RECENT RESULTS from CLEO

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MESON 2004 Krakow

- *Introduction*
- *Search for X(3872)*
- *CLEO-c Physics, Detector, and Run Plan*

  "2-body" $\psi(2S) \Rightarrow$ PV Decays

  $\psi(3770) \rightarrow$ DD Cross Section

  D meson Decay Constant, f_D

  D Semileptonics: Inclusive and Exclusive
- *Outlook and Conclusions*

CLEO Dataset Overview

CLEO detector at CESR $e^+ e^-$ collider -- Ithaca, New York, USA

CLEO II, II.V, III: High-Energy Data $b\bar{b}$ *resonances*

Υ(4S) and continuum $\Rightarrow$ years of quality B, D, τ, 2-γ physics

New Υ(1S,2S,3S), continuum $\Rightarrow$ >10x older CLEO samples

Λ_B scan; Y(5S); R_{had} scans $\Rightarrow$ more *unique* physics!

CLEO-c: Low-Energy Data ***('c' = charm)*** $c\bar{c}$ *resonances*

ψ(3770) , ψ(4140) , J/ψ, ψ(2S), ...

Detector Highlights:

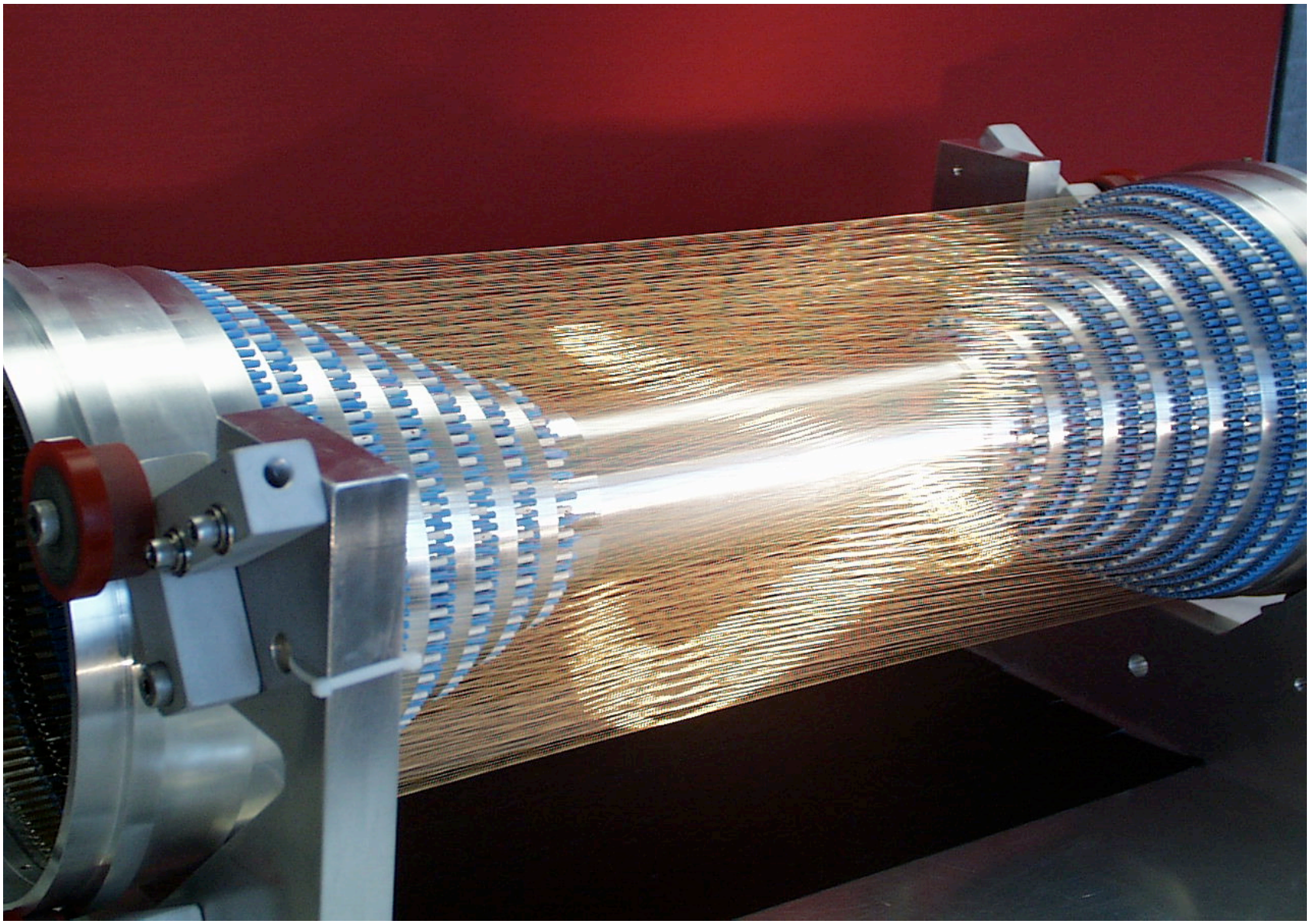
1989 -- CLEOII: CsI EM calorimeter

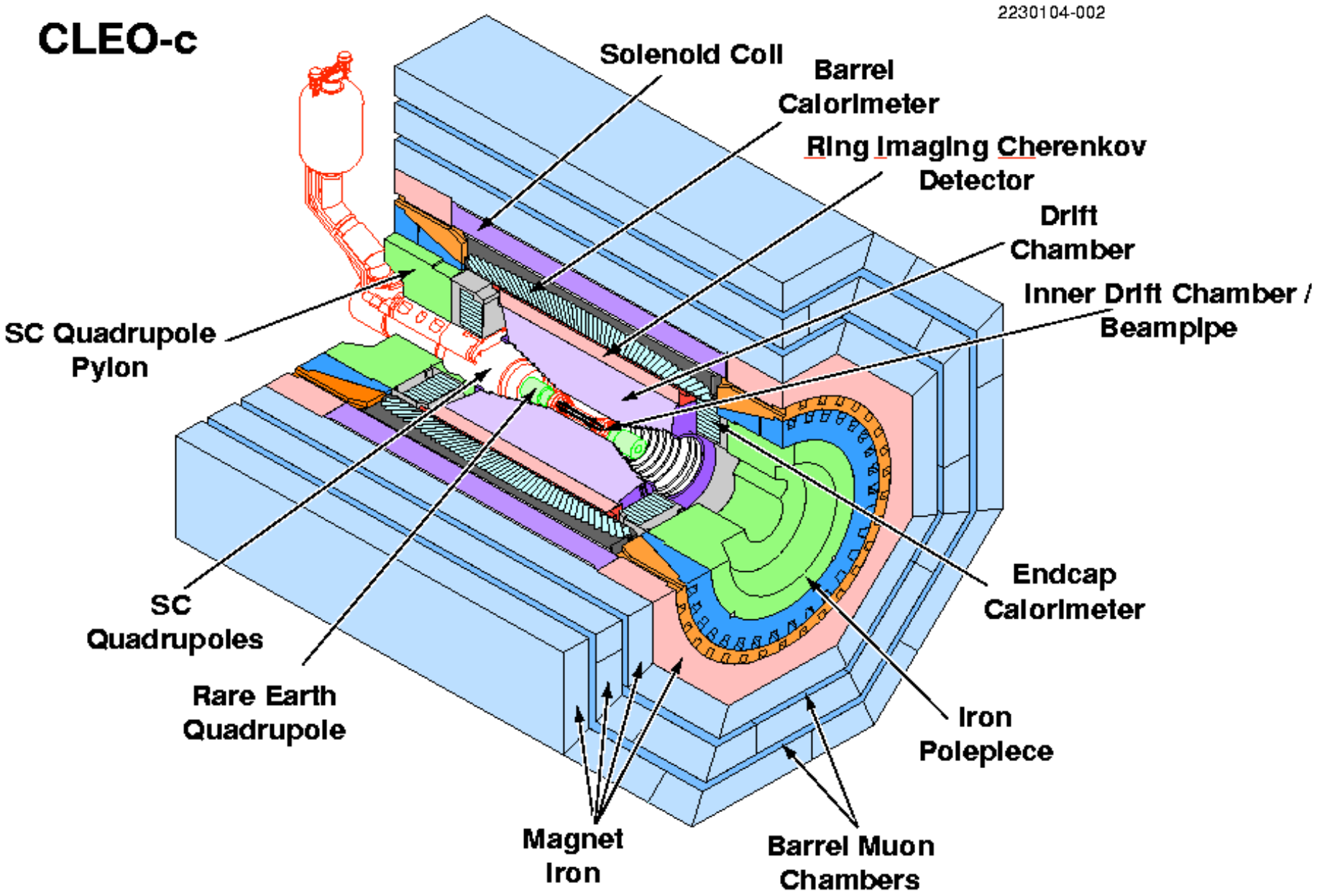
1995 -- CLEOII.V: SVX, Helium-Propane drift-chamber gas

2000 -- CLEOIII: TOF $\Rightarrow$ RICH, new drift chamber

2003 -- CLEO-c: SV3 $\Rightarrow$ "ZD" all-stereo inner drift chamber

CLEO-c 6-layer, all-stereo inner chamber





No hadron calorimeter,
most particles now below muon system threshold

Search for X(3872)

Found by Belle (in $\pi^+ \pi^-$ J/ψ final state)

Since confirmed at CDF and D0

How does it fit into charmonium spectrum, if at all?

Look for 2-photon and ISR production at CLEO:

→ Obtain information on quantum numbers, widths, etc.

2γ: $J^{PC} = 0^{\pm+}, 2^{\pm+}$ **ISR:** $J^{PC} = 1^{--}$

Use ~15 fb^{-1} CLEO III High-Energy Data

Look for $\pi^+ \pi^-$ J/ψ final state

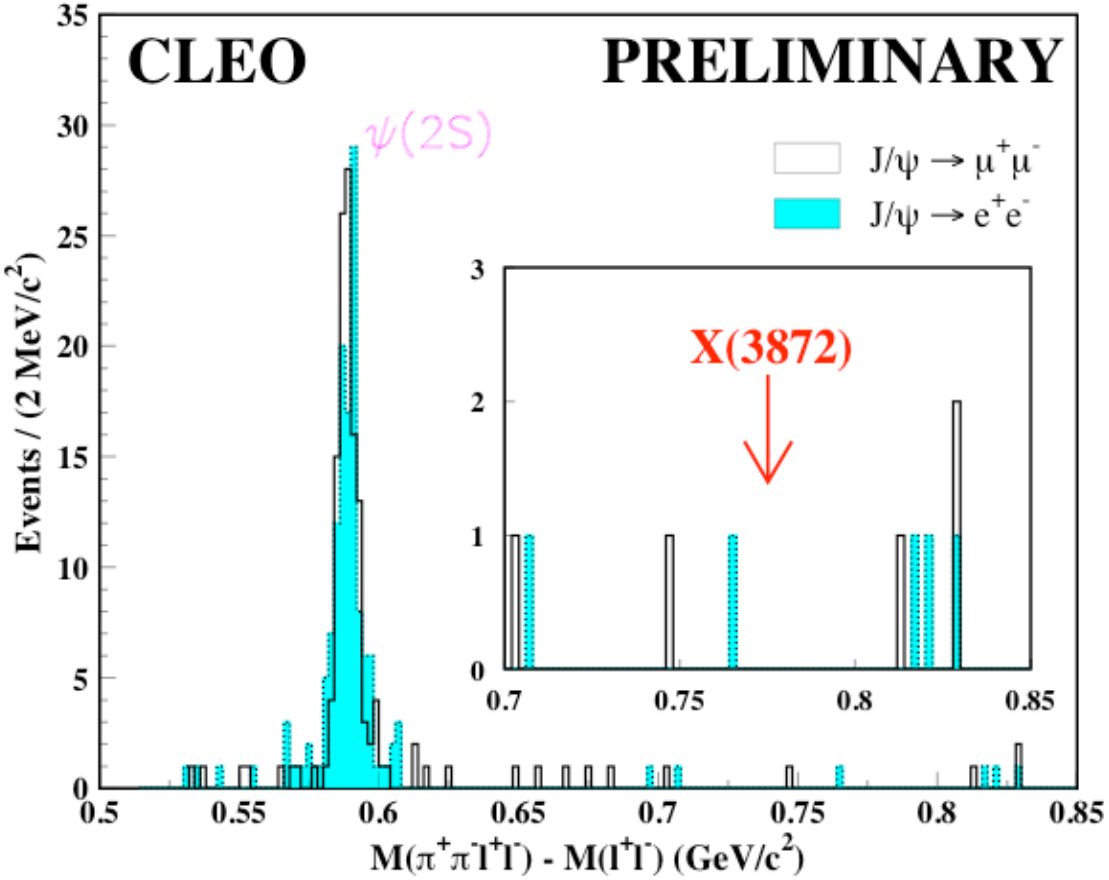
Separate prod. mechanisms with lab angles of J/ψ leptons:

→ X(3872) from ISR is highly boosted.

Note: ISR = Initial State Radiation

Search for X(3872): Results

Combined 2-photon and ISR data:



2-photon search:

$(2J+1)\,\Gamma_{\gamma\gamma}\,\boldsymbol{B}(X \to \pi\,\pi\,J/\psi)$
< 16.7 eV (90% CL)

ISR Production:

$\Gamma_{ee}\,\boldsymbol{B}(X \to \pi\,\pi\,J/\psi)$
< 6.8 eV (90% CL)

2γ: 3x-9x narrower than χ_{c0}, χ_{c2}, η_c **(If $B(X \to \pi\,\pi\,J/\psi) \sim 0.02$!)**

ISR: $\Gamma_{ee}B$ 100x smaller than ψ(2S)

The CLEO-c Physics Program

Clear up QCD issues impacting weak physics!

Precision Charm Physics

Hadronic: precise absolute BR's for D^+, D^0, D_s golden modes

Leptonic: decay constants f_D and f_{Ds}

Semi-leptonic: form factors, V_{cs}, V_{cd}

Specialized Charm Physics

D-mixing: extract of strong $K\pi$ phase!

Very clean Dalitz plots: CP violation with CP-tagged states!

Spectroscopy

Charmonium spectroscopy

Searches for glue-rich exotic states via J/ψ decays.

Many topics help validate modern lattice QCD techniques:

Need verification that claimed accuracy is achieved…

e.g., ~2% level for f_D

Nominal CLEO-c Run Plan

Main change for CESR accelerator:

Installation of 12 wiggler magnets (for damping at low energy)
6 completed, 6 being installed now.

Winter 2003/2004: 'Pilot Run' yielding results that follow

Fall 2004: *E = 3770 MeV, 3 fb^{-1} ⇒ 18,000,000 $D\overline{D}$ decays, perhaps >3,000,000 tagged D decays.*

Fall 2005: *E = 4140 MeV, 3 fb^{-1} ⇒ 1,500,000 $D_s^+ D_s^-$ events, 300,000 tagged D_s decays (480x MARK III, 130x BES II)*

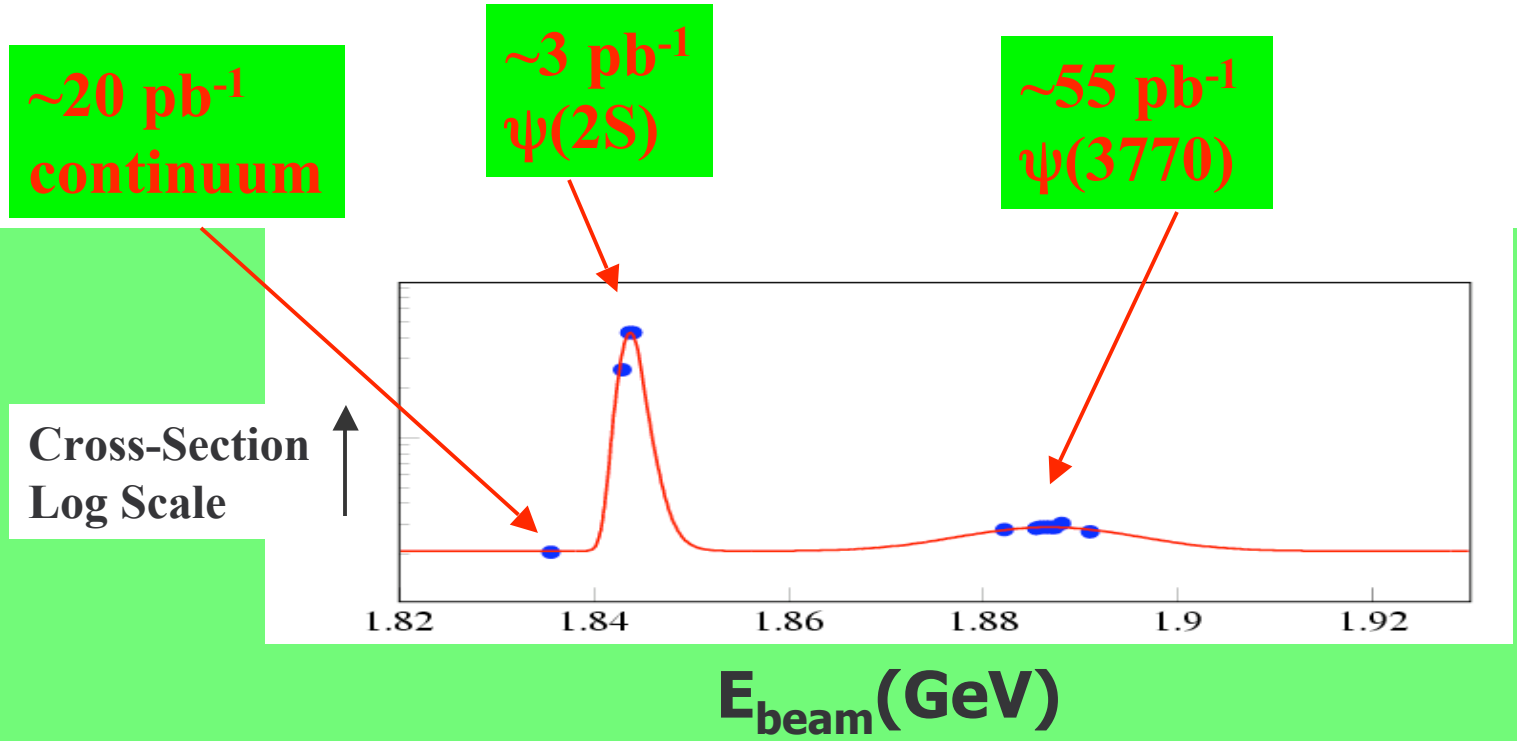
Fall 2006: *E = 3100 MeV, 1 fb^{-1} ⇒ 1,000,000,000 J/ψ decays.*

Already have some $\psi(2S)$; likely to take more…
Maybe some Λ_c data?

CLEO-c Data Collected

6 CESR Wigglers installed Summer 2003

Winter 2003/4 took data on the ψ(3770), ψ(2S), and continuum



6 Wiggler Running Luminosity ~ 5×10^{31} cm^{-2} s^{-1} On target

12 Wiggler Design Luminosity ~3×10^{32} cm^{-2}s^{-1}

$\psi(2S)$ Decays and PV Puzzle

Expect $\psi(2S)$ BR's to be ~12% of J/ψ: (Assuming equal partial width ratios, etc.)

But "PV" modes like $\rho\pi$ and $K^{*+}K^{-}$ known to be suppressed !?!

Data:

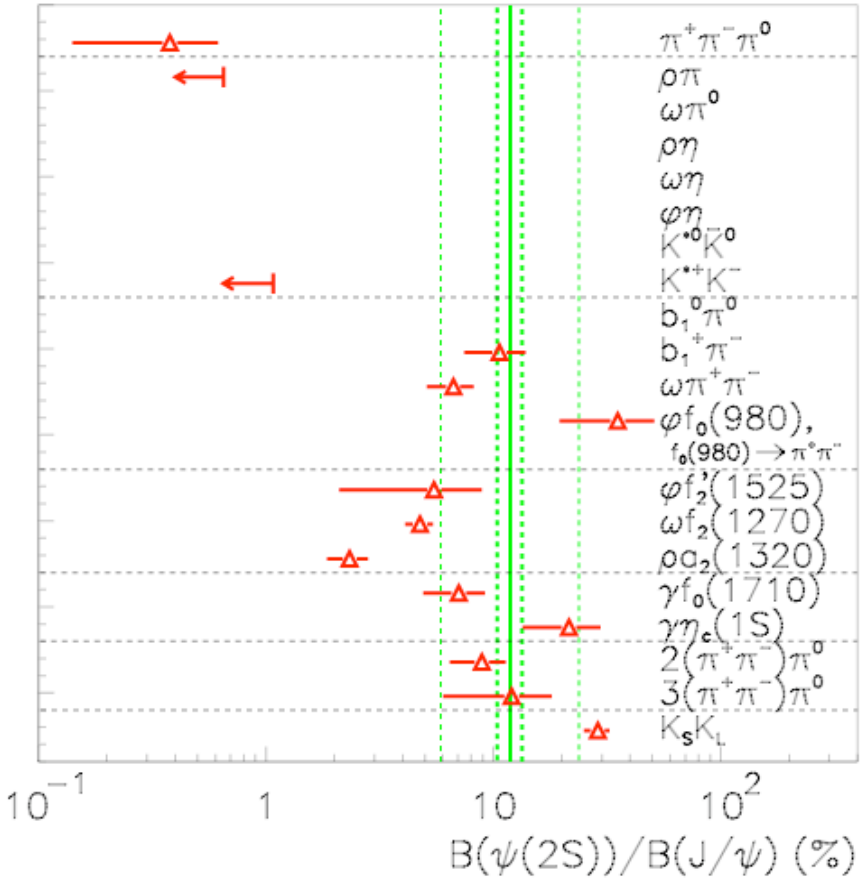
~5.5 pb^{-1} $\psi(2S)$

(incl. 2.5 pb^{-1} pre-CLEO-c)

$\Rightarrow$ 3 x 10^6 decays

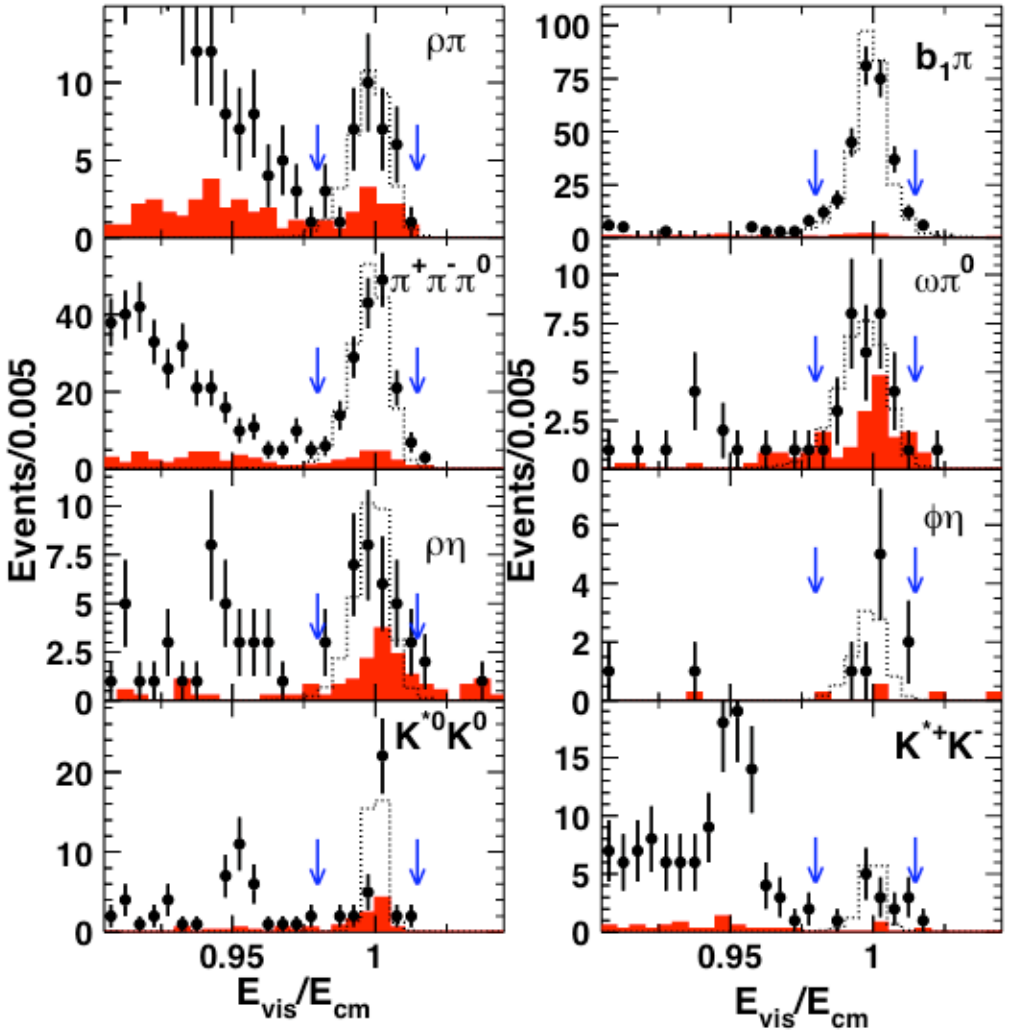
~20 pb^{-1} continuum

@ E_{cm} ~ 3.67 GeV



Note: "PV" = psedoscalar-vector

$\psi(2S)$ Decays and PV Puzzle



Analyze many final states;
Cut on resonance masses, etc…

Key variable: E_{vis} / E_{cm}

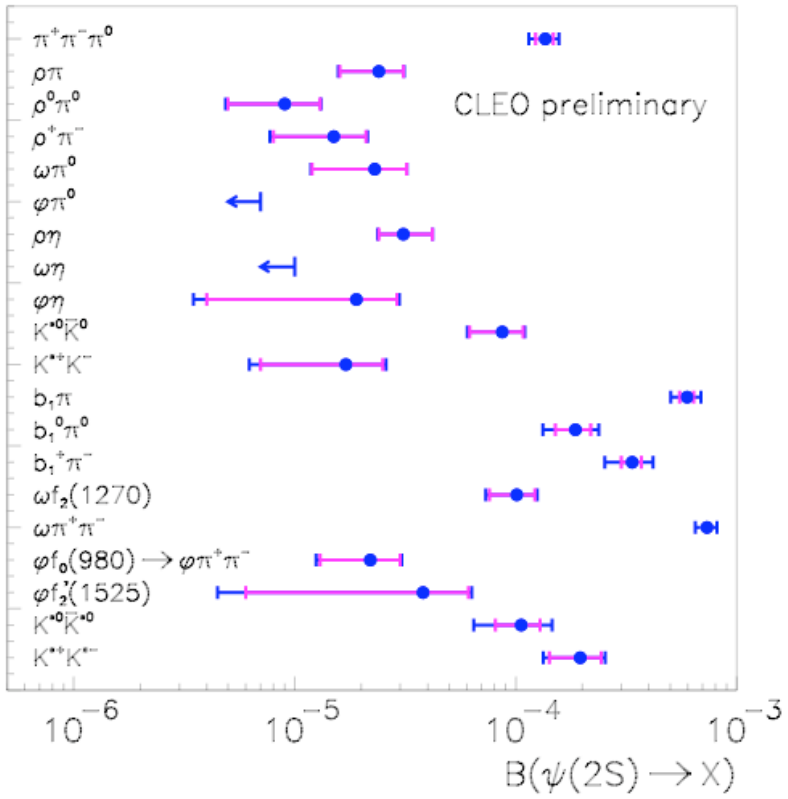
Peak at 1 assures exclusive final state

Mostly PV modes at left
Scaled continuum in red

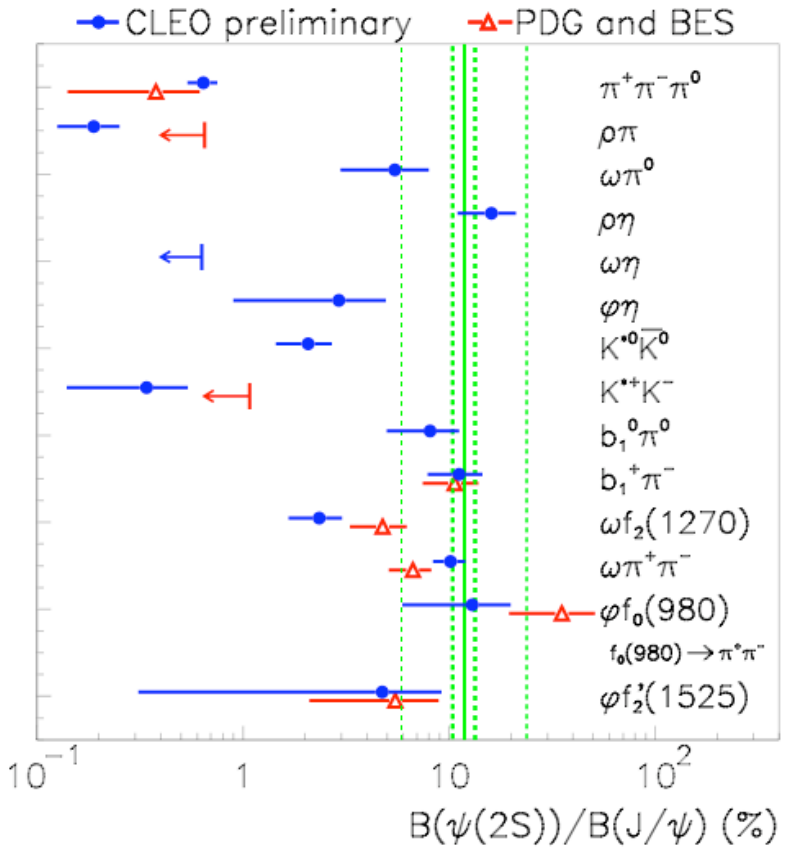
$b_1\pi$ is axial-pseudoscalar large 'monitoring' mode

$\psi(2S)$ Decays: Results

Our New Results:



Compiled with 12% rule:

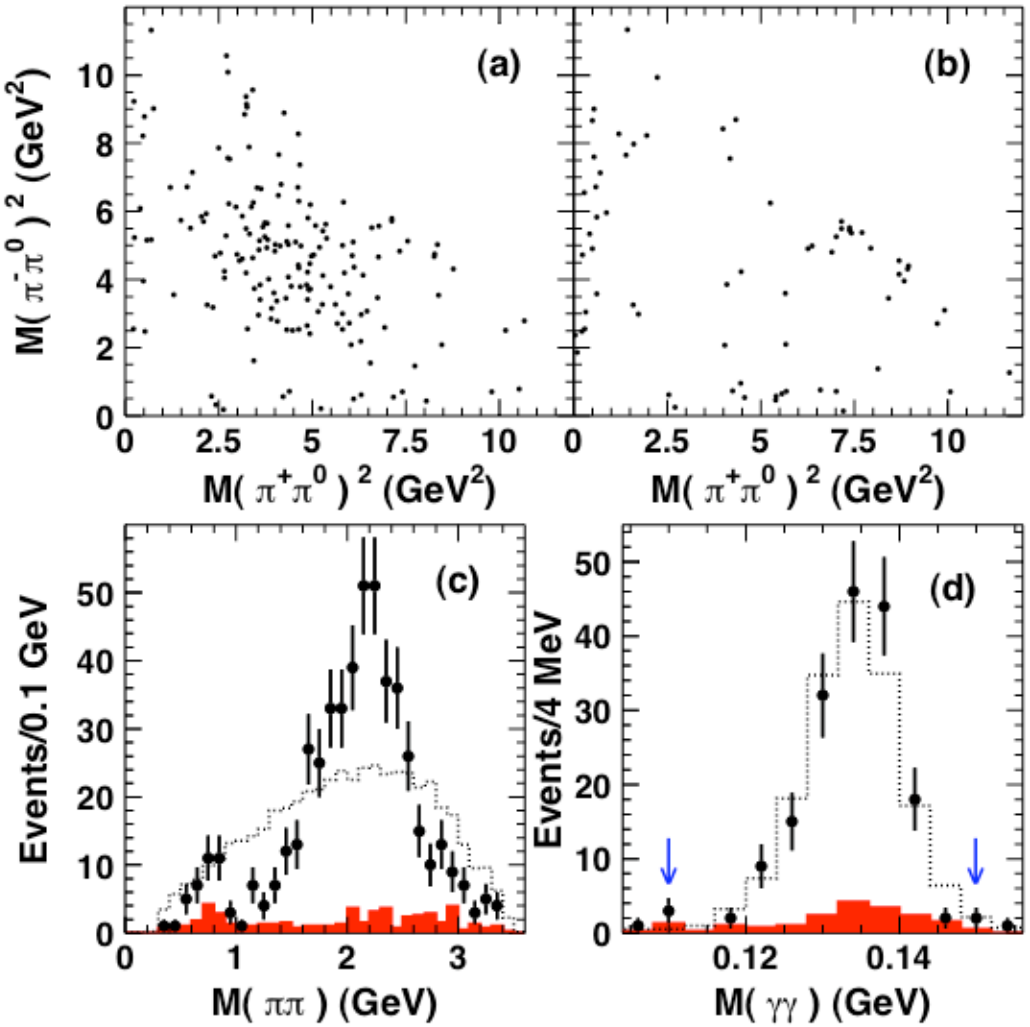


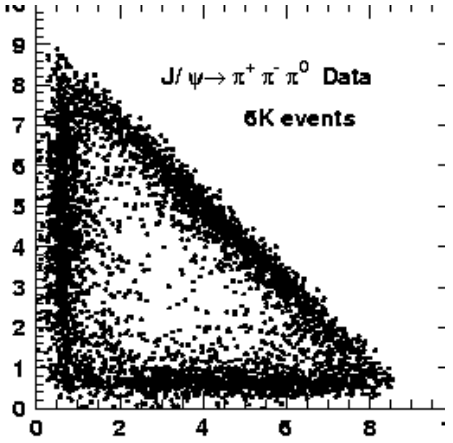
6 new modes observed! : $\omega\pi^0$, $\rho\eta$, $\phi\eta$, $K^{*0}K^0$, $K^{*+}K^-$, $b_1^0\pi^0$

(can add more non-PV modes as well…)

$\psi(2S)$: More on 3π final state…

$\psi(2S)$: ***continuum:*** ***J/ψ :***





$\psi(2S) \Rightarrow 3\pi$ decay:
NOT dominated by $\rho\pi$

Very different from
J/ψ and continuum!

Physics at the $\psi(3770)$

The $\psi(3770)$ decays primarily D meson pairs.
CLEO-c has ~55 pb^{-1} $\psi(3770)$

Most charm analyses use *tagging*:

a tag is a fully-reconstructed decay

e.g., $D^+ \Rightarrow K^- \pi^+ \pi^+$ $D^0 \Rightarrow K^- \pi^+$

plus other hadronic modes with large branching fractions

Compare single and double tag events:

Measure σ_{DD} and absolute BR's

Study Leptonics, Semileptonics:

Know 4-vectors of initial state and of the tagging D

$\Rightarrow$ can infer 4-vector of other D; only neutrino missed

Measurement of $\sigma(e^+e^- \Rightarrow DD)$

Mark III (PRL 60 89 (1988) with 9.4 pb^{-1} measured

$\sigma(e^+e^- \Rightarrow DD) = (5.0 \pm 0.5)$ nb

Pioneered double-tag method.

Recently BES II (Moriond '04) using 17 pb^{-1} measured

$\sigma(e^+e^- \Rightarrow DD) = (5.78 \pm 0.11 \pm 0.38)$ nb

BES used a single-tag method:

the D branching fractions were taken from the PDG.

Here, we use a double-tag method to find a value of independent of any branching fraction measurement.

Only use 'golden modes' for now: $D^+ \Rightarrow K^- \pi^+\pi^+$ $D^0 \Rightarrow K^-\pi^+$

General Analysis Techniques

Good K-π separation by dE/dx up to 600 MeV/c

For p > 600 MeV/c, RICH combined with dE/dx.

K^0_S are found from two tracks with a displaced vertex.

π^0's found from 2 gammas in the CsI

All Tags Use:

Momentum Conservation: $M_{bc} = (E_{beam}^2 - p_D^2)^{1/2}$

-- Substitute $E_D = E_{beam}$ (beam constrained mass)

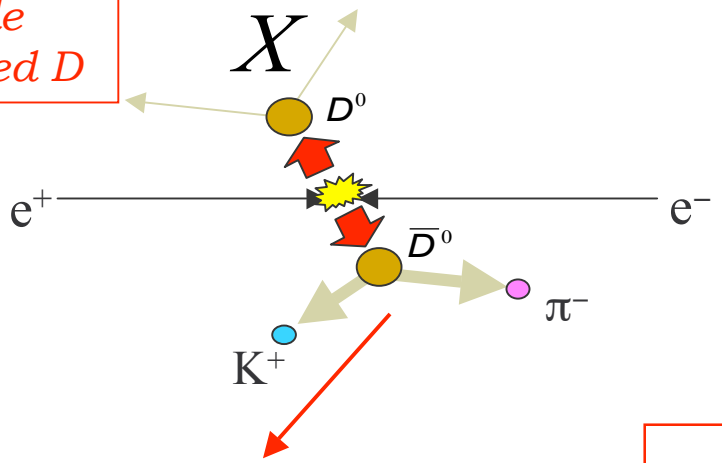
-- Better resolution (~1.5 MeV; mostly beam energy spread)

Energy conservation: $\Delta E = E_{cand} - E_{beam}$

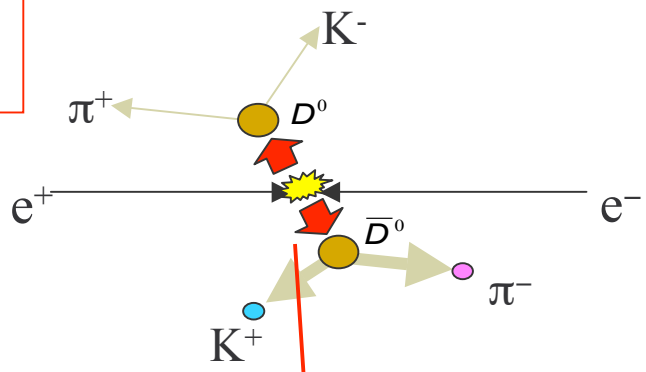
-- Peaks at 0; sensitive to Particle ID, missing particles

Measurement of $\sigma(D\bar{D})$ at $\psi(3770)$

Single tagged D



Double tagged D



$$S = 2N_{D\bar{D}} B\varepsilon_1$$

$$\varepsilon_2 = \varepsilon_1^2$$

$$D = N_{D\bar{D}} B^2 \varepsilon_2$$

$$N_{D\bar{D}} = S^2 / 4D$$

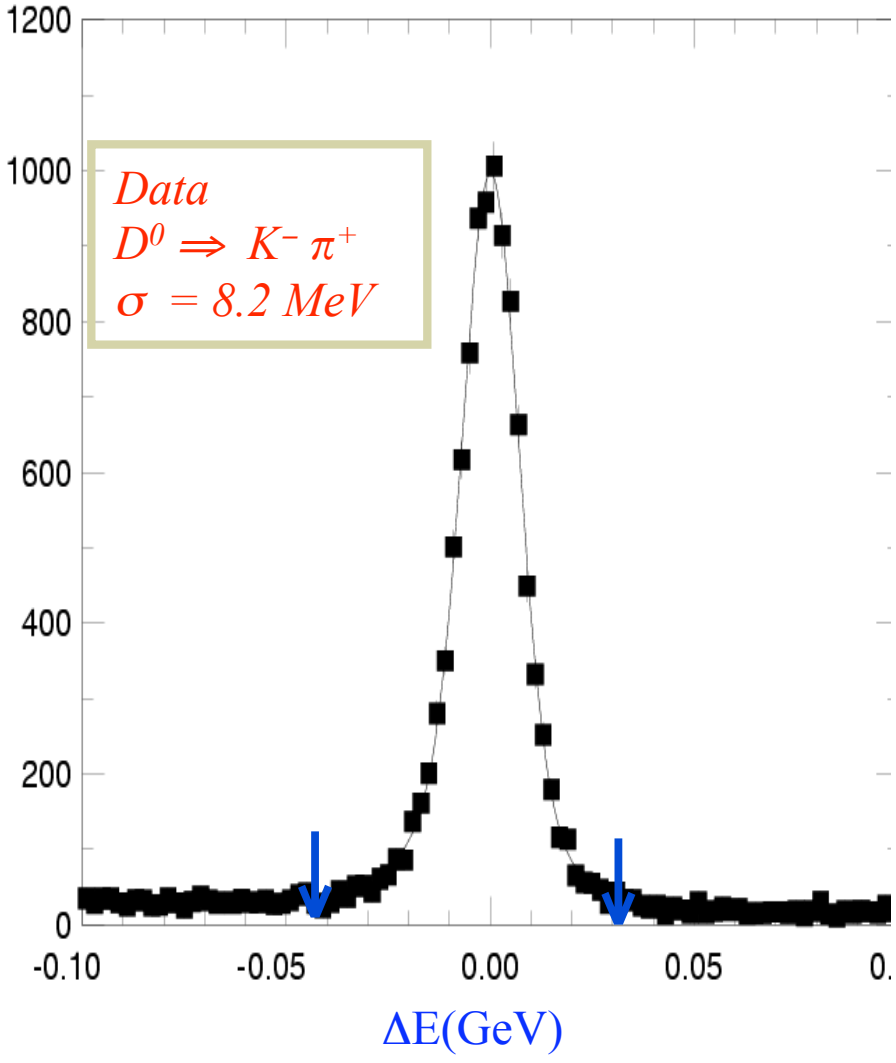
$$\sigma_{D\bar{D}} = \frac{S^2}{4DL}$$

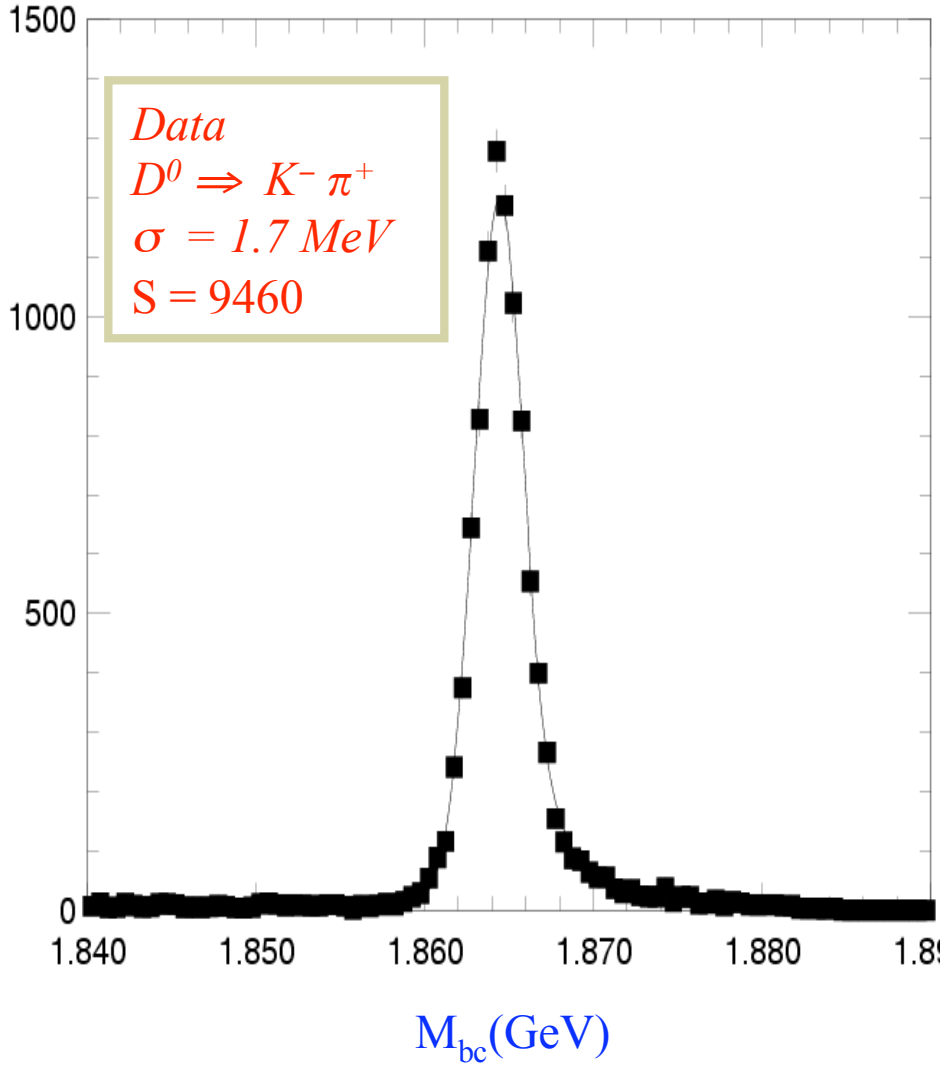
Independent of *B* (and ε in the approximation $\varepsilon_2 = \varepsilon_1^2$)

D^0 single tags -Data

Luminosity = 55.81pb^{-1}

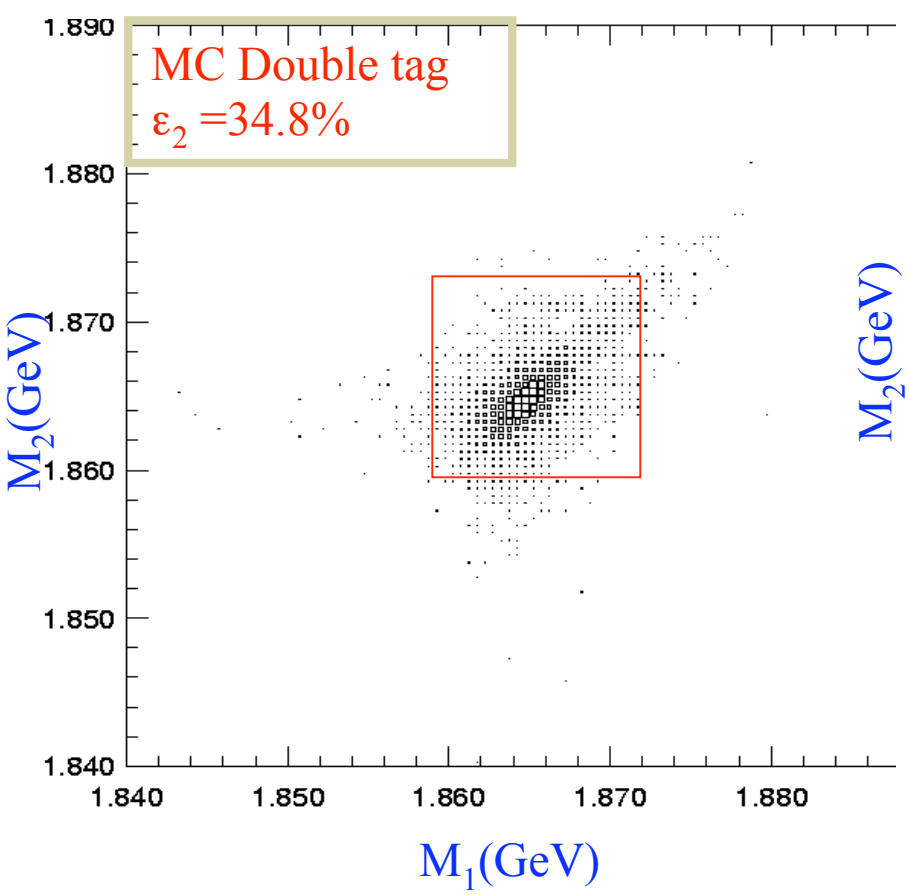
Require –40 MeV < ΔE < 30 MeV

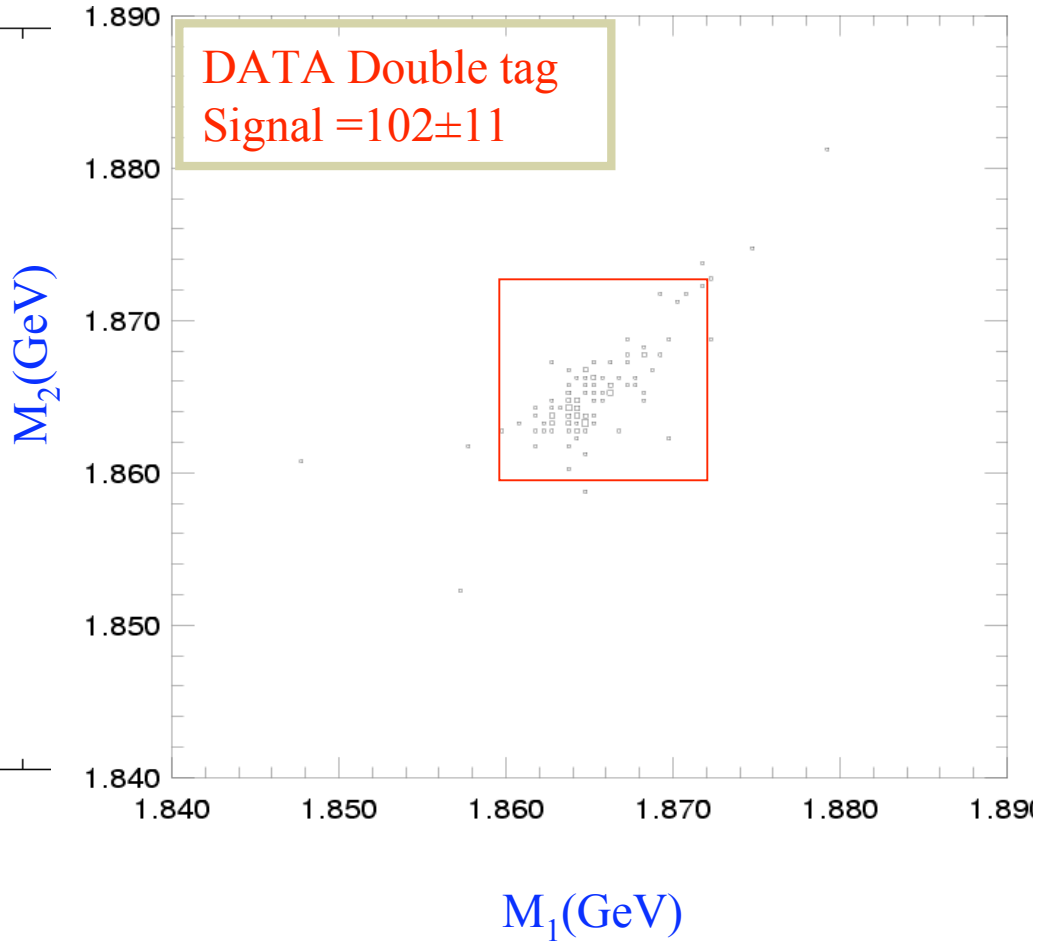




D^0 Double Tags - Monte Carlo, Data

We search for events with $D^0 \to K^-\pi^+$ and $\overline{D}^0 \to K^-\pi^+$





We find the double tag efficiency is the square of single tag efficiency with an uncertainty of 3% for $D^0 \to K^-\pi^+$

Summary for σ(DD)

Our result is independent of charm branching ratios
BES used a single tag method and the PDG BR values
Good agreement among all measurements.

	$\sigma(D^+D^-)$ (nb) (stat.err)(sys.err)	$\sigma(D^0D^0)$ (nb) (stat.err)(sys.err)	$\sigma(DD)$ (nb) (stat.err)(sys.err)	$\sigma(D^+D^-)/\sigma(D^0D^0)$
CLEO-c	**2.58±0.15 ±0.16**	**3.93±0.42±0.23**	**6.51±0.44±0.39**	**0.656**
BES	**2.52±0.07 ±0.23**	**3.26±0.09±0.26**	**5.78±0.11 ±0.38**	**0.773**
MARK III	**2.1±0.3**	**2.9 ± 0.4**	**5.0 ± 0.5**	**0.724**

Largest systematic uncertainty: luminosity measurement completely correlated!

All CLEO-c numbers are preliminary!

Measurement of $D^+ \Rightarrow \mu^+ \nu_\mu$

The leptonic decay width is given by:

$$\Gamma_{l\nu} = \frac{1}{8\pi} G_F^2 f_D^2 m_l^2 M_D \left(1 - \frac{m_l^2}{M_D{}^2}\right)^2 \left|V_{cd}\right|^2$$

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

LQCD is the only option for B physics;

f_B needed to extract CKM elements from B and B_s mixing data!

Muon candidate consistent with min-I particle,

< 0.4 GeV deposited in CsI (muons too soft for muon detector)

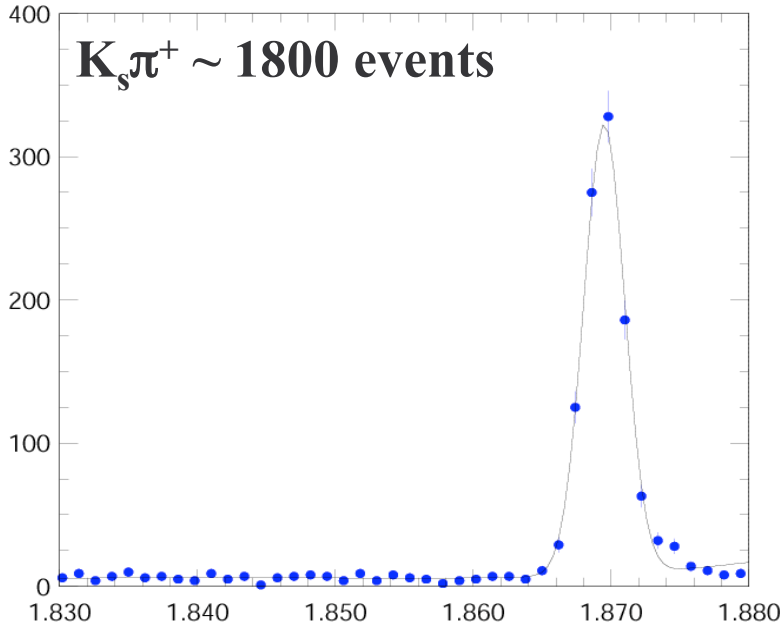
Key analysis variable: *MM*^{2} missing-mass squared

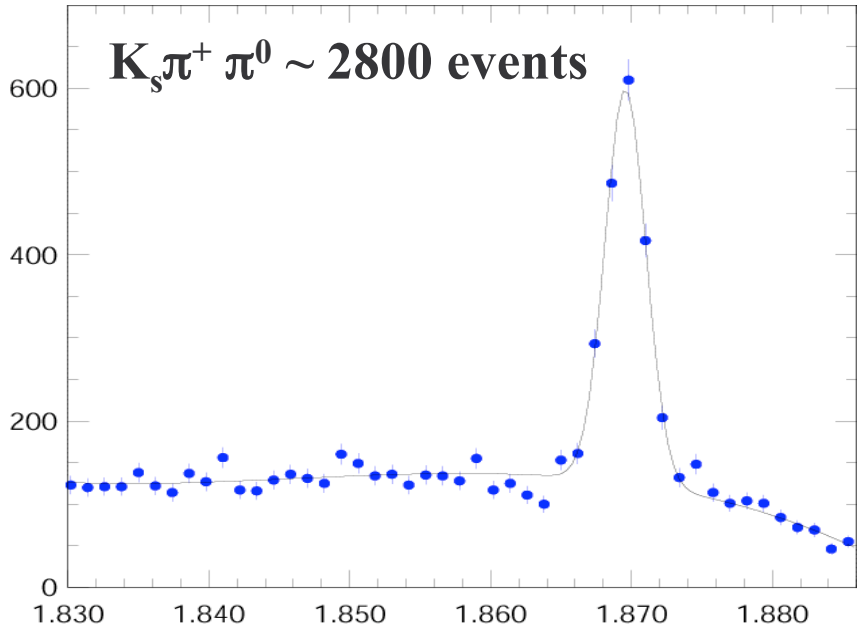
$$MM^2 = (E_{beam} - E_\mu)^2 - (-\vec{p}_{tag} - \vec{p}_\mu)^2$$

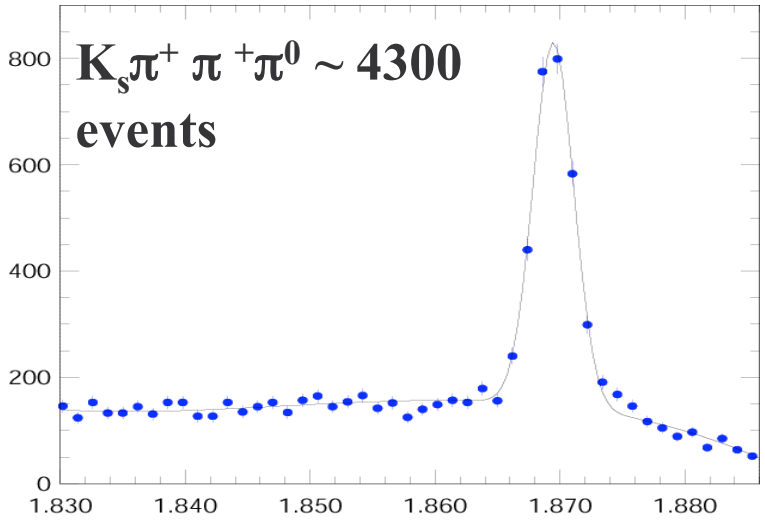
Resolution similar to $m_\pi{}^2$; pernicious $\pi^+\pi^0$ background!

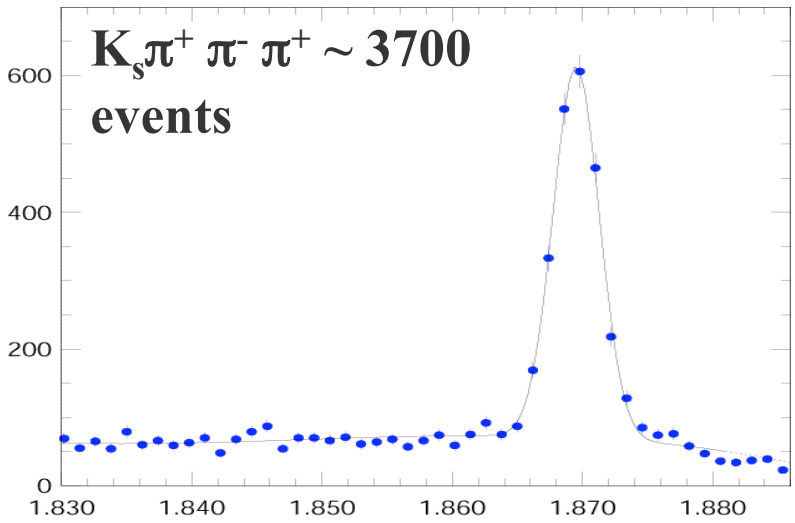
(mis-ID π^+ and lose π^0)

Add Four More D^+ Tag Modes

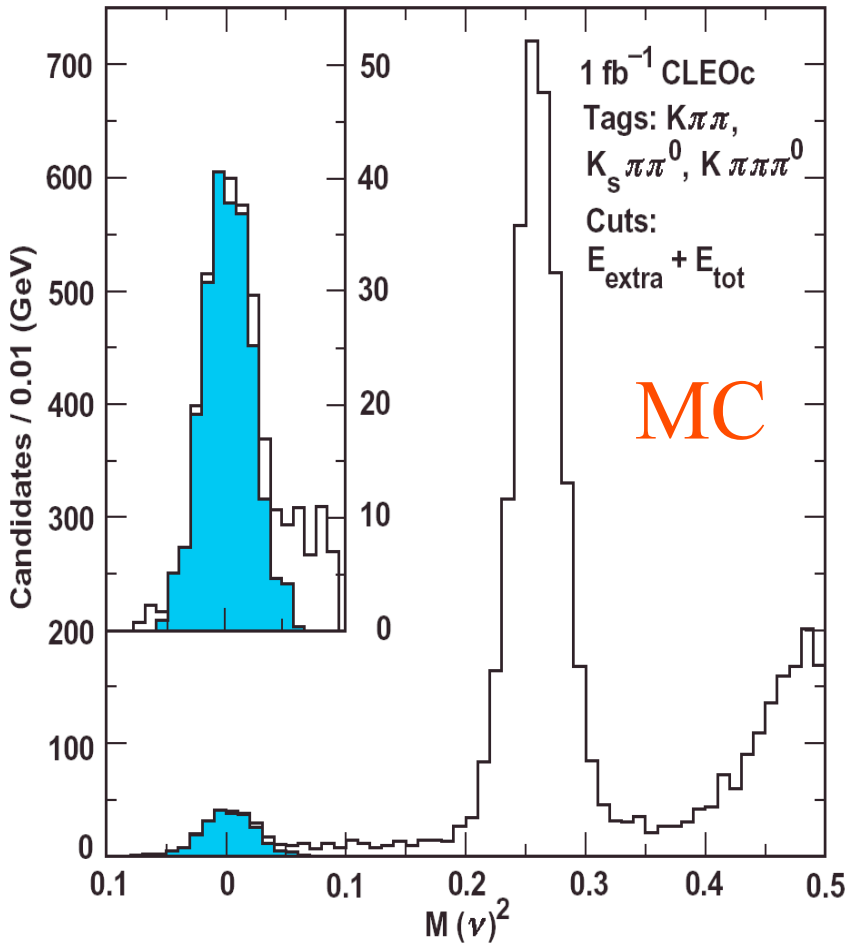


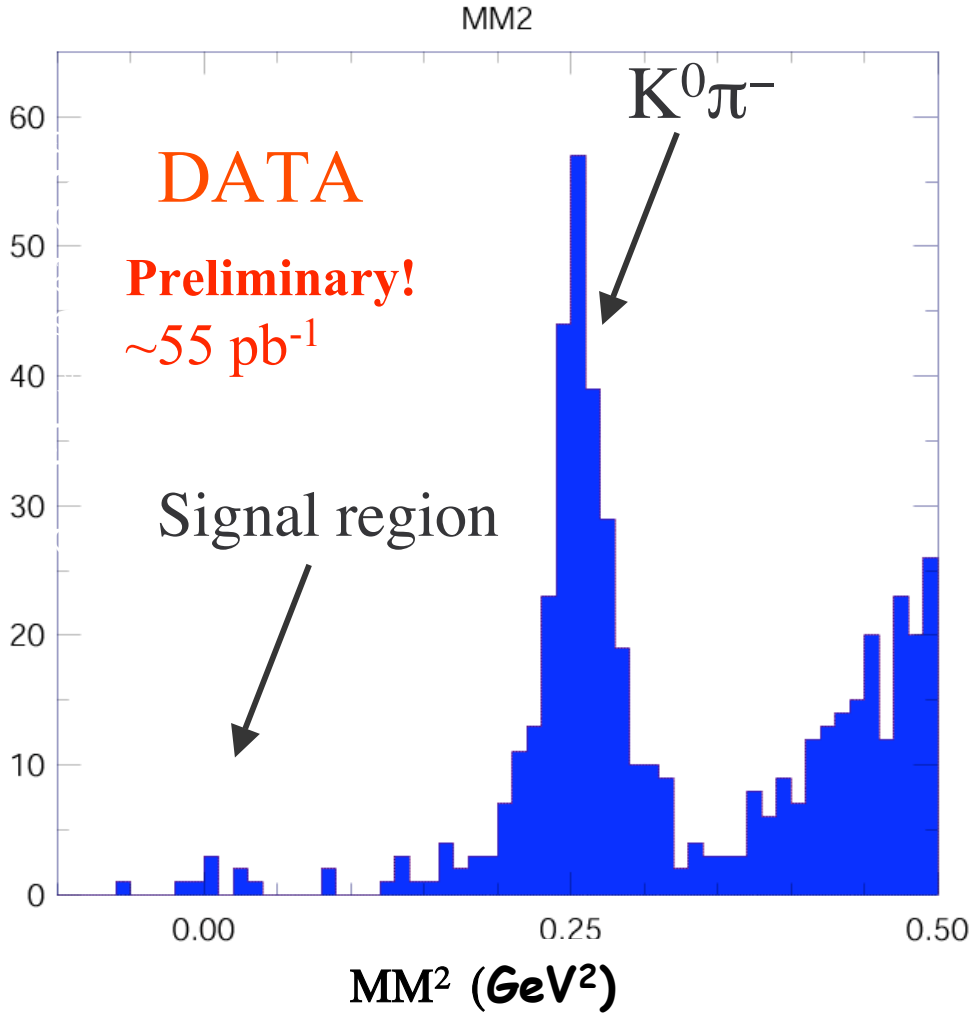






MM^2 Distribution in MC & Data





Backgrounds

$D^{\pm}$ Background:

$D^+ \to \pi^+ \pi^0$: Veto with max. shower energy cut.

$D^+ \to \bar{K}^0 \pi^+$: No reconstructed K_s , higher MM^2.

$D^+ \to \pi^0 \mu^+ \nu$: negligibly small, higher MM^2 .

$D^+ \to \tau^+ \nu$: higher MM^2 .

$D^0\bar{D}^0$ Background:

$D^0 \bar{D}^0$ can look like $D^+ D^-$:

ex: $D^0 \to K^-\pi^+$, $D^0 \to \pi^+ \mu^- \nu$

Continuum Background

Estimated backgrounds from MC

#Tags	$\pi^+\pi^0$	$K^0 \pi^+$	$D^0\bar{D}^0$	**Cont.**
26395 ±196	0.28 ±0.04	0.06 ±0.02	0.16 ±0.16	0.17 ±0.17

$D^+ \Rightarrow \mu^+ \nu_\mu$ Signal

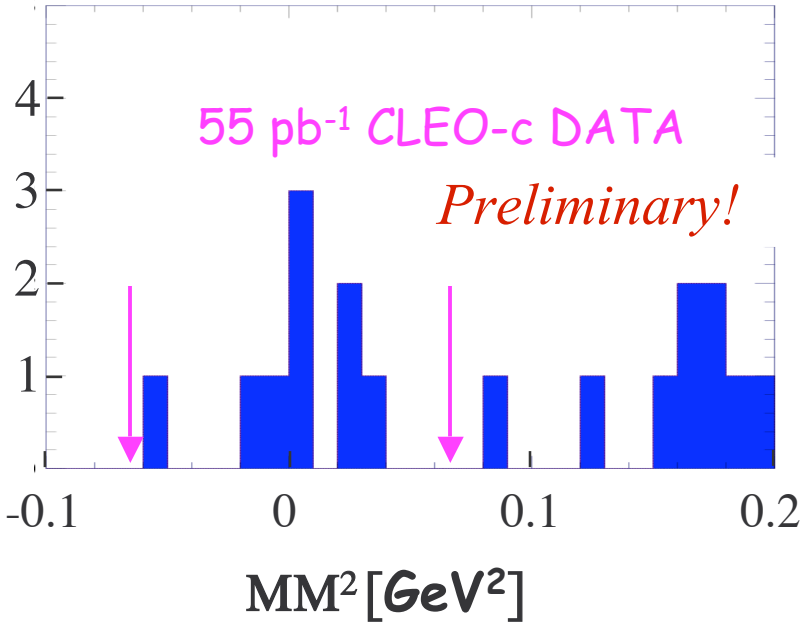
9 events within 2σ

(-0.056 < MM² < 0.056 GeV²)

0.67 ± 0.24 estimated background events.

SIGNIFICANT SIGNAL

Reconstruction efficiency ~70%



$\mathcal{B} = (4.57 \pm 1.66 \pm 0.41) \times 10^{-4}$

$f_D = (230 \pm 42 \pm 10)$ MeV

PRELIMINARY!

Statistically Limited! (larger dataset soon)

Systematic errors on $\mathcal{B}$ estimated to be:

μ detection efficiency (5%)

background, taken as 100% uncertainty (7.4%)

D^+ sample size (1%)

Inclusive Electron Spectrum

We can vastly improve measurements of the lepton spectra in $D \rightarrow Xe\nu$ for both D^+ and D^0 mesons. (and D_s later on!)

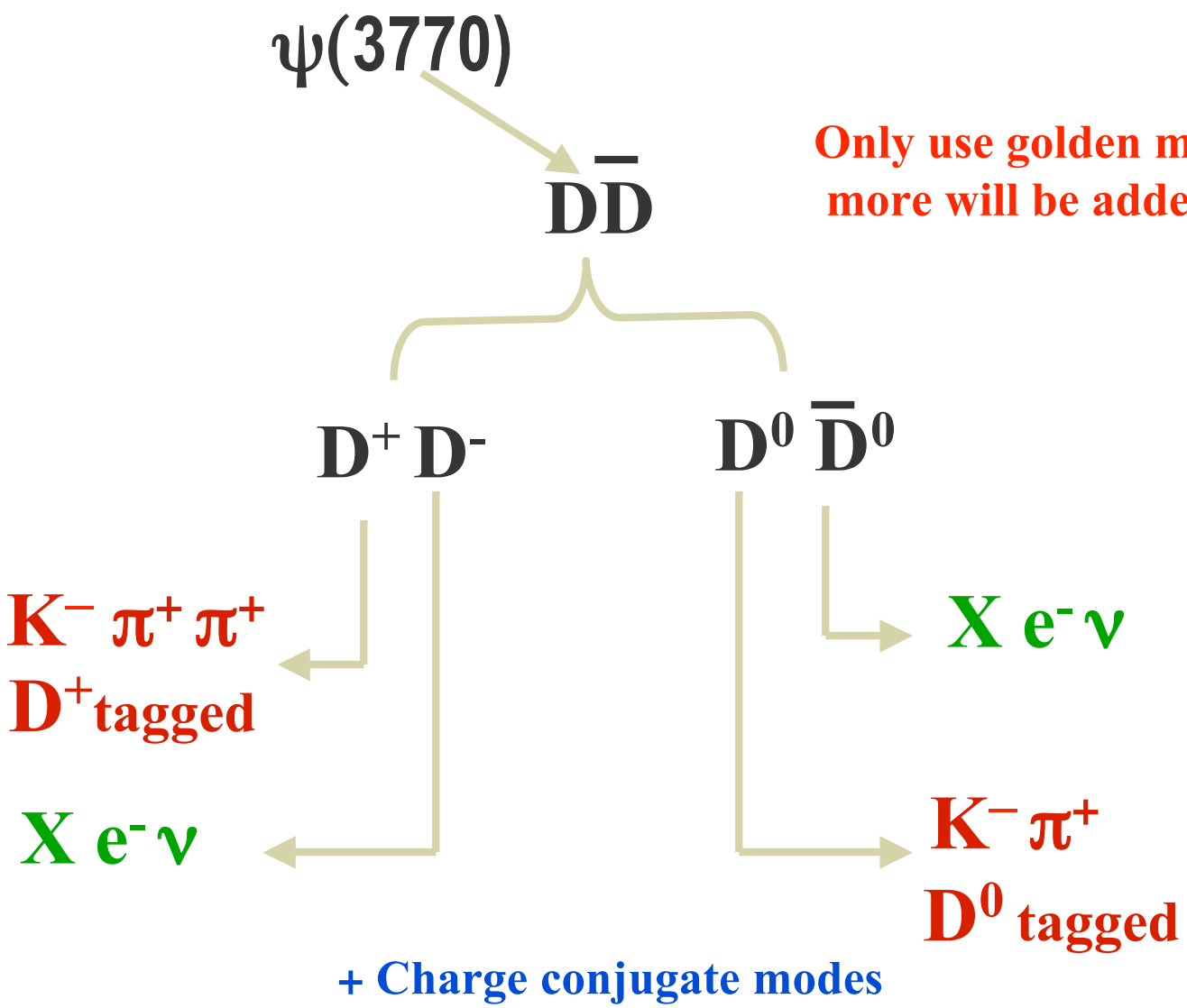
Also extract the inclusive semi-leptonic branching fractions.

Electron identification

optimized by studying radiative Bhabha events

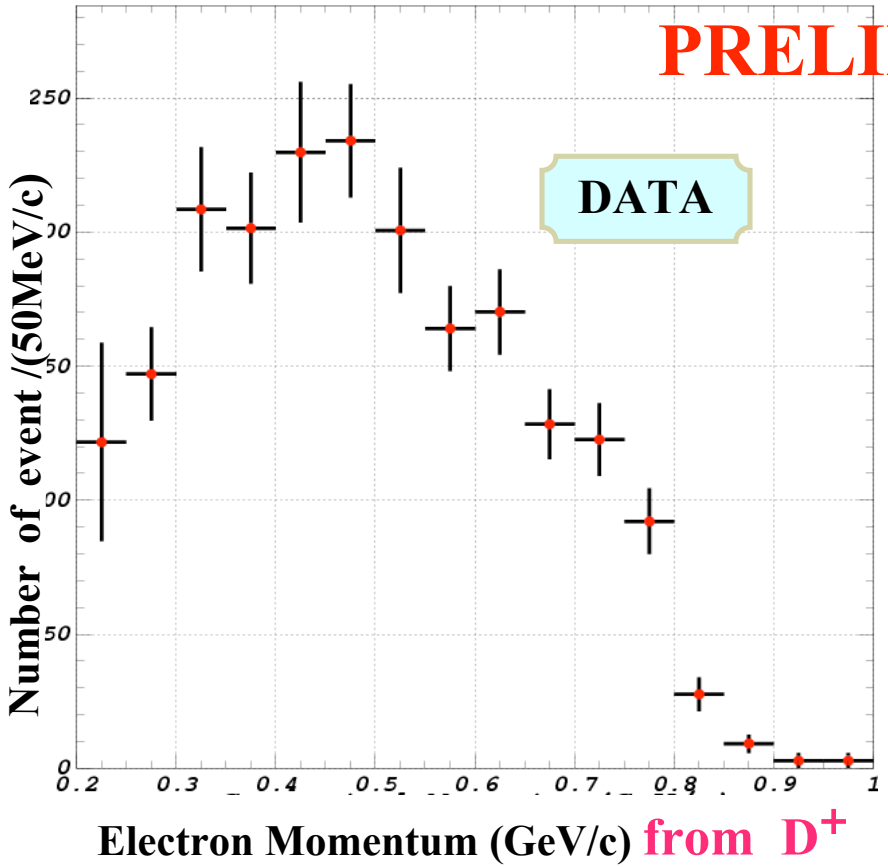
use E/p in the CsI calorimeter, dE/dx, and RICH info

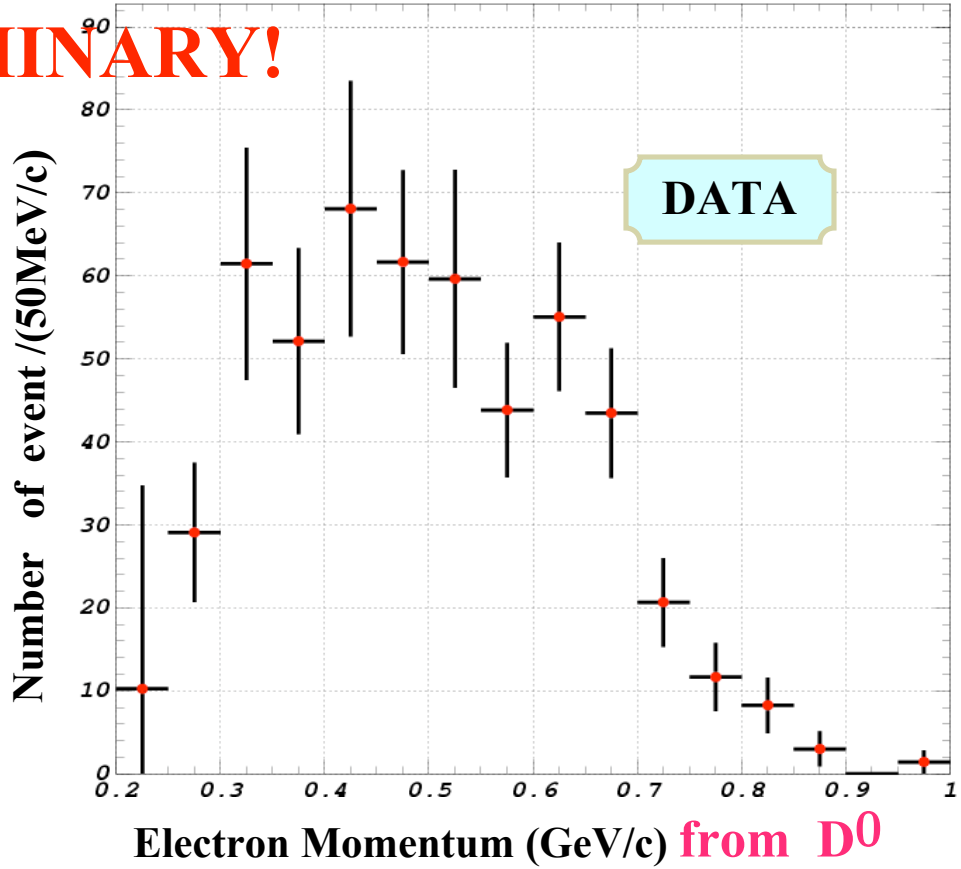
D Meson Samples



The Corrected Electron Spectra

PRELIMINARY!





Statistical Uncertainty ~ 0.6%
PDG: BR = (17.2±1.9)%

Statistical Uncertainty ~0.5%
PDG: BR = (6.75±0.29)%

(Systematic uncertainties not fully evaluated)

Will improve with added tag modes and luminosity

Exclusive Semileptonic Decays

Measurements of the rates and form-factors in exclusive semi-leptonic D decays provide:

Stringent tests of form factor models

Test accuracy of LQCD

Direct Measurements of V_{cs} and V_{cd}

Input for form factor models in the B system (for V_{ub})

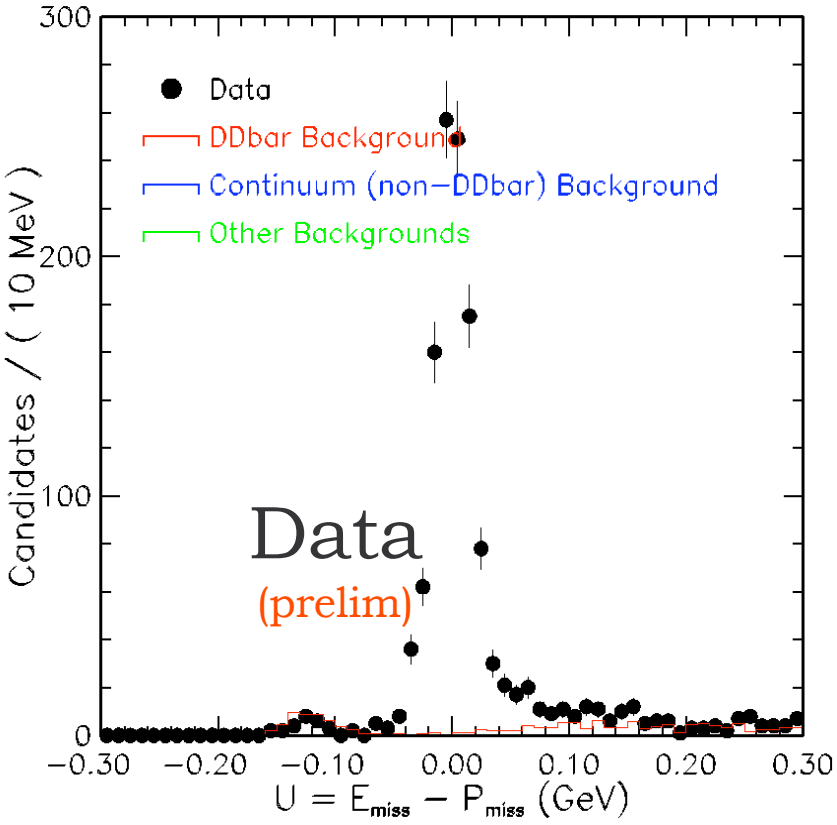
Use many modes for tagged D sample:

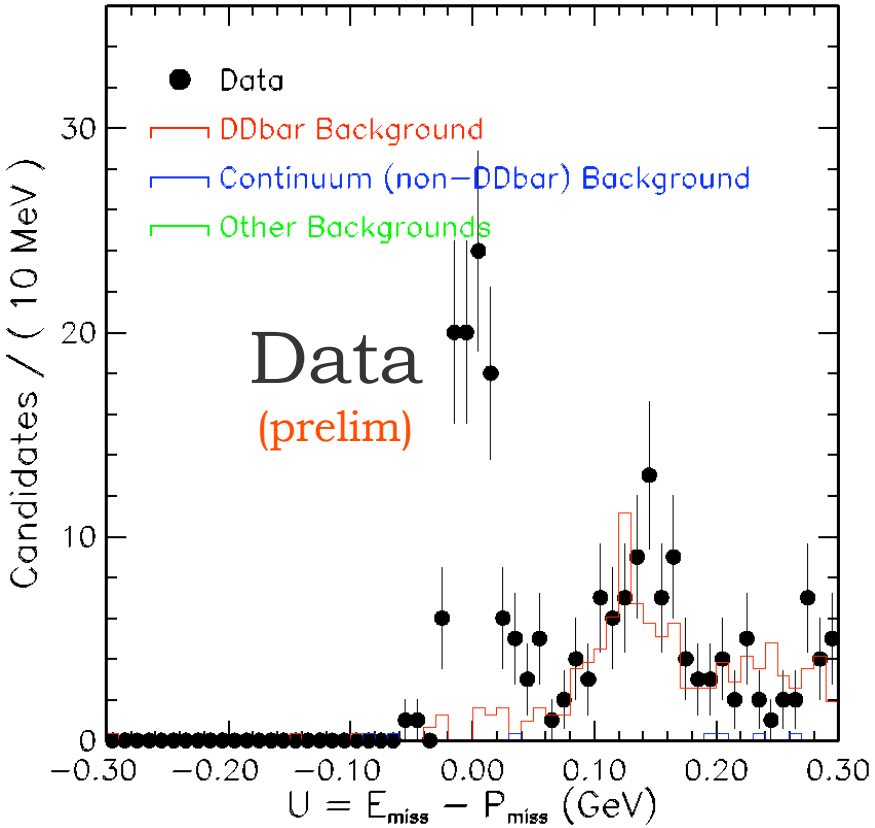
~62K D^0 (7 modes) and ~30K D^+ tags (5 modes)

Identify the remaining tracks/showers in the event;

define $U = E_{miss} - |P_{miss}|$ should peak at zero.

$D^0 \to K^- e^+ \nu$ $D^0 \to \pi^- e^+ \nu$





Excess of ~1.1K events

Cabibbo-allowed

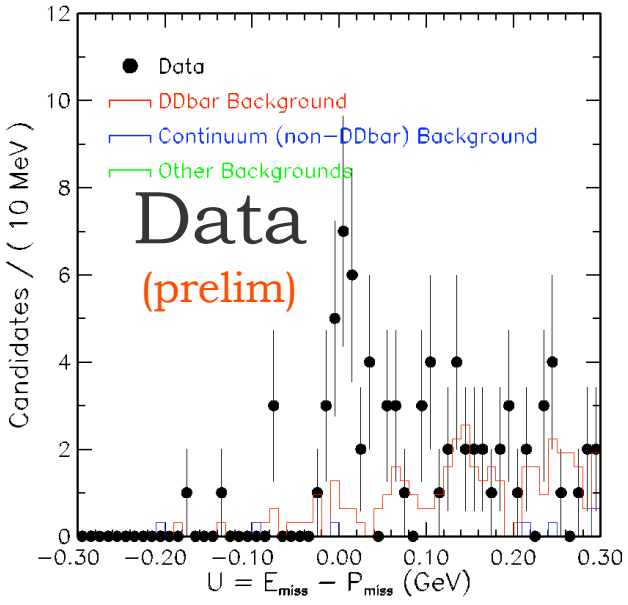
Excess of ~100 events

Cabibbo-suppressed!

ALL PRELIMINARY!

Other D^0 and D^+ Semileptonic Modes

$D^0 \to \rho^- e^+ \nu$

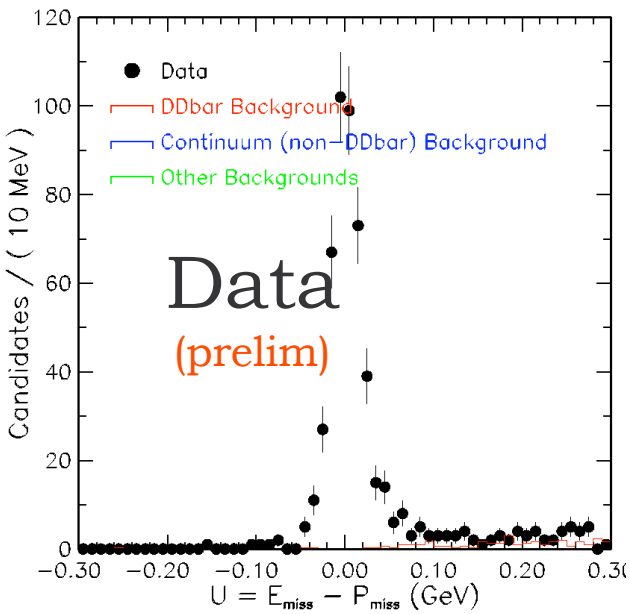


Excess ~25 events

First Observation of this Mode!

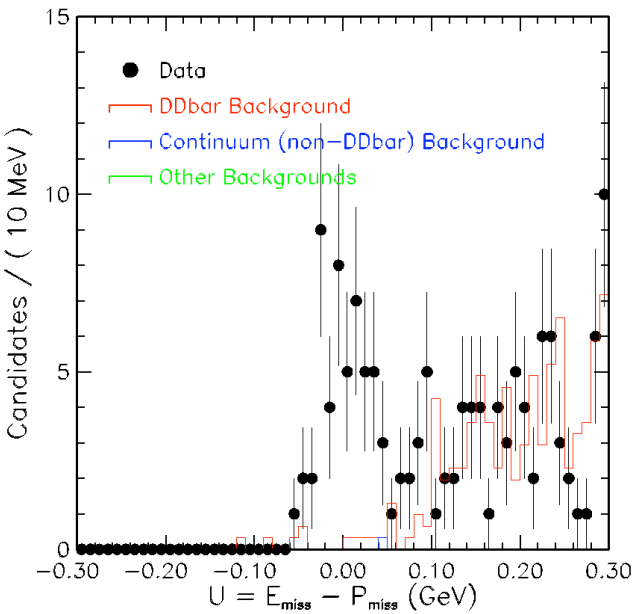
(includes non-resonant…)

$D^+ \to \overline{K^0} e^+ \nu$



Excess of ~400 events

$D^+ \to \pi^0 e^+ \nu$



Excess of ~50 events

50% BR error in PDG!

ALL PRELIMINARY!

CLEO-c Reach for Semi-Leptonics

Initial 55 pb^{-1} data sample already allows measurements of BRs for most or all of the modes considered today with statistical uncertainties comparable or smaller than those in PDG.

CLEO-c is expected to collect much more (up to3 fb^{-1}) data on $\psi(3770)$ as well as data at E_{cm} ~ 4140 MeV for D_s mesons in the coming 2 years.

The CLEO-c data will dramatically improve knowledge of the BRs of charm mesons:

$1: D^0 \to K^- e^+ \nu$

$2: D^0 \to K^{*-} e^+ \nu$

$3: D^0 \to \pi^- e^+ \nu$

$4: D^0 \to \rho^- e^+ \nu$

$5: D^+ \to \overline{K}^0 e^+ \nu$

$6: D^+ \to \overline{K}^{0*} e^+ \nu$

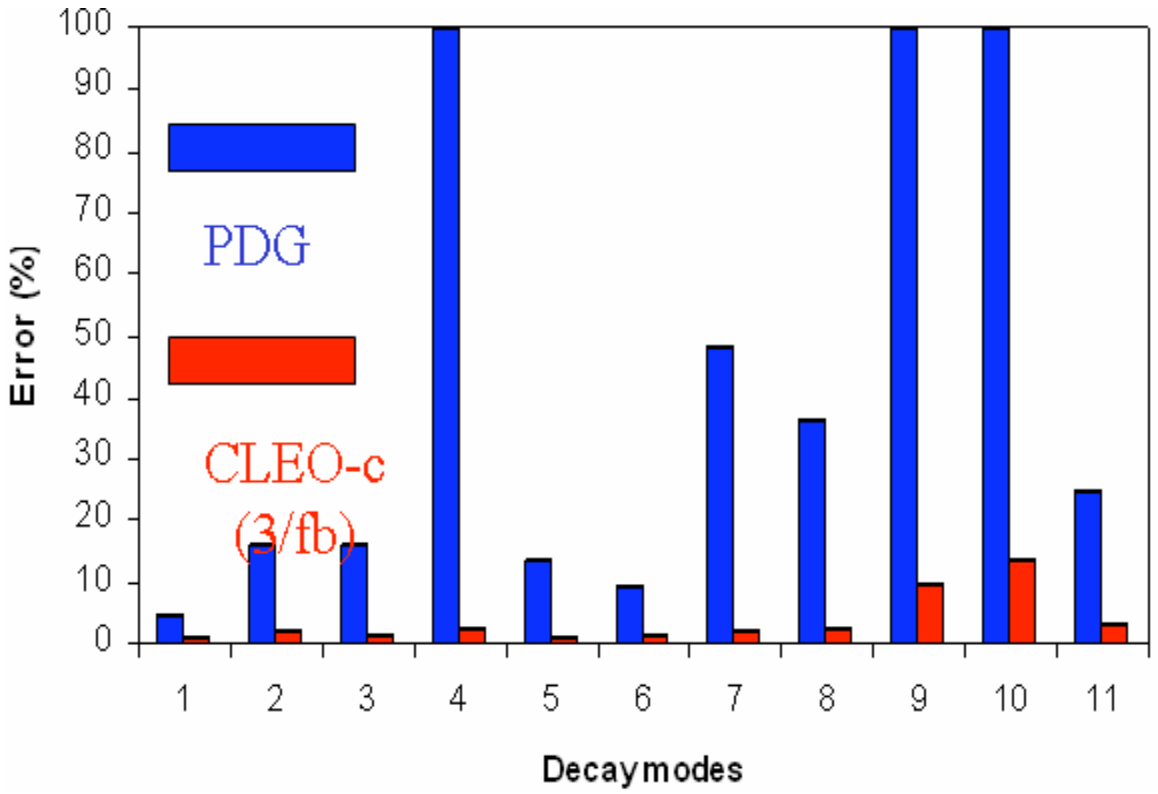
$7: D^+ \to \pi^0 e^+ \nu$

$8: D^+ \to \rho^0 e^+ \nu$

$9: D_s \to K^0 e^+ \nu$

$10: D_s \to K^{*0} e^+ \nu$

$11: D_s \to \phi e^+ \nu$



Summary and Conclusions

CLEO-c Detector is working well; 12 wigglers in soon!

Have ~55 pb^{-1} at the ψ(3770), ~3 pb^{-1} ψ(2S) (+2.5 pb^{-1} pre-CLEO-c)

and ~20 pb^{-1} continuum (below the ψ(2S) at E_{cm} ~ 3.67 GeV)

New low-energy results include:

ψ(2S) decays, including: *many new PV-puzzle modes*

Determination of DD cross section (Absolute BR's soon!)

First significant determination of f_D

Improved determination of inclusive lepton spectrum and BR

Exclusive semileptonic rates and FF soon…

Many analyses still only using golden modes! (i.e., partial tag statistics)

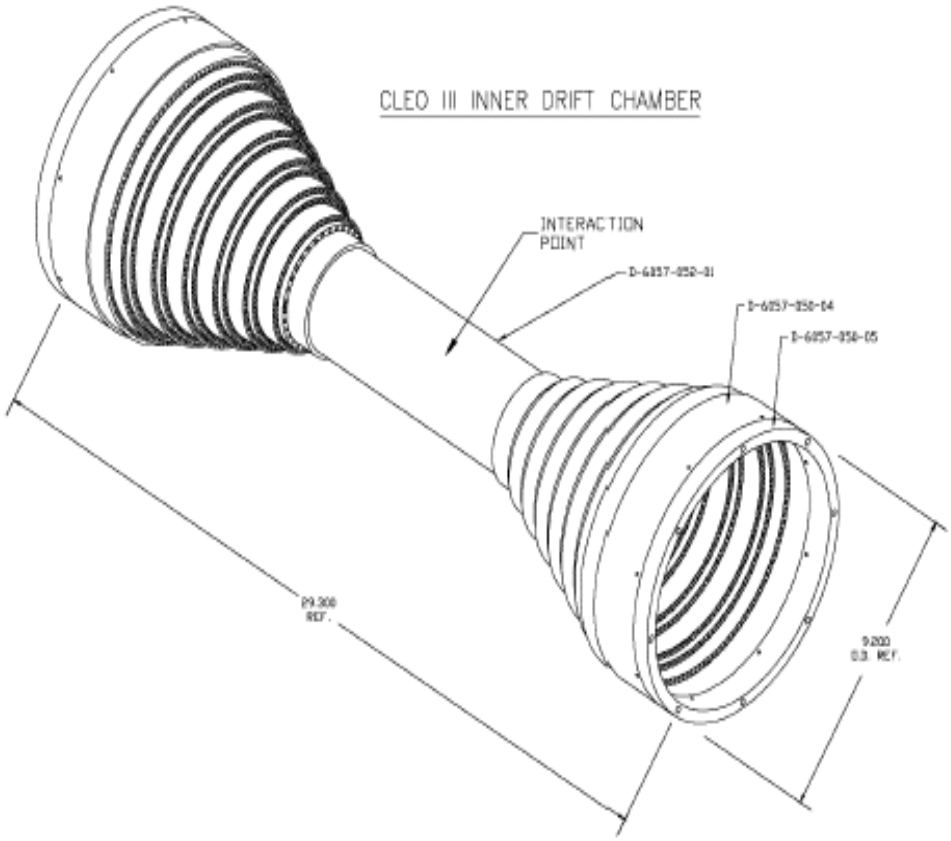
We may collect 50 times more data on the ψ(3770)

Then D_s physics, followed by J/ψ

validation and calibration data for LQCD

CLEO-c running resumes in September.

"ZD" – Inner Drift Chamber

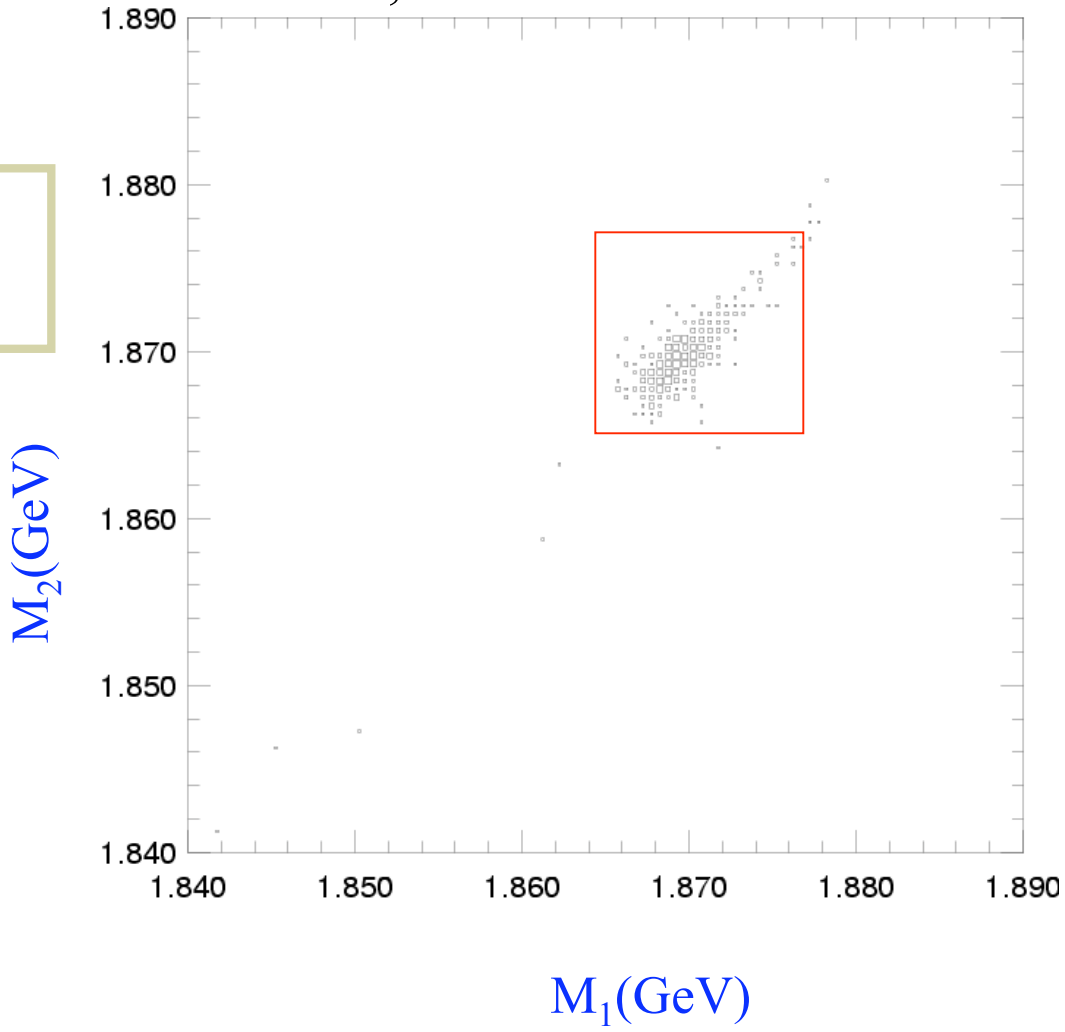


- 6 stereo layers:
  - r=5.3 cm – 10.5 cm
  - 12-15^{o} stereo angle
  - $|\cos\theta| < 0.93$
- 300, 10 mm cells
- 1% X_0, 0.8mm Al inner tube
- 60:40 Helium-Propane
- 20 μm Au-W sense wires
- 110 μm Au-Al field wires
- Outer Al-mylar skin

D^+ Double Tags - Data

- Use the Decays $D^+ \to K^-\pi^+\pi^+, D^- \to K^+\pi^-\pi^-$

Double tags
S=338±19



$\sigma(e^+e^- \to D^+D^-)$=(2.58±0.15(stat) ±0.16(syst))nb