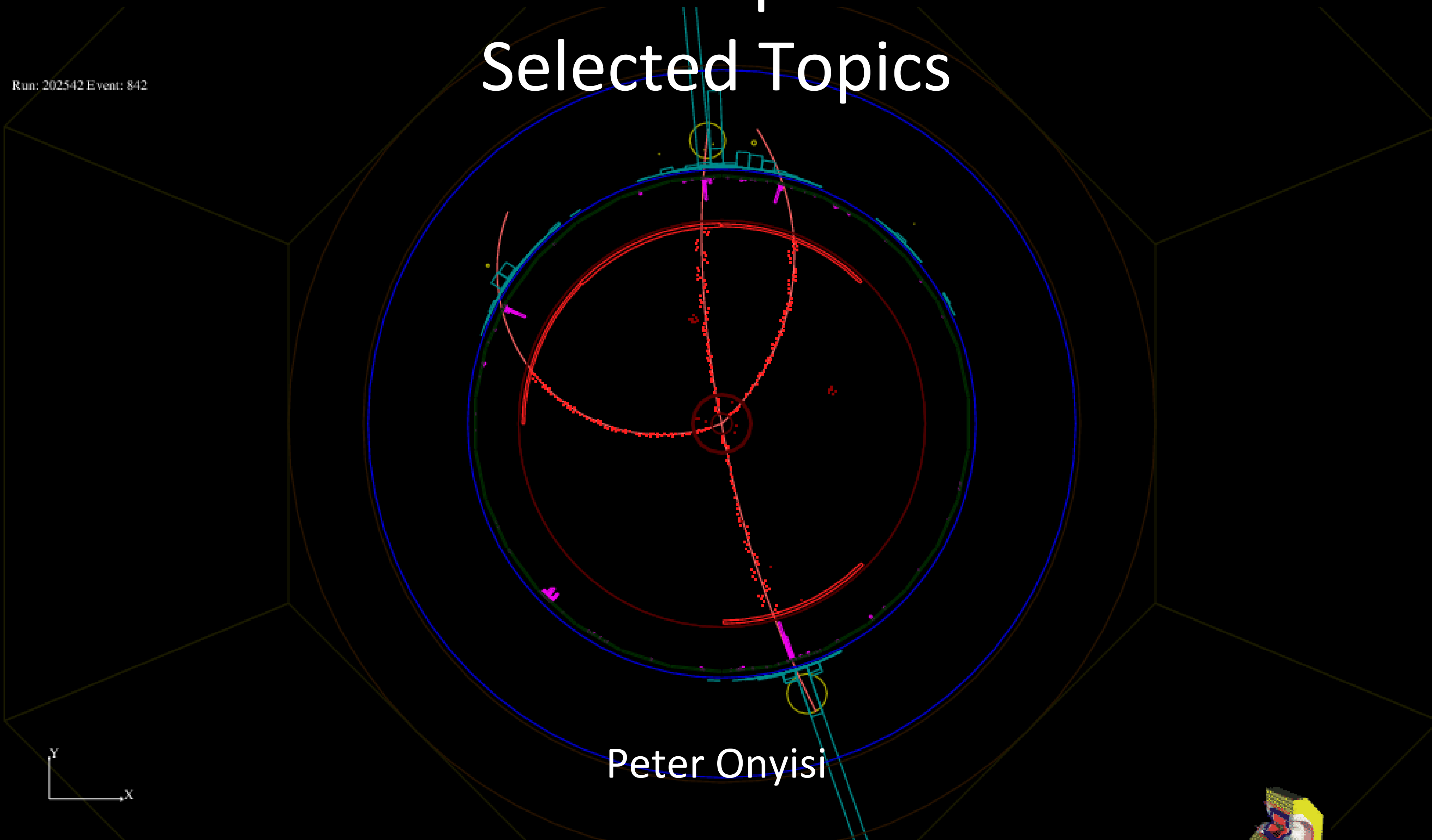
The CLEO Experiment: Selected Topics



Peter Onyisi

Rosnerfest, 1 April 2011

VOLUME 44, NUMBER 17 PHYSICAL REVIEW LETTERS 28 APRIL 1980

Observation of Three Upsilon States

Three narrow resonances have been observed in e^+e^- annihilation into hadrons at total energies between 9.4 and 10.4 GeV. Measurements of mass spacings and ratios of lepton pair widths support the interpretation of these "Υ" states as the lowest triplet-S levels of the $b\bar{b}$ quark-antiquark system.

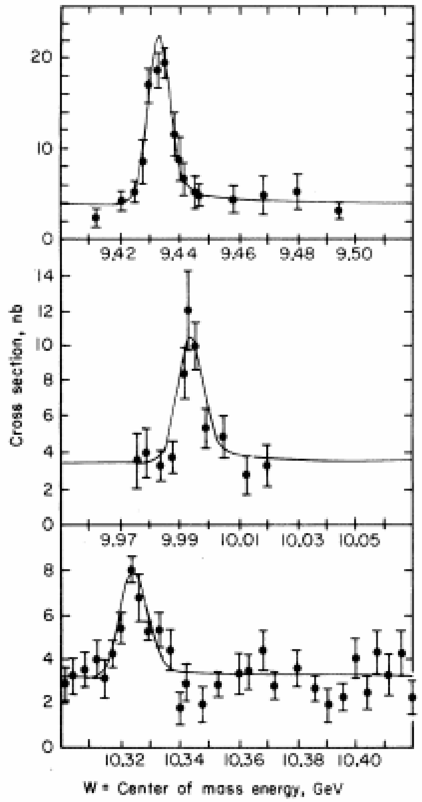


FIG. 3. Measured cross sections, including corrections for backgrounds and for acceptance, but not for radiative effects. Errors shown are statistical only. There is an additional systematic normalization error of ±20% arising from uncertainties in efficiencies and in the luminosity calibration. The energy scale has a calibration accuracy of 30 MeV. The curves show the best fit described in the text.

[11] J. L. Rosner, C. Quigg, and H. B. Thacker, Phys. Lett. 74B, 350 (1978).

CLEO cited Jon in its first paper!
(Re: the Q=-1/3 assignment of the b)

Strong/electromagnetic transitions from these states are a rich field of study

Later discovery of 4th resonance just above $B\bar{B}$ threshold set the stage for CLEO's rich career in b physics

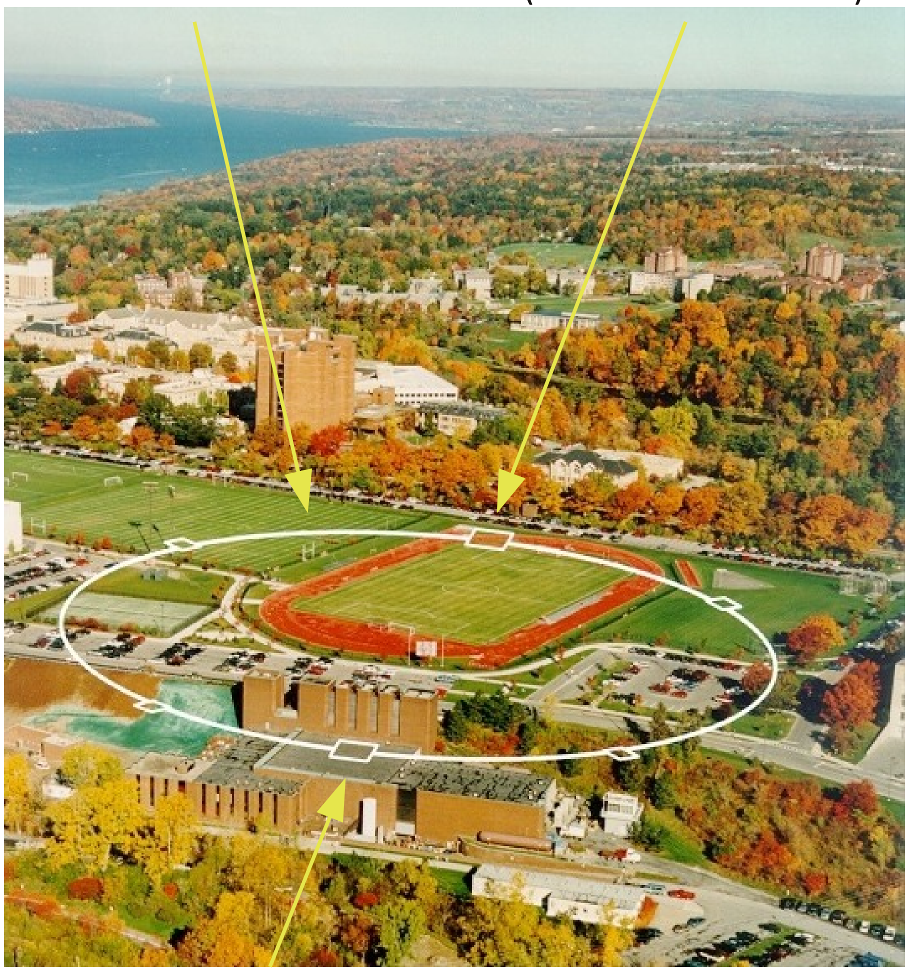
Introduction

- Jon has been involved with CLEO as a theorist and experimental collaborator
- Here are some selected highlights – they are **far** from exhaustive
- I will focus on spectroscopy and open charm – B decays will come in a later talk...

Introduction to CLEO

CESR e^+e^- storage ring

North Area
(former site of CUSB)



CLEO's location in beautiful Ithaca

(Some) of the CLEO-III collaboration

Sadly it's dismantled now...

Brief History of CLEO

- CLEO I & I.V (1979-89)
- CLEO II (1989-95)
  - CsI calorimeter
- CLEO II.V (1995-99)
  - Silicon Vertex Detector
- CLEO III (2000-03)
  - RICH Particle ID
  - New IR & tracking: Silicon, Drift Chamber
- CLEO-c (2003-08)
  - Silicon replaced by ZD inner drift chamber

- Datasets:
  - Υ(4S) (b physics) and below BB threshold (background)
  - Υ(1S-5S) for bottomonium
  - ψ(3770) and 4.17 GeV for open charm physics
  - ψ(2S) for charmonium

For more, I recommend Karl Berkelman's "A Personal History of CESR and CLEO", CLNS 02/1784

Jon's CLEO Hardware

CBX 05-5
January 31, 2005

SEARCH FOR RF INTERFERENCE SOURCES NEAR THE CLEO DETECTOR

John Dobbins [1]
Laboratory for Elementary-Particle Physics
Cornell University, Ithaca, NY 14850

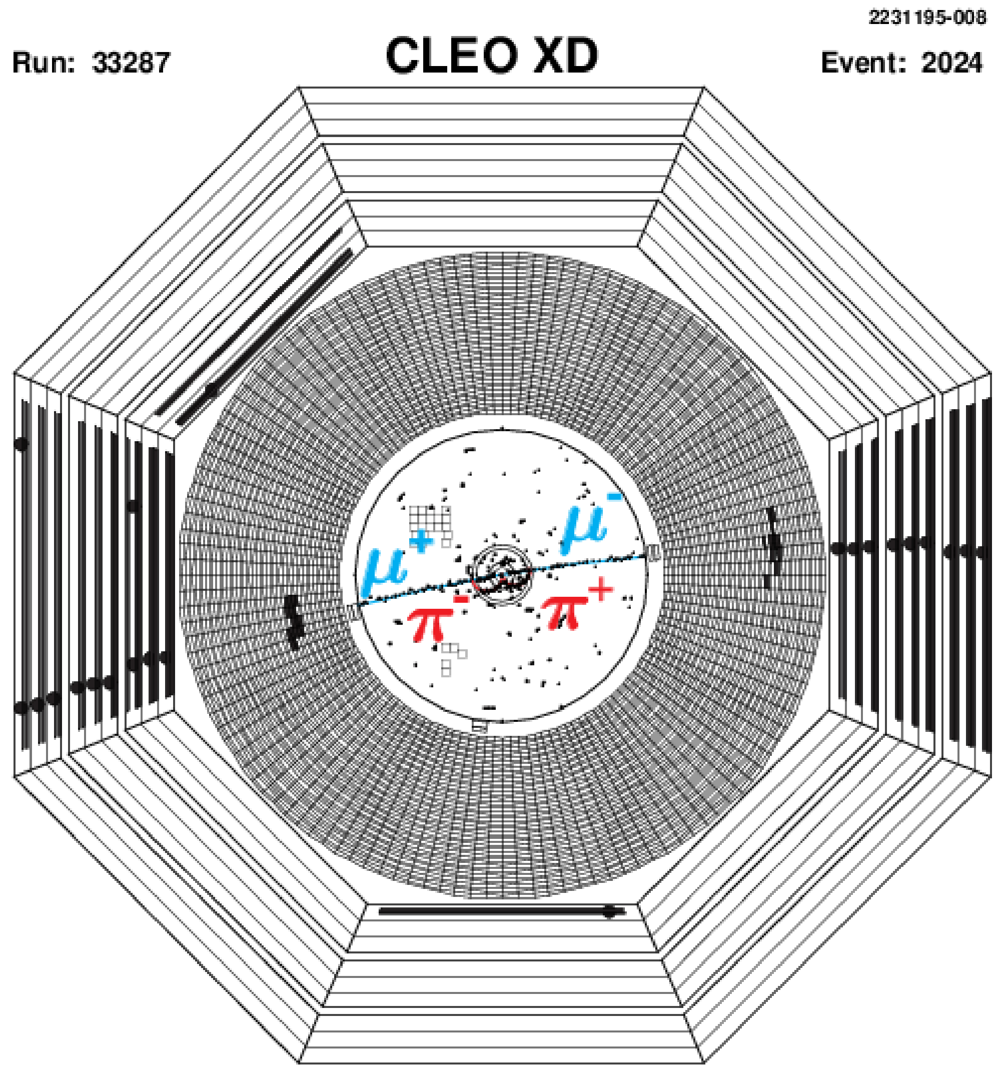
and

Jonathan L. Rosner [2]
Enrico Fermi Institute and Department of Physics
University of Chicago, 5640 S. Ellis Avenue, Chicago, IL 60637

Two dipole antennas have been installed near the CLEO Detector in order to search for sources of RF interference which might account for "red-eye" events in which large portions of the detector appear to show signals. Results of an initial survey are presented and a system for acquisition of data in a more systematic fashion is described.

Spectroscopy

CLEO II Event Display



$$\Upsilon(3S) \longrightarrow \Upsilon(2S)\,\pi^+\pi^-$$
$$\hookrightarrow \mu^+\mu^-$$

Spectroscopy

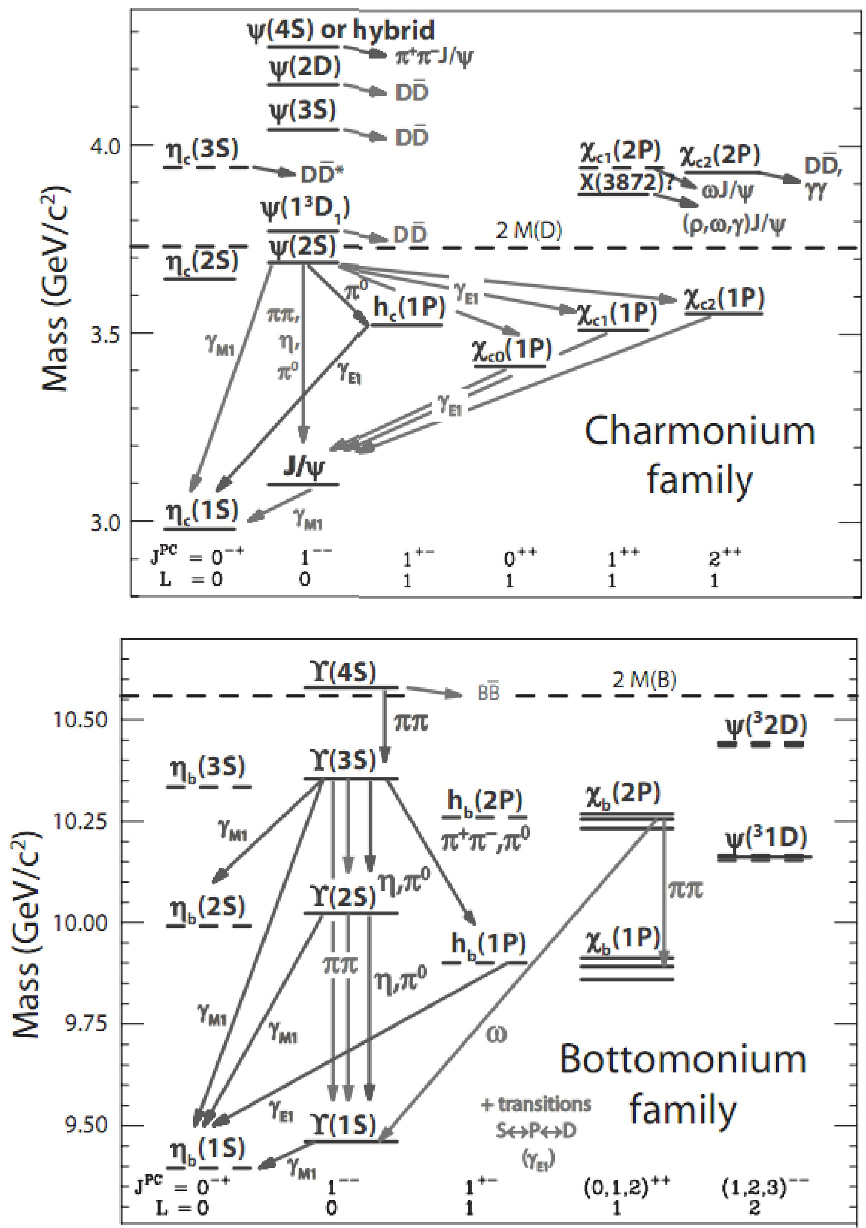
- Quarks in hadrons are bound by QCD
- Bound states and transitions are “just” quantum mechanics problems (in potential models)
  - empirical potentials
  - nonperturbative QCD matrix elements
  - relativistic corrections
  - often mixing between states & threshold effects
- After decades of study there are still many open questions!
  - Many being addressed by numerical lattice QCD calculations

"Onia" Spectroscopy and Decay

- $b\bar{b}$ and $c\bar{c}$ systems have same underlying physics, different quark masses
- Above open flavor thresholds, states are generally broad
- Only vector ($J^{PC} = 1^{--}$) states available* in e^+e^-; use cascades to study others

* ignoring γγ collisions

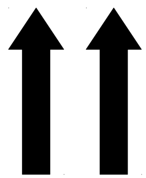
Recall spectroscopic notation: the states are labeled by quantum numbers $n\ ^{2S+1}L_J$



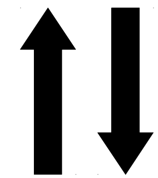
From RMP 80 1161 (2008)

Quick Guide to States

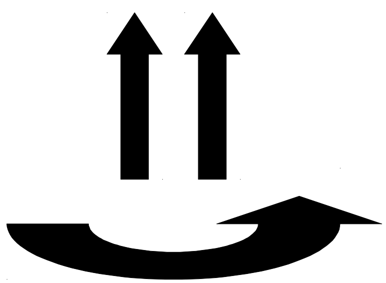
Angular momentum part

ψ, Υ = 

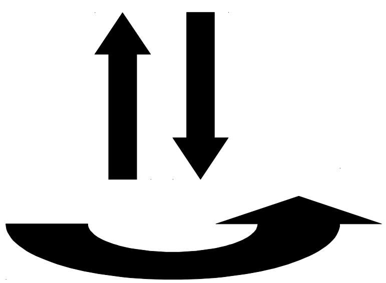
S=1, L=0

η = 

S=0, L=0

χ = 

S=1, L=1

h = 

S=0, L=1

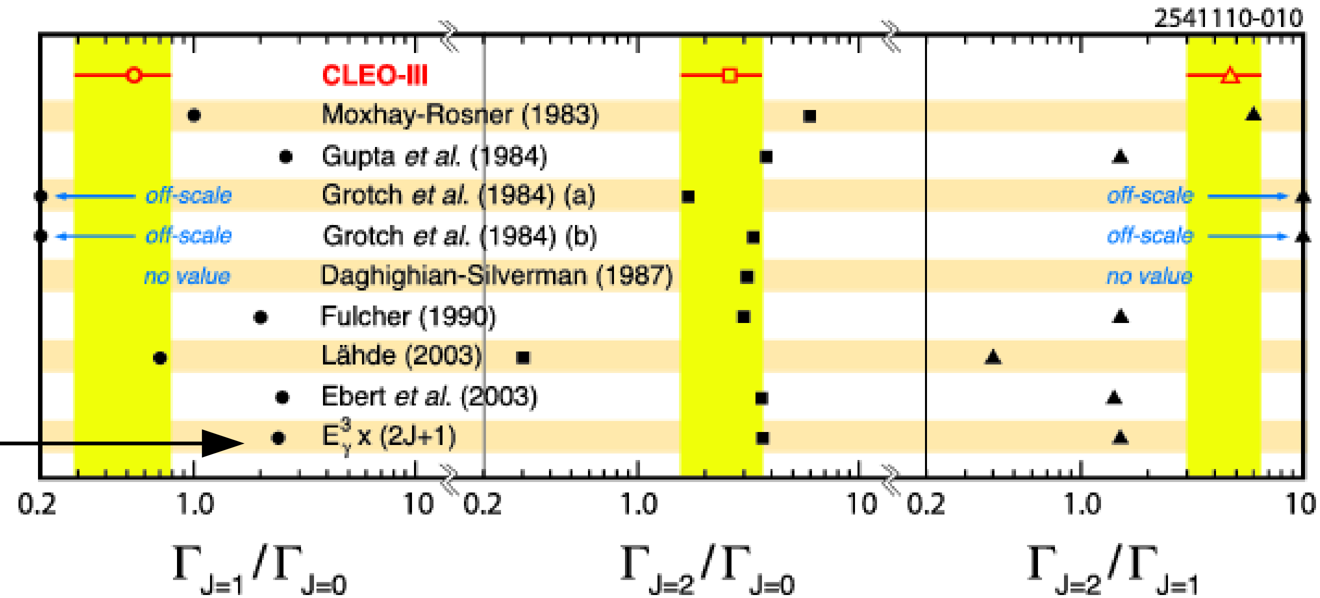
(times radial part)

Electromagnetic Transitions in $b\bar{b}$

- For example, $\Upsilon(2,3S) \to \gamma\chi_{b0,1,2}(1P) \to \gamma\gamma\Upsilon(1S)$
- Rates sensitive to wave function overlaps, e.g. $\langle 1P|r|3S\rangle$
  - this is suppressed by the radial wave functions and is very sensitive to relativistic corrections; rate predictions vary by >2 orders of magnitude

Width ratios
$\Upsilon(3S) \to \gamma\chi_{bJ}(1P)$

Nonrelativistic limit



PRD 83, 054003 (2011)

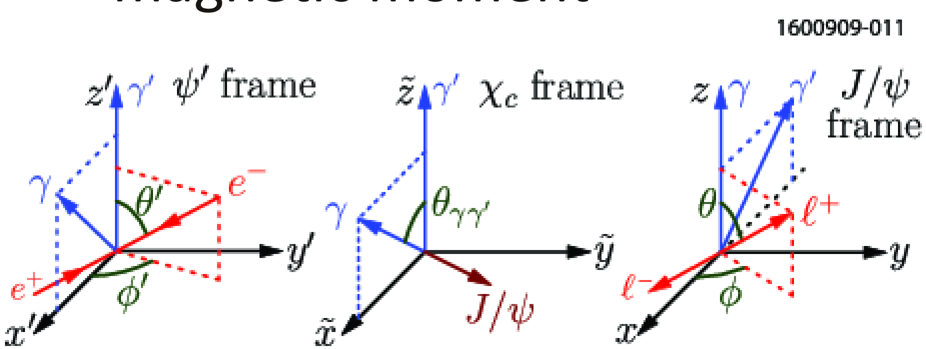
Electromagnetic Transitions in $c\bar{c}$

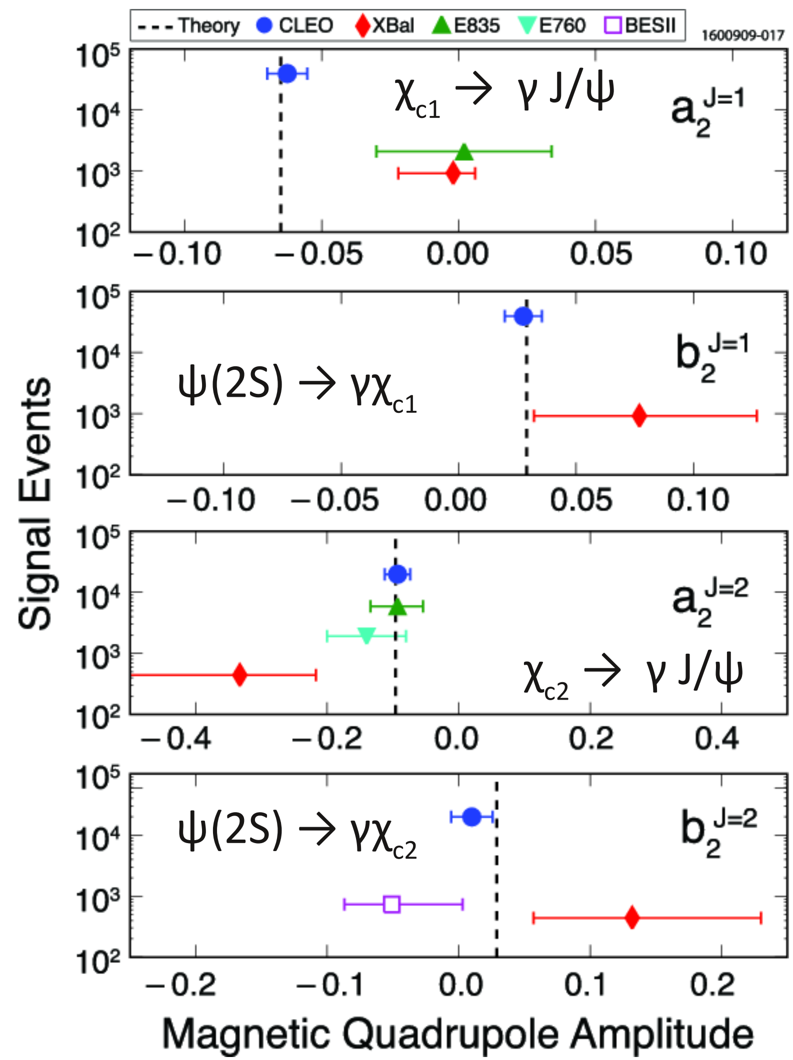
Looked at magnetic quadrupole (M2) amplitudes in $\psi(2S) \rightarrow \gamma\chi_{c1,2}(1P) \rightarrow \gamma\gamma\, J/\psi(1S)$

- Gives different angular distributions than E1

Resolved long standing question of a_2^1/a_2^2: agrees with theory

- no sign of anomalous charm magnetic moment





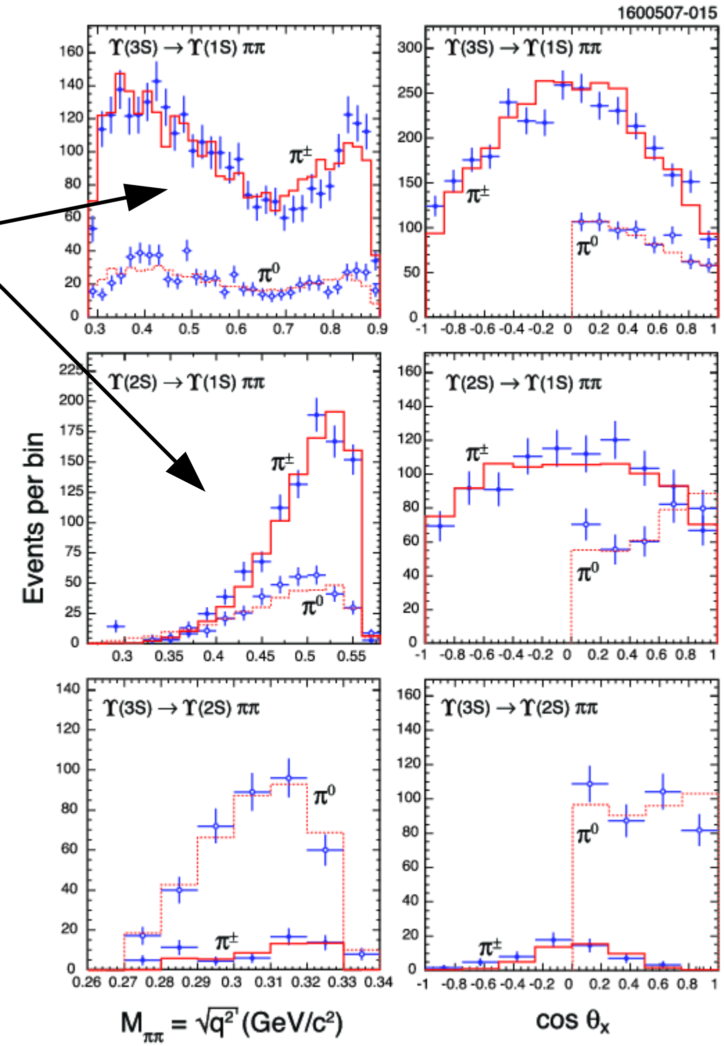
PRD 80, 112003 (2009)

"Theory": Rosner, PRD 78, 114011 (2008)

An enduring question: $\Upsilon(3S) \to \pi\pi\Upsilon(1S)$

Why is the $m(\pi\pi)$ distribution of $\Upsilon(3S) \to \pi\pi\Upsilon(1S)$ different from other dipion transitions in Υ and ψ? ("Double hump" seen since the 80s!)

- Higher-order angular (D-wave) term is dominant here but suppressed in most other cases
- Similar effect seen by BaBar for $\Upsilon(4S) \to \pi\pi\Upsilon(2S)$: $\Delta n = 2$ rule?



CLEO, PRD 76, 072001 (2007)

Discovery of the h_c

After many hints, the $^1P_1$ $c\bar{c}$ state was firmly established by CLEO in 2005 in the process

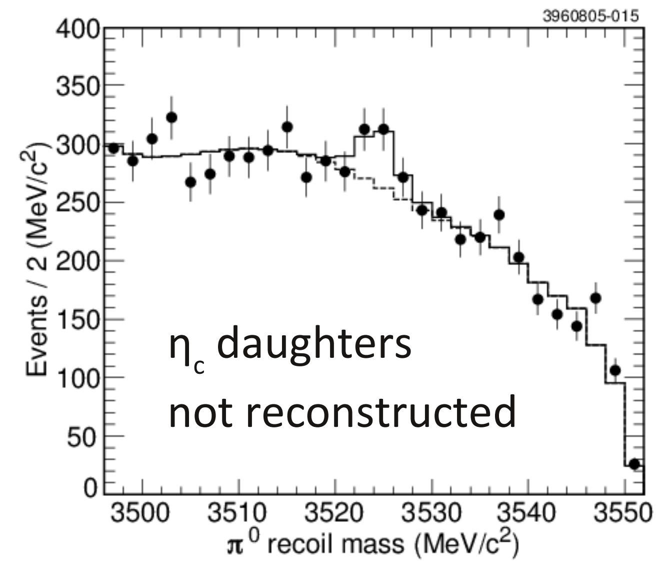
$$\psi' \rightarrow \pi^0 h_c \rightarrow \pi^0 \gamma \eta_c$$

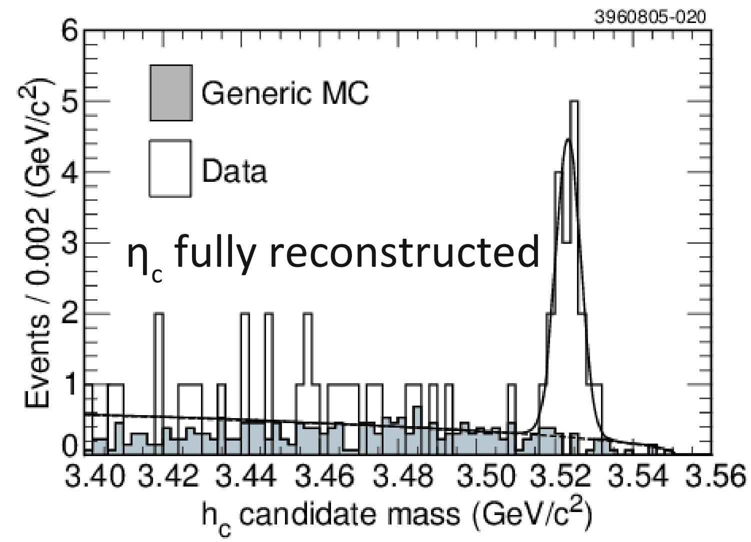
Mass comparison with the χ_c ($^3P_{0,1,2}$) states measures hyperfine splitting

$\Delta M_{HF} = +0.02 \pm 0.19 \pm 0.13$ MeV

PRL 101, 182003 (2008)

(sensitive to the form of the potential)

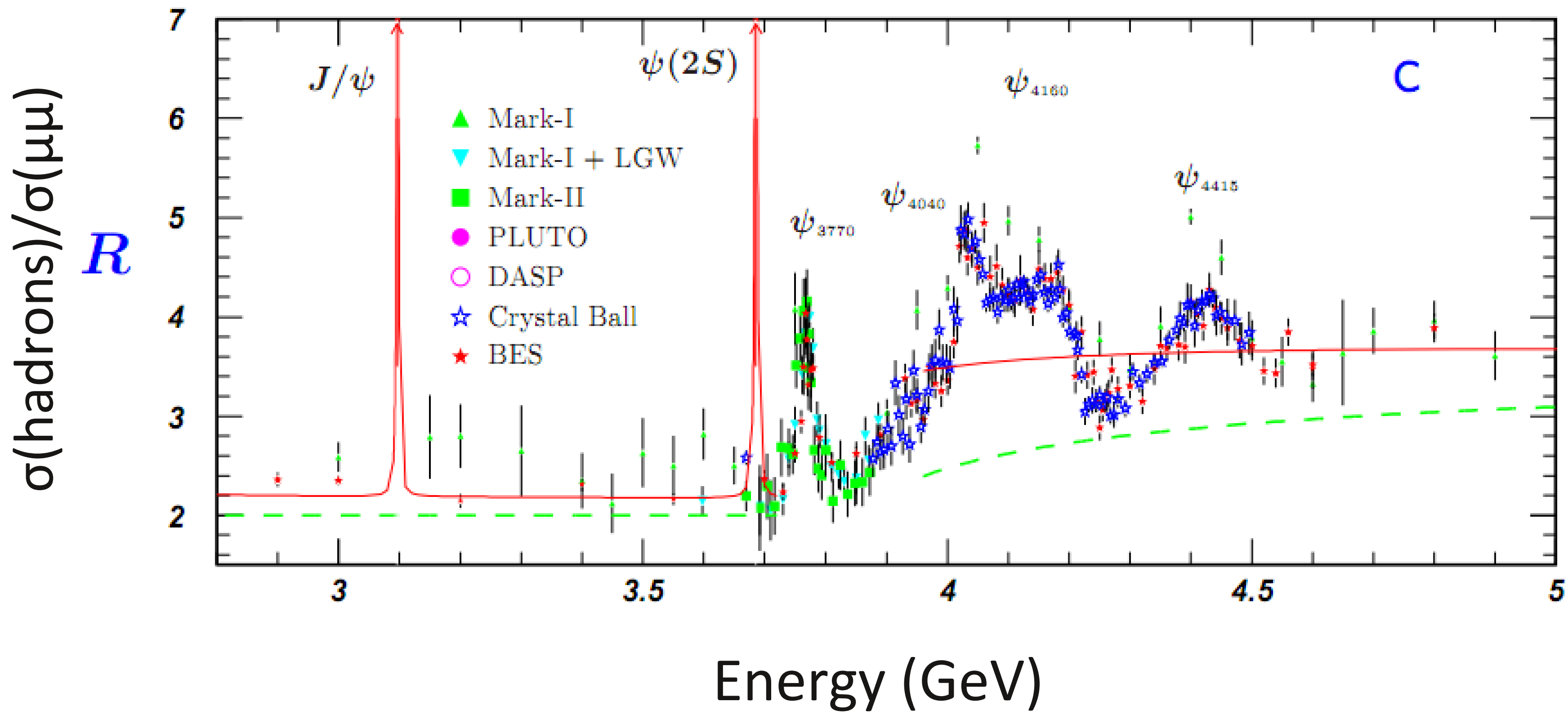




PRL 95, 102003 (2005)

Above the Threshold

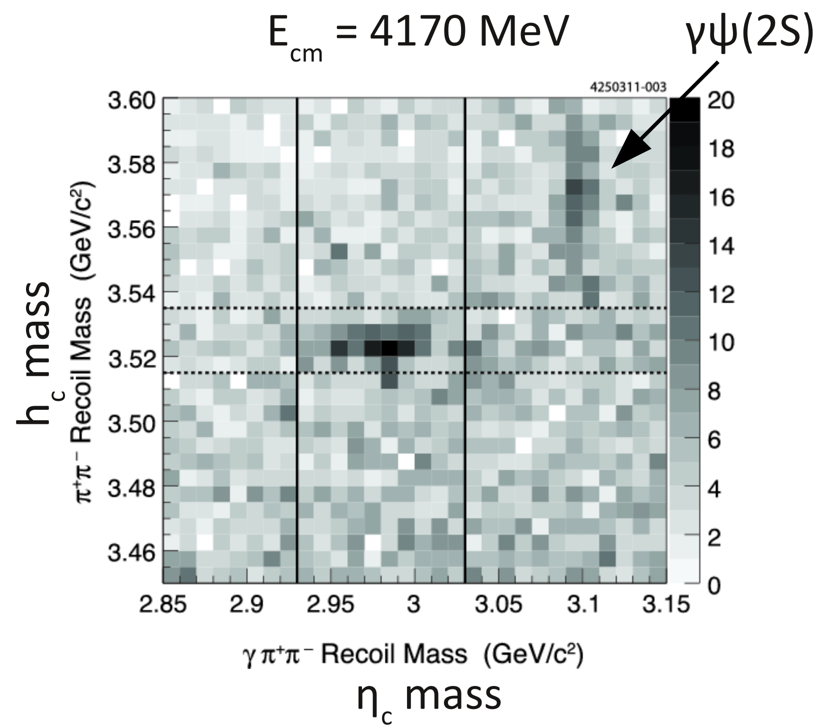
2010 PDG

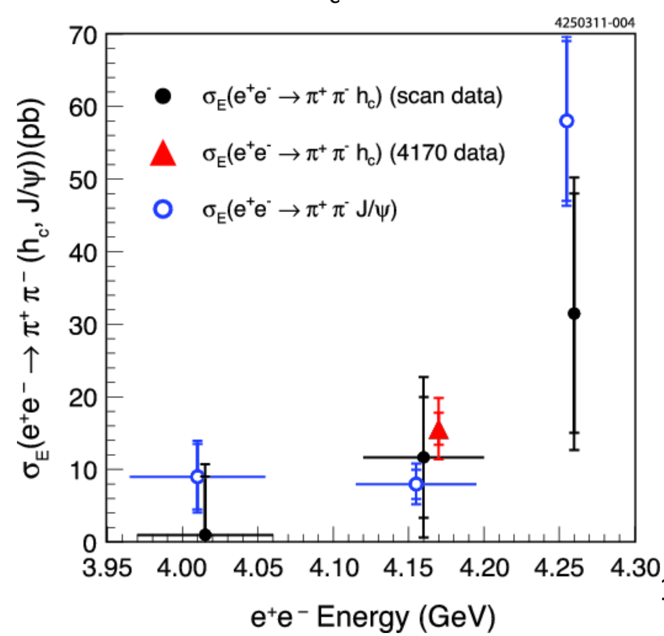


$e^+e^- \to \pi^+\pi^- h_c$ above $D\bar{D}$ threshold

- First observation
- Detected at 4170 MeV via $h_c \to \gamma\eta_c$, $\eta_c \to$ hadrons
- Hints also of ηh_c and possible enhancement from mysterious state Y(4260)
- Question: how come $\pi\pi$ h_c rate is similar to $\pi\pi$ J/ψ? (Spin flip required!)

Preliminary





Open Charm

Open Charm

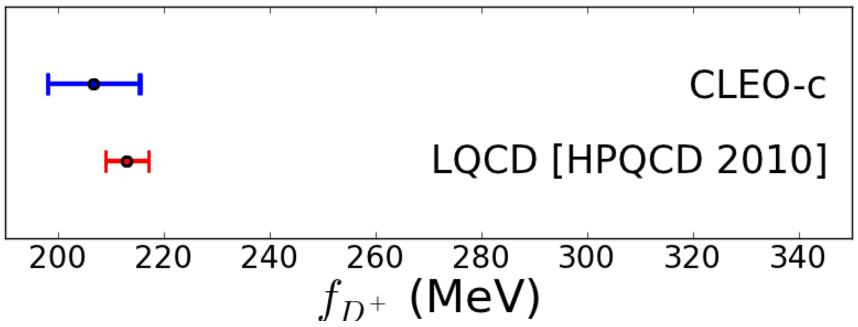
- Open charm = hadrons with charm + lighter quark
- Light quark → relativistic terms, higher order QCD
- Most decays involve interacting hadrons + resonances
- More qualitative questions
  - How do the "long distance" (light) degrees of freedom affect the hadron behavior/decay?
  - Knowledge also needed as input to other studies
- Most quantitative questions need lattice QCD for controlled understanding
- Quick Guide: $D^0 = c\bar{u}$; $D^+ = c\bar{d}$; $D_s^+ = c\bar{s}$

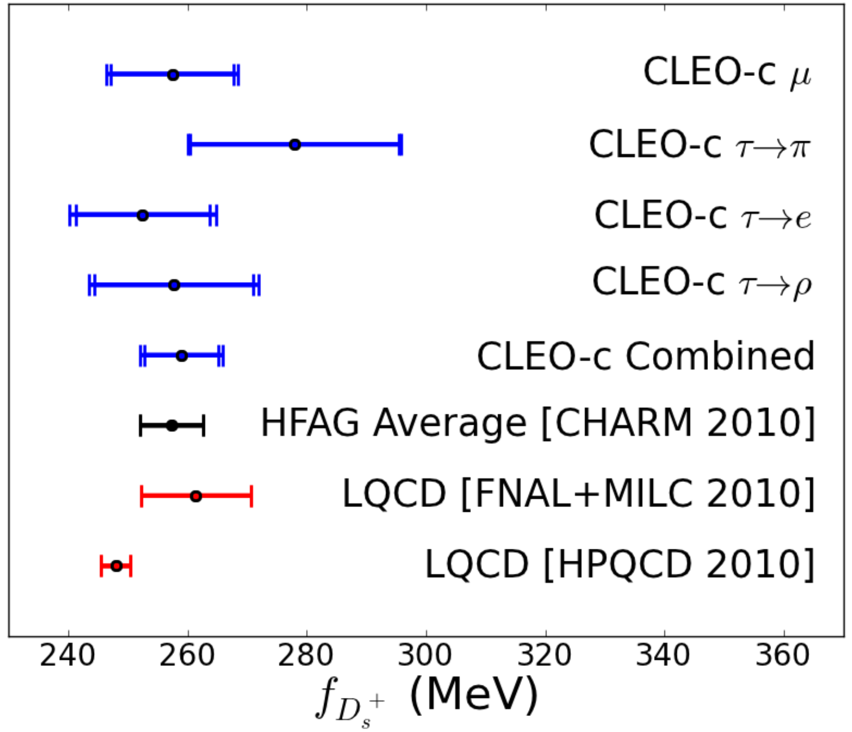
D Leptonic Decays

The quantity $f_{D(s)}$ measures how often the two valence quarks of a D^+ or D_s^+ are at zero separation

- Fundamental parameter of the meson wavefunction

CLEO-c and B-factories have provided stringent test of lattice QCD calculations



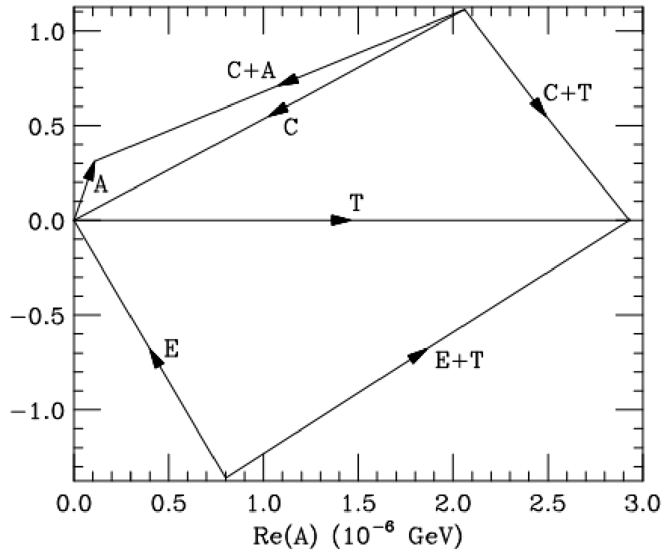


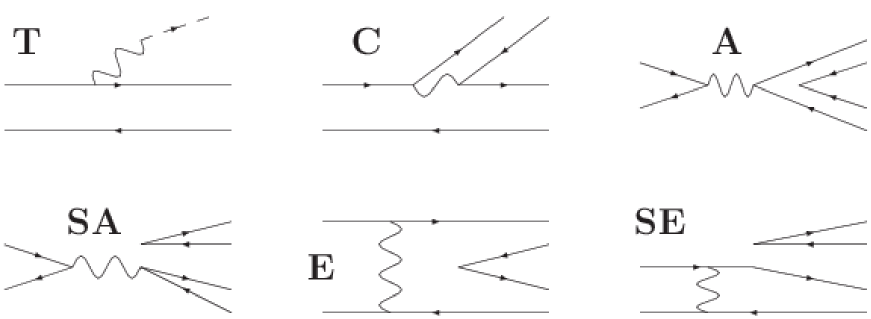
Hadronic Charm Decay Phases

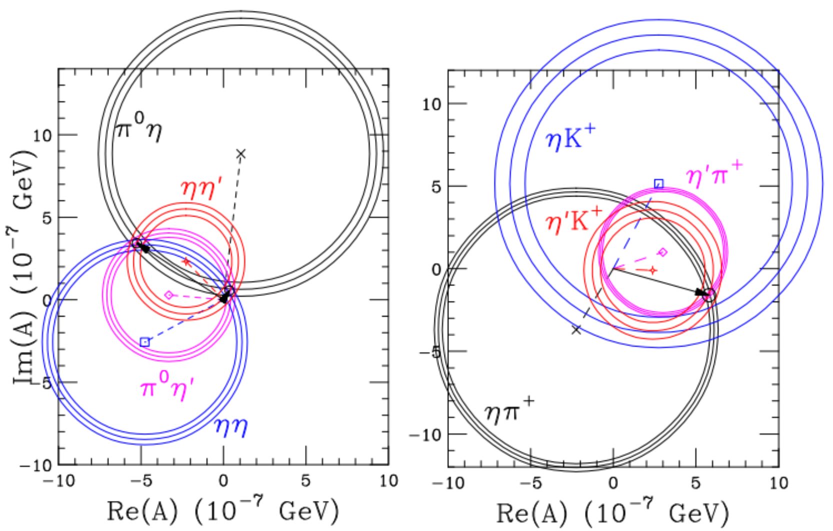
Various D decay amplitudes can be related using SU(3) symmetry and a “flavor topology” approach

CLEO-c provides the necessary branching fraction inputs

Cabibbo-favored amplitude solution







Singlet amplitudes from Cabibbo-suppressed decays

Plots from Bhattacharya & Rosner, PRD 81 014026 (2010)

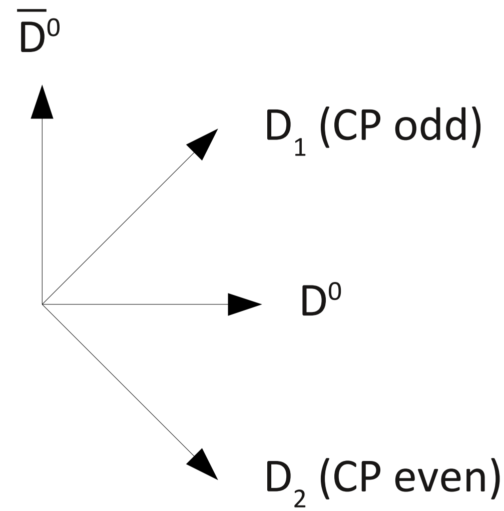
Quantum Correlations in Charm

- At 3.77 GeV center of mass, e^+e^- collisions create $D\bar{D}$ pairs in an overall CP=+1 (vector) state
  - Taking out the relative L=1, the D mesons have **opposite** CP: their decays must be **correlated** by this
  - e.g. $D^0 \to \pi^0\pi^0$ never happens in the same event as $\bar{D}^0 \to \pi^0\pi^0$ (except for CP violation!)
  - more subtly, the phases between D^0 and $\bar{D}^0$ decays to the same final state are projected out by the CP content of the other meson

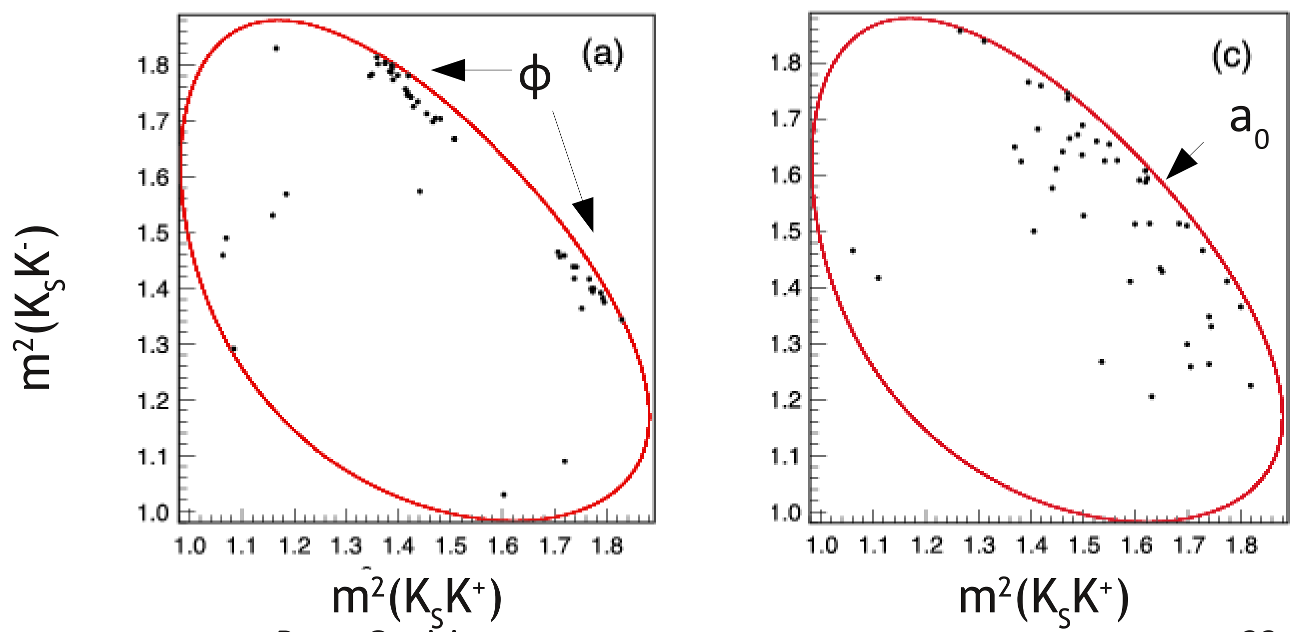
Our formalism for "The Quantum Correlation Analysis":
Gronau, Grossman, Rosner, Phys. Lett. B 508, 37 (2001).

In other words...

- The CLEO charm threshold data allows us to choose the D basis we look at
  - either flavor D^0, $\overline{D}^0$, or CP D_1, D_2
  - then interfere amplitudes as desired
- Such analyses help unitarity triangle (γ/ϕ_3) and D mixing measurements



Choosing certain decays of one meson changes what the other can do: quantum mechanics works!



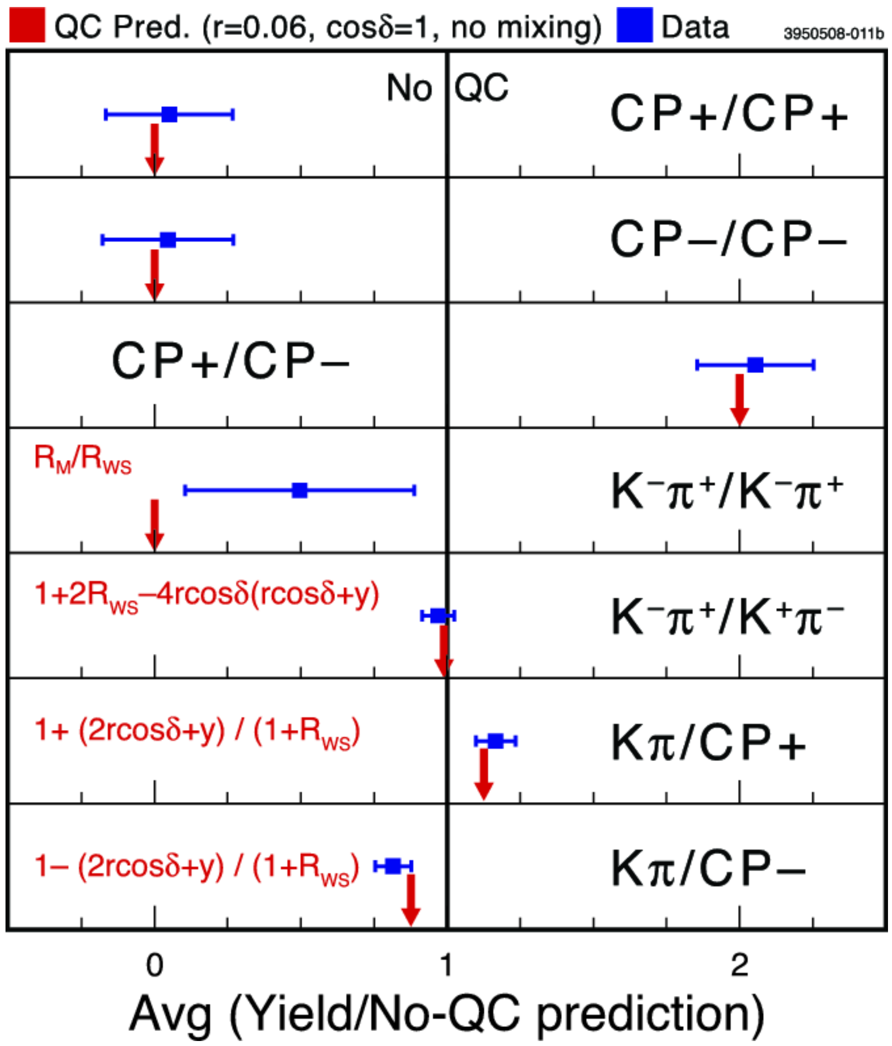
The Quantum Correlation Analysis

Measures the phase difference between $D^0 \to K^-\pi^+$ and $\overline{D}^0 \to K^-\pi^+$ amplitudes

First measurement:

$\cos\delta = 1.03\,^{+0.31}_{-0.17} \pm 0.06$

PRL 100, 221801 (2008)



A very fruitful (and ongoing) interaction between Jon and CLEO!

Personal Note:

I probably wouldn't have joined CLEO without Jon's encouragement

Thank You!