Charm Physics: Experimental Prospects

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Three Roles of Charm

1) Search for New Physics in Charm

2) Precision Tests of QCD Calculations

3) Charm Inputs to Other Measurements

Charm Experiments

- Charm Threshold (e^+e^- ~4 GeV)
  - Present: CLEO - ends data taking in 2008
  - Soon: BESIII - starts data taking in 2008
    - expect 20x CLEO data sample at BESIII
  - Future?: SuperB (INFN) - possible start 2014
    - expect 10x BESIII data sample in 1 month at SuperB
- B Threshold (e^+e^- ~10 GeV)
  - Present: BaBar - ends data taking in 2008
  - Present: Belle - ends data taking in 2009
  - Future?: KEKB upgrade $L=10^{35}$; SuperB (INFN) $L=10^{36}$
- Hadronic Production (Fixed target, ppbar, pp)
  - Past: FOCUS - 1996/7
  - Present: Tevatron - ends data taking in 2010
  - Soon: LHCb - starts data taking in 2008
    - Charm capability not fully evaluated
  - Future?: LHCb upgrade - does not require sLHC

Search for New Physics in Charm

- Very low Standard Model (SM) rates for loop processes provide unique window to observe New Physics (NP) in rare charm processes
  - Rare Decays, CP Violation, Charm Mixing)
  - NP can introduce new particles into loop

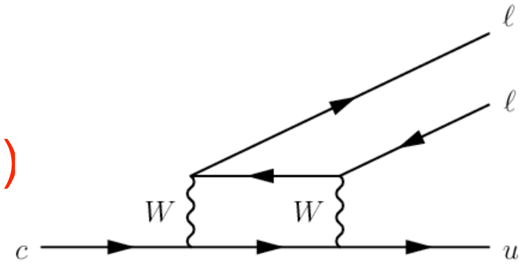
- **Different sensitivity to NP than B & K sectors**
  - Particles/couplings in rare charm processes NOT the same as rare B, K

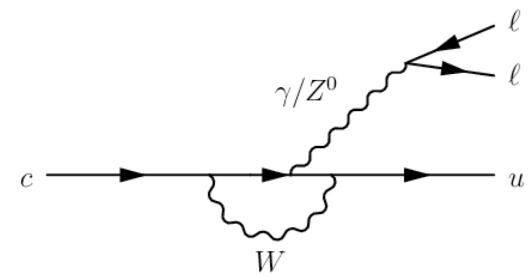
Search for New Physics in Charm

- Rare Charm Decays

(GIM suppressed: BF($c \rightarrow ull$)~10^{-8})

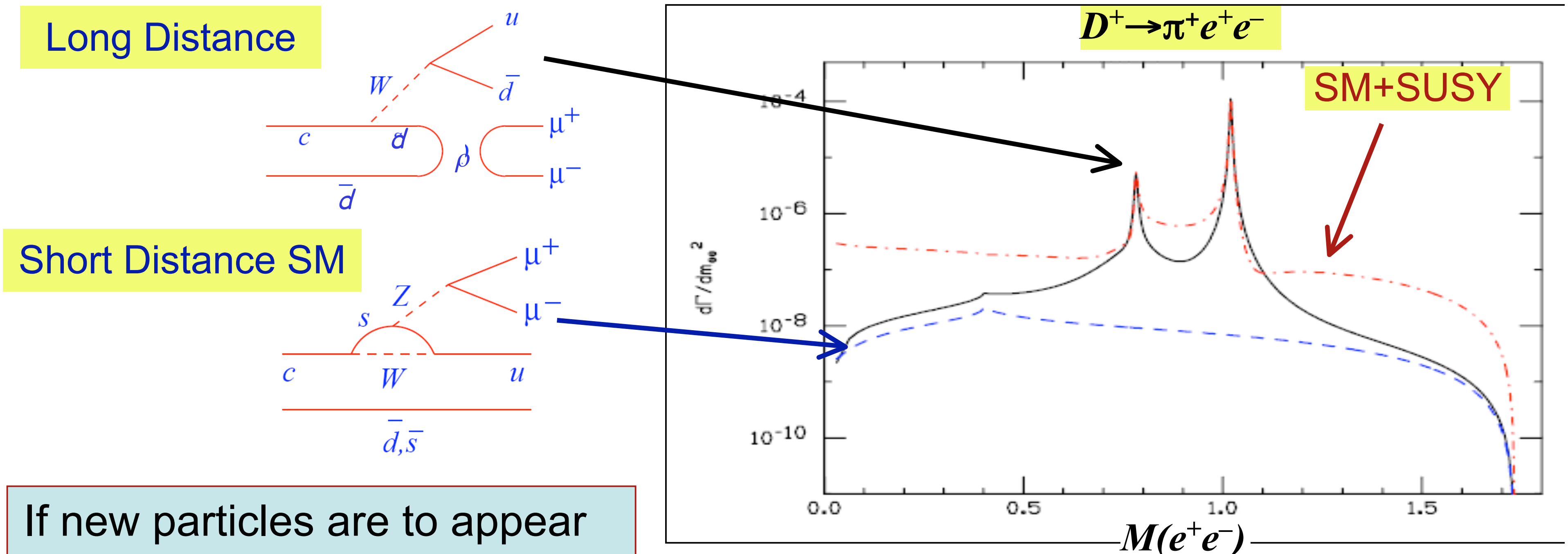
  - FCNC decays only occur in loop diagrams in SM:





- Charm Mixing - Large CPV in mixing indicates New Physics
  - SM $x \equiv \Delta m/\Gamma \leq y \equiv \Delta\Gamma/2\Gamma$, NP in loops implies x >> y
  - long range effects complicate predictions
- Direct CP Violation - (New Physics could be ~%)
  - Cabibbo Favored (CF) & Doubly Cabibbo Suppressed (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 $A_S=[+]_S-[-]_S$ ~ $-3.3\text{x}10^{-3}$; $A_S = -A_L$
  - Singly Cabibbo Suppressed Decay
    - expect $O(\lambda^4)$ ~ 10^{-3} from CKM matrix

D Rare Decays



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

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

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

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

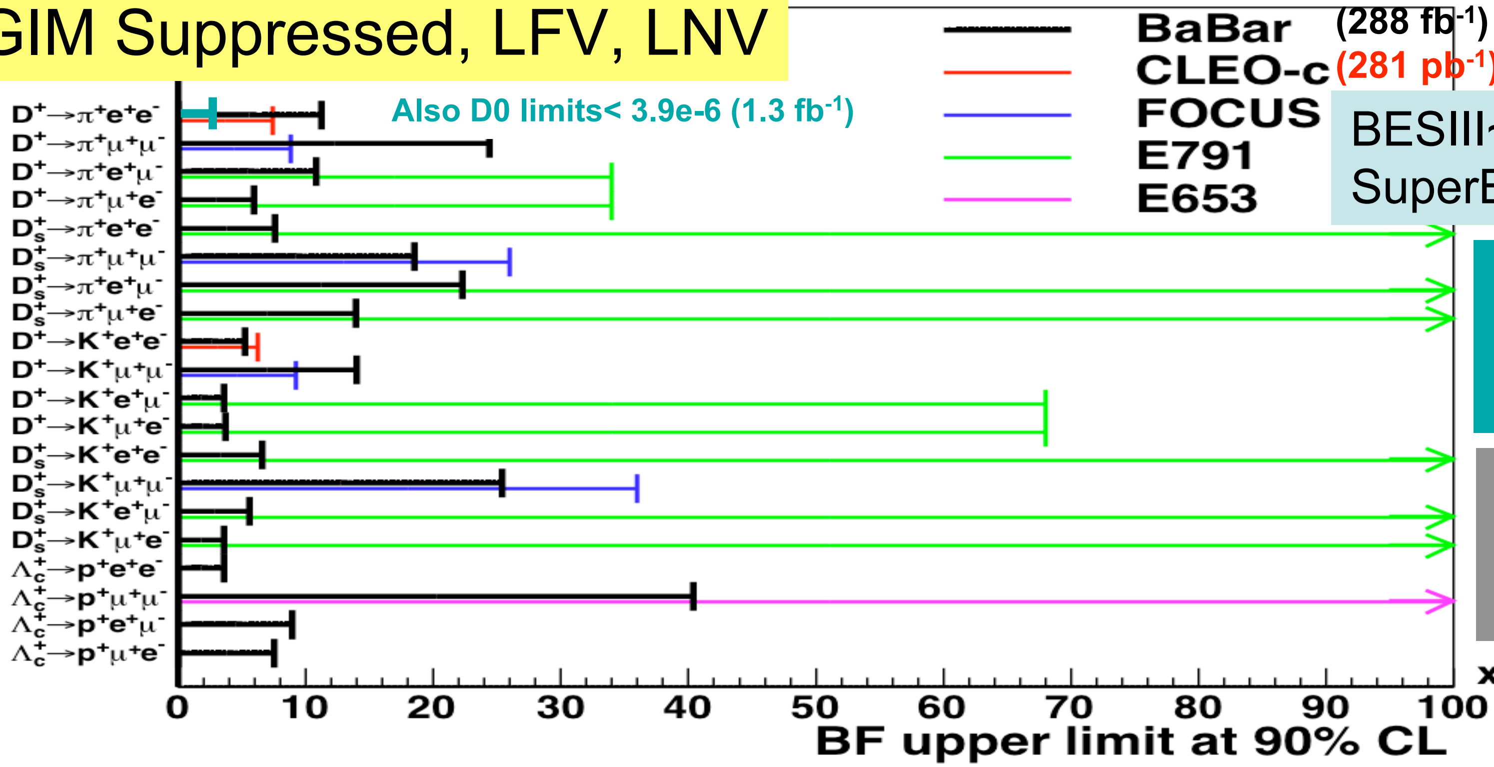
Experimental Sensitivity

Leptonic $D \to ee, \mu\mu$ (SM $<10^{-15}$), $D \to e\nu$ (SM~10^{-8}) $D_s \to e\nu$ (SM~10^{-7})

- CLEO-c: $D \to e\nu < 2.4e^{-5}$ (281 pb^{-1}), $D_s \to e\nu < 1.3e^{-4}$ (314 pb^{-1})
- CDF: $D \to \mu\mu < 2.5e^{-6}$ (65 pb^{-1}) BaBar: $D \to ee, \mu\mu < 1.2e^{-6}, 1.3e^{-6}$ (122 fb^{-1})

BESIII~10^{-8} (20 fb^{-1}) SuperB-4 GeV (150 fb^{-1}) sensitivity to SM $D_{(s)} \to e\nu$
LHCb ~10^{-10} (10 fb^{-1}) $B \to \mu\mu$ ~10^{-10} SuperB-10 GeV (75 ab^{-1}) $B \to ee, \mu\mu$ ~10^{-10}

GIM Suppressed, LFV, LNV



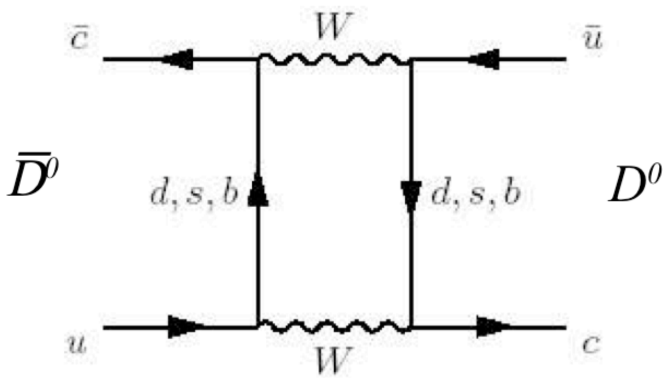
BESIII~10^{-8} (20 fb^{-1})
SuperB-4 GeV(150 fb^{-1})

BESIII/SuperB
Senstive to
SM $c \to u l^+ l^-$

e+e-@10 GeV
Tevatron, LHCb
Bkgd limited

Charm Mixing

SM Charm Mixing has down-type quarks in the loop



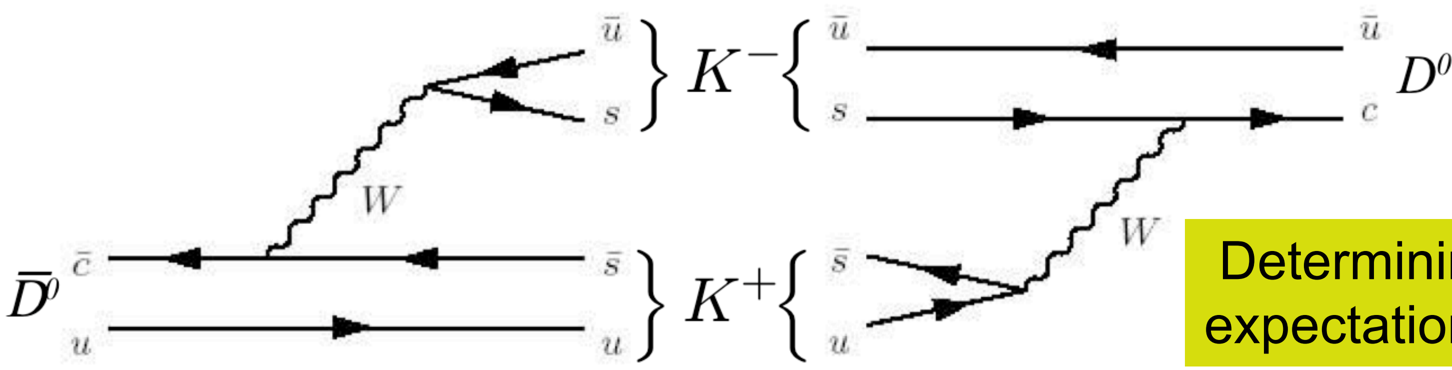
Double Cabibbo Suppressed

GIM Suppressed

SM: Short distance 10^{-6} - 10^{-3}

Long distance 10^{-3} - 10^{-2}

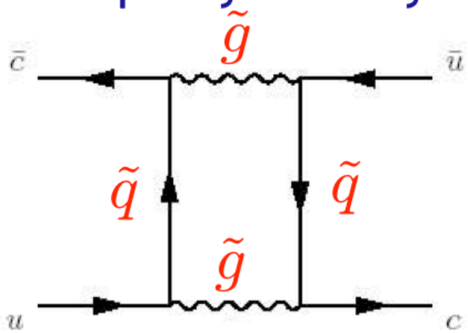
Expect hadronic intermediate states to dominate



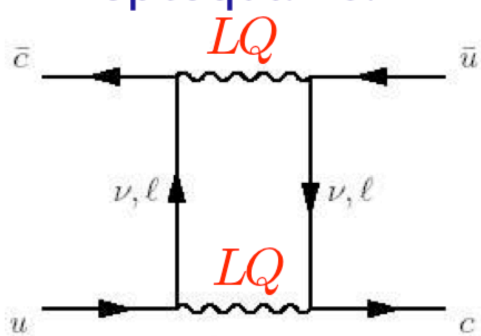
Determining SM expectation difficult

New Physics: Charm Mixing

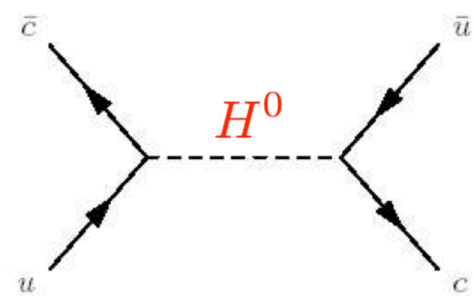
Supersymmetry:



Leptoquarks:



Extended Higgs:



- Both loop and tree level NP contributions
- Some models avoid large FCNC in B & K sectors by having large mixing in charm
- 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 New Physics

D Mixing & CPV

8 parameters describe D mixing & CPV

- $x, y, \delta, \delta 2, R_D, A_D, |q/p|, \phi$

Average of many observables

- Semileptonic Decay: R_M
  - Search for $\Gamma(D^0 \to K^{(*)+} l^- \nu)$
- CP Eigenstate: y_{CP}, A_Γ
  - $D^0(t) \to$ CP Eigenstate
- Wrong-sign $K^+\pi^-$ $R_D, x'^{\pm}, y'^{\pm}$
  - $D^0(t) \to K^+\pi^-$
- Wrong-sign $K^+\pi^-\pi^0$, $K^+3\pi$: $x, y, \delta 2, R_M$
  - $D^0(t) \to K^+\pi^-\pi^0$, $K^+3\pi$
- Dalitz plot: $x, y, |q/p|, \phi$
  - $D^0(t) \to K_s\pi^+\pi^-$:
- Quantum Correlations: R_D, R_M, y, δ
  - $e+e- \to D^0 D^0(n)\gamma(m)\pi^0$:

$$R_M = \frac{1}{2}(x^2 + y^2)$$

$$2y_{CP} = \big(|q/p| + |p/q|\big) y\cos\phi - \big(|q/p| - |p/q|\big) x\sin\phi$$

$$2A_\Gamma = \big(|q/p| - |p/q|\big) y\cos\phi - \big(|q/p| + |p/q|\big) x\sin\phi$$

$$\begin{aligned} x_{K^0\pi\pi} &= x \\ y_{K^0\pi\pi} &= y \\ |q/p|_{K^0\pi\pi} &= |q/p| \\ \mathrm{Arg}\,(q/p)_{K^0\pi\pi} &= \phi \end{aligned}$$

$$\begin{pmatrix} x'' \\ y'' \end{pmatrix}_{K^+\pi^-\pi^0} = \begin{pmatrix} \cos\delta_2 & \sin\delta_2 \\ -\sin\delta_2 & \cos\delta_2 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\delta & \sin\delta \\ -\sin\delta & \cos\delta \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

$$A_M = \frac{|q/p|^2 - |p/q|^2}{|q/p|^2 + |p/q|^2}$$

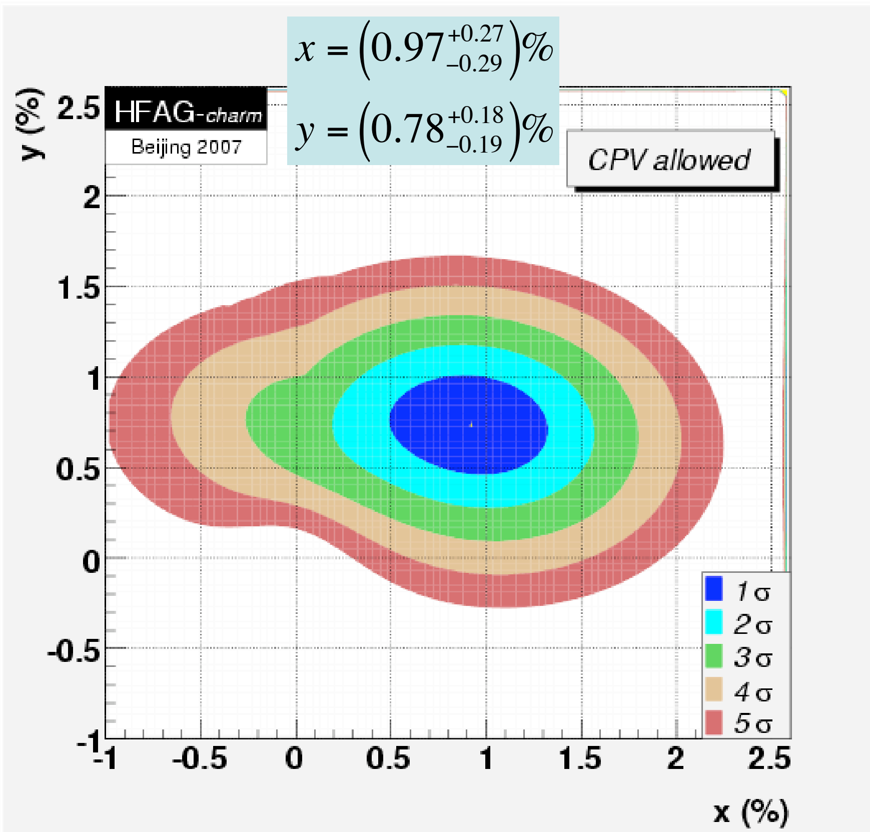
$$x'^{\pm} = \left(\frac{1 \pm A_M}{1 \mp A_M}\right)^{1/4} (x'\cos\phi \pm y'\sin\phi)$$

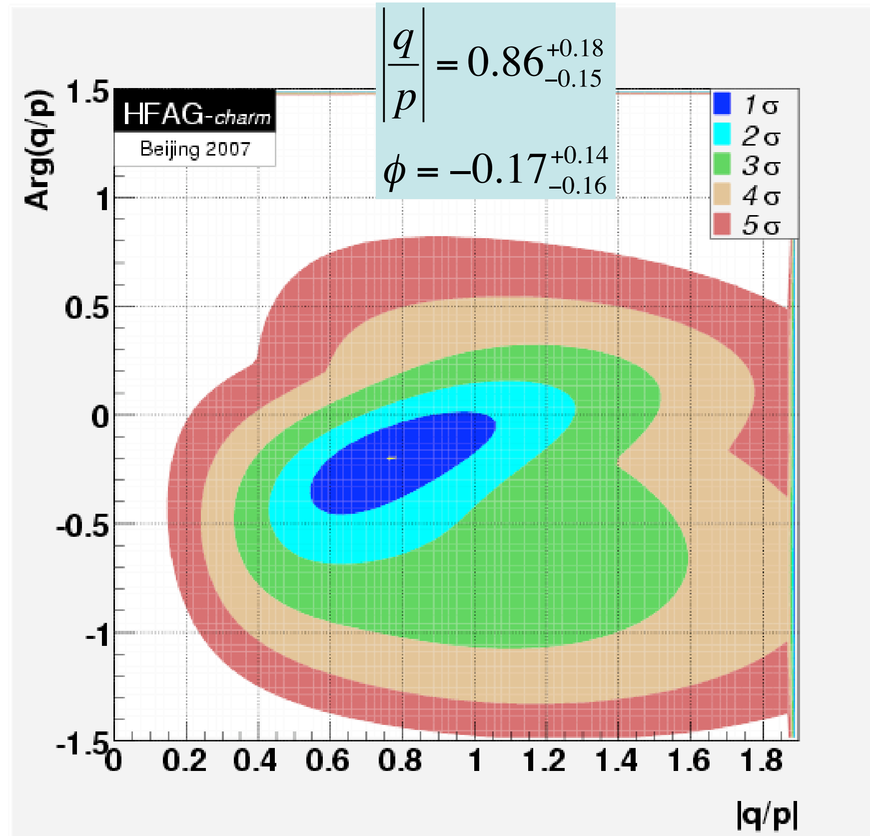
$$y'^{\pm} = \left(\frac{1 \pm A_M}{1 \mp A_M}\right)^{1/4} (y'\cos\phi \mp x'\sin\phi)$$

$$\frac{1}{2}\left[R(D^0 \to K^+\pi^-) + \overline{R}(\overline{D}^0 \to K^-\pi^+)\right] = R_D$$

$$\frac{R(D^0 \to K^+\pi^-) - \overline{R}(\overline{D}^0 \to K^-\pi^+)}{R(D^0 \to K^+\pi^-) + \overline{R}(\overline{D}^0 \to K^-\pi^+)} = A_D$$

Charm Mixing with CPV: HFAG





- Multi-dimensional average of 2-4σ results
- No mixing solution excluded at >5σ
  - Results on the upper end of SM expectations
- No CPV solution ~1σ from best fit SM expectations ~10^{-6}

Summary: Charm Mixing

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*	0.5	0.7	0.7	-
LHCb (100 fb^{-1}) Prompt D*	?	?	?	-
CLEO-c (800 pb^{-1})	20	-	8	0.2
BESIII (20 fb^{-1})	4	-	1-2	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} @Υ(4S)
- LHCb can confirm signal in $D^0 \to K\pi$ and y_{cp}
- 5σ time independent signal in y not likely @ BESIII
  - Requires ~1 month run at SuperB (4 GeV)

Expect SuperB has % level senstivity to CPV in D mixing

Direct CPV Results

A_{CP} mode	E791(%)	FOCUS(%)	CLEO(%)	BABAR(%)	Belle(%)	CDF(%)
$D^0 \to K^+\pi^-$		$18 \pm 14 \pm 4$	2^{+19}_{-20}	9.5 ± 10.3	2.3 ± 4.7	
$D^0 \to K^+\pi^-\pi^0$			9^{+25}_{-22}		-0.6 ± 5.3	
$D^0 \to K^-K^+$	$-1.0\pm4.9\pm1.2$	$-0.1\pm2.2\pm1.5$	$0.0\pm2.2\pm0.8$	0.00±0.34±0.13	0.2 ± 0.7	$1.0 \pm 1.3 \pm 0.6$
$D^0 \to \pi^-\pi^+$	$-4.9\pm7.8\pm3.0$	$4.8\pm3.9\pm2.5$	$1.9\pm3.2\pm0.8$	-0.24±0.52±0.22		$2.0 \pm 1.2 \pm 0.6$
$D^0 \to \pi^0\pi^0$			0.1 ± 4.8			
$D^0 \to K^0_S K^0_S$			-23 ± 19			
$D^0 \to K^0_S\pi^0$			0.1 ± 1.3			
$D^0 \to K^0_S\pi^+\pi^-$			$-0.9 \pm 2.1^{+1.6}_{-5.7}$			
$D^0 \to K^0_S\phi$			2.8 ± 9.4			
$D^+ \to K^0_S\pi^+$		$-1.6\pm1.5\pm0.9$	-0.6±1.0±0.3			
$D^+ \to K^0_S K^+$		$6.9\pm6.0\pm1.8$				
$D^0 \to K^-\pi^+\pi^0$			-3.1 ± 8.6			
$D^+ \to K^-K^+\pi^+$	-1.4 ± 2.9	$0.6\pm1.1\pm0.5$	-0.1±1.5±0.8	$1.4 \pm 1.0 \pm 0.8$		
$D^+ \to \phi\pi^+$	-2.8 ± 3.6					
$D^+ \to K^*K^+$	-1.0 ± 5.0			$0.9 \pm 1.7 \pm 0.7$		
$D^+ \to \pi^-\pi^+\pi^+$	-1.7 ± 4.2					
$D^0 \to \pi^+\pi^-\pi^0$			$-1^{+9}_{-7} \pm 5$			
$D^0 \to K^+\pi^-\pi^+\pi^-$					-1.8 ± 4.4	
$D^0 \to K^+K^-\pi^+\pi^-$		$-8.2 \pm 5.6 \pm 4.7$				
$D^+ \to K^0_S K^+\pi^+\pi^-$		$-4.2 \pm 6.4 \pm 2.2$				

New From BaBar

New from CLEO-c

Mode	A_{CP} (%)
$D^0 \to K^-\pi^+$	$-0.4 \pm 0.5 \pm 0.9$
$D^0 \to K^-\pi^+\pi^0$	$0.2 \pm 0.4 \pm 0.8$
$D^0 \to K^-\pi^+\pi^+\pi^-$	$0.7 \pm 0.5 \pm 0.9$
$D^+ \to K^-\pi^+\pi^+$	$-0.5 \pm 0.4 \pm 0.9$
$D^+ \to K^-\pi^+\pi^+\pi^0$	$1.0 \pm 0.9 \pm 0.9$
$D^+ \to K^0_S\pi^+$	$-0.6 \pm 1.0 \pm 0.3$
$D^+ \to K^0_S\pi^+\pi^0$	$0.3 \pm 0.9 \pm 0.3$
$D^+ \to K^0_S\pi^+\pi^+\pi^-$	$0.1 \pm 1.1 \pm 0.6$
$D^+ \to K^+K^-\pi^+$	$-0.1 \pm 1.5 \pm 0.8$

BESIII needed to see CPV in $K_S\pi^+$ (10^{-3})

BaBar approaching interesting sensitivity in SCS ~10^{-3}

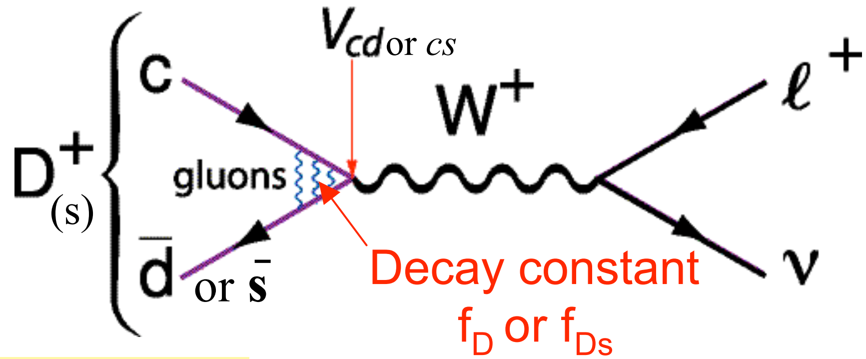
Charm Confronts QCD Calculations

- Focused & crisp challenges to theoretical techniques for QCD calculations - particularly techniques for non-perturbative QCD
  - Important if New Physics observed at LHC has strongly coupled sector

- Leptonic Decays
  - Measure decay constants f_D, f_{Ds} - stringent test of LQCD
  - Validated LQCD provides f_B, f_{Bs} - important for V_{ts}, V_{td}

- Semileptonic Decays + validated LQCD
  - Provide V_{cs}, V_{cd}, test CKM unitarity
  - Decay rates, q^2 dependence - stringent tests of LQCD
  - Improved V_{ub} - only with validated LQCD q^2 dependence calculation

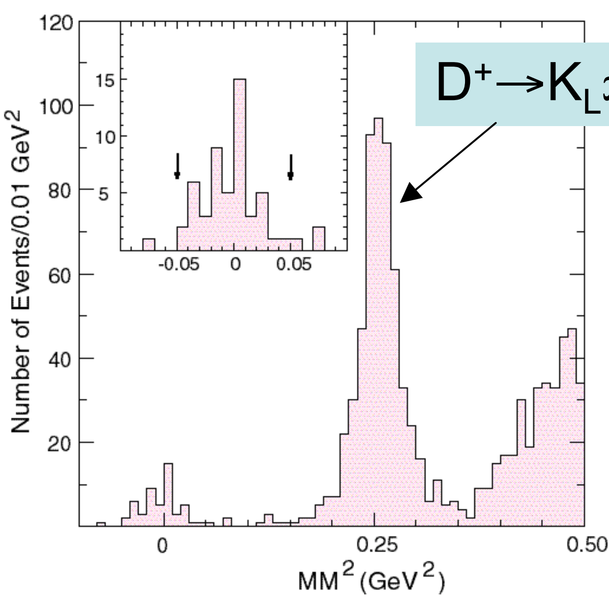
Leptonic Decays at CLEO-c

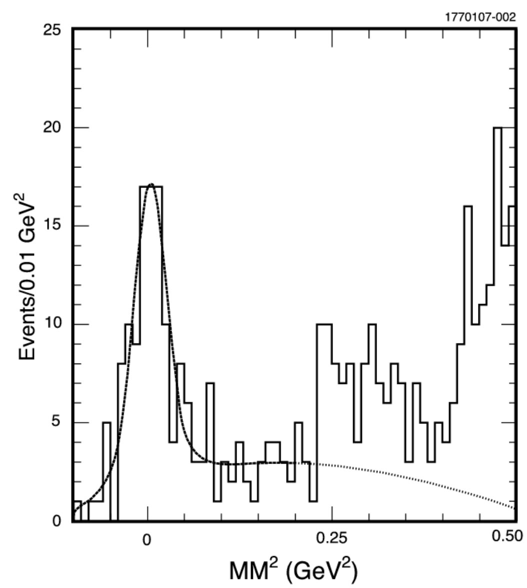


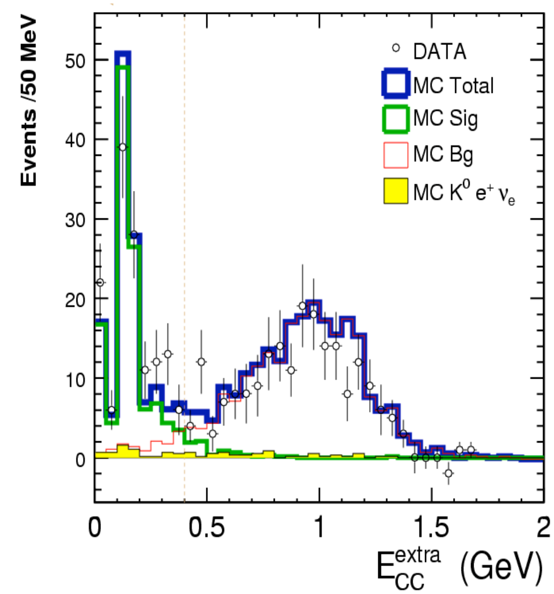
First and only measurement
$D^+ \to \mu^+ \nu$

Most Precise
$D_s^+ \to \mu^+ \nu$

Most Precise
$D_s^+ \to \tau^+ \nu,\ \tau^+ \to e^+ \nu$







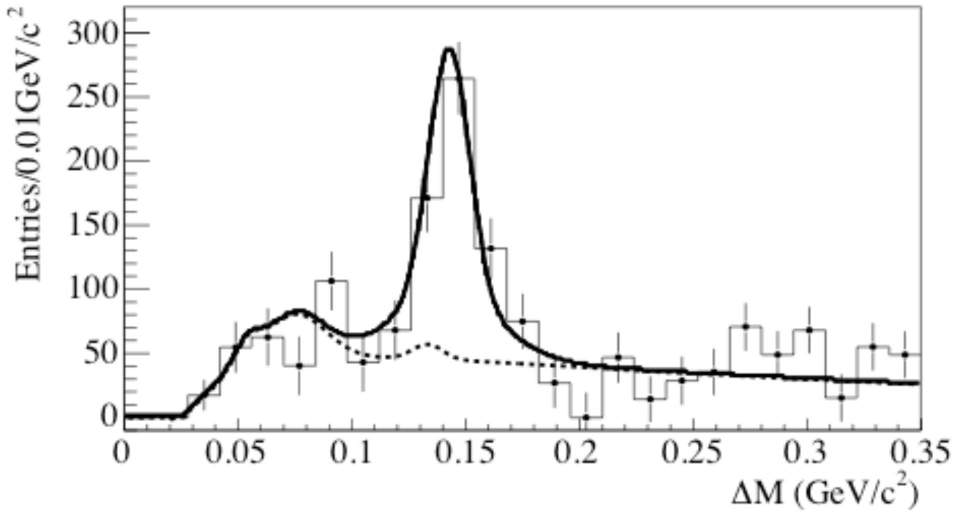
$f_{D^+} = (222.6 \pm 16.7^{+2.3}_{-3.4})$ MeV

$f_{D_s} = (274 \pm 10 \pm 5)$ MeV

BABAR & Belle $D_s \to \phi\pi$

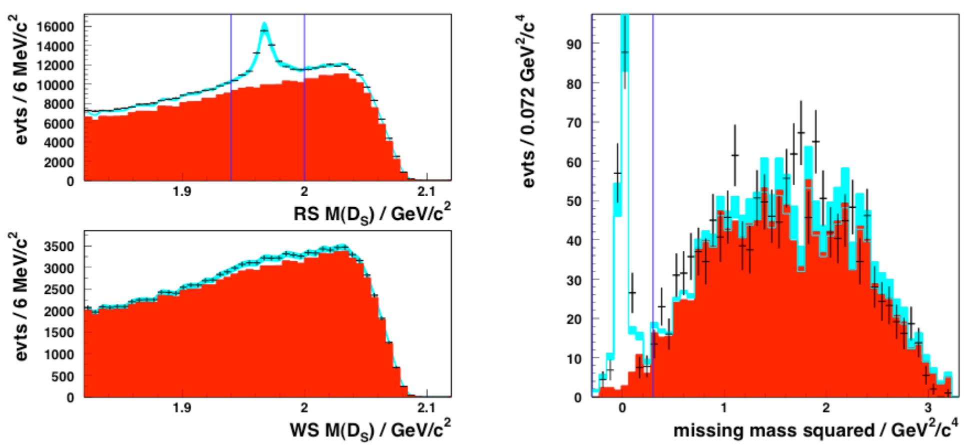
BaBar (230 fb^{-1})

- Select $e^+e^- \to cc$ events with high p D^0,D^+, D_s, D^{*+} close to B kinematic end-point
- Search for $D_s^* \to \gamma$ Ds $\to \gamma\mu\nu$ in the recoil
- $B(D_s \to \mu\nu)/B(D_s \to \phi\pi)$=0.143±0.018
- Use B(Ds $\to \phi\pi$) = (4.71±0.46)%
  BABAR PRD71 (2005) 091104, PRD74:031103,2006.
- $B(D_s \to \mu\nu)$ = (6.74±0.83±0.26±0.66)x10^{-3}
  f_{Ds} = (281 ± 17 ± 6 ± 14) MeV

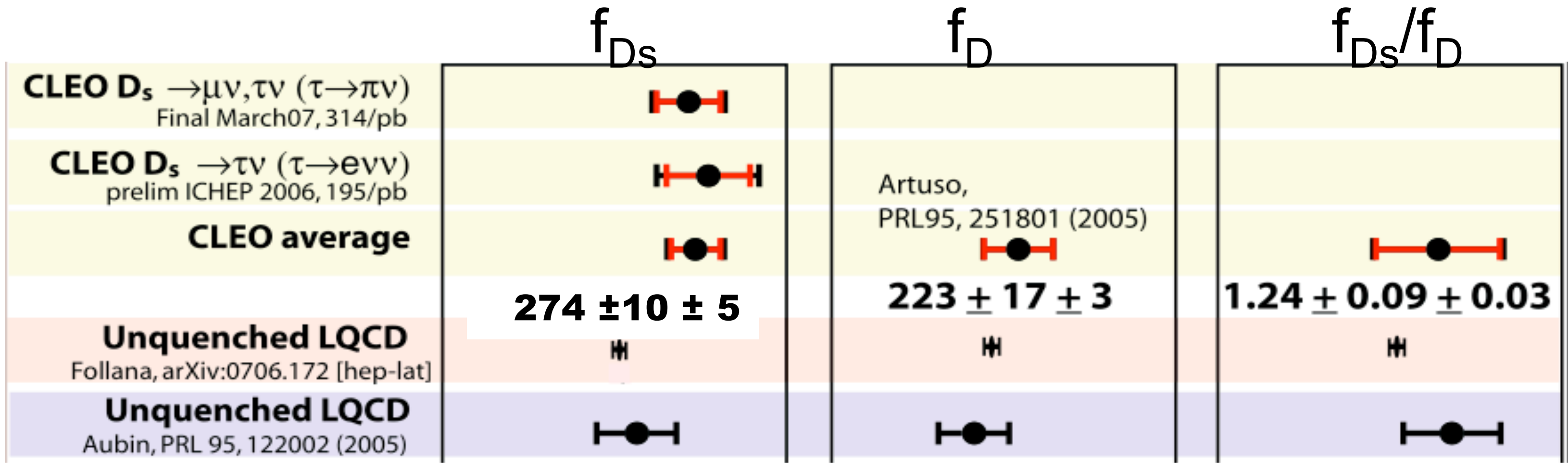


Belle (548 fb^{-1})

- D_s momentum determined by full reconstruction of the recoil system $e+e- \to D^*_sDKX$, $D^*_s \to D_s\gamma$ where X=additional π,γ from fragmentation
- $B(D_s \to \mu\nu)$ = (6.44 ±0 .76 ± 0.52)x10^{-3}
  f_{Ds} = (275 ± 17 ±12) MeV



Charm Leptonic Results Confront LQCD



- Also BaBaR f_{Ds}=283±17±7±14 MeV (relative to Ds→$\phi\pi$)

  Belle f_{Ds}=275±16±12 MeV (absolute)
- Recent LQCD - Follana et al.
  - f_{Ds} = 241±3 MeV
- Experimental average (CLEO-c + Belle)
  - f_{Ds} = 274±10 MeV

3.2 sigma discrepancy between data and LQCD!
Expect factor of two more CLEO-c data

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
- Need threshold data for f_D.
- For f_{Ds} : 0.5 fb^{-1} @4 GeV ≈ 2 ab^{-1} @10 GeV

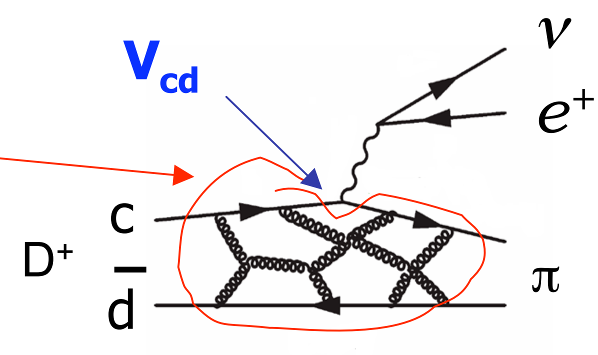
Exp't	3.77 GeV	4.17 GeV	$\sigma(f_{Ds}/f_D)$
CLEO-c	281 pb^{-1}	314 pb^{-1}	8%
CLEO-c	800 pb^{-1}	630 pb^{-1}	5%
BESIII	20 fb^{-1}	12 fb-1	<2%
SuperB	~150 fb^{-1}	~200 fb^{-1}	<1%

Semi-leptonic charm Decays, form factors, CKM elements, and tests of LQCD

Similar for D_s, B, B_s, …

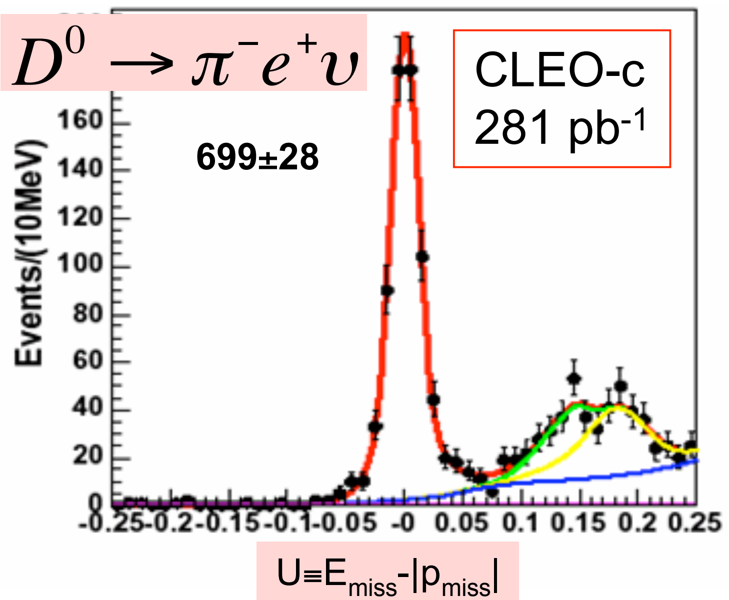
Form factor $f_+(q^2)$

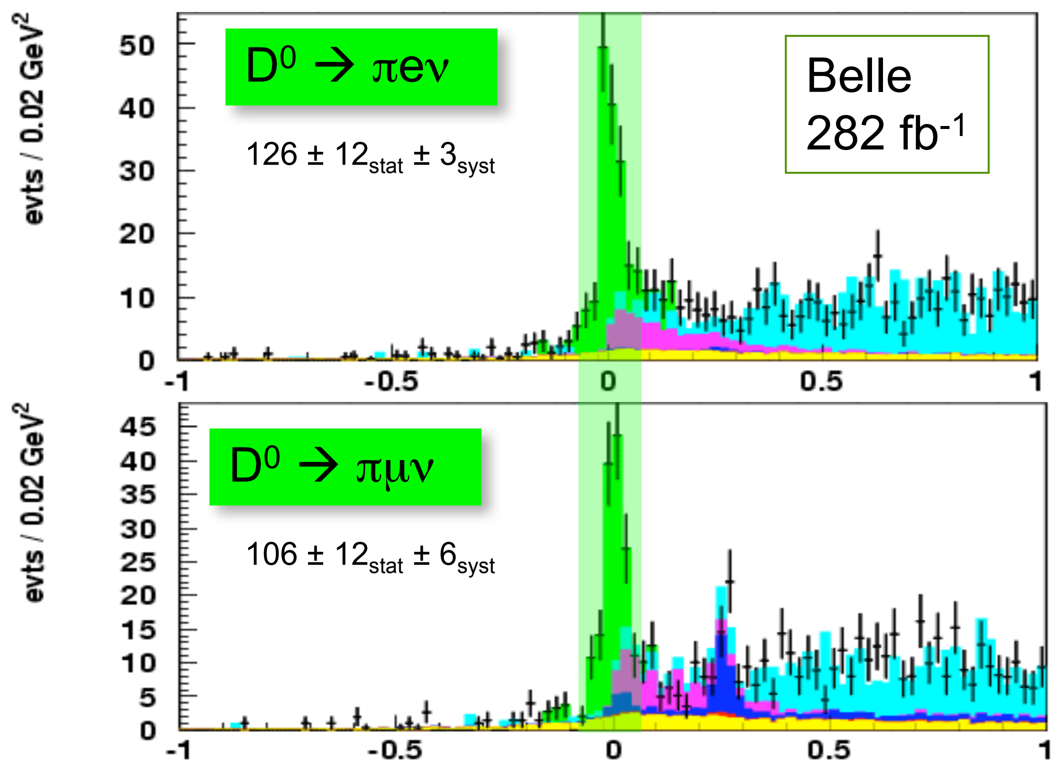
$$\frac{d\Gamma(B \to X\ell\nu)}{dq^2} = \frac{G_F^2 |V_{ub}|^2 P_P^3}{24\pi^3} |f_+(q^2)|^2$$



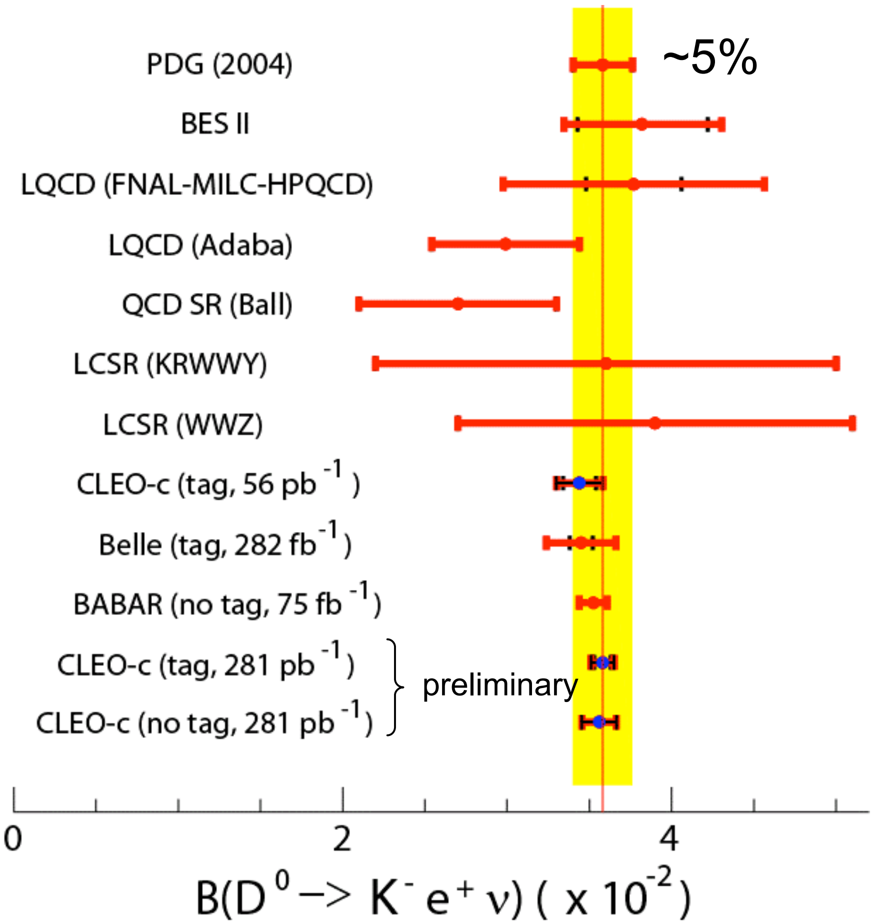
Challenge: understand QCD portion in a "simple" weak process

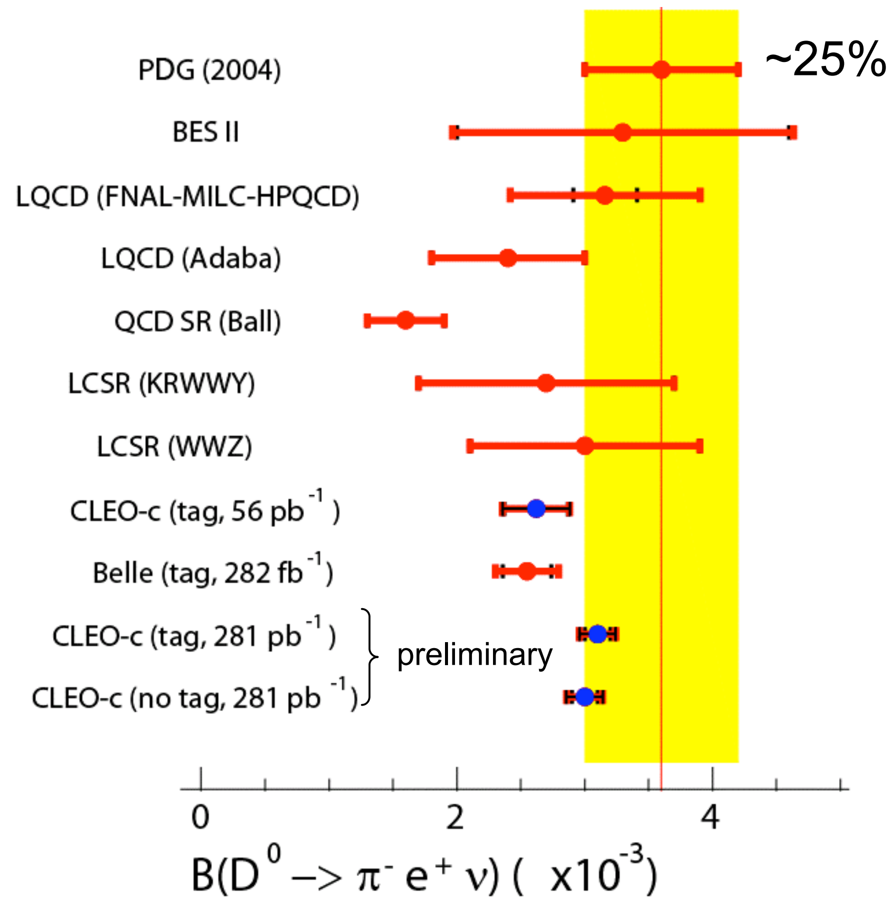
"Form factor" $f_+(q^2)$, encapsulates the long-distance QCD effects as a function of momentum transfer (q^2). Effectively, gives probability for the formation of the final state hadron





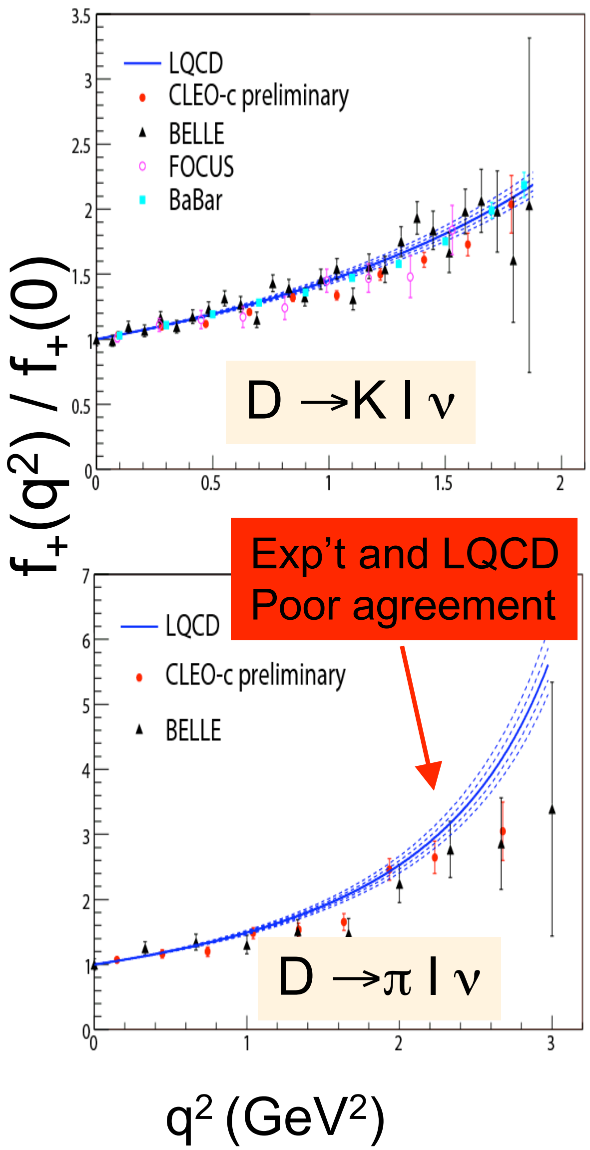
D→π,Kℓν branching fractions



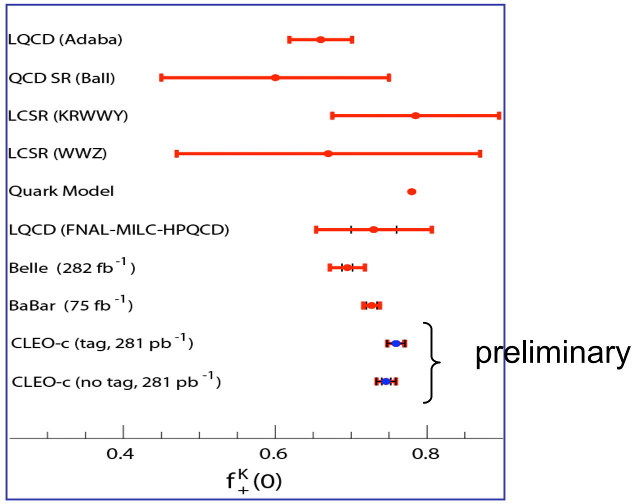


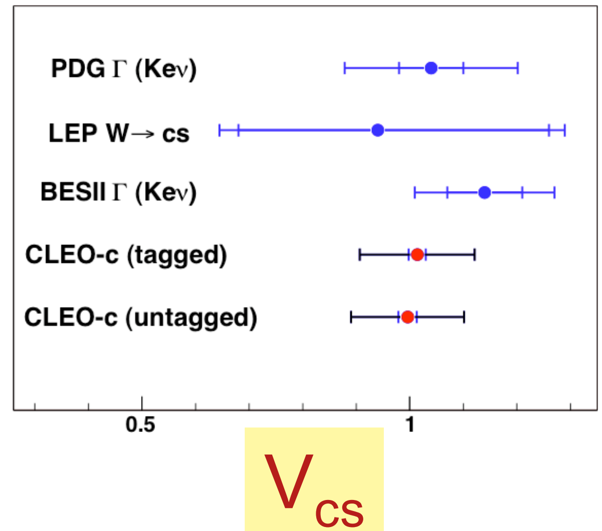
CLEO-c Semileptonic Results Confront LQCD

Recall BR is $\propto |V_{cq}|^2 \times |f_+^{\pi,K}(0)|^2$, use Becher-Hill parameterization & FNAL/MILC/HPQCD for $f_+(0)$

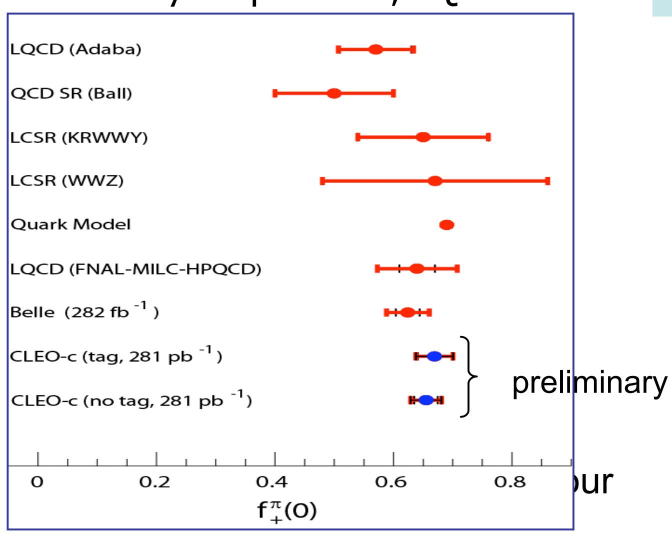


Uncertainty: Expt ~ 2%, LQCD ~ 10%

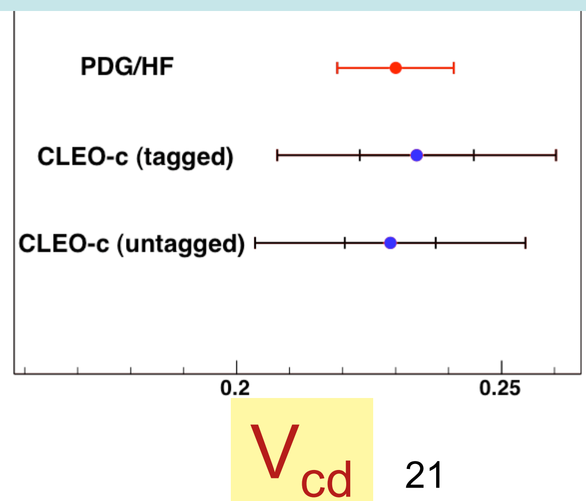




Uncertainty: Expt ~ 4%, LQCD ~ 10%



LQCD Dominant uncertainty



Charm Impact on Other Measurements

- Reducing systematic error on phase of V_{ub}
  - D (anti-D)$\rightarrow$multibody relative strong phase
- Interpretation of charm mixing
  - D (anti-D)$\rightarrow K\pi$ relative strong phase
- Determination $\sin 2\beta$ from $b \rightarrow s$ penguins
  - Measurement of $\pi\pi$, $K\pi$,KK s,p,d waves in $\chi_{c0,1,2} \rightarrow$ multibody
- f_B, f_{Bs}, V_{td}, V_{ts}
  - See previous slides
- Form Factors, V_{ub}
  - See previous slides

Quantum Correlations at Threshold

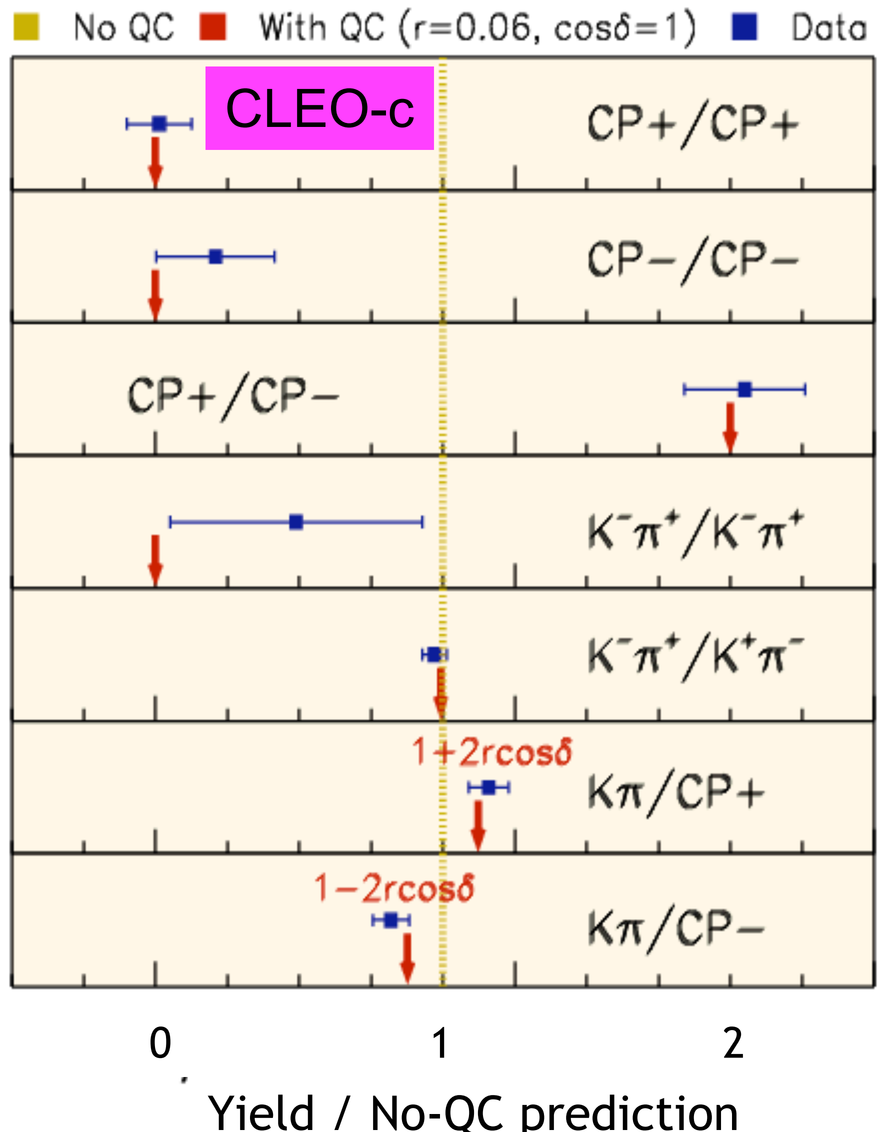
Enable strong phase measurements

- 50% smaller err. on D mixing amplitude
- sys. err. 10° → 3° on phase of V_{ub}

Initial State C = –1

$$e^+e^- \to \gamma^* \xrightarrow{\psi(3770)} D^0\bar{D}^0$$

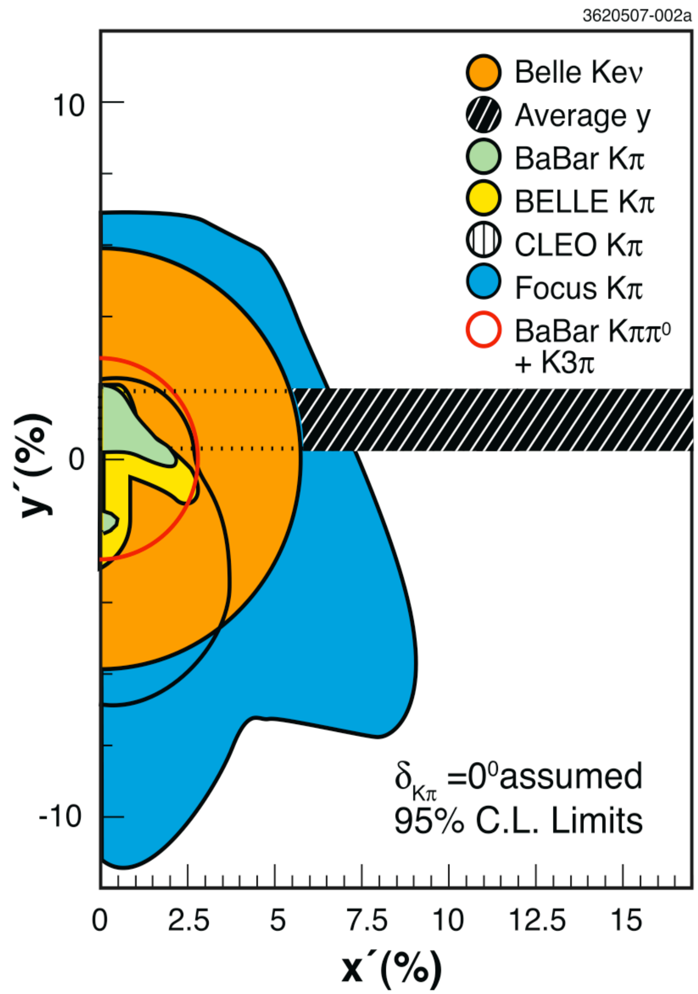
Forbidden by CP conservation	*CP+*	*CP+*
	CP–	*CP–*
Maximal enhancement	*CP+*	*CP–*
Forbidden if no mixing	$K^-\pi^+$	$K^-\pi^+$
Interference of CF with DCS	$K^-\pi^+$	$CP\pm$
	$CP\pm$	$K^-\pi^+$
Unaffected	*X*	$K^+l^-\nu$



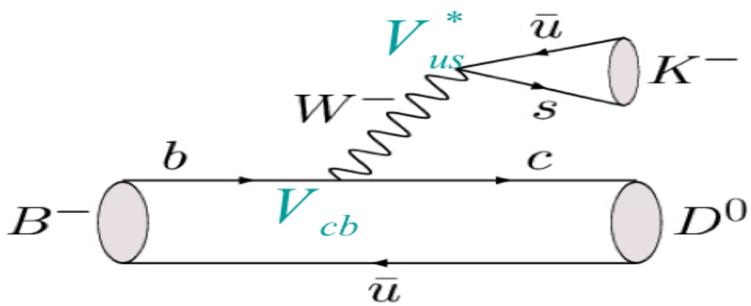
Strong Phases & Charm Mixing

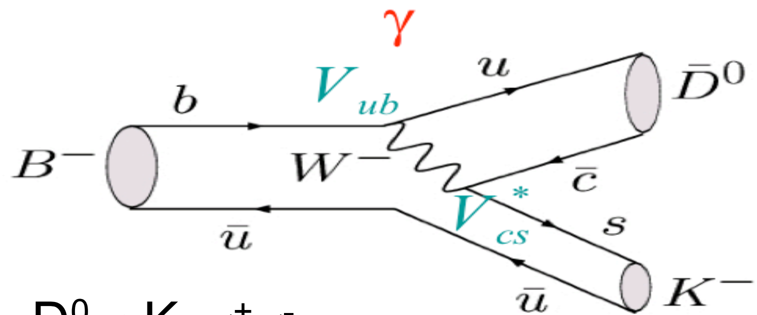
- Following method D. Asner & W. Sun Phys. Rev. D **73**, 034024 (2006)
- Charm mixing results from B-factories
  - $y \sim \Delta\Gamma$ from $\Gamma(D^0 \to K^+K^-, \pi^+\pi^-)$
  - $y' = y\cos\delta - x\sin\delta$ from $D^0 \to K^+\pi^-$
- Quantum correlations - Sensitive to $\cos\delta$
  - asymmetry in CP vs $K\pi$
  - Difference in e^+ and $K^-\pi^+$ tagged Dalitz plots ($K_S\pi^+\pi^-$)
- CLEO (preliminary) result improves World Average on y by factor of 1.5

$\cos\delta = 1.03 \pm 0.19 \pm 0.08$



Charm Impact CKM Angle γ





$B^- \to D^{0(*)}_{CP} K^{(*)-}$, $D^0 \to K_S \pi^+ \pi^-$

- CKM angle γ determined from asymmetry in $B^- \to DK^-$ decays
- Amplitude ratio and $D \to$ multibody phase difference required
  - Can be included in B-factory fit at expense of large statistical errors OR D model is assumed but then dominates systematic uncertainty
- CLEO uses correlations to directly measure phase difference
- CLEO-c will reduce systematic uncertainty on γ from 10° to 3°
  - BESIII (20 fb-1) will improve to ~1°
  - Expected statistical uncertainty B-factories ~6° (2 ab^{-1}) LHCb 3-5° (10 fb^{-1})

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

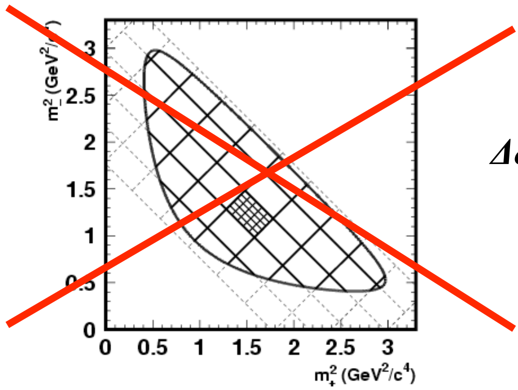
- Problem for extracting γ is due to model dependent phase difference between $f(m_+^2, m_-^2)$ and $f(m_-^2, m_+^2)$
  - $m_\pm = M(K_S\pi^\pm)$

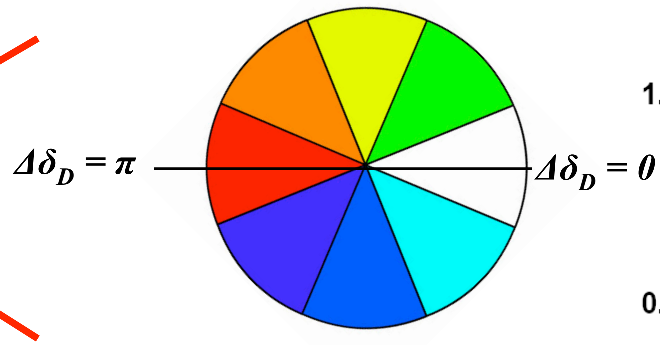
4 GeV data can help

Binned Analysis

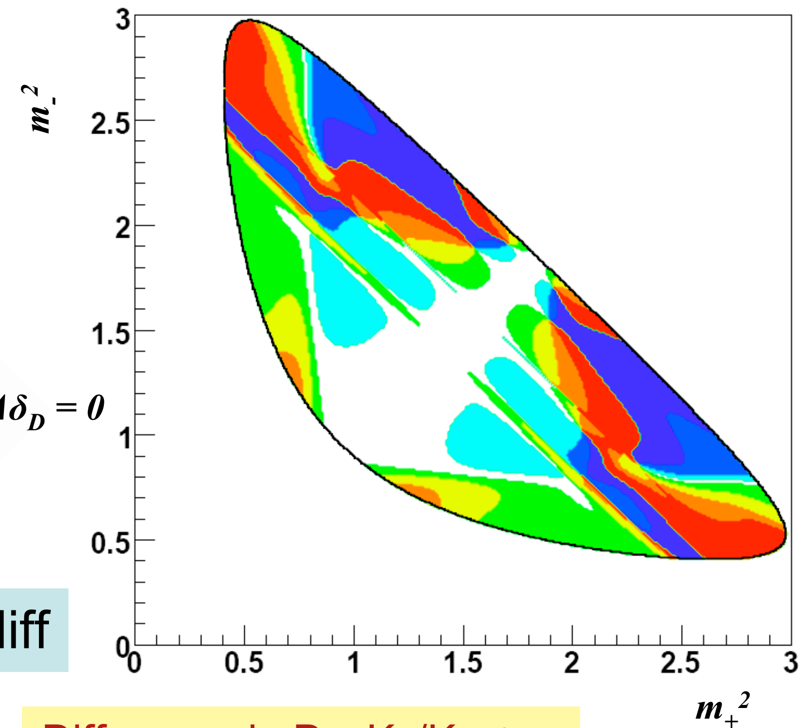
Bondar, Poluektov hep-ph/0703267v1 (2007)

Belle Collaboration, A. Poluektov *et al*. Phys. Rev. **D73**, 112009 (2006)

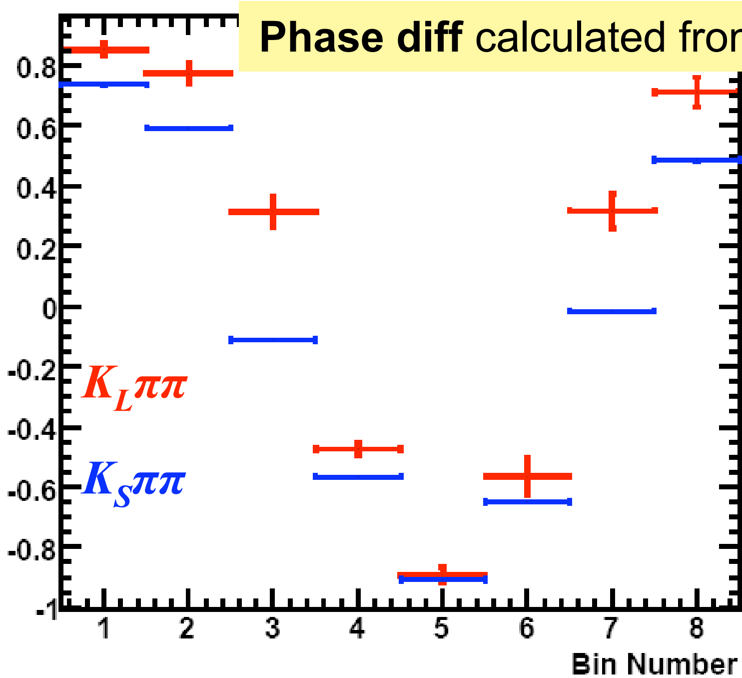




8 bins of Phase diff

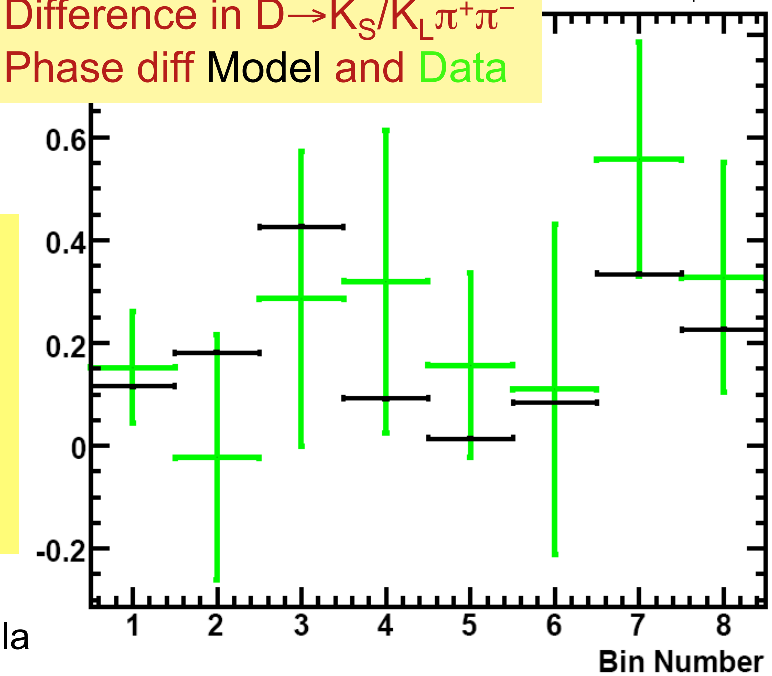


Phase diff calculated from model



Bin by bin phase diff to be used in B-factory fits for γ/ϕ_3

Difference in $D\rightarrow K_S/K_L\pi^+\pi^-$ Phase diff Model and Data



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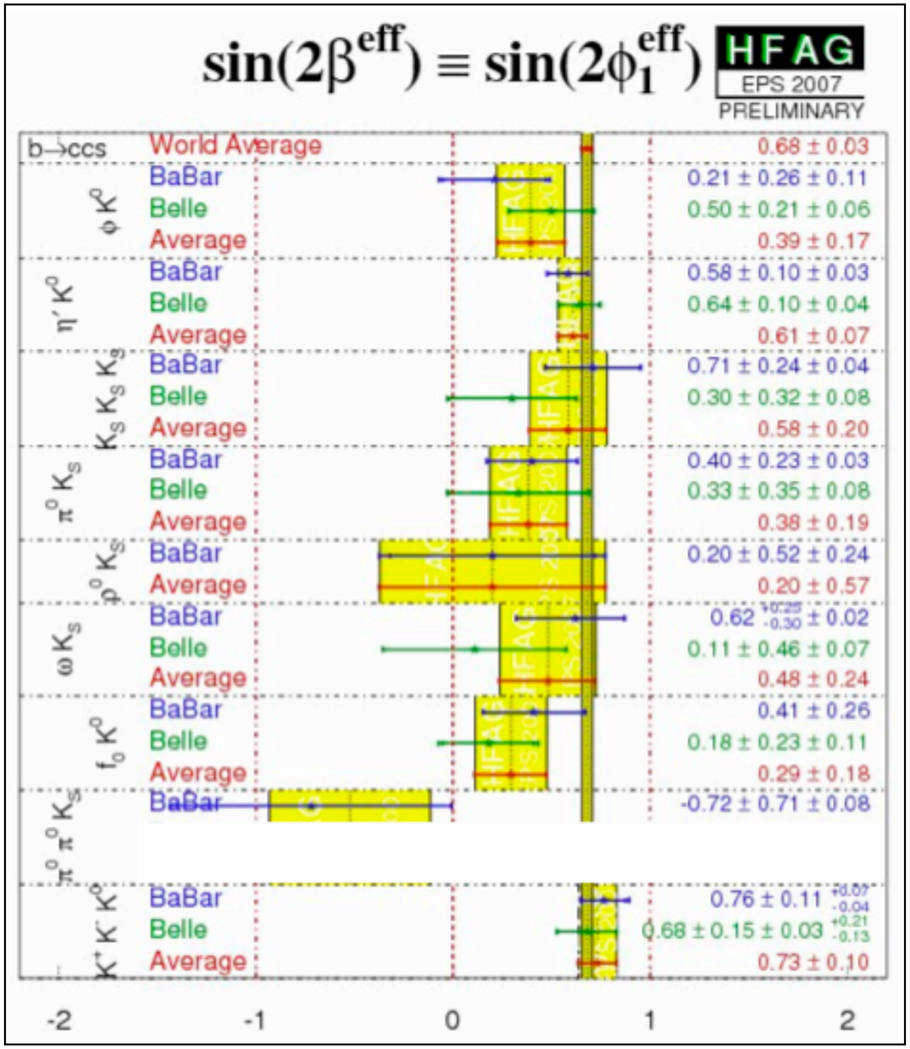
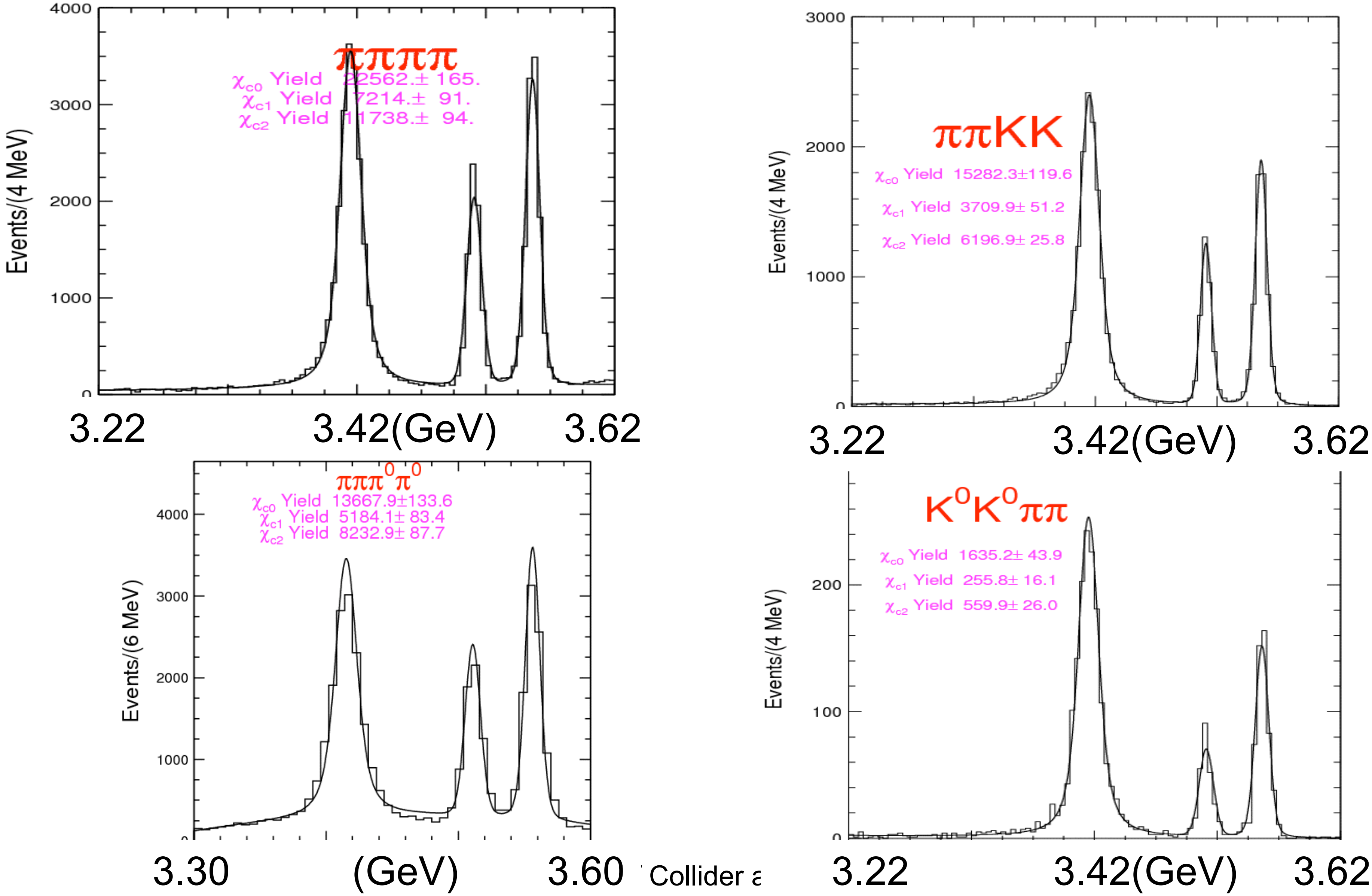
Charm and sin(2β^{eff})

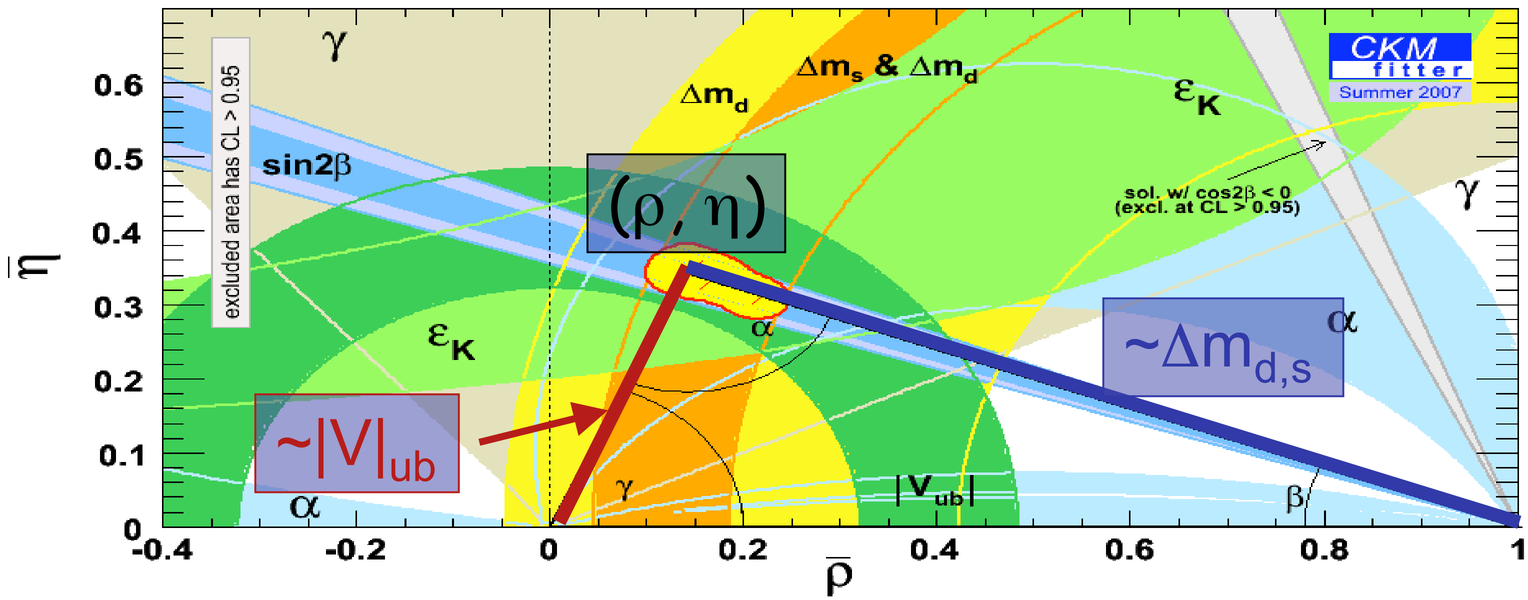


- Time dependent Dalitz plots analysis required to measure sin(2β^{eff})
  - $B(t) \to K_S K^+ K^-$, $K_S \pi^+ \pi^-$
  - $B(t) \to K_S K_S K_S$, $K_S \pi^0 \pi^0$
- D meson too light so use $\chi_{c0,1,2}$ from $\psi(2S) \to \gamma \chi_{c\ 0,1,2}$
  - study $\pi\pi$, $K\pi$, KK s,p,d-wave
- Apply to B Dalitz plots

CLEO-c $\chi_{c0,1,2}$ Data: BESIII 20x more



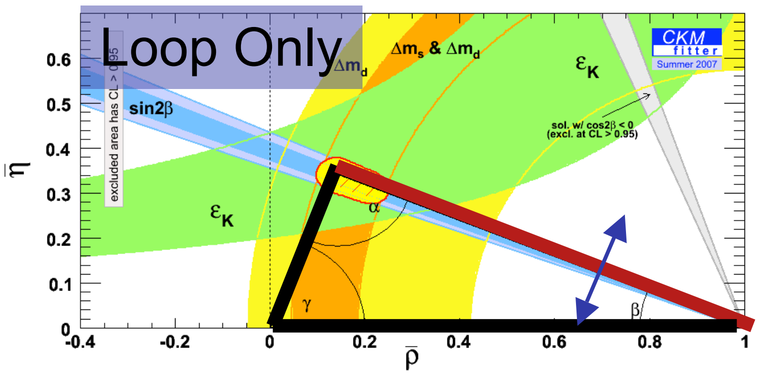
Over Constraining CKM Matrix

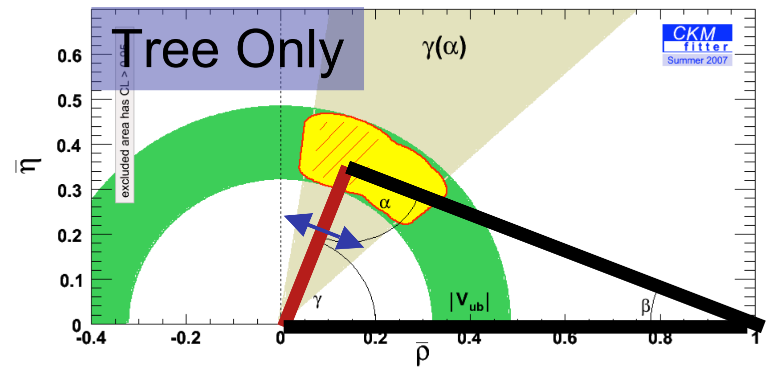


- Determination of Standard Model CP violation limited by theoretical uncertainties
- Precision charm measurements continue to hone theoretical techniques (ex. LQCD) enabling improved determination of apex (ρ, η)

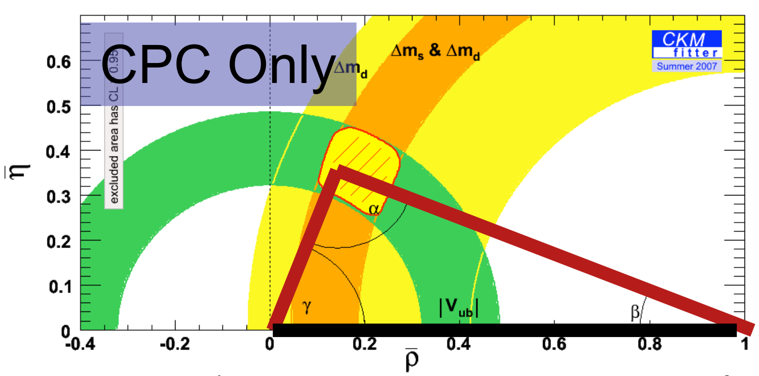
Search for New Physics

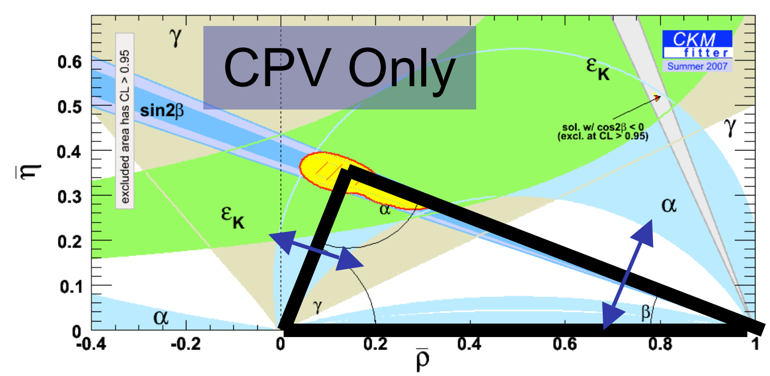
through inconsistent detemination of Standard Model CP Violation - (ρ,η) apex





CLEO-c measurements impact determination of sides and angles





of Collider and

Summary

- Three roles of charm
  1) Search for New Physics
     - Rare Decays
     - CP Violation in Mixing, Decay
  2) Precision Tests of QCD Calculations
     - (Semi-)Leptonic
     - Charmonia
  3) Inputs to other measurements
     - Strong phases for D mixing and V_{ub} phase
     - Multi-body charmonium decay for $\sin 2\beta^{eff}$
     - Decay constants + LQCD for f_B, f_{Bs}, V_{td}, V_{ts}
     - Form factors + LQCD for V_{ub}

Experiments

- e+e- @ 4 GeV
  - CLEO-c →BESIII →SuperB
    1.4 fb^{-1} →32 fb^{-1}→~350 fb^{-1}
    - Best for most results
- e+e- @ 10 GeV
  - B-factories→SuperBelle→ SuperB
    $L=10^{34}$ → $L=10^{35}$ → $L=10^{36}$
    - Best for CPV in Mixing and Decay
    - Tests of QCD possible
    - Rare decays if bkgd controlled
- Hadronic
  - Fixed Target → CDF/D0 → LHCb
    - Competitive on Mixing
    - Rare decays if bkgd controlled
    - Semileptonic form factors?
    - Difficult to extrapolate from existing studies/results