Light Meson Decay in CLAS

Moskov Amaryan

Presentation to GLUEX Collaboration

Jefferson Lab, November 12, 2014

Photoproduction and Decay of Light Mesons in CLAS

CLAS Analysis Proposal

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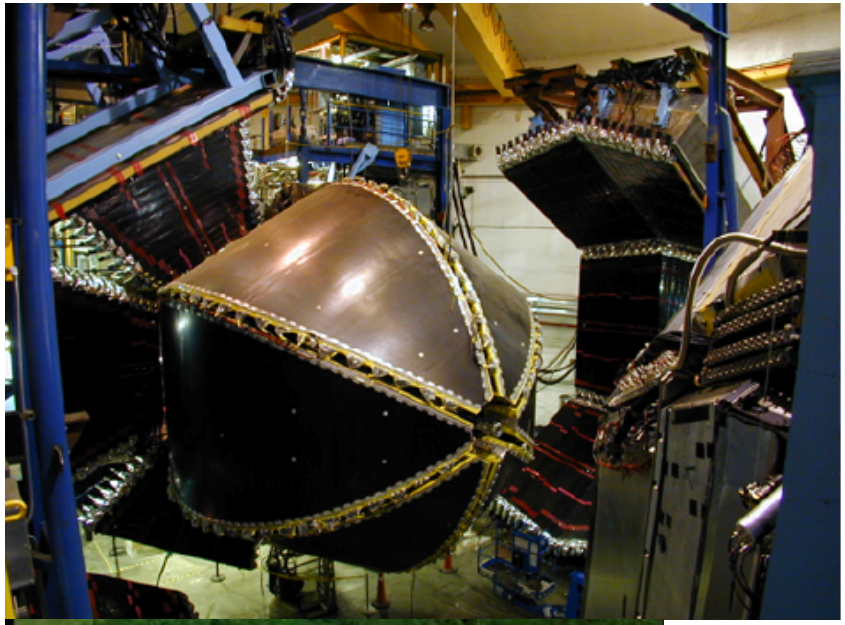
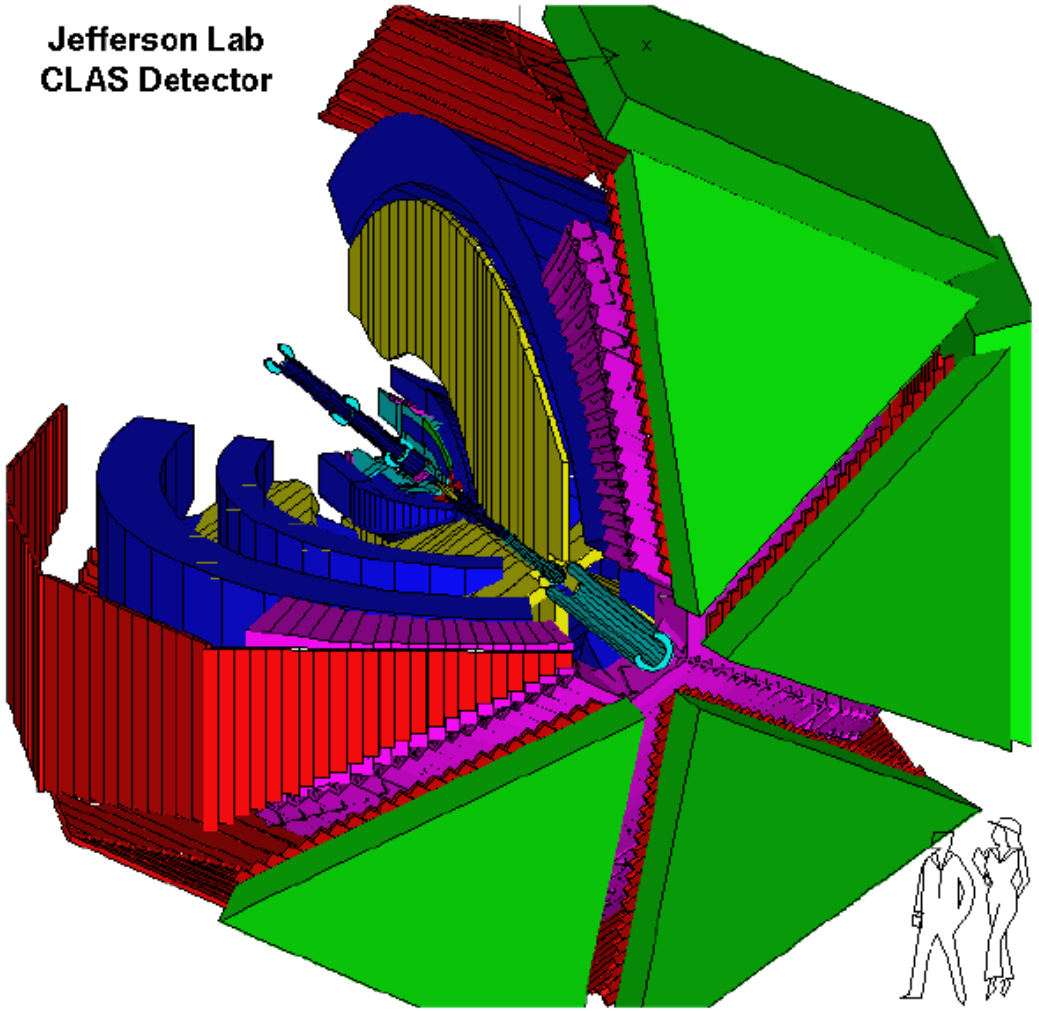
(Dated: December 24, 2012)

Outline

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

The CLAS Detector





Light Mesons in CLAS

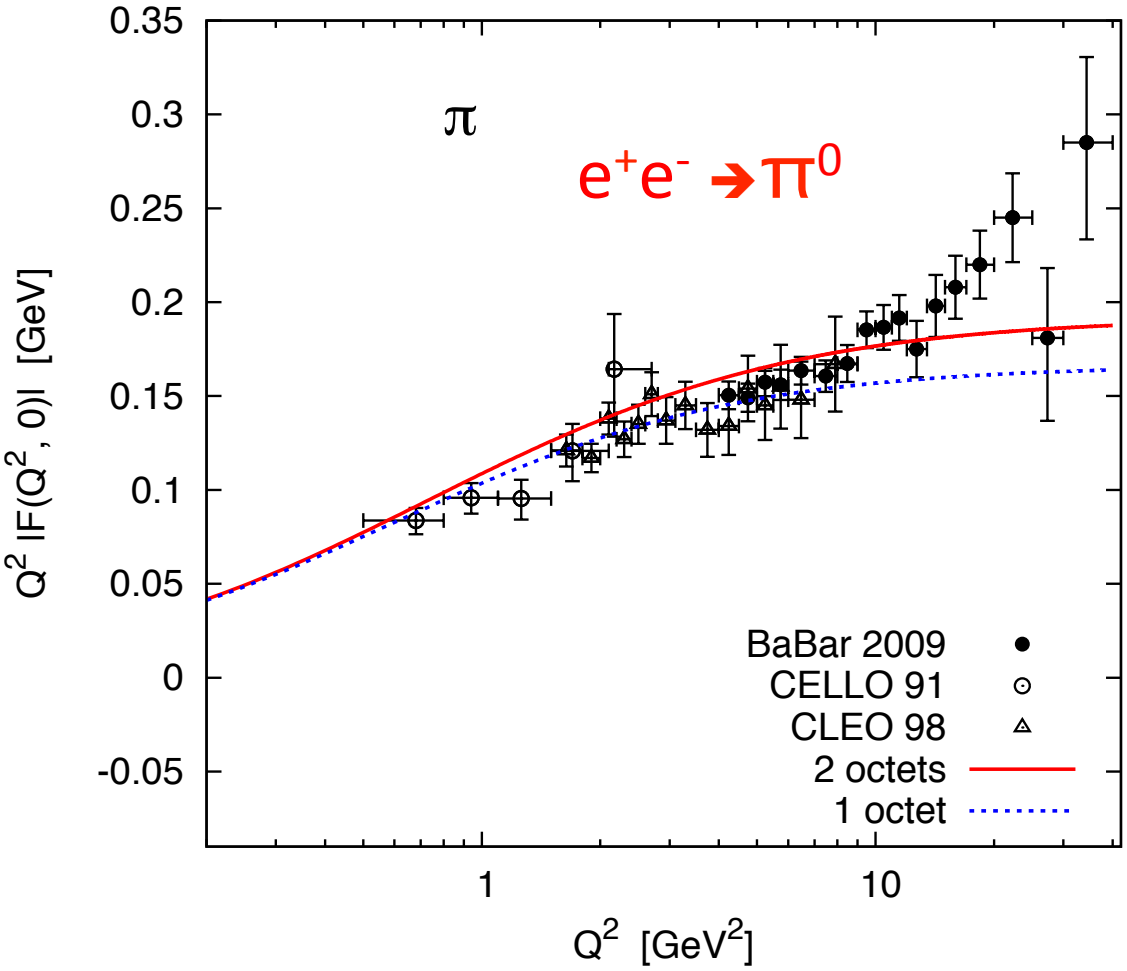
π^0	$e^+e^-\gamma$				
η	$e^+e^-\gamma$	$\pi^+\pi^-\gamma$	$\pi^+\pi^-\pi^0$ $\pi^+\pi^-$	$\pi^+\pi^-e^+e^-$	
η'	$e^+e^-\gamma$	$\pi^+\pi^-\gamma$	$\pi^+\pi^-\pi^0$ $\pi^+\pi^-$	$\pi^+\pi^-\eta$ $\pi^+\pi^-e^+e^-$	
ρ		$\pi^+\pi^-\gamma$			
ω	$e^+e^-\ \pi^0$	$\pi^+\pi^-\gamma$	$\pi^+\pi^-\pi^0$		
φ		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

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
η, ω, $\phi \rightarrow \pi^0\pi^+\pi^-$	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	

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]

(Kroll-Wada)

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

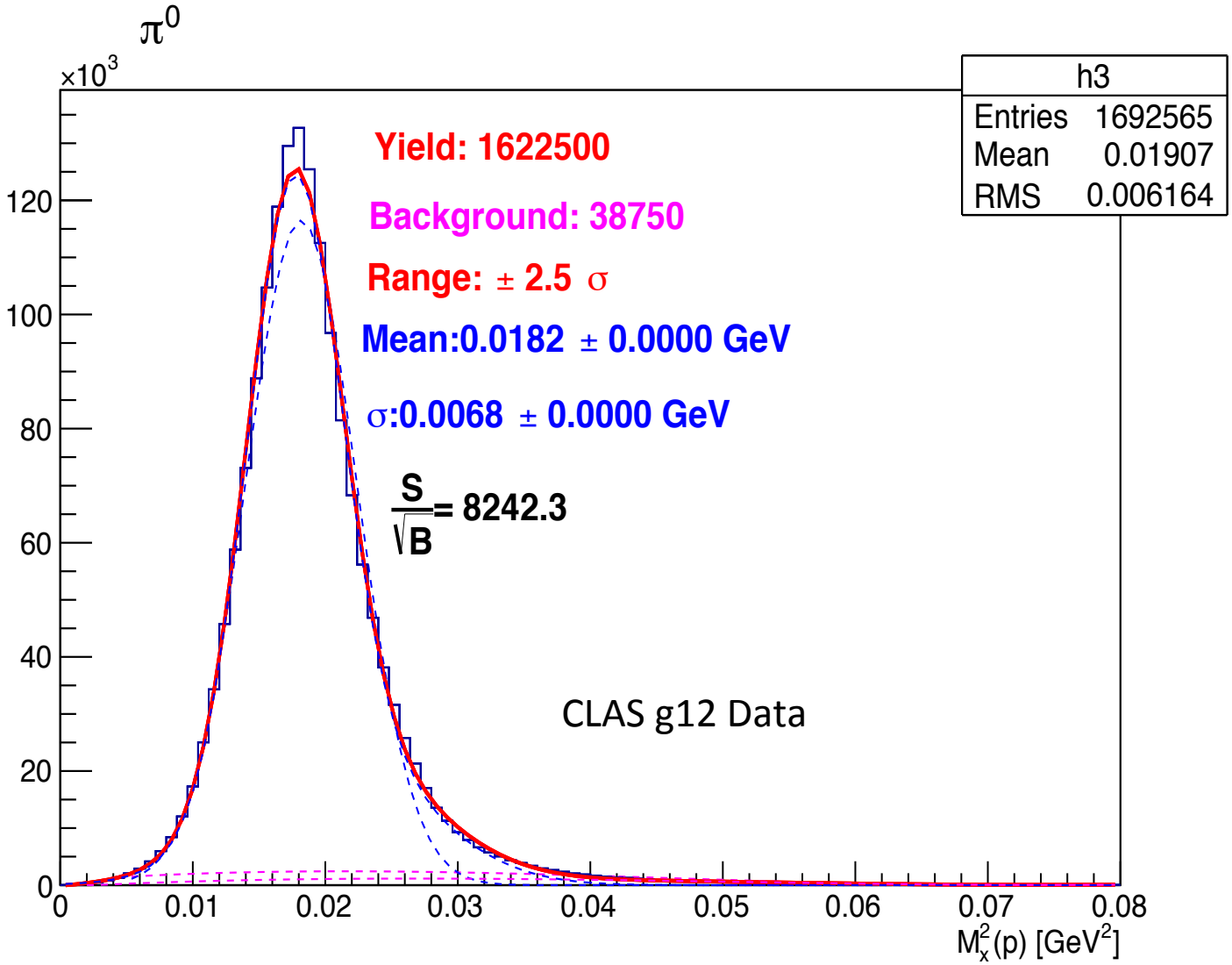
$$\left(\frac{d\Gamma}{dx}\right)_{QED} = \frac{2\alpha}{3\pi}\frac{1}{x}(1-x)^3\left(1+\frac{r}{2x}\right)\left(1-\frac{r}{x}\right)^{1/2}$$

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

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

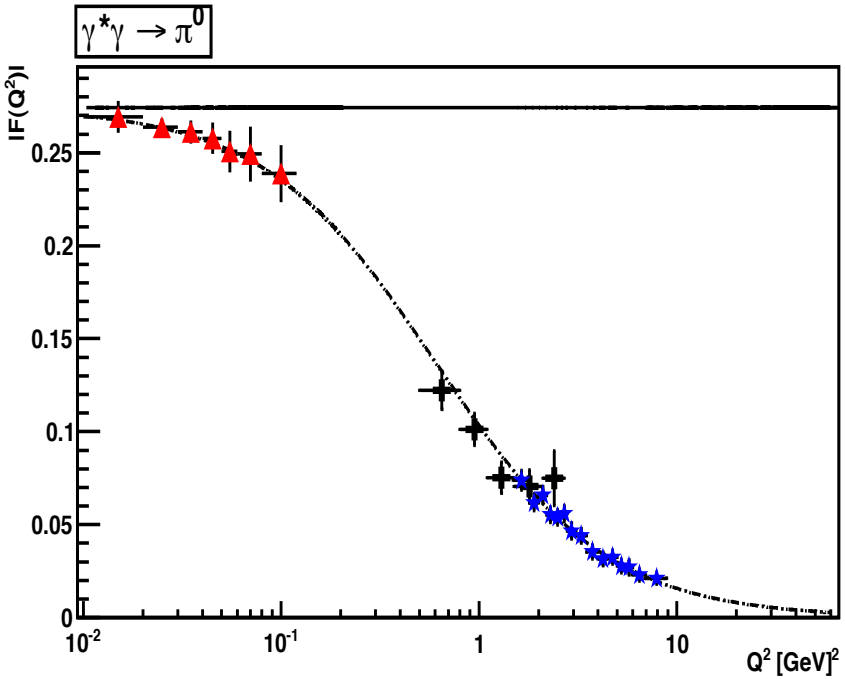
[2] H. Fonvieille, N. Bensayah, J. Berthot, P. Bertin, M. Crouau, et al., Phys.Lett. **B233**, 65 (1989).
[3] F. Farzanpay, P. Gumplinger, A. Stetz, J. Poutissou, I. Blevis, et al., Phys.Lett. **B278**, 413 (1992).
[4] R. Meijer Drees et al. (SINDRUM-I Collaboration), Phys.Rev. **D45**, 1439 (1992).

π^0 (e+e-γ)

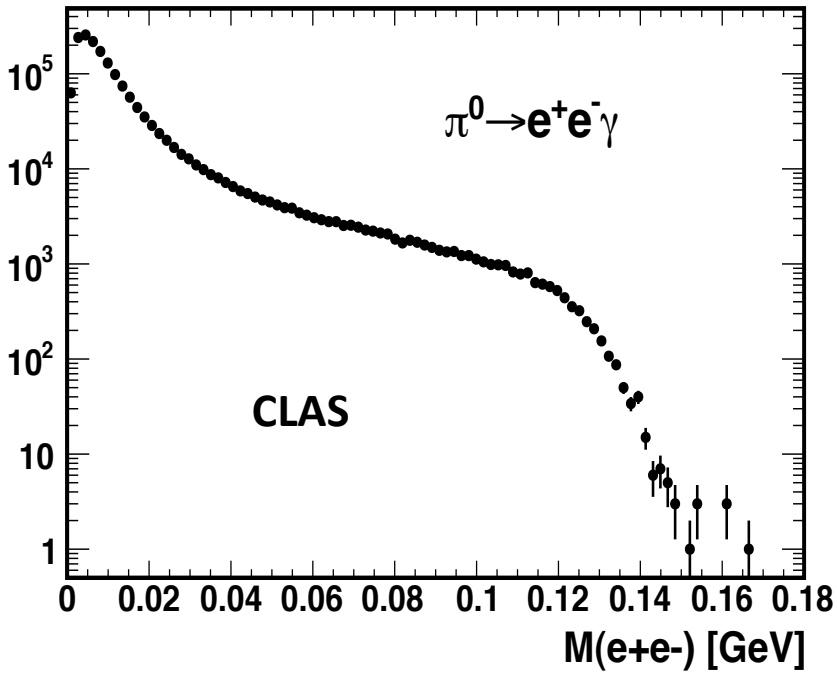

π0
×10^3
120
100
80
60
40
20
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
M_x^2(p) [GeV^2]
h3
Entries 1692565
Mean 0.01907
RMS 0.006164
Yield: 1622500
Background: 38750
Range: ± 2.5 σ
Mean:0.0182 ± 0.0000 GeV
σ:0.0068 ± 0.0000 GeV
S/√B = 8242.3
CLAS g12 Data

Transition Form Factor

KLOE-2 Proposal

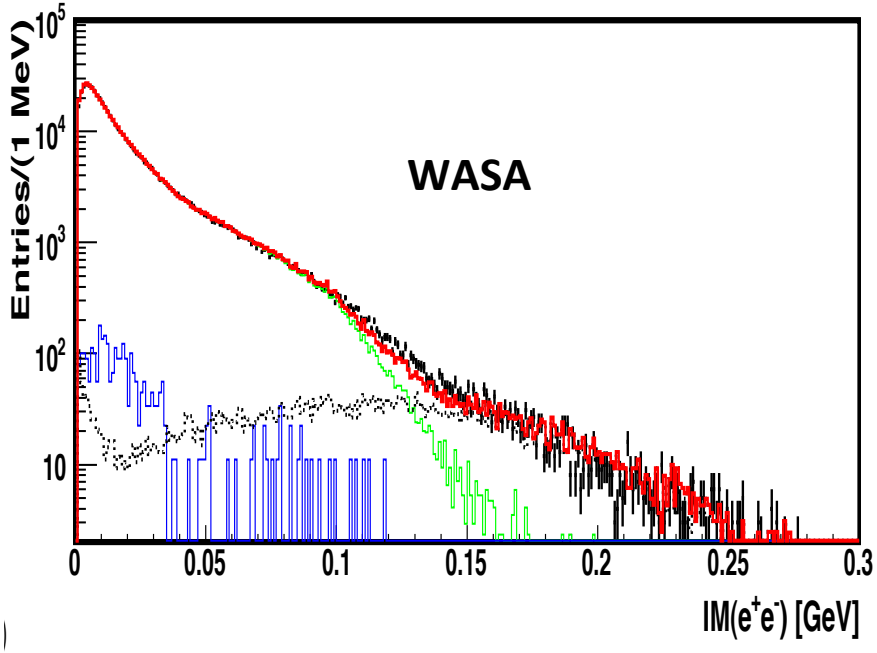


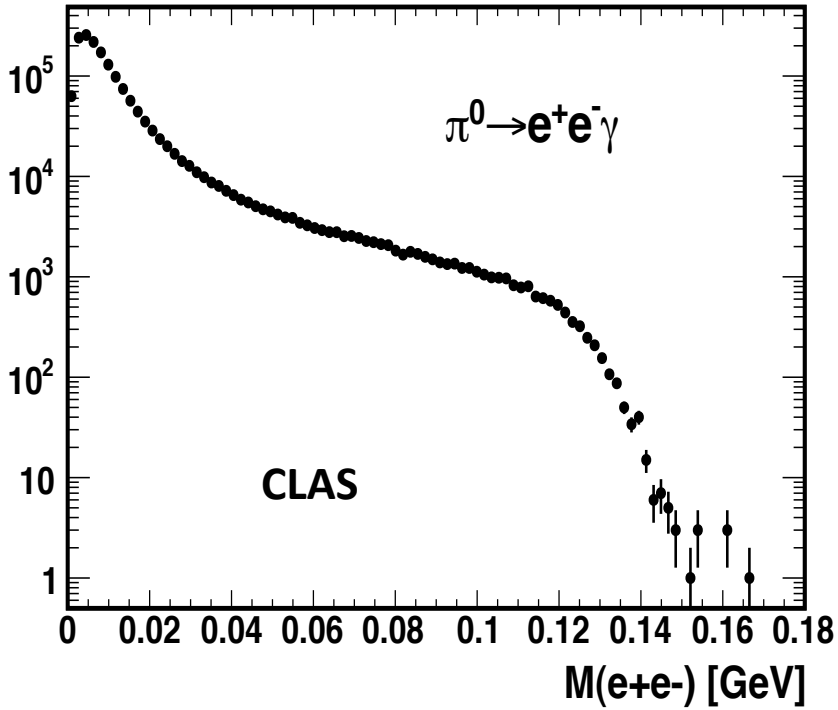
CLAS g12 Data

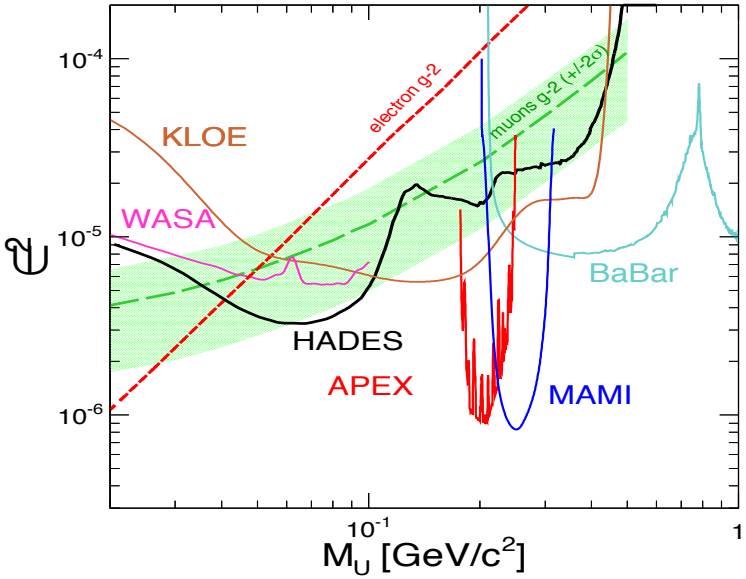


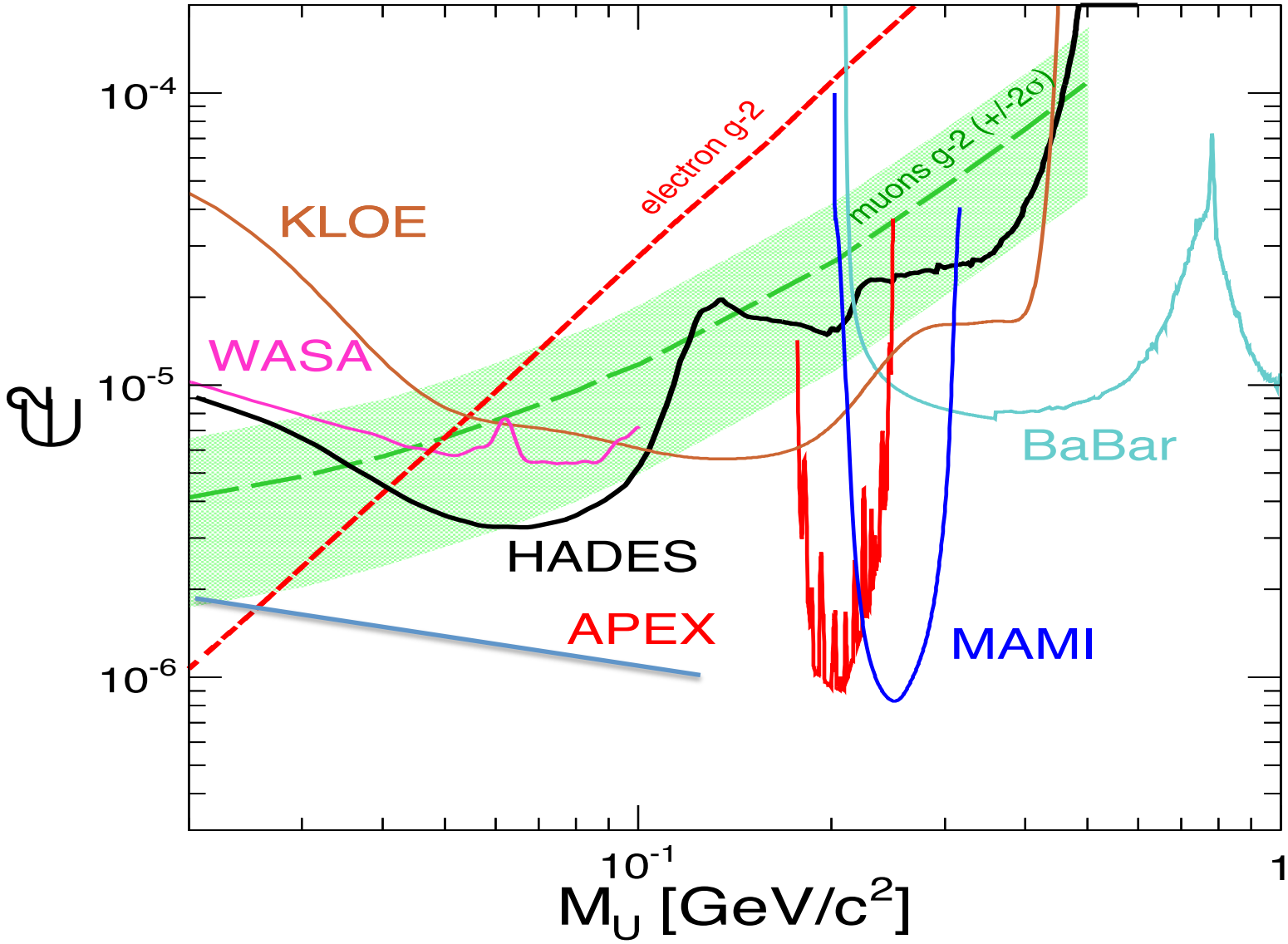
CLAS at JLAB accumulated unprecedented statistics for precision measurement of TFF slope!

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

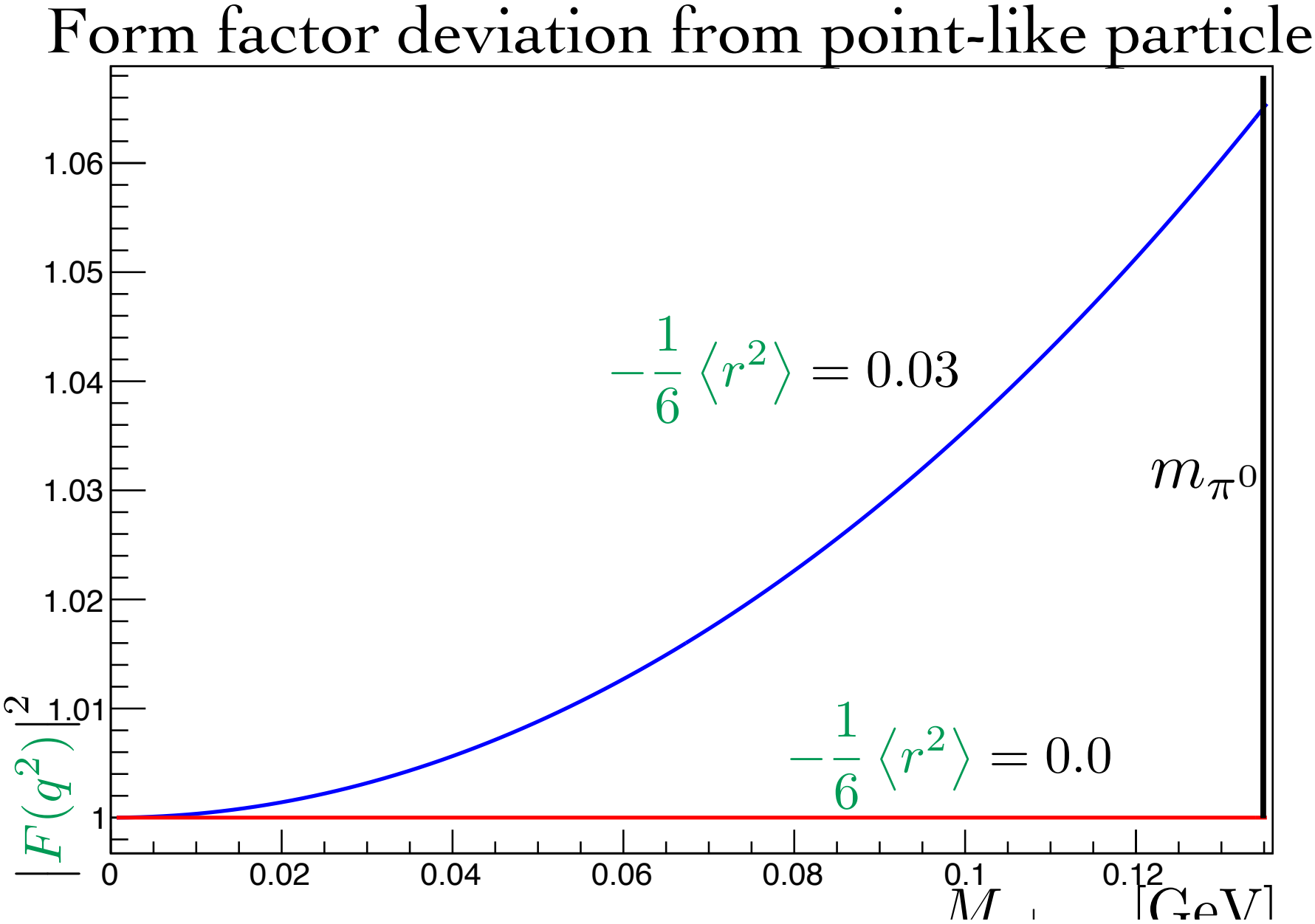

WASA
Entries/(1 MeV)
IM(e+e-) [GeV]


π0→e+e-γ
CLAS
M(e+e-) [GeV]

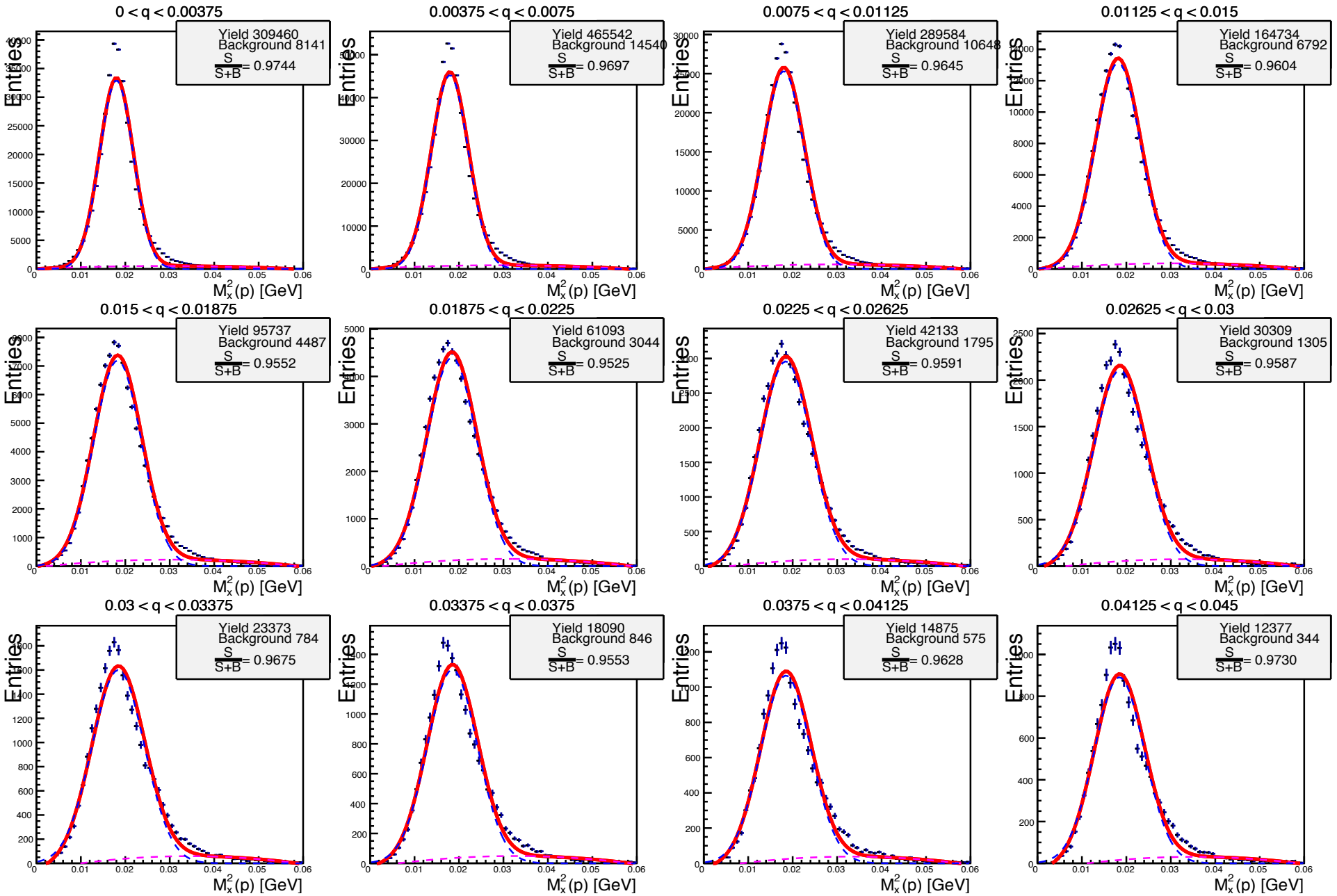

KLOE
WASA
HADES
APEX
MAMI
BaBar
electron g-2
muons g-2 (+/-2σ)
MU [GeV/c2]


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

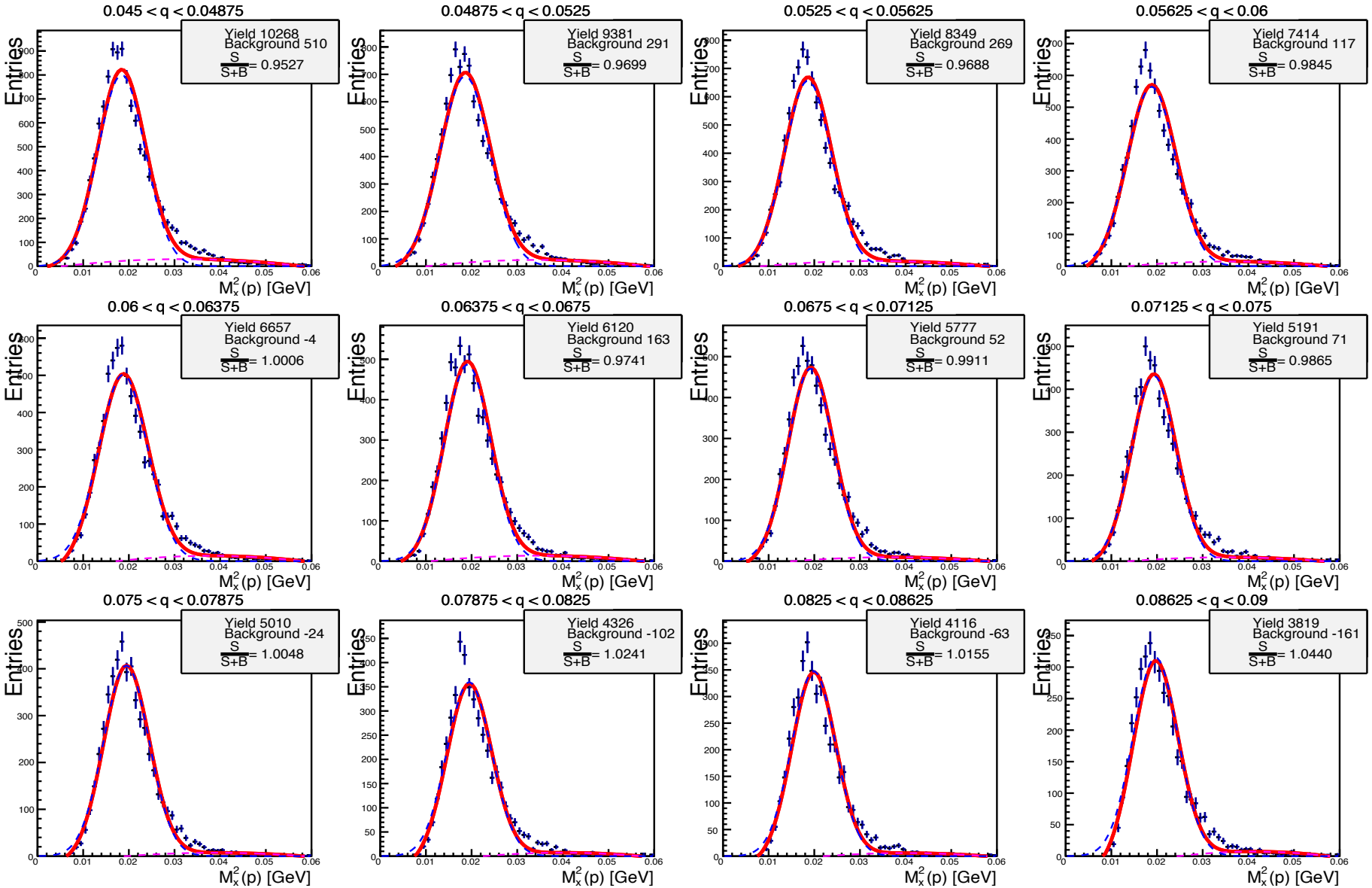
Transition Form Factor for π^0



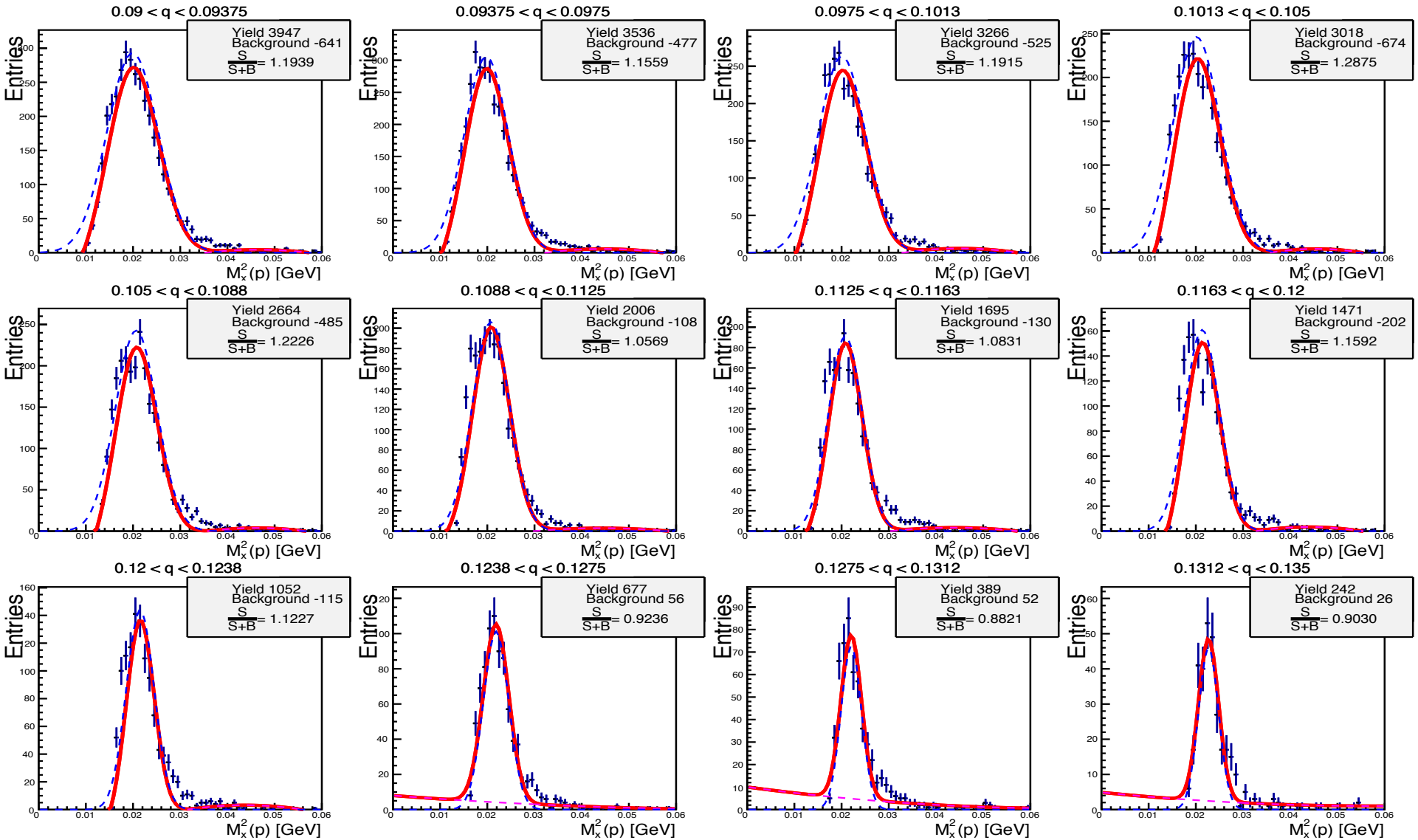
M(e+e-) Slices


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

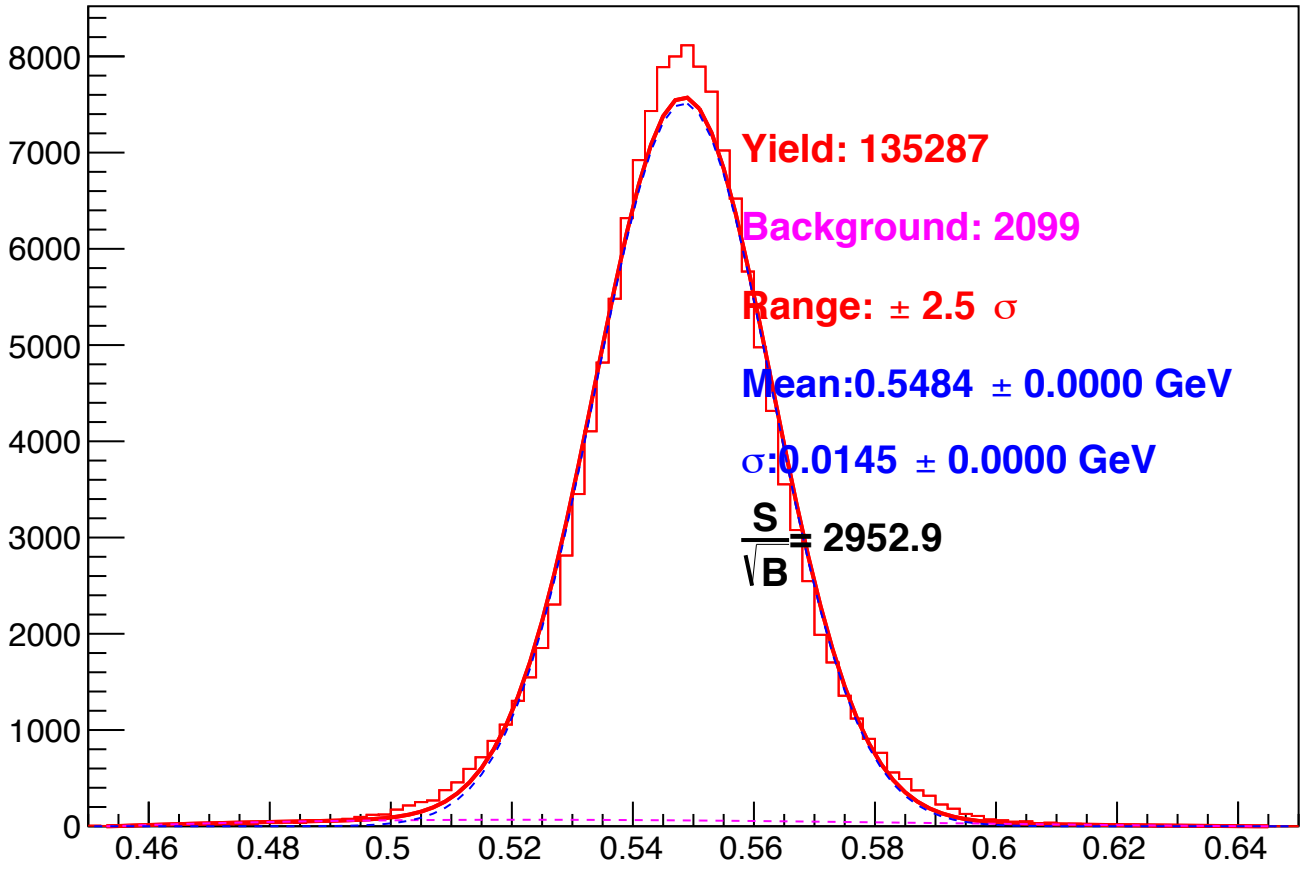

0.045 < q < 0.04875
Yield 10268
Background 510
S/(S+B) = 0.9527
0.04875 < q < 0.0525
Yield 9381
Background 291
S/(S+B) = 0.9699
0.0525 < q < 0.05625
Yield 8349
Background 269
S/(S+B) = 0.9688
0.05625 < q < 0.06
Yield 7414
Background 117
S/(S+B) = 0.9845
0.06 < q < 0.06375
Yield 6657
Background -4
S/(S+B) = 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

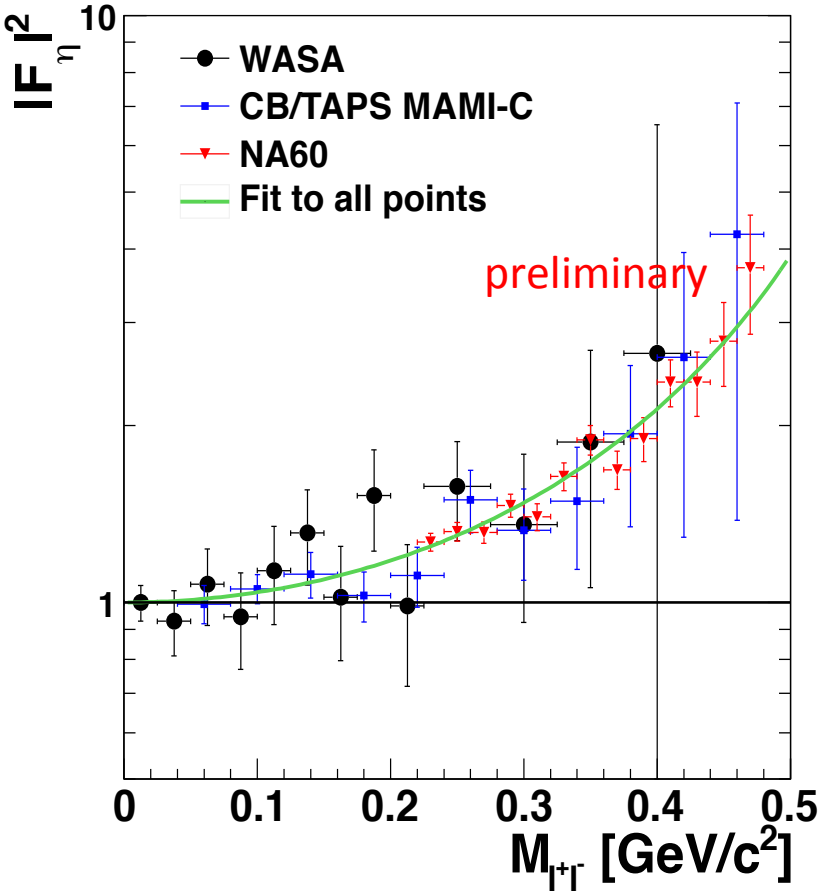
$$\frac{d\Gamma(\eta \to l^+ l^- \gamma)}{dm\Gamma(\eta \to \gamma\gamma)} = [QED] \cdot |F_\eta(m^2)|^2$$

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

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

b=<r^2>/6 (size of **η**)

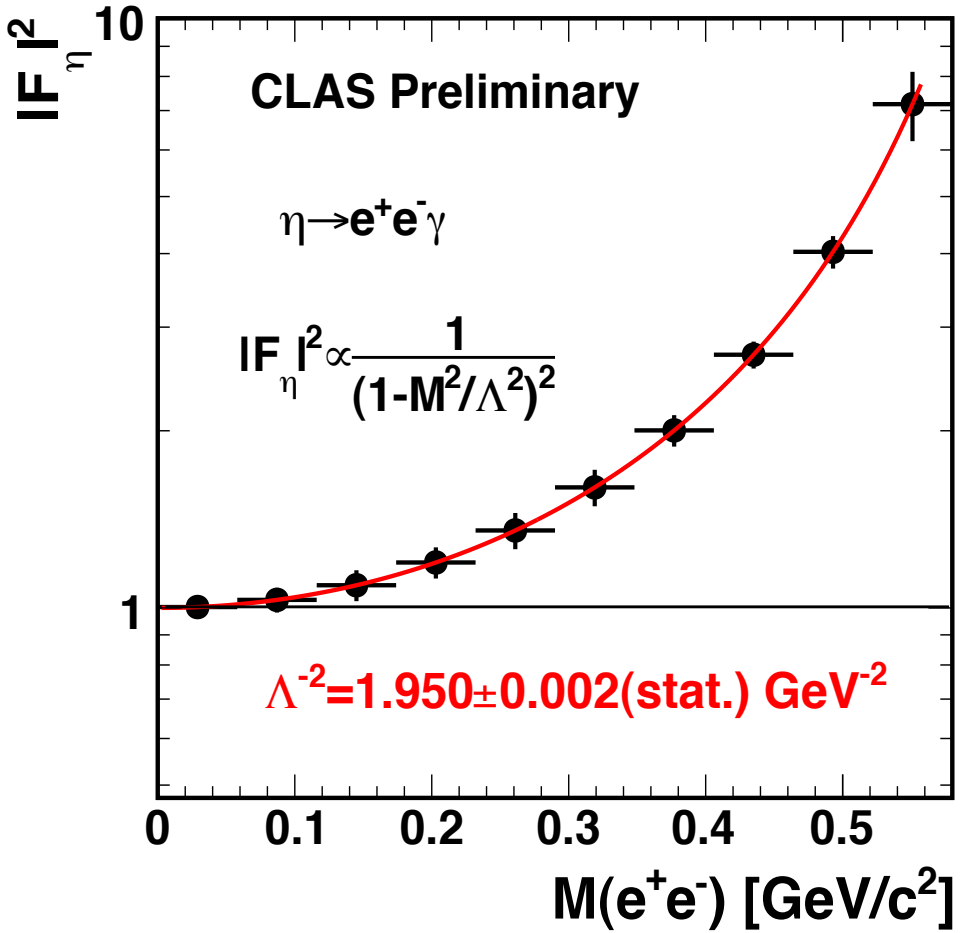
World Data



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

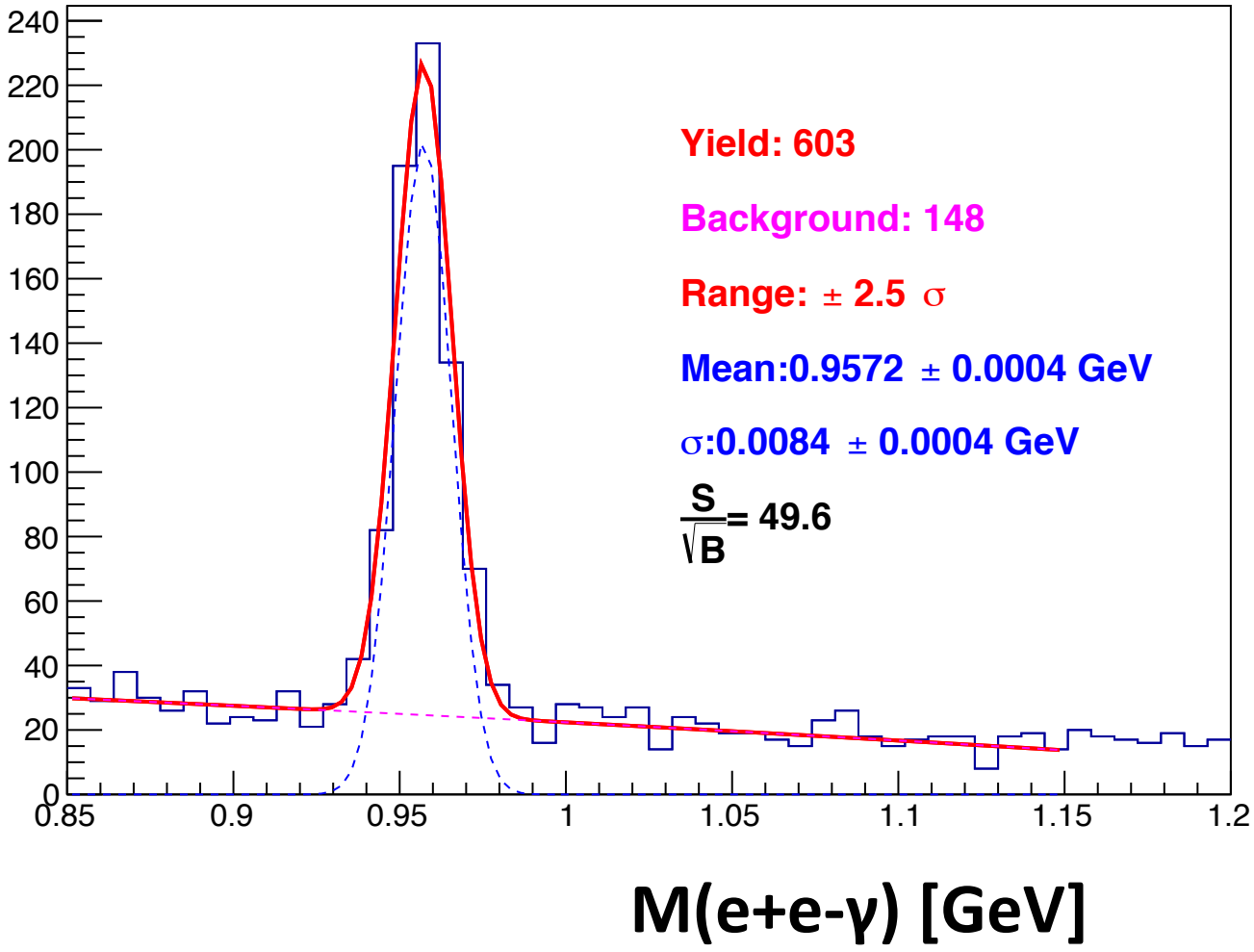
NA60 $\Lambda^{-2} = 1.95 \pm 0.17(stat.) \pm 0.05(syst.)\ GeV^{-2}$

CLAS g12 Data



CLAS syst. err. ~ 0.05 (preliminary)

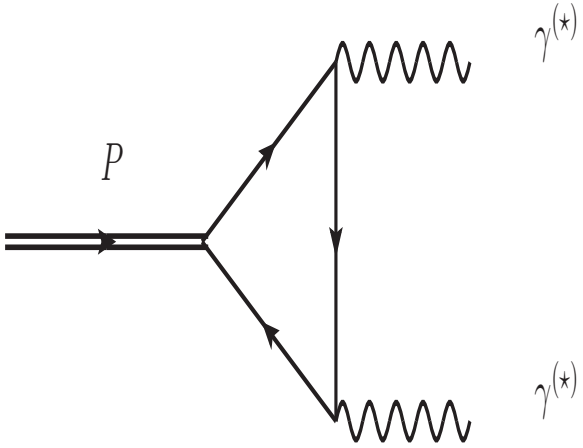
First measurement ofη’ Dalitz Decay in CLAS



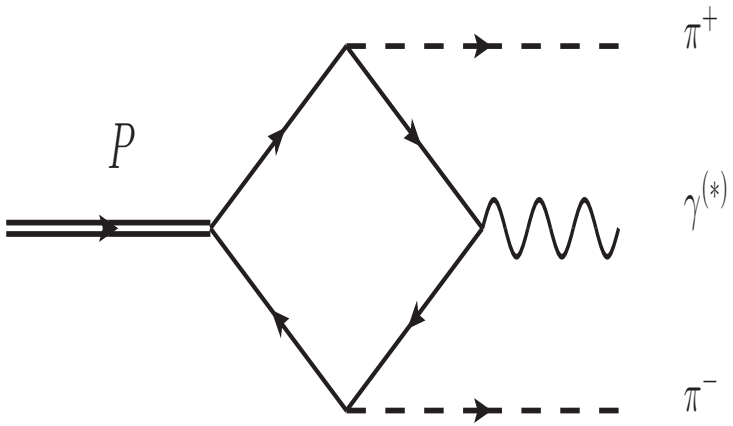
Radiative Decay $\eta(\eta') \to \pi^+\pi^-\gamma$

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

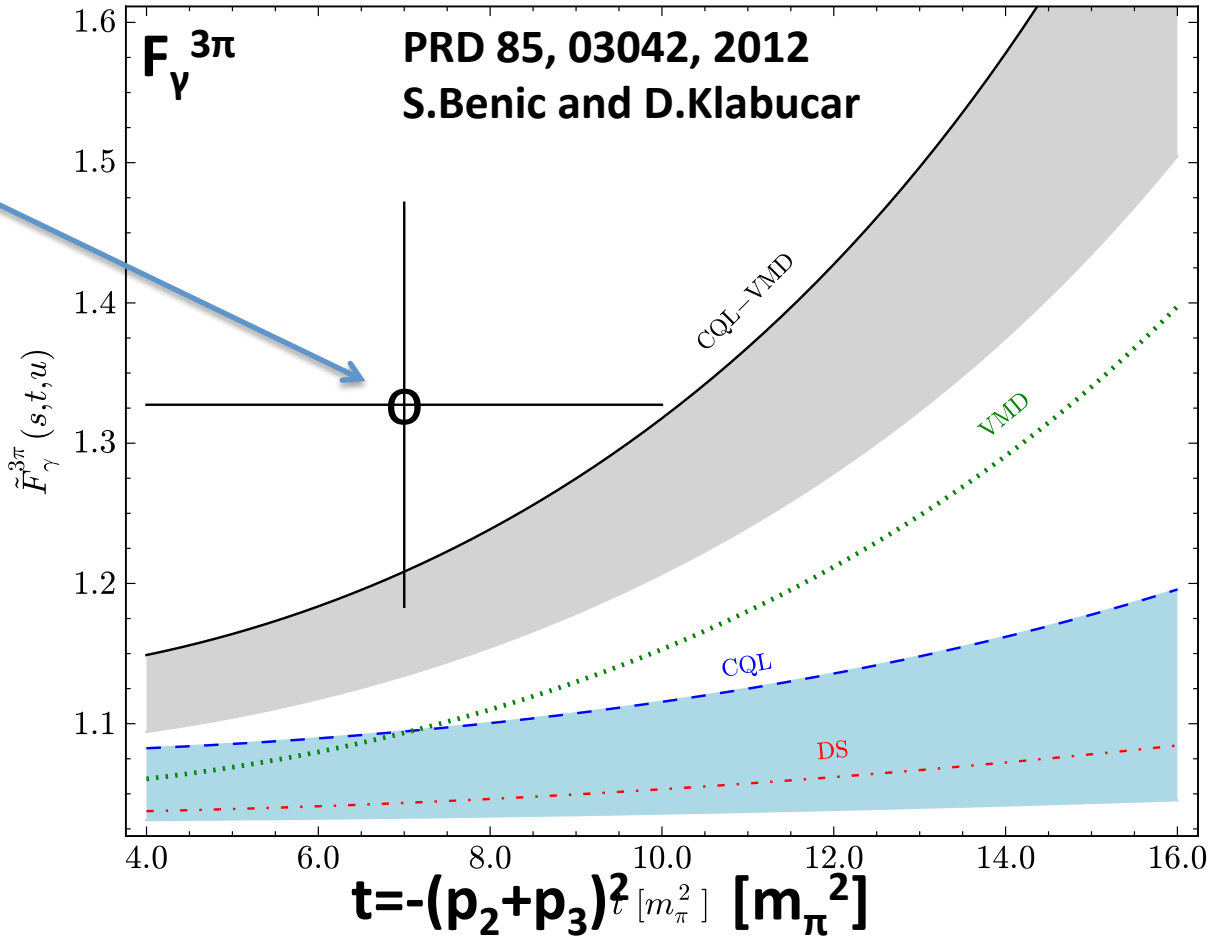
Y.M. Antipov et al.,
PRD 36(1987), 21

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

Constrained by
γγ width of π^0

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

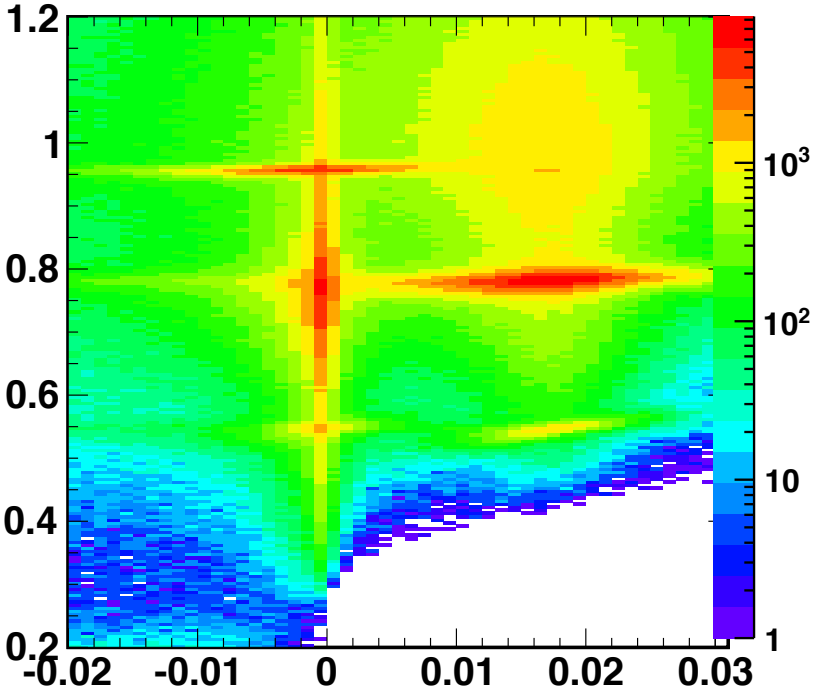
(theory prediction)



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

Very poorly measured

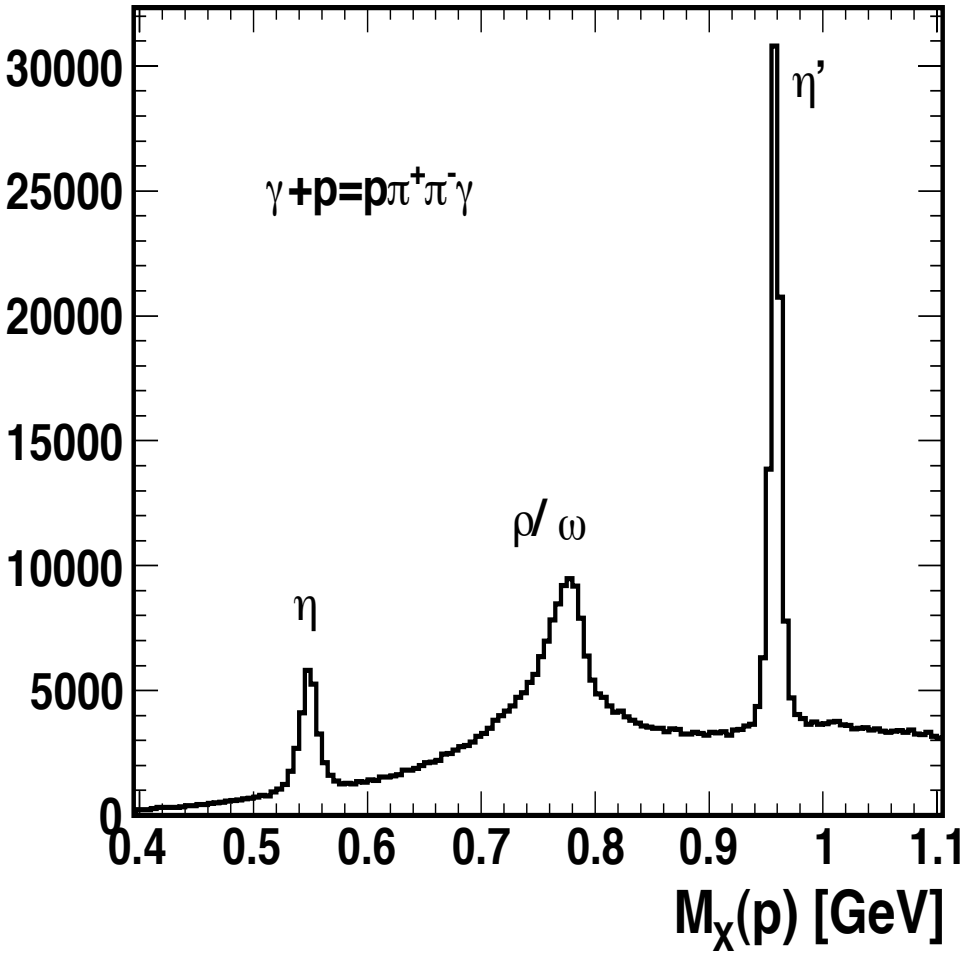
Radiative Decay $\eta,\eta' \rightarrow \pi^+\pi^-\gamma$

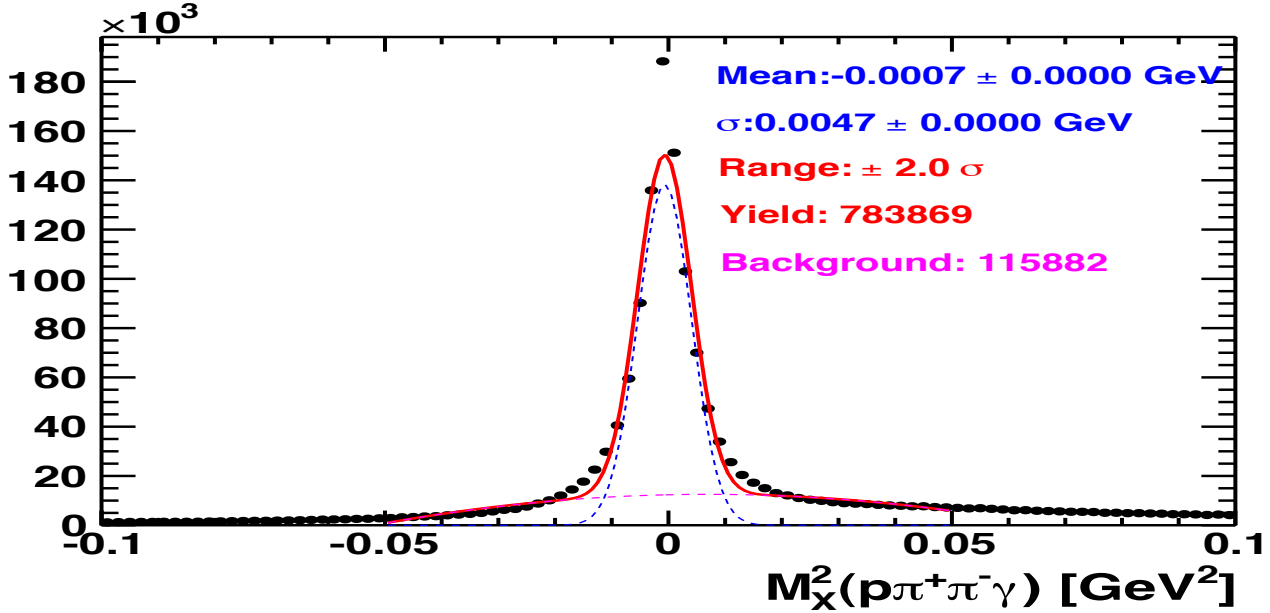


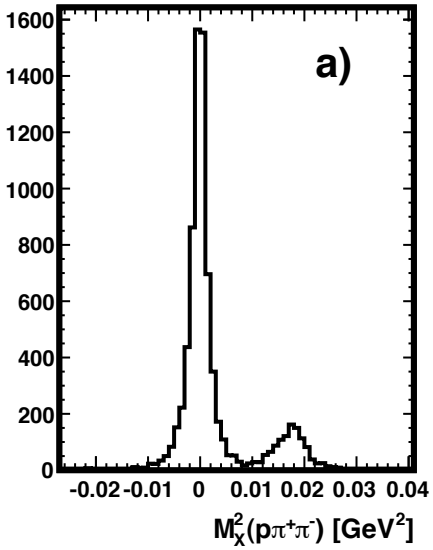
$M_X^2(p)$ versus $M_X^2(p\pi^+\pi^-)$

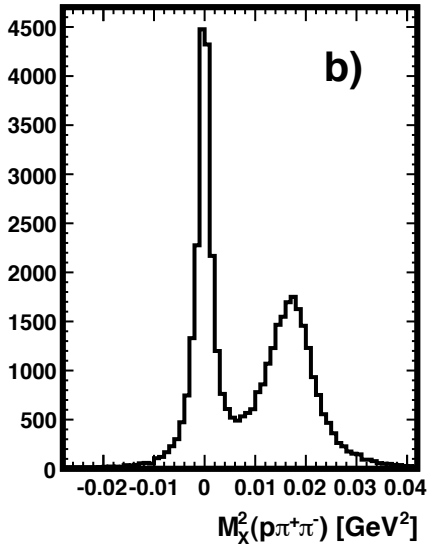
$\mathbf{ME > 0.01GeV}$

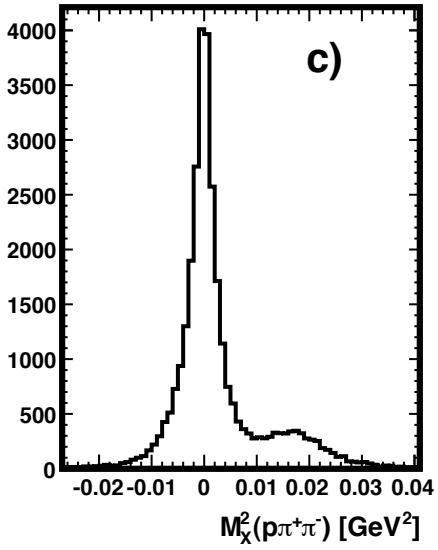
$\mathbf{ME - E_\gamma < 0.03GeV}$











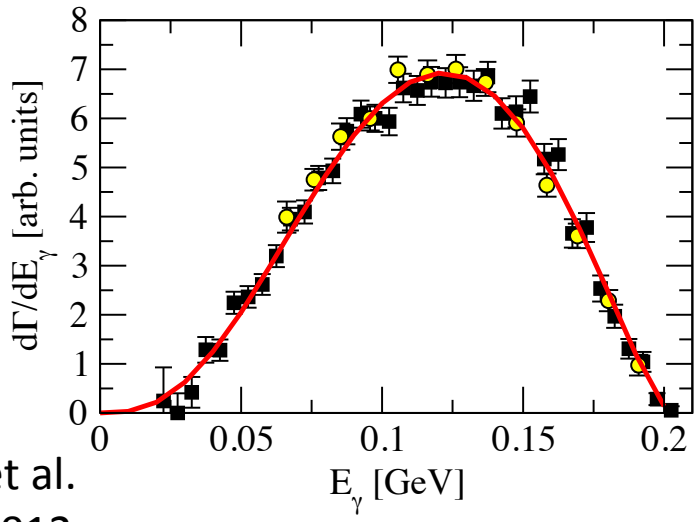
Mx(p)=0.55+-0.01 GeV

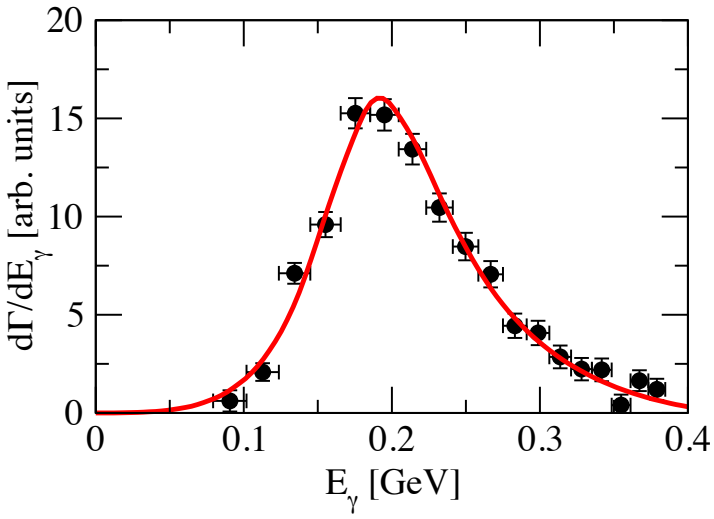
0.76+-0.06 GeV

0.96+-0.01 GeV

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

World data

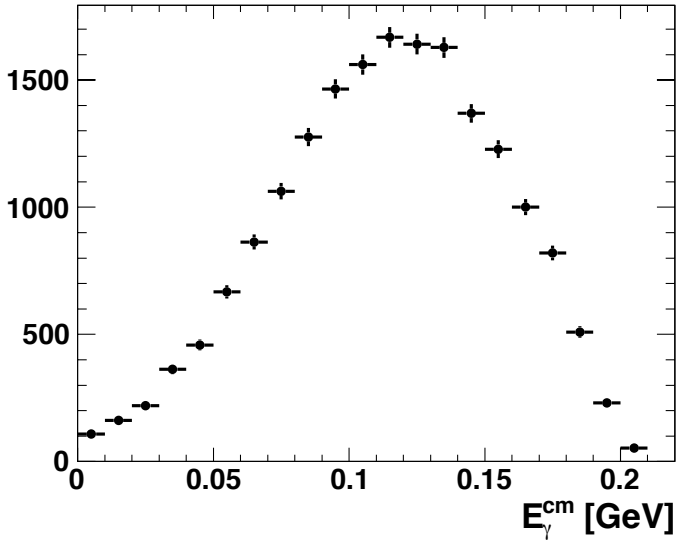


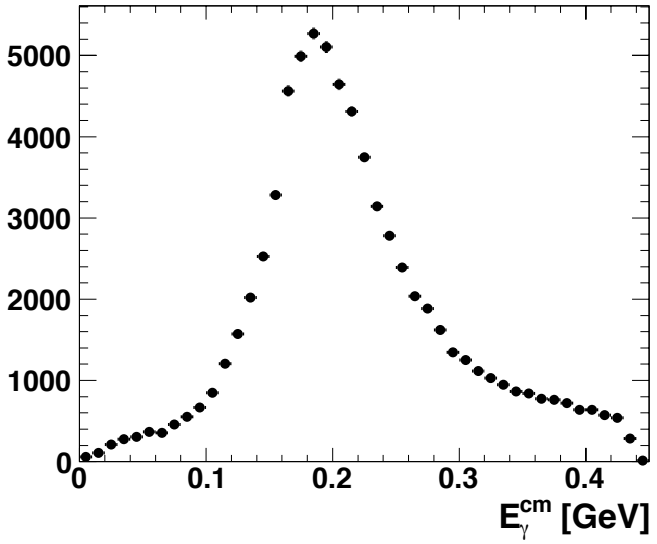


Theory:
E.Stollenwerk et al.
PL B707, 184, 2012

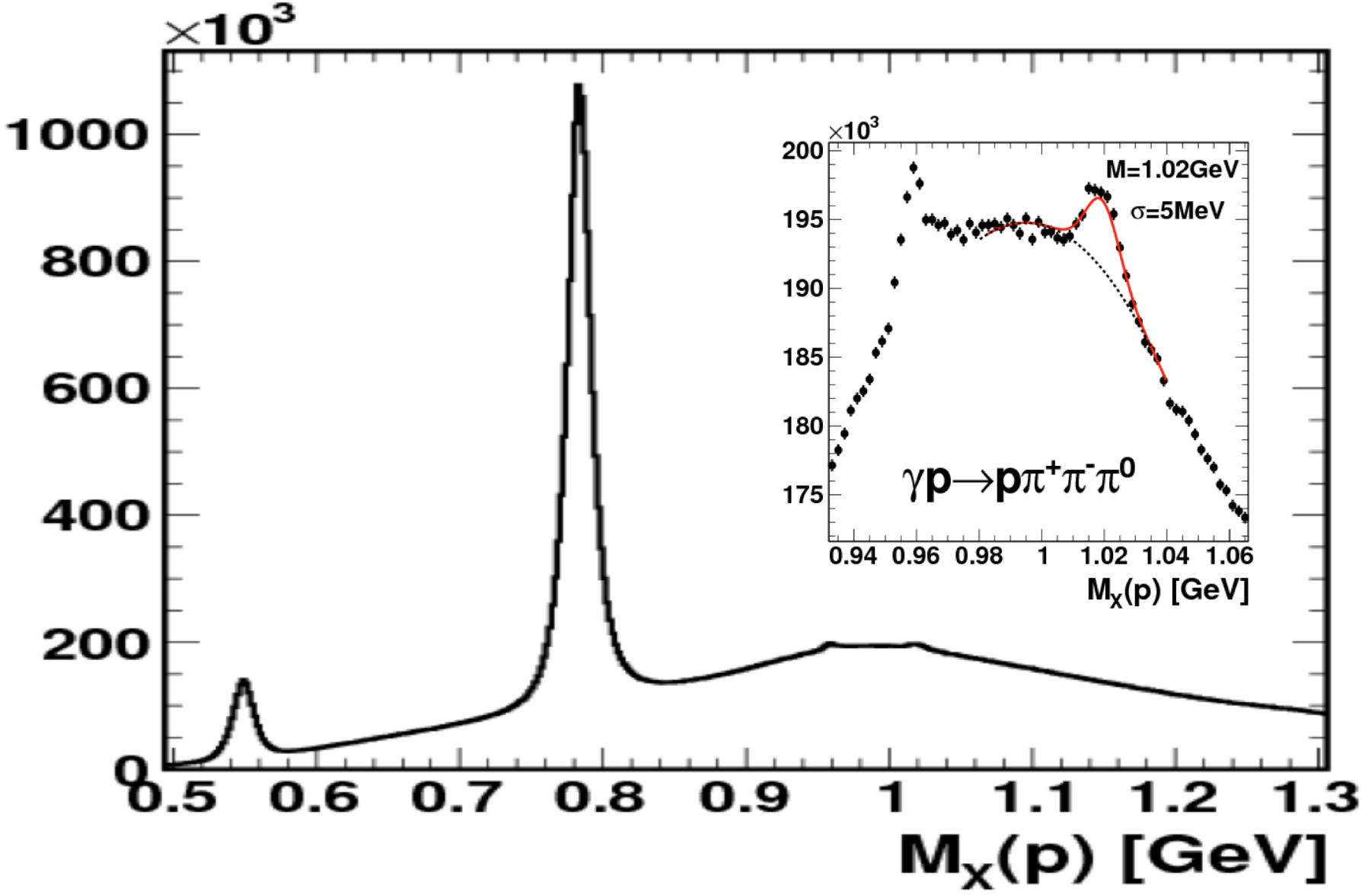
CLAS Preliminary uncorrected

10x more in CLAS



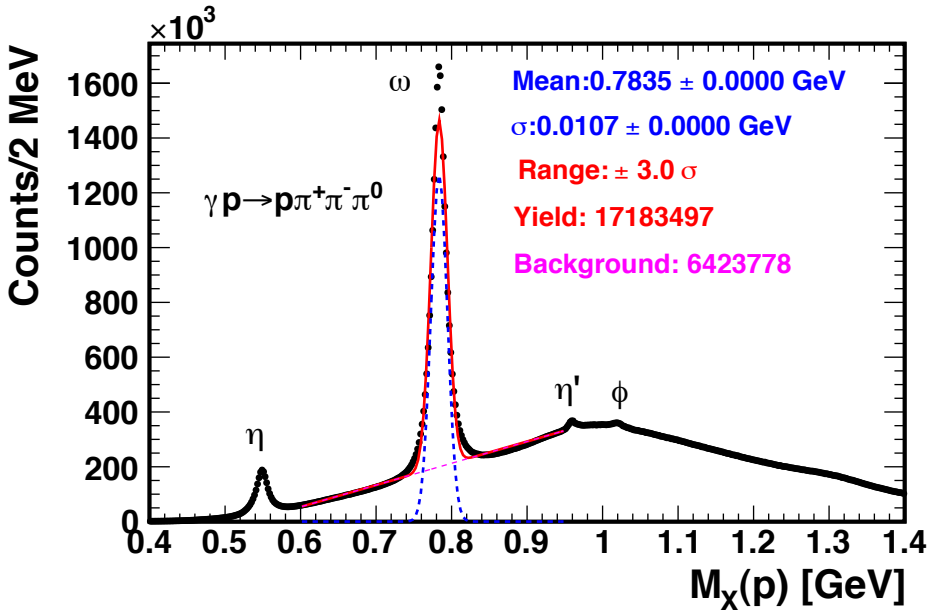


CLAS Hadronic decays: g11 Data



CLAS

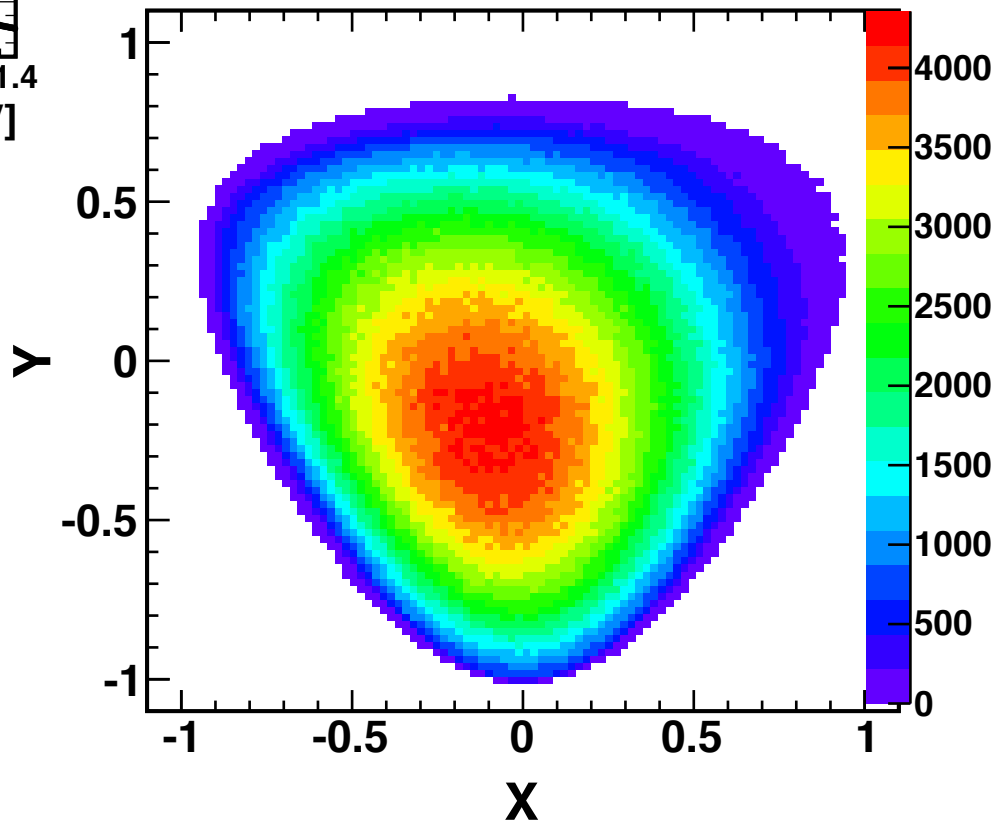
$$\omega \rightarrow \pi^+\pi^-\pi^0$$



About 17M ω's

Largest statistics in the world

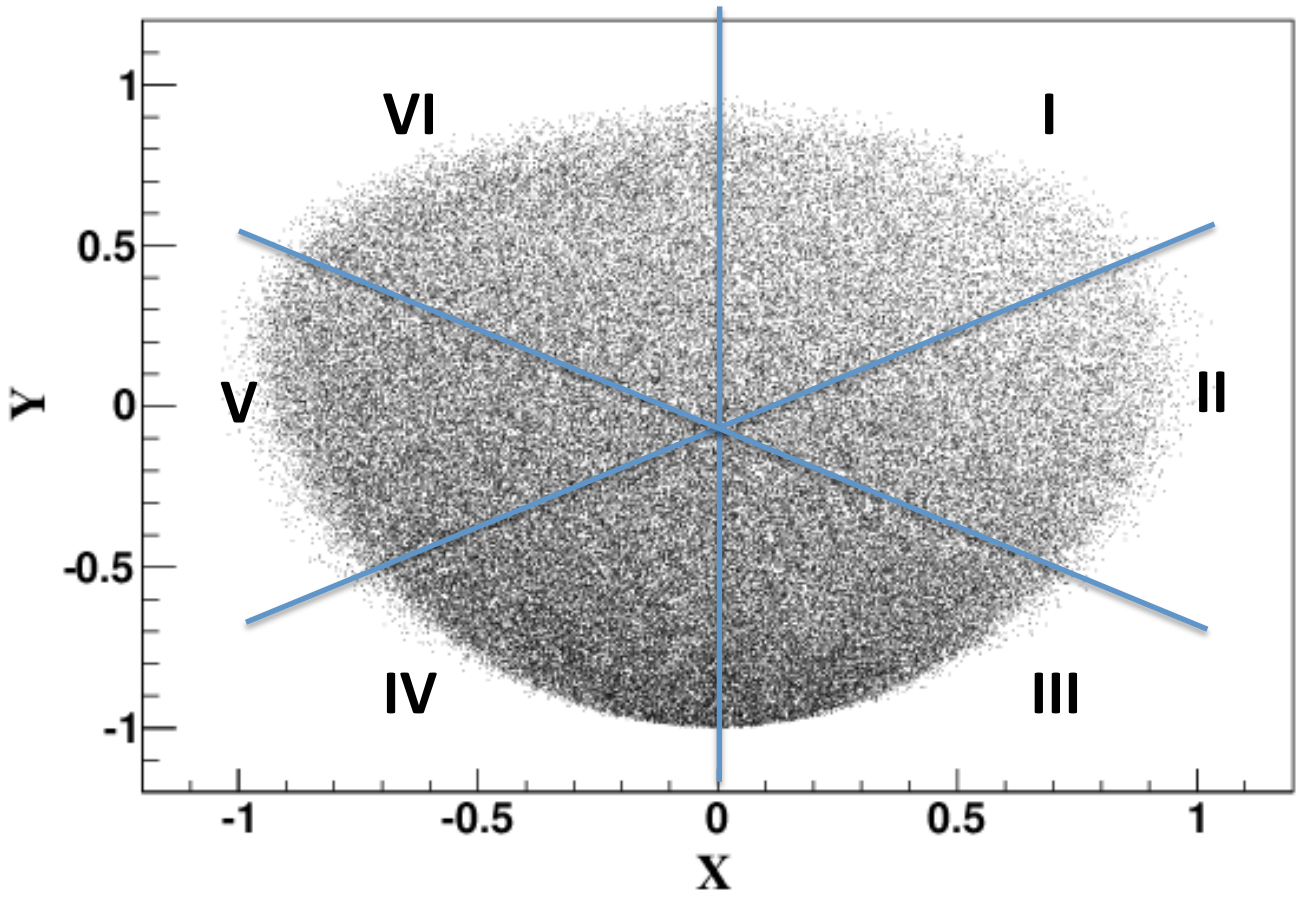
Not corrected for acceptance



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

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

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

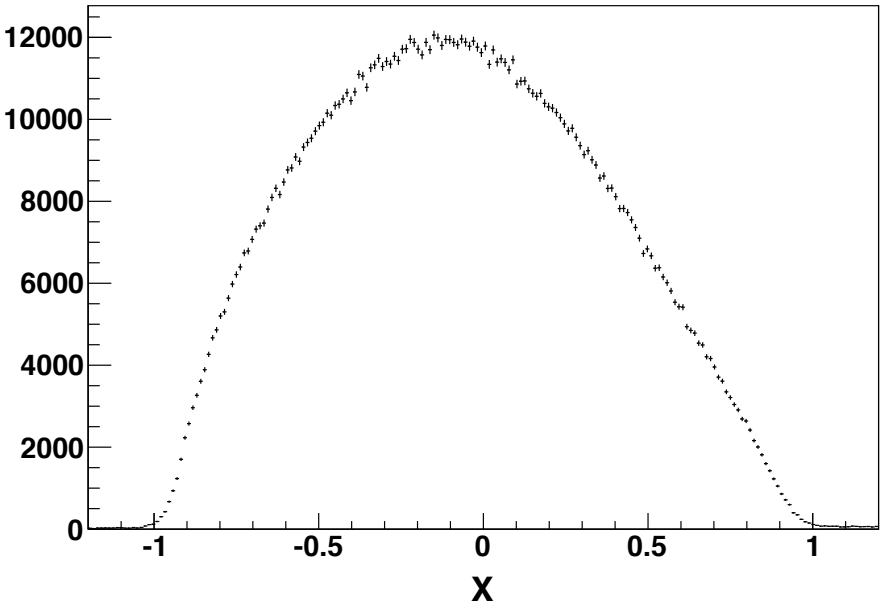
Dalitz plot projections

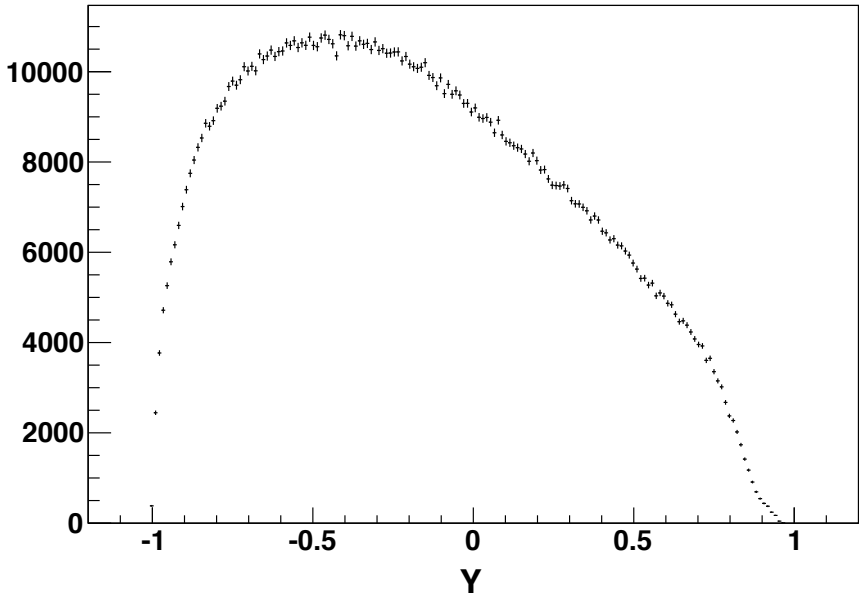
$$\eta \to \pi^+\pi^-\pi^0$$

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

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

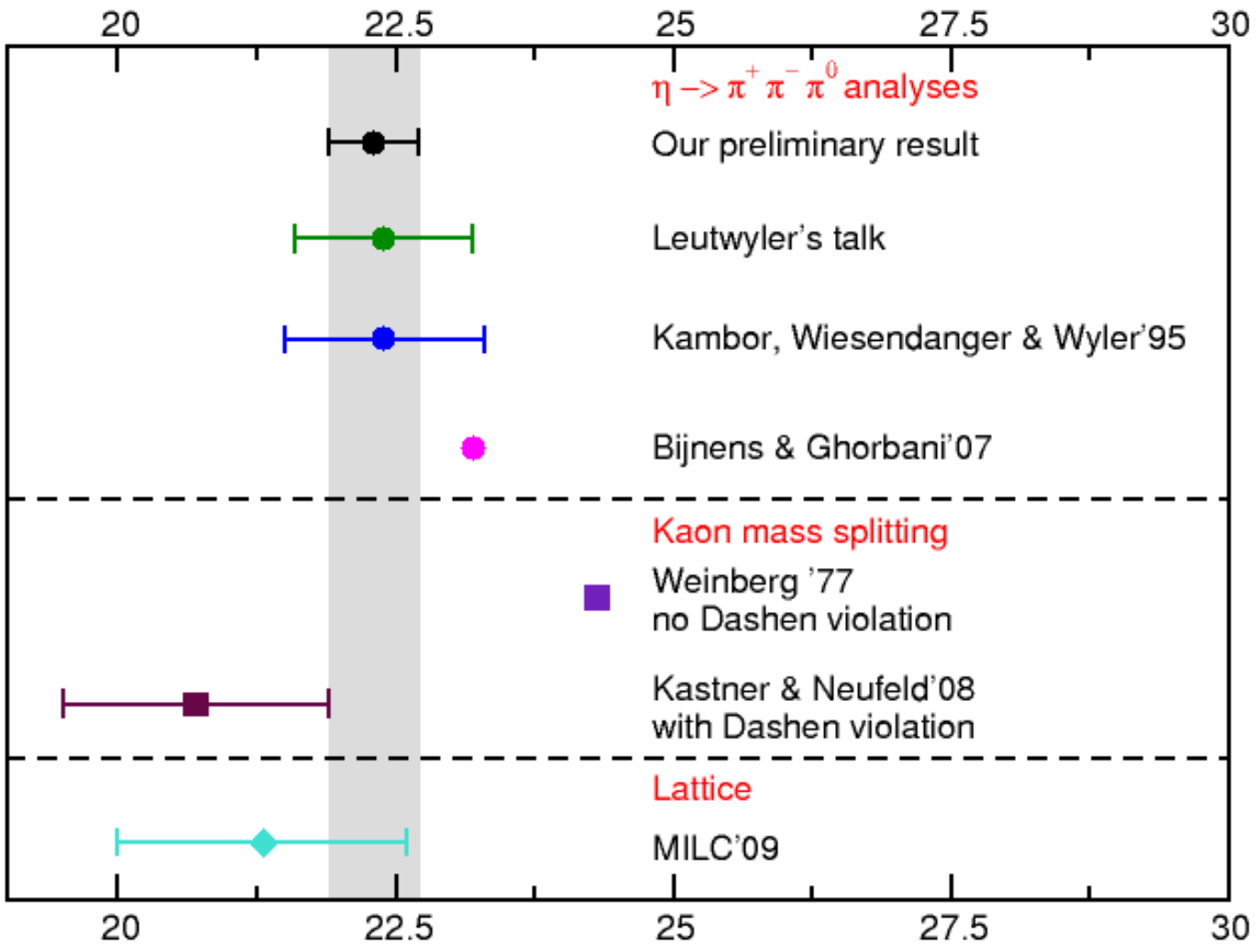
CLAS g11 Data





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

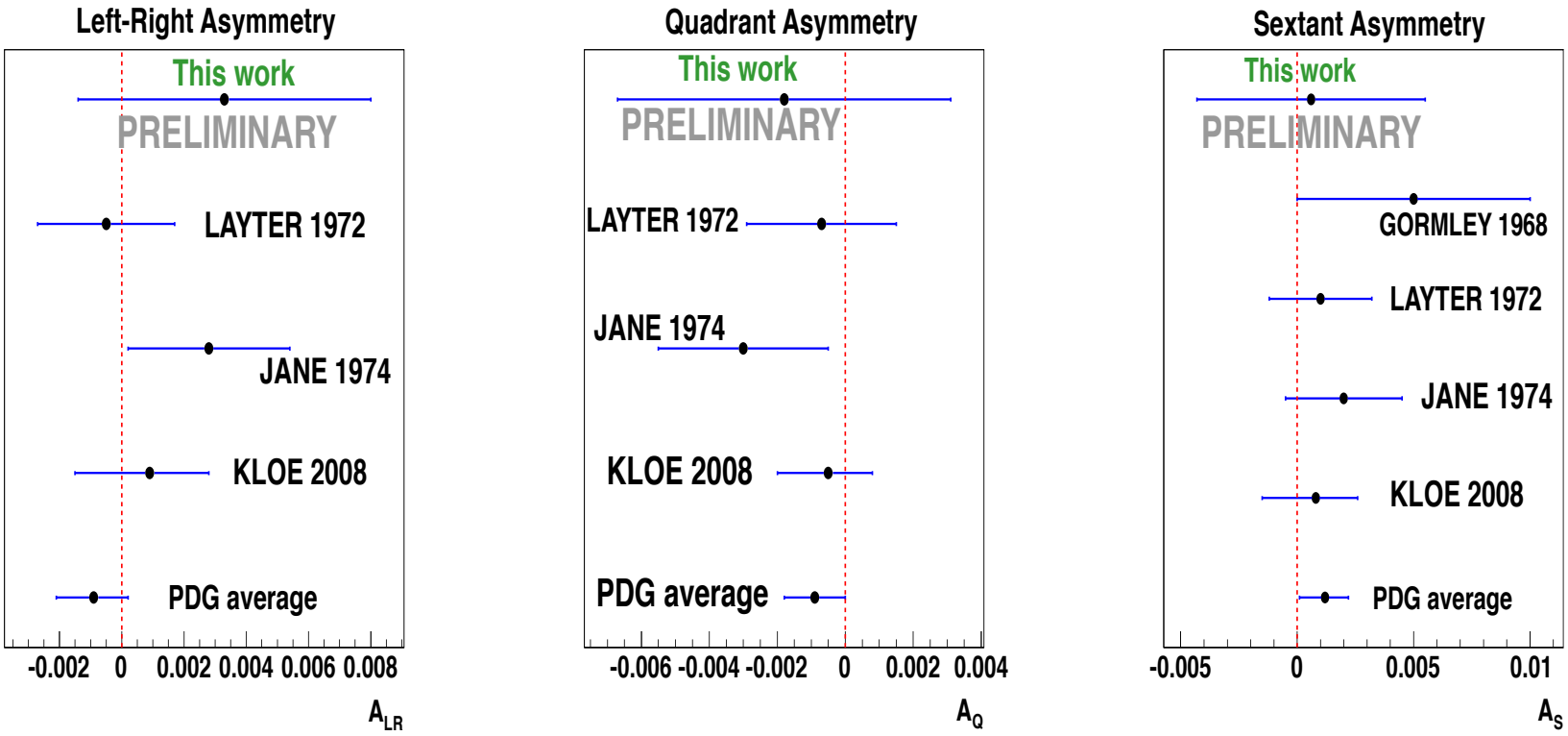
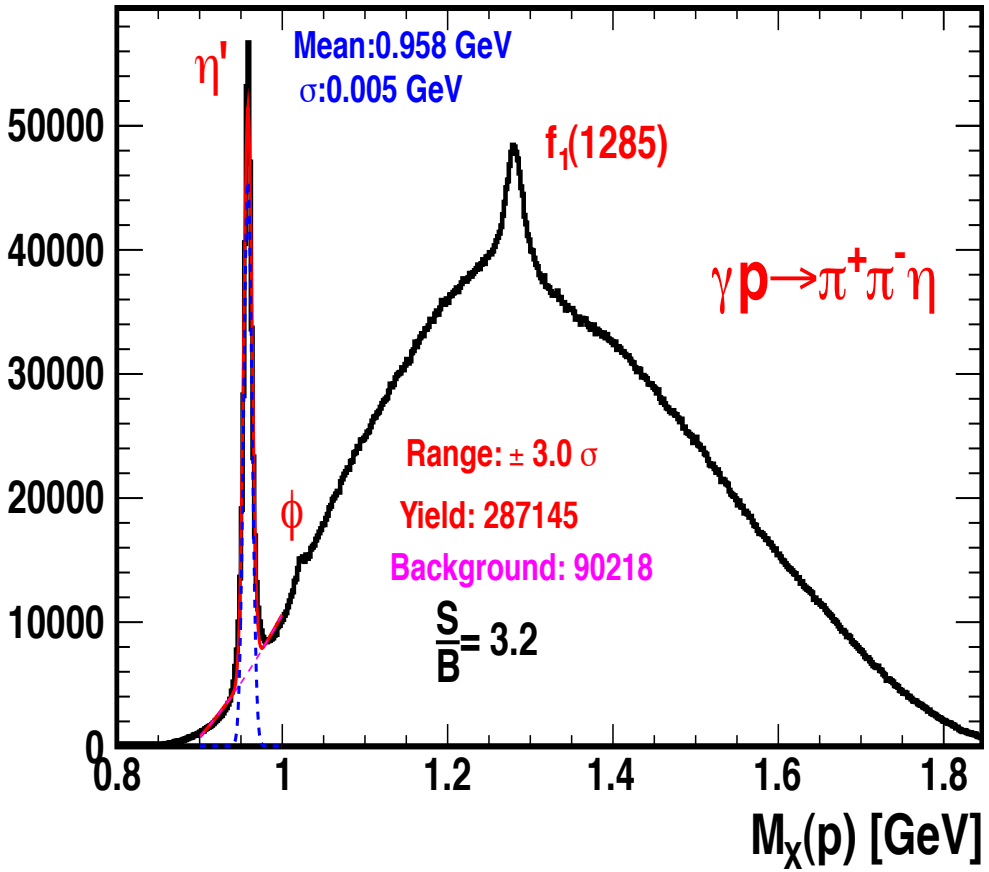


Fig. 1. Comparison of obtained values of asymmetries [7] with results determined by previous experiments [3,4,5], and a value given by PDG [6]. arXiv:1210.1758 [WASA-COSY]

CLAS expected stat. error. ~ 0.001

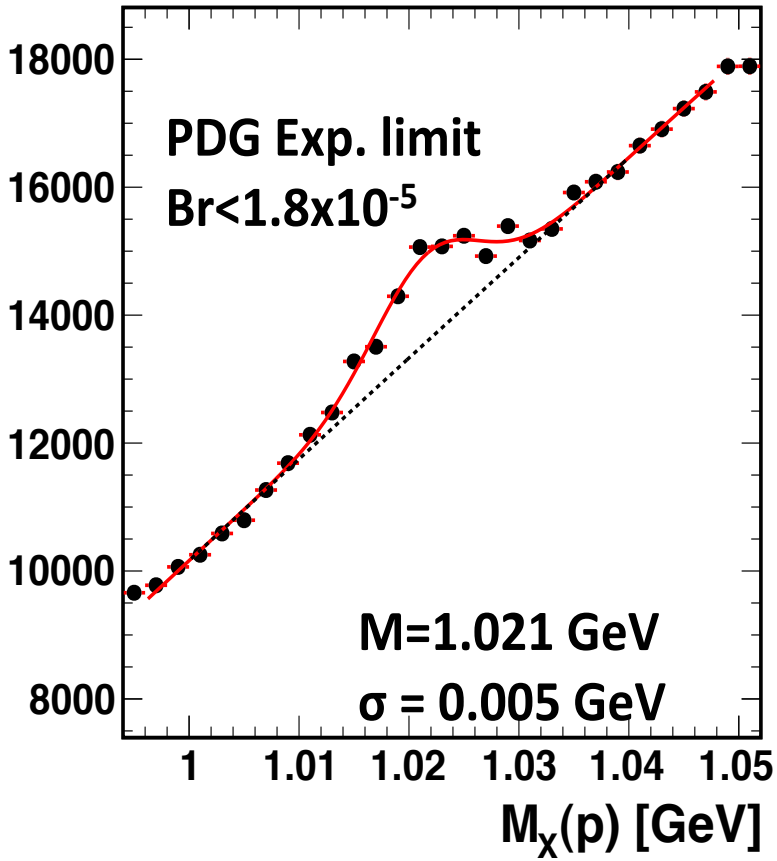
Hadronic decay

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



G-Parity violation

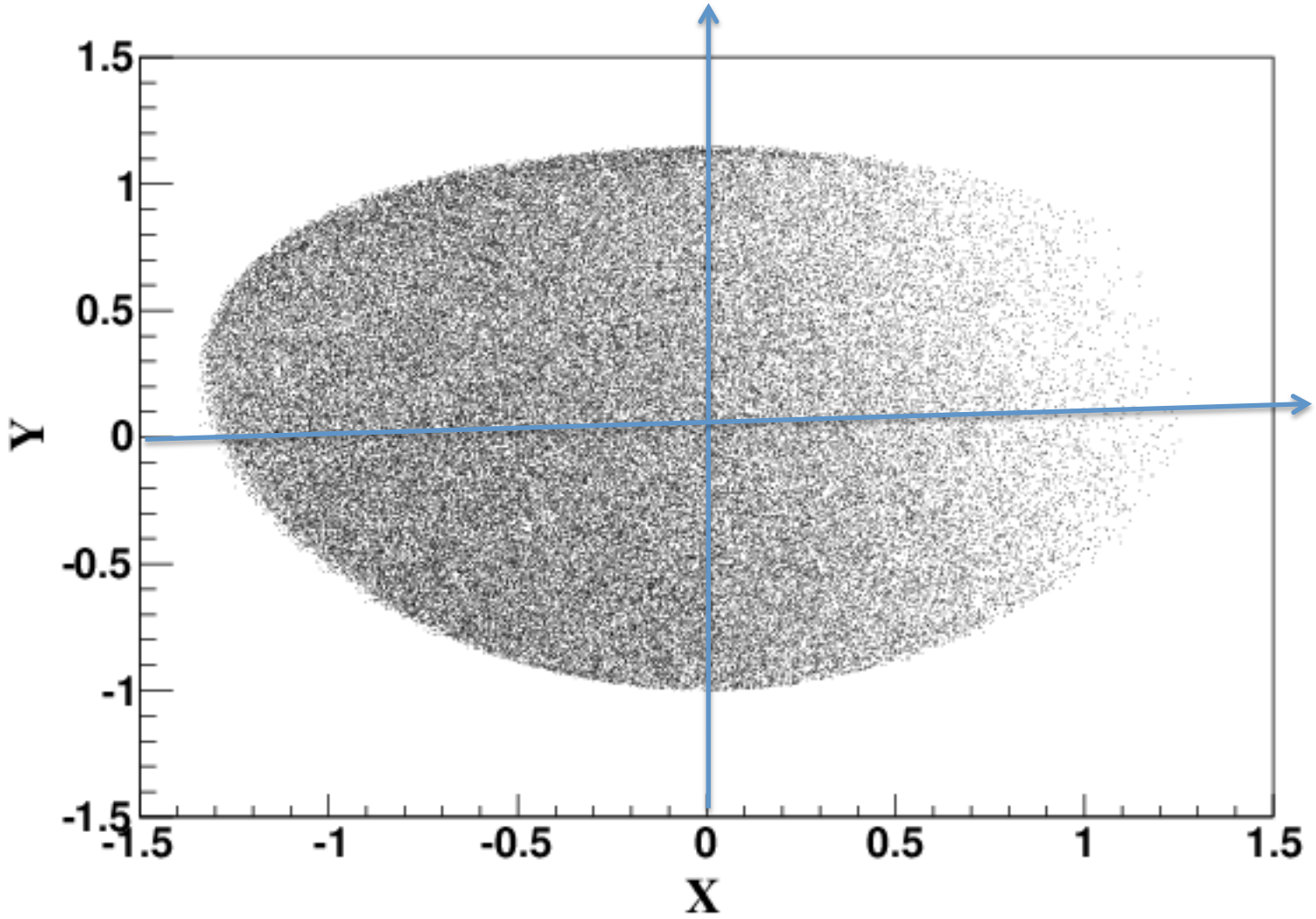
$\Phi \rightarrow \pi\pi\eta$



CLAS g11 Data (similar stat. in g12 run)

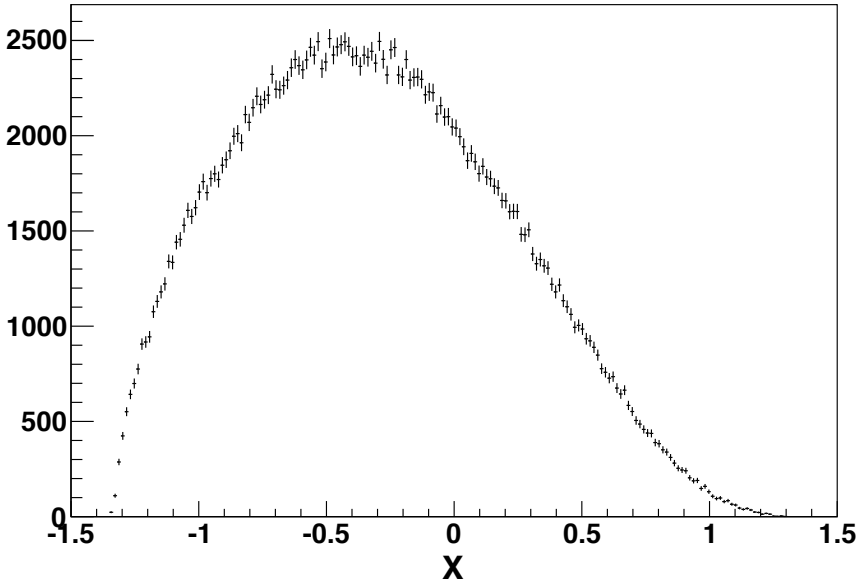
(300K, 7 times more η's than in BESIII)

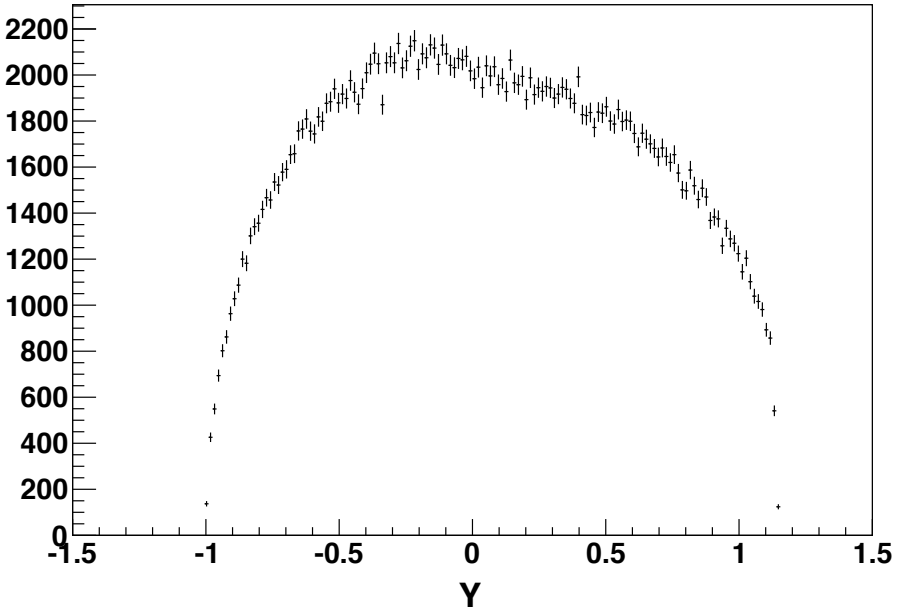
Dalitz plot $\eta' \rightarrow \pi\pi\eta$



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

CLAS Preliminary uncorrected





Par.	VES	Theory	BES	Stat err. In BES	Stat. err. In CLAS
	EPJ A26,383,2005		arXiV:1012.1117		
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

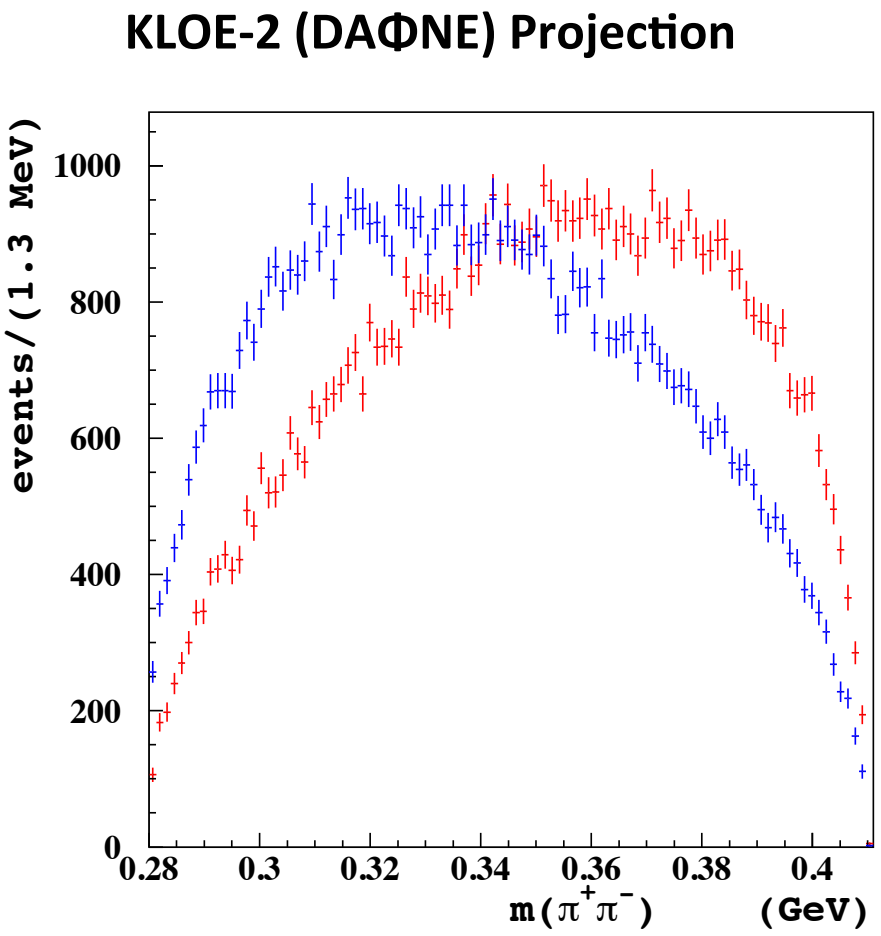
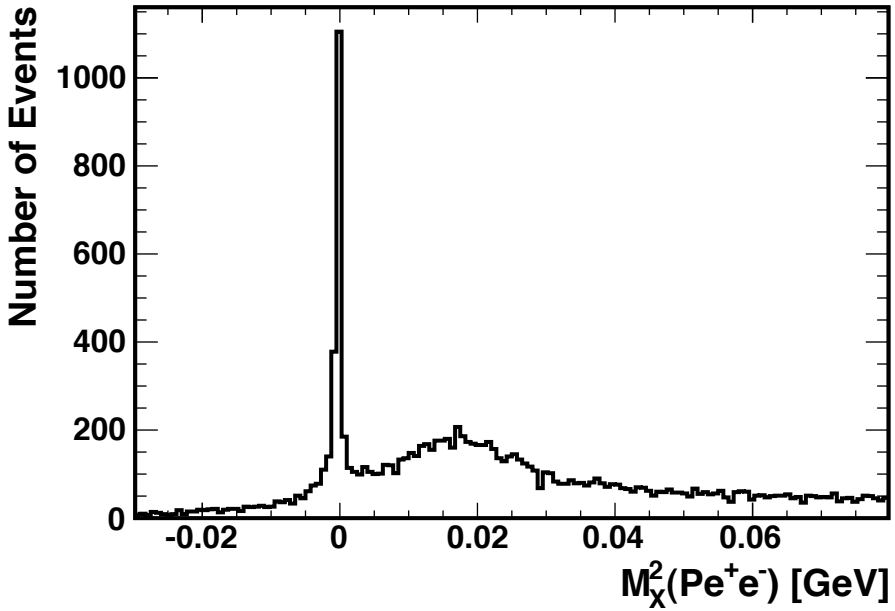
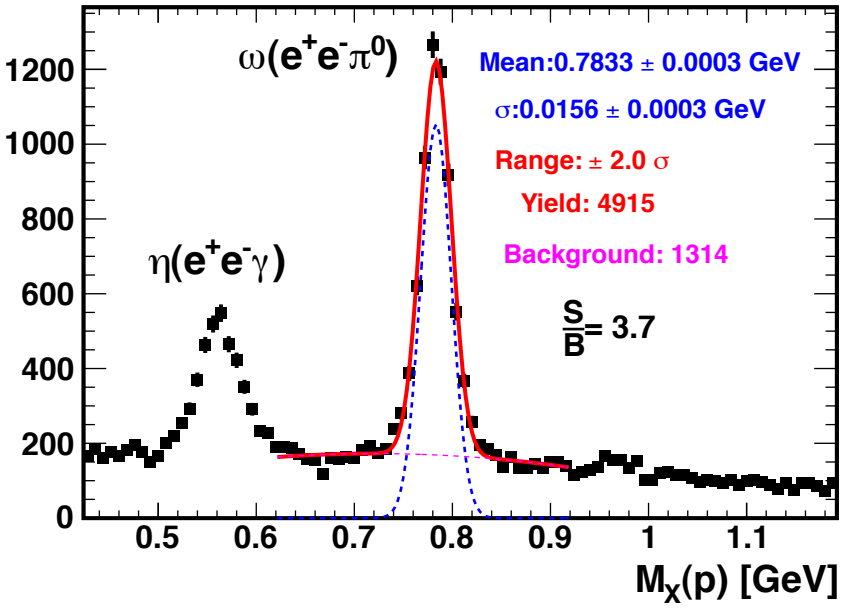


Fig. 18: The $m_{\pi^+\pi^-}$ distribution in the $\eta' \to \eta\pi^+\pi^-$ decay with the σ meson (right–centered distribution) and without (left–centered distribution) contribution.

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

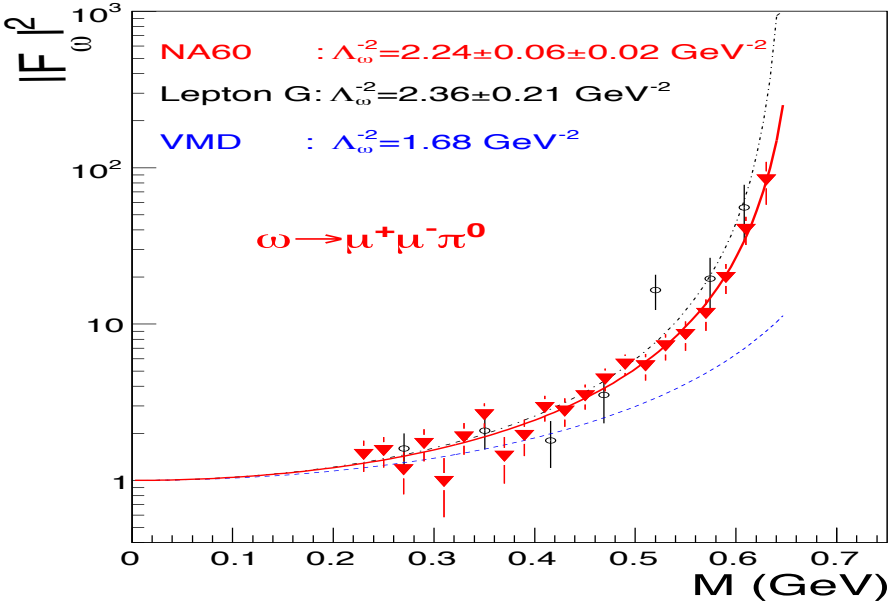
CLAS g12 Data



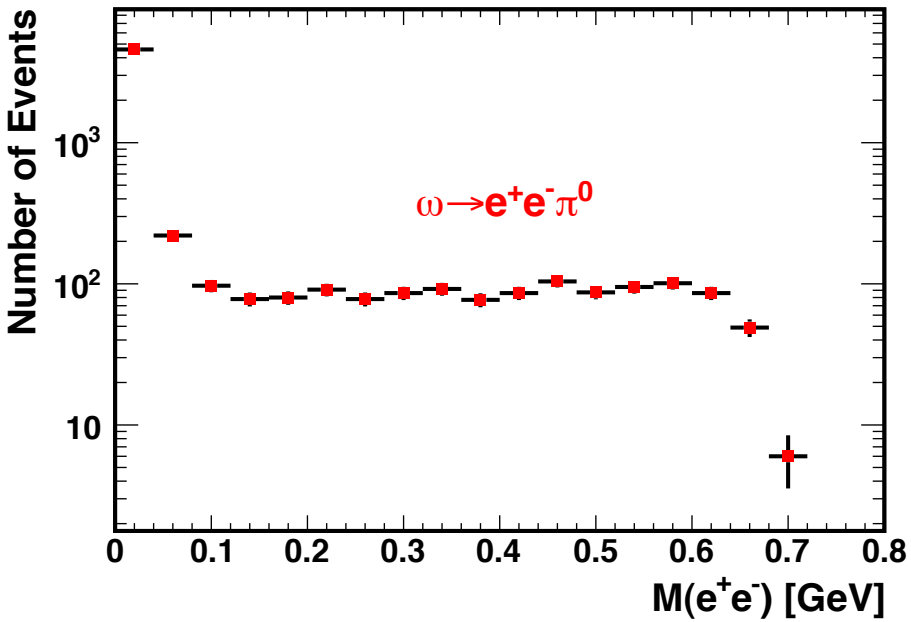


Transition Form Factor $\omega \rightarrow e^+e^-\pi^0$

World data

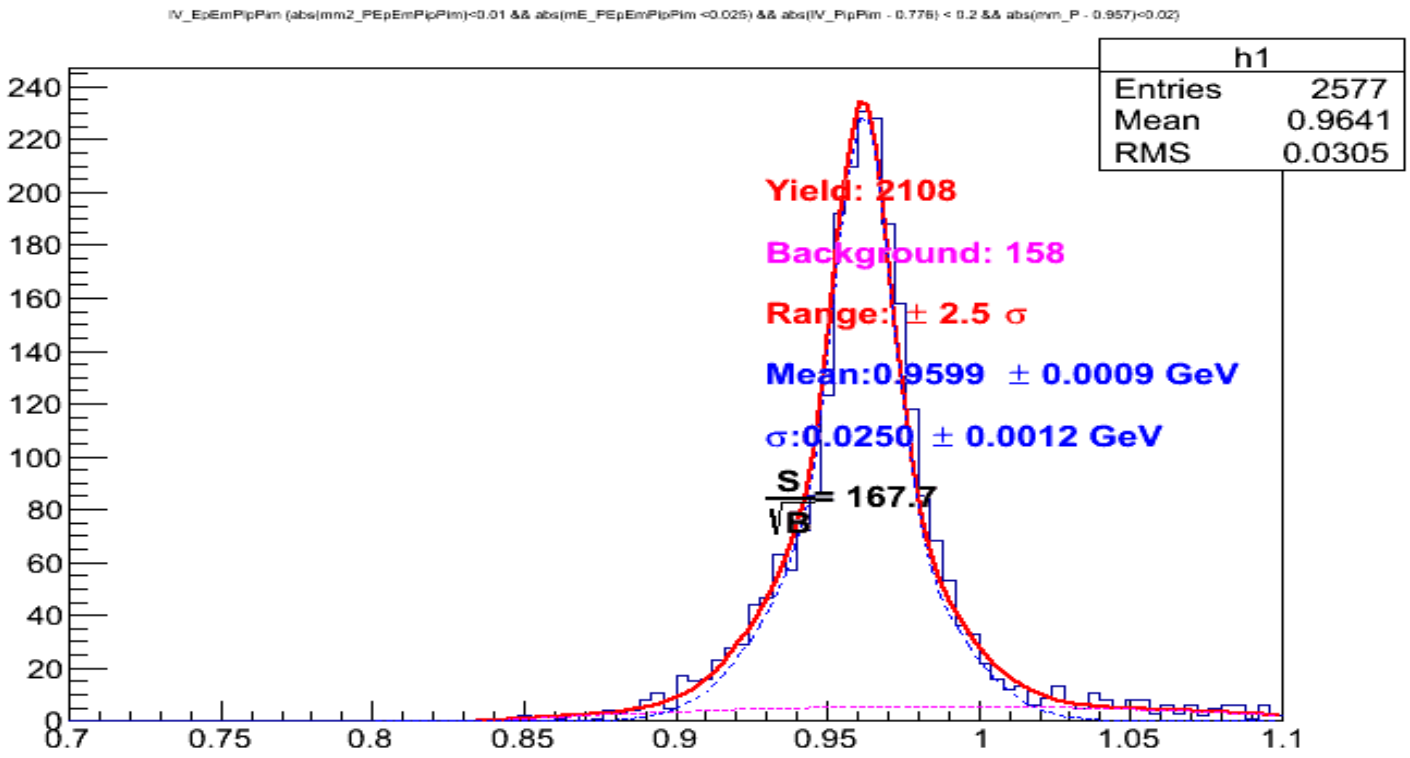


CLAS g12 Data



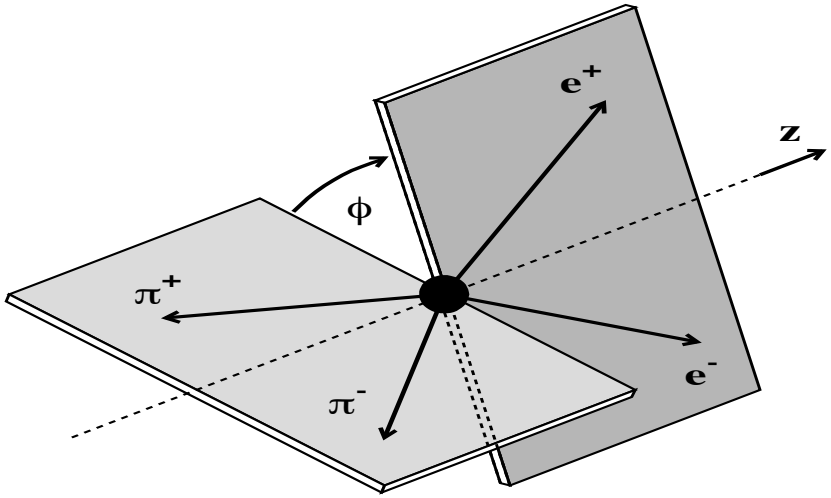
We expect significant improvement
in stat. error with CLAS Data

η,η’–>e+e-π+π-

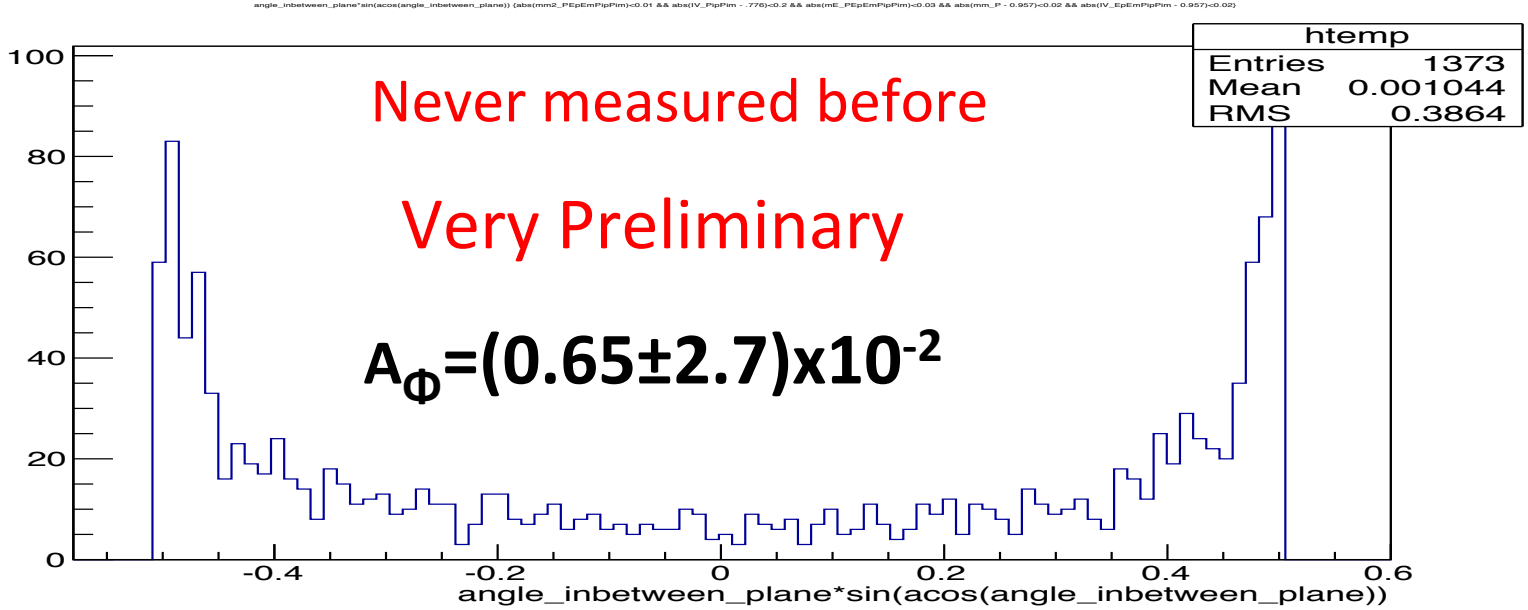


M(e+e-π+π-) [GeV]

η'–>e+e-π+π-



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



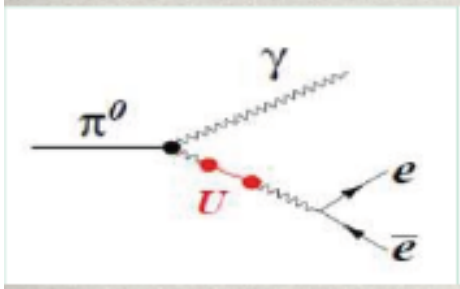
Never measured before

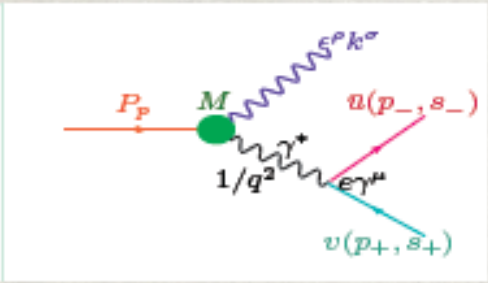
Very Preliminary

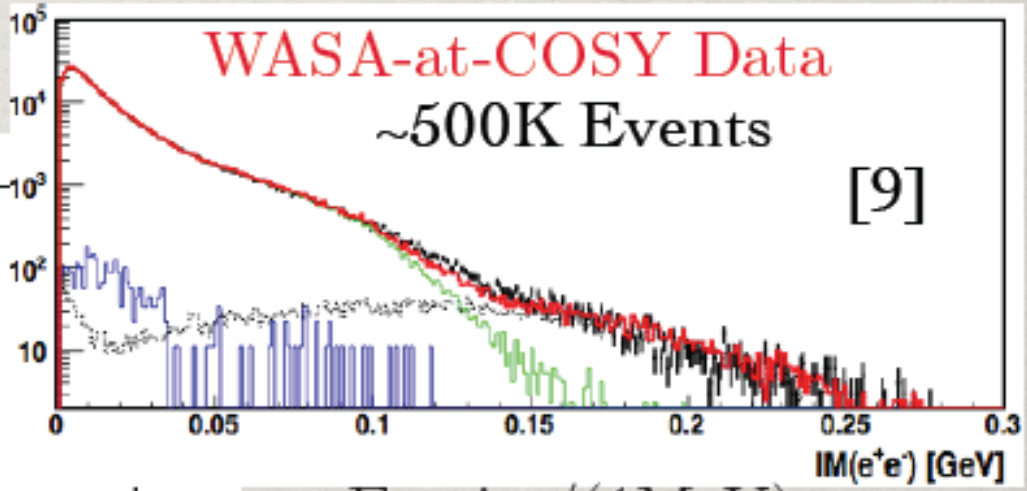
$A_\Phi = (0.65 \pm 2.7) \times 10^{-2}$

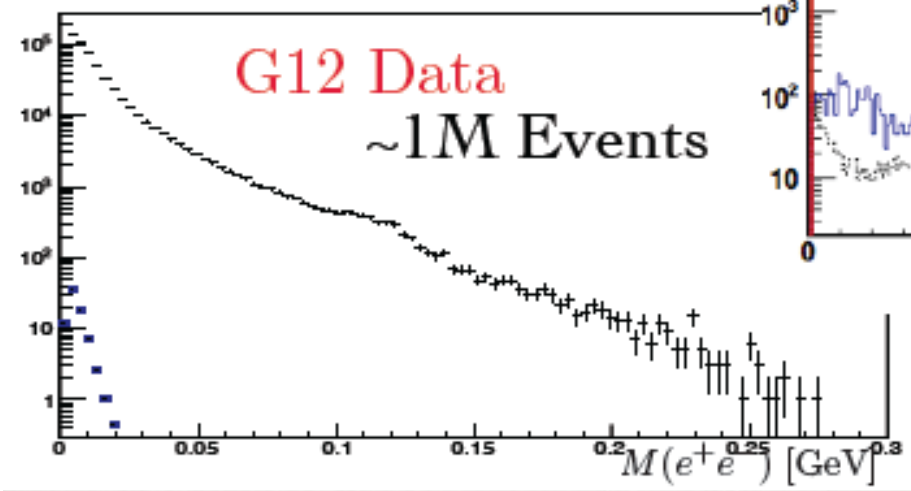
$\sin\Phi\cos\Phi$

Dark Photon





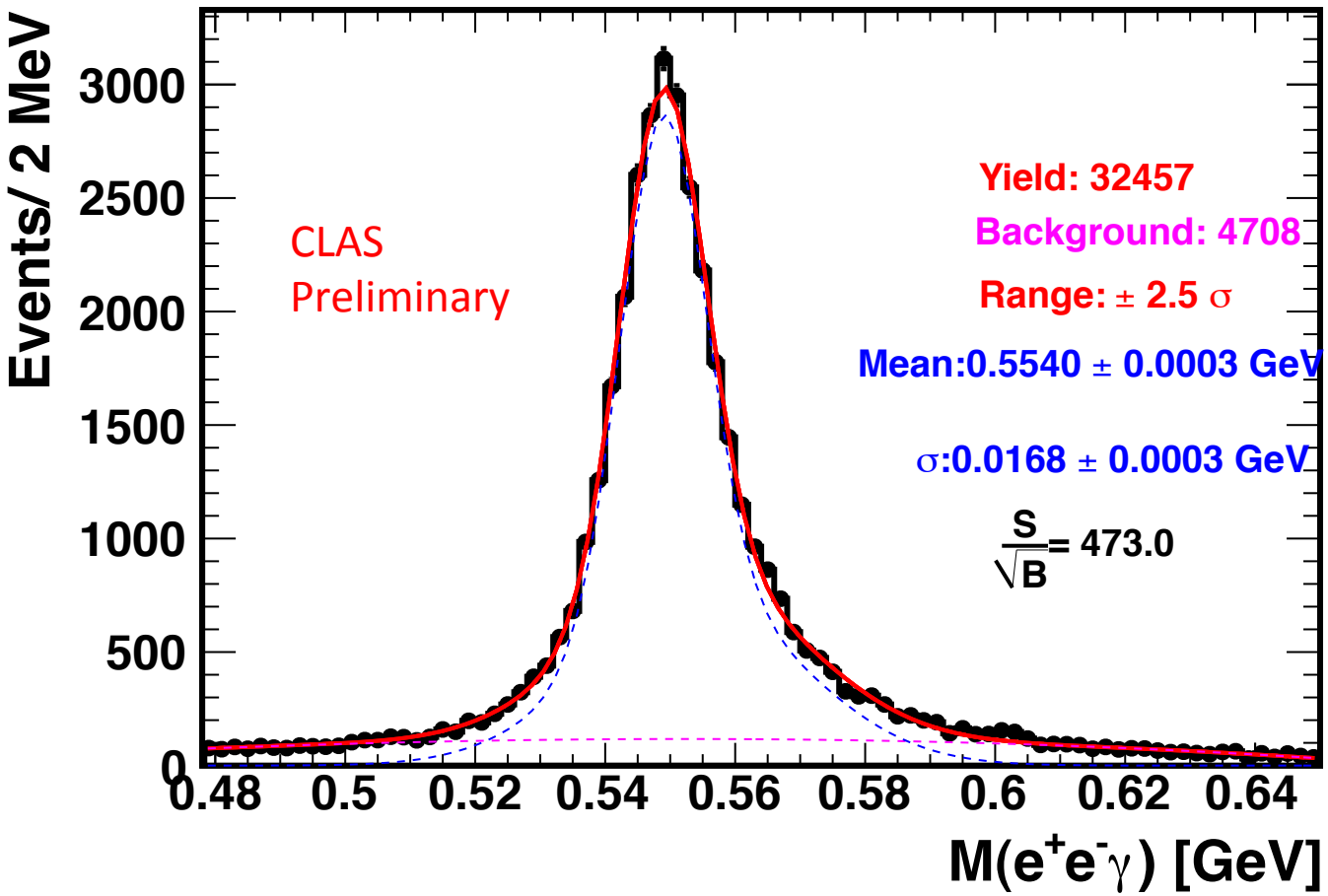


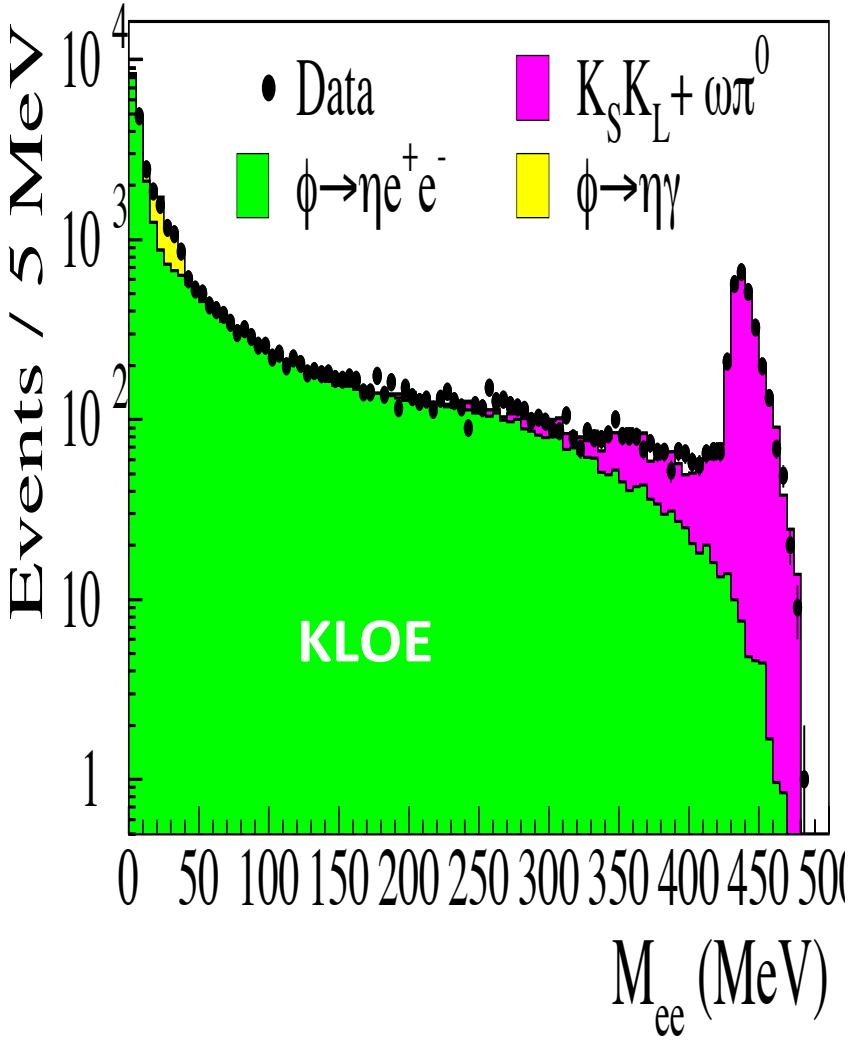


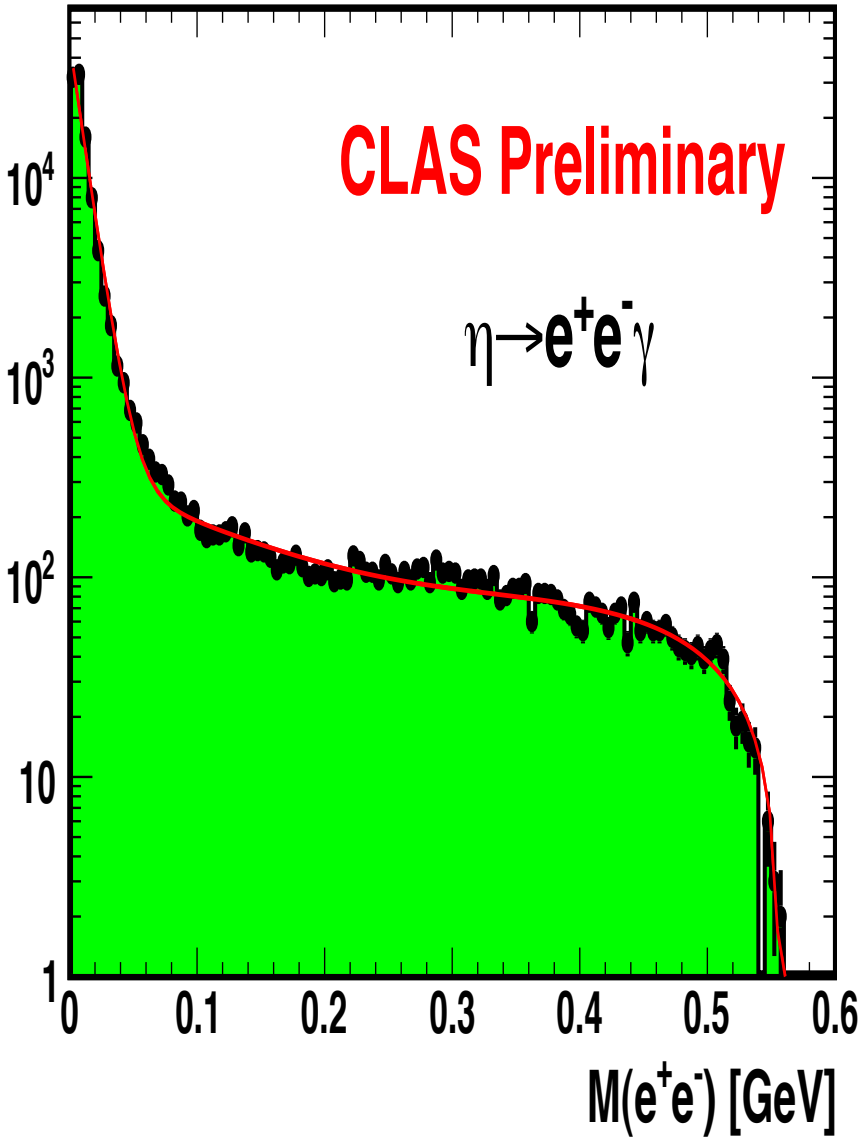
Entries/(1MeV)

- Data
- MC sum
- MC $\pi^0 \to e^+e^-\gamma$
- MC conversion
- MC $\pi^0 \to e^+e^-\gamma$ 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

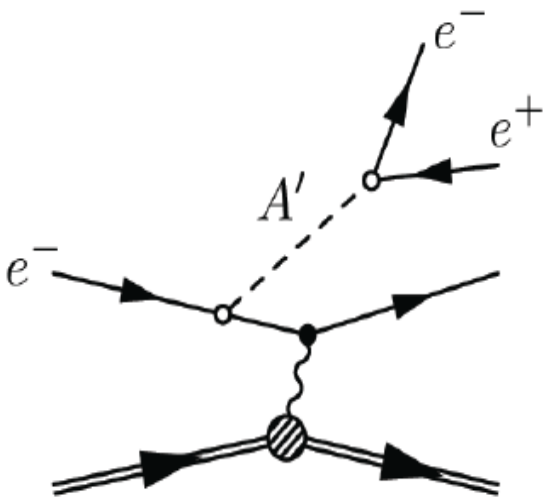
The current evidence is based on disjoint astronomical observations:
-Acoustic oscillations of the power spectrum of CMB
-The relative strength and shape of galaxy-distribution power spectrum at large wave numbers
-Observations of galactic rotation curves at distances for which little luminous matter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

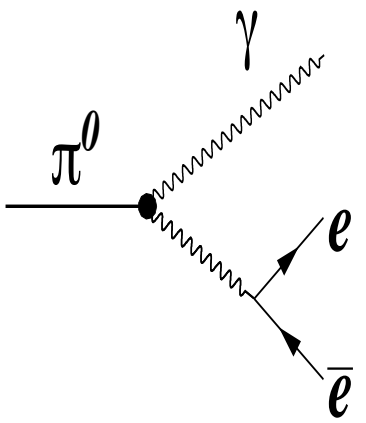
The cosmological evidence, taken collectively implies that some ~25% of the mass of Universe is in the form of Dark Matter with amazising accuracy of few percent!

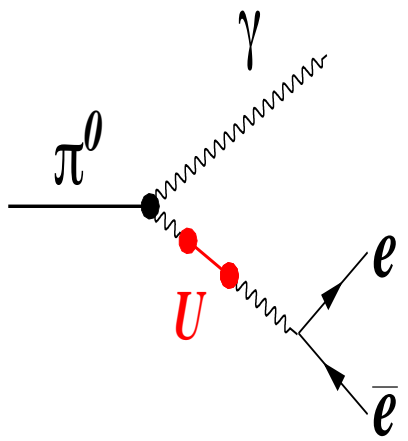
Hidden Gauge Boson

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

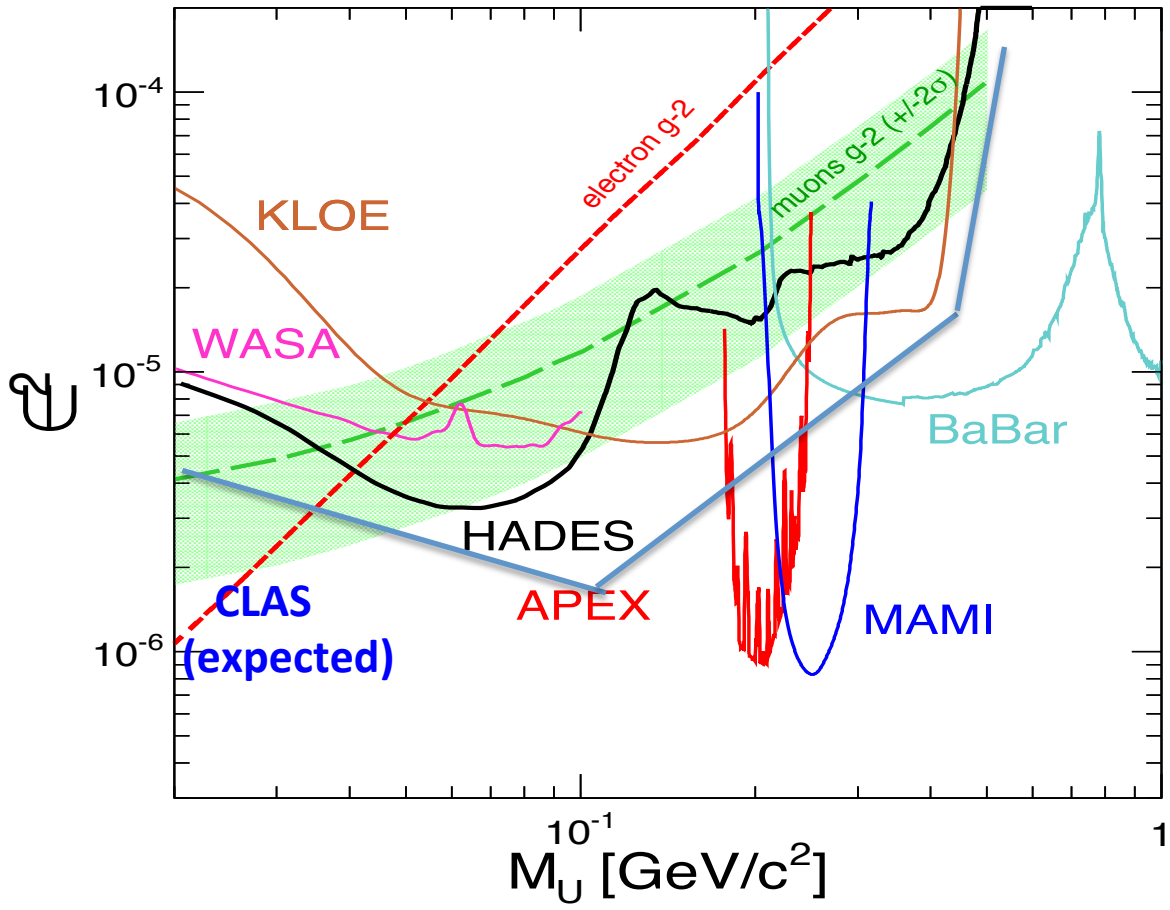
$$L_{mix} = -\frac{\epsilon}{2} F_{\mu\nu}^{QED} F_{dark}^{\mu\nu}$$







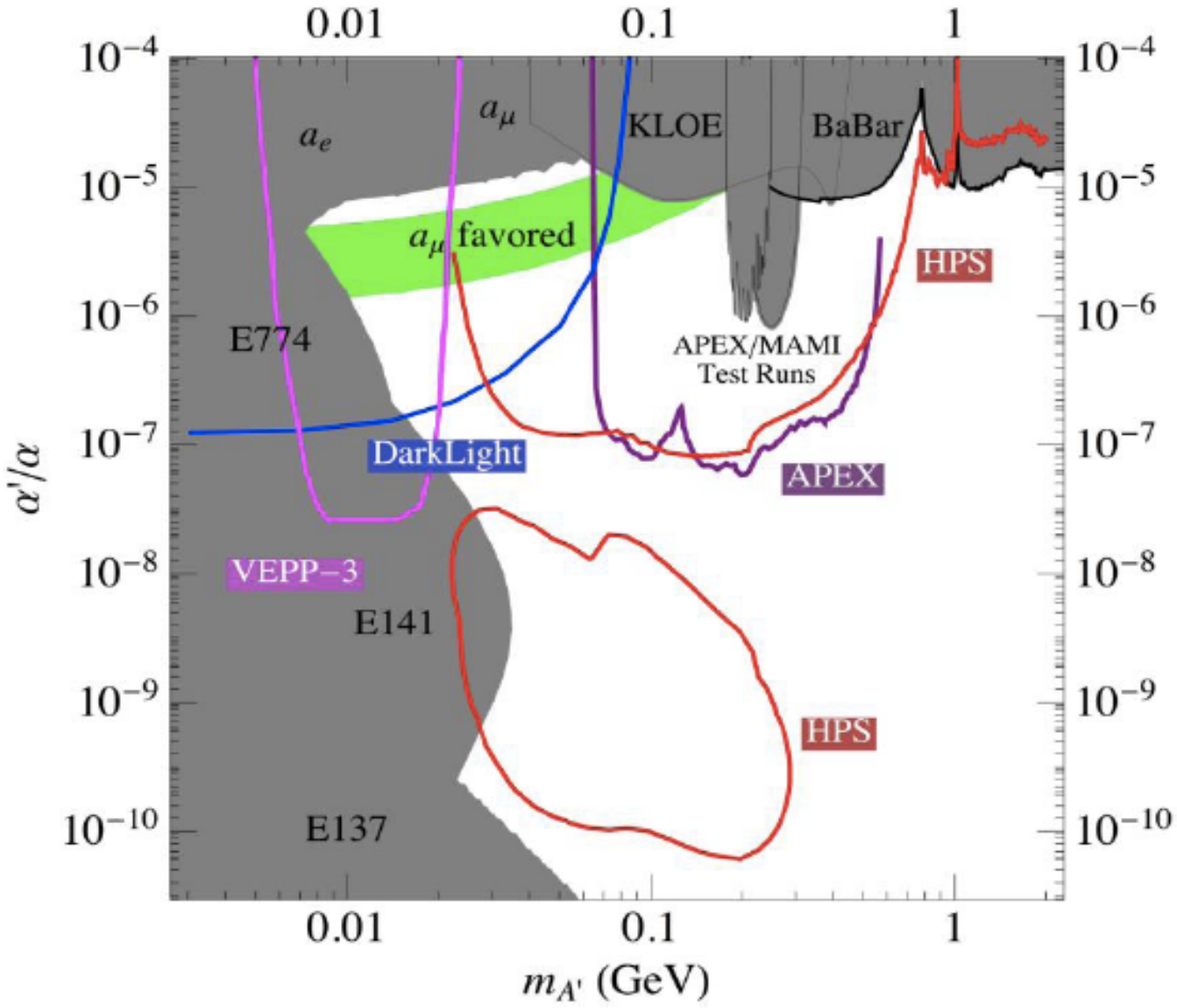
Constraints on Hidden sector coupling constant



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 !