# INCLUSIVE PION PRODUCTION IN $\pi^-\pi^-$ COLLISIONS AT HIGH ENERGIES

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Results on momentum distributions of pions emitted from the recoiling system $X^{--}$ in the reaction $\pi^-n \to pX^{--}$ are presented and interpreted in the framework of the one pion exchange model. The Feynman $x$ distributions of pions from inclusive reactions $\pi^-n^- \to \pi^- + X^-$ and $\pi^-\pi^- \to \pi^+ + X^{---}$ are similar to those observed in $\pi p$ on-mass-shell experiments and their energy dependence is consistent with predictions based on Regge–Mueller phenomenology applied to $\pi^-\pi^-$ reactions.

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In a previous publication [1] we have shown that the inclusive reaction

$$\pi^- n \to pX^{--} \tag{1}$$

in the kinematic region $|t_{np}| < 1$ (GeV/$c$)$^2$ can be adequately described by the Reggeized pion exchange model. In reference [1] we have used the measured cross sections for reaction (1) to extract the total cross sections and the charged multiplicity distributions for $\pi^-\pi^-$ scattering.

In this paper we present results on momentum distributions of pions emitted from the recoiling system $X^{--}$ for different values of the invariant mass squared $M_X^2$. From the point of view of pion exchange these distributions provide information about the inclusive reactions

$$\pi^-\pi^- \to \pi^- + X^-, \tag{2}$$

$$\pi^-\pi^- \to \pi^+ + X^{---}, \tag{3}$$

where one of the initial pions is off the mass shell. We discuss central and fragmentation production of pions in reactions (2) and (3) as a function of the pion–pion c.m. energy squared $s_{\pi\pi} \equiv M_X^2$. The results are compared with inclusive on-mass-shell handron–-proton reactions and with predictions of a Regge–Mueller type of analysis. Recently the analyses of the off-mass shell reaction $\pi^- p \to \pi^- X$ extracted from the reactions $pp \to \Delta^{++} + MM$ [2] and $pn \to p + MM$ [3] have shown good agreement between the spectra obtained in the on- and off-mass shell experiments.

The data represent a subsample of the events of reaction (1) measured in three deuterium bubble chamber experiments at 21 [4], 205 [5] and 360 GeV/$c$ [6]. The events have been selected as odd charged multiplicity events or even charged multiplicity events with an identified spectator (< 250 MeV/$c$). Recoil protons with laboratory momentum less than 1.2 GeV/$c$ were also identified by their ionization in the bubble chamber.

To obtain a relatively clean sample of events representing reactions (2) and (3) we have applied (as in Ref. [1]) additional cuts[1] by requiring

$$0.05 < |t_{np}| < 1.0\,(\mathrm{GeV}/c)^2 \quad \text{and} \quad 0.1 < M_X^2/s_{\pi n} < 0.5,$$

where $s_{\pi n}$ is the initial pion–neutron c.m. energy squared. All outgoing tracks were measured; thus, all selected events are complete and charge balanced.

However, there are some tracks for which only production angles have been determined. These are fast tracks which failed in the reconstruction either due to a secondary interaction close to the primary vertex or because the momentum was too high to be accurately measured in the bubble chamber (205 and 360 GeV/$c$ data). The number of positive tracks with badly measured momentum ($\Delta p_{lab} > p_{lab}$) ranged from 1.5% at 21 GeV/$c$ to 5% at 205 GeV/$c$ and 7% at 360 GeV/$c$. The corresponding numbers for negative tracks are 2%, 8% and 11%, respectively. We have ascribed to these tracks momenta equal to

[1] The lower $t_{np}$ cut had to be introduced in order to avoid possible contamination by proton spectators, minimize corrections expected from the Pauli exclusion principle, and reduce the smearing of kinematic variables due to the Fermi motion of unseen spectators.

half of the total unbalanced momentum divided by the number of badly measured tracks in the event (one or two). The corrected tracks contribute entirely to the beam hemisphere in the $\pi\pi(M_X)$ rest frame. Thus we were able to study pion production at 205 and 360 GeV/$c$ only in a limited region of phase space (see below).

The total numbers of events selected for the analysis of reactions (2) and (3) are given in Table I. We also show there the range of $s_{\pi\pi}$ studied and the average charged multiplicity for $\pi^-\pi^-$ interactions.

TABLE I

| $p_{lab}$, GeV/$c$ | $s_{\pi\pi}$, GeV$^2$ | Events analysed | $\langle n_{\pi\pi} \rangle$ |
|---|---|---|---|
| 21 | 4–12 | 286 | $3.28 \pm 0.09$ |
| | 12–20 | 343 | $4.02 \pm 0.09$ |
| 205 | 38–193 | 154 | $6.42 \pm 0.27$ |
| 360 | 66–338 | 95 | $7.61 \pm 0.38$ |

In the analysis of reactions (2) and (3) we use the inclusive distributions normalized to the total $\pi^-\pi^-$ cross sections [1], including elastic and inelastic events, at a given $\pi^-\pi^-$ c.m. energy. Thus, it is only important to know the normalization relative to the measured events for each charged multiplicity. Each event with multiplicity $n$ was given a weight $\omega(n)$ defined as the ratio of the published $\pi^-$d partial cross section [4–6] to the total number of measured $\pi^-$d events of the same multiplicity.

Most of the kinematic variables ($s_{\pi n}$, $t_{np}$, $s_{\pi\pi}$) depend on the target momentum, which, due to the Fermi motion, changes from one event to another. For events with a visible spectator, the target four-vector $p_n$ was taken to be $p_n = p_d - p_{spect}$, where $p_d$ and $p_{spect}$ are the deuteron and proton spectator four-vectors, respectively. For odd multiplicity events the target neutron three-momentum was assumed to be zero. The smearing in the kinematic variables due to this procedure is small compared to the errors in the experimental distributions.

For each event we have made a transformation to the rest system of the mass recoiling against the slow proton. The collision axis is defined by the direction of the exchanged particle whose four-vector was taken to be that of the target neutron minus the observed slow proton ($t$-channel Gottfried–Jackson frame). In this frame of reference we defined the usual Feynman $x$ and rapidity $y$ variables, where positive $x$ and $y$ mean that the pion is emitted along the direction of the exchanged particle.

We have checked that all accepted events conserve longitudinal momentum in the $\pi\pi$ rest frame. The percentage of the visible energy of the $M_X$ system is $(69 \pm 1)\%$ at 21 GeV/$c$ and $(64 \pm 3)\%$ at 360 GeV/$c$.

The normalized rapidity distributions for reactions (2) and (3) are shown in Fig. 1. The distributions for both $\pi^-$ and $\pi^+$ are remarkably symmetric about $y$ equal to zero. The height of the plateau exibits a dramatic rise with energy for $\pi^+$'s but only a slow increase for $\pi^-$'s.

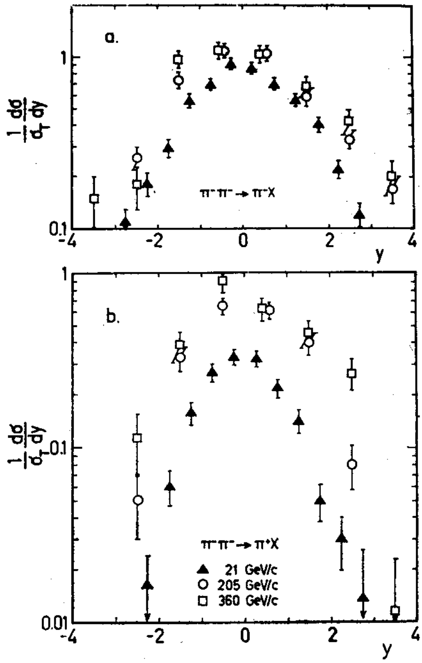


Fig. 1. Normalized rapidity distributions for the reactions a) $\pi^-\pi^- \to \pi^-X$ and b) $\pi^-\pi^- \to \pi^+X$, where $y$ is the rapidity along the direction of the exchanged particle (see text)

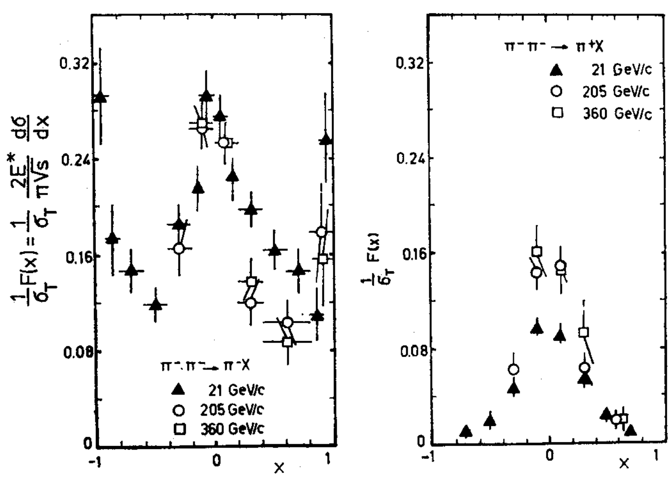


Fig. 2. $(1/\sigma_T)F(x) = \dfrac{2E}{\sigma_T\pi\sqrt{s}}\dfrac{d\sigma}{dx}$ invariant cross section for the reactions a) $\pi^-\pi^- \to \pi^-X$ and b) $\pi^-\pi^- \to \pi^+X$ where the direction of echanged particle is used to evaluate $x$ (see text)

The normalized invariant cross section integrated over the entire $p_T$ range, which is given by

$$\frac{1}{\sigma_T} F(x) = \frac{1}{\sigma_T} \int E \frac{d^3\sigma}{dp^3} d^2 p_T = \frac{1}{\sigma_T} \int \frac{2E}{\pi \sqrt{s_{\pi\pi}}} \cdot \frac{d^2\sigma}{dx \cdot dp_T^2} \cdot dp_T^2$$

is shown in Fig. 2 for reactions (2) and (3).

The distributions for both $\pi^-$ and $\pi^+$ are symmetric around $x$ equal to 0. The $\pi^-$ spectra show in addition a pronounced leading $\pi^-$ peak for $|x| > 0.8$ which we identify with elastic $\pi^-\pi^- \to \pi^-\pi^-$ scattering. This elastic peak is seen only in the data at 21 GeV/$c$. Our momentum resolution for very fast tracks at 205 and 360 GeV/$c$ is very poor and we restrict our analyses at these energies to tracks with $x > x_{cut}$, where $x_{cut}$ is $-0.4$ and $-0.2$ at 205 and 360 GeV/$c$, respectively[2].

The observation of a leading $\pi^-$ confirms the dominant role of pion exchange (e.g., compared to $\varrho^-$ exchange) in mediating reaction (1). The leading $\pi^-$ events come mainly from the reaction $\pi^- n \to p\pi^-\pi^-$ with one pion moving slowly in the laboratory ($p_{lab} \approx 0.5$ GeV/$c$) and the other having momentum close to the beam value. The cross section for such events is approximately equal to $(11.5 \pm 1.5)\%$ of the total cross section for analyzed events at 21 GeV/$c$ and to $(8 \pm 2)\%$ at 205 and 360 GeV/$c$. These values are in agreement with our estimates of elastic $\pi^-\pi^-$ scattering [1].

In order to study the energy dependence of the pion fragmentation cross sections we have integrated the $(1/\sigma_T)F(x)$ distributions over the region $0.4 < |x| < 0.8$[3]. The

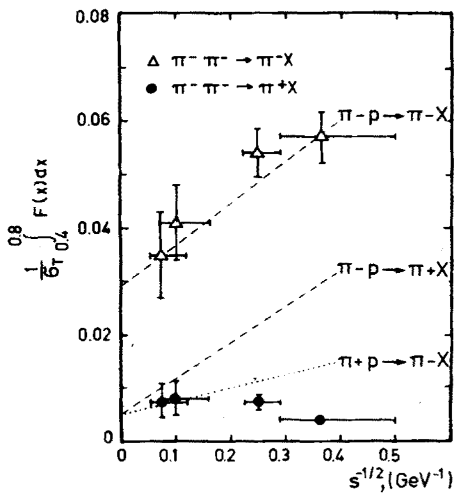


Fig. 3. The invariant cross sections for $\pi^-\pi^- \to \pi^\pm X$ as a function of $s_{\pi\pi}^{-1/2}$ for $0.4 < x < 0.8$ and integrated over all $p_T^2$. The straight lines, taken from Ref. [7], indicate the trend of $\pi p \to \pi X$ data

[2] Our resolution in $x$ for the $x$-bin $(x_{cut}, x_{cut}+0.1)$ is equal to 0.1 but improves considerably for the adjacent $x$-bin. The contribution of the corrected tracks to $(1/\sigma_T)F(x)$ for $x \approx x_{cut}$ is 30% and diminishes rapidly with increasing $x$.

[3] Since the initial $\pi^-\pi^-$ system is symmetric between the two $\pi^-$, for further studies we have folded the $x$-distributions of Fig. 2 about $x = 0$. The integrals of $(1/\sigma_T)F(x)$ distribution, are normalized to the values for one hemisphere only.

results for $\pi^-$'s and $\pi^+$'s are shown in Fig. 3 as a function of $s_{\pi\pi}^{-1/2}$ (the energy dependence expected in Regge–Mueller phenomenology). The normalized invariant cross section for reaction $\pi^-\pi^- \to \pi^-X$ is rapidly falling with energy. The trend of our data is similar to that of the reaction $\pi^-p \to \pi^-X$ [7] studied in the same $x$-region. On the other hand the $\pi^-$ fragmentation into $\pi^+$ is almost energy independent in contrast to the $\pi^\pm p \to \pi^\mp X$ [7] which clearly decrease with energy. The values of $(1/\sigma_T) \int_{0.4}^{0.8} F(x) \cdot dx$ for reactions (2) and (3) approach the same limits as the corresponding $\pi p \to \pi X$ reactions for $s_{\pi\pi} \to \infty$.

In the framework of Regge–Mueller phenomenology [8, 9] for the process $a+b \to c+X$ in the fragmentation region of particle a, the invariant cross section $E\dfrac{d^3\sigma}{dp^3}(a \to c|b)$ should have the following form (see Fig. 4a):

$$E\frac{d^3\sigma}{dp^3}(a \to c|b) = \frac{2E}{\pi\sqrt{s}} \cdot \frac{d^2\sigma}{dx dp_T^2} = A(x, p_T^2) + \sum_R B_R(x, p_T^2) \cdot s^{-1/2}, \tag{4}$$

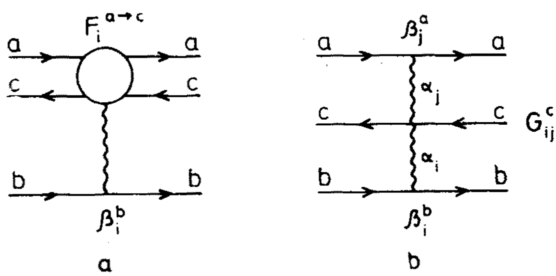


Fig. 4. Regge–Mueller diagrams for (a) fragmentation region and (b) central kinematic region

where $s$ is the (a+b) c.m. energy squared and the index R represents the $R^{\text{th}}$ Reggeon.

The first term comes from the Pomeranchuk singularity and the second term arises from the approximately exchange degenerate meson trajectories with $t = 0$, intercept $\alpha_R(0) = 0.5$. Assuming factorization of all the Reggeon amplitudes, Eq. (4) can be written [9]:

$$E\frac{d^3\sigma}{dp^3}(a \to c|b) = \beta_P^b \cdot F_P^{a\to c}(x, p_T^2) + s^{-1/2} \sum_R \beta_R^b \cdot F_R^{a\to c}(x, p_T^2) \cdot \tau_R, \tag{5}$$

where $\beta_R^b$ are the particle b–Reggeon coupling constants, $\tau_R$ is the signature of Reggeon R and $F_P^{a\to c}$ and $F_R^{a\to c}$ represent inclusive Reggeon vertices for the Pomeranchukon and Reggeon $R$.

In this notation the total a+b cross section is given by

$$\sigma^{ab}(s) = \beta_P^a \beta_P^b + s^{-1/2} \sum_R \beta_R^a \cdot \beta_R^b \cdot \tau_R. \tag{6}$$

The authors of Ref. [9] estimated the values of $\beta_j^a$ and $F_j^{a\to c}$. The only contributions to the reactions ($\pi^- \to \pi^\mp | \pi^-$) come from P, ϱ and f exchange. The standard exchange degeneracy conditions require $\beta_f^\pi = \beta_\varrho^\pi$. Similar constraints on the inclusive Reggeon vertices, $F_R^{a\to c}$ are less certain. One expects $F_f^{\pi^-\to\pi^+} = F_\varrho^{\pi^-\to\pi^+}$, but no constraints are known for the general coupling $F_R^{\pi^-\to\pi^-}$. Thus the reaction ($\pi^- \to \pi^+/\pi^-$), denoted as superexotic in Ref. [9] (ab, ab$\bar{c}$, a$\bar{c}$, b$\bar{c}$ are exotic) is expected to reach its asymptotic cross section very early. This prediction is well confirmed by our data. On the other hand, the falling cross section for the reaction ($\pi^- \to \pi^- | \pi^-$) can be interpreted as resulting from the inequality $|F_\varrho^{\pi^-\to\pi^-}| > |F_f^{\pi^-\to\pi^-}|$ as concluded in Ref. [9]. In the process ($\pi^\pm \to \pi^\pm | p$) the decrease of cross section with energy is, in the Regge–Mueller language, due to the contribution of f exchange. The contribution in this case can be ignored because of its weak coupling to the nucleon.

In contrast to $\pi^\mp$ production in the pion fragmentation region, the production of pions in the central region is due to completely different processes and shows quite different properties. In Fig. 5 we have plotted $(1/\sigma_T)\,F(x)$ distributions for reactions (2) and (3) in

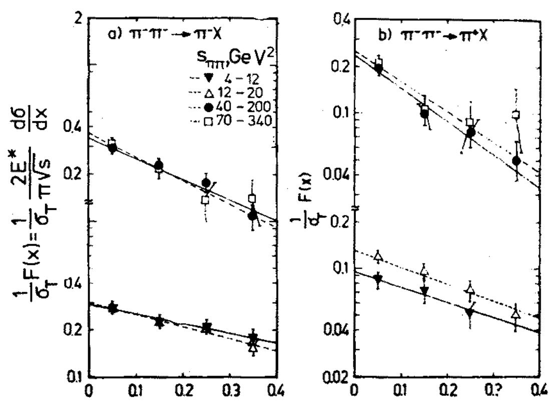


Fig. 5. Distribution of $(1/\sigma_T)F(x)$ for the reactions (a) $\pi^-\pi^- \to \pi^- X$ and (b) $\pi^-\pi^- \to \pi^+ X$ for various regions of $\pi^-\pi^-$ c.m. energy squared. The straight lines represent fits of: $(1/\sigma_T)F(x) = A\exp(B|x|)$ to the data

the $x$-region, $|x| < 0.4$ in four different regions of $s_{\pi\pi}$. An approximate exponential behaviour is observed with the slope increasing with $s_{\pi\pi}$ from 1.5 to 3 for $\pi^-$'s and from 2.5 to 5 for $\pi^+$'s. The fitted values of $(1/\sigma_T)\,F(x)$ versus $s_{\pi\pi}^{-1/4}$ are plotted in Fig. 6[4]. The central production of $\pi^+$'s incereases rapidly with energy, while the $\pi^-$ production changes very slowly. Both distributions appear to be approaching a common limit of approximately 0.4.

Existing high energy data on the energy dependence of central $\pi^\pm$ production [7, 11] indicate that the production cross sections are rising steadily for most of the measured processes. The exceptions are $\pi^-$'s produced in $\pi^-$p collisions between 8 and 40 GeV. The scaling of the distributions has not yet been reached at the highest ISR energies. However,

[4] The values of $(1/\sigma)_T F(x)$ are not corrected for K and proton contamination. These corrections should lower our $(1/\sigma_T)$. $F(x = 0)$ by at most 10% at 205 and 360 GeV [10].

the present data suggest that $(1/\sigma_T)F(x = 0)$ may approach a value of 0.4 [7, 11–14], somewhat larger than that expected several years ago (~0.25) [15].

The double-Regge expansion, represented graphically in Fig. 3b predicts for the central region [16]

$$E\frac{d^3\sigma}{dp^3} = A_{PP}(m_T)+s^{-1/4}\left(\sum_R B_{RP}(m_T)e^{y/2}+\sum_R B_{PR}(m_T)e^{-y/2}\right) + s^{-1/2}\sum_R B_{RR}(m_T), \qquad (7)$$

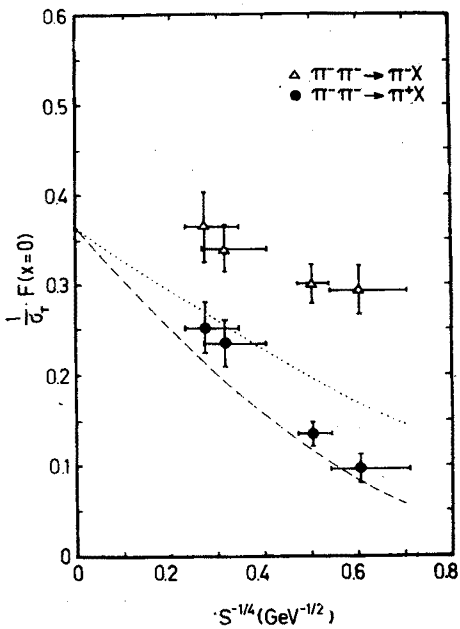


Fig. 6. Fitted values of the normalized invariant cross sections at $x = 0$ for $\pi^-$ and $\pi^+$ production in $\pi^-\pi^-$ collisions as a function of $s_{\pi\pi}^{-1/4}$. The lines represent the predictions of Eq. (8) for reactions $\pi^-\pi^- \to \pi^-X$ (dotted) and $\pi^-\pi^- \to \pi^+X$ (dashed) with the parameters taken from Ref. [11]

where $m_T$ and $y$ are the transverse mass and the c.m. rapidity of the particle c, respectively Integrating Eq. (7) over the entire $p_T$ range and assuming that each Reggeon in Fig. 4b factorizes one gets (in the notation of Eq. (5))

$$\int E\frac{d^3\sigma}{dp^3}\bigg|_{x=0} d^2p_T = \frac{1}{\pi}\frac{d\sigma}{dy}\bigg|_{y=0} = F(x=0) = \beta_P^a\beta_P^b G_{PP}^c + s^{-1/4}\Big(\sum_R \beta_P^a\beta_R^b G_{RP}^c + \sum_R \beta_R^a\beta_P^b G_{PR}^c\Big) + s^{-1/2}\sum_R \beta_R^a\beta_R^b G_{RR}^c, \qquad (8)$$

where the $G_{ij}^c$ are the values of the vertex functions at $x = 0$ integrated over $p_T$. Eq. (8) predicts the same scaling limit for $(1/\sigma_T)F(x = 0) = G_{PP}^{\pi}$ for all hadron–hadron collisions (experimentally it is being approached from below). The present experimental value (~0.4) is close to the effective value of $G^{\pi}_{pp}$ estimated from low energy pp → $\pi^{\pm}$X data [17]. Moreover, the data are roughly consistent with factorization [11–13, 17].

In the framework of Eq. (8) the observed weak energy dependence of the $\pi^-\pi^- \to \pi^-X$ inclusive cross section is due to the mutual cancellation of ϱ and f contributions to the $s_{\pi\pi}^{-1/4}$ and $s_{\pi\pi}^{-1/2}$ terms. Such an effect is expected to be strong in ππ reactions and weaker in πp collisions since Regge residues fulfill the relations $\beta^{\pi}_{\varrho} = \beta^{\pi}_{f}$ and $\beta^{p}_{f} > \beta^{p}_{\varrho}$ [9]. The mechanism of cancellation does not apply to the central production of $\pi^+$'s in $\pi^-\pi^-$ collisions. There we expect a trend similar to other reactions; namely cross sections which rapidly increase with energy.

In Fig. 6 we also show the predictions of Eq. (8) for reactions $\pi^-\pi^- \to \pi^{\mp}X$ using the values of $\beta^{\pi}_{j}$ and $G^{\pi}_{ij}$ given in Ref. [13]. The agreement is reasonable for $\pi^-\pi^- \to \pi^+X$ data but rather poor for $\pi^-\pi^- \to \pi^-X$, where the theory predicts too strong an energy dependence of $(1/\sigma_T)F(x = 0)$. A similar discrepancy has been observed in applying Eq. (8) to $\pi^-p \to \pi^-X$ reactions (compare Refs [12] and [13]). The $\pi^-\pi^- \to \pi^-X$ data suggest much weaker breaking of the f–ϱ exchange degeneracy than was assumed in Ref. [13].

The distributions of transverse momenta of pions calculated in the ππ c.m. system (Gottfried–Jackson frame) show a remarkable resemblance to those from on-mass-shell experiments. In Fig. 7 we compare the $p_T^2$ spectra of $\pi^-$'s and $\pi^+$'s for the region $4 < s_{\pi\pi} < 20\ \mathrm{GeV}^2$ with inclusive $\pi^-$ distributions from $\pi^+p$ interactions at 16 GeV/*c* [18–20]

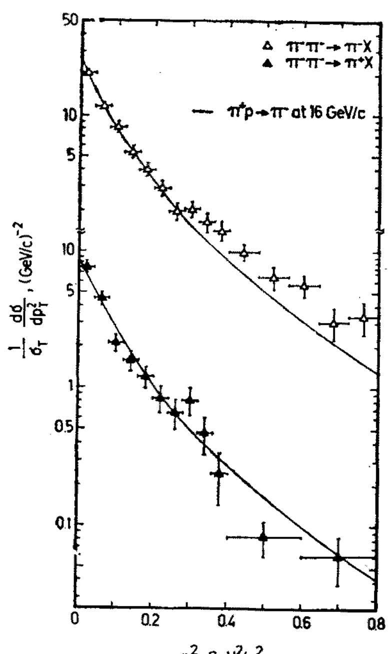


Fig. 7. Normalized distributions of $p_T^2$ for $\pi^-$ and $\pi^+$ produced in $\pi^-\pi^-$ collisions with $4\ \mathrm{GeV}^2 < s_{\pi\pi} < 20\ \mathrm{GeV}^2$. The solid lines represent the $d\sigma/dp_T^2$ distribution of $\pi^-$'s in $\pi^+p$ interactions at 16 GeV/*c* [20] and are normalized to the same area under the curves as corresponding $\pi^-$ or $\pi^+$ distributions from $\pi^-\pi^-$ collisions

normalized to the same area[5]. The curve representing $\pi^+p \to \pi^-X$ data [20] reproduces rather well the $\pi^+$ spectrum whereas it underestimates the $\pi^-$'s in the large $p_T^2$ region (only $\pi^-$'s with $|x| < 0.8$ are plotted).

The $p_T^2$-distributions of pions are steeper than $\exp(-3.4p_T^2)$ observed for directly produced particles [20, 21], which suggests that a considerable fraction of the pions is produced via resonance decays. Therefore, we have analysed $\pi^+\pi^-$ effective mass distributions to estimate the percentage of $\varrho^0$ production. A clear $\varrho^0$ signal is observed in Fig. 8a

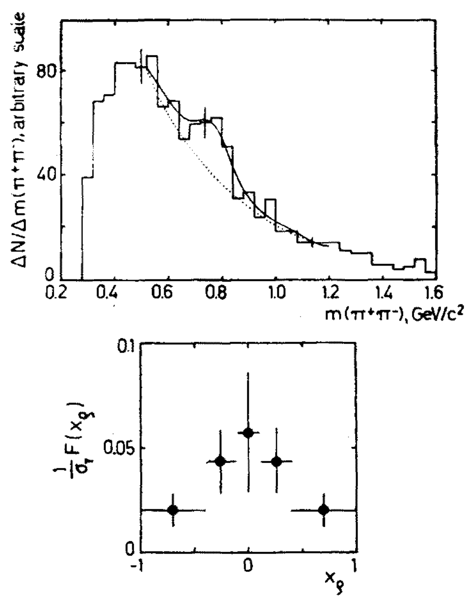


Fig. 8. (a) Effective mass spectrum $d\sigma/dm(\pi^+\pi^-)$ for 4 GeV$^2$ < $s_{\pi\pi}$ < 20 GeV$^2$. The solid line represents a fit to the data using a Breit–Wigner shape and an exponential background; (b) folded normalized invariant $x$ distribution of $\rho^0$'s produced in $\pi^-\pi^-$ collisions for 4 GeV$^2$ < $s_{\pi\pi}$ < 20 GeV$^2$

for the $s_{\pi\pi}$ region (4–20) GeV$^2$.[6] A Breit–Wigner formula fit with an exponential background (as in Ref. [18]) gives $0.48 \pm 0.13$ $\varrho^0$'s per event for $n_{\pi\pi} > 2$. Here $n_{\pi\pi}$ is the charged multiplicity of the $X^{--}$ system recoiling against the proton (($0.27 \pm 0.09$)$\varrho^0$'s per event for all $\pi^-\pi^-$ topologies). The ratio of the average numbers of $\varrho^0$'s to $\pi^+$'s (denoted by $\varrho^0/\pi^+$) for $n_{\pi\pi} > 2$ is equal to $0.35 \pm 0.09$. These values are larger than those found in $\pi^+p$ and $\pi^-p$ experiments at 16 GeV/$c$ [18, 19]: $\varrho^0/\pi = 0.19 \pm 0.02$ ($\pi^+p$) and $0.20 \pm 0.02$ ($\pi^-p$), with $\langle\varrho^0\rangle_{n\geqslant 4} = 0.30 \pm 0.03$ ($\pi^+p$) and $0.29 \pm 0.03$ ($\pi^-p$). The difference is probably related to the high probability for $\pi\pi$ interactions to produce $\varrho$'s.

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5 We take $\pi^-$ spectra in the $\pi^+$ induced reaction to avoid a possible proton contamination of the produced $\pi^+$ sample.

6 A small sample of data and poor mass resolution make it difficult to study $\varrho^0$ production at 205 and 360 GeV.

We have also examined the $\pi^+\pi^-$ effective mass, $m(\pi^+\pi^-)$ distributions for various Feynman $x_{\pi\pi}$ intervals. In Fig. 8b we show $(1/\sigma_T)F(x_\varrho)$vs $x_\varrho$. The data are folded about $x_\varrho = 0$ to decrease the statistical errors. The broad maximum around $x_\varrho = 0$ suggests both copious central $\varrho^0$-production and important contributions from the fragmentation of pions into $\varrho^0$'s.

We conclude that the Feynman $x$-distributions of pions emitted from the system recoiling against the slow proton of reaction (1) show a remarkable similarity to those observed in $\pi$p on-mass-shell experiments. The energy dependence of these distributions is consistent with predictions based on Regge–Mueller phenomenology applied to $\pi^-\pi^-$ reactions. The early scaling observed for central production of $\pi^-$'s and for fragmentation of $\pi^-$'s into $\pi^{+}$'s also can be explained within this model. The off-mass-shell $\pi\pi$ scattering appears to be a useful tool for testing model predictions for the central and fragmentation regions. In this case the central region is not contaminated by fragmentation of protons extending beyond $x = 0$. Abundant $\varrho^0$ production is observed with approximately 35% of the produced $\pi^+$'s resulting from $\varrho^0$ decays.

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