4.7 Hadronic resonances: Discovery of the c and b quarks

Until 1974

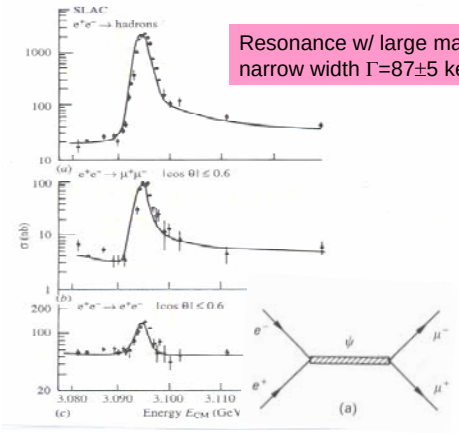
- hadronic states explained as bound states of 3 quarks (u, d, s)
- Prediction of a forth quark by theoreticians (e.g. GIM)

1974: "November Revolution" – Discovery of the J/ψ, bound state of new quark

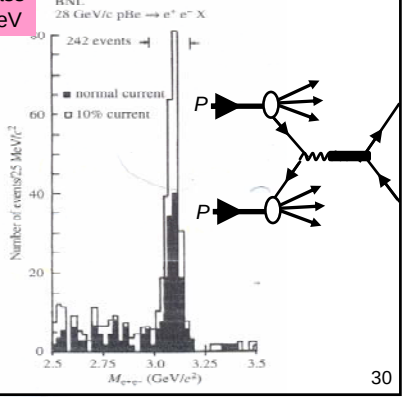
SLAC $e^+e^- \to \text{hadrons}, e^+e^-, \mu^+\mu^-$

BNL $p(28\ \text{GeV})+\text{Be} \to e^+e^-X$

Not original paper



Resonance w/ large mass narrow width Γ=87±5 keV



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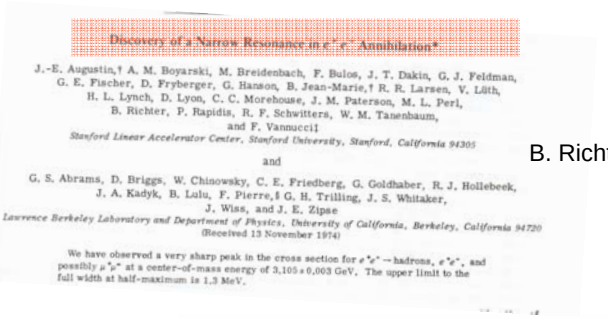


Discovery of a Narrow Resonance in e^+e^- Annihilation*

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‡

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

G. S. Abrams, D. Briggs, W. Chinowsky, C. E. 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

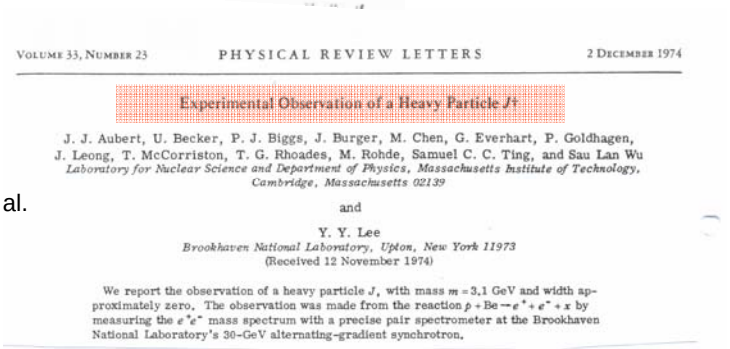
Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720

(Received 13 November 1974)

We have observed a very sharp peak in the cross section for $e^+e^- \to$ hadrons, e^+e^-, and possibly $\mu^+\mu^-$ at a center-of-mass energy of 3.105 ± 0.003 GeV. The upper limit to the full width at half-maximum is 1.3 MeV.

Both articles appeared in the same issue of Phys. Rev. Let.

B. Richter et al.



VOLUME 33, NUMBER 23 PHYSICAL REVIEW LETTERS 2 DECEMBER 1974

Experimental Observation of a Heavy Particle J†

J. J. Aubert, U. Becker, P. J. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen, J. Leong, T. McCorriston, T. G. Rhoades, M. Rohde, Samuel C. C. Ting, and Sau Lan Wu

Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

and

Y. Y. Lee

Brookhaven National Laboratory, Upton, New York 11973

(Received 12 November 1974)

We report the observation of a heavy particle J, with mass $m = 3.1$ GeV and width approximately zero. The observation was made from the reaction $p + \text{Be} \to e^+ + e^- + x$ by measuring the e^+e^- mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory's 30-GeV alternating-gradient synchrotron.

S.C.C. Ting et al.

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Brookhaven Experiment (S.Ting et al.)

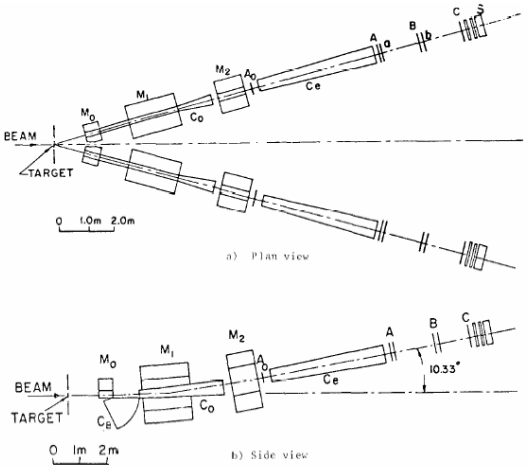
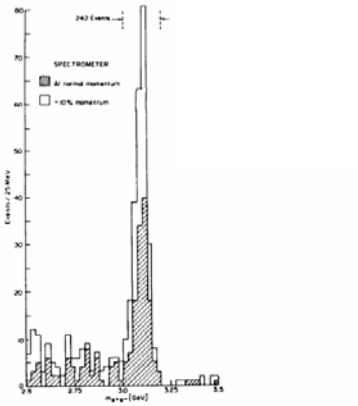


Fig. 5. Schematic diagram of the experimental set-up for the double-arm spectrometer used in our discovery of the J particle. M_0, M_1, and M_2 are dipole magnets; A_0, A, B, and C are 8000-wire proportional chambers; a and b are each 8 - 8 hodoscopes; S designates three banks of lead-glass and shower counters; C_H, C_{0_1}, and C_0 are gas Čerenkov counters.

p(28 GeV)+Be $\rightarrow e^+e^-X$



http://nobelprize.org/nobel_prizes/physics/laureates/1976/ting-lecture.pdf

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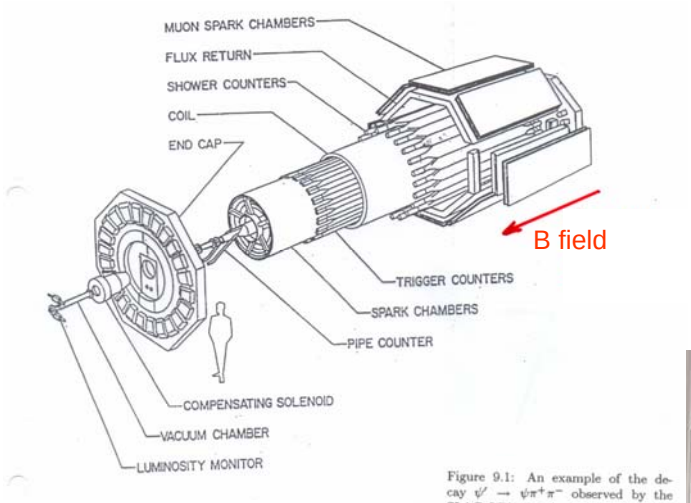
MARK-I Detector



= prototype of a compact 4π detector

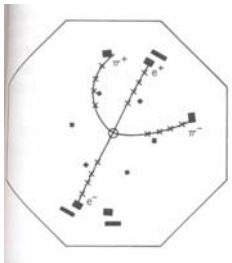


Figure 9.1: An example of the decay $\psi' \rightarrow \psi\pi^+\pi^-$ observed by the SLAC–LBL Mark I Collaboration. The crosses indicate spark chamber hits. The outer dark rectangles show hits in the time-of-flight counters. Ref. 9.5.

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New particle J/ψ (bound cc̄ state): $J^{PC}(J/\psi) = J^{PC}(\gamma) = 1^{--}$

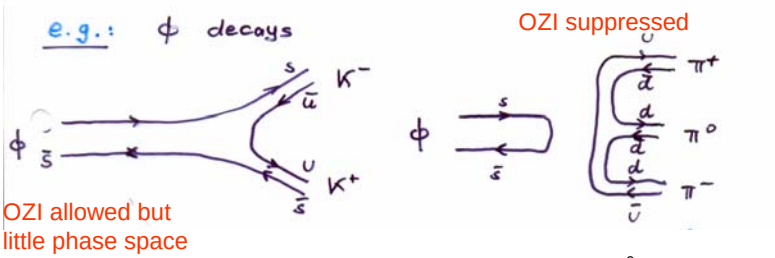
Width of resonance:

J/ψ Γ=87±5 keV compared to known resonances:

→ Extremely narrow !

ρ	Γ=149 MeV
ω	Γ= 8.4 MeV
ϕ	Γ= 4.3 MeV

OZI (**O**kubo, **Z**weig, **I**izuka) rule:



$Br(\phi \to K^+K^-) = 49\%$ $Br(\phi \to \pi^+\pi^-\pi^0) = 15.5\%$

Decays with "disconnected quark lines" are suppressed relative to decays where the quark lines are connected.

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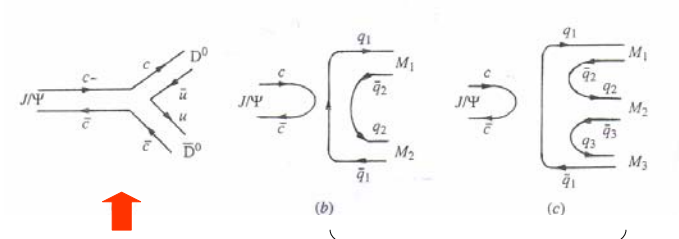
Width of J/ψ

- Narrow J/ψ peak cannot be explained in the 3 quark picture: would expect large hadronic width if particle consists of u,d,s quarks
- J/ψ was interpreted as a quark-antiquark bound state of a new heavy quark c-quark.



OZI allowed but kinematical not possible: Charmed D mesons too heavy (>1865 MeV)

OZI suppressed

= "Open Charm Threshold"

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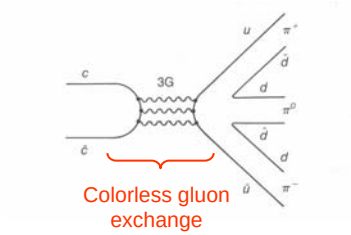
QZI rule in QCD



1 gluon exchange: not possible (color)

2 gluon exchange: not possible (C=1)

3 gluon exchange: possible (similar to positronium)

➡ Suppression ~ α_s^3

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Measurement of the J/Psi width

see C. Berger, p. 322

Breit-Wigner resonance for cross section:

spin of resonance

$$\sigma_f = \frac{1}{4}(2J+1)\frac{4\pi}{E_B^2}\Gamma_f\Gamma_e f_{BW} \quad \text{with} \quad f_{BW} = \frac{1}{(s-M_R^2)^2 + M_R^2\Gamma^2}$$

statistical factor

$$\sigma_f \approx (2J+1)4\pi\frac{\Gamma_f\Gamma_e}{M_R^2} f_{BW} \qquad f_{BW} \approx \frac{\pi}{2\Gamma}\delta(\sqrt{s}+M_R)$$

$$\underbrace{\int \sigma_f(\sqrt{s})d\sqrt{s}}_{\text{measurable}} = \frac{6\pi^2\Gamma_e\Gamma_f}{M_R^2\Gamma} \Rightarrow \left\{ \frac{\Gamma_e^2}{\Gamma}, \frac{\Gamma_e\Gamma_f}{\Gamma}, \frac{\Gamma_e\Gamma_{had}}{\Gamma} \right.$$

$$\left. \Gamma = \sum\Gamma_i \right.$$

$$\Gamma = 93.4 \pm 2.1\,\text{keV}$$

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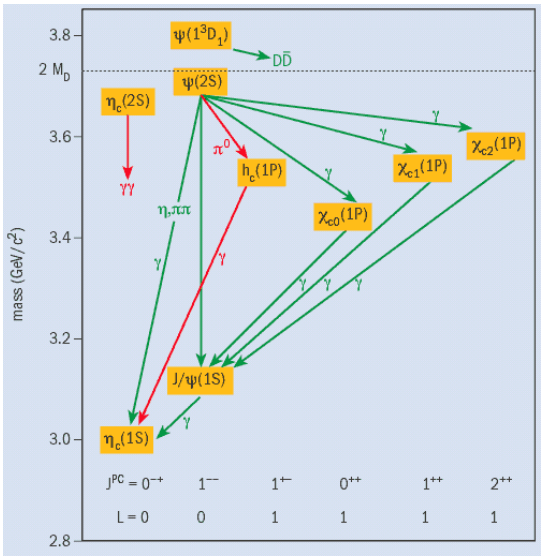
Charmonium ($c\bar{c}$) Spectroscopy



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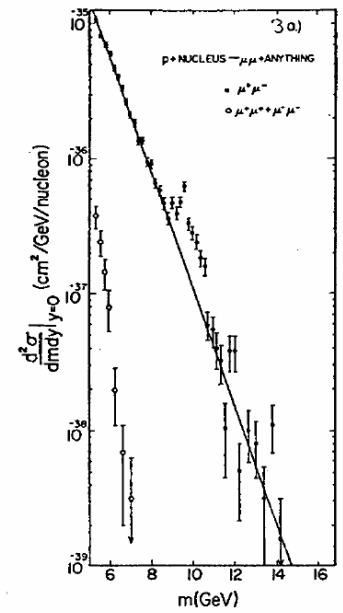
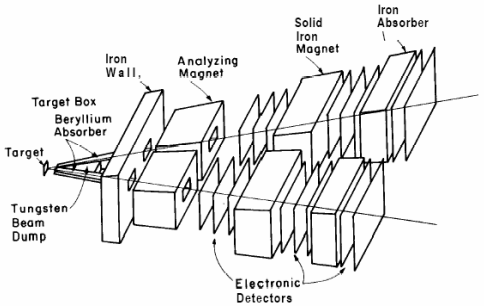
Discovery of the Upsilon ($b\bar{b}$) Resonance (1976)

Leon M. Lederman et al.

$$p + N \rightarrow \mu\mu + \text{anything}$$



OBSERVATION OF A DIMUON RESONANCE AT 9.5 GeV
IN 400 GeV PROTON-NUCLEUS COLLISIONS



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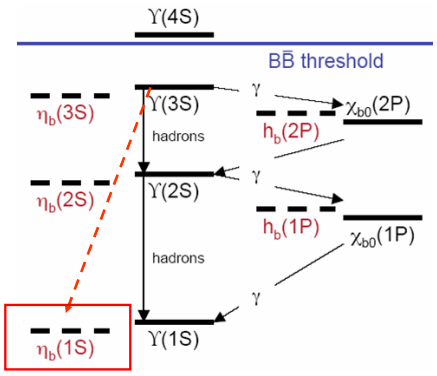
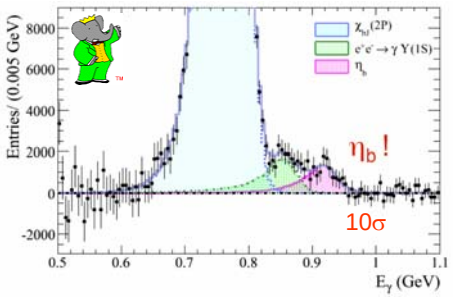
Bottonium Spectroscopy



BABAR PRL 101 (2008) 071801



$$m(\eta_b) = 9388.9^{+3.1}_{-2.3} \pm 2.7_{syst}\,\mathrm{MeV}/c^2$$

$$B(\Upsilon(3S) \to \gamma\,\eta_b) = [4.8 \pm 0.5 \pm 1.2] \times 10^{-4}$$

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