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MEASUREMENT OF THE PION POLARISABILITY AT COMPASS

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Abstract

The COMPASS experiment at CERN has investigated Primakoff reactions of 190 GeV/c pions with the Coulomb field of various target nuclei, predominatly lead, in a pilot run in the year 2004. The photoproduction process $\pi^- Z \to \pi^- Z\gamma$ is related to Compton scattering on the pion, and gives access to the electric and magnetic polarisabilities, α_π and β_π. The unique feature of the COMPASS setup to measure the equivalent reaction with identified muons during the same beam time allows for a reliable treatment of systematic apparative effects. In a first analysis, the value $\alpha_\pi = 2.5 \pm 1.7_{\mathrm{stat}} \pm 0.6_{\mathrm{sys}} \cdot 10^{-4}$ fm^3 was obtained, assuming $\alpha_\pi = -\beta_\pi$ on theoretical reasons.

1 Introduction

The electromagnetic polarisability of the pion is a longstanding challenge in strong interaction physics, being on one hand a well-defined and much scruti-

Table 1: *Experimental situation of the pion polarisabilities.*

	$\alpha_\pi + \beta_\pi$	$\alpha_\pi - \beta_\pi$ $[10^{-4}\,\mathrm{fm}^3]$
$e^+e^- \to e^+e^-\pi^+\pi^-$		
Mark II [4]	$0.22 \pm 0.07 \pm 0.04$	4.8 ± 1.0
CELLO [3]	$0.33 \pm 0.06 \pm 0.01$	
$\gamma p \to n\pi^+\gamma$		
MAMI [5]		$11.6 \pm 1.5 \pm 3.0 \pm 0.5$
$\pi^- Z \to Z\pi^-\gamma$		
Serpukhov [6]	$1.8 \pm 3.1 \pm 2.5$	12.3 ± 2.6

nised quantity of the theory, on the other hand difficult to measure experimentally, due to the short lifetime of the pion. It is a decisive quantity for chiral perturbation theory (χPT), as the low momentum limit can be realised in Compton scattering, and an unambigious prediction derived from the radiative pion decay can be provided, $\alpha_\pi = 2.93 \pm 0.5 \cdot 10^{-4}$ fm^3 and $\beta_\pi = 2.77 \pm 0.5 \cdot 10^{-4}$ fm^3 [1]. Other theoretical approaches based on sum rules or quark confinement models predict mostly the polarisabilities tending to higher values, up to a factor 3, see [2] for an overview.

The experimental situation is also not conclusive, cf. Tab. 1. Early measurements, as the Serpukhov experiment, have supported a comparatively high value for the polarisabilities, confirmed by the recent MAMI measurement, while experiments on photon-photon reactions found reasonable agreement with the χPT calculation. A new measurement with high statistics and controlled systemtics is highly eligible.

2 Primakoff measurements with COMPASS

COMPASS [7] has been set up as multi-purpose fixed-target experiment with advanced LHC generation detectors and data acquisition at the CERN super proton synchrotron. Up to present time, mostly a 160 GeV/c tertiary muon beam has been used to study deep inelastic scattering on the nucleon. During 4 weeks of the beam time in the year 2004, the beam was changed to 190 GeV/c negative pions, and the spectrometer was optimized for the detection of soft hadronic reactions, namely diffractive dissociation and Primakoff processes.

The experimental technique for observing Primakoff reactions bases on a special property following from the Weizsäcker-Williams ansatz, where the nuclear Coulomb field is decomposed into quasi-real photons, which interact with the incoming particles. Consequently, the cross section for reactions with the nuclear electric field is factorised into the equivalent photon density and a real photon scattering cross section,

$$\frac{d^3\sigma}{dQ^2 d\omega d\cos\vartheta} = \frac{\alpha_f Z^2}{\pi\omega} \cdot \frac{Q^2 - Q^2_{\min}}{Q^4} \cdot \left|F_Z(Q^2)\right|^2 \frac{d\sigma_{\gamma\pi}(\omega,\vartheta)}{d\cos\vartheta} \tag{1}$$

with α_f the fine structure constant, ω the photon energy and ϑ the photon scattering angle in the π rest frame. Since the cross section is proportional to Z^2, a heavy target such as lead is favourable for a high yield, despite the larger radiative corrections. The Q^2 range of interest is limited, such that the nuclear form factor contribution is $|F_Z|^2 \approx 1$. The Q^{-4} term, arising from the photon propagator, leads to a steep fall of the differential cross section with increasing Q^2, and the Primakoff reaction appears as peak at very small values in the Q^2 spectrum, making it experimentally distinguishable from competing reactions and combinatorial background. For the Compton scattering process [8],

$$\frac{d\sigma_{\gamma\pi}}{d\Omega} = \left(\frac{d\sigma_{\gamma\pi}}{d\Omega}\right)_B - \frac{\alpha_f m_\pi^3 s_-^2}{4s_1^2(s_+ + zs_-)}\left[(1-z)^2(\alpha_\pi - \beta_\pi) + \frac{s_1^2}{m_\pi^4}(1+z)^2(\alpha_\pi + \beta_\pi)\right] \tag{2}$$

where the Born cross section is

$$\left(\frac{d\sigma_{\gamma\pi}}{d\Omega}\right)_B = \frac{\alpha_f^2}{2s_1} \cdot \left[1 + \left(\frac{s_- + zs_+}{s_+ + zs_-}\right)^2\right] \tag{3}$$

and s_1 the squared total energy in the $\gamma\pi$ centre of momentum system and $s_\pm = s_1 \pm m_\pi^2$.

Due to the small momentum transfer to the nucleus in these reactions, the scattered pion as well as the produced photon leave the interaction point under small angles of less than a few mrad. The photons in forward direction with $E_\gamma > 40$ are observed in an electromagnetic calorimeter, which also served as trigger. The incoming and outgoing pions were measured in silicon tracker detectors with a resolution of about $10\mu m$.

3 Data Analysis

The event selection required exactly one outgoing track of high quality and measured momentum, and one cluster in the calorimeter with an energy higher than 7 GeV. While the exclusivity of the reaction can not be ensured by the cut on the total energy balance, $E_\pi - E_{\pi'} - E_\gamma <25$ GeV, a clear signature of Primakoff reactions is seen in the Q^2 spectrum, cf. Fig. 1.

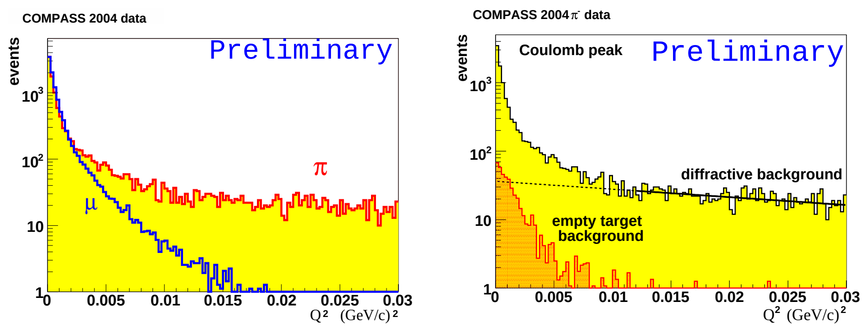

Figure 1: *Reconstructed Q^2 spectrum, showing the steep rise at small values due to Primakoff reactions. Left plot: The spectrum observed with pion beam is compared to the muon control measurement. It is seen that the contributions at higher Q^2 values are only present in the pion case, proving their origin in the additional hadronic reactions. The right plot indicates how the statistical weights are obtained in order to subtract higher-Q^2 (labelled diffractive background) and empty target contributions.*

The Primakoff events are selected with $Q^2 < 6.5 \cdot 10^{-3}$ GeV$^2/c^2$, and the non-Primakoff fraction under the peak is estimated by an extrapolation of an exponential function fitted to the Q^2 spectrum in the range $2 - 10 \cdot 10^{-2}$ GeV$^2/c^2$. The observed $\pi\gamma$-mass spectrum is presented in Fig. 2, where also the removal of background due to beam kaon decays (with a non-observed soft photon in $K^- \to \pi^-\pi^0$), is demonstrated. The mass is cut at $3.75{\cdot}m_\pi$, just below the region where ρ contributions set in.

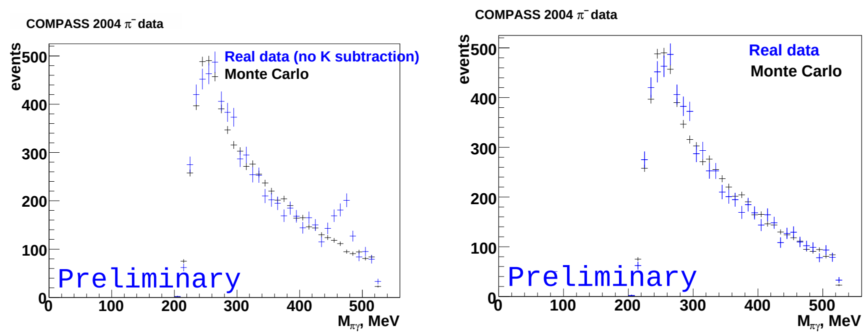

Figure 2: *The non-corrected $M_{\pi\gamma}$ spectrum shows a contribution from K decays (left), which disappear after proper "empty target" subtraction (right).*

Although most of the statistics was collected with lead target, some beam time was devoted to measure the Primakoff reaction also on carbon and copper targets. The observed Primakoff reactions show the expected Z^2-dependence of Eq. 1.

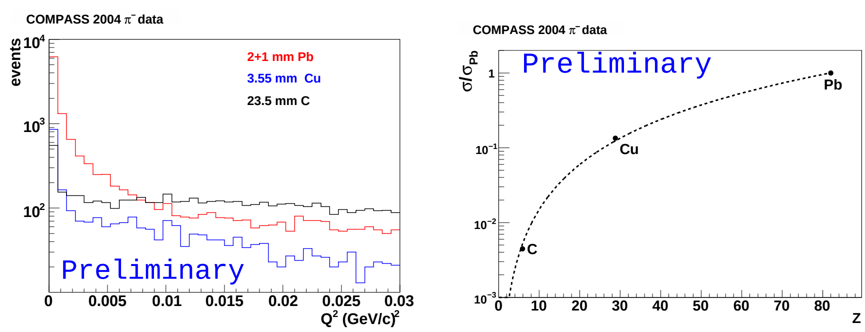

Figure 3: *Measurements of targets with different Z nuclei have all shown the characteristic Primakoff peak (left). After extracting the peak strength and normalizing to the lead luminosity, the Z^2 dependence of the Primakoff cross section is seen (right).*

In order to extract the polarisability contribution, the differential cross section $d\sigma(\alpha_\pi, \beta_\pi)/dx$ is compared to the case $\alpha_\pi{=}\beta_\pi{=}0$ of a "non-polarisable pion". Only the dependence of the relative photon energy[1] $x = E_\gamma/E_{\rm Beam}$ was investigated so far, which necessitates to make the assumption $\alpha_\pi = -\beta_\pi$, and consequently in the following only the dependence $d\sigma(\beta_\pi)/dx$ is studied.

Presently only a part of the statistics with a segmented lead target of 2+1 mm thickness was investigated, resulting in about 7500 Primakoff events. The acceptance of the apparatus is estimated using a Primakoff event generator (POLARIS [9]) and a Monte Carlo simulation by a GEANT description of the COMPASS setup. The resulting acceptance curve is depicted in Fig. 4 for both the pion and the muon beam cases, validating by the similar behaviour the estimate of systematic effects on the pion data from the interpretation of the muon data. Also, the increasing importance of the K^- ("empty target") subtraction at higher photon energies is apparent.

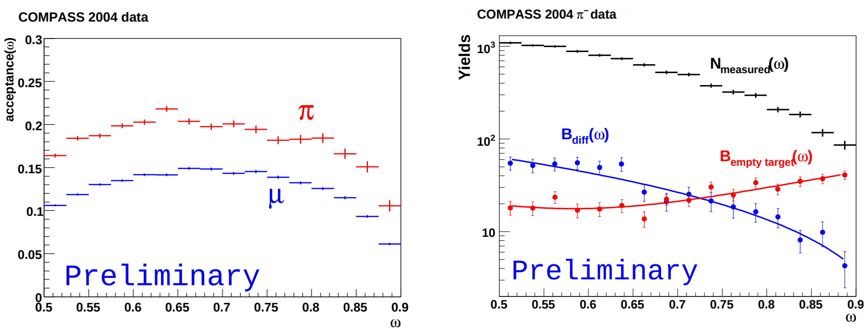

Figure 4: *The acceptance of the COMPASS spectrometer for Primakoff Compton scattering, depending on the relative outgoing photon energy (left), and the distributions of the previously discussed background contributions (right).*

In addition to the simulated acceptance correction, which was obtained using the one-photon Born approximation, the respective factors for radiative corrections were applied to the extent they have been derived up to now [10]. The resulting ratios $R = d\sigma(\beta_\pi)/d\sigma(0)$ are given in Fig. 5. It appears that a signal with the correct sign and magnitude is observed for the pion, taking the

[1]the relative photon energy is denoted "ω" in the figures

χPT prediction as a scale, while the muon data are in good agreement with the expectation of no polarisability signal. From its statistical error, an upper limit for the apparative systematic error $< 0.6 \cdot 10^{-4}\mathrm{fm}^3$ can be derived.

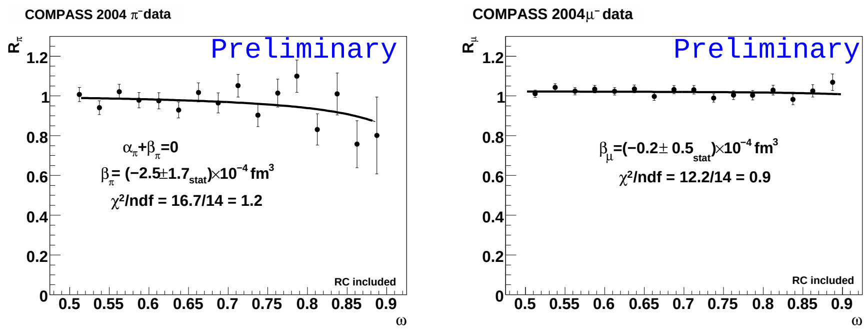

Figure 5: *Extraction of the pion magnetic polarisability β_π by its influence on the cross section shape at high relative outgoing photon energies (left). The control measurement with muon beam is shown on the right plot, giving an estimate for the apparative systematic uncertainty of the obtained result.*

4 Conclusions

The present analysis of the 2004 pion beam data demonstrates the capability of COMPASS to settle the experimental uncertainty of the pion polarisability, provided the necessary refinements of the analysis are taken on. With the full 2004 statistics evaluated, a firm estimate will be possible for a future Primakoff COMPASS data taking, including an independent extraction of α_π and β_π.

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