

Measuring the charged pion polarizability in the $\gamma\gamma \rightarrow \pi^+\pi^-$ reaction

David Lawrence, JLab

Rory Miskimen, UMass, Amherst

Elton Smith, JLab

Motivation

- Electro (α_π) and Magnetic (β_π) Polarizabilities represent fundamental properties of the charged pion in the low-energy sector of QCD
- α_π and β_π are related to the charged pion weak form factors F_V and F_A :

$$\alpha_\pi = -\beta_\pi = \frac{4\alpha_{EM}}{m_\pi F_\pi^2} (L_9^r + L_{10}^r) \propto \frac{F_A}{F_V}$$

where the low-energy constants L_{10}^r and L_9^r are part of the Gasser-Leutwyler effective Lagrangian

- Measuring the polarizabilities of the charged pion can be used to test the even-parity part of the Chiral Lagrangian
(as opposed to the odd-parity sector which is tested via anomalous processes such as $\pi^0 \rightarrow \gamma\gamma$)
- Improved measurement of $\alpha_\pi - \beta_\pi$ would reduce uncertainty contribution of hadronic light-by-light scattering to SM prediction of anomalous magnetic moment of the μ : $(g_\mu - 2)/2$
(see K. Engel, H. Patel, M. Ramsey-Musolf, *arXiv:1201.0809v2 [hep-ph]*
and *arXiv:1309.2225 [hep-ph]*)

- **LO $O(p^4)$ ChPT calculations give:**

$$\alpha_\pi - \beta_\pi = 5.6 \pm 0.2 \times 10^{-4} \text{ fm}^3$$

with

$$\alpha_\pi + \beta_\pi = 0.0 \text{ fm}^3$$



Donoghue and Holstein, 1989

- **NLO $O(p^6)$ corrections are relatively small**

$$\alpha_\pi - \beta_\pi = 5.7 \pm 1.0 \times 10^{-4} \text{ fm}^3$$

with

$$\alpha_\pi + \beta_\pi = 0.16 \pm 0.1 \times 10^{-4} \text{ fm}^3$$



*Bürgi 1996,
Gasser et al. 2006*

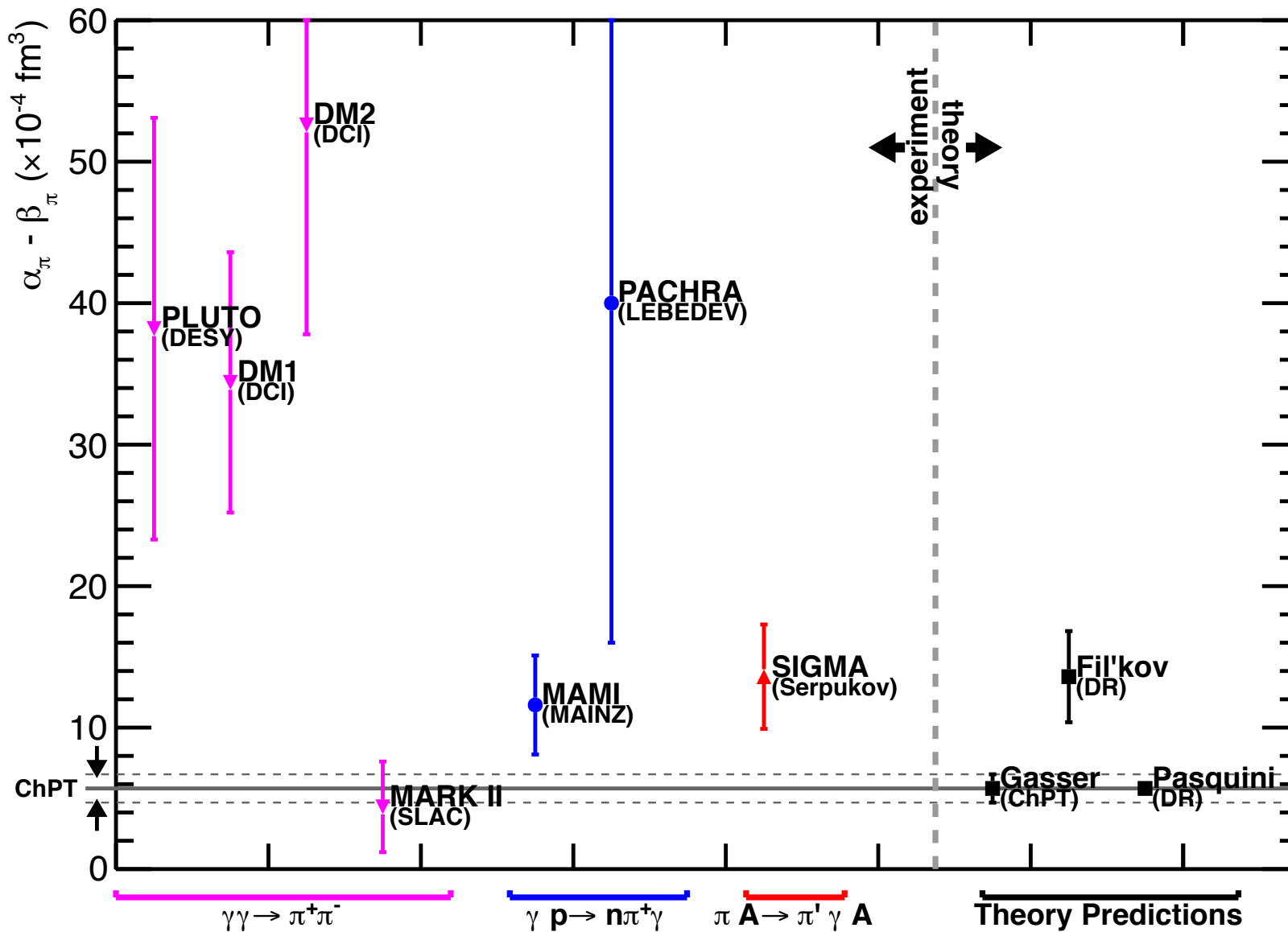
- **Dispersion Relations have been used to as well, but do not agree:**

$$\alpha_\pi - \beta_\pi = 13.0^{+2.6}_{-1.9} \times 10^{-4} \text{ fm}^3$$

*Fil'kov et al. 2006**

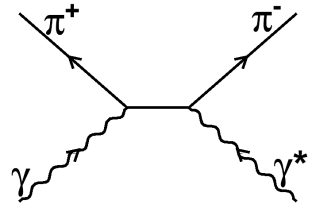
$$\alpha_\pi - \beta_\pi = 5.7 \times 10^{-4} \text{ fm}^3$$

Pasquini et al. 2008

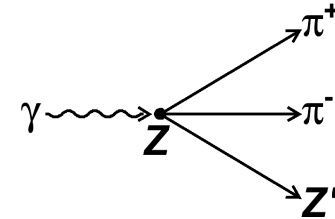


Experimental Access

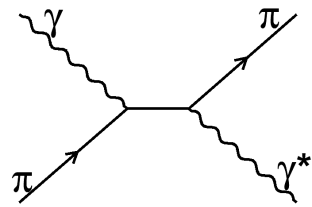
Primakoff effect



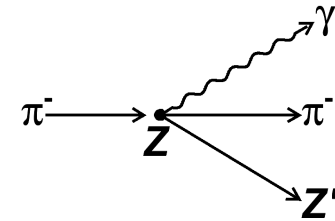
=



This experiment

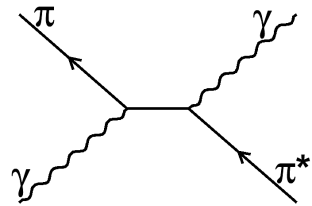


=

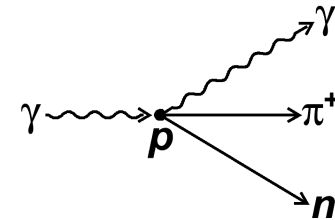


SIGMA

Radiative pion photo-production

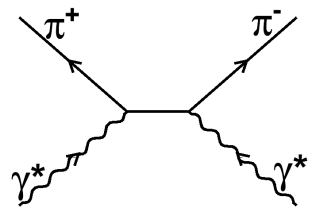


=

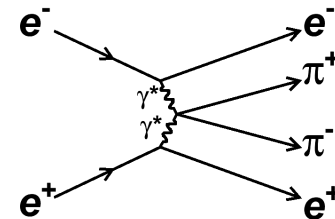


*MAMI
PACHRA*

Light by light scattering
(by crossing symmetry)

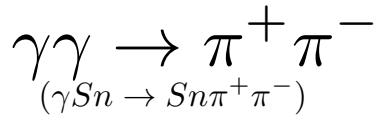


=

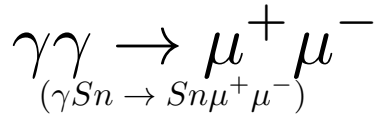


*PLUTO
DM1
DM2
MARK-II*

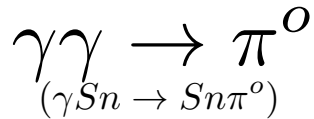
Experimental Setup



Signal reaction

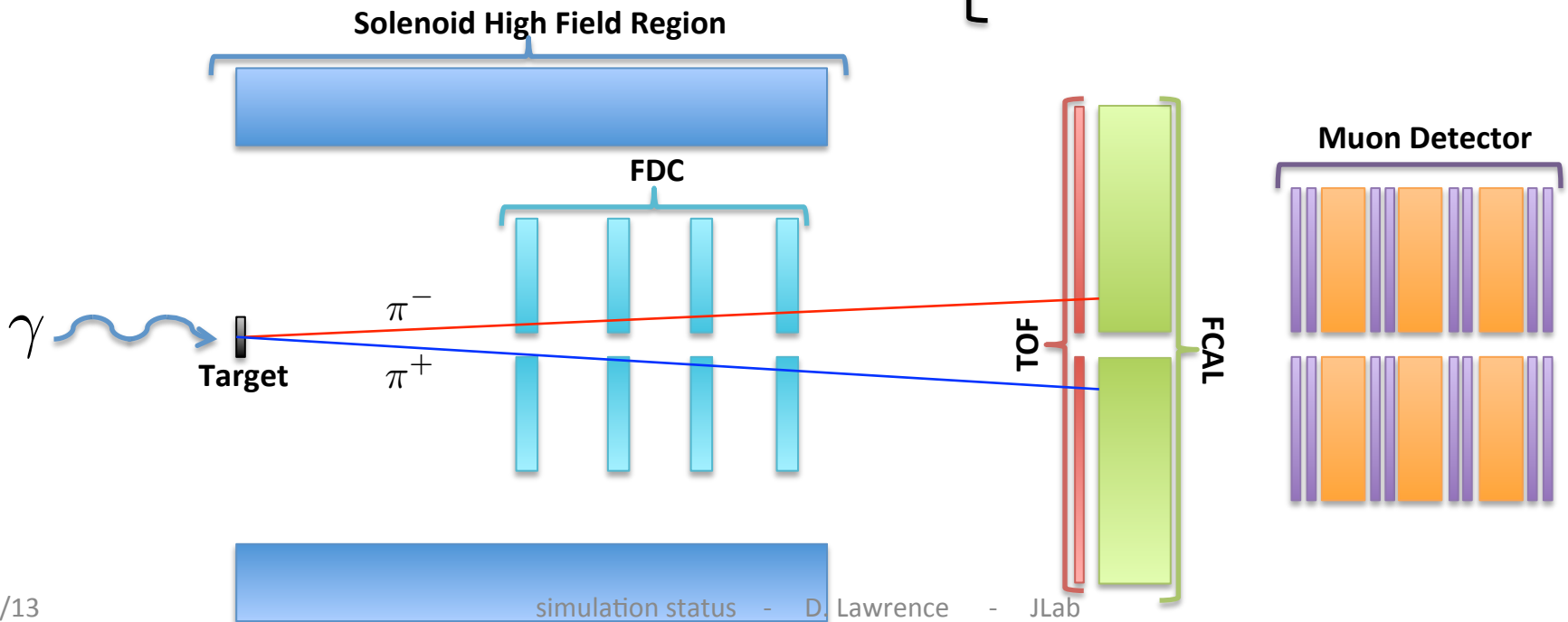


Normalization



Beam polarization

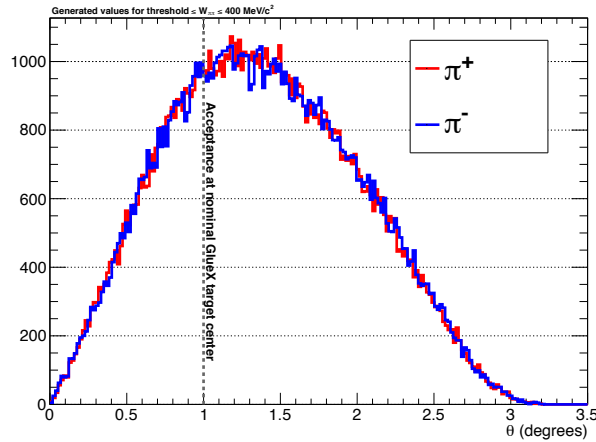
- All occur via the Primakoff effect (interaction with the Coulomb field of nucleus)
- All result in very forward going particles
- Low t ($-t < 0.005 \text{ GeV}^2$)



Kinematics of Experiment

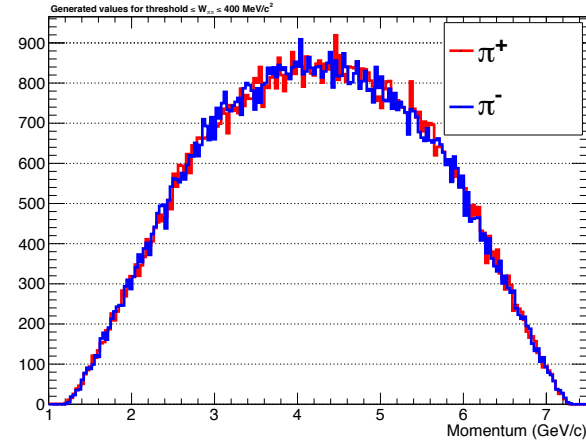
π^\pm polar angle distribution in lab frame

August 3, 2012 DL



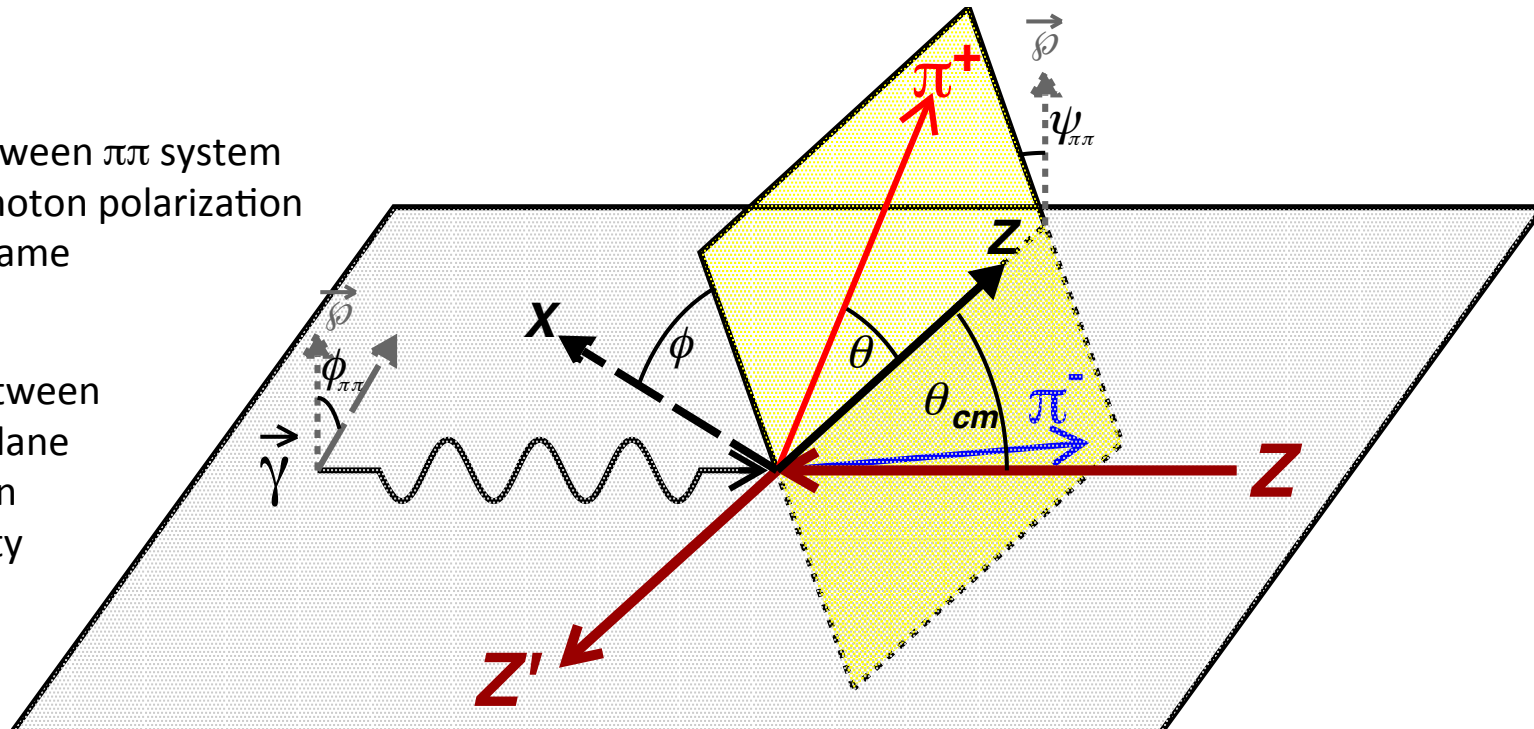
π^\pm momentum distribution in lab frame

August 3, 2012 DL



$\phi_{\pi\pi}$ is angle between $\pi\pi$ system and incident photon polarization vector in CM frame

$\psi_{\pi\pi}$ is angle between $\pi\pi$ scattering plane and polarization vector in helicity frame



Backgrounds

- Experiment will measure reaction:



- Primary backgrounds will be:

- coherent ρ^0 production followed by $\rho \rightarrow \pi\pi$ decay

- Will use angular distributions to separate Primakoff from coherent ρ^0 production (*see later slides*)

- Electromagnetic $\mu^+\mu^-$ production

- Will use dedicated detector to identify hadron showers

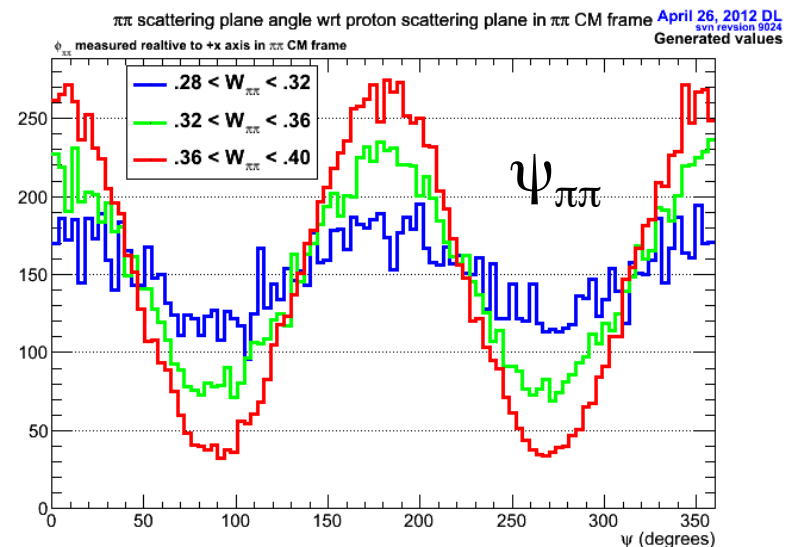
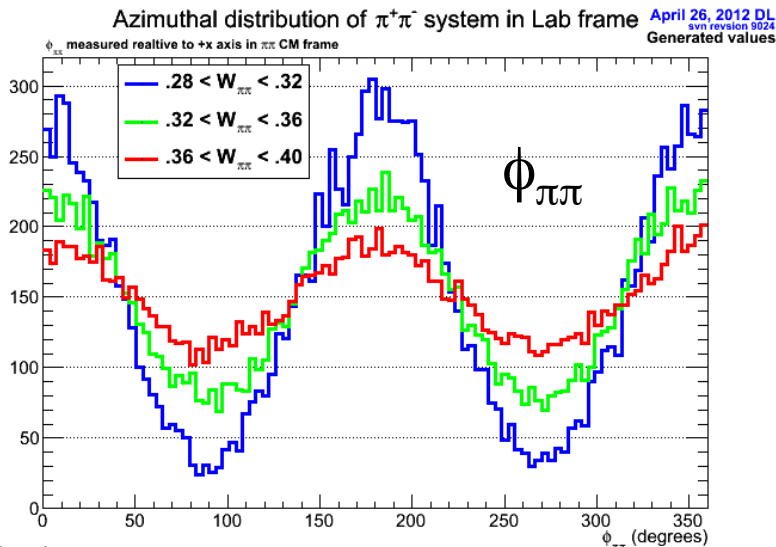
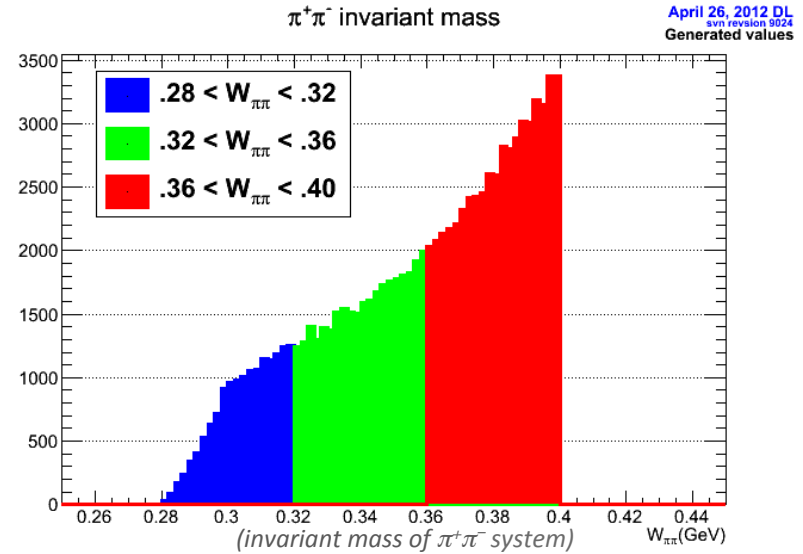
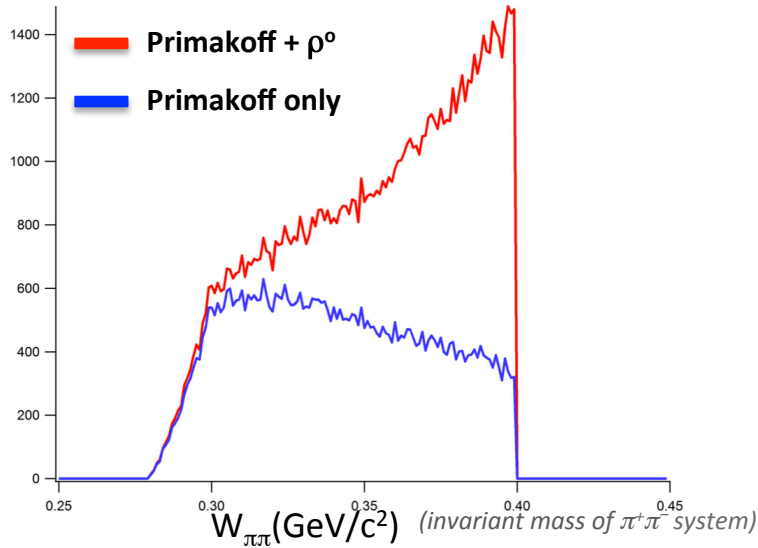
- Other potentially relevant backgrounds include:

- σ meson production (*angular distributions same as Primakoff*)

- incoherent $\pi^+\pi^-$ production

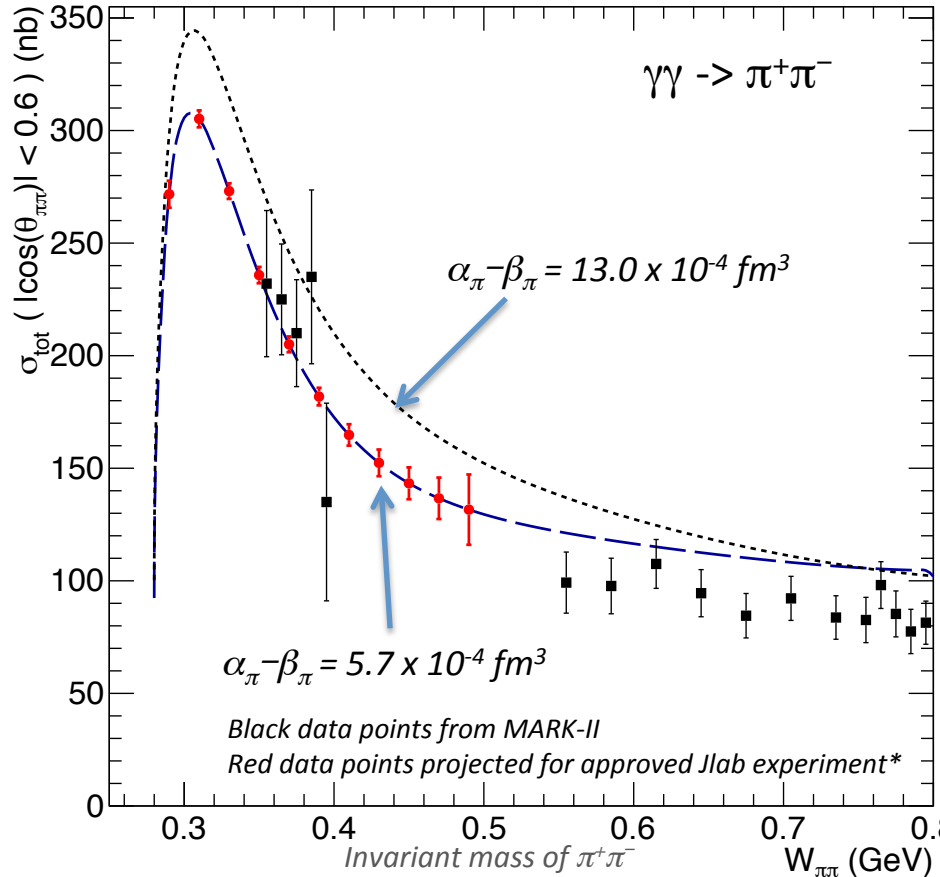
- ...

Linear Polarization of incident photon beam helps distinguish Primakoff from coherent ρ^0 production



Relating cross-section to $\alpha_\pi - \beta_\pi$

Curves from figure 5. from Pasquini et al. Phys. Rev. C 77, 065211 (2008)



Cross-section for $\gamma\gamma \rightarrow \pi^+\pi^-$ calculated based on two values of $\alpha_\pi - \beta_\pi$:

$$\alpha_\pi - \beta_\pi = 13.0 \times 10^{-4} \text{ fm}^3 \text{ (top, dotted line)}$$

$$\alpha_\pi - \beta_\pi = 5.7 \times 10^{-4} \text{ fm}^3 \text{ (solid and dashed lines)}$$

Cross-section varies by $\sim 10\%$ for factor of 2 variation in $\alpha_\pi - \beta_\pi$

Need measurement of $\sigma(\gamma\gamma \rightarrow \pi^+\pi^-)$ at few percent level



- dotted:** subtracted DR calculation with $\alpha_\pi - \beta_\pi = 13.0$
- dashed:** subtracted DR calculation with $\alpha_\pi - \beta_\pi = 5.7$
- solid:** unsubtracted DR calculation with $\alpha_\pi - \beta_\pi = 5.7$

*statistical only

Rates/Acceptance/Errors

- 500 hours of running
 - 10^7 tagged photons/second on 5% radiation length ^{116}Sn target
 - PAC approved 25 days (20 for production, 5 calibration)
- $W_{\pi\pi}$ acceptance down to $\sim 320 \text{ MeV}/c^2$
- Estimated $\sim 36\text{k}$ Primakoff events
(not including detector acceptance)

Error Budget

Errors and correction factors	Correction factor	Statistical uncertainty in correction factor
Overall statistical error		0.6 % 
Normalization to $\mu^+\mu^-$ and relative trigger efficiency		1 %
$\mu^+\mu^-$ background in $\pi^+\pi^-$ yield	0.03 %	0 %
Polarization	70%	0.2 %
Pion identified as muon, and pion decay	8 %	1%
Total systematic error		1.5 % 
Projected error in $\alpha - \beta$		10%

Summary

- Next to leading order ChPT prediction of $\alpha_\pi - \beta_\pi$ is $5.7 \pm 1.0 \times 10^{-4} \text{ fm}^3$
- Previous measurements of $\alpha_\pi - \beta_\pi$ range from $4.4 - 52.6 \times 10^{-4} \text{ fm}^3$
- A newly approved experiment to measure the charged pion polarizability $\alpha_\pi - \beta_\pi$ via the $\gamma\gamma^* \rightarrow \pi^+\pi^-$ reaction will be done using the GlueX detector at Jefferson Lab
 - *PR12-13-008*
- Total estimated uncertainty in $\alpha_\pi - \beta_\pi$ measurement is 10%
- An improved measurement of $\alpha_\pi - \beta_\pi$ would improve the SM prediction of the anomalous magnetic moment of the μ : $(g_\mu - 2)/2$



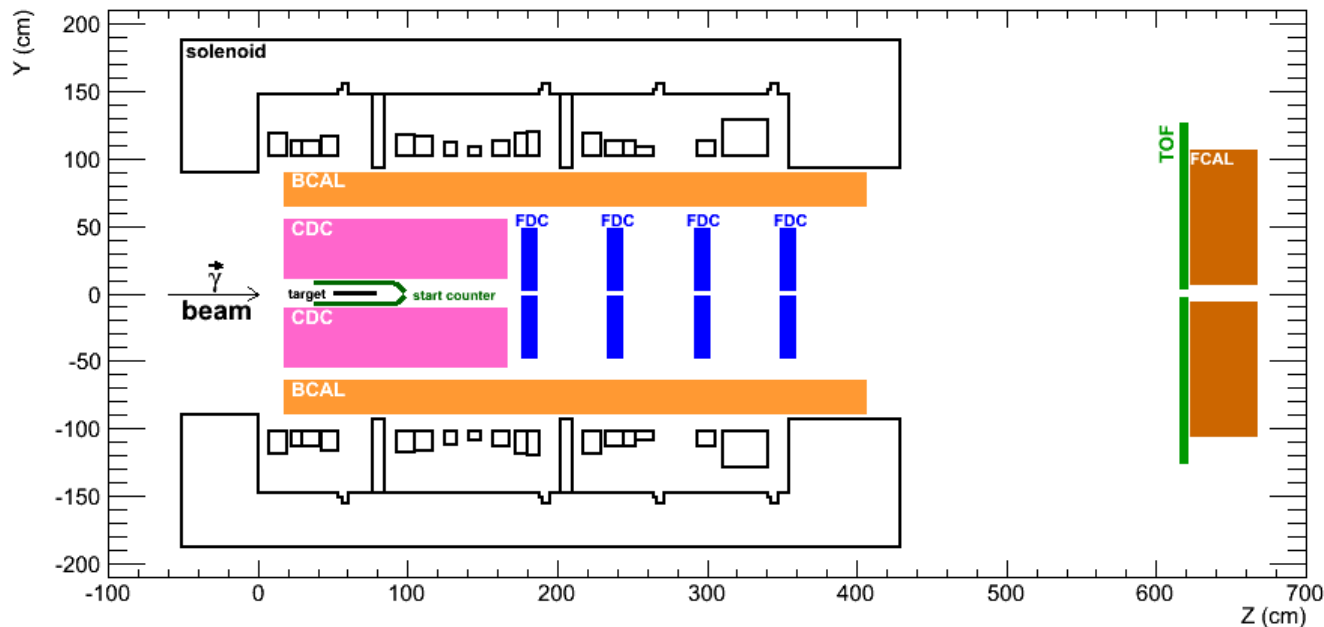
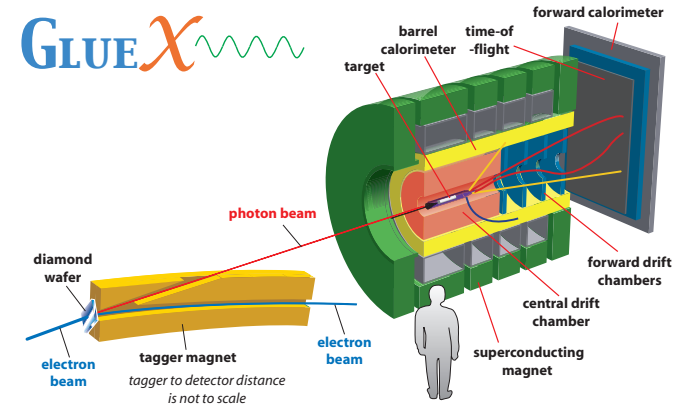
The GlueX Detector in Hall-D

New Proposal will use GlueX detector in Hall-D:

- Linearly polarized photon source ($\sim 9\text{GeV}$)
- 2T solenoidal magnetic field ($\delta p/p = \text{few } \%$)
- Drift chambers
- High resolution Time-of-flight detector

Modifications to standard GlueX setup:

- Replace LH2 target with thin Pb target
- Move target upstream to improve low-angle acceptance
- Alternate start-counter?



Anomalous magnet moment of the μ : $(g_\mu - 2)/2$

- Experimental uncertainty of $\sim 63 \times 10^{-11}$
- SM calculation has uncertainty of $\sim 49 \times 10^{-11}$
 - Hadronic light-by-light (HLBL) scattering is one of two major contributors to SM uncertainty
(other is hadronic vacuum polarization)
 - π polarizability is potentially significant contribution to HLBL that is currently omitted from current SM calculation
- g-2 collaboration at Fermilab is preparing a measurement that will reduce experimental uncertainty by a factor of 4
- A measurement of the π polarizability could help reduce the SM uncertainty significantly

For detailed info on planned Fermi-lab experiment, see http://gm2.fnal.gov/public_docs/proposals/Proposal-APR5-Final.pdf