(Recent studies of) Charmonium Decay at CLEO

Hajime Muramatsu

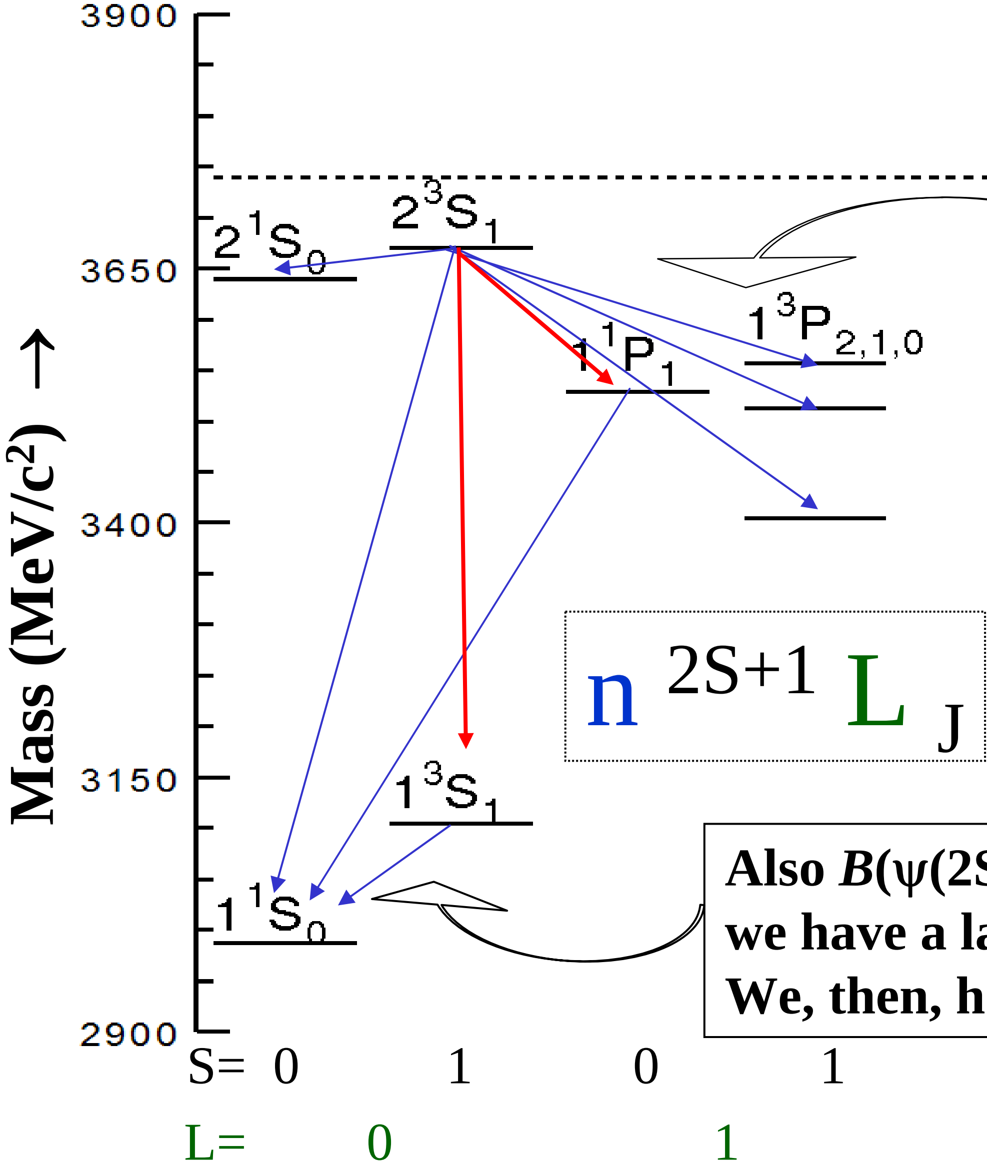
University of Rochester
For the CLEO Collaboration

$\psi(2S)$ samples

- **We had 3M $\psi(2S)$ samples previously.**
- **Took 24M more (Aug'06 - Sep'06).**
- **Total: 27M $\psi(2S)$ decays (54 pb^{-1}).**

- **allows us to do studies of;**
  - o **Multi-body χ_{cJ} decays**
    (2, 3, 4….. ~10 or more (? Yes with CLEO-c detector).
    Survey all the observable decays of χ_{cJ} states.
  - o **Direct decays of $\psi(1,2S)$.**
  - o **$\eta_c(')/h_c$ properties.**
  - o **η properties.**
  - o **etc…etc….. See the next slide.**

Charmonium States - below threshold



This is how we make χ_{cJ} states at CLEO.
$B(\psi(2S)\to\gamma\chi_{cJ}) \sim 9\%$.

SOME transitions:

- single γ
- $\pi^0/\eta/\pi^+\pi^-/\pi^0\pi^0$

Also $B(\psi(2S)\to\pi^+\pi^- J/\psi) \sim 32\%$,
we have a large tagged J/ψ sample.
We, then, have two ways to make $\eta_c(1S)$.

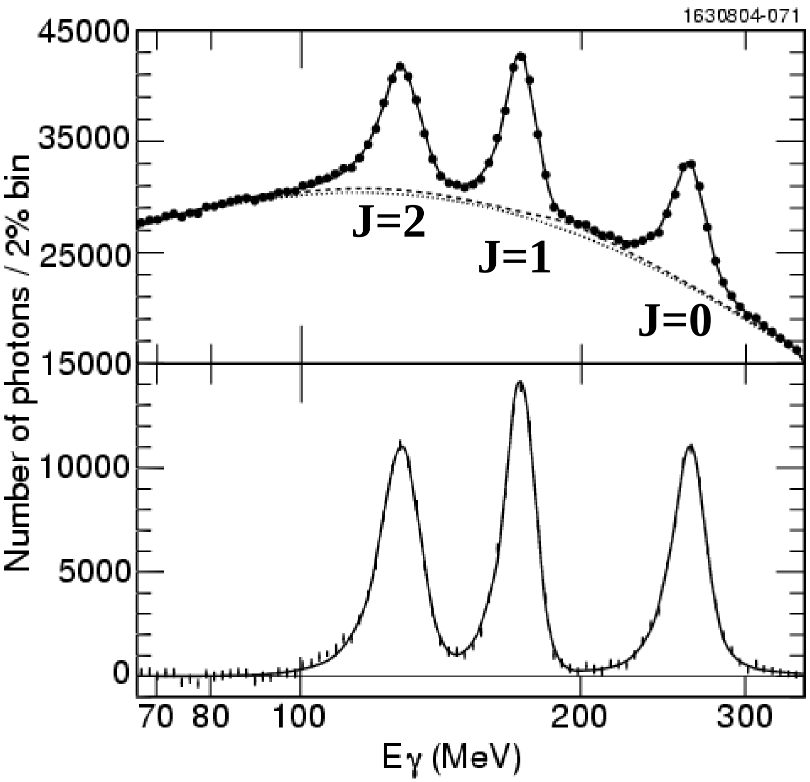
But today's topics are

- $\chi_{cJ} \rightarrow$ 2, 3, and 4-body (3M ψ(2S) data)
- Charmonium-like states above $D\bar{D}$ threshold
  - Y(4260) (scan data 3970-4260MeV: 13 pb^{-1})
  - M(D^0) ("ψ(3770)" data : 281 pb^{-1})
- $\mathcal{B}(\eta \rightarrow X)$ and M(η) (27M ψ(2S) data)

Factory of $\chi_c(1^3P_J)$ states

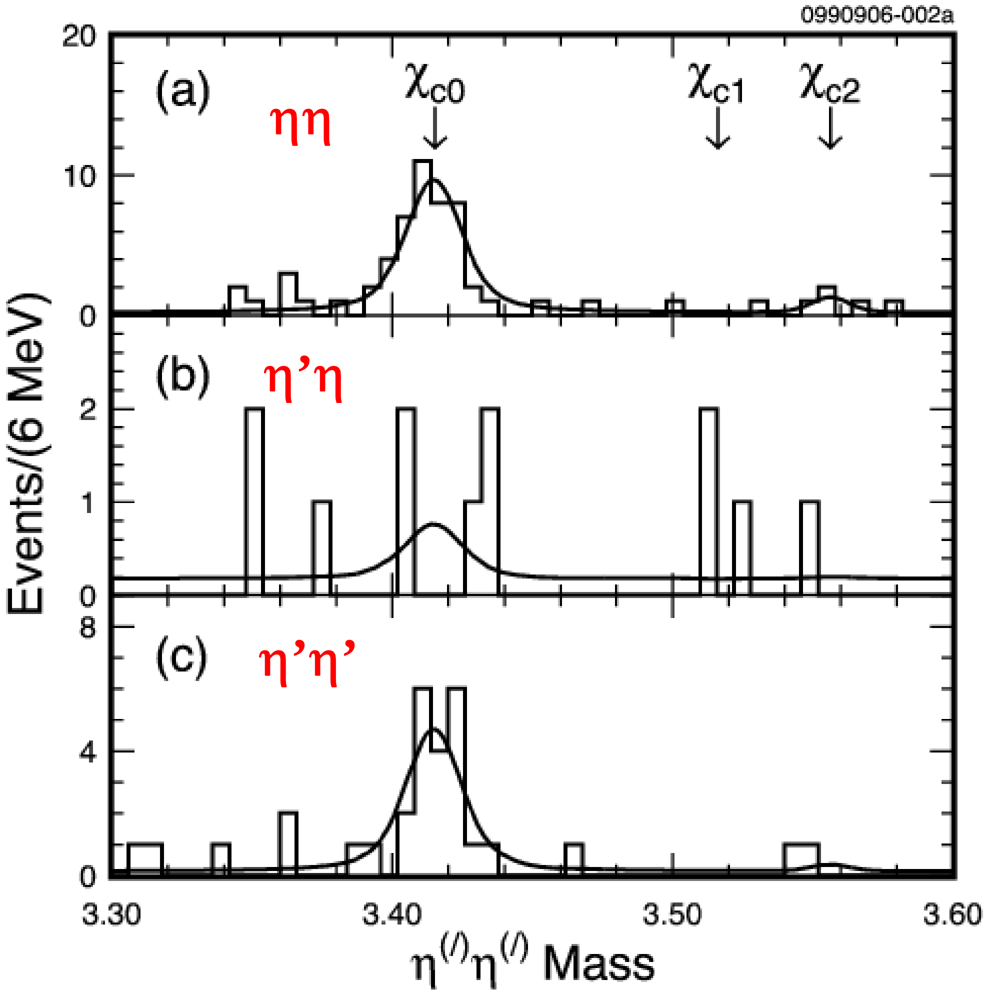
- **For each of χ_{cJ} states we have ~2~2.5M samples in all the $\psi(2S)$ data (27M).**
- **But today, results based on 3M $\psi(2S)$ sample.**
- **$\chi_{cJ} \rightarrow$ 2 body (combo of η and η')**
- **$\chi_{cJ} \rightarrow$ 3 body ($h^+h^-h^0$: 8 modes)**
- **$\chi_{cJ} \rightarrow$ 4 body (preliminary) ($h^+h^-h^0\pi^0$)**

$\psi(2S) \rightarrow \gamma X$ in 3M sample



$\chi_{cJ} \rightarrow \eta(')\eta(')$

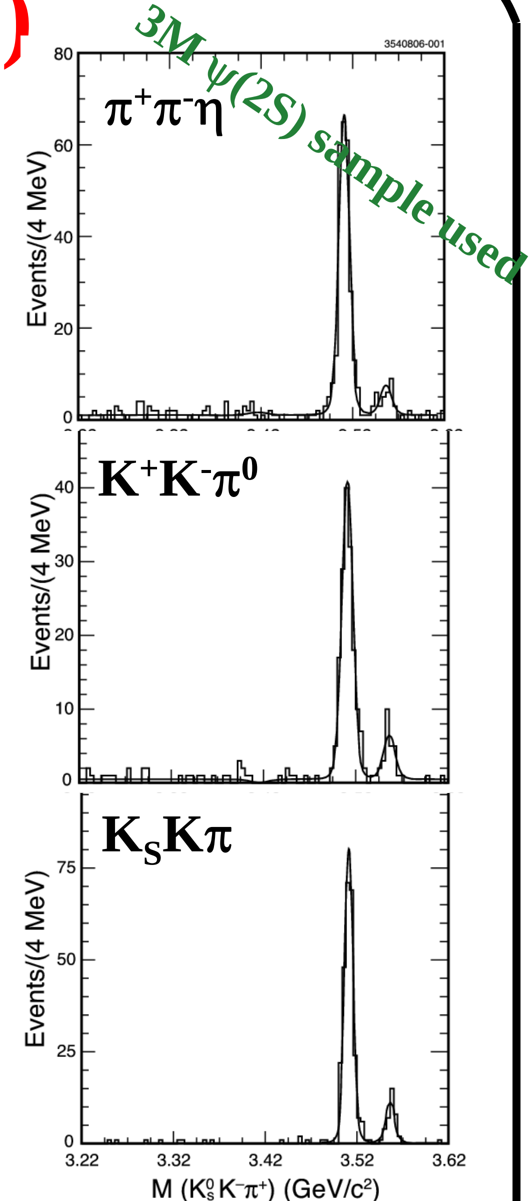
3M $\psi(2S)$ sample used



- **Two body decay. No substructure.**
- **$B(\chi_{c0} \rightarrow \eta\eta)$ = (0.31±0.05±0.04)%**
  $B(\chi_{c0} \rightarrow \eta'\eta')$ = (0.17±0.04±0.02)%
- **ULs were set for other modes. PRD75, 071101(R) (2007).**
- **According to the model of Qiang Zhou (PRD72,074001(2005)), this result indicates SOZI suppression is favored over DOZI suppression.**

$\chi_{cJ} \rightarrow h^+h^-h^0$ (8 modes)

- **Signals were seen in most of the modes PRD75, 032002 (2007).**
- **For $\chi_{c1} \rightarrow \pi^+\pi^-\eta$, $K^+K^-\pi^0$, and $K_SK\pi$, significant signals were seen.**
  $\rightarrow$ use them for Dalitz plot analysis
  (interference effects and polarization of χ_{c1} were ignored $\rightarrow$ ~20(15)% variations in Fit Fractions for $\pi\pi\eta$(KKπ) mode).



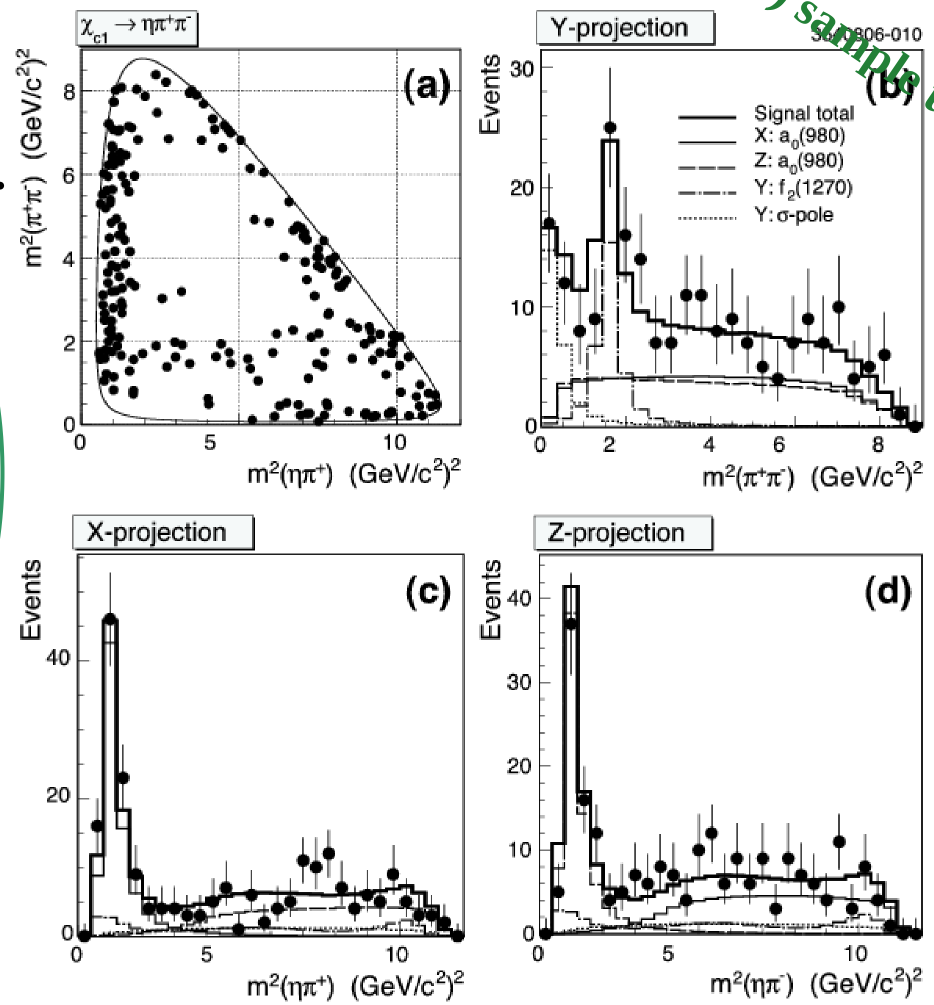
Mode	χ_{c0}	χ_{c1}	χ_{c2}
$\pi^+\pi^-\eta$	< 0.21	$5.0 \pm 0.3 \pm 0.4 \pm 0.3$	$0.49 \pm 0.12 \pm 0.05 \pm 0.03$
$K^+K^-\eta$	< 0.24	$0.34 \pm 0.10 \pm 0.03 \pm 0.02$	< 0.33
$p\bar{p}\eta$	$0.39 \pm 0.11 \pm 0.04 \pm 0.02$	< 0.16	$0.19 \pm 0.07 \pm 0.02 \pm 0.01$
$\pi^+\pi^-\eta'$	< 0.38	$2.4 \pm 0.4 \pm 0.2 \pm 0.2$	$0.51 \pm 0.18 \pm 0.05 \pm 0.03$
$K^+K^-\pi^0$	< 0.06	$1.95 \pm 0.16 \pm 0.18 \pm 0.14$	$0.31 \pm 0.07 \pm 0.03 \pm 0.02$
$p\bar{p}\pi^0$	$0.59 \pm 0.10 \pm 0.07 \pm 0.03$	$0.12 \pm 0.05 \pm 0.01 \pm 0.01$	$0.44 \pm 0.08 \pm 0.04 \pm 0.03$
$\pi^+K^-\overline{K}^0$	< 0.10	$8.1 \pm 0.6 \pm 0.6 \pm 0.5$	$1.3 \pm 0.2 \pm 0.1 \pm 0.1$
$K^+\bar{p}\Lambda$	$1.07 \pm 0.17 \pm 0.10 \pm 0.06$	$0.33 \pm 0.09 \pm 0.03 \pm 0.02$	$0.85 \pm 0.14 \pm 0.08 \pm 0.06$

$\chi_{c1} \to \pi^+\pi^-\eta$

3M $\psi(2S)$ sample used

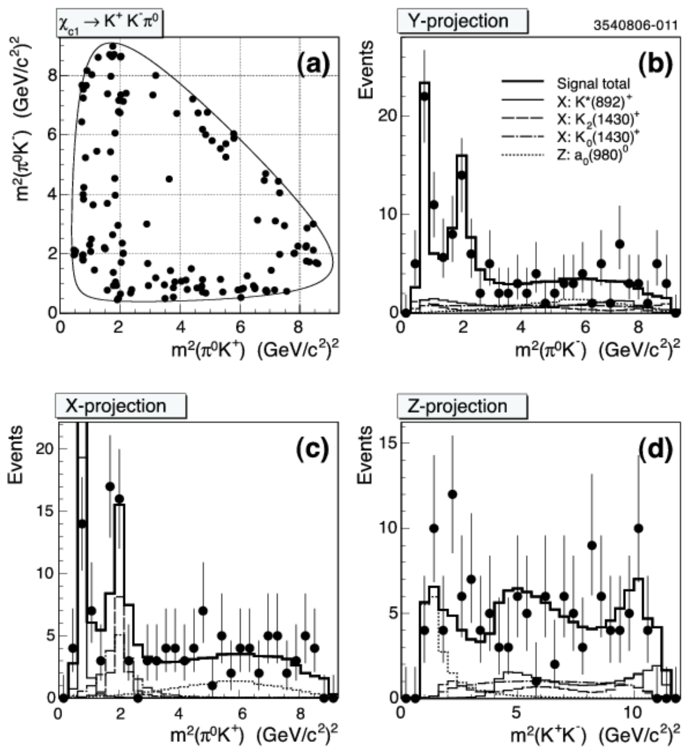
Additional uncertainty in
Fit Fraction due to model dependence.

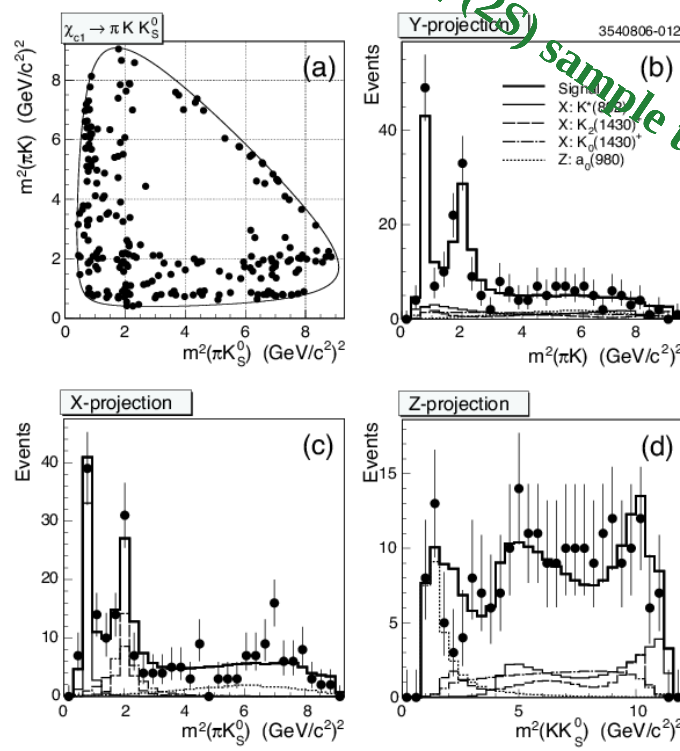
Mode	Fit Fraction(%)
$a_0(980)\pi$	75.1±3.5±4.3±15.0
$f_2(1270)\eta$	14.4±3.1±1.9± 2.9
$\sigma\eta$	10.5±2.4±1.2± 2.1



$\chi_{c1} \to K^+K^-\pi^0$ and $K_SK\pi$

3M $\psi(2S)$ sample used





Combined fits with isospin constraints

Mode	Fit Fraction(%)
$K^*(892)K$	$31.4 \pm 2.2 \pm 1.7 \pm 4.7$
$K^*_0(1430)K$	$30.4 \pm 3.5 \pm 3.7 \pm 4.6$
$K^*_2(1430)K$	$23.1 \pm 3.4 \pm 7.1 \pm 3.5$
$a_0(980)\pi$	$15.1 \pm 2.7 \pm 1.5 \pm 2.3$

Additional uncertainty in Fit Fraction due to model dependence.

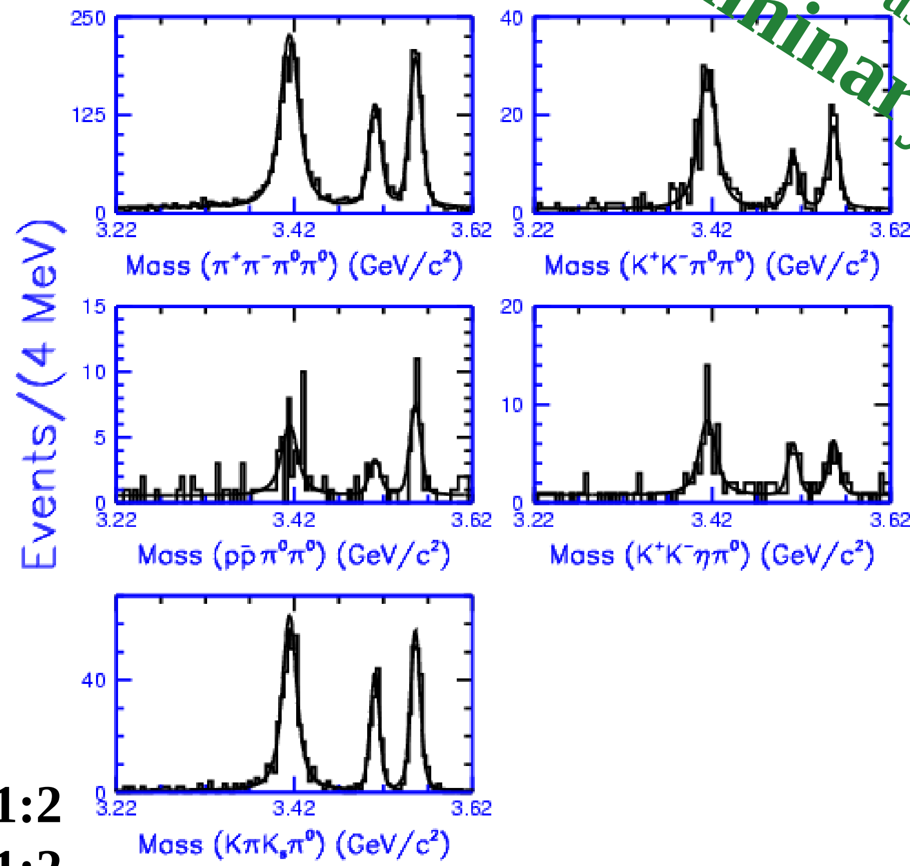
$\chi_{cJ} \to h^+h^-h^0\pi^0$

3M $\psi(2S)$ sample used

Preliminary

- **Now 4 body decay.**
  I wonder how many body decays of χ_{cJ} we could see with the 27M sample
- **Many substructures were seen**
  Only considered significant ones (>4σ).

Mode	χ_{c0}	χ_{c1}	χ_{c2}
	B.F. (%)	B.F. (%)	B.F. (%)
$K^{*0}K^0\pi^0$	0.56±0.15	0.38±0.11	0.59±0.14
$K^{*0}K^{\pm}\pi^{\mp}$	-	-	0.90±0.25
$K^{*\pm}K^{\mp}\pi^0$	0.74±0.18	-	0.57±0.13
$K^{*\pm}\pi^{\mp}K^0$	0.96±0.25	-	0.90±0.25



- **They follow isospin expectations:**

$B(\chi_c \to K^{*0}K^0\pi^0)$: $B(\chi_c \to K^{*0}K\pi)$ = 1:2

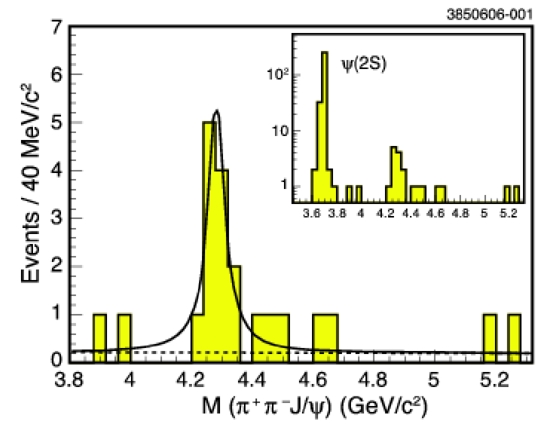
$B(\chi_c \to K^{*0}K^0\pi^0)$: $B(\chi_c \to K^{*}K^0\pi)$ = 1:2

4-body ($h^+h^-h^0\pi^0$) - II

3M ψ(2S) sample used
Preliminary

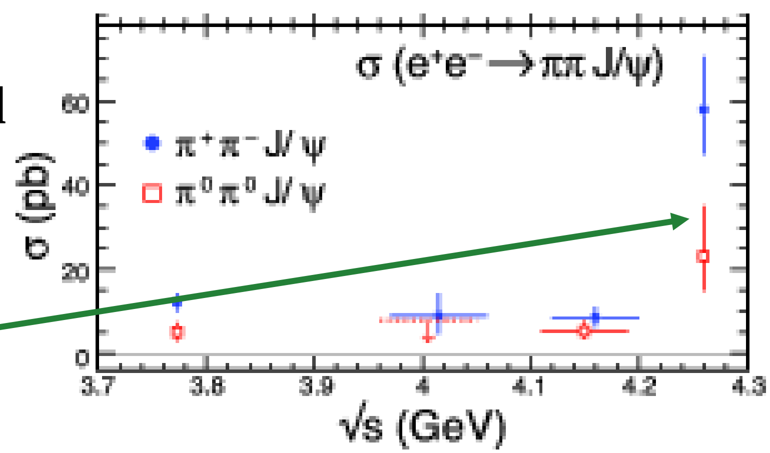
Mode	χ_{c0} B.F.(%)	χ_{c1} B.F.(%)	χ_{c2} B.F.(%)
$\pi^+\pi^-\pi^0\pi^0$	3.54±0.10±0.43±0.18	1.28±0.06±0.16±0.08	1.87±0.07±0.23±0.13
$\rho^+\pi^-\pi^0$	1.48±0.13±0.18±0.08	0.78±0.09±0.09±0.05	1.12±0.08±0.14±0.08
$\rho^-\pi^+\pi^0$	1.56±0.13±0.19±0.08	0.78±0.09±0.09±0.05	1.11±0.09±0.13±0.08
$K^+K^-\pi^0\pi^0$	0.59±0.05±0.08±0.03	0.12±0.02±0.02±0.01	0.21±0.03±0.03±0.01
$p\bar{p}\pi^0\pi^0$	0.11±0.02±0.02±0.01	< 0.05	0.08±0.02±0.01±0.01
$K^+K^-\eta\pi^0$	0.32±0.05±0.05±0.02	0.12±0.03±0.02±0.01	0.13±0.04±0.02±0.01
$K^\pm\pi^\mp K^0\pi^0$	2.64±0.15±0.31±0.14	0.92±0.09±0.11±0.06	1.41±0.10±0.16±0.10
$K^{*0}K^0\pi^0 \times K^{*0} \to K^\pm\pi^\mp$	0.37±0.09±0.04±0.02	0.25±0.06±0.03±0.02	0.39±0.07±0.05±0.03
$K^{*0}K^+\pi^\mp \times K^{*0} \to K^0\pi^0$			0.30±0.07±0.04±0.02
$K^{*\pm}K^\mp\pi^0 \times K^{*\pm} \to \pi^\pm K^0$	0.49±0.10±0.06±0.03		0.38±0.07±0.04±0.03
$K^{*\pm}\pi^\mp K^0 \times K^{*\pm} \to K^\pm\pi^0$	0.32±0.07±0.04±0.02		0.30±0.07±0.04±0.02
$\rho^\pm K^\mp K^0$	1.28±0.16±0.15±0.07	0.54±0.11±0.06±0.03	0.42±0.11±0.05±0.03

Y(4260)



- **BaBar discovered in Y(4260) $\rightarrow \pi^+\pi^- J/\psi$ in ISR.**
  PRL95, 142001 (2005)
- **We confirmed this at E_{cm}= 4260MeV (>6σ).**
  PRL96, 162003 (2006)
- **We also confirmed it in ISR production based on data taken at ~E_{cm}=M(ϒ(1,2,3,4S)).**
  PRD74, 091104 (2006)
- **Also saw Y(4260) $\rightarrow \pi^0\pi^0 J/\psi$ (5.1σ)**
  - **inconsistent with "$\chi_{cJ}\rho^0$" molecule model.**
  - **Baryonium model expects *B*(Y(4260) $\rightarrow \pi^0\pi^0 J/\psi$)/*B*(Y(4260) $\rightarrow \pi^+\pi^- J/\psi$) ~ 1.**
- **Y(4260) $\rightarrow K^+K^- J/\psi$ is seen (3.7σ) which disagrees with the above two models.**
- **12 additional modes were also searched for (transitions to ψ(2S), χ_{cJ}, and J/ψ). No evidence of strong signals.**

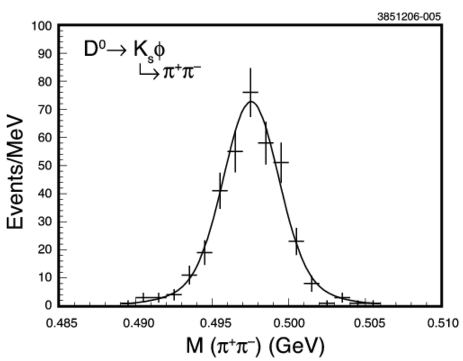
does not behave like for rest of the ψ states above $D\bar{D}$ threshold

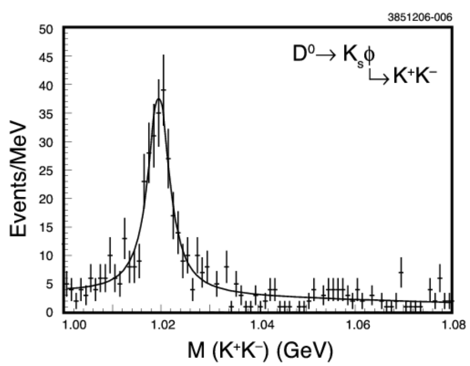


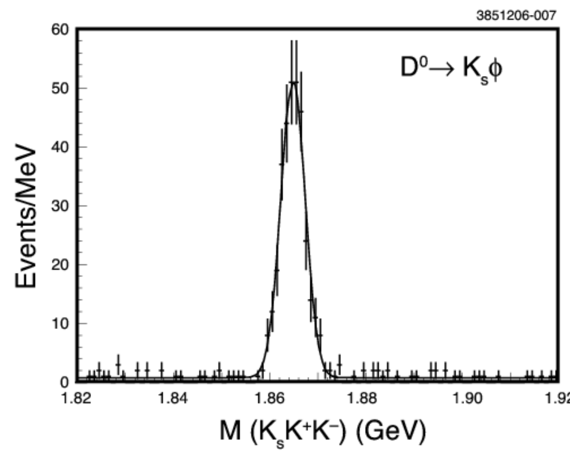
X(3872) and M(D^0)

- **Belle discovered X(3872) (PRL91, 262001 (2003)), followed by others (BaBar, Belle, D0, and CDF)**
- **One suggestion: A bound state of $D^0\overline{D}^{0*}$?**
- **E_{bind} = M(D^0)+M($\overline{D}^{0*}$) - M(X(3872)) = -0.9±2.1MeV (PDG06 ave M(D^0) = 1864.1±1.0MeV).**
- **Need to know M(D^0) more precisely.**

- **From $D^0 \to K_S\,\phi$, M(D^0) = 1864.847±0.150±0.095MeV.**
  $\to E_{bind}$ = 0.6±0.6MeV (PRL98, 092002 (2007)).
  We now need a more precise measurement of M(X(3872)):
  PDG07 ave M(X(3872)) = 3871.4±0.6MeV

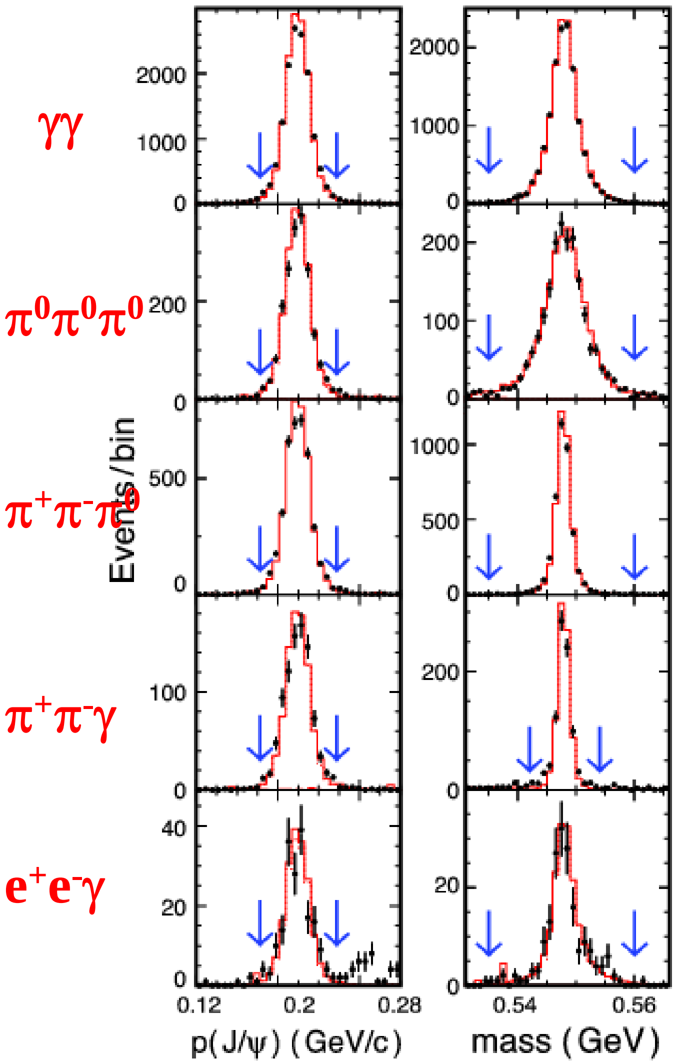






$B(\eta \to X)$

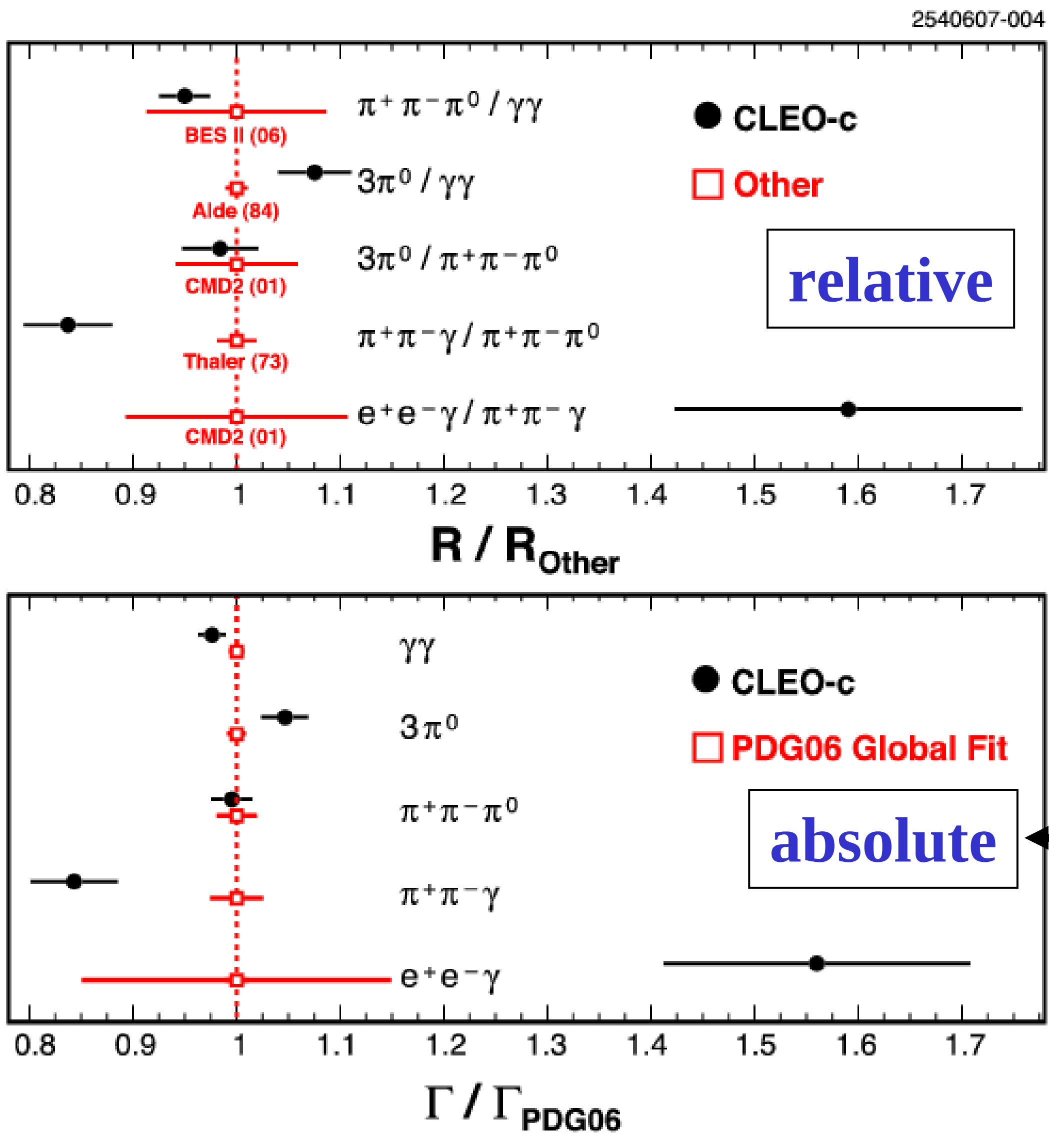
27M $\psi(2S)$ sample used



- η was discovered a long time ago (even before I was born).
- Since then, 43 measurements by many experiments.
- CLEO alone can measure most of the major modes (99.9% of generic η decays) simultaneously.
- This allows us to measure all branching fractions.
- Obtain η via $\psi(2S) \to \eta\, J/\psi$, $J/\psi \to l^+l^-$.
- Method:
  - Constrain $M(l^+l^-) \equiv M(J/\psi)$.
  - Constrain $M(l^+l^-\eta) \equiv M(\psi(2S))$.

$B(\eta \rightarrow X)$

27M $\psi(2S)$ sample used



- **arXiv:0707.1601v1 accepted for PRL publication.**

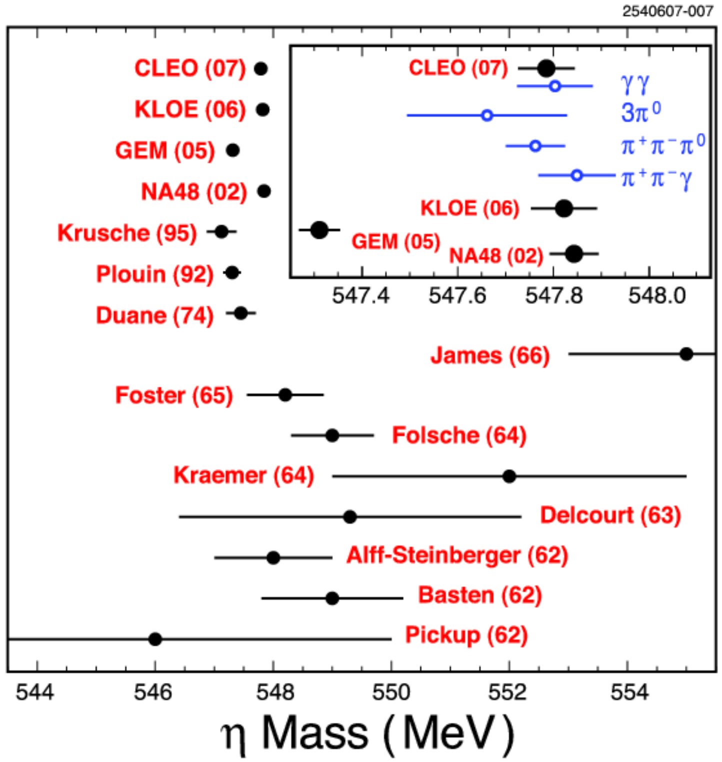
assuming these 5 modes add up to 100% of generic decays of η.

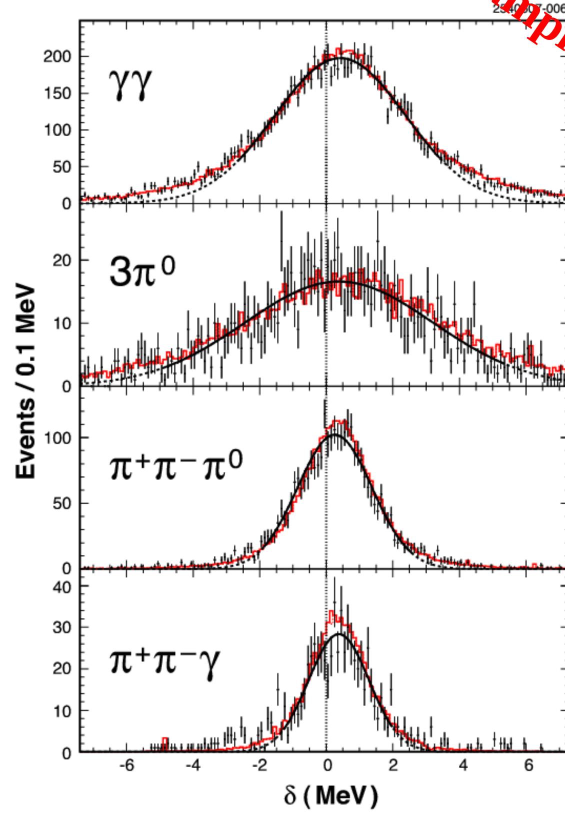
M(η)

- **Recent measurements are very accurate.**
- **One of them deviates from the other two**
  GEM's result is 6.5σ away from NA48's result.

27M ψ(2S) sample used

$\delta = M_{recon} - M(\eta:PDG06)$





- **CLEO: 547.785±0.017±0.057MeV**
  (arXiv:0707.1810v1:just accepted for PRL publication)
- **KLOE (new): 547.873±0.007±0.031MeV (arXiv:0707.4616 for LP07)**

Summary

- **Confirmation in di-pion transition from Y(4260) to J/ψ.**
  Also observed neutral di-pion transition.
  Confirmation in ISR production.
- **Precision measurement of $M(D^0)$**
  $\Rightarrow$ provides constraint for theoretical predictions of properties of X(3872) if it is $D^0\overline{D}^{*0}$ molecule.
- **$\chi_{cJ} \rightarrow$ 2, 3, and 4 body decays (many substructures were seen in 3 and 4 body decays).**
  Dalitz analysis was done for 3 body case.
  More detailed analyses can be done with 27M ψ(2S) sample.
- **Precision measurements on $\mathcal{B}(\eta \rightarrow X)$ and $M(\eta)$.**

Stay tuned!

More exciting results will come soon based on the 27M ψ(2S) sample.