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Charmed Baryon Production in Electron-Positron Annihilation

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ABSTRACT

A plausible model for the production of the lowest lying charmed baryon pairs in electron-positron annihilation is shown to be in good quantitative agreement with the recent data on the inclusive antiproton yield near the charmed baryon threshold. At higher energies well above threshold the contribution of the exclusive two-body processes which we have considered falls below the data indicating a significant antiproton yield from other channels. The inclusive production of lambdas and charged sigmas are also briefly discussed.

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Several charmed meson states have now been firmly established in electron-positron annihilation experiments at both SLAC and DESY. Recently evidence for charmed baryon pair production at SPEAR has also been presented.[1] In this experiment it was found that the inclusive production of antiprotons and, to a lesser extent, of lambdas show a rapid rise in the region $4.4 < E_{cm} < 5$ GeV which is consistent with pair production of the charmed baryons previously seen in photoproduction[2] and neutrino scattering[3] experiments at 2.26 GeV/c^2 and 2.5 GeV/c^2. Here we show that these data are in good quantitative agreement near threshold with the predictions of a plausible model for the pair production of the low-lying charmed baryons.

The differential cross section in the center of mass for the e^+e^- pair production of baryons with mass m and $J^P = 1/2^+$ is[4]

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2\beta}{4s}\left[G_M^2(s)(1+\cos^2\theta) + \frac{4m^2}{s} G_E^2(s)\sin^2\theta\right], \tag{1}$$

where $s = E_{cm}^2$, $\beta = (1 - 4m^2/s)^{1/2}$ and θ is the production angle. The form factors $G_E(s) = F_1(s) + (s/4M^2)\kappa F_2(s)$ and $G_M(s) = F_1(s) + \kappa F_2(s)$ are the usual electric and magnetic form factors. The total section is

$$\sigma = \frac{4\pi\alpha^2\beta}{3s}\left[G_M^2(s) + \frac{2m^2}{s} G_E^2(s)\right]. \tag{2}$$

We shall assume that in the production of a charmed baryon pair the virtual photon first creates a pair of charmed quarks which then acquire the necessary light quarks to form the physical baryons,[5] as illustrated in Fig. 1. That is, we neglect the diagrams in which the photon couples directly to the light quarks since these diagrams require that the relatively heavy $c\bar{c}$ pair emerge from the vacuum and therefore are expected to be suppressed. In this model we shall assume the form factors $F_1(s)$ and $F_2(s)$ near the production threshold are dominated by nearby $c\bar{c}$ resonances and therefore only the heavy charmed quark contributes to the effective charge and magnetic moment at these energies. Note thet the threshold requirement $G_E(4M^2) = G_M(4M^2)$ will automatically be satisfied. Specifically, we have taken

$$F_1(s) = F_2(s) = 2/3\,(1 - s/\Lambda^2)^{-1}, \tag{3}$$

with $\Lambda = 3.1$ GeV/c^2 and have calculated the magnetic moments μ using SU(8) symmetric quark wave functions but keeping only the contribution of the charmed quark.[6] The magnetic moments of $\Lambda_c(2.26)$, or C_0, and $\Sigma_c(2.5)$, or C_1, were found to be $2/3\ \mu_p$ and $-2/9\ \mu_p$, respectively, where $\mu_p = 2.79$ is the proton magnetic moment.

The reported evidence for charmed baryon production[1] is the rapid rise in the ratio

$$R_{p+\bar{p}} = 2R_{\bar{p}} = 2\sigma(e^+e^- \to \bar{p} + \text{anything}/\sigma_{\mu\mu}, \tag{4}$$

at the expected threshold energy. The contribution to $R_{\bar{p}}$ from the production of charmed antibaryons $\bar{B}_c$ is

$$R^c_{\bar{p}} = \frac{1}{\sigma_{\mu\mu}} \sum_{\bar{B}_c} \sigma(e^+e^- \to \bar{B}_c + \text{anything})\, P(\bar{B}_c \to \bar{P} + \text{anything}), \qquad (5)$$

where $P(\bar{B}_c \to \bar{p} + \text{anything})$ is the probability that the decay of $\bar{B}_c$ will yield a $\bar{p}$ and the sum extends over all charmed antibaryons. In our numberical calculations we have kept only the lowest lying states $\Lambda_c(2.6)$ and $\Sigma_c(2.5)$ which should give the dominant contribution near threshold. Since Σ_c decays strongly into Λ_c with the emission of a pion we have taken $P(\bar{\Sigma}_c \to \bar{p} + \text{anything}) = BR(\bar{\Lambda}_c \to \bar{p} + \text{anything})$ which we have taken to be 30%. In order to realistically compare with the data we have averaged over energy bins ΔE of 200 MeV and 500 MeV below and above $E_{cm} =$ 5 GeV, respectively. Thus we have calculated

$$R^c_{\bar{p}} = \frac{B.R.}{\sigma_{\mu\mu}\Delta E} \int_{\Delta E} \left[\sigma(e^+e^- \to \Lambda_c\bar{\Lambda}_c) + 3\sigma(e^+e^- \to \Sigma_c\bar{\Sigma}_c)\right] dE \qquad (6)$$

in our model and in Fig. 2 we have plotted $2R^c_{\bar{p}}$ on top of an assumed experimental background of $R_{p+\bar{p}} = 0.3$. The data of Piccolo, et al.,[1] are also shown in the same figure for comparison. The agreement is rather good near threshold.[7] Beyond about 6 GeV the calculated points fall with energy while the data remain approximately constant. This is to be expected since only the lowest lying exclusive $1/2^+$ charmed baryon pair states have been included in the calculation. With increasing energy numerous other channels are opening and their contributions presumably account for the inclusive data remaining flat.

A somewhat smaller increase in the inclusive production of lambdas was also reported by Piccolo, et al.[1] Their data are consistent with $R_{\overline{\Lambda}}/R_{\overline{p}}$ being about 10 to 15% and independent of energy. This ratio is a good deal smaller than the naive expectation $R_{\overline{\Lambda}} \sim R_{\overline{p}}$ near threshold which one finds in the free quark model where $BR(\Lambda_c \to \Lambda + \text{anything})/BR(\Lambda_c \to p + \text{anything}) = 1$, if small phase space corrections are neglected. A more realistic approach,[8] which includes some hard gluon corrections to the quark weak interactions, yields $R_{\overline{\Lambda}}/R_{\overline{p}} \sim 40\%$ leaving the question of branching ratios yet to be understood.

Finally we note that recently evidence for an increase in inclusive production of $\overline{\Sigma}^{\pm}$ has also been reported.[9] However, the data lie too far beyond the charmed baryon threshold for our calculations to be relevant, i.e., we expect this excess of $\overline{\Sigma}^{\pm}$ to be due to production channels beyond the low lying $\Lambda_c\overline{\Lambda}_c$ and $\Sigma_c\overline{\Sigma}_c$ states which we have considered.

In summary, we have presented a rather simple model of charmed baryon pair production in e^+e^- annihilation based on physically plausible assumptions and have shown that it agrees well with the recent data of Piccolo, et al.[1] near the production threshold. A considerably more stringent test of the physical assumptions underlying the model will be possible when the exclusive cross sections for charmed baryon pair production are measured.

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[6]For a rather different model for the form factors see the calculation of A.C.D. Wright, Phys. Letters 71B, 425 (1977).

[7]It should be emphasized that such good agreement depends critically on the choice of the form factor Eq. (3). Numerically we have explored other possibilities, e.g. a dipole form and different values of the mass Λ, and found that the agreement was rather poor.

[8]J.G. Körner, G. Kramer and J. Willrodt, DESY Preprint 78/13.

[9]T. Ferguson, et al., SLAC-PUB-2081.

FIGURE CAPTIONS

Fig. 1: The $c\bar{c}$ pair creation for the production model of charmed baryon pairs in e^+e^- annihilation. Diagrams in which the virtual photon couples to a $u\bar{u}$ or $d\bar{d}$ quark pair are neglected, as discussed in the text.

Fig. 2: The ratio $R_{p+\bar{p}}$ of the inclusive proton + antiproton cross section normalized to the μ-pair cross section as a function of the center-of-mass energy $E_{c.m.}$ The calculated points averaged over energy bins as discussion in text are indicated by crosses while the full circles are the data of reference 1.

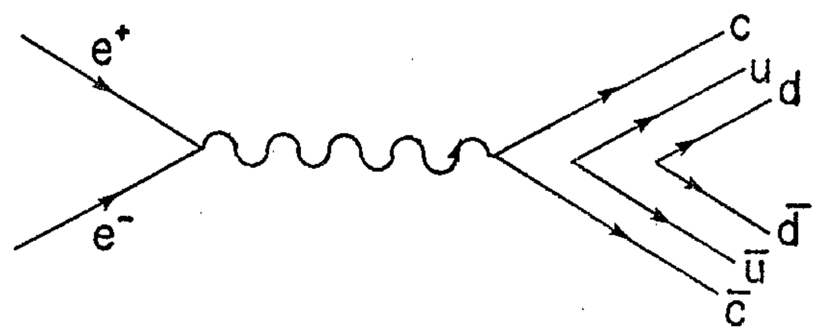

Fig. 1

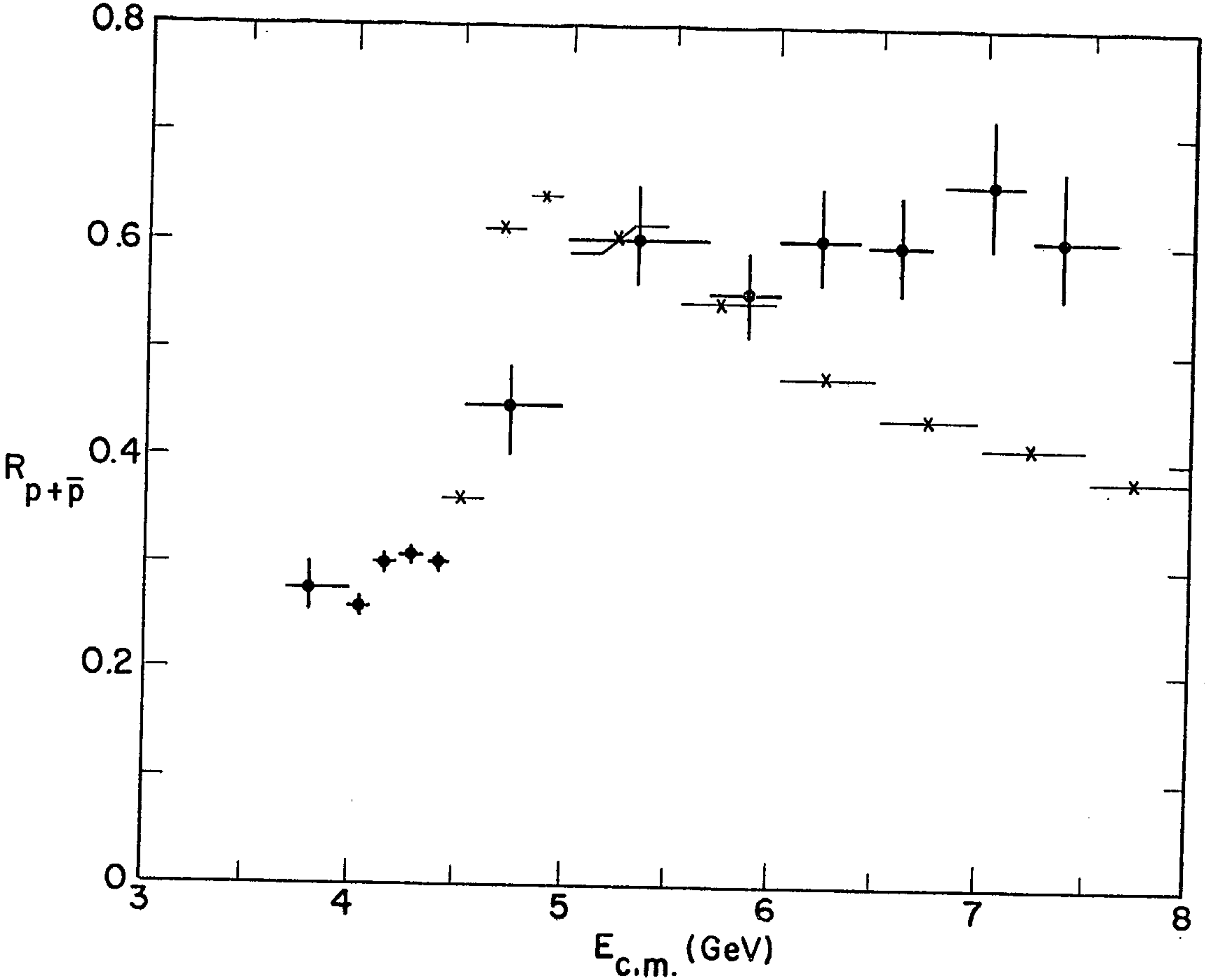

Fig. 3