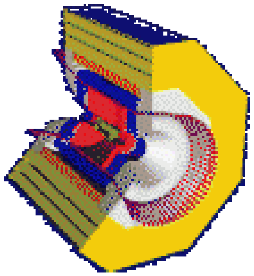

CLEO Results on Hadron Spectroscopy and Outlook for CLEO-c

Todd K. Pedlar
The Ohio State University
(for the CLEO Collaboration)
Email: todd@mail.lns.cornell.edu

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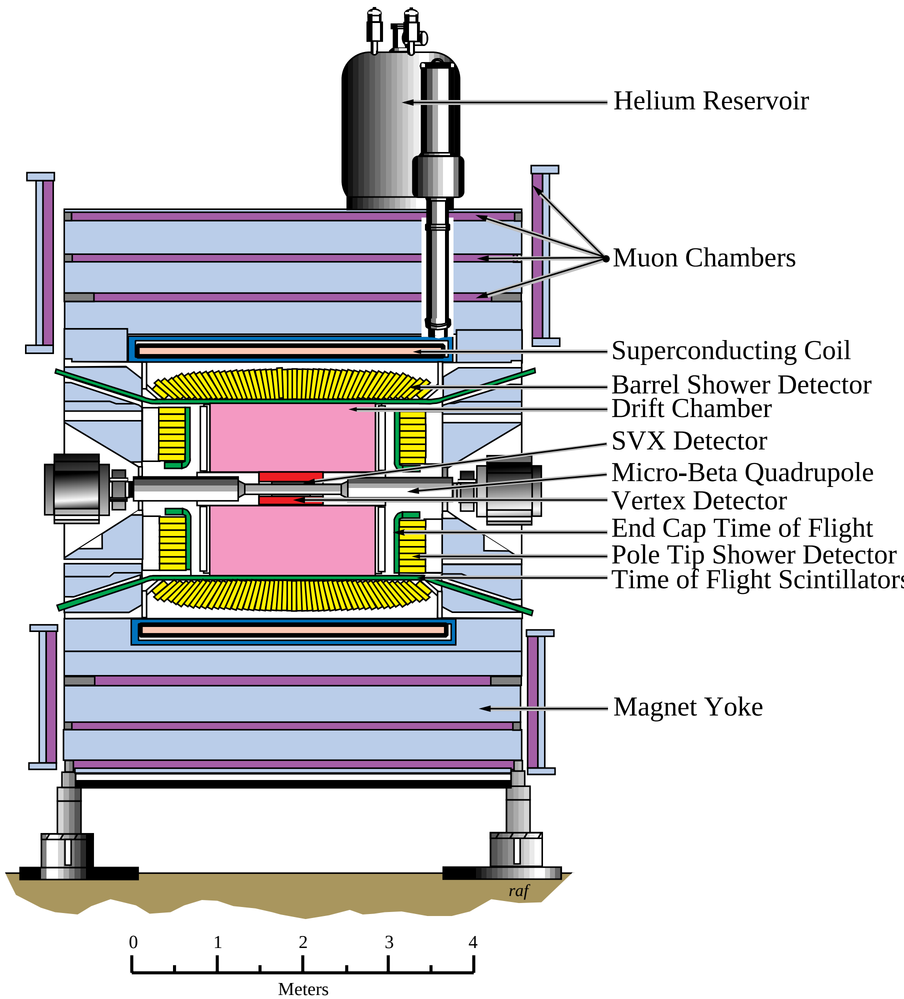
Outline

- Quick CLEO Introduction
- Hadron Spectroscopy Results from CLEO
  - Charmonium Spectroscopy in 2γ collisions
  - Mass and Width of the D^* meson
  - Search for the Radiative Decay $\Upsilon(1S) \rightarrow \gamma\eta'$
- CLEO-c: The Next Generation

* CLEO results from this talk are available as CLNS preprints from http://www.lns.cornell.edu/public/CLNS/2001/CLEO.html

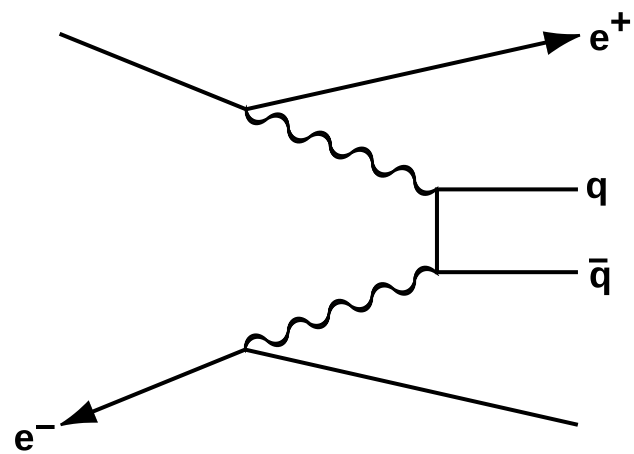
Quick CLEO Introduction

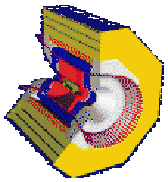
- CLEO is the detector at CESR, the symmetric e+e- collider which operates at the $\Upsilon(4S)$ (E_{cm} = 10.58 GeV) with the primary goal of B physics studies
- CLEO II & II.V datasets: 14 fb^{-1}
- Key features:
  - 51 layer main drift chamber
    - excellent momentum & dE/dx res. and tracking coverage of 93% of 4π
  - 7800 element CsI calorimeter
    - superb photon energy resolution, and 93% solid angle coverage
  - SVX installed in CLEO II.V



1) $\gamma\gamma$ partial widths of P-wave charmonia χ_{c0}, χ_{c2}

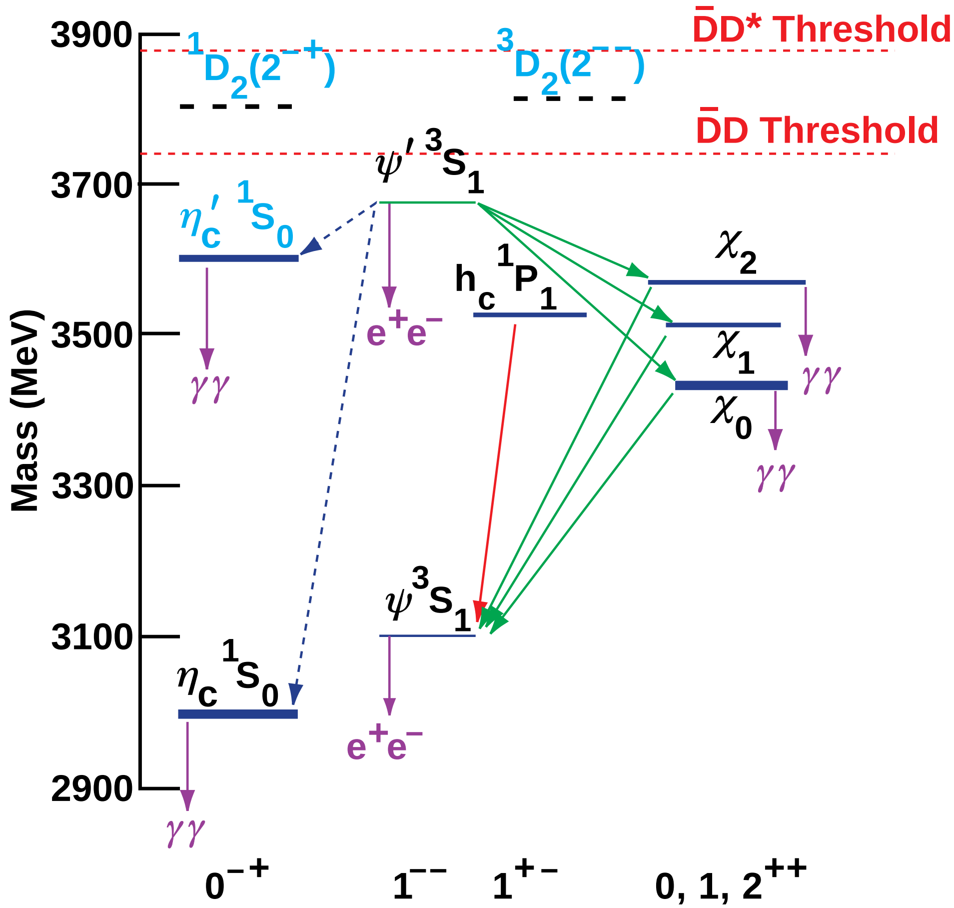
- Quarkonia may be studied at CLEO in production via $\gamma\gamma$ collisions
- This production mechanism is limited to even J, C-even states, such as the two states in view in this talk, as well as η_c, f_2, etc.
- Two-photon widths may thus be directly measured, since the yield of these states is $\propto \mathcal{L}_{\gamma\gamma} \times \Gamma_{\gamma\gamma} \times BR(f.s.)$
  - $\mathcal{L}_{\gamma\gamma}$ is a well determined QED function - BR to the final state is taken as input.





$\gamma\gamma$ partial widths of P-wave charmonia χ_{c0}, χ_{c2}

- The χ_c states of charmonium are the 1P states – the triplet of states with 1 unit of orbital angular momentum. J = 0, 1 or 2, and PC is $^{++}$.
- The $\gamma\gamma$ decay modes of charmonia shed important light upon the dynamics of quarks in strongly interacting systems. They can provide direct evidence of the strength of the strong coupling at the charm mass scale
- Ratios of $\gamma\gamma$ widths for such states are especially enlightening



$\gamma\gamma$ partial widths of P-wave charmonia χ_{c0}, χ_{c2}

- pQCD predicts at NLO: (canceling charm quark masses & charmonium wave functions)

$$R(\chi_{c0}) \equiv \frac{\Gamma_{\gamma\gamma}}{\Gamma_{gg}} = \frac{8\alpha^2}{9\alpha_S^2}\frac{(1+9.5\alpha_S/\pi)}{(1+0.18\alpha_S/\pi)}$$

$$R(\chi_{c2}) \equiv \frac{\Gamma_{\gamma\gamma}}{\Gamma_{gg}} = \frac{8\alpha^2}{9\alpha_S^2}\frac{(1-5.3\alpha_S/\pi)}{(1-2.2\alpha_S/\pi)}$$

$$R_{\gamma\gamma} \equiv \frac{\Gamma_{\gamma\gamma}(\chi_{c0})}{\Gamma_{\gamma\gamma}(\chi_{c2})} = \frac{15}{4}\frac{(1+0.18\alpha_S/\pi)}{(1-5.3\alpha_S/\pi)}$$

$$\Gamma_{gg} = \Gamma_{tot} - \Gamma_{\gamma J/\psi} - \Gamma_{ggg} = \Gamma_{tot} - \Gamma_{\gamma J/\psi} - \Gamma_{tot}(\chi_{c1})$$

Input: $\alpha_S = 0.25$ to 0.35

$\Gamma_{\gamma\gamma}(\chi_{c0}) = 3 - 5$ keV

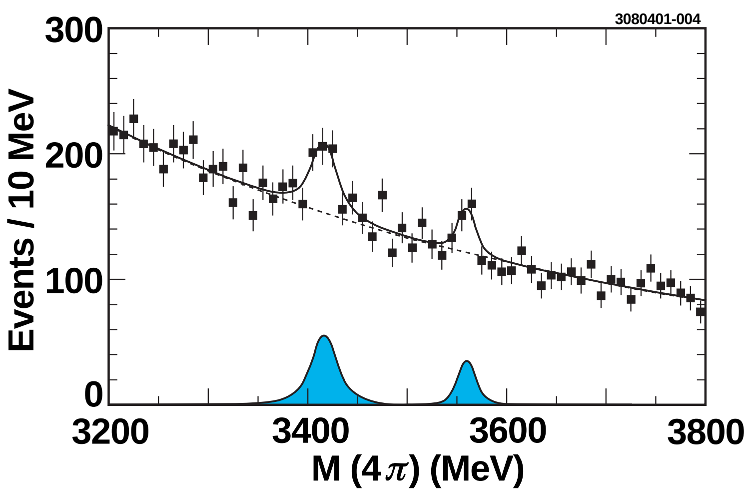
$\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.27 - 0.47$ keV

$R_{\gamma\gamma} = 7 - 9$

- N.B. There are caveats that should be recognized in making precise comparisons

$\gamma\gamma$ partial widths of 1P charmonia χ_{c0}, χ_{c2} : Results

- At CLEO, we have searched for χ_{c0} and χ_{c2} via $\pi^+\pi^-\pi^+\pi^-$:
  - $BR(\chi_{c2} \to \pi^+\pi^-\pi^+\pi^-) = 1.2 \pm 0.5\%$
  - $BR(\chi_{c0} \to \pi^+\pi^-\pi^+\pi^-) = 2.0 \pm 0.9\%$



- Other experimental results for comparison:

$$\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.47 \pm 0.17 \text{ keV (PDG2000)} \quad \text{(a)}$$
$$= 0.27 \pm 0.05 \pm 0.3 \text{ keV (FNAL E835)}$$

$$\Gamma_{\gamma\gamma}(\chi_{c0}) = 4.0 \pm 2.8 \text{ keV} \quad \text{(unpub. thesis)} \quad \text{(b)}$$

$$\Gamma_{\gamma\gamma}(\chi_{c0}) / \Gamma_{\gamma\gamma}(\chi_{c2}) = 8.7 \pm 6.9 \text{ (using (a) and (b))}$$

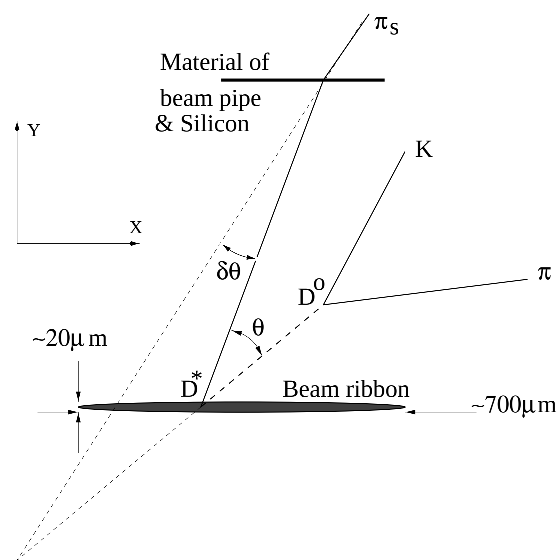
The present CLEO results:

(CLNS 01/1732) and hep-ex/0104042

$$\Gamma_{\gamma\gamma}(\chi_{c0}) = 3.76 \pm 0.65 \text{ (stat)} \pm 0.41 \text{ (syst)} \pm 1.69 \text{ (b.r.) keV}$$
$$\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.53 \pm 0.15 \text{ (stat)} \pm 0.06 \text{ (syst)} \pm 0.22 \text{ (b.r.) keV}$$
$$\Gamma_{\gamma\gamma}(\chi_{c0}) / \Gamma_{\gamma\gamma}(\chi_{c2}) = 7.4 \pm 2.4 \text{ (stat)} \pm 0.5 \text{ (syst)} \pm 0.9 \text{ (b.r.)}$$

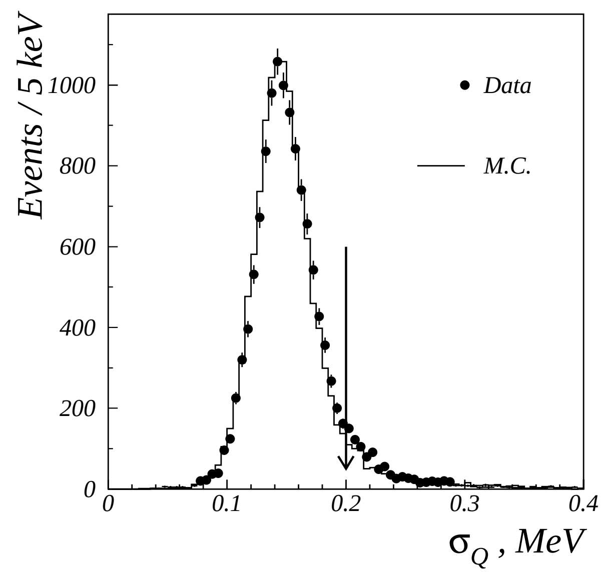
2) Measurement of the Mass and Full Width of the $D^{*\pm}$

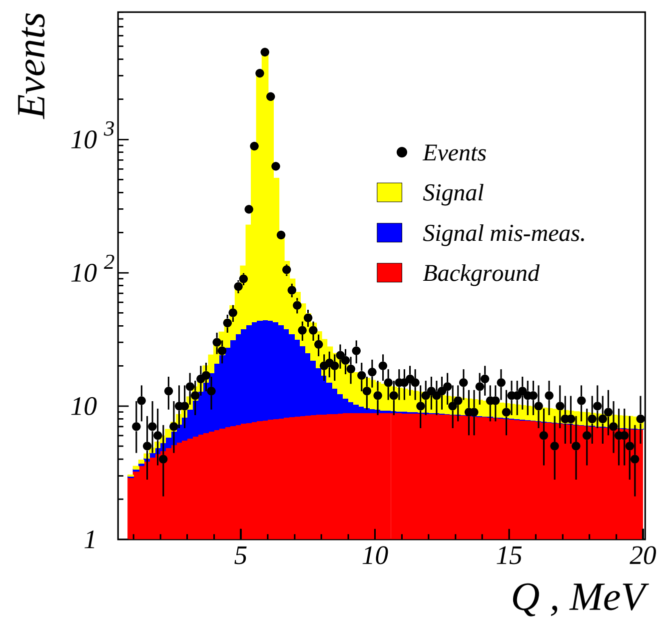
- The measurement of the width via $D^* \to D\pi$ represents an important window into non-perturbative QCD: a strong transition not possible between B^* and B
- Prior to this result, only an upper limit has been reported for the D^* full width (131 keV)
- The D^* signal is reconstructed through $D^{*+} \to D^0\pi^+_{slow} \to (K^-\pi^+)\,\pi^+_{slow}$. The full width is measured through analysis of the Q (energy release) distribution
- Key: small vertical size of CESR interaction region (10 μm)
  - Combine K^- and π^+ forming a common vertex
  - Project resultant D^0 back to interaction region
  - Remove D^0 within 0.3 radians of horizontal plane
  - Re-fit slow π, constrain to intersect the D^0 prod. point
  - Upshot: 30% improvement in Q resolution
- This analysis is done using 9.0 fb^{-1} of the CLEO II.V data set
- ~14000 D^{*+} events are obtained



Measurement of the Mass and Full Width of the $D^{*\pm}$

- Analysis points:
  - Assuming the intrinsic width of D^0 is negligible, the energy release Q is convolution of D^{*+} width and tracking system response
  - Fit the Q distribution to obtain mean (⇒ mass) and shape (⇒ width) of D^{*+}
- Q resolution (σ_Q), determined from propagation of tracking errors is shown at left. Results from the data, at right.





Measurement of the Mass and Full Width of the $D^{*\pm}$: Results

The present CLEO results:

(CLNS 01-1740 PRL and 01-1741 PRD)

$$\Gamma(D^{*\pm}) = 96 \pm 4\ (\text{stat}) \pm 22\ (\text{syst})\ \text{keV}$$

$$\Delta m = m(D^{*\pm}) - m(D^0) =$$

$$145.412 \pm 0.002\ (\text{stat}) \pm 0.012\ (\text{syst})\ \text{MeV}$$

PDG2000

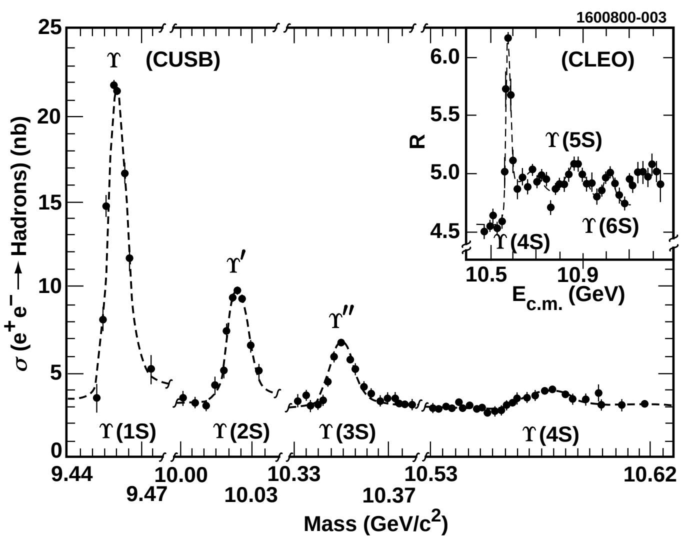
$$\Gamma(D^{*\pm}) < 131\ \text{keV}\ (90\%\ \text{CL})$$

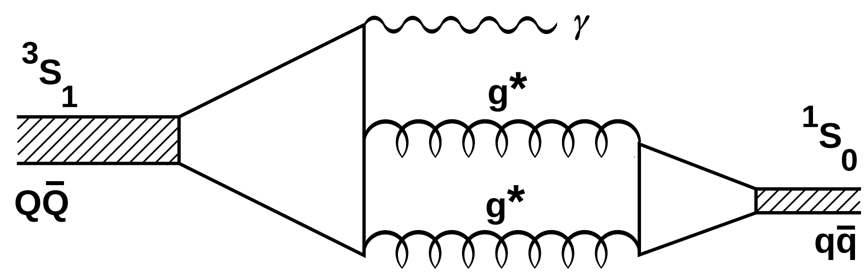
$$\Delta m = 145.436 \pm 0.016\ \text{MeV}$$

- Predictions of the D^* total width range across the board from 15 to 150 keV. This first result puts significant constraints on such predictions
- The Δm measurement is more precise than the PDG2000 average, and represents the best single result reported

3) Search for the Radiative Decay $\Upsilon(1S) \to \gamma\eta'$

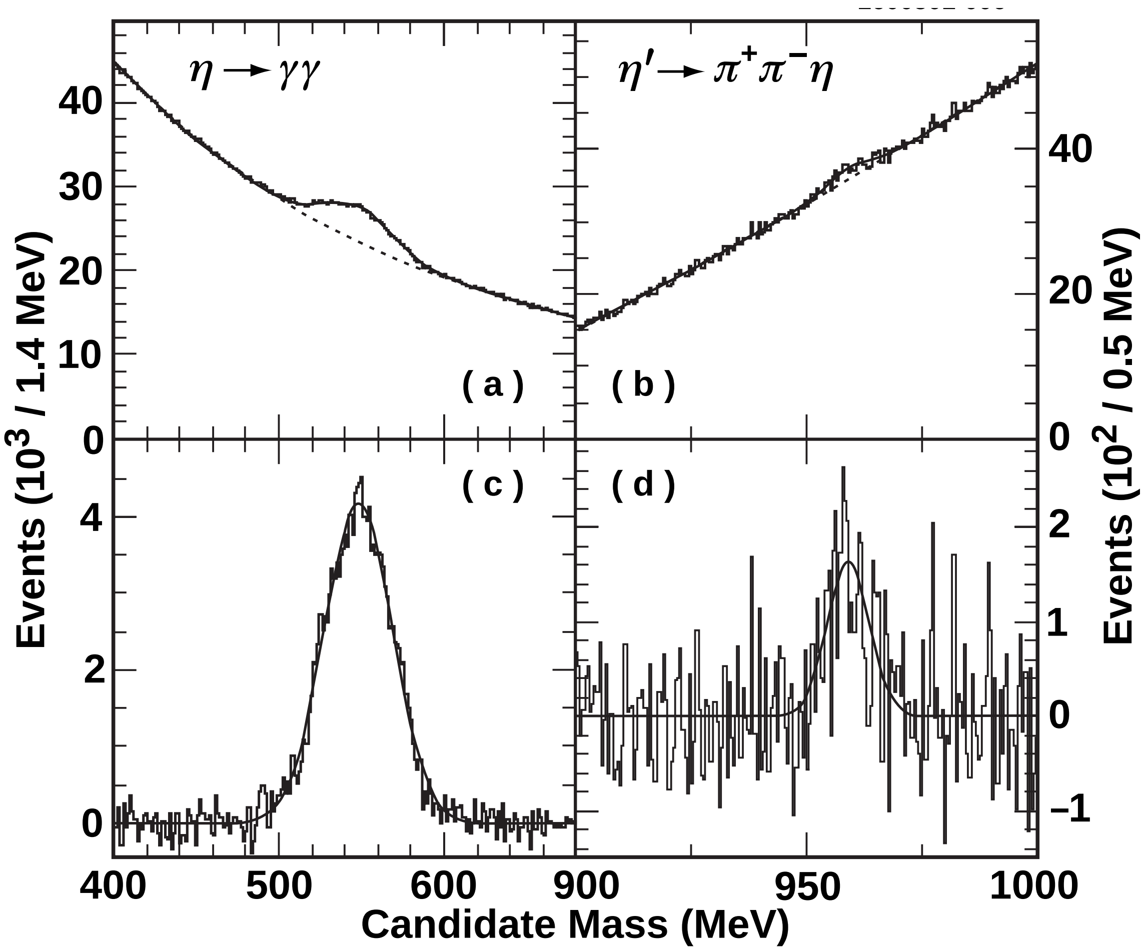
- Speculation about valence gluonic components in η' motivates this study
- Radiative decays of J/ψ have been instrumental in uncovering states which may be rich in gluonic content at the valence level
- Similar decays of $\Upsilon(1S)$ should (though branching fractions are significantly reduced) provide another window into these states





Search for the Radiative Decay $\Upsilon(1S) \rightarrow \gamma\eta'$

- In this analysis, the η' is sought in the $\eta\pi^+\pi^-$ decay (BR = 44.3%)
- η is reconstructed in
  - $\gamma\gamma$, (BR = 39.3%)
  - $3\pi^0$ (BR = 32.24%)
  - or in $\pi^+\pi^-\pi^0$ (BR = 23.0%)
- The data at right are taken from continuum near $\Upsilon(4S)$ and show clear evidence for inclusive η' production
- When η' candidates are paired with photons in the $\Upsilon(1S)$ data....



Search for the Radiative Decay $\Upsilon(1S) \to \gamma\eta'$: Results

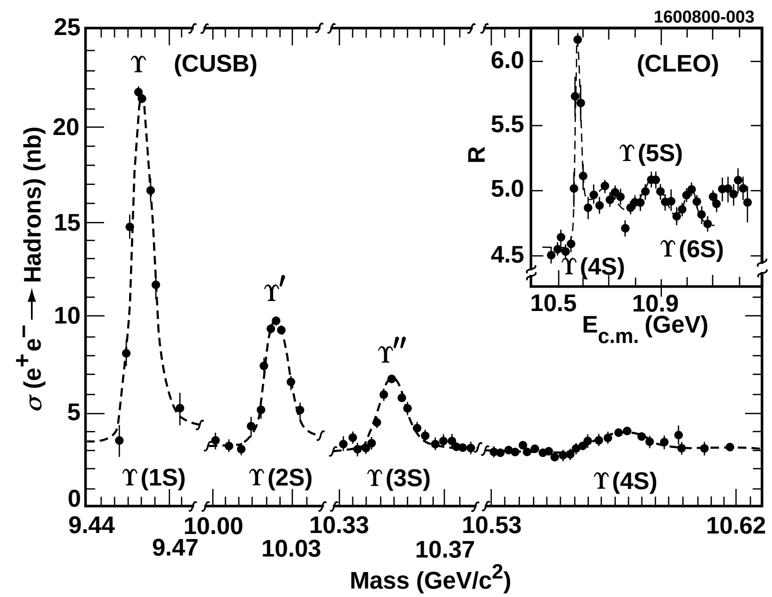
- No candidates for $\Upsilon(1S) \to \gamma\eta'$ are found in 61 pb^{-1} (1.45 M $\Upsilon(1S)$ decays)
- Translates to an upper limit : (CLNS 01- 1744) $B(\Upsilon(1S)\to\gamma\eta') = 1.6 \times 10^{-5}$ (90% CL)
- Significantly improves the present upper limit, from Crystal Ball, of 0.13%
- Puts slight constraint on theoretical predicitions. Others are well below the sensitivity afforded by the small CLEO $\Upsilon(1S)$ data set.

Author	model	BR
Körner et al.	-	$5\text{-}10 \times 10^{-5}$
Intemann	ext. VDM	$0.53\text{-}2.5 \times 10^{-6}$
Ma	NRQCD	1.2×10^{-7}

- In the next year, CLEO will collect approximately 1 fb^{-1} at the $\Upsilon(1S)$ - 17 times more data than we currently have. Thus this search, and searches for other states in radiative $\Upsilon(1S)$ decay may be made with much higher sensitivity

CLEO-c: The Next Generation

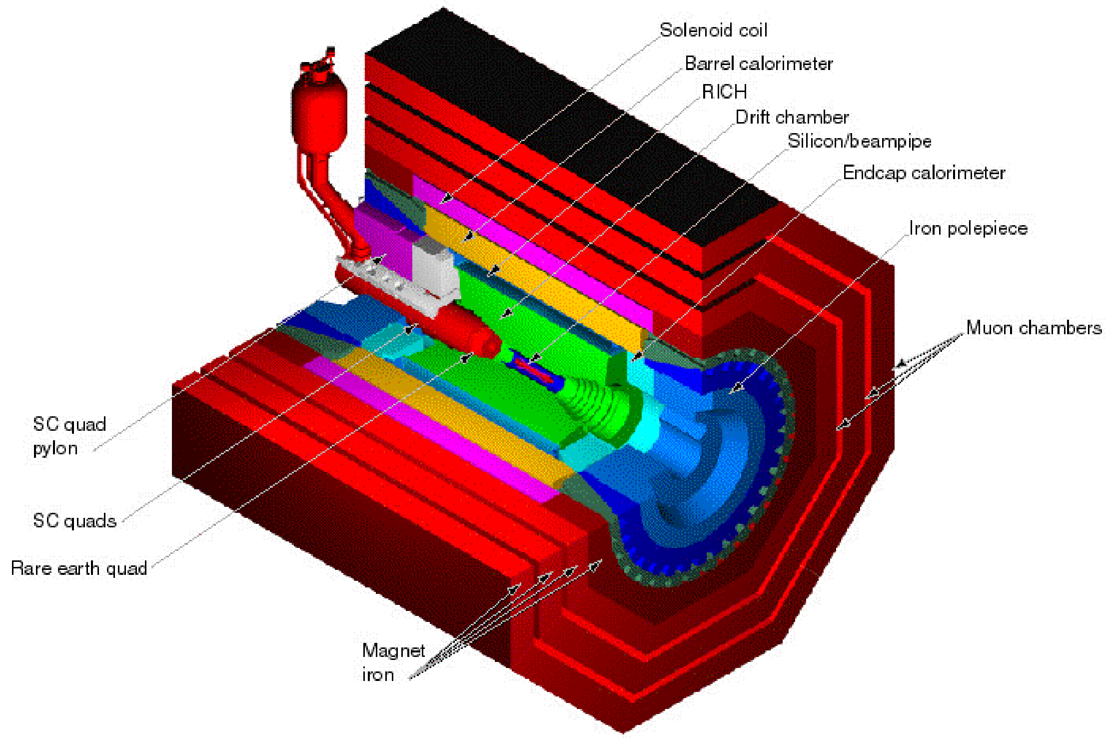
- After running for 20 years at the ϒ(4S) on June 26 of this year, the B physics era at CLEO has come to an end.
- This fall, we will begin a ~1 year run on the lower ϒ resonances, accumulating 1 fb^{-1} on each of the ϒ(1S) and ϒ(3S), and 0.5 fb^{-1} on the ϒ(2S)
- Afterward, we will transition to lower energies, to explore with very high statistics the sub 5 GeV region



- For MUCH more information on our future plans, see CLNS 01/1742 and http://www.lns.cornell.edu/public/CLEO/spoke/CLEOc/index.html

CLEO-c: The Next Generation

- CLEO-c will operate with the upgraded CLEO III detector - including RICH PID & a new drift chamber. Momentum resolutions, dE/dx resolution, and RICH PID all add to the already superb performance of the CLEO II detector
- CESR will need upgrades to run in the 3 to 5 GeV region, and should provide a luminosity of 1-5 x 10^{32} at the ψ



CLEO-c: The Next Generation

- Among the possible topics of investigation for CLEO-c are
  - D meson studies with high statistics
  - Measurements of D_S parameters
  - Studies of QCD physics at the J/ψ and ψ'
- Given the topical focus of this session, I'll concentrate on the last item where we expect that a CLEO-c can make a truly significant contribution to hadronic physics
  - The world's data set of J/ψ and ψ' decays consist of approximately 20 million ψ' and 50 million J/ψ observed by Mark III, Crystal Ball, BES, etc.
  - We expect to accumulate at least 1 fb^{-1} on the peak of J/ψ - translating to in excess of 1 billion J/ψ decays - a factor 20 larger than the whole sample of J/ψ decays, with a much superior detector. Time permitting, we will also accumulate the world's best sample of ψ' decays.

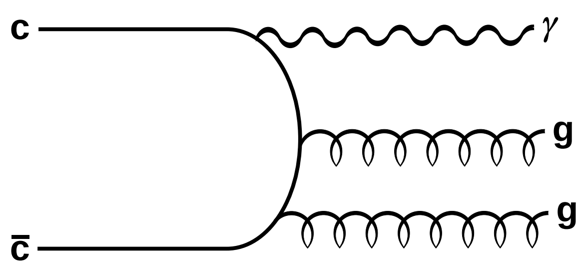
CLEO-c: The Next Generation

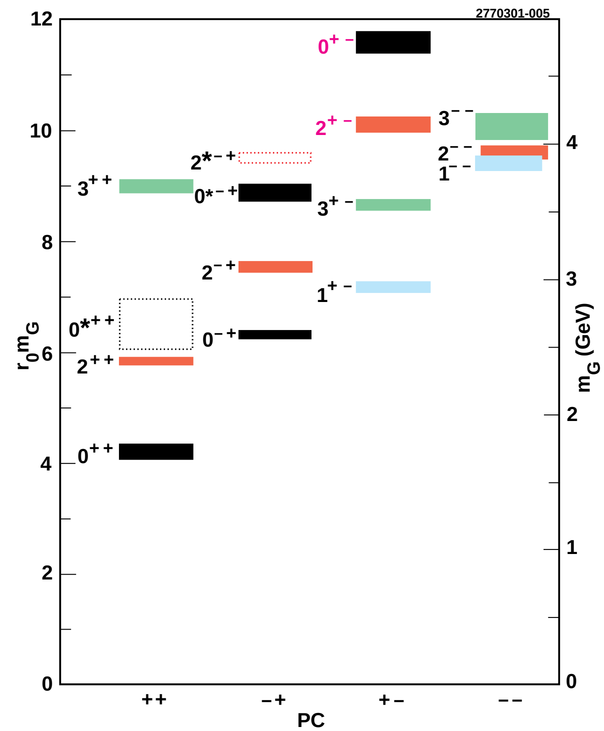
- With such data sets, precise spectroscopy will be possible. We expect to study: (among other things)
  - Glueballs and other exotica - production in J/ψ decays
    - Radiative J/ψ decays to these particularly interesting states also suffer from relatively small statistics.
  - Spectroscopy of conventional mesons from ψ' decays.
    - Most charmonium states have been observed in only a few hadronic decay modes - those in which they have been seen usually have 20-50% errors on the branching fraction - statistically very poor.

- This program, coupled with the high statistics running in the Υ system, provides a real opportunity for significant testing of lattice gauge techniques: a boon to not only the QCD/hadronic community but to those investigating heavy quark physics

CLEO-c: QCD Physics Focus

- Glueball states, wherein two or three gluons are valence partons (as quarks are in mesons & baryons), are predicted by QCD to lie between ~1.5 and 2.5 GeV
- Many candidates have been proposed - most candidates were spotted in J/ψ radiative decay, the "glueball factory"

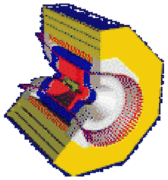




CLEO-c: QCD Physics Focus

- All the current candidate glueballs have conventional quantum numbers – they are thus expected to mix with conventional mesons, and perhaps be difficult to observe without detailed PWA and statistically significant samples in many hadronic modes
- The planned CLEO-c data set is easily large enough that such requirements are met.

- The CLEO-c detector surpasses those of Mark III and BES in:
  - tracking efficiency and resolution: substantial improvement in every possible performance parameter
  - PID: RICH and dE/dx capability offer 10's of sigma $K\pi$ separation over whole kin. range
  - photon energy and position resolution: factor 10-20 better
  - hermeticity: 25% more than BES. Essential for PWA
  - These all effectively increase the impact of the already large edge in integrated luminosity planned for CLEO-c

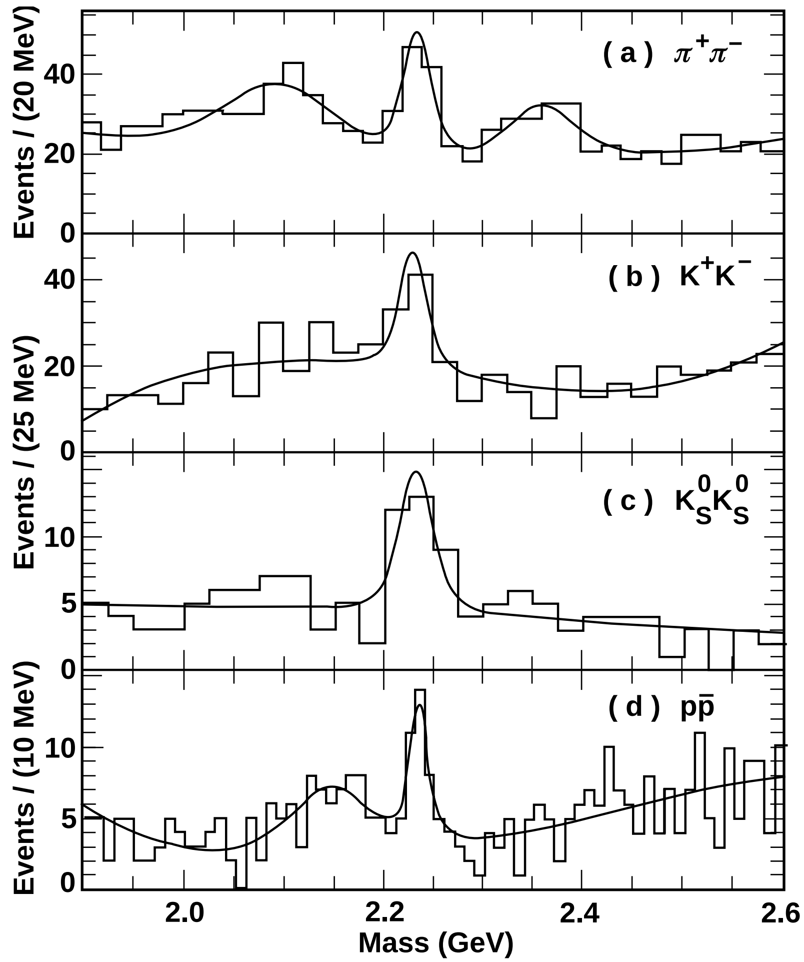


CLEO-c: QCD Physics Focus

- With a billion J/ψ's, CLEO-c would be entering new territory:
- The range of masses of produced in radiative J/ψ decays, 1-3 GeV, will be thoroughly mined for interesting phemomena
  - Partial wave analysis should result in clear spectra of scalar, tensor and exotic states
  - This should reveal masses, widths, decay modes, etc - and hopefully clean up the rather messy spectrum of states in this region.
  - In particular, glueball candidates $f_0(1370)$, $f_0(1500)$, $\theta_J(1710)$, $\xi(2230)$ will be observed with large statistics in many decay modes
- These studies will benefit from not only enormous statistics, but from the fact that 3 production mechanisms can be explored with the same detector. $J/\psi \rightarrow \gamma X$, $\Upsilon(1S) \rightarrow \gamma X$, and $e^+e^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^-X$. The latter two will help establish or debunk any glueball candidates found in the J/ψ data.

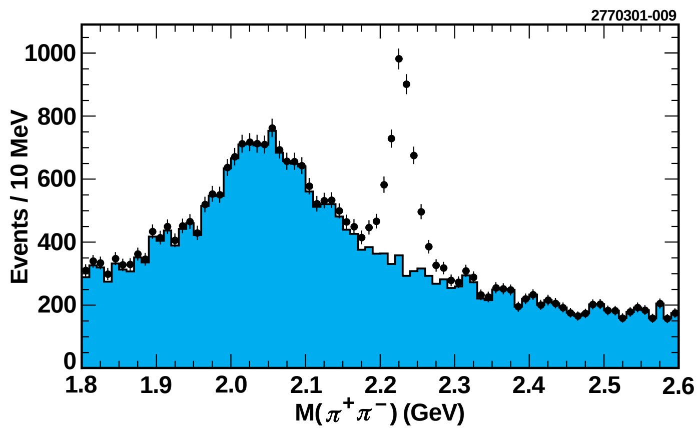
CLEO-c: QCD Physics Focus

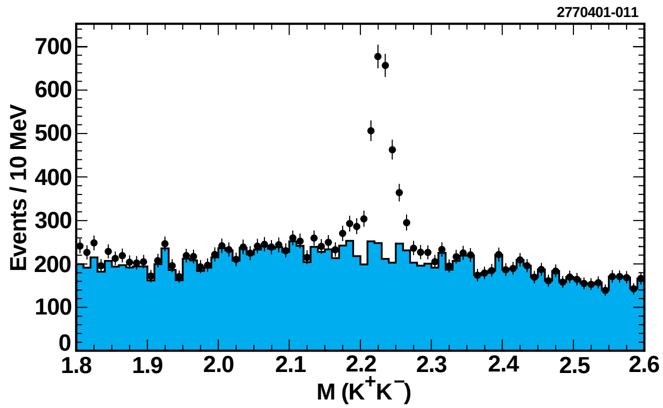
- As an example, let's consider the elusive ξ(2230), one of the more commonly touted candidates for the tensor (2^{++}) glueball
- At right are results from BES in various decay modes. BES has the only claim for the ξ(2230) in non-strange decays
  - Mark III discovered it in strange decays
  - DM2 did not observe it
  - BES reported both strange and non-strange decay modes
  - Crystal Barrel subsequently failed to find ξ(2230), casting some doubt on the BES results
  - A murky picture to say the least

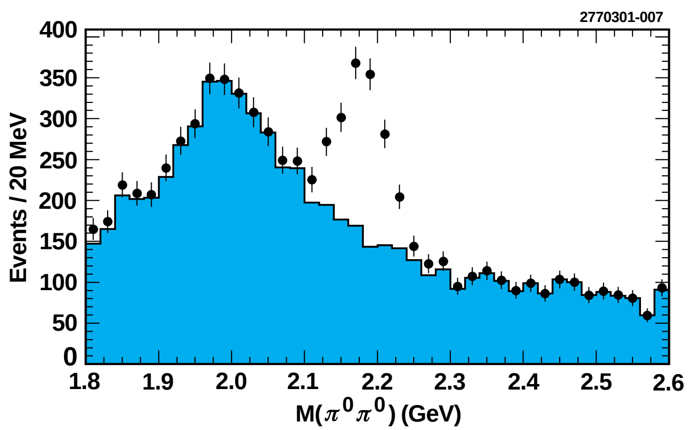


CLEO-c: QCD Physics Focus

- The plots at right and below show what CLEO-c should be capable of, assuming BES results for ξ(2230) branching fractions to be correct.
- These represent what is expected with approximately 15% of the planned data set

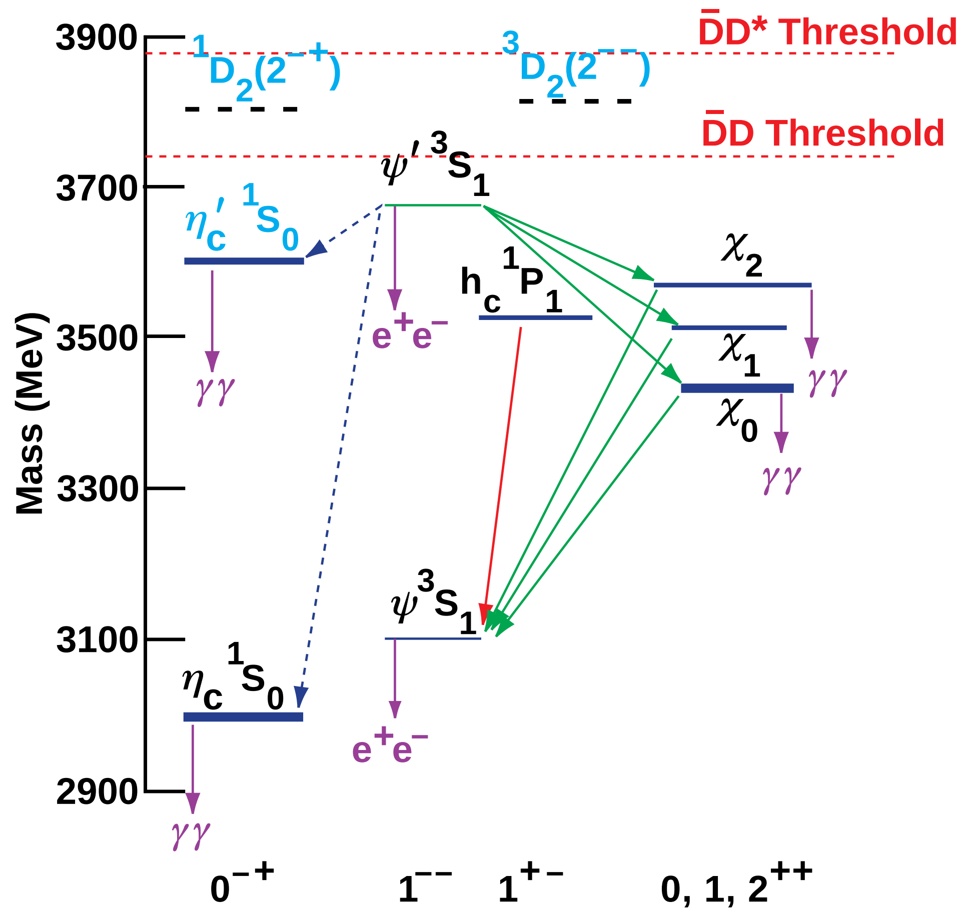






CLEO-c: QCD Physics Focus

- There is also a strong physics case to be made for studying charmonium states in both J/ψ and ψ′ decays
- Of the 8 states lying below open charm threshold, 6 are firmly established.
- Of these 6, only the J/ψ has a significant number of hadronic decay modes measured very well. Hadronic decay modes of other states are in general VERY poorly understood.
- (e.g. The best η_c BR has a 31% error)
  - 10^9 J/ψ → 10^7 η_c → 10^5 η_c in individual hadronic modes



Summary

- CLEO has contributed a wide range of results in hadron spectroscopy over the years, and more are expected from the 25 fb^{-1} CLEO II, II.V and III data sets. In this talk I have mentioned three additional results which represent first time or more precise measurements in the spectroscopy of hadrons.
- The next generation of CLEO under study should have increased impact in the study of hadronic interactions. It provides the possibility for exceedingly precise measurements of quantities thus far untouched by high statistics exploration.
  - Studies of heavy quarkonium spectroscopy – both ψ and Υ systems
  - Searches for QCD exotics, and elucidation of heavy quarkonium hadronic decays
  - Hadronic physics in the open charm sector
- CLEO-c offers a great opportunity to confront the lattice gauge community with data of unprecedented precision in both open and hidden heavy flavor spectroscopy.
- Parties interested in the possibilities of this project are welcome to contact us.