Quarkonium Production and Decay

(Selected Topics in $Q\overline{Q}$)

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Cornell University

Physics in Collision 2004

Boston University

27-29 June 2004

Why Study Quarkonia (bound states of $q\bar{q}$) ?

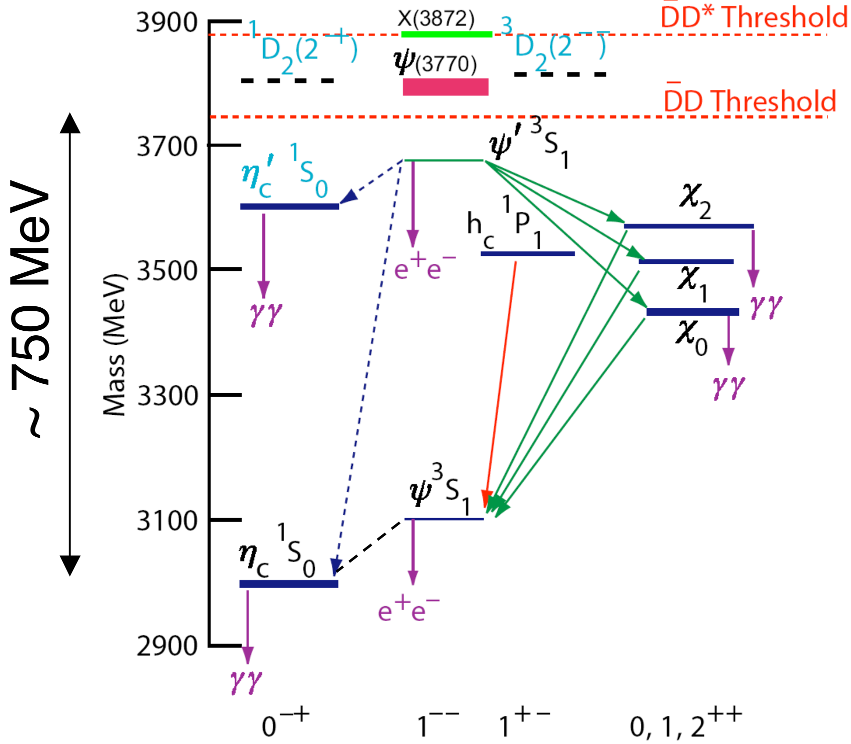
- **the QCD equivalent of positronium**
- **simplest strongly interacting systems**
- **non-relativistic for heavy quarks ($Q\bar{Q}$):**

  Q=c: $\beta^2 \sim 0.25$; Q=b: $\beta^2 \sim 0.08$

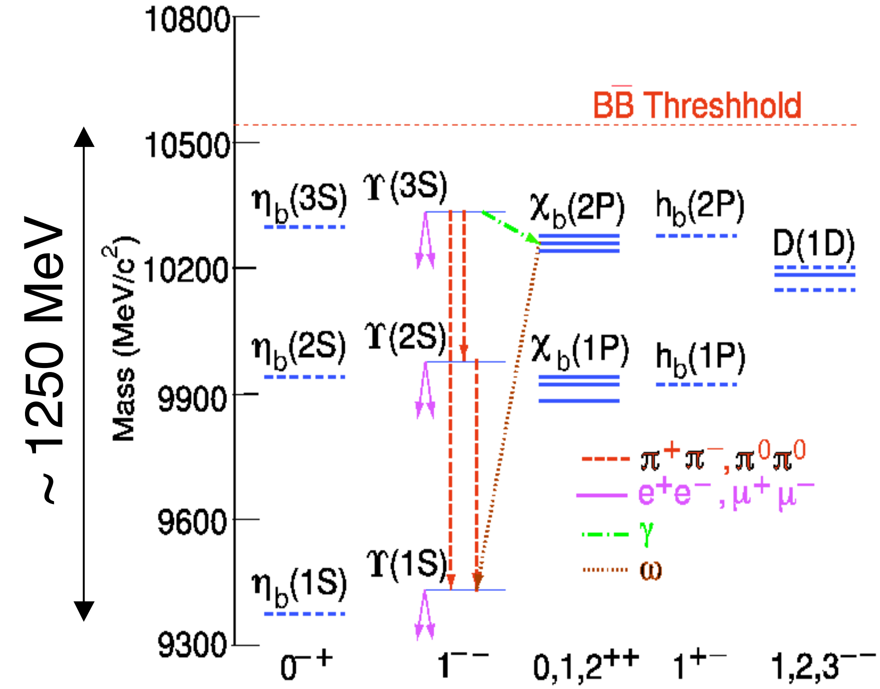
- **$V(r) = -4/3\ \alpha_s/r + k\ r$** (free v. confined)
- **Wells much deeper than for QED**
- **Important tests of Lattice QCD techniques**

The Heavy Quarkonia Spectra

Charmonium



Bottomonium



Rich spectroscopy, various production schemes, interesting decay scenarios

Topical Seminar School on Heavy Quarkonia at Accelerators

New Theoretical Tools and Experimental Techniques

Organized by the Quarkonium Working Group

October 8-11, 2004
ITP, Beijing

Organizing Committee:

- K.T. Chao (Peking Univ.)
- Y.P. Kuang (Tsinghua Univ.)
- W.G. Li (IHEP, CAS)
- J.P. Ma (ITP, CAS)
- C.F. Qiao (GSCAS)
- X.Y. Shen (IHEP, CAS)
- C.Z. Yuan (IHEP, CAS)
- M.Mangano (CERN)
- V.Papadimitriou (FNAL)
- the QWG conveners

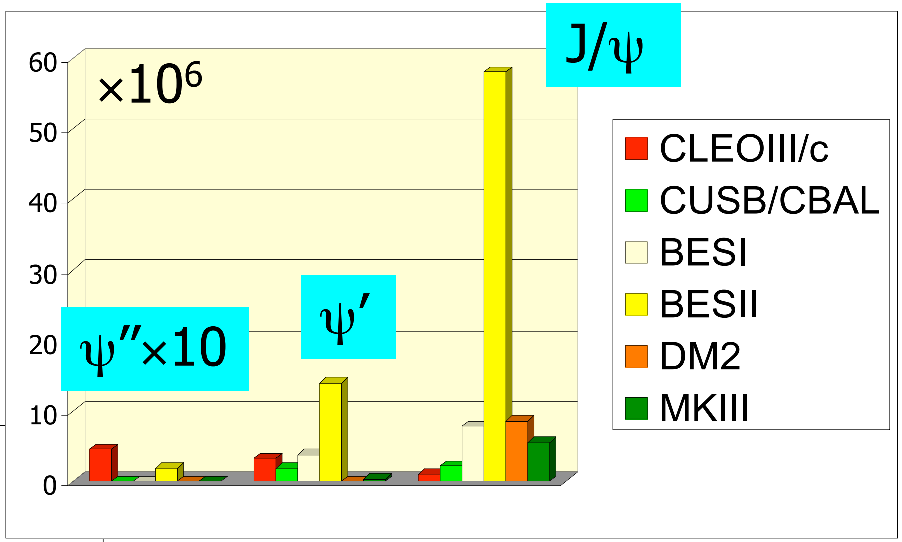
QWG Conveners:

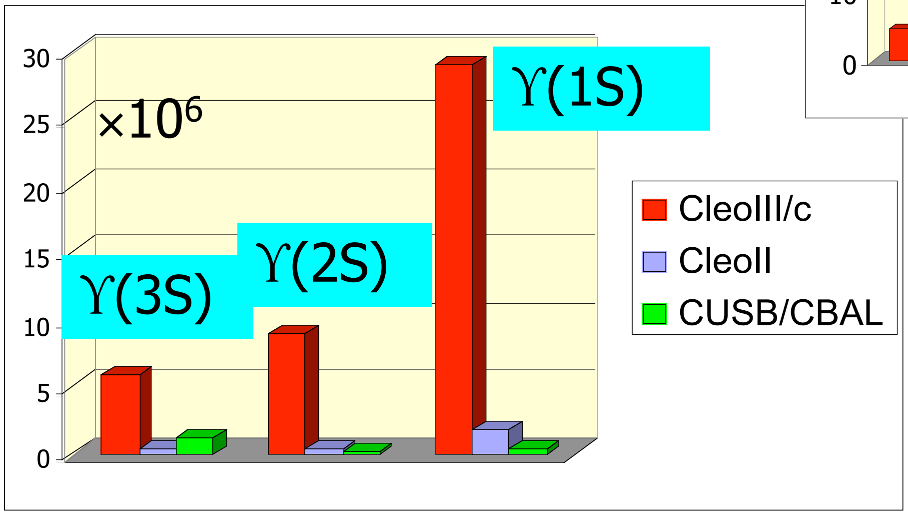
Nora Brambilla (Milano U.)
Michael Krämer (Edinburgh U.)
Roberto Mussa (Torino INFN)
Antonio Vairo (CERN)

Quarkonium Working Group CERN Yellow Report … based on first two workshops … available this summer !!!

Followed (12-15 Oct) by QWGIII Wkshp [www.qwg.to.infn.it]

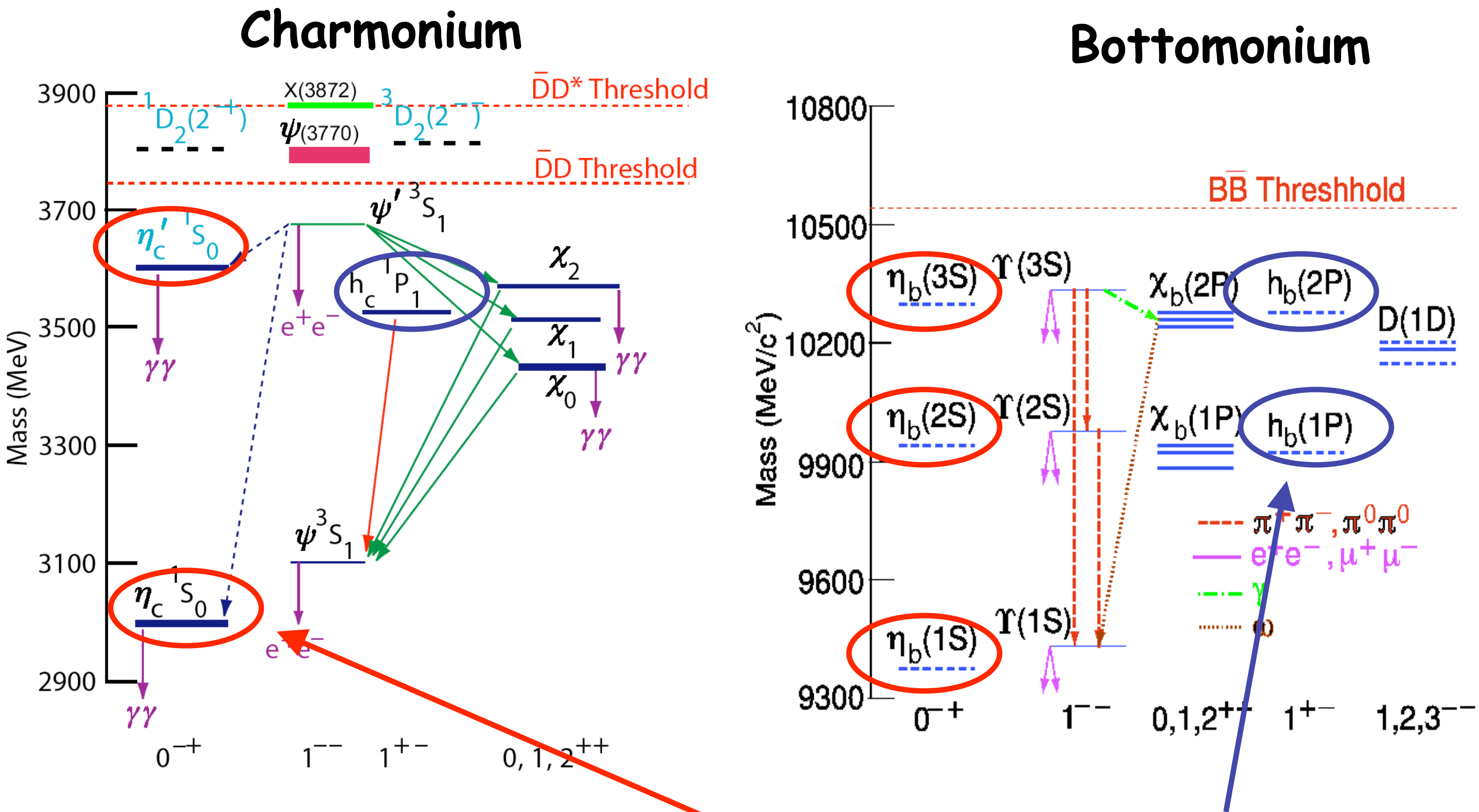
Large new datasets from e^+e^- machines on the 1^{--} vector states …





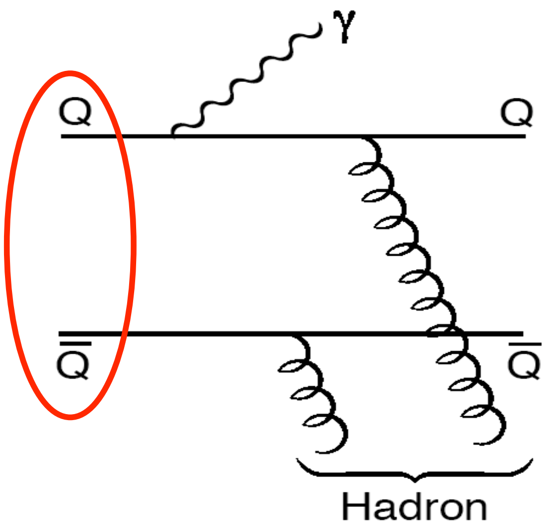
… and many new contributions from B factories and hadron colliders as well

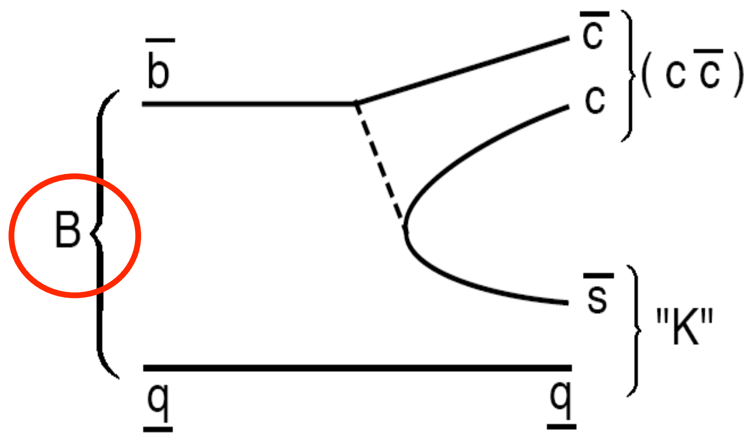
News on the $Q\bar{Q}$ Spin-Singlets

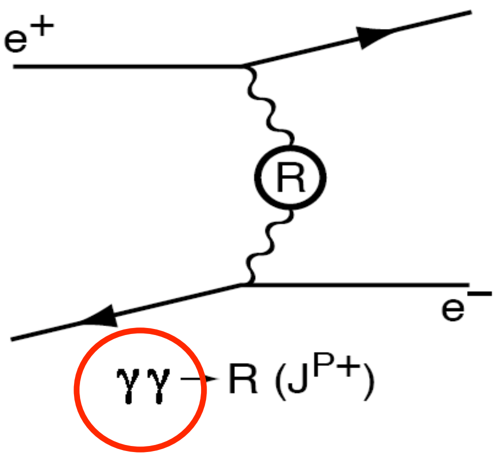


J^{PC} = 0^{-+} (η's) and 1^{+-} (h's)

Production of $Q\bar{Q}$ Spin-Singlets:







… as well as hadro-production which is the most egalitarian!

$Q\bar{Q}$ Spin-Singlets:

- $b\bar{b}$ (η_b's and h_b): limits from CLEO in '03 … no news
- h_c ($^1P_1$, 1^{+-}): not yet (maybe that is news?)
- η_c ($^1S_0$, 0^{-+}): Ground state of charmonium

  Still only ~30% of decays known … some updates

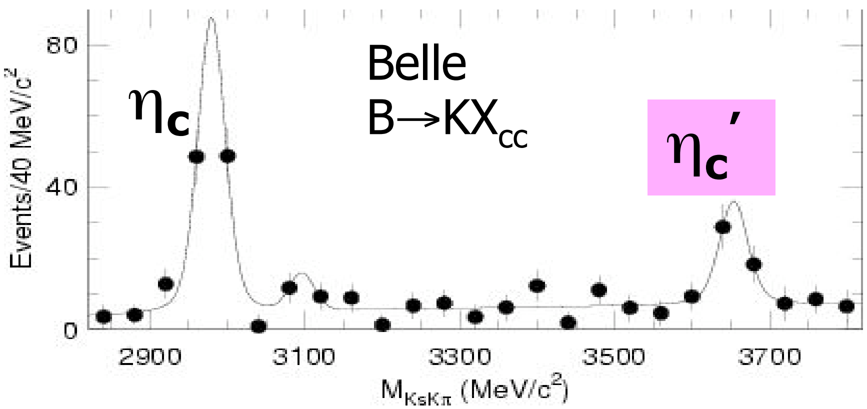
  New publ'd mass determinations … no big shifts

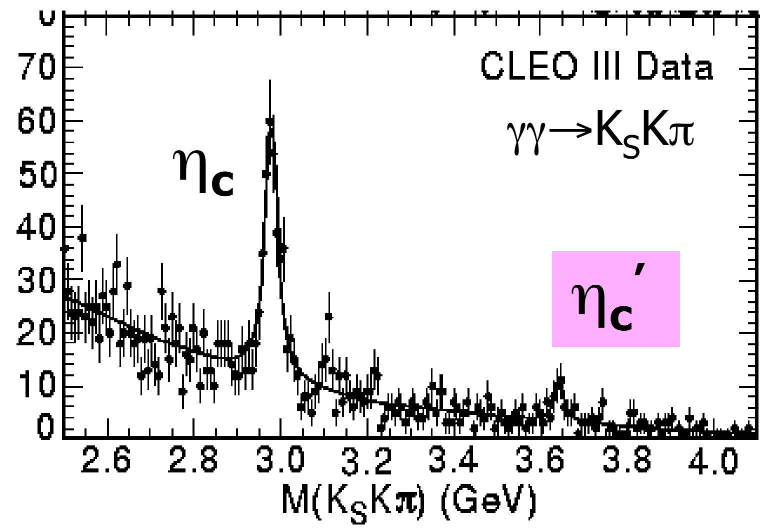
  Seen by CLEO in $\psi' \to \gamma\eta_c$ (>8σ) [LP03:hep-ph/0311243]
- See QWG Yellow Report for up-to-date information

$Q\bar{Q}$ Spin-Singlets:

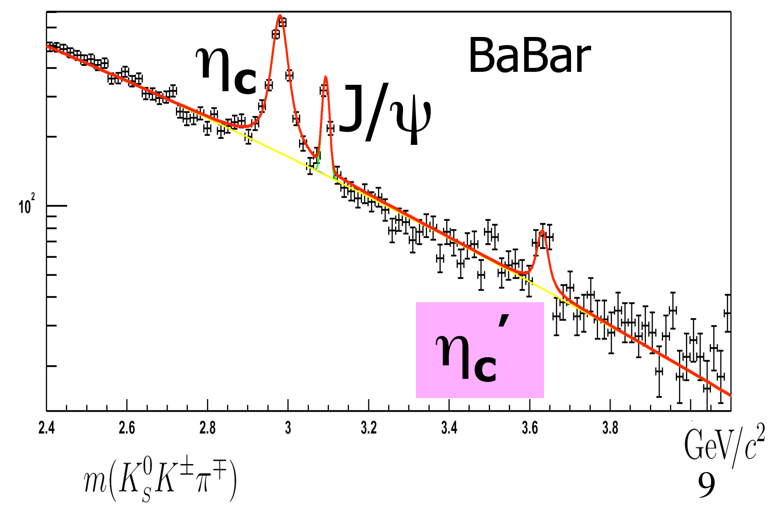
Biggest singlet news … the (re)discovery of η_c' !!

Four published observations: (Belle[2]/CLEO/BaBar) …

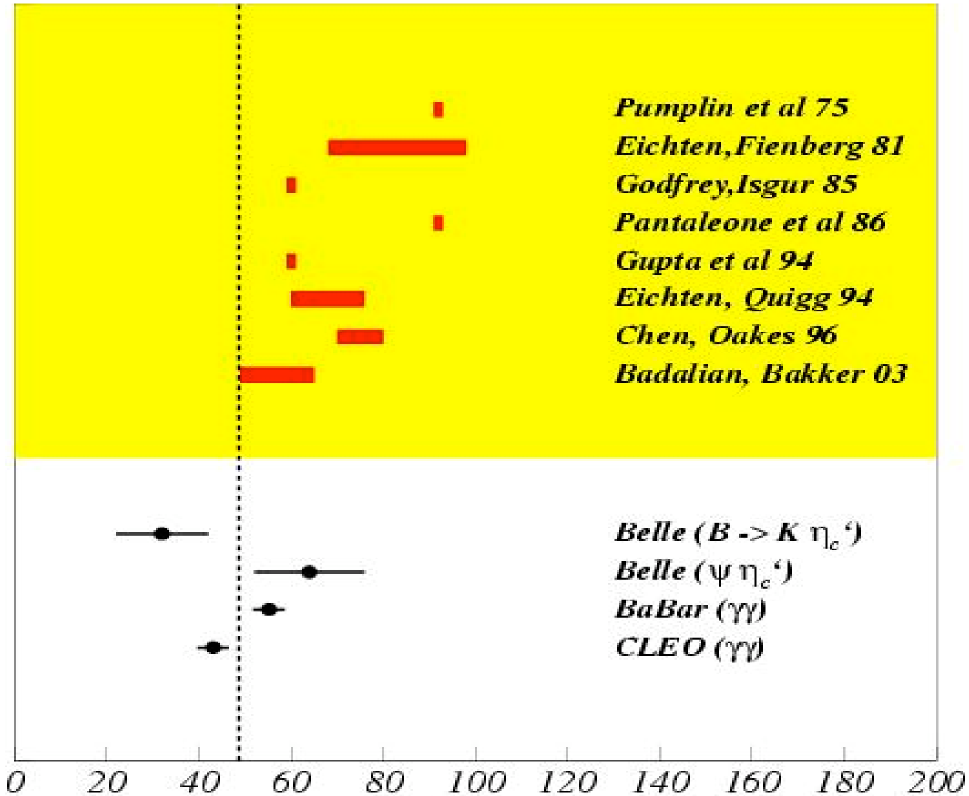




… but not seen by CLEO in radiative ψ' decays, despite ~same sensitivity as Crystal Ball!



*Belle PRL**89(2002)**102001*, PRL**89**(2002)142001
CLEO PRL**92**(2004)142001
BaBar PRL**92**(2004) 142002



$\Delta_{hf}' = m(\psi') - m(\eta_c')$ (MeV)

Δ_{hf} (spin-spin splitting)

For J/ψ and η_c, Δ_{hf} is nicely established at 117 ± 2 MeV; deep in "Coulombic" QCD well

ψ' and η_c' sample the QCD "confinement" region.

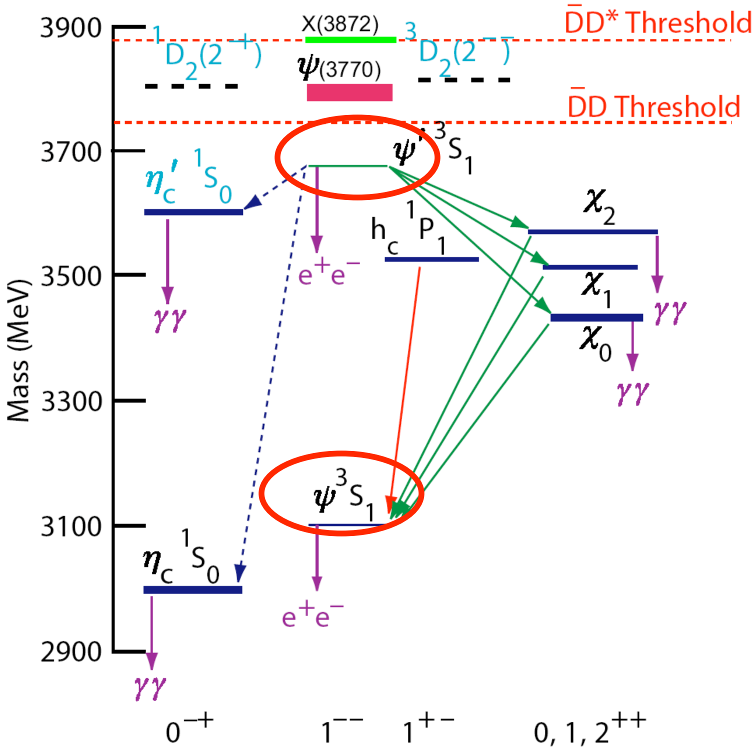
Δ_{hf}' is 49 ± 2 MeV, or ~ half the value using the older CrystalBall η_c' mass !!!

Older theory values seem high … models assumed scalar QCD potential … recent lattice (quenched) result[§] gives Δ_{hf}' spanning 40-74 MeV … ball back in theorists' court!

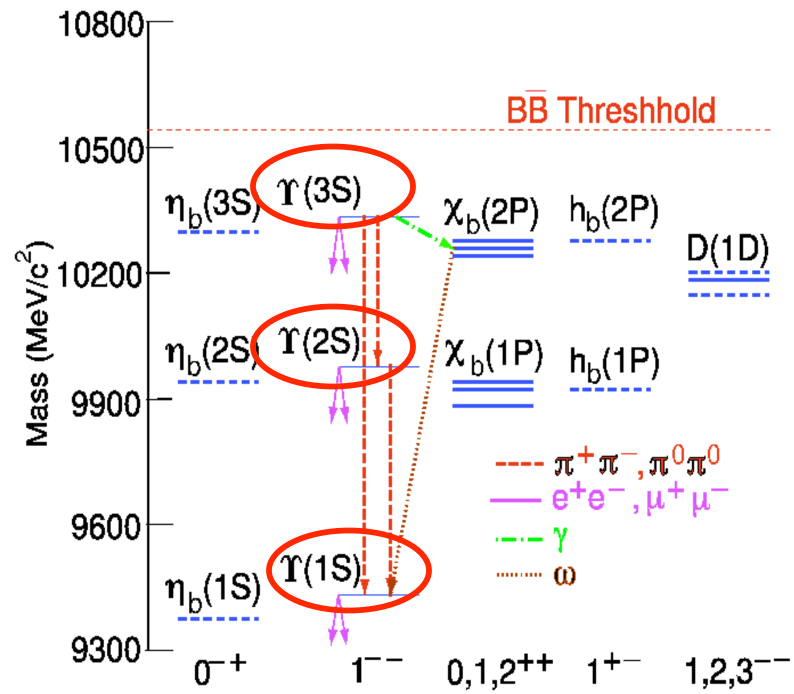
§[M. Okamoto, et al. PRD**65,** 094508]

Sampling of $Q\bar{Q}$ Vector Results

Charmonium



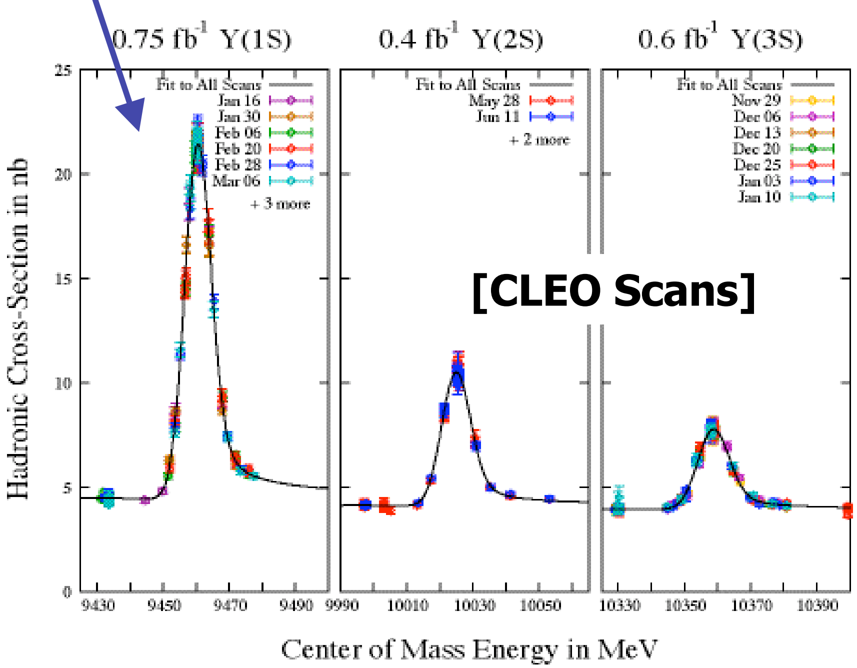
Bottomonium

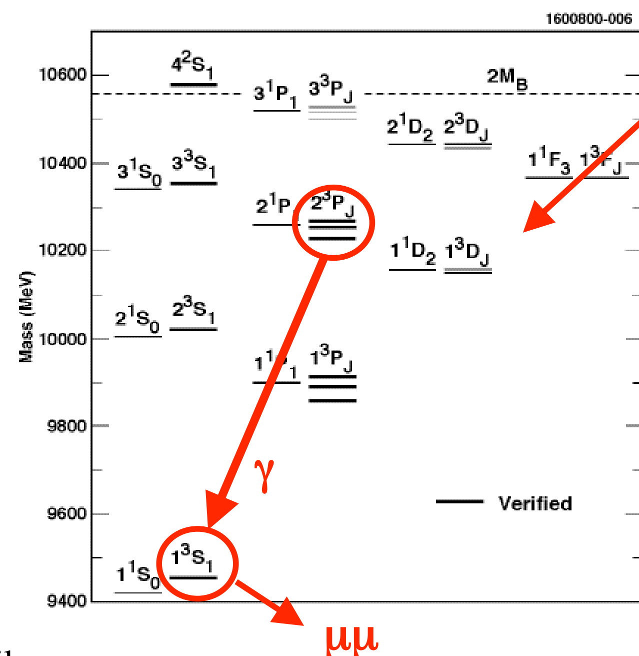


$J^{PC}=1^{--}$ … directly produced in e^+e^- annihilation

$B_{\mu\mu}$ for the Υ States

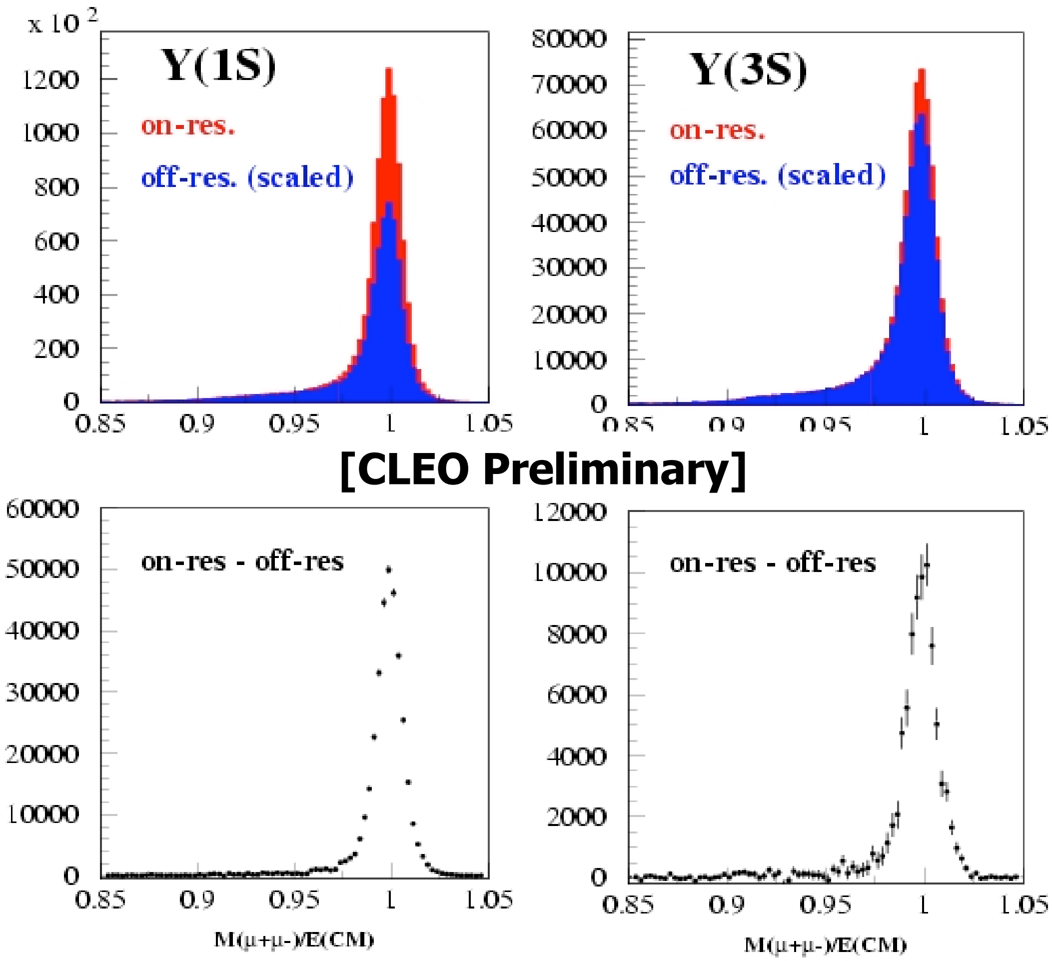
- **Importance beyond knowing $B(\Upsilon(nS) \to \mu^+\mu^-)$**
- **Needed to get Γ_{tot} for narrow resonances from Γ_{ee} ; CLEO hopes to measure Γ_{ee} to a few percent**
- **Many analyses use the $\mu^+\mu^-$ final state for cleanliness; $B_{\mu\mu}$ affects many branching fractions and partial widths**

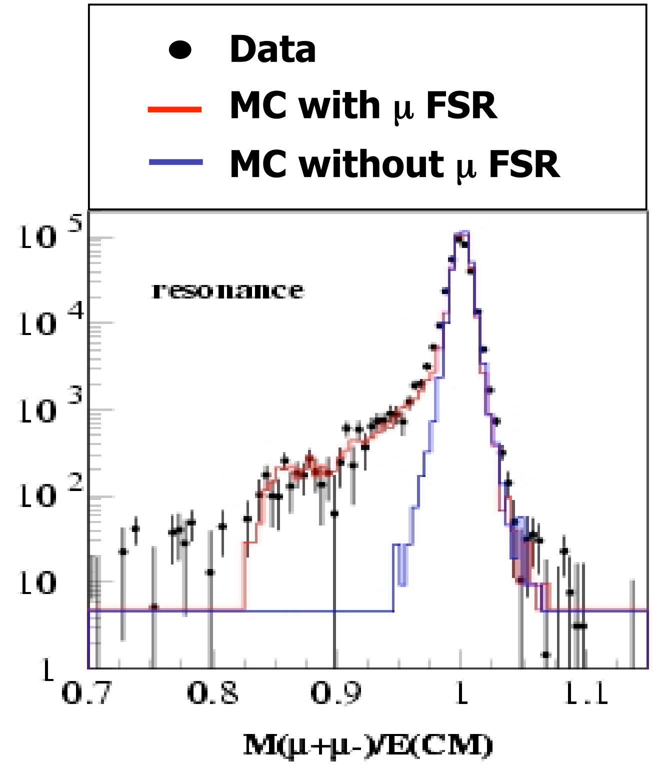




$B_{\mu\mu}(\Upsilon(nS))$

Large signals in $m_{\mu\mu}/\sqrt{s}$ after continuum subtraction at the $\Upsilon(1S)$, $\Upsilon(2S)$, and even $\Upsilon(3S)$ …





… and details such as muon FSR allow for high precision.

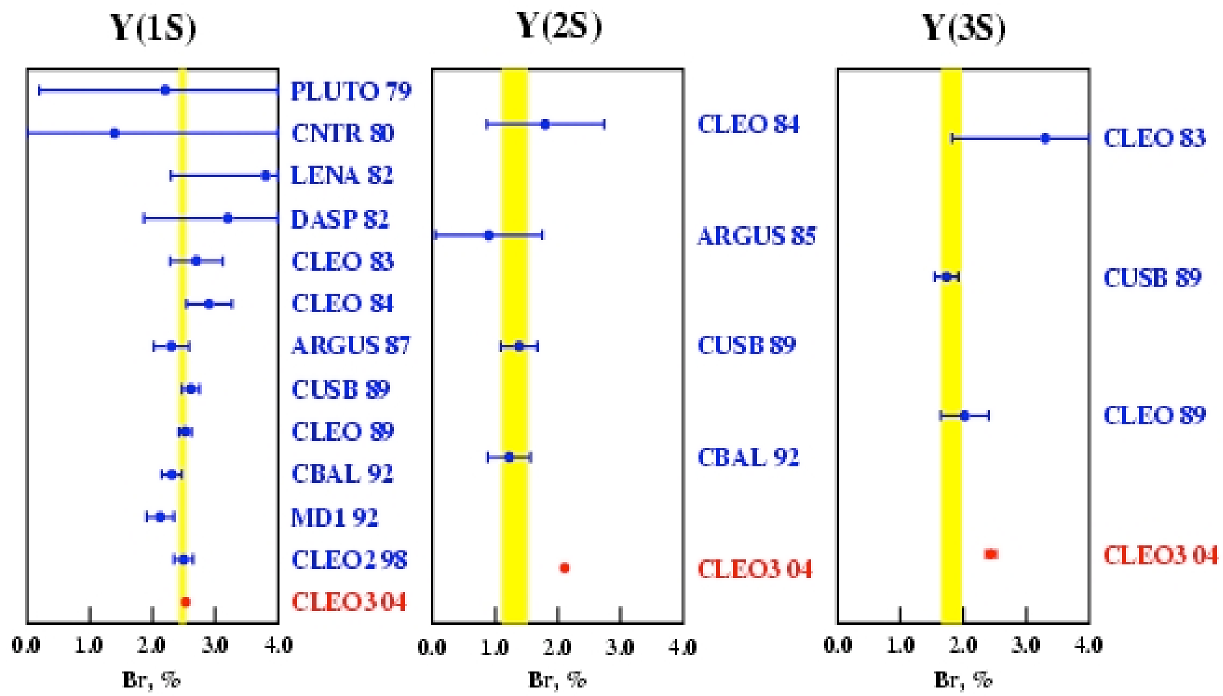
$B_{\mu\mu}$ for the Υ States **[CLEO Preliminary]**

	$B_{\mu\mu}$ (%)		Γ_{tot} (keV)	
	CLEO *preliminary*	PDG	CLEO *preliminary*	PDG
Υ(1S)	2.53 ± 0.02 ±0.05	2.48 ± 0.06	52.1 ± 1.5	52.5 ± 1.8
Υ(2S)	**2.11** ± 0.03 ±0.05	**1.31** ± 0.21	**28.0** ± 1.4	**44** ± 7
Υ(3S)	2.44 ± 0.07 ±0.05	1.81 ± 0.17	19.9 ± 2.0	26.3 ± 3.5

Few % precision reached !

$B_{\mu\mu}(\Upsilon(2,3S))$ significantly higher than prior results

Await CLEO Γ_{ee} !

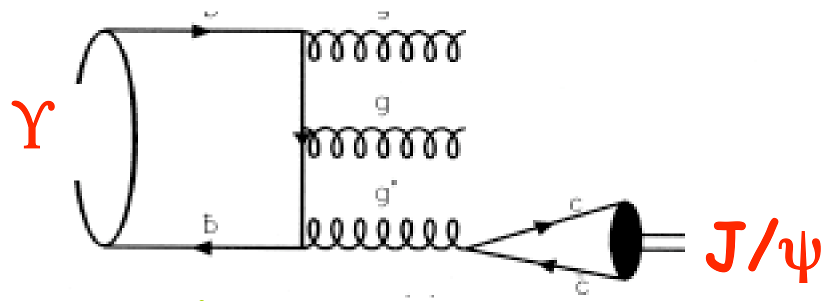


$Q\bar{Q}$ to $Q'\bar{Q}'$: $\Upsilon(1S) \to (c\bar{c})\ X$

- onia production and onia decay
- test of color-octet v. color-singlet models

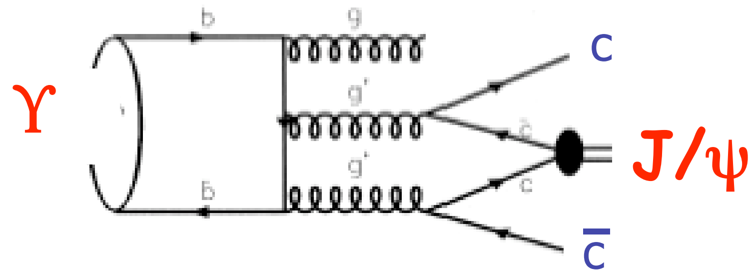
  similar rate predictions

  very different momenta spectra
- may have some relevance to $c\bar{c}c\bar{c}$ production



color-octet

[Chueng, Keung, Yuan: PRD 54, 929 (1996)]



color-singlet

[Li, Xie, Wang: PLB 482, 65 (2000)]

$\Upsilon(1S) \rightarrow J/\psi\, X$

p/p_{max} much too soft for octet model

$B(\Upsilon(1S) \rightarrow J/\psi\, X) =$

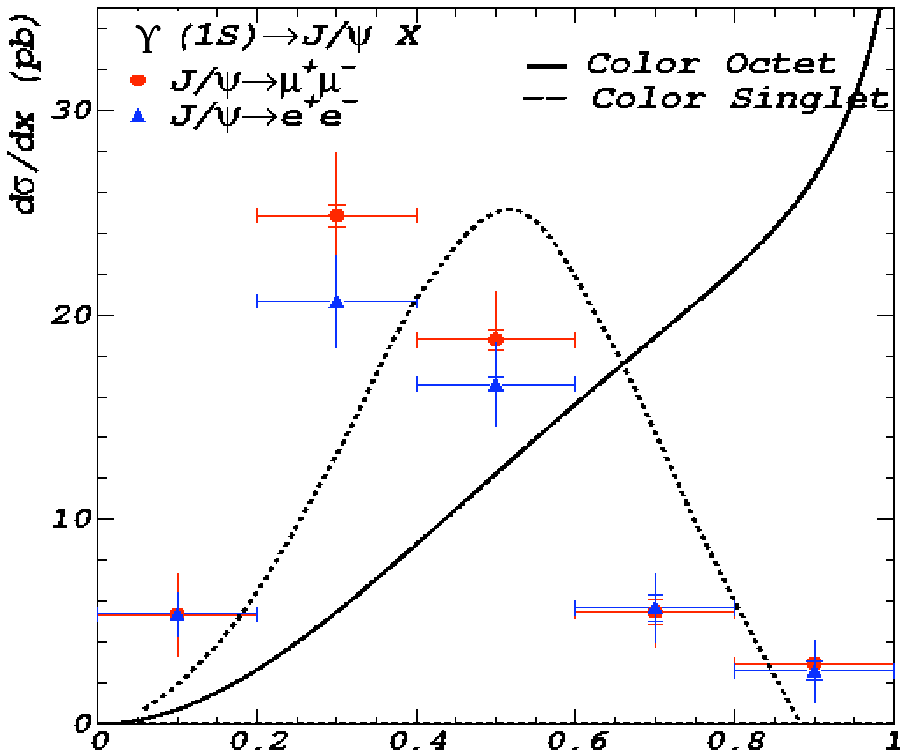
$(6.4 \pm 0.4 \pm 0.6) \times 10^{-4}$

This includes feed-down from other charmonia

Rate consistent with either octet or singlet model

Production and helicity angular distributions also determined

CLEO Preliminary

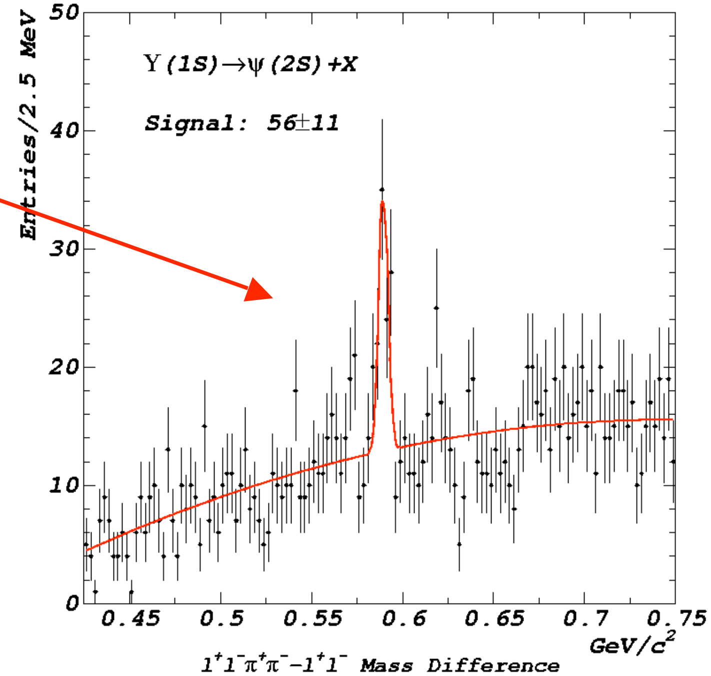


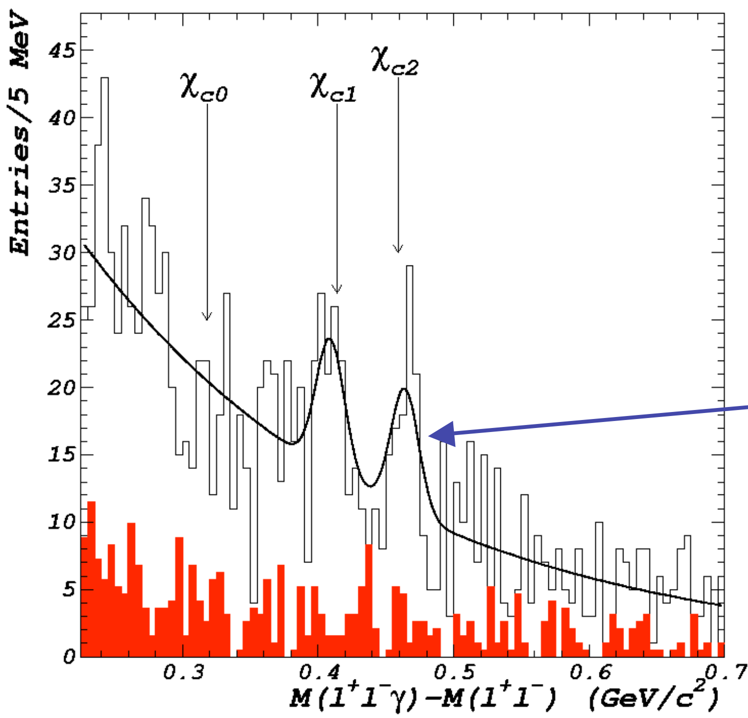
Scaled Momentum (p/p_{max})
(ggg component only!)

$\Upsilon(1S) \rightarrow (c\bar{c})\ X$

Also see first observation of $\psi'X$ …

$B(\Upsilon \rightarrow \psi' X)/B(\Upsilon \rightarrow J/\psi\ X) = (41 \pm 11 \pm 8)\%$





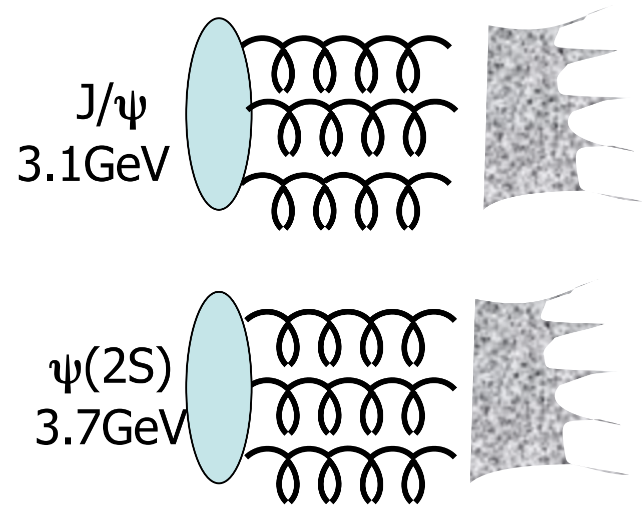
… and evidence for the two χ_c states with large Γ_{E1} …

$B(\Upsilon \rightarrow \chi_{c2}X)/B(\Upsilon \rightarrow J/\psi\ X) = (52 \pm 12 \pm 9)\%$

$B(\Upsilon \rightarrow \chi_{c1}X)/B(\Upsilon \rightarrow J/\psi\ X) = (35 \pm 8 \pm 6)\%$

… all larger than the octet predictions.

“14% Rule” or “ρπ Puzzle”



Decay through $c\bar{c}$ annihilation and production via e^+e^- both depend on $|\Psi(0)|^2$ … therefore naively expect …

$$Q_h = \frac{\mathcal{B}(\psi' \to h)}{\mathcal{B}(J/\psi \to h)} = Q_{ee} = \frac{\mathcal{B}(\psi' \to e^+e^-)}{\mathcal{B}(J/\psi \to e^+e^-)} = \sim 12\ \%$$

Complications, considerations, caveats …

- ♦ running of α_s
- ♦ helicity issues
- ♦ interference
- ♦ FF dependence on √s
- ♦ NR effects
- ♦ etc.

… so compliance within “factor of two” is probably “agreement”.

Biggest offenders: πρ and $K^*\bar{K}$ … both PV … limits on $Q_h/Q_{ee} < 0.1$

Big data sets of BES and CLEO to the rescue!!

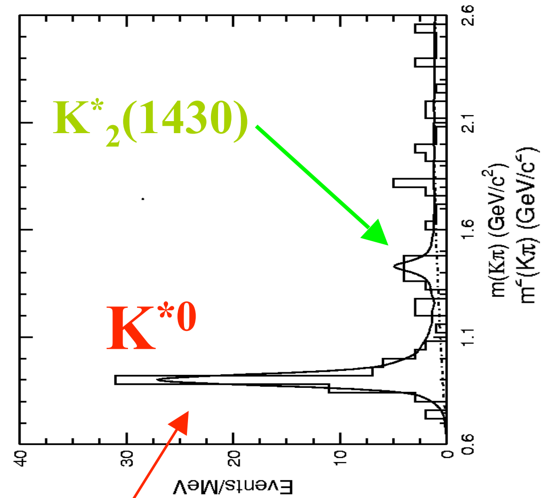
$\psi'(3686) \rightarrow K^*\bar{K}$

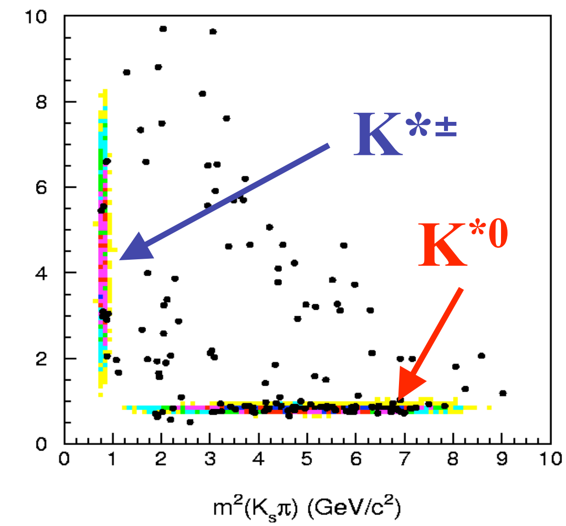
[BES preliminary]

14M ψ' events

6.4 pb^{-1} continuum

Use $K_S K^\pm \pi^\mp$ final state



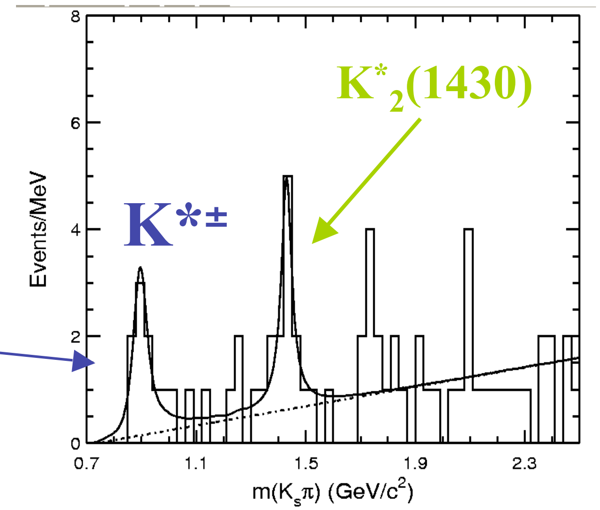


$K^{*0}K^0$

- 65.6±9.0 events, ~11σ
- $B(\psi' \rightarrow K^{*0}\bar{K}^0)$ = (15.0±2.1±1.7) ×10^{-5}
- Q_h = (3.6 ± 0.7) %

$K^{*+}K^-$

- 9.6±4.2 events, ~3.5σ
- $B(\psi' \rightarrow K^{*+}\bar{K}^-)$ = (2.9±1.3±0.4) ×10^{-5}
- Q_h = (0.6 ± 0.3) % **[suppressed!]**

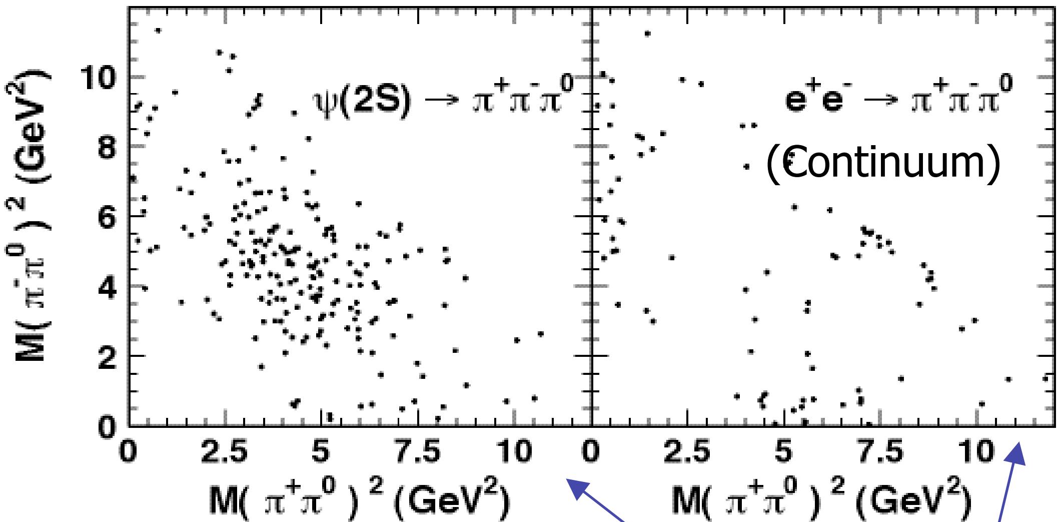


Results have no continuum subtracted (need more!)

Also have events for $\omega\pi^0$

$\psi'(3686) \to \rho\pi$

[CLEO preliminary]

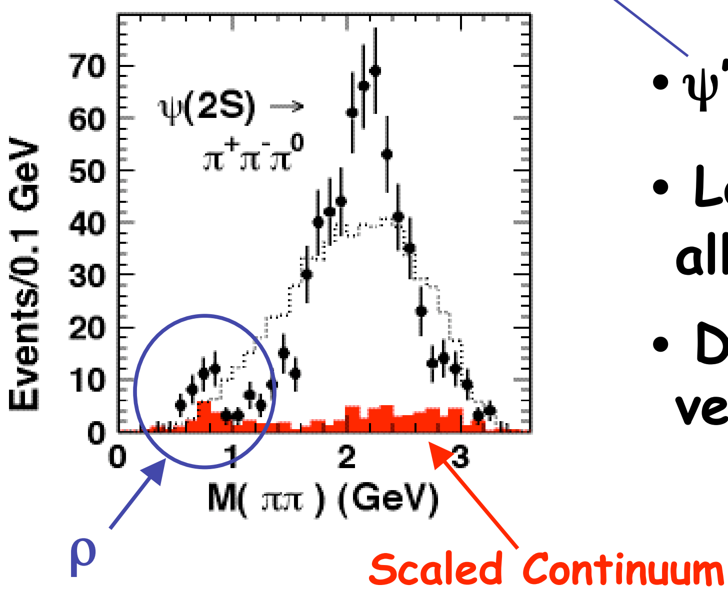


~3M ψ' events (5.5 pb^{-1})

~20 pb^{-1} continuum

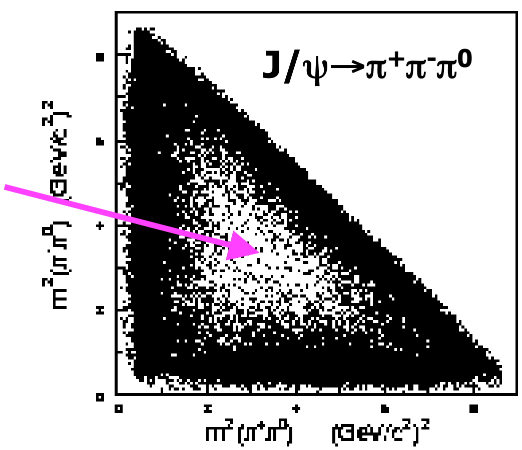
Use $\pi^+\pi^-\pi^0$ final state

- ψ' and continuum **both** show ρ signal !

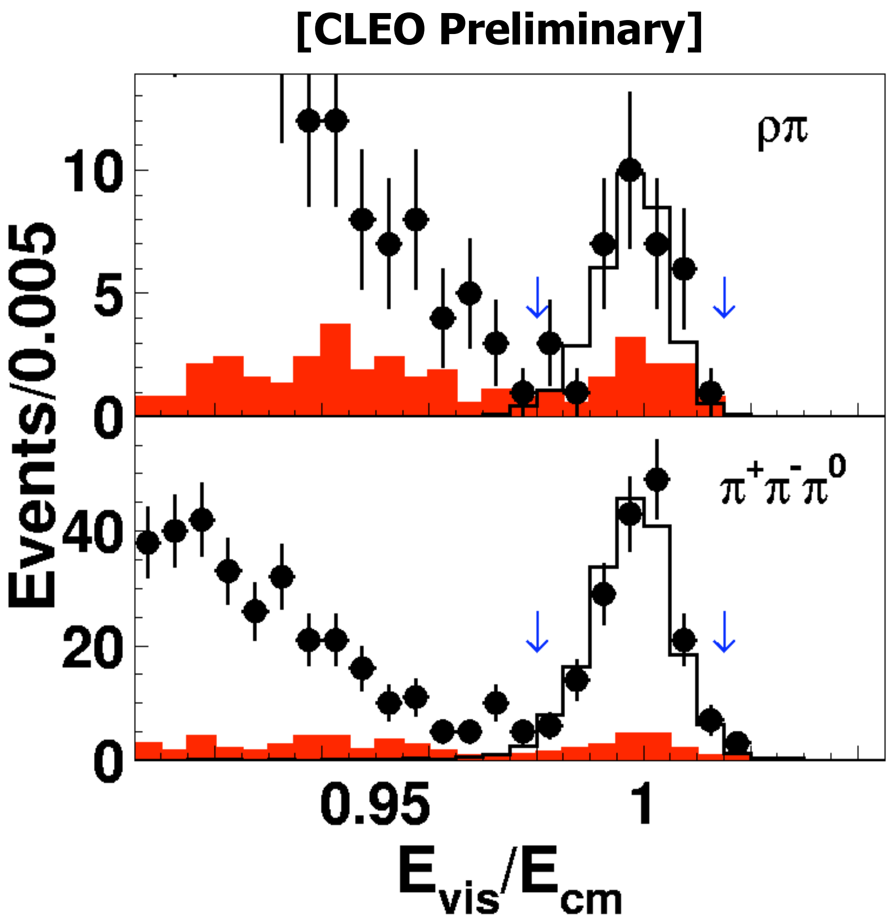


- Large continuum sample allows for subtraction
- Dalitz plot for J/ψ very empty in center !!

[BES: hep-ex/0402013]



$\psi'(3686) \rightarrow \rho\pi, \pi^+\pi^-\pi^0, \ldots$



Results based on $E_{vis}/\sqrt{s}$

$\rho\pi$:

4.2σ, Q_h/Q_{ee} = 0.016±0.006
Equal signals in both modes

$\pi^-\pi^+\pi^0$:

>6σ, Q_h/Q_{ee} = 0.053±0.011

Also see >3σ signals in $\omega\pi^0$ (IV), $\rho^0\eta$ (IV), $K^{*0}\bar{K}^0$, and $b_1\pi$ (AP).

All have continuum subtraction, but assume no interference.

Status of "Puzzle"

$\rho\pi$ and $K^*\bar{K}$ measured !!!

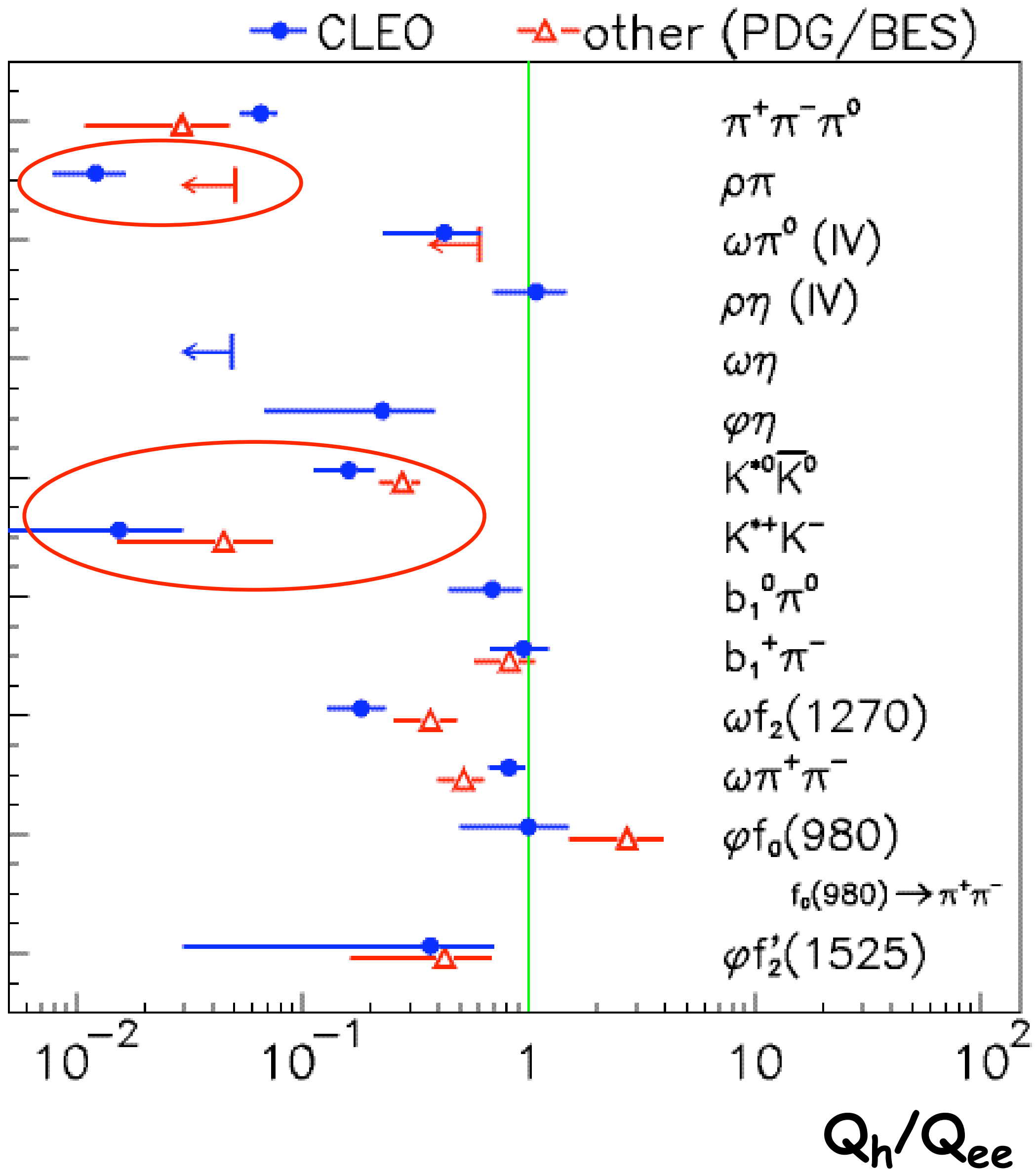
$K^{*+}\bar{K}^-$ much more suppressed than $K^{*0}\bar{K}^0$; I-spin violation large

I-spin "violating" states obey "12% Rule"

AP states not suppressed

VT states at about 1/5

Do the suppressed states show up in the $\psi(3770)$?!



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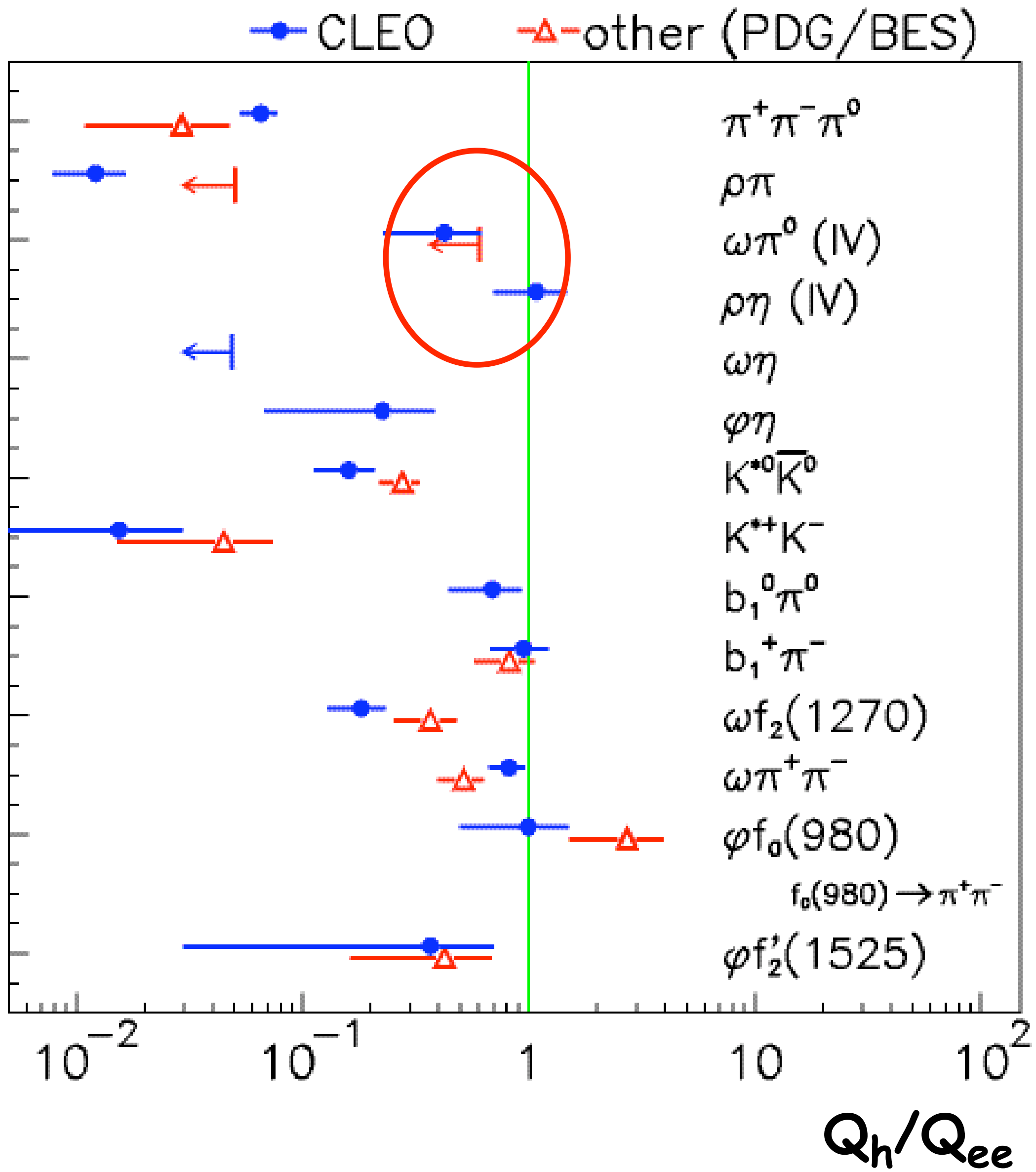

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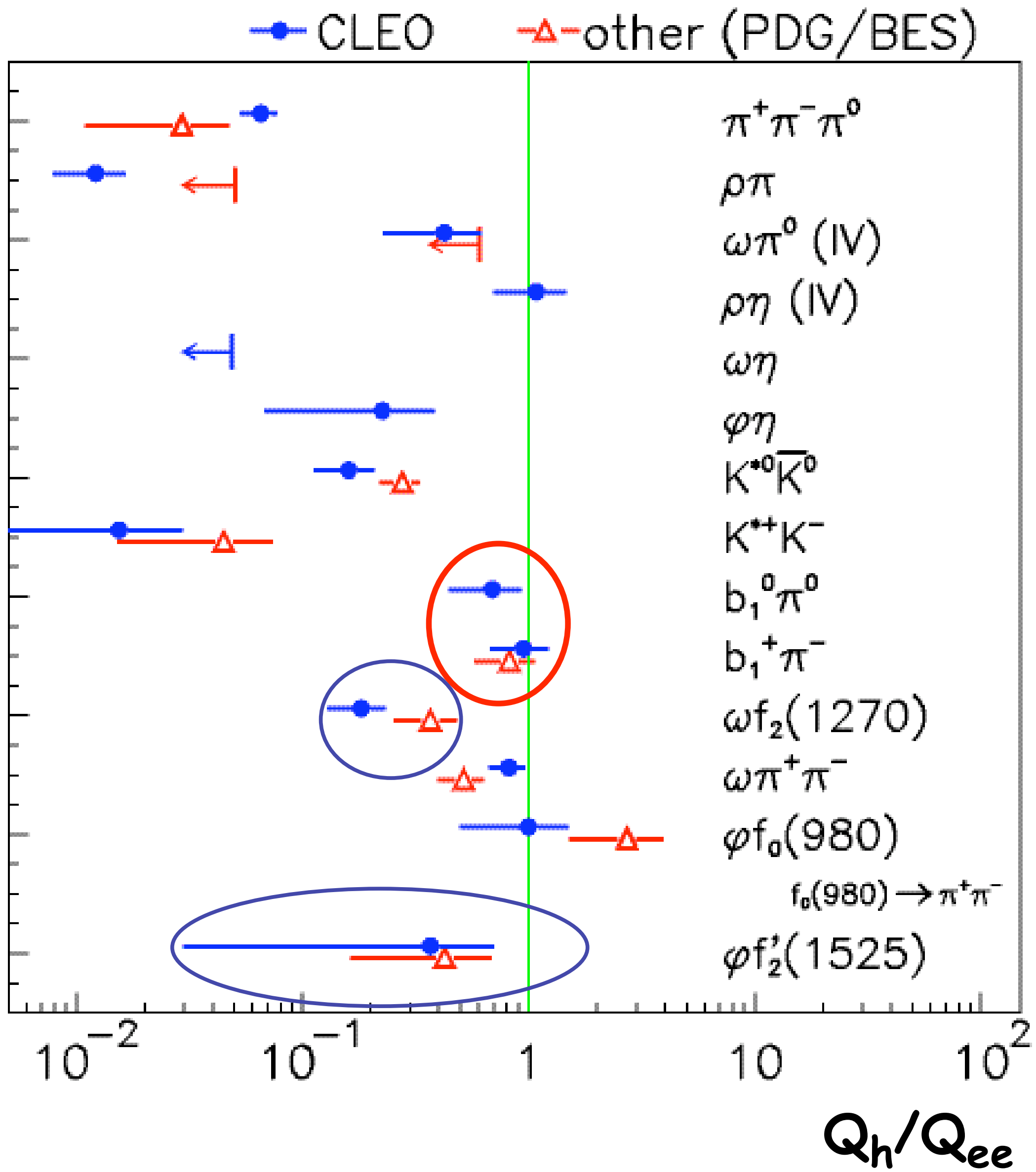

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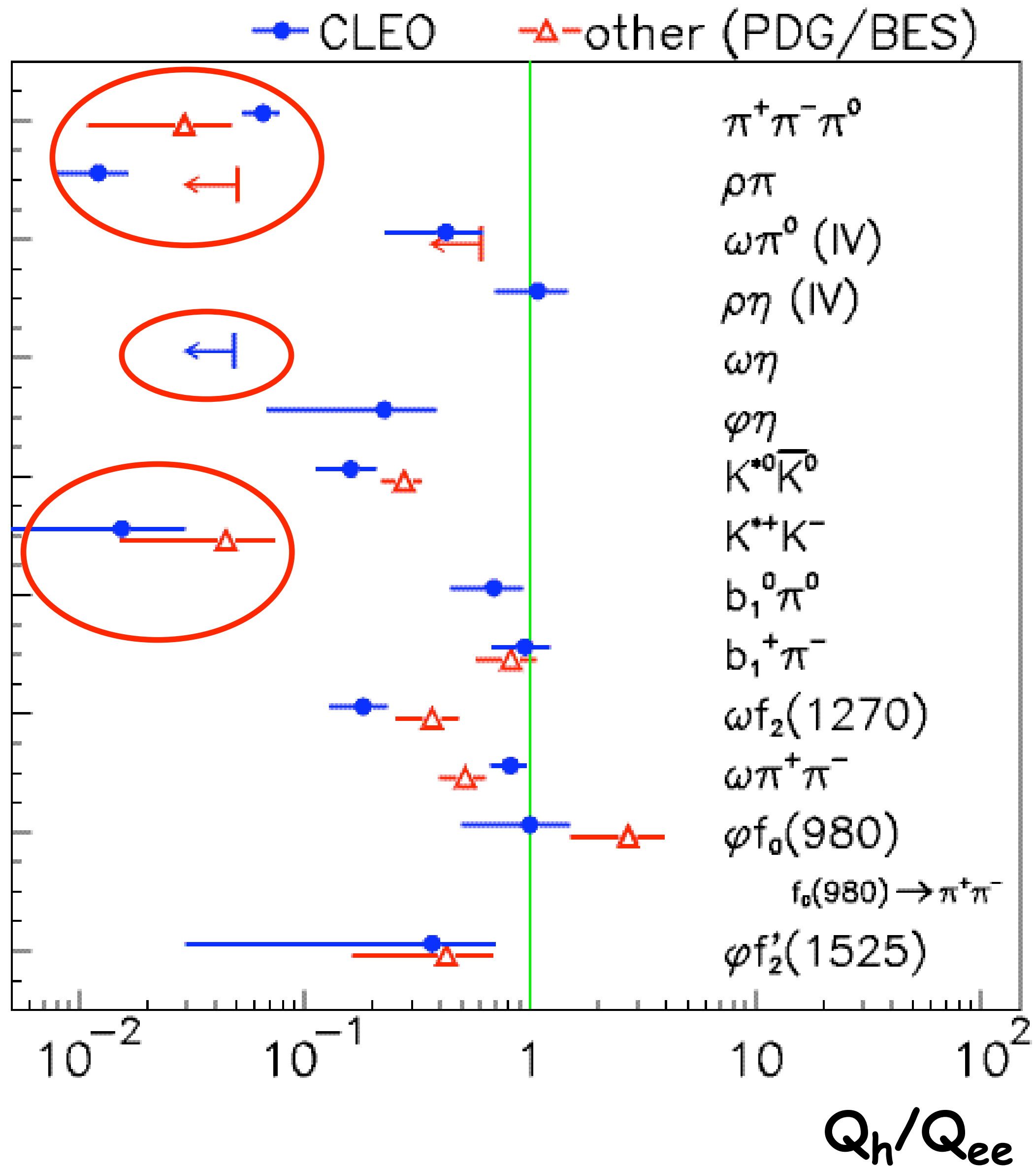
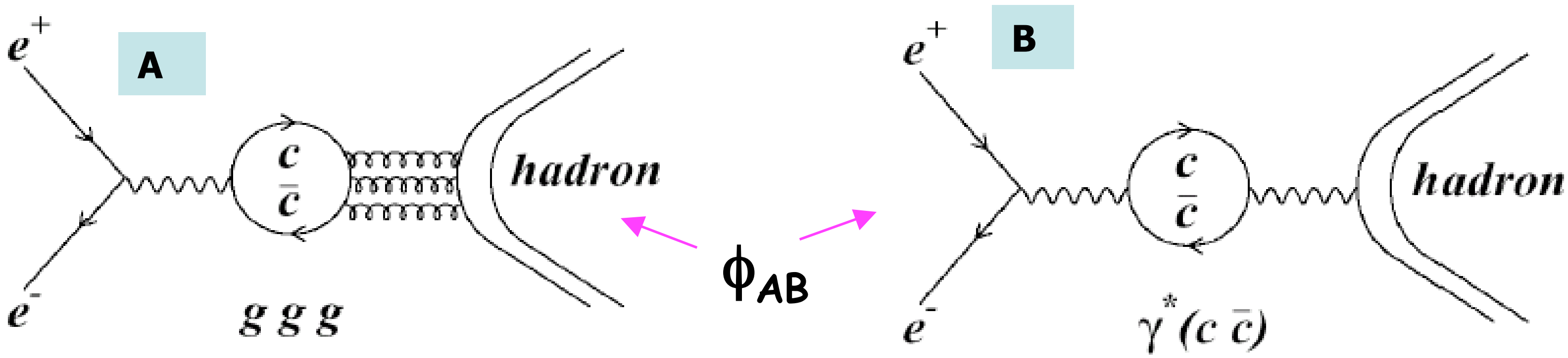


ψ' and J/ψ Decays to Two Pseudo-scalars



Three-gluon

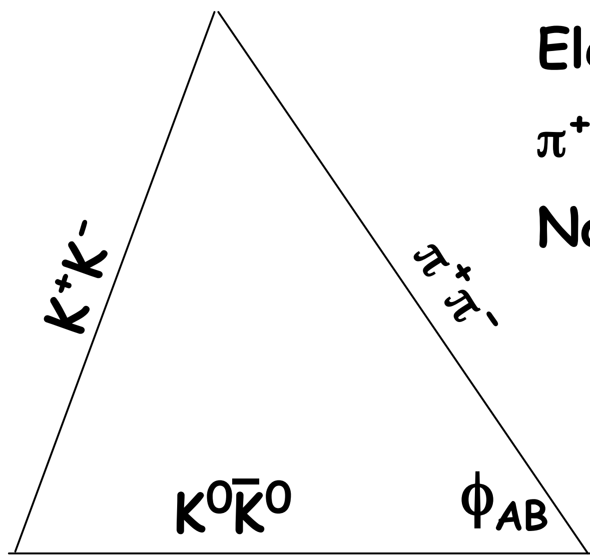
$K^0\bar{K}^0$ and K^+K^-

Not $\pi^+\pi^-$ (G-parity)

Electro-magnetic

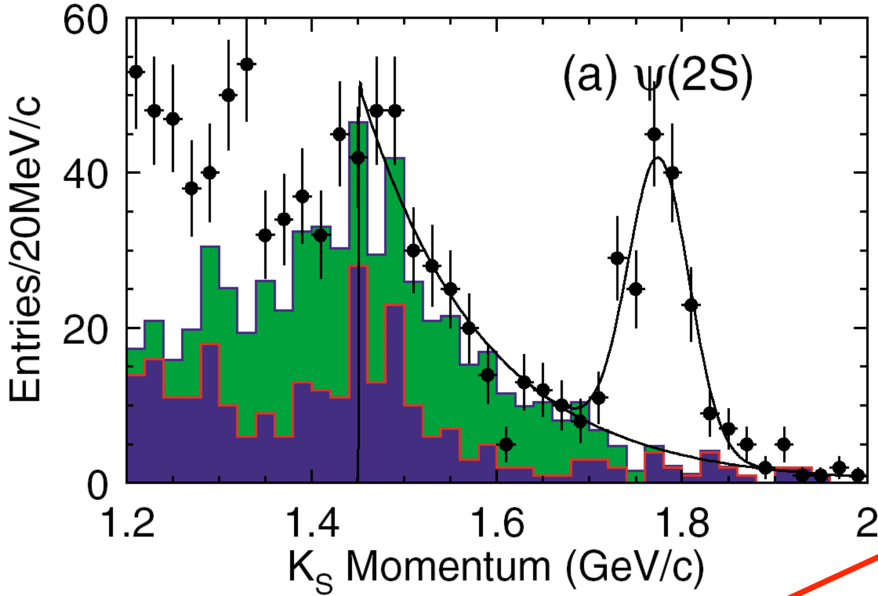
$\pi^+\pi^-$ and K^+K^-

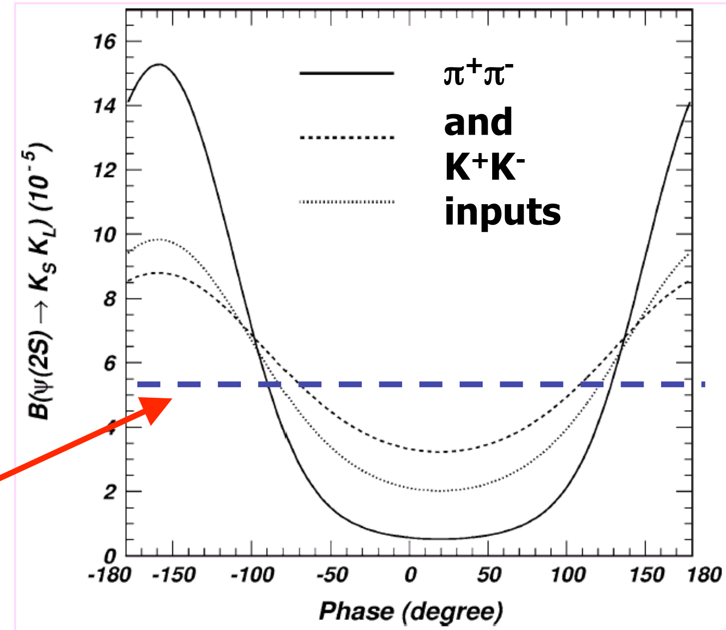
Not $K^0\bar{K}^0$ (SU(3))



ϕ_{AB} known for J/ψ (90±10)° … BES now determines ϕ_{AB} for ψ'

BES - 14 million ψ'





$B(\psi' \rightarrow K_S K_L) = (5.24 \pm 0.47 \pm 0.48) \times 10^{-5}$

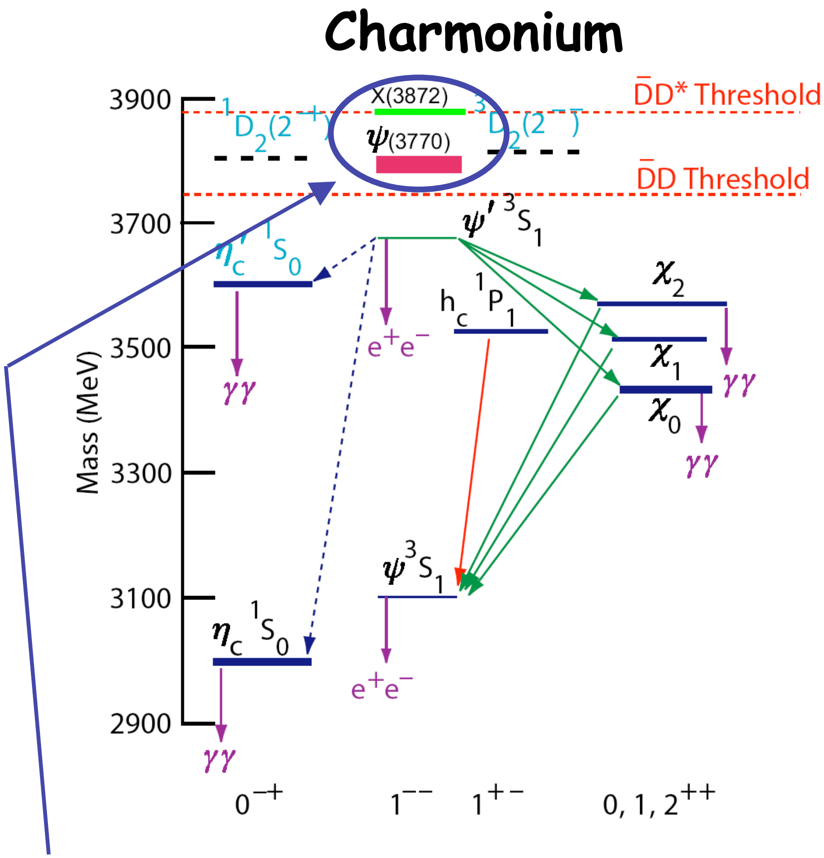
$\phi_{AB}(\psi')= -(82 \pm 29)°$ or $(121 \pm 27)°$ … consistent with $\phi_{AB}(J/\psi)$

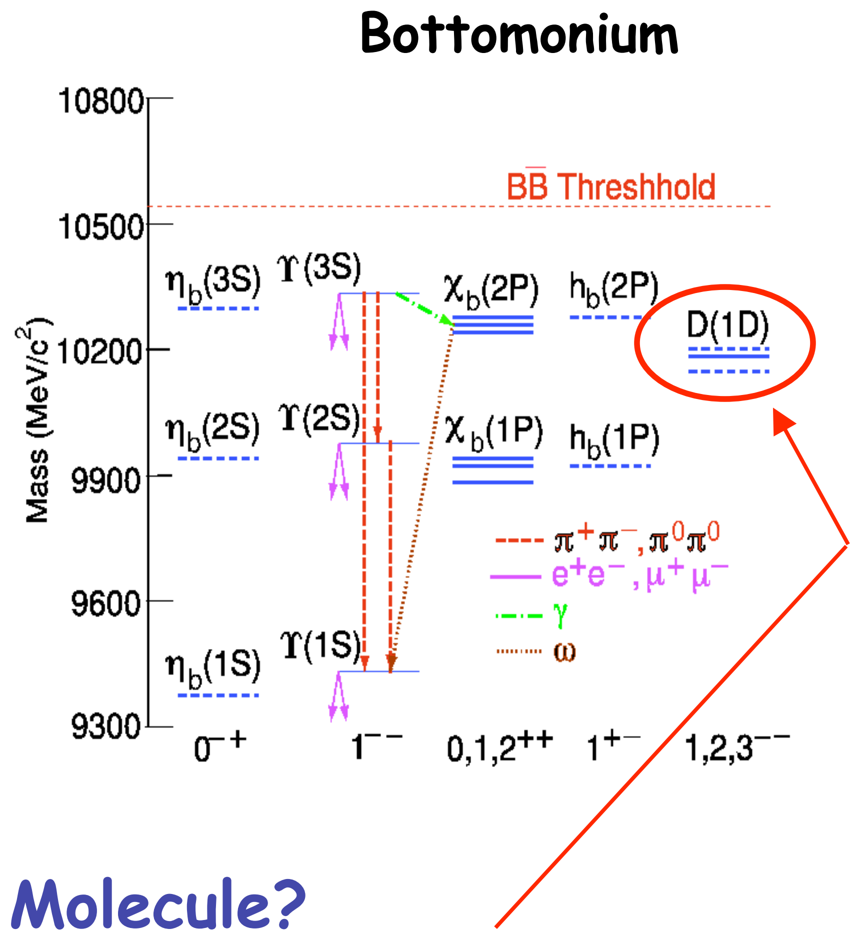
Also (re)measure $B(J/\psi \rightarrow K_S K_L) = (1.82 \pm 0.04 \pm 0.13) \times 10^{-4}$

… so $B(\psi' \rightarrow K_S K_L) / B(J/\psi \rightarrow K_S K_L) = (29 \pm 4)\%$ (12% rule viol?)

[PRL 92, 052001 (2004), PLB567, 73(2003), PRD69, 012003 (2004)]

$Q\bar{Q}$ States with L=2 ("D")

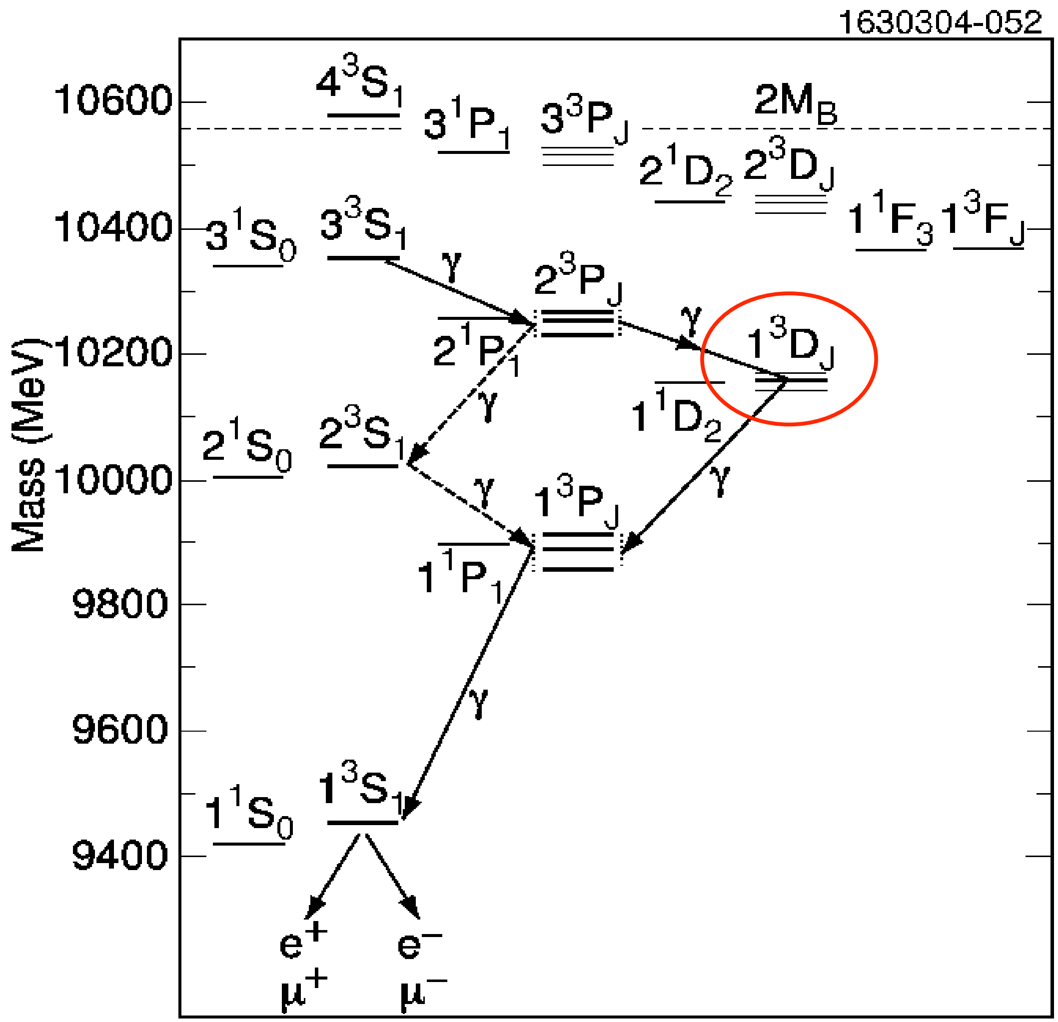




ψ(3770): $^3S_1 - {}^3D_1$ mixing? Molecule?

Υ(1D): stable - tests models and LQCD at high L !!

Final Υ(1D) Analysis Results [CLEO]



Four γ cascade; exclusive Υ(1S) channel

Background thru 2^3S_1

First reported ICHEP'02 with 80% of data … now final

Accepted by PRD
[hep-ex/0404021]

Final Υ(1D) Analysis Results [CLEO]

>10 σ significance

M = 10161.1±0.6±1.6 MeV

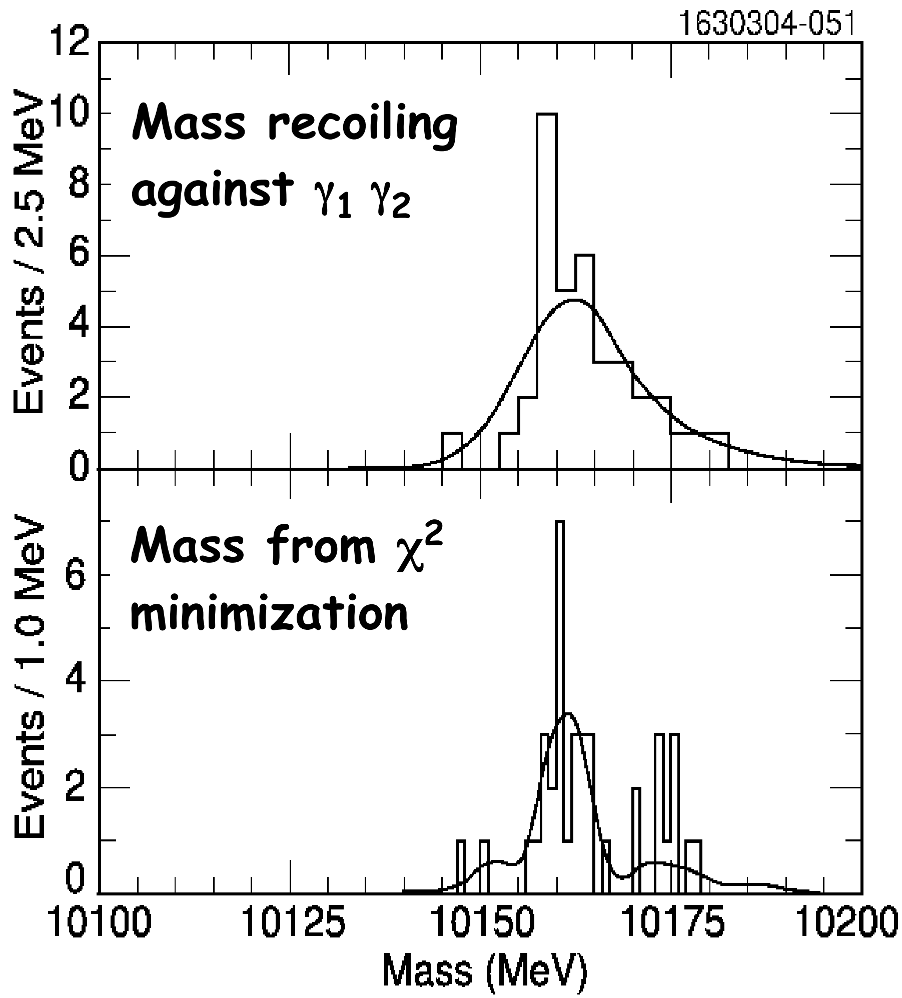
Consistent with 1 $^3D_2$

$\mathcal{B}(\Upsilon(3S) \to \gamma_1 \gamma_2 \gamma_3 \gamma_4 \ell \ell)$ =

$(2.5 \pm 0.5 \pm 0.5) \times 10^{-5}$

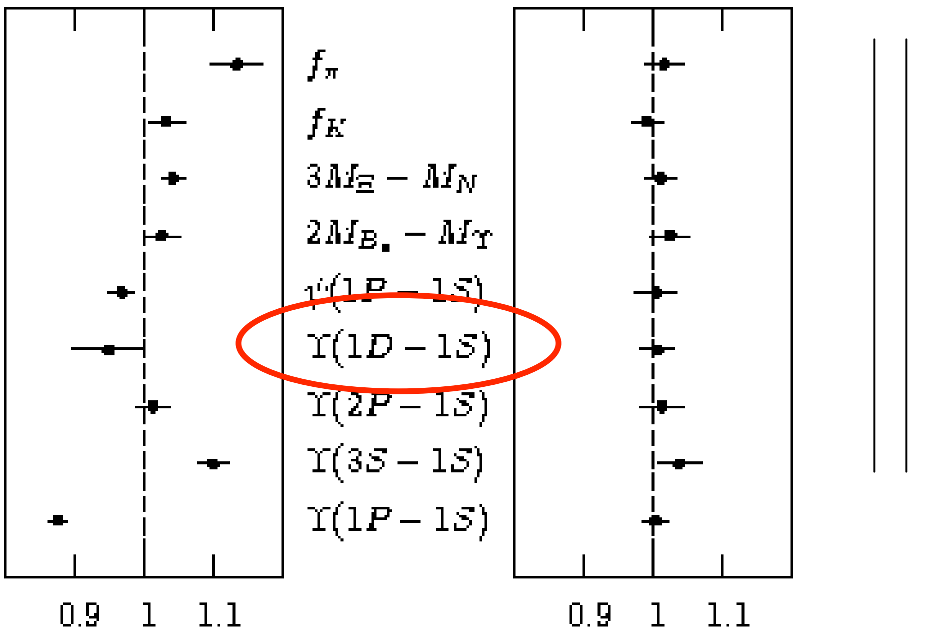
Rate consistent with theory estimates

[hep-ex/0404021; accepted by PRD]



"D" State Impact on LQCD

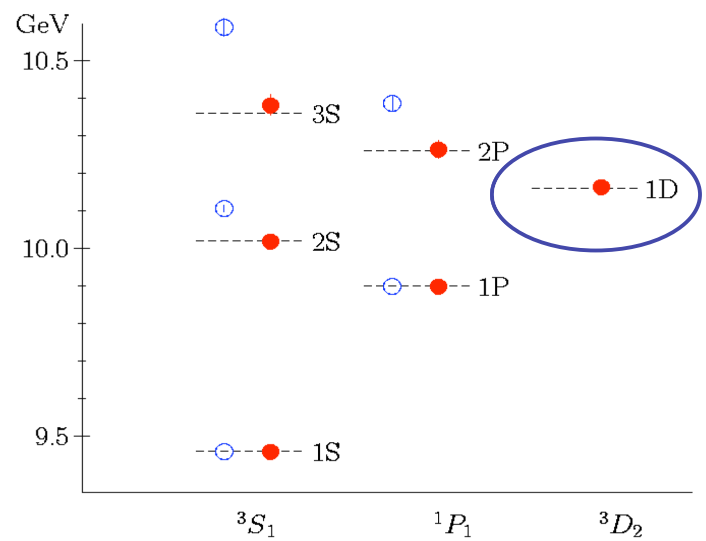
Ratio = LQCD/Expt



Quenched **Unquenched (n_f=3)**

[CTH Davies et al., PRL **92**:022001 (2004)]

Υ Spectrum

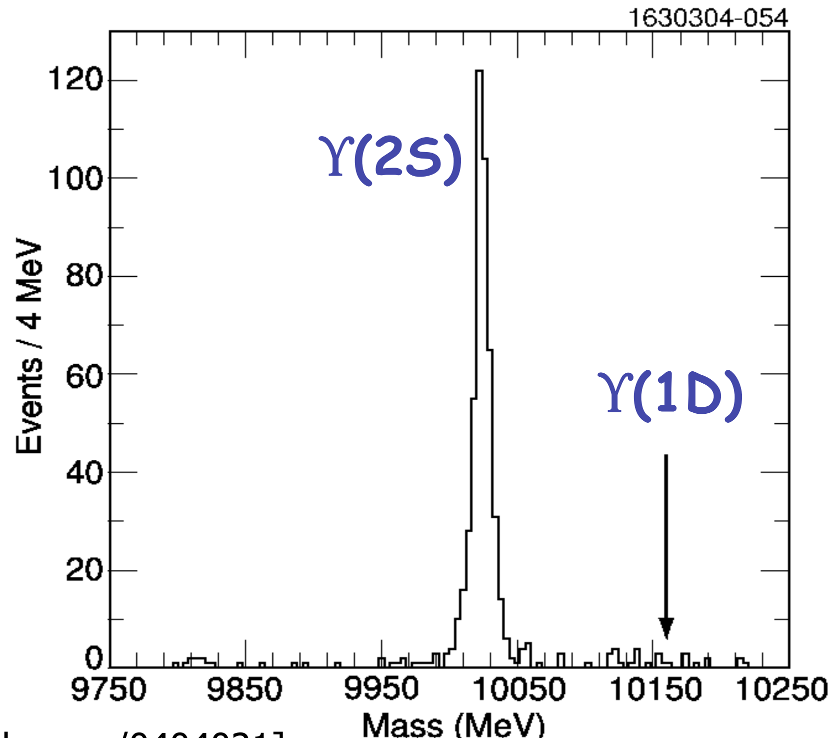


○ **Quenched**

● **$m_u = m_d = m_s/5$**

[Courtesy: G.P. Lepage]

$\Upsilon(1D)$: What is NOT seen !!!



[hep-ex/0404021]

Search for $\Upsilon(1D) \to \pi^+\pi^-\Upsilon(1S)$

Large signal from $\Upsilon(2S)$ … consistent with known rates

No events observed from $\Upsilon(1D)$; upper limits set

Limits ~7 times lower than predicted by Kuang-Yan model; ~3 times higher than Ko model
[J.L.Rosner PRD67, 097504 (2003)]

Also see no evidence for enhancement of $\Upsilon(1D) \to \eta\Upsilon(1S)$ as postulated by Voloshin [PL **B562,** 68 (2003)]

More on Nature of $\psi(3770)$

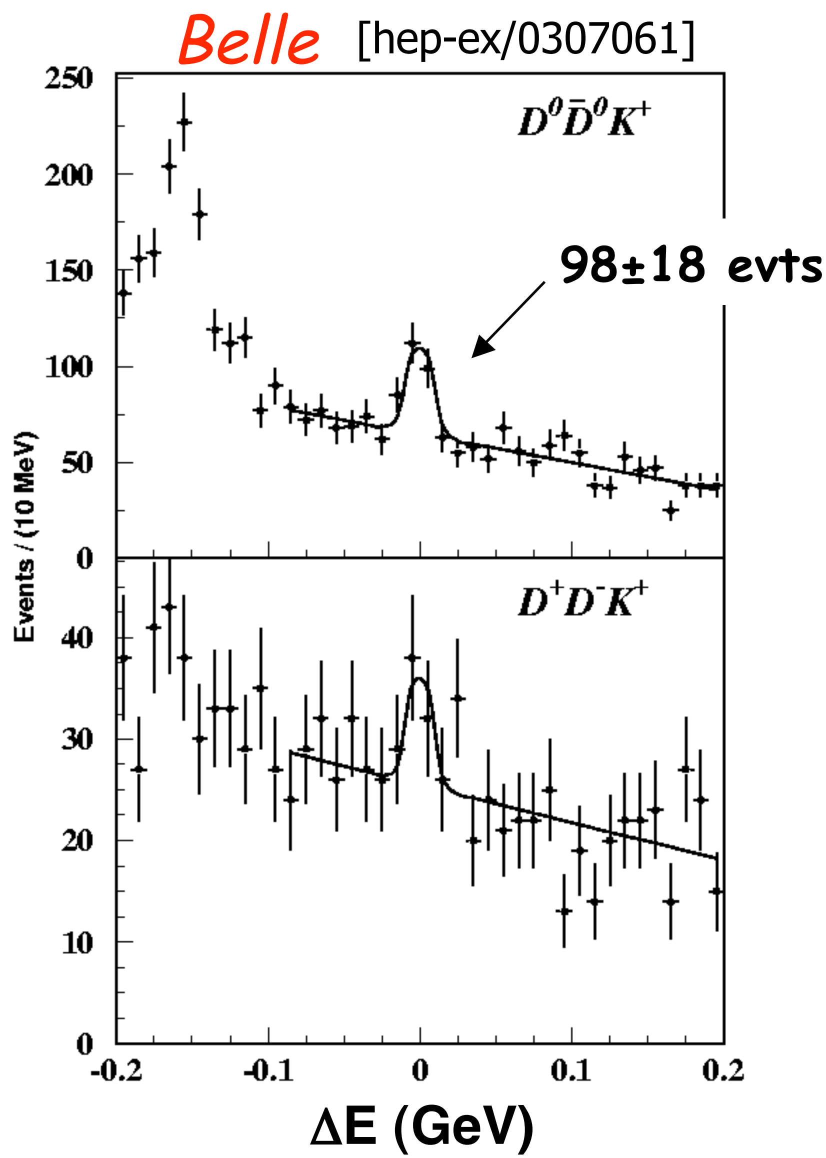
Solid signal seen by Belle in $B^+ \to K^+D^0D^0$

$D\bar{D}$ mass fit yields $\mathcal{B}(B \to K^+\psi(3770)) = (4.8 \pm 1.1 \pm 0.7) \times 10^{-4}$

~2/3 of $\mathcal{B}(B \to K^+\psi(2S))$

Large $^3S_1$-$^3D_1$ mixing?

Color-octet models predict $\mathcal{B}(B \to \psi(3770)\ X)$ at few 10^{-3}



$\psi(3770)$: Learning from Decays to $J/\psi\ \pi\pi$

- $\psi(3770) = \alpha\ {}^3S_1 + \beta\ {}^3D_1 + \gamma\ D\bar{D} + \ldots$
- $\psi(3770)$ *does* couple to e^+e^- … $\Gamma_{ee} = 0.26$ keV
- $\psi(3770) \to \pi^+\pi^-\ J/\psi$ [J. L. Rosner hep-ph/0405196]

  MarkII and BES: $\Gamma(\pi^+\pi^-\ J/\psi) = (43 \pm 14)$ keV

  CLEO 90% limit at this level too

  New BES result … larger data sample … "in preparation"

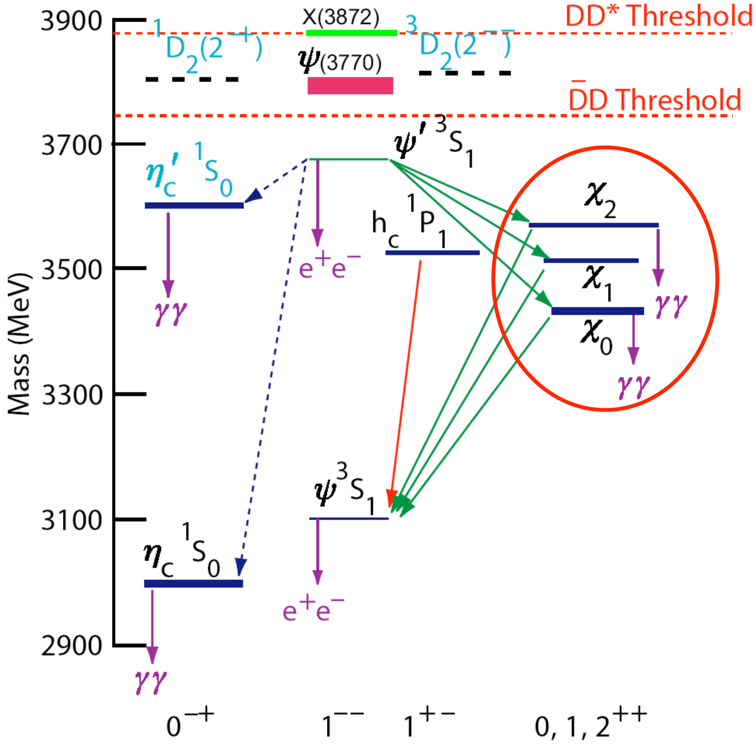
  Kuong-Yan predict 20 - 107 keV (depending on mixing)

  CLEO limit in $\Upsilon(1D)$ x7 below K-Y prediction
- Angular distribution for $\pi^+\pi^-\ J/\psi$ could sort out α, β, γ

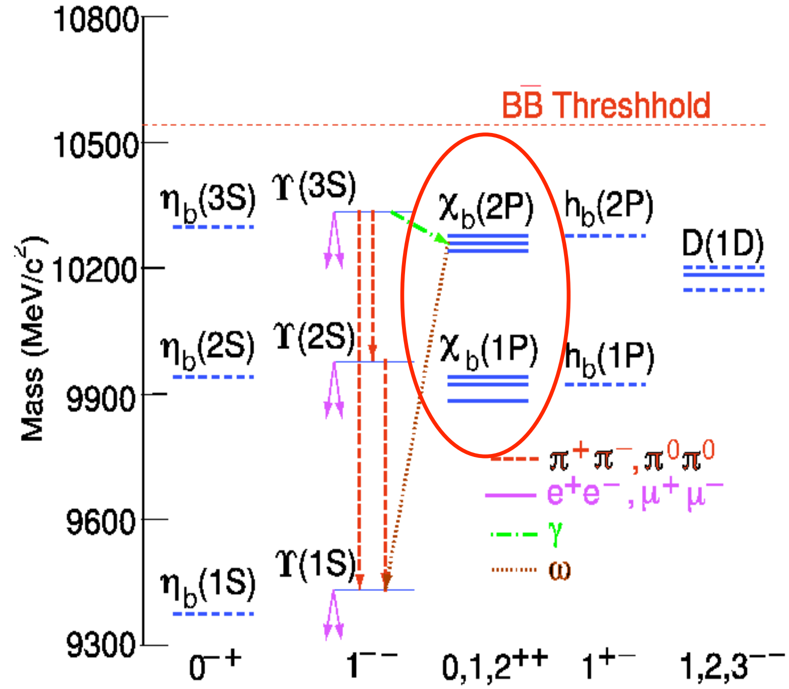
  [Voloshin - priv comm]
- Very large CLEO data sample upcoming !!

$Q\bar{Q}$ States with L=1 ("χ")

Charmonium



Bottomonium

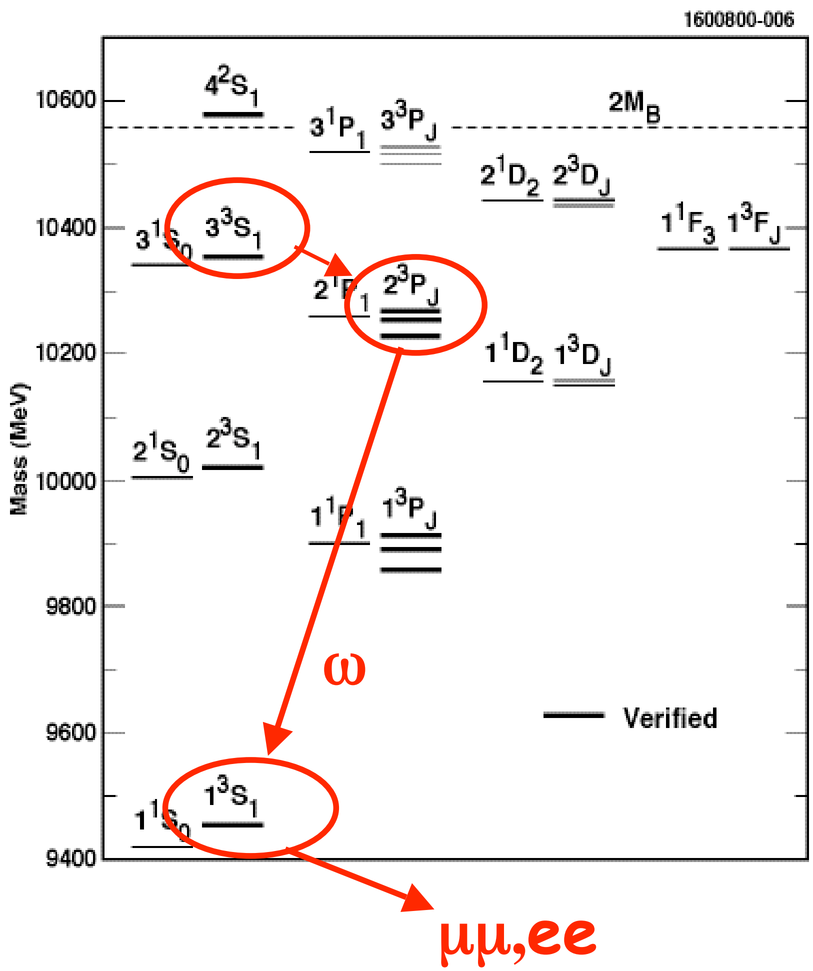


Produced copiously by E1 decays of vector parents;

… also produced in γγ fusion and in hadron colliders

Very little tabulated about decays

Observation of $\chi_b(2P) \to \omega\Upsilon(1S)$



New Υ hadronic transition - **not $\pi\pi$!**

First hadronic transition for χ_b states!

Starts with E1 γ from $\Upsilon(3S)$; ends with $\Upsilon(1S)$ to lepton pairs

Preliminary results last summer; now final, with full $\Upsilon(3S)$ data sample

$\chi_b(2P) \rightarrow \omega\Upsilon(1S)$

Final Results:

$$B(\chi_{b1}' \rightarrow \omega\Upsilon(1S)) = (1.63^{+0.35}_{-0.31}\ {}^{+0.16}_{-0.15})\%$$

$$B(\chi_{b2}' \rightarrow \omega\Upsilon(1S)) = (1.10^{+0.32}_{-0.28}\ {}^{+0.11}_{-0.10})\%$$

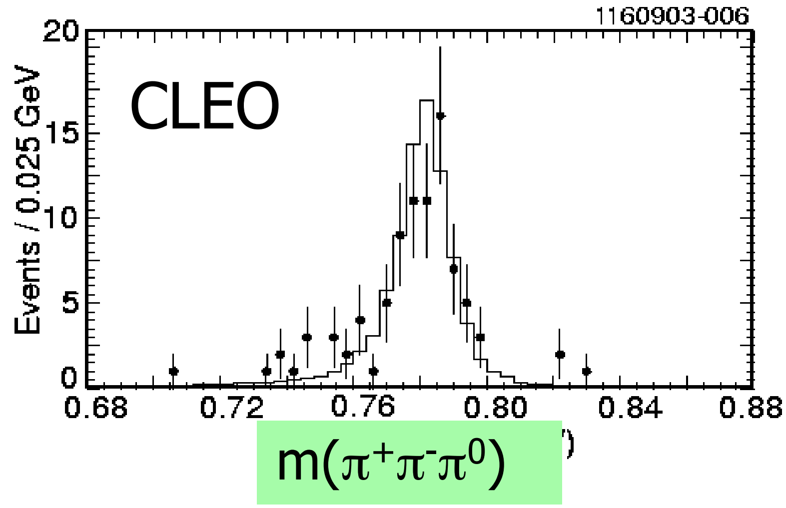
J = 0 kinematically forbidden!

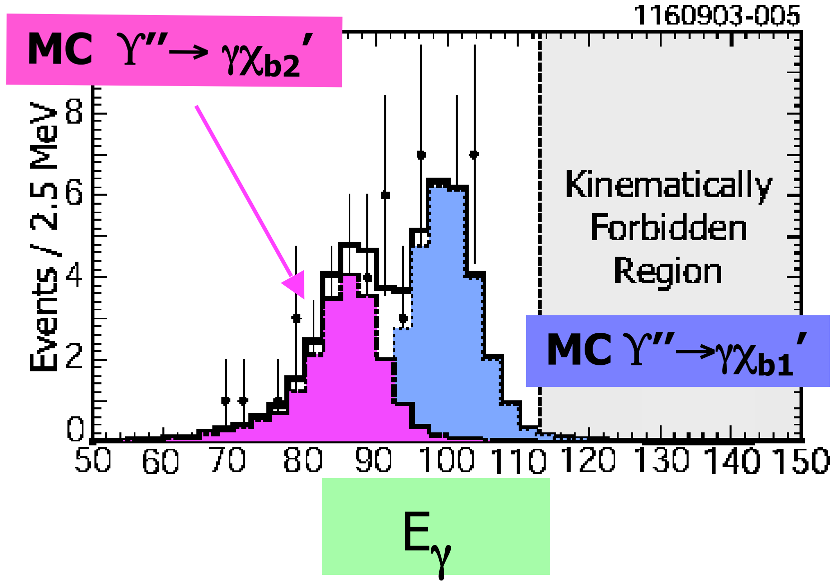
Roughly equal for J = 1 and 2

$r_{2/1}$ predicted to be 1.3 ± 0.3

[Voloshin - hep-ph/0304165]

Very large rate considering limited phase space!





[hep-ex/0311043, accepted by PRL]

Testing Color Octet Model with χ_c Decays

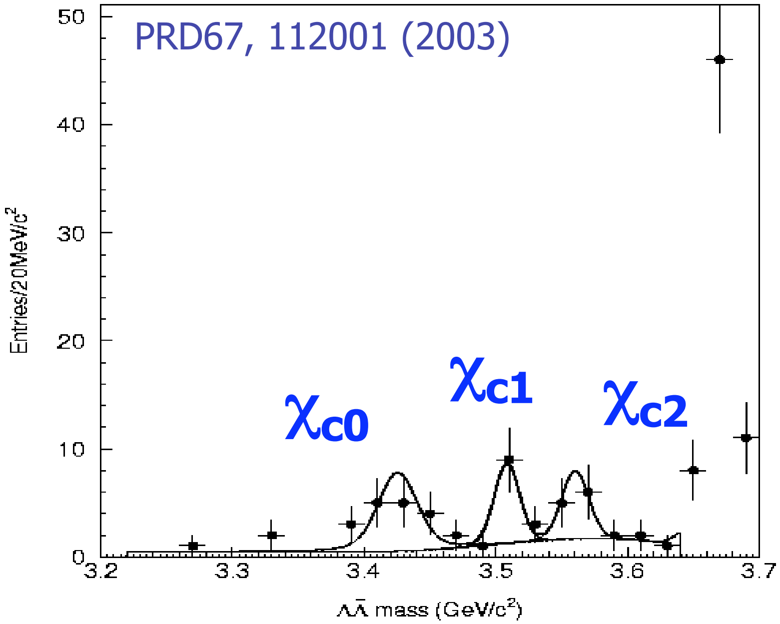
Predictions exist for $c\bar{c}$ decays to baryon-antibaryon

- contain color octet contributions
- color singlet alone cannot account for rate of $c\bar{c} \rightarrow p\bar{p}$
- indicate suppression of $\Lambda\bar{\Lambda}$ with respect to pp
- define $R_B = \Gamma(\Lambda\bar{\Lambda})/\Gamma(p\bar{p})$
- R_B = 0.60 for J=1 and 0.45 for J=2

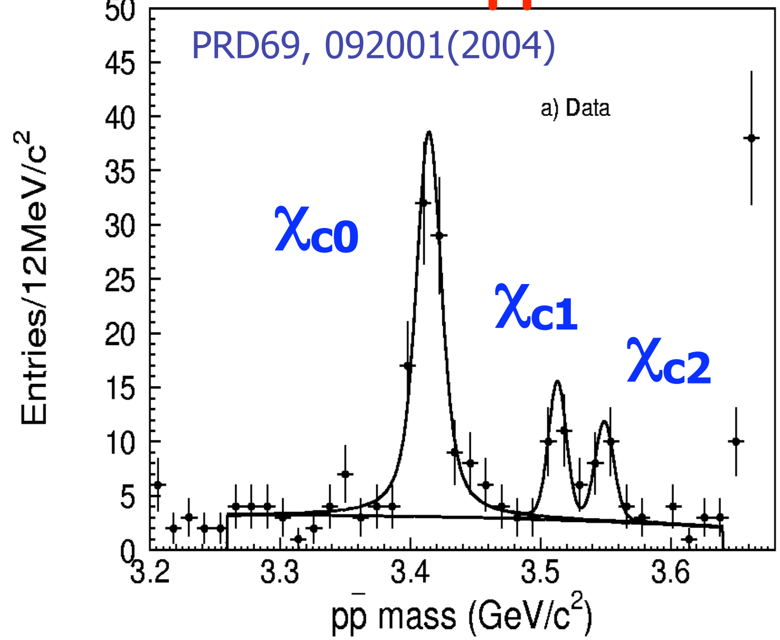
Singlet Graph Octet Graph

S. M. Wong, Eur. Phys. J. C14, 643 (2000)

BES - $\Lambda\bar{\Lambda}$



BES - $p\bar{p}$



Nice signals in $p\bar{p}$ - branching fractions consistent with PDG and same accuracy; weaker signals in $\Lambda\bar{\Lambda}$ – first measurements.

$$R_{\mathcal{B}} = \frac{n^{obs}_{\Lambda\bar{\Lambda}}/[\varepsilon_{\Lambda\bar{\Lambda}} \cdot \mathcal{B}(\Lambda \to \pi^- p)^2]}{n^{obs}_{p\bar{p}}/\varepsilon_{p\bar{p}}}$$

J = 1: R_b = 4.6 ± 2.3

J = 2: R_b = 5.1 ± 3.1

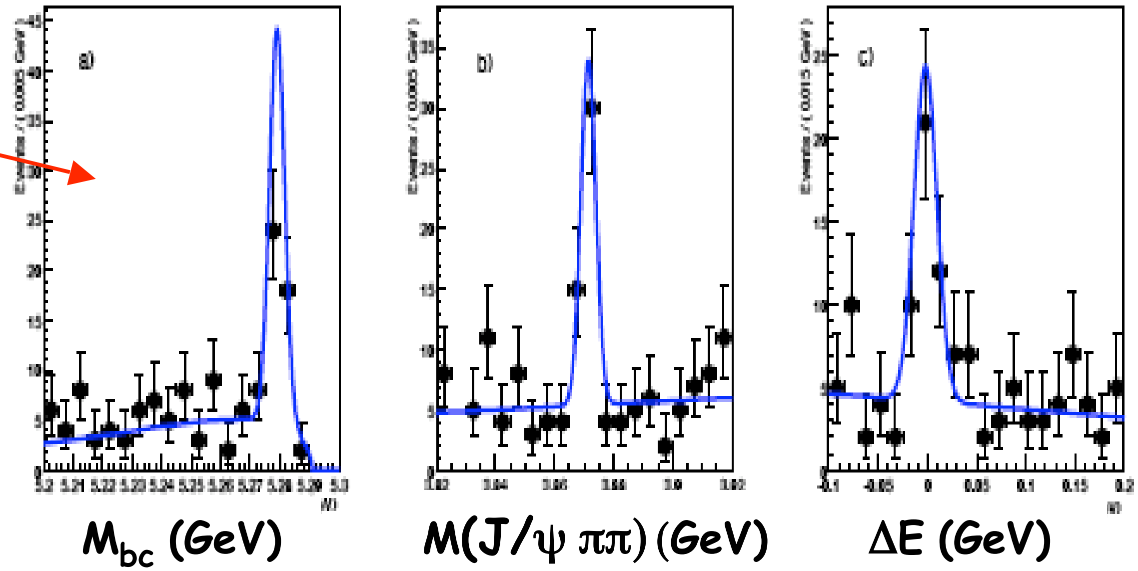
Large uncertainties, but show $\Lambda\bar{\Lambda}$ enhanced, not suppressed !

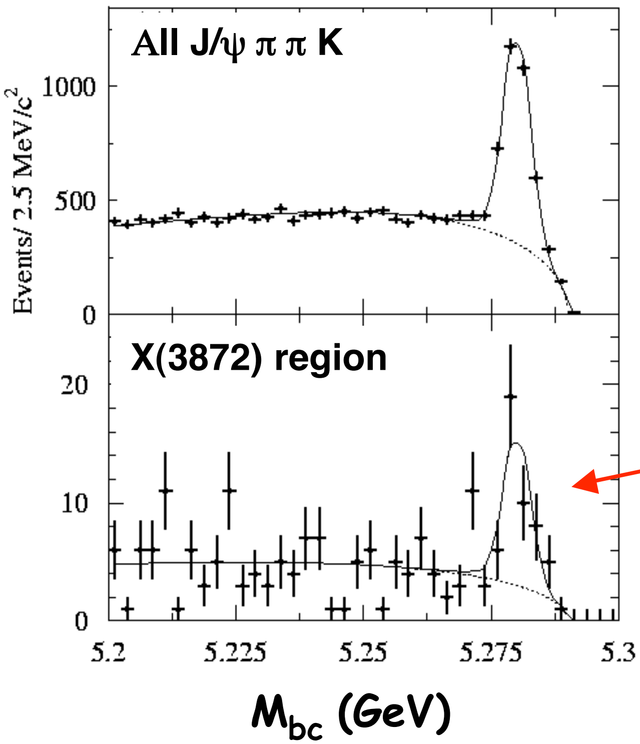
X(3872) - Just what IS it ??? $c\bar{c}$? Molecule?

Four clear sightings … two in $B^+ \rightarrow K^+X(3872)$ …

originally by Belle ($>10\sigma$) …

[PRL 91, 262001 (2003)]

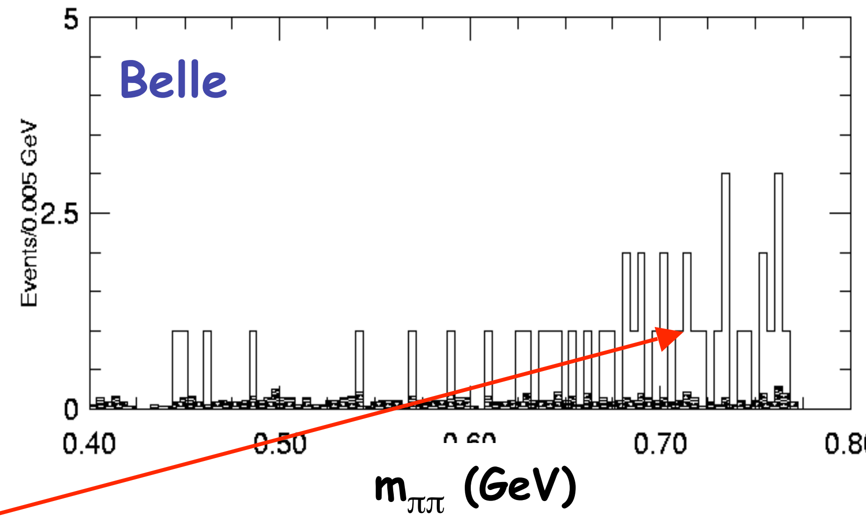




… and recently by BaBar.

[hep-ex/0406022; subm'd to PRL]

$m_{\pi\pi}$ in $X \to J/\psi\, \pi^+\pi^-$

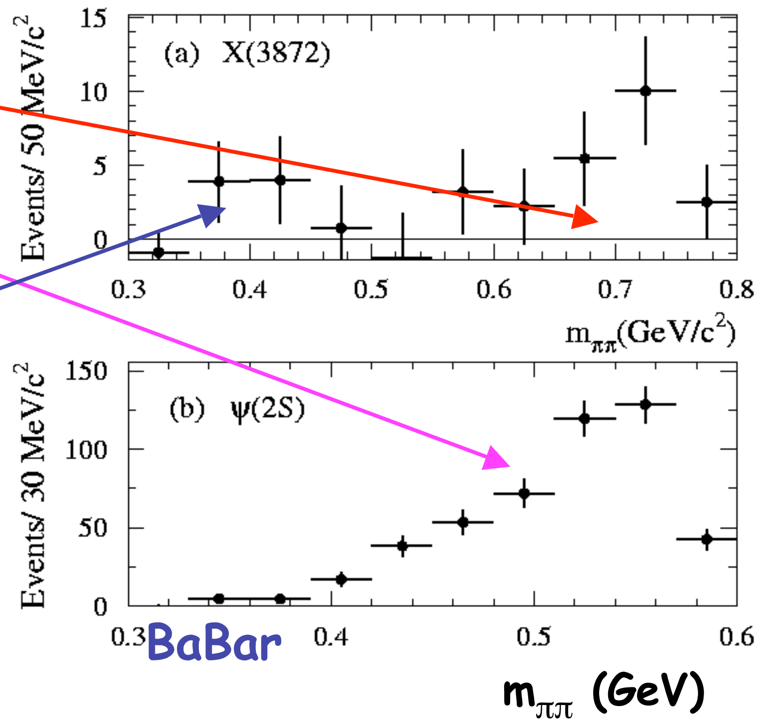


Both Belle/BaBar see similar $m_{\pi\pi}$ structure; this is used by CDF/D0 to clean up background (next slide).

Is there a ρ component (C_X=+)? Or is the high-mass region a "copy" of $\psi(3686)$ decay?

Is there really a second low-$m_{\pi\pi}$ peak similar to that observed in $\Upsilon(3S) \to \Upsilon(1S)\, \pi\, \pi$?

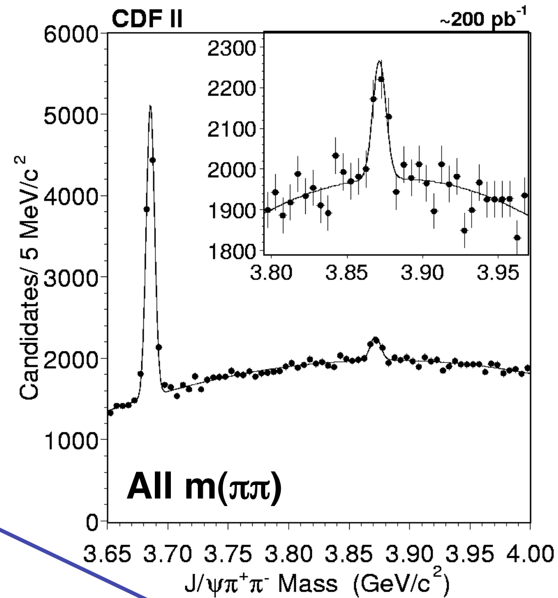
No measures or limits (yet!) for $X \to J/\psi\, \pi^0\pi^0$!! Would establish C_X = -1.



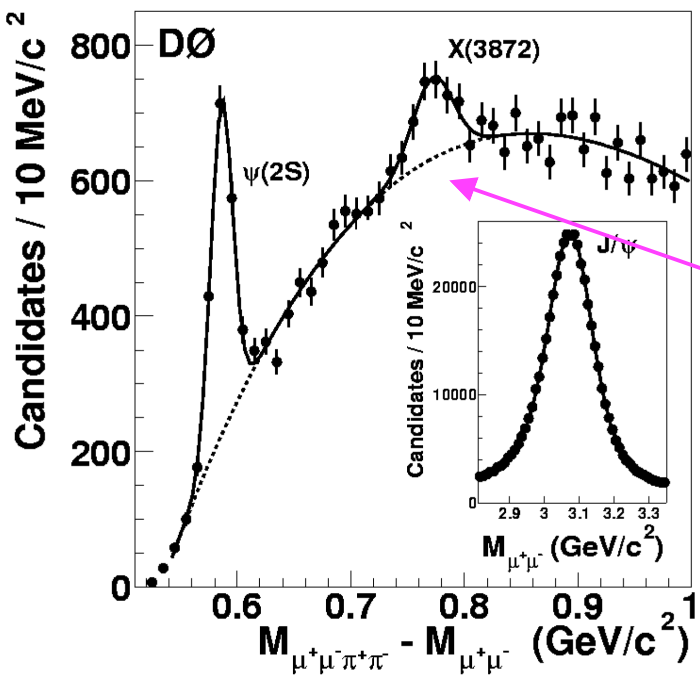
More sightings of X !!

Two clear observations in hadron production …

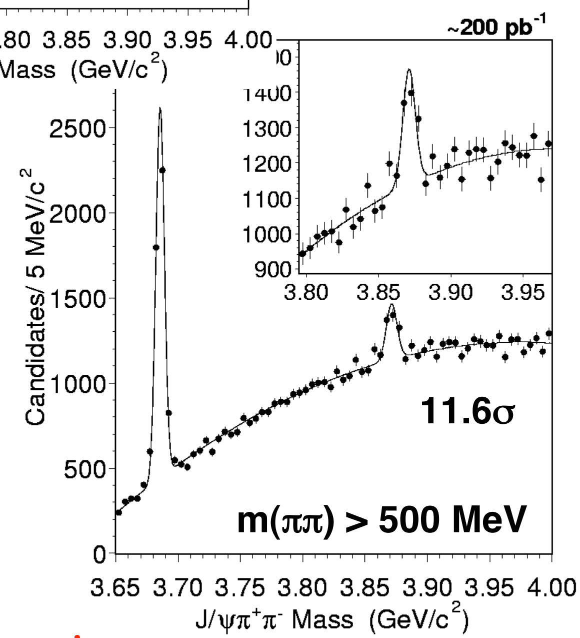
…. first CDF (QWGII)



hep-ex/0312021; sum'd to PRL



… and then recently D0.



… pretty convincing!

Basic X(3872) Parameters

Mass (GeV/c^2):

- ♥ Belle: 3872.0 ± 0.6 ± 0.5
- ♦ CDF: 3871.3 ± 0.7 ± 0.4
- ♦ D0: 3871.8 ± 3.1 ± 3.0
- ♣ BaBar: 3873.4 ± 1.4

My average:

M(X) = 3872.2 ± 0.5

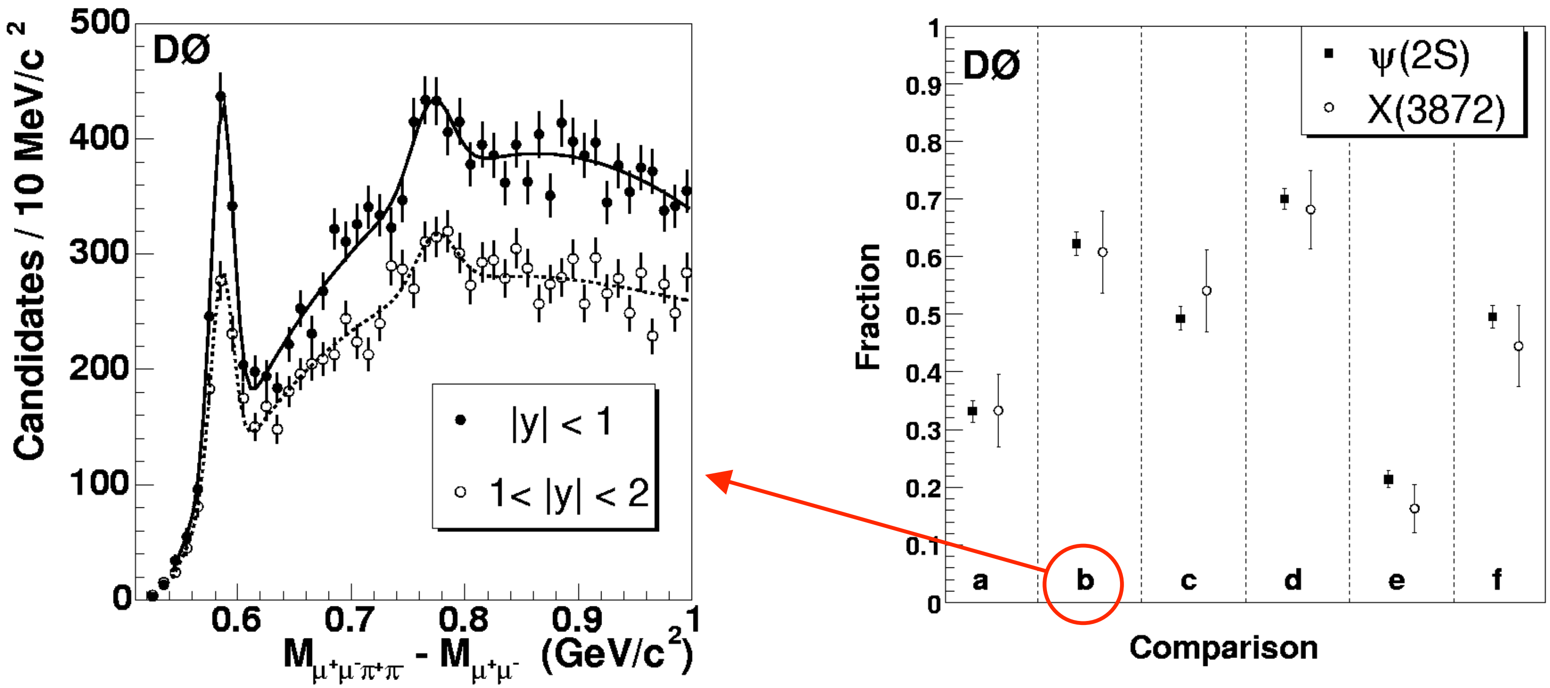
[$M(D^0 D^{0*})$ = 3871.2 ± 0.7
$M(D^- D^{+*})$ = 3879.3 ± 1.0]

Width (Γ) (MeV/c^2):

- ♥ Belle: < 2.3 (90% CL)
- ♦ CDF: consistent with resolution (5)
- ♦ D0: consistent with resolution (17)
- ♣ BaBar: smaller than resolution (~3)

NARROW!

X Production and Decay Characteristics (see also H. Evans' talk)



hep-ex/0405004; subm'd to PRL

Production fractions:

a: p_T > 15 GeV/c (transv mom)
b: y < 1 (rapidity)
e: isolated from rest of event

Decay fractions:

c: cos θ_π < 0.4 (pion helicity)
d: dL < 1mm (effec decay length)
f: cos θ_μ < 0.4 (muon helicity)

Similar studies underway at CDF.

More comparisons to ψ' [BaBar and Belle combined]

$$\frac{\mathcal{B}(B^+ \to K^+ X(3872)) \cdot \mathcal{B}(X \to J/\psi \pi^+ \pi^-)}{\mathcal{B}(B^+ \to K^+ \psi'(3686)) \cdot \mathcal{B}(\psi' \to J/\psi \pi^+ \pi^-)} = 0.062 \pm 0.011$$

… or …

$$\mathcal{B}(B^+ \to K^+ X(3872)) \cdot \mathcal{B}(X \to J/\psi \pi^+ \pi^-) = (1.37 \pm 0.25) \times 10^{-5}$$

Perhaps $X(3872) = \alpha\ (D^0 \bar{D}^{0*} + c.c.) + \beta\ (c\bar{c})$

- β^2 a few percent (?)
- α large (coincidence that $M_X = M_{D0} + M_{D0*}$?)
- $J^{PC} = 1^{++}$? (too narrow to have natural parity ?)
- minimal $D^+ \bar{D}^{-*}$ component (so much for isospin!)
- several other searches bear on J^{PC}

[Thanks to M.V., J.R., T.Skwarnicki]

More Attempts to Determine Nature of X(3872)

Belle: PRL 91, 262001('03); hep-ex/0405014

$$\frac{\Gamma(X \to \gamma \chi_{c1})}{\Gamma(X \to \pi^+\pi^- J/\psi)} < 0.89 \text{ (90\% C.L.)}$$ ⇒ **not likely $^3D_2$**

$$\frac{\Gamma(X \to \gamma \chi_{c2})}{\Gamma(X \to \pi^+\pi^- J/\psi)} < 1.1 \text{ (90\% C.L.)}$$ ⇒ **not likely $^3D_3$**

$$\frac{\Gamma(X \to \gamma J/\psi)}{\Gamma(X \to \pi^+\pi^- J/\psi)} < 0.40 \text{ (90\% C.L.)}$$ ⇒ **not likely χ_c' ($2\ ^3P_J$)**

Belle: hep-ex/0307061

$$\mathcal{B}(B^\pm \to X\ K^\pm)\mathcal{B}(X \to D^0\overline{D}^0) < 6\text{x}10^{-5} \text{ (90\% C.L.)}$$

$$\mathcal{B}(B^\pm \to X\ K^\pm)\mathcal{B}\ (X \to D^+D^-) < 4\text{x}10^{-5} \text{ (90\% C.L.)}$$

$$\mathcal{B}(B^\pm \to X\ K^\pm)\mathcal{B}(X \to D^0\overline{D}^0\pi^0) < 6\text{x}10^{-5} \text{ (90\% C.L.)}$$

~4x that for J/ψππ … expected for such a "molecule"?

[hep-ph/0310261] $\text{BES}_{\text{ISR}}: \ \Gamma_{ee}\mathcal{B}(X \to \pi^+\pi^- J/\psi) < 10 \text{ eV (90\% C.L.)}$

[CLEO Prelim.] $\text{CLEO}_{\text{ISR}}: \ \Gamma_{ee}\mathcal{B}(X \to \pi^+\pi^- J/\psi) < 7 \text{ eV (90\% C.L.)}$

not likely 1^{--}

[CLEO Prelim.] $(2J+1)\Gamma_{\gamma\gamma}\mathcal{B}(X \to \pi^+\pi^- J/\psi) < 17 \text{ eV (90\% C.L.)}$ ⇒ **not likely $0^{\pm+}$, $2^{\pm+}$**

Summary (of sorts)

New data, finished analyses, and renewed interest !!

"D" State (L=2) established in Υ system; agrees with LQCD

η_c' firmly established! $\Delta h_f'$ = 49 MeV to ~ 5% ; LQCD gives … ?

Several analyses confronting the color octet model

PV states finally observed in ψ' decay … Q_h/Q_{ee} ~ 1/50

Nature of ψ(3770) still a puzzle … more data coming SOON!

Very narrow X(3872) firmly established; many tests of J^{PC} done … inconclusive; $c\bar{c}$? $D\bar{D}^*$ molecule?

Interested … join QWG!

Thanks to all from BES, BaBar, Belle, CDF, CLEO and D0