CP Violation in Charmed Decays - A Probe of New Physics?

Philipp Frings

Faculty of Science (FNWI)
University of Amsterdam (UvA)

Dutch National Institute for Subatomic Physics (Nikhef)
Amsterdam

Supervisor: Robert Fleischer
Nikhef, Free University Amsterdam

IMPRS Workshop

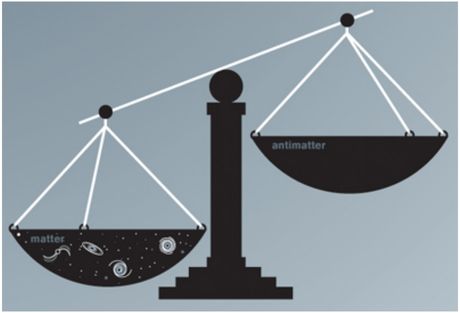
Outline

1. CP Violation
2. The Problem
3. The Treatment

Why CP violation?

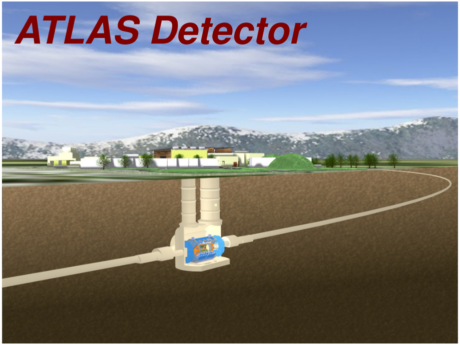
Reasons which suggest that the Standard Model (SM) is incomplete:

- Dark Matter and Dark Energy
- Neutrino Masses
- Hierarchy Problem
- Baryon Asymmetry in the Universe



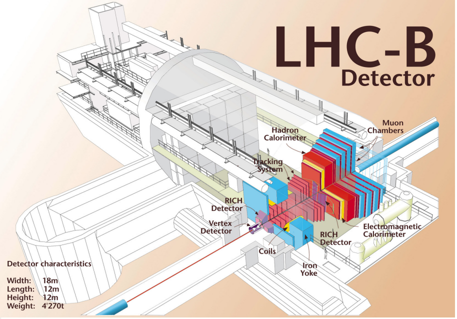
CP Violation is one way to find deviations from the SM which can lead to explanations of these facts.

Search for CP Violation = Indirect Search



There are two different ways to search for new physics (NP) ...

... **direct** and **indirect** search.



Atlas and CMS

Direct Research: Higgs?

LHCb

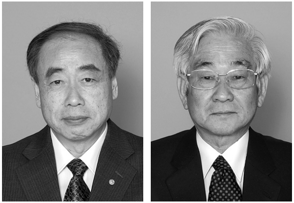
Indirect Research: Precision Tests

CP Violation

The quark mixing matrix V_{CKM} has one complex phase that generates CP violation in the SM

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

CP conjugation $\equiv$ complex conjugation of V_{CKM} to V^*_{CKM}



Nobel Prize in 2008 for Makoto Kobayashi and Toshihide Maskawa

CP Violation and CP asymmetries

$$D^0 = (c\bar{u}) \xrightarrow{CP} \bar{D}^0 = (\bar{c}u) \qquad \pi^+\pi^- \xrightarrow{CP} \pi^-\pi^+$$

> If a particle does not behave as its antiparticle this is called CP violation.

$$\Gamma(D^0 \to \pi^+\pi^-) \underbrace{\neq}_{\text{CP Violation}} \Gamma(\bar{D}^0 \to \pi^+\pi^-)$$

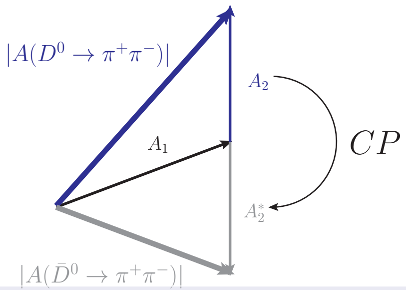
CP Asymmetry

$$A_{CP}(\pi^+\pi^-) \equiv \frac{\Gamma(D^0 \to \pi^+\pi^-) - \Gamma(\bar{D}^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to \pi^+\pi^-) + \Gamma(\bar{D}^0 \to \pi^+\pi^-)}$$

Two Kinds of CP Violation

Direct CP Violation

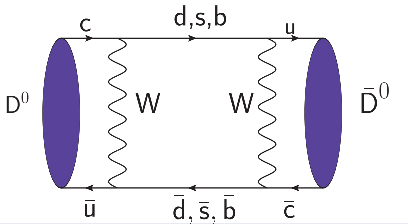
Two different processes must contribute to one amplitude.



Different for every D^0 decay

Indirect CP Violation

Indirect CP violation is generated by $D^0 - \bar{D}^0$ mixing.



The same for every D^0 decay

CP Violation in D Decays

Usual Expectation

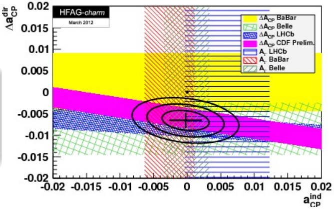
CP asymmetries in the D system are usually expected to be $\mathcal{O}(10^{-4})$.

LHCb Measurement

$$\Delta A_{CP} \equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = [-0.82 \pm 0.21(\text{stat.}) \pm 0.11(\text{syst.})]\%$$

Result has been supported by CDF with

$$\Delta A_{CP} = [-0.62 \pm 0.21(\text{stat.}) \pm 0.10(\text{syst.})]\%$$



LHCb Collaboration: hep-ex/1112.0938, CDF Note 10784

Is ΔA_{CP} a sign of new physics?

The experimental data could be:

QCD Effects?

New Physics?

We investigated the **long-distance QCD effects.**

What is $\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$ made of?

Indirect CP Violation is the same for all D^0 meson decays
$\Longrightarrow$ It cancels out in the difference

$\Longrightarrow$ ΔA_{CP} made of the difference of the direct CP asymmetries.
$\Longrightarrow$ **Look on structure of decay amplitudes.**

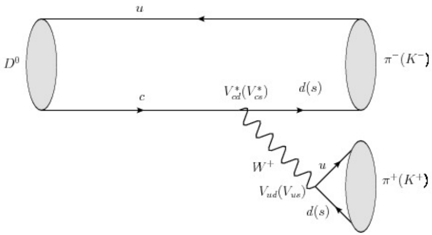
$$\mathcal{H}_{eff}^{\Delta C=1} = \frac{G_F}{\sqrt{2}} \underbrace{\sum_{q \in \{d,s\}} V_{cq}^* V_{uq} \left(C_1 Q_1^q + C_2 Q_2^q \right)}_{\text{Tree processes}} - \underbrace{V_{cb}^* V_{ub} \sum_{i=3}^{6} C_i Q_i}_{\text{Penguin processes}} + H.c.$$

Wilson Coefficients

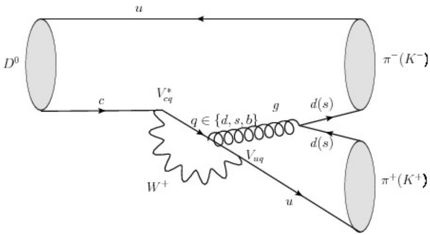
- Tree diagrams $C_1, C_2 \sim 1$
- Penguin diagrams $C_i \sim 0.1$

The effective 4 quark operators
Q cannot be computed

Leading Tree Amplitude



Leading Penguin Amplitude



$$A(D^0 \to f) = \lambda_q \mathcal{T}_f + \lambda_b \mathcal{P}_f \quad \text{with} \quad \lambda_p \equiv V^*_{cp} V_{up}.$$

Structure of Decay Amplitudes

$$A(D^0 \to f) = \lambda_q \mathcal{T}_f + \lambda_b \mathcal{P}_f \quad \text{with} \quad \lambda_p \equiv V_{cp}^* V_{up}.$$

A single *direct* asymmetry is to very good approximation:

$$a_{CP}^{dir}(f) \equiv \frac{|A(D^0 \to f)| - |A(\bar{D}^0 \to f)|^2}{|A(D^0 \to f)| + |A(\bar{D}^0 \to f)|^2} = -2\Im\left(\frac{\lambda_b}{\lambda_q}\right)\Im\left(\frac{\mathcal{P}_f}{\mathcal{T}_f}\right).$$

The full observable can hence be theoretically described by

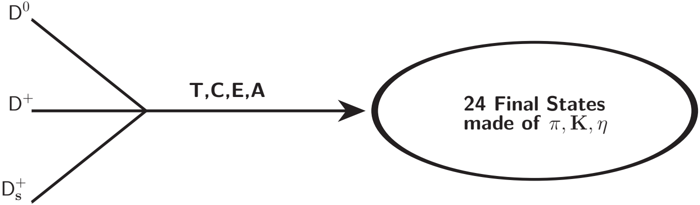
$$\Delta A_{CP} = -\underbrace{2\Im\left(\frac{\lambda_b}{\lambda_s}\right)}_{1.2\times 10^{-3}} \underbrace{\left[\Im\left(\frac{\mathcal{P}_{KK}}{\mathcal{T}_{KK}}\right) + \Im\left(\frac{\mathcal{P}_{\pi\pi}}{\mathcal{T}_{\pi\pi}}\right)\right]}_{\frac{C_i}{C_2}\sim\mathcal{O}(10^{-1})} \sim \mathcal{O}(10^{-4}).$$

Low Energy Effective Hamiltonians - SU(3) Symmetry

$$\mathcal{H}_{eff}^{\Delta C=1} = \frac{G_F}{\sqrt{2}} \sum_{q\in\{d,s\}} \lambda_q \left(C_1 Q_1^q + C_2 Q_2^q\right) - \lambda_b \sum_{i=3}^{6} C_i Q_i + H.c.$$

Assume that this Hamiltonian has a flavor SU(3) symmetry which sets: $m_u = m_d = m_s = 0$

$D \to f$ processes can be described with T, C, E and A.



How well does Flavor SU(3) work?

Decays that do not suffer from CKM suppression

$SU(3)$ works very well!

Decays that suffer from single CKM suppression like $D \to \pi^+\pi^-$ and $D \to K^+K^-$

SU(3) does not work well! The BRs do not meet the SU(3) expectation
$\Longrightarrow$ We have to take into account SU(3) breaking

Different ways to include SU(3) breaking

- Include penguins which do not contribute under SU(3)

Large Penguins?

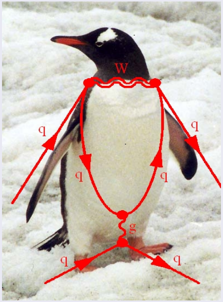
SU(3) breaking penguin topologies can explain the branching ratios

$\Longrightarrow$ It is likely that this enhancement of the penguins also influences ΔA_{CP} but it is not possible to say how large this influence actually is.

More about large penguins: Bhattacharya et al. hep-ph/1201.2351, Brod et al. hep-ph/1203.6659

Conclusions

- The Asymmetry difference is a very exciting topic because it is one of the few hints to NP at the LHC.
- Large penguin topologies are likely
- **but** QCD is not well enough understood to draw final conclusions.
- I am looking forward to new measurements which will be hopefully available this summer and give new insights.



Backup

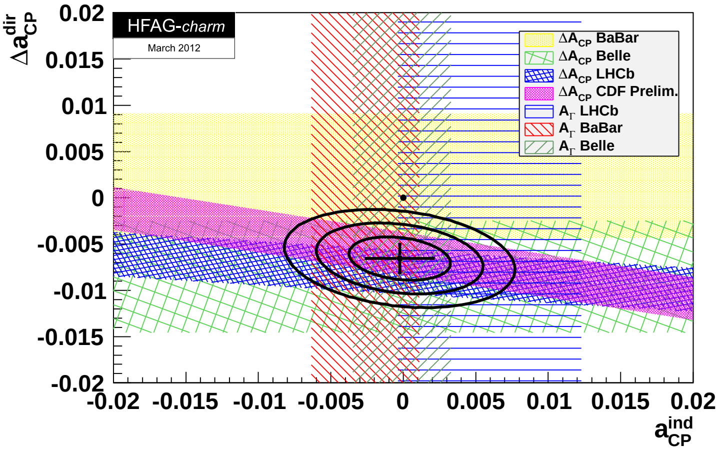
Direct CPV

$$A = |A_1| e^{i\delta_{QCD}} + |A_2| e^{i\phi_{CKM}} \quad \mathcal{CP} A = |A_1| e^{i\delta_{QCD}} + |A_2| e^{-i\phi_{CKM}}$$

All Contributing Amplitudes

$$\begin{aligned}
A(D^0 \to \pi^+\pi^-) &= \lambda_d \mathcal{T}_\pi + \lambda_b \mathcal{P}_\pi \\
A(\bar{D}^0 \to \pi^+\pi^-) &= \lambda_d^* \mathcal{T}_\pi + \lambda_b^* \mathcal{P}_\pi \\
A(D^0 \to K^+K^-) &= \lambda_s \mathcal{T}_K + \lambda_b \mathcal{P}_K \\
A(\bar{D}^0 \to K^+K^-) &= \lambda_s^* \mathcal{T}_K + \lambda_b^* \mathcal{P}_K
\end{aligned}$$

Available Data on this CP Asymmetry Difference



$$\Delta A_{CP} = \Delta a_{CP}^{dir} + \frac{< t >}{\tau_D} a_{CP}^{ind}$$