D, D_s, and Charmonium Physics at CLEO-c

Progress and Prospects

Meson 2006

June 13, 2006

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Outline

- Overview of the physics program and detector
- D/D_s Physics (CKM Motivated)
  - Energy Scan
  - Leptonic and Semi-Leptonic Form Factors
  - Hadronic Branching Fractions
- Spectroscopy (Mesons!)
  - Y(4260)
  - Dalitz Analyses of Hadronic χ_c Decay

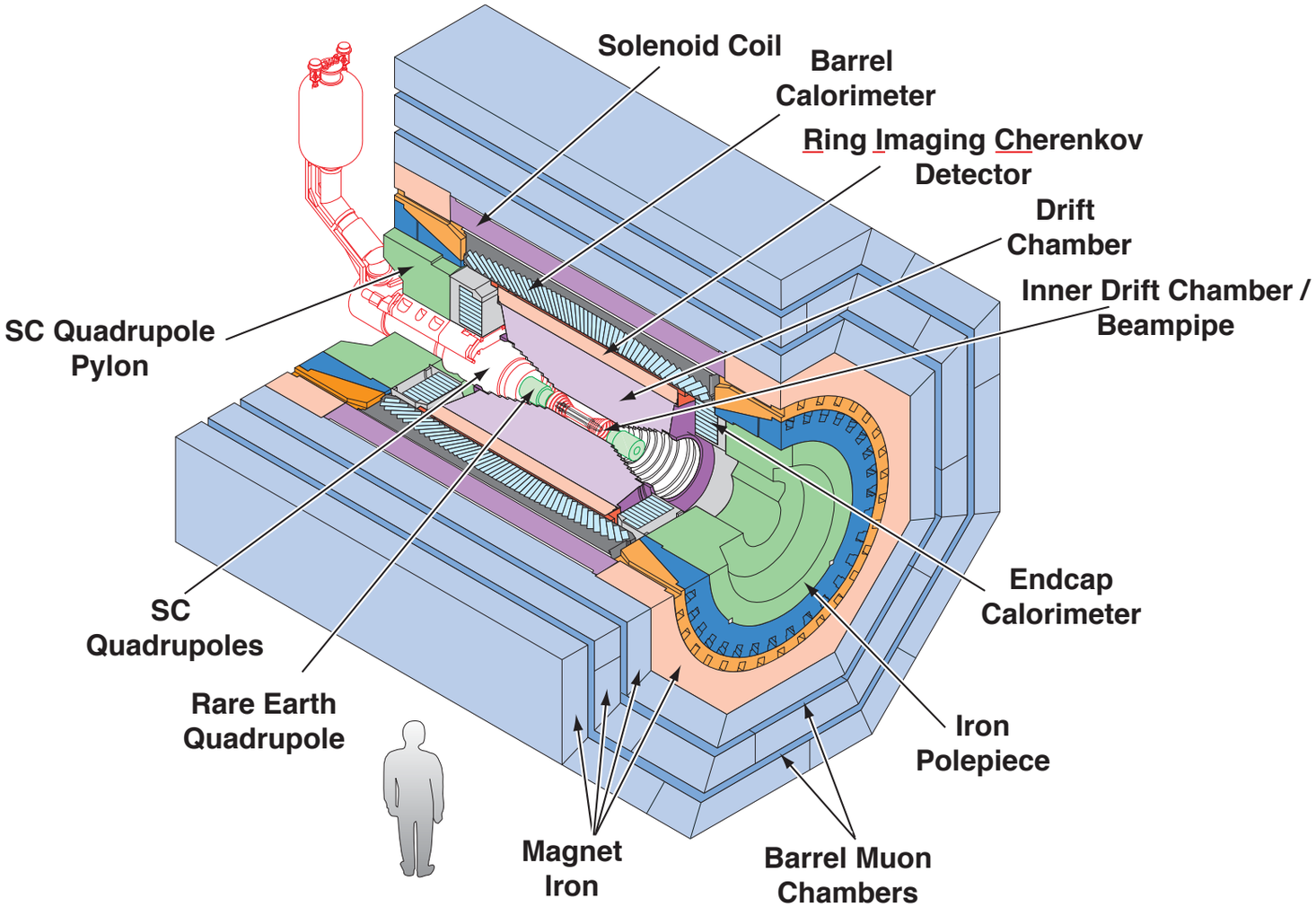
CLEO at CESR:
A ~~Beauty~~ charm Factory

- Long history of "heavy flavor physics" at CLEO

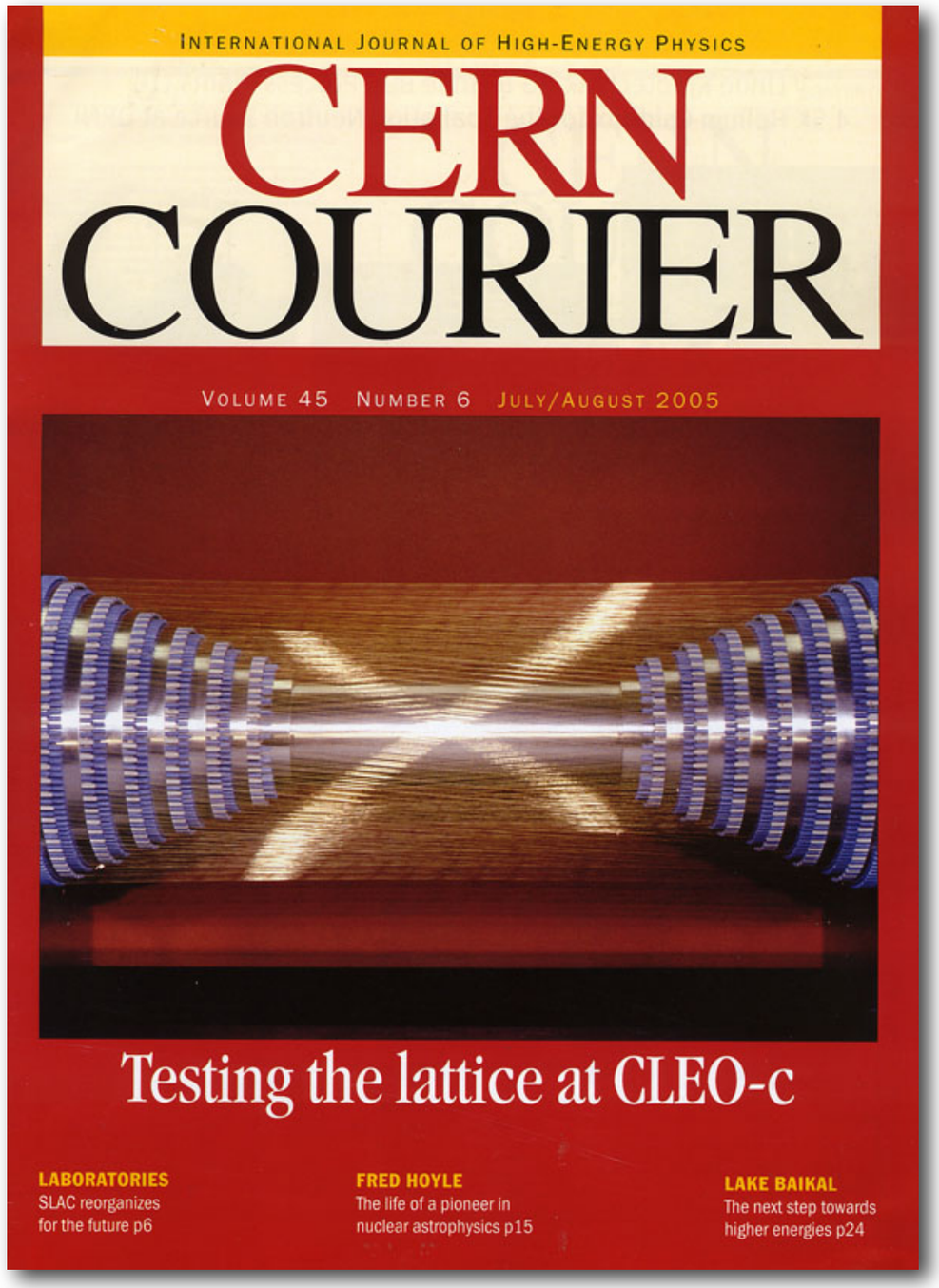
- Modern charm measurements are critical to the global program of flavor physics

- Other exciting physics possibilities in the charm system in addition to precision CKM

The CLEO-c Detector



(largely unchanged from CLEO III)



CLEO-c Thrusts

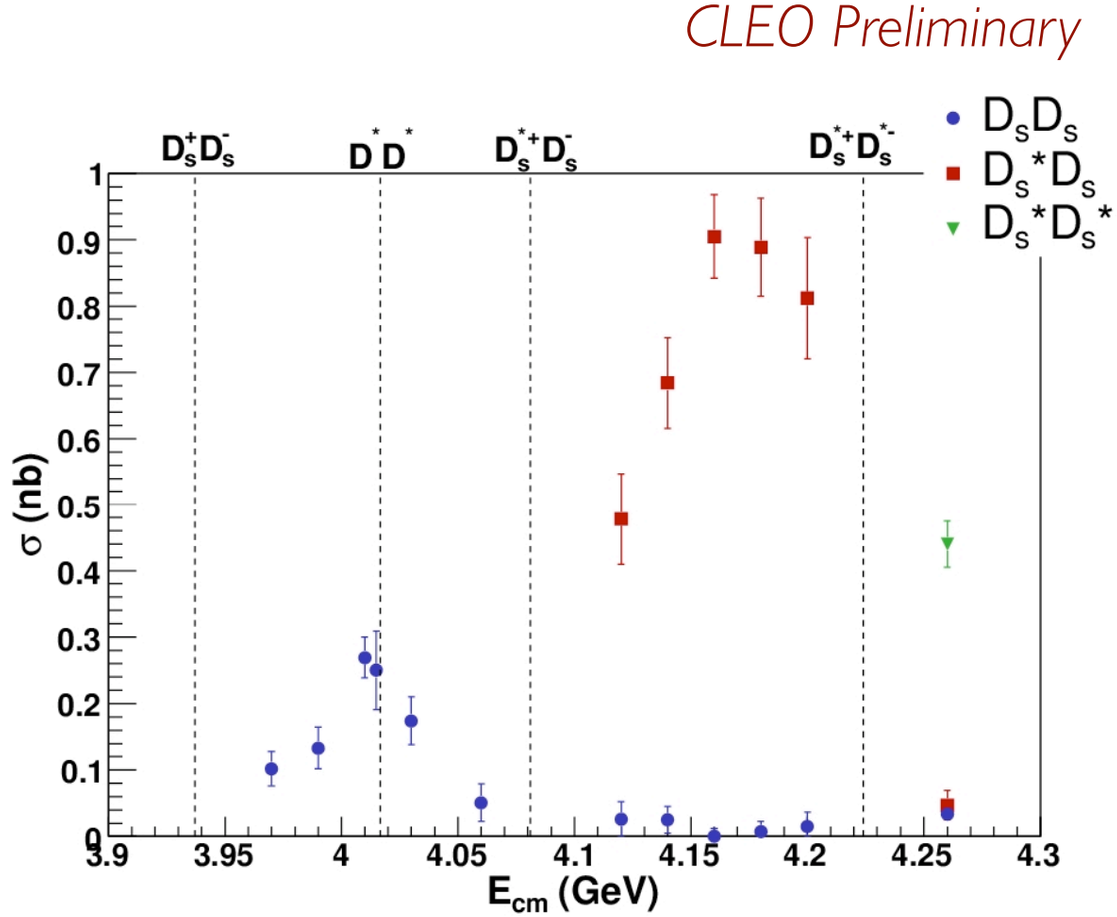
"A New Frontier of Weak and Strong Interactions"

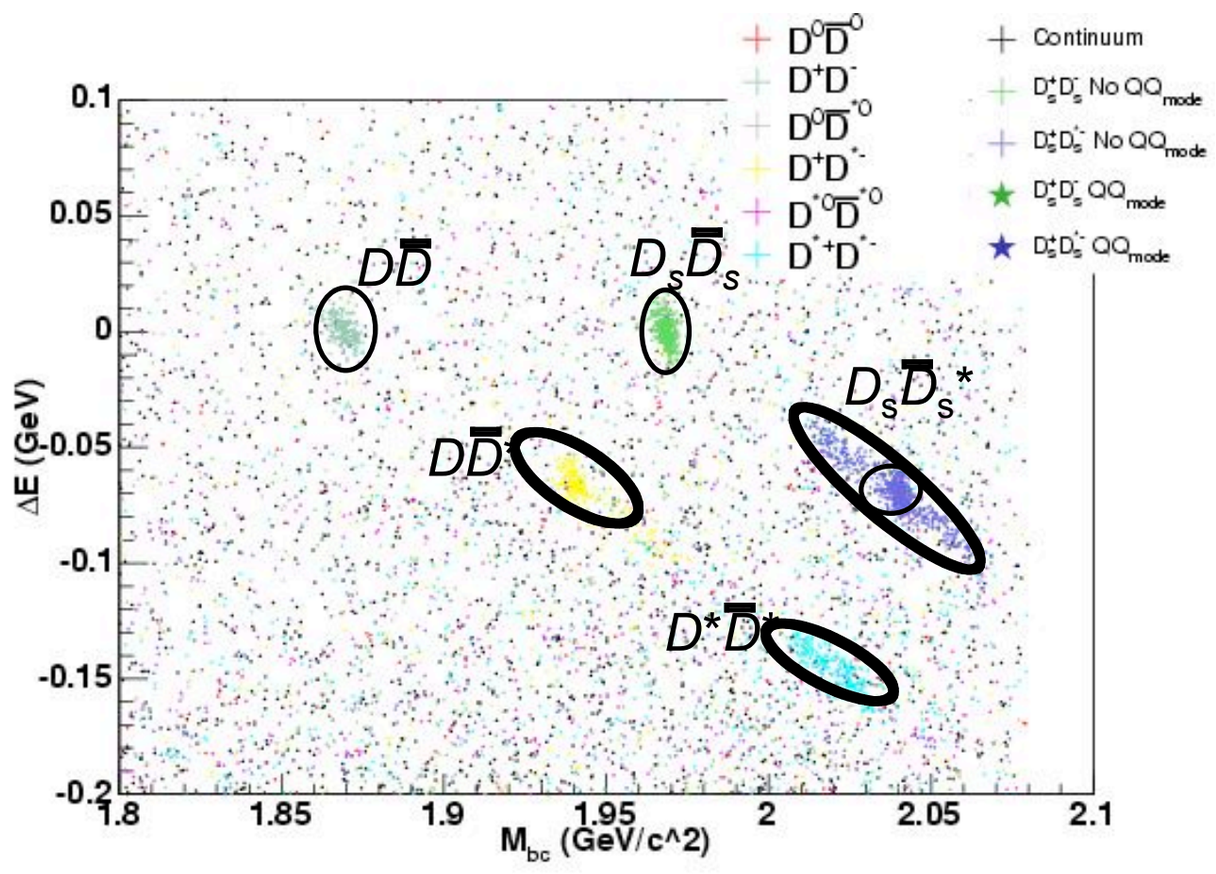
- Strong Physics:
  - studies of the meson spectrum through decays of charmonium states
- A Strong Influence on Weak Physics:
  - experimentally verify Lattice QCD calculations needed to perform precision tests of the Standard Model
  - make precision measurements of hadronic branching fractions needed to perform CKM unitarity tests
- Other Topics:
  - probe beyond-SM physics through searches for rare/forbidden processes

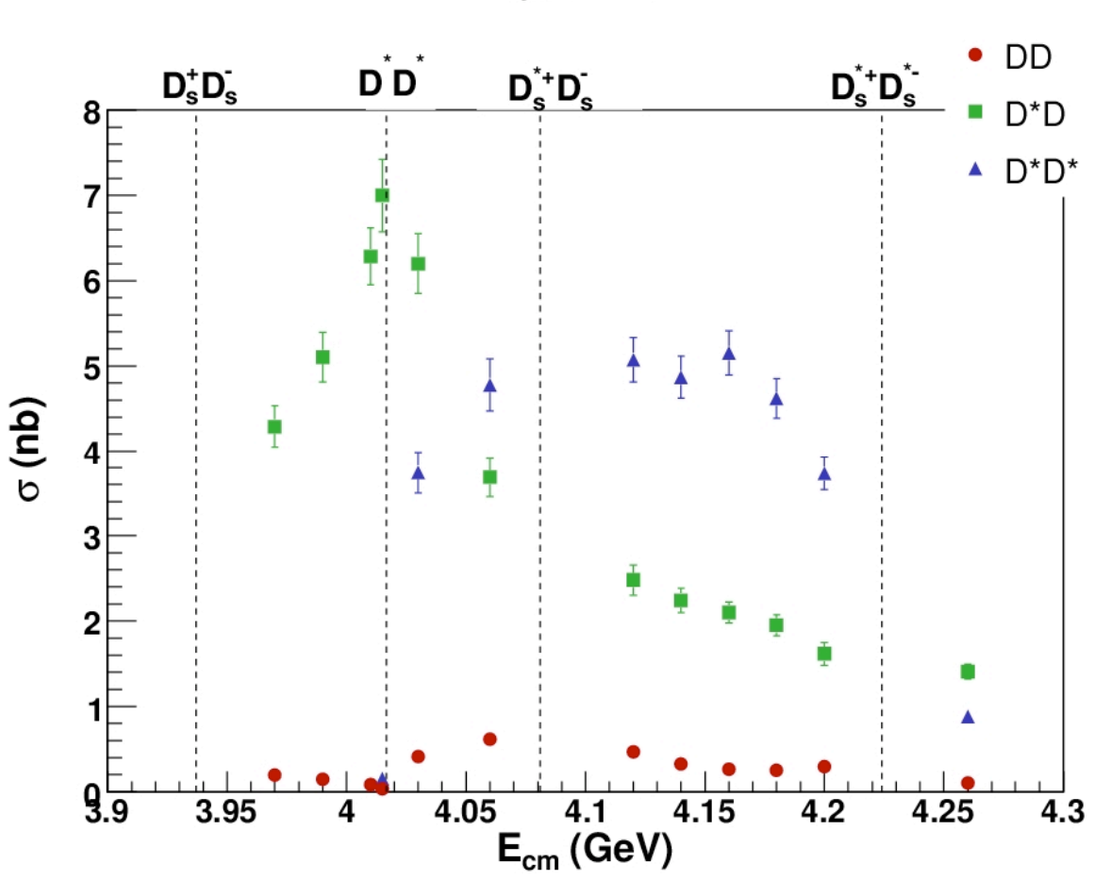
..plus many more!

Energy Scan

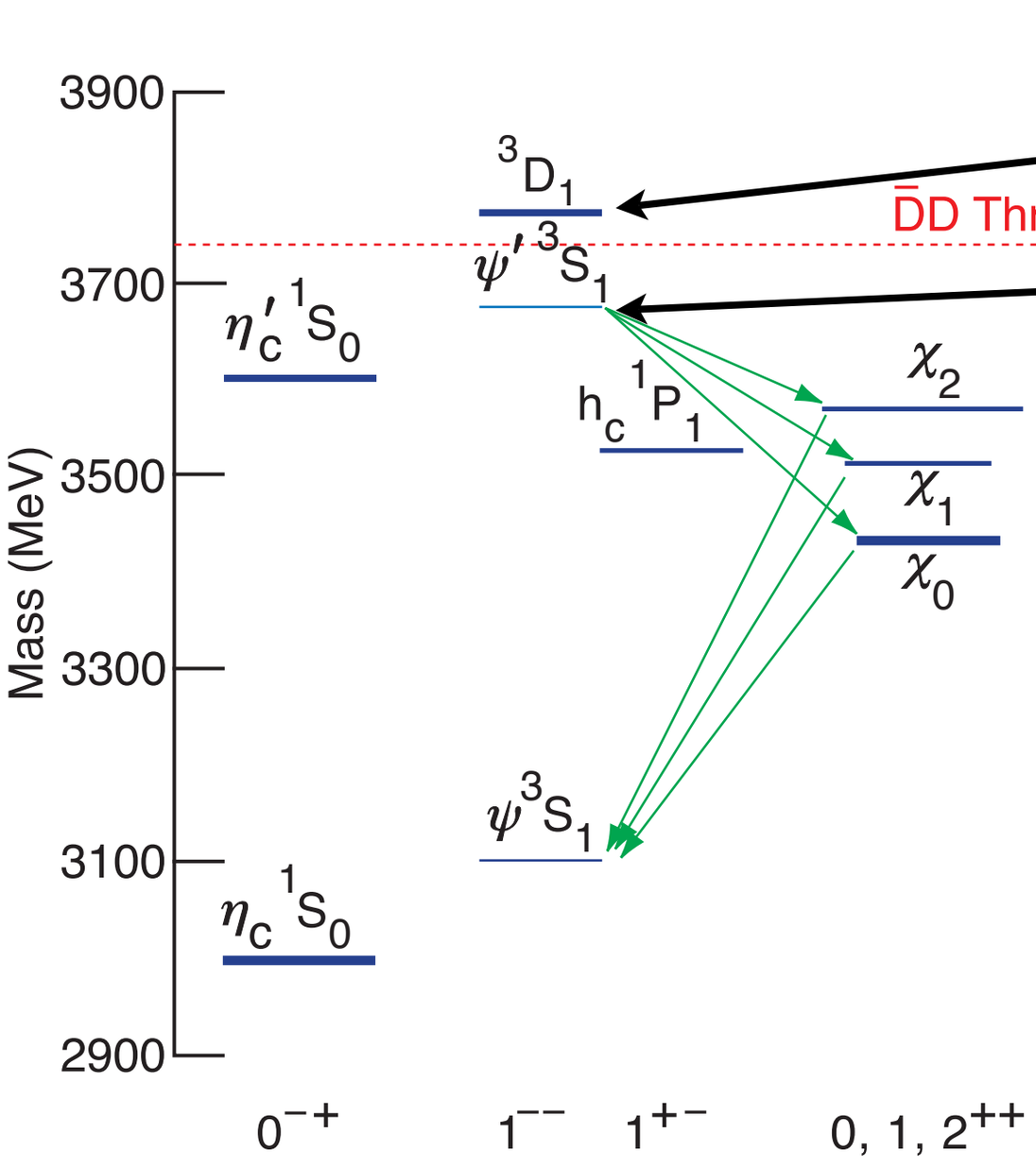
- Goal: determine optimal energy for D_s running
- Event types kinematically separated by reconstructing known D and Ds decays
- Additional data taken at 4260 MeV

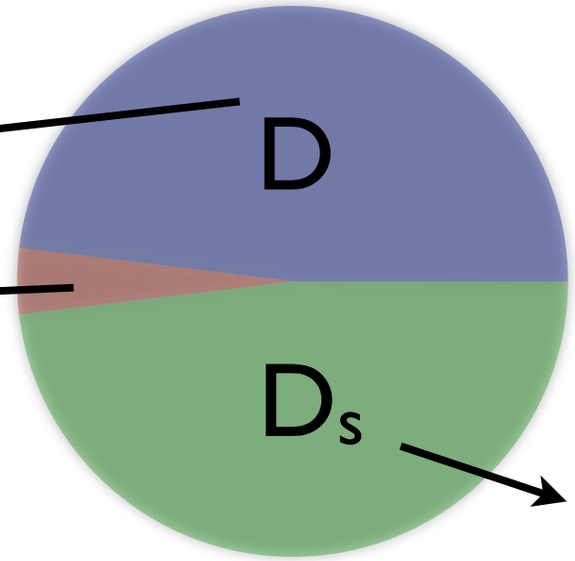






The Run Plan





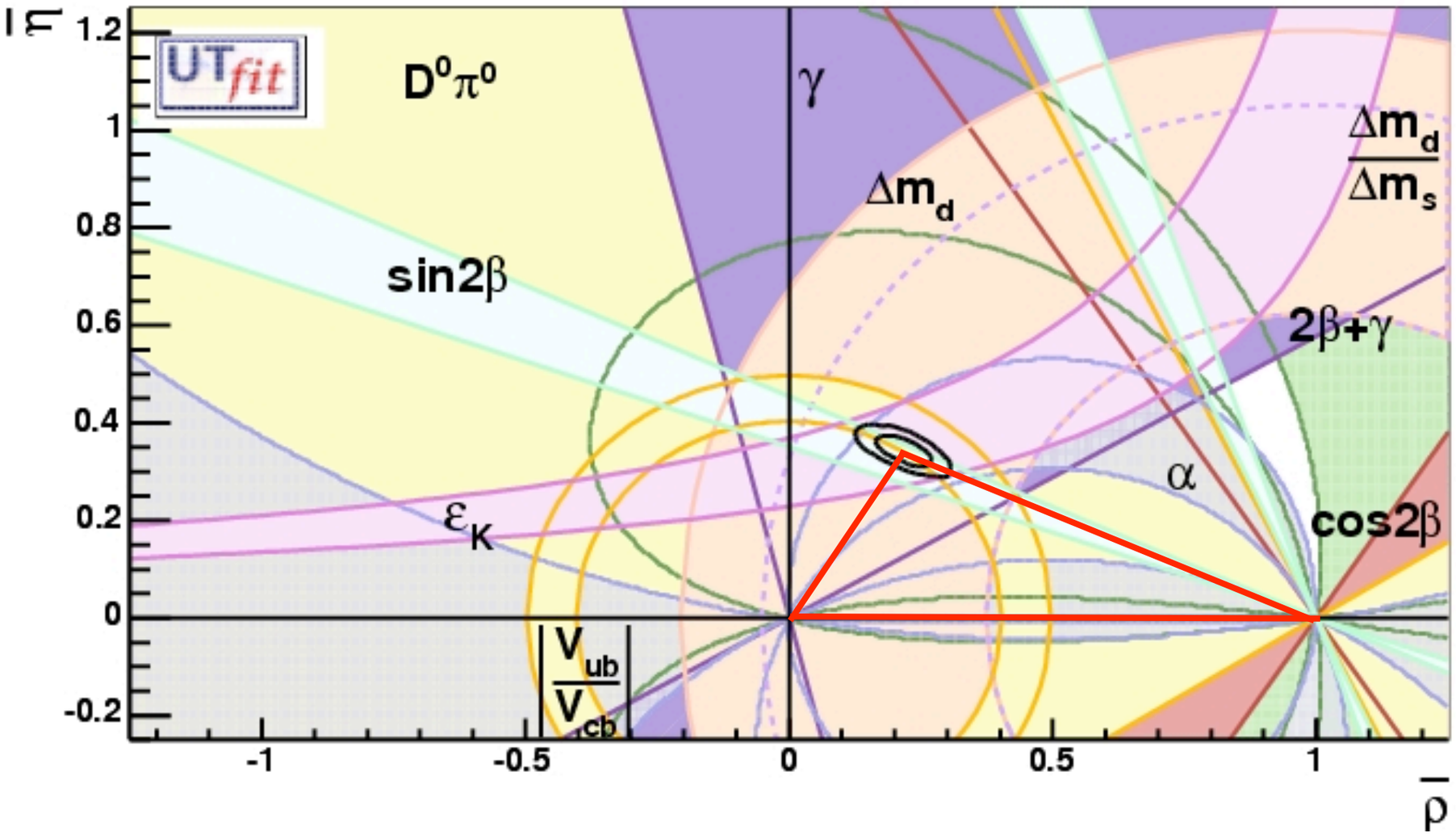
3686 MeV
3770 MeV
4170 MeV

$D_s\bar{D}_s$* cross section peak at 4170 MeV

	Current	Projected (Mar-08)
3686 MeV	6 pb^{-1}	60 pb^{-1}
3770 MeV	281 pb^{-1}	750 pb^{-1}
4170 MeV	~200 pb^{-1}	750 pb^{-1}

CLEO-c Flavor Physics Highlights

The Global Flavor Physics Program

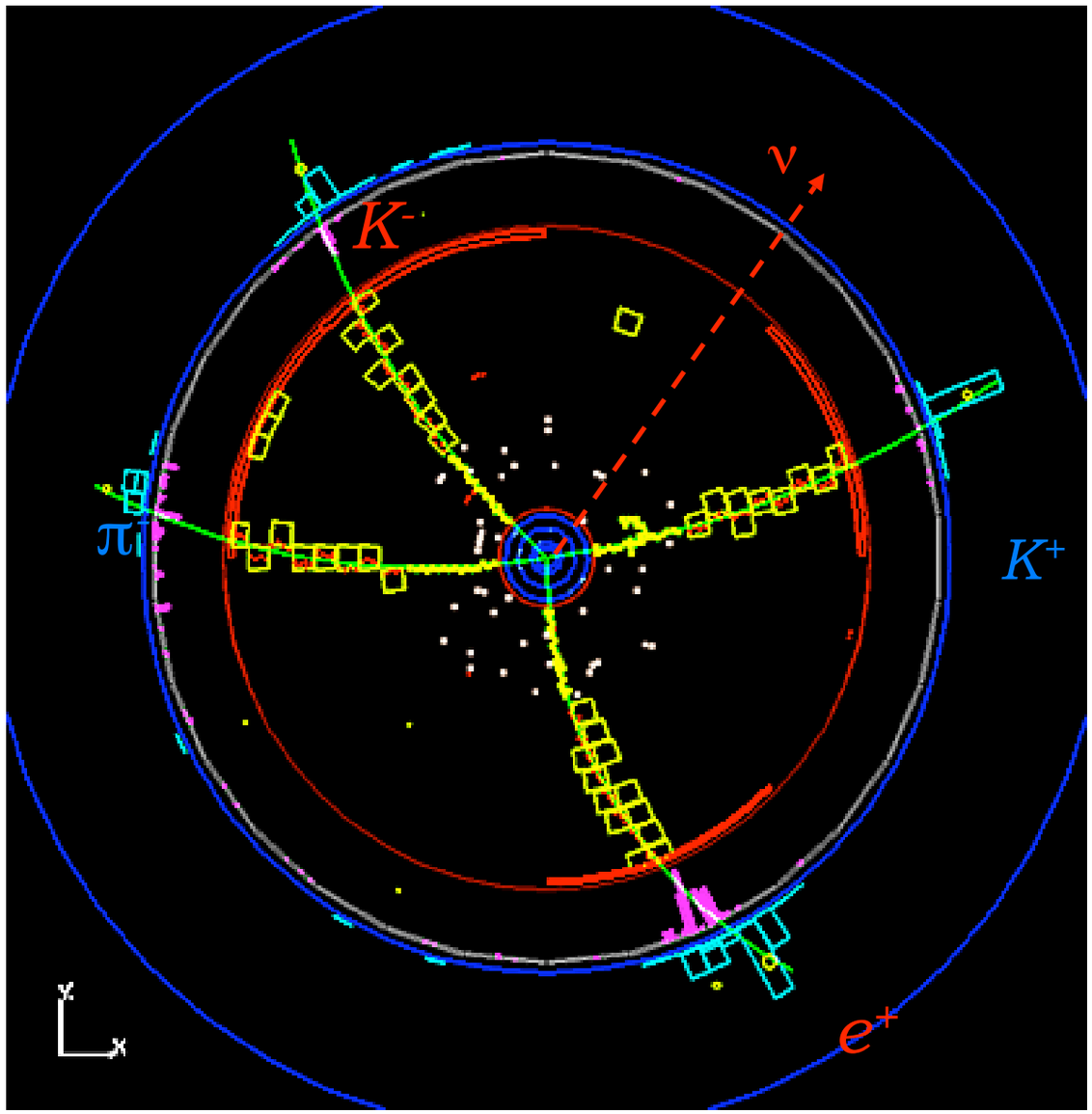


In some cases theoretical uncertainties dominate the errors on the constraints.

The CLEO-c Event Environment

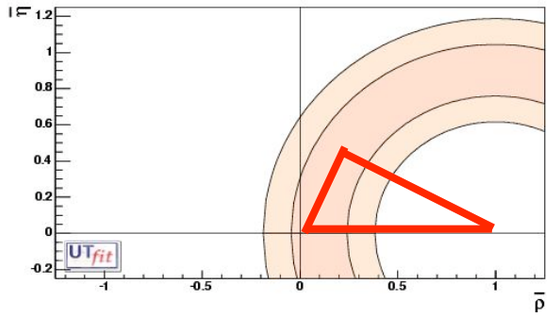
Running at $\psi(3770)$

- Very clean final state: only two D mesons
- Use "tagged" analyses to reduce background and make absolute branching fraction measurements



$\bar{D}^0 \to K^+\pi^-$ $\quad$ $D^0 \to K^-e^+\nu$

Leptonic Decay Constants



- Need f_B (f_{Bs}) from lattice to turn $B_{(s)}$ mixing measurements into constraints on $|V_{td}|$ and $|V_{ts}|$

- Verify lattice calculations of f_D and f_{Ds} by measuring

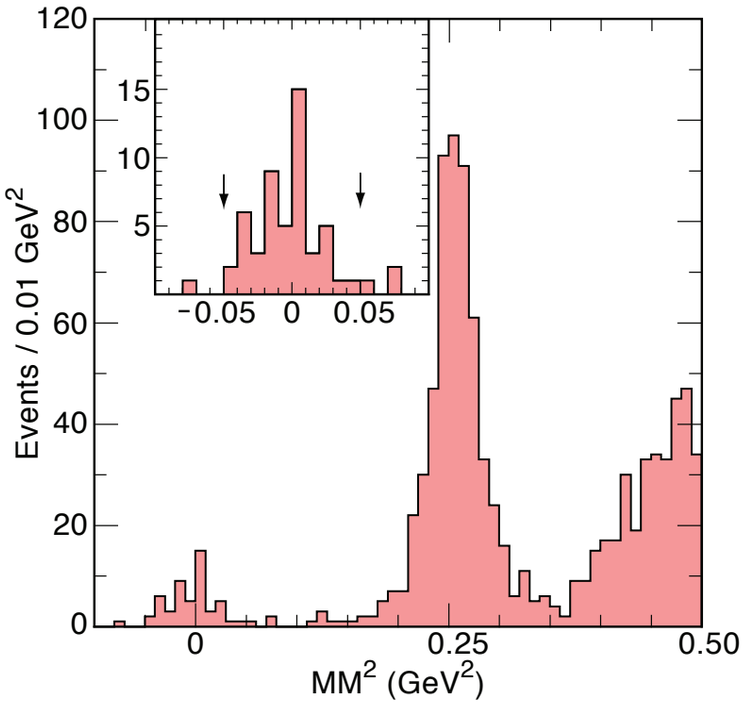
$$D \to \mu\nu \qquad D_S \to \mu\nu$$

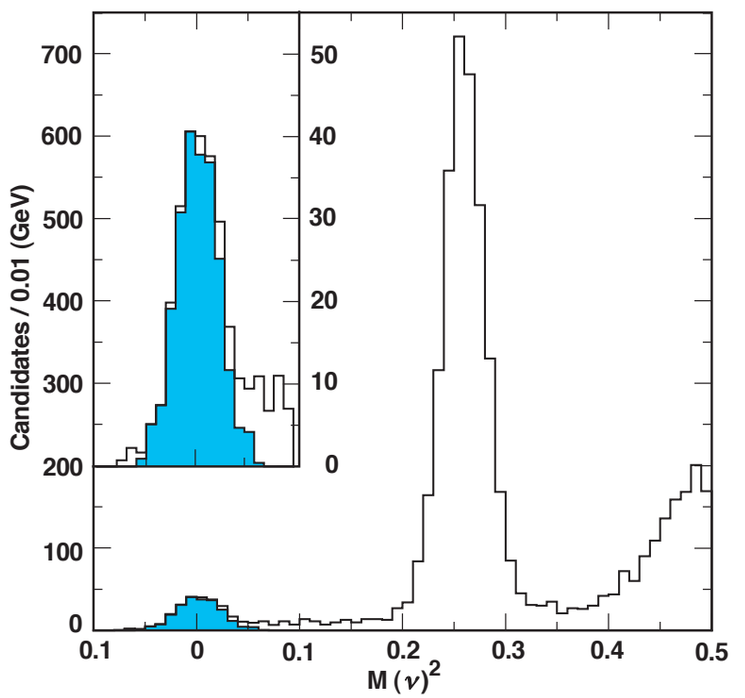
$$\Gamma\left(D^+ \to l^+\nu\right) = \frac{G_F^2}{8\pi} f_{D^+}^2 m_l^2 M_{D^+} \left(1 - \frac{m_l^2}{M_{D^+}^2}\right)^2 |V_{cd}|^2$$

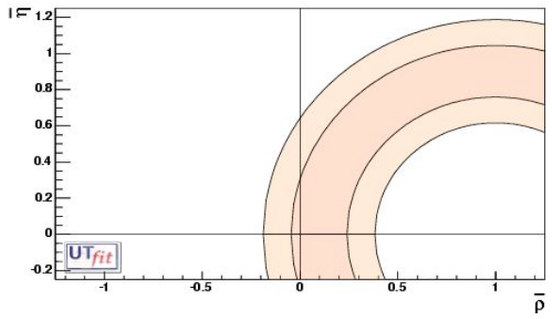
$$\mathcal{B}\left(D^+ \to \mu^+\nu\right) = \left(4.40 \pm 0.66^{+0.09}_{-0.12}\right) \times 10^{-4}$$

$$f_{D^+} = \left(222.6 \pm 16.7^{+2.8}_{-3.4}\right) MeV$$

PRL 95, 251801 (2005)







Leptonic Decay Constants

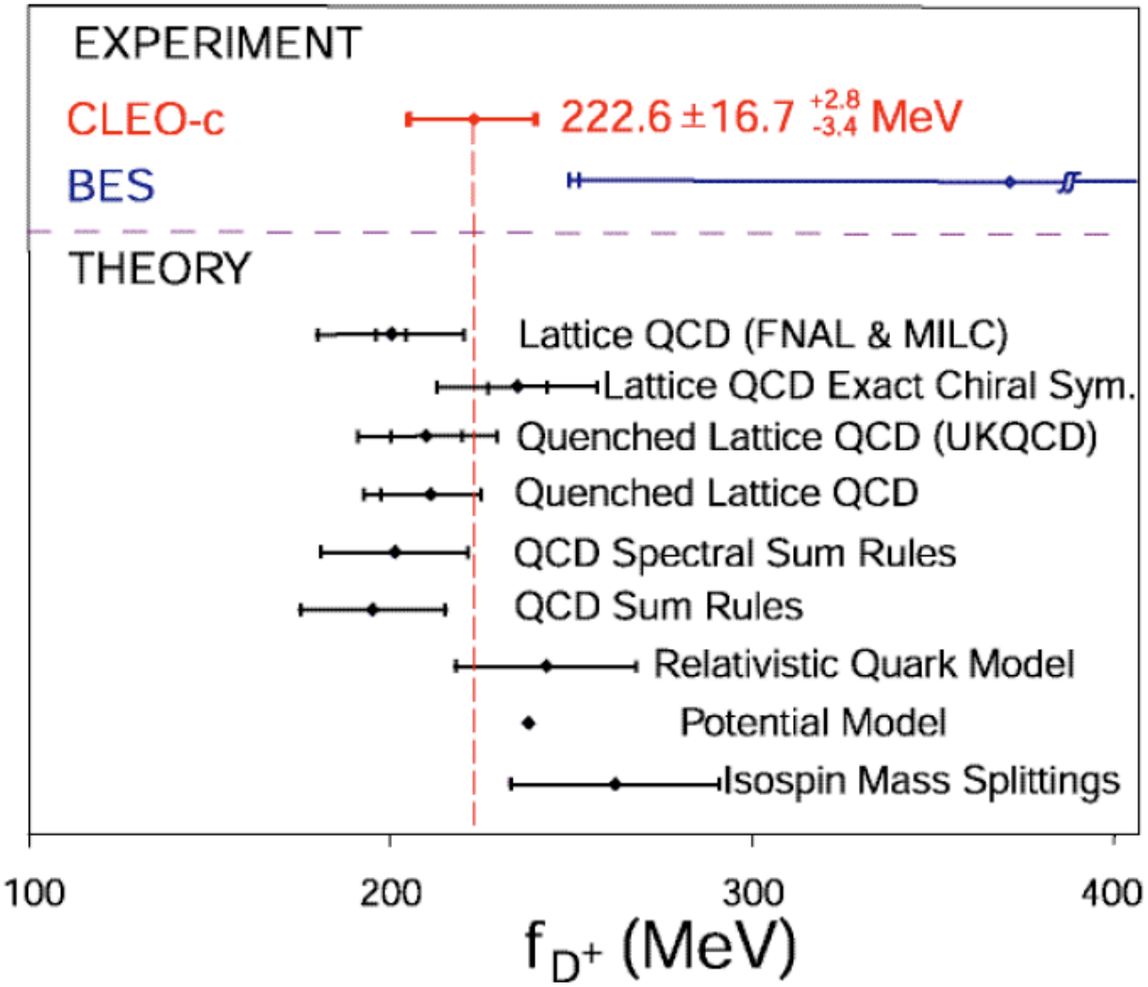
- Agreement with theoretical predictions at 10% level -- attempt to push to 3% level

- D_s results to come soon!

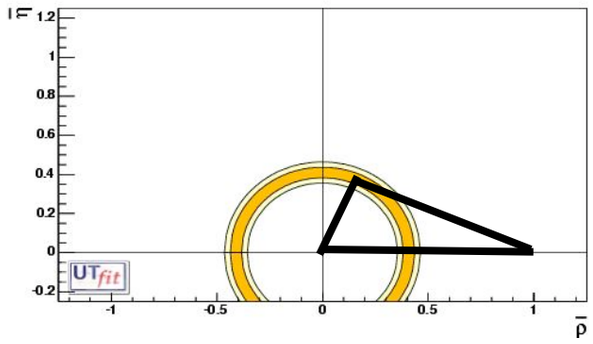
- Also upper limits on both:

$$D \to \tau\nu$$
$$D \to e\nu$$

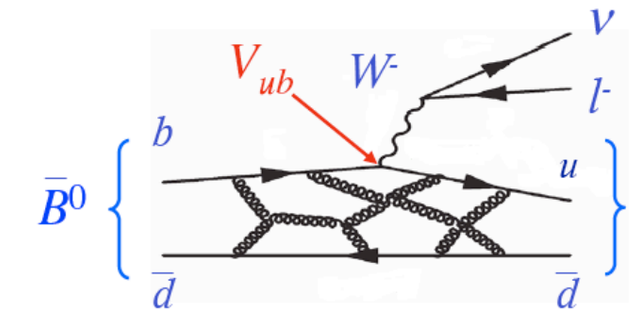
Theory Comparison

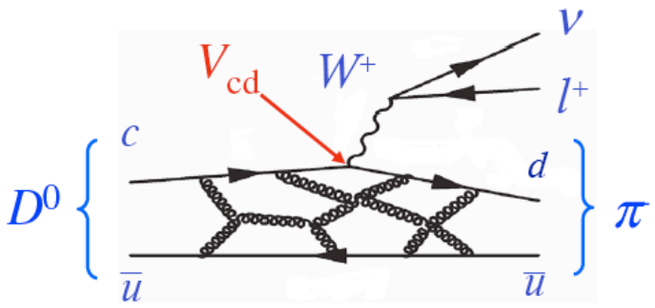


Semi-Leptonic Decays



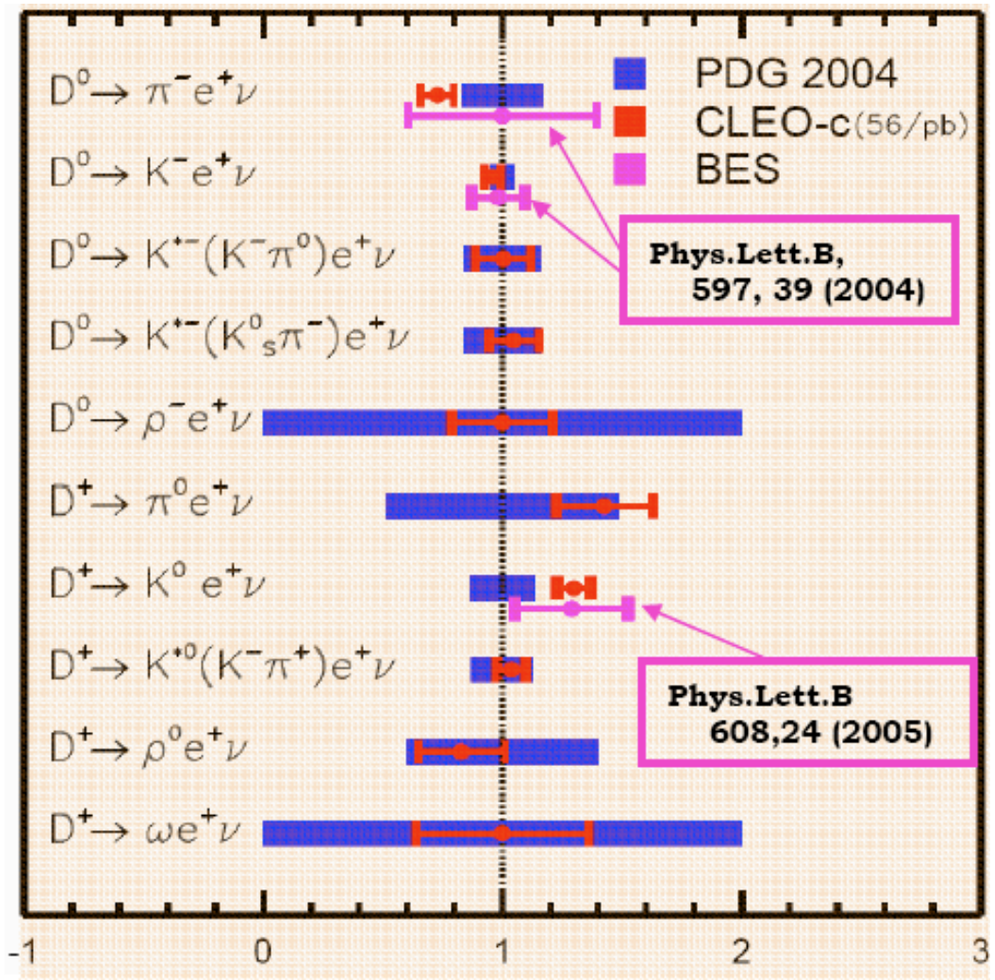
Precision measurements of D SL form factors verify *precision calculations* of B SL form factors.





- Already have most precise measurements of branching fractions
- Precision form factor results to come!

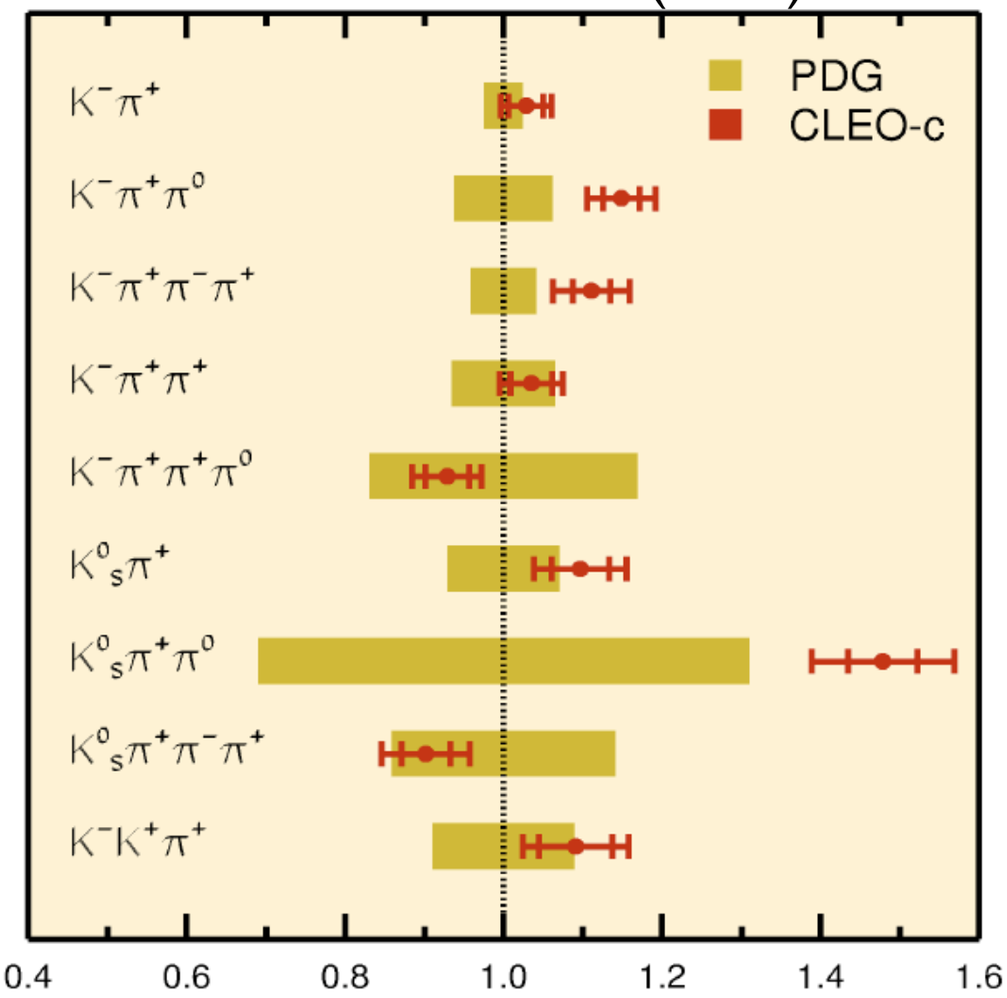
PRL 181801 (2005)
PRL 181802 (2005)



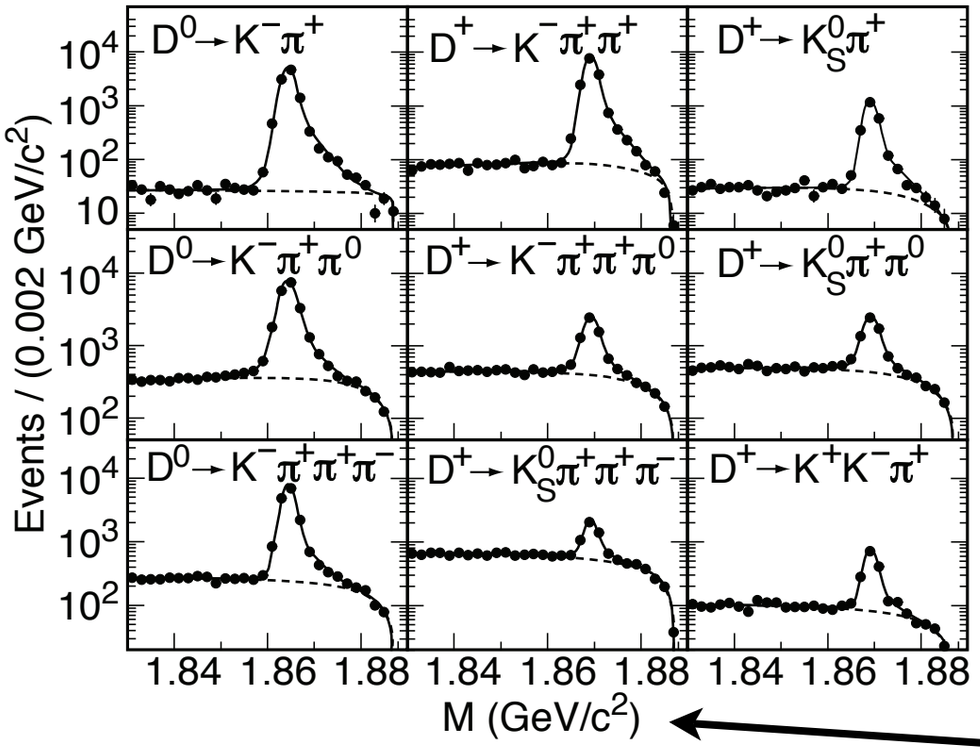
D Hadronic Branching Fractions

- Results derived from simultaneous fit of single tag and double tag events
- Most already better than PDG measurements.
- Important normalization in B decay.
- Systematics limited -- goal 1.5%

PRL 95 121801 (2005)



58 pb^{-1}
update to 281 pb^{-1} soon



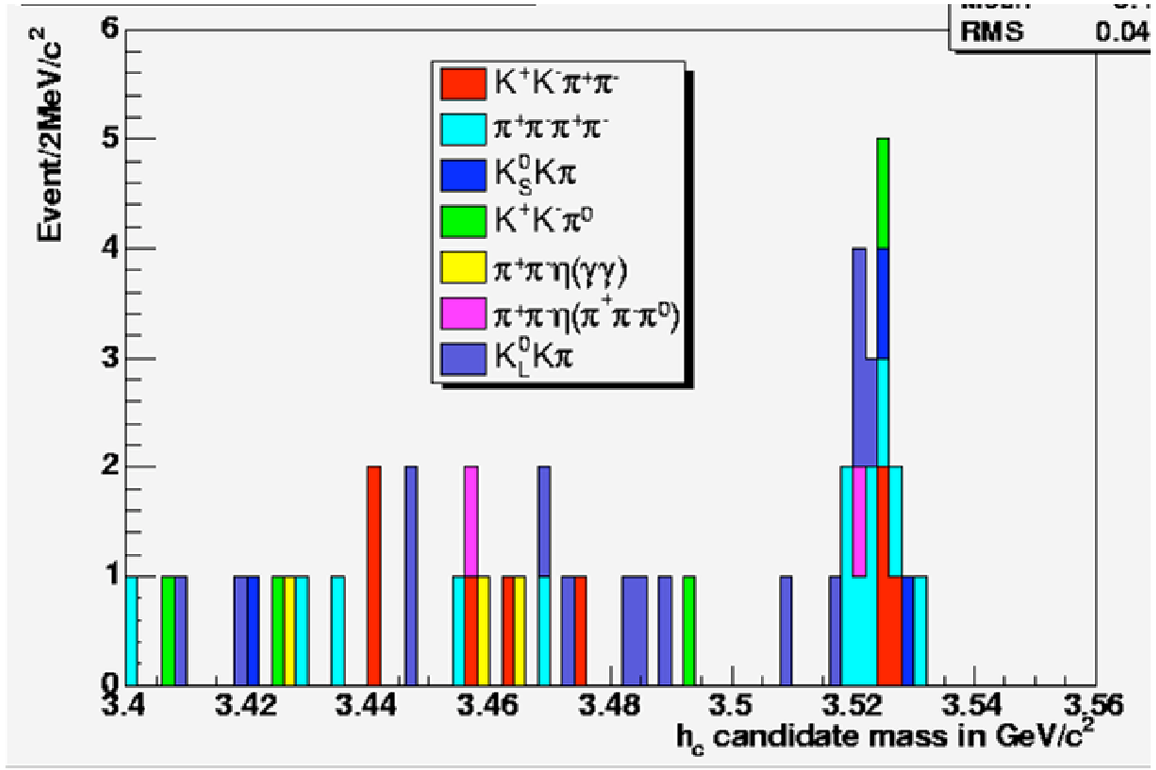
"beam-constrained" mass

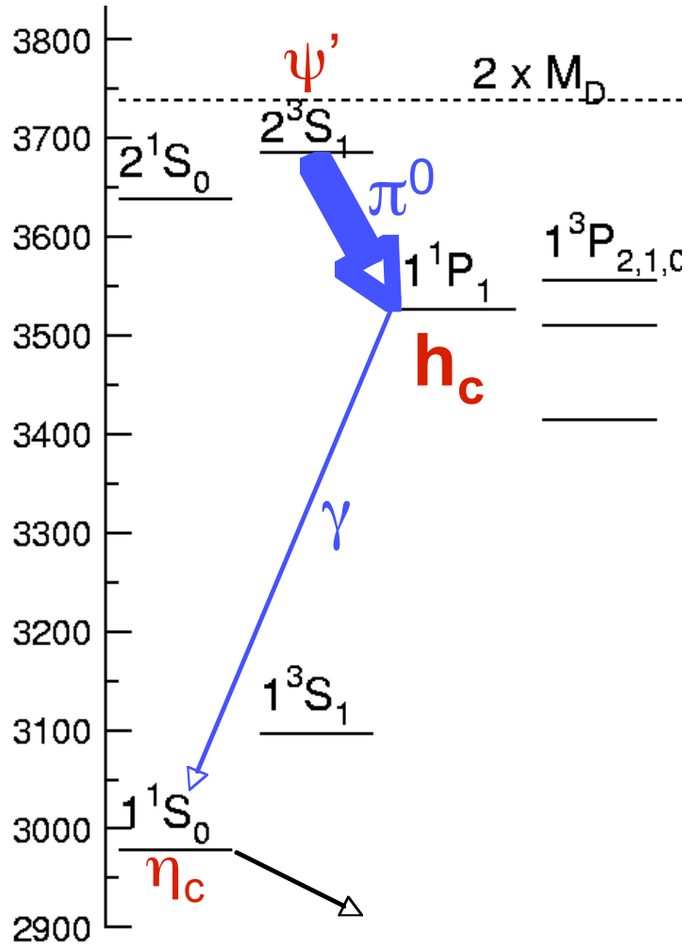
$$M = \sqrt{E_{beam}^2 - p_D^2}$$

CLEO-c Charmonium and Spectroscopy

Charmonium At a Glance

- Over 40 analyses in the past two years with preliminary sample!
- h_c discovery
- precision dilepton widths
- radiative and hadronic branching fractions
- decays to light hadrons

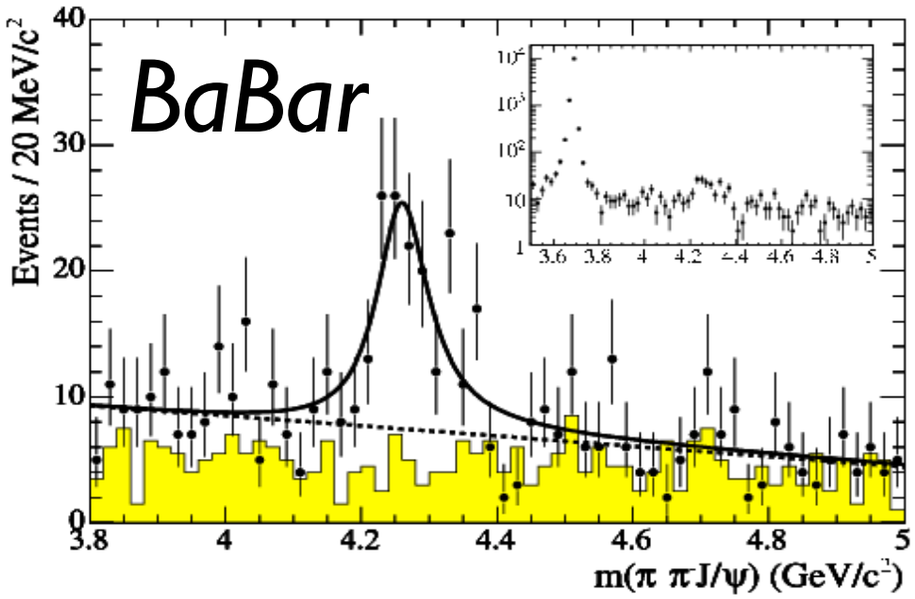


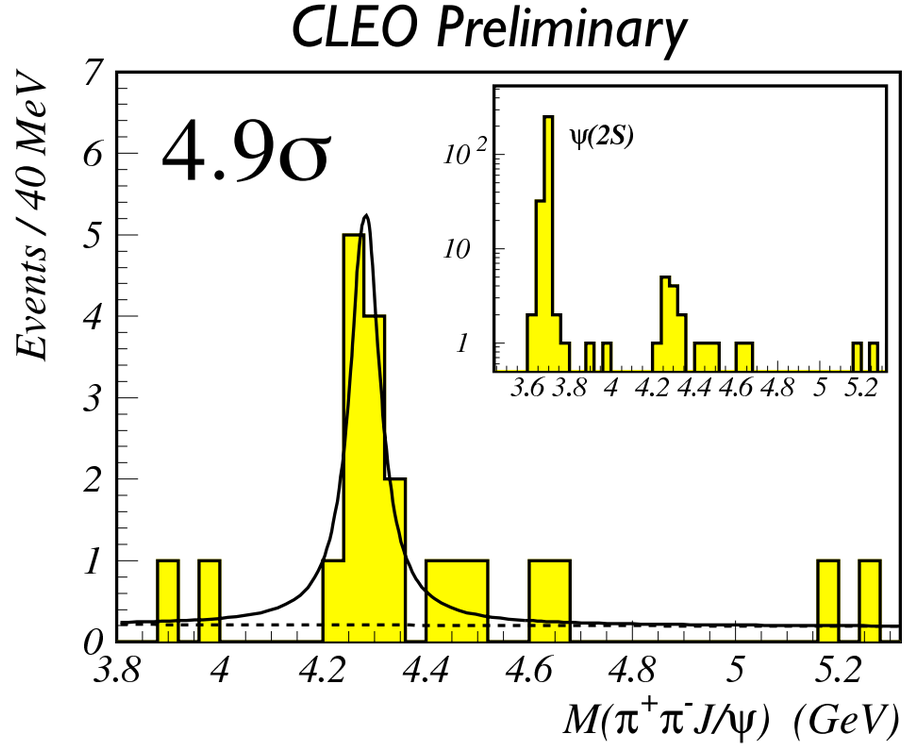


PRL 95, 102003 (2005)
PRD 72, 092004 (2005)

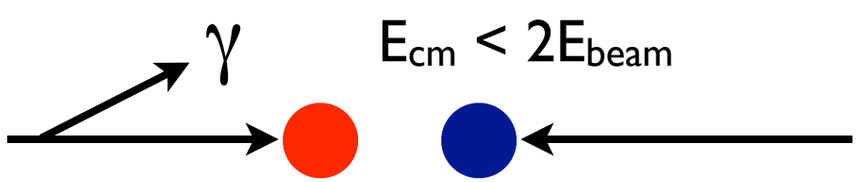
Y(4260) at CLEO

- State Y(4260) claimed by BaBar decaying into: $\pi^+\pi^- J/\psi$
- No predicted charmonium resonance at this mass
- Explanations?
- Two complementary CLEO analyses:
  - direct production at E_{cm} = 4260 MeV
  - ISR production





$$M\left(Y(4260)\right) = 4283^{+17}_{-16} \pm 20 \text{ MeV}$$
$$\Gamma\left(Y(4260)\right) = 70^{+40}_{-25} \pm 20 \text{ MeV}$$



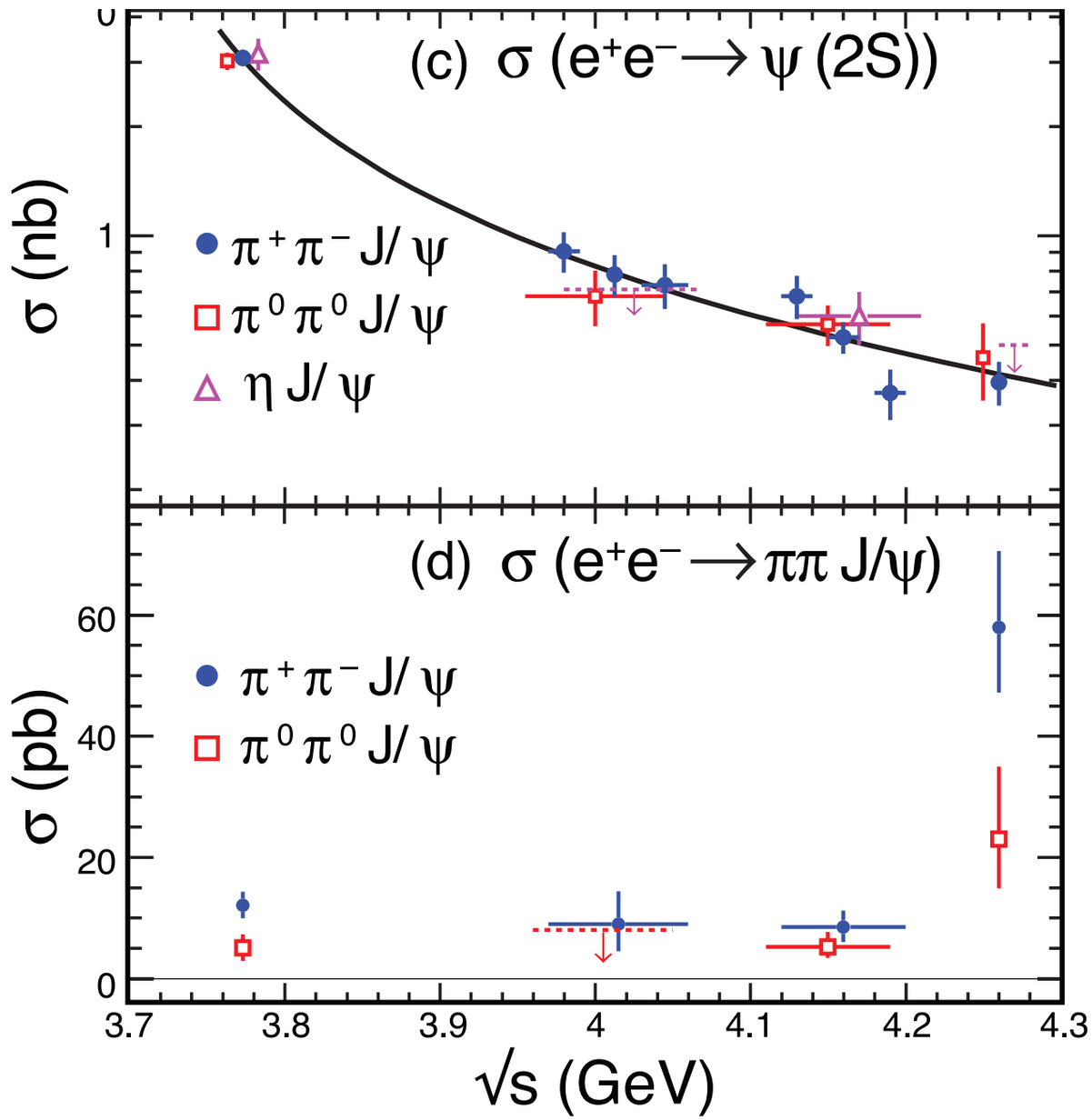
Y(4260) at CLEO-c

- Direct production provides first observation of additional decay modes:

$$\pi^+\pi^- J/\psi \ (11\sigma)$$
$$\pi^0\pi^0 J/\psi \ (5.1\sigma)$$
$$K^+K^- J/\psi \ (3.7\sigma)$$

- Some explanations ruled out -- remaining favorites:
  - charm hybrid
  - (cs)(cs) tetraquark
- Searches for open charm decays underway!

PRL 96 162003 (2006)

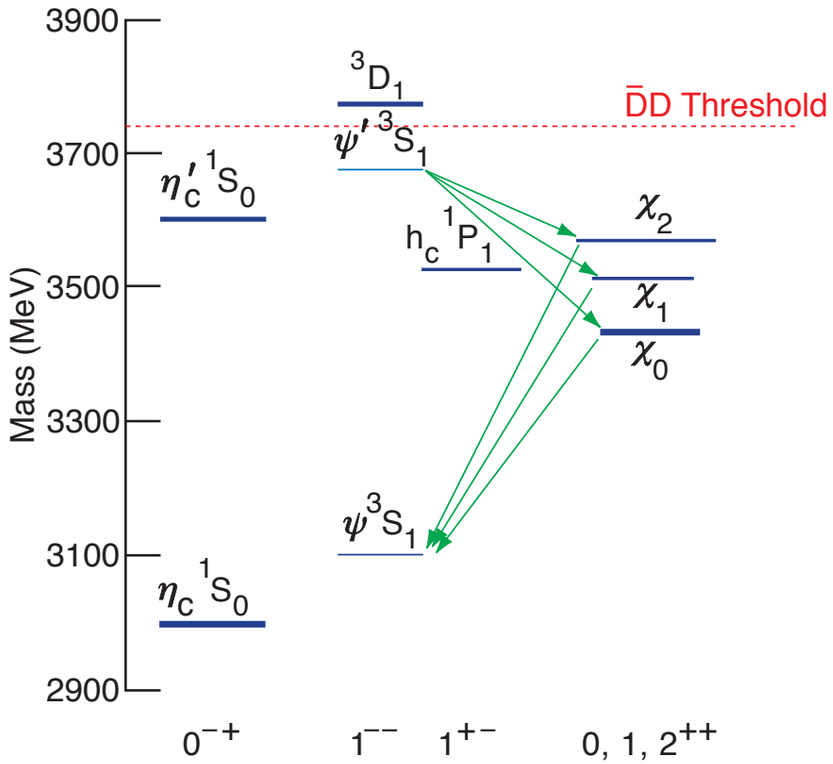


CLEO-c: A χ_c Factory

- Decays of the χ_c states provide an exciting venue for studying light quark spectroscopy

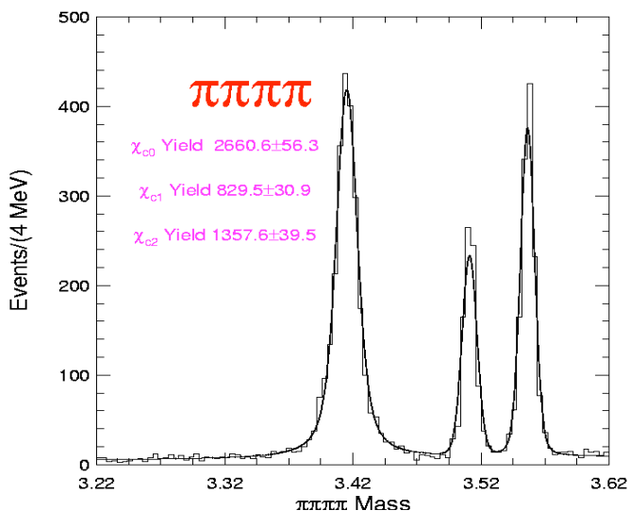
- Systematic study of χ_c branching fractions could provide information on glueball spectrum

- Challenging: probe resonant substructure through Dalitz and Partial Wave Analyses

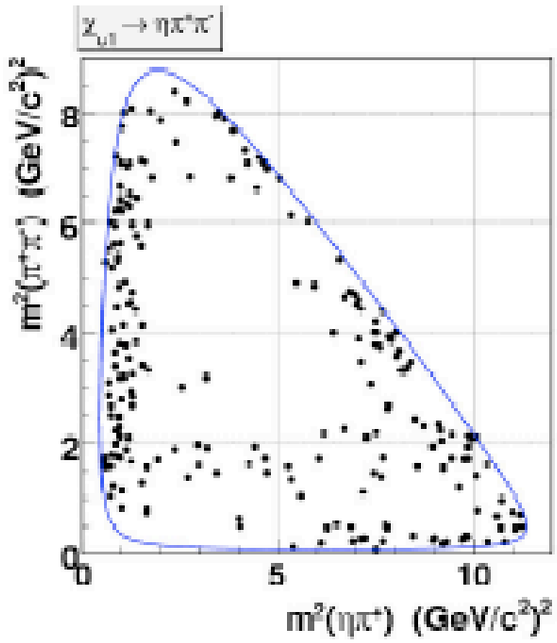


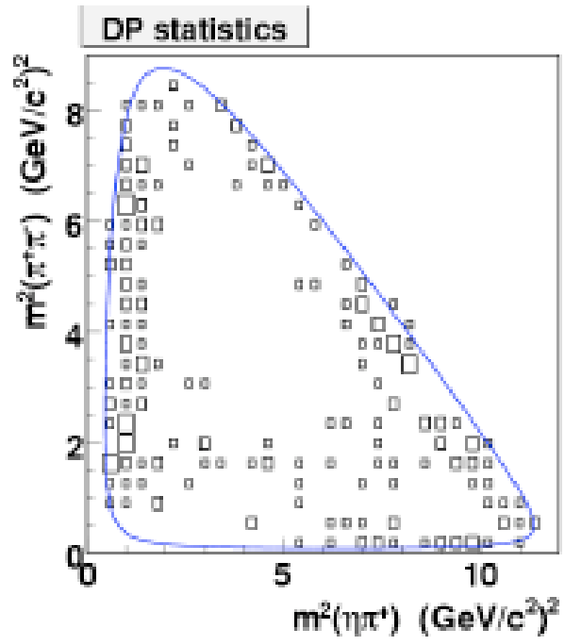
~35 hadronic modes observed already in data (preliminary branching fractions soon)

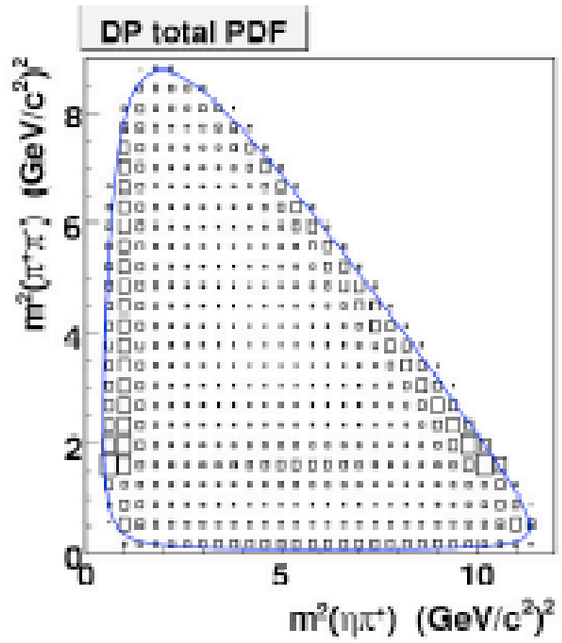
sample 4π decay channel

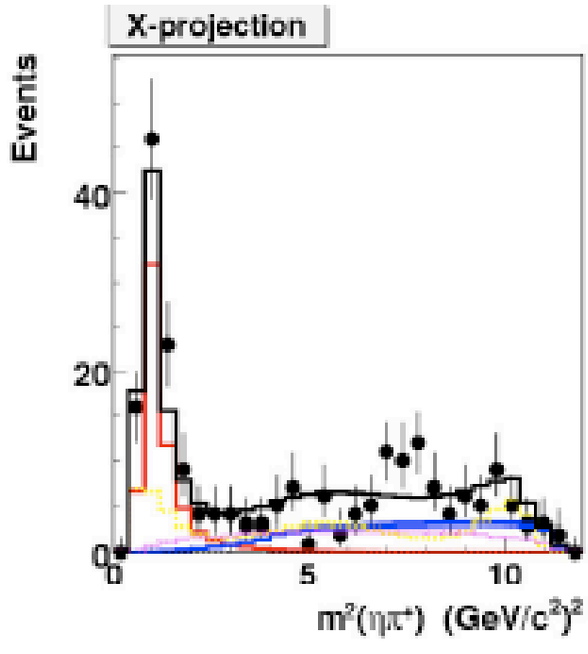


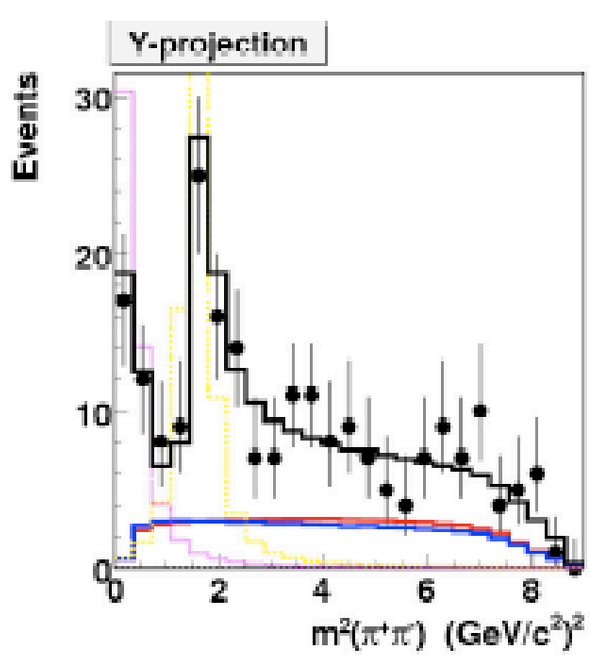
Dalitz Plot Fit: $\chi_{c1} \to \eta\pi^+\pi^-$

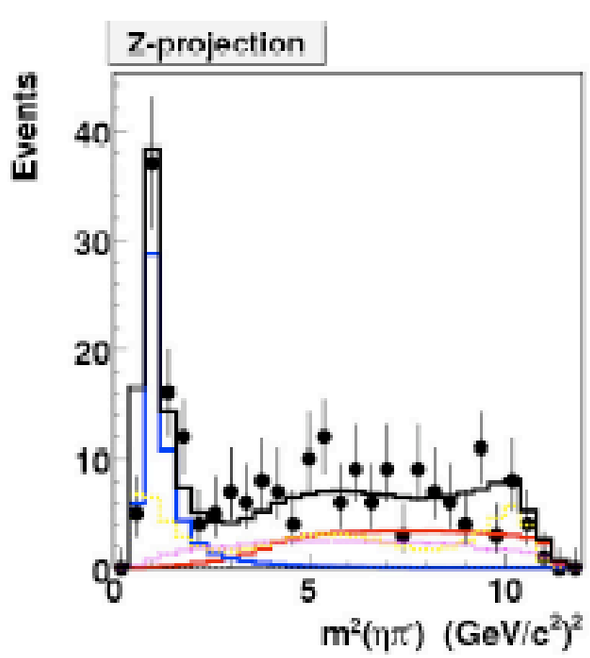












$a_0^+(980)$ $a_0^-(980)$ σ $f_2(1270)$

Dalitz Plot Fit: $\chi_{c1} \to \eta\pi^+\pi^-$

- With current statistics the Dalitz plot can be described by three resonances

- With high statistics probe for new states?

- Expect 10x more stats by fall

- Pursue 3+ body final states with full PWA

Mode	Nominal fit
$a_0(980)^+$	1
	0
$2\times$	$28.1\pm1.8\pm0.7$
$f_2(1270)$	$0.186\pm0.017\pm0.003$
	$-118\pm10\pm4$
	$35.1\pm2.9\pm1.8$
σ-pole	$0.68\pm0.07\pm0.05$
	$-85\pm18\pm15$
	$21.7\pm3.3\pm0.5$
$\sum_i FF_i$, %	113.1
$-2\sum \log L$	-460.1
Pearson/$N_{d.o.f.}$	22.0/24
P(Pearson,$N_{d.o.f.}$)	58.1%

Amplitude
Phase
Fit Fraction

CLEO Preliminary

Summary

- *CLEO-c is active on many fronts!*
- Flavor physics
  - precision tests of LQCD predictions of fD and SL decay form factors
  - precision D/Ds hadronic branching fractions
- Charmonium/Spectroscopy
  - confirmation of Y(4260) and new observed decay modes
  - light quark spectroscopy through analysis of multi-body chi decay

Stay tuned -- many exciting results yet to come!