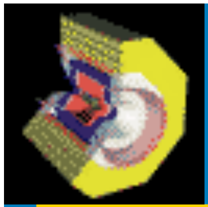

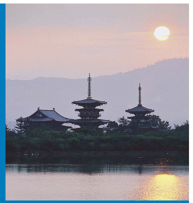

New CLEO Results on Charmonium Transitions

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on behalf of the CLEO Collaboration

6th International Workshop on Heavy Quarkonia
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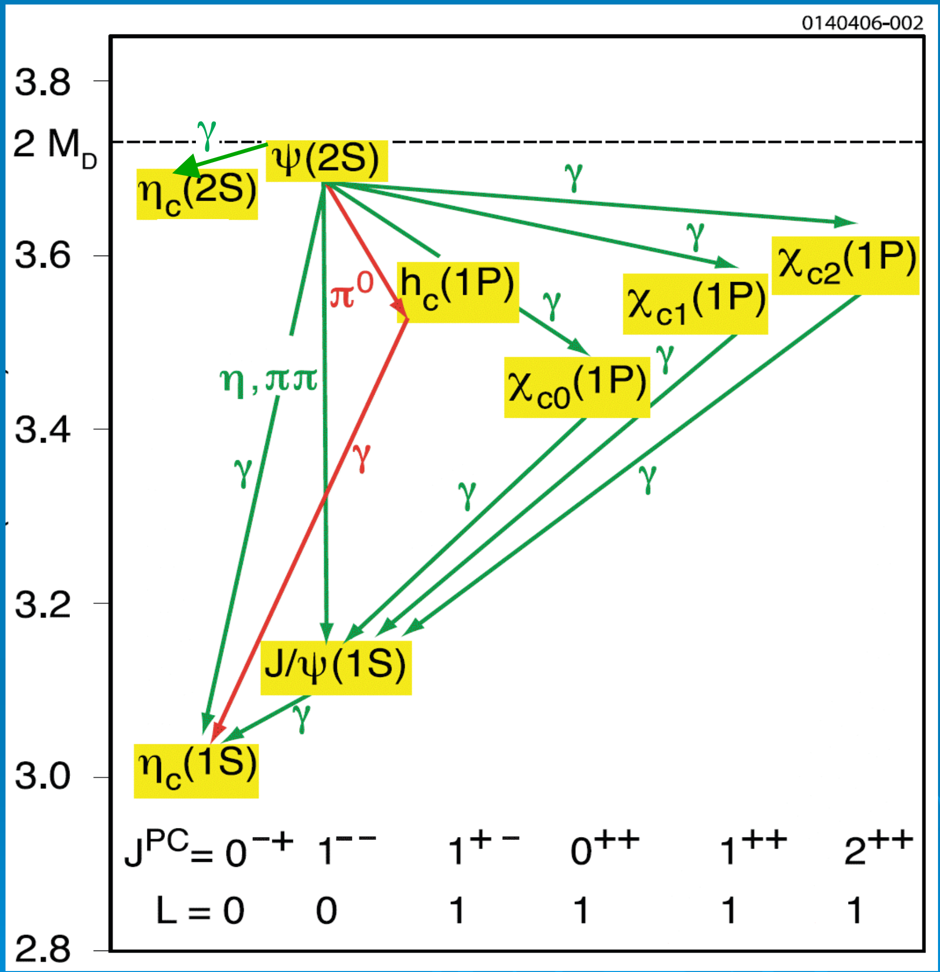
Charmonium Transitions

- Transitions between $\bar{c}c$ bound states provide a rich experimental landscape
  - Allow comparison of many QCD predictions to reality
  - Relativistic & non-perturbative regimes
- Will show measurements relating to *all* of the transitions shown at right
- CLEO datasets
  - ~1.5M $\psi(2S)$ w/CLEO III
  - ~1.5M $\psi(2S)$ w/CLEO-c
  - ~24M $\psi(2S)$ w/CLEO-c
  - ~21 pb^{-1} "continuum" ($\sqrt{s}$ = 3.67 GeV)



New Results since QWG05

- $\psi(2S) \to X\ J/\psi$ branching fractions
  - Improved systematics
  - Surprises found
- $\psi(2S)$, $J/\psi \to \gamma\ \eta_c(1S)$ branching fractions
  - Lineshape systematics
  - Implications for η_c mass
- $\psi(2S) \to \gamma\ \eta_c(2S)$ branching fraction

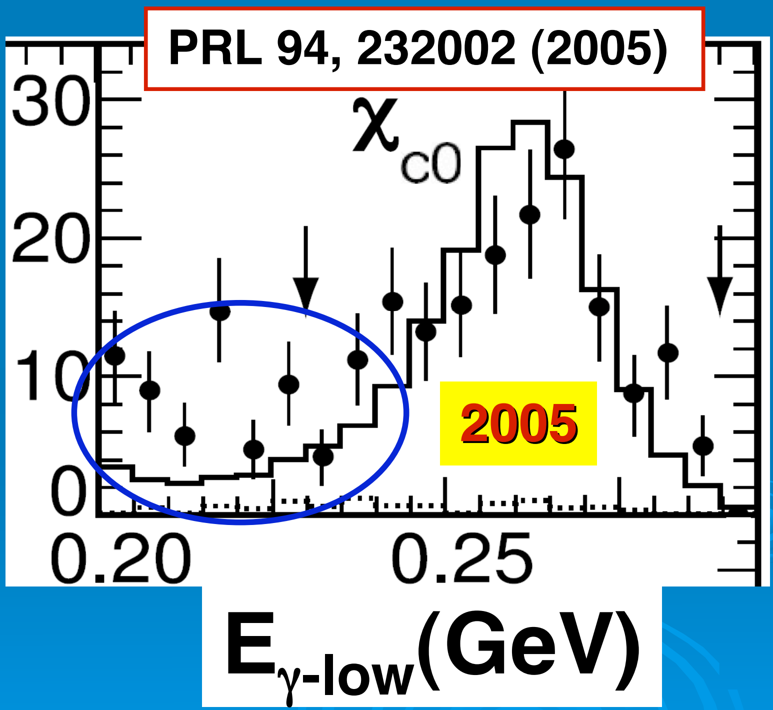
NEW for QWG !

- h_c : Final mass, product branching fraction

$\psi(2S) \rightarrow X\ J/\psi$

$\psi(2S) \to X\ J/\psi$ branching fractions

- CLEO measured all exclusive & inclusive $\psi(2S) \to X\ J/\psi$ branching fractions in a single analysis for the 1st time in 2005
  - 3M $\psi(2S)$ decays
  - $J/\psi \to e^+e^-$, $\mu^+\mu^-$
  - Absolute BR errors dominated by 3% sys error in N($\psi(2S)$)
  - Puzzle with χ_{c0} rate – too few events to diagnose

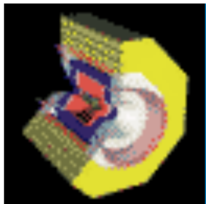


- Why do it again?
  - 8x data : solve χ_{c0} puzzle?
  - Get another crack at reducing systematic errors

Approach

- Published as PRD 78, 011102(R) (2008)
- Use the full 27M $\psi(2S)$ sample
- Use $J/\psi \to e^+e^-$, $\mu^+\mu^-$ <u>only</u> for XJ/ψ modes relative to one another
  - Use bremsstrahlung recovery
  - Constrain leptons + collinear γ's to $M(J/\psi)$
  - Loose cut on χ^2/dof <20 for vertex & mass fits
  - Background-free; all J/ψ cuts cancel in ratios

- Anchor <u>relative</u> XJ/ψ rates to a new <u>absolute</u> measurement of $B_{+-} \equiv B(\pi^+\pi^- J/\psi)$
  - Count $\psi(2S)$ <u>inclusively</u> & model acceptance
  - Count $\pi^+\pi^-$ J/ψ <u>inclusively</u> (not like 2005, not dileptons)
  - Divide the two

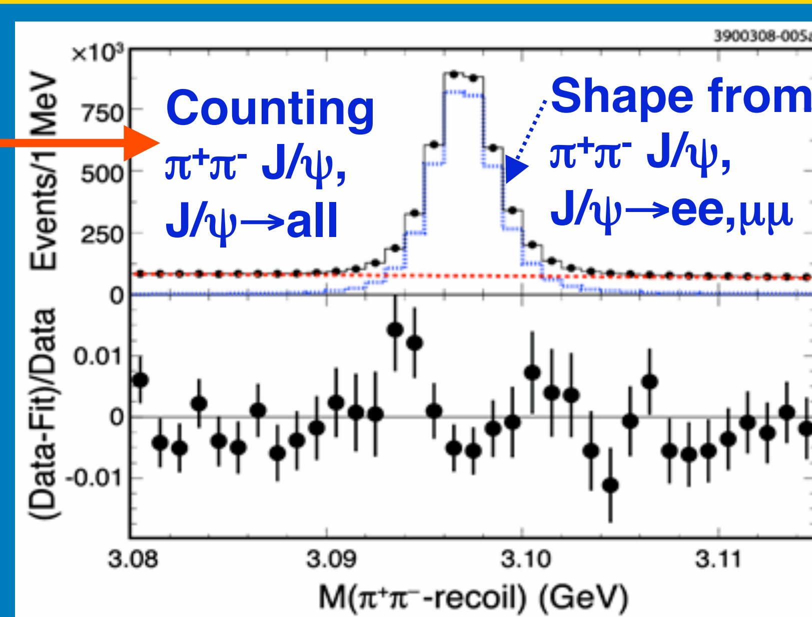


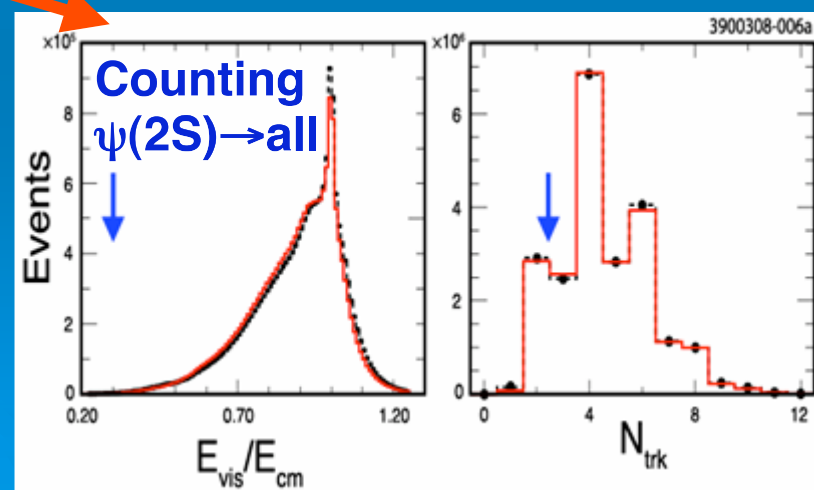
New $B_{+-} \equiv B(\pi^+\pi^- J/\psi)$ Msmt

- **Minimize systematics**
  - Fit $\pi^+\pi^-$ recoil mass for J/ψ
  - Study trigger & tracking ε's
  - Careful modeling of J/ψ, $\psi(2S)$, & χ_{cJ} decays (BRs, multiplicities)
  - Accept essentially all J/ψ, $\psi(2S)$ decays & count
    - ε=40% for $\pi^+\pi^- J/\psi$: N=9.6M events
      - Dominated by ε for wide angle $\pi^\pm$ with p_T>150 MeV
    - ε=76% for $\psi(2S)$: N=27.4M events
  - Subtract continuum with CLEO-c continuum data sample, not MC
  - Error: $\pi^+\pi^- J/\psi$ (0.7%), $\psi(2S)$ (2%)
- B_{+-} = (35.04 ± 0.07 ± 0.77) %

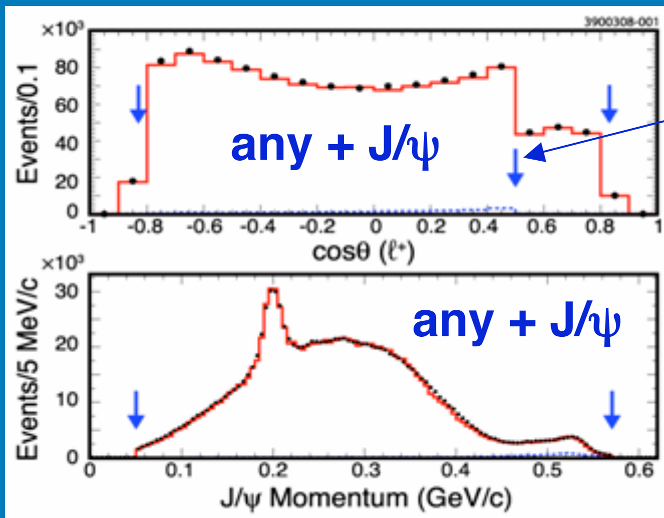
~4.4% (relative) larger than CLEO 2005

±2.2% relative total error



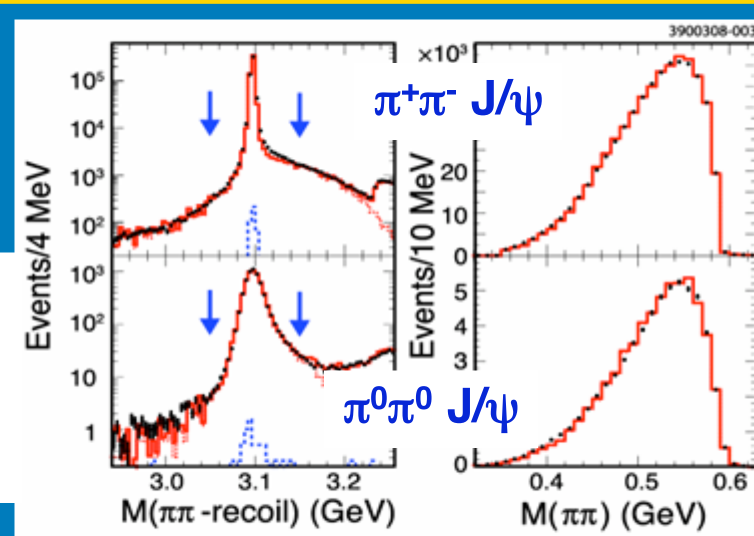


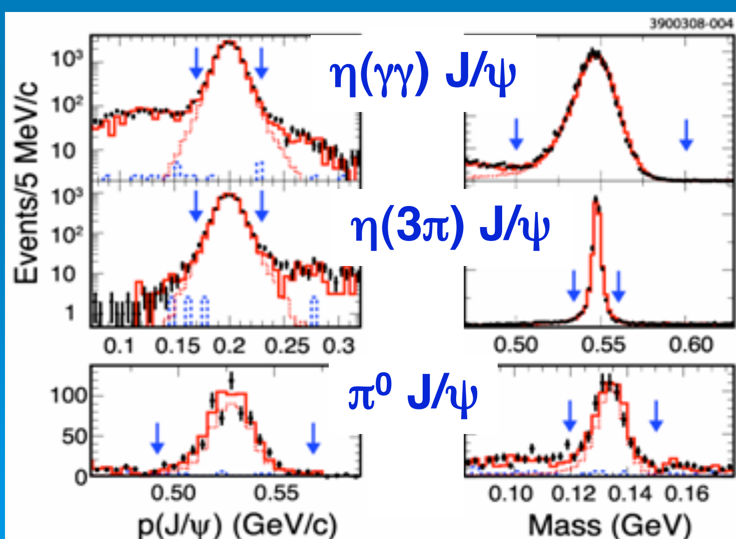
Modeling XJ/ψ, $J/\psi \rightarrow e^+e^-$, $\mu^+\mu^-$



Bhabha suppression

Points: Data
Dotted: Signal MC
Solid: All MC
Blue dash: Cont.

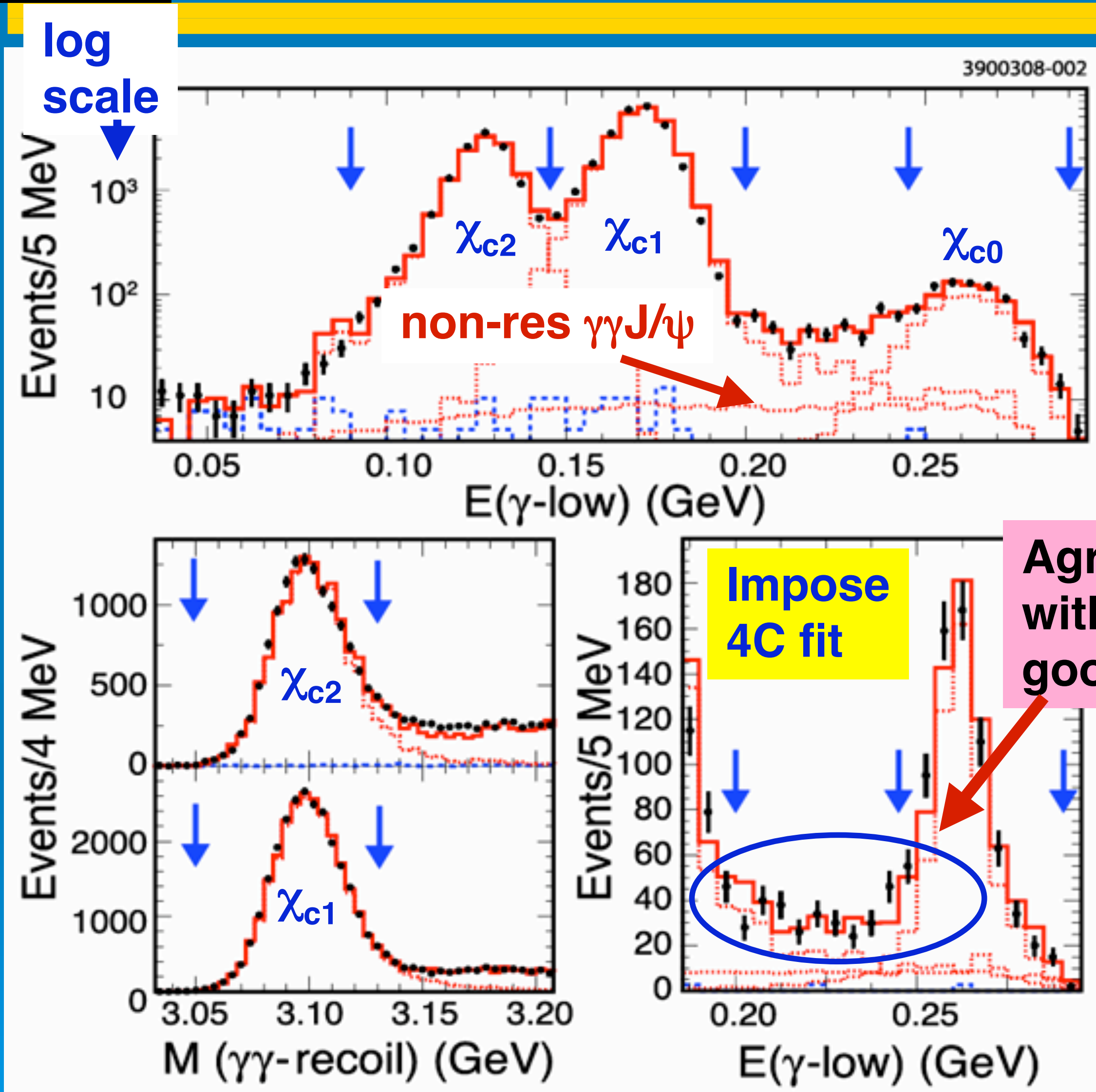




- Negligible continuum bgd
- Spectacularly good data/MC agreement

$\Rightarrow$ Tiny dependence on exact cut values

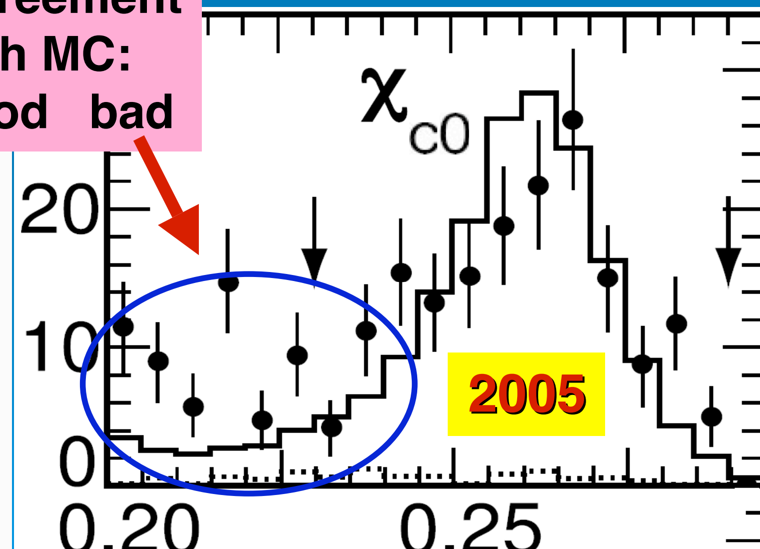
$\psi(2S) \rightarrow \gamma\,\gamma\, J/\psi$ thru χ_{cJ}

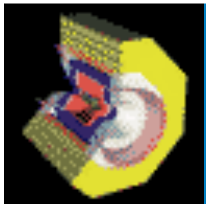


Since 2005:

- 8x data
- Put χ_{c1} BW tail into MC
- Wt χ_{cJ} BW by $E_\gamma^{\ 3}$ in MC
- Allow non-res. $\gamma\gamma J/\psi$

$\Rightarrow \chi_{c0}$ component is now ~30% smaller than CLEO 2005 result





Numerical Results

PRD 78, 011102(R) (2008)

TABLE I. For each channel: the number of events observed in $J/\psi \to \mu^+\mu^-$ after background subtraction and the detection efficiency ratio $r_h^\mu \equiv \epsilon(\psi(2S) \to h + J/\psi^{\mu^+\mu^-})/\epsilon(\psi(2S) \to \text{any} + J/\psi^{\mu^+\mu^-})$; the same for $J/\psi \to e^+e^-$; the ratio of branching fractions $\mathcal{B}(\psi(2S) \to h + J/\psi$ and $\mathcal{B}(\psi(2S) \to \text{any} + J/\psi)$; the same with respect to $\mathcal{B}_{+-}$; absolute branching fractions.

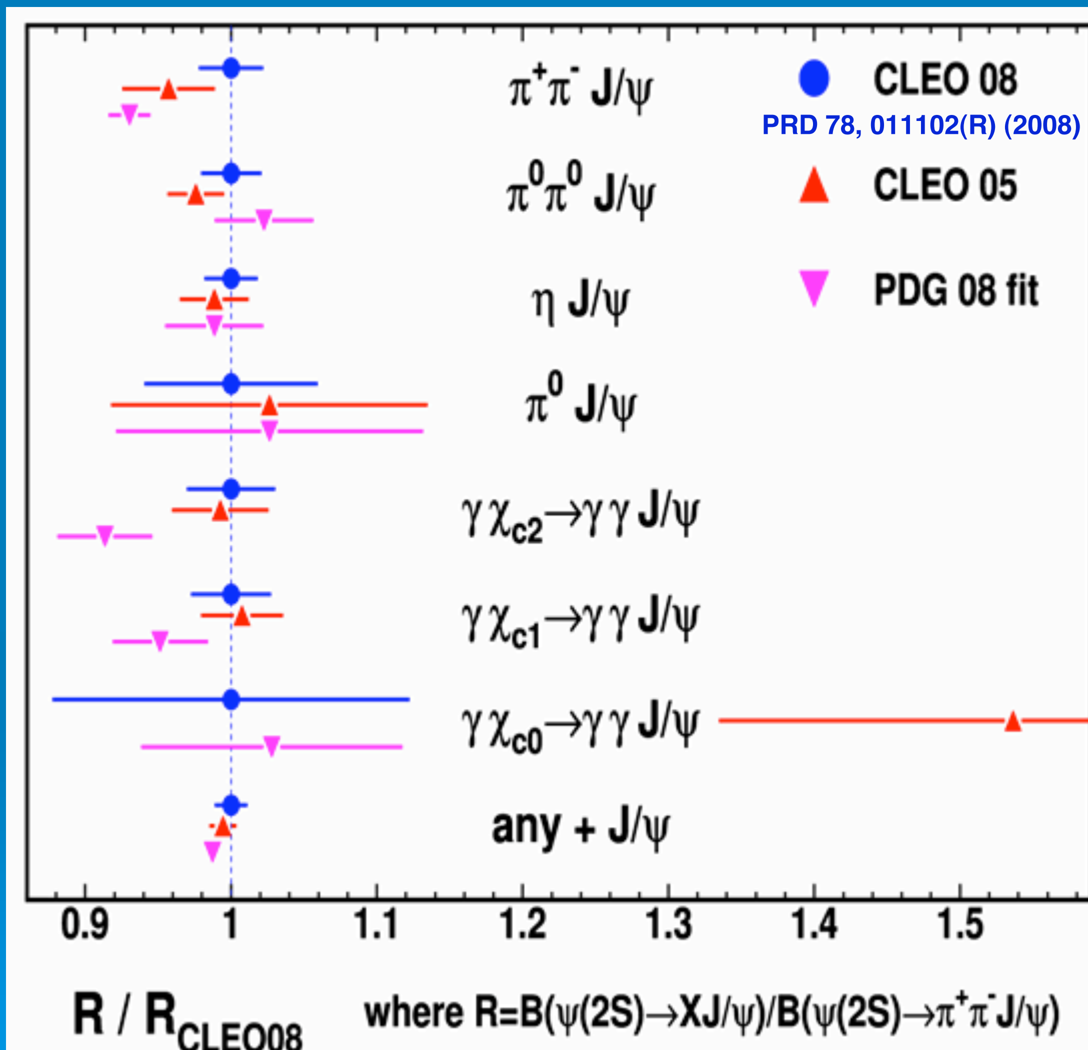
Channels	N^μ	r_h^μ	N^e	r_h^e	$\mathcal{B}/\mathcal{B}_{\text{any}}$ (%)	$\mathcal{B}/\mathcal{B}_{+-}$ (%)	$\mathcal{B}$ (%)
$\pi^+\pi^- J/\psi$	302 030	0.80	263 372	1.01	$56.04 \pm 0.09 \pm 0.62$	$\equiv 100$	$35.04 \pm 0.07 \pm 0.77$
$\pi^0\pi^0 J/\psi$	32 249	0.17	28 746	0.22	$28.29 \pm 0.12 \pm 0.56$	$50.47 \pm 0.22 \pm 1.02$	$17.69 \pm 0.08 \pm 0.53$
$\eta J/\psi$	9819	0.27	8590	0.33	$5.49 \pm 0.06 \pm 0.09$	$9.79 \pm 0.10 \pm 0.15$	$3.43 \pm 0.04 \pm 0.09$
$\pi^0 J/\psi$	289	0.19	238	0.25	$0.213 \pm 0.012 \pm 0.003$	$0.380 \pm 0.022 \pm 0.005$	$0.133 \pm 0.008 \pm 0.003$
$\gamma(\gamma J/\psi)_{\chi_{c0}}$	308	0.22	253	0.28	$0.201 \pm 0.011 \pm 0.021$	$0.358 \pm 0.020 \pm 0.037$	$0.125 \pm 0.007 \pm 0.013$
$\gamma(\gamma J/\psi)_{\chi_{c1}}$	13 244	0.34	11 619	0.44	$5.70 \pm 0.04 \pm 0.15$	$10.17 \pm 0.07 \pm 0.27$	$3.56 \pm 0.03 \pm 0.12$
$\gamma(\gamma J/\psi)_{\chi_{c2}}$	6616	0.31	5768	0.40	$3.12 \pm 0.03 \pm 0.09$	$5.56 \pm 0.05 \pm 0.16$	$1.95 \pm 0.02 \pm 0.07$
any $+ J/\psi$	676 889	$\equiv 1$	466 153	$\equiv 1$	$\equiv 100$	$178.4 \pm 0.3 \pm 2.0$	$62.54 \pm 0.16 \pm 1.55$

B[$\psi(2S) \to \gamma\gamma J/\psi$ (non-resonant)] $\leq \sim 0.1\%$

Derived quantities:

- **$B(\pi^0 J/\psi) / B(\eta J/\psi)$ = (3.88 ± 0.23 ± 0.05) %**
- **$B(\chi_{c2} \to \gamma J/\psi)$ = (24.1 ± 0.2 ± 0.9 ± 1.2) %**
- **$B(\chi_{c1} \to \gamma J/\psi)$ = (40.5 ± 0.3 ± 1.4 ± 1.8) %**
- **$B(\chi_{c0} \to \gamma J/\psi)$ = (1.35 ± 0.07 ± 0.14 ± 0.06) % (was 2.0% in 2005)**
- **B($\psi(2S) \to$ light hadrons) = (15.4 ± 1.5) % (2.9σ > scaled J/ψ rate)**
- **All these SUPERSEDE CLEO 2005 numbers**

Result Comparisons



- B_{+-} <u>much</u> larger (~7%) than PDG08 fit
- χ_{c1} , χ_{c2} larger than PDG08 fit
- χ_{c0} much <u>smaller</u> than CLEO05 result
- Improved precision for all

$\psi(2S)$, $J/\psi \rightarrow \gamma\, \eta_c(1S)$

$\psi(2S)$, $J/\psi \rightarrow \gamma\, \eta_c(1S)$ BRs

- Almost all $\eta_c(1S)$ PDG BRs tied to B($J/\psi \rightarrow \gamma\, \eta_c$)

[35] The quoted branching ratios use $B(J/\psi(1S) \rightarrow \gamma \eta_c(1S)) = 0.0127 \pm 0.0036$.

- …which is poorly measured: ~30% error
  - Why?
    - η_c has large, uncertain width: Γ~30 MeV, lineshape?
    - Just one measurement: Crystal Ball 1986
    - Inclusive measurement of photon lines not easy
      - especially when photons are soft: 114 MeV
- Lattice: Dudek et al., PRD73, 07450 (2006).
  - $B(J/\psi \rightarrow \gamma\, \eta_c) = (2.1 \pm 0.1 \pm 0.4)$ %: 1.5σ bigger than
- B($\psi(2S) \rightarrow \gamma\, \eta_c(1S)$) = (0.30±0.05) % (PDG2008)
  - 2 measurements: Crystal Ball 1986 & CLEO 2004
  - CLEO is now revisiting this with a larger dataset

Approach for $\gamma\ \eta_c(1S)$

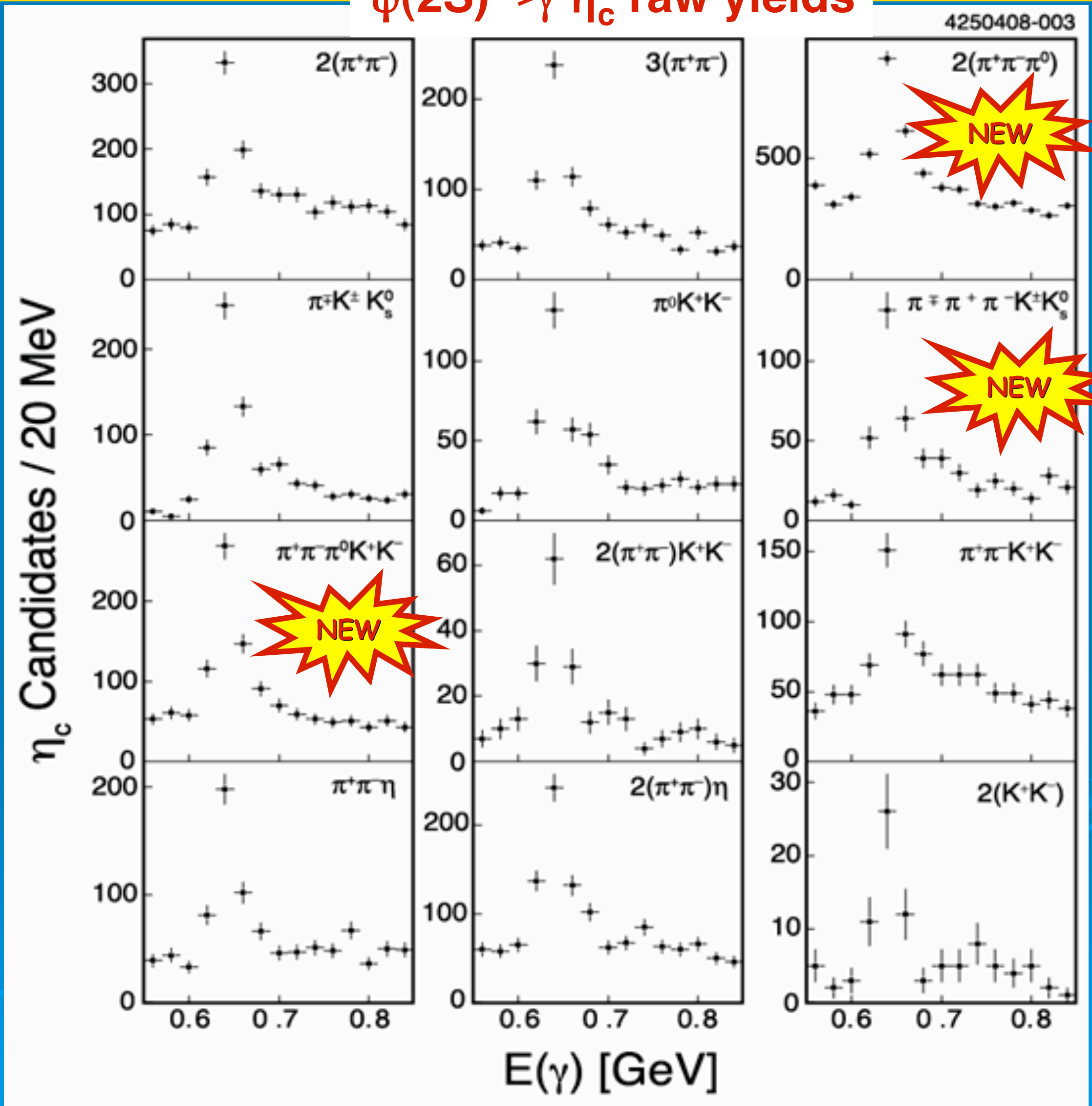
Ryan Mitchell's 2007 QWG talk was prelim version
now done: arXiv:0805.0252. Uses 24M $\psi(2S)$ sample.

1. Isolate exclusive $J/\psi \rightarrow \gamma\eta_c\ (\eta_c \rightarrow X)$ decays
   - Unusual lineshape found for $J/\psi \rightarrow \gamma\ \eta_c$!
   - Parametrize shape & fit for all X: count signal events
   - Isolate exclusive $\psi(2S) \rightarrow \gamma\eta_c\ (\eta_c \rightarrow X)$ decays
   - Unusual (different) shape found for $\psi(2S) \rightarrow \gamma\ \eta_c$
   - Empirically extract shape for all X; count signal events
2. Use lineshape found in 2. to measure $B(\psi(2S) \rightarrow \gamma\ \eta_c)$ from inclusive E_γ spectrum ($E_\gamma \approx 638$ MeV)
3. $R_X = B(\ J/\psi \rightarrow \gamma\ \eta_c{}^X\ )\ /\ B(\ \psi(2S) \rightarrow \gamma\ \eta_c{}^X\ )$ for exclusives
   - Many systematic error cancellations expected
4. Obtain $B(J/\psi \rightarrow \gamma\ \eta_c)$ by multiplying the result from 3. by the result from 4. , thereby avoiding the difficulties in an inclusive analysis search for $E_\gamma \approx 114$ MeV .

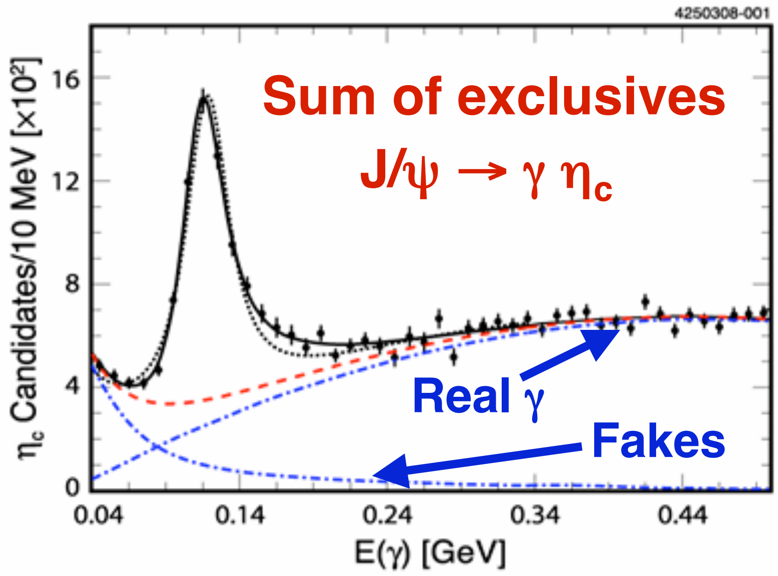
Exclusive η_c(1S) Reconstruction

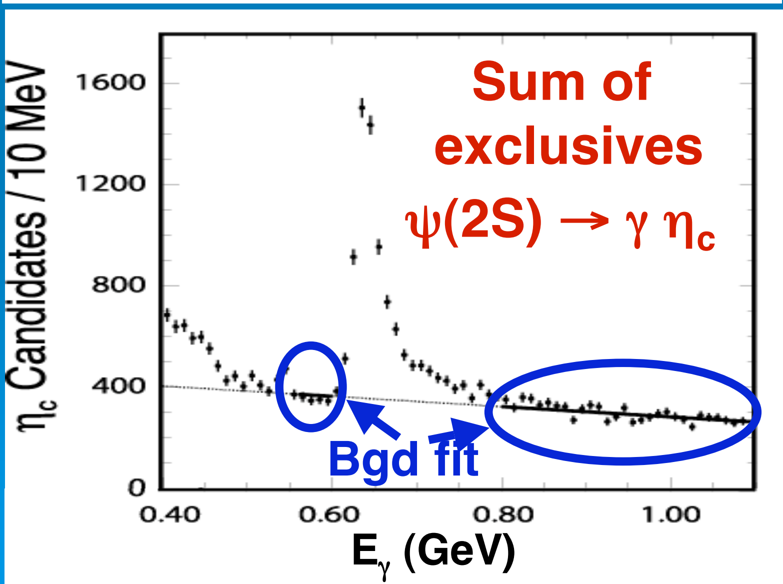
- Use all known decays (except $p\bar{p}$) + 3 new ones: 12 modes
- Full reconstruction; use dE/dx & RICH for $K^{\pm}$, $\pi^{\pm}$
- Tag J/ψ with $\pi^+\pi^-$
- Constrain to laboratory 4-momentum w/kinematic fit
- Extract signal with E_{γ} spectrum
  - **Peak at ≈ 638 MeV**

$\psi(2S) \to \gamma\, \eta_c$ raw yields



Exclusive shapes & yields





Breit-Wigner lineshape does not fit either J/ψ or $\psi(2S) \rightarrow \gamma\, \eta_c$ data!

- Steeper rise on low side; longer tail on high side
- Shapes are different from each other

$J/\psi \rightarrow \gamma\eta_c$

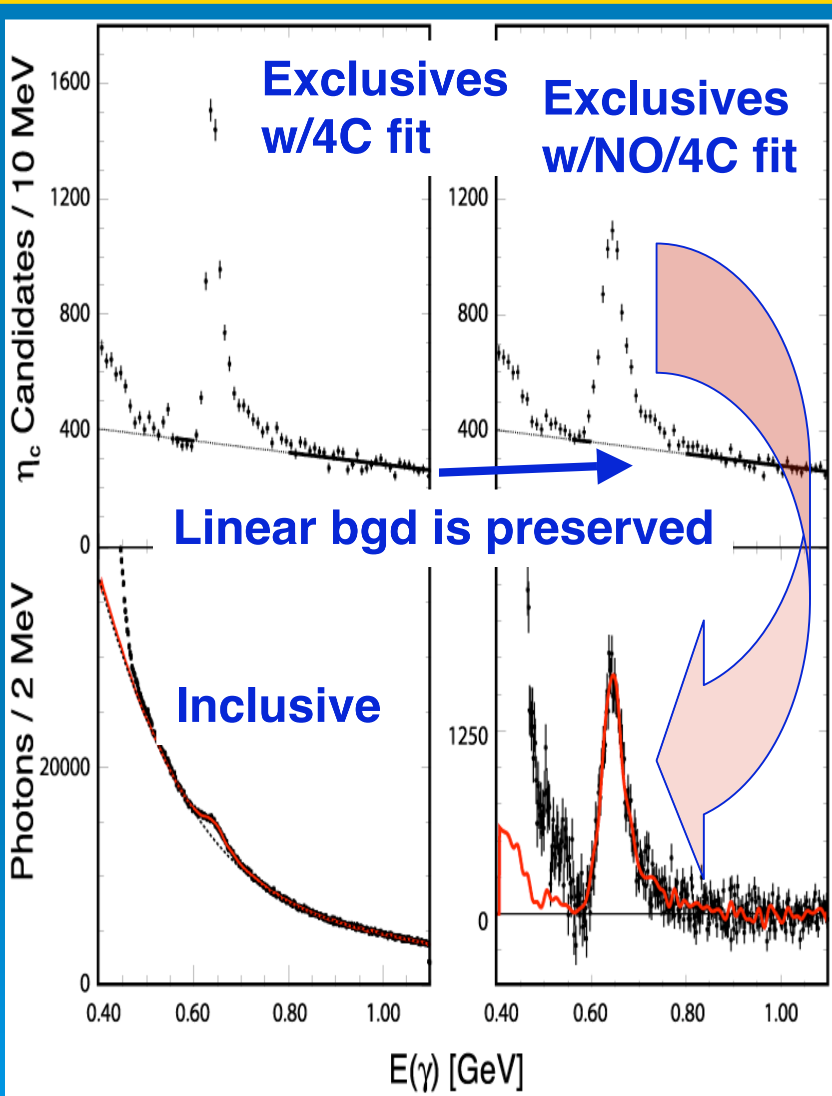
- MC: bgd has 2 smooth shapes
  - spurious showers (fakes)
  - non-signal γ's from π^0's
- Matrix element expectations motivate
  $BW \times E_\gamma^{\,3} \times \exp(\, E_\gamma^{\,2} / 8\beta^2\,)$

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

- MC predicts LINEAR bgd
- Expect $BW \times E_\gamma^{\,7} \times$ (cutoff ?)
- Count (Data – Linear Bgd) as signal

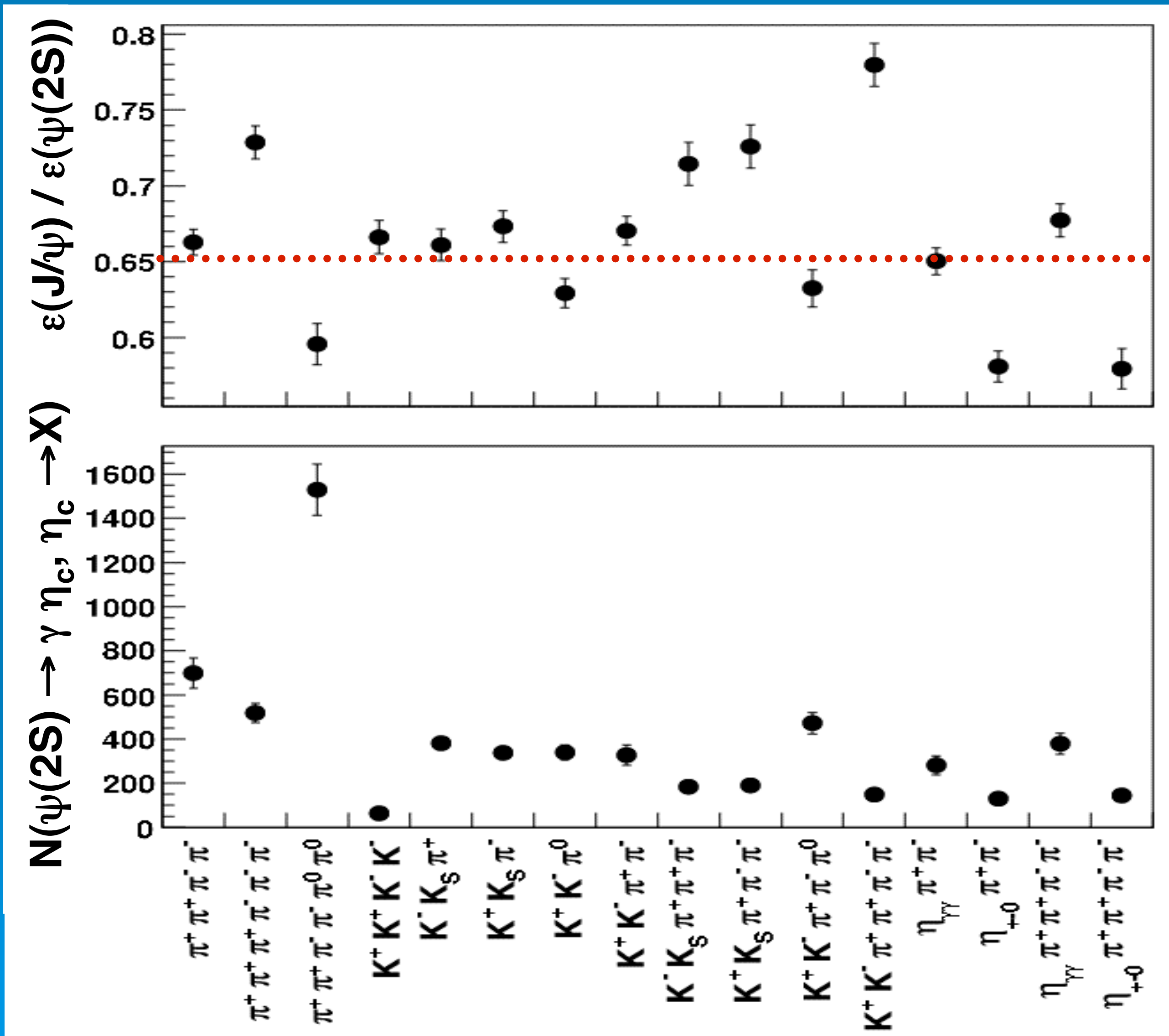
Brambilla, Jia, & Vairo, PRD 73, 054005 (2006)

Inclusive $\psi(2S) \rightarrow \gamma\, \eta_c(1S)$



- Cannot use shape from exclusives-4C-fit constrained E_γ for inclusives because inclusive distribution cannot be constrained
- Note that linear background in exclusives is identical if the unconstrained E_γ is used
- Fit inclusive E_γ to polynomial bgd + floating signal shape from bgd-subtracted exclusive distribution

ε Ratio, Number by Channel



Weighted ε-ratio of ~65% is basically the efficiency of detecting the transition dipion in $\psi(2S) \to \pi^+\pi^- J/\psi$, many other systematic errors nearly cancel

Compute BRs for $\psi(2S)$, $J/\psi \to \gamma\, \eta_c(1S)$

$$\mathcal{B}_{2S} = \frac{N^{INC}_{2S}}{\varepsilon^{INC}_{2S} N_{\psi(2S)}}$$

$$\frac{\mathcal{B}_{1S}}{\mathcal{B}_{2S}} = \frac{N^{EXC}_{1S}}{N^{EXC}_{2S}\left(\varepsilon^{EXC}_{1S}/\varepsilon^{EXC}_{2S}\right)\mathcal{B}_{\pi\pi}}$$

$$\mathcal{B}_{1S} = \frac{\left(N^{INC}_{2S}/N^{EXC}_{2S}\right) N^{EXC}_{1S}}{\varepsilon^{INC}_{2S}\left(\varepsilon^{EXC}_{1S}/\varepsilon^{EXC}_{2S}\right) N_{\psi(2S)}\mathcal{B}_{\pi\pi}}$$

From XJ/ψ analysis

N^{INC}_{2S}	59510 ± 2145
N^{EXC}_{2S}	5376 ± 199
$N^{INC}_{2S}/N^{EXC}_{2S}$	11.07 ± 0.33
N^{EXC}_{1S}	5638 ± 187
ε^{INC}_{2S}	56.37%
$\varepsilon^{EXC}_{1S}/\varepsilon^{EXC}_{2S}$	0.6515 $\approx\varepsilon(\pi^+\pi^-)$

≈independent of mode

$B(\psi(2S) \to \gamma\, \eta_c) = (4.32 \pm 0.16 \pm 0.60) \times 10^{-3}$

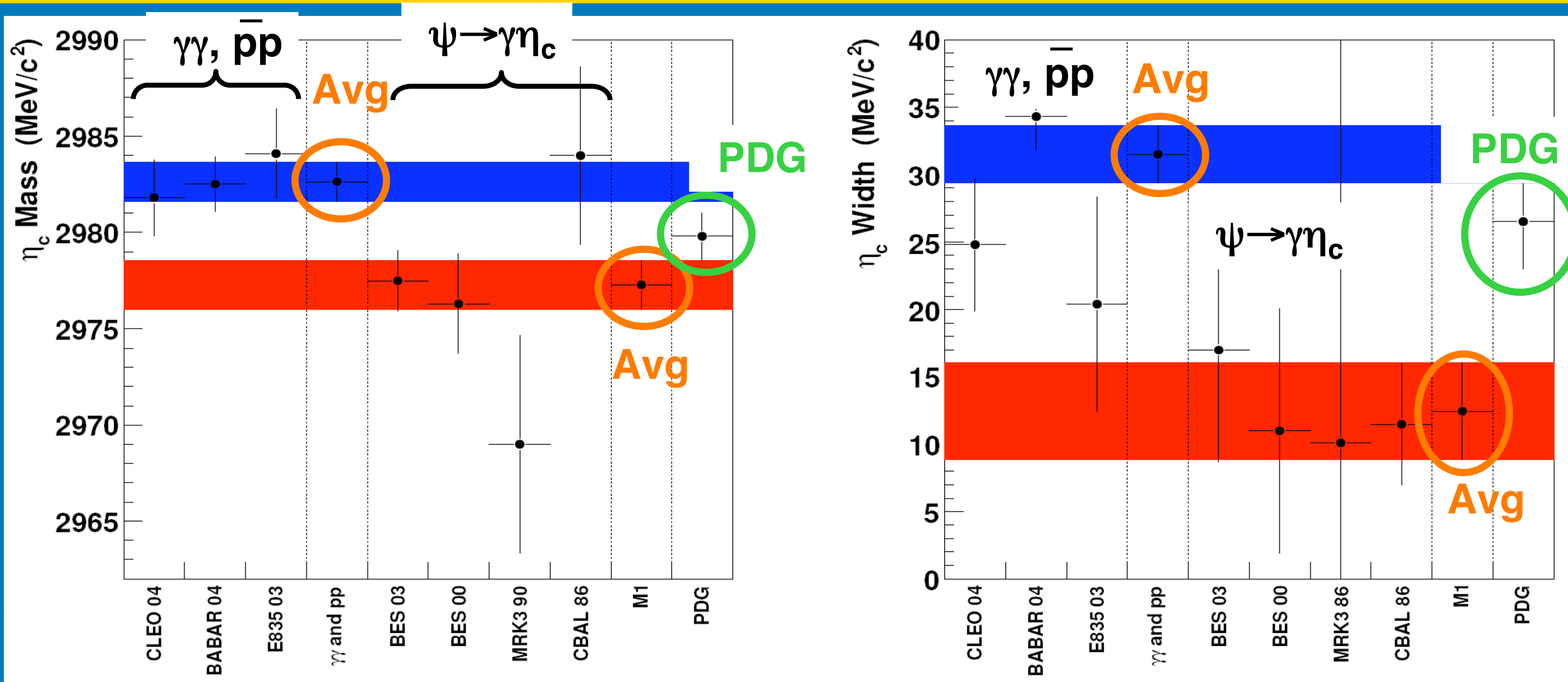
$$\frac{B(J/\psi \to \gamma\, \eta_c)}{B(\psi(2S) \to \gamma\, \eta_c)} = 4.59 \pm 0.23 \pm 0.64$$

$B(J/\psi \to \gamma\, \eta_c) = (1.98 \pm 0.09 \pm 0.30)\ \%$

arXiv:0805.0252

~15% sys err mainly from varying signal & bgd shapes & modeling unknown η_c decay modes

Lineshape effects on M, Γ



- **Values of M & Γ from M1 transitions bias the world average values**
  - **Effect of lineshape distortion w.r.t. simple BW**

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

$\psi(2S) \to \gamma\, \eta_c(2S)$

- **Not yet observed**
  - **1982 Crystal Ball sighting (M=3592 MeV, B=0.2-1.3%) discredited**
    - ➢ **CLEO put limit (at CB mass): B[$\psi(2S) \to \gamma\, \eta_c(2S)$] < 0.2%**

PRD 70, 112002, 2004

- **Too little is known about $\eta_c(2S)$:**

Experiment	M [MeV]	Γ [MeV]	Process
Belle [1]	$3654 \pm 6 \pm 8$	—	$B^\pm \to K^\pm\, \eta_c(2S), \eta_c(2S) \to K_S K^\pm \pi^\mp$
CLEO [2]	$3642.9 \pm 3.1 \pm 1.5$	$6.3 \pm 12.4 \pm 4.0$	$\gamma\gamma \to \eta_c(2S) \to K_S K^\pm \pi^\mp$
BaBar [3]	$3630.8 \pm 3.4 \pm 1.0$	$17.0 \pm 8.3 \pm 2.5$	$\gamma\gamma \to \eta_c(2S) \to K_S K^\pm \pi^\mp$
BaBar [4]	$3645.0 \pm 5.5^{+4.9}_{-7.8}$	—	$e^+e^- \to J/\psi c\bar{c}$
PDG [5]	3638 ± 4	14 ± 7	—

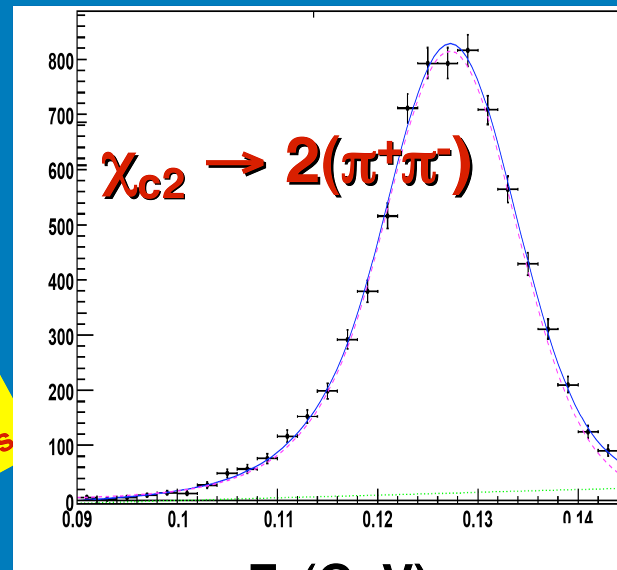
- **Mass ⇒ E_γ = 48 MeV, where $\sigma_E \approx$5 MeV<Γ**
  - **Too soft, width too uncertain for pure inclusive observation**
- **Try exclusive modes – similar to $\eta_c(1S)$**
  - **Use ~26M $\psi(2S)$ sample**
  - **Avoid modes with more than one π^0 due to larger bgds**
  - **Validate on copious χ_{c2} decays: $E_\gamma \approx$128 MeV**
  - **Also seek $\eta_c(2S) \to \pi^+\pi^-\, \eta_c(1S)$**

$\psi(2S) \to \gamma\, \chi_{c2}$ Exclusive Decays

stat errors only

Mode	Mean (MeV)	N_{sig}	B (10^{-3})	B_{PDG} (10^{-3})
$2(\pi^+\pi^-)$	127.23 ± 0.10	7215 ± 119	13.0 ± 0.2	12.5 ± 1.6
$3(\pi^+\pi^-)$	127.09 ± 0.11	6083^{+113}_{-112}	15.7 ± 0.3	8.7 ± 1.8
$K^+K^-\pi^+\pi^-$	127.20 ± 0.12	4717 ± 95	9.0 ± 0.2	10.0 ± 2.6
$K^+K^-\pi^0$	127.71 ± 0.58	219 ± 17	0.41 ± 0.03	0.36 ± 0.09
$K_S K^\pm \pi^\mp$	127.87 ± 0.43	294 ± 17	0.80 ± 0.05	0.71 ± 0.11
$\pi^+\pi^-\eta(\gamma\gamma)$	$128.15^{+0.95}_{-0.97}$	97 ± 12	0.70 ± 0.10	0.56 ± 0.15
$\pi^+\pi^-\eta(\pi^+\pi^-\pi^0)$	$126.86^{+2.10}_{-1.82}$	31 ± 7	0.55 ± 0.13	0.56 ± 0.15
$\pi^+\pi^-\eta'$	127.60	3.7 ± 5.2	0.08 ± 0.11	0.59 ± 0.22
$K^+K^-\eta(\gamma\gamma)$	127.60	29 ± 8	0.19 ± 0.05	< 0.4
$K^+K^-\eta(\pi^+\pi^-\pi^0)$	$127.96^{+2.21}_{-2.61}$	17 ± 5	0.26 ± 0.08	< 0.4
$K^+K^-\pi^+\pi^-\pi^0$	127.39 ± 0.14	3197 ± 62	12.8 ± 0.3	
$K^+K^-2(\pi^+\pi^-)$	127.24 ± 0.18	2249 ± 68	8.3 ± 0.3	
$K_S K^\pm \pi^\mp \pi^+\pi^-$	127.49 ± 0.23	1453^{+53}_{-54}	7.2 ± 0.3	-

Previously unseen modes



E_γ (GeV)

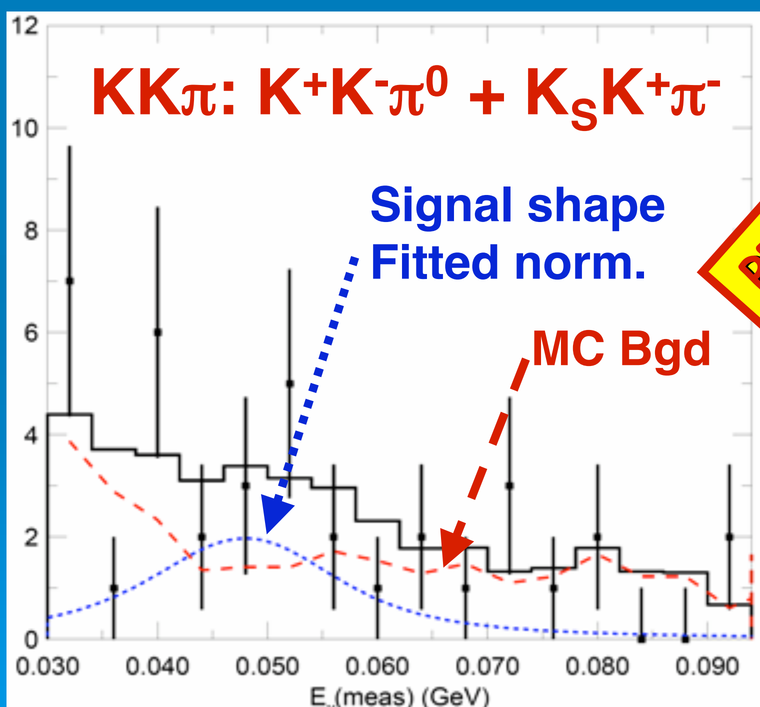
BRs are only crosschecks, not measurements.

substructure!

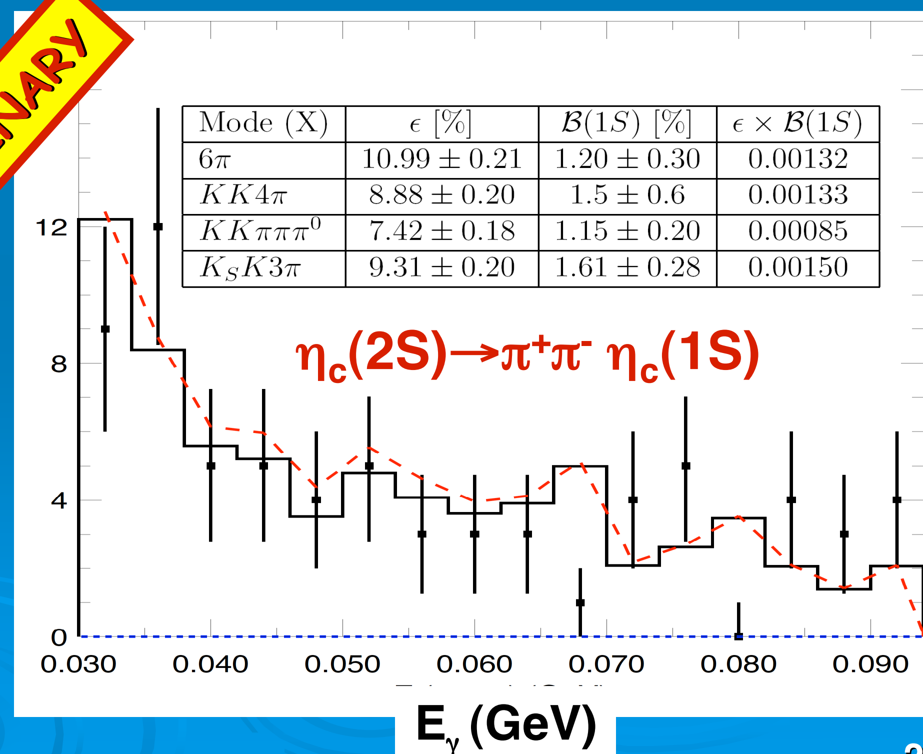
- Good agreement with previously measured BR's & E_γ value
- Find 4 previously unseen decay modes, 3 of them of substantial BR!
- Validates code & signal normalization
  - Does not test bgd modeling as these signals are very large
  - For $\gamma\, \eta_c(2S)$ fits use fixed shape, floating normalization MC of "generic" $\psi(2S)$ decays – bgd is dominated by fakes

η_c(2S) Exclusive Decays

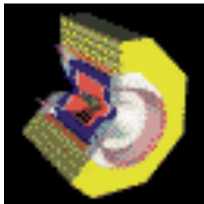
- No signals seen in any mode!
- $K\bar{K}\pi$ is key
  - Only one for which an absolute BR is known:
  - BaBar: B[$\eta_c(2S) \rightarrow K \bar{K} \pi$] = (1.9 ± 0.4 ± 0.5 ± 1.0)%
  - PDG08: B[$\eta_c(1S) \rightarrow K \bar{K} \pi$] = (7.0 ± 1.2)%



PRELIMINARY



Mode (X)	ϵ [%]	$\mathcal{B}(1S)$ [%]	$\epsilon \times \mathcal{B}(1S)$
6π	10.99 ± 0.21	1.20 ± 0.30	0.00132
$KK4\pi$	8.88 ± 0.20	1.5 ± 0.6	0.00133
$KK\pi\pi\pi^0$	7.42 ± 0.18	1.15 ± 0.20	0.00085
$K_S K3\pi$	9.31 ± 0.20	1.61 ± 0.28	0.00150



$\psi(2S) \rightarrow \gamma\, \eta_c(2S)$ Results

Mode	N_{sig} (90% C.L.)	Efficiency (%)	Systematic Uncertainty (%)	$B_1 \times B_2$ (10^{-6})
$2(\pi^+\pi^-)$	< 64.8	20.49 ± 0.16	14.3	< 14.0
$3(\pi^+\pi^-)$	< 36.6	14.22 ± 0.14	29.4	< 12.9
$K^+K^-\pi^+\pi^-$	< 35.2	19.49 ± 0.15	36.5	< 9.5
$K^+K^-\pi^0$	< 16.0	17.76 ± 0.14	47.2	< 5.2
$K_S K^\pm \pi^\mp$	< 11.0	20.40 ± 0.15	24.7	< 3.8
$KK\pi$	< 21.9	7.63 ± 0.04	26.9	< 14.1
$\pi^+\pi^-\eta$	< 4.3	5.68 ± 0.05	48.0	< 4.3
$\pi^+\pi^-\eta'$	< 4.1	8.14 ± 0.10	28.1	< 14.2
$K^+K^-\eta$	< 7.5	6.47 ± 0.05	32.1	< 5.8
$K^+K^-\pi^+\pi^-\pi^0$	< 65.4	8.74 ± 0.11	37.4	< 40.2
$K^+K^-2(\pi^+\pi^-)$	< 20.6	9.93 ± 0.11	14.0	< 9.1
$K_S K^\pm \pi^\mp \pi^+\pi^-$	< 23.9	11.39 ± 0.13	23.4	< 14.4

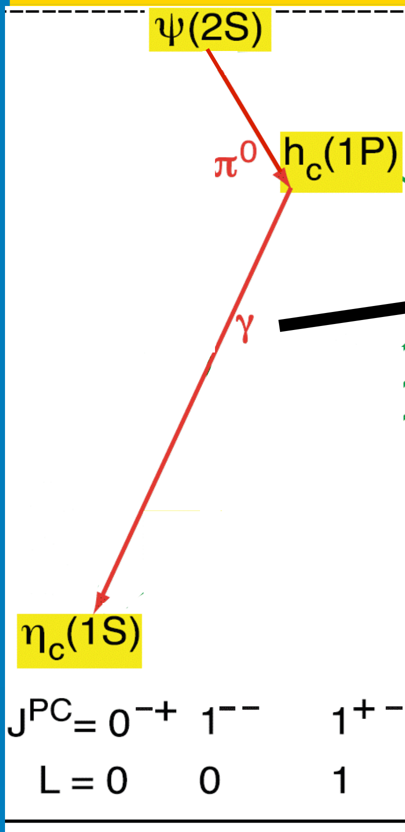
$\mathcal{B}(\psi(2S) \rightarrow \gamma\eta_c(2S))\mathcal{B}(\eta_c(2S) \rightarrow \pi^+\pi^-\eta_c(1S)) < 1.4 \times 10^{-4}$ $(90\%\ C.L.)$

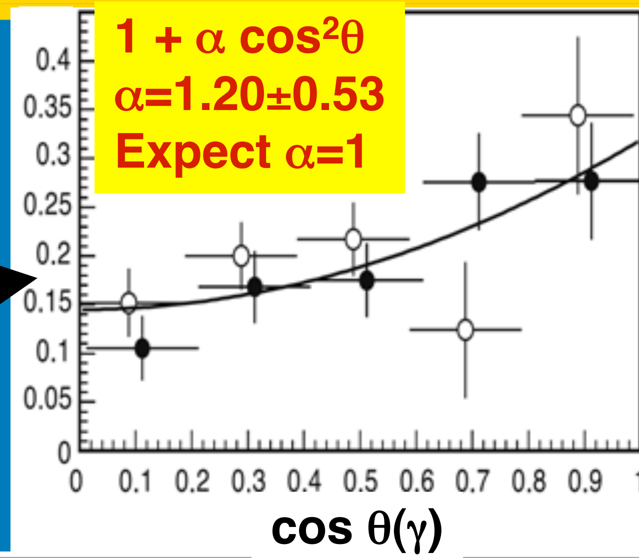
PRELIMINARY

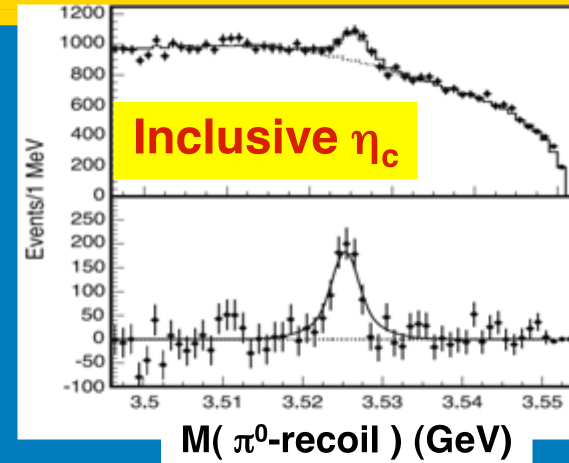
- From KKπ, **B[$\psi(2S) \rightarrow \gamma\, \eta_c(2S)$] < 7.4 x 10^{-4} @ 90%CL**
- We expect for B: estimate by scaling from $J/\psi \rightarrow \gamma\eta_c$ case: B≈(48/114)^3 x $\Gamma[J/\psi \rightarrow \gamma\, \eta_c(1S)]$ / $\Gamma_{tot}[\psi(2S)]$ = 4x10^{-4}
  - Measurement falls factor of 2 short of expected branching fraction

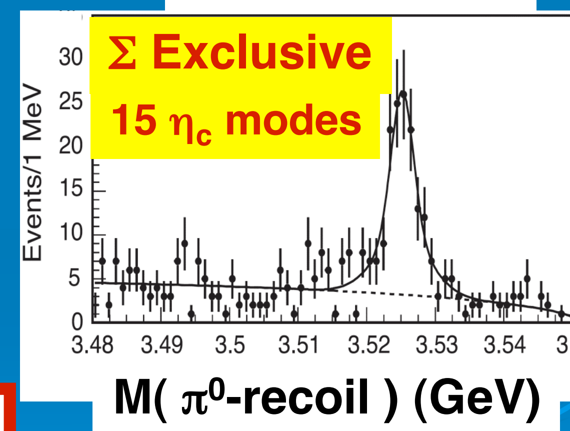
h_c

h_c: M & B($\psi(2S)\to\pi^0 h_c$) x B($h_c\to\gamma\eta_c$)









	Inclusive	Exclusive
Counts	1146 ± 118	136 ± 14
Significance	10.0σ	13.2σ
$M(h_c)$ (MeV)	$3525.35 \pm 0.23 \pm 0.15$	$3525.21 \pm 0.27 \pm 0.14$
$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^4$	$4.22 \pm 0.44 \pm 0.52$	$4.15 \pm 0.48 \pm 0.77$

$$M(h_c)_{\rm AVG} = 3525.20 \pm 0.18 \pm 0.12 \text{ MeV},$$

Also averaging in CLEO 3M result

$$(\mathcal{B}_1 \times \mathcal{B}_2)_{\rm AVG} = (4.16 \pm 0.30 \pm 0.37) \times 10^{-4}$$

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Hyperfine splitting: $\Delta M_{hf}(1P) = +0.08 \pm 0.18(\text{stat.}) \pm 0.12(\text{syst.})\text{MeV}$

Expect ~0 at lowest order

Summary & Conclusions

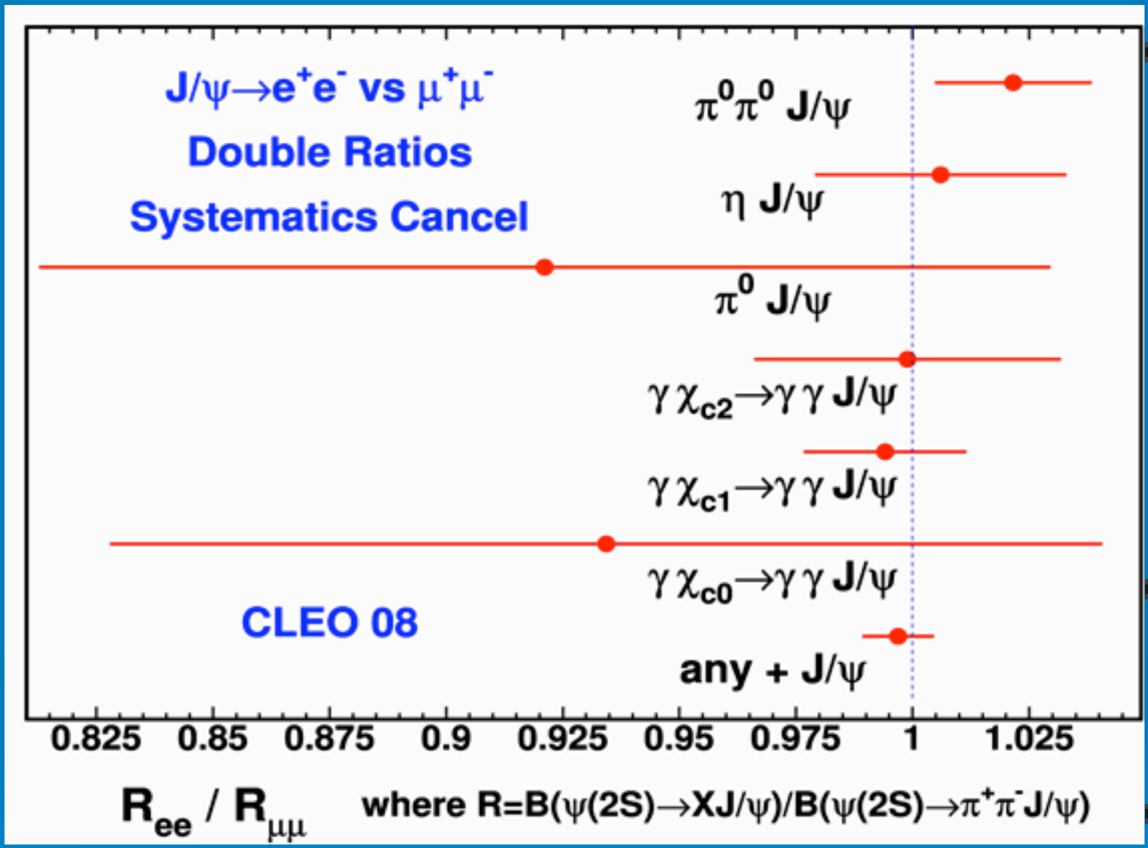
- $\psi(2S) \to X\ J/\psi$ BRs
  - Key statistical & systematic gains made
  - $B(\ \psi(2S) \to \pi^+\pi^-\ J/\psi\ ) = (\ 35.04 \pm 0.07 \pm 0.77\ )\ \%$
  - $B(\ \chi_{c0} \to \gamma\ J/\psi\ ) = (\ 1.35 \pm 0.07 \pm 0.14 \pm 0.06\ )\ \%$
- $\psi(2S),\ J/\psi \to \gamma\ \eta_c(1S)$
  - Clever approach coupled exclusive & inclusive decays
  - Found interesting & (naively) unexpected lineshape
  - BR's moved a lot
  - Lineshape seems to resolve η_c mass & width discrepancies
- $\psi(2S) \to \gamma\ \eta_c(2S)$ BR
  - Small exclusive rates trump largest dataset, modern detector, analysis expertise; improve upper limit: $B[\ \psi(2S) \to \gamma\ \eta_c(2S)\ ] < 7.4 \times 10^{-4}$
- h_c
  - Hyperfine mass splitting challenges theory: consistent with "0"
- Even the most studied channels in charmonium transitions still, in 2008, are yielding new & more precise results
  - Improvements not always in small increments
- Bodes well for a lively BES III era …

Backup Slides

Transition analyses underway at CLEO

- Partial wave analysis of $\psi(2S) \to \pi\pi\ J/\psi$
- M2 / E1 in χ_{cJ} radiative transitions

XJ/ψ Internal Cross-check



- Are e^+e^- & $\mu^+\mu^-$ results consistent with one another ?
- Check w/ rate relative to B_{+-}
- Answer: YES.

Dependence of $\eta_c(2S)$ BxB on Γ

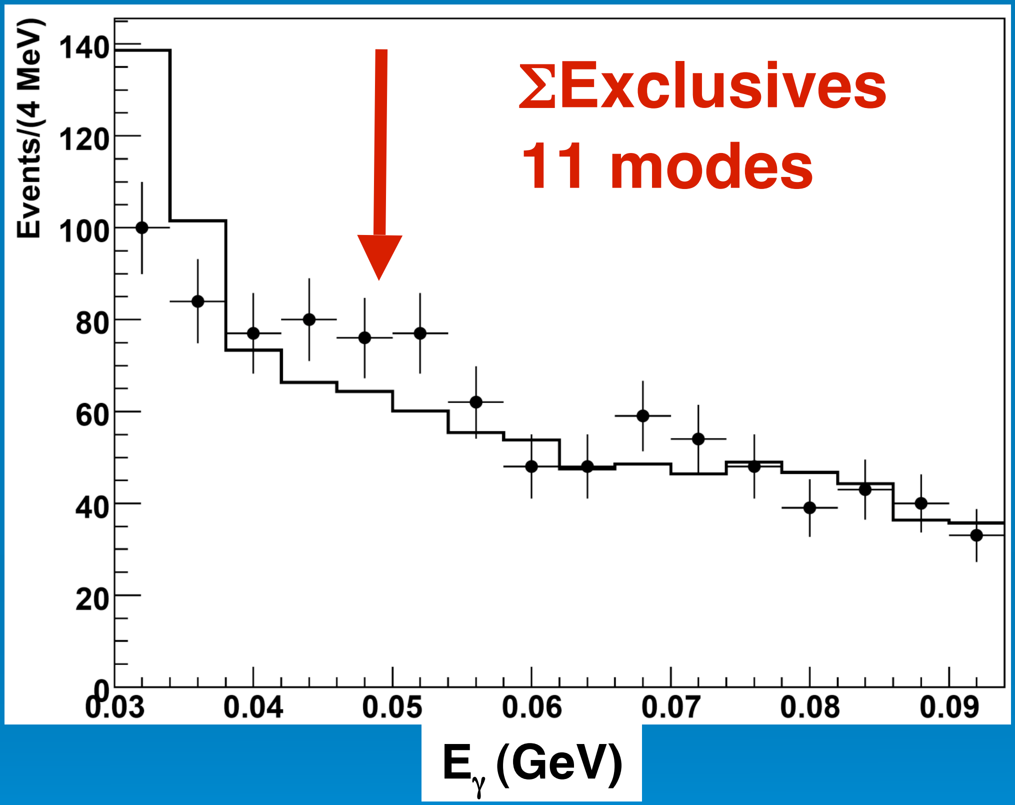
- CLEO results have been parametrized as a fcn of $\Gamma[\eta_c(2S)]$ so they can still be useful as the value of Γ is refined.
  - Dependence of upper limits is linear in Γ.

PRELIMINARY

The y-intercept and slope variables a and b are determined by $B_1 \times B_2 < a + b * \Gamma(\eta_c(2S))$.

Mode	$\Gamma(\eta_c(2S)) = 7$ MeV			$\Gamma(\eta_c(2S)) = 21$ MeV			a	b
	$N_{\rm sig}$	ϵ (%)	$B_1 \times B_2$	$N_{\rm sig}$	ϵ (%)	$B_1 \times B_2$	(10^{-6})	$(10^{-6}$ MeV$^{-1})$
4π	< 53.1	22.06	< 10.6	< 77.5	19.41	< 17.7	7.04	0.505
6π	< 26.4	14.71	< 9.0	< 49.8	13.03	< 19.1	3.88	0.727
$KK\pi\pi$	< 25.6	20.44	< 6.6	< 45.7	17.72	< 13.6	3.10	0.500
$KK\pi^0$	< 12.0	19.15	< 3.6	< 19.5	16.88	< 6.6	2.08	0.217
$K_S K\pi$	< 9.7	21.78	< 3.1	< 12.4	19.53	< 4.4	2.43	0.095
$KK\pi$	< 17.2	8.21*	< 11.2	< 26.7	7.31*	< 19.4	7.05	0.587
$\pi\pi\eta$	< 4.3	6.79*	< 3.6	< 4.3	4.97*	< 4.9	2.95	0.095
$\pi\pi\eta'$	< 4.1	9.46	< 12.3	< 4.1	6.98	< 16.6	10.1	0.309
$KK\eta$	< 7.5	7.72*	< 5.0	< 7.5	5.68*	< 6.7	4.08	0.127
$KK\pi\pi\pi^0$	< 49.4	9.47	< 28.0	< 83.9	8.16	< 55.2	14.4	1.95
$KK4\pi$	< 17.0	10.50	< 7.1	< 24.6	9.37	< 11.6	4.91	0.317
$K_S K 3\pi$	< 20.2	12.00	< 11.6	< 27.4	10.23	< 18.4	8.19	0.486

$\eta_c(2S)$ Exclusives



$\chi_{cJ} \rightarrow$ Exclusives Cross-check