# Pion Polarizability Status Report

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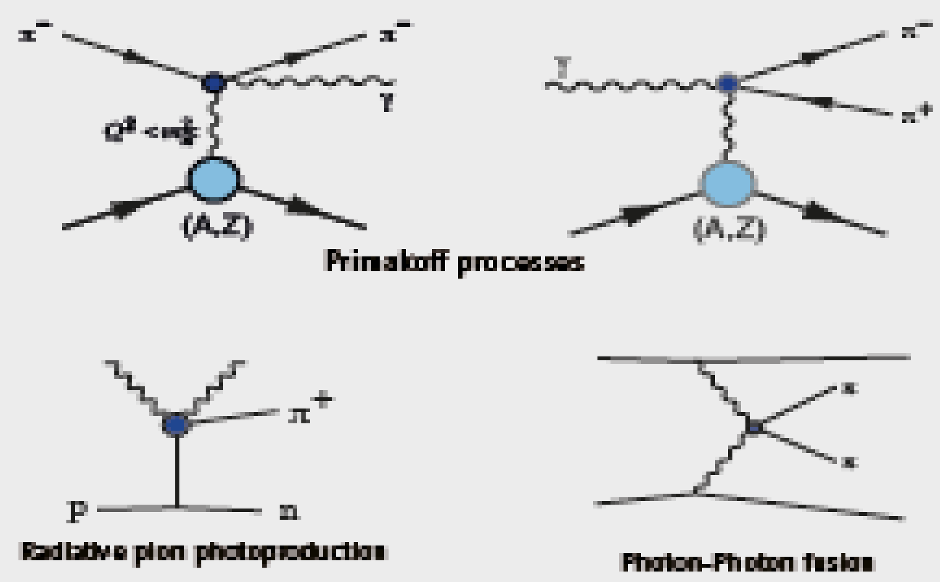
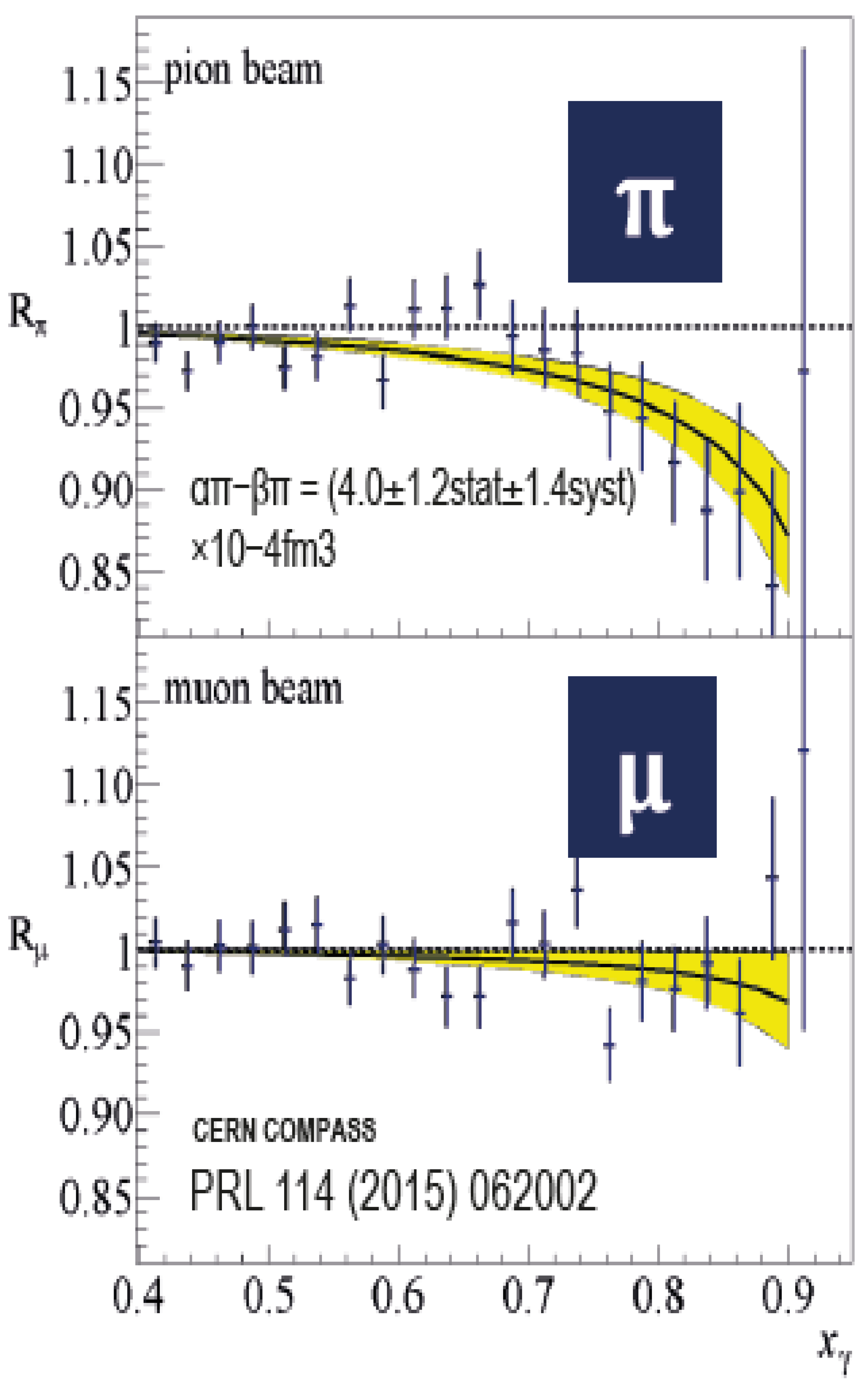
The electric $\alpha_\pi$ and magnetic $\beta_\pi$ charged pion Compton polarizabilities are of fundamental interest in the low-energy sector of quantum chromodynamics (QCD). They are directly linked to the phenomenon of spontaneously broken chiral symmetry within QCD and to the chiral QCD lagrangian. The combination ($\alpha_\pi-\beta_\pi$) was measured by: (1) CERN COMPASS via radiative pion Primakoff scattering (Bremsstrahlung) of 190 GeV/c pions in the nuclear Coulomb field, $\pi$-Z $\rightarrow$ $\pi$-Z$\gamma$, (2) SLAC PEP Mark-II via two-photon production of pion pairs, $\gamma\gamma\rightarrow\pi^+\pi^-$, and (3) Mainz Microtron MAMI via radiative pion photoproduction from the proton, $\gamma p\rightarrow \gamma\pi^+ n$. COMPASS and Mark-II agree with one another: (1) $\alpha_\pi-\beta_\pi = (4.0\pm1.2_{stat}\pm1.4_{syst})\times10^{-4}\,fm^3$, (2) $\alpha_\pi-\beta_\pi = (4.4\pm3.2_{stat+syst})\times10^{-4}\,fm^3$. The Mainz value (3) $\alpha_\pi-\beta_\pi = (11.6 \pm 1.5_{stat} \pm 3.0_{syst} \pm 0.5_{model}) \times10^{-4}\,fm^3$ is excluded on the basis of a dispersion relations calculation which uses the Mainz value as input, and gives significantly too large $\gamma\gamma\rightarrow\pi^0\pi^0$ cross sections compared to DESY Crystal Ball data. COMPASS and Mark-II polarizability values agree well with the two-loop chiral perturbation theory (ChPT) prediction $\alpha_\pi-\beta_\pi = (5.7\pm1.0)\times10^{-4}\,fm^3$, thereby strengthening the identification of the pion with the Goldstone boson of QCD.




**Methods of studying pion polarizabilities:**
Primakoff Processes: Radiative pion scattering (Bremsstrahlung) on quasi-real photons in the nuclear Coulomb field; Primakoff scattering of high energy $\gamma$'s in the nuclear Coulomb field leading to two photon fusion production of pion pairs, radiative pion photoproduction on proton $\gamma p\rightarrow\gamma\pi n$; two-photon fusion production of pion pairs $\gamma\gamma\rightarrow\pi\pi$ via the $e^+e^- \rightarrow e^+e^-\pi^+\pi^-$ reaction.

Determination of the pion polarizability by fitting the $x_\gamma$ distribution of the experimental ratios $R_\pi$ (data points) to the theoretical (Monte Carlo) ratio $R_T$ (solid line). Experimental and Theoretical Ratios are taken with respect to MC calculations with zero polararizability.

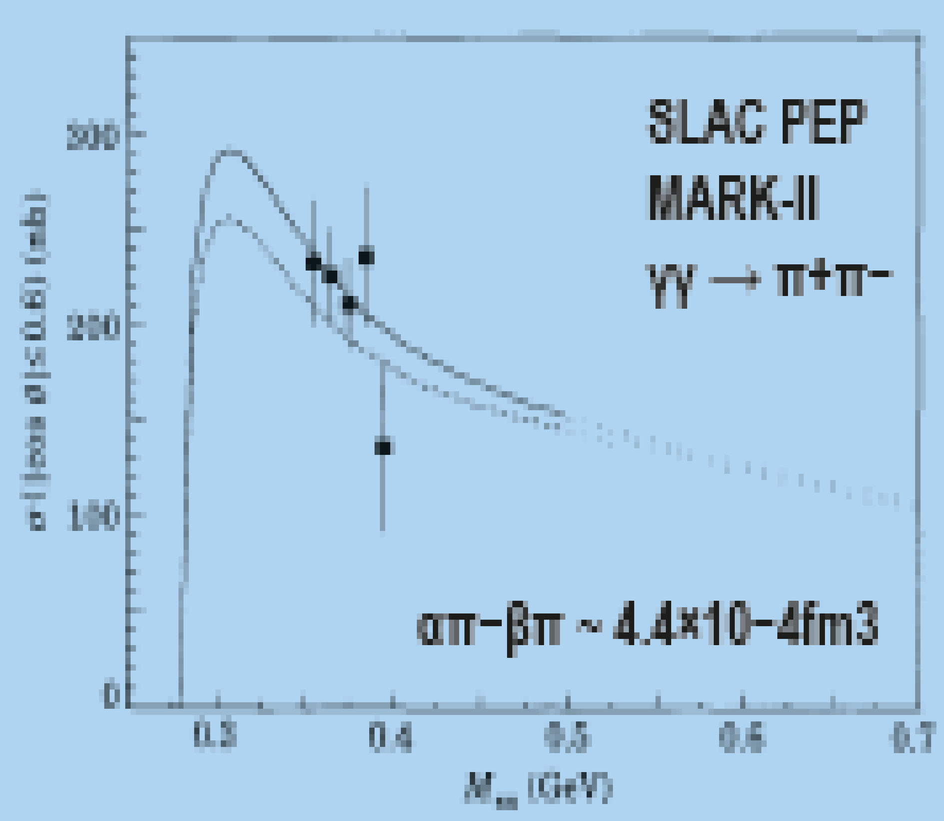



Pions of 190 GeV/c were scattered from virtual photons in the Coulomb field of a Ni target. The dependence of the $\pi^-$ Ni $\rightarrow$ $\pi^-$ Ni $\gamma$ laboratory differential cross section $\sigma$ at very small momentum transfer on $x_\gamma=E_\gamma/E_\pi$ is used to determine $\alpha_\pi$, where $x_\gamma$ is the fraction of the pion beam energy carried by the final state $\gamma$ ray. The variable $x_\gamma$ is related to the $\gamma$ scattering angle for $\gamma\pi \rightarrow \gamma\pi$, and $\alpha_\pi+\beta_\pi=0$ is assumed. Experimental ratios $R_\pi=\sigma_E(x_\gamma)/\sigma_{MC}(x_\gamma,\alpha_\pi=0)$ and best fit (solid curve) theoretical ratios $R_T=\sigma_{MC}(x_\gamma)/\sigma_{MC}(x_\gamma,\alpha_\pi=0)$ are shown in the figure. Ratios are taken with respect to MC calculations with zero polararizability. The polarizability $\alpha_\pi$ and its statistical error are extracted by fitting $R_\pi$ to:

CERN COMPASS

$$R = \frac{\sigma(x_\gamma)}{\sigma_{\alpha_\pi=0}(x_\gamma)} = \frac{N_{meas}(x_\gamma)}{N_{sim}(x_\gamma)} = 1-\frac{3}{2}\cdot\frac{m_\pi^3}{\alpha}\cdot\frac{x_\gamma^2}{1-x_\gamma}\,\alpha_\pi$$

where $\alpha$ is the fine structure constant. Systematic uncertainties were controlled by measuring $\mu^-$ Ni $\rightarrow$ $\mu^-$ Ni $\gamma$ cross sections. The best fit yields $\alpha_\pi-\beta_\pi = (4.0\pm1.2_{stat}\pm1.4_{syst})\times10^{-4}fm^3$.




Total cross section data for $M_{\pi\pi} \leq 0.5$ GeV. The theoretical curves are: Born (dash-dotted); ChPT with $\alpha_\pi-\beta_\pi \sim 4.4\times10^{-4}\,fm^3$ (solid).