$\gamma$ determination at LHCb

Angelo Carbone (INFN-Bologna) on behalf of LHCb collaboration

Focus Week “B@LHC”

27th May 2008
Overview

- Unitary Triangle prediction of SM $\gamma$ is $\sim 7^\circ$
- LHCb goal is to measure $\gamma$ in SM-clean way to match the precision of indirect measurements and check if the prediction is correct
  - Tree processes $\rightarrow$ very clean place to measure $\gamma$ even if any New Physics effect in mixing will perturb the measurements
    - $B^\pm \rightarrow D^0 K^\pm$, $B^0 \rightarrow D^0 K^{0*}$
      - direct $\gamma$ measurements using ADS, GLW and Dalitz methods
    - $B_s^0 \rightarrow D_s^0 K^\pm$
      - measure $\gamma - 2\beta_s$
  - Loop processes $\rightarrow$ a discrepancy between this and the tree-level measurements may point out New Physics in the loops
    - $B \rightarrow h^+ h^-$
      - Measure combination of $\gamma$, $\beta$ and $\beta_s$ using SU(3) symmetry

\[ V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0 \]

\[ \gamma \text{ is related to the phase between } b \rightarrow u \]
\[ b \rightarrow c \text{ transition} \]

$\gamma = (65.1 \pm 6.5)^\circ$
Current experimental status on $\gamma$ from UTfit

Direct measurements from $B \to D K$, $D^* K$ and $D K^*$

bound from $B \to D K$, $D^* K$ and $D K^*$ decays with present measurements using all the methods.

$\gamma = (88 \pm 16)^{\circ}$ ([41,123] @ 95% Prob.)

$\gamma$ up to $\pi$ ambiguity
Measuring $\gamma$ from $B \to h^+h^-$

- $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^-$ can be used to extract $\gamma$ up to U-spin breaking conditions.
- The presence of penguins is an addition opportunity to mixing to spot new physics:
  - New Physics might show up also in loops of the penguin diagrams.
  - CKM quantities from these modes can differ from the ones from tree-level modes, assuming they are unaffected from NP.
- Can also be used to probe the size of U-spin breaking, together with $B_d \to K^+\pi^-$ and $B_s \to \pi^+K^-$. 

Example of penguin diagrams:

$B^0(B_s^0)$

$\bar{b} \to u \pi^+(K^+)$

$\bar{d}(s) \to \bar{u} \pi^-(K^-)$

$\gamma$ determination at LHCb

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### U-spin \((d \leftrightarrow s\) quark exchange) symmetric modes

<table>
<thead>
<tr>
<th>(B_d \rightarrow \pi^+\pi^-)</th>
<th>(B_s \rightarrow K^+K^-)</th>
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<tbody>
<tr>
<td>T+P+(P_{EW}^C)+PA+E</td>
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- Not all exactly U-spin symmetric, E and PA contributions missing from flavour specific decays
- E and PA contributions expected to be relatively small, and can be experimentally probed by measuring the still unobserved \(B_s \rightarrow \pi^+\pi^-\) and \(B_d \rightarrow K^+K^-\) branching ratios \((BR \sim 10^{-8})\)
Event yields at LHCb up to 2fb⁻¹

- LHCb will be statistically competitive with the final luminosity of Tevatron (assuming L=6fb⁻¹) already when approaching L=0.5fb⁻¹

<table>
<thead>
<tr>
<th></th>
<th>B_d→ππ</th>
<th>B_d→Kπ</th>
<th>B_s→KK</th>
<th>B_s→πK</th>
</tr>
</thead>
<tbody>
<tr>
<td>L=0.01 fb⁻¹</td>
<td>0.18k</td>
<td>0.69k</td>
<td>0.18k</td>
<td>0.05k</td>
</tr>
<tr>
<td>L=0.5 fb⁻¹</td>
<td>9k</td>
<td>34.5k</td>
<td>9k</td>
<td>2.5k</td>
</tr>
<tr>
<td>L=2 fb⁻¹</td>
<td>36k</td>
<td>138k</td>
<td>36k</td>
<td>10k</td>
</tr>
<tr>
<td>B/S</td>
<td>0.5</td>
<td>&lt;0.06</td>
<td>0.15</td>
<td>1.9</td>
</tr>
</tbody>
</table>

\[\pi^+, K^+\]
\[\pi^-, K^-\]
Performance of hadron PID: invariant mass spectra

- One major advantage of LHCb with respect to the Tevatron (in addition to cross section of course): the particle identification system allows the different $B \rightarrow h^+h^-$ modes to be strongly separated.

- Every $h^+h^-$ channel is potentially a background for the other channels...
One major advantage of LHCb with respect to the Tevatron (in addition to cross section of course): the particle identification system allows the different $B \rightarrow h^+ h^-$ modes to be strongly separated.

...but impressive performance of RICH systems allows to select very clean samples.
\[ A_{\pi^+\pi^-} = V_{ub}^* V_{ud} \cdot T^u + V_{ub}^* V_{ud} \cdot P^u + V_{cb}^* V_{cd} \cdot P^c + V_{tb}^* V_{td} \cdot P^t \]

\[ A_{\pi^+\pi^-} = C(e^{i\gamma} - de^{i\phi}) \]

\[ \overline{A}_{\pi^+\pi^-} = C(e^{-i\gamma} - de^{i\phi}) \]

\[ C = \lambda^3 A R_b \left( T^u + P^u - P^t \right) \]

\[ \det \equiv \frac{1}{R_b} \left( \frac{P^c - P^t}{T^u + P^u - P^t} \right) \]

\[ A_{K^+K^-} = V_{ub}^* V_{us} \cdot T^u + V_{ub}^* V_{us} \cdot P^u + V_{cb}^* V_{cs} \cdot P^c + V_{tb}^* V_{ts} \cdot P^t \]

\[ A_{K^+K^-} = \frac{\lambda}{1 - \lambda^2 / 2} C' \left( e^{i\gamma} + \frac{1 - \lambda^2}{\lambda^2} d'e^{i\phi'} \right) \]

\[ \overline{A}_{K^+K^-} = \frac{\lambda}{1 - \lambda^2 / 2} C' \left( e^{-i\gamma} + \frac{1 - \lambda^2}{\lambda^2} d'e^{i\phi'} \right) \]

\[ C' = \lambda^3 A R_b \left( T'^u + P'^u - P'^t \right) \]

\[ d'e^{i\phi'} = \frac{1}{R_b} \left( \frac{P'^c - P'^t}{T'^u + P'^u - P'^t} \right) \]

\[ R_b = \frac{1}{\lambda} \left( 1 - \frac{\lambda^2}{2} \right) \frac{V_{ub}}{V_{cb}} \]

Using method and parameterization from
R. Fleischer, PLB 459 (1999) 306
\[ A_{\pi^+\pi^-} = V_{ub}^* V_{ud} \cdot T^u + V_{ub}^* V_{ud} \cdot P^u + V_{cb}^* V_{cd} \cdot P^c + V_{tb}^* V_{td} \cdot P^t \]

\[ A_{\pi^+\pi^-} = C(e^{i\gamma} - de^{i\delta}) \]

\[ A_{\pi^+\pi^-} = \overline{C}(e^{-i\gamma} - de^{i\delta}) \]

\[ C \equiv \lambda^3 A R_b \left( T^u + P^u - P^t \right) \quad \text{de}^{i\delta} \equiv \frac{1}{R_b} \left( \frac{P^c - P^t}{T^u + P^u - P^t} \right) \]

\[ A_{K^+K^-} = V_{ub}^* V_{us} \cdot \overline{T}^u + V_{ub}^* V_{us} \cdot \overline{P}^u + V_{cb}^* V_{cs} \cdot \overline{P}^c + V_{tb}^* V_{ts} \cdot \overline{P}^t \]

\[ A_{K^+K^-} = \frac{\lambda}{1 - \lambda^2/2} C' \left( e^{i\gamma} - \frac{1 - \lambda^2}{\lambda^2} d' \text{e}^{i\delta'} \right) \]

\[ \overline{A}_{K^+K^-} = \frac{\lambda}{1 - \lambda^2/2} C' \left( e^{-i\gamma} + \frac{1 - \lambda^2}{\lambda^2} d' \text{e}^{i\delta'} \right) \]

\[ C' \equiv \lambda^3 A R_b \left( \overline{T}^u + \overline{P}^u - \overline{P}^t \right) \quad d' \text{e}^{i\delta'} \equiv \frac{1}{R_b} \left( \frac{P'^c - P'^t}{\overline{T}^u + \overline{P}^u - \overline{P}^t} \right) \]

\[ R_b \equiv \frac{1}{\lambda} \left( 1 - \frac{\lambda^2}{2} \right) \left| \frac{V_{ub}}{V_{cb}} \right| \]

\[ d' \text{ is double Cabibbo enhanced... i.e. by a factor 20. For } d' = 0.5 \text{ the weak } CP\text{-violating term in the amplitude - which is sensitive to } \gamma \text{ - is 10 times less significant than the hadronic } CP\text{-conserving one} \]
\[ A_{\pi^+\pi^-} = V_{ub}^* V_{ud} \cdot T^u + V_{ub}^* V_{ud} \cdot P^u + V_{cb}^* V_{cd} \cdot P^c + V_{tb}^* V_{td} \cdot P^t \]

\[ A_{\pi^+\pi^-} = C(e^{i\gamma} - d e^{i\theta}) \]

\[ A_{\pi^+\pi^-} = C(e^{-i\gamma} - d e^{i\theta}) \]

\[ C \equiv \lambda^3 A_R b \left( T^u + P^u - P^t \right) \]

\[ d e^{i\theta} \equiv \frac{1}{R_b} \left( \frac{P^c - P^t}{T^u + P^u - P^t} \right) \]

\[ A_{K^+K^-} = V_{ub}^* V_{us} \cdot T'^u + V_{ub}^* V_{us} \cdot P'^u + V_{cb}^* V_{cs} \cdot P'^c + V_{tb}^* V_{ts} \cdot P'^t \]

\[ A_{K^+K^-} = \frac{\lambda}{1 - \lambda^2 / 2} C' \left( e^{i\gamma} + \frac{1 - \lambda^2}{\lambda^2} d' e^{i\theta'} \right) \]

\[ \bar{A}_{K^+K^-} = \frac{\lambda}{1 - \lambda^2 / 2} C' \left( e^{-i\gamma} + \frac{1 - \lambda^2}{\lambda^2} d' e^{i\theta'} \right) \]

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\[ R_b \equiv \frac{1}{\lambda} \left( 1 - \frac{\lambda^2}{2} \right) \left| \frac{V_{ub}}{V_{cb}} \right| \]

Relating by the U-spin symmetry the two amplitudes one gets

\[ d = d' \text{ and } \theta = \theta' \]

\( \gamma \) determination at LHCb

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Extraction of $\gamma$ from observables

\[
C(B_d^0 \to \pi^+\pi^-) = f_1(d, \vartheta, \gamma) \\
S(B_d^0 \to \pi^+\pi^-) = f_2(d, \vartheta, \gamma, \phi_d) \\
C(B_s^0 \to K^+K^-) = f_3(d', \vartheta', \gamma) \\
S(B_s^0 \to K^+K^-) = f_4(d', \vartheta', \gamma, \phi_s)
\]

- Once the direct and mixing-induced CP-violating terms are measured, one has a system of
  - 7 unknowns
- However, the mixing phase $\phi_d$ ($\phi_s$) is (will be) precisely measured from $B_d \to J/\psi K_S$ ($B_s \to J/\psi \phi$)
  - 5 unknowns
- Finally, relying on U-spin symmetry one eliminates two further unknowns
  - $d=d'$, $\theta = \theta'$
  - 3 unknowns, system over-constrained, $\gamma$ can be extracted unambiguously
  - one of the two U-spin relations can also be not used
LHCb sensitivity on $\gamma$ using time dependent measurements of $B_d \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$

(L=2fb$^{-1}$)

- Weak use of U-spin assumption
  - Strong phases $\theta$ and $\theta'$ left free during the fit (no U-spin assumed)
  - Strong magnitude related by U-spin $d=d'$, but allowing for a 20% U-spin breaking
  - Fit results
    68% probability, excluding non-SM solution
  - $\sigma(\gamma) = 10^\circ$
  - $\sigma(\theta) = 9^\circ$
  - $\sigma(\Delta\theta) = 17^\circ$
  - $\sigma(d) = 0.18$

\[\gamma\] determination at LHCb

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Same exercise, but with 5 years
(L=10fb\(^{-1}\))

- **Fit results**
  - 68% probability, excluding non-SM solution
  - \(\sigma(\gamma) = 5^\circ\)
  - \(\sigma(\theta) = 5^\circ\)
  - \(\sigma(\Delta\theta) = 8^\circ\)
  - \(\sigma(d) = 0.09\)

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More details
Measuring $\gamma$ from $B \rightarrow DK$

- Parameters for CKM favoured $B \rightarrow D^0 K$ and disfavoured $B \rightarrow \bar{D}^0 K$
- If $D^0$ and $\bar{D}^0$ are reconstructed in common final state than interference term involving gamma is accessed
- Amplitude ratio $r_B = |A(B \rightarrow D^0 K)| / |A(B \rightarrow \bar{D}^0 K)|$
- $\delta_B$, strong phases between amplitude $\rightarrow A(B \rightarrow D^0 K) = A(B \rightarrow \bar{D}^0 K) r_B e^{i(\delta_B - \gamma)}$

- $B^\pm$ decays ($r_B \sim 0.1$)
  - $B^-$
  - $K^-$
  - $D^0$
  - $B^+$
  - $K^-$

- $B^0$ decays (both diagrams colour suppressed $\rightarrow r_B \sim 0.4$)
  - $\bar{B}^0$
  - $D^0$
  - $\bar{B}^0$
  - $K^{*0}$

$\gamma$ determination at LHCb
Combining ADS+GLW

GLW method $\to$ $D^0$ decays in CP eigenstate ($h=K,\pi$)

\[
\Gamma(B^- \to (h^+h^-)_D K^-) = N^{hh}(1 + r_B^2 + 2r_B\cos(\delta_B - \gamma)),
\]
\[
\Gamma(B^+ \to (h^+h^-)_D K^+) = N^{hh}(1 + r_B^2 + 2r_B\cos(\delta_B + \gamma)).
\]

ADS method $\to$ $D^0$ decays in not CP eigenstate, $K\pi$

\[
\Gamma(B^- \to (K^-\pi^+)_D K^-) = N^{K\pi}(1 + (r_B r_D) + 2r_B r_D\cos(\delta_B - \delta_D^{K\pi} - \gamma)),
\]
\[
\Gamma(B^- \to (K^+\pi^-)_D K^-) = N^{K\pi}(r_B^2 + r_D^2 + 2r_B r_D\cos(\delta_B + \delta_D^{K\pi} - \gamma)),
\]
\[
\Gamma(B^+ \to (K^+\pi^-)_D K^+) = N^{K\pi}(1 + (r_B r_D)) + 2r_B r_D\cos(\delta_B - \delta_D^{K\pi} + \gamma)),
\]
\[
\Gamma(B^+ \to (K^-\pi^+)_D K^+) = N^{K\pi}(r_B^2 + r_D^2 + 2r_B r_D\cos(\delta_B + \delta_D^{K\pi} + \gamma)).
\]

- **Unknowns**: $r_B$, $\delta_B$, $d_D^{K\pi}$, $\gamma$, $N_{K\pi}$, $N_{hh}$ ($r_D=0.06$ well measured)
- With knowledge of the relevant efficiencies and BRs, the normalisation constants ($N_{K\pi}$, $N_{hh}$) can be related to one another
- Important constraint from CLEO-c $\sigma(\cos(d_D^{K\pi}))=0.1-0.2$
- **Overconstrained**: 6 observables and 5 unknowns
- same relations in the neutral system but $r_B$ expected to be $\sim 0.4$
Combining ADS+GLW

- **GLW method** $\rightarrow D^0$ decays in CP eingenstate ($h=K,\pi$)

  \[
  \Gamma(B^- \rightarrow (h^+ h^-)_D K^-) = N_{hh}^h (1 + r_B^2 + 2r_B \cos(\delta_B - \gamma)),
  \]

  \[
  \Gamma(B^+ \rightarrow (h^+ h^-)_D K^+) = N_{hh}^h (1 + r_B^2 + 2r_B \cos(\delta_B + \gamma)).
  \]

- **ADS method** $\rightarrow D^0$ decays in not CP eingenstate, $K\pi$

Only relative rates are measured, no flavour tagging id needed
full LHCb statistics can be used

- With knowledge of the relevant efficiencies and BRs, the normalisation constants ($N_{K\pi}, N_{hh}$) can be related to one another
- Important constraint from CLEO-c $\sigma(\cos(d_{D^{K\pi}})) = 0.1 - 0.2$
- **Overconstrained**: 6 observables and 5 unknowns
- same relations in the neutral system but $r_B$ expected to be $\sim 0.4$
Measuring $\gamma$ from $B^{\pm} \rightarrow D^0 K^{\pm}$ (ADS+GLW)

<table>
<thead>
<tr>
<th>Modes</th>
<th>Signal Yield</th>
<th>B/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \rightarrow D(K\pi)K$, favoured</td>
<td>56k</td>
<td>0.6</td>
</tr>
<tr>
<td>$B \rightarrow D(K\pi)K$, suppressed</td>
<td>0.71k</td>
<td>2</td>
</tr>
<tr>
<td>$B \rightarrow D(h^+h^-)K$</td>
<td>7.8k</td>
<td>1.8</td>
</tr>
</tbody>
</table>

- $\gamma$ sensitivity of 10.8°-13.8° in 2fb$^{-1}$, depending on the strong phase in the $D$ decays
- Input parameters:
  - $r_B = 0.01$
  - $\delta_B = 130^\circ$
  - $r_D = 0.06$
  - $\gamma = 60^\circ$
- Cleo-c results on $\delta_D^{K\pi}$ included

More details
CERN-LHCB-2008-011
Measuring $\gamma$ from $B^0 \rightarrow D^0 K^{*0}$ (ADS+GLW)

<table>
<thead>
<tr>
<th>Modes</th>
<th>Signal Yield</th>
<th>B/S (90%CL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0 \rightarrow D^0(K\pi)K^{*0}$, favoured</td>
<td>3.4k</td>
<td>[0.4, 2.1]</td>
</tr>
<tr>
<td>$B^0 \rightarrow D^0(K\pi)K^{*0}$, suppressed</td>
<td>0.5k</td>
<td>[2.2, 12.8]</td>
</tr>
<tr>
<td>$B^0 \rightarrow D(K^+K^-)K^{*0}$</td>
<td>0.5k</td>
<td>[0, 4.1]</td>
</tr>
<tr>
<td>$B^0 \rightarrow D(\pi^+\pi^-)K^{*0}$</td>
<td>0.1k</td>
<td>[0, 14]</td>
</tr>
</tbody>
</table>

- sensitivity of $9^\circ$ with integrated luminosity of $2\text{fb}^{-1}$
- input:
  - $rB_d = 0.4$
  - $\delta_B = 10^\circ$
  - $\gamma = 60^\circ$

More details
CERN-LHCb-2007-043
Measuring $\gamma$ from $B^{\pm} \rightarrow D^0(K_s \pi^+ \pi^-)K^\pm$

- amplitude analysis of the $D^0$ Dalitz plot leads to a determination of $\gamma$

**Integrated luminosity 2fb$^{-1}$**

Input $r_B = 0.10$, $\gamma = 60^\circ$

<table>
<thead>
<tr>
<th>Mode</th>
<th>Signal Yield</th>
<th>B/S</th>
</tr>
</thead>
</table>
| $B \rightarrow D(K_s \pi^+ \pi^-)K$ | 5k           | <0.7 |}

<table>
<thead>
<tr>
<th>Mode</th>
<th>sensitivity</th>
<th>Systematic error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \rightarrow D(K_s \pi^+ \pi^-)K$ model-depen.</td>
<td>$7^\circ$-$12^\circ$</td>
<td>$10^\circ$ (model dependence)</td>
</tr>
<tr>
<td>$B \rightarrow D(K_s \pi^+ \pi^-)K$ model-indepen.</td>
<td>$9^\circ$-$13^\circ$</td>
<td>$3^\circ$-$5^\circ$ (Cleo-c statistics)</td>
</tr>
</tbody>
</table>

Sensitivity spread due to different background scenarios

$\gamma$ determination at LHCb

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Sensitivity on $\gamma$ from ADS+GLW+Dalitz

- A global fit combining individual $\chi^2$ from the different ADS/GLW rates and Dalitz model-independent has been performed
  - Use relative efficiencies and branching fractions to relate normalisation factors
  - Include constraints from CLEO-c as additional terms in the $\chi^2$
  - Included in the global fit sensitivity from $B \to D(K3\pi)K$

Integrated luminosity 2fb$^{-1}$

<table>
<thead>
<tr>
<th>$\delta_B$ (°)</th>
<th>0</th>
<th>45</th>
<th>90</th>
<th>135</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined $B^+/B^0$ ADS/GLW</td>
<td>4.6°</td>
<td>7.6°</td>
<td>6.3°</td>
<td>7.1°</td>
<td>4.6°</td>
</tr>
<tr>
<td>+ model independent Dalitz</td>
<td>4.2°</td>
<td>5.7°</td>
<td>5.3°</td>
<td>5.7°</td>
<td>4.2°</td>
</tr>
</tbody>
</table>
Measuring $\gamma$ from $B_s \to D_s K^\pm$

- Tree level decay
  - Not affected by New Physics
- Need flavour tagging analysis to distinguish initial $B^0$ and $\bar{B}^0$
- Four time dependent decay rate

Interference between direct decay and decay after oscillation

Decay rates are sensitive to $\gamma - 2\beta_s$ and strong phases difference between T1 and T2

The mixing phase $\beta_s$ will be precisely measured from $B_s \to J/\psi \phi$, hence we can determine gamma

$\gamma$ determination at LHCb

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Yields

- Estimated branching fraction for full $B_s$ decay

<table>
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<tr>
<th>Decay</th>
<th>Branching Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \rightarrow D_s^-\pi^+$</td>
<td>$(3.4\pm0.7)\cdot10^{-3}$</td>
</tr>
<tr>
<td>$B_s \rightarrow D_s^-K^+$</td>
<td>$(2.0\pm0.6)\cdot10^{-4}$</td>
</tr>
<tr>
<td>$B_s \rightarrow D_s^+K^-$</td>
<td>$(2.2\pm0.7)\cdot10^{-5}$</td>
</tr>
</tbody>
</table>

- Event yields

<table>
<thead>
<tr>
<th>L (fb$^{-1}$)</th>
<th>$B_s \rightarrow D_s\pi$</th>
<th>$B_s \rightarrow D_sK$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.7k</td>
<td>0.03k</td>
</tr>
<tr>
<td>0.5</td>
<td>35k</td>
<td>1.6k</td>
</tr>
<tr>
<td>2</td>
<td>140k</td>
<td>6.2k</td>
</tr>
</tbody>
</table>

- $B_s \rightarrow D_s\pi$: specific background
  - Not only background but is also a control channel for measuring tagging dilution.
Sensitivity studies on $\gamma$

- Unbinned likelihood fit on decay time distributions simultaneously on $B_s \rightarrow D_s K$ and $B_s \rightarrow D_s \pi$
  - Including $B_s \rightarrow D_s \pi$ events in a simultaneous fit to constrain $\Delta \Gamma_s$ and $\Delta m_s$
  - Used tagged and untagged sample

Integrated luminosity 2fb$^{-1}$

<table>
<thead>
<tr>
<th></th>
<th>sensitivity</th>
<th>Input values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma-2\beta_s$</td>
<td>10.3°</td>
<td>60°</td>
</tr>
<tr>
<td>$\Delta m_s$</td>
<td>0.007 ps$^{-1}$</td>
<td>17.5 ps$^{-1}$</td>
</tr>
<tr>
<td>$\Delta T_1/T_2$</td>
<td>10.3°</td>
<td>0°</td>
</tr>
<tr>
<td>$</td>
<td>\lambda</td>
<td>$</td>
</tr>
</tbody>
</table>
### Sensitivity on $\gamma$ (0.5 fb$^{-1}$, 10 fb$^{-1}$)

**Sensitivity on $\gamma$, global fit**

<table>
<thead>
<tr>
<th>$\delta_B$ (°)</th>
<th>0</th>
<th>45</th>
<th>90</th>
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<th>180</th>
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<tbody>
<tr>
<td><strong>B$\rightarrow$DK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>9.2°</td>
<td>12.2°</td>
<td>10.5°</td>
<td>10.7°</td>
<td>8.6°</td>
</tr>
<tr>
<td>+ TDCPV</td>
<td>7.7°</td>
<td>9.3°</td>
<td>8.5°</td>
<td>8.6°</td>
<td>7.4°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\delta_B$ (°)</th>
<th>0</th>
<th>45</th>
<th>90</th>
<th>135</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B$\rightarrow$DK</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.4°</td>
<td>3.5°</td>
<td>2.9°</td>
<td>3.4°</td>
<td>2.3°</td>
</tr>
<tr>
<td>+ TDCPV</td>
<td>2.1°</td>
<td>2.7°</td>
<td>2.4°</td>
<td>2.6°</td>
<td>2.0°</td>
</tr>
</tbody>
</table>

**Sensitivity on $\gamma$ with loops**

<table>
<thead>
<tr>
<th>Loops</th>
<th>0.5 fb$^{-1}$</th>
<th>10 fb$^{-1}$</th>
<th>Weak U-spin assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°</td>
<td>5°</td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

- LHCb will be able to measure $\gamma$ with a precision of $5^\circ$ with $2\text{fb}^{-1}$ matching the precision of indirect measurements
  - Comparison between of $\gamma$ measured at LHCb and indirect determination will become a stringent test of the SM
- Comparison between $\gamma$ from trees and loops may show up New Physics in loops
- LHCb will be achieve a sensitivity of $2^\circ-3^\circ$ with $10 \text{ fb}^{-1}$
- LHCb's potential in charmless $B\rightarrow hhh$ ($h=\pi$ or $K$) also under study
- Other modes under consideration:
  - $B\rightarrow D(K\pi\pi^0)K$, $D(K_sKK)K$, $D^*K$, $D^*\pi$
  - $B^0\rightarrow D^*\pi$, $B^0\rightarrow D^*_\rho$, $B^0\rightarrow D^*a_1$, $B_s\rightarrow D_s^*K$ (time dependent)
    - U-spin combinations as well