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ON BARYON-ANTIBARYON CROSS SECTIONS FROM INITIAL STATE RADIATION PROCESSES AT *BABAR* AND THEIR SURPRISING THRESHOLD BEHAVIOR

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Abstract

BABAR has measured with unprecedented accuracy the $e^+e^- \to p\overline{p}$ and $e^+e^- \to \Lambda\overline{\Lambda}$ cross sections by means of the initial state radiation technique, which has the advantages of good efficiency and energy resolution, and full angular acceptance in the threshold region. A striking feature of these cross sections is their non-vanishing values at threshold. In the case of charged baryons, the phenomenon is well understood in terms of the Coulomb interaction between the outgoing baryon and antibaryon. However, such an effect is not expected for neutral baryons. We suggest a simple explanation for both charged and neutral baryon pairs based on Coulomb interactions at the valence quark level.

1 Introduction

Unexpected features [1] in recent measurements of the $e^+e^- \to p\overline{p}$ and $e^+e^- \to \Lambda\overline{\Lambda}$ cross sections in the near threshold region are pointed out in the following. *BABAR* has measured these processes [2, 3] (Fig. 1), with unprecedented accuracy, from their thresholds up to $W_{p\overline{p}(\Lambda\overline{\Lambda})} \approx 4(3)\,\mathrm{GeV}$ by means of the initial state radiation (ISR) technique ($W_{\mathcal{B}\overline{\mathcal{B}}}$ is the invariant mass of the baryon-antibaryon system and $\mathcal{B}$ stands for baryon). The main advantages in

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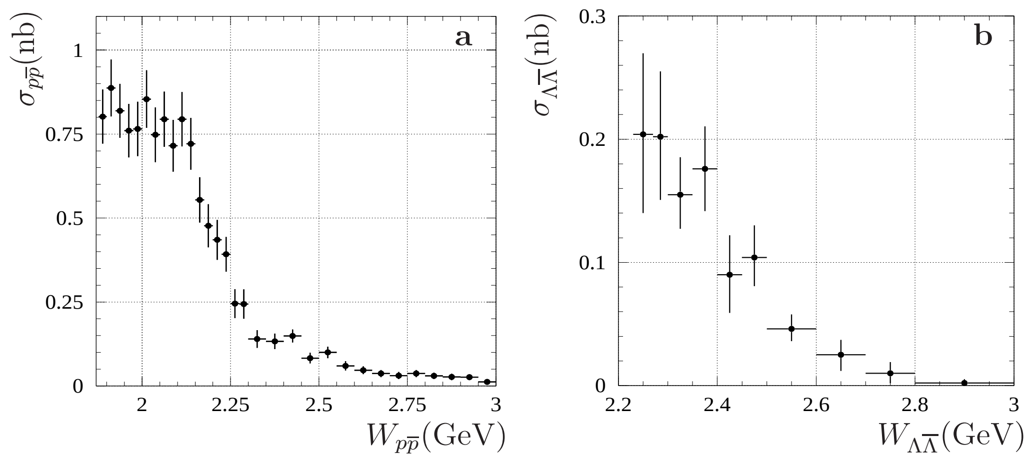

Figure 1: The $e^+e^- \to p\overline{p}$ (a) and $e^+e^- \to \Lambda\overline{\Lambda}$ (b) total cross sections [2, 3].

measuring a two body process via ISR are: a threshold efficiency quite high, a good invariant mass resolution (≈ 1 MeV), and a full angular acceptance when the radiated photon is detected.

In Born approximation the $e^+e^- \to \mathcal{B}\overline{\mathcal{B}}$ differential cross section is

$$\frac{d\sigma_{\mathcal{B}\overline{\mathcal{B}}}}{d\Omega}(W^2_{\mathcal{B}\overline{\mathcal{B}}}) = \frac{\alpha^2\beta C}{4W^2_{\mathcal{B}\overline{\mathcal{B}}}}\left[(1+\cos^2\theta)|G_M^{\mathcal{B}}|^2 + 4M^2_{\mathcal{B}}/W^2_{\mathcal{B}\overline{\mathcal{B}}}\sin^2\theta|G_E^{\mathcal{B}}|^2\right], \qquad (1)$$

where β is the baryon velocity, C is a Coulomb correction that will be discussed in the following, θ is the scattering angle in the center of mass frame, and $G_M^{\mathcal{B}}$ and $G_E^{\mathcal{B}}$ are the magnetic and electric Sachs form factors (FF).

In the case of the $e^+e^- \to p\overline{p}$ cross section $\sigma_{p\overline{p}}$ [2], Fig. 1a, we observe that: it is suddenly different from zero at threshold, being constant and ≈ 0.85 nb up to about 200 MeV above the threshold, then it drops. Similar features have been observed by *BABAR* in the $\Lambda\overline{\Lambda}$ channel [3] (Fig. 1b). In particular the cross section $\sigma_{\Lambda\overline{\Lambda}}$ is non-zero at threshold, being ≈ 0.2 nb.

In principle, due to the finite energy-bin width, experiments can not exclude vanishing cross sections at threshold with extremely sharp rises, in that case the relationship between data and predictions, reported in the following, could be accidental.

It is well known that Coulomb corrections to the Born cross section have to be accounted for in the case of production of pointlike charged fermions [4]. This correction, C in Eq. (1), is $C = 1$ (no effect) for neutral baryons, and $C(W_{\mathcal{B}\overline{\mathcal{B}}}) = (\pi\alpha/\beta)/(1-e^{-\pi\alpha/\beta})$ for charged baryons. Very near threshold the Coulomb factor behaves like $\pi\alpha/\beta$ and cancels out the phase-space β, making the cross section finite and non-zero even at $\beta = 0$. However, as it is shown in Fig. 2, as soon as the baryon velocity is no more vanishing, only few MeV above the threshold, it is $C \approx 1$ and Coulomb effects become negligible. In the case of $e^+e^- \to p\overline{p}$ the expected Coulomb-corrected cross

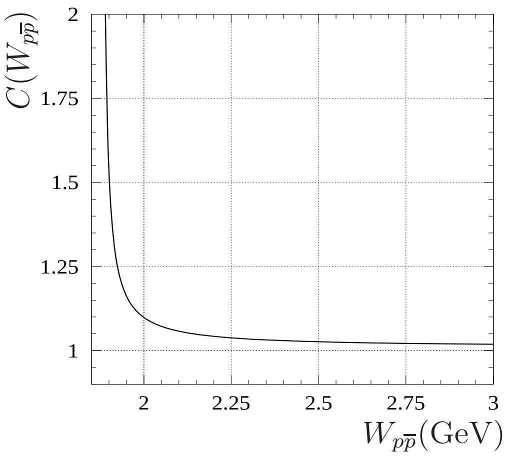

Figure 2: Coulomb enhancement factor for the $p\overline{p}$ channel.

section at threshold is

$$\sigma_{p\overline{p}}(4M_p^2) = (\pi^2\alpha^3/2M_p^2) \cdot |G^p(4M_p^2)|^2 = 0.85 \cdot |G^p(4M_p^2)|^2 \,\mathrm{nb},$$

where $G^p = G_E^p = G_M^p$ is expected at threshold from unitarity. This is in striking similarity with the measured values just above threshold if $\boldsymbol{|G^p(4M_p^2)| \approx 1}$. Hence the interpretation of the FF as the static overlap of baryon and antibaryon wavefunctions, plus a dominant contribution from the Coulomb effect explains the data.

In the case of the Λ, Coulomb effects should not be taken into account because of the neutral electric charge. It follows that, contrary to the data, Fig. 1b, the $e^+e^- \to \Lambda\overline{\Lambda}$ cross section is expected to vanish at threshold.

Some authors (e.g. Ref. [5]) emphasize that similar threshold effects, due to strong interaction, are forecast in the case of heavy quark pair production.

2 A simple interpretation at quark level

Assuming that the Coulomb dominance is not a mere coincidence, we investigate what is expected at the valence-quark level. Once quark pairs are produced they experience an attractive Coulomb interaction. For each pair there is a Coulomb amplitude with a phase to account for the displacement inside the baryon. The interference terms are suppressed by various factors (e.g.: displacement and velocity spread). In addition, the Coulomb correction for charges of the same sign vanishes at threshold (same formula for C but with negative α), then it should be a safe approximation to neglect interference terms. In the proton case we have

$$\sigma_{p\overline{p}}(4M_p^2) = (\pi^2\alpha^3/2M_p^2)(2Q_u^2 + Q_d^2) \cdot |G^p(4M_p^2)|^2 = 0.85 \cdot |G^p(4M_p^2)|^2 \, \mathrm{nb},$$

the pointlike result is recovered. In the case of the $e^+e^- \to \Lambda\overline{\Lambda}$ cross section, at quark level, with no interference at all (upper limit):

$$\sigma_{\Lambda\overline{\Lambda}}(4M_\Lambda^2) = (\pi^2\alpha^3/2M_\Lambda^2)(Q_u^2+Q_d^2+Q_s^2)\cdot|G^\Lambda(4M_\Lambda^2)|^2 = 0.4\cdot|G^\Lambda(4M_\Lambda^2)|^2 \, \mathrm{nb},$$

while at hadron level: $\sigma_{\Lambda\overline{\Lambda}}(4M_\Lambda^2) = 0$. Hence the expectation range for $\sigma_{\Lambda\overline{\Lambda}}$ at threshold, still assuming $\boldsymbol{|G^\Lambda(4M_\Lambda^2)| \approx 1}$, is $(0 \div 0.4)$ nb in **agreement with the experimental value** shown in Fig. 1b.

3 Conclusions

Data on cross sections for the processes $e^+e^- \to p\overline{p}$, $\Lambda\overline{\Lambda}$ have been discussed.

The most surprising feature is their non-zero cross section at threshold. Indeed, in Born approximation, Eq. (1), the cross section $\sigma_{\mathcal{B}\overline{\mathcal{B}}}$ is proportional to the velocity β of the baryon and, assuming analytic FF's, it must be zero at threshold. The pointlike Coulomb correction gives a factor $1/\beta$ that cancels out the phase space velocity only when charged baryons are involved. This correction is very large at threshold and just above, and can describe the data with the reasonable value $\boldsymbol{|G^p(4M_p^2)| \approx 1}$. For neutral baryons there is no pointlike Coulomb interaction, hence the cross section should vanish at threshold, in contrast with what we observe, within the errors, in the case of $\sigma_{\Lambda\overline{\Lambda}}$, Fig. 1b.

We can explain this threshold behavior by considering Coulomb interactions among the constituent quarks. In such a way, in both $p\overline{p}$ and $\Lambda\overline{\Lambda}$ channels, we obtain that the cross section data, at threshold, are fully described by the Coulomb correction and are compatible with $\boldsymbol{|G^{p,\Lambda}(4M_{p,\Lambda}^2)| \approx 1}$.

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