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Signal for bottom-baryon production in electron-positron colliding beams

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ABSTRACT

The expected contribution to the inclusive proton yield in electron-positron annihilation near the bottom-baryon production threshold is estimated. A plausible model for the production of heavy quark hadronic states, which adequately describes the observed charmed-baryon production, is assumed. Near threshold bottom-baryon production causes a step in $R_{p+\bar{p}}$ of approximately 0.1 to 0.3, which appears to be a feasible signal to search for at CESR.

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Since the discovery of the Υ at Fermilab[1] the accumulated experimental support for the bottom quarkonium picture has become overwhelmingly convincing.[2] Most recently evidence for pair production of bottom-hadrons, presumably the lightest bottom-mesons, has been observed at CESR.[3] Anticipating bottom-baryons, we have estimated the expected threshold signal in the inclusive proton plus antiproton yield for electron-positron annihilation at CESR energies.

Near threshold bottom-baryon production is expected to be dominated by the lightest states: Λ_b and Σ_b, whose quark composition can be obtained from their strange counterparts, Λ and Σ, by replacing the strange quarks by bottom quarks. To quantitatively estimate the production cross sections we have adopted the model[4] in which the heavy bottom quark pair is first produced by the virtual photon and then dressed with light quarks to form color-singlet baryons. This intuitively plausible model, although quite simple, was previously found[5] to be rather successful in describing the production of charmed-baryons observed at SPEAR.[6]

The differential cross section in the center of mass for the production of baryon pairs having mass m and spin-parity $\frac{1}{2}^+$ in electron-positron annihilation is

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

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

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

Bottom-baryon pair production, as in the case of charm,[6] is expected to produce a rapid rise near threshold in the inclusive proton-plus-antiproton ratio

$$R_{\bar{p}+p} = 2R_{\bar{p}} = 2\sigma(e^+e^- \to \bar{p} + \text{anything})/\sigma_{\mu\mu} \quad . \tag{3}$$

We shall consider, for simplicity of notation, $R_p = \frac{1}{2}R_{\bar{p}+p}$, although the experimental background problem should be less severe for $R_{\bar{p}}$. The contribution to R_p from bottom-baryons B_b is

$$R_p^b = \frac{1}{\sigma_{\mu\mu}} \sum_{B_b} \sigma(e^+e^- \to B_b + \text{anything})P(B_b \to p + \text{anything}) \tag{4}$$

where $P(B_b \to p + \text{anything})$ is the probability that the decay of B_b will yield a proton and the sum extends over all bottom-baryons.

Near threshold the lowest lying bottom-baryons, presumably Λ_b and Σ_b, should dominate R_p^b. Therefore, at low energies one expects a good approximation to be

$$R_p^b = B\left[\sigma(e^+e^- \to \Lambda_b\bar{\Lambda}_b) + 3\sigma(e^+e^- \to \Sigma_b\bar{\Sigma}_b)\right]/\sigma_{\mu\mu} \tag{5}$$

where we have assumed that Σ_b lies at least one pion mass above Λ_b and, consequently, decays strongly into Λ_b; and B is the effective inclusive branching ratio for $\Lambda_b \to p + \text{anything}$.[7]

For the form factor we shall adopt the model[4] in which the heavy bottom quark pair is electromagnetically produced, followed by strong production of light quark pairs to form the color-neutral baryons as shown in Fig. 1. The electric form factor is therefore normalized to the bottom quark charge: $G_E(0) = -1/3$; and the magnetic form factor is normalized to the bottom quark contribution to the bottom-baryon magnetic moment: $G_M(0) = \mu$. Using SU(Flavor × Spin) symmetric wave functions, but keeping only the bottom quark contribution, one finds $\mu(\Lambda_b) = -1/3\mu(p)$ and $\mu(\Sigma_b) = 1/9\mu(p)$ where $\mu(p) = 2.79$ is the proton magnetic moment. Including quark mass corrections[8] and expressing the magnetic moments in bottom-baryon magnetons introduces an additional factor (m_u/m_b)(bottom–baryon mass/proton mass), which is approximately 0.45 for Λ_b and 0.47 for Σ_b. Furthermore, we shall assume the energy dependence of the form factors near threshold is dominated by a vector meson pole in the Υ mass region. Specifically, in the numerical calculations below we have taken

$$F_1(s) = F_2(s) = -1/3(1 - s/\Lambda^2)^{-1} \tag{6}$$

where $\Lambda = m_\Upsilon = 9.46$ GeV/c^2. Note that Eq. (6) implicitly incorporates the kinematical constraint $G_E(4m^2) = G_M(4m^2)$.

The contributions to the form factors in which the virtual photon produces a light quark pair are negligible by comparison for two reasons: the subsequent strong production of the heavy quark pair is suppressed since $m_{u,d}/m_b << 1$ and, in addition, these contributions are dominated by poles in the light vector meson region and are therefore further suppressed because $(m_{\rho,\omega,\phi}/m_\Upsilon)^2 << 1$. Of course, if these contributions had been included, G_E and G_M would have been correctly normalized at $s = 0$ to the total bottom-baryon charge and magnetic moment, respectively; but here we are only concerned with energies near the bottom-baryon production threshold.

For illustrative purposes, numerical calculations of the proton yield near threshold have been done using the mass estimates[8] $m(\Lambda_b) = 5.62$ GeV/c^2 and

$m(\Sigma_b) = 5.80$ GeV/c^2, which come from the QCD inspired, semi-empirical, quark model mass formula.[9] To facilitate realistic comparison with experiment we have also averaged over energy bins $\Delta E_{cm} = 200$ MeV. In Fig. 2 we have plotted $R^b_{\bar{p}+p}/B$. Being guided by the corresponding SPEAR data on charmed-baryon production a reasonable estimate[7] of B is between 15 and 50%, so the resulting step in $R_{\bar{p}+p}$ at the bottom-baryon production threshold is expected to lie in the range 0.1 to 0.3. Since this is comparable to the background at CESR in this energy region the signal seems feasible to search for.

In summary, we have estimated the step in $R_{\bar{p}+p}$, signaling the production of bottom-baryon pairs in electron-positron annihilation, to be approximately 0.1 to 0.3, based on a physically plausible model that has worked well for charmed-baryon production. As is evident in the numerical illustration shown in Fig. 2, the contributions to $R_{\bar{p}+p}$ of the low-lying bottom-baryons, Λ_b and Σ_b, fall off rather rapidly as the energy increases substantially above threshold, where the contributions from higher bottom-baryon states, not included in the present estimate, are expected to be important. Data on <u>exclusive</u> cross sections for bottom-baryon production will provide more detailed tests of the physical assumptions underlying the model, but as for bottom-mesons, the first signal for production is most likely to be found in an inclusive channel.

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FIGURE CAPTIONS

Fig. 1: Bottom quark contribution to bottom-baryon pair production in electron-positron annihilation.

Fig. 2: The inclusive proton-plus-antiproton yield due to bottom-baryon production near threshold for $m(\Lambda_b) = 5.62\ \mathrm{GeV}/c^2$ and $m(\Sigma_b) = 5.80\ \mathrm{GeV}/c^2$.

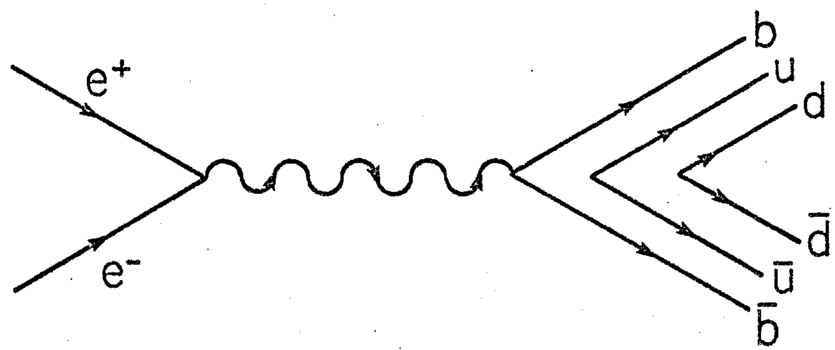

Fig. 1

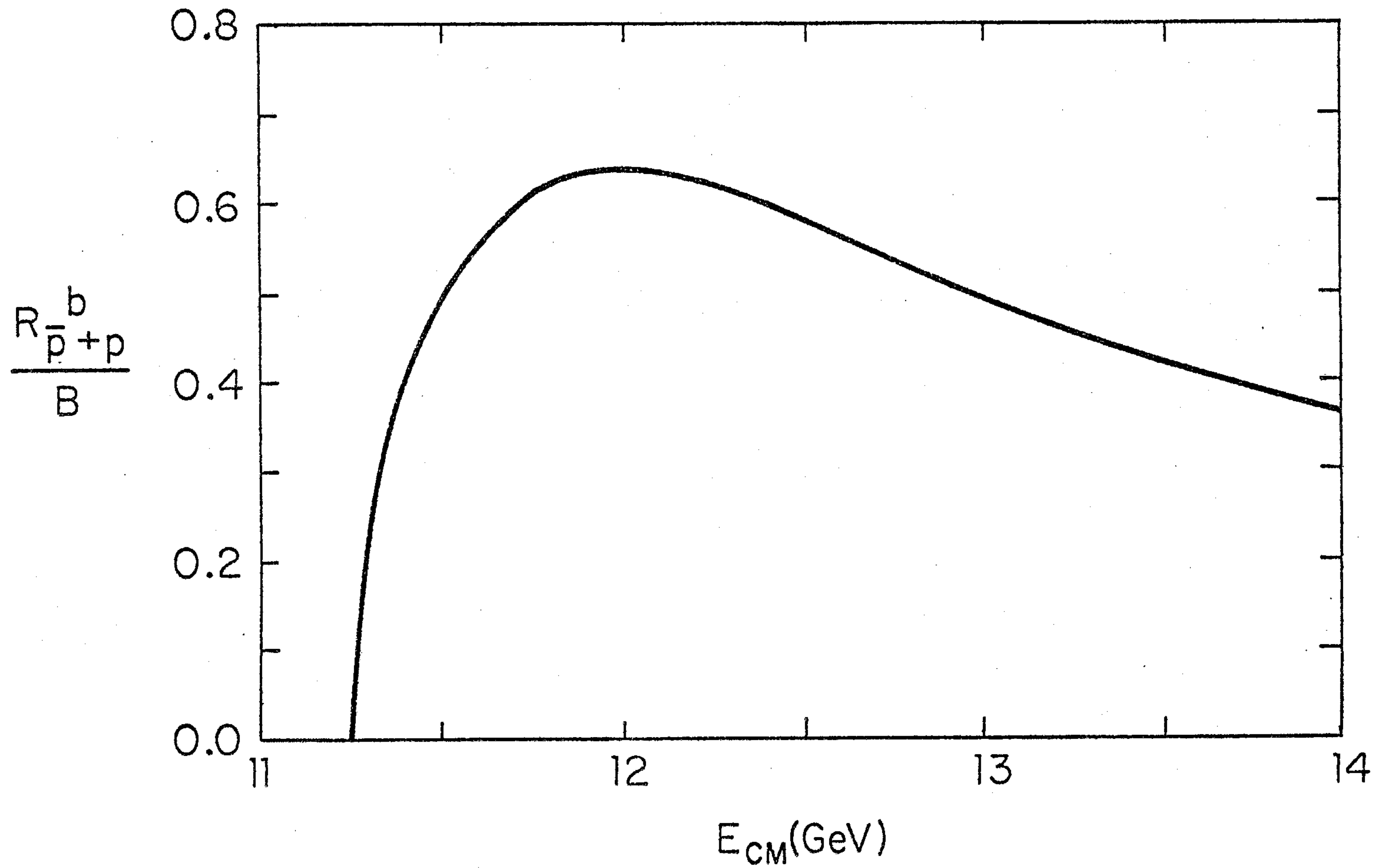

Fig. 2