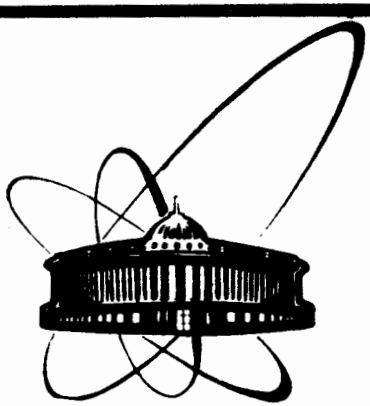

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E1-88-476

# EVIDENCE FOR HIGHER TWIST MECHANISMS IN HIGH $p_\perp$ - $\pi^- p$ EVENTS WITH PROMPT $\rho^0$ PRODUCTION AT 38 GeV/c

**RISK Collaboration**

Submitted to XXIV International Conference
on High Energy Physics, FRG, München, 1988.

1988

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We have studied the $\pi^- p$ events with a charged secondary carrying transverse momentum above 1 GeV/c. The data were taken at Serpukhov accelerator using 38 GeV/c $\pi^-$ beam to produce the high $p_\perp$ particle in the ~20 cm liquid hydrogen target placed at the forepart of the 4.7 m streamer chamber (spectrometer RISK). The event trigger employed the telescope of 3 MWPC's positioned just above the end part of the streamer chamber (last 0.7 m). This location corresponds to polar angle near 90° in c.m.s. Whole apparatus was placed inside the 1.5 T magnetic field. The trigger electronics accepted the events with at least one charged particle having transverse momentum above predetermined threshold. All charged tracks in ~3000 selected events were reconstructed using the film measurement. The details about the experimental apparatus and event reconstruction can be found elsewhere[1].

The raw transverse momentum distribution for trigger particles is displayed in fig. 1 by dots. The histograms were

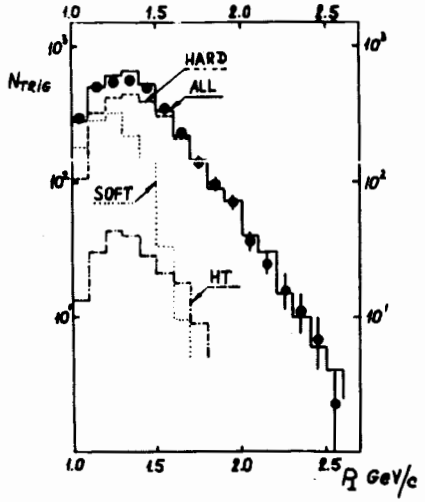
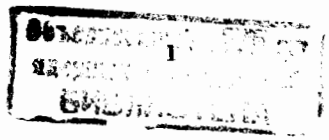



Fig. 1: The raw (not corrected for the trigger acceptance) transverse momentum distribution for the trigger particles - the dots with error bars. The histograms are LUND model predictions for the trigger particles produced in soft collisions - dotted line; in hard collisions - dashed line; in higher twist hard processes - dotted-dashed line; the sum of soft and hard processes - full line.



obtained using the LUND Monte-Carlo to generate events in soft (JETSET 6.2[2]) and hard (TWISTER 1.2[3]) $\pi^-p$ collisions at 38 GeV/c. We must note, that for the values of the trigger particle $p_\perp$ around 1 GeV/c, the employment of both models is on the verge of their applicability. The two samples are weighted according to inelastic $\pi^-p$ cross section[4] for soft interactions and calculated cross section for QCD hard subprocesses (done by TWISTER program itself). The higher twist processes, like $q\bar{q} \to gM$ and $qg \to qM$, where M is a directly produced meson, are also considered among hard collisions[5,6]. The program simulating the experimental apparatus was used to select trigger particles from generated events. In fig. 1, there are shown the proposed contributions for various underlaying mechanisms and the good agreement is seen between the experimental data and predicted final spectrum. According to these calculations the feed-through due to the soft interactions is on the level ~1/3 and the hard processes contributed ~60% of minimum twists (MT is the standard parton-parton scattering with subsequent fragmentation) and ~7% of higher twists (HT). The experimental observations of the prompt $\rho^o$-production in $\pi^-$Be interactions at 300 GeV/c[7] and prompt $\eta'$-production at ISR[8] recently reported were attributed to the HT mechanisms. We try to investigate the rôle of the HT processes in high $p_\perp$ particle production at lower energy having in mind, that the models[5,6] predict an increase of the HT contribution relative to the MT one in latter case.

The subprocess $\bar{u}u \to g\rho^o$ is one of the prominent channels among the HT processes in $\pi^-p$ interactions[6]. We note that in such mechanism the directly produced $\rho^o$-meson picks up the full momentum transfer carried by the exchange, while the $\rho^o$-meson created in parton fragmentation shares the momentum transfer with other products. Hence we tried to separate the events with prompt $\rho^o$-production selecting a pair of oppositely charged secondaries, with their net transverse momentum compensating the transverse momentum of the trigger particle. It must be mentioned here, that due to the primordial $p_\perp$ of the interacting valence $\bar{u}$ and u quarks inside the incoming $\pi^-$ and p, respectively, and also due to the distorsion of the gluon fragmentation function when a single high $p_\perp$ particle trigger is used, the differnce between the transverse momenta of the triggered secondary and directly produced $\rho^o$-meson will be biased into the trigger side in the colliding hadron's c.m.s. In fact, we apply the following cuts for the $\pi^+\pi^-$-system (all associated charged particles were taken as $\pi^-$-mesons):



i. The azimuthal angle between the trigger particle's and $\pi^+\pi^-$-system's momenta, $\Delta\Phi$, should be near to 180°, we used:

$$\Delta\Phi > 162.5^\circ \ (= 180^\circ - 17.5^\circ). \qquad (1)$$

ii. We define the algebraic sum of the transverse momentum of the $\pi^+\pi^-$-system $p_\perp^{\pi\pi}$ and of the projection of the trigger particle's transverse momentum $p_\perp^T$ in the direction of the $\pi^+\pi^-$-system:

$$\Delta p_\perp = p_\perp^{\pi\pi} + p_\perp^T.\cos(\Delta\Phi). \qquad (2)$$

The value of this variable would go to a zero, if the transverse momenta of the trigger particle and of the $\pi^+\pi^-$-system compensate each other, but taking into account the trigger bias as discussed above, this value can be slightly negative, of the order of the primordial $p_\perp$ of quarks inside the hadrons. Therefore we will take the events with the $\pi^+\pi^-$ combinations under condition, that the value of (2) is higher than some (negative) threshold.

First, in fig. 2, there are shown the $\pi^+\pi^-$-effective mass

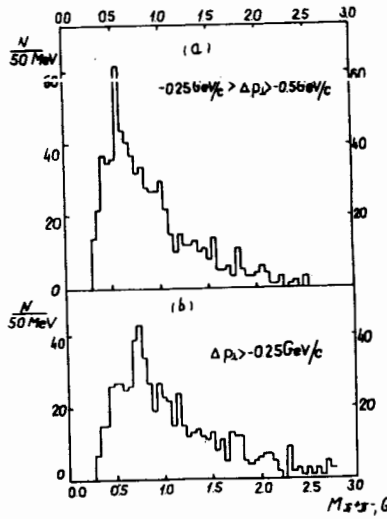



Fig. 2: The $\pi^+\pi^-$-invariant mass spectra for those $\pi^+\pi^-$-combinations, for which the azimuthal angle between the momenta of the $\pi^+\pi^-$-system and the trigger particle $\Delta\Phi > 162.5^\circ$ and the variable $\Delta p_\perp$ defined in (2) satisfy:
(a) $-0.5$ GeV/c $< \Delta p_\perp < -0.25$ GeV/c;
(b) $\Delta p_\perp > -0.25$ GeV/c.

($M_{\pi\pi}$) distributions for the $\pi^+\pi^-$-systems satisfying the condition (1), where

(a) the value of $\Delta p_\perp$ is between $-0.5$ GeV/c $< \Delta p_\perp < -0.25$ GeV/c

(b) the lower bound for it is $\Delta p_\perp > -0.25$ GeV/c.

In the latter case (b) we see well-pronounced signal, which we interprete as the $\rho^o$-production. On the other side, if the transverse momentum of the $\pi^+\pi^-$-system does not compensate the trigger particle's $p_\perp^T$ (case (a)), no enhancement in the $\rho^o$-mass region is seen.

In order to demonstrate this behavior more clearly, we fitted the $\pi^+\pi^-$-effective mass spectra obtained under condition (1) for various intervals in $\Delta p_\perp$ with the relativistic p-wave Breit-Wigner distribution with the $\rho^o$ mass and width fixed at the values $M_\rho = 770$ MeV/c$^2$ and $\Gamma_\rho = 150$ MeV/c$^2$ and a background parametrization:

$$BG(M_{\pi\pi}) = q(M_{\pi\pi}).\exp(-\beta.M_{\pi\pi}), \qquad (3)$$

where q(M) is the decay momentum. The fits were performed using events with the $\pi^+\pi^-$-effective mass from the interval 0.6 GeV/c$^2$ $< M_{\pi\pi} <$ 0.95 GeV/c$^2$, where the simple background parametrization (3) is sufficient enough and the contributions from other resonances and/or their reflections (e.g. $\omega \to \pi^+\pi^-\pi^o$, $K^* \to K\pi$, $f_2(1270) \to \pi^+\pi^-$) should be small. On the other side, the usage of the more complicated background parametrization (with more free parameters) could be dangerous with our limited statistics. The obtained result is demonstrated in the fig. 3 as the normalized $\rho^o$-meson

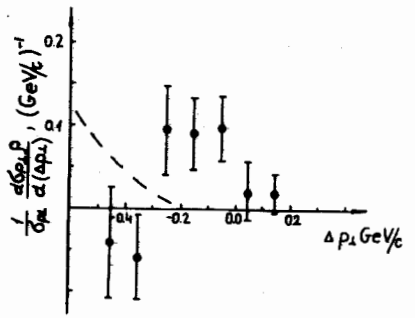



Fig. 3: The normalized distribution of the $\rho^o$-mesons in the variable $\Delta p_\perp$ (non-compensated transverse momentum, see (2)), which are produced opposite in the azimuth to the high $p_\perp$ trigger particle. The azimuthal angle between the trigger particle's and the $\rho^o$-meson's momenta is limited by $\Delta\Phi > 162.5°$.



distribution in the variable $\Delta p_\perp$ defined in (2). This distribution exhibits an enhancement of the number of events with $\rho^o$-meson in the region $\Delta p_\perp > -0.25$ GeV/c, that means when the transverse momentum of the $\rho^o$-meson practically completely compensates the $p_\perp^T$ of the trigger particle. The dashed line in the fig. 3 was obtained using generated events under the same conditions and it shows the shape of this distribution for the $\rho^o$-mesons produced via standard fragmentation in the MT processes. We are not able to normalize properly the generated distribution, because the models, which we used, overestimate the over-all $\rho^o$-production at our energy. Nevertheless, we may conclude from the shape of the $\rho^o$ spectrum in the $\Delta p_\perp$ variable, that the observed enhancement of the $\rho^o$-mesons at $\Delta p_\perp > -0.25$ GeV/c could not be explained using standard fragmentation mechanism of the $\rho^o$-production. On the other side, many of the generated HT events with directly produced $\rho^o$-mesons contribute to the $\Delta p_\perp > -0.25$ GeV/c region, but their total number (~15) is significantly lower than the number of observed events (90±30) in the same region. Because of limited Monte-Carlo statistics, which are on the level of the experimental ones, we are not able to draw any distribution for the HT events. Similar enhancement in the production of $\rho^o$-mesons, whose transverse momentum compensates the $p_\perp$ of another charged secondary in the $\pi^-$Be events was observed at 300 GeV/c[7].

We also studied the polarization properties of $\rho^o$-mesons selected by conditions (1) and $\Delta p_\perp > -0.25$ GeV/c. We define the angle $\Theta_T$ between the normal to the $\pi^+\pi^-$-system production plane (z-axis in the transversity frame) and the direction of $\pi^+$ in the $\pi^+\pi^-$ rest frame. Then we distribute selected events according to the value of $\cos\Theta_T$ into several subsamples. The same fitting procedure as described above was performed for events from each subsample. The resulting distribution of the $\rho^o$-mesons in $\cos\Theta_T$ is demonstrated in fig. 4. Since this distribution has minimum at $\cos\Theta_T = 0$, it implies, that the probability of the zero $\rho^o$ spin projection onto the normal to the production plane will be larger than its value for unpolarized $\rho^o$-mesons (1/3). We obtain the estimate of this probability, which is equal to the element of the spin-density matrix $\rho_{oo}^T$ in the transversity frame, by fitting the $\cos\Theta_T$ distribution with

$$dN_\rho/d(\cos\Theta_T) = \frac{1}{2} N_\rho.[1 + \frac{1}{2}(1 - 3\rho_{oo}^T).(1 - 3\cos^2\Theta_T)]. \qquad (4)$$

We found the result $\rho_{oo}^T = 0.86 \pm 0.23$. We checked the stability of

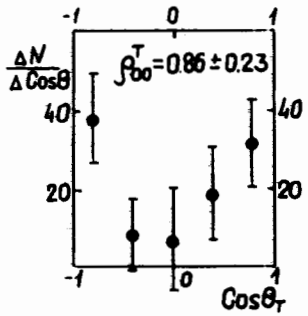



Fig. 4: The cos $\Theta_T$ distribution of the $\pi^+$-mesons from the $\rho^0 \to \pi^+\pi^-$ decay in the transversity frame for those $\rho^0$-mesons, which satisfy the same conditions as in fig. 2(b).

this estimation to the binning in cos $\Theta_T$ and background parametrization (3) using instead linear, quadratic and $q^\alpha.\exp(-\beta.M)$ shapes. The standard method, the substruction of the averaged number over the two regions of the effective mass adjacent to the $\rho^0$-mass region, was tried and also the over-all maximum likelyhood fit in $M_{\pi\pi}$ and cos $\Theta_T$ (the parametrization of background cos $\Theta_T$ distribution must be supplied in the latter case) was used to obtain the $\rho_{00}^T$ value. It was found, that the maximal deviation from the above presented mean could be -0.07 and +0.06, thus the systematic error is much smaller than the statistical one.

We analyzed the decay angle distributions in the Gottfried-Jackson frame (the z-axis is directed along the beam or target momentum in the rest frame of the $\pi^+\pi^-$-system produced in the forward or backward c.m.s. hemisphere respectively) and in the s-channel helicity frame (the z-axis is directed along the $\pi^+\pi^-$-system momentum in the colliding hadrons c.m.s.). The estimates of the spin-density matrix element $\rho_{00}$ in the investigated frames are presented in the table . It can be easy shown, that these values satisfy the constraints yielding from parity conservation and unitarity condition. Smaller $\rho^0$-spin alignment was observed in the inclusive $\pi N$ collisions at lower energies[9].

In fig.5, our estimate of the $\rho_{00}^T$ in the transversity frame is compared with the values obtained for the $\rho^0$-mesons inclusively ptoduced in the $\bar{p}p$ interactions at 5.7 GeV/c, 12 GeV/c and



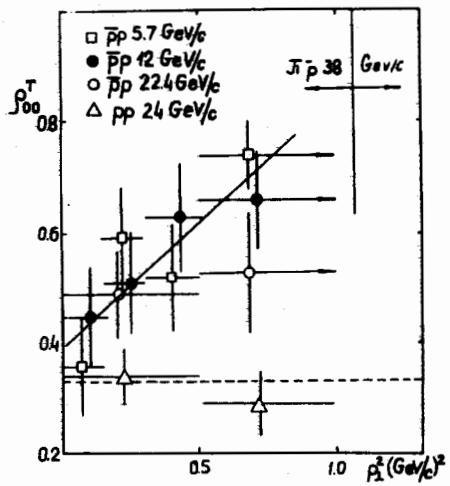



Fig. 5: The $p_\perp^2$-dependence of the spin-density matrix element $\rho_{00}^T$ in the transversity frame for the $\rho^0$-mesons produced inclusively in $\bar{p}p$ interactions at 5.7 GeV/c, 12 GeV/c and 22.4 GeV/c and in pp collisions at 24 GeV/c[10] compared with our estimate for the $\rho^0$-mesons, whose transverse momentum compensates the $p_\perp$ of trigger particle, in $\pi^-p$ high-$p_\perp$ interactions at 38 GeV/c.

22.4 GeV/c for various transverse momenta squared[10]. It must be mentioned here, that this comparison is not strictly rigorous, because the point for the $\pi^-p$ collisions at 38 GeV/c is related to the $\rho^0$-mesons, whose transverse momentum compensates the $p_\perp$ of another charged secondary and not to the inclusive $\rho^0$-production. Nevertheless, we see from fig. 5 the rapid increase of the probability for the $\rho^0$-meson to have the zero spin projection onto the normal to the $\rho^0$ production plane with the increase of its transverse momentum squared. This effect could be attributed to the valence antiquark-quark interactions, because the $\rho^0$-spin aligment is not observed in the pp collisions at comparable energy[10]. Moreover, in the HT diagrams for $\bar{q}q$ interactions, the states with zero helicity of directly produced vector mesons are strongly suppressed[6] (this is consequence of keeping gluon on mass-shell in $\bar{q}q \to gM$ subprocess). Similar explanation of the $\rho^0$-spin alignment, based on gluon emission, was originally proposed in the paper[11]. In the case of fully aligned $\rho^0$-mesons

in the helicity frame, the values of the spin-density matrix elements $\rho_{00}$ will be 0.0 and 0.5 in the helicity and transversity frames respectively. Thus, the observed behaviour of the $\rho^0$-meson polarization could be qualitatively understand as the manifestation of the HT mechanism.

In conclusion we summarize the presented results obtained from the analyzis of the associated charged production in the $\pi^-p$ events with single particle high-$p_\perp$ trigger at 38 GeV/c:

i. The enhancement of the number of events was observed, in which the trigger particle transverse momentum is practically completely compensated with the transverse momentum of the $\rho^0$-meson. The normalized $\rho^0$-meson distribution in the variable $\Delta p_\perp$ (non-compensated transverse momentum, defined in (2)) is displayed in fig. 3.

ii. It was demonstrated, that the $\rho^0$-mesons, whose transverse momentum compensates the trigger particle $p_\perp$, have large tensor polarization (or spin-alignment) in the transversity frame. The probability of the zero spin projection onto the normal to the $\rho^0$ production plane was estimated to be equal to $\rho^T_{00} = 0.86 \pm 0.23$. The results in other frames are presented in the table .

Both these effects can be at least qualitatively explained taking into the consideration the contribution of the higher twist mechanisms to the high-$p_\perp$ particle production. One of the prominent channels among the HT mechanisms was predicted to be the subprocess $\bar{q}q \to gM$, where M is directly produced vector meson[6]. The observed enhancement of the $\rho^0$-production in similar conditions at higher energy[7] was attributed to the HT processes. Presented results are in accord with the prediction of increasing rôle of the HT mechanisms at lower energies in high-$p_\perp$ particles production[5,6]. But, as we already mentioned, the observed rate of such events in this experiment is even higher than that one obtained with Monte-Carlo calculation using program TWISTER 1.2[3].The increase of the $\rho^0$-meson spin alignment with transverse momentum in $\pi^-p$ and $\bar{p}p$ collisions and also the lack of this effect in pp interactions[10] (in the latter case the subropcesses invoking antiquarks are strongly supressed) justify the conclusion about the significant contribution of the HT mechanisms to the production of high-$p_\perp$ particles in collisions of hadrons containing valence antiquark.



Table. The estimated values of the spin-density matrix element $\rho_{00}$ in the transversity, Gottfried-Jackson and helicity frames for the $\rho^0$-mesons produced in $\pi^-p$ high $p_\perp$ events at 38 GeV/c and satisfying the conditions (1) and $\Delta p_\perp > -0.25$ GeV/c ($\Delta p_\perp$ is defined in (2)). The errors are statistical only.

| Frame | $\rho_{00}$ | $\chi^2$/p.d.f. |
|---|---|---|
| Transversity | 0.86 ± 0.23 | 0.7 / 3 |
| Gottfried-Jackson | 0.14 ± 0.23 | 0.2 / 3 |
| Helicity | 0.04 ± 0.22 | 3.6 / 3 |

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Банников А.В. и др. E1-88-476
О роли механизма высших твистов в $\pi^- p$ событиях при 38 ГэВ/с с рождением $\rho^0$ мезонов большого поперечного импульса

В $\pi^- p$ взаимодействиях при 38 ГэВ/с с помощью магнитного спектрометра со стримерной камерой /установка РИСК/ изучались события с образованием по меньшей мере одной заряженной частицы /триггерной/ с поперечным импульсом выше 1 ГэВ/с, вылетающей под углом 90° в с.ц.м. Получены данные относительно корреляций между вторичными заряженными частицами, сопровождающими триггерную частицу в таких взаимодействиях. Результаты анализа свидетельствуют, что среди событий, в которых поперечный импульс триггерной частицы практически полностью компенсирован поперечным импульсом пары противоположно заряженных частиц, заметную долю составляют взаимодействия, где пара является продуктом распада $\rho^0$-мезона. Показано, что такие $\rho^0$-мезоны обладают высокой тензорной поляризацией: вероятность равенства нулю проекции спина на ось, перпендикулярную плоскости рождения $\rho^0$-мезона, составляет $0,86 \pm 0,23$. Наличие таких событий можно качественно объяснить тем, что в образовании частиц с большим поперечным импульсом вносит существенный вклад механизм высших твистов, т.е. процессы типа $q\bar{q} \to gM$ или $qg \to qM$ /M - прямо рожденный мезон/. Вместе с тем, наблюдаемое число таких событий в несколько раз выше, чем оценка, проведенная на основе ЛУНД-модели, в которой уточнены такие процессы.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

**Препринт Объединенного института ядерных исследований. Дубна 1988**

Bannikov A.V. et al. E1-88-476
Evidence for Higher Twist Mechanisms in High $p_\perp$ $\pi^- p$ Events with Prompt $\rho^0$ production at 38 GeV/c

The $\pi^- p$ interactions with at least one charged secondary produced at polar angle of ~90° in c.m.s. and having the transverse momentum above 1 GeV/c were investigated. The data were obtained using streamer chamber magnetic spectrometer RISK at 38 GeV/c $\pi^-$ beam from Serpukhov accelerator. The analysis of the associated production in reconstructed events suggests, that if the transverse momentum of a pair of oppositely charged secondaries compensates the trigger particle $p_\perp$ practically completely, this pair is the product of the $\rho^0$-meson decay in marked fraction of such events. We observed a large spin-alignment for the $\rho^0$-mesons selected as described above: the probability of zero spin projection onto the normal to the $\rho^0$ production plane is equal to $\rho_{00}^T = 0.86 \pm 0.23$. The enhancement of the number of events, in which the $\rho^0$ picks up practically full momentum transfer carrying by the exchange, and also the enlarged tensor polarization for the $\rho^0$-mesons in these events, could be qualitatively explained as manifestation of direct $\rho^0$-production via the QCD higher twist processes in the high $p_\perp \pi^- p$ collisions. At the same time, the observed effects are markedly larger, than the values predicted with QCD model, in which the higher twist corrections were included.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

**Preprint of the Joint Institute for Nuclear Research. Dubna 1988**