CLEO and **QCD:** from **Beauty** to **Charm**

(High Precision Tests of Theory)

Richard S. Galik

Cornell University

24 June 2002

With **much** thanks to **many** CLEOns!

CESR/CLEO and **CKM**:

Rich 20+ year tradition of **B** physics

Many important discoveries and measurements:

Penguins: $b \rightarrow s\gamma$ (V_{ts})

B^0 Mixing (V_{td})

Rare B decays

V_{ub} and V_{cb}

Etc.

... but **much** more, too!!

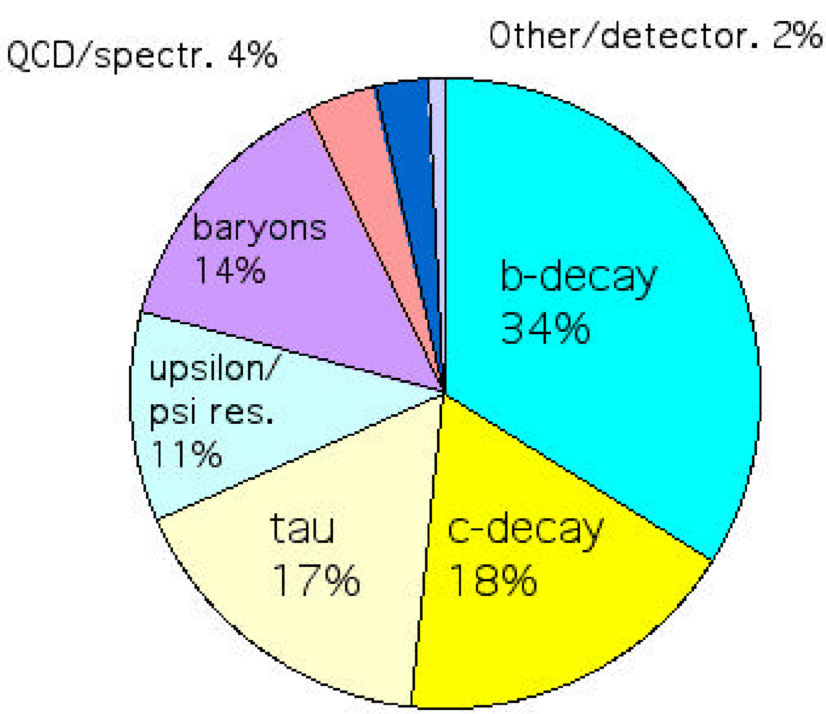
A diverse collaboration with

diverse physics interests!!

The CLEO Collaboration

- Membership:
  - ~20 Institutions
  - ~150 physicists
  - ~1/2 DOE, 1/2 NSF
  - Currently expanding…

- Publication history 1980-
  - ~330 papers
  - diverse physics:



Albany
Caltech
CMU
Cornell
Florida
Harvard
Illinois
Kansas
Minnesota
Northwestern
Ohio State
Oklahoma
Pittsburgh
Purdue
Rochester
SMU
UCSD
UCSB
Syracuse
Vanderbilt
Wayne State

CESR has performed well …

some 24 fb^{-1} in 1989-2001

some 17 million BB pairs in CLEO

… but BaBar/Belle have started up "brilliantly" … 10 fb^{-1} in first year … soon to have 100 fb^{-1}

… **no** competition from CLEO for time-dependent studies

… fading competitive stance for CLEO in rare B decay modes

So, how ***do*** CESR and CLEO continue to contribute ?!

Exploiting the experimental precision of the asymmetric B factories

result = value $\pm\ \sigma_{\mathbf{stat}} \pm\ \sigma_{\mathbf{syst}}$

$\pm\ \sigma_1$ (other experiments)

$\pm\ \sigma_2$ (theory)

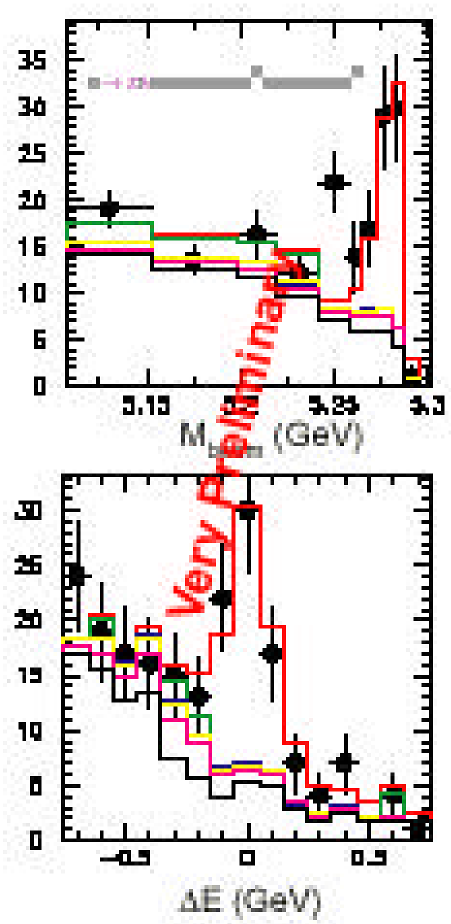
For example:

1) D branching fractions limit any result involving $B \rightarrow D$

2) Strong (NPQCD) uncertainties limit many weak interaction results (sin2β a “gold-plated” exception!)

Ex: b $\rightarrow$ u transitions (V_{ub})

CLEO



- Use $B \rightarrow \pi \ell \nu$ decays; rate gives $V_{\mathbf{ub}}$ -- in principle!
- Experimental precision at the B-Factories could approach 4% in the next 5 years
- Strong interaction effects (*i.e.* the "form factor" for the u quark materializing as a pion) are known to ~20%.

Lattice QCD to the Rescue?

- Only complete definition of QCD
- **Not** a "model" - no fudge factors
- Current (last ~5 yrs) situation: 10-20% accuracy on masses, form factors, etc.
- Can it get to a few percent for:

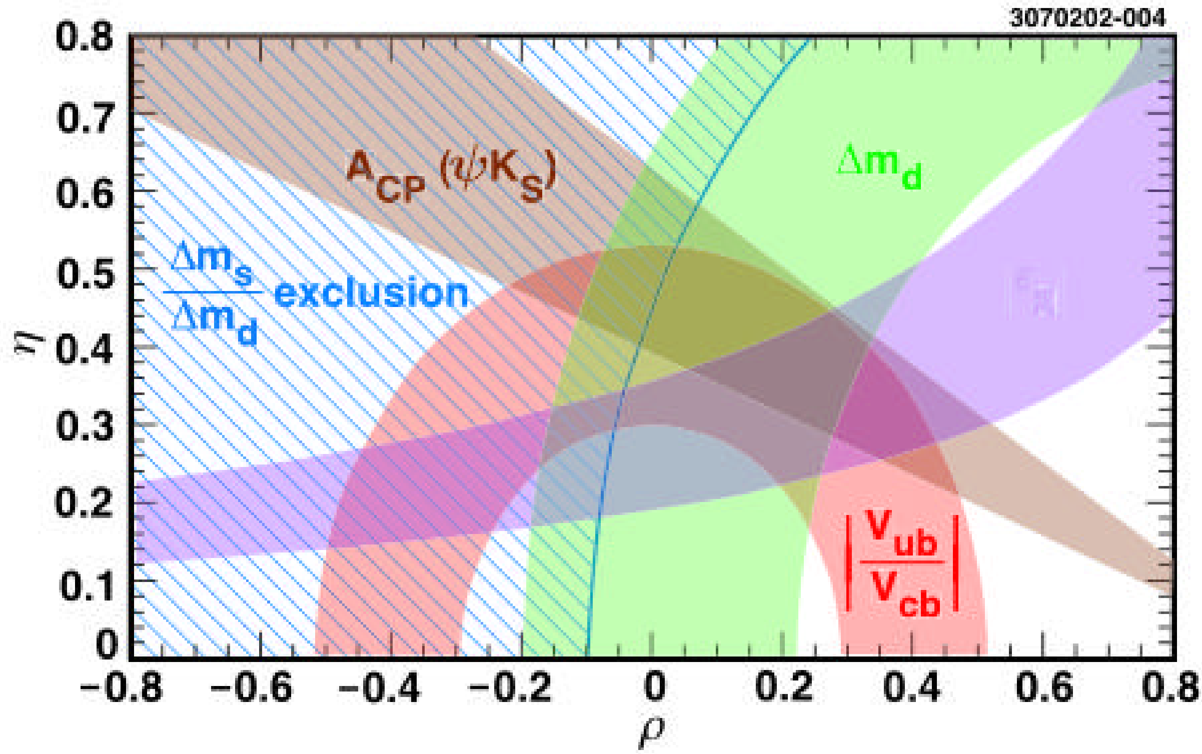
  B and D systems ?

  Υ and J/ψ systems ?

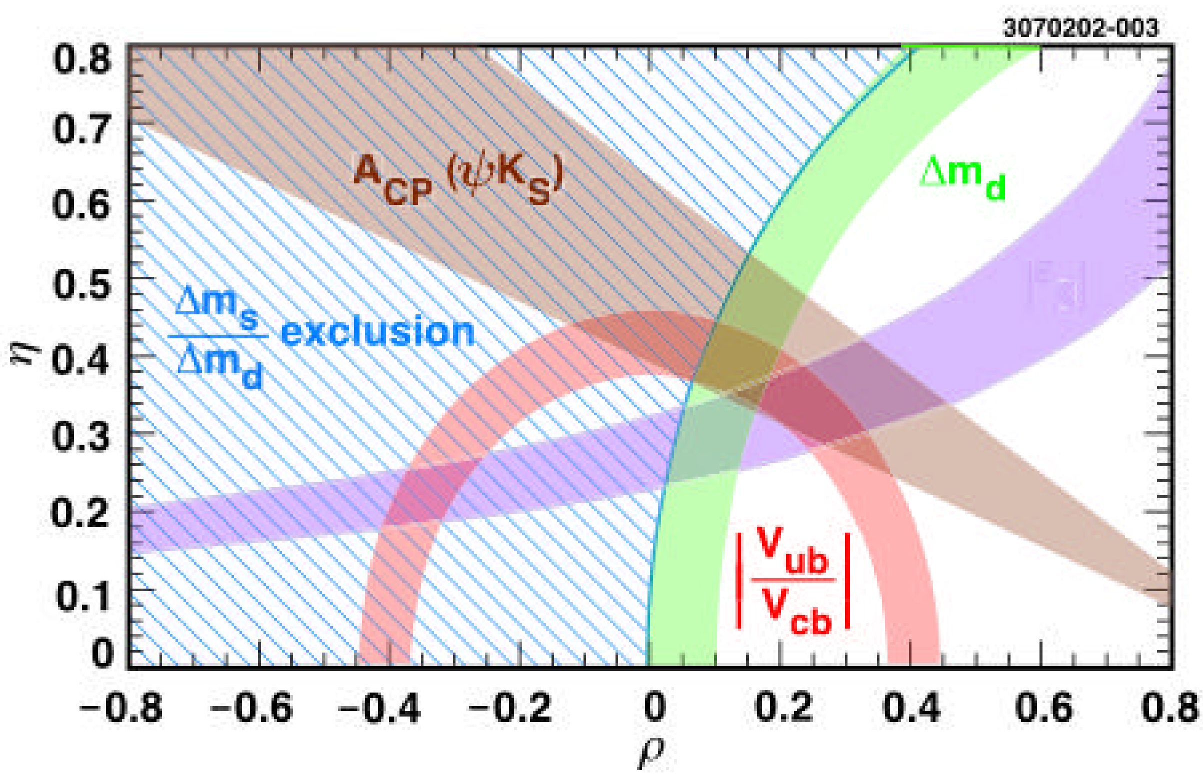
  Light hadron systems ?

  Masses, form factors, rates, etc.?

Flavor physics: CKM "now" (early 2002)



And with 2-3% theory errors:



But, would one believe these small uncertainties?

Need to show that Lattice QCD gets the "right" answer for a number of diverse quantities in b- and c- physics!

That's where the CESRc/CLEOc program fits into this picture!

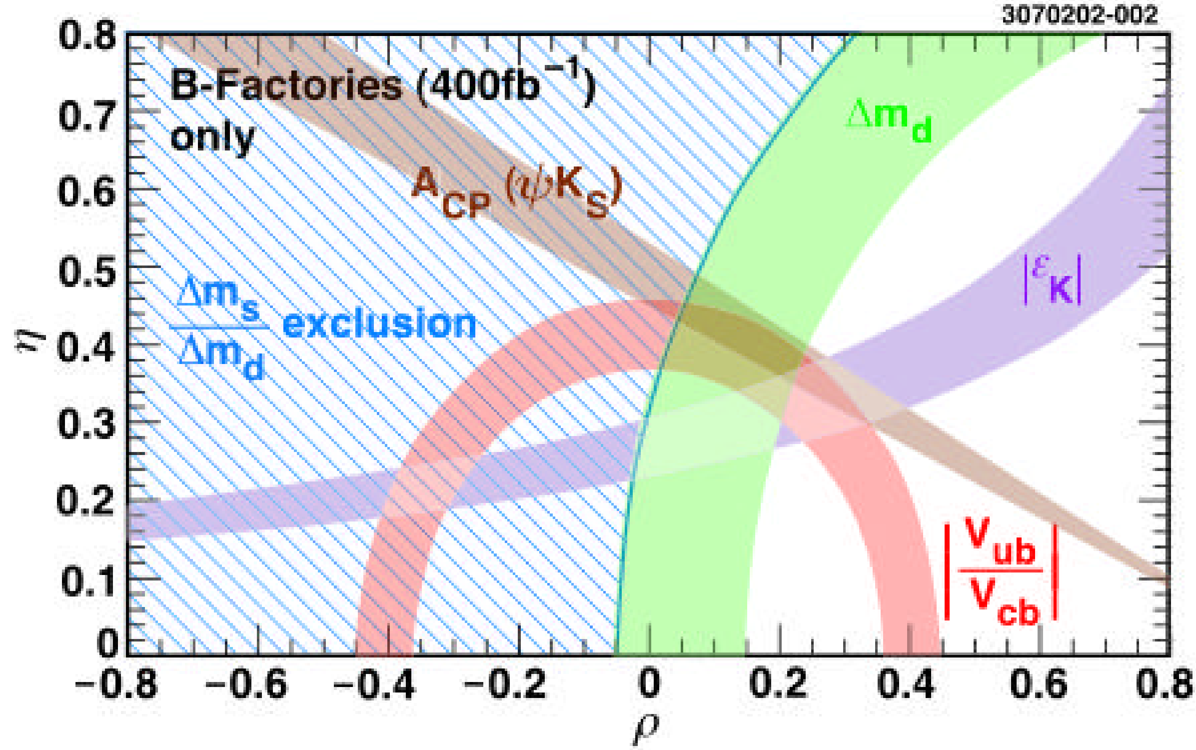
Fixed term, 3-4 year program

Precision QCD tests in b and c

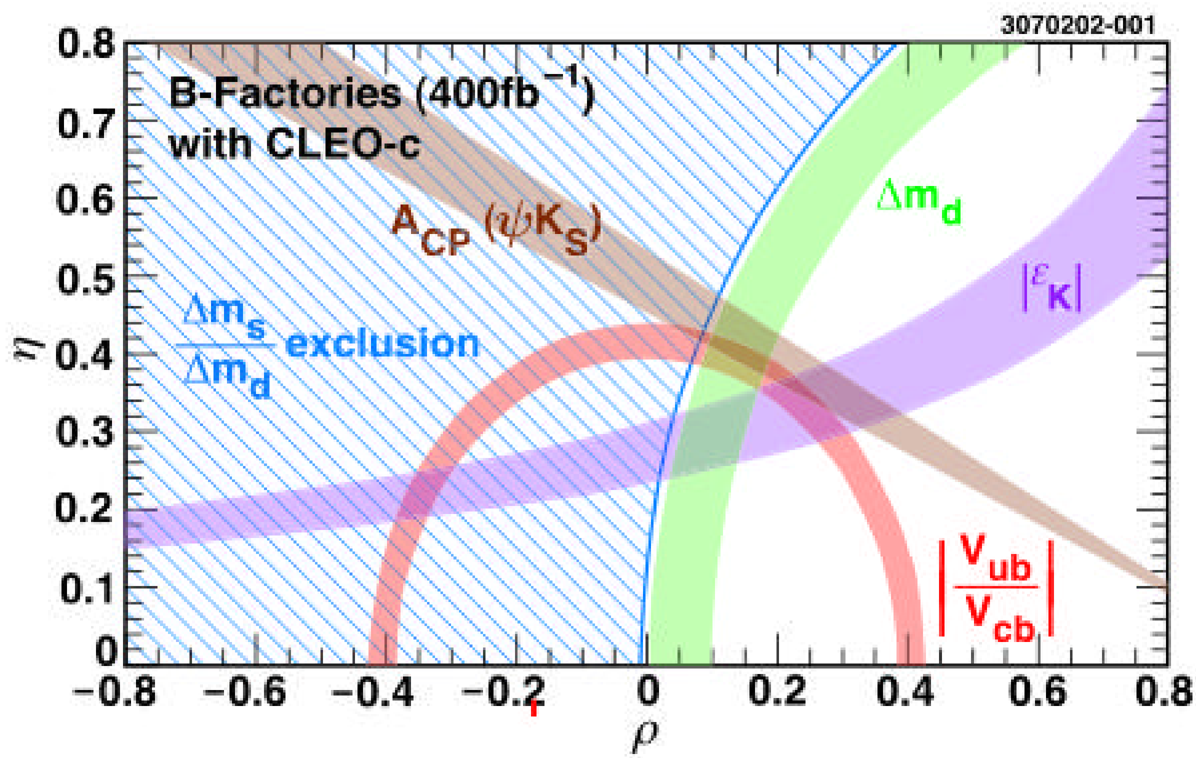
Spans 3 < $\sqrt{s}$ < 12 GeV!

See CLNS 01/1742 ("Yellow Book") or http://www.lns.cornell.edu for Project Description

B-Factories + 10% theory errors



B-Factories + 2-3% thy err (CLEO-c):



The CLEO-c Program !

2002

Prologue: Upsilons ~1fb^{-1} each

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

Spectroscopy, Matrix Elements, Γ_{ee}

10-20 times existing data

In the works

2003

Act I: $\psi(3770)$ -- 3 fb^{-1}

30M events, 6M *tagged* D decays

(310 times MARK III)

2004

Act II: $\sqrt{s}$ ~ 4100 -- 3 fb^{-1}

1.5M D_sD_s, 0.3M *tagged* D_s decays

(480 times MARK III, 130 times BES II)

2005

Act III: $\psi(3100)$ -- 1 fb^{-1}

1 Billion J/ψ decays

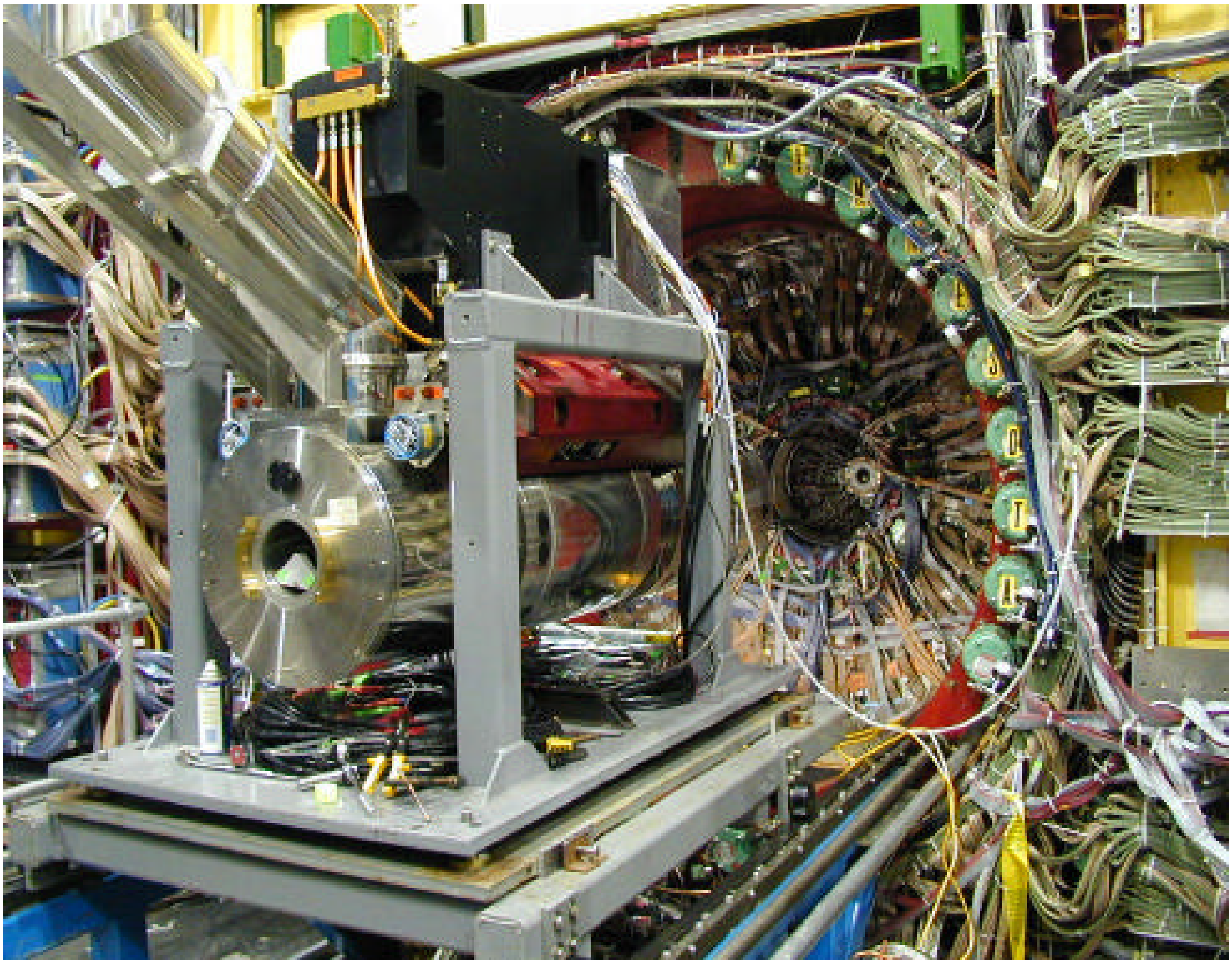
(170 times MARK III, 20 times BES II)

CESR-c: QCD from c to b

CESR needs to be able to run at all beam energies from 1.5 GeV (J/ψ) to 6.0 GeV (Λ_b pair threshold).

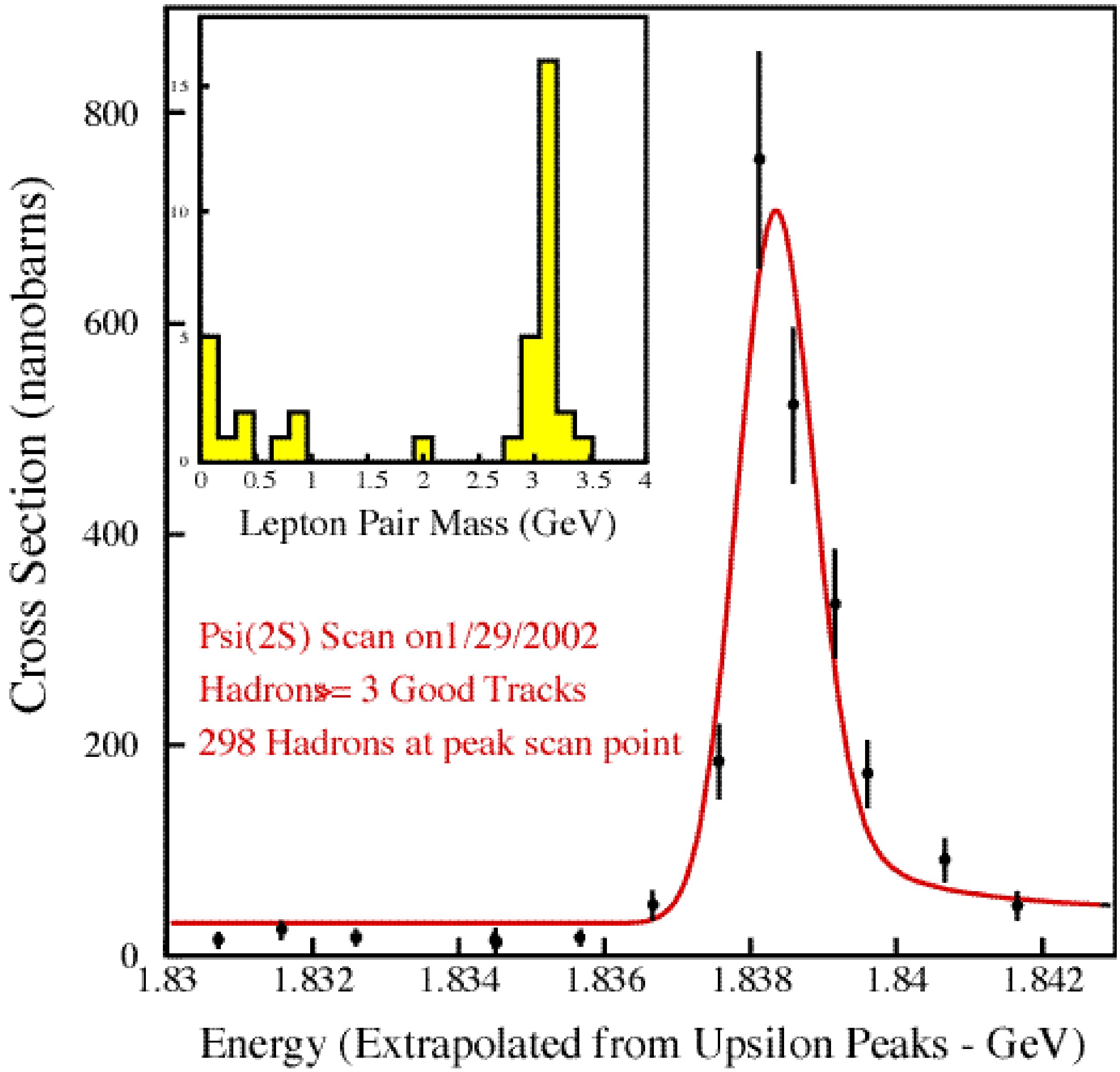
Superconducting IR magnets installed in 2001 … multiple functions… work great!

Provide increased flexibility and focusing!



Superconducting IR Magnet Assembly
Being Installed into CESR/CLEO

CESR Running NOW in the J/ψ Region



Energy and cross section look great!

CESR-c: QCD from c to b

At low energies CESR needs to greatly increase the “cooling” of the beams via synchrotron radiation (SR) to “damp” oscillations, increase injection rate, lower instability thresholds!

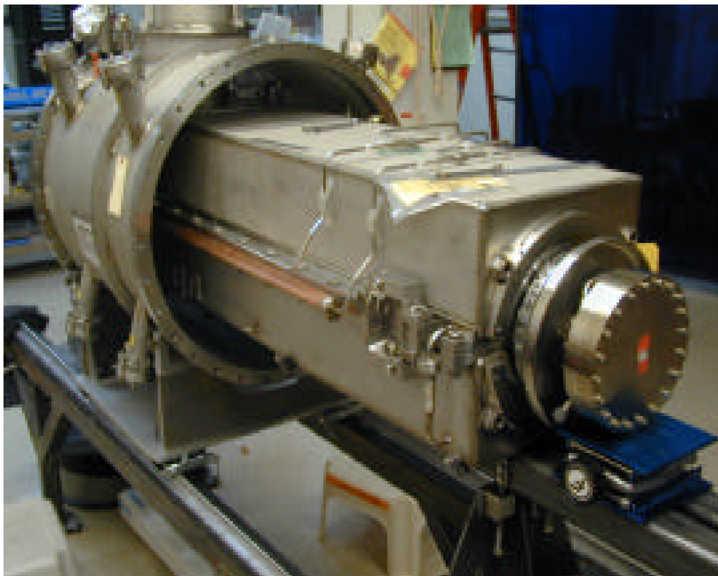
Solution? Wigglers!

- Similar to SR insertion devices
- Needed for LC damping rings
- Superferric design at 2.1 T
- Need 14 units, each 1.4 m long

Prototype Performance?

- Run “cold” at 125% design current
- Undergoing final field quality tests
- Insertion this summer!

First Wiggler is Ready!



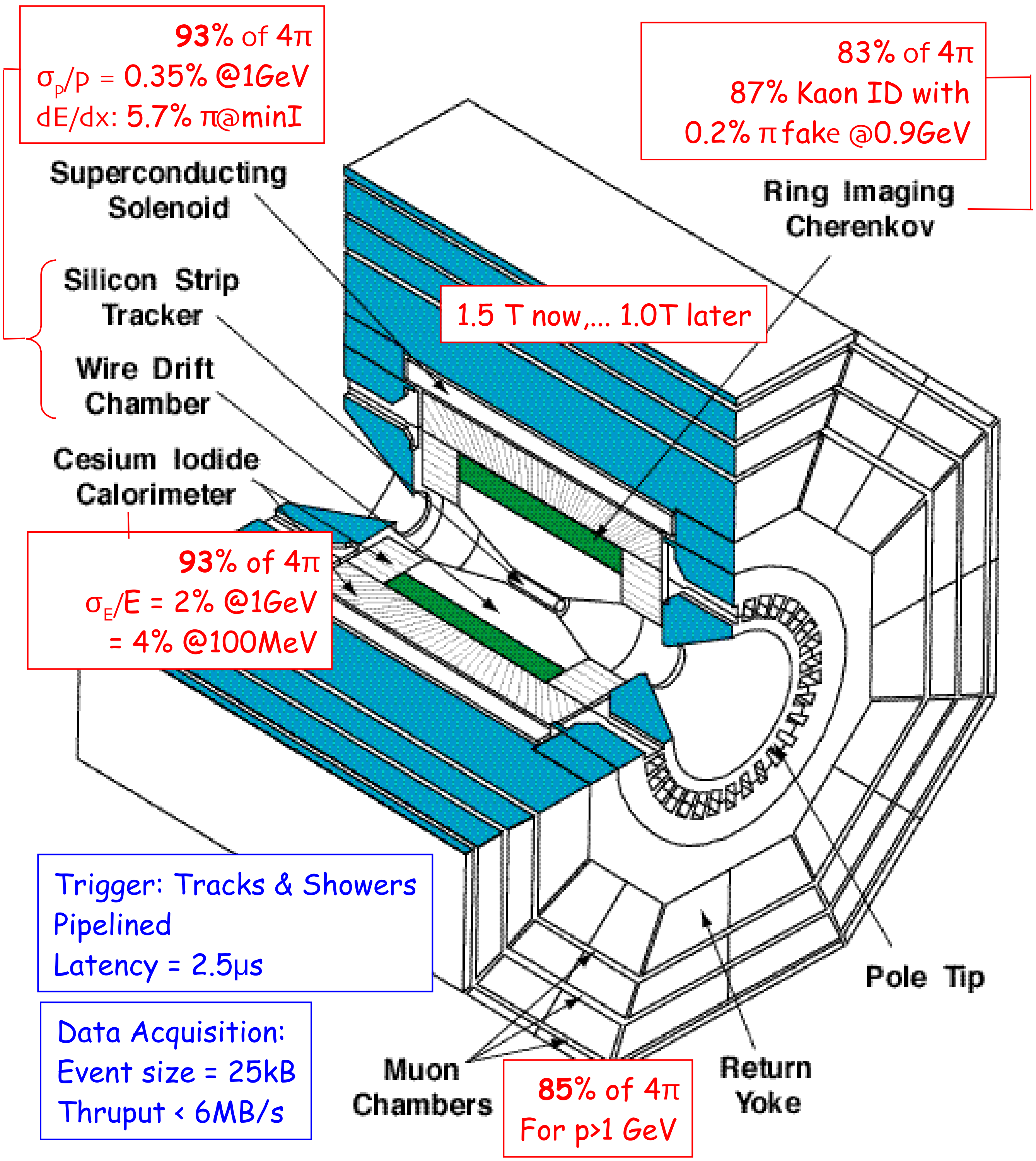
Being inserted into final cryostat after initial tests!

In L-He staging area for final tests!

To be installed early August!

… Five more in early 2003!

The CLEO III Detector



From CLEOIII to CLEO-c

Great drift chamber!

Great EM calorimeter!

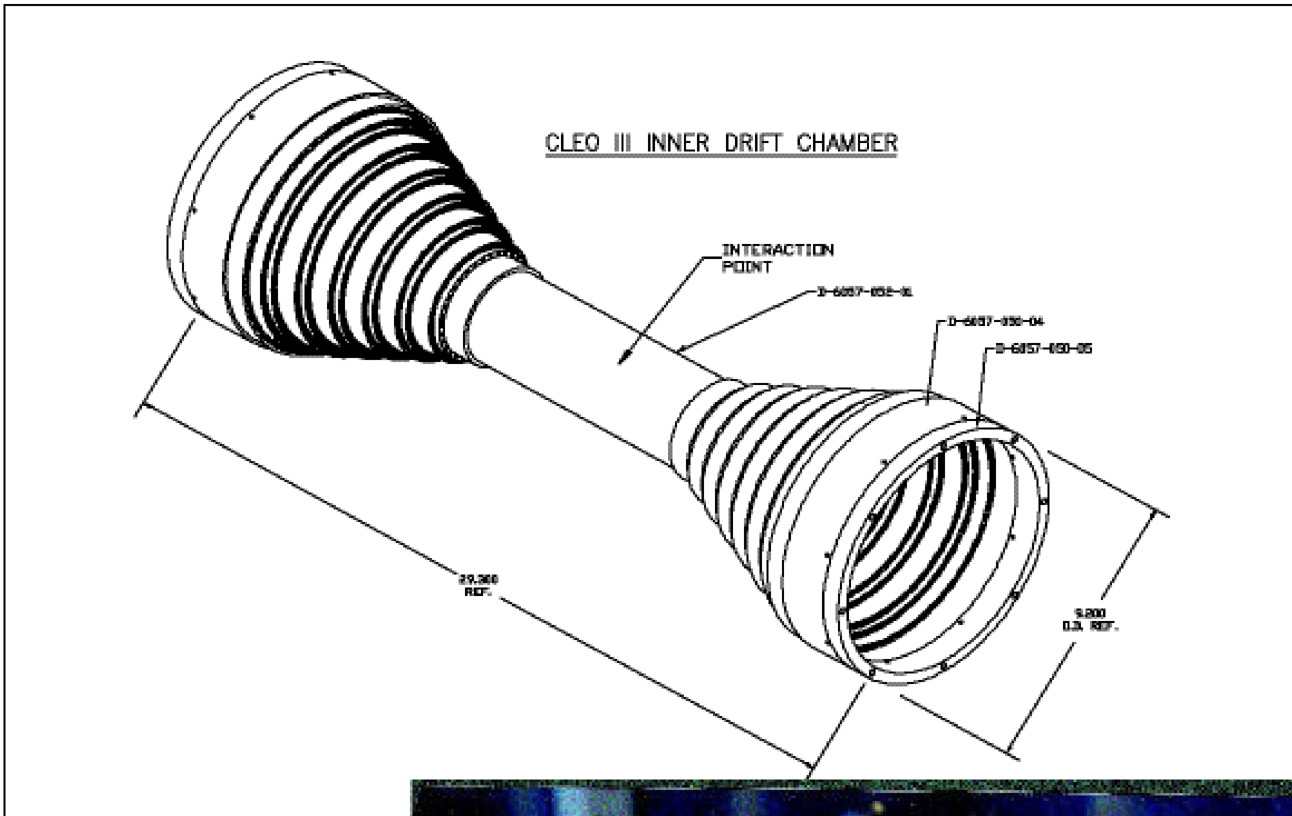
Great particle ID (RICh) !

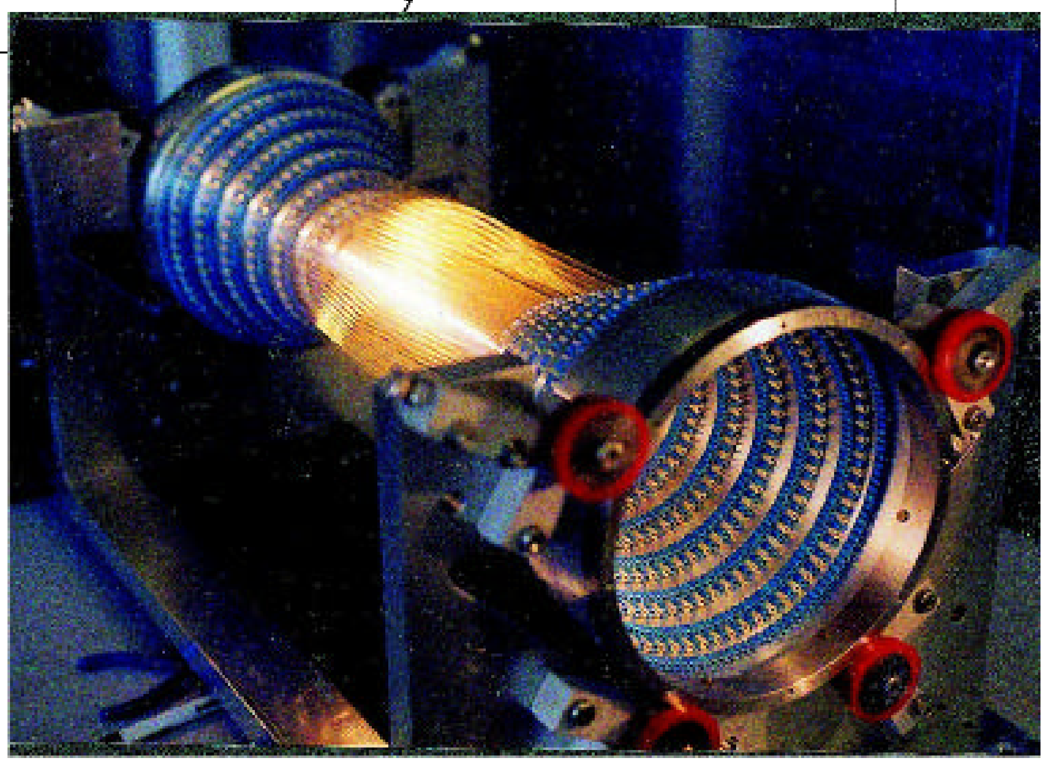
Great trigger and DAQ!

... but aging silicon vertexer

New small wire chamber!

- Small cell, 6 layers, stereo
- Extensive performance studies
- **Built** ... HV tests soon
- Installation: Early 2003

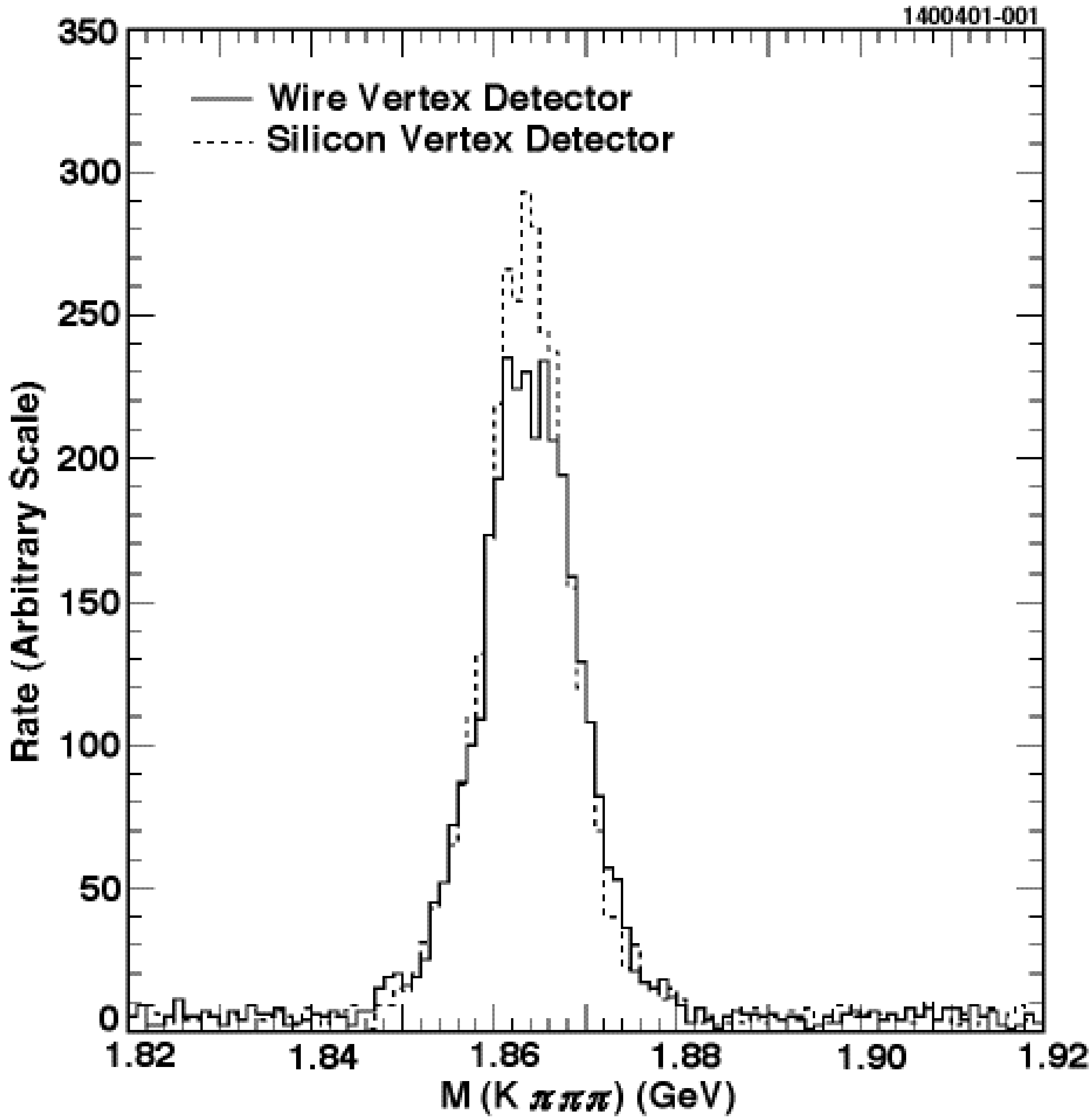




ZD!!

Strung and being tested

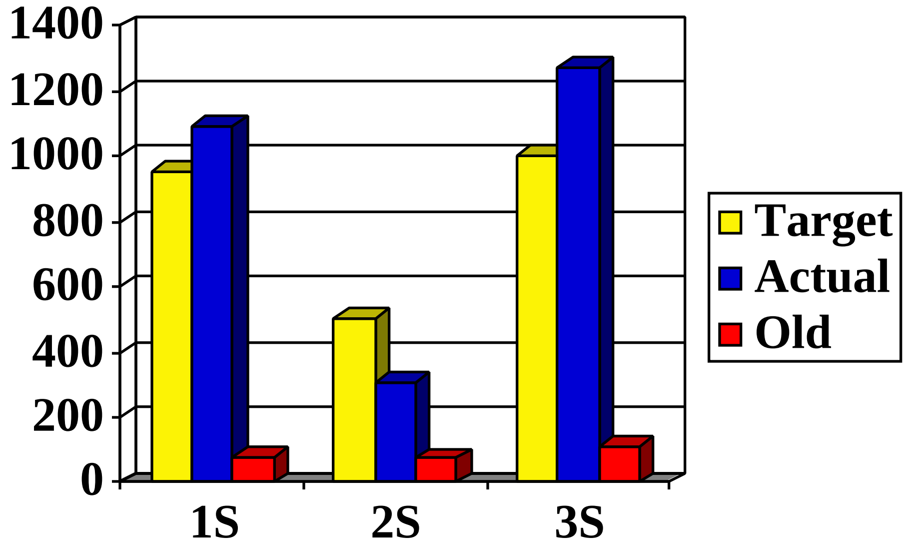
Relative Performance of New Wire Chamber



Assumes "optimistic" degradation of silicon vertex detector

Status of Υ Running

	Υ(**1**S)	Υ(**2**S)	Υ(**3**S)
Target	950	500	1000
Actual	1090	304	1270
Old	79	74	110
Status	Taken	In Progress	Processed



All in pb^{-1} for "on-resonance"

Also have "continuum" and scan data!

Two groups of Υ analyses

"**Discovery**":

D-states: (L = 2)

η_b and h_b singlets

Rare transitions (E1, had.)

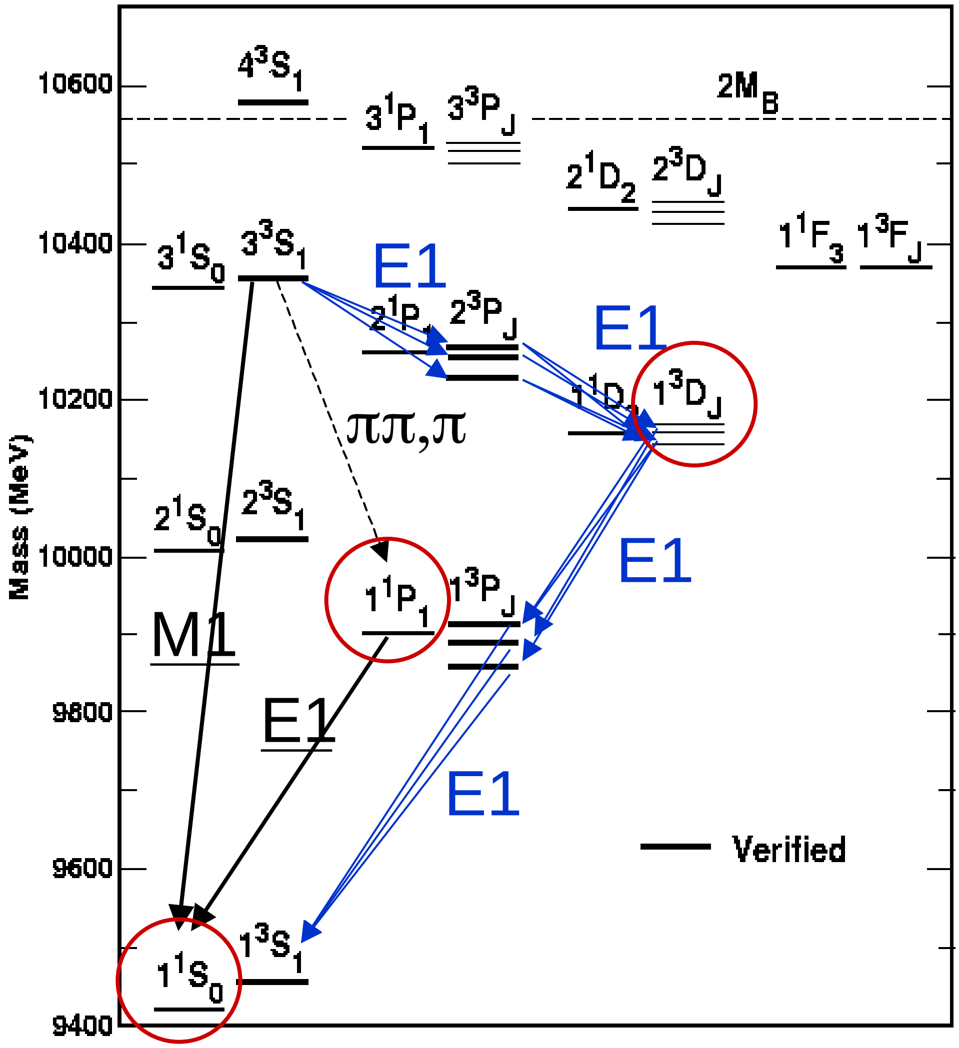
"**Precision**":

Γ_{ee}

$\mathcal{B}_{\ell\ell}$ and Γ_{tot}

hadronic transitions

Υ Discovery Potential

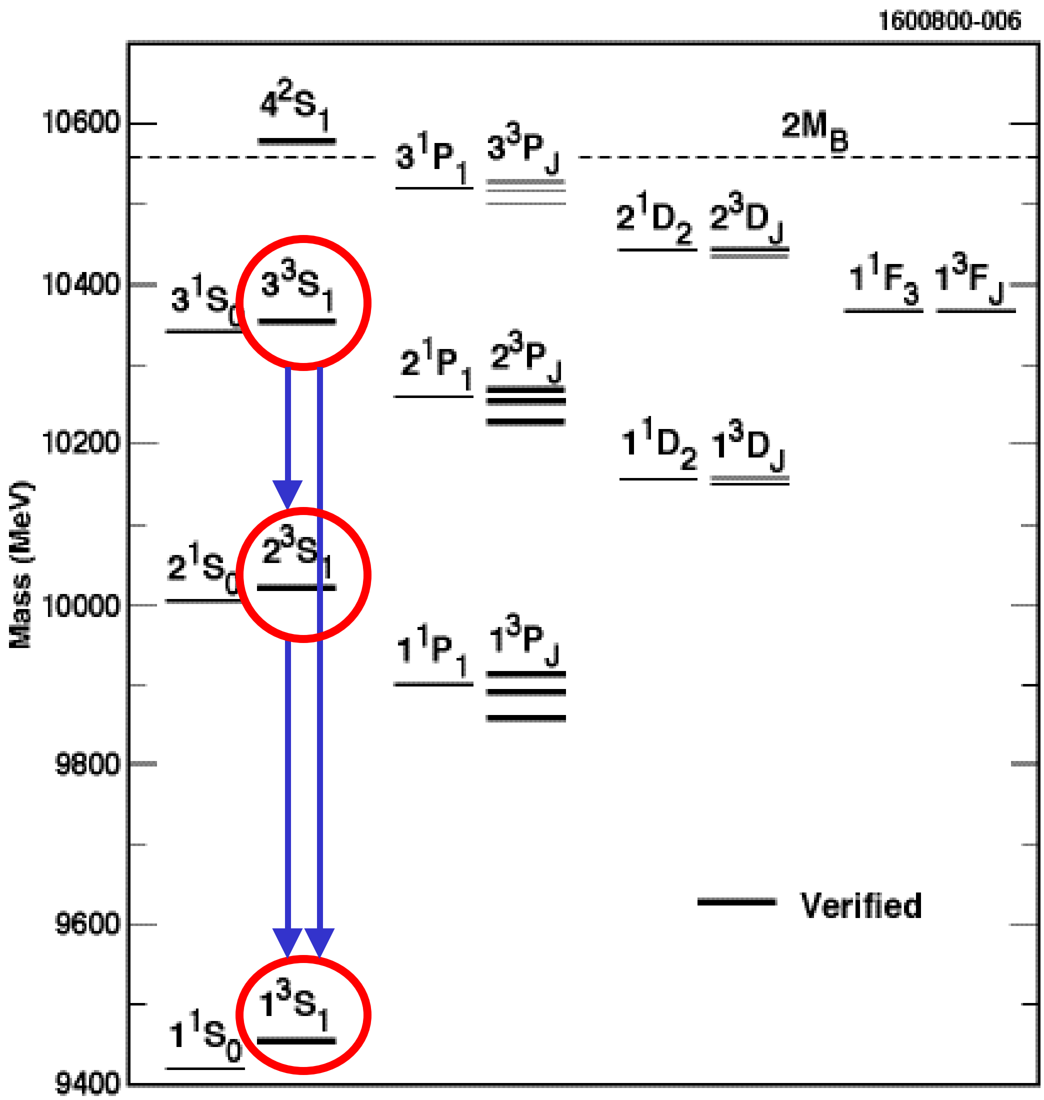


D-states

Singlets η_b and h_b

Rare transitions (h, **E1**)

Precision Υ Analyses

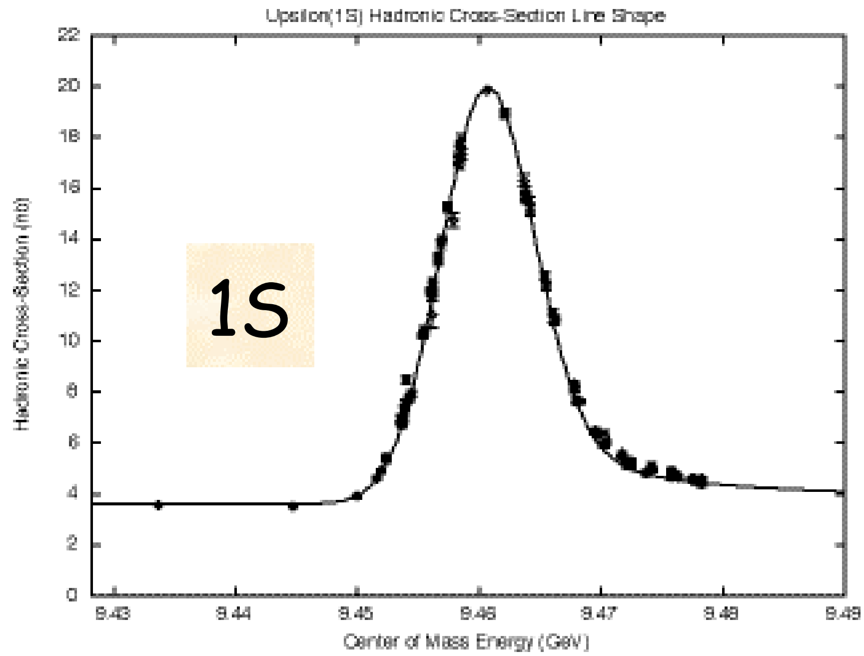


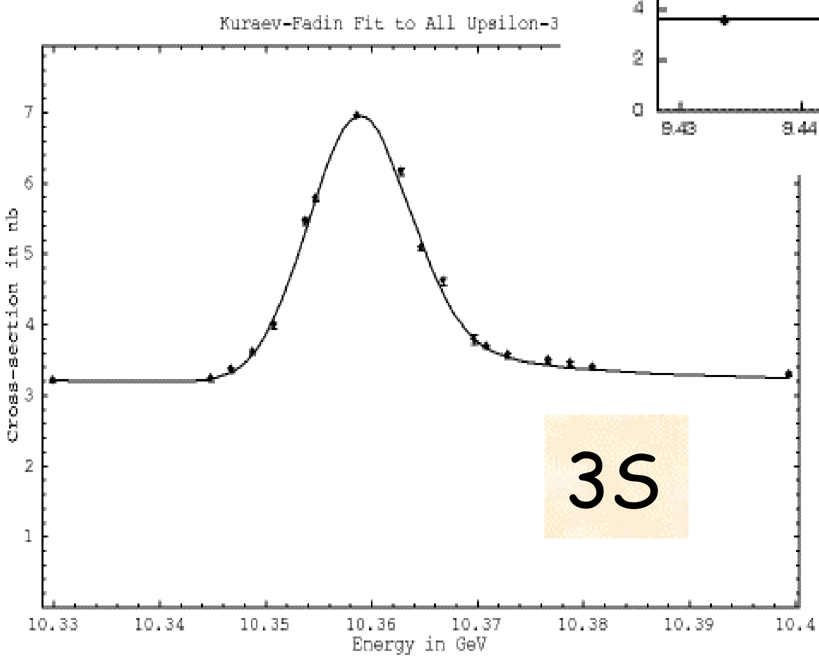
Γ_{ee} to 2-3% each (better for ratios)

$\mathcal{B}_{\mu\mu}$ to 3-4% each; Γ_{tot} to 5%

Vastly improved $\pi\pi$ studies

Υ Scans of the Lineshape





"Raw" data shown

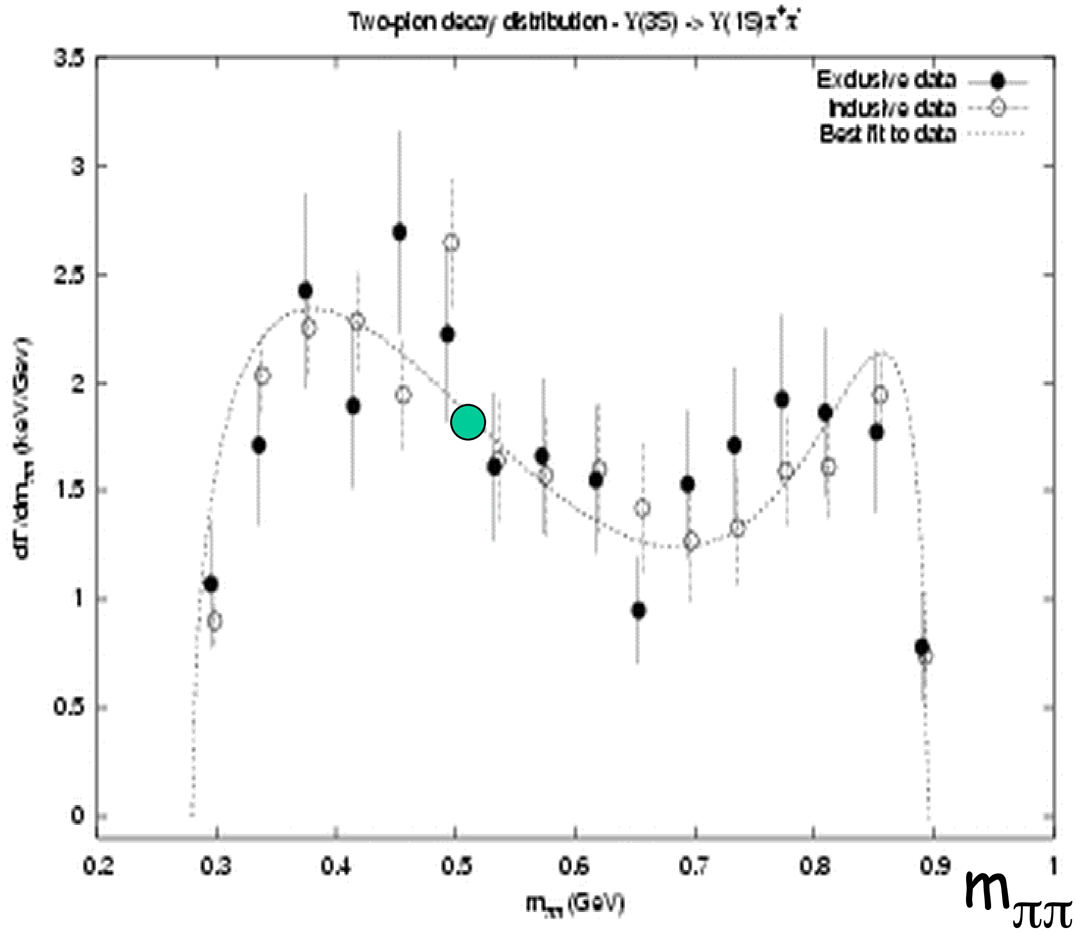
Integrated to give Γ_{ee}

Great attention paid to syst biases

Also determine $\mathcal{B}_{\mu\mu}$ and then Γ_{tot}

DiPion Invariant Mass

$\Upsilon(3S) \rightarrow \Upsilon(1S)\pi^+\pi^-$



Data with errors - CLEOII

Fit - Lahde and Riska

New CLEO statistics:

Charmed Hadrons in CLEO-c

Data samples:

ψ (3770): 3 fb^{-1} (1 "year")
30M events
~6M *tagged* D decays

$D_S D_S$: 3 fb^{-1} (1 "year")
1-2M $D_S D_S$
0.3M *tagged* D_S decays

Analyses (a sampler):

"Tagging" of D and D_s

Double Tags (Branching Fractions)

Leptonic Decays (f_D and f_{Ds})

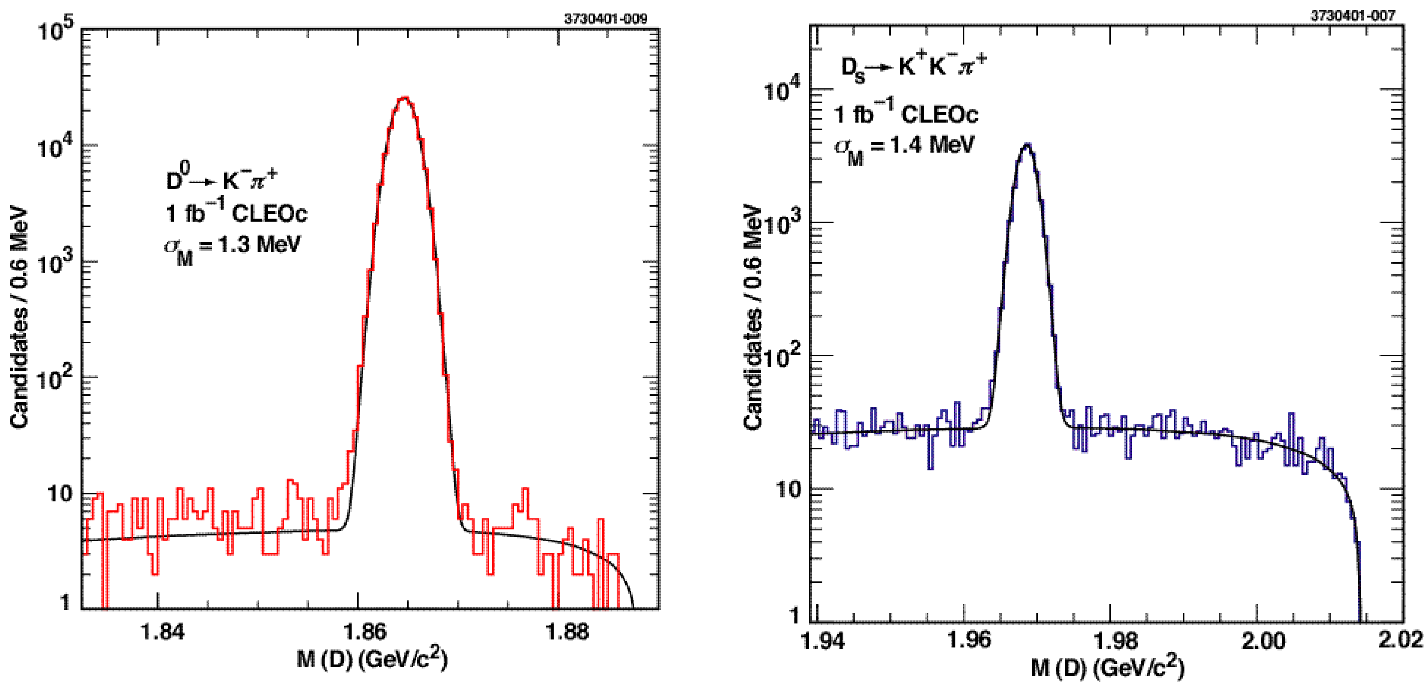
Semi-leptonic Decays (f_+/f_D)

Tagging Technology

- Pure $D\bar{D}$ or $D_s\bar{D}_s$ production
  - ✓ Many **large** branching ratios (~1-10%)
  - ✓ **High** reconstruction efficiencies
  - ✓ **Two** chances !

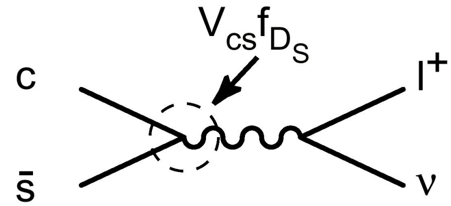
→ high net efficiency ~20% !

$D \to K\pi$; S/B ~ 5000 $D_s \to KK\pi$; S/B ~ 100



Beam Constrained Mass

$D_S \rightarrow \mu\nu$



CLEO (4.8 fb^{-1}):

f_{Ds}=280±14±25±18

stat/sys/φπ

partial width:

$$\frac{G_F^2}{8\pi} M_{D_S} m_\mu^2 (1 - \frac{m_\mu^2}{M_{D_S}^2}) f_{D_S}^2 |V_{cs}|^2$$

BaBar/Belle:(400 fb^{-1}):

$\delta f_{Ds} / f_{Ds}$: 4-8%

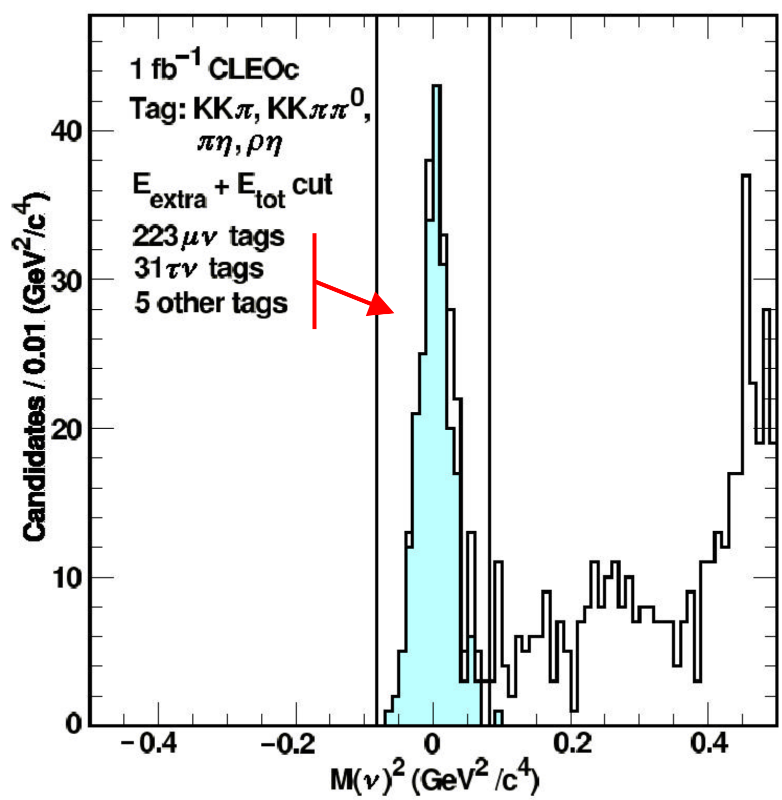
3 fb^{-1}: ~900 events

- 10 Tag Modes
- Minimal Selection Criteria
- NO μ PID

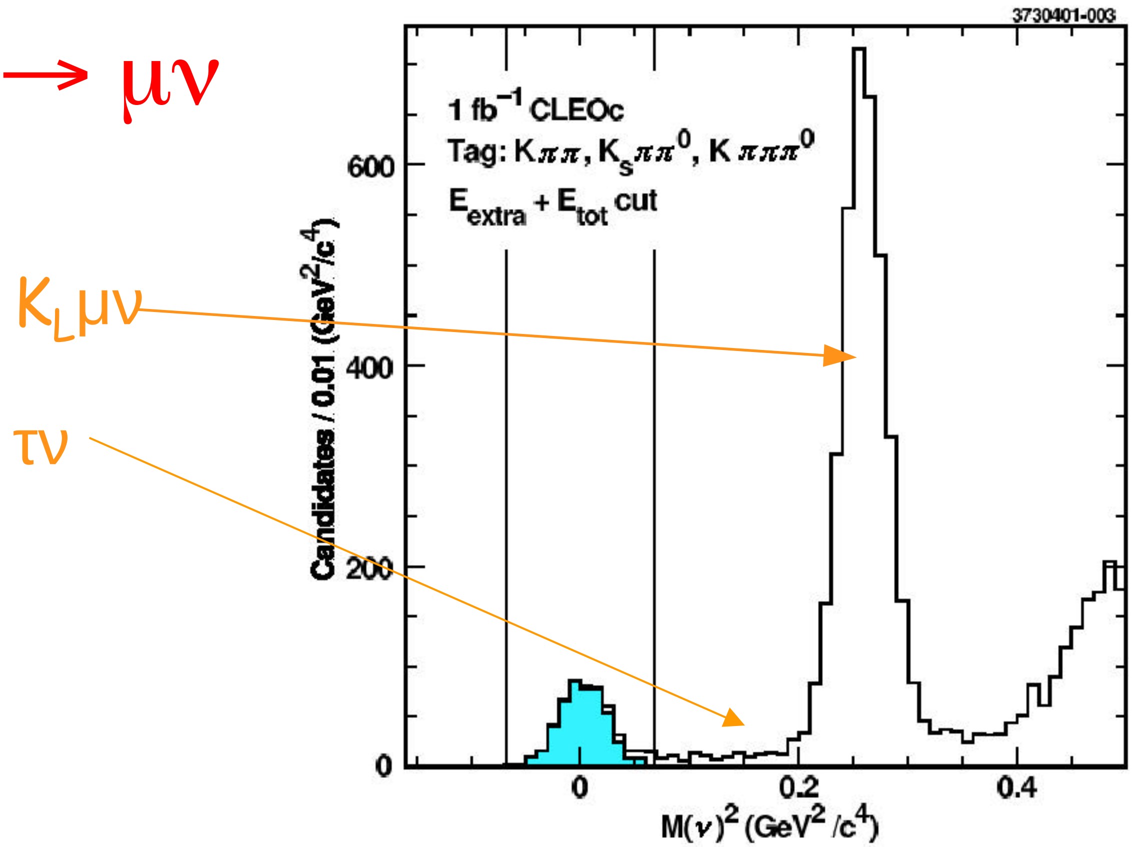
$\delta (Vf_{Ds})/(Vf_{Ds})$:

(2.0 ± 0.25 ± 1.0)%

Stat /syst/ lifetime



$D^+ \to \mu\nu$



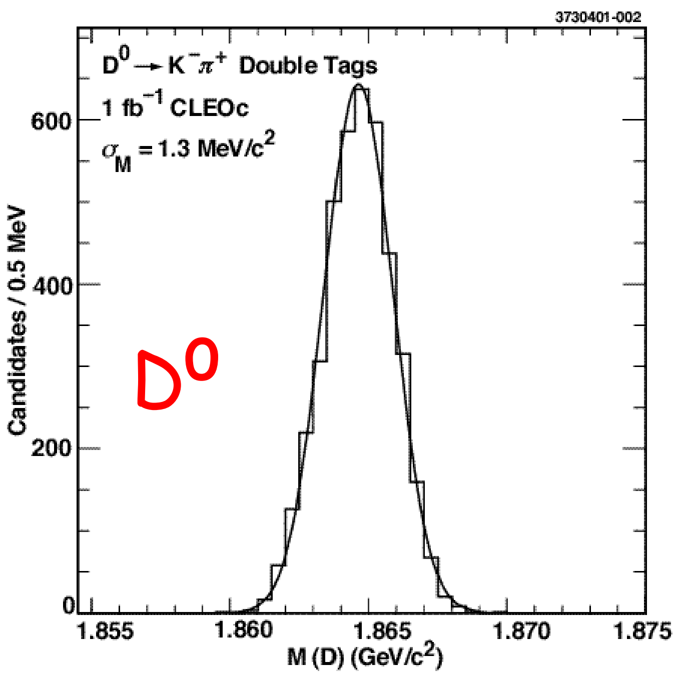
CLEO-c: 3 fb^{-1} on ψ (3770)

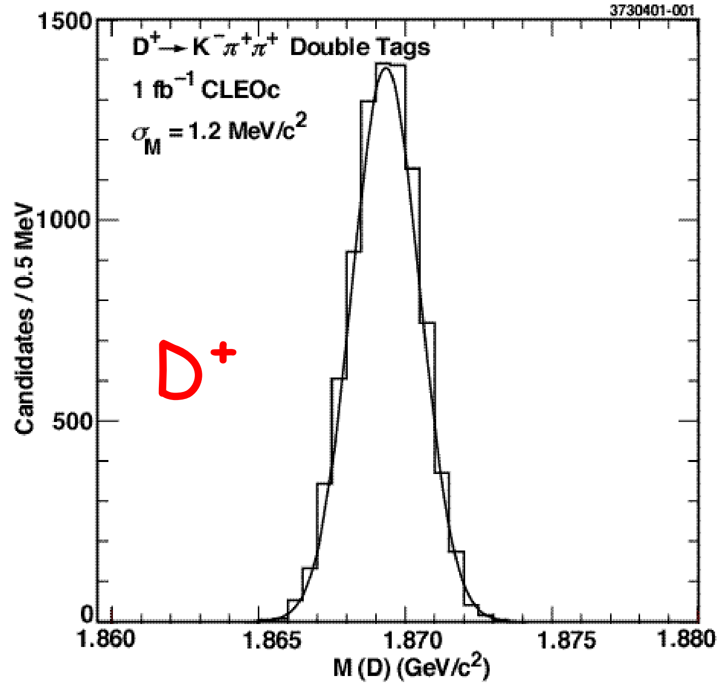
- Yield: ~ 900 events
- S:B ~ 9:1 (dominated by τν) -

$\boxed{\delta f_D|V_{cd}|/f_D|V_{cd}| \sim (2.0 \pm 0.3 \pm 0.6)\%}$

- CLEO studies: B factory >~ 7%

Double-Tagged $\mathcal{B}$ Measurements





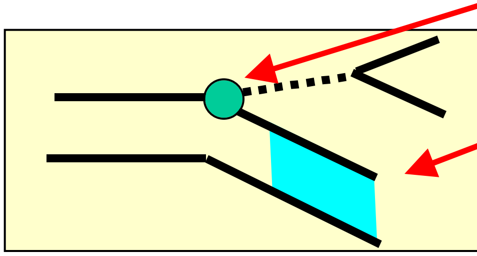
~ No background in hadronic modes

Set absolute scale for all heavy quark meas.

Mode	PDG2000 $(\delta\mathcal{B}/\mathcal{B})\%$	CLEOc $(\delta\mathcal{B}/\mathcal{B})\%$
$D^0 \to K\pi$	2.4	0.5
$D^+ \to K\pi\pi$	7.2	1.5
$D_s \to \varphi\pi$	25	1.9

Semileptonic Decays

Rate α $|V_{cj}|^2 \; |f(q^2)|^2$



Low backgrounds and high rates

Decay Mode	PDG2000 $(\delta\mathcal{B}/\mathcal{B})$ %	CLEOc $(\delta\mathcal{B}/\mathcal{B})$%
$D^0 \to Kl\nu$	5	2
$D^0 \to \pi l\nu$	16	2
$D^+ \to \pi l\nu$	48	2
$D_s \to \varphi l\nu$	25	3

Plus other vector modes…

V_{cd} and V_{cs} to ~1.5%

Form factor slopes (α) to few per cent to check theory!

Further Testing LQCD

$\Gamma(D \to \pi \ell \nu) / \Gamma(D^+ \to \ell \nu)$

Independent of $|V_{cd}|$

Semileptonic:

use e and μ

use D^0 and D^+ - tradeoffs

Leptonic: use μ and τ

$\Gamma(D_S \to \phi \ell \nu) / \Gamma(D_S \to \ell \nu)$

Incl $\mathcal{B}(\phi \to K^+K^-)$ uncertainty

Test **rate** predictions to **3.5-4%**
Test **amplitudes** at **1.5-2%**

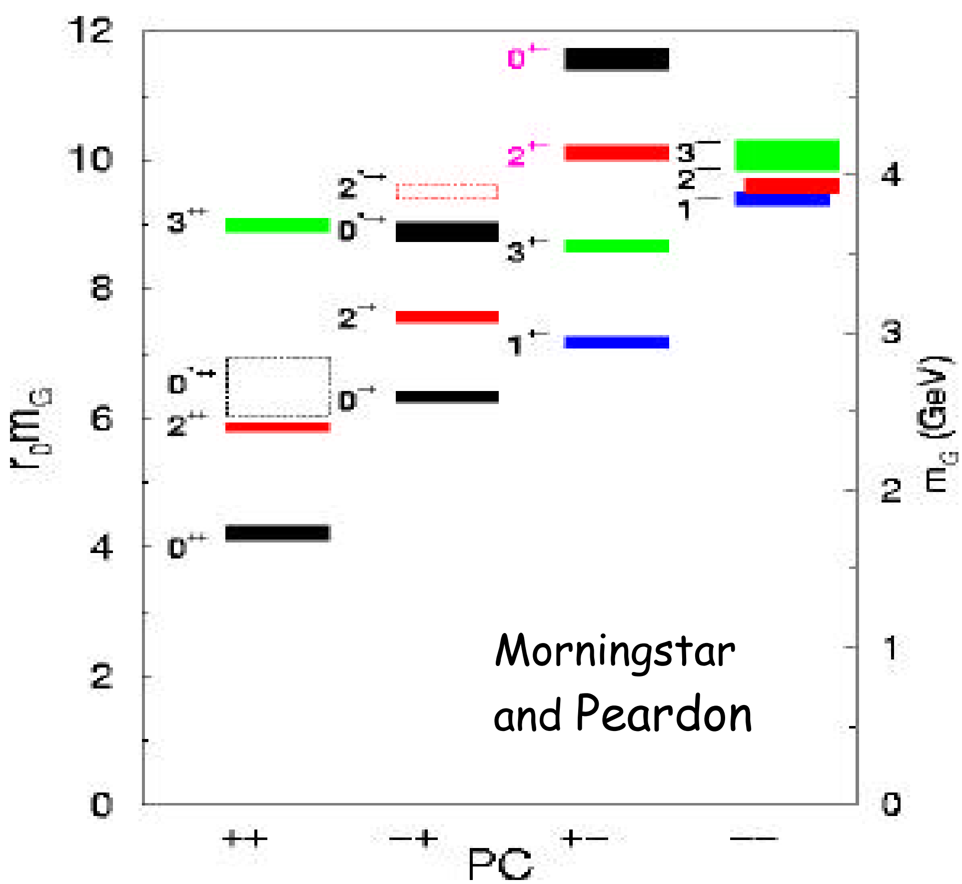
J/ψ Radiative Decays

Glue-rich environment

Look for |gg> states - glueballs!

new form of matter

“required” by QCD



A Billion J/ψ Events

Present data systematic issues

- **hadronic backgrounds in radiative decays**
- **hermticity**

Need LARGE statistics (> BES/BEPC)

Need multi-faceted approach

- **two-photon production**
- Υ **radiative decays**
- **J/ψ radiative decays**

Need mature, high quality detector

(CLEOIII !!!)

Tensor Glueball Candidate $f_J(2220)$

Expect to see in $J/\psi \rightarrow \gamma f_J$

- glue-rich environment
- predicted to be narrow (~20 MeV)
- large radiative f_2 and f_4 modes

Exclusive studies

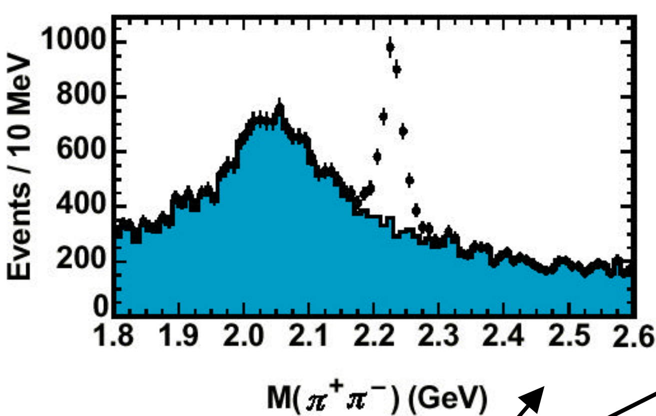
- essentially no hadronic background!
- extremely clean signatures
- large statistics

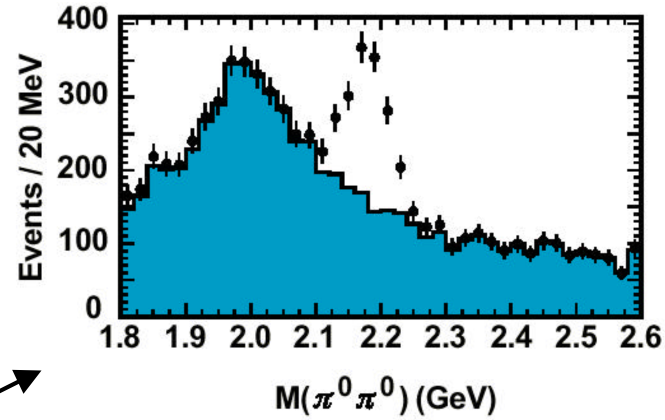
Complementary ***in***clusive studies

Complementary anti-search in $\gamma\gamma$

Complementary search in Υ decays

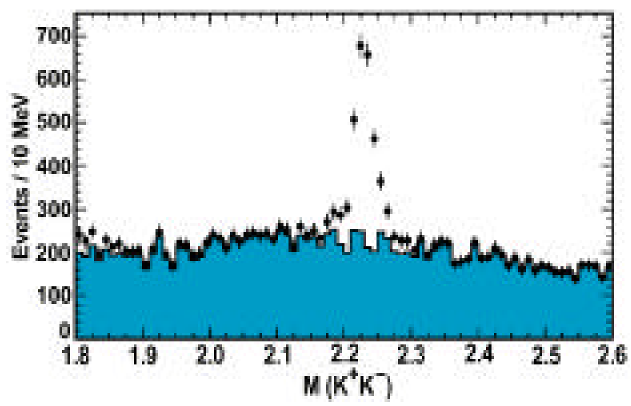
Ex: $f_J \rightarrow \pi^+\pi^-, \pi^0\pi^0, K^+K^-$





170M events

All known bckgds



	BES	CLEO-c
$\pi^+\pi^-$	74	32000
$\pi^0\pi^0$	18	13000
K^+K^-	46	18600
K_SK_S	23	5300
pp	32	8500
ηη	–	5000

BES (publ.)

CLEO-c (10^9 proj.)

Supernumerary f_0 Triplet

Observe f_0(1370, 1500, 1710)

Composed of |nn>, |ss>, and |gg>

Many approaches needed!

exclusive and inclusive decays

PWA - J^{PC} known - hermeticity

$\gamma\gamma$partial widths

A Billion?!?

Branching fractions ~ 10^{-3} - 10^{-4}

Need ~ 10^6 per channel for PWA

Samples of 10^7 insufficient

Comparison with Other Expts

China:

BES II is running now.
BES II --> BES III upgrade
BEPC I --> BEPC II upgrade, ~$10^{33?}$ lumi
being proposed
Physics after 2005 if approval & construction go ahead.

Quantity	BES II	CLEO-C
J/psi yield	50M	> 1000M
dE/dx res.	9%	4.9%
K/pi separation up to	600 MeV	1500 MeV
momentum res. (500Mev)	1.3%	0.5%
Photon resolution (100 Mev)	70 MeV	4 MeV
Photon resolution (1000 Mev)	220 MeV	21 MeV
Minimum Photon Energy	80 MeV	30 MeV
Solid angle for Tracking	80%	94%
Solid angle for Photons	75%	95%

HALL-D at TJNAL:

γp to produce states with exotic Quantum Numbers
Focus on light states with J^{PC} = 0+-, 1+-, …
Complementary to CLEO-C focus on heavy states with J^{PC}=0++, 2++, …
Physics in 2007+ ?

Other Possible Physics Topics

Taus:

m_τ from threshold scan

η parameter in $\tau \to \mu\nu\bar{\nu}$

Systematically dominated modes

R-scans:

Scan 5-8 GeV: X-ball/MkI

Basic Scan of 3.7-6 GeV

Advanced Scan: $D/D^*/D_s$

ψ'(3686):

Gateway to many states

P-V puzzle

Study of J/ψ systematics

Thoughts to take away …

The **CLEO** collaboration at **CESR** is embarking on a mission to determine a large number of measurements important to QCD with unprecedented precision.

It is a challenge to the theoretical community for predictions of similar precision to enhance our understanding of both **strong** and **EW** physics.

We at CLEO welcome **your** ideas and collaboration in maximizing the impact of the **CLEO-c** program.