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CROSS SECTIONS, AVERAGE MULTIPLICITIES AND ENERGY FRACTIONS OF NEUTRAL π - AND K-MESONS IN $\bar{p}p$-ANNIHILATIONS AT 22.4 GeV/c

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In studies of $\bar{p}p$ interactions, processes with the complete destruction of primary baryons and antibaryons in annihilation reactions $\bar{B}B \to$ mesons are of particular interest.

The separation of annihilation channels at primary momenta higher than 10 GeV/c is complicated due to increasing a fraction of events with several neutral particles. To estimate $\bar{B}B$-annihilation cross sections, the differences of $\bar{p}p$ and pp at equal energy are commonly used [1].

As the 0-prong annihilation cross section rapidly decreases with increasing energy, it is neglected at primary energy higher than 10 GeV/c [2]. Besides, the 2-prong annihilation cross section is estimated using the low energy annihilation data [2,3]. Below we use extrapolation based on the annihilation data at $P_{lab} < 10$ GeV/c in the formula:

$$\sigma_2^A = 525.\ S^{-2.01} \quad \text{(mb)} \qquad (1)$$

where S is in $(\text{GeV})^2$, $\chi^2/ND = 1.9/4$.

The $\bar{p}p - pp$ differences at 22.4 GeV/c for $n_{ch} \geq 4$ have been obtained in ref. [5].

The total $\bar{p}p$ annihilation cross sections thus estimated agree well with the experimental values directly obtained at $P_{lab.} < 10$ GeV/c and also with the data well fitted by a solid line $P_{lab}^{-0.61}$ (see fig.1).

A similar process is also used to estimate the cross sections of π^0- and K_s^0-mesons in $\bar{p}p$ annihilations [4] (see figs. 2 and 3).

In this paper we present the estimates at the total and topological cross sections of neutral π^0 and K_s^0, energy fractions and total multiplicities of particles produced in $\bar{p}p$ annihilations at 22.4 GeV/c.

The experimental data have been obtained with the help of the 2 m HBC "Ludmila" exposed to an RF separated antiproton beam at the Serpukhov accelerator.

After treating 37000 events of $\bar{p}p$ interactions, we have found 24400 γ-s. Details of the data processing are described in ref. [6].

Let us introduce the following designations: σ_n^A is the topological annihilation cross section, $\sigma^A(\pi^0)$ and $\sigma^A(K_n)$* are the annihilation cross sections of π^0- and K_n-mesons, n - is a given charged multiplicity.

* K_n is K^0 and $\bar{K}^0$.

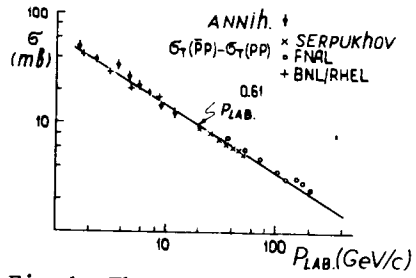

Fig.1. The energy dependence of $\bar{p}p$ annihilations and $\bar{p}p-pp$ differences. The line is the fit of the annihilation data.

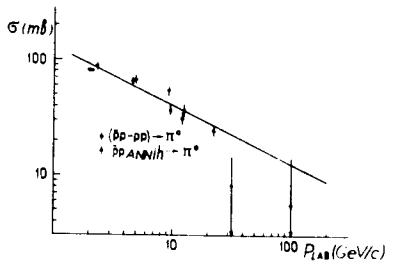

Fig.2. The energy dependence of the inclusive π^0 cross sections in $\bar{p}p$ annihilation and $\bar{p}p-pp$ differences. The line is hand-drawn to guide the eye.

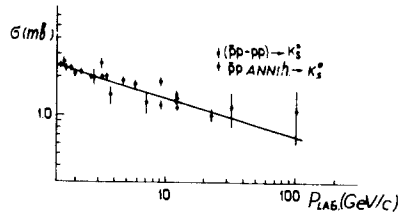

Fig.3. The energy dependence of the inclusive K^0_s cross sections in $\bar{p}p$ annihilation and $\bar{p}p-pp$ differences. The line is hand-drawn to guide the eye.

To obtain $\sigma^A(\pi^0)$, we have used the π^0 topological cross sections in pp interactions at 24 GeV/c [7a] normalized to $\sigma^{pp}(\pi^0)$ =47.2±1.2 at 22.4 GeV/c. This value follows from the formula:

$$\sigma^{pp}(\pi^0) = 29.99 + 24.89 \ln P_{lab} \text{ (mb)}, \quad P_{lab} \text{ in GeV/c} \qquad (2)$$

which describes well the data on the π^0 cross sections in pp interactions for primary momenta in an interval of 2-300 GeV/c [7] (χ^2/ND =5.1/5).

To obtain $\sigma^A(K_n)$, the topological cross sections of K_n-S in pp interactions at 19 GeV/c [8] have been used.

The resulting estimates of the annihilation π^0 and K_n cross sections as well as the average π^0 and K_n annihilation multiplicities are presented in table 1.

The average π^0 multiplicity in $\bar{p}p$ annihilation at 22.4 GeV/c is compared with the data at different primary momenta in fig.4.

The dependence of $\langle\pi^0\rangle^A$ on the number of charged particles n_{ch} in annihilation events at various primary energies is shown in fig.5.

The 22.4 GeV/c data given only for $n_{ch} \geq 4$ since the value of $\langle\pi^0\rangle^A$ at n_{ch}=2 has been obtained with a large error. As is seen, $\langle\pi^0\rangle^A$ decreases with increasing n_{ch} contrary to $\bar{p}p$ nonannihilations or pp interactions where $\langle\pi^0\rangle$ increases.

Table 1

Topological cross sections and average multiplicities of π^0- and K_n-mesons produced in $\bar{p}p$ annihilations

Topology	2 inelast.	4	6	8	10	12	14	All topologies
$\sigma_n^A(\pi^0)$, mb	1.65	4.39	9.09	5.87	2.12	0.47	0.034	23.6
	±1.22	±1.18	± 1.33	±0.74	±0.36	±0.18	±0.034	± 2.2
$\sigma_n^A(K_n)$, mb	0.12	0.3	0.36	0.34	0.10			1.74
	±0.08	±0.1	±0.09	±0.04	±0.03			±0.16
σ_n^A, mb	0.27	1.18	2.83	2.04	0.89	0.234	0.046	7.49
	±0.07	±0.15	±0.11	±0.08	±0.04	±0.013	±0.005	±0.22
$\langle\pi^0\rangle_n^A$	6.1	3.7	3.2	2.9	2.4	2.0	0.74	3.2
	±4.8	±1.1	±0.4	±0.4	±0.4	±0.8	±0.74	±0.3
$\langle K_n\rangle_n^A$	0.44	0.25	0.3	0.18	0.11			0.23
	±0.32	±0.09	±0.1	±0.02	±0.03			±0.02

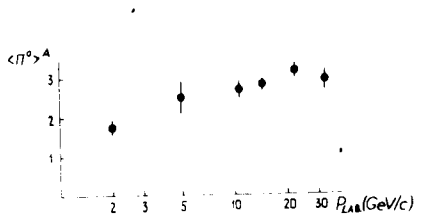

Fig.4. The energy dependence of the average π^o multiplicity in $\bar{p}p$ annihilations.

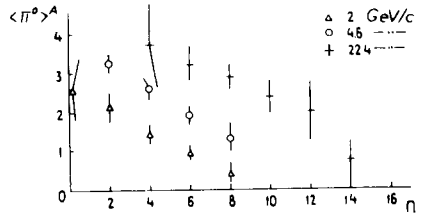

Fig.5. The topological dependence of the average π^o multiplicity in $\bar{p}p$ annihilations.

The important characteristic of the process of multiple production is the energy fraction η_c representing the energy fraction carried by the particles of a given type (in the c.m.s.).

The energy fraction η_c in $\bar{p}p$ interactions is related to the energy fractions η_c^{NA} and η_c^A of nonannihilation and annihilation channels by the formula

$$\eta_c = (1-a)\eta_c^{NA} + a\eta_c^A , \qquad (3)$$

where $a = \sigma^A / \sigma^{in}$.

From expression (3) η_c^A is equal to

$$\eta_c^A = \frac{\eta_c - (1-a)\eta_c^{NA}}{a} . \qquad (4)$$

The energy fraction η_c in the reaction $a+b \to c+X$ can be calculated from the invariant X distribution /9/

$$\eta_c(S) = \frac{\pi}{2} \int dx\, d^2p_\perp\, f_{ab}^c(x, p_\perp, S) , \qquad (5)$$

where

$$f_{ab}^c(S, \vec{p}_c) = \sigma_{ab}^{-1} E_c \frac{d^3\sigma}{d^3p} .$$

It is shown /10/ that the invariant distribution of charged pions (π^+ and π^- together) in pp interactions at 12 GeV/c coincides with that in $\bar{p}p$ nonannihilation at the same energy. Annihilation channel in this experiment has been separated experimentally. One can expect that the values of $\eta_{\pi^+ + \pi^-}$ and η_{π^o} in pp and $\bar{p}p$ nonannihilation interactions are equal. The energy fractions of $\pi^+ -, \pi^-$-and K_n-mesons in pp interactions at 24 GeV/c have been calculated from the invariant x-distribution /7a/ according to formula (5), and the energy fraction of π^o has been calculated from the phenomenological relation which well describes data in a wide range of energies /9/

$$\eta_{\pi^o}^{pp} = \frac{1}{2}(\eta_{\pi^+}^{pp} + \eta_{\pi^-}^{pp}) . \qquad (6)$$

Table 2

Energy fractions for π^-- and K_n-mesons

	pp	$\bar{p}p$	$\bar{p}p^A$
$\eta_{\pi^+ + \pi^-}$	0.215 ±0.014	0.302 ±0.004	0.66 ±0.06
η_{π^o}	0.108 ±0.007	0.156 ±0.008	0.36 ±0.05
η_{K_n}	0.0100 ±0.0012	0.0166 ±0.0003	0.044 ±0.008

The energy fraction of $\eta_{\pi^+}^{\bar{p}p}$ * at 22.4 GeV/c has been obtained in our previous paper /11/ based on the statistically separated π^+ and p spectra.

To determine $\eta_{\pi^o}^{\bar{p}p}$, we use the formula /12/

$$\eta_{\pi^o} = \frac{\langle n_\gamma \rangle \langle |p_\gamma^*| \rangle}{\sqrt{s}} , \qquad (7)$$

where $\langle n_\gamma \rangle$ is the average γ-multiplicity. $\langle |p_\gamma^*| \rangle$ is the average momentum in the c.m.s. and $\sqrt{s}$ is the total c.m.s. energy.

The energy fractions for $\pi-$ and K_n-mesons calculated by expression (4) in $\bar{p}p$ annihilation interactions are presented in table 2.

Previously in e^+e^- annihilation to hadrons the increase has been observed of the energy fraction of neutral particles with increasing primary energy /13/ in comparison with the expected value of $\eta_{\pi^o} = 1/3$. However, all particles have been assumed to be charged or neutral pions. It has been supposed /14/ that the energy dependence of coefficient $\beta = \eta_{\pi^o}/\eta_{\pi^+}$ in e^+e^-, $\bar{p}p$ annihilation is the same. As is seen from fig.6, the coefficient β in e^+e^- annihilations increases with energy and reaches the value essentially higher than 1 ($\eta_{\pi^o} > 1/3$) while in $\bar{p}p$ annihilations β is practically constant; $\beta = 1.07 \pm 0.14$ in $\bar{p}p$ annihilations at 22.4 GeV/c.

* In $\bar{p}p$ interactions $\eta_{\pi^+} = \eta_{\pi^-}$ due to CP-symmetry.

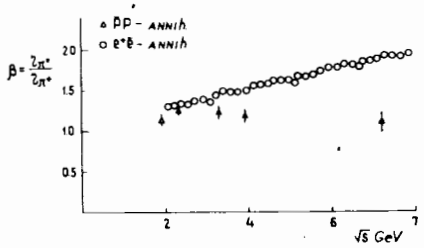

Fig.6. The enrgy dependence of the ratio of the energy fractions for neutral and charged π-s in $\bar{p}p$ and e^+e^- annihilations.

However, in a recent paper /16/ on e^+e^- annihilations, in which secondary particles (baryons, K-, π-mesons) are indentified, η_{π^0} has been found to be $0.25 \div 0.30$ ($\beta = 1$).

To compare the total average multiplicity of charged and neutral particles in inelastic and annihilation $\bar{p}p$ interactions, one should determine the average multiplicity of neutrons $\langle n \rangle$ in inelastic interactions using the relation /17/

$$\sigma^A = \sigma^{in}(1 - \langle p \rangle - \langle n \rangle - \langle \Lambda \rangle). \quad (8)$$

Hence

$$\langle n \rangle = 1 - \frac{\sigma^A}{\sigma^{in}} - \langle p \rangle - \langle \Lambda \rangle. \quad (9)$$

Substituting σ^A from table 1, $\langle p \rangle = 0.478 \pm 0.004$ /11/, $\langle \Lambda \rangle = 0.029 \pm 0.002$ /18/, we get from formula (9) $\langle n \rangle = 0.31 \pm 0.03$ which is in agreement with a value of 0.37 ± 0.11 obtained previously by another method /19/.

The particle multiplicities of inelastic and annihilation $\bar{p}p$ interactions at 22.4 GeV/c are compared to those in pp interactions at 24 GeV/c given in table 3. Note that due to CP symmetry $\langle n \rangle = \langle \bar{n} \rangle$, $\langle \Lambda \rangle = \langle \bar{\Lambda} \rangle$, $\langle K^0 \rangle = \langle \bar{K}^0 \rangle$ in $\bar{p}p$ interactions. As is seen from the data of table 3, the total multiplicity of particles produced in annihilations is 40%-30% larger than that for inelastic pp and $\bar{p}p$ interactions.

Table 3

Particle multiplicities for pp, $\bar{p}p$ and $\bar{p}p^A$ interactions

	pp (24 GeV/c)	$\bar{p}p$ (22.4 GeV/c)	$\bar{p}p^A$(22.4 GeV/c)
$\langle n$ charged $\rangle$	4.25 ± 0.03	4.58 ± 0.02	6.8 ± 0.2
$\langle \pi^0 \rangle$	1.75 ± 0.05	1.84 ± 0.06	3.2 ± 0.3
$\langle K_n \rangle$	0.082 ± 0.003	0.116 ± 0.006	0.27 ± 0.03
$\langle \Lambda + \bar{\Lambda} \rangle$	0.039 ± 0.003	0.058 ± 0.004	
$\langle n + \bar{n} \rangle$	0.66 ± 0.02	0.62 ± 0.06	
All	6.78 ± 0.06	7.22 ± 0.09	10.2 ± 0.4

The following results have been obtained:

1. The estimates of the topological cross sections and the average multiplicities of π^0 and K_n in $\bar{p}p$ annihilation at 22.4 GeV/c have been obtained.
2. The energy fractions of π^0 and K^0 in the annihilation channel have been determined.
3. The energy fractions of π^0 in $\bar{p}p$ annihilations are approximately equal to that of η_{π^+} and practically independent of primary energy.
4. The total multiplicity of charged and neutral particles in $\bar{p}p$ annihilation at 22.4 GeV/c is equal to 10.2 ± 0.4 which is much larger than the corresponding value for inelastic pp and $\bar{p}p$ interactions.

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Батюня Б.В. и др. Определение сечений, средних множественностей и коэффициентов неупругости при образовании нейтральных π- и K-мезонов в $\bar{p}p$-аннигиляционных взаимодействиях при 22,4 ГэВ/с E1-82-475

Для определения сечений, средних множественностей и коэффициентов неупругости π^0 и K_n, образующихся в $\bar{p}p$-аннигиляционных взаимодействиях при 22,4 ГэВ/с, использовались данные о разности соответствующих характеристик в $\bar{p}p$- и pp-взаимодействиях. Средняя множественность π^0 в $\bar{p}p$-аннигиляционных взаимодействиях равна $3,2\pm0,3$ и превышает аналогичные данные для неупругих pp- и $\bar{p}p$-взаимодействий. Определен коэффициент неупругости π^+, π^0 и K_n/K^0 или $\bar{K}^0$ / мезонов, образующихся в аннигиляционных взаимодействиях: $\eta_{\pi^+}=0,33\pm0,22$, $\eta_{\pi^0}=0,36\pm0,05$, $\eta_{K_n}=0,044\pm0,008$. Полная множественность заряженных и нейтральных частиц, образующихся в $\bar{p}p$-аннигиляций при 22,4 ГэВ/с, равна $10,2\pm0,4$ и превышает соответствующие величины для неупругих $\bar{p}p$- и pp-взаимодействий.

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Batyunya B.V. et al. Cross Sections, Average Multiplicities and Energy Fractions of Neutral π- and K-Mesons in $\bar{p}p$-Annihilations at 22.4 GeV/c E1-82-475

To estimate cross sections, average miltiplicities and energy fractions carried by π^0 and K_n in $\bar{p}p$ annihilations at 22.4 GeV/c, $\bar{p}p-pp$ differences have been used.

The average multiplicity of π^0 in $\bar{p}p$ annihilations at 22.4 GeV/c is equal to 3.2 ± 0.3 that is larger than the values 1.50 ± 0.05 and 1.84 ± 0.06 for pp and $\bar{p}p$ interactions, respectively.

The energy fractions carried by π^+, π^0 and K_n(K^0 or $\bar{K}^0$) have been determined: $\eta_{\pi^+}=0.33\pm0.02$; $\eta_{\pi^0}=0.36\pm0.05$; $\eta_{K_n}=0.044\pm0.008$.

The energy fractions of π^0 in $\bar{p}p$ annihilations are approximately equal to those of η_{π^+} and practically independent of primary energy.

The total multiplicity of charged and neutral particles in $\bar{p}p$ annihilations at 22.4 GeV/c equals 10.2+0.4 which is much larger than the corresponding value for inelastic pp and $\bar{p}p$ interactions.

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