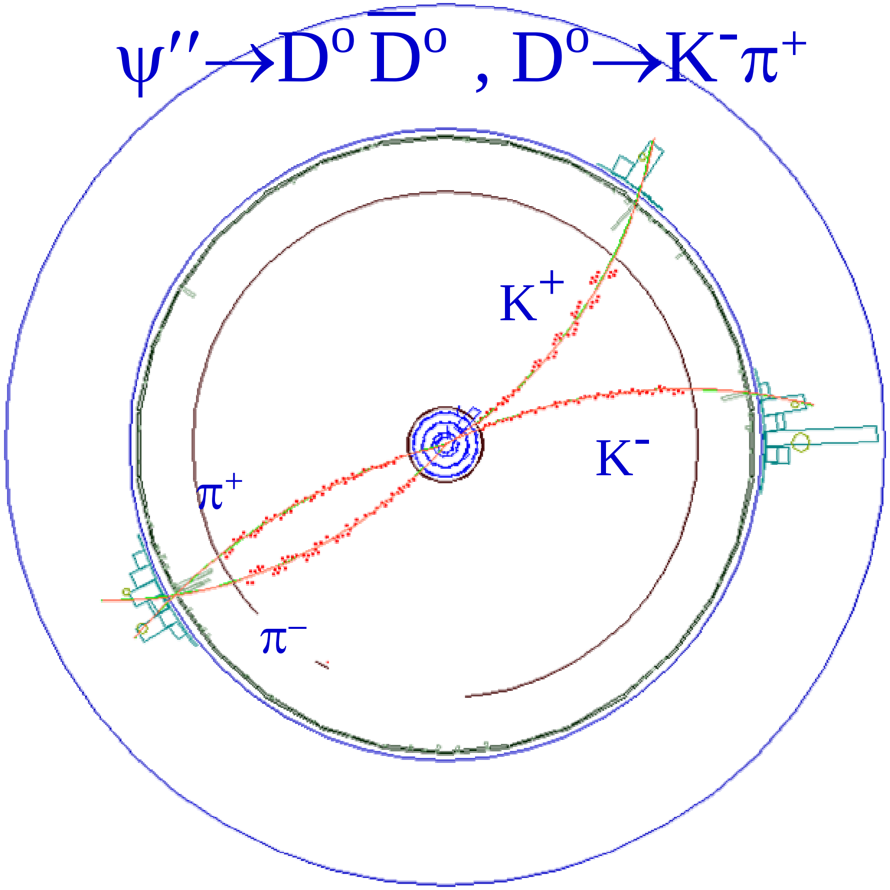
CLEO-c

Status & Prospects

David Asner

University of Pittsburgh



Beauty '03 – 9th International Conference on B-Physics at Hadron Machines

CLEO-c Physics Program

Charm measurements

Precise charm absolute branching ratio measurements

Leptonic decays: decay constants f_D and f_{Ds}

Semileptonic decays: form factors, V_{cs}, V_{cd}, test unitarity

Hadronic decays: normalize B physics

QCD studies

Precise measurements of quarkonia spectroscopy

Searches for glue-rich exotic states: Glueballs and hybrids

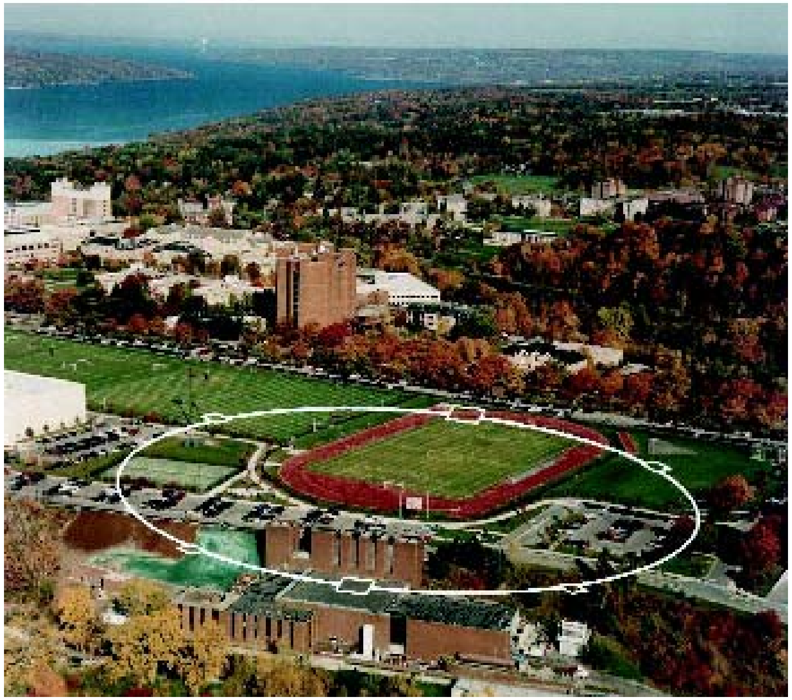
Probes for Physics beyond the Standard Model

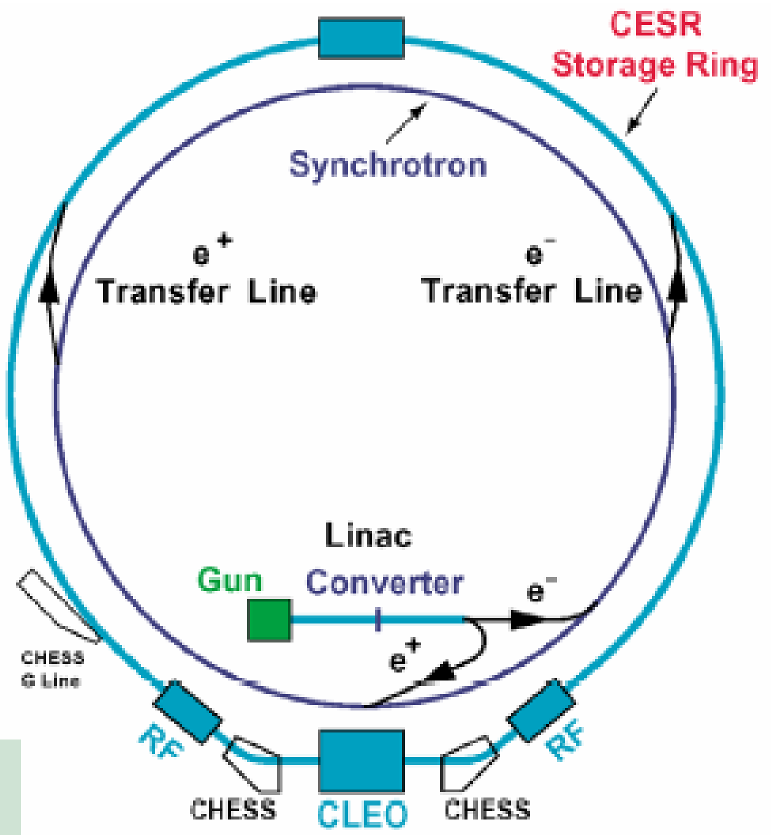
D-mixing, CP Violation, rare D decays

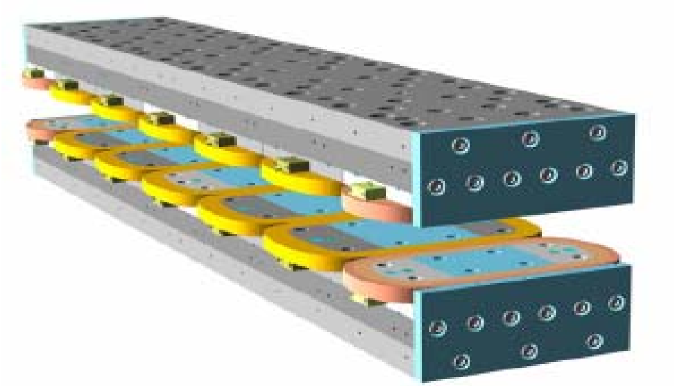
Possible additions to Run Plan

ψ' spectroscopy, τ threshold, Λ_c threshold, R scan

The Cornell Electron Storage Ring







12 additional wigglers to improve transverse cooling

E = 1.5 – 5.6 GeV

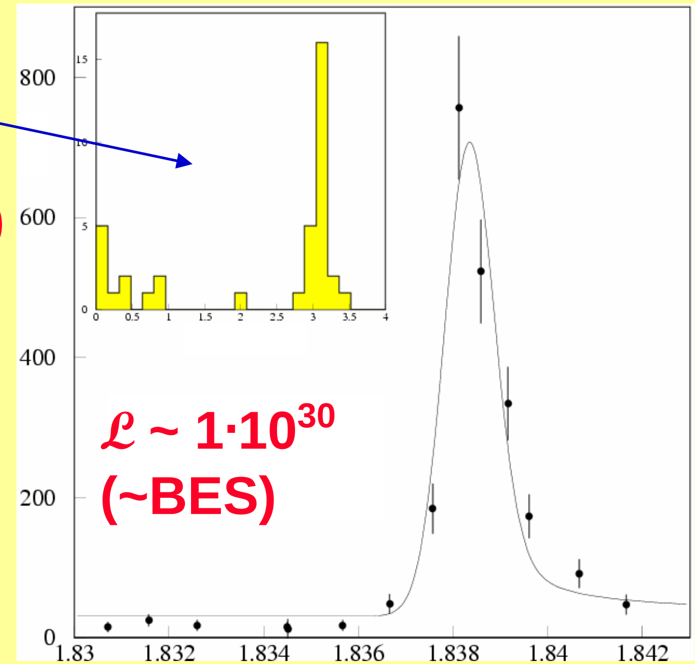
CESR-c

CESR: $\mathcal{L}(\Upsilon(4S)) = 1.3\cdot10^{33}\ cm^{-2}\ s^{-1}$

One day scan of ψ':

$\psi' \to J/\psi\ \pi\pi$
$J/\psi \to \mu\mu$

σ(nb)



$\mathcal{L} \sim 1\cdot10^{30}$ (~BES)

E_{beam}

CESR-c:

$\sqrt{s}$	$\mathcal{L}(10^{32}\ cm^{-2}\ s^{-1})$
3.1 GeV	2.0
3.77 GeV	3.0
4.1 GeV	3.6

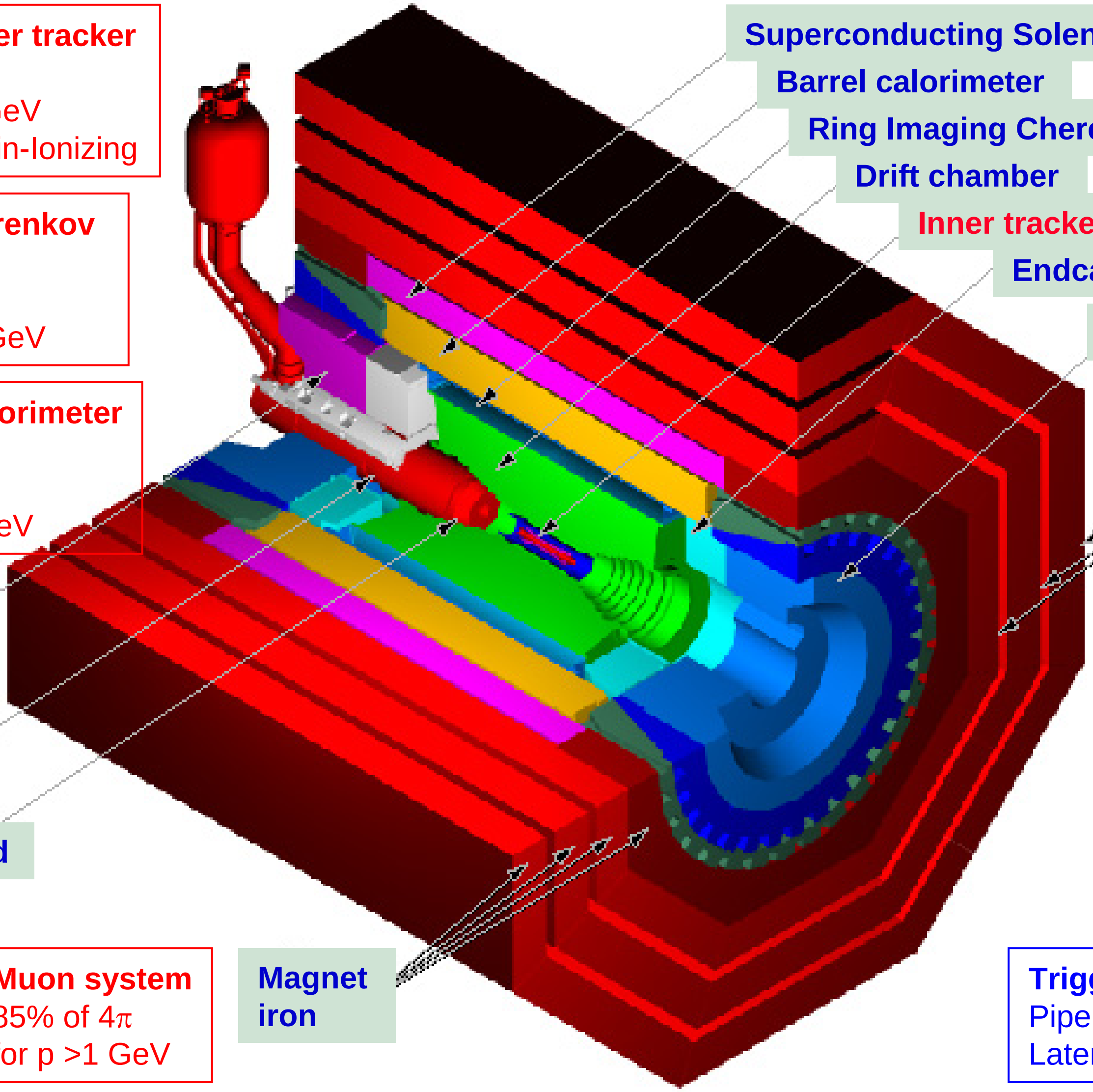
Expected machine performance: $\Delta E_{beam} \sim 1.2$ MeV at J/ψ

The CLEO-c Detector

Drift chamber/ Inner tracker
93% of 4π
s_p/p = 0.35% @ 1 GeV
dE/dx: 5.7% p @ min-Ionizing

Ring Imaging Cherenkov
83% of 4π
87% Kaon ID with
0.2% π fake @ 0.9GeV

Cesium Iodide Calorimeter
93% of 4π
s_E/E = 2% @ 1GeV
= 4% @ 100MeV



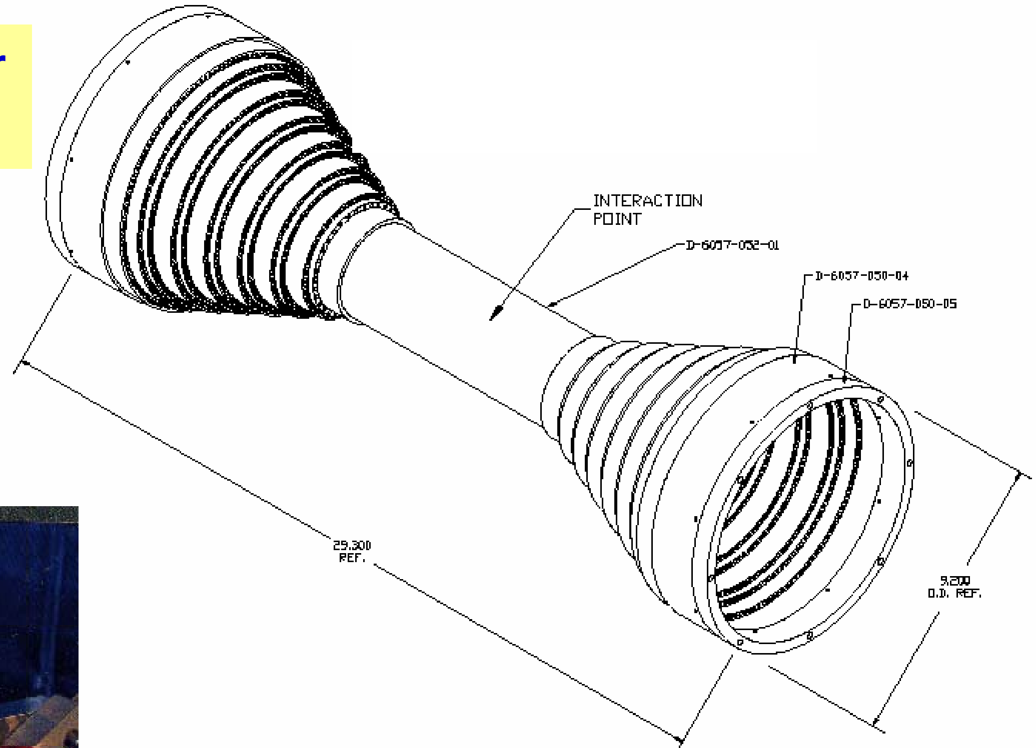
Muon system
85% of 4π
for p >1 GeV

Data Acquisition
Event size = 25kB
Thruput < 6MB/s

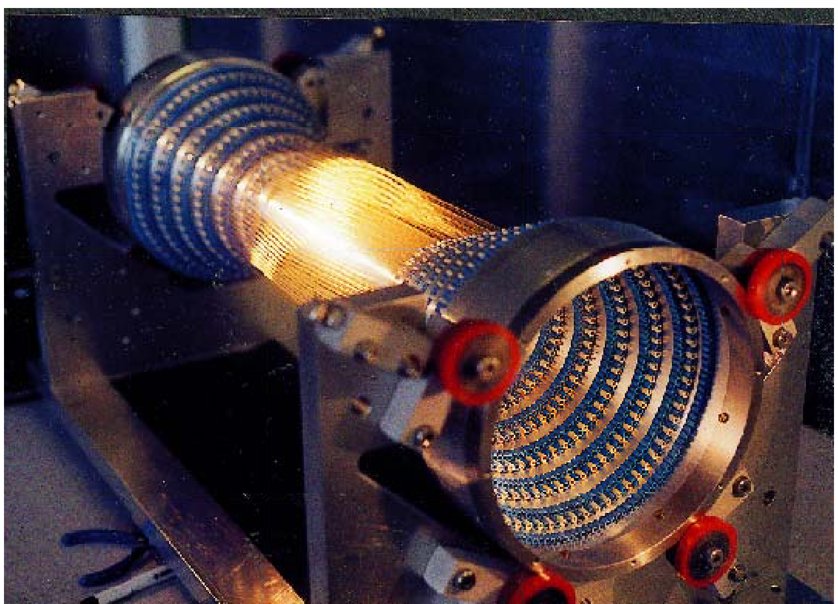
Trigger - Tracks & Showers
Pipelined
Latency = 2.5ms

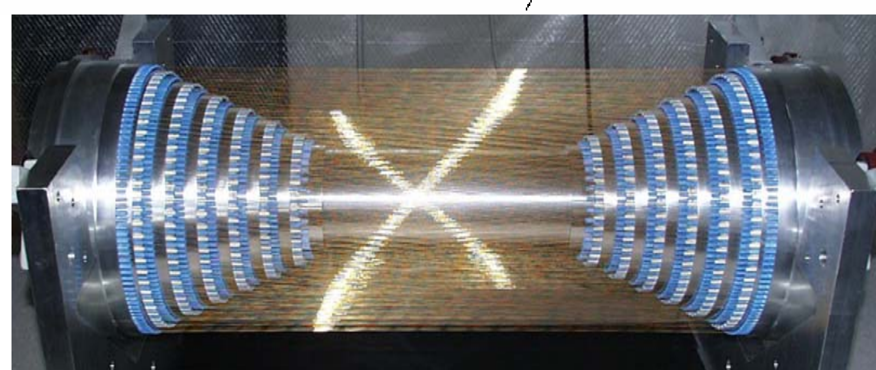
NEW - Inner Drift Chamber

Replace Silicon Vertex Detector with Inner Drift Chamber

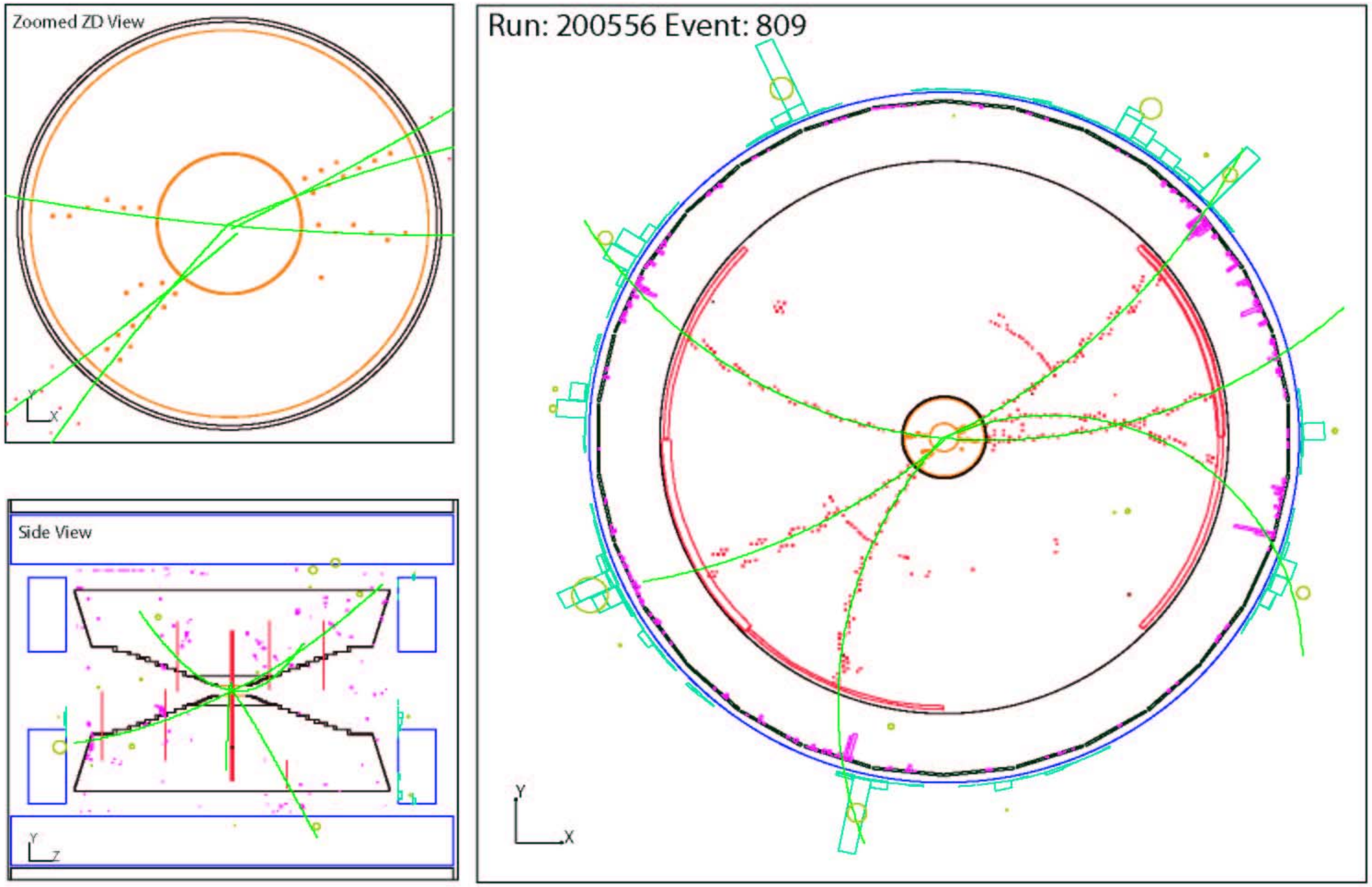


6 layers
2cm < R < 12cm
All stereo
300 channels





ψ(3770) Hadronic Event



First Collisions in CLEO-c with ZD
Beam Energy 1.888 GeV ψ(3770)
August 25, 2003

Run Plan

2002 – 2003	Upsilons	~1-2 fb^{-1} each at $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, and ~½ fb^{-1} at $\Upsilon(5S)$
Epilogue & Prologue	Spectroscopy, matrix elements, Γ_{ee}, η_b, h_c	
	Last run of CLEO III @ $\Upsilon(5S)$ on March 3rd 2003	

Year 1

$\psi(3770)$ ~3 fb^{-1} ($\psi(3770) \rightarrow D\bar{D}$)

30 million $D\bar{D}$ events, 6 million *tagged* D decays

310 times MARK III data

Year 2

$\sqrt{s}$ ~ 4140 MeV ~3 fb^{-1}

1.5 million $D_s\bar{D}_s$ events, 0.3 million *tagged* D_s decays

480 times MARK III data, 130 times of BES data

Year 3

$\psi(3100)$ ~1 fb^{-1}

1 billion J/ψ decays

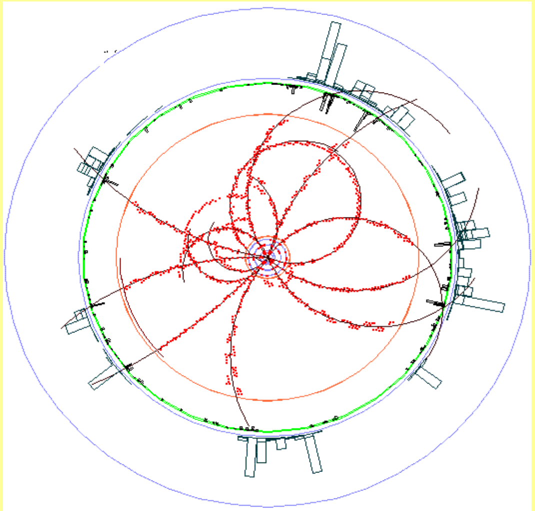
170 times MARK III data, 20 times BES II data

CLEO-c (Years 1–3)

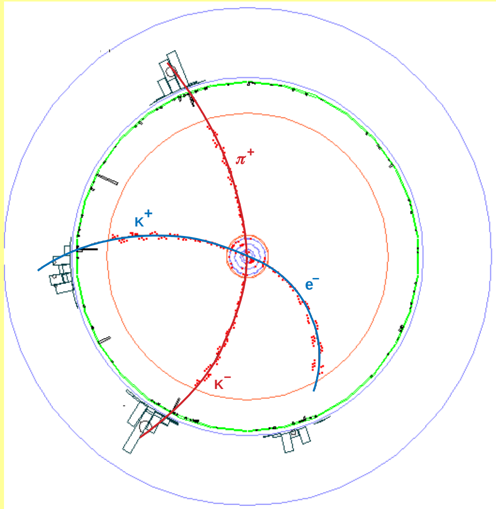
CLEO-c Signature

ψ(3770) events are simpler than ϒ(4S) events!

ϒ(4S) event



ψ(3770) event



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

The demands of doing physics in the 3 - 5 GeV range are easily met by the existing detector

BUT

B factories: 400 fb^{-1}
→ ~500M $c\bar{c}$ by 2005
What is the advantage of running at threshold?

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

- Double tag events are pristine
  These events are the key to make absolute BR measurements
- Neutrino reconstruction is clean
- Quantum coherence aids D mixing & CP violation studies

Precision Flavor Physics

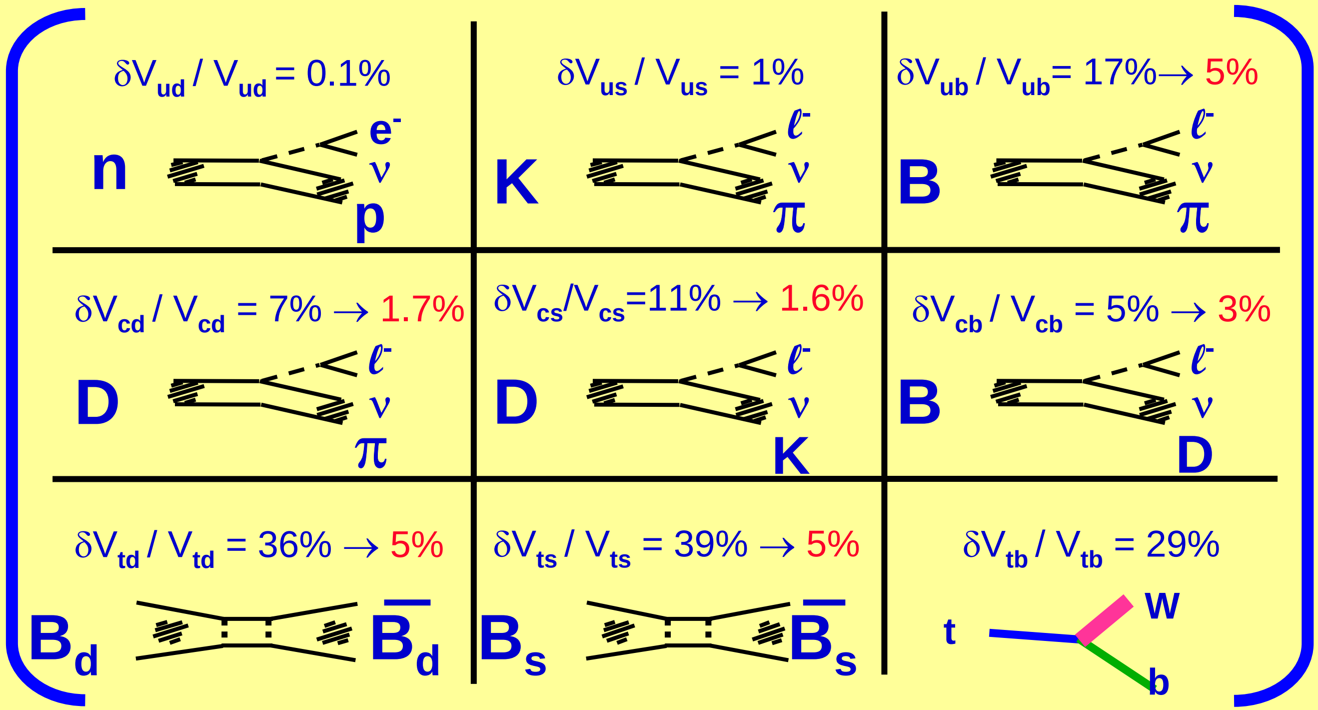
Goal for the decade:

High precision measurements of all CKM matrix elements & associated phases – over-constrain the "Unitary Triangles"

Inconsistencies → New Physics !

CKM Matrix Current Status:

Potential CLEO-c impact



Many experiments will contribute:

CLEO-c will enable precise 1st column unitarity test & new measurements at B-Factories/Tevatron to be translated into greatly improved CKM precision

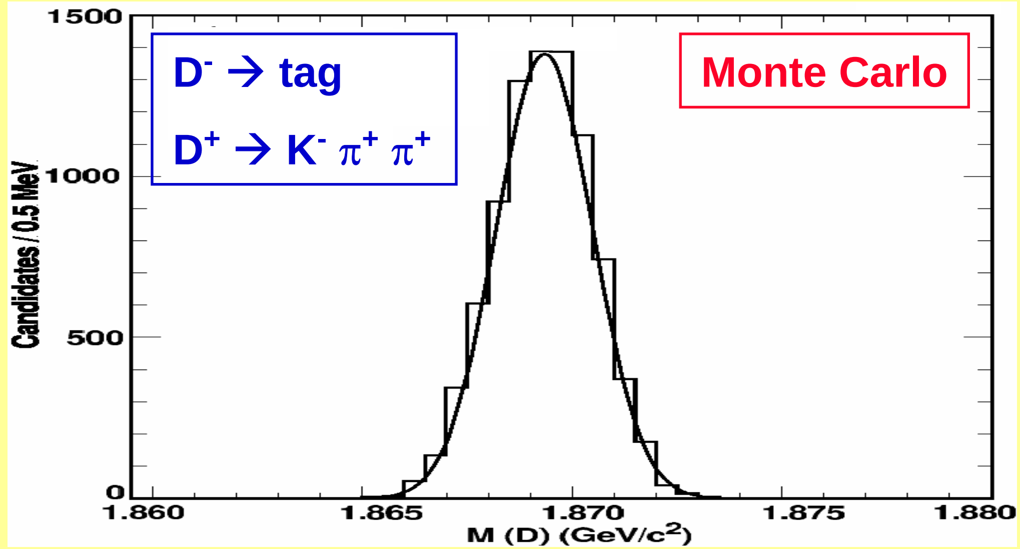
Absolute Charm Branching Ratios

Double tag technique:

Almost zero background in hadronic tag modes

Measure absolute $\mathcal{B}(D \to X)$ with double tags

$$\mathcal{B} = \frac{\#\text{ of X}}{\#\text{ of D tags}}$$



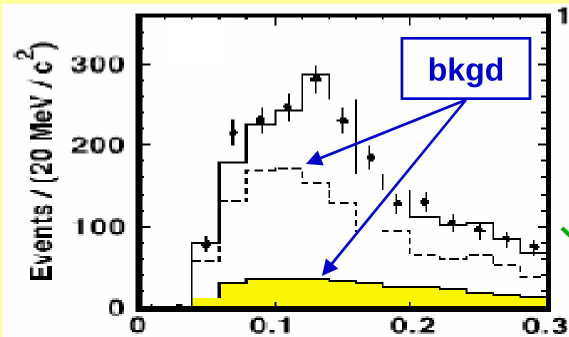
Decay	$\sqrt{s}$	$\mathcal{L}$ (fb^{-1})	Double tags	$\delta\mathcal{B} / \mathcal{B}$ (%) PDG	CLEO-c
$D^0 \to K^- \pi^+$	3770	3	53,000	2.4	0.6
$D^+ \to K^- \pi^+ \pi^+$	3770	3	60,000	7.2	0.7
$D_s \to \phi\, \pi$	4140	3	6,000	25	1.9

CLEO-c: potential to set absolute scale for all heavy quark measurements

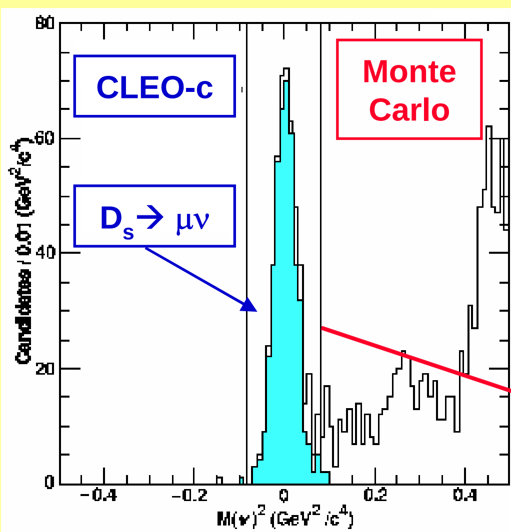
50 pb^{-1} → ~1,000 events ➔ x2 improvement (stat) on $D^+ \to K^- \pi^+ \pi^+$ PDG $\delta\mathcal{B}/\mathcal{B}$

Comparison: B Factories & CLEO-c

CLEO: f_{D_s}: $D_s^* \rightarrow D_s \gamma$ with $D_s \rightarrow \mu\nu$



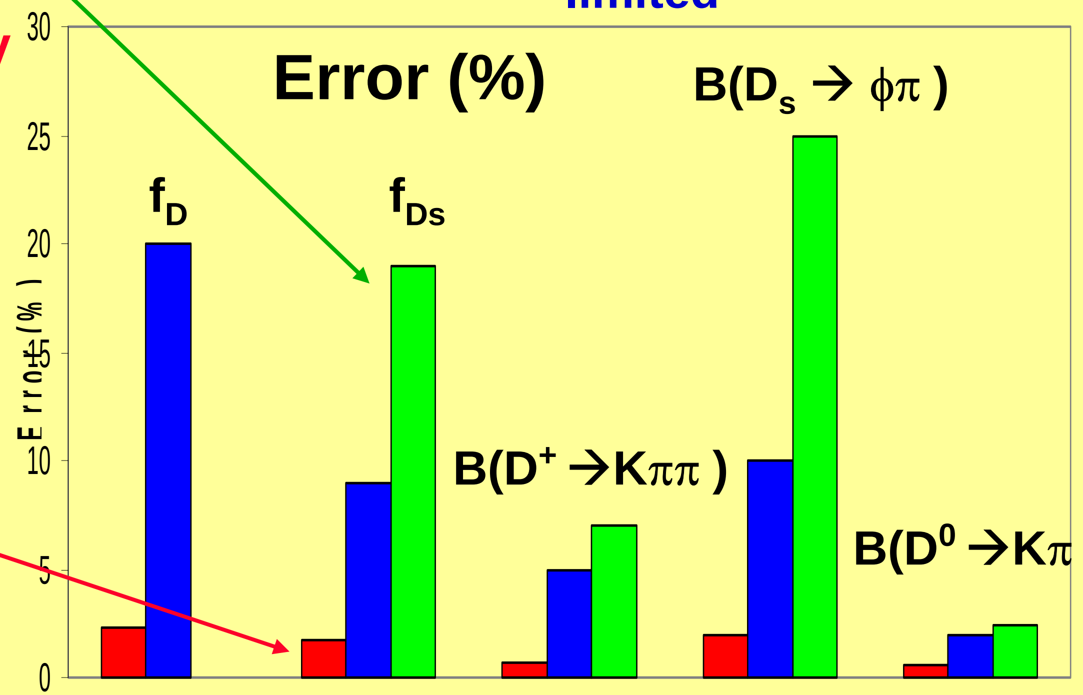
$\Delta M = M(\mu\nu\gamma) - M(\mu\nu)$ / GeV



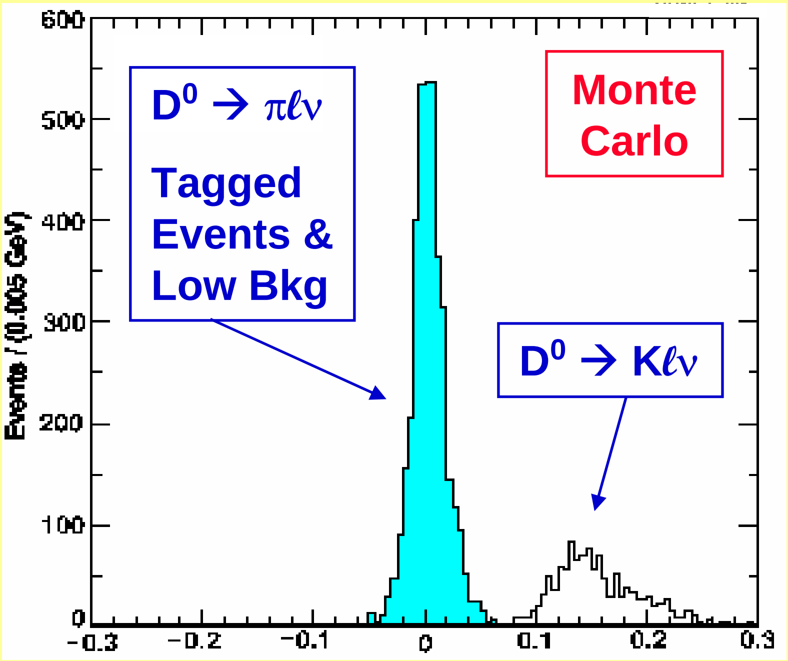
CLEO-c $3\ fb^{-1}$ — Statistics limited

B Factory $400\ fb^{-1}$ — Systematics & Background limited

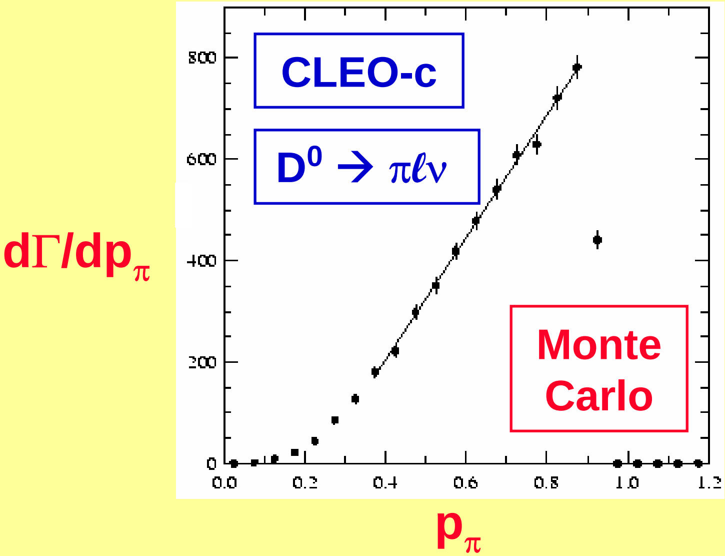
PDG

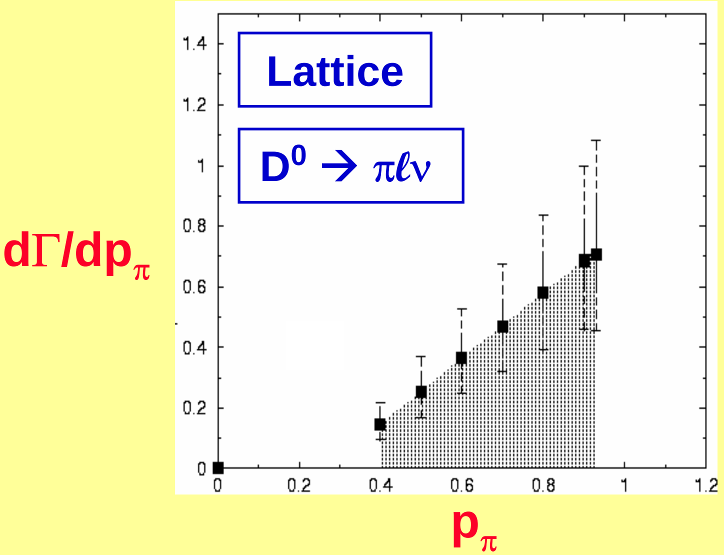


Semileptonic Decays $|V_{CKM}|^2\ |f(q^2)|^2$



$E_{miss} - P_{miss}$





First time measurement of complete set of charm PS → PS & PS → V absolute form factor magnitudes and slopes to a few % with almost no background in one experiment

Stringent test of theory!

CLEO-c Impact on Semileptonic $\delta\mathcal{B}/\mathcal{B}$

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

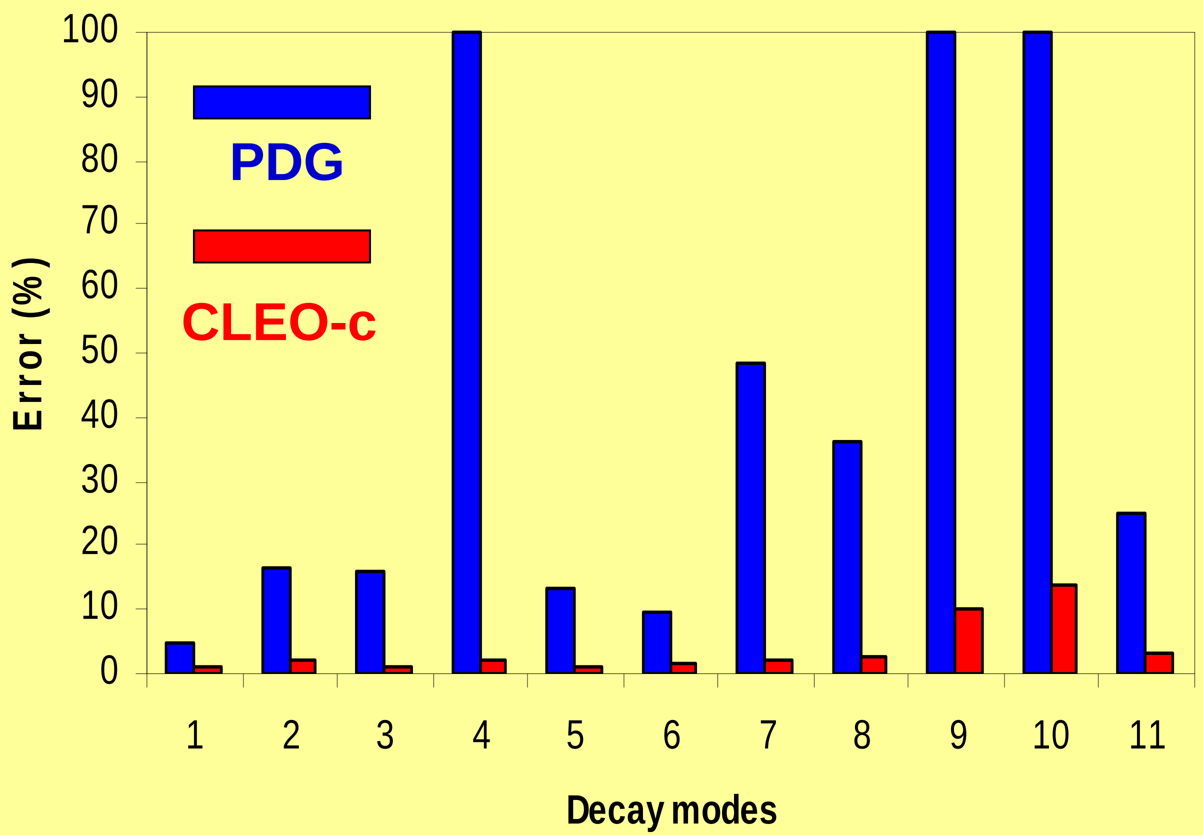
7: $D^+ \to \pi^0 e^+ \nu$

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

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

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

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



CLEO-c will make significant improvements in the precision with which each absolute charm semileptonic branching ratio is known!

CLEO-c Probes of QCD

Verify tools for strongly coupled theories
Quantify accuracy for application to flavor physics

- **ψ and ϒ spectroscopy**
  - **Masses, spin fine structure** ← Confinement, Relativistic corrections
- **Leptonic widths of S-states** ← Wave function; Tech: $f_{B,K}$ $\sqrt{B_K}$ f_{Ds}
  - **EM transition matrix elements** ← Form factors
    - **ϒ resonances done in fall 2001 - fall 2002** — **~4 fb^{-1}**
    - **J/ψ running in 2005** — **anticipate 1 billion J/ψ**

Rich calibration and testing ground for theoretical techniques → apply to flavor physics

- **Uncover new forms of matter – gauge particles as constituents**
  - **Glueballs G = | gg 〉**
  - **Hybrids H = | gq$\bar{q}$ 〉**

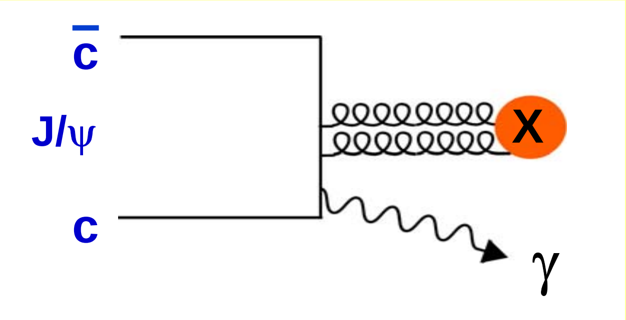
  Study fundamental states of the theory

The current lack of strong evidence for these states is a fundamental issue in QCD → Requires detailed understanding of the ordinary hadron spectrum in the 1.5 – 2.5 GeV mass range

Gluonic Matter

- **Many Glueball sightings without confirmation**

CLEO-c 1st high statistics experiment with modern 4π detector covering the 1.5 - 2.5 GeV mass range



Radiative J/ψ decays are ideal glue factory
anticipate 60 million J/ψ radiative decays

- **Branching ratios of f_0 triplet from WA102 (D. Barberis et al., Phys. Lett.B 479 59 (2000))**

$$\frac{f_0(1370) \to \pi\pi}{f_0(1370) \to K\bar{K}} = 2.17 \pm 0.90$$

$$\frac{f_0(1370) \to \eta\eta}{f_0(1370) \to K\bar{K}} = 0.35 \pm 0.21$$

$$\frac{f_0(1500) \to \pi\pi}{f_0(1500) \to \eta\eta} = 5.5 \pm 0.84$$

$$\frac{f_0(1500) \to K\bar{K}}{f_0(1500) \to \pi\pi} = 0.32 \pm 0.07$$

$$\frac{f_0(1500) \to \eta\eta'}{f_0(1500) \to \eta\eta} = 0.52 \pm 0.16$$

$$\frac{f_0(1710) \to \pi\pi}{f_0(1710) \to K\bar{K}} = 0.20 \pm 0.03$$

$$\frac{f_0(1710) \to \eta\eta}{f_0(1710) \to K\bar{K}} = 0.48 \pm 0.14$$

$$\frac{f_0(1710) \to \eta\eta'}{f_0(1710) \to \eta\eta} < 0.05(90\% cl)$$

→Input for glueball - scalar mixing models
(F. Close et al., Eur. Phys. J. C 21 531 (2001))

Mode	CLEO-c
J/ψ → γ f_0(1500): f_0(1500) → $\pi^+\pi^-\pi^+\pi^-$	123,000
J/ψ → γ f_0(1710): f_0(1710) → $\pi^+\pi^-\pi^+\pi^-$	123,000
J/ψ → γ f_0(1710): f_0(1710) → ππ	93,000
J/ψ → γ f_0(1710): f_0(1710) → KK	250,000

CLEO-c Probes of New Physics

- **Rare charm decays:**

$D \rightarrow l^+l^{`-}$ (GIM, Helicity), $Xl^+l^{`-}$ (GIM)

Sensitivity: 10^{-6} SM rate 10^{-19}, 10^{-16}

$\Rightarrow$ Search for New Physics

- **DD mixing: CKM & GIM Suppressed**

B-factory + Fixed Target experiments exploit finite D lifetime

$R(t) = e^{-t} (R_{Dcsd} + R_{Dcsd} y^{`1/2}\, t + R_{MIX} t^2)$

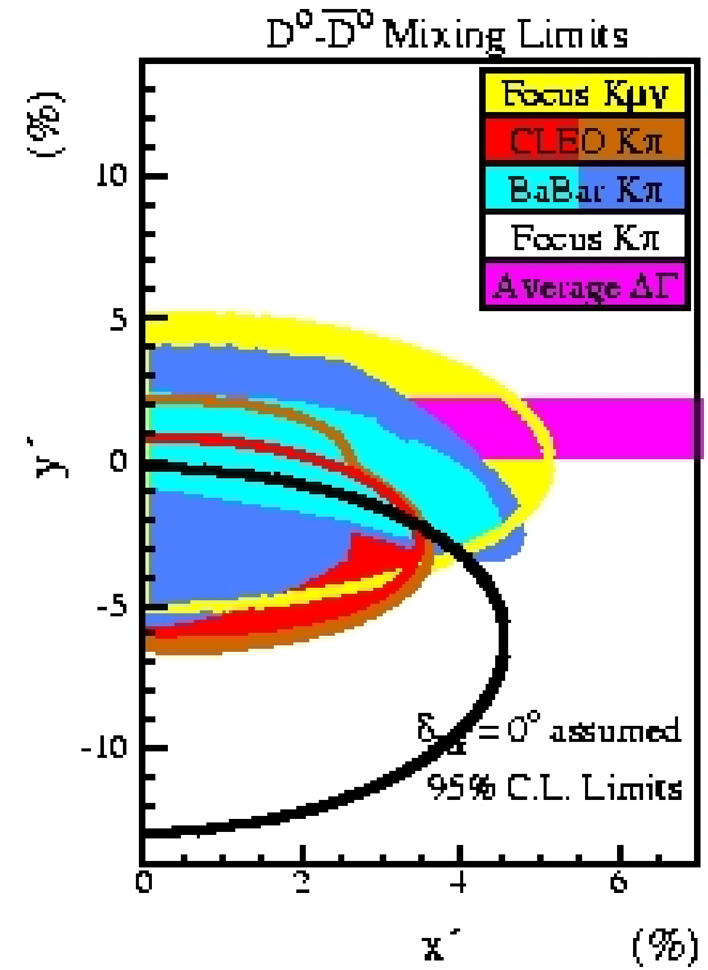
$y` = y\cos\delta - x\sin\delta$, $x` = y\sin\delta + x\cos\delta$

$R_{MIX} = ½(x^2+y^2) = ½(x^{`2} + y^{`2})$

CLEO-c cannot measure D lifetime: Exploit quantum coherance

Sensitive to $\cos\delta \sim \pm 0.07$

and $(2R_{MIX})^{1/2} < 2\%$ @ 95% C.L.



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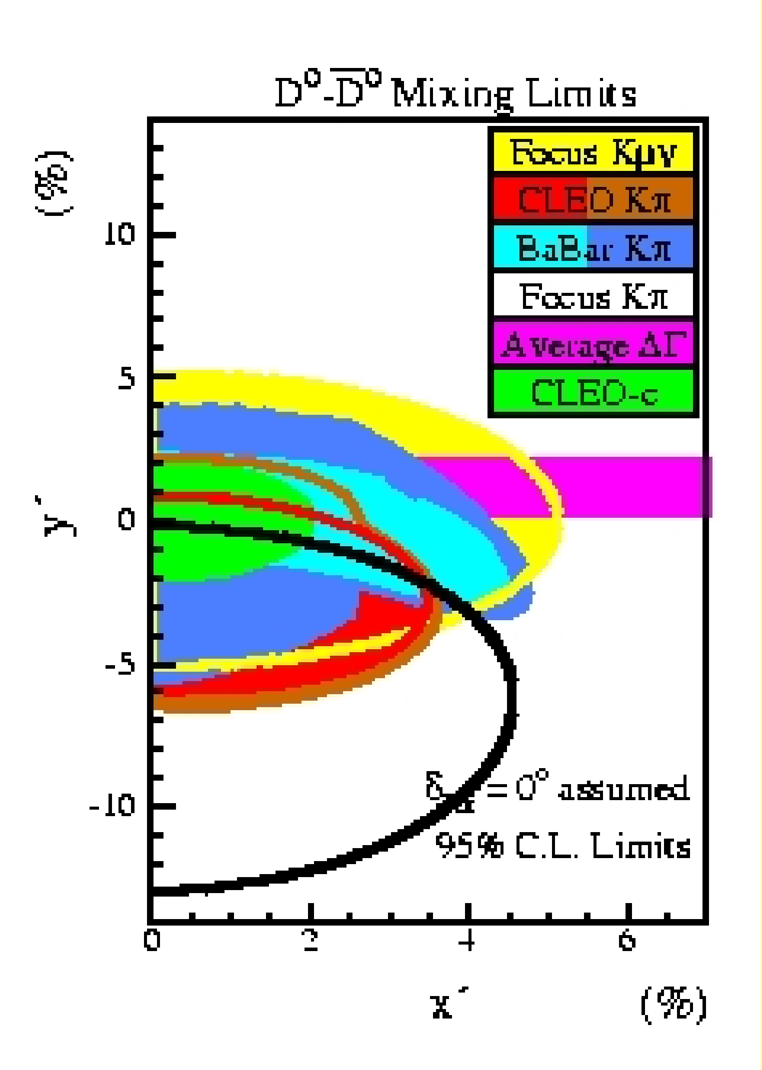


CLEO-c Probes of New Physics

- **CP violating asymmetries**

Sensitivity: $A_{CP} < 0.01$ for
$\Psi(3770) \rightarrow e/\mu$ (CP), CP=K^+K^-,$K_S\pi^0$,$K_S\omega$

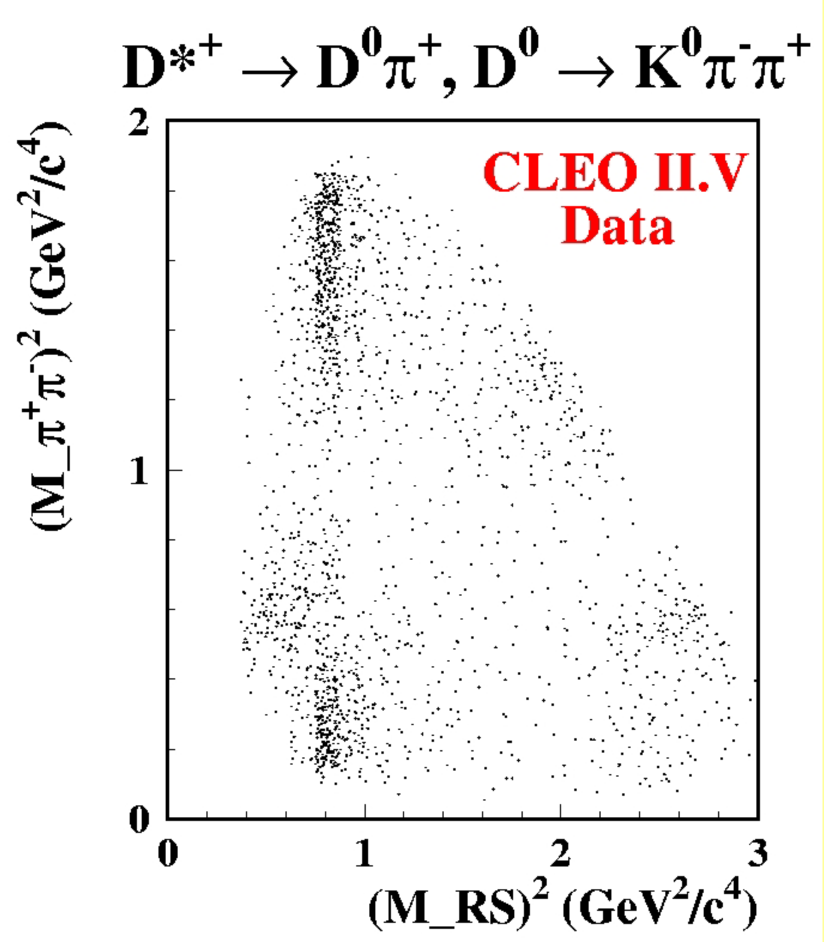
- **Interference between amplitudes on Dalitz plots such as $D \rightarrow K_S\pi^+\pi^-$ may provide greater sensitivity to CPV**

Intermediate states include

CP+: K_S $f_0(600)$, $K_Sf_0(980)$, $K_Sf_0(1370)$
CP- : $K_S\rho$, $K_S\omega$

Uncorrelated D's: CP conservation $\Rightarrow$ interference between CP+ & CP- amplitudes integrates to zero

Correlated D's: CP conservation $\Rightarrow$ interference between CP+ & CP- amplitudes locally zero



H. Muramatsu *et al.* [CLEO Collaboration.], Phys. Rev. Lett. 89 251802 (2002).

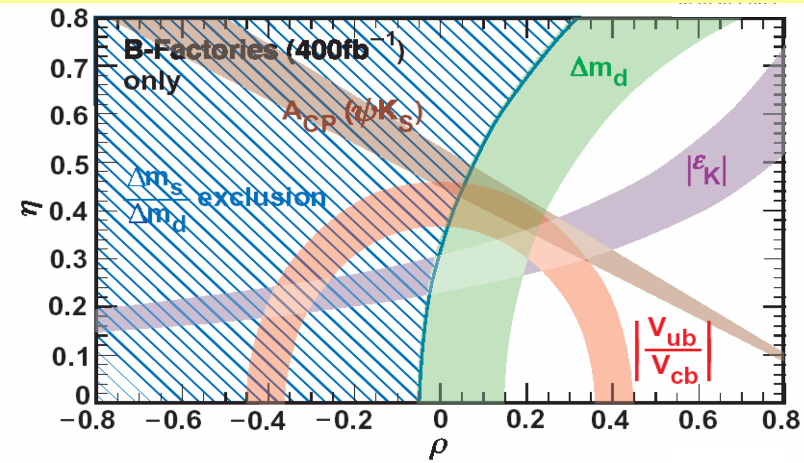
CLEO-c Physics Impact

Crucial Validation of Lattice QCD:

Lattice QCD will be able to calculate with accuracies of 1 - 2%. The CLEO-c decay constant and semileptonic data will provide a “golden” & timely test . QCD & charmonium data provide additional benchmarks.

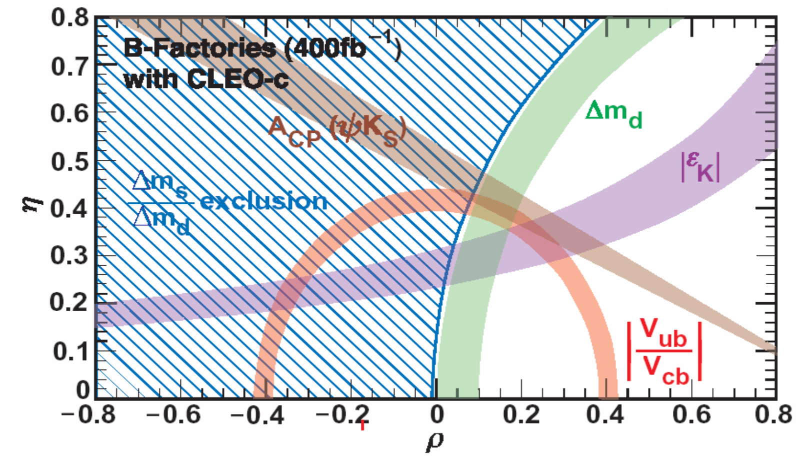
World Average ~2005 (excluding CLEO-c)

Assumes theory errors reduced by x2



World Average with CLEO-c

Theory errors = 2%



CLEO-c Physics Impact

- Absolute charm branching fractions contribute significant errors to measurements involving b's. CLEO-c can resolve this problem.

- Measuring the relative strong phase between $D^0 \rightarrow K^{*+}K^-$ and $D^0 \rightarrow K^{*-}K^+$ is crucial to determining angle γ with $B^\pm \rightarrow K^\pm D^0$, $D^0 \rightarrow K^*K$.
  J. A. Rosner & D. A. Suprun, Phys. Rev. D68 054010 (2003).

- Improved knowledge of CKM elements, which is now not very good

	V_{cd}	V_{cs}	V_{cb}	V_{ub}	V_{td}	V_{ts}
PDG	7%	11%	5%	17%	36%	39%
CLEO-c Data and LQCD / B Factory/Tevatron Data & CLEO-c Lattice Validation	1.7%	1.6%	3%	5%	5%	5%

PDG

CLEO-c Data and LQCD

B Factory/Tevatron Data & CLEO-c Lattice Validation

- The potential to observe new forms of matter – glueballs & hybrids – and new physics – D mixing / CP Violation / rare decays – provides a discovery component to the CLEO-c research program.

The CLEO-c Collaboration

The

CLEO-c

Collaboration

Carleton University
Carnegie Mellon University
Cornell University
University of Florida
George Mason University
University of Illinois
University of Kansas
University of Minnesota
Northwestern University
University of Oklahoma
University of Pittsburgh
University of Puerto Rico
Purdue University
Rensselaer Polytechnic Institute
University of Rochester
Southern Methodist University
Syracuse University
University of Texas - Pan American
Vanderbilt University
Wayne State University