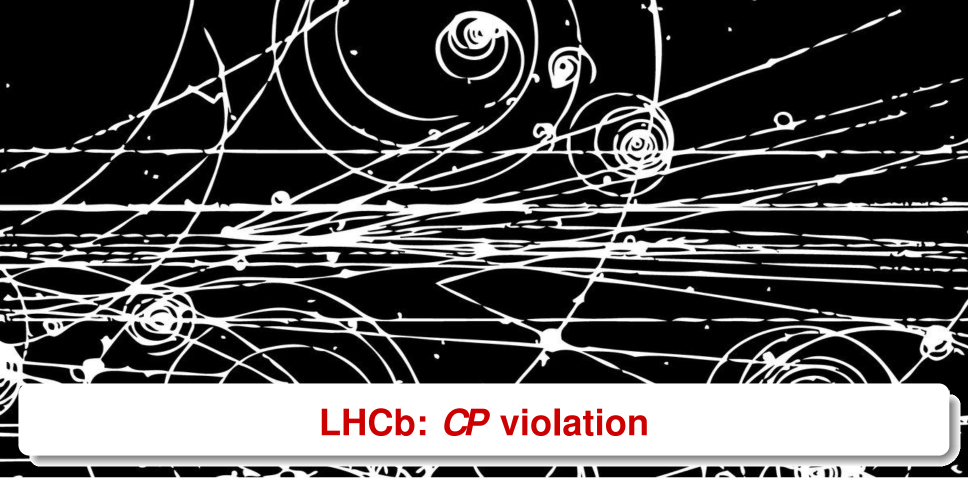
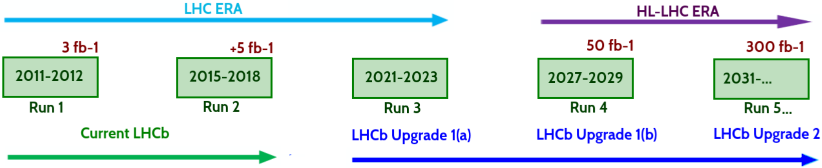


LHCb: *CP* violation

Francesca Dordei
on behalf of the LHCb collaboration
CERN

Workshop on the physics of HL-LHC, and perspectives for HE-LHC - October, 31st 2017

Outline



Many detector improvements foreseen relevant for CPV analyses:

- VErtex LOcator with timing info, Magnet side stations to increase low momentum tracking efficiency, improved ECAL for neutrals reconstruction, and so on.
- Don't miss the talks by Mark Williams, Preema Pais, and Gregory Ciezarek on Wednesday!

In this talk I will:

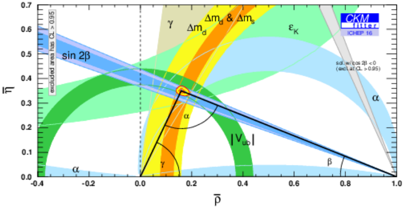
- Refer to the milestones indicated above, following LHCb Upgrade II Expression of interest;
- Emphasise several **CKM angle measurements** & **charm CPV**;
- Summarise current status of art, highlighting main systematics;
- Compare estimated experimental and theoretical uncertainties.

A huge success...

- Sources of $\not{CP}$ Beyond-the-Standard-Model (BSM) are needed to explain the large matter/antimatter asymmetry observed in the universe. [A. D. Sakharov, JETP Lett. 5, 24-27 (1967)]
- Measurements overconstrain the SM picture of $\not{CP}$ $\Rightarrow$ potential high sensitivity to NP.

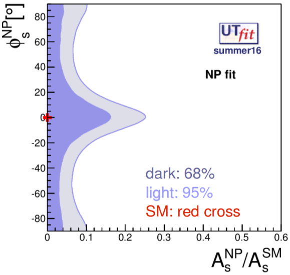
B^0 **Triangle**: larger angles, similar size sides

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0.$$



[CKMfitter Group]

Room for NP in B_s^0 system



[UTFit Group]

- All of the measurements agree very well
- In the presence of relevant NP, the various contours would not cross each other in a single point
- The SM works so remarkably well that we have to make more and more precise measurements

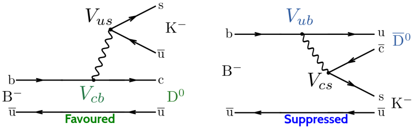
$\Rightarrow$ **we need HL-LHC!!!**

Status of γ

$\gamma = -\arg(V_{ud}V^*_{ub}/V_{cd}V^*_{cb})$

- γ is still the **least well-known** angle of the Unitarity Triangle
- Measurements of γ from B decays mediated only by **tree-level** transitions provide a "standard candle" for the SM ⇒ **Theoretically clean** $[\delta\gamma/\gamma] \lesssim \mathcal{O}(10^{-7})$ [JHEP 1401 (2014) 051]
- This can be compared with γ values from B decays involving **loop-level** transitions, such as $B^0_{d,s} \to hh'$ decays ($h = K, \pi$), to get **signs of NP**.

Can be measured in the interference between $b \to c$ and $b \to u$ transitions, eg:



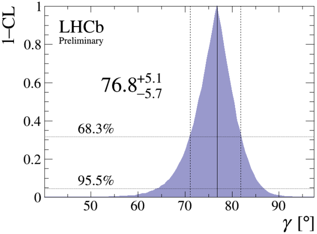
γ is statistically challenging because of small signal yields (BR $\approx 10^{-7}$), interference between favored and suppressed decays is small

⇒ Collecting a lot of luminosity is the key to achieve the ultimate precision.

State of art of γ

LHCb combination of several Run I measurements:

- 71 observables and 32 parameters
- Frequentist and Bayesian interpretations
- Both show good agreement



$$\boxed{\gamma(\mathrm{LHCb}) = \left(76.8^{+5.1}_{-5.7}\right)^\circ}$$

[LHCb-CONF-2017-004]

- LHCb precision (∼ 5.5°) dominates world average

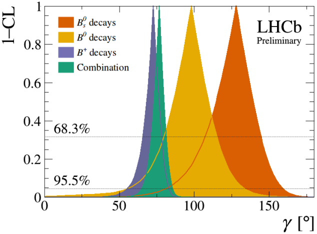
$$\boxed{\gamma(\mathrm{HFAG\ CKM\,2017}) = \left(73.5^{+4.3}_{-5.0}\right)^\circ}$$

[arXiv:1612.07233]

- To be compared with the CKM fit indirect determination:

$$\boxed{\gamma(\mathrm{CKM\,FITTER}) = \left(65.3^{+1.0}_{-2.5}\right)^\circ}$$

[CKMfitter Group]



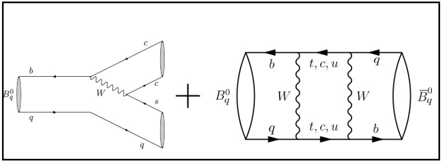
Prospects for γ

- Indirect uncertainties will decrease as lattice becomes better: **need to improve direct precision!**

Sample	$\sigma_{\text{stat}}(\gamma)^{\circ}$
Run 1	8
Run 2	4
Upgrade	~ 1
Phase-2 upgrade	<0.5

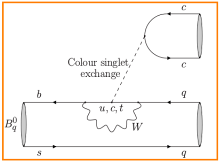
- **Belle-II targets a precision of $\sim 2^{\circ}$ at the end of data-taking (2025)**
- Studies underway to quantify the impact of better reconstruction of $hh\pi^0$ modes and better low momentum tracking for high multiplicity modes $\Rightarrow$ **Huge statistical potential not included in table above!**
- Future BESIII **charm inputs** also need to be considered
  - Current γ combination syst. due to CLEO inputs $\sim 2^{\circ}$ [LHCb-PUB-2016-025]
  - Additional BESIII run at $\psi(3770)$ under consideration - $\sigma(\gamma) \sim 0.5^{\circ}$ [LHCb-PUB-2016-025]
- Comparison of γ measurements made in single decay modes interesting in Phase-2 (1° sensitivity) $\Rightarrow$ **NP in tree level different for different final states**
- Constrain $\beta_{(s)}$ without penguin contaminations

CP violation in interference between mixing and decay



Dominant SM "tree" contribution

+



Higher order "penguin" contributions from non-perturbative hadronic effects

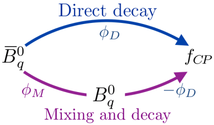
+

NP could be difficult to distinguish from penguins...

- $\phi_q = \phi_M - 2\phi_D = -2\beta_q + \Delta\phi_q + \delta_q^{NP}$,
  $\beta_q = \arg\left(\frac{V_{tq}V_{tb*}}{V_{cq}V_{cb}^{*}}\right)$

ϕ_s and ϕ_d determined via global fit to experimental results ignoring contributions from penguin diagrams:

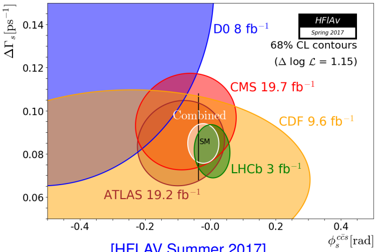
- $\phi_s^{\mathrm{SM}} \equiv -2\arg\left(-\frac{V_{ts}V_{tb*}}{V_{cs}V_{cb}^{*}}\right) = -37.6^{+0.7}_{-0.8}$ mrad
  [CKM Fitter]
- $\sin 2\beta^{\mathrm{SM}} \equiv \sin 2\arg\left(-\frac{V_{cd}V_{cb*}}{V_{td}V_{tb}^{*}}\right) = 0.740^{+0.020}_{-0.025}$
  [CKM Fitter]



Predictions are very precise!

State of art of ϕ_s

Extensively studied in LHCb, CMS, ATLAS with Run I.
Although there has been impressive progress since the initial measurements at CDF/D0, **the uncertainty needs to be further reduced:**



[HFLAV Summer 2017]

LHCb:

- $J/\psi\phi$ [PRL114, 041801 (2015)]
- $J/\psi K^+K^-$ [arXiv:1704.08217 (2017)]
- $J/\psi\pi^+\pi^-$ [Phys. Lett. B736, (2014) 186]
- $\psi(2S)\phi$ [Phys. Lett. B762 (2016) 253-262]
- $D_s^+D_s^-$ [PRL113, 211801 (2014)]

CMS:

- $J/\psi\phi$ [Phys. Lett. B 757 (2016) 97]

ATLAS:

- $J/\psi\phi$ [JHEP 08 (2016) 147]

$$\boxed{\phi_s = -21 \pm 31 \text{ mrad}}$$

[HFLAV Summer 2017]

$$\boxed{\phi_s^{SM} = -37.6^{+0.7}_{-0.8} \text{ mrad}}$$

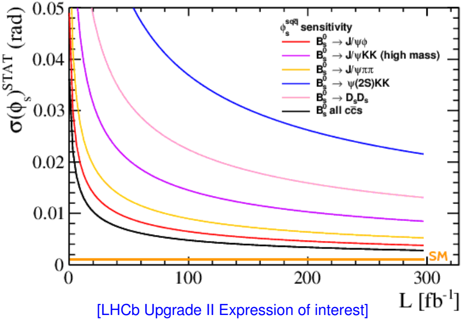
[CKM Fitter]

- World average consistent with SM prediction;
- Exp. uncertainty almost a factor of 30 larger than predictions.

Future of ϕ_s at LHCb

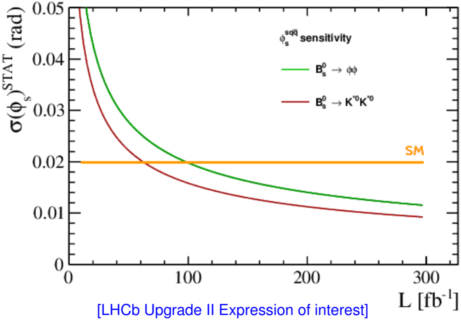
Evolution of the statistical uncertainty on ϕ_s as function of collected integrated luminosity at LHCb, scaled using present performances of the detector and expected running conditions:

ϕ_s from $b \to c\bar{c}s$ transitions



[LHCb Upgrade II Expression of interest]

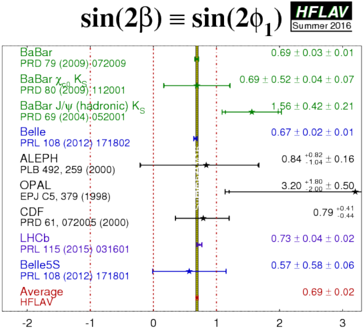
ϕ_s from $b \to s\bar{q}q$ transitions



[LHCb Upgrade II Expression of interest]

- LHC is the only player able to measure ϕ_s
- Complementary channels like $b \to s\bar{s}s$ would greatly benefit from the more eff. hadron-trigger
- Overall LHCb statistical uncertainty $\boxed{@300\ \mathrm{fb}^{-1}:\ \sigma_{\phi_s^{b\to c\bar{c}s}} < 3\ \text{mrad and } \sigma_{\phi_s^{b\to s\bar{s}s}} < 10\ \text{mrad}}$

State of art of $\sin(2\beta)$



[HFLAV Summer 2017]

LHCb:

- $S_{J/\psi K^0_S} = 0.731 \pm 0.035 \pm 0.020$ [PRL 115, 031601 (2015)]
- $S_{J/\psi(ee)K^0_S} = 0.83 \pm 0.08 \pm 0.01$ [arXiv:1709.03944 (2017)]
- $S_{\psi(2S)K^0_S} = 0.84 \pm 0.010 \pm 0.01$ [arXiv:1709.03944 (2017)]
- **New LHCb average** (not included below):

  $S_{LHCb} = 0.760 \pm 0.034$ [arXiv:1709.03944 (2017)]

Belle:

- $S_{J/\psi K^0_S} = 0.670 \pm 0.029 \pm 0.013$ [PRL 108, 171802 (2012)]

Babar:

- $S_{J/\psi K^0_S} = 0.662 \pm 0.039 \pm 0.012$ [PRD 79, 072009 (2009)]

$$\boxed{S \equiv \sin 2\beta = 0.691 \pm 0.017}$$

[HFLAV Summer 2017]

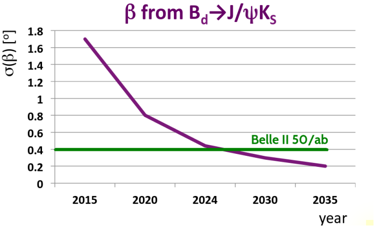
$$\boxed{S^{SM} \equiv \sin 2\beta^{SM} = 0.740^{+0.020}_{-0.025}}$$

[CKM Fitter]

- LHCb has reached the precision of B-factories
- Small tension of B-factories results with SM predictions to be clarified

Future of sin (2β) at LHCb

At LHC, LHCb will have the leading role in the competition with BelleII!
Prospects:

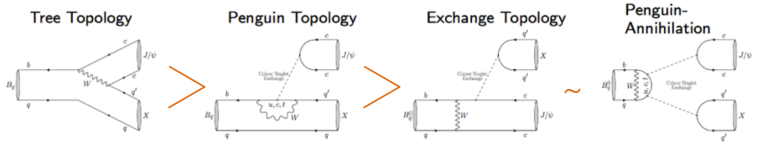


[LHCb Upgrade II Expression of interest]

[B physics experiments comparison]

- Sizeable systematic uncertainties wrt statistical ones.
- Overall LHCb statistical uncertainty $\boxed{@300\ \mathrm{fb}^{-1}: < 0.003}$
- Important to compare Belle II and LHCb results for consistency checks.

Penguin pollution



Experimentally

- Penguin contribution is suppressed by a factor of λ^2 in the $\not{CP}$ key modes
  $B^0 \to J/\psi K^0_S$ = **T + P**
  $B^0_s \to J/\psi \phi$ = **T + P + E + PA**
- Access to penguin contribution via SU(3) counterparts not suppressed w.r.t. tree level [Fleischer, De Bruyn]
- Ignore non-factorisable SU(3) breaking
- $\Delta\phi_s^{Peng} = 1.4^{+9.8}_{-12.6}{}^{+2.6}_{-2.3}$ [Phys. Lett. B742 (2015) 38, JHEP 11 (2015) 082].

ϕ_s:

- $B^0_s \to J/\psi \overline{K}^{*0}$ - JHEP 11 (2015) 082
- $B^0 \to J/\psi \rho^0$ - Phys. Lett. B742 (2015) 38
- $B^0 \to J/\psi \omega$ - Under study

β:

- $B^0_s \to J/\psi K_S$ - Phys. Rev. Lett. 115 (2015) 031601
- $B^0 \to J/\psi \pi^0$ - Under study

Penguin pollution in the HL-LHC era

Modes to be investigated in the future.

Control Modes for $B_s^0 \to J/\psi\,\phi$

- High precision CP analysis of $B^0 \to J/\psi\,\rho^0$: Determination of penguin parameters
- Search for $B_s^0 \to J/\psi\,\rho^0$ and/or $B^0 \to J/\psi\,\phi$: Control contribution from E + PA
- High precision CP analysis of $B^0 \to J/\psi\,\omega$: Control contribution from E + PA
- High precision CP analysis of $B_s^0 \to J/\psi\,\overline{K}^{*0}$: Cross check, test of SU(3)

Control Modes for $B^0 \to J/\psi\,K_S^0$

- High precision CP analysis of $B_s^0 \to J/\psi\,K_S$: Determination of penguin parameters
- High precision CP analysis of $B^0 \to J/\psi\,\pi^0$: Determination of penguin parameters
- Search for $B_s^0 \to J/\psi\,\pi^0$: Control contributions from E + PA in $B^0 \to J/\psi\,\pi^0$

A lot of complementarity here between LHC experiments and Belle II!

CP violation in *B* mixing

Interest triggered by D0 anomalous like-sign dimuon asymmetry [Phys. Rev. D 89, 012002 (2014)]

- $$a_{sl} \equiv \frac{\Gamma(\overline{B}^0_{(s)}(t)\to f)-\Gamma(B^0_{(s)}(t)\to\bar{f})}{\Gamma(\overline{B}^0_{(s)}(t)\to f)+\Gamma(B^0_{(s)}(t)\to\bar{f})} \simeq \frac{\Delta\Gamma}{\Delta M}\tan\phi_M$$

LHCb measured both $a_{sl}^{d,s}$ using Run I

- $\boxed{a_{sl}^{s} = (3.9 \pm 2.6(\mathrm{stat}) \pm 2.0(\mathrm{syst}))\cdot 10^{-3}}$

  [Phys. Rev. Lett. 117, 061803 (2016)]

- $\boxed{a_{sl}^{d} = (-0.2 \pm 1.9(\mathrm{stat}) \pm 3.0(\mathrm{syst}))\cdot 10^{-3}}$

  [Phys. Rev. Lett. 114, 041601 (2015)]

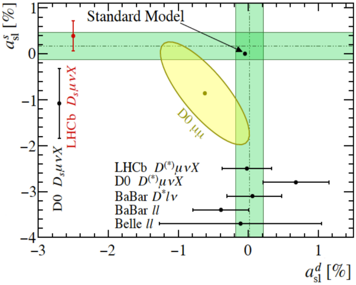
Clear motivation for @300 fb^{-1}!!

- Main syst of statistical nature
- $\boxed{@300\ \mathrm{fb}^{-1}\text{: 4 (100) times larger}}$ than the theoretical uncertainty for a_{sl}^{d} (a_{sl}^{s})

$\not{C}\not{P}$ in mixing is very small in the SM

$$\boxed{\begin{array}{ll} a_{sl}^{d}(B^0)^{SM} & = (-4.7 \pm 0.6)\cdot 10^{-4} \\ a_{sl}^{s}(B^0_s)^{SM} & = (2.22 \pm 0.27)\cdot 10^{-5} \end{array}}$$

[Lenz & Nierste, arXiv:1102.4274 [hep-ph]]



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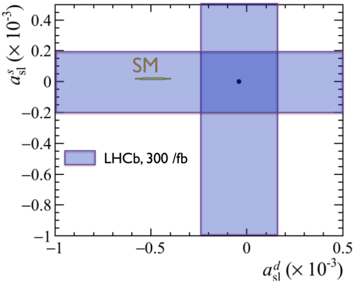


[LHCb Upgrade II Expression of interest]

The B^0 width difference $\Delta\Gamma_d$

A **deviation of $\Delta\Gamma_d$ from SM** prediction could be a potential explanation for the anomalous like-sign dimuon charge asymmetry measured by the D0 collaboration [arXiv:1409.6963 (2014)] [Phys. Rev. D 89, 012002].

This observable represents a clean null test of the SM, complementary to a_{sl} and $\sin(2\beta)$.

$$\left|\frac{\Delta\Gamma_d}{\Gamma_d}\right|^{\rm SM} = (0.42 \pm 0.08)\cdot 10^{-2} \qquad \left|\frac{\Delta\Gamma_d}{\Gamma_d}\right|^{\rm Exp} = (-0.2 \pm 1.0)\cdot 10^{-2}$$

[arXiv:1409.6963 (2014)] [HFLAV Summer 2017]

DELPHI	$\lvert\Delta\Gamma_d\rvert/\Gamma_d < 18\%$ at 95% CL	[Z. Phys. C76, 579 (1997)]
BaBar	$-6.8\% < \text{sign}(Re_{\lambda_{CP}})\Delta\Gamma_d/\Gamma_d < 8.4\%$	[Phys.Rev.D 70:012007 (2004)]
Belle	$\text{sign}(Re_{\lambda_{CP}})\Delta\Gamma_d/\Gamma_d = (1.7 \pm 1.8 \pm 1.1)\%$	[Phys. Rev. D 85, 071105(R) (2012)]
LHCb	$\Delta\Gamma_d/\Gamma_d = (-4.4 \pm 2.5 \pm 1.1)\%$	[JHEP04 (2014) 114]
ATLAS	$\Delta\Gamma_d/\Gamma_d = (-0.1 \pm 1.1 \pm 0.9)\%$	[JHEP06 (2016) 081]

Both LHCb and ATLAS measure it comparing the decay time distributions of $B^0 \to J/\psi K^0_S$ and $B^0 \to J/\psi K^{*0}$ decays [J. Phys. G 42 (2015) 119501]:

- LHCb measurement still on a limited data sample (2011 only)
- $@50(300)\ \mathrm{fb}^{-1}$: $\sigma^{\Delta\Gamma_d/\Gamma_d}_{\rm stat} \sim 0.3(0.09)\cdot 10^{-2}$

Direct *CP* violation in charm

Charmed hadrons provide the only way to probe *CP* violation with up-type quarks.
In the SM *CP* violation in charm is expected to be $< \mathcal{O}(10^{-3})$ [Phys. Rev. D, 85, 079901 (2012)]

$$A_{raw}(D \to X) = \frac{N(D \to X) - N(\overline{D} \to \overline{X})}{N(D \to X) + N(\overline{D} \to \overline{X})} \qquad A_{raw} \approx A_{CP} + A_P + A_D$$

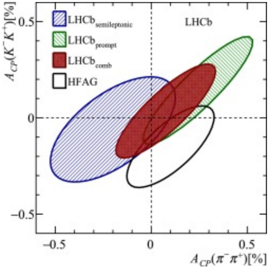
LHCb studied *CP* asymmetries in $D^0 \to K^+K^-, \pi^+\pi^-$:

$$\boxed{A_{CP}(K^+K^-) = (0.04 \pm 0.12(\mathrm{stat}) \pm 0.10(\mathrm{syst}))\%}$$

$$\boxed{A_{CP}(\pi^+\pi^-) = (0.07 \pm 0.14(\mathrm{stat}) \pm 0.11(\mathrm{syst}))\%}$$

- Main syst: statistics available in control samples, e.g. $D^+ \to K^0_S\pi^+$
- Downstream track trigger could help [LHCb-PUB-2017-006]

[Phys.Lett. B 03 (2017) 62]



Prospects for upgrade era:

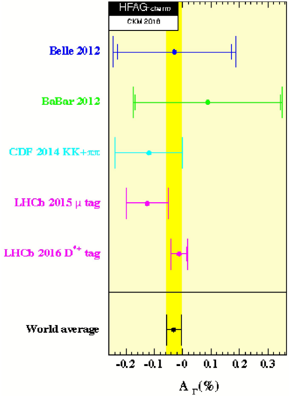
- Low momentum track reconstruction: significant stat. increase especially for higher multiplicity *D* modes
- Improved calorimetry: use e.g $D^0 \to \phi(\rho)\gamma$
- Review assumption of no CPV in CF decays
- $\boxed{@300\ \mathrm{fb}^{-1}\text{: } \sigma(A_{CP}(K^+K^-)) \approx 7.5 \cdot 10^{-5}}$

Indirect *CP* violation in charm

The time-dependent *CP* asymmetry to a *CP* eigenstate final state (K^+K^-, $\pi^+\pi^-$) is:

$$A_{CP}(t) = \frac{\Gamma(D^0(t) \to f) - \Gamma(\overline{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D}^0 \to f)} \simeq a^f_{dir} - A_\Gamma \frac{t}{\tau_D} \quad \text{where} \quad A_\Gamma \equiv \frac{\widehat{\Gamma}_{D^0\to f} - \widehat{\Gamma}_{\overline{D}^0\to f}}{\widehat{\Gamma}_{D^0\to f} + \widehat{\Gamma}_{\overline{D}^0\to f}}$$

A_Γ is the asymmetry between the D^0 and $\overline{D}^0$ effective decay widths and it is sensitive to indirect *CP* violation. The **SM expectation** is: $A_\Gamma < \mathcal{O}(10^{-3})$ [arXiv:1612.07233]



Combination of $f = KK, \pi\pi$ measurements in Run I:

$$\boxed{A_\Gamma = (0.13 \pm 0.28(\text{stat}) \pm 0.10(\text{syst})) \times 10^{-3}}$$

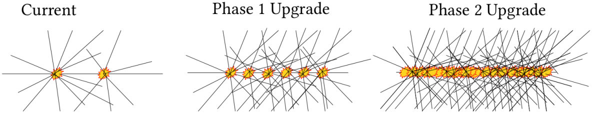
[arXiv:1702.06490 (2017)]

- Main syst: background from secondary decays

Prospects for upgrade era:

- Dalitz time-dep. $D^0 \to K^0_s \pi^+\pi^-$ x/y precision $\mathcal{O}(10^{-5})$
- $\boxed{@300\ \text{fb}^{-1}\text{: } \sigma(A_\Gamma(K^+K^-)) \approx 1.5 \cdot 10^{-5}}$

Challenges of the upgrade era



Assuming that the same detector performances will be kept has to be taken with a grain of salt, in the good and the bad!

- Several challenges associated with high occupancies (See Mark Williams' talk *"LHCb Timing Tracker Impact"*)
  - Flavour tagging performance
  - Correct PV association ⇒ impact on decay time resolution
  - Particle identification performance
  - Higher levels of combinatorial background

Charm system specific:

- Expected signal yields for relevant decays at 300 fb^{-1} are $\mathcal{O}(10^9)$
- ⇒ keep data size "reasonable" in the offline stage [arXiv:1604.05596]
- ⇒ Detector asymm. and decay-time acc. to be controlled to 10^{-5} precision
- ⇒ Necessity of huge MC samples to validate analyses

Complementarity wrt LHC/Belle II

LHCb will exploit the full potential of the HL-LHC in flavour physics.

- Almost alone for TD hadronic final states
- Only exp. capable to study CPV in baryons and charm

ATLAS and CMS will contribute significantly in many CPV analyses, thanks to new upgraded detectors and the new trigger strategy.

- Large improvements foreseen for $B_s^0 \to J/\psi\phi$;
- Tracker upgrade will allow precision studies of some fully hadronic modes.

Belle-II will perform very competitive and also complementary measurements.

- x10 higher effective tagging efficiency for TD B mixing studies;
- Cover modes with many π^0, η, ω that are difficult in LHC.

LHC experiments plus Belle-II will make a huge advance in our understanding of flavour!

Conclusions

- **Interest in precision flavour measurements is stronger than ever** ⇒ If no direct evidence of NP pops out of the LHC, flavour physics can play a key role;
- We must push forward to use as efficiently the unique opportunity of a High-Luminosity Hadronic Collider
- Improvements in calorimetry and low-momentum track reconstruction will open up many little-explored modes
- Vast majority of CPV observables will remain **statistically limited in HL-LHC era** ⇒ HE-LHC?

Thanks for your attention!

Backup Slides

CP violation phenomenology

Due to interfering amplitudes with different CKM phases in transitions of particles and antiparticles

CP violation in decay (direct $\not{CP}$)

Different *CP* conjugate decay amplitudes:

$$\mathcal{A}(P \to f) \neq \mathcal{A}(\overline{P} \to \bar{f})$$

possible also for charged hadrons

Ex. $B^0_{(s)} \to K^+\pi^-$ vs $\overline{B}^0_{(s)} \to K^-\pi^+$

CP violation in mixing

$\not{CP}$ in mixing arises for neutral mesons:

$$\mathcal{P}(P \to \overline{P}) \neq \mathcal{P}(\overline{P} \to P)$$

or in terms of mass/flavour eigenstates:

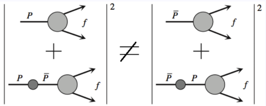
$|q/p| \neq 1$, $(|P_{L,H}\rangle = p|P^0\rangle \pm q|\overline{P}^0\rangle)$

Ex. Semileptonic asymmetry $a_{sl}^{s,d}$

CP violation in interference between mixing and decay

Interference between $P \to f$ and $P \to \overline{P} \to f$, where f is a non-flavour specific final state:

$$\frac{\mathcal{A}(\overline{P} \to f) - \mathcal{A}(P \to f)}{\mathcal{A}(\overline{P} \to f) + \mathcal{A}(P \to f)} = \frac{C_f \cos(\Delta M\, t) - S_f \sin(\Delta M\, t)}{\cosh\left(\frac{\Delta\Gamma\, t}{2}\right) + A_f^{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma\, t}{2}\right)}$$

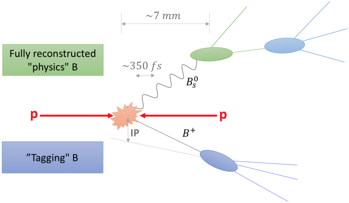


S_f: $\not{CP}$ in interference between mixing and decay.
C_f: direct $\not{CP}$.

Ex. $\not{CP}$ phase ϕ_s, golden channel: $B^0_s \to J/\psi\phi$

Beauty and charm phenomelogy

[Int. J. Mod. Phys. A 30, 1530022 (2015)]



BEAUTY SIGNATURES

- Mass $m(B^+) = 5.28$ GeV
- Daughter p_T $\mathcal{O}(1 \text{ GeV})$
- Lifetime $\tau(B^+) \sim 1.6$ ps
- Flight distance ~ 1 cm
- Common signature: detached $\mu\mu$ $B \to J/\Psi(\to \mu\mu)X$

CHARM SIGNATURES

- Mass $m(D^0) = 1.86$ GeV
- Sizeable daughter p_T
- Lifetime $\tau(D^0) \sim 0.4$ ps
- Flight distance ~ 4 mm
- Can be produced in B decays

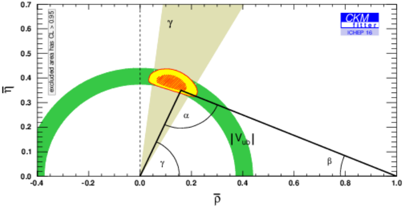
- **Impact parameter resolution**
  - E.g. LHCb: $\sigma_{IP} \sim 20\ \mu\text{m}$ for high-p_T
- **Momentum & invariant mass resolution**
  - E.g. LHCb: $\sigma_p/p \sim 0.5 - 1\%$
- **Decay-time resolution**
  - E.g. LHCb: $\sigma_t \sim 45$ fs

- **Particle Identification**
  - E.g. LHCb: Kaon ID eff. $\sim$ 95%
  - Pion mis-ID fraction of 10%
  - Muon ID eff. $\sim$ 97%
- **Large number of beauty and charm hadrons**
  - $\sigma(b\bar{b}) \approx 515\mu\text{b}$ @ 13 TeV
    [JHEP 10 (2015) 172]
  - Charm rate $\sim$ 20 times larger

Tree vs loop measurements

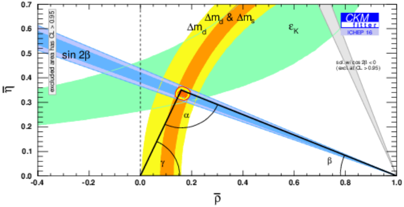
If we assume NP enters only (mainly) at loop level, it is interesting to compare:

Parameters (ρ, η) from processes dominated by tree diagrams (V_{ub} ,V_{cb} , γ, ...)



[CKMfitter Group]

with the ones from loop diagrams (ΔM_d, ΔM_s , β, ε_K , ...)



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- At LHC we measure all relevant quantities but ε_K

Need to improve the precision of the measurements at tree level to (dis-)prove the existence of NP contributions in loops.

Limiting factors on γ in the high-statistics era

Where will we become limited, as things stand:

- Most $B \to DK$ modes rely on CLEO strong phase measurements at the $\psi(3770)$
- Allows for model independence; crucial in the high-statistics era
- Current systematic due to CLEO inputs $\sim 2^\circ$
- Some D modes not analysed by CLEO; some would benefit from D-phasespace-binned analysis

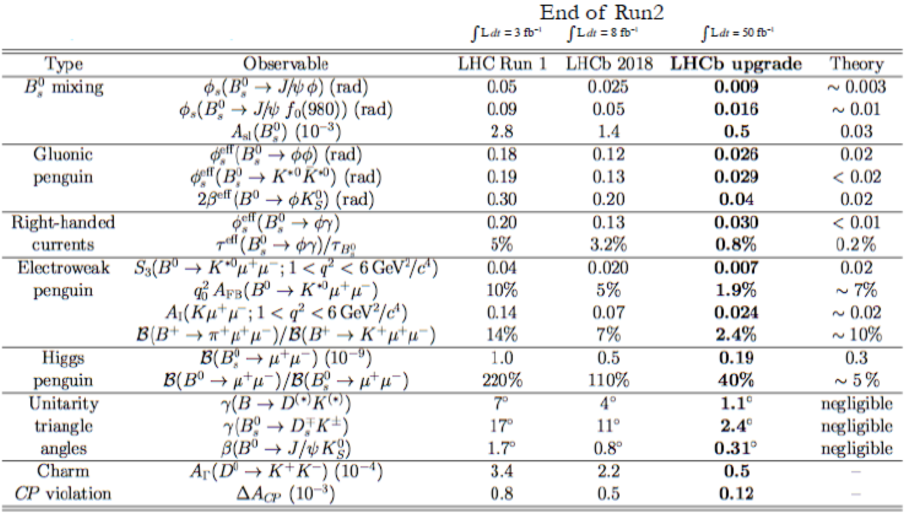
Available now:

- Quadruplication of the CLEO dataset at BES III ($\to$ systematic $\sim 1^\circ$)
- Measurement in $D \to K\pi$ (Int.J.Mod.Phys.Conf.Ser. 31 1460305)
- Preliminary results in $D \to K_s^0\pi\pi$

To avoid systematic limitation in the upgrade era:

- Full spectrum of strong phase measurements with full 15-20 fb^{-1} at BES III

LHCb upgrade



			End of Run2		
		$\int L\,dt = 3\ \text{fb}^{-1}$	$\int L\,dt = 8\ \text{fb}^{-1}$	$\int L\,dt = 50\ \text{fb}^{-1}$	
Type	Observable	LHC Run 1	LHCb 2018	**LHCb upgrade**	Theory
B_s^0 mixing	$\phi_s(B_s^0 \to J/\psi\,\phi)$ (rad)	0.05	0.025	**0.009**	~ 0.003
	$\phi_s(B_s^0 \to J/\psi\, f_0(980))$ (rad)	0.09	0.05	**0.016**	~ 0.01
	$A_{\rm sl}(B_s^0)$ (10^{-3})	2.8	1.4	**0.5**	0.03
Gluonic penguin	$\phi_s^{\rm eff}(B_s^0 \to \phi\phi)$ (rad)	0.18	0.12	**0.026**	0.02
	$\phi_s^{\rm eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$ (rad)	0.19	0.13	**0.029**	< 0.02
	$2\beta^{\rm eff}(B^0 \to \phi K_S^0)$ (rad)	0.30	0.20	**0.04**	0.02
Right-handed currents	$\phi_s^{\rm eff}(B_s^0 \to \phi\gamma)$	0.20	0.13	**0.030**	< 0.01
	$\tau^{\rm eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	5%	3.2%	**0.8%**	0.2%
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.04	0.020	**0.007**	0.02
	$q_0^2\,A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	10%	5%	**1.9%**	$\sim 7\%$
	$A_{\rm I}(K\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.14	0.07	**0.024**	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	14%	7%	**2.4%**	$\sim 10\%$
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ (10^{-9})	1.0	0.5	**0.19**	0.3
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	220%	110%	**40%**	$\sim 5\%$
Unitarity triangle angles	$\gamma(B \to D^{(*)}K^{(*)})$	7°	4°	**1.1°**	negligible
	$\gamma(B_s^0 \to D_s^{\mp}K^{\pm})$	17°	11°	**2.4°**	negligible
	$\beta(B^0 \to J/\psi\, K_S^0)$	1.7°	0.8°	**0.31°**	negligible
Charm *CP* violation	$A_\Gamma(D^0 \to K^+K^-)$ (10^{-4})	3.4	2.2	**0.5**	–
	ΔA_{CP} (10^{-3})	0.8	0.5	**0.12**	–