$\begin{array}{c} {\sf CLEO-c \ Introduction} \\ D_S \ {\sf Physics \ Results} \\ {\sf Charmonium \ Physics \ Results} \end{array}$

Recent Heavy Flavor Results from CLEO-c

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CLEO-c Introduction

2 D_S Physics Results

- $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S}
- Discovery of $D_S^+ \rightarrow p\bar{n}$

Oharmonium Physics Results

- η_c Production in Radiative Decays
- Discovery of $J/\psi {\rightarrow} \gamma \gamma \gamma$
- *h_c* Properties



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CLEO-c

- CLEO-c is about to complete (3 March) $\,$ cL its 5th and final year, ending \sim 30 years of heavy flavor physics at CESR $\,$
- CLEO-c Data Sets for Today's talk:
 - $\sim 300 \times 10^3 (D_S D_S^*)$
 - $\bullet\ \sim 24.5\times 10^6\psi'$



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 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of $D_S^+ \rightarrow p\bar{n}$

D_S Studies at $\sqrt{s} = 4170 MeV$

- D_S Physics is studied at CLEO by running at the energy providing maximal yield of $D_S^{*\pm}D_S^{\mp}$
- Scan found max at 4170 MeV of $\sigma(D_S D_S^*) \simeq 1$ nb



 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of $D_S^+ \rightarrow p\bar{n}$

CLEO Charm Studies at $\sqrt{s} = 4170 MeV$



- For the two D_S analyses which follow, we employ double tagging
- Fully reconstruct one charm decay: $n_{ST} = 2NB_{ST}\epsilon_{ST}$
- Observe other D_S (sig) decay
- (Possibly) observe photon from D_S* and combine with tag OR signal side, and kin. fit
- $n_{DT} = 2N\mathcal{B}_{ST}\mathcal{B}_{sig}\epsilon_{DT}$
- Finally obtain $\mathcal{B}_{sig} = \frac{n_{DT}}{n_{ST}} \frac{\epsilon_{ST}}{\epsilon_{DT}}$

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 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of $D_S^+ \rightarrow p\bar{n}$

$D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S}



• Purely leptonic decays of pseudoscalars like *D_S* probe the hadronic annihilation vertex:

$$\Gamma(P^+ \rightarrow \ell^+ \nu) = \frac{1}{8\pi} G_F^2 f_P^2 m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right) |V_{cs}|^2$$

• Measurement provides important input/test for theory in calculating f_{B_S}

 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of $D_S^+ \rightarrow p\bar{n}$

Basic Analysis Method

- Previous CLEO results measure $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ with $\tau^+ \rightarrow \pi^+ \nu_{\tau}$. In this present analysis we use $\tau^+ \rightarrow e^+ \nu_e \bar{\nu}_{\tau}$
- First identify D_S^- tag in one of three modes (12947 ± 150 ST):





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 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of $D_S^+ \rightarrow p\bar{n}$

$D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$: From ST to DT to signal yield



 $n_{ST} = 12947 \pm 150$ $n_{DT} = 102 \pm 12$ $B_{sig} = \frac{n_{DT}}{n_{ST}} \frac{\epsilon(ST)}{\epsilon(DT)}$

- Next Allow one additional track (e⁺) opposite ST
- Use $E_{extra} \equiv \Sigma(E_{\gamma,unassoc.})$. Expect peak corresponding to $D_{S}^{*+} \rightarrow D_{S}^{+}(\gamma, \pi^{0})$
- Bkg in side-band subtracted E_{extra} dominated by $D_S^+ \rightarrow Xe^+\nu$
- Syst err dominated by the uncertainty in $D_S^+ \rightarrow Xe^+\nu$ branching fractions.

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 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of $D_S^+ \rightarrow p\bar{n}$

 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ and f_{D_S} Summary

Final BF result: $B(D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}) = (6.17 \pm 0.71 \pm 0.34)\%$ and using $|V_{cs}| = 0.9738$ (and G_F , m_{τ} , M_{D_S}) we obtain f_{D_S}

• With this measurement:

 $f_{D_S} = 273 \pm 16 \pm 8 \ \text{MeV}$

• Combined with the previous result (which used $\tau^- \rightarrow \pi^- \nu_{\tau}$ and $D_S^+ \rightarrow \mu^+ \bar{\nu}_{\mu}$) of $f_{D_S} = 274 \pm 13 \pm 7 \ MeV$, (PRD95, 251801 (2005)) we have

 $f_{D_S} = 274 \pm 10 \pm 5$ MeV,

which is the most precise result to date. Submitted to PRL: arxiv.org/0712.1175



 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of $D_S^+ \rightarrow p\bar{n}$

$D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ and f_{D_S} Summary

• Finally, combine w/our result

$$\label{eq:f_D_beta} \begin{split} \mathbf{f}_{\mathrm{D}^+} &= 223 \pm 17 \pm 3 \\ \mathrm{MeV} \text{ to obtain} \end{split}$$

 $\frac{f_{D_{\rm S}}}{f_{\rm D^+}} = 1.23 \pm 0.10 \pm 0.03$

- Ultimate $\sqrt{s} = 4170$ MeV sample will push rel. uncertainty on f_{D_S} to $\sim 2.5\%$
- Submitted to PRD: arxiv.org/0712.1175

CLEO D _s →μν,τν (τ→πν) Final March07, 314/pb	Hei		
$\textbf{CLEO D}_{s} \rightarrow \! \tau \nu \left(\tau {\rightarrow} \! e \nu \nu \right)$		Artuso,	
CLEO average	10 1 1 1 1 1 1 1 1 1 1	PRL95, 251801 (2005) 223 ± 17 ± 3	1.23 ± 0.10 ± 0.03
Unquenched LQCD Follana (arXiv:0706.1726)	■ 241(3)	■ 208(4)	1.162(9)
Unquenched LQCD Aubin, PRL 95, 122002 (2005)	Heri	HeH	H+++
Quenched L. (QCDSF) All Khan, hep-lat/0701015	HINH	H	101
Quenched L. (Taiwan) Chiu. PLB 624, 31 (2005)	HOH	HOH	HOH
Quenched L. (UKQCD) Lellouch, PRD 64, 094501 (2001)	нөн	нен	HOH
Quenched Lattice Becirevic, PRD 60,074501 (1999)	Het .	Hel	
QCD Sum Rules Bordes, hep-ph/0507241	H	H H H	Iei
QCD Sum Rules Narison, hep-ph/0202200	⊢ ●	HeH	Hel
Quark Model Ebert, PLB 635, 93 (2006)	•	•	•
Quark Model Cvetic, PLB 596, 84 (2004)	⊢ •→	H H H	•
Light Front QM Linear Chol.hep-ph/0701263	•		•
Light Front QM HO Chol.hep-ph/0701263	•	•	•
Potential Model Wang, Nucl. Phys. A744, 156 (2004)	•	•	•
Light Front QCD alcedo, Braz. J. Phys. 34, 297 (2004)	•	•	•
Isospin Splittings Amundsen, PRD 47, 3059 (1993)	0.0 0.0 0.0		The Real
	200 250 300	200 300) 1 1.2 1.
	f _D (MeV)	f _D (MeV)	f _{De} / f _D

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 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of $D_S^+ \rightarrow p\bar{n}$

Discovery of $D_S^+ \rightarrow p\bar{n}$



- The only kinematically-allowed baryon-antibaryon decay of any ground-state charmed meson
- The mechanism? weak annihilation. Interestingly, was predicted in 1980 by Pham (PRL45, 1663) as 'smoking gun' signal for annihilation
- Rather than searching for the \bar{n} directly, instead we use a double-tag + missing mass strategy very similar to that used in the measurement of $D_S^+ \rightarrow \ell^+ \bar{\nu}_\ell$

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 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of $D_S^+ \rightarrow p\bar{n}$

Observation of D_S^- Tags

Step 1: Observe D_S^- in one of 8 tag modes (27700 ST's)



 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of $D_S^+ \rightarrow p\bar{n}$

Mass Recoiling against $D_S(tag)\gamma$ Combination



- Step 2: Find γ and calculate mass recoiling against it and D_S ST's within 2σ of D_S mass*
- Selection for further analysis lies between the two arrows (16955 $D_S^+\gamma$ candidates)



Note: The D_S and γ needn't actually be daughters of ${D_S}^*$ for this to work

 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of $D_S^+ \rightarrow p\bar{n}$

Next Step: Got Proton?



- Observe proton and calculate missing p^{μ} . Combine missing p^{μ} and proton for $D_{S}^{+} \rightarrow p\bar{n}$ candidate
- Kin. fit for $D_{\varsigma}^{*+} \rightarrow \gamma D_{\varsigma}^{+}(sig)$ or $D_{S}^{*-}\gamma D_{S}^{-}(tag)$
- Select better fit and calculate missing mass



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 $D_S^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of $D_S^+ \rightarrow p\bar{n}$

Missing Mass Distributions (Data)



Essentially no background! (< 1.1 events in signal region) Signal events: 13.0 ± 3.6



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 ${D_S}^+ \rightarrow \tau^+ \bar{\nu}_{\tau}$ Br. Frac. and f_{D_S} Discovery of ${D_S}^+ \rightarrow p\bar{n}$

Discovery of $D_S^+ \rightarrow p\bar{n}$ Summary

Final result:

CLEO Preliminary

 $B(D_{S}^{+} \rightarrow p\bar{n}) = (1.30 \pm 0.36^{+0.12}_{-0.16}) \times 10^{-3}$

- Syst. uncertainties primarily come from D_S^- tags, signal shape, fitting, bkg subtraction
- From this and the $D_S^+ \rightarrow \mu^+ \bar{\nu}_{\mu}$ rate, we may learn something about baryon production
- We know of no recent prediction of the rate for this process



 η_c Production in Radiative Decays Discovery of $J/\psi \rightarrow \gamma \gamma \gamma$ η_c Properties

Charmonium Physics Results



We present these new results taken from our sample of 24.5M ψ^\prime decays

- Radiative decay BFs for $\psi(nS) \rightarrow \gamma \eta_c$
- Discovery of $J/\psi \rightarrow \gamma \gamma \gamma$
- Mass and product BF for h_c produced in $\psi' \rightarrow \pi^0 h_c$

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 η_c Production in Radiative Decays

History of η_c Observed in $\psi(nS) \rightarrow \gamma \eta_c$

$\Gamma(\gamma \eta_c(1S))/\Gamma_{total}$						Г99/Г
VALUE (units 10 ⁻²)	EVTS	DOCUMENT IL	>	TECN	COMMENT	
0.30±0.05 OUR AVER	AGE					
$0.32 \pm 0.04 \pm 0.06$	2560	⁸⁵ ATHAR	04	CLEO	$e^+ e^- \rightarrow \gamma X$	
0.28 ± 0.06		86 GAISER	86	CBAL	$e^+ e^- \rightarrow \gamma X$	
85 ATHAR 04 used Γ_{η_i}	(15) =	24.8 ± 4.9 MeV t	o obtai	n this re	sult.	
86 GAISER 86 used F $_\eta$	_c (15) =	11.5 ± 4.5 MeV	to obtai	in this re	sult.	

$\Gamma(\gamma \eta_c(1S))/\Gamma_t$	otal					Г ₁₀₈ /Г
VALUE	EVTS	DOCUMENT ID		TECN	COMMEN	IT
0.0127 ± 0.0036		GAISER	86	CBAL	$J/\psi \rightarrow$	γX
• • • We do not i	use the followin	ig data for average	s, fits	, limits,	etc. • •	•
0.0079 ± 0.0020	273 ± 43	60 AUBERT	06E	BABR	$B^{\pm} \rightarrow$	K [±] X _c
seen	16	BALTRUSAIT	84	MRK3	$J/\psi \rightarrow$	$2\phi\gamma$
60 Calculated by t	the authors usi	og an average of B	(1/2)	$\rightarrow \sim n$	$) \times B(n)$	$\rightarrow K\overline{K}\pi$) from

BALTRUSAITIS 86, BISELLO 91, BAI 04 and $B(\eta_c \rightarrow K\overline{K}\pi) = (8.5 \pm 1.8)\%$ from ALIBERT OFF

- Most η_c decay rates pegged to these BFs
- J/ψ rad decay has always been "too small"
- (Recent JLab) calculation 2.0 \pm $0.1 \pm 0.4 \ keV$
- $\pi^+\pi$ 3150 2900 n 2S+1 L

• In addition: some discrepancies concerning η_c mass and width among raditative decay vs direct formation methods



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 η_c Production in Radiative Decays Discovery of $J/\psi \rightarrow \gamma \gamma \gamma$ h_c Properties

 E_{γ} lineshape: $J/\psi \rightarrow \gamma \eta_c(exc.)$



- $\bullet\,$ BKG determined by MC
- Good fit requires modification of simple BW by factors $\propto E_{\gamma}^3$ and $exp(E_{\gamma}^2/\beta)$
- M using unmodified BW: 2976.7 \pm 0.6 MeV (c.f. previous radiative decay measurements)
- M using modified form: 2982.2 \pm 0.6 MeV (c.f. direct formation measurements)
- Note: we are not claiming a mass measurement





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 η_c Production in Radiative Decays Discovery of $J/\psi \rightarrow \gamma \gamma \gamma$ h_c Properties

Measurement of $B(\psi(nS) \rightarrow \gamma \eta_c)$

- We find a similarly lineshape in ψ(2S) radiative decay:
- In this hindered M1 decay, the BW is modified by a factor $\propto E_{\gamma}^7$



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• Fit isn't good, however - so the exclusive shape will in fact be used to fit the inclusive spectrum (12 modes, summed)

 $\begin{array}{l} \eta_{\rm c} \mbox{ Production in Radiative Decays} \\ \mbox{Discovery of } J/\psi {\rightarrow} \gamma \gamma \gamma \\ h_c \mbox{ Properties} \end{array}$

Measurement of $B(\psi(nS) \rightarrow \gamma \eta_c)$:

$$B(\psi(2S) \to \gamma \eta_c(1S)) = \frac{[N_{2S,INC}]}{[\varepsilon_{2S,INC}]} \times \frac{1}{N_{\psi(2S)}}$$

$$\frac{\mathcal{B}(J/\psi \to \gamma \eta_e(1S))}{\mathcal{B}(\psi(2S) \to \gamma \eta_e(1S))} = \frac{[\mathcal{N}_{1\mathrm{S},\mathrm{EXC}}]}{[\mathcal{N}_{2\mathrm{S},\mathrm{EXC}}] \times \left[\frac{\varepsilon_{1\mathrm{S},\mathrm{EXC}}}{\varepsilon_{2\mathrm{S},\mathrm{EXC}}}\right]} \times \frac{1}{\mathcal{B}_{\pi\pi}}$$

$$\mathcal{B}(J/\psi \to \gamma \eta_{c}(1S)) = \frac{\left[\frac{\mathcal{N}_{2S,\mathrm{INC}}}{\mathcal{N}_{2S,\mathrm{EXC}}}\right] \times \left[\mathcal{N}_{1S,\mathrm{EXC}}\right]}{\left[\varepsilon_{2S,\mathrm{INC}}\right] \times \left[\frac{\varepsilon_{1S,\mathrm{EXC}}}{\varepsilon_{2S,\mathrm{EXC}}}\right]} \times \frac{1}{\mathcal{N}_{\psi(2S)} \times \mathcal{B}_{\pi\pi}}$$

N_{2S} Fits: Use the exclusive histogram to fit the inclusive spectrum.

N_{1S} **Fits:** Use the BW \times E³ \times f(E) line shape.

Branching FractionCLEO-cPDG2006 $\mathcal{B}(\psi' \rightarrow \gamma \eta_c)$ $(4.02 \pm 0.11 \pm 0.52) \times 10^{-3}$ $2.6 \pm 0.4 \times 10^{-3}$ $\mathcal{B}(J/\psi \rightarrow \gamma \eta_c)$ $(2.07 \pm 0.09 \pm 0.35)\%$ $1.3 \pm 0.4\%$ • This supercedes our previous result based on 3M ψ' decays in PRD 70, 112002 (2004)Image: CLEO Preliminary• Note: $\mathcal{B}(J/\psi \rightarrow \gamma \eta_c)$ is substantially higher than the C.Ball result of $1.3 \pm 0.4\%$ CLEO Preliminary

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N_{2S,INC}: Number of inclusive $\psi(2S) \rightarrow \gamma \eta_c$

N_{2S,EXC}: Number of exclusive $\psi(2S) \rightarrow \gamma \eta_c$

N_{1S,EXC}: Number of exclusive $\psi(2S) \rightarrow \pi \pi J/\psi$; $J/\psi \rightarrow \gamma \eta_c$

 $N_{\psi(2S)}$: Number of $\psi(2S)$

B_{nu}: B($\psi(2S) \rightarrow \pi^+\pi^-J/\psi$) (currently using CLEO's published number).

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 $\begin{array}{l} \eta_c \mbox{ Production in Radiative Decays} \\ \hline {\rm Discovery \ of \ } J/\psi {\rightarrow} \gamma \gamma \gamma \\ h_c \mbox{ Properties} \end{array}$

Discovery of $J/\psi \rightarrow \gamma \gamma \gamma$

- Only one system has been observed to decay to a non-resonant combination of three γ: ortho-positronium
 - $\mathcal{B}(J/\psi \rightarrow \gamma \gamma \gamma) < 5.5 \times 10^{-5}$.
 - $\mathcal{B}(\omega \rightarrow \gamma \gamma \gamma) < 1.9 \times 10^{-4}$.
 - $\mathcal{B}(Z \rightarrow \gamma \gamma \gamma) < 1 \times 10^{-5}$.
- Kwong predicts ${\cal B}(J/\psi{ o}\gamma\gamma\gamma)\sim 10^{-5}$
- We present here the first observation, a 6σ measurement, of this decay of J/ψ
- Method in brief:
 - Tag J/ψ in $\pi^+\pi^-$ decay of ψ'
 - Require 3 γ with no $\pi^0/\eta/\eta\prime/\eta_c$ substructure
 - Kin. fit of $\pi^+\pi^-\gamma\gamma\gamma$ to p^μ of ψ' (tight χ^2 cut)





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 $\begin{array}{l} \eta_c \mbox{ Production in Radiative Decays} \\ \hline {\rm Discovery \ of \ } J/\psi {\rightarrow} \gamma \gamma \gamma \\ h_c \mbox{ Properties} \end{array}$

Discovery of $J/\psi { ightarrow} \gamma \gamma \gamma$



- Hard cuts in $M_{\gamma\gamma}$ to reject $Ps \rightarrow \gamma\gamma$
- Remaining bkg. removed thru kin. fit:
 - (blue:) $J/\psi \rightarrow \gamma \pi^0 \pi^0$
 - (green:) NR bkg (determined from $\pi^+\pi^-$ recoil mass sb)



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Discovery of $J/\psi {
ightarrow} \gamma \gamma \gamma$



The Singlet States of Heavy Quarkonia

- In the past few years, new experimental work in the charmonium region has yielded observation of the previously unseen states below open charm threshold: namely, $\eta_c(2S)$ and $h_c(1P)$.
- These states are of critical importance in understanding the $q\bar{q}$ potential: only handle on the spin-spin (or hyperfine) interaction (excellent tests of LQCD and QCD Potential models)

$$\Delta M_{hf} \equiv M(^{3}L) - M(^{1}L); \quad M(^{3}L) = rac{\sum_{J} [J(J+1)M_{J}]}{\sum_{J} [J(J+1)]}$$

 Neither the 2S nor the 1P splittings are known well: we present here an updated measurement from CLEO-c of the 1P splitting.



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 $\begin{array}{l} \eta_c \mbox{ Production in Radiative Decays} \\ \mbox{Discovery of } J/\psi {\rightarrow} \gamma \gamma \gamma \\ h_c \mbox{ Properties} \end{array}$

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Previous CLEO and E835 Results (2005)



- E835 and CLEO both observe $h_c \rightarrow \gamma \eta_c$
- Their masses disagreed ... and lay on opposite sides of $(\langle M({}^{3}P) \rangle = 3525.4 \text{ MeV}).$

$$\begin{split} M_{h_c,CLEO} &= 3524.4 \pm 0.6 \pm 0.4 \ \textit{MeV} \ \textit{PRD72,092004} \ (2005) \\ M_{h_c,E835} &= 3525.8 \pm 0.2 \pm 0.2 \ \textit{MeV} \ \textit{PRL} \end{split}$$

 $\begin{array}{l} \eta_c \mbox{ Production in Radiative Decays} \\ \mbox{Discovery of } J/\psi {\rightarrow} \gamma \gamma \gamma \\ h_c \mbox{ Properties} \end{array}$

Measurements of h_c Properties



Inclusive:

- Observe γ , $E_{\gamma}=503\pm35$ MeV
- Reconstruct $\pi^0{\rightarrow}\gamma\gamma$ and fit spectrum of masses recoiling against π^0
- Signal shape from MC; Bkg.
 obtained from data (no E_γ cut)

Exclusive:

- No constraint on E_{γ}
- Reconstruct 18 different hadronic final states of η_c
- Reconstruct $\pi^0 \rightarrow \gamma \gamma$ and analyze spectrum of masses that recoil against π^0



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 $\begin{array}{l} \eta_c \mbox{ Production in Radiative Decays} \\ \mbox{Discovery of } J/\psi{\rightarrow}\gamma\gamma\gamma \\ \textbf{h}_c \mbox{ Properties} \end{array}$

h_c Properties - Results

Inclusive:

$$\begin{split} \mathcal{B}(\psi' \to \pi^0 h_c) \times \mathcal{B}(h_c \to \gamma \eta_c) &= (3.95 \pm 0.41 \pm 0.52) \times 10^{-4} \\ \mathcal{M}(h_c) &= 3525.35 \pm 0.24 \pm 0.21 \; \text{MeV} \end{split}$$

Exclusive:

$$M(h_c) = 3525.35 \pm 0.27 \pm 0.20 \ MeV$$

Combined Mass Measurements:

$$M(h_c) = 3525.35 \pm 0.19 \pm 0.15 \ MeV$$

 $\Delta M_{hf} = -0.05 \pm 0.19 \pm 0.16 \ MeV$





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Additional Comments on the h_c Results

Comments on partial widths:

- Expect $\Gamma(h_c \rightarrow \gamma \eta_c)$ and $\Gamma_{tot}(h_c)$ to be similar to the analogous χ_1 quantities: Thus expect $\mathcal{B}(h_c \rightarrow \gamma \eta_c) = 0.36 \pm 0.02$.
- Our $\mathcal{B}_1 \times \mathcal{B}_2$ then implies $\mathcal{B}(\psi' \rightarrow \pi^0 h_c) = (1.10 \pm 0.14) \times 10^{-3}$, which is similar to the other isospin violating ψ' decay: $\mathcal{B}(\psi' \rightarrow \pi^0 J/\psi) = (1.26 \pm 0.13) \times 10^{-3}$.

and on mass:

- $\Delta M(1P) = -0.05 \pm 0.19 \pm 0.16$ MeV is $\simeq 0$
- Caveat: the standard spin-weighting used in calculating $\langle M({}^{3}P) \rangle$ is good only to first order: hence it assumes the spin-orbit splitting is perturbatively small. In charmonium, the $M({}^{3}P_{2}) M({}^{3}P_{0})$ isn't *exactly* small (~ 140 MeV).



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 $\begin{array}{ll} & \text{CLEO-c Introduction} \\ D_S & \text{Physics Results} \\ \text{Charmonium Physics Results} \\ \end{array} \begin{array}{l} \eta_c & \text{Production in Radiative Decay} \\ \text{Discovery of } J/\psi \rightarrow \gamma \gamma \gamma \\ h_c & \text{Properties} \end{array}$

Summary

(Prelim: red; Submitted: blue)

- New measurement: $f_{D_S} = 274 \pm 10 \pm 5$
- First Observation : $\mathcal{B}(D_S \rightarrow p\bar{n}) = (1.30 \pm 0.36^{+0.12}_{-0.16}) \times 10^{-3}$
- New measurements

$$\begin{split} \mathcal{B}(\psi' \! \to \! \gamma \eta_c) &= (4.32 \pm 0.16 \pm 0.65) \times 10^{-3} \\ \mathcal{B}(J/\psi \! \to \! \gamma \eta_c) &= (2.07 \pm 0.09 \pm 0.35)\% \end{split}$$

• First Observation:

 $\mathcal{B}(J/\psi{
ightarrow}\gamma\gamma\gamma)=(1.17^{+0.34}_{-0.29}{\pm}0.14){ imes}10^{-5}$

- New measurement of $M(h_c) = 3525.26 \pm 0.19 \pm 0.12$ MeV
- Keep listening... more to come.

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Todd Pedlar (for the CLEO-c Collaboration)



For information and to register, visit: www.lepp.cornell.edu/Events/CLEOCESRSymp/

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Recent Heavy Flavor Results from CLEO-c

 η_c Production in Radiative Decays Discovery of $J/\psi \rightarrow \gamma \gamma \gamma$ h_c Properties

BACKUP SLIDES



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 $\begin{array}{lll} & \text{CLEO-c Introduction} \\ D_S & \text{Physics Results} \\ \text{Charmonium Physics Results} \\ \end{array} \qquad \begin{array}{lll} & \eta_c & \text{Production in Radia} \\ & \text{Discovery of } J/\psi \rightarrow \gamma\gamma \\ & h_c & \text{Properties} \end{array}$

$$D_S^+ \rightarrow \tau^+ \nu_{\tau}$$

TABLE I: Summary of ST yield $(n_{\rm ST})$, ST mass sideband scaling factor (s), DT yield $(n_{\rm DT})$, and the number of estimated backgrounds (b), where n(R) is the yield in the ST mass signal region, n(B) is the yield in the ST mass sideband, and $n_{\rm DT}^{(0)}$ is the sideband subtracted DT yield before background correction.

Tag Mode	$n_{\rm ST}(R)$	$n_{\rm ST}(B)$	s	$n_{\rm ST}$	$n_{\rm DT}(R) \ n_{\rm DT}(R)$	$n_{\rm DT}^{(0)}$	b	$n_{\rm DT}$
$D_s^- \rightarrow \phi \pi^-$	5243	391	0.997	4853.0 ± 75.1	49	$0\ 49.0\pm7.0$	8.8 ± 0.6 4	40.2 ± 7.0
$D_s^- \rightarrow K^- K^{*0}$	9020	3661	1.010	5321.0 ± 112.8	55	$3\ 52.0\pm7.6$	8.6 ± 0.7 4	43.4 ± 7.6
$D^s \to K^- K^0_S$	3499	710	1.022	2773.1 ± 65.0	24	$2\ 22.0 \pm 5.1$	4.0 ± 0.4 1	18.0 ± 5.1

•
$$n_{ST} = 12947 \pm 150; \ n_{DT} = 102 \pm 12$$

- $B_{SG} = \frac{n_{DT}}{n_{ST}} \frac{\epsilon(ST)}{\epsilon(DT)}$
- $\epsilon(DT)$ includes $B(\tau^+ \rightarrow e^+ + \bar{\nu}_{\tau} + \nu_e) = (17.84 \pm 0.05)\%$
- Syst err dominated by branching fractions of D_S decays which compose the backgrounds in the E_{energy} distribution (4.5% relative). Total syst. err is 5.5% relative.
- Final result: $B(D_S^+ \rightarrow \tau^+ \bar{
 u}_{ au} = 6.17 \pm 0.71(stat) \pm 0.34(syst)$



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 $\begin{array}{l} \eta_c \mbox{ Production in Radiative Decays} \\ \mbox{Discovery of } J/\psi{\rightarrow}\gamma\gamma\gamma \\ \textbf{h}_c \mbox{ Properties} \end{array}$

$D_S \rightarrow p\bar{n}$ Missing Mass (γ -tagged Monte Carlo)



Todd Pedlar (for the CLEO-c Collaboration)

 $\begin{array}{l} \eta_c \mbox{ Production in Radiative Decays} \\ \mbox{Discovery of } J/\psi{\rightarrow}\gamma\gamma\gamma \\ \textbf{h}_c \mbox{ Properties} \end{array}$

h_c Properties: η_c decays used

- No constraint on E_{γ}
- Reconstruct 18 different hadronic final states:





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Previous CLEO Results on h_c

