Charged pion polarizability measured in $\gamma\gamma \to \pi^+\pi^-$

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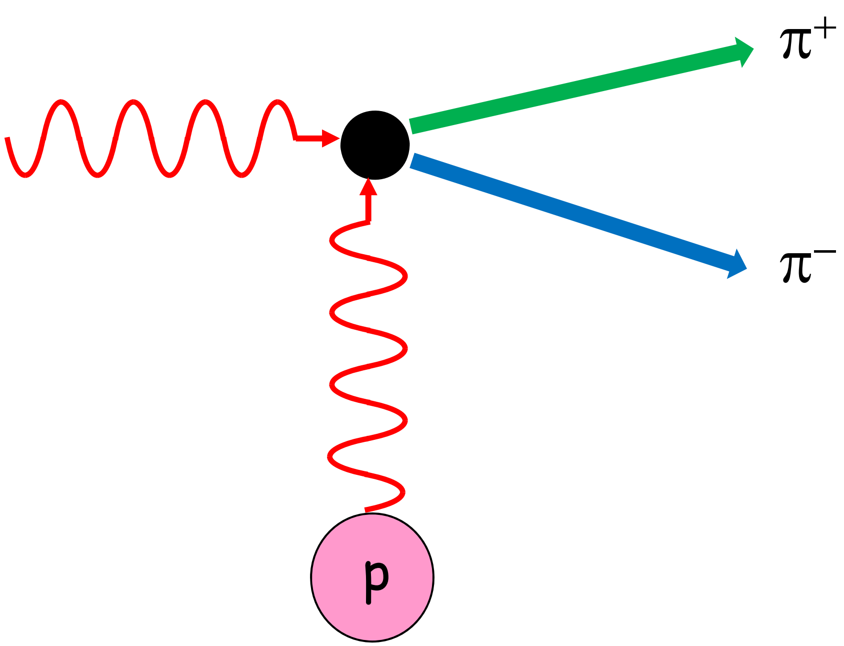
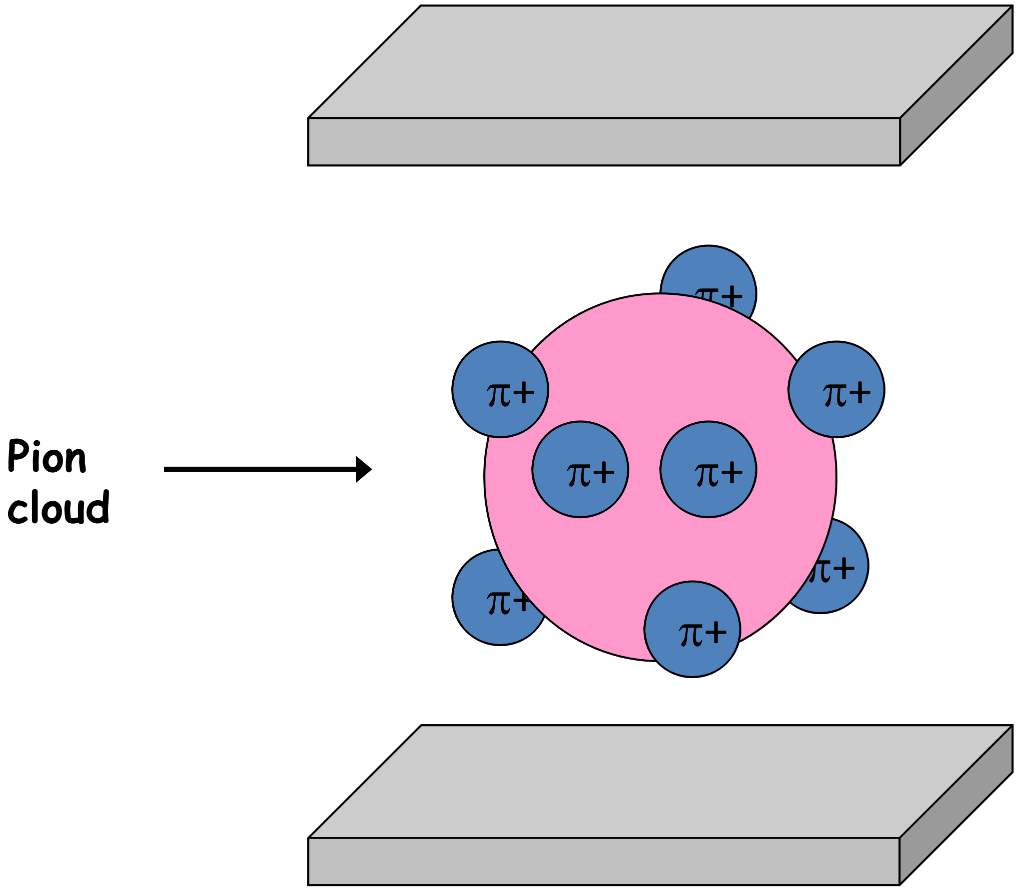


Hadron polarizabilities are fundamental constants that encode information about the structure of hadrons.

The pion is the lightest strongly interacting particle observed in nature. QCD symmetries are especially relevant in predicting properties of the pion.

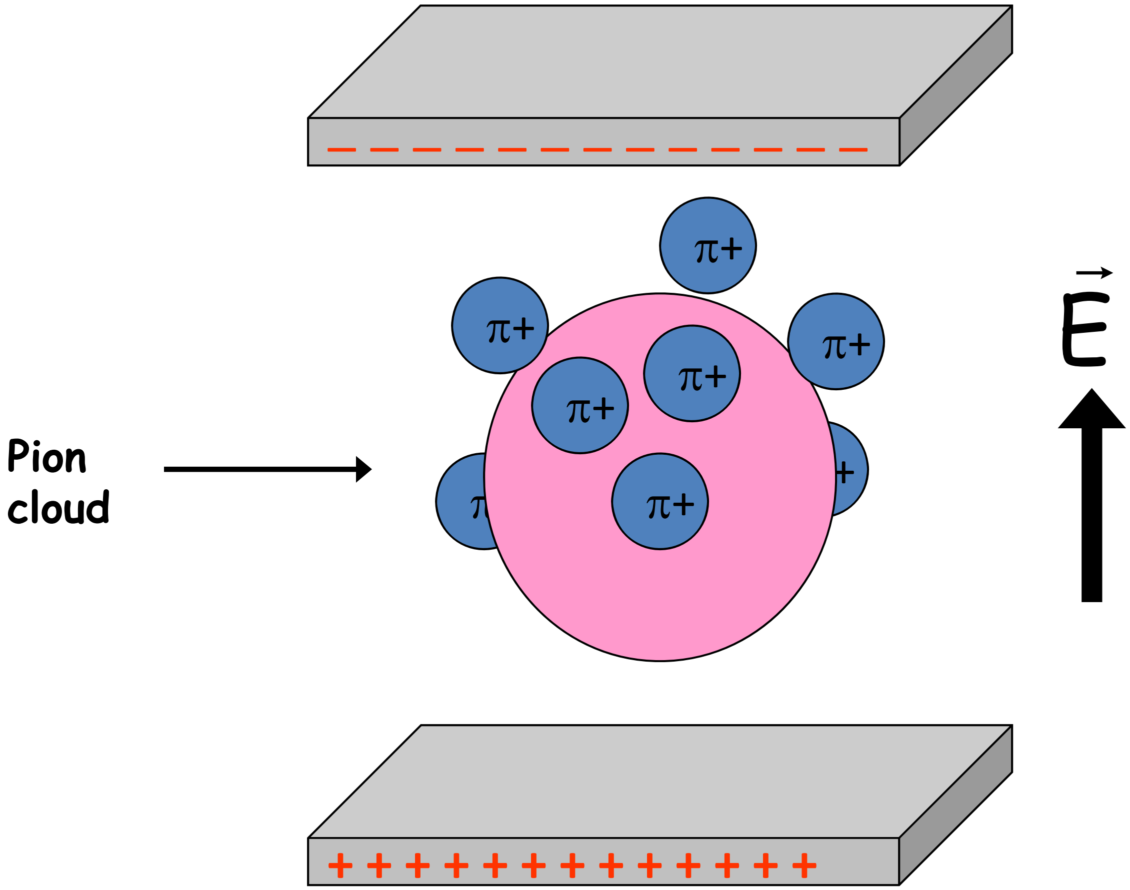
- Theoretical predictions
- Previous experiments
- Primakoff experiment in Hall D to measure $\alpha_{\pi+} - \beta_{\pi+}$

Proton electric polarizability α



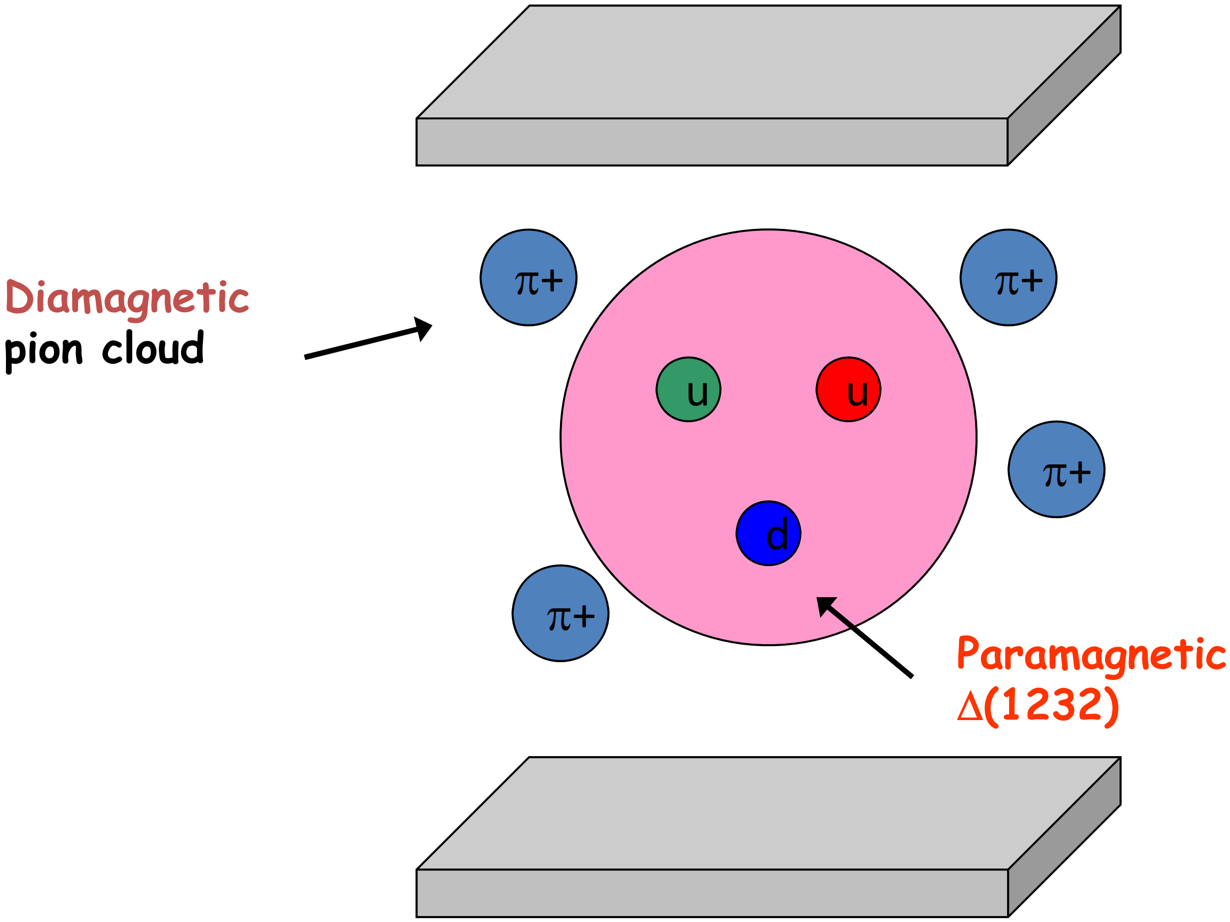
Electric polarizability: proton between charged parallel plates

Proton electric polarizability α



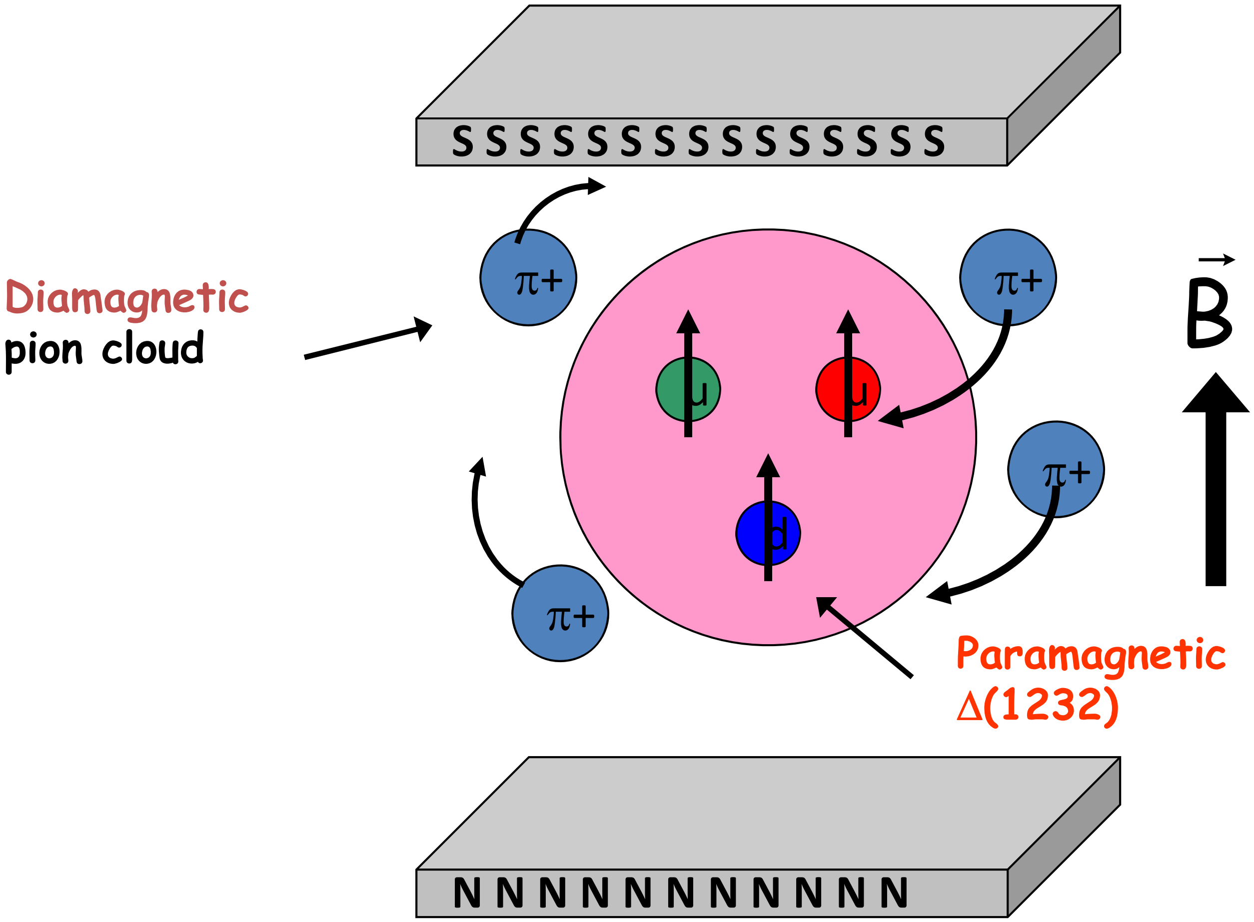
Electric polarizability: proton between charged parallel plates

Proton magnetic polarizability β



Magnetic polarizability: proton between poles of a magnetic

Proton magnetic polarizability β



Magnetic polarizability: proton between poles of a magnetic

Theory:

PCAC and leading order $O(p^4)$ ChPT both predict that the electric and magnetic polarizabilities of the charged pion, α_π and β_π , are related to the charged pion weak form factors F_V and F_A in $\pi^+ \to e^+\nu\gamma$

$$\alpha_{\pi^+} = -\beta_{\pi^+} \propto \frac{F_A}{F_V} = \frac{1}{6}\left(L_6 - L_5\right)$$

where L_6 and L_5 are parameters of the Gasser and Leutwyler effective Lagrangian*. Using recent results from the PIBETA collaboration†, the $O(p^4)$ ChPT prediction for the charged pion electric and magnetic polarizabilities are

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

The $O(p^6)$ corrections are predicted# to be relatively small, *giving*

$$\alpha_{\pi^+} + \beta_{\pi^+} = 0.16 \times 10^{-4}\,\mathrm{fm}^3 \qquad \alpha_{\pi^+} - \beta_{\pi^+} = 5.7 \pm 1.0 \times 10^{-4}\,\mathrm{fm}^3$$

* J. Gasser and H. Leutwyler, Ann. Phys. 158, 142 (1984).
† M. Bychkov et al., Phys. Rev. Lett., 103, 051802 (2009).
\# U. Burgi, Nucl. Phys. B479, 392 (1996) and J. Gasser, M.A. Ivanov, and M. E. Sainio, Nucl. Phys. B745, 84 (2006).

Previous Experiments

Three different experimental techniques have been used to determine $\alpha_{\pi+}$ and $\beta_{\pi+}$.

- $\pi A \to \pi' \gamma A$ in the Primakoff region, effectively Compton scattering on the pion. Serpukov obtained $\alpha_{\pi+}$-$\beta_{\pi+}$ = 13.6 $\pm 2.8_{stat} \pm 2.4_{sys} \times 10^{-4}$ fm^3 †

- Radiative pion photoproduction $\gamma p \to \gamma' \pi^+ n$ at low *t*, effectively Compton scattering off a virtual pion. Investigated most recently at Mainz #, the result $\alpha_{\pi+}$-$\beta_{\pi+}$ = 11.6 $\pm 1.5_{stat} \pm 3.0_{sys} \times 10^{-4}$ fm^3 is in agreement with Serpukov. Combining statistical and systematic errors in quadrature, Mainz differs by 1.7σ from the ChPT prediction.

- $e^+e^- \to \gamma\gamma \to \pi^+\pi^-$. Sensitive to the combination $\alpha_{\pi+}$-$\beta_{\pi+}$. Wide range of experimental results, $4.4 < \alpha_{\pi+} < 52.6 \times 10^{-4}$ fm^3. *

* See J. Gasser, M.A. Ivanov, and M. E. Sainio, Nucl. Phys. B745, 84 (2006).
† Yu. M. Antipov et al., Phys. Lett. B121, 445 (1983).
# J. Ahrens et al., Eur. Phys. J. A23, 113 (2005).

Experimental summary

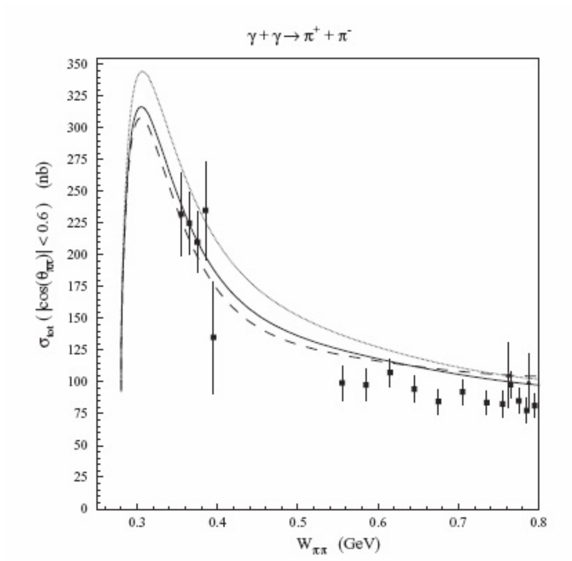
• Based on existing data, difficult to assess the extent of agreement or disagreement with theory.

• Generally recognized that the most model-independent way to measure polarizabilities is through Compton scattering.

i. The Serpukov (real pion) and Mainz (virtual pion) results agree that $\alpha_{\pi+}$-$\beta_{\pi+}$ is approximately twice size predicted by ChPT, albeit with large errors.

ii. The Compass (Primakoff) collaboration initially reported a value for $\alpha_{\pi+}$-$\beta_{\pi+}$ in agreement with ChPT, then retracted the result.

• The $\gamma\gamma \to \pi^+\pi^-$ experiments have been hampered by sparse data and the lack of a reliable theoretical model for calculating cross sections.



Existing data: approximately 400 events in the region of interest $W_{\pi\pi}$ < 0.5 GeV.

J. Boyer et al. (MARK-II Collaboration), Phys. Rev. D 42, 1350 (1990).

Measuring $\gamma\gamma \rightarrow \pi^+\pi^-$ in Hall D

• Measure $\gamma\gamma \rightarrow \pi^+\pi^-$ cross sections via the Primakoff effect using the GlueX detector in Hall D.

$$\frac{d^3\sigma}{d\Omega_{\pi\pi}^{Lab} d\Omega_{\pi}^{CM} dW_{\pi\pi}} = \frac{d\Gamma\left(\gamma\gamma \rightarrow \pi^+\pi^-\right)}{d\Omega_{\pi}^{CM} dW_{\pi\pi}} \frac{8\alpha Z^2}{W_{\pi\pi}^3} \frac{\beta^3 E_\gamma^4}{Q^4} \left|F_{EM}(Q)\right|^2 \sin^2\theta_{\pi\pi}$$

where the differential rate for $\gamma\gamma \rightarrow \pi^+\pi^-$ is given by

$$\frac{d\Gamma\left(\gamma\gamma \rightarrow \pi^+\pi^-\right)}{d\Omega_{\pi}^{CM} dW_{\pi\pi}} = \frac{d\sigma\left(\gamma\gamma \rightarrow \pi^+\pi^-\right)}{d\Omega_{\pi}^{CM}} \frac{W_{\pi\pi} k_{\pi}^{CM}}{8\pi^2}$$

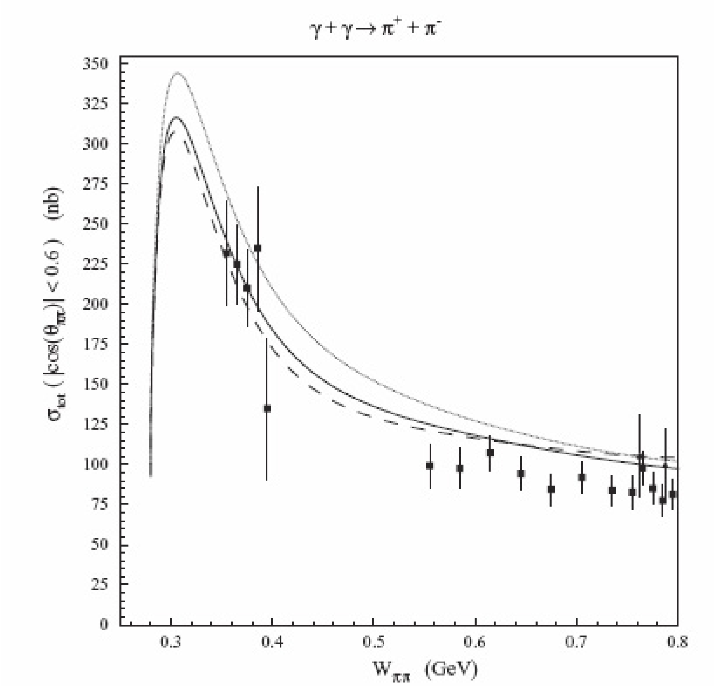
• *Assuming 30 cm LH_2 target, 10^7 photons/s, and 1000 hours of running, then 30,000 $\pi^+\pi^-$ Primakoff events are produced in the threshold region up to $W_{\pi\pi} \approx 0.5$ GeV. About 100× existing data sample.*

• Need to calculate the acceptance, and resolution in $W_{\pi\pi}$, $\theta_{\pi\pi}^{Lab}$, and θ_{π}^{CM} using GlueX. Aram Teymurazyan made some progress in doing this in early 2010, need to continue effort.

Theoretical model for $\gamma\gamma \rightarrow \pi^+\pi^-$

• Pasquini and collaborators have recently shown that the pion polarizability predictions of dispersion theory and ChPT are consistent [†].

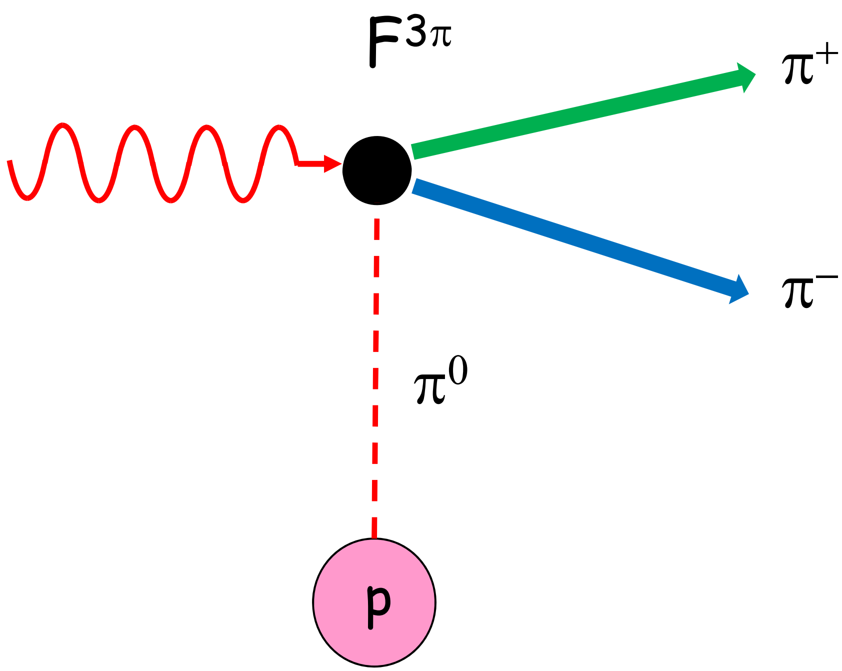
• Subtracted dispersion relation calculation[†] provides a solid theoretical basis for the calculation of $\gamma\gamma \rightarrow \pi^+\pi^-$ cross sections with only one input parameter, $\alpha_{\pi+}$-$\beta_{\pi+}$.



• Will study the sensitivity of σ_{tot} and $d\sigma/d\Omega_\pi^{CM}$ to $\alpha_{\pi+}$-$\beta_{\pi+}$.

† B. Pasquini, D. Drechsel, and S. Scherer, Phys. Rev. C 77, 065211 (2008).

Background that is coherent with $\gamma\gamma \rightarrow \pi^{+}\pi^{-}$



$F^{3\pi}$ is predicted by the chiral anomaly