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A Proposal to Search for Charmed Particle Production Near Threshold

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Abstract

We propose to search for charmed particle production thresholds by looking for anomalies in the ratio of K^-/π^- production at $P_T \simeq 1$ GeV/c as the incident energy is varied. Any anomalous behavior will be further investigated using a two arm effective mass spectrometer.

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I Introduction

We propose to search for charmed mesons and baryons produced at the C0 Internal Target. These measurements would consist of two steps. First we would precisely determine the energy dependence of the K/π ratio, looking for abrupt changes or anomalies when a threshold for pair production of charmed particles is crossed. Second, we would combine the apparatus used for the K/π ratio measurement with the high resolution spectrometer which we are now constructing for experiment 198 to do effective mass searches for two body decays of these particles. The first step of this program could be started immediately.

II Motivation

It has been widely speculated that the narrow resonance recently observed at SPEAR and BNL (J or ψ(3105))[1] is a charmed vector singlet (Ortho charmonium). Borchardt, Mathur and Okubo[2] have demonstrated that the measured properties of this particle are indeed consistent with SU(4) when symmetry breaking of the same magnitude seen in SU(3) is included. From their calculation they estimate the other charmed vectors and pseudoscalar mesons to have masses of about 2.2 GeV/c. They also estimate masses for charmed baryons to be in the range of 4 ~ 5 GeV/c^2[3]. These charmed particles are expected to be produced in pairs, the production threshold for charmed meson pairs being ~25 GeV and for charmed baryons 50 GeV. The lightest of these particles should decay weakly predominantly into final states containing strange particles. From simple quark model considerations it is expected that the production cross section for charmed pairs in p-p collisions should be considerably larger than the cross section for producing the singlet. The reported cross section for $pp \to J \to e^+e^-$ is $\sim 10^{-34} cm^2$ (ref. 4). Including all decay channels this becomes a total production cross section of $\sim 10^{-32}$ cm^2.[5] Charmed pair production is conservatively estimated to be one or two orders of magnitude above this.[6]

The C0 area is ideal for searching for particles of this type. The availability of a continuously varying incident energy coupled with high luminosity makes high precision searches for thresholds feasible. Also, since the energy varies during each pulse, the energy dependence of different processes can be detected in a quite bias free manner. These thresholds may occur in the 20-50 GeV incident energy range, energies only available at C0. Pair production may involve charmed reggeon exchange. Since these trajectories most likely have fairly low intercepts the cross section for this reaction might very well peak not far above threshold.[7]

III Technique

We assume charmed meson pairs are produced according to

$$\begin{array}{l} p + N \to c + \bar{c} + X \\ \qquad\qquad \hookrightarrow K + \pi \end{array}$$

If we take a mass of 2.2 GeV for charmed mesons as given in Ref. 2 we determine that a K meson at 90° in the CM originating from a $K\pi$ decay of a charmed meson, produced at pair production threshold, to have a lab momentum of 4 GeV/c and a lab angle of 15° from the incident beam direction. By virtue of the high Q value of the decay this K meson has a relatively high transverse momentum, $P_T \simeq 1$ GeV/c, where K's from less exotic origins are somewhat damped. Since K^+'s and K^-'s are produced in equal strength in charmed pair production we choose to look for K^-'s since their normal production is abour an order of magnitude below K^+ production. Similar considerations obtain at higher energy for charmed baryon pair production.

For the first part of this measurement we plan to install a simple small aperture single magnet spectrometer in the tunnel at C0. The magnet position will be variable from 15° to 40° from the beam line and will bend negative particles produced in the target vertically. In front and in back of the magnet will be hodoscopes of small scintillation counters. The rear arm will also have a gas Cherenkov counter to separate π's from K's. A Cherenkov counter in front will be used to separate K's and p^-'s.

A one meter long 18 kg magnet will bend 4.0 GeV/c particles by .14 rads. The bending angle will be determined to within ±2.5 mrads by the front hodoscope and two rear hodoscopes. The solid angle will be limited to be within the 4" I.D. gas Cherenkov counter whose exit window will be ~4 meters downstream from the target. The $K(\pi^-)$ momentum will be determined to an accuracy of $\Delta P \sim \pm .07$ GeV/c at the 15° setting, the accuracy improving at the other lower momentum runs. For the second stage of this proposal this resolution could be improved by the addition of finer counters and/or MWPC's.

The experiment will thus be to count K^-'s and π^-'s, produced in an internal target, in small incident energy bins ($\Delta E_{CM} \sim .1$ GeV) during the accelerator ramping cycle. Accidental π's and K's and one extra monitor will be recorded for each incident energy bin. The data will be stored event by event using a 4K memory (PHA) and tape drive (non-computer) as for E188. The beam intensity, radial and vertical position will be checked for abnormalities before a set of data is kept. Runs will be taken at a variety of transverse and longitudinal momenta and over the entire incident energy swing of the accelerator. We would vary the angle from 15° where the detection is the hardest but the signal to noise is best out to 40° where the detection is easiest and the signal to noise worst. Systematic features which usually plague experiments of this type such as detection efficiency, solid angle acceptance, decays in flight, interaction in counters and windows etc., do not contribute an energy dependent effect of the type we're interested in measuring.

The second stage of these measurements would explore any anomalies seen in the K/π ratio by carefully examining the Kπ mass spectrum in a two arm system using the previously described spectrometer together with the high resolution recoil spectrometer we are currently preparing for experiment #198. In this case we will be sensitive to $K^-\pi^+$ decays of neutral charmed mesons, and Kp decays for neutral charmed baryons. The details of spectrometer angles will depend upon the results found in Step 1. We estimate that for a charmed meson mass of 2.2 GeV/c^2 we can obtain an effective mass resolution of $\Delta M \simeq \pm 10$ MeV. Again seeing the development of this spectrum as a function of energy should be quite valuable.

IV Sensitivity and Rates

Using the CERN results for $PP \to K^-X$ at an incident energy of 24 GeV[8] we find for $x = 0$ and $P_T \simeq 1$ GeV/c; $d\sigma/d\Omega^*dP^* \approx 4\times10^{-30}$ cm^2/sr GeV/c. For a transverse momentum bite of 0.03 GeV/c, we have for inclusive K^-'s, $d\sigma/d\Omega^* \simeq 10^{-31}$ cm^2/sr. At threshold, assuming isotropic decays, we get for K^-'s of charmed parentage $d\sigma/d\Omega^* = \sigma_T B/4\pi$. Here σ_T is the total production cross section and B is an effective branching ratio for one or the other charmed particle to ultimately yield a K^-. Taking $B = 1$ and $\sigma_T = 10 \times \sigma_T(PP \to J + x) \simeq 10^{-31}$ cm^2, we get $d\sigma/d\Omega^* \simeq 10^{-32}$ cm^2/sr. Thus we could see a rather abrupt 10% increase in the K/π ratio as we pass through threshold. With 1~2% relative precision in each energy bin this should be rather apparent. Of course, if the cross section is higher the effect would be more dramatic.

For 1% (2%) statistical accuracy on the K^- yield we need $10^4 (3 \times 10^3)$ counts per energy bin (one energy bin ≃ 10 millisecs of ramp). For a

50 cm^2 defining aperture 5 meters from the target $\Delta\Omega_{lab} = A/R^2 = 2\mathrm{x}10^{-4}\,\mathrm{sr}$. Also $d\Omega_{cm}/d\Omega_{lab} \simeq 10$ at $P_{inc} = 25$ GeV/c. First we would explore the region using a rotating carbon filament target. Here we can achieve target densities of ~1.5 x 10^{-6} gms/cm^2. We estimate the rates for K^-'s per second as being

$$K^-/\mathrm{sec} \simeq 10^{13}\ \frac{\mathrm{prot}}{\mathrm{trav}} \mathrm{x}\ 5\mathrm{x}10^{4}\ \frac{\mathrm{trav}}{\mathrm{sec}} \mathrm{x}\ 10^{-30}\ \frac{\mathrm{cm}^2}{\mathrm{sr}_{lab}} \mathrm{x}\ 2\mathrm{x}10^{-4}\mathrm{sr}\mathrm{x}6\mathrm{x}10^{23}\underbrace{\mathrm{x}1.5\mathrm{x}10^{-6}}_{\mathrm{gm/cm}^2}$$

= 100 K^-'s/sec or 1 K^-'s/10 millisec/cycle

(Rotating Carbon Target)

Thus for each setting we can accumulate 1% statistics in each bin in about a day of continuous running. It may be necessary to reduce the target density in order to lower the radiation in the area. Our rates will be reduced proportionately.

Only in hydrogen is the CM energy clearly defined. Thus it may be interesting to take some measurements from hydrogen. In this case the target density is reduced by about a factor of 10. The counting rate would thus be

= 10 K^-'s/sec or 0.1 K^-'s/10 millisec/cycle

(Gas Jet Target)

In this case fifteen shifts of running should give 2 to 3% statistics in each energy bin. This would require about two weeks of running per setting.

V <u>Details</u>

i) Manpower

The group proposing this program is currently preparing for Experiment 198. We expect that we could measure the K/π ratio without impeding progress on the construction of the recoil spectrometer. If indeed we found some interesting anomalies in this ratio the E198 spectrometer would be used in a more detailed search for these charmed states. Otherwise our experiment 198 program will proceed as planned.

ii) Schedule

We could start setting up the ratio measurements immediately. The essentials of the apparatus are on hand and could be assembled into a working spectrometer in 4 ~ 5 weeks. After another 2 ~ 3 weeks of tuning and testing we would be ready to take data.

iii) Apparatus

The University of Rochester Particle Physics Group has two working Cherenkov counters which are suitable for this spectrometer.[9] The Harvard magnet used in Expt. 184 is still at C0 and might be available for our use. We are building hodoscopes for Expt. 198 and these could be put into use essentially right away.

VI Conclusion

The importance of looking for these particles can't be overstated. In the proposal we suggest a systematic search for them exploiting the unique features of the C0 internal target laboratory.

References and Footnotes

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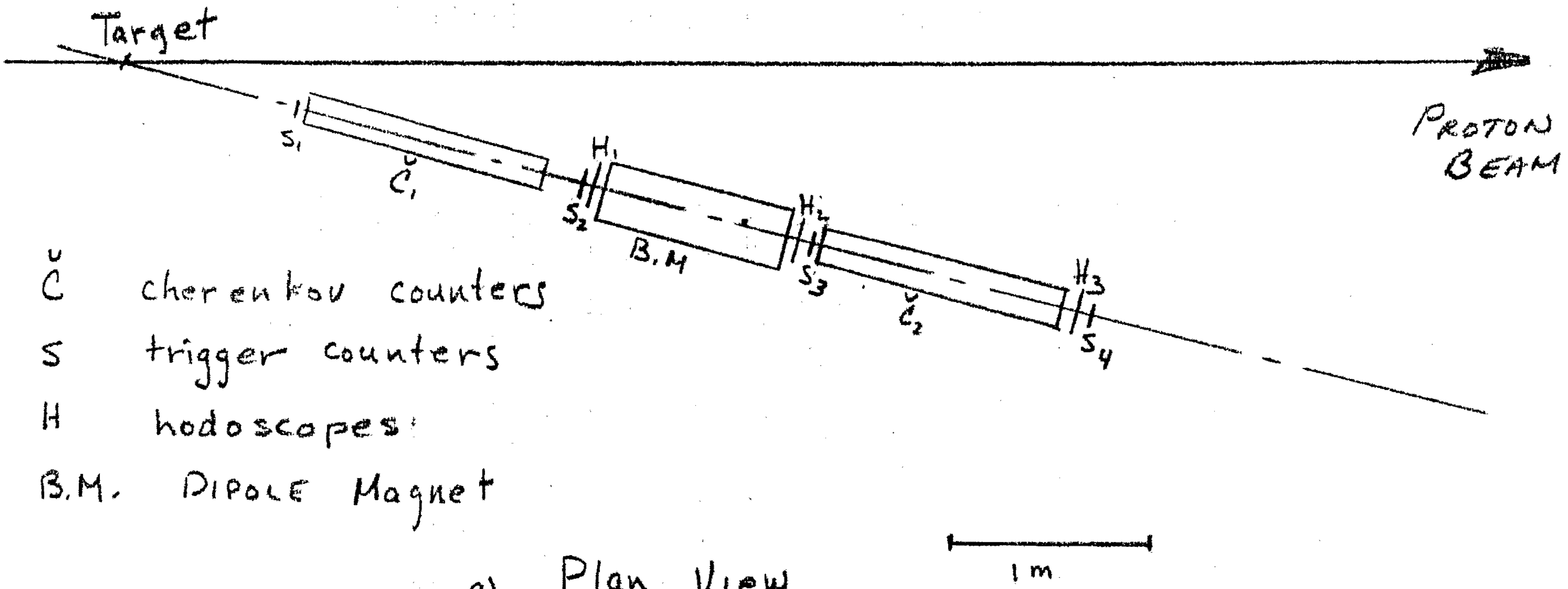
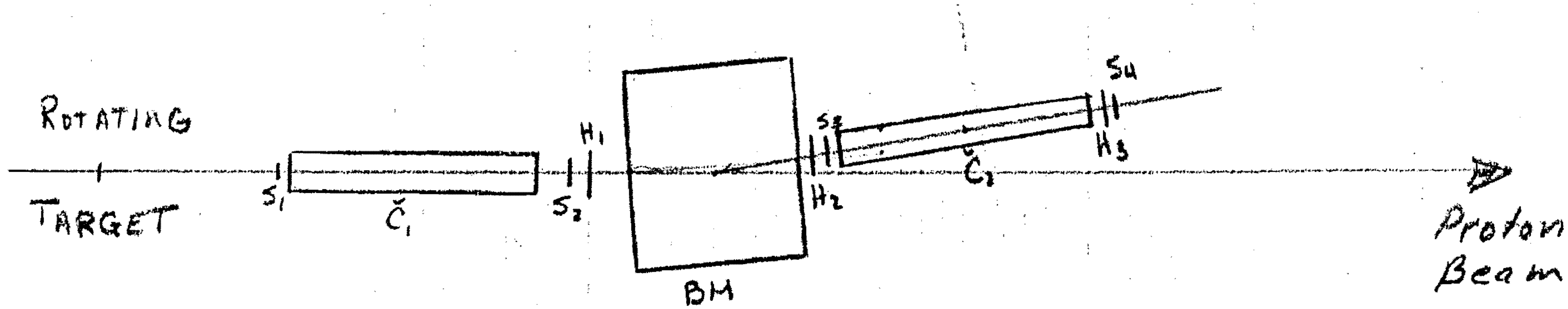
Figure Captions

1. A schematic view of the spectrometer described in this proposal.
    a) Plan view
    b) Elevation
2. $pp \rightarrow K^- x$ yields at 24 GeV/c from ref. 8.



a) Plan View



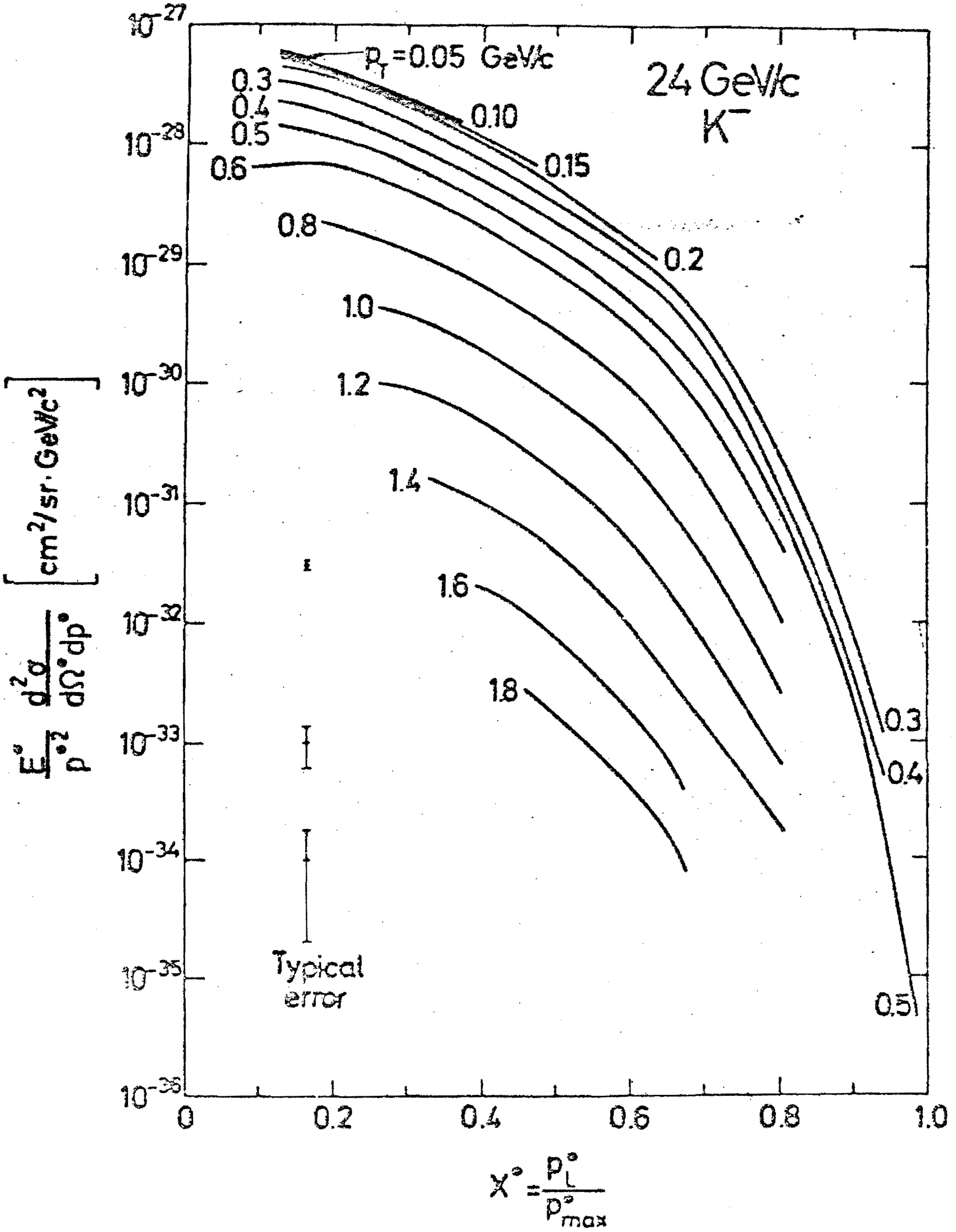
b) Elevation View

Fig 1.

FIGURE 2

pp → K^-X

p_{INC} = 24 GeV/c



ATTACHMENT

A POSSIBLE EXPLANATION OF THE NEW RESONANCE IN e^+e^- ANNIHILATION *

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ABSTRACT

We propose that the recently discovered resonance in e^+e^- annihilation is a member of the $15 \ominus 1$ dimensional representation of the SU(4) group. This hypothesis is consistent with the various experimental features reported for the resonance. In addition, we make a prediction for the masses of the charmed vector mesons belonging to the same representation.

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Very recently a new type of resonance which couples to the hadrons and the leptons has been discovered[1] both at SLAC and BNL. Denoting this structure as $\psi(3105)$, SLAC has quoted the mass and width of this resonance as

$$\begin{aligned} M_\psi &= 3.105 \pm 0.003 \text{ Gev.} \\ \Gamma_\psi &\leqq 1.3 \text{ Mev.} \end{aligned} \tag{1}$$

In this note, we discuss the theoretical interpretation of this structure. For simplicity, we assume the spin of ψ to be one. Writing the effective interaction of ψ with the electron-positron pair as

$$\begin{aligned} H' &= ig\,\bar{e}\gamma_\mu(a + b\gamma_5)e\,\psi_\mu \\ |a|^2 &+ |b|^2 = 1 \end{aligned} \tag{2}$$

the total production cross-section of ψ, integrated over the width of ψ is computed to be

$$\int ds\, \sigma(e\bar{e} \to \psi) = \pi g^2. \tag{3}$$

From the experimentally measured cross-section, we estimate[2]

$$g^2 = 2.4 \quad 10^{-5} \quad . \tag{4}$$

Next using this value, we compute the partial decay width for $\psi \to e\bar{e}$ to be

$$\Gamma\ (\psi \to e\bar{e}) = \frac{g^2}{12\pi} M_\psi \approx 2.0 \text{ Kev.} \tag{5}$$

Experimentally, from the figures in ref. (1), we roughly estimate $\Gamma\ (\psi \to e\bar{e})/\Gamma(\psi \to \text{all}) \approx 1/25$, so that we expect

$$\Gamma\ (\psi \to \text{all}) \approx 50 \text{ Kev.} \tag{6}$$

We propose that ψ is a member of the $15 \oplus 1$ dimensional representation V_α ($\alpha = 0, 1, \ldots 15$) of SU(4). This representation for the vector mesons (1^-) will contain the usual nonet (ρ , K^*, ω , ϕ), an SU(3) charm carrying triplet (C_u, C_d, C_s) consisting of the I = 1/2 vector mesons C_u, C_d and an I = 0 strangeness carrying meson C_s, a corresponding charge conjugate SU(3) triplet ($\bar{C}_u$, $\bar{C}_d$, $\bar{C}_s$), and the uncharmed meson ψ. Note that ω, ϕ and ψ are identified with the physical states resulting from a mixing between the V_0, V_8 and V_{15} members of the representation. We claim that the various experimental features reported for ψ are consistent with this hypothesis. In addition, we predict the masses of the charmed mesons.

First, we would like to point out that this hypothesis can explain the value of g in Eq. (4) obtained from experimental results. We shall assume that parity is conserved in the interaction (2); later we shall discuss possible ways of testing this assumption. Assuming (as for ρ, ω and ϕ) that ψ is coupled to the $e\bar{e}$ system through a virtual photon exchange, we obtain from Eq. (3)

$$g^2 = (4\pi\alpha)^2 \, G_\psi^2 / M_\psi^4 \qquad (7)$$

where α is the fine structure constant and G_ψ is the effective coupling between ψ and the photon. Now G_ψ can be estimated from the following considerations. Assuming that the electromagnetic current has, besides the usual structure $V_\mu^3 + \frac{1}{\sqrt{3}} V_\mu^8$, an extra contribution xV_μ^{15} in the SU(4) theory, where[3] $x \approx 1$, we may use Weinberg's first spectral function sum rule to estimate G_ψ, if we neglect the mixing problem. Using the <u>ansatz</u> of pole dominance for spectral functions, we estimate

$$G_\psi^2 / M_\psi^2 \approx G_\rho^2 / M_\rho^2 . \qquad (8)$$

With the experimental value for G_ρ or using the KSRF relation[4] $G_\rho^2 / M_\rho^2 = f_\pi^2$, where f_π is the π - decay constant (numerically $f_\pi \simeq m_\pi$, the pion mass), we obtain from Eqs. (7) and (8),

$$g^2 \approx 1.7 \;\; 10^{-5} \qquad (9)$$

which is close to the result (4).

We now turn to the intriguing question why the width of ψ should be as small as the result quoted in (1) or obtained in (6). Essentially this arises from considerations of ω, ϕ, ψ mixing which lead to the result that ψ has predominantly a $\bar{p}'p'$ quark structure (p' is the fourth charm carrying quark) with very small admixtures of $\bar{p}p + \bar{n}n$ and $\bar{\lambda}\lambda$. This is not unexpected and the situation here is analogous to the usual ω, ϕ mixing theory, where ϕ has predominantly a $\bar{\lambda}\lambda$ quark structure. Physically this implies that the decay of ψ into ordinary hadrons is highly suppressed. Furthermore, if the charmed particle masses are $\gtrsim$ 1.5 Gev., decays like $\psi \rightarrow C\bar{C}$ would be energetically forbidden. In order to obtain the mass formulas for broken SU(4), we assume in direct generalization of the SU(3) theory, that the mass splitting arises from an interaction

$$H_{int} = T_8 + \alpha T_{15} \qquad (10)$$

where T_8 and T_{15} belong to the same 15-plet of SU(4). Note that T_{15} breaks SU(4) to the level of SU(3), and T_8 breaks SU(3) down to SU(2) in the usual manner.

The matrix elements of the squared mass-matrix for the $15 \oplus 1$ representation of vector mesons V_α can then be written as

$$\begin{aligned} (M^2)_{ij} &= \bar{M}^2 \delta_{ij} + D(d_{i8j} + \alpha\, d_{i15j}) \\ (M^2)_{0i} &= A\,(\delta_{8i} + \alpha\, \delta_{15i}) \\ (M^2)_{00} &= \bar{M}_0^2 \end{aligned} \tag{11}$$

where $i,j = 1, \ldots 15$, $\bar{M}^2$ and $\bar{M}_0^2$ are the SU(4) invariant squared masses of the 15-plet and singlet respectively, and D and A are the reduced matrix elements. The matrix (11) contains the off diagonal matrix elements $(M^2)_{8,15}$, $(M^2)_{0,8}$, $(M^2)_{0,15}$. Diagonalizing the matrix in this sector, we can determine the five unknown parameters in (11) by using the known masses of ρ, K^*, ω, ϕ and ψ. Numerically we obtain the values[5]

$$\begin{aligned} &\bar{M}^2 = 2.8\ (\mathrm{Gev.})^2, \quad D = -0.23\ (\mathrm{Gev.})^2, \quad \alpha = 21.6 \\ &\bar{M}_0^2 = 3.5\ (\mathrm{Gev.})^2, \quad A = -0.19\ (\mathrm{Gev.})^2 . \end{aligned} \tag{12}$$

Furthermore, the physical states ϕ, ω, and ψ are to a very good approximation given by the simple relations

$$\begin{aligned} \phi &= \cos\theta\, V_8 - \sin\theta\, \tfrac{1}{2}(\sqrt{3}\, V_0 + V_{15}) \\ \omega &= \sin\theta\, V_8 + \cos\theta\, \tfrac{1}{2}(\sqrt{3}\, V_0 + V_{15}) \\ \psi &= \tfrac{1}{2}(V_0 - \sqrt{3}\, V_{15}) \end{aligned} \tag{13}$$

where θ is the usual ω,ϕ mixing angle in the SU(3) theory. Note in particular that in terms of quark content $\psi \approx |\bar{p}'p'\rangle$. Our numerical analysis in fact shows that the admixture of quark structures ($\bar{p}p + \bar{n}n$) and $\bar{\lambda}\lambda$ in the state ψ is less than 5%. As an illustration we find that the width for $\psi \to K\bar{K}$ is about 8 Kev.

The numerical values in (12) predict the following masses for charmed vector mesons

$$\begin{aligned} M(C_u) &= M(C_d) = 2.19 \text{ Gev.} \\ M(C_s) &= 2.22 \text{ Gev.} \end{aligned} \qquad (14)$$

Using the same value for α in the mass formulas for pseudoscalar mesons, we find almost the same masses for the corresponding charmed pseudoscalar mesons. These charmed particles could decay weakly into the usual hadrons and leptons, and for short enough lifetime could have escaped detection[6]. If we believe in the GIM construction[7] for the weak charged currents, it should be noted that for the emitted hadrons, the Cabibbo angle favors decay modes where at least one strange particle is produced, so one would expect predominantly the $K\pi$, $K\bar{K}$, or $K\pi\pi$ etc. as final particle states.

It is interesting to note that if we define

$$G = g^2 / M_\psi^2$$

then using the estimate (4), we see that G is numerically also close to the usual Fermi constant G_F of weak interactions[8]. The identification of ψ with the intermediate vector boson mediating weak interactions, at a mass value given by (1), would contradict the mass constraint imposed by the currently popular unified gauge theory models of weak and electromagnetic interactions[9]. Experimentally, the question can be settled in principle by investigating whether parity is conserved or not in the two and three body decays of ψ , in much the same fashion as was done for the θ and τ modes of decay of the kaon.

Details of this paper with further developments of our hypothesis will be published later. We would like to thank Professor T. Ferbel and Dr. D. Weingarten for stimulating discussions.

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