A SIMPLE EXPLANATION FOR THE ENHANCED BARYON RATE IN DIRECT Υ DECAYS

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The enhanced baryon rate observed in direct Υ decays in comparison with the e^+e^- continuum is explained in the framework of standard hadronization models. The major part of the present disagreement between the Lund model and experimental data is removed when recent measurements of inclusive charmed baryon branching ratios are taken into account. A different treatment of quark and gluon jets is not needed to explain the measurements.

The formation of hadrons during the final stage of fragmentation processes still has not found a theoretical description based on first principles. Instead several QCD-inspired phenomenological models have been used to approach this subject, especially for e^+e^- annihilation processes. However, attempts to interpret experimental data by comparing with model predictions have often to yield unique and satisfactory answers about the underlying physical quantities and mechanisms, because of the many free parameters available within these models.

In addition two major theoretical problems have challenged model developers, posed by the discovery of gluon jets [1] and the observation of baryons in the hadronic final state [2]. For the former, the question arose whether gluons, due to their colour octet charges, fragment differently from quarks. Some models suggested, beside topological differences between quark and gluon jets, deviations in the composition of the hadronic final states, i.e. a large fraction of isoscalar particles [3] or baryons [4] in gluon jets. Moreover, the observation of baryons in e^+e^- reactions required that in most models special concepts for baryon production has to be introduced by hand [5–8].

In 1981 both of these puzzles were brought together when the DASP II Collaboration observed a much larger proton rate on the Υ, which decays dominantly via three gluons, compared with continuum events at about the same energy [9]. This result was later confirmed and improved by CLEO [10] and ARGUS [11,12].

Today the production rate for many particle species in the continuum around 10 GeV and in direct Υ decays are known with high precision, especially from recent ARGUS measurements [11–15]. For a comparison of Υ and continuum data it is advantageous to define the ratio of production rates

$$r=\frac{\text{hadron rate per event in direct } \Upsilon \text{ decays}}{\text{hadron rate per event in the continuum}}$$

in which several common dependencies cancel out.

In fig. 1 the values of r for different hadrons are shown. Two characteristic features can be derived directly from this plot:

(1) The production rates for all baryons (except the $\Lambda(1520)$) on the Υ are larger by a factor 2–3 compared with continuum data.

(2) The production rates of mesons are only slightly enhanced in Υ decays with respect to continuum data.

The latter point, in particular, is important since it demonstrates that the baryon enhancement in Υ decays is not a pure mass effect as assumed for example in cluster hadronization models [16]. The most important question in this context is whether the larger baryon rate in Υ decays reflects specific properties of gluon fragmentation or of the three-jet topology.

It seems natural to begin a quantitative study with a model where the hadronization of quark and gluon

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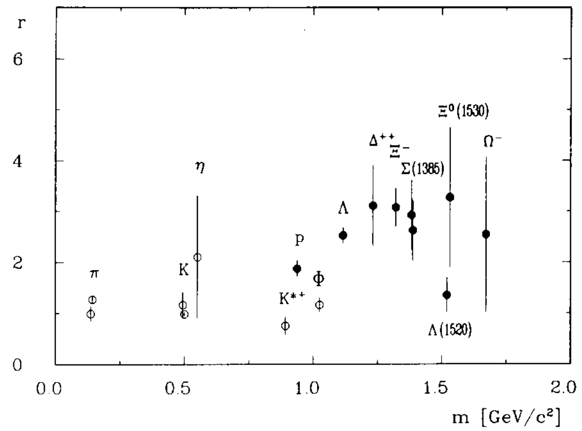

Fig. 1. Measured ratio r for different particles. The numbers were taken from recent ARGUS measurements [11–15]. The two values for π, K and Σ (1385) correspond to the different charge states of these particles, ordered in mass.

jets is treated equally. For this purpose the Lund event generator (JETSET 6.2) was chosen here, since it describes most data on fragmentation reasonably well. The gluon jet is treated within the Lund framework [5] as a transverse excitation of the colour field, an extension which does not influence much the properties, and only slightly the numbers, of generated hadrons.

Using the Lund program in its standard parametrization one indeed obtains a larger baryon rate in Υ decays then in the continuum (see table 1), an observation which has been traced back to the following sources [5]:

– A general increase of the order of 25% in multiplicity in Υ decays, which of course affects both mesons and baryons.

– A smaller number of baryons in continuum $c\bar{c}$ events. Since both a baryon and an antibaryon must be formed, baryon production in events containing charmed particles is suppressed within the model by a factor of two due to the restricted phase space. In the continuum, charm production accounts for about 40% of the total hadronic rate and therefore its influence on the hadron rates is large.

– Since diquarks cannot be produced as primary partons in the continuum, one obtains a "natural" suppression of leading baryons. This effect is small and is of the order 10%. (Note that even using the "popcorn" option, the Lund model is effectively a diquark model were diquarks are split into two quarks, one of which then recombines with a third quark into another diquark.)

Table 1 shows that, for most baryons, the values for r given by the standard Lund model are much smaller than the corresponding measured ones. In addition, none of the factors noted above can be responsible for the strong variation of r between 1.1 and 2.8 for different baryons species. Only for the r-values of the proton and $\Sigma^-(1385)$ good agreement between data and the model is obtained.

In fact, this limited agreement provides a hint at the origin of the general discrepancy between data and Lund model. The different model predictions for the r-values of $\Sigma^-(1385)$ and its isotriplet partner $\Sigma^+(1385)$ show that isospin violating processes are responsible for the deviation between model and data. Here two isospin violating effects have to be considered, both relevant only for the continuum data:

(1) The primary decay of the virtual photon into a quark and an antiquark, which favours the production of primary u- and c- over d- and s-quarks.

Table 1

Ratio r of rates of direct Υ decays over continuum for different baryon species. The table shows a comparison between data and two Lund model predictions using inclusive Λ_c branching ratios into Λ of 20% (modified Lund) and 64% (standard Lund)

Baryon	r (measured)	r (standard Lund)	r (modified Lund)
p	1.9 ± 0.2	1.8	2.1
Λ	2.5 ± 0.2	1.5	2.2
Ξ^-	3.1 ± 0.4	1.7	1.9
$\Sigma^+(1385)$	3.3 ± 0.9	1.6	2.6
$\Sigma^-(1385)$	2.6 ± 0.6	2.8	3.2
$\Xi^0(1530)$	3.3 ± 1.4	1.3	2.1
Ω^-	2.5 ± 1.5	1.1	1.8

(2) The weak decays of charmed baryons into baryons of the SU(3) octet and decuplet.

Indeed the different Lund model predictions for the r-values of $\Sigma^+(1385)$ and $\Sigma^-(1385)$ arise from the $q\bar{q}$ data as can be shown by comparing the production rates of these particles per multihadronic event. The Lund model predicts in its standard parametrization for $q\bar{q}$ events the ratio of rates

$$R=\frac{n(\Sigma^+(1385))}{n(\Sigma^-(1385))}=1.8\ ,$$

while the experimental value for continuum data [11] is $R=0.93\pm0.25$. Note that this is an additional difference between model and data which is independent of the hadron rates on the Υ.

This discussion hints at two possible sources for the observed discrepancies between model and data. The first possibility is an additional suppression of baryons as leading particles in quark jets. This approach is theoretically well motivated and was already predicted by different models [7,17]. It could also explain the discrepancies in the particle momentum spectra, where at least for protons and Λ's the Lund model yields a spectrum which is too hard [11,18]. On the other hand a significantly lower r-value for the proton than for other baryons has been measured [12]. This is not predicted if the baryon enhancement in Υ decays is caused mainly by a suppression of leading baryons, since one would expect that such a mechanism affects all varieties of baryons about equally.

Consequently a different explanation for the enhanced baryon production in Υ decays has to be searched for. As has already been stressed, the decays of charmed baryons into the SU(3) octet and decuplet states, still poorly measured, contribute to the rates of the individual baryon species in the continuum and therefore introduce large uncertainties in model predictions. This argument is only in a restricted sense true for protons and neutrons, since charmed baryons will finally decay with about 50% probability into p and n, respectively. Hence for protons one expects good agreement between the predictions of the Lund model and the data, which indeed is observed. The fact that the experimental r-value of the proton [12] is lower than that of strange baryons indicates that charmed baryons have low branching ratios into hyperon states.

In fact this ansatz solves the puzzle of the different $\Sigma^+(1385)$ and $\Sigma^-(1385)$ rates in Lund $q\bar{q}$ events. The Monte Carlo analysis shows that due to the flavour content of the Λ_c and the fragmentation scheme used within the Lund model for its decay, the Λ_c branching ratio into $\Sigma^+(1385)$ is much larger than that into $\Sigma^-(1385)$. This explains the major part of their different rates within this model. Setting the branching ratios of Λ_c into $\Sigma(1385)$ states to 0, the Lund model yields $R=1.2$ in agreement with the data.

Therefore a conservative approach consists in modifying the branching ratios of charmed baryons in an appropriate way, before looking for additional physical input to models. Most charmed baryons will finally decay via the Λ_c, and therefore its branching ratios are the most relevant ones. Recently, new measurements of the inclusive Λ_c branching ratio into the Λ hyperon have been published. In addition, the Λ has the most precisely determined r-value, making it an ideal object for parameter tuning. The currently available values of $\mathrm{Br}(\Lambda_c\to\Lambda X)$ are

(1) Two direct measurements of (23 ± 10)% and (49 ± 24)% from photon beam experiments [19,20].

(2) (19^{+10}_{-6})% from studies of inclusive Λ production and Λ/lepton correlations in B events (ARGUS) [21]. This is still in contradiction with a CLEO measurement, which implies a larger branching ratio of about (60 ± 20)% [22]. In both cases Ξ_c production has been neglected, which would further reduce $\mathrm{Br}(\Lambda_c\to\Lambda X)$.

(3) The HRS Collaboration demonstrated from data on inclusive Λ production a correlation between an additional strangeness suppression for baryons and the Λ_c branching ratio into Λ [23]. Assuming no such extra strangeness suppression, which is supported by the inclusive baryon rates from the ARGUS experiment [11], a branching ratio for $\Lambda_c\to\Lambda X$ of the order of 20% is obtained.

Hence, experimental information favours an inclusive Λ_c branching ratio into Λ between 20% and 30%, while, due to the many unknown exclusive branching ratios, the Lund event generator uses a fragmentation scheme for the Λ_c decay which gives the much too large value for $\mathrm{Br}(\Lambda_c\to\Lambda+X)$ of 64%.

In order to study the influence of charmed baryon branching ratios, the value of $\mathrm{Br}(\Lambda_c\to\Lambda X)$ was changed to 20% in a simulation using the Lund event generator. As a first approximation, decay of the Λ_c

into baryon states other than p, n and Λ were neglected. The values obtained for r are included in table 1 (modified Lund) and agree much better with the data. As an example, for the Λ one now obtains $r=2.2$ compared to $r=1.5$ in the standard Lund parametrization, while the measured value is 2.5 ± 0.2.

For most other baryons the agreement is even better, but the experimental uncertainties are also larger. Only for the Ξ^- does one find a predicted r-value of 1.9 which is too small compared with the measured result of 3.1 ± 0.4. A better agreement between the model and the data can be achieved by reducing the inclusive Ξ_c branching ratios into the Ξ states, but so far no experimental data are available on this point. Alternatively, one could interpret this discrepancy as indirect evidence that either the production rate of Ξ_c states, or their branching ratio into SU(3) octet Ξ states is less than assumed in the Lund model.

One remaining question is why the Λ(1520) shows a much lower enhancement than other baryons. Judging from the momentum spectra [24], the answer seems to be a suppression of the rate on the ϒ at low x, where the spectrum even falls below that in the continuum. This effect can therefore not be explained, for example, by a large branching ratio of Λ_c into Λ(1520). Presumably a better understanding is needed of how orbital angular momenta of particles are formed, since the Λ(1520) is in a $L=1$ state.

It should be stressed that correcting the charmed baryon branching ratios does not remove the discrepancy between the Lund model and continuum data for the baryon momentum spectra at high x [11,18], since baryons from Λ_c decays mostly populate the region of medium $x \sim 0.5$. Certainly the situation could be improved by tuning the parameters of the fragmentation function, but a more physical interpretation is of course desirable. In two publications [25,26] modifications of the Lund fragmentation function were suggested which gave good agreement between the model and the measured baryon spectra for continuum data. If would be interesting to see whether these models can describe the baryon spectra on the ϒ [11] where the shapes of the measured spectra are even harder than those of the Lund model.

In conclusion the higher baryon rate in direct ϒ decays in comparison with that in the continuum is quantitatively explained by taking into account the recently measured inclusive branching ratios of charmed baryons, especially for the Λ_c. The remaining deviations between Lund model and data are less than 15%. No special treatment of gluon fragmentation is necessary. Though the analysis was based on the Lund model, it can be applied easily to any other fragmentation model. It also should be emphasized that this explanation does not depend strongly on a specific baryon production mechanism. One can expect that even mesons have r-values in the order of 1.5–1.9, if they are rarely produced in the decay of charmed particles (e.g. possibly tensor mesons).

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