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# ANGULAR DEPENDENCE OF SYMMETRIC HADRON PAIR PRODUCTION IN $\pi^- p$ COLLISIONS AT $\sqrt{s}$=8.7 GeV

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## Abstract

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The angular dependence of symmetric hadron pair production cross section with effective mass in the range 2.4-5.4 GeV/$c^2$ at $\sqrt{s}$=8.7 GeV is measured with a double arm spectrometer. The results are compared with a QCD calculations.

## Аннотация

Волков А.А. и др. Угловая зависимость образования симметричных адронных пар в $\pi^- p$-столкновениях при $\sqrt{s}$=8.7 ГэВ: Препринт ИФВЭ 93-101. – Протвино, 1993. – 7 с., 1 рис., 2 табл., библиогр.: 13.

На двухплечевом спектрометре измерена угловая зависимость сечений образования симметричных адронных пар с эффективной массой в диапазоне от 2,4 до 5,4 ГэВ/$c^2$ при $\sqrt{s}$ = 8,7 ГэВ. Экспериментальные данные сравниваются с расчетами по модели, основанной на КХД.

The measurement of symmetric hadron pair production at high transverse momentum is a means of parton-parton dynamic interaction investigation, since, firstly, it is generally accepted that large $P_T$ hadrons are produced as a result of hard scattering of hadron constituents – quarks, gluons, and, perhaps, diquarks; secondly, as it has been shown experimentally [1] at $x_T > 0.2$ ($x_T = 2P_T/\sqrt{s}$) a leading hadron carries away a larger fraction of the jet momentum (80-90%); thirdly, the angular dependence of these symmetric hadron pairs is not practically influenced by the hadron intrinsic transverse momentum $k_T$ in colliding hadrons [2]. Besides the fragmentation process leads to the result that large $P_T$ hadron in major cases contains a scattered parton. Thus the quantum numbers of the hadron must partially reflect the flavor of the fragmenting parton [3]. At comparatively low energies large deviations from scaling and contribution of diquark interaction [4],[5] can be expected.

This article presents the experimental data on the dependence of $h^+h^-$ pair production invariant differential cross section (where h=$\pi$, K, p) in $\pi^-p$ collisions on the angle of pair scattering in the pair rest reference ($\theta$). The measurements of the cross section angular dependences of symmetric hadron pair and two-jet event production in $pp$, $p\bar{p}$-collisions have been carried out in several experiments [1,6-10]. However the results on $\pi^-p$-collisions are obtained for the first time. This is mainly explained by two reasons: relatively low intensity of $\pi^-$ beams and at the same time difficulties in detecting of such rare events as production of symmetric hadron pairs at large $P_T$.

The measurements are carried out with a double-arm spectrometer described in detail elsewhere [11] at 8.7 GeV energy in the c.m.s. of $\pi^-p$-collisions. Pion beam with the intensity up to $10^8$ $\pi^-$/s first strikes a 40-cm hydrogen target and then an absorber. The beam position and its intensity are measured by multichannel and solid electrode ion chambers. The chambers are calibrated at low beam intensity by scintillation and Cherenkov counters placed into the beam. The chamber calibration precision is 10%. The spectrometer is based upon a double gap magnet with the angle between the gap axes 320 mrad. This provides the detection of hadron pairs produced back-to-back in pp-collisions at $\sqrt{s}$=11.5 GeV. After the magnet particle trajectory coordinates are measured by drift chambers.The particles ($\pi$, K, p) are identified by a spectrometer of Cherenkov rings (SCOCH) [12] with known momentum defined by the particle bending angle in the magnetic field. To suppress the counting rate from electromagnetic showers there is installed a lead absorber 30 cm thick with a scintillation counter after it put into the trigger. The trigger of one arm is organized by the coincidence of 4 scintillation counters, the double-arm trigger is the coincidence of the single-arm triggers.

The whole spectrometer can be rotated in the horizontal plane around the target center up to 60 mrad. The measurements are carried out for two values of the angle: 0 mrad and 60 mrad.

The data analysis consists of geometrical reconstruction, evaluation of momentum and angle of particle emission from the target, particle identification by the radius of the Cherenkov ring measured by the SCOCHs. Then after background subtraction the data are corrected for the detection efficiency different particle species. The cross sections are calculated with Monte Carlo modelling of the experiment.

For the analysis of the angular dependence of the pair production cross section the data are selected by requiring:

1. $P_{T1,2} > 1$ GeV/c, where $P_{T1}$ and $P_{T2}$ are the transverse momenta of the $h^-$ and $h^+$ hadrons, respectively;
2. $|P_{T1} - P_{T2}| < 0.6$ GeV/c;
3. $2.4 < M_{h^+h^-} < 5.4$ GeV/$c^2$, where $M_{h^+h^-}$ — effective mass of hadron pair;
4. $160^\circ < |\phi_1 - \phi_2| < 200^\circ$, where $\phi_1$ and $\phi_2$ are the azimuthal angles of the hadrons.

The absolute value of the pair longitudinal momentum in the c.m.s. for all pairs satisfying the aforementioned criteria is not exceeding 1 GeV/c.

The invariant differential cross section of hadron pair production of various species versus $Cos\theta$ is presented in Table 1. The angle $\theta$ in the rest system of the hadron pair is defined by the expression:

$$Cos\,\theta = \frac{Sin(\frac{\vartheta_1-\vartheta_2}{2})}{Sin(\frac{\vartheta_1+\vartheta_2}{2})},$$

Table 1. The angular dependence of the invariant differential cross sections of symmetric hadron pair production.

| Sort | Mass (GeV/$c^2$) | $Cos\,\theta$ | $E_1E_2\frac{d^6\sigma}{d^3p_1d^3p_2}$ (pb/GeV$^4$) |
|---|---|---|---|
| $\pi^+\pi^-$ | 3.5 | −0.44 | 26.9 ± 3.0 |
| | | −0.37 | 19.2 ± 1.5 |
| | | −0.30 | 17.4 ± 1.8 |
| | | −0.12 | 8.6 ± 1.2 |
| | | −0.04 | 10.6 ± 0.5 |
| | | 0.04 | 10.1 ± 0.4 |
| | | 0.12 | 11.2 ± 1.3 |
| | | 0.30 | 17.5 ± 1.7 |
| | | 0.37 | 27.1 ± 2.1 |
| | | 0.44 | 50.1 ± 4.6 |
| $\pi^+K^-$ | 3.5 | −0.45 | 5.72 ± 1.95 |
| | | −0.37 | 2.87 ± 0.71 |
| | | −0.30 | 2.77 ± 1.01 |
| | | −0.13 | 1.36 ± 0.38 |
| | | −0.04 | 1.93 ± 0.20 |
| | | 0.04 | 1.60 ± 0.21 |
| | | 0.12 | 2.56 ± 0.67 |
| | | 0.29 | 2.85 ± 0.61 |
| | | 0.37 | 4.14 ± 0.81 |
| | | 0.44 | 3.45 ± 2.24 |
| $K^+\pi^-$ | 3.5 | −0.44 | 5.50 ± 2.34 |
| | | −0.37 | 5.95 ± 0.92 |
| | | −0.29 | 5.67 ± 1.10 |
| | | −0.12 | 5.13 ± 0.84 |
| | | −0.04 | 3.45 ± 0.29 |
| | | 0.04 | 3.66 ± 0.28 |
| | | 0.13 | 4.38 ± 0.93 |
| | | 0.30 | 6.39 ± 1.61 |
| | | 0.37 | 11.1 ± 1.5 |
| | | 0.45 | 23.2 ± 3.5 |
| $K^+K^-$ | 3.5 | −0.45 | 7.83 ± 2.09 |
| | | −0.37 | 1.70 ± 0.81 |
| | | −0.30 | 3.06 ± 0.94 |
| | | −0.12 | 3.49 ± 0.66 |
| | | −0.04 | 2.65 ± 0.27 |
| | | 0.04 | 2.52 ± 0.25 |
| | | 0.12 | 2.40 ± 0.64 |
| | | 0.29 | 4.74 ± 1.19 |
| | | 0.37 | 5.18 ± 1.20 |
| | | 0.45 | 7.82 ± 2.68 |

Table 1.(Continued)

| Sort | Mass (GeV/$c^2$) | $Cos\,\theta$ | $E_1 E_2 \frac{d^6\sigma}{d^3p_1 d^3p_2}$ (pb/GeV$^4$) |
|---|---|---|---|
| $p\pi^-$ | 3.5 | −0.47 | $5.74 \pm 1.49$ |
| | | −0.38 | $2.73 \pm 1.21$ |
| | | −0.30 | $2.64 \pm 1.88$ |
| | | −0.16 | $1.71 \pm 0.44$ |
| | | −0.05 | $0.82 \pm 0.23$ |
| | | 0.05 | $1.73 \pm 0.31$ |
| | | 0.15 | $1.47 \pm 0.41$ |
| | | 0.27 | $4.82 \pm 0.86$ |
| | | 0.37 | $4.58 \pm 1.62$ |
| | | 0.44 | $6.31 \pm 2.61$ |
| $\pi^+\bar{p}$ | 3.5 | −0.43 | $24.0 \pm 5.7$ |
| | | −0.37 | $21.1 \pm 3.3$ |
| | | −0.27 | $21.6 \pm 2.0$ |
| | | −0.15 | $21.7 \pm 1.4$ |
| | | −0.05 | $15.9 \pm 0.8$ |
| | | 0.05 | $14.5 \pm 0.8$ |
| | | 0.15 | $26.6 \pm 1.8$ |
| | | 0.31 | $51.7 \pm 8.3$ |
| | | 0.38 | $68.3 \pm 5.8$ |
| | | 0.47 | $123 \pm 8$ |
| $p\bar{p}$ | 3.8 | −0.46 | $6.13 \pm 2.19$ |
| | | −0.37 | $6.36 \pm 1.32$ |
| | | −0.28 | $4.30 \pm 1.31$ |
| | | −0.13 | $2.53 \pm 0.67$ |
| | | −0.05 | $2.80 \pm 0.33$ |
| | | 0.05 | $3.38 \pm 0.36$ |
| | | 0.13 | $3.62 \pm 0.67$ |
| | | 0.28 | $5.85 \pm 1.44$ |
| | | 0.37 | $10.0 \pm 2.0$ |
| | | 0.46 | $24.4 \pm 3.4$ |

where $\vartheta_1$ and $\vartheta_2$ are polar angles of the $h^-$ and $h^+$ hadrons, respectively, in the c.m.s. The cross section errors presented in table 1 include statistical errors of the measurements and the Monte-Carlo simulation of the detector acceptance only. The absolute normalization precision of the cross sections is evaluated to be 15% and is mainly determined by the monitor absolute calibration, the momentum determination precision and various corrections. The systematic error of $Cos\theta$ determination, associated with $\pi^-$ beam size on the target and precise knowledge of the detector geodesy, is not larger than 0.02.

As seen from Table 1 there is some asymmetry of angular dependence between forward-backward scattering for all pair sorts. The presence of this asymmetry may be explained by the difference between constituents of colliding $\pi^-$-mesons and protons.

The shape of the angular dependence of hadron pairs produced in $\pi^- p$ collisions is described by the first order perturbative QCD:

$$\frac{d\sigma}{dz} \Big/ \frac{d\sigma}{dz}\Big|_{z=0} = A(1-z)^{-n} + B(1+z)^{-n}, \quad (1)$$

where n, A, B are parameters and $z = cos\theta$.

The experimental results for all pairs versus $Cos\theta$ are fitted by expression (1). The obtained values of n, A, B and $\chi^2$ per number of the degrees of freedom are presented in Table 2. As seen from the table the values of the n, A, B parameters for various pair sorts differ from each other. This is due to the different production mechanisms of hadron pairs.

In article [13] that was published before the experimental measurements, the angular dependence of the $\pi^+\pi^-$ pair production cross section in the lowest perturbative order of QCD for pair mass 4 GeV/c$^2$ at $\sqrt{s} = 8.7$ GeV had been calculated. For the calculation the following values of the parameters have been chosen: QCD parameter $\Lambda = 0.4$ GeV/c, the average intrinsic parton momentum $< k_T >= 400$ MeV/c. To cut the infinities of constituent cross sections at small values of momentum transfer the regularization parameter $m^2 = 1$ GeV$^2$ has been added to the values of $\hat{s}$, -$\hat{t}$, -$\hat{u}$.

Fig.1 shows the angular dependence of $\pi^+\pi^-$ pair production with mass 4 GeV/c$^2$ based on the experimental data and on the calculation [13]. One can see from Fig.1 the calculations are in a qualitative accordance with the experimental data. The quantitative comparison depends on the chosen parameters of the model, the used approximation, and also on the chosen fragmentation function.

Our measurements are in a good agreement with the published results on the angular dependence of the cross section of the symmetric hadron pair production in $pp$-collisions at $\sqrt{s} = 11.5$ GeV [10].

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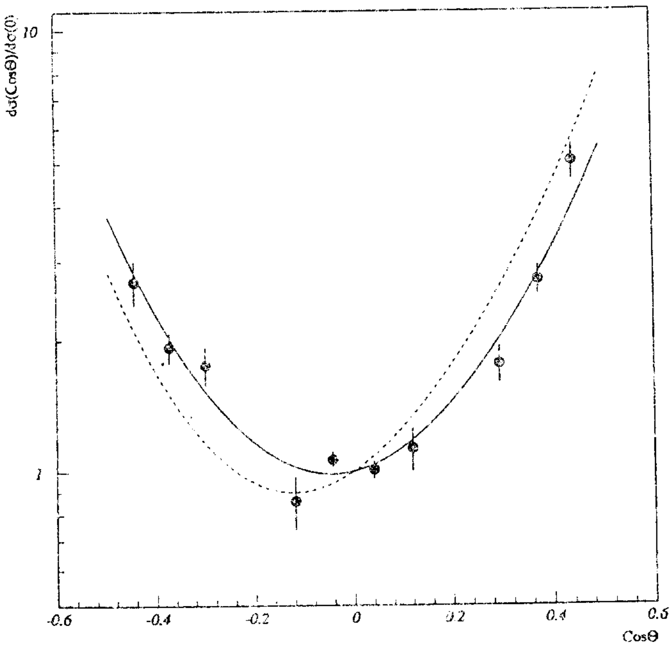


Figure 1. The angular dependence of invariant differential cross sections of $\pi^+\pi^-$-pair production. The full line is the fitting of the experimental data with mass 3.5 GeV/c$^2$ by function (1) ($n = 3.21 \pm 0.21$), the dashed line is the calculation based on QCD with mass 4 GeV/c$^2$ ($n$=3.45) from article [13].

Table 2. The fitted parameter values of cross section angular dependence of hadron pair production by function (1).

| Sort | A | B | n | $\chi^2$/d. of f. |
|---|---|---|---|---|
| $\pi^+\pi^-$ | $0.59 \pm 0.03$ | $0.41 \pm 0.02$ | $3.21 \pm 0.12$ | 2.12 |
| $\pi^+K^-$ | $0.56 \pm 0.08$ | $0.44 \pm 0.07$ | $2.77 \pm 0.37$ | 0.77 |
| $K^+\pi^-$ | $0.67 \pm 0.05$ | $0.33 \pm 0.04$ | $3.26 \pm 0.22$ | 1.61 |
| $K^+K^-$ | $0.67 \pm 0.10$ | $0.33 \pm 0.08$ | $2.21 \pm 0.42$ | 1.64 |
| $p\pi^-$ | $0.73 \pm 0.03$ | $0.27 \pm 0.02$ | $3.62 \pm 0.11$ | 7.7 |
| $\pi^+\bar{p}$ | $0.67 \pm 0.33$ | $0.33 \pm 0.07$ | $4.07 \pm 0.38$ | 1.58 |
| $p\bar{p}$ | $0.71 \pm 0.07$ | $0.29 \pm 0.05$ | $3.65 \pm 0.25$ | 0.95 |

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