5. Hadronic resonances: Discovery of the c quarks

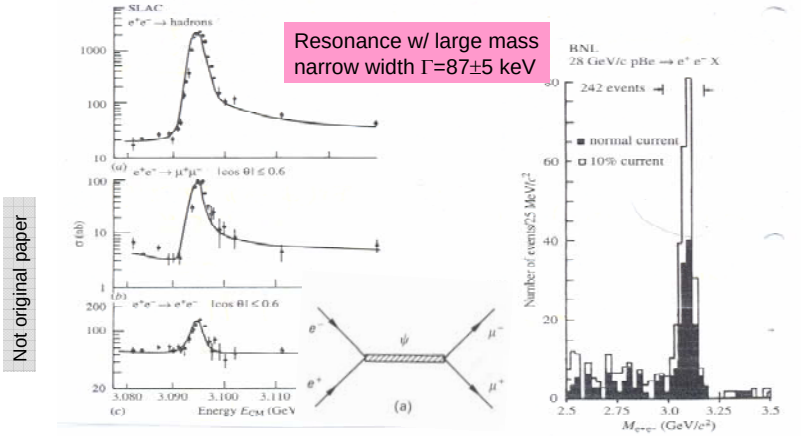
Until 1974

- 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

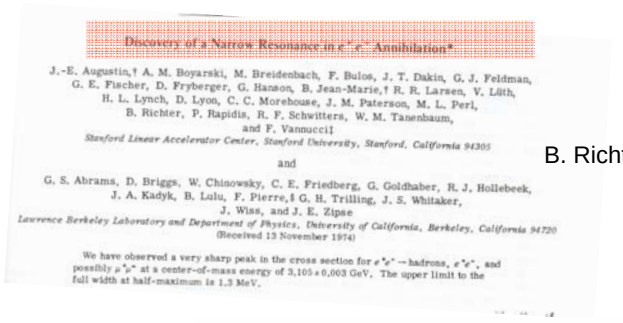
SLAC $e^+e^- \rightarrow \text{hadrons}, e^+e^-, \mu^+\mu^-$

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



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

Not original paper



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

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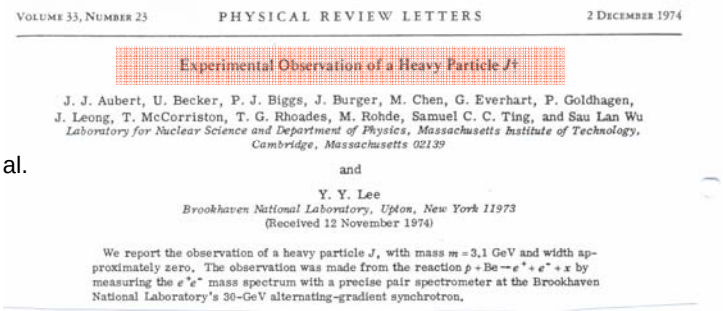
(Received 13 November 1974)

We have observed a very sharp peak in the cross section for $e^+e^- \rightarrow$ 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

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and

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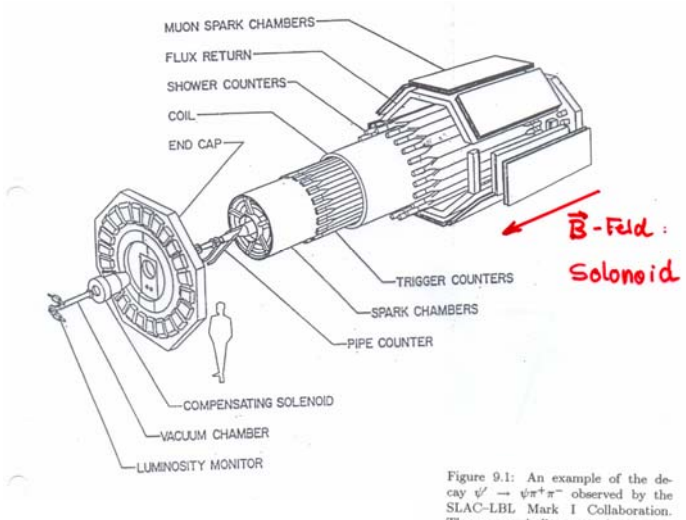
(Received 12 November 1974)

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 $p + \text{Be} \rightarrow e^+ + e^- + x$ 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.

MARK-I Detector



= prototype of a compact 4π detector

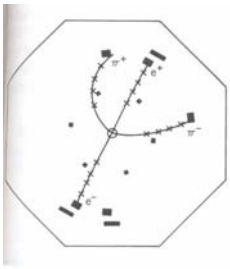


Figure 9.1: An example of the decay $\psi' \to \psi\pi^+\pi^-$ observed by the SLAC–LBL Mark I Collaboration. The crosses indicate spark chamber hits. The outer dark rectangles show hits in the time-of-flight counters. Ref. 9.5.

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

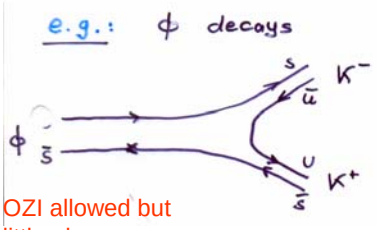
Width of resonance:

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

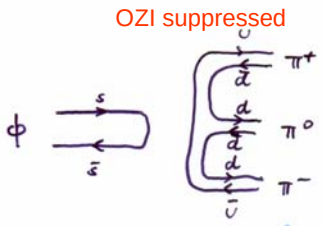
OZI (**O**kubo, **Z**weig, **I**izuka) rule:



OZI allowed but little phase space

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

OZI suppressed

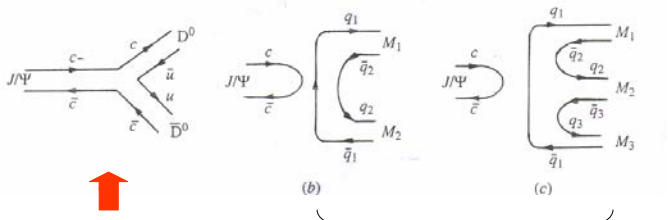


$Br(\phi \to \pi^+\pi^-\pi^0) = 15.5\%$

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

Width of J/ψ

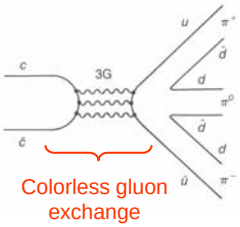
- Narrow J/ψ peak cannot be explained in the 3 quark picture: would expect large hadronic width if particle consists of u,d,s quarks
- J/ψ was interpreted as a quark-antiquark bound state of a new heavy quark c-quark.



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

OZI suppressed

QZI rule in QCD



Colorless gluon exchange

1 gluon exchange: not possible (color)

2 gluon exchange: not possible (C=1)

3 gluon exchange: possible (similar to positronium)

➡ Suppression ~ α_s^3