RESULTS ON CHARM AND BEAUTY PRODUCTION FROM THE CERN WA92 EXPERIMENT

The Beatrice Collaboration

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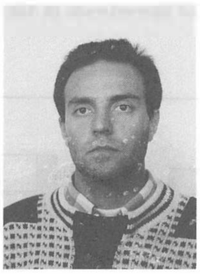

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Abstract

We give results concerning the production of charm and beauty hadrons in π^- interactions in thin metal targets at $\sqrt{s} = 26$ GeV. In order to select events containing heavy quarks we used the combined information of the CERN Ω' spectrometer and of a high-resolution silicon detector that allowed direct observation of the decay vertices of short-lived hadrons. In the 20% of our data sample analysed so far we have 81 events where the decay vertices of two charmed hadrons are detected. These double-charm events, for which the purity ($\sim$ 85%) has been estimated directly from the data, have been used to study the azimuthal-angle correlation between pairs of charmed hadrons. Results are compared with QCD predictions. The same data sample is used to search for the production of beauty particles. Preliminary indications are that the number of events found is compatible with published measurements of the beauty cross-section.

1 Introduction

The WA92 [1] experiment at CERN was designed for the study of beauty hadroproduction using a 350 GeV/c π^- beam incident on a thin target. To contend with the very low cross section for beauty production (a few nb at the energy considered) a trigger that had high selectivity but a large beauty acceptance was devised. Using a specially designed high-resolution silicon microstrip telescope, the direct observation of beauty decays has been possible.

In the first part of this paper we briefly summarize the experimental setup. We then describe a study of the angular correlations between charmed pairs. Finally we present some preliminary results on beauty production.

2 The experimental setup

The WA92 experiment has been performed at the Ω' magnetic spectrometer facility in the CERN West Area, using a 350 GeV/c π^- beam incident on a 2 mm thick copper or tungsten target.

The trajectory of the incoming beam particle was measured by 10 silicon-microstrip detectors (SMD) of 20 μm pitch. Tracks of charged interaction products were measured by a vertex detector that was formed from 12 SMD of 25 μm pitch and 5 SMD of 50 μm pitch. The region between the target and the vertex detector, where beauty and charm decays were most likely to occur, was equipped with 17 SMD of 10 μm pitch with analogue readout, closely packed along the beam direction. This device, referred to as decay detector (DkD) [2], gives a high resolution picture of the event.

The Ω' spectrometer was situated downstream of the vertex detector. The spectometer comprises a series of multiwire proportional chambers positioned in a 1.8 T dipolar magnetic field, and a pair of drift chambers. A lead-glass electromagnetic calorimeter and a muon filter (consisting of layers of iron and RPC planes) [3] were located downstream of the spectrometer, as shown schematically in figure 1.

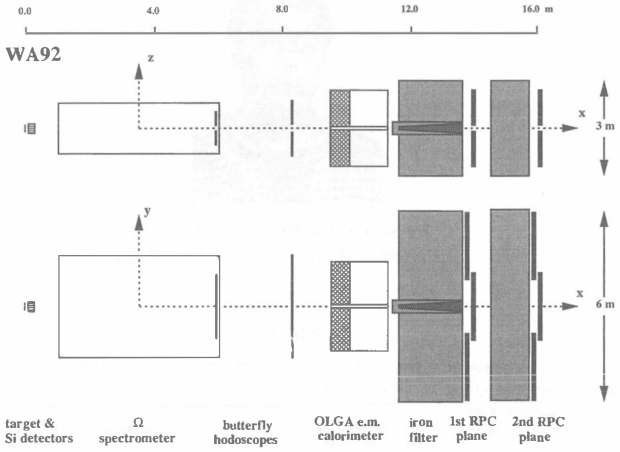

Figure 1: Schematic view of the WA92 setup (upper = side view, lower = plan view).

The trigger used in the WA92 experiment is a multilevel trigger with a large acceptance for beauty decays [4]. An event was recorded if at least two of the following conditions were verified simultaneously:

- At least two tracks were found with large (> 100 μm) impact parameters with respect to the interaction vertex. This search is performed by a dedicated processor [5].
- At least one particle was recognised as having a momentum component of > 0.6 GeV/c in the vertical direction [6].
- At least one muon whose trajectory could be extrapolated to the interaction region was identified [7].

The trigger gave a rejection factor of $\sim$ 30 for minimum-bias events. It accepted 35% of beauty and 10% of charm particles.

The WA92 experiment collected data during two periods, in 1992 and 1993, recording 150 million events. Results presented here refer to the first half of the 1992 data sample ($45 \cdot 10^6$ events, which correspond to 1/5 of the total sensitivity), where a 2 mm thick copper target was used.

The data processing has been performed in two steps. In the first step events were passed through a filter, which verified the trigger conditions by means of a fast reconstruction program which was able to reject some trivial background that escaped the online processors. This step reduced the data sample by a factor 3. In the second step charged-particle tracks were reconstructed and vertices were found.

3 Results on associated charm production

While a large amount of data are available on charm production at fixed-target energies, the possibility of making definite theoretical predictions in the framework of perturbative QCD is limited by the small charm-quark mass. Only recently have calculations of the fully exclusive parton cross sections for heavy-quark production at order $O(\alpha_S^3)$ [8, 9, 10] become available.

However, in the case of charm, non-perturbative effects are expected to be quite significant. Certain distributions, for example the azimuthal correlation of charmed pairs, should be considerably influenced by the primordial transverse momentum of the incoming partons, which will tend to boost the produced pair in the transverse direction. This effect adds to the $O(\alpha_S^3)$ effects of gluon radiation, which also gives a boost to the produced pair. The azimuthal angle distribution of the charmed pair, which is peaked at 180° when only $O(\alpha_S^2)$ diagrams are taken into account, is thus broadened.

Using data from the WA92 experiment it has been possible to extract a relatively pure sample of events in which the associated production of charmed pairs is observed and to study the azimuthal correlations [11]. The analysis was performed as described below.

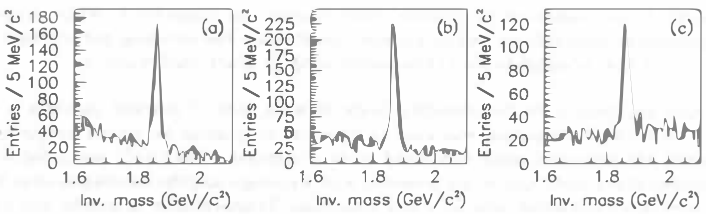

Figure 2: Invariant mass distributions for D mesons in the $D \to K + n\pi$ decay mode, for $n = 1$(a), 2(b) and 3(c).

Events were selected where at least one secondary vertex found in the region covered by the SMDs was consistent with being due to a decay $D \to K + n\pi$, $n = 1, 2, 3$. The invariant mass for the tracks linked to the secondary vertex was required to be within 2σ from the expected value for a given decay hypothesis. Invariant mass plots for neutral and charged D mesons are shown in figure 2.

In this way it has been possible to select approximately 2000 hadronic charm decays with a background of less than 25%. Of this sample, 140 events contained at least one other secondary vertex in the SMDs region in addition to the charm candidate. An event was subsequently discarded if any of its secondary vertices (identified only topologically) were consistent with the decay of a strange hadron or could be attributed to interactions in the DkD planes (an interaction could be recognized from the high energy release in the silicon detector due to nucleus break-up). Surviving events were studied using a display of the events in the SMD, looking for possible tracking inefficiencies or vertex-finding errors. After this step the sample was reduced to 81 events.

With this analysis it was possible to evaluate the background directly from the experimental data. This could be done by determining the fraction of events identified as DD or $\bar{D}\bar{D}$. The flavour of a fully reconstructed hadronic D-meson was unambiguously known except in the cases where more than one decay hypothesis gave an invariant mass in the selection window. If the accompanying vertex is due to the decay of a charged charmed particle, then the particle flavour can be deduced from the total charge associated with the vertex. Using the information of the DkD, it was possible to check if a secondary vertex was consistent with a charged particle decay, i.e. if no charged tracks were missed or erroneously added to the vertex. It was then determined that the background in the sample of associated-charm candidates was less than 15%.

The azimuthal opening angle between the two charm candidates in an event was measured in the plane transverse to the beam direction. The orientation of this plane was computed for each event to take into account the beam divergence. The error on the azimuthal angle was always less than 10°.

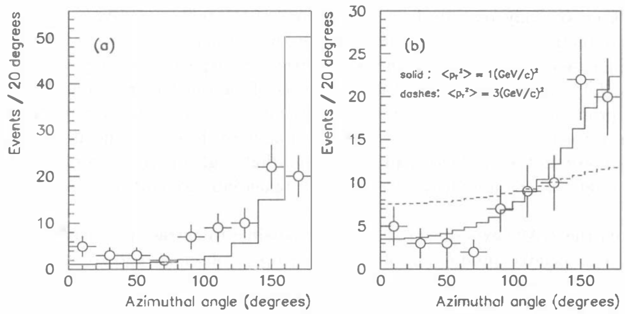

Figure 3: Charmed pairs azimuthal correlations. Data (circles) are compared to NLO perturbative QCD quark predictions from [10] (a) and to a simple model where the incoming partons have a non perturbative p_T kick that is added to the LO perturbative QCD quark predictions (b).

The raw data distribution for the azimuthal angle between pairs of charmed particles is shown in figure 3(a). A detailed simulation was used to evaluate acceptances for charm events and the acceptance versus the azimuthal angle was found to be a constant. The $O(\alpha_S^3)$ perturbative QCD calculations predict that c and $\bar{c}$ quarks are produced with a stronger angular correlation than the one which is observed in experimental data for c and $\bar{c}$ hadrons. Fragmentation of quarks into hadrons cannot alone account for this difference.

In order to try to quantify the size of the effects which broaden the azimuthal-angle distribution the experimental data have been compared with a simple model [10] where a p_T kick distributed as $dN/dp_T^2 \propto e^{-p_T^2/<p_T^2>}$ was added to the incoming partons and then the LO perturbative QCD calculations were performed. This comparison is shown in figure 3(b) for two different values of

$< p_T^2 >$. A $< p_T^2 >$ of the order of 1 $(\text{GeV}/c)^2$ is large enough to account for all the effects that boost the $c\bar{c}$ system in the transverse plane.

Other data from charm hadroproduction experiments [12, 13] seem to favour rather broad correlations which, using the same naïve model as described above, can be fitted with $< p_T^2 > \sim 2-3\ (\text{GeV}/c)^2$. Such a large value for the transverse component of the momentum of the incoming parton has not been observed in other heavy-quark production processes, for example charm photoproduction [14].

4 Preliminary results on beauty

Given the very small exclusive branching ratios for beauty decay into all charged particles our beauty search cannot be based on mass reconstructions but must rather be based largely on topological analysis, using the imaging properties of the DkD. The selection and identification criteria, which should have high efficiency for beauty events, have been studied using simulation.

The strategy adopted in this analysis aims at reducing the 45 million events in the initial sample to a small sample, to be studied in detail using an interactive graphics display program.

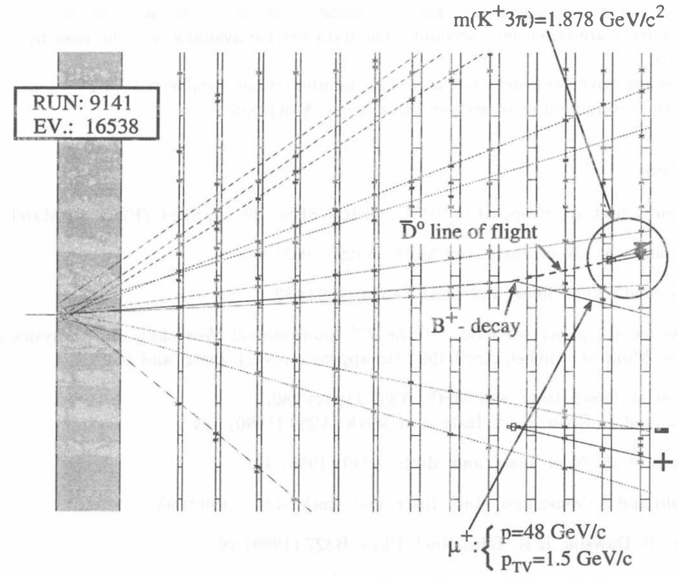

Figure 4: Example of a candidate beauty event. This event shows a fully reconstructed D meson and a muon that both point to a kink clearly visible in the DkD region. This event belongs to both *muon* and *non-primary charm* classes.

The event categories on which our attention has been concentrated up to now are the following:

- *Non-primary charm:* events where a charmed meson is identified by its invariant mass and where its line of flight does not point to the primary vertex ($\sim$ 2500 events).
- *Multivertex:* events with at least three secondary vertices and two secondary tracks each with a p_T larger than 600 MeV/c or one secondary track with a p_T larger than 1.5 GeV/c ($\sim$ 1200 events).

- *Muon:* events with a non-primary muon with a p_T larger than $0.8 - 1.4$ GeV/c and at least one secondary vertex. The p_T cut depends on the number and on the quality of secondary vertices in the event ($\sim$ 4000 events).

The background to the selected events was studied directly on the data using the same selection criteria but requiring that secondary vertices should be identified as interactions in the DkD silicon microstrip planes.

So far some 20 events consistent with being beauty events have been found. Most of these events, like the one shown in figure 4, are characterized by a cascade decay configuration. The analysis work is still in progress, but the beauty events found to date are compatible with a beauty cross section of ~ 5 nb/nucleon assuming a linear dependence on the nucleon number A.

5 Summary and outlook

The Beatrice collaboration has performed a fixed-target experiment that studies the hadroproduction of heavy quarks using a large-acceptance trigger together with a high-resolution microstrip telescope.

Analysis of associated charm production has been performed, using a sample of events with low background, and good agreement with perturbative QCD calculations is found once small non-perturbative effects are taken into account. The data sample available will increase by a factor 5 in the near future.

Beauty decays have been detected and their number is compatible with $\sigma_{b\bar{b}} = 5$ nb/nucleon assuming that the production cross-section has a linear A dependence.

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