The CLEO-c / CESR-c Program: How we got here & First Results!

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Carnegie Mellon University & CLEO Collaboration

Carnegie Mellon University
22 Nov 2004
30th Anniversary of November Revolution!

**Experimental Observation of a Heavy Particle $J^+$**


*Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*

and

Y. Y. Lee

*Brookhaven National Laboratory, Upton, New York 11973*

*(Received 12 November 1974)*

We report the observation of a heavy particle $J$, with mass $m = 3.1$ GeV and width approximately zero. The observation was made from the reaction $p + \bar{p} \rightarrow e^+ e^-$ by measuring the $e^+ e^-$ mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory’s 30-GeV alternating-gradient synchrotron.

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**Discovery of Charm Quark:**

**$J/\psi$ Charm-Anticharm Meson**

---

**Solidifies Standard Model;**

**Meanwhile, in Ithaca...**
The CESR $e^+e^-$ Collider is Born

1973: Sketched by Tigner
1979: Begins operating at bottom-antibottom energies

The “little accelerator that could”...and still does!
Outline

Past:

Particle Phenomenology and Weak Flavor Physics

“Present”:

The CLEO-c and CESR-c Transition: Why charm physics at threshold?

Peek at Future:

First Results from our Pilot Run!
Particles of Standard Model

Note 3 copies, or “generations”

Spin-1/2 Matter Particles (Fermions)

Spin-1 Force Carriers (‘Gauge’ Bosons)
**Ordinary Matter**

Only “First Generation”: $u,d,e, \nu_e$

Nucleus of $u,d$; plus $e$

$\nu_e$: beta decay, fusion,...

**neutron beta decay:**

W

$e^-$ $\nu_e$

n

u

p

d

d

d

d

"green fog" **

= strong force

(quarks always bound!)

** a.k.a. “brown muck”
Particle Physics Phenomenology

Interactions = vertices in Feynman diagrams
can “spin around” vertices in space-time...

Note: fermions lines never end inside diagram...
Electromagnetic Interaction

One basic vertex:

any charged particle + photon
strength = electric charge

Perturbative:

Power series in $\alpha_{EM} \ (\sim e^2 = 1/137)$
Lowest-order diagram usually enough

...but also precision with loops!

c.f. $g-2$ (anomalous magnetic moment)
The Other Interactions

Weak: \(( W^{\pm}, Z^0 ) \)
- perturbative, but...
- strength varies (depends on quark types, or “flavors”)
- violates discrete symmetries (\( P, C, \text{CP}, T \)),
- doesn’t conserve several quantum #’s… (flavors)
⇒ Interesting!

Strong: \(( g = \text{gluon} ) \)
- uniform strength vertices
- non-perturbative: very hard to calculate
- No free quarks: always strong effects!
⇒ confuses any weak measurement w/ quarks
### Vertices for all Gauge Bosons

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**Neutral:**
- fermion unaltered
- Each gen. same
- Never changes gen.
  ( "no FCNC" )

**Charged:**
- fermion changes
- Mixes generations for quarks**

** ν mass & oscillations are another colloquium..."
Glossed over a few things...

Are empty boxes really empty?
Further, “grand” unification, proton decay, leptoquarks...

$Z^0$ couplings more complicated than the table indicates
Due to nature of Electro-Weak symmetry breaking
Detailed studies at LEP “$Z^0$ factory” at CERN Laboratory
Parity Violation in e-deuteron scattering and atomic transitions

Neutrino caveats
Neutrono masses and mixing very topical now!
Double beta decay and Majorana vs. Dirac mass

Gauge-only Vertices
Weak: studied at LEP (ZWW, $\gamma$WW, ...)
Strong: related to 2004 Nobel Prize (ggg & loops)

But there’s enough richness in the W interactions to keep us plenty busy today...
Strengths of all $W^\pm$ couplings

CKM Mixing Matrix: 9 elements

$\text{Ampl}(q_i \Rightarrow q_j W) \sim V_{ij}$

( $V_{ij}$ also appear in meson mixing... )

Weak Decays:

$u,d,c,t$ decay: normal

$s \Rightarrow u W^- : \text{ slow}$

$b \Rightarrow c W^- : \text{ very slow}$
**Cabibbo-Kobayashi-Maskawa Matrix**

*Wolfenstein Parameterization:* exploits unitarity, hierarchy of size

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<td>λ</td>
<td>$A\lambda^3 (\rho-i\eta)$</td>
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<td>c</td>
<td>$-\lambda$</td>
<td>1</td>
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<td>$A\lambda^3 (1-\rho-i\eta)$</td>
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4 parameters: 
- \(\lambda\) (~ 0.22) 
- \(|V_{ij}| \sim \lambda^n\)
- \(A, \rho, \eta\) (of order 1)

Concentrate on \(\rho, \eta\): 
- in smallest elements 
- \(\eta \Rightarrow CP\) violation
Oddities of Weak Interaction

Violates Discrete Symmetries, Flavor Quantum #'s:

-- Violates parity: 1956 \((^6\text{Co} \text{ beta decay, etc.})\)
-- Violates CP: 1964 \((K_L \text{ meson decays})\)

-- Causes all “non-trivial” decays \((\Delta F = \pm 1\) \(F = \text{‘flavor’}\))
  (via \(W^\pm\), not \(Z^0\)...)
-- Allows neutral meson “mixing”: e.g., \(B^0 \leftrightarrow \overline{B^0}\)

“Weak” force:

But still visible, since it causes particle type to change!

However:

Strong force complicates interpretation of data
### Measure from $B^0 - B^0$ mixing

(not @ CLEO)

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**B Physics & Small CKM Elements**

Measure from $B$ decays

(@ CLEO, et al.)

*Note strong interaction fog...*

Measure from $B^0 - B^0$ mixing

(not @ CLEO)
Over-constraining the CKM Matrix

1st x 3rd column unitarity:

\[ V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0 \]

\[ \Rightarrow \text{normalize to } |V_{cd} V_{cb}^*| = A \lambda^3 \]

Makes triangle: \( V_{ub}^* + V_{td} = 1 \)

“Unitarity Triangle”

Recent snapshot of knowledge of key CKM parameters

Exp’t: 3 B meson and 1 Kaon
Why Do We Measure $\rho, \eta$ ??

We don't really care what $\rho, \eta$ are ...  
... we care if results from different measures of them are the same!

-- Is the theory internally consistent?

-- Or is there a hint of "new physics"

But now the issue is becoming theoretical precision.

Foreshadowing: Charm physics can help!
The CLEO-c/CESR-c Transition

Weak Flavor Physics & CLEO
B’s: too much of a good thing?
D’s: neglected cousin?
Spectrum of Heavy Quarkonium

(cc) and (bb) mesons

Charmonium

Bottomonium

e^+e^- colliders create ψ's (cc) and Υ's (bb)

Below "open flavor threshold": annihilate into gluons and/or photons
Above: decay into flavored meson pairs: D̄D̄ (or B̄B̄) meson pairs
Decays of Quarkonium

Below flavor threshold: \( QQ \) re-annihilate!

\[ QQ \] annihilate (mostly to gluons):
gives spray of lighter quarks

Above flavor threshold: \( Q \& Q \) separate: can study!

\[ \Upsilon(4S) \Rightarrow B^+ B^-, B^0 \bar{B}^0 \]
\[ \psi(3770) \Rightarrow D^+ D^-, D^0 \bar{D}^0 \]

These are the two “best” quarkonia:
-- no energy for any extra particles: ONLY meson pairs
“Botany”: Flavored Heavy Mesons

\[ B^+ = \overline{b}u \quad B^0 = \overline{b}d \quad B^0_s = \overline{b}s \]
\[ D^+ = \overline{c}u \quad D^0 = \overline{c}d \quad D^+_s = \overline{c}s \]

(not the most consistent naming conventions...)

light ones: \( K \) with an \( s \) quark (common in \( D \) decays)
\( \pi \) with all \( u,d \) quarks

Study Weak Interactions (in flav'd meson decays):
\( \Upsilon(4S) \) & \( \psi(3770) \) decays (source of flav'd mesons):
Good kinematic constraints on meson pairs

These heavy mesons decay weakly (\( V_{ub}, V_{cb} \))
Neutral mesons can “mix” (\( V_{td}, V_{ts} \))

...but don’t forget quarks are bound inside mesons: strong int. effects!
CLEO/CESR B Physics Era:

A History of Performance & Innovation

Superconducting RF & final-focus quads

Pretzels, crossing angles, multi-bunch, ...
CLEO, B Physics, Competition...

B physics is perfect for studying CKM
CLEO** exploited the $\Upsilon(4S)$ for >20 years!

** and ARGUS @ DESY

But, new things were needed:

More luminosity
Asymmetric beam energies:
  if B’s move, measure time dependence:
  directly get angles of Unitarity Triangle

Dedicated “B factory” Accelerators:

PEP-II at SLAC, BaBar detector Stanford
KEK-B at KEK, Belle detector Japan
SLAC/KEK: Dedicated B Factories

New machines successful!
Caught CLEO by 2000/01
(CLEO had \( \rightarrow \sim 20 \) fb\(^{-1} \))

What do we do now???
-- symm. high luminosity.?
-- something “new”?

Great success for HEP!
But for local economy?
Of course, everyone always wants to build a bigger machine...

...but the real future was at lower energy!

We were (almost) perfect for charm physics
Better Theory through Experiment...

Current Theory
And Experiment
mostly b quark

Same Experiment,
Better Theory
lattice verified
with experiment!
easier with c quark
Charm Helping B Physics

\[ f_D \text{ LQCD} = \text{exp't} \, ? \]

\( f_D \) is a “decay constant”:
- chance that quarks are at same place
- \( \sim |\psi(0)|^2 \) : square of wavefunction at origin
  
  (weak interaction is short-range)

**Lattice QCD:**
- Calculate strong force on computers

**Leptonic D Decays**

use LQCD \( f_B \) here

get \( V_{td}, V_{ts} \)
Charm Helping B Physics

Form factors, CKM
FF help w/ B decays

“Form Factor”:
~ Chance quarks can bind into final state
Relate $B \rightarrow \pi e\nu$ to $D \rightarrow \pi e\nu$

get $V_{ub}$

Semileptonic
$D$ Decays
Charm Helping B Physics

Absolute Branching fractions
(decay rates) for normalization

B decays most often to Charm:
Form factors less of an issue for $B \rightarrow D\nu$
But $B$ decay is normalized to charm

Hadronic
$D$ Decays
The CLEO-c Physics Program

Clear up QCD issues impacting all weak physics!

Precision Charm Physics  (main topic today; but no $D_s$ data yet)

Leptonic: decay constants $f_D$ and $f_{D_s}$
Semi-leptonic: form factors, $V_{cs}$, $V_{cd}$
Hadronic: precise absolute BR's for $D^+, D^0, D_s$ golden modes

Specialized Charm Physics  (no time today)

$D$-mixing: extract of strong $K\pi$ phase!
Very clean Dalitz plots: CP violation with CP-tagged states!

Charmonia and Spectroscopy  (few plots at end; no $J/\psi$ data yet)

Charmonium spectroscopy, $\psi(2S)$ decays
Searches for glue-rich exotic states via $J/\psi$ decays.

Many topics help validate modern lattice QCD techniques:
Need verification that claimed accuracy is achieved... e.g., ~2% level for $f_D$
Why a Charm Renaissance Now?

I've explained why charm is so good, but:

  * Why not vigorously pursued before?
  * It was discussed ... as a "tau-charm factory" ...

There have been, and still are, several charm experiments, but...

-- charm decays are not CKM-suppressed \((c \Rightarrow sW)\) is full-strength
-- charm mesons \((D's)\) "decay too fast to mix"

  * Naively: a "poor cousin" of B physics?

Needs of B physics were at first DATA, not better theory

  * But now they need the assistance of charm!

**BEPC/BESII in Beijing:**

  * already ran as a less-fancy version of CESR-c/CLEO-c

A big upgrade is in progress, but this will run only after we are done...
Nominal CLEO-c Run Plan

Main change for CESR accelerator:
Installation of 12 wiggler magnets (for damping at low energy)

Winter 2003/2004: 6-wiggler ‘Pilot Run’ yielding results that follow

Year 1: $E = 3770$ MeV, 3 fb$^{-1}$ $\Rightarrow$ 18,000,000 $D\bar{D}$ decays,
> 3,000,000 tagged $D$ decays.

Year 2: $E = 4140$ MeV, 3 fb$^{-1}$ $\Rightarrow$ 1,500,000 $D_s^+ D_s^-$ events,
300,000 tagged $D_s$ decays

Year 3: $E = 3100$ MeV, 1 fb$^{-1}$ $\Rightarrow$ 1,000,000,000 $J/\psi$ decays.

Already have some $\psi(2S)$; likely to take more...
Maybe some $\Lambda_c$ data as well?
Superconducting Wiggler Magnets (x12)

Induce synchrotron radiation:
add damping to stabilize beams**
(ring 'too large' for lower energy)

** I'm not doing justice to the fascinating accelerator physics!
“ZD” for CLEO-c: 6-layer, stereo chamber
First Results!

(All results PRELIMINARY!)
CLEO-c Pilot Run Data

6 CESR Wigglers installed Summer 2003
Winter 2003/4: data on the $\psi(3770)$, $\psi(2S)$, continuum

- $\sim 20$ pb$^{-1}$ continuum
- $\sim 3$ pb$^{-1}$ $\psi(2S)$
- $\sim 60$ pb$^{-1}$ $\psi(3770)$

Cross-Section (Log Scale)

$E_{\text{beam}}$ (GeV)

6 Wiggler Running Luminosity $\sim 5 \times 10^{31}$ cm$^{-2}$ s$^{-1}$
12 Wiggler Design Luminosity $\sim 3 \times 10^{32}$ cm$^{-2}$ s$^{-1}$
CLEO-c Pilot Run Data

Integrated $\mathcal{L} = 89.6/110.6$ pb$^{-1}$

Integrated Luminosity (1/pb)

Physics at the $\psi(3770)$

Most charm analyses use tagging:

- A tag is a fully-reconstructed decay

  e.g., $D^+ \rightarrow K^- \pi^+ \pi^+$, $D^0 \rightarrow K^- \pi^+$,
  and other common hadronic modes

**Tagging:** gives direction of $p_D$;
reduces combinatorics, background!

Compare # of single, # of double tag events:

- Measure $\sigma_{DD}$ and absolute hadronic branching fractions

Study Leptonic/Semileptonic decays of other $D$:

- Know 4-momentum of initial state and of the tagging $D$
  \[ \Rightarrow \text{know 4-momentum of other } D; \text{ infer missed neutrino} \]
General Analysis Techniques

Charged Tracks: \( K^\pm \) and \( \pi^\pm \) (and \( \pi^\pm \) can build \( K_s \)):
- find in wire drift chamber via ionization
- \( dE/dx \), RICH to distinguish \( K \) from \( \pi \); \( E/p \) for \( e \)

Photons (can pair to find \( \pi^0 \)):
- find energy without a track in CsI calorimeter

Kinematics predicts us \( E_D, |p_D| \):

Momentum Conservation: \( M_{bc} = (E_{\text{beam}}^2 - p_{\text{cand}}^2)^{1/2} \)
- Substitute \( E_D = E_{\text{beam}} \) (\( M_{bc} \) = “beam-constrained mass”)
- Better resolution (~1.5 MeV; mostly beam energy spread)

Energy conservation: \( \Delta E = E_{\text{cand}} - E_{\text{beam}} \)
- Peaks at 0; sensitive to Particle ID, missing particles

Tagging: gives direction of \( p_D \);
- reduces combinatorics, background!
Types of Decays and Physics

Hadronic: (e.g., $D^0 \rightarrow K^- \pi^+$)
-- no neutrinos, "fully reconstruct"
-- Use as "tags"

measure hadronic reference branching fractions
use to reconstruct other decays with neutrinos

Leptonic: (e.g., $D^+ \rightarrow \mu^+\nu$)
-- decay constant & CKM elements from mixing

Semileptonic: (e.g., $D^0 \rightarrow K^- e^+\nu$)
-- form-factors & CKM elements

Both leptonic & semileptonic help us learn about CKM quark-mixing matrix: with not just c, but also b quarks
Tagged Semileptonic Event!

\[ D^0 \Rightarrow K^- e^+ \nu \quad \text{vs.} \quad D^0 \Rightarrow K^+ \pi^- \]
“Single Tags”: Find one D decay

Notice the log scale:

Very clean data!

Note: high-side tail is from beams radiating photons
“Double Tags”: Find both D’s

$M_{bc1}$ vs. $M_{bc2}$

(simulated)
(easier to see…)

$M_{bc}$ projections
(real Data)
\[ \sigma(DD), \text{ Branching Fractions} \]

**Single tag**

- \[ X \]
- \[ e^+ \rightarrow D^0 \rightarrow K^+ \pi^- \]
- \[ S = 2 N_{DD} B \varepsilon_1 \]
- \( S \): # Single tags
- \[ \sigma_{DD} = S^2 / 4DL \]
- Independent of \( B \) (and \( \varepsilon \), if \( \varepsilon_2 = \varepsilon_1^2 \))

**Double tag**

- \[ e^+ \rightarrow D^0 \rightarrow K^- \pi^- \]
- \[ D = N_{DD} B^2 \varepsilon_2 \]
- \( D \): # Double tags
- \[ B = 2D\varepsilon_1 / S\varepsilon_2 \]
- Independent of \( N_{DD} \) typical Achilles’ heel

\[ N_{DD} = \sigma_{DD} L \]
- \( B \): Branching frac
- \( \varepsilon \): Detection eff’y

**Combining**

- \[ N = S + D \]
**Absolute Hadronic Decay Fractions**

**Ratio of single and double tags:**
-- need MC efficiency
-- DO NOT need # DD pairs

Statistically powerful already
(inner error bars)

Systematics will improve:
more work and more data
(much progress already in hand...)
Measurement of $D^+ \Rightarrow \mu^+ \nu_\mu$

The leptonic decay width is given by:

$$\Gamma_{\ell\nu} = \frac{1}{8\pi} G_F^2 f_D^2 m_\ell^2 M_D (1 - \frac{m_\ell^2}{M_D^2})^2 |V_{cd}|^2$$

Branching frac. implies $f_D$: Vital check of LQCD calc'ns.

$LQCD$ is the only option for B physics ($B \Rightarrow \ell\nu$ too small to see)

Muon candidate consistent with min-I particle,

$<0.4 \text{ GeV} \text{ deposited in CsI} \quad (\text{too soft for muon detector})$

Key analysis variable: $MM^2$ missing-mass squared

$$MM^2 = (E_{beam} - E_\mu)^2 - (\vec{P}_{\text{tag}} - \vec{P}_\mu)^2$$

Resolution similar to $m_\pi^2$; pernicious $\pi^+\pi^0$ background!

(mis-ID $\pi^+$ and lose $\pi^0$ ... looks like signal!)
**MM\(^2\) Distribution in MC & Data**

**MC**

Simulation from BEFORE 1st data…

**DATA**

...looks just like real data!
(simul. was ~16x data)
\[ D^+ \Rightarrow \mu^+ \nu_\mu \text{ Signal} \]

8 candidate events within \(2\sigma\) in \(MM^2\)

1.07 background events estimated

\(\Rightarrow\) **SIGNIFICANT SIGNAL**

Reconstruction efficiency \(\sim 70\%\)

\[ B = (3.5 \pm 1.4 \pm 0.6) \times 10^{-4} \]

\[ f_D = (201 \pm 41 \pm 17) \text{ MeV} \]

**Statistically limited:** *easy to improve with more data*

Many systematics also improve w/ more data...
Pre-CLEO-c Semileptonics results

\[ D^0 \rightarrow K^- e^+ \nu \quad \text{and} \quad D^0 \rightarrow \pi^- e^+ \nu \]

Decays with K are 10x more common than \( \pi \):
Separate via "particle ID" techniques (hard)

CLEO-c: excellent kinematic separation!

Recent CLEO (to appear in PRL)
World’s best

But note Kaons under pion peak...
Exclusive Semileptonic Decays

Test accuracy of LQCD form factors
Relate to B decay form factors (for $V_{ub}$)
Direct Measurements of $V_{cs}$ and $V_{cd}$

Use many hadronic modes for tag sample

Identify the remaining tracks/showers in the event;
define $U = E_{\text{miss}} - |P_{\text{miss}}|$ (should peak at 0)
CLEO-c Neutral D Tags

Individual modes

sum of 9 modes
Semileptonics: New CLEO-c results

\[ D^0 \rightarrow K^- e^+ \nu \]

X-axes: \( U = E_{\text{miss}} - |P_{\text{miss}}| \)

\[ D^0 \rightarrow \pi^- e^+ \nu \]

Kaons now safely to side of pion peak!

Points: data
Histogram: MC
Colors show MC prediction for source
Semileptonic Form Factors

pre CLEO-c:

Can use to help understand related $B$ decays

$D^0 \Rightarrow K^- l^+ \nu$  
$D^0 \Rightarrow \pi^- l^+ \nu$

CLEO-c pilot:
Other Semileptonic Modes

$D^0 \rightarrow K^{*-} e^+ \nu_e$

Very clean!

$D^0 \rightarrow \rho^- e^+ \nu_e$

First observation!
CLEO-c Reach for Semileptonics

Pilot run data already contains best measurements and first observations... (and I haven’t showed any $D^+$ today)

Planned data sample would literally re-write the Particle Data Group (PDG) listings!

\[
\begin{align*}
1: D^0 &\rightarrow K^- e^+ \nu \\
2: D^0 &\rightarrow K^*^- e^+ \nu \\
3: D^0 &\rightarrow \pi^- e^+ \nu \\
4: D^0 &\rightarrow \rho^- e^+ \nu \\
5: D^+ &\rightarrow \overline{K}^0 e^+ \nu \\
6: D^+ &\rightarrow \overline{K}^{0*} e^+ \nu \\
7: D^+ &\rightarrow \pi^0 e^+ \nu \\
8: D^+ &\rightarrow \rho^0 e^+ \nu \\
9: D_s &\rightarrow K^0 e^+ \nu \\
10: D_s &\rightarrow K^{*0} e^+ \nu \\
11: D_s &\rightarrow \phi e^+ \nu
\end{align*}
\]
Inclusive Electron Spectrum

Vastly improve measurements of the lepton spectra in $D \rightarrow X_{e\nu}$ for both $D^{+}$ and $D^{0}$ mesons.

(and $D_{s}$ later on!)

Also extract inclusive semi-leptonic branching fractions.

Electron identification (cleaner than muons!)

optimized by studying radiative Bhabha events

use CsI calorimeter, $dE/dx$, and RICH info
Electron Spectra

Electron Momentum (GeV/c) from $D^+$

Statistical Uncertainty $\sim 0.6$

PDG: BR = (17.2±1.9)%

Electron Momentum (GeV/c) from $D^0$

Statistical Uncertainty $\sim 0.5$

PDG: BR = (6.75±0.29)%

(Systematic uncertainties not fully evaluated)

Will improve with added tag modes and luminosity
What CLEO-c replaces:

Inclusive leptons from charm:
Previous state-of-the-art

Delco 1979
(D₀ & D⁺ combined)

source of “secondary leptons”
at B factories
Other CLEO-c Physics

Now:

\[ \psi(2S) \text{ decays: shedding light on mysteries;} \]
\[ \text{observing many new decays} \]
\[ h_c \text{ discovery (charmonium state)} \]
\[ \text{Photon transitions among charmonia} \]

Future:

\[ D_s: \text{ same type of studies as } D^{0/+} \]
\[ J/\psi: \text{ source of gluon-rich decays} \]
\[ \text{studies of hadronic spectroscopy} \]
Physics from the $\psi(2S)$ Sample

Light charmonium spectroscopy

$h_c$ discovery
(new charmonium state)

$\psi(2S) \Rightarrow \chi_{cJ} \gamma$
Photon Transition Lines

![Graph of $h_c$ mass recoiled from $\pi^0$](image1)
![Graph of photon transition lines](image2)
Physics from the $\psi(2S)$ Sample

Our New Results:

Compiled with 12% rule:

6 new modes observed! : $\omega \pi^0$, $\rho \eta$, $\phi \eta$, $K^*0 K^0$, $K^+ K^-$, $b_1^0 \pi^0$

(can add more non-PV modes as well...)
Summary and Outlook

CLEO-c Detector and CESR-c Ring are working well
12 wigglers in for recent (Sep/Oct '04) data-taking
  Added ~40 pb$^{-1}$ to current ~60 pb$^{-1}$ at the $\psi(3770)$,
  More running mid-Dec '04 to 1 Apr '05
    (with prospect of increased performance!)
  Later, $D_s$ physics, followed by $J/\psi$

Many results already headed for publication:
  Absolute hadronic BR's (and $D\bar{D}$ cross sections)
  First significant determination of $f_D$
  Inclusive lepton spectrum and BR
  Exclusive semileptonic rates and form factors
  $\psi(2S)$ decays, $h_c$ discovery, ...
Acknowledgments

CLEO Colleagues:
~140 now; perhaps 350+ over my 9+ years
Built detectors, took data, performed analyses, ...
And local colleagues: T. Ferguson, H. Vogel, etc.

CESR Physicists:
For 25 years of unparalleled innovation and luminosity

LEPP Staff:
Invaluable Support

And a special thanks to:
Marina Artuso, Ian Shipsey, & Dave Rice
for leading the CLEO-c/CESR-c Task Forces
that made it all happen