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THE DISCOVERY OF CHARM

G. Goldhaber

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THE DISCOVERY OF CHARM

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In my talk I will cover the period 1973-1976 which saw the discoveries of the J/ψ and ψ' resonances and most of the Psion spectroscopy, the τ lepton and the D^o,D^+ charmed meson doublet. Occasionally I will refer briefly to more recent results.

Since this conference is on the history of the weak-interactions I will deal primarily with the properties of "naked charm" and in particular the weakly decaying doublet of charmed mesons.

Most of the discoveries I will mention were made with the SLAC-LBL Magnetic Detector or "MARK I" which we(1) operated at SPEAR from 1973 to 1976. (See Fig. 1) The groups involved in this work were those of Martin Perl and Burton Richter of SLAC and William Chinowsky, Gerson Goldhaber and George Trilling of LBL. The MARK I was then modified to include a "Lead Glass Wall" (LGW) for improved photon and electron detection. This involved a new physics group from LBL, who built the LGW, A. Barbaro-Galtieri et al as well as a continuing group from SLAC, M. Perl et al to provide continuity in the use of the MARK I.

During the course of the LGW experiment we were engaged in building a new and improved SLAC-LBL Magnetic Detector the "MARK II" which returned to SPEAR in 1978 and was moved to PEP in 1980. We are currently working on an upgrade of the MARK II detector for a subsequent move to the SLC.

A Brief History of the Discovery of the ψ and Psion Spectroscopy

My personal reminiscences regarding the ψ have already been published(2) and I will not repeat them here.

We started our experiment at SPEAR with an energy scan. Since we had not expected narrow structures(3) we measured the cross section in 100 MeV steps in beam energy, i.e., 200 MeV steps in E_{cm}. Fig. 2 shows our data as presented by Burton Richter at the London Conference in June 1974. The data was in good agreement with the earlier CEA and Frascati results(4) and showed a roughly constant cross section from 2.5 to 4.8 GeV. And yet - the data was not completely flat, and we were sufficiently intrigued with the high points at 3.2 GeV and 4.2 GeV that we decided to take additional intermediate points in June 1974 at 3.1 and 3.3 GeV as well as around 4.2 GeV. As I discussed elsewhere(2) it was an irregularity in the new 3.1 GeV data point - as reanalyzed by Roy Schwitters in October 1974 - which convinced us, in early November 1974 that we had to remeasure this region before we could publish our cross section data. Fig. 3 shows the ψ signal which we found on November 10, 1974, by scanning in very small steps. We thus realized that the increase in cross section we first noted at 3.2 GeV and the anomalies at 3.1 GeV were the result of the presence as well as the radiative tail of this enormous resonance.

The next day we learned from Samuel Ting about the MIT BNL results on the J –

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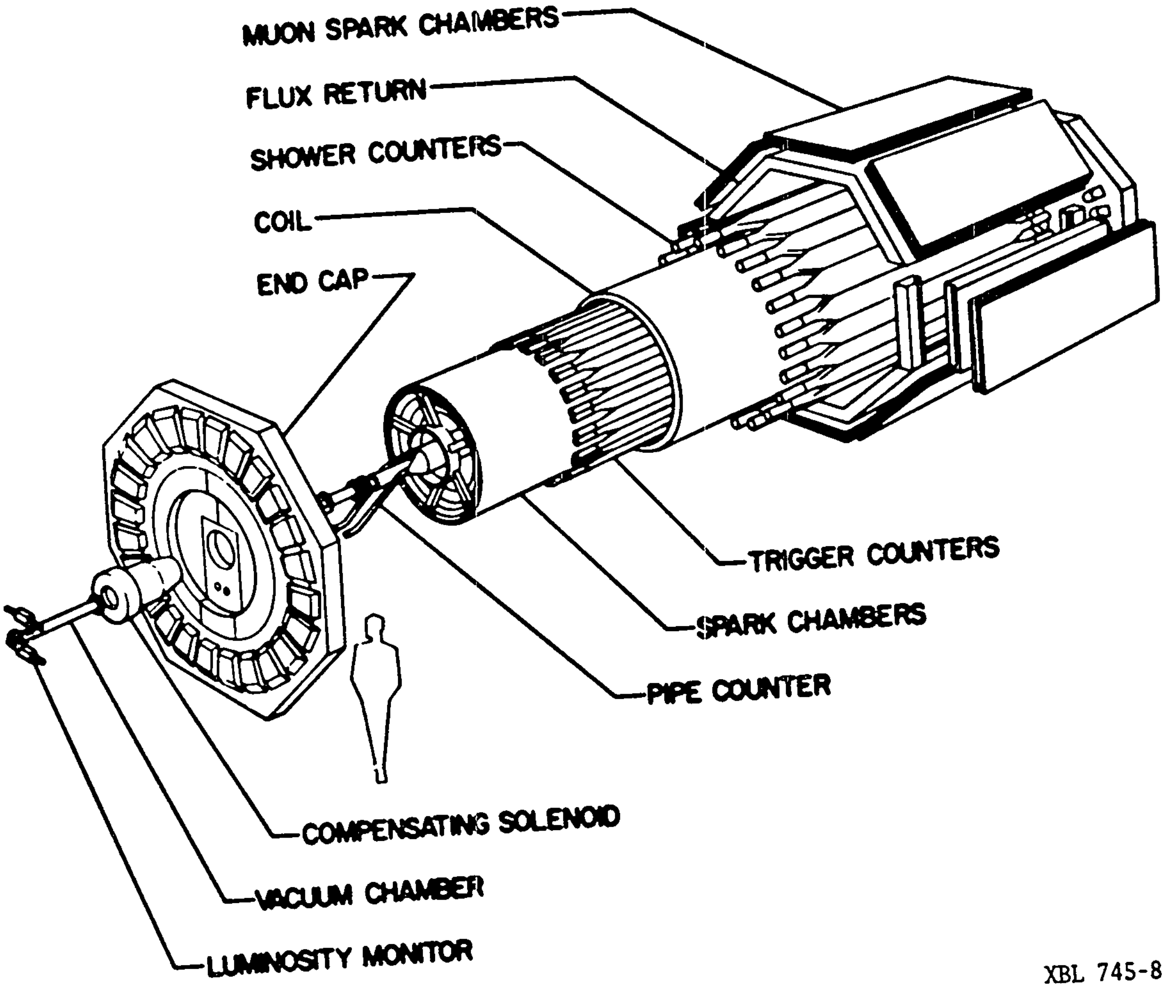

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Fig. 1. The MARK I SLAC-LBL magnetic solenoid detector.

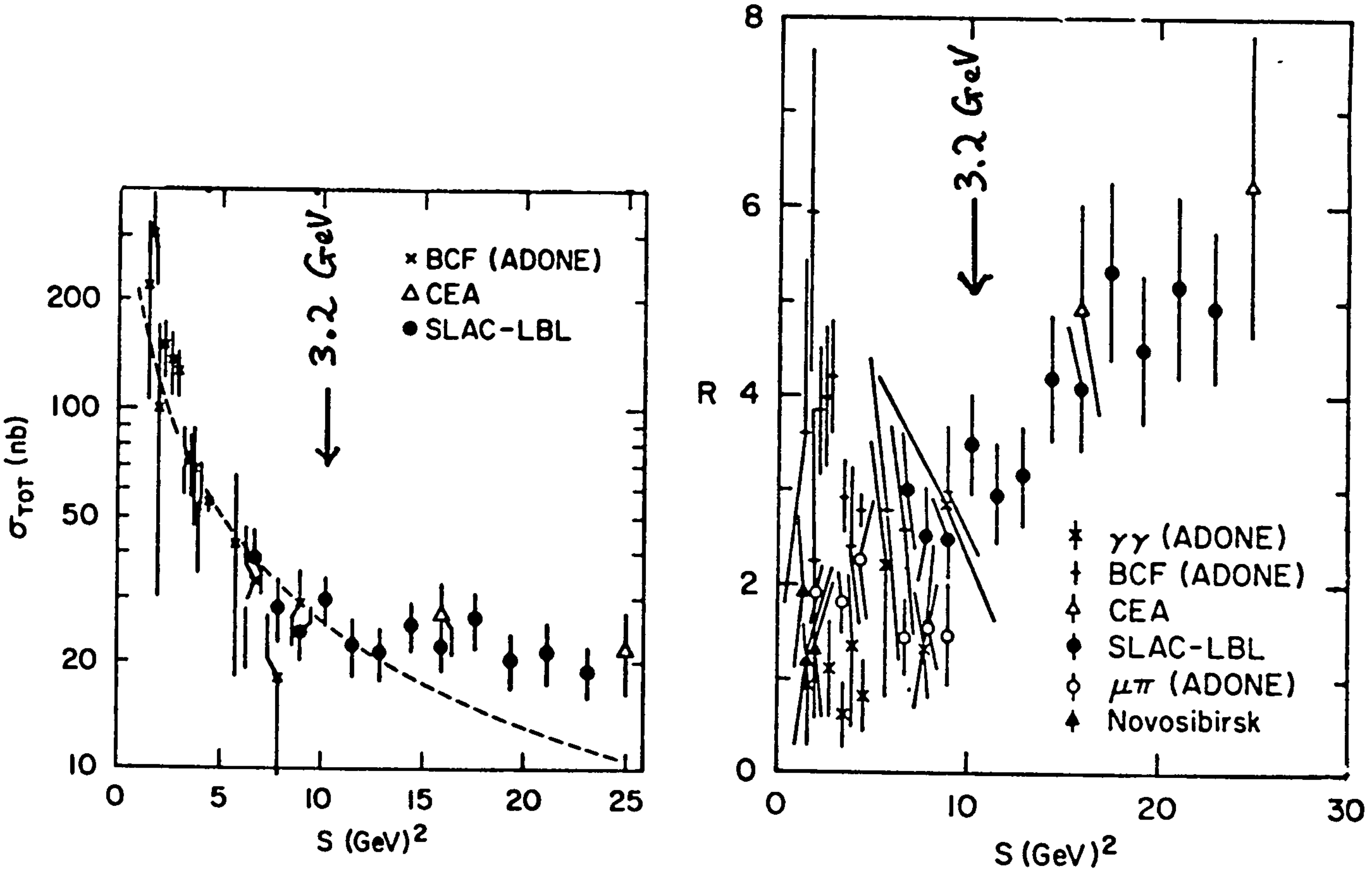

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Fig. 2. The first cross section and R = $\sigma_{\mathrm{Had}}/\sigma_{\mu\mu}$ measurements with the SLAC-LBL MARK I detector taken in 200 MeV steps. Earlier data is also shown.

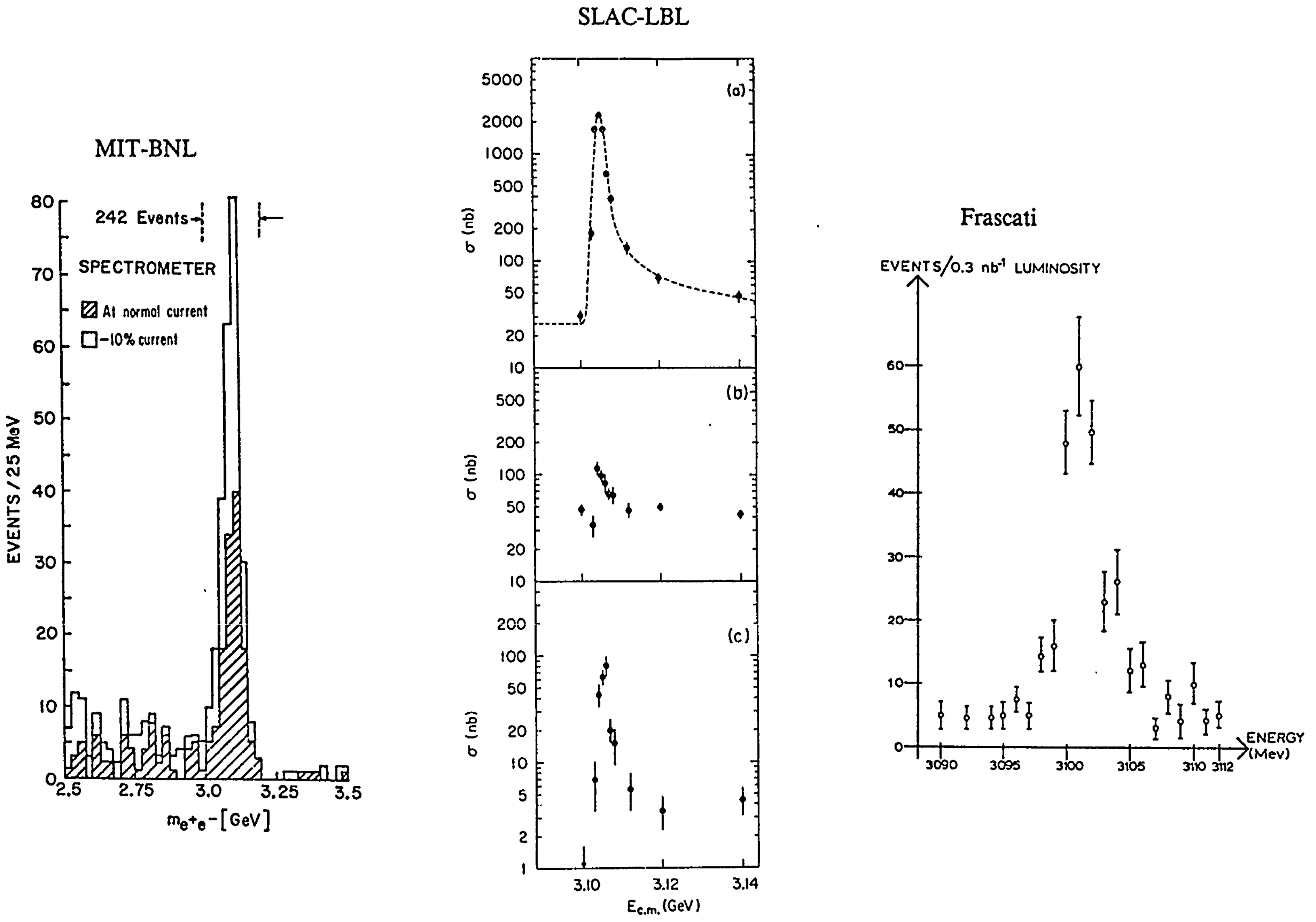

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Fig. 3. The discovery of the J by the MIT-BNL group, the ψ by the SLAC-LBL group and the confirmation of the J/ψ by the Frascati groups.

clearly the same effect.(5) As the messages about these results reverberated around the world we got a rapid confirmation of the J/ψ from the groups at Frascati who managed to push the energy of their e^+e^- ring from the maximum design value of 3.0 GeV up to 3.1 GeV! This is also illustrated in Fig. 3, and, in fact, all 3 papers were published in the same issue of Physical Review Letters.(6,7,8)

Encouraged by our remarkable result we decided to look for more sharp peaks! Burton Richter(9) together with Ewan Paterson and Robert Melen was able to modify the SPEAR operation so as to run in a mode in which the energy was stepped up by 1 MeV every minute while Martin Breidenbach was able to modify our analysis system so that the resulting cross section points could be calculated on-line. Fig. 4a illustrates a real time test of this new setup which shows clearly that in this mode of operation a resonance like the ψ can be readily discovered. Indeed 10 days later during the early morning of November 21 the ψ' was discovered. See Figs. 4b and 4c. A later confirmation of these results by the DASP group at DESY is shown in Fig. 4d.

Emboldened by this success, after taking a day or two off to write the ψ' paper, (10) we continued our scan and scanned on and on and on ... Fig. 5 gives the results of this scan and illustrates clearly that no other *narrow* resonance showed up, since, unfortunately, SPEAR was not designed to reach 10 GeV! We did however find a broad resonance at 4.4 GeV and considerable structure near 4.03 GeV. In Fig. 6 I show a later plot (1977) which shows this structure as well as the ψ'' (3770) discovered by the LGW collaboration.(11)

During the period November 1974 to May 1976 enormous progress was made in understanding the properties of the ψ and ψ', and in unraveling the entire Psion spectroscopy.

Thus for the ψ and ψ' we measured the spin and parity in interference experiments with Bhabha scattering $J^P = 1^-$ the quantum numbers G = (-), I = 0, from final state studies, the numerous branching ratios, the transitions $\psi' \rightarrow \psi\pi^+\pi^-$ and $\psi' \rightarrow \psi\eta$. Following a DASP discovery(12) of a P state intermediate between ψ and ψ', the χ states $^3P_0$, $^3P_1$ and $^3P_2$ obtained from $\begin{array}{l}\psi' \rightarrow \chi\gamma \\ \qquad\;\; \hookrightarrow \gamma\psi\end{array}$ and also from direct hadronic χ decays were identified. The detailed studies of the transitions between these states came later from work by the MPPSSD collaboration(13) and the crystal ball collaboration.(14)

During this period also, Martin Perl came up with a remarkable piece of scientific deduction.(15) Martin found 24 $e^\pm\mu^\mp$ candidates among non-colinear 2 prong events with no extra gamma's. He interpreted these events as examples of a possible heavy lepton. As we all know subsequent experimentation proved him to be right! He had indeed found the third - or τ - lepton. But this is a story Martin should tell!

Where does the name ψ come from?

We started out(2) calling the resonance SP (3105) for about 1 day where SP stood for SPEAR, however, we soon realized that a 2 letter name was unsuitable. The name ψ came from a cursory look I made through the Particle Data Group booklet for an unused, yet pronounceable, Greek letter--while on the phone to George Trilling and then to Burton Richter. Little did we know that the resonance would end up with 2 letters, J/ψ anyhow! All the same--we evidently "got a sign" later, from the reaction: $\begin{array}{l}\psi' \rightarrow \psi\pi^+\pi^- \\ \qquad\;\; \hookrightarrow e^+e^-\end{array}$ that our choice of the Greek letter ψ was an auspicious one! See Fig. 7.

What does this all have to do with charm?

While our work on the ψ and ψ' was not influenced by theoretical predictions the work on the Psion spectroscopy was! In particular there now came a ground swell of theoretical papers interpreting the effects we were observing (see Fig. 8)--the front runners among these theories was the one suggesting that the J/ψ contained "hidden charm"

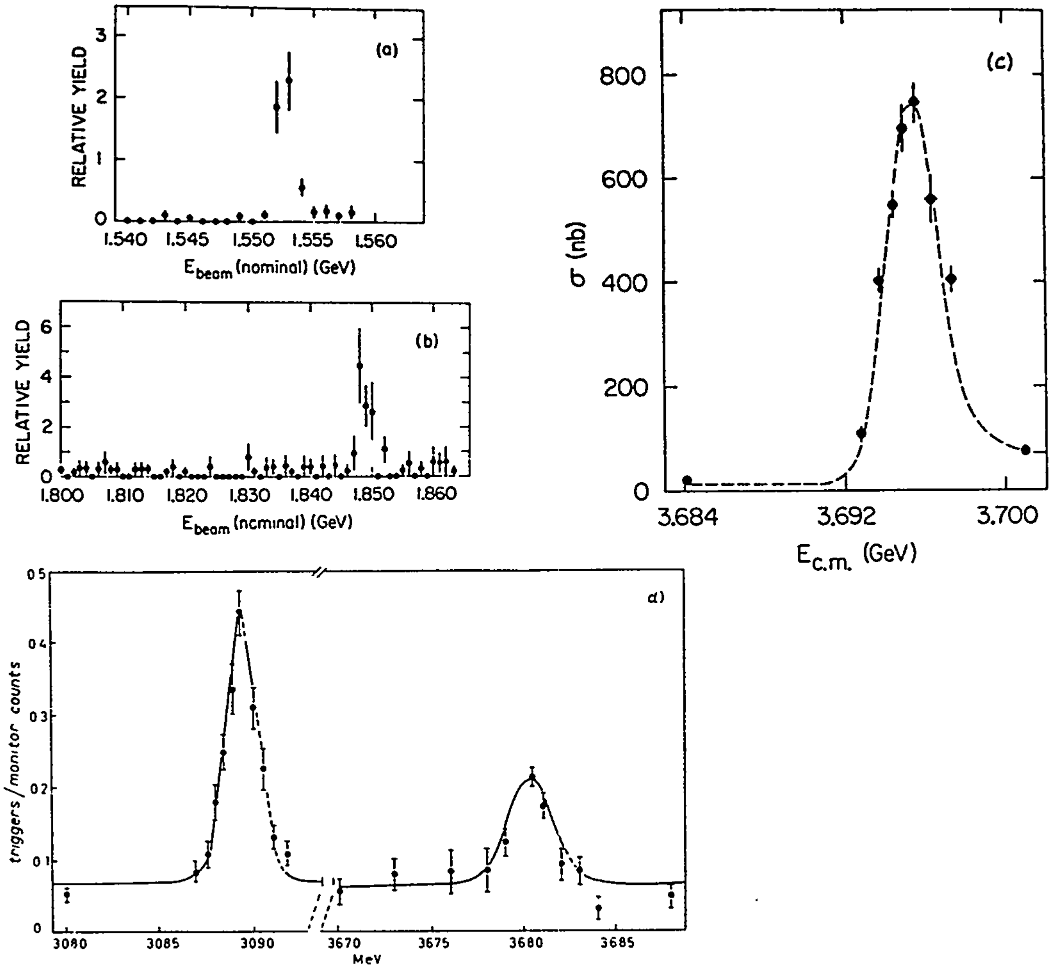

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Fig. 4. Discovery of the ψ′.
a. Test of the 1 MeV/minute scan over the ψ region.
b. Observation of the ψ′ by this scan.
c. More detailed scan on the ψ′.
d. Confirmation of the J/ψ and ψ′ by the DASP group at DESY.

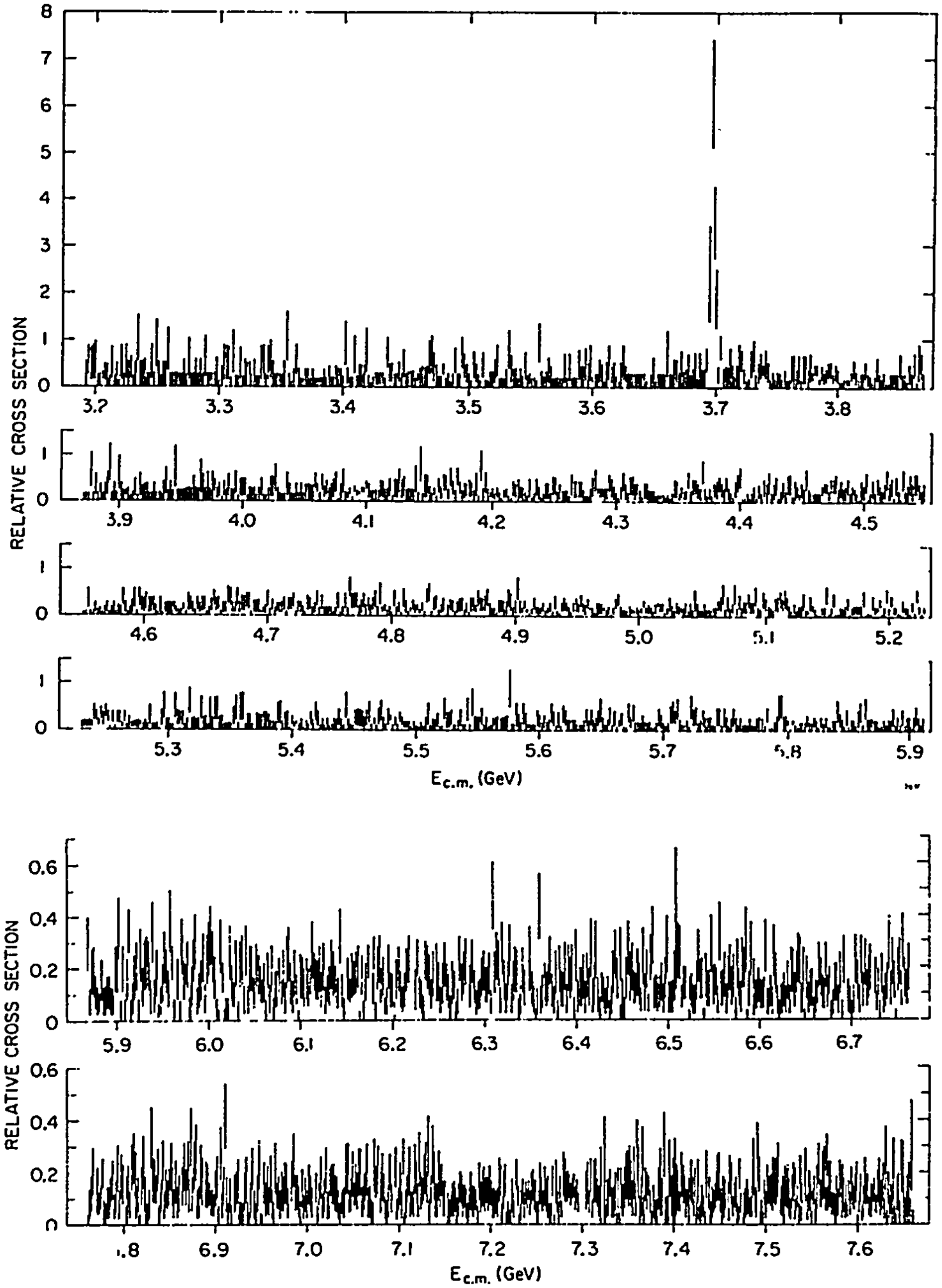

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Fig. 5. Search for additional narrow resonances up to 7.5 GeV. MARK I data taken over several running periods.

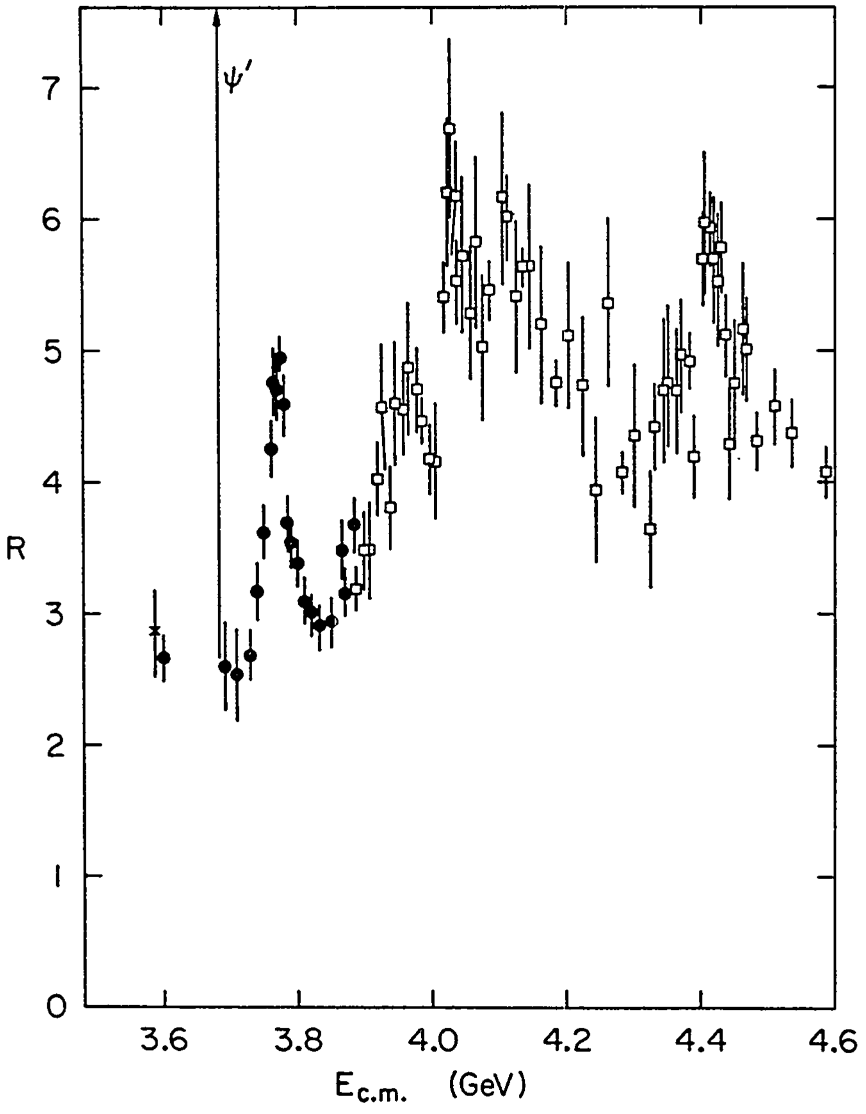

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Fig. 6. Broad resonance structures above the ψ′. MARK I and LGW data.

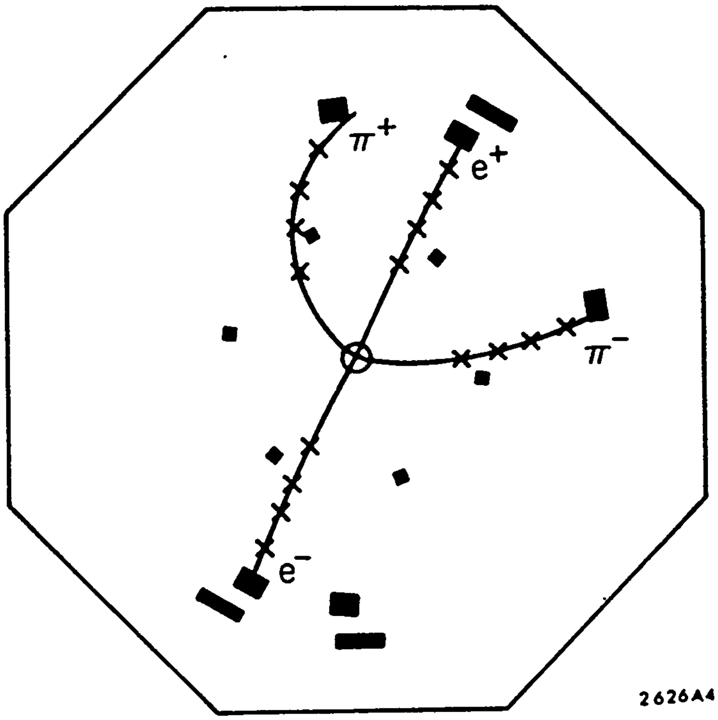

Fig. 7. Example of the decay $\psi' \to \pi^+\pi^-\psi$, $\psi \to e^+e^-$

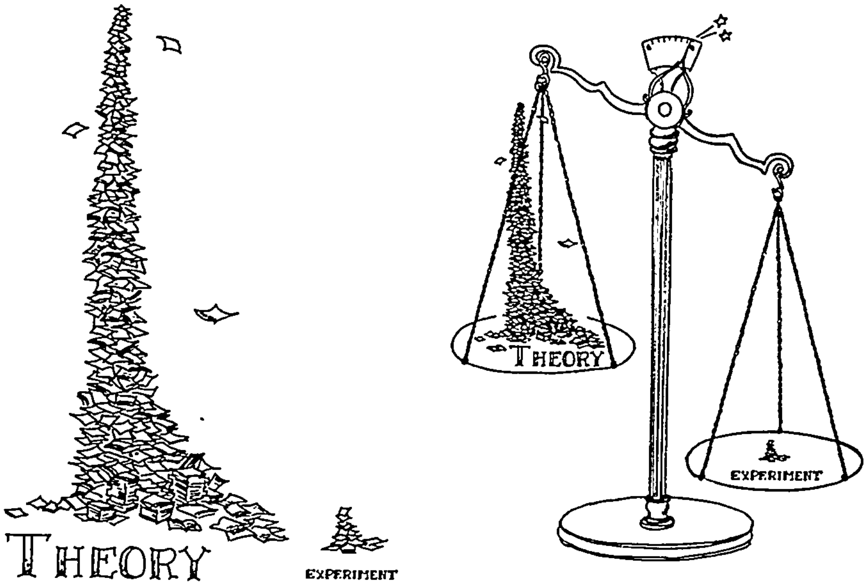

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Fig. 8. Cartoon by J.D. Jackson indicating the status of experimental and theoretical papers on the J/ψ with addition by Roy Schwitters (right hand side) sketched by Bob Gould.

namely, that it was a bound state of $c\bar{c}$ quarks, which had been predicted earlier.(16) while the narrowness of the ψ was explained by the Okubo-Zweig-Iizuka or OZI rule. If this was so, one expected to see particles with "naked charm.(17) Yet it took from November 1974 to May 1976 to find a clear peak(18) in the $K^- \pi^+$ and $K^-\pi^+\pi^-\pi^+$ mass distributions(19,20) at M = 1865 MeV. It was immediately clear that we had discovered a new meson M^0, and soon thereafter the charged mode M^+. The remaining questions were: could this be yet another K*? Was this particle indeed the predicted charmed meson? What led to the belief, and general acceptance, that we had something new and very different from a K* here?

The Case for Charmed Mesons

(i) Threshold. For a new K*(1865) we also expect a threshold. But that is expected at ~2.360 GeV [K*(1865) + K] or even ~2.755 GeV [K*(1865) + K*(890)]. However the experimental threshold lies above 3.7 GeV (see Fig. 9). In the charm theory a threshold is expected at $E_{cm} = 2\,M_D \simeq 3.73$ GeV, corresponding to $e^+e^- \rightarrow D^0\,\bar{D}^0$. In fact, the ψ'' (3770) discovered later,(11) is a resonance just above threshold which decays predominantly into $D^0\,\bar{D}^0$ and D^+D^-.

(ii) Associated Production. For a new K*(1865) we expect associated production with K or perhaps with K*(890) but there is no known reason to expect K*(1865) + $\bar{K}$*(1865) associated production. Experimentally we find that all observed events corresponding to the 1865 MeV/c^2 peak occur in associated production with either equal or higher mass objects. Figure 10 shows the experimental recoil mass spectrum in which we use the measured momentum of the $K\pi$ system together with the measured $K\pi$ invariant mass as well as a fixed mass with the nominal value M = 1865 MeV/c^2.

(iii) The charged decay mode. For a K* with I = 1/2 we also expect a charged decay mode. For three-body decays this would have to be the nonexotic[†] mode $K^{\mp}\,\pi^+\,\pi^-$. Experimentally we observe the exotic decay mode $K^{\mp}\,\pi^{\pm}\,\pi^{\pm}$ but do not observe the nonexotic decay mode (see Figure 11); neither do we observe the I = 5/2 triply-charged $K^{\mp}\,\pi^{\mp}\,\pi^{\mp}$ decay mode (not shown here). Thus if the peak corresponds to a K* it must have I = 3/2; i.e., an exotic K*, which (incidentally) would be the first clear case of an exotic meson state. If we adopt the point of view that we are dealing with an exotic K*, we would still have to invent an explanation for the peculiar fact that the $I_z = \pm\,1/2$ states (the nonexotic combinations $K^{\mp}\,\pi^+\,\pi^-$) are suppressed.

On the other hand our observations are in good agreement with charm theory in which Cabibbo-enhanced hadronic weak decays obey a $\Delta C = \Delta S$ rule, that is the charmed quark c decays weakly to $s\bar{d}u$. Thus in $D^+(C = 1, S = 0)$ decay, for example, the final state has $C = 0$, $S = -1$ together with $Q = +1$; i.e., the charged final state is predicted to be exotic. This point holds explicitly for the charm model and would not necessarily be true for other new types of mesons M composed of $\bar{q}Q$.

(iv) Experimental width. For a K* of mass 1865 MeV/c^2 we might expect a width $\Gamma \approx 50-200$ MeV/c^2, although admittedly for an exotic K* we have no clear prediction. Experimentally, we find $\Gamma < 40$ MeV/c^2 from the mass spectrum; however, by making use of the information from the recoil spectrum as well this limit becomes $\Gamma < 2$ MeV/c^2.

Charm theory predicts that the decays we are dealing with are weak decays and estimates are: $\tau \sim 10^{-13}$ sec. or roughly $\Gamma \sim 10^{-2}$ eV.

(v) Evidence for parity nonconservation or the "$\tau - \theta$ puzzle" revisited. For a K* we expect parity conservation in the decay; this should hold even for an exotic K*. Experimentally we find evidence for parity nonconservation. This is based on a study of the

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[†] Here exotic refers to the fact that the strangeness is opposite to the charge of the $K^{\mp}\,\pi^{\pm}\,\pi^{\pm}$ object, an impossibility for a quark-antiquark combination of the conventional quarks.

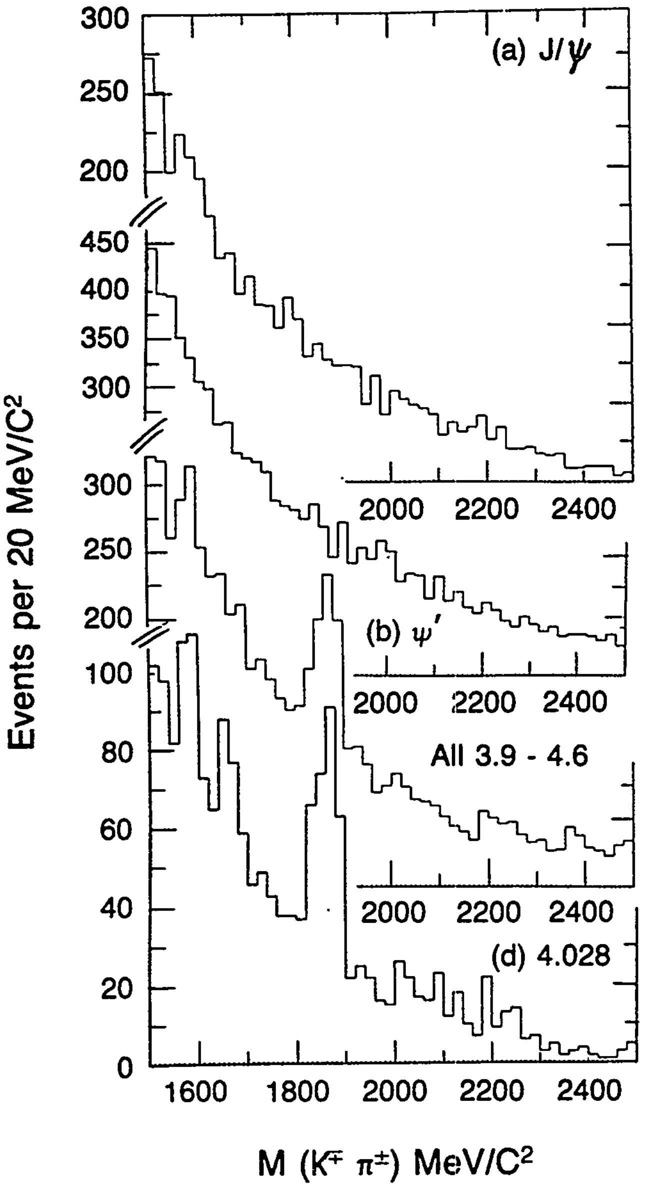

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Fig. 9. A composite of the Kπ mass distribution for the J/psi region, the ψ' region and the $E_{cm} = 3.9 - 4.6$ GeV region as well as the $E_{cm} = 4.028$ GeV data separately. SLAC-LBL MARK I data.

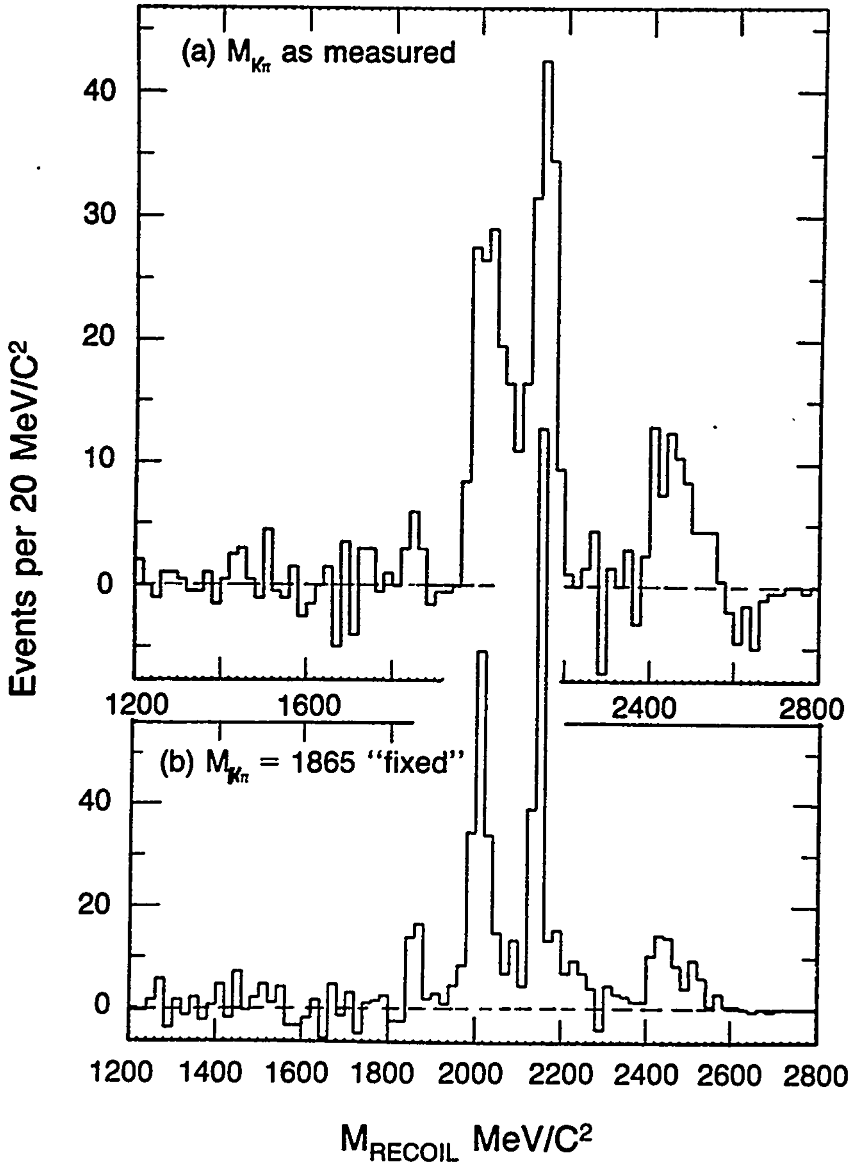

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Fig. 10. a. M_{recoil} distribution against the $K\pi$ signal as measured.
b. M_{recoil} distribution against the $K\pi$ signal for fixed $M_{K\pi}$ = 1865 MeV/c². Each distribution is background subtracted. It is noteworthy that the recoil sharpens up considerably when $M_{K\pi}$ is taken as a unique mass. SLAC-LBL MARK I data.

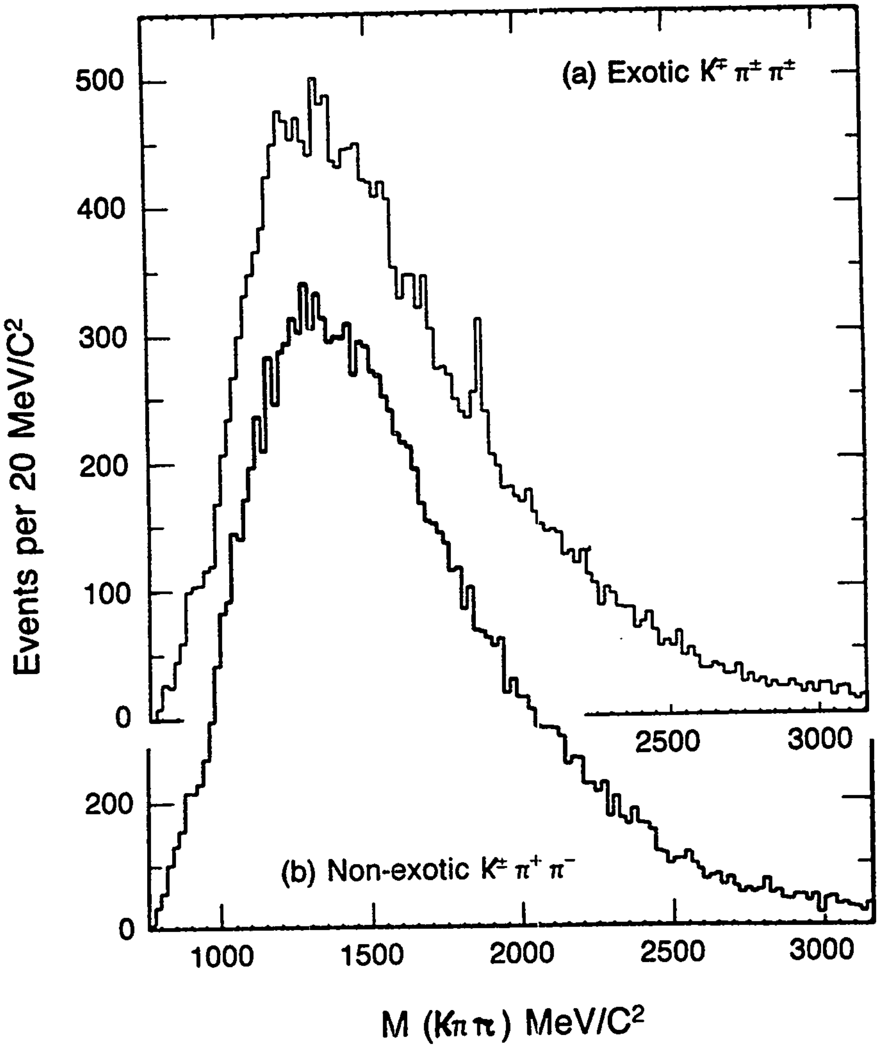

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Fig. 11. a. Mass distribution for the exotic $K\pi\pi$ combination showing the D^+ peak. b. Mass distribution for the non-exotic $K\pi\pi$ combination. SLAC-LBL MARK I data.

Dalitz plot for $K^{\mp}\ \pi^{\pm}\ \pi^{\pm}$ decay and the assumption that the charged and neutral states are an I-spin multiplet. If parity is conserved in the $K^{\mp}\ \pi^{\pm}$ decay we must have the natural spin parity series $J^P = 0^+, 1^-, 2^+$, etc. For the $K^{\mp}\ \pi^{\pm}\ \pi^{\pm}$ decay mode: $J^P = 0^+$ is ruled out for three pseudoscalars in the final state by angular momentum and parity consideration.

$J^P = 1^-, 2^+$, give Dalitz plot distributions which vanish on the boundary. Our data rule this out clearly.(21) Thus we have strong evidence for parity nonconservation and hence a weak decay, consistent with the charm theory predictions.

(vi) Higher mass states. For a K*(1865) there is no specific prediction for a next higher mass state. Experimentally we find from the recoil mass spectrum (see Figure 10) a next higher mass state at 2,006 GeV/c^2. From charm theory a state D* is predicted with mass $M_{D^*} \sim 2$ GeV/c^2. If, without prejudicing the case, we use the nomenclature of charm theory, the observed three peaks in the recoil spectrum can be interpreted as:

$$e^+e^- \rightarrow D^0\bar{D}^0 \quad (1)$$

$$\rightarrow D\bar{D}^* \text{ and } \bar{D}D^* \quad (2)$$

$$\rightarrow D^*\bar{D}^* \quad (3)$$

although the detailed structure is complicated(24), the identity of the possible fourth peak in the recoil mass spectrum near 2.43 GeV/c^2 is not established as yet.

Furthermore, the decay modes

$$D^{*0} \rightarrow D^0\pi^0 \quad (4)$$

$$\rightarrow D^0\gamma \quad (5)$$

have been identified and proceed with comparable rates. These two are the only important D^{*0} decay modes. The fact that D^{*0} has a large radiative decay indicates that it must be narrow and chooses to decay into a D^0 rather than directly into a $K^-\ \pi^+$ as might be expected for K*(2006). We must conclude that a special quantum number (presumably charm) is conserved in D^{*0} decay to the D^0.

Similar arguments can also be given for the decays(25)

$$D^{*+} \rightarrow D^0\pi^+ \quad (6)$$

$$\rightarrow D^+\pi^0 \quad (7)$$

$$\rightarrow D^+\gamma \quad (8)$$

(vii) Spin. For a K*(1865) one might expect spin values of $J = 3 - 4$, although again for an exotic K* all bets are off. An analysis of the events represented by reaction (2) given above can rule out simultaneous spin assignments for the states at 1865 and 2006, respectively, of 0 and 0 as well as 1 and 0, while the assignments 0 and 1 are consistent with the data.(22) Charm theory predicts $J^P = 0^-$ and 1^- for the D and D*, respectively. These values had been confirmed in more recent measurements.(23)

(viii) Lifetime. For a K* the lifetime is that typical of strong interaction viz. $10^{-23} - 10^{-24}$sec. Charm theory predicts weak decay lifetimes in the 10^{-13} sec. region.

Emulsion measurements in cosmic rays(18) and in neutrino beams had observed neutral and charged decays occurring ~10-200 μ from the parent interaction. Recently the lifetimes of the D^0 as well as the D^+ have been directly measured for identified decays in emulsions, high resolution Bubble Chambers, and electronic detectors with Vertex chambers-such as the SLAC-LBL MARK II detector. The present best average values are(26)

$$\tau_{D^0} = (4.4^{+0.8}_{-0.6}) \text{ x } 10^{-13} \text{ sec.}$$

$$\tau_{D^+} = (9.2^{+1.7}_{-1.2}) \text{ x } 10^{-13} \text{ sec.}$$

(ix) Semileptonic decays. The DASP experiment at DESY has identified electrons in multiprong events ($N > 3$) with a maximum signal observed in the $E_{cm} = 4.0-4.2$ GeV region. They have also observed K^+-e correlations which peak in the same E_{cm} region. Furthermore the PLUTO group at DESY have observed K_s^0 correlations also peaked in the $E_{cm} = 4.05$ GeV region. More recently the decay modes

$$D^0 \rightarrow K^- e^+ \nu$$

$$\rightarrow K^{*-} e^+ \nu$$

have been identified and the decay spectrum measured in the LGW and DELCO experiments at SPEAR(23) as well as in the DESY experiments. The existence of semileptonic decays is further proof for the weak interaction being responsible for D decays as predicted for charmed quarks.

(x) The Cabibbo-suppressed decay modes. The charm model also predicts a specific ratio between Cabibbo enhanced and suppressed decay modes. For example,

$$(D^0 \rightarrow \pi^- \pi^+)/(D^0 \rightarrow K^- \pi^{+)} = \tan^2 \theta_c$$

where θ_c is the Cabibbo angle. The decay modes

$$D^0 \rightarrow \pi^+ \pi^-$$

and

$$D^0 \rightarrow K^+ K^-$$

were later observed in the SLAC-LBL MARK II detector.(23) The average value for the two decay modes is indeed consistent with the above relation.

Establishment of the Cabibbo suppressed decay modes is another characteristic requirement of charmed quarks.

(xi) The F-meson. In addition to the D^0 and D^+, the isodoublet of the charm model, which correspond to $\bar{u}c$ and $\bar{d}c$, an additional singlet $\bar{s}c$ is predicted. This object was expected to have decay modes into two strange particles, $F^+ \rightarrow K^+K^-\pi^+$, for example. This state was hard to find, at first. Early indications were observed at a mass of 2040 MeV, but very recently the clear observation has been made in the CLEO experiment at CESR, the ARGUS experiment at DORIS and the TASSO experiment at PETRA.(27) These experiments observe the decay $F^+ \rightarrow \phi\,\pi^+$ at a mass of $M_F = 1970$ MeV/c^2.

These observations together with possible evidence for an F^* from ARGUS and the TPC at PEP, complete the picture, and give us an unambiguous identification of the charmed mesons.

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REFERENCES

1. The physicists involved in the initial experiment were: J.-E. Augustin, A.M. Boyarski, M. Breidenbach, F. Bulos, J.T. Dakin, G.J. Feldman, G.E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie, R.R. Larsen, V. Lüth, H.L. Lynch, D. Lyon, C.C. Morehouse, J.M. Paterson, M.L. Perl, B. Richter, P. Rapidis, R.F. Schwitters, W.M. Tanenbaum, and F. Vannucci of SLAC and G.S. Abrams, D. Briggs, W. Chinowsky, C.W. Friedberg, G. Goldhaber, R.J. Hollebeek, J.A. Kadyk, B. Lulu, F. Pierre, G.H. Trilling, J.S. Whitaker, J. Wiss, and J.E. Zipse of LBL.
2. A discovery story of the ψ. Gerson Goldhaber. "Adventures in Experimental Physics" vol. 5, Epsilon, p. 131, Editor, B. Maglich (World Science Education, Princeton, New Jersey, 1976). It is interesting to note here that the earlier observation of J.H.Christenson, et al. [Phys. Rev. Lett. 25, 1523(1970)] showing a broad shoulder in the μ pair mass, between 3 and 4 GeV/c^2 , was finally understood (Leon Lederman, unpublished note, December 16, 1974) when the J/ψ discoveries were made.
3. The paper by C.E. Carlson and P.G.O. Freund [Phys. Lett. *39B,* 349(1972)] talks about a vector meson with "hidden charm" but was not known to us.
4. First cross section measurements in the 3-5 GeV region at CEA and in the low energy region at Frascati.
   A. Litke et al., Phys. Rev. Lett. *30,* 507 (1973),
   G. Tarnopolsky et al., Phys. Rev. Lett. *32,* 432 (1974),
   F. Ceradini et al., Phys. Lett. *47B,* 80 (1973),
   Bacci et al., Phys. Lett. *44B,* J33 (1973).
5. A discovery story of the J. Samuel Ting "Adventures in Experimental Physics", vol. 5, Epsilon, p. 115.
6. Discovery of the J. J. Aubert et. al. Phys. Rev. Lett. *33,* 1402(1974).
7. Discovery of the ψ. J. E. Augustin, et al. Phys. Rev. Lett. *33,* 1406(1974).
8. Confirmation of the J/ψ. C. Bacci et. al. Phys. Rev. Lett. *33,* 1908(1974).
9. A discovery story of the ψ and ψ'. Burton Richter. "Adventures in Experimental Physics", vol. 5, Epsilon, p. 143.
10. Discovery of the ψ'. G.S. Abrams, et al. Phys. Rev. Lett. *33* 1953(1974).
11. Discovery of the ψ''. P.A. Rapidis et al. Phys. Rev. Lett. *39,* 526(1977).
12. Discovery of a P state. W. Braunschweig, et al. Phys. Lett. *57B,* 407(1975). Discovery of the χ states, J. S, Whittaker, et al. Phys. Rev. Lett. *37* 1596(1976), W. Tannenbaum, et al. Phys. Rev. *17D,* 1731(1978) and V. Vannucci, et al, Phys. Rev. *15D,* 1814(1977).
13. Study of radiative transitions. C.J. Biddick et. al. Phys. Rev. Lett. *38,* 1324(1977).
14. Precision study of radiative transitions. E.D. Bloom and C.W. Peck. Ann. Rev. Nucl. Part. Sci. *33,* 193(1983). Editors: J.D. Jackson, H.E. Gove, and R.F. Schwitters.
15. Discovery of the τ. M. Perl, et al, Phys. Rev. Lett. *35* 1989(1975).
16. The prediction of charmed quarks. J.D. Bjorken and S. Glashow. Phys. Lett. *11,* 255(1964). S.L. Glashow, J. Iliopoulos and L. Maiani. Phys. Rev. *D2,* 1285(1970).
17. The prediction of the properties of charmed mesons and baryons. GIM in Ref. 16; G.A. Snow. Nuclear Physics *B55,* 465(1973); S.L. Glashow, in Experimental Spectroscopy--1974, AIP Conference Proceedings No. 21, edited by D.A. Garelick (American Institute of Physics, New York, 1974), p. 387; M.K. Gaillard, B.W. Lee, and J.L. Rosner, Rev. Mod. Phys. *47,* 277(1975); A. De Rujula, H. Georgi, and S.L. Glashow, Phys. Rev. *D12,* 147(1975); M.B. Einhorn and C. Quigg, Phys. Rev. *D.12,* 2015(1975).

18. Earlier indications of possible charmed particle production have come from cosmic-ray emulsion studies, K. Niu, et al. Prog. Theor. Phys. *46, 1644(1971),* as well as from experiments involving neutrino interactions. See, for example: J. Blietschau, et al., Phys. Lett. *34,* 419(1975); E.G. Cazzoli, et al., Phys Rev. Lett. *34,* 1125(1975); J. Blietschau, et al, Phys. Rev. Lett. *60B,* 207(1976); J. von Krogh, et al, Phys. Rev. Lett. *36,* 710(1976); B.C. Barish, et al., Phys. Rev. Lett. *36,* 939(1976). Subsequent to our work, evidence for a charmed baryon has also been presented from a photoproduction experiment at Fermilab; B. Knapp, et al., Phys. Rev. Lett. *37,* 882(1976), and in later work at CERN and with the MARK II detector. See Ref. 25.
19. The discovery of a charmed meson, D^0. G. Goldhaber, F.M. Pierre et al., Phys. Rev. Lett. *37,* 255(1976).
20. The discovery of the charged decay mode D^+. I. Peruzzi, M. Piccolo et al., Phys. Rev. Lett. *37,* 569(1976).
21. Evidence for parity violation in charmed meson decays. J. E. Wiss, G. Goldhaber, et al. Phys. Rev. Lett. *37,* 1531(1976).
22. Spin analysis of charmed mesons. H. K. Nguyen, J. E. Wiss, et al., Phys. Rev. Lett. *39,* 262(1977).
23. References to more recent papers can be found in G. Goldhaber and J.E. Wiss. Ann. Rev. Nucl. Part. Sci. *30,* 337(1980). Editors: J.D. Jackson, H.E. Gove and R.F. Schwitters.
24. Study of the D^* decay modes. G. Goldhaber, J. E. Wiss, et al. Phys. Lett. *69B, 503(1977).*
25. The observation of $D^* \rightarrow D^0\pi^+$. G. J. Feldman, I. Perruzzi, et al. Phys. Rev. Lett. *38, 1313(1977).*
26. A review of lifetime measurements. R.A. Sidwell, N.W. Reay and N.R. Stanton. Ann. Rev. Nucl. Part. Sci. *33,* 539(1983). Editors: J.D. Jackson, H.E. Gove and R.F. Schwitters.
27. For very recent references see: Particle Data Group, Rev. Mod. Phys. *56 II,* (1984).