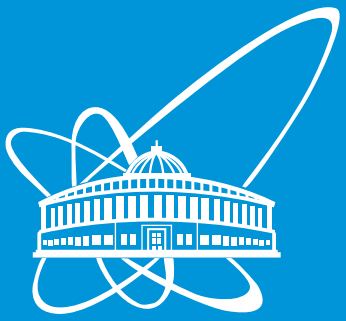

СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
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ИССЛЕДОВАНИЙ

Дубна

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PARTIAL WAVE ANALYSIS AND EVALUATION OF RESONANCE POLARIZATION IN 3π PRODUCTION IN $\pi-$Be COLLISIONS AT 37 GeV/c*

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1. Introduction

It is well known that quarks are confined and escape from direct observation. Instead of quarks we observe jets of hadrons into which quarks fragment. However, measurement of jet characteristics allows us to judge to some extent the quark characteristics, e.g. the electric charge or the momentum (yet with some unavoidable error due to fundamental indefiniteness of the jet content because of slow hadrons) or the spin of quarks and gluons through the angular distributions of jets. The problem is how quark polarization could be measured.

There are several ways to do this:

1. To measure the polarization of a self-analyzing hadron into which the quark fragments in a semi-inclusive DIS, e.g. Λ-hyperon [1]. The drawback of this method, however, is a rather low rate of quark fragmentation into a Λ-particle ($\approx 2\%$) and especially its predominant sensitivity to s-quark polarization.

2. To measure the spin-dependent T-odd parton fragmentation function (PFF) [2, 3, 4] responsible for the left-right asymmetry in fragmentation of a transversely polarized quark with respect to the quark momentum–spin plane. (The so-called "Collins asymmetry" [5].)

3. To measure the transverse handedness in multi-particle parton fragmentation [6], i.e. the correlation of quark spin 4-vector s_μ and particle momenta k_ν of particles in a jet, $\epsilon_{\mu\nu\sigma\rho} s^\mu k_1^\nu k_2^\sigma k^\rho$

The latter two methods are comparatively new, and only in the last years some experimental indications the T-odd PFF [7, 8, 9, 10] and the transverse [11] handedness have appeared. In particular, it is rather large ($\approx 10\%$) handedness transverse to the production plane observed in the diffractive production of $(\pi^-\pi^+\pi^-)$ triples from nuclei by the 40 GeV/c π^-–beam. It resembles the single spin asymmetry behavior and shows a clear dynamic origin in the sense that its invariant mass $m_{3\pi}$ dependence indicates a resonance character of the phenomenon.

In this paper we continue to investigate this problem in more detail using the high statistics of the VES collaboration [12] for the process

$$\pi^- + A \to (\pi^-\pi^+\pi^-) + A \,. \tag{1}$$

In Sec. 2 the main definitions and notation are given, in Sec. 3 the raw data results for the handedness are described, Sec. 4 is devoted to the Partial Wave Analysis (PWA), and Sec. 5 is a Conclusion.

2. Definitions and notation

The handedness was defined as the asymmetry of the process probability W with respect to the spatial component of an axial 4-vector $n_\mu \propto \epsilon_{\mu\nu\sigma\rho} k_1^\nu k_2^\sigma k^\rho$, where k's are 4-momenta of particles of a system in question ($k = k_1 + k_2 + k_3 + \cdots$), with respect to some direction $\boldsymbol{i}$ ($n_i = \boldsymbol{ni}$)

$$H_i = \frac{W(n_i > 0) - W(n_i < 0)}{W(n_i > 0) + W(n_i < 0)} = \alpha_i P_i \tag{2}$$

and was shown to be proportional to the system polarization P_i (at least for system spins 1/2 and 1). The direction $\boldsymbol{i}$ could be chosen to be longitudinal (L) with respect to the momentum $\boldsymbol{k}$ or transverse ($T1$ or $T2$).

For reaction (1), let the normal to the plane of production of a secondary pion triple ($\pi_f^- \pi^+ \pi_s^-$) be

$$\boldsymbol{N} = (\boldsymbol{v}_{3\pi} \times \boldsymbol{v}_b)\,, \tag{3}$$

where $\boldsymbol{v}_b = \boldsymbol{k}_b/\epsilon_b$ and $\boldsymbol{v}_{3\pi} = \boldsymbol{k}_{3\pi}/\epsilon_{3\pi}$ are the velocities of the initial π^- beam and 3π system and the indices f and s label fast and slow π^-'s in the Lab frame of reference. The normal to the "decay plane" of the triple is defined as

$$\boldsymbol{n} = (\boldsymbol{v}_f^- - \boldsymbol{v}^+) \times (\boldsymbol{v}_s^- - \boldsymbol{v}^+)\,, \tag{4}$$

where $\boldsymbol{v}_{f(s)}^-$ or $\boldsymbol{v}^+$ are the velocities of the fast (slow) π^- or π^+.

The transverse handedness, according to (2), is[1]

$$H_{T1} = \frac{W(\boldsymbol{Nn} > 0) - W(\boldsymbol{Nn} < 0)}{W(\boldsymbol{Nn} > 0) + W(\boldsymbol{Nn} < 0)}\,. \tag{5}$$

Two other components of the handedness, H_L and H_{T2}, are connected with the sign of $\boldsymbol{n} \cdot \boldsymbol{v}_{3\pi}$ and $\boldsymbol{n} \cdot (\boldsymbol{v}_{3\pi} \times \boldsymbol{N})$ respectively and are defined similar to (5). They are forbidden by the parity conservation in the strong interaction and have to be zero.

[1]It is easy to show that this quantity is Lorentz invariant if the particle order in the triple is fixed. In our case we have two identical π^- particles, so the decay plane has no selected "left" or "right" side and we are forced to use the given particle ordering.

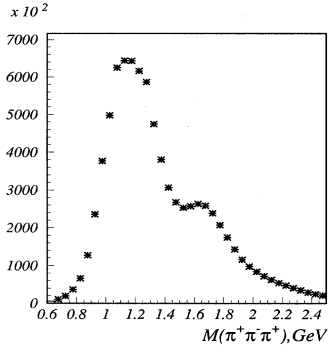

Figure 1. *Raw data invariant mass spectrum of the pion triples.*

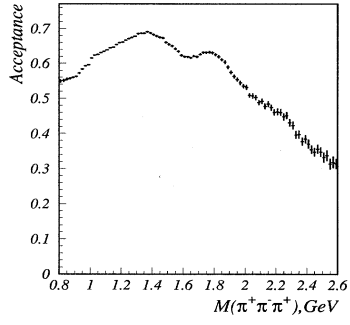

Figure 2. *Acceptance of the VES setup.*

3. The raw data results on the handedness

As was mentioned before, we used $\pi^-\pi^-\pi^+$ data collected by VES collaboration [12] for our analysis. The data were produced by the 37.0 GeV/c π^--beam on a beryllium target and were collected by a general-purpose multi-particle magnet spectrometer with full identification of final states by a lead-glass calorimeter and a multichannel Čerenkov counter. We used events in the $m_{3\pi}$ interval 0.6–2.5 GeV and $t' = |t - t_{max}|$ interval 0.0–1.0 GeV^2/c^2. At total of about $9 \cdot 10^6$ events produced on the Be target were used in the analysis.

More detailed description of the VES setup can be found in [12]. The raw data $m_{3\pi}$ distribution without acceptance corrections is given in Fig. 1. The dependence of the VES setup ac-

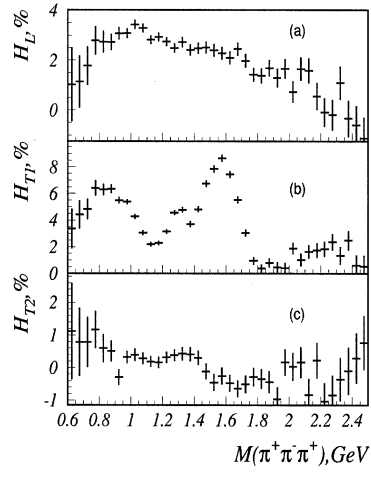

Figure 3. *Raw data handedness dependence of the invariant 3π mass, (a) longitudinal, (b) and (c) transverse.*

ceptance on the invariant mass of the pion triple $m_{3\pi}$ for this reaction is given in Fig. 2. This distribution was calculated for the physical event distribution, so the bump at $m_{3\pi} \approx 1.7$ GeV corresponds to production of the $\pi_2(1670)$ meson, which has a better acceptance due to its wave function structure.

The same events were analyzed using Exp. (5) for the handedness H_{T1} transverse to the triple production plane and similar formulas for H_L and H_{T2}. The raw data results of this analysis are presented in Fig.3. One can see that in contrast to the $m_{3\pi}$ spectrum (Fig. 1), where no prominent resonance peak is seen, the transverse handedness spectrum H_{T1} (Fig. 3b) reveals distinct peaks in the region of $a_2(1320)$ and $\pi_2(1670)$. Curious enough is the absence of a prominent peak in the region of $a_1(1230)$ and a bump in the region of $800\,GeV$. Note, however, that the systematic errors due to apparatus corrections are rather large (this is demonstrated by a non-zero value of the longitudinal handedness H_L in Fig. 3a) and have to be taken into account. This was done together with the PWA considered below.

4. The partial wave analysis

The PWA was performed by the modified Illinois University program which uses the cascade model [13]. The modifications consist in the following main changes:

- The program is partially rewritten to handle a large number of events ($\approx 10^7$) and fitting parameters ($\approx$ 500–700). New methods for multidimensional integration and maximization of likelihood are implemented;
- The Au-Morgan-Pennington parametrization [14] is used for description of the $J^P = 0^+$ $\pi\pi$-resonance. This amplitude was decoupled into the $f_0(980)$ resonance and the remaining broad wave without sharp structures. Both parts are separately included in the analysis.
- The relativistic covariant amplitudes of S.U. Chung [15] are used. In comparison with conventional helicity amplitudes, they include some multiplicative corrections depending upon the gamma-factor and helicity of the intermediate isobar in the three-particle rest frame. The corrections are essential mainly for the $1^+, 2^-$ and 3^+ states of the $\rho\pi$ system. In particular, they noticeably change the 1^+ wave which became an almost pure S-wave in the $\rho\pi$-system.

- The 2^- F-wave state of the $\rho\pi$-system is added to the set of states which appears to be rather large.

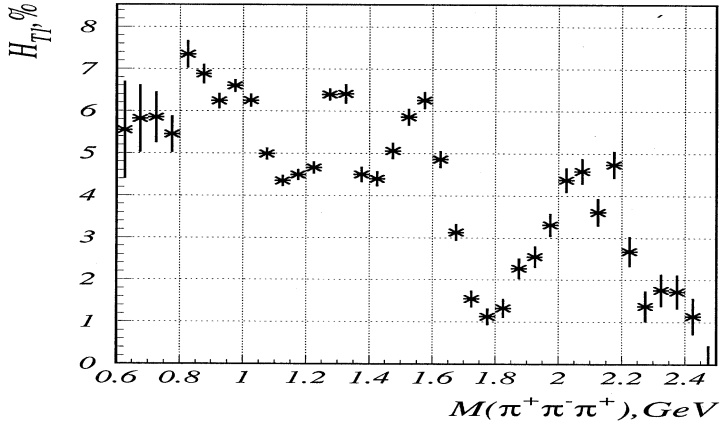

Figure 4. *Spectrum of the transverse handedness H_{T1} after acceptance corrections.*

In addition, the PWA program automatically includes the acceptance corrections. As a result of the PWA, the handednesses H_L and H_{T2} become compatible with zero (average over $m_{3\pi}$ $\overline{H_L} = 0.09 \pm 0.13\%$ and $\overline{H_{T2}} = -0.02 \pm 0.13\%$). Contrary to this, more prominent resonance peaks are revealed in the spectrum of the transverse handedness H_{T1} (Fig. 4).

However, interpretation of these peaks calls for more investigation since no prominent peaks are seen in the diagonal density matrix elements. A possible exception is the element $(1^+, 1^+)$, where a bump in the region of 1200 MeV is seen (Fig. 5) and can be interpreted as production of the a_1-meson whose polarization should be a few percent. An interesting question is the a_1 handedness (i.e. polarization) dependence of x_F, k_T and t' variables which have to be investigated in the future. Another intriguing point is a strange sharp peak in the region 2200 MeV since no 3π resonance is known in this region. To what spin-parity it corresponds is also a question for the future.

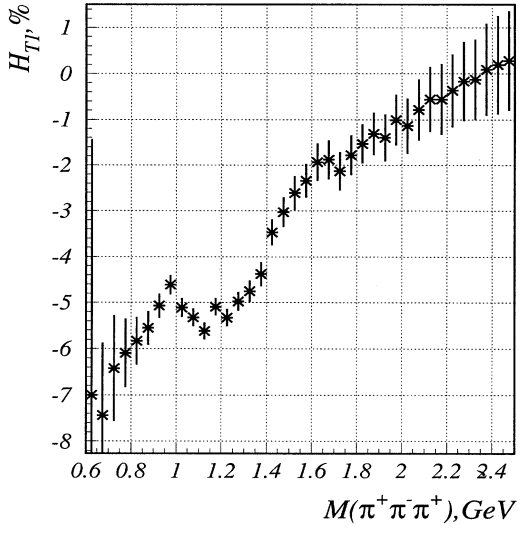

Figure 5. *Dependence of H_{T1} on the invariant 3π mass for the diagonal $(1^+, 1^+)$ density matrix element.*

5. Conclusion

Using the high statistics of the VES collaboration, we have obtained the transverse handedness of the pion triples produced by a pion beam. It reveals very rich resonance-type dependence on the pion triple invariant mass. The partial wave analysis shows the nonzero polarization of the a_1-meson and a rather complicated picture for other $I^G = 1^-$ resonances. The polarization and its dependence on x_F, k_T and t' will be found after calculation of the analyzing power of the $a_1 \to 3\pi$ decay.

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Ефремов А.В. и др. E1-2000-322
Парциально-волновой анализ и оценка поляризации резонансов, рожденных в π – Be-соударениях при 37 ГэВ/с

На экспериментальном материале коллаборации VES наблюдена большая корреляция между плоскостями рождения и распада $(\pi^-\pi^+\pi^-)$-системы (поперечная handedness) в процессе диссоциации π-мезонов на ядерной мишени при 37 ГэВ/с. Исследована ее зависимость от инвариантной массы пионной тройки. Из проведенного парциально-волнового анализа явно следует поляризация рожденных резонансов.

Работа выполнена в Лаборатории физики частиц ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 2000

Efremov A.V. et al. E1-2000-322
Partial Wave Analysis and Evaluation of Resonance Polarization in 3π Production in π – Be Collisions at 37 GeV/c

Large correlation of production and decay planes (transverse handedness) of the $(\pi^-\pi^+\pi^-)$-system produced by the 37 GeV/c π^--beam on the nuclear target is observed in the experimental data of the VES collaboration. The dependence of the handedness on the invariant mass of the pion triple is investigated. The partial wave analysis clearly shows resonance polarization.

The investigation has been performed at the Laboratory of Particle Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 2000

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