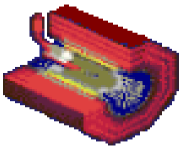
CLEO-c and CESR-c:

A New Frontier of Electroweak And QCD Physics

CLEO-c



CESR-c

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University of Illinois

On behalf of CLEO Collaboration

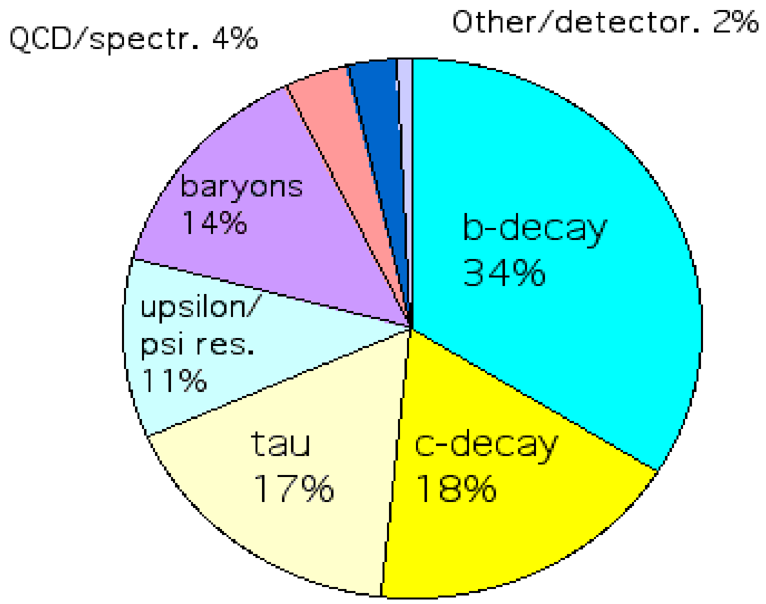
Wilson Laboratory, Cornell University

Ithaca, NY

The CLEO Collaboration

- Membership:
  - ~20 Institutions
  - ~155 physicists
  - ~1/2 DOE, 1/2 NSF
  - Currently expanding...

- Publication history 1980-
  - ~320 papers
  - diverse physics:

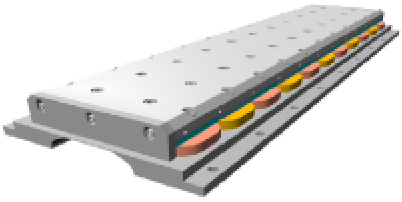


Albany
Caltech
CMU
Cornell
Florida
Harvard
Illinois
Kansas
Minnesota
Ohio State
Oklahoma
Purdue
Rochester
SLAC
SMU
UCSD
UCSB
Syracuse
Vanderbilt
Wayne State

What is CESR-c ?

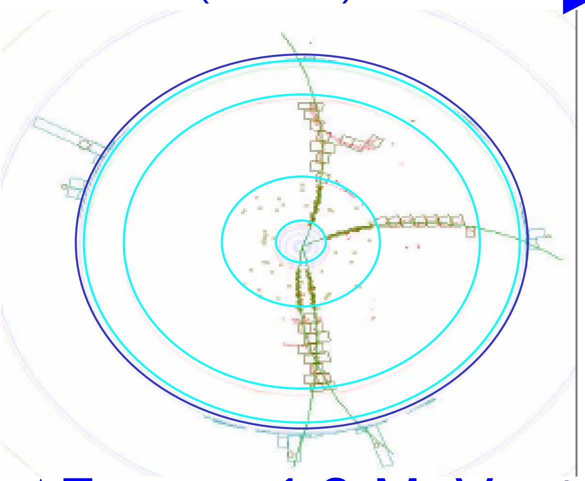
- Modify for low-energy operation: add wigglers for transverse cooling

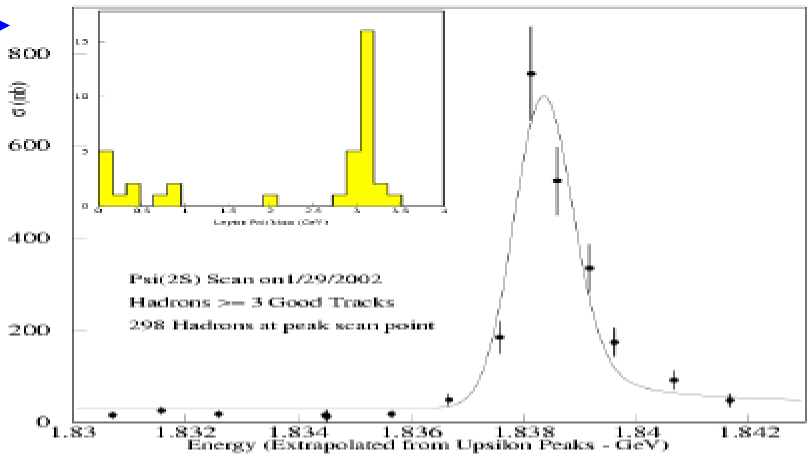
- Expected machine performance:



Ecm	*L* (10^{32} cm^{-2} s^{-1})
3.1 GeV	2.0
3.77 GeV	3.0
4.1 GeV	3.6

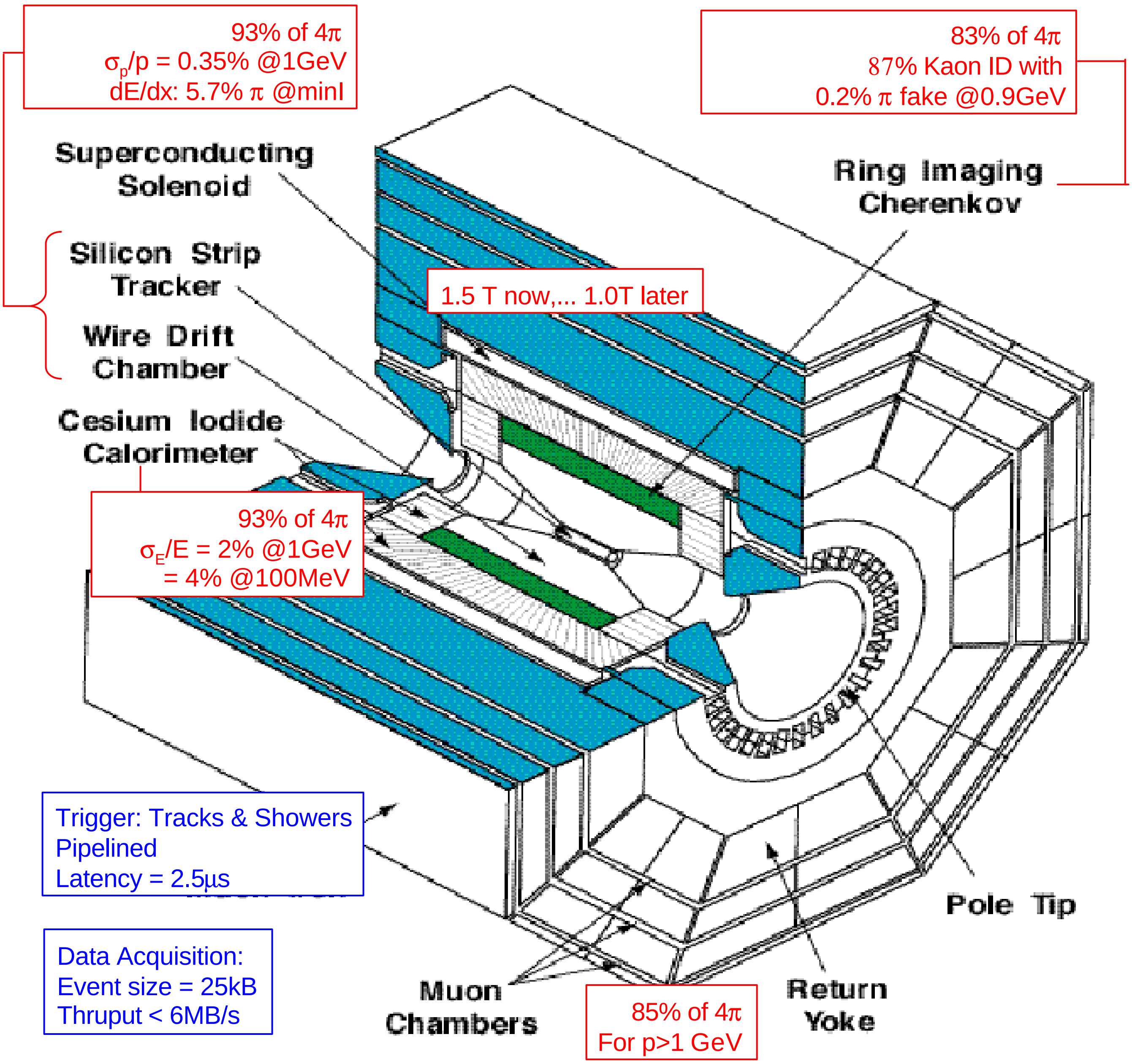
One day scan of the ψ':
(1/29/02)





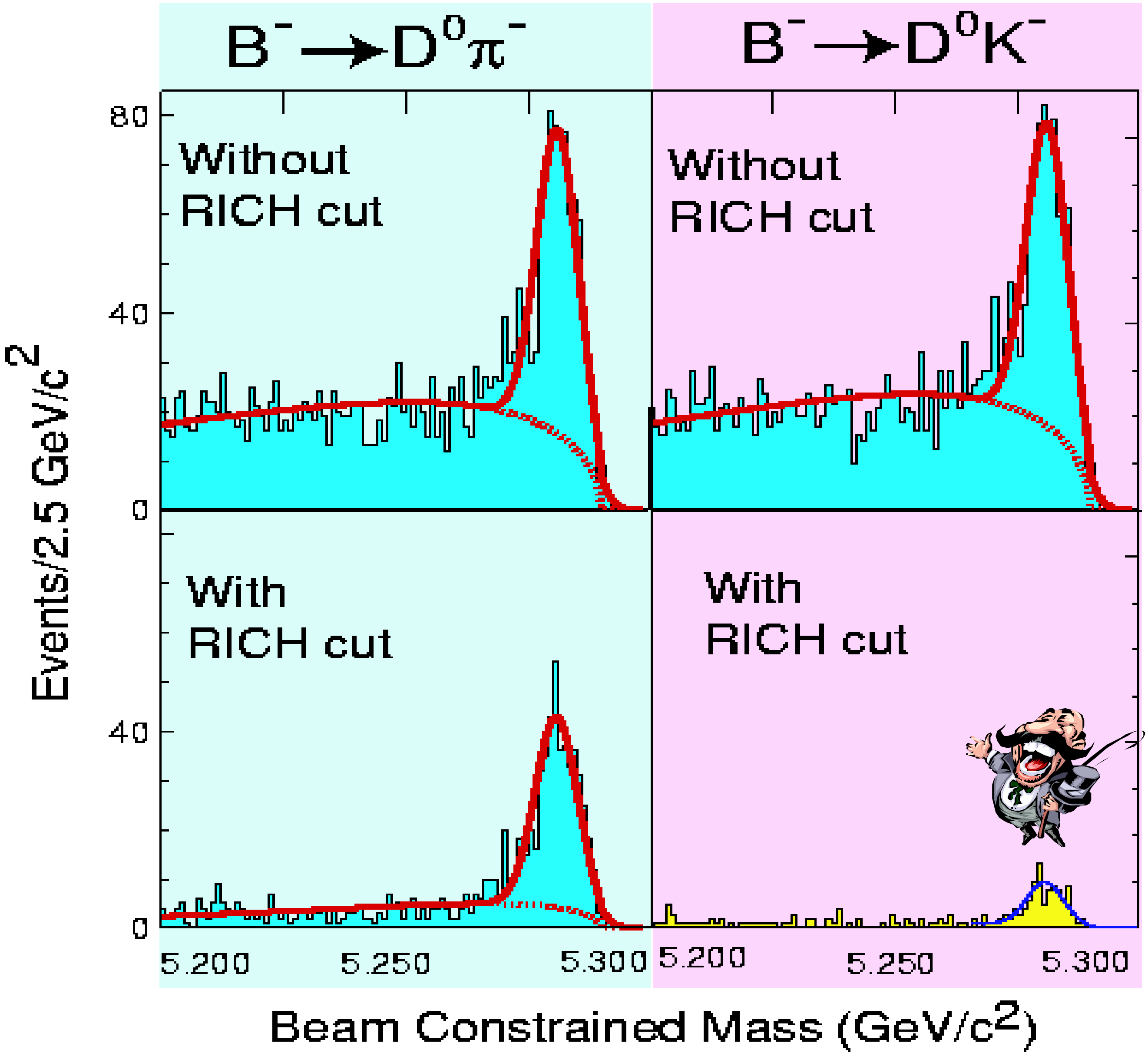
- ΔE_{beam} ~ 1.2 MeV at J/ψ

CLEO III Detector
→ CLEO-c Detector



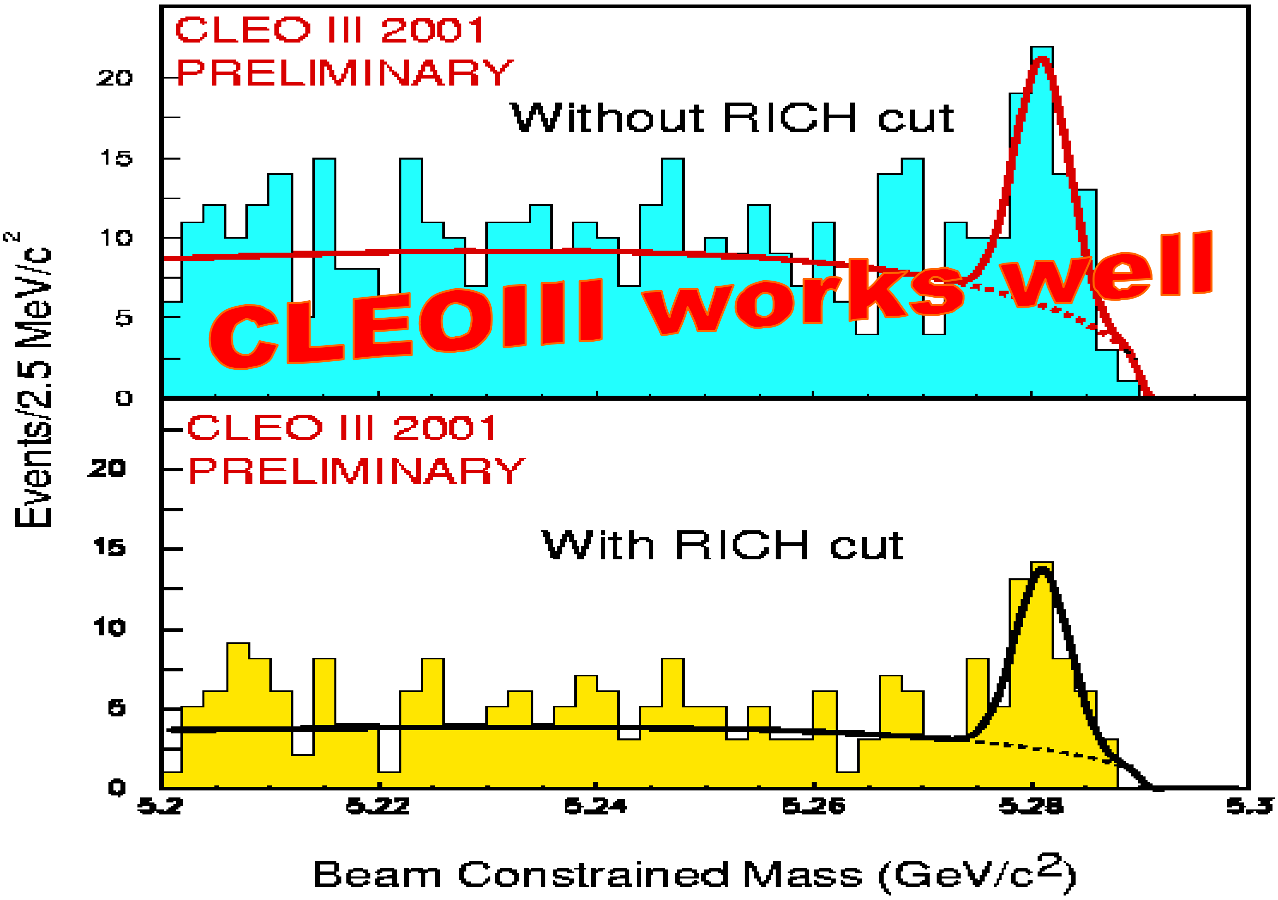
Look What RICH did to our Data !

CLEO III 2001 PRELIMINARY



How well does CLEO III work?
1st results from CLEO III data at Lepton-photon 2001

$\overset{(-)}{B^0} \to K^{\pm}\pi^{\mp}$



Yield $B\to K\pi$	BR($B\to K\pi$)($\times10^{-6}$) CLEOIII	CLEO(1999)
$29.2^{+7.1}_{-6.4}$	$18.6^{+4.5+3.0}_{-4.1-3.4}$	$18.8^{+2.8}_{-2.6} \pm 1.3$

Preliminary

Good agreement: between CLEOIII & CLEO II & with BaBar/Belle.

The CLEO-c Program

2002

Prologue: Upsilons ~1-2 fb^{-1} ea.
Υ(1S) ,Υ(2S), Υ(3S)...
Spectroscopy, Matrix Elements, Γ_{ee}
10-20 times existing world's data

2003

Act I: $\psi(3770)$ -- 3 fb^{-1}
30M events, 6M *tagged* D decays
(310 times MARK III)

2004

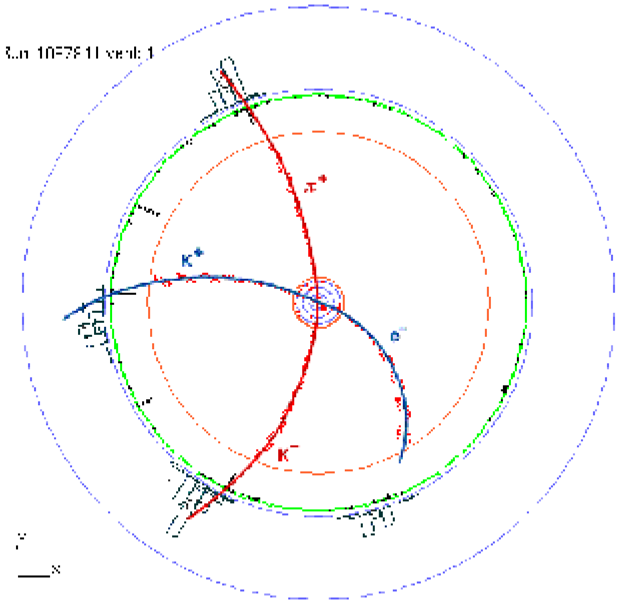
Act II: vs ~ 4100 -- 3 fb^{-1}
1.5M D_sD_s, 0.3M *tagged* D_s decays
(480 times MARK III,
130 times BES II)

2005

Act III: $\psi(3100)$ -- 1 fb^{-1}
1 Billion J/ψ decays
(170 times MARK III
20 times BES II)

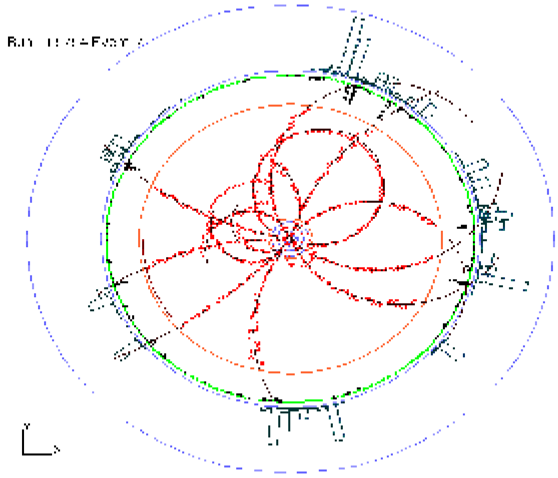
Why run on threshold Resonances ?

- Charm events produced at threshold are extremely clean
- Large σ, low multiplicity
- Pure initial state: no fragmentation
- Signal/Background is optimum at threshold



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

- Double tag events are pristine
  - These events are key to making absolute branching fraction measurements
- Neutrino reconstruction is clean
- Quantum coherence aids D mixing and CP violation studies



A typical Y(4S) event:

Tagging Technique

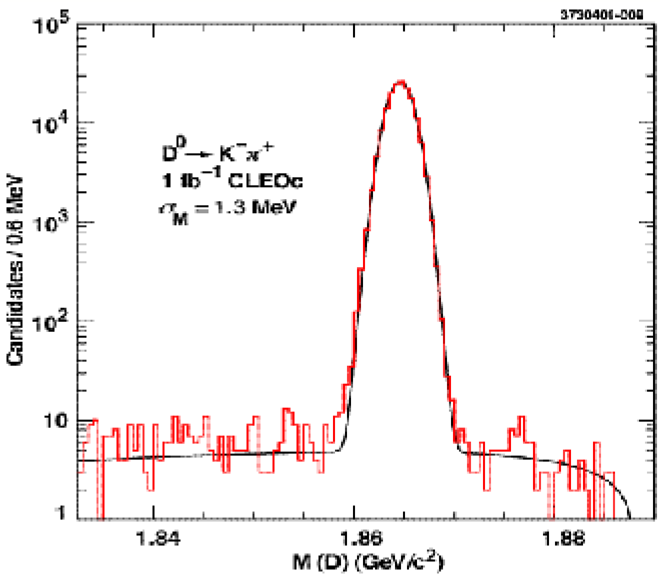
- Pure $D\bar{D}$ or $D_s\bar{D}_s$ production
  - Many high branching ratios (~1-10%)
  - High reconstruction eff
  - Two chances

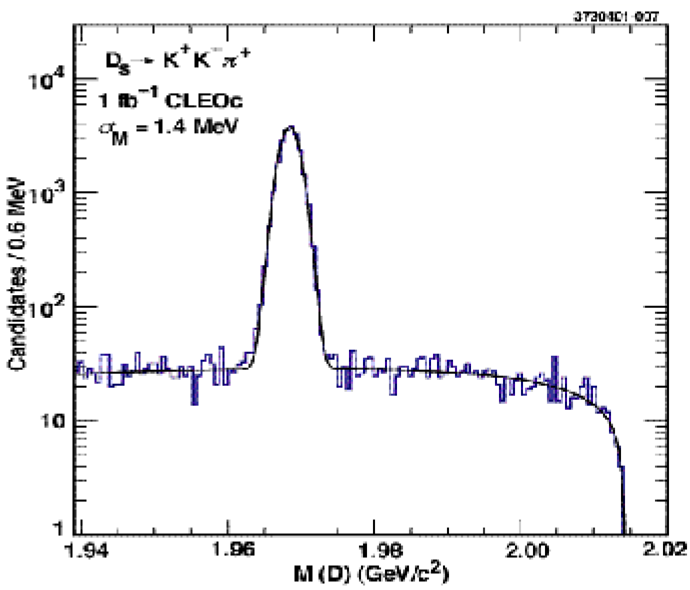
6M D tags
300K D_s tags

$\rightarrow$ high net efficiency ~20% !

$D \rightarrow K\pi$ tag.
S/B ~ 5000

$D_s \rightarrow KK\pi$ tag.
S/B ~ 100





Beam constrained mass

Why CLEO-c ? Why Now ?

- We expect great advances in flavor and electroweak physics during the next decade:
  - Tevatron (CDF, D0, BTeV,CKM).
  - B-Factories (BaBar, Belle).
  - LHC (CMS, ATLAS, LHC-b).
  - Linear Collider (?).
- What could CLEO-c possibly have to offer this program?

To score nice goals we absolutely need an excellent player who can make the Perfect passes at the perfect time

→ CLEO-c

Precision Standard Model Tests

Absolute hadronic charm branching ratios with 1-2% errors.

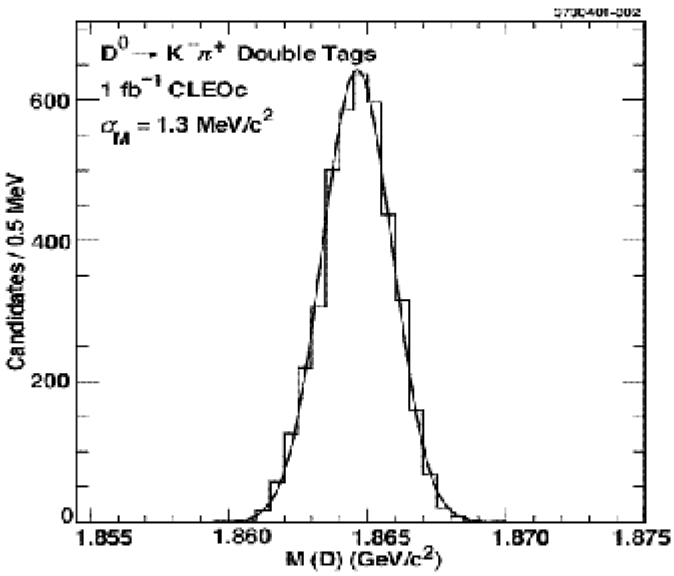
f_{D+} and f_{Ds} at ~2% level.

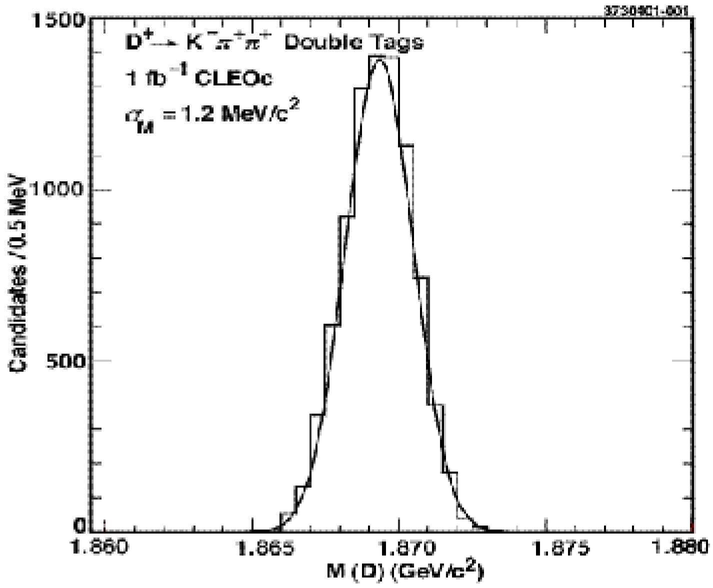
Semileptonic decay form-factors (few % accuracy).

Contribution to CKM Measurements

Absolute Branching Ratios

~ Zero background in hadronic modes





Set absolute scale for all heavy quark meas.

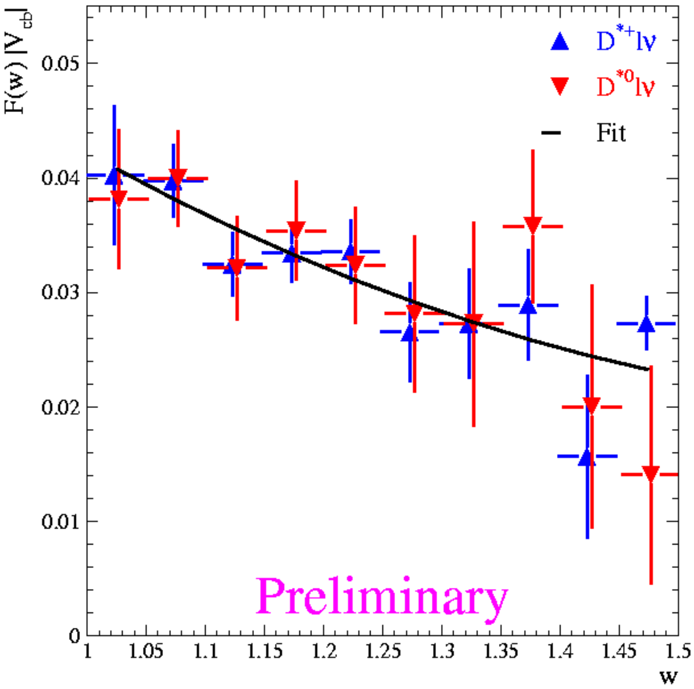
Decay Mode	PDG2000 ($\delta B/B$ %)	CLEOc ($\delta B/B$ %)
$D^0 \to K\pi$	2.4	0.5
$D^+ \to K\pi\pi$	7.2	1.5
$D_s \to \phi\pi$	25	1.9

The importance of absolute Charm BRs

V_{cb} from zero recoil in $B \rightarrow D^* \ell^+ \nu$

$$\left|V_{cb}\right| = (46.4 \pm 1.4 \pm 2.0 \pm 2.1) \times 10^{-3}$$

CLEO LP01

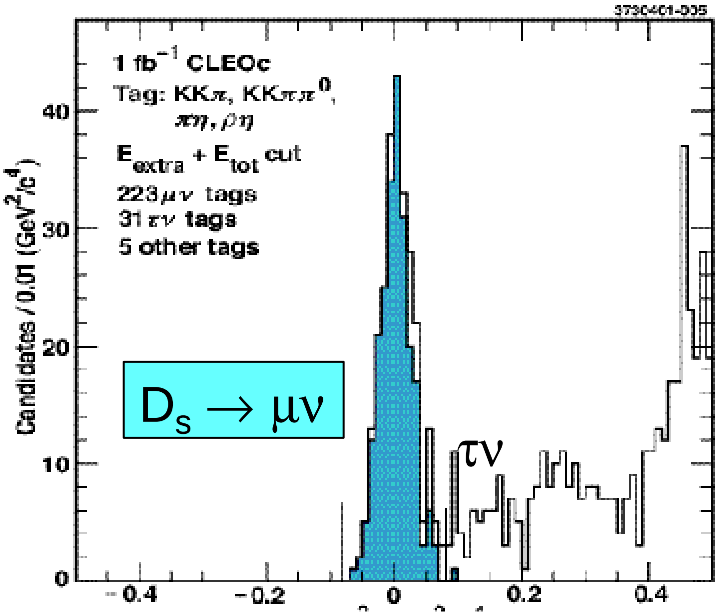


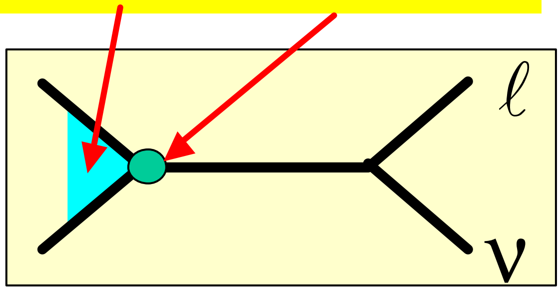
Stat: 3.1% Sys 4.3% theory 4.6%

Dominant Sys: ε_{π}slow, form factors

& $B(D \rightarrow K\pi)$
$dB/B=1.3\%$

Decay Constants: $|f_D|^2\ |V_{CKM}|^2$

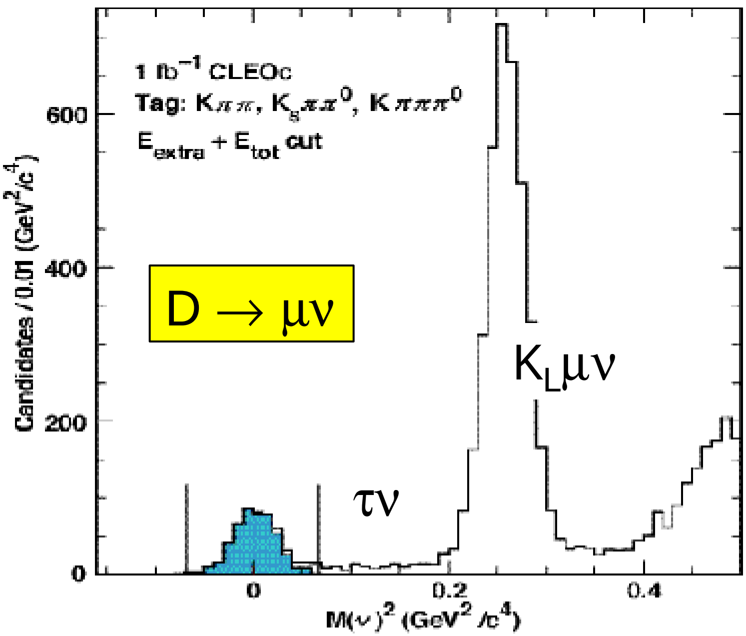




$$\frac{df_{D_s}}{f_{D_s}} \approx 2.1\%$$

(Now: ±35%)

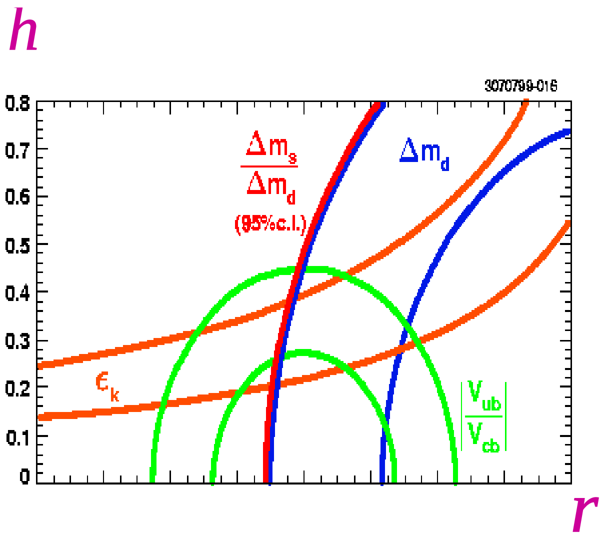
$\mathrm{Br}(D_s \to \mu^+\nu)$



$$\frac{df_D}{f_D} \approx 2.6\%$$

(Now: ±100%)

Importance of measuring f_D & f_{Ds}: Vtd & Vts

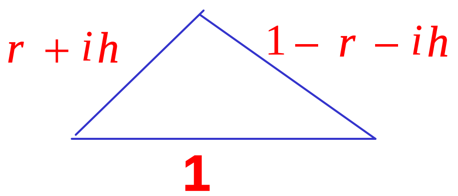


$$\Delta M_d = 0.50 ps^{-1}\left[\frac{\sqrt{B_{B_d}}\, f_{B_d}}{200MeV}\right]^2\left[\frac{|V_{td}|}{8.8\times10^{-3}}\right]^2$$

$$\frac{s(r)}{r} = 0.5\,\frac{s(\Delta M_d)}{\Delta M_d} \oplus \frac{s(f_B\sqrt{B_{B_d}})}{f_B\sqrt{B_{B_d}}}$$

1.8%

~15%
(lattice)



$$\frac{\Delta M_d}{\Delta M_s} \propto \left[\frac{\sqrt{B_{B_d}}\, f_{B_d}}{\sqrt{B_{B_s}}\, f_{B_s}}\right]^2\left[\frac{|V_{td}|}{|V_{ts}|}\right]^2$$

~5% (lattice)

Lattice predicts f_B/f_D & f_{Bs}/f_{Ds} with small errors
if precision measurements of f_D & f_{Ds} existed (they do not)
could substitute in above ratios to obtain precision estimates of f_B & f_{Bs} and hence precision determinations of Vtd and Vts
Similarly f_D/f_{Ds} checks f_B/f_{Bs}

Comparison between B factories & CLEO-C

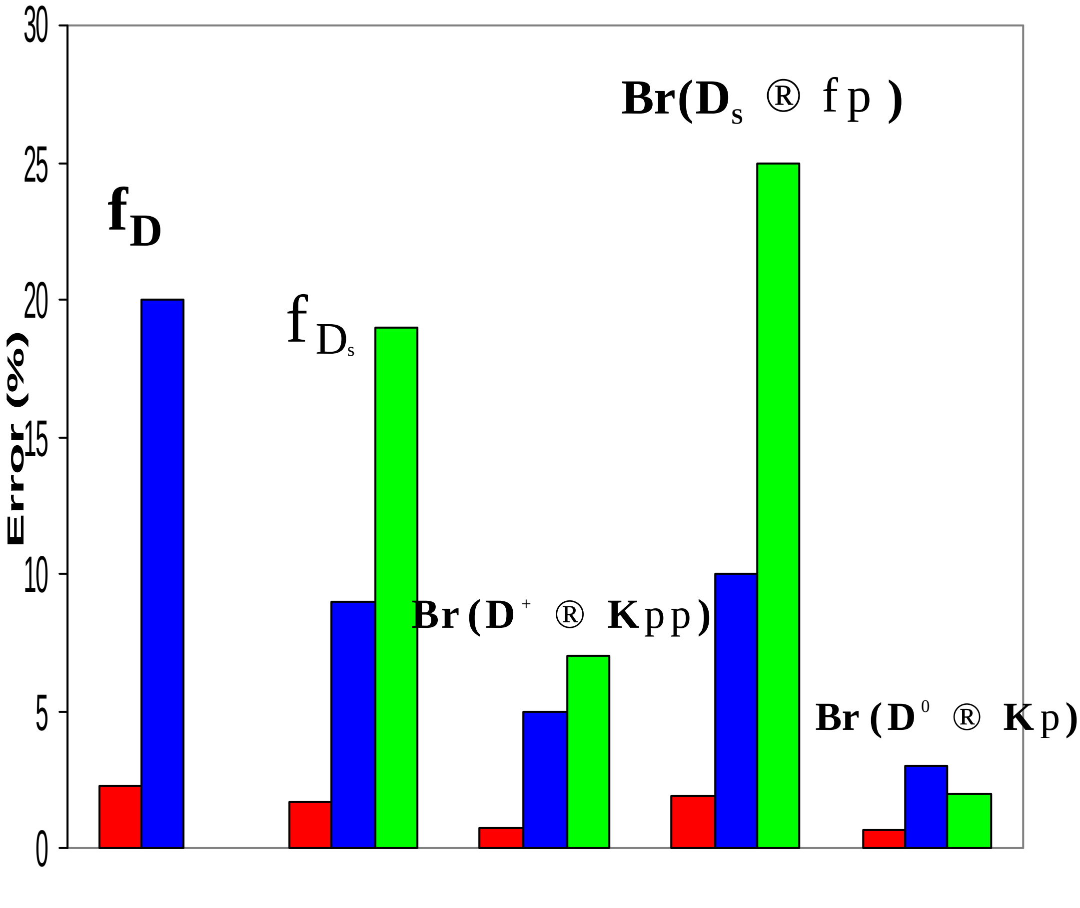
CLEO-c
3 fb^{-1}

Statistics limited

BaBar
400 fb^{-1}

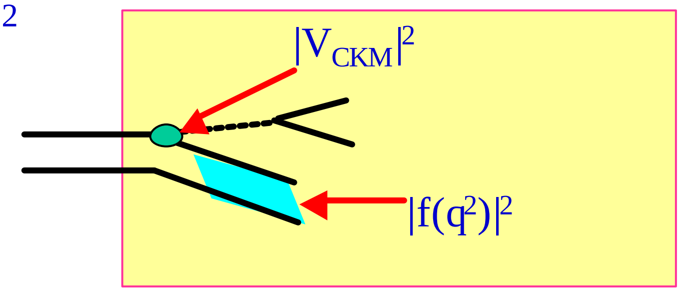
Current

Systematics &
Background limited



Semileptonic Form Factors.

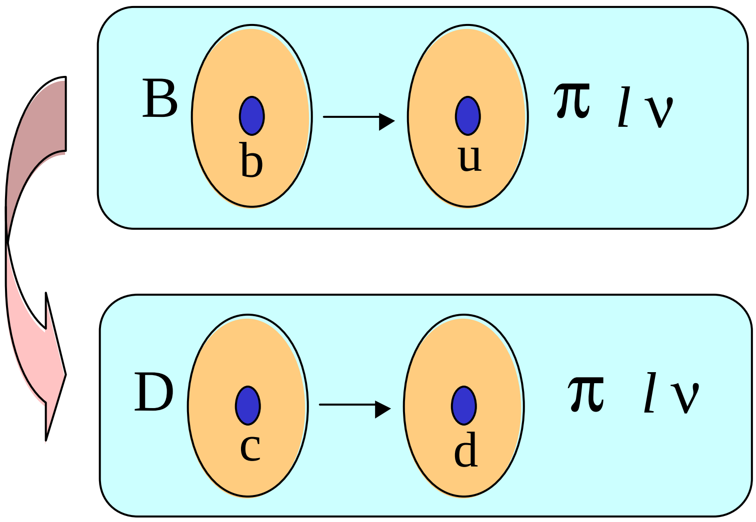
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^2}\left|V_{cs}\right|^2 P_K^3 \left| f_+(q^2)\right|^2$$



Absolute magnitude & shape of form factors is a great test of theory.

i.e.

HQET



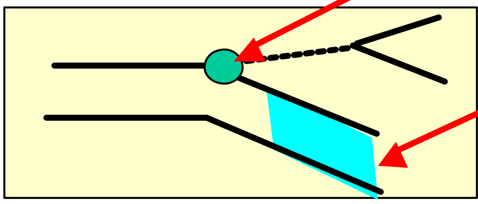
1) Measure $D \to \pi$ form factor in $D \to \pi l \nu$ (CLEO-c): Calibrate LQCD to 1%.

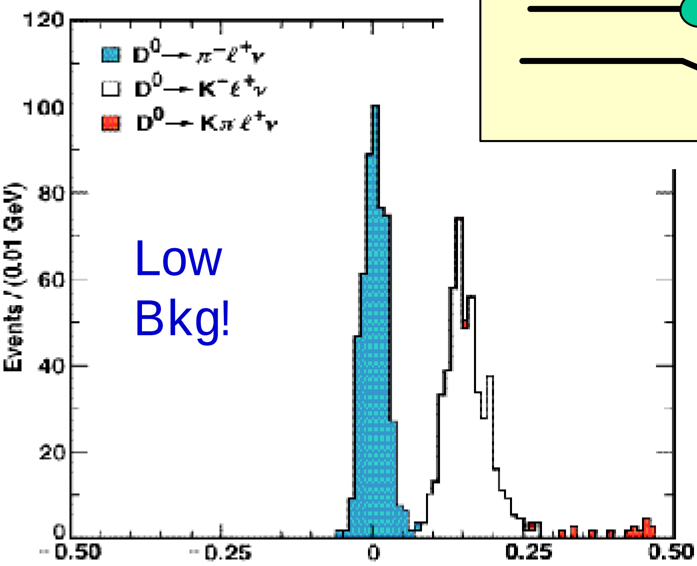
2) Extract V_{ub} at BaBar/Belle using *calibrated* LQCD calc. of $B \to \pi$ form factor.

3) Precise (5%) V_{ub} is a vital CKM cross check of $\sin 2\beta$.

4) Absolute rate gives direct measurements of V_{cd} and V_{cs}.

Semileptonic Decays $|V_{CKM}|^2 \; |f(q^2)|^2$





$U = E_{miss} - P_{miss}$

Decay Mode	PDG2000 ($\delta B/B$ %)	CLEOc ($\delta B/B$ %)
$D^0 \to K l \nu$	5	1.6
$D^0 \to \pi l \nu$	16	1.7
$D^+ \to \pi l \nu$	48	1.8
$D_s \to \phi l \nu$	25	2.8

Plus vector modes...

Semileptonic dB/B, Vcd, & Vcs

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

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

$3: D^0 \to p^- e^+ n$

$4: D^0 \to r^- e^+ n$

$5: D^+ \to \bar{K}^0 e^+ n$

$6: D^+ \to \bar{K}^{*0} e^+ n$

$7: D^+ \to p^0 e^+ n$

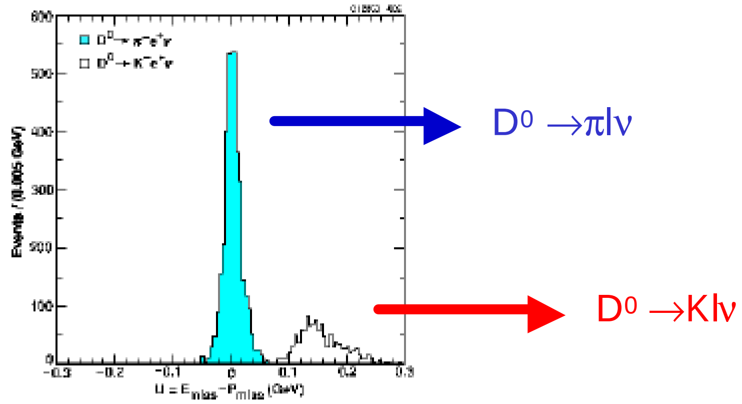
$8: D^+ \to r^0 e^+ n$

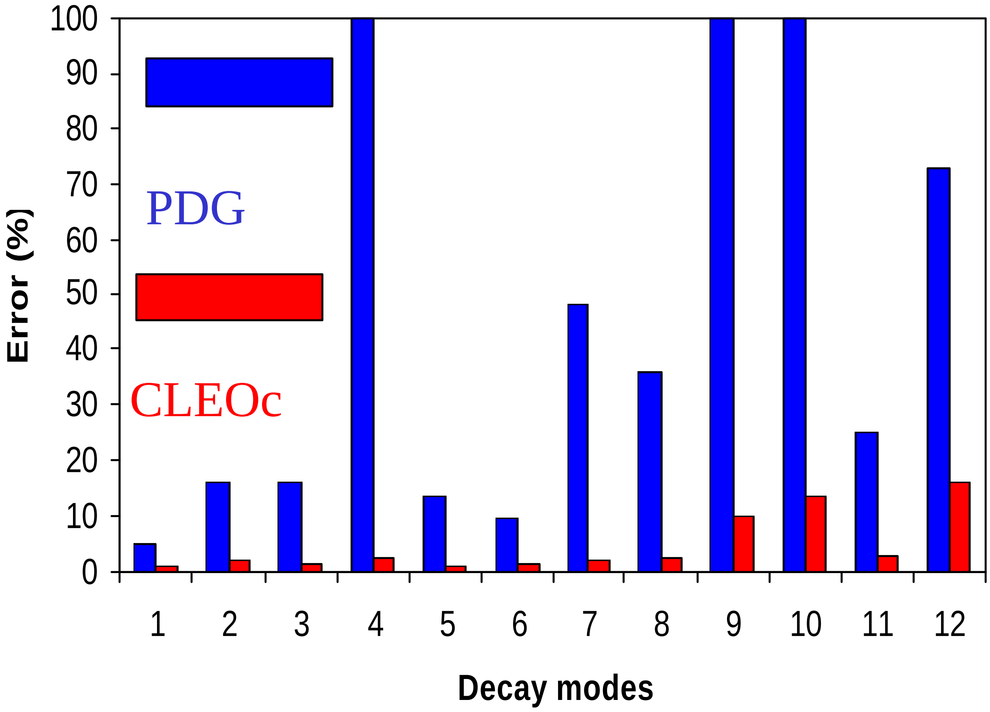
$9: D_s \to K^0 e^+ n$

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

$11: D_s \to f e^+ n$

$12: \Lambda_c \to \Lambda e^+ n$





$D^0 \to K^- e^+ u$ δVcs /Vcs = 1.6% (now: 11%)

$D^0 \to p^- e^+ u$ δVcd /Vcd = 1.7% (now: 7%)

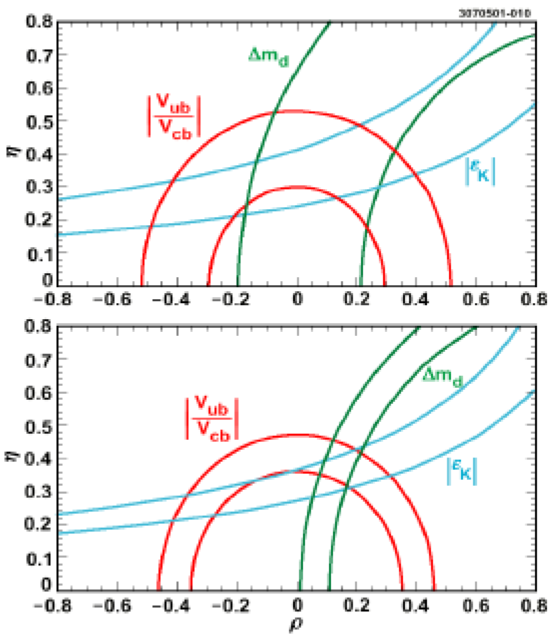
Use CLEO-c validated lattice + B factory
B→ρ/π/η/lν for ultra precise Vub

How can CLEO-c Contribute to CKM Measurements ?

An illustration using a variant of the 95% Scan method.

Allowed regions of the r - h plane using:

- current experimental results and
- conservative theoretical uncertainties



Allowed regions of the r - h plane using:

- current experimental results and
- theoretical uncertainties of O(1%)
- 2% decay constants and 3% semileptonic form factors

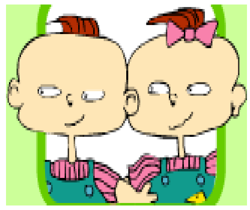
CLEO-c: Probes of new Physics

Mixing sensitivity at the 1% level.

CP violation sensitivity at the 1-2% level.

- Rare Decays. Sensitivity: 10^{-6}

Charm Mixing

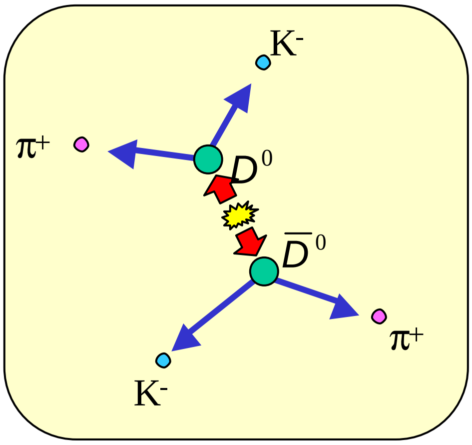


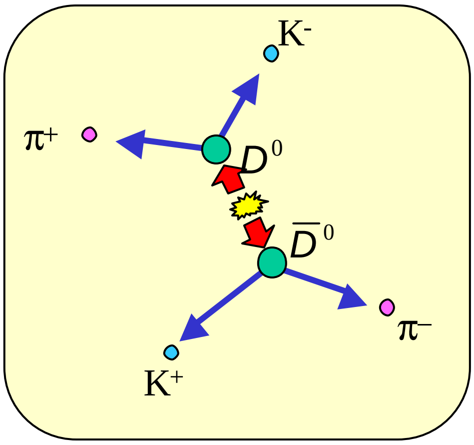
$e^+e^- \rightarrow \psi'' \rightarrow D^0\bar{D}^0$

Quantum coherance

→ **NO DCSD**

Ratio of Rates:





$$\frac{\Gamma(K^-\pi^+, K^-\pi^+)}{\Gamma(K^-\pi^+, K^+\pi^-)} = \frac{1}{2}\left(x^2 + y^2\right) \rightarrow R_{mixing}$$

To 1st order, where $\begin{cases} x = \Delta M/\Gamma \\ y = \Delta\Gamma/2\Gamma \end{cases}$

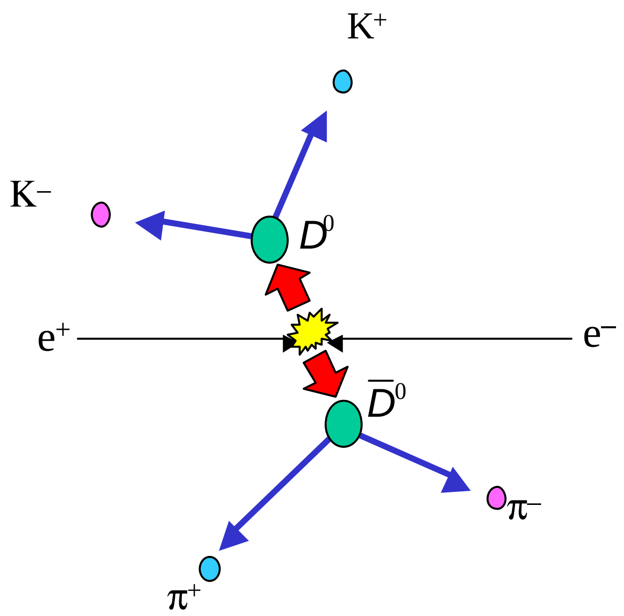
CP Violation

At the $\psi(3770)$

$$e^+e^- \rightarrow \psi'' \rightarrow D^0\bar{D}^0$$

$J^{PC} = 1^{--}$

i.e. CP+



Suppose both D^0's decay to CP eigestates f_1 and f_2:
These can **NOT** have the **same CP** :

Observing this is evidence of ~~CP~~

$$CP(f_1\,f_2) = \underbrace{CP(f_1)\,CP(f_2)}_{+}\,\underbrace{(-1)^l}_{-\ (\text{since } l = 1)} = CP-$$

Ex: $(K^+K^-)(p^+p^-)$

Compare to B Factories

	CLEO-C 2-4fb-1	BaBar 400 fb-1	Current Knowledge
f_D |Vcd|	**1.5-2%**	**10-20%**	n.a.
f_Ds |Vcs|	**$\leq$1%**	**5-10%**	19%
Br(D+ -> $K\pi\pi$)	**1.5%**	**3-5%**	7%
Br(Ds -> $\phi\pi$)	**2-3%**	**5-10%**	25%
Br(D-> $\pi l\nu$)	**1.4%**	**3%**	18%
Br(Λc -> p $K\pi$)	**6%**	**5-15%**	26%
A(CP)	**~1%**	**~1%**	3-9%
x'(mix)	**0.01**	**0.01**	0.03

Statistics limited.

Systematics & background limited.

Additional topics

- Ψ' spectroscopy (10^8 decays) $\eta'_c h_c \ldots$
- $\tau^+\tau^-$ at threshold (0.25 fb^{-1})
  - measure m_τ to $\pm$ 0.1 MeV
  - heavy lepton, exotics searches
- $\Lambda_c\bar{\Lambda}_c$ at threshold (1 fb^{-1})
  - calibrate absolute $BR(\Lambda_c \to pK\pi)$
- $R=\sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$
  - spot checks

Likely to be added to run plan

If time permits

The CLEO-c Program: Summary

- Huge data set
  - 20-500 times bigger than previous experiment
- Modern and understood detector
- Experienced Collaboration
- Powerful physics case
  - Precision flavor physics -
  - Nonperturbative QCD -
  - Probe for New Physics
- Very small and well-controlled backgrounds
- Very small and well-understood systematic errors
- A large number of and wide variety of precision measurements to challenge and validate theory

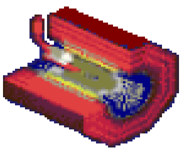
CLEO-c Physics Impact

- CLEO-C workshop (May 2001) : successful
  ~120 participants, 60 non-CLEO
- Snowmass working groups E2/P2/P5 : acclaimed CLEO-c
- HEPAP endorsed CLEO-c

- CESR/CLEO Program Advisory Committee
Sept 28 Endorsed CLEO-c
- Proposal submission to NSF was on October 15,2001
- Site visit on Jan/Feb 2002: Endorsed CLEO-c
- Science Board March 2002,
- Expect approval shortly thereafter
- See http://www.lns.cornell.edu/public/CLEO/spoke/CLEOc/
for project description

Invitation

CLEO-c



CESR-c

If interested in our program you are more than welcome to join us. We have room for you !

More information is available in CLEO Web page: www.lns.cornell.edu/public/CLEO/spoke/CLEOc

Contact person: spoke@mail.lns.cornell.edu