STUDY OF CHARM CORRELATIONS IN $\pi^- - N$ INTERACTIONS AT $\sqrt{s} \approx 26$ GeV

THE BEATRICE COLLABORATION

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Abstract

We report on the associated production of charmed hadrons in π^- -nucleon interactions at $\sqrt{s} \approx 26$ GeV at the CERN Ω' spectrometer. Results on the azimuthal correlation of charmed particle pairs are presented and compared to the predictions of Next-to-Leading-Order QCD calculations.

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High energy hadronic interactions may be described in the context of the so-called QCD-improved parton model[1]. In this model scattering processes result from elementary interactions between quarks and gluons in the hadrons. At Leading Order (LO) the processes that contribute to the production of heavy-quark pairs are quark-antiquark annihilation and gluon-gluon fusion, the latter being dominant at $\sqrt{s} \approx 26$ GeV.

The LO processes produce $c\bar{c}$ pairs where the c and $\bar{c}$ are emitted back-to-back in the parton-parton centre-of-mass system. This would suggest that, when produced in a fixed target interaction, D and $\bar{D}$ mesons should tend to be emitted in opposite directions in the plane perpendicular to the incoming beam. The distribution of the $D\bar{D}$ opening angle $\Delta\phi$ in this plane should then be sharply peaked at 180° . However, because of the relatively small mass of the charmed quark, the LO approximation may not adequately describe the production process. In particular, effects normally suppressed by powers of the heavy-quark mass might be significant and large contributions from Next-to-Leading-Order (NLO) corrections are likely.

Detailed calculations at order $O(\alpha_s^3)$ of charm production in hadronic interactions have recently been carried out[2, 3, 4, 5]. On the basis of these calculations comparisons have been made of expectations at LO and NLO for various choices of renormalisation scale, charm quark mass, parton distribution functions and Λ_{QCD} . In general the theoretical evaluations of the total and differential cross sections for charm production are subject to large uncertainties. Smaller uncertainties affect the prediction of the $\Delta\phi$ distribution. A widening of the predicted $\Delta\phi$ distribution is expected when taking into account higher than NLO processes. Other effects, depending, for example, on the parton transverse momentum, the radiation of soft gluons and parton fragmentation may also influence the width of the $\Delta\phi$ distribution.

Here we report on a measurement of the azimuthal angle correlation of charmed particle pairs produced in collisions of $350 \text{ GeV}/c \pi^-$ on nuclei. We discuss our results in the framework of perturbative QCD and compare them with other measurements relating to hadroproduction and photoproduction.

The WA92 experiment has been performed at the CERN Ω' magnetic spectrometer. The main objective of the experiment has been to study the hadroproduction of beauty particles. To this end the experiment has made use of a high resolution imaging detector and a trigger for secondary vertices, leptons and charged particles having large transverse momentum. With this setup it has additionally been possible to obtain a large sample of fully reconstructed charmed particles.

Coordinates on the paths of beam particles, directed towards a 2 mm thick copper target, have been measured using 10 silicon microstrip detector (SMD) planes of $20 \mu\text{m}$ pitch. In tracking charged particles emerging from interactions in the target use has been made of a vertex detector consisting of 12 SMD planes of $25 \mu\text{m}$ pitch and 5 SMD planes of $50 \mu\text{m}$ pitch. A so-called decay detector (DkD)[6], formed of 17 SMD planes having $10 \mu\text{m}$ pitch and analog readout, has been positioned in the region between the target and the vertex detector where decays of beauty particles and charmed particles occur with high probability. The target and the SMD planes were located upstream of the Ω' spectrometer, in a region of low magnetic field, as shown in figures 1 and 2.

The Ω' spectrometer consists of several drift and multiwire proportional chambers, the latter placed in a 1.8 T dipolar magnetic field, and provides a momentum resolution $\Delta p/p^2 = 1.6 \cdot 10^{-4} (\text{GeV}/c)^{-1}$. A lead-glass electromagnetic calorimeter and a muon filter[7] are downstream of the spectrometer. Two butterfly-shaped scintillator hodoscopes [8] positioned in front of the electromagnetic calorimeter have been used to identify charged particles emitted with large transverse momentum.

We have used a multilevel trigger, recording events if at least two of the following conditions were satisfied simultaneously:

- At least one secondary vertex is present in the DkD region, the identification of secondary vertices being based on the recognition by a fast processor of at least two tracks having large impact parameter with respect to the primary interaction vertex[9, 10].
- There is at least one charged particle with a momentum component $p_T > 0.6 \text{ GeV}/c$ in the plane transverse to the beam direction.
- There is at least one muon that originates from the interaction region.

The trigger acceptance is 3% for minimum-bias events and 10% for charm events.

The experiment has collected data during 1992 and 1993, recording on tape a total of 150 million events. Results presented here are based on an analysis of 45 million events from the 1992 data sample.

Data have been processed in two steps. In the first step a filtering is performed, requiring the trigger conditions to be verified by a fast reconstruction program. The filtering allows rejection of events erroneously accepted by the online processors and reduces the data sample by a factor of three. In the second step there is full reconstruction of charged particle trajectories and vertices.

An event is selected for analysis if it contains, in the region of the SMD planes, at least one vertex that is not associated with a secondary interaction in the DkD - interactions in the DkD planes being characterised by a high energy release, resulting from nuclear break-up - and for which the invariant mass for the $D \rightarrow K + n\pi$ ($n = 1, 2, 3$) hypotheses is within $\pm 2\sigma$ of the mass-peak of the relevant D meson, σ being the standard deviation of a gaussian fit to the peak. Invariant-mass distributions are shown in figure 3.

Summing over all channels we identify 1946 ± 57 hadronic charm decays over a background of 496 ± 20 events. In 140 events, in addition to the vertex of the charm candidate, another secondary vertex is reconstructed in the region of the SMD planes. An event is retained for subsequent analysis if the topologically identified secondary vertex cannot be attributed to an interaction in the DkD planes or to the decay of a strange hadron, and if in the plane perpendicular to the beam direction the distance, R , between the two secondary vertices in the event is greater than $100 \mu\text{m}$. The requirement $R > 100 \mu\text{m}$ results in the error on differences in azimuthal angle having a mean value of 1° and always being much smaller than 10° .

A sample of 113 events remains after imposing the selection criteria. Visual examination of the event images provided by the SMD planes permits the elimination of events where the secondary vertices are spurious. The event sample ultimately obtained, referred to in the following as the signal sample, consists of 102 events for which there is evidence that both D and $\bar{D}$ decay vertices are present.

Events from the signal sample in which there are at least two secondary vertices and where one of the secondary vertices has 2, 3 or 4 prongs and a $K + n\pi$ ($n=1,2,3$ as appropriate) effective mass in the D side band ($1.75 < M < 1.80 \text{ GeV}/c^2$ or $1.94 < M < 2.1 \text{ GeV}/c^2$) are considered background. These events constitute the control sample and are treated in the same way as the events of the signal sample. The control sample has been normalised to 25% of the signal sample according to the measured signal/noise ratio at the charm peak.

The difference in azimuthal angle, $\Delta\phi$, of the two charmed particle candidates in an event is evaluated from the positions of the associated secondary vertices with respect to the primary interaction vertex, in the plane transverse to the beam direction. The $\Delta\phi$ distribution before and after background subtraction is shown in figure 4.

We have performed a detailed simulation to evaluate the acceptances for charm events, generated using a combination of Pythia 5.4[11] and Fluka[12]. The simulation indicates that the probability of a charm event being accepted is independent of the difference in azimuthal angle of the charmed particles produced. We note that from NLO calculations it is expected that c and $\bar{c}$ quarks should be produced more back-to-back than is observed experimentally, as shown in figure 5(a).

The effect of charm-quark fragmentation has been evaluated with the simulation, using the model of Peterson with the standard choice of parameters. Comparing the $\Delta\phi$ distributions for generated $c\bar{c}$ pairs and for hadronized $c\bar{c}$ pairs it is evident that hadronization alone cannot account for the difference between the data and the NLO calculation, as shown in figure 6.

To quantify the size of the effects that widen the $\Delta\phi$ distribution the experimental data are compared with a model[5] where a transverse component, p_T , distributed as $dN/dp_T^2 \propto e^{-p_T^2/\langle p_T^2 \rangle}$, is added to the incoming parton momentum before performing the NLO perturbative QCD calculations. Comparisons are shown in figure 5(b) for two different values of $\langle p_T^2 \rangle$, a good description of the data being obtained for $\langle p_T^2 \rangle \approx 0.3 (\text{GeV}/c)^2$.

Data from other charm hadroproduction experiments[13, 14, 15], shown in figure 7(a-c), seem to favour a $\Delta\phi$ distribution that, applying the model described above, cannot be fitted with a $\langle p_T^2 \rangle$ smaller than $1 (\text{GeV}/c)^2$. Such a large effect is not observed in charm photoproduction[16] as shown

in figure 7(d). A value of $\langle p_T^2 \rangle \approx 1 \text{ (GeV}/c)^2$ [5] was required to describe WA92 results obtained before background subtraction[17], showing the sensitivity of the $\Delta\phi$ distribution to the treatment of background.

The WA92 collaboration has performed an analysis of correlated charm production for a sample of events with low background. The results are in good agreement with NLO QCD calculations once small non-perturbative effects are taken into account.

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Figure 1: Schematic view of the WA92 setup: Decay Detector. The continuous (dashed, dotted) lines represent $10\text{ }\mu\text{m}$ pitch silicon microstrip detectors measuring the z (y , inclined) coordinate of the tracks.

The WA92 vertex detector

Figure 2: Schematic view of the WA92 setup: Vertex Detector. The continuous (dashed, dotted) lines represent 25 or 50 μm pitch silicon microstrip detectors measuring the z (y , inclined) coordinate of the tracks.

Figure 3: Invariant-mass distributions: (a) $D^0 \rightarrow K^- \pi^+$, (b) $D^+ \rightarrow K^- \pi^+ \pi^+$, (c) $D^0 \rightarrow K^- \pi^- \pi^+ \pi^+$ and charge-conjugate hypotheses.

Figure 4: Charmed pair azimuthal correlation : (a) open circles: WA92 data without background subtraction; dashed histogram: background distribution, (b) data after background subtraction

Figure 5: Charmed pair azimuthal correlation: WA92 data are compared with predictions from (a) an NLO perturbative QCD calculation, and (b) a model where a parton transverse momentum, p_T , is added to the NLO perturbative QCD predictions (dotted line : $\langle p_T^2 \rangle = 1.0 \text{ GeV}^2/c^2$, solid line : $\langle p_T^2 \rangle = 0.3 \text{ GeV}^2/c^2$).

Figure 6: Charmed pair azimuthal correlation for $c\bar{c}$ quarks (solid line) and $D\bar{D}$ mesons (dotted line).

Figure 7: WA92 data are compared to the data of (a) NA32 (hadroproduction), (b) WA75 (hadroproduction), (c) E653 (hadroproduction) and (d) E687 (photoproduction). All distributions are normalized to those of WA92.