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Pion Polarizability at CERN COMPASS

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Abstract: The electric α_π and magnetic β_π charged pion polarizabilities characterize the induced dipole moments of the pion during $\gamma\pi$ scattering. These fundamental characterisitcs of the pion provide stringent tests of various theoretical models, for example chiral perturbation theory (ChPT). CERN COMPASS investigated pion Compton scattering $\gamma\pi \rightarrow \gamma\pi$, via radiative pion Primakoff scattering (Bremsstrahlung of 190 GeV/c negative pions) in the nuclear Coulomb field of the Ni nucleus: $\pi + \text{Ni} \rightarrow \pi + \gamma + \text{Ni}$. The resulting data are equivalent to $\gamma\pi$ Compton scattering for laboratory γ's having momenta of order 1 GeV/c incident on a target pion at rest. The data yield preliminary polarizability values $\alpha_\pi = -\beta_\pi = (1.9\pm0.7_{stat}\pm0.8_{syst})\times10^{-4}\text{fm}^3$, in agreement with ChPT.

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http://pos.sissa.it

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1. Introduction

The electric α_π and magnetic β_π charged pion polarizabilities characterize the induced dipole moments of the pion during $\gamma\pi$ scattering. These moments are induced via the interaction of the γ's electromagnetic field with the quark substructure of the pion. In particular, α_π is the proportionality constant between the γ's electric field and the electric dipole moment, while β_π is similarly related to the γ's magnetic field and the induced magnetic dipole moment. The polarizabilities are fundamental characterisitcs of the pion. They provide stringent tests of various theoretical models like chiral perturbation theory (ChPT), dispersion sum rules, QCD sum rule and quark confinement models. All theories predict that $\alpha_\pi+\beta_\pi$ is close to zero.

2. The COMPASS pion polarizability experiment

The COMPASS collaboration at CERN detemined $\alpha_\pi-\beta_\pi$ by investigating pion Compton scattering $\gamma\pi \to \gamma\pi$ at center-of-mass energies below 3.5 pion masses. Compton scattering was measured via radiative pion Primakoff scattering (Bremsstrahlung of 190 GeV/c negative pions) in the nuclear Coulomb field of the Ni nucleus: $\pi + Ni \to \pi + \gamma + Ni$. The Primakoff process is illustrated in Fig. 1. Exchanged quasi-real photons are selected by isolating the sharp Coulomb peak observed at lowest momentum transfers to the target nucleus, $Q^2 < 0.0015\ GeV^2/c^2$. The resulting data are equivalent to $\gamma\pi \to \gamma\pi$ Compton scattering for laboratory γ's having momenta of order 1 GeV/c incident on a target pion at rest. In the reference frame of this target pion, the cross section is sensitive to $(\alpha_\pi-\beta_\pi)$ at backward angles of the scattered γ's. This corresponds to forward angles in the laboratory frame for the highest energy Primakoff γ's.

COMPASS used a beam of negative hadrons (~97% pions & 3% kaons). The COMPASS spectrometer has a silicon tracker to measure precise meson scattering angles, electromagnetic calorimeters for γ detection and for triggering, and Cherenkov threshold detectors for K/π separation. Systematic uncertainties were controlled by many tests, including replacing pions by muons while keeping the same beam momentum. The muon Compton scattering cross section is precisely known, since muons have no internal structure and therefore have zero polarizabilities. From a 2009 data sample of 60,000 events, assuming $\alpha_\pi+\beta_\pi=0$ based on theory, the extracted preliminary pion polarizabilities were determined. Higher statistics data taken in 2012 will allow an independent and high precision determination of α_π and β_π without assuming $\alpha_\pi+\beta_\pi=0$, and a first determination of Kaon polarizabilities.

3. Determination of the pion polarizability and comparison with theory.

Assuming $\alpha_\pi+\beta_\pi=0$, the dependence of the laboratory differential cross section on $x_\gamma=E_\gamma/E_\pi$ is used to determine α_π, where x_γ is the fraction of the beam energy carried by the final state γ.
Let $\sigma_E(x_\gamma,\alpha_\pi)$ and $\sigma_{MC}(x_\gamma,\alpha_\pi)$ denote the experimental and calculated (via Monte Carlo simulation) laboratory frame differential cross section for a pion (polarizability α_π) as function of x_γ; such that $\sigma_{MC}(x_\gamma,\alpha_\pi=0)$ denotes the cross section for a point-like pion having zero polarizability. The $\sigma_E(x_\gamma,\alpha_\pi)$ (Real Data) are obtained after subtracting backgrounds from the $\pi + Ni \to \pi + \gamma + Ni$ diffractive channel and the $\pi + Ni \to \pi + \pi^0 + Ni$ diffractive and Primakoff channels. Experimental ratios $R_E=\sigma_E(x_\gamma,\alpha_\pi)/\sigma_{MC}(x_\gamma,\alpha_\pi=0)$ and theoretical ratios $R=\sigma_{MC}(x_\gamma,\alpha_\pi)/\sigma_{MC}(x_\gamma,\alpha_\pi=0)$ are shown in Fig. 2. The polarizability α_π and its statistical error are extracted by fitting R_E to

$$R = \frac{3}{2} \cdot \frac{m_\pi^3}{\alpha} \cdot \frac{x_\gamma^2}{1-x_\gamma}\,\alpha_\pi$$

Here, m_π is the pion mass, α is the fine structure constant, and the ratio R is shown in Fig. 2 as the solid curve. Systematic uncertainties were controlled by measuring $\mu + \mathrm{Ni} \to \mu + \gamma + \mathrm{Ni}$ cross sections. The main contribution to the systematic uncertainties comes from the Monte Carlo description of the COMPASS setup. Comparing the x_γ dependences of R_E and R yields: $\alpha_\pi = -\beta_\pi = (1.9\pm0.7_{\mathrm{stat}}\pm0.8_{\mathrm{syst}})\times10^{-4}\mathrm{fm}^3$ or equivalently $\alpha_\pi - \beta_\pi = (3.8\pm1.4_{\mathrm{stat}}\pm1.6_{\mathrm{syst}})\times10^{-4}\mathrm{fm}^3$.
Fig. 3 shows previous polarizabilty data [1], the preliminary COMPASS data, and the ChPT prediction.The COMPASS polarizabilities agree with ChPT, $\alpha_\pi - \beta_\pi = (5.7\pm1.0)\times10^{-4}\mathrm{fm}^3$ [1].

Fig. 1: Primakoff Process: Radiative pion scattering (Bremsstrahlung) on quasi-real photons in the nuclear Coulomb field.

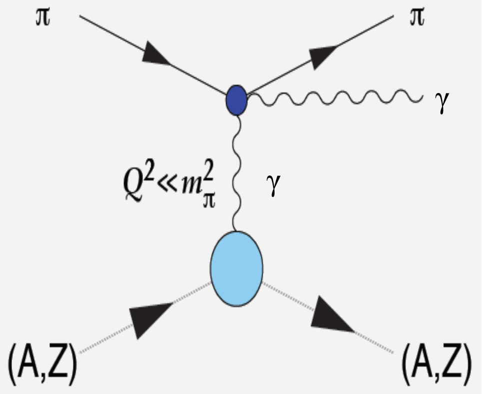
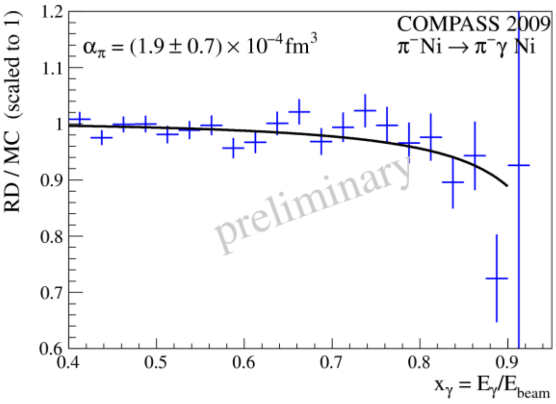


Fig. 2: Fit to the x_γ distribution of the ratio of Real Data (RD) to a Monte Carlo (MC) simulation with zero polarizabilities.



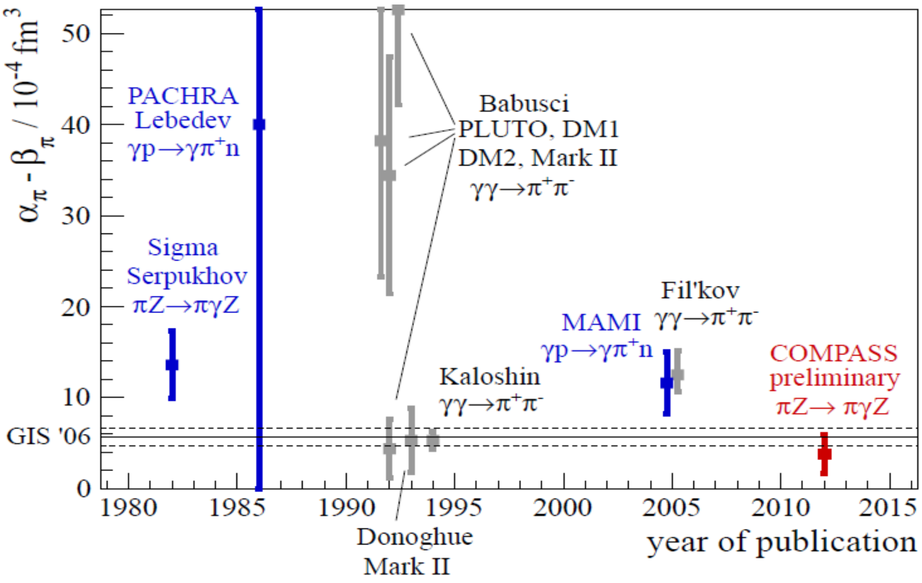


Fig. 3: Overview of world polarizability data and ChPT prediction (GIS'06 [1])

References

[1] J. Gasser et al., (2006). Revisiting $\gamma\gamma \to \pi^+ \pi^-$ at low energies. Nucl. Phys. B745, 84-108