Baryon production in B decays and e^+e^- collisions

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We present a summary of the recent progresses in the study of baryonic decays of B and B_s mesons, obtained at the B-factories. In particular the first evidence of charmless, baryonic B_s decays is reported by the Belle collaboration, while a detailed study of the resonant substructures in $B^0 \to \Lambda_c^+ \bar{p}\pi^+\pi^-$ is performed by the BaBar collaboration. The Belle collaboration studied also, for the first time, the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\chi_b(1P)$ exclusive annihilation modes with hyperon -anti-hyperon pairs in the final state. Finally, from the study of the inclusive $\Lambda\Lambda$ and $\Lambda p\pi^-$ mass spectrum, a first study on the H-dibaryon production from $\Upsilon(1S)$ and $\Upsilon(2S)$ is performed too.

1 Baryons from B decays

A number of exclusive decays of B mesons involving a baryon anti-baryon ($\mathcal{B}\bar{\mathcal{B}}$) pair have been reported since the early days of B-physics [1]. This is not surprising if we consider that this family represents approximatively 7% of the B decays. Among the features of such decays, one of the most studied and discussed is the invariant mass spectrum of the $\mathcal{B}\bar{\mathcal{B}}$ pair, that often (but not always) presents a large enhancement in the area close to the kinematic threshold. One possible model [2] suggests that, since the local conservation of the baryonic number requires baryon and anti-baryon to be produced simultaneously, a gluon with large virtual mass is required for a large $M(\mathcal{B}\bar{\mathcal{B}})$ value. Since it's unlikely to emit a gluon highly off mass shell, a production of $\mathcal{B}\bar{\mathcal{B}}$ near threshold is expected. The same argument can be used to explain the suppression of the two body final states, which are forced to have the highest $M(\mathcal{B}\bar{\mathcal{B}})$ possible, with respect to the multi body ones, and in general the strong dependence of the branching ratio from the number of bodies produced together with the $\mathcal{B}\bar{\mathcal{B}}$ pair. Even if this approach correctly describes the primary features of this kind of decay, it leaves som open questions: it does not describe properly the angular distribution observed in $B^+ \to p\bar{p}K^+$ and it does not predict the absence of near threshold enhancement in the process $B^0 \to \Lambda_c^+\bar{p}\pi^+\pi^-$.
In order to describe this behavior, a more sophisticate model has been recently developed [3]. This model relies on the basic assumption that the Feynman propagators in the diagrams that contribute to the baryon decays can be collapsed in a point-like interaction, and then this collapsed diagrams can be rearranged in different categories. The category responsible for the low mass enhancement is characterized by a two-meson like rearrangement of the quarks: the decays of this intermediate, virtual mesonic state $M \to \mathcal{B}\bar{\mathcal{B}}$ is interpreted as the source of the low mass enhancement, and thus its absence can be explained with the absence of a di-mesonic contribution to the total decay amplitude.
A totally different approach is also possible, assuming the presence of a resonant, bound or quasi-bound state of the two baryons. This exotic interpretation allows to describe, in the same

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framework, the observed enhancement in B meson decays and in $J/\psi \to \gamma p\bar{p}$ (the so called $X(1835)$) [4]. However, despite the observed enhancement in the low mass region, it is not clear if the presence of new resonances alone could explain completely the observed phenomena in quarkonium ad B meson decays. On the other hand the model based on the Feynman diagram rearrangement cannot be directly applied in the description of the strong J/ψ decays, thus requiring a different explanation for what is observed in the B mesons and in the charmonium sector.

1.1 Charmless decays

From the experimental point of view, the Belle collaboration recently studied the decay channels $B^- \to p\bar{p}l^-\bar{\nu}$, with $l^- = e^-, \mu^-$ and $B^0 \to \bar{\Lambda}p\pi^-\gamma$. The first one allow to test two different prediction: one, obtained with the standard model calculation [5], predicts a branching fraction of $10^{-5} - 10^{-6}$ while the second one, that includes the effects due to the baryonic form factors, predicts a much larger value of $(1.04 \pm 0.38) \times 10^{-4}$ [6]. The second channel can be used as benchmark for the test of the multiplicity hierarchy, since its dynamic is very close to the one to known decay $B^0 \to \bar{\Lambda}p\gamma$. The presence of a neutrino in $B^- \to p\bar{p}l^-\bar{\nu}$ imposes the complete reconstruction of the $\Upsilon(4S) \to B^-(\to p\bar{p}l^-\bar{\nu})B^+(\to X)$ event where the B^+ is reconstructed in its most common charmed decays. Once the B^+ is reconstructed, together with the p, $\bar{p}$ and lepton from the signal B, the recoil mass is expected to peak exactly at $M_{rec} = 0$ if only a neutrino is missing. Instead of the large signal predicted by the form factor-based calculation, a weak signal with a significance of 3.05σ is observed in the e mode (Fig. 1) and the corresponding, preliminary branching ratio value is $BF[B^- \to p\bar{p}e^-\bar{\nu}] = (8.22^{+3.74}_{-3.20}\ (\text{stat.})\ \pm 0.55\ (\text{syst.})) \times 10^{-6}$, in agreement with the prediction from [5].

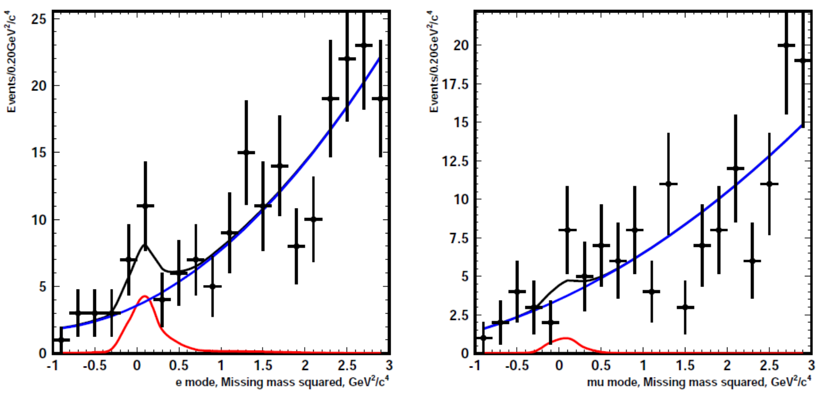

Figure 1: Missing mass in $B^- \to p\bar{p}l^-\bar{\nu}$ candidate events, for $l = e^-$ (left) and $l = \mu^-$ (right).

The analysis of $B^0 \to \bar{\Lambda}p\pi^-\gamma$ proceeds in a completely different way. Since in this case there is no expected missing energy, an inclusive reconstruction is possible. The price to be paid for an increased efficiency is a large background contribution due to the non resonant, hadronic process $e^+e^- \to q\bar{q}$. The background is rejected using a multivariate discriminant that combines different informations on the topological shape of the event, which is expected to be spheric in the case of Υ decays and jet-like in the case of non resonant $q\bar{q}$ production. The simultaneous fit of ΔM and M_{bc} do not result in a significant signal yield (Fig. 2), thus an upper limit at 90% confidence level is calculated obtaining $BF[B^0 \to \bar{\Lambda}p\pi^-\gamma] < 6.68 \times 10^{-7}$, about one order of magnitude below the measured branching fraction for $B^0 \to \bar{\Lambda}p\gamma$. This result is unexpected in a framework in which the short term interaction is the dominant effect, that predicts $BF[B^0 \to \bar{\Lambda}p\pi^-\gamma] >> BF[B^0 \to \bar{\Lambda}p\gamma]$.

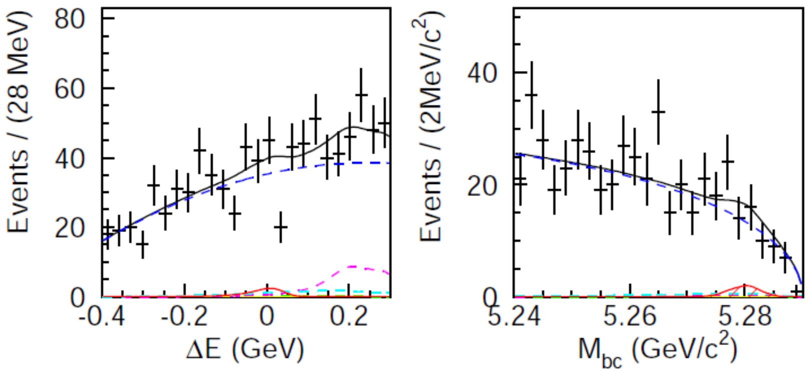

Figure 2: Distributions of ΔE (left) and M_{bc} in $B^0 \to \bar{\Lambda} p \pi^- \gamma$ candidate events.

1.2 Charmed decays

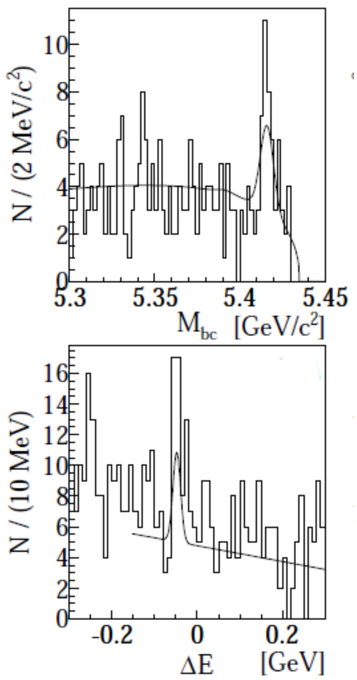

Figure 3: Distributions of ΔE (top) and M_{bc} (bottom) in $B^0 \to \Lambda_c^+ \bar{\Lambda} \pi^-$ candidate events. Λ_c is reconstructed in the $K^- p \pi^+$ mode.

Concerning the charmed baryonic decays, two results were recently released: the evidence of baryonic decay $B_s \to \Lambda_c^+ \pi^- \bar{\Lambda}$ by Belle and a detailed study of the phase space structures in $B^0 \to \Lambda_c^+ \bar{p} \pi^+ \pi^-$ by BaBar [7]. The latter one, in particular, is the physics case that triggered the development of the quark rearrangement model. The first one represents the first evidence of a baryonic decay of the B_s, with a significance of 4.4σ (Fig. 3) and a measured branching fraction $\mathcal{B}[B_s \to \Lambda_c^+ \pi^- \bar{\Lambda}]$ =$(3.6 \pm 1.1$ (stat.) $^{+0.3}_{-0.5}$ (syst.) ± 0.9 (Λ_c^+ decay) ± 0.7 (number of B_s)) $\times 10^{-4}$. The low statistic, unfortunately, does not allow to make any strong statement about the structures in the phase space and the invariant mass distribution of $\Lambda_c^+ \bar{\Lambda}$ pair. The study of the substructures is, on the other side, the main aim of a large study conducted by BaBar on $B^0 \to \Lambda_c^+ \bar{p} \pi^+ \pi^-$. The total branching fraction for this process is know to be large, but an analysis of the possible contribution from intermediate, 3-body states was never done before. The adopted approach relies on the analysis of the invariant mass distributions of different $\Lambda_c^+ \pi$, $p\pi$ and $\Sigma_c \pi$ pairs, where the Σ_c is reconstructed in its decay $\Sigma_c \to \Lambda_c^+ \pi$. From the invariant mass spectrum of $\Lambda_c^+ \pi^+$ (Fig. 4) and $\Lambda_c^+ \pi^-$ (Fig. 5) in reconstructed $B^0 \to \Lambda_c^+ \bar{p} \pi^+ \pi^-$ events, strong contributions from intermediate, three body decays clearly appear, with four peaks due to, respectively, $\Sigma_c(2455)^{++}$, $\Sigma_c(2455)^0$, $\Sigma_c(2520)^{++}$, and $\Sigma_c(2520)^0$. The total non Σ_c-resonant component is measured to be $(79 \pm 4(\text{stat.}) \pm 20(\text{syst.})) \times 10^{-5}$, to be compare with a total branching ratio $\mathcal{B}[B^0 \to \Lambda_c^+ p \pi^+ \pi^-] = (123 \pm 5 \pm 7 \pm 32) \times 10^{-5}$. The analysis of the baryon anti-baryon invariant mass spectrum shows, respectively, a small enhancement in $M(\bar{p}\Sigma_c(2455)^{++})$, no deviation from the expected phase-space flat trend in $M(\bar{p}\Sigma_c(2520)^{++})$ and an anti-enhancement in $M(\bar{p}\Sigma_c(2455)^0)$, while the available statistic does not allow to draw conclusions on $M(\bar{p}\Sigma_c(2520)^0)$. The contradictory behavior observed in these channels can be explained in the framework of the quark rearrangement model.

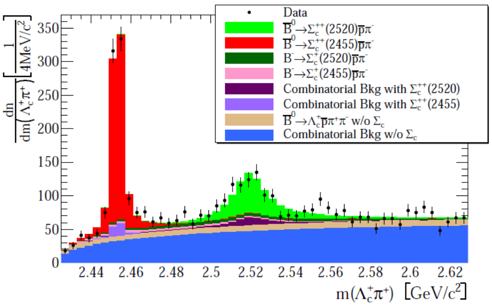

Figure 4: Invariant mass of $\Lambda_c^+\pi^+$ in reconstructed $B^0 \to \Lambda_c^+\bar{p}\pi^+\pi^-$ candidate events. The different contributions due to intermediate 3-body decays are shown with different colors.

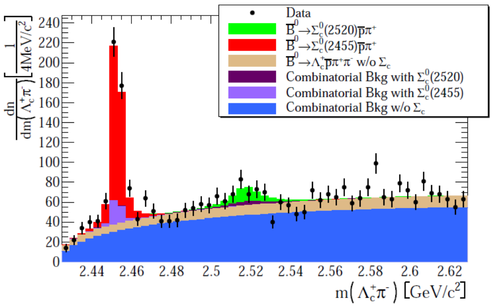

Figure 5: Invariant mass of $\Lambda_c^+\pi^-$ in reconstructed $B^0 \to \Lambda_c^+\bar{p}\pi^+\pi^-$ candidate events. The different contributions due to intermediate 3-body decays are shown with different colors.

2 Baryons and baryonic states from bottomonium decays

One of the missing pieces of the puzzle could be the study of the baryon production in bottomonium annihilation. The main annihilation channel for $\Upsilon(nS)$ resonances is the one in three gluons, hence the partonic environment that evolves in the final states products is completely different from the one that describes a B mesons. Also the J/ψ decays into ggg too, but the limited phase space does not allow the decay into baryonic, many body final states, thus limiting the number of possible studies that can be carried on. Recently Dobbs et al. [8], in private study conducted using the CLEO datasets, reported the first observation of $\Upsilon(nS)$ exclusive decays with a $p\bar{p}$ pair in the final states. Even if no study of the phase space is conducted, the basic phenomenology of these decays resemble the one observed in the B meson decays: the two body final states are suppressed and the branching ration increase proportionally to the number of bodies in the final state, showing the same hierarchy dependence observed in the B meson system. No results has been presented so far concerning the exclusive annihilations of quarkonium with hyperons in the final state. Two systematic studies were conducted on the inclusive production of baryons from bottomonium decays, first by the Argus Collaboration [9] and then, more recently, by CLEO [10]. One of the features that emerge from these studies is a strong enhancement of the hyperons production from the bottomonium, with respect to the rate observe in continuum $e^+e^- \to q\bar{q}$; the nature of this enhancement, not described by the available generators, is still not understood. Two studies done at Belle aim to gain insight on the low energy QCD effects that can emerge for the three gluon state produced in bottomonium decays, focusing in particular on the inclusive and exclusive production of hyperons.

Table 1: Upper limits on branching ratios $\times 10^6$

Channel	$\mathcal{H}=\Lambda$	$\mathcal{H}=\Xi$	$\mathcal{H}=\Omega$
$\Upsilon(2S) \to \mathcal{H}\bar{\mathcal{H}}$	0.16	0.70	1.8
$\Upsilon(2S) \to \mathcal{H}\bar{\mathcal{H}}\pi^0$	0.78	2.3	6.1
$\Upsilon(2S) \to \mathcal{H}\bar{\mathcal{H}}\eta$	0.88	2.7	7.3
$\Upsilon(2S) \to \mathcal{H}\bar{\mathcal{H}}\pi^+\pi^-$	0.09	0.60	2.0
$\Upsilon(1S) \to \mathcal{H}\bar{\mathcal{H}}$	0.51	1.6	5.8
$\Upsilon(1S) \to \mathcal{H}\bar{\mathcal{H}}\pi^0$	2.3	6.9	22
$\Upsilon(1S) \to \mathcal{H}\bar{\mathcal{H}}\eta$	4.2	19	21
$\Upsilon(1S) \to \mathcal{H}\bar{\mathcal{H}}\pi^+\pi^-$	1.4	4.3	8.3
$\chi_{bJ}(1P) \to \mathcal{H}\bar{\mathcal{H}}$	0.87	3.6	11
$\chi_{bJ}(1P) \to \mathcal{H}\bar{\mathcal{H}}\pi^+\pi^-$	0.49	2.3	11

The first one consists in a large campaign for the measurement of exclusive decays with hyperon - antihyperon pairs involved. A total of 48 channels, consisting in $\mathcal{H}\bar{\mathcal{H}}$ plus K^+K^-, $\pi^+\pi^-$, $p\bar{p}$ pairs and π^0's are studied using the $\Upsilon(1S)$ and $\Upsilon(2S)$ samples. At the moment of this conference, only the results on the two and three body decays were available, and no signal is observed in the searched final states (Tab. 1). This results is somehow expected looking back at the know two-body suppression observed on the B decays. More detailed results are expected soon. The large amount of Hyperons and the high branching ratio for the production of deuteron [11], a bound baryon-baryon state, motivates the search for exotic hyperon-hyperon bound states in the bottomonium decays. Among these states, one of the most famous is the H dibaryon postulated by Jaffe using the MIT bag model [12]: a completely antisymmetric arrangement of 6 quark (*uuddss*, namely the same quark content of $\Lambda\Lambda$ pair) with mass close to $2M_\Lambda$. The lifetime of such object is predicted to be strongly depended on the invariant mass, ranging from 10^{-26} s if the mass largely exceed the $2M_\Lambda$ threshold, to few hours if the mass is below the $M_\Lambda + M_p + M_\pi$ threshold [13 14]. The current prediction from lattice QCD indicates a mass slightly below $2M_\Lambda$ [15 16 17]. The actual experimental measurement of the H mass are indirect, and rely on the $\Lambda\Lambda$ binding energy estimated from the decay products of doubly-Λ hypernuclei: the most stringent limit comes from the so called Nagara event, that infers $M_H > 2223.7$ MeV, 7.66 MeV below the $2M_\Lambda$ threshold [18]. Using the samples of $\Upsilon(1S)$ and $\Upsilon(2S)$, a study of the $\Lambda\Lambda$ and $\Lambda p\pi$ invariant mass is performed by Belle, in the region from the $\Lambda p\pi$ up to 50 MeV above the $\Lambda\Lambda$ threshold [19]. No significant deviation from the background-only hypothesys is found, and a mass dependent upper limit is thus determined (Fig. 6). Even if this upper limit is 20 times smaller than the value measured to the deuteron production, this is not th e final word on the existence of the H dibaryon. We know that the dominant, if not unique, production mechanism for the deuteron in quarkonium decays is the proton-nucleon recombination. If, on this basis, we postulate that the production of bound states in ggg decays is dominated by this mechanism, an unstable H dibaryon with mass above $2M_\Lambda$ can exists and a possible explanation of its absence form the bottomonium decay productions would be that its creation mechanism is not dominated by $\Lambda\Lambda$ recombination. The H dybarion could be stable or meta-stable ($c\tau > 1$ m), thus it does not decay within the acceptance of the Belle detector and escapes undetected: the main argument against this hypothesys comes form the indirect measurements of the $\Lambda\Lambda$ binding energy, but as reported by T.F. Carames and A. Valcarce [20], these measurement have given, in the past 50 years, contradictory results.

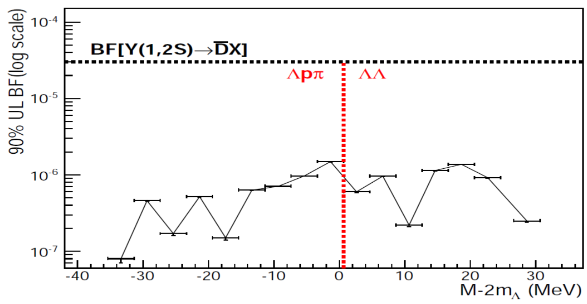

Figure 6: Upper limit for the inclusive production of H dybarion in $\Upsilon(1S)$ and $\Upsilon(2S)$ annihilations, as function of its mass. The region below $2M_\Lambda$ is studied searching for H$\rightarrow \Lambda p\pi^-$, while for the region above $2M_\Lambda$ the reaction H$\rightarrow \Lambda\Lambda$ is used.

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