Meson structure in soft hadronic reactions at COMPASS

M. Colantoni on the behalf of the COMPASS coll.

Università del Piemonte Orientale e INFN-To

Abstract. The measurement of the electric ($\overline{\alpha}_\pi$) and magnetic ($\overline{\beta}_\pi$) pion polarizabilities supplies a significant test of QCD predictions in particular in the framework of the chiral perturbation theory.

In this perspective we have measured with the COMPASS spectrometer the t-dependence of the cross section for the reactions: $\pi^- + Z \rightarrow \pi^- + Z + \gamma$, and $\mu^- + Z \rightarrow \mu^- + Z + \gamma$ selecting events corresponding to the Compton $\pi\gamma$ and $\mu\gamma$ scattering respectively. From a fit of the data of the first reaction we can extract $\overline{\alpha}_\pi$ and $\overline{\beta}_\pi$, from those of the second the point-like contribution. This procedure minimizes the systematic errors. Details on the experiment and the present status of the analysis of the data collected in 2004 will be discussed.

Keywords: pion, polarizability, Compton scattering, kaon, chiral anomaly
PACS: 11.30.Rd; 12.39.Fe; 13.40.-f; 13.60.Fz; 13.75.Gx; 14.40.Aq

INTRODUCTION

The pion electric ($\overline{\alpha}_\pi$) and magnetic ($\overline{\beta}_\pi$) polarizabilities probe the response, to an external electromagnetic field, of the $q\overline{q}$ system. Those coefficients are fundamental parameters in pion physics and calculations provide important test for pionic structure as studied in QCD, or from various effective model of the pion (see [1, 2] for a theory review).

The Chiral Perturbation theory (χPT) [3] has been very successful in describing low energy hadronic properties and provides for the pion polarizabilities:

$$\overline{\alpha}_\pi = (2.4 \pm 0.5) \cdot 10^{-4} \ \ fm^3; \quad \overline{\beta}_\pi = (-2.1 \pm 0.5) \cdot 10^{-4} \ \ fm^3 \ \text{ from ref. [4].}$$

An improvement in the theoretical error bars for these values is foreseen in a near future [5].

Taking into account for all different theoretical approaches, the predictions for $\overline{\alpha}_\pi$ fall in the range $(2.4, 8.0) \cdot 10^{-4} fm^3$, whereas for $\overline{\beta}_\pi$ vary between $(-8.0, -2.1) \cdot 10^{-4} fm^3$.

These coefficients have been measured using:

- the crossed channel of $\gamma\gamma \rightarrow \pi^+\pi^-$
- the pion photoproduction from nucleons: $\gamma + N \rightarrow \gamma + N + \pi$.
- the radiative pion nucleus scattering or Primakoff reaction: $\pi + Z \rightarrow \pi + Z + \gamma$.

The results found are listed in Table 1. They are quite uncertain, therefore more precise measurements are needed. This can be done with the COMPASS spectrometer that provides good energy, momentum and angular resolution, high acceptance and stands high beam intensity.

TABLE 1. Experimental values of $\overline{\alpha}_\pi$, $(\overline{\alpha}_\pi + \overline{\beta}_\pi)$, $(\overline{\alpha}_\pi - \overline{\beta}_\pi)$

Data	Reaction	$\overline{\alpha}_\pi$ $[10^{-4} fm^3]$
Lebedev [6]	$\gamma + N \to \gamma + N + \pi$	20±12
PLUTO [7]	$\gamma\gamma \to \pi^+\pi^-$	19.1±4.8±5.7
DM1 [8]	$\gamma\gamma \to \pi^+\pi^-$	17.2±4.6
DM2 [9]	$\gamma\gamma \to \pi^+\pi^-$	26.3±7.4
Mark II [10]	$\gamma\gamma \to \pi^+\pi^-$	2.2±1.6
Serpukhov [11]	$\pi + Z \to \pi + Z + \gamma$	6.8±1.4±1.2
Data	**Reaction**	$(\overline{\alpha}_\pi + \overline{\beta}_\pi)$ $[10^{-4} fm^3]$
Serpukhov [12]	$\pi + Z \to \pi + Z + \gamma$	1.4±3.1±2.8
Data	**Reaction**	$(\overline{\alpha}_\pi - \overline{\beta}_\pi)$ $[10^{-4} fm^3]$
Mami A2 [13]	$\gamma + p \to \gamma + \pi^+ + n$	11.6±1.5±3.0±0.5

THE PRIMAKOFF REACTION

The radiative pion nucleus scattering or Primakoff reaction is characterized by the sharp dependence on t of the cross section for very small value of t ($t \leq 10^{-3}(GeV/c)^2$) ($t = (p_\pi^b - p_\pi^s - p_\gamma)^2$ where p_π^b, p_π^s, p_γ represent respectively the four-momentum of the pion beam, the scattered pion and the real gamma). In this region the contribution of the diffractive interaction background remains small [14].

When given in the anti-laboratory system (alab), that is the rest frame of the incoming pion, the differential cross section is described by the formula:

$$\frac{d^3\sigma}{dt d\omega dcos\theta} = \frac{2\alpha^3 Z^2}{m_\pi^2 \omega} \frac{t - t_0}{t^2} |F_A(t)|^2 \cdot \left(F_{\pi\gamma}^{Pt} + \frac{m_\pi \omega^2}{\alpha} \cdot \frac{\overline{\alpha}_\pi (1 + cos^2\theta) + 2\overline{\beta}_\pi cos\theta}{(1 + \frac{\omega}{m_\pi}(1 - cos\theta))^3} \right) \quad (1)$$

where $t_0 = (\frac{m_\pi \omega}{p_{beam}})^2$, m_π is the pion mass, ω the energy of the virtual photon in the alab system. θ is the angle between the real photon and the virtual photon directions in the alab system, α is the fine structure constant, Z is the charge of the nuclear target, $F_A(t)$ is the electromagnetic form factor of the nucleus ($F_A(t) \approx 1$ for $t < 10^{-3}(GeV/c)^2$). Here $F_{\pi\gamma}^{Pt}$ [15] describes the differential Compton cross section for the scattering of photon on a point-like spin-0 particle. The main characteristic of the cross section (Eq. 1) is that it depends on $(\overline{\alpha}_\pi + \overline{\beta}_\pi)$ at forward angles and on $(\overline{\alpha}_\pi - \overline{\beta}_\pi)$ at backward angles.

For high values of Z and higher beam momenta (t_0 gets smaller) the cross section (see Eq. 1) becomes higher. For this reason for the experiment we are reporting here a pion beam momentum of 190 GeV/c has been chosen together with a lead target. For consistency, to check for the Z^2 dependence of the cross section, also carbon (C) and copper (Cu) targets have been used. These additional measurements provide also a cross check of the diffractive background subtraction below the Coulomb region.

Unique feature of COMPASS experiment is the availability of the muon beams that allow for a measurement of $F_{\mu\gamma}^{Pt}$ in the same experimental conditions as in the pion data taking. In this way we have a better control of the systematics errors in the measurement.

A description of the COMPASS spectrometer as used for the 2004 hadron run can be found elsewhere [16]. The performances of the apparatus have been investigated with Monte-Carlo simulations [17, 18, 19, 20, 21]. In particular it was found that the resolution on t, needed to distinguish the EM contributions from the diffractive scattering, was lower than $5 \cdot 10^{-4} (GeV/c)^2$.

THE MEASUREMENT AT COMPASS

Here will be described the *preliminary* analysis of the 2004 data taken with 190 GeV/c pion minus beam and the lead target. In a beam period of about 5 days we collected a total beam flux of more than $10^{11}\pi$.

To detect pions ($|\overrightarrow{p^s_\pi}|$ 20-110 GeV/c) we added to the COMPASS setup [16] a scintillator hodoscope just in front of the second electromagnetic calorimeter (ECAL2), about 36 m downstream of the target. The energy of the gammas was measured in ECAL2. The coincidence of these two detectors was the trigger selecting Primakoff events and allowing together with the track reconstruction the complete determination of the energy of the $\pi\gamma$ system. For high energy gammas (E_γ>100 GeV) when pion momentum is lower than 20 GeV/c and then the pion can not be detected by the hodoscope, the trigger was given by ECAL2 alone. During the analysis a single pion track was required in the trackers upstream of the hodoscope.

For the data analysis we applied the following main cuts:

1. the reconstructed position of interaction vertex has to fall within ± 5 cm of the position of 3 mm Pb target,
2. total energy $E_{tot} = E_\pi + E_\gamma = E_{beam} \pm 25 GeV$,
3. $t < 1.5 \cdot 10^{-3} (GeV/c)^2$.

In fig.1a is reported the reconstructed position of the interaction vertex distribution along the beam axis, from which the target and the nearby detectors can be clearly distinguished. The plot of E_{tot}, obtained selecting only the target events, is given in fig.1b. The peak of the E_{tot} distribution is well centered around the nominal energy of the beam. Applying the E_{tot} cut we can get the t-dependence of the yield given in fig.2. The shape of the distribution is clearly consistent with what is expected for a Coulomb interaction. The mentioned cuts strongly suppress (factor 10) the contamination from the K^- (4.5% of the beam) decay, $K^- \rightarrow \pi^- + \pi^0$, where a K^- is misidentified and only one photon coming from the $\pi^0 \rightarrow \gamma\gamma$ decay is detected by the trigger. This can be also seen in fig.2 where the remain background from the strong interaction is minimal and will be also reduced from the analysis of the runs taken with an empty target. Other systematic errors will be evaluated from the data collected with the muon beam in the same experimental conditions. The data analysis is still in progress. In the figures is shown less than one tenth of the available statistics. When all the data will be analyzed we expect to have four times more data than in the previous Primakoff experiment [11, 12]

OTHER MEASUREMENTS

We foresee, in the Primakoff program, also the the measurement, for the first time, of the kaon polarizabilities. The pion beam contains about the 4.5% of kaons that will be selected with Cerenkov Differential counters with Achromatic ring focus (CEDAR)[22]. These detectors were successful tested in the 2004 pilot hadron run. We plan to use them in the 2007 hadron runs.

Because of the good spatial resolution of ECAL2, we can detect events with two photons in coincidence to reconstruct the π^0 mass. This allows to study the process $\pi^- + (Z,A) \rightarrow \pi^- + (Z,A) + \pi^0$ in parallel to the polarizabilities measurements. The goal is to extract the value of the pion form factor $F_{3\pi}$ in order to check the relation with the chiral axial anomaly term F_π via the low energy theorem [23].

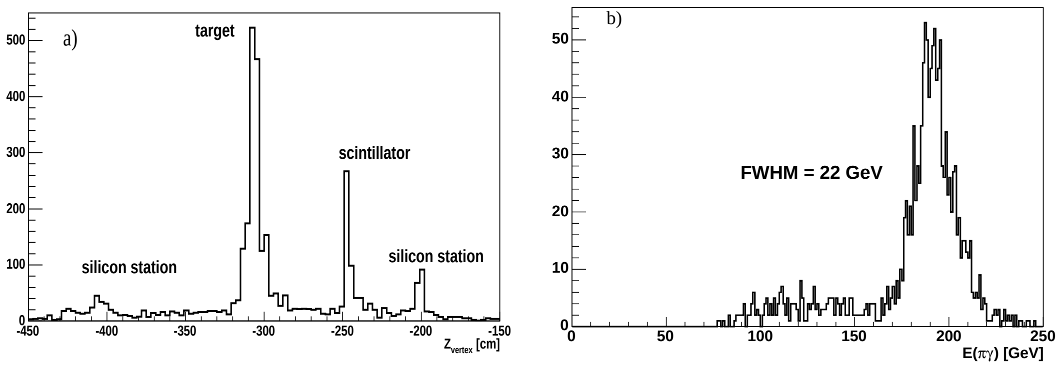

FIGURE 1. a) Vertex distribution along beam axis, b) Total energy of the system $\pi\gamma$

CONCLUSION

The COMPASS 2004 pilot hadron run was successfully completed, collecting an integrated beam flux of more than 10^{11} pions for the polarizabilities measurement. A preliminary analysis shows clearly the signature for the Primakoff reaction, and the statistics expected for this analysis is about 30-40K events that is at least four times larger than in the previous Primakoff experiment [11, 12]. Therefore COMPASS can provide a more precise measurement of the pion polarizabilities. The first measurement of the kaon polarizabilities and important checks of the chiral anomaly hypothesis are also foreseen for the near future.

REFERENCES

1. J. Portoles, M.R. Pennington, *The second DaΦne* Physics Handbook v.2, 579 (1999), hep-ph/9407295
2. C.A. Wilmot, R.H. Lemmer, Phy. Rev. C 65, 035206 (2002)
3. S. Weinberg, Physica **A 96** 327 (1979), J. Gasser and H. Leutwyler, Annals Phys. **158** 142 (1984), J. Gasser and H. Leutwyler, Nucl. Phys. **B250** 465 (1985)
4. U. Bürgi, Phys. Lett. **B377** 147 (1996)

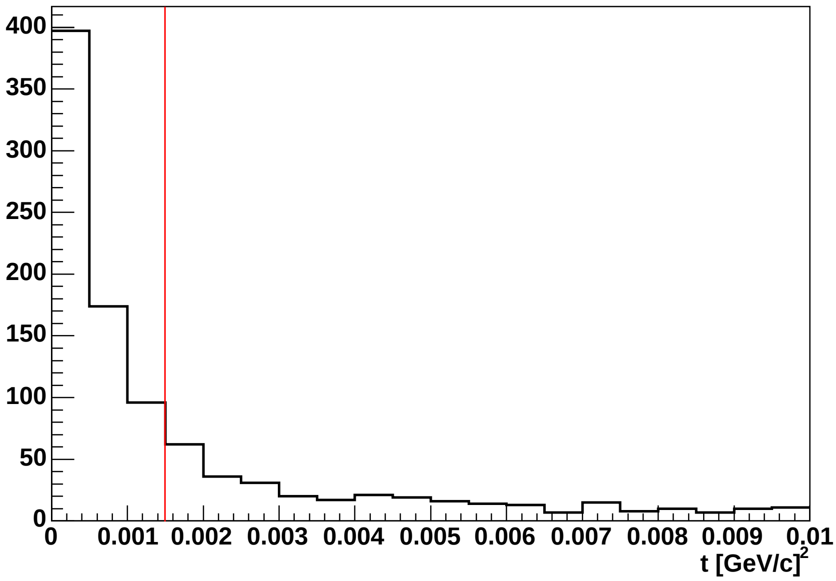

FIGURE 2. Yield plotted vs *t*

5. J. Gasser, Future Physics @ COMPASS, CERN Yellow Report 2004
6. T.A. Aibergenov et al., Cezch J. Phys B 36, 948 (1986)
7. C. Berger et al., Z. Phys. **C26** 199 (1984)
8. A. Courau et al., Nucl. Phys. **B271** 1 (1986)
9. Z. Ajaltoni et al.,*VII Int. workshop on photon-photon collision* Paris (1986)
10. J. Boyer et al., Phys. Rev **D42**, 1350 (1990), D. Babusci et al., Phys Lett. **B277**,158 (1992)
11. Yu M. Antipov et al., Phys. Lett. **B121**, 445 (1983)
12. Yu M. Antipov et al., Z. Phys. **C26**, 495 (1985)
13. J. Ahrens et al., Eur. Phys. J **A23** 113 (2005)
14. M. Colantoni, Czech. J. Phys. 55 43 (2005) Supp. A
15. M. Buenerd, Nucl. Phys. **A361** 111 (1995)
16. COMPASS Collaboration, *Proposal for a Common Muon Proton Apparatus for Structure and Spectroscopy*, http://wwwcompass.cern.ch/, A. Ferrero Czech. J. Phys. 55 35 (2005) Supp. A
17. M. A. Moinester, Pion polarizabilities and Hybrid meson structure at COMPASS, hep-ex/0012063
18. M. Sans Merce, Ph.D thesis, Ludwig Maximilians University, Munich, 2001
19. R. Kuhn, Diploma thesis, Technical University,Munich, 2001
20. A. Olchevski, M. Faessler, Experimental requirements for COMPASS Initial Primakoff Physics program, COMPASS coll. Meeting 2001.
21. M. Colantoni, Ph.D thesis,Universitá di Torino, Torino, 2002, XL International Winter Meeting on Nuclear Physics, Bormio, Italy, January 21-26, 2002
22. C. Bovet et al., The Cedar counters for particle identificationin the SPS beams: A description and an operation manual, SPS-note-82-40
23. S.L. Adler, Phys. Rev. 177 2426 (1969); J.S. Bell, R. Jackiw, Nuovo Cimento 60A 47 (1969)