HEAVY FLAVOUR HADRONS IN PROTON FRAGMENTATION

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(*Received June 16, 1980*)

We suggest that charm particles observed in pp collisions at the CERN ISR are proton fragments i.e. contain valence quarks of the initial protons. This hypothesis is also extended to production of bottom and top particles. The most striking prediction is that the observed D^+ mesons are decay products of charm Λ_c^* and/or bottom Λ_b baryons. This prediction may help to discover Λ_b.

PACS numbers: 13.85. Hd, 14.40. Pe

Recently, production of charmed D^+ mesons [1] and charmed Λ_c^+ baryons [2] has been seen in proton–proton collisions at the CERN Intersecting Storage Rings. A rather strong signal has been observed in the proton fragmentation region, at large Feynman x, which gives a large value for the total charm production cross section when extrapolated over the whole x and p_T range. These observations are totally incompatible with expectations based on perturbative QCD calculations [3] which predict that charmed hadrons should be produced centrally, at small x, and with cross section at the level of 5–10 μb. In contrary to that, experiments give value as large as few hundreds of microbarns.

In this letter we suggest that the observed charmed particles are fragmentation hadrons or their decay products. They are produced by recombination of slow heavy flavour sea quarks with valence quarks of the initial proton. We also suggest that the proton fragmentation is the important source of bottom/top hadrons. Our hypothesis explaines the fragmentation-like shape of the $d\sigma/dx$ distribution of charmed baryons Λ_c^+ [4] and gives other predictions concerning the production of heavy flavour hadrons. In particular we predict that the

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observed D^+ mesons are decay products of charmed Λ_c^* and/or bottom Λ_b baryons produced as fragments of the incident proton. This may be an important hint in searching for Λ_b.

We shall not discuss here the origin of the relatively large, as compared to the perturbative QCD predictions, number of $c\bar{c}$ pairs necessary to explain the magnitude of the Λ_c^+ cross section. We take the probability ξ_c that $q\bar{q}$ sea is a $c\bar{c}$ pair as a free parameter. Similarly, the contributions of $b\bar{b}$ and $t\bar{t}$ quark pairs are measured by probabilities ξ_b and ξ_t, respectively[1].

The quark recombination model is rather successful in phenomenological interpretation of features seen in the proton fragmentation into light flavour hadrons (those containing only u, d and s quarks and antiquarks) [6]. We assume that the fragmentation into heavy flavour hadrons proceeds similarly as it does into strange hadrons. The latter case has been recently discussed in details in the probabilistic quark recombination model approach in Ref. [7]. Following this line we introduce three probabilities A_1, A_2 and A_3 of the following three processes, respectively:

1. three valence quarks of the initial proton recombine into three distinct outgoing hadrons,
2. two valence quarks of the initial proton recombine into one outgoing baryon and the third (say, q_3) emerges in another hadron,
3. all three valence quarks emerge in the same outgoing baryon.

Obviously $A_1+A_2+A_3 = 1$.

In collision class 1 the valence quarks can emerge either in a meson or in a baryon, and the same applies to q_3 in collisions class 2. We call η the probability for such a quark to recombine into a meson. The probability for it to recombine into a baryon is then $\eta' = 1-\eta$. Finally we call ξ_s the probability for a sea quark to be a strange one. The probability ξ_s can be estimated from K^+/π^+ ratio in the fragmentation region and one gets $\xi_s = 0.10$. One can express in terms of the above parameters the mean multiplicity of any strange hadron produced in the fragmentation process. According to the analysis performed in Ref. [7] we have: $A_2 \approx 0.6$, $A_1 \approx 0.05$, $\eta \approx 1$, $\eta' \approx 0$. With the sufficient for us accuracy we can neglect collisions of class 1, and also the fragmentation into baryons containing a single valence quark. This gives the following approximate relations for the average multiplicities of strange baryons

$$\bar{n}_{\mathrm{uds}} \approx 2\bar{n}_{\mathrm{uus}} \approx \tfrac{2}{3} A_2 \xi_s, \tag{1}$$

$$\bar{n}_{\mathrm{dds}} \approx 0. \tag{2}$$

The experimentally observed Σ^- production which is a "dds" baryon can be explained as a two-step process — the production of a "uds" baryon which decays into a Σ^- hyperon.

The consequence of the discussed picture is that strange mesons composed of $s\bar{d}$ and $s\bar{u}$ pairs can not be directly produced via a proton fragmentation as none of these (anti)quarks

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[1] We are tempted to believe that the non-perturbative creation of the $c\bar{c}$, $b\bar{b}$ and $t\bar{t}$ components occurs, similarly as it is the case with the $s\bar{s}$ component. However, even within perturbative approach there are several higher order effects which are not included in the previous calculations. For instance, soft $c\bar{c}$ pair production associated with large-p_T scattering may sizably increase the number of $c\bar{c}$ pairs [5].

is the valence quark of initial proton. They can, however, appear at large x values as decay products of excited strange baryons.

We assume here that the fragmentation into heavy flavour hadrons can be considered in the above framework simply by replacing ξ_s by ξ_c, ξ_b and ξ_t for charm, bottom and top flavours, respectively. From the generalized in this way relations (1) and (2) we predict the mean multiplicities of heavy flavour baryons originating in the fragmentation of initial protons. They are given in Table I in units $\frac{1}{3} A_2 \xi_i$. Mean multiplicity refers here to the ground state baryon and all higher states with the same quark content.

TABLE I

Flavour	Electric charge of a baryon			
	++	+	0	−
charm	1	2	0	—
bottom	—	1	2	0
top	1	2	0	—

Several points following from the recombination picture are worth stressing.

1. Single charge charmed baryons are more frequently produced than those with double charge. Their x distribution is roughly described by $d\sigma/dx \sim (1-x)$. Both features agree with experimental data.

2. Charm mesons D^+ and D^0 are produced in the fragmentation region only as decay products of directly produced fragmentation baryons. These baryons can be either heavier charmed baryons B_c^* with a strong decay into D^+ mesons or bottom baryons B_b which decay weakly. Due to a large mass of D meson it retains large fraction of the momentum of the parent baryon.

Experimental verification of our conjecture on D^+ meson production will give a strong support to the fragmentation picture of forward hadron production. The conjecture also suggests an efficient way of searching for bottom baryons in p–p (p–$\bar{\text{p}}$) collisions. Analogous arguments apply for searching for top baryons in collisions with a bottom meson produced. Their production as fragmentation hadrons assures better signal-to-noise ratio.

3. The production of neutral charm and top baryons and negative bottom baryons is suppresed with respect to other charge states by a factor of the order of Σ^-/Λ ratio.

Finally we should like to point out that the cross section for Λ_c^+ of the order of 100 μb requires $\xi_c \approx 0.01$. Comapring this value with $\xi_s \approx 0.1$ we observe that

$$\frac{\xi_c}{\xi_s} \approx \frac{m_s^2}{m_c^2},$$

where m_i stands for a mass of a quark with flavour i. Speculating that this regularity is roughly maintained for other flavours we expect (at energies well above threshold) the cross sections for bottom and top hadrons of the order of 10 μb and 1 μb, respectively, assuming $m_t \approx 15$ GeV.

Although the cross section for the production of charm baryons is much larger than that for bottom ones we expect that both flavours can contribute to the D^+ meson production at large x with roughly the same intensity. Most of the charmed baryons produced via fragmentation of initial protons will have mass too low to decay into D^+ meson whereas all bottom baryons will be above this threshold.

In conclusion if the suggested in this letter fragmentation mechanism and the magnitudes of cross sections are indeed relevant for new flavour hadron production then p–p collisions at Isabelle and p–$\bar{p}$ collisions at the CERN collider will provide a rather favourable conditions for searching for new flavour hadrons and for study of it decay properties.

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