Heavy Quark Resonances

B. Gittelman, Cornell University
Session Organizer

HEAVY QUARK RESONANCES

B. Gittelman
Cornell University
Ithaca, New York 14853

This session contained three papers on the properties of quarkonium and a paper summarizing the status of current knowledge of e^+e^- physics.

Measurements of the Properties of the Upsilon Family from e^+e^- Annihilation

H. Meyer, University of Wuppertal

Dr. Meyer reported on the experimental results of the three groups, DASPL, PLUTO, and DHHM, working on the DORIS storage ring at DESY. All three groups have observed the Υ as a bump in the total hadronic cross section vs. energy distribution. From the location of the bump and the magnitude of the cross section at resonance, one obtains the Υ mass and the partial decay rate Γ_{ee}. The average of the reported values are $M(\Upsilon) = 9.46 \pm 0.01$ GeV and $\Gamma_{ee}(\Upsilon) = 1.29 \pm 0.15$ GeV. DASP 2 and DHHM have observed the Υ'. The average value of the mass is $M(\Upsilon') = 10.015 \pm 0.02$ GeV and the partial width is $\Gamma_{ee}(\Upsilon') = 0.335 \pm 0.15$ Gw. Using the mass difference $\Delta M(\Upsilon'-\Upsilon) = 0.555 \pm 0.022$, the mass of the third resonance (K. Ueno et al., PRL 42, 486 (1979)) may be refitted to give the value $M(\Upsilon'') = 10.41 \pm 0.05$ GeV.

The Υ is considered to be a bound system of b and $\bar{b}$ quarks. This new quark has a 1/3 unit of charge. There are two arguments supporting this interpretation. The continuum value of $R = \sigma(e^+e^- \to \text{Hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$ does not increase by more than a half unit at energies above the Υ. The value of $\Gamma_{ee}(\Upsilon)$ is 4 times smaller than $\Gamma_{ee}(\psi)$ suggesting charge 1/3 rather than charge 2/3 as is the case for charm. This latter evidence has been made more compelling by considering $\Gamma_{ee}(\Upsilon')$ also (see Rosner, Quigg, and Thacker).

The branching fraction for $\Upsilon(9.46) \to \mu^+\mu^-$ has been measured. The results are $(2.2 \pm 2.0) \times 10^{-2}$ (PLUTO), $(2.5 \pm 2.1) \times 10^{-2}$ (DASPL), and $(1.0 \pm 3.4) \times 10^{-2}$ (DHHM). Using the mean of the first two values, $(2.3 \pm 1.4) \times 10^{-2}$ and assuming $\Gamma_{\mu\mu} = \Gamma_{ee}$, one obtains the total width $\Gamma(\Upsilon) = 57 \pm 35$ KeV.

QCD predicts the Υ to decay into three gluons which after dressing leads to final states of three hadronic jets. Dr. Meyer presented evidence for the 3 gluon decay. The data indicate:

(1) The Υ does not decay into 2 jets. There is a strong change in the sphericity of the events obtained on the Υ compared to those obtained off the resonance.

(2) The events from the Υ tend to be coplanar.

(3) The data are well fitted by a 3 gluon Monte Carlo and are in disagreement with a phase space Monte Carlo.

(4) If one accepts the 3 jet hypothesis, the distribution of the jet axis opening angles is in good agreement with what may be expected for a spin 1 gluon and in disagreement with a prediction for a spin 0 object. Furthermore, the angular distribution of the highest momentum jet axis relative to the incident beam agrees more closely with what is expected for spin 1.

$$\text{Theory} \begin{cases} 1 + 0.39 \cos^2\theta & \text{Spin} = 1 \\ 1 - 0.99 \cos^2\theta & \text{Spin} = 0 \end{cases}$$

$$\text{PLUTO Measurement} \quad 1 + (0.83 \pm 0.23)\cos^2\theta$$

(5) The gluon is supposed to couple equally well to all quarks. If the Υ decays through gluons, the number of K^0 mesons in the final state will be effected. A calculation of K^0's one might expect under various assumptions gives

Assumed Final State Flavor Ratios	Number of K^0 / Event
u: d: s 4:1:1	0.29
u: d: s: c = 4:1:1:4	0.58
u: d: s: c = 1:1:1:1	0.43

The PLUTO experiment finds $N(K^0)$/event = 0.39 ± 0.03 on the Υ in agreement with the flavor blind gluon hypothesis.

Dr. Meyer emphasized the difficulty of demonstrating 3 jets at Υ energies. He described the data as consistent with the QCD picture. For those who remain unconvinced, he suggested waiting until Toponium is found. At Toponium energies the three jet character will be obvious.

Interepretation of Recent e^+e^- Results

H. Harari, Weizmann Institute

The speaker attempted to provide perspective on the role to be played by e^+e^- physics within the framework of the Electro-Weak Theory. In this brief summary I am unable to provide the flavor of his discussion. Accordingly I will only list those items which bear directly on current problems and experiments.

A. Charm

1. Charmonium - Most theorists are relieved to find the experiments (Crystal Ball and Mark 2) now repudiate the $\eta_c(2850)$ and the $\chi(3450)$. On the other hand, new data presented to the conference (Crystal Ball) suggest that η_c may have been seen at a mass of 2.976 GeV in the inclusive photon spectrum of $\psi'(3690)$ (i.e., $e^+e^- \to \psi'(3690) \to \gamma + U(2976)$). If this is the case, one should see a signal in $\psi(3100) \to \gamma + U(2976)$ at the few percent level. We eagerly await the next installment from the Crystal Ball experiment. There is additional interest in a careful measurement of the inclusive photon spectrum from the ψ. Both the shape and the magnitude are important.

2. Charm Decays - There are no fundamental problems between theory and experiment in this field. However, there are a few holes in the picture. We need experimental verification that the Cabibbo angle between s and d is the same as between c and u. One way to get at this angle is to measure $\Gamma(c \to s + e + \nu)/\Gamma(c \to d + e + \nu)$. Our attention was also directed to the need to confirm the existence of the F^+ meson and to resolve the puzzle of the apparent existence of two Λ_c's with close but distinct mass values of 2.26 and 2.29 GeV.

B. B Mesons

There was a paper submitted to the conference reporting the first evidence for B mesons. This particle was seen in $B^+ \to D^0 \pi^+\pi^0$ and $B^0 \to \psi K^-\pi^+$ mass plots at m = 5.3 GeV. However, the bump is only 3 std. dev above the background, and we were encouraged to be patient and wait until the experimenters have more data to enhance the statistical significance of the signal. Soon we should also be seeing $B \to D + \ell + \nu$ from $e^+e^- \to B\bar{B}$.

C. Υ Mesons

A most important problem for PETRA and PEP is to find the top quark threshold. The current data from PETRA sets a lower limit of 15 GeV for the mass of this quark. If nature is kind, the Υ meson mass will be less than 17 GeV so that the existing machines will be able to study its properties. If one can produce Υ mesons in the e^+e^- machines, this should be a rich source of B mesons since the t quark decays primarily to bW^+ in the standard model.

D. τ Mesons

Current experimental information about τ mesons is in good agreement with the interpretation of this particle as a heavy sequential lepton. In particular, branching fractions into $\pi\nu$, $\rho\nu$, and $A\nu$ have been measured, and the muon momentum spectrum from $\tau \to \mu\nu\bar{\nu}$ indicates V-A interaction. The situation looks so clean that the MARK J experiment is already using the $e^+e^- \to \tau^+\tau^-$ cross section to test QED. The remaining questions are

(1) Improve the upper limit of the mass of ν_τ.

(2) Set limits on $\tau \to (e\gamma)$, $(\mu\gamma)$, and $(\ell\ell\ell)$.

E. Evidence for Gluons

Dr. Harari expressed cautious acceptance that the high energy three jet analysis of the four experiments at PETRA have demonstrated existence of gluon bremsstrahlung. He echoed some reservations regarding the 3 gluon decay analysis of Υ reported in the previous paper and emphasized the importance of finding Toponium.

Production of Heavy Quark-Antiquark Bound States in Hadron-Hadron Collisions

L. Camilleri, CERN

A. Production of the Charmonium P States

Data were presented on πP and PP → γψ + anything from 4 experiments. The ψ was identified by its decay into $\ell^+\ell^-$. A bump is seen in the γψ mass spectrum corresponding to χ(3508) and a cross section is derived. This cross section is relevant to understanding the large difference between ψ and ψ' yields in hadronic collisions. The results are tabulated below.

Experiment	Initial State	$\sqrt{S}$	<x>	Detect via	$\frac{\chi \to \gamma\psi}{\text{All } \psi}$
C.Kourkoumelis et al.	PP	62	0	e^+e^-	.47 ± .08
A.G. Clark et al.	PP	62	0	e^+e^-	$.15 \pm^{.10}_{.15}$
T.B.W. Kirk et al.	π^-P	20	0.45	$\mu^+\mu^-$	.70 ± .28
Y.Lemoingne et al.	π^-P	∿18	0.2	$\mu^+\mu^-$	.11 ± .036

Unfortunately, these results are so diverse that one cannot draw conclusions about the cross sections.

B. Energy Dependence of Υ Production in PP Collisions

Data on the energy dependence of Υ production for $20 < \sqrt{S} < 62$ GeV has been accumulated from five experiments. When plotted vs. $m/\sqrt{S}$ the spectrum has the same shape as that for ψ production. The relative magnitude between the two excitation curves is ∿500. From dimensional analysis one might write

$$B(\Upsilon\to\ell^+\ell^-)\sigma(pp \to \Upsilon x) = \frac{1}{m_\Upsilon^3}\Gamma(\Upsilon \to \ell^+\ell^-)F_\Upsilon\left(\frac{m_\Upsilon}{\sqrt{S}}\right)$$

$$B(\psi\to\ell^+\ell^-)\sigma(pp \to \psi x) = \frac{1}{m_\psi^3}\Gamma(\psi \to \ell^+\ell^-)F_\psi\left(\frac{m}{\sqrt{S}}\right)$$

Setting $F_\Upsilon = F_\psi$ and using $\Gamma_{\psi\to ee} = 4.69$ KeV, $\Gamma_{\Upsilon\to ee} = 1.33$ KeV, one obtains $(B\sigma)_\psi/(B\sigma)_\Upsilon = 100$ which is off by a factor of 5.

C. Production of Υ in $\pi^\pm p$ Collisions

The NA3 experiment at the SPS presented data on $\pi^\pm p \to \Upsilon X$. The ratio of Υ:Υ':Υ'' = 1:0.3:0.15 is consistent with the values found for pp collisions. Their results are given below.

$\sqrt{S}$ (GeV)	19.4	19.4	22.9
Particle	π^+(200 GeV)	π^-(200 GeV)	π^-(280 GeV)
Events(Υ+Υ'+Υ'')	53 ± 12	55 ± 15	66 ± 20
$\beta \frac{d\sigma}{dy}$(pb/nucleon)	2.7 ± .09	2.1 ± 0.7	3.4 ± 1.3
βσ(pb/nucleon)	1.9 ± 0.6	1.5 ± 0.5	2.4 ± 0.9
σ(GeV/c²)	4.2 ± 1.0	0.87 ± 0.26	0.70 ± 0.22

The last entry, α, is the ratio of the number of Υ's to the continuum at 9.46 GeV. Their mass resolution was approximately 1 GeV.

D. Comparison of Υ to the Continuum

Various distributions of muon pairs coming from Υ production were compared to those coming from the continuum. The angular distribution of the μ^+ momentum in the Υ rest frame relative to the direction of Υ laboratory momentum vector is found to be consistent with isotropy. In contrast, the muon pairs from the continuum have a distribution consistent with $1 + \cos^2\theta$. The transverse momentum distribution of $\vec{p}_{\mu+} + \vec{p}_{\mu-}$ relative to the incident beam is found to be greater for Υ then for the continuum. The above facts were interpreted as evidence that the Υ production mechanism is distinct from the Drell-Yan process.

The Interpretation of the Spectra of Heavy Quark-Antiquark Bound States

C. Quigg, FNAL

This paper deals with a wide variety of the theoretical problems of Quarkonium. The emphasis was on what information can be obtained from the non relativistic potential theory. As an illustration, the potential $V(r) = \lambda r^\nu$ was chosen where λ and ν are to be determined from the ψ data. Using energy differences between the lowest three ^{3}s states, the parameter ν is fixed. The fine splitting $(E_{2s} - E_{2p})$

was then calculated and shown to be consistent with experiment. Given this crude potential one may calculate the energy of other states and their wave functions. This provides a tool to stimulate further experiment. Having parametrized the $q\bar{q}$ potential for charm, we might hope the same potential applies to other quarks. If this is the case, many properties may be predicted. As an example, Dr. Quigg reviewed the compelling argument by which a limit was set on the quark charge from the leptonic widths of Υ and Υ'. In general each physical observable provides a constraint on the properties of the potential. The most common of these are the ground state quarkonium mass, the level spacings, $\Gamma(e^+e^-)$of the various states, $\Gamma(E1)$ and $\Gamma(M1)$ for photon transitions, and the mass of the lightest meson possessing the new flavor. As a further illustration, the energy of all the triplet levels of the Υ family up to the 5^3s at 10.85 GeV were given. Some properties of the Toponium family of mass 30 GeV were predicted. The speaker also reviewed recent progress on the more general problem of determining the potential from the energy levels and discussed the need for work on relativistic and radiative corrections.