CP violation in beauty and charm at Upgrade II

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SM picture accounts for wide range of measured CP observables

But there is still room for NP!

More and more precise measurements are needed to reveal possible inconsistencies

 Majority of measurements are still statistically limited after Run2

We will take advantage of the HL-LHC era to produce a very precise picture of the physics of flavour

All the expected sensitivity for Phase 2 upgrade are taken from arXiv.1808.08865
Measurement of $\gamma$ is crucial since it is still the least well-known UT angle

Only CP-violating parameter that can be measured at the tree-level alone providing a good test for the SM (assuming no NP in tree-level decays [PRD92 (2015) 033002])

Theoretically clean: $\delta_{\gamma}^{\text{th}}/\gamma < \mathcal{O}(10^{-7})$ [JHEP 1401 (2014) 051]

Comparing tree-level with loop-level determination to get signs of NP

Tree-level

Direct measurement $\gamma = (72.1^{+5.4}_{-5.7})^\circ$

Loop-level

Indirect measurement (CKM fitter) $\gamma = (65.80^{+0.94}_{-1.29})^\circ$
Status of $\gamma$ measurements at LHCb

3 fb$^{-1}$ Run1 data
+ 2 fb$^{-1}$ Run2 data (2015-2016)
not yet included in LHCb combination [LHCb-CONF-2018-002]

<table>
<thead>
<tr>
<th>Model</th>
<th>$h^+h^-$</th>
<th>$\pi^+\pi^-\pi^+\pi^-$</th>
<th>$K^+\pi^+$</th>
<th>$K^0\pi^+\pi^-$</th>
<th>$K^0\pi^+\pi^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLW</td>
<td>PLB777 (18) 16</td>
<td>PRD93 (16) 112018 JHEP08(19)41 JHEP08(19)41</td>
<td>JHEP17(17)156</td>
<td>PRD92(15)112005 PLB777(18)16</td>
<td></td>
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<tr>
<td>ADS</td>
<td>PLB760 (16) 117 PRD91(25)112014</td>
<td>PLB760 (16) 117 PRD91(25)112014</td>
<td>JHEP08(19)41 JHEP17(17)156</td>
<td>JHEP17(17)156</td>
<td>PRD92(15)112005</td>
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<tr>
<td>GGSZ</td>
<td>JHEP08(18)176</td>
<td>JHEP10(14)97</td>
<td>JHEP08(16)137</td>
<td>JHEP06(16)131</td>
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</tr>
<tr>
<td>GLS</td>
<td>PLB733(14)36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Different modes as a consistency check
- Complementary measurements: different challenges and different source of systematic uncertainties
The LHCb combination

- Combination using $B^+ \to D(\ast)K(\ast)^+$, $B^0 \to DK^0$, $B^0 \to D^\mp \pi^\pm$ and $B^0_s \to D_s^\mp K^\pm$ decays in a maximum likelihood fit.

- Most precise determination of $\gamma$ by single experiment:
  \[ \gamma = (74.0^{+5.0}_{-5.8})^\circ \]

- In agreement with world averages.

- Target precision with Run2 data: $\sigma(\gamma) = 4^\circ$.
Upgrade2 \( \gamma \) prospects

**ADS/GLW**

- Statistically limited
- Dominant systematic uncertainties expected to scale with statistics
  - Instrumentation asymmetries (calibration samples)
  - Background contributions (studies with larger sample)

**GGSZ**

- Statistically limited
- Precision of external charm inputs
  - Current syst. due to CLEO inputs \( \sim 2^\circ \)
  - Future datasets at BESIII crucial
- Dalitz efficiency (data/simulation agreement, fast simulation techniques)

**TD**

- Syst. Unc. from decay time acceptance and resolution and from calibration of flavour tagging
- Expected to scale with statistics due to the data-driven methods
Improvements in the detector will make new modes entering the game

- Improvements in the electromagnetic calorimeter ECAL (granularity and energy resolution)
  - ADS/GLW and GGSZ with modes with an additional $\pi^0$ in the final state ($hh\pi^0$, $K_s^0\pi\pi\pi^0$) or $D^{*0}$
- Improvements in low-momentum tracking with addition of magnet-side stations (soft track reconstruction, removal of ghosts)
- Reduction in the VELO material: improve vertex resolution
  - Multi body decays ($D \rightarrow 4\ell$)
• Sub-degree precision level on $\gamma$:
  $\sigma(\gamma) \sim 0.35^\circ$ with 300 fb$^{-1}$

• Belle II precision of $1.5^\circ$ with 50 ab$^{-1}$
Status of $\sin 2\beta$

$\sin(2\beta) \equiv \sin(2\phi_1)$

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Year</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaBar</td>
<td>2009</td>
<td>0.69 ± 0.03 ± 0.01</td>
</tr>
<tr>
<td>BaBar $\chi_c^0$ K$_s$</td>
<td>2009</td>
<td>0.69 ± 0.52 ± 0.04 ± 0.07</td>
</tr>
<tr>
<td>BaBar J/$\psi$ (hadronic) K$_s$</td>
<td>2004</td>
<td>1.56 ± 0.42 ± 0.21</td>
</tr>
<tr>
<td>Belle</td>
<td>2012</td>
<td>0.67 ± 0.02 ± 0.01</td>
</tr>
<tr>
<td>ALEPH</td>
<td>1998</td>
<td>0.84 ±0.02 ± 0.16</td>
</tr>
<tr>
<td>OPAL</td>
<td>1998</td>
<td>3.20 ±1.00 ± 0.50</td>
</tr>
<tr>
<td>CDF</td>
<td>2000</td>
<td>0.79 ±0.41</td>
</tr>
<tr>
<td>LHCb</td>
<td>2015</td>
<td>0.76 ± 0.03</td>
</tr>
<tr>
<td>Belle5S</td>
<td>2017</td>
<td>0.57 ± 0.58 ± 0.06</td>
</tr>
<tr>
<td>Average HFLAV</td>
<td></td>
<td>0.70 ± 0.02</td>
</tr>
</tbody>
</table>

- **Accessed via interference in $B^0$ mixing and decay**
- **Golden channel:** $B^0 \rightarrow J/\psi K^0_s$
- **LHCb measurements**
  - $B^0 \rightarrow J/\psi K^0_s$ (Run1)  
    [PRL115(2015)031601]
  - $B^0 \rightarrow D^+ D^- $ (Run1)  
    [PRL117(2016)261801]
  - $B^0 \rightarrow \psi(2S) K^0_s$, $B^0 \rightarrow J/\psi(e^+ e^-) K^0_s$ (Run1)  
    [JHEP11(2017)170]
  - $B^0 \rightarrow D^{*\pm} D^{\mp}$ (Run1 + Run2)  
    arXiv:1912.03727
Prospects for $\sin 2\beta$

- Systematic uncertainties:
  - tag asymmetries in bkg,
  - flavour tagging calibration,
  - decay-time efficiency

- Not expected to be limiting since control samples will scale with increased data

- Need clearly a good flavour tagging performance

- Good control of $K^0-\bar{K}^0$ CP violation and nuclear cross-section asymmetry

- Control of penguin pollution

- $\sigma_{stat} = 0.003$ at $300\,\text{fb}^{-1}$

- Belle II at $50\,\text{ab}^{-1}$: $\sigma_{stat} = 0.005$
CP violation in $B_s$ mixing and decay:

- CP-violating phase arising from interference between mixing and decay
- Precisely predicted by the SM
- Golden channel: $B_s^0 \rightarrow J/\psi \phi$
- Exploited not only by LHCb but also by ATLAS and CMS
- Measurement in other channels by LHCb to improve precision and as consistency check
  - $B_s^0 \rightarrow J/\psi \phi$ [EPJC79(2019)706] (2015+2016)
  - $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ [PLB797(2019)134789] (2015+2016)
  - $B_s^0 \rightarrow D_s D_s$ [PRL113(2014)211801]
  - $B_s^0 \rightarrow \psi(2S)\phi$ [PLB762(2016)253]
  - $B_s^0 \rightarrow J/\psi KK$ high mass [JHEP08(2017)037]

Indirect measurement:
- $\phi_s = -36.4 \pm 1.2$

Experimental uncertainty $\gg$ uncertainty on indirect determination
Run2 data results [EPJC79(2019)706, PLB797(2019)134789]

- Flavour-tagged decay-time dependent angular analysis
- Flavour tagging and excellent time resolution are a key ingredients
- Simultaneous fit to the decay time and three helicity angles in 6 $m(K^+K^-)$ bins and in $m(\pi^+\pi^-)$
- Per-candidate decay time error calibrated using prompt $J/\psi$ control sample
- Studies of variation of efficiency with angular variables and decay-time acceptance are fundamental (data-driven approach)
- Resonance modelling of the $\pi^+\pi^-$ spectrum is giving one of the largest systematics

\[ N(B_s^0 \to J/\psi K^+K^-) \sim 117K \]

\[ N(B_s^0 \to J/\psi \pi^+\pi^-) \sim 33.5K \]
Combination of LHCb results

\[ \phi_s = -0.042 \pm 0.025 \text{ rad} \]
\[ |\lambda| = 0.993 \pm 0.010 \]
\[ \Gamma_s = 0.6563 \pm 0.0021 \text{ ps}^{-1} \]
\[ \Delta \Gamma_s = 0.0813 \pm 0.0048 \text{ ps}^{-1} \]

- $\phi_s$ consistent with SM
- $\lambda$ consistent with no direct CPV
Prospects for U2

- Fundamental to maintain (or improve) current detector performance: vertex position resolution and decay time resolution for high pile-up conditions
- Improve flavour-tagging (sensitive to event multiplicity)
- Include new modes (as it has been already done for $B^0_s \rightarrow D^+_s D^-_s$ and $B^0 \rightarrow D^+ D^-$ (which will benefit from the enhanced trigger efficiency for hadrons) but also $B^0_s \rightarrow J/\psi (ee) \phi$ and $B^0_s \rightarrow J/\psi \eta^{(')}$ involving neutrals with improved calorimeter performance
- Control of penguin pollution using SU(3) flavour (expected to be $\lesssim 1.5 \text{ mrad}$) using $B^0 \rightarrow J/\psi \pi^0$ and $B^0_s \rightarrow J/\psi K^0_s$ (already studied) from Belle II and improving ECAL capabilities

\[
\sigma(\phi_s) \sim 4 \text{ mrad from } B^0_s \rightarrow J/\psi \phi \\
\sigma(\phi_s) \sim 3 \text{ mrad from combined modes}
\]
\[ \phi_{\ell}^{s\bar{s}\bar{s}} \text{ and } \phi_{\ell}^{d\bar{d}s} \text{ from charmless} \]

- \( B_s^0 \to \phi\phi: \bar{b} \to s\bar{s}s \) gluonic penguin: excellent probe of physics BSM
- Measurement using 5 fb\(^{-1}\) (Run1 + 2015 + 2016)
- Statistically limited
- Main syst. unc.: angular acceptance determined from simulations

\[ \phi = -0.073 \pm 0.115 \pm 0.027 \text{ rad} \]

- \( B_s^0 \to (K^+\pi^-)(K^+\pi^-): \bar{b} \to d\bar{d}s \)
- Measurement using Run1 data
- Comparable statistical and syst. unc.
- Main systematic uncertainties:
  - Acceptance determination from simulations
  - Modelling of the \( K\pi \) spectrum

\[ \phi = -0.10 \pm 0.13 \pm 0.14 \text{ rad} \]
Prospects for $\phi_s^{ss\bar{s}}$ and $\phi_s^{d\bar{d}s}$

- $\phi_s^{ss\bar{s}}$ statistically limits with full U2 data sample
- Syst. Unc. expected to scale with statistics
- Treatment of acceptance: rapid simulation due to large samples needed
- For $\phi_s^{d\bar{d}s}$, modelling of the $K\pi$ spectrum irreducible ($\sigma_{syst} \sim 0.03$ rad)

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>$3 \text{ fb}^{-1}$</th>
<th>$23 \text{ fb}^{-1}$</th>
<th>$50 \text{ fb}^{-1}$</th>
<th>$300 \text{ fb}^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s^0 \rightarrow \phi\phi$</td>
<td>0.154</td>
<td>0.039</td>
<td>0.026</td>
<td>0.011</td>
</tr>
<tr>
<td>$B_s^0 \rightarrow (K^+\pi^-)(K^-\pi^+)$ (inclusive)</td>
<td>0.129</td>
<td>0.033</td>
<td>0.022</td>
<td>0.009</td>
</tr>
<tr>
<td>$B_s^0 \rightarrow K^<em>(892)^0\bar{K}^</em>(892)^0$</td>
<td>$-$</td>
<td>0.127</td>
<td>0.086</td>
<td>0.035</td>
</tr>
</tbody>
</table>
CP violation in three-body $B$ decays

- Interest due to the observation of large CPV in localised regions of the phase space [PRD90 (2014) 112004] not only associated with a resonance
- Rescattering process can generate additional strong phase difference
- Several quasi-two-body amplitudes interfering in multi-body final state decays with access to strong and weak phases
- Extraction of CKM parameters by combining amplitude measurements using isospin partner decays
- Amplitude analysis of $B^+ \rightarrow \pi^+ K^+ K^-$ [PRL123(2019)231802] and $B^+ \rightarrow \pi^+ \pi^+ \pi^-$ [PRD101(2020)012006]
- Observed CPV in rescattering in $B^+ \rightarrow \pi^+ K^+ K^-$
- For $B^+ \rightarrow \pi^+ K^+ K^-$
  - Significant CP at low $m(\pi^+ \pi^-)$
  - Large CPV in the $f_s(1270)$ region (tensor resonance)
  - Observed CPV in the interference between S and P interference
Measurement of $A_{CP}$ are currently statistically limited

Current dominant systematic uncertainties
- Parametrisation of signal and backgrounds
- Modelling of efficiency on the Dalitz phase space
- Amplitude model (Resonance fixed parameters and alternative models)

$B \rightarrow hhh$ measurement will become systematically limited
- Parametrisation of signal and backgrounds will scale with integrated luminosity
- Modelling of efficiency on the Dalitz phase space: larger simulation samples, more uniform efficiencies
- Amplitude model will not scale with data
CP violation in charmless

- CP violation studies in $B^0 \rightarrow \pi^+\pi^-$ and $B^0_s \rightarrow K^+K^-$: constraints on $\gamma$ and $-2\beta_s$ [JHEP10(2013)183, PRD98(2018) 032004]

- Determination of the angle $\alpha$ using $B \rightarrow \pi\pi$, $B \rightarrow \rho\rho$, $B \rightarrow \pi^+\pi^-\pi^0$
  - CP measurements in $B^0 \rightarrow \pi^+\pi^-$ will be dominated by LHCb
  - Possibility to study $B^+ \rightarrow \pi^+\pi^0$ (as done for the $B^+ \rightarrow K^+\pi^0$) with the improvements in the calorimeter system
  - $B^0 \rightarrow \rho^0\rho^0$ study of CP violating parameters will be performed at LHCb (Time integrated angular analysis performed with Run1 data [PLB747 (2015) 468])
  - $B \rightarrow \pi^+\pi^-\pi^0$ with the improvements in the calorimeter system but need tagged time-dependent analysis and knowledge of the resonant substructures
  - Other golden modes more criticals ($B^0 \rightarrow \pi^0\pi^0$, $B^0 \rightarrow \rho\rho^+$)

- Belle II will dominate $\alpha$ measurement

- Loop-dominated modes will become interesting due to the more efficient hadron trigger and improved ECAL
  - Decay-time-dependent flavour-tagged Dalitz analysis of $B^0_s \rightarrow K^0_s hh$ decays will be possible in the U2 thanks to the large yields available (Time integrated analysis with Run1 data [PRL120(2018) 261801])
**CP violation in $b$ baryon decays**

- LHCb is the only experiment to have access to $b$-baryon decays

- Measurement program of CPV is on-going

  - $\Lambda^0_b \to K^0_sp\pi$ [JHEP04(2014)087]
  - $\Lambda^0_b \to \Lambda hh$ [JHEP05(2016)081]
  - $\Lambda^0_b \to ph$ [PLB787(2018)182]
  - $\Lambda^0_b \to D^0pK$ [PRD89(2014)032001]
  - $\Lambda^0_b \to phhh$ [EPJC79(2019)745, Nature Phys12(2017)341, JHEP08(2018)039, 1912.10741] with the first observation of $P$ violation at $5.5\sigma$ integrated over phase space and CP violation at $2.9\sigma$ in regions of phase space

- Very large yields open to new $b$-baryons and new decay modes

- Not only $b$-baryons but also charm baryons ($\Xi^+_c$)

- Main experimental issues
  - Particle-antiparticle production asymmetries
  - Detector reconstruction asymmetries: difficult to calibrate different interactions baryons/antibaryons with material

- Use quantities not affected by experimental effects ($\Delta A_C$, TPA, ET, ...)
Charm physics

- Motivations: unique access to mixing and CPV in the up-type quark sector
- Taking advantage of the enormous ($\sim 10 \text{ MHz}$) production rate of charm mesons and baryons expected in the $U2$
- Fully software trigger and use of real-time analysis is fundamental
- First observation of CPV in charm ($5.3\sigma$) using Run1+Run2 data! [PRL122 (2019) 211803]
  \[ \Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-1.54 \pm 0.29) \times 10^{-3} \]
  Cancellation of both production and detection asymmetries!
- Extended program to measure CP asymmetries in many different channels
- Exploit both direct CP and mixing and time-dependent measurements
Direct CP
Direct CPV in \( D \rightarrow K^- K^+ \) and \( D \rightarrow \pi^- \pi^+ \)

- Enhanced sensitivity to direct CPV through a measurement of \( \Delta A_{CP} \)
- Disentangle the two contributions measuring the two individual asymmetries \( A_{CP}(K^- K^+) \) and \( A_{CP}(\pi^- \pi^+) \)

- Measurement of \( A_{CP}(K^- K^+) \) with Run1 data [PLB767(2017)177]
- Asymmetries subtracted using control samples
- Statistical precision reduced to the kinematic weighting due to the different topologies of the decays
- No systematic uncertainties expected to have irreducible contributions but need a precise control of the detection asymmetries (\( K^0 \) asymmetry due to the knowledge of the material budget)

<table>
<thead>
<tr>
<th>Sample (( \mathcal{L} ))</th>
<th>Tag</th>
<th>Yield ( D^0 \rightarrow K^- K^+ )</th>
<th>Yield ( D^0 \rightarrow \pi^- \pi^+ )</th>
<th>( \sigma(\Delta A_{CP}) ) [%]</th>
<th>( \sigma(A_{CP}(hh)) ) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1–2 (9 fb(^{-1}))</td>
<td>Prompt</td>
<td>52M</td>
<td>17M</td>
<td>0.03</td>
<td>0.07</td>
</tr>
<tr>
<td>Run 1–3 (23 fb(^{-1}))</td>
<td>Prompt</td>
<td>280M</td>
<td>94M</td>
<td>0.013</td>
<td>0.03</td>
</tr>
<tr>
<td>Run 1–4 (50 fb(^{-1}))</td>
<td>Prompt</td>
<td>1G</td>
<td>305M</td>
<td>0.007</td>
<td>0.015</td>
</tr>
<tr>
<td>Run 1–5 (300 fb(^{-1}))</td>
<td>Prompt</td>
<td>4.9G</td>
<td>1.6G</td>
<td>0.003</td>
<td>0.007</td>
</tr>
</tbody>
</table>
Direct CPV

- Other channels which can gain from the improved downstream tracking, calorimetry and trigger in Upgrade2
  - CPV enhanced to the percent level such as in $D^0 \to K_s^0 K_s^0$ [JHEP 1811 (2018) 048] and $D^0 \to K_s^0 K_s^{*0}$ [PRD93(2016)052018]
  - $D_s^+ \to K_s^0 \pi^+$, $D^+ \to K_s^0 K^+$, $D^+ \to \phi \pi^+$ [PRL122(2019)191803]
  - Decays with neutrals: $D^+ \to \eta' \pi^+$, $D_s^+ \to \eta' \pi^+$ [PLB771(2017)21] or radiative decays $D^0 \to \phi \gamma$ and $D^0 \to \rho \gamma$
  - Quasi-two body modes such as $D^0 \to K^* K$, $D_s \to \rho K$: overlapping amplitudes in $D \to hhh$ decays with varying strong phase
  - $D^0 \to h^+ h^- h^+ h^-$ using both T-odd asymmetries [JHEP10(2014)005], energy test [PLB769(2017)345] or model-dependent analysis
  - Charmed baryons

<table>
<thead>
<tr>
<th>Current Best</th>
<th>LHCb U2 $(300 \text{ fb}^{-1})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{\text{CP}}(D^0 \to K_s^0 K_s^0)$</td>
<td>Belle</td>
</tr>
<tr>
<td>$A_{\text{CP}}(D^0 \to K_s^0 K_s^{*0})$</td>
<td>LHCb $(9 \text{ fb}^{-1})$</td>
</tr>
<tr>
<td>$A_{\text{CP}}(D^+ \to \pi^+ \pi^0)$</td>
<td>Belle</td>
</tr>
<tr>
<td>$A_{\text{CP}}(D^+ \to \phi \pi^+)$</td>
<td>LHCb $(4.8 \text{ fb}^{-1})$</td>
</tr>
<tr>
<td>$A_{\text{CP}}(D^+ \to K_s^0 K^+)$</td>
<td>LHCb $(6.8 \text{ fb}^{-1})$</td>
</tr>
<tr>
<td>$A_{\text{CP}}(D^+ \to K_s^0 \pi^+)$</td>
<td>LHCb $(6.8 \text{ fb}^{-1})$</td>
</tr>
<tr>
<td>$A_{\text{CP}}(D^+ \to \eta' \pi^+)$</td>
<td>LHCb $(3 \text{ fb}^{-1})$</td>
</tr>
</tbody>
</table>
Mixing and time-dependent CPV
Time-dependent CP of $D^0$ mesons into CP eigenstates ($D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$)

$A_{CP} \simeq A_{CP}^{dir} - \frac{t}{\tau_D} A_{\Gamma}$

Experimentally robust

- Self-conjugate final state: detection asymmetry only from tagging $\pi^+$ or $\mu^+$
- Sensitive to detector asymmetries through correlations between momentum and proper decay time
- Large CF $D^0 \rightarrow K^-\pi^+$ control sample

Measurement using $5.4 \text{ fb}^{-1}$ [PRD101 (2020) 012005]

<table>
<thead>
<tr>
<th>Sample ($\mathcal{L}$)</th>
<th>Tag</th>
<th>Yield $K^+K^-$</th>
<th>$\sigma(A_{\Gamma})$</th>
<th>Yield $\pi^+\pi^-$</th>
<th>$\sigma(A_{\Gamma})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1–2 (9 fb$^{-1}$)</td>
<td>Prompt</td>
<td>60M</td>
<td>0.013%</td>
<td>18M</td>
<td>0.024%</td>
</tr>
<tr>
<td>Run 1–3 (23 fb$^{-1}$)</td>
<td>Prompt</td>
<td>310M</td>
<td>0.0056%</td>
<td>92M</td>
<td>0.0104%</td>
</tr>
<tr>
<td>Run 1–4 (50 fb$^{-1}$)</td>
<td>Prompt</td>
<td>793M</td>
<td>0.0035%</td>
<td>236M</td>
<td>0.0065%</td>
</tr>
<tr>
<td>Run 1–5 (300 fb$^{-1}$)</td>
<td>Prompt</td>
<td>5.3G</td>
<td>0.0014%</td>
<td>1.6G</td>
<td>0.0025%</td>
</tr>
</tbody>
</table>

SM predictions $A_{\Gamma}^{SM} \approx 0.3 \times 10^{-4}$

Need to save 50 billion CF $D^0 \rightarrow K^-\pi^+$ control decays
**WS/RS ratio**

**LHCb measurement for** $D^0 \to K^-\pi^+$ (Run1 + 2015 + 2016) [PRD 97 (2018) 031101]

**Similar analysis for** $D^0 \to K^+\pi^-\pi^+\pi^-$

**Phase-space integrated measurement** [PRL 116 (2016) 241801]

**Enhanced sensitivity thanks to the variation of strong phases in the phase space (but strong phases have to be determined)**

**Magnet-side stations will increase flavour-tagged charm sample (from the charge of the low-momentum pion)**

**Syst. Unc. estimated using control samples, no irreducible contributions**
Conclusions

- For the beauty sector: great progress in probing SM, but considerable space for NP remains
- LHCb will drive tree-level CPV $\gamma$ precision through Phase 2 to sub-degree precision
- $\phi_s$ will be measured with a precision of 3 mrad: good control of penguin pollution
- Test of CPV in charm has just started: expected $10^{-5}$ precision
- Improve/maintain detector performance (vertex/time resolution, flavour tagging/PID/...)
- Use high-yield control channels to control efficiencies
Spare Slides