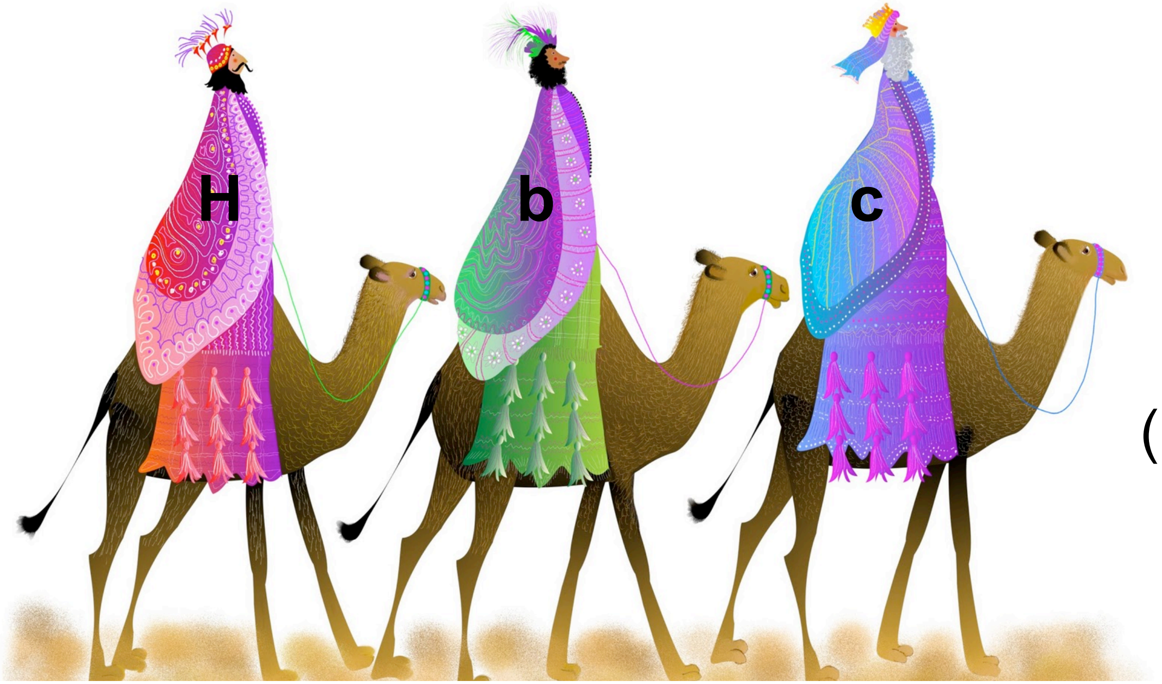
Charm Physics in LHCb,
first evidence of CP violation in charm decays



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on behalf of the LHCb Collaboration

Outline

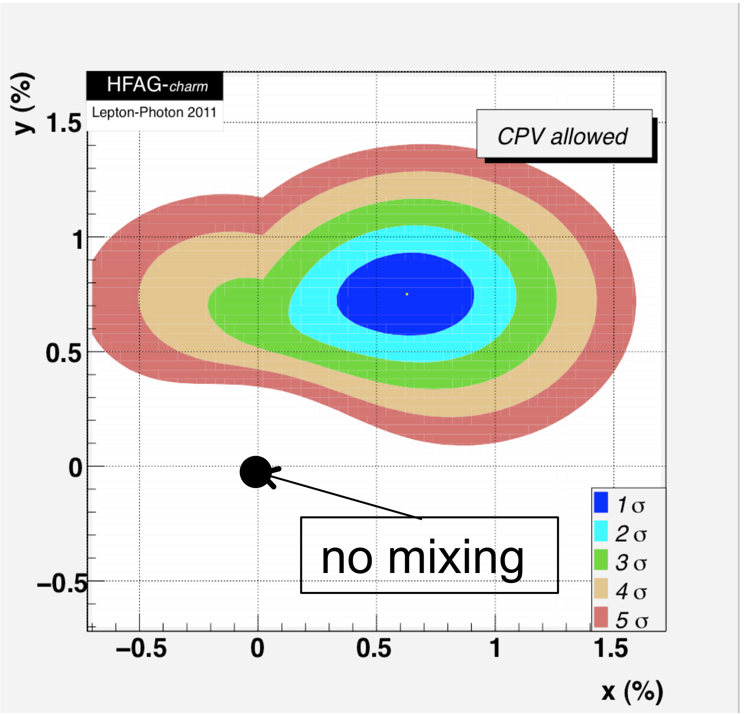
- **Introduction:**
    - why we are interested in charm physics
    - types of CP violation
- **LHCb and measurements of CP violation in charm sector**
    - charm particles in LHCb
    - the trigger and charm physics
    - results for CP violation measurements in LHCb
        - in decays of $D^0 \rightarrow K^+K^-$ vs $D^0 \rightarrow \pi^+\pi^-$
        - for Dalitz plots in decays of $D^+ \rightarrow K^-K^+\pi^+$
- **Summary**

Motivation

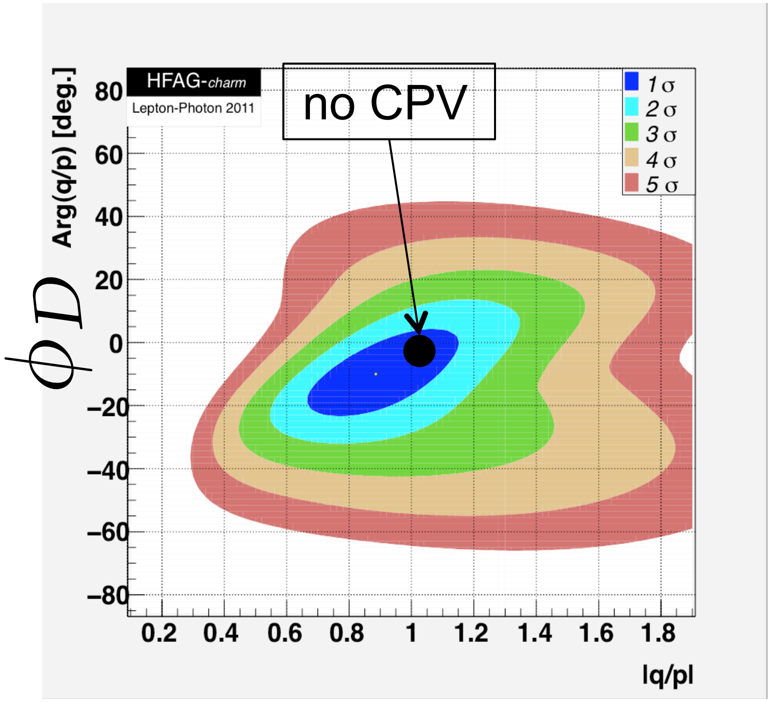
First measurement of mixing D^0-anti-D^0, 2007, Belle, BaBar

- opens possibilities of rich structure of CP violation in charm sector

$$y = \frac{\Delta\Gamma}{2\Gamma}$$



$$x = \frac{\Delta m}{\Gamma}$$



CPV if $\Phi_D \equiv (-M_{12}/\Gamma_{12}) \neq 0$ lub $|q/p| \neq 1$

So far there was no experimental evidence of CPV in charm sector

→ natural next step: search for CPV in charm sector

Why are we interested in charm sector?

Three types of CP violation:

1. **in mixing**: different rates **(indirect)**

$$D^0 \longrightarrow \text{anti-}D^0 \quad \neq \quad \text{anti-}D^0 \longrightarrow D^0$$

2. **in decay amplitudes**: decays of particle and antiparticle are not the same **(direct)**

$$D^0 \longrightarrow f \quad \neq \quad \text{anti-}D^0 \longrightarrow \text{anty-}f$$

3. **in interference** between mixing and direct decay **(indirect)**

$$\begin{tikzcd}
D^0 \arrow[rr, "A"] \arrow[dr, leftrightarrow] & & f = \text{anti-}f \\
& \text{anti-}D^0 \arrow[ur, "\text{anti-}A"'] &
\end{tikzcd}
\qquad
\begin{tikzcd}
\text{anti-}D^0 \arrow[rr, "\text{anti-}A"] \arrow[dr, leftrightarrow] & & f = \text{anti-}f \\
& D^0 \arrow[ur, "A"'] &
\end{tikzcd}$$

- In SM expected CPV in charm sector is small ($\lesssim 10^{-3}$)
  - much smaller than in the beauty sector

→ perfect place for New Physics searching (**small background from SM**)

- Input to b physics
  - many b mesons decay to c particles (b→c) ~50% transitions

Charm particles in LHCb

LHCb was built for b physics:

- for precise measurements of CPV in b decays and their very rare decays

- c particles decays are reconstructed as well
  - measured at LHCb cross-sections at 7 TeV pp:

$$\sigma(b\bar{b}) \sim 0.3\ mb$$

$$\sigma(c\bar{c}) \sim 6\ mb \sim 20 \times \sigma(b\bar{b}) \longleftarrow \boxed{\sim 10\%\text{ of }\sigma_{inel}}$$

Phys.Lett.B694(2010) 209-216 ,   LHCB-CONF-2010-013

- large cross-section → a lot of charm particles produced

- possibilities of very precise measurements of **charm particles as well**

- LHCb is a precision detector
  - **VELO** – resolution of IP: 38 μm for $p_T \approx 1$ GeV
  - **Track reconstruction system –** lifetime resolution ~ 50 fs: 0.1 $\tau(D^0)$
  - **RICH –** very good particle identification for π and K: misidentification < 5%

- Charm physics competes with beauty physics
  → **limited possibilities to save data**

The trigger and charm physics

LHC rate ~15 MHz

c-anti-c ~10%

c-anti-c ~50%

hardware

L0 ~1 MHz
3 subdetectors:
ECAL, HCAL, Muon

After L0 **~500 kHz c-anti-c** events

No possibility of an inclusive charm trigger!

Possible only dedicated exclusive trigger lines tuned for the needs of specific analyses to deliver high signal efficiency and purity

software

Hlt1 (partial reconstruction) **~50 kHz** (efficiency ~50 %)

Hlt2 (full reconstruction) **3 kHz**
2 kHz – b physics
1 kHz – dedicated exclusive lines of **D→hh/3h/4h** (efficiency 50-90%)

example: 5k $D^{*\pm}\rightarrow(D^0\rightarrow K^\pm K^{-+})\pi^\pm$ for 1 pb^{-1} (**2010:** 38 pb^{-1}, **2011:** 1.1 fb^{-1})

Methods of CPV measurements in charm sector

Two types of analysis:

- **time dependent measurements**
  (provide information about CP violation in mixing and in interference)
  [examples: LHCb-PAPER-2011-032, LHCb-CONF-2011-061]
  full list at the end

- **time integrated measurements**
  (provide information about CP violation in decays and in mixing)

Two examples of measurements in LHCb

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

Particle-antiparticle asymmetry

We want to measure asymmetry between charm particles and antiparticles

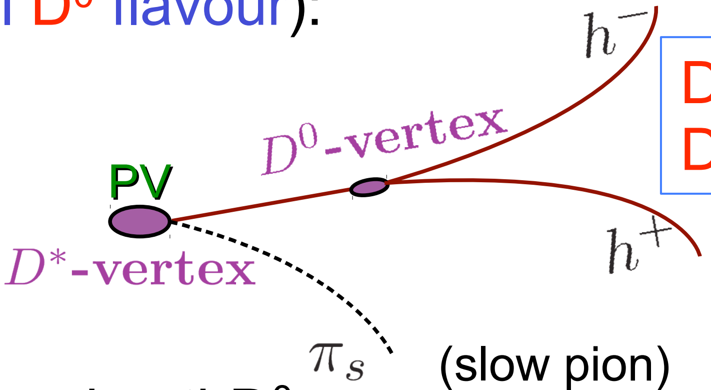
$$A_{CP} \equiv \frac{N_{CP}(D^0 \to h^- h^+) - N_{CP}(\bar{D}^0 \to h^- h^+)}{N_{CP}(D^0 \to h^- h^+) + N_{CP}(\bar{D}^0 \to h^- h^+)}$$

where $h = K, \pi$

- **We have to identify D^0 and anti-D^0**

- We use decays of $D^{*\pm}$
  (the sign of slow pion is used to tag the initial D^0 flavour):

$D^{*+} \to D^0 \pi^+_s$
$D^{*-} \to$ anti-$D^0 \pi^-_s$



(slow pion)

$D^0 \to K^- K^+$
$D^0 \to \pi^- \pi^+$

Measured total asymmetry (RAW) between D^0 and anti-D^0:

$$A_{RAW}(f)^* \equiv \frac{N(D^{*+} \to D^0(f)\pi^+) - N(D^{*-} \to \bar{D}^0(\bar{f})\pi^-)}{N(D^{*+} \to D^0(f)\pi^+) + N(D^{*-} \to \bar{D}^0(\bar{f})\pi^-)}$$

$f = K^- K^+ , \pi^- \pi^+$

What asymmetry we measure at LHCb

Raw asymmetry A_{RAW} is a sum of a few physical asymmetries:

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

CP asymmetry

detector asymmetry of D^0 reconstruction

detector asymmetry of π_s reconstruction

production asymmetry of D* **in primary vertex** (different numbers of D^{*+} and D^{*-})

$$A_{CP}, A_D, A_P \equiv \frac{N_{CP}(D^0) - N_{CP}(\bar{D}^0)}{N_{CP}(D^0) + N_{CP}(\bar{D}^0)}$$

Detector asymmetries for K^-K^+ and $\pi^-\pi^+$ cancel since the final states are symmetric

$$A_D(K^-K^+) = A_D(\pi^-\pi^+) = 0$$

Detector $A_D(\pi_s)$ and production $A_P(D^*)$ asymmetries will cancel if we subtract raw asymmetries A_{RAW} for K^-K^+ and $\pi^-\pi^+$

- for this reason we measure their difference

$$\boxed{\begin{aligned}\Delta A_{CP} &\equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) \\ &= A_{RAW}(K^+K^-)^* - A_{RAW}(\pi^+\pi^-)^*\end{aligned}}$$

Although the first order asymmetry is canceled in ΔA_{CP} we have to check whether there are any unexpected second order effects.

Selection of prompt $D^{*\pm}$ (D^0)

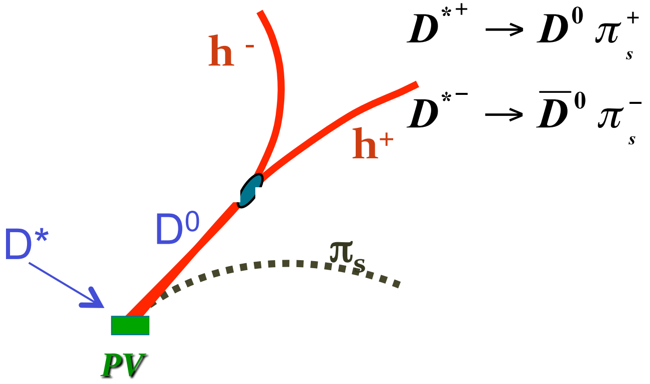
We use $D^{*\pm}$ produced in primary vertex

To separate prompt $D^{*\pm}$ and secondary $D^{*\pm}$ decays we use χ^2(IP) parameter

Two production types of $D^{*\pm}$ (D^0):

- **prompt** – produced in primary vertex (PV)

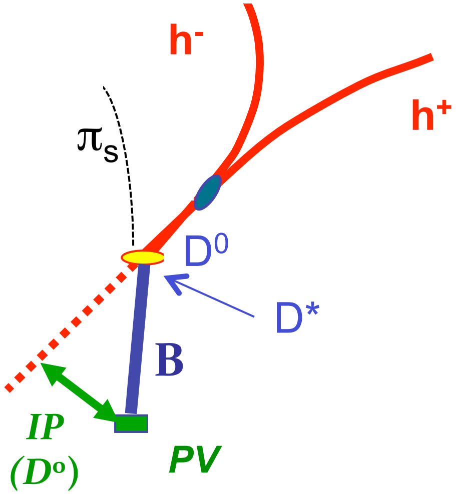
IP(D^0)~0
χ^2(IP)~0



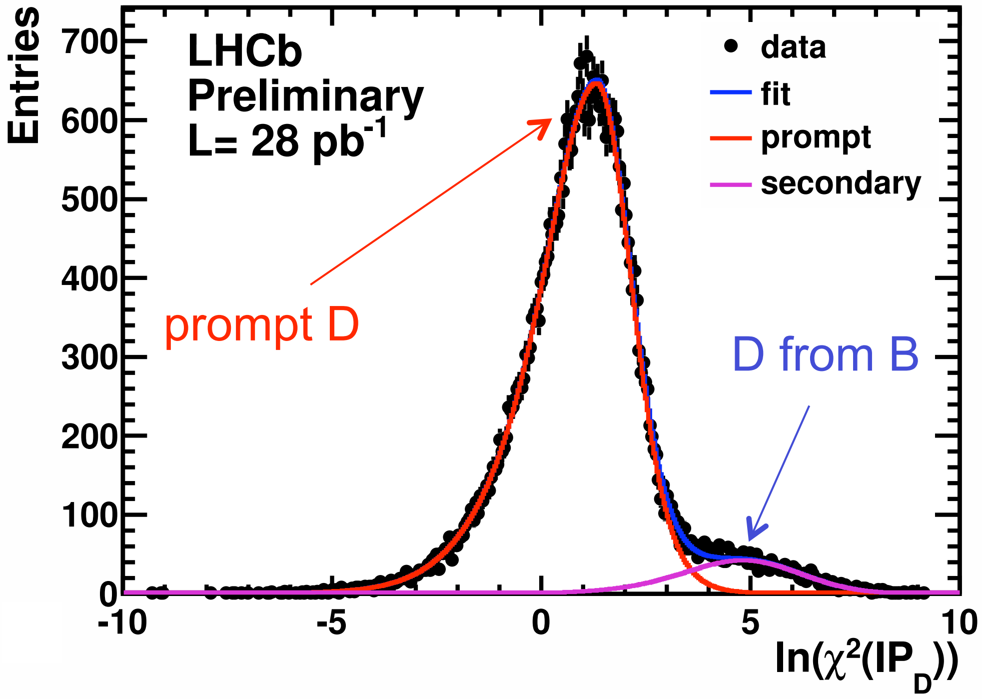
$$D^{*+} \to D^0 \pi_s^+$$
$$D^{*-} \to \overline{D}^0 \pi_s^-$$

- **secondary** – produced in B decays [B(B→$D^{*\pm}$(D)X)]

IP(D^0)>0
χ^2(IP)>0



Example for $D^0 \to K^+K^-$



IP – impact parameter
with respect to the PV

χ^2(IP) – IP significance

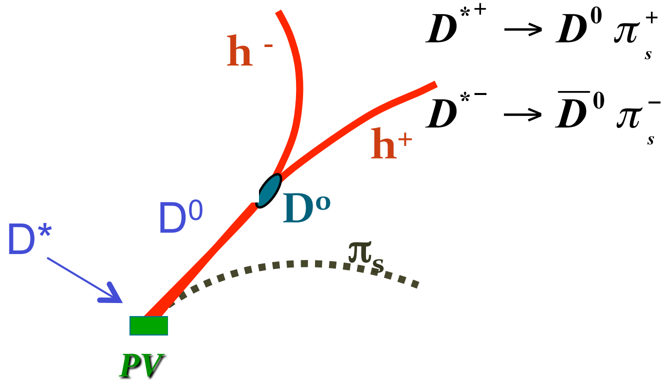
We use χ^2 since it is more effective

Selection criteria

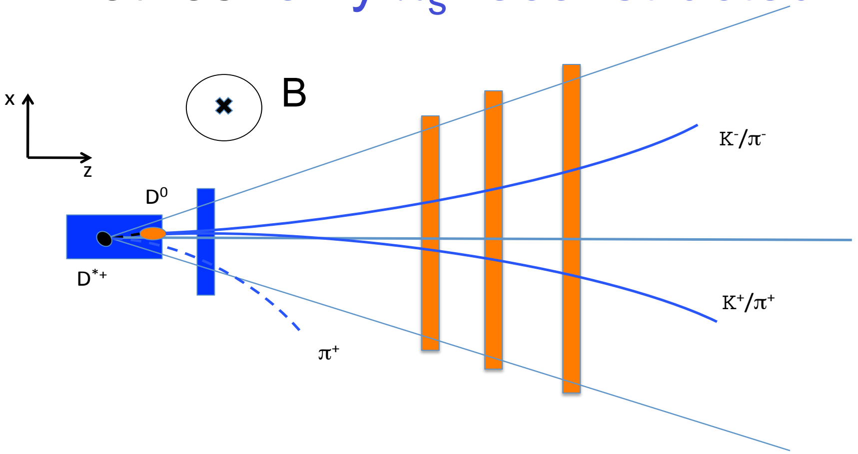
$D^{*+} \rightarrow D^0 \pi^+_s$, $D^{*-} \rightarrow$ anti-$D^0 \pi^-_s$

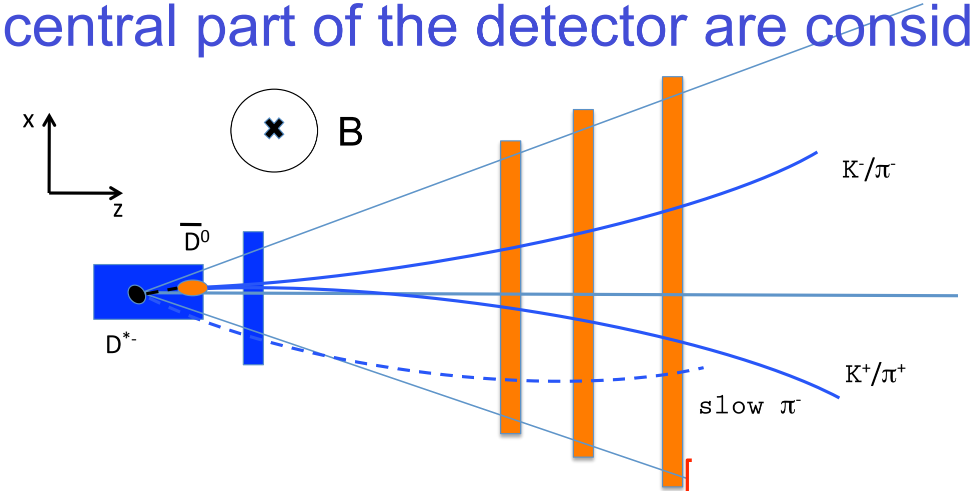
$D^0 \rightarrow K^- K^+$, $D^0 \rightarrow \pi^- \pi^+$

- Impact parameter significance for D^0: $\chi^2\ IP(D^0) < 9$
- Vertex fit quality of D^0 (D^*)
- Track fit quality for all the tracks $K^- K^+ \pi^\pm_s$, $\pi^- \pi^+ \pi^\pm_s$
- Transverse momentum of D^0: $p_T(D^0) > 2$ GeV
- Proper lifetime of D^0: $ct > 100\ \mu m$
- Identification of K and π



- Fiducial cuts to exclude edges where we have large D^{*+}/D^{*-} acceptance asymmetries: only π_s reconstructed in central part of the detector are considered





$D^{*+} \rightarrow D^0 \pi^+$ unreconstructed $D^{*-} \rightarrow$ anti-$D^0 \pi^-_s$ reconstructed

→ large asymmetry between D^{*+} and D^{*-} in edges of acceptance region

- Mass window of D^0: $1844 < m(D^0) < 1884$ MeV

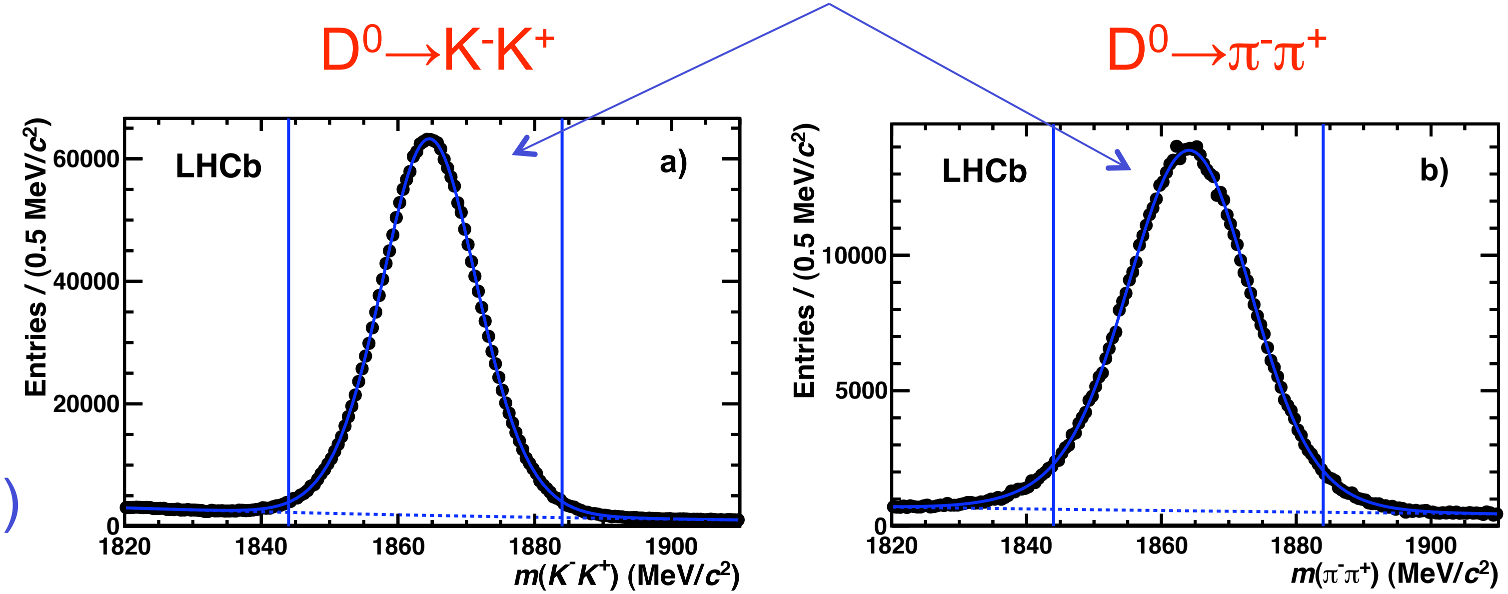
Invariant mass of K^-K^+ and $\pi^-\pi^+$

D^0 decays come from
$D^{*+} \rightarrow D^0\pi^+$ decays
in region:
$0 < \delta m < 15$ MeV

$\delta m = m(D^0\pi^+) - m(D^0) - m(\pi^+)$

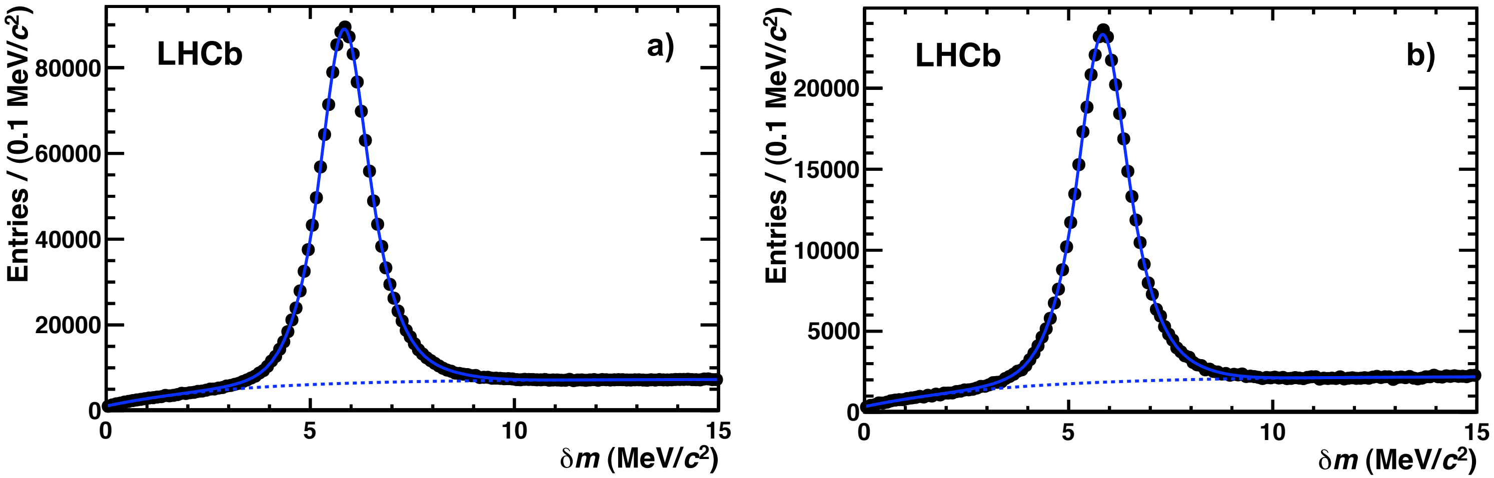
This is NOT a Monte Carlo

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



For window mass:
$1844 < m(D^0) < 1884$ MeV

$1844 < m(D^0 \rightarrow K^-K^+) < 1884$MeV $1844 < m(D^0 \rightarrow \pi^-\pi^+) < 1884$MeV



arXiv:1112.0938

K^-K^+: 1.4million events
$\pi^-\pi^+$: 381k events

$L = 0.62$ fb^{-1} (2011)

From fits to δm we measured $\Delta A_{CP} \equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$

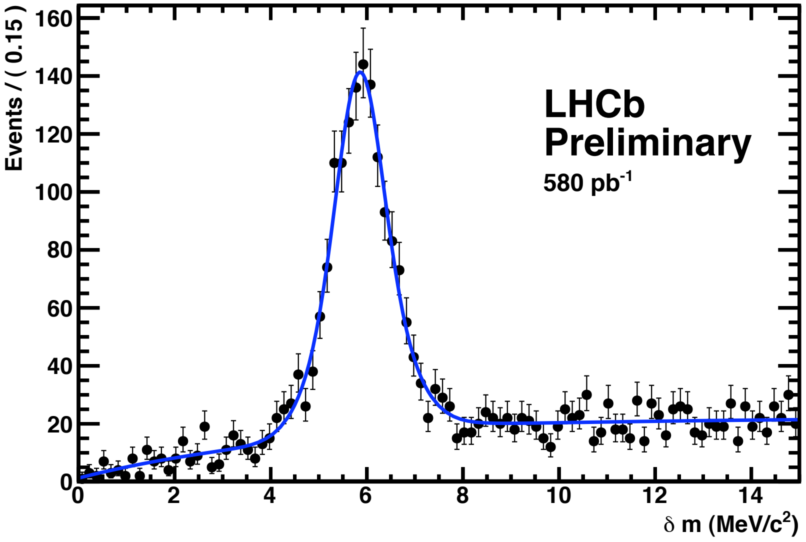
Measurement procedure of ΔA_{CP} at LHCb

- Raw asymmetries $A_{RAW}(K^-K^+)$ and $A_{RAW}(\pi^-\pi^+)$ are obtained from simultaneous fits for both distributions (D^0 and anti-D^0) $\delta m = m(D^0\pi^+) - m(D^0) - m(\pi^+)$ in **216 bins**:
  - 54 kinematic bins of $p_T(D^*), \eta(D^*), p(\pi_s)$
    - production and detector asymmetries can depend on p_T and η
    - reconstruction efficiencies for K^- and K^+ or π^- and π^+ can be different
  - x 2 = 108 bins

    two polarizations of magnetic field
  - x 2 = 216 bins

    two periods of data taking: before and after technical stop: 350 pb^{-1}, 270 pb^{-1}
  - 432 independent fits for $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$

Example: first bin for
$D^0 \to K^-K^+$, MagUp



- **216 values of ΔA_{CP}:**

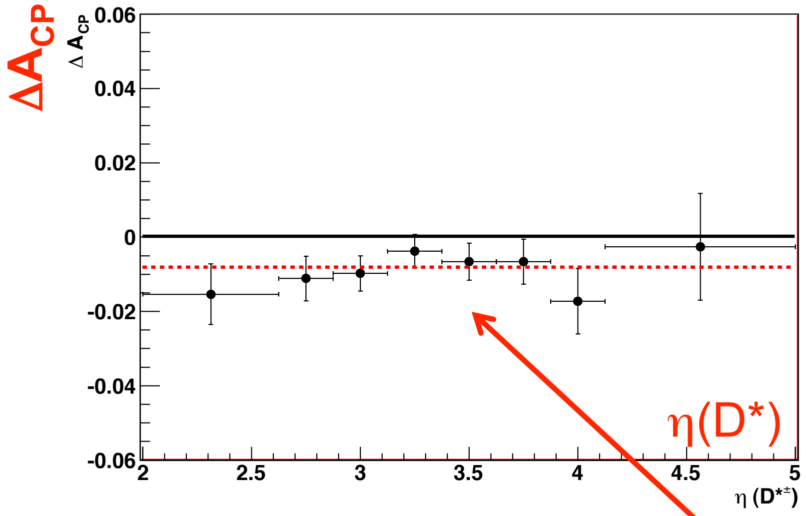
$$\boxed{\begin{aligned}\Delta A_{CP} &\equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)\\ &= A_{RAW}(K^+K^-)^* - A_{RAW}(\pi^+\pi^-)^*\end{aligned}}$$

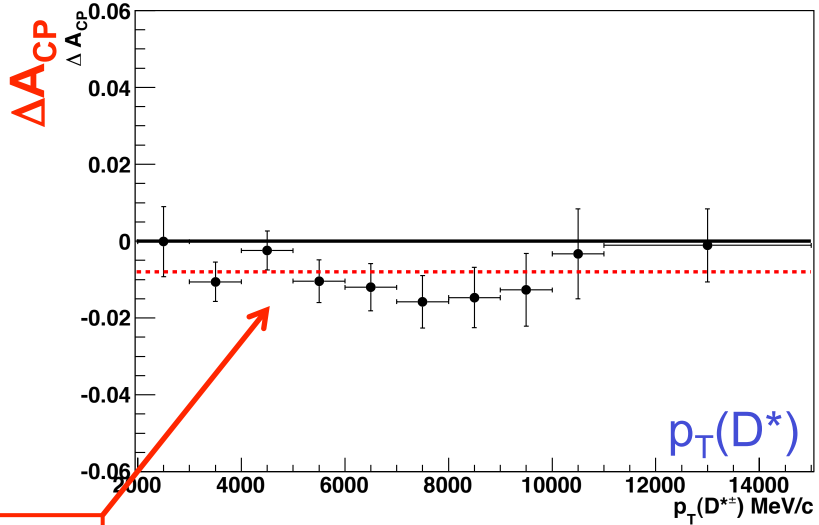
It was checked that measured asymmetries are consistent in all bins →

- Final ΔA_{CP} → weighted average
- **Total statistical uncertainty of ΔA_{CP}:** $\boxed{\mathbf{0.21\%}}$

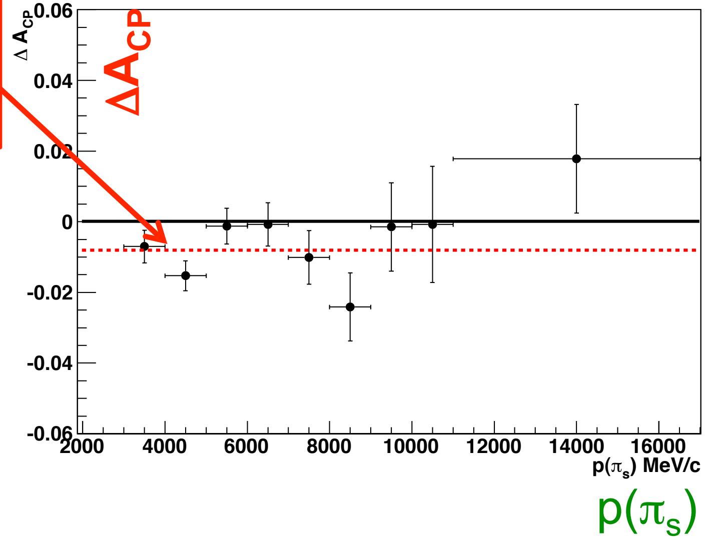
Kinematic variable dependencies

Measured ΔA_{CP} in bins of three variables: $\eta(D^*)$, $p_T(D^*)$ i $p(\pi_s)$





Red line – final result



No dependence of measured ΔA_{CP} on $\eta(D^*)$, $p_T(D^*)$ and $p(\pi_s)$ → checks that possible second order asymmetries are negligible

Systematic uncertainties

Systematic uncertainties which have the highest contribution:

- Fit procedure: **0.08 %**
  - evaluated as a change in ΔA_{CP} between baseline fit and not using any fitting at all (just sideband subtraction in δm for KK and $\pi\pi$ modes)

- Multiple candidates: **0.06 %**
  - evaluated as a mean change in ΔA_{CP} when removing multiple candidates, keeping only one candidate per event chosen at random

- Kinematic binning: **0.02%**
  - evaluated as a change in ΔA_{CP} between full 216-bin kinematic binning and "global" analysis with just one giant bin

Total systematic uncertainty: **0.11%**

Final result (weighted average, LHCb 2011, **0.62 fb^{-1}**):

$$\boxed{\Delta A_{CP} = [-0.82 \pm 0.21^{stat} \pm 0.11^{syst}]\%} \longrightarrow \boxed{\text{FIRST EVIDENCE}}$$

significance: **3.5 σ**

ΔA_{CP} interpretation

CPV asymmetry of each final state is a sum of:

CPV in decays and in mixing

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

Mean proper time in used sample (acceptances are a function of time for K$^-$K$^+$ and $\pi^-\pi^+$ are not the same)

[JHEP 1106 (2011) 089]

Lifetime of D^0 (PDG)

$$\Delta A_{CP} \equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$$

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

Since CPV in mixing is universal and does not depend on a final state, contributions from mixing would cancel in subtraction, but the mean proper time difference of D^0 is not zero in used samples for K$^-$K$^+$ and $\pi^-\pi^+$:

$$\frac{\Delta\langle t \rangle}{\tau} = \frac{\langle t_{KK} \rangle - \langle t_{\pi\pi} \rangle}{\tau} = (9.8 \pm 0.9)\%$$

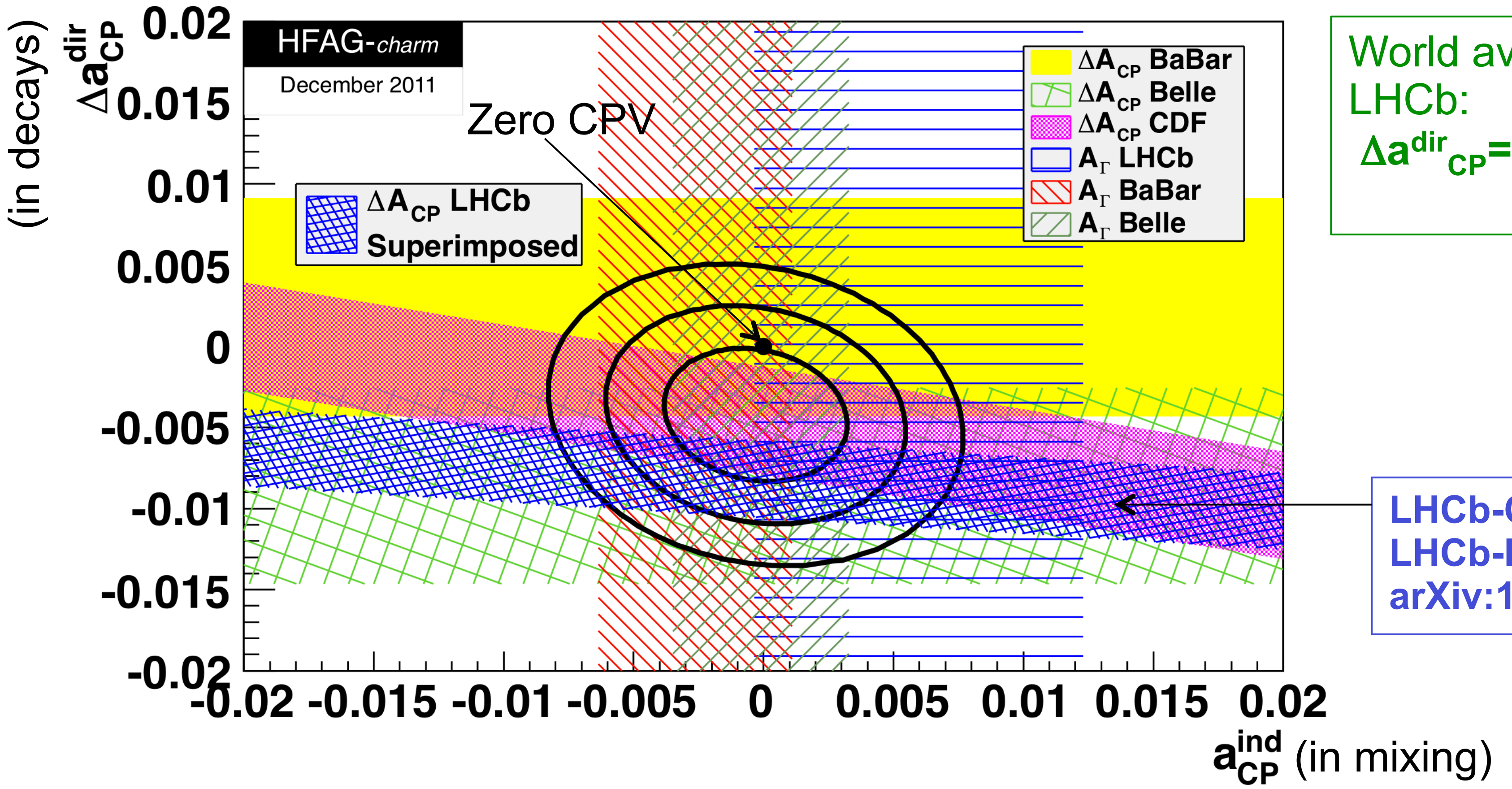
Contributions from CPV in mixing suppressed in one order of magnitude

In good approximation **we measure the difference of CPV in charm decays**

→ good motivation to search CPV in other channels

Comparison with the world average

First evidence for CP violation in charm decays



World average before LHCb:
Δa^{dir}_{CP}= (-0.42 ± 0.27) %
1.6σ from zero

LHCb-CONF-2011-061
LHCb-PAPER-2011-023
arXiv:1112.0938

LHCb 2011, 0.62 fb^{-1}:

$$\boxed{\Delta A_{CP} = [-0.82 \pm 0.21^{stat} \pm 0.11^{syst}]\%}$$

significance: 3.5 σ

LHCb 2011 total 1.1 fb^{-1} (remaining ~500 pb^{-1} is analyzed)

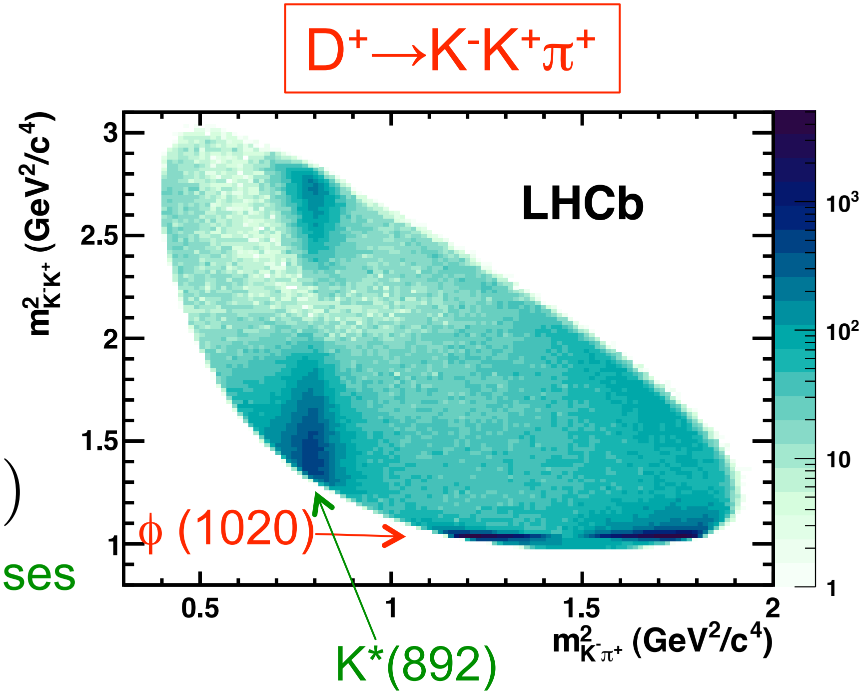
Searches for CP violation in D± → hhh decays

Finding the evidence of CP violation in $D^0 \rightarrow hh$ decays gives hope to find this asymmetry in other decays as well, for example in $D^\pm \rightarrow hhh$

Decays of D → hhh:

- decay products form many resonance states visible in Dalitz plot
- large strong phase differences between resonance states necessary to observe the CP asymmetry

$$Asym_{CP} \sim |A_1||A_2| sin(\underbrace{\phi_1 - \phi_2}_{\text{weak phases}}) sin(\underbrace{\delta_1 - \delta_2}_{\text{strong phases}})$$



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

➡ We hope to observe **the local charge asymmetries**

✧ The charge asymmetry can be measured locally in regions of Dalitz plots

✧ In one region the charge asymmetry can be positive and in another negative.

✧ Local asymmetries can be washed out when integrated over the Dalitz plot.

➡ **To find asymmetries we compare locally Dalitz plots for D^+ and D^-.**

Searches for CP violation in $D^{\pm}$ decays

- For each bin in a region of Dalitz plot we measure **local charge asymmetry**
- Instead of: $\Delta(i) \equiv \frac{N^i(D^+)-N^i(D^-)}{N^i(D^+)+N^i(D^-)}$

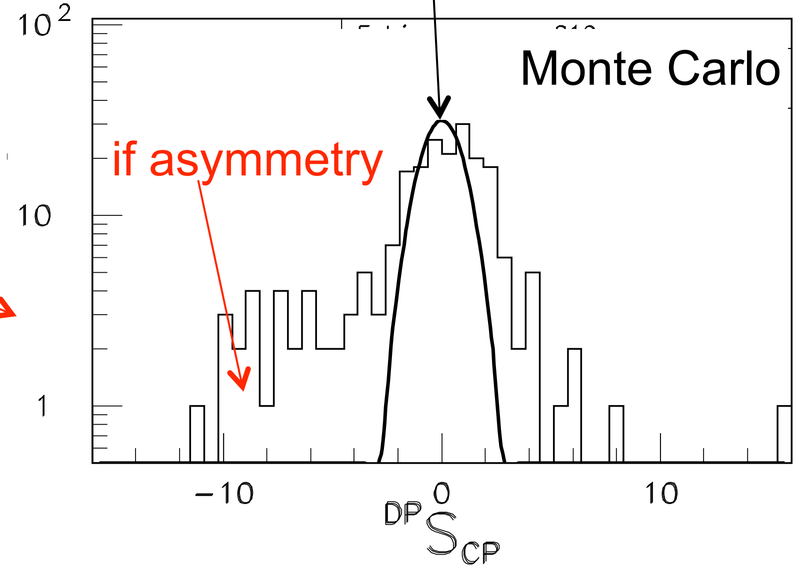
calculate **S_{CP} (Miranda procedure)**:

$$\boxed{S^i_{CP} \equiv \frac{N^i(D^+)-N^i(D^-)}{\sqrt{N^i(D^+)+N^i(D^-)}}}$$

[Bediaga et al. Phys.Rev.D80(2009)096006]

- S_{CP} is a significance of a difference between D^+ and D^-
- For the first time it was used to find local signals in astronomy [Astr. Jour. 272:317, 1983]
- The method does not depend on a model
- In this presentation the method is used for three body decays: $D^+_{(s)} \rightarrow h^-h^+h^+$ (h=K,π)

If no CPV (**only statistical fluctuations**) then **S_{CP} is Gauss distribution (μ=0, σ=1)**



Also χ^2 test can be used: $\chi^2=\Sigma {S^i_{CP}}^2$
→ **p-value –** probability of obtaining value of the test that is equal or greater than the one obtained, assuming that the null hypothesis (no CPV) is true

- **The two methods are equivalent**

Decays of $D^+_{(s)} \to h^-h^+h^+$ (h=K,π)

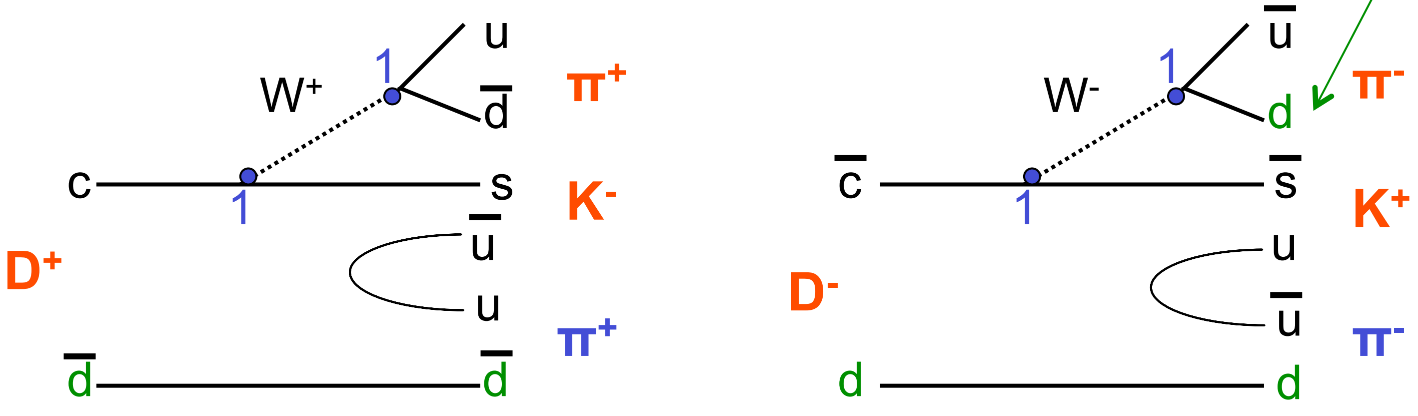
There are three classes of analyzed decays:

- Cabibbo favored (**CF**)
- singly Cabibbo suppressed (**SCS**)
- doubly Cabibbo suppressed (**DCS**)

can be also s quark: 1→ λ (SCS)

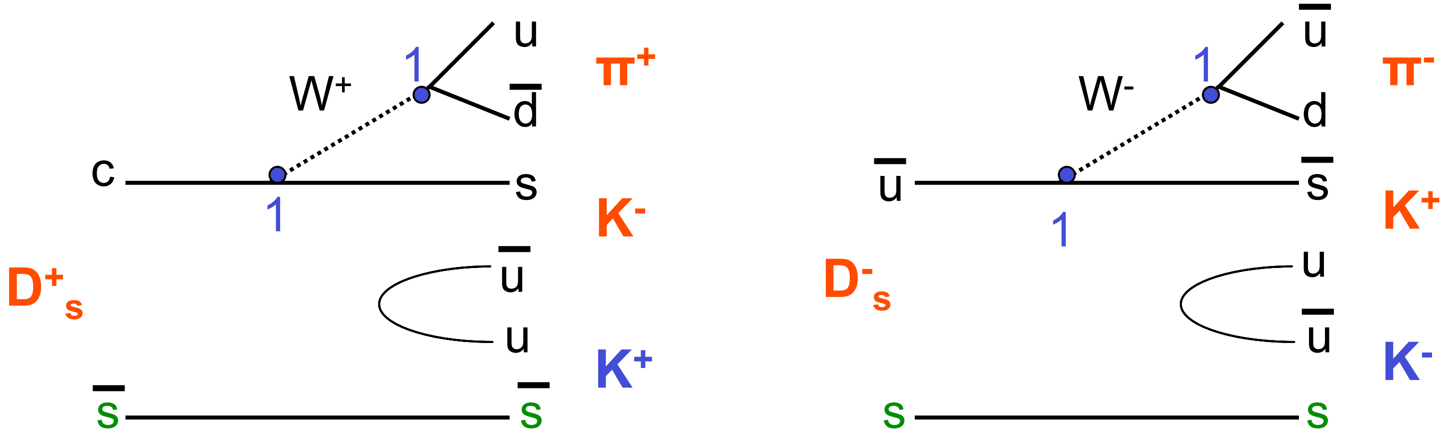
$D^+ \to K^-\pi^+\pi^+$

CF



$D^+_s \to K^-K^+\pi^+$

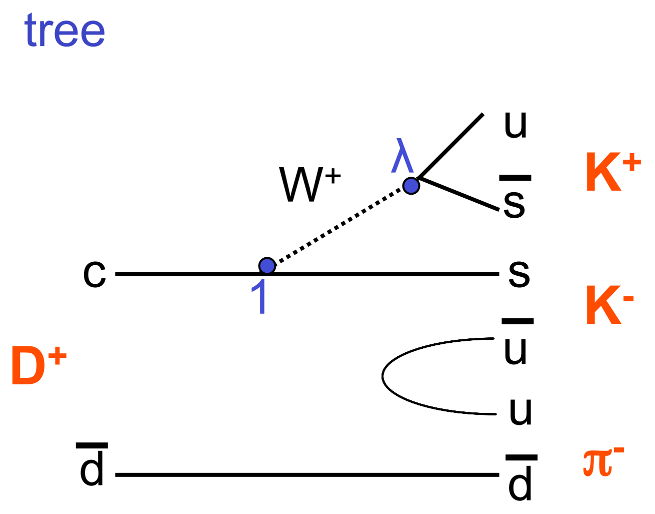
CF

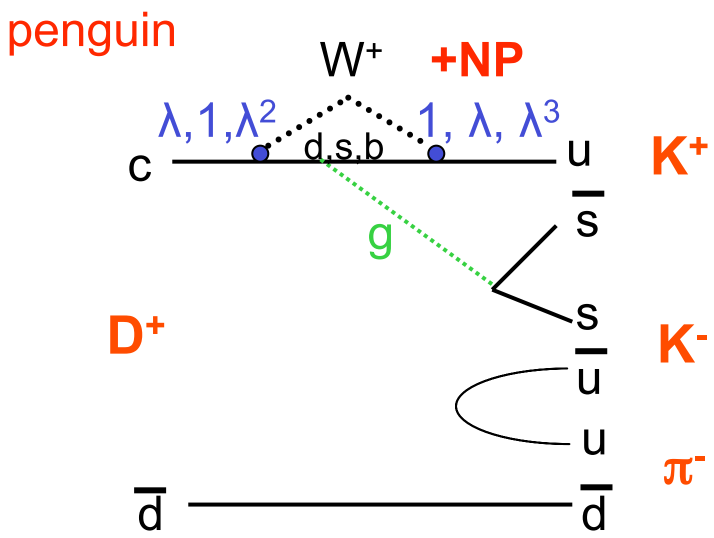


Singly Cabibbo suppressed decays

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

$\lambda = 0.22$


tree


penguin

- SCS decay can be realized also via penguin diagram
- tree and penguin amplitudes can interfere
- **SM** predictions of CPV in the decays **~0.1 %**
- in penguin **loops the new particles** can be exchanged

➡ **Penguin diagrams open possibilities for finding New Physics**

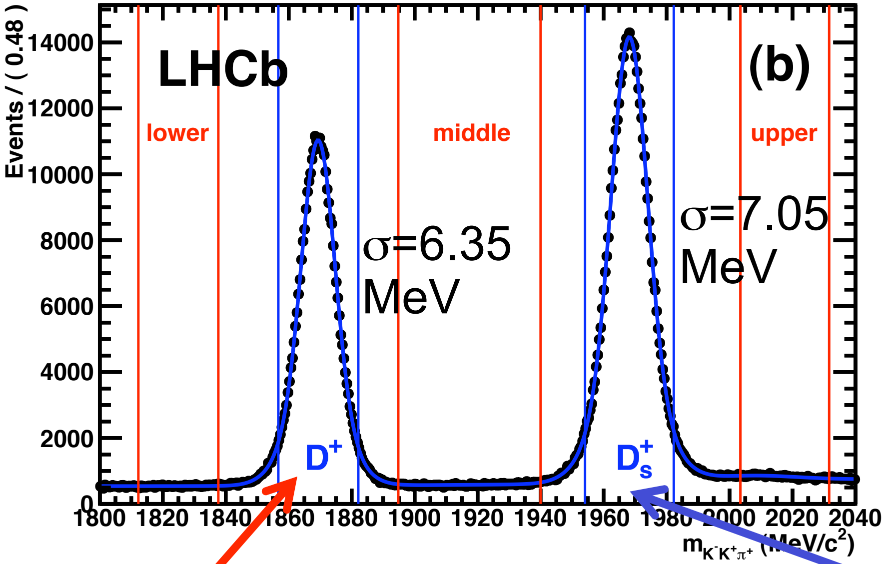
Signal decay (SCS): $D^+ \rightarrow K^- K^+ \pi^+$

Control decays (CF): $D^+_s \rightarrow K^- K^+ \pi^+$, $D^+ \rightarrow K^- \pi^+ \pi^+$

Reconstruction of $D^+_{(s)} \to h^- h^+ h^+$ decays in LHCb

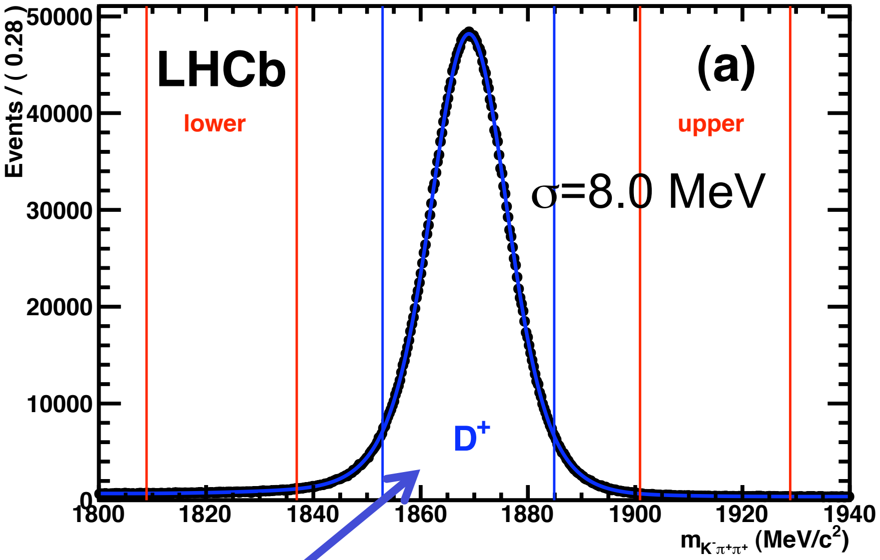
The analysis is based on 2010 dataset of **38 pb^{-1}**

$D^+_{(s)} \to K^- K^+ \pi^+$



$m_{KK\pi}$ (MeV)

$D^+ \to K^- \pi^+ \pi^+$



$m_{K\pi\pi}$ (MeV)

Signal decay (SCS) $D^+ \to K^- K^+ \pi^+$
After background subtraction in window 2σ: **330k events**, purity ~90%

Control decays (CF):
$D^+_s \to K^- K^+ \pi^+$: 460k, purity ~90%
$D^+ \to K^- \pi^+ \pi^+$: 3.4million, purity ~98%

Strategy

The method allows us to see the difference between D^+ and D^-.

Measured asymmetry can come from:

- production asymmetry
- detector asymmetries (for example K^+ and K^- interact in the detector in different ways → different efficiencies in the reconstruction for particle and antiparticle)
- background asymmetry
- CP asymmetry

- The best way is to cancel pollution asymmetries:
  to cancel global asymmetries (example production asymmetry)
  we normalize Dalitz plots for D^+ and D^-, as:

$$S^i_{CP} \equiv \frac{N^i(D^+) - \alpha N^i(D^-)}{\sqrt{N^i(D^+) + \alpha^2 N^i(D^-)}} \qquad \alpha = \frac{N(D^+)}{N(D^-)}$$

- Remaining pollution asymmetries can be **estimated** from comparison of different control decays and sidebands (no CPV expected) with signal decay (CPV expected).

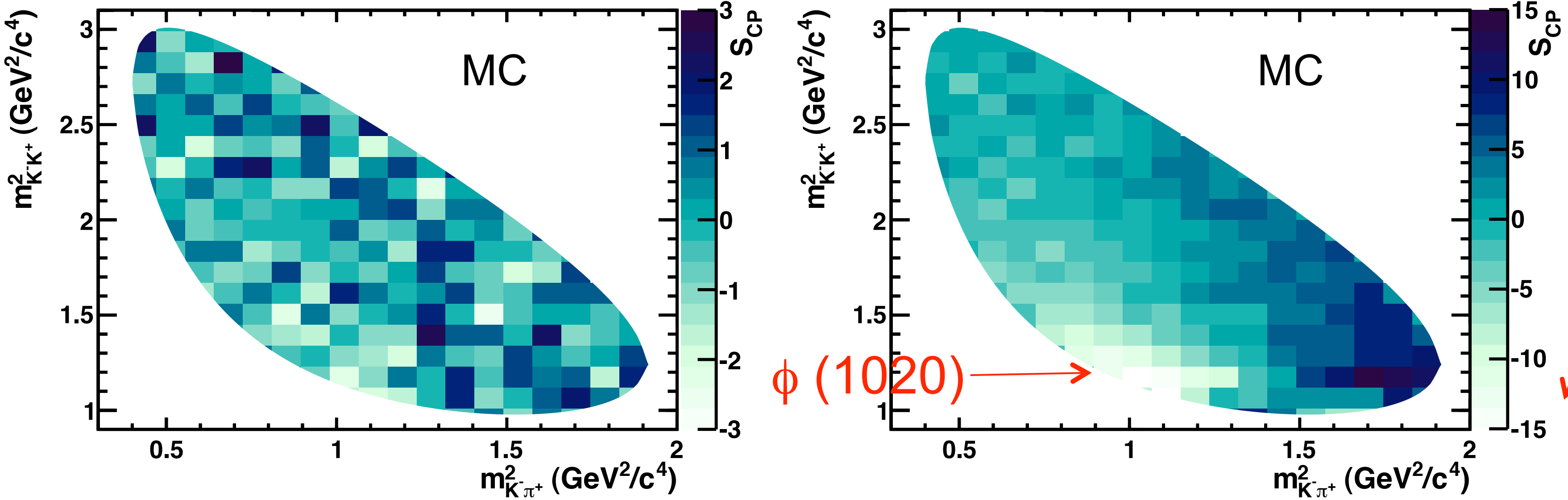
Tests of the method

- **Check the response of the method on Monte Carlo (Dalitz models from CLEO-c, arXiv:0807.4545):**
  - should not generate signal where it is not expected
  - should give a visible signal where it is expected

$D^+ \to K^- K^+ \pi^+$

Sample 50 times bigger than 2010

5×10^7 events with 4^0 weak phase difference between amplitudes for resonance of $\phi(1020)$ from $D^+ \to \phi\pi^+$ a $D^- \to \phi\pi^-$



ϕ (1020)

The same bins

Different scale of S_{CP}

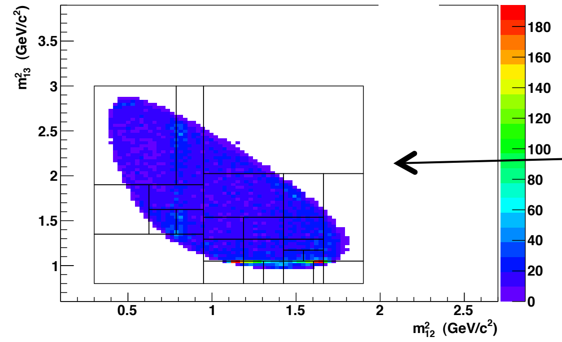
If no CPV then no signal (good)
P-value ~5%
→ no CP asymmetry

If CPV then P-value ~10^{-100}
– there is CP asymmetry
– visible sign change of S_{CP} in ϕ region

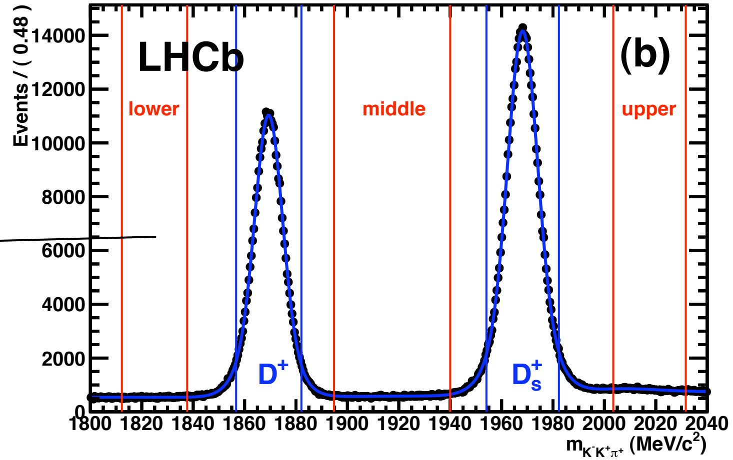
Tests of method

- **For control decays and sidebands asymmetry is not observed**
  - detector, production and background asymmetries are under control

25 bins, different width



Control decay $D^+_s \to K^- K^+ \pi^+$ and sidebands

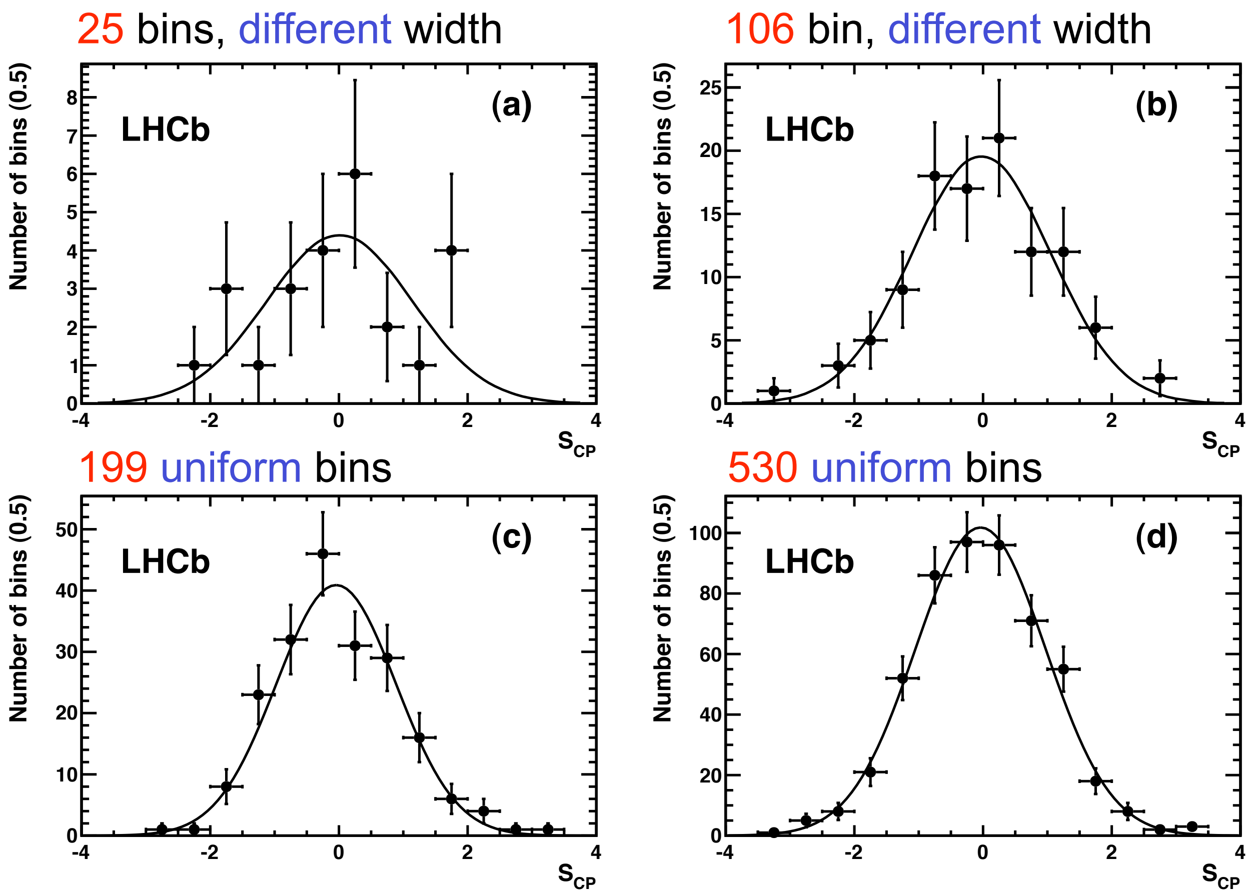


	P-value
Window of D_S	34.4%
Left sideband	8.7%
Middle sideband	50.8%
Right sideband	36.5%

No evidence of CPV in control decay also sidebands around $D^+ \to K^- K^+ \pi^+$ signal look completely fine

Since all checks look OK, the method can be used for the decay where we expect CP violation, for signal $D^+ \to K^- K^+ \pi^+$

Results for $D^+ \rightarrow K^- K^+ \pi^+$ (signal)


25 bins, different width

106 bin, different width

199 uniform bins

530 uniform bins

We have tried various widths and various numbers of bins in the Dalitz plot

- S_{CP} distributions consistent with standard Gauss distribution (μ~0, σ~1)
- P-values are all above 10 %

	μ	σ	χ^2/ndf	P-value
(a)	0.01±0.23	1.13±0.16	32.0/24	12.7%
(b)	-0.024±0.010	1.078±0.074	123.4/105	10.6%
(c)	-0.043±0.073	0.929±0.051	191.3/198	82.1%
(d)	-0.039±0.045	1.011±0.34	519.5/529	60.5%

No evidence for CP violation in the 2010 dataset of 38 pb^{-1}

LHCb-PAPER-2011-017
arXiv:1110.3970

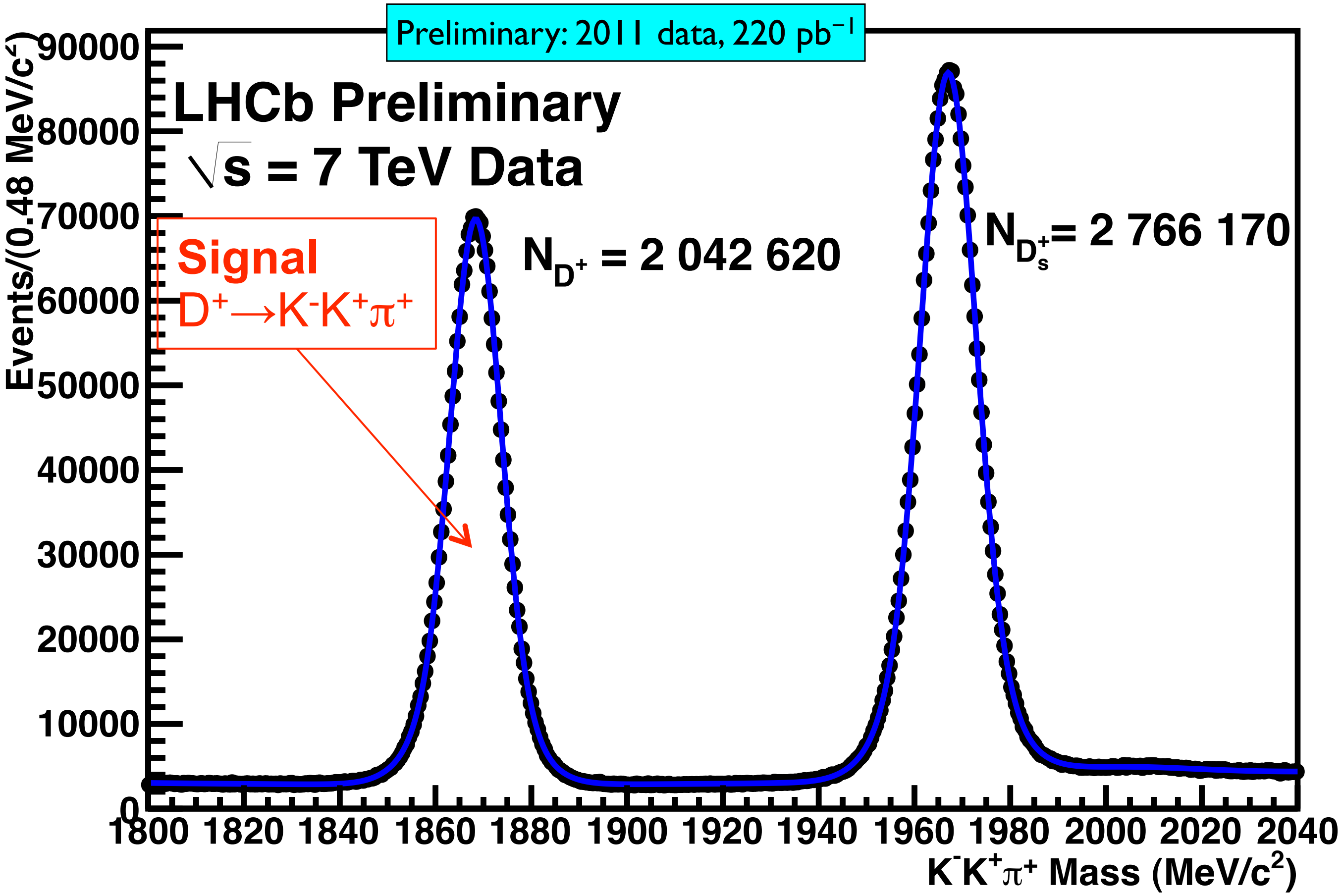
2011 dataset: decays of $D^+ \to K^- K^+ \pi^+$ (signal)

2010: 38 pb^{-1}, 370k events

- no CPV observed

2011: **1.1 fb^{-1} (30 times more events)**

- analysis is continued



Signal
$D^+ \to K^- K^+ \pi^+$

For 220 pb^{-1}:
N(**D**) **~ 2 million**
N($D_{s.}$) ~ 2.8 million
5 times more events than in 2010

For **1.1 fb^{-1}**
Additional 5 times more
N(**D**) **~ 10 million**
N(D_s) ~ 14 million

Summary

- **At LHCb the difference of CP violation in charm sector has been observed** for decays $D^0 \to K^- K^+$ and $D^0 \to \pi^- \pi^+$ for 2011 dataset of $L = 0.62\ fb^{-1}$ (LHCb-CONF-2011-061, LHCb-PAPER-2011-023, arXiv:1112.0938)

$$\boxed{\Delta A_{CP} = [-0.82 \pm 0.21^{stat} \pm 0.11^{syst}]\%}$$

Significance 3.5σ

  - ✧ First evidence of CP violation in charm decays
  - ✧ Contribution from CP violation in mixing is suppressed in one order of magnitude

- **No evidence for CP violation in decays of $D^+ \to K^- K^+ \pi^+$** in the 2010 dataset of $L = 38\ pb^{-1}$ (LHCb-PAPER-2011-017, arXiv:1110.3970)
  - ✧ 2011 dataset of $1.1\ fb^{-1}$ is analyzed

Other LHCb charm results

Published papers:

- Search for CP violation in decays
  LHCB-PAPER-2011-017, arXiv:1110.3970, submitted to Phys.Rev.D
- Evidence for CP violation in time-integrated $D^0 \to h^- h^+$ decay rates
  LHCB-PAPER-2011-023, arXiv:1112.0938, submitted to Phys.Rev.Lett.

- Measurement of mixing and CP violation parameters in two-body charm decays
  LHCB-PAPER-2011-032, arXiv:1112.4698, submitted to JHEP
  Time dependent measurements, based on 2010 data, 29 pb^{-1}

1. Ratio of lifetimes in D^0 decays to the CP eigenstate f_{CP} ($D^0 \to K^+K^-$) with respect to decays to the CP non-eigenstate $f_{non\text{-}CP}$ ($D^0 \to K^-\pi^+$):

$$y_{CP} \equiv \frac{\Gamma(D^0 \to f_{CP})}{\Gamma(D^0 \to f_{non-CP})} - 1 = \frac{\Gamma(D^0 \to K^+K^-)}{\Gamma(D^0 \to K^-\pi^+)} - 1$$

$$y_{CP} = (5.5 \pm 6.3^{\text{stat}} \pm 4.1^{\text{syst}}) \times 10^{-3}$$

2. Asymmetry of lifetimes in decays of D^0 and anti-D^0 to the CP eigenstate K^+K^-:

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

$$A_\Gamma = (-5.9 \pm 5.9^{\text{stat}} \pm 2.1^{\text{syst}}) \times 10^{-3}$$

Both results on y_{CP} and A_Γ are in agreement with the current world averages.
No evidence for indirect CP violation in charm sector has been observed.

Other LHCb charm results

Published papers:

- Search for CP violation in decays
  LHCB-PAPER-2011-017, arXiv:1110.3970, submitted to Phys.Rev.D
- Evidence for CP violation in time-integrated $D^0 \rightarrow h^- h^+$ decay rates
  LHCB-PAPER-2011-023, arXiv:1112.0938, submitted to Phys.Rev.Lett.
- Measurement of mixing and CP violation parameters in two-body charm decays
  LHCB-PAPER-2011-032, arXiv:1112.4698, submitted to JHEP

Conference notes:

2011

- A search for time-integrated CP violation in $D^0 \rightarrow h^- h^+$ decays
  LHCB-CONF-2011-061
- Measurement of the Charm Mixing Parameter y_{CP} in Two-Body Charm Decays
  LHCB-CONF-2011-054
- Measurement of the CP Violation Parameter A_Γ in Two-Body Charm Decays
  LHCB-CONF-2011-046
- A search for time-integrated CP violation in $D \rightarrow hh$ decays and a measurement of the D^0 production asymmetry
  LHCB-CONF-2011-023
- Time integrated ratio of wrong-sign to right-sign $D^0 \rightarrow K\pi$ decays in 2010 data at LHCb
  LHCB-CONF-2011-029

2010

- Prompt charm production in collisions at $\sqrt{s} = 7$ TeV
  LHCB-CONF-2010-013

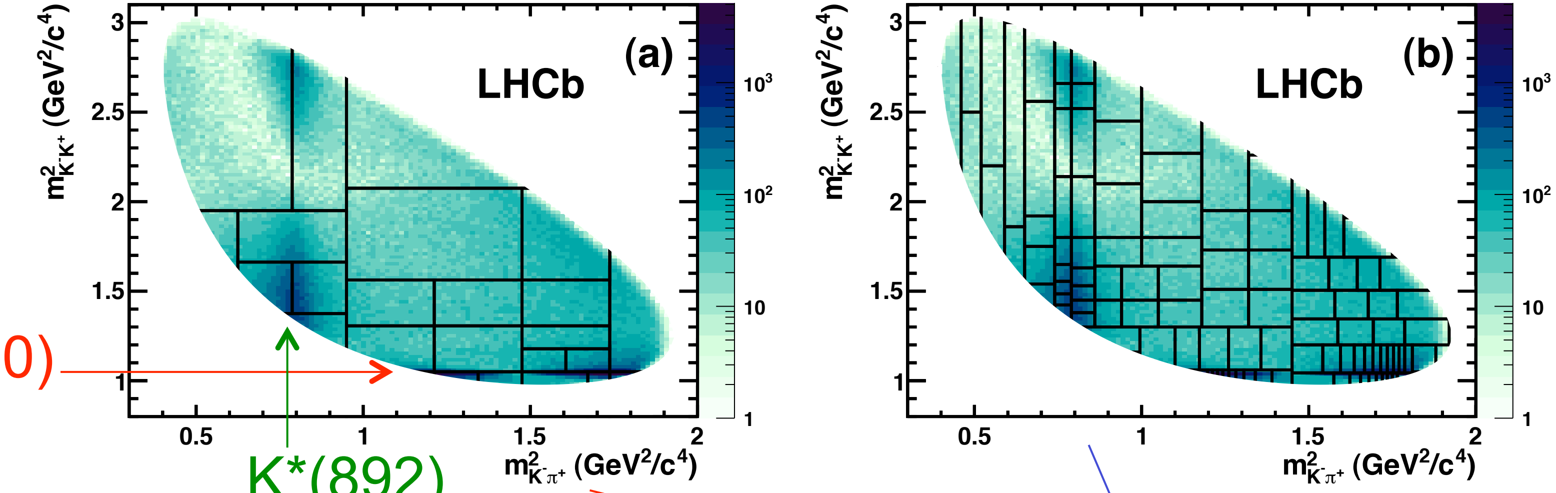
Backup

Number of bins test

Bins with different widths

Signal $D^+ \to K^- K^+ \pi^+$

Monte Carlo



25 bins

108 bins

φ (1020)

K*(892)

	P(3σ)	**P(3σ)**
No CPV	0%	1%
6^0 weak phase difference in φ(1020)	99%	98%
4^0 weak phase difference in φ(1020)	76%	41%

Version with 25 bins is better

100 the same experiments and check how many times obtained 3σ

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{\mathrm{ud}} & V_{\mathrm{us}} & V_{\mathrm{ub}} \\ V_{\mathrm{cd}} & V_{\mathrm{cs}} & V_{\mathrm{cb}} \\ V_{\mathrm{td}} & V_{\mathrm{ts}} & V_{\mathrm{tb}} \end{pmatrix} = \begin{pmatrix} 1 & \lambda & \lambda^3 \\ -\lambda & 1 & \lambda^2 \\ -\lambda^3 & -\lambda^2 & 1 \end{pmatrix}$$