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ABSTRACT

We present the analysis of data samples taken by the WA77 experiment for $\pi^- \text{Be}$ interactions at 300 and 150 GeV/c . The trigger selects a pair of oppositely charged particles with $p_T \geq 2 \text{ GeV}/c$ balancing the transverse momentum of a third high- p_T track. The primary aim of this experiment was the search for higher-twist production, mainly that of vector mesons. Since there are definite predictions for the polarization of mesons produced in fragmentation and through the higher-twist mechanism, we study the polarization properties of clearly identified mesons, namely the ϕ and $f_2(1270)$ mesons. The results are compatible with no polarization. This can be interpreted as a production dominantly due to parton fragmentation.

KEYWORDS

particle production, mesons, polarization

1 INTRODUCTION

In the high- p_T range (we shall often use in this paper the word *high* - p_T as meaning ≥ 2 GeV/ c which is rather *medium* - p_T) hadronic interactions are supposed to proceed through hard parton scattering followed with subsequent fragmentation into hadrons. In the medium p_T range, the higher-twist mechanism could become important [1, 2]. This last mechanism should be interpreted as a direct production of high- p_T mesons through parton processes like $\bar{q}q \rightarrow Mg$ (where M is a directly produced meson). Such a mechanism does not contribute at higher p_T due to an extra p_T^{-2} suppression factor with respect to leading twist processes. It could be observable however for p_T of a few GeV/ c by exploiting the fact that directly produced mesons pick up the whole momentum transfer in the hard process and are not accompanied by other fragmentation products. On the other hand, the fragmentation of the opposite parton produces several particles which have to share the momentum transfer available in the hard process. Quantitative predictions based on both perturbative and non-perturbative QCD (sum rules) have been published [1, 2].

Beside the study of p_T spectra and p_T compensation, another possibility to look for the higher-twist signal is to measure the polarization of vector and/or tensor mesons. There are specific predictions [2, 3] for the polarization behaviour of promptly produced mesons while hadrons produced in parton fragmentation are supposed to be unpolarized. Vector mesons directly produced in hard scattering would have spin aligned. In the higher-twist process $\bar{q}q \rightarrow Mg$ (where M is a vector meson) the produced meson prefers to have its spin aligned along its helicity axis in the CM frame of the higher-twist subprocess, as a result of the assumption of vanishing gluon mass produced on the opposite side. According to QCD predictions [2] one could expect a probability of about 90 % for promptly produced ρ^0 mesons in π^-p interactions to have helicity ± 1 . The higher-twist production of ϕ mesons in scattering of particles without valence strangeness content has to be negligible and hence we expect no polarization to be observed due to their dominant production through parton fragmentation. The QCD study of polarization properties of directly produced tensor mesons [3] leads to stringent differences between ordinary $q\bar{q}$ mesons and glueballs (bound states of two gluons). Only helicity even states are expected in the first case while dominant ± 1 helicity states in the production of tensor mesons would point towards the occurrence of glueballs.

The spin alignment of ρ^0 was studied using $\bar{p}p$ and pp bubble chamber data [4]. In pp interactions, where direct production of mesons is suppressed due to the lack of valence antiquark, no polarization was observed. On the other hand, for ρ^0 produced in $\bar{p}p$ collisions, where a sizeable higher-twist production can be expected, spin alignment on the s -channel helicity axis is seen and this effect increases with p_T . Similar spin behaviour of ρ mesons produced in π^-p interactions at 40 GeV/ c with a high- p_T trigger was observed [5]. In similar conditions no spin alignment was observed for ϕ mesons[6], as expected.

In this paper we describe the study of ϕ meson spin alignment (sometimes also called tensor polarization) produced in π^- -Be interactions at 150 and 300 GeV/c at $p_T \geq 2$ GeV/c. We also present the analysis for $f_2(1270)$ produced in the same conditions. In section 2 we give a brief description of the data samples and the procedure for spin analysis. The results are presented in section 3 and in section 4 we summarize our conclusions.

2 EXPERIMENTAL ANALYSIS

The experimental data were obtained by the WA77 collaboration using the Omega spectrometer at the CERN SPS in π^- -Be interactions at two beam momenta (150 and 300 GeV/c). The main aim of this experiment was the study of higher-twist production and the search for glueballs, the production of which is supposed to be enhanced by this mechanism. The apparatus was triggered for events containing three tracks with p_T above 1 GeV/c. In the accepted configuration two of them on one side in azimuthal angle have to carry opposite charges and the third trigger particle compensates the transverse momentum of the pair (hence being on the opposite side in the azimuthal projection). The high- p_T particles were produced in the central rapidity region. After reconstruction we selected events with the trigger pair having $p_T^{pair} \geq 2$ GeV/c and the rapidity between 2.73 and 3.73. The third particle had transverse momentum larger than 1 GeV/c and the angular separation from the total pair momentum in the azimuthal projection was greater than 120° . After selection we obtained two samples of events of about 2×10^5 events each, one for 150 GeV/c and the other for 300 GeV/c beam momentum. Details about the experimental setup, the trigger and the selection procedure are given elsewhere [7].

We use the following method for the spin analysis of resonances assumed to decay into the trigger pair. We classify the events in subsamples according to the cosine values of the angle Θ between the positive particle of the pair and the axis along which the spin alignment is studied in the rest frame of the pair. The mass assignment of the decay products depends on the resonance under investigation. Then the effective mass spectra for each subsample was fitted by means of the sum of a Breit-Wigner resonance shape and a background term, using the Maximum Likelihood method. We used spin dependent relativistic Breit-Wigner functions with varying width. In the $f_2(1270)$ case we also tried the modified mass dependence of the width according to ref.[8] motivated by our experimental data (the high mass tail is reduced by a negative power of the mass in the expression for the width). The resonance shape was multiplied by the fitted background in order to take into account the final state phase space and divided by the two-particle phase space factor of the decay products to avoid double counting :

$$(1) \quad \frac{dN}{dm} \propto BKG(m) \times \left[1 + \frac{m}{q} \cdot BW(m)\right],$$

where :

$$BW(m) \propto \frac{\Gamma(m)}{(m^2 - m_{res}^2)^2 + \Gamma^2 m_{res}^2},$$

$$\Gamma(m) = \left(\frac{q}{q_{res}}\right)^{2l+1} \frac{m_{res}}{m} \Gamma_{res} + RSL$$

and m is the mass, q is the corresponding decay momentum, Γ is the resonance width. The values with the subscript res are the tabulated values [9]. The background was parametrized with the simple form :

$$(2) \quad BKG(m) = (m - m_{th})^\alpha \times \exp(-b \cdot m),$$

where m_{th} is the threshold mass and α and b are free parameters, because the fit was performed in a limited mass range. The mass resolution RSL was added linearly to the Breit–Wigner width and fitted on the total mass spectrum. During the fitting of the subsample mass spectra the resolution was fixed to the value found on the total spectrum. We checked the mass resolution and the resolution function shape by simulation (5.5 MeV for $\phi \rightarrow K^+ K^-$ decay and 22 MeV for $f_2(1270) \rightarrow \pi^+ \pi^-$ decay). By fitting the mass spectrum for each subsample we obtained the $\cos \Theta$ distribution for the resonance.

The observed $\cos \Theta$ distribution has to be corrected for acceptance. For this purpose, we have used a simple Monte-Carlo simulation. We have generated the resonances under study with a flat distribution in rapidity (in the above-mentioned rapidity window) and with the experimental p_T distributions [10]. Then we let the resonance decay isotropically and we recorded its $\cos \Theta$ with respect to various axes (see below). We traced the decay products through the experimental apparatus and required the fulfilment of all trigger conditions. The $\cos \Theta$ distributions for accepted resonances are proportional to the geometrical acceptances in each $\cos \Theta$ bin. To correct the observed distributions we divided the raw distributions by the corresponding acceptance functions.

The corrected $\cos \Theta$ distribution contains the information about the resonance polarization. If this distribution is flat (independent of $\cos \Theta$), the resonance is produced unpolarized. For simplicity we assume only the possibility of tensor polarization, which means that we fit only the diagonal elements of the polarization density matrix assuming their symmetry with respect to zero spin projection (the probabilities to have spin projections $+1$ and -1 are equal and for tensor mesons the probabilities of spin projections $+2$ and -2 are also assumed to be equal)¹. Hence for vector resonances we have only one free parameter (apart from the normalization) to describe the $\cos \Theta$ spectrum : we choose as free parameter the element ρ_{00} of the polarization density matrix, which is the probability to have spin projection 0 on the axis under study. The

¹In fact the polarization vector could be non-zero only in transverse directions for mesons produced in strong interactions because of parity conservation.

other non zero elements under our assumption are $\rho_{11} = \rho_{-1-1} = (1 - \rho_{00})/2$ and the $\cos \Theta$ distribution for vector resonances has the following form :

$$(3) \quad \frac{dN}{d(\cos \Theta)} \propto (-1 + 3 \rho_{00}) \times \cos^2 \Theta + (1 - \rho_{00}),$$

which is flat for unpolarized production, i.e. $\rho_{00} = 1/3$. For tensor resonances we have two parameters to describe the $\cos \Theta$ distribution : we choose the elements ρ_{11} and ρ_{22} of the polarization density matrix. In this case, the other non-zero elements are $\rho_{-1-1} = \rho_{11}$, $\rho_{-2-2} = \rho_{22}$ and $\rho_{00} = 1 - 2 \cdot (\rho_{11} + \rho_{22})$. The $\cos \Theta$ spectrum is described by :

$$(1) \quad \frac{dN}{d(\cos \Theta)} \propto (9 - 30 \rho_{11} - 15 \rho_{22}) \times \cos^4 \Theta + (-6 + 24 \rho_{11} + 6 \rho_{22}) \times \cos^2 \Theta + (1 - 2 \rho_{11} - \rho_{22}),$$

which is constant for unpolarized tensor mesons, i.e. $\rho_{11} = \rho_{22} = 1/5$.

To estimate resonance polarization effects, we fitted the corrected $\cos \Theta$ distributions with the above formulae and appropriate normalizations, using the Least Squares method. The weights were proportional to the inverse square of the errors obtained from the Maximum Likelihood fit of the resonance signal, the errors have been corrected for acceptance. The Monte-Carlo sample used for the acceptance calculation was more than an order of magnitude larger than the experimental one, thus we neglected the Monte-Carlo statistical errors.

3 RESULTS

We used the method described in the previous section for the analysis of two resonances, the vector meson ϕ and the tensor meson $f_2(1270)$, which are clearly seen in the K^+K^- (figure 1a) and $\pi^+\pi^-$ (figure 1b) mass spectra respectively. The analysis of other resonances is more difficult because of the presence of non negligible reflections nearby or because they can be produced through other resonance decays. This last case can be illustrated by ρ^0 meson. A part of this signal is produced via the decay $\eta' \rightarrow \rho^0 \gamma$ in which the ρ^0 is fully polarized and has only spin projections ± 1 along the direction of the γ seen from the ρ^0 rest frame. Such an effect is not easy to take into account, mainly because of the uncertainty on the relative number of ρ^0 mesons produced in this way ; this can weaken the interpretation of polarization results. We fitted the mass spectra only in a restricted region around the resonance peak : for the ϕ meson in the interval $0.988 \text{ GeV}/c^2 \leq m_{KK} \leq 1.188 \text{ GeV}/c^2$ and for the $f_2(1270)$ meson in the interval $1.0 \text{ GeV}/c^2 \leq m_{\pi^+\pi^-} \leq 1.5 \text{ GeV}/c^2$. This was chosen in order to be able to load all these events in memory (which is needed for the Maximum Likelihood fit) and also to avoid problems with reflections when using the proposed simple description of background. We have checked on the total mass spectra that the numbers of the resonances obtained by this method are consistent with those found by fitting all mass spectra [8] taking into account reflections [10].

We investigated the polarization of these mesons in two frames :

i. s -channel helicity frame : the axis with respect to which the angle Θ_H is measured, is defined as the line of the flight of the meson seen from the CMS of the incoming π^- and target nucleon;

ii. transversity frame : we measure the angle Θ_T with respect to the direction defined by the vector product of the meson momentum and the incident particle momentum [11].

In figure 2 we show our results for the ϕ meson in the 300 GeV/ c data sample. Here we give the mass plots for 6 subsamples defined according to bins in $\cos \Theta_H$ together with the results of the Maximum Likelihood fit performed as described in preceding section. We have calculated also the χ^2 per degree of freedom, using a 4 MeV/ c^2 mass bin and have obtained reasonable values between 0.74 to 1.68 for the different subsamples. In figure 3 we show the dependence of the acceptance on $\cos \Theta_H$. The acceptance behaviour could be sensitive to other parameter distributions assumed by the Monte-Carlo procedure, namely to the resonance p_T spectra. Therefore we have calculated the acceptance dependence, not only with the mean value of the exponent n in the experimental p_T^{-n} distributions [10], but we also allowed this exponent to vary by $\pm 3\sigma$. We conclude from figure 3 that the variation of resonance p_T spectra have no strong effect on the acceptance distribution in $\cos \Theta_H$. Finally, in figure 4a the corrected ϕ meson spectra in $\cos \Theta_H$ are shown, together with the Least Squares fit to the distribution (3). This gives $\rho_{00} = 0.43 \pm 0.06$ with $\chi^2/ndf = 5.2/4$. Because this result is consistent with the value for unpolarized vector mesons, we have also calculated the χ^2 under the assumption $\rho_{00} = 1/3$ and we obtain $\chi^2/ndf = 7.7/5$. The same procedure was repeated for the 150 GeV/ c data sample and the corrected distribution in $\cos \Theta_H$ for ϕ mesons is given in figure 4b. All values obtained for ρ_{00} and χ^2/ndf are listed in table 1.

The results for ϕ meson production in $\cos \Theta_T$ are shown in figure 4b and 4d for 300 GeV/ c and 150 GeV/ c data samples respectively. They are not far from being flat. Results of the corresponding fits are also listed in table 1.

The corresponding analysis was repeated for $f_2(1270)$ meson using formula (4). The corrected distributions are presented in figure 5 : a and b for s -channel helicity frame (300 GeV/ c and 150 GeV/ c data samples respectively); c and d for transversity frame (300 GeV/ c and 150 GeV/ c data samples respectively). All these distributions are consistent with being flat, so we again evaluate the χ^2/ndf for the unpolarized case, $\rho_{11} = \rho_{22} = 1/5$. The results are summarized in table 2.

We have investigated the stability of the results with respect to the slope values of the p_T spectra [10] for resonance production and we have tried different background parametrizations. We fixed the exponent α in formula (2) to 1 (one free parameter less) or we added a quadratic term in the exponential function (one free parameter more). Then we varied the $\cos \Theta$ binning, from 5 to 8 equal intervals. For $f_2(1270)$ we also used unequal binning in order to equalize the bin populations. The systematic errors given in Tables 1 and 2 are the maximum deviations

obtained using the above mentioned changes. They are mainly due to the variation of slopes of the p_T spectra.

4 CONCLUSIONS

We have presented the investigation of the polarization properties of the high- p_T mesons, namely the vector ϕ and the tensor $f_2(1270)$ produced in hadronic collisions at relatively high (for polarization studies) incident energies. This was allowed by the trigger which was able to select the net momentum of the charged particle pair without unacceptable deterioration of angular distributions due to acceptance effects.

We have estimated the ρ_{00} element of the polarization density matrix for ϕ mesons in the s channel helicity frame and in the transversity frame. We find it close to the value for unpolarized vector mesons (1/3) at both energies. Similar conclusions can be drawn also for $f_2(1270)$: the polarization density matrix elements ρ_{11} and ρ_{22} are consistent with the value expected for unpolarized tensor mesons (1/5). The hypothesis of no polarization has in all cases a good probability. Taking into account the estimated systematic uncertainties we conclude that we do not observe any significant polarization effect. Thus for the ϕ meson we observe no polarization as predicted by dominant fragmentation production. For the $f_2(1270)$ meson the observation of no polarization means that we do not observe any substantial production of $f_2(1270)$ via the higher-twist mechanism.

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Beam momentum	ρ_{00}	systematic error	χ^2/ndf	probability for $\rho_{00} = 1/3$
Helicity frame				
300 GeV/ c	0.43 ± 0.06	± 0.06	5.2/4	17%
150 GeV/ c	0.46 ± 0.05	± 0.06	1.2/4	22%
Transversity frame				
300 GeV/ c	0.25 ± 0.05	± 0.05	1.3/4	48%
150 GeV/ c	0.29 ± 0.04	± 0.05	6.0/4	19%

Table 1: Summary of the results for ϕ meson.

Beam momentum	ρ_{11}	systematic error	ρ_{22}	systematic error	χ^2/ndf	probability for $\rho_{11}=\rho_{22}=1/5$
Helicity frame						
300 GeV/ c	0.16 ± 0.03	± 0.04	0.21 ± 0.02	± 0.04	0.8/3	36%
150 GeV/ c	0.21 ± 0.03	± 0.04	0.16 ± 0.03	± 0.03	0.5/3	24%
Transversity frame						
300 GeV/ c	0.23 ± 0.03	± 0.05	0.20 ± 0.02	± 0.03	0.2/3	50%
150 GeV/ c	0.21 ± 0.03	± 0.03	0.20 ± 0.02	± 0.04	5.5/3	27%

Table 2: Summary of the results for $f_2(1270)$ meson.

Figure 1: The effective mass distributions for 300 GeV/c data (a) in ϕ region assuming K^+K^- mass assignment and (b) in $f_2(1270)$ region assuming $\pi^+\pi^-$ mass assignment. The full lines are the results of the fit and the dashed lines represent the fitted background.

Figure 2: The effective mass distributions for different $\cos \Theta_H$ intervals in ϕ region assuming K^+K^- mass assignment. The full lines are the results of the fit and the dashed lines represent the fitted background.

Figure 3: The $\cos \Theta_H$ dependence of the acceptance for ϕ mesons : full line – assuming the nominal p_T^{-n} distribution for ϕ mesons ($n = 10.3$), dashed line – the exponent enlarged by 3σ ($n = 11.2$), dotted line – 3σ subtracted from the exponent ($n = 9.4$). The values for the exponent n are taken from ref. [10].

Figure 1: The corrected $\cos \Theta$ distributions for ϕ mesons in the helicity frame : (a) and (b) in the transversity frame : (c) and (d) for 300 GeV/c and for 150 GeV/c data respectively.

Figure 5: The corrected $\cos \Theta$ distributions for $f_2(1270)$ mesons in the helicity frame : (a) and (b) in the transversity frame : (c) and (d) for 300 GeV/c and for 150 GeV/c data respectively.