Introduction

- 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 $\pi^o \to \gamma\gamma$)

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

$$\alpha_\pi = -\beta_\pi = 2.78 \pm 0.1 \times 10^{-4}\ \text{fm}^3$$

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

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

with

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

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

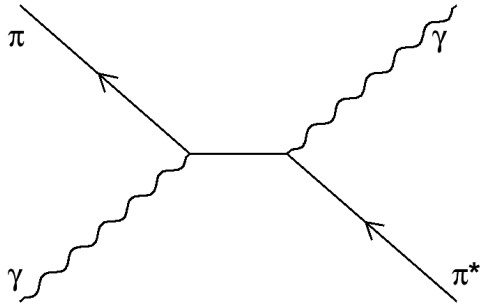
$$\alpha_\pi - \beta_\pi = 13.0 + 2.6 - 1.9 \times 10^{-4}\ \text{fm}^3$$ *Fil'kov et al. 2006*

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

Experimental Access

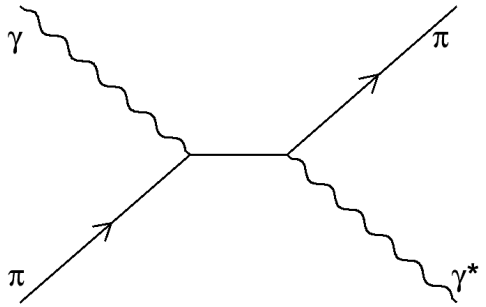
The best way to access polarizabilities of the charged pion is through Compton scattering off the π.

Radiative pion photo-production



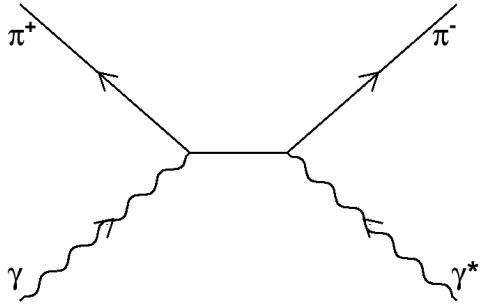
No pion target exists requiring us to access it through other means.

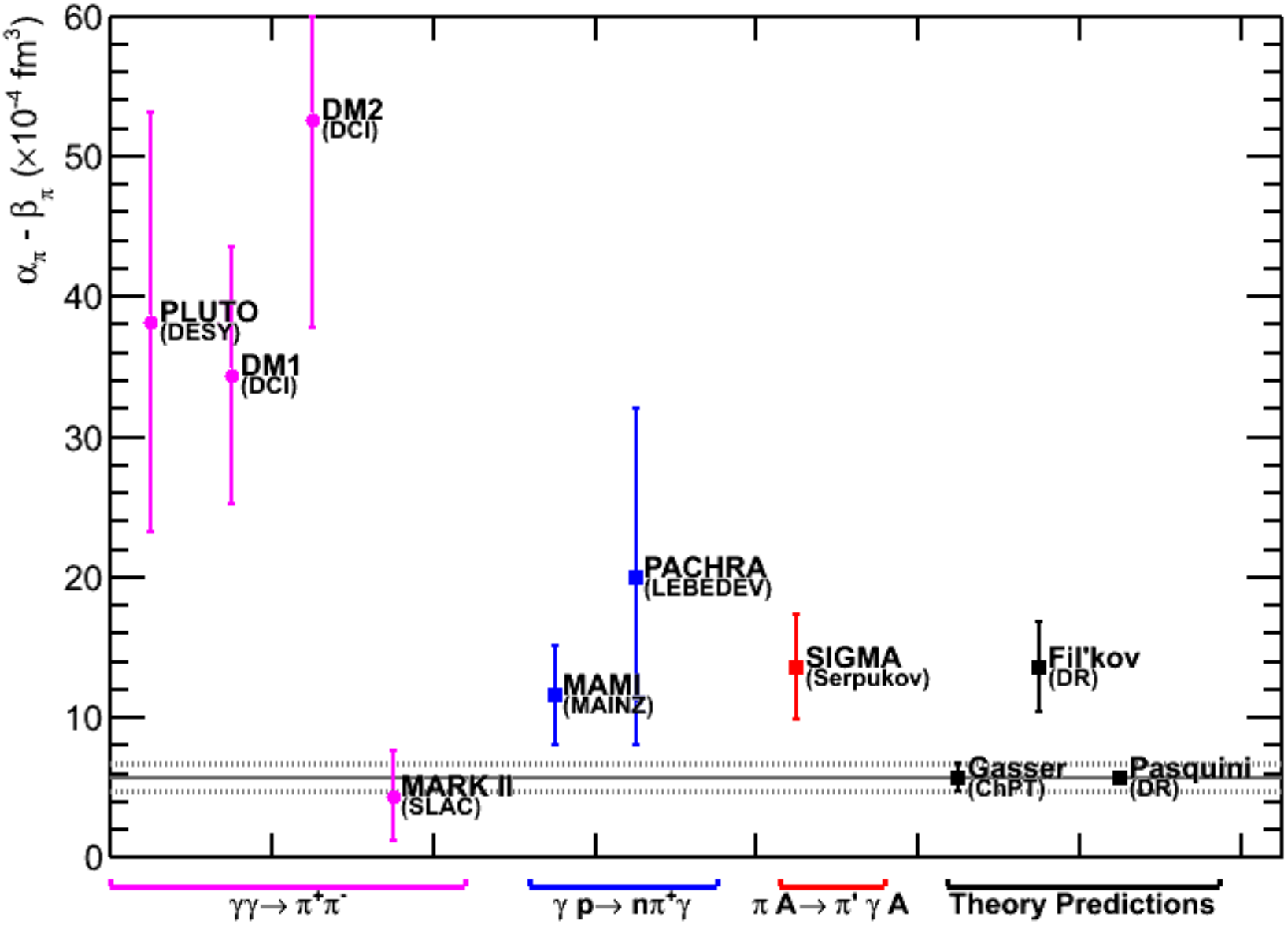
Primakoff effect



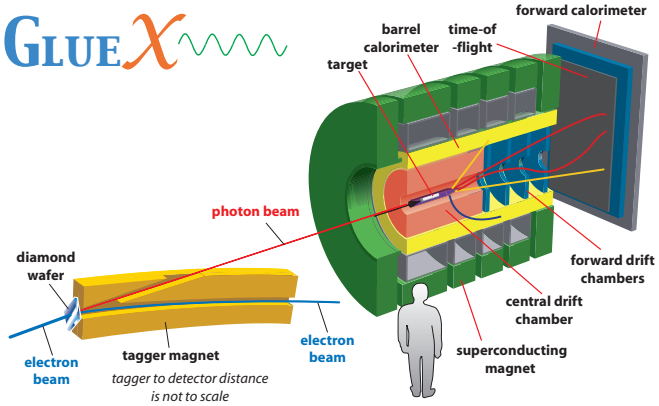
We fall back to using nearly real targets from the particle field of a nucleus.

Light by light scattering
(by crossing symmetry)




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

The Glue Detector in Hall-D

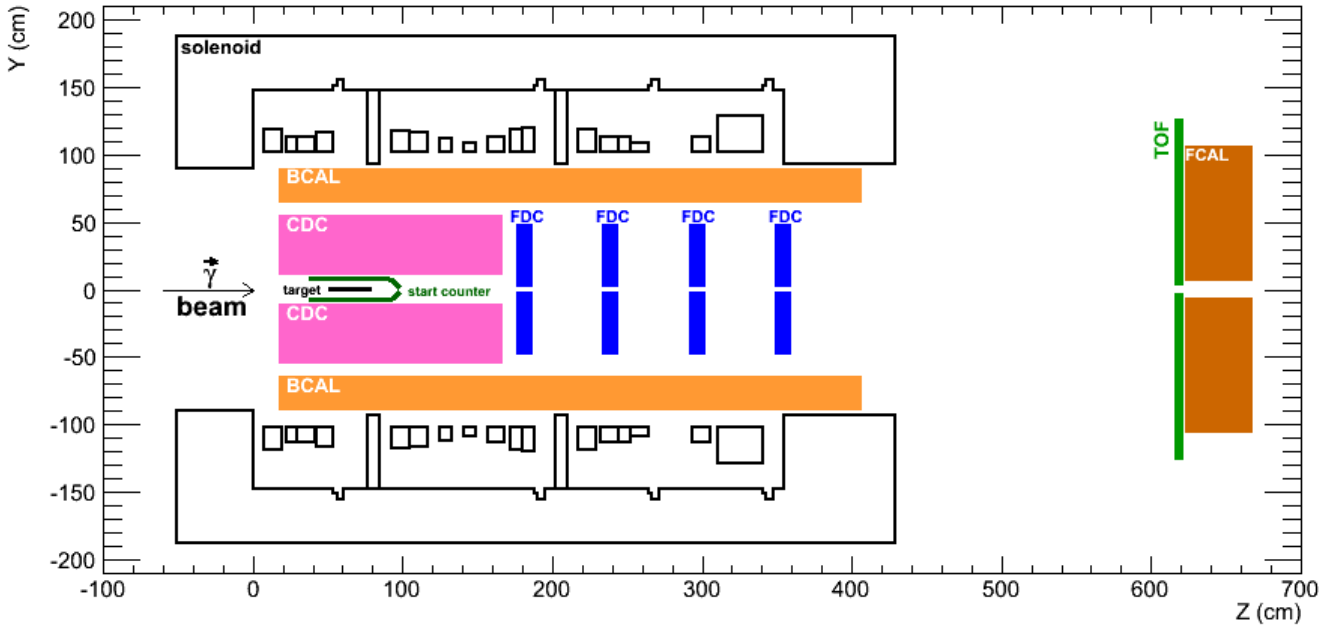


New Experiment will use GlueX detector in Hall-D:

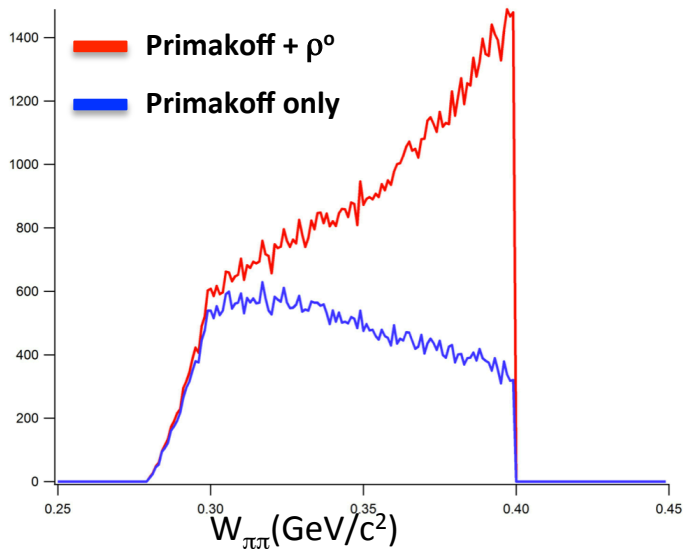
- Linearly polarized photon source (~9GeV)
- 2T solenoidal magnetic field (δp/p = few %)
- Drift chambers
- High resolution Time-of-flight detector

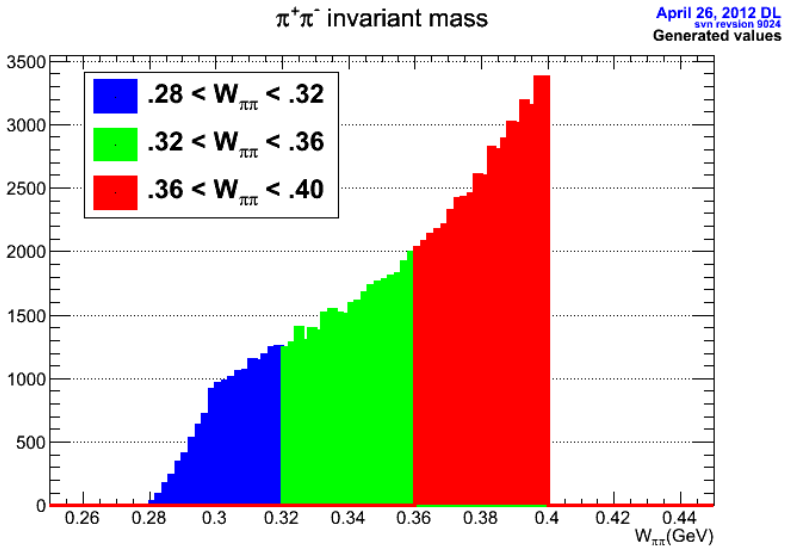
Modifications to standard GlueX setup:

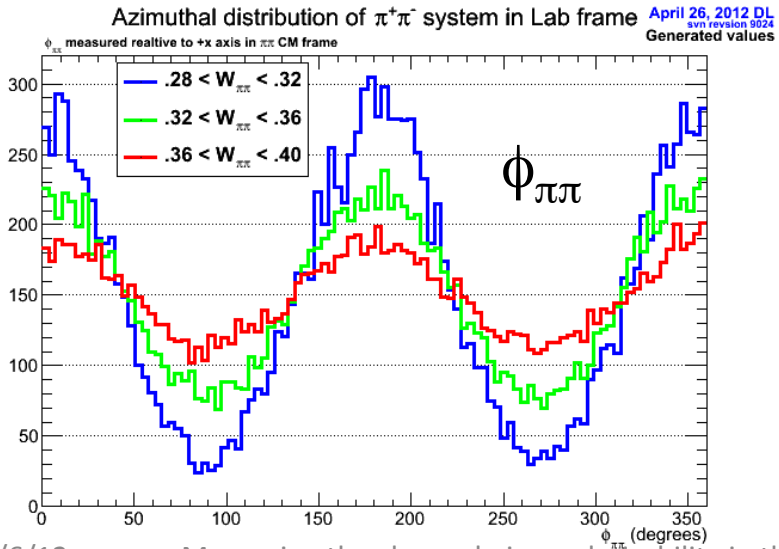
- Replace LH2 target with thin Pb target
- Move target upstream to improve low-angle acceptance
- Alternate start-counter?

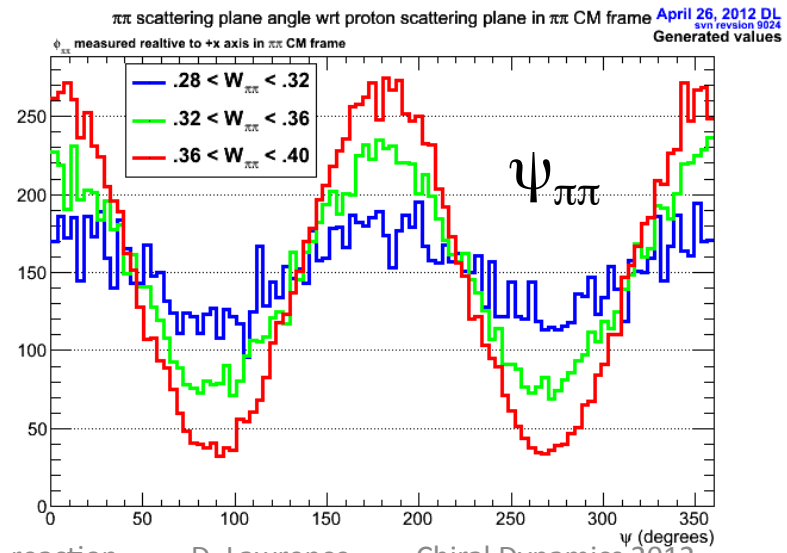


Linear Polarization of incident photon beam helps distinguish Primakoff from coherent ρ^o production









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

Figure from Letter of Intent for current experiment based on similar figure from Pasquini et al. Phys. Rev. C 77, 065211 (2008)

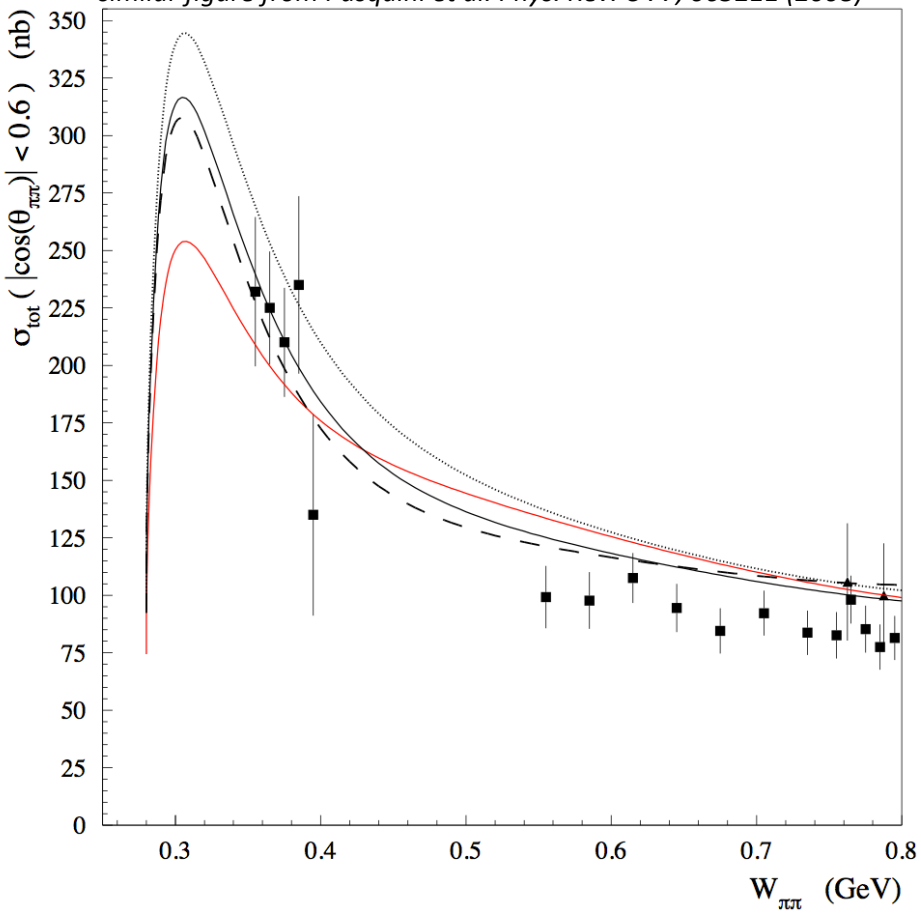


Figure 1: $\gamma\gamma \to \pi^+\pi^-$ cross sections. Red curve: Born approx. (no polarizability effect); black solid: unsubtracted DR calculation with $\alpha_\pi - \beta_\pi = 5.7$; dashed: subtracted DR with $\alpha_\pi - \beta_\pi = 5.7$; dotted: subtracted DR with $\alpha_\pi - \beta_\pi = 13.0$.

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

Detector Rates/Acceptance

- 10^7 tagged photons/second on target
- 500 hours of running
- Estimated ~36k Primakoff events
  (contrast this with the ~400 events of the MARK-II measurement, the most accurate to date using the $\gamma\gamma$->$\pi\pi$ reaction)

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

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

Summary

- A new experiment to measure the charge pion polarizability α_π-β_π via the $\gamma\gamma^*\rightarrow\pi^+\pi^-$ reaction is being developed using the GlueX detector at Jefferson Lab
- Previous measurements of α_π-β_π disagree by a factor > 2
- Theoretical predictions of α_π-β_π disagree by a factor ≈ 2 (5.7×10^{-4} fm^3 vs. 13.0×10^{-4} fm^3)
- An improved measurement of α_π-β_π would improve the SM prediction of the anomalous magnetic moment of the μ: $(g_\mu-2)/2$