NEUTRAL PION PRODUCTION IN $\bar{p}p$ ANNIHILATIONS AT 2.0 GeV/c

B.S. Chaudhary, S.N. Ganguli, A. Gurtu, P.K. Malhotra,
U. Mehtani, R. Raghavan and A. Subramanian

Tata Institute of Fundamental Research,
Bombay 400005, India

(Presented by P.K. Malhotra)

The importance of $\bar{p}p$ annihilation lies in the hope that a study of this process may lead to an understanding of the pionization process in pp interactions at high energies. For this reason the study of $\bar{p}p$ interactions has received a great deal of attention in recent years. However, most of these studies have concentrated on charged particles in the final states and, for practical reasons, only a few attempts have been made to study the π^0 component.

We present here preliminary results on π^0 production in $\bar{p}p$ interactions at 2 GeV/c. The results are based on a total of 58.32K events and 24.36K gammas recorded in 60.3K pictures (good frames), which forms a part of 200K pictures taken in the 1.5 m chamber with a built-in track-sensitive hydrogen target (TST) at Rutherford High Energy Laboratory. The TST, whose inside dimensions were $135 \times 33.3 \times 4.5$ cm^3, had 6 mm thick perspex windows and a metal top. Surrounding the TST was a mixture of neon-hydrogen with the molar concentration of neon being 77%; this corresponds to a radiation length of 40.7 cm. Because of the relatively high conversion probability for γ-rays, such an assembly allows the study of not only the inclusive π^0 production but also the π^0 multiplicity distribution for each charged topology.

Of the 60.3K pictures, 23.02K pictures were scanned for all events, i.e. those with charged particle multiplicity $n \geq 0$, with or without associated γ-rays or V^0's. The remaining 37.62K pictures were scanned for only those events which had either two or more associated γ-rays or one or more V^0's. The entire film has been scanned twice. The scanning efficiency for a double scan is 0.99 for all events, 0.97 for 0-prong events, and 0.99 for γ-rays. Although measurements on events with associated two or more γ-rays are being carried out, the preliminary results reported here are based on the scanning information only. Furthermore, only about 30% of the beam tracks are due to antiprotons, the bulk of the remaining tracks being due to muons -- small π^- contamination is not ruled out.

Table 1 gives the topological cross-sections σ_n, which have been deduced by normalizing the total number of events to correspond to the known $\sigma_{tot}(\bar{p}p) = 90.2 \pm 0.04$ mb $^{1)}$. The data on topological cross-sections on $\bar{p}p$

interactions at around 2.0 GeV/c have so far been lacking[1]. The values deduced from interpolation of the data at neighbouring energies are, however, found to be in good agreement with those of Table 1.

The observed number of γ-rays for each charge topology are also given in Table 1. In order to obtain $\langle n_{\pi^0} \rangle$, the average number of π^0, for each charge topology we need to know P_γ, the average conversion probability. For the purpose of this preliminary analysis we have estimated P_γ by assuming that for any given number of pions in the final state, the momentum and angular distributions of pions are determined by phase space alone. Using the CERN program FOWL and incorporating the fiducial volume constraints, we find that $P_\gamma = 0.30$, more or less independent of the number of pions in the final state. Assuming that all γ-rays result from π^0 decay, we obtain the results presented in Table 1 and Figs. 1 and 2. We have used $\sigma(\bar{p}p \to \bar{n}n) = 4.7 \pm 0.8$ mb, $\sigma(\bar{p}p \to \bar{p}p) = 28 \pm 2$ mb, total annihilation cross-section $\sigma_{an} = 48.1$ mb [1], and have neglected the small π^0 production in inelastic channels to obtain results for annihilations. Figure 1 shows the inclusive π^0 cross-section

$$\sigma_n(\pi^0) \equiv \sum_{n_{\pi^0}} n_{\pi^0} \sigma(n, n_{\pi^0}) \tag{1}$$

for $\bar{p}p$ annihilations at 2 GeV/c. It may be noted that the dominant π^0 production takes place in two and four prongs. The π^0 total inclusive cross-section is found to be $\sigma(\pi^0) = 79.8 \pm 0.5$ mb. Averaged over all topologies, we find $\langle n_{\pi^0} \rangle_{an} = 1.66 \pm 0.1$, $\langle n_- \rangle_{an} = 1.63 \pm 0.03$, and the average total multiplicity of π^0 and charged particles $\langle n_{tot} \rangle_{an} = 4.92 \pm 0.1$ for $\bar{p}p$ annihilations at 2.0 GeV/c.

We have attempted to obtain the π^0 multiplicity distribution for each charged prong topology using the corresponding gamma distribution. Except for the six-prong topology for which we get a good fit with $P_\gamma = 0.30$, for all others the fits are relatively poor and appear to require varying values of P_γ. In view of this and pending further investigation, we do not present the π^0 multiplicity distributions here.

Figure 2 shows $\langle n_{\pi^0} \rangle$ as a function of n_-, the negatively charged particle multiplicity. The line drawn represents a linear fit of the type

$$\langle n_{\pi^0} \rangle = \alpha n_- + \beta \tag{2}$$

to the annihilation data. The values obtained are $\alpha = -0.50 \pm 0.08$ and $\beta = 2.48 \pm 0.27$ with $\chi^2 = 0.8$ for 3 degrees of freedom. Thus we conclude that in $\bar{p}p$ annihilations at 2 GeV/c, $\langle n_{\pi^0} \rangle$ decreases with n_-.

It is interesting to compare our $\bar{p}p$ data (E_{cm} = 2.43 GeV) on $n_{\pi^0}(n_-)$ with a) that of pp collisions at 23 GeV/c for which the c.m. energy radiated into particle production is 2.43 GeV (assuming inelasticity of 0.5), b) $\bar{p}p$ interactions at $p_{lab} > 2.0$ GeV/c.

In Fig. 3 we compare our results with those of pp interactions at 19 GeV/c $^{2)}$, which is the closest to 23 GeV/c for which data exist. It may be noted that whereas $\langle n_{\pi^0} \rangle$ decreases with n_- for $\bar{p}p$ annihilations, it is flat, or slightly rising, for 19 GeV/c pp collisions. This clearly indicates that processes responsible for π^0 production for $\bar{p}p$ annihilations are different from those of pp interactions. Figure 3 also shows the data for $\bar{p}p$ annihilations at 4.6 GeV/c $^{3)}$ for $n_- \geq 1$. The shape of this distribution is nearly the same as that of $\bar{p}p$ annihilations at 2.0 GeV/c, and the higher $\langle n_{\pi^0}(n_-) \rangle$ is consistent with the higher available energy in the c.m. system. A possible explanation of a negative α for $\bar{p}p$ annihilations at low energies is the dominance of ρ-meson production in annihilation channels as compared to pp interactions$^{3)}$. This observation can also be explained by invoking a narrow distribution of pion (charged plus neutral) multiplicity for annihilations as compared to pp interactions, some evidence for which seems to exist$^{3,4)}$. We may remark here that the simple explanation offered by Bardadin-Otwinowska et al.$^{5)}$ for variation of α with energy appears to be inadequate for the case of $\bar{p}p$ annihilations.

Dao et al.$^{6)}$ have measured $\langle n_{\pi^0}(n_-) \rangle$ distribution in $\bar{p}p$ interactions (25% annihilations and remaining inelastics) at 14.75 GeV/c and find that $\langle n_{\pi^0} \rangle$ increases fairly fast with n_-. The slope $\alpha = +0.5 \pm 0.1$ is the same as one finds in pp collisions at $p_{lab} \sim 100$ GeV/c $^{7)}$. Since $\alpha \approx 0$ for 15 GeV/c pp collisions and one expects a similar value for $\bar{p}p$ <u>inelastic</u> collisions, in the absence of a specific measurement for annihilations alone we <u>assume</u> that $\alpha \simeq 0.5$ for $\bar{p}p$ annihilations at 15 GeV/c. In Fig. 4 we plot the available values of α as a function of c.m. available energy, as has been done by Dao and Whitmore$^{7)}$, including those for $\bar{p}p$ annihilations (Table 2). It is interesting to observe that there is a sharp transition in α-values for $\bar{p}p$ annihilations in going from 3.25 to 5.4 GeV available energy. It can be predicted from Fig. 4 that $\alpha = 0$ for $E_{cm} \approx 4$ GeV, i.e. $p_{lab} \approx 7.5$ GeV/c for $\bar{p}p$ annihilations. The idea of a critical point involving phase transitions between two kinds of hadron fluids, as proposed by Thomas$^{8)}$ and Arnold et al.$^{9)}$, seems attractive in explaining this feature. In this connection it would be interesting to look for evidence of sharp changes in the proportion of different resonances, such as ρ, ω, etc., produced in $\bar{p}p$ annihilations at $p_{lab} \approx 7.5$ GeV/c.

Acknowledgements

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Table 1

Observed topological cross-sections σ_n, inclusive π^0 cross-sections $\sigma_n(\pi^0)$, and average π^0 multiplicity $\langle n_{\pi^0}\rangle$, as a function of charged particle multiplicity

Charged prongs n	No. of events a)	Gammas recorded	σ_n (mb)	$\sigma_n(\pi^0)$ (mb)	$\langle n_{\pi^0}\rangle$	
					All excluding elastic	Annihilation
0	4694	2005	7.26 ± 0.2	6.7 ± 0.3	0.93 ± 0.1	2.6 ± 0.9
2	34991	11623	54.1 ± 0.4	37.0 ± 1.8	1.45 ± 0.2	2.14 ± 0.3
4	15802	9637	24.4 ± 0.3	32.1 ± 1.6	1.31 ± 0.2	1.44 ± 0.2
6	2776	1081	4.29 ± 0.1	3.9 ± 0.2	0.92 ± 0.1	0.92 ± 0.1
8	54	9	0.084 ± 0.02	0.043 ± 0.14	0.52 ± 0.17	0.52 ± 0.17
≥ 0	58317	24355	90.2	79.8 ± 0.5	1.37 ± 0.05	1.66 ± 0.1

a) These numbers correspond to 60.29K frames. The number of events actually recorded varies with n but is approximately 0.451 of these numbers. The scanning loss for low momentum transfer elastic events is estimated to be 1.0 mb, i.e. 1.9% of the two-prong cross-section.

Table 2

Fitted values of α for $\bar{p}p$ annihilations

p_{lab} (GeV/c)	E_{cm} (GeV)	α	References
2.0	2.43	-0.5 ± 0.08	This work
4.6	3.25	-0.7 ± 0.10	3
14.75	5.43	+0.48 ± 0.07	6

Figure captions

Fig. 1 : Distribution of inclusive π^0 cross-sections $\sigma_n(\pi^0)$ for $\bar{p}p$ annihilations at 2 GeV/c.

Fig. 2 : Dependence of $\langle n_{\pi^0} \rangle$ on n_-, the negative particle multiplicity. The line drawn is $\langle n_{\pi^0} \rangle = -0.50n_- + 2.48$, which is the best fit to the annihilation data.

Fig. 3 : Comparison of $\langle n_{\pi^0}(n_-) \rangle$ for $\bar{p}p$ annihilations at 2 GeV/c with the same for pp interactions at 19 GeV/c (Ref. 2) and $\bar{p}p$ annihilations at 4.6 GeV/c (Ref. 3).

Fig. 4 : Plot of α versus available energy in the c.m. system for different hadron-nucleon collisions. This figure is the same as in Ref. 7 except for the $\bar{p}p$ annihilation points (Table 2) which we have included. The solid line represents the prediction of critical fluid model (Refs. 7 to 9). The dashed line is drawn connecting the $\bar{p}p$ points.

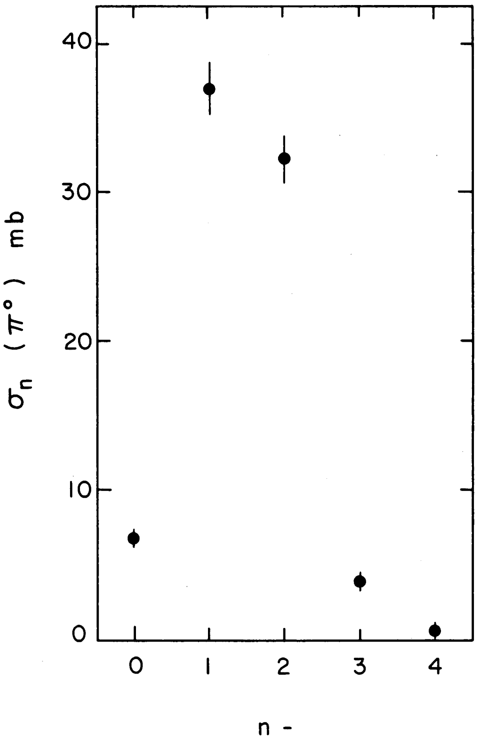

Fig. 1

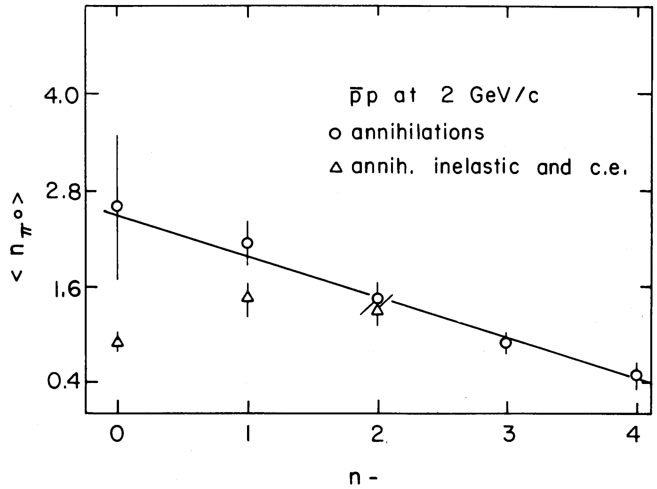

Fig. 2

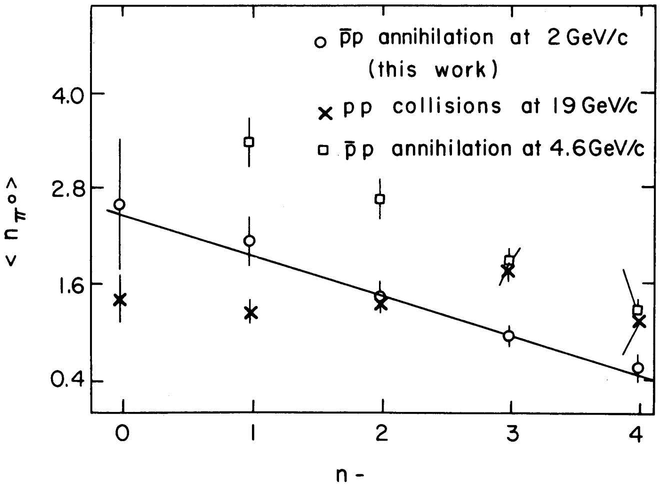

Fig. 3

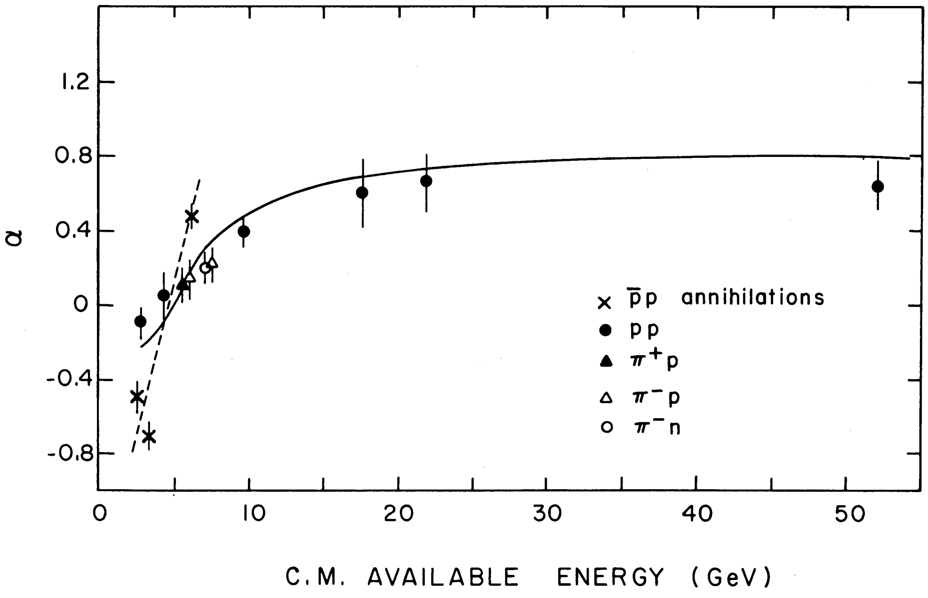

Fig. 4

DISCUSSION

- *Degrange:*

Did you try to fit exclusive channels with a different number of neutral pions?

- *Malhotra:*

In this preliminary analysis we have used the scanning data only. We plan to use the measured quantities for γ and to fit each event separately.