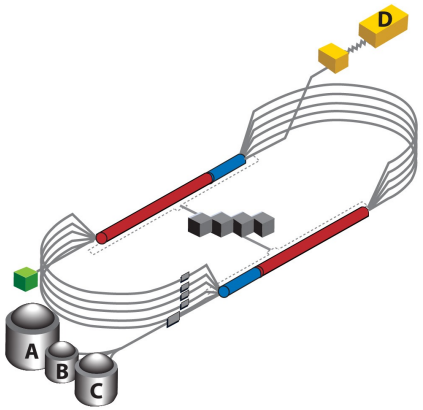
Light Meson Decays from Photon-Induced Reactions with CLAS

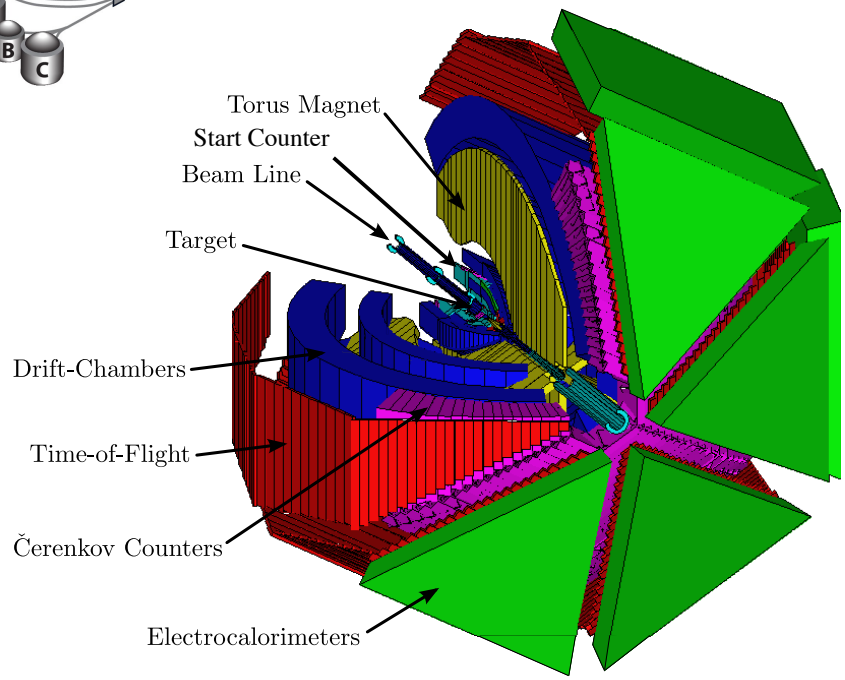
18 September 2015
XVI International Conference on Hadron Spectroscopy

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



CLAS

- Forschungszentrum Jülich
- Thomas Jefferson National Accelerator Facility
- Old Dominion University
- Petersburg Nuclear Physics Institute
- INFN, Sezione di Genova
- The George Washington University
- Florida State University
- University of South Carolina
- Arizona State University
- Indian Institute of Technology Indore
- JARA|FAME
- Florida International University
- University of Glasgow
- Catholic University of America
- Institut für Experimentalphysik I
- HISKP and Bethe Center for Theoretical Physics (BCTP)
- Universität Bonn
- Rensselaer Polytechnic Institute
- Skobeltsyn Nuclear Physics Institute
- University of Georgia
- Institut für Theoretische Physik II
- Norfolk State University
- Institute for Advanced Simulation

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 [GeV] < Eγ < 3.815 [GeV]	60 - 65 nA 5.714 GeV e^- beam 1.142 [GeV] < Eγ < 5.425 [GeV]
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
~$1x10^9$ events 21 TB of raw data	~$5x10^9$ events 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	$\eta, \omega, \Phi \to \pi^-\pi^+\pi^0$	Dalitz plot analysis
$\omega \to \pi^0 e^+e^-$	Transition Form Factor	$\eta' \to \pi^-\pi^+\eta$	Dalitz plot analysis/meson mixing
$\eta(') \to \pi^0 e^+e^-$	C violation	$\Phi \to \pi^-\pi^+\eta$	G-parity violation
$\eta(') \to \pi^-\pi^+e^+e^-$	CP violation	$\Phi \to \omega\gamma$	C violation, rare decay

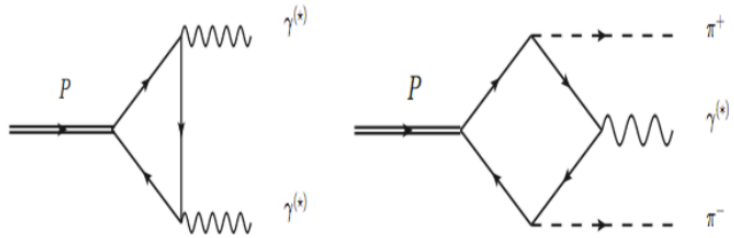
Box Anomaly from η(')→π⁻π⁺γ

Njencheu Georgie Mbianda, Moskov 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' →$\pi^-\pi^+\gamma$ can also proceed via the box anomaly.



triangle box

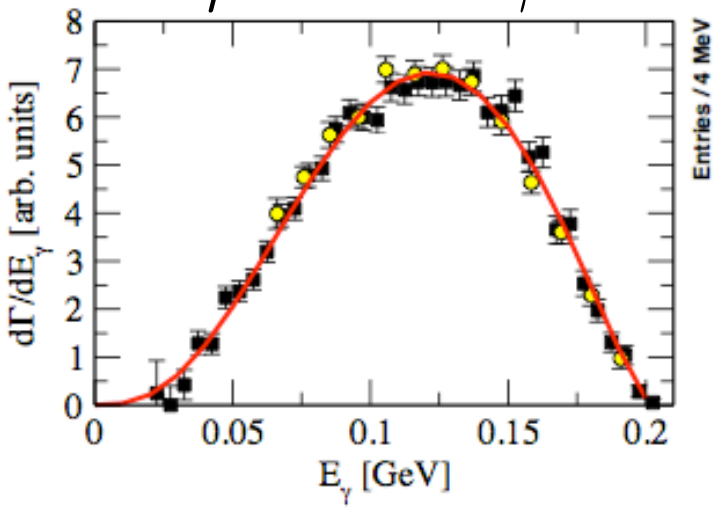
$$\frac{d\Gamma(\eta \to \pi^+\pi^-\gamma)}{ds_{\pi\pi}} = |AP(s_{\pi\pi})F_V(s_{\pi\pi})|^2\,\Gamma_0(s_{\pi\pi})$$

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

Experimental Results

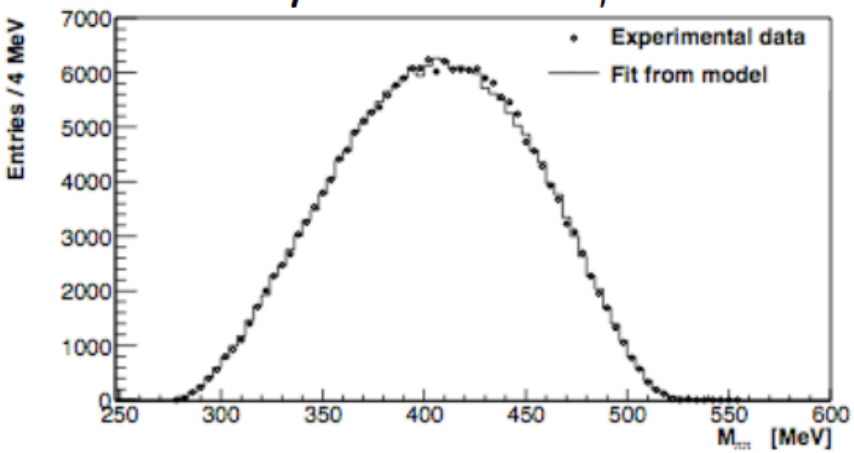
WASA-at-COSY

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



KLOE

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



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

$\alpha = \left(1.32 \pm 0.08_{\mathrm{stat}}\ ^{+0.10}_{-0.09\ \mathrm{syst}} \pm 0.02_{\mathrm{theo}}\right) GeV^{-2}$ [3]

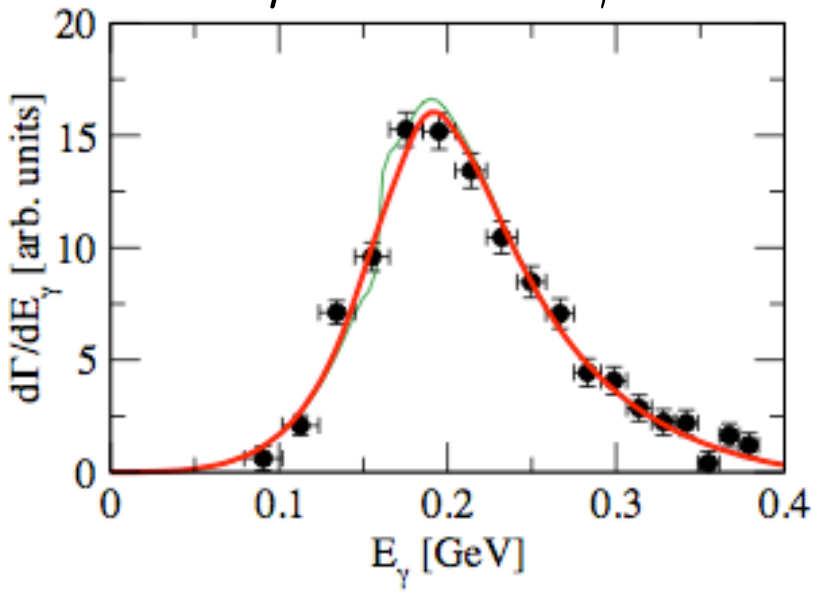
$$s_{\pi\pi} = m^2 - 2E_\gamma m$$

HADRON2015 talk:
Daniel Lersch: The eta decay program at WASA-at-COSY
Session: Spectroscopy of Mesons
Tuesday 17:15

[1]F.Stollenwerk et al., Phys. Lett. B707:184-190, 2012
[2]P. Adlarson et al., Physics Letters B 707 (2012)
[3]Babusci, D. et al., Phys.Lett. B718 (2013) 910-914

Experimental result from CRYSTAL BARREL at LEAR

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



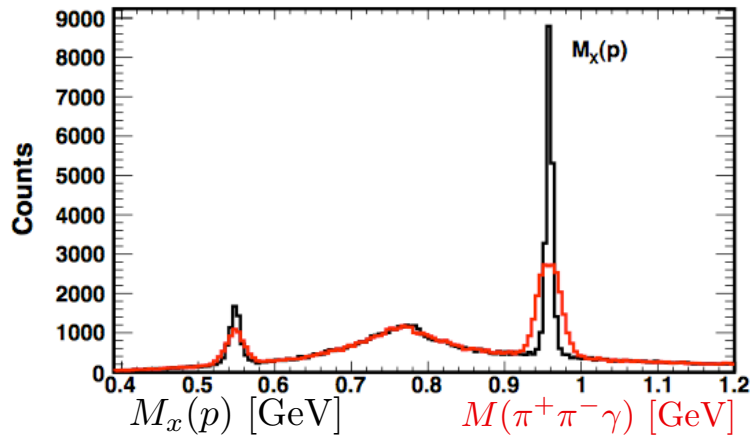
$$\alpha' = (1.8 \pm 0.49 \pm 0.04)\ \mathrm{GeV}^{-2}$$ [1]

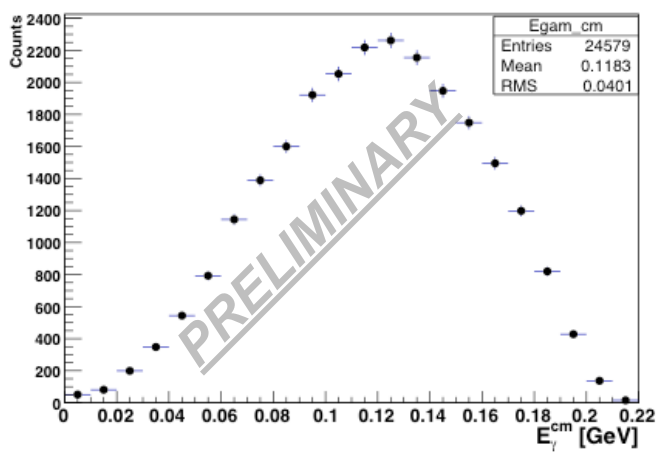
$$s_{\pi\pi} = m^2 - 2E_\gamma m$$

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

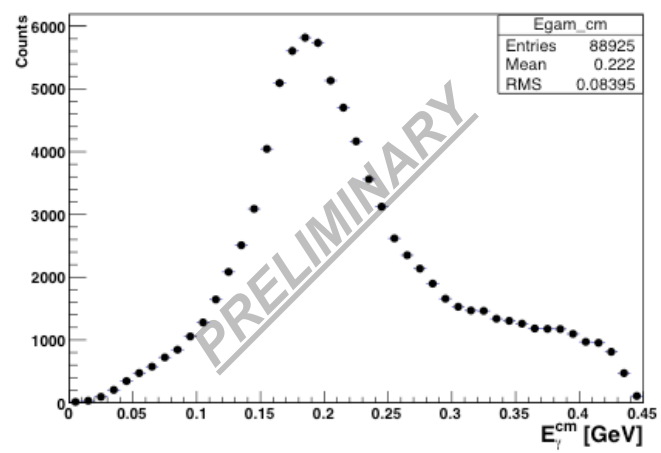
CLAS Raw Data

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





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



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

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

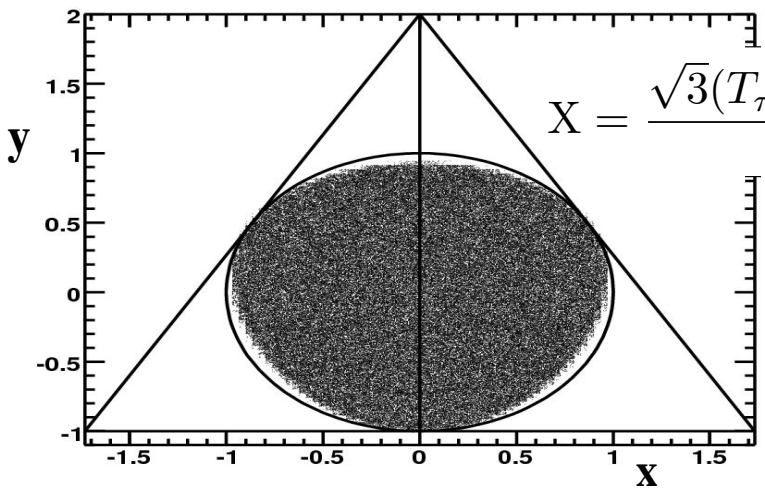
Sudeep Ghosh, Ankhi Roy;

IIT Indore

Motivation:

- Dalitz plot of $\eta' \to \pi^- \pi^+ \eta$ provides kinematic information of the decay, enabling the study of low energy dynamics of QCD.
- The $\eta' \to \pi^- \pi^+ \eta$ decay has a low Q-value due to relatively heavy decay products, thus helping to test the effective chiral Lagrangian theory

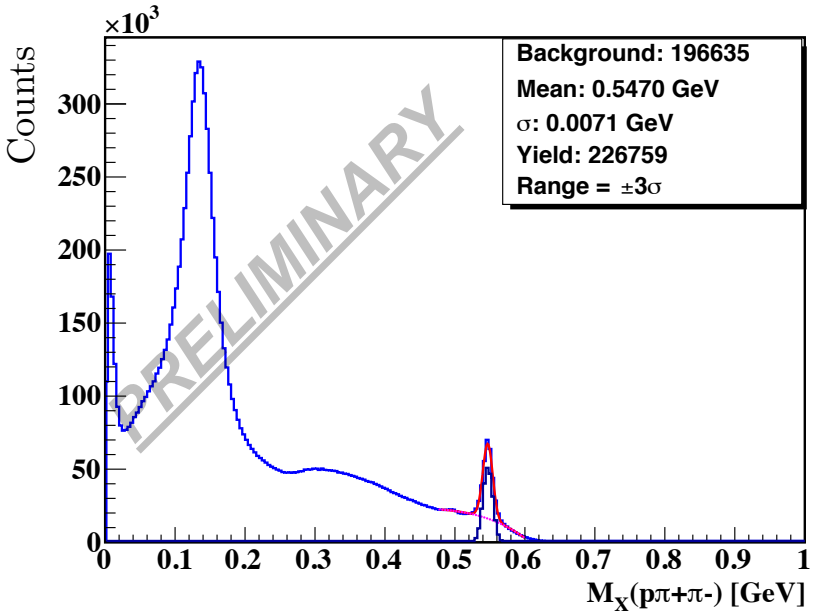
Dalitz Plot Geometry



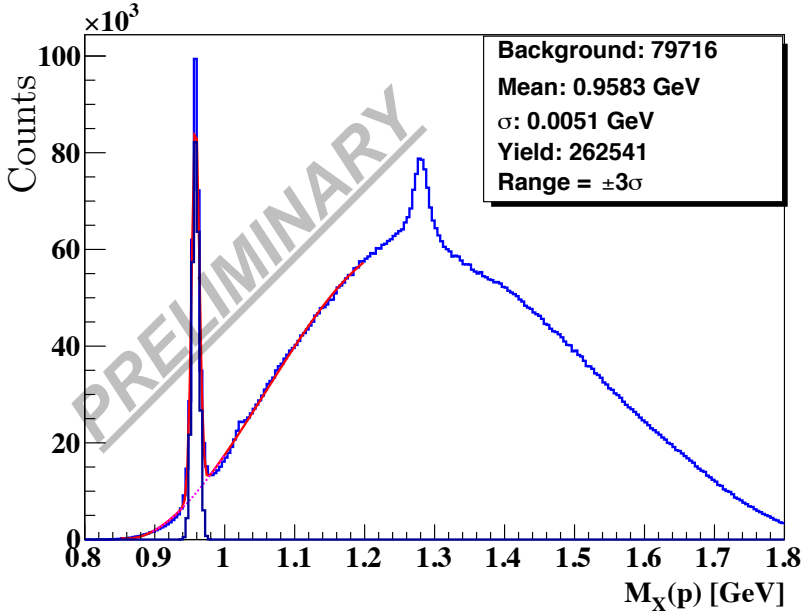
$$X = \frac{\sqrt{3}(T_{\pi^+} - T_{\pi^-})}{Q} \quad Y = \frac{(m_\eta + 2m_\pi)}{m_\pi} \cdot \frac{T_\eta}{Q} - 1$$

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

Dalitz Plot of $\eta' \rightarrow \pi^- \pi^+ \eta$



Missing mass of $p\pi^-\pi^+$ for events where $M_x(p)=0.958\pm0.015$ GeV



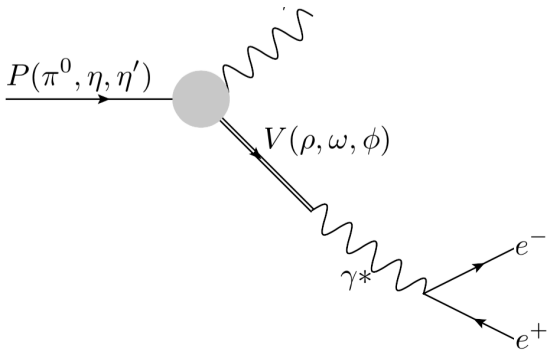
Missing mass of p for events where $M_x(p\pi^-\pi^+)=0.5\pm0.015$ GeV

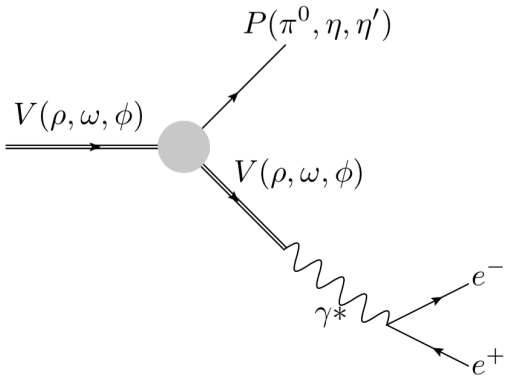
See next talk by Sudeep Ghosh for more details

Transition Form Factors

Michaela Schever, Michael C. Kunkel, Susan Schadmand, Jim Ritman;

Institut für Kernphysik, Forschungszentrum Jülich

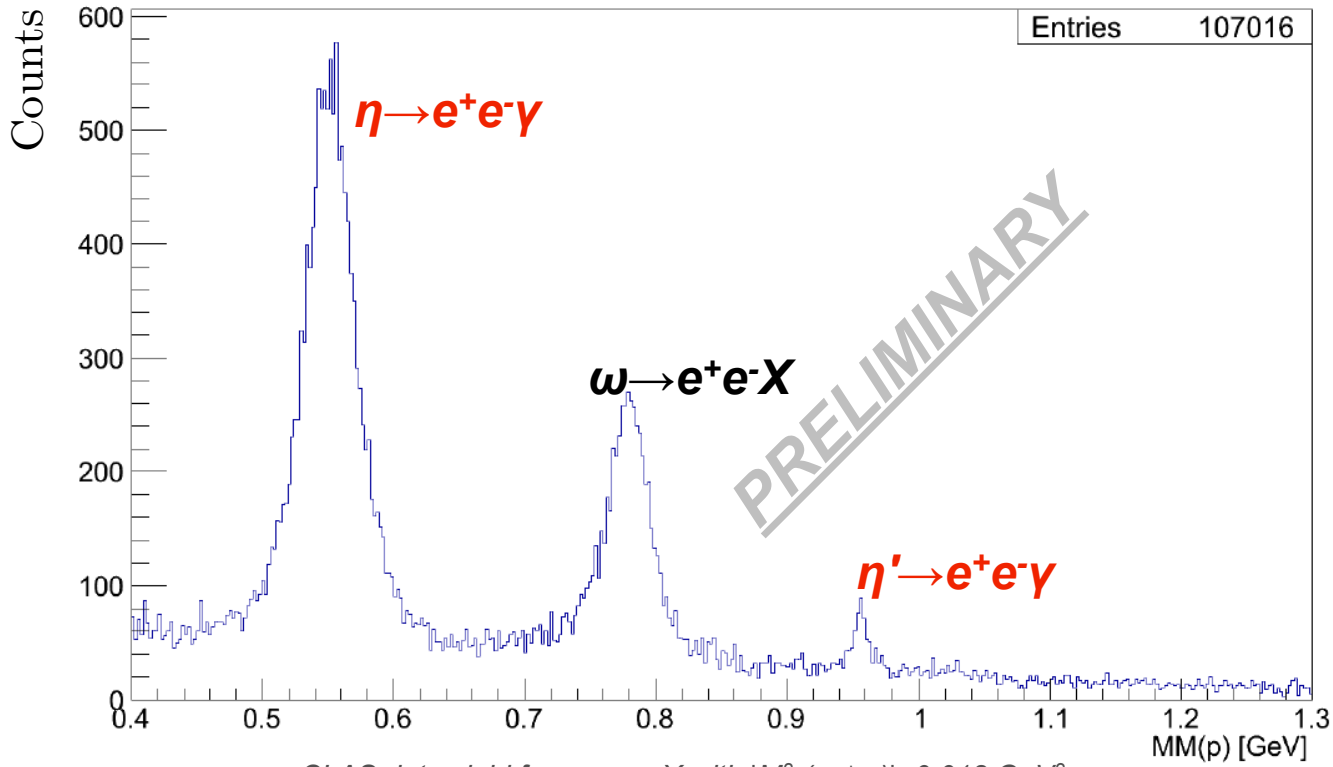




Motivation:

- 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 η form factor is needed to interpret the muon g-2 experiment.

η, ω, η' Yield



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

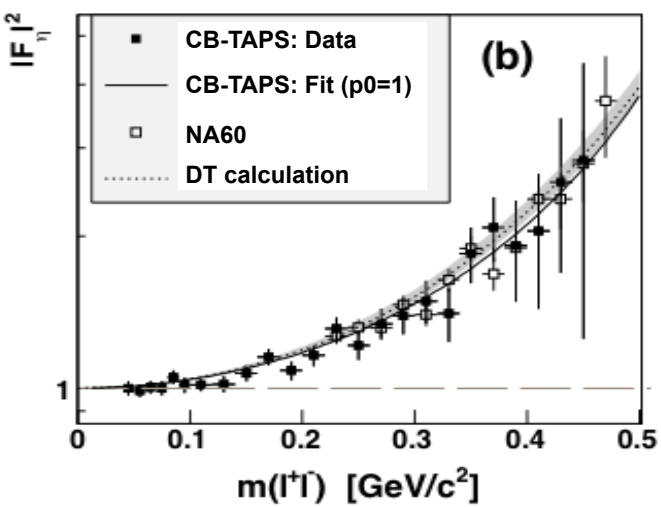
η Transition Form Factors

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

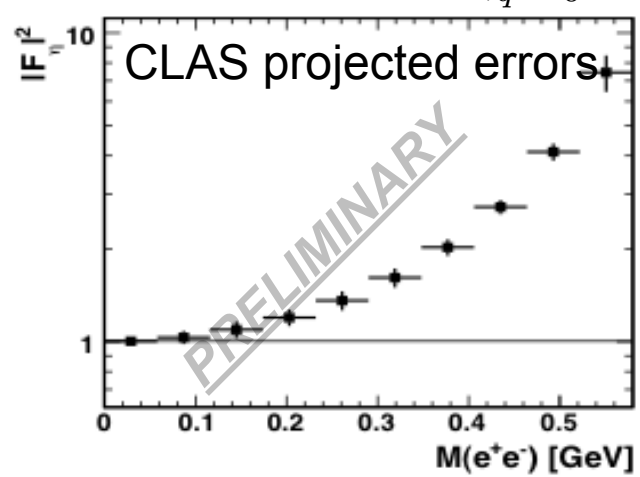
$$F(q^2) = [1-\frac{q^2}{\Lambda^2}]^{-1}$$

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

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



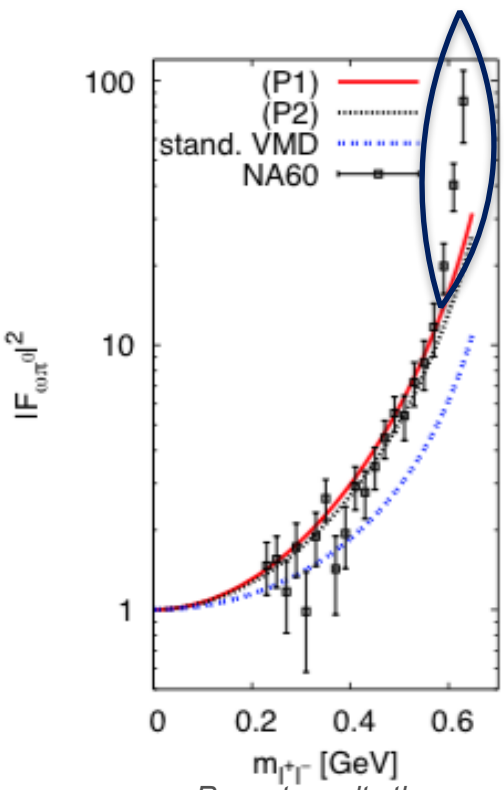
Recent results the η transition form factor with errors. Image Source: Phys. Rev. C 89, 044608



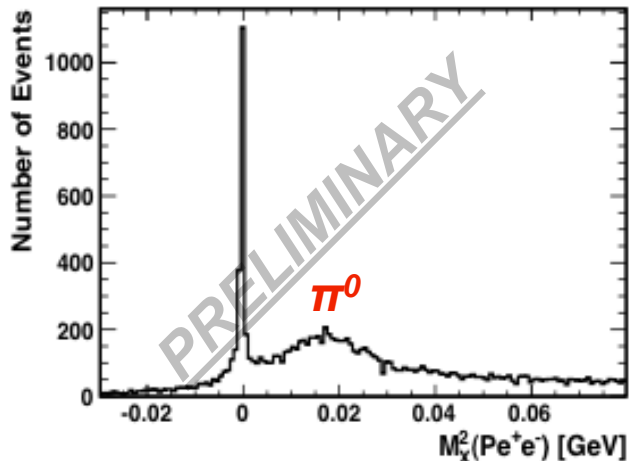
CLAS projected errors on η transition form factor

ω Transition Form Factor

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

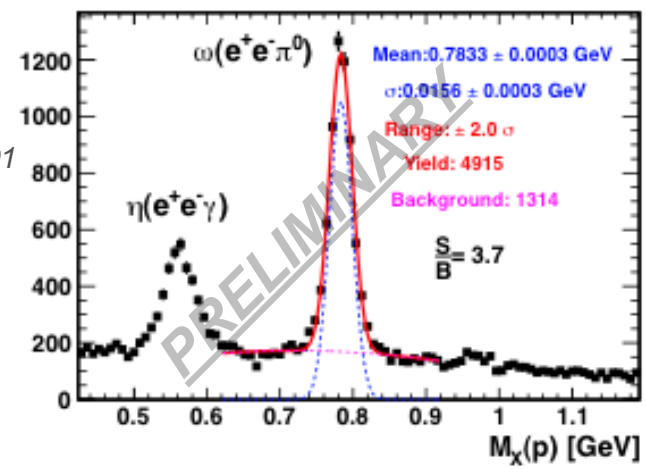


Recent results the ω transition form factor. Image Source: Conference Proceedings

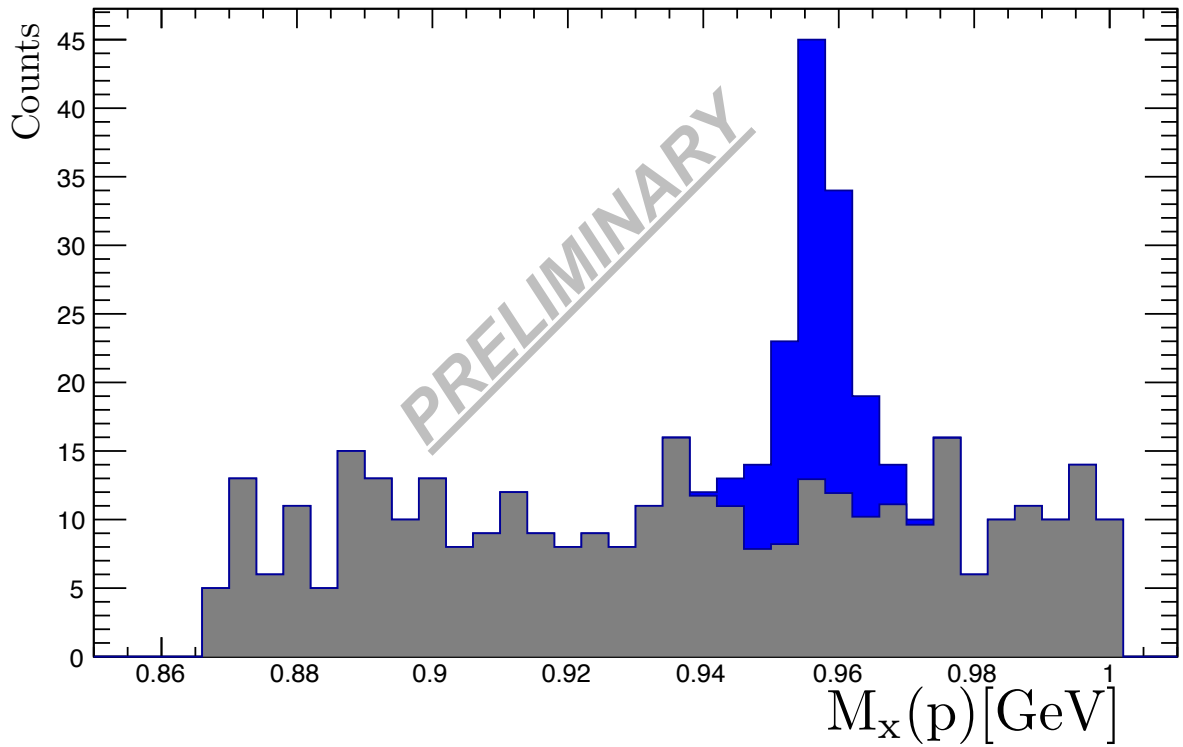


CLAS data yield from γp→pe⁺e⁻X with $M_x(p) = M_\omega \pm 0.031$ GeV

CLAS data yield from γp→pX with $M^2_x(pe^+e^-) = M^2_{\pi 0} \pm 0.01$ GeV²



$\eta' \to e^+e^-\gamma$ Branching Ratio



BESIII $\Gamma(\eta' \to \gamma e^+e^-)/\Gamma(\eta' \to \gamma\gamma)$ $(2.13 \pm 0.09(\text{stat.}) \pm 0.07(\text{sys.})) \times 10^{-2}$ from 864 events [1]

CLAS preliminary BR consistent with BESIII results from 89 events
First estimate from cut-based analysis

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

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
BESIII (η′→γe+e−)	1.60 ± 0.17(stat) ± 0.08(sys) GeV^{-2} [1]	864
CELLO (η′→γμ+μ−)	1.7 ± 0.4 GeV^{-2} [2]	75
CLAS (η′→γe+e−)	TBD	89

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

Current statistical error cannot discern the correct theoretical model

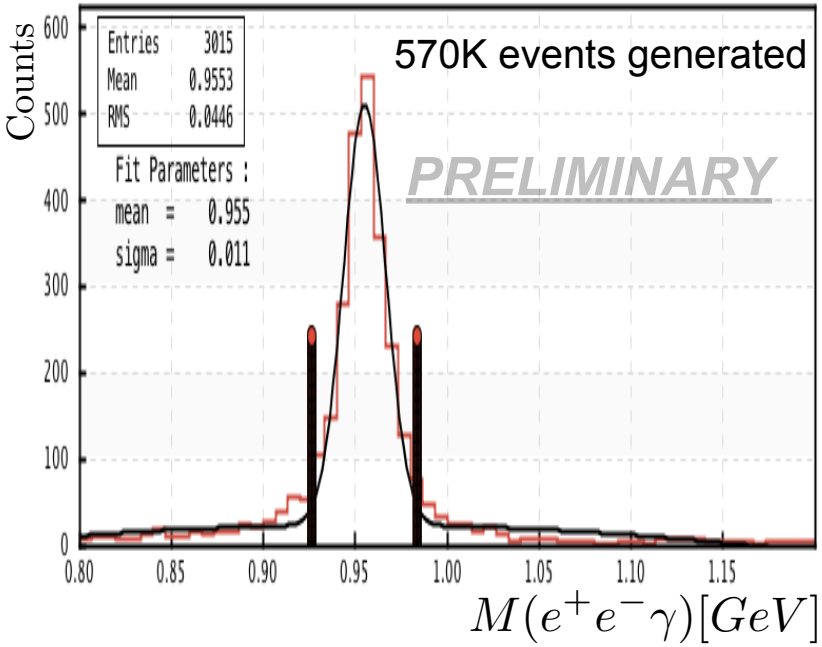
[1]M. Ablikim et al., Phys.Rev. D92 (2015) 012001
[2]R. I. Dzhelyadi et al., Phys. Lett. B 88, 379 (1979)

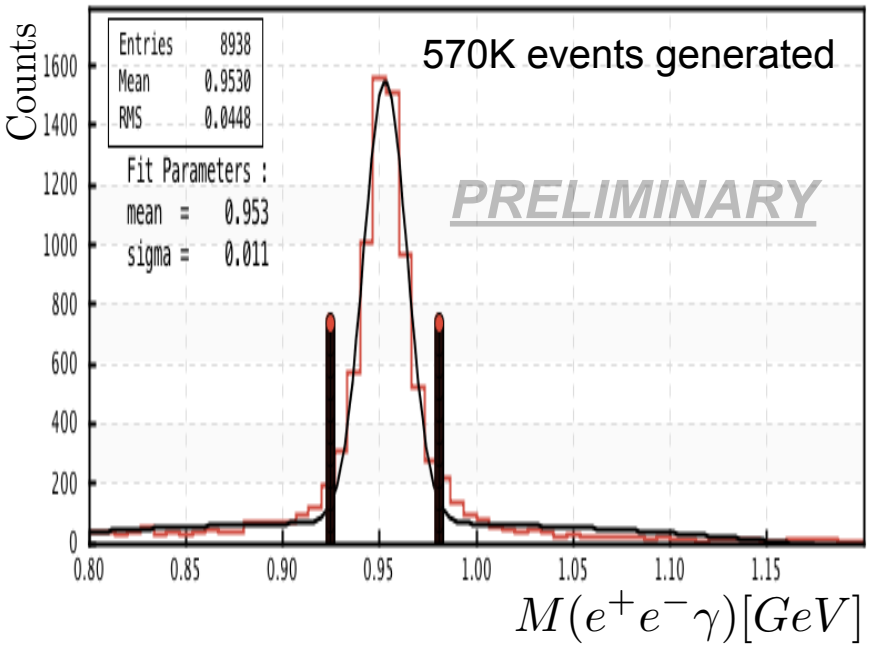
CLAS12 e^+e^- pair physics

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

CLAS $\xi(e^+e^-)/\xi(\pi^+\pi^-)$ can be range 10^5 - 10^{11}
CLAS e^+e^- efficiency (ε) range 1 - 10^{-2}

CLAS12 η' Measurement

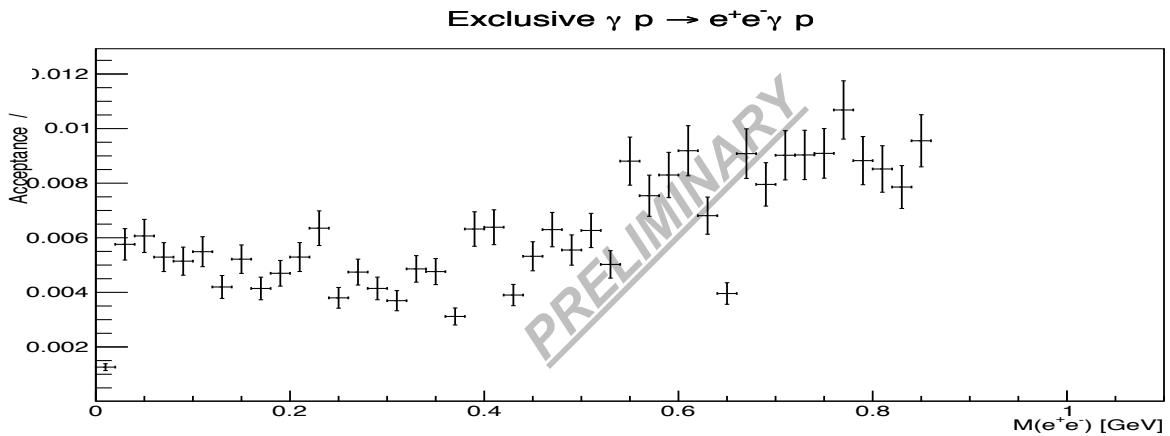


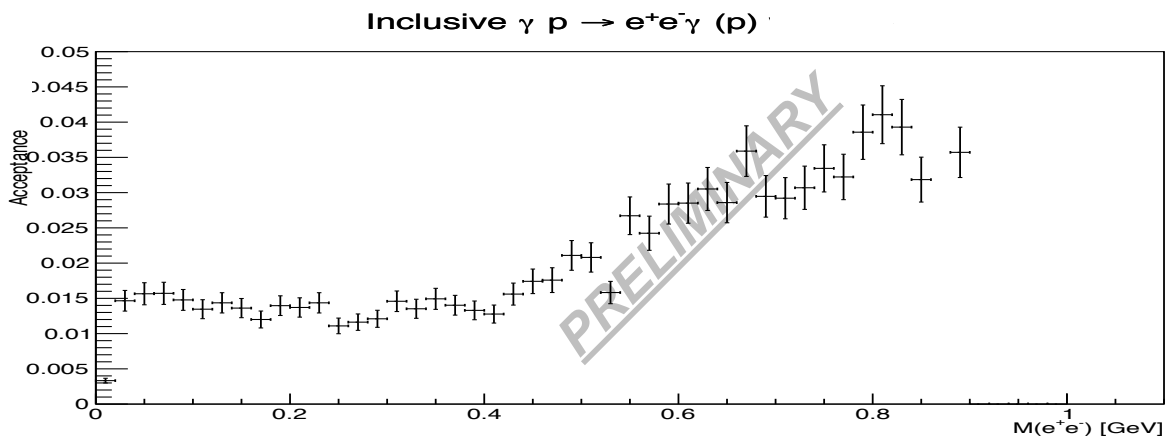


Fully Exclusive γp→η'p→ γe+e−p	Inclusive γp→η'(p)→ γe+e−(p)

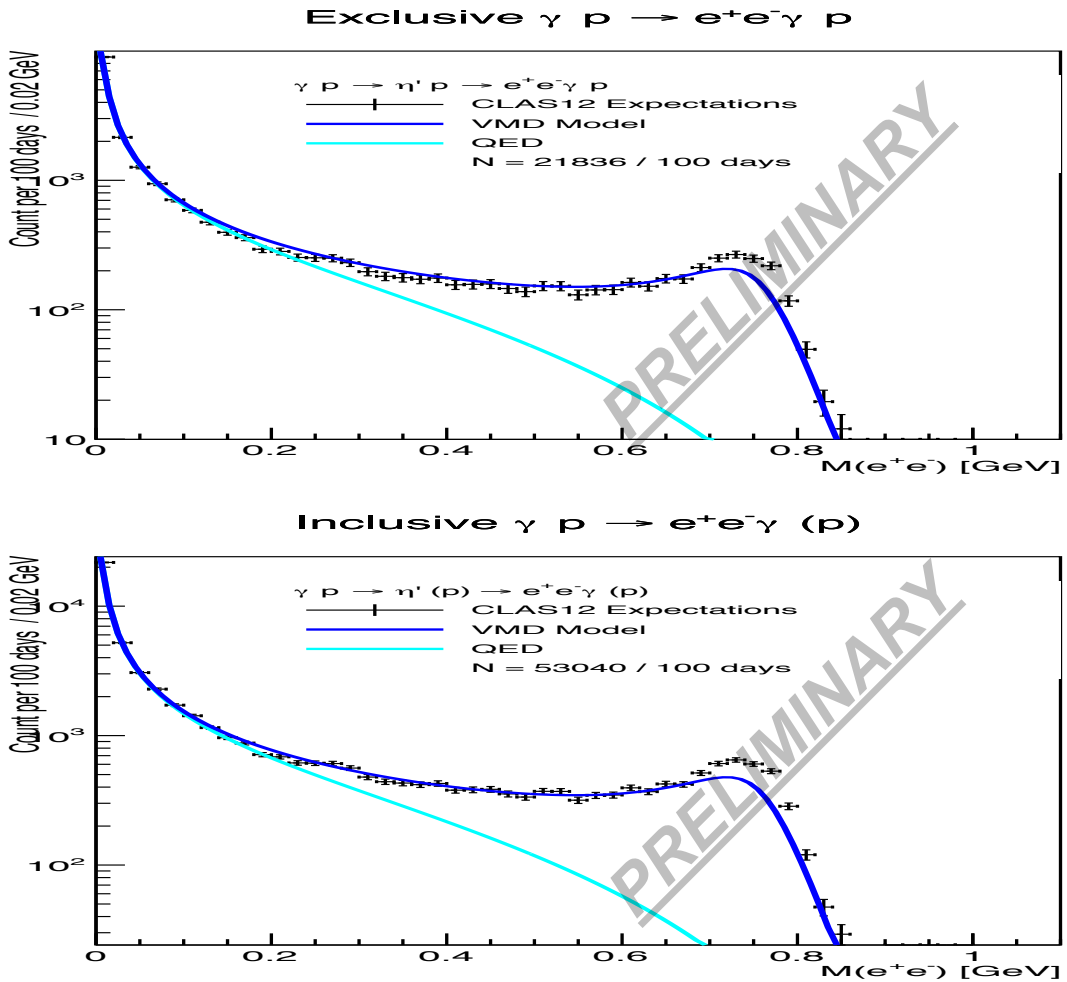
CLAS12 η' Acceptance

e^+e^- Acceptance





CLAS12 η' Rates



Within 100 days of beam-time CLAS can measure the η' transition form factor with a statistical uncertainty ~1%

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 CLAS12 data:
  - Hadron transition form factors.
  - Branching ratios of meson conversion decays.
  - Fundamental properties of hadrons
- Currently seeking applicant for PhD for η transition form factor measurement

END

Box Anomaly

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

$$\Gamma_0(s_{\pi\pi}) = \frac{1}{3\cdot 2^{11}\cdot \pi^3 M_\eta^3}\left(M_\eta^2 - s_{\pi\pi}\right)^3 s_{\pi\pi}\cdot\beta_\pi^3$$

$$\text{with } \beta_\pi = \sqrt{1-4M_\pi^2/s_{\pi\pi}}.$$

- the pion vector form factor can be approximated by the polynomial

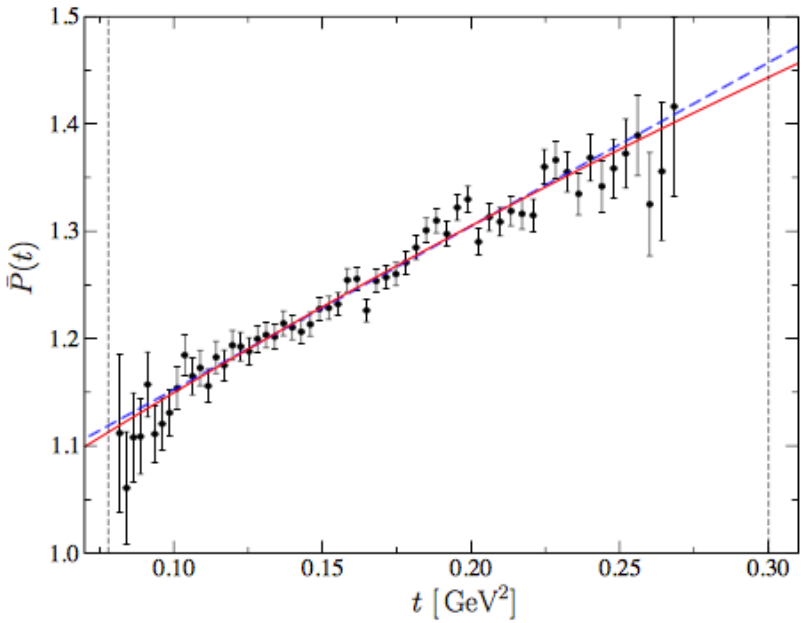
$$|F_V(s_{\pi\pi})| \approx 1 + (2.12\pm0.01)s_{\pi\pi} + (2.13\pm0.01)s_{\pi\pi}^2 + (13.80\pm0.14)s_{\pi\pi}^3$$

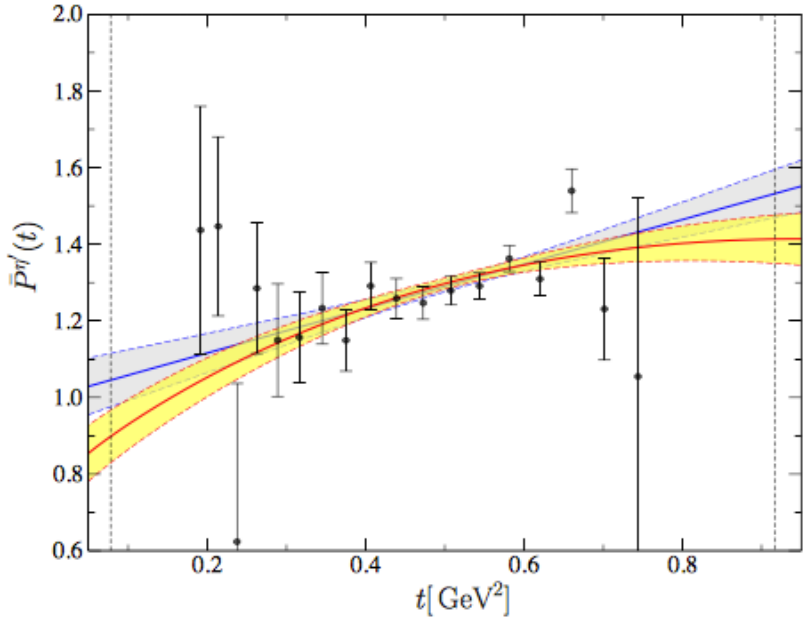
- Expansion around $s_{\pi\pi} = 0$ gives the process specific function

$$P(s_{\pi\pi}) = 1 + \alpha\cdot s_{\pi\pi} + \mathcal{O}(s_{\pi\pi}^2)$$

- from which α can be measured.

Recent Theory for η and η'





$\alpha_\Omega = (1.52 \pm 0.06)\,\mathrm{GeV}^{-2}$ with Omnes function instead of F_V

$\alpha_\Omega = (1.42 \pm 0.06)\,\mathrm{GeV}^{-2}$ with effect of a_2 vector meson exchange

[1]

$\alpha'_\Omega = (0.6 \pm 0.2)\,\mathrm{GeV}^{-2}$ from linear fits

$\alpha'_\Omega = (1.4 \pm 0.4)\,\mathrm{GeV}^{-2}$ from red curves

[1]Eur.Phys.J. C75 (2015) 6, 283

Light Meson Decays in CLAS

CLAS Approved Analysis (CAA)

CLAS Light Meson Decay (LMD) Program Institutional Contributors

- Old Dominion University, Norfolk, Virginia 23529
- Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg 188300, Russia
- INFN, Sezione di Genova, 16146 Genova, Italy
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- Florida State University, Tallahassee, Florida 32306
- University of South Carolina, Columbia, South Carolina 29208
- Arizona State University, Tempe, Arizona 85287-1504
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- Jülich Center for Hadron Physics, Forschungszentrum Jülich, 52425 Jülich, Germany
- Florida International University, Miami, Florida 33199
- Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606
- University of Glasgow, Glasgow G12 8QQ, United Kingdom
- Catholic University of America, Washington, DC 20064
- Institut für Experimentalphysik I, Ruhr Universität Bochum, 44780 Bochum, Germany
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- Norfolk State University, Norfolk, VA 23504, USA
- Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany

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

Sudeep Ghosh, Anki Roy;

IIT Indore

Motivation:

- Dalitz plot of $\eta' \to \pi^- \pi^+ \eta$ provides kinematic information of the decay, enabling the study of low energy dynamics of QCD.
- The $\eta' \to \pi^- \pi^+ \eta$ decay has a low Q-value due to relatively heavy decay products, thus helping to test the effective chiral Lagrangian theory
- $f(X,Y)=N \cdot (1+a(Y)+b(Y)^2 +c(X)+d(X)^2)$

Parameters	*VES*	*Theory*	*BESIII*	*Stat. err. in BESIII*	*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*	*...*	*+0.019±0.012*	*±0.011*	*±0.004*
d	*-0.082±0.019*	*+0.010±0.019*	*-0.073±0.013*	*±0.012*	*±0.004*

Future CLAS e+e- pair detection

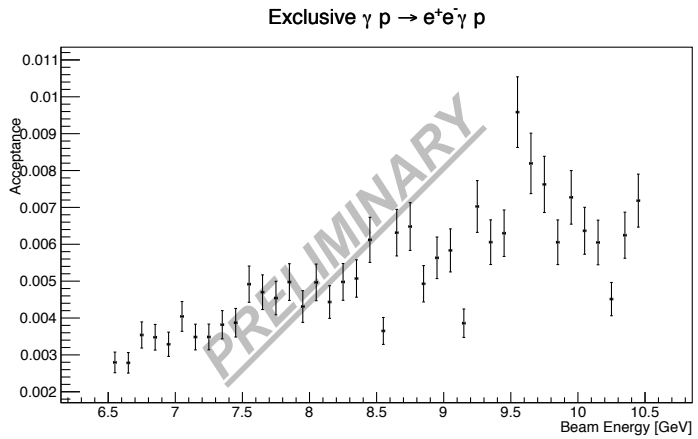
Studies of e+e- pair detection with CLAS is currently performed with intent for PAC proposal directed toward the measurements of transition form factors.

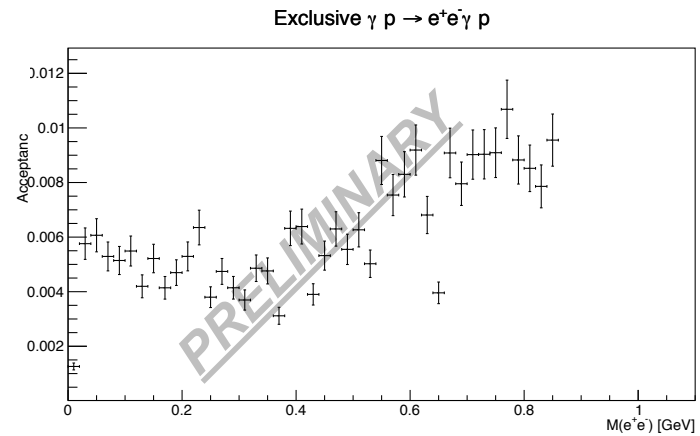
Using the new CLAS detector, including High Threshold Cherenkov Counters (HTCC), Low Threshold Cherenkov Counters (LTCC), Pre-Calorimeter (PCAL) and/or Electro-Magnetic Calorimeter (EC), $\xi(e^+e^-)/\xi(\pi^+\pi^-)$ can be ~ 10^9, while efficiency (ε) ~ 10^{-2}

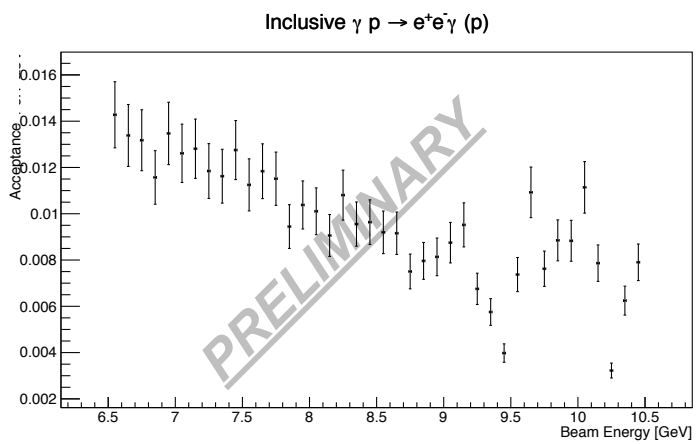
Combination	$\xi(e^+e^-)/\xi(\pi^+\pi^-)$	ε
HTCC/LTCC/PCAL/EC	10^{11}	~ 10^{-2}
HTCC/LTCC/PCAL	10^7	~ 1
HTCC/LTCC	10^5	~ 1
LTCC/PCAL/EC	10^8	~ 10^{-2}
LTCC/EC	10^6	~ 10^{-2}
HTCC/PCAL/EC	10^9	~ 10^{-2}

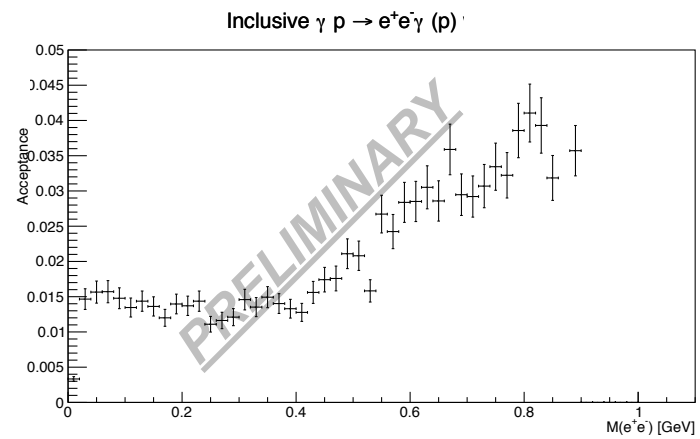
Future CLAS η' Acceptance

Beam Acceptance	e^+e^- Acceptance









Future CLAS η' Rates

$$N_{\eta' \to e^+e^-\gamma} = \epsilon \; \Phi \; \rho_t \; \frac{\Gamma_{\eta' \to e^+e^-\gamma}}{\Gamma_{total}} \; \sigma$$

ϵ is acceptance

$\frac{\Gamma_{\eta' \to e^+e^-\gamma}}{\Gamma_{total}}$ is the branching ratio of the Dalitz decay

Φ is flux

ρ_t is target areal density $[\mathrm{g/cm^2}] = (2. \; / \; 2.01588) \cdot 0.0717 \cdot 5$

σ is total cross-section