$\Delta A_{CP}$ in Charm Decays at LHCb

B. Viaud
(LAL-in2p3)

On behalf of the LHCb collaboration
Why Charm Physics?

■ Charm Physics is essentially a 2-generation physics: any CPV above $O(0.1\%)$ means something new.

  $\rightarrow NP$, or unexpected strong effects

■ D-D mixing, CP violating decays and rare decays involve FCNC’s that are strongly GIM-suppressed (low mass down-type quarks in the loop)

  $\rightarrow NP$ contributions can have measurable effects (not hidden by SM)

■ FCNC with down-type quarks in the loop: constrain NP couplings that can’t be reached by B/K decays.

  $\rightarrow$ Complementarity with the B-physics program.

■ Very large samples of charmed particles at hadronic colliders!

$\rightarrow$ Charm decays are a good place to look for NP and constrain its properties!
Two complementary ways to seek CPV (and NP) in Charm Decays

- D oscillate, so one can look for two manifestations of indirect CPV
  - CPV in mixing: $\bar{D}0 \rightarrow D0 \neq D0 \rightarrow \bar{D}0$
  - CPV in the interplay between mixing and decay

- $A(D \rightarrow f) \neq A(D \rightarrow f)$: direct CPV

Direct CPV is as good an opportunity as indirect
  - Mixing is slow, strong phases can be large in decays.
  - While indirect CPV is nearly universal, direct depends a lot on the final state. Measuring many brings many complementary clues.

- CPV is small: $\sim 0.1\%$ to $\sim 1\%$ for direct CPV $\Leftrightarrow$ What’s SM; What’s NP? Probably an order of magnitude below for indirect CPV.

Today: direct CPV @ LHCb.

Focus on the current most precise example: $Acp(KK)-Acp(\pi\pi)$
**Key point:** huge $b$ and $c$ production in high $E_p$ $p$-$p$ collisions

- @ $\sqrt{s}=7$ TeV: $\sigma(pp \rightarrow bb^+X)=(284 \pm 20 \pm 49) \mu b$ [1]
  
  $\sigma(pp \rightarrow cc^+X)=(6100 \pm 930) \mu b$ [2]

*In $1fb^{-1}$: $\sim10^{12}$ $cc^-$ pairs in LHCb’s acceptance*

**Key point:** dedicated experiment, optimized for *Flavor Physics* in a **hadronic** environment.

- Forward detector
- Performant vertexing, $p$ and $M$ reconstruction, particle-ID
- Very selective, polyvalent and configurable trigger.

Typical Performance

- **Charged tracks momentum**: $\sigma_p/p = 0.35-0.55\%$, $\sigma_m = 10-20$ MeV/c²
- **ECAL**: $\sigma E/E = 10\%/\sqrt{E} \oplus 1\%$ (E in GeV)
- **muon-ID**: $\varepsilon(\mu \rightarrow \mu) \sim 95\%$, mis-ID rate($\pi \rightarrow \mu$)~1%
- **K-$\pi$ separation**: $\varepsilon(K \rightarrow K) \sim 95\%$, mis-ID rate($\pi \rightarrow K$)~10%
- **Proper time**: $\sigma_t \sim 30-50$ fs, $\sigma_z \sim 60 \mu$m (Prim. Vtx) $\sigma_z \sim 150 \mu$m (Secondary Vtx)

B-field polarity can be reversed: **Up** or **Down**
**Trigger Efficiency**
- ~30% for multibody hadronic modes
- ~90% for di-muons

**Ex 1/fb:**
\[ \sim 0.5M \ D^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^- \] on tape

**Output Rate**
- 3-4 kHz in 2011
- 4.5 kHz in 2012

**High PT candidates**
High PT displaced tracks matched with L0 objects.

**Full reconstruction (ex: lifetimes)**
Inclusive/exclusive modes
Highly configurable.
Easy to add/remove/prescale modes.
Peak Luminosity

- 2011: $3-4 \times 10^{32}/cm^2/s$
- 2012: $4 \times 10^{32}/cm^2/s$
- $<\#\text{collisions}>$ per bunch crossing $\sim 1.5$

“Luminosity Leveling” to obtained that from LHC’s luminosity

2011

- Delivered Lumi: 1.2195 fb
- Recorded Lumi: 1.1067 fb

Integrated Luminosity (1/10)

2012

- Delivered Lumi: 291.42 pb
- Recorded Lumi: 270.92 pb

Integrated Luminosity (1/10)

~1.0 fb$^{-1}$ @ $\sqrt{s}=7$ TeV

0.3 fb$^{-1}$ @ $\sqrt{s}=8$ TeV
**Peak Luminosity**

- 2011: $3-4 \times 10^{32}/\text{cm}^2/\text{s}$
- 2012: $4 \times 10^{32}/\text{cm}^2/\text{s}$
- $\langle \#\text{collisions} \rangle$ per bunch crossing $\sim 1.5$

“Luminosity Leveling” to obtained that from LHC’s luminosity

2011

2012

Hope to record 1.5 fb$^{-1}$ in 2012 + 2.5 fb$^{-1}$ in 2015/2016

$L_{\text{tot}} = 5\text{fb}^{-1}$
\[ \Delta A_{CP} = A_{CP}(D^0 \rightarrow K^+K^-) - A_{CP}(D^0 \rightarrow \pi^+\pi^-) \]

- 0.6 fb^{-1} (2011)
Analysis Strategy

- Measure a time-integrated asymmetry

\[ A_{\text{raw}}(f) = \frac{N(D^{*+} \rightarrow D^{0}(f)\pi^{+}) - N(D^{*-} \rightarrow D^{0}(f)\pi^{-})}{N(D^{*+} \rightarrow D^{0}(f)\pi^{+}) + N(D^{*-} \rightarrow D^{0}(f)\pi^{-})} \]

- First order Taylor Expansion:

\[ A_{\text{RAW}}(f)^* = A_{\text{CP}}(f) + A_D(f) + A_D(\pi_s) + A_P(D^{*+}) \]

Use D*:

\[ Q_{\text{slow } \pi} \text{ tells } D^{0}\text{'s flavor} \]

When \( f = \pi^+\pi^- \) or \( K^+K^- \): no detection asymmetry between \( D \) and \( \bar{D} \)

\[ \rightarrow A_D(f) = 0 \]

Similar for \( f = \pi^+\pi^- \) and \( K^+K^- \)

\[ \Delta A_{\text{RAW}} = A_{\text{RAW}}(K^+K^-) - A_{\text{RAW}}(\pi^+\pi^-) = \Delta A_{\text{CP}} \]
\[ \Delta A_{\text{RAW}} = A_{\text{RAW}}(K^+K^-) - A_{\text{RAW}}(\pi^+\pi^-) = \Delta A_{\text{CP}} \]

- This rule gives a very robust way to detect a CPV effect

- But remember! It can be broken by
  
  - Large asymmetries (\(>>1\%\)): Taylor Expansion breaking down
  
  - Dependence of \(A_p(D^*)\) and \(A_D(\pi_s)\) upon \(\varepsilon(KK)/\varepsilon(\pi\pi)\).
    
    \textit{Ex:} \(A_D(\pi_s)\) depends upon the \(\pi_S\) phase space, and KK and \(\pi\pi\) selections favor a different region.
  
  - Different and asymmetric peaking backgrounds.

- So the fun in this analysis is to avoid those problems.

Main protections:

- Measurements in separate bins of \(P_T\) and \(\eta\) of \(D^*\)'s, \(P\) of \(\pi_S\)
- Fiducial cuts to remove regions of large asymmetry
- Many checks...
What does $\Delta A_{CP}$ measure exactly?

- Time integrated asymmetries: a combination of direct & indirect CPV.

$$A_{CP}(f) \approx a_{CP}^{dir}(f) + \frac{\langle t \rangle}{\tau} a_{CP}^{ind}$$

Depends on $<t>$ of the $D^0$ in the sample ($\sim$ time given the mixing to interfere).

- Indirect CPV universal to a very good approximation, but lifetime acceptance can differ between $KK$ and $\pi\pi$.

$$\Delta A_{CP} = [a_{CP}^{dir}(K^-K^+) - a_{CP}^{dir}(\pi^-\pi^+)] + \frac{\Delta \langle t \rangle}{\tau} a_{CP}^{ind}$$

→ Also measure $\Delta <t>$ to disentangle each contribution

- A year ago...

HFAG combination

$$a_{CP}^{ind} = (-0.03 \pm 0.23)\%$$

$$\Delta a_{CP}^{dir} = (-0.42 \pm 0.27)\%$$

Consistency with NO CPV hypothesis: 28%
Cut-based selection: use the decay topology and kinematics, and LHCb’s PID performance.

- Track & Vertex fit quality
- Tracks must not come from the primary vertex (PV) & ct(D)>100 μm.
- D must come from the PV, to reject D* from B decays
- \(\theta\) between D\(^0\) in lab frame and its daughters in D\(^0\) rest frame: |\(\cos\theta\)|<0.9
- Tracks identified as kaon/pions using PID info from the RICH
- \(P_T(D)>2\) GeV/c

N.B. This offline selection applied on candidates that fired a similar (looser) selection in the High Level trigger
Fiducial cuts

The magnetic field breaks the symmetry of the detector

Kinematic regions where $A_{RAW}$ can reach 100%!

Borders where $\pi^+/\pi^-$ are swept out while $\pi^-/\pi^+$ are swept in.

(this includes also the beam pipe)
Kinematic regions where $A_{RAW}$ can reach 100%!

- Breaks the formalism (too large an angle for a Taylor expansion)
- Possible second order effects if the efficiency for being in this region differs between KK and $\pi\pi$.
- Depends more on $P_x$ than on $P_{T,D^*}$, $\eta_{D^*}$ or $P_{\text{slow } \pi}$

Thus: not treated perfectly by the kinematics binning

- Left-right binning + the fact that $\sim 1/2$ the sample is taken with B-field Up and $\sim 1/2$ with B-field Down should limit the overall effect.
However, to be more robust, sacrifice 25% of the statistics with **Fiducial cuts**
Fiducial cuts

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- Possible second order effects if the efficiency for being in this region differs between KK and $\pi\pi$.
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Mass spectra and signal yields

\[ \delta m = m(h^+h^-\pi^+) - m(h^+h) - m(\pi^+) \]

- **LHCb**
  - **K⁻K⁺**
    - Yield (1436±2)x10³
  - **π⁻π⁺**
    - Yield (381±1)x10³

**Signal window**

**1844 < m(D⁰) < 1884 MeV/c²**
In 216 bins
54 bins in $P_{T,D^*} \times \eta_{D^*} \times P_{\text{slow} \pi} \times \text{left/right}$
$\times 2 \text{ Mag Up / Mag Down}$
$\times 2 \text{ Before/After an LHC technical stop}$

Fit to $\delta m$ distributions

1. **Signal**: double gaussian convolved with a function describing an asymmetric tail.
   - $D^{*+}$ and $D^{*-}$ parameters float separately.

2. **Background**: $B[1 - \exp\left(- (\delta m - \delta m_0)/C \right)]$

Finally: $A_{\text{RAW}}$ and $\Delta A_{\text{RAW}}$ in each bin, then weighted average

$$\Delta A_{CP} = (-0.82 \pm 0.21_{\text{stat}})\%$$

($\chi^2 / NDF = 211/215$)

Fit to background subtracted decay time distributions yields:

$$\Delta \langle t \rangle / \tau = [9.83 \pm 0.22(\text{stat.}) \pm 0.19(\text{syst.})]\%$$

⇒ This would essentially be a direct CPV
<table>
<thead>
<tr>
<th>Effect</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta A_{CP}$ with vs. without Fiducial cuts</td>
<td>0.01%</td>
</tr>
<tr>
<td>Background peaks (+their asymmetry) from $m(D^0)$ sideband injected into TOYs to check the effect on the fit.</td>
<td>0.04%</td>
</tr>
<tr>
<td>$\Delta A_{CP}$ with fit vs. sideband subtraction cuts</td>
<td>0.08%</td>
</tr>
<tr>
<td>$\Delta A_{CP}$ with multiple candidates vs. only one allowed per event</td>
<td>0.06%</td>
</tr>
<tr>
<td>$\Delta A_{CP}$ with kinematical bins vs. one single bin</td>
<td>0.02%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>0.11%</strong></td>
</tr>
</tbody>
</table>

$\Delta A_{CP} = (-0.82 \pm 0.21\text{stat} \pm 0.11)\%$

3.5 $\sigma$ from no CPV.
Cross Checks

- Electron and muon vetoes on the soft pion and D⁰ daughters
- Different kinematic binnings
- Stability of result vs data-taking runs
- Stability vs kinematic variables
- Toy MC studies of fit procedure, statistical errors
- Tightening of PID cuts on D⁰ daughters
- Tightening of kinematic cuts
- Variation with event track multiplicity
- Use of other signal, background line-shapes in the fit
- Use of alternative offline processing (skimming/stripping)
- Internal consistency between subsamples (splitting left/right, field up/field down)
Cross Checks

- No evidence of dependence on relevant kinematic variables
Stability with time

A technical stop occurred here

Stability wrt PID

No significant variation of $\Delta A_{CP}$ when tightening the cut on the hadron PID information provided by the RICH

$PID$ tight+

$\Delta A_{CP} = (-0.88 \pm 0.26_{stat})\%$

$PID$ tight++

$\Delta A_{CP} = (-1.03 \pm 0.31_{stat})\%$

Internal consistency: a closer look

Split the 216 bins into 8 smaller sets and check $\chi^2$ for each, and between them:

$\chi^2 / NDF = 6.7/7$

<table>
<thead>
<tr>
<th>Subsample</th>
<th>$\Delta A_{CP}$</th>
<th>$\chi^2 / ndf$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-TS, field up, left</td>
<td>$(-1.22 \pm 0.59)%$</td>
<td>13/26(98%)</td>
</tr>
<tr>
<td>Pre-TS, field up, right</td>
<td>$(-1.43 \pm 0.59)%$</td>
<td>27/26(39%)</td>
</tr>
<tr>
<td>Pre-TS, field down, left</td>
<td>$(-0.59 \pm 0.52)%$</td>
<td>19/26(84%)</td>
</tr>
<tr>
<td>Pre-TS, field down, right</td>
<td>$(-0.51 \pm 0.52)%$</td>
<td>29/26(30%)</td>
</tr>
<tr>
<td>Post-TS, field up, left</td>
<td>$(-0.79 \pm 0.90)%$</td>
<td>26/26(44%)</td>
</tr>
<tr>
<td>Post-TS, field up, right</td>
<td>$(+0.42 \pm 0.93)%$</td>
<td>21/26(77%)</td>
</tr>
<tr>
<td>Post-TS, field down, left</td>
<td>$(-0.24 \pm 0.56)%$</td>
<td>34/26(15%)</td>
</tr>
<tr>
<td>Post-TS, field down, right</td>
<td>$(-1.59 \pm 0.57)%$</td>
<td>35/26(12%)</td>
</tr>
<tr>
<td>All data</td>
<td>$(-0.82 \pm 0.21)%$</td>
<td>211/215(56%)</td>
</tr>
</tbody>
</table>
World Wide

<table>
<thead>
<tr>
<th>Year</th>
<th>Experiment</th>
<th>Results</th>
<th>$\Delta(t)/\tau$</th>
<th>$\langle t \rangle/\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Belle</td>
<td>$A_\Gamma = (0.01 \pm 0.30 \text{ (stat.)} \pm 0.15 \text{ (syst.)})%$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2008</td>
<td>BaBar</td>
<td>$A_\Gamma = (0.26 \pm 0.36 \text{ (stat.)} \pm 0.08 \text{ (syst.)})%$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2011</td>
<td>LHCb</td>
<td>$A_\Gamma = (-0.59 \pm 0.59 \text{ (stat.)} \pm 0.21 \text{ (syst.)})%$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2008</td>
<td>BaBar</td>
<td>$A_{CP}(KK) = (0.00 \pm 0.34 \text{ (stat.)} \pm 0.13 \text{ (syst.)})%$</td>
<td>$0.00$</td>
<td>$1.00$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$A_{CP}(\pi\pi) = (-0.24 \pm 0.52 \text{ (stat.)} \pm 0.22 \text{ (syst.)})%$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Belle</td>
<td>$\Delta A_{CP} = (-0.86 \pm 0.60 \text{ (stat.)} \pm 0.07 \text{ (syst.)})%$</td>
<td>$0.00$</td>
<td>$1.00$</td>
</tr>
<tr>
<td>2011</td>
<td>LHCb</td>
<td>$\Delta A_{CP} = (-0.82 \pm 0.21 \text{ (stat.)} \pm 0.11 \text{ (syst.)})%$</td>
<td>$0.10$</td>
<td>$2.08$</td>
</tr>
<tr>
<td>2012</td>
<td>CDF Prelim.</td>
<td>$\Delta A_{CP} = (-0.62 \pm 0.21 \text{ (stat.)} \pm 0.10 \text{ (syst.)})%$</td>
<td>$0.25$</td>
<td>$2.58$</td>
</tr>
</tbody>
</table>

CDF public note 10784

Zero CPV

$$a_{CP}^{\text{ind}} = (-0.025 \pm 0.231)\%$$

$$\Delta a_{CP}^{\text{dir}} = (-0.656 \pm 0.154)\%$$

Agreement with no CPV: $6 \times 10^{-5}$
**Predictions are difficult with D mesons**

- Too light (heavy) for the techniques that work in B (K) physics

**Present consensus**

- Difficult for the SM to generate more than $O(10^{-4}-10^{-3})$
  (canonic point of view till 2011)
- But possible: one can think of Hadronic enhancements pushing it up to $O(1\%)$
- Would help: Individual asymmetries
- Would help: Several decay modes should be affected by the same NP, but not the same strong effects: compare $A_{CP}$ measured in each mode to distinguish enhanced contributions of higher order standard model diagrams from NP effects

**Ex:**

\[ \rightarrow D^+_S \rightarrow K_S h^+; \ \phi h^+ \]

\[ \rightarrow D^+ \rightarrow K + \bar{K}^*0; \ K^*+\bar{K}^0 \]

\[ \rightarrow D^+ \rightarrow \rho^0 \pi^+; \ \pi^+ \pi^0; \ \pi^+ \eta' \]

\[ \rightarrow D_S \rightarrow K^+\phi, \ K^+\eta', \ K^{(*)0}\pi^+ \]

\[ \rightarrow D \rightarrow h^+h^-h^+; \ h^+h^-h^+h^- \]

See, e.g.,

Isidori, Kamenik, Ligeti, Perez (arXiv:1111.4987)
Cheng, Chaing (arXiv:1201.0785)
Pirtskhalava, Uttararat (arXiv:1112.5451)
Prospects

Short term (1.1 or 2.5 fb⁻¹)

- **Update** \( \Delta A_{\text{CP}} = A_{\text{CP}}(K^+K^-) - A_{\text{RAW}}(\pi^+\pi^-) \)
  
  \( \rightarrow \sigma \) from 0.25% to \( \sim 0.15\% \) may be enough to confirm a 4-5\( \sigma \) effect.

- **\( \Delta A_{\text{CP}} \) with \( D^+_{(S)} \rightarrow K_S h^+ \) vs. \( \phi h^+ \) (work started !)**
  
  \( \rightarrow \) Expect \( \sim 7M \) \( D^+ \rightarrow \phi \pi^+ \) and \( \sim 3.5M \) \( D^+ \rightarrow K_S \pi^+ \)

  Belle: \( \Delta A_{\text{CP}} (D^+ \rightarrow \phi \pi^+ \text{ vs. } D^+_{(S)} \rightarrow \phi \pi^+) = (0.51 \pm 0.28 \pm 0.05)\% \) with \( 0.238M \) \( D^+ \rightarrow \phi \pi^+ \)

  \textbf{PRL 108, 071801 (2012)}

  Belle: \( A_{\text{CP}} (D^+ \rightarrow K_S \pi^+) = (0.36 \pm 0.09 \pm 0.07)\% \) with \( 1.7M \) events

  \( CPV \) due to the kaon

  \textbf{arXiv:1203.6409}

- **Dalitz analyses of \( D \rightarrow h^+h^-h^-, h^+h^+h^-h^- \) modes**

Longer term: LHCb upgrade (2019)
Control of systematic effects: good ex. of precision physics @ pp collider.

Evidence for CPV in charm decays at LHCb

→ Mostly a direct CPV
→ Not yet a $5\sigma$ effect
→ But not far from it when combined with other experiments ($4\sigma$)

Could be SM, could be NP, it’s anyway very interesting.

There’s a large Charm physics programme at LHCb. Other modes will be studied in the future to over-constrain the problem.

And don’t forget the LHCb’s upgrade!

⇒ Stay tuned (at least for the next 15 years 😊)!
Back-up
LHC’s Schedule

- **2009**: LHC startup, $\sqrt{s} = 900$ GeV
- **2011**: $\sqrt{s}=7\sim8$ TeV, $L=6\times10^{33}$ cm$^{-2}$ s$^{-1}$, bunch spacing 50 ns
- **2013**: Go to design energy, nominal luminosity
- **2016**: $\sqrt{s}=13\sim14$ TeV, $L\sim1\times10^{34}$ cm$^{-2}$ s$^{-1}$, bunch spacing 25 ns
- **2018**: Injector and LHC Phase-1 upgrade to full design luminosity
- **2022**: HL-LHC Phase-2 upgrade, IR, crab cavities?
- **2030?** $\sqrt{s}=14$ TeV, $L=5\times10^{34}$ cm$^{-2}$ s$^{-1}$, luminosity levelling

- **Atlas, CMS**
  - ~20-25 fb$^{-1}$
  - ~2.5 fb$^{-1}$
  - ~75-100 fb$^{-1}$
  - ~6.5 fb$^{-1}$
  - ~350 fb$^{-1}$
  - ~19 fb$^{-1}$
  - ~3000 fb$^{-1}$
  - ~57 fb$^{-1}$

*M.Nessi, Chamonix 2012*
Upgraded LHCb (start by 2019)

Should bring ~180 times more hadronic charm decays!

- 50 fb\(^{-1}\) with \(L_{\text{peak}}=1-2 \times 10^{33}\) cm\(^{-2}\)s\(^{-1}\)
- At \(\sqrt{s}=14\) TeV: \(\sigma_{\text{CC}} \sim 1.8\) times larger
- Fully software trigger: Trigger Efficiency on hadronic decays \(\times 2\)
  (reduce the role the hardware L0 trigger)

-This means \(\sim 460M D^0 \rightarrow K^+ K^- \) & \(130M D^0 \rightarrow \pi^+ \pi^-\).
  Naïve extrapolation: \(\sigma_{\text{Acp}} \sim 0.015\%\). That’s far below the current systematics. A part of the statistic could be sacrificed to improve it.

-Also for decays like \(D^+_{(S)} \rightarrow K_S h^+ \) vs. \(\phi h^+\), will we probably be pushing on the systematics by then.

-And many other things: DCS, precision Dalitz studies, etc...

See e.g. “Workshop on the Implications of LHCb measurements”, CERN, April 16-18, 2012
Preliminary estimates!

Not everything is solved by increasing the statistics. In some cases, some will be sacrificed to improve systematics.
<table>
<thead>
<tr>
<th>samples</th>
<th>parameter(s)</th>
<th>precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS/RS $K\pi$</td>
<td>$(x'^2, y')$</td>
<td>$\mathcal{O}[(10^{-5}, 10^{-4})]$</td>
</tr>
<tr>
<td>WS/RS $K\mu\nu$</td>
<td>$r_M$</td>
<td>$\mathcal{O}(5 \times 10^{-7})$</td>
</tr>
<tr>
<td>WS/RS $K\mu\nu$</td>
<td>$</td>
<td>p/q</td>
</tr>
<tr>
<td>$D^{*+} \to D^0\pi^+$; $D^0 \to K^-K^+$, $\pi^-\pi^+$</td>
<td>$\Delta A_{CP}$</td>
<td>0.015%</td>
</tr>
<tr>
<td>$D^{*+} \to D^0\pi^+$; $D^0 \to K^-K^+$</td>
<td>$A_{CP}$</td>
<td>0.010%</td>
</tr>
<tr>
<td>$D^{*0} \to D^0\pi^+$; $D^0 \to \pi^-\pi^+$</td>
<td>$A_{CP}$</td>
<td>0.015%</td>
</tr>
<tr>
<td>$D^{*0} \to D^0\pi^+$; $D^0 \to K^0_\pi^-\pi^+$</td>
<td>$(x, y)$</td>
<td>(0.015%, 0.010%)</td>
</tr>
<tr>
<td>$D^{*0} \to D^0\pi^+$; $D^0 \to K^-K^+ (\pi^-\pi^+)$</td>
<td>$y_{CP}$</td>
<td>0.004% (0.008%)</td>
</tr>
<tr>
<td>$D^{*0} \to D^0\pi^+$; $D^0 \to K^-K^+ (\pi^-\pi^+)$</td>
<td>$A_\Gamma$</td>
<td>0.004% (0.008%)</td>
</tr>
<tr>
<td>$D^{*0} \to D^0\pi^+$; $D^0 \to K^-K^+ \pi^-\pi^+$</td>
<td>$A_T$</td>
<td>$2.5 \times 10^{-4}$</td>
</tr>
<tr>
<td>$D^+ \to K^0_\pi K^+$</td>
<td></td>
<td>10^{-4}</td>
</tr>
<tr>
<td>$D^+ \to K^-K^+\pi^+$</td>
<td></td>
<td>5 \times 10^{-5}</td>
</tr>
<tr>
<td>$D^+ \to \pi^-\pi^+\pi^+$</td>
<td></td>
<td>8 \times 10^{-5}</td>
</tr>
</tbody>
</table>
Reminder:

$$\Delta A_{CP} = \left[ a_{CP}^{dir}(K^-K^+) - a_{CP}^{dir}(\pi^-\pi^+) \right] + \frac{\Delta \langle t \rangle}{\tau} a_{CP}^{ind}$$

$$\Delta \langle t \rangle \neq 0$$ since the lifetime acceptance differs between $KK$ and $\pi\pi$

e.g. Smaller $KK$ opening angle: easier to miss cut vetoing tracks from Primary Vertex.

Fit to background subtracted decay time distributions yields:

$$\Delta \langle t \rangle / \tau = [9.83 \pm 0.22{\text{(stat.)}} \pm 0.19{\text{(syst.)}}] \%$$

Essentially due to the fraction of $D^*$ from $B$ decays
Reminder: \[ \Delta A_{CP} = [a_{CP}^{dir}(K^-K^+) - a_{CP}^{dir}(\pi^-\pi^+)] + \frac{\Delta \langle t \rangle}{\tau} a_{CP}^{ind} \]

\[ \Delta \langle t \rangle \neq 0 \text{ since the lifetime acceptance differs between } KK \text{ and } \pi\pi \]

e.g. Smaller KK opening angle: easier to miss cut vetoing tracks from Primary Vertex.

Fit to background subtracted decay time distributions yields:

\[ \Delta \langle t \rangle / \tau = [9.83 \pm 0.22(\text{stat.}) \pm 0.19(\text{syst.})] \% \]

**Indirect CPV mostly cancels**
<table>
<thead>
<tr>
<th>Sample</th>
<th>Observable</th>
<th>Sensitivity (1.0 fb(^{-1}))</th>
<th>Sensitivity (2.5 fb(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tagged ( KK )</td>
<td>( y_{CP} )</td>
<td>( 6 \times 10^{-4} )</td>
<td>( 4 \times 10^{-4} )</td>
</tr>
<tr>
<td>Tagged ( \pi \pi )</td>
<td>( y_{CP} )</td>
<td>( 11 \times 10^{-4} )</td>
<td>( 7 \times 10^{-4} )</td>
</tr>
<tr>
<td>Tagged ( KK )</td>
<td>( \Gamma )</td>
<td>( 6 \times 10^{-4} )</td>
<td>( 4 \times 10^{-4} )</td>
</tr>
<tr>
<td>Tagged ( \pi \pi )</td>
<td>( \Gamma )</td>
<td>( 11 \times 10^{-4} )</td>
<td>( 7 \times 10^{-4} )</td>
</tr>
<tr>
<td>Tagged WS/RS ( K \pi )</td>
<td>( x^2 )</td>
<td>( 7 \times 10^{-5} )</td>
<td>( 4 \times 10^{-5} )</td>
</tr>
<tr>
<td>Tagged WS/RS ( K \pi )</td>
<td>( y' )</td>
<td>( 13 \times 10^{-4} )</td>
<td>( 8 \times 10^{-4} )</td>
</tr>
<tr>
<td>Tagged ( K_S \pi \pi )</td>
<td>( x )</td>
<td>( 4 \times 10^{-3} )</td>
<td>( 3 \times 10^{-3} )</td>
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<tr>
<td>Tagged ( K_S \pi \pi )</td>
<td>( y )</td>
<td>( 3 \times 10^{-3} )</td>
<td>( 2 \times 10^{-3} )</td>
</tr>
<tr>
<td>Tagged ( K_S \pi \pi )</td>
<td>(</td>
<td>q/p</td>
<td>)</td>
</tr>
<tr>
<td>Tagged ( K_S \pi \pi )</td>
<td>( \phi )</td>
<td>25°</td>
<td>15°</td>
</tr>
</tbody>
</table>

Preliminary estimates!
FULL 40 MHz FE READOUT

RICH
New photon detectors

Calorimeter+Muon
Remove M1, SPD, PS
New calorimeter FE electronics

Tracking
New silicon trackers
Reduce straw coverage +
  a) fiber tracker
  b) larger silicon tracker

Vertex Locator
a) New pixel detector
  b) Improved strip detector