Absolute Hadronic D^0 and D^+ Branching Fractions at CLEO-c

Werner Sun, Cornell University
for the CLEO-c Collaboration

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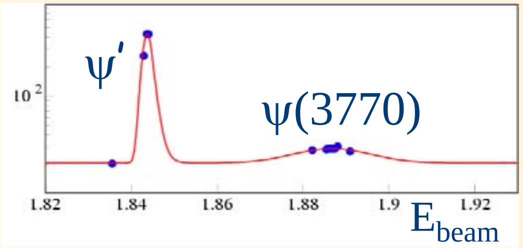
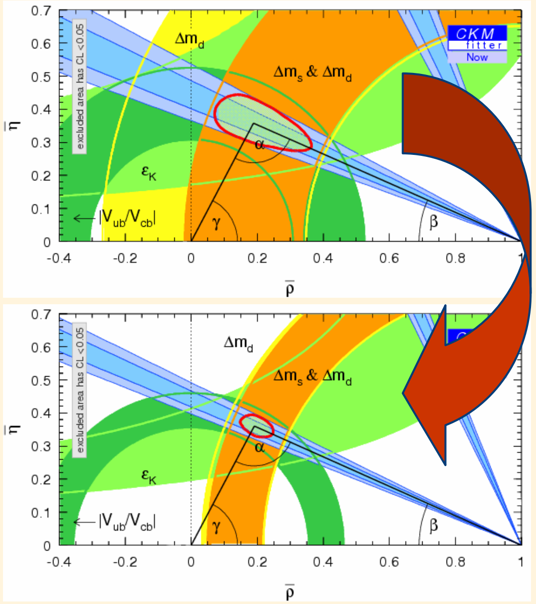
Introduction to CLEO-c
Branching fraction measurement technique
Results
Future directions

The CLEO-c Program

- Run CESR at $\sqrt{s}$ = 3—5 GeV to study D and D_s at threshold, search for exotics at ψ.
- Precise measurements of:
  - D, D_s hadronic branching fractions:
    - Input to V_{cb}, 5% error.
    - For CLEO V_{cb}, 1.4% from $\sigma(\mathcal{B})$, total syst 4.3%
  - D semileptonic $\mathcal{B}$'s and form factors:
    - V_{cs}, V_{cd} to ~ 1% (current errs. 16% and 7%).
    - $c \to ul\nu$ FFs to test LQCD$\to V_{ub}$ (25% err.→5%).
  - D and D_s decay constants:
    - Validate LQCD, use to predict f_B & f_{Bs} → V_{td} & V_{ts} (40% error → 5%).
- Improve understanding of strong and weak interactions (6 of 9 CKM matrix elements).
- Currently running at $\psi(3770) \to D\bar{D}$, no D_s.

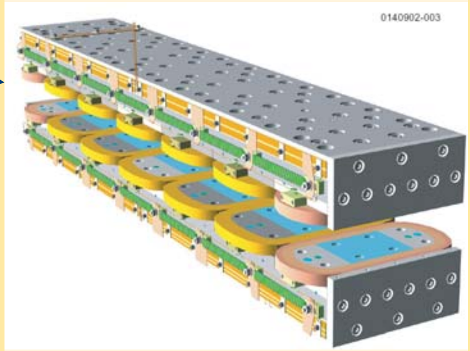


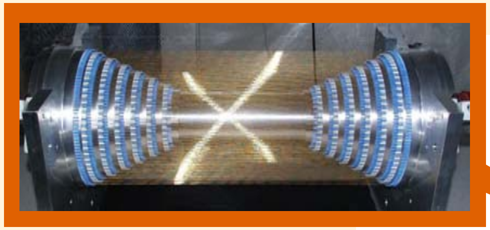


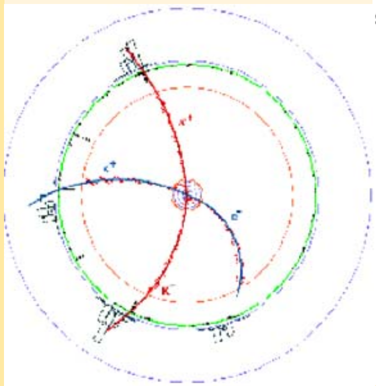
Current analysis based on 60 pb^{-1} pilot run from fall '03—spring '04

CLEO-c and CESR-c

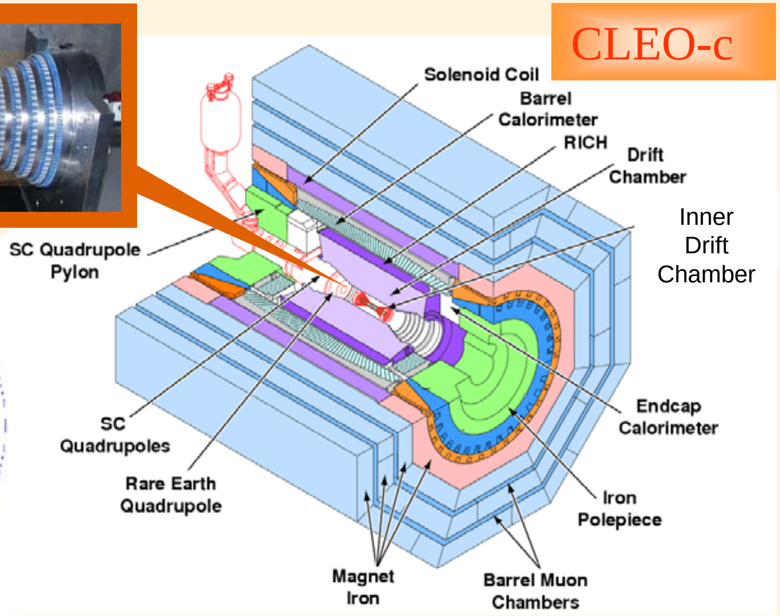
- CESR III → CESR-c:
  - Added 12 SC wiggler magnets to decrease emittance, damping time.
  - Only 6 were in place for the present dataset.
- CLEO III → CLEO-c:
  - Silicon vertex detector → stereo drift chamber.
  - B field 1.5 → 1.0 T
- Tracking: 93% of 4π
  - 53 layers.
  - σ_p/p ~ 0.6% at 1 GeV.
- CsI calorimeter: 93% of 4π
  - 7800 crystals.
  - σ_E/E ~ 2.2% at 1 GeV.
- 2 sources of particle ID:
  - dE/dx in drift chamber.
  - RICH: 80% of 4π
  - Combined ε (K or π) > 90%.
  - Fake rate < 5%.



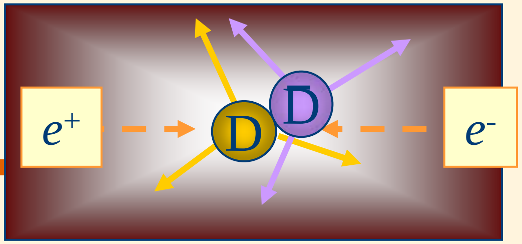




- Experimental features:
  - Low multiplicity, bkgs.
  - Simple initial state: $e^+e^- \to \psi(3770) \to D\bar{D}$, no extra fragmentation.
  - *D* tagging—this analysis reconstructs 10% of all *D* decays.



Overview of Technique



- Single tag (ST) = one D reconstructed: $n_i = N_{DD}\mathcal{B}_i\varepsilon_i$
  - Identifies charge and flavor of other D.
  - Establishes well-defined subsample to search for other D.
- Double tag (DT) = both reconstructed: $n_{ij} = N_{DD}\mathcal{B}_i\mathcal{B}_j\varepsilon_{ij}$

$$B_i \approx \frac{n_{ij}}{n_j}\frac{\varepsilon_j}{\varepsilon_{ij}} \qquad N_{DD} \approx \frac{n_i n_j}{n_{ij}}\frac{\varepsilon_{ij}}{\varepsilon_i\varepsilon_j}$$

- When all information combined, statistical $\sigma(\mathcal{B}) \sim \sigma(N_{DD})$.
- Independent of $\mathcal{L}$ and cross sections.
- Correlated systematic uncertainties cancel.
- Kinematics analogous to $\Upsilon(4S)\rightarrow B\bar{B}$: identify D with
  - $M_{BC} = \sqrt{E_{beam}^2 - |p_D|^2}$ $\quad\sigma(M_{BC}) \sim 1.3$ MeV, x2 with π^0
  - $\Delta E = E_{beam} - E_D$ $\quad\sigma(\Delta E) \sim 7$—$10$ MeV, x2 with π^0
- Reference modes $D \rightarrow K^-\pi^+$ and $K^-\pi^+\pi^+$ normalize other $\mathcal{B}$ measurements from other experiments.
- Same dataset as ICHEP04, but analysis updated.

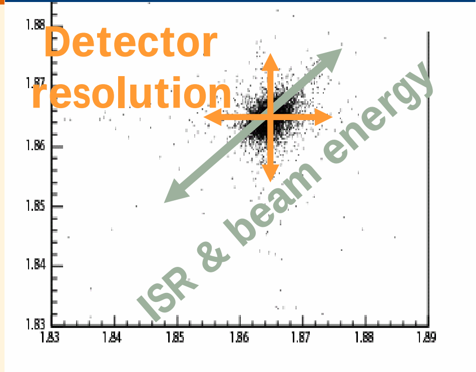
D^0
$K^-\pi^+$
$K^-\pi^+\pi^0$
$K^-\pi^+\pi^+\pi^-$

D^+
$K^-\pi^+\pi^+$
$K^-\pi^+\pi^+\pi^0$
$K^0_S\pi^+$
$K^0_S\pi^+\pi^0$
$K^0_S\pi^+\pi^-\pi^+$
$K^+K^-\pi^+$

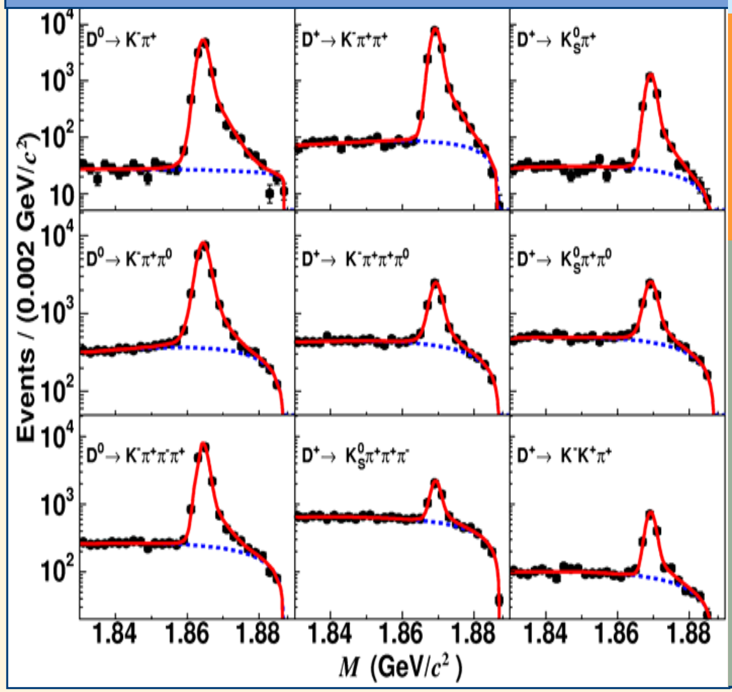
Yield Fits

- Unbinned ML fits to M_{BC} (1D for ST, 2D for DT)
  - Signal function includes ISR, $\psi(3770)$ line shape, beam energy smearing, and detector resolution.
  - Signal parameters from DT fits, then apply to ST.
  - Background: phase space ("ARGUS function").
- D and $\overline{D}$ yields and efficiencies separated.

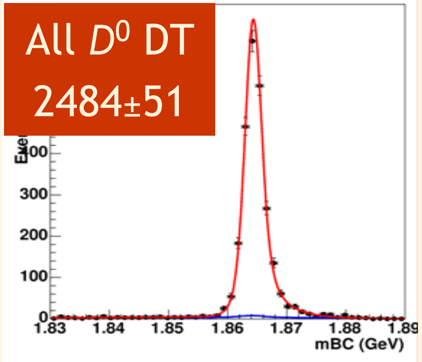
DT signal shape

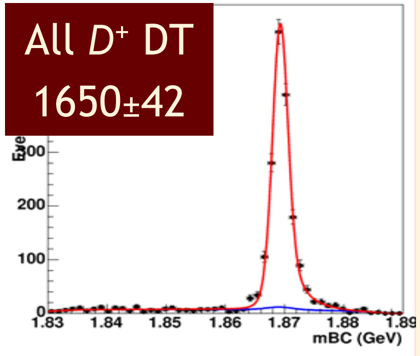


M_{BC} (log scale) for ST modes: $D+\overline{D}$



Mode	N_D (10^3)	$\overline{N}_D$ (10^3)	$<\varepsilon_D>$(%)
$K\pi$	5.11±0.07	5.15±0.07	65.1±0.2
$K\pi\pi^0$	9.51±0.11	9.47±0.11	31.6±0.1
$K\pi\pi\pi$	7.44±0.09	7.43±0.09	43.8±0.1
$K\pi\pi$	7.56±0.09	7.56±0.09	51.0±0.1
$K\pi\pi\pi^0$	2.45±0.07	2.39±0.07	25.7±0.1
$K^0_s\pi$	1.10±0.04	1.13±0.04	45.7±0.3
$K^0_s\pi\pi^0$	2.59±0.07	2.50±0.07	22.4±0.1
$K^0_s\pi\pi\pi$	1.63±0.06	1.58±0.06	31.2±0.1
$KK\pi$	0.64±0.03	0.61±0.03	41.1±0.4





Branching Fraction Fitter

- $\mathcal{B}$ and N_{DD} extracted from χ^2 fit.
- Include both statistical and systematic errors (with correlations):
  - All experimental inputs treated consistently.
  - $\mathcal{B}(D^0)$ and $\mathcal{B}(D^+)$ statistically independent, but correlated by common systematics.
- Efficiency, crossfeed, background corrections performed directly in fit.
  - Predicted DCSD explicitly removed as background.
- See arXiv:physics/0503050 for more details.

Fit Inputs:

$$\mathbf{c} = \mathbf{E}^{-1} (\mathbf{n} - \mathbf{F}\mathbf{b})$$

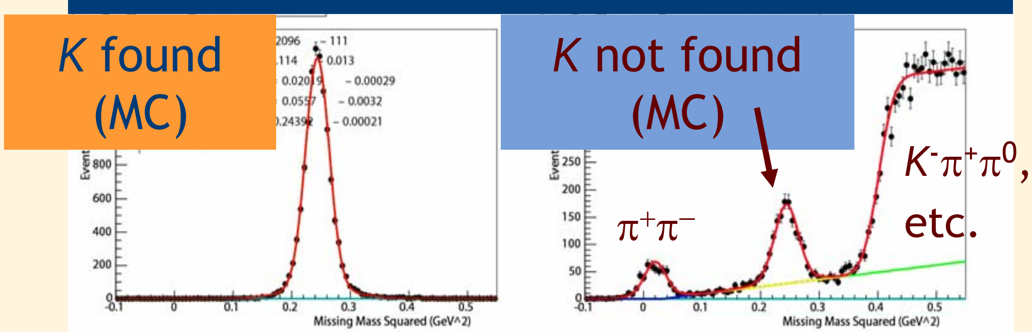
Yields	**n** (n)	$\mathbf{V_n}$ ($n \times n$)
Bkgnds	**b** (b)	$\mathbf{V_b}$ ($b \times b$)
Signal effs	**E** ($n \times n$)	$\mathbf{V_E}$ ($n^2 \times n^2$)
Bkgnd effs	**F** ($n \times b$)	$\mathbf{V_F}$ ($nbxnb$)

Systematic Uncertainties

- Dominant error: MC simulation of tracking, K^0_S, and π^0 efficiencies.
  - Correlated among all particles of a given type—adds up quickly.
  - Missing mass technique to compare data and MC.
  - Fully reconstruct entire event, but deliberately leave out one particle.
  - Fraction of MM peak where the last particle is found = efficiency.
  - Depends on event cleanliness.

Example: K^- efficiency from $D^0 \to K^-\pi^+$

$\varepsilon \approx 91\%$ in fiducial volume



Source	Uncertainty (%)
Tracking/K^0_s/π^0	0.7/3.0/2.0
Particle ID	0.3 π /1.3 K
Trigger ε	< 0.2
ΔE cut	1.0—2.5 per D
FSR	0.5 ST / 1.0 DT
$\psi(3770)$ width	0.6
Resonant substructure	0.4—1.5
Event environment	0.0—1.3
Yield fit functions	0.5
Data processing	0.3
Double DCSD	0.8

Neutral DT: interference between Cabibbo-favored and DCSD on both sides.

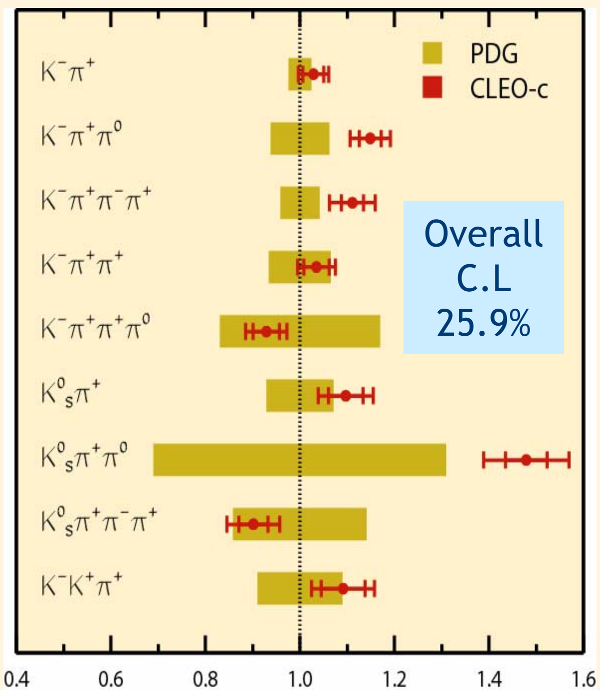
Fit Results

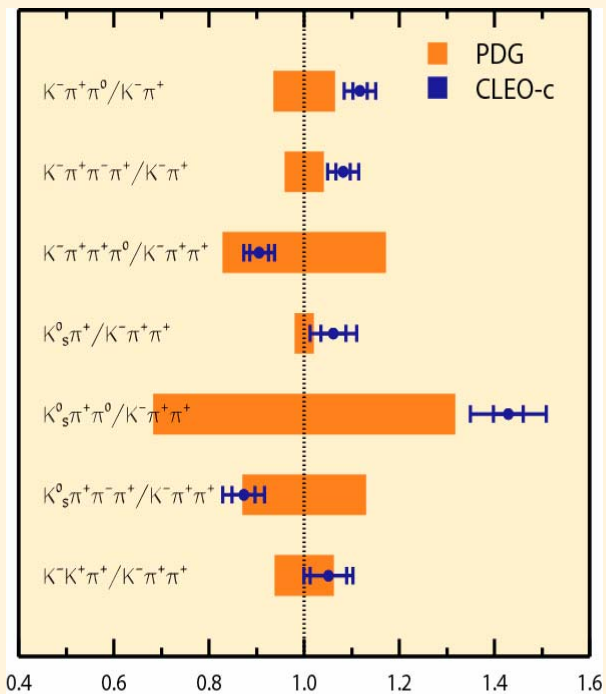
- Precision comparable to PDG WA.
- Statistical errors: ~2.0% neutral, ~2.5% charged from total DT yields.
- σ(systematic) ~ σ(statistical).
  - Many systematics measured in data, will improve with time.
- Simulation includes FSR, so we measure $\mathcal{B}$ (final state + nγ).
  - Using efficiencies without FSR correction would lower $\mathcal{B}$.
- N_{DD} includes continuum and resonant production.
- $\mathcal{L}$ determination being updated; no new cross sections since ICHEP, yet.
- $N_{D^+D^-}/N_{D^0\bar{D}^0} = 0.78 \pm 0.02 \pm 0.02$.

Parameter	Value	no FSR
$N_{D^0\bar{D}^0}$	$(2.01\pm0.04\pm0.02)\times10^5$	-0.2%
$R^0 = K^-\pi^+$	$(3.91\pm0.08\pm0.09)\%$	-2.0%
$K^-\pi^+\pi^0$	$(14.9\pm0.3\pm0.5)\%$	-0.8%
$K^-\pi^+\pi^+\pi^-$	$(8.3\pm0.2\pm0.3)\%$	-1.7%
$N_{D^+D^-}$	$(1.56\pm0.04\pm0.01)\times10^5$	-0.2%
$R^+ = K^-\pi^+\pi^+$	$(9.5\pm0.2\pm0.3)\%$	-2.2%
$K^-\pi^+\pi^+\pi^0$	$(6.0\pm0.2\pm0.2)\%$	-0.6%
$K_S^0\pi^+$	$(1.55\pm0.05\pm0.06)\%$	-1.8%
$K^0_S\pi^+\pi^0$	$(7.2\pm0.2\pm0.4)\%$	-0.8%
$K^0_S\pi^+\pi^-\pi^+$	$(3.2\pm0.1\pm0.2)\%$	-1.4%
$K^+K^-\pi^+$	$(0.97\pm0.04\pm0.04)\%$	-0.9%
$K^-\pi^+\pi^0/R^0$	$3.65\pm0.05\pm0.011$	+1.2%
$K^-\pi^+\pi^+\pi^-/R^0$	$2.10\pm0.03\pm0.06$	+0.3%
$K^-\pi^+\pi^+\pi^0/R^+$	$0.61\pm0.01\pm0.02$	+1.7%
$K_S^0\pi^+/R^+$	$0.165\pm0.004\pm0.006$	+0.4%
$K^0_S\pi^+\pi^0/R^+$	$0.75\pm0.02\pm0.03$	+1.4%
$K^0_S\pi^+\pi^-\pi^+/R^+$	$0.34\pm0.009\pm0.014$	+0.8%
$K^+K^-\pi^+/R^+$	$0.101\pm0.004\pm0.002$	+1.3%

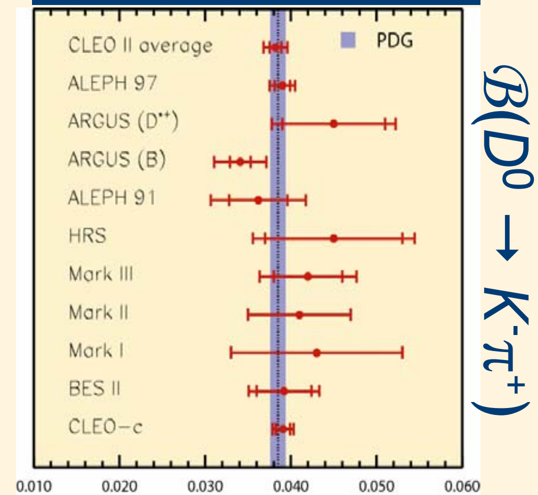
Comparison with PDG 2004

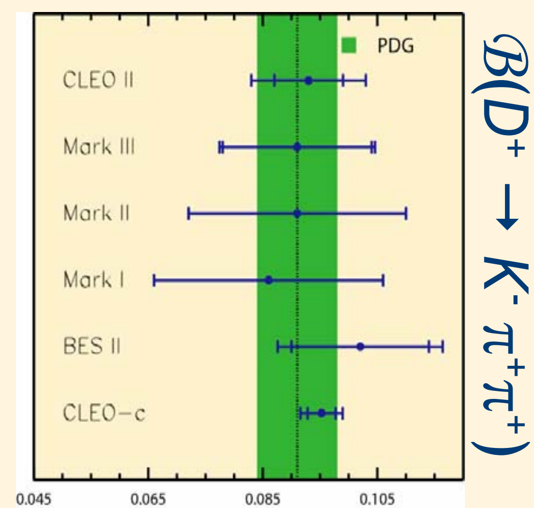
- Measurements and errors normalized to PDG.
- PDG global fit includes ratios to $K^-\pi^+$ or $K^-\pi^+\pi^+$.
- No FSR corrections in PDG measurements.
- Our measurements also correlated (statistics and efficiency systematics).





Other *direct* meas.





Future Directions

- Improve measurements with more data (goal 3 fb^{-1}).
  - 275 pb^{-1} projected for this summer.
  - Will lower both statistical and systematic uncertainties.
  - With 1 fb^{-1}, < 2% errors on $K^-\pi^+$ and $K^-\pi^+\pi^+$—systematics limited.

- $D^0\overline{D}^0$ quantum coherence negligible: only flavored final states.
- But with *CP* eigenstates, exploit coherence to probe mixing.
  - $x = \Delta M/\Gamma$, $y = \Delta\Gamma/2\Gamma$, r = DCS-CF amp. ratio, δ = DCS-CF phase diff.
  - *Time-integrated* yields sensitive to mixing, e.g. $\Gamma(D\rightarrow CP\pm)\sim 1\mp y$.
  - Mixing entangled with DCSD, separate with semileptonics.
- Simultaneous fit for hadronic and semileptonic $\mathcal{B}$s + x, y, r, δ.
- With 1 fb^{-1}: $\sigma(y)\sim 1\%$ (same as current WA)
  $\sigma(x\sin\delta)\sim 1.5\%$ (current: $x\cos\delta + y\sin\delta < 1.8\%$ at 95% C.L.).
- CLEO-c also sensitive to new physics through rare phenomena.
- See also D. Asner in WG5.

Summary

- One major goal of CLEO-c: measure hadronic *D* branching fractions (preprint to appear as CLNS 05-1914, CLEO 05-6).
- Three more years of data taking.
- Branching fractions in 60 pb^{-1} competitive with world averages.
  - $\mathcal{B}(D^0 \to K^-\pi^+)$ measured to 3.1% (PDG 2.4%).
  - $\mathcal{B}(D^+ \to K^- \pi^+\pi^+)$ measured to 3.9% (PDG 6.5%).
- Over 4x more data for this summer.
  - Will lower statistical *and* systematic errors.
- D_s branching fractions with $\sqrt{s} \sim 4.14$ GeV running.
- Reduce error on V_{cb}.
- Contribute to stringent test of CKM unitarity.