Charm Physics:

Contribution to WG2 Report on Flavour in the ERA of the LHC

David Asner
Carleton University

On behalf of S. Fajfer, M. Artuso, I.I. Bigi, D.G. Cassel,
B. Golob, H. Mahlke, J. Napolitano, A.A. Petrov,
J.L. Rosner, P. Spradlin, S.Stone, G. Wilkinson

"Charm" Data Samples

- Reach of Current experiments
  - CLEO-c
    - 0.75 fb^{-1} @3.77 GeV - 2.7×10^6 D^0D^0 pairs & 2.1×10^6 D+D-
    - 0.75 fb^{-1} @4.17 GeV - 7×10^5 $D_s^{*+}D_s^- + D_s^{*-}D_s^+$
  - BABAR, Belle (combined 2 ab^{-1}) - 10^{10} charm mesons
  - CDF, D0 (combined 16 fb^{-1})
- Reach of approved experiments
  - BESIII
    - 20 fb^{-1} @3.77 GeV - 72×10^6 D^0D^0 pairs & 56×10^6 D+D-
    - 12 fb^{-1} @4.17 GeV - 11×10^6 $D_s^{*+}D_s^- + D_s^{*-}D_s^+$
  - LHCb (10 fb^{-1})
  - PANDA
- Reach of proposed experiments
  - LHCb upgrade(100 fb^{-1}),
  - Super B-factory (50 ab^{-1} @10 GeV) - 2.5×10^{11} charm mesons
    - 150 fb^{-1} @3.77 GeV - 5.4×10^8 D^0D^0 pairs & 4.2×10^8 D+D-
    - 200 fb^{-1} @4.17 GeV - 1.9×10^8 $D_s^{*+}D_s^- + D_s^{*-}D_s^+$

Outline of Charm Section

- Motivation for continued study of charm
  - On the advantages of running at threshold
- Two Roles of Charm Physics at Threshold
  - Precision CKM physics
    - Demonstrate sufficient control over QCD
    - Tests of theoretical calculations - (L)QCD
    - CKM magnitudes, angles, unitarity tests
  - Rare Processes
    - D Mixing, CPV and Rare Decays
    - Window for New Physics

Impact of Charm Physics - I

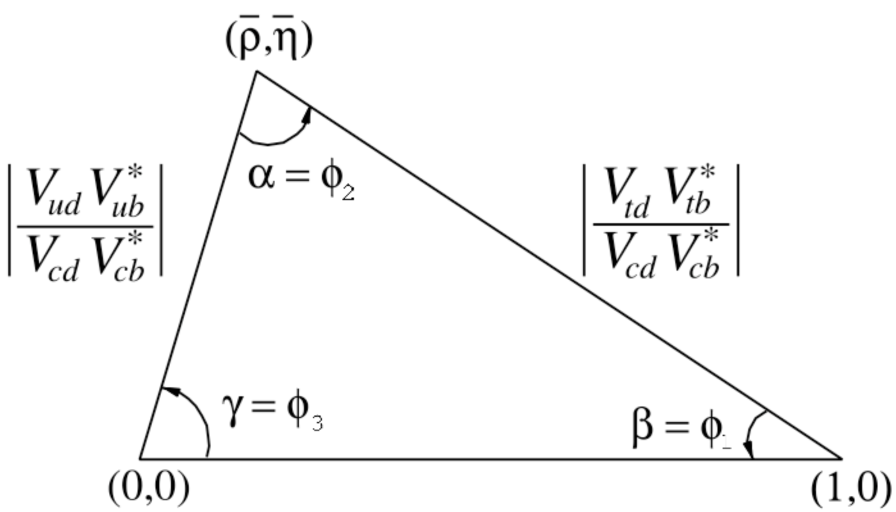
- Precision CKM
    - Over constrain CKM with results from B-sector
    - Inconsistencies indicate New Physics
    - Precision charm required for precision CKM results in B sector
  - Leptonic Charm Decays $D \to \ell^+ \nu$: Check QCD calculations
    - Measure decay constants fD, fDs
    - Improved f_B possible from f_D measurement + LQCD
    - Important for $|V_{td}|$, $|V_{ts}|$ and $|V_{ts}|/|V_{td}|$
  - Semileptonic decay rates & form-factors: Check QCD calculations
    - Measurements of $|V_{cs}|$ and $|V_{cd}|$
    - Test theoretical form factor models in D meson decays
    - Impacts prediction of form factors for B meson decays
    - Important for $|V_{ub}|$ and $|V_{cb}|$
  - Hadronic Charm Decays - $B \to$Charm is dominant
    - Important for $|V_{cb}|$ and γ/ϕ_3
    - Engineering numbers useful for other studies
      - absolute $\mathcal{B}$'s, resonant substructure, phases on Dalitz plots, especially versus CP eigenstates, final state interactions

Impact of Charm Physics - II

- Search for New Physics in Charm Sector
  - Very low SM rates for loop processes provide unique window to observe NP in rare charm processes (rare decays, CPV & mixing)
    - NP can introduce new particles into loop
  - Different sensitivity to NP than B and K sectors
    - Particles & couplings in rare charm processes NOT the same as rare B, K
  - Rare Charm Decays (Heavily GIM suppressed: BF($c \rightarrow ull$)~10^{-8})
    - FCNC decays only occur in loop diagrams in SM:
  - Charm Mixing (Large CPV in mixing indicates New Physics)
    - Mixing is Double Cabibbo suppressed & GIM mechanism suppressed
    - SM $x \equiv \Delta m/\Gamma \lesssim y \equiv \Delta\Gamma/2\Gamma$ short distance 10^{-6}-10^{-3}, long distance 10^{-3}-10^{-2}
    - NP in loops implies $x >> y$; long range effects complicate predictions.
  - CP Violation - Direct (New Physics could be ~%)
    - CF & DCS decay: Direct CPV requires New Physics
      - Exception: interference between CF & DCS amplitudes to $D^{\pm} \rightarrow K_{S,L}\pi^{\pm}$
      - SM contribution due to K^0 mixing is $A_S=[+]_S-[-]_S$ ~ -3.3×10^{-3}; $A_S = -A_L$
    - SCS decay
      - expect $O(\lambda^4)$ ~ 10^{-3} from CKM matrix

$$\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Precision CKM

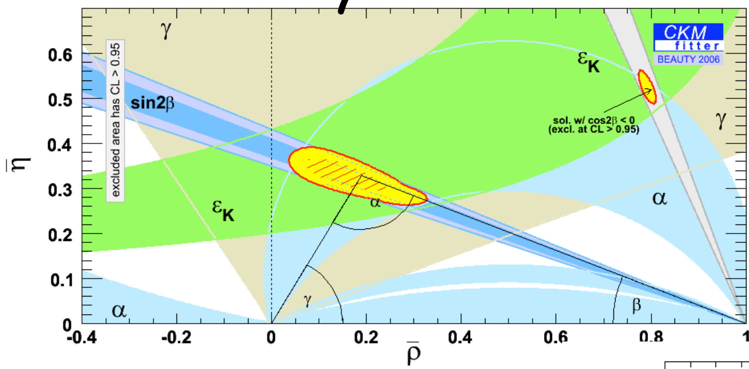


Over Constraining CKM

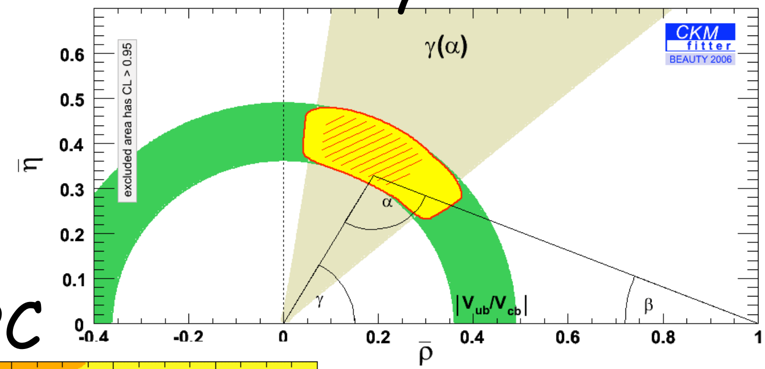
- The apex (ρ,η) of the unitarity triangle can be determined in independent ways
  - Only tree processes (no new physics)
  - Only loop processes (new physics window)
  - Only CP violating processes
  - Only CP conserving processes
  - Only CKM angles
- Inconsistency would indicate New Physics
- Precision charm measurements impact our ability to observe New Physics with precision unitarity triangle measurements in the B sector

Cottage Industry

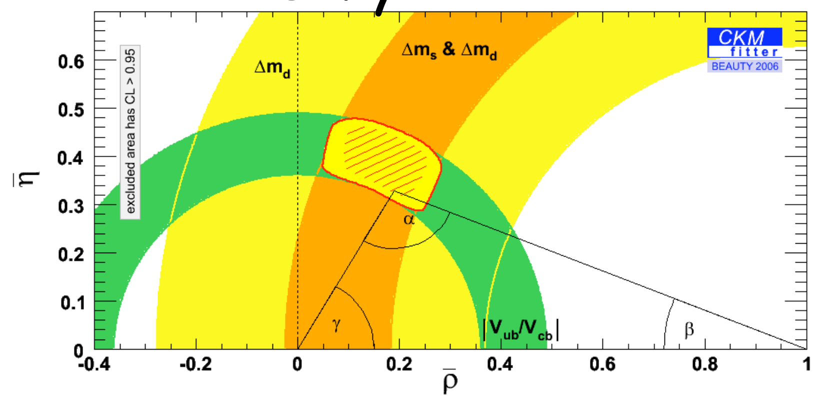
Only CPV



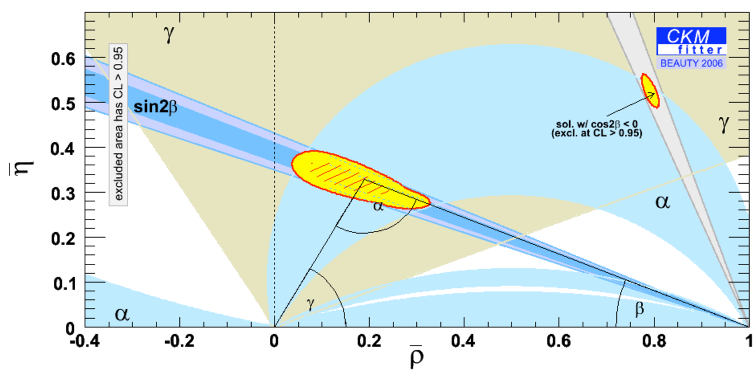
Only Tree



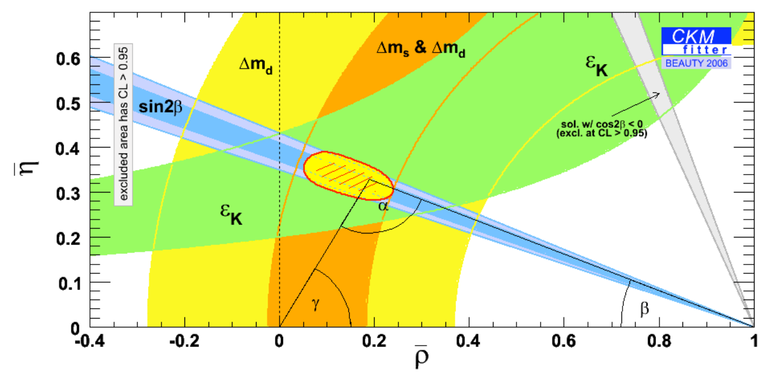
Only CPC



Only Angles

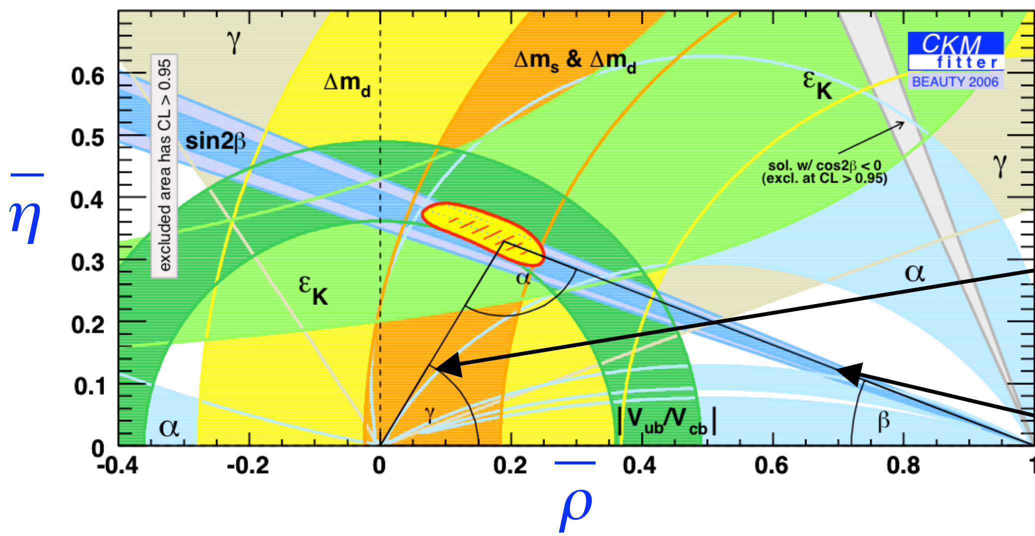


Only Loop

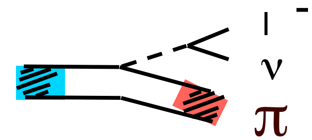


Precision Quark Flavour Physics

Discovery potential of B physics is limited by systematic errors from QCD

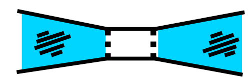


B



$$\propto \left[f^{B\to\pi}(q) \right]^2 |V_{ub}|^2$$

B_d

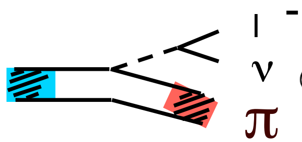


$\bar{B}_d$

$$\propto \left[f_{Bd} \right]^2 |V_{td}|^2$$

D system- CKM elements known to <1% by unitarity

D



$$\propto \left[f^{D\to\pi}(q) \right]^2 |V_{cd}|^2$$

D

$$\propto \left[f_{D+} \right]^2 |V_{cd}|^2$$

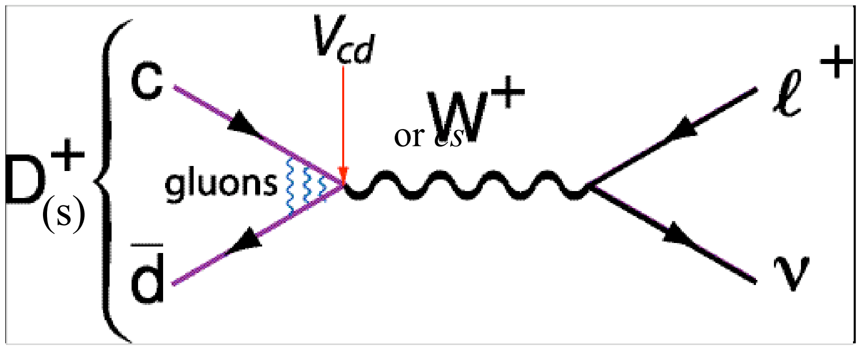
Measurements of *absolute rates* for D leptonic decays & a wide variety of semileptonic decays yield decay constants & form factors to *test* and hone QCD techniques into *precision theory* which can then be applied to the B system.

Leptonic Charm Decays
& Decay Constants

Leptonic Decays & Decay Constants

In $D_{(s)} \to \ell^+\nu$ decay, c and $\bar{q}$ annihilate, probability is $\propto$ to wave function overlap

Example :



In general for all pseudoscalars:

$$\Gamma(P^+ \to \ell^+\nu) = \frac{1}{8\pi} G_F^2 f_P^2 m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right)^2 |V_{Qq}|^2$$

Calculate, or measure if V_{Qq} is known

Comparisons with Theory

- BABAR (230 fb^{-1})

f_{Ds} = (281 ± 17 ± 6 ± 14) MeV

- CLEO-c ($D_s \to \mu\nu, \tau\nu$)

f_{Ds} = (280.1 ± 11.6 ± 6.0) MeV

- $\Gamma(D_S^+ \to \tau^+\nu)/\Gamma(D_S^+ \to \mu^+\nu)$:
  CLEO: 9.9±1.7±0.7,
  Standard Model: 9.72

  consistent with lepton universality

- CLEO-c ($D \to \mu\nu$)

$f_D = (222.6 \pm 16.7\ ^{+2.3}_{-3.4})$ MeV

CLEO-c f_{Ds}/f_{D^+}=1.26±0.11±0.03

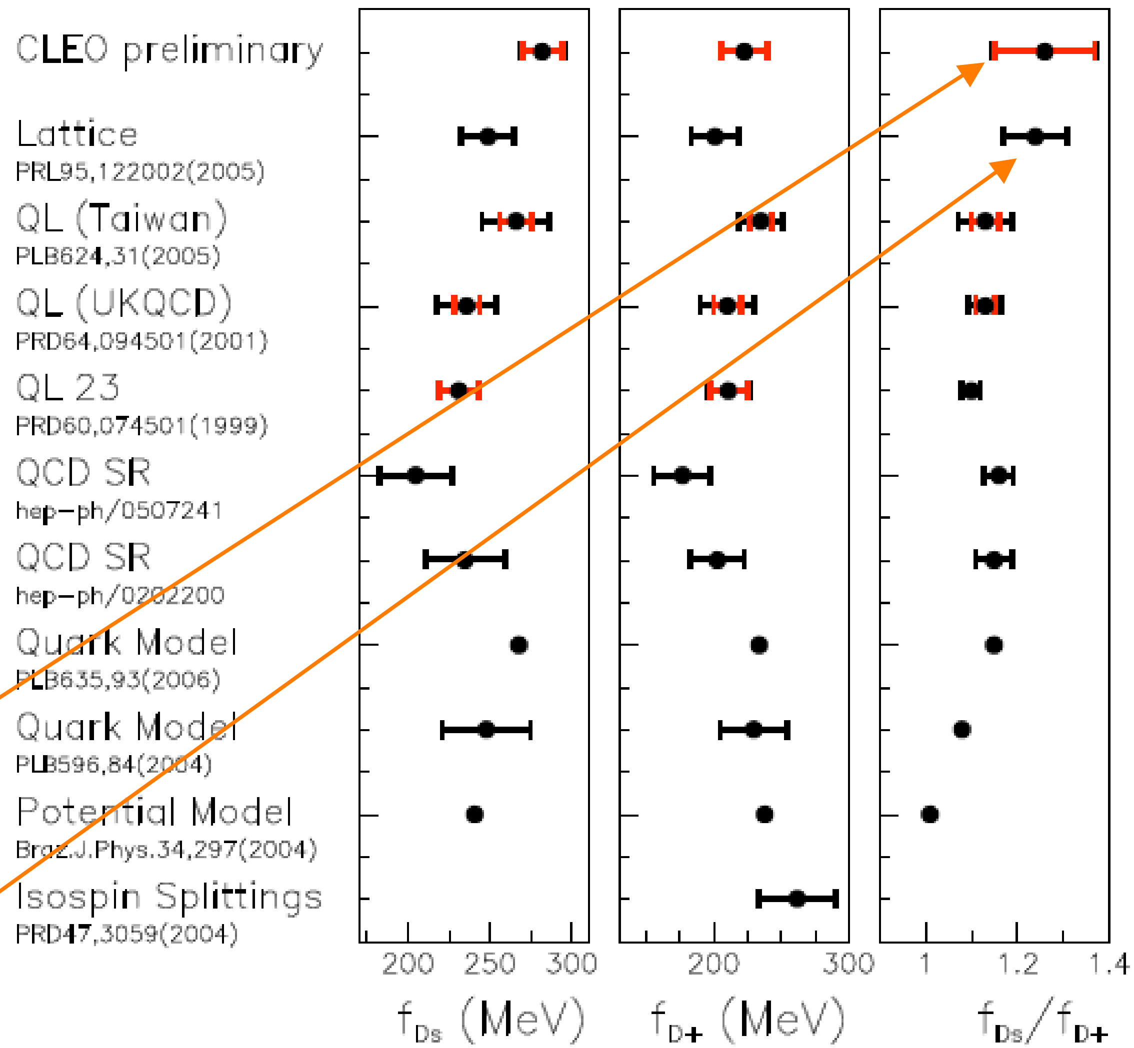
- Consistent with most models more precision needed

LQCD f_D = (201 ±3 ± 17) MeV

f_{Ds} = (249 ±3 ± 16) MeV

f_{Ds}/f_{D^+}=1.24±0.01±0.07

- Using Lattice ratio find $|V_{cd}/V_{cs}|$= 0.22±0.03



Summary: Decay Constants

- f_{Bs}/f_B is key ingredient in V_{ts}/V_{td}
- Lattice calculates $\frac{f_{B_s}\sqrt{B_{B_s}}}{f_B\sqrt{B_B}} = 1.210^{+0.047}_{-0.035}$
- Expect $f_{Bs}/f_B = f_{Ds}/f_D$ within a few %
  - From lattice still need $B_{Bs}/B_B \sim 1$
- Precision f_{Ds}/f_D enables precision V_{ts}/V_{td}
- f_D, f_{Ds} & f_{Ds}/f_D statistics limited after CLEO-c

Exp't	3.77 GeV	4.17 GeV	$\sigma(f_{Ds}/f_D)$
CLEO-c	281 pb^{-1}	310 pb^{-1}	9%
CLEO-c	750 pb^{-1}	750 pb^{-1}	5%
BESIII	20 fb^{-1}	12 fb-1	<2%
SuperB	~150 fb^{-1}	~200 fb^{-1}	<1%

Another LQCD Crosscheck

- Combining the measured leptonic and semileptonic widths

$$R_{sl} = \sqrt{\frac{\Gamma(D^+ \to \mu^+ \nu)}{\Gamma(D \to \pi \mu \nu)}}$$

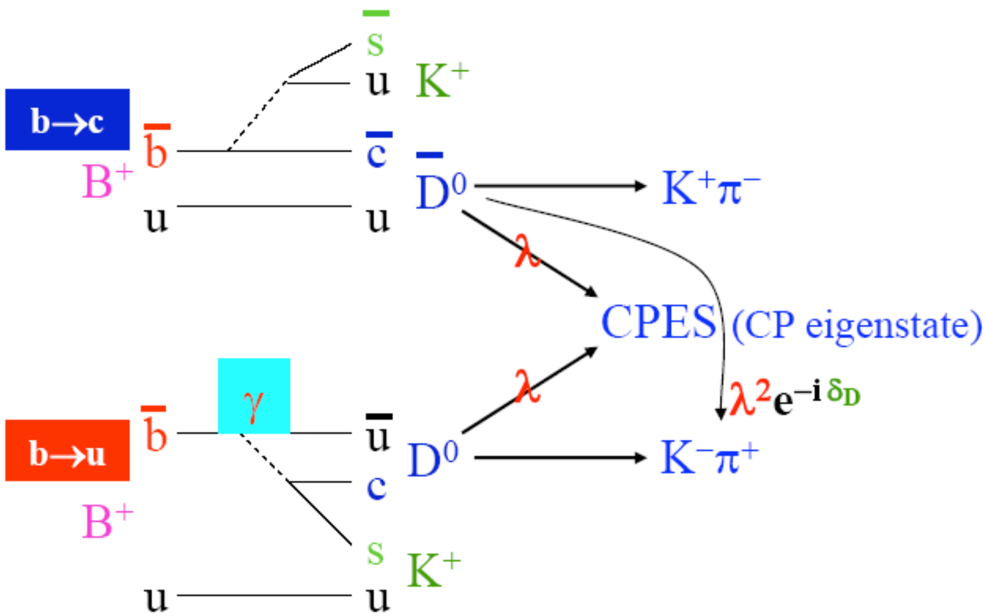
- R_{sl} independent of V_{cd}
- Assume isospin invariance
- Find

$$R_{sl}^{th} = \sqrt{\frac{\Gamma(D^+ \to \mu^+ \nu)}{\Gamma(D \to \pi \mu \nu)}} = 0.212 \pm 0.028$$

$$R_{sl}^{\exp} = \sqrt{\frac{\Gamma(D^+ \to \mu^+ \nu)}{\Gamma(D \to \pi \mu \nu)}} = 0.237 \pm 0.019$$

- Theory and data in good agreement
  - BESIII (20 fb^{-1}) will provide 1% test

Charm impact on γ/ϕ_3



Current Results: Belle & BaBar

- Belle and BaBar have studied the dependence of γ on the D decay model
  - Belle - PRD73:112009,2006 (357 fb^{-1})

$$\phi_3 = \left(53^{+15}_{-18} \pm 3 \pm 9\right)^o$$

  - BaBar – ICHEP06 hep-ex/0607104 (347 million BB pairs)

$$\gamma = \left(92 \pm 41 \pm 11 \pm 12\right)^o$$

D Decay Model Systematic Uncertainty

- Problem for extracting γ is due to model dependent phase difference between $f(m_+^2, m_-^2)$ and $f(m_-^2, m_+^2)$
  - $m_\pm = M(K_S\pi^\pm)$

CLEO-c can help

CP Tagged Dalitz Plots

- CLEO-c data is a source of CP tagged Dalitz plots
- Preliminary yields for $K_S\pi^+\pi^-$ in 281 pb^{-1}
  - Extrapolate to 750 pb^{-1} expected
- New! Use kinematic constraints to reconstruct $K_L\pi^+\pi^-$

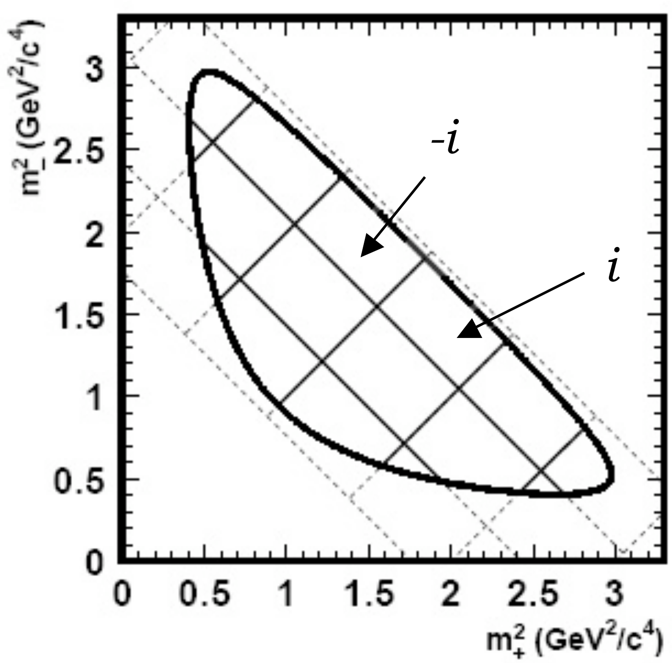
Measure c_i to reduce systematic uncertainty on γ/ϕ_3

$$c_i = \cos\delta_i = \frac{1}{2}\frac{(\overline{M}_i^- - \overline{M}_i^+)}{(\overline{M}_i^- + \overline{M}_i^+)}\frac{(K_i + K_{-i})}{\sqrt{K_i K_{-i}}}$$

CLEO-c will detemine c_i by counting yields in bin i for flavor and CP tags

K_i - flavor tag yield in bin i

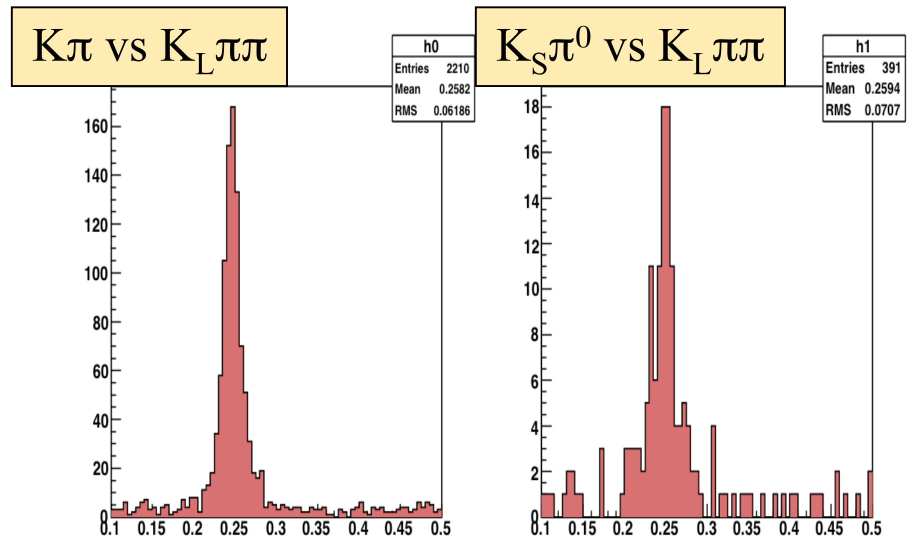
$M_i^\pm$ - CP± yield in bin i

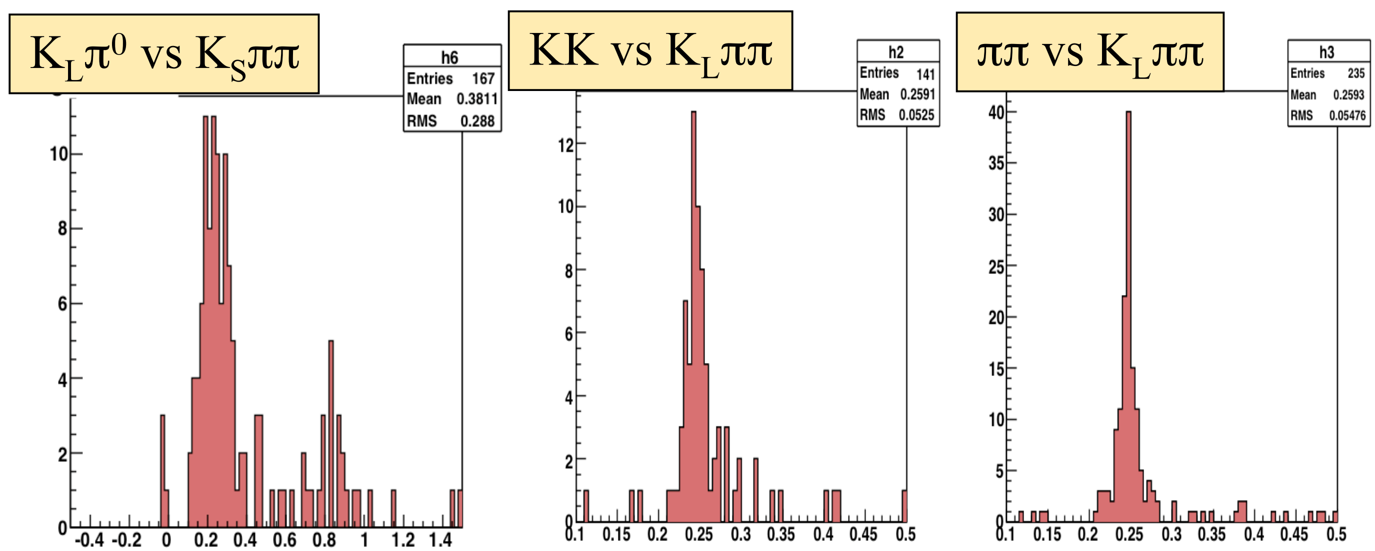


"Reconstructing" K_L

- Motivation clear - more statistics
- Method straight forward
  - Reconstruct D (Tag) on one side
  - Compute (missing mass)^2 on other
- Additional CP tags - shown today
  - $K_L\pi^0$ vs $K_S\pi^+\pi^-$
  - $K_S\pi^0$ vs $K_L\pi^+\pi^-$
  - K^+K^- vs $K_L\pi^+\pi^-$
  - $\pi^+\pi^-$ vs $K_L\pi^+\pi^-$
- Modes with $2\pi^0$'s also promising
  - $K_L\pi^0\pi^0$ vs $K_S\pi^+\pi^-$
  - $K_S\pi^0\pi^0$ vs $K_L\pi^+\pi^-$

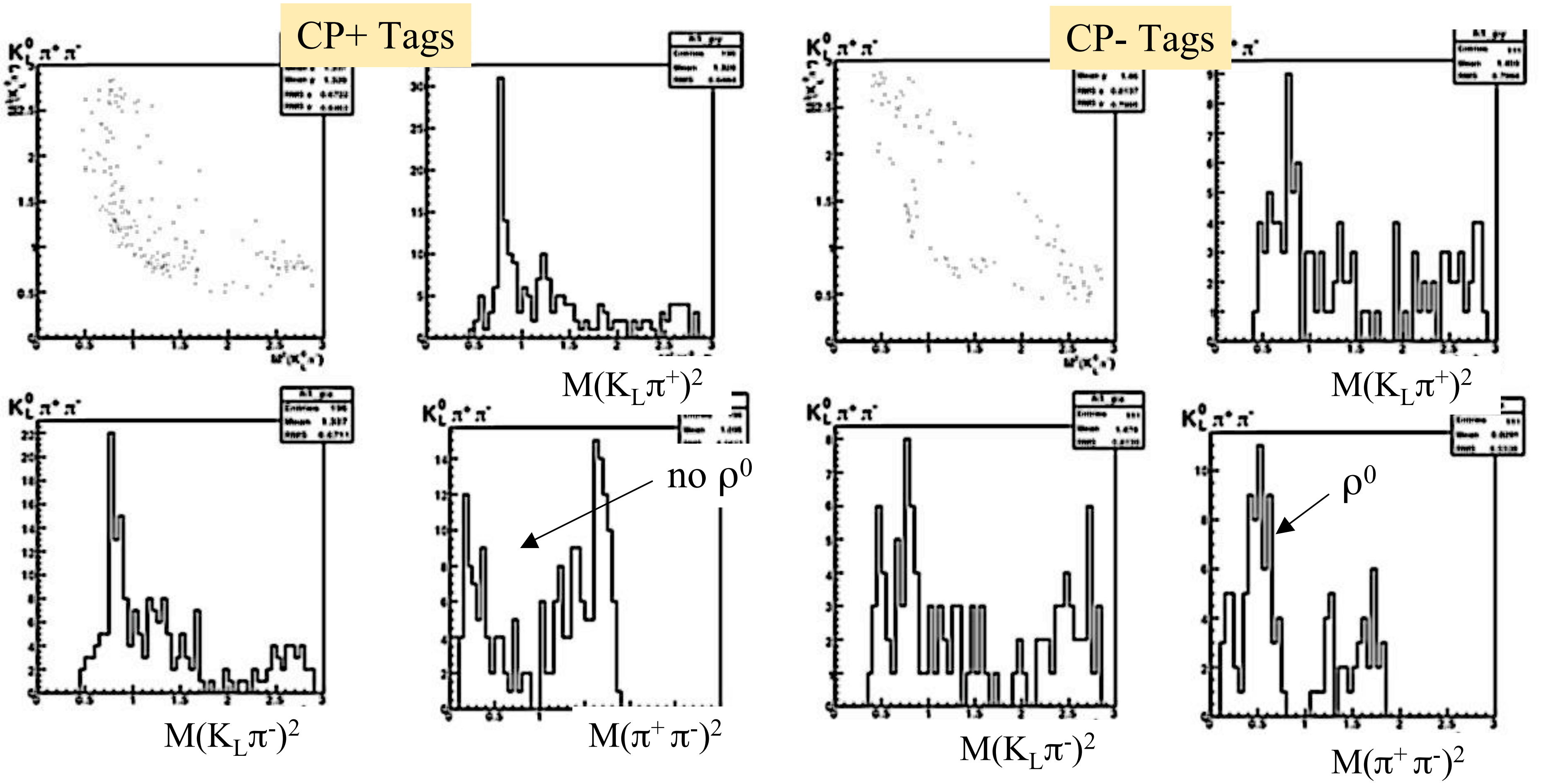
Bkgd ~5%





MM^2 (GeV)^2

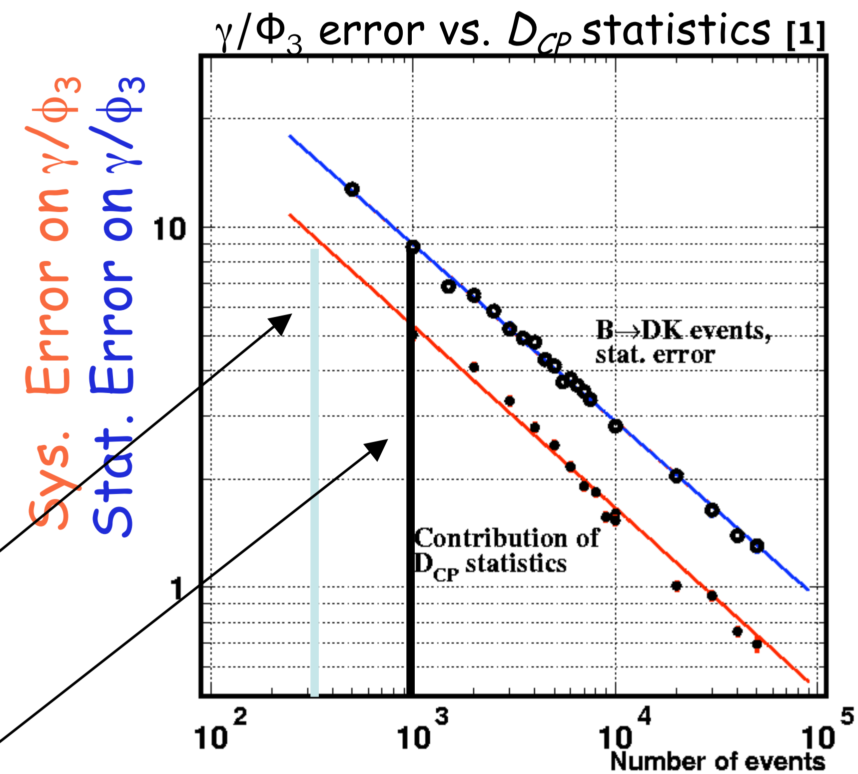
CP Tagged $K_L\pi^+\pi^-$ Dalitz Plots



- CP- tagged $K_L\pi\pi$ Dalitz plots have enhanced $K_L\rho^0$ (CP+)
- CP+ tagged $K_L\pi\pi$ Dalitz plots have no $K_L\rho^0$

Impact of CLEO-c

# of events (CLEO-c)	$K_S\pi+\pi-$		$K_L\pi+\pi-$	
	281 pb^{-1}	750 pb^{-1}	281 pb^{-1}	750 pb^{-1}
KK	66	175	134	350
$\pi\pi$	27	75	62	150
$K_S\pi^0$	95	250	103	275
$K_L\pi^0$	93	250	-	-
$K_S\pi+\pi-$	180	500	457	1200



# of B+→DK+ , D→$K_S\pi+\pi-$

# of CP tagged D→$K_S\pi+\pi-$

570 CP tags in 281 pb^{-1} → 6-7° sys. err.

~1500 CP tags expected in 750 pb^{-1} → ~4° sys. err.

~1700 "double" Dalitz tags expected in 750 pb^{-1}

[1] Bondar, Poluektov [hep-ph/0510246]

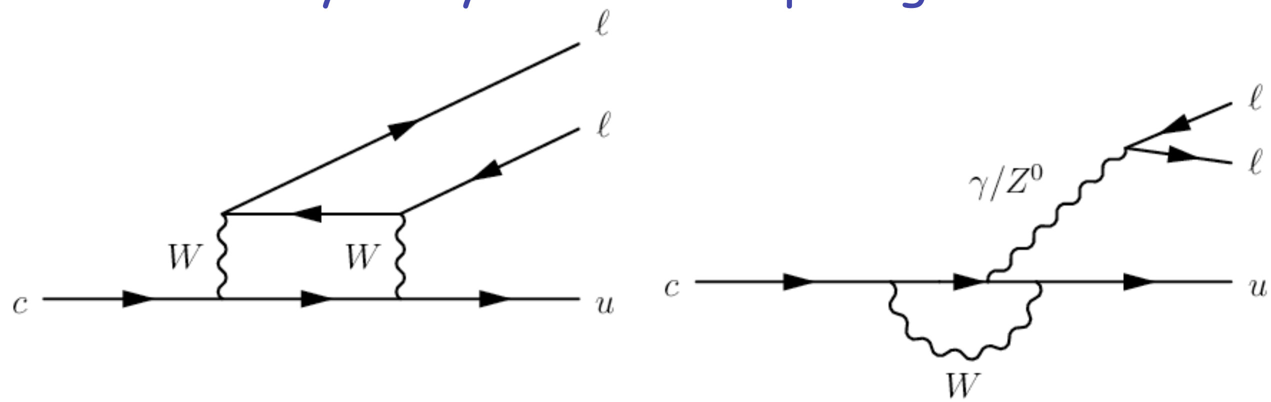
- Belle Statistics (347 fb^{-1})
  - 1 ab^{-1}/B-factory should yield ±6° statistical error
  - 20 ab^{-1} @SuperB required for ±2° statistical error

- BESIII: 20 fb^{-1}
  ⇒1° systematic

Rare Charm Decays

Rare Charm Decays

FCNC decays only occur in loop diagrams in SM:



Charm decays heavily GIM suppressed in SM: BF($c \to ull$)~10^{-8}

Rare decays provide background free probes that enhance (or suppress) rare or allow forbidden processes.

- Leptonic Decays: $D \to ee, \mu\mu, e\nu$, $D_s \to e\nu$
- GIM Suppressed: $D^0/D^+/D_s \to \pi ee$, $\pi\mu\mu$, Kee, $K\mu\mu$, ηee, $\eta\mu\mu$
- Lepton Flavor Violating: $D \to e\mu$, $D^0/D^+/D_s \to \pi e\mu$, $Ke\mu$
- Lepton Number Violating: $D^+/D_s \to \pi^- e^+ e^+$, $\pi^- \mu^+ \mu^+$, $K^- e^+ e^+$, $K^- \mu^+ \mu^+$

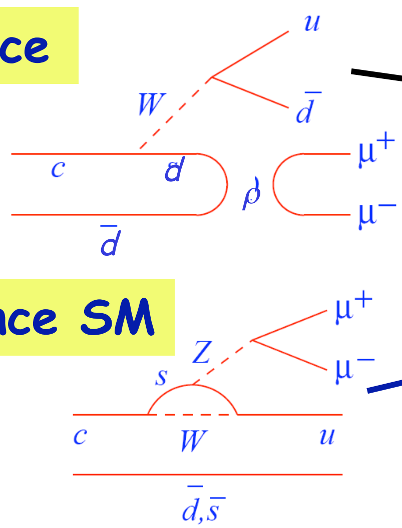
NP can introduce new particles into loop

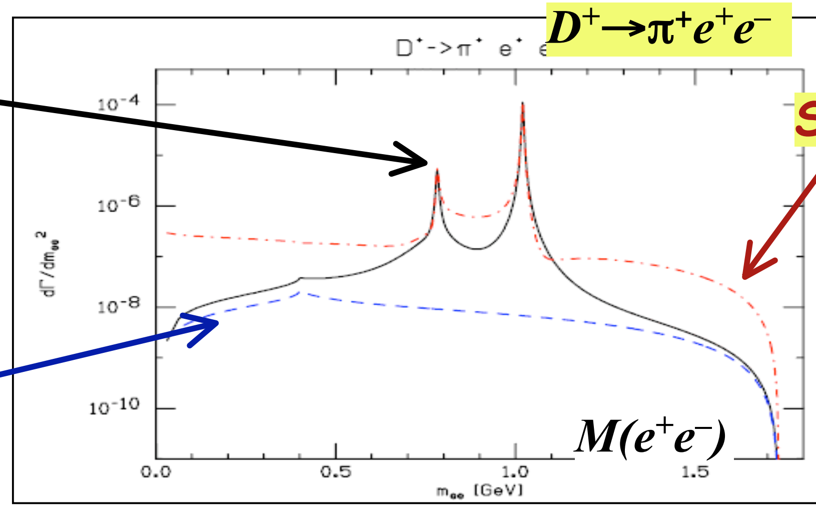
Particles and couplings in rare charm processes (Mixing, CPV, Rare Decay) are NOT the same as in Rare B, K sector

D Rare Decays

Long Distance

Short Distance SM





SM+SUSY

Standard Model

$\mathcal{B}(D^+ \Rightarrow \pi^+ e^+ e^-) \sim 2 \times 10^{-6}$

R-parity violating SUSY

$\mathcal{B}(D^+ \Rightarrow \pi^+ e^+ e^-) \sim 2.4 \times 10^{-6}$

If new particles are to appear on-shell at LHC they must appear in virtual loops & affect amplitudes in K, B and Charm

Although SM & NP rates are comparable the $M(e^+e^-)$ distributions are distinct

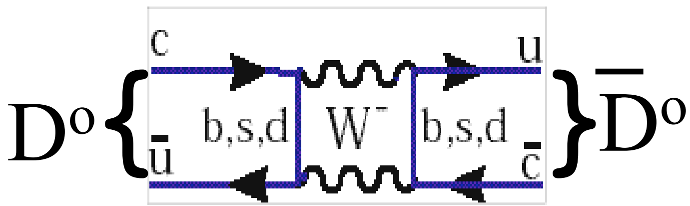
Experimental Sensitivity

Exp't	$D^0 \to \pi^0 \ell^+ \ell^-$ GIM	$D^+ \to \pi^+ \ell^+ \ell^-$ GIM	$D^+ \to \pi^- \mu e$ LFV	$D^+ \to \pi^- \ell^+ \ell^+$ LNV
Standard Model	10^{-6}	10^{-6}	~0	Forbidden
CLEO-c	1e-5	4e-6	-	2.2e-6
BESIII	5e-8	3e-8	3e-8	3e-8
SuperB (4 GeV)	2e-8	1e-8	1e-8	1e-8
B-factories	?	4e-6	4e-6	4e-6
SuperB (10 GeV)		7e-7	7e-7	7e-7
CDF/D0				
LHCb	-	?		
LHCb (upgrade)	-			

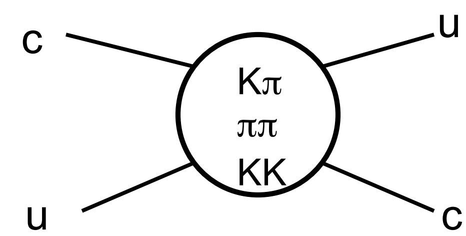
Charm Mixing

$$i\frac{\partial}{\partial t}\begin{pmatrix} D^0(t) \\ \overline{D}^0(t) \end{pmatrix} = \left(M - i\,\Gamma/2\right)\begin{pmatrix} D^0(t) \\ \overline{D}^0(t) \end{pmatrix}$$

$D^o - \overline{D}^o$ Mixing



- Double Cabibbo suppressed
- GIM mechanism cancellation
- Long Distance Contributions



d-type quarks in the loop makes SM expectations for D^o- D^o mixing small

compared with systems involving u-type quarks in the box diagram because these loops include 1 dominant super-heavy quark (t):
K^o (50%), B^o (20%) & B_s (50%)

In SM x≤y Short distance 10^{-6} - 10^{-3}
Long distance 10^{-3} - 10^{-2}

New physics (NP) in loops implies
$x \equiv \Delta m/\Gamma >> y \equiv \Delta\Gamma/2\Gamma$; but
long range effects complicate predictions.

Large CPV in mixing indicates NP

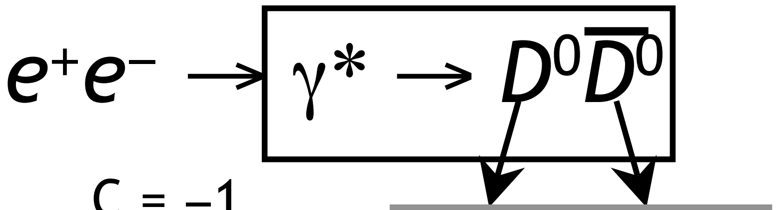
Parameter definitions

Mixing parameters: $x=\Delta M/\Gamma$, $y=\Delta\Gamma/2$
Mixing Rate: $R_M = (x^2+y^2)/2$
$D^0/\overline{D}^0$ relative strong phase δ
Effective parameters:
$y' = y\cos\delta - x\sin\delta$; $x' = y\sin\delta + x\cos\delta$

Semileptonic, CP eigenstate, Hadronic, Multibody, & Quantum Correlated final States probe different parameters

D Mixing near charm threshold

The Quantum Correlation Analysis: TQCA



C = −1

interference	$K^-\pi^+$	$K^+\pi^-$
	$K^+\pi^-$	$K^-\pi^+$
forbidden by Bose symmetry	$K^-\pi^+$	$K^-\pi^+$
	$K^-\pi^+$	$K^+l^-\nu$
	$CP+$	$K^+l^-\nu$
	$CP-$	$K^+l^-\nu$
maximal constructive interference	$K^-l^+\nu$	$K^+l^-\nu$
	$CP+$	$CP-$
forbidden by CP conservation	$CP+$	$CP+$
	$CP-$	$CP-$

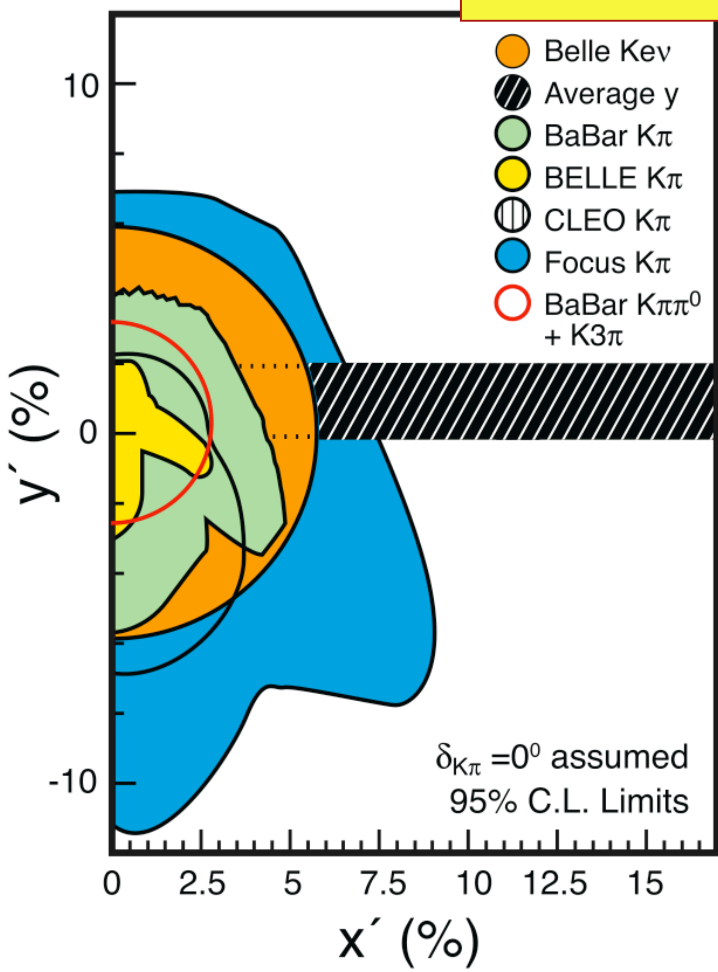
- Because of quantum correlation between $\overline{D}{}^0$ & D^0, not all final states allowed.
  - Two paths to $K^-\pi^+$ vs $K^+\pi^-$ interfere & so the rate is sensitive to DCS & strong phase
- Time integrated rate depends on both $\cos\delta_{D\rightarrow K\pi}$ and mixing parameter $y = \Delta\Gamma/2\Gamma$
  - $K^-\pi^+$ vs $K^-\pi^+$ forbidden without D mixing
- $K^-\pi^+$ vs semileptonic measures isolated decay rate and tags flavor of decaying D
  - $K^-\pi^+$ & semileptonic decays have different sensitivity to mixing vs DCSD
- D decays to CP eigenstates also interfere
  - Reconstruct vs semilep to get isolated rate
  - Reconstruct vs $K\pi$ tags for yet another dependence on y & strong phase
- CP eigenstate vs CP eigenstate shows maximal correlation
  - Double tag & single tag rates have distinct dependence on mixing & DCS

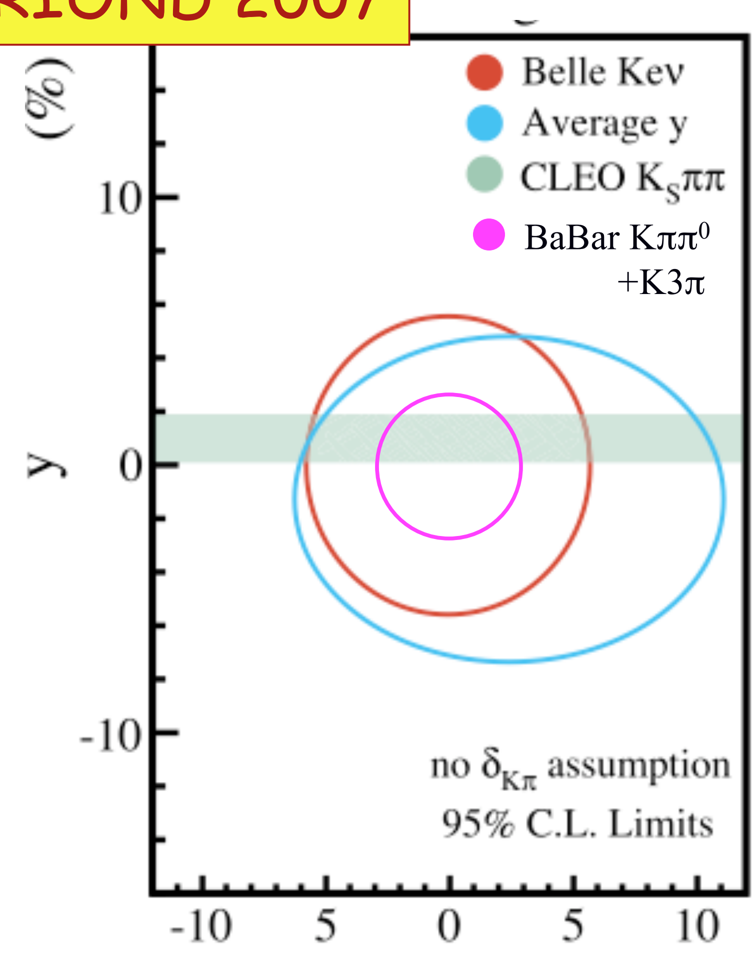
See Asner & Sun, PRD 73 034024 (2006)

Summary of Mixing Results

NO MIXING (x,y)=(0,0) excluded:
- ✓ ~2.1 σ Belle $D^0 \to K\pi$ (no CPV)
- ✓ ~2.3 σ BaBar $D^0 \to K2\pi/K3\pi$
- ✓ ~2.2 σ Average y

BEFORE MORIOND 2007





Need precision cosδ measurement (CLEO-c)
So that all limits can be expressed in x vs y

"Evidence" for D Mixing: Only 2 results > 3σ

- Babar (384 fb^{-1}) $D^0 \to K\pi$
  - c.w. Belle (400 fb^{-1})

    $x'^2 = (0.18^{+0.21}_{-0.23}) \times 10^{-3}$ $y' = (0.6^{+4.0}_{-3.9}) \times 10^{-3}$

$$x'^2 = (-0.22 \pm 0.30 \pm 0.21) \times 10^{-3}$$
$$y' = (9.7 \pm 4.4 \pm 3.1) \times 10^{-3}$$

- Belle (540 fb^{-1}) $D^0 \to KK,\pi\pi$
  - c.w. W.A. (includes Belle '03)

    $y_{CP} = (0.90 \pm 0.42)\%$

$$y_{CP} = (1.31 \pm 0.32 \pm 0.25)\%$$

- Belle (540 fb^{-1}) $D^0 \to K_S\pi\pi$
  - c.w. CLEO (9 fb-1)

    $x = (1.8 \pm 3.4 \pm 0.6)\%$ $y = (-1.4 \pm 2.5 \pm 0.9)\%$

$$x = (0.80 \pm 0.29 \pm 0.17)\%$$
$$y = (0.33 \pm 0.24 \pm 0.15)\%$$

- CLEO-c (281 pb^{-1}) - new results expected soon
  - y, x^2 and $\cos\delta$

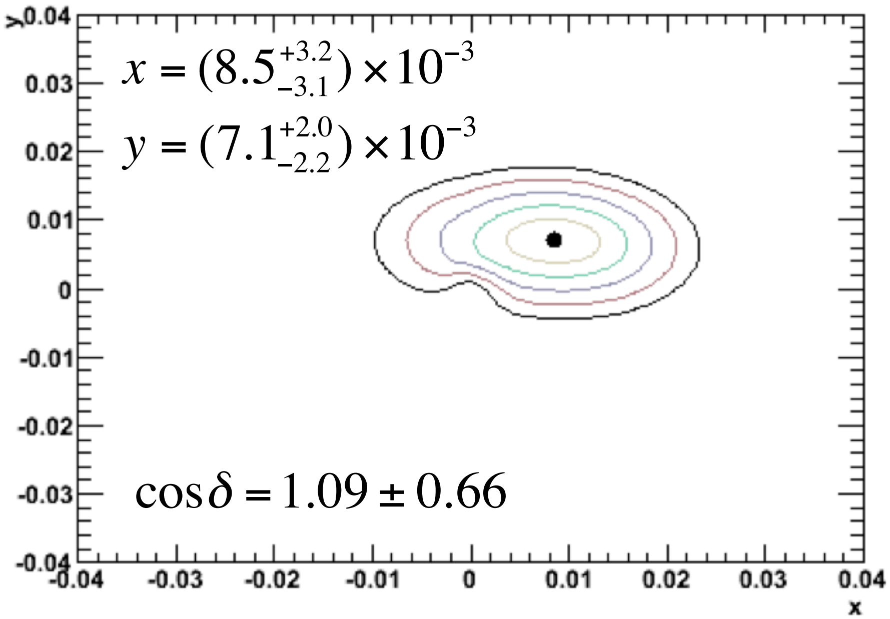
Before Moriond '07

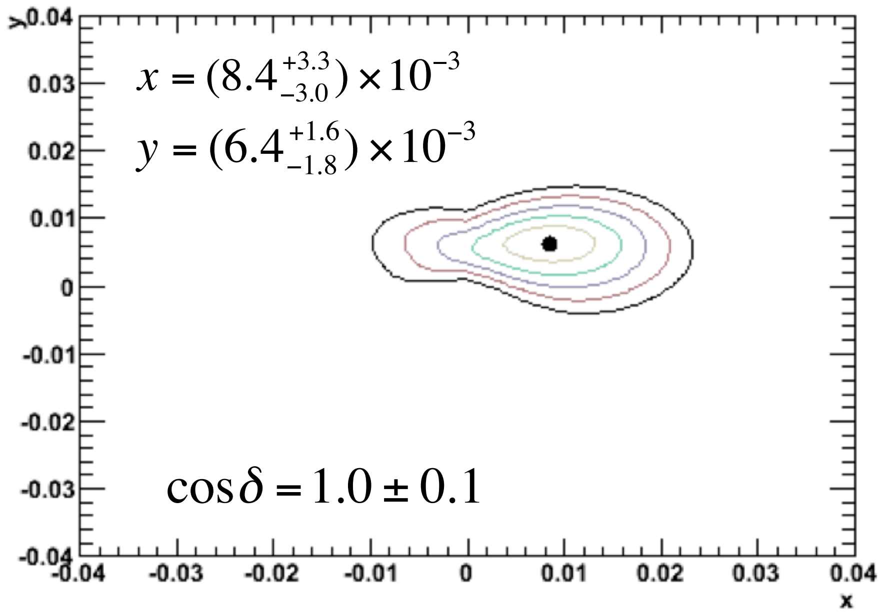
NO MIXING (x,y)=(0,0) excluded:
- ✓ ~2.1 σ Belle $D^0 \to K\pi$ (no CPV)
- ✓ ~2.3 σ BaBar $D^0 \to K2\pi/K3\pi$
- ✓ ~2.2 σ Average y_{CP}

After Moriond '07

NO MIXING (x,y)=(0,0) excluded:
- ✓ 3.9 σ BABAR $D^0 \to K\pi$ (no CPV)
- ✓ ~2.4 σ Belle $D^0 \to K_S\pi\pi$
- ✓ ~3.5 σ New Average y_{CP}=1.12±0.32

HFAG - VERY Preliminary





- With great trepidation average all results
  - Use likelihood contours where appropriate
- Consider two scenarios
  - Current results - with CLEO-c cosδ =1.09±0.66
  - Current results + anticipating cosδ = 1.0±0.1

Great Expectations

Exp't / 1 σ	y_{CP} (10^{-3})	y' (10^{-3})	x'^2 (10^{-4})	$\cos\delta$
B-factories (2ab^{-1})	2-3	2-3	1-2	-
SuperB (50 ab^{-1})	0.5	0.7	0.3	-
LHCb (10 fb^{-1}) Only B->D*	?	0.7	0.7	-
LHCb (100 fb^{-1}) Prompt D*	?	?	?	-
CLEO-c (750 pb^{-1})	10	-	2-3	0.1-0.2
BESIII (20 fb^{-1})	4	-	0.5-1	0.05
SuperB - 4 GeV (0.2 ab^{-1})	1-2	-	<0.2	<0.05

- 5σ signal in both y_{CP} & $D^0 \to K\pi$ possible with 2ab^{-1} @$\Upsilon(4S)$
- LHCb can confirm signal in $D^0 \to K\pi$ - y_{cp} study in progress
- 5σ time independent signal in y not likely @ BESIII
  - Requires ~1 month run at SuperB (4 GeV)

Charm Sector CP Violation

CPV in D Mixing

In Standard Model $x \lesssim y$ Short distance 10^{-6} - 10^{-3}
Long distance 10^{-3} - 10^{-2}

"Evidence" for mixing on high side of SM LD expectation

Could this be due (in part) to New Physics?

CP asymmetries involving D oscillations $O(10^{-6})$ in SM

Large CPV in mixing indicates NP

Current results consistent with no CP violation
Current results consistent with maximal CPV @95% C.L.

- $D^0 \rightarrow K^+\pi^-$ constrain $-99.5\% < A_M < +100\%$ @95% C.L. (Belle)
- $D^0 \rightarrow K^+K^-, \pi^+\pi^-$ $A_\Gamma \cong A_M y\cos\phi - x\sin\phi = (0.01 \pm 0.30 \pm 0.15)\%$ (Belle)
  - Consistent with both $A_M = \pm 1$ and $\sin\phi = \pm 1$

Sensitivity studies for LHCb, SuperB are incomplete.

Direct CPV

- CF & DCS decay: Direct CPV requires New Physics
  - Exception: interference between CF & DCS amplitudes to $D^{\pm} \rightarrow K_{S,L}\pi^{\pm}$
  - SM contribution due to K^0 mixing is $A_S=[+]_S-[-]_S \sim -3.3\times10^{-3}$; $A_S = -A_L$
  - New Physics could be ~%
- SCS decay
  - expect $O(\lambda^4) \sim 10^{-3}$ from CKM matrix
  - New Physics could be ~%
- Only type of CPV possible for charged mesons
- Requires two amplitudes with different strong & weak phases
  - In SM different weak phases often from tree & penguin processes

Experimentally:

- Most analyses measure asymmetry in time integrated partial widths
  - Only few % level sensitivity to Direct CPV attained
- Only few analyses measure final state distributions
  - Dalitz plots, T-odd correlation
  - Much greater sensitivity to new physics

SM Suppressed Processes

- D mixing
  - Many new results - "Evidence" of D mixing
  - Most precise technique is t-dep analysis of $D^0 \rightarrow K_S\pi^+\pi^-$ (CLEO II.V,Belle)
  - Outlook for TQCA with BESIII promising
  - First measurement of cos δ (CLEO-c)
  - ~Equivalent sensitivity 2 ab^{-1}@10 GeV ,20 fb^{-1}@4 GeV
  - Very different systematic uncertainties

Outlook for LHCb promising
Benefit from SuperB data at both 4 GeV and 10 GeV

- CP Violation - **much more work needed!**
  - No meaningful constraints on CPV in D mixing
  - Decays to final states with more than two pseudoscalars or one pseudoscalar & one vector meson contain more dynamical info than given by their widths.
  - Distribution on Dalitz plots or T odd moments can exhibit CP asymmetries considerably larger than those for the width
  - Standard Model CPV in charm is as large as 10^{-3} in particular decay channels & should be observable with current B-factories
  - BESIII should have comparable sensitivity

LHCb CPV studies required.
Improved CP constraints from SuperB (10 or 4 GeV)

- Rare Decays
  - Lots of results from FOCUS/CLEO-c/BaBar/CDF
  - ~Equivalent sensitivity 280 fb^{-1} @ 10 GeV 280 pb^{-1} @ 4 GeV
  - CLEO-c limits statistics limited. Others background limited
  - Clear advantage to threshold - BESIII (20 fb-1) statistics limited

SuperB data near 4 GeV will improve sensitivity

Charm Physics Circa 2013

- Hadronic Branching Ratios
  - D^0 & D^+ branching ratios syst. limited at (1-2)% CLEO-c
  - D_s^+ BR stat. limited at 6% CLEO-c
    - CLEO-c will improve to ~4%
    - BESIII will improve to (1-2)%
- Decay constants: statistics limited
  - f_{D+} 7.5% (281pb^{-1}) at 3770. CLEO-c
    - CLEO-c will improve to (4-5)%
    - BESIII will improve to (1-2)%
  - f_{Ds} 4.1% (200pb^{-1}) at 4170. CLEO-c
    - CLEO-c will improve to (2-3)%
    - BESIII can improve
  - $\sigma(f_D/f_{Ds})$ ~ 2% at BESIII (20 fb^{-1})
- Semileptonic Decays
  - BR of Cabibbo suppressed $D^0 \rightarrow \pi e \nu$ known to 4% CLEO-c
    - CLEO-c will improve to (2-3)%
    - BESIII can improve
  - Vcs ~ 2%, Vcd ~ 4% CLEO-c
    - CLEO-c will improve Vcd~2%
  - Precision form-factors to improve V_{ub} benefits from more 4 GeV data
- CP tagged Dalitz plot analyses e.g. $D^0 \rightarrow CP$ vs. $D^0 \rightarrow K_{S,L}\pi^+\pi^-$
  - Important for γ
  - Statistics limited
  - CLEO-c can limit sys err on $\gamma < 3^o$
- Rare Decays
  - CLEO-c sensitivity 10^{-5}-10^{-6}
  - BESIII sensititity 10^{-6}-10^{-7}
  - Standard Model rates ~10^{-8}
  - LHCb sensitivity?
  - SuperB @ ~4 GeV ~SM sensitivity
- Charm Mixing
  - Exploiting quantum coherent initial state CLEO-c will measure $\cos\delta$~±0.1
  - BESIII sensitivity to y ~few x 10^{-3}
  - Need LHCb (Upgrade) or SuperB to cover full range of SM expectations
- CP Violation
  - BESIII sensitive to ~SM asymmetry in $D^+ \rightarrow K_{S,L}\pi^+$ ~fewx10^{-3} .
  - Need LHCb (Upgrade) or SuperB to reach SM expectation in SCS decay.

Charm Physics Circa 2013

- Hadronic Branching Ratios
  - D^0 & D^+ branching ratios syst. limited at (1-2)% CLEO-c
  - D_s^+ BR stat. limited at 6% CLEO-c

1% precision in charm CKM measurements will not be attained by CLEO-c + BESIII

- D ... ed
  - ... -c
  - f_{Ds} 4.1% (200pb^{-1}) at 4170. CLEO-c
    - CLEO-c will improve to (2-3)%
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- CP tagged Dalitz plot analyses e.g. $D^0 \to CP$ vs. $D^0 \to K_{S,L}\pi^+\pi^-$
  - Important for γ

BESIII+B-factories will achieve interesting sensitivity to New Physics in rare decay, mixing and CPV. They will NOT close the window on NP in the charm sector.

- Charm Mixing
  - Exploiting quantum coherent initial state CLEO-c will measure cosδ~±0.1
  - BESIII sensitivity to y ~few x 10^{-3}
  - Need LHCb (Upgrade) or SuperB to cover full range of SM expectations
- CP Violation
  - BESIII sensitive to ~SM asymmetry in $D^+ \to K_{S,L}\pi^+$ ~few$\times 10^{-3}$.
  - Need LHCb (Upgrade) or SuperB to reach SM expectation in SCS decay.

The End

Semileptonic Charm Decays & Form Factors

Exclusive Semileptonic Decays

- Either take V_{cq} from other information & test theory, or use theory & measure V_{cq}
  - V_{cs} use $D \to K(K^*) l\nu$ to measure form-factor shapes to distinguish among models & test (L)QCD predictions
  - V_{cd} use $D \to \pi \to l\nu$
- V_{cd} & V_{cs} with precise unquenched lattice calc + V_{cb} would provide an important unitarity check
- Use $D \to \pi l\nu$ (& $\rho l\nu$) to get form-factor for $B \to \pi l\nu$ (& $\rho l\nu$) and use HQET to get V_{ub}

Semileptonic Charm Decays

- Three family unitarity constraints yield rather precise results for $|V_{cd}|$ & $|V_{cs}|$
- Get form factors from excl. semileptonic decays
- Branching fractions & q^2 distributions in data provide tests for (L)QCD calculations
  - Study both CF & CS D^0, D^+ and D_s semileptonic decays
- Branching fractions best measured at threshold
  - BESIII (20 fb^{-1}) will measure $D \to Ke\nu$, $D^0 \to \pi e\nu$ ~1%
  - SuperB (200 fb^{-1}) @ 4 GeV for $D \to \rho e\nu$, $D^+ \to \pi e\nu$ ~1%

Precision Form Factors

- Extrapolating from K sector form factor analyses of NA48/2 & E685 desire $O(10^6)$ to extract precise dynamical information
  - Way beyond the reach of BESIII
  - SuperB (500 fb^{-1}) @4 GeV yields 10^6 tagged $D^0 \rightarrow \pi e \nu$
- Noteworthy that fully reconstructed $e^+e^- \rightarrow cc$ obtains q^2 resolution and S/B comparable to threshold running
  - Comparable statistics: BESIII (20 fb^{-1}) & SuperB (140 ab^{-1})

Charm Physics Summary

Study of charm decays not 'hypothesis driven' research

- Leading charm decays are not CKM suppressed - unlike K & B

Study of Charm decays is 'hypothesis generating' research

- FCNC dynamics could be much stonger in up-type quarks
- Only charm allows full range of probes for New Physics in up-type quarks

Potentially very rich CP phenomenology on 3 Cabibbo levels

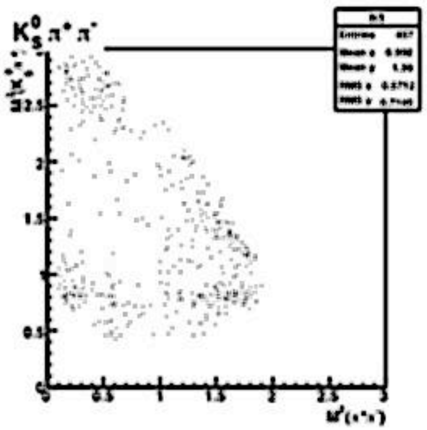
So far - the absence of any New Physics hint is not meaningful!

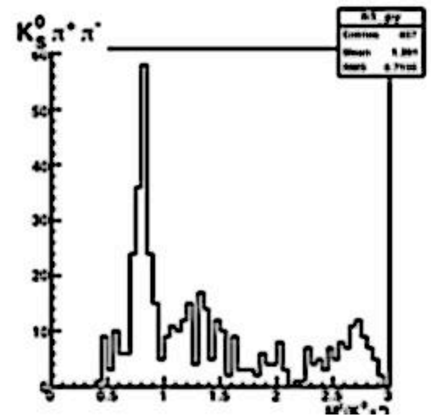
- Only just achieved interesting sensitivity … and a long way to go

Finally, precision measurements of leptonic, semileptonic & non-leptonic charm decays enable/enhance measurements in B-sector & provide precision calibration for theoretical methods

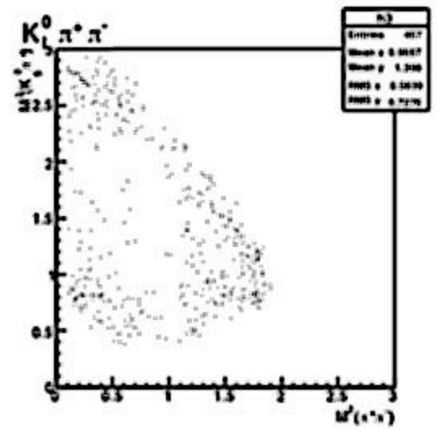
- Enable precision measurements in ρ, η plane. Use precision CKM to find NP

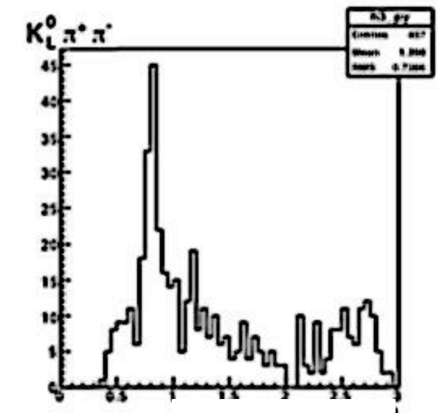
$K_S\pi^+\pi^-$ vs $K_L\pi^+\pi^-$ (CLEO-c Data)



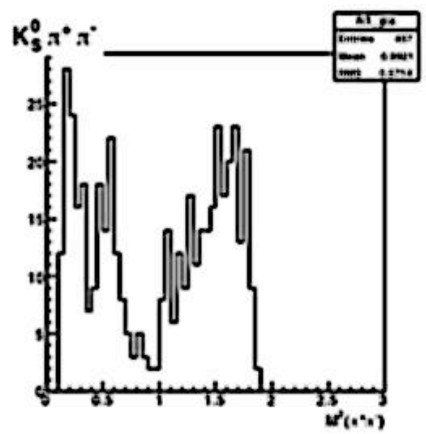


$M(K_S\pi^+)^2$

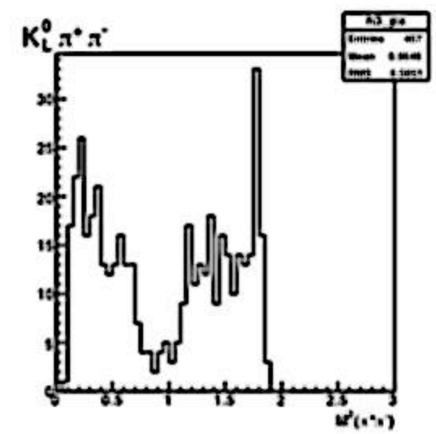




$M(K_L\pi^+)^2$



$M(\pi^+\pi^-)^2$



$M(\pi^+\pi^-)^2$