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THE ANNIHILATION OF e^+e^- AND $\bar{p}p$ AND STATISTICAL MODEL CONSIDERATIONS

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ABSTRACT: We compare data for e^+e^- and $\bar{p}p$ annihilation and find similarity in their behavior. We calculate charged and total multiplicities, fractional prong cross sections and the $\pi^+\pi^-\pi^+\pi^-$ final state cross section in a statistical model and compare our results with the data.

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Recently e^+e^- annihilation cross sections have been measured at SPEAR [1-5]. In addition to the remarkable $\psi(3105)$ and $\psi'(3695)$ resonances and the unexpected energy dependence of the total cross section, the data has further interesting features: (1) there is a strong violation of scaling in the inclusive cross sections over much of the range of the Feynman variable x, and (2) the charged versus neutral particle production multiplicity is smaller than expected.

The object of this letter is twofold. First, we make a comparison of the e^+e^- annihilation data for multiplicities and $\pi^+\pi^-\pi^+\pi^-$ final state with data for the corresponding quantities in $\bar{p}p$ annihilation, as a function of energy. The data for the two reactions show considerable similarity.

Secondly, the similarity of these data leads us to consider a statistical picture for the two reactions involving an incoherent superposition of s-channel resonances. Specifically we use the statistical bootstrap model [6-10] in which the s-channel resonances decay sequentially emitting pions one at a time. Angular distributions apart, the decay characteristics are essentially spin independent and are independent of the entrance channel; thus the similarity between final states produced by e^+e^- and $\bar{p}p$.†

A known success of this statistical picture for e^+e^- annihilation is the Boltzmann-like dependence on final momenta predicted by Engels,

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†The branching ratios of hadronic decays of $\psi(3105)$ and $\psi'(3695)$ may also be statistical (apart from $\psi' \to \psi + 2\pi$); thus the discovery of these resonances does not necessarily invalidate any of our conclusions.

Satz, and Schilling [8] and observed for $e^+e^- \to$ inclusive π^-, K^-, and $\bar{p}$ (fig. 1a). Here scaling fails precisely because E_π , etc. appear in the combination exp $(-E_\pi/T_0)$. The further inclusive and exclusive quantities considered in the present paper require more detailed calculation [9,10]. We report results from a simplified estimate in which the s-channel resonances, after emitting one pion at a time in the first steps of the decay chain, emit a pion and one ρ, ω, or η meson in the last step* (fig. 1b). This approximation to the decay chain has been used successfully in describing diffractive production of five charged pions [11]. Details of the formalism and calculations will be given in a further publication, together with a more complete treatment including the possibility of emitting η, ρ, ω and higher-mass hadrons at each step along the decay chain. It is expected that these refinements will introduce corrections particularly in the exclusive channels but will not change the behavior qualitatively.

Specifically we have calculated charged and total multiplicity, prong cross sections, and the total cross section for $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ assuming the s-channel virtual photon to couple to isovector and isoscalar spin-one hadrons with equal strength. We find little sensitivity of our results to the ratio of isovector to isoscalar coupling strengths. The results then should be applicable also to the $\bar{p}p$ reaction. The calculated fractional prong cross sections are shown in fig. 1(c) together

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*The termination of the decay chain by emission of a ρ meson allows a realistic calculation of the four-charged-pion exclusive channel, which we include in this paper. Emission of a single ρ, ω, or η earlier in the chain gives results similar to emission at the end. The six-charged-pion exclusive channel, for which data also exists, requires consideration of *multiple* ρ emission, which we do not consider here.

with available data for $\bar{p}p$ annihilation [12]. The calculation of multiplicities is shown in fig. (2a,b) along with data for e^+e^- [1,4,13,14] and $\bar{p}p$ annihilation. The calculated absolute cross section for $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ is shown in fig. (3a), along with data.

The e^+e^- and $\bar{p}p$ data are in most cases quite similar. In particular the fraction of energy emerging in the form of charged particles, about which much has been said in the e^+e^- reaction, seems to show a similar trend in the $\bar{p}p$ reaction as well.

The statistical model overall provides a reasonably good description of the data for prongs, multiplicities and the $\pi^+\pi^-\pi^+\pi^-$ mode in the lower part of the energy scale for both e^+e^- and $\bar{p}p$ reactions. It is interesting to note that in this region the exclusive reaction $\bar{p}p \to \pi^+\pi^-$ already develops forward and backward Regge-exchange peaks. Our interpretation would be that some (non-statistical) coherence among s-channel resonances is indeed present, but tends to be washed out by summing over final states in inclusive quantities, or by integrating over angles in exclusive states. For e^+e^- we do (in common with most models) predict too large a charged/total energy ratio at the high energy end and the calculated $\pi^+\pi^-\pi^+\pi^-$ cross section is somewhat low in this region. At the high energy end, the model agrees better with the $\bar{p}p$ data than with the e^+e^- data, which seems generally true wherever deviations exist between results from the two reactions. Further measurements at the high energy end should tell us whether statistical behavior persists at higher energies or whether coherent effects [7] become dominant.

As a final comparison of e^+e^- and $\bar{p}p$ annihilation, we show total cross sections in fig. 3(b). The $\bar{p}p$ data points plotted are the $\bar{p}p$ pion annihilation cross sections multiplied by an arbitrary normalization factor of 0.9×10^{-6}. The energy dependence of the $\bar{p}p$ and e^+e^- data are similar (apart from the ψ and ψ' resonance peaks, which are not shown).

We have no explanation of this similarity. Statistical models predict branching ratios. They do not describe the dynamics of production. Since at NAL energies $\bar{p}p$ and pp total cross sections are approaching one another, it seems likely that the $\bar{p}p$ annihilation cross section would go to zero at high enough energies. Noting the similar behavior of the e^+e^- and $\bar{p}p$ annihilation cross sections, the e^+e^- cross section at the high end of the SPEAR energy range, whatever its significance, might then be a transient phenomenon.

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FIGURE CAPTIONS

Fig. 1(a). Negative particle yield per unit invariant phase space versus particle total energy, from e^+e^- annihilation at total center-of-mass energy, $\sqrt{s} = 4.8$ GeV [Ref. 1]. Results are preliminary. Straight line corresponds to exp − (E/kT) with kT = 0.164 GeV.

1(b). Typical diagrams used to estimate $e^+e^- \to$ pions and $\bar{p}p \to$ pions. The heavy line represents a sum over massive resonances. Branching ratios for ρ, ω, and η decays are taken from experiment.

1(c). Fractional prong cross section predictions for e^+e^- and $\bar{p}p$ annihilation versus $\sqrt{s}$. Points represent $\bar{p}p$ data. In all calculations the hadronic volume is a sphere of radius 1.1 fermi.

Fig. 2(a). Mean charged particle multiplicity versus $\sqrt{s}$.

2(b). Total energy in charged particles divided by total hadron energy versus $\sqrt{s}$, if all charged particles have pion mass. e^+e^- data are preliminary. No errors assigned to $\bar{p}p$ points. Curves in a) and b) are our model predictions. Frascati and CEA data in (a) and (b) are taken from Richter's rapporteur's talk [Ref. 1].

Fig. 3. e^+e^- (hadronic) and $\bar{p}p$ annihilation cross sections versus $\sqrt{s}$.

(a) Exclusive four-charged-pion reaction. The curve represents our model prediction where we have used, for getting e^+e^- theoretical branching ratios, $\sigma_{total}(e^+e^- \to \text{hadrons}) = 10.4 + 178.5/s$ nb.

(b) Total hadronic cross sections. Frascati data below 2.6 GeV are not plotted because of large variations.

0 0 4 3 0 1 2 5 3

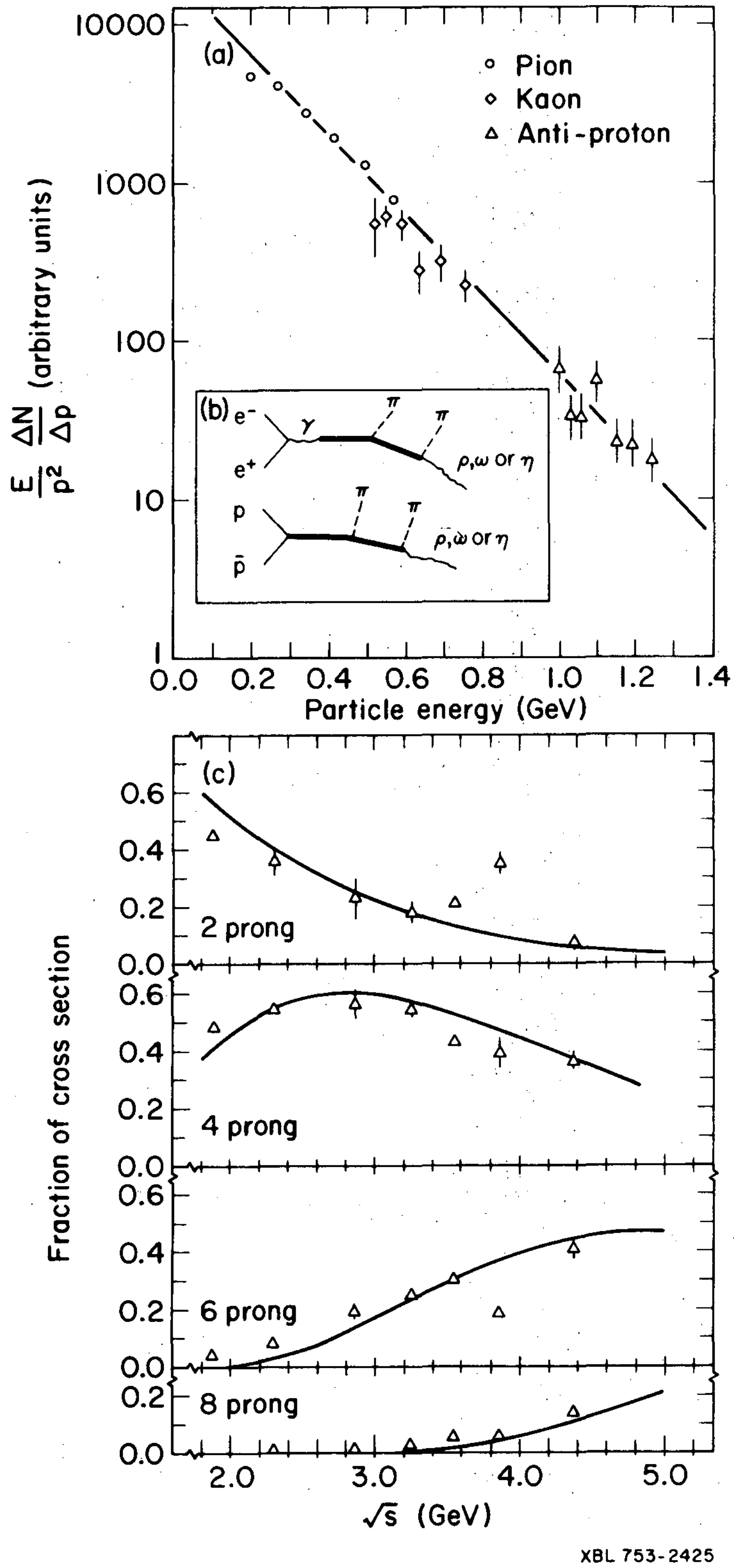

Fig. 1

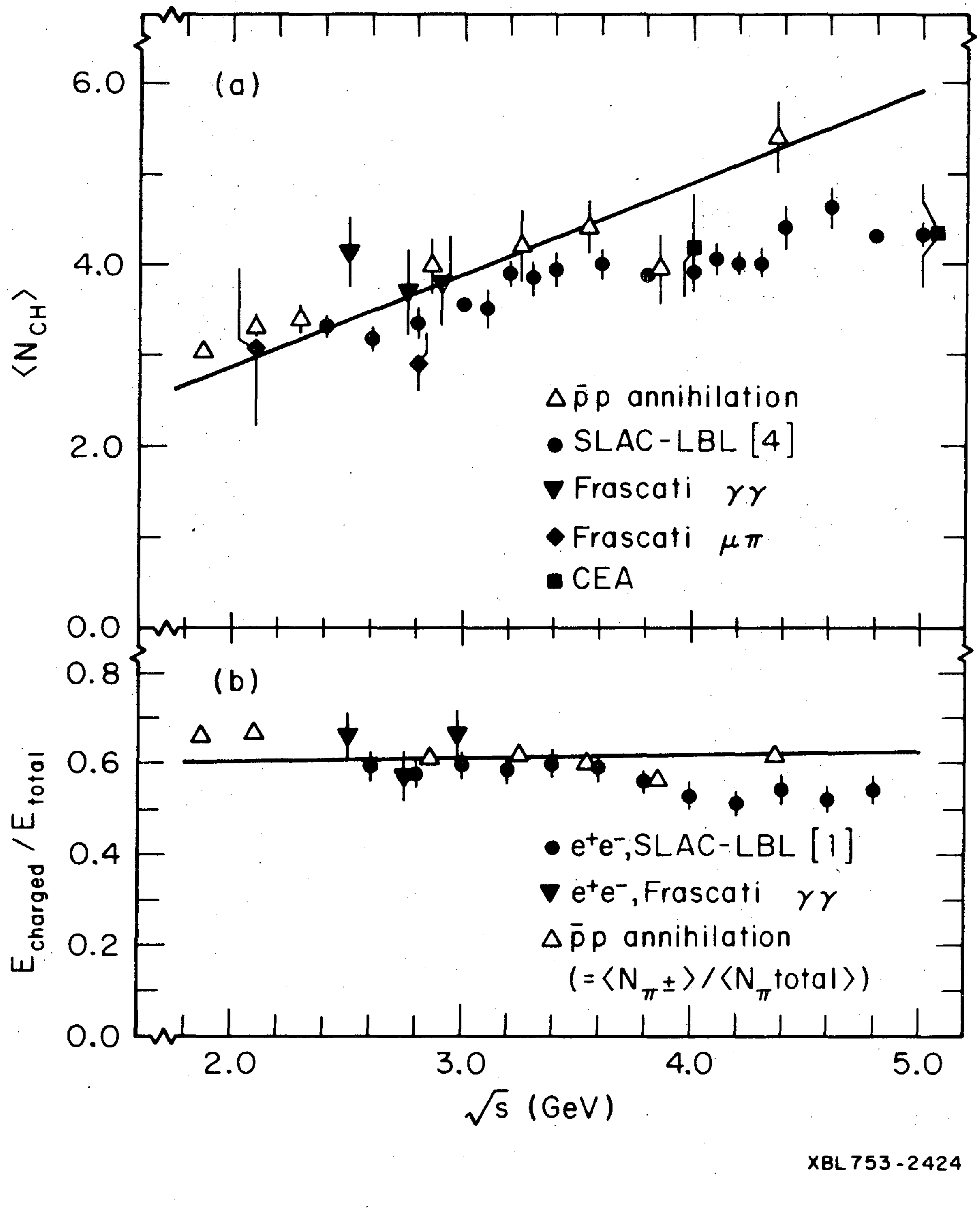
6.0
4.0
2.0
0.0
(a)
$\langle N_{CH} \rangle$
Δ p̄p annihilation
● SLAC-LBL [4]
▼ Frascati γγ
◆ Frascati μπ
■ CEA
0.8
0.6
0.4
0.2
0.0
(b)
$E_{charged} / E_{total}$
● e^+e^-,SLAC-LBL [1]
▼ e^+e^-, Frascati γγ
Δ p̄p annihilation
(= $\langle N_{\pi^\pm} \rangle / \langle N_\pi$ total$\rangle$)
2.0
3.0
4.0
5.0
$\sqrt{s}$ (GeV)
XBL 753-2424

Fig. 2

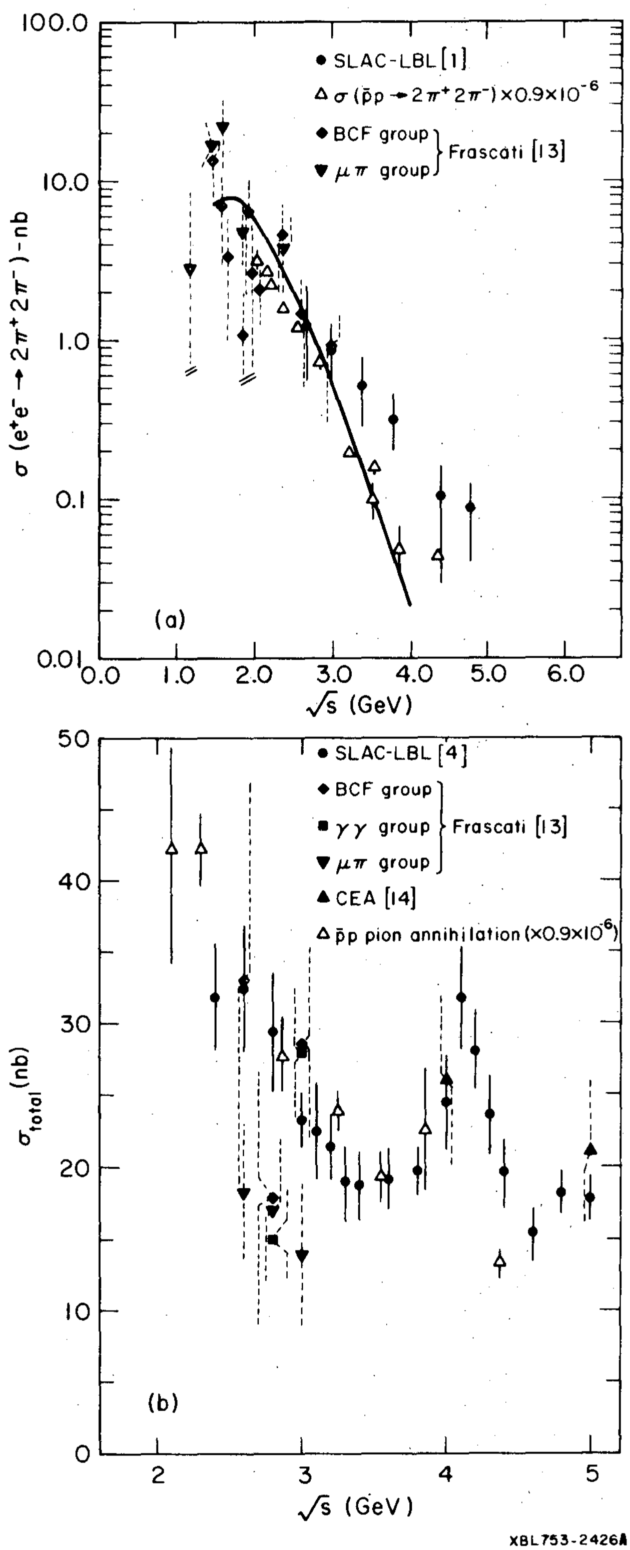
100.0
10.0
1.0
0.1
0.01
0.0
1.0
2.0
3.0
4.0
5.0
6.0
σ (e⁺e⁻ → 2π⁺2π⁻) - nb
● SLAC-LBL [1]
Δ σ (p̄p → 2π⁺2π⁻)×0.9×10⁻⁶
◆ BCF group
▼ μπ group
Frascati [13]
(a)
√s (GeV)
50
40
30
20
10
0
2
3
4
5
σ_total (nb)
● SLAC-LBL [4]
◆ BCF group
■ γγ group
▼ μπ group
Frascati [13]
▲ CEA [14]
Δ p̄p pion annihilation (×0.9×10⁻⁶)
(b)
√s (GeV)
XBL753-2426A

Fig. 3

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