Mixing and indirect CP violation in two-body Charm decays at LHCb

Tommaso Pajero - Scuola Normale Superiore & INFN, Pisa
on behalf of the LHCb collaboration
Overview

1) $A_{T}$ with Run 1 prompt data (3 fb$^{-1}$)
   [PRL 118, 261803 (2017)]

2) Mixing and CP violation in $D^0 \rightarrow K^\pm \pi^\mp$ decays
   with 2011–2016 prompt data (5 fb$^{-1}$)
   [PRD 97, 031101 (2018)]

3) $y_{CP}$ with Run 1 semileptonic-tagged data (3 fb$^{-1}$)
Mixing and CPV in charm

Mixing is established.

- Mixing parameters: \( x = \frac{m_2 - m_1}{\Gamma} \), \( y = \frac{\Gamma_2 - \Gamma_1}{2\Gamma} \), \( \Gamma = \frac{\Gamma_1 + \Gamma_2}{2} \)

- Mass eigenstates: \( |D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle \)

CPV still not observed.

- Charm is the only up-type quark where CPV can be fully investigated;
- CPV < \( \mathcal{O}(10^{-3}) \) in the SM, BSM contributions could enhance it.

https://hflav.web.cern.ch
$A_{\tau}$ with Run 1 data
$A_{\Gamma}$ definition

- Measure of indirect CPV in $D^0$ singly-Cabibbo-suppressed decays to CP eigenstates:

$$A_{\text{CP}}(t) = \frac{\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to f)} \approx A_{\text{CP}}^{\text{dir}} - A_{\Gamma}(\frac{t}{\tau}), \quad f = K^+K^-, \pi^+\pi^-$$

$$A_{\Gamma} = \frac{1}{2} \left[ \left( \frac{|q|}{|p|} - \frac{|p|}{|q|} \right) y \cos \phi + \left( \frac{|q|}{|p|} + \frac{|p|}{|q|} \right) x \sin \phi \right] \approx y \left( \frac{|q|}{|p|} - 1 \right) - x\phi$$

- If $A_{\Gamma} \neq 0 \rightarrow$ indirect CPV.

- At LHCb: measurement performed with Run 1 data (3 fb$^{-1}$)
- $D^0$ flavour from strong decay $D^{**} \rightarrow D^0 \pi^+_s$ (prompt).

[PRL 118, 261803 (2017)]
Data sample

\[ \Delta m = m(h^+h^-\pi_s^\pm) - m(h^+h^-) \]

- Cuts on \( m(h^+h^-) \), PID, IP of \( D^0 \) daughters.
Detection charge asymmetries

\[ D^{*+} \rightarrow [h^+ h^-]_{D^0} \pi^+_s \]

CP-symmetric, no asymmetries

- Trigger introduces correlations between the measured decay time of the \( D^0 \) and the momentum of the \( \pi^+_s \);
- momentum-dependent detection asymmetries reflect in time-dependent asymmetries mimicking a fake \( A_\Gamma \) value as large as \( 10^{-3} \ (3\sigma(A_\Gamma)) \).

- Reweigh the 3D momentum distribution of the \( \pi^-_s \) to match that of \( \pi^+_s \).
- Validated on \( D^0 \rightarrow K \pi^+ \) (no CPV expected).

\[ k = \frac{1}{\sqrt{p_x^2 + p_z^2}} \quad \text{and} \quad \theta_x = \arctan \left( \frac{p_x}{p_z} \right) \]
Secondary decays

- Measured decay-time of $D^0$ from $b$-hadrons biased to higher values -> their fraction increases as a function of time;
- B production asymmetry different from $D^{*+}$;
- secondary decays induce time-dependent asymmetries.

- Suppressed requiring the $D^0$ to come from PV ($\chi^2_{IP} < 9$);
- residual fraction estimated through a model whose normalization is fixed using the yields at high decay times.

$\chi^2_{IP} = \text{difference in } pp \text{ vertex-fit } \chi^2$ reconstructed with and without the particle
Results

\[ A_{\Gamma}^{KK} = (-3.0 \pm 3.2 \pm 1.0) \cdot 10^{-4} \]
\[ A_{\Gamma}^{\pi\pi} = (4.6 \pm 5.8 \pm 1.2) \cdot 10^{-4} \]

- Sys. unc. dominated by secondary decays and multi-body partially and misreconstructed D-meson decays.

- Combination with the smaller, independent muon-tagged sample \( \bar{B} \rightarrow D^0 \mu^- X \) [JHEP 04 (2015) 043]:

\[ A_{\Gamma} = (-2.9 \pm 2.8) \cdot 10^{-4} \]

- dominates the world average
- compatible with zero within 3x10^{-4}
Mixing and CPV with $D^0 \rightarrow K^\pm \pi^\mp$ decays
Mixing in $D^0 \rightarrow K^{\pm}\pi^{\mp}$

- Wrong sign (WS) decays:

  \[ D^{*+} \rightarrow D^0 \pi^+_S \rightarrow D^0 \rightarrow \bar{D}^0 \rightarrow K^+\pi^- \]

  a time-dependent WS decay rate implies mixing

- Right sign (RS) decays:

  \[ D^{*+} \rightarrow D^0 \pi^+_S \rightarrow D^0 \rightarrow \bar{D}^0 \rightarrow K^-\pi^+ \]

  decay rate nearly independent of time

Assuming negligible CPV:

\[
R(t) = \frac{\Gamma_{WS}(t)}{\Gamma_{RS}(t)} = R_D + \sqrt{R_D} y' \left( \frac{t}{\tau} \right) + \frac{(x')^2 + (y')^2}{4} \left( \frac{t}{\tau} \right)^2
\]

- DCS decay
- interference
- mixing + CF decay

\[
x' = x \cos \delta + y \sin \delta
\]
\[
y' = y \cos \delta - x \sin \delta
\]
\[
A(\bar{D}^0 \rightarrow K^+\pi^-) = -\sqrt{R_D} e^{-i\delta}
\]

\[
A(D^0 \rightarrow K^+\pi^-) = -\sqrt{R_D} e^{i\delta}
\]
CP violation in $D^0 \rightarrow K^{\pm}\pi^{\mp}$

- Measure WS/RS(t) separately for $D^{*+}$ and $D^{-}$ decays:

$$R^{\pm}(t) = \frac{\Gamma^{\pm}_{WS}(t)}{\Gamma^{\pm}_{RS}(t)} = R_D^\pm + \sqrt{R_D^\pm} y^\pm \left(\frac{t}{\tau}\right) + \frac{(x^\pm)^2 + (y^\pm)^2}{4} \left(\frac{t}{\tau}\right)^2$$

- Direct CPV

$R_D^{+} \neq R_D^{-}$

- CPV in the mixing or interference:

$x^\pm = \left| \frac{q}{p} \right|^{\pm1} [x \cos(\delta \pm \phi) + y \sin(\delta \pm \phi)]$

$y^\pm = \left| \frac{q}{p} \right|^{\pm1} [y \cos(\delta \pm \phi) - x \sin(\delta \pm \phi)]$

$\phi = \arg(q/p)$

- $D^{*+}$ production cross section and $\pi^+_s$ detection asymmetry cancel out in the ratio; need to account only for $K\pi$ detection asymmetry:

$$\frac{N^{\pm}_{WS}}{N^{\pm}_{RS}} = \frac{N(D^{*\pm} \rightarrow [K^{\pm}\pi^{\mp}]_{D^0} \pi^\pm_{s})}{N(D^{*\pm} \rightarrow [K^{\mp}\pi^{\pm}]_{D^0} \pi^\pm_{s})} = \frac{R^{\pm} e(K^{\pm}\pi^{\mp})}{e(K^{\mp}\pi^{\pm})}$$
Data sample

- 5 fb⁻¹ (2011–2016);
- prompt decays, sample selection ≈ that of $A_r$.

- $A(K^{-}\pi^+)$ accounted for employing measured asymmetries of $D^+ \rightarrow K^-\pi^+\pi^+$ and $D^+ \rightarrow \bar{K}^0\pi^+$ decays, reweighed to make their kinematic distributions coincide with that of $D^0 \rightarrow K^-\pi^+

\[ A_D(K^-\pi^+) = A_{\text{raw}}(K^-\pi^+\pi^+) - A_{\text{raw}}(\bar{K}^0\pi^+) + A_D(\bar{K}^0) \]

\[ = A_P(D^+) + A_D(K^-\pi^+) + A_D(\pi^+) \]
\[ - A_P(D^+) - A_D(\bar{K}^0) - A_D(\pi^+) \]
\[ + A_D(\bar{K}^0) \]
**Ghost tagging $\pi^+_s$**

- It may happen that clusters belonging to the $\pi_s$ track in the tracking stations upstream the magnet are matched to wrong clusters downstream it;
  - measured direction between $D^0$ and $\pi_s$ is correct $\rightarrow$ bkg peaks in $m(D^{*+})$ even if reconstructed $\rho(\pi_s)$ is wrong;
  - RS decay is tagged as much rarer $WS \approx$ half of the times.

- Misreconstruction probability must be kept well under $BR(D^{0}\rightarrow K^+\pi^-)/BR(D^{0}\rightarrow K^-\pi^+) \approx 3\times10^{-3}$
  - neural-network-based algorithm (occupancies & hit multiplicities in each subdetector, momentum of the track) [LHCb-PUB-2017-011]
  - accounts for 30—50% of sys. uncertainty.
Results

- No evidence for CPV

- If no CPV is assumed:
  \[ x^2 = (0.039 \pm 0.023 \pm 0.014) \cdot 10^{-3} \]
  \[ y' = (5.28 \pm 0.45 \pm 0.27) \cdot 10^{-3} \]

- Twice as precise as previous superseded LHCb measurement [PRL 111 251801 (2013)]
$\gamma_{CP}$ with $\bar{B} \rightarrow D^0_{\mu^-X}$ tagging
**$y_{CP}$ definition**

$$y_{CP} = \frac{\hat{\Gamma}(D^0 \rightarrow h^+h^-) + \hat{\Gamma}(\bar{D}^0 \rightarrow h^+h^-)}{2\Gamma} - 1$$

$$f = K^+K^-, \pi^+\pi^- \text{ (CP-even)}$$

$$f = K^+K^-, \pi^+\pi^- \text{ (CP-even)}$$

\[
\begin{align*}
\frac{1}{2} \left[ \left( \frac{q}{p} \right) + \left( \frac{p}{q} \right) \right] y \cos \phi - \left( \left| \frac{q}{p} \right| - \left| \frac{p}{q} \right| \right) x \sin \phi & \approx y + y \left[ \frac{1}{2} \left( \left| \frac{q}{p} \right| - 1 \right)^2 - \frac{\phi^2}{2} \right] - x \phi \left( \left| \frac{q}{p} \right| - 1 \right)
\end{align*}
\]

- equal to $y$ in the limit of no CPV;
- differences are
  - linear in mixing parameters
  - quadratic in $\phi$, $|q/p|\leq 1$

\[
\{ 5\% \text{ of } y \text{ or less} \}
\]

- current precision ($\approx 20\%$) not as competitive as $A_r$ for CPV searches;
- it is a measurement of $y$ independent of $R(t) = WS/RS$.

- First measurement at LHCb [JHEP 04 (2012) 129] with prompt decays but very limited data sample (2010, 29 pb$^{-1}$), not competitive with world average.
New LHCb measurement

- 3 fb\(^{-1}\) (Run 1);
- tagging with \(\bar{B} \rightarrow D^0 \mu^- X\)
- lower yield w.r.t. prompt decays;
- hardware and first level software trigger on the muon;
  — smaller trigger-induced decay-time biases.

- Extract \(\gamma_{CP}\) from the time-dependent ratio between \(h^+h^-\) and \(K\pi^+\) yields (same strategy as \(B_s, D_s\) lifetimes measurements at LHCb [PRL 119, 101801]).
$\bar{B} \rightarrow D^0\mu^-X$ selection

- Mainly inherited from muon-tagged $\Delta A_{CP}$ and $B_s$, $D_s$ lifetimes measurements \cite{JHEP07(2014)041, PRL119, 101801}
- loose cuts on all tracks $\chi^2_{IP}$;
- cut in the $p_T(D^0) - m_{corr}(B)$ plane to reduce contamination from combinatorial bkg., double-charmed $B$ decays, $\bar{B} \rightarrow D^0\tau^-X$

- Final contamination in $m(D^0)$ peak:
  - < 1.5% from these bkg.
  - < 1% from prompt $D^0$.  

$$m_{corr}(B) = \sqrt{m^2(D\mu) + p^2_{\perp}(D\mu) + p^2_{\perp}(D\mu)}$$

$\chi^2_{IP} = \text{difference in } pp \text{ vertex-fit } \chi^2$ reconstructed with and without the particle
Experimental strategy

- Inspired by [PRL 119, 101801]:
  - determine the yields of $h^+h^-$ and $K\pi^+$ through a fit to $m(D^0)$, separately for 19 bins of decay time;
  - minimise the $\chi^2$ from the difference of $N_i(h^+h^-) / N_i(K\pi^+)$ with the expected value:

$$\Delta \Gamma = \Gamma_{h^+h^-} - \Gamma$$

$$y_{CP} = \frac{\Delta \Gamma}{\Gamma}$$

\[ R_i = \frac{N\cdot A_i \cdot \int_{t_i}^{t_i+1} e^{-(\Gamma+\Delta \Gamma)t} \, dt}{\int_{t_i}^{t_i+1} e^{-\Gamma t} \, dt} \]

- acceptance ratio in time bin $i$ (from MC)
- normalisation factor common to all time bins
- ratio of the PDFs of $h^+h^-$ and $K\pi^+$ decays (nearly independent of the value of $\Gamma$)
Acceptance ratio

- Acceptances calculated from MC simulation of inclusive $B^0$, $B^-$ semi-muonic decays into $D^0$;
- main MC mismodellings of detector *etc.* expected to cancel in the ratio.

6% variations mainly due to $\chi^2_{IP}$ cuts
Null test (1): \[
\frac{\Gamma(D^0 \rightarrow K^-\pi^+), \chi^2_{IP} > 60}{\Gamma(D^0 \rightarrow K^-\pi^+), \chi^2_{IP} > 8}
\]

- Test the MC description of the time-dependence of the acceptance:
  - split the $K^-\pi^+$ sample in two;
  - apply a tighter cut $\chi^2_{IP} > 60$ to the $\mu^-, K^-, \pi^+$ of the numerator sample (std. is $\chi^2_{IP} > 8$);
  - measure $\Delta \Gamma$ between the two samples (should be 0).

\[\Delta_{K\pi/K\pi}^{K\pi} = (-1.8 \pm 3.3) \cdot 10^{-3} \text{ ps}^{-1}\]

uncertainty corresponds to 
\[\sigma(\gamma_{CP}) = 0.14\%\]
Null test (2): \[ \frac{\Gamma(D^+ \to K^{-}\pi^+\pi^+)}{\Gamma(D^0 \to K^{-}\pi^+)} \]

- 3-body vs. 2-body decays \(\rightarrow\) different topology, kinematics, acceptance;
- \((B^0: B^-)\) very different for \(D^0\) and \(D^+\) \(\rightarrow\) check impact of \(B\)-mixture uncertainty in MC;
- \(\tau(D^+) / \tau(D^0) \approx 2.5 \rightarrow\) sensitive to biases linear in \(\Delta \Gamma\).

\[ A_{K\pi\pi / K\pi} \]

\[ R_{K\pi\pi / K\pi} \]

\[ \approx 10\% \text{ variations} \]

\(\tau(D^+) / \tau(D^0) = 2.5141 \pm 0.0082\) compatible with PDG within 1\(\sigma\) (test limited by PDG precision 2.536 \pm 0.019).

Biases linear in \(\Delta \Gamma\) are < 0.8\% \(\Delta \Gamma\).
Other checks and systematics

- Further checks:
  \[
  \frac{\Gamma(D^+ \to K^-\pi^+\pi^+), \chi^2_{IP} > 60}{\Gamma(D^+ \to K^-\pi^+\pi^+), \chi^2_{IP} > 8}
  \]

- Systematic uncertainties:

<table>
<thead>
<tr>
<th>Source</th>
<th>KK (%)</th>
<th>ππ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finite size of MC sample (acceptance ratio)</td>
<td>0.11</td>
<td>0.15</td>
</tr>
<tr>
<td>Fit bias</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>B^0:B^- ratio and decay model</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Decay-time resolution</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>B - Bbar production asymm.</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Total sys.</td>
<td>0.11</td>
<td>0.15</td>
</tr>
<tr>
<td>Statistical</td>
<td>0.15</td>
<td>0.28</td>
</tr>
</tbody>
</table>

\[\Delta \Gamma \text{ consistent with 0 within stat. uncertainty}\]

**Fit result**

- **$y_{KK}^{CP} = (0.63 \pm 0.15 \pm 0.11)\%$**
- **$y_{\pi\pi}^{CP} = (0.38 \pm 0.28 \pm 0.15)\%$**
- **$y_{CP} = (0.57 \pm 0.13 \pm 0.09)\%$**

- Compatible and with same precision of world average ($0.835 \pm 0.155$)%;
- compatible with $y = \left(0.67^{+0.06}_{-0.13}\right)\%$ within 1σ.
Summary

- LHCb leads the world averages of all indirect CPV parameters thanks to huge c-cbar prompt production at LHC;
  - now eventually entering the region allowed by the SM, $\mathcal{O}(10^{-4})$;
- uncertainty on mixing parameters steadily decreasing, other 4 fb$^{-1}$ of data taken in 2017—2018;
- analyses still limited by the statistical uncertainty.

Thank you for your attention.
Any questions?
Backup
### $A_\Gamma$: systematics

**Table: Systematic Errors**

<table>
<thead>
<tr>
<th>Source</th>
<th>KK (10^{-4})</th>
<th>$\pi\pi$ (10^{-4})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary decays</td>
<td>0.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Discretisation of weighing procedure</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Subtraction of $\Delta m$ bkg. from random $\pi^+_s$</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Bkg. from partially-reconstructed and misidentified D-meson multi-body decays</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total sys.</strong></td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Statistical</strong></td>
<td>3.2</td>
<td>5.8</td>
</tr>
</tbody>
</table>

[PRL 118, 261803 (2017)]
$A_\Gamma$: contribution from secondary decays

$$A_{\text{raw}} = A_{\text{prim}}(t) + f_{\text{sec}}(t) \cdot [A_{\text{sec}}(t) - A_{\text{prim}}(t)]$$

$$\approx A_P(B) - A_P(D^{*+})$$

$f_{\text{sec}}$ extracted from $\ln(\chi^2_{IP})$ fit in last four time bins and extrapolated with physically-motivated empiric model to lower bins where the distributions of prompt and secondary decays can’t be easily disentangled. Uncertainty on the empiric model is the main source of systematic uncertainty.
$A_\Gamma$ and $y_{CP}$ world averages

https://hflav.web.cern.ch

$A_\Gamma$ (%)

World average
-0.20 -0.10 -0.00 0.00 0.10 0.20

C Belle 2012
BaBar 2012
CDF 2014 KK+ππ
LHCb 2015 $\mu$ tag
LHCb 2016 $D^+$ tag

World average
-0.032 ± 0.026 %

$y_{CP}$ (%)

World average
-4 -3 -2 -1 0 1 2 3 4 5

HFLAV CKM 2016

E791 1999
FOCUS 2000
CLEO 2002
Belle 2009
LHCb 2012
Belle 2012
BaBar 2012
BES III 2015

HFLAV Summer 2016

0.732 ± 2.890 ± 1.030 %
3.420 ± 1.390 ± 0.740 %
-1.200 ± 2.500 ± 1.400 %
0.110 ± 0.610 ± 0.520 %
0.550 ± 0.630 ± 0.410 %
1.110 ± 0.220 ± 0.110 %
0.720 ± 0.180 ± 0.124 %
-2.000 ± 1.300 ± 0.700 %
0.835 ± 0.155 %

LHCb 2016 D$^+$ tag

18/09/2018
Tommaso Pajero on behalf of LHCb | Mixing and CPV in 2-body charm decays

HFLAV

CKM 2016
Indirect CPV: \( D^0 \rightarrow K^\pm \pi^\mp \) vs \( A_\Gamma \)

\( D^0 \rightarrow K^\pm \pi^\mp \): determines the 8-like shape of allowed \((\phi, |q/p|)\) region; nearly full degeneracy \( \phi \rightarrow -\phi \)

\[
A_\Gamma \approx y \left( \left| \frac{q}{p} \right| - 1 \right) - x\phi
\]

---

It’s a line in the plane

- responsible for the tilt (and significant reduction of CPV-allowed region w.r.t. \( D^0 \rightarrow K^\pm \pi^\mp \) constraints only)
Tagging strategies at LHCb

To identify the flavour at production of the $D^0$ meson:

- **Prompt tag**: strong decay $D^{*+} \rightarrow D^0 \pi^+_s$
  - larger production cross section;
  - tight trigger cut on $D^0$ flight distance and $h^+, h^-$ impact parameters to improve S/B;
  - low trigger efficiency at low decay times;
  - $D^0$ points at the primary vertex (PV).

- **Semileptonic tag**: weak decay $\bar{B} \rightarrow D^0 \mu^- \bar{\nu}_\mu X$
  - lower production cross section;
  - no need to cut on $D^0$ flight distance;
  - all $D^0$ decay times collected by the trigger;
  - total yield $\approx 25\%$ of prompt one;
  - $D^0$ does not necessarily point at PV.

- **Double-tag**: $\bar{B} \rightarrow [D^0 \pi^+_s]_{D^{*+}} \mu^- \bar{\nu}_\mu X$
  - highest purity;
  - lowest yield.
## Indirect CPV prospects at LHCb Upgrade II

| Sample (L)         | Yield (×10^6) | σ(x_{Kπ}^2) | σ(y_{Kπ}) | σ(A_D)    | σ(|q/p|) | σ(φ)  |
|--------------------|----------------|-------------|-----------|------------|----------|--------|
| Run 1–2 (9 fb⁻¹)  | 1.8            | 1.5 × 10⁻⁵  | 2.9 × 10⁻⁴ | 0.51%      | 0.12     | 10°    |
| Run 1–3 (23 fb⁻¹) | 10             | 6.4 × 10⁻⁶  | 1.2 × 10⁻⁴ | 0.22%      | 0.05     | 4°     |
| Run 1–4 (50 fb⁻¹) | 25             | 3.9 × 10⁻⁶  | 7.6 × 10⁻⁵ | 0.14%      | 0.03     | 3°     |
| Run 1–5 (300 fb⁻¹)| 170            | 1.5 × 10⁻⁶  | 2.9 × 10⁻⁵ | 0.05%      | 0.01     | 1°     |

<table>
<thead>
<tr>
<th>Sample (L)</th>
<th>Tag</th>
<th>Yield K⁺K⁻</th>
<th>σ(A_Γ)</th>
<th>Yield π⁺π⁻</th>
<th>σ(A_Γ)</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>

**Physics case for an LHCb Upgrade II** [arXiv:1808.08865]

**Assumptions:**

- x2 of hadron trigger efficiency (no hardware trigger + new magnet stations);
- current LHCb performance is maintained in Upgrade II conditions;
- statistical uncertainty only with 1/√N scaling.

---

**N.B.:** this plot includes results also from multi-body decays
The LHCb detector at the LHC, JINST 3 S08005 (2008)

CKM, 18/09/2018  Tommaso Pajero on behalf of LHCb  Mixing and CPV in 2-body charm decays

Momentum (GeV/c)

K

p

Cherenkov Angle (mrad)

220

200

180

160

140

120

100

80

60

40

20

0

vertex tracker

15 + 27/\rho_T \mu m (IP)

45 fs (decay time)

dipole magnet

4 T m

along y direction

tracking stations

\delta \rho/\rho = 0.5–0.8%

for \rho = 20–200 GeV/c

Čerenkov detectors

muon chambers

hadron calorimeter

5.6 \lambda_{int} \frac{\sigma(E)}{E} = 9\% \oplus \frac{69\%}{\sqrt{E/GeV}}

electromagnetic calorimeter

25 X_0, 1.2 \lambda_{int} \frac{\sigma(E)}{E} = 1\% \oplus \frac{10\%}{\sqrt{E/GeV}}

The LHCb detector

The LHCb detector at the LHC, JINST 3 S08005 (2008)

CKM, 18/09/2018  Tommaso Pajero on behalf of LHCb  Mixing and CPV in 2-body charm decays

34