

Puzzle Pieces: Results on b and c Spectroscopy and Decay

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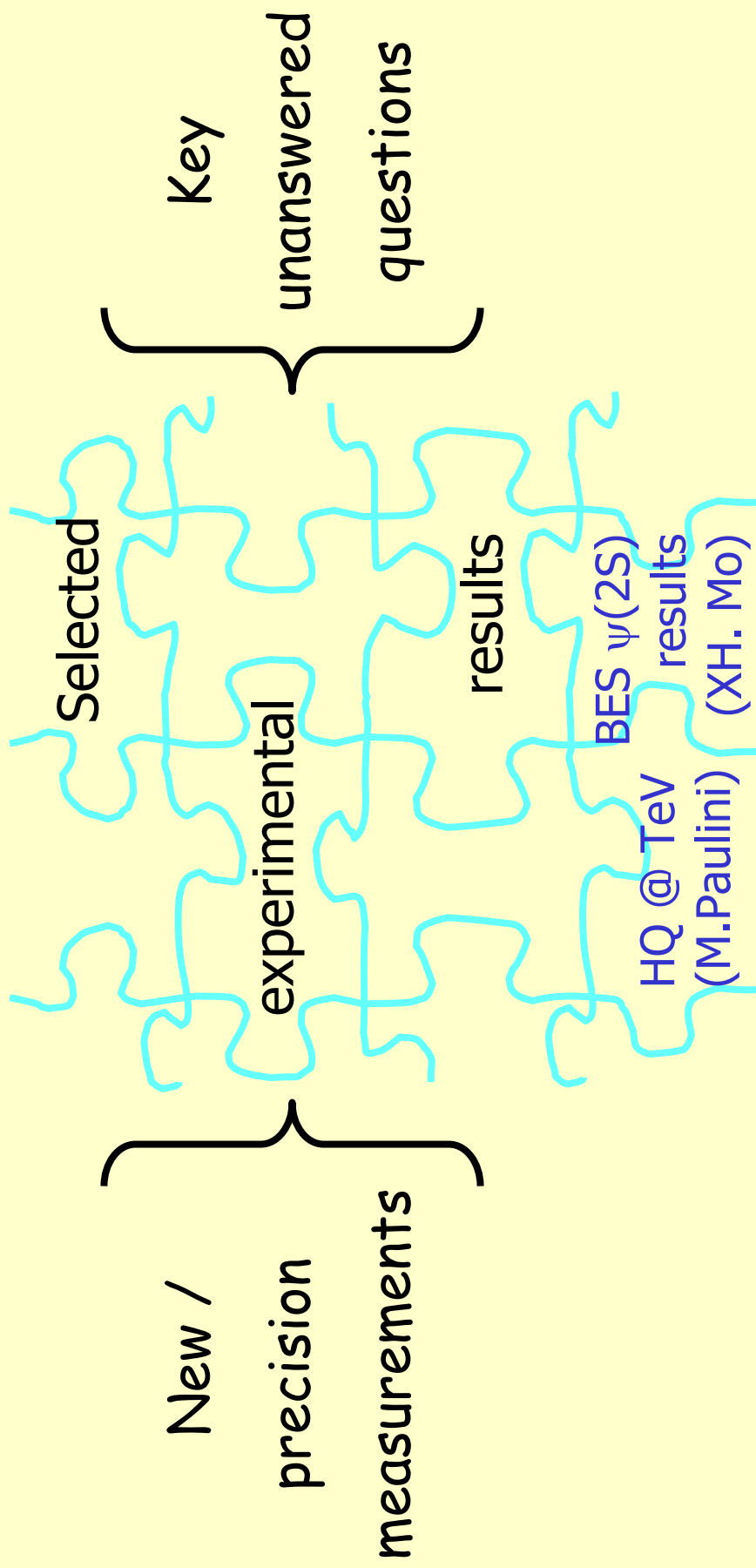
Cornell University



DAPHNE 2004



Heavy Quarkonia Puzzles



Onia States

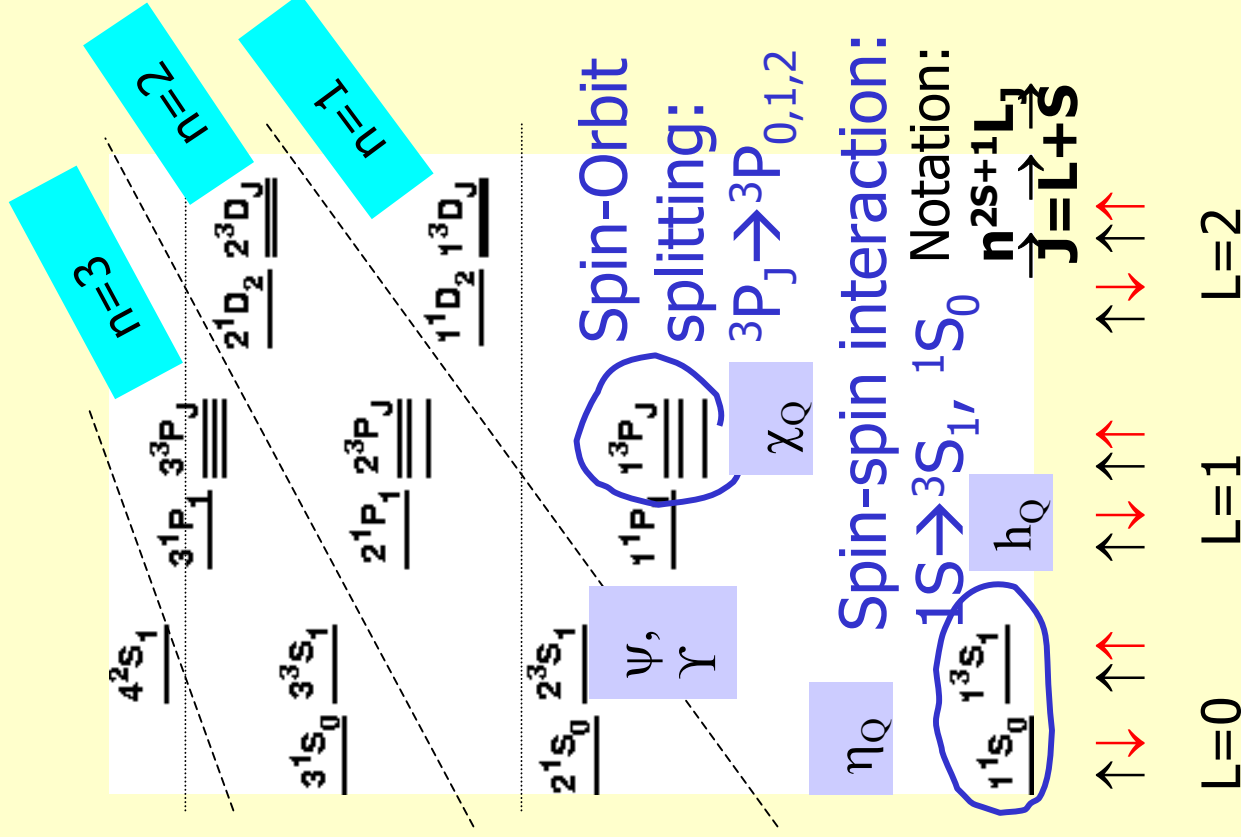
- Strongly bound $q\bar{q}$ states
- Non-relativistic QM applicable (Appelquist, Politzer)
 - QCD analog to positronium
 - Provide insight into QCD
- Low Q^2 , non-perturbative

? ? ?
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



Two Theoretical Approaches

- Potential Model:

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

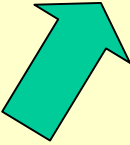
$$V_{hq}(r) = \underbrace{-\frac{4}{3}\alpha_s/r}_{\text{Short distance, 1g exch}} + \underbrace{kr}_{\text{long distance}}$$

- 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

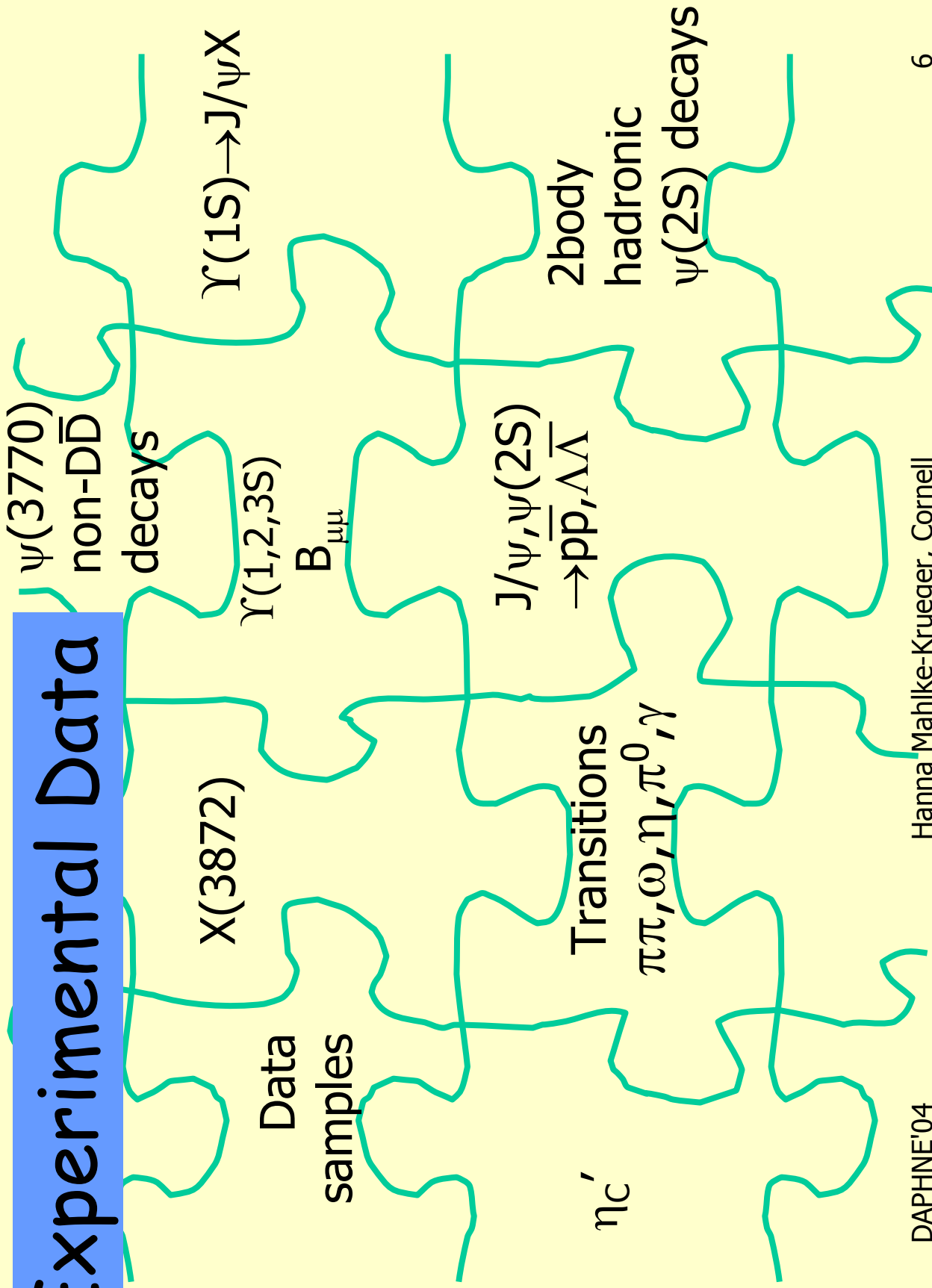
Gain insight to
underlying
interaction, QCD



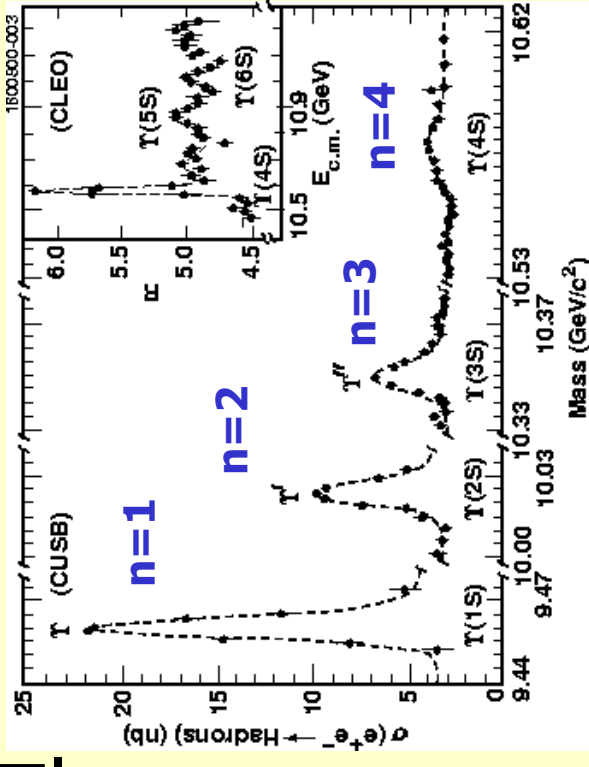
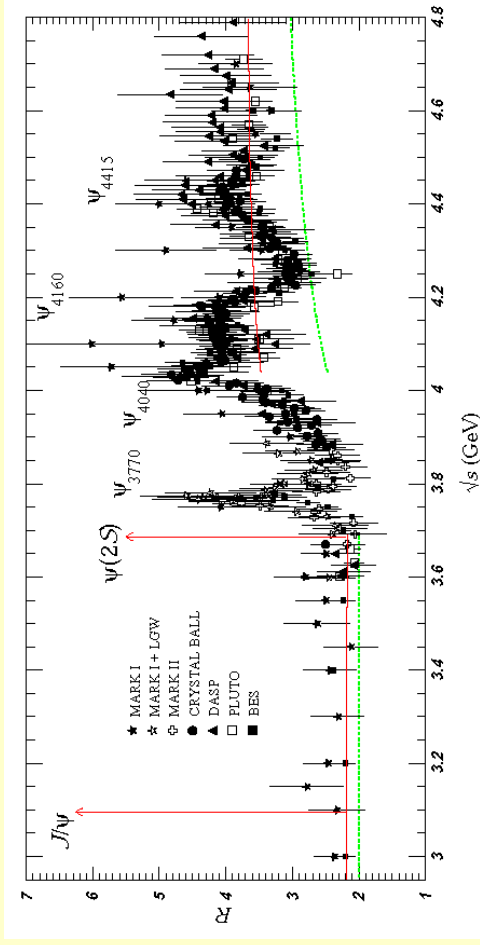
More convenient to
handle experimentally
than glueballs



Experimental Data

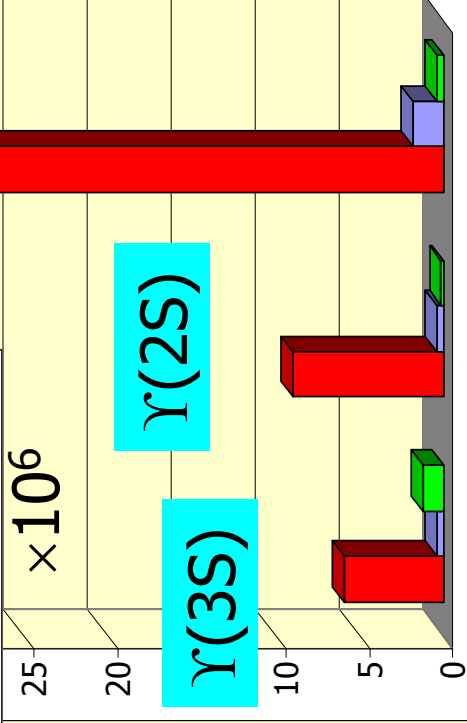
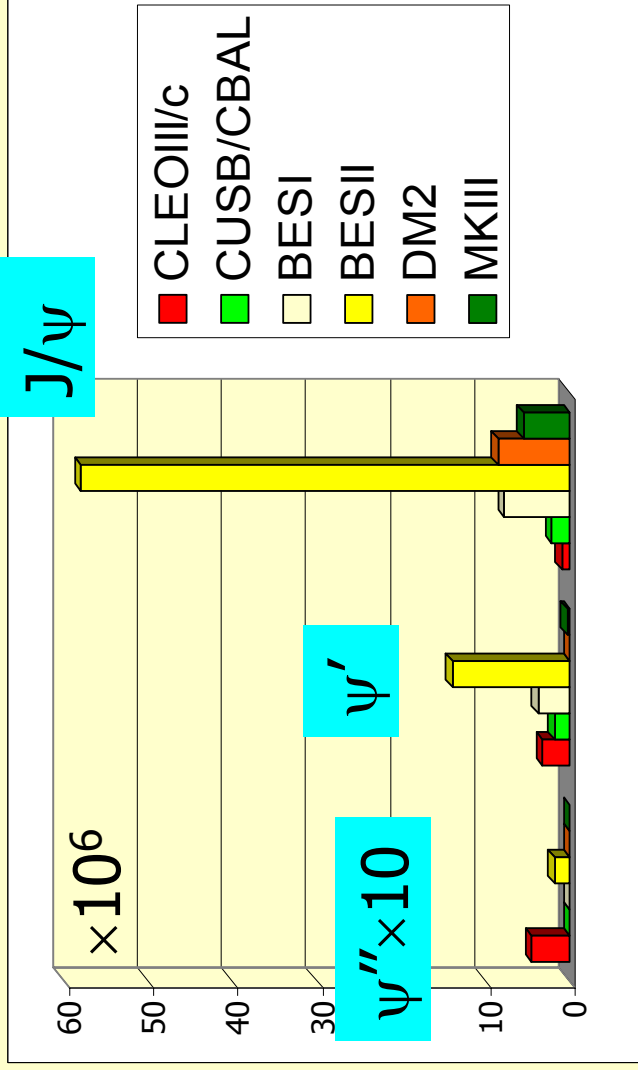


Producing quarkonia



- **e^+e^- colliders, $e^+e^- \rightarrow \gamma^* \rightarrow q\bar{q}$:**
can only directly produce states coupling to γ^* ,
i.e. n^3S_1 ($J/\psi, \Upsilon$) 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. $\psi(2S) \rightarrow \gamma\chi_{c0}$

Datasets as of spring 2004



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

X(3872)

Spectroscopy

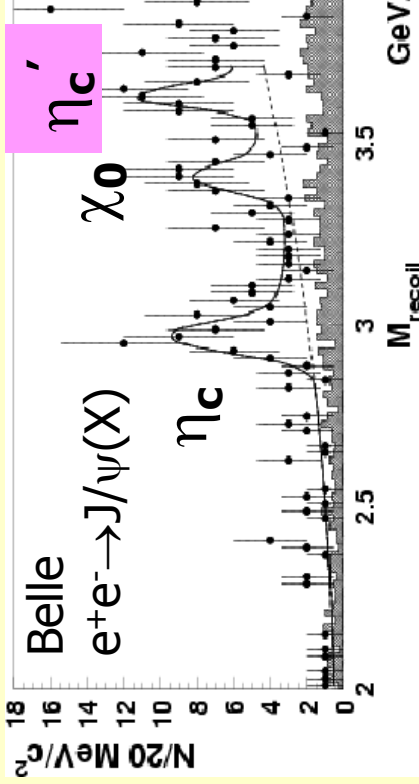
η_c'

Transitions

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

Current Experimental

Information on η_c'



Recently observed in 3 different ways:

$B \rightarrow K (K_S K^+ \pi^-)$ Belle

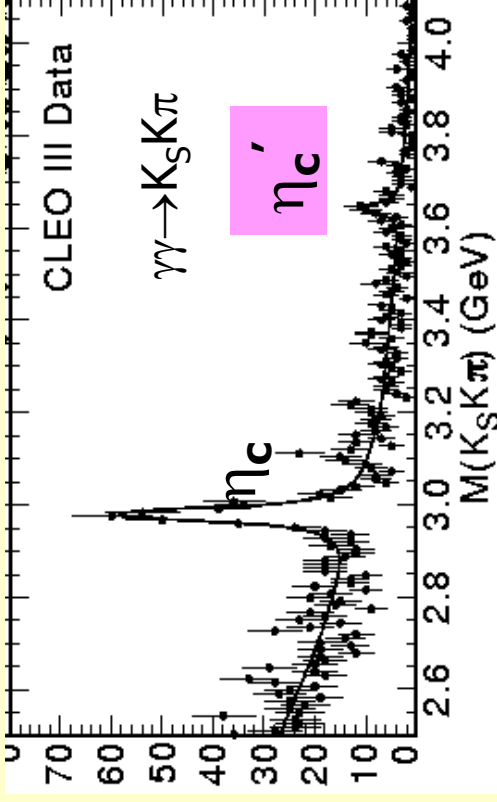
$e^+e^- \rightarrow J/\psi(X)$ (Belle)

$\gamma\gamma \rightarrow K_S K\pi$ (CLEO, BaBar)

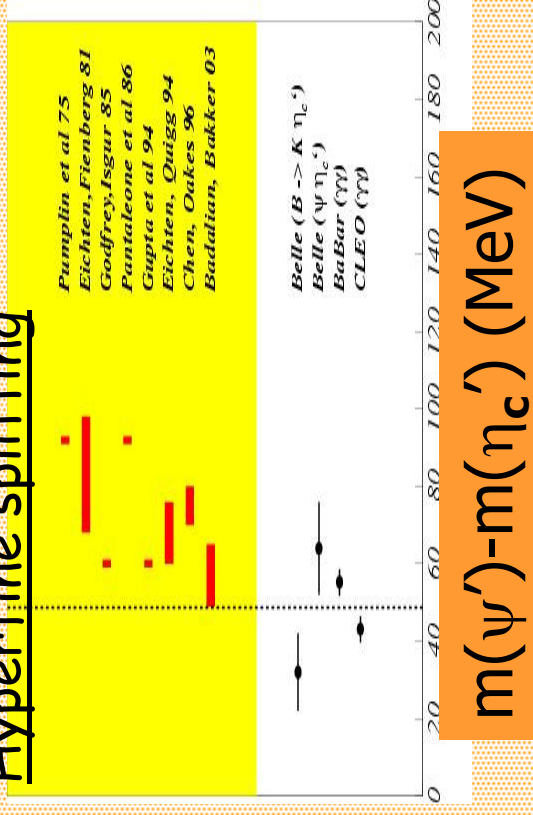
$m(\eta_c') \approx 3638 \text{ MeV}$

Old result ($\psi \rightarrow \eta_c X$, $m=3594$)

directly ruled out by CLEO.

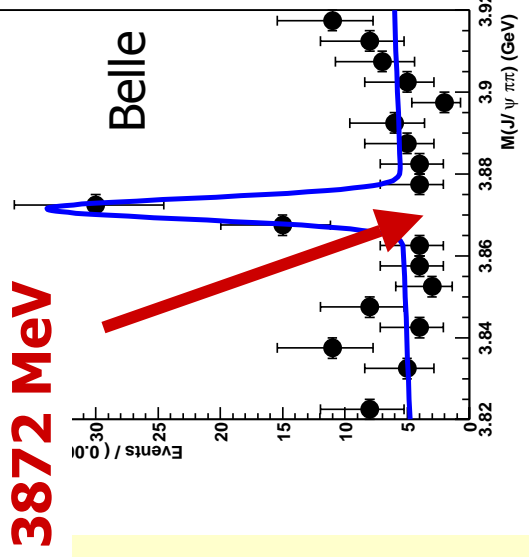


Hyperfine splitting



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

X(3872) – a cc state?



3872 MeV

Peak in $B^\pm \rightarrow K^\pm(\pi^+\pi^-J/\psi)$,
 $m = (3872.0 \pm 0.6 \pm 0.5) \text{ MeV}$,
 $\Gamma < 2.3 \text{ MeV (90\%CL) Belle}$

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

What is its nature? Study production and decay mechanisms!

❖ Charmonium state?

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

1^{++} ? $\Gamma(X \rightarrow \gamma J/\psi) / \Gamma(X \rightarrow \pi\pi J/\psi) > 1$

See 0.4 (Belle)

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

❖ DD* molecule?

$m_D + m_{D^*} = 3871.5 \pm 0.5 \text{ MeV}$

➤ Look for $X \rightarrow D(D\pi)$

$D^0 \bar{D}^0 \pi^0$ BR's $< \sim 5 \times 10^{-5}$ (Belle)
 not inconsistent

➤ Look for $X \rightarrow \pi^0 \pi^0 J/\psi$
 $\rightarrow \rho J/\psi$ component?

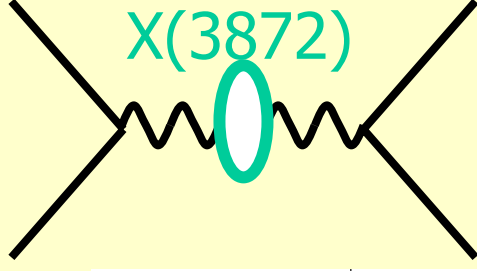
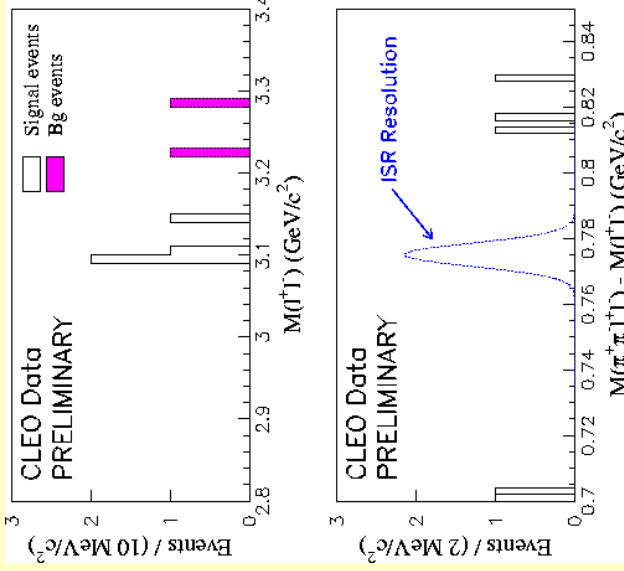
❖ Exotic state?

CLEO results on X(3872)

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

X(3872) ISR (JPC=1⁻⁻)

2γ (JPC=0⁺⁺, 2^{±±}, ...)



CLEO prelim: $\Gamma_{ee} B(X \rightarrow \pi^+ \pi^- J/\psi) < 6.8\text{eV}$
 (or, $< 1/100 \times \psi(2S)$ production rate
 in ISR for same $B_{\pi\pi J/\psi}$)

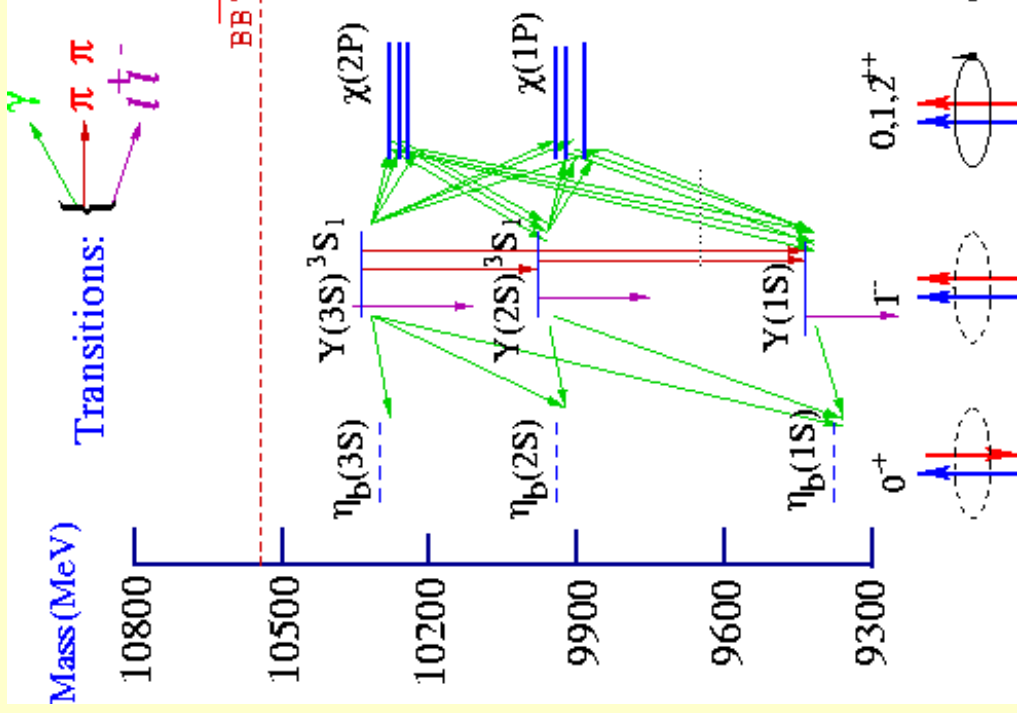
BES: $\Gamma_{ee} B(X \rightarrow \pi^+ \pi^- J/\psi) < 10\text{eV}$
 (22.3pb^{-1} at $\sqrt{s}=4.03\text{GeV}$)

CLEO prelim:
 $(2J+1)\Gamma_{\gamma} B(X \rightarrow \pi^+ \pi^- J/\psi) < 16.7\text{eV}$
 (or, $< 1/10$ the η_c production rate in $\gamma\gamma$)

Transitions

Transition Options

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



Hadronic Transitions

No charge involved:

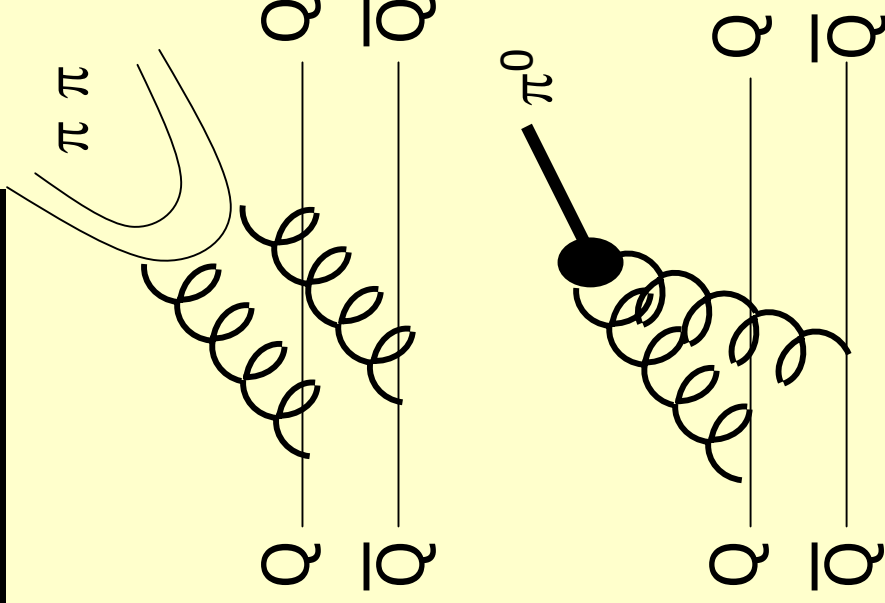
- two charged pions

or

- neutral particles

- ▶ $\pi^0 \pi^0$
- ▶ Single π^0 transitions
isospin **suppressed**
- ▶ η, ω are "rare"

Soft process.



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

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

- X is photon, $\Upsilon(1S) \rightarrow \ell^+\ell^-$

$\pi^+\pi^-\pi^0$ distribⁿ peaks at ω

- Fit for $\Upsilon(3S) \rightarrow \gamma\chi_{bj}'$,

$$\chi_{bj}' \rightarrow \omega\Upsilon(1S), J=1,2$$

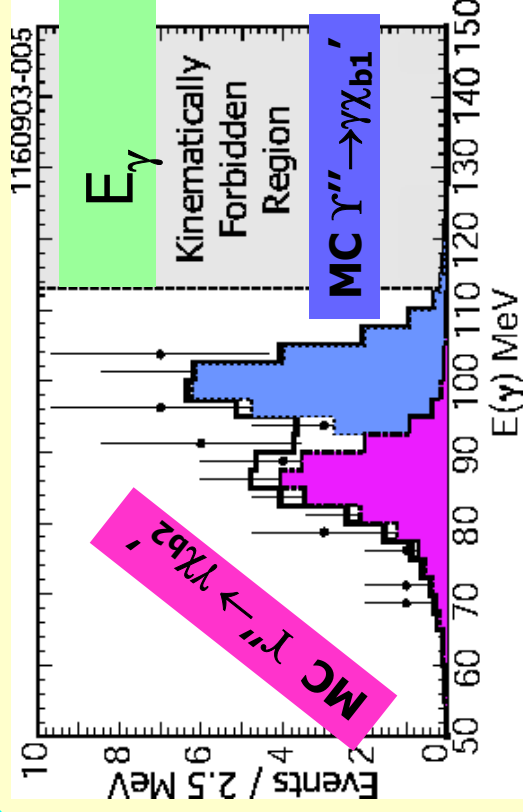
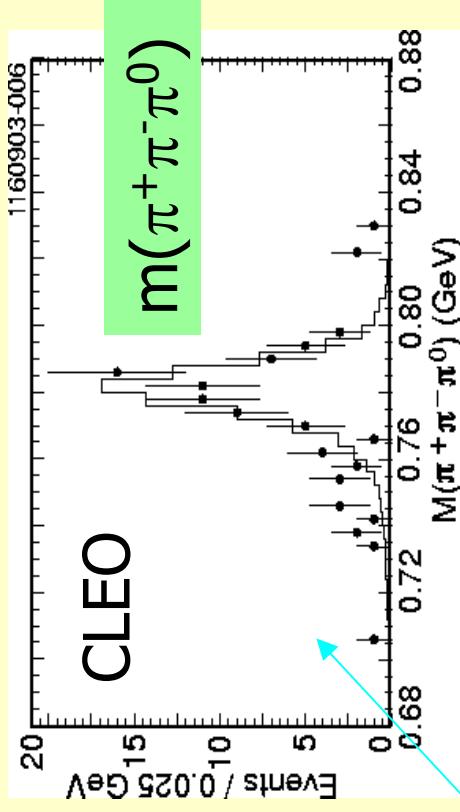
- $B(\chi_{b1}' \rightarrow \omega\Upsilon(1S)) = (1.63^{+0.31}_{-0.32} \pm 0.15 \pm 0.11) \%$

- $B(\chi_{b2}' \rightarrow \omega\Upsilon(1S)) = (1.10^{+0.35}_{-0.28} \pm 0.16 \pm 0.10) \%$

1. substantial, 2. ~equal

Voloshin hep-ph/0304165:

$$r_{2/1} = 1.3 \pm 0.3$$



$$\underline{\psi(2S)} \rightarrow \underline{\gamma\gamma J/\psi}$$

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

14% relative

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

8% relative

- Predictions for

$$B(\psi' \rightarrow \pi^0 J/\psi) / B(\psi' \rightarrow \eta J/\psi),$$

$$B(\psi' \rightarrow \eta J/\psi) / B(\Upsilon(2S) \rightarrow \eta \Upsilon),$$

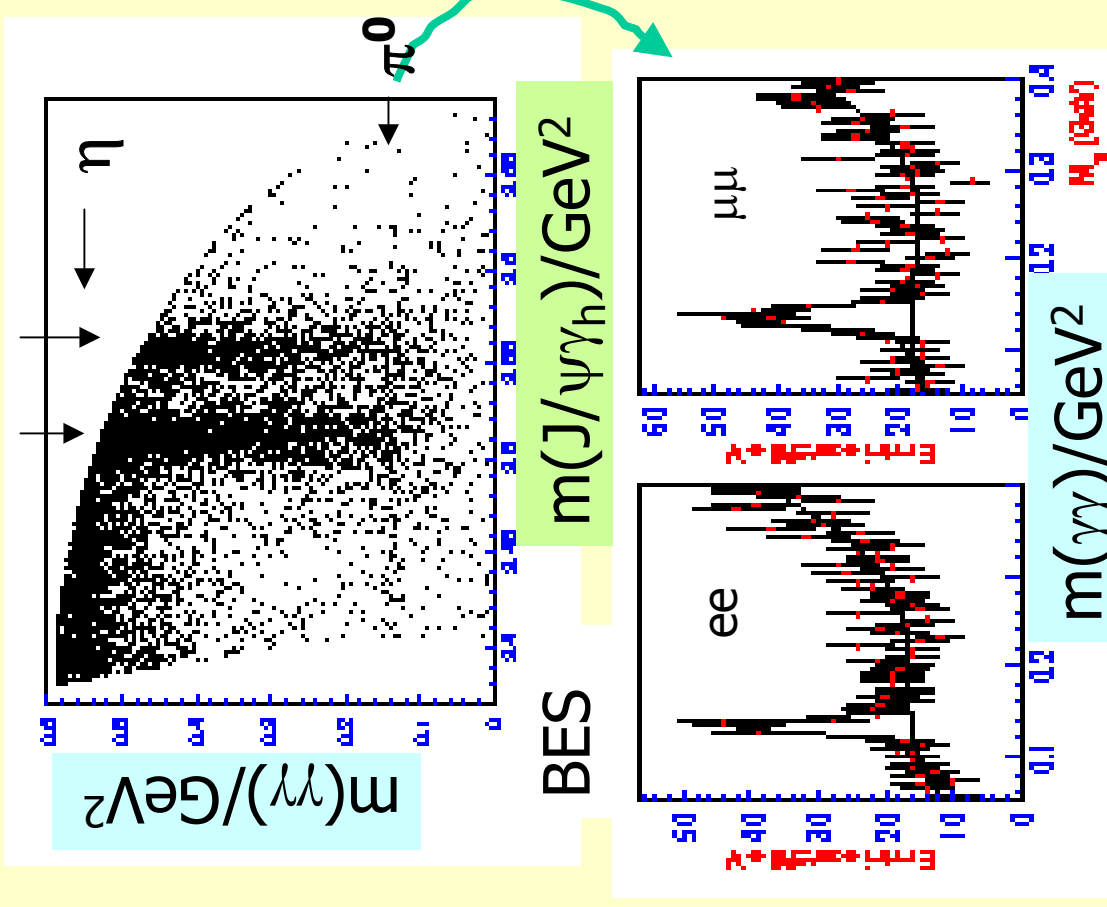
$$B(\psi' \rightarrow \eta J/\psi) / B(\Upsilon(3S) \rightarrow \eta \Upsilon),$$

... see Prof. Mo's talk

- Neutral dipion transitions in hep-ex/0404020...

$$\underline{\Upsilon(3S)} \rightarrow \underline{\pi^0 / \eta \ell^+ \ell^-}, \underline{\pi^0 / \eta} \rightarrow \underline{\gamma\gamma}?$$

Not seen, UL @ % level



Do we understand

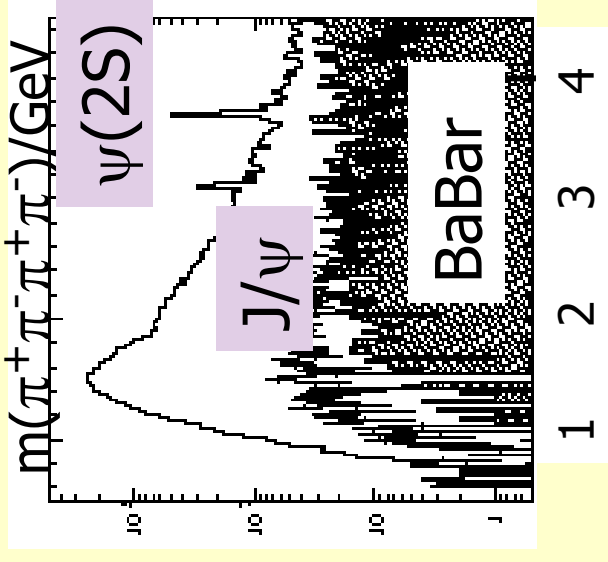
$\psi(2S) \rightarrow \pi\pi J/\psi$?

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

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

- Experiment: (PDG: $B(\psi(2S) \rightarrow \pi^0\pi^0 J/\psi) = (18.9 \pm 1.1)\%$)
 $B(\psi(2S) \rightarrow \pi^0\pi^0 J/\psi)/B(\psi(2S) \rightarrow \pi^+\pi^- J/\psi) = 0.570 \pm 0.009 \pm 0.026$
4M $\psi(2S)$ BES1, hep-ex/0404020
 $B(\psi(2S) \rightarrow \pi^+\pi^- J/\psi) = 0.361 \pm 0.015 \pm 0.037$
BaBar, radiative returns, $89\text{fb}^{-1} \sim \Upsilon(4S)$ data, hep-ex/0312063

➤ **Neutral BR too high? Charged BR too low? Expectation off?**



Decay

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

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

$\Upsilon(1,2,3S)$

$B_{\mu\mu}$

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

2body

hadronic

$\psi(2S)$ decays

Are there $\psi(3770)$ non-DD decays?

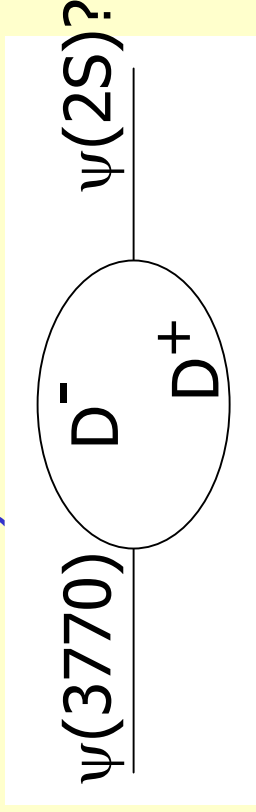
$$m(\psi(3770)) > 2m(D)$$

$$\begin{aligned} \sigma(\psi'' \rightarrow D\bar{D}) &= 5.0 \pm 0.5 \text{ nb} \\ &< \sigma(\psi'' \rightarrow \text{hadrons}) &= 7.9 \pm 0.6 \text{ nb} \end{aligned}$$

- Can the deficit be confirmed? 80%
 - BES *single* tag Moriond 04: $\sigma(\psi'' \rightarrow D\bar{D}) = 5.78 \pm 0.11 \pm 0.38 \text{ nb}$
 - CLEO-c *prelim double* tag: $\sigma(\psi'' \rightarrow DD) = 6.51 \pm 0.44 \pm 0.39 \text{ nb}$
 - Modern $\sigma(\psi'' \rightarrow \text{hadrons})$ would be good...
- Where would a 20% deficit of $\Gamma_{\text{tot}} = 24 \text{ MeV}$ 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.)



Total decay width:

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

Total widths:

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

Relative precision on total width:

$\Upsilon[1,3S]$: 3.4%, 16.9%, 13.3%, $\psi[1,3S]$: 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: $\Gamma_{\text{tot}} = \Gamma_{\ell\ell} / B_{\ell\ell}$, or $\Gamma_{ee} / B_{\mu\mu}$

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

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

Leptonic

$\chi(1,2,3S)$

Width Γ_{ee}

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

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

!

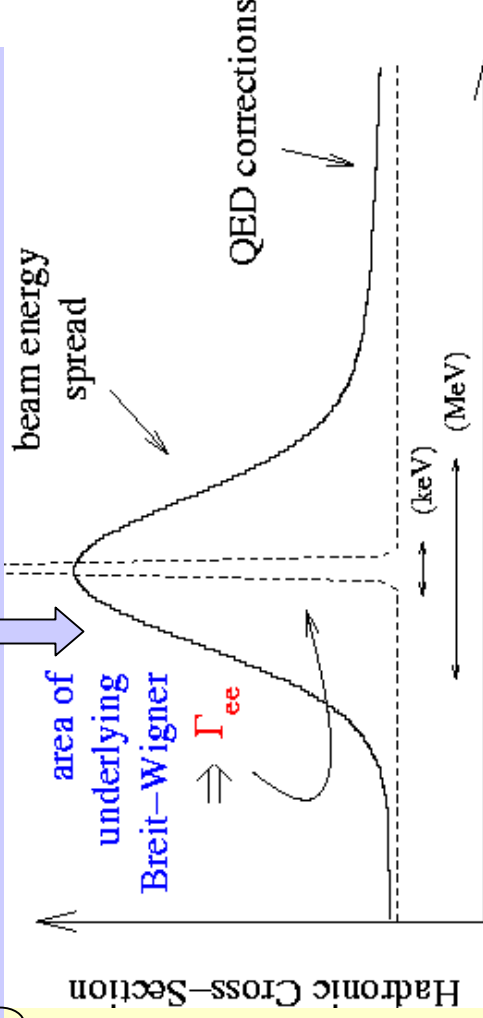
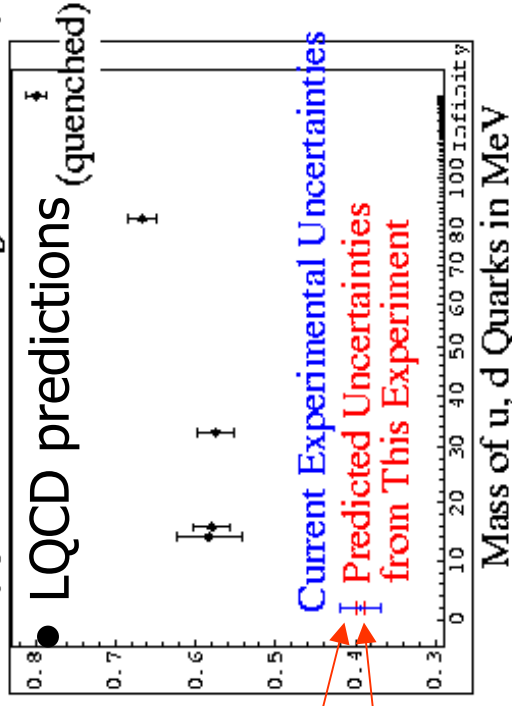
Strategy:

$$\Gamma(Y \rightarrow e^+e^-) = \frac{M_Y^2}{6\pi^2} \frac{\Gamma_{\text{total}}}{\Gamma_{\text{hadrons}}} \int d\text{Energy } \sigma(e^+e^- \rightarrow Y \rightarrow \text{hadrons})$$

External input

Hope to improve from
2/4/9% \rightarrow 2-3%.

Note! Theory points have no $1/M_b$ corrections yet.

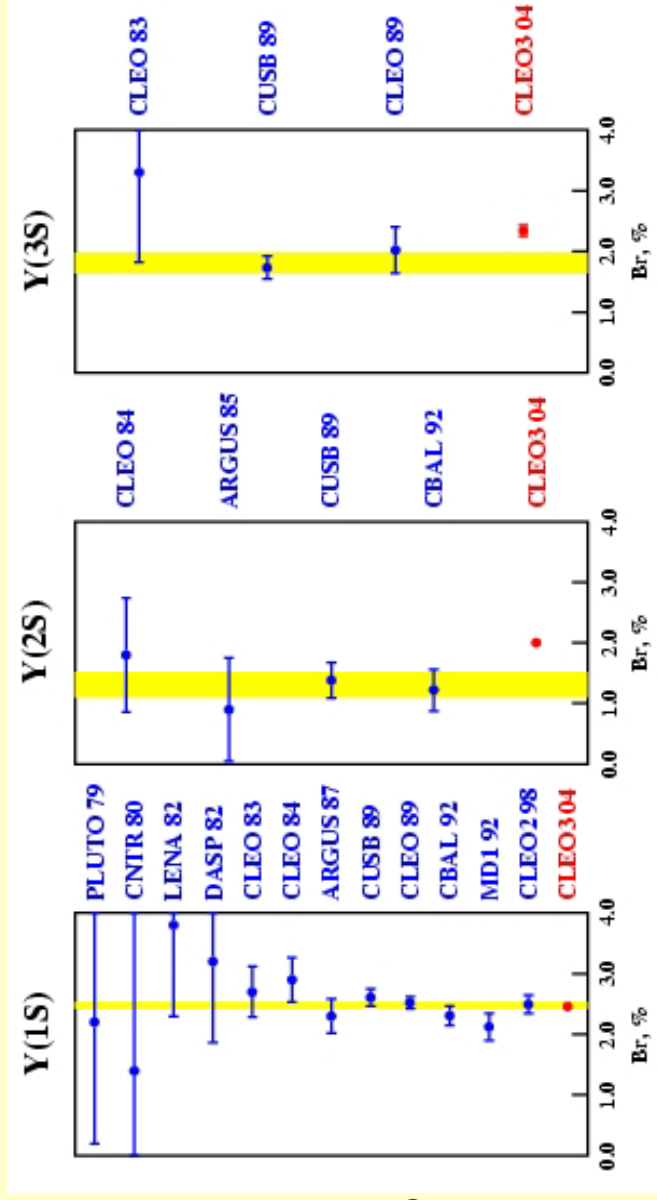


Energy

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

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

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



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

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

BESII, 58M J/ψ :

Angular distribution:

$$B(J/\psi \rightarrow p\bar{p}) = (2.26 \pm 0.01 \pm 0.14) \times 10^{-3}$$

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

α_{Proton}	α_{Λ}
1.0	1.0
0.46	0.32
0.66	0.51
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

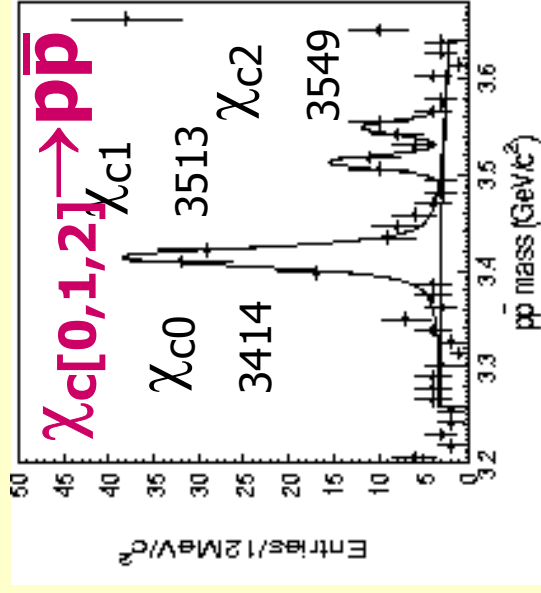
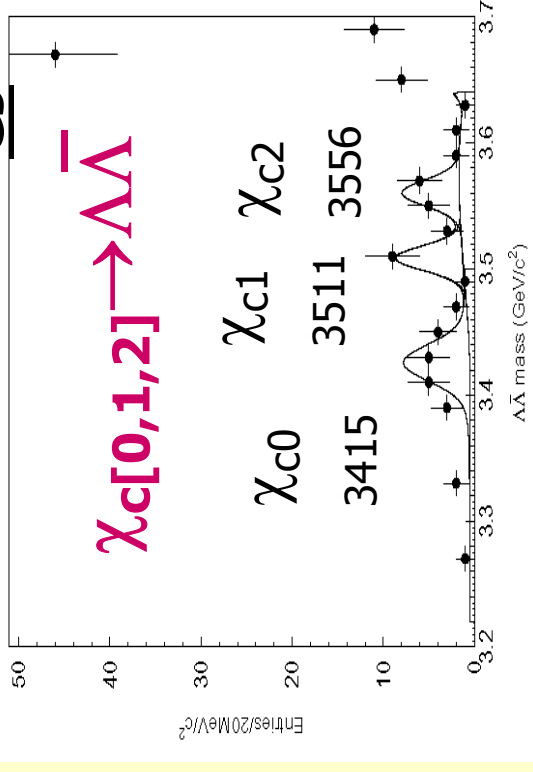
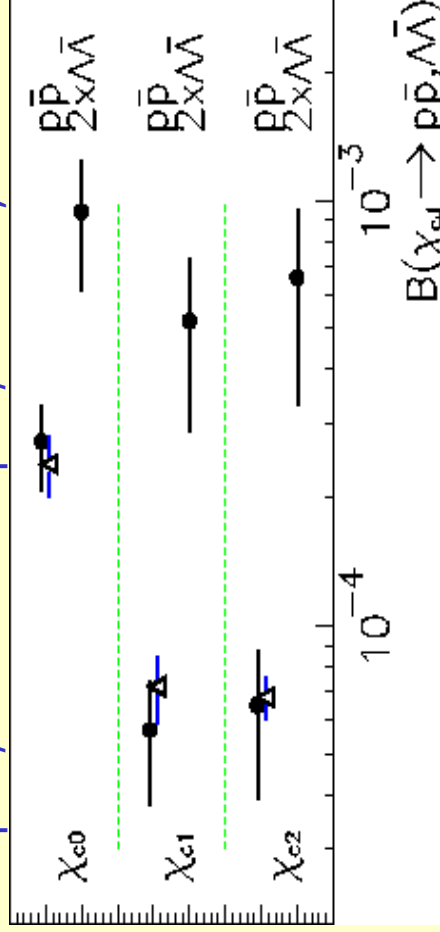
[4] hep-ex/0402034, PLB424(1998)213

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

- COM needed to describe P-wave quarkonium decays $\chi_{cJ} \rightarrow p\bar{p}$
- Based on $\chi_{c[0,1,2]} \rightarrow p\bar{p}$ meas't, generalized to $\Lambda\bar{\Lambda}$, expect $BR(\chi_{cJ} \rightarrow \Lambda\bar{\Lambda}/\chi_{cJ} \rightarrow p\bar{p}) = 1/2$ $J=1,2$
- $\chi_{c[0,1,2]} \rightarrow \Lambda\bar{\Lambda}$ 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

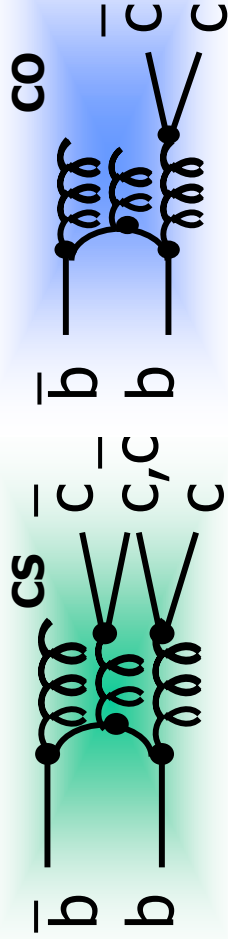


CDF $p\bar{p} \rightarrow J/\psi, \psi(2S)X \Rightarrow$

color octet mechanism:

$c\bar{c}$ in CO, become CS by radiating off a soft gluon.

Problems with other data...

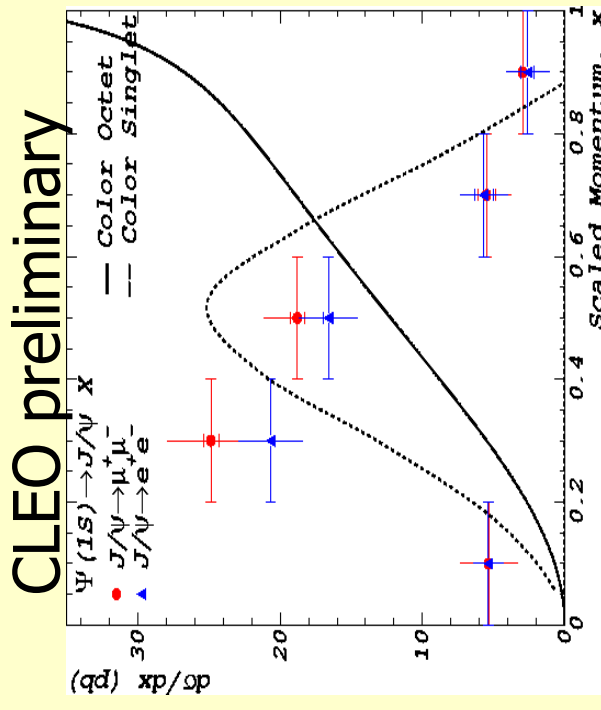


More information needed to distinguish production mechanisms.

- $\Upsilon(1S) \rightarrow J/\psi X$ is gluon rich env't; CO preferred
- **Example: x spectrum.**

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

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



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

Charmonium production

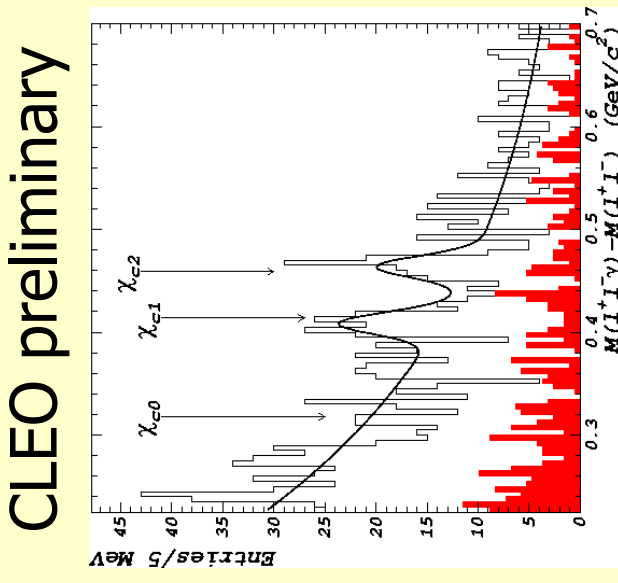
in $\Upsilon(1S)$ decays

$$\begin{aligned} \sigma(e+e^- \rightarrow q\bar{q} \rightarrow J/\psi+X) = \dots \\ \dots (1.47 \pm 0.10 \pm 0.13) \text{ pb (Belle)} \\ \dots (2.52 \pm 0.21 \pm 0.21) \text{ pb (BaBar)} \\ \dots (1.9 \pm 0.2(\text{stat})) \text{ pb (CLEO prelim)} \end{aligned}$$

$$B(\Upsilon(1S) \rightarrow J/\psi+X) = (6.4 \pm 0.4 \pm 0.6) \times 10^{-4}$$

$$\text{CS: } 5.9 \times 10^{-4}, \text{ CO: } 6.2 \times 10^{-4}$$

- 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 $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi, \chi_{cJ} \rightarrow \gamma J/\psi$

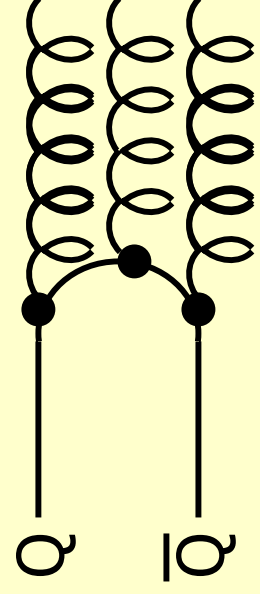


No clear conclusion
on CS vs CO
possible so far.

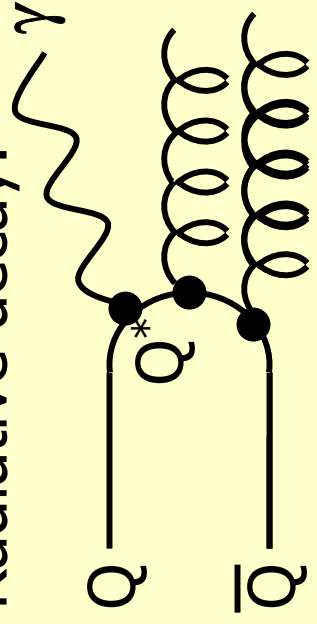
2body
hadronic
decays

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

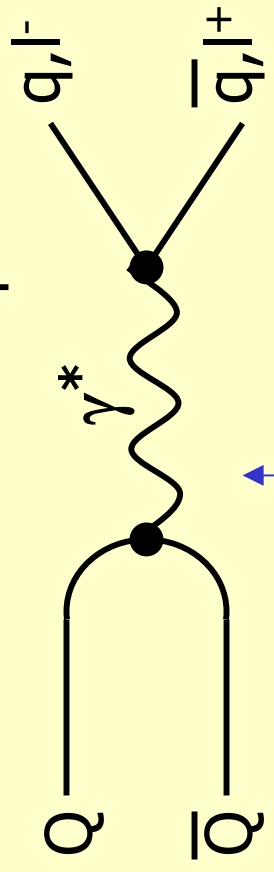
Annihilation into $3g$:



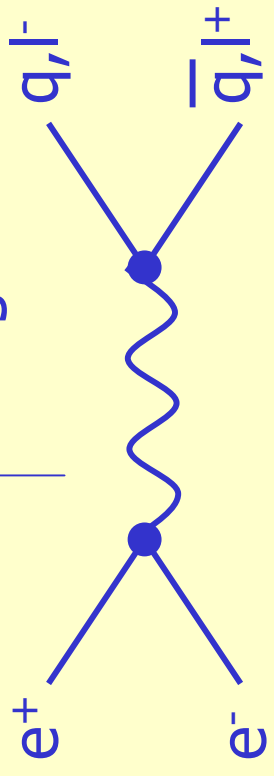
Radiative decay:



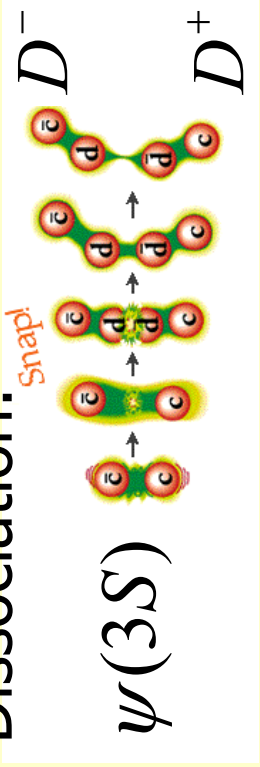
Annihilation into a photon:



background



Dissociation:

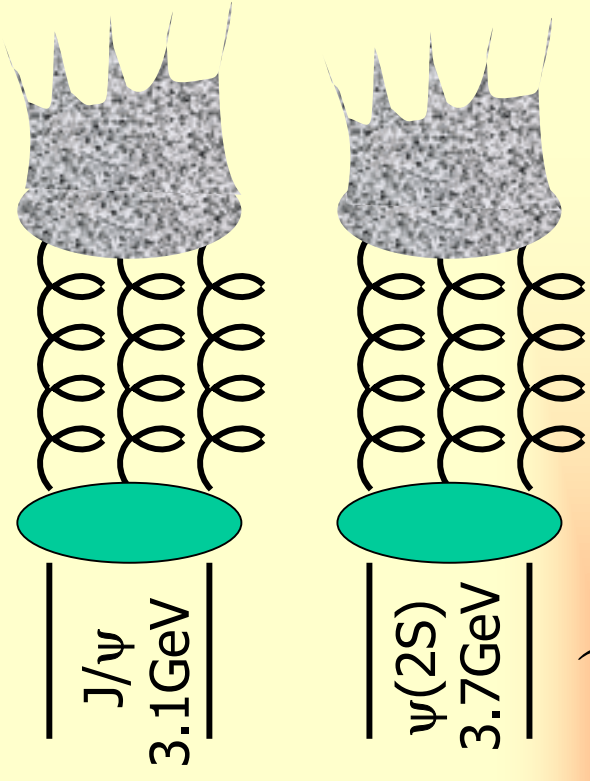


~~14%~~ ^{12%} "The rule"

If mechanism is $c\bar{c}$ annihilation

\Rightarrow decay rate $\sim |\Psi(0)|^2$

Compare with e^+e^- production:



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

Complications (and there are more):

Powers of α_S at $m_{J/\psi}$, $m_{\psi(2S)}$ 0.845 [hep-ph/09910406](https://arxiv.org/abs/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 $c\bar{c} \rightarrow \gamma^*$, not $c\bar{c} \rightarrow ggg$? (Gerard/Weyers)

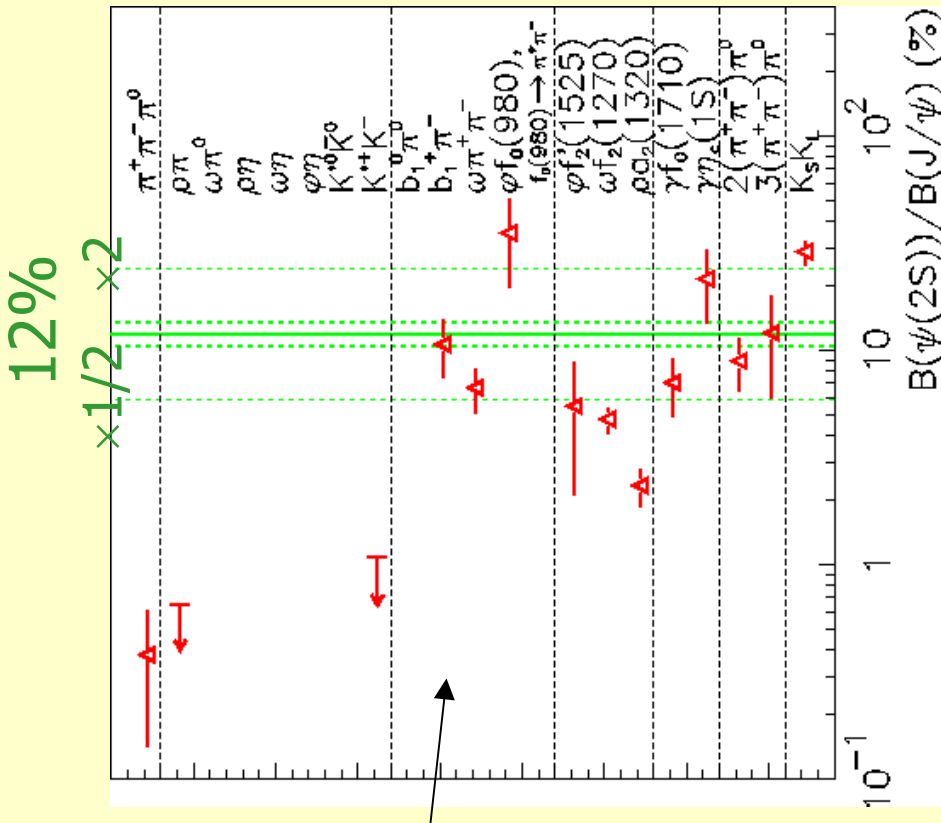
Compliance within a factor of two: "agreement"

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

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

Experimentally, situation is unclear
Theoretically, even more than unclear:
Add'l effects in J/ψ ? $\psi(2S)$? Expectation?

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



Branching Fraction

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

VP final states + some others

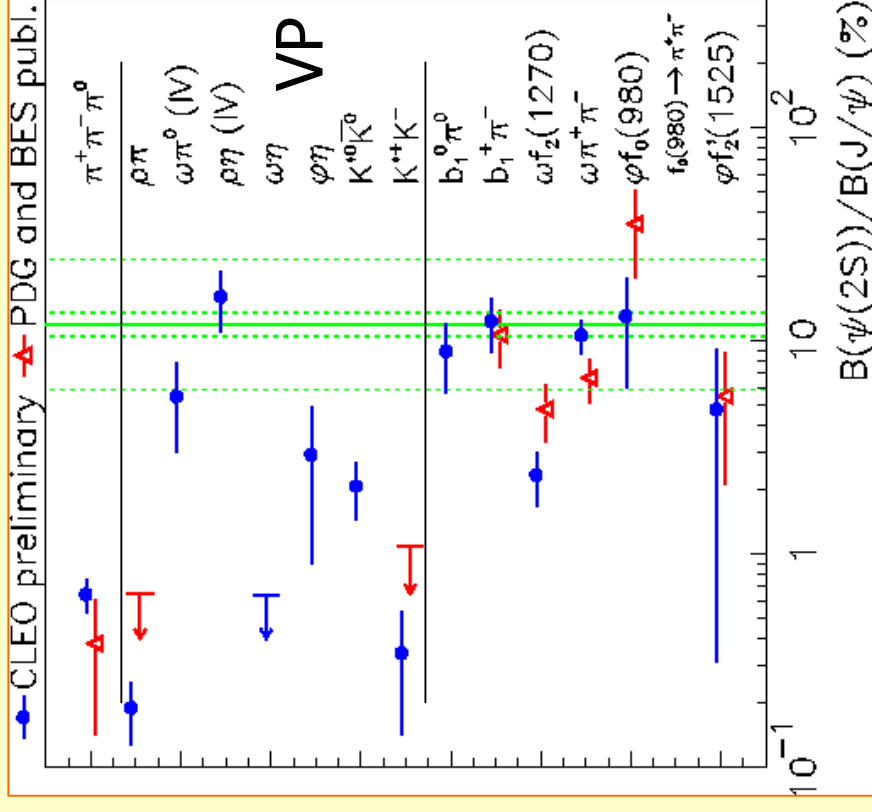
CLEO data, 3M $\psi(2S)$,
20pb⁻¹ @ $\sqrt{s}=3.67\text{GeV}$

Measure branching fractions
relative to $B(\psi(2S) \rightarrow \pi^+ \pi^- J/\psi)$,
 $J/\psi \rightarrow \mu^+ \mu^-$

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** \sim obey 12% rule

- $b_1 \pi$ and $\omega \pi^+ \pi^-$, too; ωf_2 almost

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

Channel $B(\psi(2S) \rightarrow X)$ in 10^{-6}
 stat \pm syst

$\pi^+ \pi^- \pi^0$	~ 6	136	$^{+12}_{-13}$	± 21
$\rho \pi$	4.2	24	$^{+7}_{-8}$	± 2
$\rho^0 \pi^0$	3.0	9	± 4	± 1
$\rho^+ \pi^-$	3.0	15	$^{+6}_{-7}$	± 2
$\omega \pi^0$	3.1	23	$^{+9}_{-11}$	± 2
$\phi \pi^0$	< 1	< 7		
$\rho^0 \eta$	4.5	31	$^{+11}_{-7}$	± 2
$\omega \eta$	< 1	< 10		
$\phi \eta$	2.1	19	$^{+10}_{-15}$	± 4
$K^* \bar{K}^0$	5.2	87	$^{+21}_{-25}$	± 9
$K^* + K^-$	2.6	17	$^{+8}_{-10}$	± 4

CLEO preliminary

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

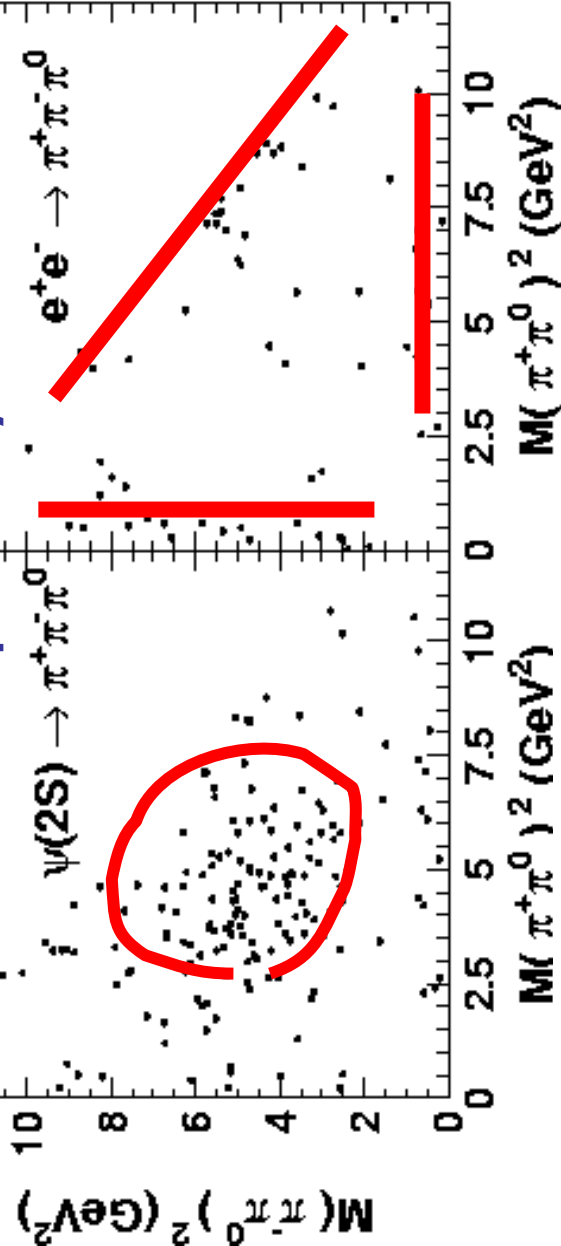
$5.5 \text{ pb}^{-1} (\sim 3M) \psi(2S),$

$20 \text{ pb}^{-1} @ 3.67 \text{ GeV}$

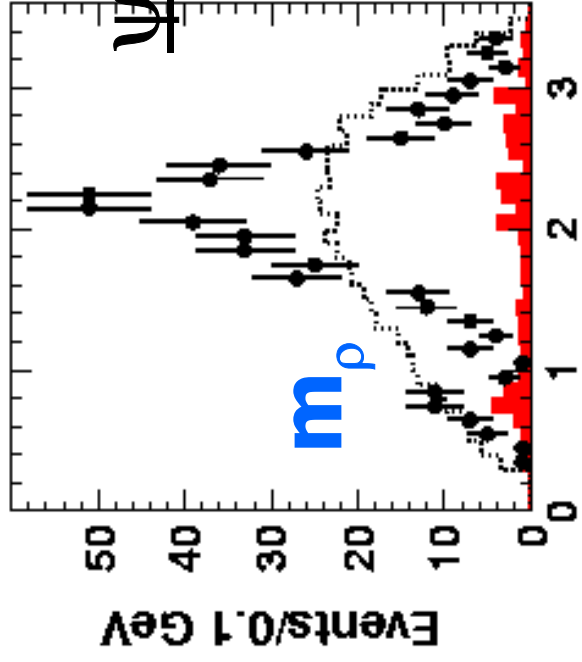
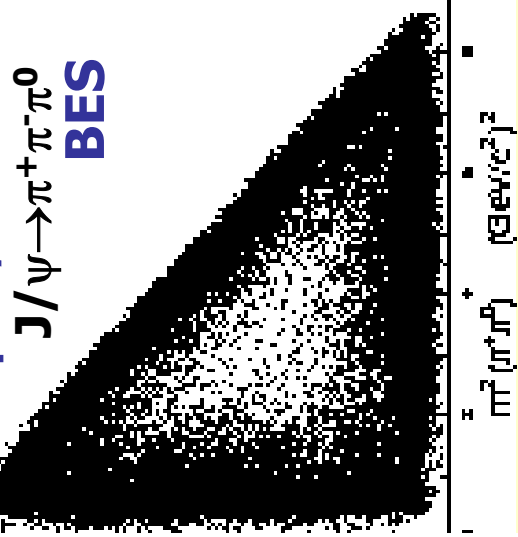
BRs not corrected for interference

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

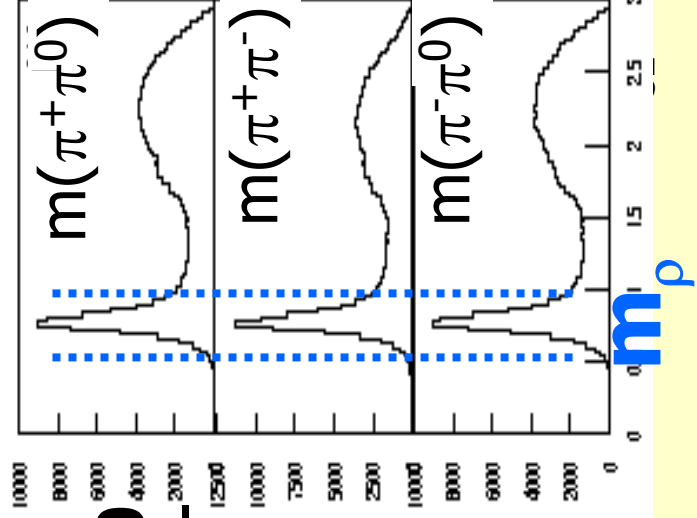
CLEO preliminary



hep-ex/0402013



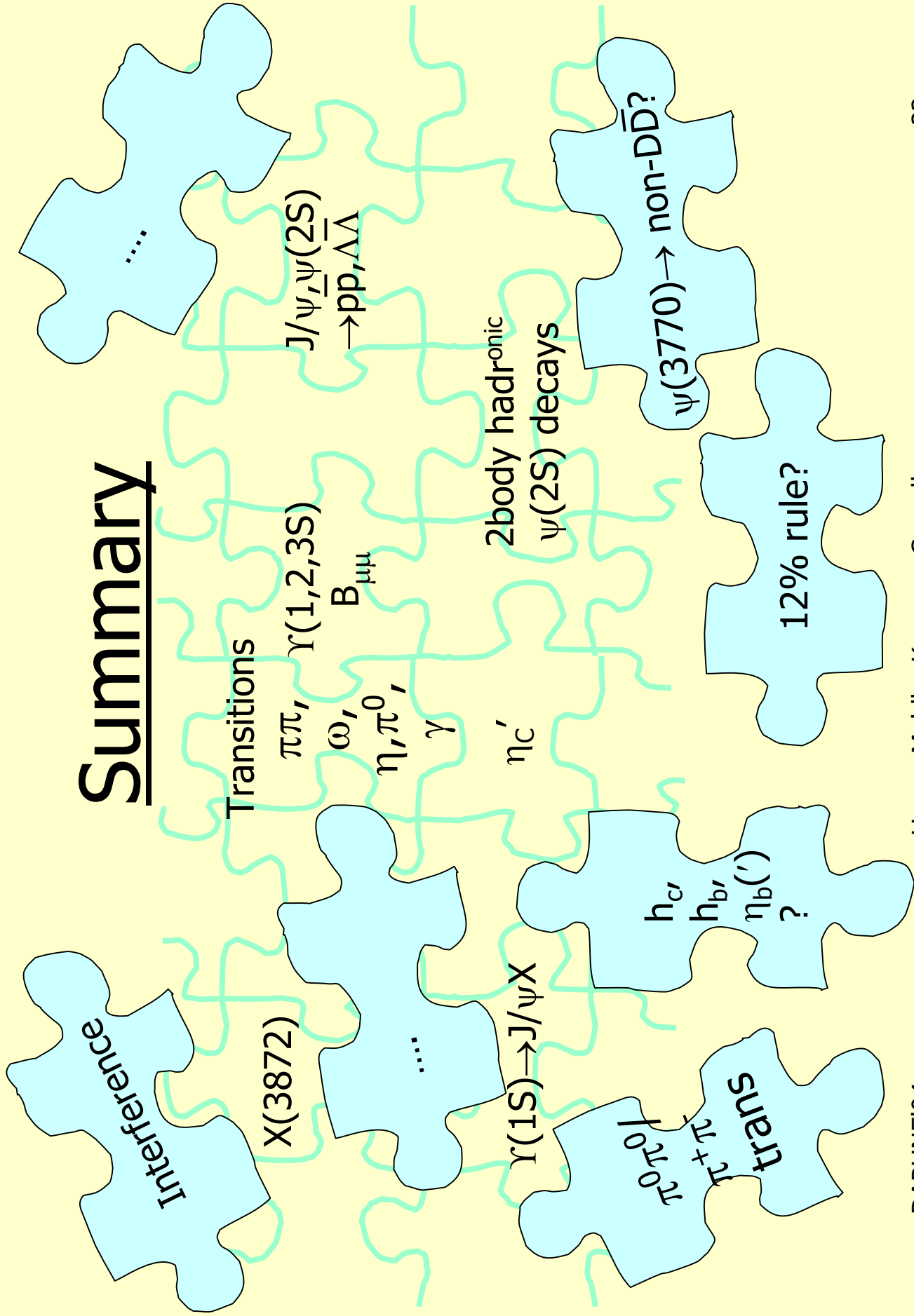
$\psi(2S) \rightarrow \pi^+\pi^-\pi^0$
production
($\rho\pi$??)



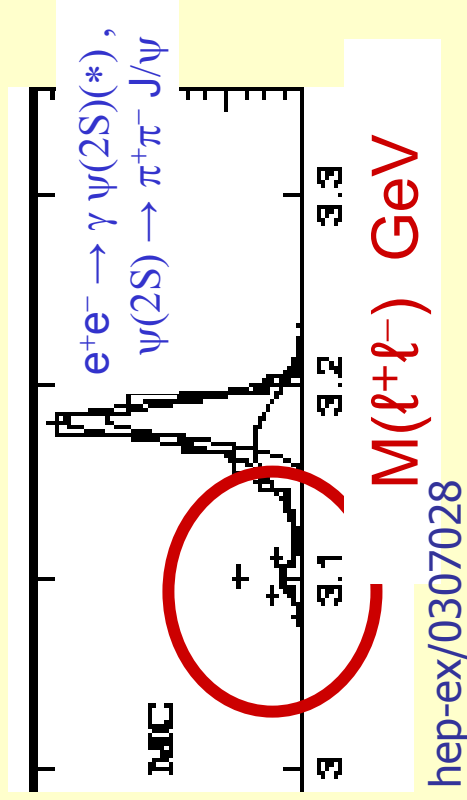
Ianna Mahlike-Krueger, Cornell

06/08/04

Summary

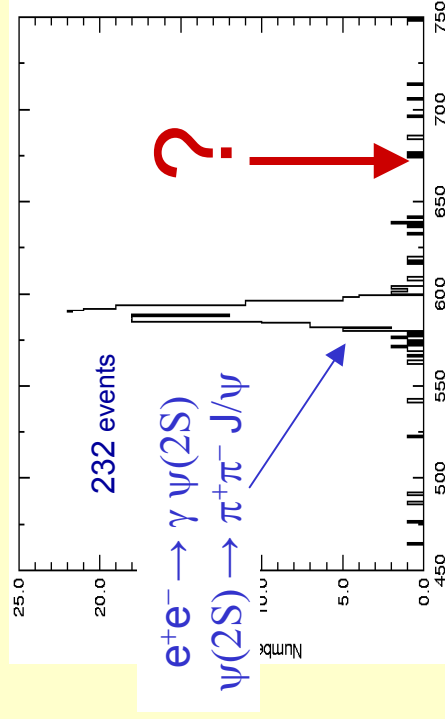


BACKUP



- 28 pb⁻¹ (3.783-3.885GeV), 1.85×10⁵ ψ'' decays
- efficiency: 16%
- 17.8±4.8 events incl 6.0±0.8 bgd (0 from cont)
- BR(ψ(3770)→π⁺π⁻J/ψ) = (0.34±0.14±0.08) %
- Γ = (80 ±32±21) keV

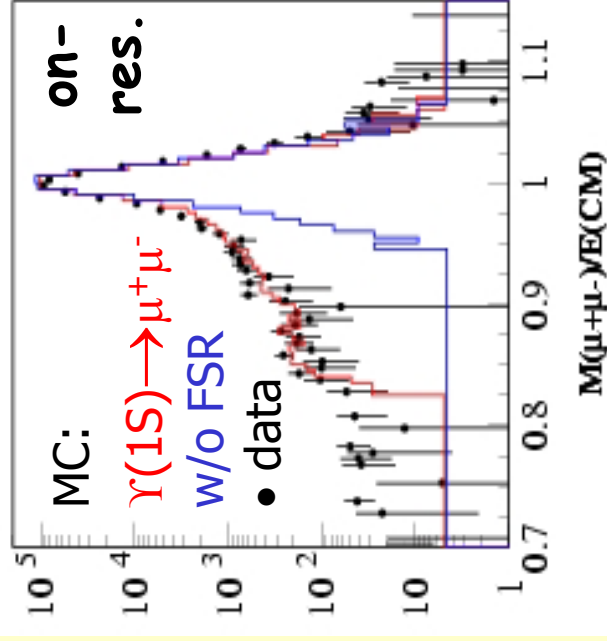
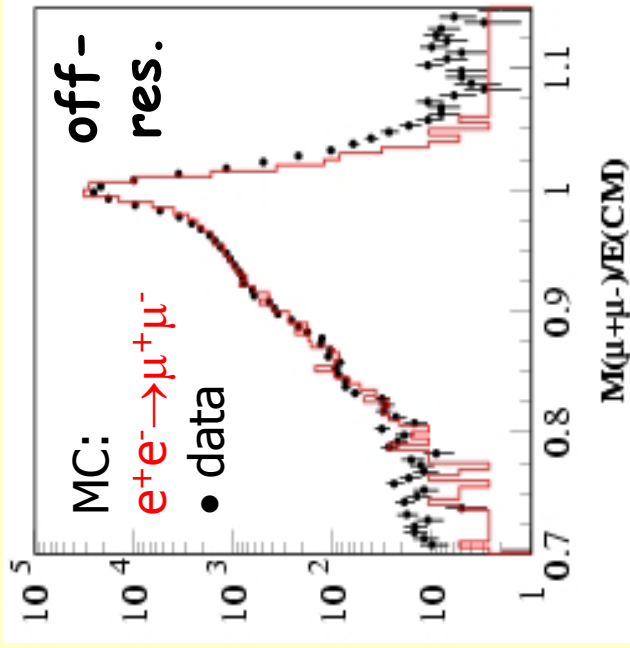
- 5.2±0.2 pb⁻¹, (4.5±0.4)10⁴ ψ'' decays
- efficiency: 37%
- < 4.75 events @ 90%CL
- BR(ψ(3770)→π⁺π⁻J/ψ(1S)) <0.26% @ 90% CL



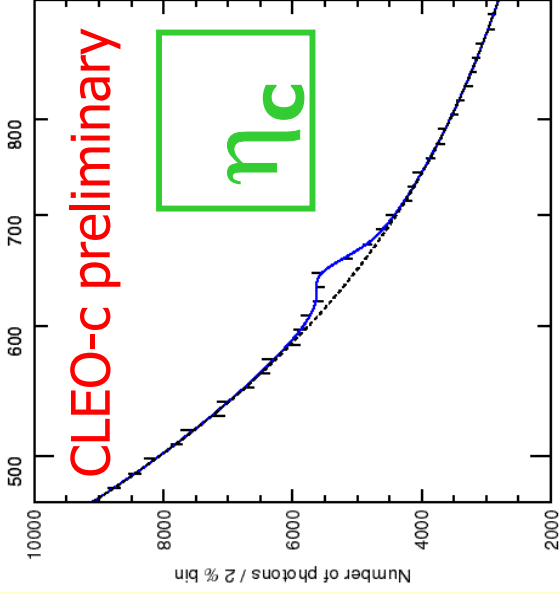
E_{cm} -Mass recoiling $\pi^+\pi^-$
T. Skwarnicki, QWG03

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

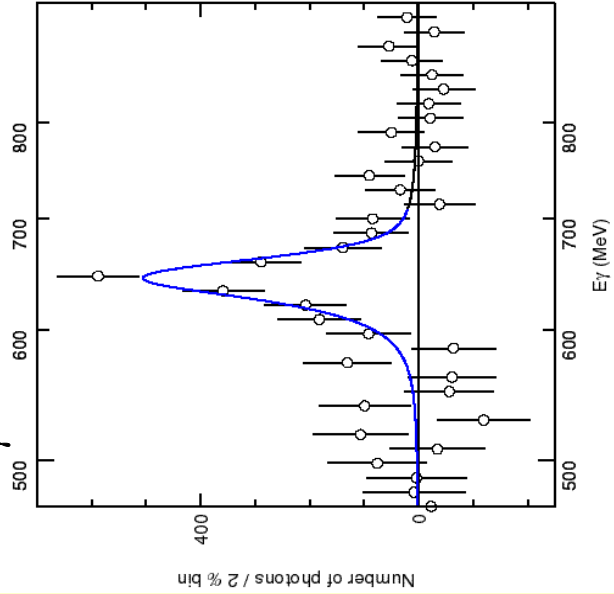
- Goal: 3-4% precision on $B_{\mu\mu}$
 - Gives $\Gamma_{\text{tot}} \rightarrow \Gamma_{ee}$
- 1.0/1.2/1.2 fb⁻¹ on-resonance
+ 0.2/0.4/0.2 fb⁻¹ off-resonance
- Backgrounds: continuum, cascade decays such as $\Upsilon(3S) \rightarrow \gamma \chi_{b0} \rightarrow \gamma \gamma \Upsilon(2S) \rightarrow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



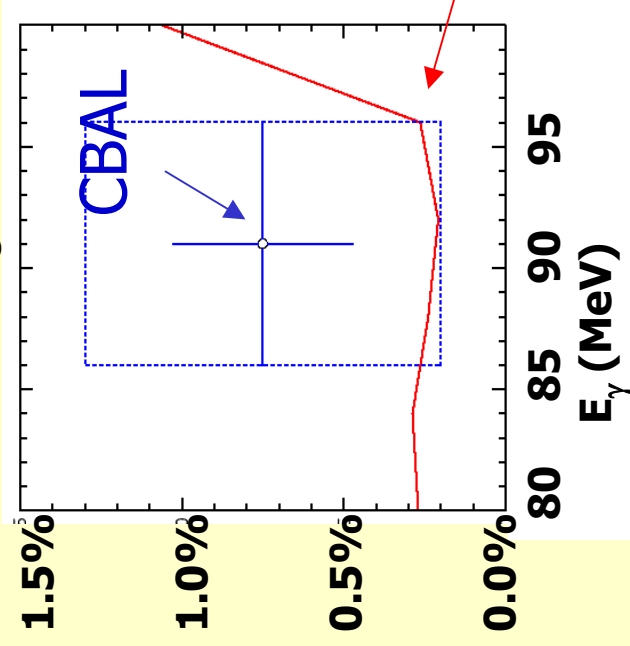
CLEO-c $1, 2^1S_0$ lines



500 600 700 800
 E_γ (MeV)



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



✓ $\eta_c(1S)$ seen @ 8.2σ

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

$\psi(2S)$ Branching Fractions

CLEO data, 3M $\psi(2S)$,
 20pb^{-1} @ $\sqrt{s}=3.67\text{GeV}$

Measure branching to
 fractions relative to
 $B(\psi(2S) \rightarrow \pi^+\pi^-\text{J}/\psi)$,
 $\text{J}/\psi \rightarrow \mu^+\mu^-$

Convert using
 $B(\psi(2S) \rightarrow \pi^+\pi^-\text{J}/\psi)$
 $= (32.3 \pm 1.4)\%$ and
 $B(\text{J}/\psi \rightarrow \mu^+\mu^-)$
 $= (5.88 \pm 0.10)\%$

Background subtracted, not
 corrected for interference

