Charm CP violation @ LHCb

Pietro Marino on behalf of LHCb collaboration
SNS & INFN-Pisa
Why is charm charming?

- Unique and powerful probe of BSM flavour effects.
  
  - Charm is an up-type quark:
    - complementary to $B$ and $K$;
    - best bounds on a generic new physics model after the kaon mixing.
  
- Huge data samples,
  
  - LHCb has the opportunity to exploit fully the charm sector as a probe for new physics.

- Charm predictions are complicated:
  
  - QCD not perturbative.
Charm mixing and CP violation

- D⁰ mixing is established.
- CP violation yet unobserved!
  - Small value expected from SM $\mathcal{O}(V_{ub}V_{cb}^{*}/V_{us}V_{cs}^{*}) \sim \mathcal{O}(10^{-3})$
  - Sensitivity close to possible BSM contribution (yields $\mathcal{O}(10^{-6})$)

### Decay CPV

$$|D^0 \rightarrow f|^2 \neq |\overline{D}^0 \rightarrow f|^2$$

### Mixing CPV

$$|D^0 \rightarrow \overline{D}^0 |^2 \neq |\overline{D}^0 \rightarrow D^0 |^2$$

### Inference CPV

$$|D^0 \rightarrow f |^2 + |\overline{D}^0 \rightarrow f |^2 \rightarrow \arg\left(\frac{qA_f}{pA_{\overline{f}}}\right) \neq 0$$

$$|D_{1,2}\rangle = p |D^0\rangle \pm q |\overline{D}^0\rangle$$

$$x = \frac{m_1 - m_2}{\Gamma}, \quad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}$$
VErtex LOcator

~(15+29/p_T)µm IP resolution
~45fs decay time resolution

Magnet
4 Tm dipole

σ_p/p ~ 0.5-1%@ 5-200 GeV/c

Tracking system

LHCb

Weight: 5600t
Height: 10m
Long: 21m

~(15+29/p_T)µm IP resolution
~45fs decay time resolution

VErtex LOcator

Magnet
4 Tm dipole

σ_p/p ~ 0.5-1%@ 5-200 GeV/c

Tracking system

Calorimeters

Muon system

Figure 38: Reconstructed Cherenkov angle for isolated tracks, as a function of track momentum in the C_4F_10 radiator [81]. The Cherenkov bands for muons, pions, kaons and protons are clearly visible. The events populate distinct bands according to their mass.

4.2.2 Photoelectron yield

The average number of detected photons for each track traversing the Cherenkov radiator media, called the photoelectron yield (N_pe), is another important measure of the performance of a RICH detector. The yields for the three radiators used in LHCb are measured in data using two different samples of events [81]. The first sample is representative of normal LHCb data taking conditions, and consists of the kaons and pions originating from the decay D_0 → K_π^+, where the D_0 is selected from D_0 → π^+ decay. The second sample consists of low detector occupancy pp → ppµ+µ events, which provide a clean track sample with very low background levels. In both samples, only high-momentum tracks are selected, to ensure that the Cherenkov angle is close to saturation.
Charm flavour tagging

- In order to measure mixing and CPV, it is necessary to identify the flavour of the $D^0$ meson.
- LHCb exploits two decays:
  - $D^{*+} \rightarrow D^0 \pi^+$ decays
  - semi-leptonic $B$-decays
First observation of $D^0$-$\bar{D}^0$ oscillation in $D^0 \rightarrow K^+ \pi^- \pi^+ \pi^-$
$D^0$ mixing with $D^0 \rightarrow K^+\pi^-\pi^+\pi^-$

- Full Run I data sample (3/fb)
- Challenges:
  - Five-dimensional phase space parametrisation.
  - Higher combinatorial background.

$$R(t) = \frac{D^0 \rightarrow K^+\pi^-\pi^+\pi^+}{D^0 \rightarrow K^-\pi^+\pi^-\pi^+} \approx r_D^2 - r_D R_D y' \frac{t}{\tau} + \frac{x^2 + y^2}{4} \left( \frac{t}{\tau} \right)^2$$

$R_D e^{-i\delta} = \langle \cos \delta \rangle + i \langle \sin \delta \rangle$

$y' = y \cos \delta - x \sin \delta$

$r_D = \text{phase space average DCS/CF ratio amplitudes}$

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[arXiv:1602.07224]

LHCb
3/fb

42x10^3

Candidates / (0.1 MeV/c^2)

Δm [MeV/c^2]

LHCb
3/fb

11x10^6

Candidates / (0.1 MeV/c^2)

Δm [MeV/c^2]

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\[ D^0 \text{ mixing with } D^0 \rightarrow K^+\pi^-\pi^+\pi^- \]

\[ \begin{align*}
R(t) & = r_D^2 - r_D R_D y' \frac{t}{\tau} + \frac{x^2 + y^2}{4} \left( \frac{t}{\tau} \right)^2 \\
\approx r_D^2 - r_D R_D y' \frac{t}{\tau} + \frac{x^2 + y^2}{4} \left( \frac{t}{\tau} \right)^2
\end{align*} \]

\[ r_D = (5.67 \pm 0.12) \times 10^{-2} \]
\[ R_D y' = (0.3 \pm 1.8) \times 10^{-3} \]

\[ \text{[arXiv:1602.07224]} \]

No mixing hypothesis reject at \(8.2\sigma\)

12/4/2016
Difference of time-integrated CP asymmetries (a.k.a. $\Delta A_{CP}$)
Direct CPV in $D^0 \rightarrow h^+ h^-$

- Time-integrated CP asymmetry:

$$A_{CP}(f) = \frac{\Gamma(D^0 \rightarrow f) - \Gamma(\bar{D}^0 \rightarrow f)}{\Gamma(D^0 \rightarrow f) + \Gamma(\bar{D}^0 \rightarrow f)}$$

- Experimentally yields are measured:

$$A_{raw}(f) = \frac{N(D^{*+} \rightarrow D^0 (\rightarrow f) \pi^+) - N(D^{*-} \rightarrow \bar{D}^0 (\rightarrow f) \pi^-)}{N(D^{*+} \rightarrow D^0 (\rightarrow f) \pi^+) + N(D^{*-} \rightarrow \bar{D}^0 (\rightarrow f) \pi^-)} \approx A_{CP}(f) + A_D(f) + A_P(D^*)$$

where

- $A_D(\pi)$: soft-pion (tag) detection asymmetry
- $A_P(D^*)$: $D^*$ production asymmetry
- $A_D(f)$: final state detection asymmetry, zero for $f = K^+ K^-, \pi^+ \pi^-$

12/4/2016

P. Marino (SNS & INFN-Pi)
Direct CPV in $D^0 \to h^+ h^-$

- Time-integrated CP violation:

$$A_{CP}(f) = \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D}^0 \to f)}$$

- Experimentally yields are measured:

$$A_{raw}(f) = \frac{N(D^{*+} \to D^0(\to f)\pi^+)}{N(D^{*+} \to D^0(\to f)\pi^+)} - \frac{N(D^{*-} \to \overline{D}^0(\to f)\pi^-)}{N(D^{*+} \to D^0(\to f)\pi^+)}$$

$$\approx A_{CP}(f) + A_D(f) + A_P(D^*)$$

- Challenging keep under control $A_D$ and $A_P$ to $\mathcal{O}(10^{-3})$. In order to access the CP asymmetry the difference between $A_{CP}(KK)$ and $A_{CP}(\pi\pi)$ is exploited:

$$A_{raw}(KK) \approx A_{CP}(KK) + A_D(\pi) + A_P(D^*)$$

$$A_{raw}(\pi\pi) \approx A_{CP}(\pi\pi) + A_D(\pi) + A_P(D^*)$$

$$\Delta A_{CP} = A_{raw}(KK) - A_{raw}(\pi\pi) = A_{CP}(KK) - A_{CP}(\pi\pi)$$
• **New** measurement with full Run I data sample (3/fb, $D^*$-tagged):

$$\Delta A_{CP} = (-0.10 \pm 0.08({\text{stat.}}) \pm 0.03({\text{syst.}}))\%$$

• Semi-leptonic tagged measurement (3/fb):

$$\Delta A_{CP} = (+0.14 \pm 0.16({\text{stat.}}) \pm 0.08({\text{syst.}}))\%$$

$D^0 \rightarrow h^+ h^-$ decays

LHCb

3/fb

$LHCb$

3/fb

$D^0 \rightarrow K^- K^+$

$LHCb$

3/fb

$D^0 \rightarrow \pi^- \pi^+$

$\delta m (\text{MeV/c}^2) = m(h^+ h^- \pi^+) - m(h^+ h^-) - m_\pi$

LHCb

3/fb

$\delta m (\text{MeV/c}^2) = m(h^+ h^- \pi^+) - m(h^+ h^-) - m_\pi$

arXiv:1602.03160

(submitted to PRL)

arXiv:1602.03160

[arXiv:1602.03160]

$\Delta A_{CP} = (-0.10 \pm 0.08({\text{stat.}}) \pm 0.03({\text{syst.}}))\%$

[arXiv:1602.03160]

(JHEP 07 (2014) 041)

$\Delta A_{CP} = (+0.14 \pm 0.16({\text{stat.}}) \pm 0.08({\text{syst.}}))\%$

$D^0 \rightarrow K^- K^+$

$D^0 \rightarrow \pi^- \pi^+$

$\times 10^3$

Candidates / (0.05 MeV/c^2)

$\times 10^3$

Candidates / (0.05 MeV/c^2)
**ΔA_{CP} state-of-the-art**

Naive average (neglecting indirect CPV contribution) = (-0.129 ± 0.072)%

World best measurement
Time dependent CP asymmetry (a.k.a. $A_{\Gamma}$)
**A_{\text{t}}**: indirect CPV in $D^0 \rightarrow h^+ h^-$ decays

- **Time-dependent CP asymmetry**:
  
  \[
  A_{CP}(t) = \frac{\Gamma(D^0(t) \rightarrow f) - \Gamma(\overline{D}^0(t) \rightarrow f)}{\Gamma(D^0(t) \rightarrow f) + \Gamma(\overline{D}^0(t) \rightarrow f)} \approx a_{\text{dir}}^{CP} - \frac{t}{\tau_{D^0}} A_{\Gamma}
  \]

- $A_{\text{t}}$ measures CPV in the mixing ($A_m$) e in the decay ($A_d$):
  
  \[
  A_{\Gamma} \approx \left[ \frac{1}{2} (A_m + A_d) y \cos \phi - x \sin \phi \right]
  \]

\[
A_m = \left| \frac{q}{p} \right|^2 - 1
\]
\[
A_d = \left| \frac{\overline{A_f}}{A_f} \right|^2 - 1
\]
**A_Γ:** indirect CPV in \( D^0 \rightarrow h^+ h^- \) decays

- Measure yields asymmetry in various bin of \( D^0 \) proper decay time:
  \[ A_{\text{raw}}^i = \frac{n_i(D^0 \rightarrow f) - n_i(\bar{D}^0 \rightarrow f)}{n_i(D^0 \rightarrow f) + n_i(\bar{D}^0 \rightarrow f)} ; \quad i = 1, \ldots, m \]

- Straight line fit of the asymmetry as function of decay time:
  \[ A_{\text{raw}}(t) = A_0 - \frac{t}{\tau_{D^0}} A_\Gamma ; \quad A_{\Gamma}(K^- \pi^+) = (0.009 \pm 0.032)\% \]

- control sample: \( D^0 \rightarrow K\pi \), where pseudo-\( A_{\Gamma}(D^0 \rightarrow K\pi) = 0 \).

\[ A_{\Gamma}(K^- K^+) = (-0.134 \pm 0.077^{+0.026}_{-0.034})\% \]

\[ A_{\Gamma}(\pi^- \pi^+) = (-0.092 \pm 0.145^{+0.025}_{-0.033})\% \]

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12/4/2016

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-0.030 ± 0.200 ± 0.080 %


-0.035 ± 0.062 ± 0.012 %


0.033 ± 0.106 ± 0.014 %


World average

-0.125 ± 0.073 %

[JHEP 1504 (2015) 043]

-0.059 ± 0.040 %

-0.2 -0.1 0 0.1 0.2 0.3

$A_\Gamma$ (%)
**LHCb state-of-the-art on** $D^0 \rightarrow h^+ h^-$ **CPV**

- $\Delta A_{CP}$ can be expressed as:
  \[
  \Delta A_{CP} = \Delta a_{CP}^{\text{dir}} \left(1 + \frac{\langle t \rangle}{\tau(D^0)} \right) y_{CP} + \frac{\Delta \langle t \rangle}{\tau(D^0)} a_{CP}^{\text{ind}}
  \]

- Using LHCb measurement for:
  \[
  A_{\Gamma} \approx -a_{CP}^{\text{ind}}
  \]
  \[
  y_{CP} = \frac{\Gamma(D^0 \rightarrow h^+ h^-)}{\Gamma(D^0 \rightarrow K^- \pi^+)} - 1
  \]

No CPV hypothesis: p-value 0.32

$\Delta a_{CP}^{\text{dir}} = (-0.61 \pm 0.76) \cdot 10^{-3}$  \[ -\quad \text{[JHEP 04 (2012) 129]} \]

$\Delta a_{CP}^{ind} = (-0.58 \pm 0.44) \cdot 10^{-3}$  \[ -\quad \text{[JHEP 04 (2015) 043]} \]

\[
\frac{\Delta \langle t \rangle}{\tau(D^0)} = 0.1153 \pm 0.0007 \text{(stat)} \pm 0.0018 \text{(syst)}
\]
\[
\frac{\langle t \rangle}{\tau(D^0)} = 2.0949 \pm 0.0004 \text{(stat)} \pm 0.0159 \text{(syst)}
\]
More Run I results to come … more charm in Run II and Upgrade
Backup
## LHCb benchmarks

<table>
<thead>
<tr>
<th>Type</th>
<th>Observable</th>
<th>Current precision</th>
<th>LHCb 2018</th>
<th>Upgrade (50 fb⁻¹)</th>
<th>Theory uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s^0$ mixing</td>
<td>$2\beta_s$ ($B_s^0 \rightarrow J/\psi \phi$)</td>
<td>0.10 [138]</td>
<td>0.025</td>
<td>0.008</td>
<td>$\sim 0.003$</td>
</tr>
<tr>
<td></td>
<td>$2\beta_s$ ($B_s^0 \rightarrow J/\psi f_0(980)$)</td>
<td>0.17 [214]</td>
<td>0.045</td>
<td>0.014</td>
<td>$\sim 0.01$</td>
</tr>
<tr>
<td></td>
<td>$a_s$</td>
<td>$6.4 \times 10^{-3}$ [43]</td>
<td>$0.6 \times 10^{-3}$</td>
<td>$0.2 \times 10^{-3}$</td>
<td>$0.03 \times 10^{-3}$</td>
</tr>
<tr>
<td>Gluonic penguins</td>
<td>$2\beta_s^{\text{eff}}$ ($B_s^0 \rightarrow \phi\phi$)</td>
<td>–</td>
<td>0.17</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>$2\beta_s^{\text{eff}}$ ($B_s^0 \rightarrow K^{*0}\bar{K}^{*0}$)</td>
<td>–</td>
<td>0.13</td>
<td>0.02</td>
<td>$&lt; 0.02$</td>
</tr>
<tr>
<td></td>
<td>$2\beta_s^{\text{eff}}$ ($B^0 \rightarrow \phi K_s^0$)</td>
<td>0.17 [43]</td>
<td>0.30</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>Right-handed currents</td>
<td>$2\beta_s^{\text{eff}}$ ($B^0_s \rightarrow \phi\gamma$)</td>
<td>–</td>
<td>0.09</td>
<td>0.02</td>
<td>$&lt; 0.01$</td>
</tr>
<tr>
<td></td>
<td>$\tau^{\text{eff}}(B_0^0 \rightarrow \phi\gamma)/\tau_{B_0}$</td>
<td>–</td>
<td>5%</td>
<td>1%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Electroweak penguins</td>
<td>$S_3(B^0 \rightarrow K^{*0}\mu^+\mu^-; 1 &lt; q^2 &lt; 6 \text{ GeV}^2/c^4)$</td>
<td>0.08 [67]</td>
<td>0.025</td>
<td>0.008</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>$s_0 A_{\text{FB}}(B^0 \rightarrow K^{*0}\mu^+\mu^-)$</td>
<td>25% [67]</td>
<td>6%</td>
<td>2%</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>$A_1(K\mu^+\mu^-; 1 &lt; q^2 &lt; 6 \text{ GeV}^2/c^4)$</td>
<td>0.25 [76]</td>
<td>0.08</td>
<td>0.025</td>
<td>$\sim 0.02$</td>
</tr>
<tr>
<td></td>
<td>$B(B^+ \rightarrow \pi^+\mu^+\mu^-)/B(B^0 \rightarrow K^+\mu^+\mu^-)$</td>
<td>25% [85]</td>
<td>8%</td>
<td>2.5%</td>
<td>$\sim 10%$</td>
</tr>
<tr>
<td>Higgs penguins</td>
<td>$B(B^0_s \rightarrow \mu^+\mu^-)$</td>
<td>$1.5 \times 10^{-9}$ [13]</td>
<td>$0.5 \times 10^{-9}$</td>
<td>$0.15 \times 10^{-9}$</td>
<td>$0.3 \times 10^{-9}$</td>
</tr>
<tr>
<td>Unitarity</td>
<td>$\gamma (B \rightarrow D^{(<em>)}K^{(</em>)})$</td>
<td>$\sim 10–12^\circ$ [244, 258]</td>
<td>$4^\circ$</td>
<td>0.9°</td>
<td>negligible</td>
</tr>
<tr>
<td></td>
<td>$\gamma (B_s^0 \rightarrow D_s K)$</td>
<td>–</td>
<td>11°</td>
<td>2.0°</td>
<td>negligible</td>
</tr>
<tr>
<td></td>
<td>$\beta (B^0 \rightarrow J/\psi K_s^0)$</td>
<td>0.8° [43]</td>
<td>0.6°</td>
<td>0.2°</td>
<td>negligible</td>
</tr>
<tr>
<td>Charm</td>
<td>$A_\Gamma$</td>
<td>$2.3 \times 10^{-3}$ [43]</td>
<td>$0.40 \times 10^{-3}$</td>
<td>$0.07 \times 10^{-3}$</td>
<td>–</td>
</tr>
<tr>
<td>CP violation</td>
<td>$\Delta A_{CP}$</td>
<td>$2.1 \times 10^{-3}$ [18]</td>
<td>$0.65 \times 10^{-3}$</td>
<td>$0.12 \times 10^{-3}$</td>
<td>–</td>
</tr>
</tbody>
</table>
\[ D^0 \rightarrow K_s^0 K_s^0 \]

### Table 2

<table>
<thead>
<tr>
<th>Category</th>
<th>( N^+ )</th>
<th>( N^- )</th>
<th>( \mathcal{A}_{CP} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>LL</td>
<td>86 ± 11</td>
<td>86 ± 12</td>
<td>0.00 ± 0.09</td>
</tr>
<tr>
<td>LD</td>
<td>82 ± 14</td>
<td>83 ± 13</td>
<td>−0.00 ± 0.11</td>
</tr>
<tr>
<td>DD</td>
<td>29 ± 14</td>
<td>66 ± 14</td>
<td>−0.39 ± 0.23</td>
</tr>
<tr>
<td>LLtrig</td>
<td>96 ± 11</td>
<td>99 ± 11</td>
<td>−0.02 ± 0.08</td>
</tr>
<tr>
<td>combined</td>
<td></td>
<td></td>
<td>−0.029 ± 0.052</td>
</tr>
</tbody>
</table>

- The reconstructed tracks can be categorised into five distinct types, see Figure 4.6:
  - **Upstream tracks** are relatively long lifetime.
  - **Long tracks** are the basis of most reconstructed decays. The momentum resolution varies about 20 MeV.
  - **Downstream tracks** have a part of the magnetic field. They are important to reconstruct the decays of mesons and baryons as these often decay outside of the VELO due to their relativistic long lifetime.
  - **D* tracks** are built out of measurements from the TT and the T stations.
  - **T-stations** are dedicated trigger lines which are accepted at random.

Other checks have been performed but found to have statistically insignificant effects.

Assuming a \( \Delta m \) resolution of 0.019 MeV, \( \mathcal{A}_{CP} \) is determined using the control channel. However, the control channel contains charged pion background, which is much larger than needed for this analysis, 1% of candidates are accepted at random.

The systematic uncertainties related to the yields from the nominal fits and the resulting asymmetries. To obtain the final result, the contributions and the fit for each of the four categories and the two slow-pion charges are accepted at random.

### Figure 3

- Distributions of \( \Delta m \) for the control channel, summed over both charges of the slow pion.
- The reconstructed tracks can be categorised into five distinct types, see Figure 4.6:
  - **Upstream tracks** are relatively long lifetime.
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The systematic uncertainties related to the yields from the nominal fits and the resulting asymmetries. To obtain the final result, the contributions and the fit for each of the four categories and the two slow-pion charges are accepted at random.
Source of uncertainty & $D^0 \rightarrow K^- K^+$ & $D^0 \rightarrow \pi^- \pi^+$ \\
Mistag probability & 0.006% & 0.05 & 0.008% & 0.05 \\
Mistag asymmetry & 0.016% & & 0.016% & \\
Time-dependent efficiency & 0.010% & & 0.010% & \\
Detection and production asymmetries & 0.010% & & 0.010% & \\
$D^0$ mass fit model & 0.011% & & 0.007% & \\
$D^0$ decay-time resolution & 0.09 & & 0.07 & \\
$B^0$-$\bar{B}^0$ mixing & 0.007% & & 0.007% & \\
Quadratic sum & 0.026% & 0.10 & 0.025% & 0.09 \\

Figure 4

- Mag. up 2011
- Mag. down 2011
- Mag. up 2012
- Mag. down 2012

All 2011
All 2012

(a) LHCb $D^0 \rightarrow K^- K^+$
(b) LHCb $D^0 \rightarrow \pi^- \pi^+$
(c) LHCb $D^0 \rightarrow K^- \pi^+$

Mag. up 2011
Mag. down 2011
Mag. up 2012
Mag. down 2012

All 2011
All 2012
Cross-checks

- Data taking year (= different energy 7/8 TeV)
- Magnet Polarity
- Trigger configuration
  - TOS: trigger on signal
  - TIS: trigger independent from signal
- cross-checks:
  - π-soft, $D^0$ kinematics
  - run number
  - PID requirements
  - $D^*$ vertex quality
  - …

χ² = 6.3 (7 ndf)
p-value = 0.50.

arXiv:1602.03160

P. Marino (SNS & INFN-Pi)
CPV in $D^0 \rightarrow K_{s0} K_{s0}$ decays

- Decay dominated by long-distance contributions:
  - short-distance contributions cancel since $V_{cd} V_{ud}^* = -V_{cs} V_{us}^*$,
  - interference terms could give a large contribution to CPV $\mathcal{O}(1\%)$;

  - Challenge: reconstruction of long-lived particles, $K_{s0} \rightarrow \pi^+\pi^-$, decaying mainly outside the region of vertex detector (VELO)

- Only one previous measurement from CLEO:
  \[ A_{CP} = (23 \pm 19)\% \]
  [PRD 63 (2011) 071101]
\( A_{CP} \) in \( D^0 \to K_s^0 K_s^0 \)

- Measurement of \( CP \) asymmetry:
  \[
  A_{\text{raw}}(K_s^0 K_s^0) \approx A_{CP}(K_s^0 K_s^0) + A_D(\pi) + A_P(D^*)
  \]

- \( D^* \)-tagged decays.
- Detection, \( A_D(\pi \pi) \), and production, \( A_P(D^*) \), asymmetries kept under control using \( D^0 \to K \pi \pi \) control sample;
  - both \( \mathcal{O}(1\%) \).
- **600 events** with the full Run1 data sample:
  \[
  A_{CP} = -0.029 \pm 0.052 \text{(stat.)} \pm 0.022 \text{(syst.)}
  \]
  - Large improvement with respect to the previous measurement (\( \sim \) factor 4).
  - Dedicate trigger in Run2.

[JHEP 10 (2015) 055]

\( \Delta m = m(K_s^0 K_s^0 \pi) - m(K_s^0 K_s^0) \)