

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_{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 $\frac{\alpha_\pi - \beta_\pi}{2}$ 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:

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

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

*Fil'kov et al. 2006**

Pasquini et al. 2008

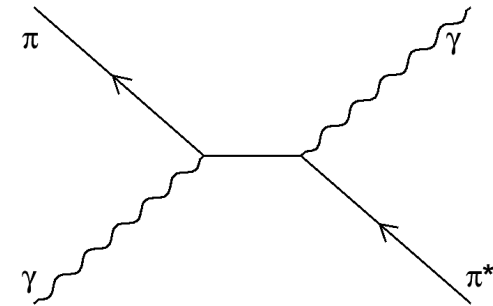
Experimental Access

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

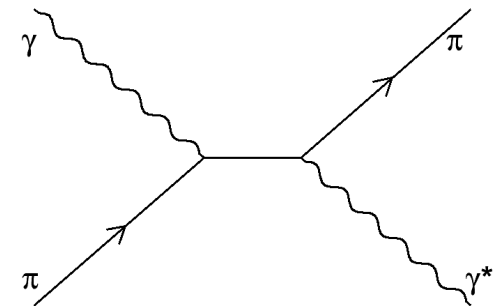
No pion target exists requiring us to access it through other means.

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

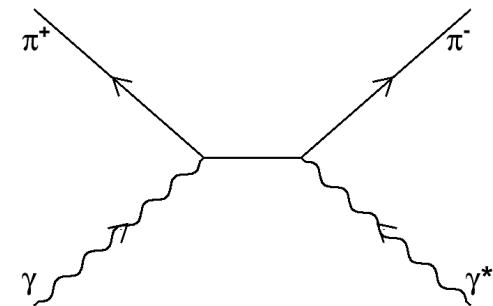
Radiative pion photo-production

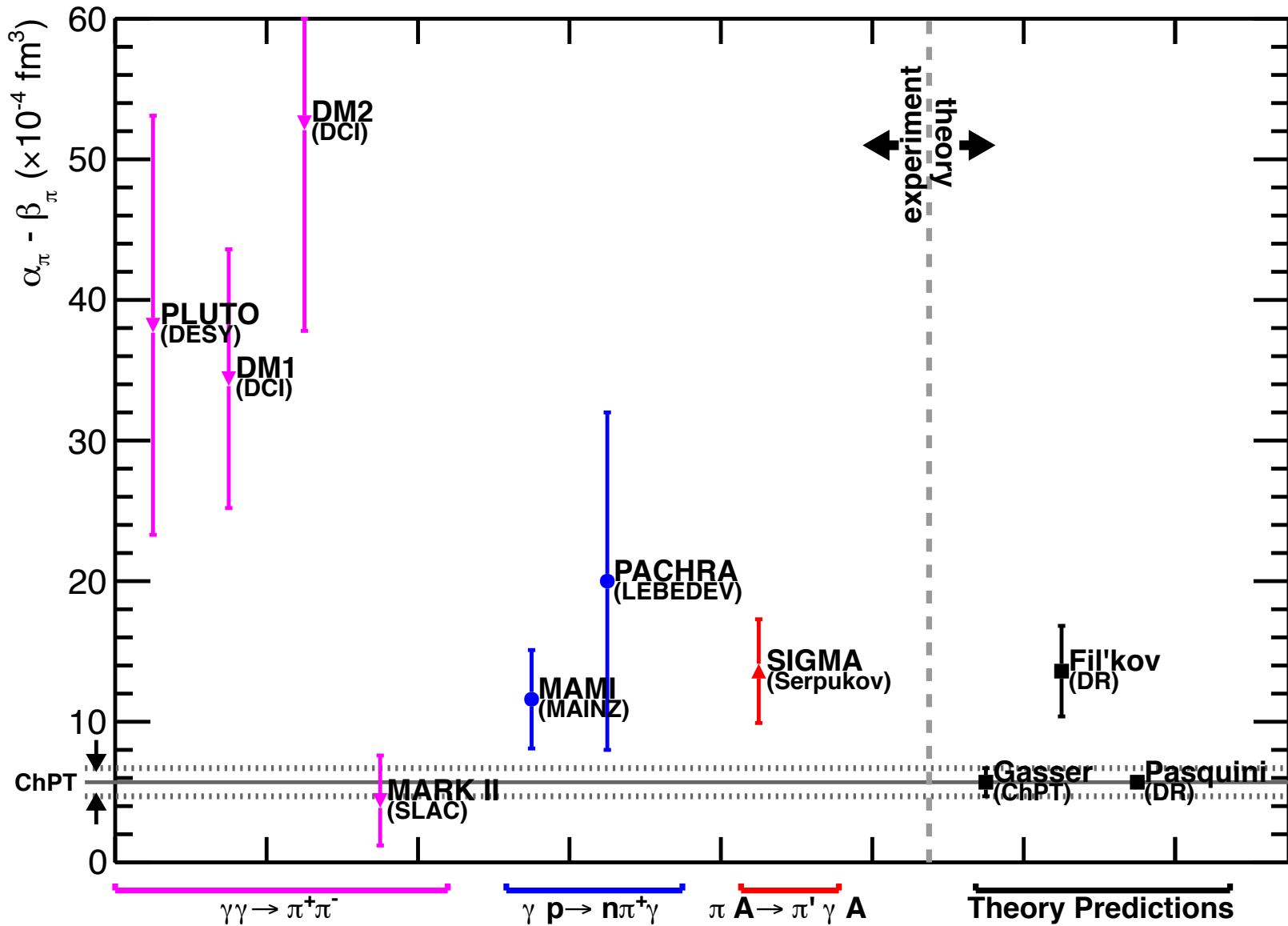


Primakoff effect



*Light by light scattering
(by crossing symmetry)*





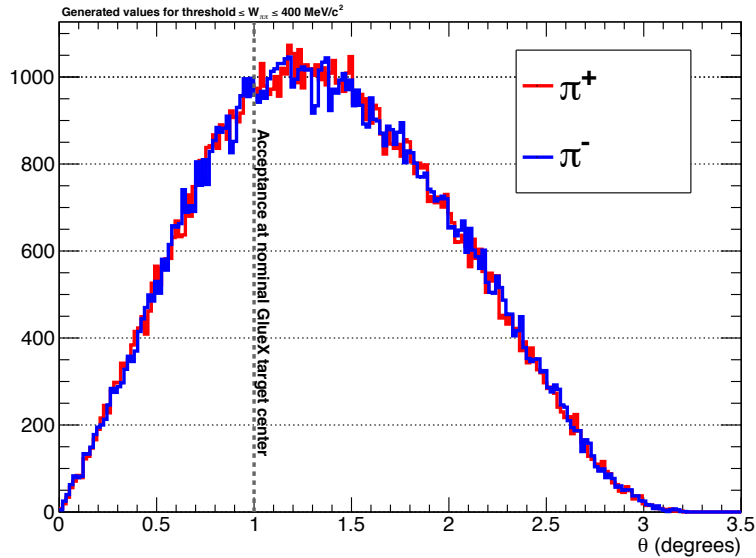
Backgrounds

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

Kinematics of Experiment

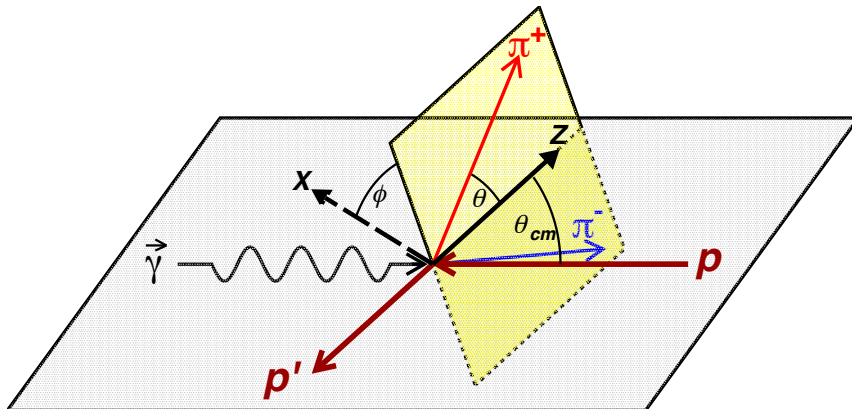
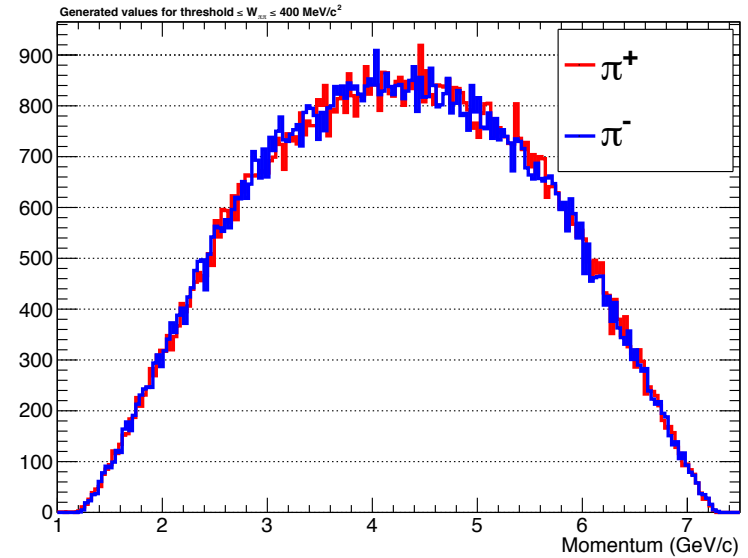
π^\pm polar angle distribution in lab frame

August 3, 2012 DL



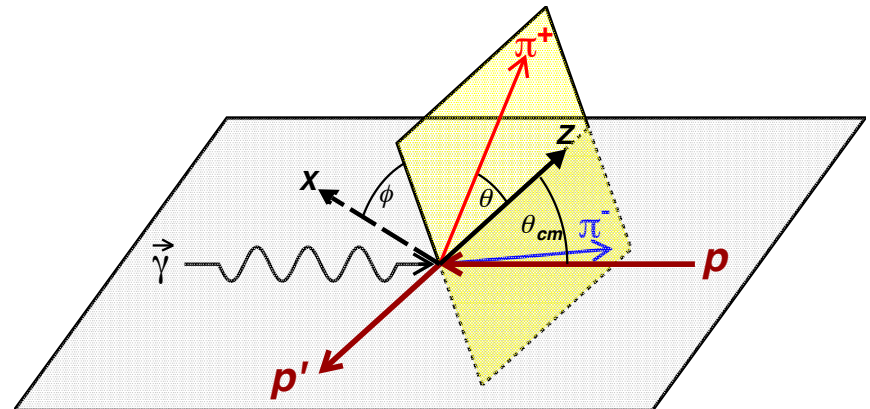
π^\pm momentum distribution in lab frame

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Picture needs updating!!

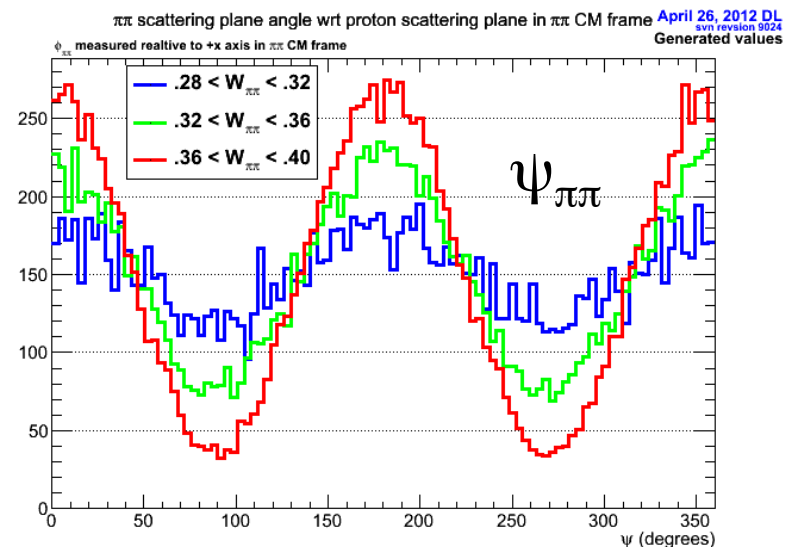
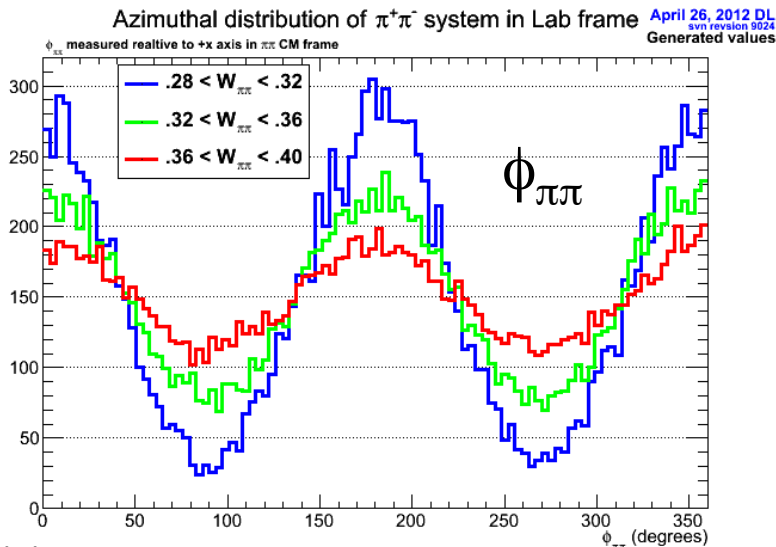
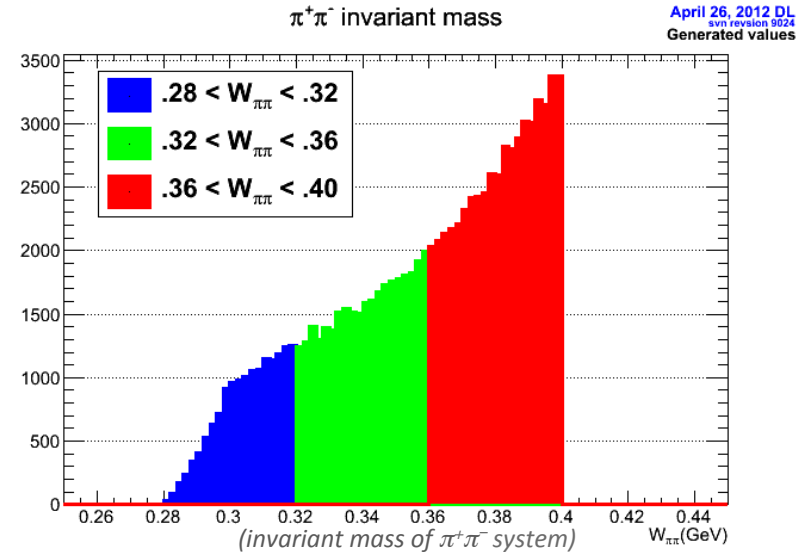
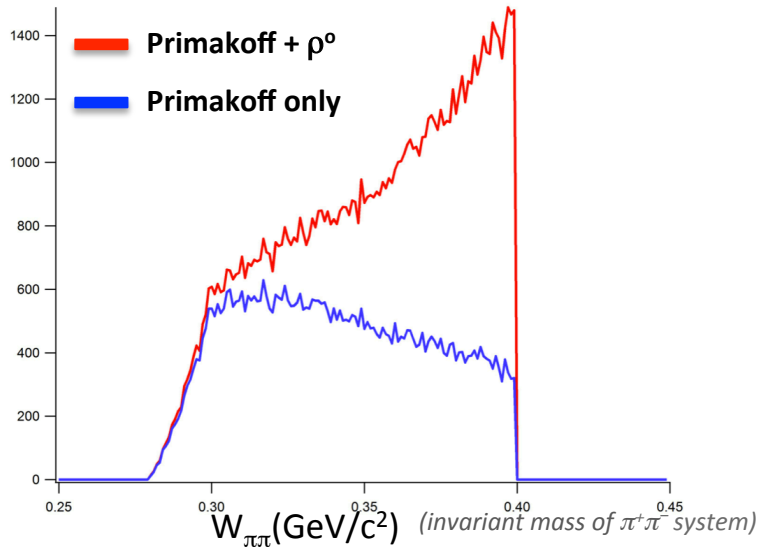
ϕ angle defined by $\pi\pi$ system in lab frame



Picture needs updating!!

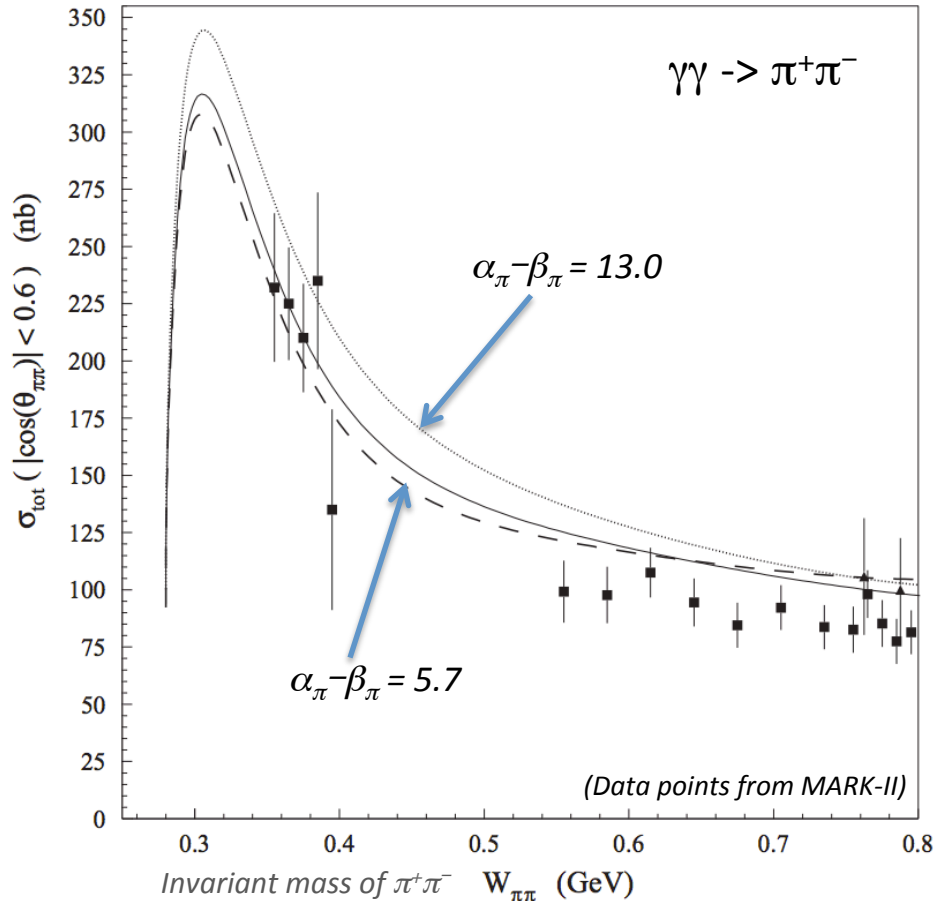
ψ angle defined by $\pi\pi$ system in helicity frame

Linear Polarization of incident photon beam helps distinguish Primakoff from coherent ρ^0 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 $\gamma\gamma \rightarrow \pi^+\pi^-$ 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

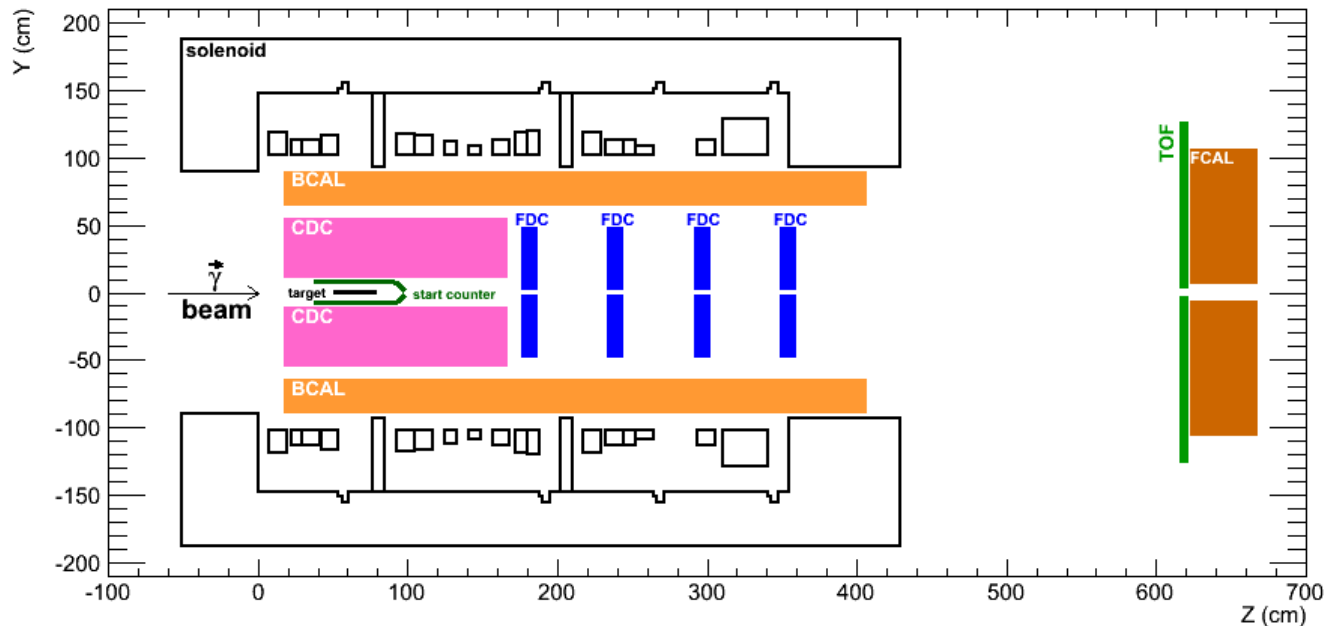
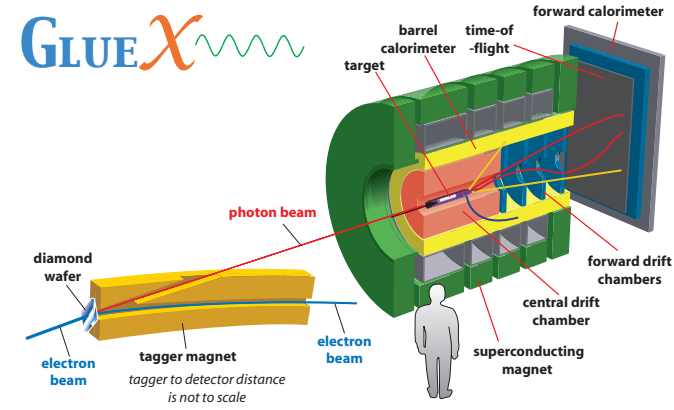
The GlueX Detector in Hall-D

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?



Detector Rates/Acceptance

- 10^7 tagged photons/second on 5% radiation length Pb target
- 500 hours of running
- $W_{\pi\pi}$ acceptance down to $\sim 320 \text{ MeV}/c^2$
(*working to improve acceptance to even lower $W_{\pi\pi}$*)
- Estimated $\sim 36\text{k}^*$ 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 $\alpha_\pi - \beta_\pi$ 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 new proposal to measure the charge pion polarizability $\alpha_\pi - \beta_\pi$ via the $\gamma\gamma^* \rightarrow \pi^+\pi^-$ 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 $\alpha_\pi - \beta_\pi$ would improve the SM prediction of the anomalous magnetic moment of the μ : $(g_\mu - 2)/2$



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