CLEO-c and CKM Physics

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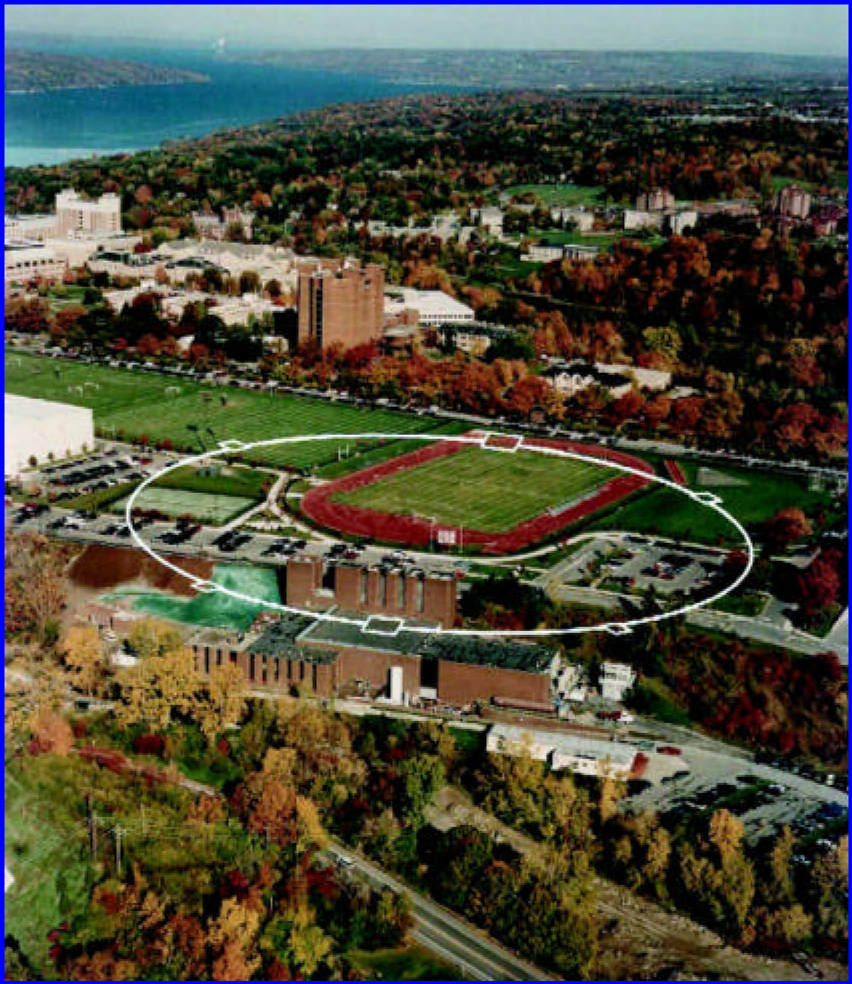
Cornell University

WIN 2003

October 7, 2003

CLEO-c and CESR-c

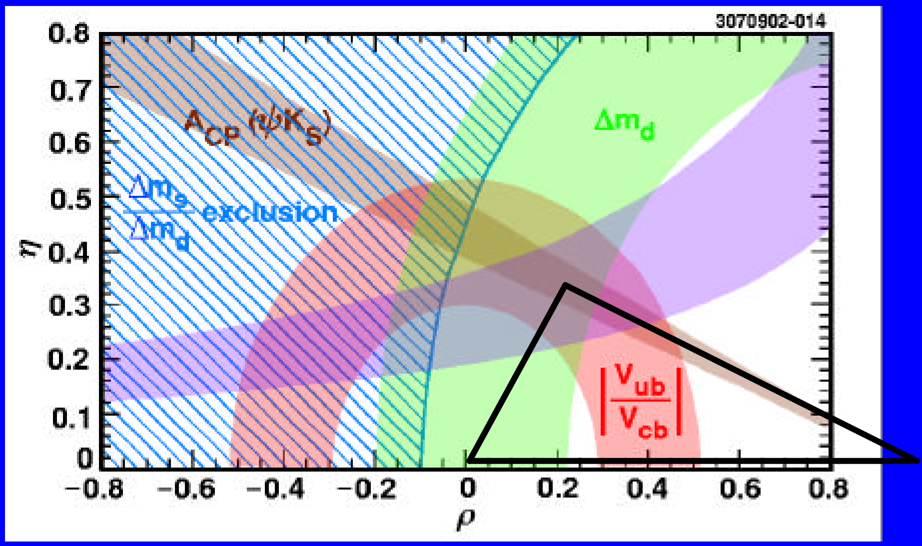


What's with the "-c"?

- CLEO detector
- Symmetric e^+e^- collider $\sqrt{s}$=10.6 GeV
- Add wigglers to improve damping and run at $\sqrt{s}$=3-6 GeV

- Access to charm threshold region
- Approved by National Science Board Feb 2003
- First Physics Run starts October 24, 2003
- 3+ year program

Context for CLEO-c



Flavor physics:

- Overconstrain V_{CKM}
- Inconsistency → new physics
- Interpretation limited by strong interaction effects

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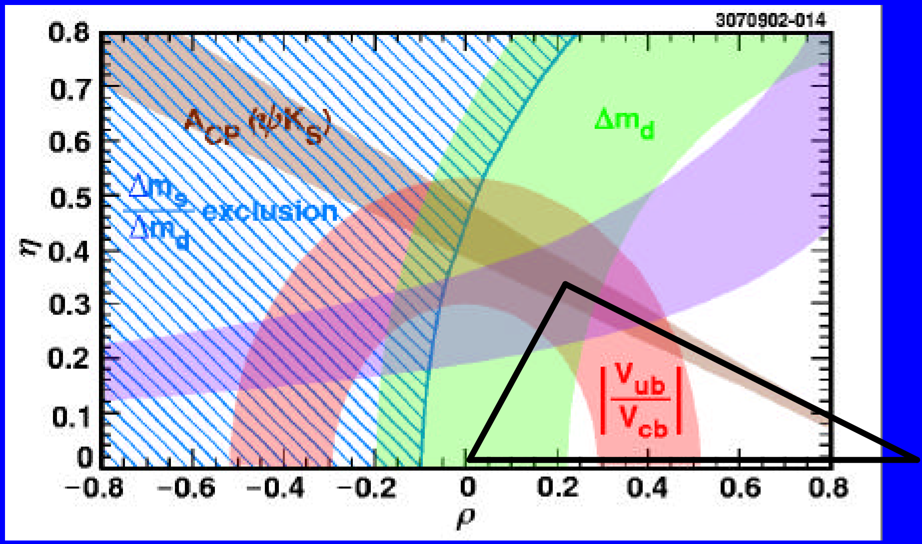

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- Sin 2β is clean
- $|V_{ub}|$ is not
- B mixing is not

Hadronic uncertainties confound the extraction of weak physics

- Non-perturbative QCD
- Perturbative QCD (on better ground)

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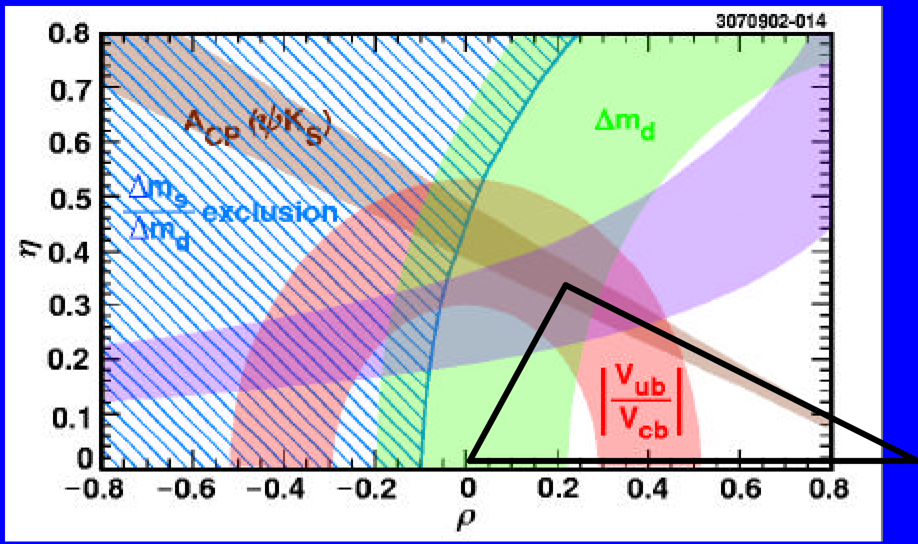

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Flavor physics:

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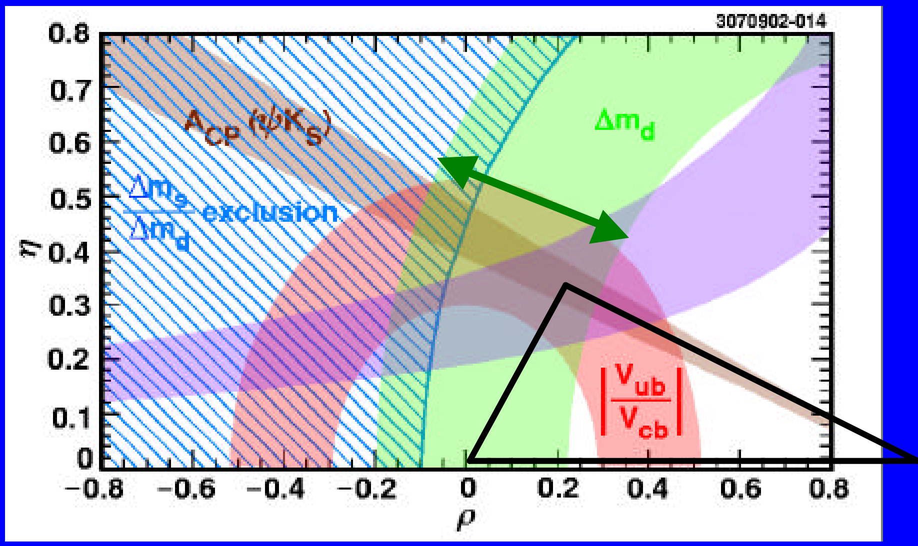
- Inconsistency → new physics
- Interpretation limited by strong interaction effects
- Measurements in Charm decays can validate QCD corrections needed to extract Weak physics from observables

UT Constraint from B mixing



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

$$\frac{s(|V_{td}|)}{|V_{td}|} = 0.5\frac{s(\Delta M_d)}{\Delta M_d} \oplus \frac{s(f_B\sqrt{B_{B_d}})}{f_B\sqrt{B_{B_d}}}$$

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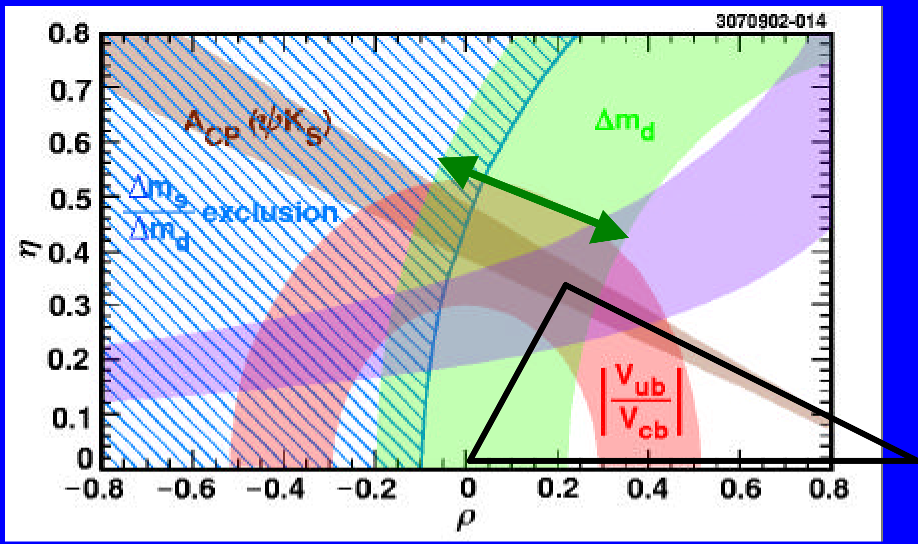

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1.2% ~15% (LQCD)

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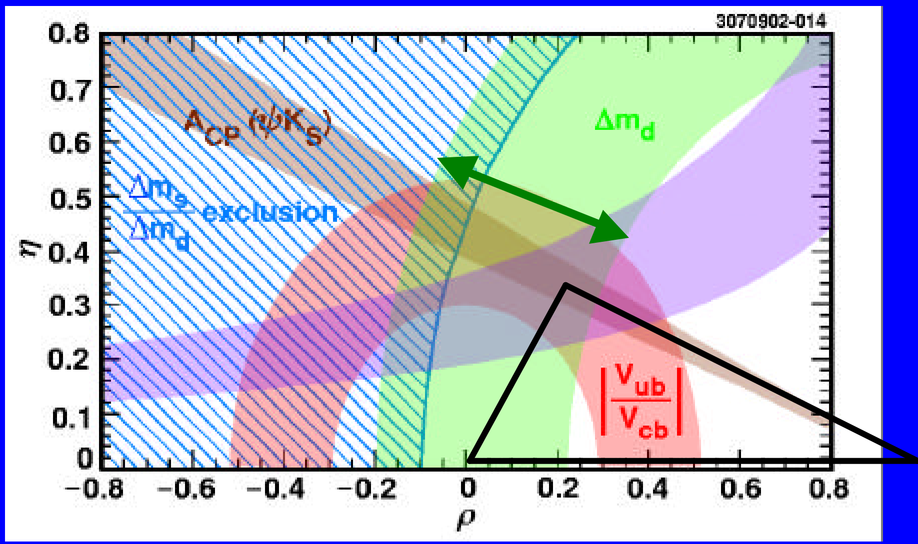

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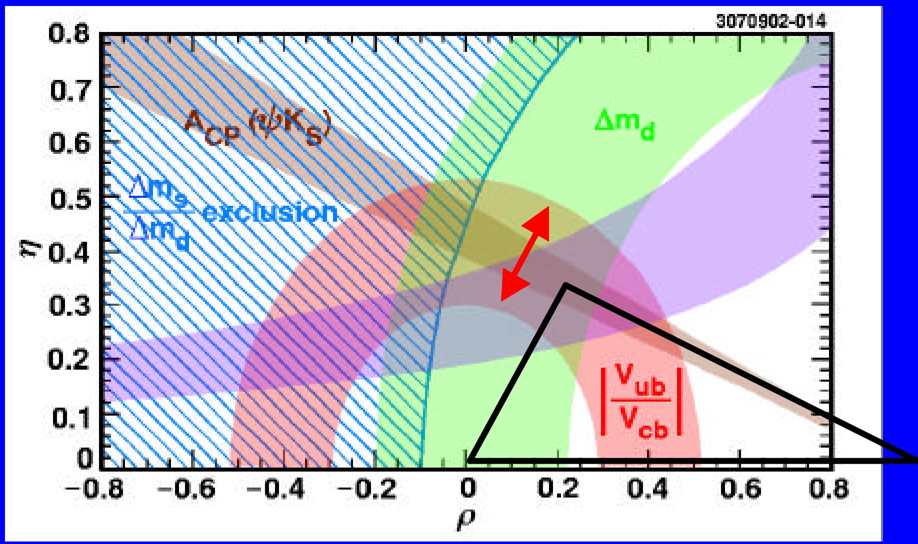
1.2% ~15% (LQCD)

- Lattice QCD predicts decay constants $f_{D(s)}/f_{B(s)}$
- If precise measurements of f_D and f_{Ds} exist, then our confidence in non-perturbative QCD calculations needed to make constraints on the UT is increased.
- Even better if B_s mixing is observed!

UT Constraint from $|V_{ub}|$



$|V_{ub}|$ from $B \rightarrow \pi l \nu$:

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2$$

Form factor $f(q^2)$:

- Not well known
- Limits $|V_{ub}|$ precision
- Predicted by LQCD

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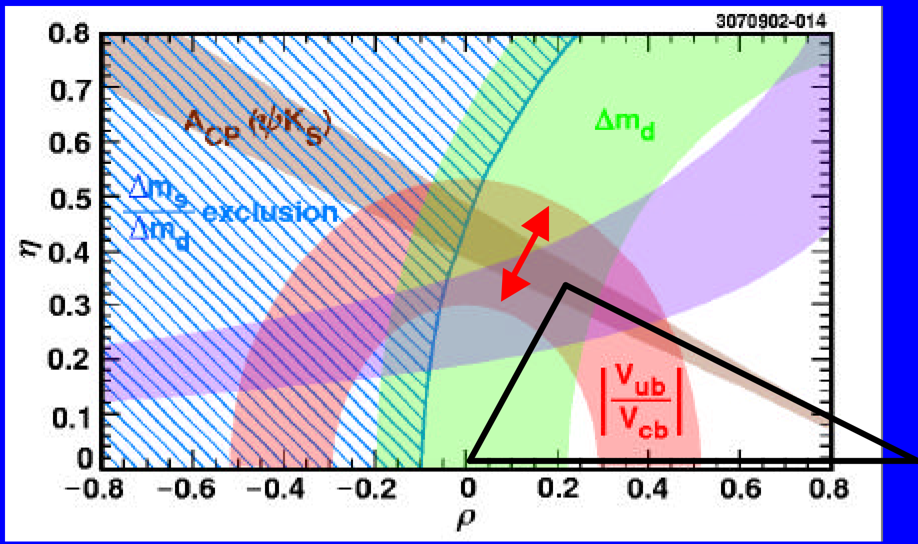

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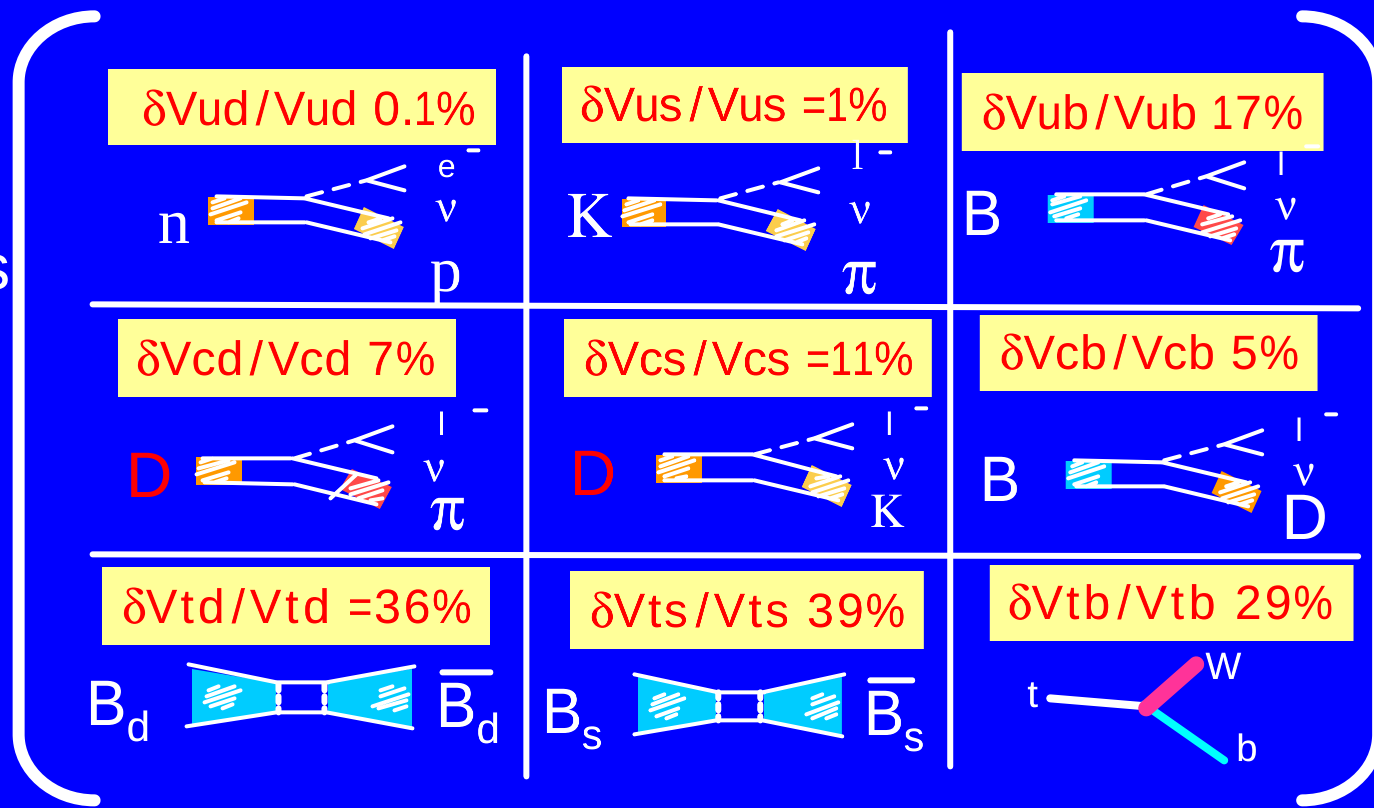
- Absolute rate and shape is a stringent test of theory
- Heavy quark symmetry relates $D \to \pi l \nu$ to $B \to \pi l \nu$
- A precise measurement of $D \to \pi l \nu$ can calibrate LQCD and allow a precise extraction of $|V_{ub}|$ from $B \to \pi l \nu$

Status of CKM Matrix

Current V_{CKM}
From direct
Measurements
-no unitarity
imposed



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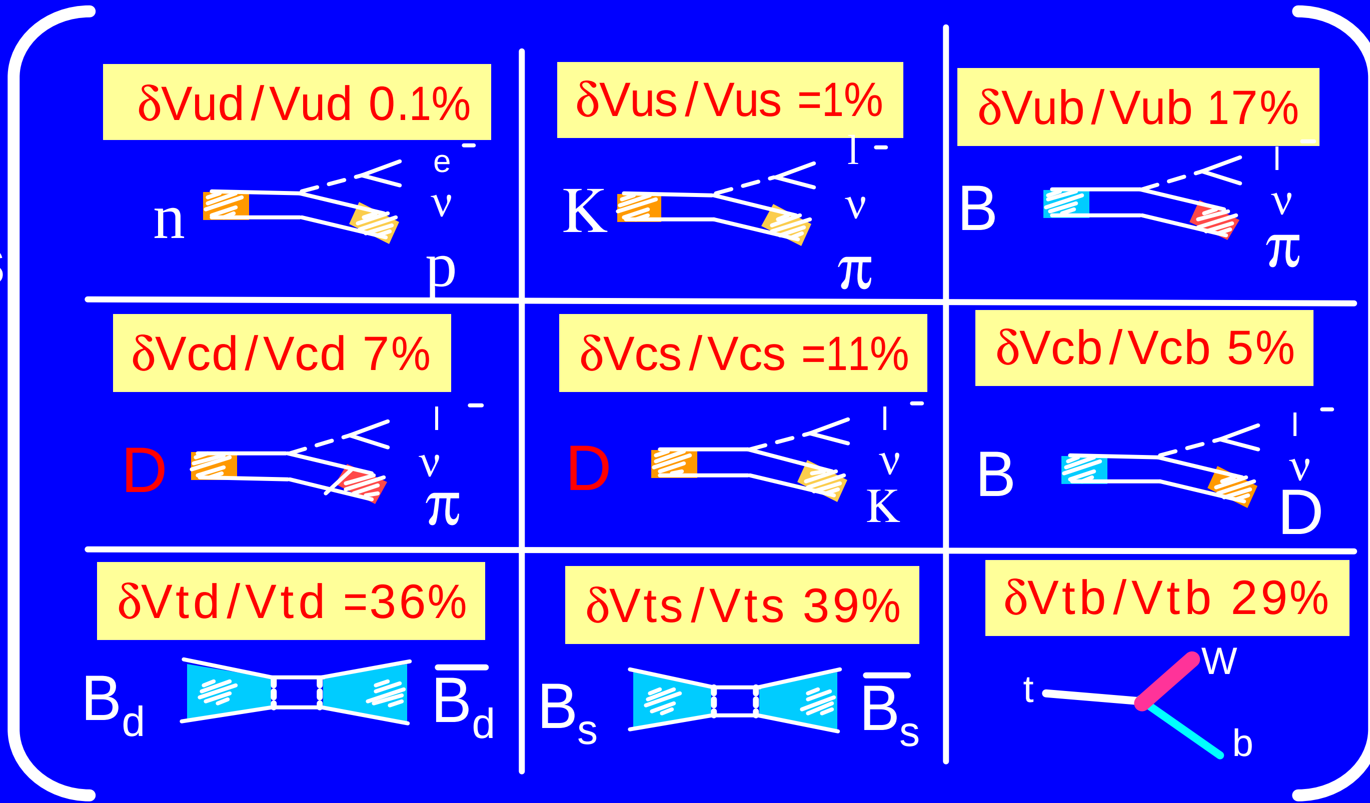

CLEO-c will redefine 2nd generation elements
And enable improvements in 3rd generation

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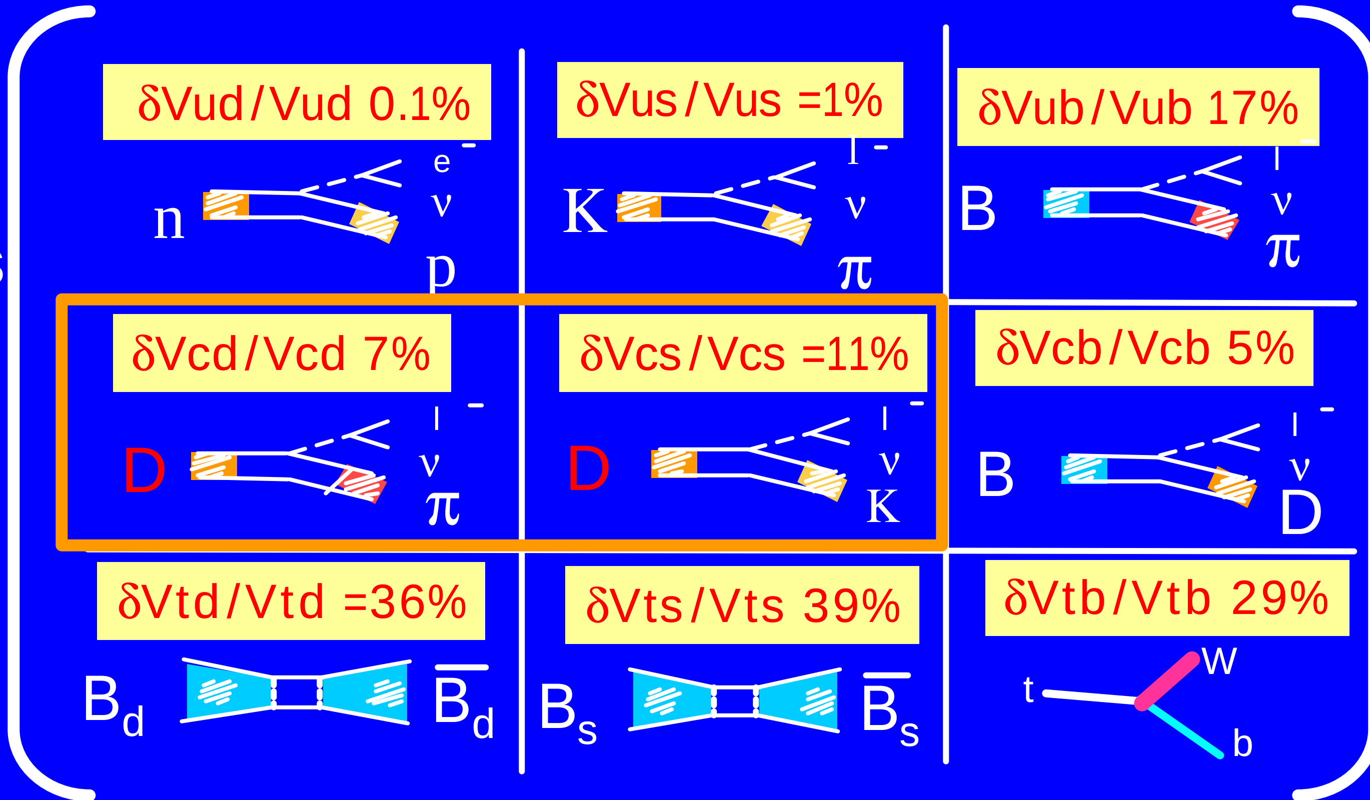

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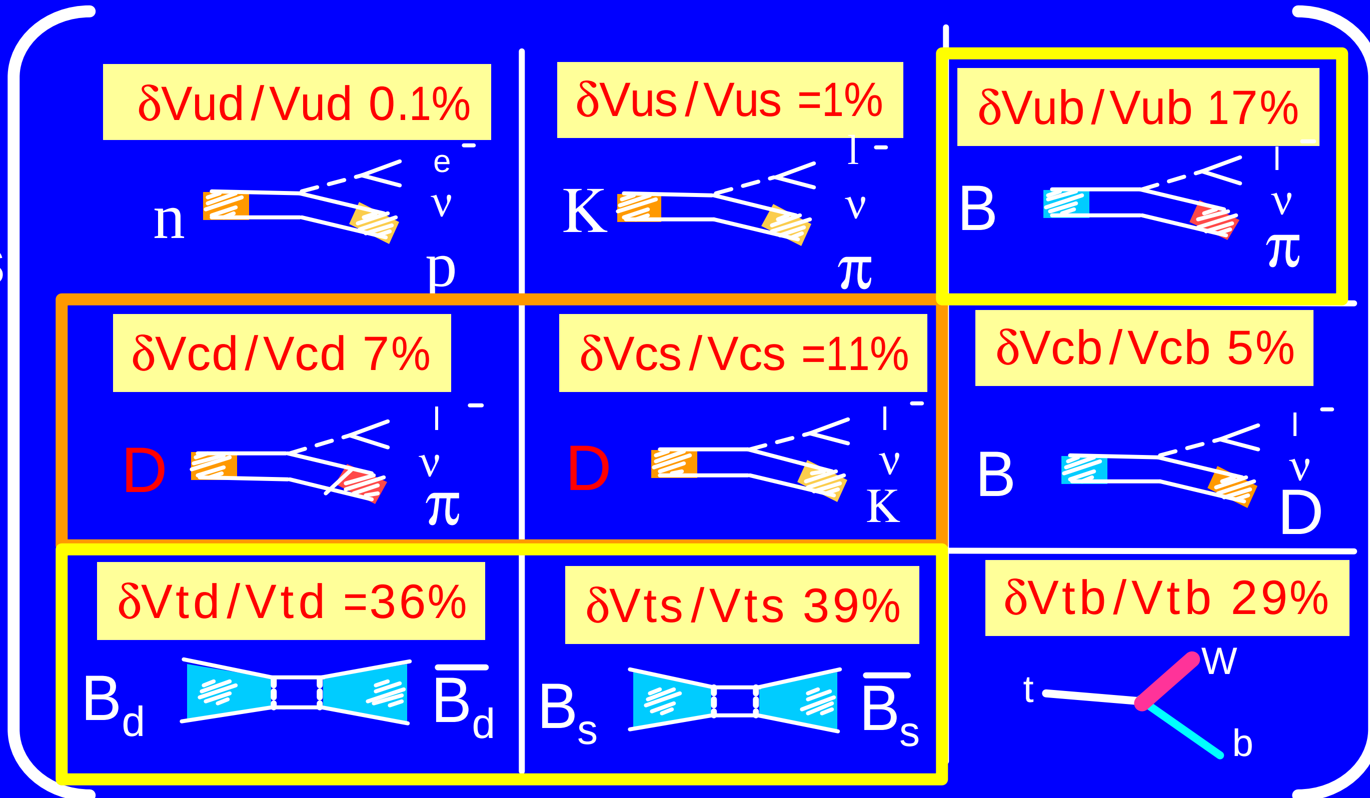

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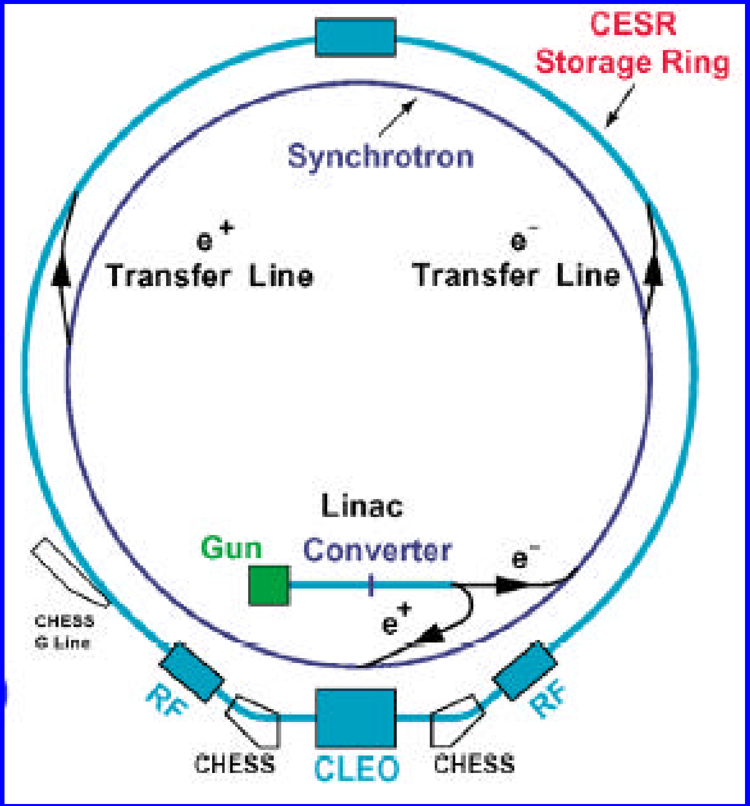
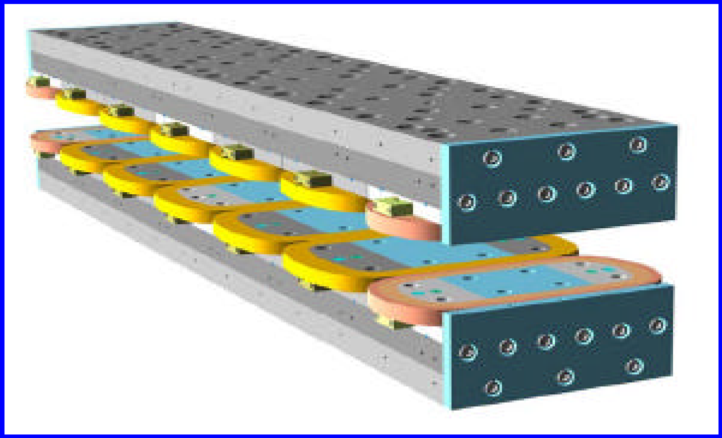
CESR-c





6/12 Wigglers E=1.5-3 GeV

Installed Spring'03

6 more March-May'04

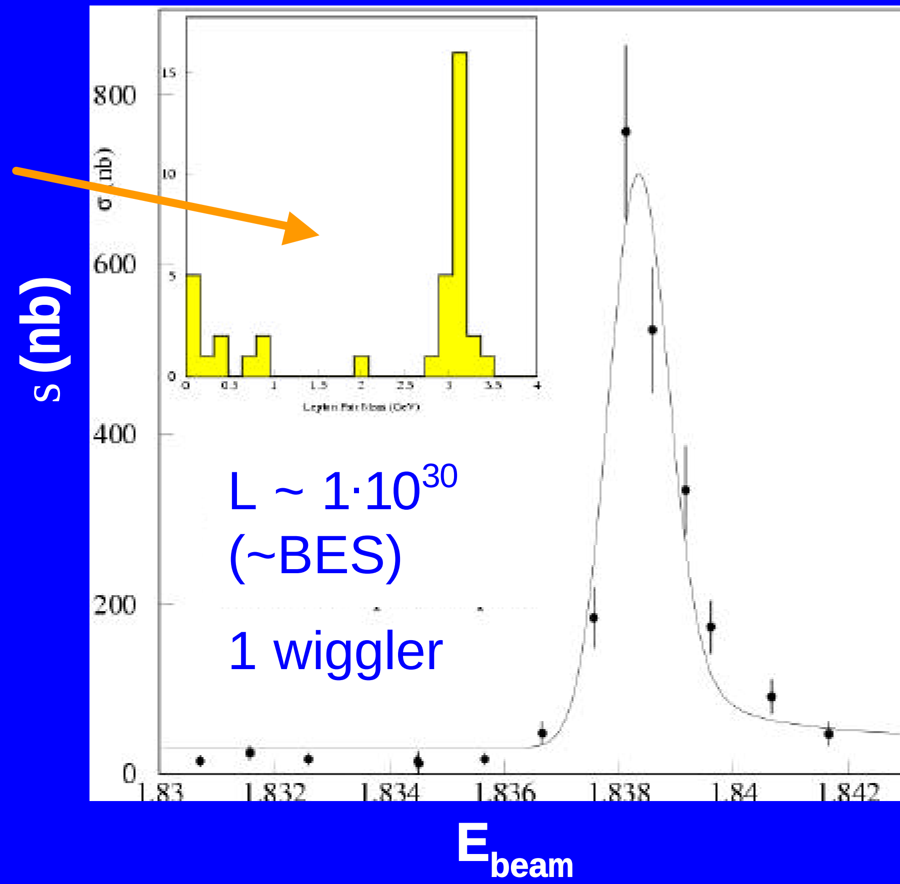
CESR-c

CESR: L(Υ(4S)) = $1.3 \cdot 10^{33}$ cm^{-2} s^{-1}

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

$J/\psi \to \mu\mu$

One day scan of ψ':

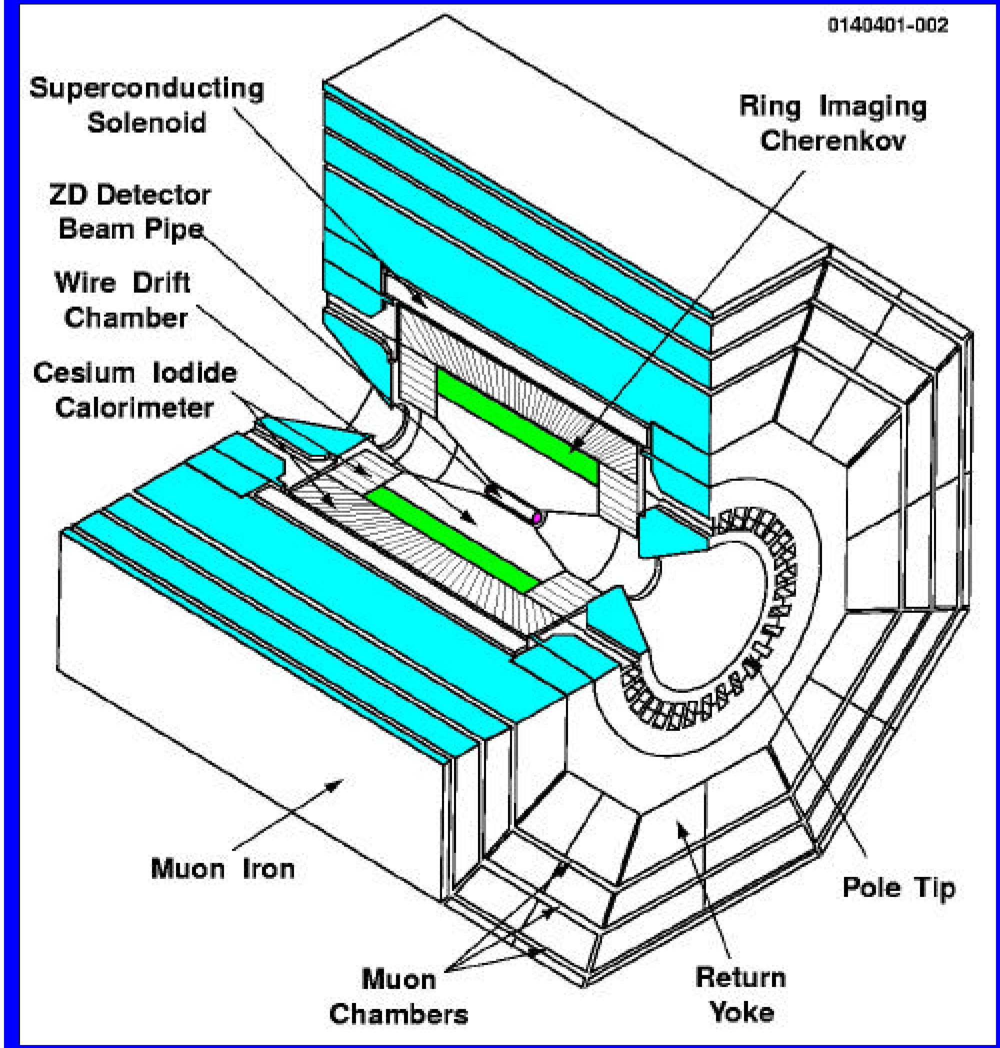


CESR-c Design Luminosity:

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

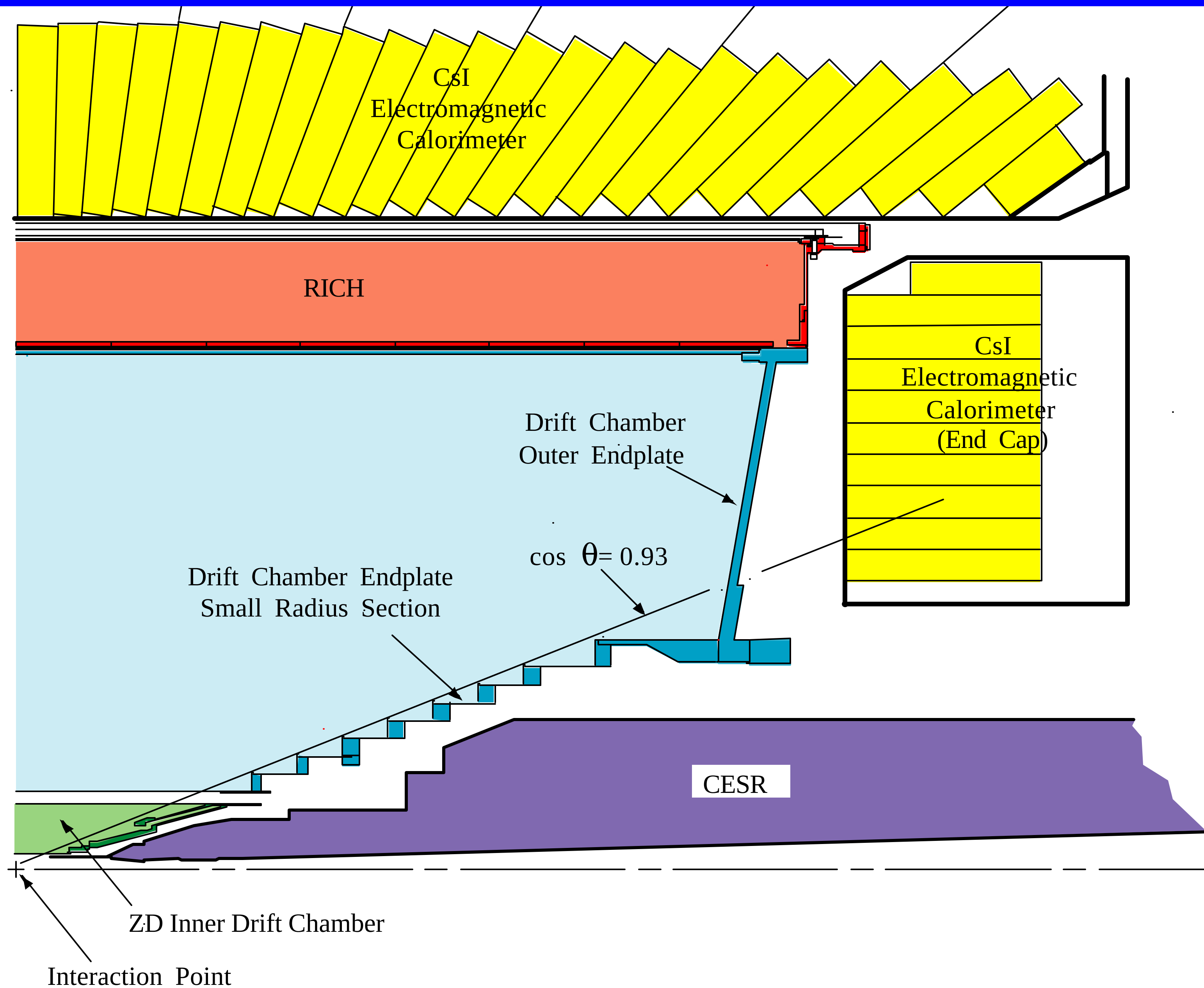
Machine performance: ΔE_{beam} ~ 1.6 MeV at ψ' (6 wigglers)

CLEO-c Detector

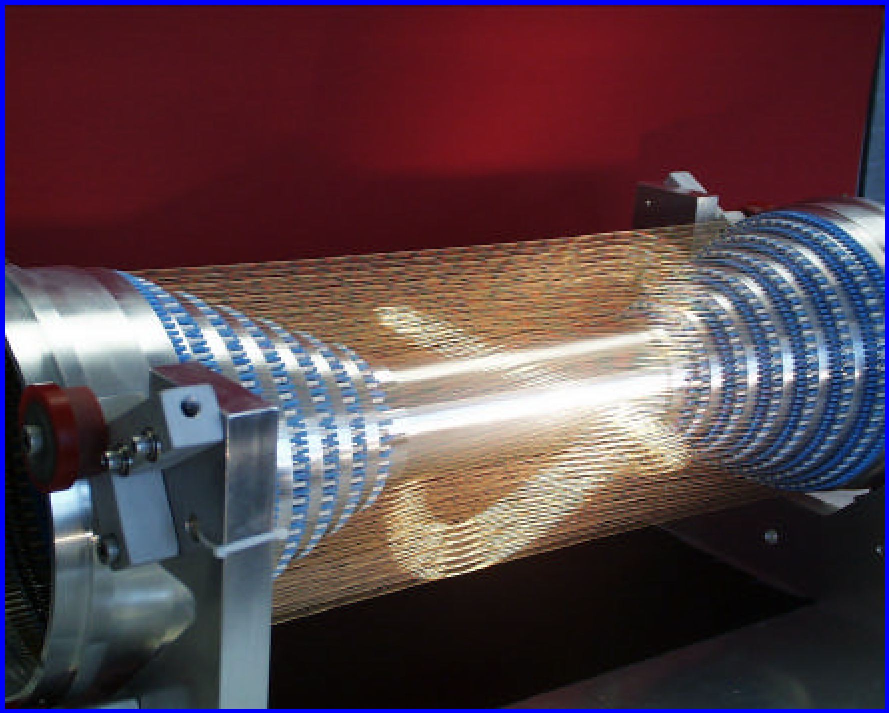


State of Art Detector:

- Drift Chamber Tracking (1 Tesla)
- RICH Particle ID
- Crystal EM Calorimetry
- 93% of solid angle
- Only small changes from CLEO III
  - B field 1.5 → 1 T
  - Silicon → ZD

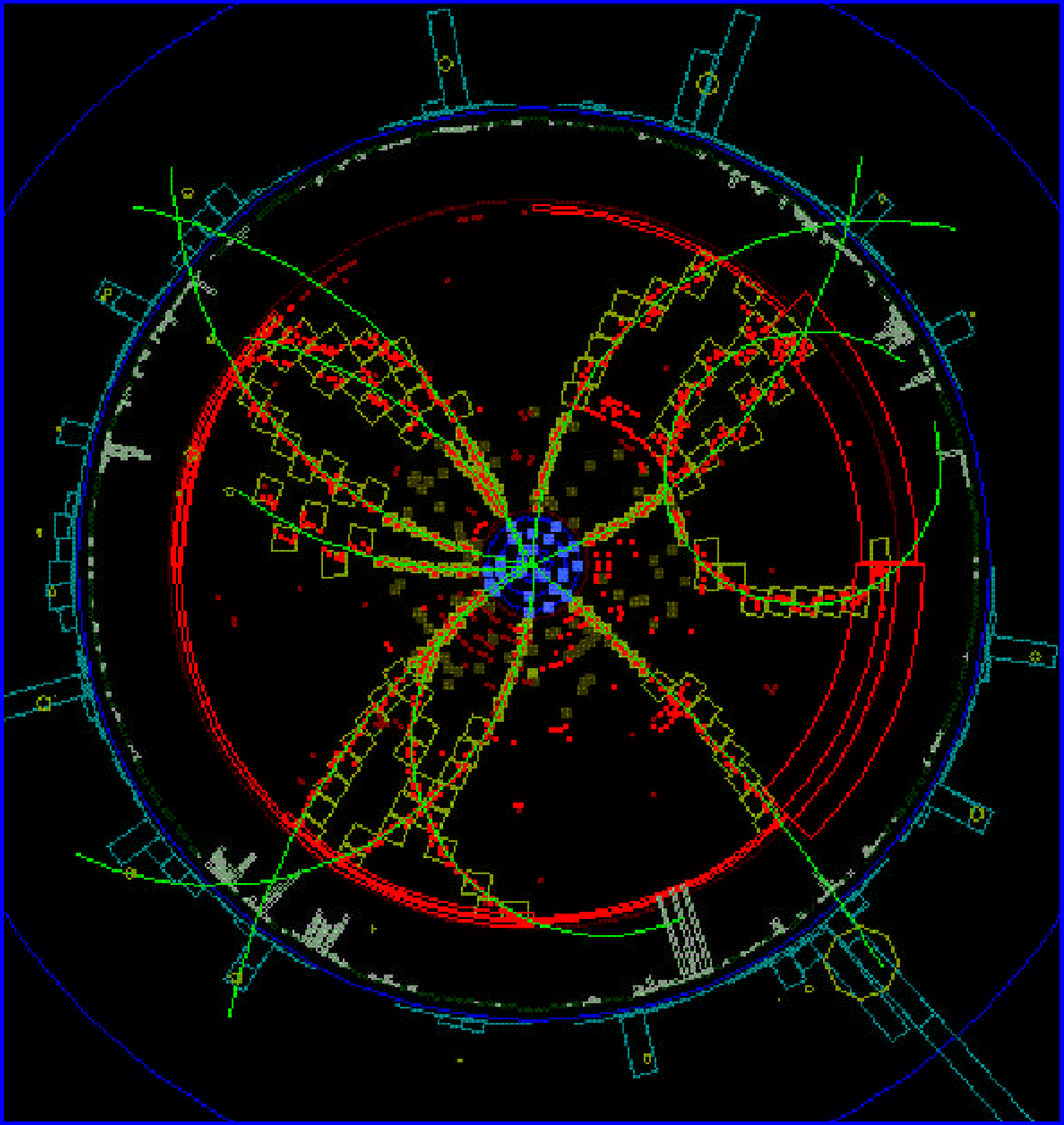

CsI
Electromagnetic
Calorimeter
RICH
CsI
Electromagnetic
Calorimeter
(End Cap)
Drift Chamber
Outer Endplate
cos θ= 0.93
Drift Chamber Endplate
Small Radius Section
CESR
ZD Inner Drift Chamber
Interaction Point

New Inner Detector



- Continuous tracking volume
- Low mass (σ_p is MS limited)
- Nothing to vertex at charm threshold!

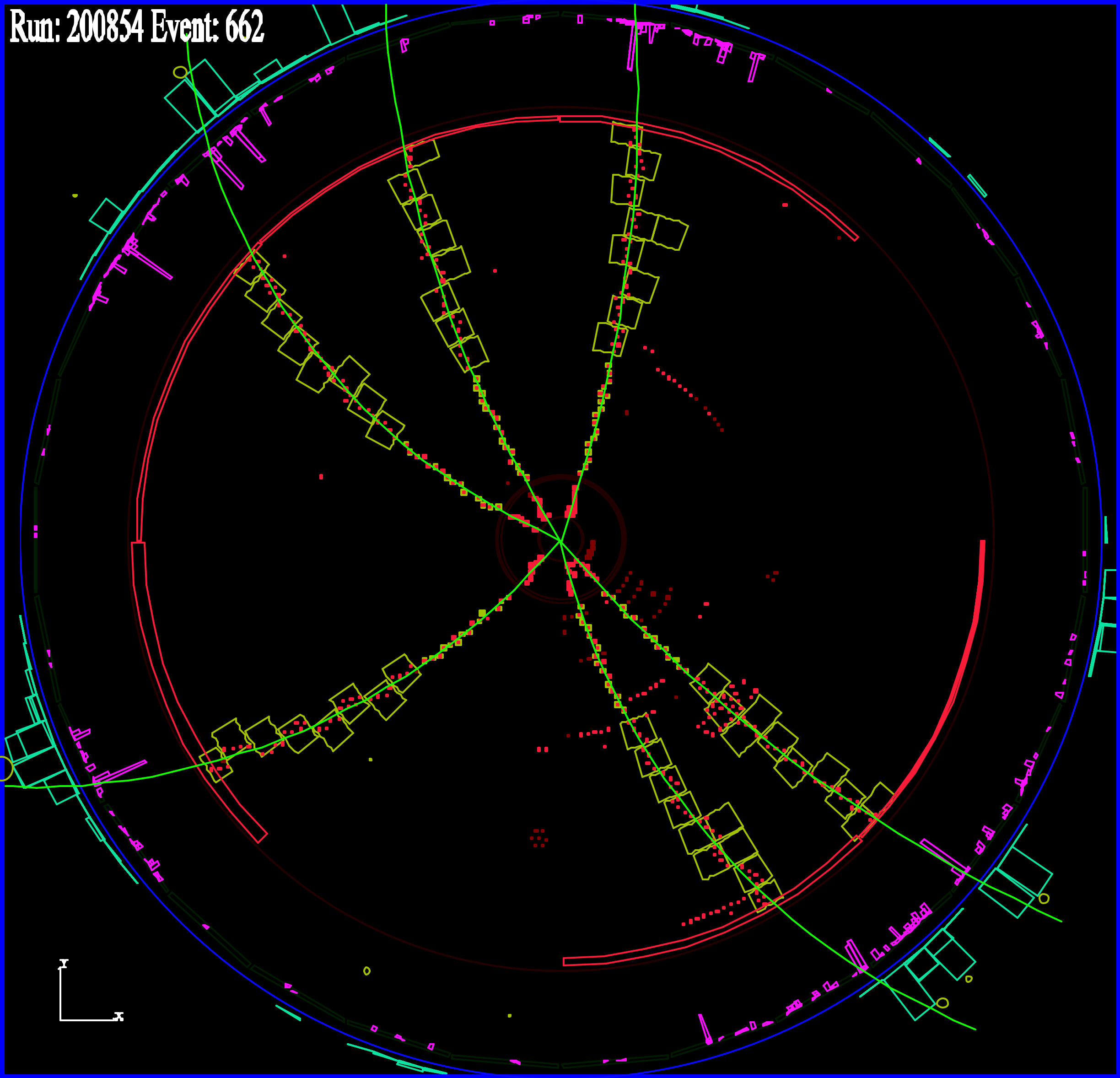
- Replaced Silicon Vertex Detector May 2003
- 6 stereo layers:
  - r=5.3 cm – 10.5 cm
  - 12-15^o stereo angle
  - $|\cos\theta| < 0.93$
- 300, 10 mm cells
- 1% X_0 inner Al tube .8mm
- Helium-Propane (60:40)
- 20 μm Au-W sense wires
- 110 μm Au-Al field wires
- Outer Al-Mylar skin



CLEO III
Y(4S)
Typical
Hadronic
Event

Average:

- 10 tracks
- 10 showers

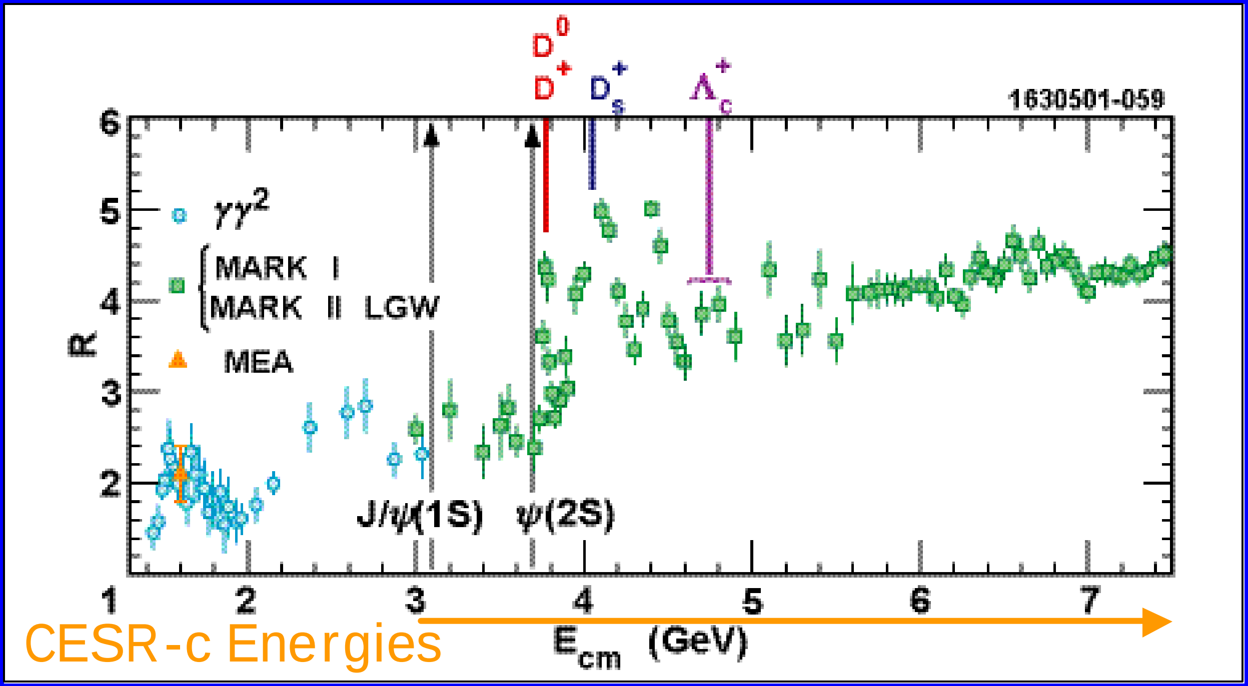


Event Recorded September 29, 2003

CLEO-c
ψ(3770)
Typical
Hadronic
Event

Average:
- 5 tracks
- 5 showers

Charm Threshold Region



- D^+D^-, $D^0\overline{D}^0$ at $\psi(3770)$
- $D_s^+ D_s^-$ at $\sqrt{s}$=4140 MeV
- Potential for $\Lambda_c^+ \Lambda_c^-$
- Will also run on J/ψ and possibly ψ'

$D\overline{D}$ cross section at ψ(3770) ~5 nb (Mark III)
$D_s\overline{D}_s$ cross section ~0.5 nb

CLEO-c Run Plan

Phase I: $\psi(3770)$ – 3 fb^{-1} ($\psi(3770) \to D\bar{D}$)

30 million DD events, 6 million *tagged* D decays

(310 times MARK III)

Phase II: $\sqrt{s}$=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, 130 times BES)

Phase III: $\psi(3100)$ – 1 fb^{-1}

1 Billion J/ψ decays

(170 times MARK III, 20 times BES II)

Now: Dec'02 — 5 pb^{-1} at $\psi(3770)$

Oct'03-Jan'04 — 50 pb^{-1} on $\psi(3770)$

Tagging Technique – Tag Purity

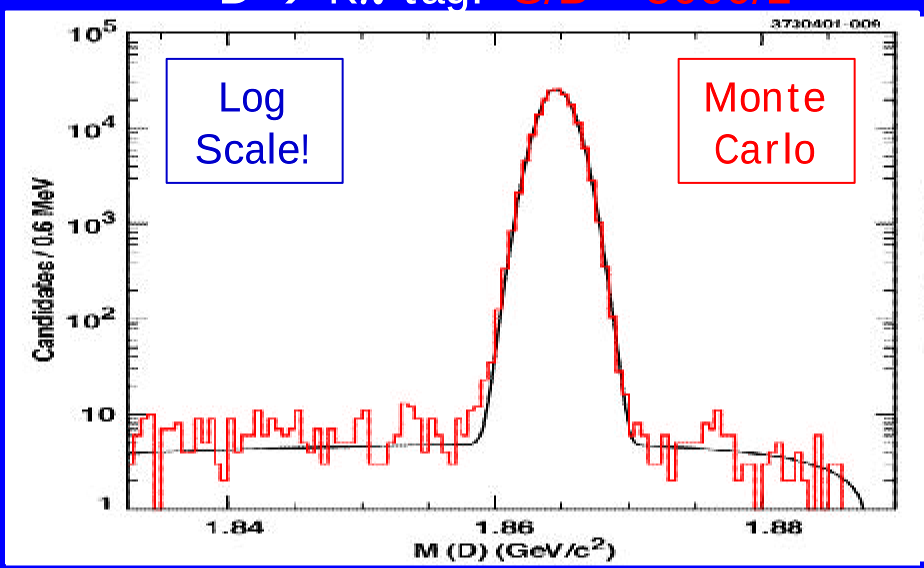
$\psi(3770) \rightarrow D\,\overline{D}$ $\sqrt{s} \sim 4140 \rightarrow D_s\,\overline{D}_s$

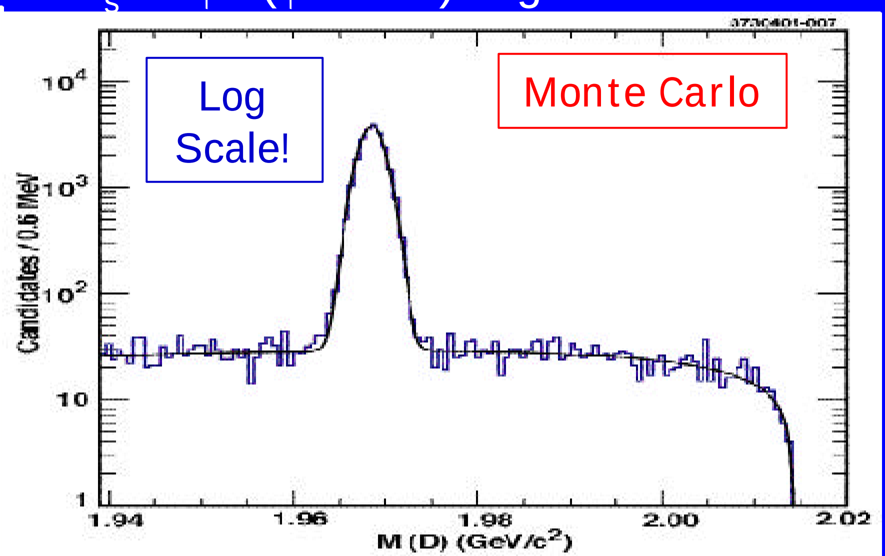
- Charm mesons have many large branching ratios (~1 - 15%)
- High reconstruction efficiency

➔ High net tagging efficiency ~20%

Anticipate 6M D tags and 0.3M D_s tags

$D \rightarrow K\pi$ tag: S/B ~ 5000/1 $D_s \rightarrow \phi\pi$ ($\phi \rightarrow KK$) tag: S/B ~ 100/1





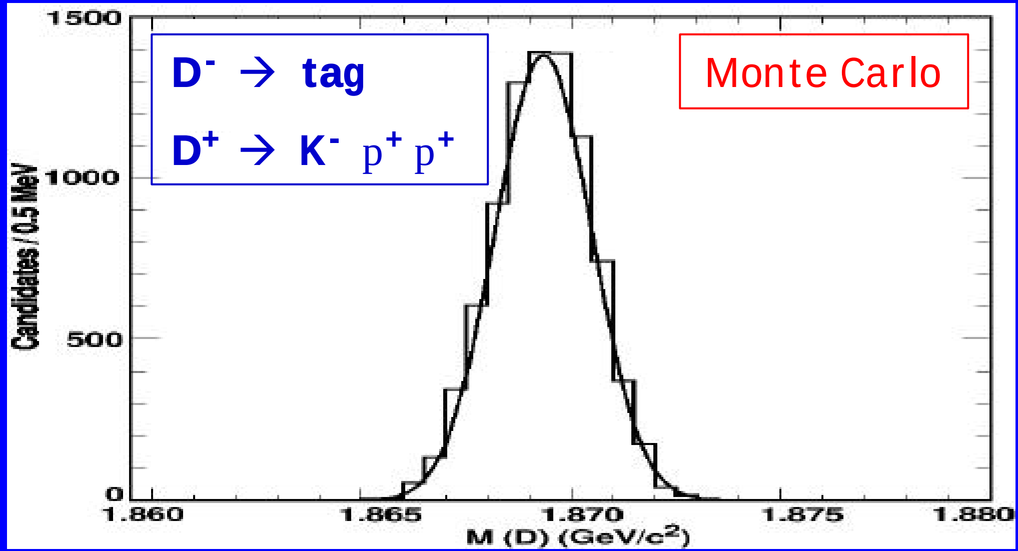
Absolute Charm Branching Ratios

Double tag technique:

Almost zero background in hadronic tag modes

Measure absolute B(D → X) with double tags

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

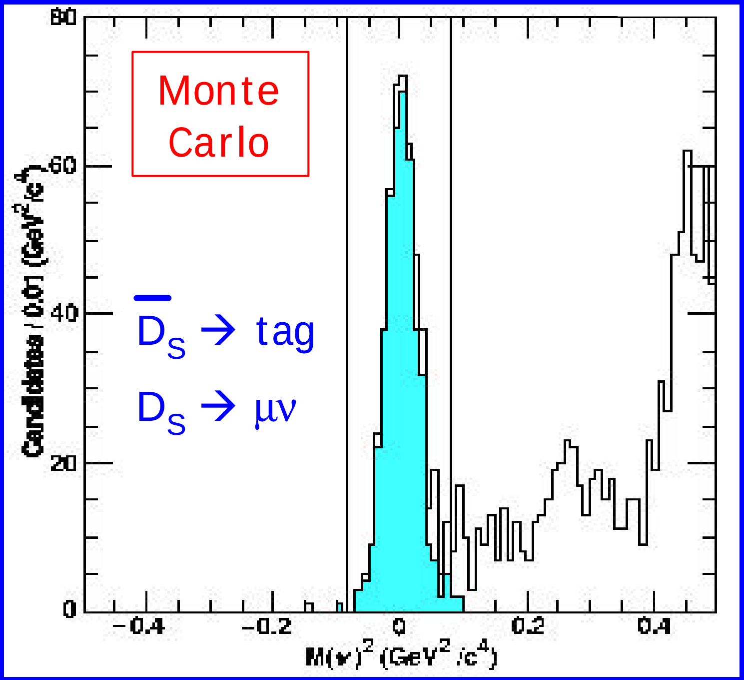


Decay	$\sqrt{s}$	L (fb^{-1})	Double tags	δB / B (%) PDG	δB / B (%) CLEO-c
$D^0 \to K^- \pi^+$	3770	3	53,000	2.4	0.6
$D^+ \to K^- \pi^+ \pi^+$	3770	3	60,000	7.2	0.7
$D_s \to \phi\, \pi$	4140	3	6,000	25	1.9

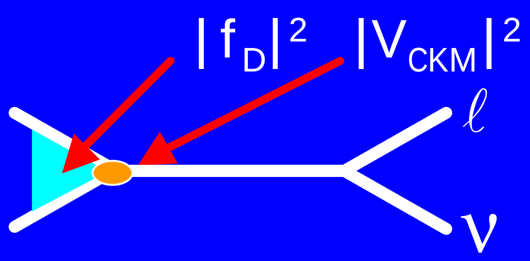
CLEO-c: potential to set absolute scale for heavy quark measurements

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

f_{Ds} from Absolute $B(D_s \to \mu^+\nu)$



- Measure absolute $B(D_s \to \mu\nu)$
- Fully reconstruct one D (tag)
- Require one additional charged track and no additional photons

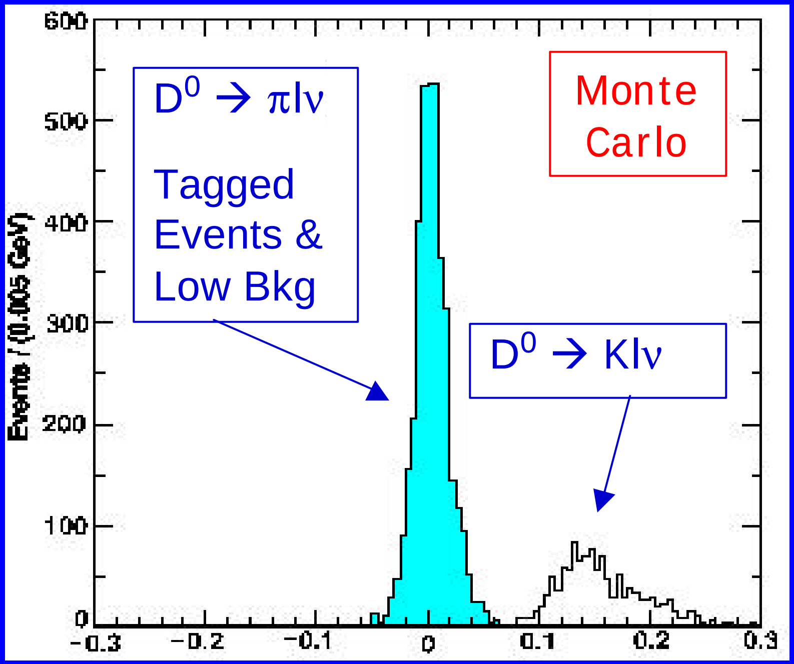


- Compute MM^2
- Peaks at zero for $D_s^+ \to \mu^+ \nu$ decay
- Expect resolution of ~$O(M_{\pi^0})$

Vcs (Vcd) known from unitarity to 0.1% (1.1%)

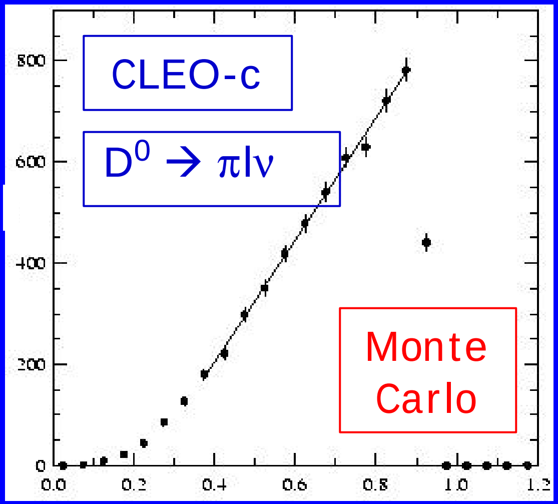
Decay Constant	Reaction	Energy (MeV)	L (fb^{-1})	δf / f (%) PDG	δf / f (%) CLEO-c
f_{Ds}	$D_s^+ \to \mu\nu$	4140	3	17	1.9
f_{Ds}	$D_s^+ \to \tau\nu$	4140	3	33	1.6
f_{D+}	$D^+ \to \mu\nu$	3770	3	UL	2.3

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



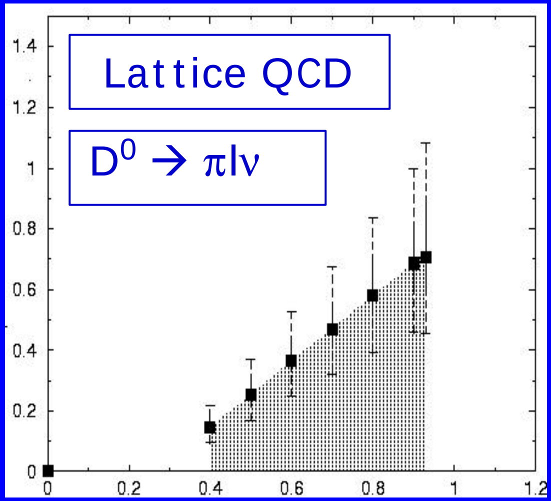
E_{miss} - P_{miss}

$d\Gamma/dp_p$



p_π

$d\Gamma/dp_p$



p_π

Measurement of complete set of charm $P \rightarrow P\, l\nu$ & $P \rightarrow V\, l\nu$ absolute form factor magnitudes and slopes to a few %:

- almost no background
- one experiment

Stringent test of theory!

CLEO-c Impact on Semileptonic $\delta B/B$

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

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

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

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

5: $D^+ \rightarrow \bar{K}^0 e^+ \nu$

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

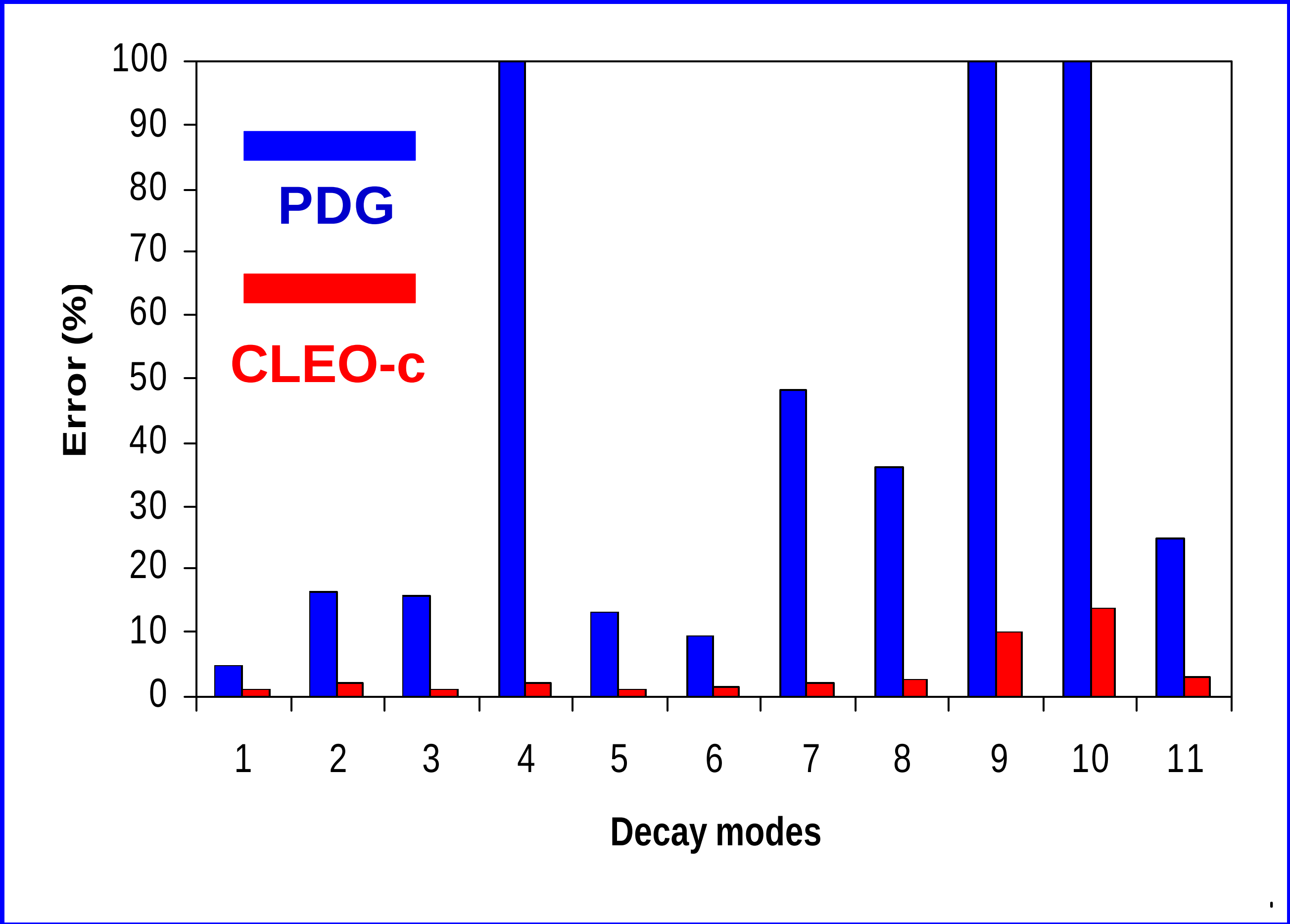
7: $D^+ \rightarrow \pi^0 e^+ \nu$

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

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

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

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



CLEO-c will make significant improvements in precision for each absolute charm semileptonic branching ratio.

Determining $|V_{cs}|$ and $|V_{cd}|$

Combine semileptonic and leptonic decays – eliminating V_{CKM}

$\Gamma(D^+ \rightarrow \pi\, l\, \nu)/\Gamma(D^+ \rightarrow l\, \nu)$ independent of $|V_{cd}|$

Test rate predictions at ~4% level

$\Gamma(D_s \rightarrow \phi\, l\, \nu)\ /\ \Gamma(D_s \rightarrow l\, \nu)$ independent of $|V_{cs}|$

Test rate predictions at ~4.5% level

Test amplitudes at 2% level

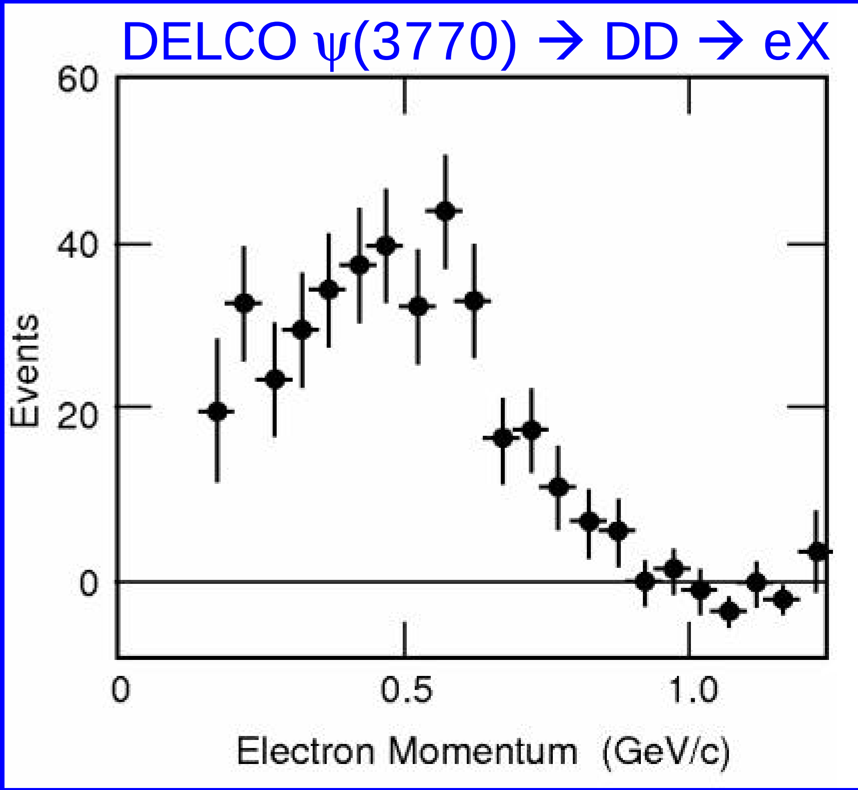
Stringent test of theory - If theory passes test ...

$D^0 \rightarrow K^- e^+ \nu$ $\delta V_{cs}/V_{cs}$ = 1.6% (now: 11%)

$D^0 \rightarrow \pi^- e^+ \nu$ $\delta V_{cd}/V_{cd}$ = 1.7% (now: 7%)

Use CLEO-c validated lattice to calculate B semileptonic form factor
➔ B factories can use $B \rightarrow \rho/\pi/\eta/l\nu$ for precise $|V_{ub}|$ determination.

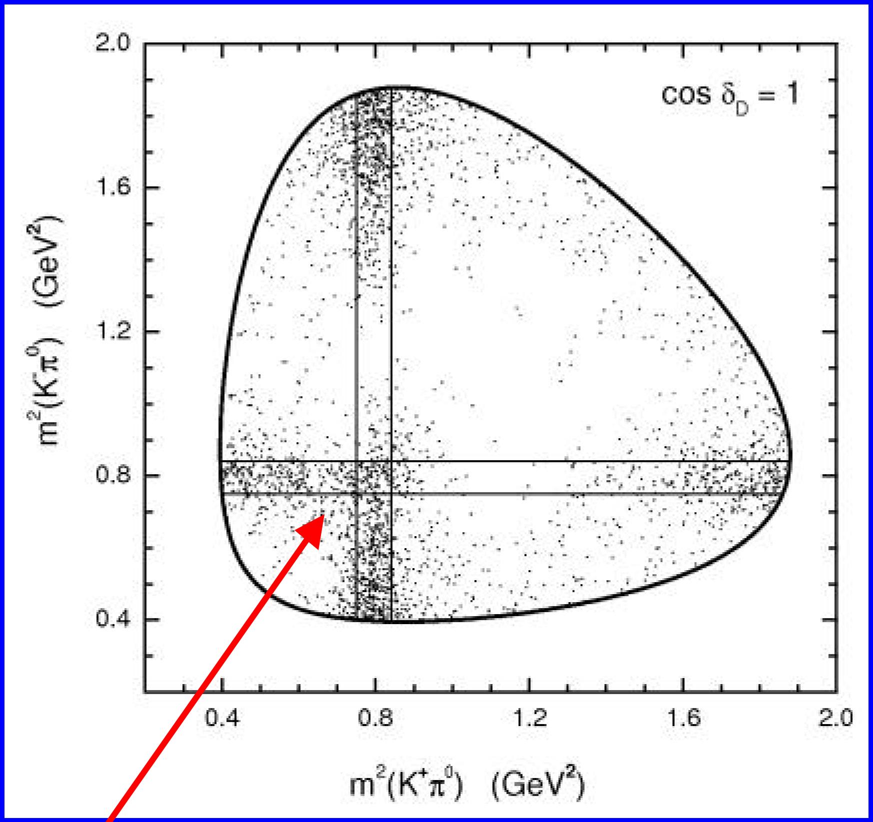
Inclusive Semileptonic Decays



Also can measure B_{SL} to get Γ_{SL}
- currently no measurement for D_s

- Significantly improved D→ X e spectrum possible using tagged D's
- Backgrounds in B→ X l ν analyses (b→c→l)
- Test of HQET: D^0, D^+, D_s^+ same to few %
  - D_s and D^+ weak annihilation contribution – a concern for $|V_{ub}|$ from E_l endpoint
  - Inclusive spectra + HQET used for $|V_{cb}|$ from b→c lν

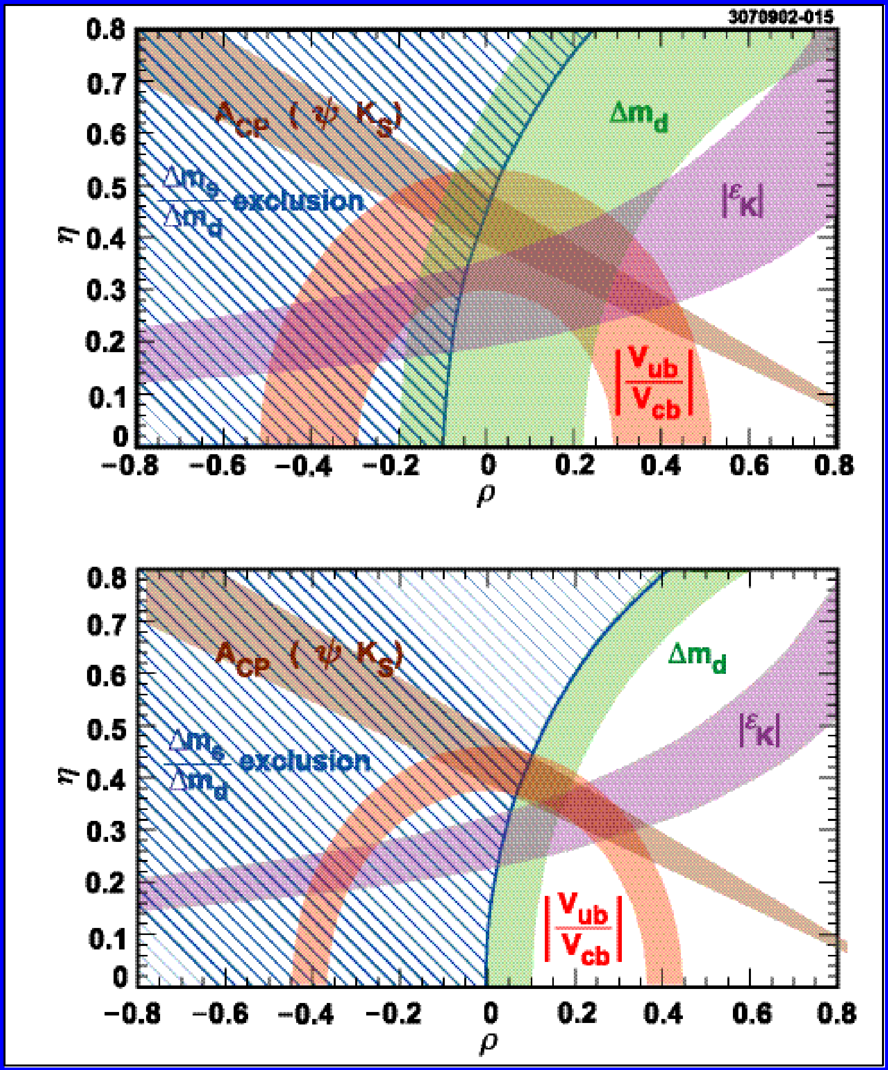
Strong Phases in Hadronic D



Interference of K^{*+} & K^{*-} bands

- Methods to measure γ in $B^\pm \rightarrow \overset{(-)}{D}{}^0 K^\pm$; $\overset{(-)}{D}{}^0 \rightarrow f$
- Aided by measurements of strong phases in hadronic D decays:
  - D→many Atwood & Soni PRD 68, 033003
  - $D^0 \rightarrow K^{*\pm}K$ Rosner & Suprun PRD 68, 054010
- CLEO-c: advantage of quantum coherence: $\psi(3770) \rightarrow D\overline{D}$; $J^P=1^-$

CLEO-c & Unitarity Triangle



- Potential Impact
  - Top: current experimental and theoretical uncertainties
  - Bottom: current experiment with 2% theory uncertainties – perhaps possible with LQCD calibrated with CLEO-c data

Potential Impact on V_{CKM}

Current V_{CKM}
From direct
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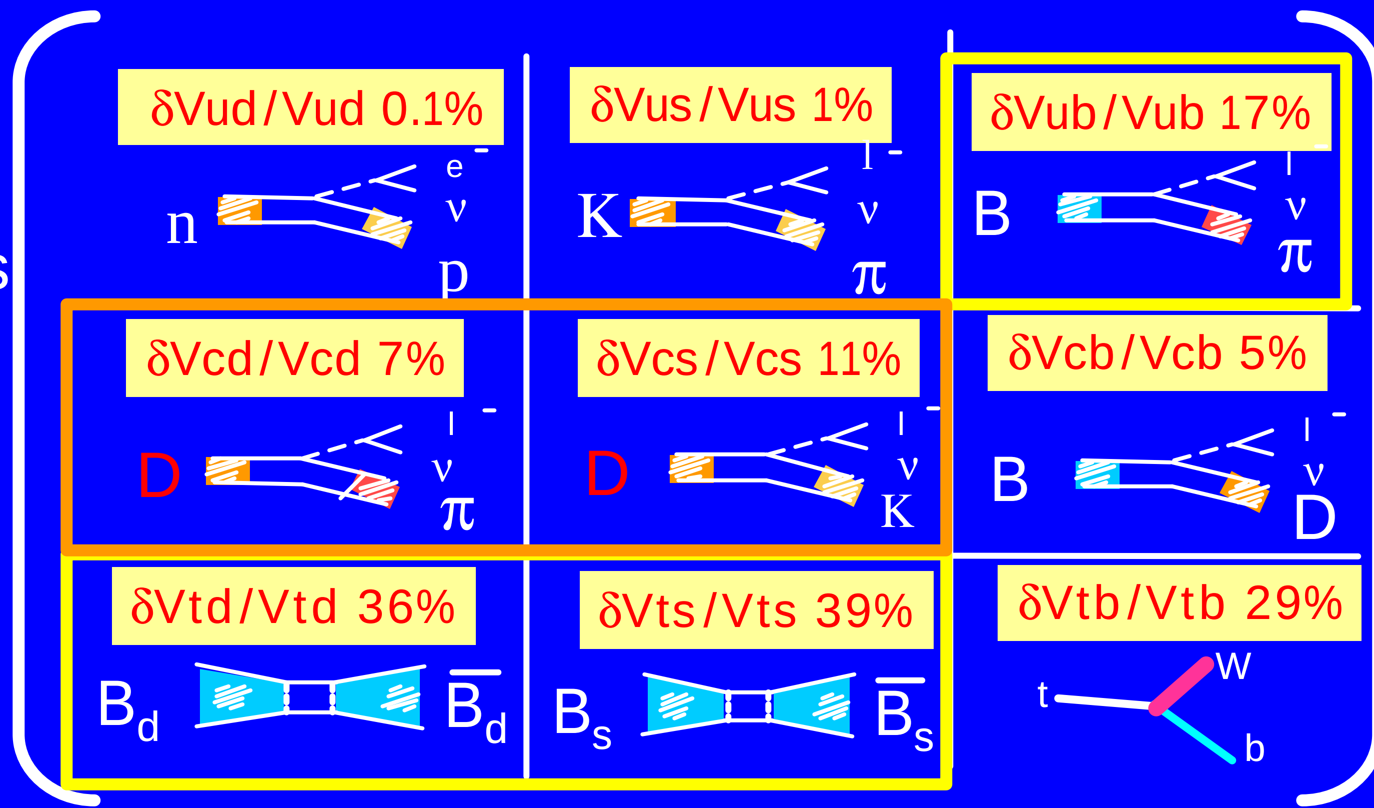
-no unitarity
imposed



CLEO-c will redefine 2nd generation elements
And enable improvements in 3rd generation

Potential Impact on V_{CKM}

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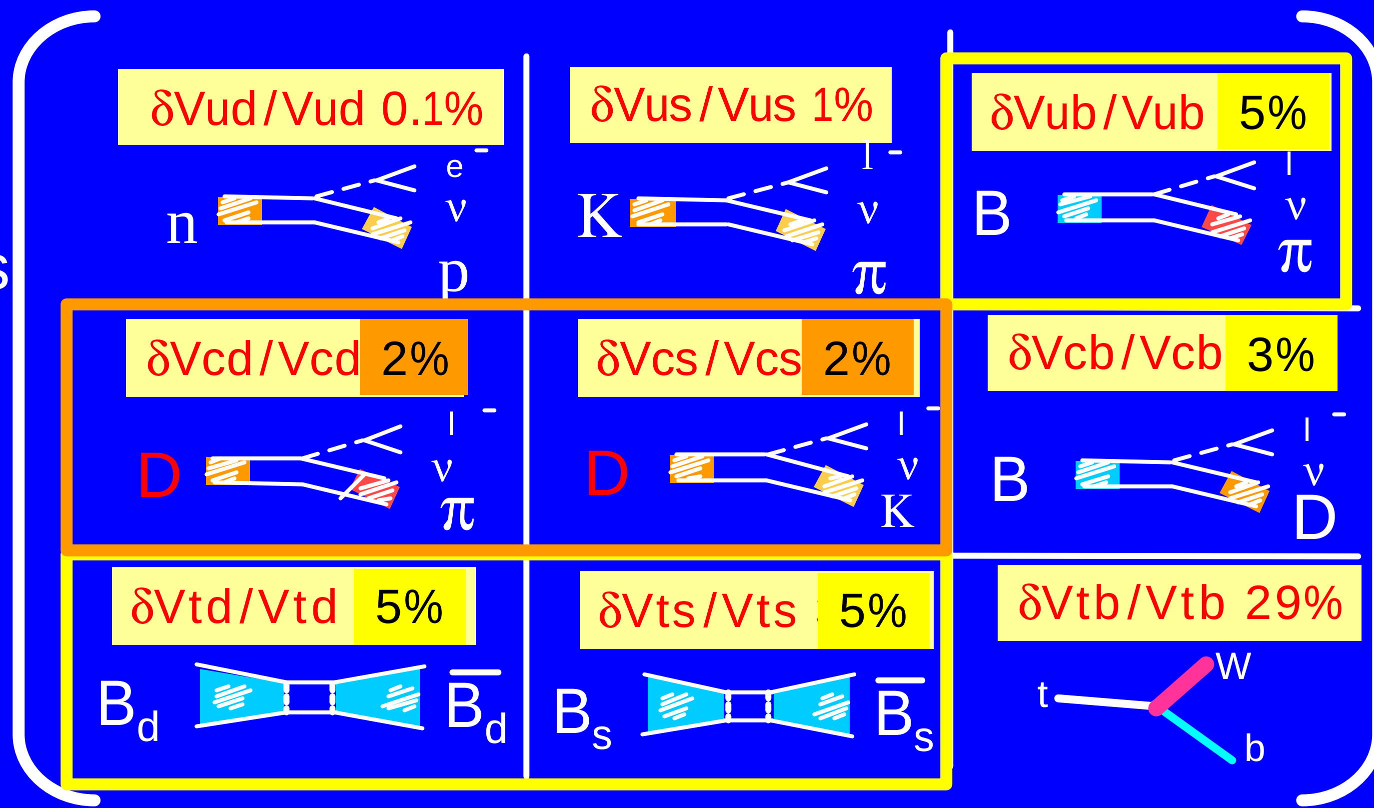
Future V_{CKM}



CLEO-c will redefine 2[nd] generation elements
And enable improvements in 3[rd] generation

Summary

- The CLEO detector is state of the art, understood at a precision level, and collecting data in the $c\bar{c}$ resonance region.
- CLEO has a long history of weak decay and CKM physics interests that will carry over to the CLEO-c program
  - CKM physics
    - semileptonic D decays: spectra, form factors, $|V_{cs}|$ & $|V_{cd}|$
    - Leptonic decays: f_D f_{Ds} informing B mixing interpretation
  - Enabling measurements of Hadronic D decays
    - Strong Phases to inform γ determinations in $B \rightarrow DK$
    - Measurement of absolute branching fractions