η’ Time-like Transition Form Factor with CLAS12

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The Standard Model (SM)

Important Questions:

- Prediction of the amount of matter that survived annihilation after the Big Bang
  - many orders of magnitude less that what is observed.
- Masses of particles are parameters in SM.
  - SM does not provide understanding why values of masses span many orders of magnitude
- Within SM, phenomena like Dark Matter and Dark Energy cannot be explain.
- Many more issues that suggest physics beyond SM
  - Currently a promising candidate to provide a signal for physics beyond SM is the muon anomaly ($a_\mu = (g - 2)/2$).

The muon anomaly ($a_\mu = (g - 2)/2$)

- Low energy observable
  - Can be measured and computed to high precision
  - Present value $a_\mu = 1\,165\,920\,89\,(63) \times 10^{-11}$ [1]
  - Deviates from prediction by ~3σ, depending on how the leading-order hadronic contributions are evaluated
    - $\Delta a_\mu = (287 \pm 80) \times 10^{-11}$
    - $\Delta a_\mu = (261 \pm 18) \times 10^{-11}$
  - Deviation not large enough to claim failure of the SM
    - Currently the largest deviation of a SM prediction from what is experimental observed
  - Largest uncertainty arise from the hadronic quantum corrections
    - Hadronic vacuum polarization (HVP)
    - Hadronic light-by-light scattering (HLbL)

[2]: Bennett, G.W. Phys. Rev., D73:072003, 2006

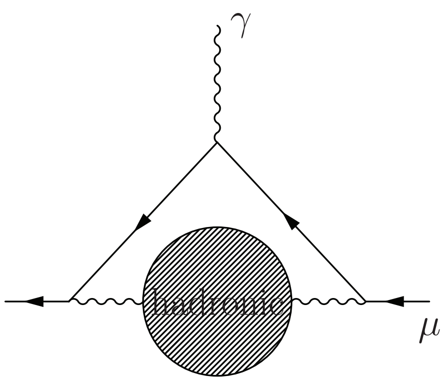
HVP and HLbL

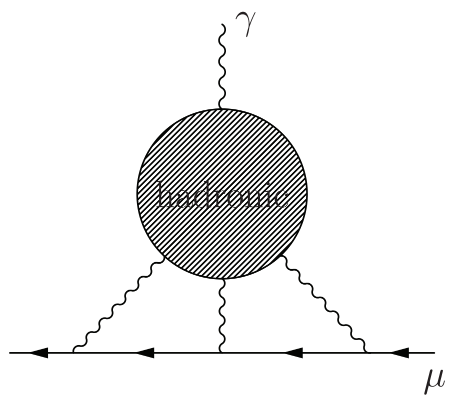
Contribution	$a_\mu \times 10^{11}$
QED (leptons + photons)	116 584 718.853 $\pm$ 0.036
Electroweak	153.6 $\pm$ 1.0
HVP: LO	6907.5 $\pm$ 47.2
NLO	-100.3 $\pm$ 2.2
NNLO	12.4 $\pm$ 0.1
HLbL	116 $\pm$ 40
NLO	3 $\pm$ 2
Theory (SM)	116 591 811 $\pm$ 62
Experiment	116 592 089 $\pm$ 63
Experiment - Theory (3.1 σ)	278 $\pm$ 88

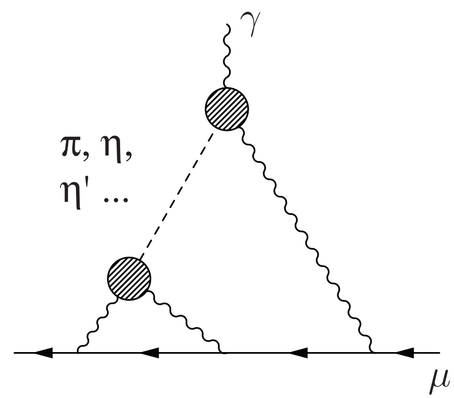
- Contributions to the muon g - 2 (Table source [2])

[2]: Nyffeler, A. arXiv:1602.03398, 2016

HVP and HLbL







- Hadronic contributions to a_μ:
  - Hadronic Vacuum Polarization (HVP) (left)
  - Hadronic light-by-light (HLbL) (middle)
  - Pion-pole contribution to HLbL (right)

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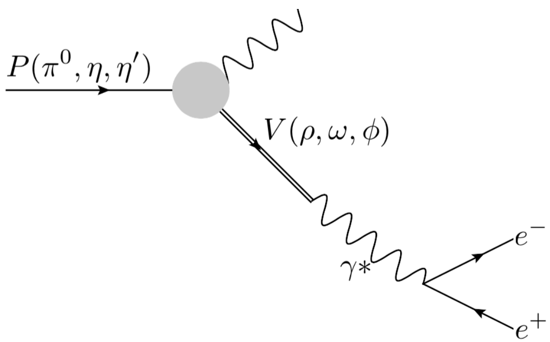
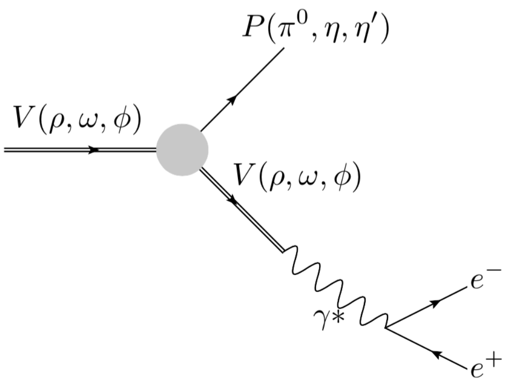
One approach quantify the hadronic corrections

- HLbL correction can be improved by measuring the space-like transition form factor at low-to-moderate momenta
  - not available at Belle / BaBar energies
- Low-to-moderate momenta is available with time-like transition form factors
- Use dispersion relations to link space-like to time-like
- Measure the time-like transition form factor
  - Using photo-production $\gamma p \rightarrow pX \rightarrow p\gamma^*\gamma \rightarrow pe^+e^-\gamma$
  - Using electro-production $ep \rightarrow e'pX \rightarrow e'p\gamma^*\gamma \rightarrow e'pe^+e^-\gamma$
- Improvements to the π^0, η, η' TFF can improve precision of the HLbL correction by 14%, 23%, 15% respectively [2].

Time-Like Transition Form Factors

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





Additional Motivation:

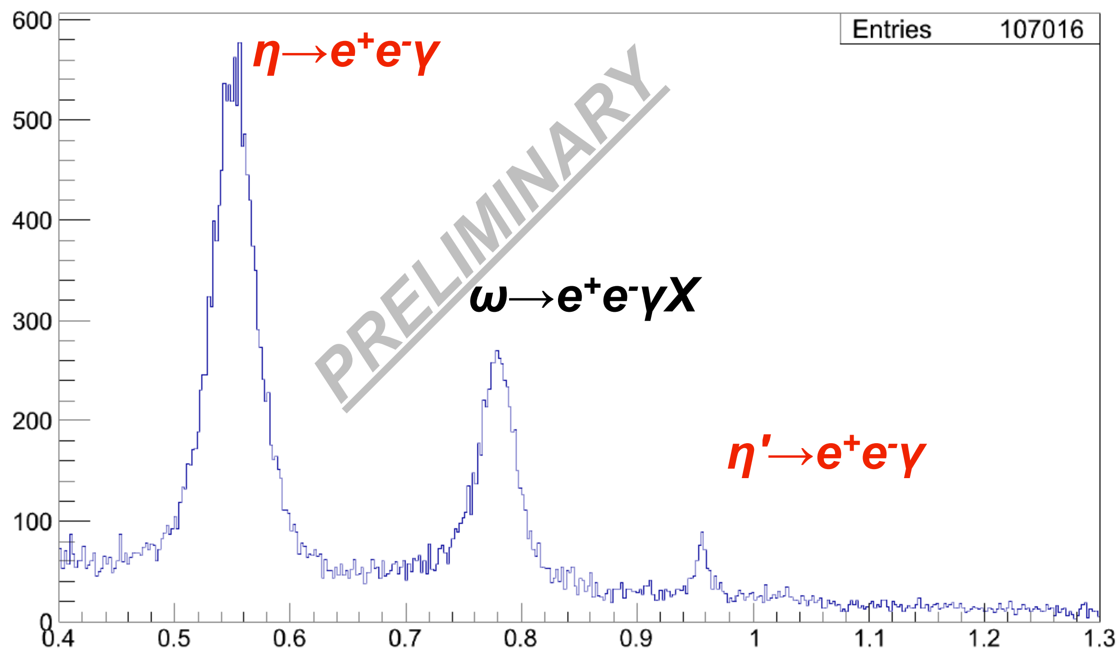
- In the VMD model the transition form factors provides insight into the meson charge radius, $\langle \mathrm{r} \rangle$.
- For pseudoscalar mesons η and η', ratio of form factors provides information on mixing angle.
- For vector meson ω there currently exist discrepancy in the measurement of the form factor with VMD model.

Transition Form Factors in CLAS

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

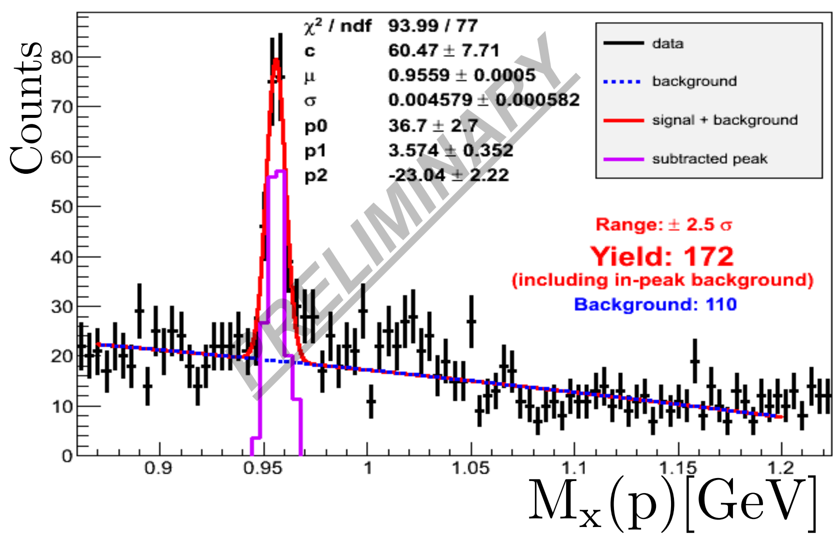
$$\langle \mathrm{r}\rangle = \frac{dF}{dq^2}\Big|_{q^2=0}$$

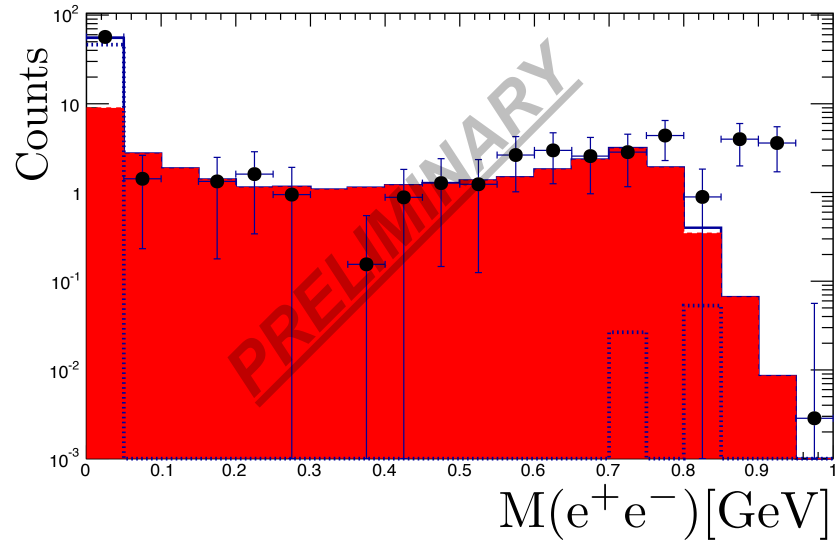
$$\frac{d\Gamma_{P_{P\to l^+l^-\gamma}}}{dq^2\,d\Gamma_{P_{P\to\gamma\gamma}}}\Big|_{\mathrm{measured}} = \frac{d\Gamma_{P_{P\to l^+l^-\gamma}}}{dq^2\,\Gamma_{P\to\gamma\gamma}}\Big|_{\mathrm{Q.E.D}}\left|F(q^2)\right|^2$$



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

η’ Transition Form Factors and Branching Ratio with CLAS





BESIII reports BR Γ(η′→γe+e−)/Γ(η′→γγ) is measured to be (2.13±0.09(stat.) ±0.07(sys.))×10^{-2} from 864 events [1]

CLAS preliminary reports BR Γ(η′→γe+e−)/Γ(η′→γγ) is consistent with BESIII from 172 events

First estimate from cut based analysis

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

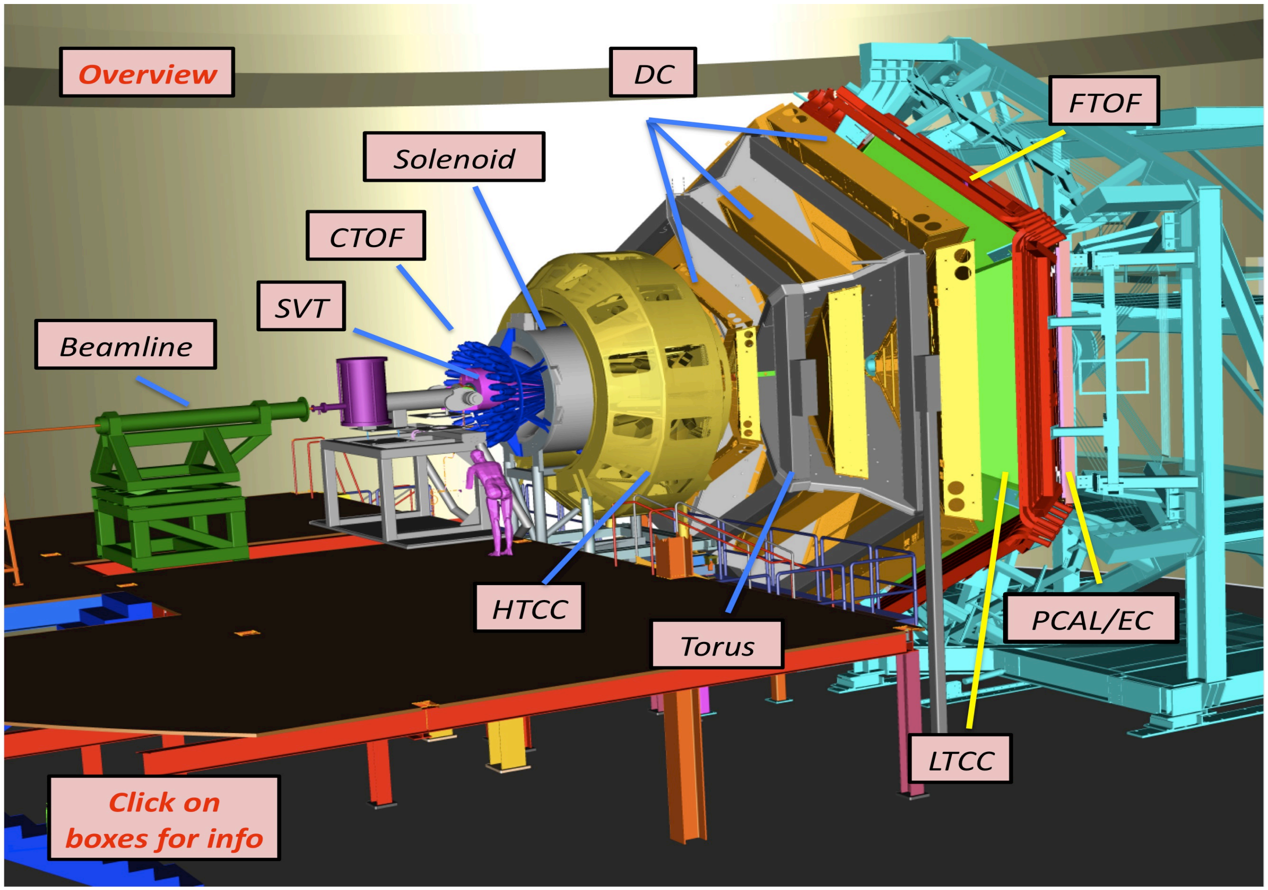
Current status of η’ charge radius

Current BESIII and CLAS data sets do not have enough statistics to determine which theoretical model fits the η′→ charge radius. 10% difference in theoretical approaches	
$\langle r \rangle$	Measurement (M) /Prediction (P)
CLAS (η′→γe+e−)	TBD
BESIII (η′→γe+e−)	(M) 1.60 ± 0.17(stat) ± 0.08(sys) GeV^{-2} [1]
CELLO (η′→γμ+μ−)	(M) 1.7 ± 0.4 GeV^{-2} [2]
Dispersion	(P) $1.53^{+0.15}_{-0.08}$ GeV^{-2}
ChPT	(P) 1.6 GeV^{-2}
VMD	(P) 1.45 GeV^{-2}

10% difference in theoretical approaches!
10% in statistical error for measurements!

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

CEBAF Large Acceptance Spectrometer (CLAS12)



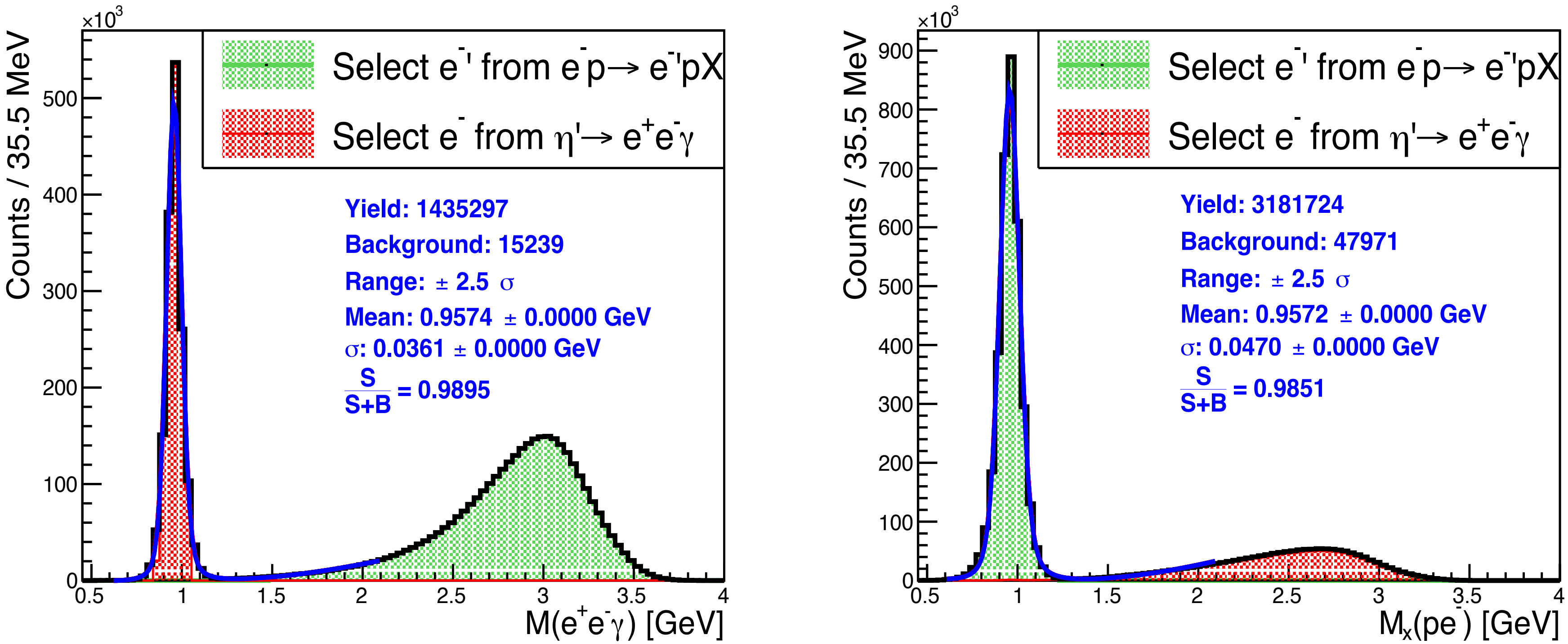
CLAS12

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

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

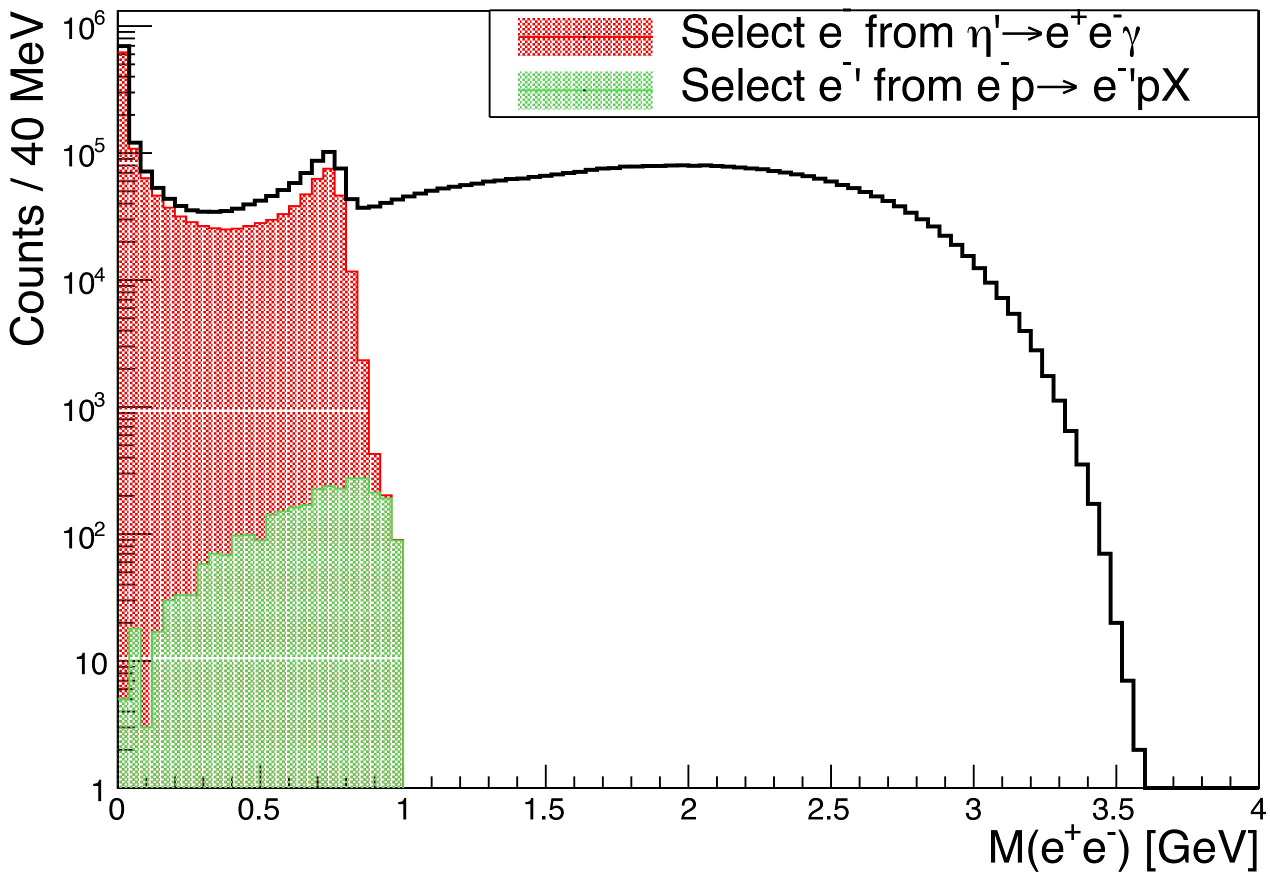
Reconstruction of $pe^+e^-\gamma(X)$ with FastMC

$ep \to pX(e^-) \to pe^+e^-\gamma(e^-)$



Contamination from combinatorics from wrong electron is minimized with isolating exclusive η' via invariant mass of $e^+e^-\gamma$

CLAS12 η' acceptance in electro-production

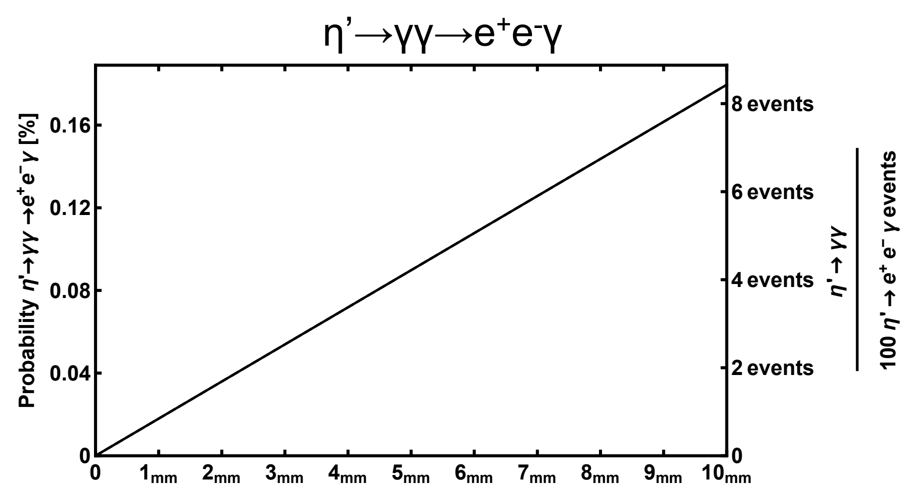


Contamination from combinatorics from wrong electron ~ 1/1000 while isolating exclusive η' via invariant mass of $e^+e^-\gamma$

e^+e^- events from external conversions

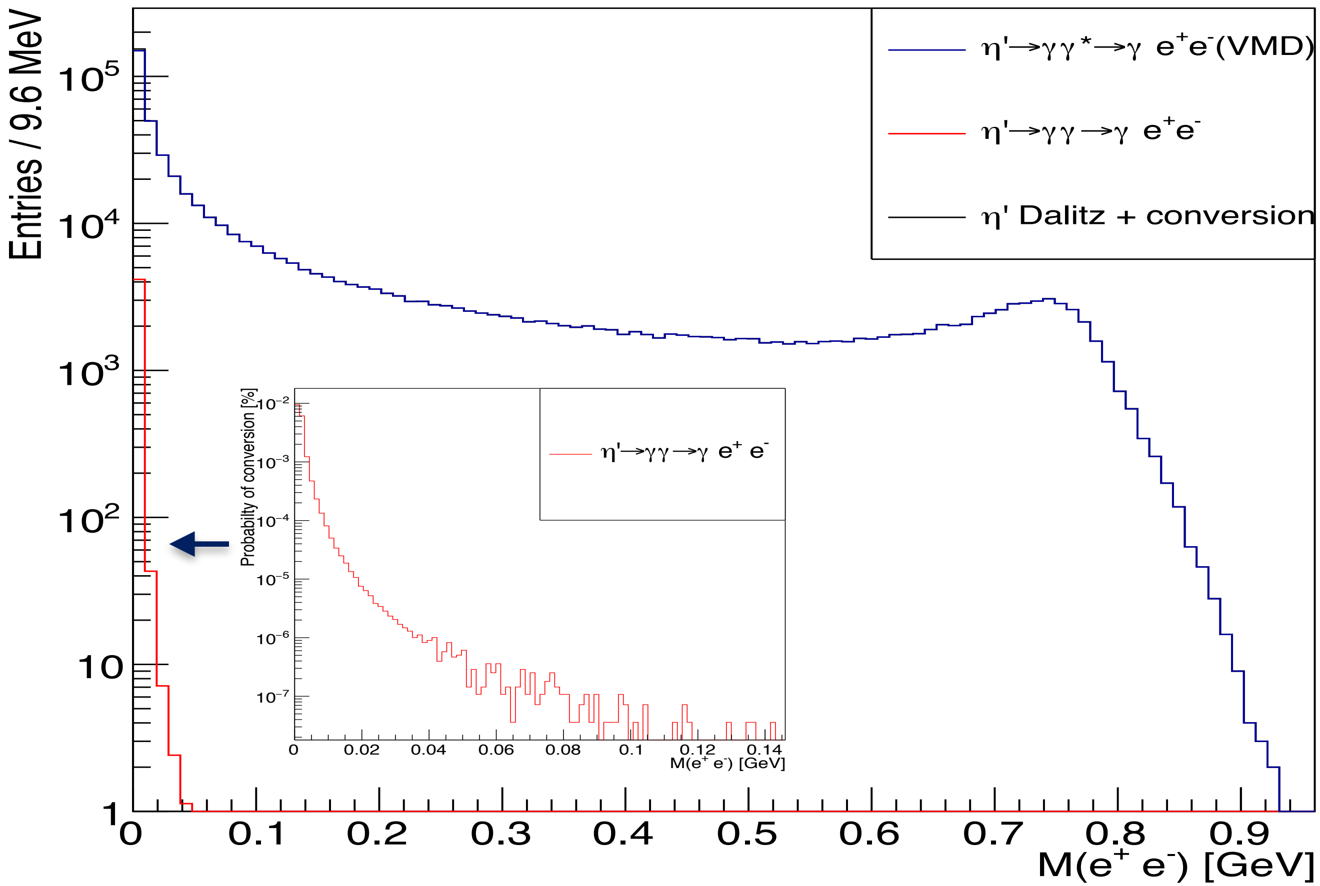
- When a photon travels through matter at energies greater than 100 MeV, it can convert into an electron-positron pair via $\gamma Z \to Z e^+ e^-$.
  - $\sigma_{\gamma \to e^+e^-} = \dfrac{A}{N_A \rho \lambda_\gamma}\ ,\ \lambda_\gamma = \dfrac{9}{7} X_0$
  - $\dfrac{dP}{dx} = \dfrac{1}{\lambda_\gamma} \exp(\dfrac{-x}{\lambda_\gamma})$

$$\frac{\Gamma_{\eta' \to e^+e^-\gamma}}{\Gamma_{\eta' \to \gamma\gamma}} = 2.13 \cdot 10^{-2}$$



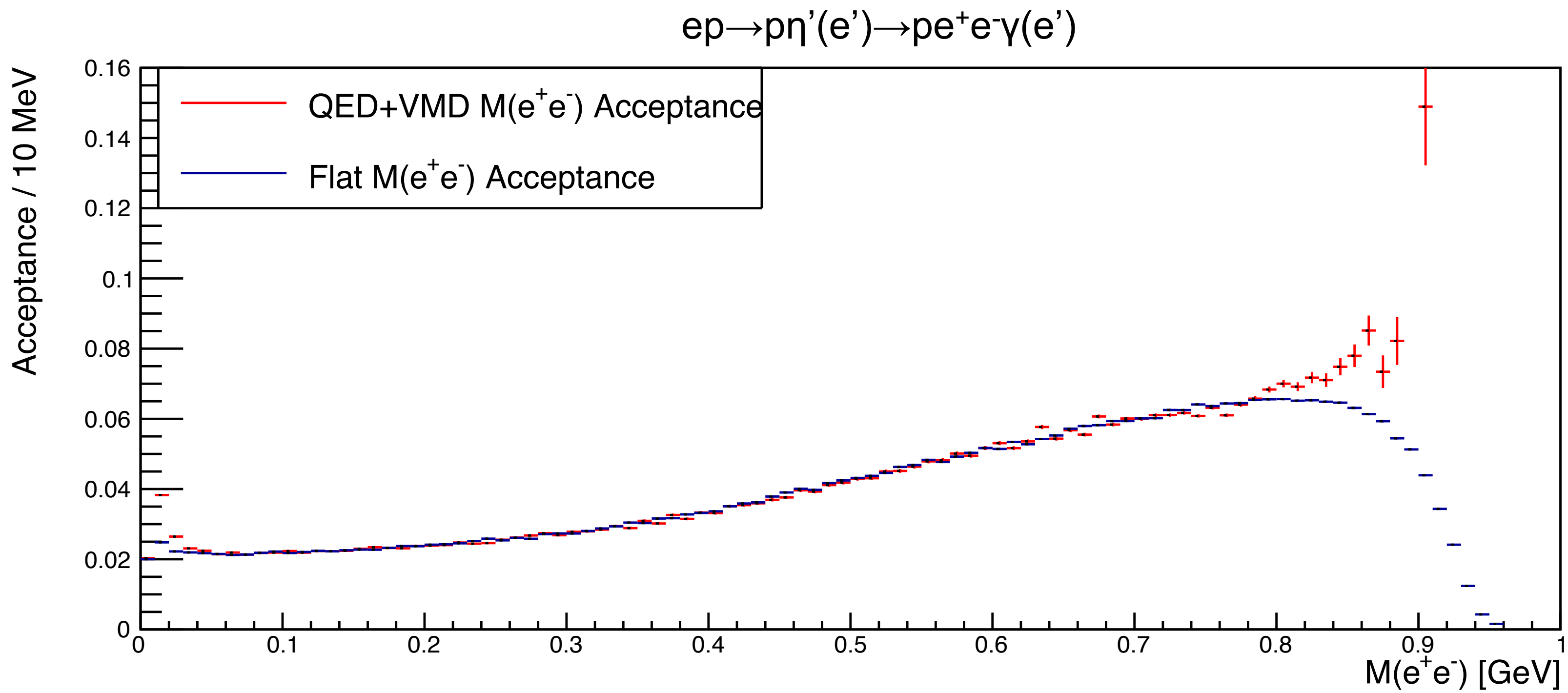
e^+e^- contamination from external conversion within 1mm of the target is ~ 1 $\eta' \to \gamma\gamma \to e^+e^-\gamma$ per 100 Dalitz $\eta' \to e^+e^-\gamma$, but moreover....

e^+e^- events from external conversions



The e^+e^- contamination from external conversions is only at low e^+e^- masses!!!

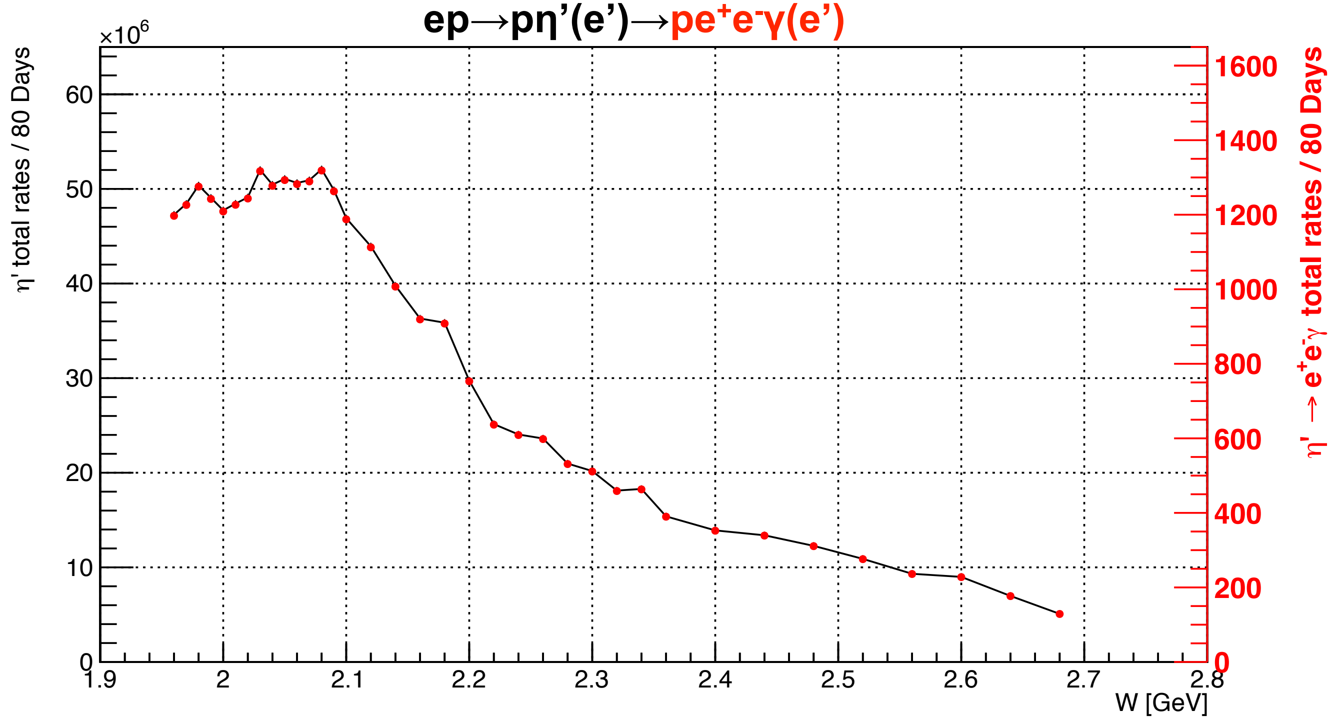
CLAS12 η' acceptance in electro-production



The acceptance for the area of interest is independent on model used to extract acceptance!

CLAS12 η' Rates with electro-production

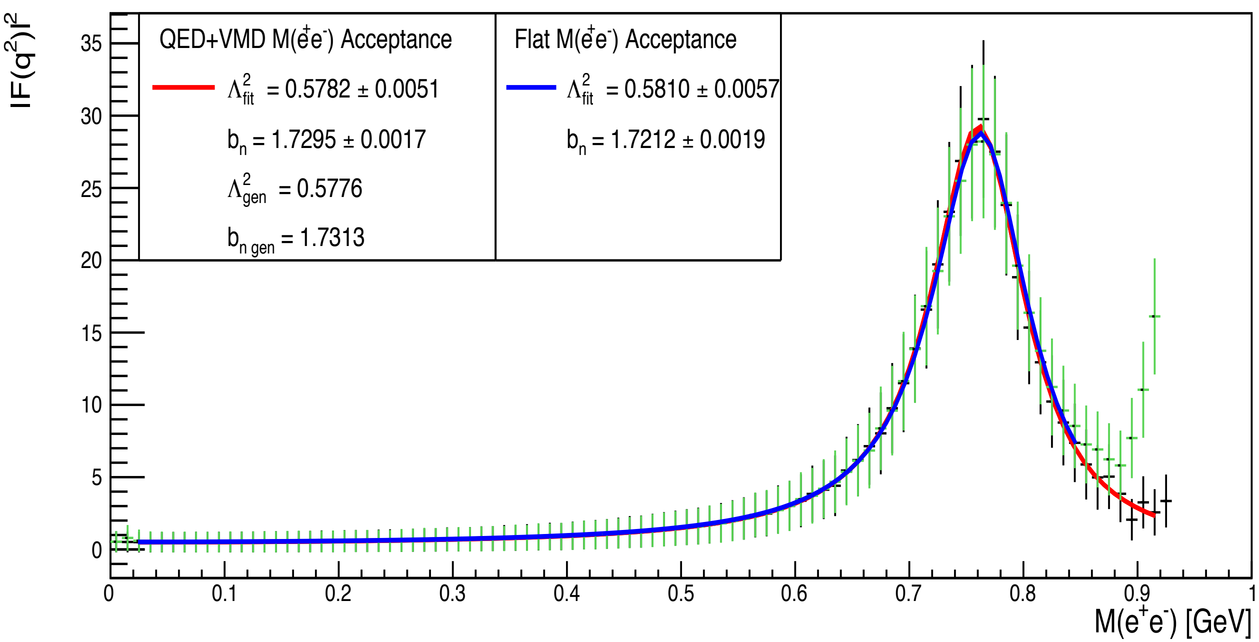
- Using standard CLAS12 electron trigger ((HTCC(Nphe>2) * [(PCAL+EC)>1.0 GeV]) to trigger on Dalitz leptons.
- The rate for mesons in electro-production where the scattered electron is left undetected (W=1.9-2.7~GeV) is ~ 80kHz[Sargsyan].



Within 80 Days of beam-time the amount of expected events recorded ~28,000
35 times more than the current measurement by BESIII!

CLAS12 η’ TFF measurement

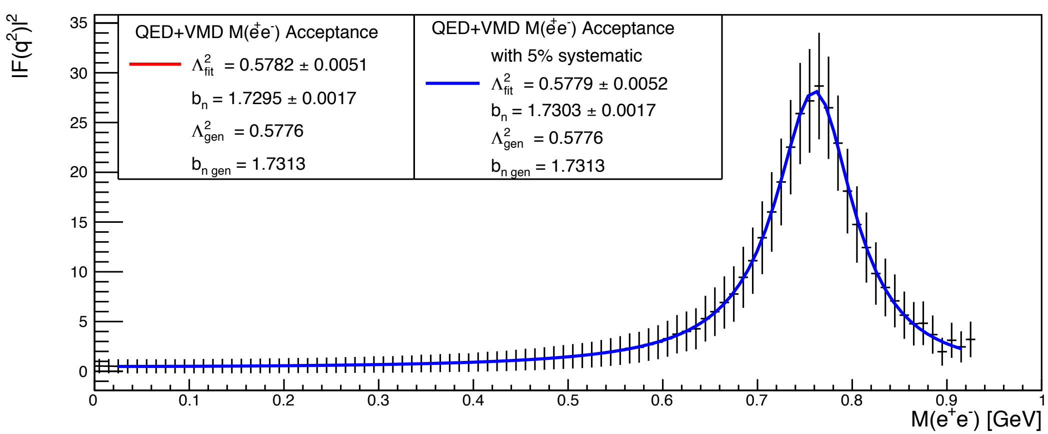
- Using the dipole approximation for the slope of the Transition form factor
  - $F(q^2) = \dfrac{1}{1 - q^2/\Lambda^2}$
    - Λ is the mass for the effective contributing vector meson



Within 80 days of beam-time CLAS can measure the η’ transition form factor with a statistical uncertainty ≲0.5%

Possible systematic uncertainty and other backgrounds

- Sources of background for e^+e^- pairs
  - Bethe-Heilter and Time-Like Comption scattering
    - Minimized from γ reconstruction in final state
  - $\pi^+\pi^-$ contamination
    - Minimized from lepton PID with HTCC+PCAL+EC
- Sources of systematics for e^+e^- pairs
  - e^+e^- Acceptance
    - Estimated systematic on Λ ~0.51%



A CLAS Proposal for PAC44

Transition Form Factor of the η' Meson with CLAS12

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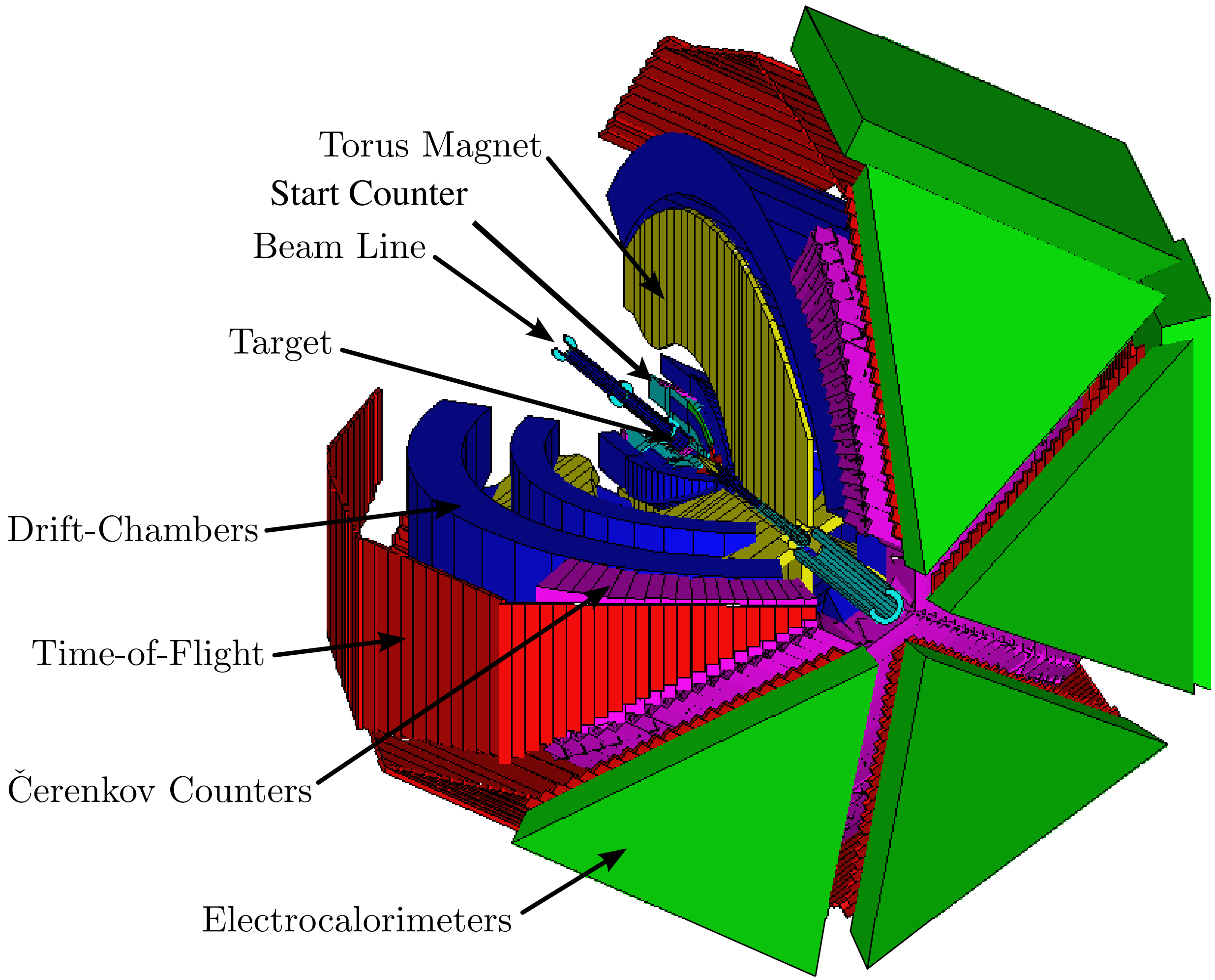
Currently waiting PAC review

Summary

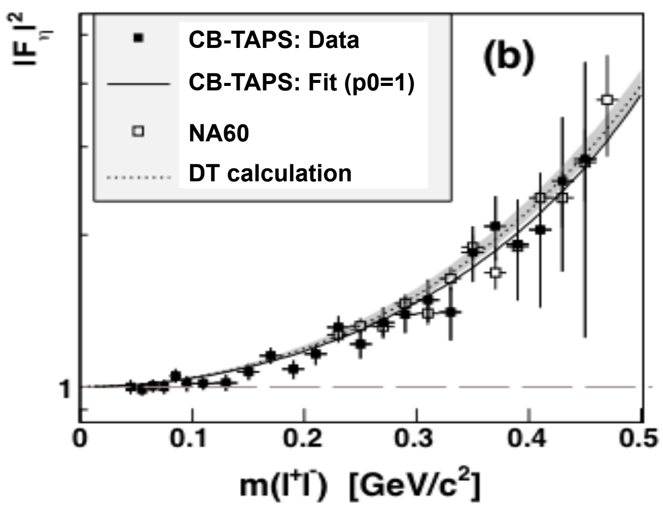
- Muon anomaly is a useful test in the SM
- Future CLAS data will provide data sets with statistics to accurately measure transition form factors (≲0.5% for η').
- Compared to current experimental uncertainties of 10% and differences in theoretical approaches of~ 10\%;
    - CLAS12 would not only be in the position to decisively discriminate between the theoretical predictions, but also pin down one of the largest uncertainties to the muon g-2 anomaly.

BACK UP

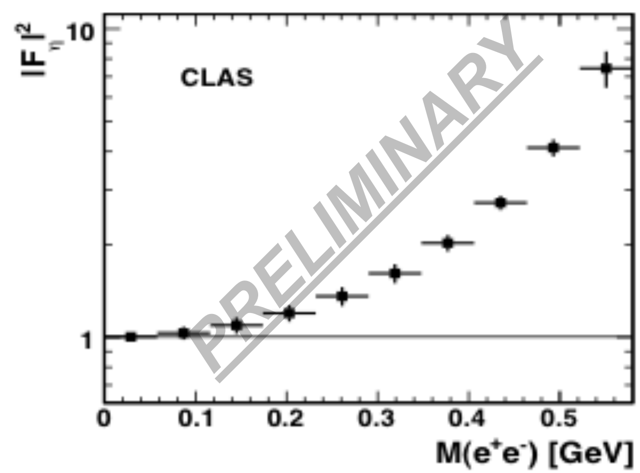
CEBAF Large Acceptance Spectrometer (CLAS)



η Transition Form Factors

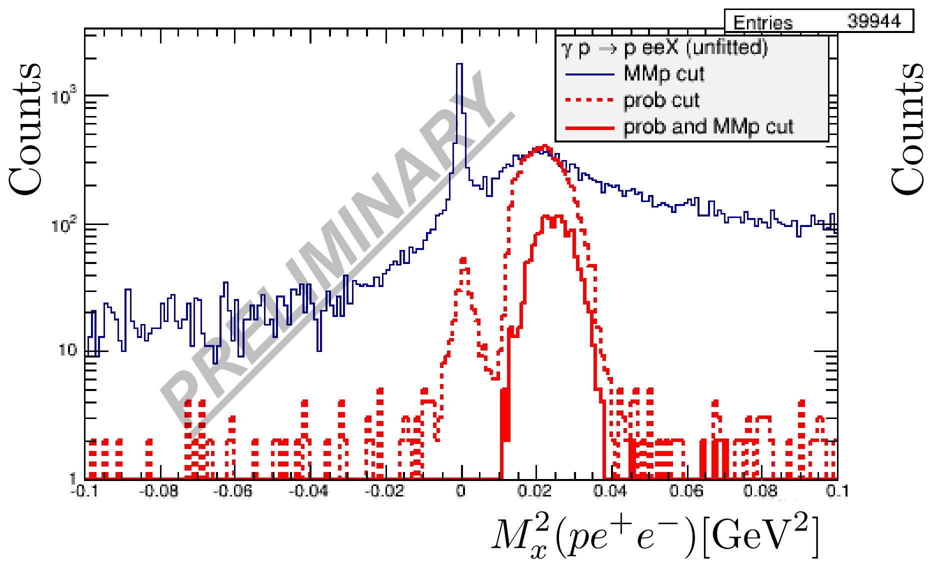


Recent results the η transition form factor with errors. Image Source: Phys. Rev. C 89, 044608

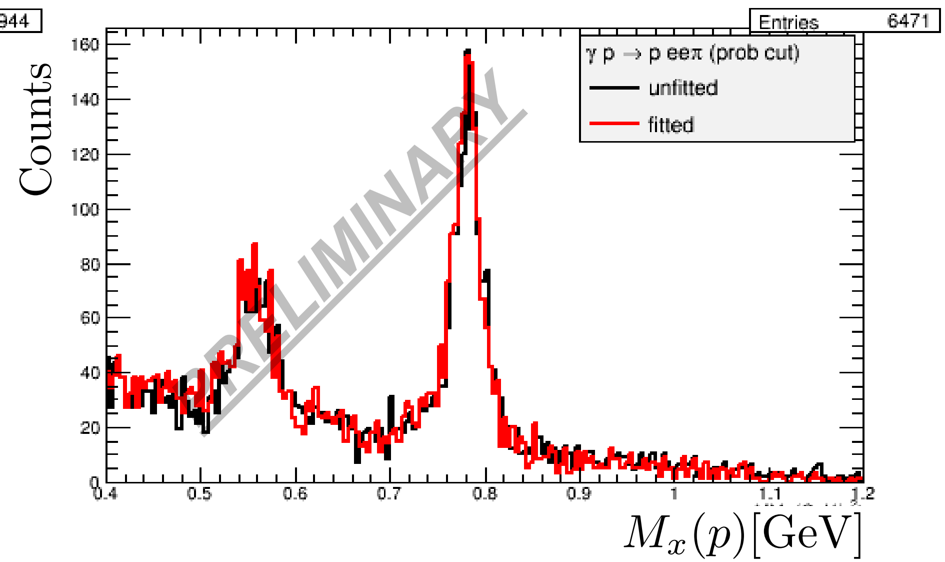


CLAS projected errors on η transition form factor

ω Transition Form Factor in CLAS

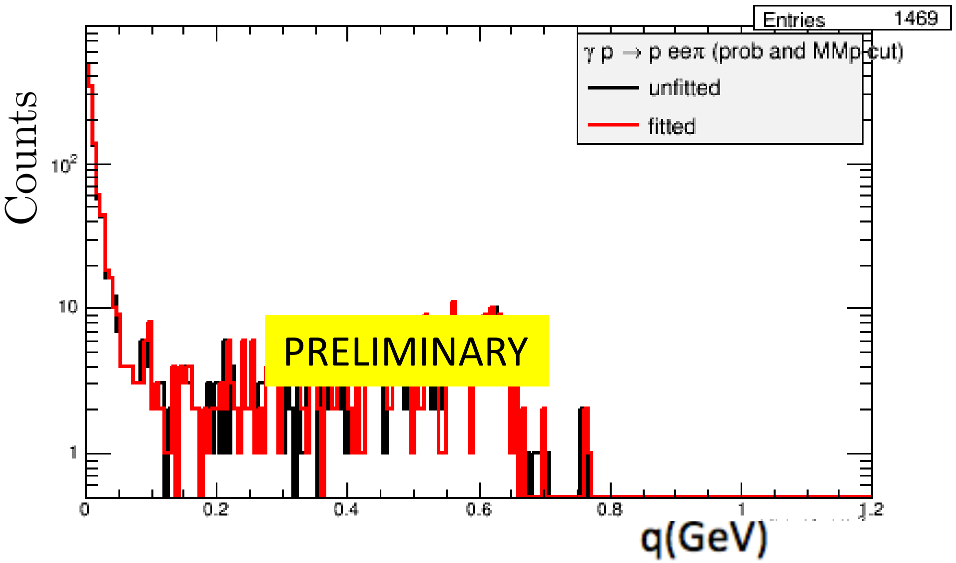


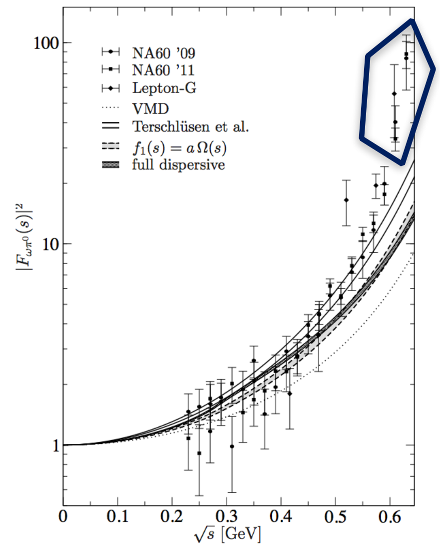
CLAS data yield from γp→pX with
$M^2_x(pe^+e^-) = M^2_{\pi 0} \pm 0.01$ GeV^2



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

ω Transition Form Factor in CLAS





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

Future CLAS 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
$\eta' \to \gamma e+e-$	$\Delta \to N e+e-$
$\omega \to \pi^0 e+e-$	$\Lambda \to n e+e-$ $\Lambda(1520) \to \Lambda e+e-$
$\Phi \to \eta e+e-$	
$J/\psi \to \pi^0 e+e-$	$\Sigma^0 \to \Lambda e+e-$ $\Sigma^+ \to p e+e-$

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

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