Light Meson Decays from Photon-Induced Reactions with CLAS

3 June 2016

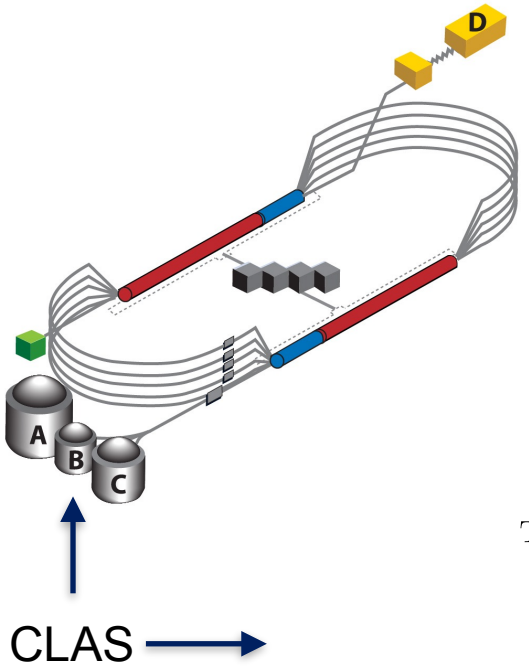
14th International Workshop on Meson Production, Properties and Interaction

Michael C. Kunkel

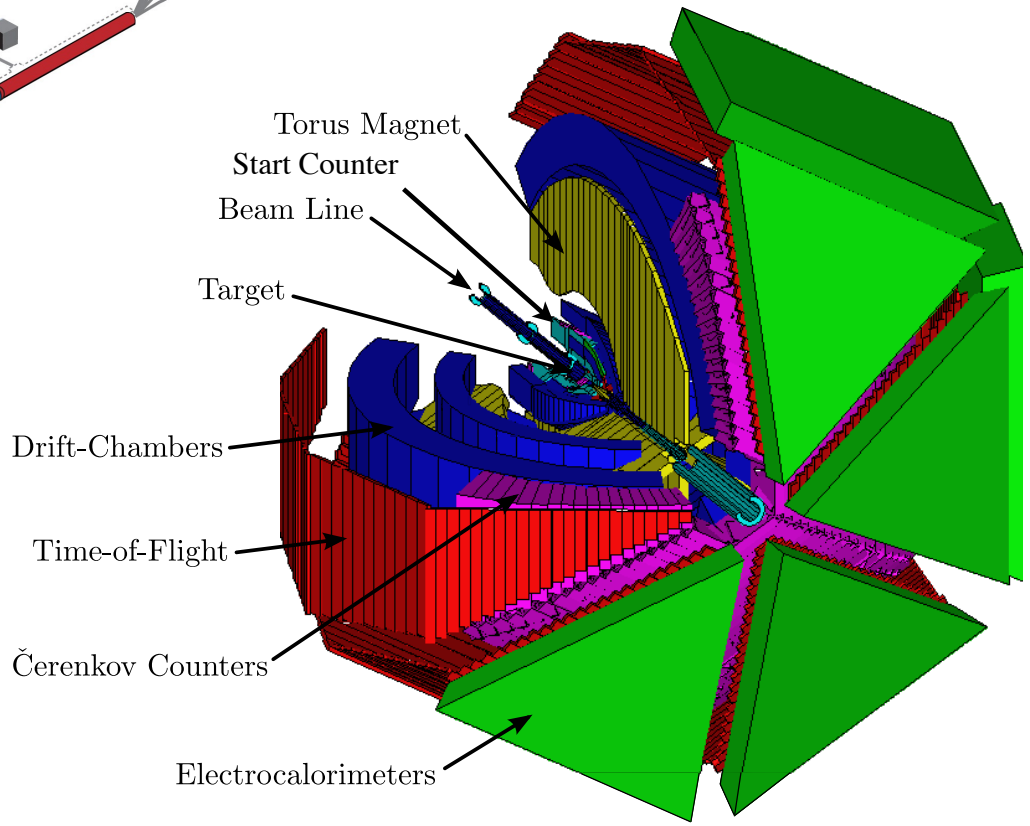
IKP-1

On behalf of the CLAS Collaboration and LMD group

CEBAF Large Acceptance Spectrometer (CLAS)



Continous Electron Beam Accelerator Facility (CEBAF) at 12 GeV



The g11 and g12 experiments

g11 $\gamma p \rightarrow pX$	g12 $\gamma p \rightarrow pX$
60 - 65 nA 4.023 GeV e^- beam 0.803 < Eγ < 3.815	60 - 65 nA 5.714 GeV e^- beam 1.142 < Eγ < 5.425
40 cm (2 cm radius) liquid H_2 target placed at CLAS center	40 cm (2 cm radius) liquid H_2 target placed -90cm from CLAS center
Trigger required at least two charged tracks in different sectors	Trigger required at least two charged tracks in different sectors for Eγ > 3.6
20×10^9 productions triggers as 21 TB of raw data	26×10^9 productions triggers as 128 TB of raw data
	Cherenkov Counters and Electromagnetic Calorimeter in trigger for entire Eγ range

CLAS Light Meson Decay (LMD) Program

Meson Decay	Physics	Meson Decay	Physics
$\pi^0 \to e^+e^-\gamma$	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 $<3.6\times10^{-3}$
$\omega \to \pi^0e^+e^-$	Transition Form Factor	$\eta, \omega, \Phi \to \pi^-\pi^+\pi^0$	Dalitz plot analysis
$\eta(') \to \pi^0e^+e^-$	C violation	$\eta' \to \pi^-\pi^+\eta$	Dalitz plot analysis/meson mixing
$\eta(') \to \pi^-\pi^+e^+e^-$	CP violation	$\Phi \to \pi^-\pi^+\eta$	G-parity violation

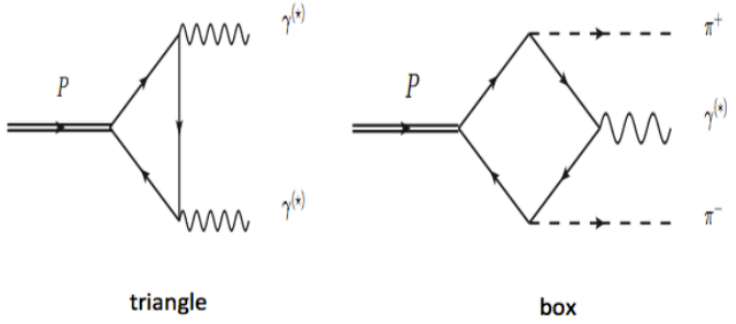
Box Anomaly from η(')→π⁻π⁺γ

N. G. Mbianda, M. Amaryan;

Old Dominion University

Motivation:

- The 2 photon decay of π^0, η, η' →γγ proceed via the triangle or axial anomaly. In contrast, radiative decays of η, η' →$\pi^-\pi^+\gamma$ proceed via the box anomaly.

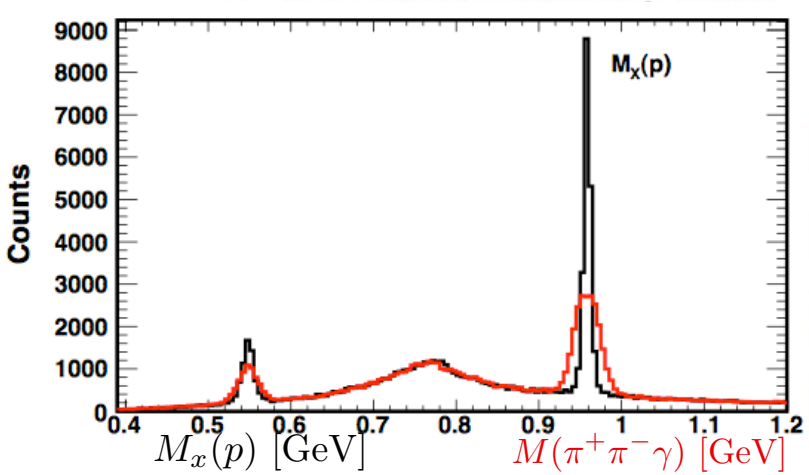


triangle box

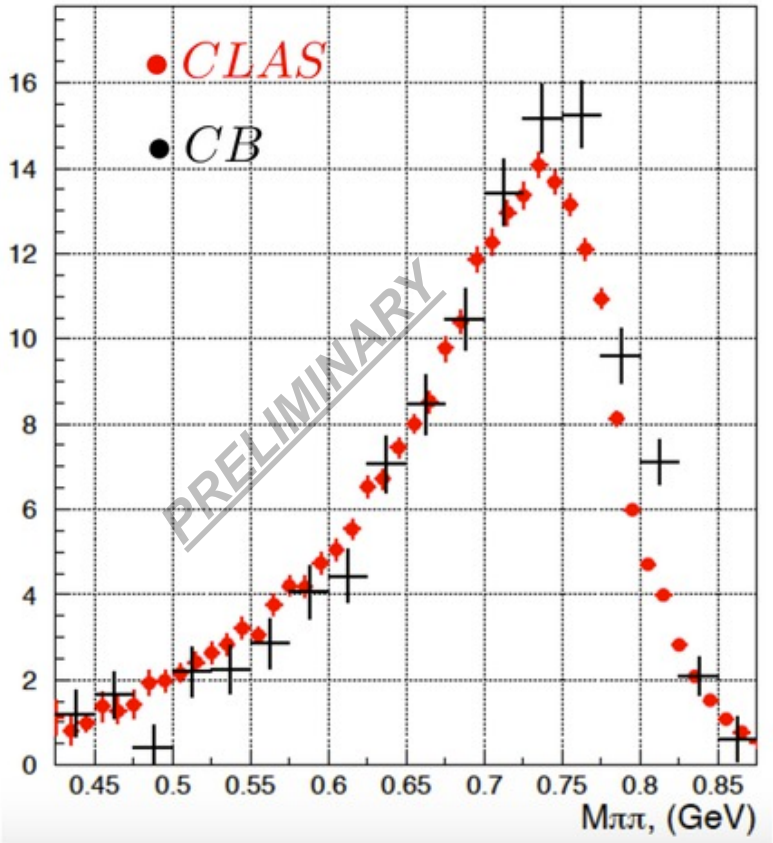
$$\frac{d\Gamma(\eta \to \pi^+\pi^-\gamma)}{ds_{\pi\pi}} = |AP(s_{\pi\pi})F_V(s_{\pi\pi})|^2\,\Gamma_0(s_{\pi\pi})$$

- Radiative test the contribution of the box anomaly, including pion FSI. FSI occur for finite quark mass.

CLAS preliminary results comparison

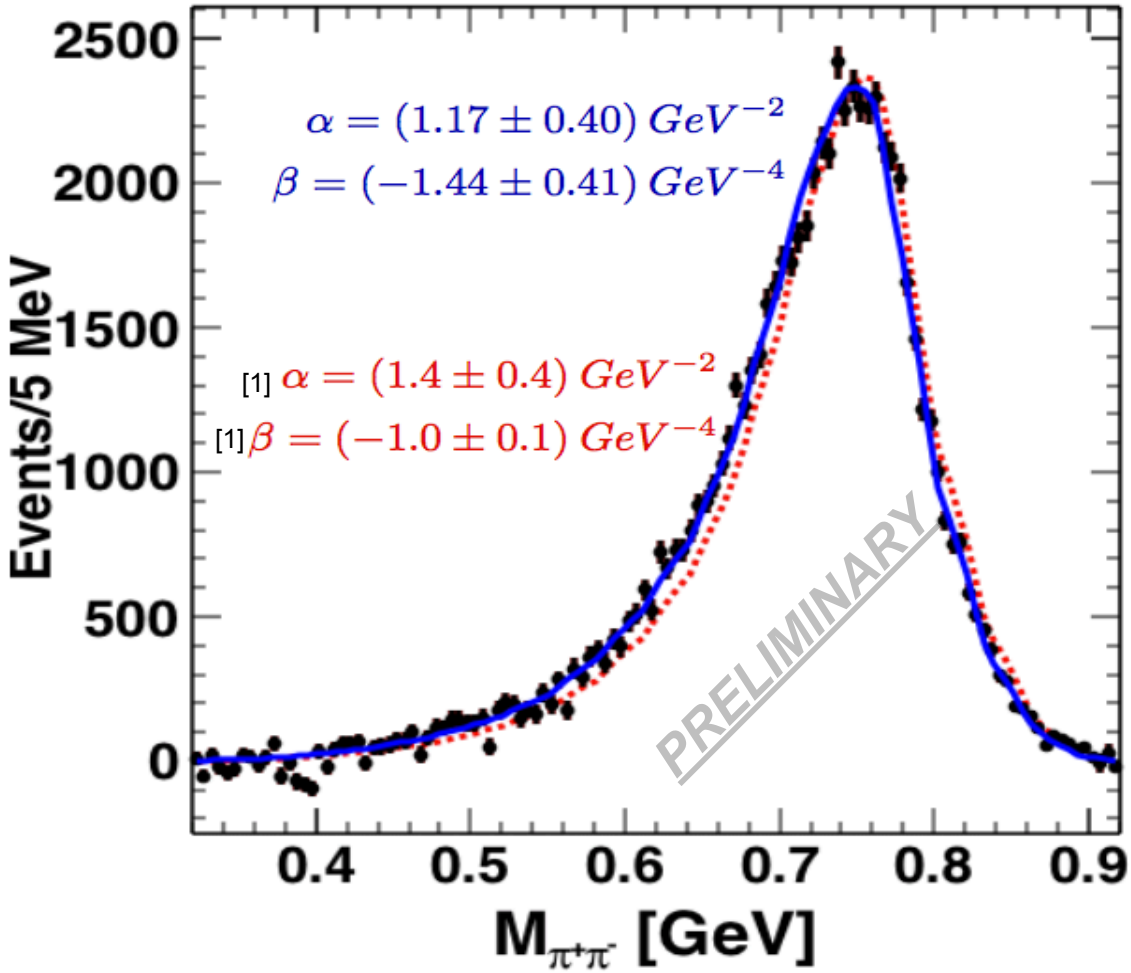


CLAS data yield for γp→p{η,η'→π+ π- γ} *from g11 data set*



CLAS Preliminary with g11 data

$$P(s_{\pi^+\pi^-}) = 1 + \alpha s_{\pi^+\pi^-} + \beta \mathcal{O}(s^2_{\pi^+\pi^-})$$



Currently finishing systematic study

[1]Kubis, B. et al., arXiv: 1504.02588v2[hep-ph]

Dalitz Plot of η'→π⁻π⁺η

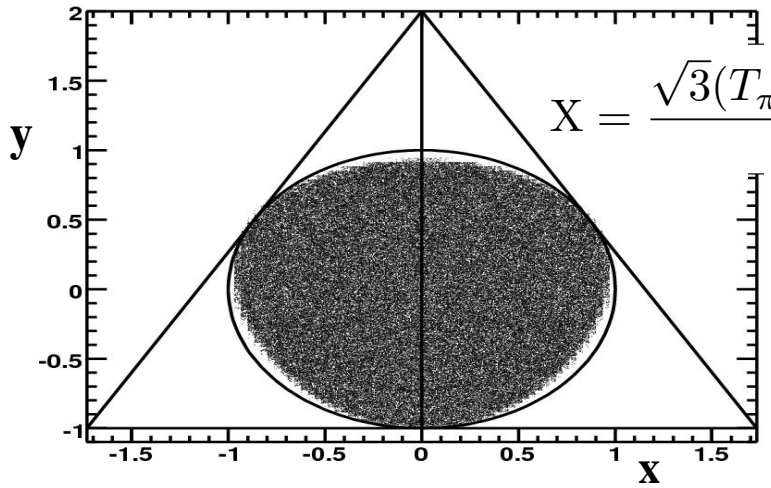
S. Ghosh, A. Roy;

IIT

Motivation:

- Dalitz plot of η'→π⁻π⁺η provides kinematic information of the decay, enabling the studying of low energy dynamics of QCD.
- The η'→π⁻π⁺η decay has a low Q-value due to relatively heavy decay products, thus helping us to test and limit the effective chiral Lagrangian theory.

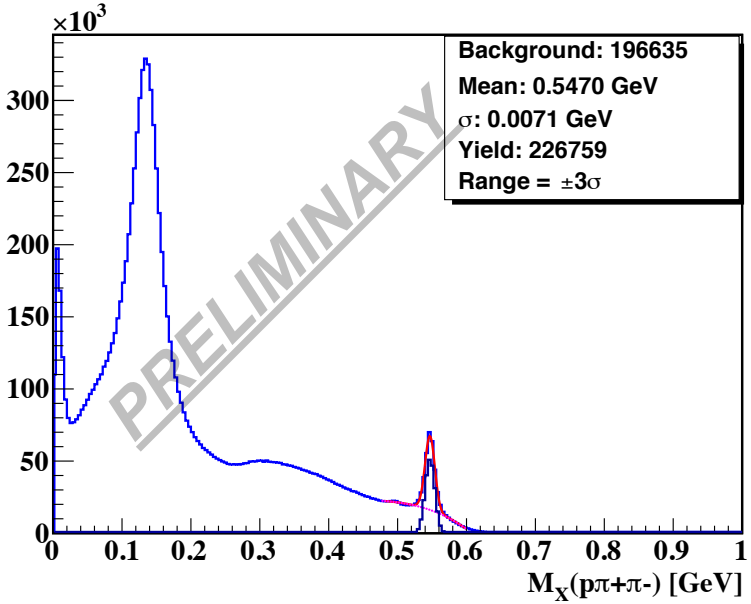
Dalitz Plot Geometry



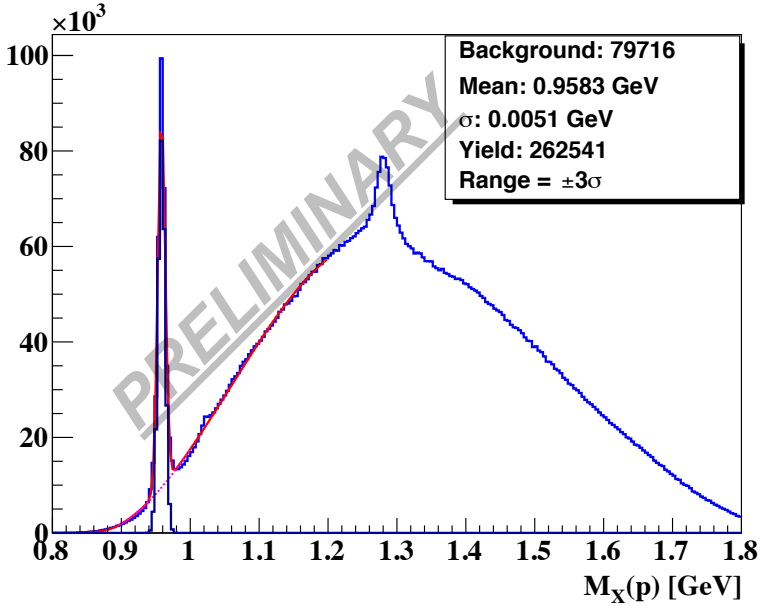
$$X = \frac{\sqrt{3}(T_{\pi^+} - T_{\pi^-})}{Q} \quad Y = \frac{(m_\eta + 2m_\pi)}{m_\pi} \cdot \frac{T_\eta}{Q} - 1$$

- $f(X,Y)=N \cdot(1+a(Y)+b(Y)^2 +c(X)+d(X)^2)$

η'→π⁻π⁺η from CLAS g12 data



Missing mass of pπ⁻π⁺ for events where $M_x(p)=0.958\pm0.015$ GeV



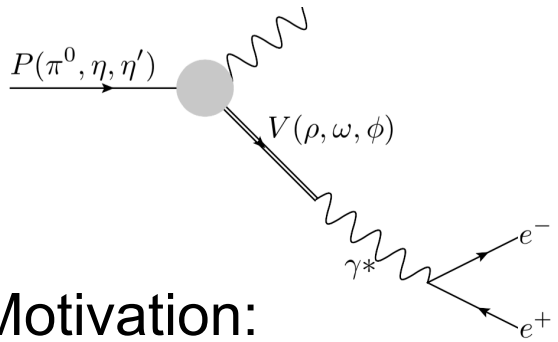
Missing mass of p for events where $M_x(p\pi^-\pi^+)=0.5\pm0.015$ GeV

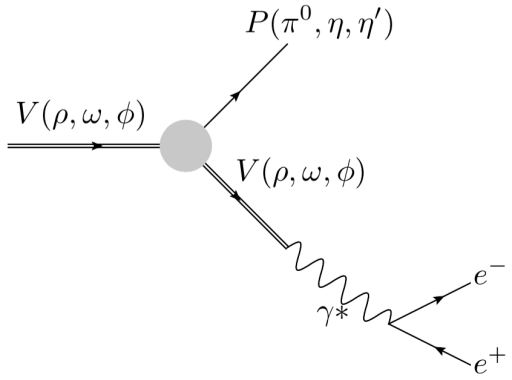
Currently finishing analysis
See Parallel Session A3 1550 by Sudeep Ghosh for detailed analysis

Transition Form Factors

J. Ritman, M. C. Kunkel, S. Schadmand;

Institut für Kernphysik, Forschungszentrum Jülich

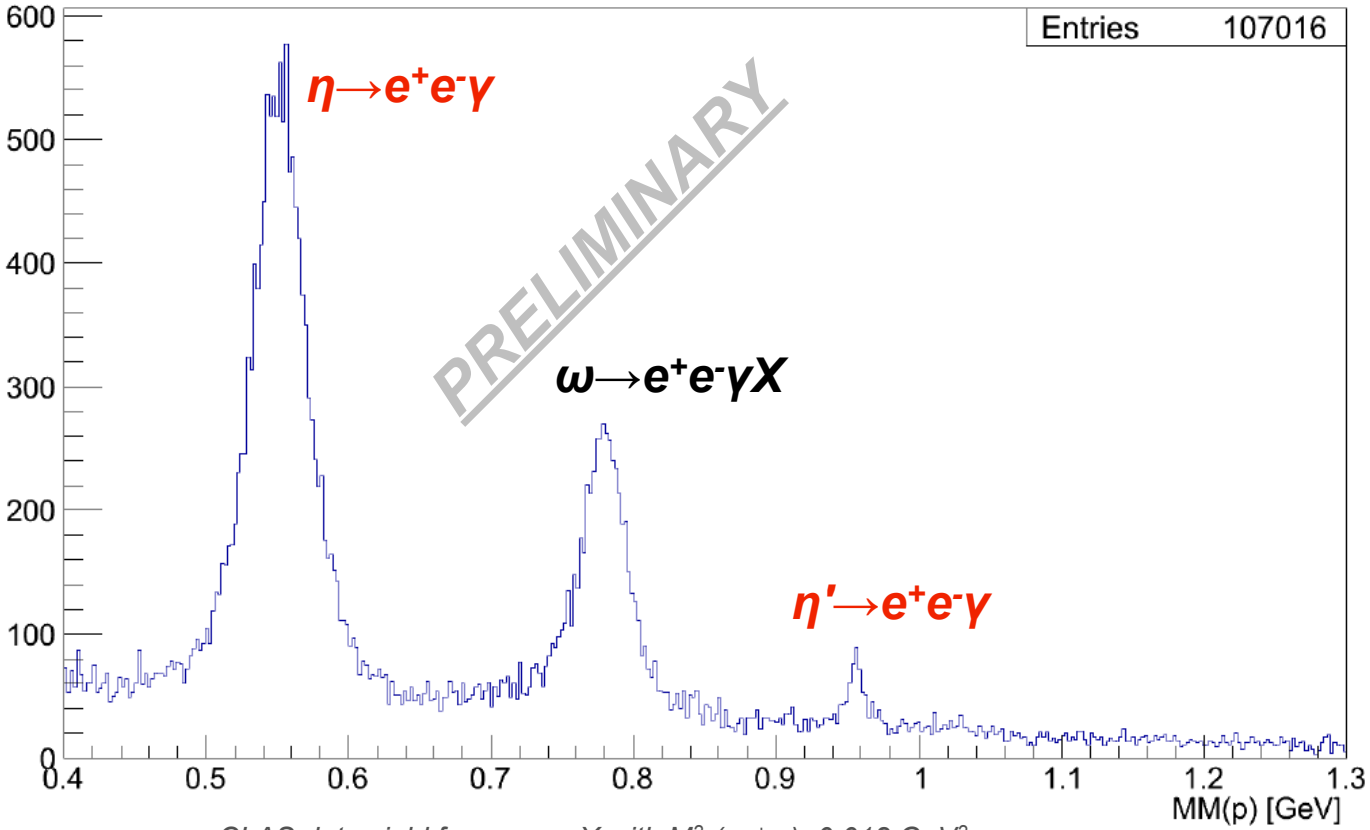




Motivation:

- Transition form factors provides insight into the meson charge radius, $\langle r \rangle$.
- Ratio of η/η' form factors provides information on η/η' mixing angle.
- For ω there is a discrepancy between the measurement and the VMD model.
- The knowledge of the P(π^0, η, η') form factor is needed for the interpretation of the g-2 experiment.

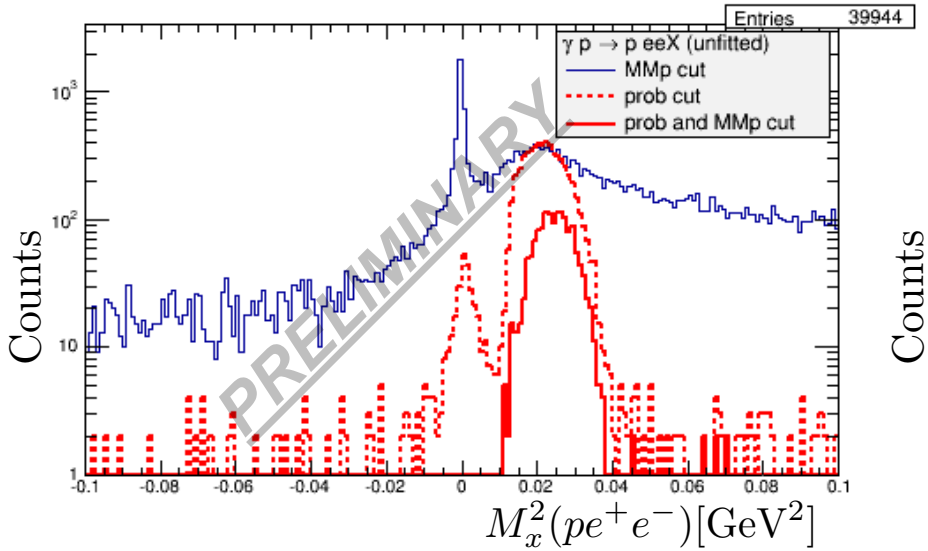
η, ω , η' Yield in CLAS g12



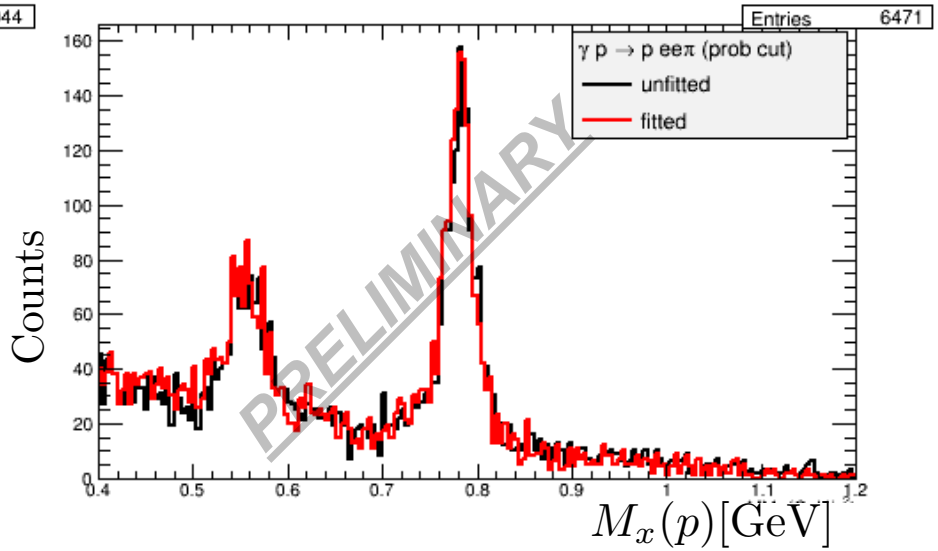
CLAS data yield from γp→pX with $M^2_X(pe^+e^-)<0.018$ GeV^2
$M_E(pe^+e^-)>0.075$ GeV and electron/positron ID

Goal: Measuring transition form factors

ω Transition Form Factor in CLAS

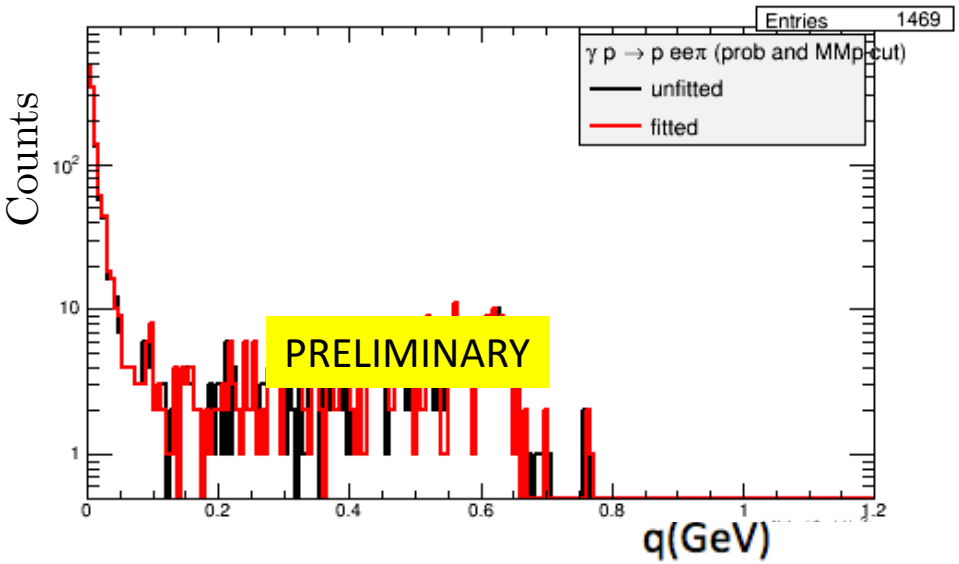


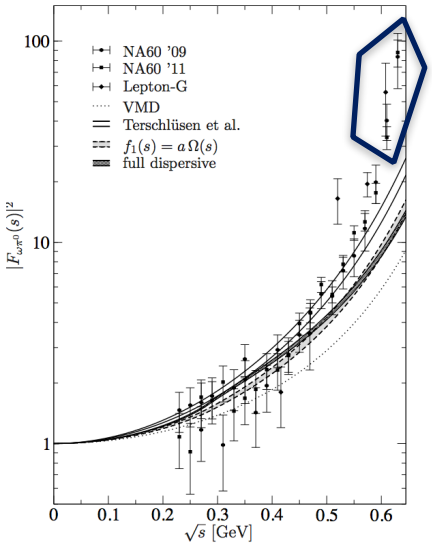
CLAS data yield from γp→pX with
$M^2_x(pe^+e^-) = M^2_{\pi 0} \pm 0.01$ GeV^2



CLAS data yield from γp→pe⁺e⁻X with
$M_x(p) = M_\omega \pm 0.031$ GeV

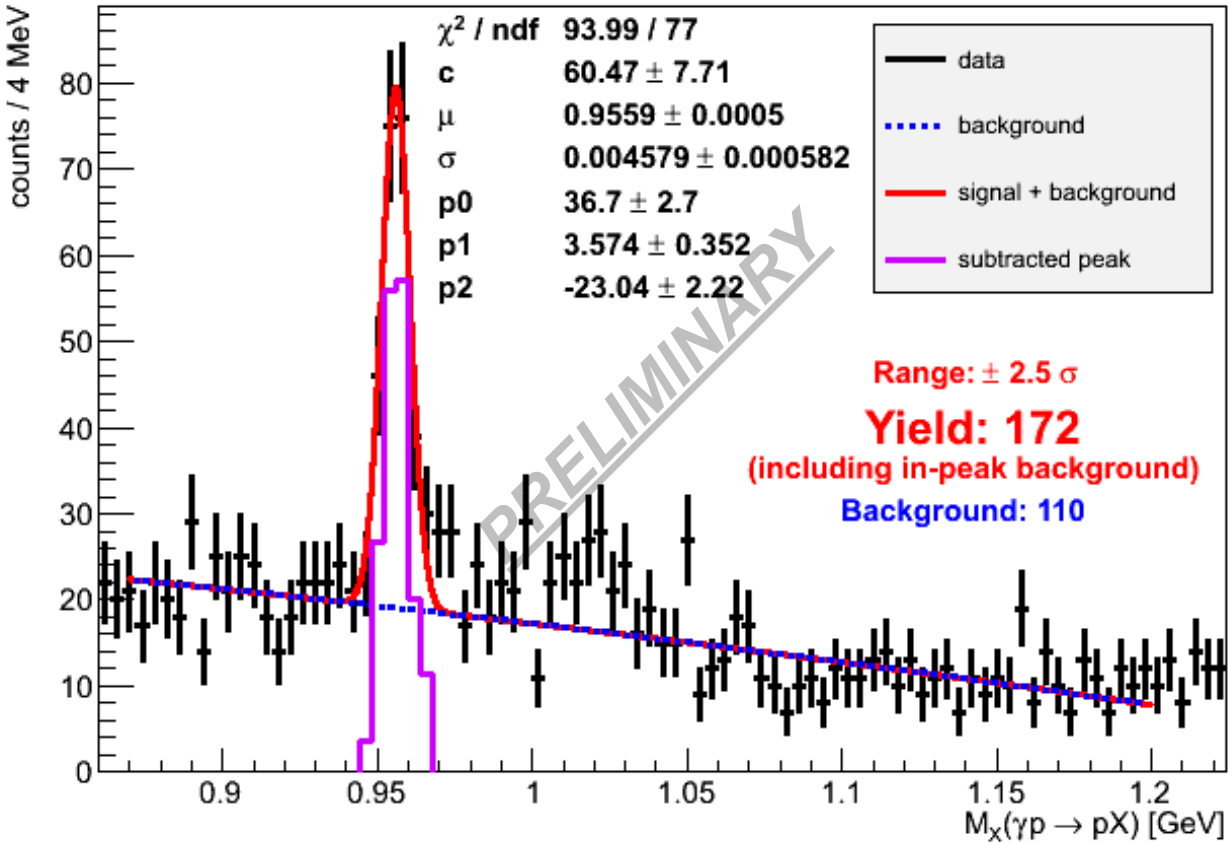
ω Transition Form Factor in CLAS





Recent results the ω transition form factor with errors. Image Source: S. P. Schneider et al., Phys. Rev. D86, p. 054013 (2012)

η’ Branching Ratio



BESIII Γ(η′→γe+e−)/Γ(η′→γγ) (2.13±0.09(stat.)±0.07(sys.))×10−2 from 864 events [1]

CLAS preliminary BR Γ(η′→γe+e−)/Γ(η′→γγ) (2.63±0.3(stat.))×10−2 from 172 events
First estimate from cut-based analysis

[1]BESIII, M. Ablikim et al., Phys.Rev. D92 (2015) 012001

Current status of η' charge radius

Current BESIII and CLAS data sets do not have enough statistics to determine which theoretical model fits the η′→ charge radius		
	$\langle r \rangle$	Number of events
CLAS (η′→γe+e−)	TBD	172
BESIII (η′→γe+e−)	(M) 1.60 ± 0.17(stat) ± 0.08(sys) GeV^{-2} [1]	864
CELLO (η′→γμ+μ−)	(M) 1.7 ± 0.4 GeV^{-2} [2]	75

Dispersion	(P) $1.53^{+0.15}_{-0.08}$ GeV^{-2}	
ChPT	(P) 1.6 GeV^{-2}	
VMD	(P) 1.45 GeV^{-2}	

Current statistical error cannot discern the correct theoretical model

[1]M. Ablikim et al., Phys.Rev. D92 (2015) 012001
[2]R. I. Dzhelyadi et al., Phys. Lett. B 88, 379 (1979)

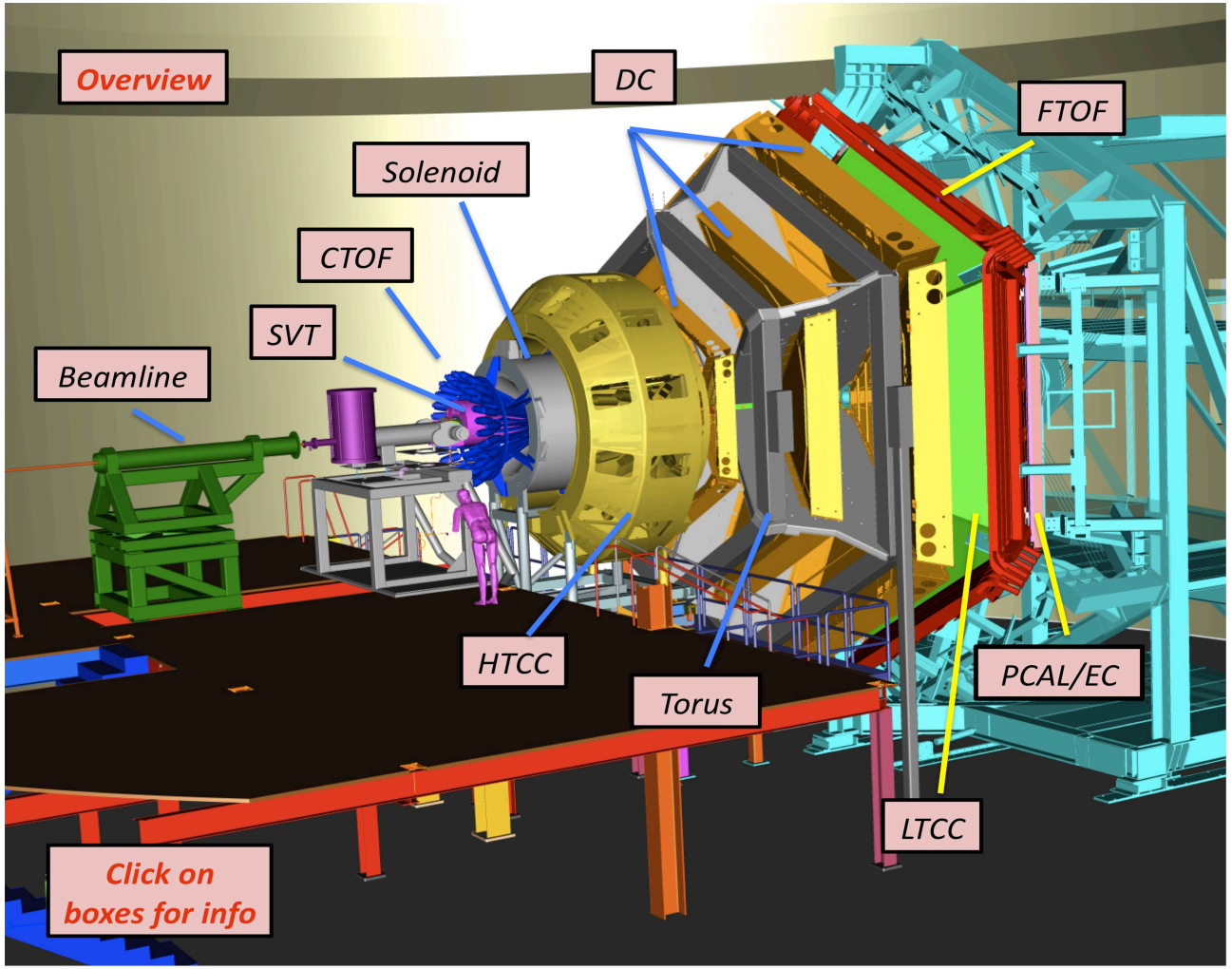
Future CLAS e+e- pair physics

Electromagnetic structure of mesons and baryons. Currently we are benchmarking the $\eta' \rightarrow \gamma e^+e^-$ decay. Here is a list of initial physics to be studied	
Meson	Baryon
$\eta' \rightarrow \gamma e^+e^-$	$\Delta \rightarrow N e^+e^-$
$\omega \rightarrow \pi^0 e^+e^-$	$\Lambda \rightarrow n e^+e^-$ $\Lambda(1520) \rightarrow \Lambda e^+e^-$
$\Phi \rightarrow \eta e^+e^-$	
$J/\psi \rightarrow \pi^0 e^+e^-$	$\Sigma^0 \rightarrow \Lambda e^+e^-$ $\Sigma^+ \rightarrow p e^+e^-$

CLAS $\xi(e^+e^-)/\xi(\pi^+\pi^-)$ can be range 10^5 - 10^{12}

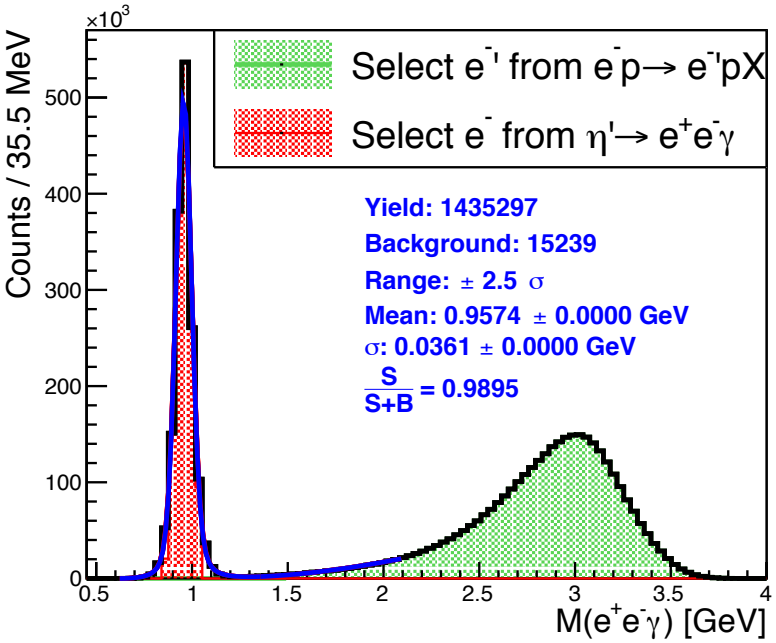
CLAS e^+e^- efficiency (ε) range 1 - 10^{-2}

CEBAF Large Acceptance Spectrometer (CLAS)

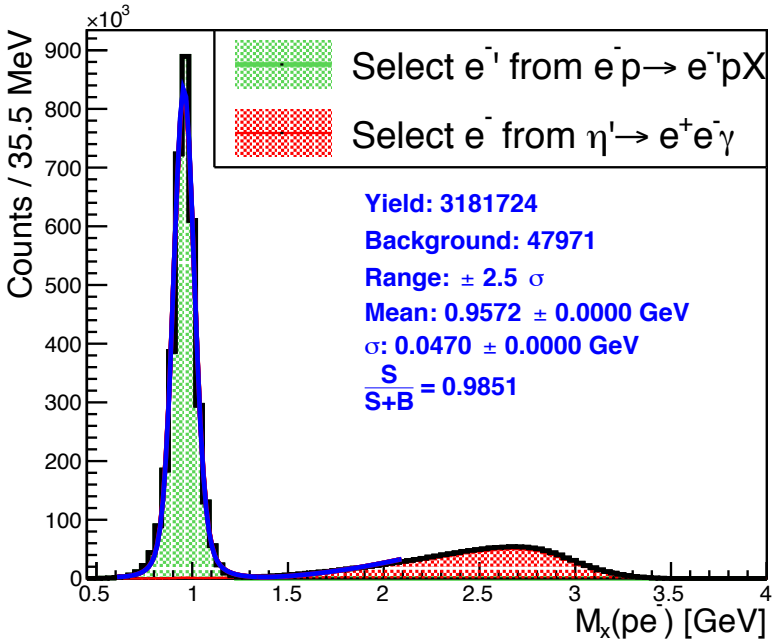


Future CLAS η' Measurement

$ep \rightarrow p\eta'(e') \rightarrow pe^+e^-\gamma(e')$

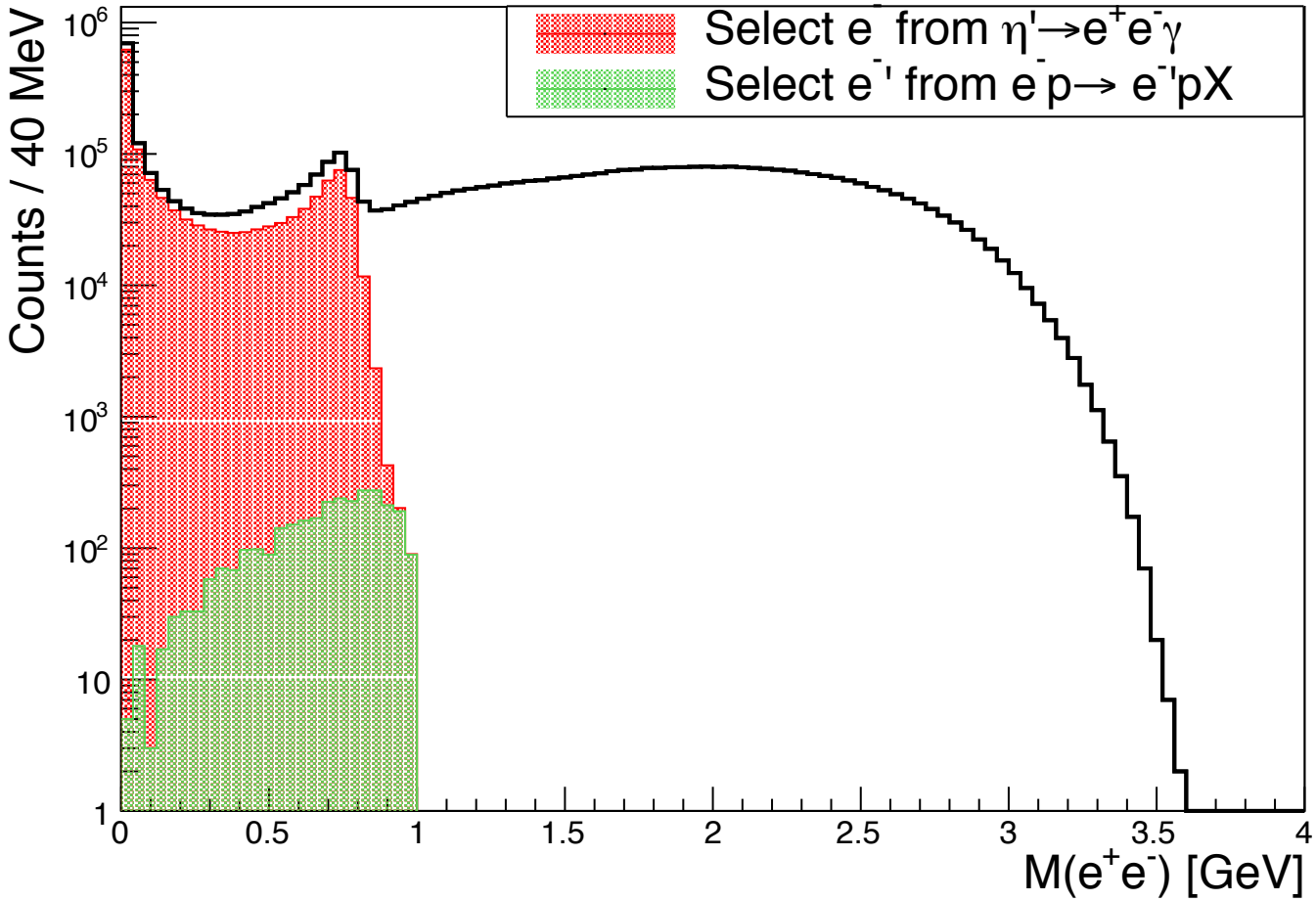


Reconstructed simulation



Reconstructed simulation

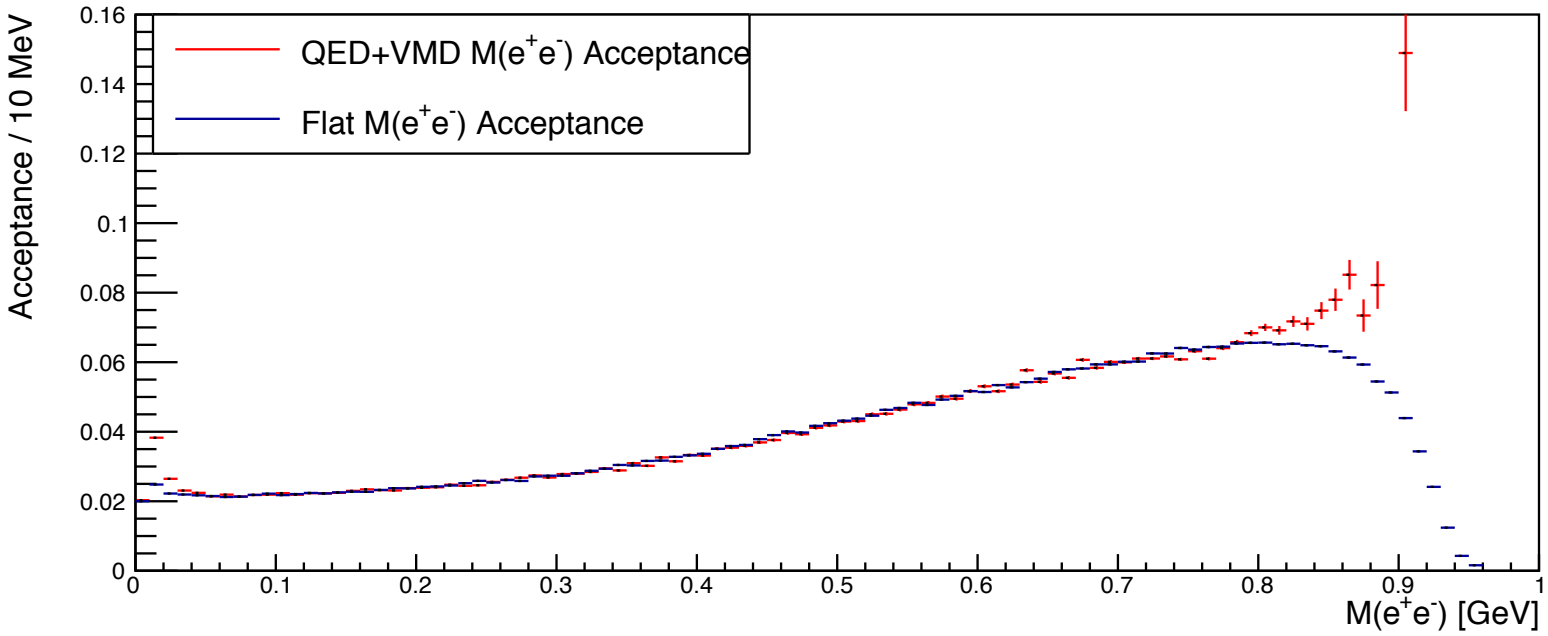
Possible Contamination



Reconstructed simulation

Contamination from wrong e^- $\lesssim$ 1/100

Future CLAS η' Acceptance

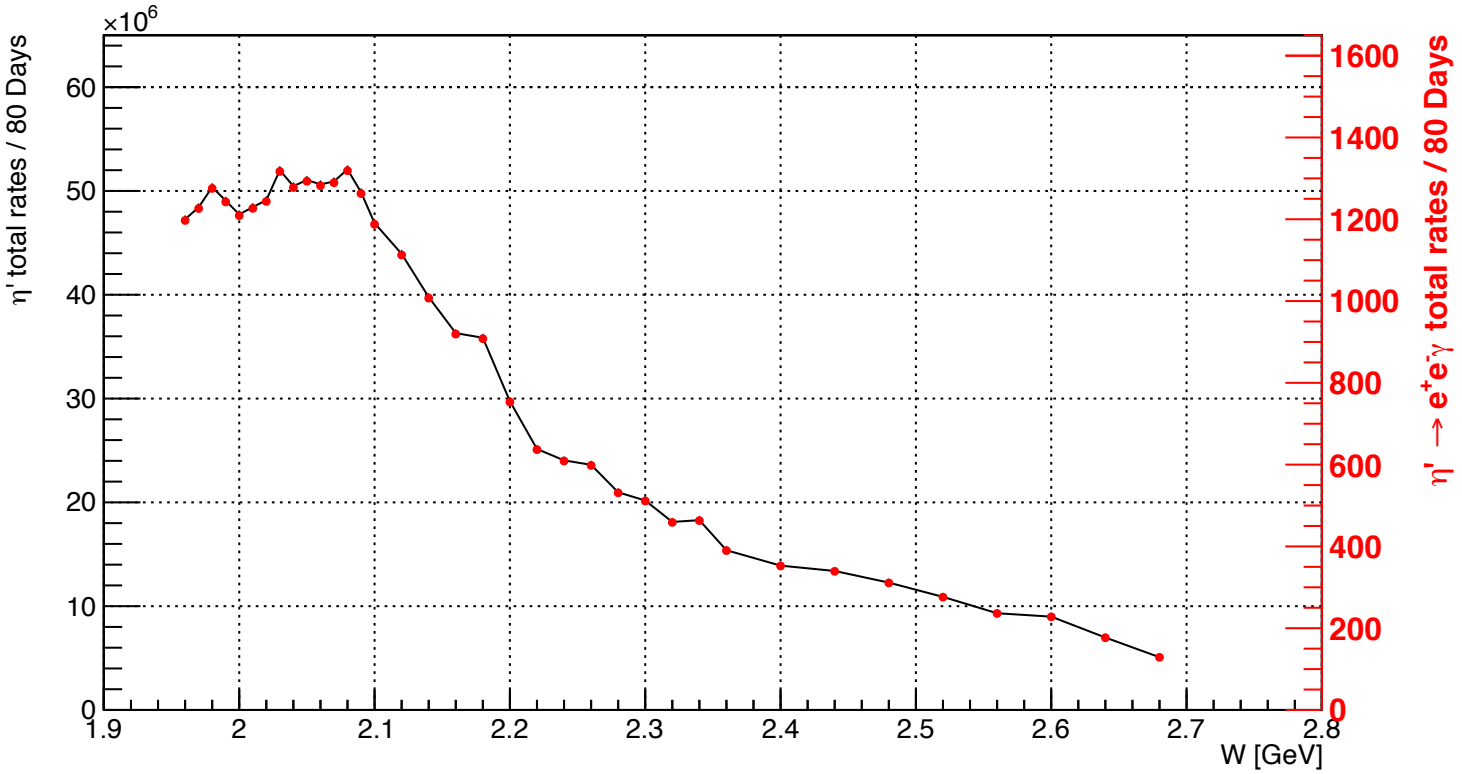


Reconstructed simulation

Acceptance appears mostly independent on input model

Future CLAS η' Rates

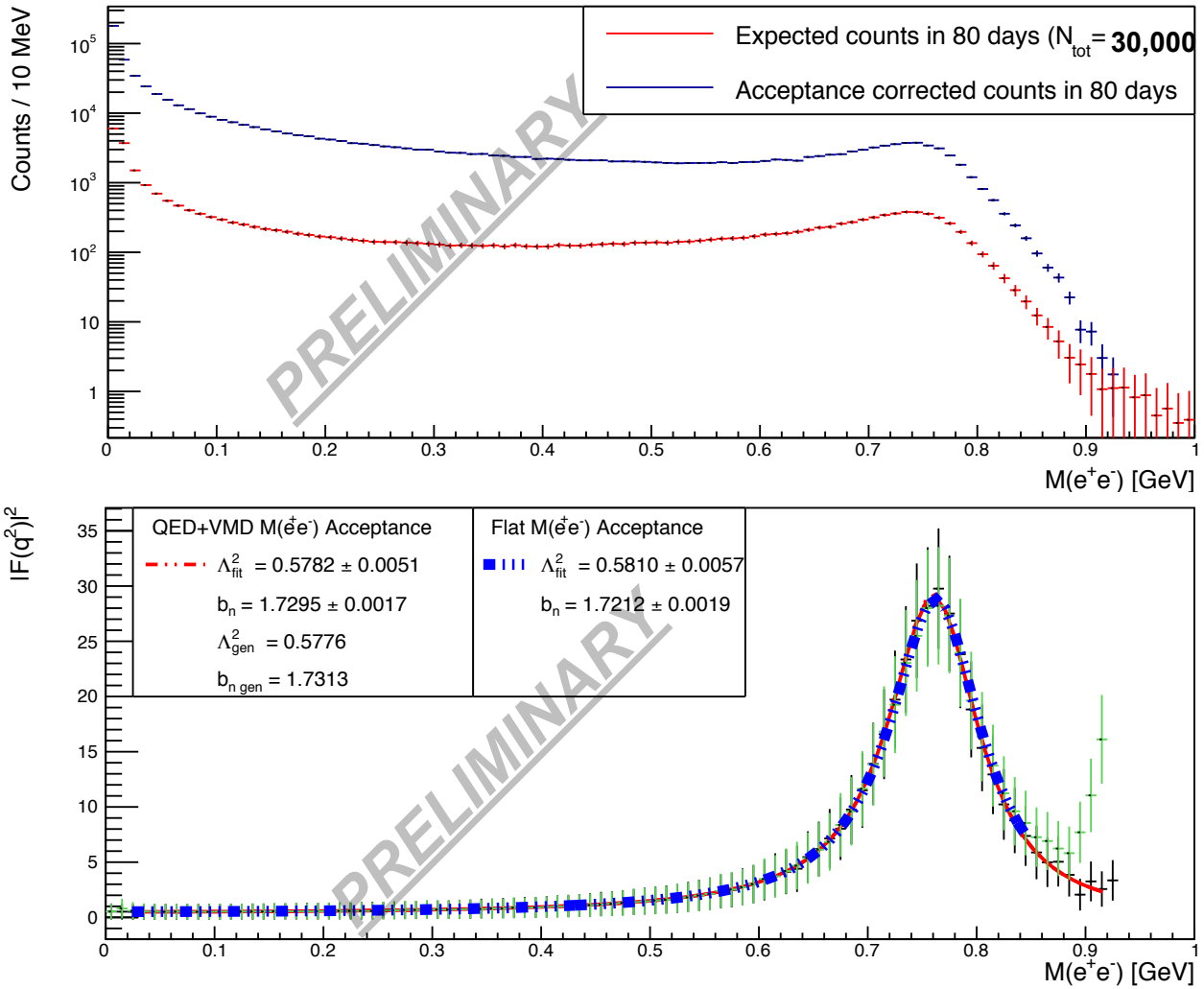
The rate for mesons in electro-production where the scattered electron is left undetected (W=1.9-2.7 GeV) is ~ 80kHz [1]



Within 80 days of beam-time, CLAS12 can accumulate ~30,000 events. 35 times more than current measurement.

[1]M. Sargsyan et al. CLAS-NOTE 90-007. Technical report, CLAS Technical Note, 1990

Possible future CLAS η' results



Within 100 days of beam-time CLAS can measure the η' transition form factor with a statistical uncertainty ~0.5%

Summary

- CLAS LMD: experimental data analysis of light meson decays
- Current statistics of CLAS data enables precise measurements of light meson decays including
  - $\pi^-\pi^+$ FSI within the anomalous decay $\eta(')\rightarrow\pi^-\pi^+\gamma$
  - Dalitz plot analysis
  - Transition form factors of pseudoscalar and vector mesons
- Future CLAS data:
  - Hadron transition form factors.
  - Branching ratios of meson conversion decays.
  - Fundamental properties of hadrons

BACKUPS

Dalitz Plot of $\eta \to \pi^-\pi^+\pi^0$

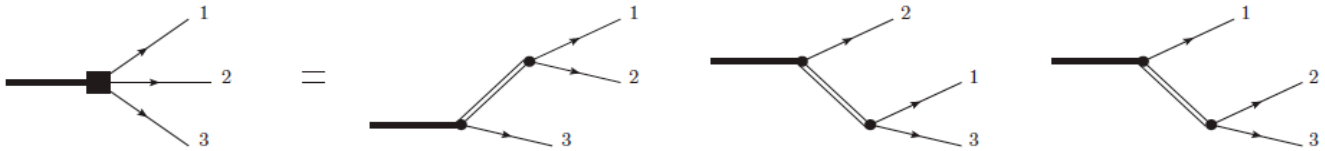
IKP: D. Lersch

JPAC: A. Szczepaniak, et. al.

Motivation:

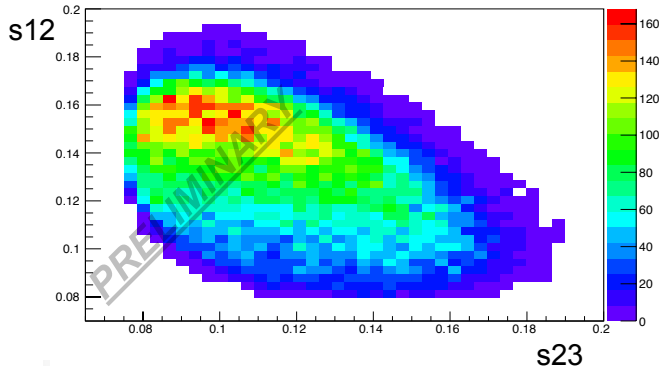
- $\eta \to \pi^-\pi^+\pi^0$ is sensitive to isospin breaking, which in QCD originates from the mass difference between the up and down quarks.

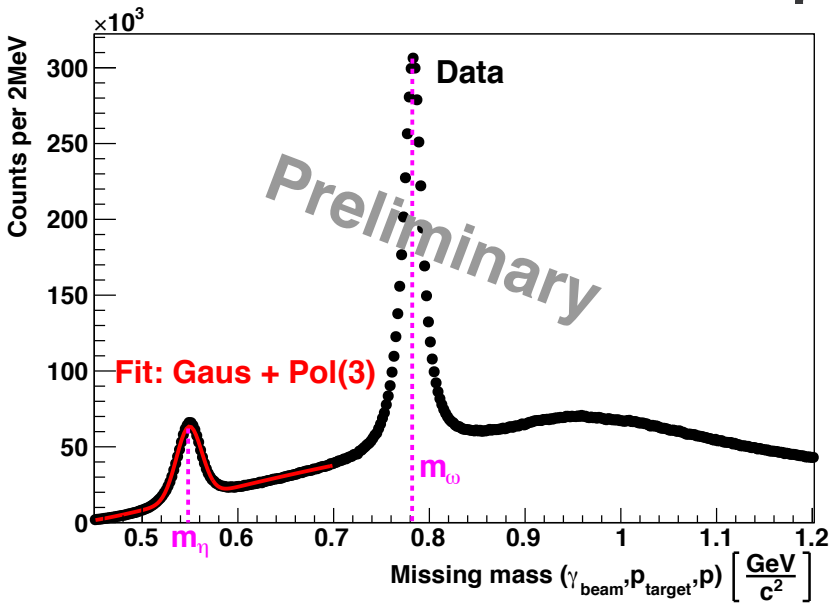
$$A(s,t) = \sum_J^{J_{max}} (2J+1)\, d^J_{1,0}(\theta_s)\, f_J(s) + \sum_J^{J_{max}} (2J+1)\, d^J_{1,0}(\theta_t)\, f_J(t) + \sum_J^{J_{max}} (2J+1)\, d^J_{1,0}(\theta_u)\, f_J(u)$$

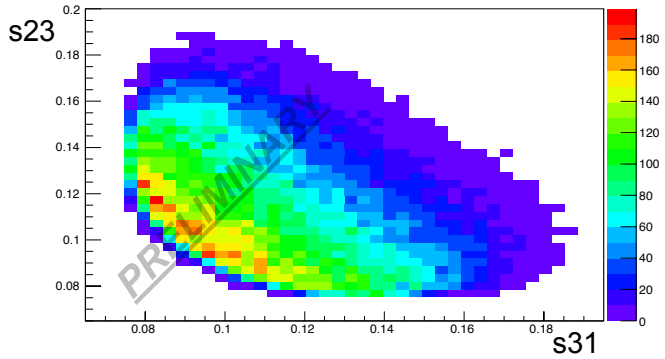


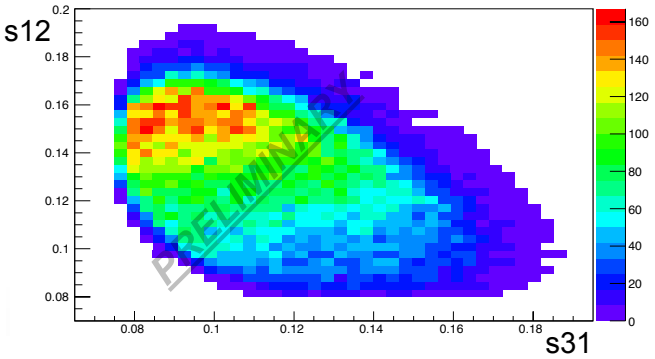
- The isobar model assumes quasi 2-body decay and is insufficient for some channels
- It is important to construct amplitudes which contain all the known physics such as 3-body interactions, coupled channel, unitarity, analyticity, etc.
- The $\eta \to \pi^-\pi^+\pi^0$ analysis is building in the three-body interaction (unitarity and analyticity) as a first step for future experimental analysis tools.

Dalitz Plot with CLAS g12 data



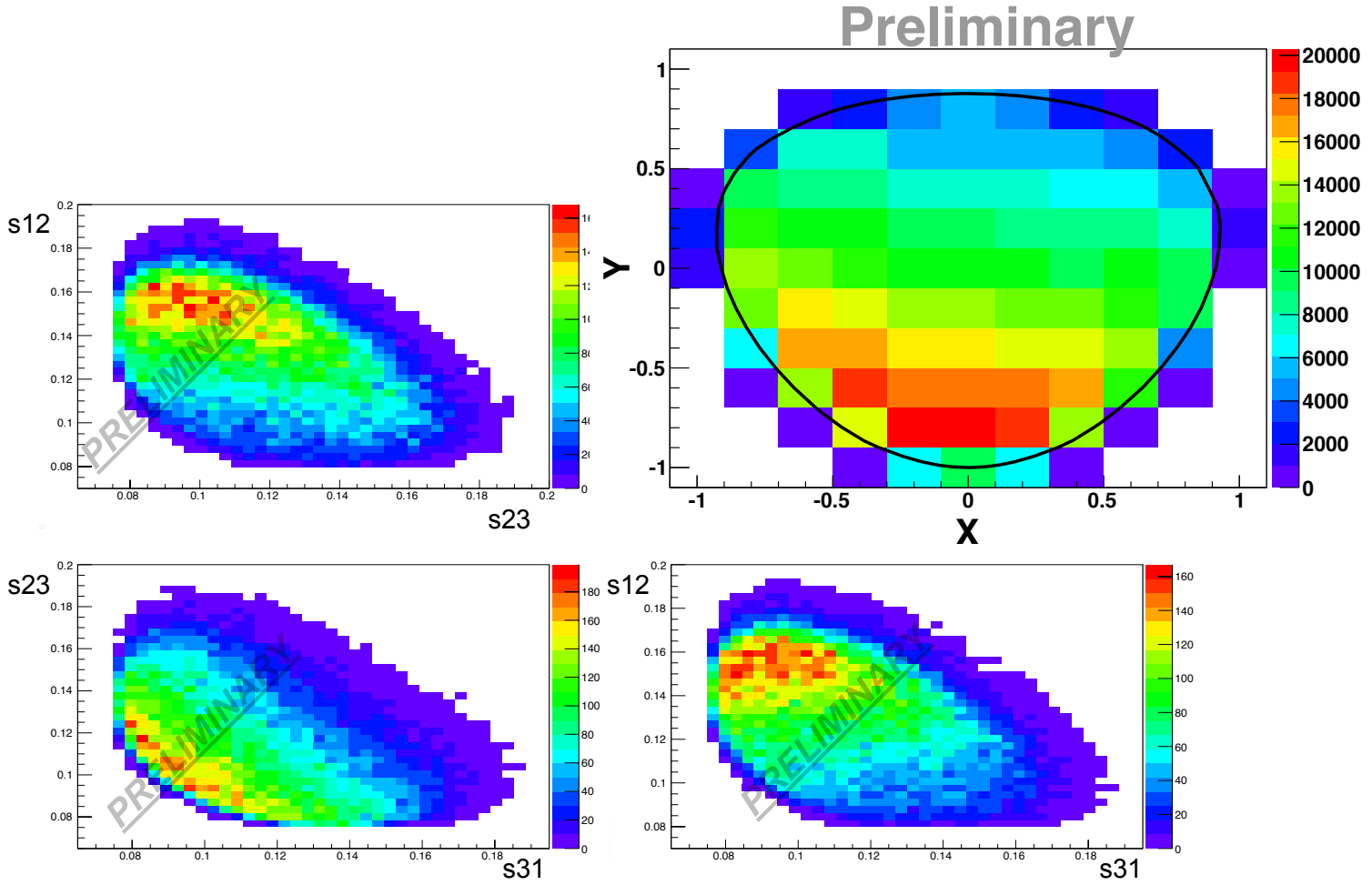






No resonances as expected

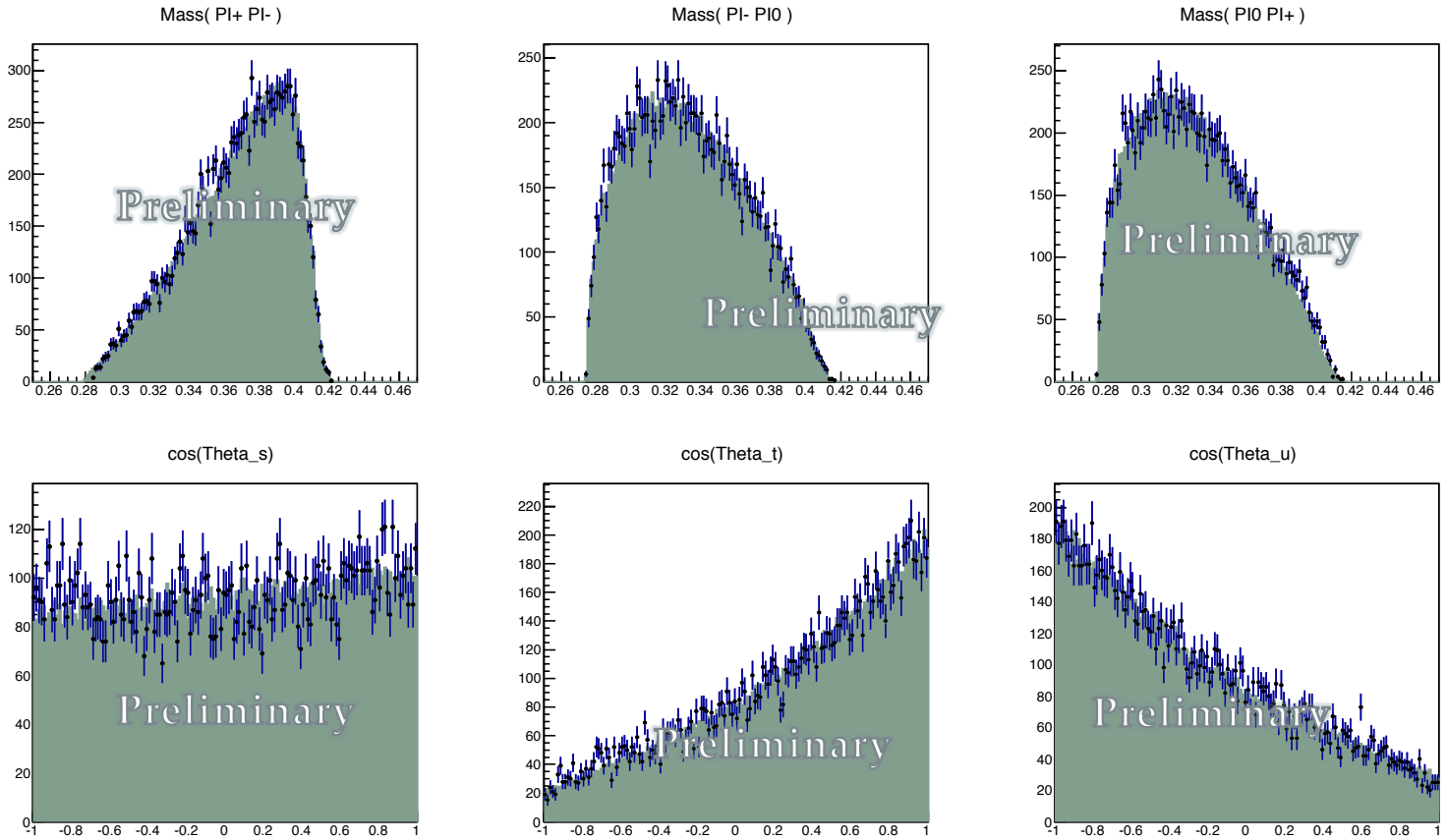
Dalitz Plot with CLAS g12 data



No resonances as expected

Dalitz Plot with g12 data

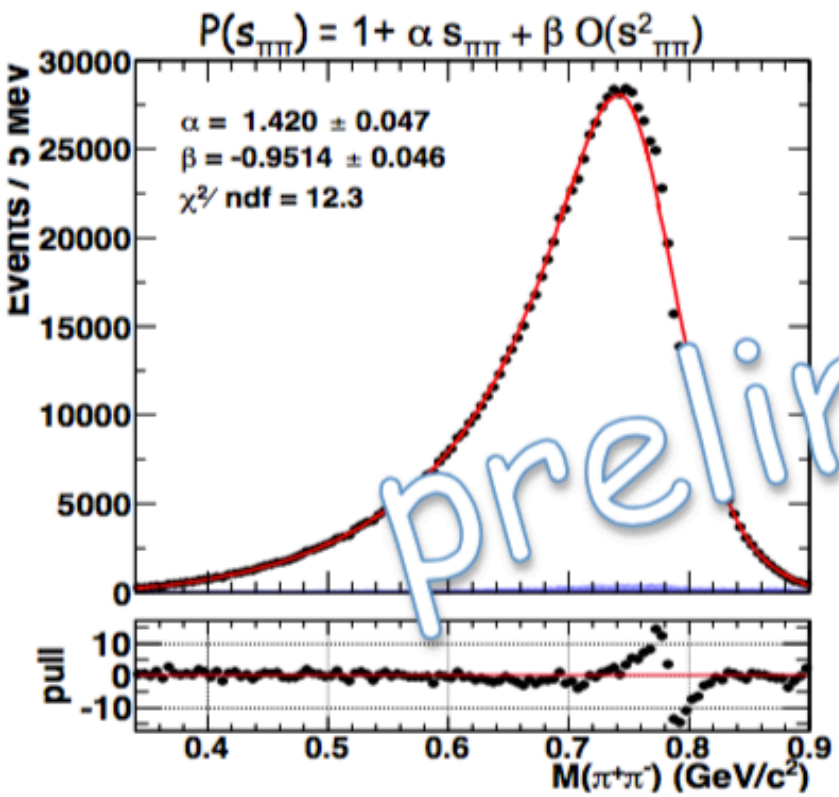
Fit after background subtraction

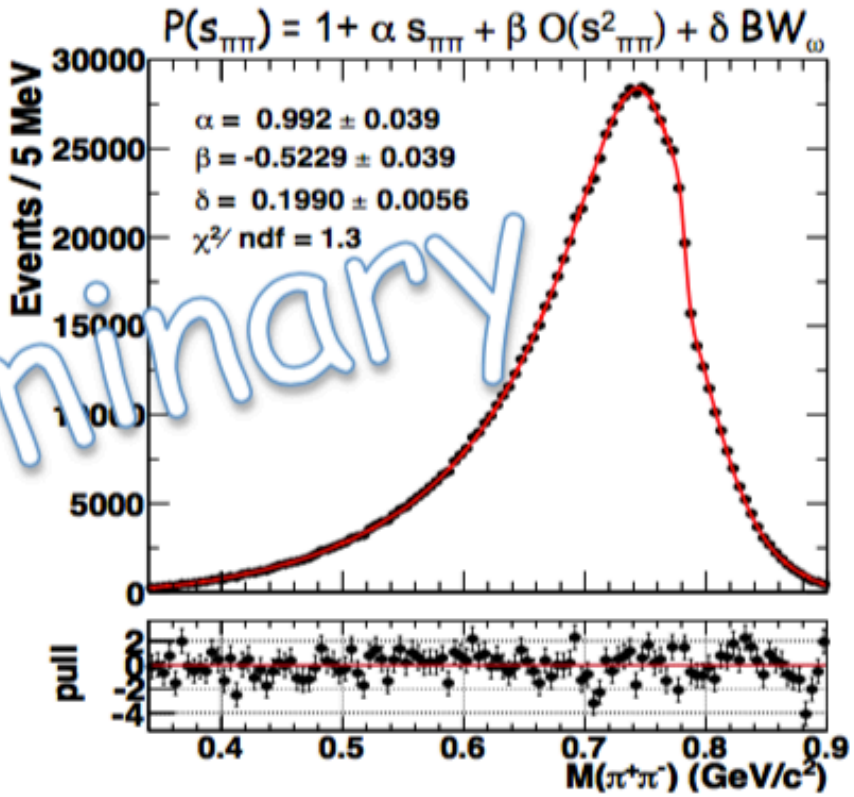


Points: CLAS data
Solid area: Model normalized to KLOE data

JPAC model fits wells to CLAS data

BACKUPS

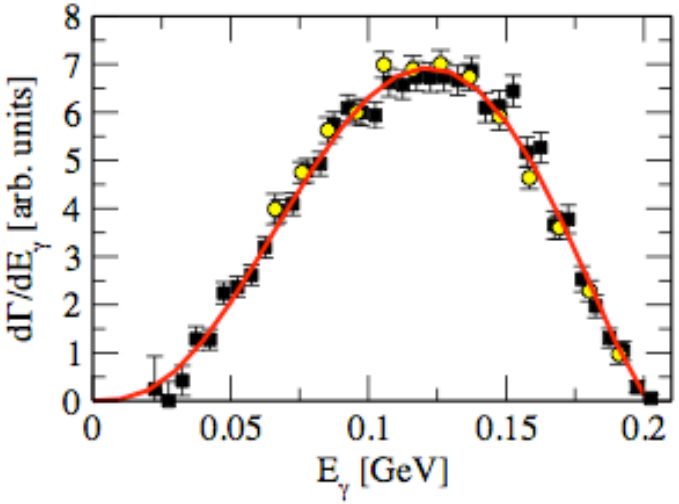




Experimental Results

WASA-at-COSY

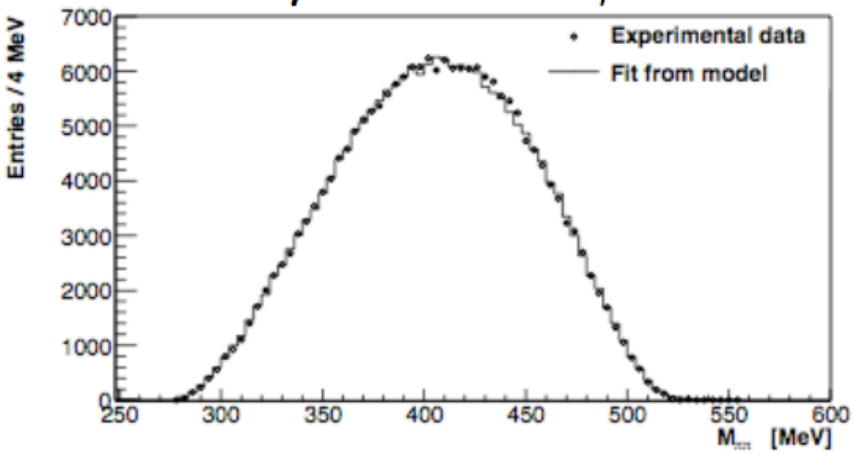
$\eta \to \pi^+\pi^-\gamma$



$\alpha = (1.89 \pm 0.25 \pm 0.59)\ \mathrm{GeV}^{-2}$ [1]

KLOE

$\eta \to \pi^+\pi^-\gamma$



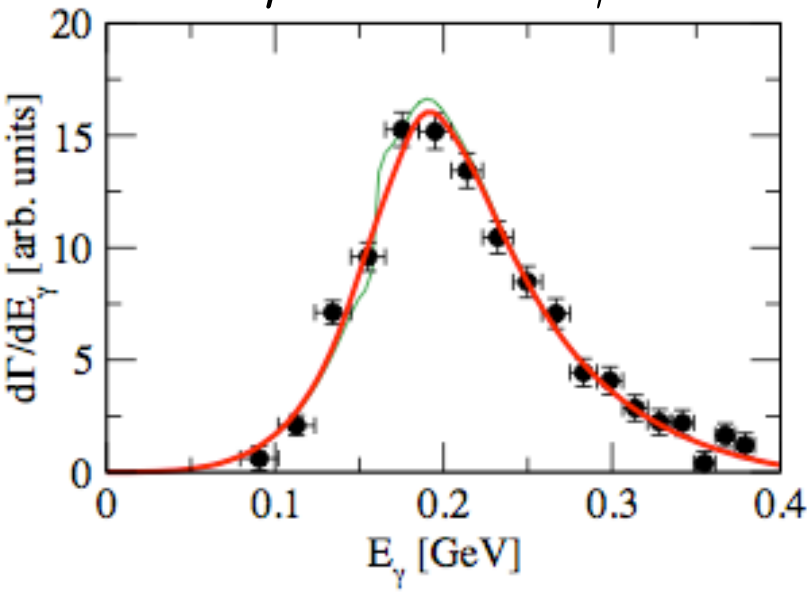
$\alpha = \left(1.32 \pm 0.08_{\mathrm{stat}}\ ^{+0.10}_{-0.09\ \mathrm{syst}} \pm 0.02_{\mathrm{theo}}\right) GeV^{-2}$[2]

$$s_{\pi\pi} = m^2 - 2E_\gamma m$$

[1]F.Stollenwerk et al., Phys. Lett. B707:184-190, 2012
[2]Phys.Lett. B718 (2013) 910-914

Experimental result from CRYSTAL BARREL at LEAR

$$\eta' \rightarrow \pi^+\pi^-\gamma$$



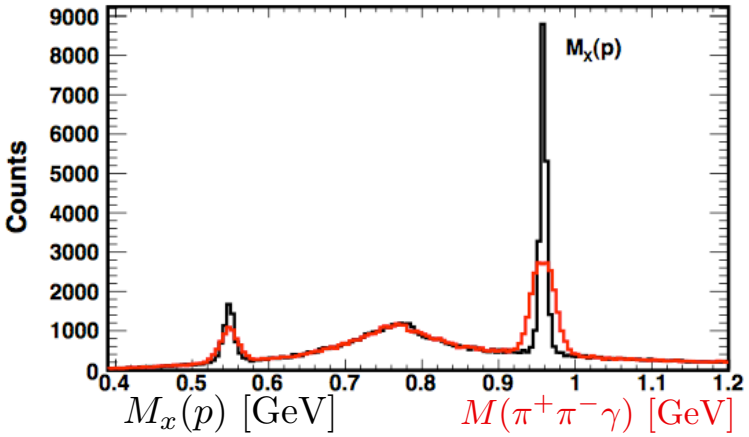
$$\alpha' = (1.8 \pm 0.49 \pm 0.04)\ \mathrm{GeV}^{-2} \quad [1]$$

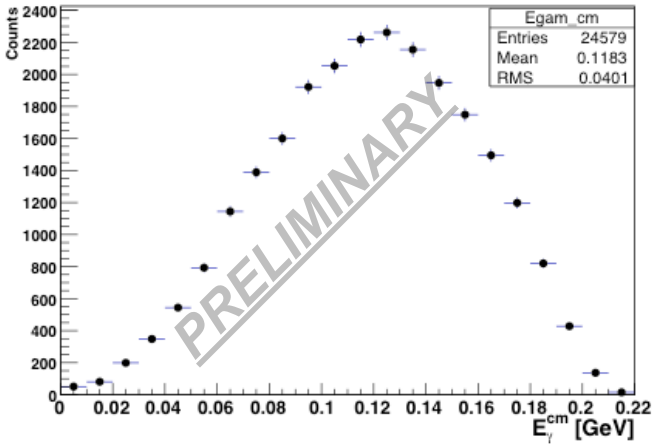
$$s_{\pi\pi} = m^2 - 2E_\gamma m$$

[1]A. Abele et al. Phys.Lett. B402, 195 (1997).

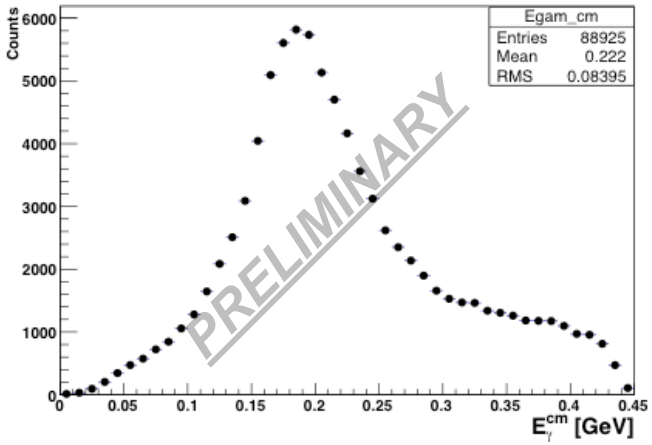
CLAS Uncorrected Data

CLAS data yield for γp→p{η,η'→π+ π- γ} *from g11 data set*





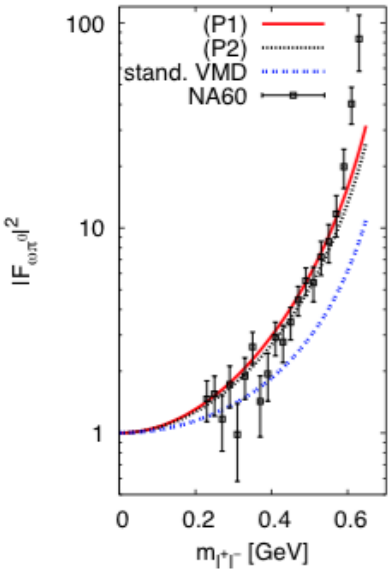
$\eta \to \pi^+\pi^-\gamma$



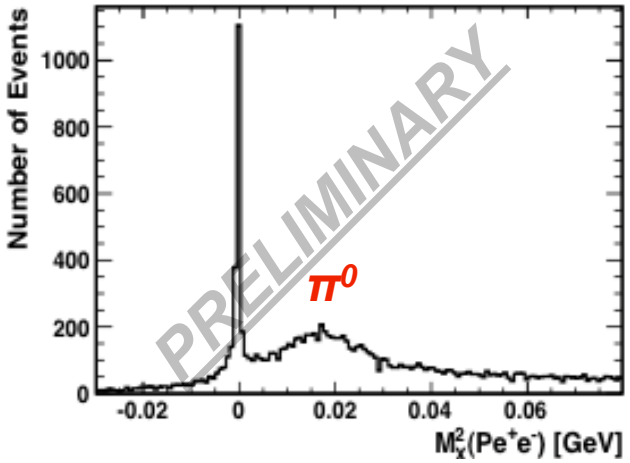
$\eta' \to \pi^+\pi^-\gamma$

ω Transition Form Factor

$$\frac{d\Gamma_{\omega\to l^+l^-\pi^0}}{dq^2 d\Gamma_{\omega\to\pi^0\gamma}} = \frac{\alpha}{3\pi q^2}\left(\left(1+\frac{q^2}{m_\omega^2-m_{\pi^0}^2}\right)^2 - \frac{4m_\omega^2 q^2}{m_\omega^2-m_{\pi^0}^2}\right)^{\frac{3}{2}}\left(1-\frac{4m_l^2}{q^2}\right)^{1/2}\left(1+\frac{2m_l^2}{q^2}\right)|\text{Q.E.D}$$

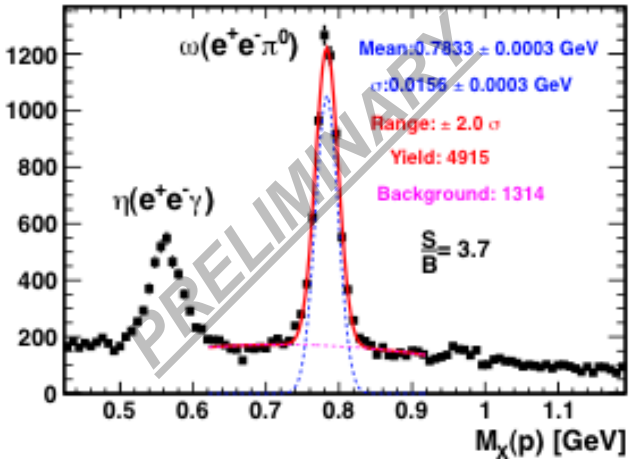


Recent results the ω transition form factor. Image Source: Conference Proceedings



CLAS data yield from $\gamma p \to p e^+ e^- X$ with $M_x(p) = M_\omega \pm 0.031$ GeV

CLAS data yield from $\gamma p \to p X$ with $M^2_x(pe^+e^-) = M^2_{\pi 0} \pm 0.01$ GeV^2



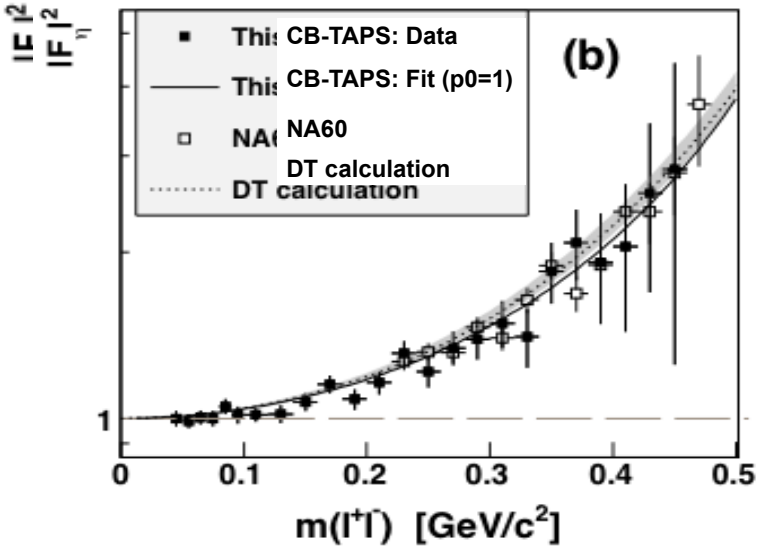
η Transition Form Factors

$$\frac{d\Gamma_{P\to l^+l^-\gamma}}{dq^2 d\Gamma_{P\to\gamma\gamma}} = \frac{2\alpha}{3\pi q^2}\left(1-\frac{q^2}{m_P^2}\right)^3\left(1-\frac{4m_l^2}{q^2}\right)^{1/2}\left(1+\frac{2m_l^2}{q^2}\right)|_{\text{Q.E.D}}$$

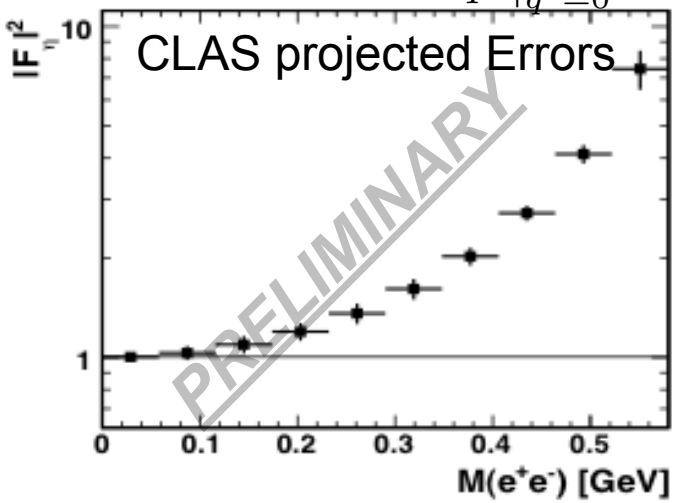
$$F(q^2) = [1-\frac{q^2}{\Lambda^2}]^{-1}$$

$$\frac{d\Gamma_{P_{P\to l^+l^-\gamma}}}{dq^2 d\Gamma_{P_{P\to\gamma\gamma}}}|_{\text{measured}} = \frac{d\Gamma_{P_{P\to l^+l^-\gamma}}}{dq^2\Gamma_{P\to\gamma\gamma}}|_{\text{Q.E.D}}\left|F(q^2)\right|^2$$

$$\langle r\rangle = \left.\frac{dF}{dq^2}\right|_{q^2=0}$$



Recent results the η transition form factor with errors. Image Source: Phys. Rev. C 89, 044608



CLAS projected errors on η transition form factor