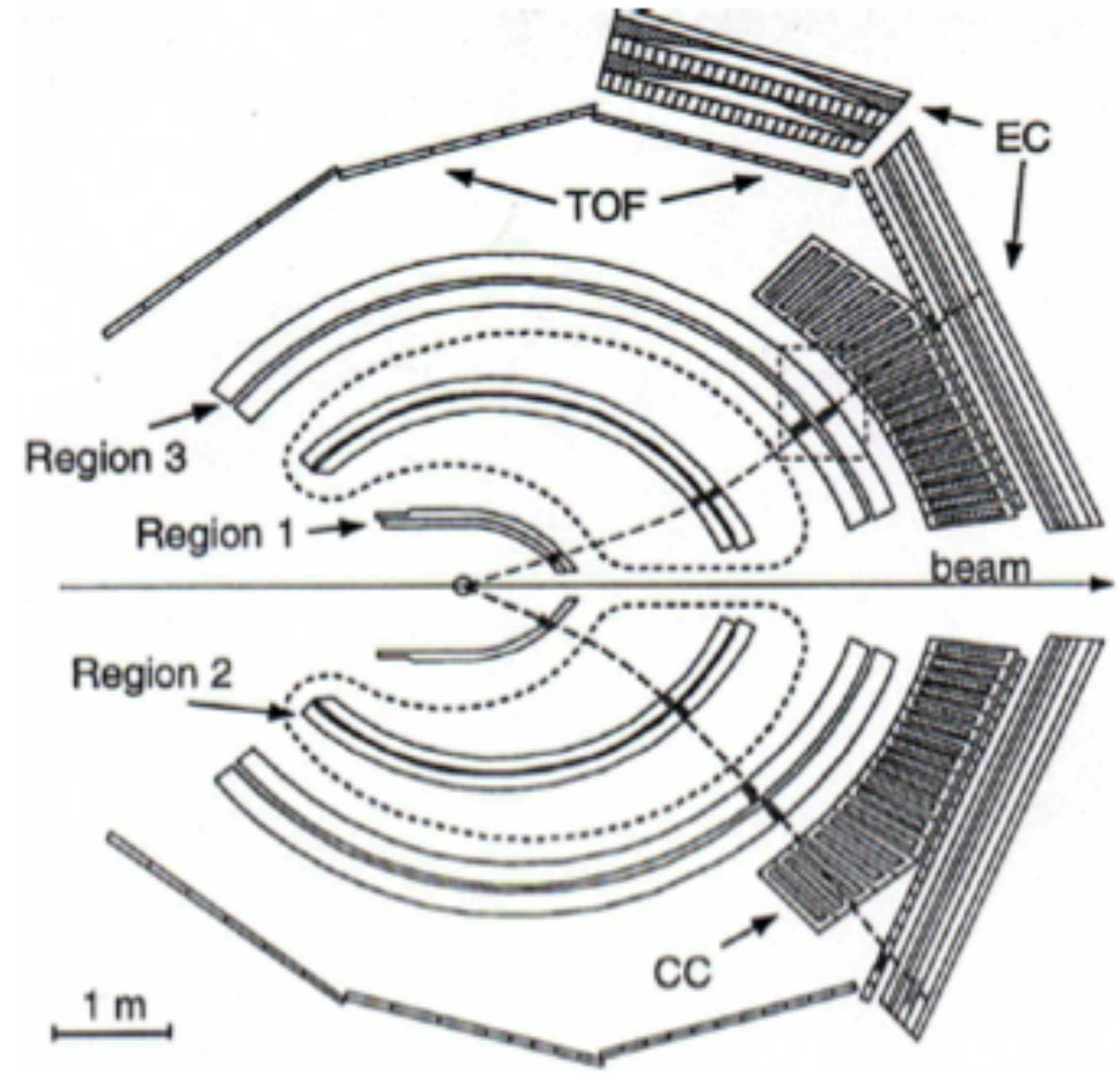
- Published experimental value for the form factor (extracted from cross-section measured at Serpukhov) of the Primakoff process $\pi^-\gamma^* \to \pi^0\pi^-$ is

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

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

Photon tagger and other subsystems of CLAS Detector





Use of the 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.

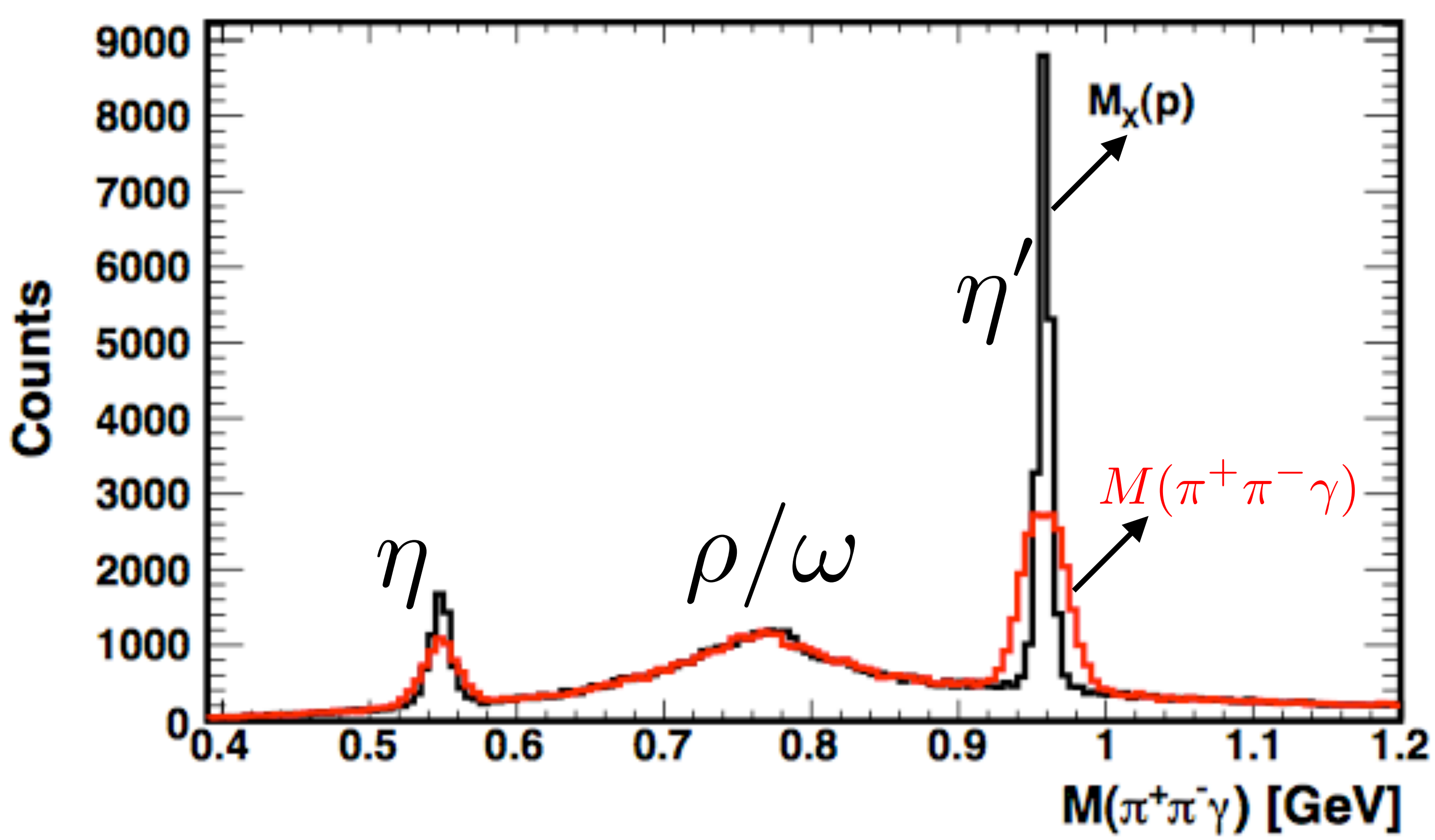
g11 Overview

- The g11 experiment ran in the summer of 2004 with principal aim of searching the exotic Θ^+ pentaquark state.
- Beam current was between 60-65 nA with average unpolarized electron beam at 4.023 GeV.
- 40 cm (4 cm wide) Liquid H_2 target.
- A gold radiator of 10^{-4} radiation length used.
- Trigger required at least two charged tracks in different sectors.
- 20 billion triggers stored as 21 TB of raw data.

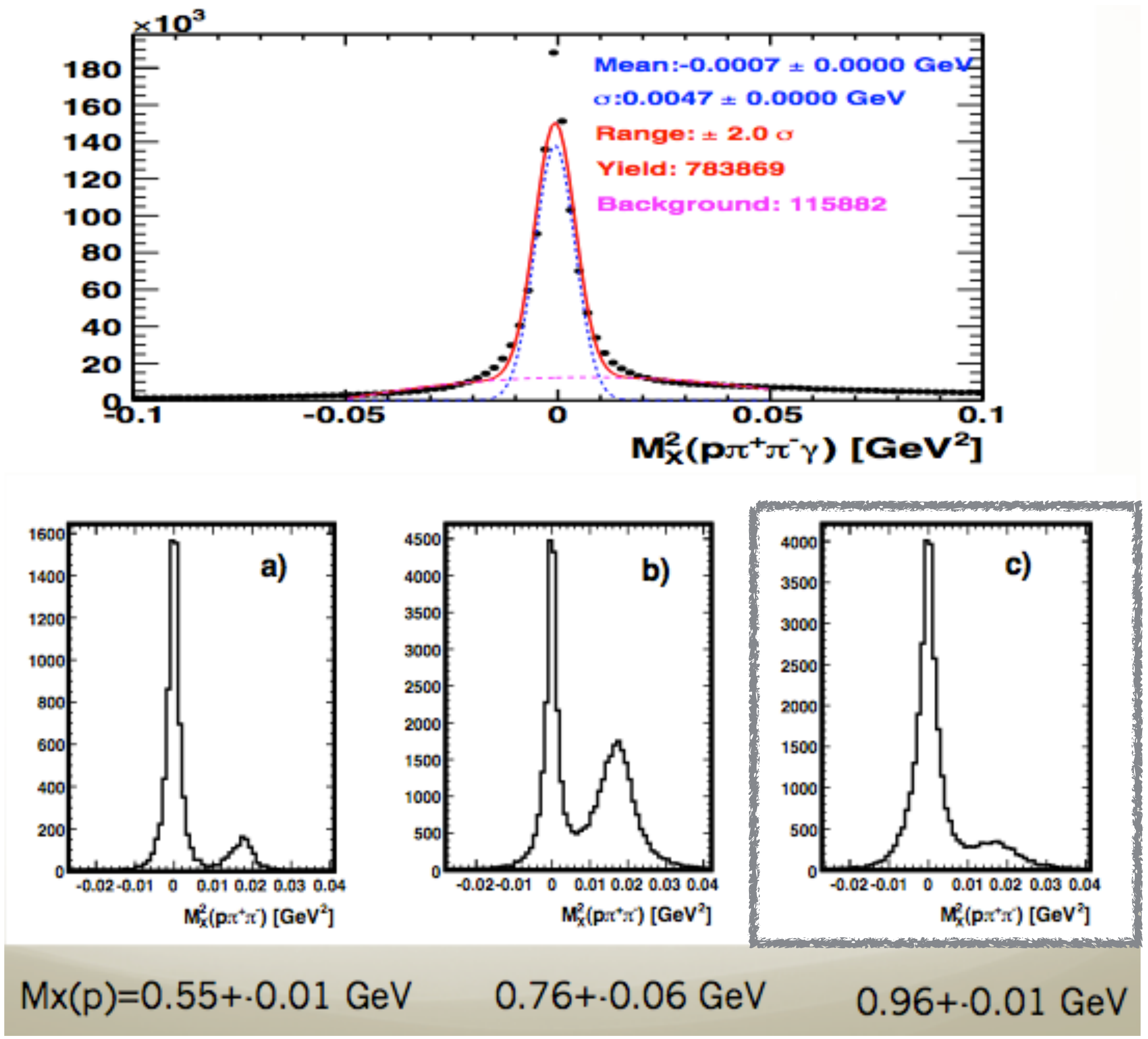
Event Selection and Particle Identification

- Since a trigger required at least 2 charged track (g11), we cannot detect events with mesons decaying into entirely neutral particles in the final state.
- Events with 3 charged tracks identified as proton, π+ and π- in addition of a tagged photon were selected.
- To identify a type of particle, the CLAS Simple Event Builder (SEB) package is used.
- The package calculates the velocity, β_{meas} of the detected particle and compares it to the expected velocity, β_{cal} corresponding to the measured momentum and masses of different possible types of particles.
- The particle type is chosen based on the minimum difference between the measured and expected velocities.

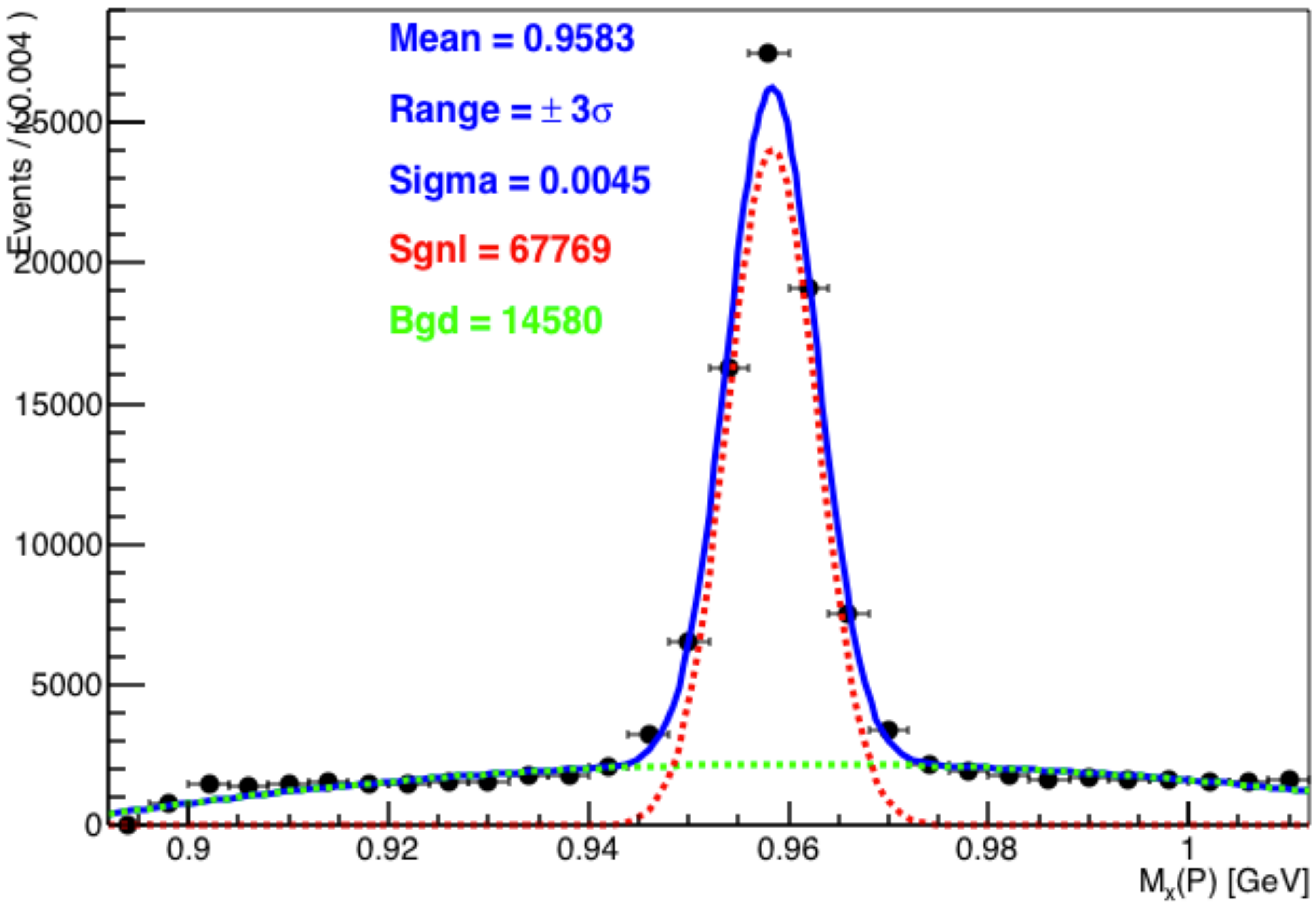
Missing Mass off the Proton for $\gamma p \rightarrow p\{\eta, \eta' \rightarrow \pi^+ \pi^- \gamma\}$ from g11 Data Set



Missing mass of all detected final state particles and neutral pion separation



Signal Events



SIMULATION

- MC: Events are generated as per the cross section and the decay matrix element
- 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

Extracting free parameter α

- The radiative decay matrix element can be written as:

$$|\mathcal{M}|^2 \sim |F_V(S_{\pi\pi})|^2 (1 + \alpha m^2 + o(m^2))^2 E_\gamma^2 q^2 sin^2(\theta)$$

so that the decay rate can be factorized as:

$$\frac{\partial w}{\partial m} = C_\alpha f(m) (1 + \alpha m^2 + o(m^2))^2 : \int_{m_{min}}^{m_{max}} \frac{\partial w}{\partial m} dm = 1$$

- We defined the following functions:

$$F_0(m) \equiv C_0 \cdot f(m) : \int_{m_{min}}^{m_{max}} F_0(m)\ dm = 1$$

$$F_1(m) \equiv C_1 \cdot f(m) \cdot m^2 : \int_{m_{min}}^{m_{max}} F_1(m)\ dm = 1$$

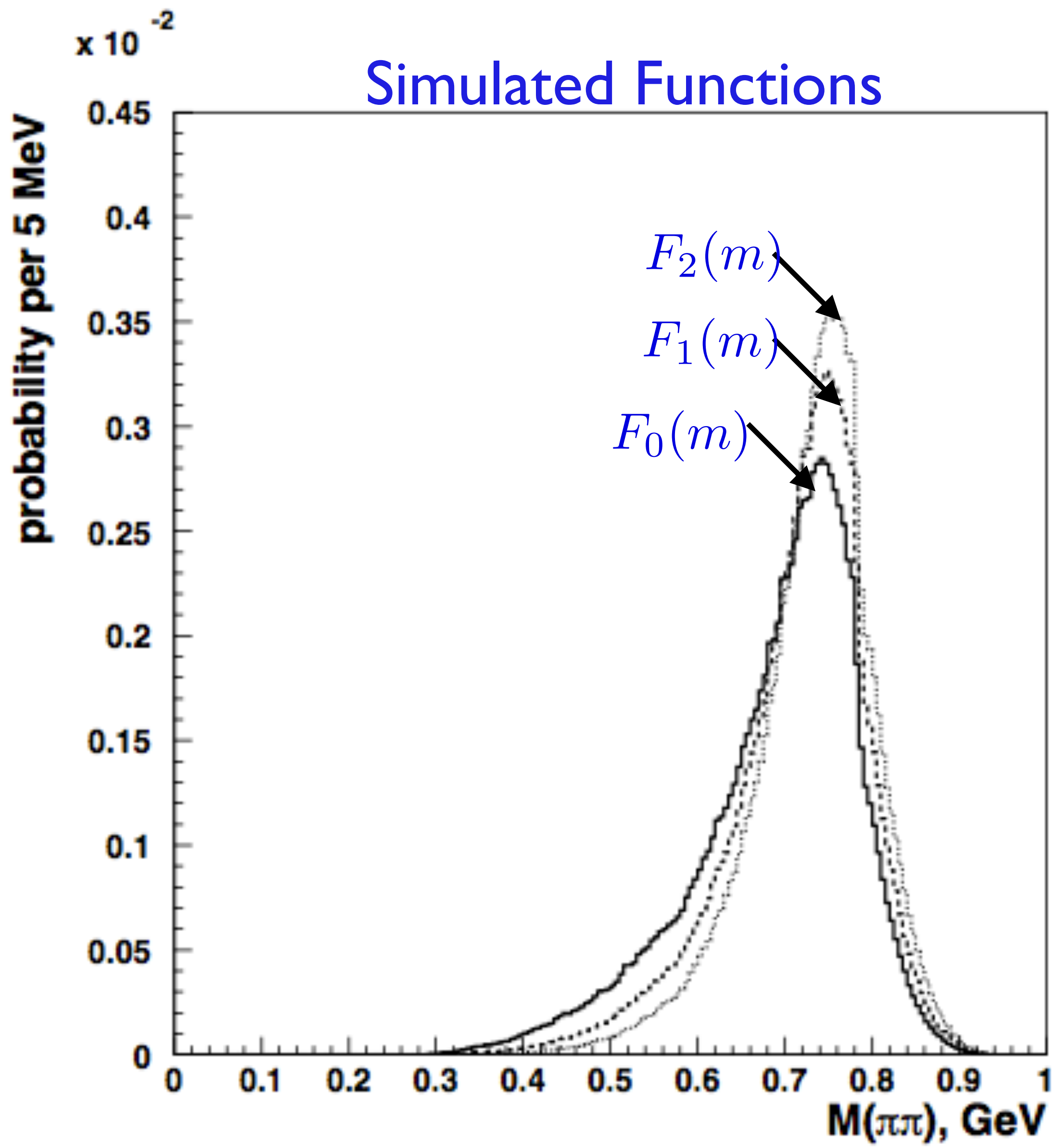
$$F_2(m) \equiv C_2 \cdot f(m) \cdot m^4 : \int_{m_{min}}^{m_{max}} F_2(m)\ dm = 1$$

- and also defined the parameters $I_i = \frac{C_0}{C_i}$ so that $\frac{\partial w}{\partial m} = C\{F_0(m) + 2\alpha I_1 F_1(m) + \alpha^2 I_2 F_2(m)\}$

- where $C = \frac{1}{1+2\alpha I_1 + \alpha^2 I_2}$ due to normalization.

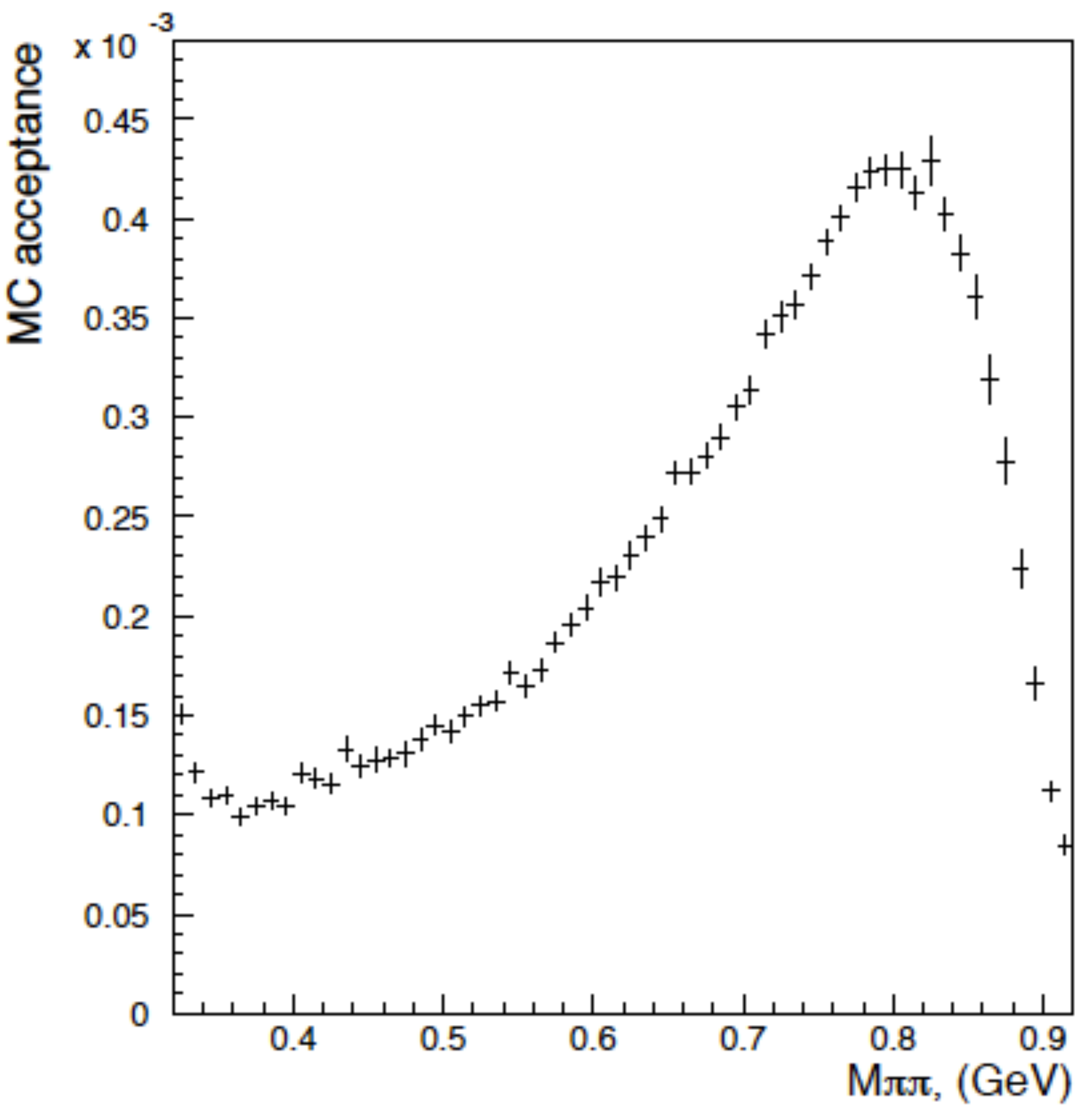
- Before using the decay rate function in the fitting procedure, it should be convoluted with the detector acceptance and resolution function:

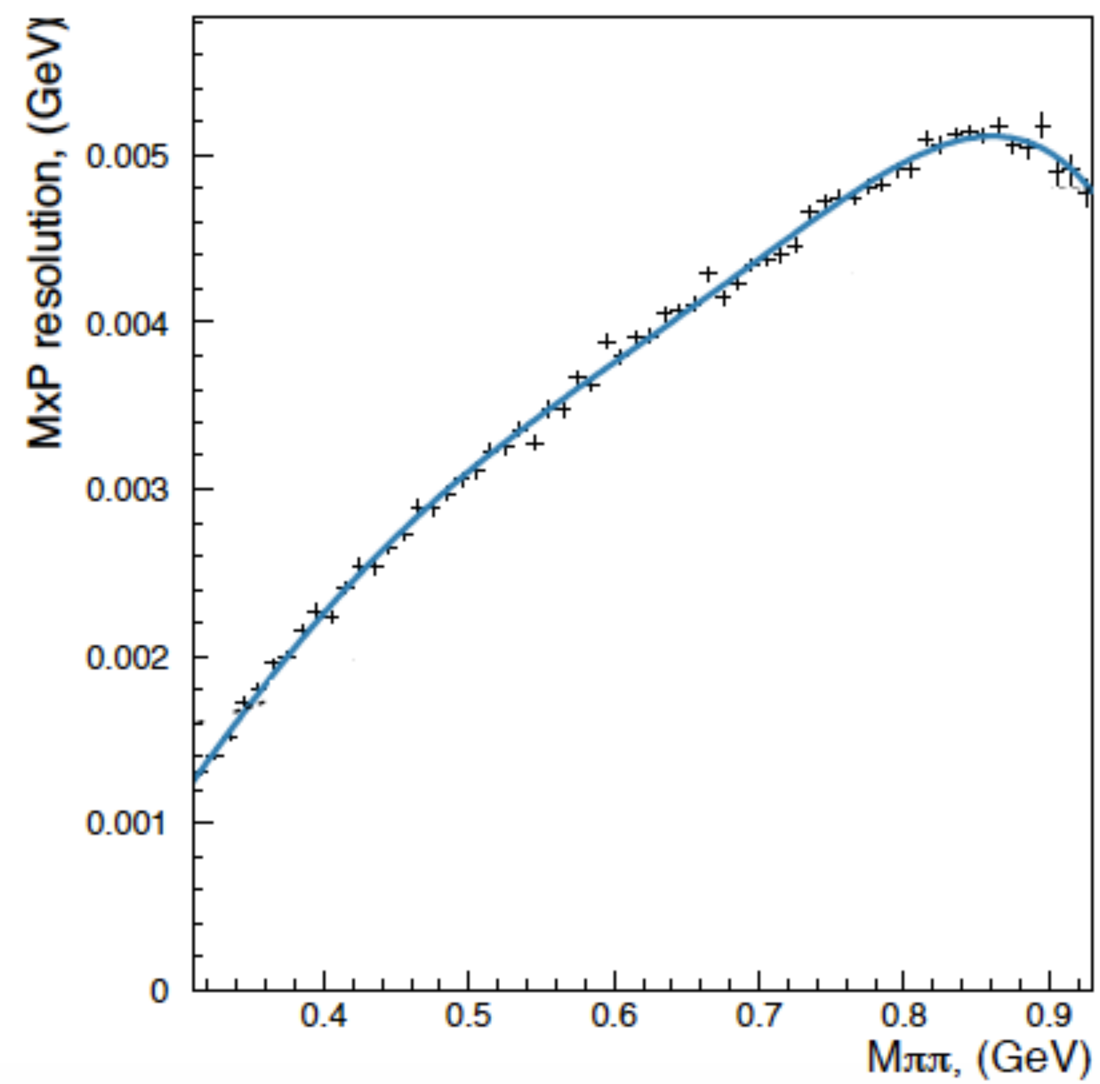
$$\frac{\partial w}{\partial m_{meas.}}(m_{meas.}) = \int_{m_{min}}^{m_{max}} \frac{\partial w}{\partial m}(m) \cdot r(m, m_{meas.})\ dm$$



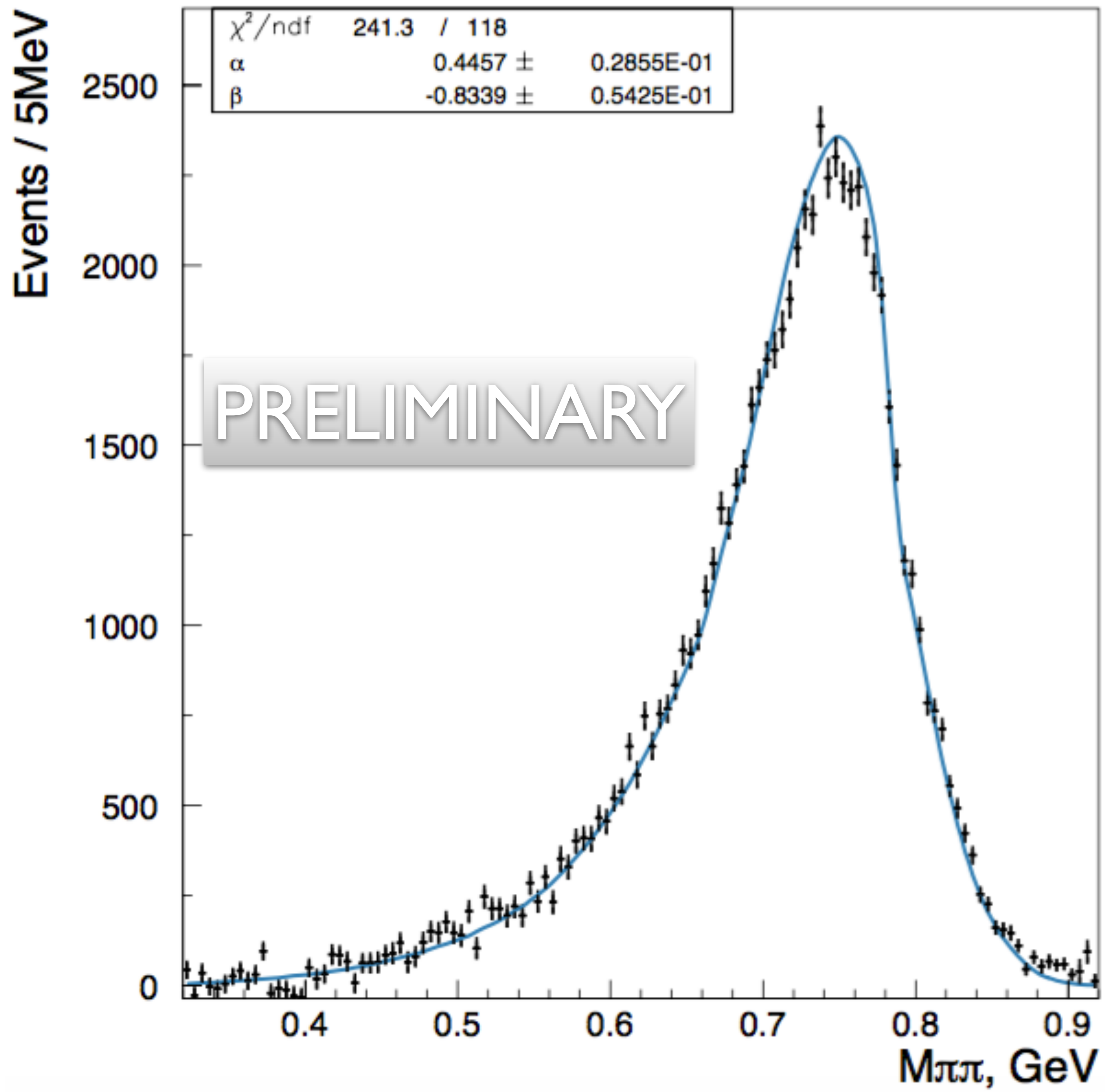
CLAS Acceptance & Resolution

- 20 million events were simulated for each two pion invariant mass bin
- Resolution in the missing mass off the proton (mx_P) also obtained

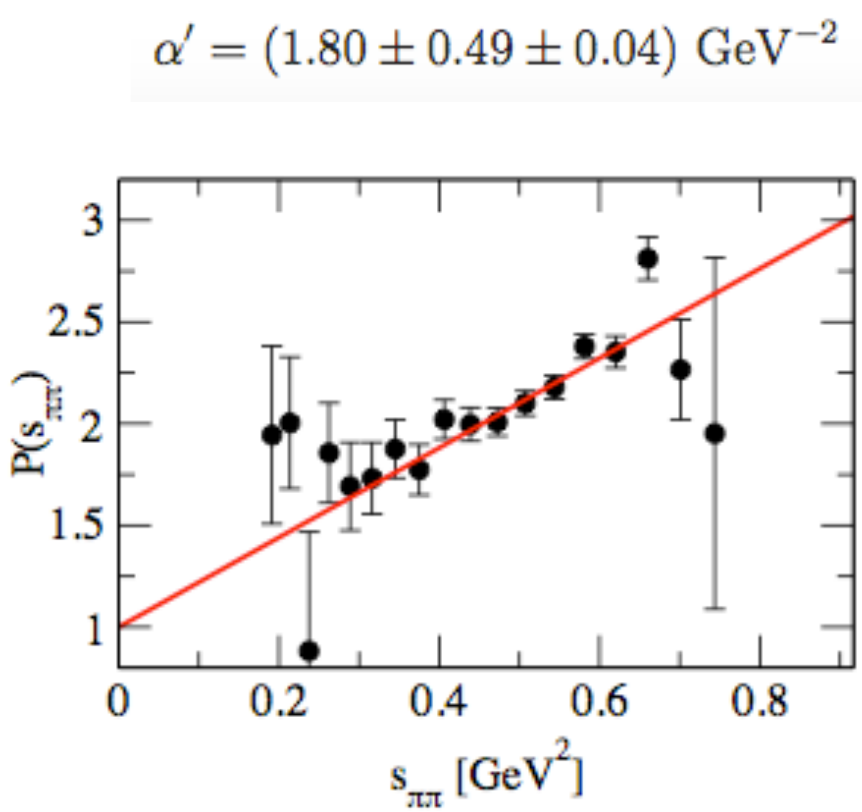




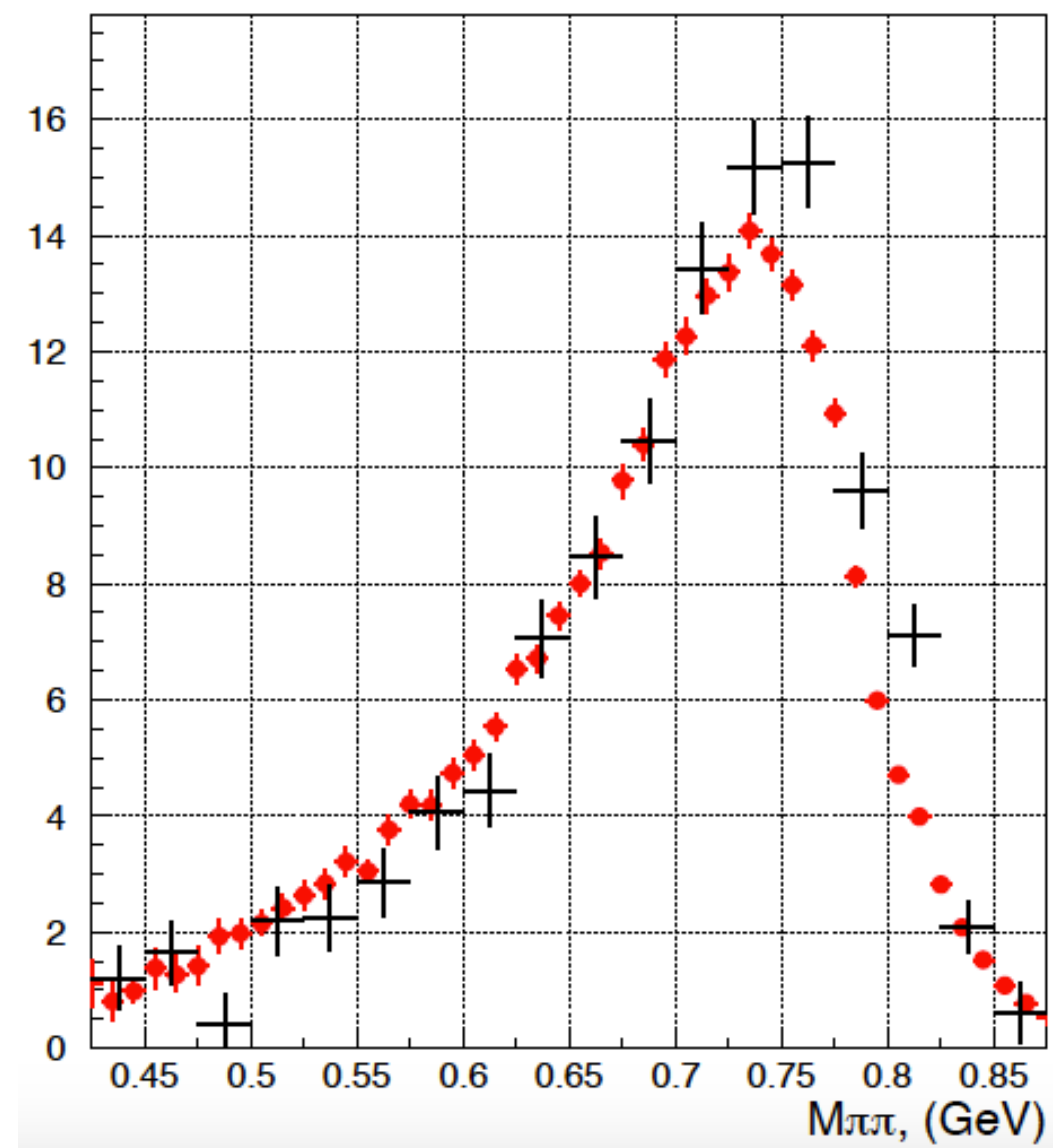
CLAS Preliminary



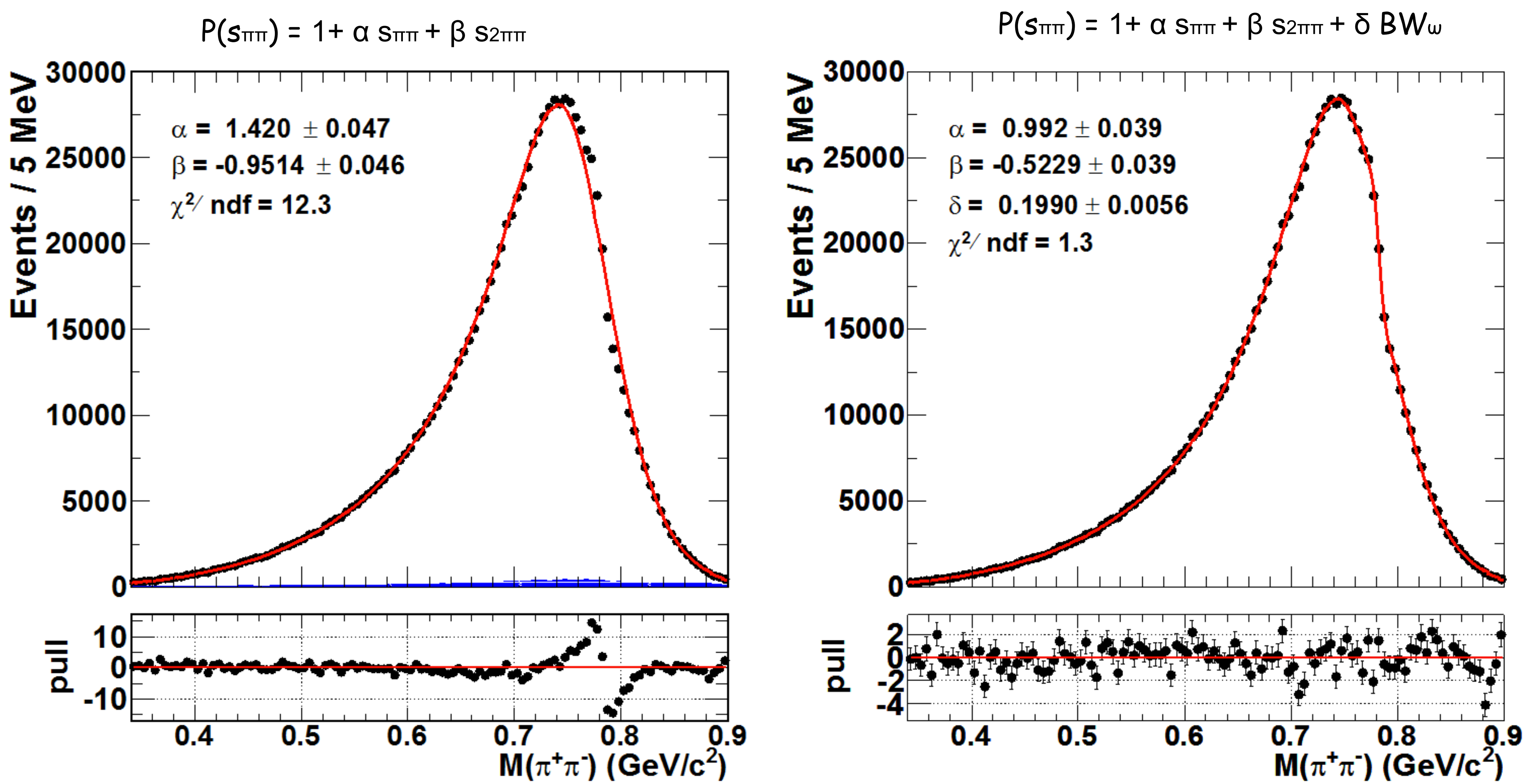
Data from CRYSTAL BARREL and CLAS Preliminary (red points).



$\alpha = 0.45 \pm 0.029[GeV^{-2}]$
$\beta = -0.83 \pm 0.054[GeV^{-4}]$



BESIII Preliminary



Expectations

- Extract the ‘box’ anomaly amplitude $A_{\gamma}^{3\pi}$.
- Do systematic studies.