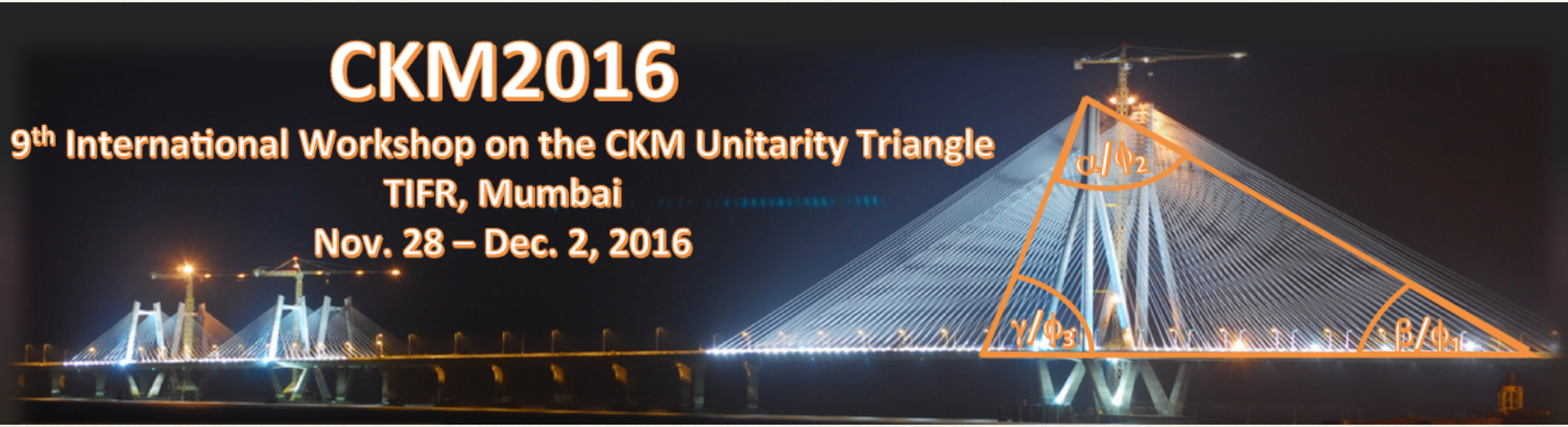

Charm Physics & CKM

Carla Göbel
PUC-Rio

Outline

- **Three main topics discussed here**
  - Direct CPV
  - Indirect CPV
  - Measurements of $|V_{cq}|$

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- **But certainly the fun continues in the charming working groups!**

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- **But certainly the fur… …ing working groups!**

Working Group 7 (WG 7): Mixing and CP violation in the D system: x, y, $|q/p|$, ϕ, x_{12}, y_{12}, ϕ_{12}, DCPV in D decays
Conveners:
Ayan Paul (Theory) Email: ayan.paul@roma1.infn.it and apaul2@alumni.nd.edu
Angelo di Canto (E… …t) Email: angelo.di.canto@cern.ch
… …) Email: Giulia.Casarosa@pi.infn.it

Working Group 1 (WG 1): V_{ud}, V_{us}, V_{cd}, V_{cs} and semileptonic/leptonic D decays
Conveners:
Takashi Kaneko (Theory) Email: Takashi.Kaneko@kek.jp
Xiao-Rui Lyu (Experiment) Email: xiaorui@ucas.ac.cn
Arantza Oyanguren (Experiment) Email: Arantza.Oyanguren@ific.uv.es

Working Group 3 (WG 3): Rare B, D, and K decays: including radiative and electroweak penguin decays and $B_{(s)} \to \ell^+\ell^-$, constraints on V_{td}/V_{ts}
Conveners:
Enrico Lunghi (Theory) Email: elunghi@indiana.edu
Akimasa Ishikawa (Experiment) Email: akimasa@epx.phys.tohoku.ac.jp
Justine Serrano (Experiment) Email: serrano@cppm.in2p3.fr
Matthew Moulson (Experiment) Email: Matthew.Moulson@lnf.infn.it

Introduction

- Charm mesons and baryons play an important role in studies of weak and strong interactions

- Masses $\mathcal{O}$ (2GeV) ➪ theoretical challenge for description of hadronic transitions

- Unique environment with up-type dynamics (e.g. oscillations)

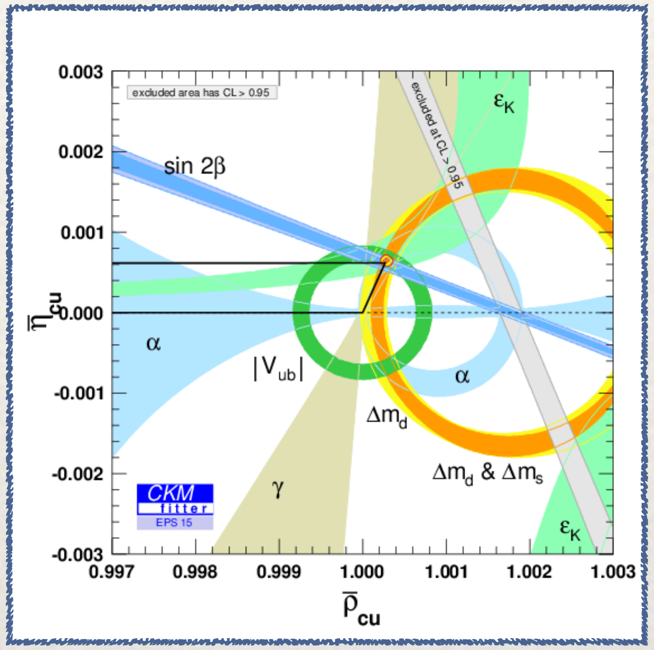
- Tiny expectations of CP violation and FCNC processes ➪ excellent for New Physics (NP) searches

- Many studies in charm as important inputs for the b-physics sector (γ, $|V_{qb}|$, etc)

CP violation in Charm

- The well know CKM matrix does not have charm as a protagonist for CP violation:

$$\begin{pmatrix} 1-\lambda^2/2-\lambda^4/8 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda+A^2\lambda^5(1/2-\rho-i\eta) & 1-\lambda^2/2-\lambda^4(1+4A^2)/8 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta)+A\lambda^5(\rho+i\eta)/2 & -A\lambda^2+A\lambda^4(1/2-\rho-i\eta) & 1-A^2\lambda^4/2 \end{pmatrix}$$



- A very squashed unitary triangle...

$$\underset{\lambda}{V^*_{ud}V_{cd}} + \underset{\lambda}{V^*_{us}V_{cs}} + \underset{\lambda^5}{V^*_{ub}V_{cb}} = 0$$

- CP violation appearing only through mixing and/or in Cabibbo-suppressed modes
  - Level of CP violation in the SM hard to estimate. Expected asymmetries $\mathcal{O}(10^{-3})$
  - NP can enhance expectations. But should really reach $\mathcal{O}(10^{-2})$ or higher .... otherwise hard to disentangle from CKM mechanism!

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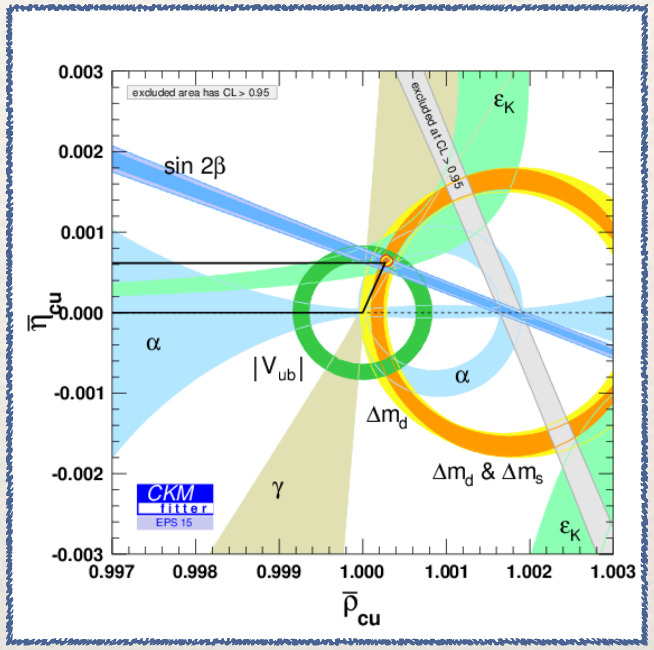

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LOOK EVERYWHERE!

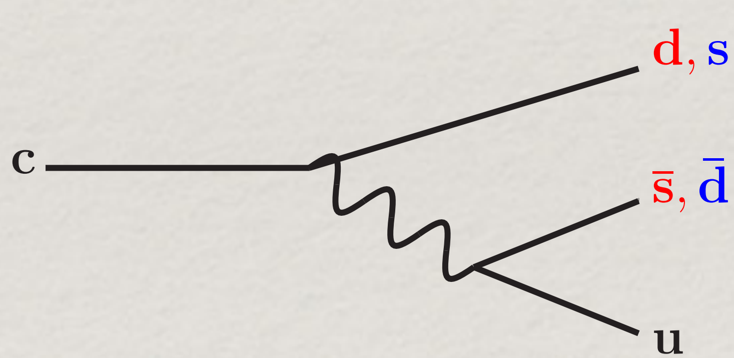
Direct CP violation

Direct CP Violation: 2-body

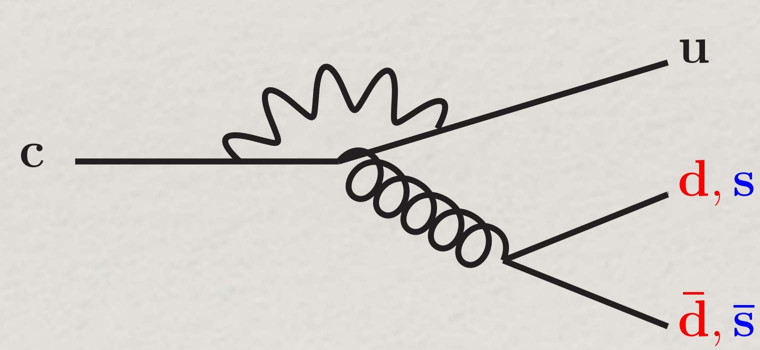
- Occurs when $A(D \to f) \neq \bar{A}(\bar{D} \to \bar{f})$
- In any case, necessary to have at least 2 interfering amplitudes with both weak and strong phase differences
- In two-body decays, direct CPV is searched for through time-integrated asymmetries

$$A_{\mathrm{CP}} = \frac{\Gamma(D \to f) - \Gamma(\bar{D} \to \bar{f})}{\Gamma(D \to f) + \Gamma(\bar{D} \to \bar{f})}$$

- In the Standard Model, direct CP violation in charm appears in Single-Cabibbo suppressed (SCS) decays



$O(\lambda) + iO(\lambda^5)$



$i\,O(\lambda^5)$

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

A. Carbone, WG7, Today

- Reminding the famous actor ΔA_{CP}

$$\Delta A_{\text{CP}} = A_{\text{CP}}(D^0 \to K^+K^-) - A_{\text{CP}}(D^0 \to \pi^+\pi^-)$$

- ΔA_{CP} is mostly a measurement of direct CP violation:

$$\Delta a_{\text{CP}}^{\text{dir}} = \frac{|A_f|^2 - |\bar{A}_{\bar{f}}|^2}{|A_f|^2 + |\bar{A}_{\bar{f}}|^2}$$

- 2016 came with the awaited update on D*-tagged sample from LHCb from the full 3fb^{-1} LHCb, PRL 116 191601 (2016)

ΔA_{CP} = (-0.10±0.08±0.03)%

- and followed with individual results

LHCb, ArXiv:1610.09476

A_{CP}(KK) = (0.04±0.12±0.10)%

A_{CP}(ππ) = (0.07±0.14±0.11)%

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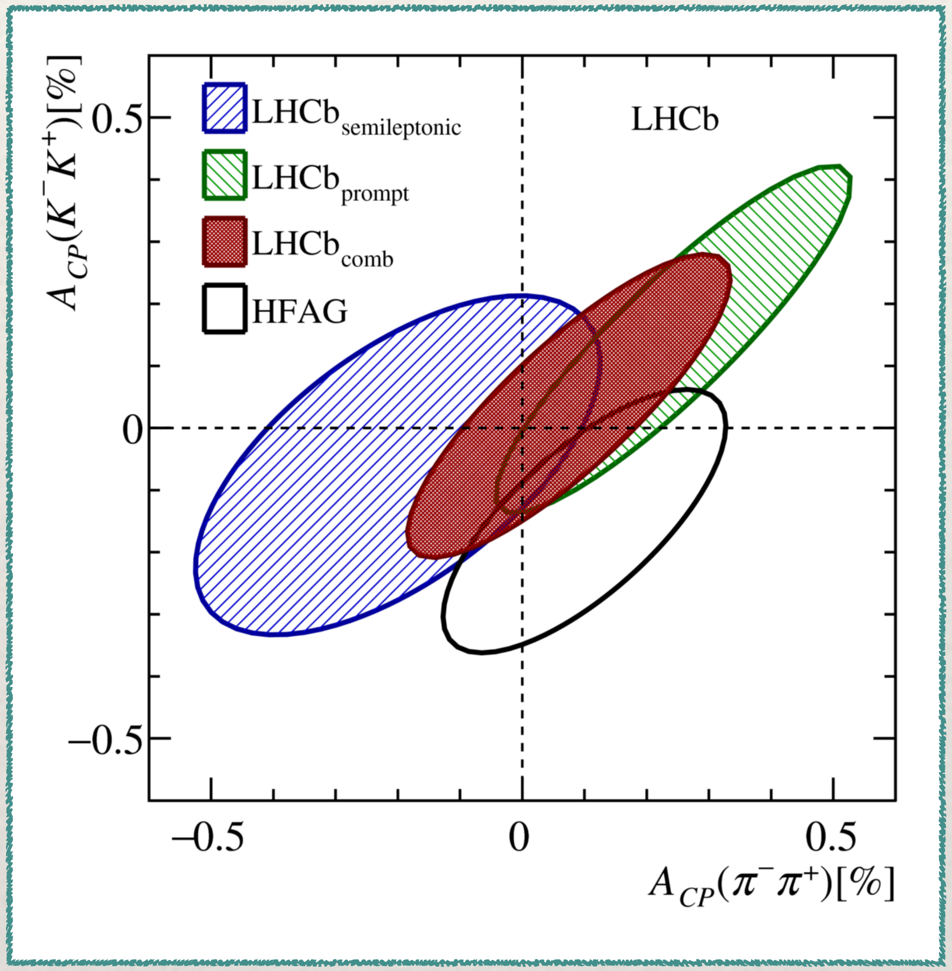

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Good news is that sensitivity has reached 10^{-3} in a single mode
Bad news that there are no news

Time-integrated asymmetries

V. Bhardwaj, WG7, Tuesday

$D^0 \to K_S K_S$ — Belle

CONF-1609 ArXiv 1609.06393

- CP violation should be enhanced even through CKM only. Upper limit 1.1%

Nierste & Schach Phys. Rev. D92, 054036 (2015)

- Belle measures

A_{CP} = (-0.02 ±1.53 ±0.17)%

- To be compared to the recent LHCb

JHEP 10 (2015) 055

A_{CP} = (2.9 ±5.2 ±2.2)%

$D^0 \to V\gamma$ — Belle

CONF-1611 ArXiv 1603.03257

- Radiative decays sensitive to NP (chromomagnetic dipole operators)

$A_{CP}(D^0 \to \varphi\gamma)$ = (-9.4 ±6.6 ±0.1)%

$A_{CP}(D^0 \to K^*\gamma)$ = (-0.3 ±2.0 ±0.0)%

$A_{CP}(D^0 \to \rho\gamma)$ = (5.6 ±15.2 ±0.6)%

$D^+_{(s)} \to \eta' \pi^+$ — LHCb

LHCb-PAPER-2016-04

$A_{CP}(D^+)$ = (-0.61 ±0.72 ±0.55±0.12)%

$A_{CP}(D^+_s)$ = (-0.82 ±0.36 ±0.24±0.27)%

M. Gersabeck, WG7, Tuesday

$D^+ \to K_{S,L} K^+ (\pi^0)$ — BESIII

Preliminary for CHARM16

Mode	$\mathcal{A}_{CP}$ (%)
$K^0_S K^\pm$	-1.5 ± 2.8 ± 1.6
$K^0_S K^\pm \pi^0$	1.4 ± 4.0 ± 2.4
$K^0_L K^\pm$	-3.0 ± 3.2 ± 1.2
$K^0_L K^\pm \pi^0$	-0.9 ± 4.1 ± 1.6

R-X Lyu, WG7, Thursday

$D^+ \to K_L e^+ \nu_e$ — PRD 92 (2015) 112008

$A_{CP}(D^+)$ = (-0.59 ±0.60 ±1.48)%

Time-integrated asymmetries

V. Bhardwaj, WG7, Tuesday

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$A_{CP}(D^0 \to$ … (-9.4 ±6.6 ±0.1)%

A_{CP}(… -0.3 ±2.0 ±0.0)%

… 6 ±15.2 ±0.6)%

Most uncertainties still $\mathcal{O}(\%)$

Yet room for NP searches!

… $K_{S,L} K^+ (\pi^0)$ — BESIII

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M. Gersabeck, WG7, Tuesday

Direct CP Violation: Multi-body

- In multi-body decays, CPV can be studied through the phase space: **local asymmetries** larger than integrated ones
  - Direct comparison of distributions: just a **yes** or **no**

    Miranda method, Energy test

  - Model-dependent amplitude analyses -> direct access to phases
  - Triple-product asymmetries (4-body, baryons):

$$C_T = \vec{p}_3 \cdot (\vec{p}_1 \times \vec{p}_2) \Rightarrow \mathrm{CP}(C_T) = -\mathrm{C}(C_T) = -\bar{C}_T$$

- Rich environment, many potential (SCS) channels:

$D^+ \to K^- K^+ \pi^+$
$D^+ \to \pi^- \pi^+ \pi^+$
$D_s^+ \to K^- K^+ K^+$

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

$\Lambda_c^+ \to p\, K^- K^+$
$\Lambda_c^+ \to p\, \pi^+ \pi^+$
etc ...

J. Rademacker, M. Gersabeck, WG7, Tuesday

- Also important for γ measurements in D^0 decays (see later)

Direct CP Violation: Multi-body

$D^0 \rightarrow K_S K^{\pm} \pi^{\mp}$ Dalitz analysis

LHCb

PRD 93 (2016) 052018

Resonance	Δ(Fit fraction) [%] GLASS	Δ(Fit fraction) [%] LASS
	$D^0 \to K_S^0 K^- \pi^+$	
$K^*(892)^+$	$0.6 \pm 1.0 \pm 0.3$	$0.9 \pm 1.0 \pm 0.3$
$K^*(1410)^+$	$1.4 \pm 0.8 \pm 0.2$	$1.2 \pm 1.6 \pm 0.2$
$(K_S^0\pi)^+_{S\text{-wave}}$	$1 \pm 4 \pm 3$	$-2.3 \pm 3.5 \pm 3.3$
$\overline{K}^*(892)^0$	$-0.43 \pm 0.30 \pm 0.03$	$-0.47 \pm 0.29 \pm 0.03$
$\overline{K}^*(1410)^0$	$0.3 \pm 1.0 \pm 0.1$	$0.4 \pm 0.7 \pm 0.1$
$(K\pi)^0_{S\text{-wave}}$	$2.2 \pm 1.3 \pm 0.4$	$2.6 \pm 2.2 \pm 0.4$
$a_2(1320)^-$	$-0.20 \pm 0.13 \pm 0.05$	$-0.15 \pm 0.10 \pm 0.05$
$a_0(1450)^-$	$-0.0 \pm 0.4 \pm 0.4$	$-0.4 \pm 0.4 \pm 0.4$
$\rho(1450)^-$	$0.3 \pm 0.7 \pm 0.6$	$-0.3 \pm 0.7 \pm 0.6$
	$D^0 \to K_S^0 K^+ \pi^-$	
$K^*(892)^-$	$-1.1 \pm 0.7 \pm 0.2$	$-0.9 \pm 0.7 \pm 0.2$
$K^*(1410)^-$	$0.6 \pm 2.7 \pm 2.4$	$-2 \pm 4 \pm 2$
$(K_S^0\pi)^-_{S\text{-wave}}$	$2 \pm 6 \pm 6$	$-4 \pm 6 \pm 6$
$K^*(892)^0$	$-0.4 \pm 0.4 \pm 0.0$	$-0.4 \pm 0.4 \pm 0.0$
$K^*(1410)^0$	$1.9 \pm 1.1 \pm 0.2$	$1.6 \pm 0.8 \pm 0.2$
$(K\pi)^0_{S\text{-wave}}$	$-4 \pm 5 \pm 5$	$-9 \pm 6 \pm 5$
$a_0(980)^+$	$2.2 \pm 2.8 \pm 2.4$	$4.6 \pm 3.3 \pm 2.4$
$a_0(1450)^+$	$-0.21 \pm 0.30 \pm 0.23$	$-0.4 \pm 0.4 \pm 0.2$
$\rho(1700)^+$	$-0.07 \pm 0.25 \pm 0.19$	$-0.27 \pm 0.27 \pm 0.19$

$D^0 \rightarrow \pi^-\pi^+\pi^-\pi^+$ amplitude analysis

d'Argent et al, CLEO data legacy

preliminary , shown at CHARM 2016

- As $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$, can provide important input for γ in B→ DK

Decay mode	A_i^{CP} [%]
$D^0 \to \pi^- a_1(1260)^+$	5.0 ± 3.2
$D^0 \to \pi^+ a_1(1260)^-$	6.8 ± 13.2
$D^0 \to \pi^- \pi(1300)^+$	-7.4 ± 8.0
$D^0 \to \pi^+ \pi(1300)^-$	-9.6 ± 16.5
$D^0 \to \pi^- a_1(1640)^+$	7.8 ± 12.5
$D^0 \to \pi^- \pi_2(1670)^+$	6.7 ± 14.0
$D^0 \to \sigma f_0(1370)$	-8.7 ± 4.5
$D^0 \to \sigma \rho(770)$	26.3 ± 15.2
$D^0 \to \rho(770)\rho(770)$	-46.7 ± 34.0
$D^0[P] \to \rho(770)\rho(770)$	-9.1 ± 7.9
$D^0[D] \to \rho(770)\rho(770)$	-7.9 ± 8.3
$D^0 \to f_2(1270) f_2(1270)$	-28.7 ± 20.7
$D^0 \to \pi^+\pi^-\pi^+\pi^-$	-5.5 ± 3.3

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

Energy Test

LHCb

LHCb-PAPER-2016-044, in prep.

- Unbinned, model-independent method to search for local CP violation
- Pioneered by LHCb, alternative for the binned (aka Miranda) method

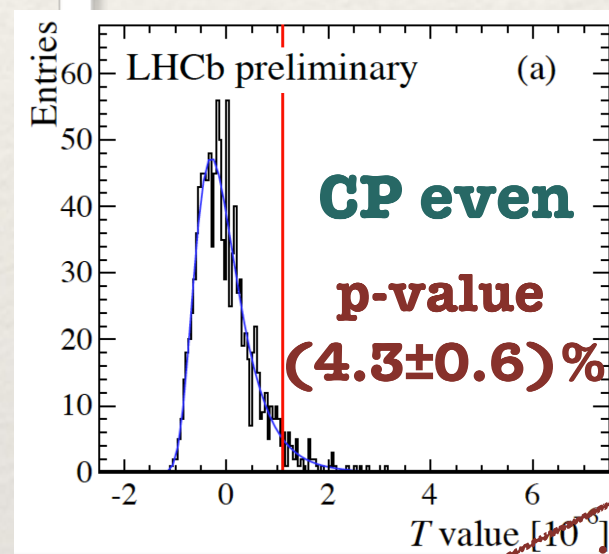
  $D^0 \to \pi^- \pi^+ \pi^0$, PLB 740 (2015) 158
- Construct a test-statistic T used to compare the average distances of events in phase space

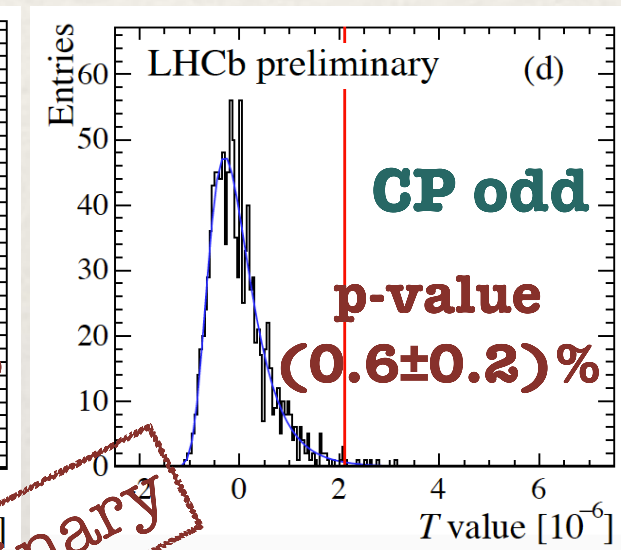
$$T = \sum_{i,j>i}^{n} \frac{\psi_{ij}}{n(n-1)} + \sum_{i,j>i}^{\bar{n}} \frac{\psi_{ij}}{\bar{n}(\bar{n}-1)} - \sum_{i,j}^{n,\bar{n}} \frac{\psi_{ij}}{n\bar{n}}$$

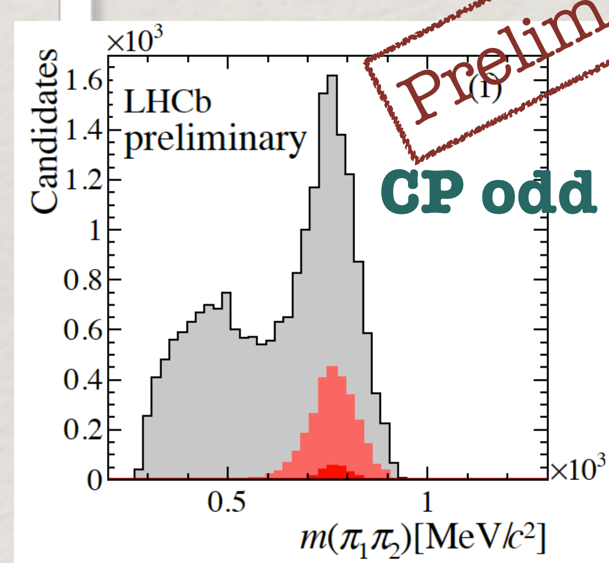
- Two tests:
  - compare $\mathbf{D^0}$ and $\mathbf{\bar{D}^0}$ CP-even
  - compare $C_T>0$ and $C_T<0$ (triple product) CP-odd

M. Gersabeck, WG7, Tuesday

- From simulation, sensitivity for CP violation at least 3σ found to be
  - ~ 4-5% in amplitude
  - ~ 3-4° in phases
  - assuming main contribution coming from $a_1(\rho^0\pi)\pi$ and $\rho^0\rho^0$







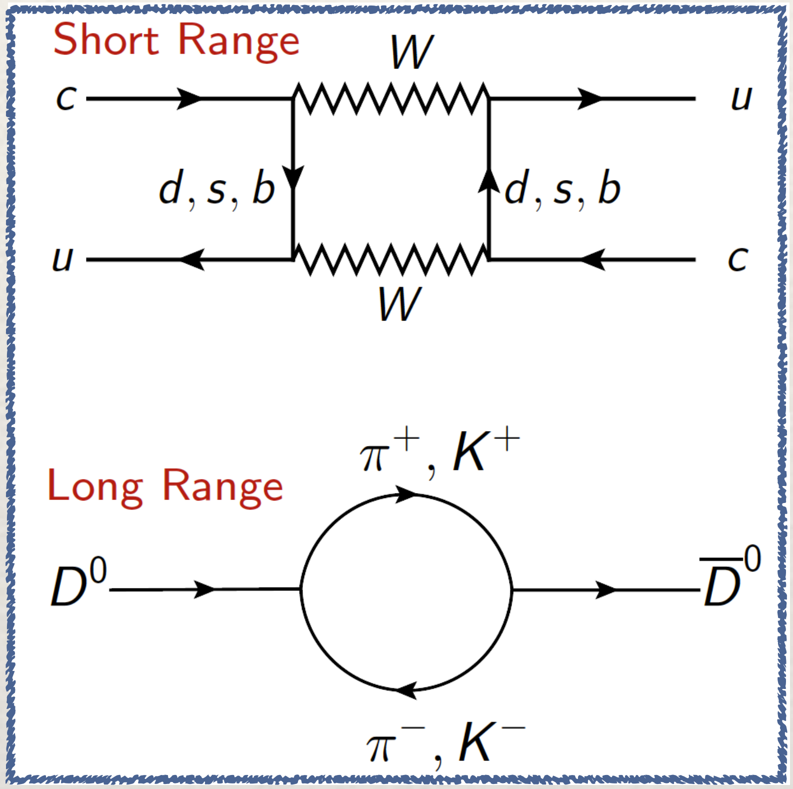
CP odd marginally consistent with CP conservation

Mixing and Indirect CP violation

Mixing and Indirect CP violation

- Mixing in the up-quark sector only occurs for D meson
  already firmly established

- Both short- and long-distance effects contribute:



$$|D_1\rangle = p|D^0\rangle + q|\bar{D}^0\rangle$$

$$|D_2\rangle = p|D^0\rangle - q|\bar{D}^0\rangle$$

$$m = \frac{m_1 + m_2}{2} \, , \, \Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$$

$$\boxed{x = \frac{\Delta m}{\Gamma}} \qquad \boxed{y = \frac{\Delta \Gamma}{2\Gamma}}$$

- **Indirect CP violation** with very modest expectations in the SM
  - Occur if $|q/p| \neq 1$ or $\phi = \arg(q/p) \neq 0$

- CP violation observables in mixing/induced: $\mathbf{A_\Gamma}$, $\mathbf{y_{CP}}$

Indirect CP violation: fundaments

- Two CP-related observables: A_Γ and y_{CP}
- With still no sign of direct CP violation in $D^0 \to KK, \pi\pi$ at $\mathcal{O}(10^{-3})$,

A_Γ primarily probes indirect CP violation:

CP violation in interference

$$A_\Gamma = \frac{\hat{\Gamma}(D^0 \to f) - \hat{\Gamma}(\bar{D}^0 \to f)}{\hat{\Gamma}(D^0 \to f) + \hat{\Gamma}(\bar{D}^0 \to f)} = \frac{1}{2}\left[\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) y\cos\phi - \left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) x\sin\phi\right]$$

CP violation in mixing

- It relates to $A_{CP}(t)$ by $A_{\mathrm{CP}}(t) \approx a_{\mathrm{CP}}^{\mathrm{dir}} + a_{\mathrm{CP}}^{\mathrm{ind}} \frac{t}{\tau_D}$ with $a_{CP}^{ind} = - A_\Gamma$

- Again, in the absence of direct CP violation, y_{CP} is given by

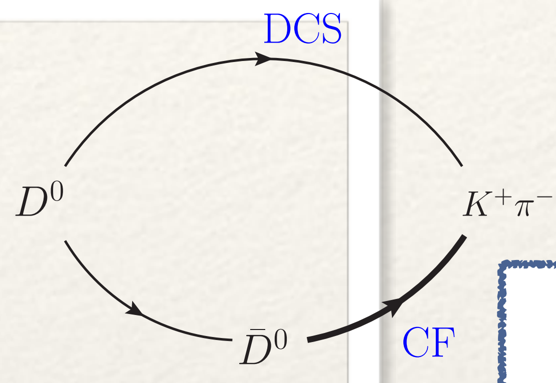
$$y_{\mathrm{CP}} = \frac{\hat{\tau}(D^0 \to K^-\pi^+)}{\hat{\tau}(D^0 \to K^+K^-)} - 1 = \frac{1}{2}\left[\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) y\cos\phi - \left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) x\sin\phi\right]$$

- and $y_{CP} = y$ for no CP violation

Mixing with(out) CPV

$D^0 \to K^{\pm}\pi^{\mp}$

$$R(t)^{\pm} = R_D^{\pm} + \sqrt{R_D^{\pm}}y'^{\pm}\left(\frac{t}{\tau}\right) + \frac{(x'^{\pm})^2 + (y'^{\pm})^2}{4}\left(\frac{t}{\tau}\right)^2$$

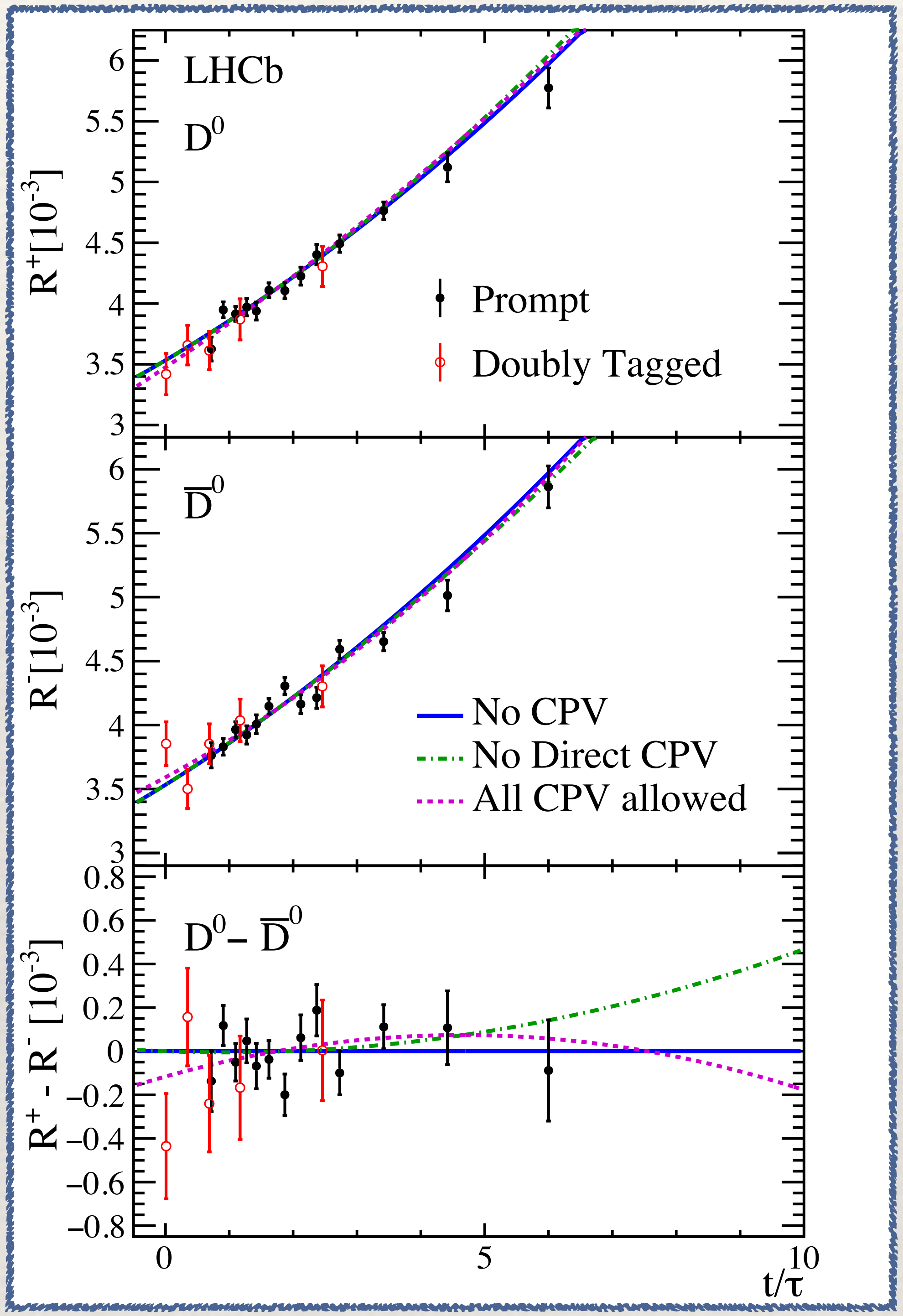


K. Maguire, WG7, Thursday

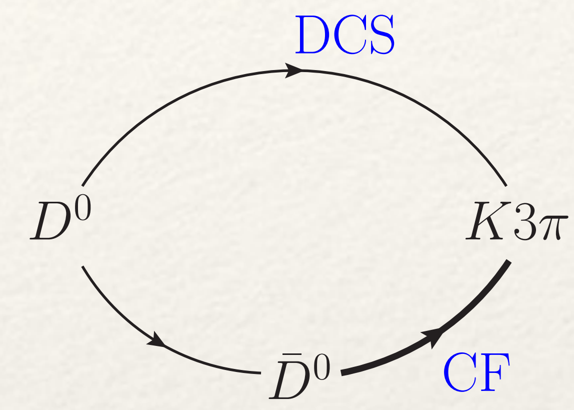
LHCb
arXiv :1611.06143

- Incremental measurement with bins with low decay time from double-tagged events $B \to [D^*(D \to K\pi)\pi]\,\mu\,\nu_\mu$

Parameter	DT + Prompt	Prompt-only
No CPV		
$R_D[10^{-3}]$	3.533 ± 0.054	3.568 ± 0.067
$x'^2[10^{-4}]$	0.36 ± 0.43	0.55 ± 0.49
$y'[10^{-3}]$	5.23 ± 0.84	4.8 ± 0.9
χ^2/ndf	96.6/111	86.4/101
All CPV allowed		
$R_D^+[10^{-3}]$	3.474 ± 0.081	3.545 ± 0.095
$(x'^+)^2\,[10^{-4}]$	0.11 ± 0.65	0.49 ± 0.70
$y'^+[10^{-3}]$	5.97 ± 1.25	5.1 ± 1.4
$R_D^-[10^{-3}]$	3.591 ± 0.081	3.591 ± 0.090
$(x'^-)^2\,[10^{-4}]$	0.61 ± 0.61	0.60 ± 0.68
$y'^-[10^{-3}]$	4.50 ± 1.21	4.5 ± 1.4
χ^2/ndf	95.0/108	85.9/98



Mixing in 4-body!



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

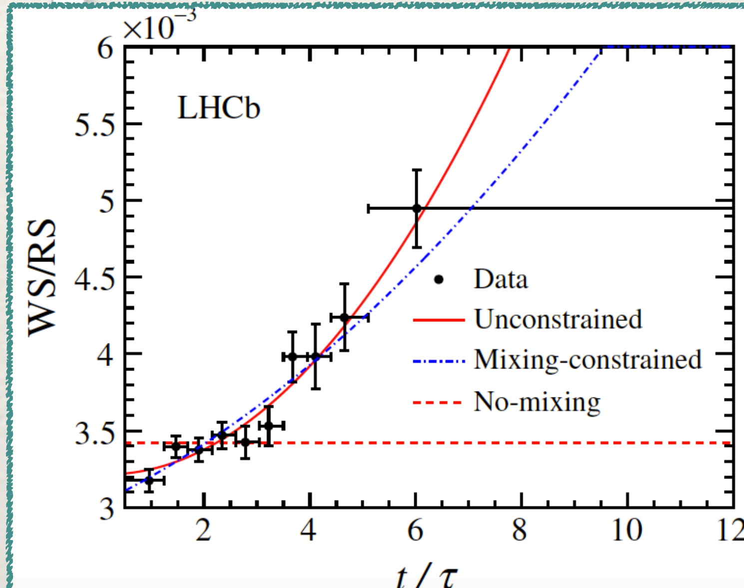
LHCb

PRL 116 (2016) 241801

- D^0 flavour tagged through $D^{*\pm}$ chain
- Measures wrong-sign (WS) to right-sign(RS) in bins of decay time

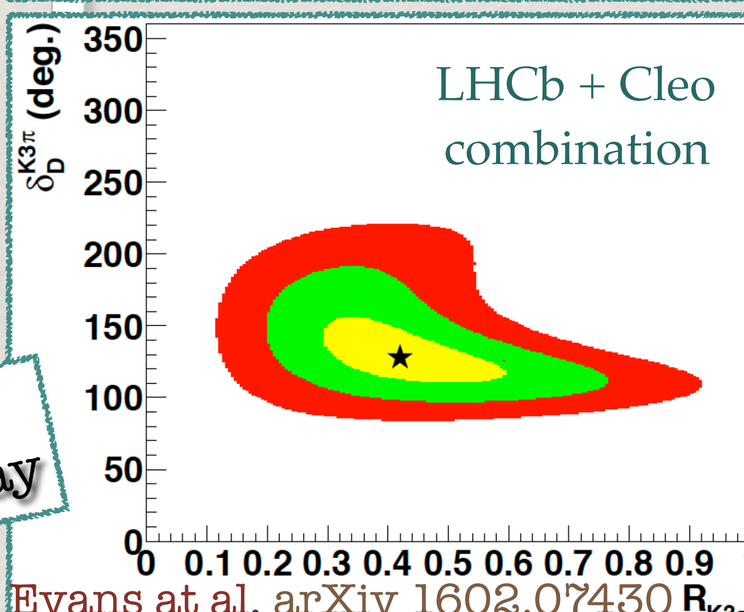
$$R(t) = (r_D^{K3\pi})^2 - r_D^{K3\pi}(R_D^{K3\pi} \cdot y')\frac{t}{\tau} + \frac{x^2+y^2}{4}\left(\frac{t}{\tau}\right)^2$$

$$y' = y\cos\delta_D^{K3\pi} - x\sin\delta_D^{K3\pi}$$



- $r_D^{K3\pi}$, $R_D^{K3\pi}$, $\delta_D^{K3\pi}$ needed for γ in $B \to D(K3\pi)K$
- Fit constraining x, y to world averages:

$$r_D^{K3\pi} = (5.50 \pm 0.07) \times 10^{-2}$$
$$R_D^{K3\pi} \cdot y'_{K3\pi} = (-3.0 \pm 0.7) \times 10^{-3}$$



Evans at al, arXiv 1602.07430

M. Martinelli, WG7, Thursday

S. Harnew, WG5, Thursday

$D^0 \to h^0\pi^+\pi^-$

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

V. Bhardwaj, WG7, Tuesday

PhysRevD 93 (2016) 112014

- Time-dependent Dalitz plot analysis: unbinned logL fit to $(t, s(\pi^-\pi^0), s(\pi^+\pi^0))$

$x = (1.5 \pm 1.2 \pm 0.6)\%$

$y = (0.2 \pm 0.9 \pm 0.5)\%$

$D^0 \to K_S\pi^+\pi^-$

LHCb ($1 fb^{-1}$)

JHEP 04 (2016) 033

- Model independent technique: uses info from Cleo-c: yields T_i and strong phase differences $\Delta\delta_{D,i}$ in Dalitz bins

$x = (-0.86 \pm 0.53 \pm 0.17)\%$

$y = (0.03 \pm 0.46 \pm 0.13)\%$

- The way to go in the future!

  Dalitz modelling adds irreducible systematics!

M. Martinelli, WG7, Thursday

$D^0 \to h^0 \pi^+ \pi^-$

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

V. Bhardwaj, WG7, Tuesday

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M. Martinelli, WG7, Thursday

$D^0 \to h^0\pi^+\pi^-$

R-X Lyu, WG7, Thursday

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

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$D^0 \to K_S \pi^+ \pi^-$ — LHCb ($1 fb^{-1}$)

JHEP 04 (2016) 033

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- The way to go in the future!

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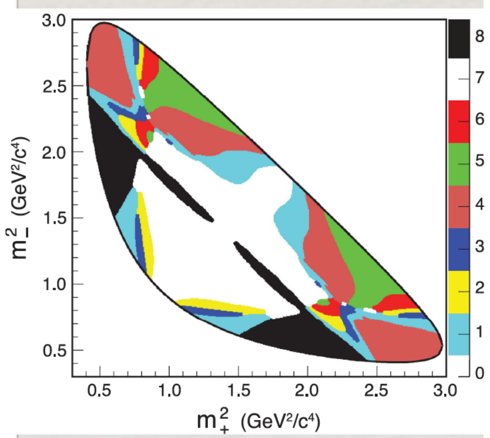
M. Martinelli, WG7, Thursday

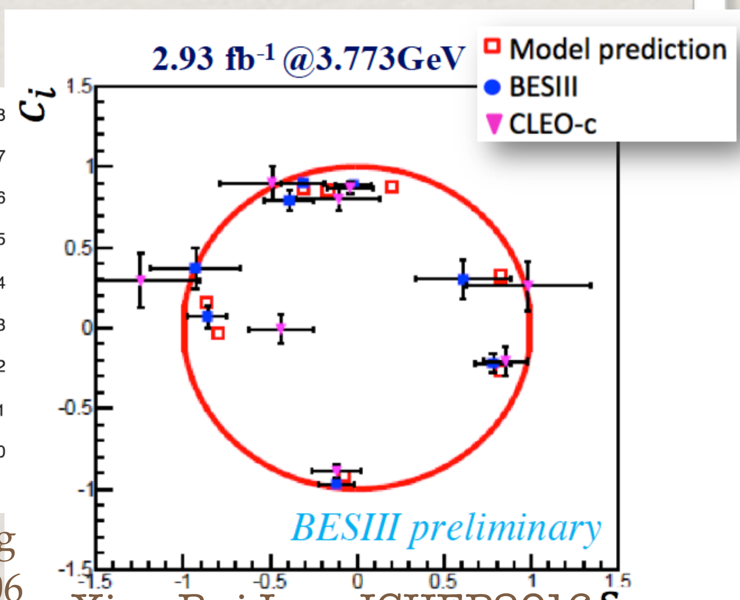
$D^0 \to K_S \pi^+ \pi^-$ — BESIII

preliminary at CHARM & others

- Quantum correlations in $\psi(3370)$ to tag D flavour and CP
- Obtain $c_i = \cos(\Delta\delta_{D,i})$ and $s_i = \sin(\Delta\delta_{D,i})$
- Precision improved wrt to Cleo-c
- Fundamental for the GGSZ method for γ - uncertainty due to c_i, s_i reduced by ~40%



BaBar 2008 optimal binning
CLEO, PRD 82 (2010) 112006



Xiao-Rui Lyu, ICHEP2016

Recent results on A_Γ and y_{CP}: Belle and BES

BES III PLB 744 (2015) 339

- Quantum-correlated pairs D^0 - $\bar{D}^0$
- CP-tagging technique:
  - one D^0 CP-tagged (via a few CP eigenstates)
  - the other decaying semi-leptonically (combined Keν and Kμν)

$$y_{CP} \approx \frac{1}{4}\left(\frac{\mathcal{B}_{D_{CP-}\to l}}{\mathcal{B}_{D_{CP+}\to l}} - \frac{\mathcal{B}_{D_{CP+}\to l}}{\mathcal{B}_{D_{CP-}\to l}}\right)$$

- Assuming no direct CP violation,

y_{CP} = (-2.0±1.3±0.7)%

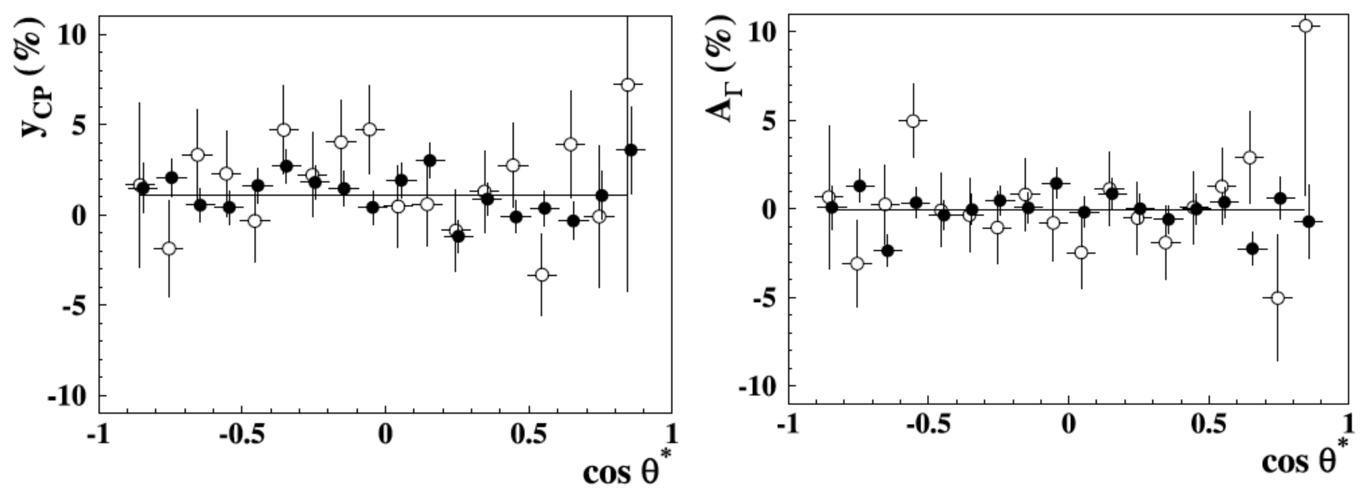
- Still statistically limited but should improve with other channels being added

R-X Lyu, WG7, Thursday

Belle PLB 753 (2016) 412

- Final data set
- Simultaneous fit to $D^0 \to K^-\pi^+$, $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$
- Fits in bins of cosθ*

y_{CP} = (1.11±0.22±0.09)%
A_Γ = (-0.03±0.20±0.07)%



V. Bhardwaj, WG7, Tuesday

New results on A_Γ : LHCb

K. Maguire, WG7, Thursday

- **LHCb updates D^*-tagged A_Γ with two different techniques**

Unbinned Method

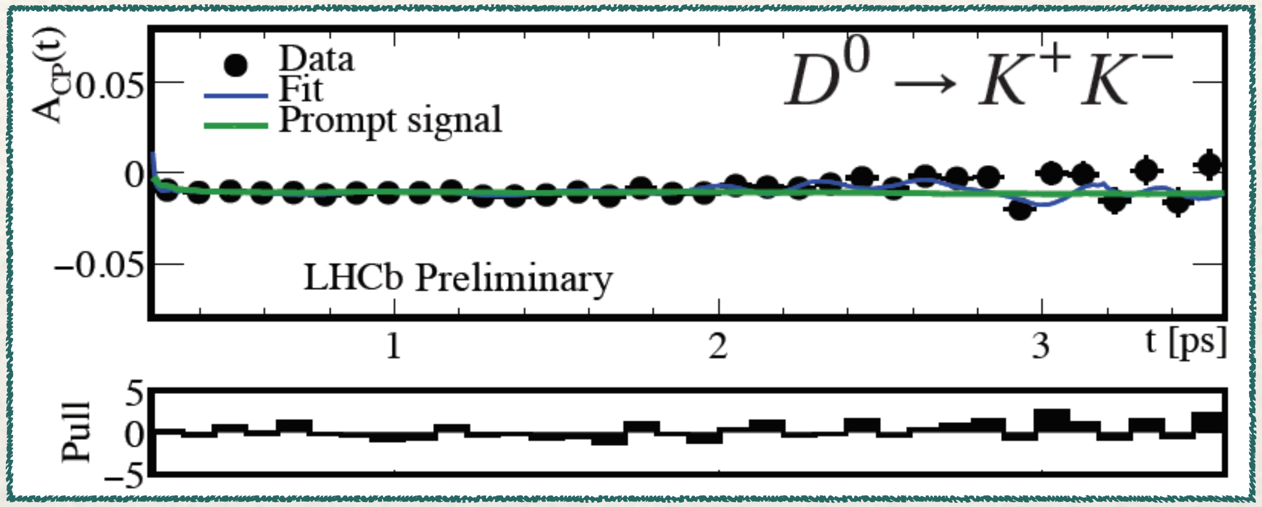
LHCb-CONF-2016-010

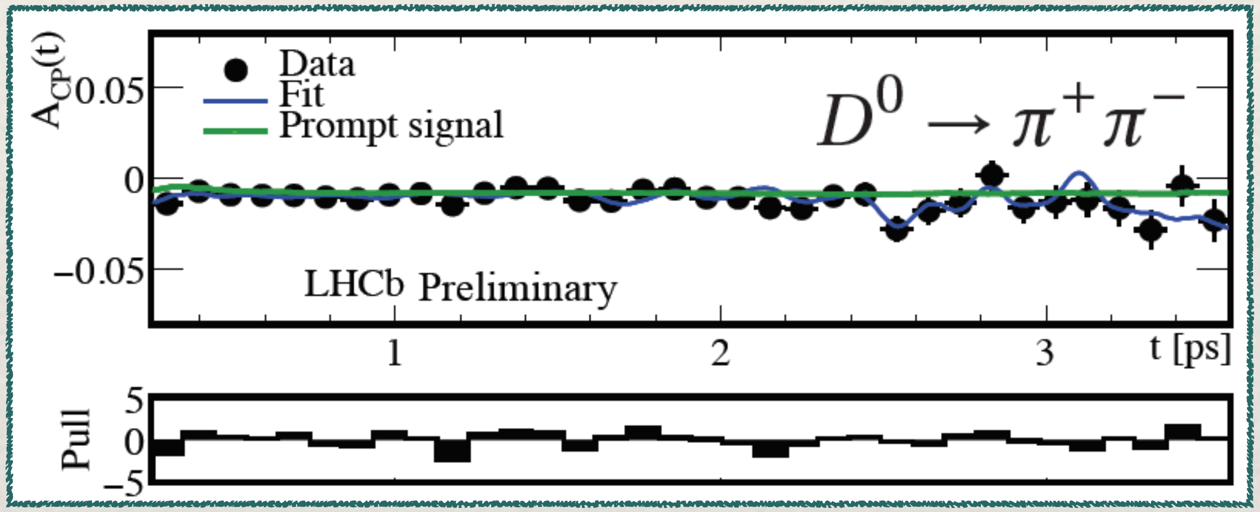
- Analysis with 2012 data sample ($2fb^{-1}$)
- Unbinned maximum likelihood fits to obtain the effective lifetimes
- Per-event acceptance (swimming method)

- Check with control channel $D^0 \to K^-\pi^+$:

$A_\Gamma^{(K\pi)}$ (2012) = $(-0.07\pm0.15)\times10^{-3}$ ✅

- Combine with previous results from 2011 ($1fb^{-1}$)





Preliminary

2011+2012 Combination ($3\ fb^{-1}$)

A_Γ (KK) = $(-0.14\pm0.37\pm0.10)\times10^{-3}$

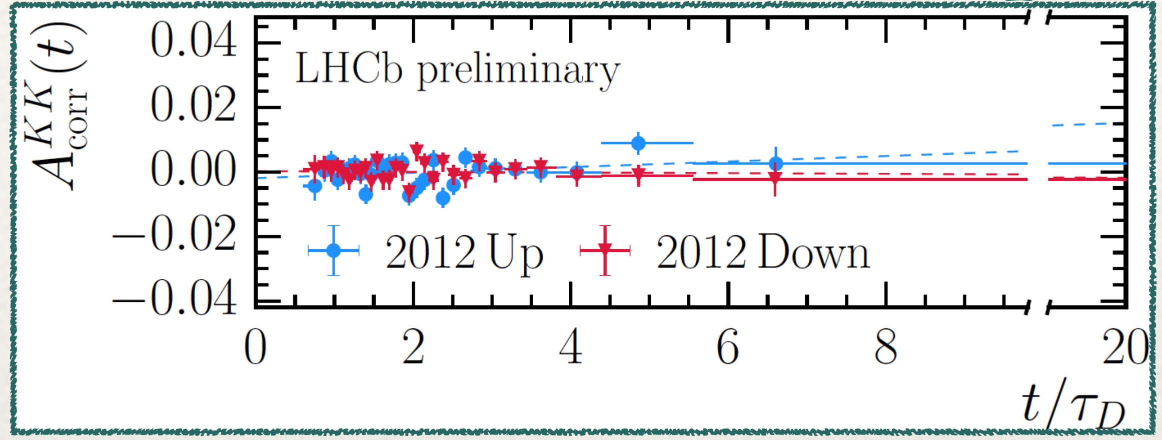
A_Γ ($\pi\pi$) = $(0.14\pm0.63\pm0.15)\times10^{-3}$

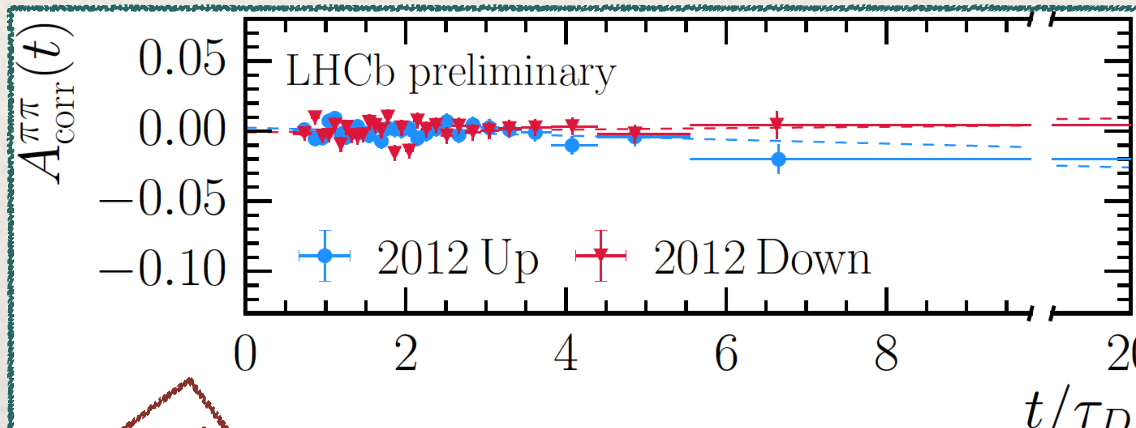
$A_\Gamma = (-0.07\pm0.32\pm0.11)\times10^{-3}$

New results on A_Γ : LHCb

K. Maguire, WG7, Thursday

LHCb updates D*-tagged A_Γ with two different techniques





Binned Method

LHCb-CONF-2016-009

- Analysis with full data ($3fb^{-1}$)
- Asymmetry $A_{CP}(t)$ looked in bins of decay proper time

$$A_{CP}(t) = a^{dir}_{CP} - \frac{t}{\tau_D} A_\Gamma$$

- Detection asymmetries are corrected using control channel $D^0 \to K^-\pi^+$. A_Γ consistent to zero

$A_\Gamma^{K\pi} = (0.16 \pm 0.10) \times 10^{-3}$ ✅

Preliminary

Full 3 fb^{-1} results:

A_Γ (KK) = $(-0.30 \pm 0.32 \pm 0.14) \times 10^{-3}$

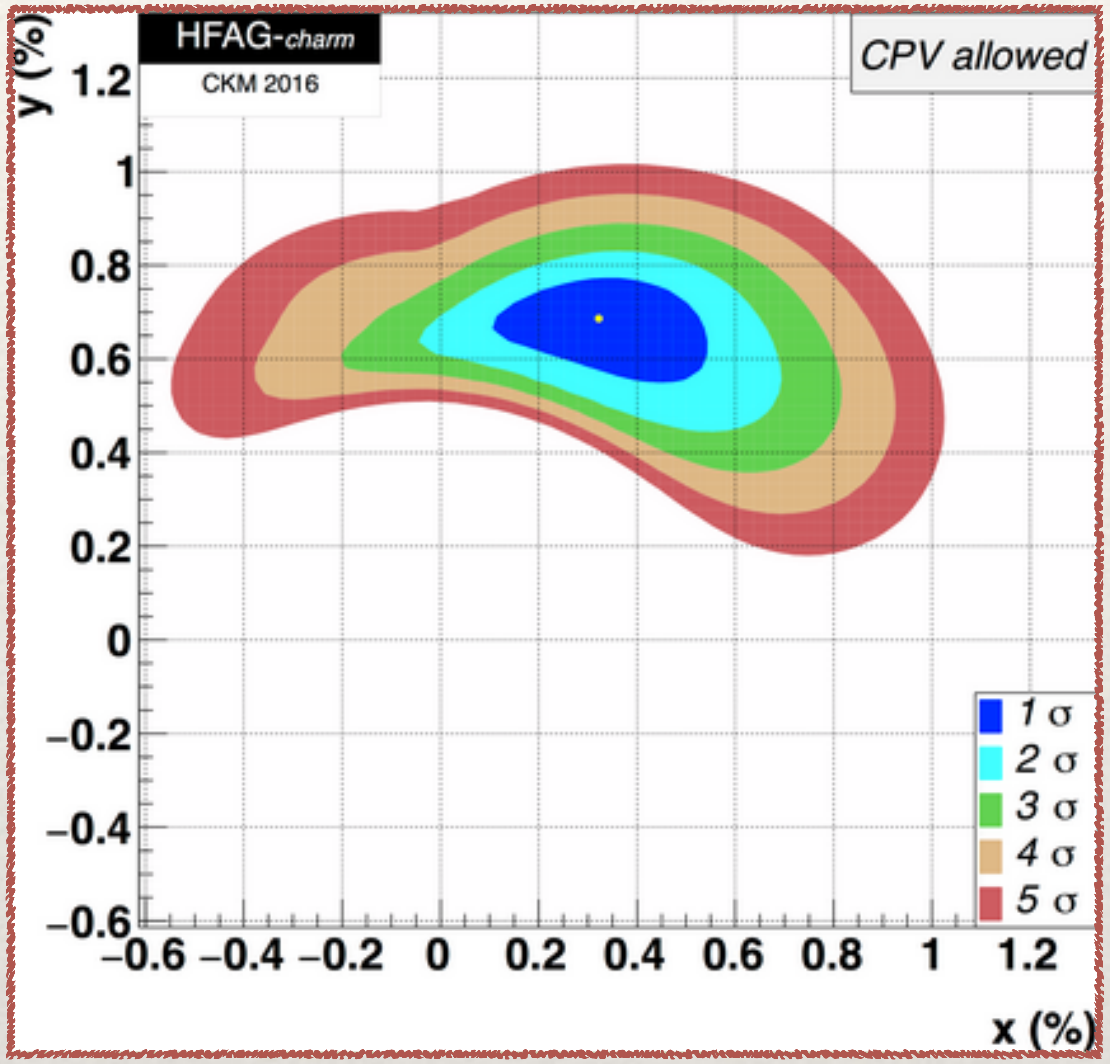
A_Γ ($\pi\pi$) = $(0.46 \pm 0.58 \pm 0.16) \times 10^{-3}$

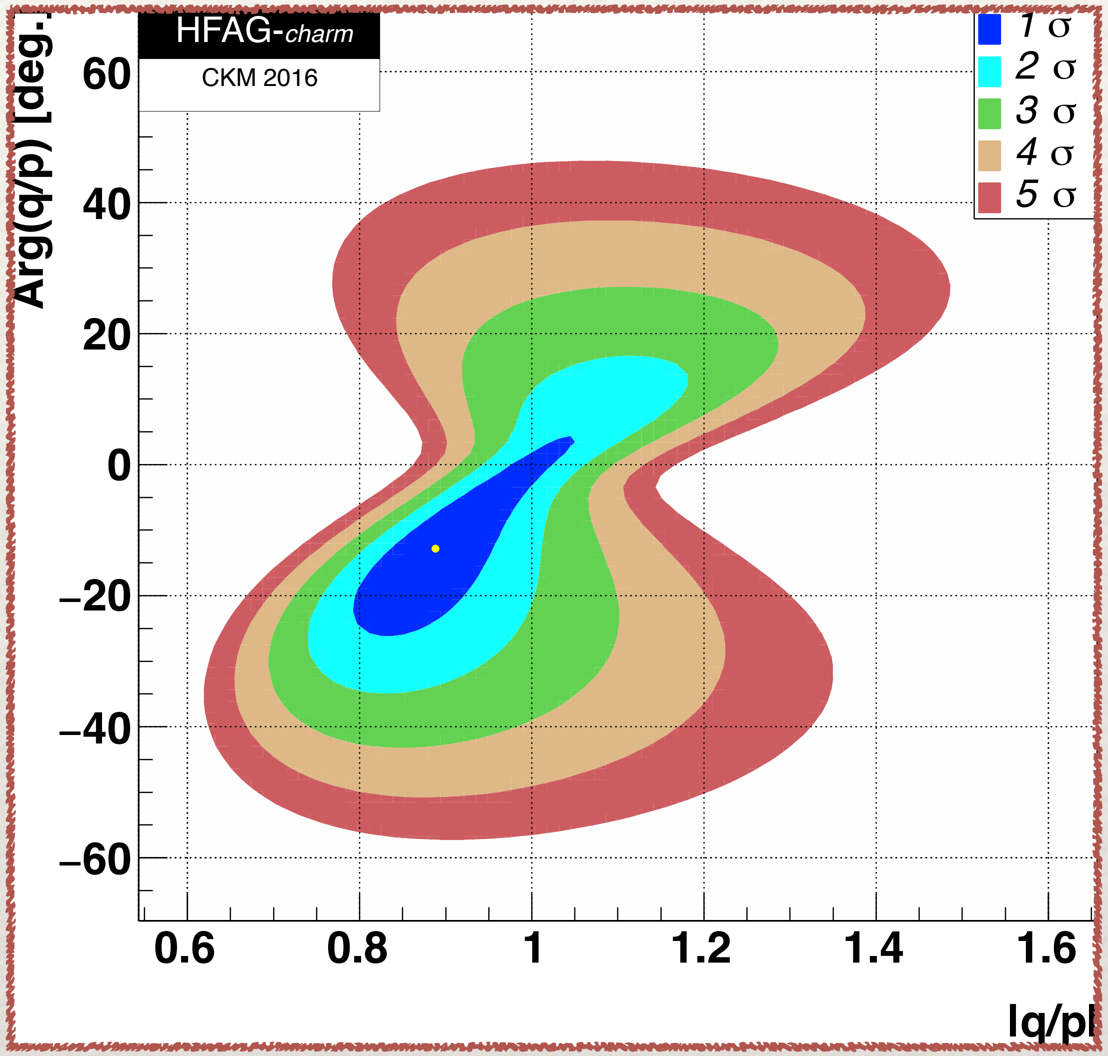
$A_\Gamma = (-0.12 \pm 0.28 \pm 0.10) \times 10^{-3}$

Most precise CP violation measurement so far!

So: There is Mixing….

HFAG Status 2016





$x = 0.32 \pm 0.14$

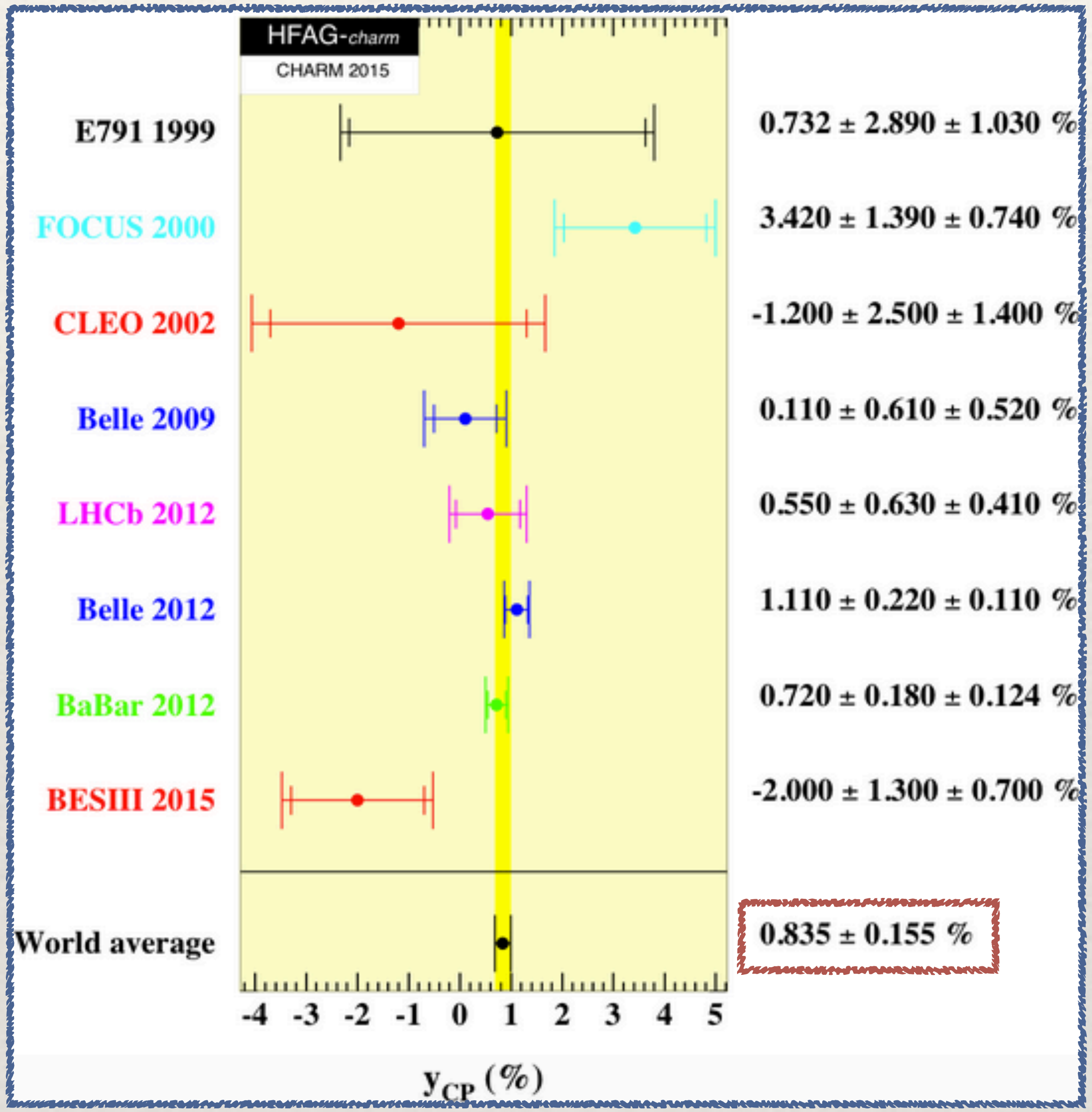
$y = 0.69_{-0.07}^{+0.06}$

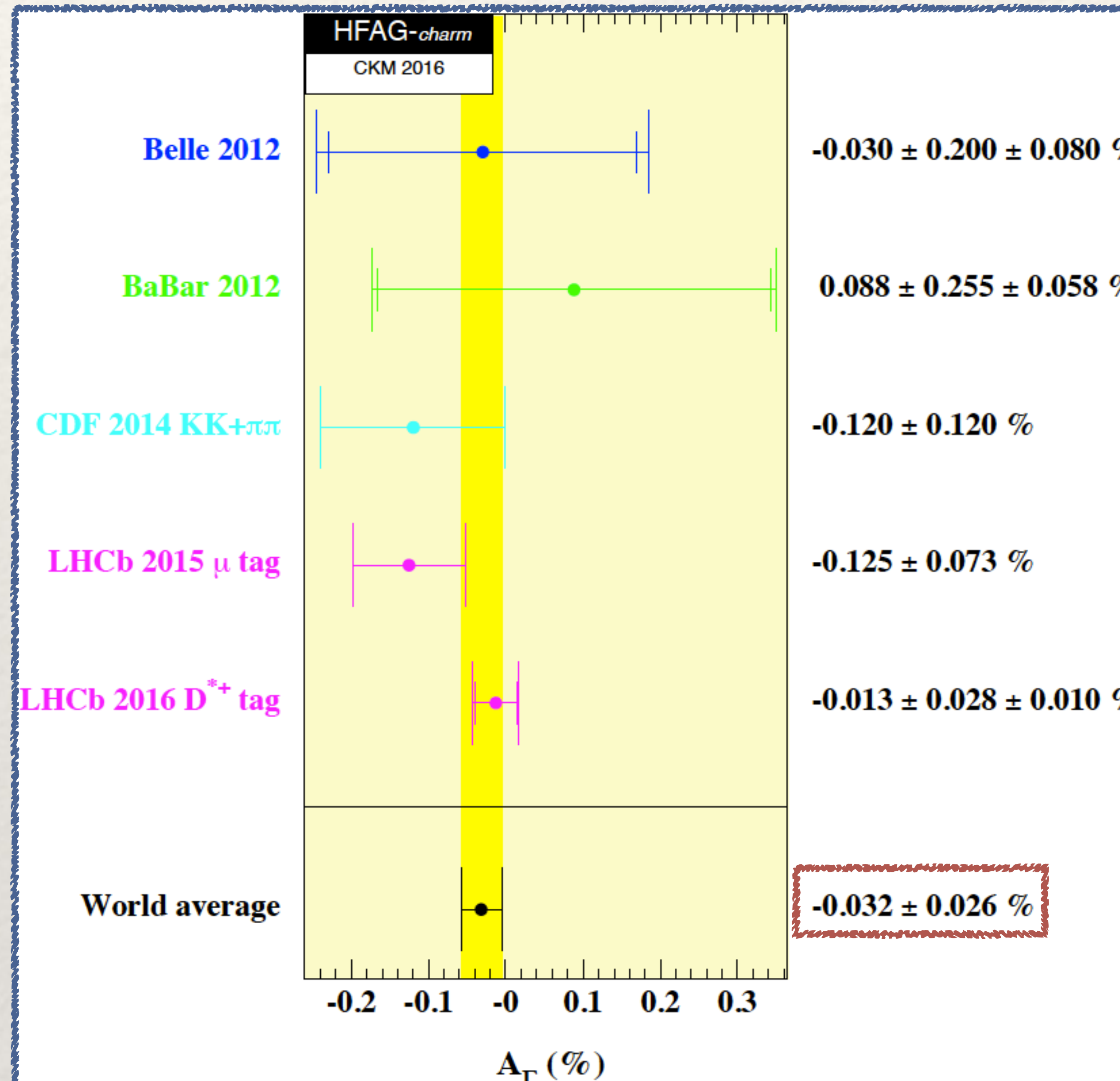
$|q/p| = 0.89_{-0.07}^{+0.08}$

$\varphi = (-12.9_{-8.7}^{+9.9})^{o}$

... yet no CP violation in mixing

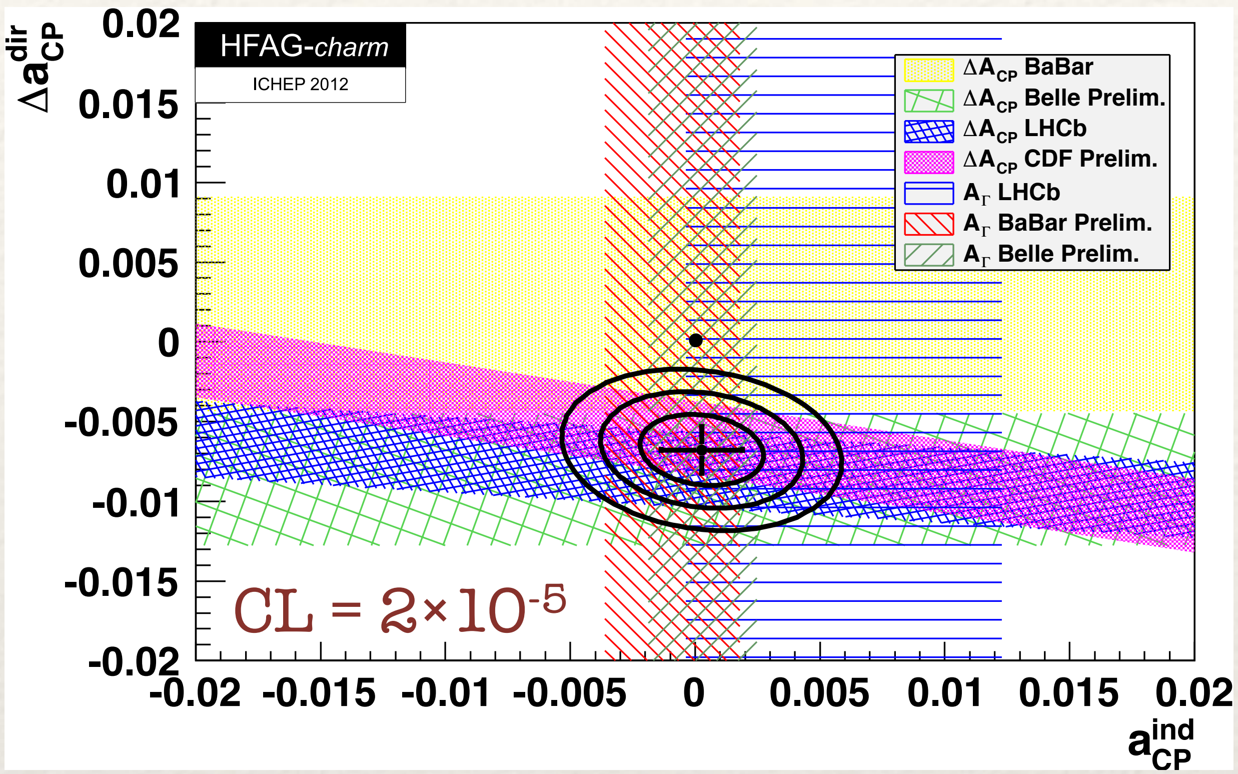
HFAG Status 2016



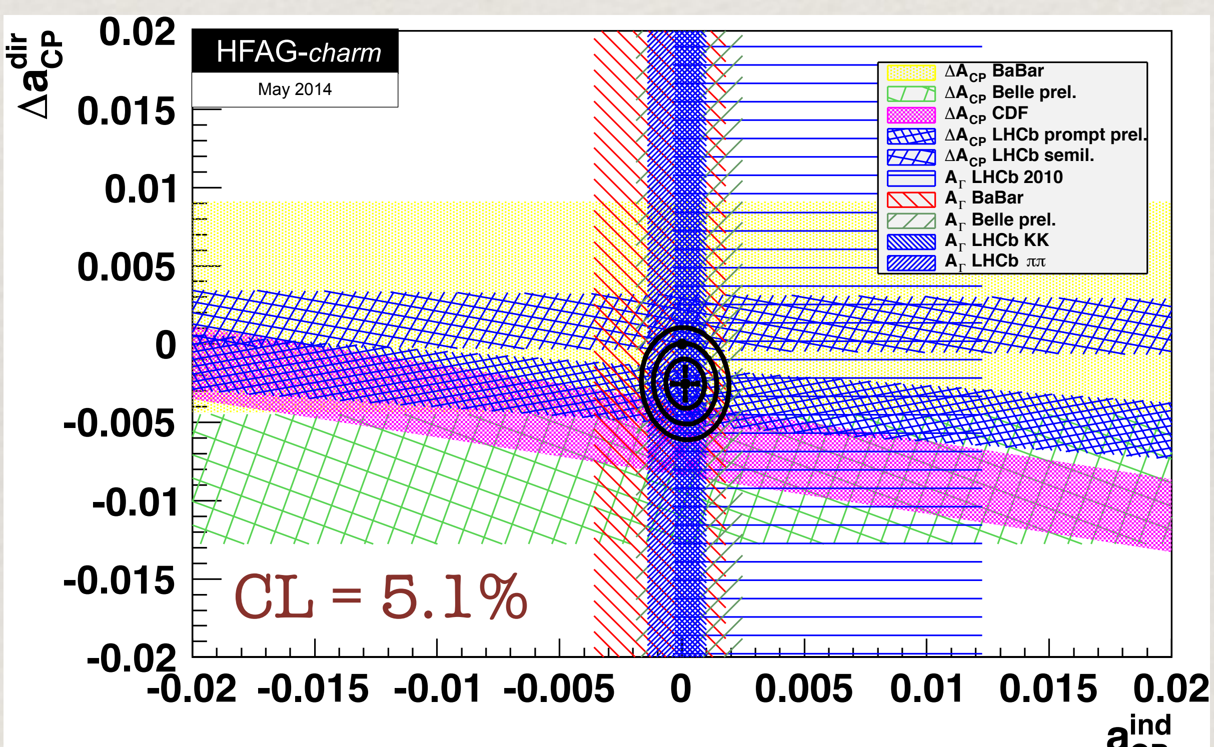


… and no Direct CP violation

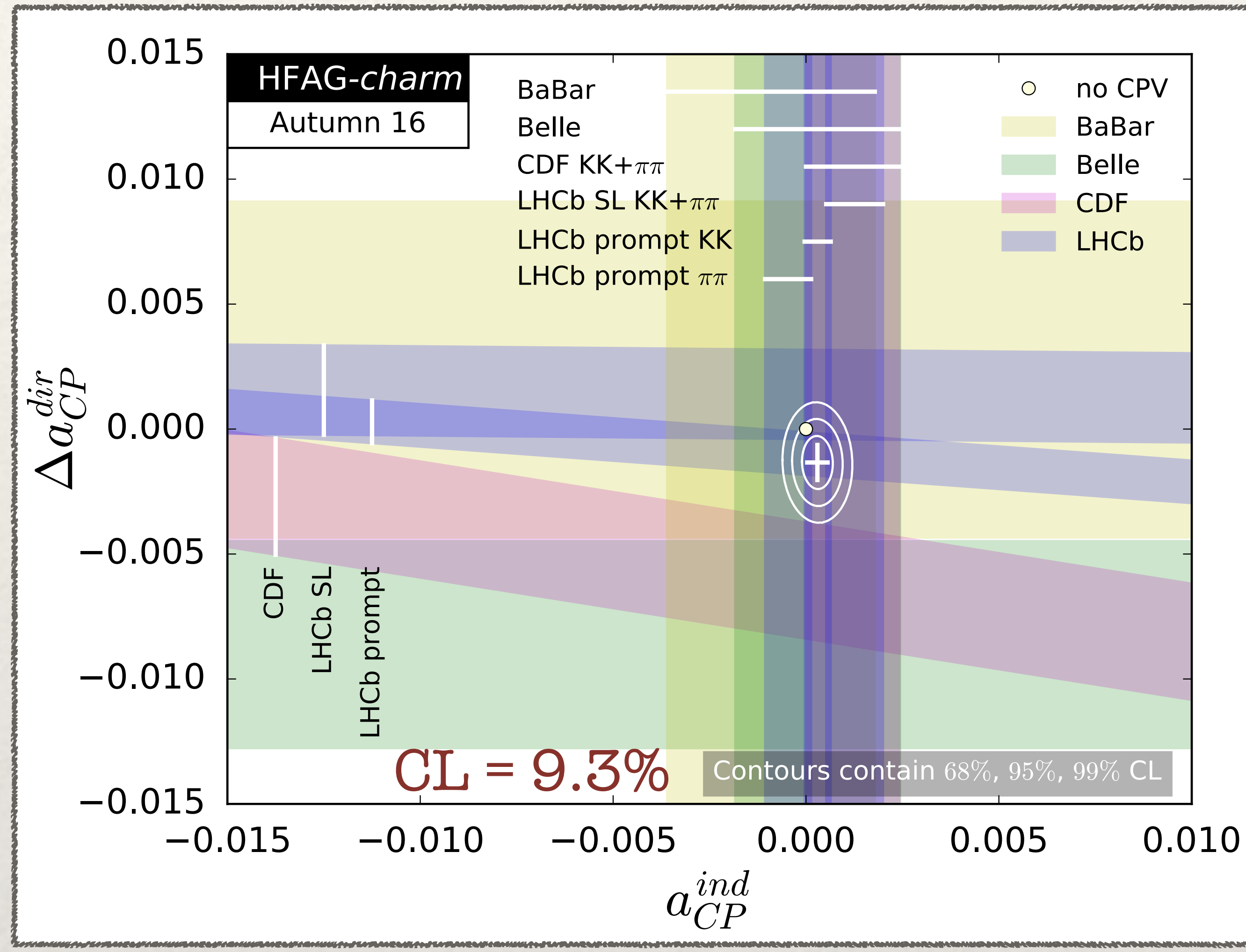
HFAG Status 2012



HFAG Status 2014



HFAG Status 2016



$$a_{CP}^{ind} = (3.0 \pm 2.6)\times 10^{-4}$$
$$\Delta a_{CP}^{dir} = (-1.3 \pm 0.7)\times 10^{-3}$$

V_{cd} and V_{cs}

CKM elements: V_{cd} and V_{cs}

- Charm leptonic and semi-leptonic decays enable the measurement of CKM elements $|V_{cd}|$ and $|V_{cs}|$

$$\mathcal{B}(D_q^+ \to \ell^+\nu_\ell) = \frac{G_F^2}{8\pi}\tau_{D_q} f_{D_q}^2 |V_{cq}|^2 m_{D_q} m_\ell^2 \left(1 - \frac{m_\ell^2}{m_{D_q}^2}\right)$$

$$\frac{d\Gamma(D \to P\bar{\ell}\nu_\ell)}{dq^2\, d\cos\theta_\ell} = \frac{G_F^2 |V_{cq}|^2}{32\pi^3} p^{*\,3} |f_+(q^2)|^2 \sin\theta_\ell^2$$

- Theoretical input is necessary: decay constants f_{Ds}, f_D and form-factors $f_+^{K,\pi}(q^2=0)$ ➪ coming from Lattice QCD

- Fundamental for precise test of CKM unitarity in the second row

- More recent (< 2y) experimental activity comes from BaBar and BESIII (important increase in precision)

CKM elements: new results

BES III

H. Ma, WG1, Tuesday

$D^+_s \to \mu(\tau)\nu$ PRD 94, 072004 (2016)

$\mathcal{B}(D^+_s \to \mu^+\nu_\mu) = (0.517 \pm 0.075 \pm 0.021)\%$

$\mathcal{B}(D^+_s \to \tau^+\nu_\tau) = (3.28 \pm 1.83 \pm 0.37)\%$

$D^+ \to \mu^+\nu_\mu$ PRD 89, 051104(R) (2014)

$f_{D+}|V_{cd}| = (45.75 \pm 1.20 \pm 0.39)$ MeV

$D^0 \to \pi^- e^+\nu_e$ PRD 92 (2015) 072012

$f_+^\pi(0)\ |V_{cd}| = 0.1435 \pm 0.0018 \pm 0.0009$

$D^0 \to K^- e^+\nu_e$

$f_+^K(0)\ |V_{cs}| = 0.7172 \pm 0.0025 \pm 0.0035$

Y. Zheng, WG1, Tuesday

$D^+ \to K_L^0 e^+\nu_e$ PRD 92 (2015) 112008

$f_+^K(0)\ |V_{cs}| = 0.728 \pm 0.006 \pm 0.011$

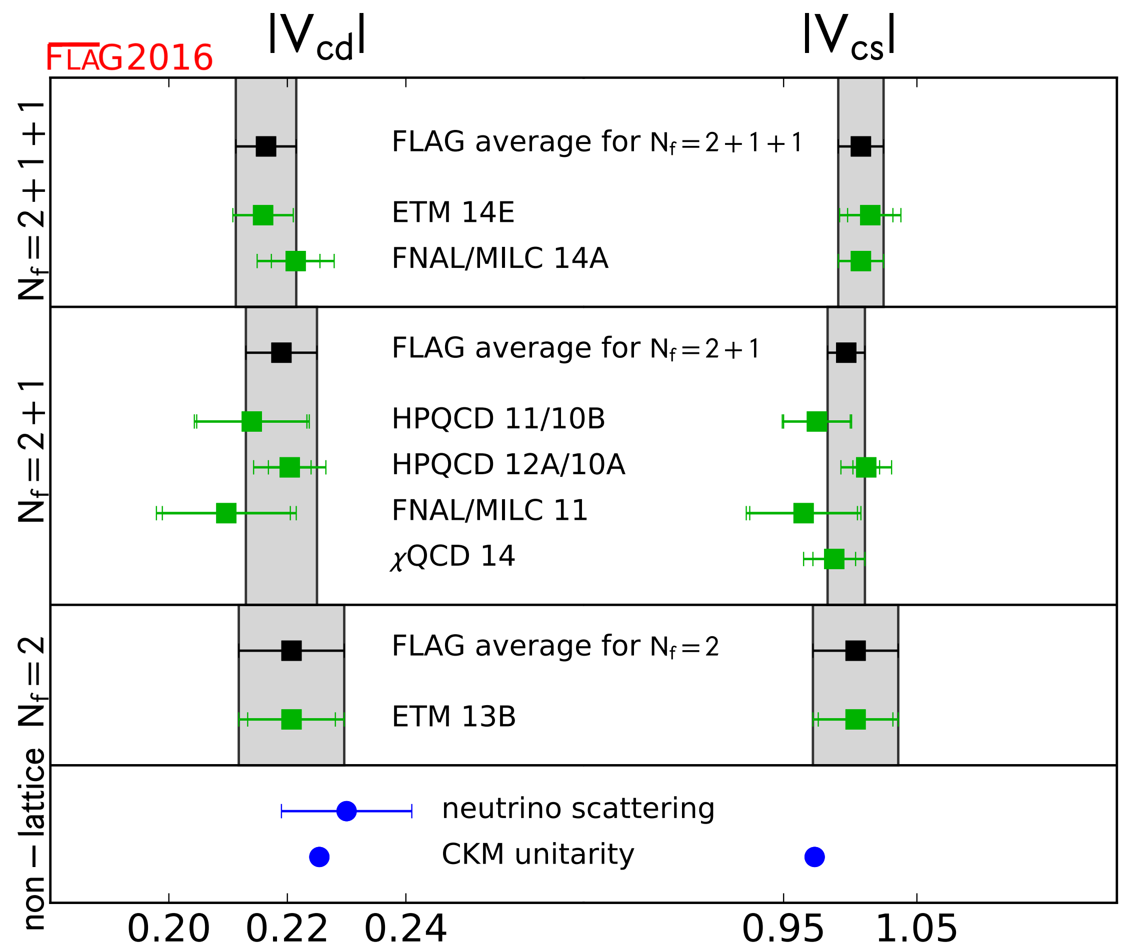
A. Soffer, WG1, Tuesday

$D^0 \to \pi^- e^+\nu_e$ **BaBar** PRD 91 (2015) 052022

$f_+^\pi(0)\ |V_{cd}| = 0.1374 \pm 0.0038 \pm 0.0022 \pm 0.0009$

$|V_{cd}| = 0.206 \pm 0.007_{exp} \pm 0.009_{LQCD}$

V_{cd} and V_{cs}: status from FLAG



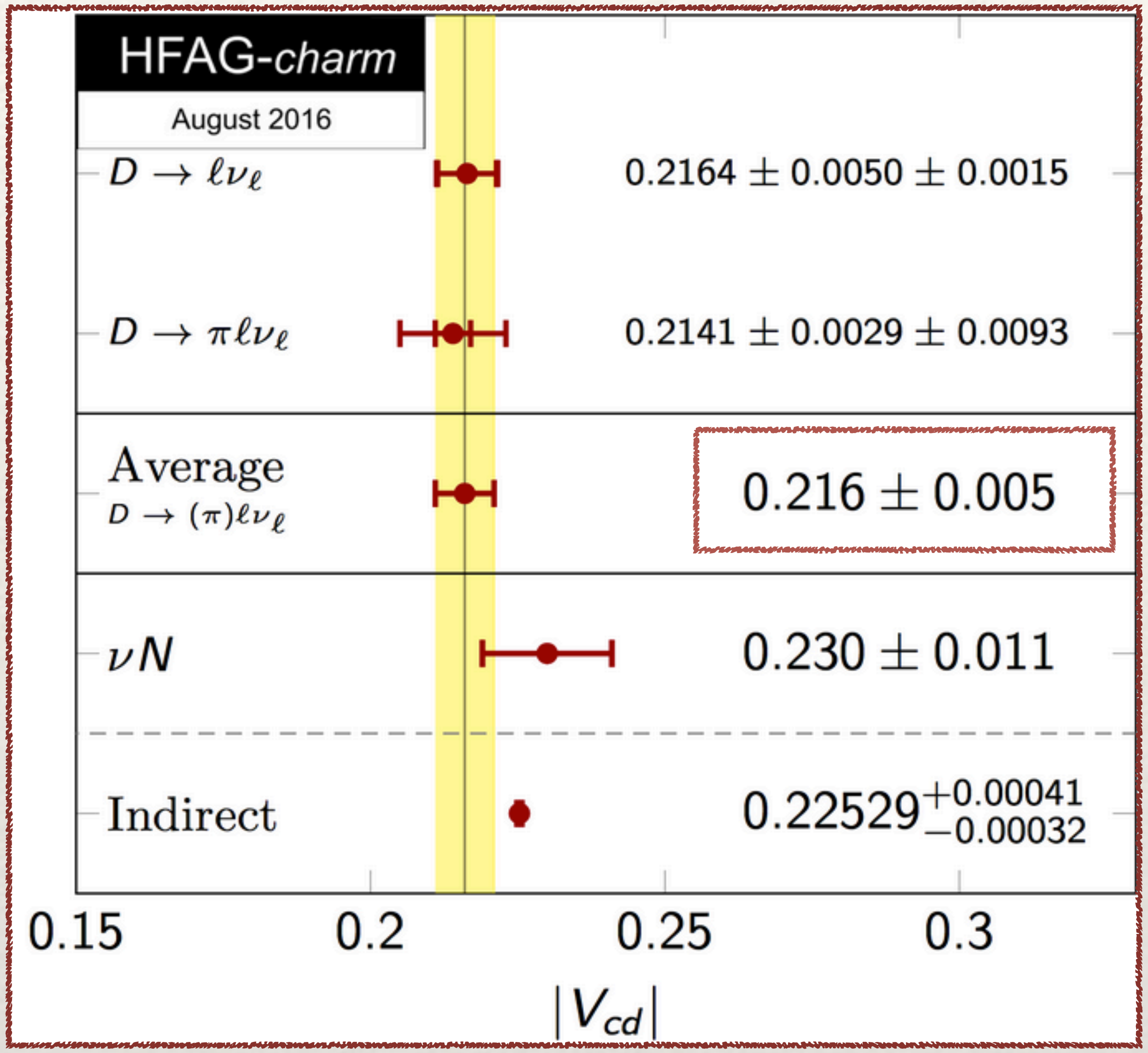
S. Aoki et al., arXiv:1607.00299

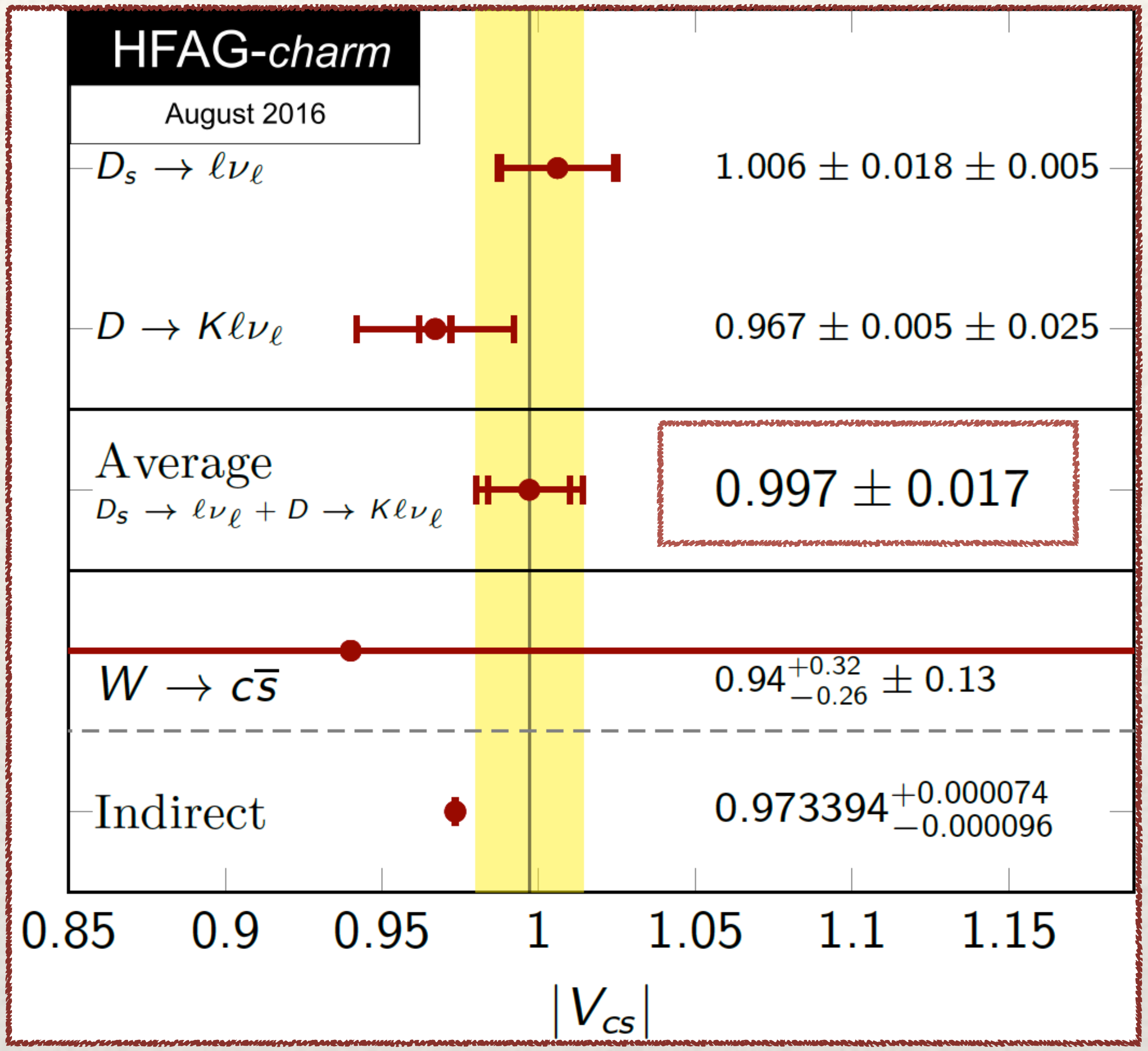
Uses:
- PDG (2016) averages for lept. decays
- HFAG (2014) averages for semi-lept. decays

	from	Ref.	$\lvert V_{cd}\rvert$	$\lvert V_{cs}\rvert$
$N_f = 2+1+1$	f_D & f_{D_s}		0.2164(51)	1.008(17)
$N_f = 2+1$	f_D & f_{D_s}		0.2195(61)	1.004(18)
$N_f = 2$	f_D & f_{D_s}		0.2207(89)	1.004(32)
$N_f = 2+1$	$D \to \pi\ell\nu$ and $D \to K\ell\nu$		0.2140(97)	0.975(26)
PDG	neutrino scattering	[25]	0.230(11)	
Rosner 15 (*for the* PDG)	CKM unitarity	[2]	0.2254(7)	0.9733(2)

a few 2σ tensions when compared to values constrained by CKM unitarily

CKM elements: status from HFAG





Updated with most recent results from BaBar and BES III

LHCb entering the game?
A. Davis, WG1, Tuesday

… not to forget: Baryons

- Charmed baryons can provide important information on weak/strong dynamics in general, complementary to that from D mesons

- In particular, in the CKM context,
  - Input for Λ_b physics (including V_{ub})
  - Search for CP violation in the SCS decays $\Lambda_c^+ \to p\,\pi^+\pi^-$ and $\Lambda_c^+ \to p\,K^+K^-$

- News from Belle and BES III:

BES III arXiv:1608.00407

- Measures $\Lambda_c^+ \to p\,\pi^+\pi^-$ and $\Lambda_c^+ \to p\,K^+K^-$ BR relative to $\Lambda_c^+ \to pK^+\pi^-$

Belle PRL 117, 011801 (2016)

- 1st observation of the DCS $\Lambda_c^+ \to p\,\pi^+K^-$

BES III PRL 116 (2016) 052001

- 12 Λ_c^+ BF measured, including $\Lambda_c^+ \to p\,K^+\pi^-$ used for normalisation

Conclusions …

Mat Charles

Charm plenary @ CKM 2014

Futurology

CKM 2016:

- LHCb will be the main game in town.
- Data on tape will be worth about a factor 2 more than today.
- Hopefully all Run I analyses finished. Notable absences today include:
  - y_{CP} in $D^0 \to h^+h^-$
  - (x,y) from $D^0 \to K_S\, h^+h^-$
- Some early Run II charm analyses
- Solid improvement but not statistical jump w.r.t. today
- More input from BES-III, especially for $D^0 \to$ KS h^+h^- ?

Conclusions …

Mat Charles
Charm plenary @ CKM 2014

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  - y_{CP} in $D^0 \to h^+h^-$ — from BESIII & Belle but not LHCb 😟
  - (x,y) from $D^0 \to K_S\, h^+h^-$ — 1 fb^{-1} 😐
- Some early Run II charm analyses ✅
- Solid improvement but not statistical jump w.r.t. today ✅
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Conclusions …

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Charm plenary @ CKM 2014

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- Some early Run II charm analyses ✅
- Solid improvement but not statistical jump w.r.t. today ✅
- More input from BES-III, especially for $D^0 \rightarrow KS\ h^+h^-$? ✅ 🎉

- Since CKM2014, there were really a number of interesting results in Charm Physics!
- Special mention to
  - LHCb runI completion of A_Γ and ΔA_{CP}
  - 1st observation of mixing in a 4-body decay (LHCb)
  - Still some nice results from BaBar and Belle!
  - BESIII efforts on $K_S\pi\pi$, $|V_{cq}|$ absolute BF's of Λ_c decays

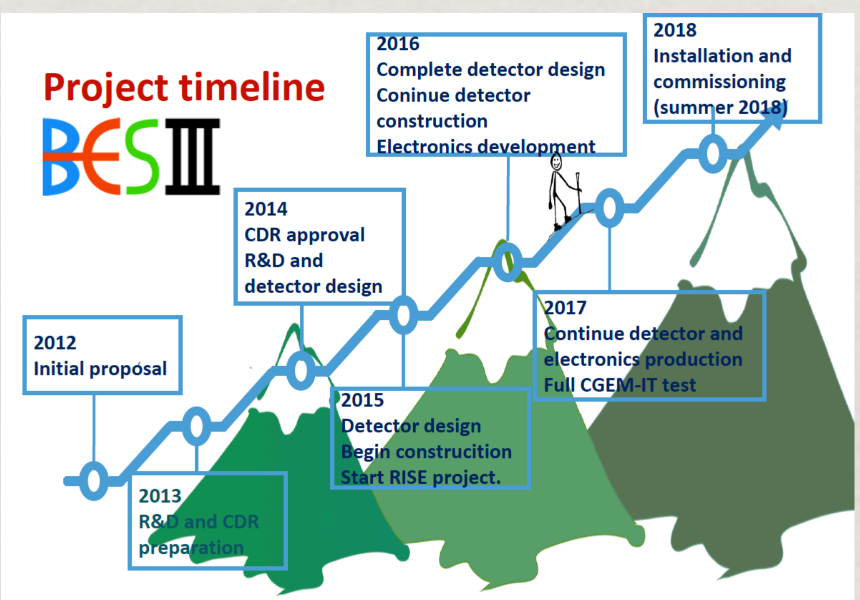
for BESIII & LHCb synergy, see LHCb-PUB-2016-025

…and what's next?

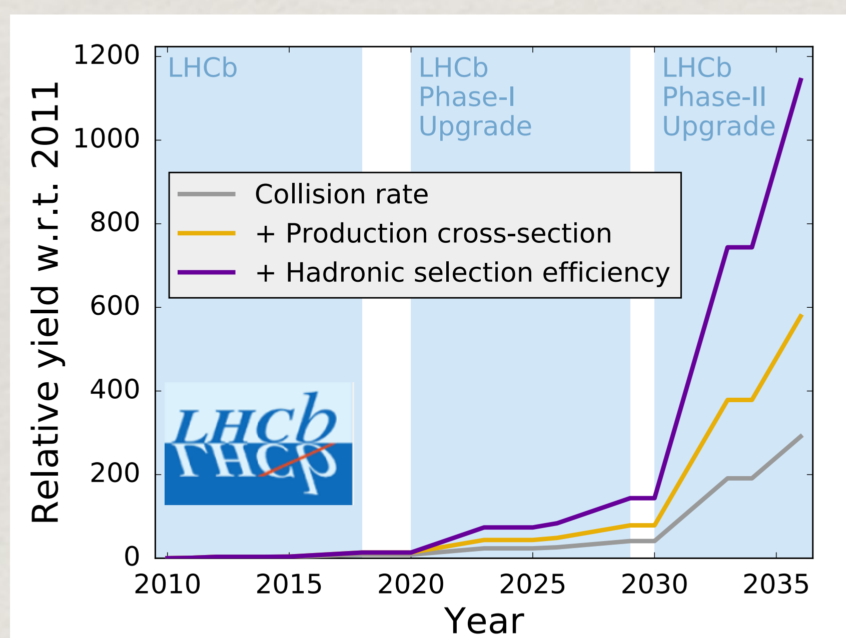
- For a few modes already reaching 10^{-3}, the observation of CP violation will no longer be a sign of New Physics
- Yet, specially for direct CP violation, we do not know where it would appear first, either due to SM or NP

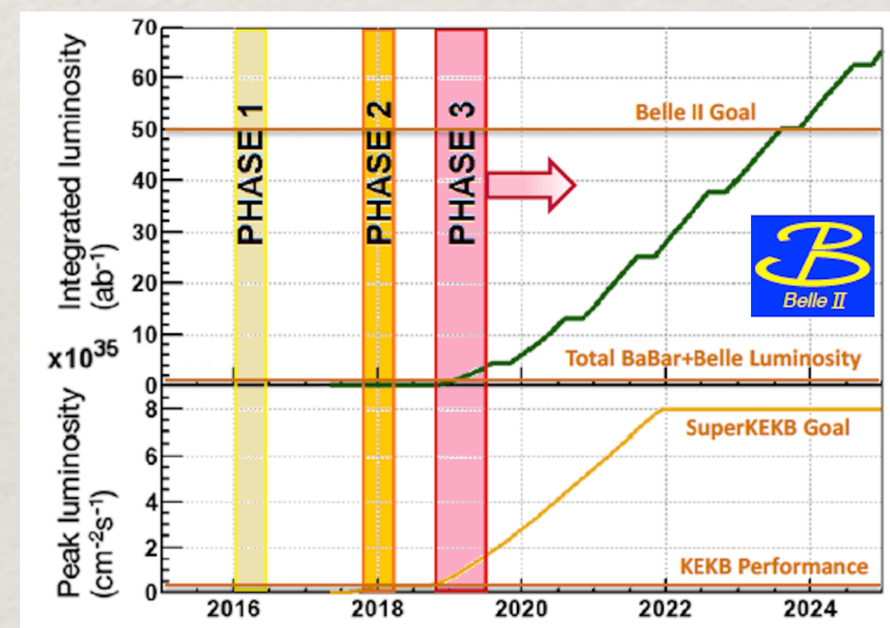
LOOK EVERYWHERE!

- Various analyses still in the oven with current data!
- Next couple of years will witness fresh data from LHCb and BESIII
- … and soon Belle 2 comes into the game



X. Shen, CHARM 2016





Alan Schwartz, CHARM