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PRODUCTION AND DECAYS OF D^* MESONS¶

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ABSTRACT

We report measurements of inclusive π^0 and γ production in e^+e^- annihilation at c.m. energy $E_{c.m.} = 4.028$ GeV with the Crystal Ball detector at SPEAR. The decays $D^* \to \pi^0 D$, $D^* \to \gamma D$ are observed and allow determination of the D^{*0}-D^0 mass difference, production ratio and γ/π^0 decay ratio's. In addition, the resonance parameters of the $\psi''(3770)$ resonance are given.

The total hadronic cross section in e^+e^- annihilation is dominated above open charm threshold by the $\psi''(3770)$ resonance, which decays into $D\bar{D}$ pairs, and resonances above 4 GeV of which the one centered at $E_{c.m.} = 4.028$ GeV decays into charmed meson pairs containing predominantly D^*. Comparison of inclusive π^0 and γ spectra taken at these two resonances yield information about the production of D^*'s and their decay into D's.

The apparatus and the selection procedure for hadronic events are described elsewhere.[1] Figure 1a shows the relative hadronic cross section R as function of c.m. energy: it is characterized by the radiative tails of the ψ and ψ' resonances above a non-charmed background and shows the ψ'' at $E_{c.m.}$ = 3770 MeV:

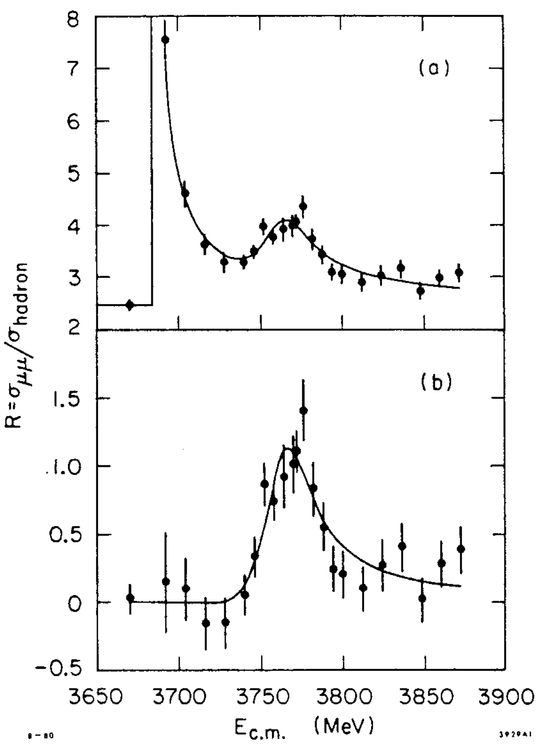

Fig. 1. (a) Relative hadronic cross section $R \equiv \sigma_{HAD}/\sigma_{\mu\mu}$ near the ψ''. The solid line is the fit to (1). (b) R of the ψ'' contribution.

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$$R = R_{\text{NON-CHARM}} + \psi_{\text{RAD TAIL}} + \psi'_{\text{RAD TAIL}} + \psi'' \qquad (1)$$

Assuming a non-relativistic Breit-Wigner resonance form of the ψ'' with an energy dependent width due to the closeness of the $D\bar{D}$ threshold,[2] the mass M, hadronic width Γ and leptonic width Γ_{ee} of the ψ'' can be determined. Figure 1b shows the ψ'' resonance after subtracting all other contributions. In Table I, the results of the fit are given and compared with previous measurements, with which they agree well.

TABLE I
ψ'' Resonance Parameters

Experiment	Mass* (MeV)	Γ_{ee} (eV)	Γ (MeV)
Crystal Ball	3768 ± 2	308 ± 56	36 ± 8
LGW[2]	3772 ± 3	345 ± 85	28 ± 5
Delco[3]	3770 ± 2	180 ± 60	24 ± 5
Mark II[4]	3764 ± 2	276 ± 50	24 ± 5

* The mass determination of all experiments have a common additional uncertainty of 4 MeV due to the absolute SPEAR energy calibration.

The resonance at $E_{c.m.} = 4.028$ GeV serves as a source of D^*, the decay of which into $D\pi^0$ or $D\gamma$ will result in almost monochromatic π^0 or γ's due to the low Q value of production and decay. The width of the π^0 or γ energy distribution depends on the particle recoiling against the D^*: for example, if the D^{*0} is produced in the mode $D^{*0}\bar{D}^{*0}$ the decay π^0's have energies from 138-147 MeV and the decay γ's have energies from 122-157 MeV, while if the D^{*0} is produced in the mode $D^{*0}\bar{D}^0$, the π^0 has energies from 135-160 MeV and the γ has energies from 87-185 MeV. Previous information of the π^0 and γ decay of the D^* came from D recoil spectra as measured by the Mark I.[5] Here we will measure the π^0 and γ directly.

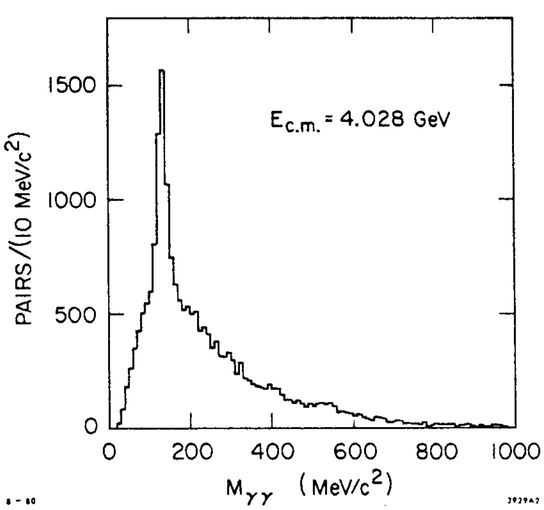

Fig. 2. Mass of all γ-γ pairs of 18k hadronic events at $E_{c.m.}$ = 4.028 GeV.

In order to determine the π^0 energy spectrum, the invariant masses of all $\gamma\gamma$ pairs in each event are calculated (Fig. 2). A prominent peak at the π^0 mass is observed above a background from uncorrelated pairs. The pairing which maximizes the number of π^0 is chosen and by constraining the masses to the π^0 mass, the energies of the photons $E_{\gamma 1}$, $E_{\gamma 2}$ are fitted and summed to form the π^0 energy $E_{\pi^0} = E_{\gamma 1} + E_{\gamma 2}$. Fig. 3a shows the low energy part

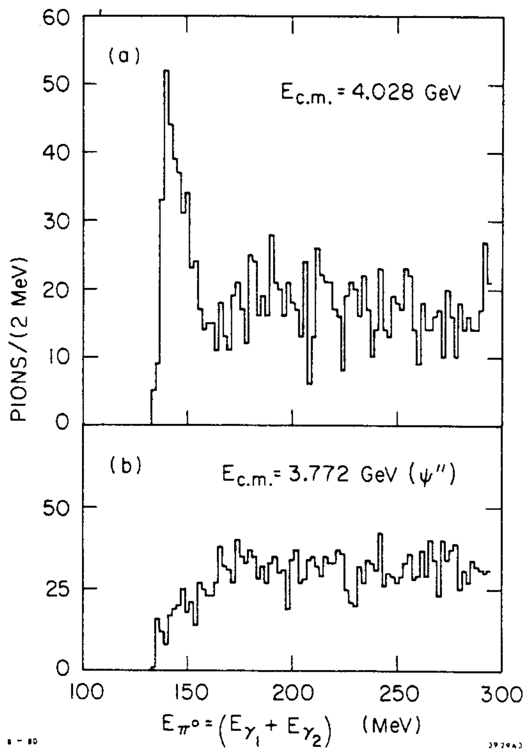

Fig. 3. (a) Energy spectrum of π^o's at $E_{c.m.} = 4.028$ GeV. (b) Energy spectrum of π^o's at $E_{c.m.} = 3.772$ GeV.

of the π^o spectrum for 18k hadronic events at $E_{c.m.} = 4.028$ GeV and Fig. 3b the corresponding spectrum from 36k hadronic events at the ψ'', which is below the D^*D threshold. A distinct peak from the decay $D^* \to \pi^o D$ is seen for $E_{c.m.} = 4.028$ GeV (Fig. 3a) above the background from D decays and non charmed background as determined at the ψ'' (Fig. 3b).

The π^o spectrum is fitted with the smooth ψ'' background and the contribution from a Monte Carlo simulation of the following sources of π^o: (i) $D^{*o}\bar{D}^{*o} \to D^o\pi^o$; (ii) $D^{*o}\bar{D}^o + \bar{D}^{*o}D^o \to D^o\pi^o$; (iii) $D^{*+}D^{*-} \to \pi^o D^+$; and (iv) $D^{*+}D^- + D^{*-}D^+ \to \pi^o D^+$ as a function of the charmed meson masses $m(D^{*o})$, $m(D^o)$.[6] The fit gives the product of production cross section σ_j and decay branching ratios, BR, into π^o for the different D^* modes (i)-(iv). The spectrum is sensitive to the $D^{*+}D^{*-}/D^{*o}\bar{D}^{*o}$ ratio, the D^{*o}-D^o mass difference and the $D^*\bar{D}^*/D^*\bar{D}$ production ratio. The relative contribution of $D^{*o}\bar{D}^o$ and $D^{*+}D^-$ cannot be determined. A typical fit to the π^o energy spectrum is shown in Fig. 4.

We determine the contribution from $D^{*+}D^{*-}$ production to be small and find

			Mark I[5]
$m(D^{*o}) - m(D^o)$	=	$142.2 \pm 0.5 \pm 1.5$	(142.7 ± 1.7)
$m(D^{*o})$	=	$2006 \pm 2 \pm 1.5$	(2006 ± 1.5)
$m(D^o)$	=	$1864 \pm 2 \pm 1.5$	(1863.3 ± 0.9)

where the first error is statistical and the second error an estimate of the systematical uncertainties. The previous measurements from Mark I[5] are in parenthesis. The production rate times branching ratios are:

$$\frac{\sigma(D^{*+}D^{*-}) \cdot BR(D^{*+} \to \pi^o D^+)}{\sigma(D^{*o}\bar{D}^{*o}) \cdot BR(D^{*o} \to \pi^o D^o)} < 0.11 \quad (90\%\ \text{C.L.})$$

$$\frac{\sigma(D^{*o}\bar{D}^o + \bar{D}^{*o}D^o) BR(D^{*o} \to \pi^o D^o) + (D^{*+}D^- + D^{*-}D^+) BR(D^{*+} \to \pi^o D^+)}{\sigma(D^{*o}\bar{D}^{*o}) BR(D^{*o} \to \pi^o D^o)} = 2.47 \pm 0.61$$

If we assume reasonable branching ratios[5] $BR(D^{*+} \to \pi^o D^+) = 0.3$ and $BR(D^{*o} \to \pi^o D^o) = 0.6$ and also $\sigma(D^{*o}\bar{D}^o) = \sigma(D^{*+}D^-)$ we get

$$r \equiv (\sigma(D^{*o}\bar{D}^o) + \sigma(\bar{D}^{*o}D^o))/\sigma(D^{*o}\bar{D}^{*o}) \approx 1.6$$

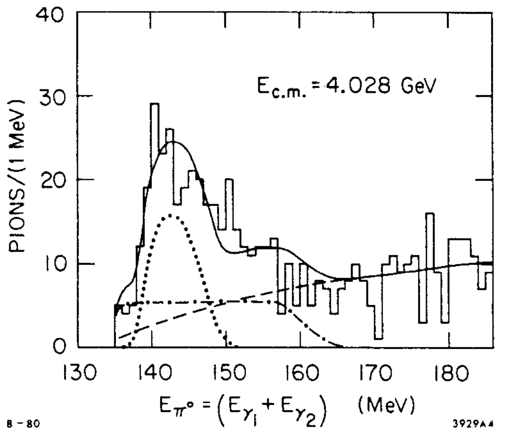

Fig. 4. Energy spectrum of π^o at $E_{c.m.} = 4.028$ GeV with fitted contributions from ψ'' background (---), $D^{*o}\bar{D}^{*o}$ (···) and D^*D (-·-·). ($M(D^{*o}) = 2006$, $M(D^o) = 1863$.)

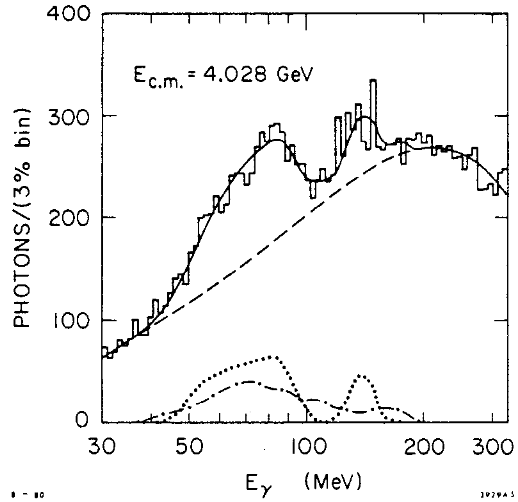

Fig. 5. Energy spectrum of γ's at $E_{c.m.} = 4.028$ GeV with contributions from ψ'' background (---), $D^{*o}\bar{D}^{*o}$ (···) and $D^{*o}\bar{D}^o$ (-·-·).

(in agreement with the measurement of Mark I[5] $r = 0.95 \pm 0.34$ and theoretical prediction of the Cornell group[7] $r = 1.35$).

Additional information about D^* decays comes from the photon spectrum at $E_{c.m.} = 4.028$ GeV. Again the spectrum is fitted to a background from D decays and non-charmed background as determined at the ψ'' resonance and contributions from a Monte Carlo simulation of $D^*\bar{D}^*$ and $D^*\bar{D} + \bar{D}^*D$ production with subsequent decays into π^o and γ's. Figure 5 gives the inclusive spectrum which shows (above the ψ'' background) contributions from $D^* \to D\pi^o \to \gamma\gamma$ (centered at $E_\gamma = 70$ MeV) and $D^* \to D\gamma$ (centered at 140 MeV). The relative population of the two peaks allows to compute the branching ratio into γ's directly:

$$\frac{\sum \sigma_i(D^*)BR_i(D^* \to \gamma D)}{\sum \sigma_i(D^*)\left(BR_i(D^* \to \gamma D) + BR_i(D^* \to \pi^o D)\right)} = 0.31 \pm 0.06$$

where the sum extends over production of $D^{*o}\bar{D}^{*o}$, $D^{*+}D^{*-}$, $D^{*o}\bar{D}^o + \bar{D}^{*o}D^o$, $D^{*+}D^- + D^{*-}D^+$, respectively. The error reflects the uncertainty in the background subtraction. In order to deduce the $BR(D^{*o} \to \gamma D^o)$, we make the following assumptions, as suggested by the fit to the π^o spectrum, the Mark I measurements[5] and theoretical calculations[8]:

$$\sigma(D^{*+}D^{*-})BR(D^{*+} \to \pi^o D^+) \ll \sigma(D^{*o}\bar{D}^{*o})BR(D^{*o} \to \pi^o D^o)$$

$$\sigma(D^{*+}D^{*-})BR(D^{*+} \to \gamma D^+) \ll \sigma(D^{*o}\bar{D}^{*o})BR(D^{*o} \to \gamma D^o)$$

$$\sigma(D^{*+}D^-)\ BR(D^{*+} \to \gamma D^+) \ll BR(D^{*o}\bar{D}^o)BR(D^{*o} \to \gamma D^o)$$

$$\sigma(D^{*+}D^-) = \sigma(D^{*o}\bar{D}^o)$$

$$BR(D^{*+} \to \pi^o D^+) = 0.3$$

We get $BR(D^{*o} \to \gamma D^o) \approx 0.37$ in agreement with the Mark I measurement[5] $BR(D^{*o} \to \gamma D^o) = 0.45 \pm 0.15$.

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