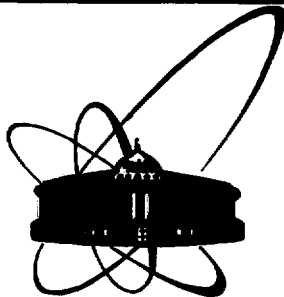


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**CROSS SECTIONS,
AVERAGE MULTIPLICITIES
AND ENERGY FRACTIONS OF NEUTRAL
 π - AND K-MESONS
IN $\bar{p}p$ -ANNIHILATIONS AT 22.4 GeV/c**

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B.V.Batyunya, I.V.Boguslavsky, I.M.Gramenitsky, R.Lednicky,
V.Vrba, Z.Zlatanov

Joint Institute for Nuclear Research, Dubna, USSR

E.G.Boos, V.V.Samoilov, T.Temiraliev, V.V.Fillipova
Institute of High Energy Physics, Alma-Ata, USSR

S.Y.Levonian

Lebedev Institute of Physics, Moscow, USSR

N.B.Dashian

Yerevan Institute of Physics, Yerevan, USSR

P.Villanen, E.Hannula

Department of High Energy Physics, University of Helsinki,
Helsinki, Finland

R.K.Dementiev, I.A.Korzhavina, E.M.Leikin, V.I.Rud, L.A.Tikhonova,
Institute of Nuclear Physics, Moscow State University, Moscow,
USSR

I.Herynek, P.Reimer, M.Lokajicek, J.Ridky

Institute of Physics, Czechoslovak Academy of Sciences, Prague,
CSSR

A.Valkarova, M.Suk

Nuclear Centre of Charles University, Prague, CSSR

A.M.Khudzadze, G.O.Kuratashvili, T.P.Topuria, V.D.Tsintsadze

Institute of High Energy Physics, Tbilisi, USSR

In studies of $\bar{p}p$ interactions, processes with the complete destruction of primary baryons and antibaryons in annihilation reactions $\bar{B}B \rightarrow \text{mesons}$ 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:

$$\sigma_2^2 = 525 \cdot S^{-2.01} \quad (\text{mb}) \quad (1)$$

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

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

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 $P_{lab}^{-0.01}$ (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. ^{4/}.

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 .

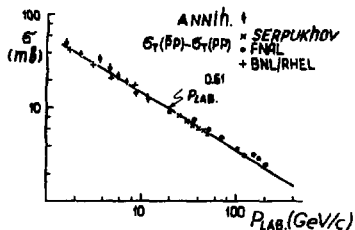


Fig. 1. The energy dependence of $\bar{p}p$ annihilations and $\bar{p}p$ - pp differences. The line is the fit of the annihilation data.

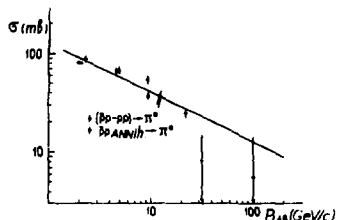


Fig. 2. The energy dependence of the inclusive π^0 cross sections in $\bar{p}p$ annihilation and $\bar{p}p$ - pp differences. The line is hand-drawn to guide the eye.

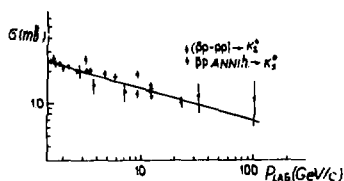


Fig. 3. The energy dependence of the inclusive K^0 cross sections in $\bar{p}p$ annihilation and $\bar{p}p$ - pp differences. The line is hand-drawn to guide the eye.

To obtain $\sigma^A(\pi^0)$, we have used the π^0 topological cross sections in pp interactions at 24 GeV/c ^{17a} normalized to $\sigma^{pp}(\pi^0) = 47.2 \pm 1.2$ at 22.4 GeV/c. This value follows from the formula:

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

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 ¹⁷ ($\chi^2/ND = 5.1/5$).

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 $\langle n^0 \rangle^A$ 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 $n_{ch} > 4$ since the value of $\langle n^0 \rangle^A$ at $n_{ch} = 2$ has been obtained with a large error. As is seen, $\langle n^0 \rangle^A$ decreases with increasing n_{ch} contrary to $\bar{p}p$ nonannihilations or pp interactions where $\langle n^0 \rangle$ 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 ± 1.22	4.39 ± 1.18	9.09 ± 1.03	5.87 ± 0.74	2.12 ± 0.36	0.47 ± 0.18	0.034 ± 0.034	23.6 ± 2.2
$\sigma_n^A(K_n), MB$	0.12 ± 0.08	0.3 ± 0.1	0.86 ± 0.09	0.34 ± 0.04	0.10 ± 0.03			1.74 ± 0.16
σ_n^A, MB	0.27 ± 0.07	1.18 ± 0.15	2.83 ± 0.11	2.04 ± 0.08	0.89 ± 0.04	0.234 ± 0.013	0.046 ± 0.005	7.49 ± 0.22
$\langle n^0 \rangle_n^A$	6.1 ± 4.8	3.7 ± 1.1	3.2 ± 0.4	2.9 ± 0.4	2.4 ± 0.4	2.0 ± 0.8	0.74 ± 0.74	3.2 ± 0.3
$\langle K_n \rangle_n^A$	0.44 ± 0.32	0.25 ± 0.09	0.3 ± 0.1	0.18 ± 0.02	0.11 ± 0.03			0.23 ± 0.02

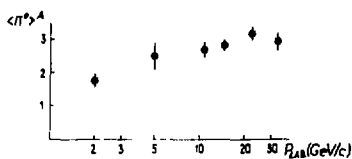


Fig. 4. The energy dependence of the average π^0 multiplicity in $\bar{p}p$ annihilations.

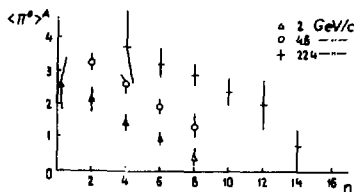


Fig. 5. The topological dependence of the average π^0 multiplicity in $\bar{p}p$ annihilations.

The important characteristic of the process of multiple production is the energy fraction η_0 representing the energy fraction carried by the particles of a given type (in the c.m.s.).

The energy fraction η_0 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

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

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

From expression (3) η_c^A is equal to

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

The energy fraction η_0 in the reaction $a + b \rightarrow c + X$ can be calculated from the invariant X distribution^{/9/}

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

where

$$f_{ab}^c(S, \vec{p}_c) = \sigma_{ab}^{-1} E_0 \frac{d^3 \sigma}{d^3 p}.$$

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^0} in pp and $\bar{p}p$ nonannihilation interactions are equal. The energy fractions of π^+ , π^- 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^0 has been calculated from the phenomenological relation which well describes data in a wide range of energies^{/9/}

$$\eta_{\pi^0}^{pp} = \frac{1}{2} (\eta_{\pi^+}^{pp} + \eta_{\pi^-}^{pp}). \quad (6)$$

Table 2
Energy fractions for π^- - and K_n -mesons

	pp	$\bar{p}p$	$\bar{p}p^A$
$\eta_{\pi^+ + \pi^-}$	0.215 <u>+0.014</u>	0.302 <u>+0.004</u>	0.66 <u>+0.06</u>
η_{π^0}	0.198 <u>+0.007</u>	0.156 <u>+0.008</u>	0.36 <u>+0.05</u>
η_{K_n}	0.0100 <u>+0.0012</u>	0.0166 <u>+0.0003</u>	0.044 <u>+0.008</u>

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 $\eta_{\pi^0}^{\bar{p}p}$, we use the formula ^{/12/}

$$\eta_{\pi^0} = \frac{\langle n_\gamma \rangle \langle |p_\gamma^*| \rangle}{\sqrt{s}}, \quad (7)$$

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 π^- 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 $\eta_{\pi^0} = 1/3$. However, all particles have been assumed to be charged or neutral pions. It has been supposed ^{/14/} that the energy dependence of coefficient $\beta = \eta_{\pi^0} / \eta_{\pi^+}$ 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 ($\eta_{\pi^0} > 1/3$) 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.

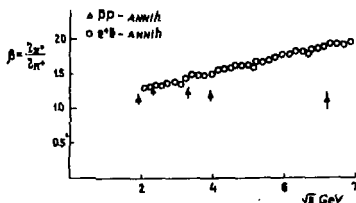


Fig. 6. The energy dependence of the ratio of the energy fractions for neutral and charged π -s in $\bar{p}p$ and e^+e^- annihilations.

However, in a recent paper ^{/18/} on e^+e^- annihilations, in which secondary particles (baryons, K^- , π -mesons) are identified, η_{π^0} has been found to be 0.25 ± 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)
$\langle n \text{ charged} \rangle$	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_0 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 $\bar{p}p$ and $p\bar{p}$ interactions.

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

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

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

To estimate cross sections, average multiplicities 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, respecti-
vely.

The energy fractions carried by π^+ , π^0 and K_n (K^0 or \bar{K}^0)
have been determined: $\eta_{\pi^+} = 0.33 \pm 0.02$; $\eta_{\pi^0} = 0.36 \pm 0.05$; $\eta_{K_n} = 0.044 \pm$
 0.008 .

The energy fractions of π^0 in $\bar{p}p$ annihilations are approxi-
mately 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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