CP Violation in Charm at LHCb

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Outline

1. CP Violation

1.1. CP Violation - general

Why CP Violation is so important?

Carla Göbel

CP violation is an essential aspect for understanding the Universe

⋆ Big Bang(14M years ago): matter and antimatter produced equally

⋆ Today: structures in the universe are made of matter
- no antimatter as primary cosmic rays
- no evidence for antigalaxies

⋆ Matter-antimatter asymmetry: $n_{\text{barions}}/n_\gamma \sim 10^{-9}$

⋆ Sakharov Conditions (67)

1. baryon number violation
2. C and CP violation
3. departure from thermal equilibrium

⋆ In the Standard Model (SM), $\not{CP}$ comes from the flavor mixture matrices (quarks & leptons)

⋆ but it is not enough ...

History: CP violation in the neutral Kaon system ...

- K^0 & $\overline{K^0}$ are produced via the strong interaction

$$\pi^- p \to K^0 \Lambda^0$$
$$\pi^- p \to \overline{K}^0 K^0 p$$

but they are unstable and decay through weak interaction

- Two states are observed
  - $K_L^0 \Rightarrow \tau(K_L^0) = 0.5 \times 10^{-7} s$
  - $K_S^0 \Rightarrow \tau(K_S^0) = 0.9 \times 10^{-10} s$

decaying as: $K_L^0 \to \pi^+\pi^-\pi^0$ and $K_S^0 \to \pi^+\pi^-$

- opposite parities: $P(\pi^+\pi^-\pi^0) = -1$ and $P(\pi^+\pi^-) = +1$

evidence for PARITY violation in weak decays

The neutral kaon system

- Although violating P and C separately, it was believed that weak decays conserve CP

- K^0 and $\overline{K}^0$ are not CP eigenstates

$$CP|K^0\rangle = -C|K^0\rangle = -|\overline{K}^0\rangle$$
$$CP|\overline{K}^0\rangle = -C|\overline{K}^0\rangle = -|K^0\rangle$$

while

$$|K_1^0\rangle \equiv \frac{1}{\sqrt{2}}\left(|K^0\rangle - |\overline{K}^0\rangle\right) \quad \Rightarrow \quad CP|K_1^0\rangle = +|K_1^0\rangle$$
$$|K_1^0\rangle \equiv \frac{1}{\sqrt{2}}\left(|K^0\rangle + |\overline{K}^0\rangle\right) \quad \Rightarrow \quad CP|K_2^0\rangle = -|K_2^0\rangle$$

- it was natural to associate

$$K_1^0 \leftrightarrow K_S^0 \qquad K_S^0 \to \pi\pi \qquad CP = +1$$
$$K_2^0 \leftrightarrow K_L^0 \qquad K_L^0 \to \pi\pi\pi \qquad CP = -1$$

not quite exact ...

The neutral kaon system

- in 64, it was observed that K_L also decays to $\pi\pi$

$$\mathrm{BR}(K_L^0 \to \pi^- \pi^+) \sim 10^{-3}$$

- K_L^0 and K_S^0 are *almost* CP eigenstates

$$K_S^0 = \frac{|K_1^0\rangle + \epsilon|K_2^0\rangle}{\sqrt{1+|\epsilon|^2}} \quad K_L^0 = \frac{|K_2^0\rangle + \epsilon|K_1^0\rangle}{\sqrt{1+|\epsilon|^2}}$$

with $|\epsilon| \sim 3 \times 10^{-3}$

CP is violated by the weak interaction

- Besides:

$$\mathrm{BR}(K_L^0 \to \pi^+ e^- \bar{\nu}_e) \propto |\langle \bar{K}^0|K_L^0\rangle|^2 \propto |1-\epsilon|^2$$
$$\mathrm{BR}(K_L^0 \to \pi^- e^+ \nu_e) \propto |\langle K^0|K_L^0\rangle|^2 \propto |1+\epsilon|^2$$

($K_L^0 \to \pi^- e^+ \nu_e$ 0.7% more likely than $K_L^0 \to \pi^+ e^- \bar{\nu}_e$)

$\Rightarrow$ we can unumbiguously say that the *electron* is the one produced least often in the decays of K_L

an absolute distinction between matter and antimatter

How to search for CP violation

- $\not{C}P$ occurs when $\Gamma(M \to f) \neq \Gamma(\bar{M} \to \bar{f})$
  Let two different processes leading to the same final state $\mathcal{A}(M \to f) = \mathcal{A}_1 + \mathcal{A}_2$

  $$\Gamma(M \to f) \propto |\mathcal{A}_1|^2 + |\mathcal{A}_2|^2 + 2\Re(\mathcal{A}_1 \mathcal{A}_2^*)$$

  $$\Gamma(\bar{M} \to \bar{f}) \propto |\bar{\mathcal{A}}_1|^2 + |\bar{\mathcal{A}}_2|^2 + 2\Re(\bar{\mathcal{A}}_1 \bar{\mathcal{A}}_2^*)$$

  but $|\mathcal{A}_k| = |\bar{\mathcal{A}}_k|$ (at least in the SM), thus $\not{C}P$ occurs for $\Re(\mathcal{A}_1 \mathcal{A}_2^*) \neq \Re(\bar{\mathcal{A}}_1 \bar{\mathcal{A}}_2^*)$
- particular cases:
  - $\not{C}P$ induced through mixing
    weak phase appears in the mixing diagrams $P^0 \rightleftharpoons \bar{P}^0$
  - interference between mixing and decay
    when $P^0 \to f$ interferes with $P^0 \to \bar{P}^0 \to f$
  - direct $\not{C}P$ by interfering decay amplitudes
    different weak phase between two decay paths

1.2. $\not{C}P$ & the CKM matrix

CP Violation & the CKM Matrix

$\not{CP}$ in the hadronic sector comes from the complex nature of the Cabibbo-Kobayashi-Maskawa Matrix

1973:
Kobayashi & Maskawa suggest the theoretical mechanism for $\not{CP}$ by introducing a 3th quark family

M. Kobayashi and T. Maskawa, *Prog. Theor. Phys.* **49**, 652 (1973).

2001:
$\not{CP}$ is observed in the b sector (BaBar e Belle)

B. Aubert *et al. (BaBar Collab.), Phys. Rev. Lett.* **87**, 091801 (2001).
K. Abe *et al. (Belle Collab.), Phys. Rev. Lett.* **87**, *091802* (2001).

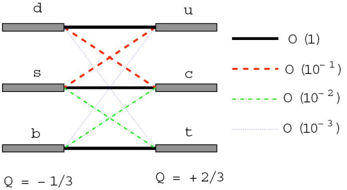
CP Violation & the CKM Matrix

♣ The CKM mixing matrix:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

orthogonal + unitary $\Rightarrow$ 3 real parameters + 1 phase

♣ There is a hierarchy on the elements: transitions within family predominate



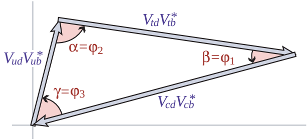
$$|V_{\mathrm{CKM}}| = \begin{pmatrix} 0.974 & 0.227 & 0.004 \\ 0.227 & 0.973 & 0.042 \\ 0.008 & 0.042 & 0.999 \end{pmatrix}$$

CP Violation & the CKM Matrix

- A convenient parametrization (Wolfenstein)

$$V = \begin{pmatrix} 1-\lambda^2/2-\lambda^4/8 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2-\lambda^4/8(1+4A^2) & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2+A\lambda^4/2(1-2(\rho+i\eta)) & 1+A^2\lambda^4/2 \end{pmatrix}$$

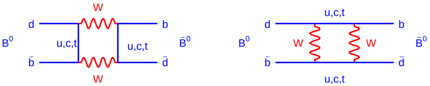
- unitarity+orthogonality:
  $\sum_i V_{ij} V^*_{ik} = \delta_{jk} \quad \sum_j V_{ij} V^*_{kj} = \delta_{jk}$
- 6 triangles in a complex plane
- experimental tests more sensitive for triangles with sides of the same order $\Rightarrow$ transitions involving b quark

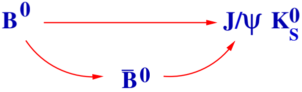


$\Rightarrow$ B meson processes provide sizeable $\not{C}\!P$ signs

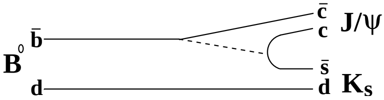
The Golden Plate Mode: $B_d \to J/\psi K_S$

- $C\not{P}$ through $B^0 - \bar{B}^0$ mixing and decay:





- main decay diagram:



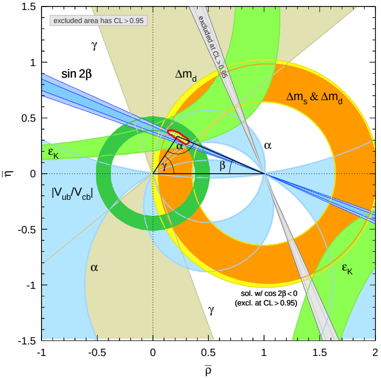
$\propto \; V_{cb}^{*} V_{cs}$

$$\mathcal{M} \propto \frac{V_{tb}^{*} V_{td} V_{td} V_{tb}^{*}}{\left| V_{tb}^{*} V_{td} \right|^2} = e^{-2i\beta}$$

- time dependent asymmetry measurement:

$\sin 2\beta = 0.676 \pm 0.020$ (HFAG average)

The Success of the CKM mechanism: restrictions in the $\rho\eta$ plane



- more than 40 years between $\not{C}\!P$ in kaons and in B's
- no $\not{C}\!P$ in charm observed yet (discussed next)
- so far in good agreement with the SM scenario
- ... but a common belief that SM is not the ultimate answer to $\not{C}\!P$

- New Physics introduces new particles, dynamics and symmetries at $\Lambda \sim$ TeV
- $\not{C}\!P$ from New Physics can appear at any moment now !?!

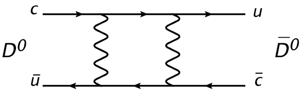
2. $\not{C}P$ in Charm

2.1. Why study CP violation in charm?

Why study CP violation in charm?

★ Mixing and CPV

- $\not{C}P$ and mixing well established in K and B systems
- charm system is the only up-quark sector which can exhibit these phenomena
  $\rightarrow \pi^0$ is its own antiparticle and top does not hadronize....
- mixing in $D^0 - \bar{D}^0$ now verified with $\sim 10\sigma$
  (no single 5σ though)



mass eigenstates:

$$|D_1\rangle = p|D^0\rangle + q|\bar{D}^0\rangle$$
$$|D_2\rangle = p|D^0\rangle - q|\bar{D}^0\rangle$$

$$m = \frac{m_1+m_2}{2}, \quad \Gamma = \frac{\Gamma_1+\Gamma_2}{2}$$

$$\boxed{x = \frac{\Delta m}{\Gamma}} \quad \boxed{y = \frac{\Delta\Gamma}{2\Gamma}}$$

- Indirect $\not{C}P$ arising through $D^0 - \bar{D}^0$ mixing estimated to be $\mathcal{O}(10^{-4})$ in the SM
  but up to $\mathcal{O}(10^{-2})$ in NP

Y. Grossman, A. L. Kagan, and Y. Nir, Phys. Rev. D 75, 036008 (2007)

Why study CP violation in charm?

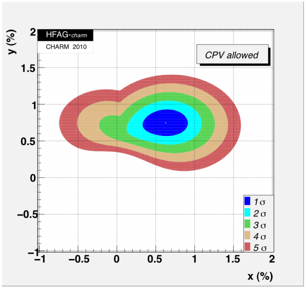
some mixing observables sensitive to $C\!\!\!/P$

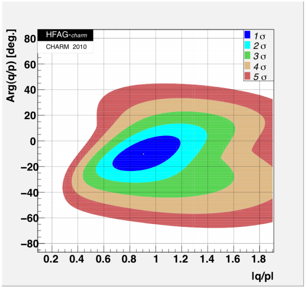
$$2y_{CP} = (|q/p| + |p/q|)\, y\cos\phi - (|q/p| - |p/q|)\, x\sin\phi$$
$$2A_\Gamma = (|q/p| - |p/q|)\, y\cos\phi - (|q/p| + |p/q|)\, x\sin\phi$$

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

In the absence of $C\!\!\!/P$: $|q/p| = 1,\ \phi = 0,$
$y_{CP} = y,\ A_\Gamma = 0$

otherwise manifestation of $C\!\!\!/P$!!

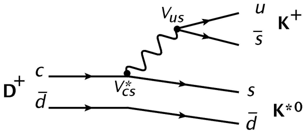


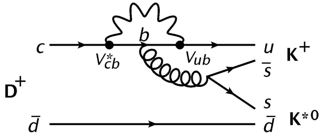


Why study CP violation in charm?

★ Direct C$\not{P}$

- in the SM, appears in single-Cabibbo suppressed channels:





penguin diagram has $\mathcal{I}m(\mathcal{A}) \propto \lambda^5$ in the SM

$\Rightarrow$ asymmetries $\mathcal{O}(10^{-4} - 10^{-3})$

NP can enhance to $\mathcal{O}(10^{-3} - 10^{-2})$

In summary:

charm represents a unique sector for searches of C$\not{P}$ (both direct and through mixing)

clear windows for NP due to the low SM predictions

2.2. Approaches to search for $\not{C}\not{P}$ in charm

Approaches to search for $\not{C}\not{P}$ in charm

There are two main lines to search for $C\not{P}$ in charm decays:

♣ Time Dependent Measurements in $D^0 - \bar{D}^0$ system

- rely on studying the decay rate as a function of the propertime
- important to "tag" the flavor of the D produced

usually done with the chain $D^{*+} \to D^0\pi^+$ and $D^{*-} \to D^0\pi^-$

- Some examples:

  - decays to CP final states: h^+h^- $(h = K, \pi)$

    ⋆ lifetime ratio of single-Cabibbo suppressed wrt Cabibbo-favored probes y_{CP}

    ⋆ lifetime asymmetry for D^0 and $\bar{D}^0$ provides A_Γ

  - Interference between $D^0 \to K^+\pi^-$ ("wrong sign" - WS) and $D^0 \to \bar{D}^0 \to K^+\pi^-$ ("right sign" - RS)

    get the time dependent ratio of WS(t)/RS(t)

Approaches to search for $\not{C}\!P$ in charm

♣ Time Integrated Measurements, both neutral and charged D's

- compare "populations" for particle and antiparticle, in different ways
- Some examples:

  - Single-Cabibbo (SC) 2-body decays $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$

    ⋆ search for CP asymmetry in the integrated rates

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

    by comparing total yields

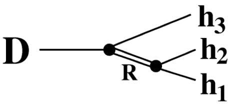
  - SC 3-body decays $D^+ \to K^+K^-\pi^+$, $D^+ \to \pi^-\pi^+\pi^+$

    look for localized $\not{C}\!P$ signs in the reaction phase space

⇒ discussing this last topic ....
important for results shown later

CP Violation through 3-body decays

- in 3-body decays, resonances are produced very often together with the weak process



ex.: $D^+ \rightarrow \phi\, \pi^+$, $\phi \rightarrow K^- K^+$

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

Only the final state is observed:

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

- to understand the dynamics of the decay (including resonant substructures) $\Rightarrow$ need to study the phase space of the reaction: "Dalitz Plot"

Invariants:

$s_{12} \equiv m_{12}^2 = (p_1 + p_2)^2$

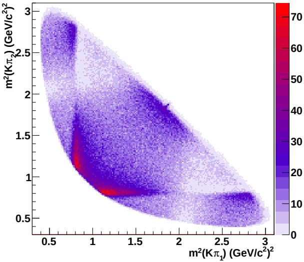
$s_{13} \equiv m_{13}^2 = (p_1 + p_3)^2$

$s_{23} \equiv m_{23}^2 = (p_2 + p_3)^2$

kinematical constraint:

$m_D^2 = s_{12} + s_{13} + s_{23} - \Sigma m_i^2$

$$\frac{d\Gamma}{ds_{12}\, ds_{13}} = \frac{1}{(2\pi)^3 32 M^3} \, |\mathcal{A}|^2$$



CP violation through the Dalitz plot

For direct $\not{CP}$ studies: mainly two approaches

- ♣ Amplitude Analysis for particle and antiparticle
  - the total decay amplitude for a 3-body process written as a coherent sum of quasi two-body modes
    $$\mathcal{A} = a_{nr}\, e^{i\delta_{nr}} + \sum_j a_j\, e^{i\delta_j}\, \mathcal{A}_j$$
    - $\mathcal{A}_j$ are model dependent (phenomenological amplitudes)
    - the phases δ_j accomodate both weak and strong phases
  - fit for particle and antiparticle separately, compare results
- ♣ Compare the Dalitz plots in a model independent way
  - divide the Dalitz surface in "bins" for particle and antiparticle
  - compare the population

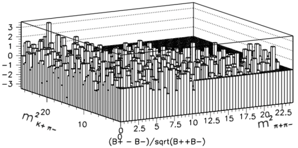
Comparing Dalitz Plot surfaces - *Mirandizing*

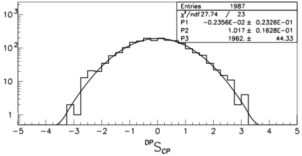
I. Bediaga *et. al* PRD **80** 096006 2009

- divide the Dalitz plot in bins and calculate the significance of the difference in the population for particle and antiparticle

$$S_{CP}(i) = \frac{N(i) - \alpha \bar{N}(i)}{\sqrt{N_{obs}(i) + \alpha^2 \bar{N}_{obs}(i)}}$$

- $\alpha \bar{N}$ is the yield after correcting for (global) production and/or instrumental asymmetries between particle and antiparticle $\alpha = N_{tot}/\bar{N}_{tot}$
- if only statistical fluctuations are present, the distribution of $S_{CP}(i)$ should be Gaussian



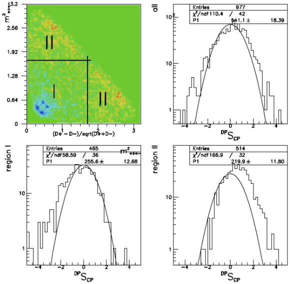


- if deviations from Gaussian appear - spread across the Dalitz plot or just in localized regions - this is direct evidence for $\not{C}\not{P}$

Comparing Dalitz Plot surfaces - *Mirandizing*

★ Example with $D^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$

from PRD **80** 096006 2009



- toy model generated with $f_0\pi$, $\sigma\pi$, $\rho\pi$ and NR
- a 1% phase difference (3.6°) is introduced for $\rho^0\pi^+$
- $\sim$ 1 M events generated for either D^+ and D^-
- departure from Gaussian globally and in both regions I and II

★ General Comments:

- sensitive to local asymmetries rather than global asymmetry (total width) ☺
- no model dependence: $\mathcal{S}_{\rm CP}$ is a direct measure of $\not{C}\!P$: even for small asymmetries or relatively small samples ☺
- very good to search for early signs of $\not{C}\!P$! ☺
- no actual measurements of $\not{C}\!P$ parameters ☹

3. The LHCb experiment and Charm

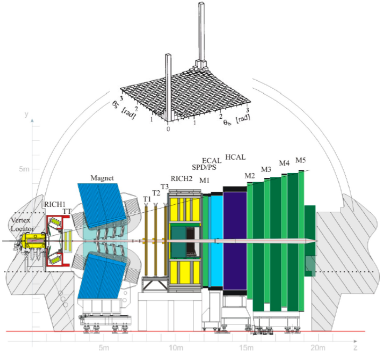
3.1. The LHCb experiment

The LHCb Experiment

The LHCb Experiment

LHCb design

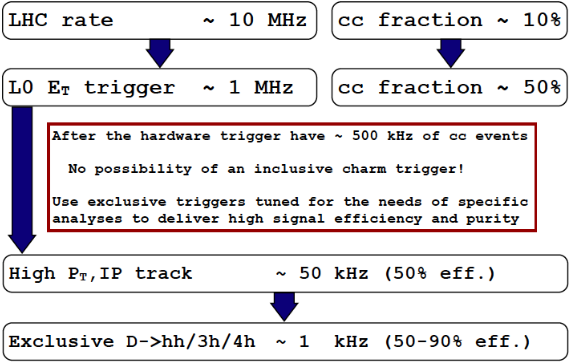
- a forward spectrometer:
  good acceptance for $b\bar{b}$
  $2 < \eta < 5$
- excellent vertexing and proper time resolution
  $\sigma_\tau = 50fs$ (compared to $\tau_D \sim 410\text{fs}$, $\tau_B \sim 1500\text{fs}$)



- very good tracking and momentum resolution
  $\sigma_p/p \sim 0.15 - 0.35\%$
- excellent particle ID (specially K/π discrimination)
  kaon ID eff $\sim 95\%$, misid $\sim 7\%$
- excellent features for charm physics too!!!

Charm Production & Trigger in LHCb

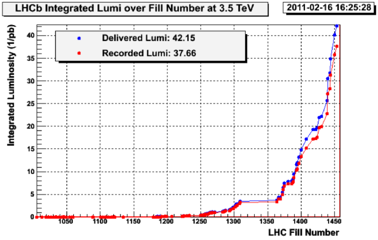
- Two types of charm production:
  - *prompt* - created at the PV
  - *secondary* - from B decay ($\mathcal{B} \sim 50\%$)
- $\sigma(c\bar{c}) \sim 20 \times \sigma(b\bar{b}) \Rightarrow$ much more prompt charm!
- Trigger

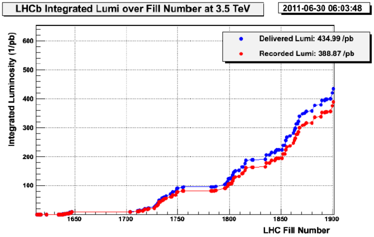


2010 – 2011 Data Taking

pp collisions at $\sqrt{s} = 7$ TeV since March 2010

2010 data taking: 37 pb^{-1} 2011: $\sim$390 pb^{-1} collected so far

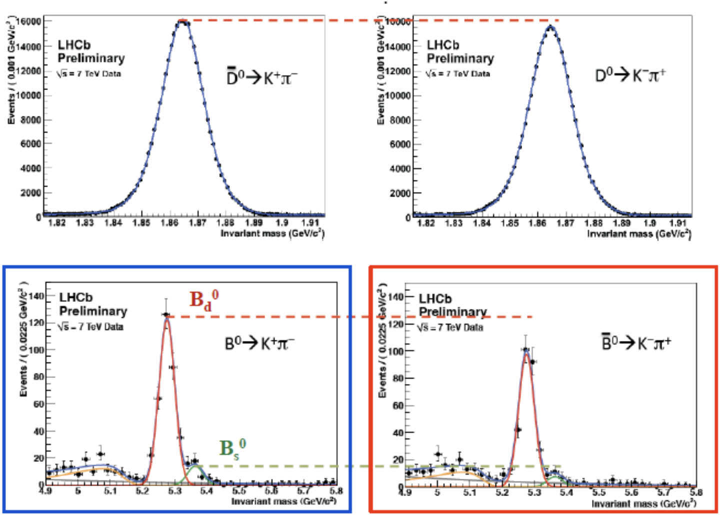




- currently running at $3 \times 10^{32} cm^{-2} s^{-1}$
- $\sim$ 1 fb^{-1} expected by the end of 2011

… results shown here correspond to 2010 data

last years's first signs of $\not{C}\not{P}$ ... in B's

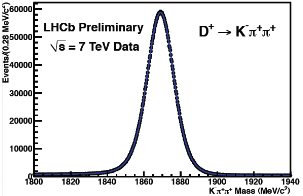


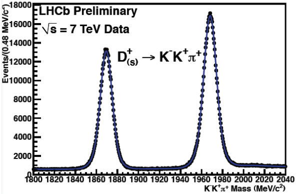
3.2. Results for $\not{C}\not{P}$ searches in charm at LHCb

Direct CP Violation in $D^+ \to K^- K^+ \pi^+$

$\Rightarrow$ Search for $\not{C}P$ signs by a direct comparison of D^+ and D^- Dalitz plots

- Use *Mirandizing* method to search for $\not{C}P$
- not sensitive to global asymmetries
- 2010 data sample:
  - 390K $D^+ \to K^- K^+ \pi^+$
  - 550K $D_s^+ \to K^- K^+ \pi^+$
  - 4M $D^+ \to K^- \pi^+ \pi^+$
- 2010 data set is $\sim 20\times$ Cleo's (PRD D 78, 072003(2008))



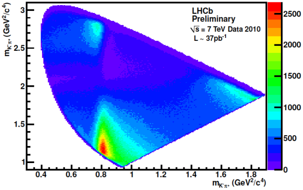


PUC RIO

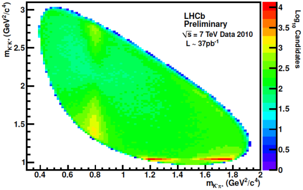
LHCb

Direct CP Violation in $D^+ \to K^- K^+ \pi^+$

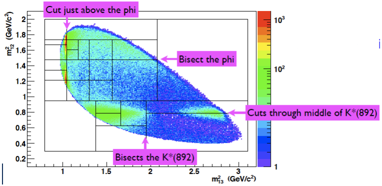
$D^+ \to K^- \pi^+ \pi^+$



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



- several studies to shown the absence of local asymmetries
  - sidebands
  - control channels $D^+ \to K^- \pi^+ \pi^+$ and $D_s \to K^- K^+ \pi^+$
- toy studies on binning choice to improve sensitity



- blind analysis until all controlled... and then *unblind*

Direct CP Violation in $D^+ \to K^- K^+ \pi^+$

calculate χ^2/dof from the significance of each Dalitz bin:

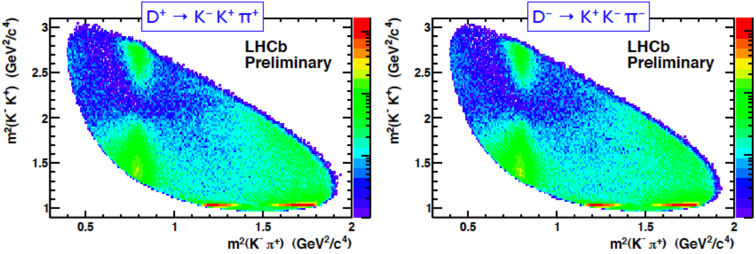
$$\chi^2/\text{dof} = \sum_i \frac{\{\mathcal{S}_{CP}(i)\}^2}{\text{nbins} - 1}$$

With baseline physics-driven binning:

MagUp	35.6/24 ⇒ 6.0%
MagDown	27.4/24 ⇒ 28.5%
Combined	32.0/24 ⇒ 12.7%

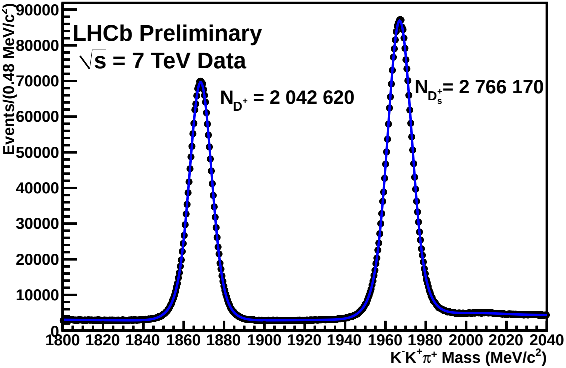
No evidence for CP violation in the 2010 dataset of 38 pb^{-1}

Preliminary: 2010 data, 38 pb^{-1}



Direct CP Violation in $D^+ \to K^- K^+ \pi^+$

just a glance of what's coming for 2011 (220 pb^{-1}) ....



... for 1 pb^{-1} we will be testing the "window" between NF and SM and *signs of* $\not{C}\not{P}$ *might well appear!*

$D \to h^+h^-$ - Time Integrated

- $D \to h^+h^-$ can manifest time-integrated asymmetries both from
  - indirect C̸P (final-state independent)
  - direct C̸P (final-state dependent)

⇒ Look for CP asymmetries in $D \to K^-K^+$ and $D \to \pi^-\pi^+$

⇒ $D \to K^-\pi^+$ as control channel

- CP asymmetry is defined by $A_{CP} = \frac{\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to \bar{f})}{\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to \bar{f})}$
- what we measure, instead, is

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

- A_{RAW} can have contributions from
  - production
  - detection (particle interaction and/or reconstruction)
  - and ... C̸P
- study *tagged* and *untagged* modes

tagged (*) : $D^{*+} \to D^0(h^+h^-)\pi_s^+$ and $D^{*-} \to \bar{D}^0(h^+h^-)\pi_s^-$

$D \to h^+h^-$ - Time Integrated

- thus, A_{RAW} is expanded as

$$A_{RAW}(f) = A_{CP}(f) + A_D(f) + \qquad + A_P(D^0)$$
$$A_{RAW}(f)^* = A_{CP}(f) + A_D(f) + A_D(\pi_s) + A_P(D^{*+})$$

physics CP asymmetry

Detection asymmetry of D^0

Detection asymmetry of soft pion

Production asymmetry

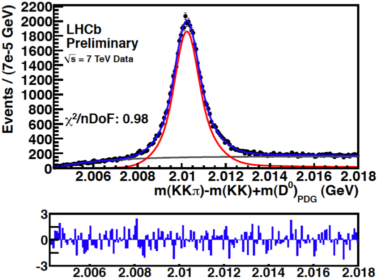
- construct observables for which unknown asymmetries cancel
- without external inputs:

$$A_{CP}(KK) - A_{CP}(\pi\pi) = A_{RAW}(KK)^* - A_{RAW}(\pi\pi)^*$$

  - indirect $\not{C}P$ expected to cancel (since it is final-state independent)
  - expect non-zero result if there is direct $\not{C}P$
  - complementary NP search to A_Γ
- also possible to get info on production asymmetry

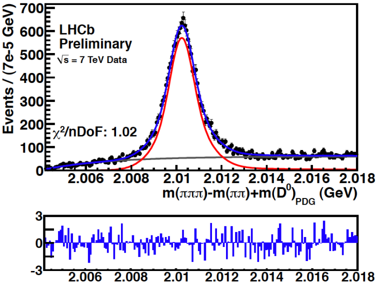
Getting $A_{CP}(KK) - A_{CP}(\pi\pi)$

tagged K^+K^-



$\text{yield}=1.16 \times 10^5$ for 37 pb^{-1}

tagged $\pi^+\pi^-$



$\text{yield}=0.36 \times 10^5$ for 37 pb^{-1}

- study also in bins of (p_T, η) and magnet polarities, early and late data

Getting $A_{CP}(KK) - A_{CP}(\pi\pi)$

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⇒ Results:

- systematic studies:
  D^0 mass window (0.20%), multiple candidates (0.13%), modeling lineshapes (0.06%), binning in (p_T, η) (0.01%),
- systematics dominated by conservative estimates due to large statistical uncertainties; expects to decrease with statistics

preliminary

$$A_{CP}(KK) - A_{CP}(\pi\pi) = (-0.28 \pm 0.70_{stat} \pm 0.25_{syst})\%$$

Comparisons:

Experiment	$A_{CP}(KK)$-$A_{CP}(\pi\pi)$ in %	Reference
Belle	$-0.86 \pm 0.60_{stat} \pm 0.07_{syst}$	Phys.Lett.B670 (2008) 190
BaBar*	$+0.24 \pm 0.62_{stat}$	Phys.Rev.Lett.100 (2008) 061803
CDF*	$-0.46 \pm 0.33_{stat}$	CDF note 10296 (preliminary)

*naive difference from individual measurements of $A_{CP}(KK)$ and $A_{CP}(\pi\pi)$ ignoring systematics; all input measurements are dominated by statistical uncertainty

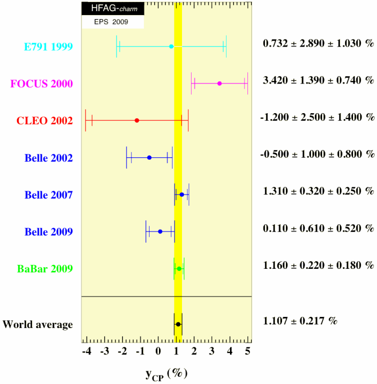
Time Dependent $\not{C}P$ from $D \to hh$

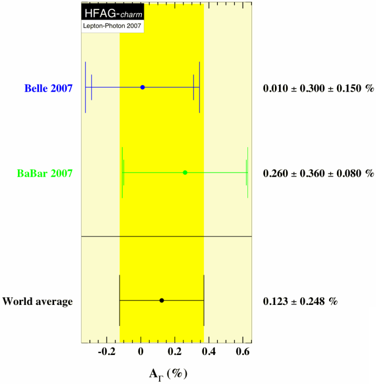
⋆ recall the quantities y_{CP} and A_Γ

$$y_{CP} \equiv \frac{\hat{\Gamma}(K^-K^+)}{\hat{\Gamma}(K^-\pi^+)} - 1 = \frac{\tau(K^-\pi^+)}{\tau(K^-K^+)} - 1$$

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

⇒ both measurements made through lifetime ratios

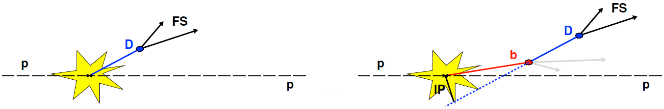




Time Dependent $\not{C}\not{P}$ from $D \to hh$

... Some analysis details ...

- use decay chain $D^{*+} \to D^0(h^+h^-)\pi^+$ to tag the flavour of D^0 (and correspondingly for $\bar{D}^0$)
- for the Lifetime fit: mainly two concerns
  - charm can be produced promptly or from B decay



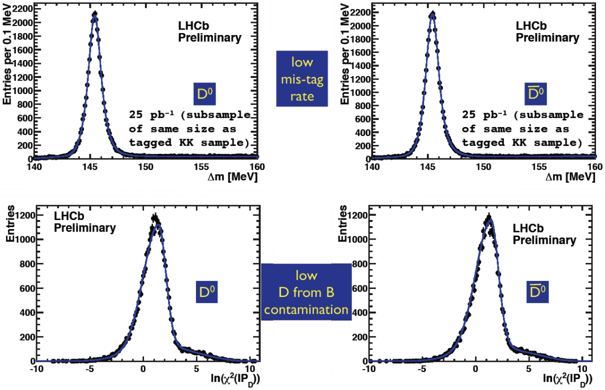
important to discriminate these two sources for *production* and *time-dependent measurements*
$\Rightarrow$ use the IP χ^2 of the D

  - lifetime distribution biased due to trigger & offline selection acceptances
    use an algorithm to obtain the per-event acceptance $\Rightarrow$ move the PV, rerun the trigger (possible due to software trigger)
    $\Rightarrow$ "swimming method"

Time Dependent $\not{C}\not{P}$ from $D \to hh$

KK and $\pi\pi$ measurements for A_Γ and y_{CP} underway and still "blind"

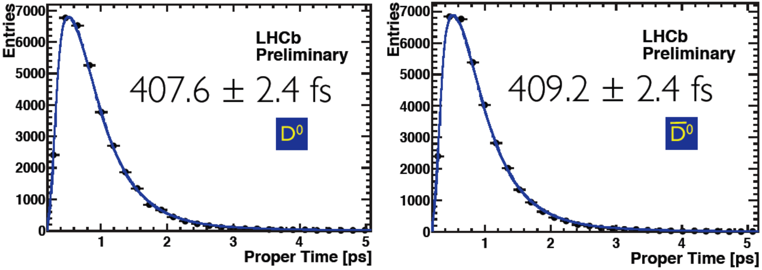
$\Rightarrow$ here the results for control channel $D^0 \to K^-\pi^+$



validation of the procedure:

no $\not{C}\not{P}$ expected in $K\pi$ $\Rightarrow$ $A_\Gamma^{K\pi} = 0$

Time Dependent $\not{C}P$ from $D \to hh$



$$\bar{\tau}(D^0)_{\mathrm{PDG}} = 410.1 \pm 1.5 \text{ ps}$$

preliminary

$$A_{\Gamma}^{K\pi,eff} = \frac{\tau^{eff}(\bar{D}^0) - \tau^{eff}(D^0)}{\tau^{eff}(\bar{D}^0) + \tau^{eff}(D^0)} = (-2 \pm 4) \times 10^{-3}$$

3.3. Prospects for 2011/2012

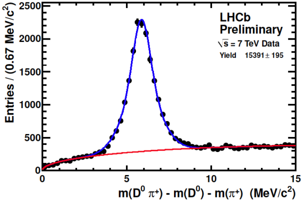
CP violation in $D^0 \to K_S h^+ h^-$

$\Rightarrow$ Very rich environment

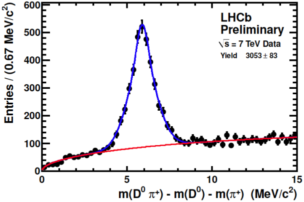
- CP eigenstates as intermediate states
- rich Dalitz plot structure
- both Cabibbo-favored and DCS final states
- promising D^0 $\not{C}P$ and mixing studies
  - time dependent amplitude analysis
  - direct access to $\not{C}P$ and mixing parameters (strong phases measured!)
- current results from BaBar and Belle with $\sim$ 540K for $K_S\pi\pi$
- explicit trigger implemented for 2011

2010 data

$D^{*+} \to D^0(K_S\pi^+\pi^-)\pi^+$

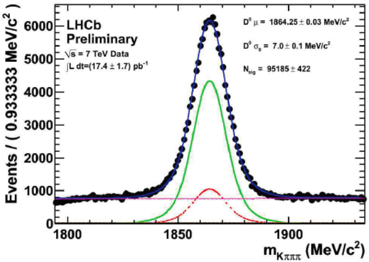


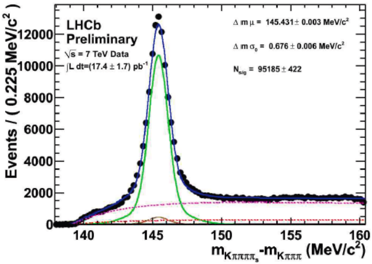
$D^{*+} \to D^0(K_S K^+ K^-)\pi^+$



$D^0 \to h^+h^+h^-h^-$

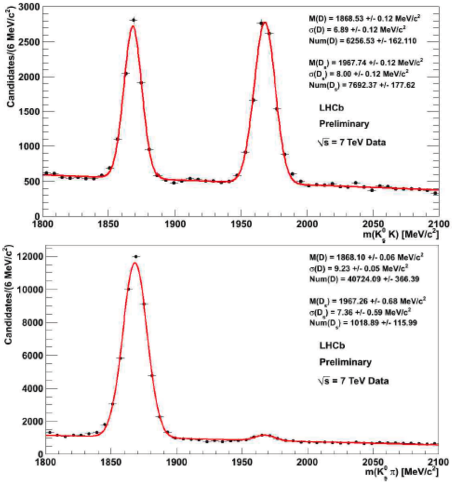
- one of the largest $\not{C}\!P$ effect was observed through T-odd observable
  angle between planes $\pi^+\pi^-$ and e^+e^- in $K_L \to \pi^+\pi^-e^+e^-$
- similar mechanism can be at work in $D^0 \to K^+K^-\pi^+\pi^-$
- look for asymmetry in the distribution of the angle between K^+K^- and $\pi^+\pi^-$ planes
  FOCUS (2005) pioneered this study; BaBar with 47K events measured $A_T^{CP} = (0.10 \pm 0.51 \pm 0.44)\%$
- LHCb competitive by the end of 2011





$D^{\pm}_{(s)} \to K_S h^{\pm}$

- CF and DCS decays:
  $D^+ \to K_S\pi^+$,
  $D_S^+ \to K_S K^+$
- CS decays:
  $D^+ \to K_S K^+$,
  $D_s \to K_S \pi^+$
- $\not{CP}$ through $K^0 - \bar{K}^0$ in the SM: expect asymmetries $\sim 0.3\%$
- values of $\mathcal{O}(1\%)$ would sign for NP
- no evidence so far of $\not{CP}$ (Belle)



4. Conclusions

Conclusions

Charm Decays: great potential to search for New Physics in an environment with low SM $\not{C}P$ "background"

- LHCb has a broad program on charm physics
- mainly focused on mixing and CPV
  but also spectroscopy and rare decays (not covered here)
- First (preliminary) results presented here (2010 data):

  ⋆ no evidence for $\not{C}P$ in $D^+ \to K^- K^+ \pi^+$
  pvalue of 12.7% in 25 Dalitz bins for 390K events

  ⋆ $A_{CP}(KK) - A_{CP}(\pi\pi) = (-0.28 \pm 0.70_{stat} \pm 0.25_{syst})\%$

- dedicated triggers for many modes aiming to search for $\not{C}P$: $D^0 \to h^+h^-$, $D^+ \to 3h$, $D^0 \to 4h$, $D^0 \to K_S hh$, $D^+ \to K_S h$, etc
- plenty of charm foreseen for 2011
  for instance $\sim$ 200K $D^0 \to K^-\pi^+$ per pb^{-1} being recorded !