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Meson-Resonance Production in p-p Interactions at 53-GeV (c.m.) Energy

A. Böhm
III. Physikalisches Institut der Technischen Hochschule Aachen, Aachen, Germany

and

G. Van Dalen, A. Kernan, J. Layter, and B. Shen
University of California, Riverside, California 92502

and

F. Ceradini, F. Muller, B. Naroska, M. Nussbaum,[a] A. Orkin-Lecourtois, and C. Rubbia[b]
CERN, Geneva, Switzerland

and

D. DiBitonto
Harvard University, Cambridge, Massachusetts 02138

and

J. Irion, D. Schinzel, H. Seebrunner, A. Staude, R. Tirler, R. Voss, and Č. Zupančič
Sektion Physik der Universität, Munich, Germany

and

M. Block
Northwestern University, Evanston, Illinois 60201
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At the CERN intersecting storage ring the inclusive differential cross section $[d\sigma/d\sigma]_{y=1}$ has been measured for f^0, g^0, $K^{*0}(1420)$, and $\bar{K}^{*0}(1420)$ production: We obtain 0.58 ± 0.05 mb, 0.09 ± 0.05 mb, 38 ± 15 μb, and 26 ± 13 μb, respectively. The corresponding total inclusive cross sections are estimated to be 2.62 ± 0.26 mb, 0.40 ± 0.22 mb, 154 ± 60 μb, and 107 ± 52 μb, respectively. The magnitude of the K^* cross section implies a cross section of approximately 5 μb for production of a charmed $D\bar{D}$ pair.

A variety of models exist for particle production in high-energy ($\sqrt{s}\gtrsim 20$ GeV) hadronic interactions. In order to discriminate between these models production cross sections for a range of masses and flavors are needed. In fact, apart from the ψ and Υ states there is virtually no information to date on the production of mesons with mass above 1 GeV. We report here a measurement of the total inclusive cross section for f^0, g^0, $K^{*0}(1420)$, and $\bar{K}^{*0}(1420)$ production in proton-proton interactions at c.m. energy of 53 GeV.[1]

The experiment was carried out at the CERN intersecting storage ring (ISR). The apparatus (Fig. 1) consisted of two magnetic spectrometers, each furnished with four multiwire-proportional-chamber modules. The spectrometers $S1$ and $S2$ were in the horizontal plane on either side of

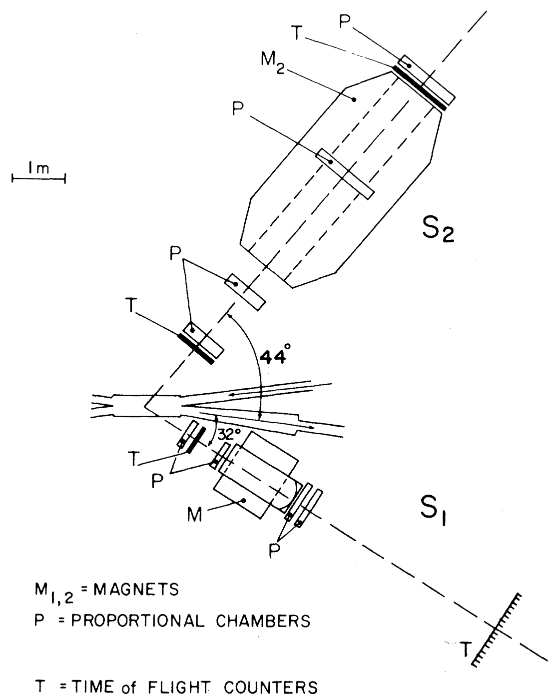

FIG. 1. Spectrometers $S1$ and $S2$ at intersection $I6$ of the CERN ISR.

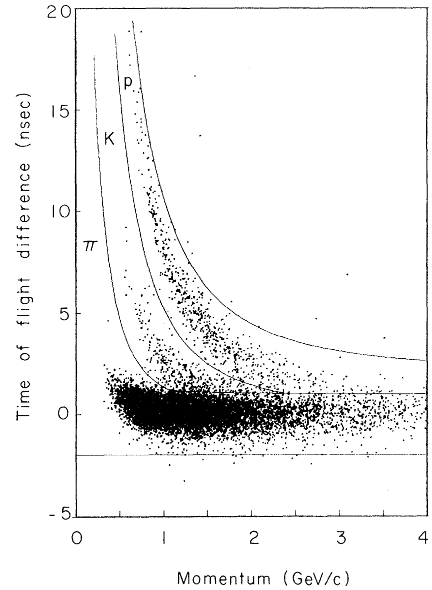

FIG. 2. Time of flight vs momentum for a sample of negative particles in the spectrometer $S1$. Identification criteria for π, K, and p are indicated. Time of flight is expressed relative to that for $\beta = 1$ particles.

beam 2 at 32° and 44°, respectively. The spectrometer acceptances for high-momentum particles were 11.6 and 25.2 ms, respectively, with low-momentum cutoffs at 0.5 and 0.7 GeV/c respectively. Spectrometer $S1$ had a momentum resolution $\delta p/p$ of 2.9% (standard deviation) for 2 GeV/c pions. The momentum resolution of spectrometer $S2$ was $\delta p/p$ of 1.6% for 2-GeV/c pions. The mass resolution is determined by $\delta p/p$ and was calculated to be $\delta M/M$ of 0.017. The spectrometers have been described in detail elsewhere.[2,3]

Time-of-flight measurement was used in each spectrometer for particle identification. The measurement accuracy was 0.5 nsec (standard deviation) for a path length of 6.5 m in each spectrometer. Figure 2 shows time of flight versus momentum for a sample of negative tracks in spectrometer $S1$. Particles were identified as pion, kaon, or proton/antiproton according to which of these three hypotheses best fit the measured time of flight and momentum. Because the largest fraction of all hadrons at the present ISR energies [~ 53 GeV (c.m.)] are pions, particles with time of flight within 1 nsec (2 standard deviations) of that expected for pions up to 1.2 GeV/c are correctly identified, as are 90% of protons up to 2.0 GeV/c. With these identification criteria no kaons are identified above 2.3 GeV/c. Contamination of the proton-antiproton and kaon samples is estimated at less than 10% and 30%, respectively, and occurs primarily above 2.0 and 1.2 GeV/c, respectively.

The trigger requirement was at least one charged particle in each spectrometer. In 100 h of ISR running at c.m. energy of 53 GeV and an average luminosity of 1.5×10^{31} cm^{-2} sec^{-1}, a total of about 1.5×10^{6} triggers were recorded, The integrated luminosity was obtained from a luminosity monitoring system operated during the data taking. The effective integrated luminosity was 2.7×10^{36} cm^{-2}, taking into account the efficiency of particle reconstruction and apparatus dead time. Data processing yielded 659 083 events with one track in each spectrometer. The fraction of pions, kaons, and proton-antiprotons in the events was 0.84, 0.05, and 0.11, respectively.

Figures 3(a) and 4(a) show invariant-mass distributions for the 235 620 $\pi^+\pi^-$ and 28 462 $K^\pm\pi^\mp$ events, respectively. The cutoff around 1 GeV/c^2 in invariant mass is due to acceptance. In order to detect the presence of resonances these experimental distributions have been compared with "background" distributions obtained by randomly combining particles from different events into

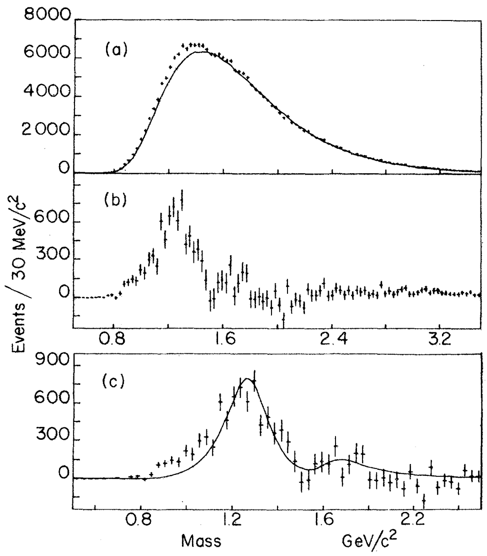

FIG. 3. (a) Invariant-mass plot for $\pi^+\pi^-$; the smooth curve is a background distribution as described in the text. (b) Difference between observed and background distribution in (a). (c) Same as (b) with fit of two coherent Breit-Wigner amplitudes.

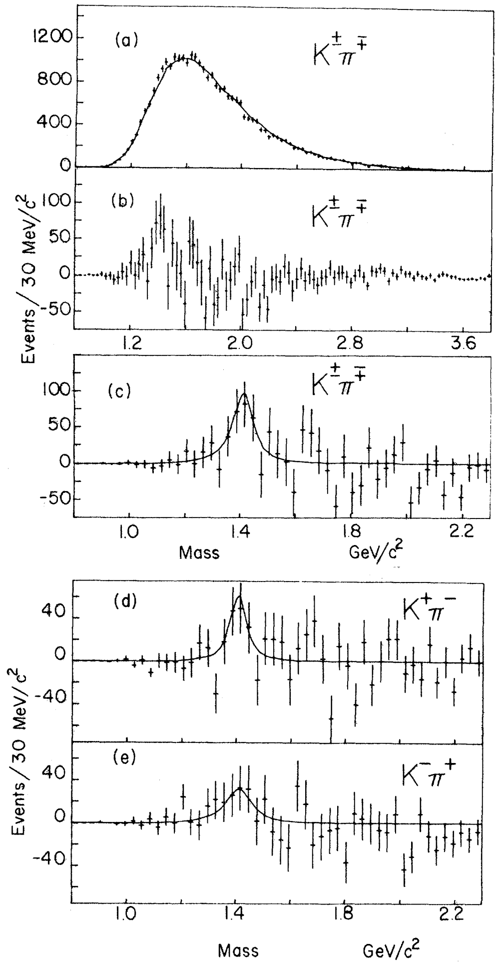

FIG. 4. (a) Invariant-mass plot for $K^+\pi^-$ and $K^-\pi^+$ combined; the smooth curve is a background distribution as described in the text. (b) Difference between observed and background distribution in (a). (c) Same as (b) with superimposed Breit-Wigner form. (d) Same as (c) for $K^+\pi^-$. (e) Same as (c) for $K^-\pi^+$.

pairs. This procedure takes into account the spectrometer acceptances and can give distributions with an order of magnitude more statistical precision than the actual data. A total of over 9 $\times 10^6$ "background" events were generated and assigned a weight of 659 038, equal to the total number of experimental events. The smooth curves in Figs. 3(a) and 4(a) are the $\pi^+\pi^-$ and $K^\pm\pi$ background distributions.

The experimental signal remaining after background subtraction is displayed in Figs. 3(b) and 4(b). In the $\pi^+\pi^-$ distribution [Fig. 3(b)] there is a prominent structure at about 1.25 GeV/c^2 and one less prominent around 1.7 GeV/c^2. These structures are most readily associated with $f^0(1270)$ and $g^0(1680)$ which are known to decay strongly to $\pi^+\pi^-$.[4] The structure in Fig. 4(b) around 1.4 GeV/c^2 may correspond to $K^{*0}(1420)$ and its charge conjugate. For $M_{K\pi} \sim 1.4$ GeV the kaon is in the momentum range 0.8–1.4 GeV/c [following from $M_{12}{}^2 \simeq 2p_1p_2(1-\cos\theta_{12})$], and hence is well identified (see Fig. 2).

In order to verify the production of these resonances the structures in Figs. 3(b) and 4(b) fitted with a Breit-Wigner form; the Breit-Wigner amplitude was modified to include the dependence of invariant mass on acceptance as determined by a Monte Carlo calculation (see below). The $\pi^+\pi^-$ mass spectrum to Fig. 3(b) was fitted with a coherent sum of two Breit-Wigner amplitudes. The masses of f^0 and g^0 were fixed at 1.27 and 1.63 GeV/c^2 corresponding to the centers of the observed structures, and compatible with measured values[4]; the widths were fixed at 0.25 GeV/c^2. The magnitudes and relative phase of the Breit-Wigner forms were varied in the fit. The fitted curve [Fig. 3(c)] corresponds to a total of 6564 $\pm$ 646 f^0 events and 1399 $\pm$ 760 g^0 events.

Figure 4(c) shows a Breit-Wigner fit to the structure at 1.4 GeV/c^2 in the $K^\pm\pi^\mp$ distribution. The mass and width of the K^{*0} as well as the number of resonance events were variables in the fit. A total of 360 $\pm$ 111 events are seen for a K^* of mass 1411 $\pm$ 14 MeV/c^2 and Γ of 82 $\pm$ 34 MeV/c^2, consistent with the mass and width expected for the $K^{*0}(1420)$.[4] Similar fits to the separate $K^+\pi^-$

TABLE I. Masses, widths, and cross sections for f^0, g^0, and $K^*(1420)$ measured in this experiment. The data have been corrected for unobserved decay modes. The last column shows the cross sections predicted by the Bourquin-Gaillard particle production model (Ref. 5).

Resonance	Mass[a] (MeV/c^2)	Width[a] (MeV/c^2)	Observed events	$[d\sigma/dy]_{y=1}$	σ	$\sigma_{\text{B-G}}$
f^0	1270	250	6564±646	0.58±0.05 mb	2.62±0.26 mb	1.48 mb
g^0	1630	250	1399±760	0.09±0.05 mb	0.40±0.22 mb	.42 mb
$K^{*0}(1420)$	1407±15	61±32	197±77	38±15 μb	154±60 μb	167 μb
$\bar{K}^{*0}(1420)$	1412±30	109±61	156±76	26±13 μb	107±52 μb	167 μb
$K^{*0}+\bar{K}^{*0}$	1411±14	82±34	360±111	65±20 μb	261±81 μb	334 μb

[a] f^0 and g^0 masses and widths were fixed.

and $K^-\pi^+$ data are displayed in Figs. 4(d) and 4(e). Results of the fits are summarized in Table I.

The acceptance of the apparatus for f^0, g^0, and $K^*(1420)$ is limited to c.m. rapidity $y \simeq 0.9-1.2$ and $p_T \simeq 0.0-1.0$ GeV/c. In order to determine the total production cross section of these resonances it is necessary to know the dependence of the production process on y, p_T, and particle mass. We have made a Monte Carlo calculation of the acceptance of our apparatus using the Bourquin-Gaillard (B-G) parametrization of $d^2\sigma/dy\,dp_T$ as a model for particle production, and assuming isotropic decay of the resonances.[5] The resulting values of σ and $[d\sigma/dy]_{y=1}$ are given in Table I.

The total cross sections in Table I depend upon the validity of the Bourquin-Gaillard parametrization of differential inclusive cross sections. We remark that the B-G formula has been very successful in describing the inclusive distributions of the "nonleading" particle from π to J/ψ and ψ' over a wide range of energy.[5] We also note that the measured total inclusive cross sections in Table I are in reasonable agreement with the predictions of the B-G cross-section formula[5]:

$$\sigma(\text{cm}^2) = 0.4\times 10^{-20} y_{\max}^{\;2} \times \exp(-5.13/y_{\max}^{\;0.38}) \frac{M}{(M+2)^{12.3}} .$$

For $K^*(1420)$ production a mass M of 1420 + 495 MeV/c^2 is used in this formula, reflecting Bourquin and Gaillard's assumption of the production of a composite $S=0$ system, i.e., local conservation of strangeness. According to this formula the inclusive cross section, $\sigma_{D\bar{D}}$, for production of a charmed $D\bar{D}$ pair should be about 4% of the cross section for production of $[K^*(1420)+\bar{K}]$. Thus the $K^{*0}(1420)$ observed cross section implies $\sigma_{D\bar{D}} = 5\pm 2$ μb. It should be emphasized that the total cross sections given here are based on the assumption of dominant central ($x\simeq 0$) production and do not include contributions from diffractive particle production (i.e., "leading" particles).

A recent study of ω^0, ρ^0, and $K^*(890)$ production in proton-proton interactions at $\sqrt{s}$ of 53 GeV gave a ratio of 0.5 ± 0.2 and 0.36 ± 0.13 for K^*/ρ and K^*/ω, respectively.[6] In that work, which lacked kaon identification, it was argued that $K^*(890)$ production may be comparable with ρ and ω production since these three mesons are members of the same SU(3) nonet. In the present experiment, which has kaon identification, we find that for f^0 and $K^*(1420)$ which belong to the same $(J^P)C_n = (2^+)+$ nonet the ratio $K^*(1420/f^0$ is 0.06 ± 0.02.

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(a) Permanent address: Physics Department, University of Cincinnai, Cinciniati, Ohio.

(b) Also at Harvard University, Cambridge, Mass.

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