Meson spectroscopy in diffractive dissociation of high-energetic pions at COMPASS

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Abstract. COMPASS at CERN uses hadron and muon beams with up to 200 GeV/c momentum, produced from the SPS proton beam, for investigations in hadron structure and spectroscopy.

From a pilot run with a 190 GeV/c pion beam on a lead target, various results are presented. In the region of low momentum transfer, interference of photon-exchange and strong production of the $a_1(1260)$ and $a_2(1320)$ resonances is observed, revealing the different nature of the two interactions.

Keywords: Partial-wave analysis, Chiral Lagrangians, Meson production, Inelastic scattering: many-particle final states, Light mesons
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INTRODUCTION

COMPASS [1] investigates hadron structure and spectroscopy by various methods, scattering hadron and muon beams with up to 200 GeV$/c$ from the CERN SPS facility off fixed targets. A more detailed description of the setup for hadron spectroscopy as operated in the years 2008 and 2009, as well as an overview of the structure physics results obtained with muon beam, can be found in these proceedings [2, 3]. In 2004, first data were taken with a 190 GeV$/c$ pion beam on various nuclear targets. Mostly lead was used, featuring the highest fraction of Primakoff events as discussed in the following section.

INTERACTIONS AT LOW MOMENTUM TRANSFER

Connecting high rate capability with high precision, COMPASS is ideally suited to study exclusive reactions of pions scattering off nuclear targets. At low momentum transfer, two interactions compete. At extremely low momentum transfer, corresponding to large impact parameters compared to the radius of the nucleus, the cross section is dominated by electromagnetic interaction. The pions scatter off the quasi-real photon density surrounding the nuclear charge Z, as first explained by Weizsäcker and Williams, and treated in the general case of photon-induced hadron reactions by Pomeranchuk and Shmushkevich [4]. At higher momentum transfer, $Q^2 > 0.001$ GeV$^2/c^2$, the strong interaction via pomeron exchange takes over.

The 2004 data taking was primarily designed to detect the reaction $\pi\gamma \to \pi\gamma$, containing a contribution from the pion polarisability, and other reactions to be triggered by the calorimetry of the neutral particles in the final state. This calorimetric trigger featured a subtle but relevant error, making it impossible to reach the required systematic precision.

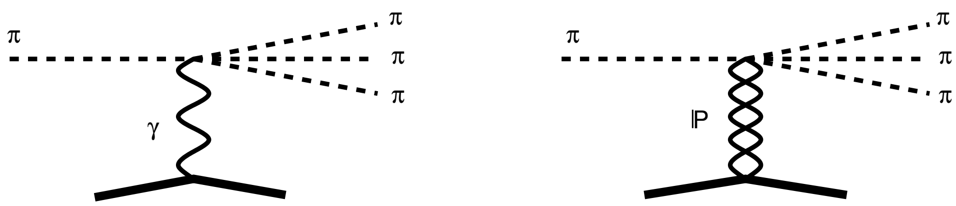

FIGURE 1. Reaction mechanisms in pion-nucleus scattering at low momentum transfer, as explained in the text.

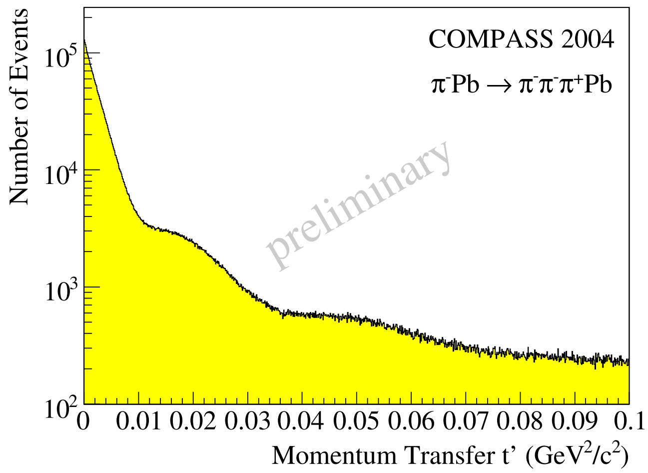

FIGURE 2. Measured momentum transfer spectrum in the reaction π^-Pb $\rightarrow$ Pb$\pi^-\pi^-\pi^+$. The Primakoff region $t' < 0.001$ GeV$^2/c^2$ covers only the lowest bins of the distribution, the adjacent low-t' region up to $t' < 0.01$ GeV$^2/c^2$ shows the characteristic $e^{-bt'}$ behaviour of a soft pomeron exchange. At higher momentum transfer, the more complex pion-nucleus diffraction pattern, also including inelastic nuclear processes, becomes apparent.

In a beam time in 2009, a new digital trigger was successfully tested and is proposed to be used in a high-precision future run [5].

In addition to the faulty trigger, in 2004 an independent trigger on the number of outgoing charged particles was implemented. This allowed to analyze reactions like π^- Pb $\rightarrow$ Pb $\pi^-\pi^-\pi^+$, as discussed in the following. The two involved reaction mechanisms are sketched in Fig. 1. The distribution of momentum transfer obtained in the data analysis is presented in Fig. 2.

DISSOCIATION INTO THREE CHARGED PIONS

The analysis of the reaction π^- Pb $\rightarrow$ Pb $\pi^-\pi^-\pi^+$ from the 2004 data could be pursued on a high level of precision. For the region of high momentum transfer $|t| > 0.1$ GeV^2/c^2 in π^-Pb $\rightarrow$ Pb$\pi^-\pi^-\pi^+$, a partial wave analysis has been performed, leading to the observation of a $J^{PC} = 1^{-+}$ exotic state [6].

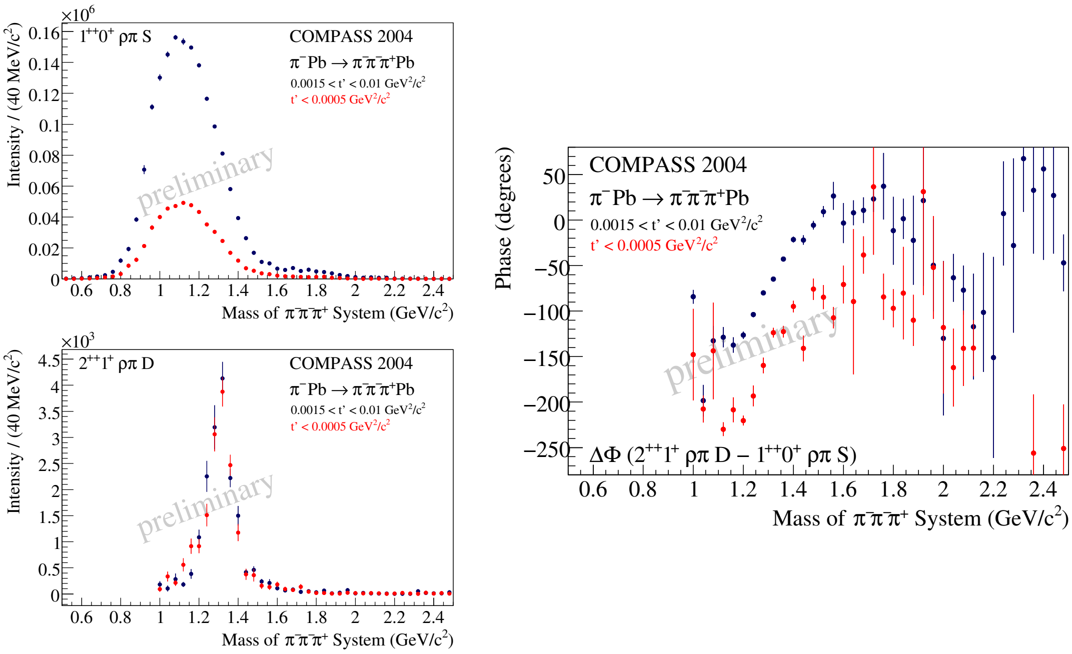

FIGURE 3. Result of the partial wave analysis for the $1^{++}0^{+}$ and $2^{++}1^{+}$ contributions in different t' windows. The intensity of the a_2 signal is about equal in the Primakoff $t' < 0.0005$ and in the low-t' range $0.0015 < t' < 0.01$, while the a_1 Primakoff signal is about a factor 3 weaker. In both cases, the phase between the the two waves exhibits the walk of the narrow a_2 resonance on the high-energetic tail of the a_1 (right graph). Their position is relatively shifted by about 90°, indicating the different production phases introduced by the exchange of a photon or a pomeron, respectively.

The spectrum of low momentum transfer of the same final state is presented in Fig. 2. The partial wave analysis has been performed in two steps, owing to the different production mechanisms involved: First, the t' spectrum was examined in two windows, one for the Primakoff region $t' < 0.0005$ GeV^2/c^2 and one for the low-t' region, 0.0015 GeV^2/c$^2 < t' < 0.01$ GeV^2/c^2. In both windows the main resonances $a_1(1260)$ and $a_2(1320)$ are observed with their respective quantum numbers, the a_1 strength being relatively suppressed in the Primakoff region compared to the diffractive low-t' region, cf. Fig. 3. The phase motion is similar in both cases, but its position is shifted between the two cases, pointing to the different production mechanisms for the a_2 resonance.

Secondly, the analysis was performed in finer t' slices but a rather broad $m_{3\pi}$ window, presented in Fig. 4. Here, the strength of the a_2 at very low t' shows the steep rise characteristic for Primakoff production, convoluted with the experimental resolution. This very clear signal triggered a closer look at the full mass spectrum of the 3-pion final state in Primakoff production. Exceeding the precision of the SELEX statistics [8], it appears feasible to extract for the first time the strength of the $\pi\gamma \to 3\pi$ reaction close to its threshold, for which a, yet untested, tree graph calculation from ChPT [9], recently also higher-order loop contributions [10], exist.

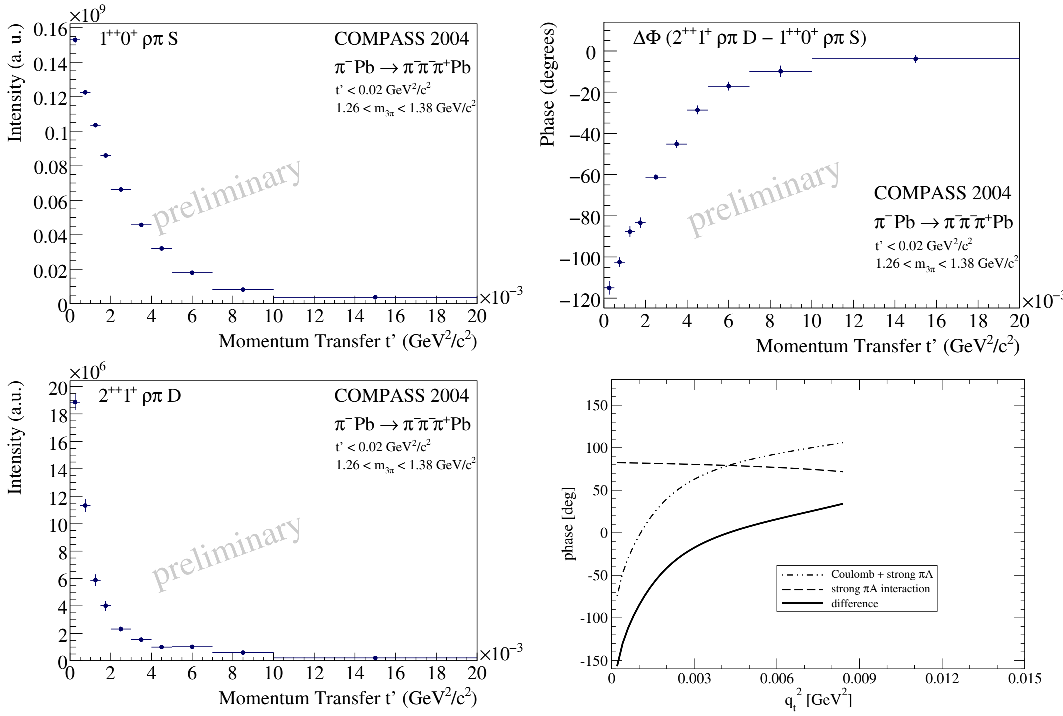

FIGURE 4. Result of the partial wave analysis for the two waves as in Fig. 3, now in fine t' slices. Plots on the left: While the intensity of the a_1 follows about the t' dependence of the diffractive slope (cf. Fig. 2), the a_2 signal features the steep Primakoff rise at small t'. The relative phase difference (upper right plot) vanishes with increasing t', indicating that at higher momentum transfer the production mechanism for a_2 becomes dominated by strong interacting, as it is for the a_1. The lower-right plot shows this phase walk evaluated in the Glauber model following [7].

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