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FURTHER INVESTIGATION OF BEAUTY BARYON PRODUCTION AT THE ISR

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ABSTRACT

A recent publication by M. Basile et al. claims evidence for a hadronic state with beauty flavour, $\Lambda_b \rightarrow D^0 p \pi^-$, produced in pp collisions at $\sqrt{s} = 63$ GeV. We report a negative result from an experiment which has used the same detector and has significantly higher sensitivity. In addition we show that neither experiment can observe such a signal, the data available being about two orders of magnitude below the minimum required.

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1. INTRODUCTION

The observation of a heavy baryonic state was recently reported [1] in the channel $p\pi^-K^-\pi^+$ with a mass of $\approx 5.4 \text{ GeV}/c^2$; this state was produced in pp collisions at $\sqrt{s} = 63 \text{ GeV}$ and detected using the SFM detector [2] at the ISR. The interpretation of this state as Λ_b was supported by a peak in the $K^-\pi^+$ mass distribution at the D^0 mass and by an associated e^+ trigger which might have originated from the leptonic decay of a $\bar{B}$ meson produced in pair with the Λ_b . This experiment, hereafter referred to as BCF, estimated the Λ_b signal to be 30 ± 5 combinations with $\Lambda_b \rightarrow p\pi^-D^0$ and $D^0 \rightarrow K^-\pi^+$.

In the course of an experimental program to study the production of heavy flavours [3], we performed a similar experiment using physically the same detector, a comparable trigger, the same beam energy, and an integrated luminosity of the same order of magnitude. The BCF experiment used an earlier version of our track-reconstruction program. Important improvements introduced into the program used in the present analysis increased the detection efficiency of the secondary tracks and the precision in the determination of the particle momenta. We ended up, therefore, with considerably more events which fulfill the selection criteria of the BCF experiment. On this basis we should observe the purported Λ_b of that experiment. However, we have found no signal. From the study of sensitivity, we conclude that such a signal should indeed not be observed.

2. EXPERIMENTAL PROCEDURE AND RESULTS

The top view of the SFM detector used in the present experiment is shown in fig. 1. It consists of a set of proportional wire chambers which record trajectories of particles.

A hardware road system selects events with a track in the trigger region; a two stage Cerenkov counter selects the electrons. Its stability in time is controlled by light diodes. The triggering particles cover a c.m.s. rapidity $|y| < 0.35$ and an azimuthal angle $|\phi| < 9^\circ$ with respect to

the beams. We started with 340 000 electron candidates about 50% of which are positive. From these we removed small angle e^+e^- pairs by energy loss measurements in a proportional chamber close to the interaction region (dE/dx chamber, fig. 1) and large angle e^+e^- pairs by a cut on effective mass. Similar criteria in the BCF experiment left a 55% contamination of non-prompt positrons with $p_T > 0.8$ GeV/c, where p_T is the c.m.s. momentum transverse to the beam direction; this contamination is mainly due to non-rejected pairs from Dalitz decay and γ conversion.

The BCF experiment used an electromagnetic shower detector in their trigger to reduce the hadronic background to a negligible amount. We did not use this detector in our trigger, but we did use it to study our rejection efficiency. Fig. 2 shows the pulse height spectrum for the triggers with (a) and without (b) a Cerenkov signal. From these spectra we evaluate the hadron contamination to be 25%. We have performed such an analysis for different intervals of the transverse momentum p_T , of the trigger particle. The resulting hadron contamination versus trigger p_T is shown in fig. 2(c). An independent determination of the hadronic contamination of our electron triggers has been performed using the spectrum of pulse heights in the dE/dx chamber. Due to the relativistic rise, the electron spectrum is shifted with respect to the pion spectrum. By fitting the observed spectrum to a linear combination of these two spectra we obtained results comparable to those with the shower counter (fig. 2(c)).

This enabled us to determine the hadron contamination of our trigger sample integrated over transverse momenta above 0.8 GeV/c to be equal to 35%. The remaining 65% of our triggers are positrons. The Monte-Carlo calculation [4] shows that about half of them are prompt. Using this number we determined the e/π ratio to be $(1.7 \pm 0.6) \times 10^{-4}$ for $p_T > 0.8$ GeV/c in agreement with other experiments [5]. In conclusion, 32% of our triggers are prompt e^+ , the corresponding number for the BCF experiment being 45%.

The set of proportional wire chambers used in the present experiment to record trajectories of secondary particles is identical to the set used in the BCF experiment with the exception of two chambers opposite to the

trigger region. In the BCF experiment these chambers were moved outside the magnetic field; this lowered the efficiency to detect with the required precision tracks opposite to the trigger. As described later, the observation of such a track is a necessary condition to accept the event for the final analysis.

In what follows we will describe our analysis in detail. The prescriptions introduced by the BCF Collaboration have been followed exactly [1,2]. We have, therefore, restricted our sample to events with a positive trigger. Their transverse momenta, p_T , have to be larger than 0.8 GeV/c and the relative momentum error, $\Delta p/p$ smaller than 15%. This requirement leaves us with 18 136 events. Among these we then retain those exhibiting in addition one (or more than one) positive particle with Feynman x larger than 0.32 and $\Delta p/p$ smaller than 30%. We remain with 4771 events. We then require that the number of charged particles existing in addition to the above two should be larger than 6; each one of these particles must have a relative momentum resolution better than 30%. We end with 4149 events. This is the final sample which should contain the sought Λ_b signal.

Most of the secondary particles cannot be identified. The existing time-of-flight system allows the identification of only $\approx 7\%$ of the secondaries. Following the BCF procedure we assume that the positive track with $x > 0.32$ is the proton (if there is more than one we take each of them in turn). Disregarding this positive track and the identified positron we use the remaining 7 or more tracks to construct the two-body mass spectrum shown in fig. 3(a). Here we have plotted all possible pair combinations of positive and negative particles assuming the negative to be a K^- and the positive to be a π^+ . A cut is then applied upon this alleged " $K^-\pi^+$ " spectrum and events retained within a region 150 MeV/c² wide around the D^0 mass. Two regions have been tried: one identical to that used by the BCF experiment (1.725 to 1.875 GeV/c²) and another one centred on the nominal value of the D^0 mass (1.863 GeV/c²). The events with at least one " $K^-\pi^+$ " combination in the D^0 region were used to produce the $p\pi^-K^-\pi^+$ spectrum of fig. 4. Here we have plotted the mass spectrum of the "proton" track, the " $K^-\pi^+$ in the D^0 " tracks plus any of the other

negative tracks assumed to be a pion. Only those combinations contribute to the spectrum which have the c.m.s. rapidity larger than 1.4 and are produced together with a particle the azimuthal angle of which differs from the azimuthal angle of the triggering electron by more than 90° .

We do not try to justify the above procedure (nor to discuss its combinatorial consequences) for which ref. [1] should be consulted. We only observe that no signal appears at the position expected for the Λ_b . The dotted histogram in fig. 4 containing 213 ± 36 combinations in the peak represents the BCF signal scaled to our statistics^(*). What we observe is at most 30 ± 16 combinations.

In spite of the absence of the Λ_b signal we have looked for $D^0 \rightarrow K^- \pi^+$ decays in $p\pi^- K^+ \pi^-$ combinations with the mass in the interval 5.35 to 5.50 GeV/c^2 . The mass spectrum of $K^- \pi^+$ pairs from these combinations is plotted in fig. 3(b). No D^0 signal can be seen.

We conclude that despite nearly identical conditions, the two experiments do not agree.

3. ESTIMATION OF THE POSSIBLE SIGNAL SIZE

Over and above the negative result of our analysis we can estimate the maximum size of the signal which might be observed in the two experiments and we find it too small to be observable.

Let us define the following quantities:

$S =$ number of observed events with a $\Lambda_b \rightarrow p\pi^- D^0$ associated with a $\bar{B} \rightarrow e^+ + \text{anything}$, $D \rightarrow K^- \pi^+$ and a proton with $x_F > 0.32$ (fast proton).

(*) The number of 213 ± 36 expected combinations in fig. 4 has been obtained by scaling the BCF signal by two factors. The first is equal to $0.32/0.45$ in order to take into account the different fractions of prompt positron triggers in the two experiments. The second is equal to 10 and renormalizes the continuous part of the BCF $p\pi^-(K^- \pi^+)D^0$ spectrum to the corresponding region of our spectrum.

- N = number of events with an e^+ trigger and with a fast proton ($x > 0.32$),
 ϵ = (number of prompt e^+)/(number of e^+ triggers),
 ρ = (number of e^+ from $\bar{B}$)/(number of prompt e^+),
 B_1 = (number of Λ_b)/(number of beauty hadrons produced),
 B_2 = branching ratio ($\Lambda_b \rightarrow p\pi^-D^0/\Lambda_b \rightarrow \text{proton} + \text{anything}$), when protons are fast,
 B_3 = branching ratio ($D^0 \rightarrow K^-\pi^+/D^0 \rightarrow \text{all}$),
 ϵ_{SFM} = probability to detect in the SFM two pions and a kaon from a Λ_b decay.

From the above definitions it follows that the expected signal, S is given by

$$S = N \cdot \epsilon \cdot \rho \cdot B_1 \cdot B_2 \cdot B_3 \cdot \epsilon_{\text{SFM}} \quad (1)$$

In our experiment $N = 4771$, $\epsilon = 0.32$ and $\epsilon_{\text{SFM}} = 0.5$. Not all of the e^+ observed can possibly be associated to the $\bar{B}$ decay. Hence ρ must be smaller than 1; on the basis of the spectrum expected from $\bar{B}$ decays [6] and the measured positron spectrum (fig. 5) we estimate that at most ρ is 15%. This value was obtained by assuming that the transverse momentum spectrum of the positrons is saturated at 2 GeV/c by $\bar{B}$ decays only. In fact in this region about 30% of the positrons come from vector meson decay [5,7]. This lowers the above estimate for the upper limit on ρ to $\sim 10\%$.

The branching ratio B_3 has been measured [7] to be $(3 \pm 0.6)\%$. Let us make the extreme assumption that all beauty hadrons produced are Λ_b 's ($B_1 = 1$) and that these decay only via $\Lambda_b \rightarrow p\pi^-D^0$ ($B_2 = 1$). We then obtain an upper bound for the number of Λ_b decays which can be observed in our sample

$$S \leq 2.2 \text{ events} \quad (2)$$

Hence a sample of events comparable in size with that analyzed by us would be very unlikely to generate a statistically significant signal.

Let us now apply the same consideration to the BCF data. The upper limit for the number of Λ_b decays which could be seen in the BCF sample is obtained by scaling up our limit (2) by the factor $0.45/0.32$ which is the ratio of the different fractions of prompt positrons in the two triggers. The result must be renormalized by the ratio of the number of events times the probability to observe a $p\pi^-K^-\pi^+$ system. This factor can be estimated by comparing the levels of smooth background in the $p\pi^-K^-\pi^+$ mass plots of the two experiments. We find the ratio of the background levels to be $\sim 1:10$. This value comes from the ratio of event samples (1025 for BCF vs 4149 in our sample) and the ratio of three-particle detection efficiencies. As a result we find that the upper limit for the Λ_b signal which could be observed by the BCF Collaboration is

$$S \leq 2.2 \cdot \frac{.45}{.32} \cdot \frac{1}{10} \approx 0.3 \text{ event} \quad (3)$$

It should be stressed that the above estimate has been obtained with the unacceptable extreme assumptions $B_1 = B_2 = 1$. Values such as $B_1 \approx 0.5$ and $B_2 \lesssim 0.1$ are still high but are more realistic. They would lead to upper limits which are lower by a factor of 20 than those given by (2) and (3).

4. CONCLUSIONS

We have shown that in the relatively small samples of events in either experiment, the contribution of $\Lambda_b \rightarrow D^0 p \pi^-$, $D^0 \rightarrow K^-\pi^+$ cannot exceed a few events. This agrees with the negative result of our experiment. Instead it contradicts the interpretation of [1]. In order to raise the upper bound on the signal to a statistically observable level, one would need about one hundred times more events. The small branching ratio for $D^0 \rightarrow K^-\pi^+$ is the main contribution in setting the upper limits for the Λ_b in the experiments discussed. Further studies of Λ_b production would be well advised to introduce a trigger which more efficiently selects the event sample on the basis of visible decays of charm hadrons.

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FIGURE CAPTIONS

- Fig. 1 Top view of the Split Field Magnet detector.
- Fig. 2 Pulse-height spectrum of the electromagnetic shower counter in the case of our triggers:
- (a) trigger particles with $0.6 \text{ GeV/c} < p_T < 0.8 \text{ GeV/c}$ associated with a Cerenkov counter signal;
 - (b) same as (a) but no Cerenkov signal (scaled to the same number of triggers in two first bins as (a));
 - (c) percentage of hadron contamination versus transverse momentum of the trigger particle.
- Fig. 3 Mass distribution of $(K^- \pi^+)$ pairs:
- (a) All combinations;
 - (b) Combinations contributing to the $5.35\text{--}5.50 \text{ GeV/c}^2$ region of the $p\pi^- K^- \pi^+$ mass spectrum (full line) and to adjacent regions (dashed line).
- Fig. 4 Mass distribution of $p\pi^- K^- \pi^+$ system when the $K^- \pi^+$ mass is in the region $1.725 - 1.875 \text{ GeV/c}^2$. The dotted line indicates the signal expectation deduced from [1]. The smooth background level has been estimated from six bins adjacent to the $5.35 - 5.50 \text{ MeV/c}^2$ region.
- Fig. 5 Transverse momentum spectrum of positron triggers for events with a fast positive particle ($x > 0.32$) observed. The dashed line shows the maximum contribution of positrons from decays of an antibeauty meson.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5