Charmonium and J/ψ Physics

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Charmonium and J/ψ Physics

tcf number of events per **Month**		
Luminosity	10^{32}	10^{33}
J/ψ	1.0×10^{8}	1.0×10^{9}
ψ′	0.5×10^{8}	0.5×10^{9}

(w/o monoch.)

Largest Existing Sample to date from BES; ~9M J/ψ and ~1.5M ψ′. The tcf would increase the statistics by factor 1000.
For reviews see SLAC-343 (June 1989) and papers by Barnes and Close

Physics Topics

Search for Glueballs

Charmonium Tests

Phase Shift Studies

Precision Measurement Tests

Other topics (ρπ, Γ) in Seth and Gu talks

Gluonium Resonances

Search: 2 gluon states ($J^{PC}=0^{++},0^{-+},1^{++}$), especially the lowest lying scalar glueball ~1.5 GeV.

Status: DM2/Mk3/BES studied J/ψ radiative decays and observed several states in $K\overline{K}$(theta), $K\overline{K}\pi$(iota), $K\overline{K}(\xi)$. Results differ on spin and masses.

Why is this interesting?
$\Rightarrow$MK3 evidence of scalar signal in $K\overline{K}$ decays
$\Rightarrow$Quark Model scalar nonet is badly broken unlike the light quark vector and tensor nonets and $\chi_{0,1,2}$(b,c).
$\Rightarrow$Hints that scalar f_o is really several states?

Overlapping resonances make it difficult to pinpoint scalar resonance. Spin parity studies are difficult and ambiguous. Theory does not provide mass or width, only rough guidelines.

How does one get definitive scalar glueball evidence??

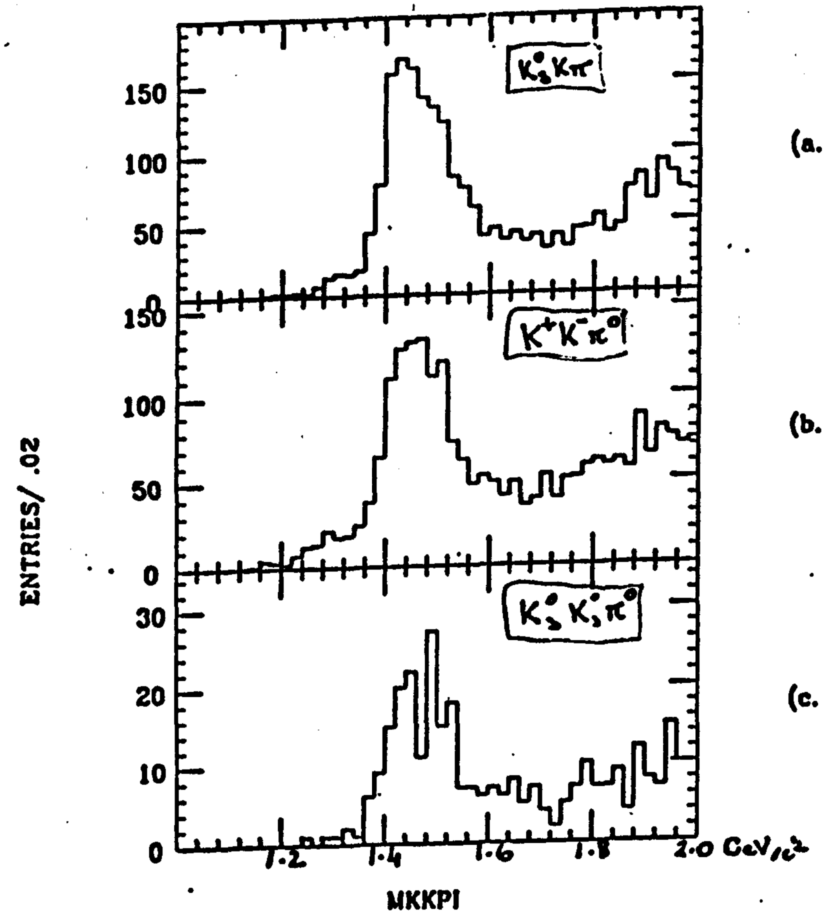
Most likely Scenario: high statistic spin parity study of 2 and 3 body decays. This requires very high statistics and excellent angular acceptance (Crystal Calor.) especially in the forward direction. Unlikely to lead to any surprises as dramatic as J/ψ discovery that makes break through?

Possible Results or Surprises from other expts. ?
(1) BNL (states with η's) or LEAR or E760
(2) 3 gluon resonances or vector glueballs
($\psi' \to \pi\pi G_V$)
(3) resonances in semileptonic decays,
$Ds \to K\bar{K}$[illegible], $K\bar{K}\pi + e\nu$

Other topics; hybrids (gluons + $q\bar{q}$), 4 quark states
If it is too difficult to unravel glueballs in light quark decays are there other "Smoking Gun Tests"?

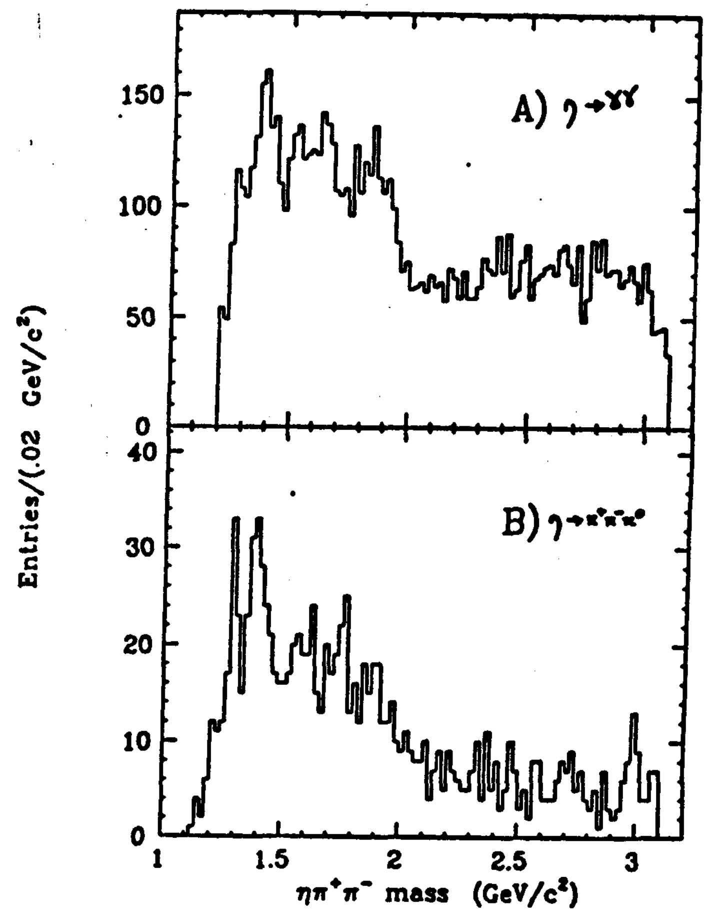
(a) exotic quantum numbers ($0^{-+}, 1^{-+}, 2^{-+}$),
  p wave $\eta\pi^{\circ}$
(b) "exotic flavor";
  hidden strangeness state,ex. $\phi\pi, \phi\omega$
  new charmonium states? $c\bar{c}$+glue, ex. $\eta\Psi$
  (it might be a cleaner system to probe)

$J/\psi \to \gamma K\bar{K}\pi$



2) $KK\pi$ invariant mass in radiative J/ψ decays seen in MarkIII

$J/\psi \to \gamma \eta \pi\pi$



8) Mass $\eta\pi^+\pi^-$ in MarkIII.

3 body decays into $K\bar{K}\pi$, $\eta\pi\pi$

LASS Partial Wave Analysis

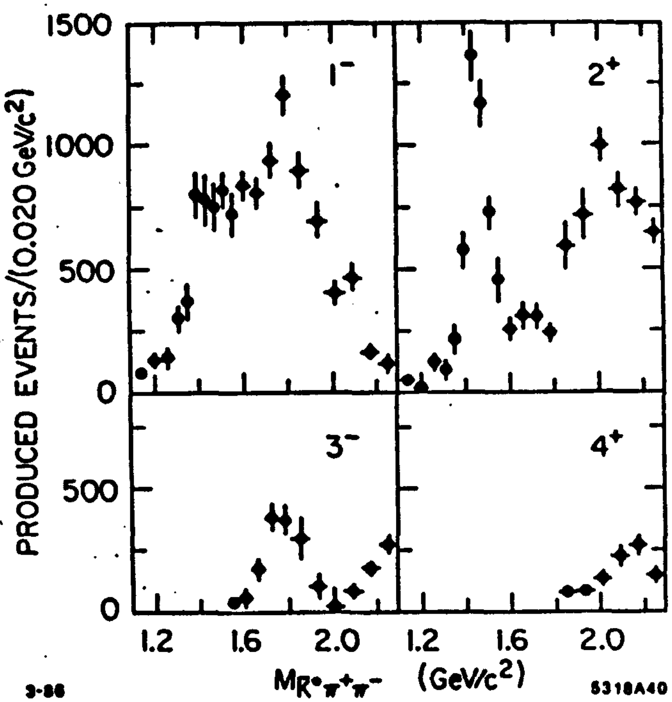


Fig. 4

$\bar{K}^0\pi^+\pi^-$ Results
90K event sample

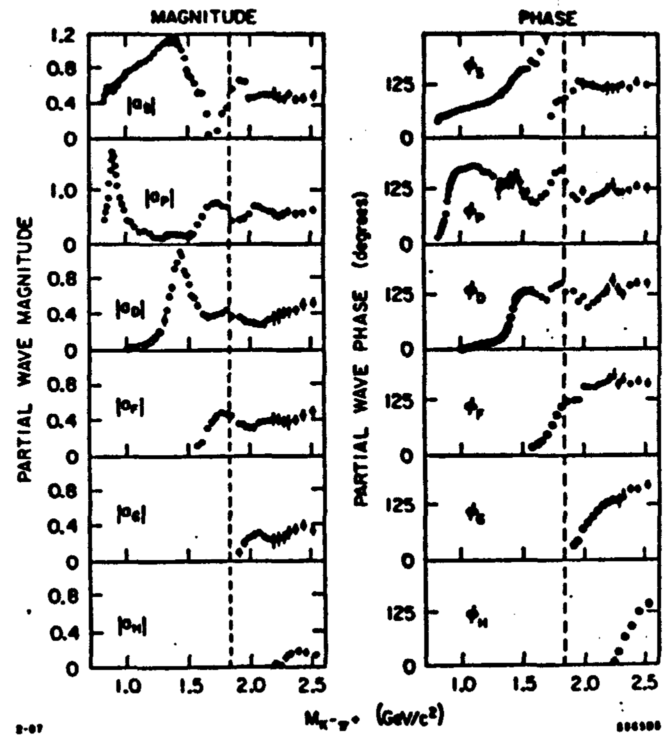


Fig. 5

$K\pi$ Results
730k event sample

Projected Event Sample

Table I

Comparison of observed event rates in e^+e^- and K^-p production for several different hadronic final states. The recoil particle is indicated in parentheses. The observed events are those seen in e^+e^- by the Mark III and in K^-p interactions with LASS. The projected events are as might be expected from large scale experiments at a tau-charm factory and at a kaon factory (see text).

	OBSERVED EVENTS		PROJECTED EVENTS	
FINAL STATE	MARK III	LASS	TAU-CHARM 1000× Mark III	KAON 100× LASS
K_sK_s	(γ) 590	(Λ) 411	(γ) 6×10^5	(Λ) 4×10^4
K^-K^+	(γ) 4400 (ϕ) 320	(Λ) 12294	(γ) 4×10^6 (ϕ) 3×10^5	(Λ) 1.2×10^6
$K^{*0}\overline{K}^{*0}$	(γ) 811	(Λ) 1650	(γ) 8×10^5	(Λ) 2×10^5
$K\overline{K}\pi$	(ϕ) 670	(Λ) 3900	(ϕ) 7×10^5	(Λ) 4×10^5

Comment LASS experience ⇒ 10^5-10^6 events in sample in high acceptance detector for full PWA.

Charmonium Tests

<u>Masses</u>:

η_c' needs confirmation, CB weak evidence

$^1P_1$ found, E760 measured very precisely mass

<u>Width Measurements</u>

Is there a problem between smaller e+e- widths and larger E760 widths? See Seth talk.

<u>Decay Rates</u>:

Need abs. BR's needed to normalize $\chi_c, \eta_c \to p\bar{p}$ and $K\bar{K}\pi$ for E760 which measures product BR of $p\bar{p} \to X \to \gamma\gamma, ee, J/\psi, \psi'$ and 2γ experiments which detect $\gamma\gamma \to \eta_c \to K\bar{K}\pi$. In tcf we could combine best features of Crystal Ball + solenoidal mag. detector to measure inclusive ($J/\psi \to \gamma + X$) and exclusive modes ($J/\psi \to \gamma\eta_{cc} \to p\bar{p}, K\bar{K}\pi$).

Can test E760 measurement of BR($J/\psi \to ee$) $\times$BR($J/\psi \to p\bar{p}$) in the reaction $p\bar{p} \to J/\psi \to ee$ with the time reversed tcf measurement of $ee \to J/\psi \to p\bar{p}$ and the abs. BR($J/\psi \to p\bar{p}$) and BR($J/\psi \to ee$) from $\psi' \to \pi\pi J/\psi$

$J/\psi \to \gamma\gamma\gamma$ and $\eta_c \to \gamma\gamma$ rates measure $|R(0)|^2$ and the c quark charge. The $J/\psi \to \gamma\gamma\gamma$ is not yet measured and the $\eta_c \to \gamma\gamma$ has large errors. $\sigma(\gamma\gamma) \simeq 8\%$
$\sigma(\gamma\gamma\gamma) \simeq 3\%$

<u>R(ee→hadrons) Bumps</u>

In e^+e^- production just above charm cc threshold several large resonances are seen at 4.03, 4.16 and 4.4 GeV.

4.03 GeV: $\sigma(D^*\bar{D}^*) > \sigma(D\bar{D})$: There is a long standing problem that the D*D* rate is much larger than DD at 4.03 by a factor 10. Is this a $D^*\bar{D}^*$ molecule? BES has just run at 4.03 and clearly observes a large $D^*\bar{D}^*$ and $D\bar{D}^*$ signal as MarkI did. The $\gamma D^\circ \bar{D}^\circ$ will be very important for indirect CP violation search. See Izen talk.

3.9 GeV: Close suggests this is where a vector hybrid is being produced? A search for $ee \to \eta\psi_H, \psi_H \to \eta\psi$ where ψ_H is a $c\bar{c}g$ hybrid state.

Status of Charmonium Measurements (single most precise value)

State	Mass MeV	Width	Spin	BR(ee/γγ) %	hadronic decays
η_c	2974.4±1.9	~~7±7~~ >15 MeV E760	0^{-+}	.06±.035 7±3 keV	few decays *
J/ψ	3096.9±.09	85.5±6 KeV *	1^{--}	5.92±.15±.2 *	many decays
χ_0	3417±.8	13.5±3	consistent*	.04±.02	few decays *
χ_1	3510±.04	.88±.11	consistent*		few decays *
χ_2	3556±.07	1.98±.17	consistent*	.02 (E760)	few decays *
$^1P_1$	3526.2±.2	.9±.44	? *	?	pp,J/ψ+π *
$\eta_c(2s)$	3594±5 (E760 no signal) *	<8 *	? *	?	? *
ψ′	3686±0.1	.308±.036	1^{--}	.88±.13 *	many decays
ψ(3.77)	3764±5	24±5	1^{--}		DD *
ψ(4.03)	4040±10	52±10	1^{--}		D*D*,D*D, DD,DsDs *
ψ(4.14)	4159±20	78±20	1^{--}		D*D*,D*D, DD,DsDs* *
ψ(4.42)	4414±7	33±10	1^{--}		

* tcf can improve this measurement

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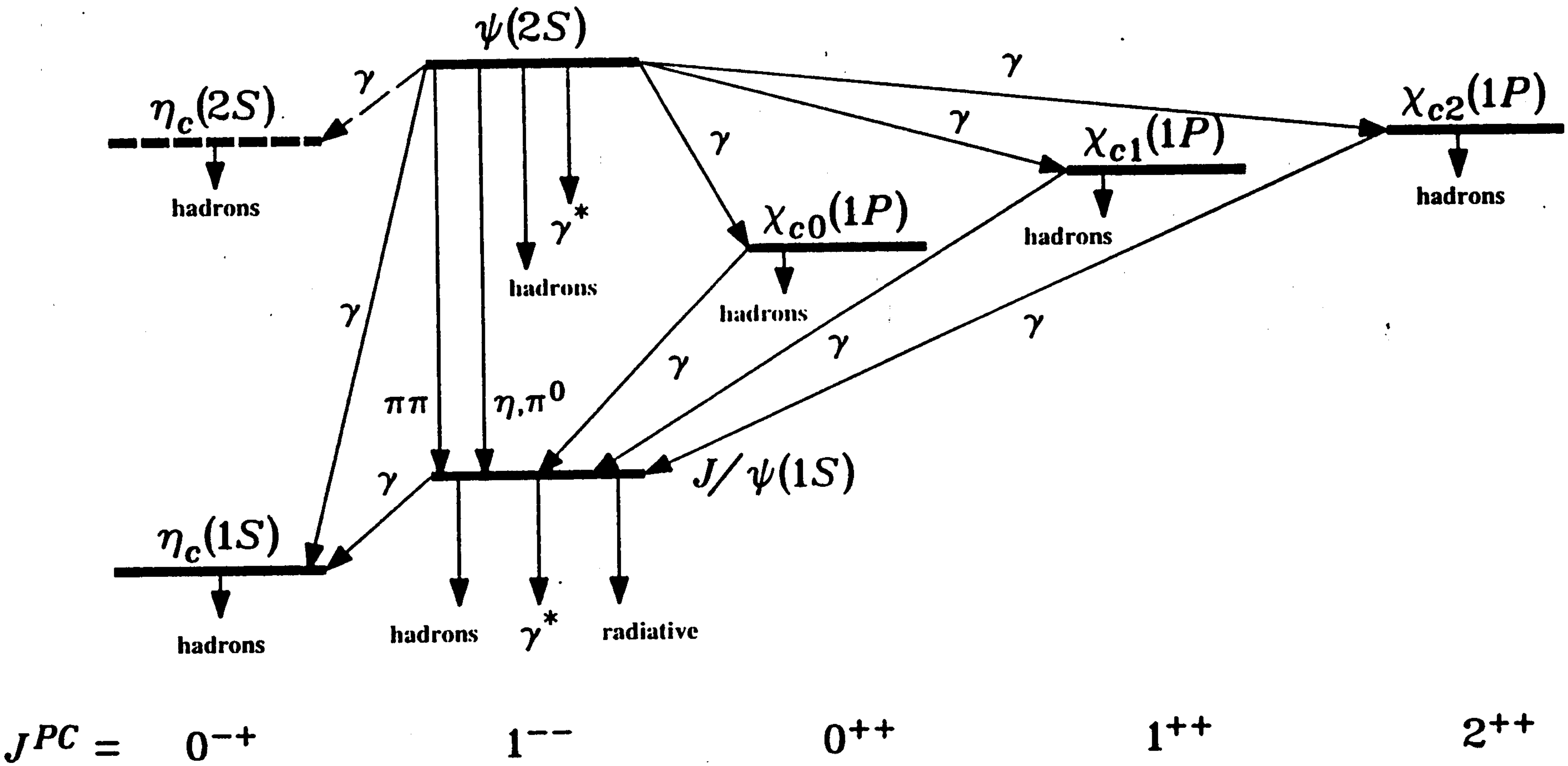
THE CHARMONIUM SYSTEM



The current state of knowledge of the charmonium system and transitions, as interpreted by the charmonium model. Uncertain states and transitions are indicated by dashed lines. The notation γ^* refers to decay processes involving intermediate virtual photons, including decays to e^+e^- and $\mu^+\mu^-$.

Study of Phase Shifts

(conjecture)

A large fraction of the HEP community will be attempting to detect CP violation.If Direct CP violation is found there will be a new industry to unravel the strong phases?

Is it useful to study $\pi\pi$ and $K\pi$ phase shifts or rescattering in high statistics J/ψ hadronic decays? Is this a better place than fixed target experiments?

From $D \rightarrow K\pi$ and $K\pi\pi$ the data is consistent with large rescattering. For $D \rightarrow K\pi$ the result was $\delta_{1/2} - \delta_{3/2} = 77°$

Could we use $J/\psi \rightarrow K^*K \rightarrow K^-\pi^+\pi^\circ, K^\circ K^+\pi^-$ and $J/\psi \rightarrow K^*K^{**} \rightarrow K\overline{K}\pi\pi$ to study rescattering at the D? (need to extract each spin & isospin PW)

More theoretical input is needed to understand if program might be beneficial.

Study of Precision Measurement

Example in BR($J/\psi \to ee$) from $\psi' \to \pi\pi J/\psi, J/\psi \to ee$ of what might is required in precision measurements.

Technique is measure the inclusive number of J/ψ events in $\pi^+\pi^-$ recoil in ψ' decays and the number exclusive $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to ee$ events then the ratio is after efficiency corrections is

$$BR(J/\psi \to ee) = \frac{N(\psi' \to \pi\pi J/\psi, J/\psi \to ee)/\varepsilon_1}{N(\psi' \to J/\psi + X)/\varepsilon_2}$$

In the Mark III measurement the number of events in the numerator was ~1000 and the number in the denominator ~30,000. The result was [5.92±.15±.20]%. See Gu talk for BES numbers.

If this measurement is performed at a tcf, the number events would increase a factor 1000. Thus the statistical error would be reduced by a factor ~30 and we would have 5.92±.007±.20. The question is how do we determine systematic error in this case.

We need to develop better criteria on such precision measurements, especially one that allows well defined comparisons with other experiments. It might be useful to develop a likelihood estimate of how likely the ~~detector~~ data is modelled correctly.

It will be very important to have reactions that can provide benchmark calibrations and cross checks of the detector for precision BR measurements (~1% fractional error) and for measurements of angular distributions.

The J/ψ and will provide many reactions that can be useful benchmark calibration checks. This includes many exclusive decays, $J/\psi \rightarrow \rho\pi$, ee, μμ, K*K, $p\bar{p}$, $K_S K_L$ and $\psi' \rightarrow \pi\pi J/\psi$.

These decays will be useful for
(1) tracking & trigger acceptance*
(2) charge conjugation checks
(3) angular acceptance checks
(4) resolution checks

Note: to check to level of 0.1% needs ~1m events

In the Mark III measurement the systematic error was estimated by varying the cuts and the modelling and adding them in quadrature the errors. Such a method is clearly incorrect for a high precision measurement.

How can we estimate the systematic error that far exceeds the statistical error?

There are several issues

(1) Is the physics reaction (production and decay) understood to better than 1%?
(2) Is the background under the peak understood to better than 1%?
(3) Is the detector modelling understood to better than 1%?

To the extent that the result does not have a correct physical model, detector efficiency and background, the result must be uncertain.

Precision background modelling will be difficult requiring many BR's of charmonium, charm and tau decays.

angular distributions for the J/ψ and the
and a $1+\cos^2\theta_l^*$ distribution [8] for the
s Monte Carlo simulation, all angles are
lecay particle's helicity frame. We also in-
ts of final-state radiation [9], energy loss,
the charged pions. A comparison between
e Monte Carlo samples is shown in Fig. 3.
and reconstruction efficiency for the $\pi^+\pi^-$
ess (2), ϵ_2, depends on the J/ψ charged-
ity. We estimate the multiplicity distribu-
iring the number of charged tracks for
$/\psi$ peak region in Fig. 2 and subtracting
multiplicity distribution from background
and below the peak. The resulting multi-
tion is consistent with measurements from
sample [10]. The estimation of the
ach charged-track multiplicity is obtained
Monte Carlo samples with decays of the
ent numbers of charged and neutral points
iency ϵ_2, shown in Table I, is obtained by
efficiencies for different charged-track mul-
ding to the measured charged-track multi-
ions.

tic error on the branching fractions arises
ources. The effects of different selection
imated by varying the criteria and observ-
n the branching fractions. The changes
1 selection criteria cancel in the ratio and
the branching fractions. For the leptons,
$\cos\theta|$ criteria from 0.8 to 0.5 and the
teria from 1.0 to 1.3 GeV/c each contrib-
al error of 1%. The identification criterion
changed from the requirement of signals
hambers to the requirement of a 0.5-GeV
wer energy in the barrel calorimeter [12].
ergy requirement for electrons in the barrel
is varied by 0.1 GeV around the nominal
The relative systematic errors on the
ctions from these changes in the identifi-
are less than 0.5% for muons and 0.2% for

butions to the systematic error arise from
for obtaining efficiencies, fit results, and
background estimates. The uncertainty in the ϵ_1 measurement is obtained by the following procedure. Events containing two pions and at least one identified lepton are isolated. The efficiency for observing the second lepton is then obtained from this sample. By comparing the efficiencies determined from this method and the Monte Carlo calculation, the contribution to the systematic error

$e^+e^-, \mu^+\mu^-$ mass from $\psi' \to \pi^+\pi^- e^+e^-$

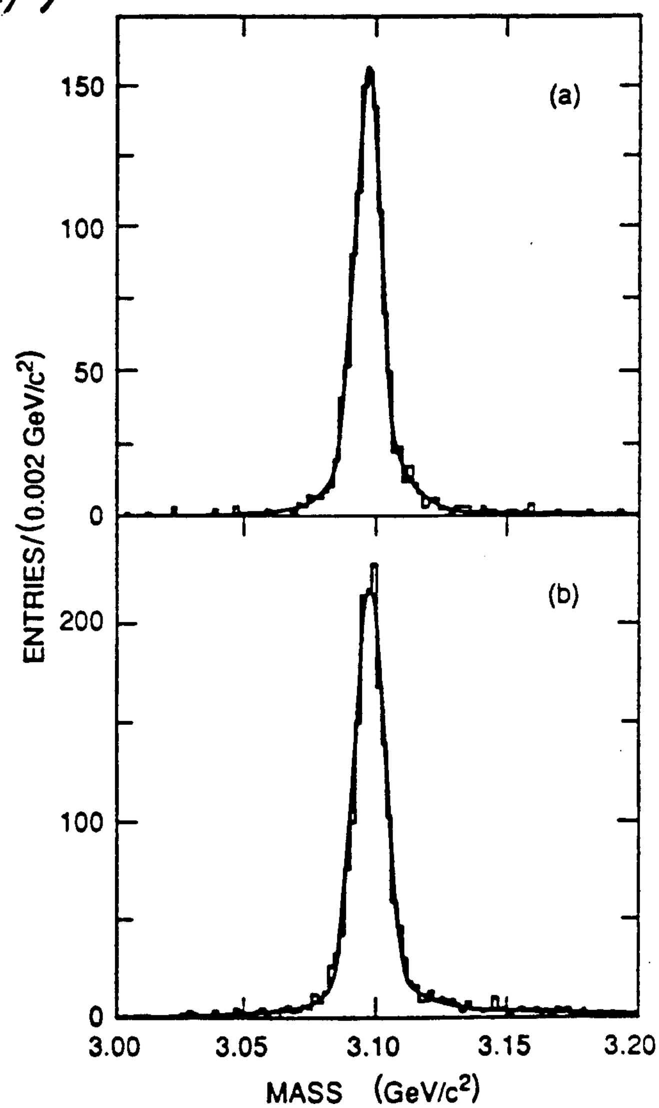


FIG. 1. The $M_{\rm recoil}$ distribution for process (1); a fit to the spectrum with two Gaussian functions and a quadratic polynomial term is shown as a solid curve. (a) Data set A. (b) Data set B. The non-Gaussian tails visible in (a) and (b) are reproduced by the Monte Carlo samples.

B	μ	897	$33\,500 \pm 260$	0.234	0.513	$5.87 \pm 0.20 \pm 0.1$

for observing both leptons is estimated to be 2%. The uncertainty in the ϵ_2 measurement is obtained by varying the model of the J/ψ multiplicity distribution, and is estimated to be 2%. The fitting procedure to obtain the total number of J/ψ's contributes 1%. Potential background processes such as $\psi(2S) \rightarrow \eta J/\psi$, with $\eta \rightarrow \pi^0\pi^+\pi^-$ or $\eta \rightarrow \gamma\pi^+\pi^-$, and those with photon conversions, are negligible. Adding all of these contributions

Missing Mass from $\psi' \to \pi^+\pi^- + X$

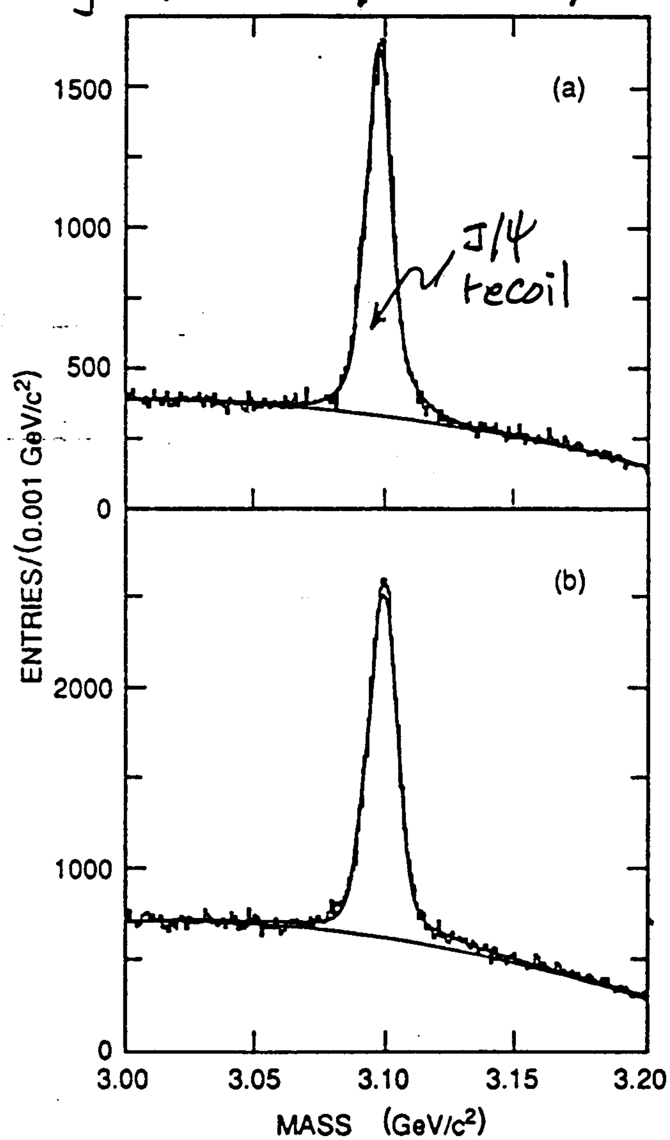


FIG. 2. The $M_{\rm recoil}$ distribution for process (2): a fit using the same signal shape as in Fig. 1, with an additional quadratic polynomial background term, is shown as a solid curve. (a) Data set A. (b) Data set B.

in quadrature, the fractional systematic
surements of the branching fractions is

Combining the results from the two
periods, we obtain

$$B(J/\psi \rightarrow e^+e^-) = (5.92 \pm 0.15 \pm 0$$

$$B(J/\psi \rightarrow \mu^+\mu^-) = (5.90 \pm 0.15 \pm ($$

Assuming lepton universality, we ob
$\rightarrow l^+l^-) = (5.91 \pm 0.11 \pm 0.20)\%$.

The experimental ratio of quarko
rates,

$$[\Gamma(\text{quarkonium} \rightarrow ggg)]/[\Gamma(\text{quarko}$$

can be used in the framework of QCD
the strong couping constant α_s. We fo
tion of Ref. [2] and include the effe
corrections with a factor parametrize
Using the QCD relation between $\alpha_s(\mu$
the two ratios $[\Gamma(J/\psi \rightarrow ggg)]/[\Gamma(J/\iota$
$[\Gamma(\Upsilon(1S) \rightarrow ggg)]/[\Gamma(\Upsilon(1S) \rightarrow \mu^+\mu^-$

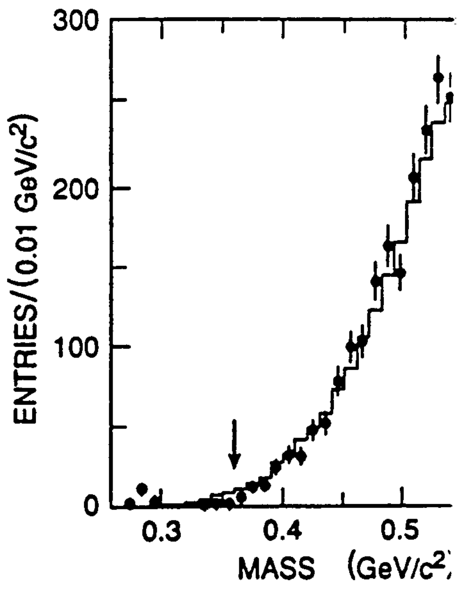


FIG. 3. The $\pi^+\pi^-$ invariant mass dis
from process (1) for the combined data se
the combined Monte Carlo samples (sol
two-pion invariant mass cut of 0.36 GeV/c
vertical arrow.

Other Comments on "Engineering" Physics

① Very high J/ψ statistics ($\sim 10^9$)
allows precision measurement of ω, η, η'
using $J/\psi \to p\bar{p}[\omega, \eta, \eta']$
Expect few $\times 10^6$ in each channel
$\Rightarrow$ 0.5% measurement (PDG 2-5%)

② Threshold study of D^0, D^+, D^{*0}, D^{*+} may be possible to get precision mass comparable to beam energy error.
If excitation is possible near threshold then $\delta m = \frac{p\,\delta p}{m}$ since $m = \sqrt{E_{beam}^2 - p^2}$
(PDG $\sigma(m) = .5$-$.7$ for D^+, D^0, $.6$-1.4 for D^{*+}, D^{*0})
If form factor known, resolution will improve as in tau mass measurement.

SUMMARY

Scalar Glueball or non-$q\bar{q}$ particle searches are most interesting, however it has been problematic. Clear cut spin-parity tests are difficult. Advances may come from unexpected discoveries.

Much of Charmonium is either not measured or poorly measured. Many measurements would be complementary to E760 and LEAR.

Hadronic J/ψ and ψ' decays might contribute to a study of rescattering effects which is important for CP violation measurements.

J/ψ and ψ' decays for detector checks and cross checks of BR measurements will be invaluable for high precision measurements of BR's, angular distributions and charge conjugation tests.