A SHORT PSION TOUR

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Abstract : Topics covered are (i) J/ψ radiative and two-body hadronic decays. (ii) The J^{PC} problem for c = + states between J/ψ - ψ'. (iii) The complex structure of R or σ_{tot} for $3.8 < \sqrt{s} \leq 4.6$ GeV. (iv) Charm signals in $e^+e^- \to \ell^\pm + x$ and $e^+e^- \to \mu e$ + hadrons.

Introduction

My brief is on psion phenomenology, which I take to mean e^+e^- physics up to about 5 GeV. The glamorous region is above 3.8 GeV. Nevertheless, the existence of much excellent data at J/ψ and ψ' obliges us to look at these states. We can expect them to provide us with information on the new particles themselves, and on meson spectroscopy at lower energies through J/ψ hadronic decays[1].

Above 3.8 GeV the obsessive questions are

(i) why is σ_{tot} so complicated?

(ii) where is the charm signature almost everybody expects?

(iii) is there really a heavy lepton? You will hear about this from Perl.

The new particles will be assumed to be built of heavy quarks (e.g. $c\bar{c}$). I follow custom and ignore color models. This should not be taken to mean that they are definitely excluded by data.

J/ψ

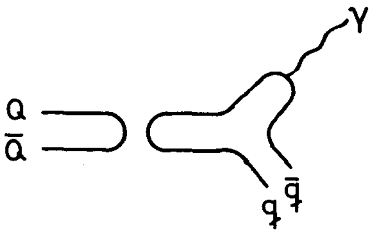
a) Radiative Decays[2]

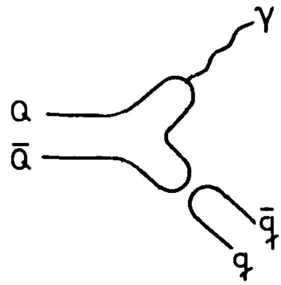
These are strikingly big - no sign of an $O(\alpha)$ suppression of $\eta\gamma$ relative to $\pi^o\rho^o$, for example.

Table 1

J/ψ	Γ	
$\pi^o\rho^o$	300 ±120 eV	(SLAC-LBL)
$\eta'\gamma$	(4 ±2.5) $\eta\gamma$	(DESY - HEIDELBERG)
$\eta\ \gamma$	95 ±29 eV	(DASP)
$x\ \gamma$	< 7 keV	(HEPL)
$\pi^o\gamma$	< 700 eV	(DASP)[2]
$\pi^+\pi^-\gamma$	< $\rho^o\pi^o$	

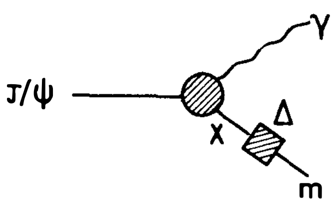
Vector dominance (ρ,ω,ϕ) would lead us to expect $\Gamma(\pi^0\gamma) \approx 1$ eV, $\Gamma(\eta\gamma) \approx \frac{1}{3}\Gamma(\pi^0\gamma)$ and $\Gamma(\eta'\gamma) \approx 0$. Radiative decays take place via the (quark model) diagrams:





The data seems to be telling us to ignore the first. At face value, the second implies $\Gamma(\eta'\gamma) \gg \Gamma(\eta\gamma) \gg \Gamma(\pi^0\gamma)$ [3]. This is because the singlet η' is favored to mix with $Q\bar{Q}$, η should be suppressed by $O(\sin^2\theta_{ps})$ - the mixing angle, $\theta_{ps} \sim -10^0$ - and $\pi^0\gamma$ is forbidden by isospin, $I_{Q\bar{Q}} = 0$.

To be quantitative, take the old pole model for mixing,



Then (ϵ is the $Q\bar{Q}$ content of the state up to first order in Δ):

$$\Gamma(J/\psi \to m\gamma) = |\epsilon_m(m^2)|^2\ \Gamma(J/\psi \to x\gamma) \cdot \mathrm{RMF}$$

$$\epsilon_m = \frac{\Delta(m^2)}{m_x^2 - m_m^2} \cdot \begin{cases} \cos\theta_{\eta'} & \text{for } \eta' \\ \sin\theta_\eta & \text{for } \eta \end{cases} \qquad (1)$$

$\Delta(m^2)$ is the mixing term in the singlet mass matrix and RMF stands for relative momentum factors[4]. Now if the mixing is pure singlet (no intrinsic SU_3 breaking),

$$\frac{\Gamma(\eta'\gamma)}{\Gamma(\eta\gamma)} \approx 4 \pm 2.5^{\,2} \quad \text{implies} \quad \begin{array}{lcl} |\epsilon_{\eta'}/\epsilon_{\eta}| & \approx & 2.1 \,, \\ |\Delta(m^2_{\eta'})/\Delta(m^2_{\eta})| & \approx & 0.4 \,. \end{array} \qquad (2)$$

The mass dependence of the mixing interaction has almost cancelled out the $\sin\theta$ suppression of $Q\bar{Q}$ content in the η. Alternatively, SU_3 braking in the light quark content of the x (as for J/ψ) could give a small $\eta'\gamma/\eta\gamma$ ratio with no m^2 dependence of Δ. In either case, this "solves" the puzzle of why $\psi' \to \eta J/\psi$ is so large (there is virtually no octet suppression as originally assumed)[5]. It <u>implies</u>[3]:

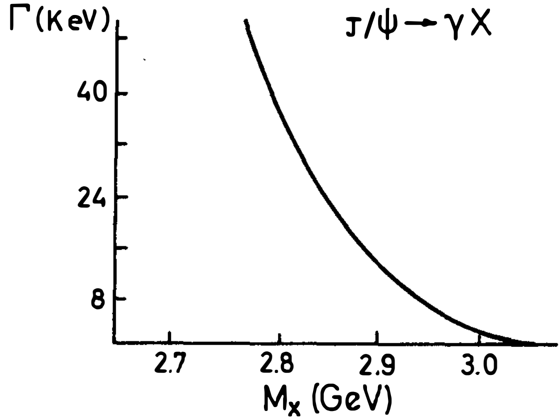
(i) $J/\psi \to \pi^o\gamma$, $A_2^o\gamma$ or $\pi_N^o\gamma$ very small (1 - 10 eV level).
Everything here rests on this!

(ii) $J/\psi \to \pi\pi\gamma$ and $K\bar{K}\gamma$ may also be big (at least for not too large dimeson mass and/or $J^{PC} = 0^{++}$).

(iii) $J/\psi \to f\gamma$ and $f'\gamma$ are small. This depends on $\Delta(m^2)$ being very small at m_f^2 (or for $J^{PC} = 2^{++}$) or on ideal mixing in the light quark sector implying very small $Q\bar{Q}$ content.
If this prediction fails, check $f'\gamma/f\gamma$ (1/2 for pure singlet mixing, << 1 for big SU_3 breaking as for J/ψ). Look for $J/\psi \to 4\,\pi^{\pm}\gamma$, $2\,\pi^{\pm}\,2\,K^{\pm}\,\gamma$, $N\bar{N}\,\gamma$ too

(iv) $$\frac{e^+e^- \to \eta' + J/\psi}{e^+e^- \to \eta + J/\psi} \approx \frac{J/\psi \to \eta'\gamma}{J/\psi \to \eta\,\gamma} \cdot \text{RMF} \quad \text{at, say, } \sqrt{s} \sim 4.2 \text{ GeV.}$$

The decay $J/\psi \to x\gamma$ remains. Using $\omega \to \pi^o\gamma$ or $\phi \to \eta\gamma$ times a Clebsch and a factor $m_V^2/m_{J/\psi}^2$ (to scale the magnetic moment of the constituents) charm gives the figure:

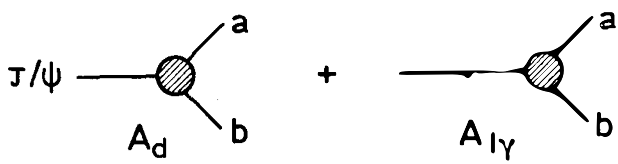


Even allowing a factor 2 error, the large expected $\Gamma(J/\psi \to x\gamma)$ may cause trouble for the quark model if $m_x \approx 2.8$ GeV.[2] What about the limits on decays like $x \to p\bar{p}$ or $x \to 4\,\pi\pm$? In any non relativistic $Q\bar{Q}$ model $\Gamma(x \to \gamma\gamma)/\Gamma(J/\psi \to e\bar{e}) = 3\,e^2$ where e = 2/3 for charm. Now we produce a comparative table (I take $B(J/\psi \to x\gamma \to 3\,\gamma) \sim 2 \cdot 10^{-4})^2$.

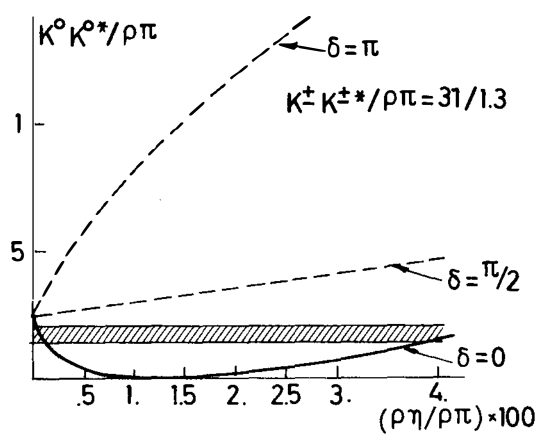
J/ψ		x	
$\frac{p\bar{p}}{e\bar{e}}$	$\sim .030 \pm .007$	$\frac{p\bar{p}}{\gamma\gamma}$	$\lesssim 1$ (2)
$\frac{4\,\pi^{\pm}\pi^{o}}{e\bar{e}}$	$\sim .58 \pm .16$	$\frac{4\,\pi^{\pm}}{\gamma\gamma}$	$\lesssim 10$?

The $4\,\pi^{\pm}/\gamma\gamma$ number is my guess from the SLAC-LBL data. An obvious (and crude) estimate from this is that $\Gamma(x) \lesssim 10 - 30\ \Gamma(J/\psi)$.

b) Two-Body Decays[6]



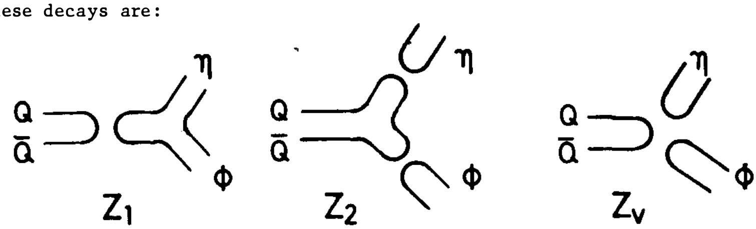
SU_3 says that $U_{J/\psi} = U_\gamma = 0$ implies $K^\pm \bar{K}^{*\mp}/\pi^\pm\rho^\mp = 1$. Data and p^3 phase space gives 0.42 ±.13. Converting this into light quark content, we get (assuming $A_{1\gamma} = 0$) (light quarks in J/ψ) ∝ $0.69(u\bar{u} + d\bar{d}) + 0.21\, s\bar{s}$ (23^o mixing into an octet $q\bar{q}$ state). Besides SU_3 breaking we have to remember that direct and 1γ amplitudes can be coherent[7] (e. g. for πρ, $K\bar{K}^*$; only 1γ survives for ηρ). Putting $\Gamma(ab) = |A_{1\gamma} + A_{direct}|^2$ and Re $A_{1\gamma}A_d = \cos\delta |A_{1\gamma}||A_d|$ it is straightforward to predict $K^oK^o/\pi\rho$ as a function of the ρη size for fixed $K^\pm \bar{K}^{*\mp}/\pi^\pm\rho^\mp$ (octet SU_3 breaking assumed). This checks on the possibility of big 1γ effects. Data is shown as a band:



The experimental fact that $K^o\bar{K}^{*o} \approx K^\pm \bar{K}^{*\mp}$ does <u>not</u> imply $A_{1\gamma} = 0$!

Evidently you neglect 1γ effects at your peril; nevertheless, I will do so in the following discussion. It is important to look for channels like $J/\psi \to \rho\eta$, $\Sigma^{0}\bar{\Lambda}$,...

There are two theoretically very interesting decays: $J/\psi \to \eta\phi$ and $\eta'\phi$ ($\eta\omega$ and $\eta'\omega$, also important, are hard to measure). The quark comic book diagrams for these decays are:



(Z_n means Zweig's rule is broken n times, and the first two diagrams correspond to mixing of $q\bar{q}$ in J/ψ and $Q\bar{Q}$ in η or φ; the last to possible Zweig's rule breaking in the vertex.)

We can now take two approaches. Conservative: $Z_o \gg Z_1 \gg Z_2 \gtrsim Z_{vertex}$. A growing number of radicals[8], led by Harari[5], like Z_2, Z_v to be big - perhaps dominant. A test:

$$\frac{\Gamma(J/\psi \to \eta\ \phi)}{\Gamma(J/\psi \to \eta\ \phi)} = \begin{cases} \frac{1}{2} & Z_1 \text{ only (assumes } SU_3) \\ \frac{\Gamma(J/\psi \to \eta'\gamma)}{\Gamma(J/\psi \to \eta\ \gamma)} & Z_2 \text{ only} \end{cases} \tag{3}$$

Of course, all three can be present and interfering. $\Gamma(\eta\phi)/\Gamma(\pi\rho)$ might turn out to be anomalously big if Z_2, Z_v are large, but SU_3 breaking and 1γ will make it hard to draw conclusions unless the effect is dramatic[9].

Similar remarks can be made about the ratio $\pi^+\pi^-\phi/\pi^+\pi^-\omega$ at small ππ masses. Big mixing of $u\bar{u} + d\bar{d}$ and $s\bar{s}$ in the ϵ(700) can make Z_1 (and $\pi^+\pi^-\phi/\pi^+\pi^-\omega$) larger than one would naively expect, assuming Z_2 only. If this is true it implies $f\phi/f\omega \ll 1$ and $f'\phi/f'\omega \gg 1$. As to inclusive J/ψ decays, we have the following schema ($d\sigma(a) = d\sigma^a/d^P$).

conservative	radical	
$d\sigma(\eta') \lesssim d\sigma(\eta)$	$d\sigma(\eta') >> d\sigma(\eta) >$	(4)
$\approx d\sigma(K_s) = d\sigma(K^+)$	$d\sigma(K_s) = d\sigma(K^+)$	
% events with η	% events with η	
$\lesssim$ % with $K\overline{K}$	>> % with $K\overline{K}$	

It is important to check for such effects; if found they would offer dramatic support for the ideas of references 5, 7. If they are not found, we will still learn something new about Zweig's rule.

ψ'

The direct decay $\psi' \to$ hadrons seems to amount to $\approx$ 10 – 20 keV [10]. This is comparable to the radiative width of ψ' to the P_c/χ states[11]. This does not seem too unreasonable (compare $\Gamma(\phi \to \eta\gamma)/\Gamma(\phi \to 3\pi) = 0.2$; remember that ϕ is built of charge $-1/3$ quarks, which suppresses $\Gamma(\phi \to \eta\gamma)$). On the other hand, $\psi' \to \gamma x$ has not been seen despite the much larger phase space compared to $\psi' \to \gamma\, P_c/\chi$. It is usually argued that this is because the ψ' and x wave functions are orthogonal[12], but there is not much evidence elsewhere for such suppressions (the small $\rho'(1600) \to \pi^+\pi^-$ may be relevant here).

There is an upper limit (reported at this meeting) on $\psi' \to \omega x$ of about twice $\psi' \to \eta\, J/\psi$. If we use $M_x = 2.8$ GeV, our mixing model and p^3 phase space, this puts a limit on $Q\overline{Q}$ in the ω,

$$\left| \frac{\langle\omega | Q\overline{Q}\rangle}{\langle\eta | Q\overline{Q}\rangle} \right| \lesssim .5 \qquad (5)$$

which is not very restrictive in view of $\epsilon_{\eta'}/\epsilon_\eta$. Also note that this decay is sharply cut off by phase space as $m_x \to 2.91$ GeV.

Many peoples' notebooks must contain material on spin and parity determinations for $P_c/\chi(3.5)$ and $P_c'/\chi(3.4)$; there are also several papers[13]. Nevertheless, I allow myself some remarks, so as to illustrate the problems involved. Henceforth θ_γ is the angle of the first photon in $\psi' \to \gamma_1 P_e/\chi$ with respect to the e^+e^- axis; $\theta_{\gamma\gamma}$ (or $\theta_{\gamma\pi}$) the angle of the second photon (π) with respect to the direction of the first in the P_c/χ CM. Azimuthal angles are averaged; C,P,T are assumed good. Two examples:

a) <u>P_e'/χ (3.4): is it really 0^{++}?</u>

Since

$P_c'/\chi(3.4) \to \pi^+\pi^-$ or K^+K^- it is 0^{++} or 2^{++}

(I assume $J < 3$). If in

$$\frac{d\Gamma}{d\cos\theta_\gamma} = |M_1|^2 \sin^2\theta_\gamma + |M_0|^2 \frac{1 + \cos^2\theta_\gamma}{2} \qquad (6)$$

(The subscript labels the helicity of the P_c/χ),

$M_1 \neq 0$ then $J^{PC} = 2^{++}$. If $M_1 = 0$ an isotropic $\cos\theta_{\pi\gamma}$ distribution proves $J^{PC} = 0^{++}$. This is because for $J = 2$ the distribution is <u>constrained</u> to be

$$\frac{dP}{d\cos\theta_{\gamma\pi}} \propto (\cos^2\theta_{\gamma\pi} - \frac{1}{3})^2 . \qquad (7)$$

Reason: $M_1 = 0$ implies that the recoil $P_e'/\chi(3.4)$ has zero helicity if $J = 2$. This gives (7).

b) <u>$P_c/\chi(3.5)$: excluding $J = 0$</u>

(1) If $P_c/\chi \to \pi\pi$ see the P_c'/χ' case. If not, $|M_1| \neq 0$ proves $J \geq 1$ as before. Distinguishing $J = 1$ and $J = 2$ can be hard.

(2) If $|M_1| = 0$ then for $J = 1$ (The argument is similar for $J = 2$)

$$\frac{d\Gamma}{d\cos\theta_{\gamma\gamma}} = |N_0|^2 \sin^2\theta_{\gamma\gamma} + 2|N_1|^2 \cos^2\theta_{\gamma\gamma} \qquad (8)$$

The subscript is the helicity of the recoiling J/ψ (analyzed via $J/\psi \to \ell\bar{\ell}$) in the P_e/χ rest frame with the z-axis now along the direction of the second photon in this frame. $J = 0$ can now be excluded as follows: either

$|N_0| \neq |N_1|$; this implies $J \geq 1$ since $dP/d\cos\theta_{\gamma\gamma}$ has to be constant for J = 0. If $|N_0| = |N_1|$ this can mimic the distribution for J = 0, but then the recoil J/ψ is longitudinally polarized. This is forbidden for J = 0. The signal for longitudinal polarization is a dip when the $\ell\bar{\ell}$ axis moves parallel to the direction of the second γ.

(3) Luck can help. A term $\alpha\cos^4\theta_{\gamma\gamma}$ in $d\Gamma/d\cos\theta_{\gamma\gamma}$ can only occur for $J \geq 2$. The decays $P_c/\chi \to \gamma\gamma$ and $\rho^o_{T,L}\ \rho^o_{T,L}$ are forbidden for J = 1.

This is a schema; real life will be less simple. Analysis of every available decay will probably be needed to get spins and parities of the intermediate states.

3.8 - 4.6 GeV

We 've seen the new results on R in this region. Why so complicated? A sampling of proposals:

(1) $Q\bar{Q}$ models

Maybe the $Q\bar{q} + \bar{Q}q = D\bar{D}$ threshold is above 5 GeV, and this structure is due to many $Q\bar{q}\bar{Q}q$ bound states[14]. These states ought to decay to J/ψ + hadrons, x + hadrons, ..., much of the time.

Color models

These can have many 1^{--} states in this region[15]. Also, the existence of natural parity levels below ψ' hints at excited states with J/ψ color quantum numbers not too much higher in mass. Then we expect to see inclusive J/ψ somewhere above 4 GeV.

An experimental statement one hears is that if J/ψ are present at all (e.g. at 4.2 GeV), then at a level much below the J/ψ + ψ' radiative tails. This amounts to 0.7 nb at 4.2 GeV, and I infer at $\sqrt{s}$ = 4.2 GeV

$$\frac{\sigma(e^+e^- \to J/\psi + \ldots)}{\sigma(e^+e^- \to \text{hadrons})} < 1\,\% \; (?)$$

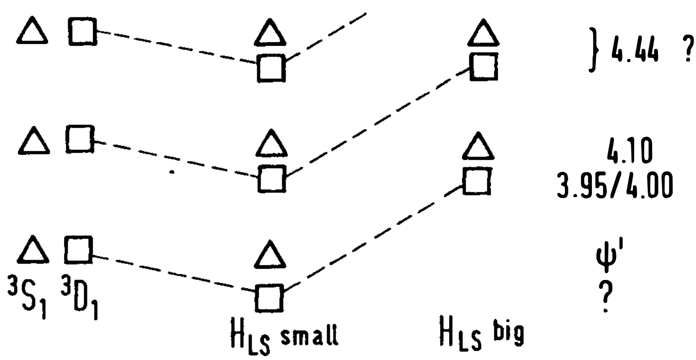
Hopefully real limits will soon be available. These models could then be in real difficulty[16].

(2) Thresholds (without interferences)

It is easy to show that even with p^3 phase space and dipole form factors it it not possible to produce a structure like that at 3.95 GeV solely from two subsequent thresholds (e.g. $D\bar{D}$ and $D^*\bar{D}$). Of course, the conventional model has many thresholds, plus what comes next.

(3) D-wave $Q\bar{Q}$

Every excited $3S_1$ $Q\bar{Q}$ level has (non relativistically) a $^3D_1$ partner. If they mix with the S-waves (tensor forces), they can couple to e^+e^-. Maybe near threshold they decay to hadrons ($D\bar{D}$) via the S-wave admixture too. Then if there is no interference a D-wave resonance has the same ΔR (base to peak) as its S-wave partner. As for the location of these D-wave levels, see the sketch:



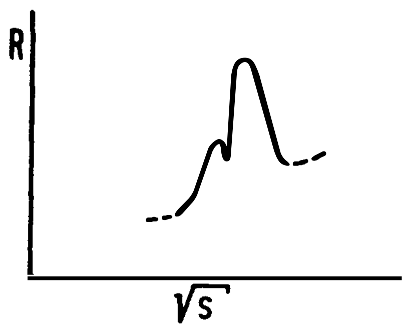
Small spin-orbit splittings would favor 2^3D, near 3^3S_1, etc. There are now two suboptions (ignoring thresholds now). Both take for granted that the 4.4 GeV bump is mostly D-wave (because it is narrow and $\Gamma_{e\bar{e}}$ is small).

(i) No interference:

The $\psi(4.4)$ and the 3.95 GeV bump are both D-waves. If so, why do they both have roughly the same width? One is much closer to threshold than the other and ought to be narrower. Besides this, $\Gamma_{e^+e^-}$ is comparable, and this raises the question why the D-wave partner of the ψ' does not have a similarly large $\Gamma_{e^+e^-}$ (it would then be easy to find - assuming that L·S forces and the ψ_D-ψ' spacing are small).

(ii) Interference:

The significant structure might not be the 3.95 GeV "bump", but the dip just above it, followed by a sharp rise. This option might allow a small Γ_{had}, $\Gamma_{e^+e^-}$ for the D-wave state. A very small $\Gamma_{e^+e^-}$ for $^3D_1$ near the ψ' would then be more credible. Since the D and S states have the same decays, it may not be possible to see a clear narrow pure D-wave resonance in some channel, as one can for $\omega \to 3\pi$. The figure may look familiar to you:



Maybe the 4.4 GeV is also partly an interference structure. Of course, the standard model has both these D states and multiple thresholds around 4 GeV. For this reason the structure there ought to be more complicated than around 4.4 GeV.

We can expect even more exotic explanations in the near future. Almost certainly we can also expect more experimental surprises.

Charm?

Charm searches in e^+e^- have concentrated (unsuccessfully so far[17]) on few body nonleptonic decays. What about semileptonic charm decay signals? Near charm threshold, $e^+e^- \to D\bar{D}$ followed by $D \to \ell^+\nu_e \bar{K} + \ldots$ is expected (seen in $\nu_\mu N$[18]) and these decays are less model dependent than nonleptonic ones. For instance, the $\Delta C = \Delta S = 1$ rule should work well[19]. What signatures should we look for? These are surely cleanest near threshold, so we start off there, and assume that the signal is from $e^+e^- \to D\bar{D}$. Much of this works at higher energies too, since the D from $e^+e^- \to \bar{D}D^*$, $D^* \to D\pi$ or $D\gamma$ has most of the parent momentum. The only difference is that N_π or N_γ in such events increases through the resonance region. The thresholds are D^+D^-, $D^0\bar{D}^0$; $\bar{D}D^*$, ...; $F\bar{F}$,... At high energies $D\bar{D}$ + multihadron is probably dominant, the average D momentum small and the model dependence large.

Near Threshold

(1) $\mu e/e\bar{e}/\mu\bar{\mu}$ + hadrons

This is proportional to $B^2_{c\to\ell}$; relative to the heavy lepton μe signal[20], the charm μe + hadrons should be multiplied by $B^2_{c\to\ell}\,\Delta R_c/B^2_{L\to\ell}\,\Delta R_L$. It should follow the bumps in R. $D_{\ell 3}$ and $D_{\ell 4}$ decays are most likely, and we ignore the rest. For $\theta_c = 0$ quark diagrams give[19]:

$$D_{\ell 3}:\quad D^+ \to \ell^+ \nu_\ell \bar{K}^0 \;;\quad D^0 \to \ell^+ \nu_\ell K^- \;;\quad F^+ \to \ell^+ \nu_\ell\, \eta,\eta'$$

$$D_{\ell 4}:\quad D^+ \to \ell^+ \nu_\ell (\bar{K}\pi)^0;\quad D^0 \to \ell^+ \nu_\ell (\bar{K}\pi)^-;\quad F^+ \to \ell^+ \nu_\ell (K\bar{K})^0$$

For pure $D_{\ell 4}$, $I_{\bar{K}\pi} = 1/2$, $I_{K\bar{K}} = 0$ and it becomes interesting to look for K^* and ϕ. The extremes of pure $D_{\ell 3}$, $D_{\ell 4}$ can also be distinguished near threshold ($D^+D^-, D^0\bar{D}^0$) by measuring $\langle N_{had}\rangle$ recoiling against $\ell\bar{\ell}$: for $D_{\ell 3}, \langle N_{had}\rangle \sim 2$ and for $D_{\ell 4}, \langle N_{had}\rangle \sim 4$. For the $D_{\ell 3}$ case, 3/8 of the events have ≥ 1 K_S.

Above F^+F^- threshold, this fraction decreases for $D_{\ell 3}$ and becomes ~5/12 for pure $D_{\ell 4}$ decay. In the latter case there will be a non-negligible number of events with <u>two</u> K_S. Similarly for $K^{\pm}$. Notice that for pure $D_{\ell 3}$, K^- and K_S never occur together. Remember that if the $\bar{D}D^*$, $\bar{D}^*D^*$, ... threshold is very nearby this picture is confused somewhat. But then $D^* \to D\gamma$ and the difficulty is modest.

(2) <u>μ/e + hadrons</u>

If $B_{c\to\ell}$ is small, this may be the only way to see charm via semileptonic decays. Of course, neutrino data speaks for a large $B_{c\to\ell} \sim B_{L\to\ell}$ [21]. Again, the signal should follow the $\sqrt{s}$ variation of R. If nonleptonic charm decays are dominant (e. g. ≳80 %), and if they lead mostly to ≥ 4 body final states (2 and 3 body decays have not been seen), then $\langle N_{had}\rangle$ for these events should be much larger than for (1): $\langle N_{had}\rangle \approx 6 - 8$. We expect 1 - 2 kaons per event.

Of course, $e^+e^- \to e/\mu$ + hadrons gets a contribution from heavy lepton production and decay. If L is a conventional sequential heavy lepton decaying solely via the known charged weak current, the recoiling $\langle N_{ch}\rangle \approx 1 - 2$ and a cut $\langle N_{ch}\rangle \geq 3$ eliminates ≈ 80 % of this contamination[22]. Hopefully most of the charm signal survives. We expect that the low N_{ch} events will not follow the variation of R and that the large N_{ch} will.

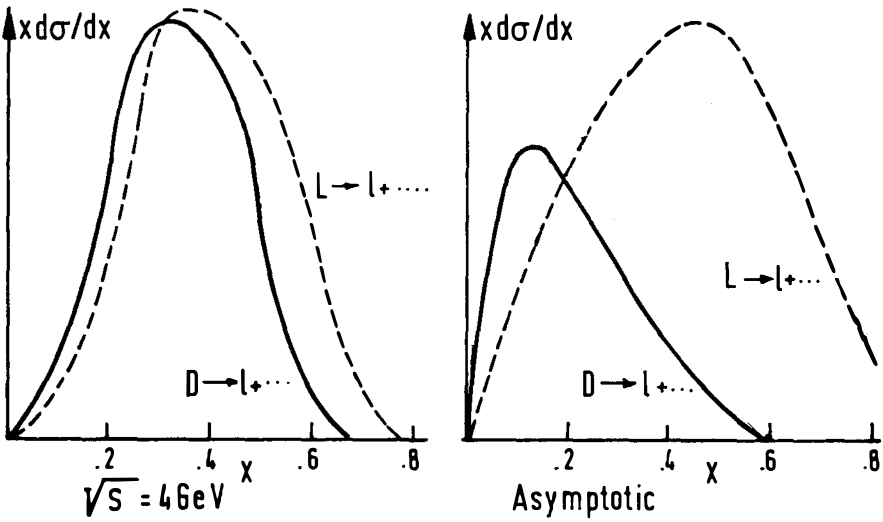
What should the inclusive lepton spectra look like?[23] Let us assume the following:

(i) Near threshold $E_D \approx \sqrt{s}/2$. For $D\bar{D}$ this is exact; for $\bar{D}D^*$ or $\bar{D}^*D^*$ it is approximate.

(ii) Asymptotically, the D(F) distribution in $x d\sigma/dx \propto x^a(1 - x)^b$; b = 1,2 are popular and we put b = 2 (to agree with $e^+e^- \to h^{\pm} + \ldots$). Less motivated is a = 1 (it prevents $\langle n_D\rangle \propto \ln s$ with a large coefficient).

(iii) The inclusive $D \to \ell^+ + \ldots$ distribution equals that for $c \to \ell^+ \nu_\ell s$ with V-A currents and $m_c = 1.5$ GeV, $m_s = 0.5$ GeV. The results differ little from those for $D_{\ell 3}$ decay with a constant matrix element.

(iv) Do-it-yourself normalization. We compare charm $\to \ell + \ldots$ to $L \to \ell + \ldots$ (V-A, $m_{\nu_L} = 0$)[22] with the same ΔR and the same B_ℓ. Note that the plot is for $x d\sigma/dx$.



Evidently, momentum cuts on p_ℓ discriminate against a charm signal at large $\sqrt{s}$ but not near threshold, where charm signals are also enhanced by the resonances.

There is experimental μe data in the range $4 \lesssim \sqrt{s} \leq 7.4$ GeV, but it is not yet clear what constraints on semileptonic charm decays this imposes. Hopefully we will soon find out.

Acknowledgements

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References and Footnotes

1) Two examples will have to serve:

(i) If narrow SU_3 singlet "quarkless" states exist around 1 - 2 GeV (P. Freund and Y. Nambu, Phys. Rev. Lett. 34 (1975) 1645), look for them in mass plots or recoiling against, e. g., $\pi^+\pi^-$.

(ii) $J/\psi \to \pi B$ (KK_B) are allowed by isospin (plus U-spin). πA_1 and (KK_A) only go via 1γ. This provides a nearly pure K_B state, and may help to disentangle K_A and K_B (see G. Brandenburg et al., SLAC-PUB-1697, December 1975).

2) B. Wiik, Stanford Lepton-Photon Symposium, 1975 (ed. W.T. Kirk).

G. Wolf, this meeting.

J. Heinze, Stanford Lepton-Photon Symposium, quotes $\eta'\gamma/\eta\gamma = 4 \pm 2.5$.

3) T.F. Walsh, Lett. Nuovo Cim. 14 (1975) 290.

R. Cahn, M. Chanowitz, Phys. Lett. 59B (1975) 277.

J. Ellis, Schladming lectures (1975).

T. Inami, K. Kawarabayashi, S. Kitakado, Phys. Lett. 61B (1976) 60.

Mixing material:

A. Kazi, G. Kramer, D. Schiller, DESY 75/10, 75/11 and 75/38.

Mass-dependent mixing:

A. De Rujula, S. Glashow, Phys. Rev. Lett. 34 (1975) 46.

4) For a universal hadron radius r, it seems reasonable to parametrize the momentum factors by $p^{2\ell+1}(1 + r^2p^2)^{-n}$ where n is some power given, e.g., by a vertex form factor.

5) Cf. H. Harari, Phys. Lett. 60B (9176) 172.

6) G. Abrams, Stanford Lepton-Photon Symposium 1976.

7) H. Kowalski, T.F. Walsh, DESY 76/02.

S. Rudaz, Cornell preprint.

8) Chan Hong-Mo, Ken-ichi Konishi, J. Kwiecinski, R.G. Roberts, Rutherford preprint RL-75-177 (T. 146).
C. Rosenzweig, Pittsburgh preprint PITT-156 (December 1975).
M. Schmid, D.M. Webber, C. Sorensen, Zürich preprint.
T. Inami et al., Ref. 3.

9) Preliminary evidence indicates that $\eta\phi/\pi\rho$ is small (F. Vanucci and G. Feldman, private communications).

10) Inferred from Ref. 6.

11) S. Whitaker (this meeting) quotes 7 ±3 % BR for $\psi' \to \chi(3.4) + \gamma$. Henceforth I assume that $P_c(3.5) = \chi(3.5)$ and that the possible[2] $P'_c(3.4) = \chi(3.4)$. These states may be distinct, and there may be more (e.g. x', a $J = 2\ {}^3P_2$ ...). See the talk of G. Feldman, Stanford Lepton-Photon Symposium, the discussion which follows it, and reports at this meeting.

12) E. Eichten et al., Phys. Rev. Lett. 34 (1975) 369.

13) G. Karl, S. Meshkov, J.L. Rosner, preprint, August 1975.
P.K. Kabir, A.J.G. Hey, preprint (1975).
H.B. Thacker, P. Hoyer, LBL preprint 4606, October 1975.

14) M. Bander, G.L. Shaw, P. Thomas, S. Meshkov, Irvine preprint (1975).
C. Rosenzweig, Pittsburgh, PITT-158 (1975).
Such exotics are interesting in their own right, whether or not they are prominent in R.

15) B. Stech, this meeting and DESY Summer School (September 1975).

16) In the conventional (e.g. charm) scheme, low energy inclusive J/ψ production might be present at a level comparable to $J/\psi \to$ hadrons decay suppression, $\sim 10^{-3}$; J/ψ production is only Zweig-allowed for $\sqrt{s} > m_{J/\psi} + m_x$, where J/ψ should be seen recoiling against 1^1S_o, 1^3P_J, 2^1S_o, 2^3P_J, ... $Q\bar{Q}$ states (and may be the only way to see some of these). If the $\nu_\mu N \to \mu^- \mu^-$ + ... events are due to $D\bar{D}$ production by uncharmed currents, it indicates a ~1 % probability to make $Q\bar{Q}$ in a deep inelastic process. Then in e^+e^- inclusive J/ψ production might exist at the percent level for $\sqrt{s} > m_{J/\psi} + m_x$.

17) G. Feldman, Stanford Lepton-Photon Symposium (1975).

18) H. Deden et al., Phys. Lett. 58B (1975) 361.
J. Blietschav et al., Phys. Lett. 60B (1976) 207.
J. von Krogh et al., Wisconsin preprint (1976).

19) M.K. Gaillard, B.W. Lee, J.L. Rosner, Revs. Mod. Phys. 47 (1975) 277.

20) M. Perl, this meeting.

21) C. Rubbia, Stanford Lepton-Photon Symposium (1975).

22) K. Fujikawa, N. Kawamoto, DESY 76/01, and references there.

23) I want to thank K. Fujikawa for his help here.