What Can be Learned from Decay of Light Mesons ?

Moskov Amaryan

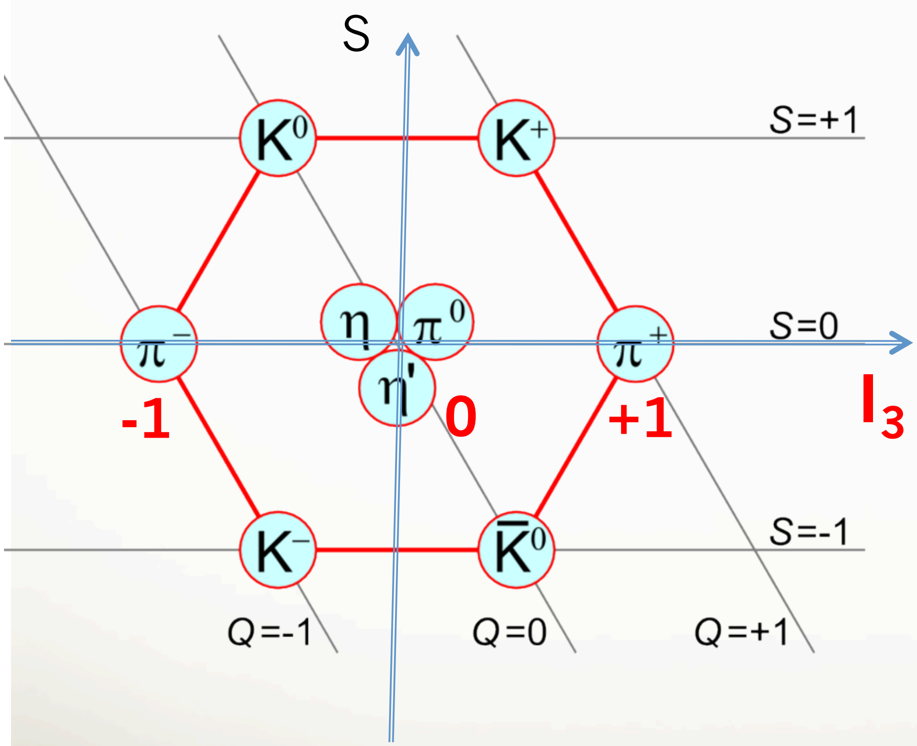
November 14, 2012

Outline

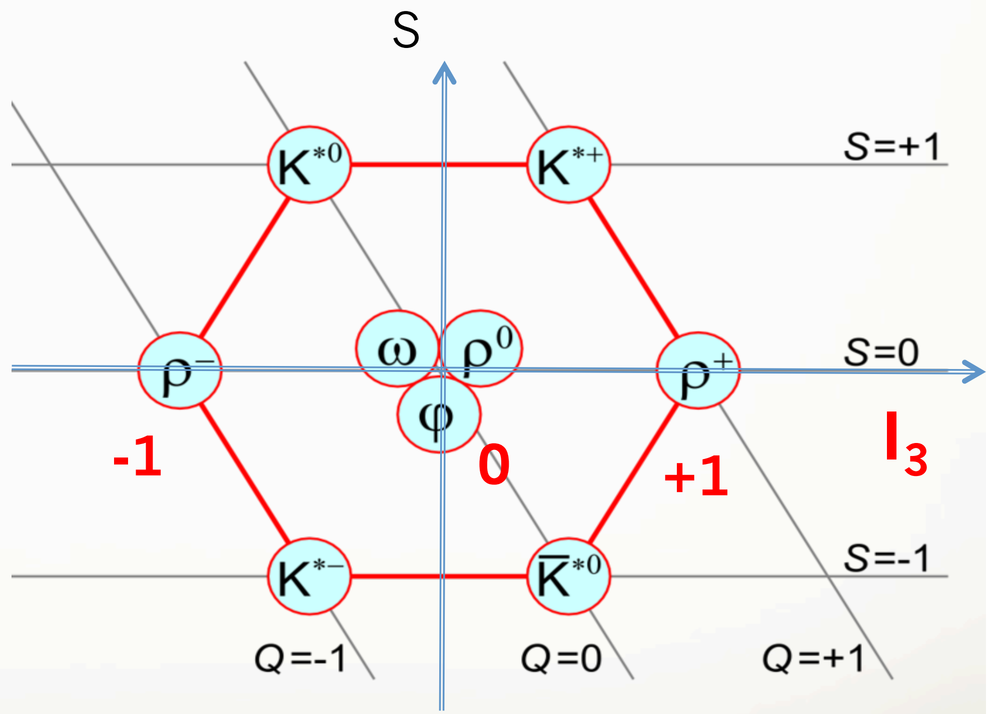
- -Introduction
- -Dalitz Decays
- -Radiative Decays
- -Hadronic Decays
- -Summary

Light (u,d,s) Mesons (not all)

Pseudoscalar $J^P=0^-$



Vector $J^P=1^-$



Parity	$P=(-1)^{L+1}$
C-parity	$C=(-1)^{L+S}$
G-parity	$G=C(-1)^I=(-1)^{L+S+I}$

Gell-Mann-Nishidjima:

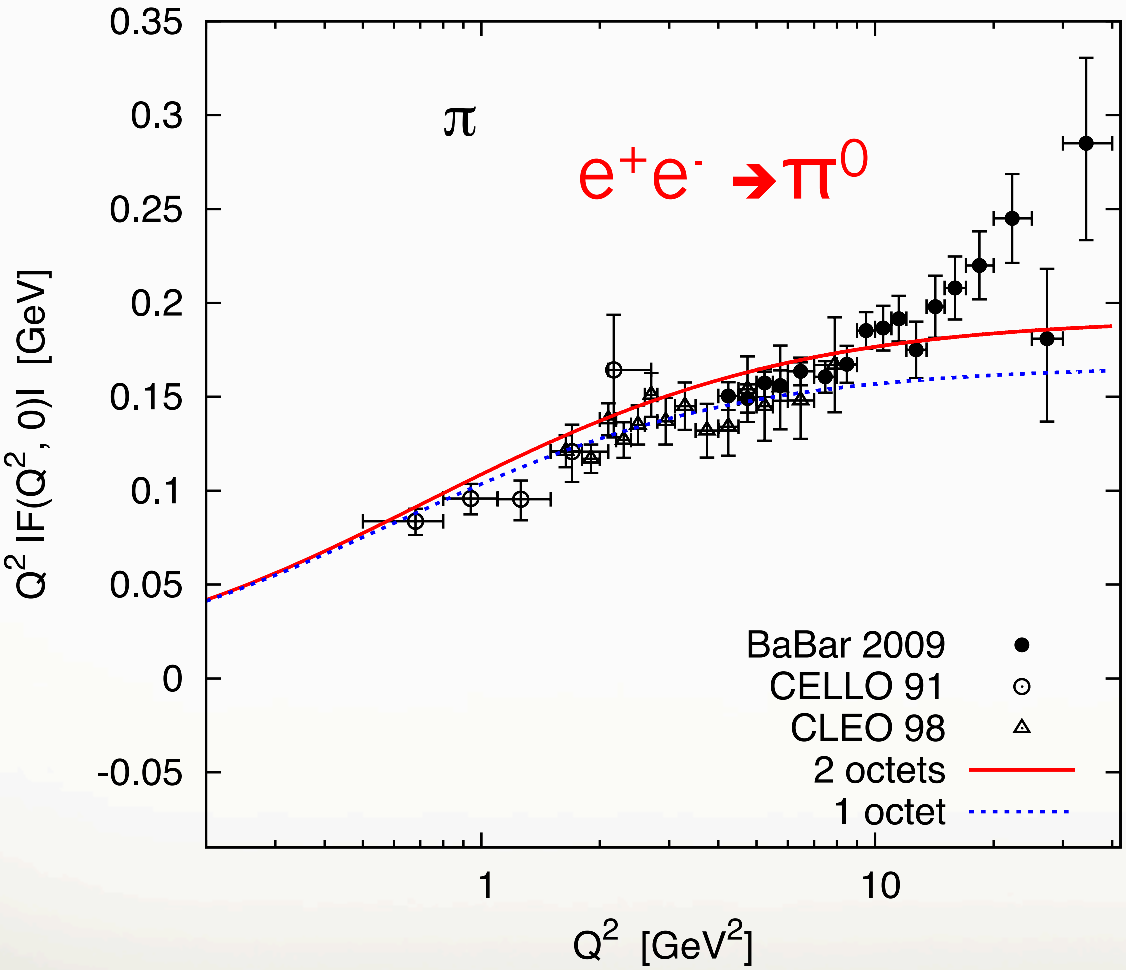
$$Q=I_3+Y/2$$

$$Y=B+S$$

Light Mesons in CLAS

π^0	$e^+e^-\gamma$				
η	$e^+e^-\gamma$	$\pi^+\pi^-\gamma$	$\pi^+\pi^-\pi^0$		
η'	$e^+e^-\gamma$	$\pi^+\pi^-\gamma$	$\pi^+\pi^-\pi^0$	$\pi^+\pi^-\eta$	
ρ		$\pi^+\pi^-\gamma$			
ω	$e^+e^-\pi^0$	$\pi^+\pi^-\gamma$	$\pi^+\pi^-\pi^0$		
φ			$\pi^+\pi^-\pi^0$	$\pi^+\pi^-\eta$	

Space-Like Form Factor



$F(Q^2) \sim 1 + a_\pi Q^2$

Well measured at $Q^2 > 0.5\,\text{GeV}^2$

$a_\pi = 0.0309 \pm 0.0008 \pm 0.0009$ (CLEO)

Time-Like Form Factor $\pi^0 \to e^+e^-\gamma$

The slope is measured with very large errors:

$$a_\pi = -0.11 \pm 0.03 \pm 0.08 \quad [2]$$
$$a_\pi = +0.026 \pm 0.024 \pm 0.0048 \quad [3]$$
$$a_\pi = +0.025 \pm 0.014 \pm 0.026 \quad [4]$$

Here a_π is defined from the following expression for the decay rate [5]

$$\frac{d\Gamma(\pi^0 \to e^+e^-\gamma)}{dx\Gamma(\pi^0 \to \gamma\gamma)} = (\frac{d\Gamma}{dx})_{QED} \times |F(x)|^2$$

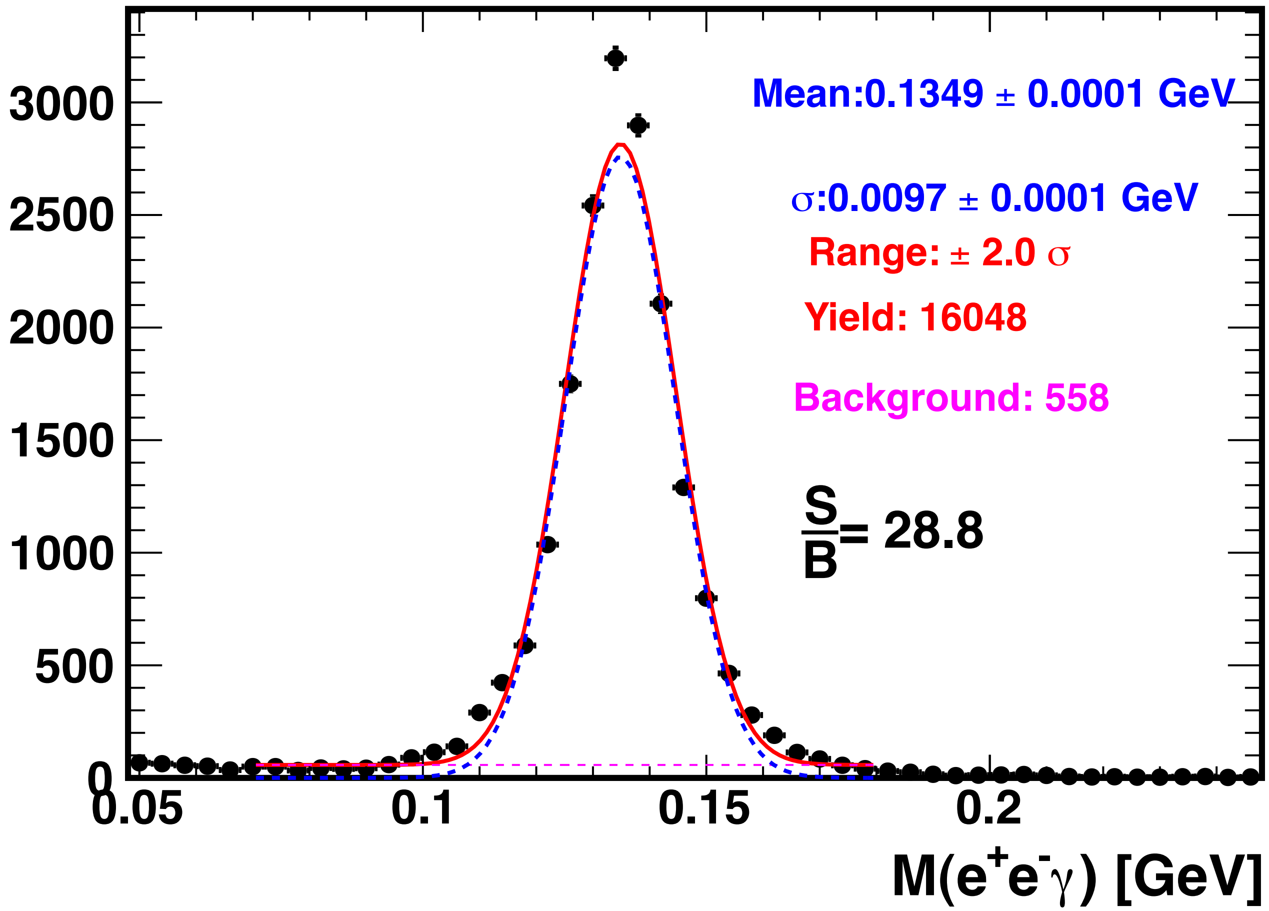
(Kroll-Wada)

$$(\frac{d\Gamma}{dx})_{QED} = \frac{2\alpha}{3\pi}\frac{1}{x}(1-x)^3(1+\frac{r}{2x})(1-\frac{r}{x})^{1/2}$$
$$F(x) = 1 + a_\pi x$$

where $x = m^2_{e^+e^-}/m^2_{\pi^0}$, $r = 4m_e^2/m^2_{\pi^0}$, and $F(x)$ is π^0 transition form factor.

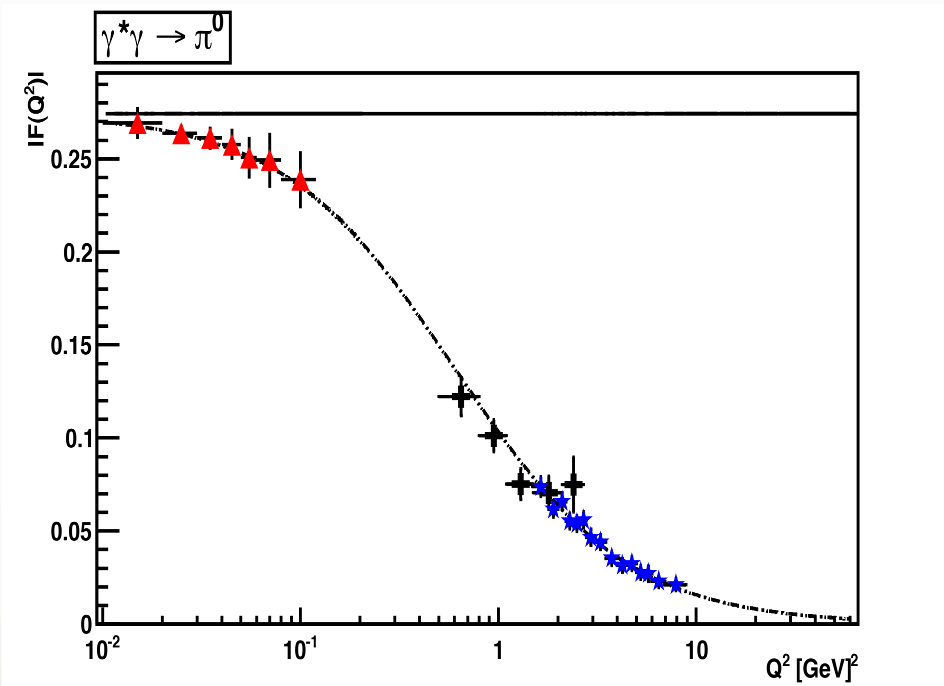
[2] H. Fonvieille, N. Bensayah, J. Berthot, P. Bertin, M. Crouau, et al., Phys.Lett. **B233**, 65 (1989).
[3] F. Farzanpay, P. Gumplinger, A. Stetz, J. Poutissou, I. Blevis, et al., Phys.Lett. **B278**, 413 (1992).
[4] R. Meijer Drees et al. (SINDRUM-I Collaboration), Phys.Rev. **D45**, 1439 (1992).

CLAS g12 Data

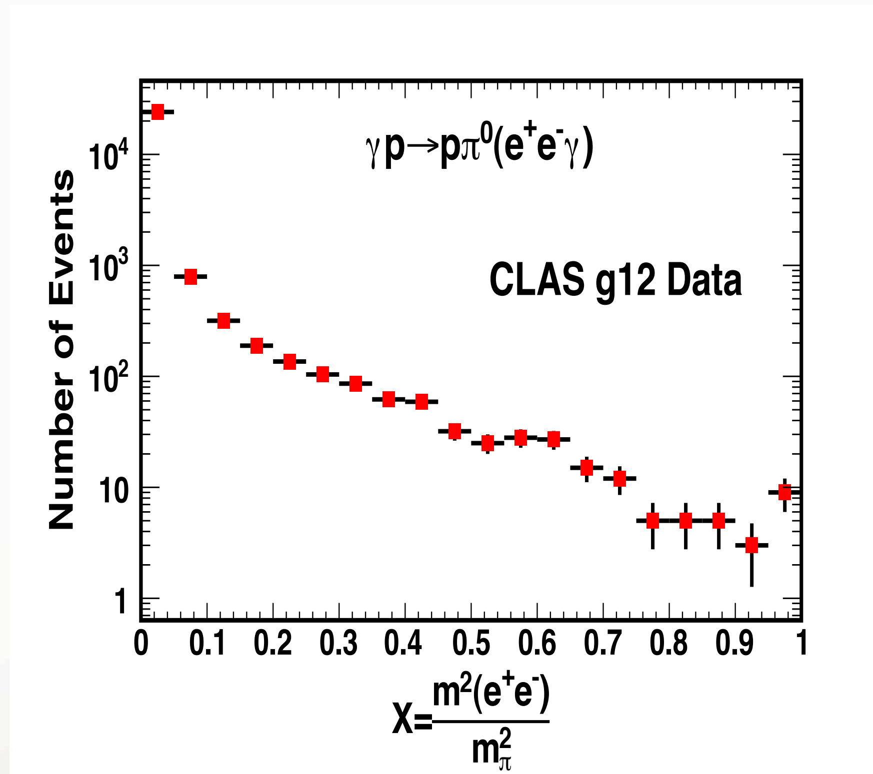


Transition Form Factor

KLOE-2 Proposal



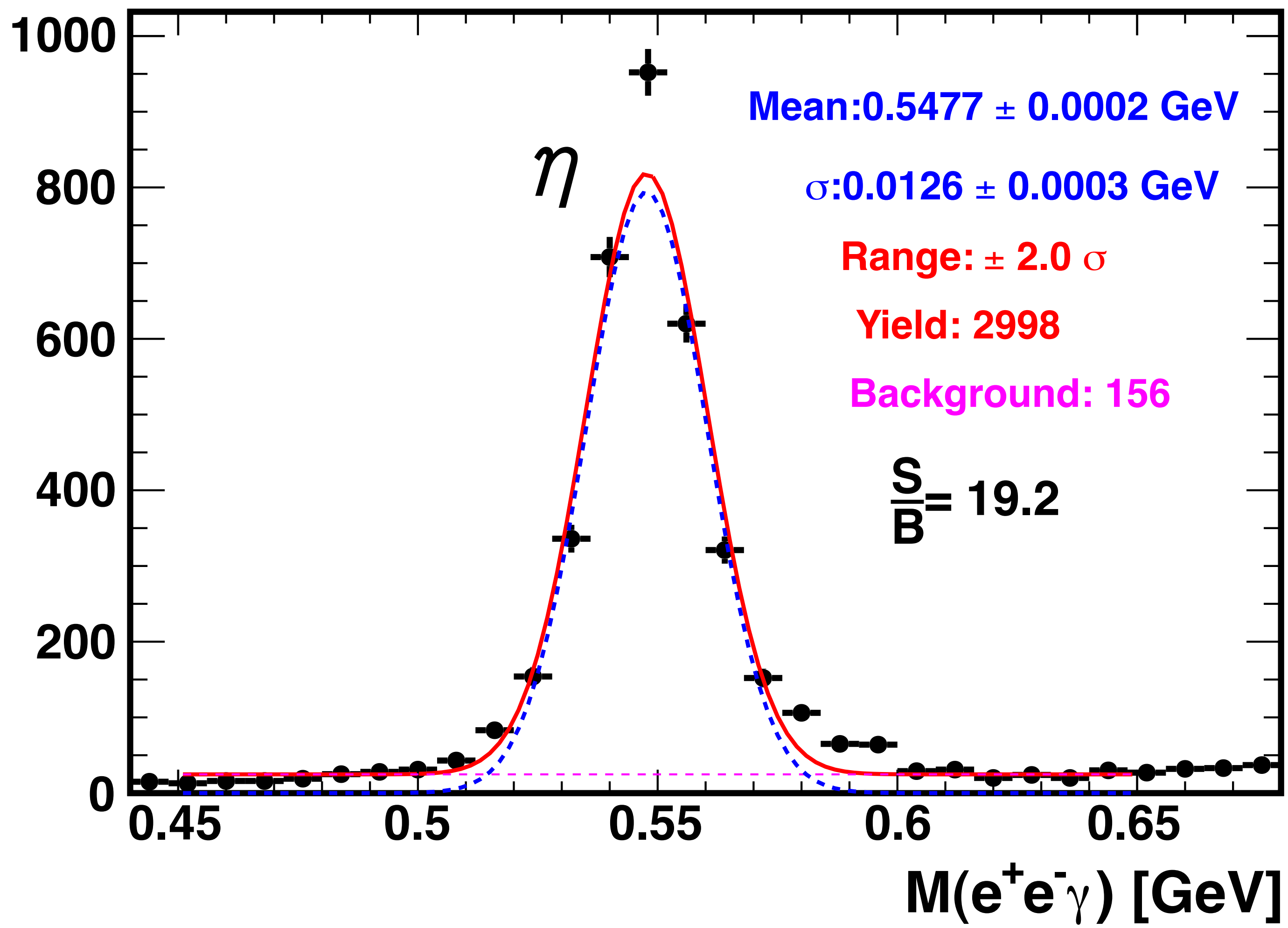
CLAS g12 Data



CLAS at JLAB accumulated unprecedented statistics for precision measurement of TFF slope!

Important for LbyL radiative corrections to Anomalous Magnetic Moment of Muon g-2

CLAS g12 Data



Time-Like Form Factor of η

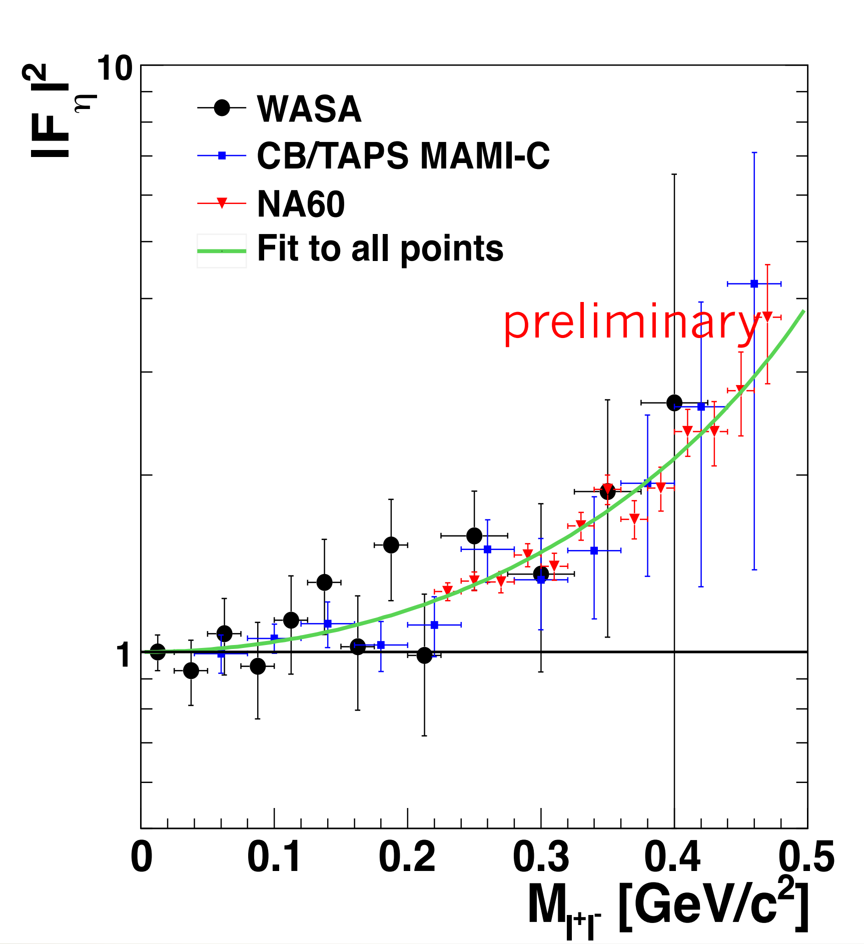
$$\frac{d\Gamma(\eta \to l^+ l^- \gamma)}{dm\Gamma(\eta \to \gamma\gamma)} = [QED] \cdot |F_\eta(m^2)|^2$$

$$F(m^2) = \frac{1}{1 - \frac{m^2}{\Lambda^2}}$$

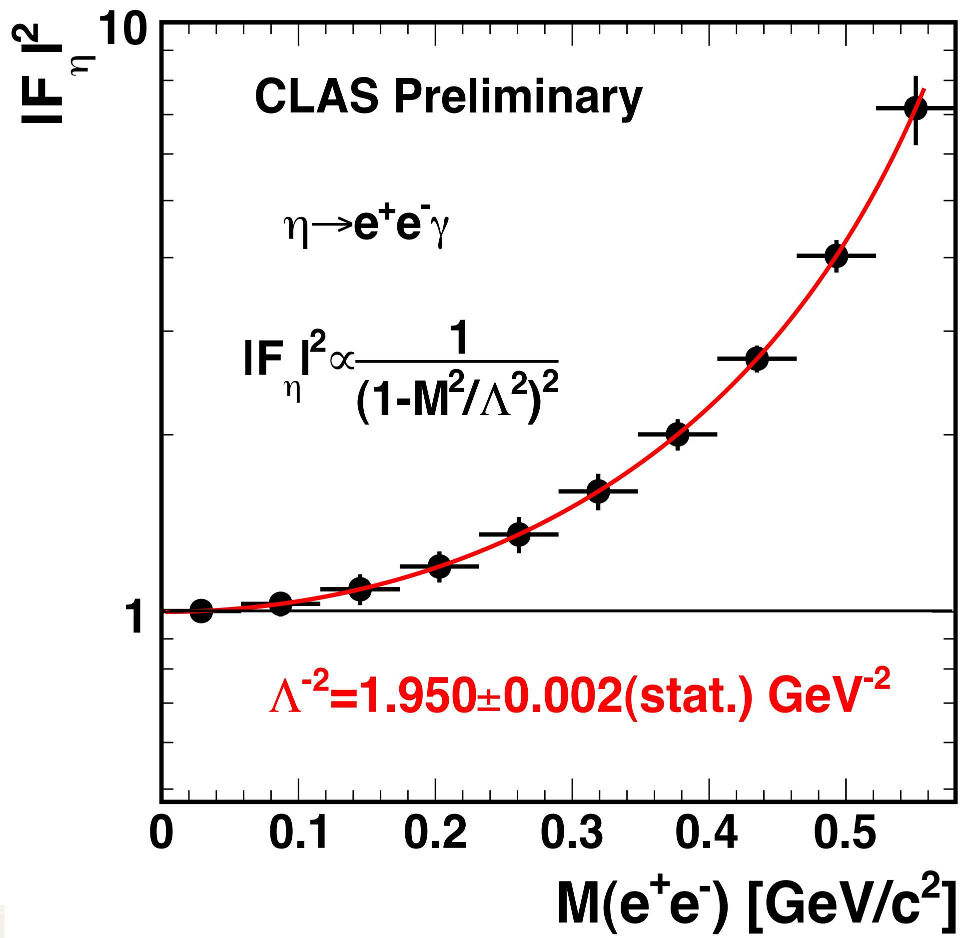
$$b = |\frac{dF}{dm^2}|_{m^2=0} = \Lambda^{-2}$$

b=<r^2>/6 (size of η)

World Data



CLAS g12 Data

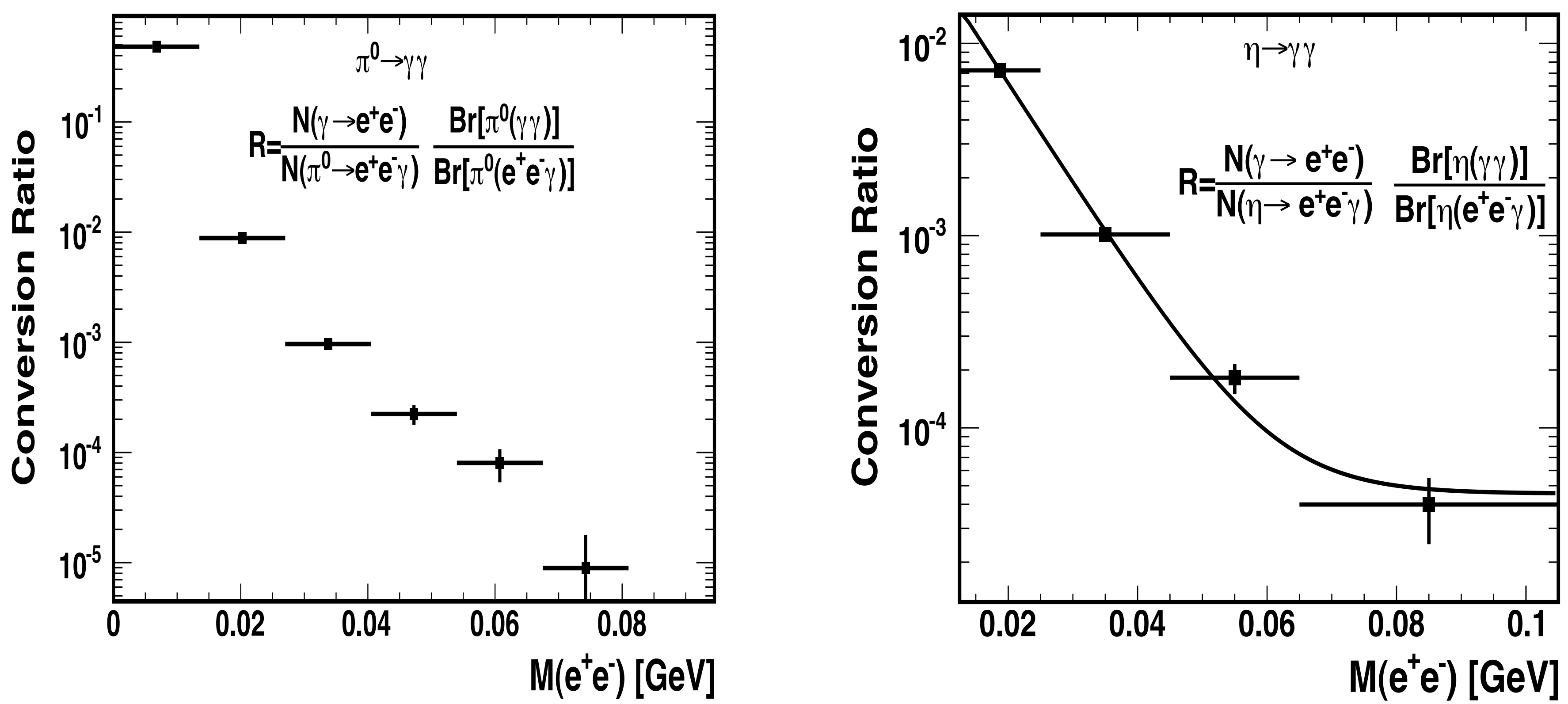


CB/TAPS $\Lambda^{-2} = 1.92 \pm 0.35(stat.) \pm 0.13(syst.) \quad GeV^{-2}$

NA60 $\Lambda^{-2} = 1.95 \pm 0.17(stat.) \pm 0.05(syst.) \quad GeV^{-2}$

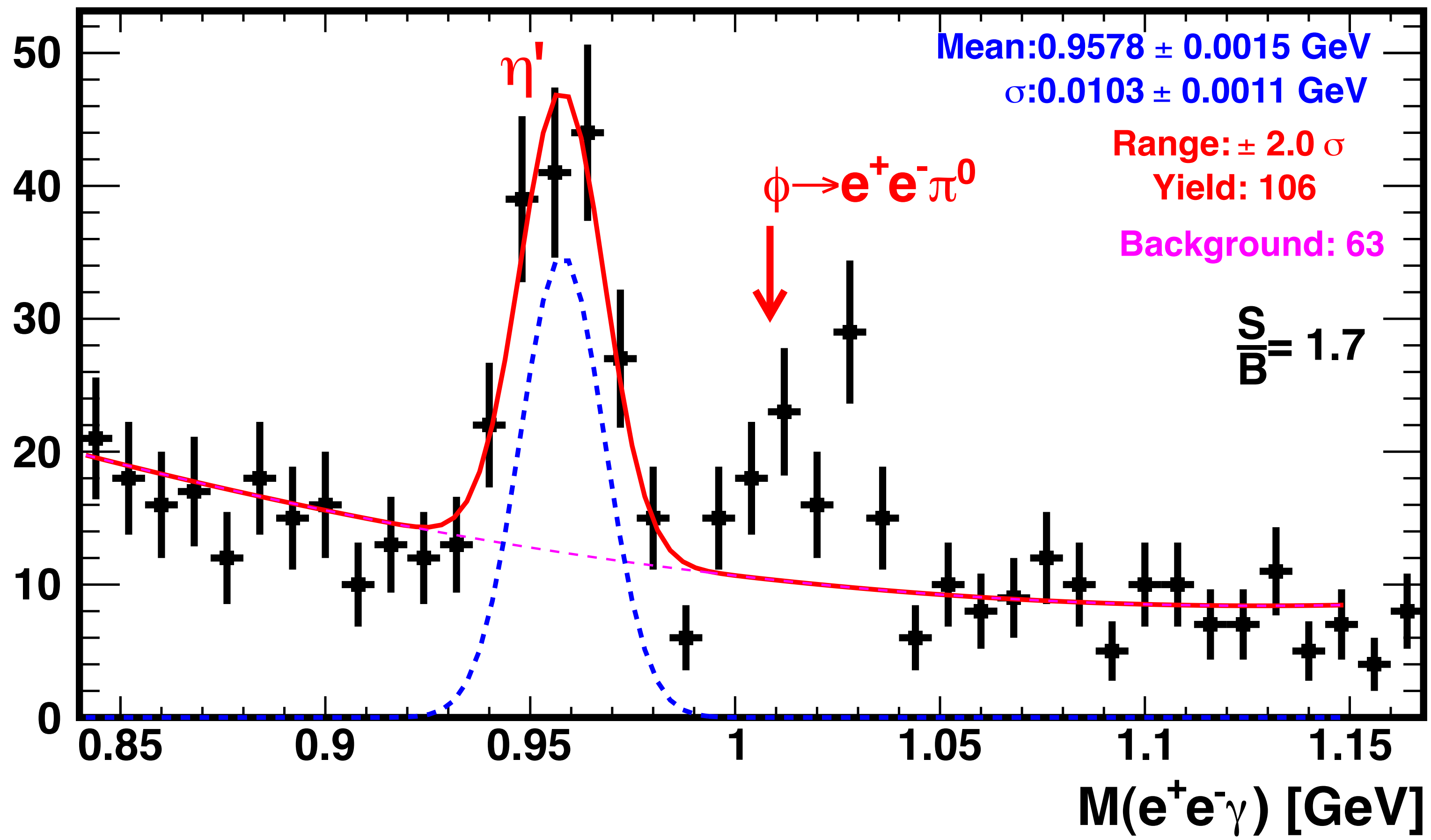
CLAS syst. err. ~ 0.05 (preliminary)

Photon Conversion in CLAS (MC Simulation)



Photon conversion contribution is <1%
(except for first bin for π^0)

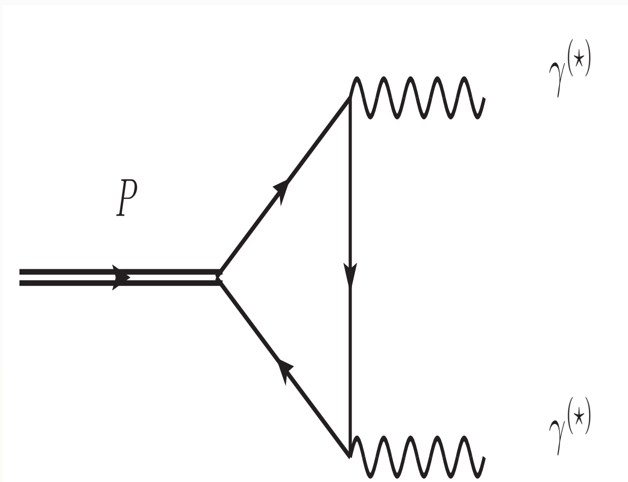
First measurement of Dalitz Decay of eta' from CLAS

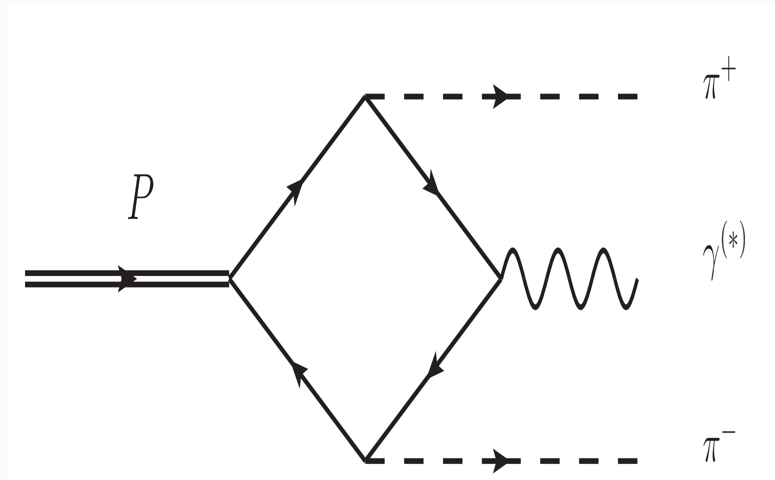


Radiative Decay $\eta(\eta') \to \pi^+\pi^-\gamma$

Why is it interesting?

Access to Box Anomaly





Triangle (PVV)

Box (VPPP)

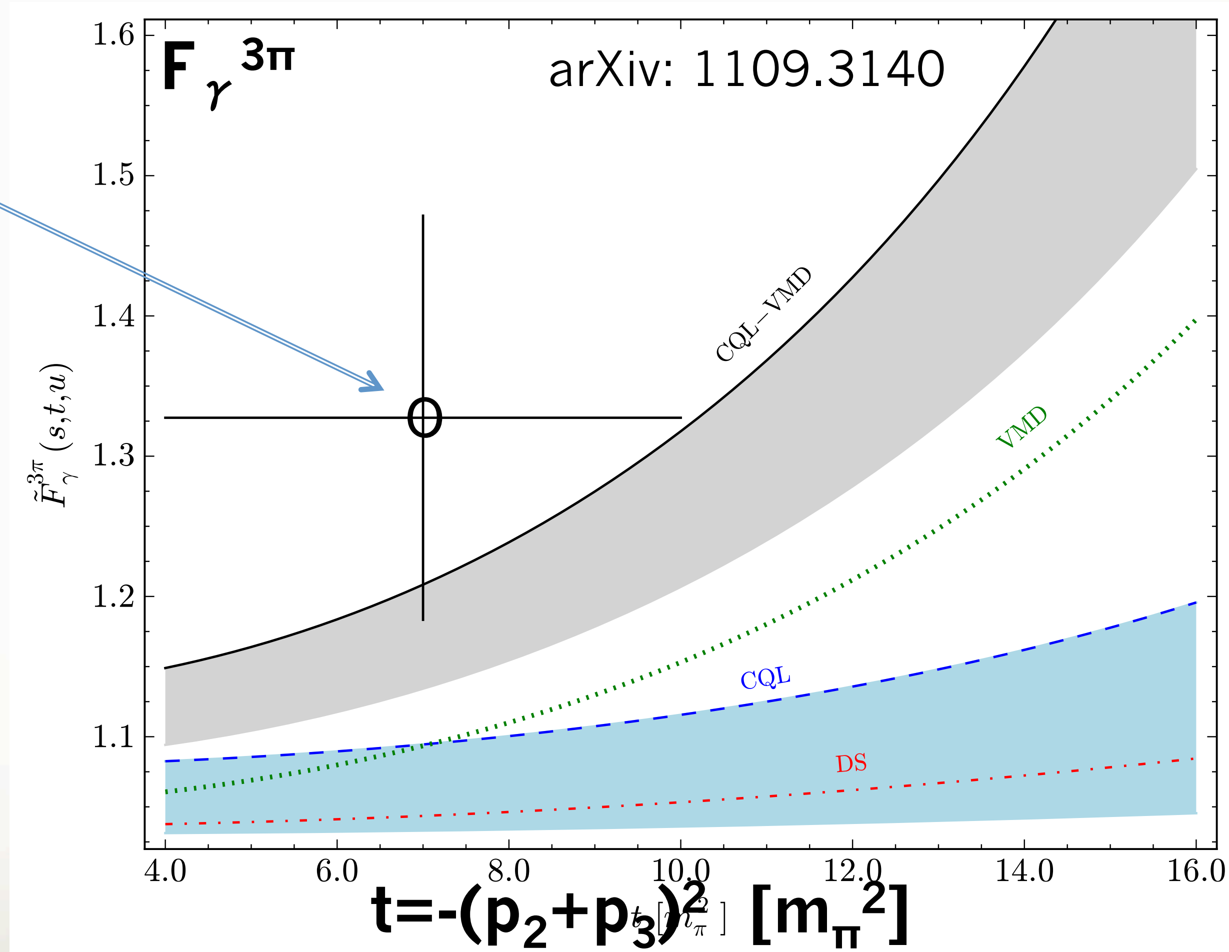
It gives an access to the box anomaly term of Wess-Zumino-Witten Lagrangian

Also via Primakoff effect in COMPASS experiment (long standing problem)

$$\pi^-\gamma \to \pi^-\pi^0$$

Box Anomaly $\gamma\pi^- \rightarrow \pi^-\pi^0$

Y.M. Antipov et al., PRD 36(1987), 21



$$A_\pi^{2\gamma} = \frac{e^2 N_c}{12\pi^2 f_\pi}$$

Constrained by $\gamma\,\gamma$ width of π^0

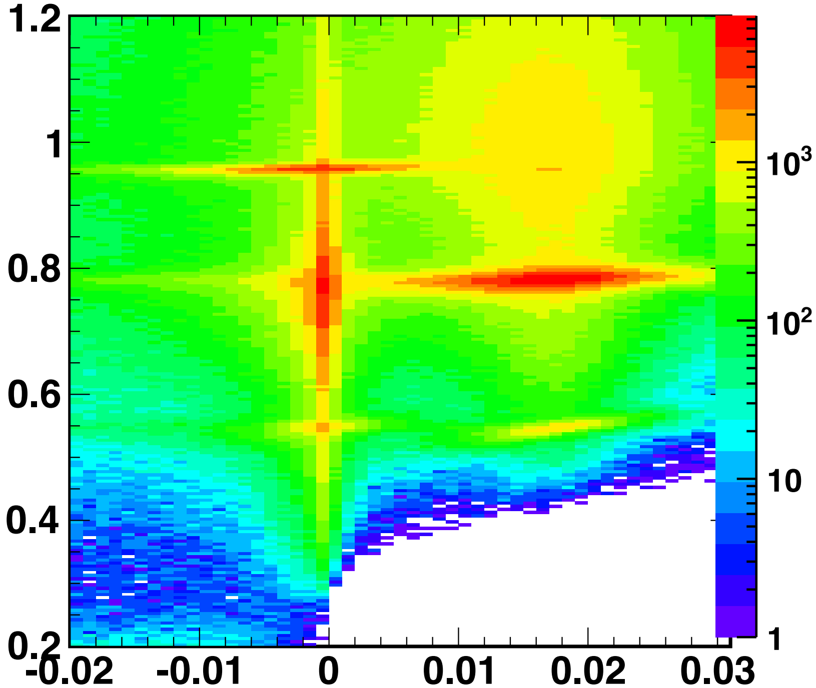
$$A_\pi^{2\gamma} = e f_\pi^2 A_\gamma^{3\pi}$$

(theory prediction)

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

Very poorly measured

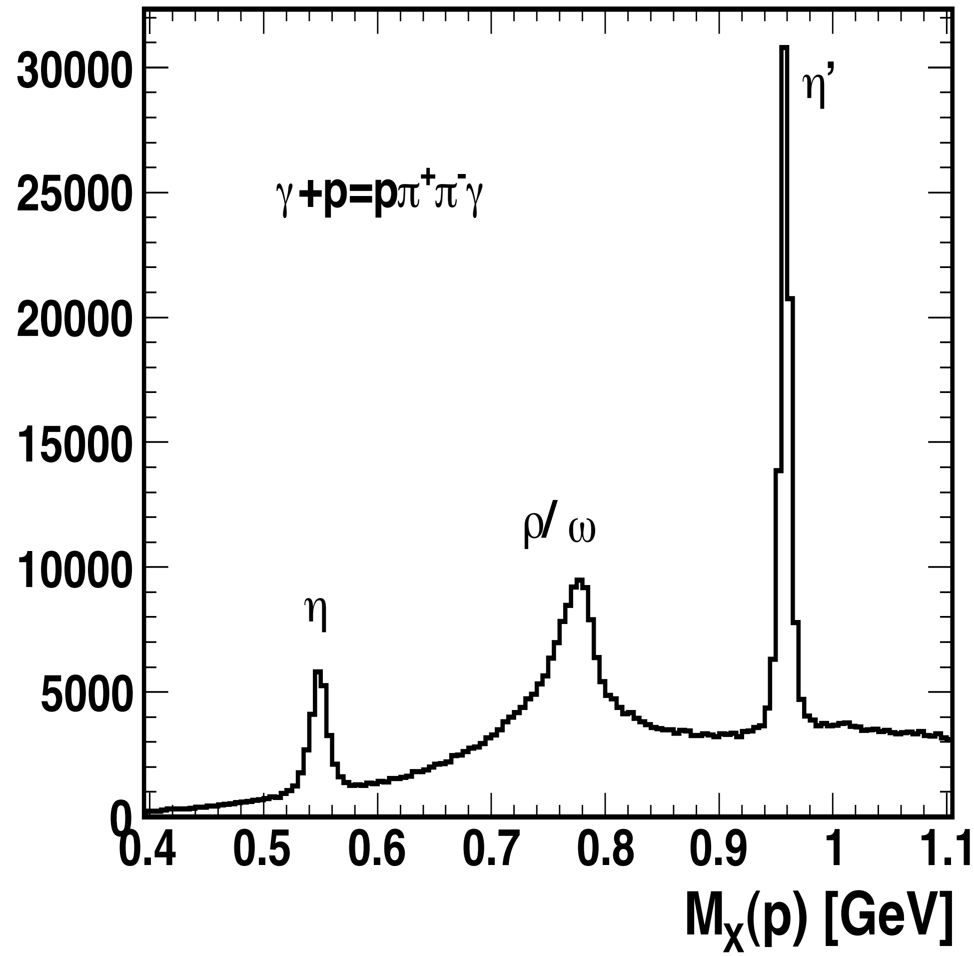
Radiative Decay $\eta,\eta' \rightarrow \pi^+\pi^-\gamma$

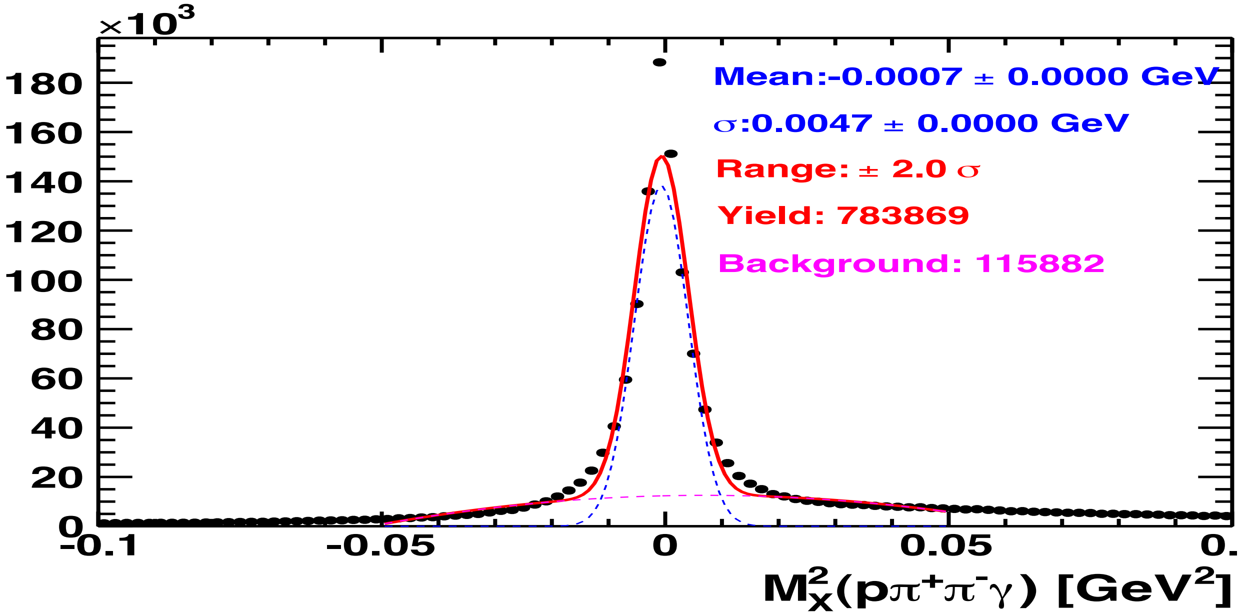


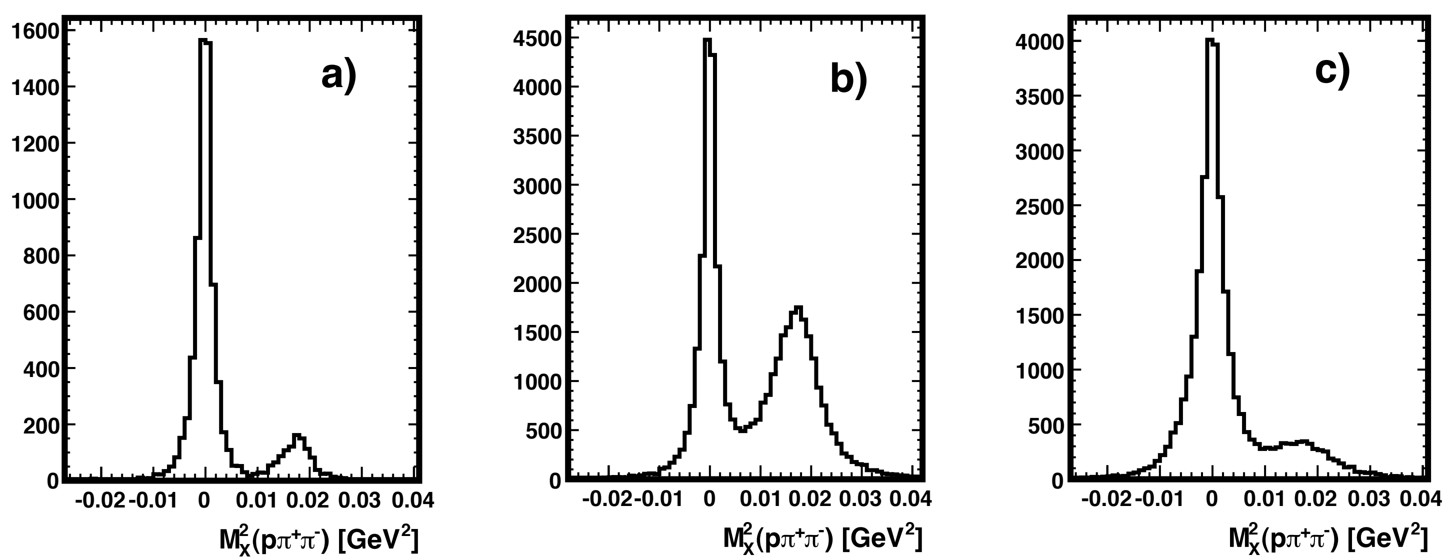
$M_X^2(p)$ versus $M_X^2(p\pi^+\pi^-)$

$\mathbf{ME > 0.01GeV}$

$\mathbf{ME - E_\gamma < 0.03GeV}$

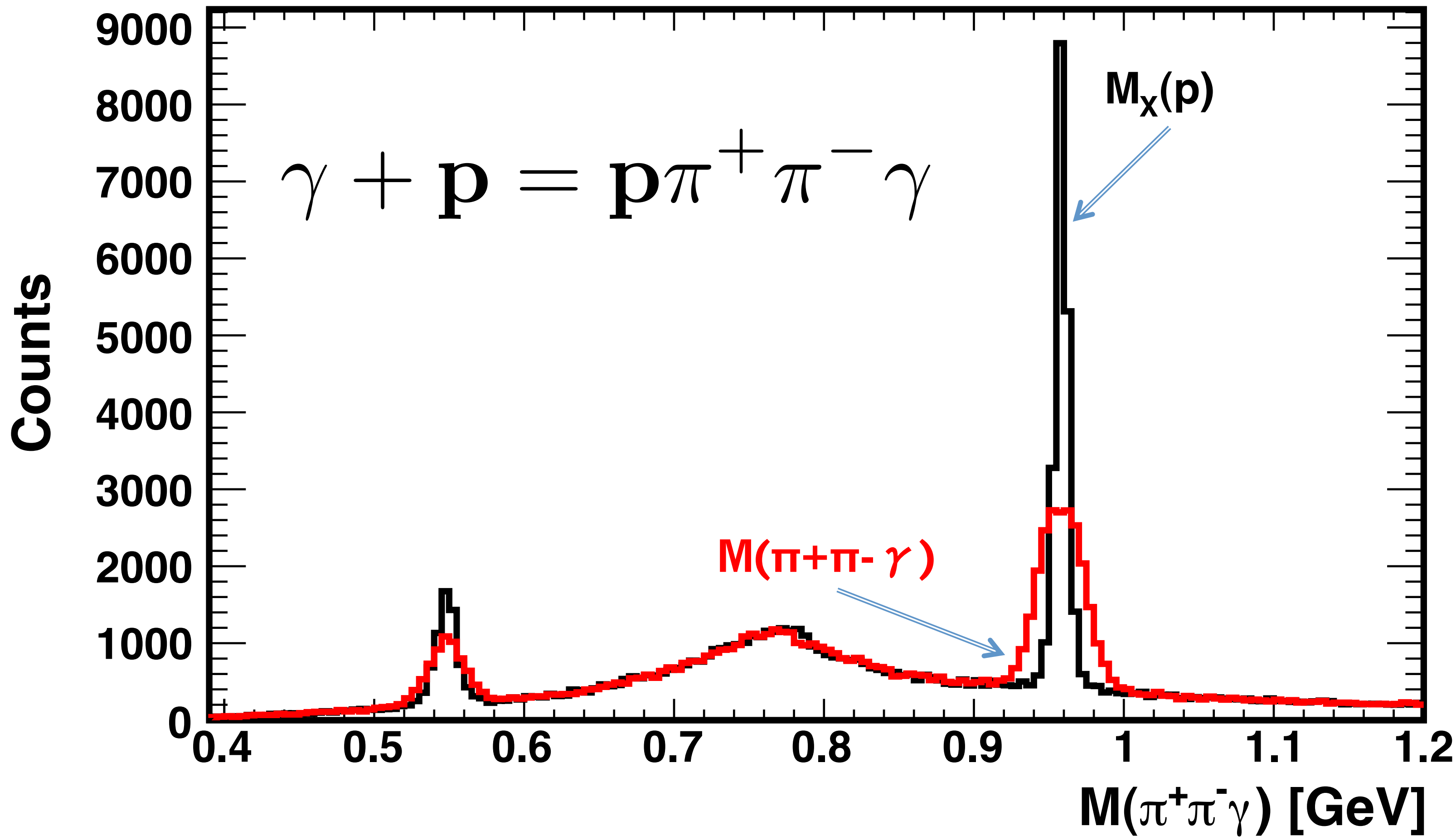






Mx(p)=0.55+-0.01 GeV 0.76+-0.06 GeV 0.96+-0.01 GeV

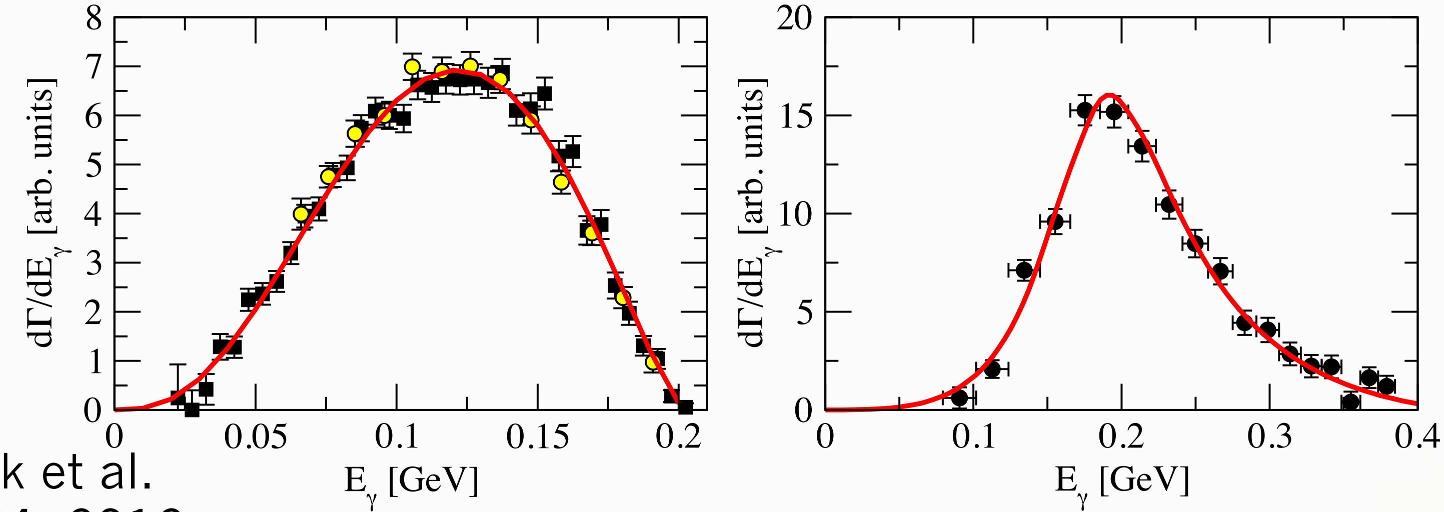
Invariant Mass vs Missing Mass



Missing Mass Resolution is much better as expected

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

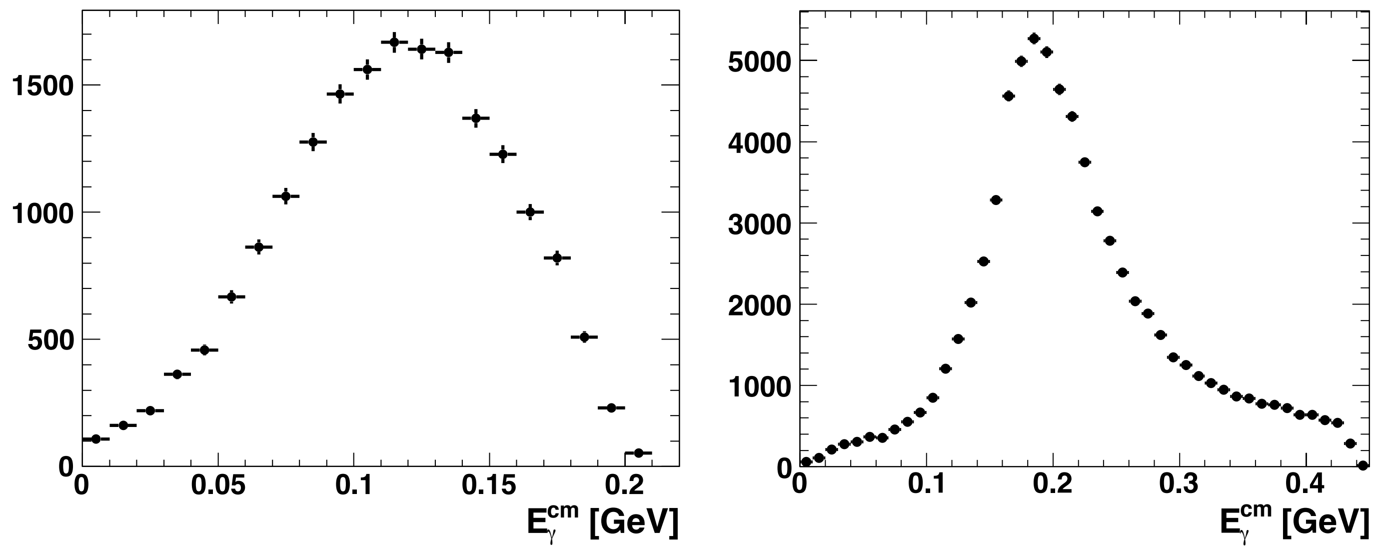
World data



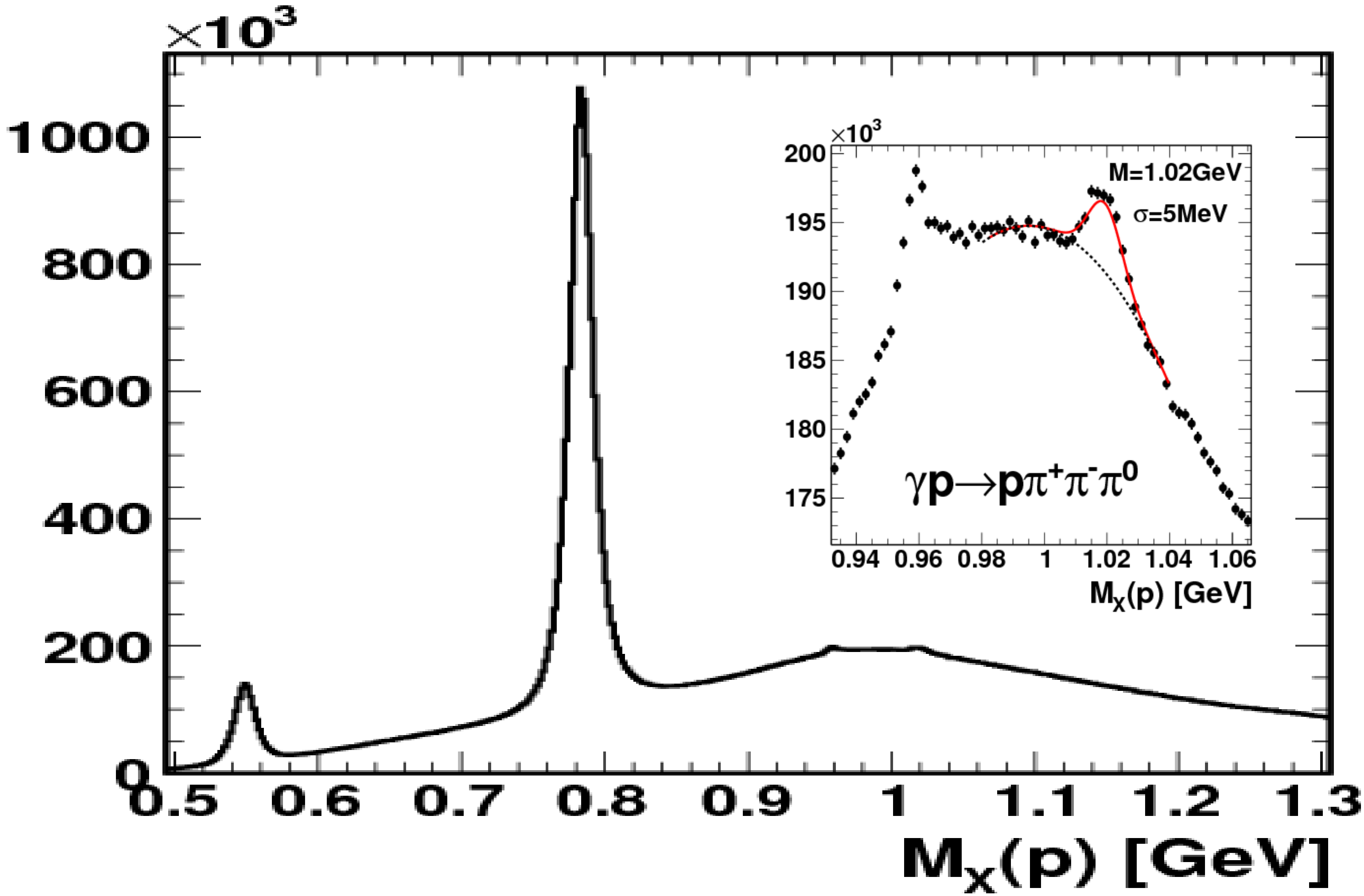
Theory:
E.Stollenwerk et al.
PL B707, 184, 2012

CLAS Preliminary uncorrected

10x more in CLAS

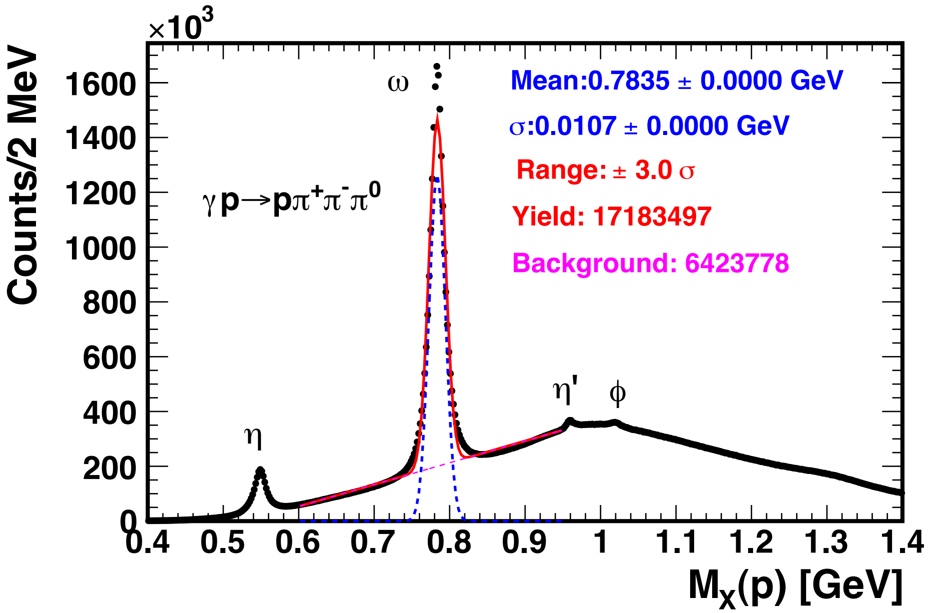


CLAS Hadronic decays: g11 Data

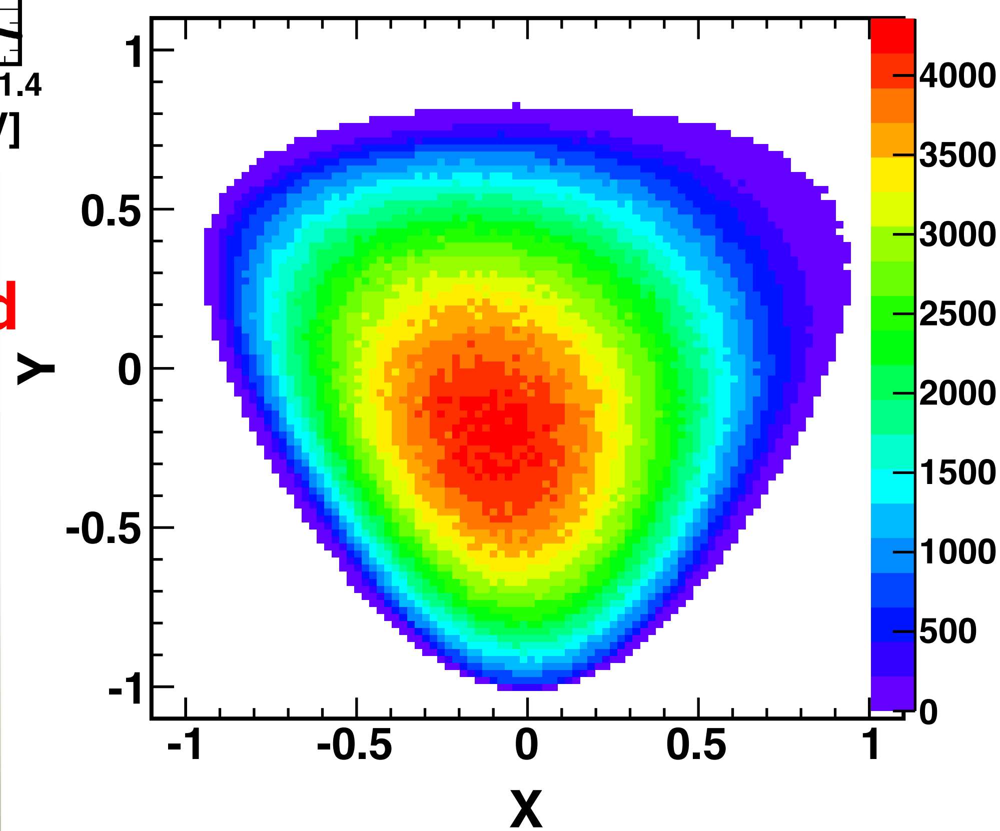


CLAS

$$\omega \to \pi^+\pi^-\pi^0$$



Not corrected for acceptance



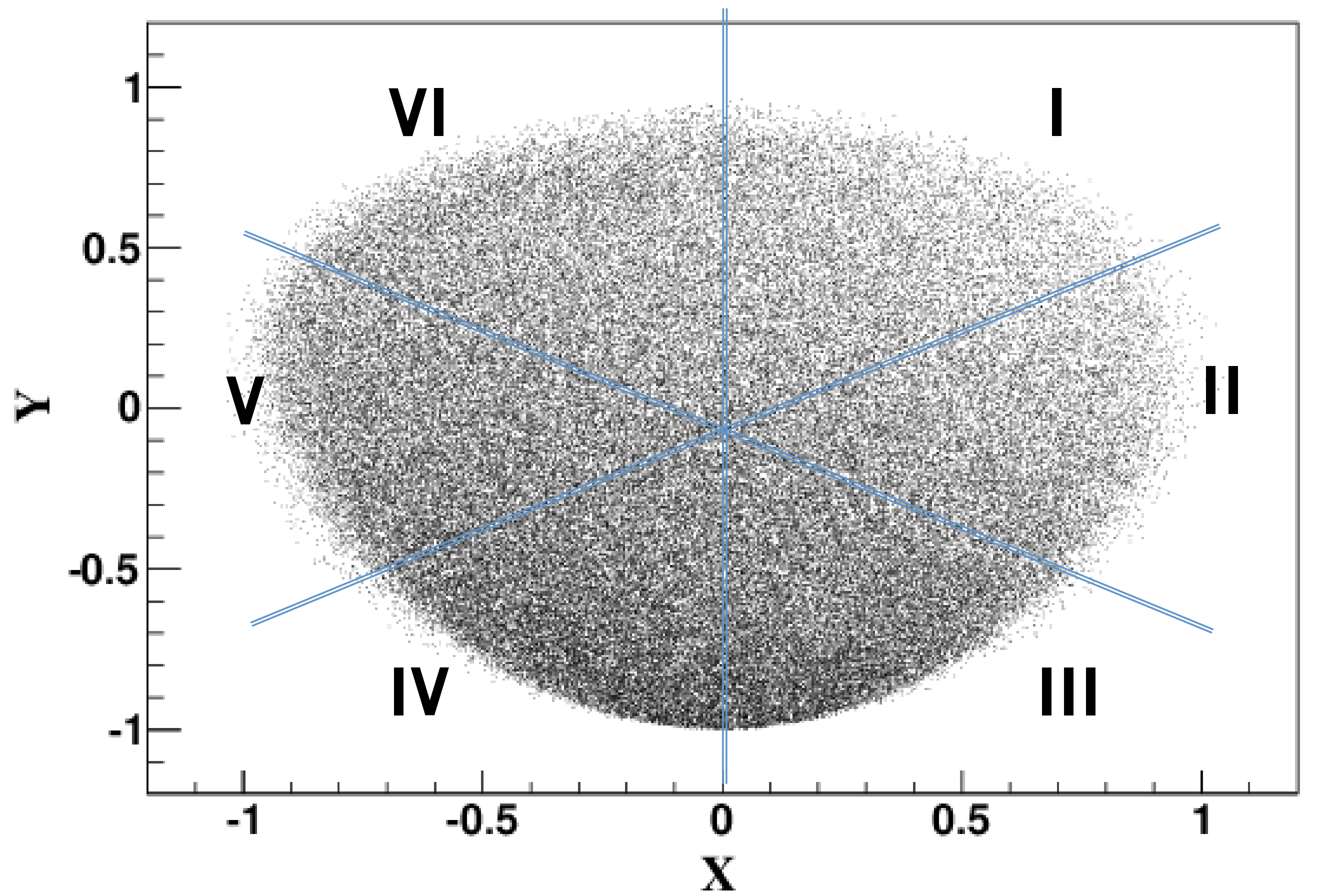
About 17M ω's

Largest statistics in the world

$$X = \frac{\sqrt{3}}{Q}(T_{\pi^+} - T_{\pi^-}), \qquad Y = \frac{3T_{\pi^0}}{Q} - 1$$

$$Q = T_{\pi^+} + T_{\pi^-} + T_{\pi^0}$$

CLAS $\eta \to \pi^+\pi^-\pi^0$



$$X = \frac{\sqrt{3}}{Q}(T_{\pi^+} - T_{\pi^-}), \qquad Y = \frac{3T_{\pi^0}}{Q} - 1$$

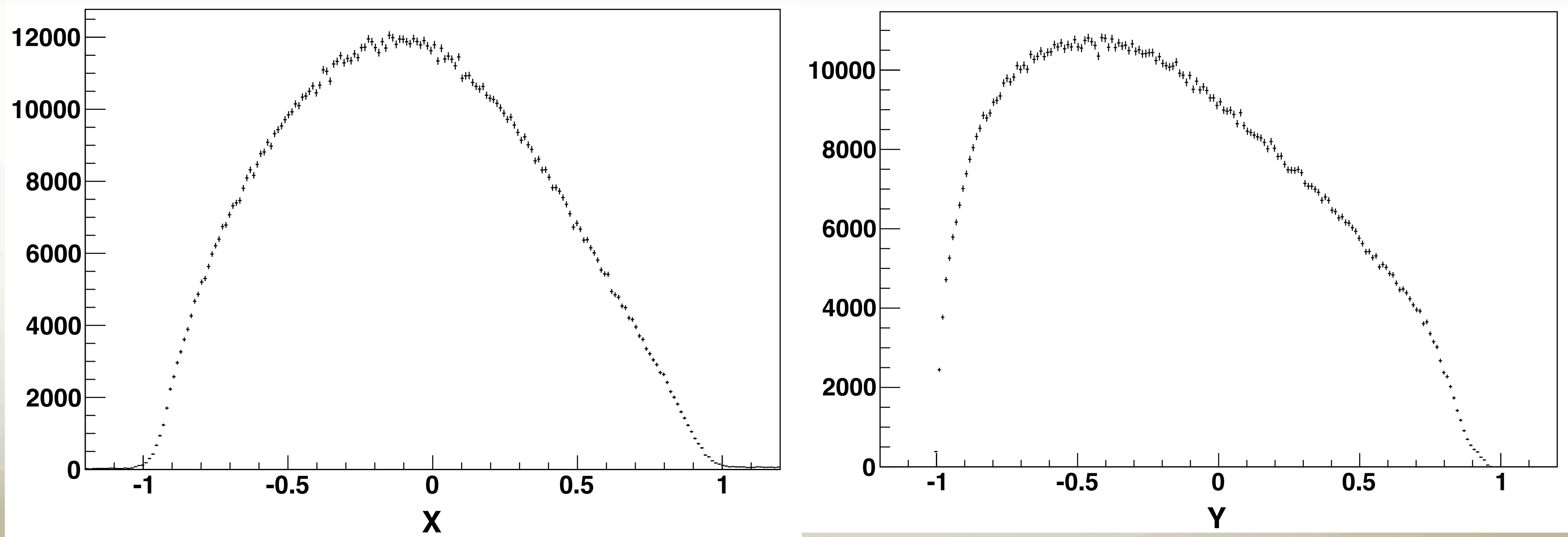
~2M events

Dalitz plot projections $\eta \to \pi^+\pi^-\pi^0$

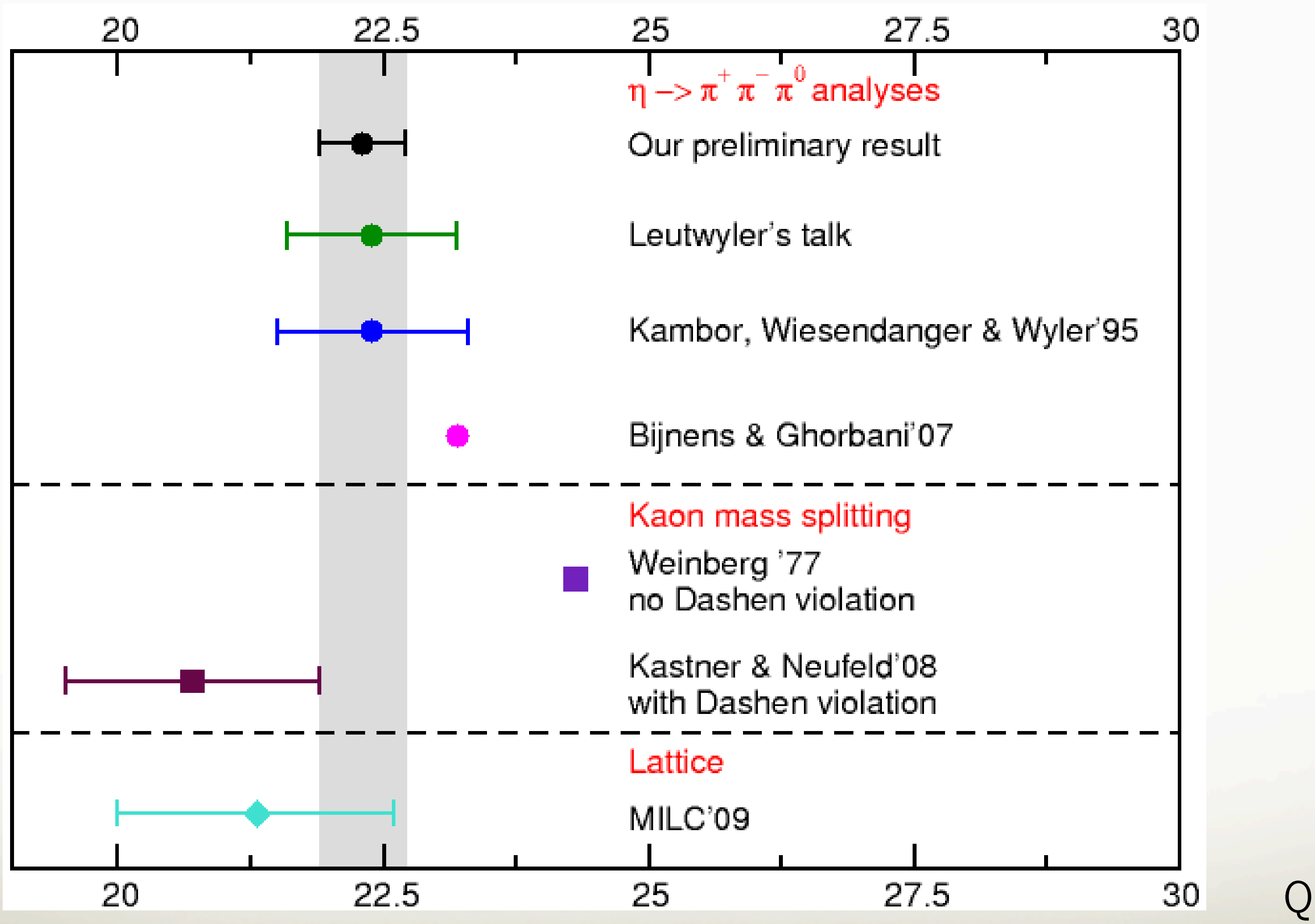
$$M^2 = A(1 + aY + bY^2 + cX + dX^2)$$

$$A \propto \frac{1}{Q^2} = \frac{m_d^2 - m_u^2}{m_s^2 - \hat{m}^2}; \quad \hat{m} = \frac{m_u + m_d}{2}$$

g11 Data



Quark mass ratio G.Colangelo et al., arXiv:0910.0765



From Particle Data Group:

$\boxed{\eta}$

$$I^G(J^{PC}) = 0^+(0^{-+})$$

Mass $m = 547.853 \pm 0.024$ MeV
Full width $\Gamma = 1.30 \pm 0.07$ keV

C-nonconserving decay parameters

$\pi^+\pi^-\pi^0$	left-right asymmetry $= (0.09^{+0.11}_{-0.12}) \times 10^{-2}$
$\pi^+\pi^-\pi^0$	sextant asymmetry $= (0.12^{+0.10}_{-0.11}) \times 10^{-2}$
$\pi^+\pi^-\pi^0$	quadrant asymmetry $= (-0.09 \pm 0.09) \times 10^{-2}$
$\pi^+\pi^-\gamma$	left-right asymmetry $= (0.9 \pm 0.4) \times 10^{-2}$
$\pi^+\pi^-\gamma$	β (D-wave) $= -0.02 \pm 0.07$ (S = 1.3)

Test of C-Parity Violation

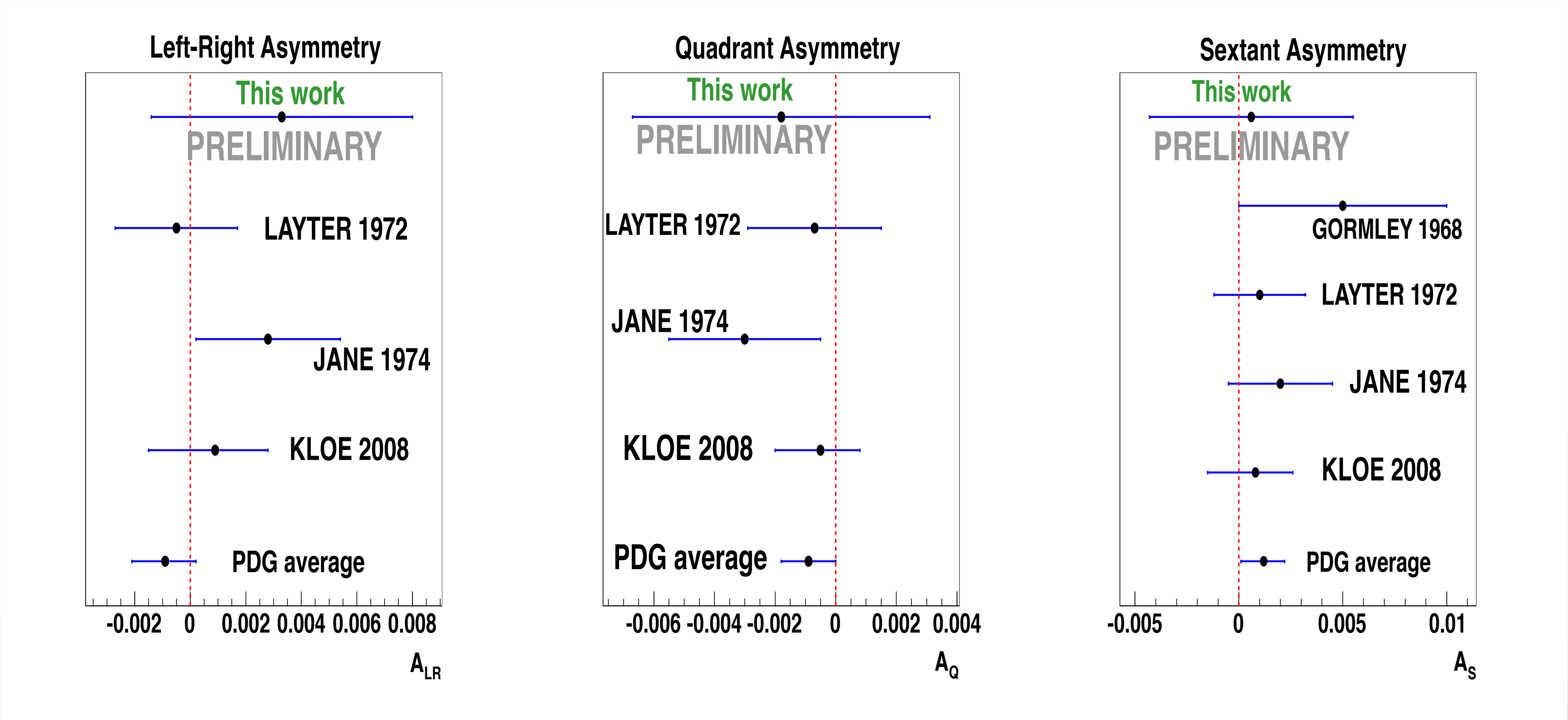


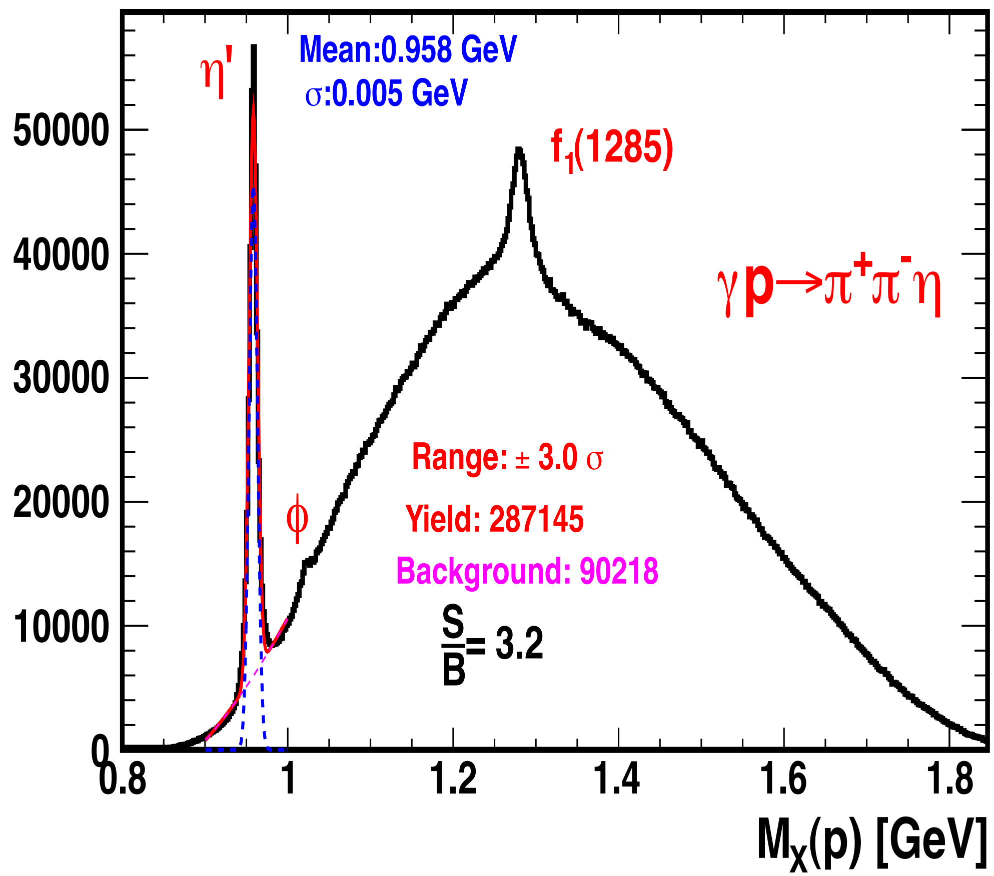
Fig. 1. Comparison of obtained values of asymmetries [7] with results determined by previous experiments [3,4,5], and a value given by PDG [6].

arXiv:1210.1758 [WASA-COSY]

CLAS expected stat. error. $\delta \leq 0.001$

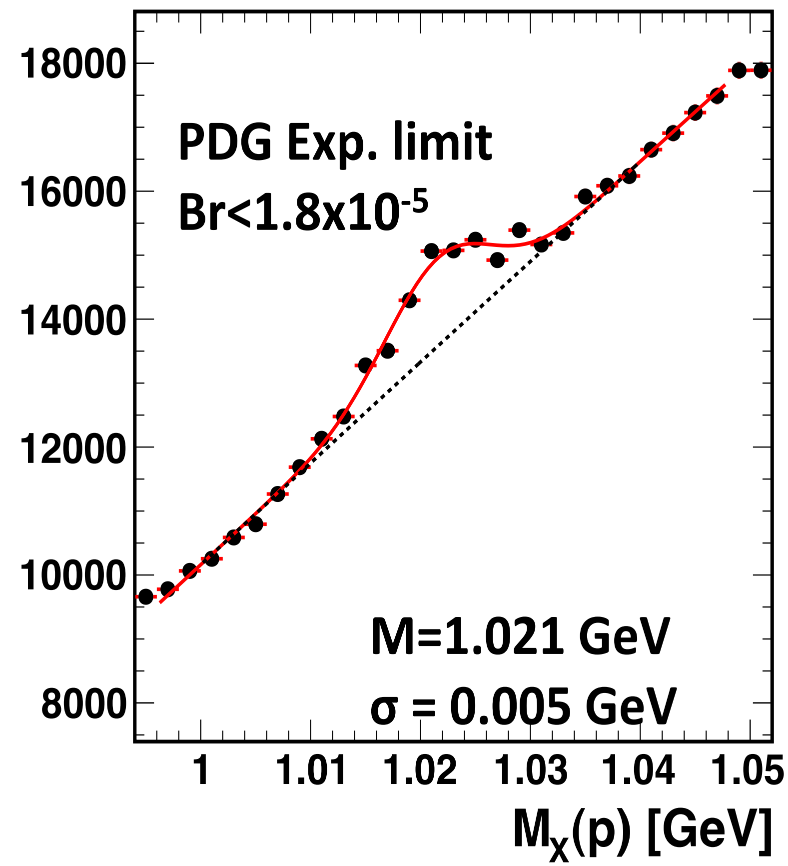
Hadronic decay

$\eta' \rightarrow \pi\pi\eta$



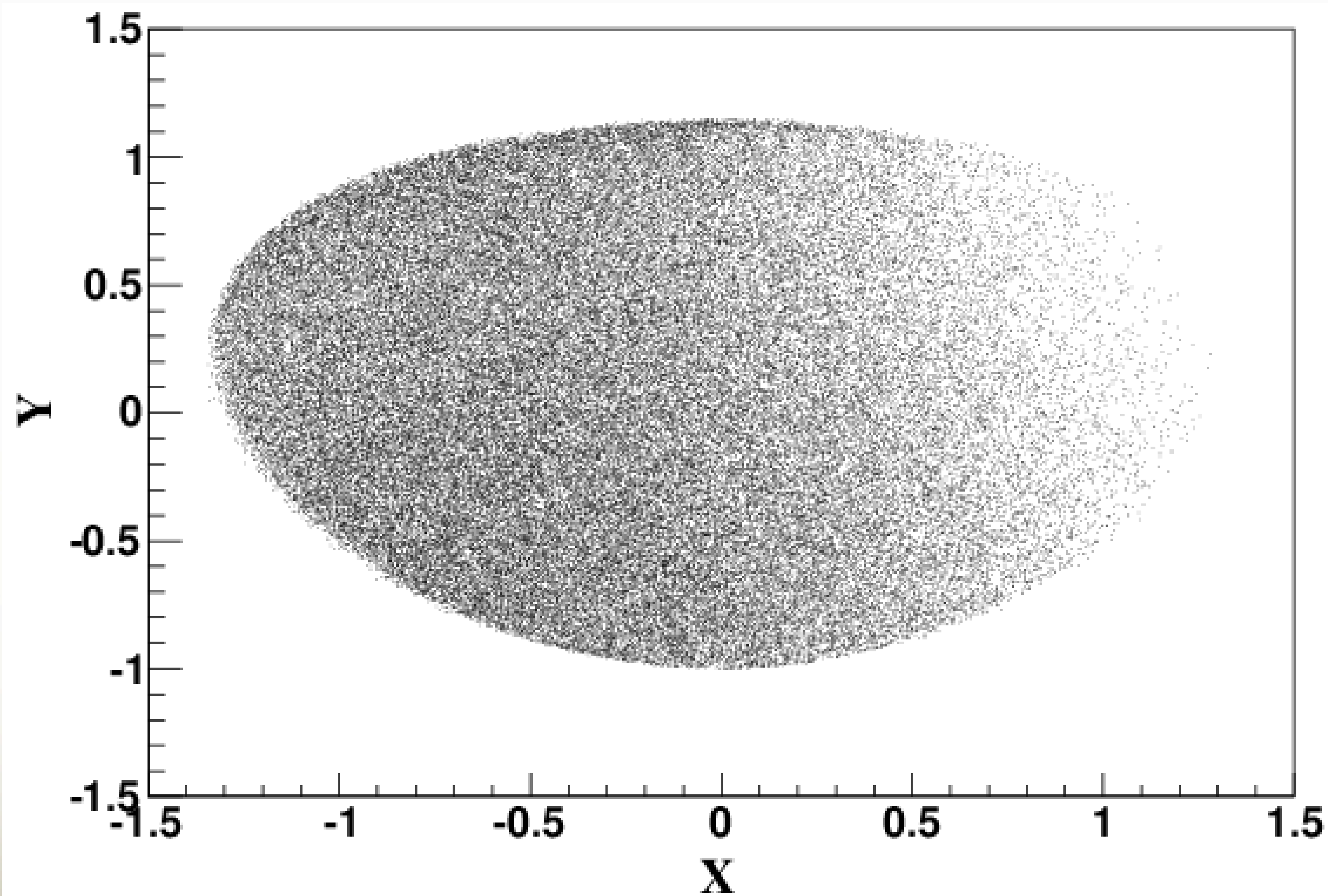
G-Parity violation

$\Phi \rightarrow \pi\pi\eta$



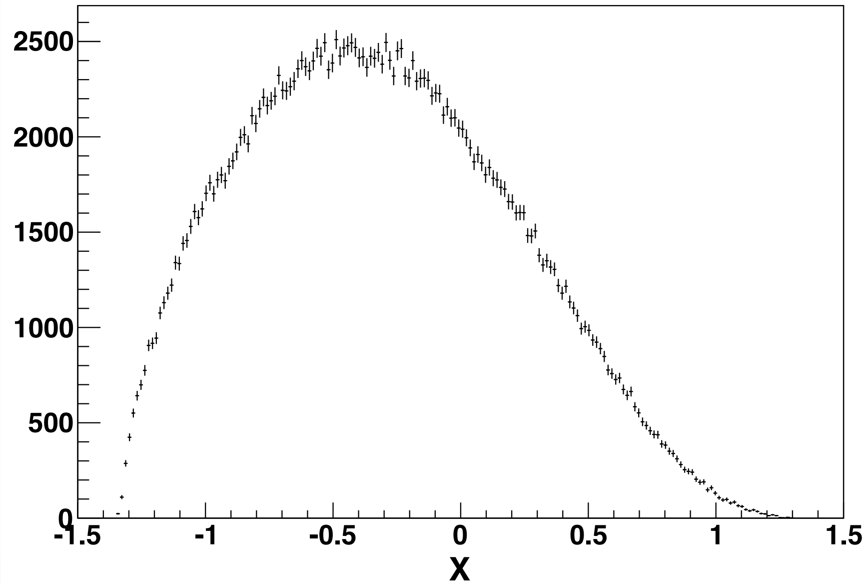
CLAS g11 Data (7 times more η' than in BESIII)
another 3 times more on tape (from CLASg12 run)

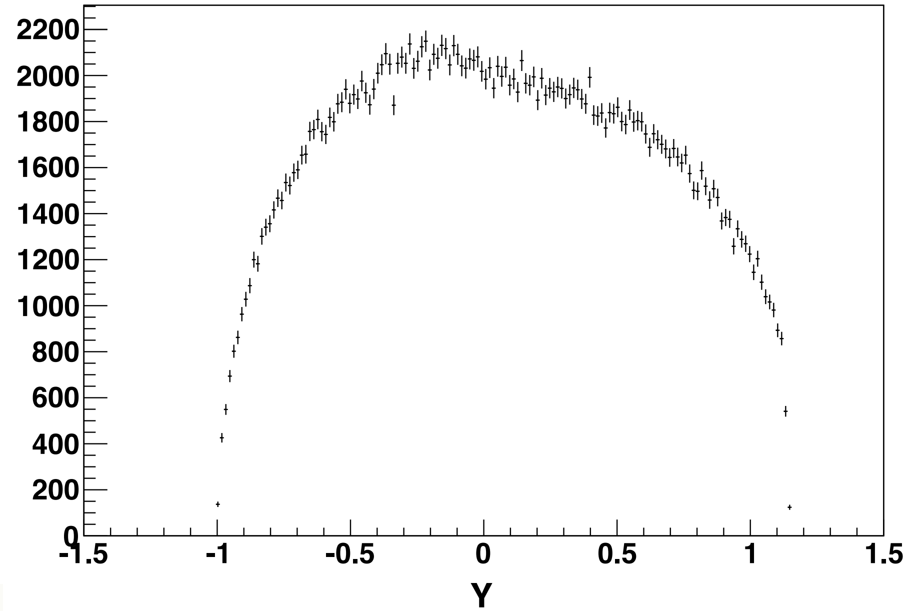
Dalitz plot η’➔ππη



Dalitz plot projections $\eta' \rightarrow \pi\pi\eta$

CLAS Preliminary uncorrected





Par.	VES EPJ A26,383,2005	Theory	BES arXiV:1012.1117	Stat err. In BES	Stat. err. In CLAS
a	-0.127+-0.018	-0.116+-0.011	-0.047+-0.012	+-0.011	+-0.004
b	-0.106+-0.032	-0.042+-0.034	-0.069+-0.021	+-0.019	+-0.006
c	+0.015+-0.018	----------------	+0.019+-0.012	+-0.011	+-0.004
d	-0.082+-0.019	+0.010+-0.019	-0.073+-0.013	+-0.012	+-0.004

Testing Scalar Mesons in π+π- from η ’

arXiv:1003.3868

Based on Fariborz and Schechter model PRD 67,054001,2003

KLOE-2 (DAΦNE) Projection

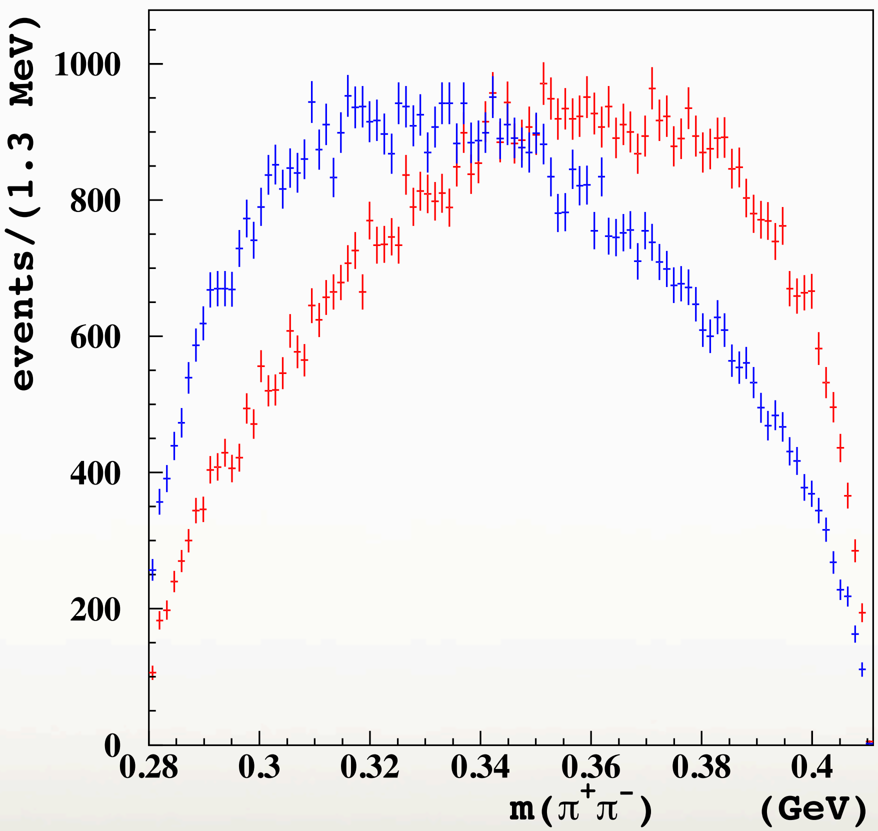
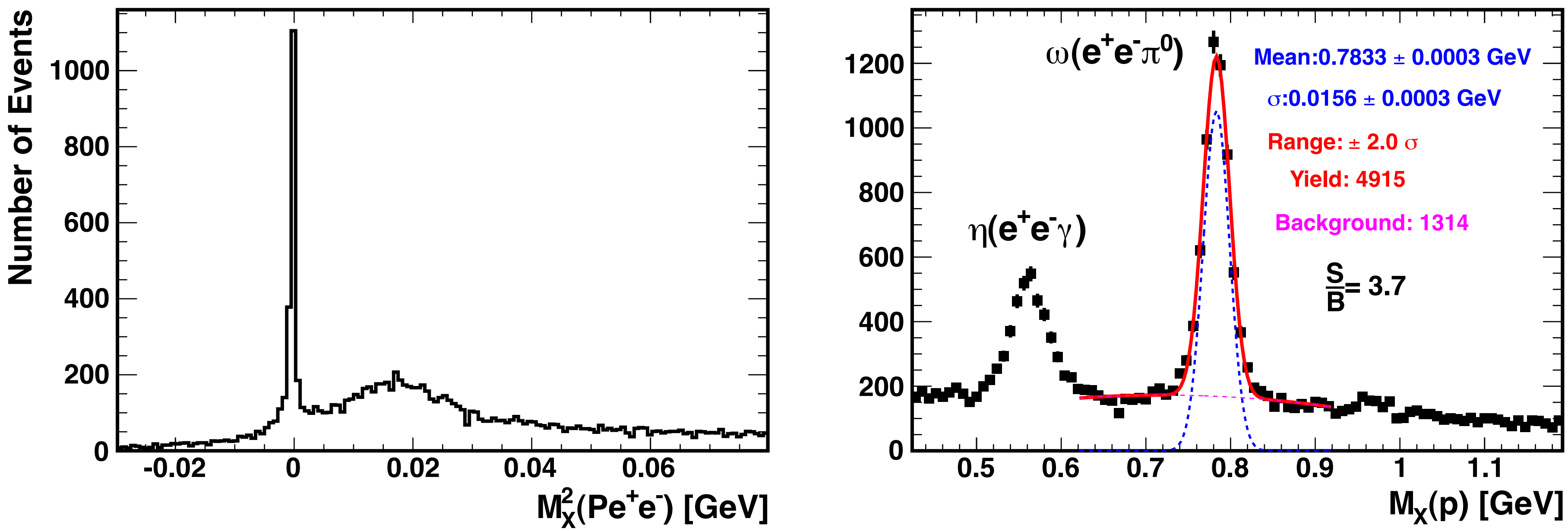


Fig. 18: The $m_{\pi^+\pi^-}$ distribution in the $\eta' \to \eta\pi^+\pi^-$ decay with the σ meson (right–centered distribution) and without (left–centered distribution) contribution.

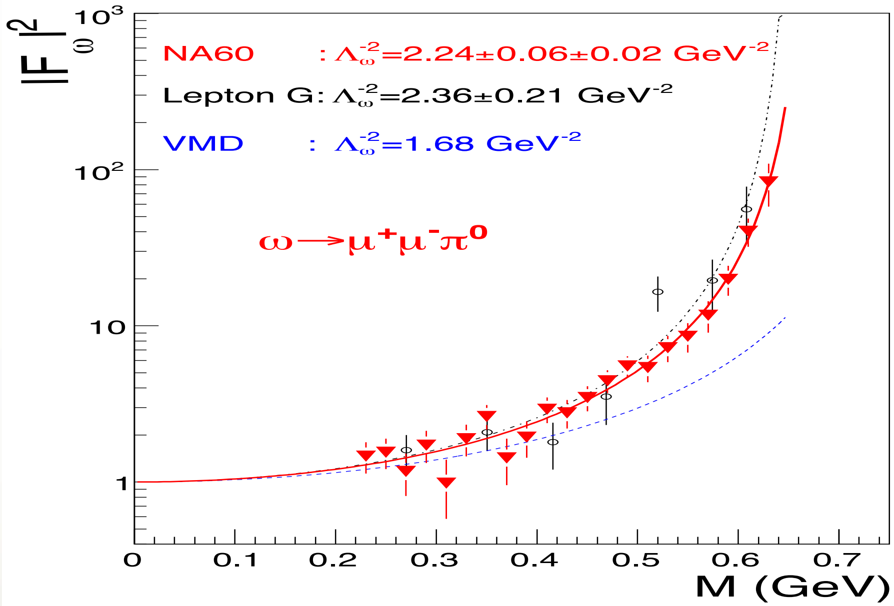
Dalitz decay $\omega \rightarrow e^+e^-\pi^0$

CLAS g12 Data

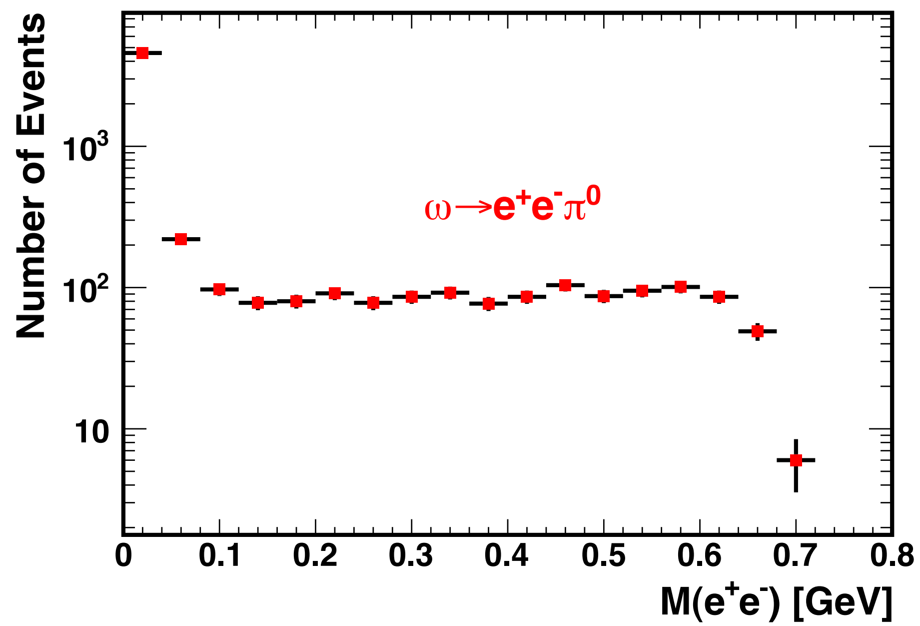


Transition Form Factor $\omega \rightarrow e^+e^-\pi^0$

World data



CLAS g12 Data



We expect significant improvement
in stat. error with CLAS Data

Photoproduction and Decay of Light Mesons in CLAS

CLAS Analysis Proposal

M.J. Amaryan (spokesperson),[1,*] Ya. Azimov,[2] M. Battaglieri,[3] W.J. Briscoe,[4] V. Crede,[5] R. De Vita,[3] C. Djalali,[6] M. Dugger,[7] G. Gavalian,[1] L. Guo,[8,9] H. Haberzettl,[4] C.E. Hyde,[1] D.G. Ireland,[10] F. Klein,[11] B. Kopf,[12] B. Kubis,[13] A. Kubarovsky,[14,15] V. Kubarovsky,[9] M.C. Kunkel,[1] B. McKinnon,[10] K. Nakayama,[16] C. Nepali (spokesperson),[1] E. Pasyuk,[9] M.V. Polyakov,[17,2] B.G. Ritchie,[7] J. Ritman,[18,19,12] C. Salgado,[20] S. Schadmand (spokesperson),[18,19] S.P. Schneider,[13] I. Strakovsky,[4] D. Weygand,[9] U. Wiedner,[12] and A. Wirzba[18,19,21]

[1]Old Dominion University, Norfolk, Virginia 23529
[2]Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg 188300, Russia
[3]INFN, Sezione di Genova, 16146 Genova, Italy
[4]The George Washington University, Washington, DC 20052
[5]Florida State University, Tallahassee, Florida 32306
[6]University of South Carolina, Columbia, South Carolina 29208
[7]Arizona State University, Tempe, Arizona 85287-1504
[8]Florida International University, Miami, Florida 33199
[9]Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606
[10]University of Glasgow, Glasgow G12 8QQ, United Kingdom
[11]Catholic University of America, Washington, DC 20064
[12]Institut für Experimentalphysik I, Ruhr Universität Bochum, 44780 Bochum, Germany
[13]Helmholtz-Institut für Strahlen- und Kernphysk (Theorie) and Bethe Center for Theoretical Physics, Universität Bonn, D-53115 Bonn, Germany
[14]Rensselaer Polytechnic Institute, Troy, New York 12180-3590
[15]Skobeltsyn Nuclear Physics Institute, 119899 Moscow, Russia
[16]Department of Physics and Astronomy, University of Georgia, Athens, GA 30602, USA
[17]Institut für Theoretische Physik II, Ruhr–Universität Bochum, D–44780 Bochum, Germany
[18]Institut für Kernphysik, Forschungszentrum, Jüelich, Germany
[19]Jülich Center for Hadron Physics, Forschungszentrum Jülich, 52425 Jüich, Germany
[20]Norfolk State University, Norfolk, VA 23504, USA
[21]Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany

(Dated: September 30, 2012)

Summary

We expect to release at least the following results:

1. Transition form factor of π^0 in the time-like region from Dalitz decay $e^+e^-\gamma$
2. Transition form factor of η in the time-like region from Dalitz decay $e^+e^-\gamma$
3. Branching ratio $\eta' \to e^+e^-\gamma$ for the first time
4. Measurement of E_γ distribution in radiative decay $\eta \to \pi^+\pi^-\gamma$
5. Measurement of E_γ distribution in radiative decay $\eta' \to \pi^+\pi^-\gamma$
6. Transition form factor of ω in time-like region from Dalitz decay $\omega \to e^+e^-\pi^0$
7. Dalitz plot analysis of hadronic decay $\eta \to \pi^+\pi^-\pi^0$
8. Dalitz plot analysis of hadronic decay $\eta' \to \pi^+\pi^-\eta$
9. First observation of G-parity violating decay $\phi \to \pi^+\pi^-\eta$