Measuring the charged pion polarizability in the $\gamma\gamma \to \pi^+\pi^-$ 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 $\pi^o \to \gamma\gamma$)

- 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**

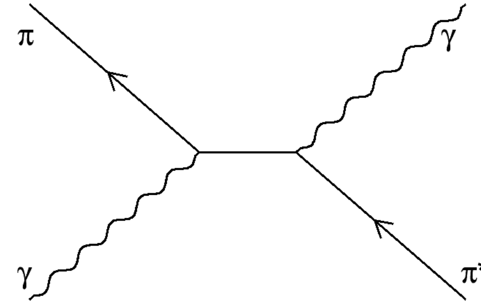
$$\alpha_\pi - \beta_\pi = 5.7 \times 10^{-4}\ \text{fm}^3$$ *Pasquini et al. 2008*

Experimental Access

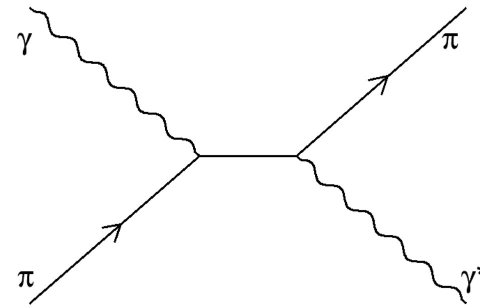
The best way to access polarizabilities of the charged pion is through Compton scattering off the π.

No pion target exists requiring us to access it through other means.

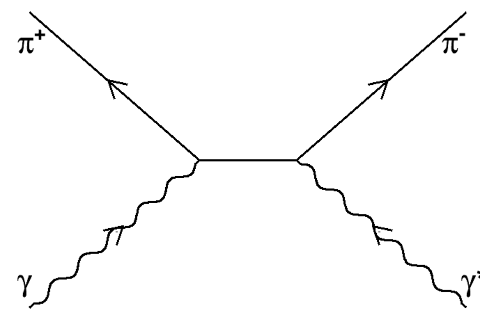
We fall back to using nearly real targets from the particle field of a nucleus.



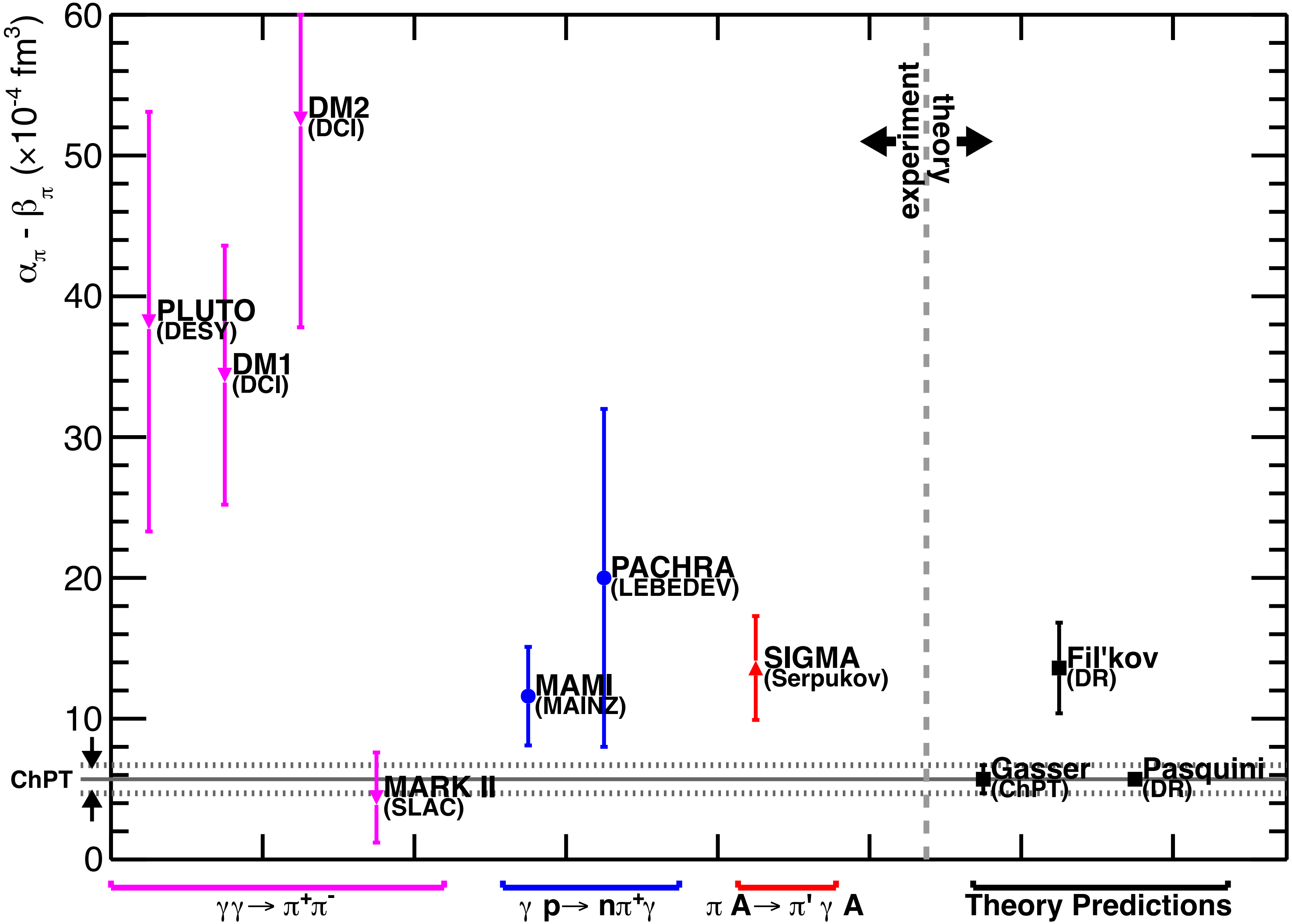
Radiative pion photo-production



Primakoff effect



Light by light scattering
(by crossing symmetry)



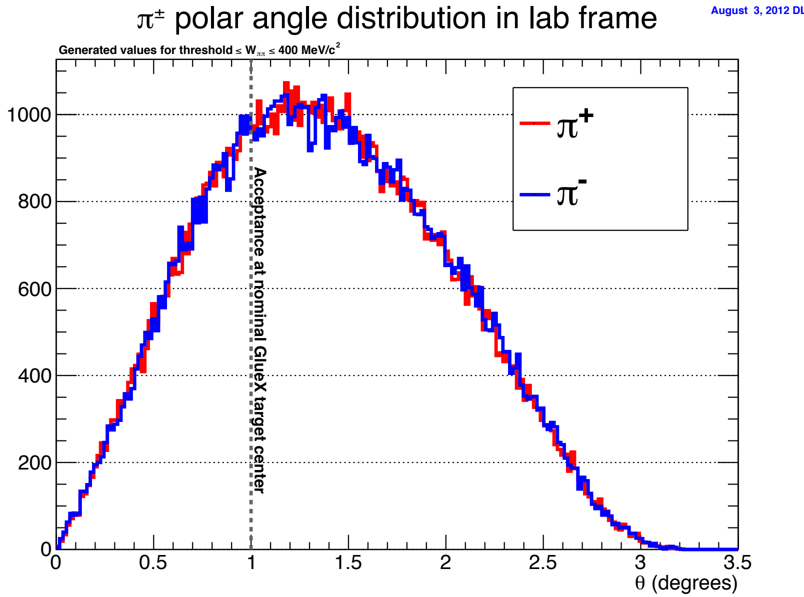
$\alpha_\pi - \beta_\pi$ ($\times 10^{-4}$ fm^3)
60
50
40
30
20
10
0
ChPT
experiment
theory
DM2
(DCI)
PLUTO
(DESY)
DM1
(DCI)
PACHRA
(LEBEDEV)
MAMI
(MAINZ)
SIGMA
(Serpukov)
Fil'kov
(DR)
MARK II
(SLAC)
Gasser
(ChPT)
Pasquini
(DR)
$\gamma\gamma \rightarrow \pi^+\pi^-$
γ p$\rightarrow$ n$\pi^+\gamma$
π A$\rightarrow$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

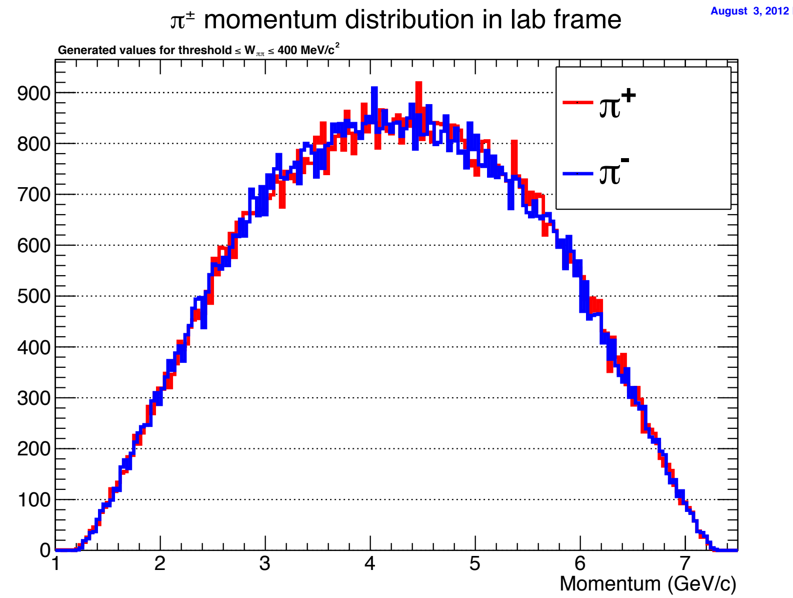
Backgrounds

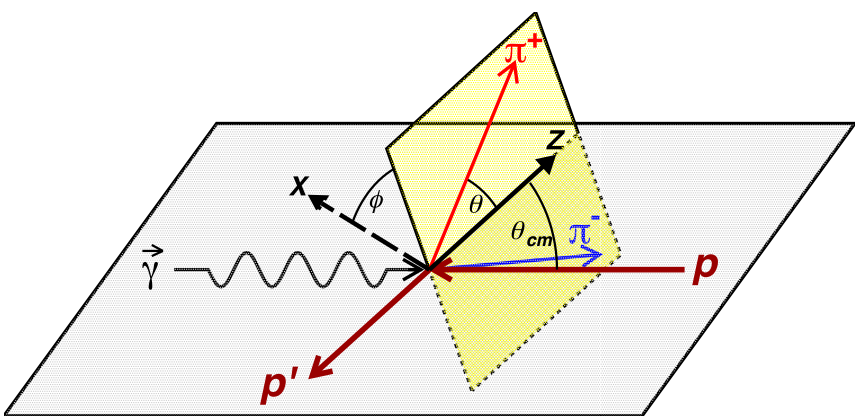
- Primary background will be coherent ρ^o production followed by $\rho \to \pi\pi$ decay
  - Will use angular distributions to separate Primakoff from coherent ρ^o production *(see later slides)*

- Currently gathering list of other potentially relevant backgrounds including:
  - σ meson production *(angular distributions same as Primakoff)*
  - incoherent $\pi^+\pi^-$ production
  - …

Kinematics of Experiment

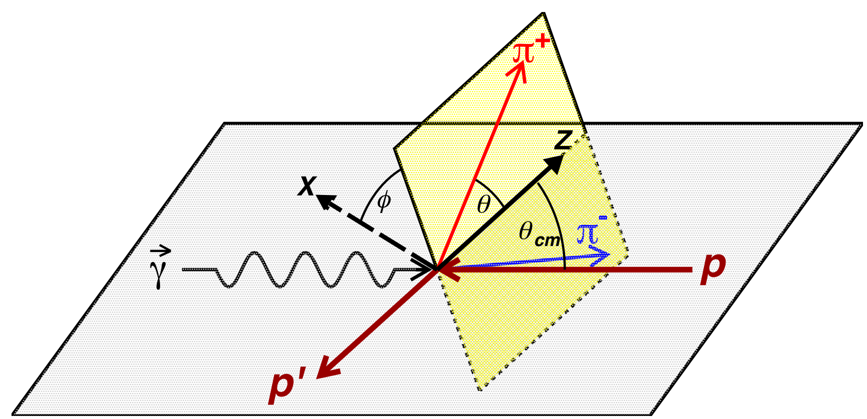






Picture needs updating!!

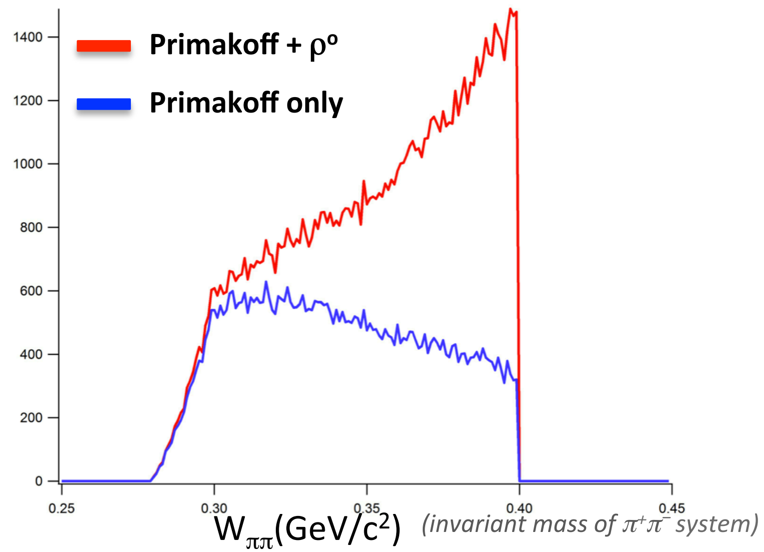
ϕ angle defined by $\pi\pi$ system in lab frame

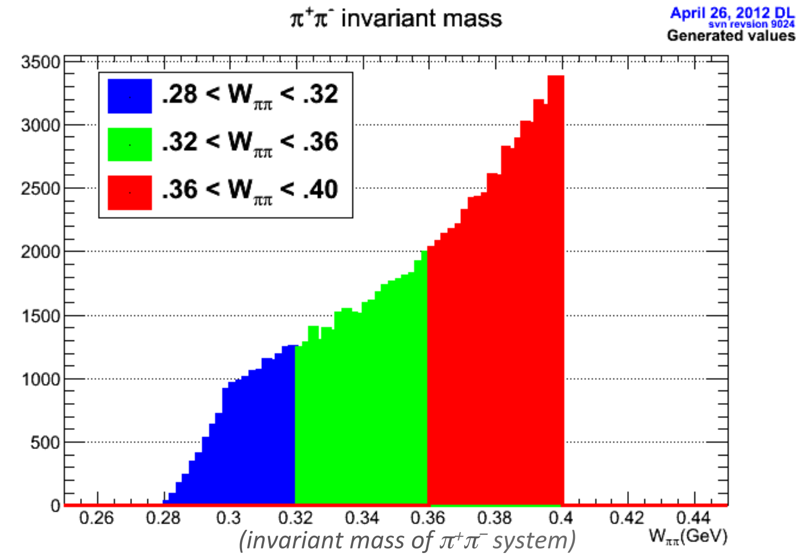


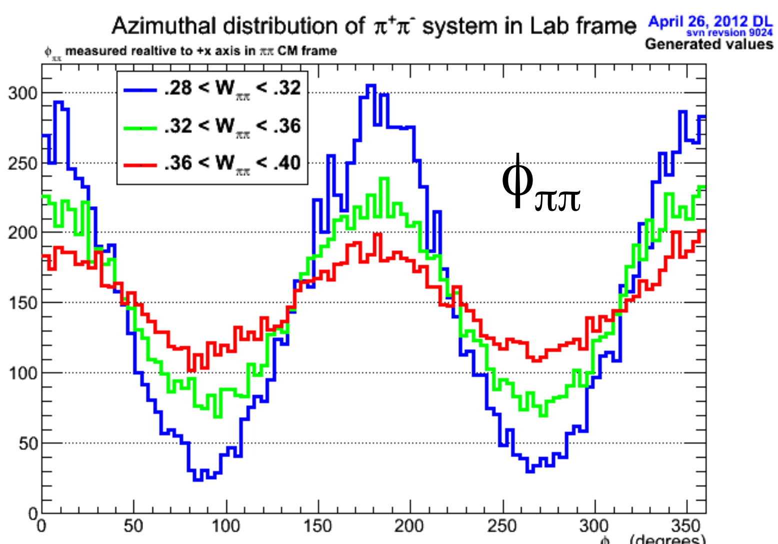
Picture needs updating!!

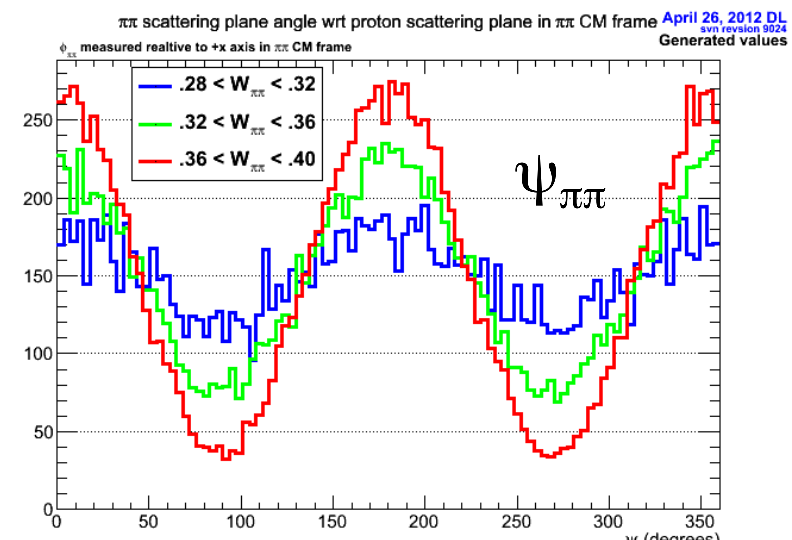
ψ angle defined by $\pi\pi$ system in helicity frame

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



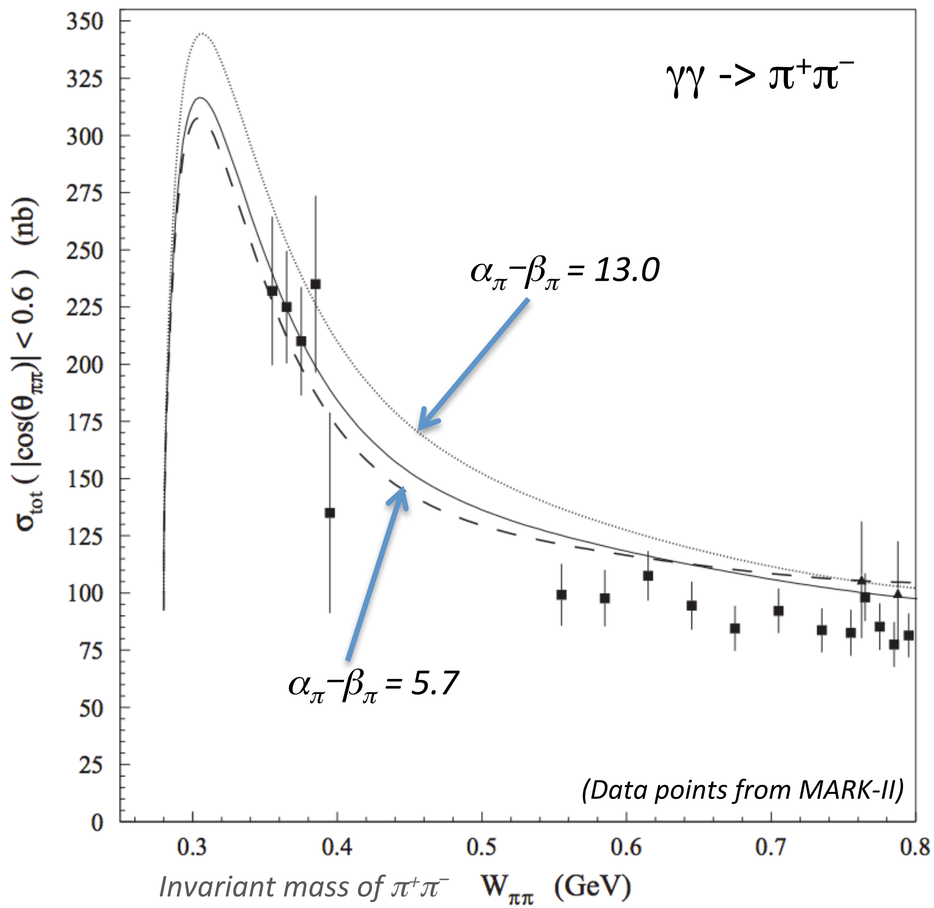






Relating cross-section to $\alpha_\pi - \beta_\pi$

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 $\alpha_\pi - \beta_\pi$:

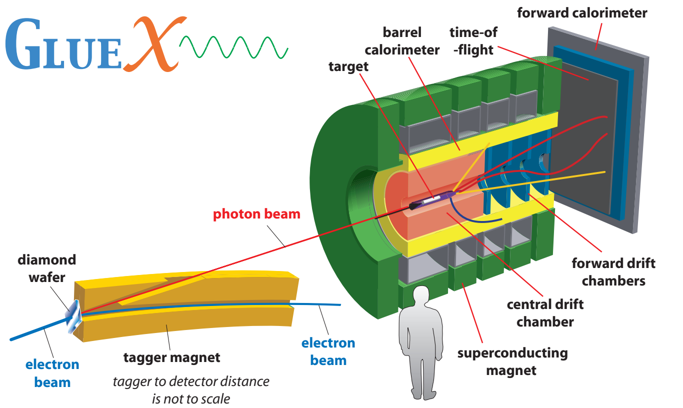
$\alpha_\pi - \beta_\pi = 13.0 \times 10^{-4}$ fm^3 (top, dotted line)

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

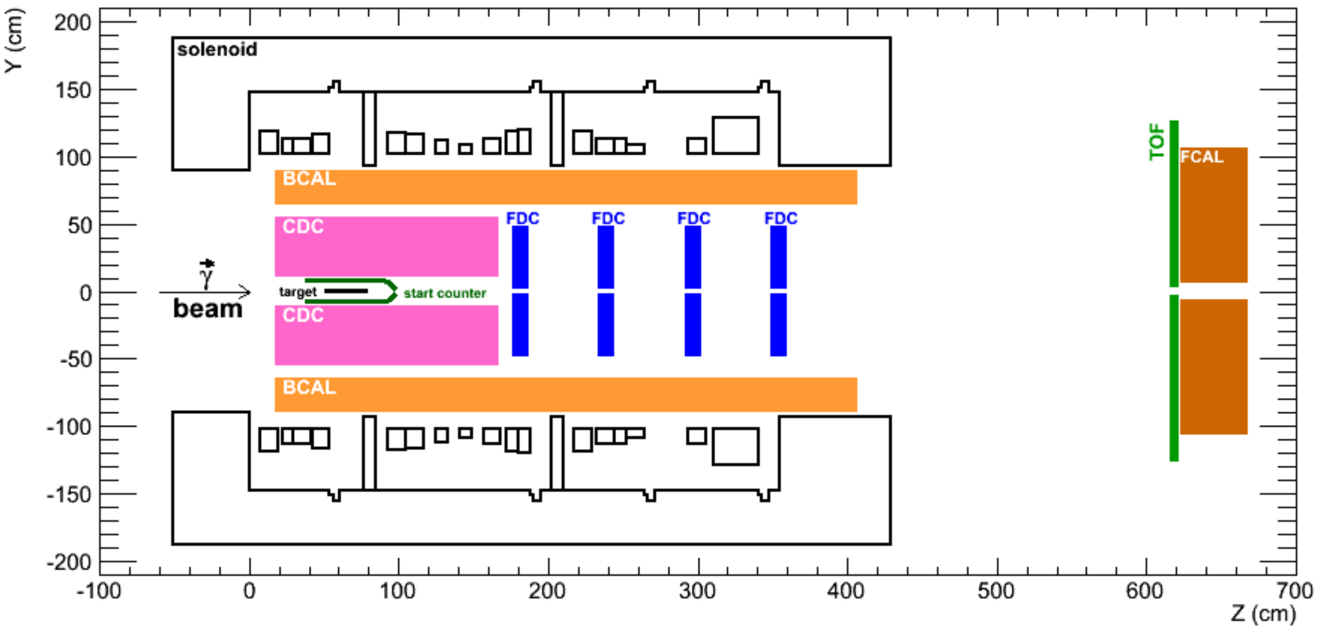


New Proposal will use GlueX detector in Hall-D:

- Linearly polarized photon source (~9GeV)
- 2T solenoidal magnetic field ($\delta p/p$ = 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 $\gamma\gamma^*$->$\pi^+\pi^-$ 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