CERN EP/79-13
14 February 1979

ON THE PRODUCTION OF CHARMED MESONS
IN HIGH-ENERGY PROTON-PROTON COLLISIONS

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ABSTRACT

We perform an analysis of lepton-pair data collected at the CERN ISR at centre-of-mass energies $\sqrt{s} = 53$ and 63 GeV in three different configurations. We find that a large fraction of the non-resonant lepton-pair low-mass spectrum can be attributed to the semi-leptonic decay of charmed meson pairs that are produced in the pp collision.

If no other process than charm production contributes to the electron-pair sample, the cross-section for inclusive production of a $D\bar{D}$ pair in the central rapidity region is 10.1 ± 2.3 μb per unit of rapidity.

(Submitted to Physics Letters B)

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1. INTRODUCTION

Despite several attempts, no direct observation of charmed mesons [1] centrally produced in hadronic interactions has been reported so far. Upper limits and estimates of the charmed meson production cross-section have been inferred from existing data with the help of dynamical models describing the production mechanism. Since available data explore only limited regions of phase space, such estimates are strongly model-dependent. In a single experiment [2-4] at the CERN ISR, measurements of lepton-pair production have been made in three different configurations. We examine in this work whether the three measurements can be consistently, and globally, interpreted in terms of the semi-leptonic decay of charmed meson pairs. Owing to the different configuration of the three measurements, our result is less model-dependent than in previous analyses.

2. THE DATA

The lepton-pair measurements discussed here were performed at the CERN ISR using a three-arm spectrometer (Fig. 1). Detailed descriptions of the detector, of the experimental techniques, and of the methods of data reduction have been previously published [2-4]. Each of the three measurements detected lepton pairs produced in the central rapidity region, $|y| \leq 0.5$, at centre-of-mass energies $\sqrt{s} = 53$ and 63 GeV. They differed in the nature of the detected leptons, in their mean azimuthal opening angle $\Delta\phi$, and in the range of accepted momenta. The main characteristics of each measurement are summarized in Table 1. We also quote the integrated luminosities for which data were collected in each configuration and the pair detection efficiencies resulting from the application of various selection criteria to obtain good rejection against hadrons and other backgrounds.

In the " $e\mu$ " measurement [2] we detected $e^+\mu^\pm$ pairs having $\Delta\phi \approx \pi/2$. The magnetized iron spectrometer was designed to give the muon charge, but was not sufficiently accurate to provide a measurement of the muon momentum. While the invariant mass distribution of the detected $e\mu$ pairs is not measured, its lower cut-off is about 1.1 GeV/c². The most plausible interpretation of $e\mu$ events is charm production.

In the "same-side" measurement [3] we detected e^+e^- pairs having $\Delta\phi \approx 0$. The measured invariant mass distribution is dominated by ρ meson decays above $0.7 \text{ GeV}/c^2$ and by Dalitz decays of ϕ and η mesons below $0.2 \text{ GeV}/c^2$. We restrict the present analysis to the mass interval $0.2 < m < 0.6 \text{ GeV}/c^2$, where their contributions can be reliably subtracted. It should be noted, however, that processes other than charm production may contribute to this mass range. For example, if single photons were directly produced at a rate of 1% of that of neutral pions, we estimate, using a simple description of internal conversion [5], a 25% contribution to the electron-pair data in the mass range of this analysis.

In the "opposite-side" measurement [4] we detected e^+e^- pairs having $\Delta\phi \approx \pi$. We restrict the present analysis to masses below $2.2 \text{ GeV}/c^2$ for which the J/ψ radiative tail is very small and can easily be subtracted. High-mass dilepton spectra are known to be correctly described by the Drell-Yan mechanism [6]; although such a description cannot be reliably extended to the region below the J/ψ , a substantial contribution from direct electron pairs cannot be excluded.

3. THE MODEL

We assume that in the central rapidity region, to which the present analysis is restricted, charm production is dominated by $D\bar{D}$ pair production. The production of other charmed mesons, as well as that of charmed baryons, is not explicitly taken into account. The semi-leptonic decays of the $D(1865)$ are assumed to have a 5% branching fraction [7] for each of the four channels $K\ell\nu$, $K^*(892)\ell\nu$, and $K^*(892)\mu\nu$. We use the calculation of Ali and Yang [8] to describe the momentum spectrum of the decay leptons. For the model to be completely defined the $D\bar{D}$ production mechanism must still be specified. In our model, its main features are inspired from the properties of hadronic production of lighter hadrons. Bourquin and Gaillard [9], using the results of an extensive phenomenological analysis of various production data, have proposed a model in which the production of a $D\bar{D}$ cluster and its subsequent isotropic decay into a D and a $\bar{D}$ mesons are treated independently. We retain this factorization hypothesis but do not specify the distributions of the cluster transverse momentum p_T and of the cluster mass

$M = 2(M_D^2 + q^2)^{1/2}$ (q is the D momentum in the cluster rest frame). In the Bourquin-Gaillard model these distributions are extrapolated from $p\bar{p}$ data, but the mechanisms of $D\bar{D}$ production and of $p\bar{p}$ production may differ substantially [10]. Our lepton-pair data limit the ranges in which these distributions can vary, since each of the three measurements explores different kinematic regions of the $D\bar{D}$ system: the "opposite-side" measurement favours large-mass, low transverse momentum $D\bar{D}$ pairs, the "same-side" measurement favours low-mass, large transverse momentum $D\bar{D}$ pairs, and the $e\mu$ measurement corresponds to an intermediate situation. We assume exponential forms for the p_T^2 and q^2 distributions,

$$d\sigma/dp_T^2 \propto \exp(-p_T^2/2\alpha_p^2)$$

$$d\sigma/dq^2 \propto \exp(-q^2/2\alpha_q^2) .$$

We have checked that the final result is not sensitive to reasonable modifications of this assumption (such as using exponential forms in p_T and q). The Bourquin-Gaillard parametrization corresponds approximately to $\alpha_p \approx 1.13$ GeV/c and $\alpha_q \approx 0.31$ GeV/c.

Finally the $D\bar{D}$ cluster production cross-section is assumed to have a Gaussian rapidity-dependence, with variance $\alpha_y = 0.84$, closely resembling that of the Bourquin-Gaillard model. This is a reasonable assumption as long as we do not attempt an extrapolation of the production cross-section to small angles.

4. RESULTS

We first perform an analysis in which all electron pairs considered in Table 1 are assumed to originate from the semi-leptonic decay of charmed meson pairs. Using the model of the preceding section we vary α_p , α_q , and the $D\bar{D}$ production cross-section σ_{tot} , to reproduce the data of Table 1. The best fit, $\chi^2 = 8.0$ for 5 degrees of freedom, is obtained for

$$\sigma_{tot} = 21.9 \pm 5.0 \text{ } \mu\text{b}$$

$$\alpha_p = 1.40 \pm 0.15 \text{ GeV/c}$$

$$\alpha_q = 0.73 \pm 0.11 \text{ GeV/c} .$$

The corresponding numbers of events calculated for each of the three experiments are listed in Table 1, where they are compared to the data. The value obtained for α_q is significantly larger than that of the Bourquin-Gaillard model. As a result, the mean transverse momentum of inclusively produced D mesons is $\approx 1.16 \pm 0.08$ GeV/c, compared to ≈ 0.8 GeV/c in the Bourquin-Gaillard model.

In the opposite-side measurement, the observed mean transverse momentum of the electron pair is 0.45 ± 0.04 GeV/c. However, this quantity is determined by the detector acceptance and is well reproduced by the model for a wide range of α_p and α_q : its inclusion in the fit provides no additional constraint.

The transverse momentum distribution of the decay electron, calculated for the parameters of the best fit, is shown in Fig. 2 as a ratio to inclusive pion production [11]. It reaches $\approx 0.8 \times 10^{-4}$ at ≈ 1.4 GeV/c transverse momentum and accounts for a large fraction of the data of Büsser et al. [12]. Finally we note that the value obtained for σ_{tot} corresponds to a cross-section of 10.1 ± 2.3 μb per unit of rapidity in the central region; owing to the limited angular acceptance of the detector, it is this quantity, rather than σ_{tot} , which is actually measured in the present experiment.

We perform another analysis in which we consider the results of each electron pair measurement to provide an upper bound for charm production. For each value of the pair of parameters (α_p, α_q) , we evaluate the value of σ_{tot} above which the number of predicted events becomes too large (by 2 standard deviations) in at least one of the eight measurements listed in Table 1. The measurements limiting σ_{tot} vary over the (α_p, α_q) plane as expected from the different lepton-pair configurations to which they correspond. This is illustrated in Fig. 3, where the upper limit (95% confidence level) of the $D\bar{D}$ production cross-section per unit of rapidity in the central region is displayed versus α_p and α_q . It never exceeds 33 μb per unit of rapidity, a value corresponding to $\alpha_p = 0.7$ GeV/c, $\alpha_q = 0.15$ GeV/c.

5. SUMMARY

A consistent description of lepton-pair data collected in three different configurations has been obtained, corresponding to a $D\bar{D}$ production cross-section

of $10.1 \pm 2.3 \mu\text{b}$ per unit of rapidity in the central region. Upper limits for charm production have been evaluated for different values of the parameters describing $D\bar{D}$ production; they never exceed $33 \mu\text{b}$ per unit of rapidity to 95% confidence level.

Acknowledgements

We wish to acknowledge very fruitful conversations with Drs. M. Bourquin, D. Drijard and J.-M. Gaillard.

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Table 1
Number of measured and calculated events in the three measurements

Measurement	Acceptance ($ y \leq 0.5$)	Efficiency (%)	Luminosity (10^{37} cm^{-2})	Mass range (GeV/c^2)	Number of events	
					Measured	Calculated
$e\mu$ (Ref. 2)	$ \Delta\phi - \pi/2 \lesssim 0.4$ $p(e) \gtrsim 0.6 \text{ GeV}/c$ $p_T(\mu) \gtrsim 1 \text{ GeV}/c$	14 ± 3	2.0	-	32 ± 16	41.7
Same-side (Ref. 3)	$ \Delta\phi \lesssim 0.4$ $p(e) \gtrsim 0.5 \text{ GeV}/c$ $p_T(e^+e^-) \gtrsim 2.3 \text{ GeV}/c$	33 ± 4.5	2.8	0.2 to 0.4 0.4 to 0.6	22 ± 12.4 43 ± 7	45.3 32.3
Opposite- side (Ref. 4)	$ \Delta\phi - \pi \lesssim 0.4$ $p(e) \gtrsim 0.6 \text{ GeV}/c$	28 ± 4	2.8	1.2 to 1.4 1.4 to 1.6 1.6 to 1.8 1.8 to 2.0 2.0 to 2.2	22 ± 7.2 43 ± 7.7 49 ± 8.2 22 ± 7.0 14 ± 9.8	21.2 43.8 39.9 27.7 17.1

Figure captions

Fig. 1 : Schematic cross-section of the three-arm spectrometer normal to the beams. The two electron arms, labelled 1 and 2, contain a drift chamber stack (DC), a magnet (M), a Čerenkov counter (C), another drift chamber stack (DC), and a lead-glass array (LG). The muon arm, labelled 3, contains an absorber, a proportional chamber stack (PC), a magnetized iron absorber, and another proportional chamber stack (PC). Events of the e_1e_1 or e_2e_2 type are recorded in the same-side electron-pair experiment of Ref. 3, events of the e_1e_2 type in the opposite-side electron-pair experiment of Ref. 4, and events of the $e_1\mu$ or $e_2\mu$ type in the experiment of Ref. 2.

Fig. 2 : The electron-to-pion ratio as a function of transverse momentum, calculated with the parameters of the best fit described in the text ($\sigma_{\text{tot}} = 21.9 \mu\text{b}$, $\alpha_p = 1.40 \text{ GeV/c}$, $\alpha_q = 0.73 \text{ GeV/c}$).

Fig. 3 : Lines of constant upper limits to the charm production cross-section per unit of rapidity in the (α_p, α_q) plane, labelled in microbarns per unit of rapidity. In the region on the left-hand side of the dotted line (labelled O.S.) upper limits are obtained from the opposite-side data; on its right hand side (S.S.) from the same-side data.

Fig. 1

Fig. 2

Fig. 3