The Decay of Open Charm - or - D-physics – a (very) Selective Review

Topics

- Rare Charm Processes as probes of New Physics
- Charm Impact on Precision CKM

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Canada's Capital University

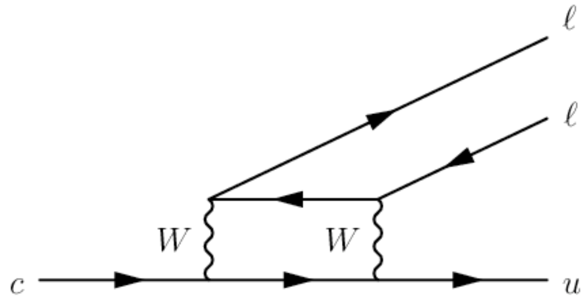
Rare Charm Processes

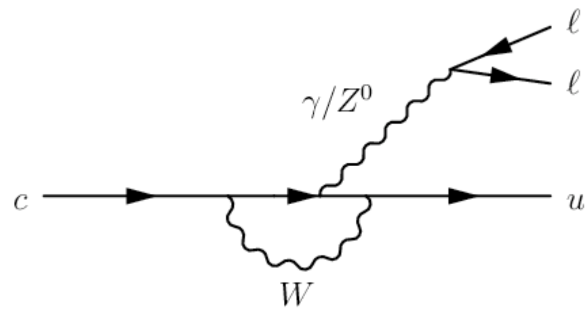
-Charm provides constraints on beyond SM physics that is distinct from B and K sectors

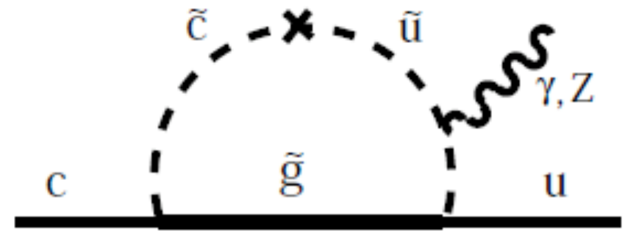
-Only now are experiments reaching "interesting" sensitivity

- Rare Decays = Search for New Physics
- Charm Mixing $\rightarrow$ Constraints on New Physics
- CP Violation = Search for New Physics
  - In mixing
  - In decay

Search for New Physics (NP) in Charm Sector







Very low SM rates (BF($c \to ull$)~10^{-8}) for loop processes provide unique window to observe NP in rare charm processes

- Rare Decays, D^0-D^0 oscillations & CP Violation
- NP can introduce new particles into loop

New particles appearing on-shell at LHC must appear in virtual loops & affect amplitudes in K, B and Charm

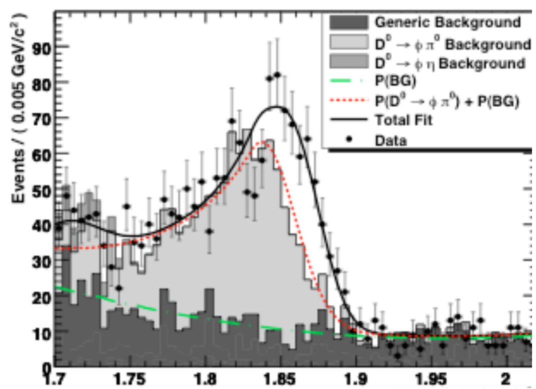
- Particles and couplings in rare charm processes are NOT the same as in rare B and K processes

Rare Charm Decay Rates Modified by NP

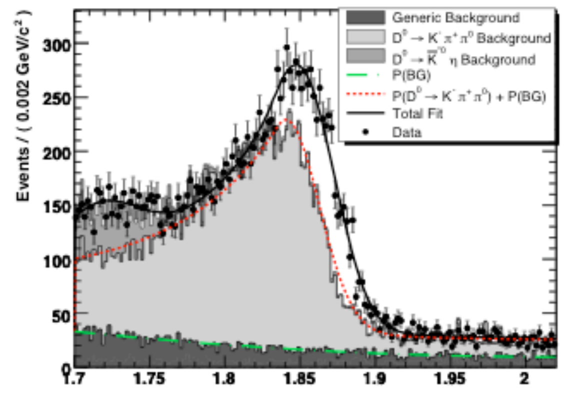
- Radiative - $D \to (\gamma,\phi,K^*)\gamma$ SM 10^{-4} - 10^{-6}
  - CLEO $D \to \gamma\gamma$ < 2.6×10^{-5} @90% C.L.
  - BABAR $D \to \phi\gamma$ $(2.73 \pm 0.30 \pm 0.36) \times 10^{-5}$ (new)
  - BABAR $D \to K^*\gamma$ $(3.22 \pm 0.20 \pm 0.27) \times 10^{-4}$ (new)
- Leptonic $D \to \mu\mu$ SM<10^{-13} RPV SUSY~10^{-7}
  - CDF < 4.3×10^{-7} @90% C.L. (new)
- GIM Suppressed $D \to \pi ll$ SM~10^{-6}
  - Distinguish NP from SM with dilepton invariant mass, FB asymmetries
    - D0 $D \to \pi\mu\mu$ < 3.9×10^{-6}
    - CLEO-c $D \to \pi ee$ < 4.7×10^{-6}
- Lepton Flavor Violation - BABAR @90% C.L.
  - $D \to e^+\mu^-$ < 8.1×10^{-7} $D^+ \to K^+ e^- \mu^+$ < 3.7×10^{-6}
  - $D_s^+ \to K^+ e^- \mu^+$ < 3.6×10^{-6} $\Lambda_c^+ \to p e^- \mu^+$ < 7.5×10^{-6}
- Lepton Number Violation $D^+ \to \pi^- e^+ e^+$
  - CLEO-c < 3.6×10^{-6} @90% C.L

Rare Charm Decays: New Results

NEW at ICHEP08



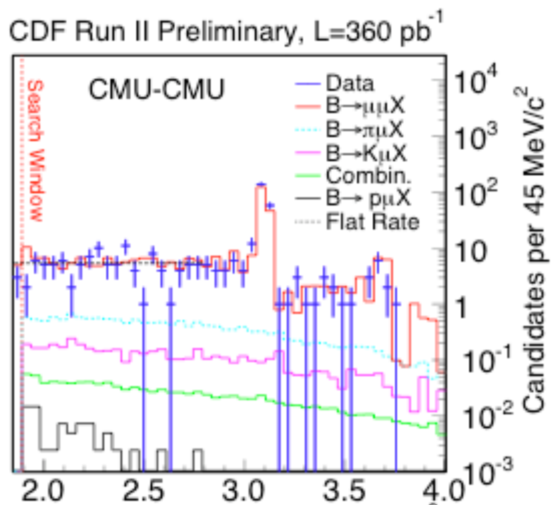
M(KKγ)



M(Kπγ)

First observation of
$D \to K^*\gamma$
$(3.22 \pm 0.20 \pm 0.27) \times 10^{-4}$
Long Distance
Interactions not NP

CDF Public Note 9226



M(μμ)

$D \to \mu\mu < 4.3 \times 10^{-7}$

R-parity coupling violating constraint
$\lambda_{21k}\lambda_{22k} = 1.5\sqrt{B(D^0 \to \mu^+\mu^-)} < 9.8 \times 10^{-4}$

D^0-$\overline{D}^0$ Mixing

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

Two state system: $\left|D_{1,2}\right\rangle = p\left|D^0\right\rangle \pm q\left|\overline{D}^0\right\rangle$
Mass Eigenstates≠Flavor Eigenstates

D^0–$\overline{D}^0$ transitions observables

$$x = \frac{\Delta M}{\Gamma}, \quad y = \frac{\Delta \Gamma}{2\Gamma} \qquad R_M = \tfrac{1}{2}\left(x^2 + y^2\right)$$

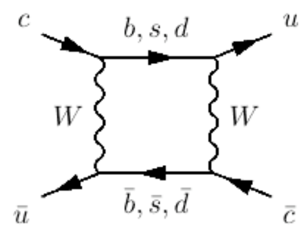
$$x' = x\cos\delta_{K\pi} + y\sin\delta_{K\pi}$$
$$y' = y\cos\delta_{K\pi} - x\sin\delta_{K\pi} \qquad \left|\frac{q}{p}\right| \qquad Arg\left(\frac{q}{p}\right)$$

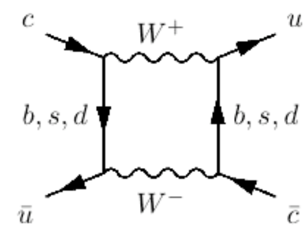
Boxes and loops in charm transitions involve down-type quarks – this gives charm system unique new physics sensitivity.

SM calculations based on box diagrams alone gives x~10^{-5}, y~10^{-7} [Falk et al. PRD 65 (2002) 054034]

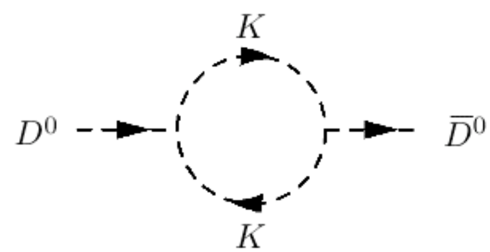
Long distance effects dominate x, y
Any CPV clear evidence for New Physics

Short-distance



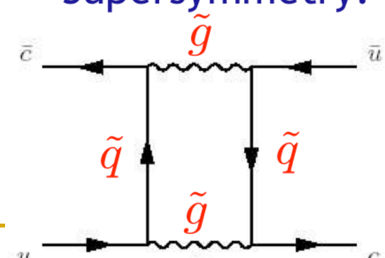


Long-distance

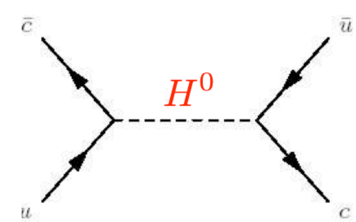


New-physics

Supersymmetry:



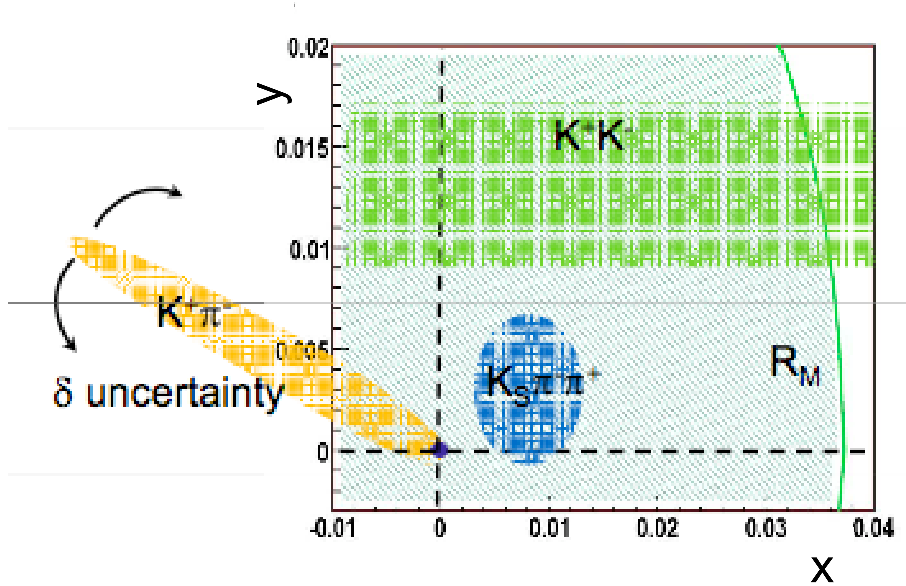
Extended Higgs:



D^0-$\overline{D}^0$ Mixing:

Numerous recent, exciting results on charm mixing

- 'Wrong sign' $K^{(*)}e\nu$ (R_M)
  - BELLE PRD 77 (2008) 112003
  - BaBar PRD 76 (2007) 014018
- 'Wrong sign' $K\pi$ (x'^2, y')
  - BELLE PRL 96 (2006) 151801
  - BaBar PRL 98 (2007) 211802
  - CDF PRL 100 (2008) 121802
- Eigenstate lifetime analyses: y_{CP}
  - BaBar arXiv:0712.2249
  - BELLE PRL 98 (2007) 211803
- $K_S\pi^+\pi^-$ Dalitz analyses: x,y
  - BELLE PRL 99 (2007) 131803
- Quantum Correlation: $\delta_{K\pi}$
  - CLEO-c PRL 100 (2008) 221801



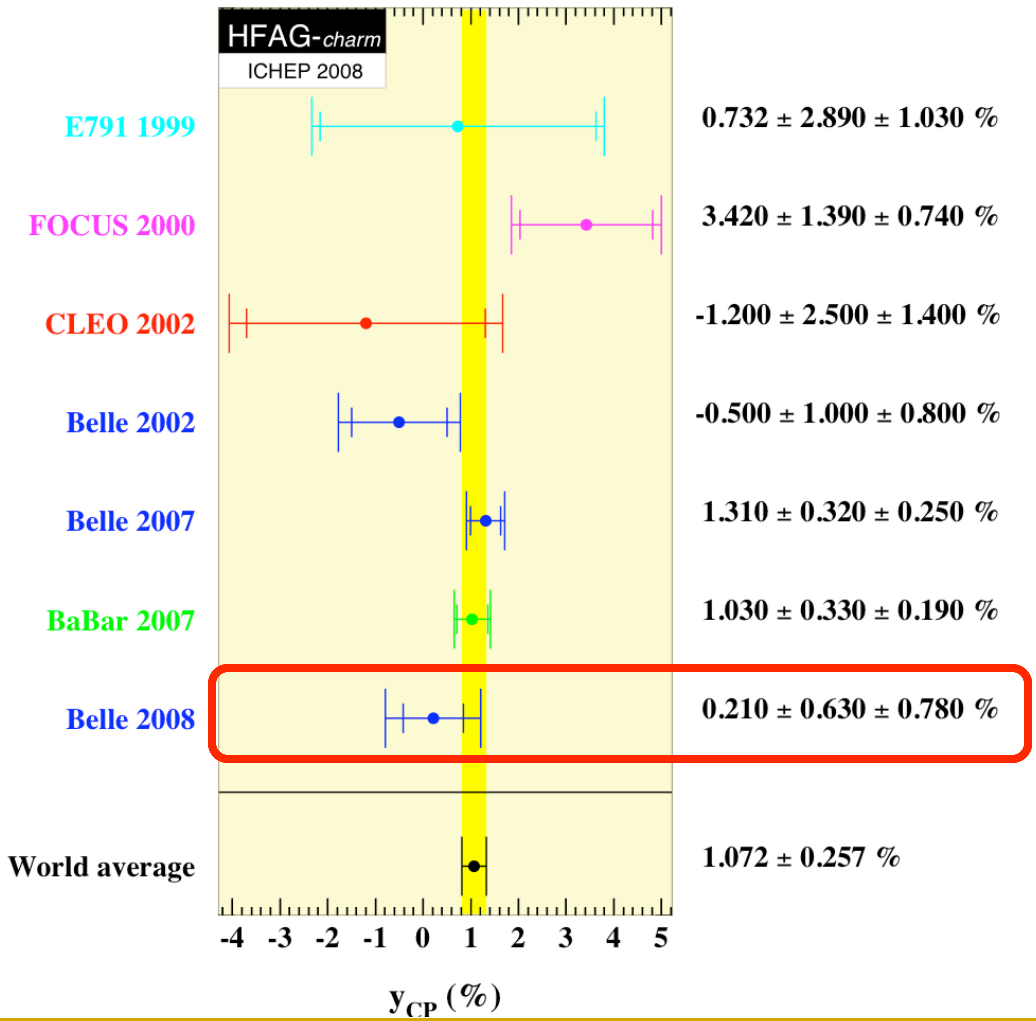
New ICHEP08

Belle: y_{CP} $D^0 \rightarrow K_S K^+ K^-$
(see talk by Brian Meadows)
BABAR: 'wrong-sign' $D^0 \rightarrow K^+\pi^-\pi^0$
arXiV:0807.4544

D^0-$\overline{D}^0$ Mixing:

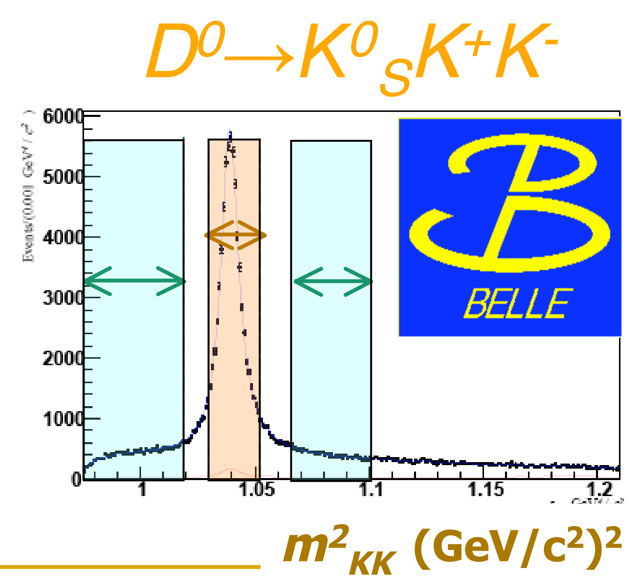
New HFAG Average for ICHEP08

http://www.slac.stanford.edu/xorg/hfag/charm/index.html



Previous measurements all from $D^0 \to KK, \pi\pi$ (CP+)

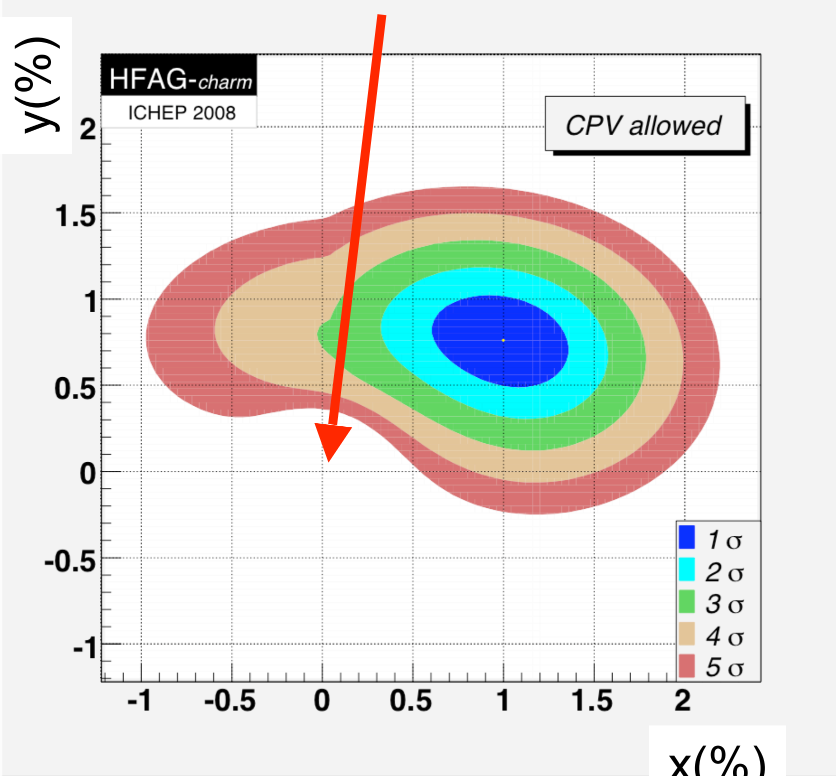
New Belle result uses Dalitz plot analysis of $D^0 \to K_S K^+ K^-$, dominated by $D^0 \to K_S \phi$ (CP-)



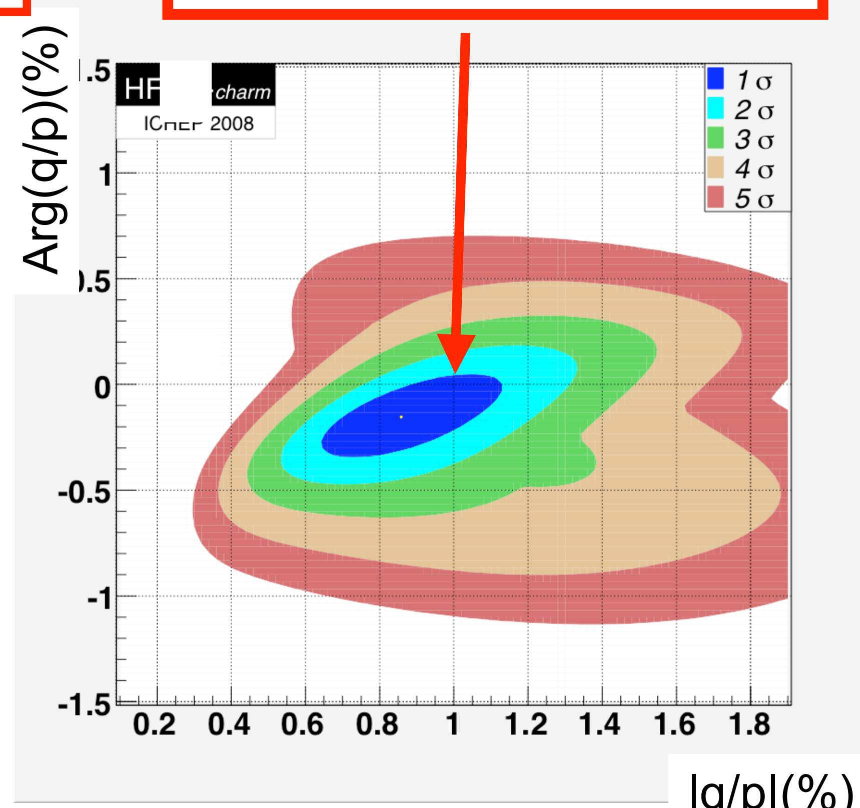
D^0-$\overline{D}^0$ Mixing:

New HFAG Average for ICHEP08
http://www.slac.stanford.edu/xorg/hfag/charm/index.html

No mixing (x,y) ≠ (0,0) excluded at 9.8σ



No evidence for CP violation



$x = 1.00\pm^{0.24}_{0.25}$ % 3.4σ

$y = 0.76\pm^{0.17}_{0.18}$ % 4.1σ

$|q/p| = 0.86\pm^{0.17}_{0.15}$

$\mathrm{Arg}(q/p) = (8.8\pm^{7.6}_{7.2})^{\circ}$

D^0-$\overline{D}^0$ Mixing Interpretation: Assume NP saturates x_D

	Model	Approximate Constraint
Extra Fermions	Fourth Generation	$\|V_{ub'}V_{cb'}\| \cdot m_{b'} < 0.5$ (GeV)
	$Q = -1/3$ Singlet Quark	$s_2 \cdot m_S < 0.27$ (GeV)
	$Q = +2/3$ Singlet Quark	$\|\lambda_{uc}\| < 2.4 \cdot 10^{-4}$
	Little Higgs	Tree: See entry for $Q = -1/3$ Singlet Quark Box: Parameter space can reach observed x_D
Extra Gauge Bosons	Generic Z'	$M_{Z'}/C > 2.2 \cdot 10^3$ TeV
	Family Symmetries	$m_1/f > 1.2 \cdot 10^3$ TeV (with $m_1/m_2 = 0.5$)
	Left-Right Symmetric	No constraint
	Alternate Left-Right Symmetric	$M_R > 1.2$ TeV ($m_{D_1} = 0.5$ TeV) $(\Delta m/m_{D_1})/M_R > 0.4$ TeV^{-1}
	Vector Leptoquark Bosons	$M_{VLQ} > 55(\lambda_{PP}/0.1)$ TeV
Extra Scalars	Flavor Conserving Two-Higgs-Doublet	No constraint
	Flavor Changing Neutral Higgs	$m_H/C > 2.4 \cdot 10^3$ TeV
	FC Neutral Higgs (Cheng-Sher)	$m_H/\|\Delta_{uc}\| > 600$ GeV
	Scalar Leptoquark Bosons	See entry for RPV SUSY
	Higgsless	$M > 100$ TeV
Extra Dimensions	Universal Extra Dimensions	No constraint
	Split Fermion	$M/\|\Delta y\| > (6 \cdot 10^2$ GeV)
	Warped Geometries	$M_1 > 3.5$ TeV
Extra Symmetry	MSSM	$\|(\delta_{12}^u)_{\text{LR,RL}}\| < 3.5 \cdot 10^{-2}$ for $\tilde{m} \sim 1$ TeV $\|(\delta_{12}^u)_{\text{LL,RR}}\| < .25$ for $\tilde{m} \sim 1$ TeV
	SUSY Alignment	$\tilde{m} > 2$ TeV
	Supersymmetry with RPV	$\lambda'_{12k}\lambda'_{11k}/m_{\tilde{d}_{R,k}} < 1.8 \cdot 10^{-3}/100$ GeV
	Split Supersymmetry	No constraint

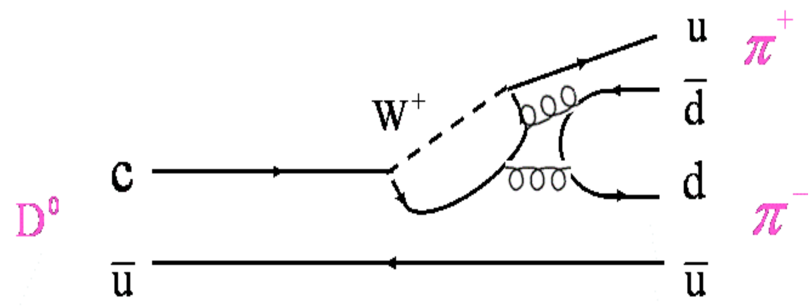
Golowich, Hewett, Pakvasa and Petrov, PRL 98 (2007) 181801

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 $A_S=[+]_S-[-]_S \sim -3.3\text{x}10^{-3}$;$A_S = -A_L$
- Experimental limits currently % level

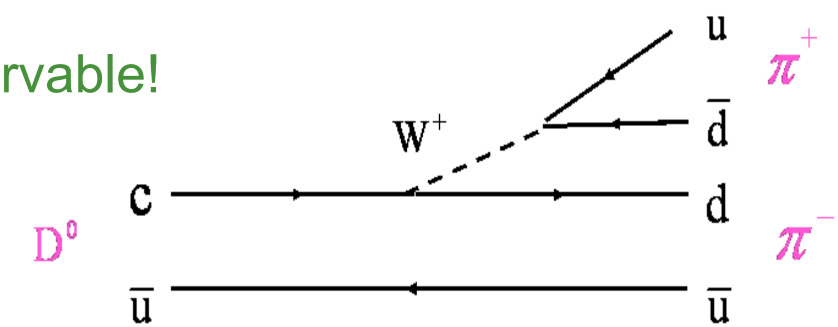
Singly Cabibbo Suppressed (SCS) decays



Interference between tree & penguin can generate direct CP asymmetries which:

- Could reach ~10^{-3} in SM - may be observable!

- In NP models effects of ~10^{-2} possible (Grossman, Kagan, Nir, PRD 75 (2007) 036008)



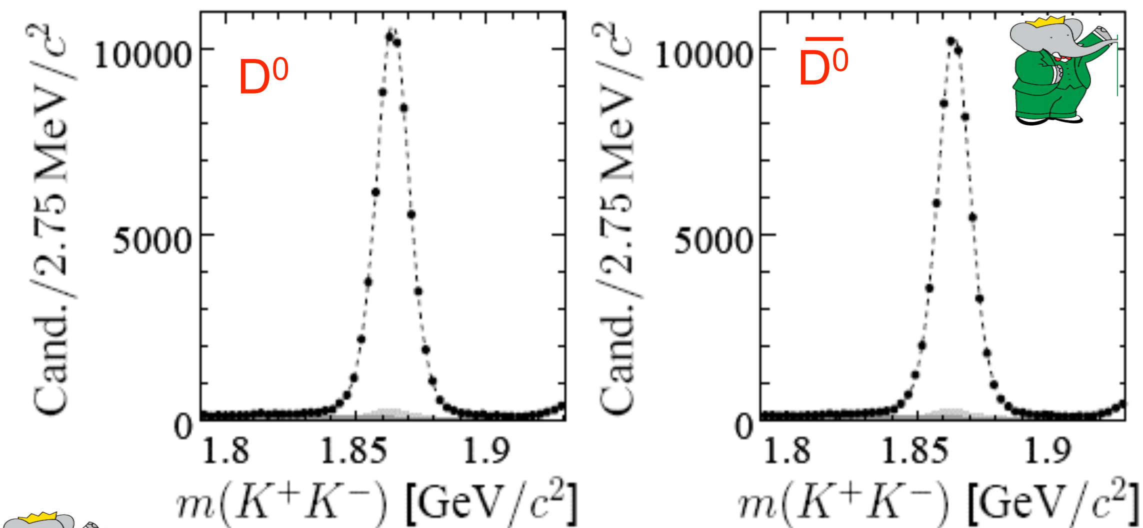
CPV searches in $D^0 \to KK, \pi\pi$

Measure asymmetry in time integrated rates:

$$A_{CP} = \frac{\Gamma(D^0 \to KK(\pi\pi)) - \Gamma(\overline{D}^0 \to KK(\pi\pi))}{\Gamma(D^0 \to KK(\pi\pi)) + \Gamma(\overline{D}^0 \to KK(\pi\pi))}$$

Distinguish D flavor from ‘slow pion’ charge in $D^* \to D^0\pi$

BaBar, PRD 100 (2008) 061803   386 fb^{-1} , ~130k KK events



Improved systematic uncertainty

Use $K\pi$ events to calibrate out asymmetries in slow π reconstruction.

Form CP asymmetry in bins of θ to account for EW (γ-Z) FB asymmetries.

BaBar $A(KK)_{CP}$ = [0.00 ± 0.34 (stat) ± 0.13 (syst)]%

Belle $A(KK)_{CP}$ = [-0.43 ± 0.30 (stat) ± 0.11 (syst)]% ArXiV:0807.0148 submitted to PLB

Entering interesting territory !

CPV Searches in Multibody (n≥3) Decays

BaBar & Belle study of $D^0 \rightarrow K^+K^-\pi^0, \pi^+\pi^-\pi^0$

CLEO study of $D^+ \rightarrow K^+K^-\pi^+$

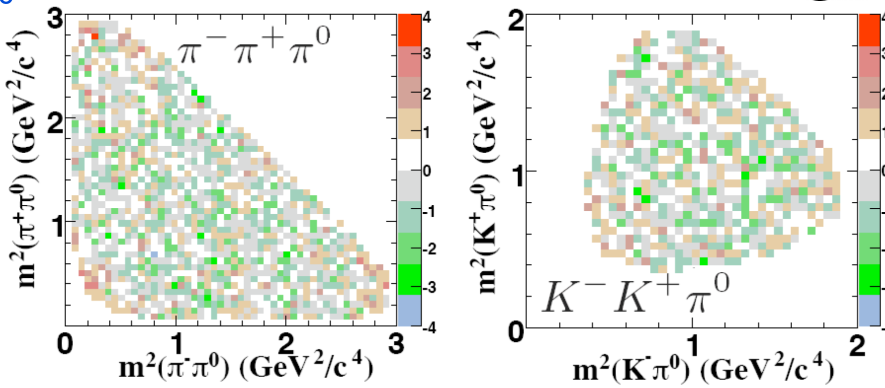
Several complementary analyses:

Increased Sensitivity

$\mathcal{O}(\%)$
- Look for phase space integrated asymmetry.
- Form residuals of D^0, D^0 w.r.t. mean in Dalitz space
- Look for difference in angular moments of D^0 & D^0 distributions
- Compare amplitude fits of D^0 & D^0 Dalitz plot (model dependent)

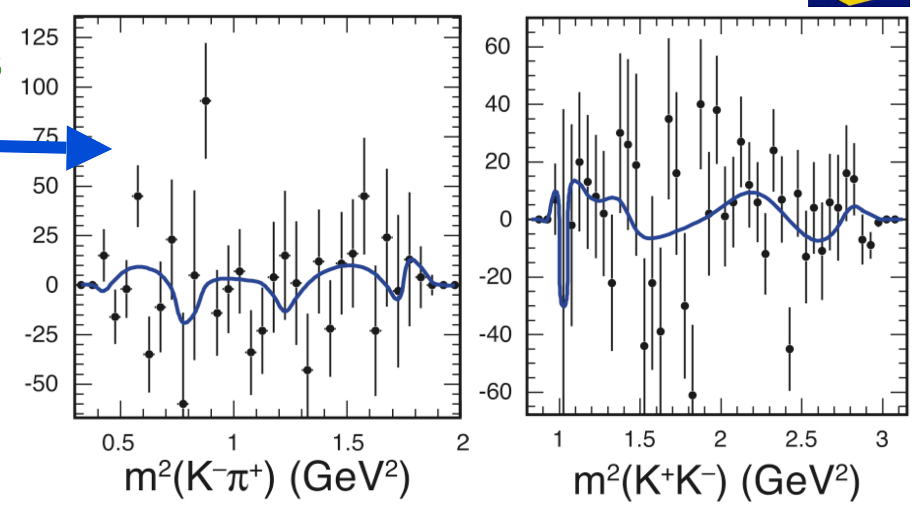
$\mathcal{O}(‰)$

BABAR 385 fb^{-1}, arXiv:0802.4035



Consistent with no CPV at 33% and 17%

CLEO 818 pb^{-1}, arXiv:0807.4545



Other examples:

FOCUS T-odd moments in $D \rightarrow KK\pi\pi$

PLB 622 (2005)

CLEO amplitude fits of D^0 & $\overline{D}^0$ $D \rightarrow K_S\pi\pi$

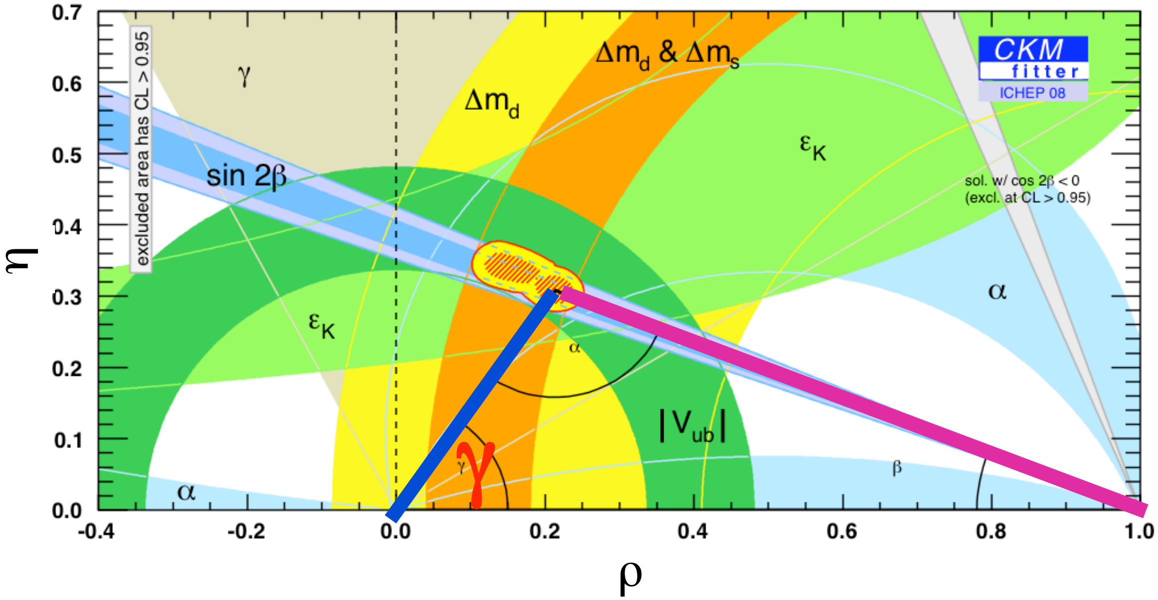
PRD 70:091101,2004

D decays and the CKM unitarity triangle

1) Charm impact on measurements of $\sin 2\beta$ with $b \rightarrow sg$
2) Charm impact on measurements of γ with $B \rightarrow DK$
3) Lattice QCD tests in Charm sector & the 'mixing side'
4) Lattice QCD tests in Charm sector & the 'V_{ub} side'

The Unitarity Triangle and D decays

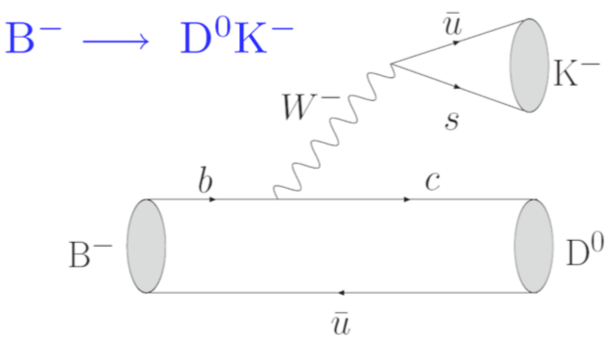
Classical unitarity triangle is constrained by quantities measured in B decays

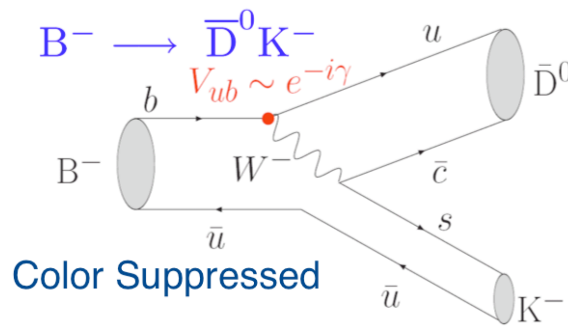


But *key* measurements have high dependence (direct & indirect) on D decays:

- Tree-level measurements of angle γ in $B \rightarrow DK$
  Uncertainties in D Decay will dominate uncertainty at LHCb
- 'Vub side' - LQCD errors dominate
  $D \rightarrow \pi$ form factors (normalization & q^2 dependence) test/develop LQCD
- 'Mixing' side - Depends on LQCD calculation of $(f_B \sqrt{B_B}\ ) / (f_B \sqrt{B_B}\ )$
  Measure f_{Ds}/f_D to test LQCD

γ from $B^\pm \to DK^\pm$

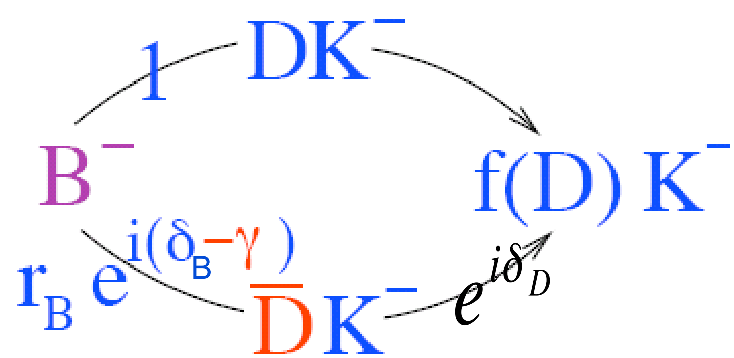




$= r_B e^{i(\delta_B-\gamma)}$

$$\frac{< B^- \longrightarrow \overline{D}^0 K^- >}{< B^- \longrightarrow D^0 K^- >} = r_B e^{i(\delta_B-\gamma)} \qquad r_B \equiv \left| \frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)} \right| \sim 0.1$$

- Extraction through interference between b→u and b→c transitions
- Require D^0 & $\overline{D^0}$ decay to a common final state, f(D).
  - Dalitz Modes $K^0{}_S\pi\pi$;
  - ADS Modes $K\pi$; $K\pi\pi\pi$
- Tree level processes: little sensitivity to New Physics → SM 'standard candle'



Charm Analyses Impact Gamma

ICHEP08 HFAG

- Measurement of $\delta_D^{K\pi} = 22^{+11+9}_{-12-11}$ OR $\delta_D^{K\pi} = 22.5^{+10.5}_{-12.0}$

$$\Gamma(\mathrm{B}^- \rightarrow (\mathrm{K}^+\pi^-)_\mathrm{D}\mathrm{K}^-) \propto r_B^2 + (r_D^{K\pi})^2 + 2r_B r_D^{K\pi} \cdot \cos(\delta_B + \delta_D^{K\pi} - \gamma)$$

- Measurement of 'coherence factor' $R_{K3\pi}$ & $\delta_D^{K3\pi}$

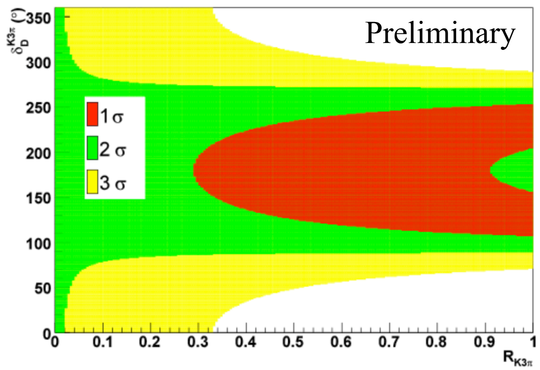
$$\Gamma(\mathrm{B}^- \rightarrow (\mathrm{K}^+3\pi)_\mathrm{D}\mathrm{K}^-) \propto r_B^2 + (r_D^{K3\pi})^2 + 2R_{K3\pi} r_B r_D^{K3\pi} \cdot \cos(\delta_B + \delta_D^{K3\pi} - \gamma)$$

- Measurement of D/$\overline{\mathrm{D}}$ phase difference across $K_S\pi^+\pi^-$ Dalitz plot - Dominant systematic error for BaBar, Belle

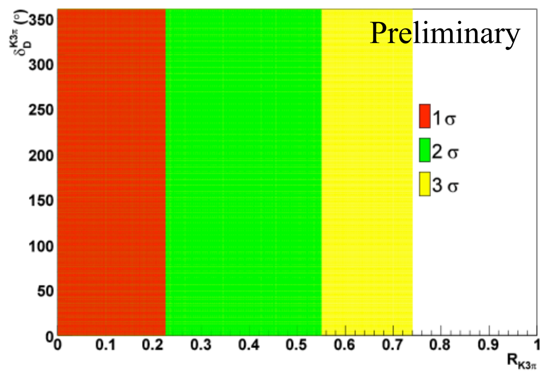
- All analyses exploit Quantum Correlated initial state of $\psi(3770) \rightarrow D_1 D_2$

$\delta_D^{K3\pi}$ *vs.* $R_{K3\pi}$ Parameter Space Constraints

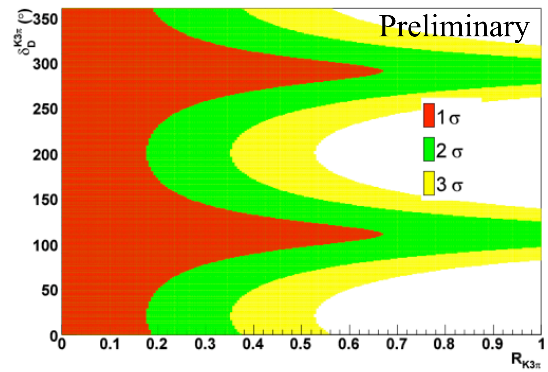
$K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$ vs. CP



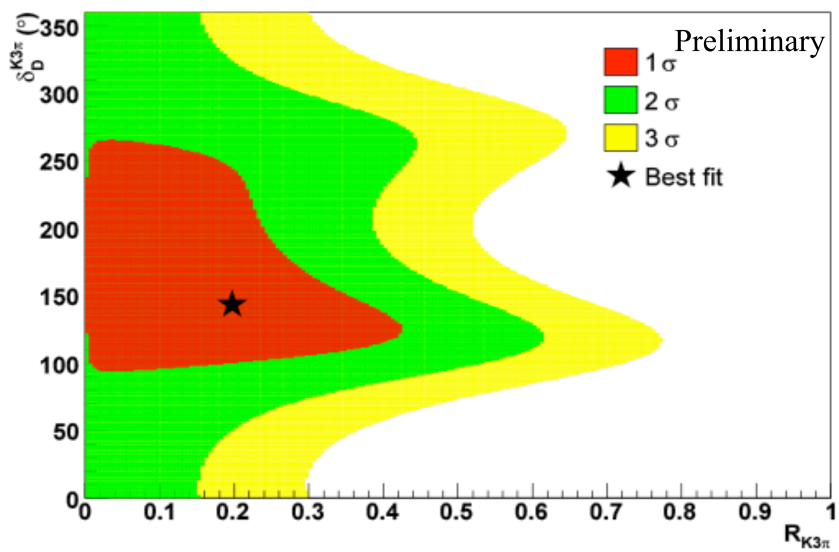
$K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$ vs. $K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$



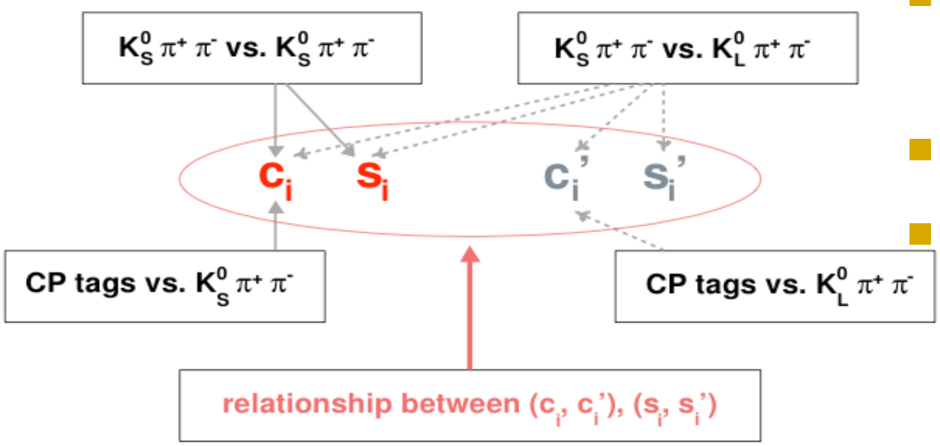
$K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$ vs. $K^{\pm}\pi^{\mp}$



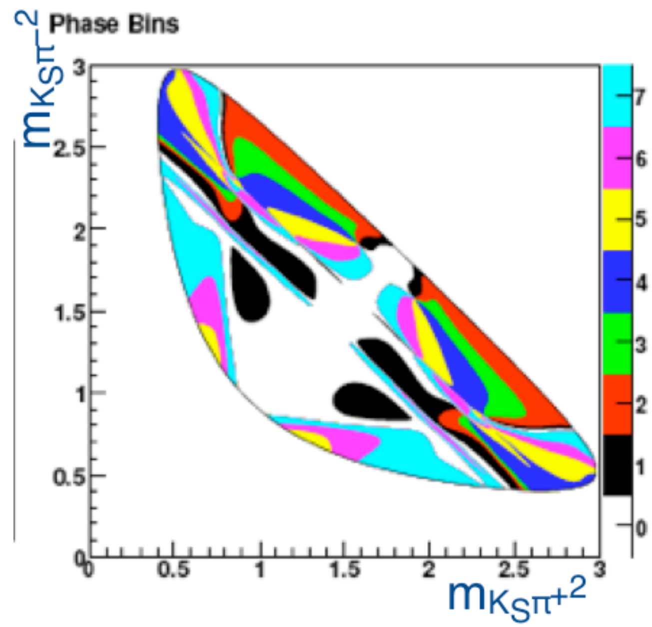
- Combine results to make confidence plots for $R_{K3\pi}$
- Low coherence is preferred
- Allows accurate r_B determination useful for all $B^{\pm} \to DK^{\pm}$ decays
- Better measurement of r_B improves the measurements of γ via ADS method.



CLEO-c Event Samples for $B \to DK$, $D \to K_S \pi^+ \pi^-$



- Need to know phase difference δ_D between D & $\bar{D}$ across Dalitz plot
- $c_i \equiv \langle \cos(\delta_D(x,y)) \rangle_i$ $s_i \equiv \langle \sin(\delta_D(x,y)) \rangle_I$
- Choose bins of similar phase δ_D



$$c_i = \frac{(M_i^+/S_+ - M_i^-/S_-)}{(M_i^+/S_+ + M_i^-/S_-)} \frac{(K_i + K_{\bar{i}})}{2\sqrt{K_i K_{\bar{i}}}}.$$

$S_+(S_-)$, number of single tags for CP even(odd) modes.

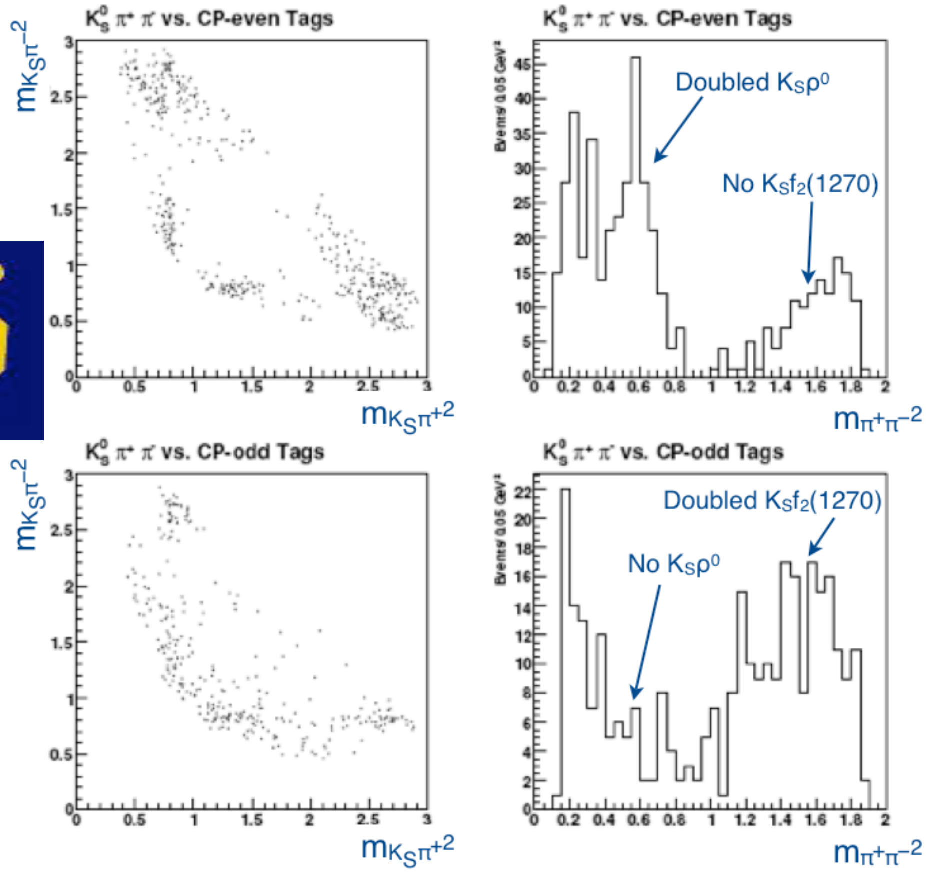
$M_i^+(M_i^-)$, yields in each bin of Dalitz plot in CP even(odd) modes.

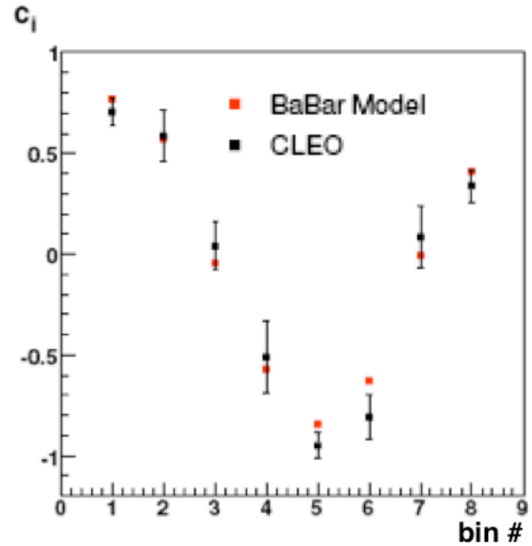
$K_i(K_{\bar{i}})$, yields in each bin of Dalitz plot in flavor modes.

CP Tagged $K_S\pi^+\pi^-$ only sensitive to c_i

- Results for c_i using 8 bins:

CLEO-c Preliminary (818 pb^{-1})
http://beach2008.sc.edu/includes/documents/sessions/he.talk.pdf



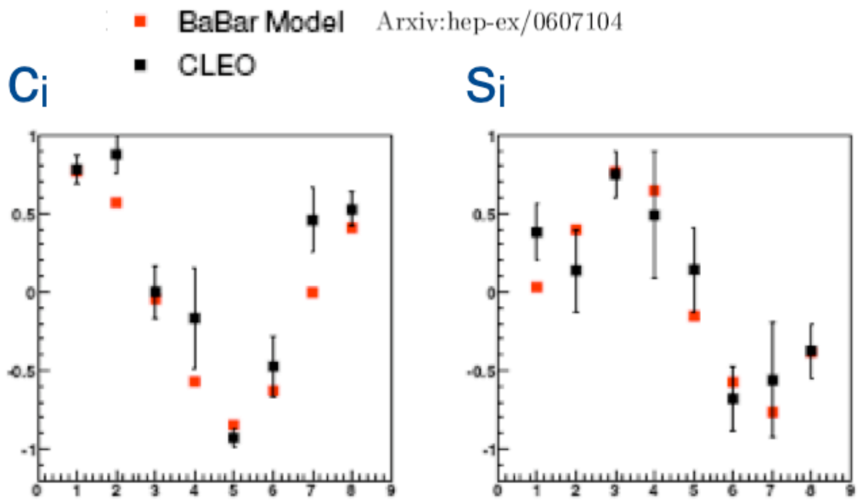


c_1	0.706±0.069±0.028
c_2	0.586±0.126±0.037
c_3	0.041±0.120±0.043
c_4	-0.510±0.178±0.074
c_5	-0.949±0.063±0.029
c_6	-0.807±0.108±0.039
c_7	0.085±0.154±0.046
c_8	0.339±0.082±0.024

- ~ 800 CP-tagged events

BABAR Collaboration, Arxiv:hep-ex/0607104

$K_S\pi^+\pi^-$ vs $K_S\pi^+\pi^-$ sensitive to c_i , s_i



CLEO-c Preliminary (818 pb^{-1})

http://beach2008.sc.edu/includes/documents/sessions/he.talk.pdf

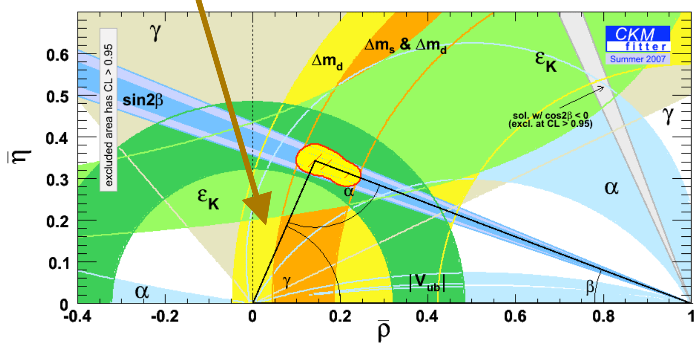
	Value		Value
c_1	0.779±0.087±0.062	s_1	0.380±0.179±0.085
c_2	0.874±0.120±0.113	s_2	0.137±0.260±0.084
c_3	0.003±0.166±0.152	s_3	0.749±0.145±0.053
c_4	-0.165±0.323±0.152	s_4	0.490±0.400±0.093
c_5	-0.929±0.058±0.044	s_5	0.141±0.268±0.085
c_6	-0.472±0.196±0.099	s_6	-0.679±0.203±0.059
c_7	0.459±0.204±0.170	s_7	-0.558±0.367±0.106
c_8	0.526±0.109±0.114	s_8	-0.376±0.169±0.060

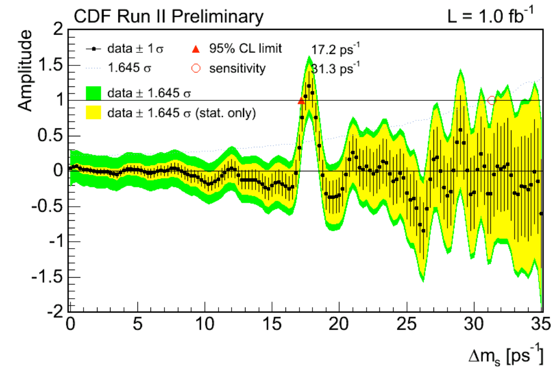
- Combined result from CP tagged $K_S\pi^+\pi^-$ and $K_S\pi^+\pi^-$ vs $K_S\pi^+\pi^-$ samples expect to yield a 2^o error (replaces 7^o systematic error due to D decay model)
- Addition of CP tagged $K_L\pi^+\pi^-$ and $K_L\pi^+\pi^-$ vs $K_S\pi^+\pi^-$ samples further expected to yield 1^o error

Lattice QCD and the 'Mixing Side'

'V_{ub} Side' of unitarity triangle determined
By $b \rightarrow u$ transitions e.g. $B \rightarrow \pi l \nu$

η





Very well known (~0.3%),
since observation of B_s mixing

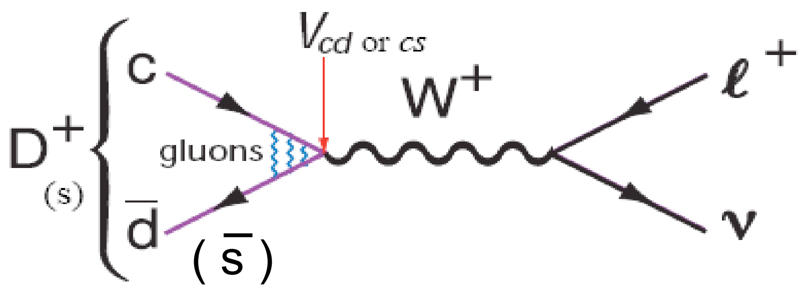
$$\text{Length} = (f_{B_s}\sqrt{B_{B_s}}) / (f_{B_d}\sqrt{B_{B_d}}) \;\sqrt{(\Delta m_d \, m_{B_d} / \Delta m_s \, m_{B_s})} = |V_{td}/V_{ts}|$$

Calculated on lattice – present *assigned* uncertainty ~5% (and will decrease)

Highly desirable to cross-check lattice against experiment - go to D system !

Leptonic D Decays and Decay Constants

In D^+ and D_s c and spectator quark can annihilate to produce leptonic final state:



In general, for all pseudoscalars:

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

Since V_{cd} and V_{cs} well known, can extract f_D and f_{D_s} and compare with lattice !

Measurements of $D_{(s)} \to l\nu$ Branching Fractions

Precise measurements now exist for:

D_s

- $\mu^+\nu$, $\tau^+ (\to\pi^+\nu)\upsilon$ CLEO-c (PRL 99 (2007) 071802; arXiv:0704.0437 + FPCP08)
- $\mu^+\nu$ BELLE (Phys.Rev.Lett.100:241801,2008 arXiv:0709.1340)
  & BaBar (Phys.Rev.Lett.98:141801,2007 hep-ex/0607094)
- $\tau^+ \to (e^+\nu\nu)\nu$ CLEO-c (PRL 100 (2008) 161801)

D^+

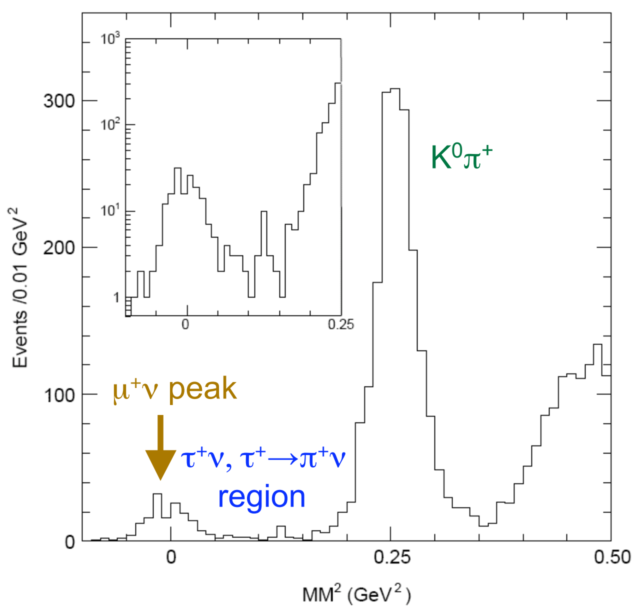
- $\mu^+\nu$ CLEO-c (accepted by Phys. Rev. D. arXiv:0806.2112)

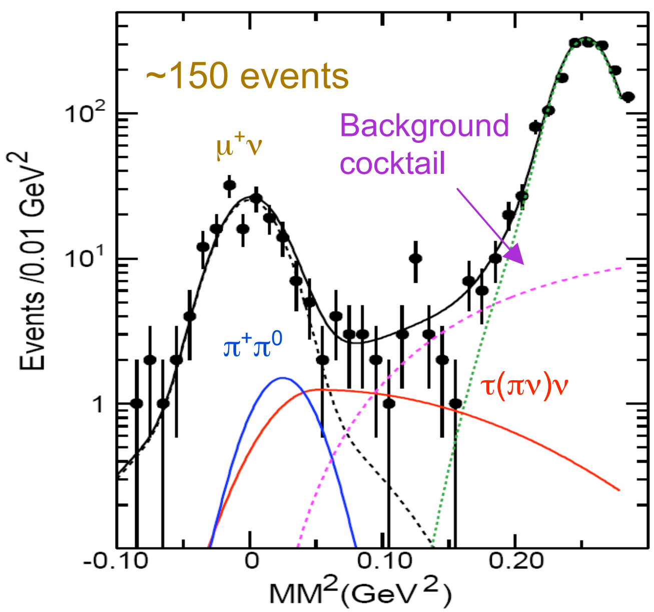
Basic methods for $\mu\nu$ measurement:

- CLEO-c: for f_D reconstruct one D^+ , look for MIP (μ), and then compute missing mass squared (similar for f_{Ds}, but here exploit $D_sD_s^*$ production in 4170 MeV dataset)
- Belle: infer presence of D_s from recoiling mass against reconstructed D & fragmentation. Add candidate μ and compute missing mass
- Babar: Select e+e- → cc events with high momentum D^0, D+, D_s, D*+ close to B kinematic end-point. Search for $D_s^* \to \gamma$, $D_s \to \gamma\mu\nu$ in the recoil

CLEO-c $D^+ \rightarrow \mu^+\nu$

Missing mass squared distribution (incld. log zoom with fit):



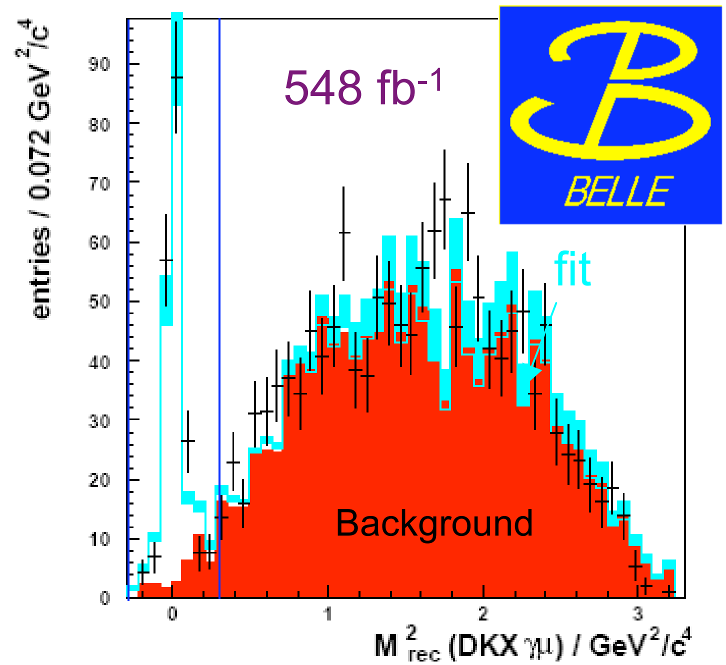


$BR(D^+ \rightarrow \mu^+\nu) = (3.82 \pm 0.32 \pm 0.09) \times 10^{-4}$

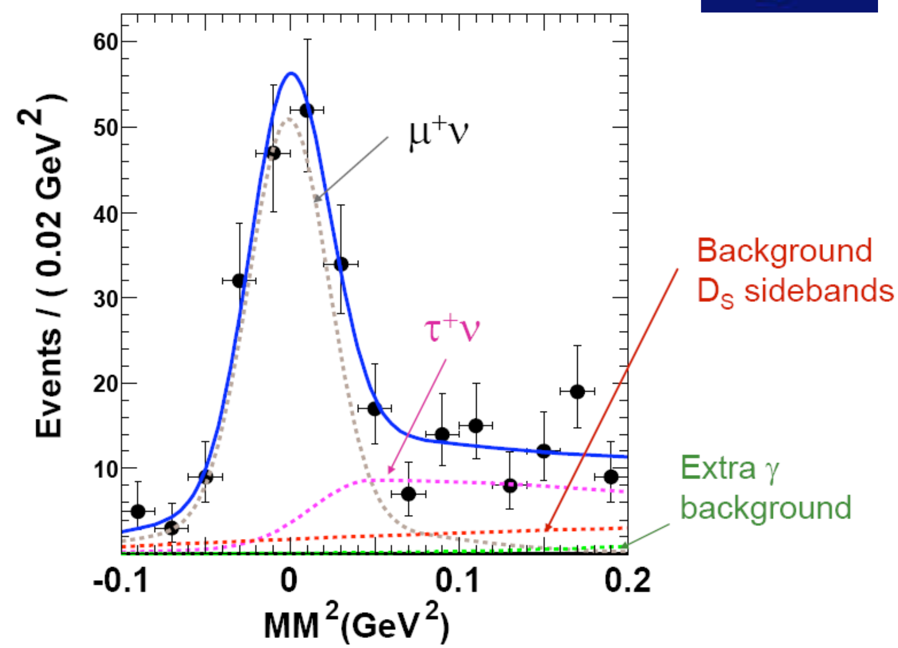
$f_D = (205.8 \pm 8.5 \pm 2.5)$ MeV

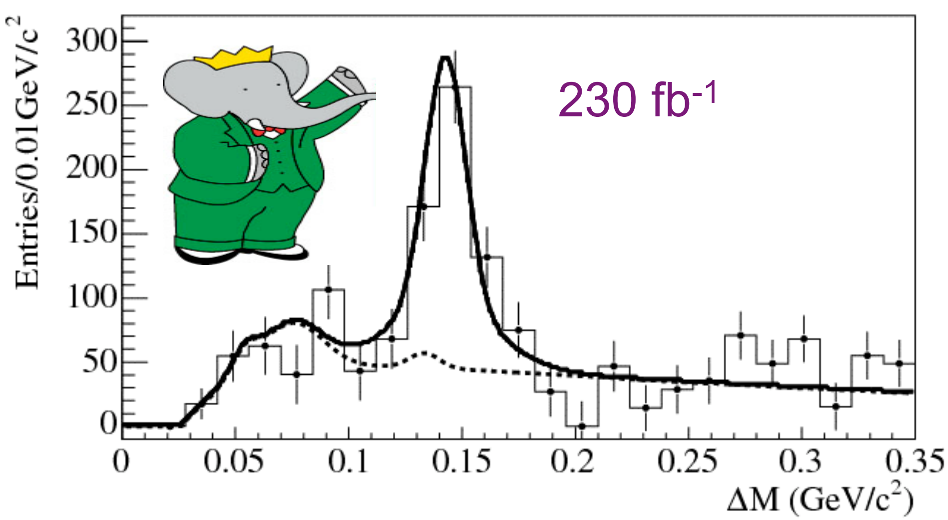
(result with $\tau\nu/\mu\nu$ fixed at SM expectation)

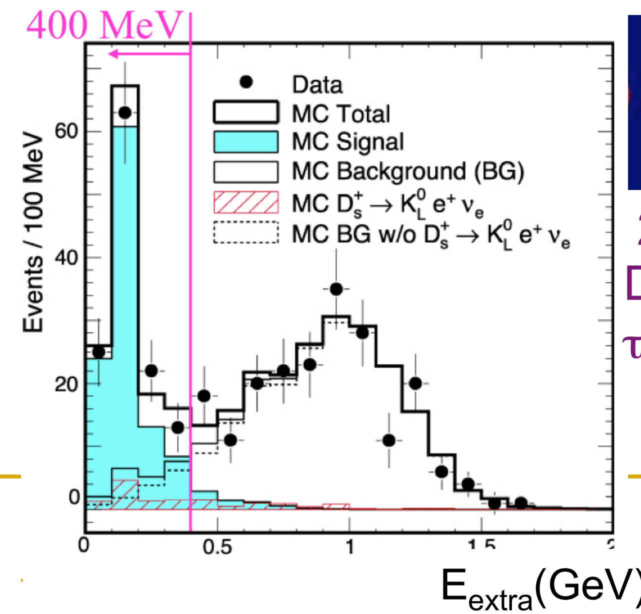
$D_s \to \mu^+\nu$ & $D_s \to \tau^+\nu$



CLEO-c prelim: 424 pb^{-1}
$D_s \to \mu\nu + D_s \to \tau\nu,\ \tau \to \pi\nu\nu$

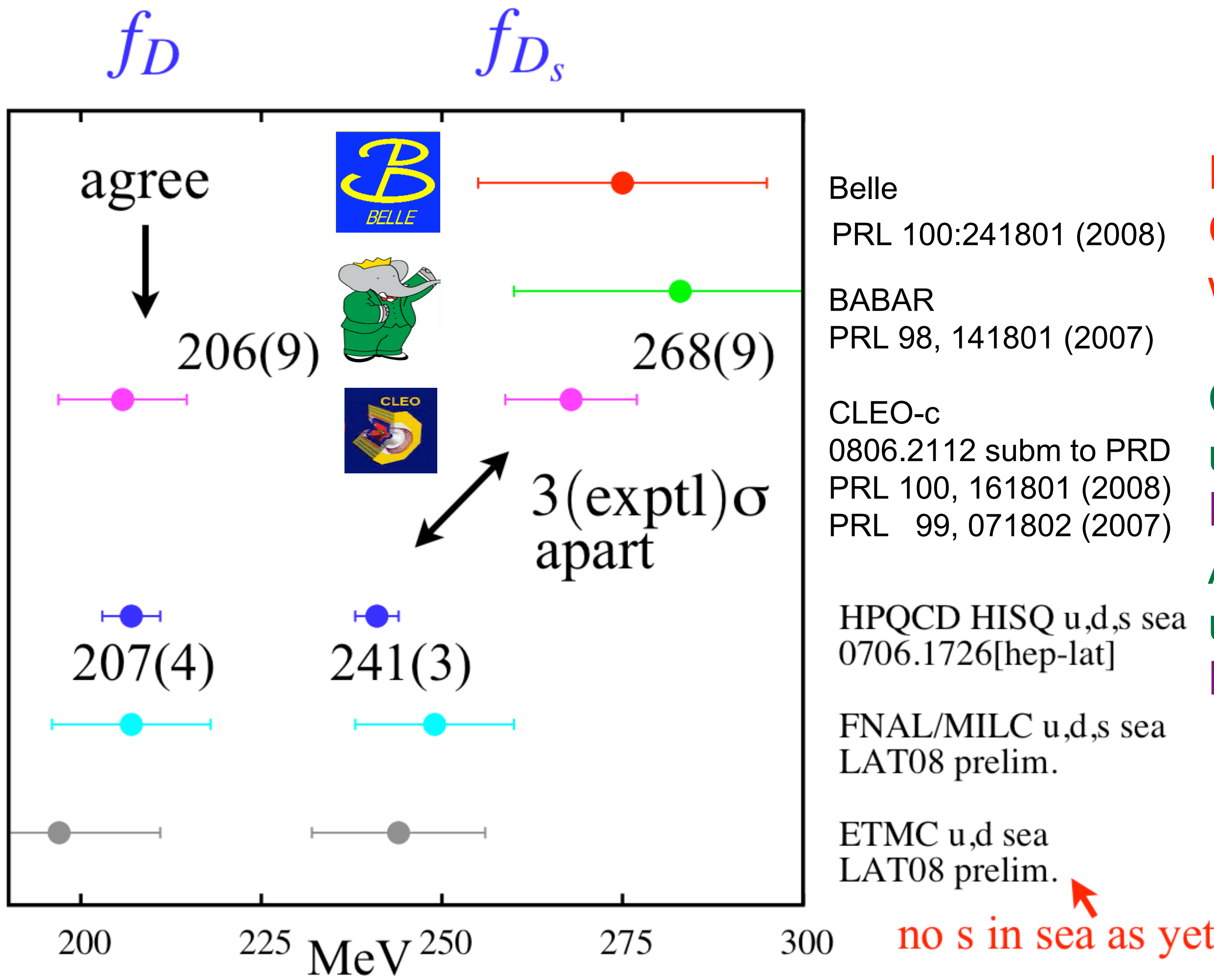






298 pb^{-1}
$D_s \to \tau\nu$,
$\tau \to e\nu\nu$

D^+ and D_s Decay Constants: the Global Picture

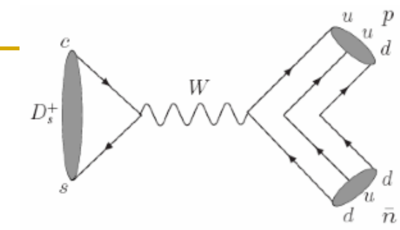


Final D_s results from CLEO-c expected soon with full data sample

Current CLEO results use 70% of data for $D_s \to \mu\nu + D_s \to \tau\nu,\ \tau \to \pi\nu\nu$

And use 50% of data for $D_s \to \tau\nu,\ \tau \to e\nu\nu$

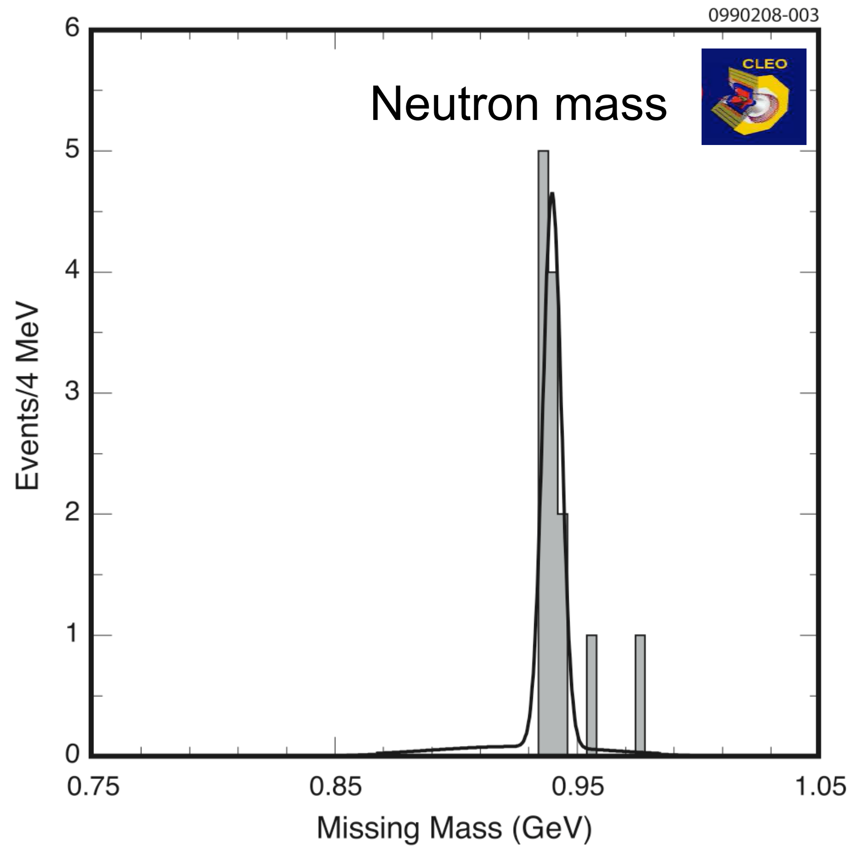
$D_s \rightarrow p\bar{n}$: First Observation



PRL 100, 181802 (2008)

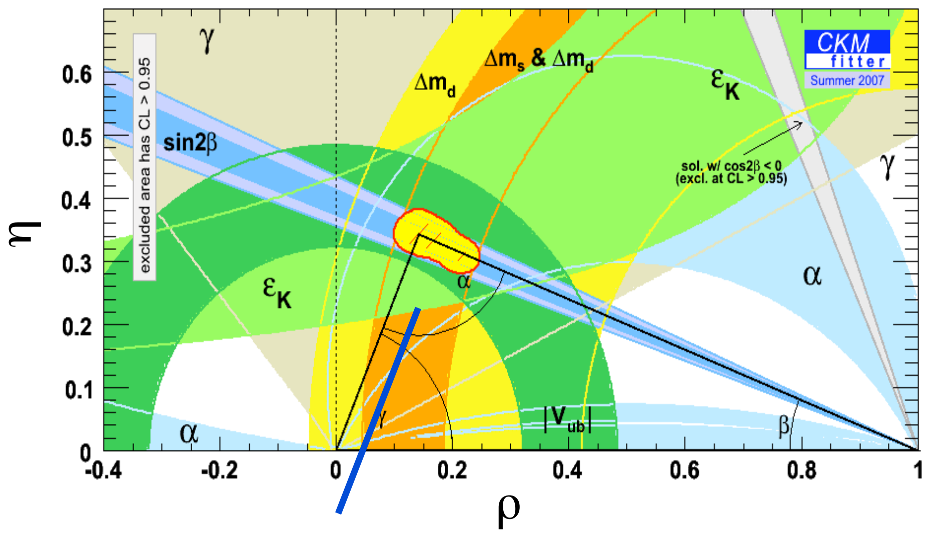
- Same analysis technique as $D \rightarrow \mu\nu$
- Only kinematically allowed D meson baryonic decay
- Consequence for understanding W annihilation dynamics

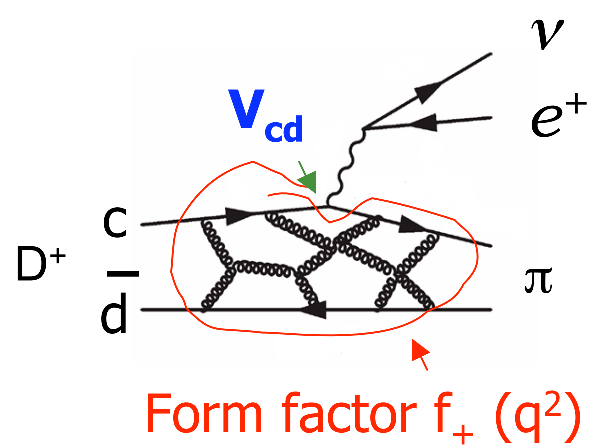
Chen, Cheng, Hsiao 0803.2910v3 [hep-ph]



$$\mathcal{B}(D_s^+ \to p\bar{n}) = (1.30 \pm 0.36^{+0.12}_{-0.10}) \times 10^{-3}$$

Lattice QCD and the 'Vub Side'





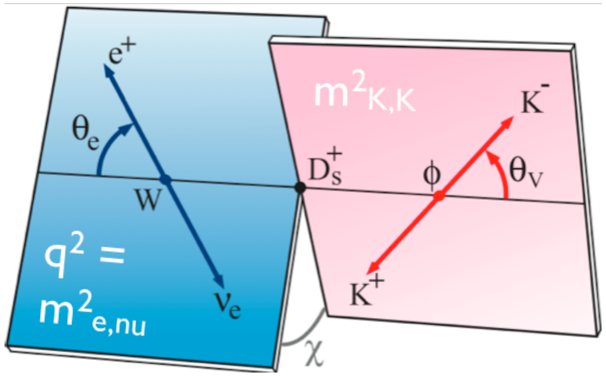
- Direct determination of V_{cd} & V_{cs} from charm semileptonic decay + LQCD

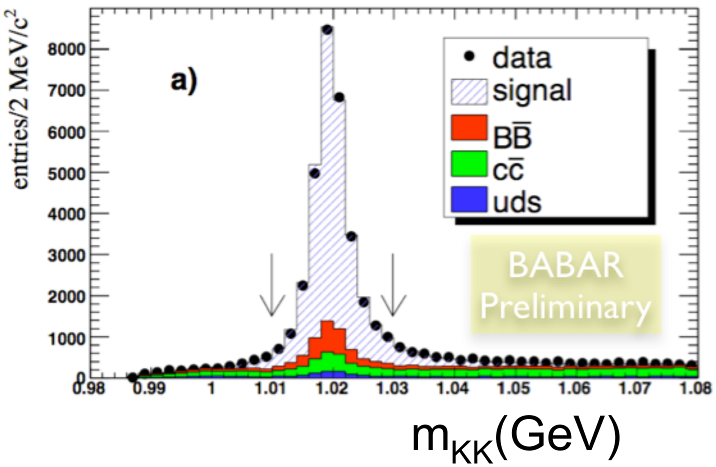
Strongly Correlated
Do Not Average

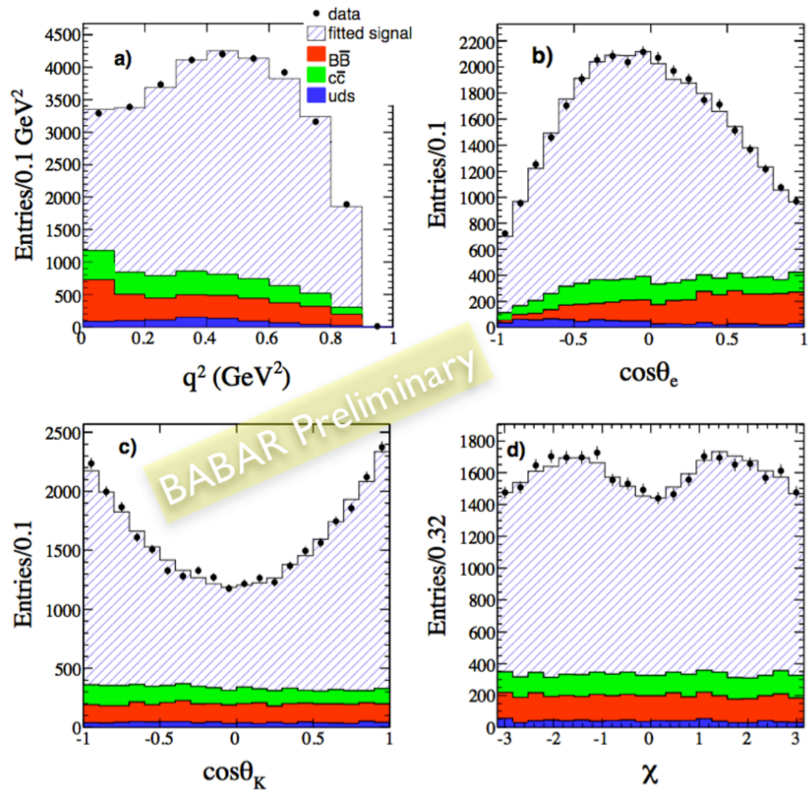
	$\lvert V_{cs}\rvert$	$\lvert V_{cd}\rvert$
(tagged *prelim*)	1.014±0.013±0.009±0.106	0.234±0.010±0.004±0.024
(untagged *final*)	1.015±0.010±0.011±0.106	0.217±0.009±0.004±0.023
	stat syst LQCD	stat syst LQCD

- Assume $V_{cs\ (cd)} = V_{ud\ (us)}$ & use data to test LQCD calculations
  - Both Form Factor and Normalization
- Potentially lead to improved FF and Normalization calculations for semileptonic b decays - and improved V_{ub}

$D_s \to K^+K^-e\nu$ Form Factors & LQCD







- r_V=1.868 ± 0.061 ± 0.079 → r_V=1.35 ± 0.08
- r_2=0.763 ± 0.072 ± 0.062 → r_2=0.98 ± 0.09
- r_0=15.3 ± 2.6 ±1.0 - first evidence for $D_s \to f_0 e\nu$

Agrees well with hep-lat/0109035

Summary & Outlook

Rare Charm Decays: Experiments entering interesting territory - expect more results soon from CLEO, B-factories and Tevatron that provide constraints on New Physics.

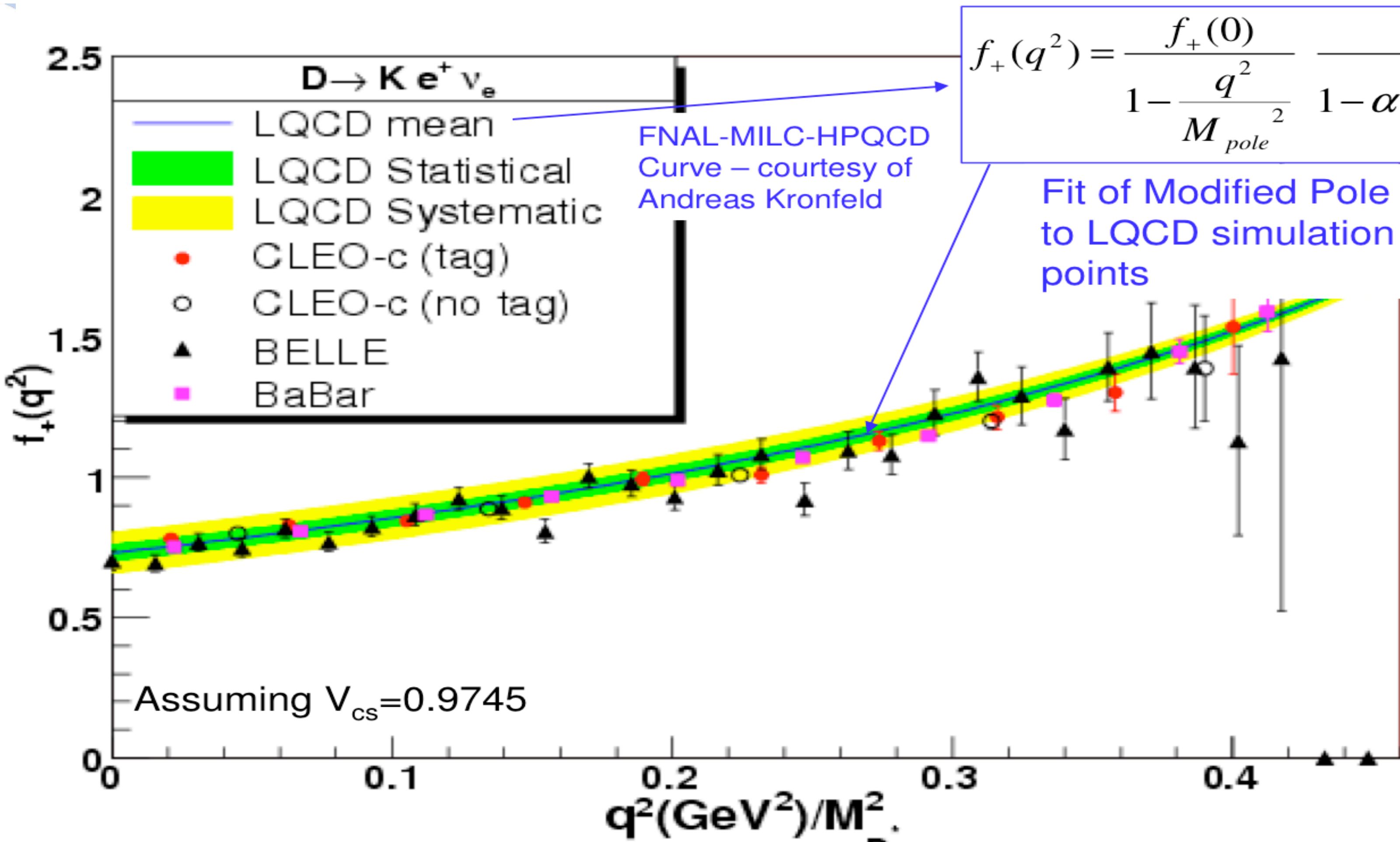
Charm Mixing: Discovery of D^0-D^0 oscillation points the way forward to searches for CPV and New Physics

CP Violation: Experiments entering interesting territory due to data driven estimates of systematic uncertainties

Precision CKM tests: Success of the B-factories and the Tevatron has meant that unitarity triangle tests are entering a new, precision era. Charm input is a vital ingredient,

Future: Tighter constraints on New Physics, more stringent tests of LQCD, more precise input to B-physics expected soon from CLEO, B-factories & Tevatron. In the near future charm results from BESIII & LHCb. SuperB is required for charm (B & τ) sector(s) to be fully engaged in understanding NP observed at LHC.

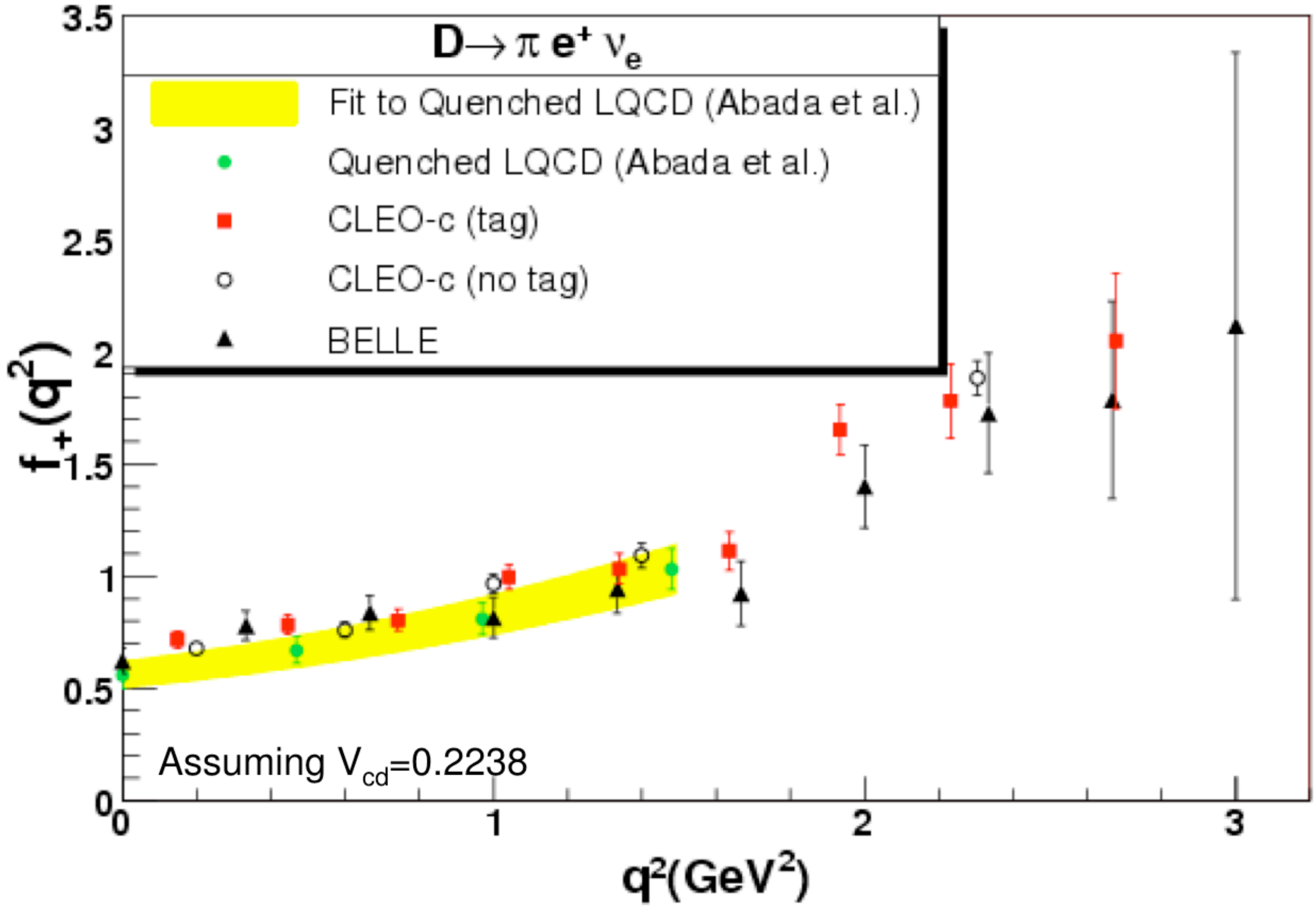
Pseudo-scalar Form Factor: LQCD vs Exp't



$$f_+(q^2) = \frac{f_+(0)}{1-\frac{q^2}{M_{pole}^2}}\;\frac{1}{1-\alpha\frac{q^2}{M_{pole}^2}}$$

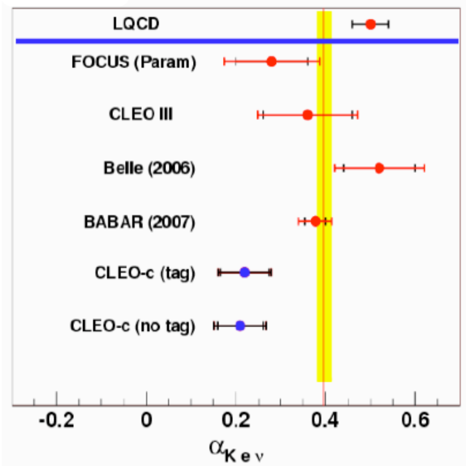
- Theoretical errors larger than experimental

Pseudo-scalar Form Factor: LQCD vs Exp't

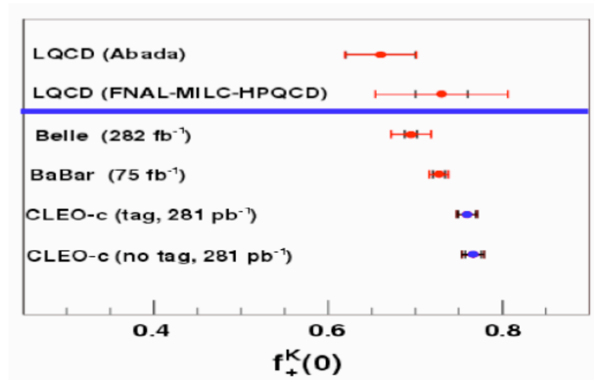


Tests of LQCD

Slope



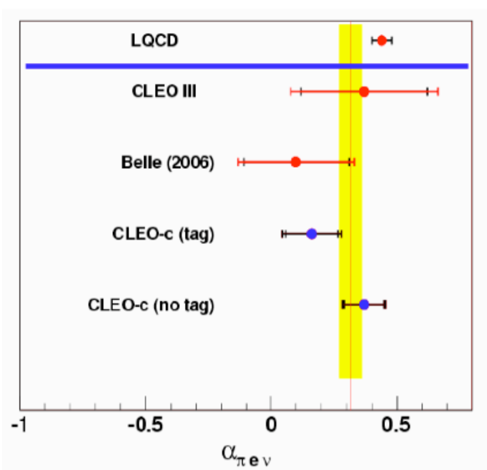
Normalization (assuming $|V_{cs\ (cd)}|=|V_{ud\ (us)}|$)

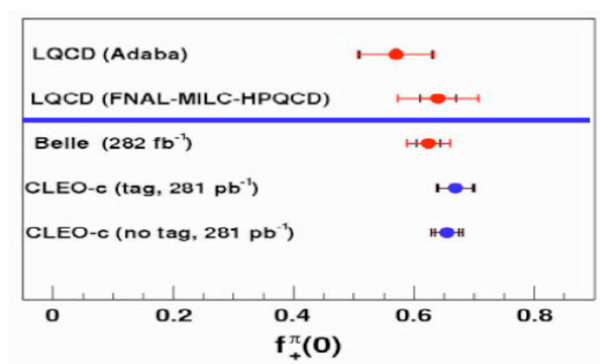


$D \to K e \nu$

Normalization errors

Channel	Experi-ments	theory
$D \to K e \nu$	2%	10%
$D \to \pi e \nu$	4%	10%

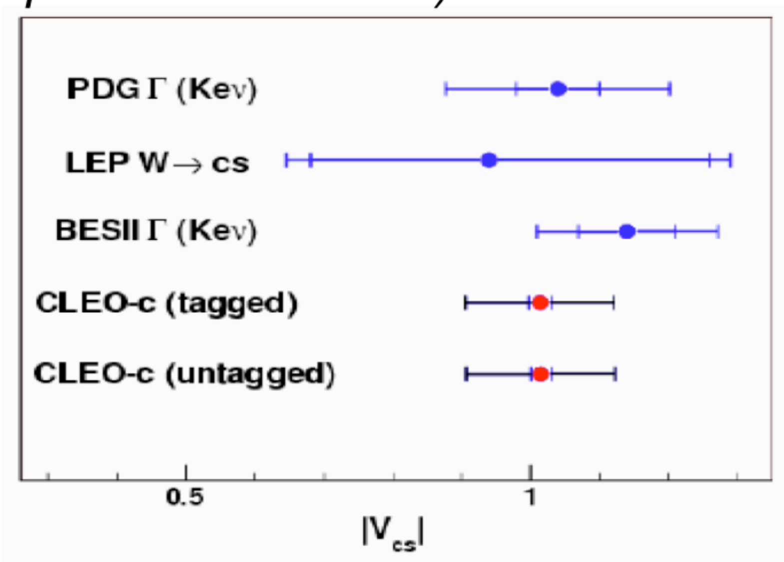


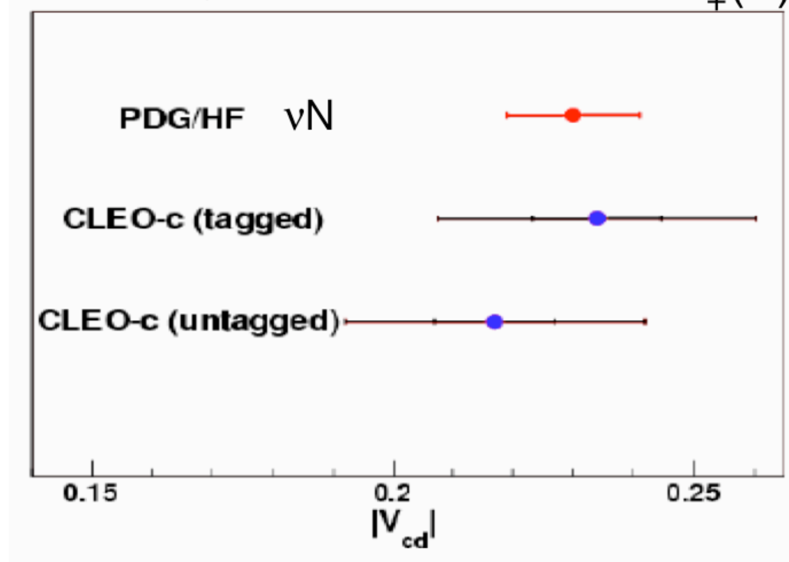


$D \to \pi e \nu$

Vcs and Vcd

Combine measured $|V_{cx}|f_+(0)$ values (*fit of Hill&Becher f.f. parameterization)* with FNAL-MILC-HPQCD calculations for $f_+(0)$





CLEO-c (results are strongly correlated – do not average)

	$\|V_{cs}\|$	$\|V_{cd}\|$
(tagged *prelim*)	1.014±0.013±0.009±0.106	0.234±0.010±0.004±0.024
(untagged *final*)	1.015±0.010±0.011±0.106	0.217±0.009±0.004±0.023
	stat syst LQCD	stat syst LQCD

- Improvements in LQCD calculations are needed