Quark Confinement and the Hadron Spectrum VI 2004
21 - 25 September 2004
Tanka Village ****

"Heavy and Light": Hadron Spectroscopy and Strong Interaction Dynamics from CLEO III and CLEO-c

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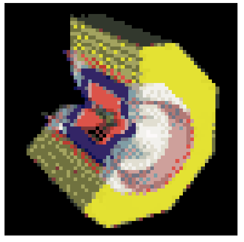
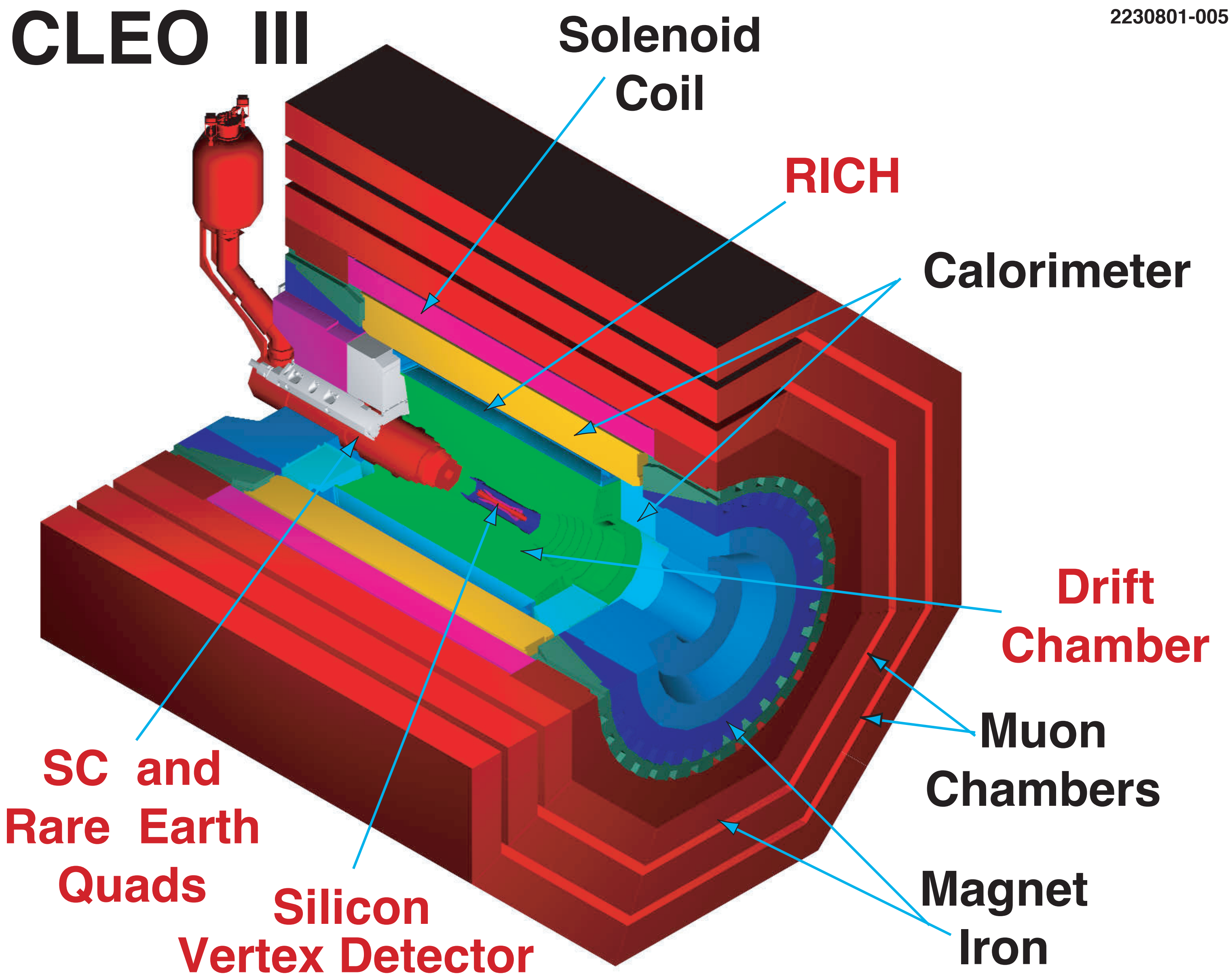
for the CLEO Collaboration

Rensselaer

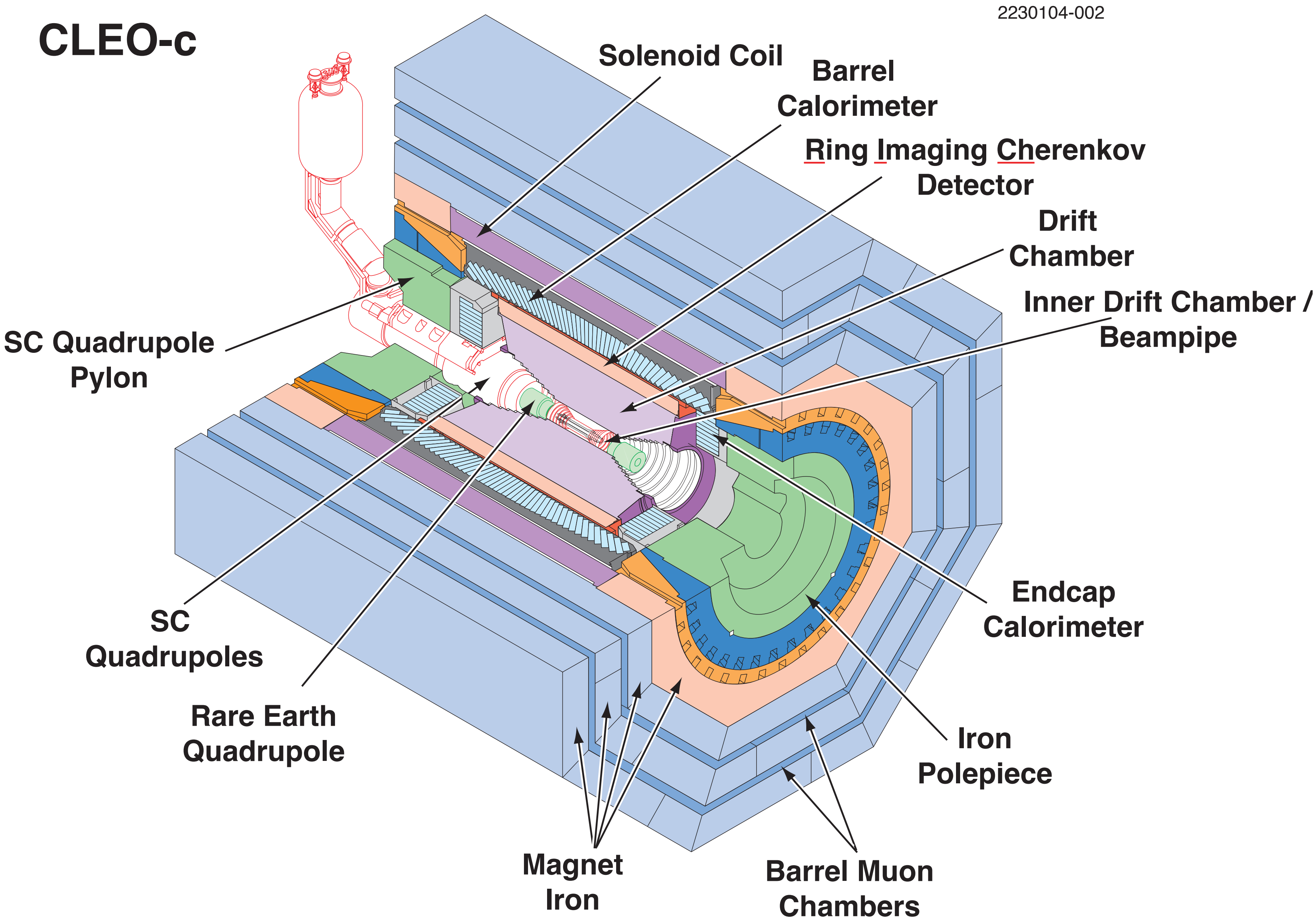


CORNELL UNIVERSITY LEPP
LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS

CLEO III: ... 2002



CLEO-c: 2003...


CLEO-c
2230104-002
Solenoid Coil
Barrel Calorimeter
Ring Imaging Cherenkov Detector
Drift Chamber
Inner Drift Chamber / Beampipe
SC Quadrupole Pylon
SC Quadrupoles
Rare Earth Quadrupole
Magnet Iron
Barrel Muon Chambers
Iron Polepiece
Endcap Calorimeter

Topics Covered in this Talk

New (and Developing) Results

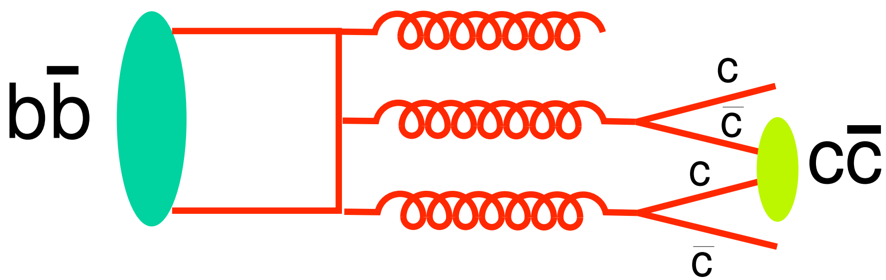
- Color Singlet vs Octet in $\Upsilon(1S)\rightarrow J/\psi+X$
- Branching Ratios for $\Upsilon(nS)\rightarrow\mu^+\mu^-$
- Decays of the $\psi(2S)$
- Strong Physics from Weak Decays of D^+,D^0
- Measuring the Scalar Meson Mass Matrix

There is a lot that I'm leaving out!!

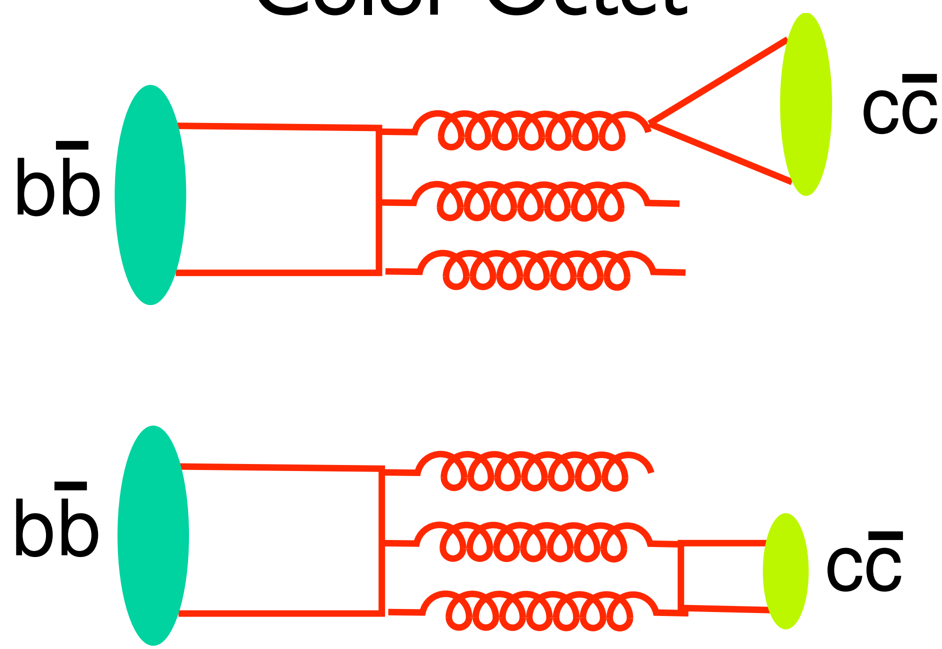
Color Singlet vs Octet in $\Upsilon(1S) \rightarrow J/\psi + X$

hep-ex/0407030 *(Accepted for Phys.Rev.D)*

Color Singlet



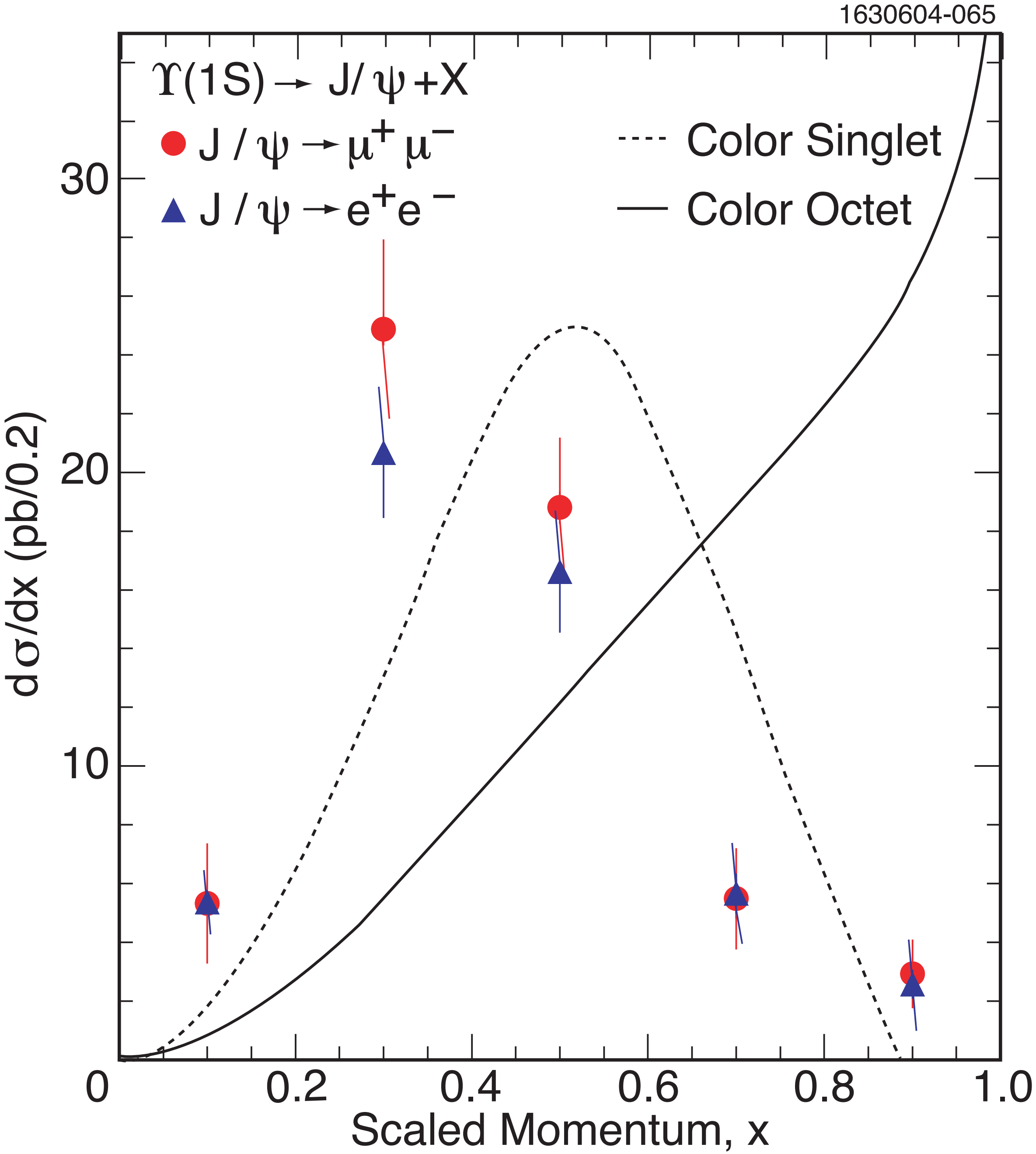
Color Octet



Color singlet mechanism predicts a softer J/ψ momentum spectrum because of additional charmed particles

Note: J/ψ Production mechanism important for RHIC physics (See M. Leitch talk yesterday, Session D.)

Result



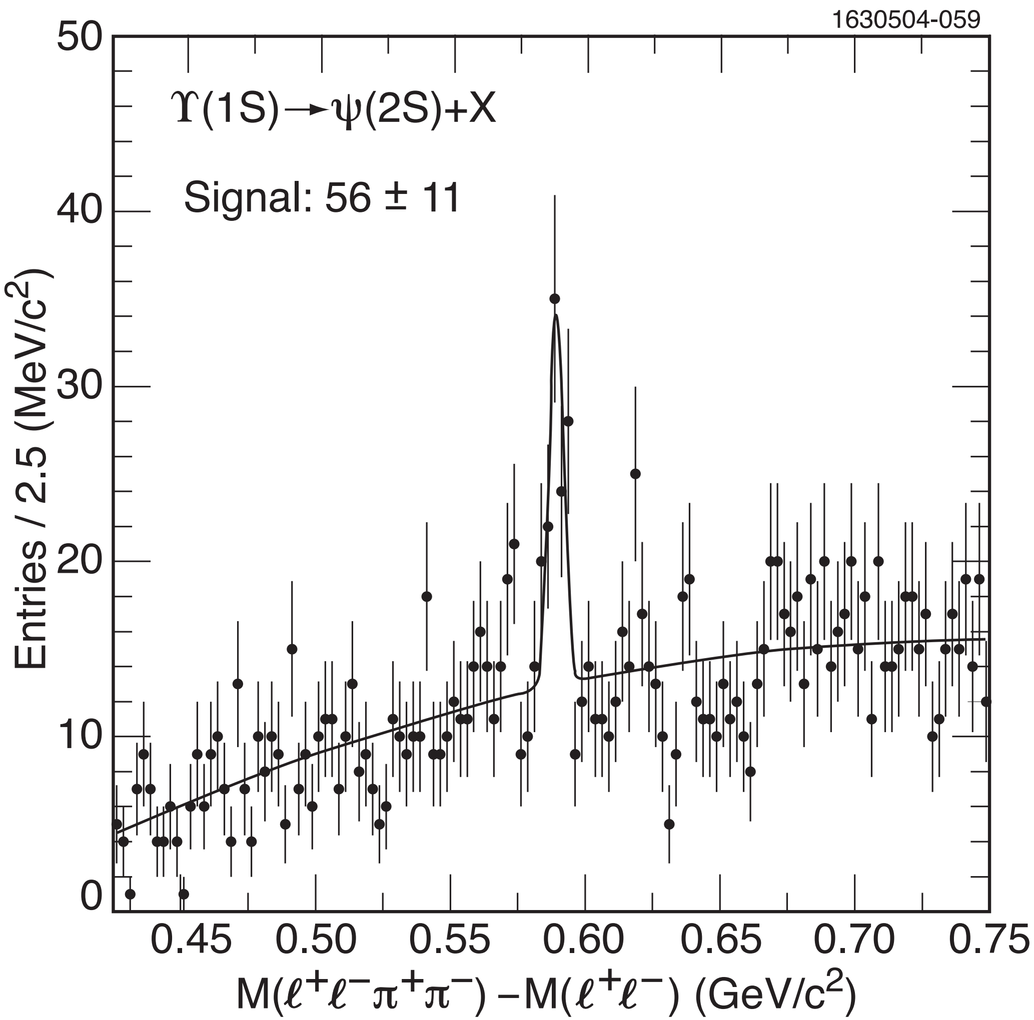
Mechanism is still not understood!

Find branching ratio $(6.4 \pm 0.4 \pm 0.6) \times 10^{-4}$ consistent with either color singlet or octet

CLEO plans to search for open charm in these decays.

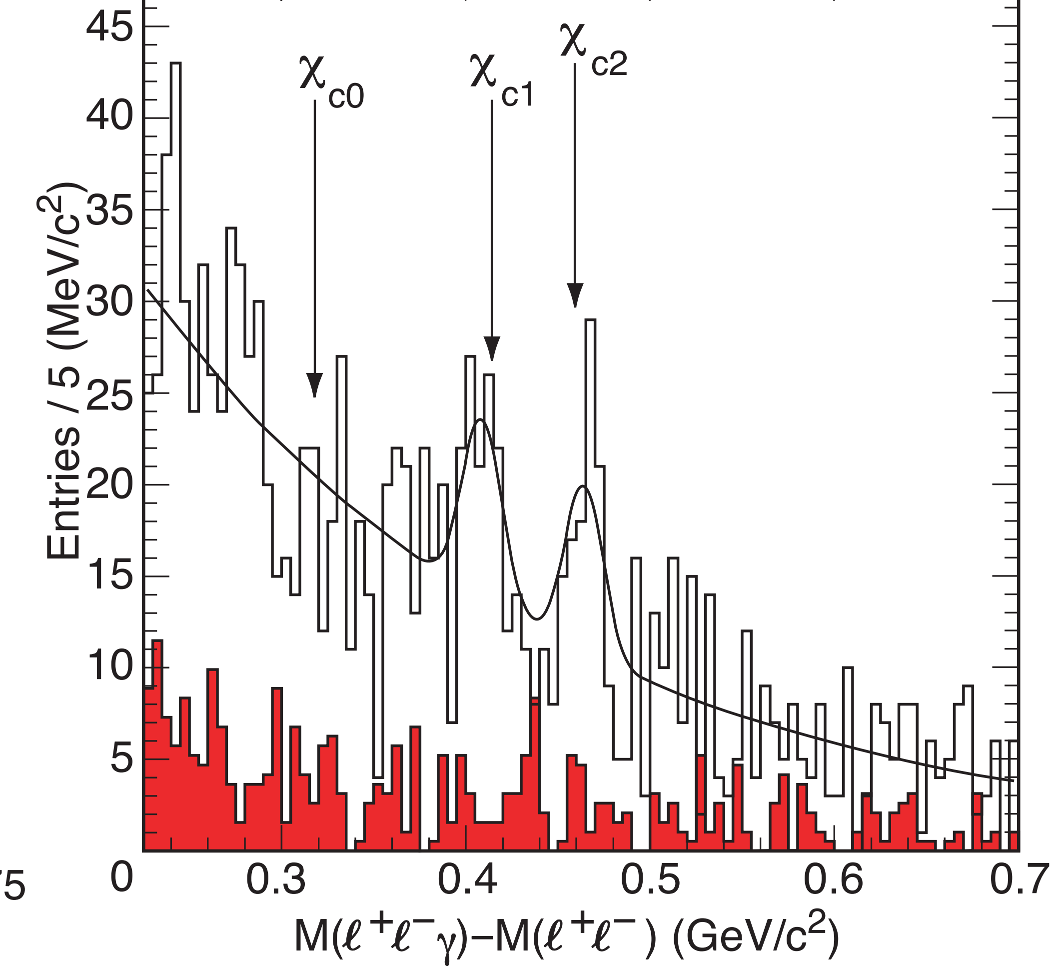
Results: Other Charmonium States

$\psi(2S)$



$\mathcal{B}/\mathcal{B}_{J/\psi}$=0.41±0.11±0.08

χ_{cj}



$\mathcal{B}(j=1)/\mathcal{B}_{J/\psi}$=0.35±0.08±0.06

$\mathcal{B}(j=2)/\mathcal{B}_{J/\psi}$=0.52±0.12±0.09

Branching Ratios for $\Upsilon(nS)\to\mu^+\mu^-$

hep-ex/0409027 *(Submitted to Phys.Rev.Lett.)*

The total widths Γ_{tot} of the narrow upsilon resonances are *too small* to measure directly.

We instead use two separate measurements (and lepton universality) to extract $\Gamma_{tot}=\Gamma_{ee}/B_{\mu\mu}$:

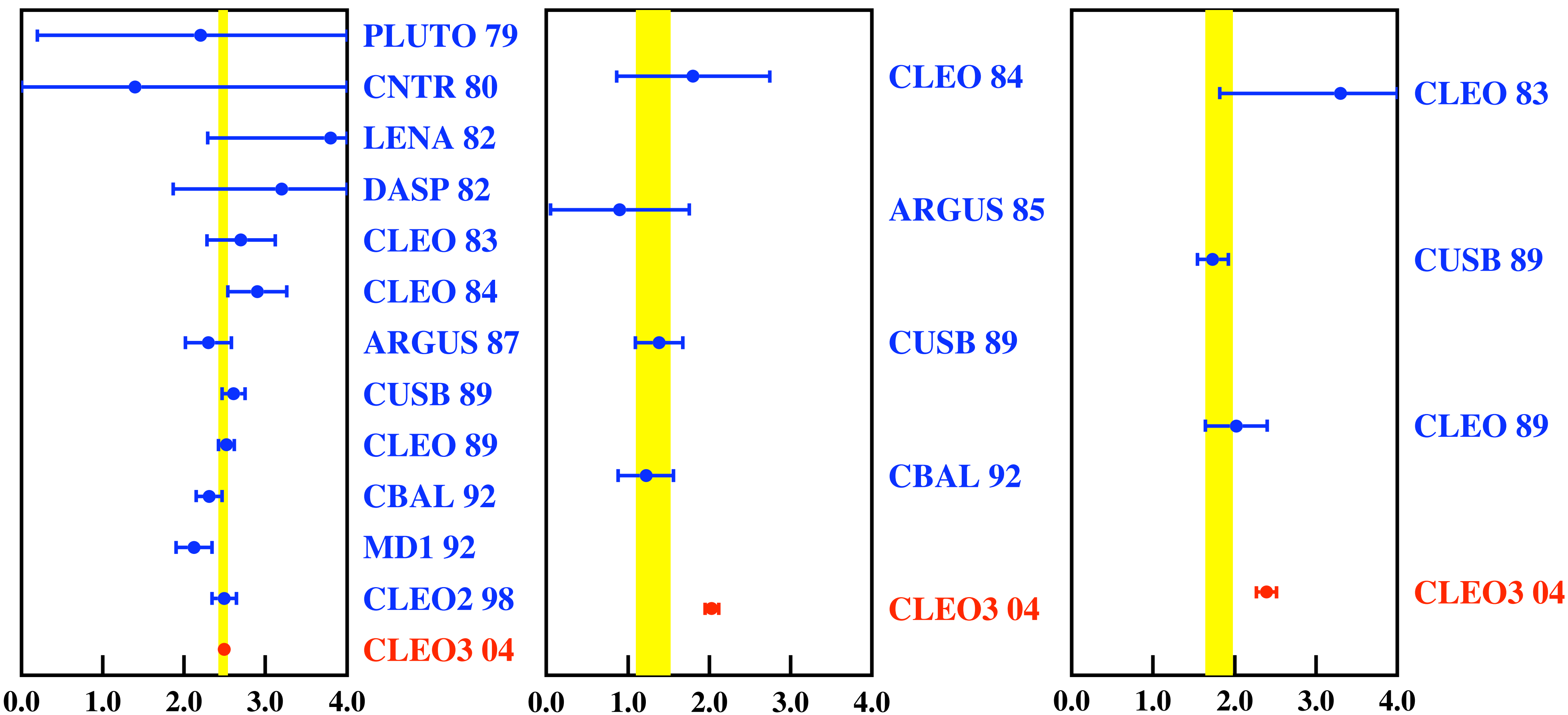
- Branching ratios $B_{\mu\mu}$ from $\Upsilon(nS)\to\mu^+\mu^-$
  New results presented here

- Γ_{ee} from cross section for $e^+e^-\to\Upsilon(nS)\to$hadrons
  Analysis in progress

Our goal is to match the precision of LQCD predictions!

Results

Branching ratios (%):



$\Upsilon(1S)$ $\Upsilon(2S)$ $\Upsilon(3S)$

Total widths (keV):

Errors dominated by $\sigma(e^+e^-)$

52.8 ± 1.8 29.0 ± 1.6 20.3 ± 2.1

Decays of the $\psi(2S)$

Various Measurements Just Completed or In Progress

- Inclusive Photon Spectrum

  hep-ex/0408133 *(Submitted to Phys.Rev.Lett.)*

* $\psi(2S) \rightarrow$ Vector + Pseudoscalar

  hep-ex/0407028 *(Submitted to Phys.Rev.Lett.)*

- Multibody Decays

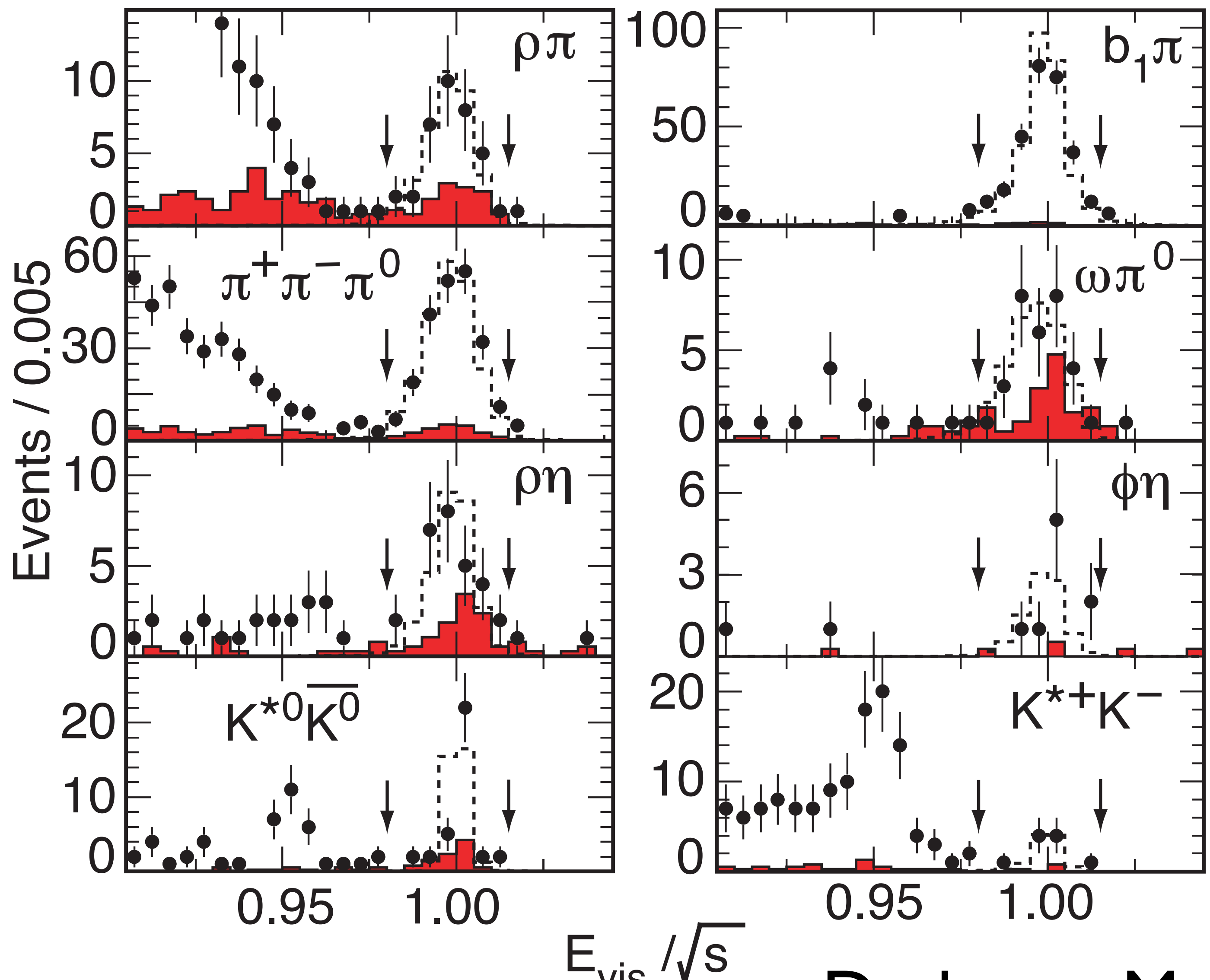
  hep-ex/0408084 *(Preliminary)*

- Search for the h_c

  Several analyses (inclusive and exclusive) in progress

Results: ψ(2S)→ Vector + Pseudoscalar

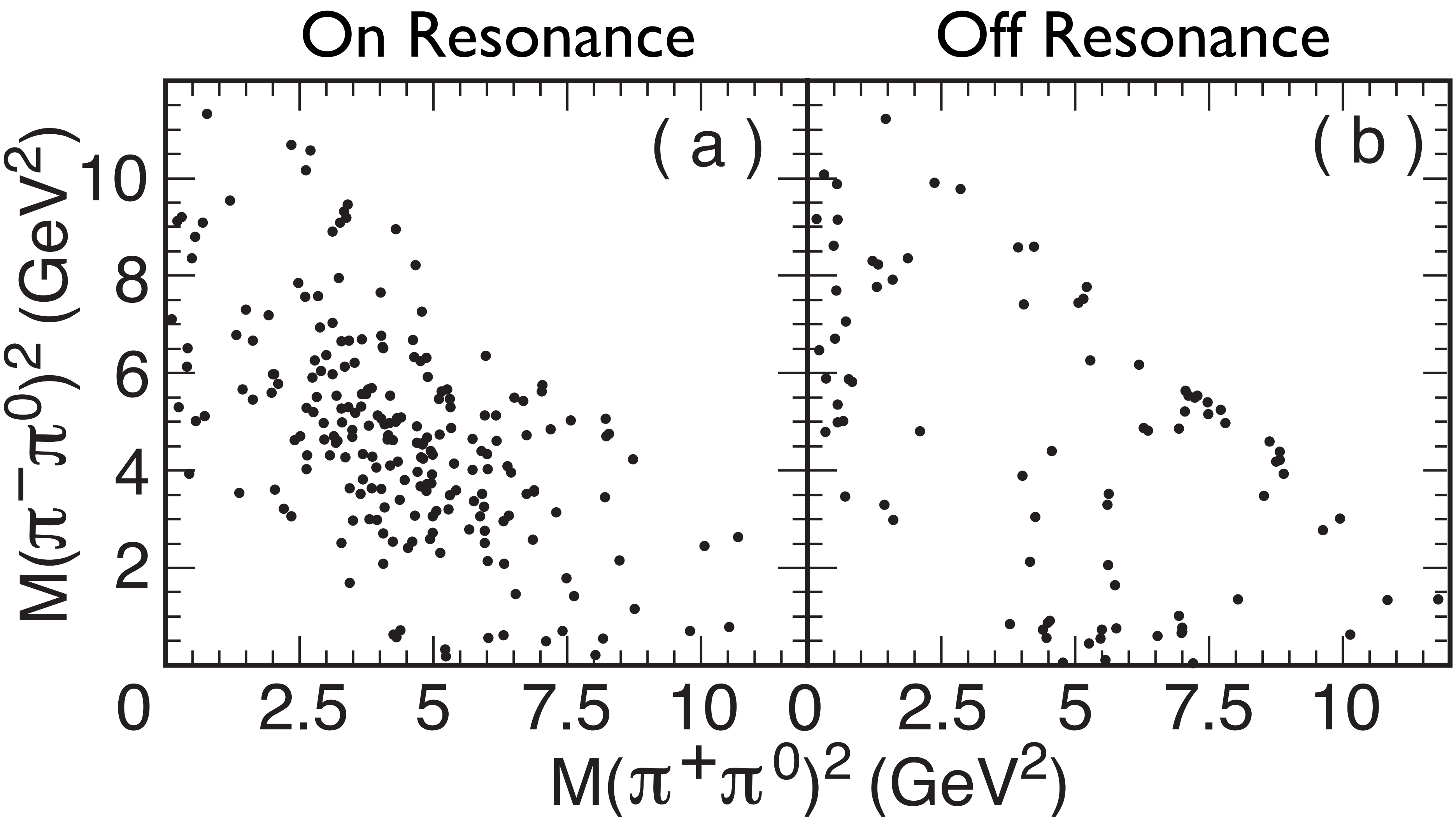
Data Taken **On** and **Off** Resonance



Dashes = Monte Carlo

Results: $\psi(2S) \rightarrow$ Vector + Pseudoscalar

Focus on $\pi^+\pi^-\pi^0$ including $\rho\pi$



Note: Data taken off resonance is important *and* is a measurement in its own right!

Strong Physics from Weak Decays of D^0,D^+

Three Pieces of Physics:

1) Three body decays of D mesons

Evidence (or not) for low mass scalar mesons

2) Form Factors in $D^0 \rightarrow \{K^-, \pi^-\} e^+ \nu_e$

CLEO III: hep-ex/0407035 *(Submitted to Phys.Rev.Lett.)*
CLEO-c: hep-ex/0408077 *(Preliminary)*

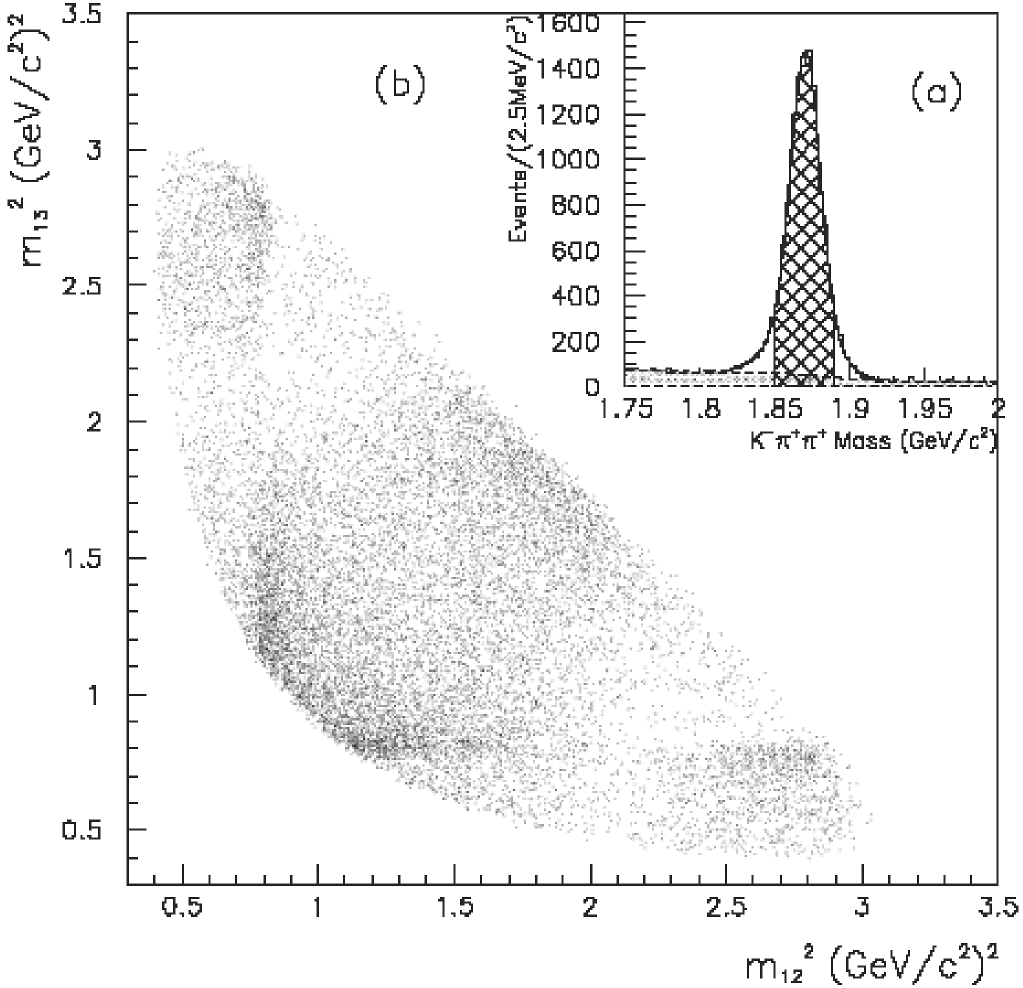
3) D^+ Decay Constant in $D^+ \rightarrow \mu^+ \nu_\mu$

CLEO-c: hep-ex/0408071 *(Preliminary)*

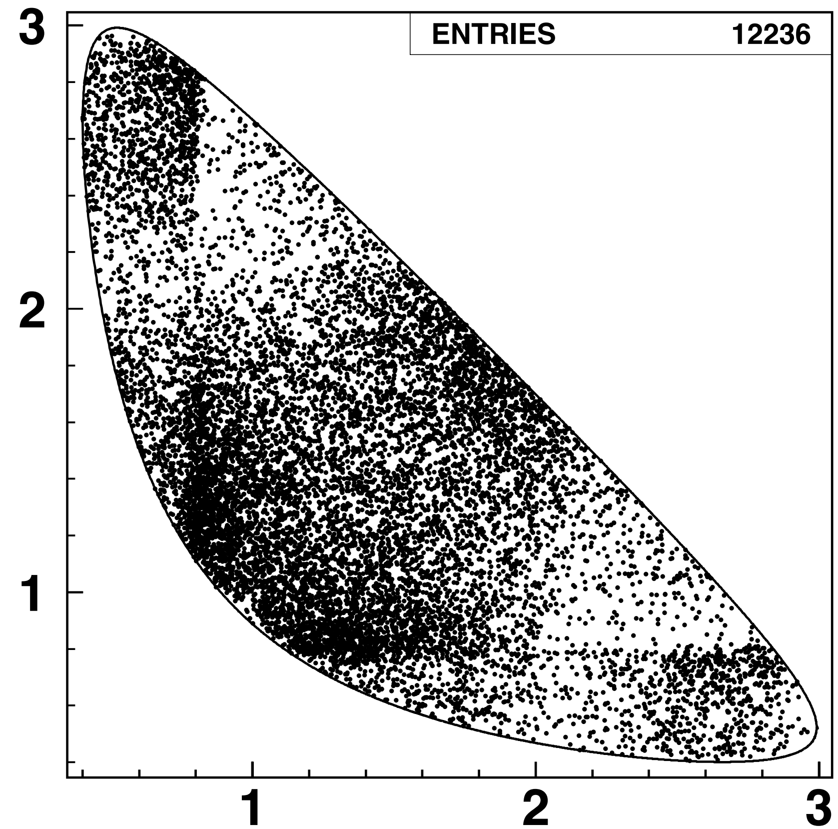
I) Three body decays of D mesons

Example: $\kappa \to K^- \pi^+$ *in* $D^+ \to K^- \pi^+ \pi^+$ *??*

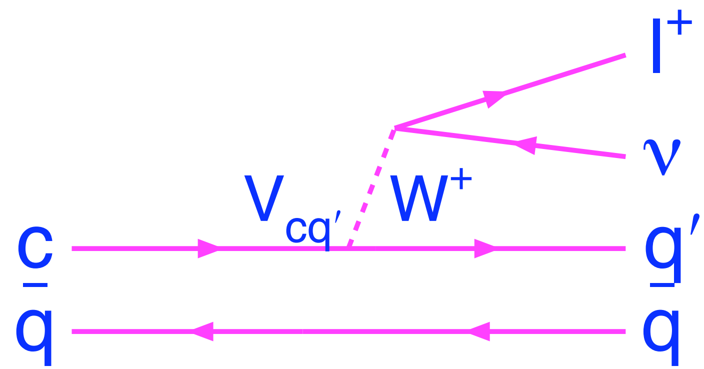
Fermilab E791



CLEO-c



2) Form Factors in $D^0 \to \{K^-, \pi^-\} e^+ \nu_e$



Various techniques (including Lattice QCD) used to calculate the form factor as a function of q^2.

CLEO-III: Use “continuum” inclusive D^0 production

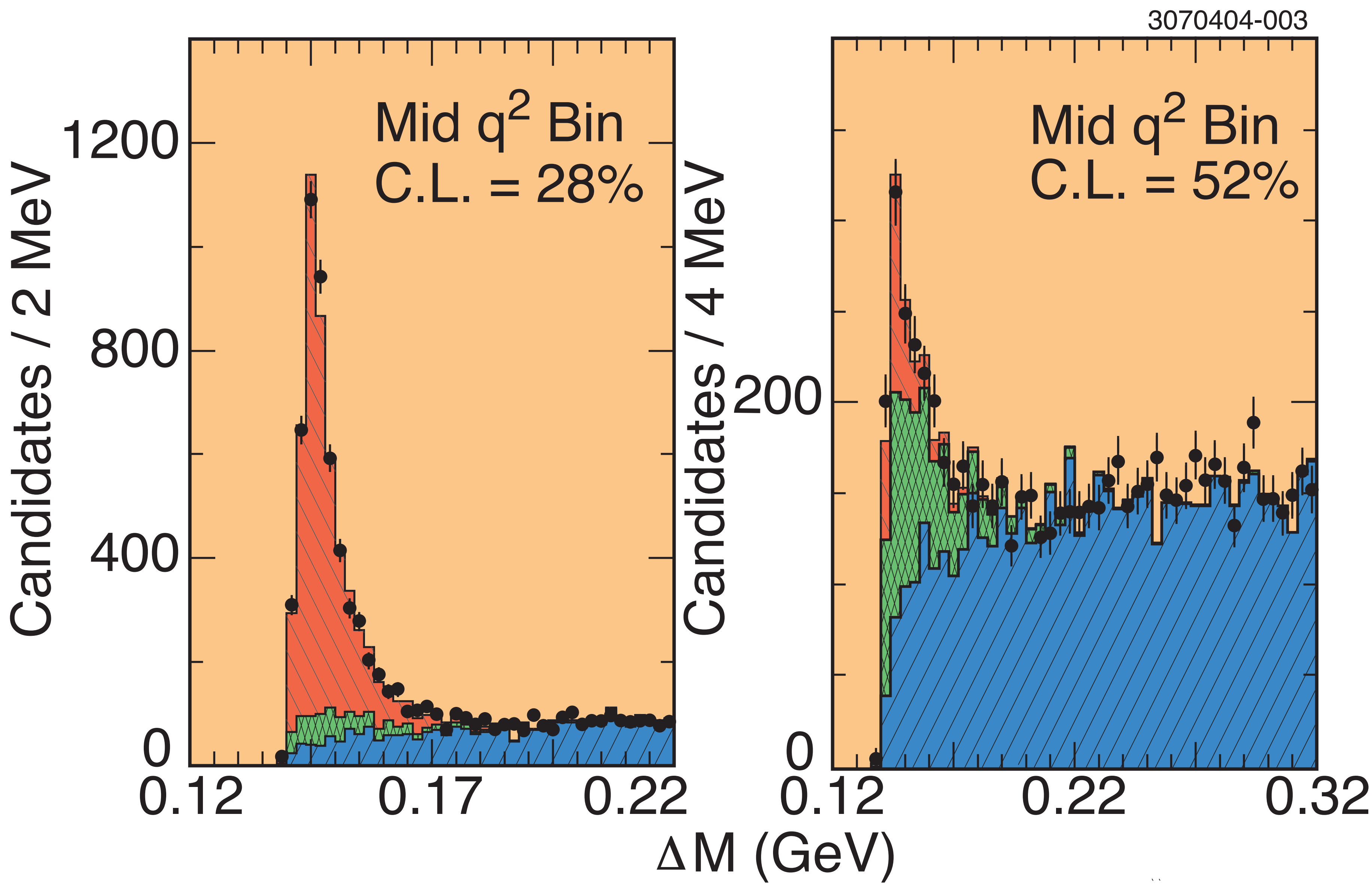
CLEO-c: Use “tagged” exclusive D^0 production

Note: $V_{cs} \gg V_{cd}$ so $\Gamma(D^0 \to K^- e^+ \nu_e) \gg \Gamma(D^0 \to \pi^- e^+ \nu_e)$

➥ *The π’s have a potentially large background from K’s!*

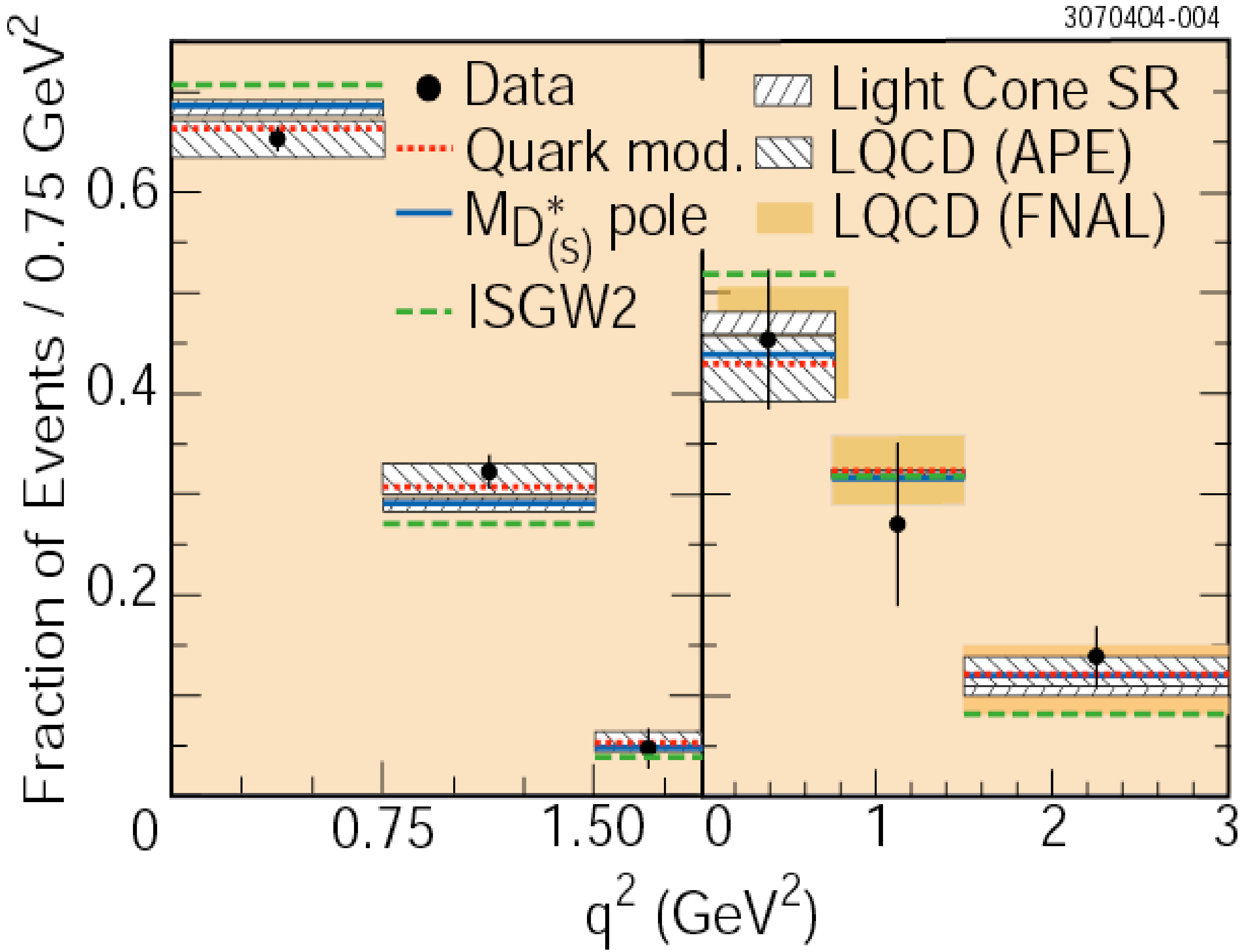
CLEO III $D^0 \to \{K^-, \pi^-\} e^+ \nu_e$

Difficult Analysis

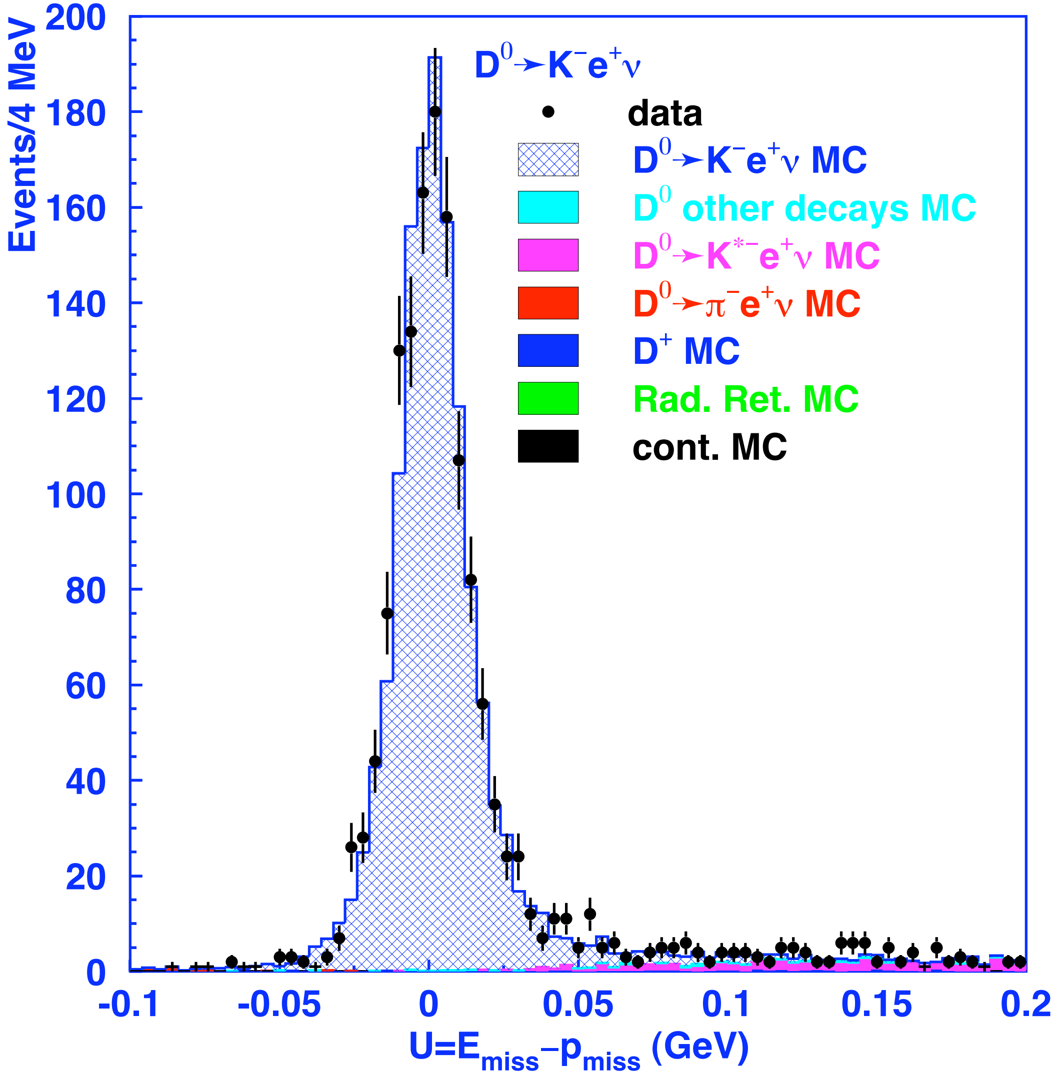


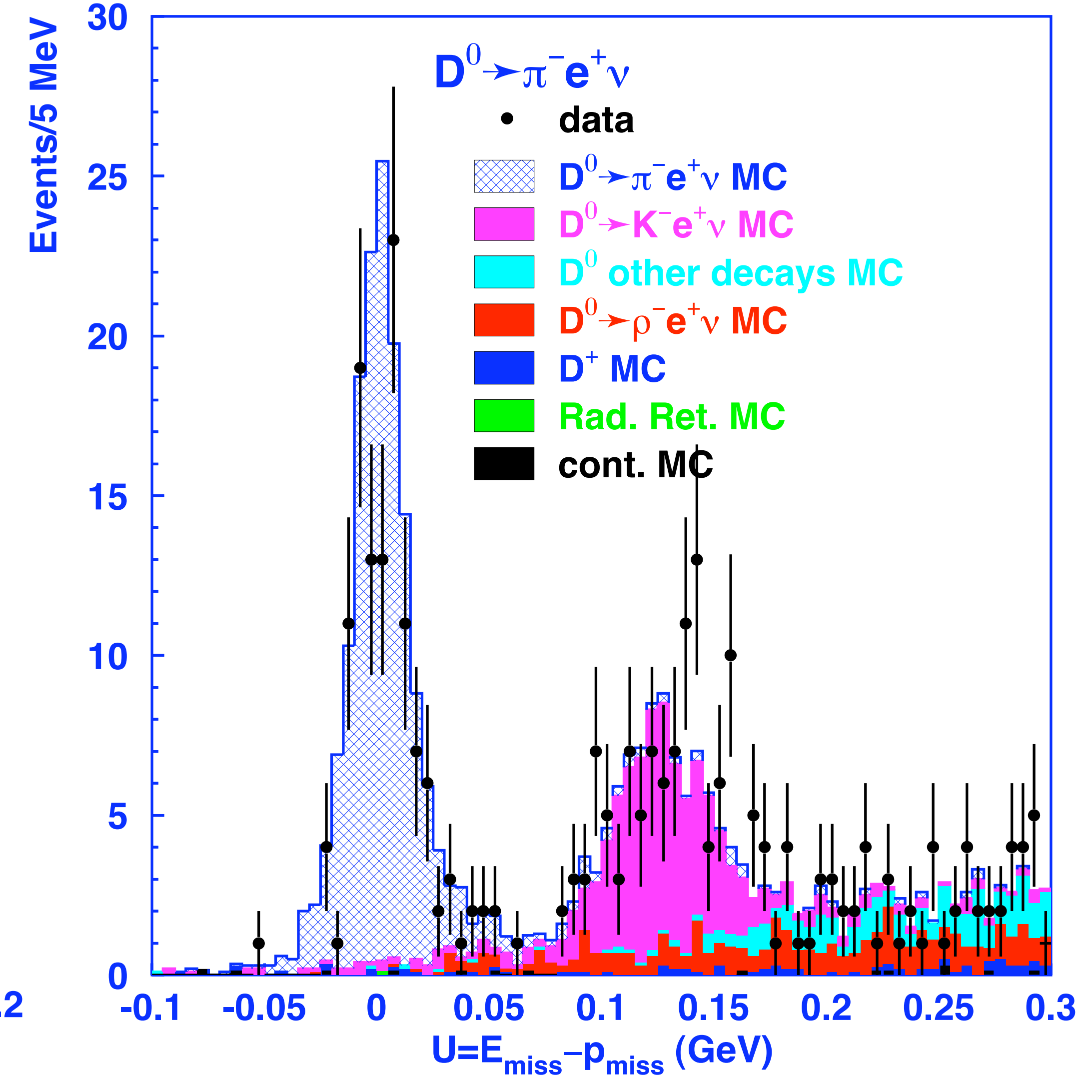
Results: Form Factors

(CLEO III $D^0 \to \{K^-, \pi^-\} e^+ \nu_e$)



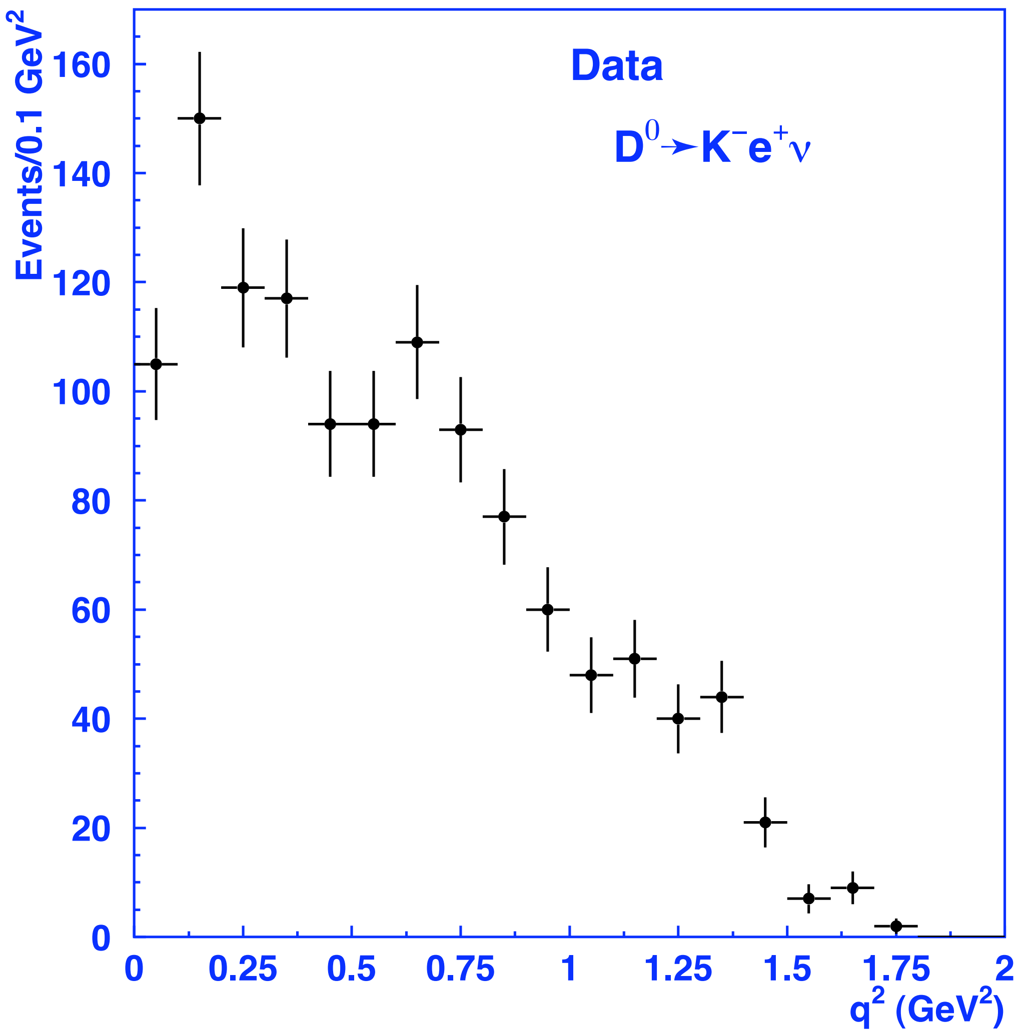
Cleaner Analysis in CLEO-c

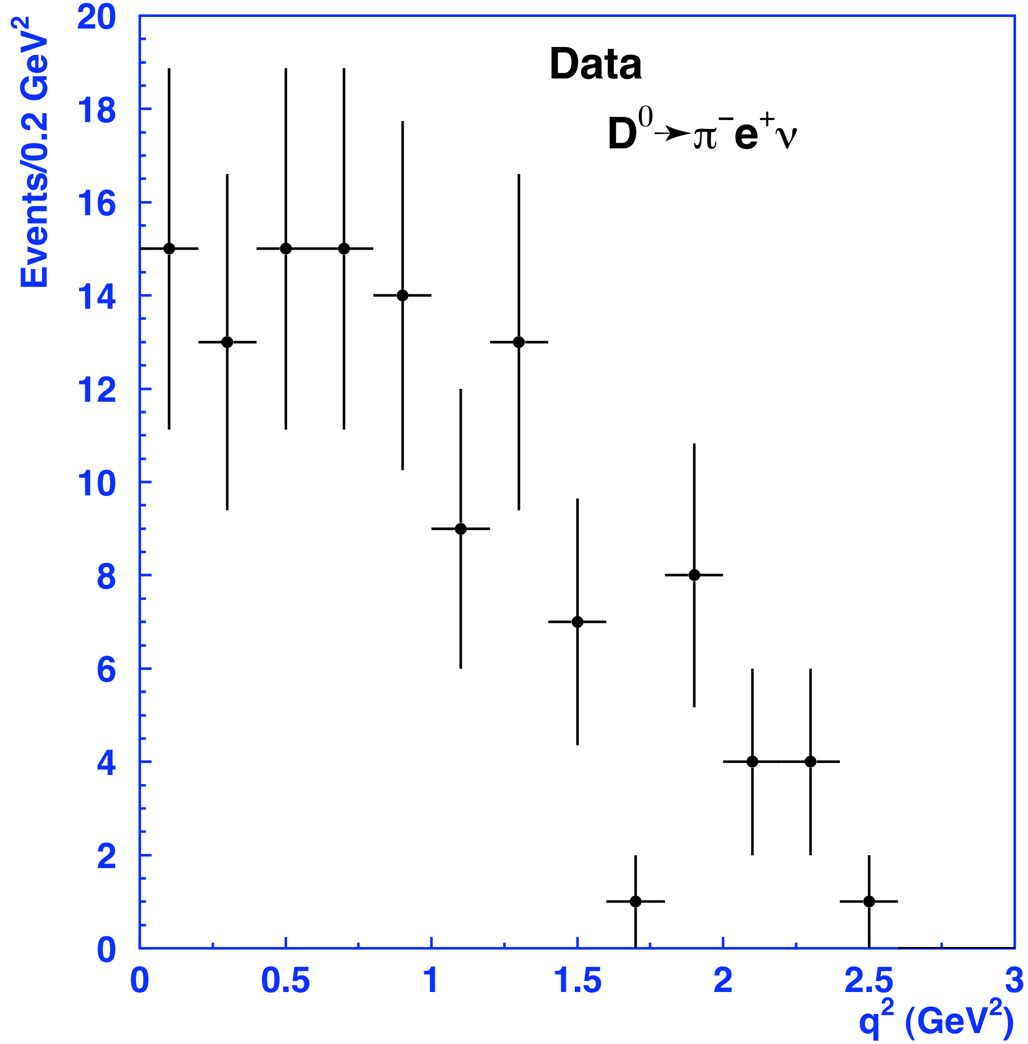




Preliminary Results

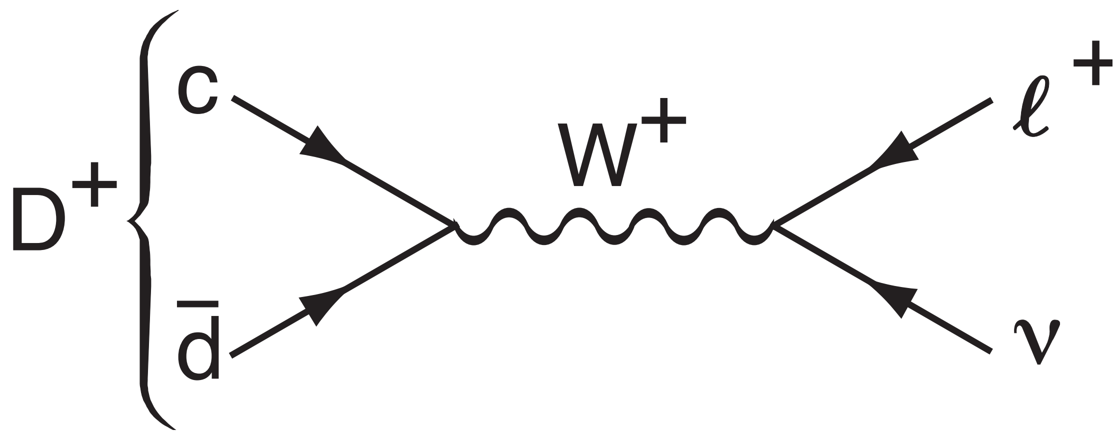
CLEO-c $D^0 \to \{K^-, \pi^-\} e^+ \nu_e$ *Uncorrected Spectra*





Expect ≈50 times as much data in upcoming runs!

3) D^+ Decay Constant in $D^+ \to \mu^+ \nu_\mu$



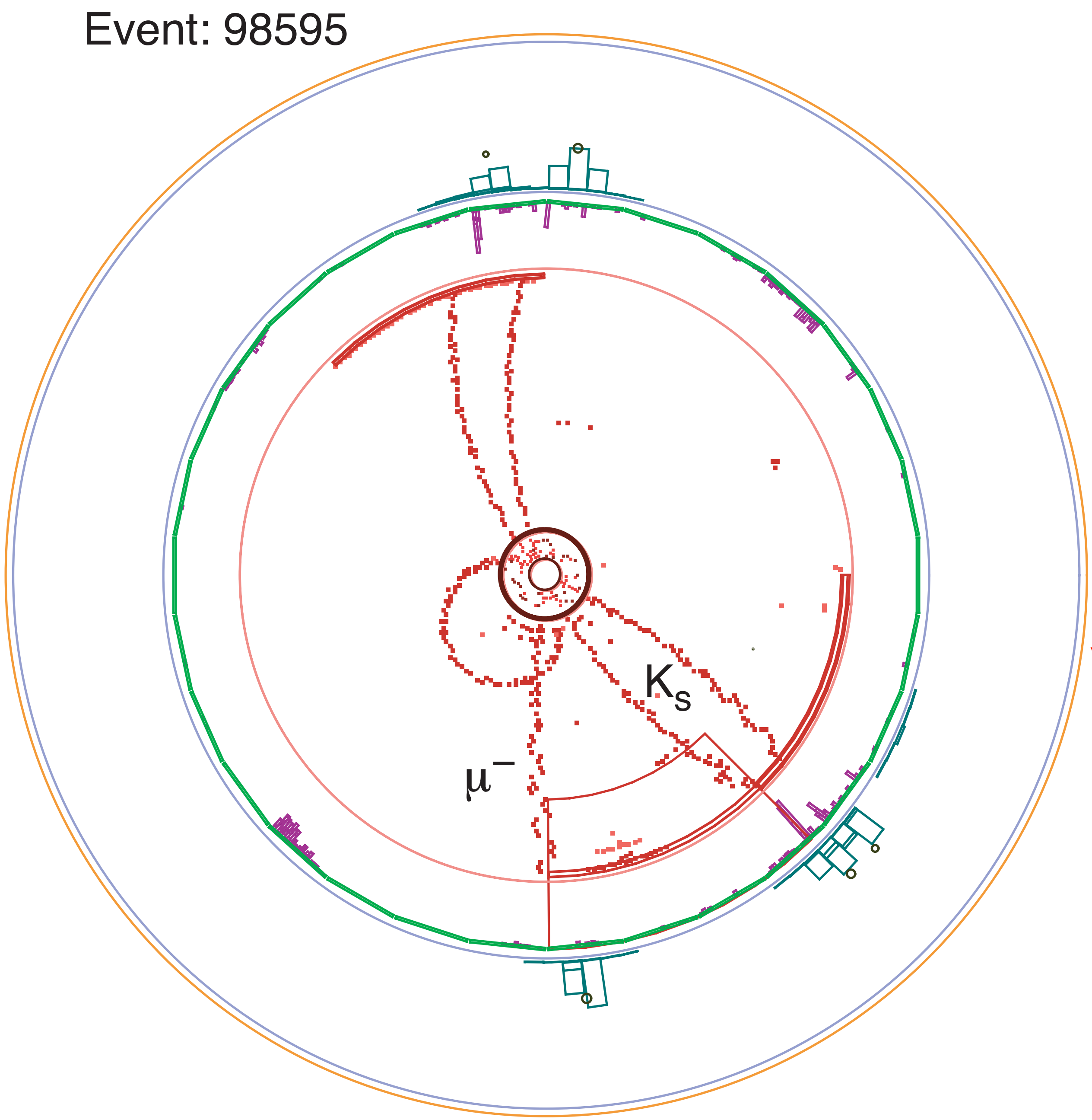
f_{D^+} can be calculated in Lattice QCD and in models.

However, $\mathcal{B}(D^+ \to \mu^+ \nu_\mu) \sim 10^{-4}$ is small.

Therefore, backgrounds can be a severe problem.

Measurement is very well suited to CLEO-c!

Example: Data from $\psi(3770) \rightarrow D^+D^-$

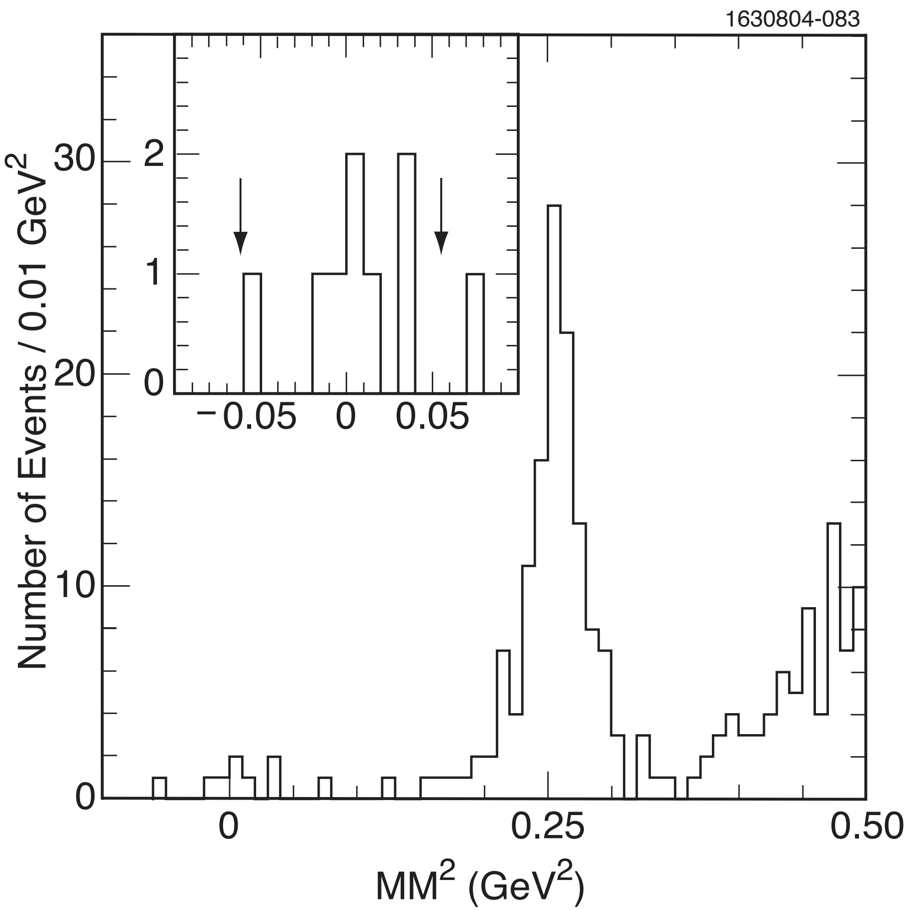


Tag the event using $D^+ \rightarrow K_S \pi^+ \pi^+ \pi^-$

Look opposite for $D^- \rightarrow \mu^- \nu_\mu$ with "missing" neutrino

Similar event topology from $D^- \rightarrow \pi^- K^0$

Preliminary Results (CLEO-c $D^+ \to \mu^+ \nu_\mu$)



Background estimate:

Mode	$\mathcal{B}$ (%)	# of events
$\pi^+\pi^o$	0.13 ± 0.02	0.31 ± 0.04
$K^o\pi^+$	2.77 ± 0.18	0.06 ± 0.05
$\tau^+\nu$	$3.2\times\ \mu^+\nu$	0.36 ± 0.08
$\pi^o\mu^+\nu$	0.31 ± 0.15	negligible

Find eight events with an estimated backround of one

$\mathcal{B}$ =$(3.5\pm1.4\pm0.6)\times10^{-4}$

$f_{D^+}=(201\pm41\pm17)$ MeV

Consistent with LQCD

Plenty more data to come!

Measuring the Scalar Meson Mass Matrix

Establishing the lightest glueball using CLEO-c

QCD predicts three light isoscalar $J^{PC}=0^{++}$ mesons:

$$\frac{1}{\sqrt{2}}\left[u\bar{u}+d\bar{d}\right] \qquad s\bar{s} \qquad \text{glueball}$$

Three states are observed in nature:

$$f_0(1370) \qquad f_0(1500) \qquad f_0(1710)$$

How are these states mixed?

The answer should give us insight into hadron dynamics

Mixing is described by a mass matrix

$$\begin{bmatrix} M_{n\bar{n}} & \Delta_{ns} & \Delta_{ng} \\ \Delta_{ns}^{\star} & M_{s\bar{s}} & \Delta_{sg} \\ \Delta_{ng}^{\star} & \Delta_{sg}^{\star} & M_g \end{bmatrix}$$

Lattice QCD calculations of M_g are well known.

What are the prospects for calculating other matrix elements, in particular the off-diagonal ones?

See Lee and Weingarten, Phys.Rev. D61(2000)014015

Plans for CLEO-c: J/ψ Radiative Decay

Populate states using $J/\psi \rightarrow \gamma f_0$

Measure decay rates for $f_0 \rightarrow \gamma V$

See Close, Donnachie, Kalashnikova, Phys.Rev.D67(2003)074031

Radiative Decay Widths in keV							Γ_{Tot}
	$f_0 \to \gamma\rho(770)$			$f_0 \to \gamma\phi(1020)$			MeV
State	L	M	H	L	M	H	
$f_0(1370)$	443	1121	1540	8	9	32	$\sim$300
$f_0(1500)$	2519	1458	476	9	60	454	109
$f_0(1710)$	42	94	705	800	718	78	125

Goal for CLEO-c: 10^9 J/ψ

Conclusions

- CLEO is enjoying life after B physics, with much of our research program aimed at hadronic spectroscopy and dynamics.
- Many new results are out now, based on our first low energy data sets.
- Much more data to come, to increase our statistics and to explore new ground.

Thank You!