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Radiative Width of the a_2 Meson[†]

The SELEX Collaboration

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We present data on coherent production of the $(\pi^+\pi^-\pi^-)$ system by 600 GeV/c pion beam in the reaction $\pi^- + A \to A + (\pi^+\pi^-\pi^-)$ for the C, Cu and Pb targets. The Primakoff formalism was used for extracting the radiative width of the a_2 meson. We obtain a preliminary value $\Gamma(a_2^- \to \pi^-\gamma\ ) = 225 \pm 25(\text{stat}) \pm 45(\text{syst})$ keV.

1 Introduction

Radiative decay widths of mesons and baryons are powerful tools for understanding the structure of elementary particles and for constructing a dynamical theory of hadronic systems. Straightforward predictions for radiative widths make possible the direct comparison of experimental data and theory.

The small value of the branching ratios of radiative decays makes it difficult to measure them directly, if there is a large background from the strong decay channels with $\pi^0 \to \gamma\gamma$ in the final state with one lost photon. For this reason most experimental data for these decays have been obtained using production reactions in the Coulomb field of the nuclei. Studying the inverse reaction (the so called Primakoff[2] formalism) $\gamma + \pi^- \to M^-$ provides a relatively clean method for the determination of the radiative widths.

The Primakoff reaction works better when the energy of the beam particles is increased. However, very good

spatial resolution is needed to extract the signal at small t where the electromagnetic processes dominate over the strong interaction.

SELEX (E781) had a beam energy of 600 GeV and had a high resolution vertex detector which made it possible to explore the features of the Primakoff reaction.

The differential cross section for the Primakoff reaction

$$\pi^- + Z \to Z + a_2^-, \quad a_2^- \to \pi^-\pi^-\pi^+ \tag{1}$$

can be written as a function of the mass of the final state (M) and the square of the four-momentum transfer to the nucleus (t) as follows

$$\frac{d\sigma}{dt\ dM} = 8\pi\alpha Z^2(2J_{a_2}+1)\Gamma_\gamma \left(\frac{M}{M^2-m_\pi^2}\right)^3 g_\gamma(M) g_{a_2}(M) \frac{2}{\pi}\frac{m_{a_2}^2\Gamma_{a_2}}{(M^2-m_{a_2}^2)^2+m_{a_2}^2 g_{a_2}^2(M)\Gamma_{a_2}^2}\frac{t-t_{min}}{t^2}|F(t)|^2 \tag{2}$$

Here α is the fine-structure constant, Z is the charge of the nucleus, $F(t)$ is the electromagnetic form factor of the nucleus, J_{a_2} is the spin of the a_2 meson and t_{min} is the minimum four-momentum transfer:

$$t_{min} \approx (M^2 - m_\pi^2)^2/4P_{beam}^2, \tag{3}$$

where P_{beam} is the beam momentum. In our case $P_{beam} = 600$ GeV and for the a_2 meson with the mass 1.32 GeV we have

$$t_{min} \approx 2 \cdot 10^{-6} GeV^2 \tag{4}$$

The t-distribution for the Primakoff reaction is characterized by a sharp peak with the maximum near $t = 2 \cdot t_{min}$. The influence of the nuclear form factor is small in the region of $t < 0.001$ GeV^2 where we expect the Primakoff signal. It is less than 5% for the Pb target and 3% for the Cu target.

The mass-dependent total width and the partial widths $\Gamma(a_2 \to all)$, $\Gamma(a_2 \to \pi\gamma)$ and $\Gamma(a_2 \to \rho\pi)$ can be rewritten in terms of resonance widths as follows: $\Gamma(a_2 \to \pi\gamma) = \Gamma_\gamma g_\gamma(M)$ and $\Gamma(a_2 \to \rho\pi) = \Gamma_\rho g_\rho(M)$, where $g_\gamma(m_{a_2}) = g_\rho(m_{a_2}) = 1$. We used $g(a_2 \to all) = g(a_2 \to \rho\pi)$.

For the energy dependence of the widths we used

$$g_\gamma(M) = \left(\frac{k}{k_0}\right)^3 \frac{2k_0^2}{k^2+k_0^2} \tag{5}$$

$$g_{a_2}(M) = \left(\frac{q}{q_0}\right)^5 \frac{2q_0^2}{q^2+q_0^2} \tag{6}$$

where k and q are the momenta in the $\pi\gamma$ and $\rho\pi$ frames, respectively.

Numerically integrating over M and t from t_{min} up to 0.001 GeV^2 we get the cross section for the reaction (1) in this t-interval

$$\sigma_{\text{Primakoff}} = \int_{t_{min}}^{0.001} \frac{d\sigma}{dt\ dM} dt\ dM = \Gamma(a_2 \to \pi\gamma) \cdot C, \tag{7}$$

where $C = 27.2,\ 626,\ 4870\ (mb/GeV)$ for the C, Cu and Pb targets respectively.

Table 1: Statistics of the experiment.

Target	Number of Events
Carbon	2 760 523
Copper	1 997 972
Lead	549 092

2 Cuts and Statistics of the experiment

The following cuts were applied in order to extract the reaction

$$\pi^- + A \to A + (\pi^-\pi^-\pi^+) \tag{8}$$

from the exclusive trigger stream of SELEX data:

1. The beam transition radiation detector shows that the beam particle is a pion.
2. For the quasielastic peak, the difference between the beam particle momentum and the sum of momenta of three secondaries must be less than 17.5 GeV/c.
3. The z-position of the interaction must be in the vicinity of a C, Cu or Pb target.
4. The energy deposition in the Photon-1 detector must be less than 2 GeV.
5. The average distance between the point of interaction and all tracks (beam and secondaries) must be less than 20, 25 and 75 μm for the C, Cu and Pb targets.

The event statistics are presented in Table 1.

3 Primakoff Production of the a2 Meson

The p_T^2 distribution of the (3π)-system for the Cu target is shown in Fig. 1a as an example. The distribution was fitted by the sum of two exponentials. The slope for the coherent production was found to be close to the previously published data [3]. The p_T^2 distributions for all targets have an enhancement in the region of small p_T^2 . The two exponentials fit yields a slope for the second term greater than 1000 GeV^{-2} which corresponds to the Monte Carlo estimate for the Primakoff reaction.

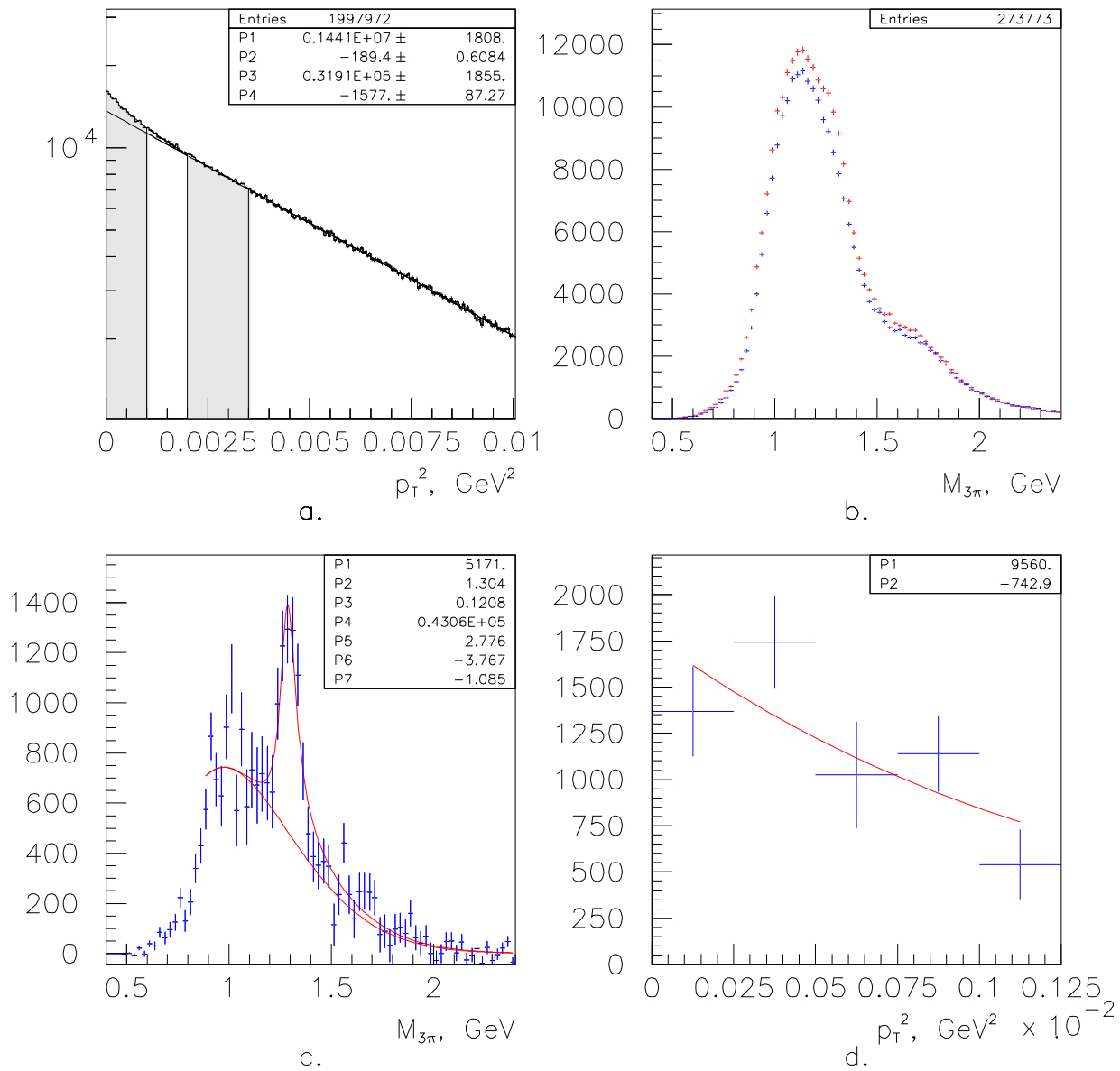

Figure 1: Primakoff production of the a_2 meson on Copper target in the reaction: $\pi^- + Cu \to Cu + (\pi^-\pi^+\pi^-)$. a. p_T^2 distribution of (3π)-system. The Primakoff signal is clearly seen in the region of small p_T^2 . b. $M_{3\pi}$ distribution. The first curve(light points) is for events with $p_T^2 < 0.001$ GeV^2, the second one is for events in the band $0.002 < p_T^2 < 0.0035$ GeV^2. c. Result of subtraction of two curves (see b). d. p_T^2 distribution of the a_2 meson.

Two p_T^2 regions were defined (the shaded regions in Fig. 1a). In the first one ($p_T^2 < 0.001$ GeV^2) the Primakoff mechanism dominates. We used the second one $0.0015 < p_T^2 < 0.0035$ GeV^2 for the estimation of the background from the coherent production of the (3π)-system.

The $\pi\pi\pi$ mass spectra for these two regions are shown in Fig. 1b for the Cu target. The result of the subtraction of these histograms is shown in Fig. 1c. A clear a_2 meson signal is seen. The distributions were fitted using Eq. (2) integrated over t. The mass and width of the resonance were determined using the combined data from all targets: $M_{a_2} = 1304 \pm 5$ MeV, $\Gamma_{a_2} = 121 \pm 20$ MeV. The mass and the width of the peaks are in good agreement with the mass and width of the a_2 meson. The number of a_2 events was found to be 1587 ± 480, 5170 ± 590 and 2945 ± 400 for the C, Cu an Pb targets, respectively.

To make sure that the a_2 meson is produced via the Primakoff mechanism we divided the data into five p_T^2 -bins each 0.00025 GeV^2 and repeated the subtraction procedure. We got 5 histograms for each target similar to Fig. 1c. After the fit of the mass spectra and the determination the number of a_2 mesons in each bin the p_T^2 distribution was extracted and shown in Fig. 1d. The slope was determined for every target. It is consistent with the Primakoff distribution smeared by the resolution of the experimental setup.

4 Monte Carlo

A simple Monte Carlo program was written to simulate the p_T^2 -distribution for the Primakoff production of the a_2 meson. The p_T resolution had these different values for the different targets: $\sigma(p_{Tx}) = \sigma(p_{Ty}) = 16$, 17 and 20 MeV for the C, Cu and Pb targets, respectively.

The subtraction procedure efficiency was evaluated using the Monte Carlo simulation:

$$\varepsilon(subtr.) = \frac{\int_0^{0.001} \frac{d\sigma'}{dt}dt - k \int_{0.0015}^{0.0035} \frac{d\sigma'}{dt}dt}{\int_0^{0.001} \frac{d\sigma}{dt}dt} \qquad (9)$$

where σ is the Primakoff cross section, σ' is the Primakoff cross section smeared by the experimental resolution and k is the normalization factor. These efficiencies were found to be $\varepsilon = 0.697$, 0.630 and 0.488 for the C, Cu and Pb targets.

5 Absolute Normalization

The Primakoff approach gives the possibility to determine the radiative width only in the case when the absolute cross section of the reaction (1) is measured. This is the crucial point for the experiment. At the present stage of analysis we use the cross section for the reaction (8) from E272 [3]. We determined the product of $(L \cdot \varepsilon)$ and didn't need to evaluate the reconstruction efficiency ε alone. Here L is the luminosity. The experiment E272 was done in a beam with energy 200 GeV. We assumed that the coherent cross section of the reaction (8) is independent of the beam energy. The simplest estimation based on Regge theory confirms this assumption.

We determined the absolute cross section in the p_T^2 region close to zero to avoid the acceptance corrections:

$$(L \cdot \varepsilon) = \frac{\int_{t_{min}}^{t_{max}} \frac{dN}{dt}dt}{\int_{t_{min}}^{t_{max}} \frac{d\sigma}{dt}dt} \qquad (10)$$

where $\frac{dN}{dt}$ is the differential t-distribution from SELEX data, $\frac{d\sigma}{dt}$ is the differential cross section from E272 data, $t_{min} = 0$, 0.001, 0.0015 GeV^2 and $t_{max} = 0.020$, 0.020, 0.006 GeV^2 for three targets. $(L \cdot \varepsilon) = 881558$, 149302, 17831 events/mb for the C, Cu and Pb targets, respectively.

6 Radiative Width of the a_2 Meson

The radiative width of the a_2 meson was determined using the expression

$$\Gamma(a_2^- \to \pi^-\gamma) = \frac{N_{a_2}}{C \cdot (L\varepsilon) \cdot CG \cdot BR \cdot \varepsilon(subtr.)} \qquad (11)$$

where $CG(a_2 \to \rho\pi)$=0.5 is the Clebsch-Gordon coefficient, $BR(a_2 \to \rho\pi)$=0.701 is the branching ratio, C is determined by numerical integration (see Eq. (7)), $(L\varepsilon)$ is the product of the luminosity and the reconstruction efficiency (see Eq. (10)). The radiative width was determined for all three targets: C, Cu and Pb. The results are shown in Fig. 2. As can be seen from this figure the results are consistent with each other, confirming the Coulomb production of the a_2 meson. The average value over all targets is

$$\Gamma(a_2^- \to \pi^-\gamma) = 225 \pm 20(\text{stat}) \pm 45(\text{syst}) \text{ keV} \qquad (12)$$

The major sources of uncertainty in this result are the normalization procedure [3] and the errors in the determination of the number of a_2 events. The PDG value for the $\Gamma(a_2^- \to \pi^-\gamma) = 295 \pm 60$ keV is shown in Fig. 2 as well.

7 Conclusion

Based on a weighted average over the C, Cu and Pb targets of the values for $\Gamma(a_2^- \to \pi^-\gamma)$ we present the preliminary value of $225 \pm 20(\text{stat}) \pm 45(\text{syst})$ keV for the radiative width of the a_2 meson. Our result has the best world statistical error [4,5] for the radiative width of the a_2 meson. The systematic error can be reduced in the future by accurate measurement of the $(\pi^+\pi^-\pi^-)$ coherent cross section using SELEX data.

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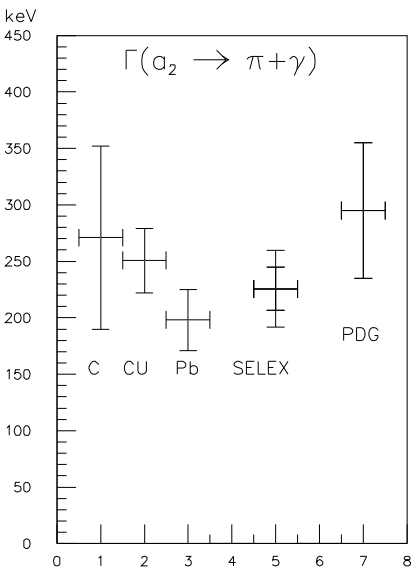

Figure 2: The radiative width $\Gamma(a_2^- \to \pi^-\gamma$) for the C, Cu and Pb targets. The average of SELEX result (with statistical and systematic errors) and the PDG value are shown as well.

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