Pointlike Baryons?

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Abstract

A peculiar feature, observed in the \textit{BABAR} data on $e^+e^- \rightarrow B\overline{B}$ cross sections ($B$ stands for baryon), is the non-vanishing cross section at threshold for all these processes. This is the expectation due to the Coulomb enhancement factor acting on a charged fermion pair. Remarkably, in the case of $e^+e^- \rightarrow p\overline{p}$ it is found that Coulomb final state interactions largely dominate the cross section at threshold and it turns out a form factor $|G_p(4M_p^2)| \simeq 1$, as a pointlike fermion. Also in the case of $e^+e^- \rightarrow \Lambda_c\overline{\Lambda_c}$, as recently measured by Belle for the first time, a pointlike behavior is suggested for the charmed charged baryon, being the form factor at threshold $|G_{\Lambda_c}(4M_{\Lambda_c}^2)| \simeq 1$, even if within a large error. In the case of neutral strange baryons the non-vanishing cross section at threshold is interpreted as a remnant of quark pair Coulomb interaction before the hadronization, taking into account the asymmetry between attractive and repulsive Coulomb factors. Besides strange baryon cross sections are successfully compared to U-spin invariance relationships.

1. \(\sigma(e^+e^- \rightarrow B\overline{B})\) at threshold

Unexpected features, observed by \textit{BABAR} \cite{1,2} in the case of baryon pairs production and already pointed out \cite{3}, are revisited in the following as well as a further evidence in the charm sector, as recently found by Belle \cite{4}. They concern cross section measurements at the corresponding threshold energy regions of

\[ e^+e^- \rightarrow p\overline{p} \] (1)

and

\[ e^+e^- \rightarrow \Lambda\overline{\Lambda}, \beta, \Lambda\Sigma\beta. \] (2)

\textit{BABAR} has measured the cross section (1) with unprecedented accuracy and the cross sections (2) for the first time (fig. 1). Recent results achieved by Belle concerning

\[ e^+e^- \rightarrow \Lambda_c\overline{\Lambda_c} \] (3)

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are also consistent (fig. 2) with the aforementioned features of $p\bar{p}$.

Both, BABAR and Belle, have obtained their results by means of the initial state radiation technique (ISR), in particular detecting the photon radiated by the incoming beams. There are several advantages in measuring two body processes in this way: even exactly at threshold the efficiency is quite high, a very good invariant mass resolution is achieved ($\sim 1$ MeV comparable to symmetric storage rings) and a full angular acceptance is also obtained, due to the detection of the radiated photon.

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**Figure 1:** $e^+e^- \rightarrow p\bar{p}$ (a), $e^+e^- \rightarrow \Lambda\bar{\Lambda}$ (b), $e^+e^- \rightarrow \Sigma^0\Sigma^0$ (c), and $e^+e^- \rightarrow \Lambda\Sigma^0$ (d) total cross sections, as measured by BABAR [1, 2]. The gray vertical lines indicate the production thresholds.

In Born approximation the differential cross section for the process $e^+e^- \rightarrow B\bar{B}$ is

$$
\frac{d\sigma(e^+e^- \rightarrow B\bar{B})}{d\Omega} = \frac{\alpha^2 \beta C}{4W_{B\bar{B}}^2} \left[ (1+\cos^2\theta)|G_{M}(W_{B\bar{B}})|^2 + \frac{4M_{B}^2}{W_{B\bar{B}}^2} \sin^2\theta|G_{E}(W_{B\bar{B}})|^2 \right], \quad (4)
$$

where $W_{B\bar{B}}$ is the $B\bar{B}$ invariant mass, $\beta$ is the velocity of the outgoing baryon, $C$ is a Coulomb enhancement factor, that will be discussed in more detail in the following, $\theta$...
is the scattering angle in the center of mass frame and, $G^B_M$ and $G^B_E$ are the magnetic and electric Sachs form factors (FF). At threshold it is assumed that, according to the analyticity of the Dirac and Pauli FF’s as well as to the S-wave dominance, there is one FF only: $G^B_E(4M^2_B) = G^B_M(4M^2_B) \equiv G^B(4M^2_B)$.

The following peculiar features have been observed, in the case of $e^+e^- \rightarrow p\bar{p}$ [1]: the total cross section $\sigma(e^+e^- \rightarrow p\bar{p})$ is suddenly different from zero at threshold, as it is shown in fig. [1], being $0.85 \pm 0.05$ nb (by the way it is the only endothermic process that has shown this peculiarity).

Babar data on $\sigma(e^+e^- \rightarrow p\bar{p})$ show a flat behavior, within the experimental errors, in an interval of about 200 MeV above the threshold and then drop abruptly. The angular distributions show a dominance of the electric FF $G^p_E$ just above threshold and then a behavior driven by the contribution of magnetic FF $G^p_M$.

Long time ago a final state Coulomb correction to the Born cross section has been pointed out in the case of charged fermion pair production [5]. This Coulomb correction is usually introduced as an enhancement factor, $C$ in eq. (4). It corresponds to the squared value of the Coulomb scattering wave function at the origin, assumed as a good approximation in the case of a long range interaction added to a short range one, the so called Sommerfeld-Schwinger-Sakharov rescattering formula [5, 6]. This factor has a very weak dependence on the fermion pair total spin, hence it is assumed to be the same for $G_E$ and $G_M$ and
can be factorized. The Coulomb enhancement factor is

\[ C(W_{BB}) = \begin{cases} 
1 & \text{for neutral } B \\
\frac{\pi \alpha/\beta}{1 - e^{-\pi \alpha/\beta}} & \text{for charged } B
\end{cases}, \quad \beta = \sqrt{1 - \frac{4M_B^2}{W_{BB}^2}}. \tag{5} \]

In Ref. [7] a similar formula is obtained, but \(1/\beta \rightarrow 1/\beta - 1\), anyway not affecting the following considerations. Very near threshold the Coulomb factor is \(C(W_{BB}^2 \rightarrow 4M_B^2) \approx \pi \alpha/\beta \), so that the phase space factor \(\beta\) is cancelled and the cross section is expected to be finite and not vanishing even exactly at threshold. However, as soon as the fermion relative velocity is no more vanishing, actually few MeV above the threshold, it is \(C \approx 1\) and Coulomb effects can be neglected.

In the case of \(e^+e^- \rightarrow p\bar{p}\) the expected Coulomb-corrected cross section at threshold is

\[ \sigma(e^+e^- \rightarrow p\bar{p})(4M_p^2) = \frac{\pi^2}{2M_p^2} |G_p^p(4M_p^2)|^2 \simeq 0.85 \cdot |G_p^p(4M_p^2)|^2 \text{ nb}, \]

in striking similarity with the measured one. Therefore the Coulomb interaction dominates the energy region near threshold and it is found

\[ |G_p^p(4M_p^2)| = 0.97 \pm 0.04 \text{(stat)} \pm 0.03 \text{(syst)}. \]

That is, a \(p\bar{p}\) pair produced at threshold behaves like a pointlike fermion pair. In the following this feature is suggested to be a general one for baryons. It looks as if the FF at threshold, interpreted as \(B\) and \(\overline{B}\) wave function static overlap, coincides with the baryon wave function normalization, taking into account S-wave is peculiar of fermion pairs at threshold. In the case of meson pair production, the total angular momentum conservation requires a P-wave, that vanishes at the origin as well as the quoted Coulomb enhancement factor and the cross section has a \(\beta^3\) behavior near threshold. Tiny Coulomb effects in the case of meson pairs have been extensively pursued [8]. Angular momentum and parity conservation allow, in addition to the S-wave, also a D-wave contribution.

The angular distribution, averaged in a 100 MeV interval above the threshold, has a behavior like \(\sin^2 \theta\), i.e. dominated by the electric FF, and then a behavior like \((1 + \cos^2 \theta)\), i.e. driven by the magnetic FF contribution [see eq. (4) and fig. 3]. In particular the different behavior at threshold and the dominance of the electric FF are consistent with a sudden and large D-wave contribution. In Ref. [9] the relative phase and therefore the S- and D-wave complex FF’s, \(B_S^p\) and \(B_D^p\), have been extracted, by means of a dispersion relation, applied to the space-like ratio \(G_E^p/G_M^p\) and to the \(BABAR\) time-like \(|G_E^p/G_M^p|\) (fig. 3). The S-wave has a sharp drop above threshold, as shown in fig. 4, consistent with a Coulomb dominance. The D-wave vanishes at the origin, it is not affected by the Coulomb enhancement factor and the corresponding D-wave only cross section should behave as \(\beta^5\) at threshold. S-wave and D-wave have opposite trends, producing the observed plateau in the total cross section. Actually, since Coulomb corrections affect the S wave rather than the D wave, the cross section should be written in terms of \(\sqrt{C}B_S\) and \(B_D\). The outcome is under investigation [10].

The aforementioned arguments can be tested in the case of \(e^+e^- \rightarrow \Sigma^+\Sigma^+\) and it should be at threshold, in agreement with the U-spin expectation too: \(\sigma(e^+e^- \rightarrow \Sigma^+\Sigma^+) \simeq \)
\[ |B_p^S| W_p^2 (\text{GeV}) \]

\[ |B_p^D| W_p^2 (\text{GeV}) \]

Figure 4: S-wave (a) and D-wave (b) FF’s as obtained in an updated version of Ref. [9], from a dispersive analysis based on the BABAR data on the total \(e^+e^- \to p\bar{p}\) cross section and the time-like ratio \(|G_E/G_M|\). The point at threshold, included in the fit, is exactly zero for the D-wave (b), while it is \(\simeq 1\) for the S-wave (a).

\[ \sigma(e^+e^- \to p\bar{p}) \cdot (M_p/M_{S\Sigma^+})^2 \simeq 0.53 \text{ nb}. \] This measurement has not yet been done, but it is within the BABAR and Belle capabilities by means of ISR.

Recently Belle has measured for the first time the \(e^+e^- \to \Lambda_c \bar{\Lambda}_c\) cross section [4]. A resonant behavior, just above threshold, has been pointed out. The anomalously high cross section close to the \(p\bar{p}\) one, prefigures a similar FF. Still the cross section is not zero at threshold. In fig. 2 the \(G^{\Lambda_c}\) effective FF is reported, obtained under the hypothesis that \(|G_{E}^{\Lambda_c}| = |G_{M}^{\Lambda_c}|\), as it is expected at threshold. That is the best one can do lacking angular distributions. The FF at threshold is achieved by taking the mean value of the first and the second point of the \(\Lambda_c \bar{\Lambda}_c\) cross section given in Ref. [4]. This procedure or similar recipes to cure the threshold behavior must be used because, due to the finite energy-resolution, the events at threshold are spread in an energy bin that extends itself below \(W_{\Lambda_c \bar{\Lambda}_c} = 2M_{\Lambda_c}\). A systematic uncertainty of 30% is estimated for this procedure, to be added in quadrature to the other systematic errors. Taking into account the Coulomb correction, the statistical errors and the overall systematic quoted errors added in quadrature, mostly due to the uncertainties in the \(\Lambda_c\) branching ratios, it is found:

\[ |G^{\Lambda_c}(4M_{\Lambda_c}^2)| = 1.1 \pm 0.3(\text{stat}) \pm 0.4(\text{syst}). \]

That is close, in a tantalizing way, to the aforementioned suggested feature: baryon pairs, produced at threshold, behave as pointlike fermions. The hypothesis it is a general feature for baryons is strengthened by the gap between \(4M_{\Lambda_c}^2\) and \(4M_{p}^2\). Extrapolating to \(e^+e^- \to \Lambda_c \bar{\Lambda}_c\) it should be at threshold \(\sigma(e^+e^- \to \Lambda_c \bar{\Lambda}_c) \simeq 23 \text{ pb},\) which means one of the most important hadronic channels at those energies.
2. The puzzle of neutral baryon form factors

The peculiar features of $e^+e^- \rightarrow p\bar{p}$ have been observed by BABAR [2] also in the case of $e^+e^- \rightarrow \Lambda\bar{\Lambda}$, $\bar{\Lambda}\Sigma^0$ (fig. 1b, c, d), even if within bigger experimental errors. In particular the cross section $\sigma(e^+e^- \rightarrow \Lambda\bar{\Lambda})$ is different from zero at threshold, being $0.20 \pm 0.05$ nb. The cross sections $\sigma(e^+e^- \rightarrow \Sigma^0\Sigma^0)$ and $\sigma(e^+e^- \rightarrow \Lambda\Sigma^0)$ have been measured by BABAR for the first time. At threshold, assuming a smooth extrapolation from the first data point, it is $\sigma(e^+e^- \rightarrow \Sigma^0\Sigma^0) = 0.03 \pm 0.01$ nb and $\sigma(e^+e^- \rightarrow \Lambda\Sigma^0) = 0.047 \pm 0.023$ nb. In all these cases final state Coulomb effects should not be taken into account and a finite cross section at threshold is not expected. Nevertheless, in the case of the neutral $\Lambda$ baryon, not only the cross section data, but also the ratio $|G^{\Lambda}_{E}/G^{\Lambda}_{M}|$ have a trend similar to $|G^{p}_{E}/G^{p}_{M}|$.

One might investigate what is expected in the debatable hypothesis a two steps process occurs: at first unbound quark pairs are produced coherently and then the hadronization takes place. Hence the finite cross section at threshold should be a remnant of the initial step. Valence quarks only are considered in the following. For each quark pair there is a Coulomb attractive amplitude times the quark electric charge and each amplitude has a phase taking into account the displacement of the quark pair inside the baryon. In addition to the quark pair Coulomb interaction there are contributions from quarks belonging to different pairs. However there are several suppression factors for them: relative phase, velocity spread and moreover most of them, coming from quarks having charges of the same sign, are repulsive ones. There is no symmetry between repulsive and attractive Coulomb interactions and this asymmetry might explain why there is a non-vanishing cross section at threshold even for neutral baryon pairs. In fact in the case of repulsive Coulomb interaction the Sommerfeld formula is (charges $Q_q$ and $Q_{\Sigma}$ have the same sign):

$$C(W_{\Sigma\Xi}) = \frac{-\pi\alpha|Q_qQ_{\Sigma}|/\beta}{1 - \exp(+\pi\alpha|Q_qQ_{\Sigma}|/\beta)} W_{\Sigma\Xi} \rightarrow 0,$$

i.e. $C = 0$ at threshold. Considering only Coulomb enhancement factors due to quark pairs, the same cross section is expected in the $p\bar{p}$ case:

$$\sigma(e^+e^- \rightarrow p\bar{p})(4M_p^2) = \frac{\pi^2\alpha^3}{2M_p^2}(2Q_u^2 + Q_d^2) \simeq 0.85 \text{ nb},$$

while, for instance in the $\Lambda$ case, it is:

$$\sigma(e^+e^- \rightarrow \Lambda\bar{\Lambda})(4M_\Lambda^2) = \frac{\pi^2\alpha^3}{2M_\Lambda^2}(Q_u^2 + Q_d^2 + Q_s^2) \simeq 0.4 \text{ nb}.$$

Hence in the case of $e^+e^- \rightarrow \Lambda\bar{\Lambda}$ the expectation range is $(0 - 0.4)$ nb to be compared to the experimental value at threshold $\sigma(e^+e^- \rightarrow \Lambda\bar{\Lambda}) = 0.20 \pm 0.05$ nb.

According to the U-spin invariance [12], assuming a negligible electromagnetic transition between U-spin triplet and singlet, strange baryon magnetic FF’s are related, being:

$$G_{\Sigma^0} - G_{\Lambda} + \frac{2}{\sqrt{3}}G_{\Lambda\Sigma^0} = 0. \quad (6)$$
In terms of adimensional quantities there is a good agreement with the $BABar$ results, assuming real same-sign FF’s at threshold:

$$M_{\Sigma^0} \sqrt{\sigma_\beta} - M_\Lambda \sqrt{\sigma_\Lambda} + \frac{2}{\sqrt{3}} M_{\Lambda \Sigma^0} \sqrt{\sigma_\Lambda \Sigma^0} = (-0.1 \pm 2.0) \times 10^{-4}.$$ 

The $\beta$ cross section at threshold, due to the aforementioned relationship with $e^+e^- \to \Lambda \overline{\Lambda}$ and $e^+e^- \to \Lambda \Sigma^0$, is predicted to be: $\sigma_\beta = 0.03 \pm 0.03$ nb.

Vector mesons poles in the unphysical region below threshold ($Q^2 < 4M_B^2$) largely account for the cross sections above threshold. An extrapolation of the strange baryon magnetic moments (i.e. $Q^2 = 0$) is not expected a priori. However, if there is no sign change in the space-like region, analyticity requires time-like asymptotic FF’s should have at least the same sign. Therefore the $e^+e^- \to \Lambda \overline{\Lambda}$ and the $e^+e^- \to \Lambda \Sigma^0$ amplitudes are supposed to be both negative in agreement with the magnetic moments. The $e^+e^- \to \Sigma^0 \overline{\Sigma^0}$ turns out to be also negative, in fair disagreement with this statement.

![Figure 5: The $e^+e^- \to n\overline{\pi}$ total cross section as measured by the FENICE Collaboration [13].](image)

An important process to understand the neutral baryon puzzle is $e^+e^- \to n\overline{\pi}$. The cross section $\sigma(e^+e^- \to n\overline{\pi})$ has been measured only once, long time ago by FENICE at the $e^+e^-$ storage ring ADONE [13] and it was found $\sigma(e^+e^- \to n\overline{\pi}) \approx 1$ nb, as shown in fig. 5. According to the above mentioned assumption on U-spin invariance it should be $G_n = \frac{3}{2}G_\Lambda - \frac{1}{2}G_{\Sigma^0}$, hence

$$\sigma(e^+e^- \to n\overline{\pi}) = \frac{1}{4} \left(3\sqrt{\sigma_\Lambda}M_\Lambda - \sqrt{\sigma_\beta}M_{\Sigma^0}\right)^2 \frac{1}{M_n^2} = 0.5 \pm 0.2$ \text{nb.} \quad (7)$$

Unfortunately it is very unlike that $BABar$ or Belle will ever be able to measure this process by means of the ISR, but results on this process are expected by BESIII [14] and...
VEPP2000 [13].

It has to be reminded that various theoretical models and phenomenological descriptions have made predictions on baryon time-like FF’s [16].

3. Conclusions

All the $e^+e^- \to B\bar{B}$ cross sections, as measured by BABAR, do not vanish at threshold. In the case of $e^+e^- \to pp$ this behavior is explained by the $pp$ Coulomb enhancement factor and it comes out that $|G_p(4M_{pp}^2)| \approx 1$, that is proton pairs behave as pointlike fermions. This cross section is remarkably flat near threshold: it turns out that S- and D-wave have opposite trends, producing this peculiar behavior and the S-wave contribution has a steep drop above threshold, consistent with Coulomb dominance. A pointlike behavior is suggested also in the case of the $\Lambda_c$ FF at threshold, as recently achieved by Belle. Neutral strange baryons show a non-vanishing cross section at threshold too, which might be interpreted as a remnant of quark pair Coulomb interaction before hadronization. A consistent framework of strange baryon FF’s is obtained requiring the suppression of electromagnetic transitions between U-spin singlet and triplet. Neutron and $\Sigma^+$ FF’s are demanded to check this picture of baryon FF’s.

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References

[1] B. Aubert et al. [BABAR Collaboration], Phys. Rev. D 73, 012005 (2006) [arXiv:hep-ex/0512023].
[2] B. Aubert et al. [BABAR Collaboration], Phys. Rev. D 76, 092006 (2007) [arXiv:0709.1988 [hep-ex]].
[3] R. Baldini, S. Pacetti, A. Zallo and A. Zichichi, [arXiv:0711.1725] [hep-ph].
[4] G. Pakhlova et al. [Belle Collaboration], Phys. Rev. Lett. 101, 172001 (2008) [arXiv:0807.4458 [hep-ex]].
[5] A. D. Sakharov, Zh. Eksp. Teor. Fiz. 18, 631 (1948) [Sov. Phys. Usp. 34, 375 (1991)].
[6] A. Sommerfeld, *Atombau und Spektrallinien* (Vieweg, Braunschweig, 1944), Vol. 2, p.130.
[7] J. Schwinger, *Particles, Sources, and Fields*, Vol. III, p. 80.
[8] G. Castellani, S. Reucroft, Y. N. Srivastava, J. Swain and A. Widom, [arXiv:hep-ph/0509089] and references therein.
[9] M. B. Voloshin, Mod. Phys. Lett. A 18, 1783 (2003); S. Dubynskiy, A. Le Yaouanc, L. Oliver, J. C. Raynal and M. B. Voloshin, Phys. Rev. D 75, 113001 (2007) [arXiv:0704.0293 [hep-ph]]; G. P. Lepage, Phys. Rev. D 42, 3251 (1990); D. Atwood and W. J. Marciano, Phys. Rev. D 41, 1736 (1990).
[10] R. Baldini, S. Pacetti, A. Zallo, in preparation.
[11] D. Park, *Introduction to strong interactions* (W. A. Benjamin, Inc., New York, 1966).
[13] A. Antonelli et al., Nucl. Phys. B 517, 3 (1998).
[14] D. M. Asner et al., arXiv:0809.1869.
[15] A. A. Botov, A. D. Bukin, V. B. Golubev, V. P. Druzhinin, S. I. Serednyakov and K. Y. Skovpen, Nucl. Phys. Proc. Suppl. 162, 41 (2006).
[16] M. A. Belushkin, H. W. Hammer and U. G. Meissner, Phys. Rev. C 75, 035202 (2007) arXiv:hep-ph/0608337; C. Q. Geng and Y. K. Hsiao, Phys. Rev. D 75, 094005 (2007) arXiv:hep-ph/0606006; J. Haidenbauer, H. W. Hammer, U. G. Meissner and A. Sibirtsev, Phys. Lett. B 643, 29 (2006) [arXiv:hep-ph/0606064]; H. W. Hammer, Eur. Phys. J. A 28, 49 (2006) [arXiv:hep-ph/0602121]; R. Bijker and F. Iachello, Phys. Rev. C 69, 068201 (2004) arXiv:nucl-th/0405028; F. Iachello and Q. Wan, Phys. Rev. C 69, 055204 (2004); J. P. B. de Melo, T. Frederico, E. Pace and G. Salme, In the Proceedings of Workshop on $e^+e^-$ in the 1-GeV to 2-GeV Range: Physics and Accelerator Prospects - ICFA Miniworkshop - Working Group on High Luminosity $e^+e^-$ Colliders, Alghero, Sardinia, Italy, 10-13 Sep 2003, pp FRWP006 [arXiv:hep-ph/0312255]; F. Iachello, In the Proceedings of Workshop on $e^+e^-$ in the 1-GeV to 2-GeV Range: Physics and Accelerator Prospects - ICFA Miniworkshop - Working Group on High Luminosity $e^+e^-$ Colliders, Alghero, Sardinia, Italy, 10-13 Sep 2003, pp FRWP008 [arXiv:hep-ph/0312255].
[17] A. Datta and P. J. O’Donnell, Phys. Lett. B 567, 273 (2003) [arXiv:hep-ph/0306097]; M. Karliner and S. Nussinov, Phys. Lett. B 538, 321 (2002) [arXiv:hep-ph/0202234]; M. Karliner, Nucl. Phys. Proc. Suppl. 108, 84 (2002) [arXiv:hep-ph/0112047]; M. Karliner, in Proc. of the $e^+e^-$ Physics at Intermediate Energies Conference ed. Diego Bettoni, In the Proceedings of $e^+e^-$ Physics at Intermediate Energies, SLAC, Stanford, California, 30 Apr - 2 May 2001, pp W10 [arXiv:hep-ph/0108106]; J. R. Ellis and M. Karliner, New J. Phys. 4, 18 (2002) [arXiv:hep-ph/0108259]; S. Dubnicka, A. Z. Dubnickova and P. Weisenpacher, arXiv:hep-ph/0001240; R. Baldini, S. Dubnicka, P. Gauzzi, S. Pacetti, E. Pasqualucci and Y. Srivastava, Eur. Phys. J. C 11, 709 (1999); V. F. Dmitriev and A. I. Milstein, Nucl. Phys. Proc. Suppl. 162, 53 (2006) arXiv:nucl-th/0607003].