Light Meson Decay in CLAS

Moskov Amaryan

On behalf of the CLAS Collaboration

Future Directions in Spectroscopy Analysis

Jefferson Lab, November 20, 2014

Photoproduction and Decay of Light Mesons in CLAS

CLAS Analysis Proposal

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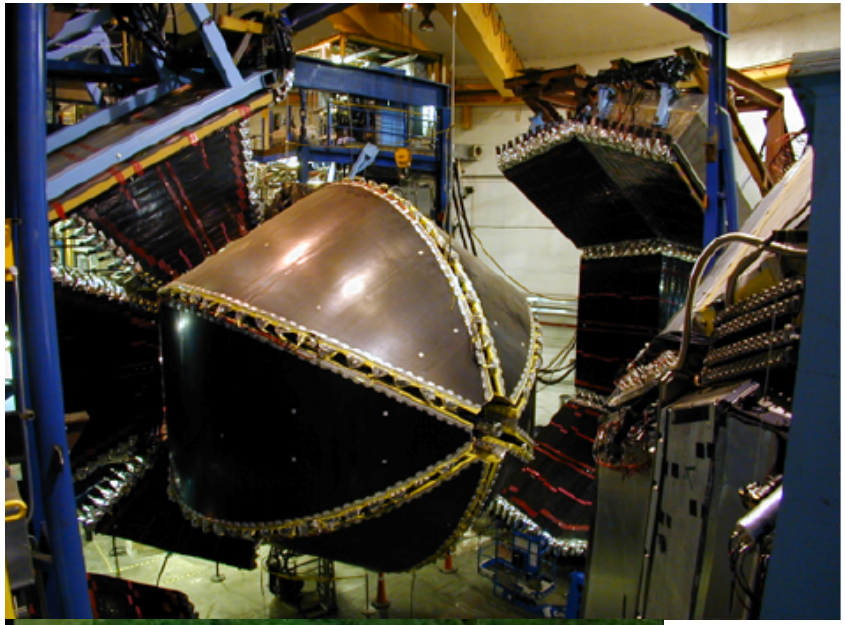
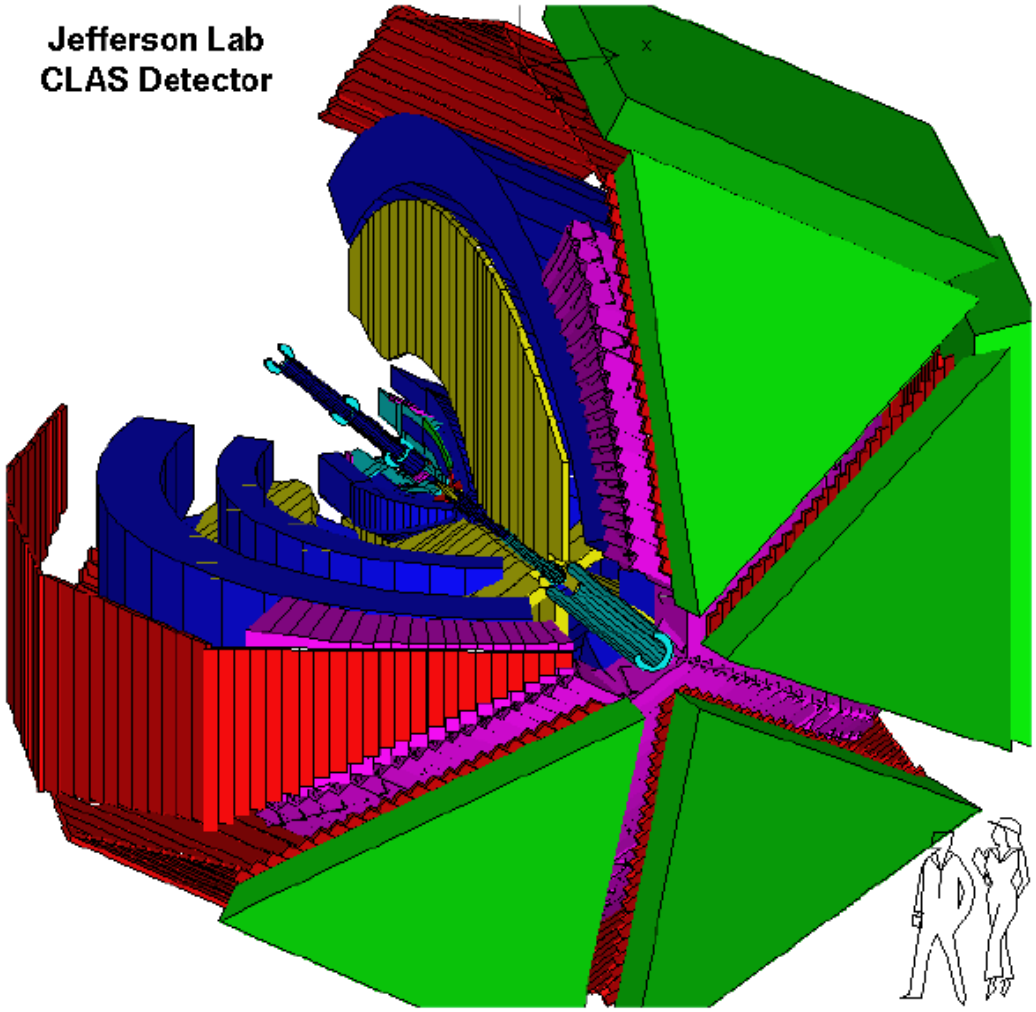
(Dated: December 24, 2012)

Outline

-Introduction
-Dalitz Decays
-Radiative Decays
-Hadronic Decays
-Search for Dark Photon
-Summary

The CLAS Detector





Light Mesons in CLAS

π^0	$e^+e^-\gamma$				
η	$e^+e^-\gamma$	$\pi^+\pi^-\gamma$	$\pi^+\pi^-\pi^0$ $\pi^+\pi^-$	$\pi^+\pi^-e^+e^-$	
η'	$e^+e^-\gamma$	$\pi^+\pi^-\gamma$	$\pi^+\pi^-\pi^0$ $\pi^+\pi^-$	$\pi^+\pi^-\eta$ $\pi^+\pi^-e^+e^-$	
ρ		$\pi^+\pi^-\gamma$			
ω	$e^+e^-\ \pi^0$	$\pi^+\pi^-\gamma$	$\pi^+\pi^-\pi^0$		
φ			$\pi^+\pi^-\pi^0$	$\pi^+\pi^-\eta$	
f1(1285)				$\boldsymbol{\pi^+\pi^-\eta}$	

List of Meson Decays

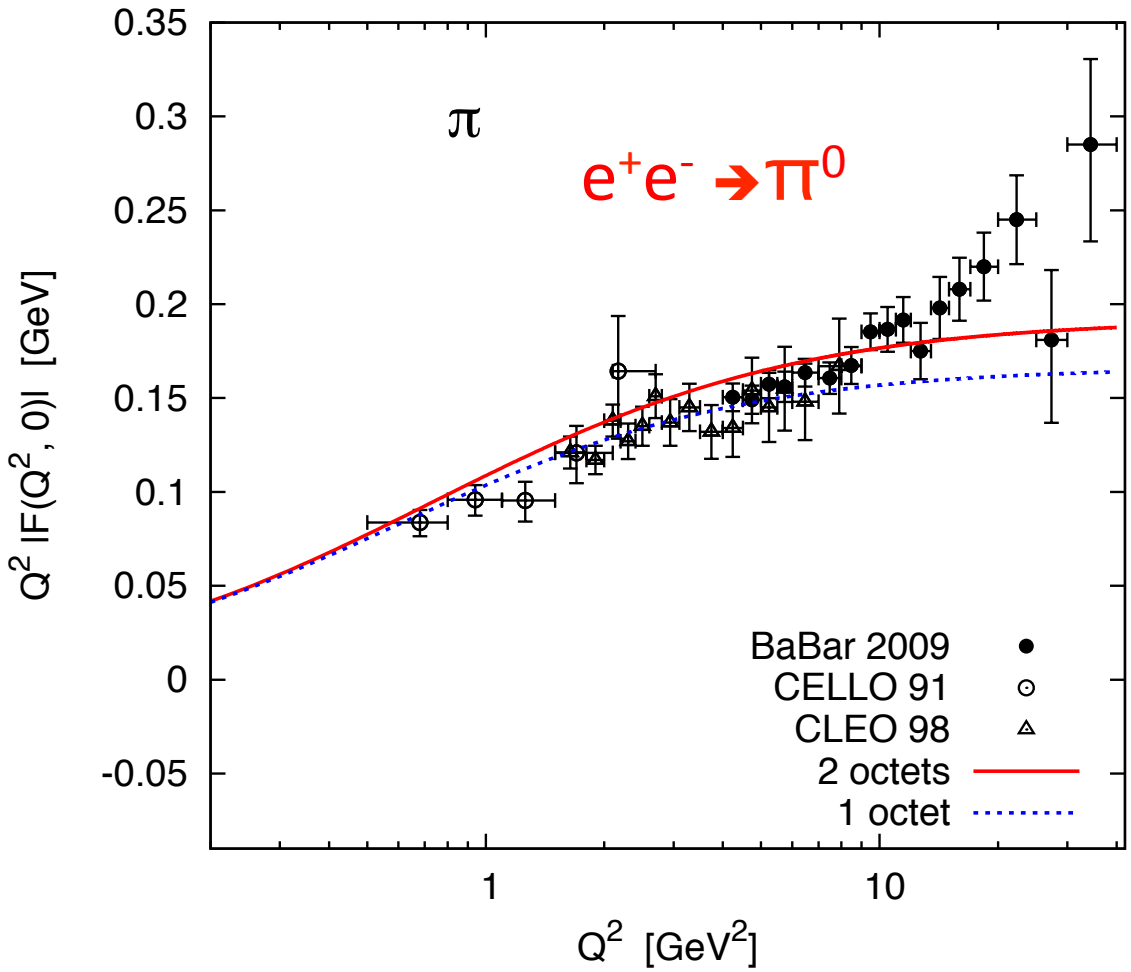
From Lmdwiki

meson decay	physics	people
$\pi \rightarrow \gamma e^+e^-$ $\eta(') \rightarrow \gamma e^+e^-$	transition form factor, Me+e- (dark photon)	Michael Kunkel Michaela Schever (master student Aachen/Juelich)
$\omega \rightarrow \pi^0 e^+e^-$	transition form factor	Susan Schadmand +
$\eta(') \rightarrow \pi^0 e^+e^-$	C violation	Haiyun Lu
$\eta(') \rightarrow \pi^+\pi^- e^+e^-$	CP violation	
$\eta('),\omega \rightarrow \pi^+\pi^-\gamma$	box anomaly upper limit branching ratio	Georgie Mbianda Njencheu
$\eta, \omega, \phi \rightarrow \pi^0\pi^+\pi^-$	Dalitz plot analysis η ω ϕ	Haiyun Lu, Diane Schott Carlos Salgado + , Chris Pederson Haiyun Lu
$\eta' \rightarrow \pi^+\pi^-\gamma\gamma$ $\phi \rightarrow \pi^+\pi^-\eta$	Dalitz plot analysis/meson mixing G-parity violation	Sudeep Ghosh
$\phi \rightarrow \omega\gamma$	C parity violation, ϕ rare decay	Haiyun Lu
NULL	invisible decay	Haiyun Lu
f_1	isospin symmetry breaking, f1 decay through rho	Haiyun Lu
$\eta' \rightarrow \pi\pi\pi\pi$	test anomalies	

Retrieved from "https://wiki.jlab.org/lmd/index.php?title=List_of_Meson_Decays&oldid=795"

- This page was last modified on 22 October 2014, at 02:12.

Space-Like Form Factor



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

Well measured at $Q^2 > 0.5 GeV^2$

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

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

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]

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

(Kroll-Wada)

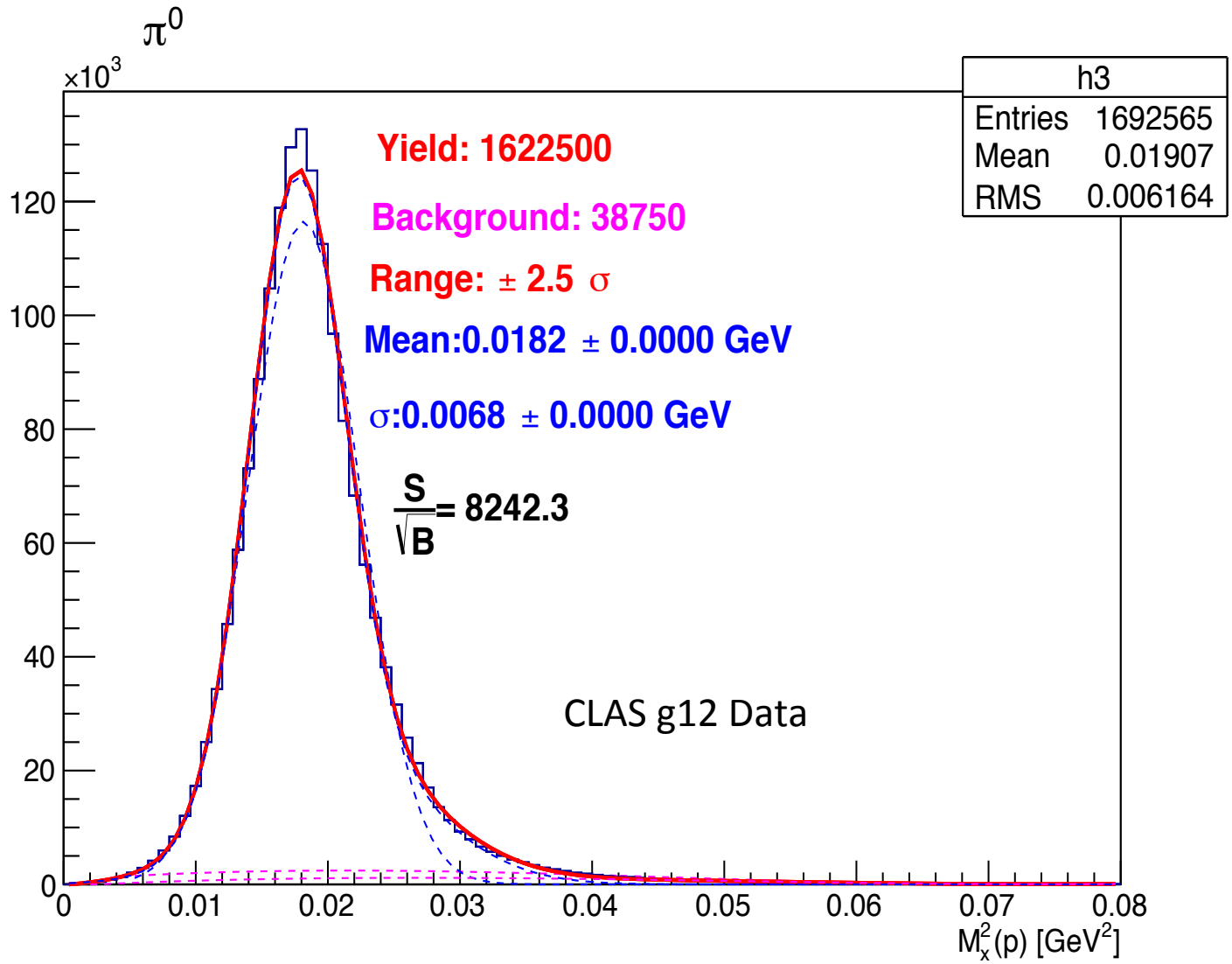
$$\left(\frac{d\Gamma}{dx}\right)_{QED} = \frac{2\alpha}{3\pi}\frac{1}{x}(1-x)^3\left(1+\frac{r}{2x}\right)\left(1-\frac{r}{x}\right)^{1/2}$$

$$F(x) = 1 + a_\pi x$$

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

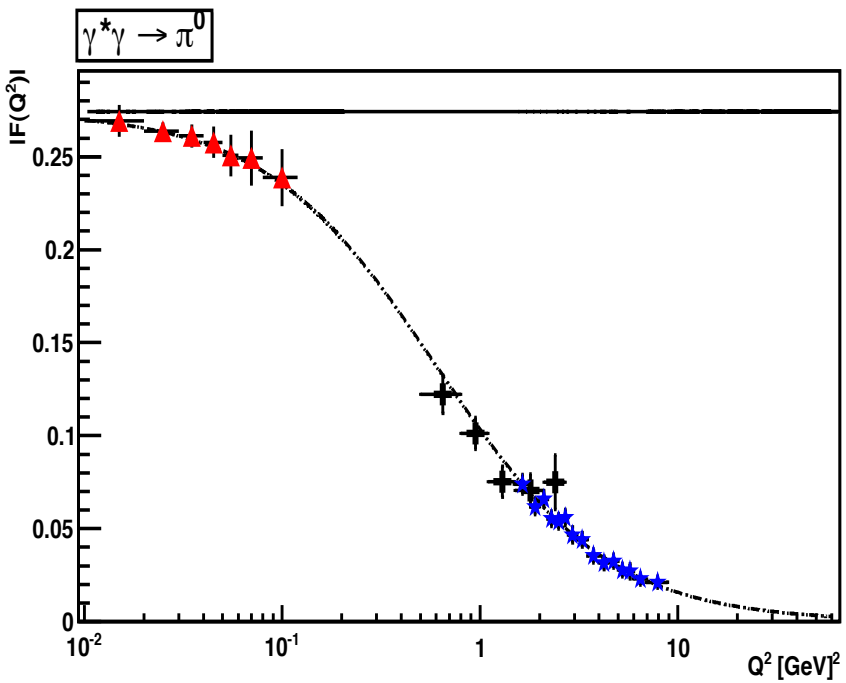
[2] H. Fonvieille, N. Bensayah, J. Berthot, P. Bertin, M. Crouau, et al., Phys.Lett. **B233**, 65 (1989).
[3] F. Farzanpay, P. Gumplinger, A. Stetz, J. Poutissou, I. Blevis, et al., Phys.Lett. **B278**, 413 (1992).
[4] R. Meijer Drees et al. (SINDRUM-I Collaboration), Phys.Rev. **D45**, 1439 (1992).

π^0(e+e-γ)

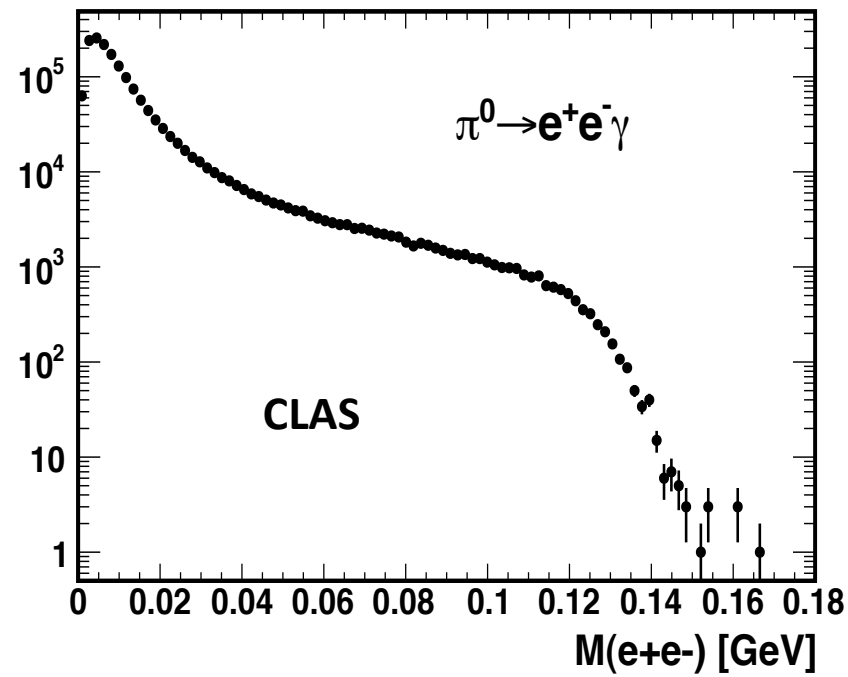

π0
×10^3
h3
Entries 1692565
Mean 0.01907
RMS 0.006164
Yield: 1622500
Background: 38750
Range: ± 2.5 σ
Mean:0.0182 ± 0.0000 GeV
σ:0.0068 ± 0.0000 GeV
S/√B = 8242.3
CLAS g12 Data
0
20
40
60
80
100
120
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
M_x^2(p) [GeV^2]

Transition Form Factor

KLOE-2 Proposal

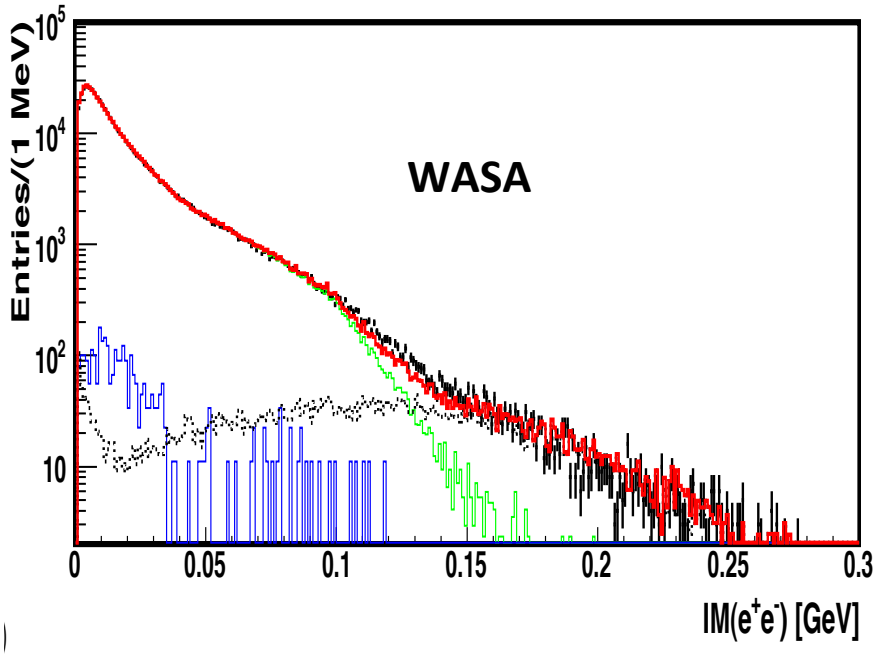


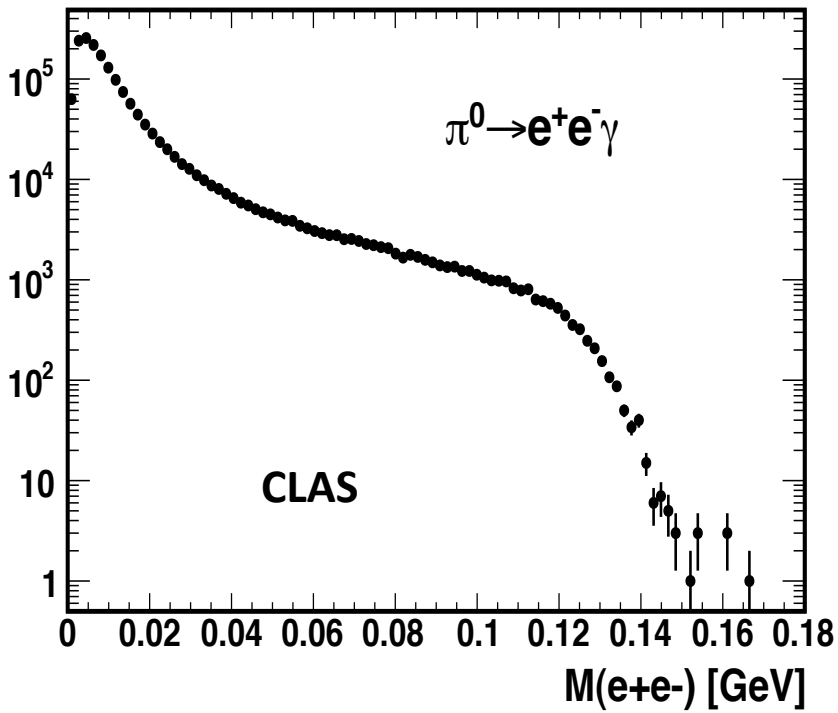
CLAS g12 Data

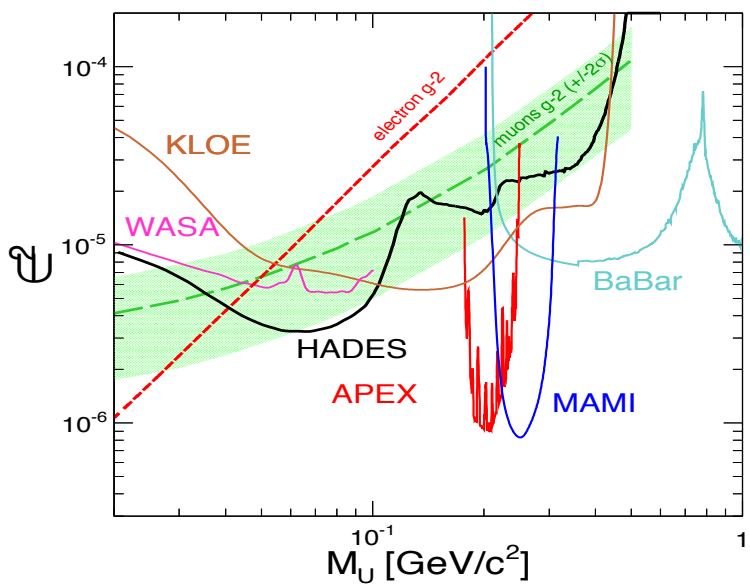


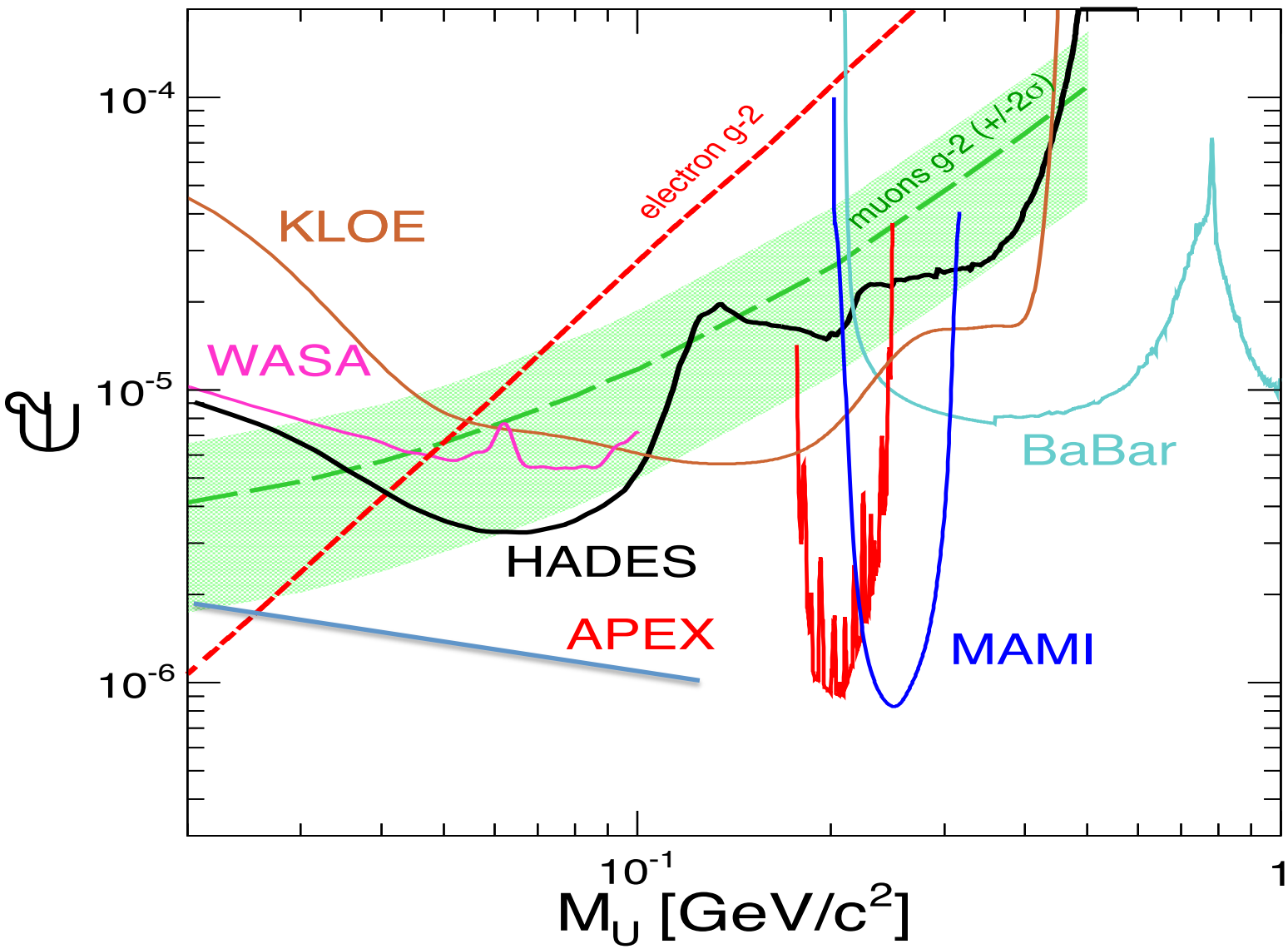
CLAS at JLAB accumulated unprecedented statistics for precision measurement of TFF slope!

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


WASA
Entries/(1 MeV)
IM(e+e-) [GeV]

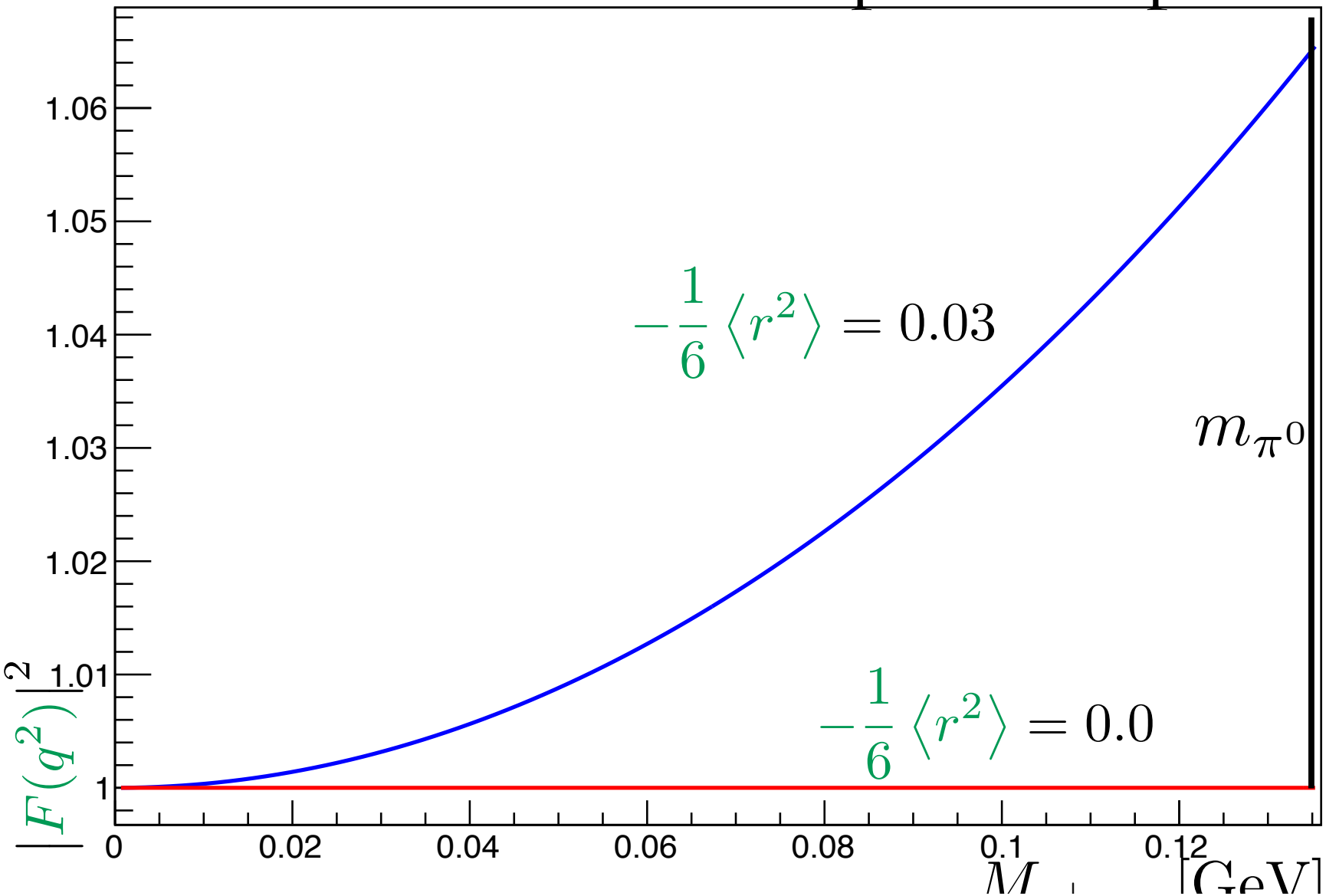

π0→e+e-γ
CLAS
M(e+e-) [GeV]


KLOE
WASA
HADES
APEX
MAMI
BaBar
electron g-2
muons g-2 (+/-2σ)
ψ
M_U [GeV/c^2]

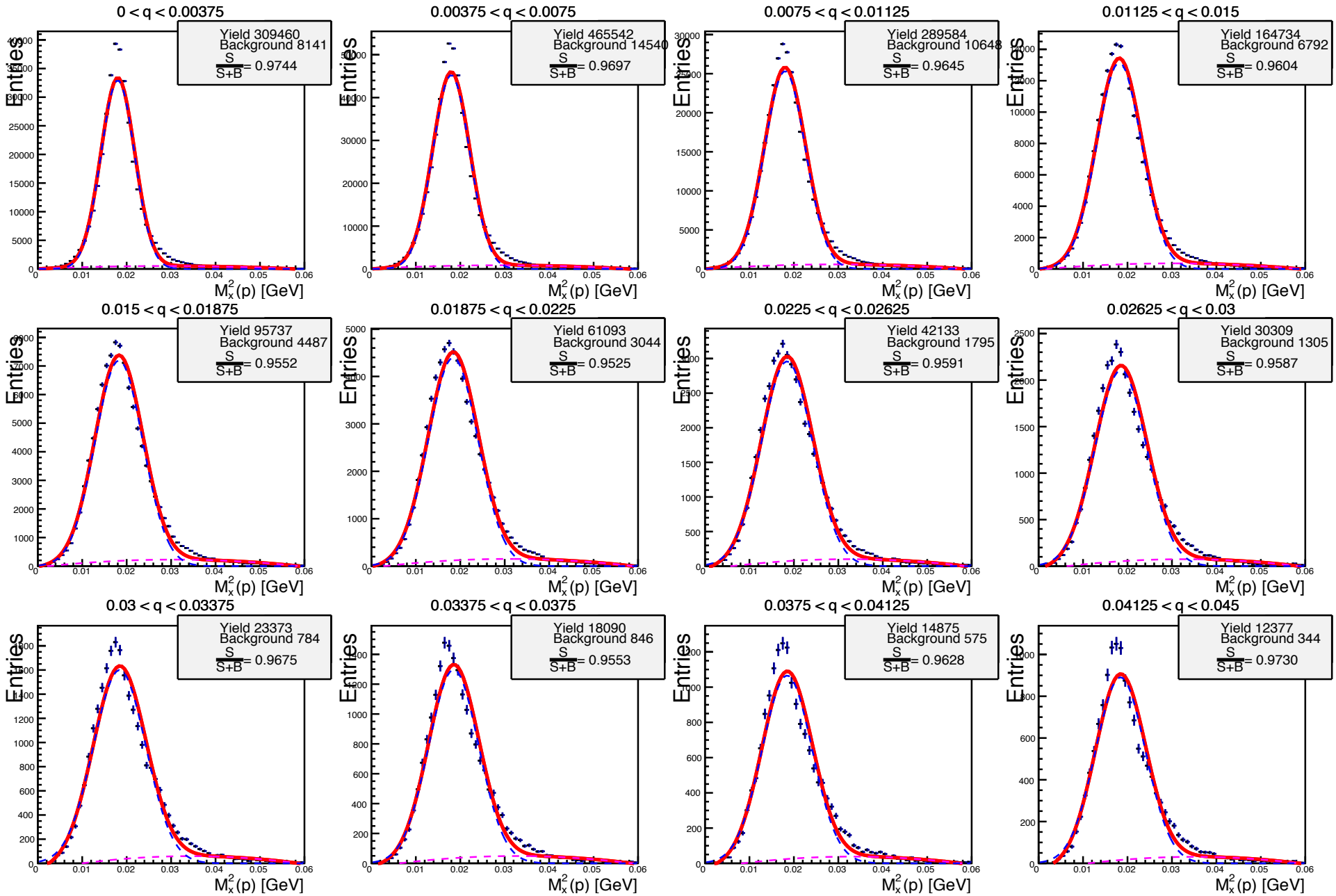

10^{-4}
10^{-5}
10^{-6}
Ψ
KLOE
WASA
electron g-2
muons g-2 (+/-2σ)
BaBar
HADES
APEX
MAMI
10^{-1}
1
M_U [GeV/c^2]

Transition Form Factor for π^0

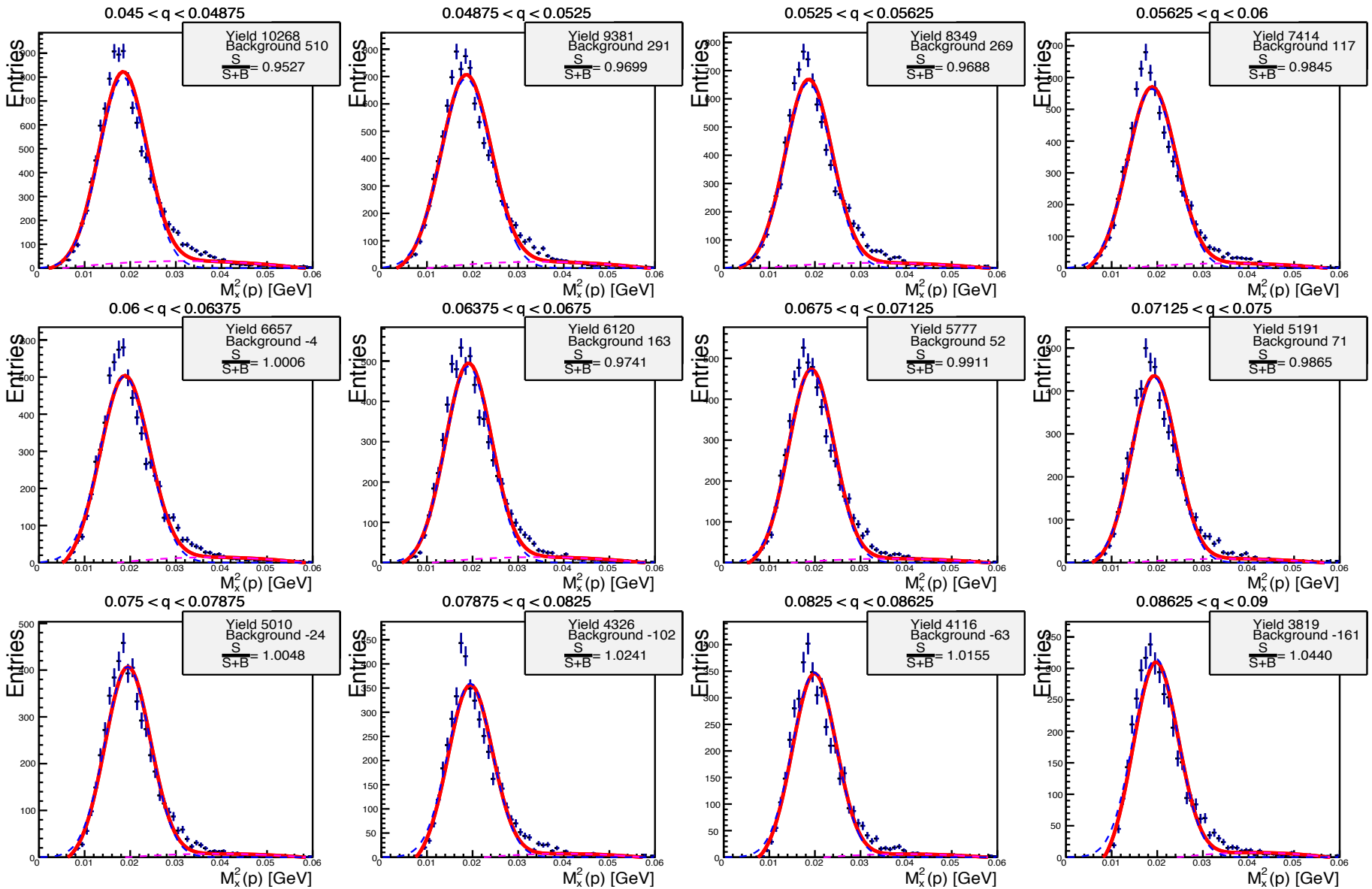
Form factor deviation from point-like particle



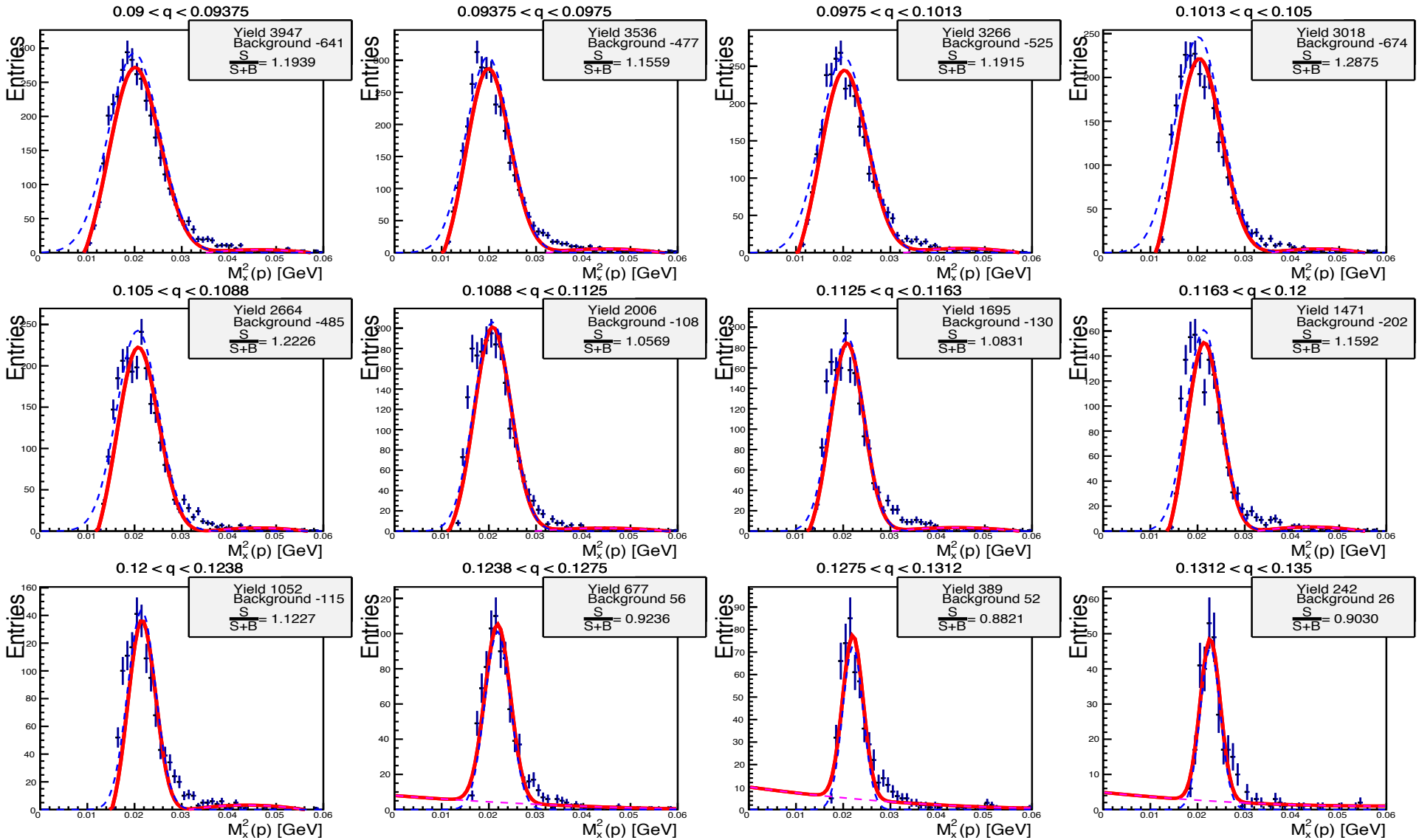
M(e+e-) Slices


0 < q < 0.00375
Yield 309460
Background 8141
S/(S+B) = 0.9744
0.00375 < q < 0.0075
Yield 465542
Background 14540
S/(S+B) = 0.9697
0.0075 < q < 0.01125
Yield 289584
Background 10648
S/(S+B) = 0.9645
0.01125 < q < 0.015
Yield 164734
Background 6792
S/(S+B) = 0.9604
0.015 < q < 0.01875
Yield 95737
Background 4487
S/(S+B) = 0.9552
0.01875 < q < 0.0225
Yield 61093
Background 3044
S/(S+B) = 0.9525
0.0225 < q < 0.02625
Yield 42133
Background 1795
S/(S+B) = 0.9591
0.02625 < q < 0.03
Yield 30309
Background 1305
S/(S+B) = 0.9587
0.03 < q < 0.03375
Yield 23373
Background 784
S/(S+B) = 0.9675
0.03375 < q < 0.0375
Yield 18090
Background 846
S/(S+B) = 0.9553
0.0375 < q < 0.04125
Yield 14875
Background 575
S/(S+B) = 0.9628
0.04125 < q < 0.045
Yield 12377
Background 344
S/(S+B) = 0.9730
Entries
$M_x^2(p)$ [GeV]

M(e+e-) Slices

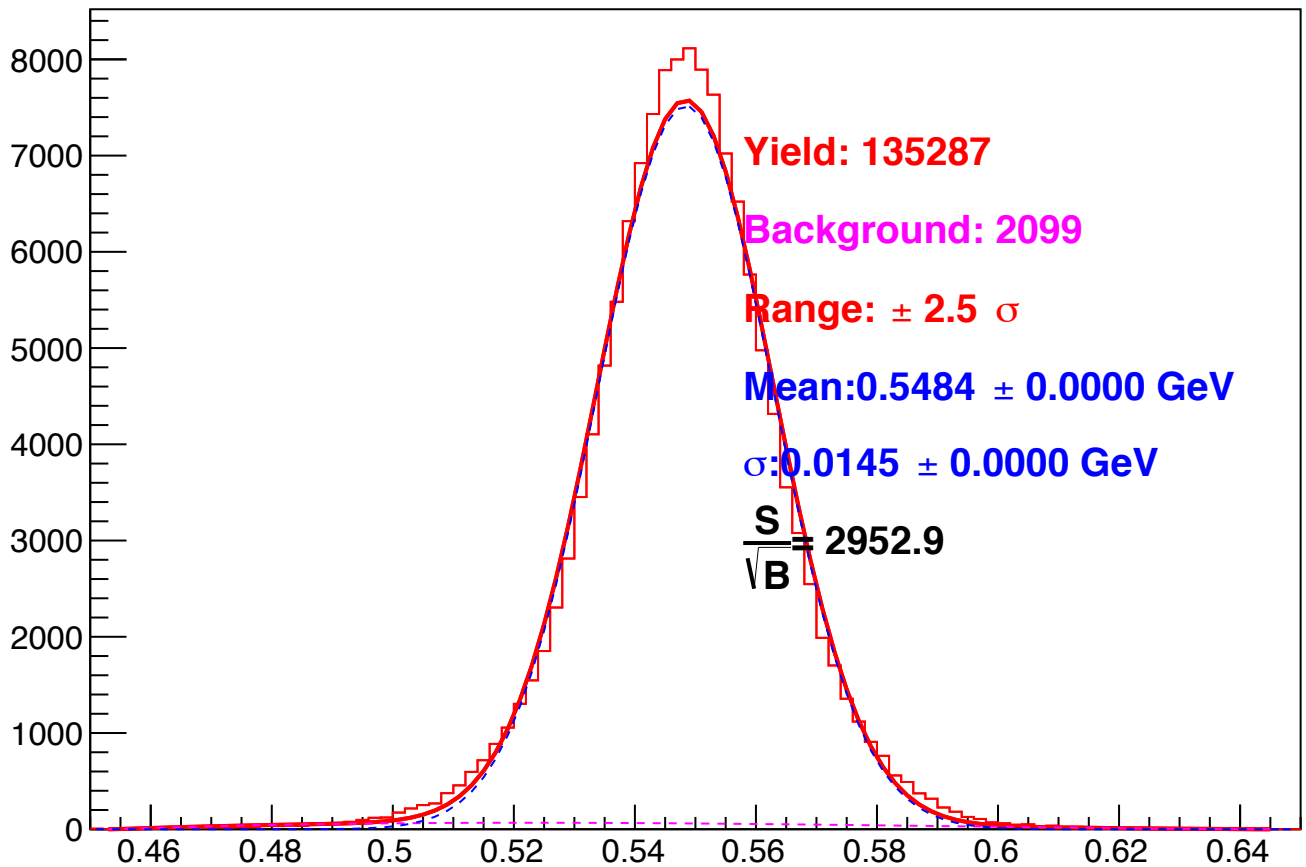

0.045 < q < 0.04875
Yield 10268
Background 510
S/(S+B) = 0.9527
0.04875 < q < 0.0525
Yield 9381
Background 291
S/(S+B) = 0.9699
0.0525 < q < 0.05625
Yield 8349
Background 269
S/(S+B) = 0.9688
0.05625 < q < 0.06
Yield 7414
Background 117
S/(S+B) = 0.9845
0.06 < q < 0.06375
Yield 6657
Background -4
S/(S+B) = 1.0006
0.06375 < q < 0.0675
Yield 6120
Background 163
S/(S+B) = 0.9741
0.0675 < q < 0.07125
Yield 5777
Background 52
S/(S+B) = 0.9911
0.07125 < q < 0.075
Yield 5191
Background 71
S/(S+B) = 0.9865
0.075 < q < 0.07875
Yield 5010
Background -24
S/(S+B) = 1.0048
0.07875 < q < 0.0825
Yield 4326
Background -102
S/(S+B) = 1.0241
0.0825 < q < 0.08625
Yield 4116
Background -63
S/(S+B) = 1.0155
0.08625 < q < 0.09
Yield 3819
Background -161
S/(S+B) = 1.0440
Entries
$M_x^2(p)$ [GeV]

M(e+e-) Slices


0.09 < q < 0.09375
Yield 3947
Background -641
S/(S+B) = 1.1939
0.09375 < q < 0.0975
Yield 3536
Background -477
S/(S+B) = 1.1559
0.0975 < q < 0.1013
Yield 3266
Background -525
S/(S+B) = 1.1915
0.1013 < q < 0.105
Yield 3018
Background -674
S/(S+B) = 1.2875
0.105 < q < 0.1088
Yield 2664
Background -485
S/(S+B) = 1.2226
0.1088 < q < 0.1125
Yield 2006
Background -108
S/(S+B) = 1.0569
0.1125 < q < 0.1163
Yield 1695
Background -130
S/(S+B) = 1.0831
0.1163 < q < 0.12
Yield 1471
Background -202
S/(S+B) = 1.1592
0.12 < q < 0.1238
Yield 1052
Background -115
S/(S+B) = 1.1227
0.1238 < q < 0.1275
Yield 677
Background 56
S/(S+B) = 0.9236
0.1275 < q < 0.1312
Yield 389
Background 52
S/(S+B) = 0.8821
0.1312 < q < 0.135
Yield 242
Background 26
S/(S+B) = 0.9030
Entries
$M_x^2(p)$ [GeV]

CLAS g12 Data

η(e+e-γ)



Time-Like Form Factor of η

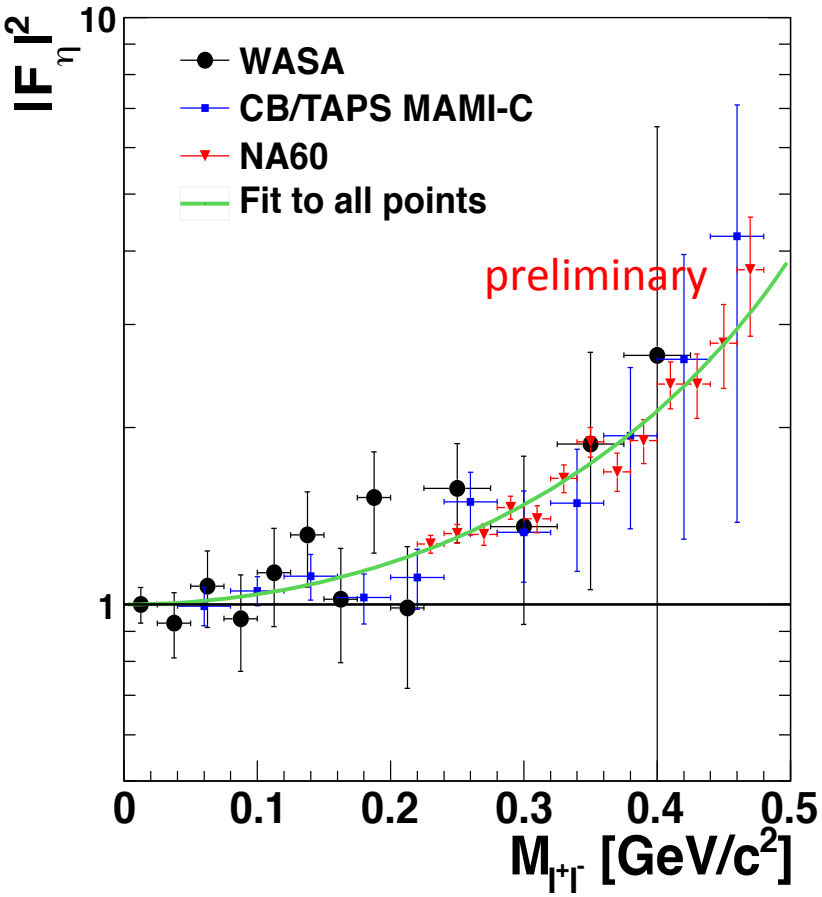
$$\frac{d\Gamma(\eta \to l^+ l^- \gamma)}{dm\Gamma(\eta \to \gamma\gamma)} = [QED] \cdot |F_\eta(m^2)|^2$$

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

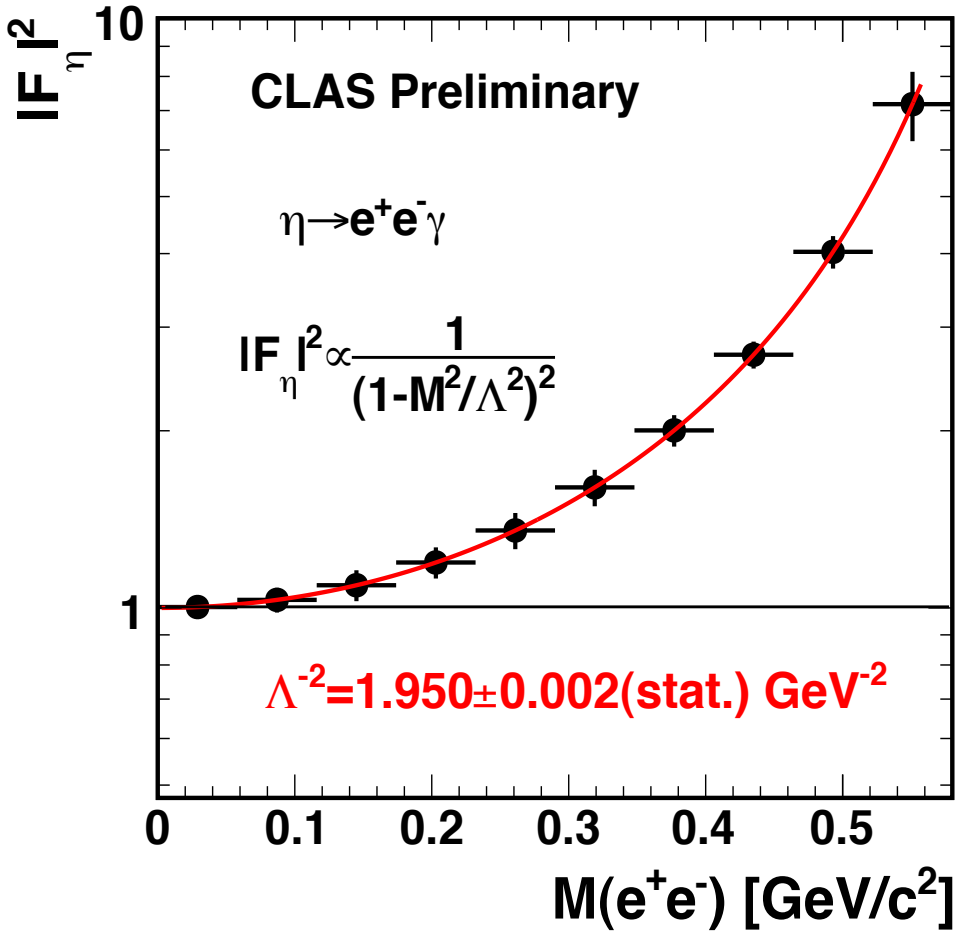
$$b = |\frac{dF}{dm^2}|_{m^2=0} = \Lambda^{-2}$$

b=<r^2>/6 (size of **η**)

World Data



CLAS g12 Data

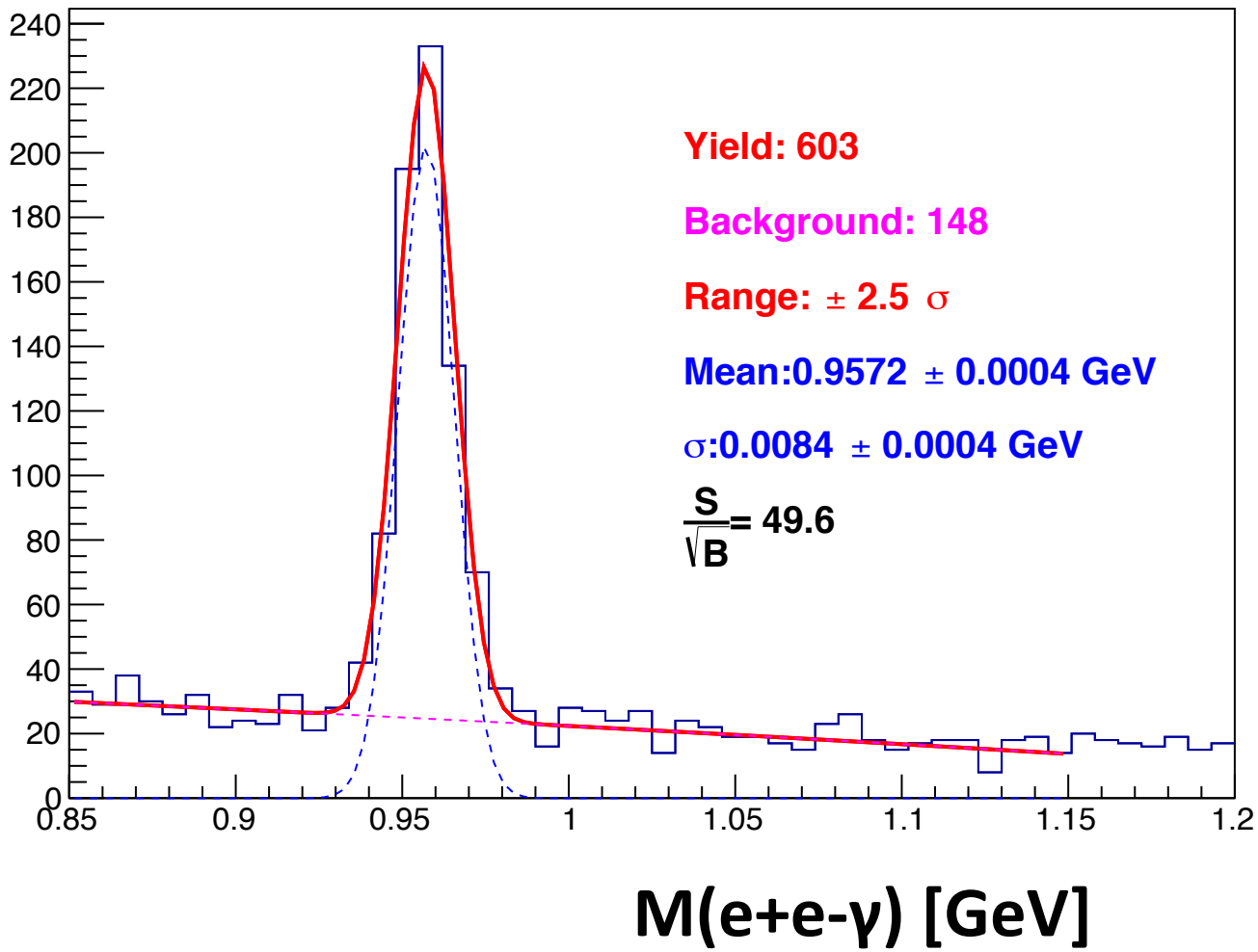


CB/TAPS $\Lambda^{-2} = 1.92 \pm 0.35(stat.) \pm 0.13(syst.) \quad GeV^{-2}$

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

CLAS syst. err. ~ 0.05 (preliminary)

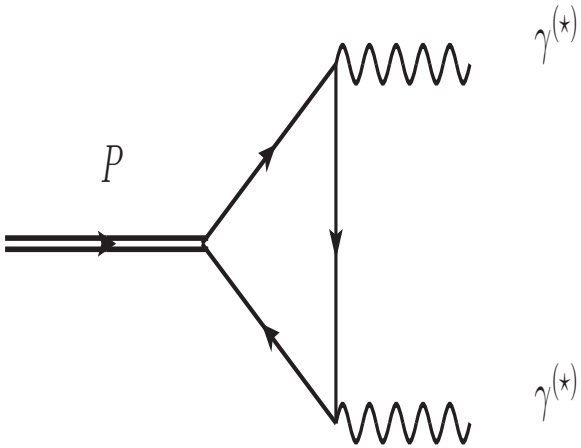
First measurement ofη' Dalitz Decay in CLAS



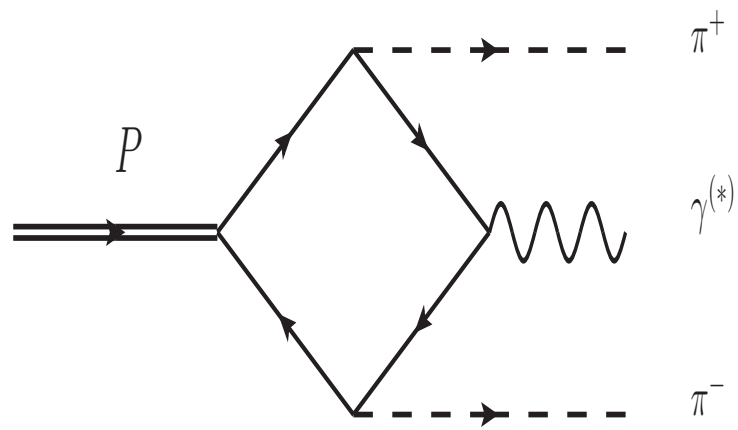
Radiative Decay $\eta(\eta') \to \pi^+\pi^-\gamma$

Why is it interesting?

Access to Box Anomaly



Triangle (PVV)



Box (VPPP)

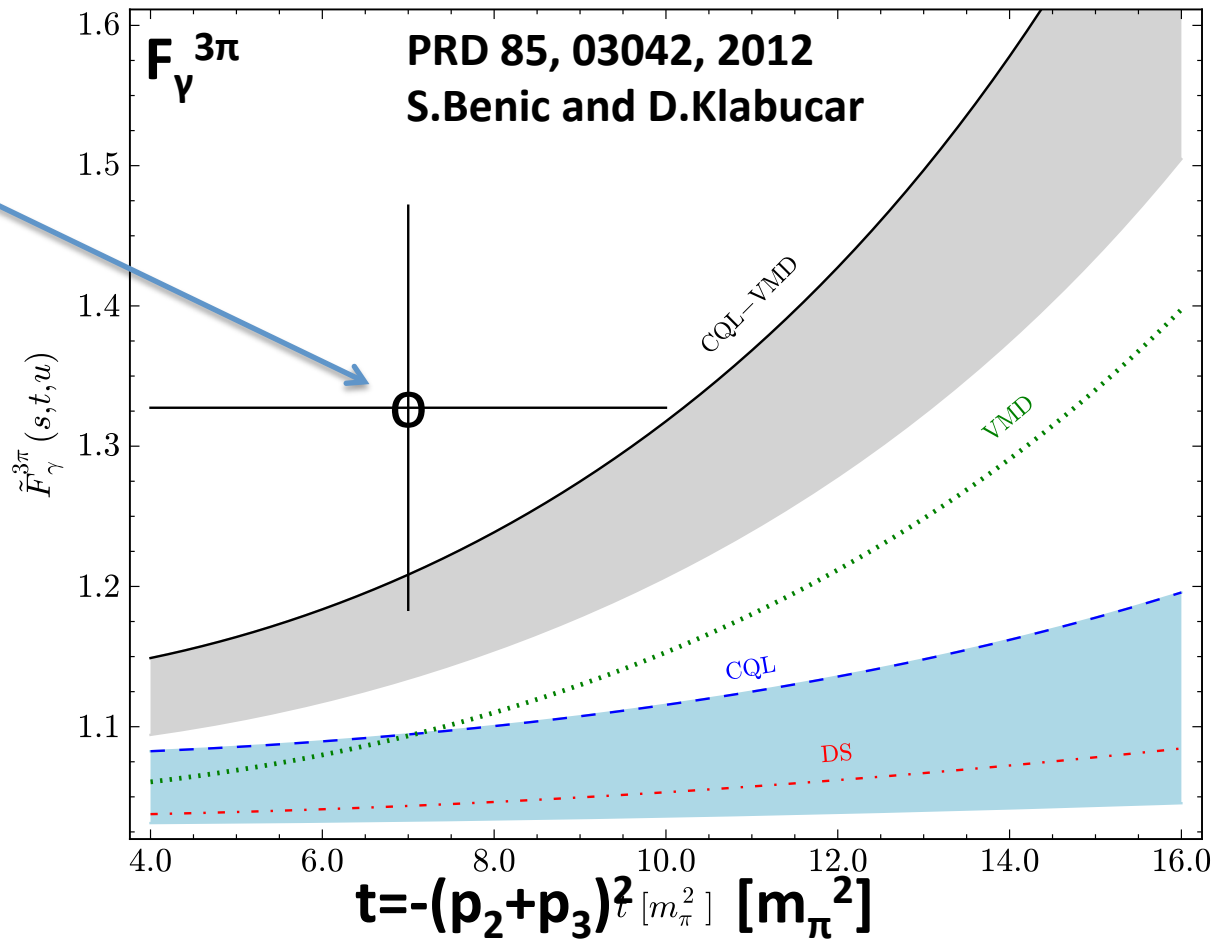
It gives an access to the box anomaly term of Wess-Zumino-Witten Lagrangian

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

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

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

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
γγ width of π^0

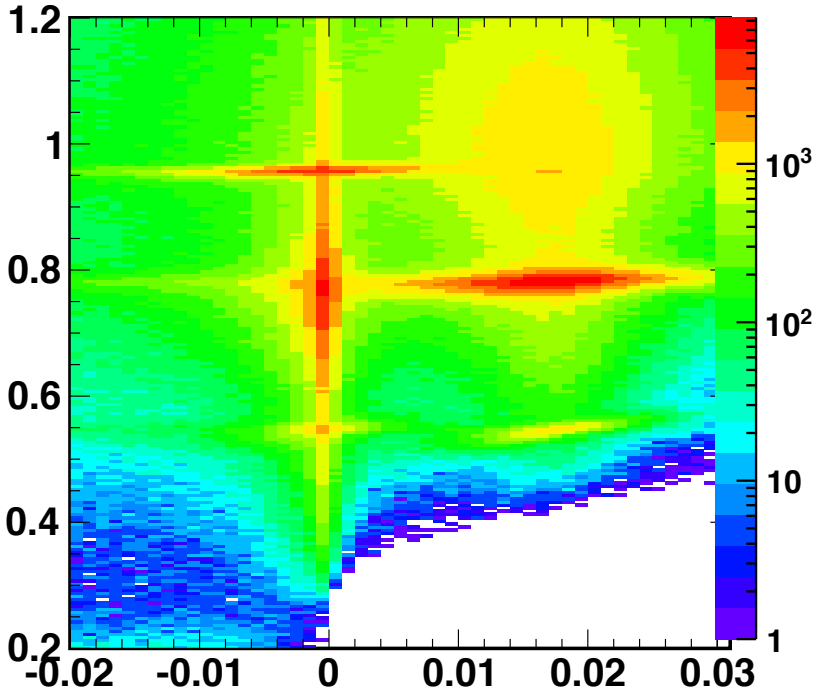
$$A_\pi^{2\gamma} = e f_\pi^2 A_\gamma^{3\pi}$$

(theory prediction)

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

Very poorly measured

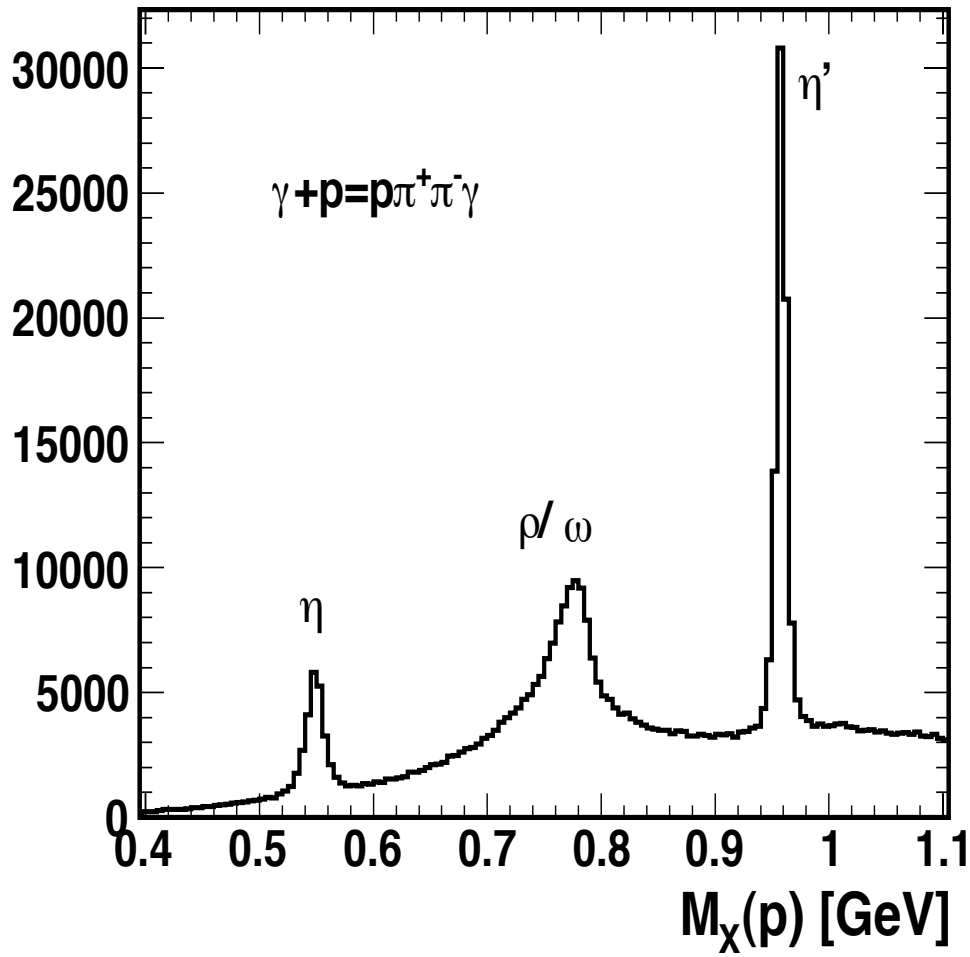
Radiative Decay $\eta,\eta' \rightarrow \pi^+\pi^-\gamma$

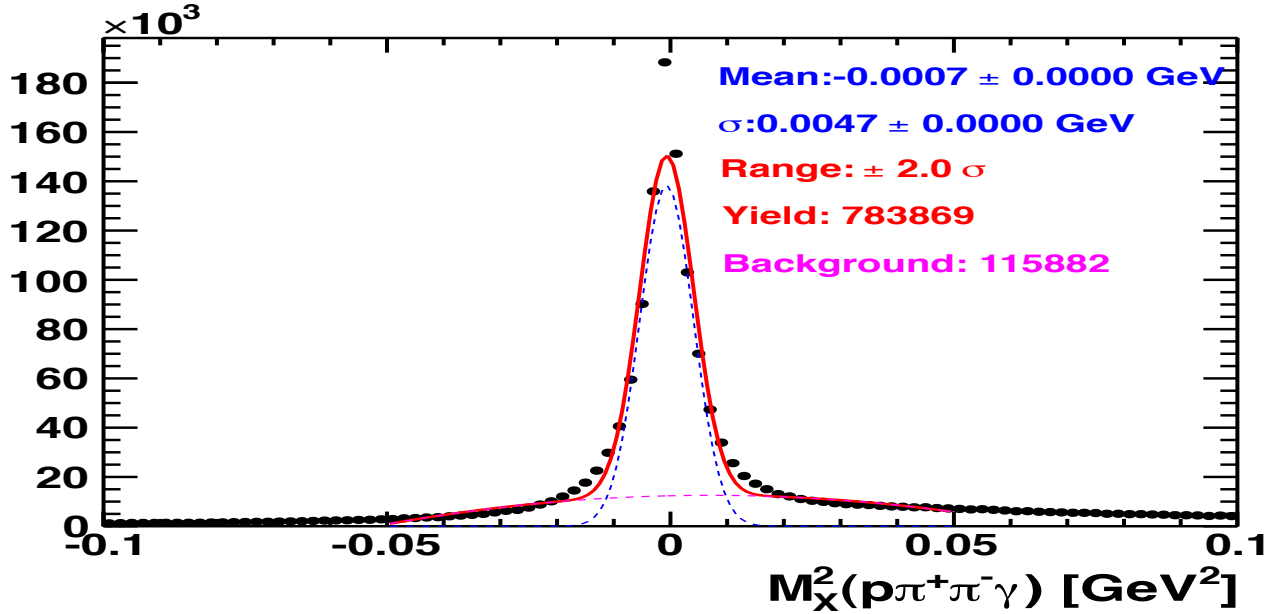


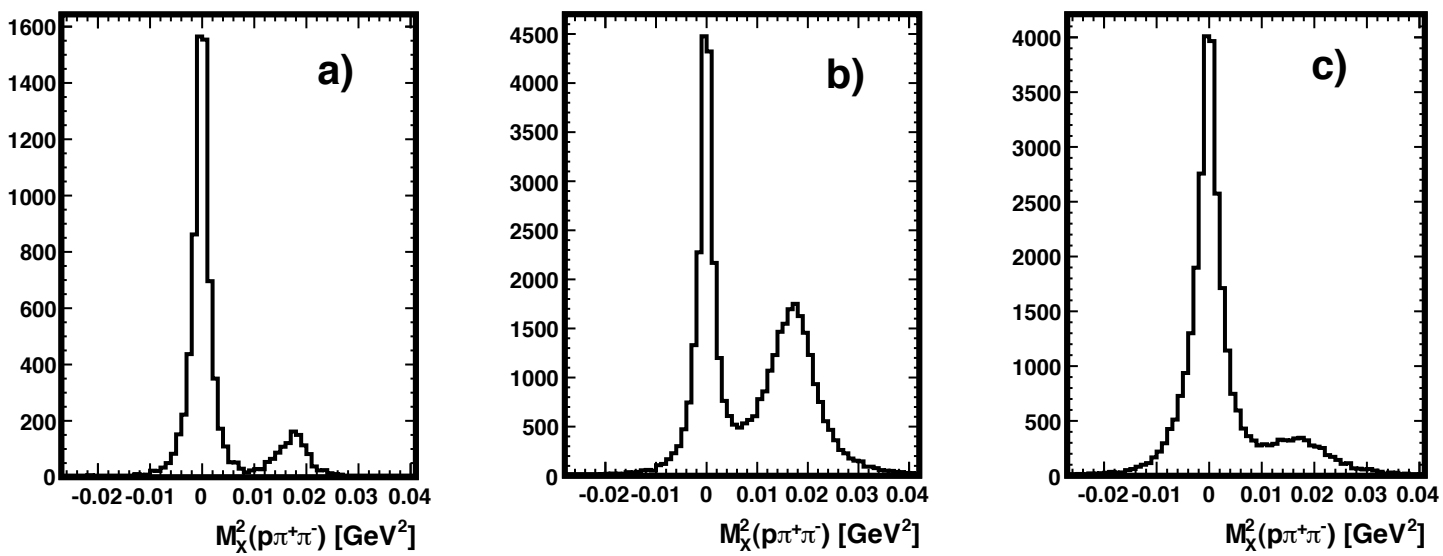
$M_X^2(p)$ versus $M_X^2(p\pi^+\pi^-)$

$$\mathbf{ME} > \mathbf{0.01GeV}$$

$$\mathbf{ME} - \mathbf{E}_\gamma < \mathbf{0.03GeV}$$







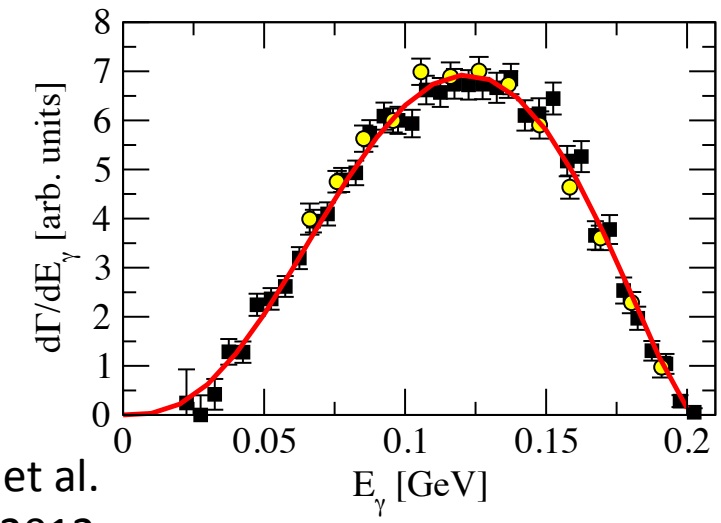
Mx(p)=0.55+-0.01 GeV

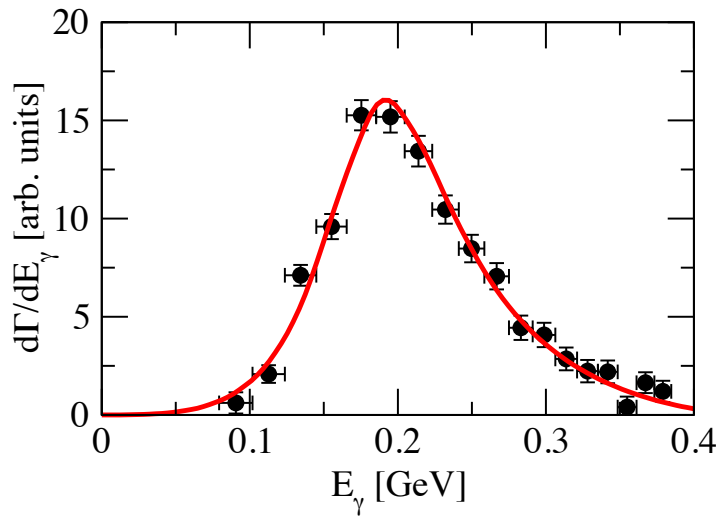
0.76+-0.06 GeV

0.96+-0.01 GeV

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

World data

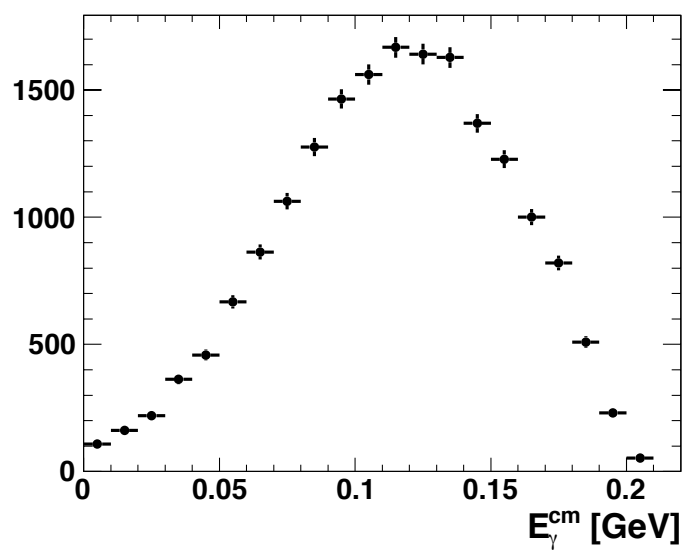


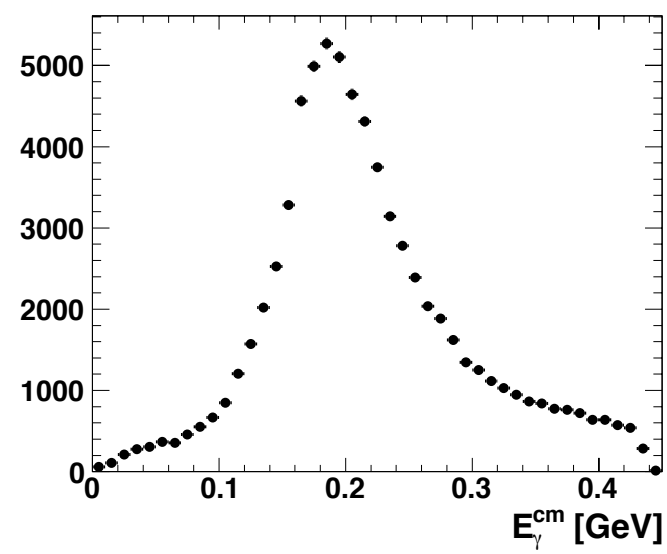


Theory:
E.Stollenwerk et al.
PL B707, 184, 2012

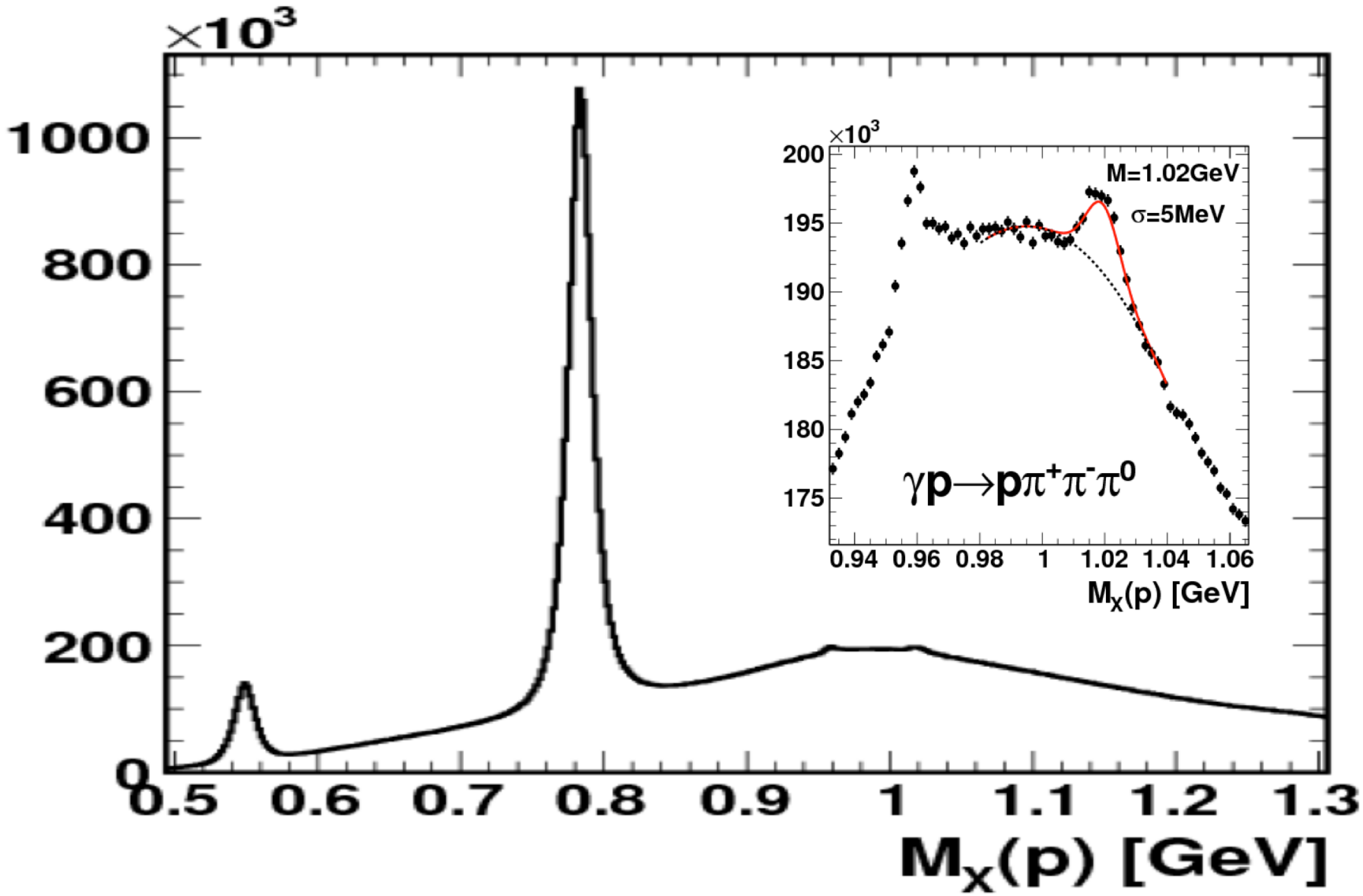
CLAS Preliminary uncorrected

10x more in CLAS



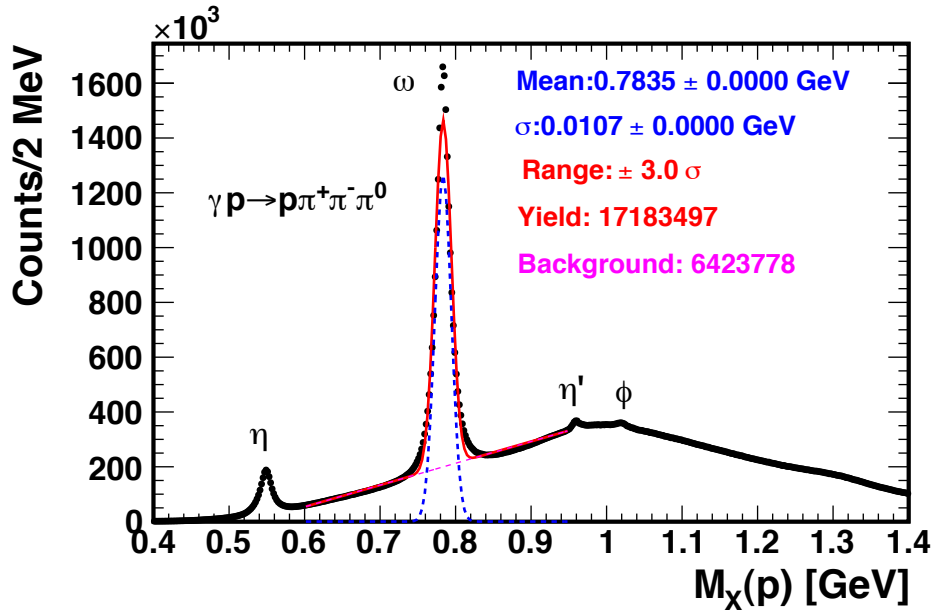


CLAS Hadronic decays: g11 Data



CLAS

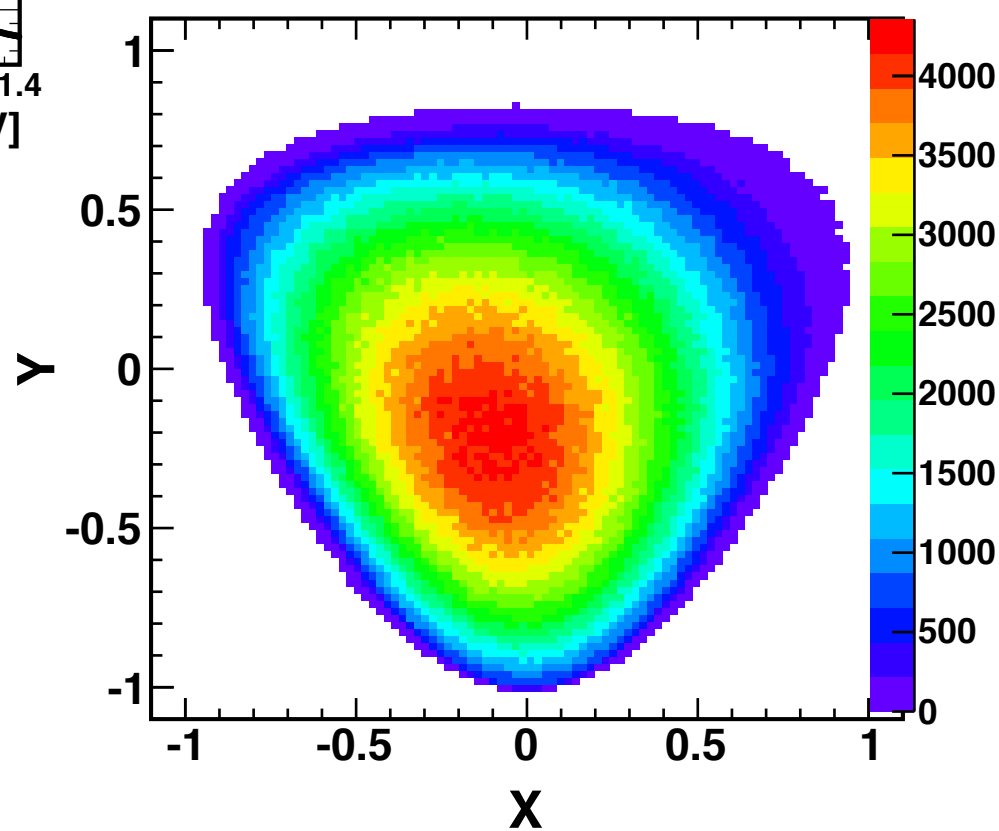
$$\omega \rightarrow \pi^+\pi^-\pi^0$$



About 17M ω's

Largest statistics in the world

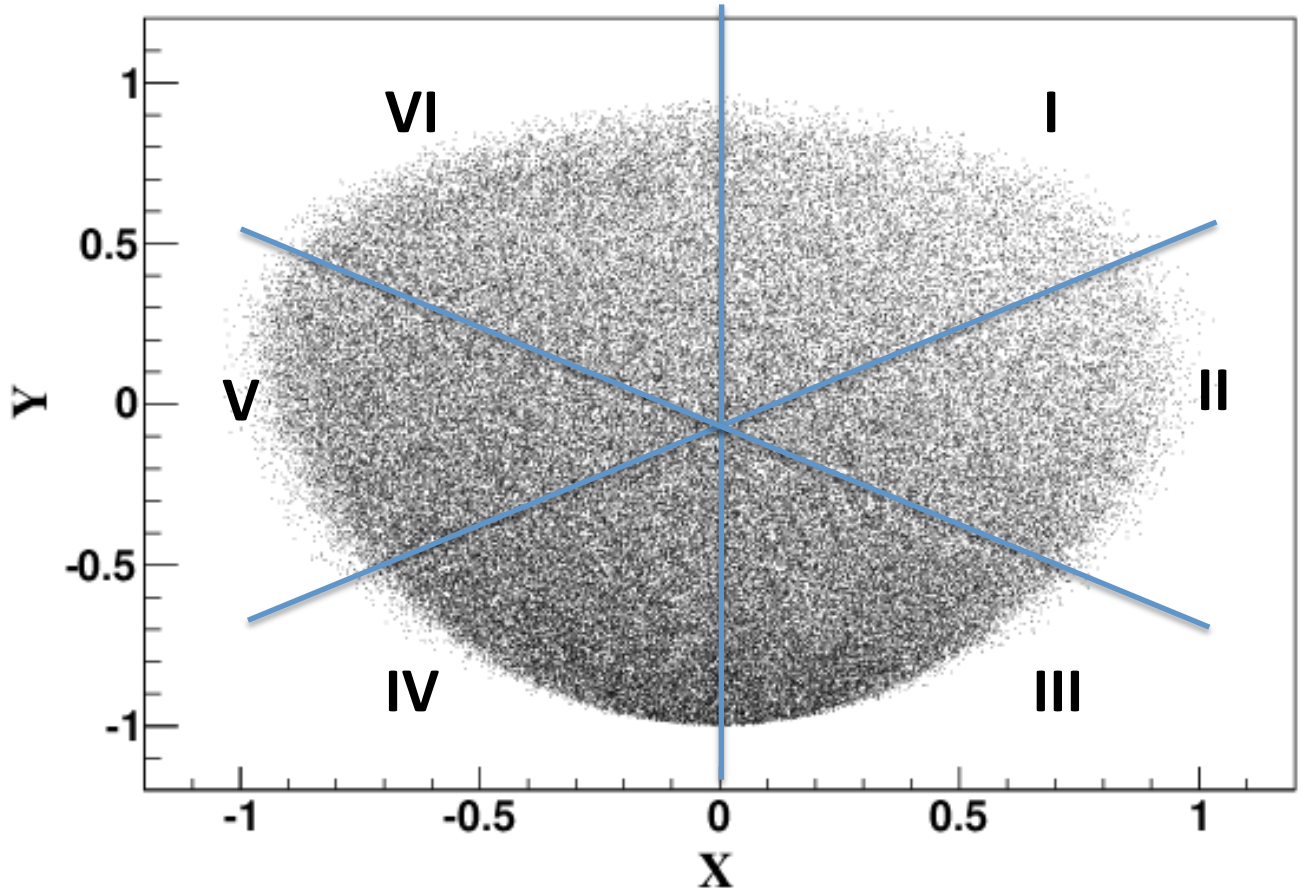
Not corrected for acceptance



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

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

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

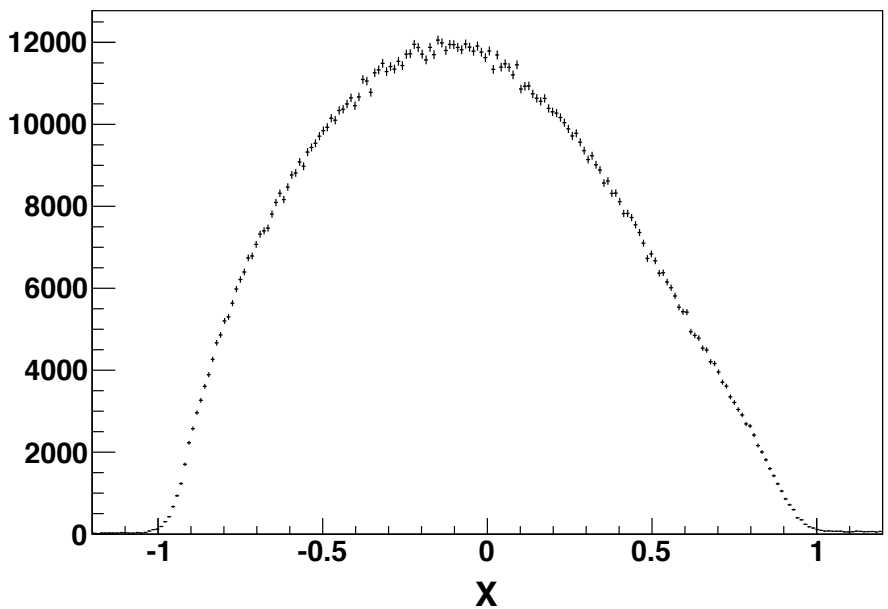
Dalitz plot projections

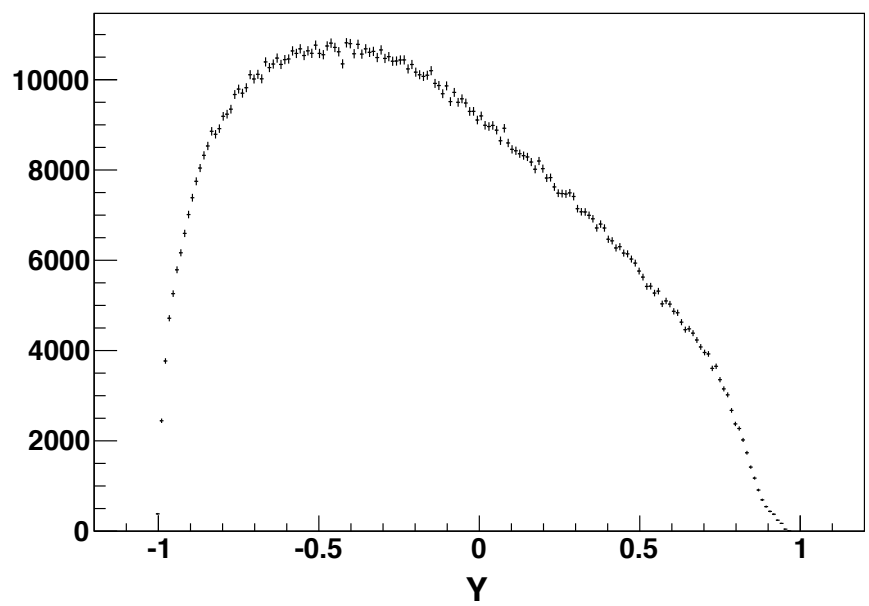
$$\eta \to \pi^+\pi^-\pi^0$$

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

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

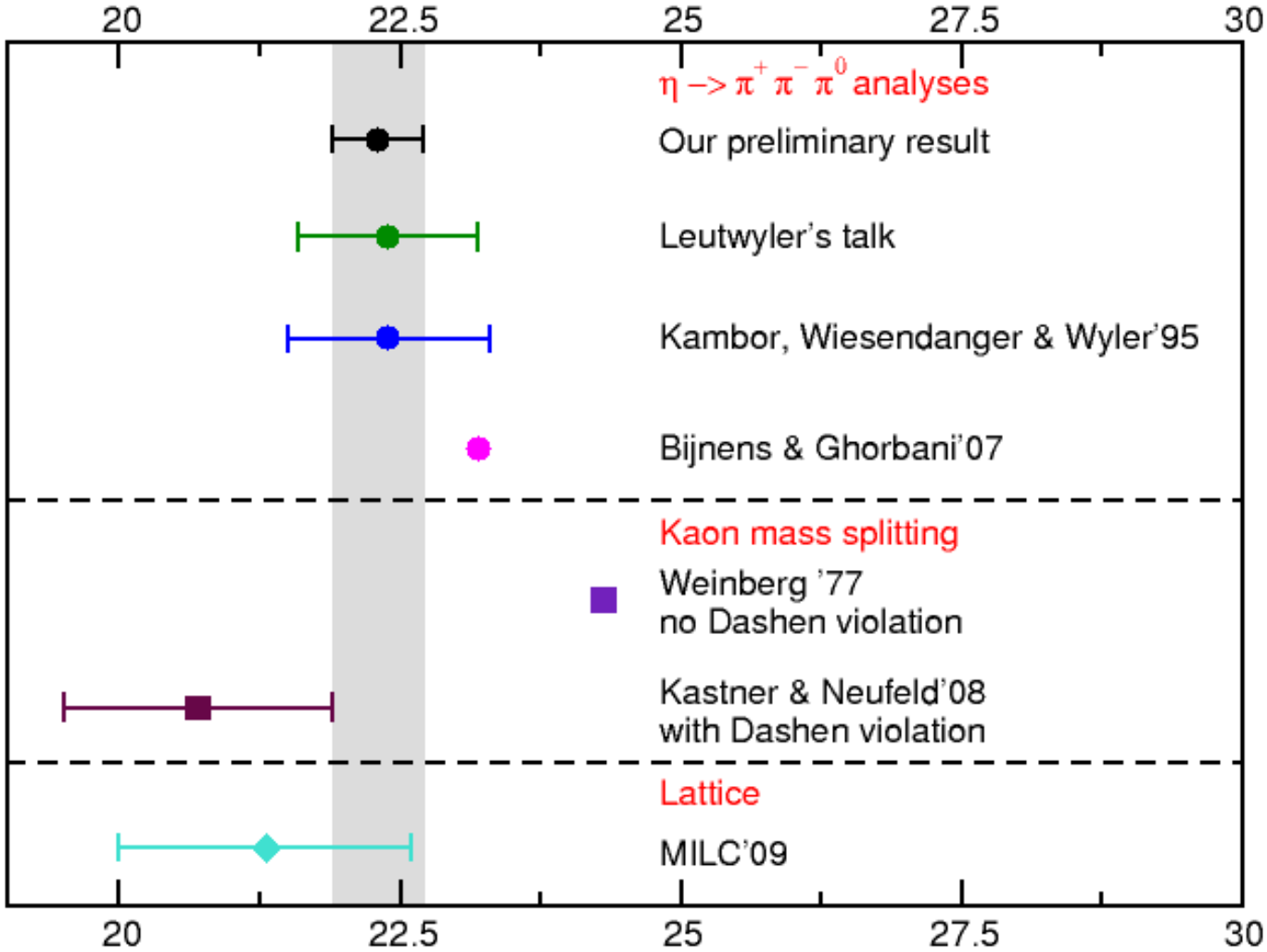
CLAS g11 Data





Quark mass ratio

G.Colangelo et al., arXiv:0910.0765



Q

What else could be improved ?

From Particle Data Group:

η

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

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

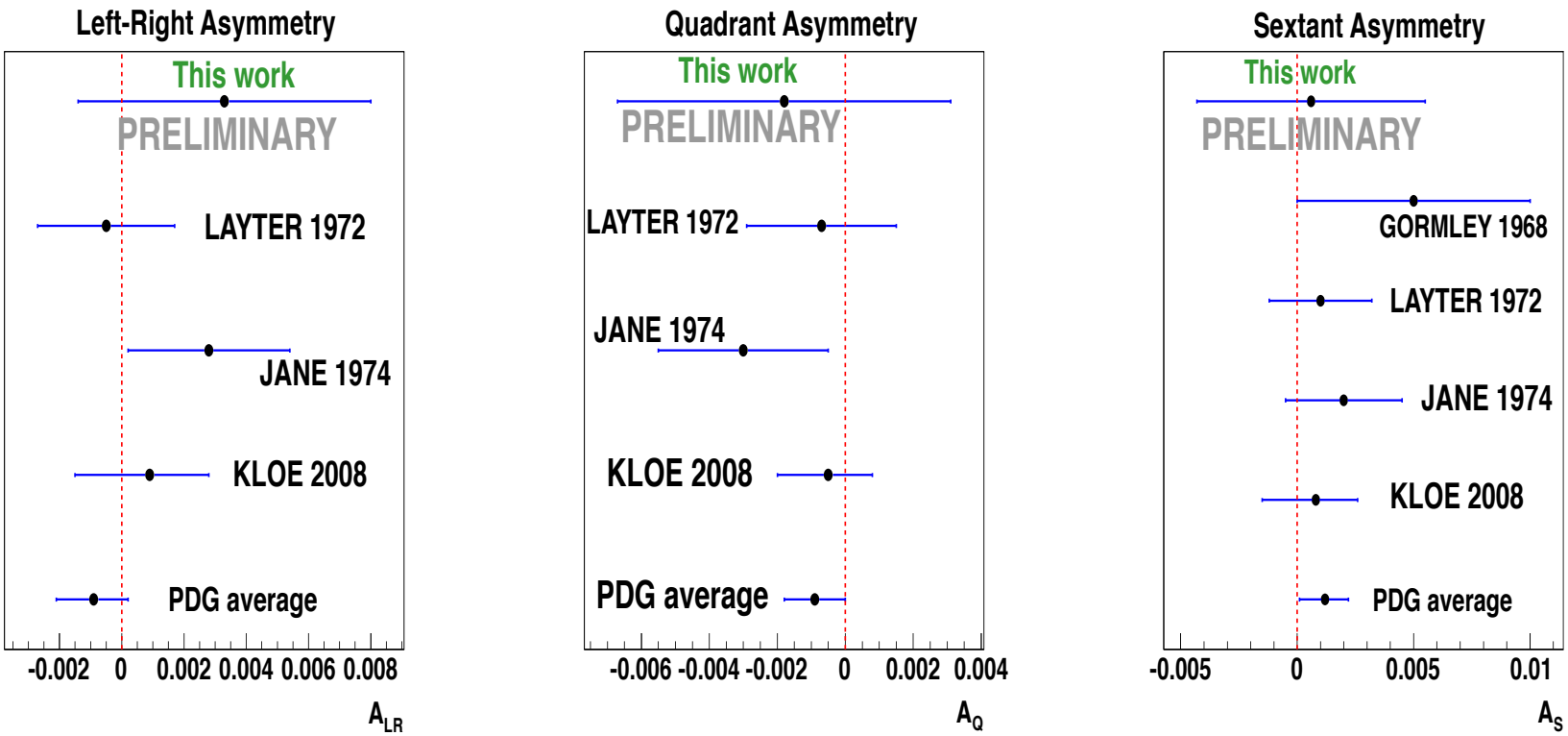
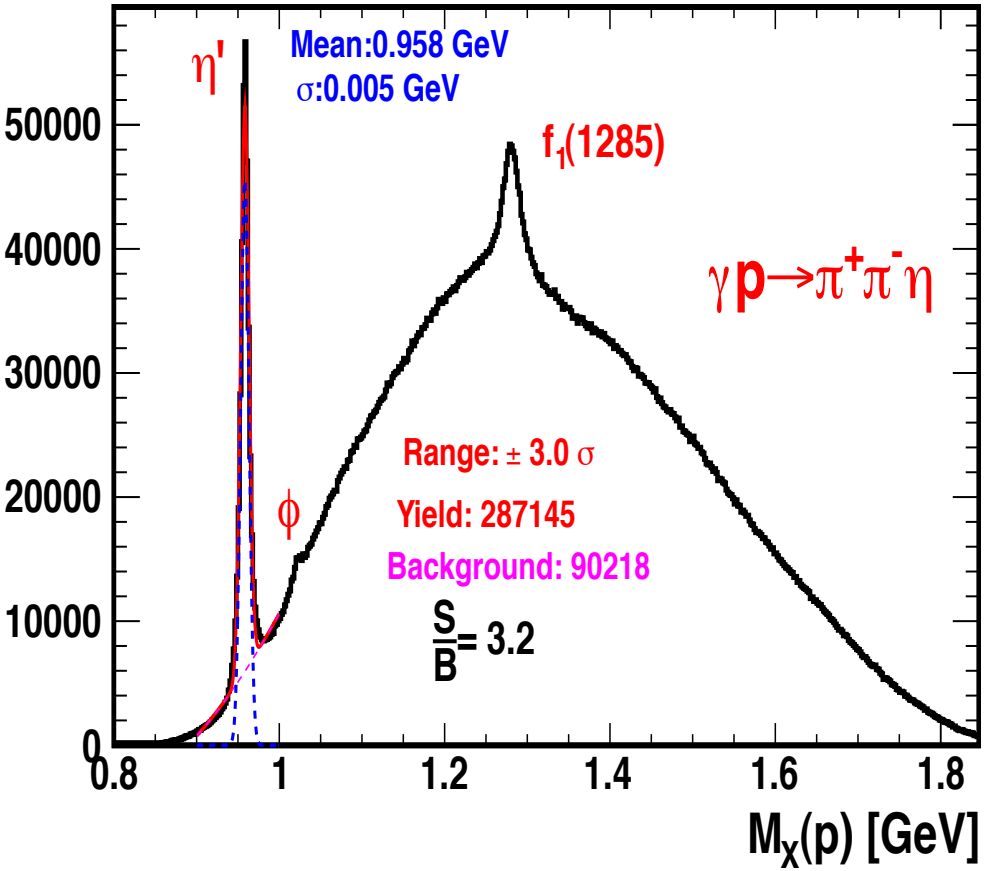


Fig. 1. Comparison of obtained values of asymmetries [7] with results determined by previous experiments [3,4,5], and a value given by PDG [6]. arXiv:1210.1758 [WASA-COSY]

CLAS expected stat. error. ~ 0.001

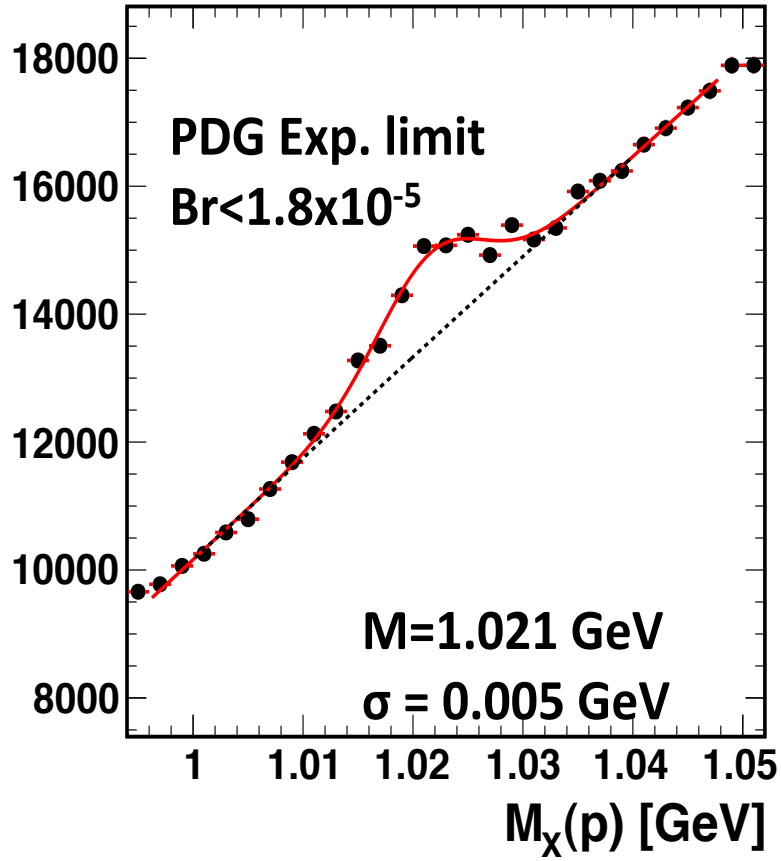
Hadronic decay

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



G-Parity violation

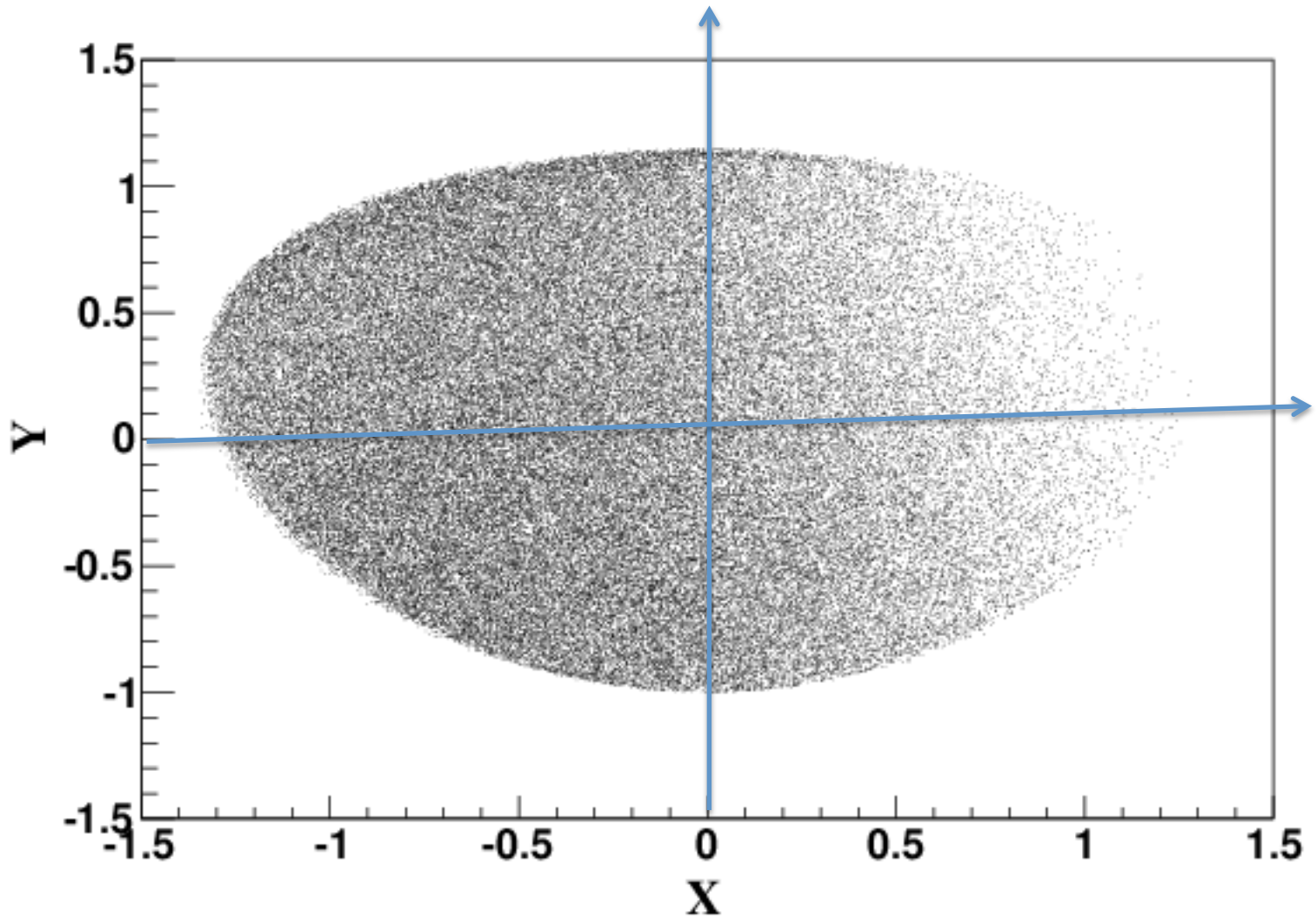
$\Phi \rightarrow \pi\pi\eta$



CLAS g11 Data (similar stat. in g12 run)

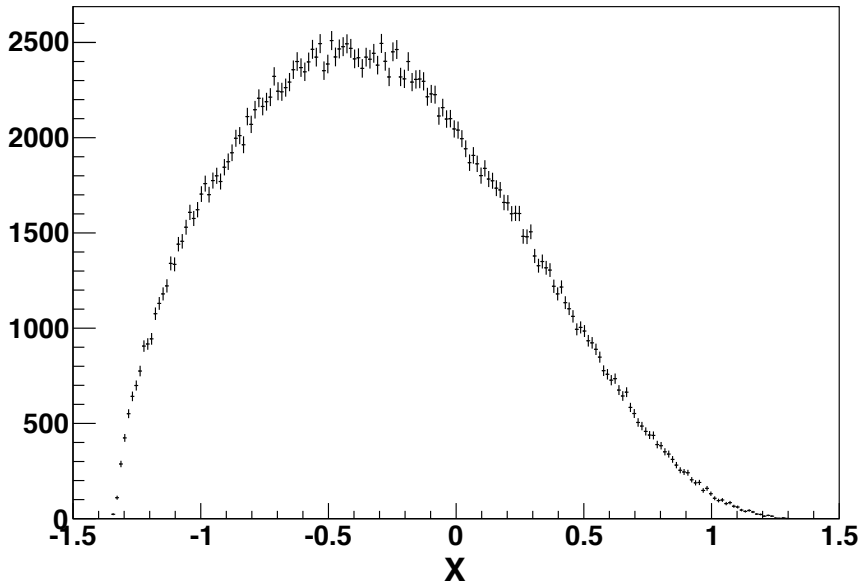
(300K, 7 times more η's than in BESIII)

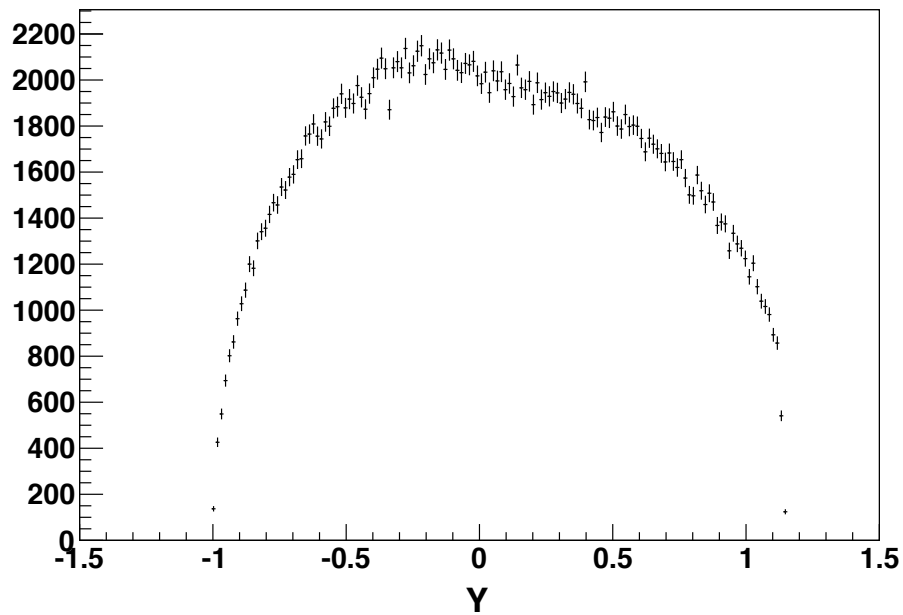
Dalitz plot η'➔ππη



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

CLAS Preliminary uncorrected





Par.	VES (EPJ A26,383,2005)	Theory (EPJ A26,383,2005)	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

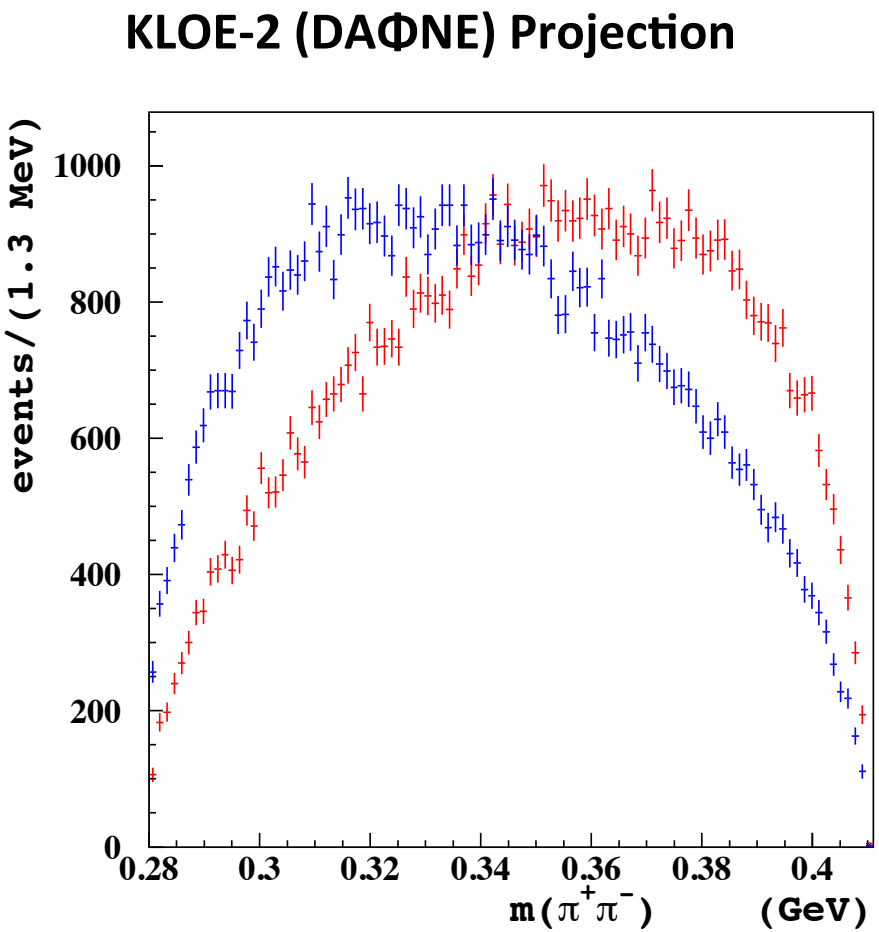
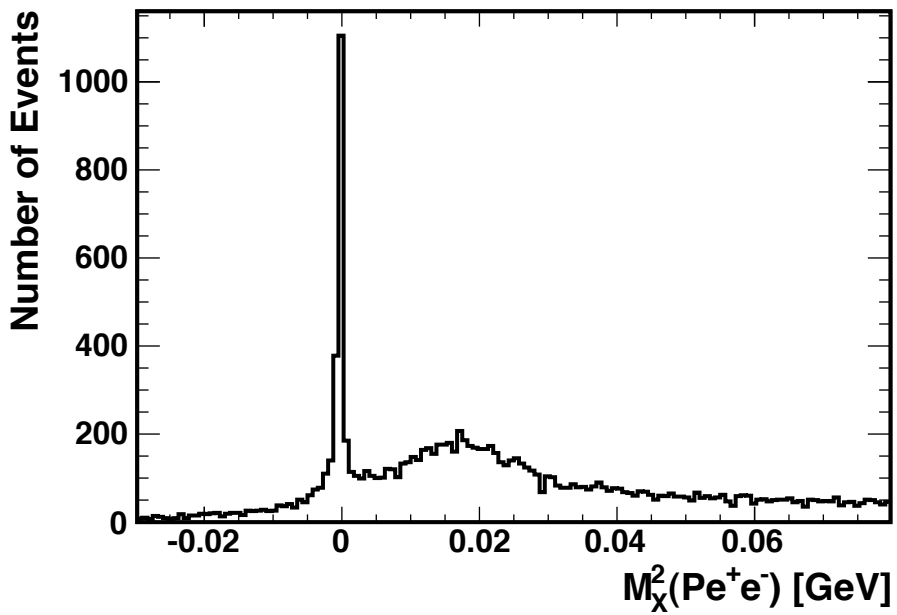
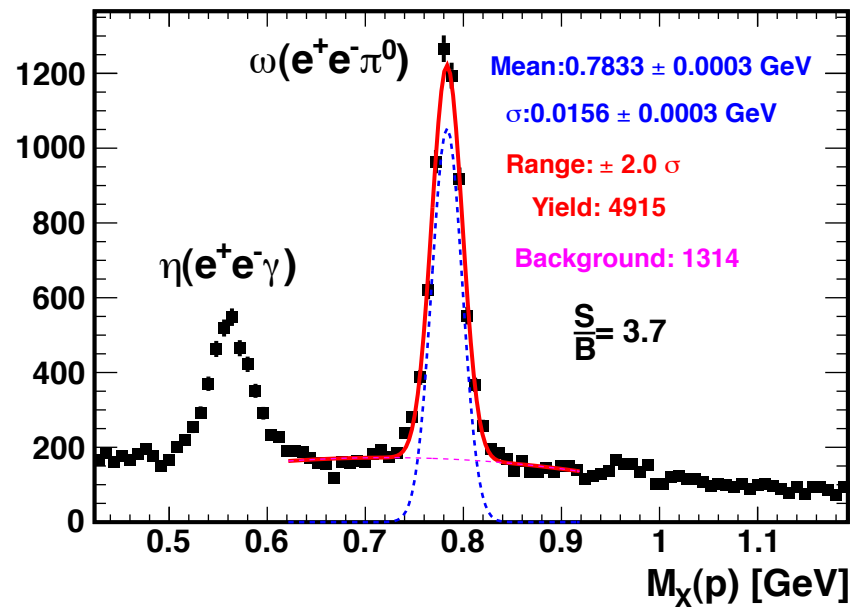


Fig. 18: The $m_{\pi^+\pi^-}$ distribution in the $\eta' \to \eta\pi^+\pi^-$ decay with the σ meson (right–centered distribution) and without (left–centered distribution) contribution.

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

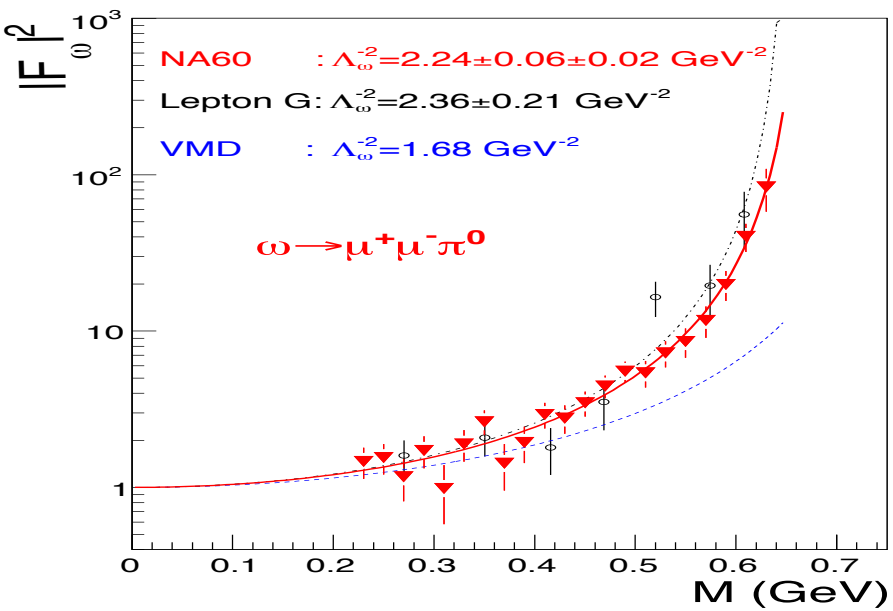
CLAS g12 Data



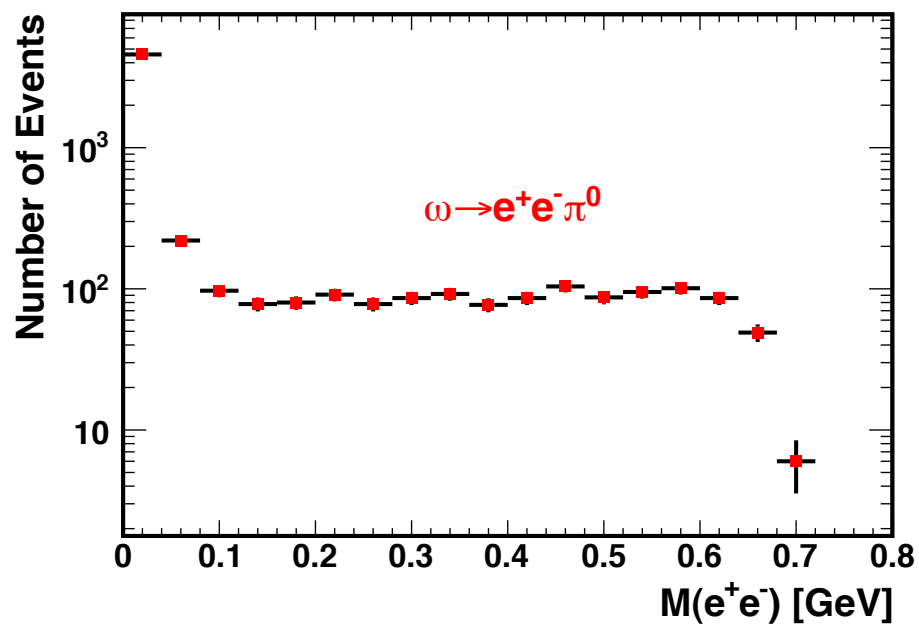


Transition Form Factor $\omega \rightarrow e^+e^-\pi^0$

World data

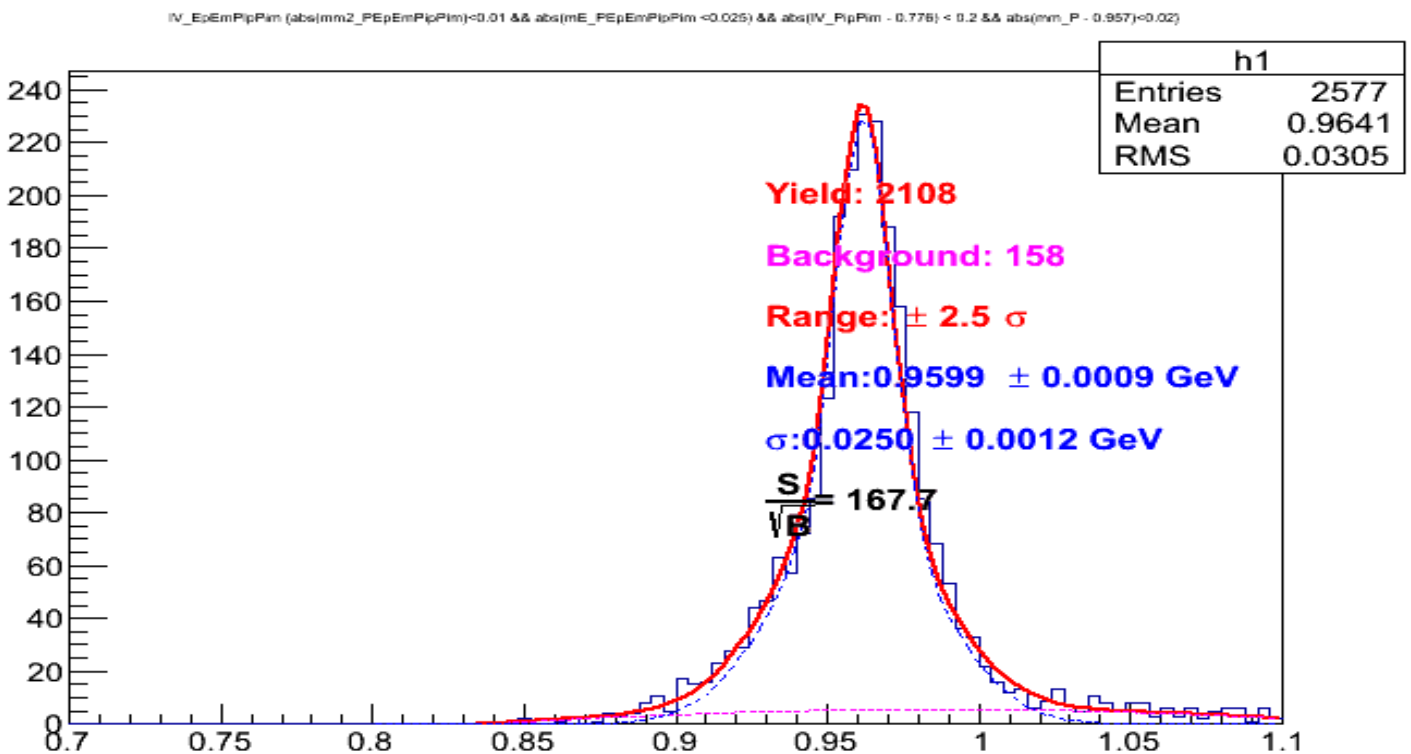


CLAS g12 Data



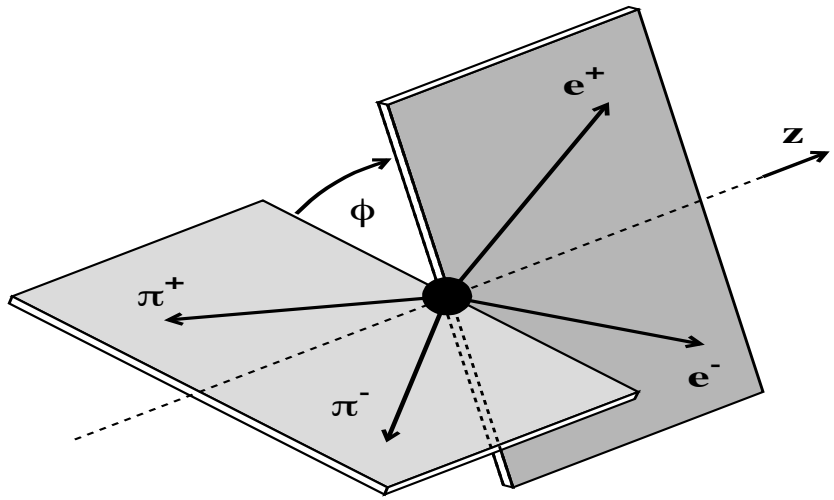
We expect significant improvement
in stat. error with CLAS Data

η,η’–>e+e-π+π-

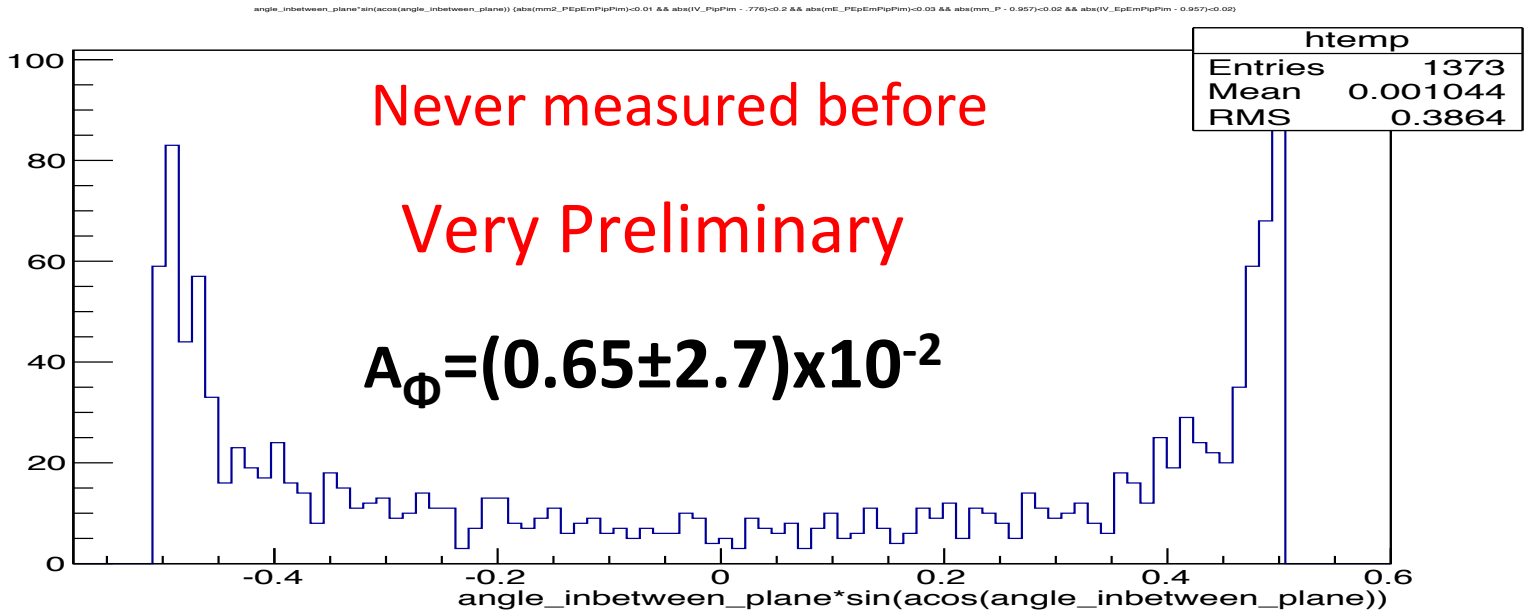


M(e+e-π+π-) [GeV]

η'–>e+e-π+π-

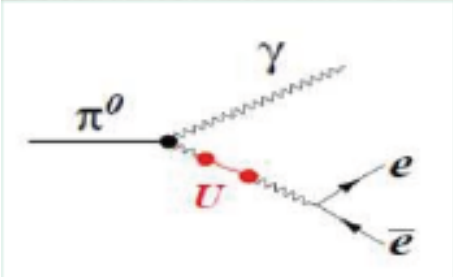


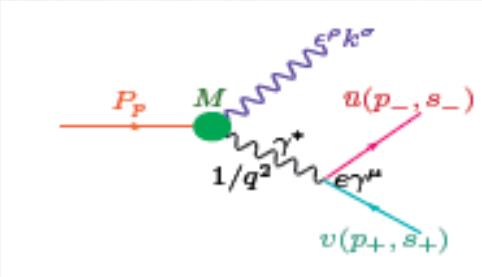
$$A_\Phi = (N^+ - N^-)/(N^+ + N^-)$$

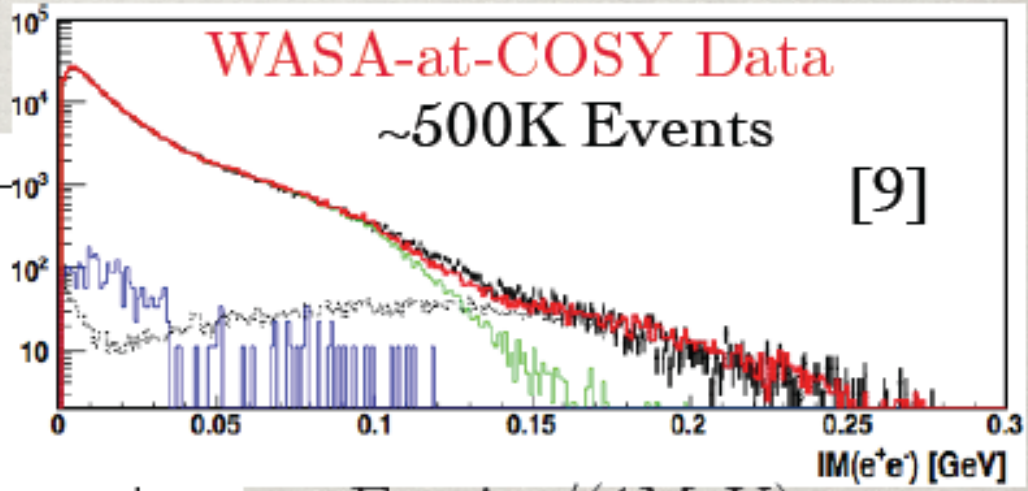


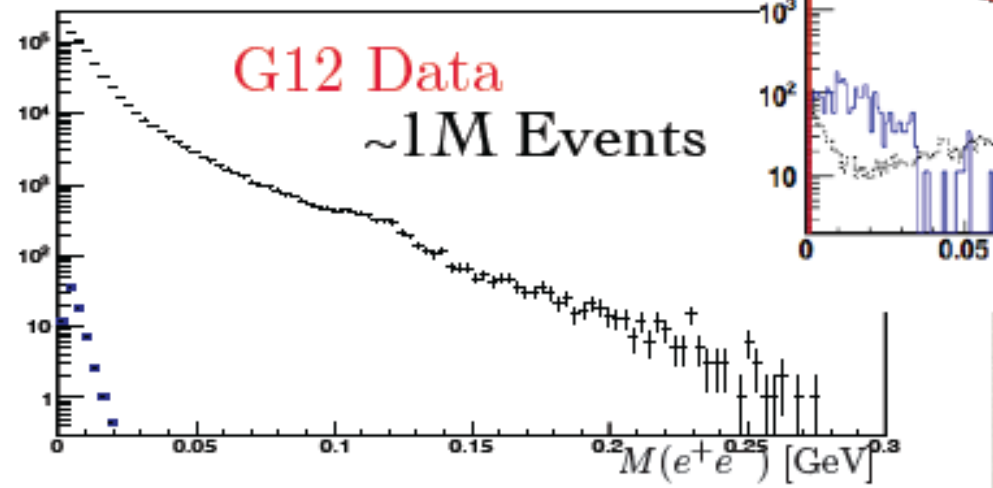
sinΦcosΦ

Dark Photon





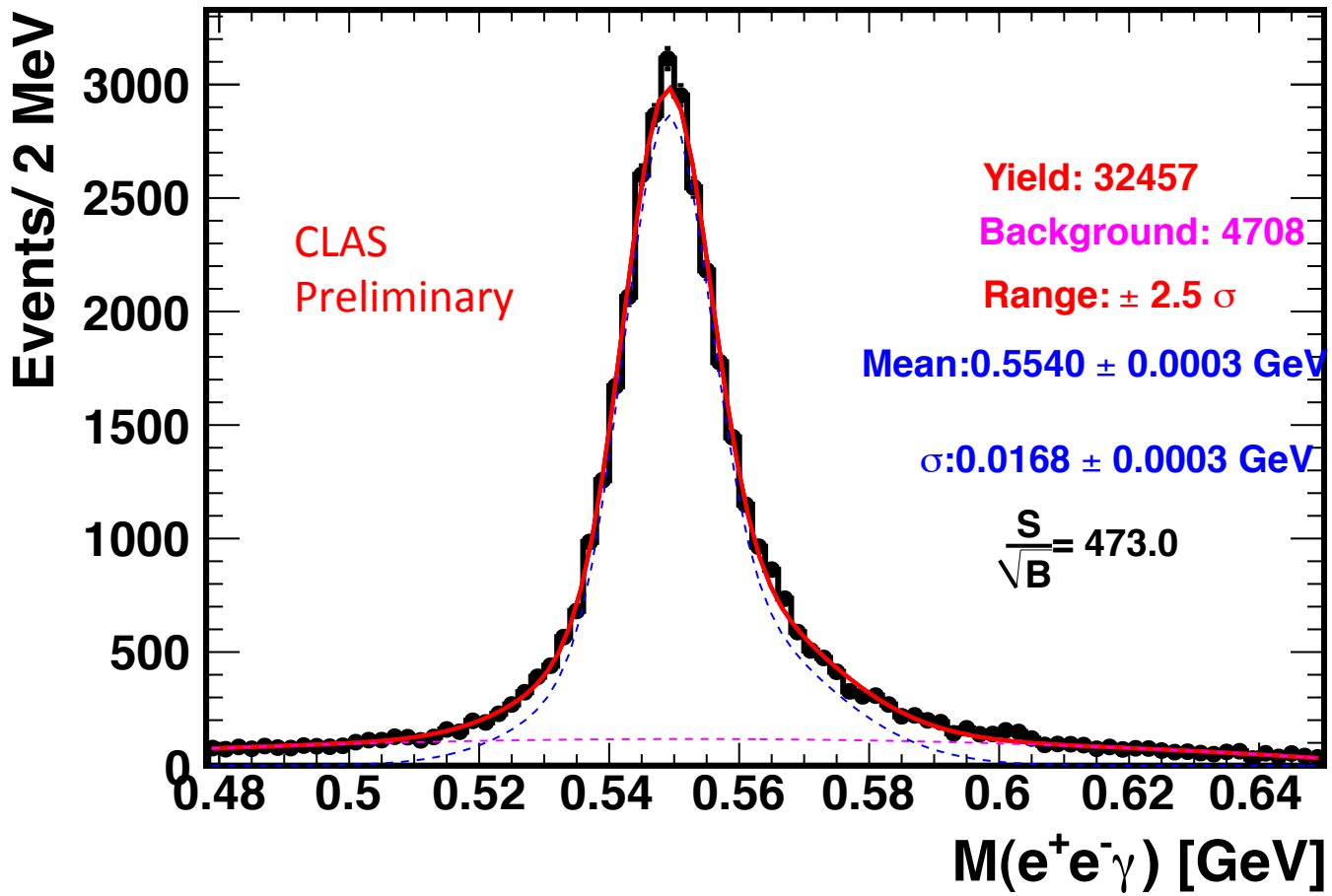


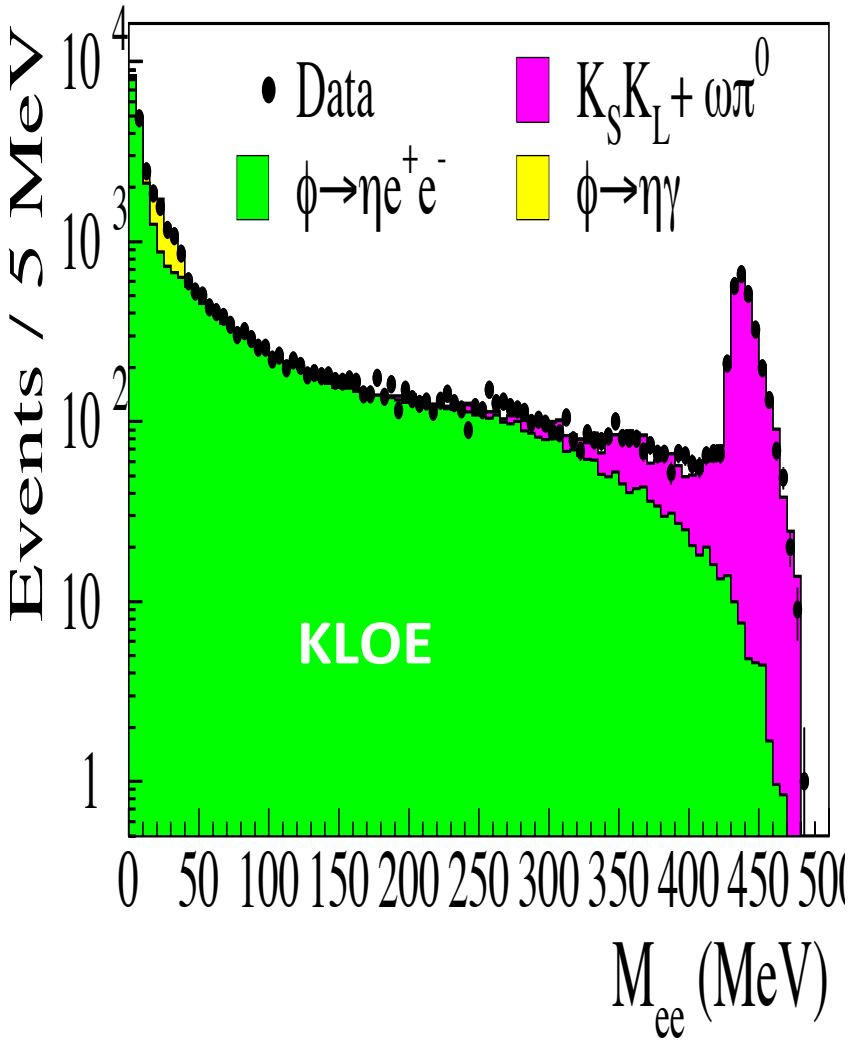


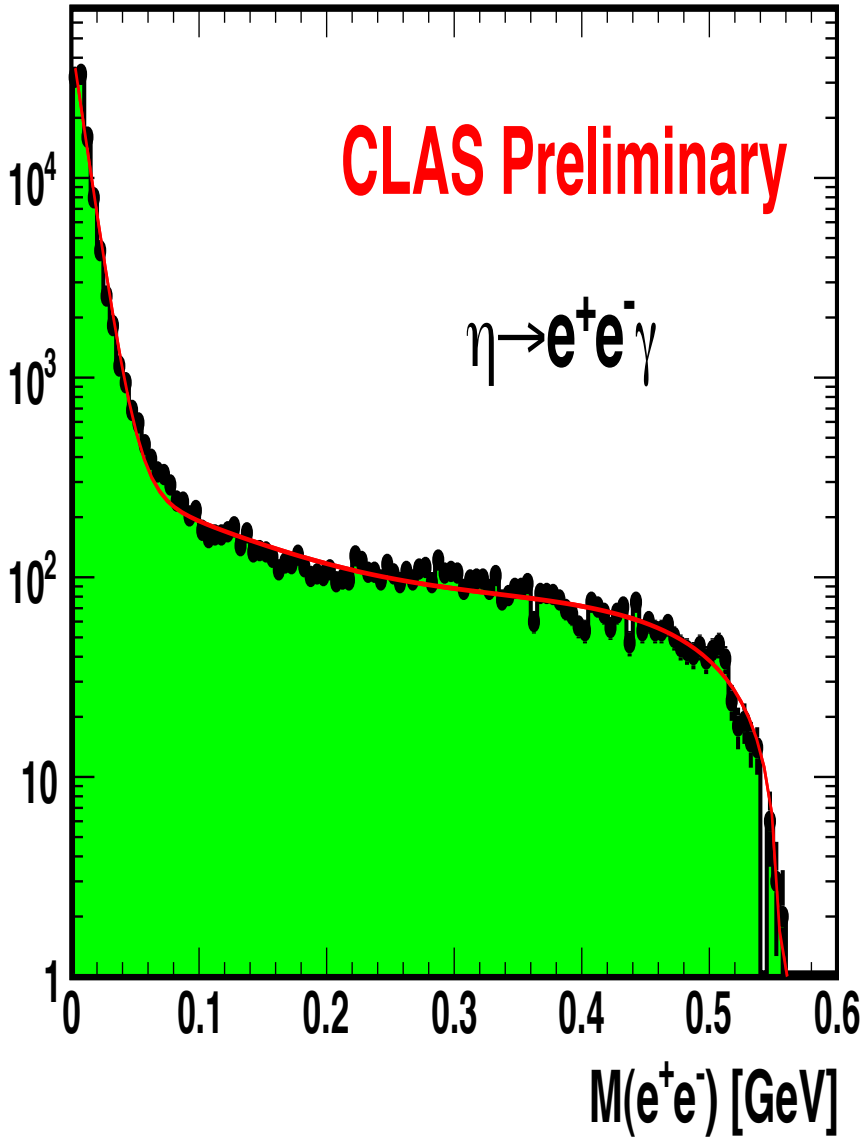
Entries/(1MeV)

- Data
- MC sum
- MC $\pi^0 \rightarrow e^+e^-\gamma$
- MC conversion
- MC $\pi^0 \rightarrow e^+e^-\gamma$ plus false e^+ from π^+

Dalitz Decay of η in CLAS




Events / 5 MeV
Data
$K_S K_L + \omega\pi^0$
$\phi \to \eta e^+ e^-$
$\phi \to \eta\gamma$
KLOE
M_{ee} (MeV)


CLAS Preliminary
$\eta \to e^+ e^- \gamma$
$M(e^+e^-)$ [GeV]

Dark Matter, Hidden Sector and Heavy Photons

-A key problem in modern physics is nature of dark matter
-There is no doubt that much of the mass-energy content of universe is in the form of yet unknown Dark Matter

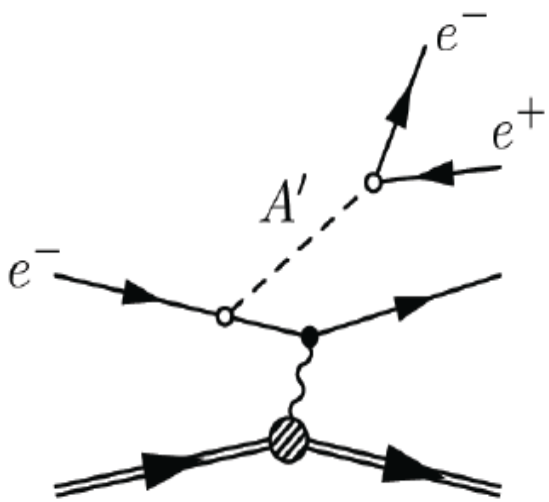
The current evidence is based on disjoint astronomical observations:
-Acoustic oscillations of the power spectrum of CMB
-The relative strength and shape of galaxy-distribution power spectrum at large wave numbers
-Observations of galactic rotation curves at distances for which little luminous matter is present

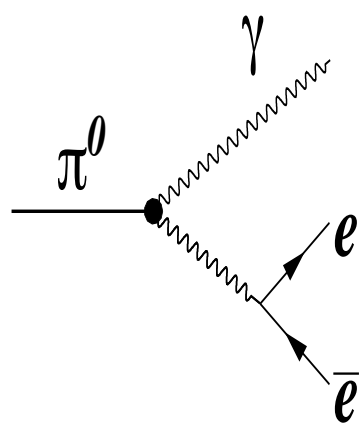
The cosmological evidence, taken collectively implies that some ~25% of the mass of Universe is in the form of Dark Matter with amazising accuracy of few percent!

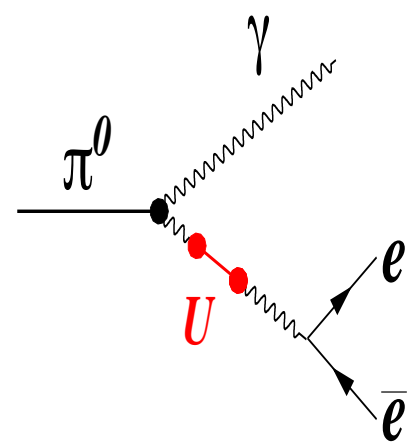
Hidden Gauge Boson

$$L = L_{SM} + L_D - L_{mix}$$

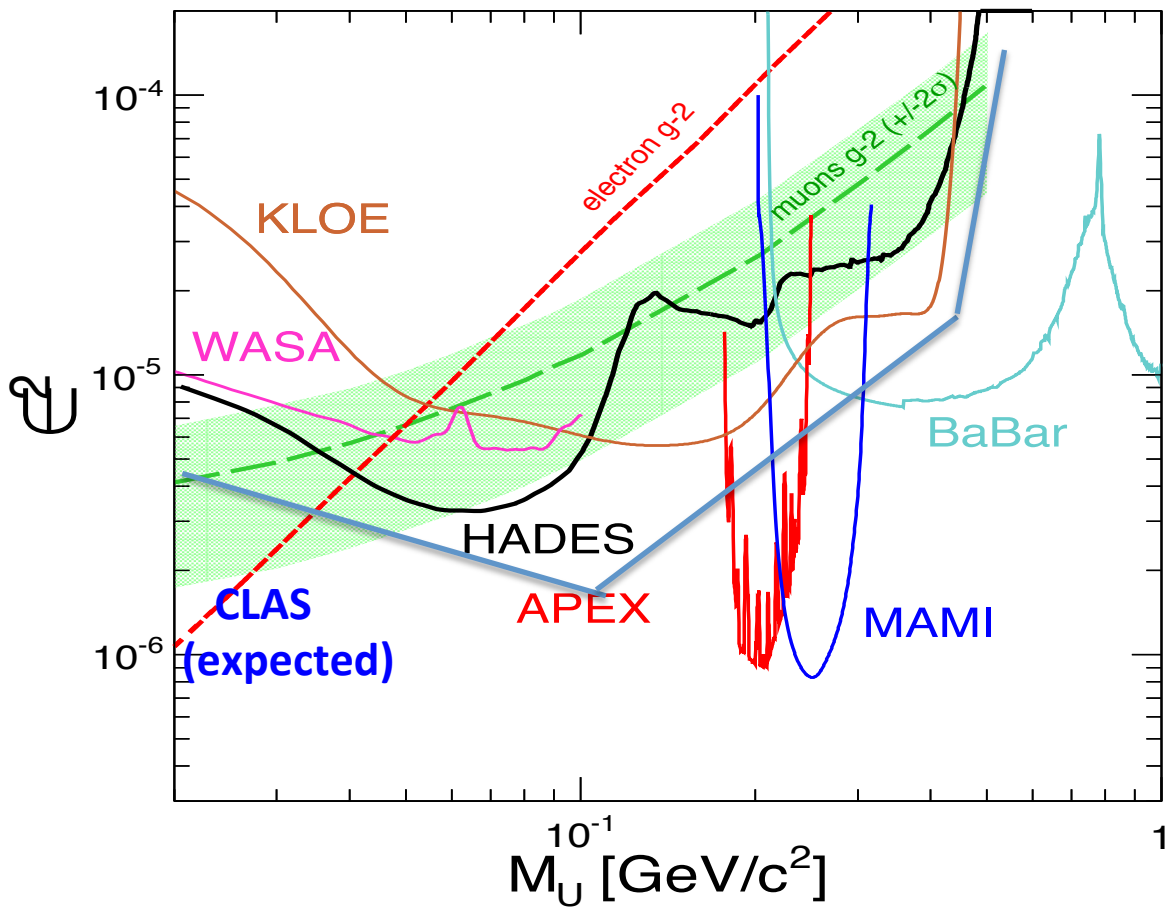
$$L_{mix} = -\frac{\epsilon}{2} F^{QED}_{\mu\nu} F^{\mu\nu}_{dark}$$







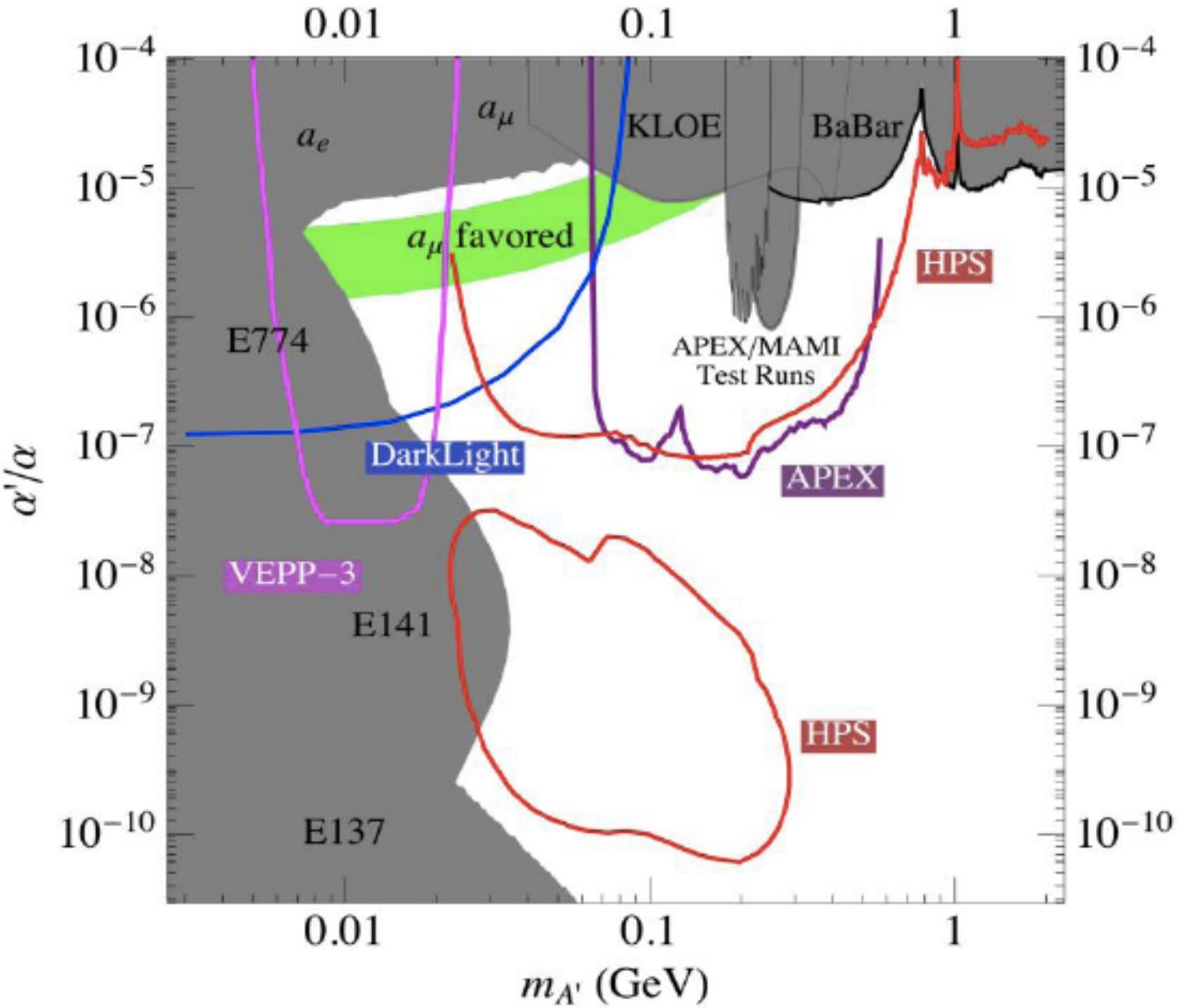
Constraints on Hidden sector coupling constant



HADES arXiv:1311.0216

WASA Phys.Lett. B726 (2013) 187-193

Constraints on Hidden sector coupling constant



Summary

CLAS Collaboration collected huge amount of statistics in photoproduction and decay of light mesons including:

-Dalitz Decays
-Radiative Decays
-Hadronic decays

-This will allow to measure Transition Form Factors of light mesons
-Make Experimental test of Box Anomaly Term
-Measure Quark Mass Ratio
-Test fundamental C and CP symmetries
-Search for Dark Photon
-Search for invisible decays

Some of these results will be released very soon

THANK YOU !