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

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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^r_{10} and L^r_9 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 $\pi^o \rightarrow \gamma\gamma$)

- 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])

- 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:

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

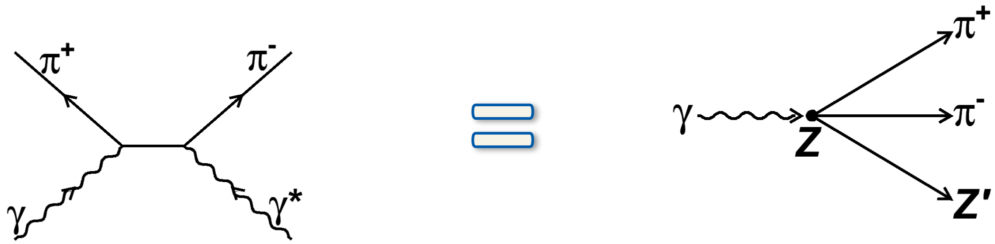
*Fil'kov et al. 2006**

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

Pasquini et al. 2008

Experimental Access

Primakoff effect



This experiment

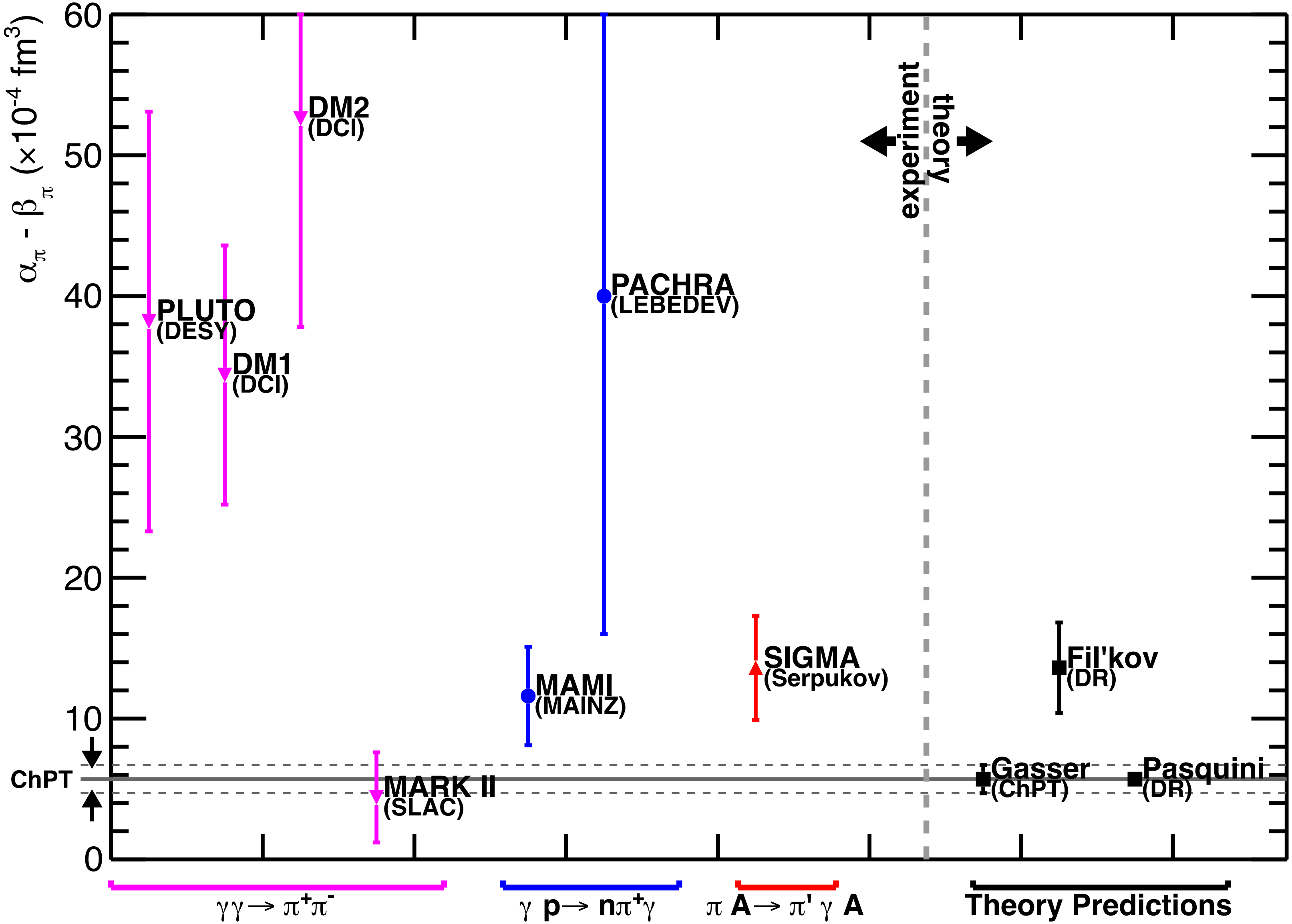
SIGMA

Radiative pion photo-production

MAMI
PACHRA

Light by light scattering
(by crossing symmetry)

PLUTO
DM1
DM2
MARK-II



$\alpha_\pi - \beta_\pi$ ($\times 10^{-4}$ fm^3)
60
50
40
30
20
10
0
ChPT
experiment
theory
DM2
(DCI)
PLUTO
(DESY)
DM1
(DCI)
PACHRA
(LEBEDEV)
MAMI
(MAINZ)
SIGMA
(Serpukov)
MARK II
(SLAC)
Fil'kov
(DR)
Gasser
(ChPT)
Pasquini
(DR)
$\gamma\gamma \to \pi^+\pi^-$
γ p $\to$ n$\pi^+\gamma$
π A $\to$ π' γ A
Theory Predictions

Experimental Setup

$$\gamma\gamma \rightarrow \pi^+\pi^-$$
$$(\gamma Sn \rightarrow Sn\pi^+\pi^-)$$

Signal reaction

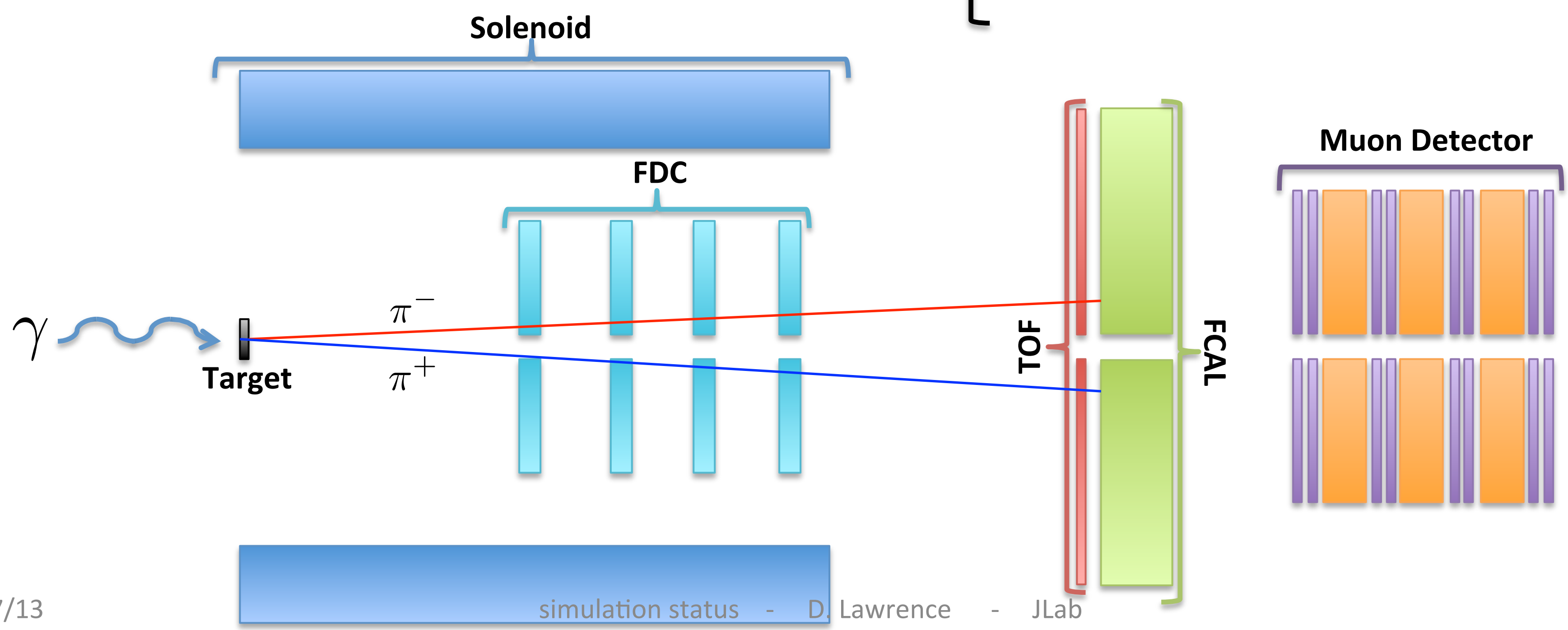
$$\gamma\gamma \rightarrow \mu^+\mu^-$$
$$(\gamma Sn \rightarrow Sn\mu^+\mu^-)$$

Normalization

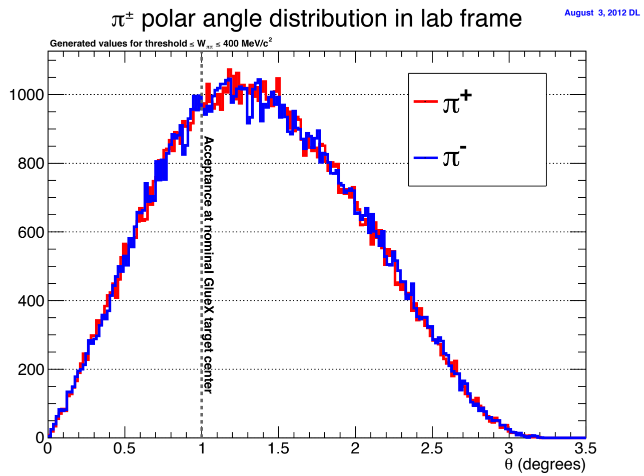
$$\gamma\gamma \rightarrow \pi^o$$
$$(\gamma Sn \rightarrow Sn\pi^o)$$

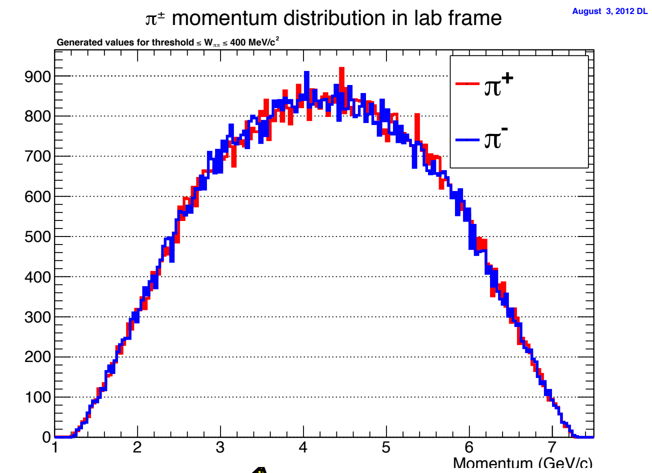
Beam polarization

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



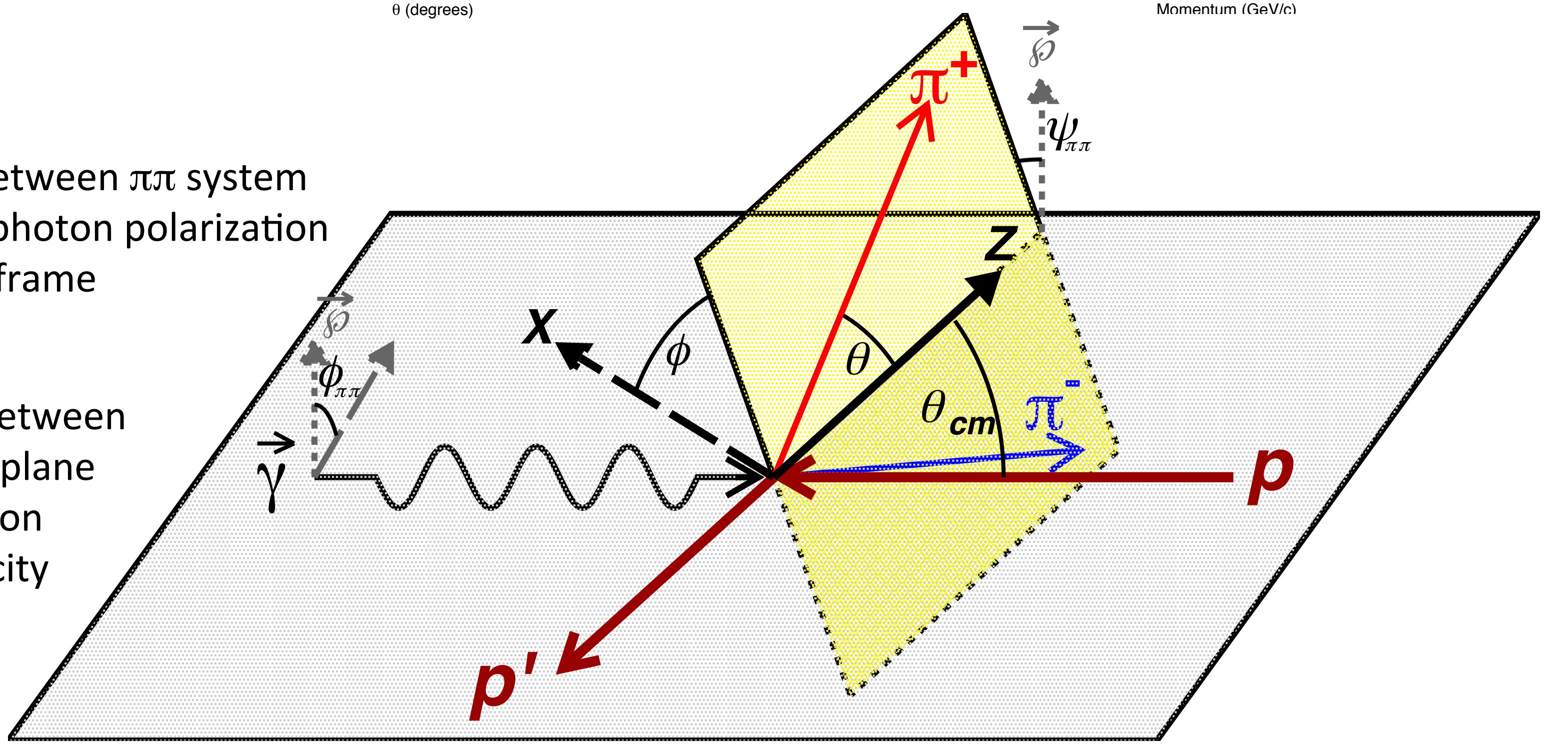
Kinematics of Experiment





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

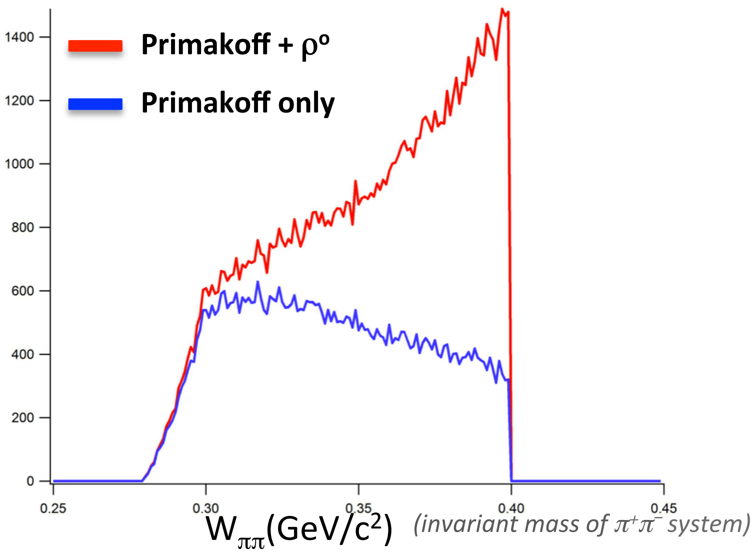
$\psi_{\pi\pi}$ is angle between ππ scattering plane and polarization vector in helicity frame

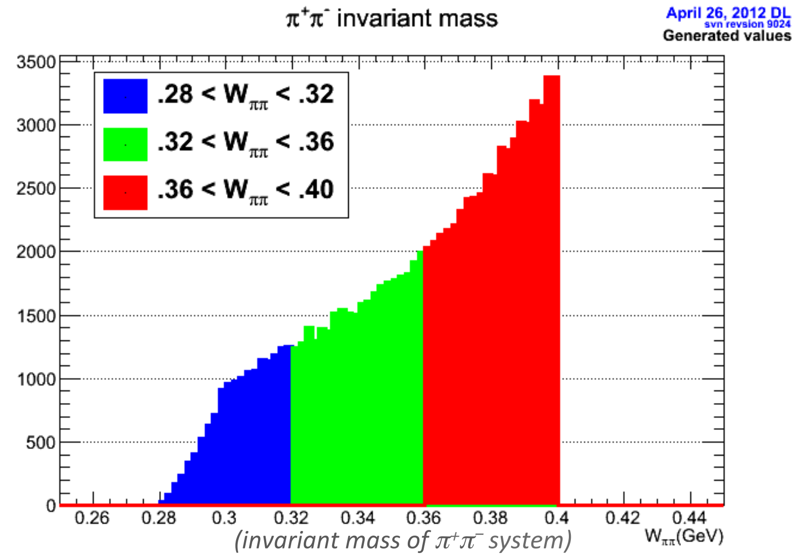


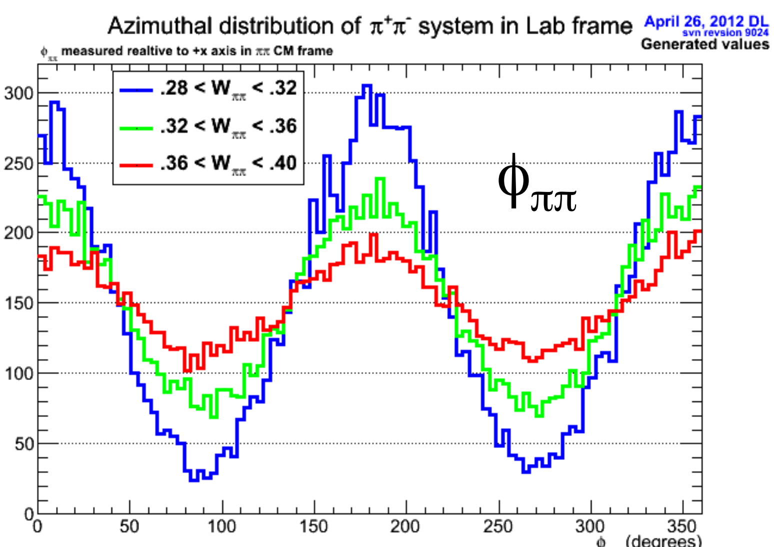
Backgrounds

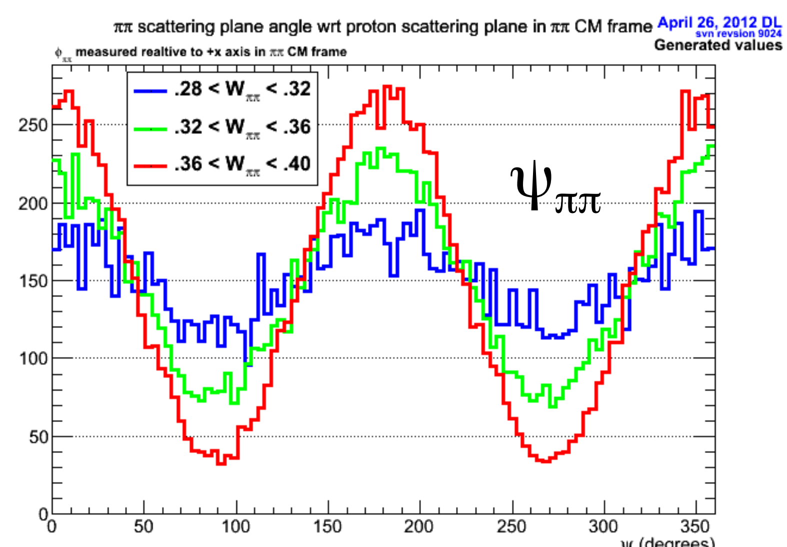
- Experiment will measure reaction:
  $\gamma\ Sn^{116} \to Sn^{116}\ \pi^+\pi^-$
- Primary backgrounds will be:
  - coherent ρ^o production followed by $\rho \to \pi\pi$ decay
    - Will use angular distributions to separate Primakoff from coherent ρ^o production *(see later slides)*
  - Electromagnetic $\mu^+\mu^-$ production
    - Will use dedicated detector to identify hadron showers
- Currently gathering list of other potentially relevant backgrounds including:
  - σ meson production *(angular distributions same as Primakoff)*
  - incoherent $\pi^+\pi^-$ production
  - …

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



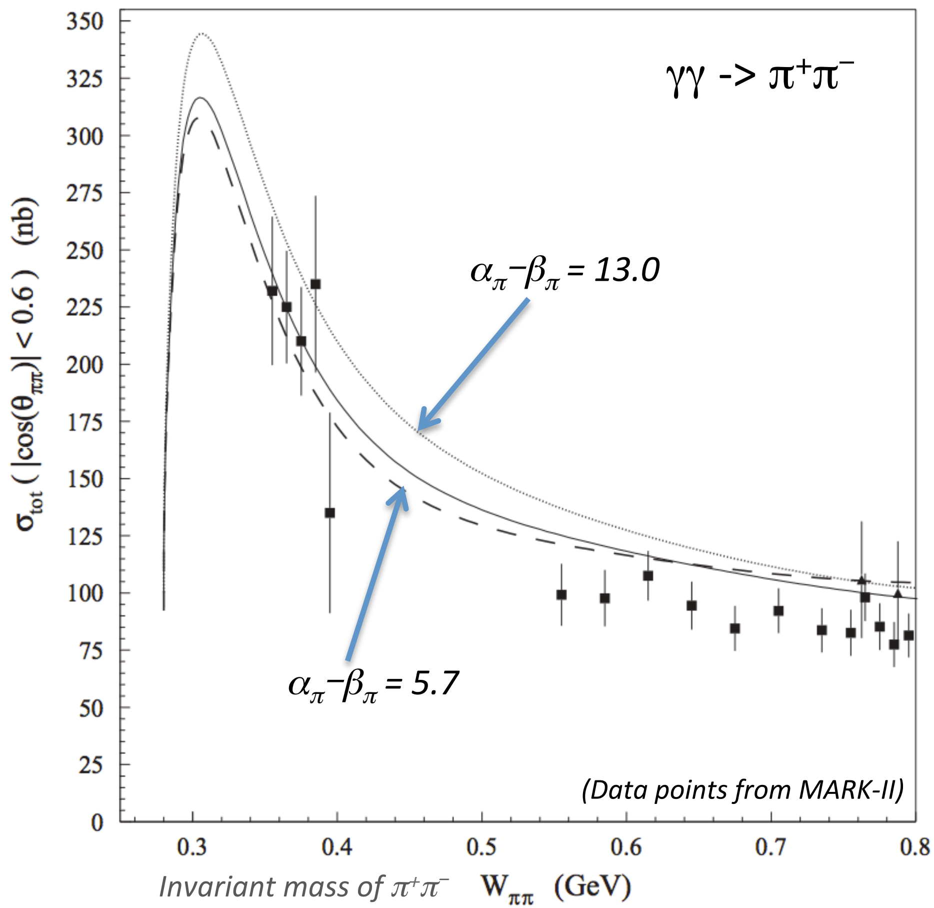






Relating cross-section to $\alpha_\pi - \beta_\pi$

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



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 $\alpha_\pi - \beta_\pi = 5.7$

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

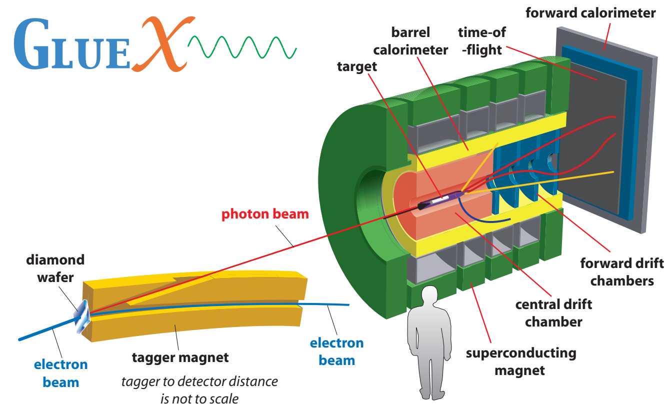
$\alpha_\pi - \beta_\pi = 13.0 \times 10^{-4}\ fm^3$ (top, dotted line)

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

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

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

The GlueX Detector in Hall-D

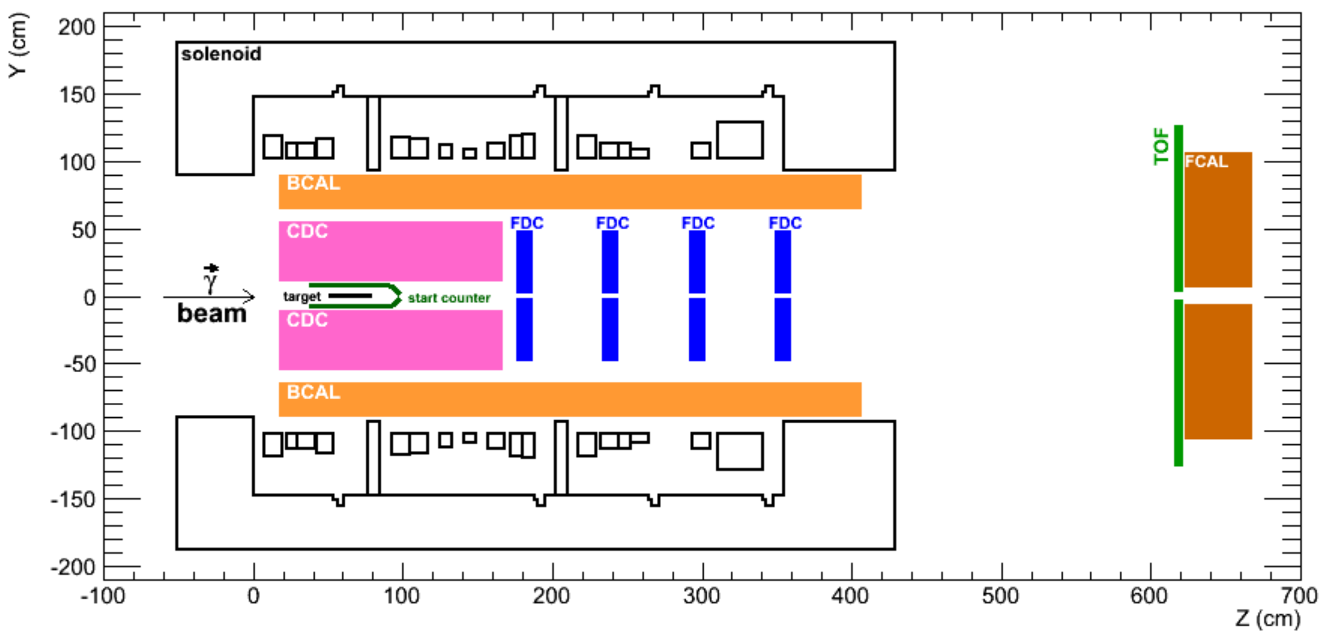


New Proposal will use GlueX detector in Hall-D:

- Linearly polarized photon source (~9GeV)
- 2T solenoidal magnetic field (δp/p = 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?



Detector Rates/Acceptance

- 10^7 tagged photons/second on 5% radiation length Pb target
- 500 hours of running
- $W_{\pi\pi}$ acceptance down to ~320 MeV/c^2
  (working to improve acceptance to even lower $W_{\pi\pi}$)
- Estimated ~36k* Primakoff events
  (contrast this with the ~400 events in the acceptance of the MARK-II measurement)

** before detector acceptance*

Summary

- Next to leading order ChPT prediction of α_π-β_π is 5.7 ± 1.0 x 10^{-4} fm^3
- Previous measurements of α_π-β_π range from 4.4 - 52.6 x 10^{-4} fm^3
- A new proposal to measure the charge pion polarizability α_π-β_π via the $\gamma\gamma^*\to\pi^+\pi^-$ reaction is being developed that will use the GlueX detector at Jefferson Lab
- Letter of Intent submitted to PAC in June 2012. PAC has encouraged development of full proposal
  - will be submitted in next PAC, spring/summer 2013
- Work is ongoing to identify relevant backgrounds and determine detector acceptance
- An improved measurement of α_π-β_π would improve the SM prediction of the anomalous magnetic moment of the μ: $(g_\mu-2)/2$


Backups

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

- Experimental uncertainty of ~ 63×10^{-11}
- SM calculation has uncertainty of ~ 49×10^{-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