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SPIN ALIGNMENT OF $K^{*}(892)^{\pm}$ MESONS PRODUCED IN NEUTRON-CARBON INTERACTIONS

EXCHARM Collaboration

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The inclusive hadroproduction of $K^*(892)^\pm$ has been studied since more than 30 years, but the role of meson spin in the production dynamics is still not understood in details. Spin phenomena in inclusive reactions with non-polarized beam and target are described by spin density matrix ρ of the final state particle. The ρ_{00} element represents relative intensity of vector mesons with zero z-component of the spin. A deviation of ρ_{00} from the value $\frac{1}{3}$ indicates spin alignment. A number of phenomenological models is suggested to predict spin behavior in vector-meson inclusive hadroproduction. For example, in the semiclassical model [1] the spin alignment is expected for leading mesons, while for the non-leading ones $\rho_{00} \sim \frac{1}{3}$. An early experiment [2] reported no spin alignment of $K^*(892)^\pm$ produced in pp interactions at 12 and 24 GeV. Significant spin alignment has been observed for leading vector mesons inclusively produced by charged kaons: for $K^*(892)^+$ and $K^*(892)^0$ in K^+p reaction at 8.2 GeV [3], 32 GeV [4] and 70 GeV [5], for $K^*(892)^-$ and $\bar{K}^*(892)^0$ in K^-p interactions at 14.3 GeV [6] and 32 GeV [7].

The spin alignment of $K^*(892)^\pm$ mesons produced inclusively in neutron beam has been studied for the first time in the EXCHARM experiment and the results are presented in this paper .

The EXCHARM setup is a forward magnetic spectrometer, placed in the neutral beam 5N of Serpukhov accelerator. Neutrons were produced on the internal beryllium target by 70 GeV primary protons at zero angle to the proton orbit. A 20 cm lead filter suppressed γ background. Accelerator magnets and a special sweeping magnet $SP-129$ rejected an admixture of charged particles in the beam. The neutron energy spectrum [8] peaks at 58 GeV and has an effective width of 9 GeV. The $K^*(892)^\pm$ were produced in neutron interactions with a 1.3g/cm^2 (1.5 cm) long carbon target located in front of the spectrometer. The spectrometer analyzing dipole magnet SP-40A causes a transverse momentum kick of 0.455 GeV/c with an alternative polarity. The charged particles produced in neutron-carbon interactions were detected by 11 proportional chambers with 2 mm wire spacing, 25 coordinate planes in total (16 planes upstream and 9 – downstream the magnet). Two gas threshold Čherenkov counters filled with freon and air at the atmospheric pressure were used for a charged particle identification. Hodoscopes of two scintillator counter planes and three planes of proportional chambers were included in the trigger system. The trigger requirement selected events with at least 4 charged particles passing through the spectrometer. A more detailed description of the apparatus can be found elsewhere [9].

The analysis has been performed using 184.4×10^6 neutron-carbon interactions recorded in the experiment.

The strange resonances $K^*(892)^\pm$ have been selected by their decays into neutral kaon and charged pion:

$$
\begin{array}{l}
n\ ^{12}C \to K^*(892)^\pm \ + \ X \\
\quad\quad \hookrightarrow \quad K^0(\bar{K}^0)\ \pi^\pm \\
\quad\quad\quad\quad \hookrightarrow \quad K_S \to \pi^+\pi^-
\end{array}
\tag{1}
$$

The neutral kaons have been identified via decays of short lived mode $K_S \to \pi^+\pi^-$. A pair of opposite charged particles (V^0) has been considered as a K_S candidate if:

- closest distance of approach between the V^0 tracks is less than the experimental resolution (0.2 cm);
- momentum ratio of the positive track to the negative one is less than 5, in order to suppress the background from Λ^0 decays;
- invariant mass of the $\pi^+\pi^-$ system is within ± 30 MeV^2 the PDG value of K_S;
- Čherenkov identification of each charged particle is not consistent with kaon or proton/antiproton hypothesis.

Each combination of a K_S candidate with an additional track has been regarded as $K^*(892)^\pm$ candidate if it meets the following requirements:

- distance between the additional track and reconstructed K_S trajectory is less than 0.2 cm;
- decay vertex of $K^*(892)^\pm$ is located within the target;
- K_S candidate life time is larger than $0.1\tau_S$ (τ_S is the PDG life time of K_S), in order to suppress the background caused by interactions in the target;
- Čherenkov identification of additional charged particle is not consistent with kaon or proton/antiproton hypothesis;
- $K^*(892)^\pm$ candidate momentum is larger than 12 GeV/c.

The invariant mass (M) spectra of selected 521480 $K_S\pi^+$ and 553785 $K_S\pi^-$ combinations are presented in Fig.1(a) and (b), respectively.

Signals of decays (1) have been estimated as a result of mass spectrum approximation in the region of 0.74–1.20 GeV/c^2 by the superposition of background and signal with relative rate (a):

$$\frac{dN}{dM} = BG(M)[1 + aBW(M)], \tag{2}$$

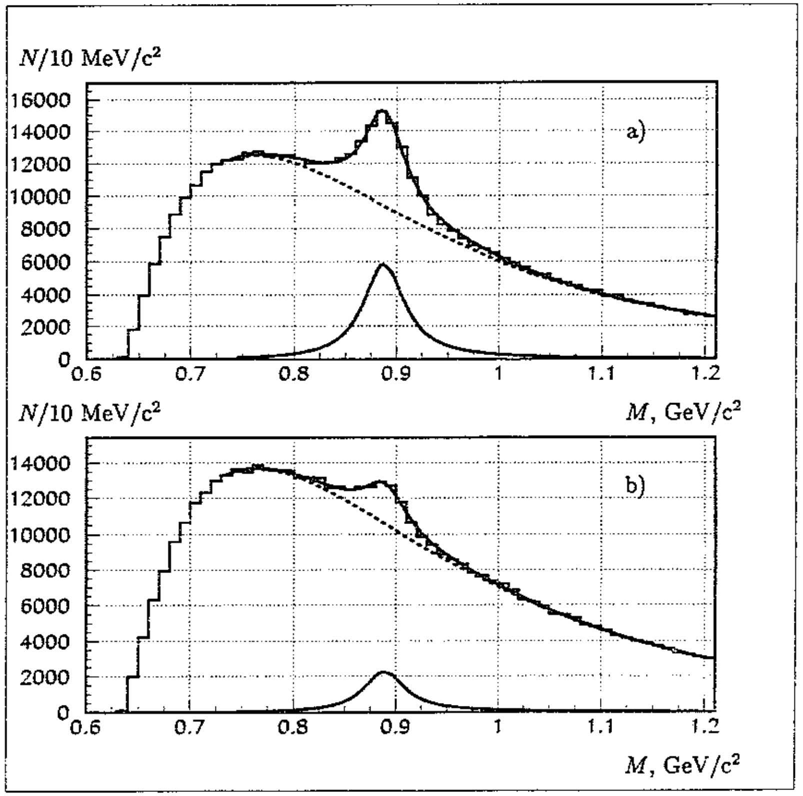

Fig. 1. Invariant mass spectra of $K_S\,\pi^+$ (a) и $K_S\,\pi^-$ (b) combinations; the dashed curve represents the background; the shaded spectrum shows the signal contribution.

where the signal is represented by the relativistic P-wave ($l = 1$) Breit-Wigner distribution $BW(M)$ with the mass-dependent width Γ_R:

$$
\begin{aligned}
BW(M) &= \frac{M M_R \Gamma_R}{(M^2 - M_R^2)^2 + M_R^2 \Gamma_R^2}, \\
\Gamma_R &= \Gamma + 4\sigma^2, \quad \sigma^2 = \sigma_{res}^2 + \sigma_{bin}^2, \\
\Gamma &= \Gamma_0 \left(\frac{p^*}{p_R^*}\right)^{2l+1} \frac{1 + R p_R^{*2}}{1 + R p^{*2}},
\end{aligned}
\tag{3}
$$

where p^* is the pion momentum and p_R^* is the pion momentum in the resonance maximum (both in the the resonance rest frame). The mass resolution (σ_{res}) and binning effects (σ_{bin}) have been considered as simple modifications of the total width. The $K^*(892)^\pm$ range parameter $R \simeq 12.1$ is taken according to its PDG value [10].

The background $BG(M)$ is represented by a smooth function

$$BG(M) = b_1(M - M_{thr})^{b_2} \exp(b_3 M + b_4 M^2), \quad (4)$$

where M_{thr} is the resonance mass threshold and $b_1, \ldots, b_4$ are free parameters. The influence of the effective phase space on the shape of resonance has been taken into account in the product $BG(M)\dot{B}W(M)$. A total of 39180 ± 1070 $K^*(892)^+$ decays and 15280 ± 970 $K^*(892)^-$ decays have been observed (the errors contain also the systematic uncertainties related tot the fit procedure).

The evaluation of ρ_{00} is based on the vector-meson decay angular distribution

$$W(|\cos\theta|) = \frac{3}{2}[1 - \rho_{00} + (3\rho_{00} - 1)\cos^2\theta], \quad (5)$$

where the angle θ is the polar angle of $\pi^\pm$ momentum-vector in the decay $K^*(892)^\pm \to K^0\pi^\pm$. The measurements have been carried out in the transversity frame of $K^*(892)^\pm$ at rest. The z-axis is determined as a normal to the production plane, y-axis has an opposite direction to the K^* momentum defined in the lab system. The x-axis is defined by the right-hand coordinate system.

To measure ρ_{00} the selected $K^*(892)^\pm$ have been divided in five intervals on $|\cos\theta|$. The relevant numbers of signal, background events, and corresponding errors have been evaluated by approximations of invariant mass spectra as described above in each of the $|\cos\theta|$ intervals. Supposing that the background has no spin alignment, the corresponding distribution has been used as a measure for the acceptance corrections. The normalized angular distributions of pions from $K^*(892)^+$ and $K^*(892)^-$ decays corrected by the acceptance are given in Fig.2 (a) and (b), respectively.

The key assumption that the background has no spin alignment and could be used for relative acceptance corrections has been proved independently. The $K^*(892)^\pm$ inclusive production (with no spin alignment) including the background events has been simulated by FRITIOF model [11]. Charged particle tracking through the setup was realized in GEANT-based program [12]. The comparison of P_L, P_T^2 and charged multiplicity between the simulated events and the experimental data has shown a fair agreement, improved at the next stage by weighting procedure. Both simulations of the signal and background give similar results on the acceptance as a function of $|\cos\theta|$ which agree well with the background behavior in the experiment.

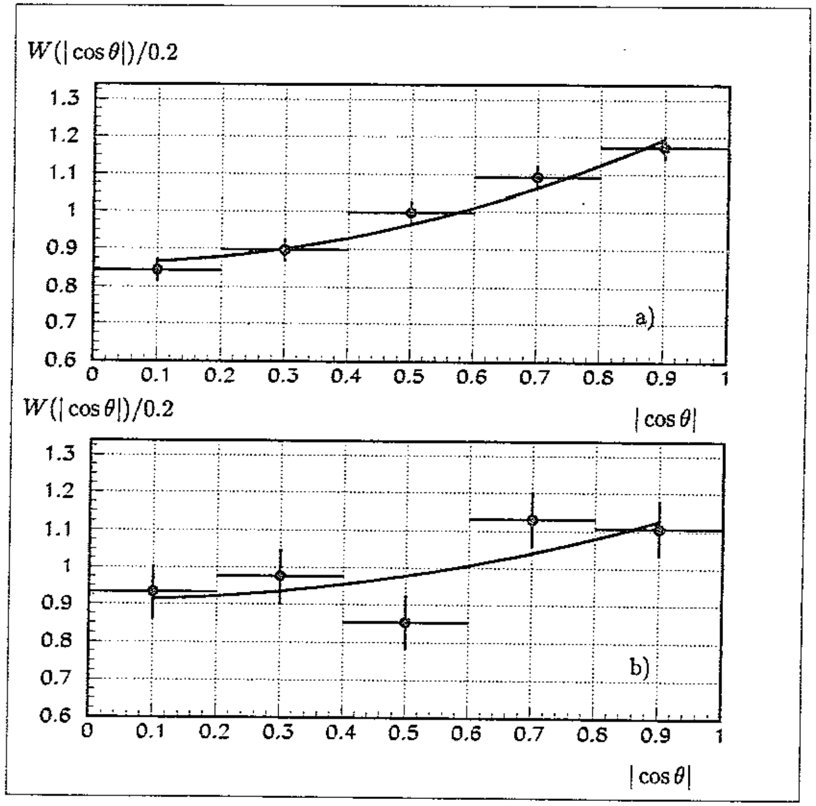

Fig. 2. Angular distribution of the pion from the resonance decay for $K^*(892)^+$ (a) and $K^*(892)^-$ (b) in the transversity frame.

The approximation of $|\cos\theta|$-spectra by formula (5) are shown in Fig.2 (a) and (b) by solid lines. As a result of this approximation, the ρ_{00} have been obtained: 0.424 ± 0.011 for $K^*(892)^+$, and 0.393 ± 0.025 for $K^*(892)^-$.

A systematic error has been calculated by combining in quadrature the contributions from: detector asymmetry, trigger bias, acceptance and beam geometry uncertainties. The corresponding errors have been estimated as a deviation of ρ_{00} from the mean value due to: alternative polarity of magnetic field (0.01), simulated difference in trigger conditions related to the charged multiplicity (0.01), different $K_S\pi^+$ and $K_S\,\pi^-$ acceptances (0.01) and varied positions of internal target (0.002). As a result the systematic error of $\Delta = 0.018$ has been obtained.

The measurement of ρ_{00} as a function of P_T has been performed in six nonequidistant intervals[2] on P_T. The same procedure as described above has been used for the estimation of ρ_{00} in each of P_T intervals. The systematic error Δ listed above has been shared among intervals (i) of P_T according to the formula $\Delta_i = \sigma_i \Delta[\sum(1/\sigma_i^2)]^{1/2}$, where σ_i is the statistical error [10]. The obtained ρ_{00} dependences on P_T are shown in Fig.3 (a) for $K^*(892)^+$ and (b) for $K^*(892)^-$. One can see a clear P_T dependence of the matrix element ρ_{00} for

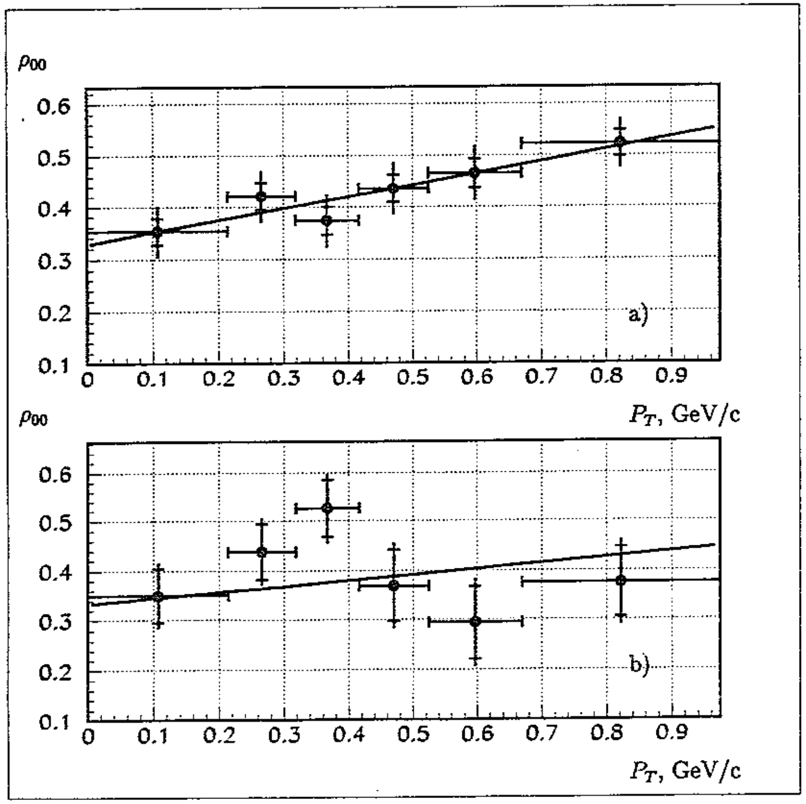

Fig. 3. P_T-dependence of the spin density matrix element ρ_{00} for $K^*(892)^+$ (a) and $K^*(892)^-$ (b) in the transversity frame; the statistical errors are enlarged quadratically by the systematic ones.

the $K^*(892)^+$ mesons. The P_T dependence of ρ_{00} for $K^*(892)^+$ is approximated by a linear function $\rho_{00}(P_T) = a + bP_T$. The obtained parameters are $a = 0.328 \pm 0.023_{stat} \pm 0.037_{sys}$ and $b = 0.23 \pm 0.045_{stat} \pm 0.073_{sys}$. The value of $a = \rho_{00}(0)$ is compatible with 1/3, as expected by kinematic reasons. This indicates the absence of significant additional uncertainties in the $K^*(892)^+$

[2] Each interval on P_T contains roughly the same number of K^* decays.

analysis. If the constraint $a = \rho_{00}(0) = 1/3$ is recquired, the slope parameter b is estimated as $b = 0.22 \pm 0.022_{stat} \pm 0.035_{sys}$.

Using the same constraint $a = \rho_{00}(0) = 1/3$ in the $K*(892)^-$ case, the slope $b = 0.12 \pm 0.057_{stat} \pm 0.039_{sys}$ is obtained (Fig.3 (b)) .

Conclusions

A clear deviation from the value of $\frac{1}{3}$ is observed for ρ_{00} indicating the spin alignment of $K^*(892)^+$ produced inclusively in neutron-carbon interactions at 57±9 GeV. It has been obtained that leading vector meson $K^*(892)^+$ has spin alignment, increasing with P_T. Some indications on spin alignment of non-leading $K^*(892)^-$ have been obtained, but with low statistical significance. The present precise measurement is in agreement with the result obtained in K^+ beam [5]. Thus the qualitative theoretical expectations [1] of leading particle effect in spin alignment are confirmed.

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