First evidence for CP violation in charm decays at LHCb. A short presentation

A rational choice from the Angelo Carbone seminar at CERN, 6 December 2011

LHC Seminar

First evidence for CP Violation in charm decays at LHCb

by Angelo Carbone (Universita e INFN (IT))

Tuesday, December 6, 2011 from **11:00** to **12:00** (Europe/Zurich)
at CERN (Main Auditorium)

Description The LHCb Collaboration has recently observed evidence of CP violation in neutral D meson decays. CP violation in the charm sector is generically expected to be very small in the Standard Model, but can be enhanced in many models of new physics. In this seminar we will present the results of a search for time-integrated CP violation in D0 -> h- h+ (h=K,pi) decays, performed with around 0.6 fb-1 of data collected by LHCb in 2011. The difference in CP asymmetry between D0 -> K- K+ and D0 ->pi- pi+, Delta A_CP = A_CP(K- K+) - A_CP(pi- pi+) is measured to be Delta A_CP = [-0.82 +- 0.21 (stat.) +- 0.11 (syst.)]%. This differs from the hypothesis of CP conservation by 3.5 sigma. Prospects for improved measurements of this quantity and other CP-violating observables in the charm sector will be briefly discussed.

Material Poster Slides

Organised by M. Spiropulu, M. Mangano, G. Unal........................ **Tea and Coffee will be served at 10h30**

LHCb search for time-integrated CP-violation in $D^0 \to K^-K^+, \pi^-\pi^+$ decays

LHCb search for time-integrated CP-violation in $D^0 \to K^-K^+, \pi^-\pi^+$ decays

LHCb has measured, ΔA_{CP}, the difference between the time-integrated CP asymmetries in the decays $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ and obtained a preliminary result of ΔA_{CP} = -0.82 ± 0.21 (stat) ± 0.11 (syst) %. This is the most precise search for CP violation in singly Cabibbo suppressed charm decays, and is the first evidence of CP violation in the charm system

- HCP conference presentation, Paris, 14/11/2011
- Conference report: LHCb-CONF-2011-061
- Preprint: CERN-PH-EP-2011-208 and journal link
- LHC Seminar presentation, CERN, 06/12/2011
- Explanation for the non-expert

http://lhcb.web.cern.ch/lhcb/lhcb_page/physics_results/recent_lhcb_results/Search_for_CP_violation_in_charm.html

Why search for CP violation in charm ?

The charm sector is a promising place to probe effects of physics beyond SM.

In the last years: resurgence of interest since evidence for D0 mixing was first seen.

Babar, Belle
arXiv:hep-ex/0703020
arXiv:hep-ex/0703036

Mixing well-established at level which is consistent with, but at the upper end of, SM expectations.

No evidence for CP violation in charm decays has yet been found

HFAG arXiv:1010.1589

Why search for CP violation in charm ?

SM charm physics is CP conserving to first approximation (dominance of 2 generation)

New Physics (NP) can enhance CP-violating observables

Unitary triangle for charm

$$V_{ud}V_{cd}^* + V_{us}V_{cs}^* + V_{ub}V_{cb}^* = 0$$

$$\sim\lambda \qquad \sim\lambda \qquad \sim\lambda^5$$

With b-quark contribution neglected: only 2 generations contribute
→ real 2x2 Cabibbo matrix

CP violation in charm

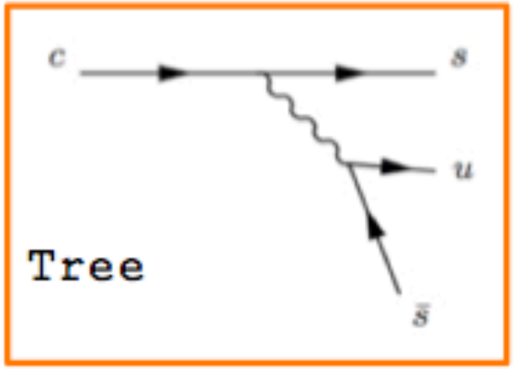
- 3 modes of observing CP violation:
  - in mixing: rates of $D^0 \rightarrow \bar{D}^0$ and $\bar{D}^0 \rightarrow D^0$ differ → indirect
  - in decay: amplitudes for a process and its conjugate differ → direct
  - in interference between mixing and decay diagrams → indirect
- In the SM indirect CP violation expected to be very small and universal for CP eigenstates → $O(10^{-3})$
- Direct CP violation expected small as well
  - Negligible in Cabibbo-favoured modes (SM tree dominates everything)
  - In singly-Cabibbo-suppressed modes: up to $O(10^{-4} - 10^{-3})$ plausible
- Both can be enhanced by NP, in principle up to O(%)

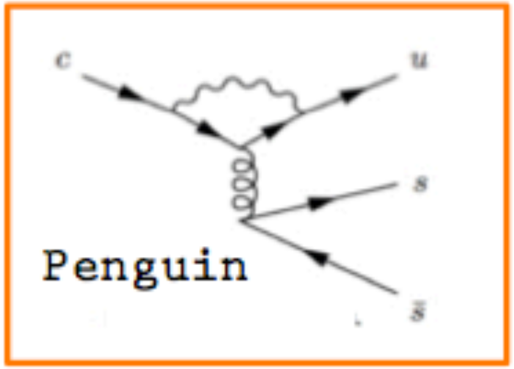
Bianco, Fabbri, Benson & Bigi, Riv. Nuovo. Cim 26N7 (2003)
Grossman, Kagan & Nir, PRD 75, 036008 (2007)
Bigi, arXiv:0907.2950

Bobrowski, Lenz, Riedl & Rorhwild, JHEP 03 009 (2010)
Bigi, Blanke, Buras & Recksiegel, JHEP 0907 097 (2009)

Where to look for CP violation?

- Singly Cabibbo Suppressed (SCS) decays are an interesting sector for direct CPV searches
- Interference between Tree and Penguin can generate direct CP asymmetries
  - Several classes of NP can contribute
  - … but also non-negligible SM contribution



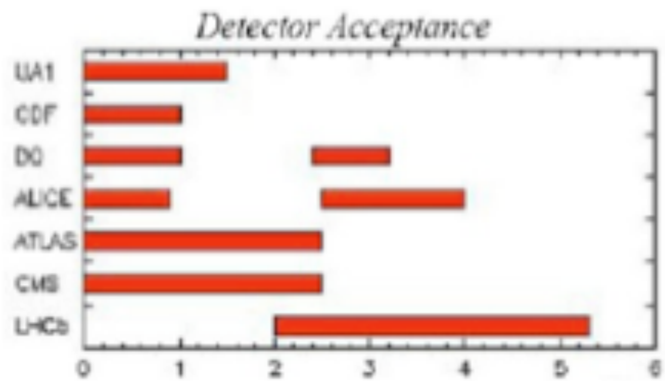


Today special guest

Time-integrated asymmetries in $D^0 \rightarrow hh$

LHCb at LHC

LHCb **detector** covers the forward region at the LHC in a unique rapidity range: $2<\eta<5$.

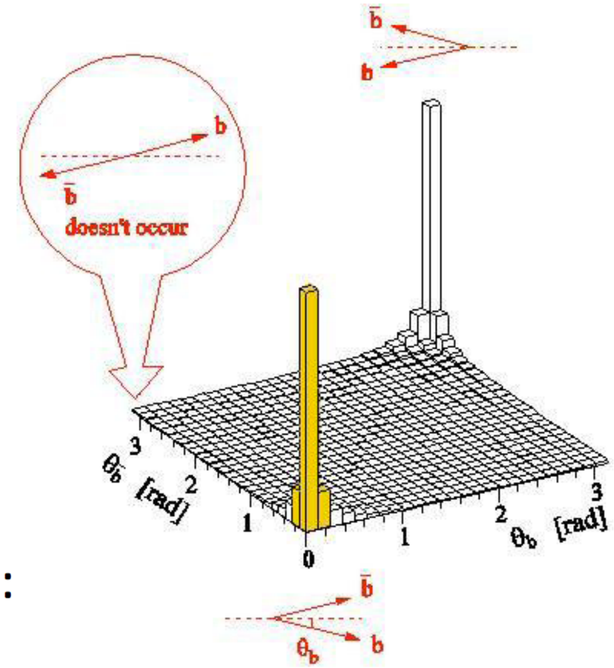


LHCb exploits the strongly forward peaked heavy quark production: covering only 4% of solid angle the acceptance for b-quark production cross section is ~40%.

Large cross sections (at 7 TeV):

$\sigma(bb)$ = 284±53 μb; now ~10^{11} b decays on tape

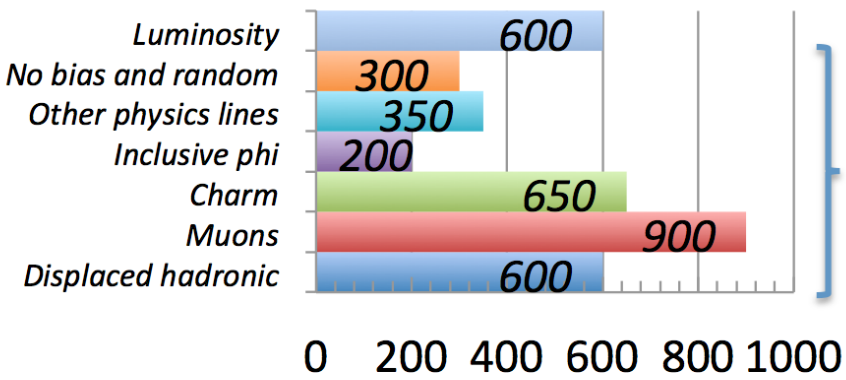
$\sigma(cc)$ = 6100±930 μb; now ~10^{12} D decays on tape.



Trigger:

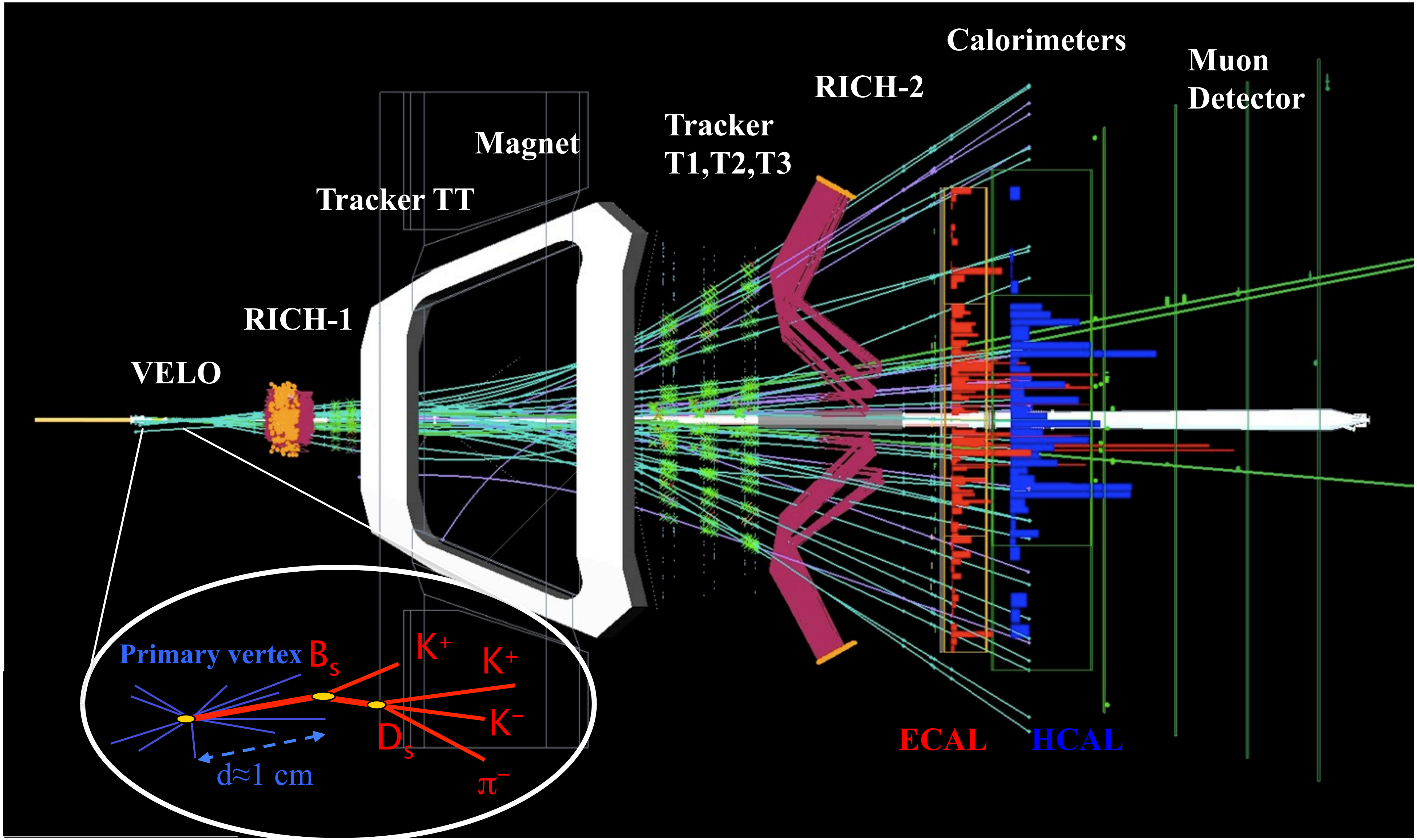
L0 (hardware): **~1 MHz** from **high p_T** μ, e, γ, h candidates.

High Level Trigger (HLT1+HLT2, software): **~3 kHz** global event reconstruction plus selections



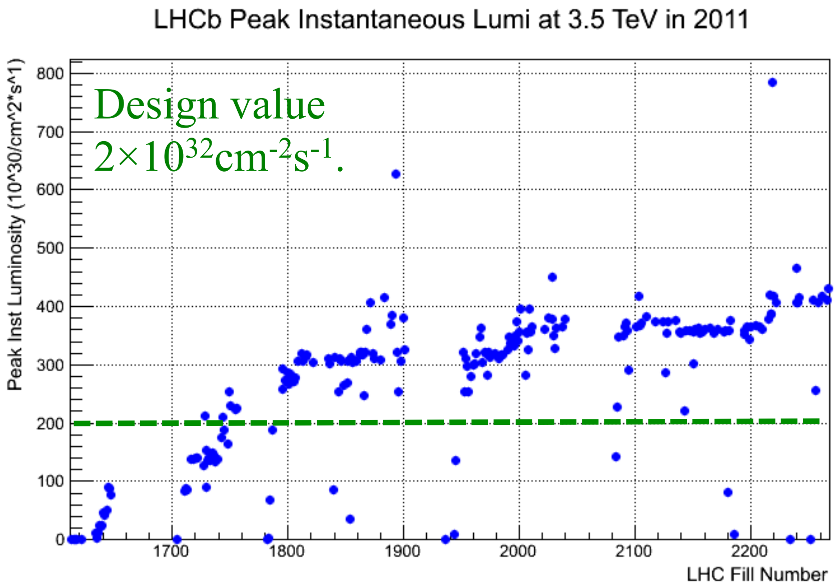
Physics:
3 kHz

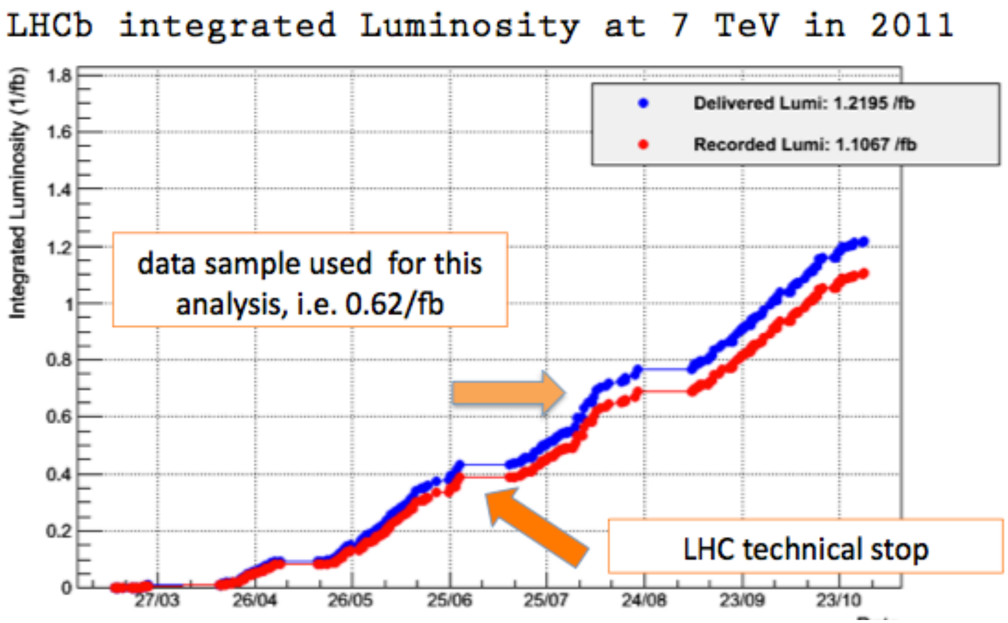
LHCb detector

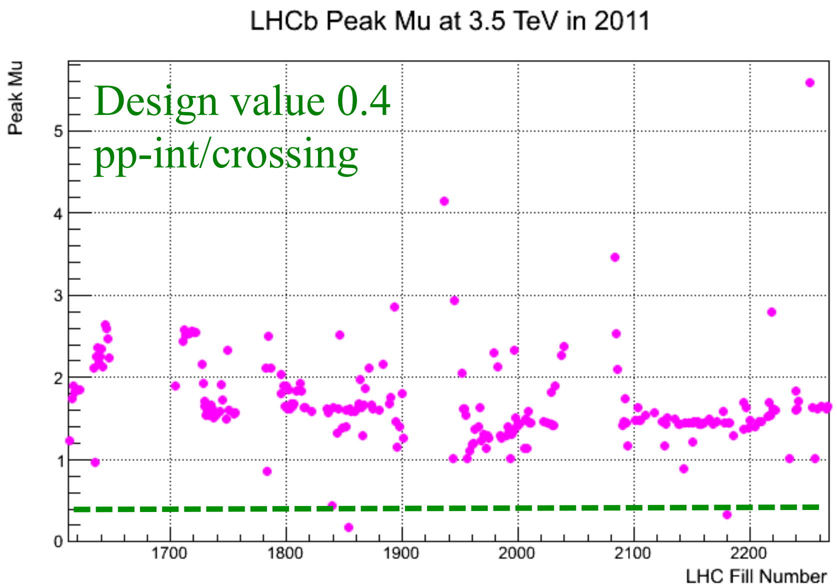


Data taking in 2011

- **1.1 fb^{-1}** acquired in 2011;
- 91% data taking efficiency, including data quality;
- Well **beyond design parameters**: peak luminosity and μ (pp-interactions per bunch crossing);
- **Luminosity leveling** at $3.5\times10^{32}cm^{-2}s^{-1}$ nicely working with both magnet polarities







Time-integrated CP asymmetry
(what we measure at LHCb)

- We are looking for CP asymmetry defined as

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

with f=KK and f=ππ and

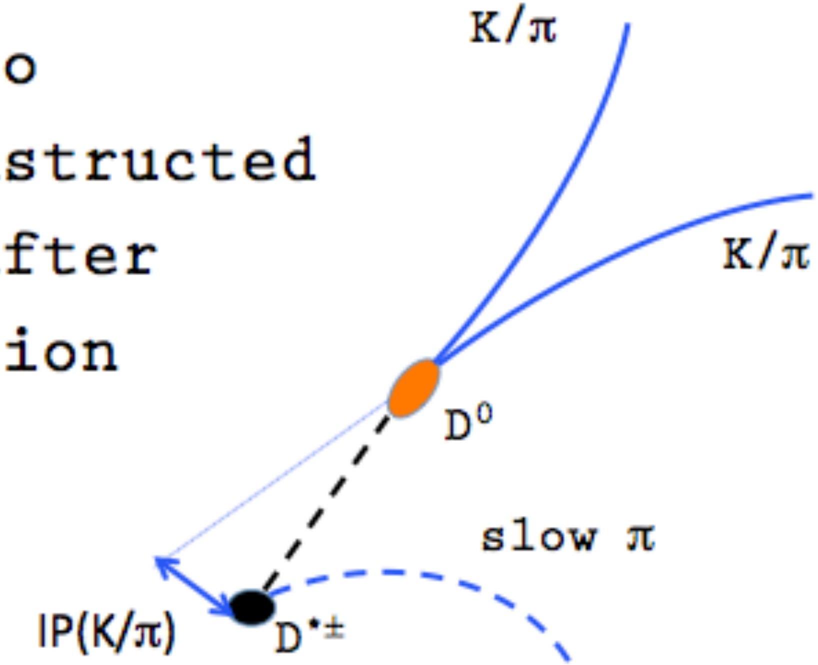
- The flavor of the initial state (D^0 or $\overline{D}^0$) is tagged by requiring a $D^{*+} \to D^0\pi^+_s$ decay, with the flavour determined by the charge of the slow pion (π^+_s)
- "slow" because of its lower average momentum (~5 GeV/c) with respect to the D^0 daughters (~30 GeV/c)

Time-integrated CP asymmetry
(what we measure at LHCb)

- The raw asymmetry for tagged D^0 decays to a final state f is given by

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

- where N(X) refers to the number of reconstructed events of decay X after background subtraction



Time-integrated CP asymmetry
(what we measure at LHCb)

- What we measure is the physical asymmetry plus asymmetries due both to production and detector effects

$$A_{\mathrm{raw}}(f) = A_{CP}(f) + A_{\mathrm{D}}(f) + A_{\mathrm{D}}(\pi_s) + A_{\mathrm{P}}(D^{*+})$$

Physics CP asymmetry

Detection asymmetry of D^0

Production asymmetry

Detection asymmetry of "slow" pions

First order expansion assumes raw asymmetry not large
- ... which is true: O(%)

Time-integrated CP asymmetry
(what we measure at LHCb)

- … if we take the raw asymmetry difference

$$\Delta A_{CP} \equiv A_{raw}(KK) - A_{raw}(\pi\pi) = A_{CP}(KK) - A_{CP}(\pi\pi)$$

- the production and the "slow" pion detection asymmetries will cancel

ΔA_{CP} interpretation

- The physics asymmetry of each final state may be written at first order as [arXiv:1103.5785]

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

  - $a^{dir}_{CP}(f)$ is the direct CP asymmetry in the decay
  - $\langle t \rangle$ is the average decay time → experiment dependent
  - τ is the D^0 lifetime
  - $a^{ind}_{CP}(f)$ is the CP asymmetry due to the the mixing and/or the interference between mixing and decay
- To a good approximation $a^{ind}_{CP}(f)$ does not depend on the final state [arXiv:0609178], and so:

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

- In the limit of U-spin symmetry, $a^{dir}_{CP}(f)$ is equal in magnitude and opposite in sign for K^+K^- and $\pi^+\pi^-$
- Interpretation of ΔA_{CP} depends on experiment

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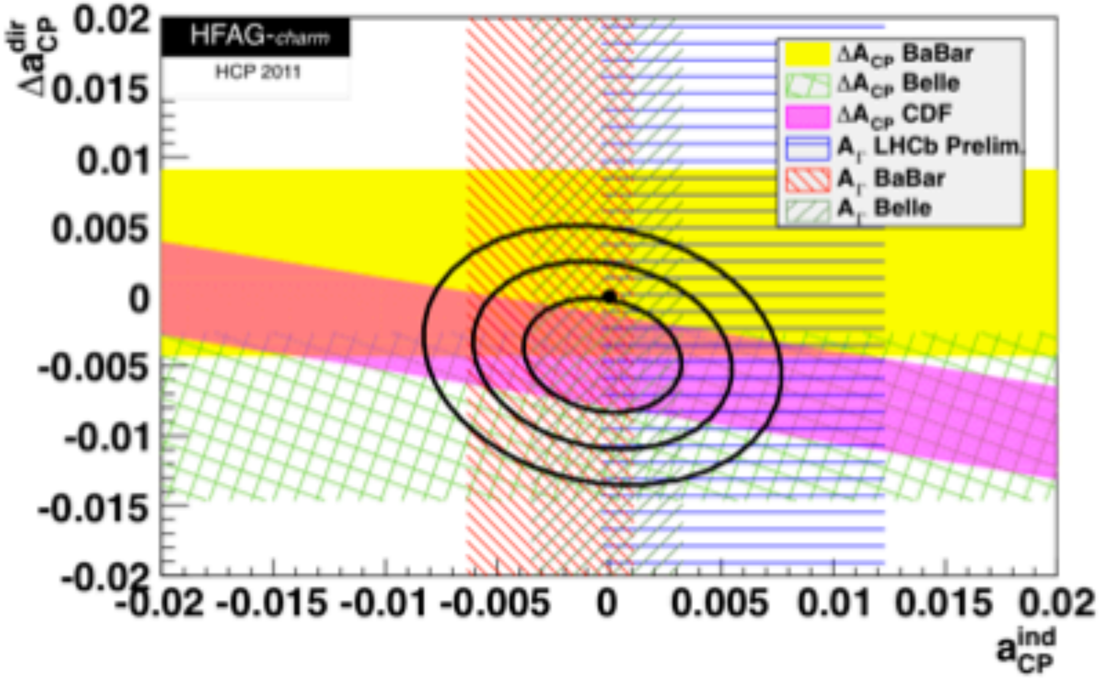
Experimental status
(ΔA_{CP})



World average $\Delta a_{CP}{}^{dir}$
1.6σ from zero

HFAG combination

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

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

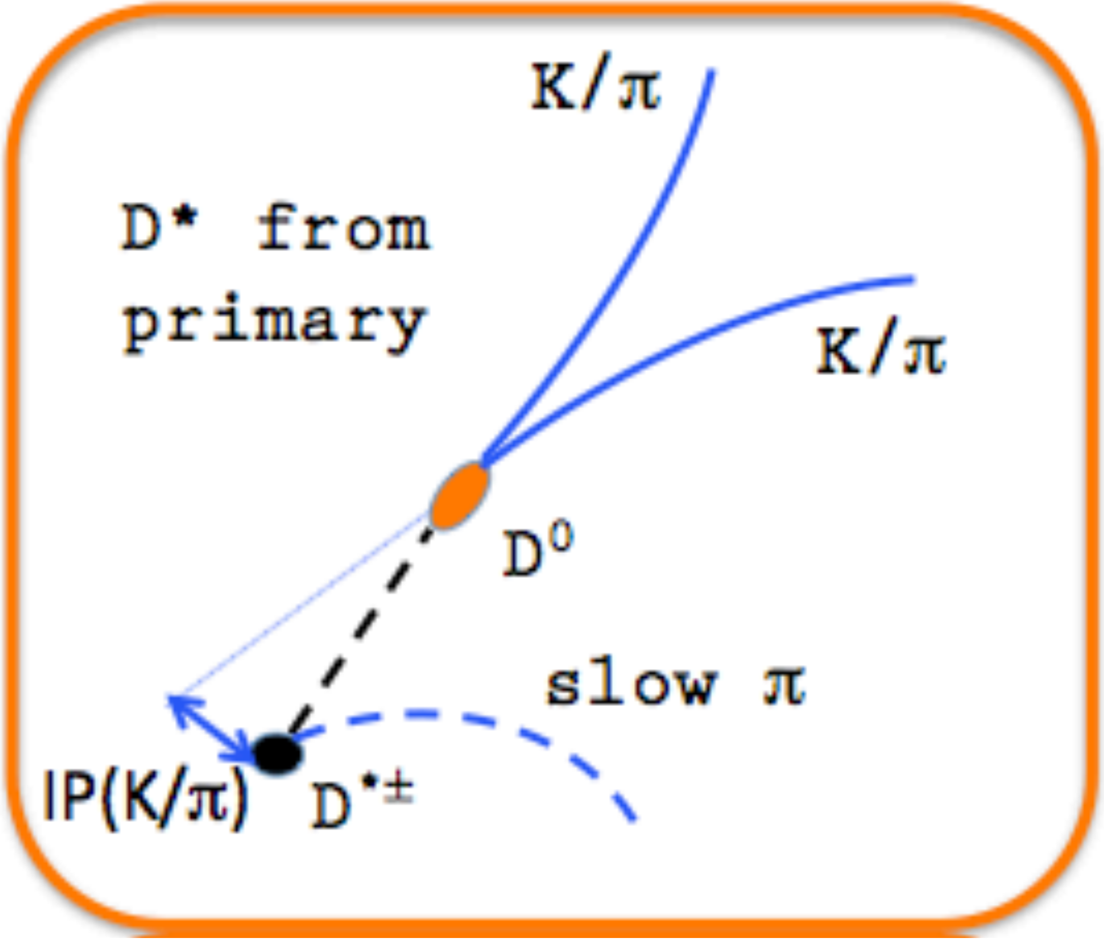
Consistency with NO CPV hypothesis: 28%

Recent CDF measurement
ΔA_{CP}=[-0.46±0.31±0.12]%
arXiv:1111.5023

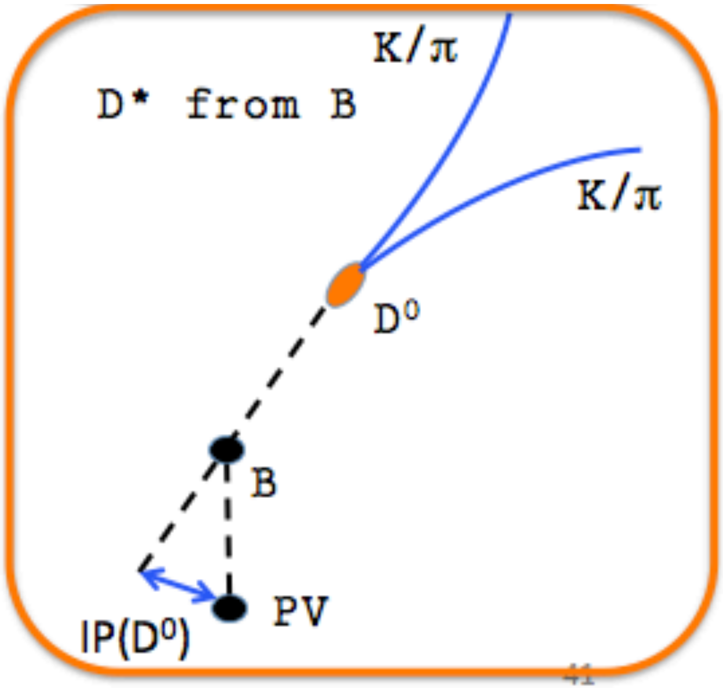
ΔA_{CP} extraction strategy

- ΔA_{CP} robust against systematics, however detector effect can induce different fake asymmetries for KK and ππ:
  - Dependence of $A_P(f)$ and $A_D(f)$ with respect to KK/ππ efficiency ratio
- Solution: divide data into bins of the variable (such that no correlation within bin) and treat each bin independently.
  - Divide data into kinematic bins of p_T of D^{*+}, η of D^{*+}, p of slow pion.
- Along similar lines:
  - split by magnet polarity (B field up/down)
  - split into left/right hemisphere (slow pion momentum points left/right of the bending plane)
  - split into two run groups (before & after technical stop)
- 216 independent measurements of ΔA_{CP}

Event selection

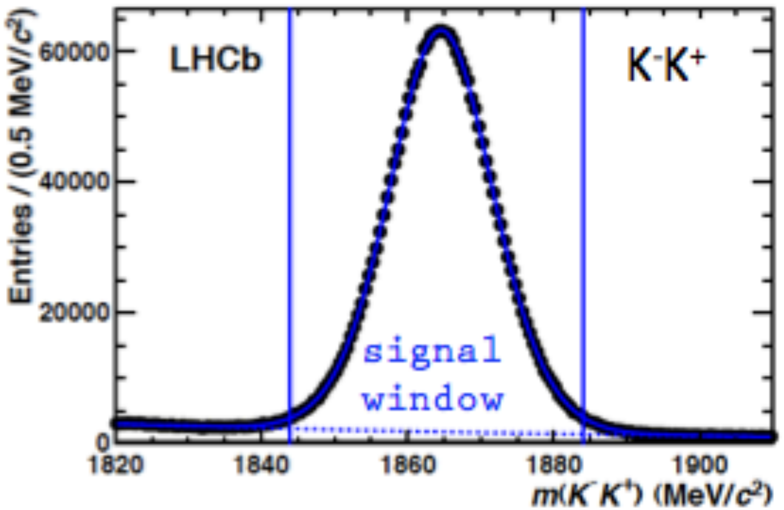


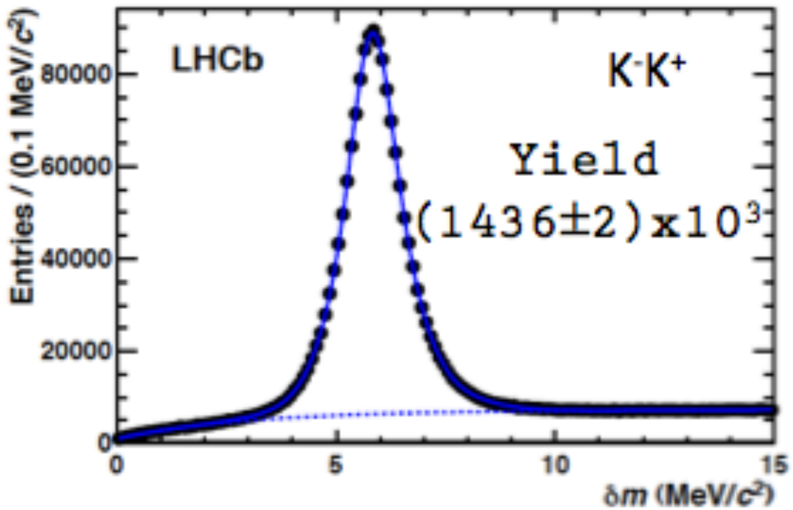
Reject D^0 from B:
after all cuts ~3%
of contamination;
only lifetime
measurement
affected not ΔA_{CP}.



Mass spectra

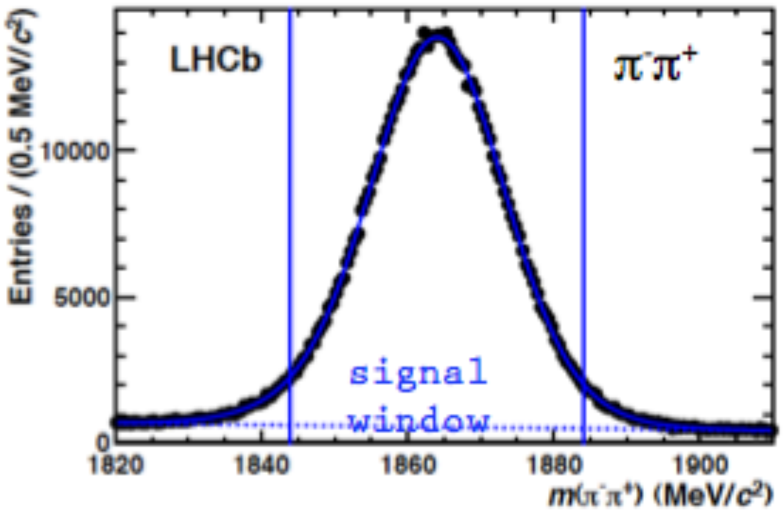
$\delta m = m(h^+h^-\pi^+) - m(h^+h^-) - m(\pi^+)$

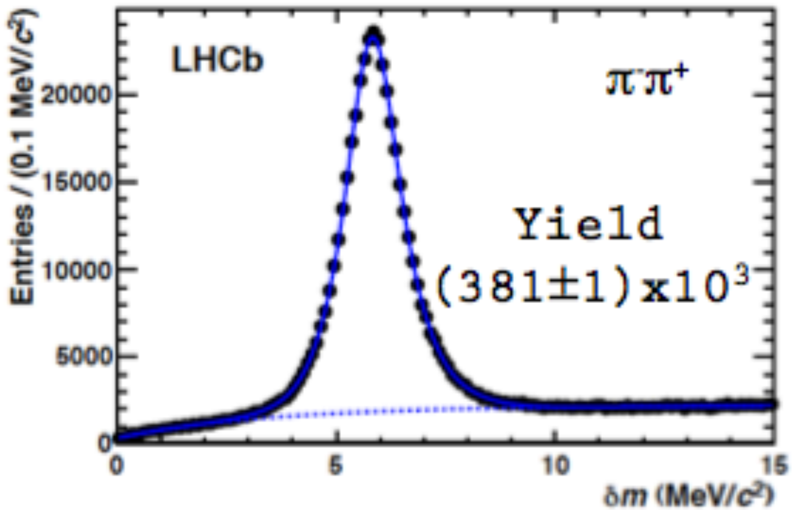




$1844 < m(D^0) < 1884$ MeV/c^2

$1844 < m(D^0) < 1884$ MeV/c^2





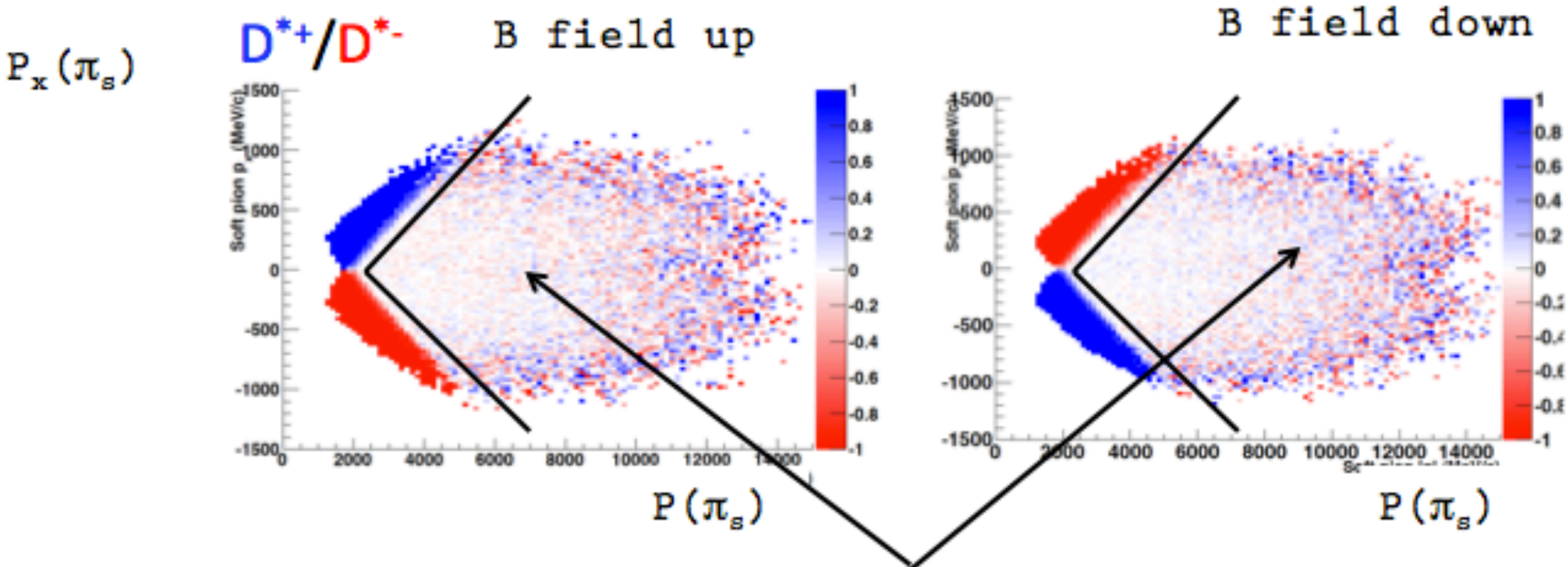
Fiducial cuts

- There are regions of phase space where only D^{*+} or only D^{*-} is kinematically possible.
  - this causes large value of A_{CP}^{Raw} up to 100% in the edges regions where only D^{*+} or D^{*-} is reconstructed
- This asymmetry is independent of the D^0 decay modes but it breaks the assumption that the raw asymmetries are small
- and it carries a risk of second-order systematic effects if the ratio of efficiencies of $D^0 \rightarrow K^- K^+$ and $D^0 \rightarrow \pi^- \pi^+$ varies in the affected region.

Fiducial cuts

- The edge regions are therefore excluded with cuts in the slow pion(P_x,P) plane.

Raw asymmetry of $D^{*+} \to D^0(KK)\pi^+$ and cc in the (P_x,P) plane of slow pion



Accepted region
reject 25% of events

Fit procedure

- Use 1D fits to mass difference

$$\delta m = m(h^+h^-\pi^+) - m(h^+h) - m(\pi^+)$$

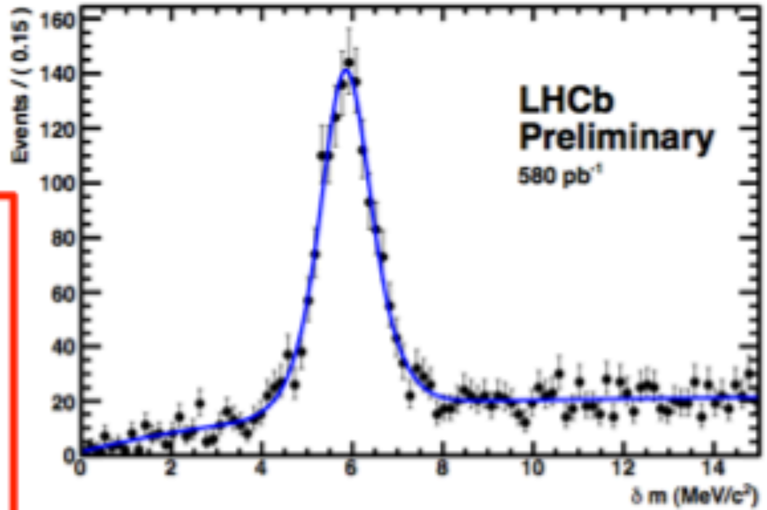
- Signal model: double-Gaussian convolved with a function accounting for the asymmetric tail:

$$B(\delta m; s) = \Theta(\delta m)\,\delta m^s$$

- Background model:

$$h(\delta m) = B\left[1 - \exp\left(-\frac{\delta m - \delta m_0}{c}\right)\right]$$

Example fit $D^* \to D^0(KK)\pi$ in one kinematic bin



Consistency for ΔA_{CP} among 216 kinematic bins:
$\chi^2/NDF=211/215$
(χ^2 prob. 56%)

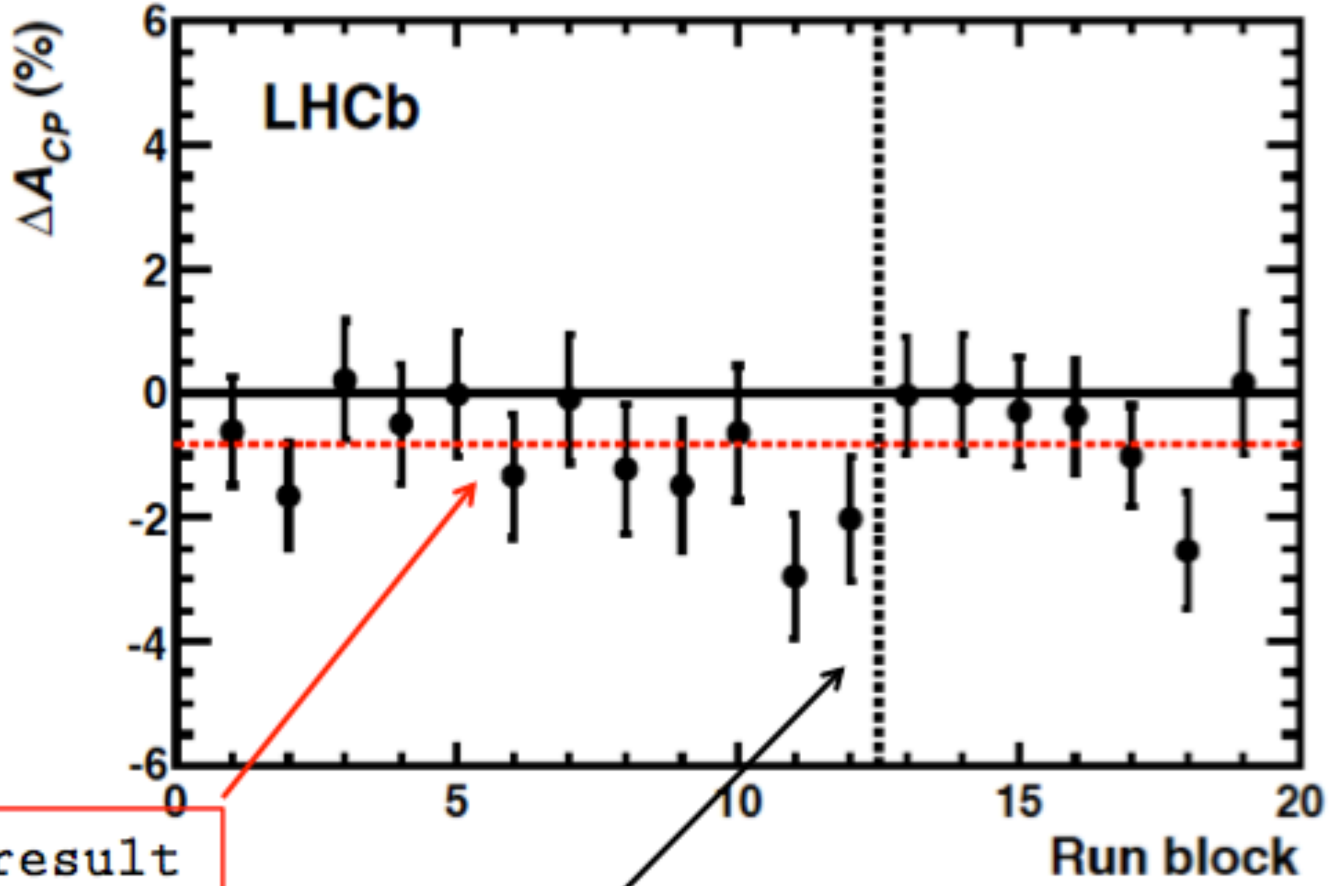
A weighted average of the kinematic bins yields the result
$\Delta A_{CP} = [-0.82 \pm 0.21(\text{stat.})]\%$ 56

Further cross checks

Numerous crosschecks carried out, including:

- Electron and muon vetoes on the soft pion and on the 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 D^0 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, etc)

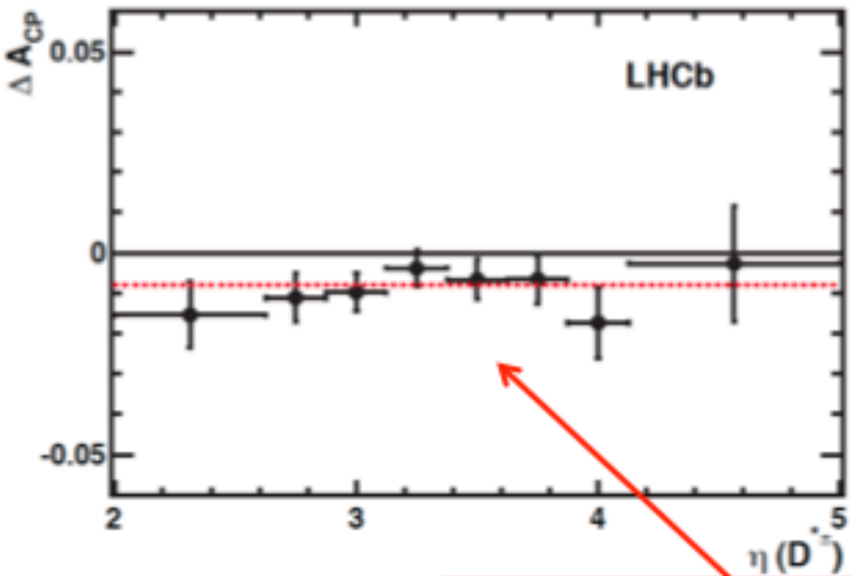
Stability of result vs data-taking runs

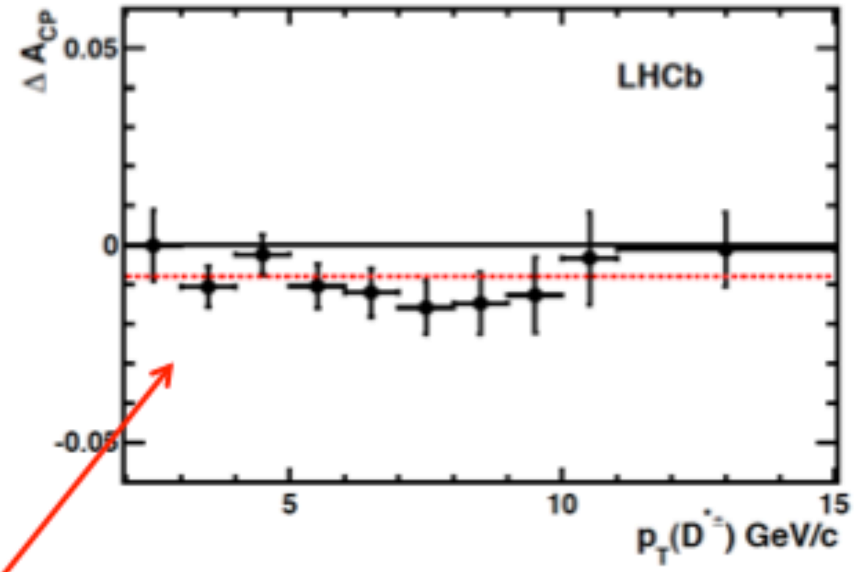


Final result (dashed line)

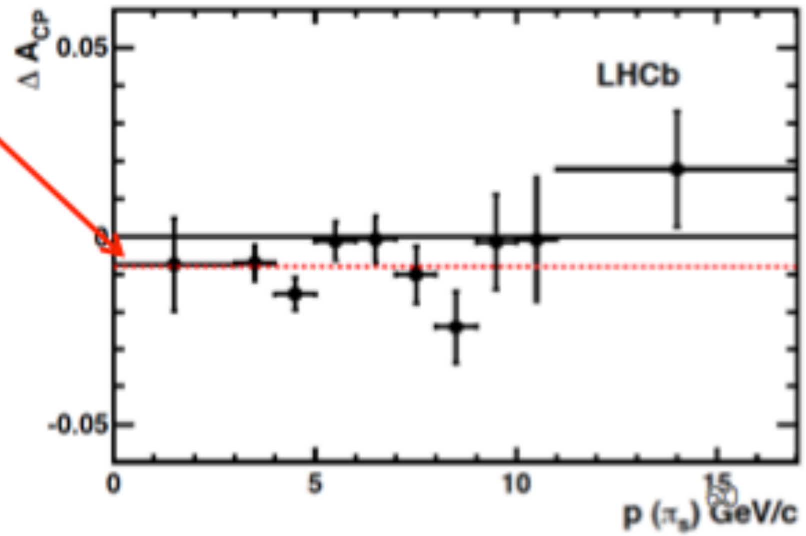
Before and after a technical stop

Stability of result on relevant kinematic variables





Final result (dashed line)



No evidence of dependence on relevant kinematic variables

Internal consistency between subsamples

- Disjoint subsamples of data split according
  - to magnet polarity
  - the sign of P_x of the tagging slow pion
  - whether the data were taken before or after the technical stop.
- The χ^2 probability for consistency among the subsamples is 45% (χ^2/ndf=6.7/7).

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

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Systematic uncertainties

- **Kinematic binning: 0.02%**
  - Evaluated as change in ΔA_{CP} between full 216-bin kinematic binning and "global" analysis with just one giant bin.
- **Fit procedure: 0.08%**
  - Evaluated as change in ΔA_{CP} between baseline and not using any fitting at all (just sideband subtraction in δm for KK and $\pi\pi$ modes)
- **Peaking background: 0.04%**
  - Evaluated with toy studies injecting peaking background with a level and asymmetry set according to D^0 mass sidebands (removing signal tails).
- **Multiple candidates: 0.06%**
  - Evaluated as mean change in ΔA_{CP} when removing multiple candidates, keeping only one per event chosen at random.
- **Fiducial cuts: 0.01%**
  - Evaluated as change in ΔA_{CP} when cuts are significantly loosened.
- **Sum in quadrature: 0.11%**

Result

$$\Delta A_{CP} = [-0.82 \pm 0.21(\text{stat.}) \pm 0.11(\text{sys.})]\,\%$$

Significance: 3.5σ

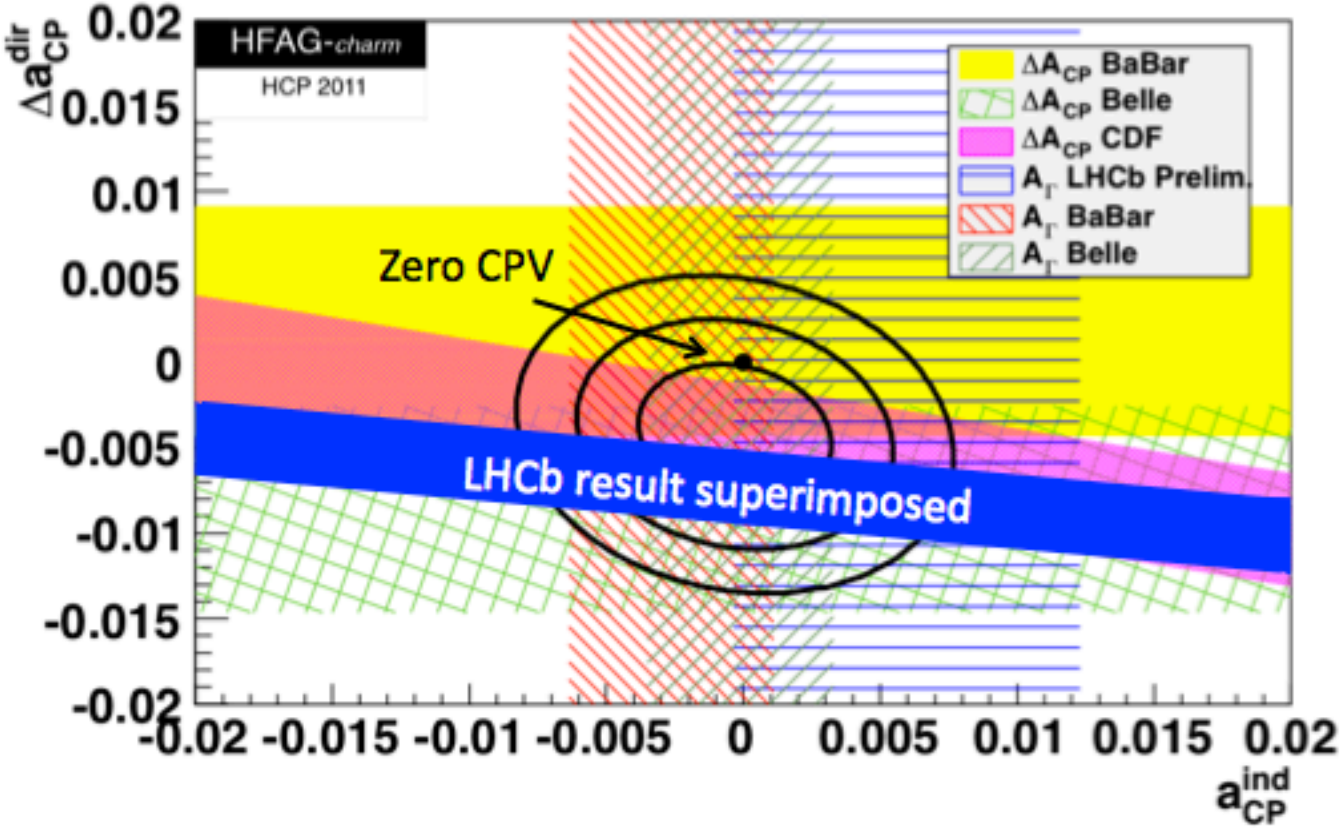
Interpretation: lifetime acceptance

- Lifetime acceptance differs between $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$
  - e.g. smaller opening angle => short-lived $D^0 \rightarrow K^+K^-$ more likely to fail cut requiring daughters not to point to PV than $D^0 \rightarrow \pi^+\pi^-$
- Need this to compute how much indirect CPV could contribute.
- Background-subtracted average decay time of D^0 candidates passing the selection is measured for each final state, and the fractional difference with respect to world average D^0 lifetime is obtained:

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

- Systematics:
  - world-average D^0 lifetime 0.04%
  - fraction of charm from B-hadron decays 0.18%
  - background-subtraction procedure 0.04%
- Remind: $$\Delta A_{CP} = [a_{CP}^{\text{dir}}(K^-K^+) - a_{CP}^{\text{dir}}(\pi^-\pi^+)] + \frac{\Delta\langle t\rangle}{\tau} a_{CP}^{\text{ind}}$$
- ... so indirect CP violation mostly cancel

Comparison with the world average



LHCb measurement, interpreted assuming no a_{CP}^{ind}, is consistent with HFAG averages based on previous results (1.1 sigma)

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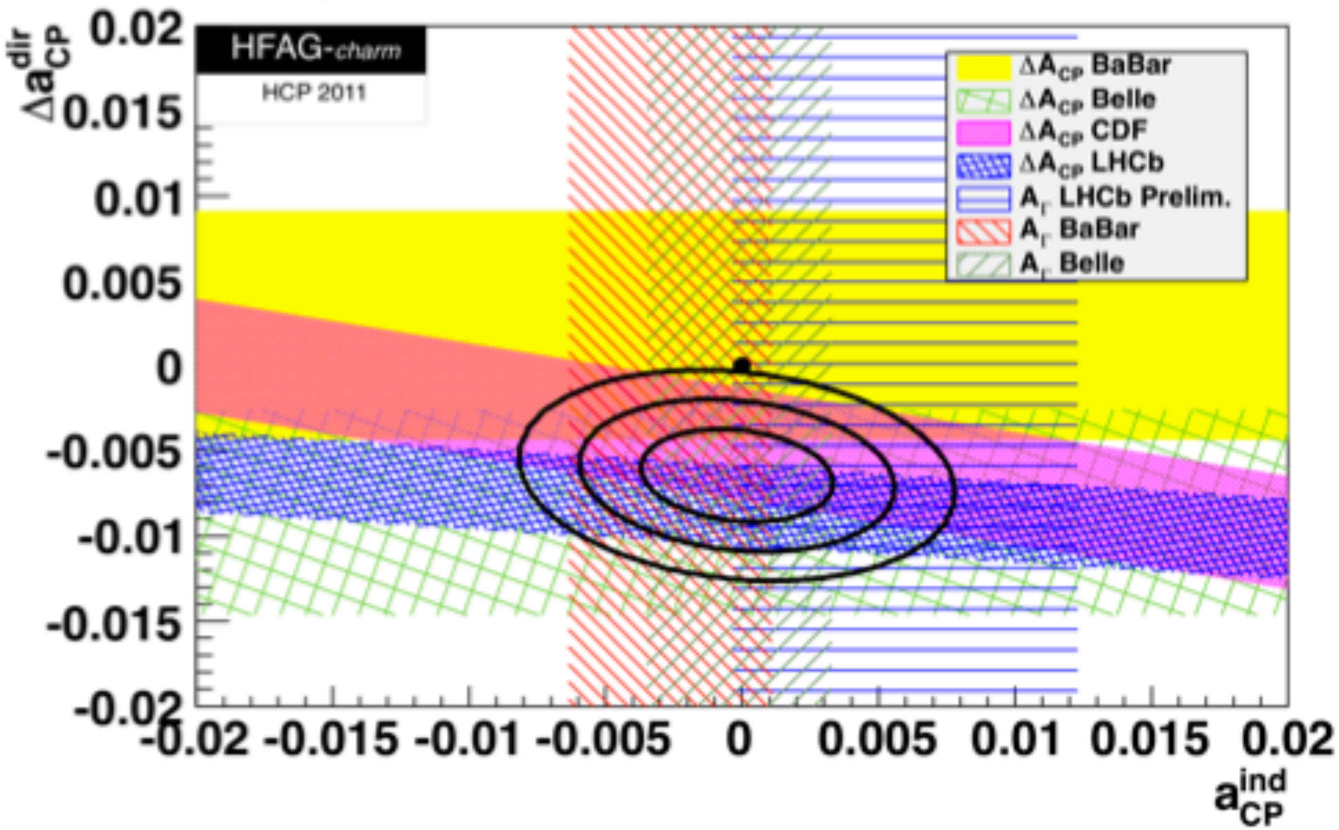
New HFAG combination
(with LHCb result)



$$a_{CP}^{ind} = (-0.02 \pm 0.23)\% \qquad \Delta a_{CP}^{dir} = (-0.65 \pm 0.18)\%$$

Consistency with NO CP violation: 0.15%

LHCb Prospects

- Current measurement of ΔA_{CP} performed with 60% of 2011 recorded sample
  - To establish whether this result is consistent with the SM will require the analysis of more data (work in progress, as well as improved theoretical understanding
- Measure ΔA_{CP} with D^0 from B semileptonic decays
- Look for direct CPV in other SCS modes, especially 3 body ones
- In addition to direct CPV search, perform time dependent measurements to look for indirect CPV, i.e. A_Γ and studies of $D^0 \to K_S hh$

Summary

First evidence of CP violation in charm sector

$$\Delta A_{CP} = [-0.82 \pm 0.21(\text{stat.}) \pm 0.11(\text{sys.})]\,\%$$

Significance 3.5σ (incl. statistical and systematic uncertainties)

Our value is consistent with HFAG average (1σ)

Magnitude of central value larger than current SM expectation ... but charm is notoriously difficult to pin down theoretically

Looking forward to more data and many new charming results!

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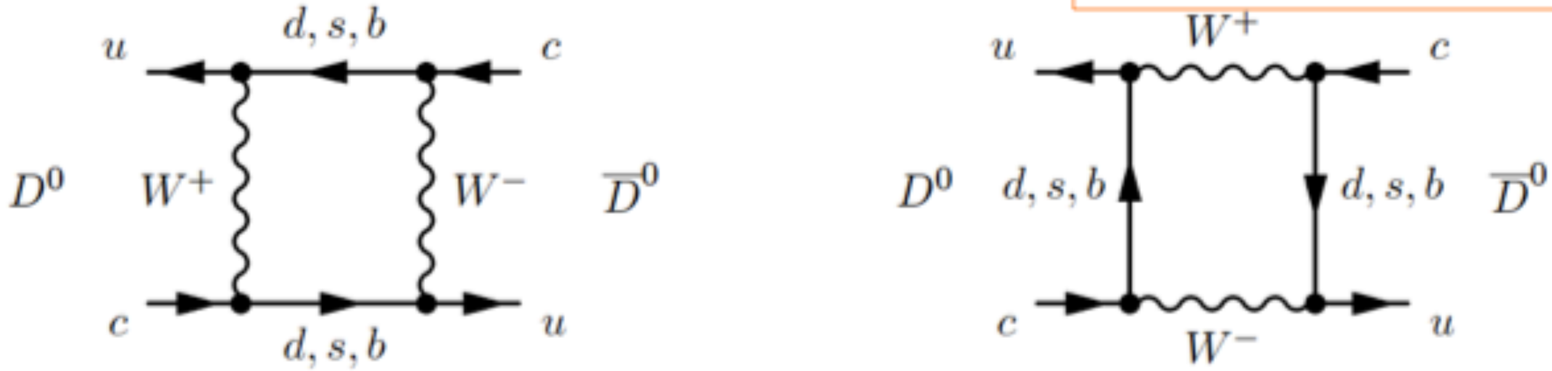
Additional information

Why search for CP violation in charm ?

CP-violating asymmetries in the charm sector provide a unique probe for physics beyond the Standard Model (SM)

Interest increased in the past few years since evidence for D^0 mixing was first seen

BaBar, Belle,
arXiv:hep-ex/0703020
arXiv:hep-ex/0703036

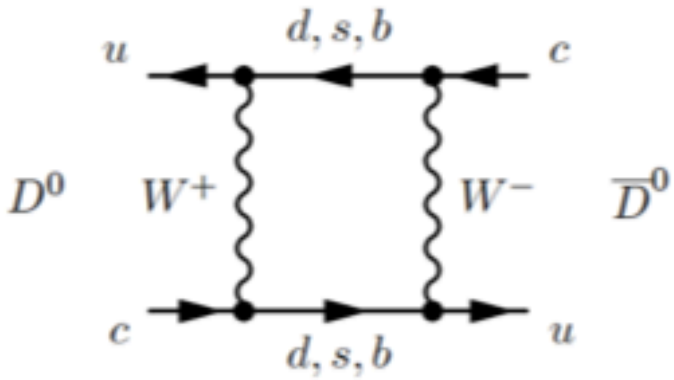


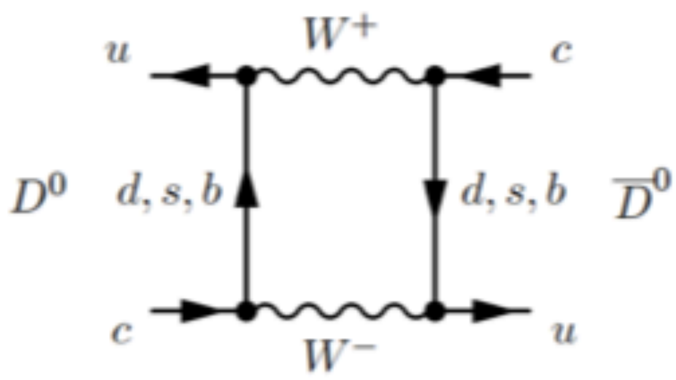
Why search for CP violation in charm ?

D^0 mixing is well established at a level which is consistent with, but at the upper end of SM expectations

HFAG arXiv:1010.1589

No evidence for CP violation in charm decays has yet been found





Experimental status
(individual A_{CP})

Year	Experiment	CP Asymmetry in the decay mode D0 to π+π-	[Γ(D0)-Γ(D0bar)]/[Γ(D0)+Γ(D0bar)]
2010	CDF	M.J. Morello (CDF Collab.), Preprint (CHARM 2010).	+0.0022 ± 0.0024 ± 0.0011
2008	BELLE	M. Staric et al. (BELLE Collab.), Phys. Lett. B 670, 190 2008).	+0.0043 ± 0.0052 ± 0.0012
2008	BABAR	B. Aubert et al. (BABAR Collab.), Phys. Rev. Lett. 100, 061803 (2008).	-0.0024 ± 0.0052 ± 0.0022
2002	CLEO	S.E. Csorna et al. (CLEO Collab.), Phys. Rev. D 65, 092001 (2002).	+0.019 ± 0.032 ± 0.008
2000	FOCUS	J.M. Link et al. (FOCUS Collab.), Phys. Lett. B 491, 232 (2000).	+0.048 ± 0.039 ± 0.025
1998	E791	E.M. Aitala et al. (E791 Collab.), Phys. Lett. B 421, 405 (1998).	-0.049 ± 0.078 ± 0.030
.	.	COMBOS average	+0.0020 ± 0.0022

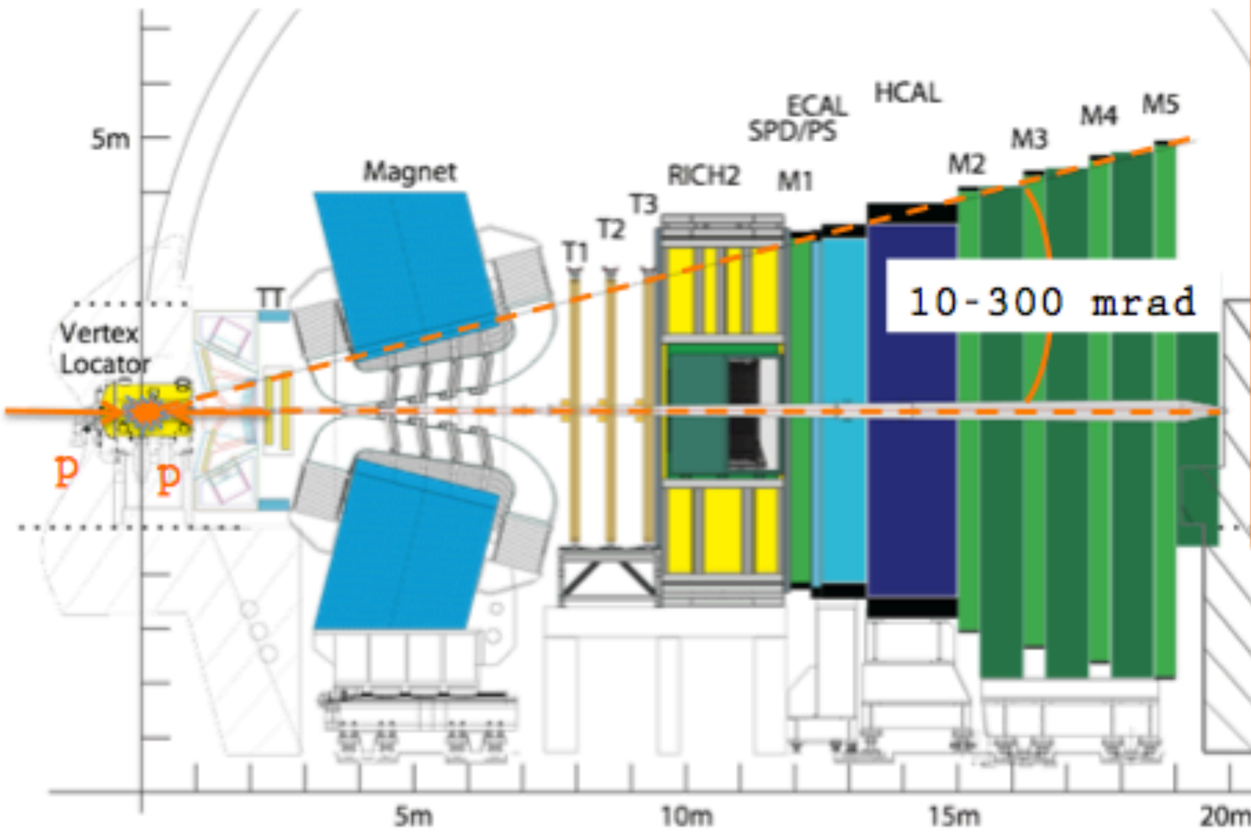
Year	Experiment	CP Asymmetry in the decay mode D0 to K+K-	[Γ(D0)-Γ(D0bar)]/[Γ(D0)+Γ(D0bar)]
2011	CDF	A. Di Canto (CDF Collab.), Preprint (BEAUTY 2011).	-0.0024 ± 0.0022 ± 0.0010
2008	BELLE	M. Staric et al. (BELLE Collab.), Phys. Lett. B 670, 190 (2008).	-0.0043 ± 0.0030 ± 0.0011
2008	BABAR	B. Aubert et al. (BABAR Collab.), Phys. Rev. Lett. 100, 061803 (2008).	+0.0000 ± 0.0034 ± 0.0013
2002	CLEO	S.E. Csorna et al. (CLEO Collab.), Phys. Rev. D 65, 092001 (2002).	+0.000 ± 0.022 ± 0.008
2000	FOCUS	J.M. Link et al. (FOCUS Collab.), Phys. Lett. B 491, 232 (2000).	-0.001 ± 0.022 ± 0.015
1998	E791	E.M. Aitala et al. (E791 Collab.), Phys. Lett. B 421, 405 (1998).	-0.010 ± 0.049 ± 0.012
1995	CLEO	J.E. Bartelt et al. (CLEO Collab.), Phys. Rev. D 52, 4860 (1995).	+0.080 ± 0.061
1994	E687	P.L. Frabetti et al. (E687 Collab.), Phys. Rev. D 50, 2953 (1994).	+0.024 ± 0.084
.	.	COMBOS average	-0.0023 ± 0.0017

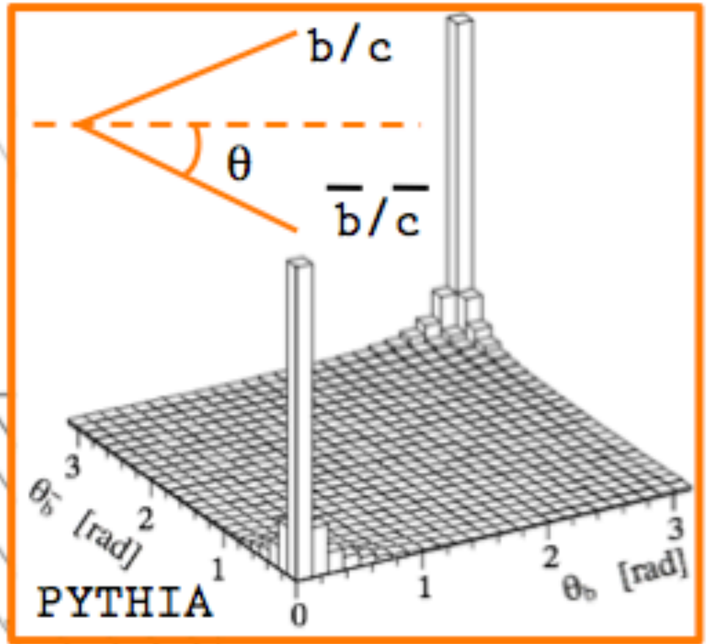
Dominated by CDF, especially for $D^0 \rightarrow \pi^+\pi^-$

K^+K^- and $\pi^+\pi^-$ values consistent with zero but have opposite sign.

The LHCb detector

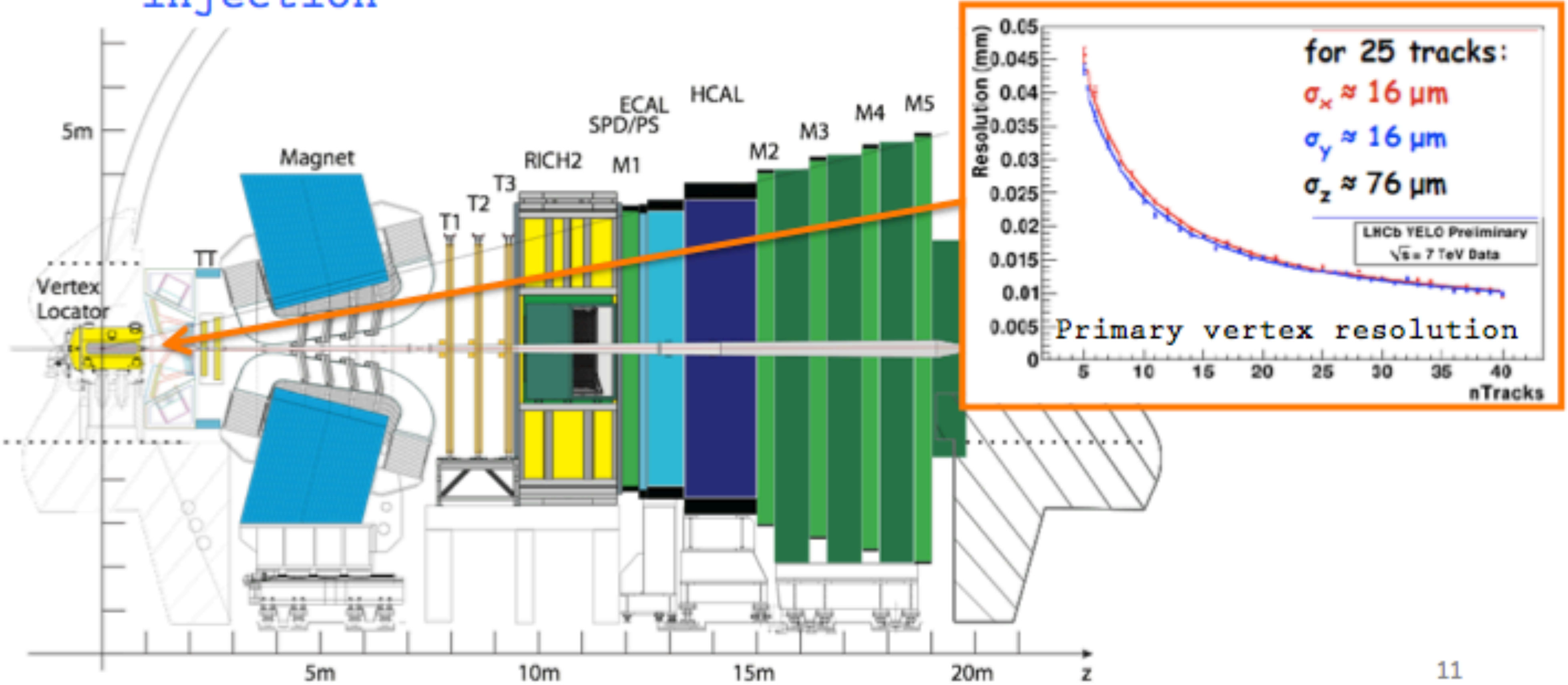
- Forward-peaked production of heavy quarks → LHCb designed as forward spectrometer (operating in collider mode)





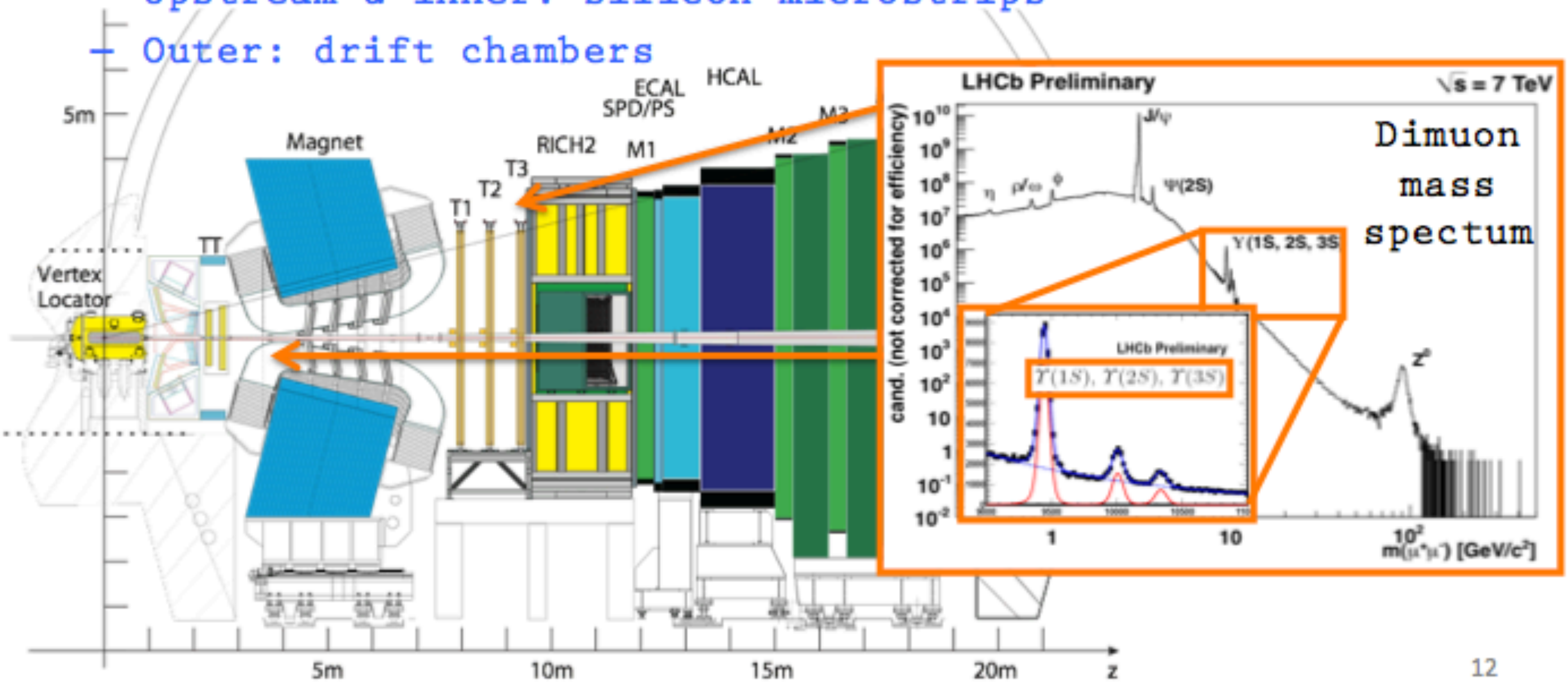
The LHCb detector

- VELO: precision vertexing
  - 42x2 silicon planes, strip pitch 40-100 μm
  - 7mm from beam during data-taking retracted during injection



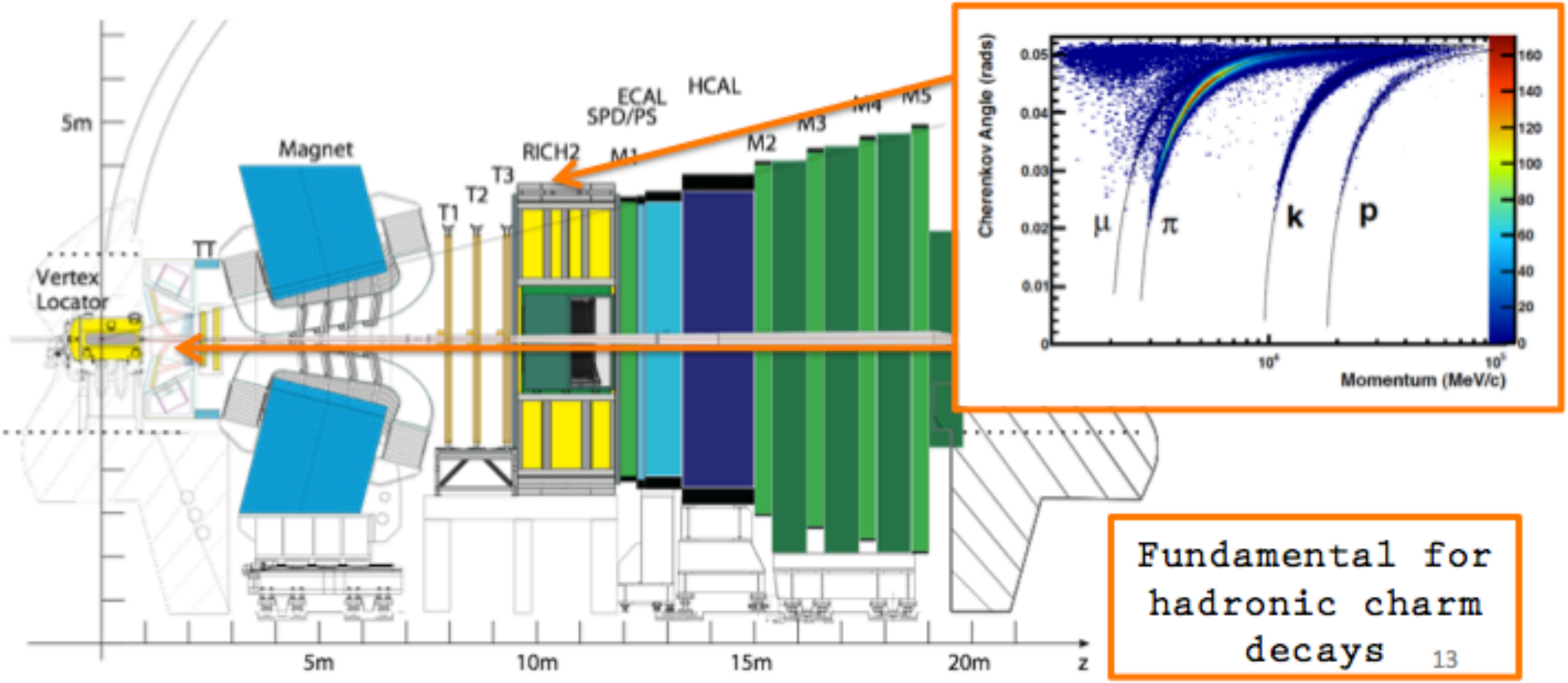
The LHCb detector

- TRACKER systems
  - Magnetic field reverse during data taking, integrated B field 4 Tm. Momentum resolution 0.4-0.6%
  - Stations upstream and downstream of magnet
  - Upstream & inner: silicon microstrips
  - Outer: drift chambers



The LHCb detector

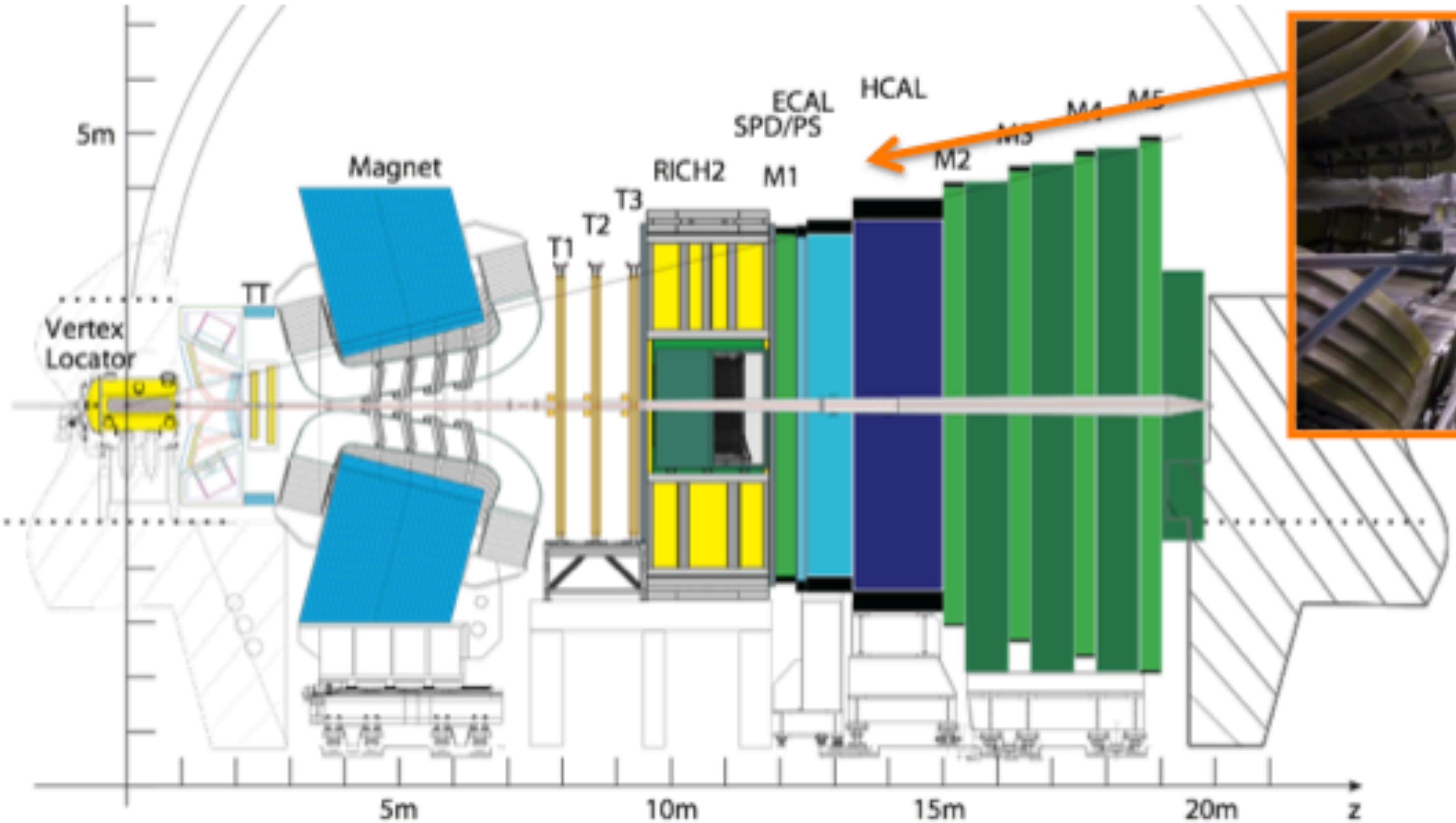
- RICH detectors: hadron ID
  - RICH1 uses aerogel and C_4F_{10} to cover 2-60 GeV/c
  - RICH2 uses CF_4 to cover 20-100 GeV/c
  - Excellent π/K/p separation up to 100 GeV/c



Fundamental for hadronic charm decays 13

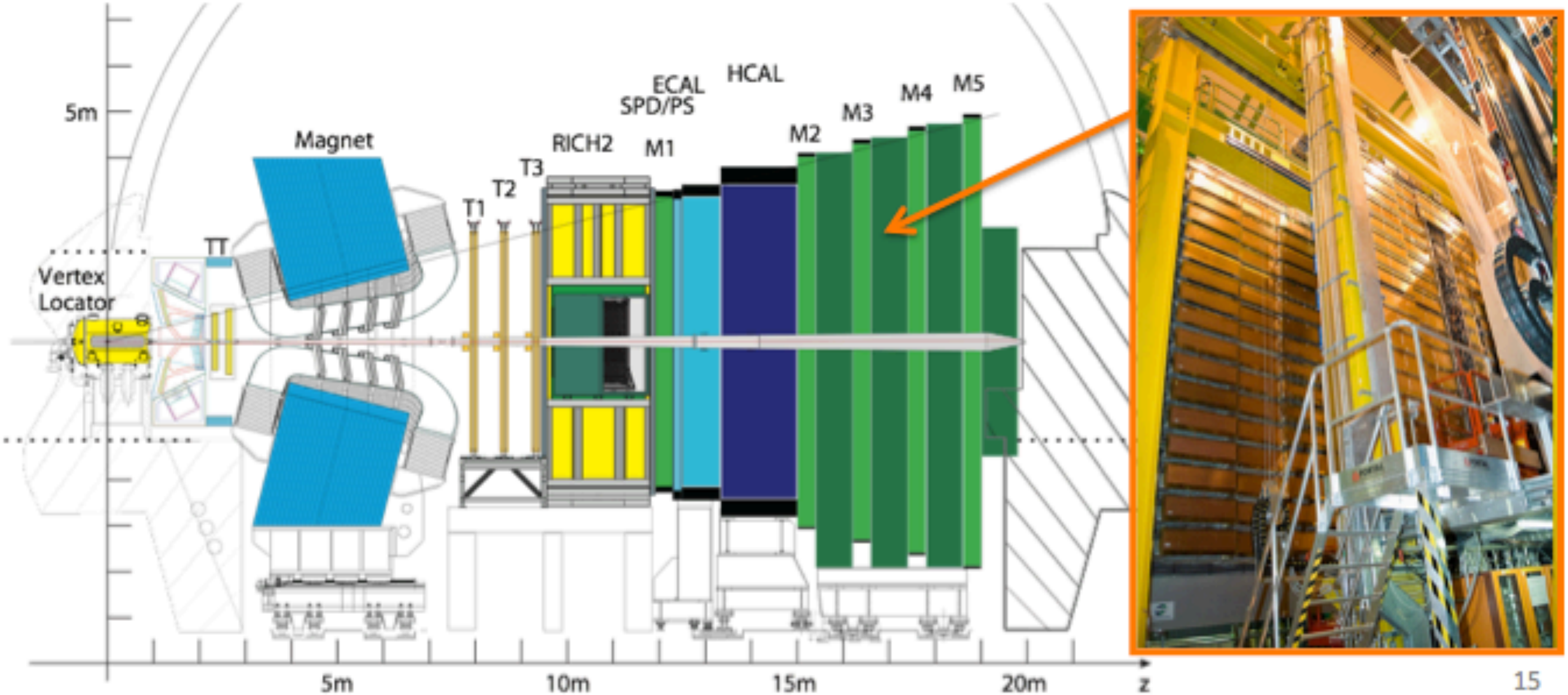
The LHCb detector

- CALORIMETERS: trigger, photon/electron ID
  - Preshower + SPD + electromagnetic + hadronic calorimeters
  - Vital for hardware-level hadron triggering

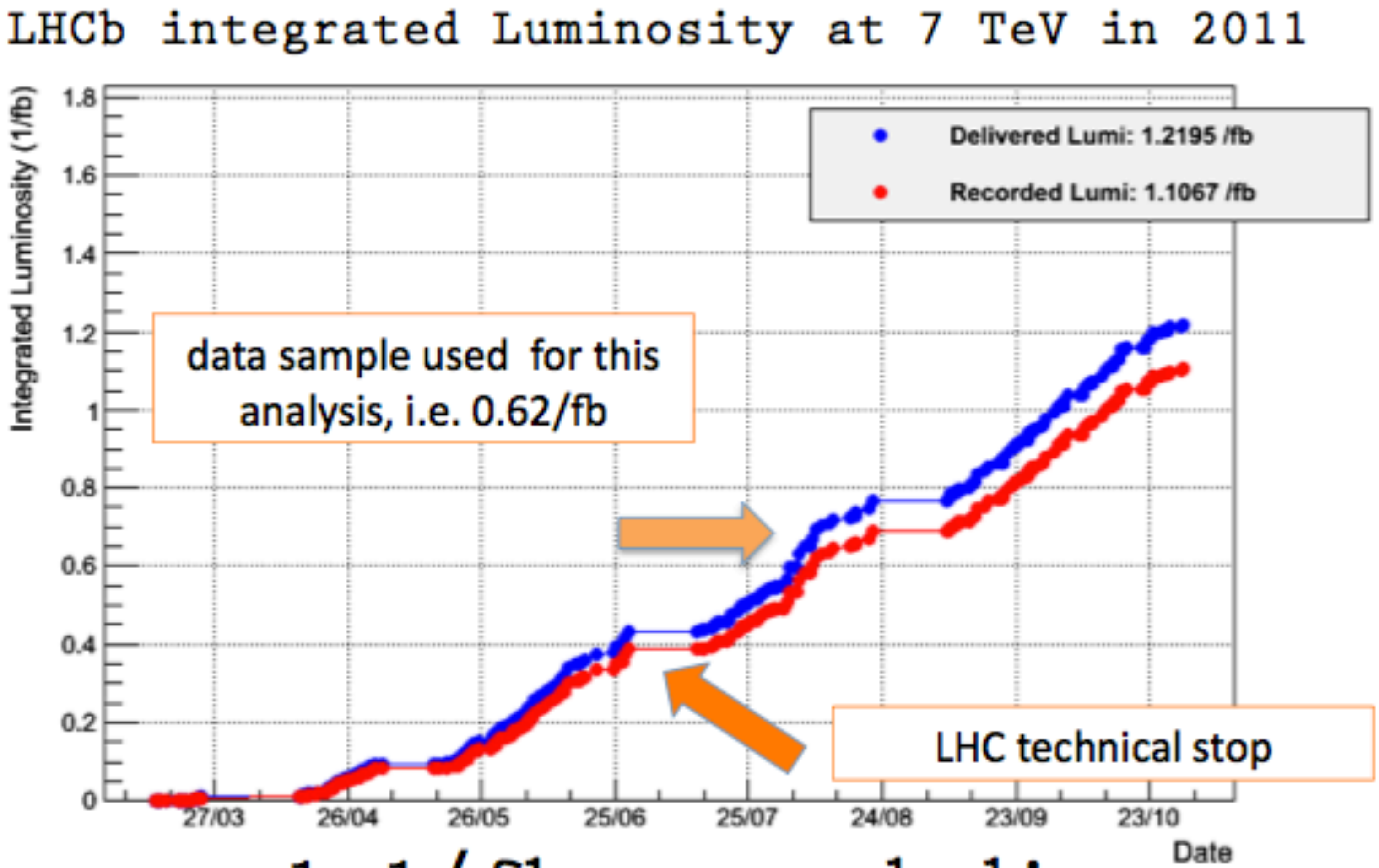


The LHCb detector

- **MUON STATIONS: muon ID**
  - Five stations, used also in hardware trigger.
  - Excellent muon/pion separation (single hadron mis-ID rate 0.7% Phys. Lett. B699 (2011) 330)



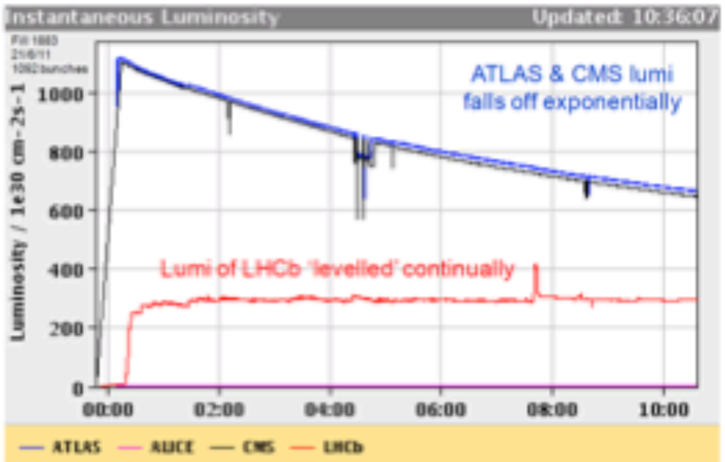
Data-taking

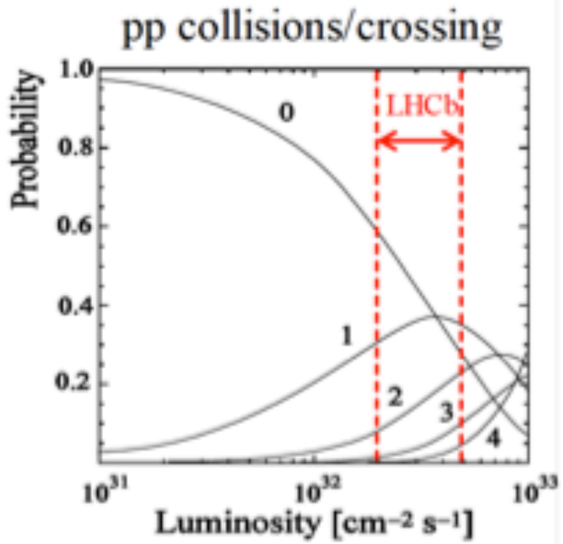


1.1/fb recorded!

Running strategy

- LHCb has different runnings condition with respect to ATLAS and CMS
  - lower luminosity at the interaction point
- LHCb ran above its design luminosity
  - Average $L \sim 3 \times 10^{32}$ $cm^{-2}s^{-1}$ (nominal 2×10^{32})
  - less bunches than nominal (50 ns bunch spacing)
- Need to cope with higher occupancies
  - More pile-up: average $\mu \sim 1.5$ (nominal 0.5)
  - Continuous, automatic adjustment of offset of colliding beams.





The trigger
(from charm point of view)

LHC bunch-crossing frequency
Max possible 40 MHz
Visible collision 10 MHz

↓ 10 MHz

L0:hardware trigger
Hadrons: require cluster with high E_T
Also muon, electron triggers

↓ 1 MHz

HLT1:inclusive software trigger
Hadrons: require track with high IP, p_T
Also muon, electron and other triggers

↓ 50 kHz

HLT2:exclusive software trigger
Require fully reconstructed D^0, D^+, D_s^+

→ 3 kHz

Storage
About 3kHz total rate
1kHz charm[20]

After hardware trigger we already have 50% $c\bar{c}$ events (500 kHz).

No possibility of an inclusive charm trigger!

Instead, we select useful/ reconstructable events from the most sensitive modes.

Time-integrated CP asymmetry
(what we measure at LHCb)

- What we measure is the physical asymmetry plus asymmetries due both to production and detector effects

First order expansion assumes raw asymmetry not large
- ... which is true: O(%)

$$A_{\rm raw}(f) = A_{CP}(f) + A_{\rm D}(f) + A_{\rm D}(\pi_{\rm s}) + A_{\rm P}(D^{*+})$$

- $A_{CP}(f)$: Physics CP asymmetry
- $A_{\rm D}(f)$: Detection asymmetry of D^0
- $A_{\rm D}(\pi_{\rm s})$: Detection asymmetry of "slow" pions
- $A_{\rm P}(D^{*+})$: Production asymmetry

- $D/\overline{D}$ (as well as $B/\overline{B}$) production asymmetries need to be taken into account in proton-proton interactions at LHC

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Time-integrated CP asymmetry
(what we measure at LHCb)

- What we measure is the physical asymmetry plus asymmetries due both to production and detector effects

First order expansion assumes raw asymmetry not large
– ... which is true: O(%)

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

Physics CP asymmetry

Detection asymmetry of D^0

Production asymmetry

Detection asymmetry of "slow" pions

- No detection asymmetry for D^0 decays to K^-K^+ or $\pi^-\pi^+$

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Event selection

The following offline selection cuts have been applied on events which fired the software trigger explicitly on D^0 candidate:

Track fit quality for all the tracks

D^0 and $D^{*\pm}$ vertex fit quality

Transverse momentum of D^0 (p_T>2 GeV)

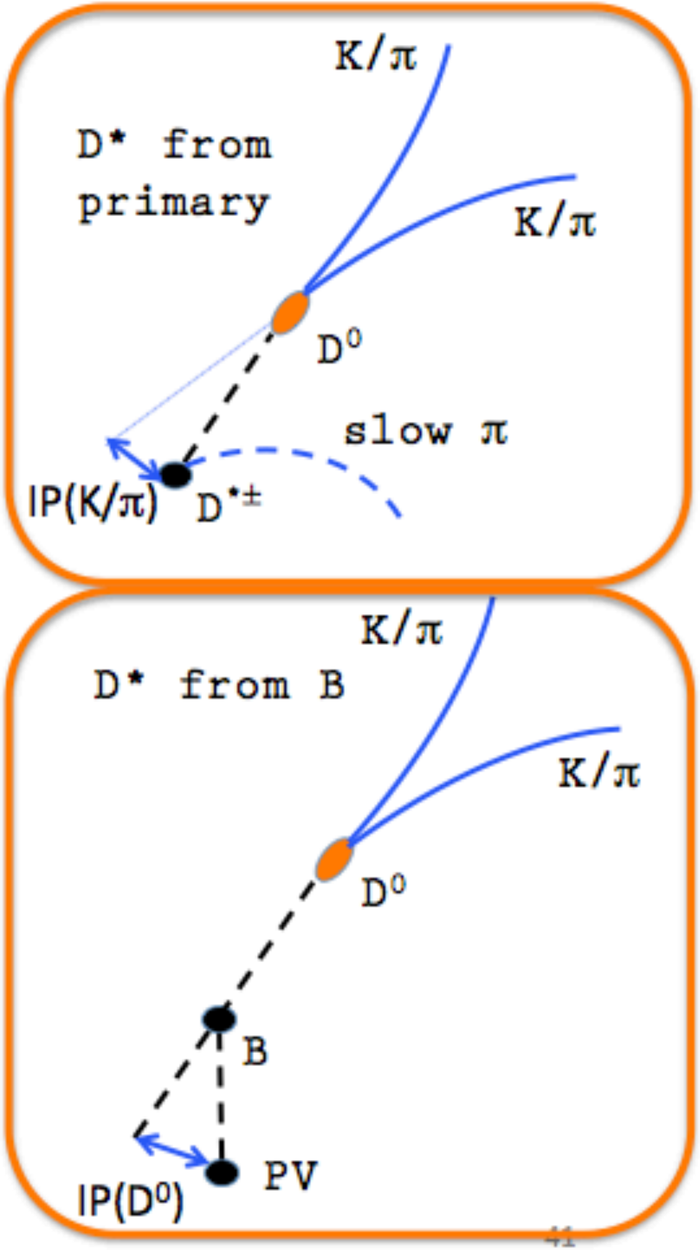
Proper lifetime of D^0 (ct>100μm)

Angle between the D^0 momentum in the lab frame and its daughter momenta in the D^0 rest frame (|cos θ| <0.9)

D^0 must point back to primary vertex (reject D^0 coming B)

→ 3% of B contamination after this cut

→ only lifetime measurements effected not ΔA_{CP}



Event selection

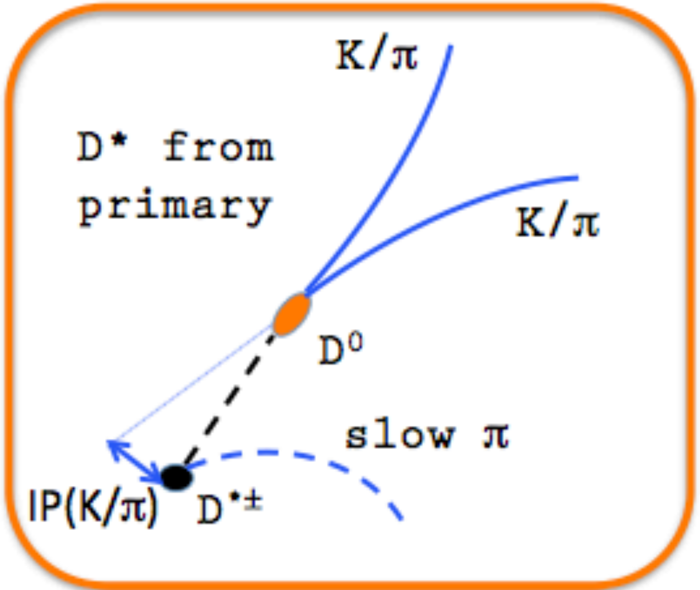
The following offline selection cuts have been applied on events which fired the software trigger explicitly on D^0 candidate:

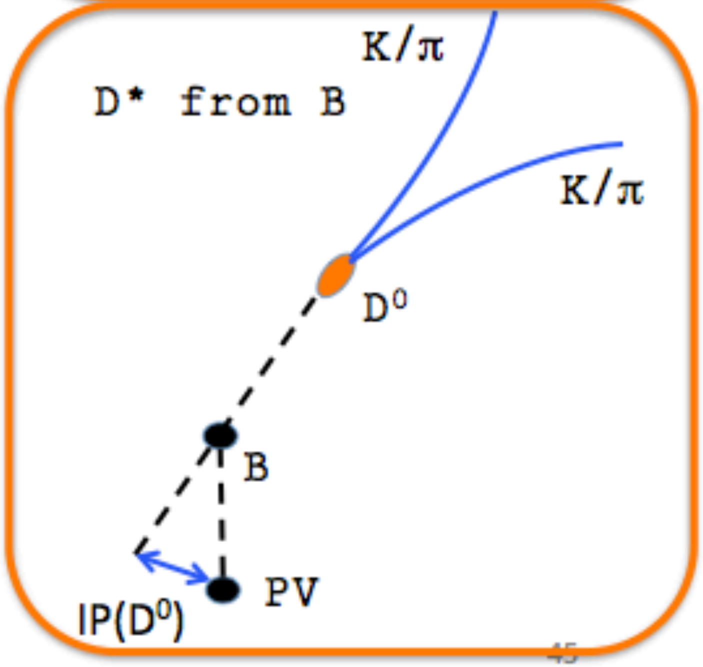
D^0 daughter tracks must not point back to the primary

Kaon/pion hadron ID cuts imposed with RICH information

Fiducial cuts to exclude edges where the B-field caused large D^{*+}/D^{*-} acceptance asymmetry

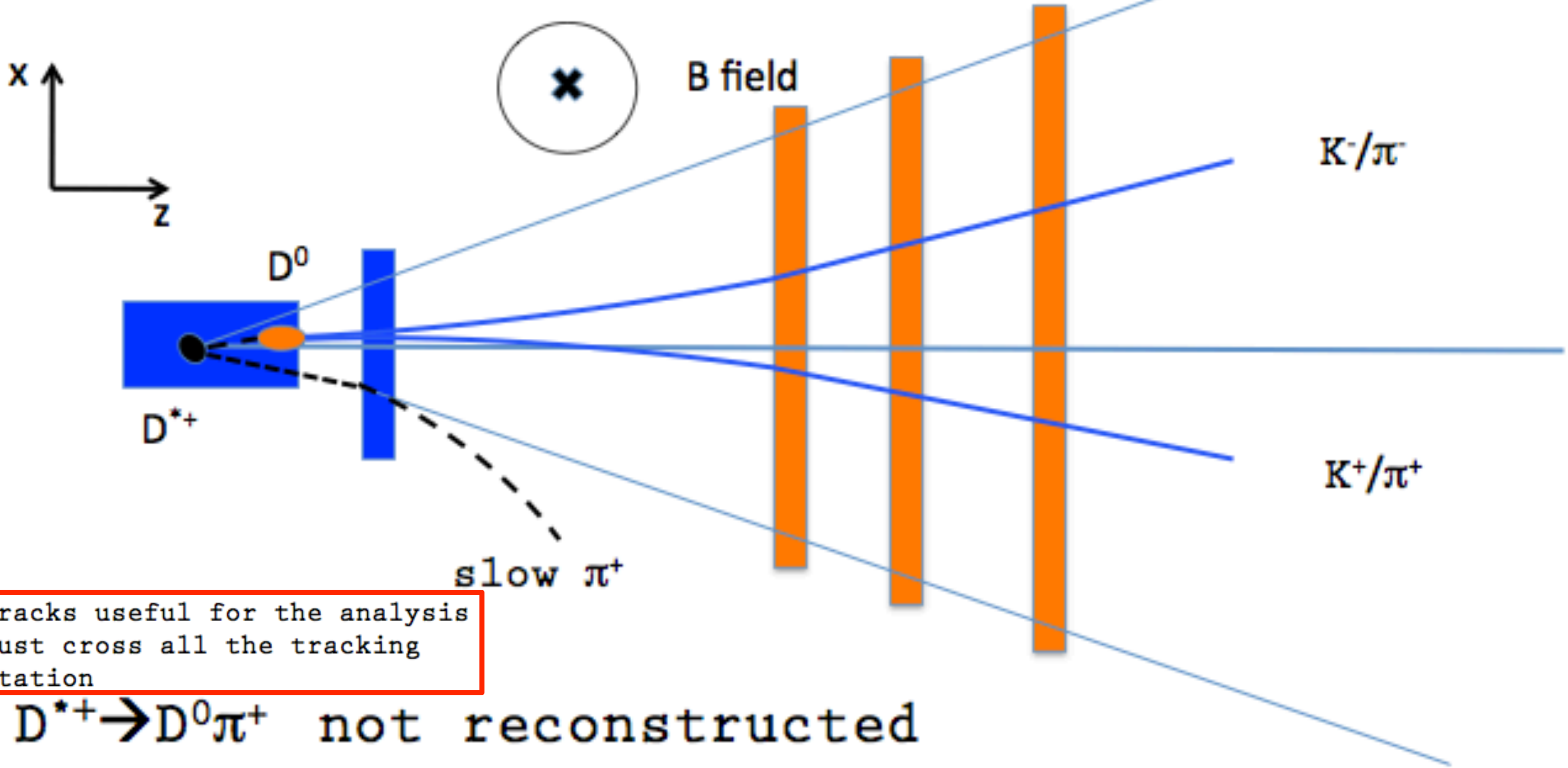
D^0 mass window ($1844 < m(D^0) < 1884$ MeV/c^2)





D^{*+}/D^{*-} reconstruction efficiency

LHCb simplified bending plane view
Only tracking systems shown
Arbitrary scale used



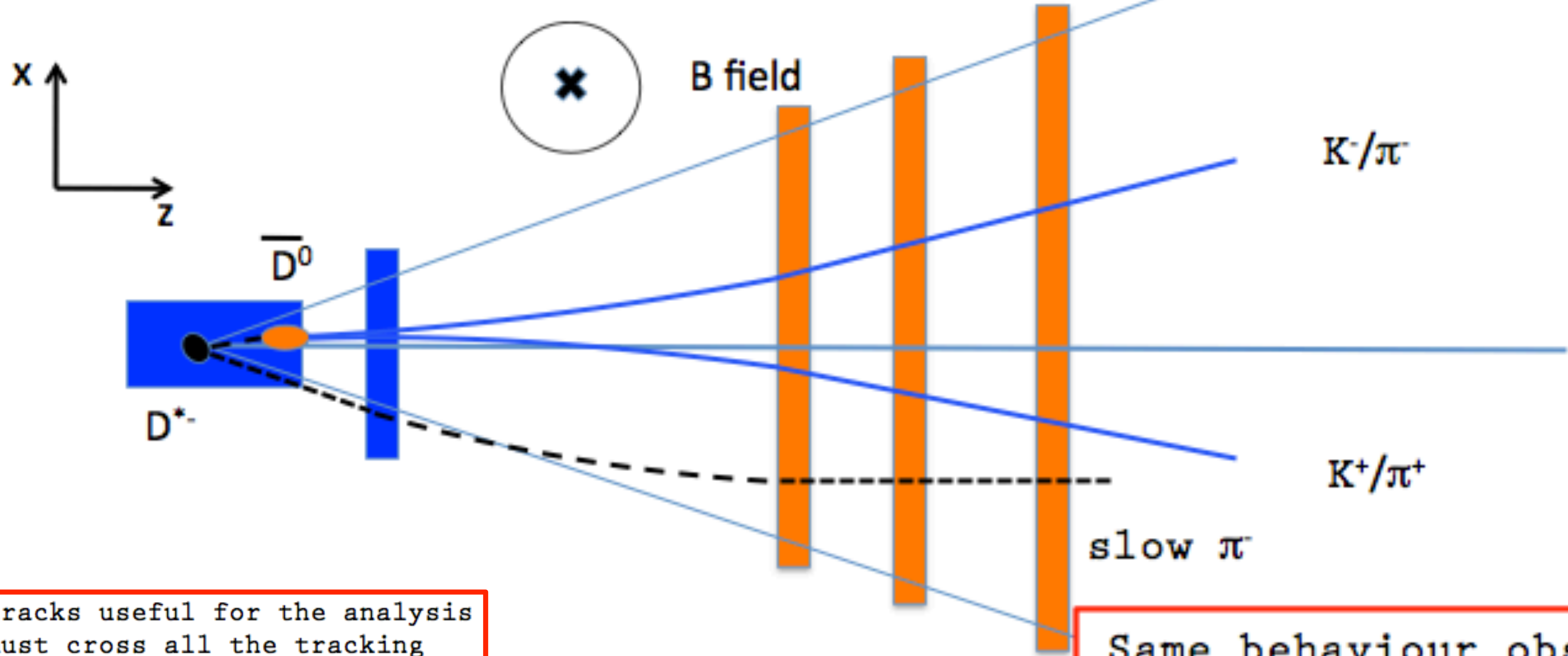
tracks useful for the analysis must cross all the tracking station

$D^{*+} \rightarrow D^0\pi^+$ not reconstructed

48

D^{*+}/D^{*-} reconstruction efficiency

LHCb simplified bending plane view
Only tracking systems shown
Arbitrary scale used



tracks useful for the analysis must cross all the tracking station

$D^{*+} \to D^0\pi^+$ not reconstructed
$D^{*-} \to D^0\pi^-$ reconstructed

Same behaviour observed also for tracks which cross the beam-pipe, (i.e. small $|P_y/P_z|$ of slow π)

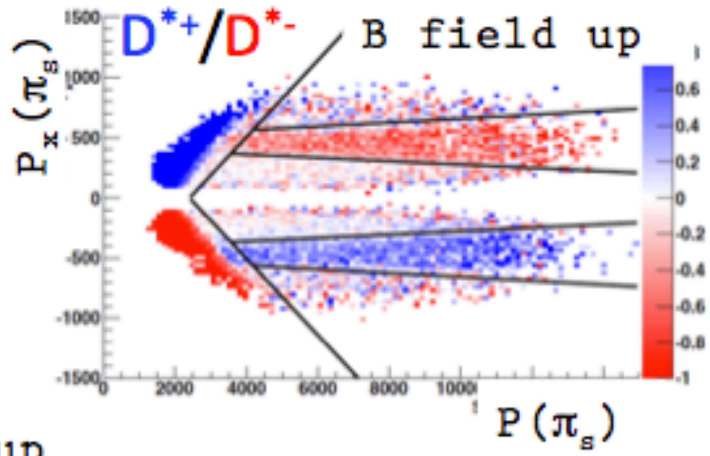
Fiducial cuts

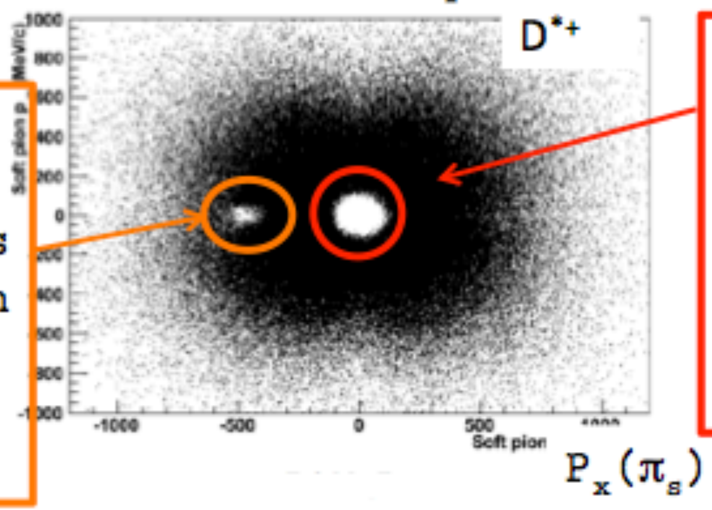
- The edge regions are therefore excluded with cuts in the slow pion(P_x,P) plane.

Further 5% events rejected

Raw asymmetry of
$D^{*+} \to D^0(KK)\pi^+$ + cc in the
(P_x,P) plane of slow pion

$|P_y/P_z|$(slow π)<0.2
beam pipe region





Soft pions swept through the beam pipe where there is no tracking station
These events are lost
Charged dependent

Soft pions go directly into the beam pipe
(low P_x and P_y)
These events are lost
No charge dependents

Fiducial cuts

- The edge regions are therefore excluded with cuts in the slow pion(P_x,P) plane. Further 5% events rejected

Raw asymmetry of
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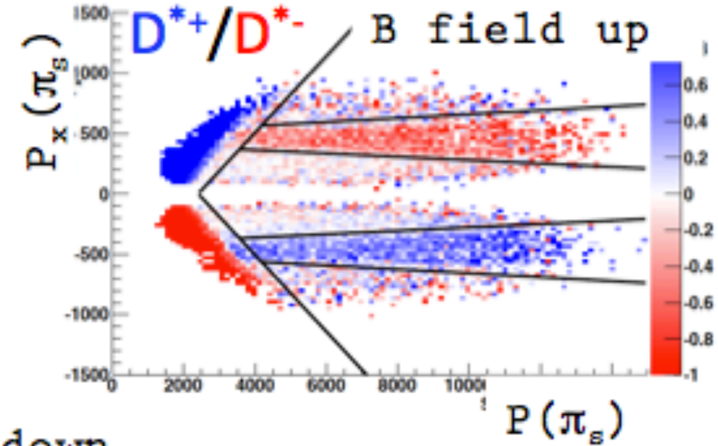

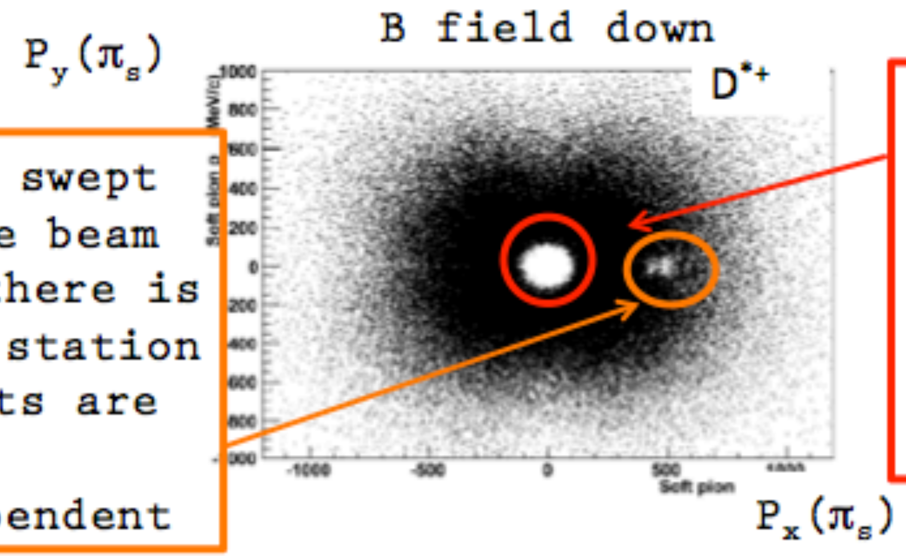

Soft pions swept
through the beam
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These events are
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Charged dependent

Soft pions go
directly into the
beam pipe
(low P_x and P_y)
These events are
lost
No charge dependents

Further cross checks

- Numerous crosschecks carried out, including:
  - Electron and muon vetoes on the soft pion and on the 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 D^0 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, etc)

Tightening of PID cuts on D^0 daughters

- The measurement is repeated with progressively more restrictive RICH particle identification requirements, finding values

tight PID cut	tight++ PID cut
$(-0.88 \pm 0.26)\%$	$(-1.03 \pm 0.31)\%$

- consistent with the baseline result

Peaking background

- Mis-reconstructed D^{*+} decays that peaks in δm but not $m(D^0)$, i.e.:
  - $D^{*+} \rightarrow D^0(K^-\pi^+\pi^0)\pi^+$, where the π^0 is missing and the π^- is mis-reconstructed as K or proton
  - Semi-leptonic D^0 decays
- Background studied on δm from the D^0 sidebands, upper and lower, after signal-subtraction, leaving the component that does not peak in $m(D^0)$.
- Estimated to be 1% both for KK and $\pi\pi$.
- Systematic evaluated with toy studies injecting peaking background with a level and asymmetry from this study.

LHC as a charm and beauty factory

Large production of charm and beauty
Cross sections at $\sqrt{s}$=7 TeV measured by LHCb:
$\sigma_{b\bar{b}}(pp \rightarrow bbX) = (284 \pm 20 \pm 49)\mu b$
$\sigma_{c\bar{c}}(pp \rightarrow ccX) = (6.10 \pm 0.93) mb$
charm is ~20 times more abundant than beauty

Phys. Lett. B694: 209-216, 2010
LHCb-CONF-2010-013

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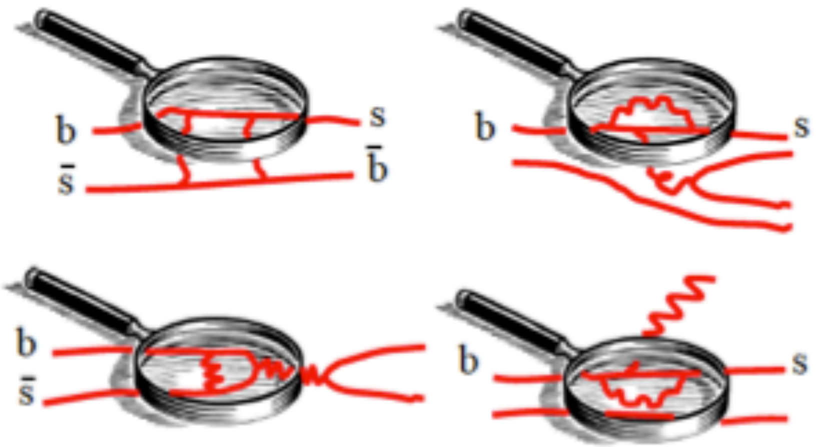
The LHCb experiment

LHCb is the dedicated flavour physics experiment at the LHC

ATLAS and CMS search for the direct production of new states

LHCb is designed to search for the indirect effect of such states on charm and beauty decays via virtual production



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