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γ AND π° PRODUCTION IN $\bar{p}p$ INTERACTIONS AT 22.4 GeV/c

Dubna - Alma-Ata - Helsinki - Moscow - Prague - Tbilisi Collaboration

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We present here results of the analysis of 2440 e^+e^- pairs out of 37000 $\bar{p}p$ interactions at 22.4 GeV/c obtained by exposing the HBC Ludmila to a RF separated antiproton beam at the Serpukhov accelerator. The experimental procedure and some results concerning $\gamma(\pi^\circ)$ production in 22.4 GeV/c $\bar{p}p$ interactions have been published elsewhere /1/.

Due to large losses of γ-s in the backward c.m.s. hemisphere, these γ-s were replaced by those from the forward hemisphere, reflected about $p_L^* = 0$, according to cp-symmetry.

In Table 1 we present some average characteristics of γ-s and π°-mesons. The latter are obtained from the relations /2/:

$$\langle |p_L^*| \rangle_{\pi^\circ} = 2 \langle |p_L^*| \rangle_\gamma , \tag{1}$$

$$\langle p_L^{*2} \rangle_{\pi^\circ} = 3 \langle p_L^{*2} \rangle_\gamma - \frac{m_{\pi^\circ}^2}{4} , \tag{2}$$

$$\langle p_T^2 \rangle_{\pi^\circ} = 3 \langle p_T^2 \rangle_\gamma - \frac{m_{\pi^\circ}^2}{2} , \tag{3}$$

which are valid under the assumption that π°-s are the only source of γ-s.

Table 1

Mean values for different momentum variables of γ and π°.

	$\langle p^{lab} \rangle$ GeV/c	$\langle \lvert p^* \rvert \rangle$ GeV/c	$\langle \lvert p_L^* \rvert \rangle$ GeV/c	$\langle p_L^{*2} \rangle$ (GeV/c)^2	$\langle p_T \rangle$ GeV/c	$\langle p_T^2 \rangle$ (GeV/c)^2
γ	1.004 $\pm$.038	0.285 $\pm$.007	0.197 $\pm$.007	0.114 $\pm$.010	0.169 $\pm$.004	0.052 $\pm$.003
π°			0.394 $\pm$.014	0.337 $\pm$.029		0.147 $\pm$.009

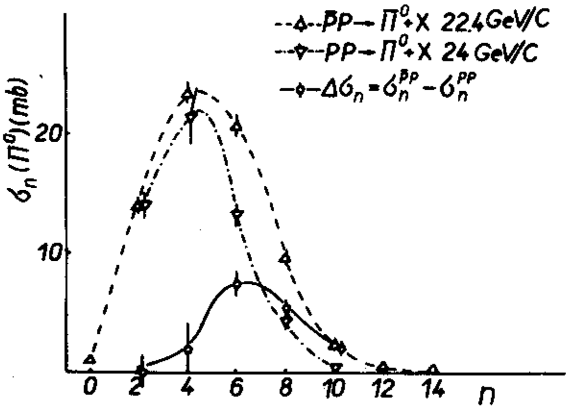

Fig.1. Topological cross sections for π°-production in $\bar{p}p$ (22.4 GeV/c) and pp (24 GeV/c) interactions and their differences $\Delta\sigma_n = \sigma_n^{\bar{p}p} - \sigma_n^{pp}$.

The total and topological cross sections of π° production are determined as follows

$$\sigma(\pi^{\circ}) = \frac{1}{2}\sigma(\gamma), \qquad \sigma_n(\pi^{\circ}) = \frac{1}{2}\sigma_n(\gamma), \tag{4}$$

where n is the number of charged particles in an event. In order to estimate the cross section of π° production in annihilation channels, we use the difference of the topological cross sections $\sigma_n(\pi^{\circ})$ in $\bar{p}p$ (22.4 GeV/c) and pp (24 GeV/c) /3/ interactions for the events with $n \geq 2$. This is a reasonable approximation at low energies ($p_{lab} < 10$ GeV/c), where annihilation has been separated. At high energies ~90% of the total annihilation cross sections is accounted by the difference of the $\bar{p}p$ and pp cross sections based on Regge phenomenology /4/.

The topological cross sections of π° production in $\bar{p}p$ and pp interactions and their differences are presented in Fig.1 and Table 2. It is seen that the fraction of "annihilation" π°-s increases from 9% for n = 4 to 89% for n = 10 and becomes ~100% for $n \geq 12$. The average number of charged particles associated with the "annihilation" π°-s equals 7.00 ± 0.41. For all events with π°-s this value is equal to 4.92 ± 0.34 which coincides, within errors, with the charged particle multiplicity in all inelastic events $\langle n \rangle = 4.69 \pm 0.05$ /5/.

In high energy experiments /6/ the correlation has been observed between the average number of π°-s, $\langle n_{\pi^{\circ}} \rangle$, and the number of associated charged particles which can be described by the linear dependence

$$\langle n_{\pi^{\circ}} \rangle = a + bn_{-} \tag{5}$$

Table 2

The topological cross sections of π^{0}-s production in $\bar{p}p$ and pp interactions and their differences

Topology	$\sigma_n(\pi^0)$ $\bar{p}p \to \pi^0(22.4)$ mb	$\sigma_n(\pi^0)$ $pp \to \pi^0(24)$ mb	$\sigma_n^{\bar{p}p} - \sigma_n^{pp}$ mb	$\beta = \frac{\Delta\sigma_n}{\sigma_n^{\bar{p}p}}$	$<n_{\pi^0}>$ $\bar{p}p$ (22.4)
0	1.06 ±0.18				1.63 ±0.33
2	14.05 ±0.75	13.92 ±0.96	0.13 ±1.22	0.01	1.59 ±0.18
4	23.50 ±0.99	21.46 ±0.65	2.04 ±1.18	0.09	1.66 ±0.08
6	20.69 ±0.97	13.02 ±0.36	7.67 ±1.03	0.37	2.19 ±0.12
8	9.75 ±0.70	4.36 ±0.23	5.39 ±0.74	0.55	2.39 ±0.19
10	2.34 ±0.35	0.25 ±0.06	2.09 ±0.36	0.89	1.65 ±0.26
12	0.47 ±0.18		0.47 ±0.18	1.0	1.96 ±0.79
14	0.034 ±0.034		0.034 ±0.034	1.0	0.57 ±0.60
all	71.89 ±1.78	53.0 ±1.2	17.8 ±2.2		1.84 ±0.06
$\langle n \rangle$	4.92 ±0.34		7.00 ±0.41		

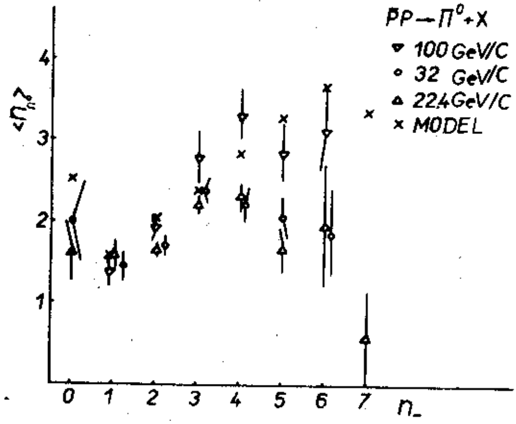

Fig.2. Average number of π^0–s vs number of negative particles, n_-.

This linear law is not valid at large n_- because of energy consideration. In fig.2 we display $<n_{\pi^0}>$ vs n_- for $\bar{p}p$ interactions at 100 [7], 32 [8] and 22.4 GeV/c. As is seen, the linear increase of $<n_{\pi^0}>$ with n_- takes place in the interval $1 \leqslant n \leqslant 4$. For $n_- > 4$, $<n_{\pi^0}>$ at 22.4 and 32 GeV/c is smaller than $<n_{\pi^0}>$ at 100 GeV/c in accordance with a weaker phase space limitation in the latter case. Besides, the data at 100 GeV/c indicate a possible increase of the $<n_{\pi^0}>$ and n_- correlation with increasing energy. The value of the parameter b calculated in the interval $0 \leqslant n_- \leqslant 4$ is equal to 0.26 ± 0.06 in our experiment. This is in agreement with the critical liquid model [9], which predicts the slope to be independent of the type of colliding particles and to increase with increasing free energy E_a^* (see fig.3).

Previously we have compared our experimental data on charged particle production in $\bar{p}p$ interactions at 22.4 GeV/c [11] with the events generated according to the quark-parton model [12]. The dependence of $<n_{\pi^0}>$ on n_- presented in fig.2 for generated events shows that the π^0 yeld is overestimated in the model: $<n_{\pi^0}>_{mod} = 2.12$ as compared to $<n_{\pi^0}>_{exp} = 1.84 \pm 0.06$. The data are described by the model only for $n_- = 1$ and 3. The linear dependence of $<n_{\pi^0}>$ on n_- is specific to the models with abundant resonance production. For example, if π-mesons are produced only in the decays of ω-type resonances, then $<n_{\pi^0}> = n_-$. The dependence becomes weaker in the case when ρ-mesons are the sources of π-mesons [13]. The overestimated value of $<n_{\pi^0}>_{mod}$ for $n_- \geqslant 4$ is likely to be due to the overevaluated resonance yield in the model (the fraction of

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* The free energy E_a is equal to $\sqrt{S} - 2m_p$ and to $\sqrt{S}$ for non-annihilation and annihilation channels, respectively. According to a 23% contribution of annihilation to the total inelastic $\bar{p}p$ cross section at 22.4 GeV/c, we get $E_a = 5.17$ GeV.

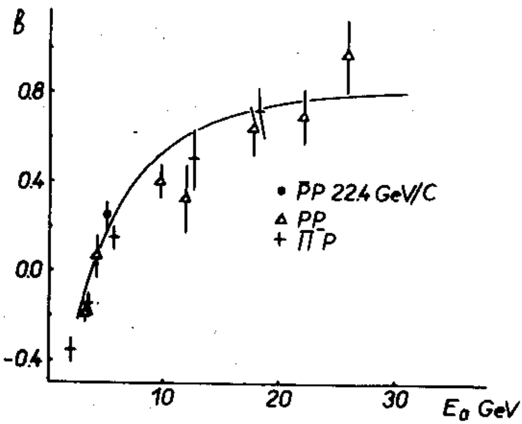

Fig.3. Slope parameter b in eq.(5) vs free energy E_a for different reactions [10]. The full line is the prediction of the critical liquid model.

directly produced π-s in the model is only ~7% of all π-mesons).

According to the hypothesis of scaling in the mean [14], the one-particle inclusive distributions of the longitudinal and transverse momenta in multiparticle reaction scale as follows:

$$\frac{1}{\sigma_n}\frac{d\sigma_n}{d\xi_n} = \phi_L(\xi_n), \quad \xi_n = \frac{p_L^*}{\langle|p_L^*|\rangle_n}, \tag{6}$$

$$\frac{1}{\sigma_n}\frac{d\sigma_n}{d\eta_n} = \phi_T(\eta_n), \quad \eta_n = \frac{p_T}{\langle p_T\rangle_n}, \tag{7}$$

where σ_n is the topological cross section and the functions ϕ_L and ϕ_T are independent of primary energy, multiplicity and initial states.

We check the validity of scaling in the mean in the reactions

$$\bar{p}p \to \gamma + X, \tag{8}$$

$$\bar{p}p \to \pi^{\circ} + X \tag{9}$$

at 22.4 GeV/c.

The values $\langle|p_L^*|\rangle$ and $\langle p_T\rangle$ for γ-s are given in Table 3 for $n = 2,4,6$ and for all topologies.

The distributions $\phi_L(\xi_n)$ calculated for different topologies as well as for all the events of the reaction (8) are displayed in fig.4. The concentration of the data points near each other indicates the independence of charged multiplicity. The solid curve in fig.4 is the result of approximation of the corresponding distributions in the reaction $\pi^- p \to \gamma + X$ at

Table 3

The average longitudinal and transverse momenta of γ-s. (The 5 GeV/c $\pi^- p$-data are from ref.15).

Topology	2	4	6	All $\bar{p}p \to \gamma + X$ 22.4 GeV/c	All $\pi^- p \to \gamma + X$ 5 GeV/c
$\langle \lvert p_L^* \rvert \rangle_n$ GeV/c	0.235 $\pm$0.017	0.211 $\pm$0.012	0.178 $\pm$0.010	0.197 $\pm$0.007	0.147 $\pm$0.004
$\langle p_T \rangle_n$ GeV/c	0.158 $\pm$0.007	0.178 $\pm$0.007	0.176 $\pm$0.007	0.168 $\pm$0.004	0.172 $\pm$0.002

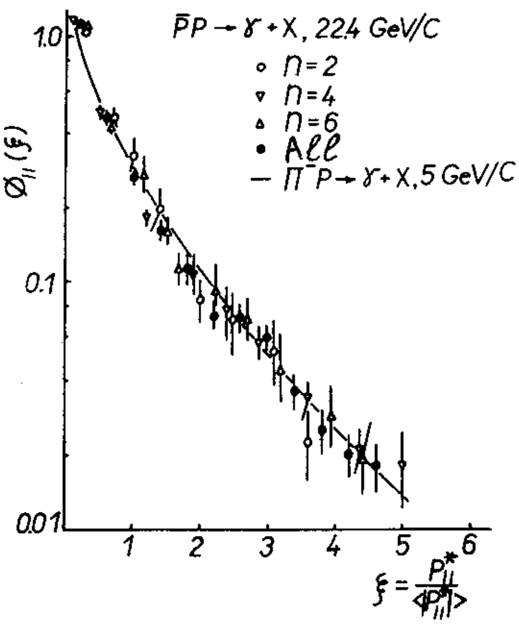

Fig.4. Normalized distribution $\frac{1}{\sigma}\frac{d\sigma}{d\xi}$ for different topologies n in the reactions $\bar{p}p \to \gamma + X$ at 22.4 GeV/c. The full line approximates the data in the reaction $\pi^- p \to \gamma + X$ at 5 GeV/c.

5 GeV/c [15]. It also well describes our data thus indicating the independence of $\phi_L(\lambda)$ on the type of colliding particles and their energy.

To obtain the scaling distribution $\phi_L(\xi)$ for π^0-s, we use the integral equation [15].

$$\frac{1}{\sigma}\frac{d\sigma}{d\xi_\gamma} = \langle |p_L^*| \rangle \int_A^\infty \frac{\phi_L(\xi_{\pi^0})}{\langle |q_L^*| \rangle \sqrt{\xi_{\pi^0}^2 + \frac{m^2}{\langle |q_L^*| \rangle^2}}}, \qquad (10)$$

Table 4

Parameters of function (12)

	A_1	A_2	χ^2/D.F.
$\bar{p}p \to \pi^\circ + X$, 22.4 GeV/c	1.08 $\pm$0.07	1.10 $\pm$0.05	15/10
$\pi^- p \to \pi^\circ + X$, 5 GeV/c	1.04 $\pm$0.03	1.05 $\pm$0.02	54/71

where $\phi_L(\xi_{\pi^\circ}) = \frac{1}{\sigma}\frac{d\sigma}{d\xi_{\pi^\circ}}$,

$p^*_L(q^*_L)$ is the longitudinal momentum of $\gamma(\pi^\circ)$ and m is the π° mass. The lower integration limit depends on ξ_γ in the following way

$$A = 2\xi_\gamma - \frac{m^2}{8\xi_\gamma<|p^*_L|>^2}. \qquad (11)$$

The normalized experimental ξ_γ distributions shown in fig.4 were fitted by formula (10) with the function

$$\phi_L(\xi_{\pi^\circ}) = A_1 \exp(-A_2|\xi_{\pi^\circ}|) \qquad (12)$$

with A_i (i = 1,2) as free parameters. In Table 4 these parameters are compared with the corresponding ones in the reaction $\pi^- p \to \pi^\circ + X$ at 5 GeV/c. As these parameters agree within errors, we can conclude that the distribuons $\frac{1}{\sigma}\frac{d\sigma}{d\xi}$ are independent of colliding particles and incident energy.

In fig.5 we compare the distribution $\phi_L(\xi)$ in the reaction (9) with the quark-parton model predictions /12/. Despite the overestimation of π°-production, the normalized distribution is well described by the model.

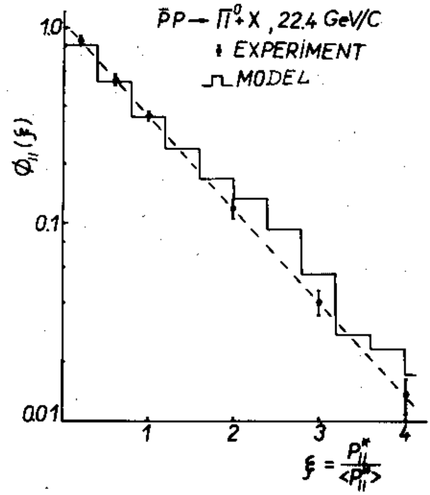

Fig.5. Experimental and quark-parton model distributions $\frac{1}{\sigma}\frac{d\sigma}{d\xi}$ in the reaction $\bar{p}p \to \pi^\circ + X$ at 22.4 GeV/c.

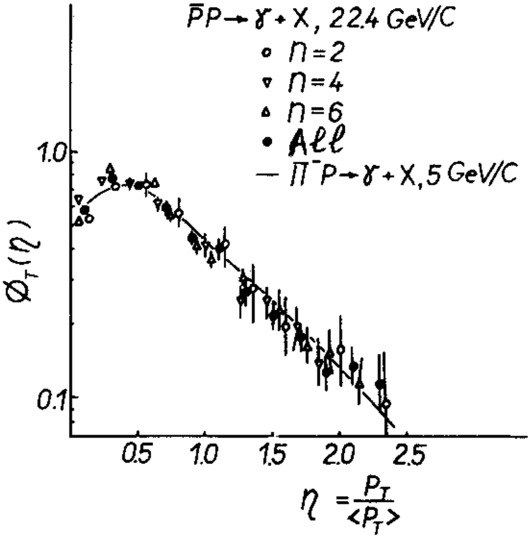

Fig.6. Normalized distribution $\frac{1}{\sigma}\frac{d\sigma}{d\eta}$ for different topologies in the reactions $\bar{p}p \to \gamma + X$ at 22.4 GeV/c. The full line approximates the data in the reaction $\pi^- p \to \gamma + X$ at 5 GeV/c.

The scaling distribution $\phi_T(\eta_n)$ for the reaction (8) in terms of the transverse scaling variable $\eta_n = \frac{p_T}{\langle p_T \rangle_n}$ is shown in fig.6 in comparison with the corresponding distributions in the reaction $\pi^- p \to \gamma + X$ at 5 GeV/c. Again, $\phi_T(\eta_n)$ seems to be independent of multiplicity, the type of colliding particles and primary energy.

Conclusions:

1. The average number of charged particles accompanying "annihilation" π^o-s (7.00 ± 0.41) is higher than the one for all events with π^o-s (4.92 ± 0.34).

2. The value of the slope parameter b in eq.(5) determined in an interval of $0 \leq n_- \leq 4$ is in agreement with the critical liquid model prediction.

3. The hypothesis of scaling in the mean is found to be valid for γ-s and π^o-s.

4. The quark-parton model slightly overestimates the average number of π^o-s, but describes well the normalized $\phi_L(\xi)$-distribution.

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