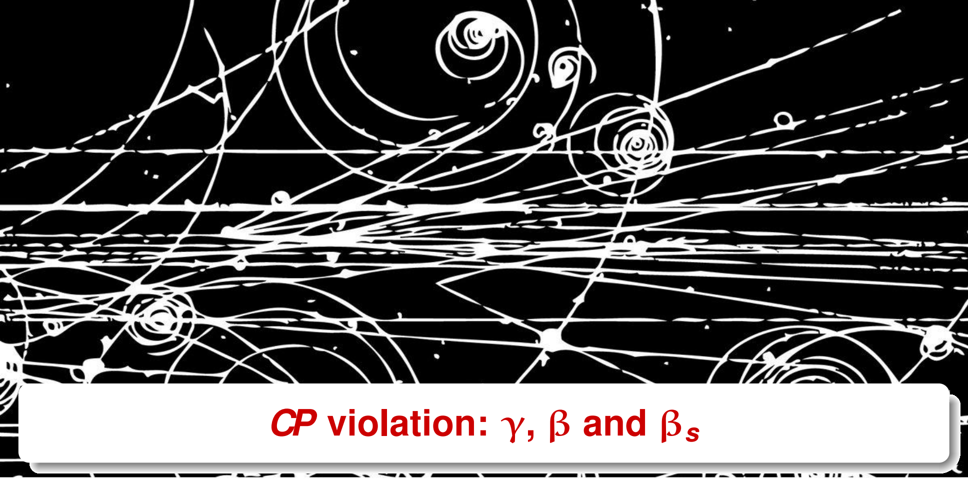


CP violation: γ, β and β_s

Francesca Dordei
on behalf of the LHCb collaboration
CERN

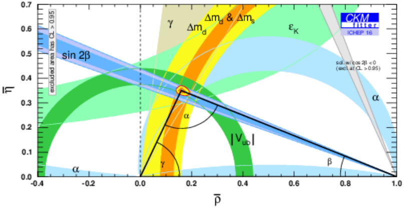
Implications of LHCb measurements and future prospects - November, 08th 2017

A huge success...

- Measurements overconstrain the SM picture of $\not{CP}$ $\Rightarrow$ potential high sensitivity to NP.

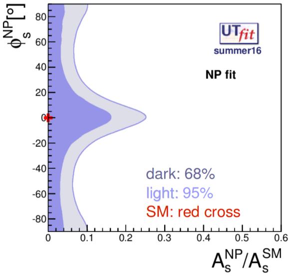
B^0 Triangle: larger angles, similar size sides

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



[CKMfitter Group]

Room for NP in B_s^0 system



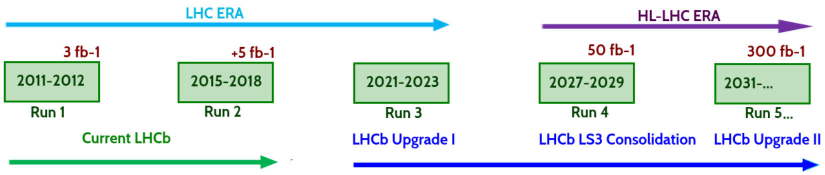
[UTFit Group]

- 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

Outline and upgrade reminder

In this talk I will:

- Summarise current status of art of γ, β and β_s
- Give some perspectives for the evolution of these measurements, following LHCb Upgrade II Expression of interest;
- Refer to the milestones indicated below.
- Don't miss Greig Cowan's talk on *Future LHCb upgrades and long-term physics prospects*

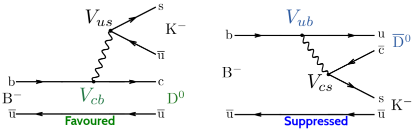


Status of γ

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

- 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 (assuming no new physics in tree-level decays [Phys. Rev.D 92, 033002 (2015)])
  $\Rightarrow$ **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:



Small signal yields (BR $\approx 10^{-7}$), small interference effects ($\sim 10\%$) $\Rightarrow$ Combining a plethora of independent decay modes is the key to achieve the ultimate precision.

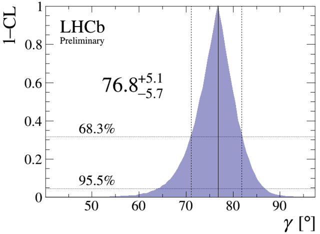
State of art of γ

LHCb combination of several Run 1 measurements:

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

$$\gamma(\text{LHCb}) = (76.8^{+5.1}_{-5.7})^\circ$$

[LHCb-CONF-2017-004]



- LHCb precision ($\sim$ 5.5°) dominates world average

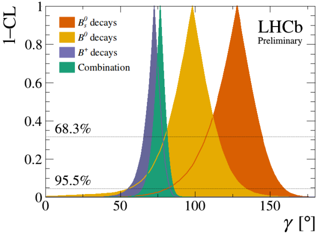
$$\gamma(\text{HFLAV CKM 2017}) = (73.5^{+4.3}_{-5.0})^\circ$$

[arXiv:1612.07233]

- To be compared with the CKM fit indirect determination:

$$\gamma(\text{CKM FITTER}) = (65.3^{+1.0}_{-2.5})^\circ$$

[CKMfitter Group]



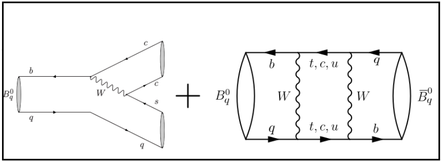
Prospects for γ

- 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 I	~ 1
Upgrade II	<0.5

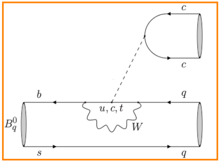
- **Belle-II targets a precision of $\sim$ 1.5° at the end of data-taking (2025)**
- Studies underway to quantify the impact of better reconstruction of $hh\pi^0$ modes and better low momentum tracking for high multiplicity modes $\Rightarrow$ **Huge statistical potential not included in table above!**
- 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 after Upgrade II (1° sensitivity) $\Rightarrow$ **NP in tree level different for different final states**
- Constrain $\beta_{(s)}$ without penguin contaminations $\Rightarrow$ 2° sensitivity on $\gamma - 2\beta_s$ from $B_s^0 \to D_s K$

CP violation in interference between mixing and decay



Dominant SM "tree" contribution

+



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

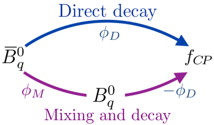
+

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:

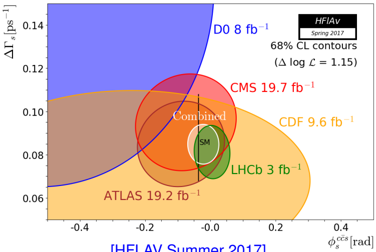
- $\phi_s^{\rm SM} \equiv -2\arg\left(-\frac{V_{ts}V_{tb*}}{V_{cs}V_{cb}^*}\right) = -37.6^{+0.7}_{-0.8}$ mrad
  [CKM Fitter]
- $\sin 2\beta^{\rm SM} \equiv \sin 2\arg\left(-\frac{V_{cd}V_{cb*}}{V_{td}V_{tb}^*}\right) = 0.740^{+0.020}_{-0.025}$
  [CKM Fitter]



Predictions are very precise!

State of art of ϕ_s

Extensively studied in LHCb, CMS, ATLAS with Run 1.
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)]
- $J/\psi K^+K^-$ above $\phi(1020)$[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]

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

[HFLAV Summer 2017]

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

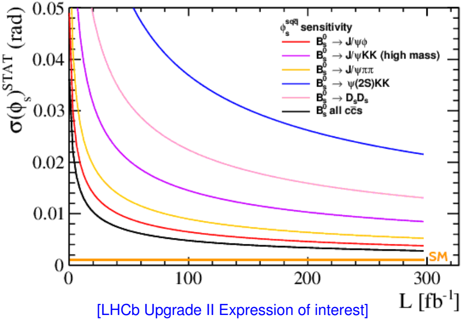
[CKM Fitter]

- World average (dominated by LHCb) consistent with SM prediction;
- Exp. uncertainty almost a factor of 30 larger than uncertainty of indirect determination when penguin pollution is ignored.

Future of ϕ_s at LHCb

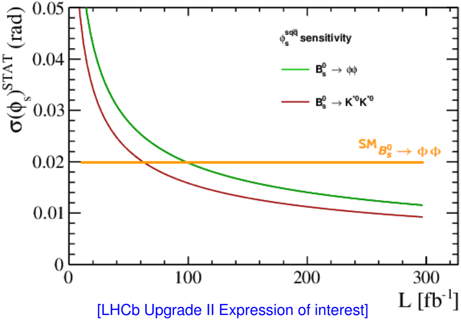
Evolution of the statistical uncertainty on ϕ_s as function of collected integrated luminosity at LHCb, scaled using present performances of the detector and expected running conditions:

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



[LHCb Upgrade II Expression of interest]

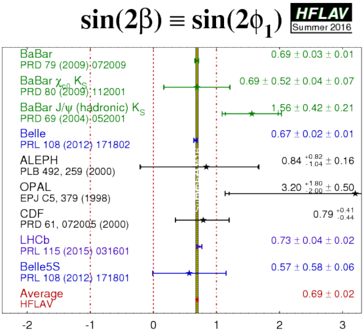
ϕ_s from $b \to s\bar{q}q$ transitions



[LHCb Upgrade II Expression of interest]

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

State of art of sin (2β)



[HFLAV Summer 2017]

LHCb:

- $S_{J/\psi K_S^0} = 0.731 \pm 0.035 \pm 0.020$ [PRL 115, 031601 (2015)]

Belle:

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

Babar:

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

$$S \equiv \sin 2\beta = 0.691 \pm 0.017$$

[HFLAV Summer 2017]

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

[CKM Fitter]

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

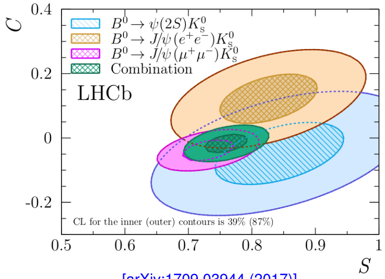
$\sin(2\beta)$ from B^0 to $J/\psi(ee)K_s^0$ and $\psi(2S)K_s^0$

The asymmetry between B^0 and $\overline{B}^0$ decays to $J/\psi(ee)K_s^0$ and $\psi(2S)K_s^0$ is (taking $\Delta\Gamma_d \equiv 0$):

$$\mathcal{A}_{[c\bar{c}]K_S^0}(t) \approx S\sin(\Delta m\, t) - C\cos(\Delta m\, t) \qquad \text{where } S = \sin(2\beta)$$

$$C(B^0 \to J/\psi(e^+e^-)K_S^0) = 0.12\,^{+0.07}_{-0.07}\,(\text{stat}) \pm 0.02\,(\text{syst})$$
$$S(B^0 \to J/\psi(e^+e^-)K_S^0) = 0.83\,^{+0.07}_{-0.08}\,(\text{stat}) \pm 0.01\,(\text{syst})$$

$$C(B^0 \to \psi(2S)(\mu^+\mu^-)K_S^0) = -0.05\,^{+0.10}_{-0.10}\,(\text{stat}) \pm 0.01\,(\text{syst})$$
$$S(B^0 \to \psi(2S)(\mu^+\mu^-)K_S^0) = 0.84\,^{+0.10}_{-0.10}\,(\text{stat}) \pm 0.01\,(\text{syst})$$



[arXiv:1709.03944 (2017)]

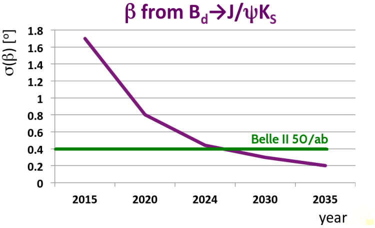
New LHCb average:

$$S(B^0 \to [c\bar{c}]K_S^0) = 0.760 \pm 0.034 \qquad C(B^0 \to [c\bar{c}]K_S^0) = -0.017 \pm 0.029$$

- Precision of $\sin(2\beta)$ from LHCb improved by 20%;
- Reduce tension with SM predictions.

Future of $\sin(2\beta)$ at LHCb

Prospects:

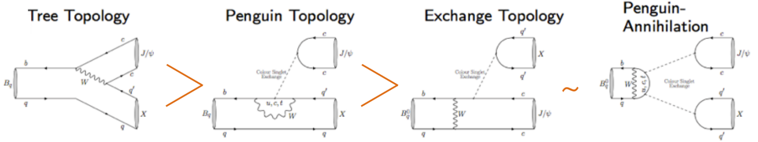


[LHCb Upgrade II Expression of interest]

[B physics experiments comparison]

- Sizeable systematic uncertainties wrt statistical ones.
- Overall LHCb statistical uncertainty @300 fb^{-1}: < 0.003

Penguin pollution



Experimentally

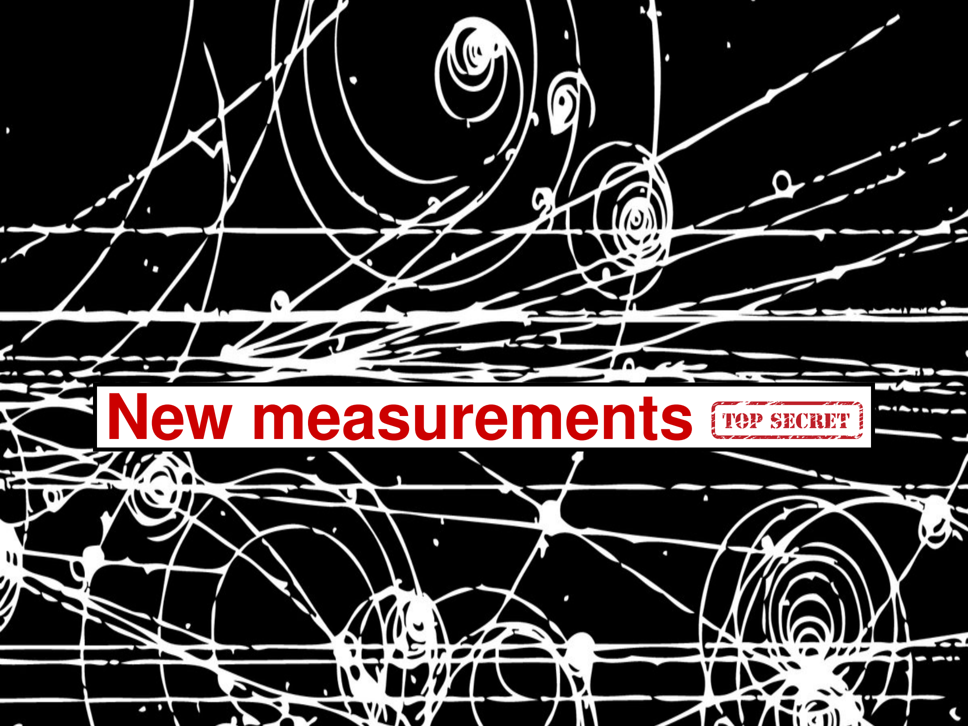
- Penguin contribution is suppressed by a factor of λ^2 in the $\not{CP}$ key modes
  $B^0 \to J/\psi K^0_S$ = **T + P**
  $B^0_s \to J/\psi \phi$ = **T + P + E + PA**
- Access to penguin contribution via SU(3) counterparts not suppressed w.r.t. tree level [Fleischer, De Bruyn]
- Ignore non-factorisable 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



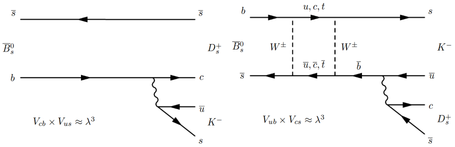
New measurements

TOP SECRET

γ from $B_s^0 \to D_s^{\mp} K^{\pm}$ decays NEW

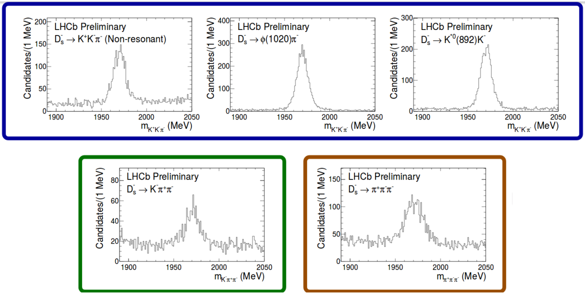
[LHCb-PAPER-2017-047 (2017)]

- *CP* asymmetry in mixing and decay in $B_s^0 \to D_s^{\mp} K^{\pm}$ decays sensitive to $(\gamma - 2\beta_s)$.
- Both decay amplitudes are $\mathcal{O}(\lambda^3)$ $\Rightarrow$ large interference ($\mathcal{O}(35\%)$)!



The analysis is based on *pp* collision data sample of $3\,\mathrm{fb}^{-1}$ collected at LHCb in Run 1.

- Update of LHCb-CONF-2016-015 (2016)
- Three D_s^- final states considered: $KK\pi\,(\phi\pi^-,\ K^{*0}K^-,\ \mathrm{Non\ Resonant})$, $K\pi\pi$, $\pi\pi\pi$.



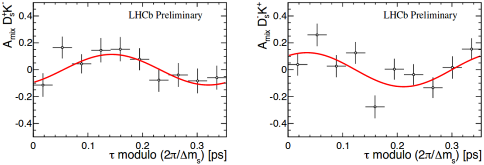
γ from $B_s^0 \to D_s^{\mp} K^{\pm}$ decays NEW

[LHCb-PAPER-2017-047 (2017)]

- Perform multivariate fit (MDFit) to $m(D_s^{\mp} K^{\pm})$, $m(hhh)$ (with $h = K$, π from $D_s^{\mp}$ decays) and the companion PIDK distribution.
- Use MDFit results to **subtract background** events and perform a time-dep. signal only fit.
- Use $B_s^0 \to D_s^- \pi^+$ as control channel.
- Combination of **Opposite Side** [Eur. Phys. J. C72 (2012) 2022] and **Same Side Kaon taggers** [(JINST 11 (2015) P05010]

  $\Rightarrow$ Overall tagging power $5.80 \pm 0.25\,\%$
- Most of the **systematic sources** have been revisited after several cross checks.

$$
\begin{aligned}
C_f &= 0.73 \pm 0.14 \pm 0.05\,,\\
A_f^{\Delta\Gamma} &= 0.39 \pm 0.28 \pm 0.15\,,\\
A_{\bar{f}}^{\Delta\Gamma} &= 0.31 \pm 0.28 \pm 0.15\,,\\
S_f &= -0.52 \pm 0.20 \pm 0.07\,,\\
S_{\bar{f}} &= -0.49 \pm 0.20 \pm 0.07\,,
\end{aligned}
$$

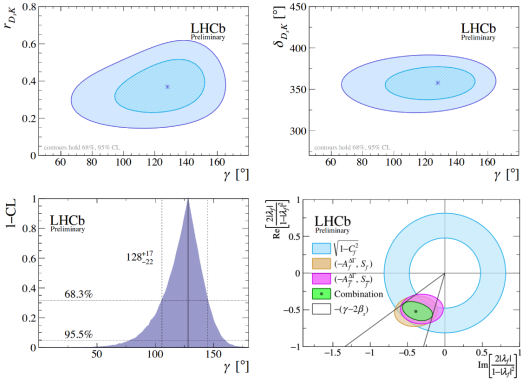


γ from $B_s^0 \to D_s^{\mp} K^{\pm}$ decays NEW

[LHCb-PAPER-2017-047 (2017)]

Assuming $\phi_s \approx -2\beta_s$ as external input:

$\gamma = (128^{+17}_{-22})^{\circ}$ $\delta = (358^{+13}_{-14})$ $r_{D_s K} = (0.37^{+0.010}_{-0.09})$



- 3.6 σ evidence for *CP* violation in $B_s^0 \to D_s^{\mp} K^{\pm}$ decays.
- 2.3 σ from all other LHCb measurements combined.

Decays of charmed b-mesons to two c-mesons NEW

[LHCb-PAPER-2017-045 (2017)]

- Decays of B_c^+ mesons to two open-charm (excited) mesons, like $B_c^+ \to D_{(s)}^+ D$, have been proposed to measure γ.
- Smaller yields than $B^+ \to DK^+$, but interference is larger: $r_{B_c^+} \approx 1$
- **Challenges**: small production cross-section, the short lifetime, the complex final state, and possibly small branching fractions.

LHCb performed the **first search of these decays** using Run 1 data.

Charm mesons are reconstructed in the following final states:

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

Strategy: branching fractions are measured relative to large B^+ signals in data

Decays of charmed b-mesons to two c-mesons NEW

Measured branching fractions (in parentheses upper limits @95 C.L. from asymptotic CL_s method):

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D_s^+ \overline{D}^0)}{\mathcal{B}(B^+ \to D_s^+ \overline{D}^0)} = (3.0 \pm 3.7) \times 10^{-4} (< 1.1 \times 10^{-3}),$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D_s^+ D^0)}{\mathcal{B}(B^+ \to D_s^+ \overline{D}^0)} = (-3.8 \pm 2.6) \times 10^{-4} (< 4.7 \times 10^{-4}),$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D^+ \overline{D}^0)}{\mathcal{B}(B^+ \to D^+ \overline{D}^0)} = (8.0 \pm 7.5) \times 10^{-3} (< 2.2 \times 10^{-2}),$$

$$\frac{f_c}{f_u}\frac{\mathcal{B}(B_c^+ \to D^+ D^0)}{\mathcal{B}(B^+ \to D^+ \overline{D}^0)} = (2.9 \pm 5.3) \times 10^{-3} (< 1.4 \times 10^{-2}),$$

Also BR for excited *c*-mesons (D_s^*, D^{*0}, D^{*+}) have been measured

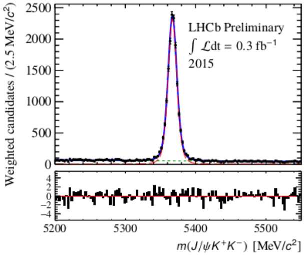
$\Rightarrow$ No evidence found

Near future of ϕ_s at LHCb

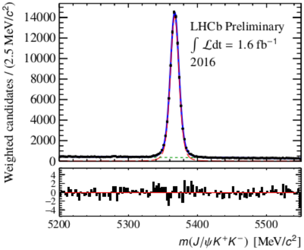
TOP SECRET

Currently finalising analysis of $B_s^0 \to J/\psi K^+K^-$ decays from 2015 and 2016

$N_{sig}^{2015} \sim 16000$



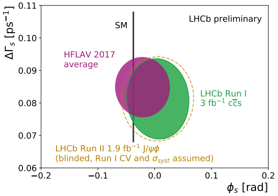
$N_{sig}^{2016} \sim 96000$



Peaking background subtracted $J/\psi K^+K^-$ invariant mass distributions

WARNING: Central value for Run II shifted to Run I

WARNING: Run II syst from Run I



Expected statistical uncertainty on main physics parameters using 2015 + 2016 data:

- $\sigma_{stat}(\phi_s) \sim 0.042$ rad (Run I: 0.049 rad)
- $\sigma_{stat}(\Delta\Gamma_s) \sim 0.0080\ ps^{-1}$ (Run I: $0.0091\ ps^{-1}$)
- $\sigma_{stat}(\Gamma_s/\Gamma_d) \sim 0.005$ (HFLAV: 0.004)

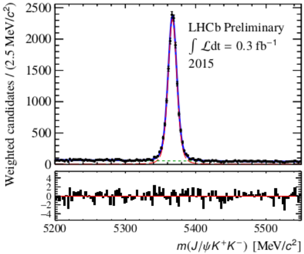
No limiting systematic uncertainties foreseen.

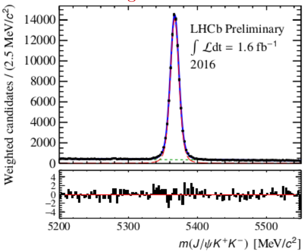
Near future of ϕ_s at LHCb

TOP SECRET

Currently finalising analysis of $B_s^0 \to J/\psi K^+ K^-$ decays from 2015 and 2016

$N_{sig}^{2015} \sim 16000$ $N_{sig}^{2016} \sim 96000$

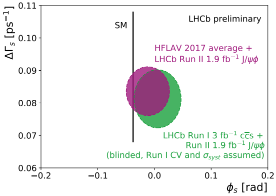




Peaking background subtracted $J/\psi K^+ K^-$ invariant mass distributions

WARNING: Central value for Run II shifted to Run I

WARNING: Run II syst from Run I



Expected statistical uncertainty on main physics parameters using 2015 + 2016 data:

- $\sigma_{stat}(\phi_s) \sim 0.042$ rad (Run I: 0.049 rad)
- $\sigma_{stat}(\Delta\Gamma_s) \sim 0.0080\ \mathrm{ps}^{-1}$ (Run I: $0.0091\ \mathrm{ps}^{-1}$)
- $\sigma_{stat}(\Gamma_s/\Gamma_d) \sim 0.005$ (HFLAV: 0.004)

No limiting systematic uncertainties foreseen.

Conclusions

- Interest in precision flavour measurements is stronger than ever $\Rightarrow$ If no direct evidence of NP pops out of the LHC, flavour physics can play a key role;
- All results in this sector in good agreement with SM;
- Majority of measurements still statistically limited and on Run 1;
- Time to exploit the potentials of Run 2!!
- Good prospects for the precision measurements in the upgrade phase.


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 $\not{C}\not{P}$)

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

$\not{C}\not{P}$ 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:

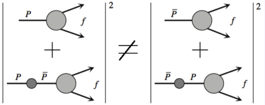
$|q/p| \neq 1$, $(|P_{L,H}> = p|P^0> \pm q|\overline{P}^0>)$

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

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:

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

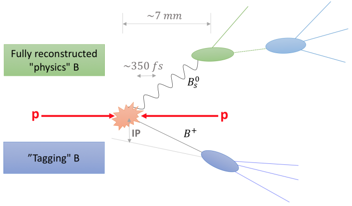


S_f: $\not{C}\not{P}$ in interference between mixing and decay.
C_f: direct $\not{C}\not{P}$.

Ex. $\not{C}\not{P}$ 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 $\mathcal{O}(1$ 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

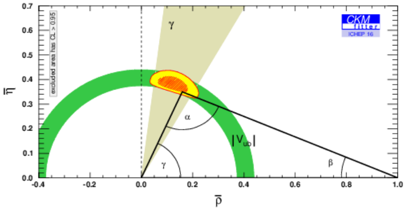
- **Impact parameter resolution**
  - E.g. LHCb: $\sigma_{IP} \sim 20\ \mu$m for high-p_T
- **Momentum & invariant mass resolution**
  - E.g. LHCb: $\sigma_p/p \sim 0.5 - 1\%$
- **Decay-time resolution**
  - E.g. LHCb: $\sigma_t \sim 45$ fs

- **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**
  - $\sigma(b\bar{b}) \approx 515\mu$b @ 13 TeV [JHEP 10 (2015) 172]
  - Charm rate ~ 20 times larger

Tree vs loop measurements

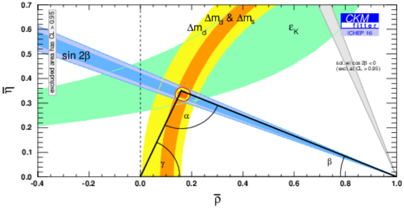
If we assume NP enters only (mainly) at loop level, it is interesting to compare:

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 , ...)



[CKMfitter Group]

- 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

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 $B^0 \to J/\psi\pi^0$

LHCb upgrade

			End of Run2		
		$\int L\,dt = 3\,\mathrm{fb}^{-1}$	$\int L\,dt = 8\,\mathrm{fb}^{-1}$	$\int L\,dt = 50\,\mathrm{fb}^{-1}$	
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	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	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%**	$\sim 7\%$
	$A_{\rm I}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	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**	–