Puzzle Pieces: Results on b and c Spectroscopy and Decay

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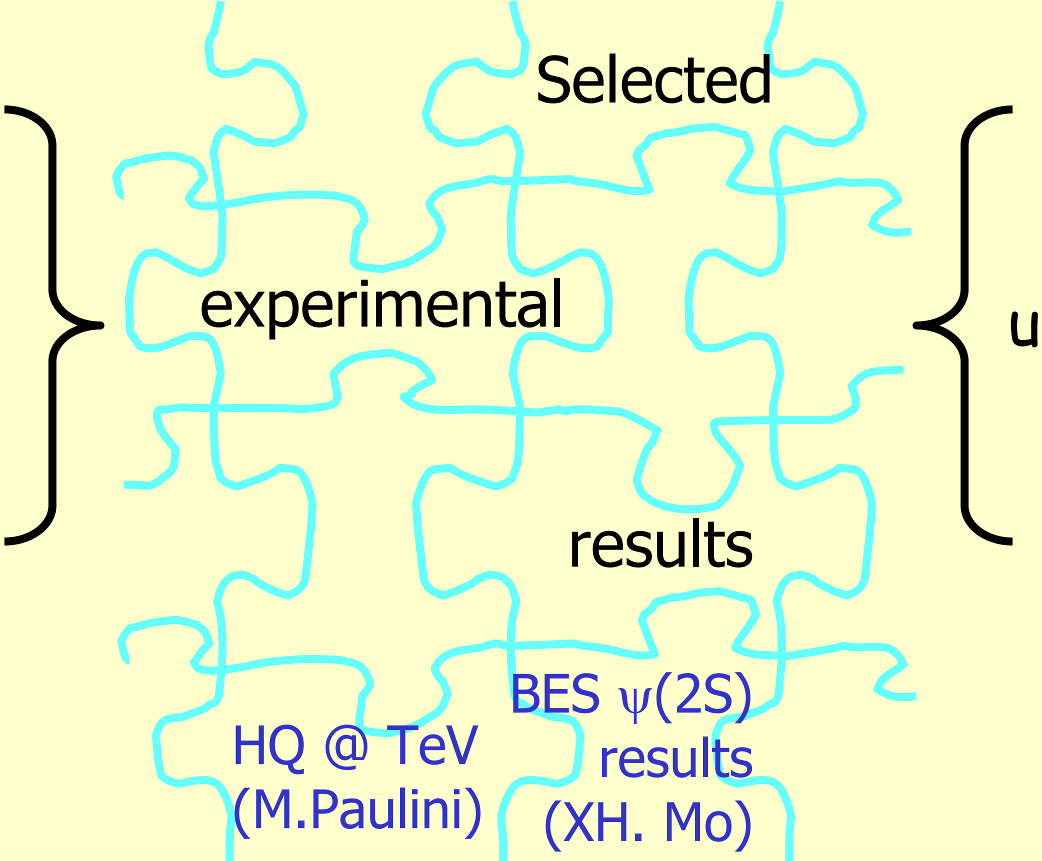
DAPHNE 2004

Heavy Quarkonia Puzzles



New / precision measurements

Selected experimental results

HQ @ TeV (M.Paulini)

BES ψ(2S) results (XH. Mo)

Key unanswered questions

Onia States

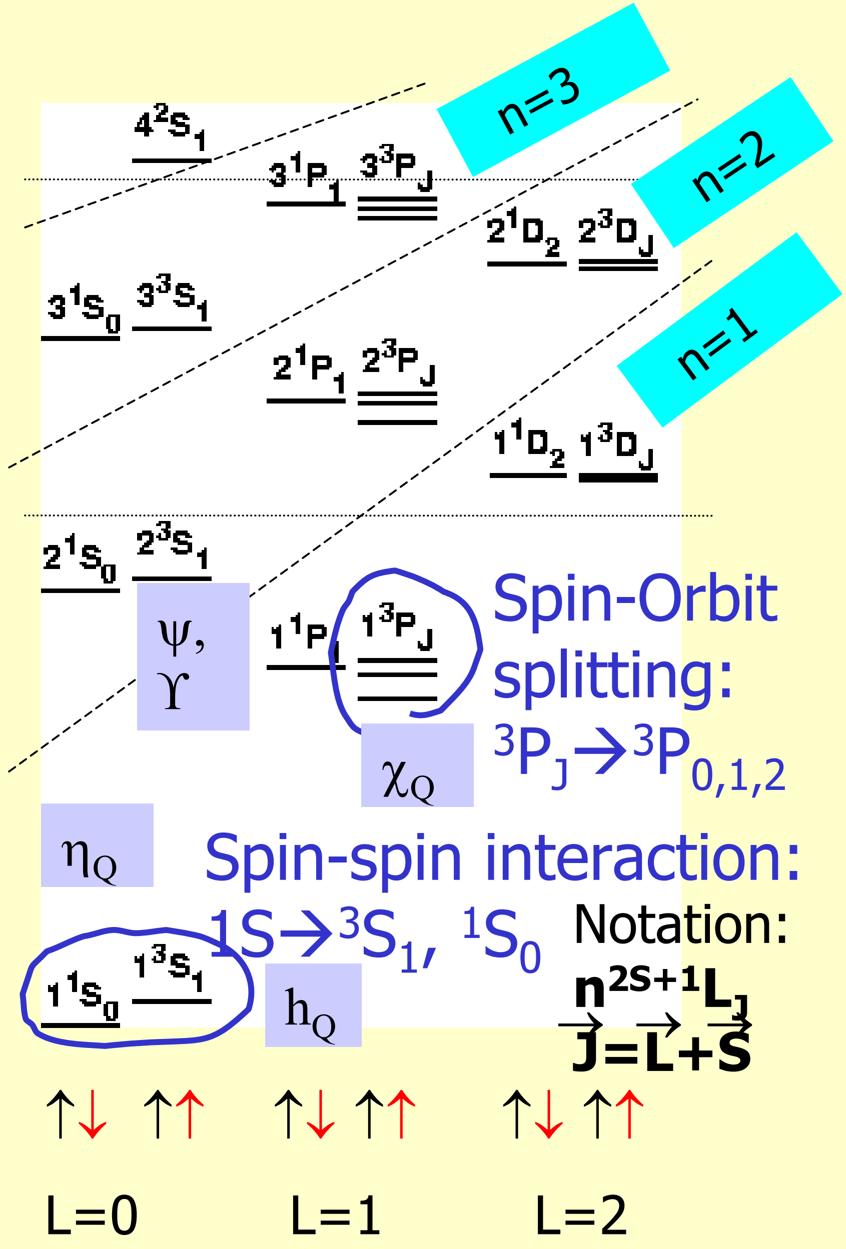
- Strongly bound $q\bar{q}$ states
- Non-relativistic QM applicable (Appelquist, Politzer)
  - QCD analog to positronium
  - Provide insight into QCD
- Low Q^2, non-perturbative

? **Masses**
? **Widths**
? **Production**
and decay dynamics
Partly discovery, partly precision measurements

$b\bar{b}$: 560MeV

$c\bar{c}$: 589MeV

e^+e^-:5×10^{-6}MeV



Spin-Orbit splitting: $^3P_J \rightarrow {}^3P_{0,1,2}$

Spin-spin interaction: $1S \rightarrow {}^3S_1$, $^1S_0$

Notation: $n^{2S+1}L_J$

$\vec{J}=\vec{L}+\vec{S}$

Two Theoretical Approaches

- Potential Model:
  Cf. hydrogen; Coulomb, $V_H(r) = - \alpha_{em}/r$

  Short distance,1g exch   long distance

  $V_{hQ}(r) = \; - (4/3)\, \alpha_s/r \; + \; k\, r$

- Lattice QCD (the only complete definition of QCD):
  recent breakthrough allows predictions at the % level; needs experimental data to verify that match this precision!

❖ **positronium** energy levels, spacing and decay rates
⇒ fine-tune **QED** parameters
quarkonium ⇒ **QCD**

Why Investigate Heavy Quarkonia?

Simplest strongly interacting systems

Fairly non-relativistic

Excellent place to study an important region of the Standard Model

Gain insight to underlying interaction, QCD

More convenient to handle experimentally than glueballs

Experimental Data

$\psi(3770)$ non-$D\bar{D}$ decays

X(3872)

$\Upsilon(1,2,3S)$ $B_{\mu\mu}$

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

Data samples

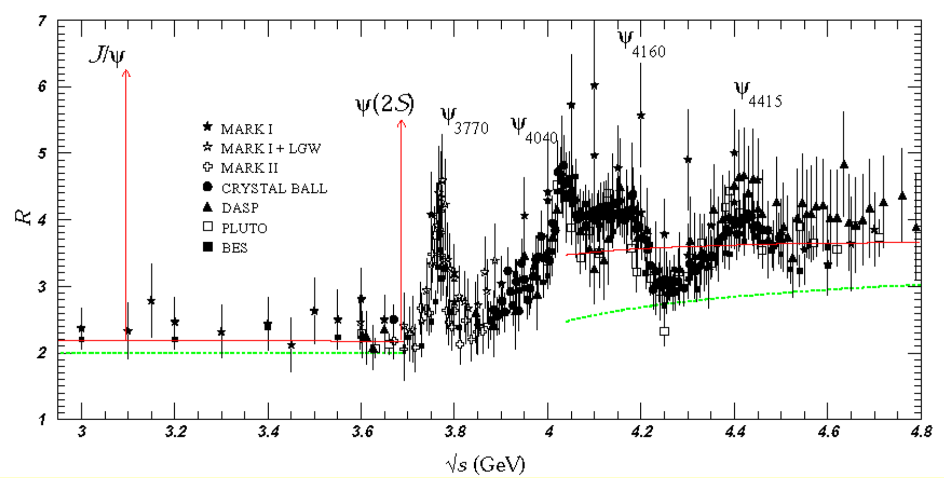
Transitions $\pi\pi,\omega,\eta,\pi^0,\gamma$

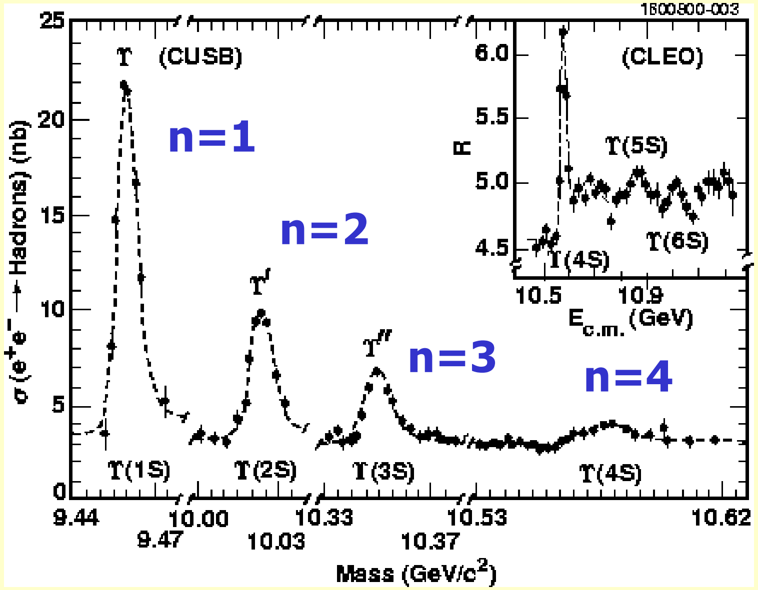
$J/\psi,\psi(2S)\rightarrow p\bar{p},\Lambda\bar{\Lambda}$

2body hadronic $\psi(2S)$ decays

$\eta_c{}'$

Producing quarkonia

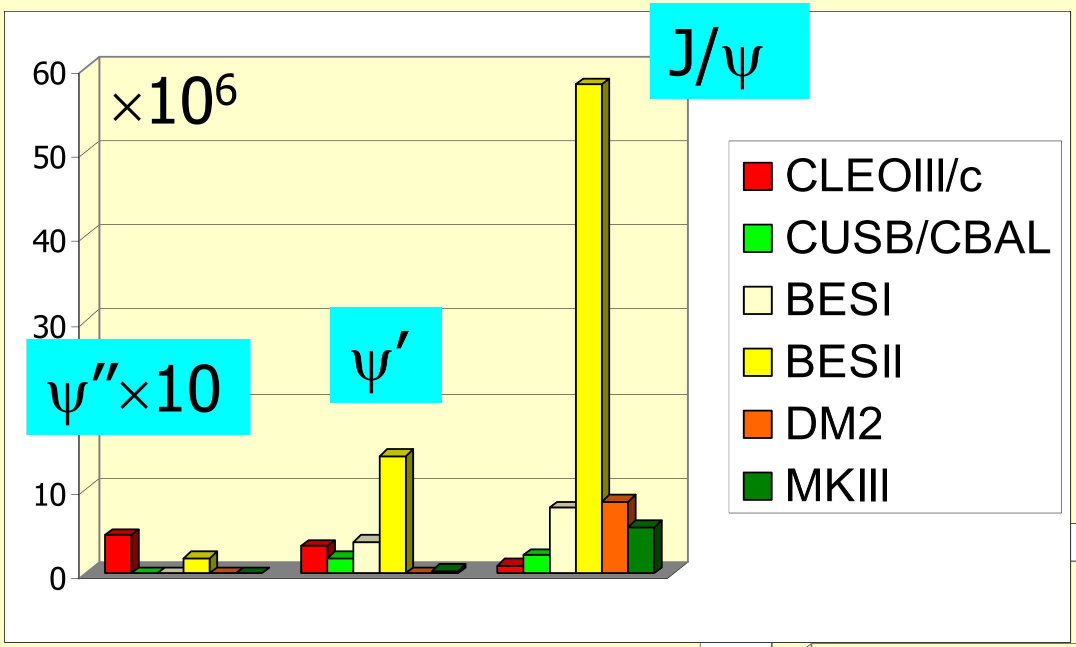


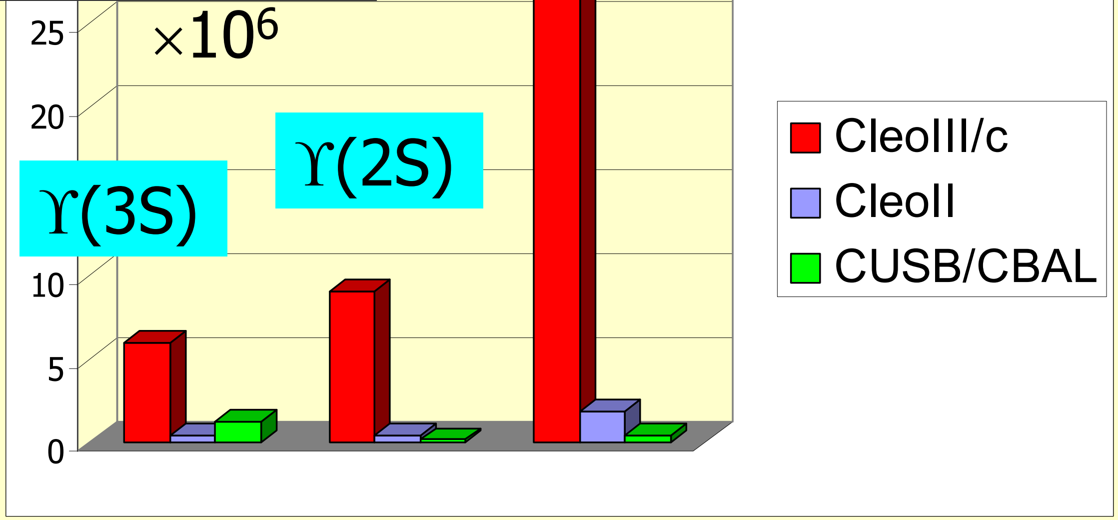


- **e^+e^- colliders,** $e^+e^- \rightarrow \gamma^* \rightarrow q\bar{q}$:
  can only directly produce states coupling to γ^*,
  i.e. n^3S_1 (J/ψ, ϒ) with a tiny admixture of n^3D_{1-}
- **two real photon collisions:** J=0,2 ($\eta_{[b,c]}$, $\chi_{[b,c][0,2]}$)
- **hadron colliders** any energy, no quantum number restrictions, but not as clean
- **transition** from higher up, e.g. $\psi(2S) \rightarrow \gamma\chi_{c0}$

Data Samples

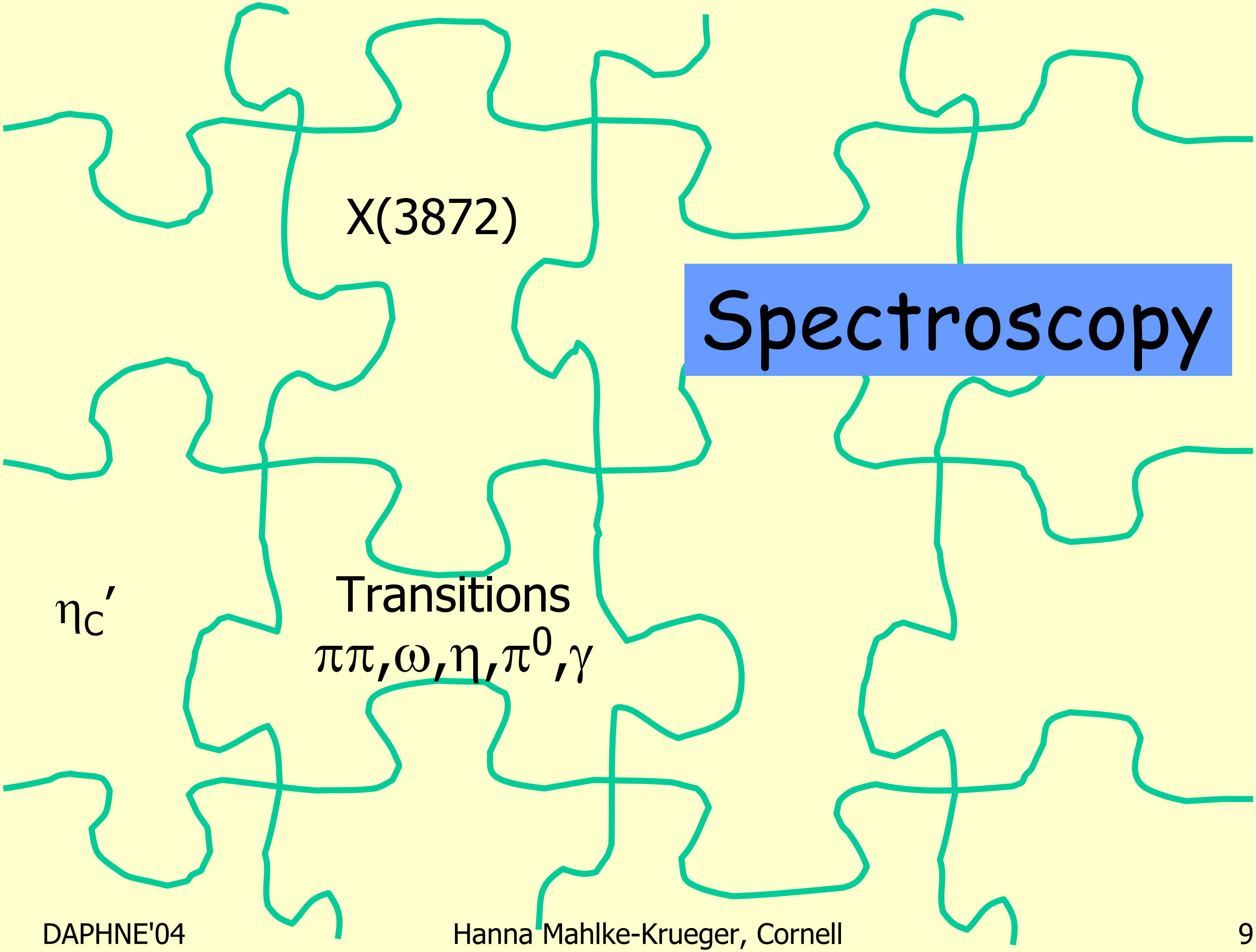
Datasets as of spring 2004





- Cross section falls as n increases
- Additional data samples for special purposes

Spectroscopy

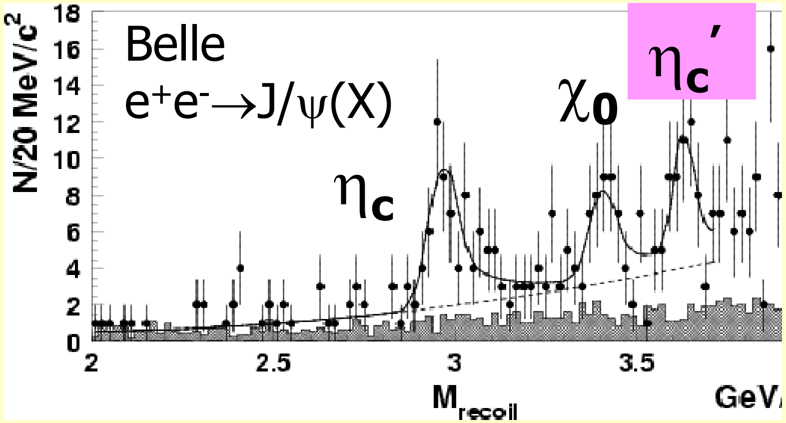


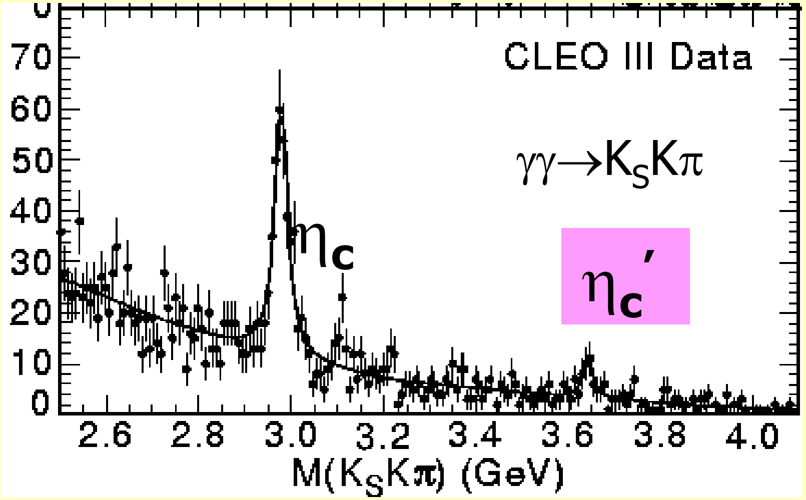
X(3872)

Transitions
$\pi\pi,\omega,\eta,\pi^0,\gamma$

η_c'

Current Experimental Information on η_c'





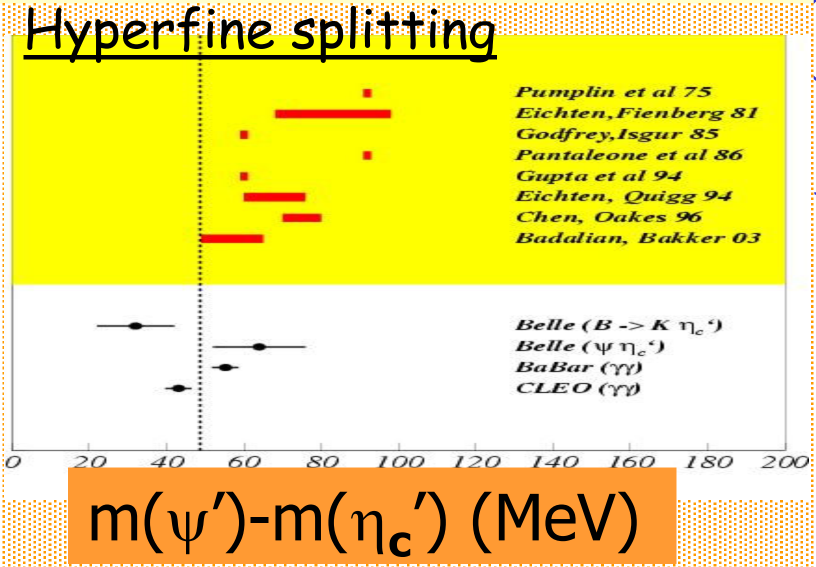
CBAL PRL48(1982)70, BaBar hep-ex/0311038,
Belle PRL89(2002)102001, PRL 89(2002)142001,
CLEO PRL 92(2004)142001

Recently observed in 3 different ways:

$B \to K\ (K_S K^+ \pi^-)$ Belle
$e^+e^- \to J/\psi(X)$ (Belle)
$\gamma\gamma \to K_S K\pi$ (CLEO, BaBar)

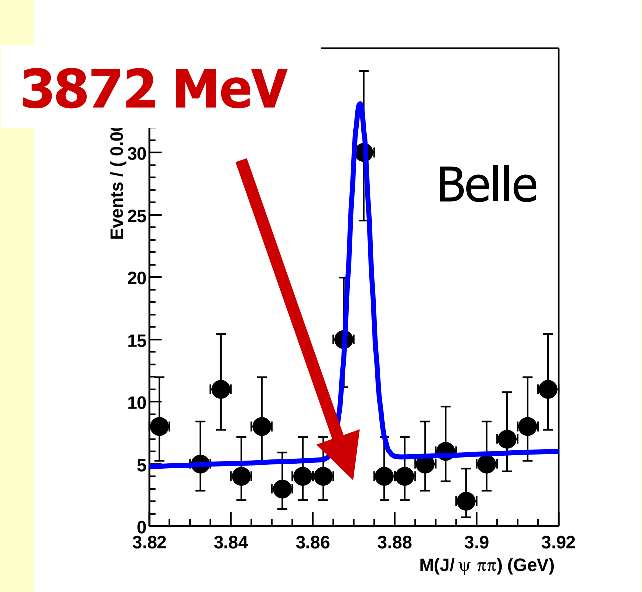
$m(\eta_c') \approx$ 3638 MeV

Old result ($\psi \to \eta_c' X$, m=3594) directly ruled out by CLEO.



New 2S splitting about half as big, ~48MeV $\Rightarrow \Delta m(2S)/\ \Delta m(1S) \approx 0.5$.
Theory needs to accommodate this!

X(3872) – a $c\bar{c}$ state?



Peak in $B^\pm \to K^\pm(\pi^+\pi^- J/\psi)$,
m = (3872.0 ±0.6±0.5) MeV,
Γ < 2.3 MeV (90%CL) Belle

Also in $p\bar{p} \to (\pi^+\pi^- J/\psi)X$:
m = (3871.3 ±0.7±0.4) MeV CDF
m = (3871.8 ±3.1±3.0) MeV D0

Belle PRL91:262001,2003, hep-ex/0405014; CDF hep-ex/0312021;
D0 hep-ex/0405004; BaBar hep-ex/0402025, BES hep-ph/0310261

What is its nature? Study production and decay mechanisms!

- **Charmonium state?**

$1^3D_{2,3}=2^{--},3^{--}$? $\Gamma(X\to\gamma\chi_{c1,2})/\Gamma(X\to\pi\pi J/\psi)>2$
See <0.89/1.1 (Belle)

1^{++} ? $\Gamma(X\to\gamma J/\psi)/\Gamma(X\to\pi\pi J/\psi)>1$
See 0.4 (Belle)

1^{--} ? Look in ISR production (next slide)

- **DD* molecule?**

$m_D+m_{D^*}$ = 3871.5±0.5 MeV

- Look for $X\to D(D\pi)$

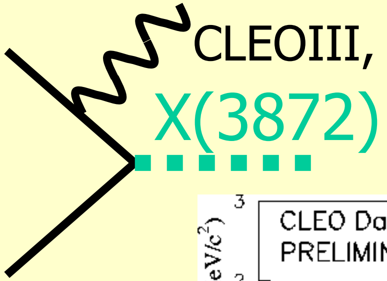
$D^0\bar{D}^0\pi^0$ BR's< $\sim 5\times10^{-5}$ (Belle)
not inconsistent

- Look for $X\to \pi^0\pi^0 J/\psi$
  $\to$ $\rho J/\psi$ component?

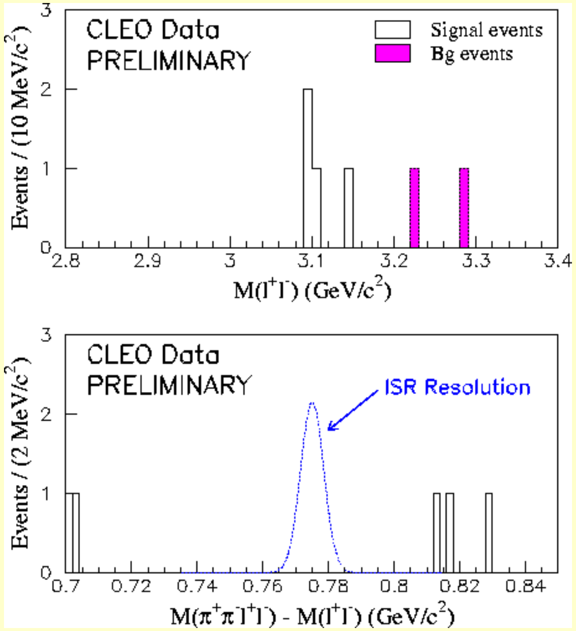
- **Exotic state?**

CLEO results on X(3872)

CLEOIII, $15fb^{-1}$, $\sqrt{s}$=9.46…11.30GeV, $X(3872)\rightarrow\pi^+\pi^-J/\psi$, $J/\psi\rightarrow\ell^+\ell^-$



ISR ($J^{PC}=1^{--}$)



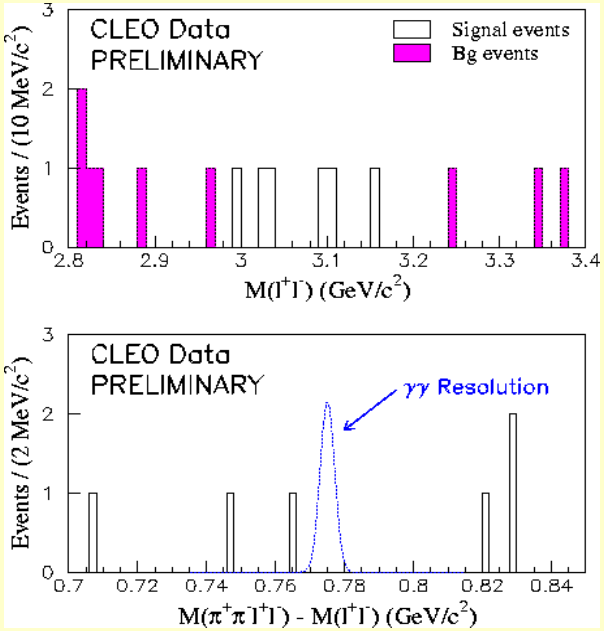
CLEO prelim: Γ_{ee} $B(X\rightarrow\pi^+\pi^-J/\psi) < 6.8eV$

(or, <1/100×ψ(2S) production rate in ISR for same $B_{\pi\pi J/\psi}$)

BES: Γ_{ee} $B(X\rightarrow\pi^+\pi^-J/\psi) < 10eV$

($22.3pb^{-1}$ at $\sqrt{s}$=4.03GeV)

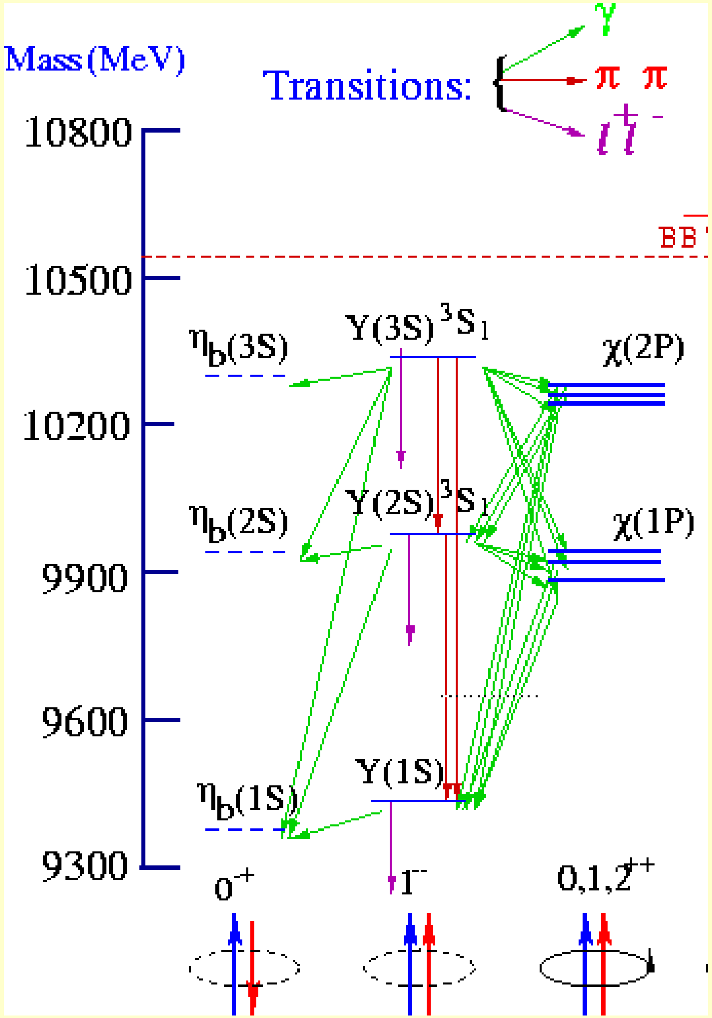
2γ ($J^{PC}=0^{\pm+}, 2^{\pm+}, \ldots$)



CLEO prelim:
$(2J+1)\Gamma_{\gamma\gamma}$ $B(X\rightarrow\pi^-\pi^+J/\psi) < 16.7eV$

(or, <1/10 the η_c production rate in γγ)

Transition Options



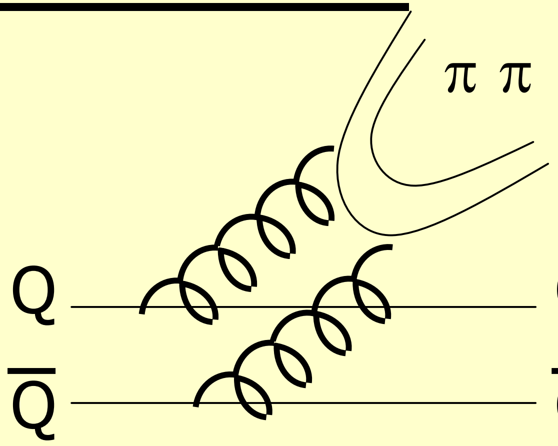
- Hadronic:
  - $\pi^0, \eta, \omega, \pi^+\pi^-$ - no kaons; splitting too small
- Photonic:
  - E1: $\Delta L=1, \Delta S=0$
  - M1: $\Delta L=0, \Delta L=1$

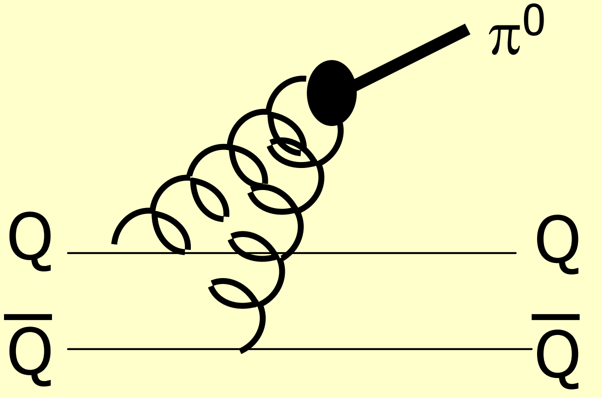
Hadronic Transitions

No charge involved:

- two charged pions
  or
- neutral particles
  - $\pi^0 \pi^0$
  - Single π^0 transitions isospin **suppressed**
  - η, ω are “rare”

Soft process.



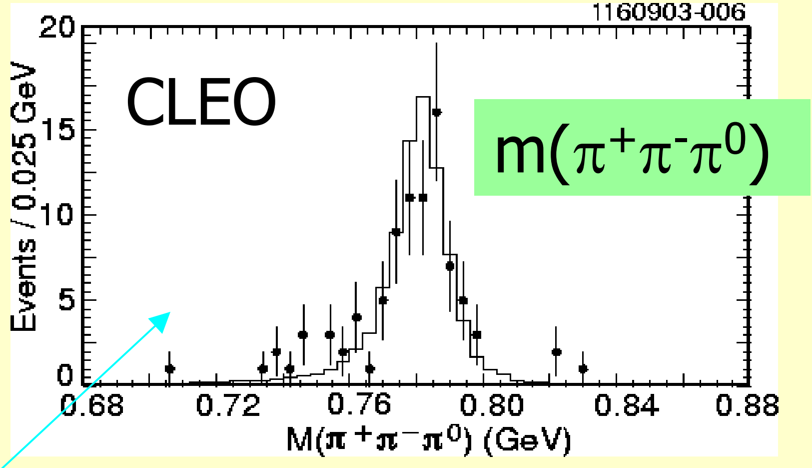


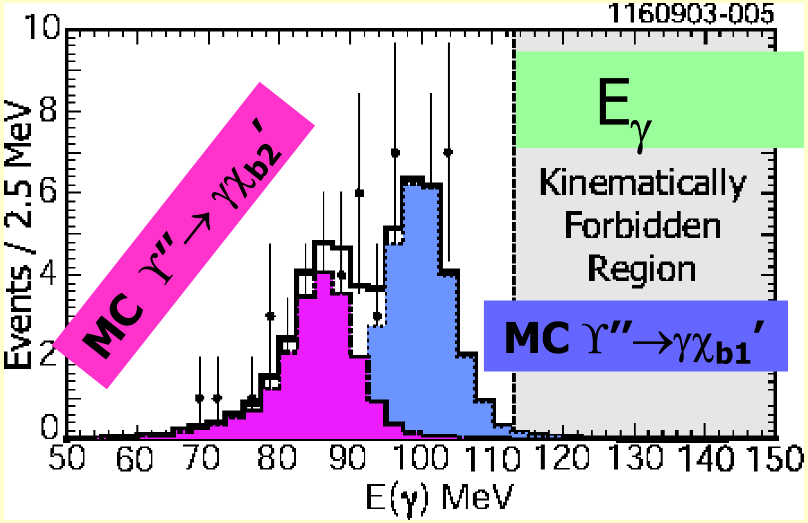
hep-ex/0311043, acc by PRL

$\chi_{bJ}' \rightarrow \omega\Upsilon(1S)$: 1st non-$\pi$ hadronic transition in bb

$\Upsilon(3S) \rightarrow \pi\pi\pi\Upsilon(1S)+X$:

- X is photon, $\Upsilon(1S) \rightarrow \ell^+\ell^-$
  $\pi^+\pi^-\pi^0$ distrib^n peaks at ω
- Fit for $\Upsilon(3S) \rightarrow \gamma\chi_{bJ}'$, $\chi_{bJ}' \rightarrow \omega\Upsilon(1S)$, J=1,2





- $B(\chi_{b1}' \rightarrow \omega\Upsilon(1S)) = (1.63\,{}^{+0.32}_{-0.31}\,{}^{+0.11}_{-0.15})\%$
- $B(\chi_{b2}' \rightarrow \omega\Upsilon(1S)) = (1.10\,{}^{+0.35}_{-0.28}\,{}^{+0.16}_{-0.10})\%$

1. substantial, 2. ~equal

Voloshin hep-ph/0304165:
$r_{2/1}=1.3\pm0.3$

$\psi(2S) \to \gamma\gamma J/\psi$

$B(\psi' \to \pi^0 J/\psi) = (1.43 \pm 0.14 \pm 0.13) \times 10^{-3}$

14% relative

$B(\psi' \to \eta J/\psi) = (2.98 \pm 0.09 \pm 0.23)\%$

8% relative

- Predictions for
  $B(\psi' \to \pi^0 J/\psi)/B(\psi' \to \eta J/\psi)$,
  $B(\psi' \to \eta J/\psi)/B(\Upsilon(2S) \to \eta\Upsilon)$,
  $B(\psi' \to \eta J/\psi)/B(\Upsilon(3S) \to \eta\Upsilon)$,

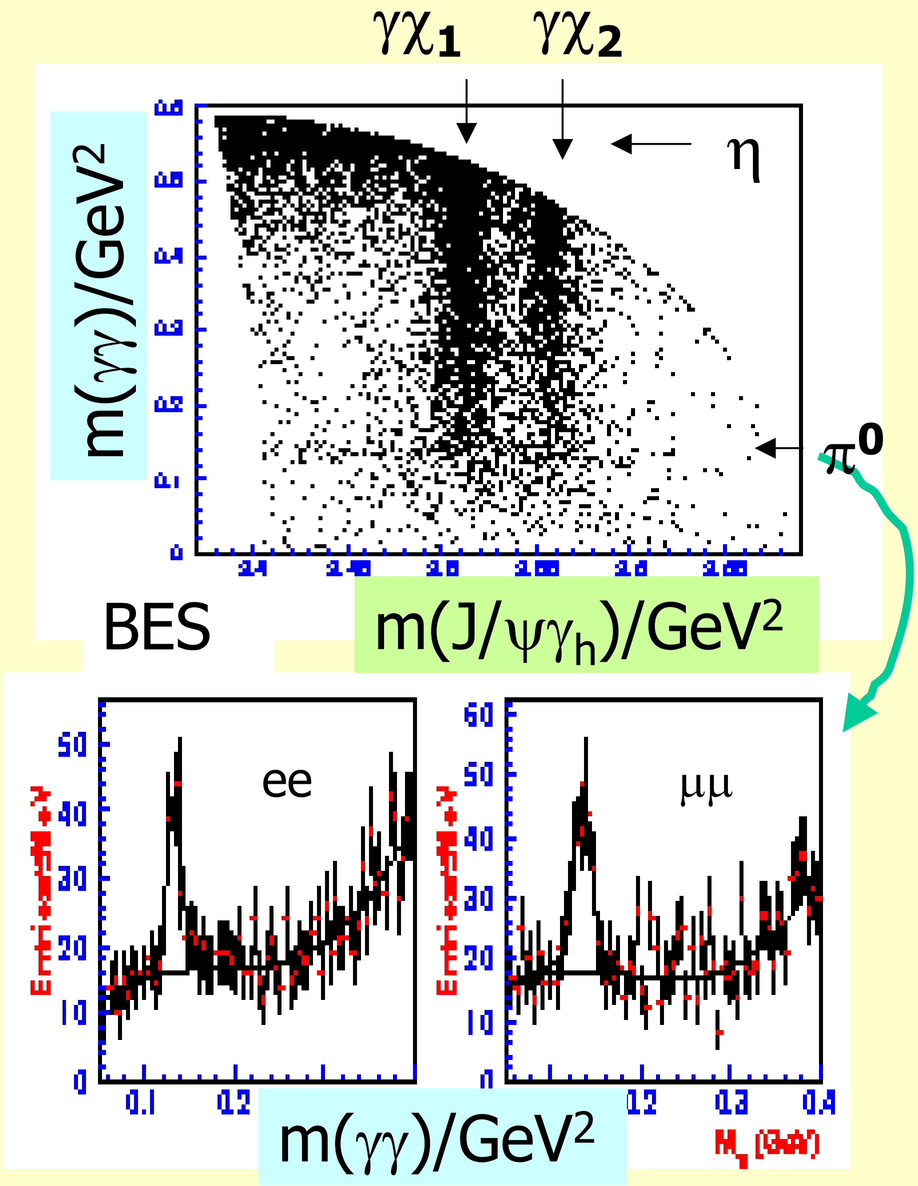
  … see Prof. Mo’s talk

- Neutral **di**pion transitions in hep-ex/0404020…

$\Upsilon(3S) \to \pi^0/\eta\ell^+\ell^-, \pi^0/\eta \to \gamma\gamma$?

Not seen, UL @ ‰ level

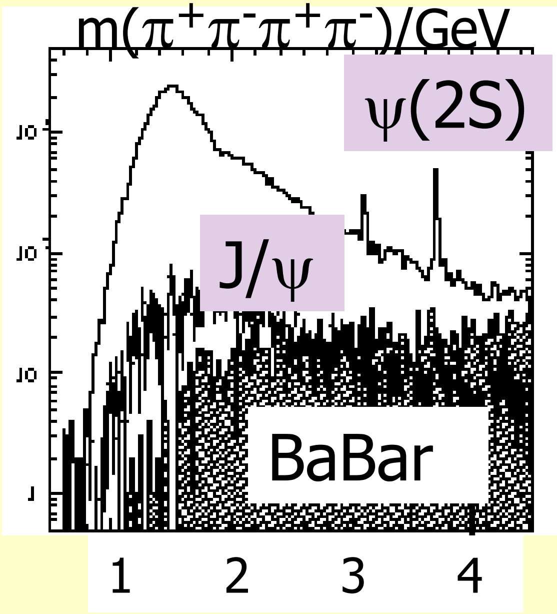
hep-ex/0403023



DAPHNE'04
06/08/04

Hanna Mahlke-Krueger, Cornell

Do we understand $\psi(2S) \to \pi\pi J/\psi$?



Charged dipion transitions often used as normalizing mode; single most precise measurement: (32.3±1.4)% (BES '02)

Expect $B(\psi(2S)\to\pi^0\pi^0 J/\psi)/B(\psi(2S)\to\pi^+\pi^- J/\psi)=0.5$ from isospin. Phase space correction: a few %. Others??

- Experiment: (PDG: $B(\psi(2S)\to\pi^0\pi^0 J/\psi) = (18.9\pm1.1)\%$)

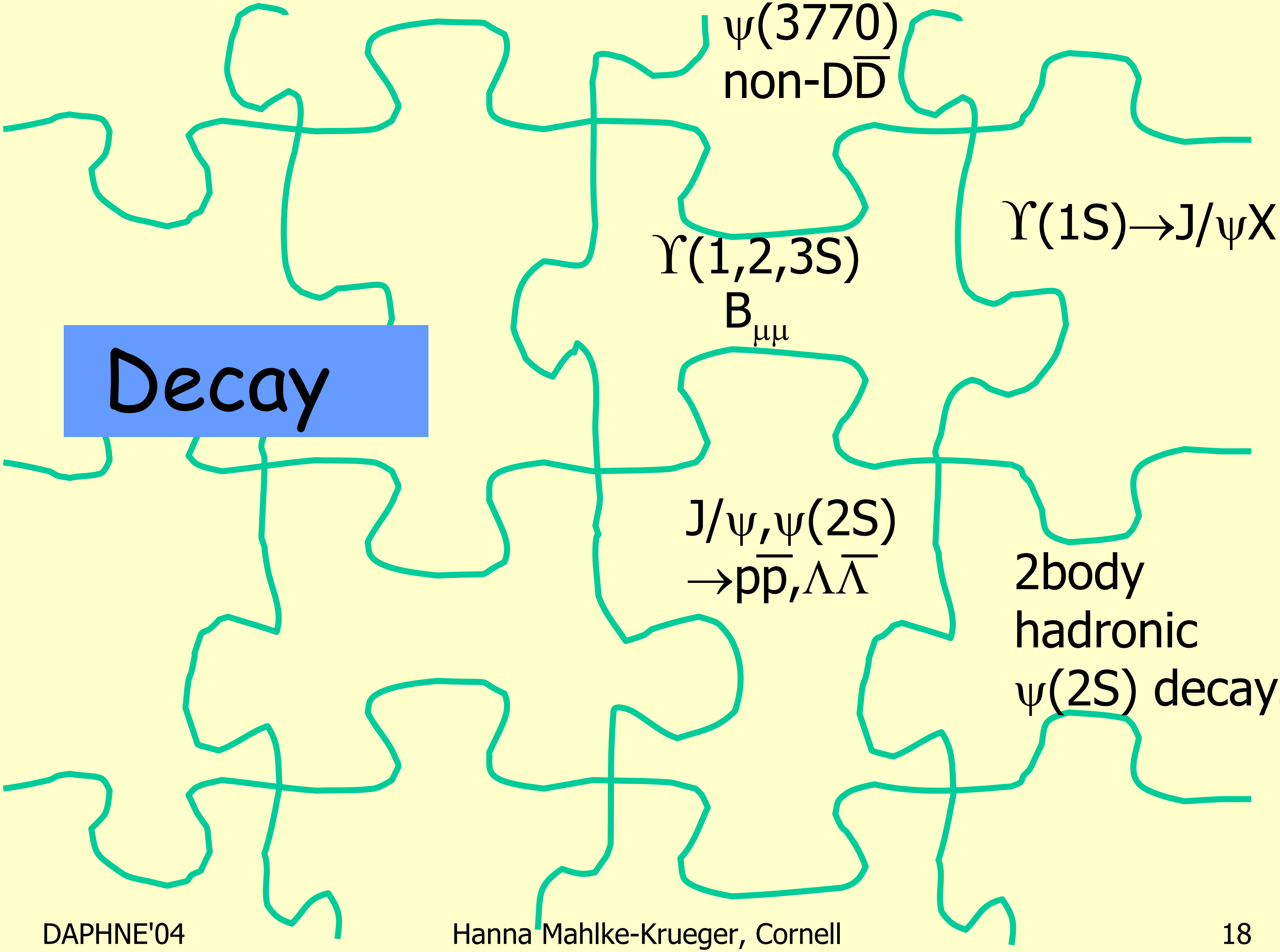
  $B(\psi(2S)\to\pi^0\pi^0 J/\psi)/B(\psi(2S)\to\pi^+\pi^- J/\psi)=0.570\pm0.009\pm0.026$

  4M $\psi(2S)$ BESI, hep-ex/0404020

  $B(\psi(2S)\to\pi^+\pi^- J/\psi)=0.361\pm0.015\pm0.037$

  BaBar, radiative returns, 89fb^{-1} ~$\Upsilon(4S)$ data, hep-ex/0312063

➢ Neutral BR too high? Charged BR too low? Expectation off?



Decay

$\psi(3770)$ non-$D\overline{D}$

$\Upsilon(1S) \to J/\psi X$

$\Upsilon(1,2,3S)$ $B_{\mu\mu}$

$J/\psi, \psi(2S) \to p\overline{p}, \Lambda\overline{\Lambda}$

2body hadronic $\psi(2S)$ decays

Are there $\psi(3770)$ non-$D\bar{D}$ decays?

$m(\psi(3770)) > 2m(D)$

$\sigma(\psi'' \rightarrow D\bar{D}) = 5.0 \pm 0.5$nb

$< \sigma(\psi'' \rightarrow \text{hadrons}) = 7.9 \pm 0.6$nb

80%

- Can the deficit be confirmed?
  - BES *single* tag Moriond 04: $\sigma(\psi'' \rightarrow D\bar{D}) = 5.78 \pm 0.11 \pm 0.38$ nb
  - CLEO-c prelim *double* tag: $\sigma(\psi'' \rightarrow DD) = 6.51 \pm 0.44 \pm 0.39$ nb
  - Modern $\sigma(\psi'' \rightarrow \text{hadrons})$ would be good…
- Where would a 20% deficit of Γ_{tot}=24MeV show up?

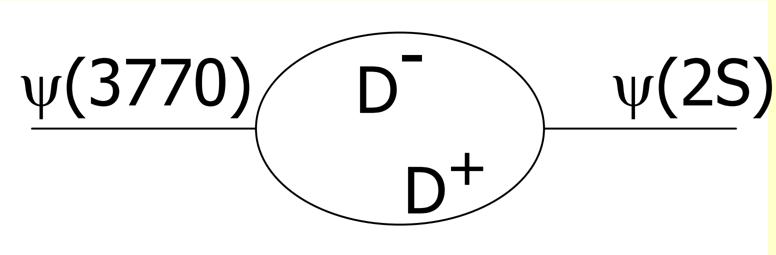
  Rosner: rad decays at most 600 keV, $J/\psi\pi\pi$ 100keV.

Does $\psi(2S) \leftrightarrow \psi(3770)$ mixing happen?

Do modes expected from J/ψ that are rare on $\psi(2S)$ mix away?

Understanding $\psi(2S)$ will help with $\psi(3770)$!

(Don't expect BIG rates.)



MarkIII PRL 60(1988)89 CBAL CALT-68-1150 (1984), MarkII SLAC-219 (1979)

$\Upsilon(1,2,3S)$ $B_{\mu\mu}$

Total decay width:

$$\underline{\Gamma_{tot} = \Gamma_{had} + \Gamma_{ee} + \Gamma_{\mu\mu} + \Gamma_{\tau\tau}?}$$

Total widths:

1S total widths ~keV, big portions not accounted for by exclusive decays measured thus far

Relative precision on total width:

$\Upsilon[',"]$: 3.4%, 16.9%, 13.3%, $\psi[',"]$: 5.7%, 7.9%, 11.4%

Leptonic decay widths:

confront LQCD *percent level* predictions

test lepton universality

compare $\Gamma_{\ell\ell}$ relative to $\Gamma_{ggg,\gamma gg,\, q\bar{q}}$

narrow resonances: $\Gamma_{tot} = \Gamma_{\ell\ell} / B_{\ell\ell}$, or $\Gamma_{\mathbf{ee}}/\mathbf{B}_{\mu\mu}$

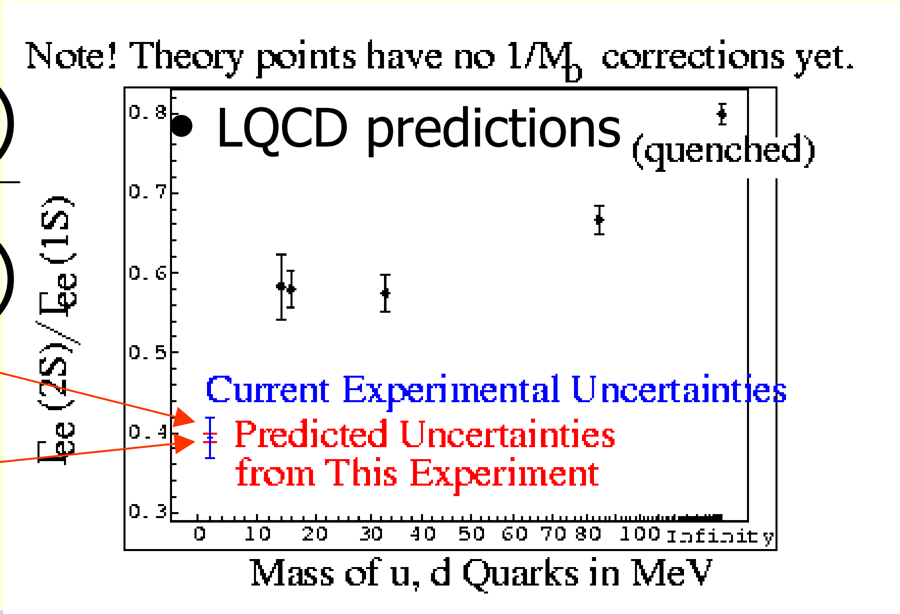
$\psi(2S)$ scan data published last year (BES)

$\Upsilon(1,2,3S)$: Γ_{ee} under study; $B_{\mu\mu}$ preliminary results (CLEO)

Leptonic Υ(1,2,3S) Width Γ_{ee}

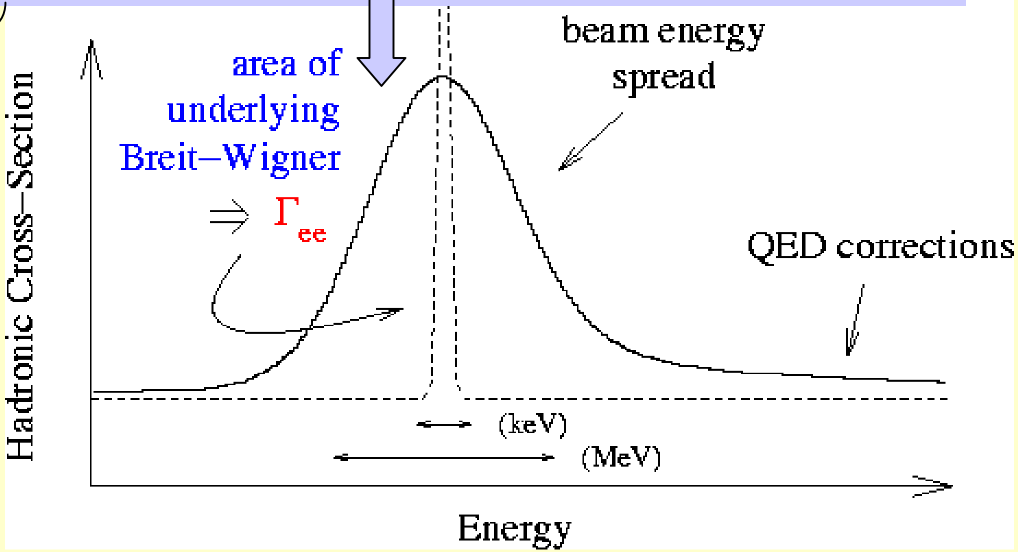
$$\frac{\Gamma_{ee}(2S)}{\Gamma_{ee}(1S)}$$

!



Strategy:

$$\Gamma\left(Y \to e^+e^-\right) = \frac{M_Y^2}{6\pi^2} \underbrace{\frac{\Gamma_{total}}{\Gamma_{hadrons}}}_{\text{External input}} \int dEnergy \;\; \sigma\left(e^+e^- \to Y \to hadrons\right)$$

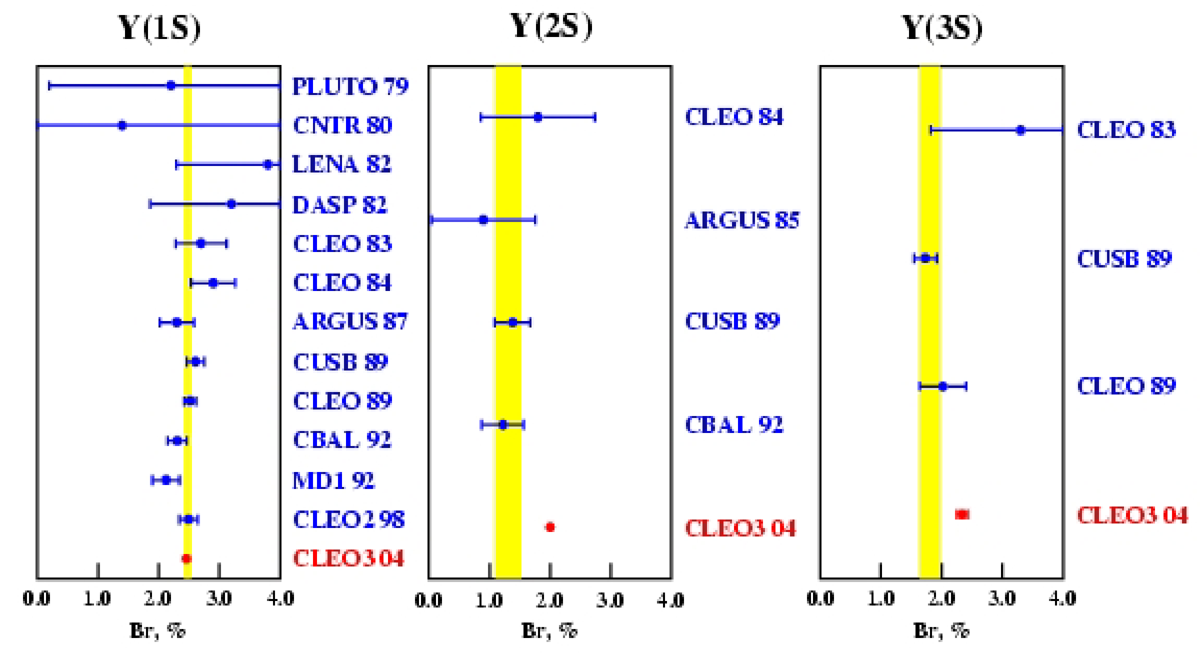


Hope to improve from 2/4/9% → 2-3%.

$B(\Upsilon(1,2,3S)\rightarrow\mu^+\mu^-)$ Results

	$B_{\mu\mu}$ in %		Γ_{tot} in keV	
	CLEO preliminary	PDG	CLEO preliminary	PDG
$\Upsilon(1S)$	2.46 ± 0.02 ±0.05	2.48 ± 0.06	53.4 ± 1.5	52.5 ± 1.8
$\Upsilon(2S)$	2.00 ± 0.03 ±0.05	1.31 ± 0.21	29.5 ± 1.4	44 ± 7
$\Upsilon(3S)$	2.34 ± 0.07 ±0.05	1.81 ± 0.17	20.7 ± 2.1	26.3 ± 3.5

- Desired precision reached (LQCD!)
- $B_{\mu\mu}(\Upsilon(2,3S))$ larger than previous results → lower Γ_{tot}



$J/\psi\rightarrow X_b\bar{X}_b$, $X=p,\Lambda$

BESII, 58M J/ψ:

$B(J/\psi\rightarrow p\bar{p})=$
$(2.26 \pm 0.01 \pm 0.14)\times10^{-3}$

Angular distribution:

$dN/d\cos\theta_X=1+\alpha\cos^2\theta_X$

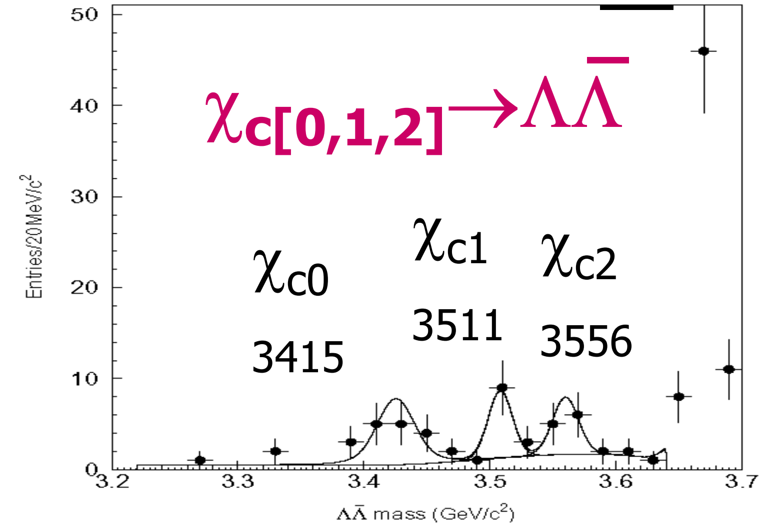
α_{Proton}	α_Λ	
1.0	1.0	Neglect m_X and m_q [1]
0.46	0.32	Include m_X [2]
0.66	0.51	Include m_X and m_q [3]
0.676±0.55	0.52 ±0.35	Experiment [4]

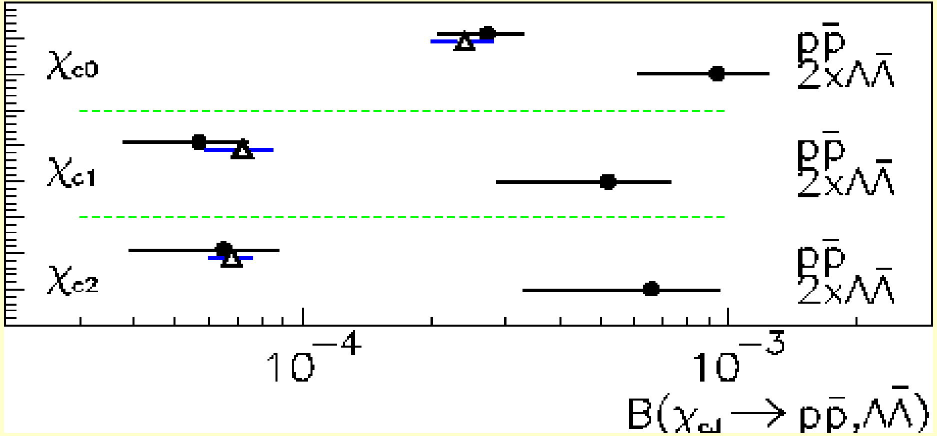
[1] Brodsky, Lepage, PRD24(1981)2848
[2] Claudson et al., PRD25(1982)1345
[3] Carimalo, IntJModPhysA2(1987)245
[4] hep-ex/0402034, PLB424(1998)213

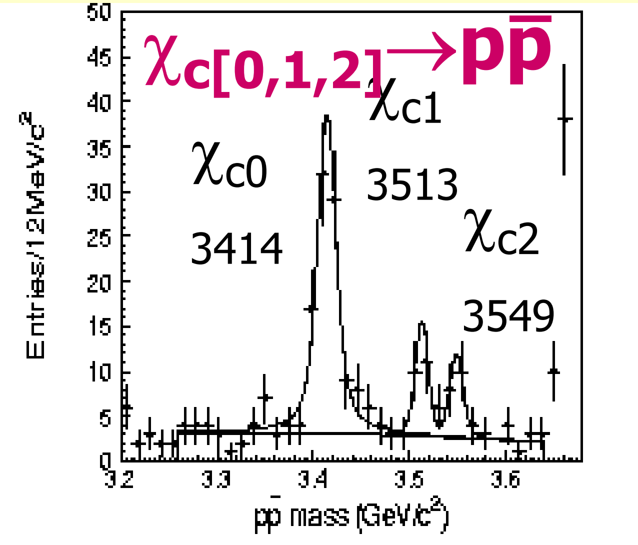
$\chi_{c[0,1,2]} \rightarrow p\bar{p}, \Lambda\bar{\Lambda}$ from $\psi(2S) \rightarrow \gamma\chi_{CJ}$

- COM needed to describe P-wave quarkonium decays $\chi_c \rightarrow p\bar{p}$
- Based on $\chi_{c[0,1,2]} \rightarrow p\bar{p}$ meas't, generalized to $\Lambda\Lambda$, expect BR($\chi_{cJ} \rightarrow \Lambda\Lambda / \chi_{cJ} \rightarrow p\bar{p}$) =1/2 J=1,2
- $\chi_{c[0,1,2]} \rightarrow \Lambda\bar{\Lambda}$ see excess BESII: $\chi_{c[0,1,2]} \rightarrow p\bar{p}$, within 1σ of previous measurement and $p\bar{p}$ $\rightarrow \chi_{cJ} \rightarrow \gamma J/\psi$: confirm excess

hep-ex/0401011 & hep-ex/0304012, BESII

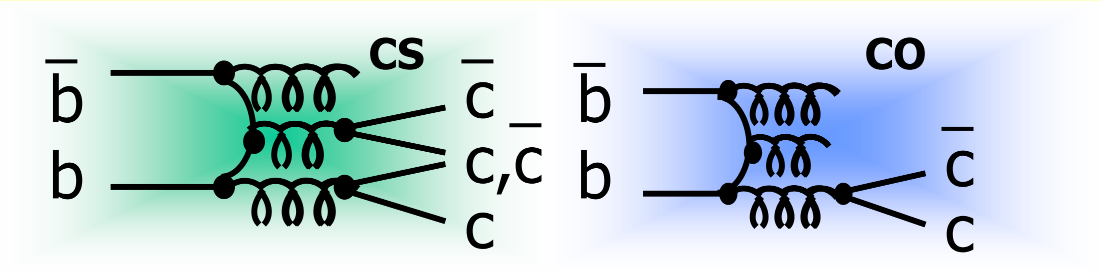






$\Upsilon(1S)\rightarrow J/\psi X$

CDF $p\bar{p} \rightarrow J/\psi, \psi(2S)X$ rates ⇒ **color octet mechanism**: $c\bar{c}$ in CO, become CS by radiating off a soft gluon. Problems with other data…

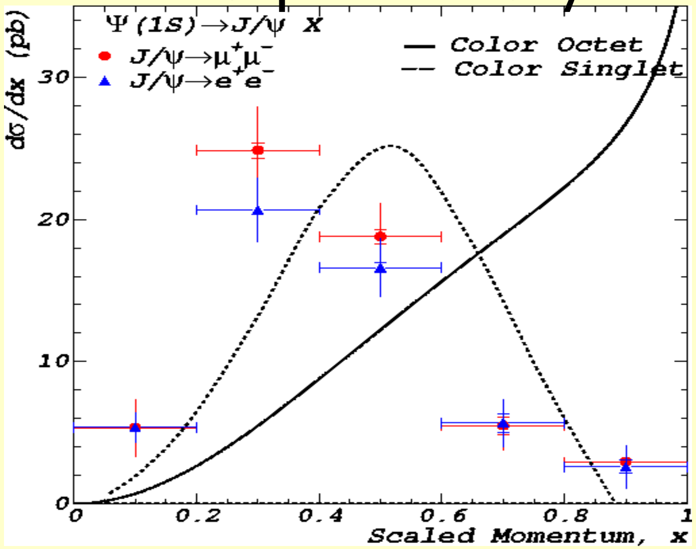


More information needed to distinguish production mechanisms.

- $\Upsilon(1S)\rightarrow J/\psi X$ is gluon rich env^t; CO preferred
- **Example: x spectrum.**

  CO peaks near x=1; modifications due to multiple soft g emission

CLEO preliminary



scaled J/ψ momentum x; $\overline{q\bar{q}}$ and continuum subtracted (use $\Upsilon(4S)$ as continuum)

Charmonium production in $\Upsilon(1S)$ decays

$\sigma(e+e- \rightarrow q\bar{q} \rightarrow J/\psi+X)=\ldots$

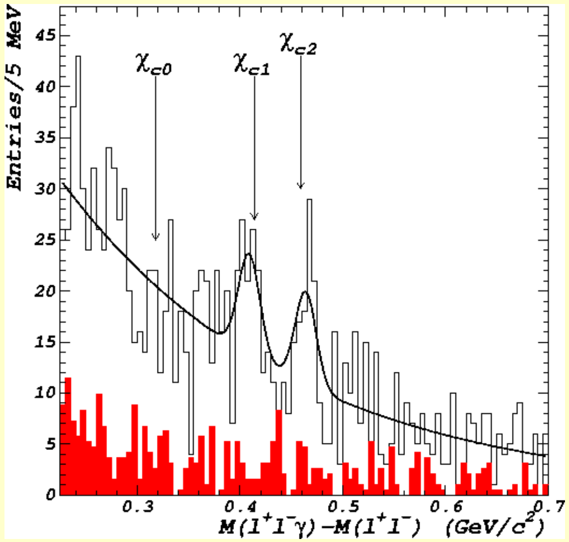
…(1.47±0.10±0.13) pb (Belle)
…(2.52±0.21±0.21) pb (BaBar)
…(1.9±0.2(stat)) pb (CLEO prelim)

$B(\Upsilon(1S)\rightarrow J/\psi+X) = (6.4\pm0.4\pm0.6)\times10^{-4}$

CS: 5.9×10^{-4}, CO: 6.2×10^{-4}

- 90% is ggg, $gg\gamma$
- Includes feed-down from $\Upsilon(1S) \rightarrow \psi(2S),\chi_{c0,1,2}+Y \rightarrow J/\psi+X+Y$.
  Identify through
  $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$, $\chi_{cJ} \rightarrow \gamma J/\psi$

CLEO preliminary

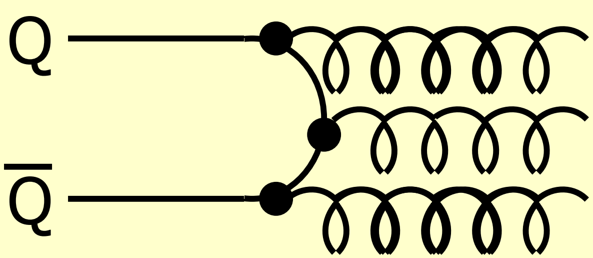


No clear conclusion on CS vs CO possible so far.

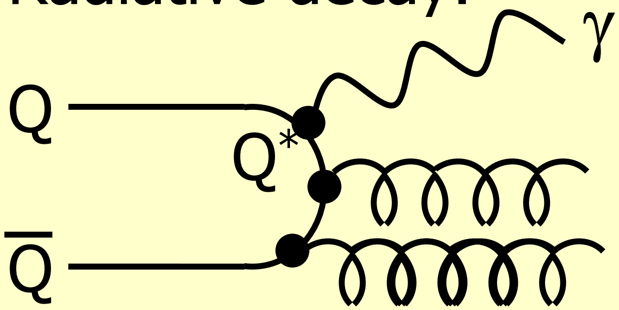
2body
hadronic
decays

$Q\bar{Q}$ decays into light hadrons

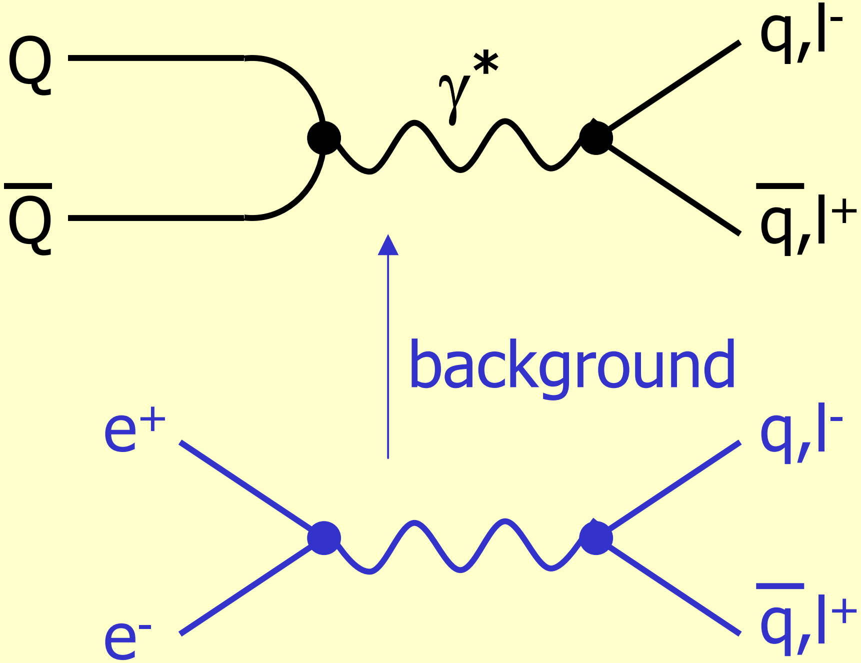
Annihilation into 3g:



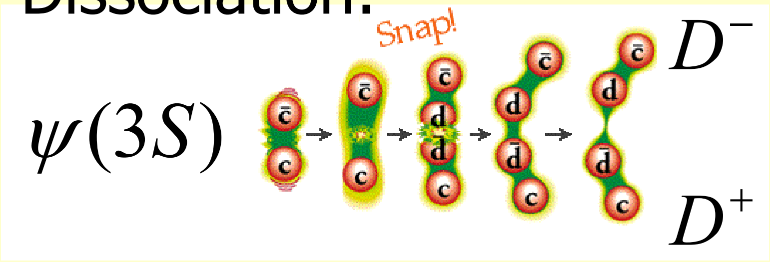
Radiative decay:



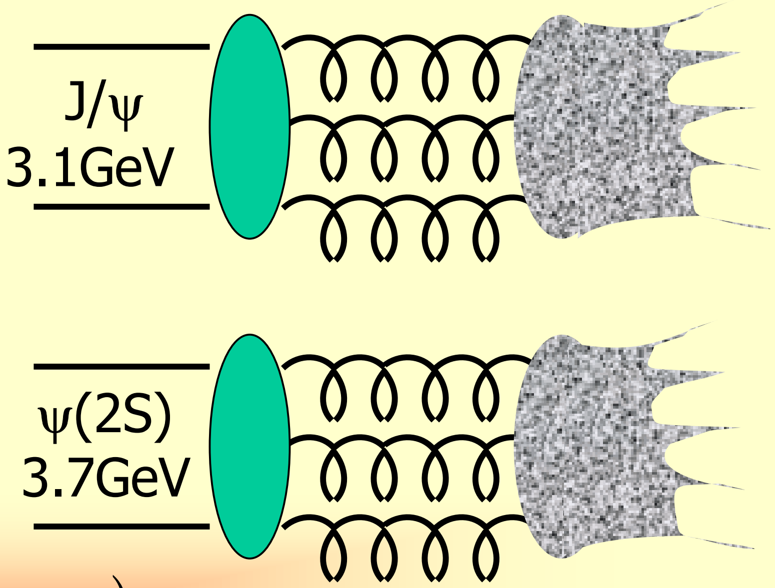
Annihilation into a photon:



Dissociation:



"The ~~14~~ 12% rule"



If mechanism is $c\bar{c}$ annihilation
$\Rightarrow$ decay rate ~ $|\Psi(0)|^2$
Compare with e^+e^- production:

$$Q_h = \frac{B(\psi(2S) \to H)}{B(J/\psi \to H)} = \frac{B(\psi(2S) \to e^+e^-)}{B(J/\psi \to e^+e^-)} \approx (12.3 \pm 0.9)\%$$

Complications (and there are more):

Powers of α_S at $m_{J/\psi}$, $m_{\psi(2S)}$ 0.845 hep-ph/09910406
Form factor E_{CM} dependence? $3.686^2/3.097^2=1.4$
Non-relativistic corrections
Interference with continuum Prof. Mo's talk
Only for $c\bar{c}\to\gamma^*$, not $c\bar{c}\to ggg$? (Gerard/Weyers)

Compliance within a factor of two: "agreement"

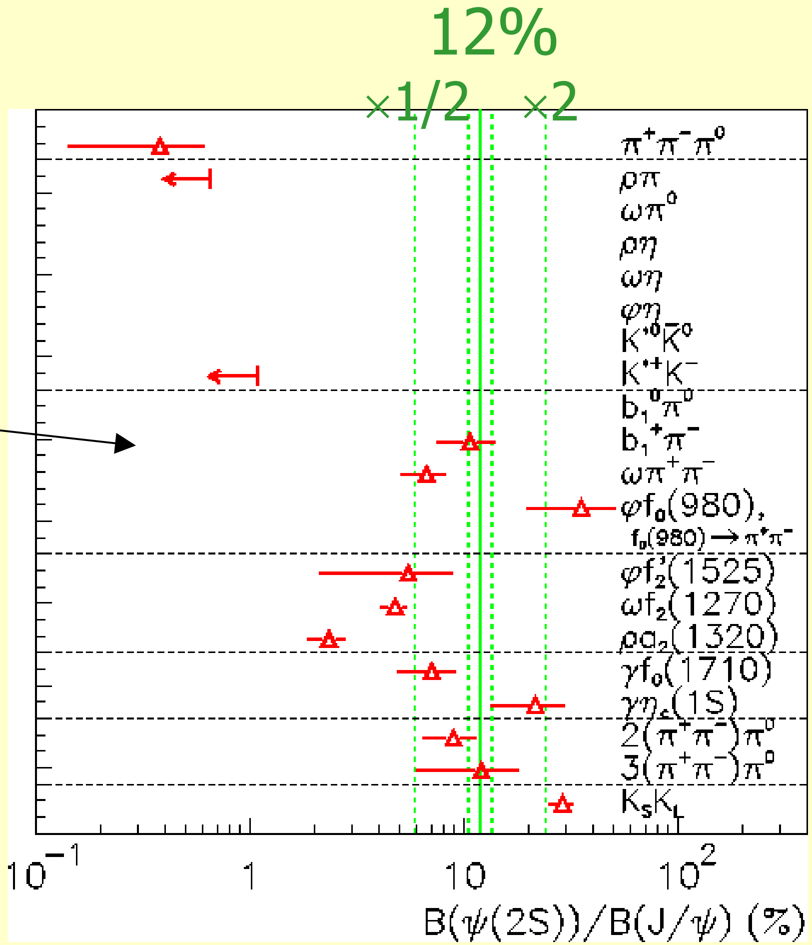
Two-body hadronic ψ(2S) decays

- ψ(2S) BR's: Not many are precisely measured
- ψ(2S), 12% rule: Nail down systematic deviation of certain channels?

Experimentally, situation is unclear

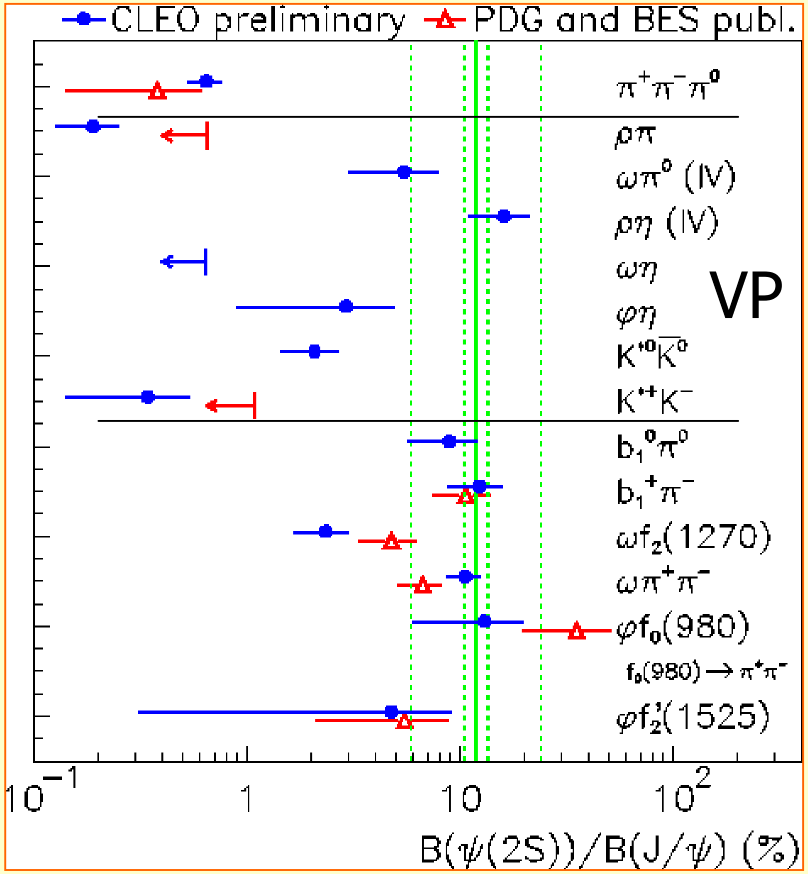
Theoretically, even more than unclear: Add'l effects in J/ψ? ψ(2S)? Expectation?

- Good understanding of continuum background and impact of interference is crucial!



Branching Fraction Ratio: $\psi(2S)/J/\psi$

- VP final states + some others
- CLEO data, 3M $\psi(2S)$, 20pb^{-1} @ $\sqrt{s}$=3.67GeV
- Measure branching fractions relative to $B(\psi(2S)\to\pi^+\pi^- J/\psi, J/\psi\to\mu^+\mu^-)$
- BF's range from 10^{-5} to 10^{-3}
- Background subtracted, not corrected for interference
- Good statistical power of continuum sample is key!



- $\rho\pi$, K^*K **measured**
- **IV channels** ~obey 12% rule
- $b_1\pi$ and $\omega\pi^+\pi^-$, too; ωf_2 almost

Biggest violators: $\pi^+\pi^-\pi^0$, $\rho\pi$, $K^{*+}K^-$, $\omega\eta$

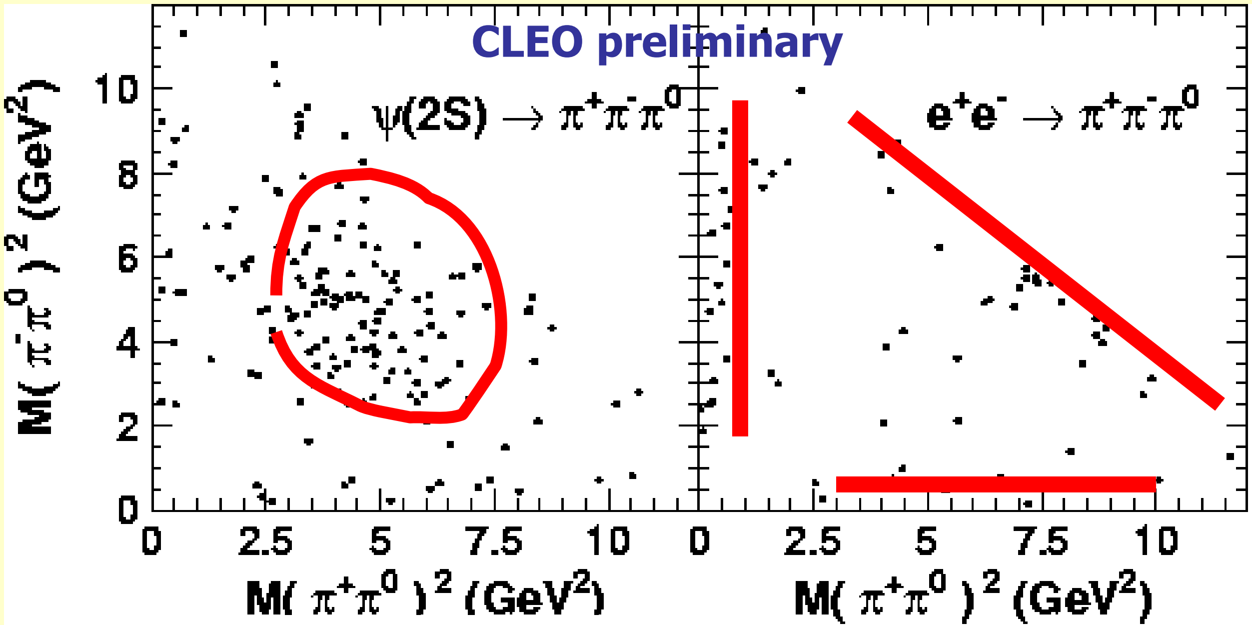
Hadronic $\psi(2S)$ BR's

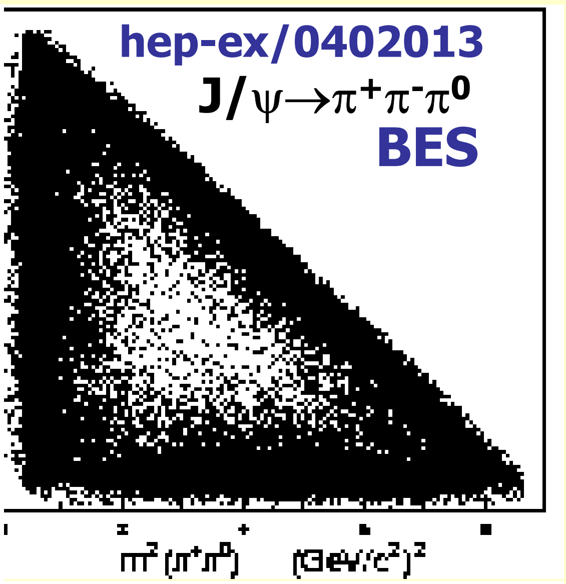
5.5pb^{-1}(~3M) $\psi(2S)$,
20pb^{-1}@3.67 GeV
BRs not corrected for interference

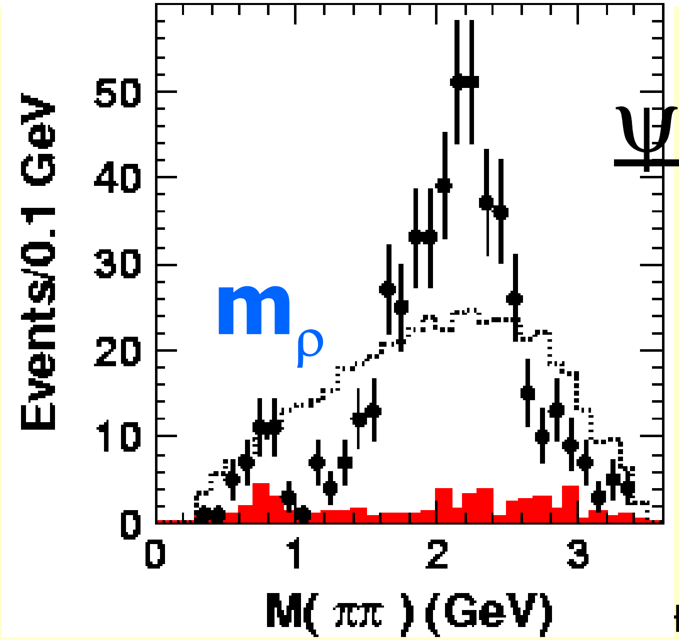
Channel	stat signif in σ	B($\psi(2S)\to X$) in 10^{-6} ±stat ±syst
$\pi^+\pi^-\pi^0$	~6	$136\ ^{+12}_{-13}\ \pm 21$
$\rho\pi$	4.2	$24\ ^{+7}_{-8}\ \pm 2$
$\rho^0\pi^0$	3.0	$9\ \pm 4\ \pm 1$
$\rho^+\pi^-$	3.0	$15\ ^{+6}_{-7}\ \pm 2$
$\omega\pi^0$	3.1	$23\ ^{+9}_{-11}\ \pm 2$
$\phi\pi^0$	<1	<7
$\rho^0\eta$	4.5	$31\ ^{+11}_{-7}\ \pm 2$
$\omega\eta$	<1	<10
$\phi\eta$	2.1	$19\ ^{+10}_{-15}\ \pm 4$
$K^{*0}\bar{K}^0$	5.2	$87\ ^{+21}_{-25}\ \pm 9$
$K^{*+}K^-$	2.6	$17\ ^{+8}_{-10}\ \pm 4$

CLEO preliminary

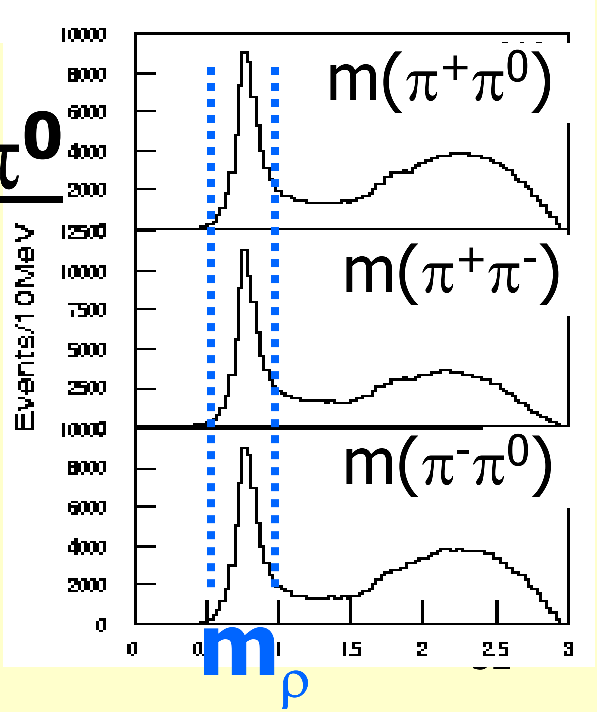
$b_1{}^0\pi^0$	~6	$205\ ^{+38}_{-45}\ \pm 30$
$b_1{}^+\pi^-$	~6	$369\ ^{+40}_{-41}\ \pm 76$
$\omega f_2\,(1270)$	5.7	$101\ ^{+21}_{-25}\ \pm 12$
$\omega\pi^+\pi^-$	~6	$762\ \pm 40\ \pm 76$
$\phi f_0\,(980)$ $\times B(f_0\to\pi^+\pi^-)$	3.3	$22\ ^{+8}_{-9}\ \pm 3$
$\phi f_2{}'\,(1525)$	2.0	$38\ ^{+23}_{-32}\ \pm 10$
$K^{*0}\bar{K}^{*0}$	5.0	$106\ ^{+23}_{-25}\ \pm 33$
$K^{*+}K^{*-}$	4.9	$196\ ^{+48}_{-54}\ \pm 32$



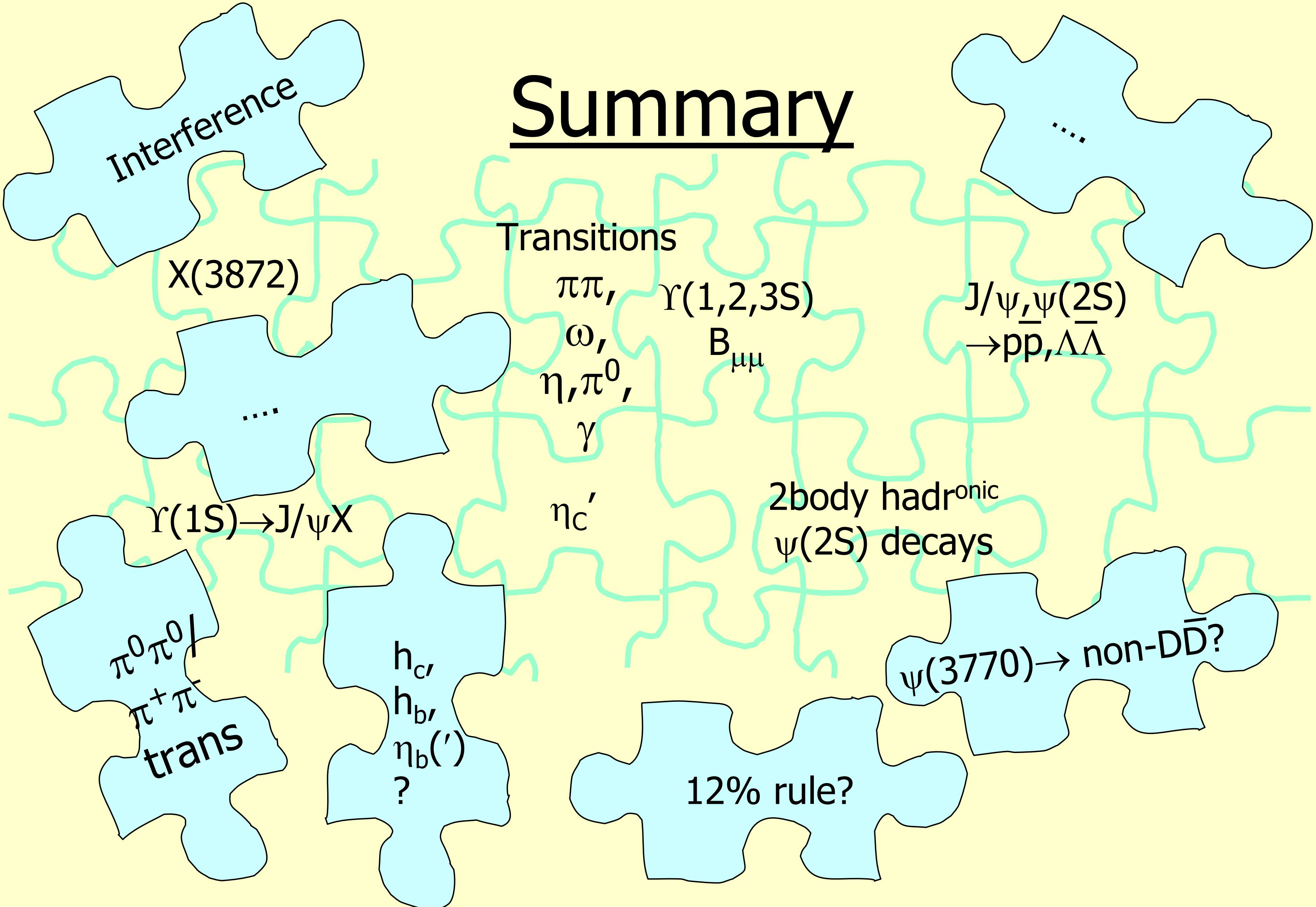




$\psi(2S) \to \pi^+\pi^-\pi^0$ production ($\rho\pi$??)



Summary



Interference

X(3872)

….

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

$\pi^0\pi^0$/ $\pi^+\pi^-$ trans

h_c,
h_b,
$\eta_b(')$
?

Transitions

$\pi\pi$,
ω,
η,π^0,
γ

$\Upsilon(1,2,3S)$
$B_{\mu\mu}$

η_c'

2body hadr$^{\mathrm{onic}}$
$\psi(2S)$ decays

12% rule?

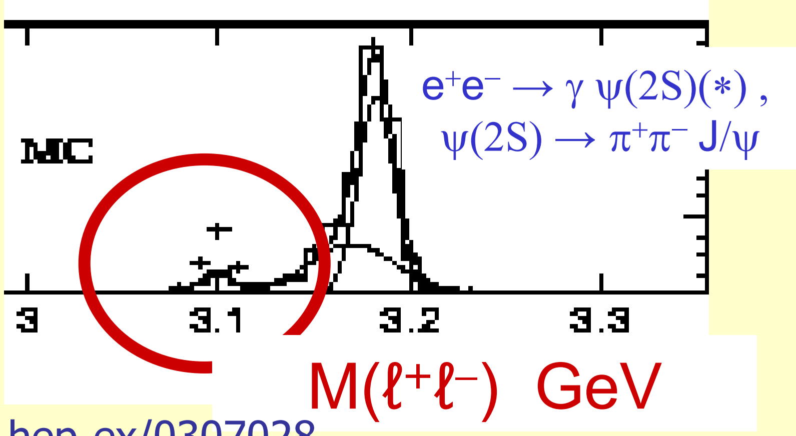
….

$J/\psi,\psi(2S)$
$\rightarrow p\bar{p},\Lambda\bar{\Lambda}$

$\psi(3770)\rightarrow$ non-$D\bar{D}$?

BACKUP

BESII $\psi(3770) \rightarrow \pi^+\pi^- J/\psi$ CLEO-c



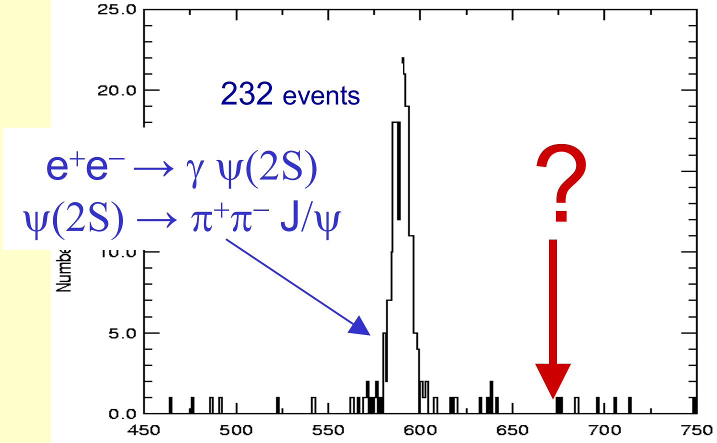
hep-ex/0307028

- 28 pb^{-1} (3.783-3.885GeV), 1.85×10^5 ψ'' decays
- efficiency: 16%

➢ 17.8±4.8 events incl 6.0±0.8 bgd (0 from cont)
$BR(\psi(3770)\rightarrow\pi^+\pi^- J/\psi)$
= (0.34±0.14±0.08) %
Γ = (80 ±32±21) keV

- 5.2±0.2 pb^{-1}, $(4.5\pm0.4)10^4$ ψ'' decays
- efficiency: 37%

➢ < 4.75 events @ 90%CL
$BR(\psi(3770)\rightarrow\pi^+\pi^- J/\psi(1S))$
<0.26% @ 90% CL



E_{cm} -Mass recoiling $\pi^+\pi^-$

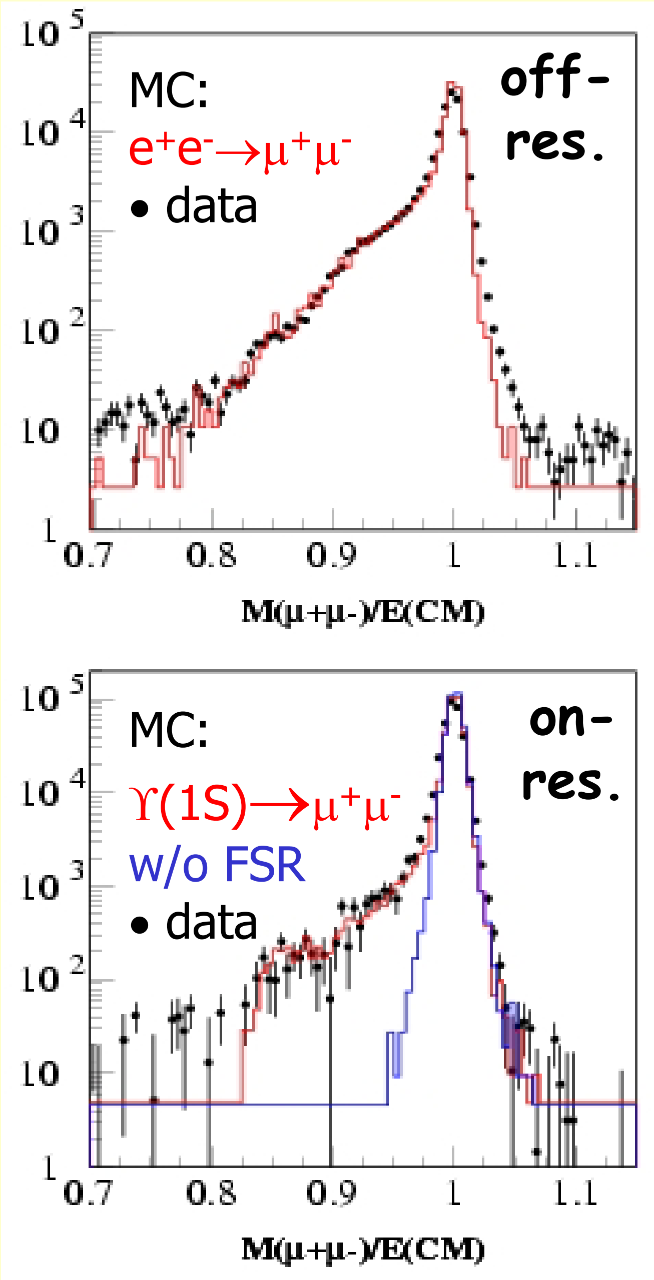
T. Skwarnicki, QWG03

Hanna Mahlke-Krueger, Cornell

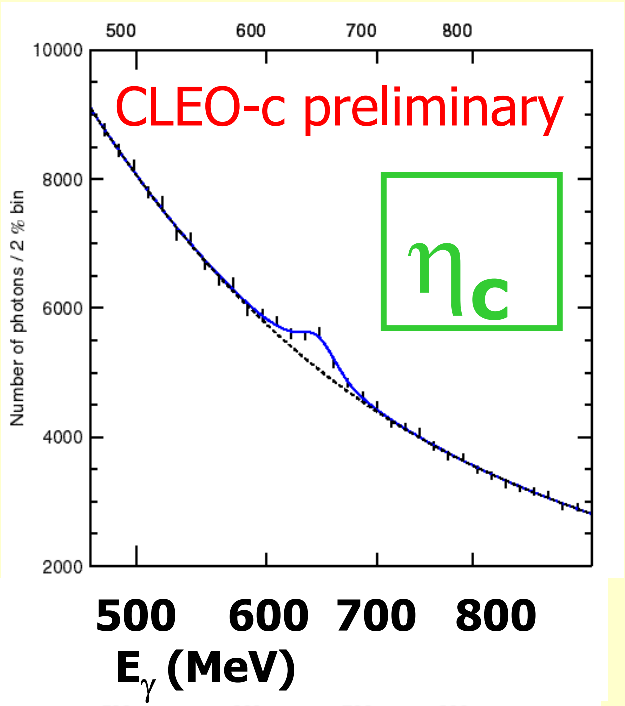
06/08/04

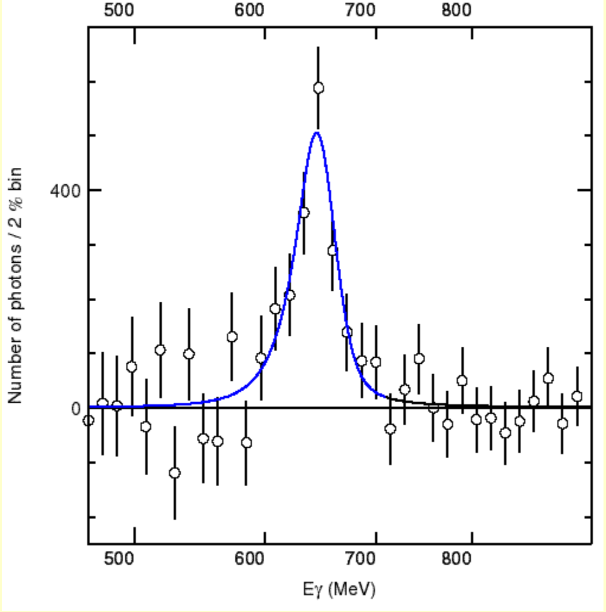
$B(\Upsilon(1,2,3S) \rightarrow \mu^+\mu^-)$

- Goal: 3-4% precision on $B_{\mu\mu}$
  - Gives $\Gamma_{tot} \rightarrow \Gamma_{ee}$
- 1.0/1.2/1.2 fb^{-1} on-resonance + 0.2/0.4/0.2 fb^{-1} off-resonance
- Backgrounds: continuum, cascade decays such as $\Upsilon(3S) \rightarrow \gamma\chi_{b0} \rightarrow \gamma\gamma\Upsilon(2S) \rightarrow \gamma\gamma\mu\mu$, cosmic ray events
- Good understanding of data

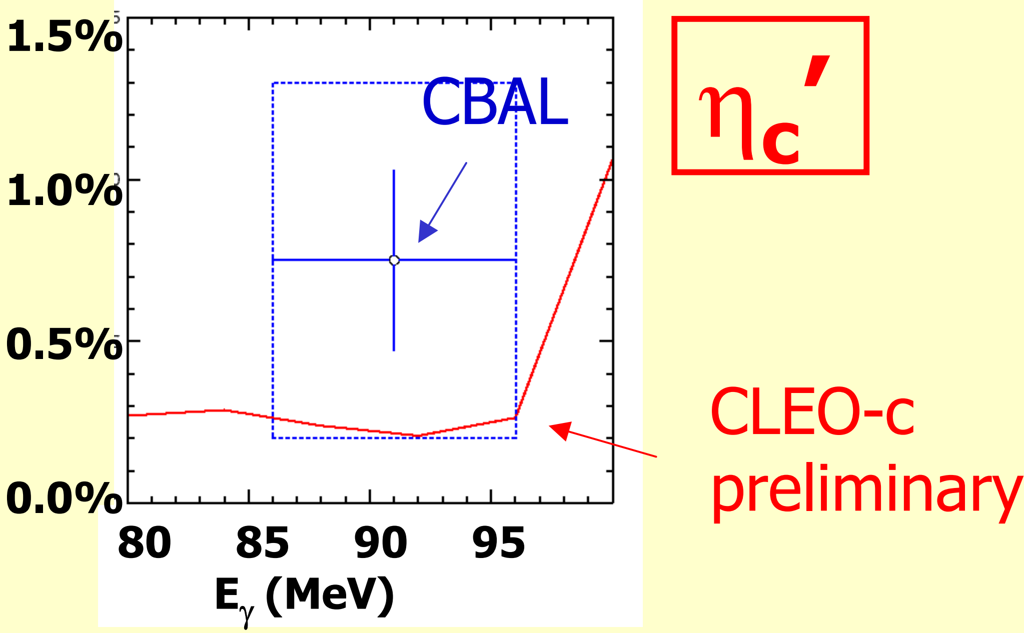


CLEO-c 1,2$^1S_0$ lines





BR($\psi(2S) \to \eta_c(2S)\gamma$):



✓ $\eta_c(1S)$ seen @ 8.2σ

✗ $\eta_c(2S)$ in the CBAL preferred region ruled out

$\psi(2S)$ Branching Fractions

- CLEO data, 3M $\psi(2S)$, 20pb^{-1} @ $\sqrt{s}$=3.67GeV
- Measure branching fractions relative to $B(\psi(2S)\rightarrow\pi^+\pi^- J/\psi$, $J/\psi\rightarrow\mu^+\mu^-)$
- Convert using $B(\psi(2S)\rightarrow\pi^+\pi^- J/\psi)$ =(32.3±1.4)% and $B(J/\psi\rightarrow\mu^+\mu^-)$ =(5.88±0.10)%
- Background subtracted, not corrected for interference