Bottomonium and Charmonium at CLEO

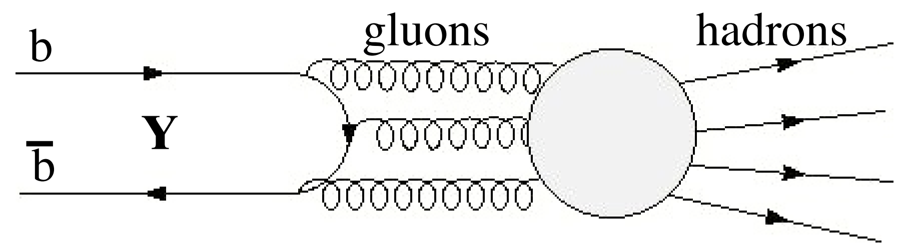
Ryan Mitchell
(on behalf of CLEO)
Indiana University
Moriond QCD 2007

Bottomonium and Charmonium as a QCD Laboratory

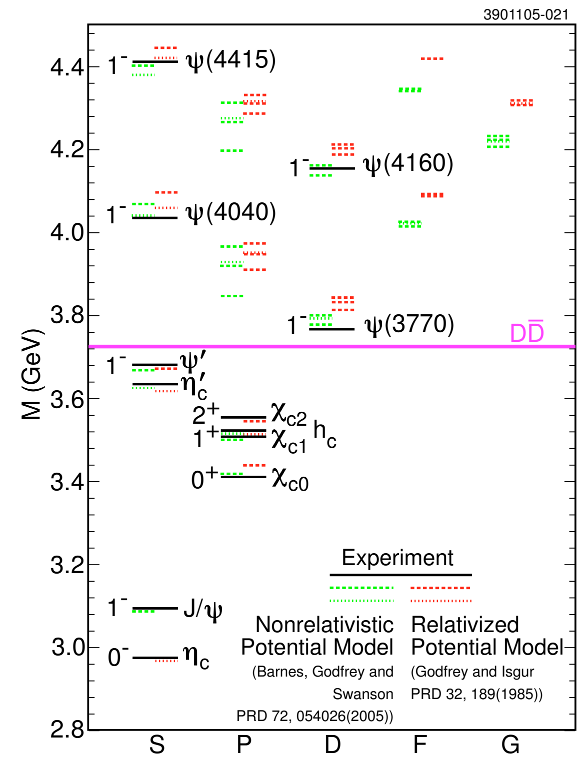
- ***spectroscopy***: energy levels and types of QCD bound states
- ***hadronic decays***: hadronization of gluons
- ***hadronic transitions***: access to "soft" gluons
- ***di-lepton widths***: probing wave-functions at the origin
- ***EM transitions***: interpreting the nature of bound states
- ***light quark dynamics***: narrow "onia" states provide a clean and well-understood source of light quark states
- ***interesting comparisons***: bottomonium vs. charmonium vs. the $q\bar{q}$ continuum.
- ***etc... etc...***

This Talk

I. Using Upsilon decays to study gluon hadronization.

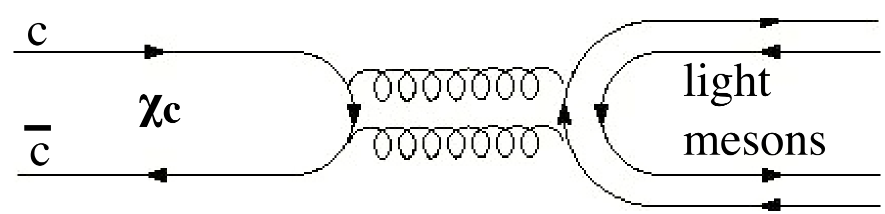


II. The interpretation of heavy charmonium states.



Y(4260)?
X(3872)?

III. Using charmonia to probe light quark dynamics.



Bottomonium at CLEO-III

Dedicated running at the
Υ(1S), Υ(2S), Υ(3S)
(and off-resonance regions):
November 2001 - December 2002.

CESR at Cornell University

e^+e^- collisions at $\sqrt{s} \sim 10$ GeV

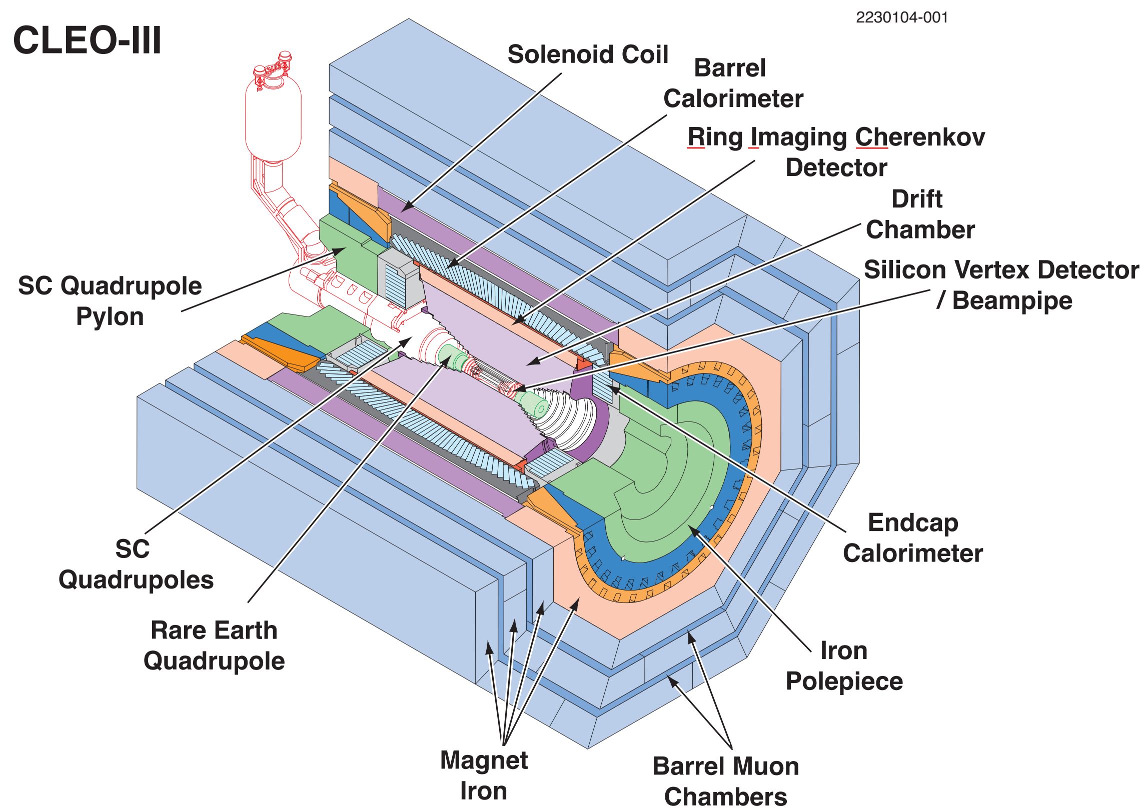
2000 - 2003

Samples:

Υ(1S) ~ 21M events

Υ(2S) ~ 10M events

Υ(3S) ~ 5M events



Analysis efforts include:

- quark and gluon hadronization
- hadronic transitions
- radiative transitions
- spectroscopy
- di-lepton widths
- searches for exotic particles

Charmonium at CLEO-c

CESR at Cornell University

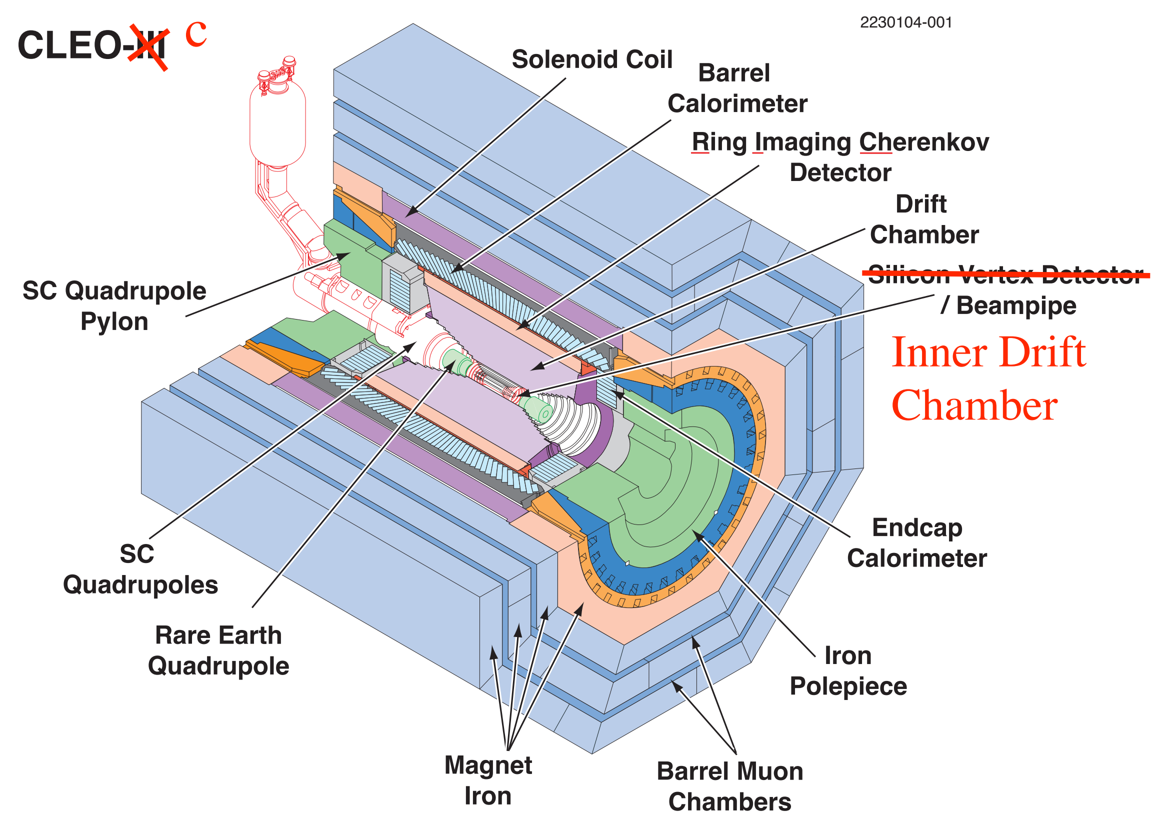
e^+e^- collisions at $\sqrt{s}$ ~ ~~10 GeV~~ ~ 4 GeV

~~2000 - 2003~~ 2003 - present

Samples:

3.97 - 4.26 GeV ~ 60 pb^{-1}
4.17 GeV ~ 300 pb^{-1}
$\psi(3770)$ ~ 300 pb^{-1}
$\psi(2S)$ ~ 3M (1.5M CLEO-III) + ~ 25M events

currently running at $\psi(3770)$



Analysis efforts include:

- spectroscopy
- light quark dynamics
- hadronic decays
- hadronic transitions
- radiative transitions
- di-lepton widths
- searches for exotic particles

I. Bottomonium and Fragmentation

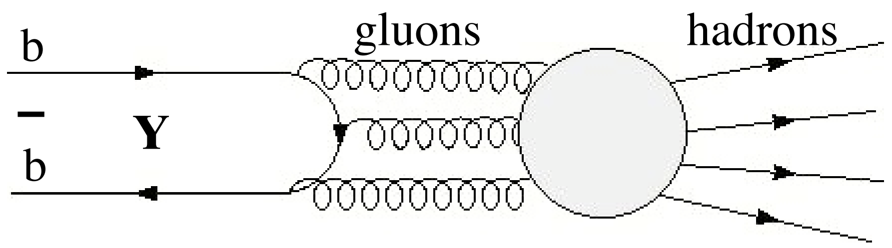
- Compare particle production in a "glue-rich" environment:

  Upsilon decays: $\Upsilon \rightarrow ggg, gg\gamma$

  to a "quark-rich" environment:

  the continuum: $e^+e^- \rightarrow q\bar{q}, q\bar{q}\gamma$.

- Study the production of (anti-)deuterons in Upsilon decay (*"coalescence" of p and n in a dense environment*).



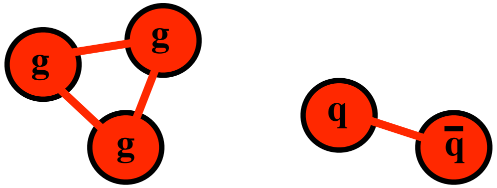
Comparing Quark and Gluon Environments

- In 1984, CLEO I found an excess of baryons per event in $\Upsilon(1S) \to ggg$ over $e^+e^- \to q\bar{q}$.

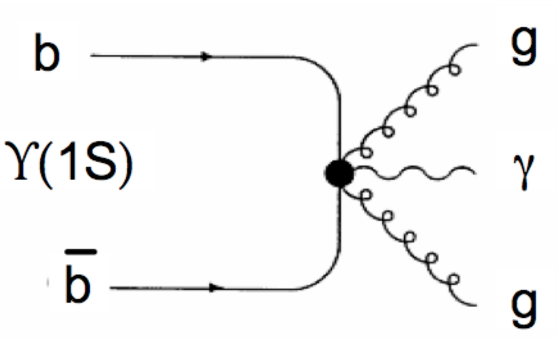
  Hard to interpret:

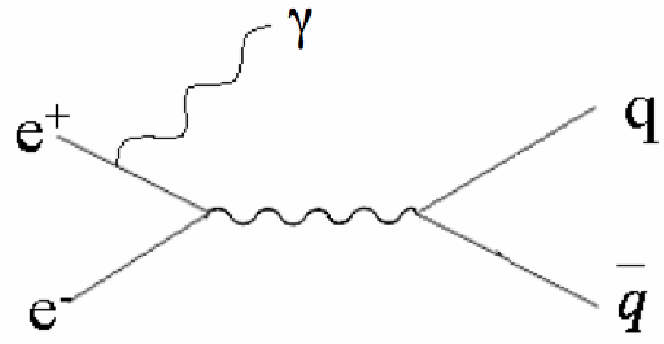
  comparing 3 partons vs. 2

  comparing 3 strings vs. 1



- Recent analysis:
  - Confirms and extends 1984 results.
  - Plus, compares $gg\gamma$ to $q\bar{q}\gamma$ in bins of E_γ by tagging photons *(compares 2 partons vs. 2, 1 string vs. 1)*:



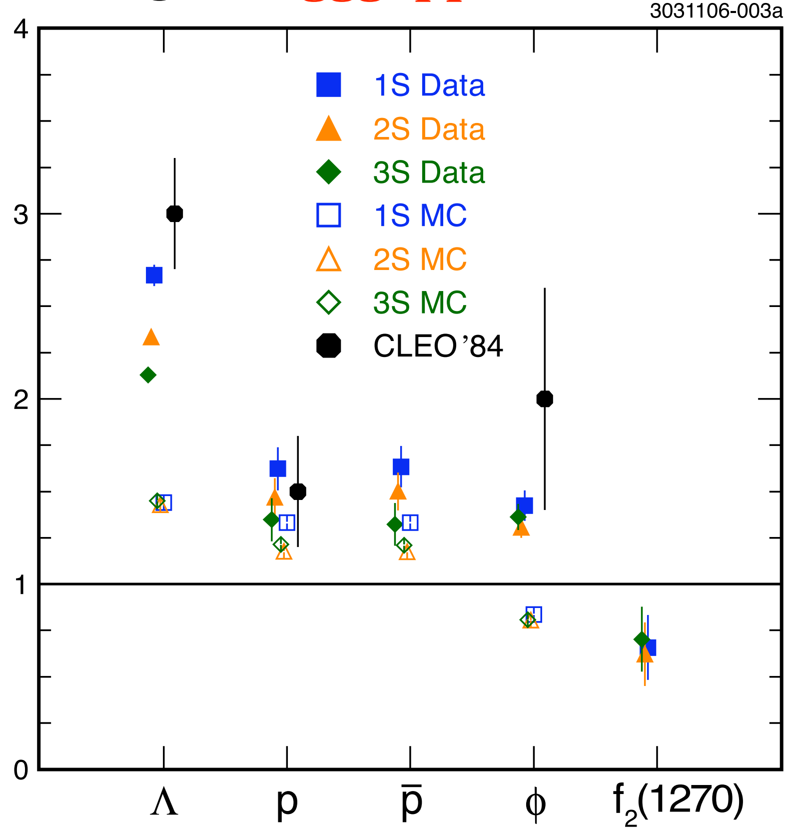


Comparing Quark and Gluon Environments

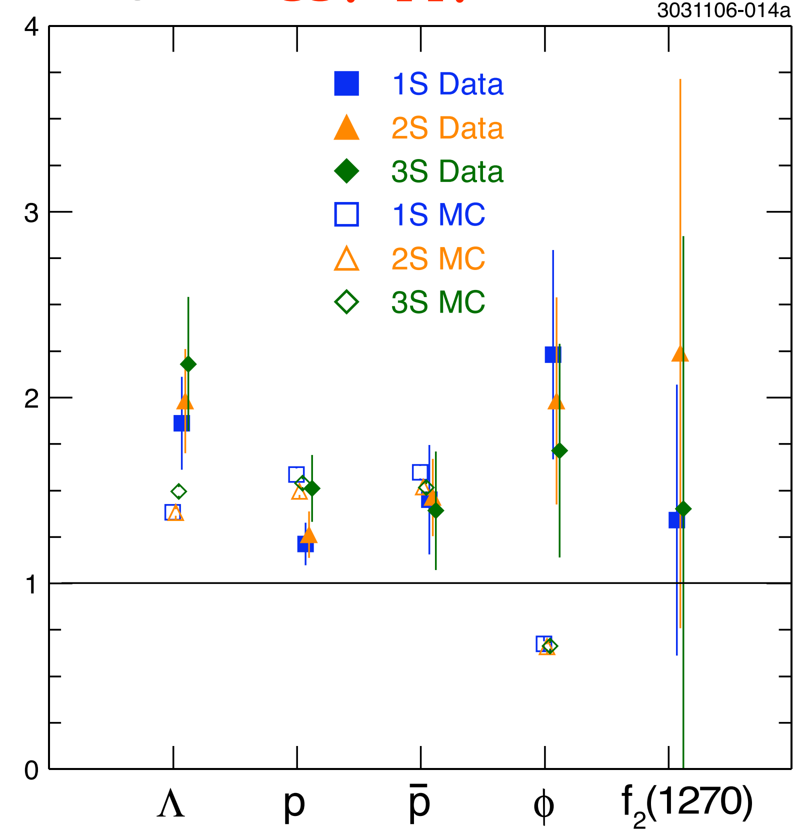
preliminary
(hep-ex/0607052)

Compare to MC:
JetSet 7.4 string model tuned to LEP data at $\sqrt{s} = 90$ GeV

Integrated ggg/$q\bar{q}$ Enhancement



Integrated ggγ/$q\bar{q}$γ Enhancement



"Enhancement" $= \int \frac{Y\_production(p)}{continuum\_production(p)} dp \qquad \int \frac{Y\_production(E_\gamma)}{continuum\_production(E_\gamma)} dE_\gamma$

Conclusions:

1. Baryon enhancements decrease in ggγ/$q\bar{q}$γ.
2. N_g and N_q are important; not just $\sqrt{s}$.
3. JetSet 7.4 (using a string model) does not reproduce this effect.

Anti-Deuterons in Υ(1S) Decays

PRD 75, 012009 (2007)

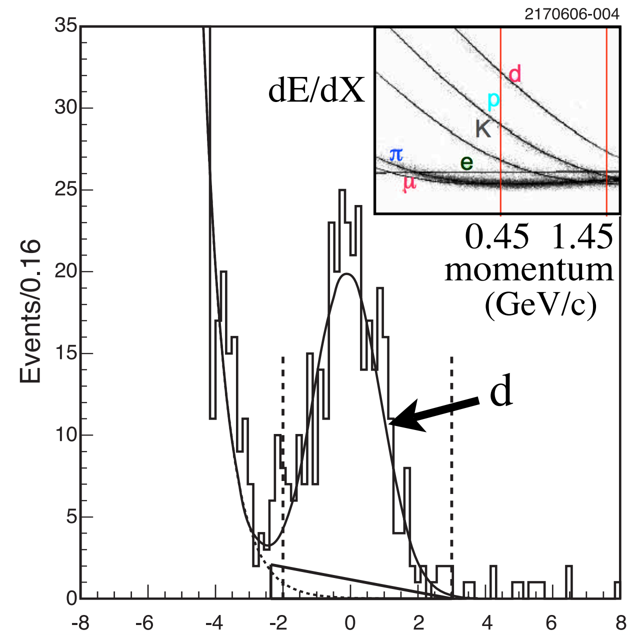
- CLEO observes an enhancement of anti-deuterons in Υ(1S) decays.
- Use anti-deuterons to reduce backgrounds (and use deuterons as a cross check).
- Cleanly select anti-deuterons using dE/dx.
- We find:

$$\frac{B(\Upsilon(1S) \to ggg, gg\gamma \to \bar{d}X)}{B(\Upsilon(1S) \to ggg, gg\gamma \to X)} = (3.36 \pm 0.23 \pm 0.25) \times 10^{-5}$$

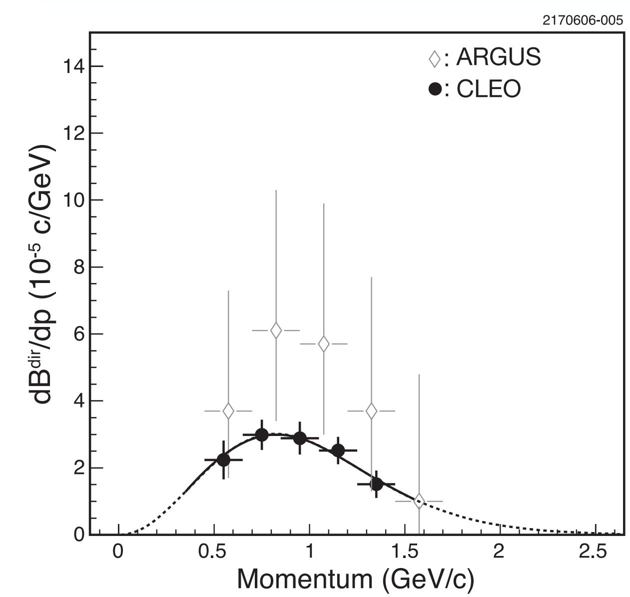
- Comparing to the continuum:

$$\sigma(e^+e^- \to \bar{d}X) < 0.031 pb \qquad \frac{\sigma(e^+e^- \to \bar{d}X)}{\sigma(e^+e^- \to hadrons)} <\sim 1 \times 10^{-5}$$

- Theoretical models are based on “coalescence”.



$$\chi_d \equiv \frac{(dE/dx)_{measured} - (dE/dx)_{expected,d}}{\sigma_{dE/dx}}$$



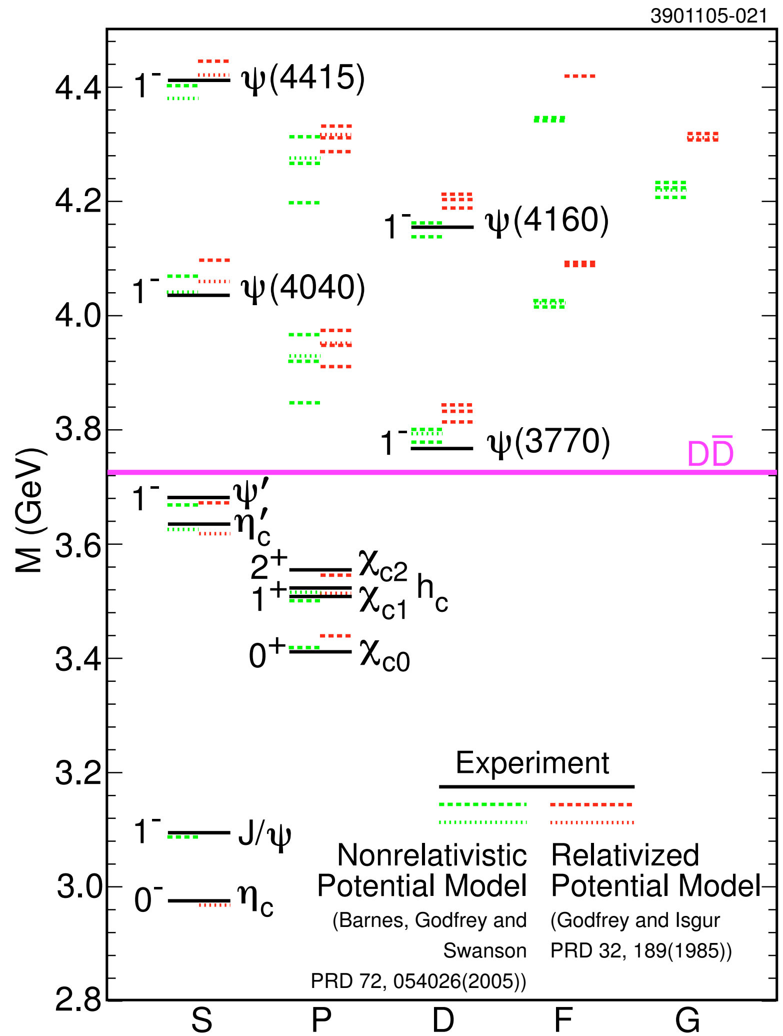
II. Heavy Charmonium

Exciting times in charmonium spectroscopy.

Hybrids? Molecules? Four quark states?

Recent CLEO results address:

- Y(4260)
- X(3872)
- ψ(3770)



Y(4260)?
X(3872)?

Y(4260)

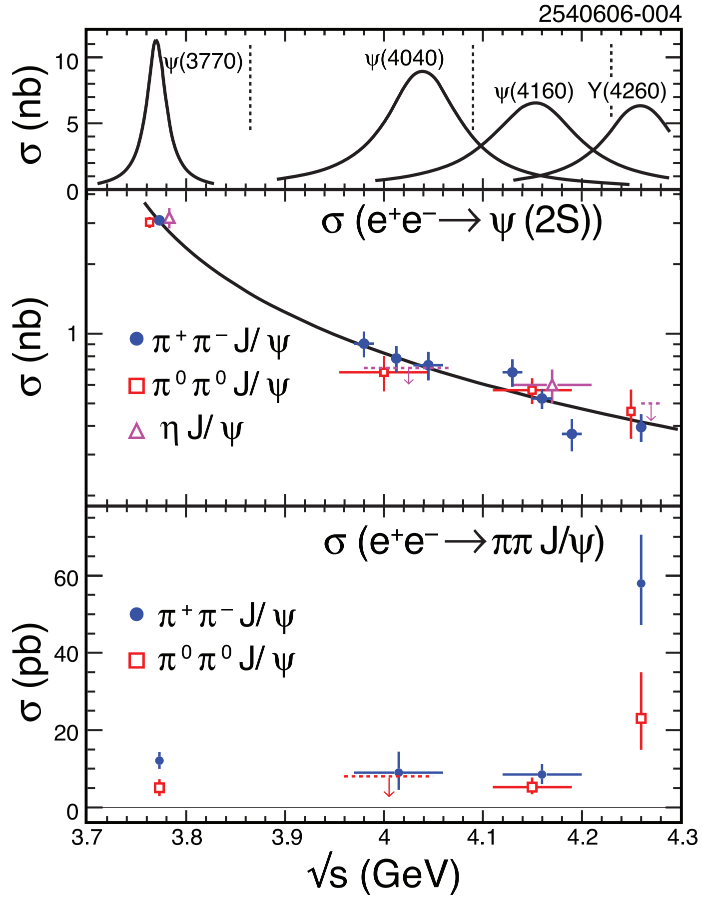
First observed by BaBar in Initial State Radiation (ISR) decaying to $\pi^+\pi^- J/\psi$.

Must have $J^{PC} = 1^{--}$.

But no convenient spot for it in conventional $c\bar{c}$ charmonium.

Is it a hybrid? *($c\bar{c}g$?)*

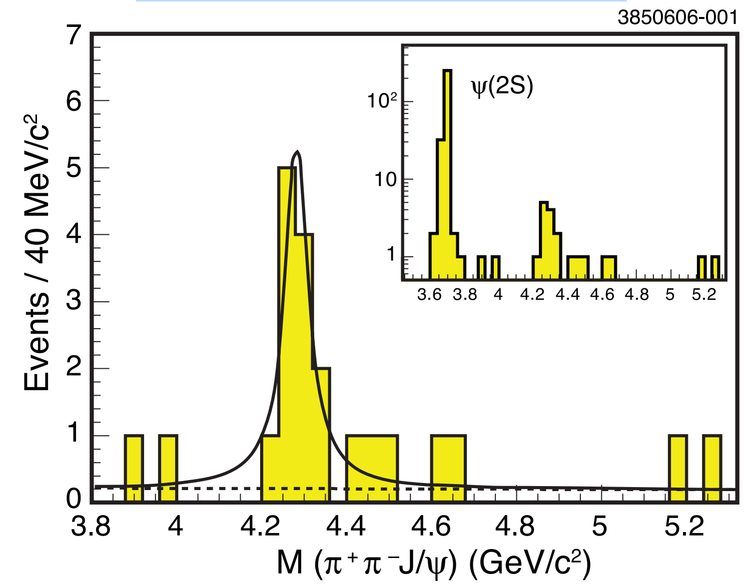
PRL 96, 162003 (2006).



CLEO-c e^+e^- energy scan:

- $J/\psi\pi^+\pi^-$:$J/\psi\pi^0\pi^0$ ratio favors isoscalar
- evidence for $J/\psi K^+K^-$ (3.7σ)

PRD 74, 091104 (2006).



CLEO-III ISR using Υ data:

- reconstruct $\pi^+\pi^- J/\psi(l^+l^-)$
- confirmation of BaBar
- confirms $J^{PC} = 1^{--}$
- $M = 4284^{+17}_{-16} \pm 4$ MeV
- $\Gamma = 73^{+39}_{-25} \pm 5$ MeV

X(3872)

PRL 98, 092002 (2007)

Discovered by Belle in $B \rightarrow KX$, $X \rightarrow \pi\pi J/\psi$.

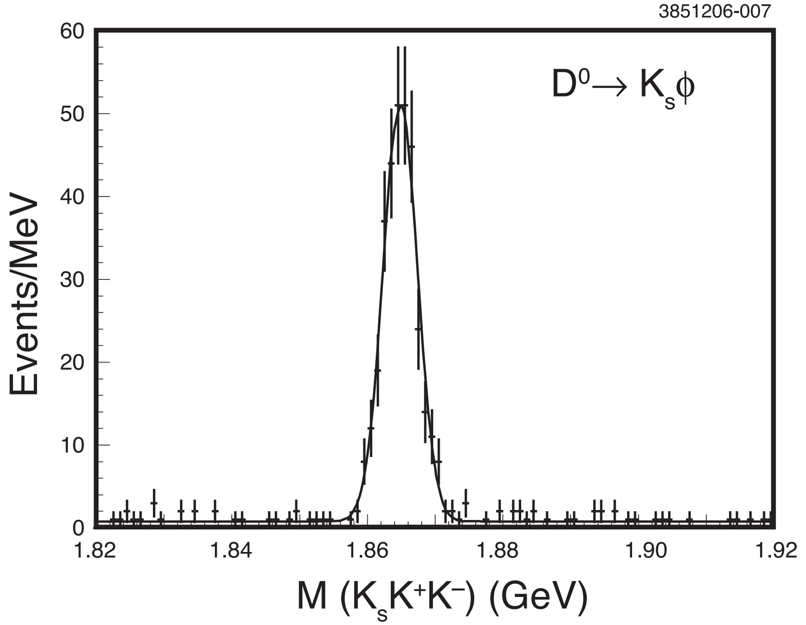
Quantum numbers likely 1^{++}.

Mass is very nearly $M(D^0) + M(D^{0*})$:

$M(X) - M(D^0) - M(D^{0*})$	PDG 2006
$= M(X)$	(3871.2 ± 0.5 MeV)
$- 2 \times M(D^0)$	(1864.1 ± 1.0 MeV)
$- (M(D^{0*}) - M(D^0))$	(142.12 ± 0.07 MeV)
= 0.9 ± 2.1 MeV	

Molecule? 4-quark state? Coincidence?

CLEO's precise D^0 mass measurement brings M(X) even closer to $M(D^0) + M(D^{0*})$.



New D^0 Mass = 1864.847 ± 0.150 ± 0.095 MeV

New mass difference = $M(X(3872)) - M(D^0) - M(D^{0*})$

= – 0.6 ± 0.6 MeV

⇒ *Coincidence is less likely.*

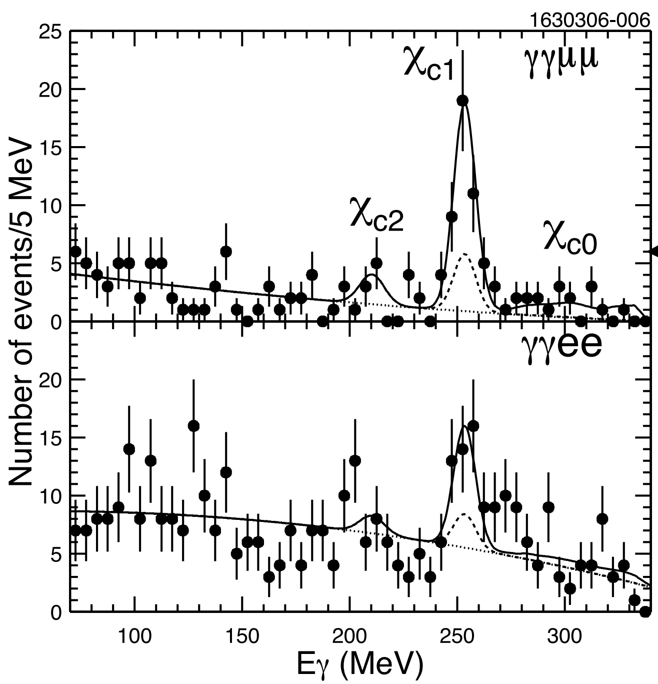
$\psi(3770)$

- The radiative decays $\boldsymbol{\psi(3770)\rightarrow\gamma\chi_{cJ}}$ reinforce its interpretation as the 1^3D_1 state of charmonium.
- New CLEO measurements are in good agreement with *relativistic* calculations.

combined CLEO results
$B(\psi(3770)\rightarrow\gamma\chi_{cJ})$

	$\psi(3770)\rightarrow\gamma\chi_{cJ}$ $J=0$	$J=1$	$J=2$
$\mathcal{B}$ (%)	0.73 ± 0.09	0.29 ± 0.06	<0.09
Γ (keV)	172 ± 30	70 ± 17	<21
Theory Γ predictions			
Rosner non-relativistic	523 ± 12	73 ± 9	24 ± 4
Ding-Qin-Chao			
non-relativistic	312	95	3.6
relativistic	199	72	3.0
Eichten-Lane-Quigg			
non-relativistic	254	183	3.2
coupled-channel	225	59	3.9
Barnes-Godfrey-Swanson			
non-relativistic	403	125	4.9
relativistic	213	77	3.3

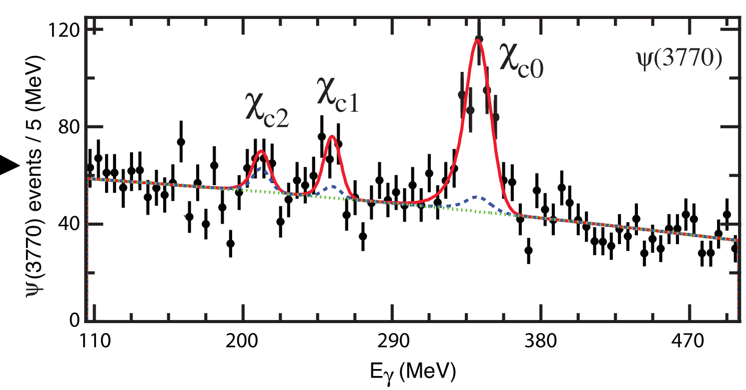
PRL 96, 182002 (2006).



Two independent analyses of $B(\psi(3770)\rightarrow\gamma\chi_{cJ})$:

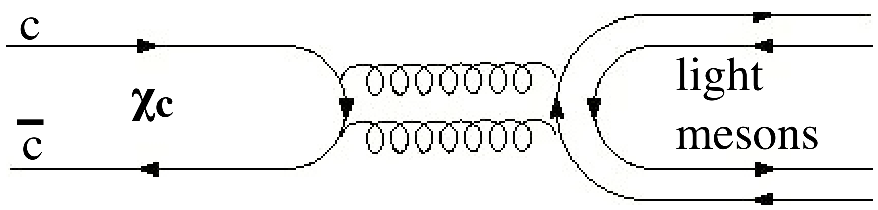
1. $\psi(3770)\rightarrow\gamma\chi_{cJ}$ with $\chi_{cJ}\rightarrow\gamma J/\psi(l^+l^-)$
2. $\psi(3770)\rightarrow\gamma\chi_{cJ}$ with $\chi_{cJ}\rightarrow(2K, 2K2\pi, 4\pi, 6\pi)$ using $\psi(2S)$ decays as normalization.

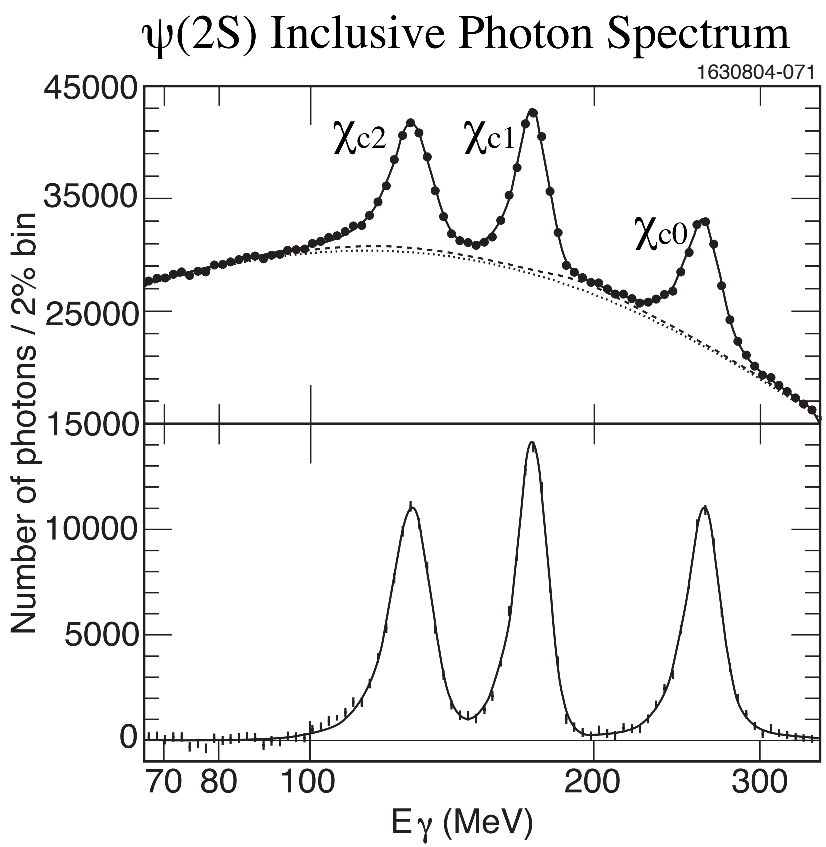
PRD 74, 031106 (2006).



III. χ_c Decays to Light Mesons

- χ_{cJ} decays are:
  - Interesting in their own right; χ_{cJ} hadronic decays are not well known, in general.
  - A "controlled" source of light hadrons, complementary to other sources (e.g. J/ψ radiative decays).
  - Produced copiously (~9% BF's each) in the reaction: $e^+e^- \rightarrow \psi(2S) \rightarrow \gamma\chi_{cJ}$
- CLEO's new ~25M $\psi(2S)$ dataset is ready for analysis.





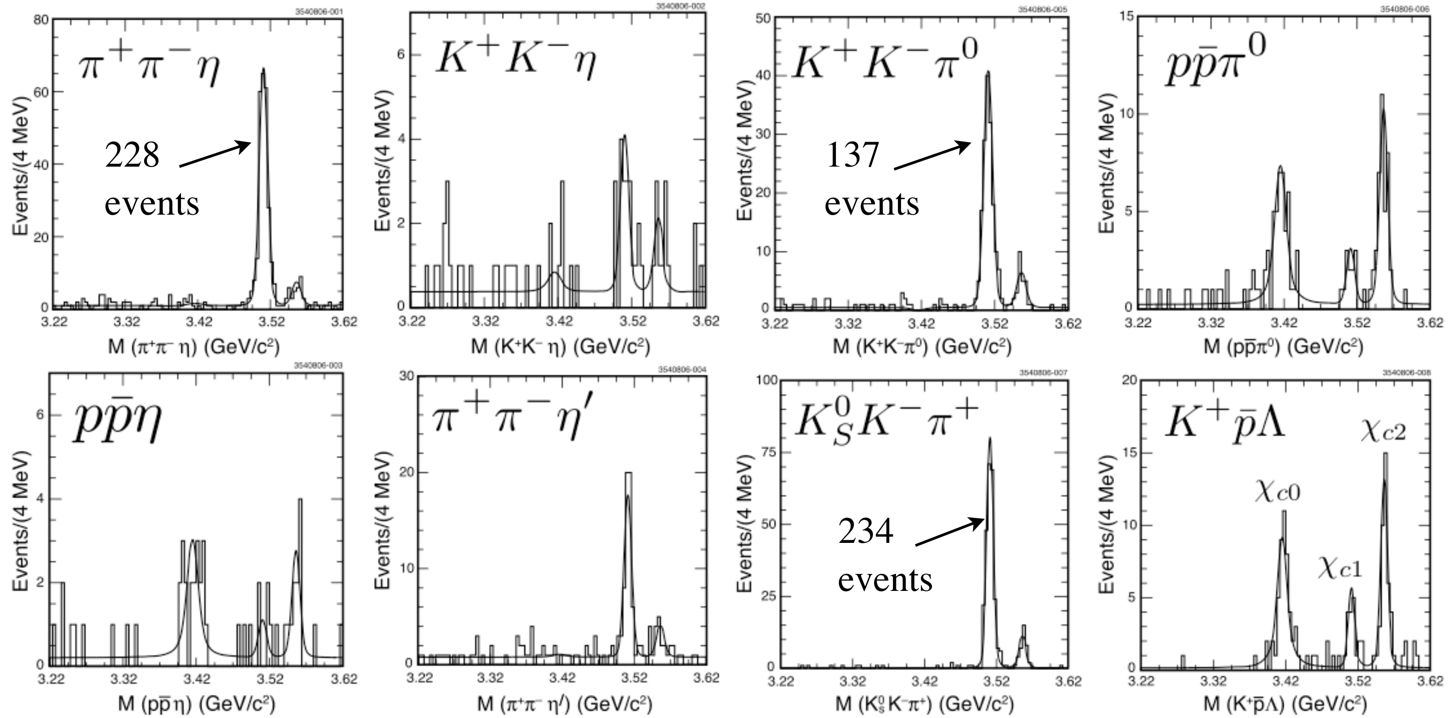
$\chi_c \to h^+h^-h^0$

PRD 75, 032002 (2007)

A selection of 3-body decays based on 3M ψ(2S).

Many first observations.

$\chi_{c1} \to \pi^+\pi^-\eta$, $K^+K^-\pi^0$, and $K_SK^-\pi^+$ have sufficient statistics for a substructure analysis.

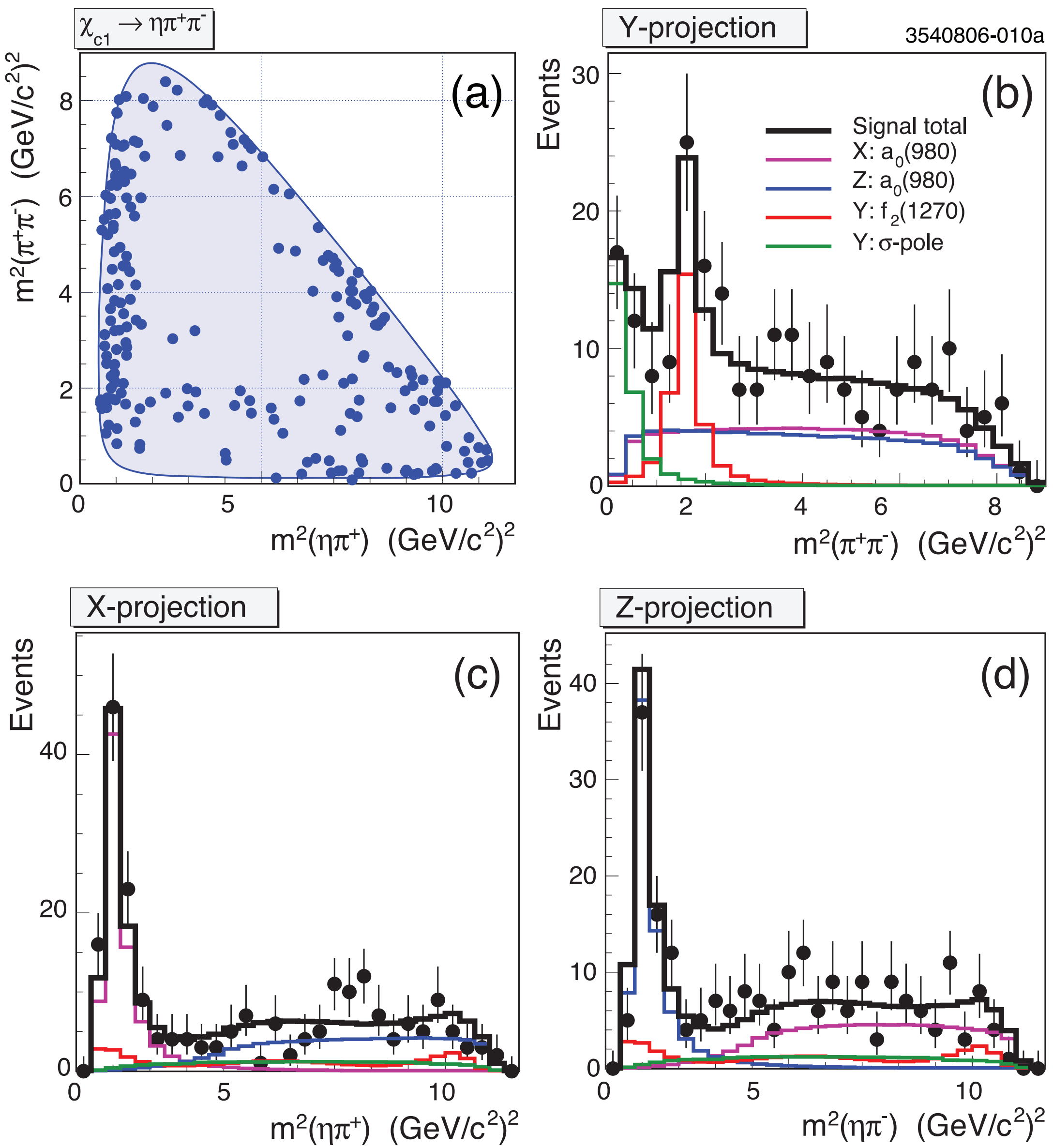


Mode	χ_{c0}	χ_{c1}	χ_{c2}
$\eta\pi^+\pi^-$	< 0.021	$0.52 \pm .03 \pm .03 \pm .03$	$0.051 \pm .011 \pm .004 \pm .003$
ηK^+K^-	< 0.024	$0.034 \pm .010 \pm .003 \pm .002$	< 0.033
$\eta p\bar{p}$	$0.038 \pm .010 \pm .003 \pm .02$	< 0.015	$0.019 \pm .007 \pm .002 \pm .002$
$\eta'\pi^+\pi^-$	< 0.038	$0.24 \pm .03 \pm .02 \pm .02$	< 0.053
$\pi^0K^+K^-$	< 0.006	$0.200 \pm .015 \pm .018 \pm .014$	$0.032 \pm .007 \pm .002 \pm .002$
$\pi^0 p\bar{p}$	$0.059 \pm .010 \pm .006 \pm .004$	$0.014 \pm .005 \pm .001 \pm .001$	$0.045 \pm .007 \pm .004 \pm .003$
$\overline{K}^0K^+\pi^-$*	< 0.010	$0.84 \pm .05 \pm .06 \pm .05$	$0.15 \pm .02 \pm .01 \pm .01$
$\Lambda K^+\bar{p}$*	$0.114 \pm .016 \pm .009 \pm .007$	$0.034 \pm .009 \pm .003 \pm .002$	$0.088 \pm .014 \pm .007 \pm .006$

* includes charge conjugate

$\chi_c \rightarrow h^+h^-h^0 \quad (\pi^+\pi^-\eta)$

PRD 75, 032002 (2007)

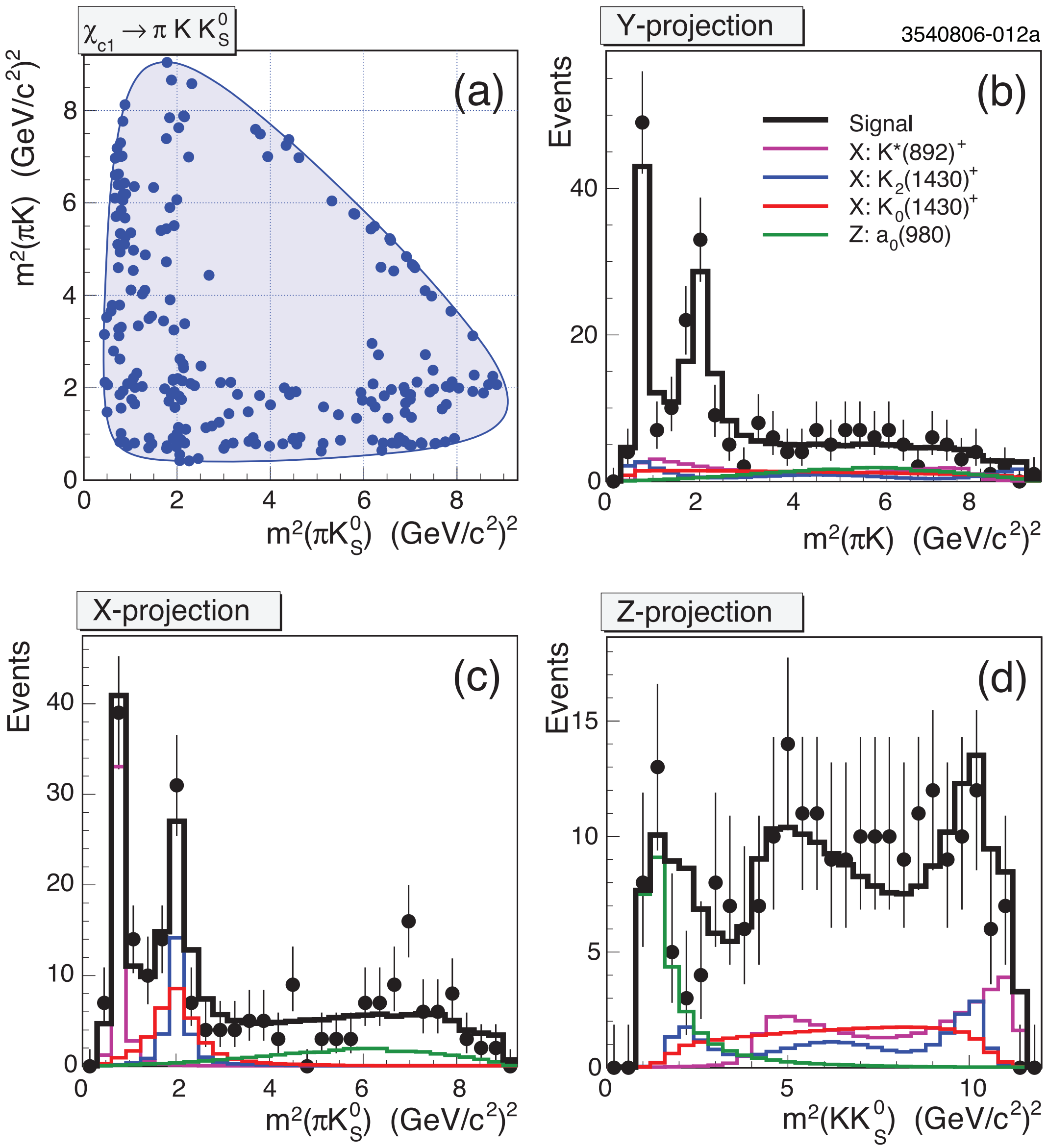


Substructure in $\chi_{c1} \rightarrow \pi^+\pi^-\eta$

- Use a simple model of non-interfering resonances coming from a spin-1 parent. *(this describes the dominant structure, but will be refined with more statistics).*
- Find significant contributions from $a_0\pi$, $f_2\eta$, and $\sigma\eta$.
- No exotic structures apparent.

$\chi_c \to h^+h^-h^0 \quad (K_SK^-\pi^+)$

PRD 75, 032002 (2007)

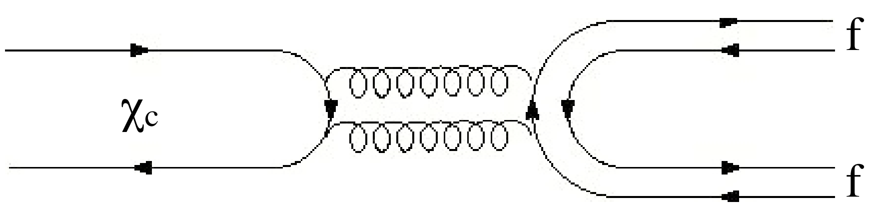


Substructure in $\chi_{c1} \to K_SK^-\pi^+$

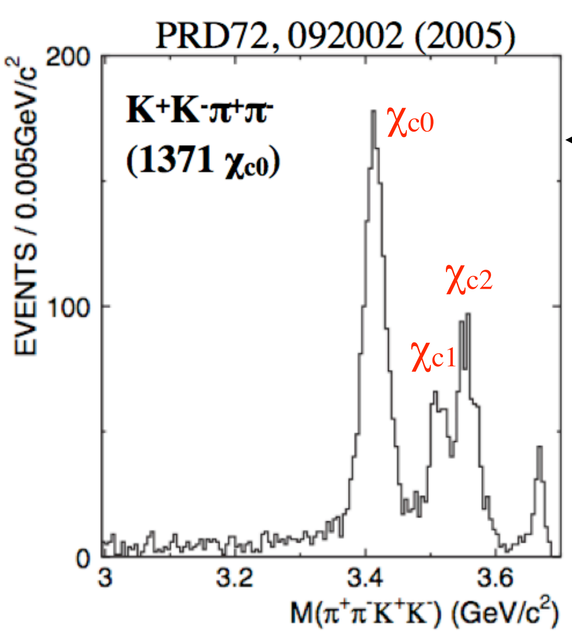
- Use the same non-interfering resonance model.
- Simultaneously fit $K_SK^-\pi^+$, $K_SK^+\pi^-$, and $K^+K^-\pi^0$ using isospin constraints.
- Find significant contributions from $a_0\pi$, $K^*(892)K$, $K_2^*(1430)K$, and $K_0^*(1430)K$.
- No exotic structures apparent.

$\chi_{c0} \to KK\pi\pi$ (BES)

- χ_{cJ} substructure analyses will soon move to full partial wave analyses.



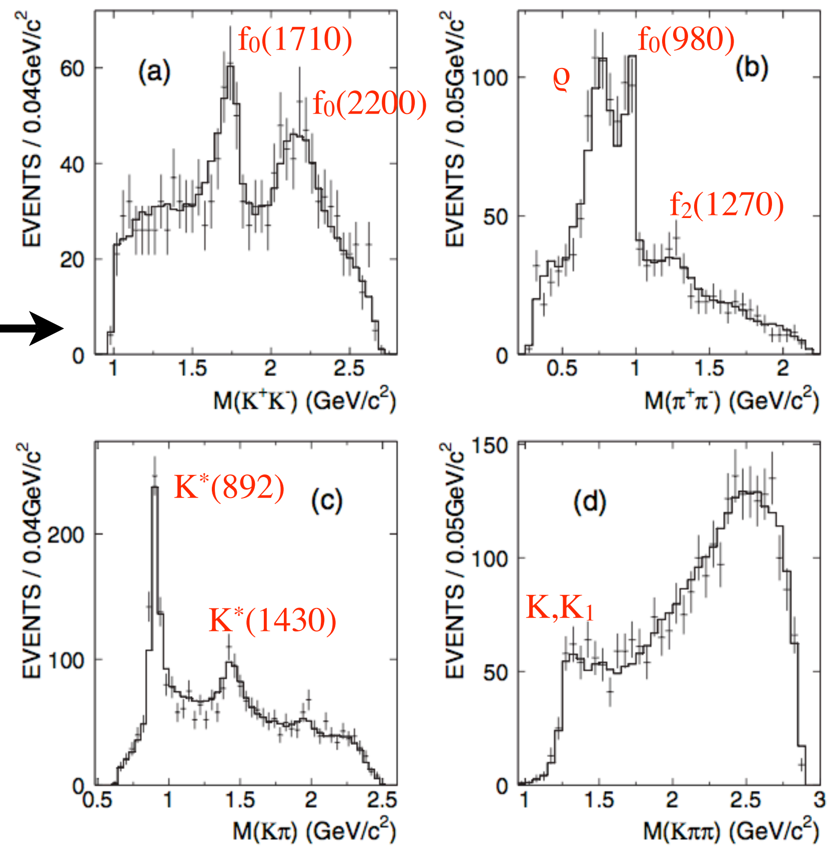
- Example:
  - $\chi_{c0} \to KK\pi\pi$ is an excellent source of scalars (f_0) and tensors (f_2).
  - This work was pioneered by BES.



<u>BES results</u>

14M $\psi(2S)$

Rich Substructure!



$\chi_{c0} \rightarrow KK\pi\pi$ (Building on BES)

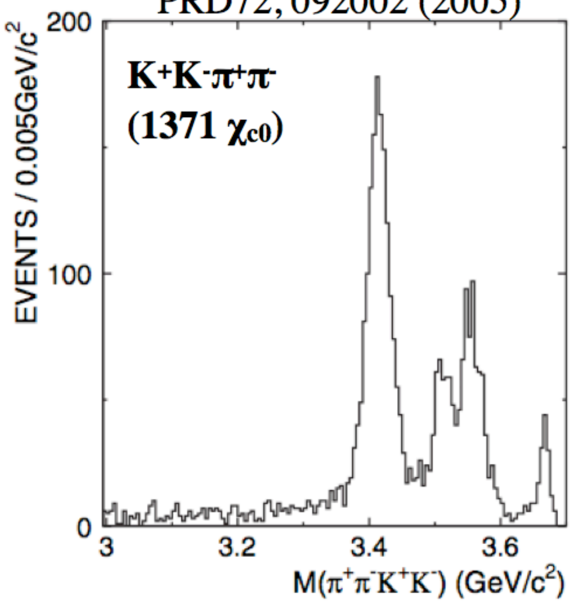
"first look"

Building on the BES results.

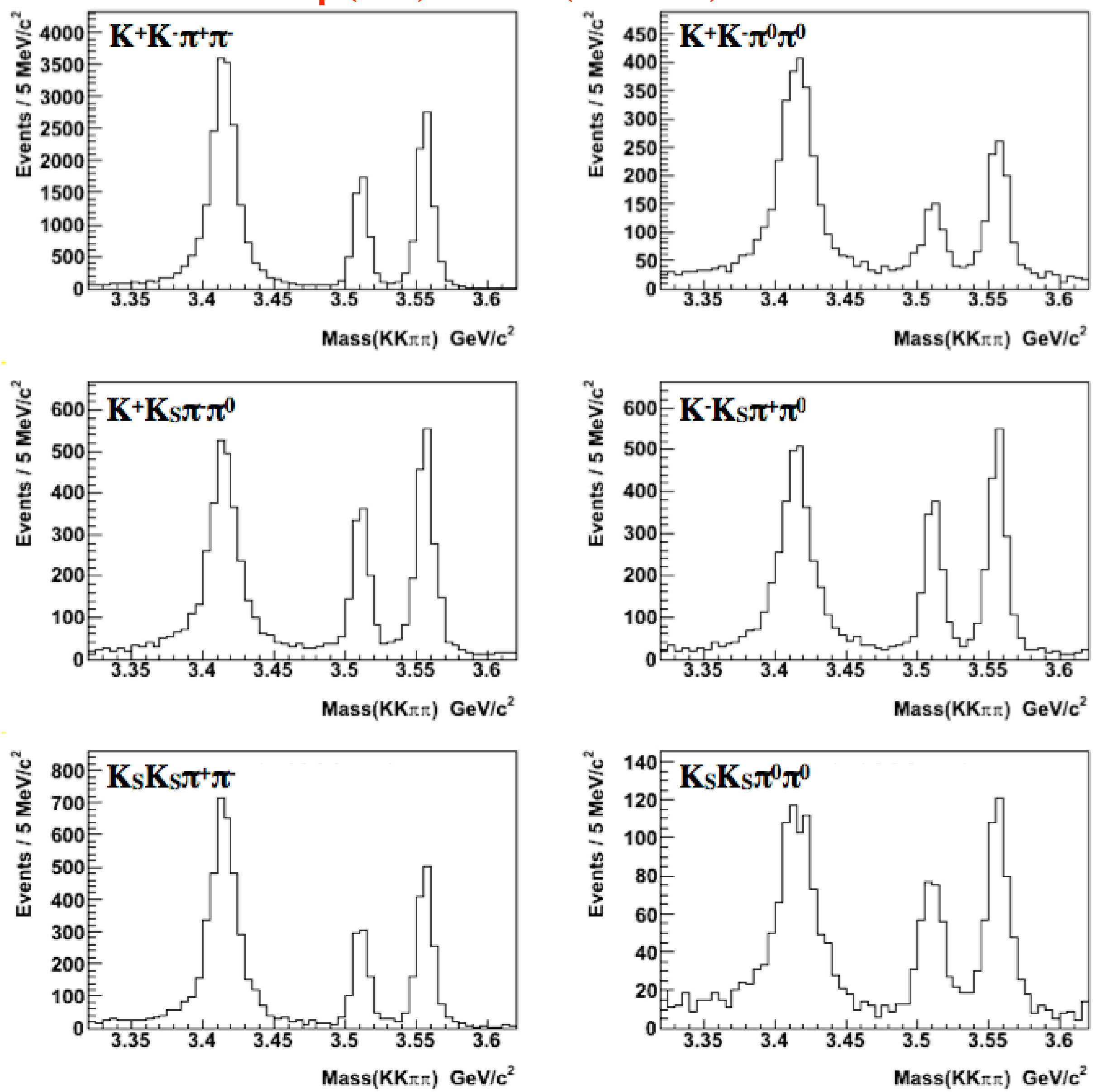
Use isospin constraints to simultaneously fit 6 $KK\pi\pi$ modes.

BES: 14M $\psi(2S)$

PRD72, 092002 (2005)



ALL CLEO-c $\psi(2S)$ data (~26M) in 6 $KK\pi\pi$ modes!



Summary

- The bottomonium and charmonium efforts at CLEO are very active, and span a very wide range...
  - Fragmentation in Upsilon decays.
  - Heavy Charmonium States.
  - Light Quark Dynamics.
- Many exciting results to come.