Results and prospects for Charm Physics at LHCb

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on behalf of the LHCb Collaboration

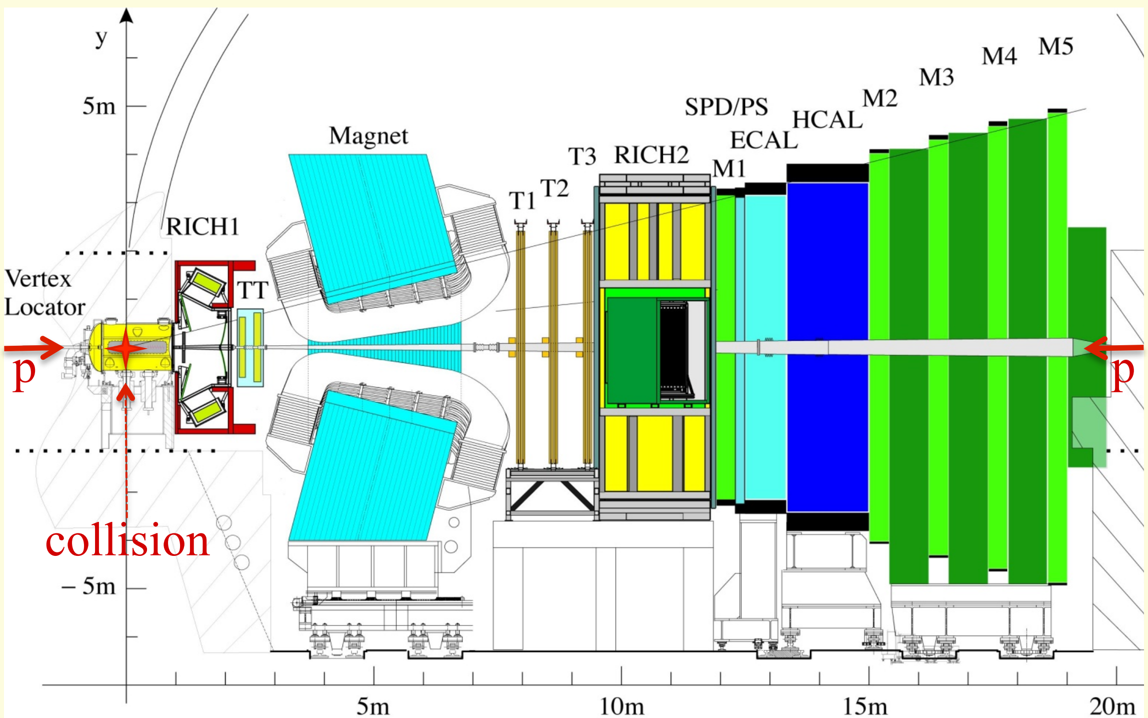
Meeting of the Division of Particles and Fields of the American Physical Society

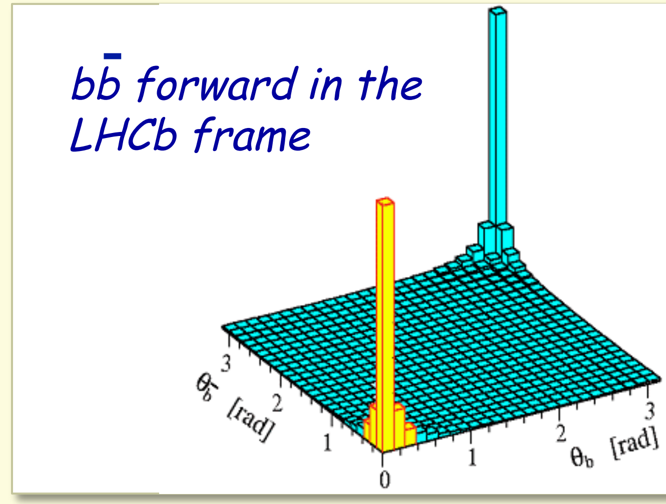
Outline

- LHCb experiment
- Charm physics
- LHCb measurement in the charm sector:
  - Search of CP violation in $D^+ \rightarrow K^- K^+ \pi^+$ [LHCb-Paper in preparation]
  - Measurements of direct and indirect CP violation: A_Γ [LHCb-CONF-2011-046] and ΔA_{CP} [LHCb-CONF-2011-023]
- Conclusion

The LHCb experiment

- LHCb is an experiment dedicated to heavy flavour physics at the LHC.
- Its primary goal is to look for indirect evidence of new physics in CP violation and rare decays of beauty and charm hadrons.
- Heavy flavour are produced predominantly close to beam direction



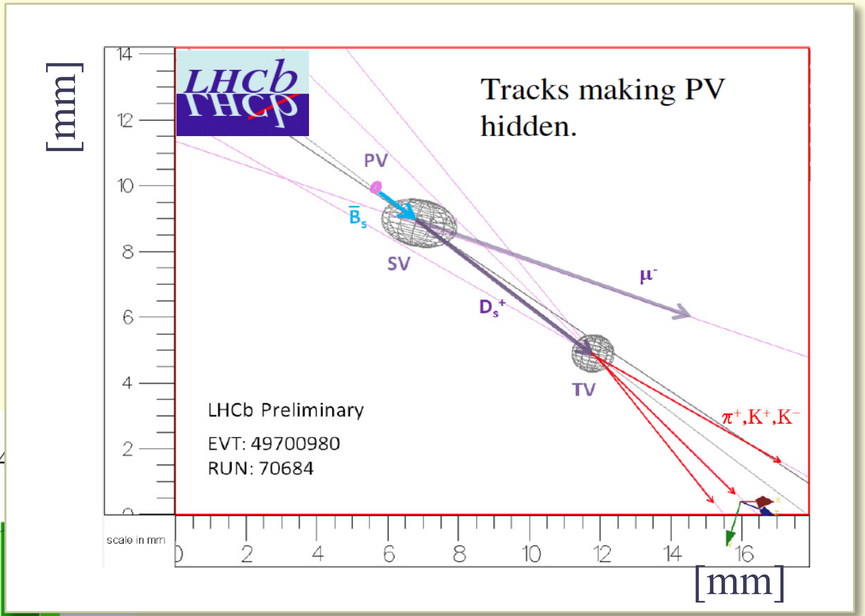


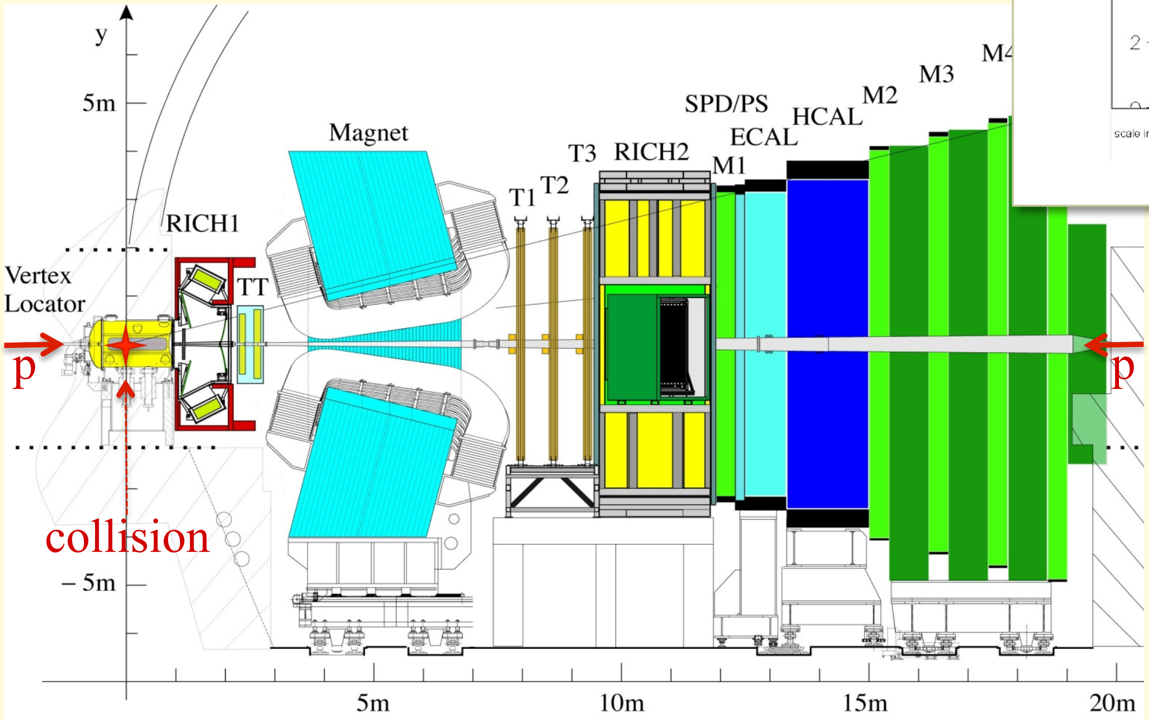
LHCb experiment
⇨Forward spectrometer:
$1.9 < \eta < 4.9$

The LHCb experiment

Main detector requirements for the reconstruction of the flavour decay:

- Excellent vertex resolution : σ_{PV} ~13 μm for x and y
- ➔ Proper-time resolution ~ 50 fs
- Good momentum resolution: $\Delta p/p$ = 0.35% - 0.5%





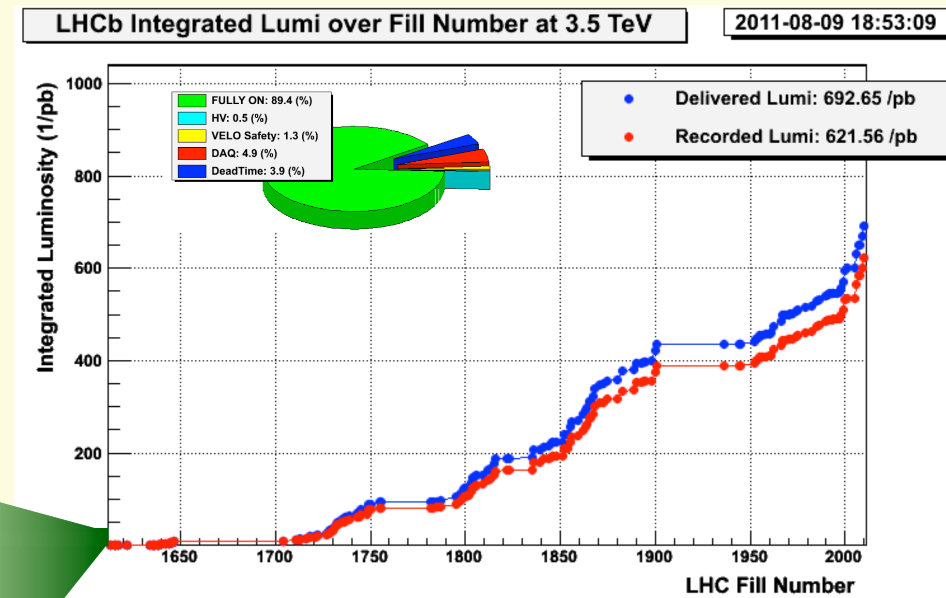
- Good particle identification [K/π separation]
- High efficiency trigger

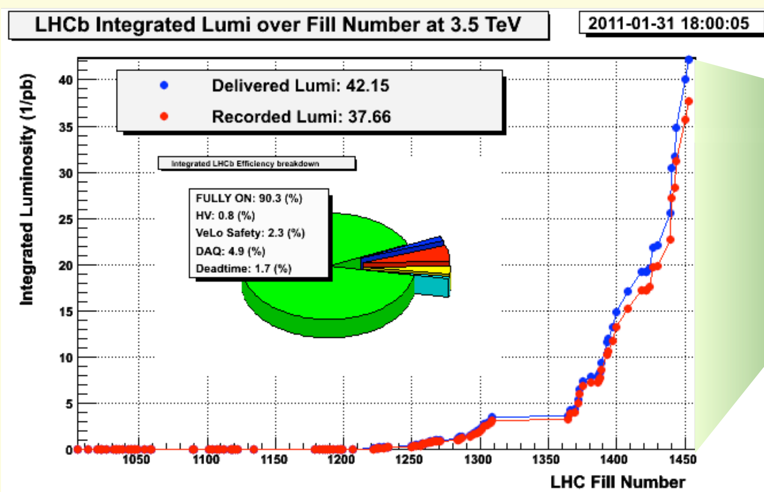
Data Taking

- Results just using 2010 sample with an integrated luminosity of 38 pb^{-1}
- Integrated Luminosity in 2011 (so far…) L= 621 pb^{-1}

➠ a order of magnitude more integrated luminosity in 2011

- Writing out events with fully reconstructed charm hadrons at a rate of 1 kHz





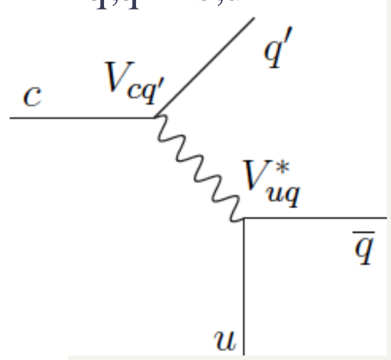
Charm Physics

- CP violation in charm provides a unique probe of New Physics (NP)
  - sensitive to NP in the up sector
  - SM charm physics is CP conserving to first approximation (2 generation dominance)
- CP violation contributions:
  - in mixing: rate of $D^0 \rightarrow \overline{D^0}$ and $\overline{D^0} \rightarrow D^0$ differ
  - in decay: amplitudes for a process and its conjugate differ
  - in interference between mixing and decay diagrams
- In singly-Cabibbo-suppressed modes (10^{-4}) plausible, $O(10^{-3})$ possible

Three types of D into 2 body decay:

- Cabibbo Favored (SC): $D^0 \rightarrow K^- \pi^+$
- Singly Cabibbo Suppressed (SCS): $D^0 \rightarrow K^- K^+$; $D^0 \rightarrow \pi^- \pi^+$
- Doubly Cabibbo Suppressed (DCS): $D^0 \rightarrow K^+ \pi^-$

q,q' = s,d

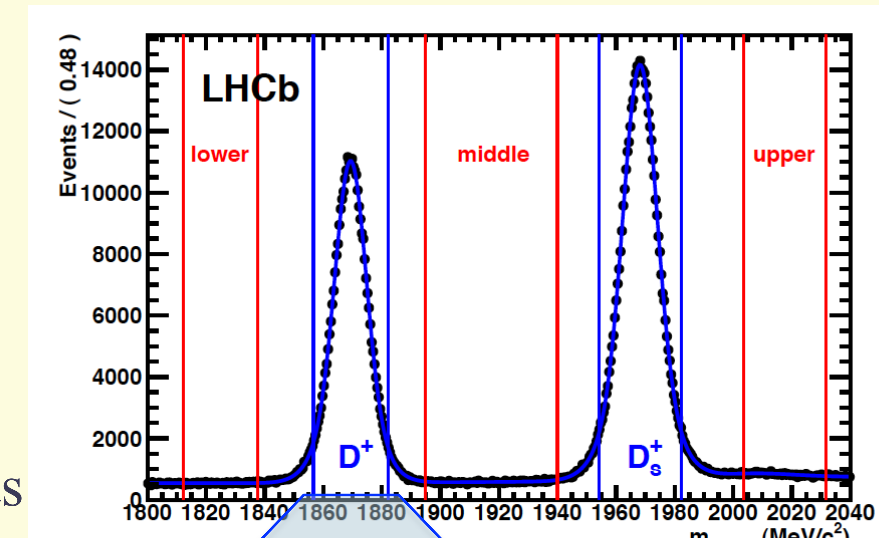


Search of CP violation in $D^+ \rightarrow K^- K^+ \pi^+$

[LHCb-Paper in preparation]

Search of CP violation in $D^+ \to K^- K^+ \pi^+$

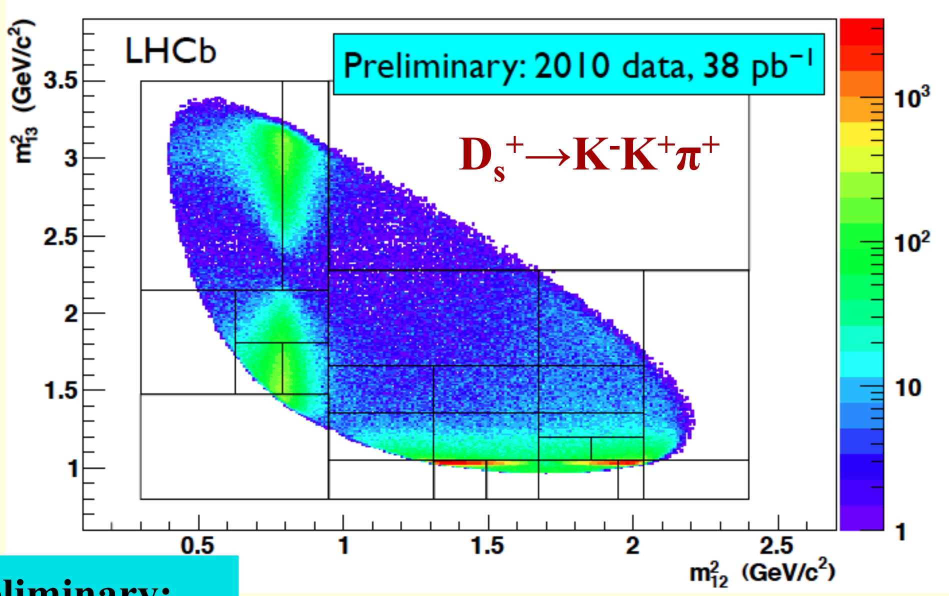
- Model independent search for direct CP violation in the SCS decay $D^+ \to K^- K^+ \pi^+$
- 2010 data L~38 pb^{-1} ⇨ 10 and 20 times more signal event than in previous BaBar and CLEO-c results
- Direct comparison on a bin-by-bin basis between D^+ and D^- Dalitz plots ⇨ a local CP asymmetry
  - Different binning schemes (sensitive to range of CPV scenarios)
- Method based on Miranda approach:
  [Phys. Rev. D80 (2009) 096006]
  - Asymmetry significance in each bin
  - Evaluation of the χ^2/ndf ⇨ probability value



Yield of 370k
Purity of 91.5%

Control channels

- Investigation of no CP asymmetries by data-driven method
  - Control channel $D_s^+ \to K^- K^+ \pi^+$
  - Sidebands $D^+ \to K^- K^+ \pi^+$
  - Control channel $D^+ \to K^- \pi^+ \pi^+$
- Combine the two magnet polarities to cancel various small left-right asymmetries



✓ No evidence of fake asymmetries in the control mode

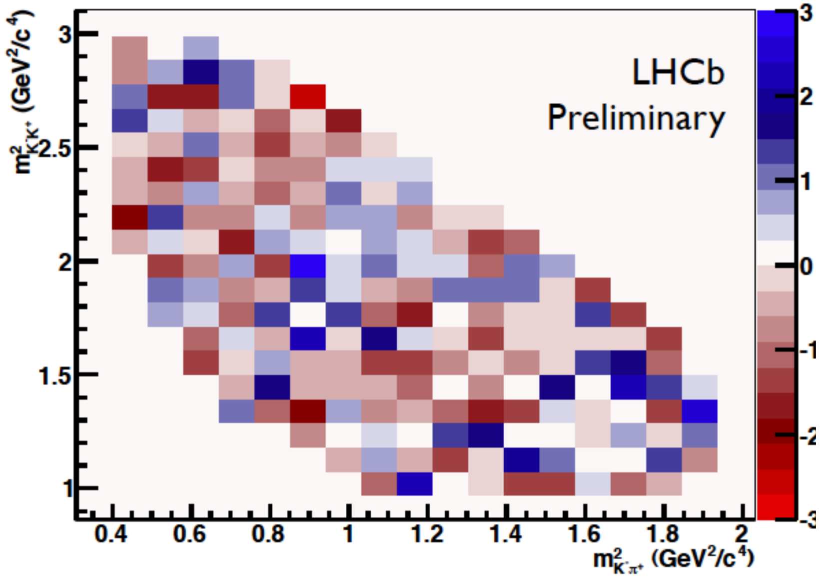
✓ Sidebands around the D^+ signal peak look fine

✓ Method very robust against systematic effects

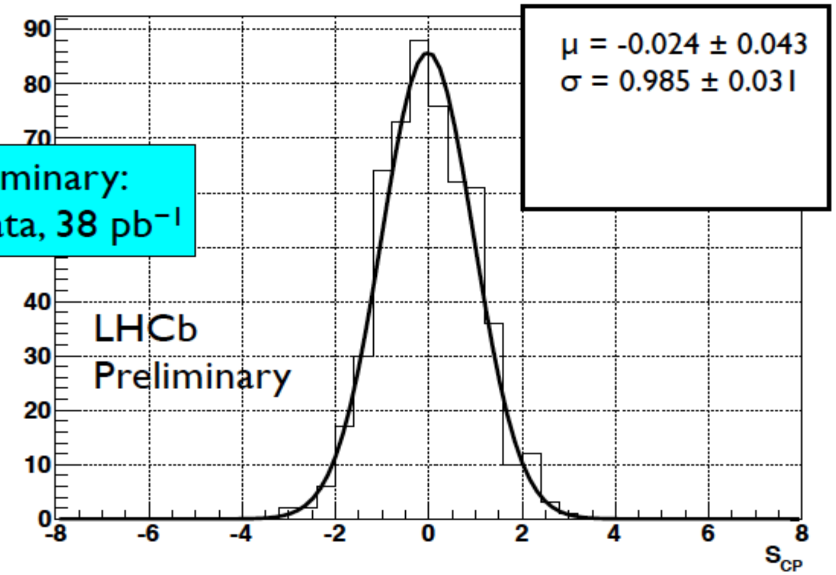
Preliminary: 2010 data, 38 pb^{-1}

Window	Magnet Up	Magnet Down	Combined
Lower sideband	32.7%	10.1%	8.7%
Middle sideband	31.4%	27.7%	50.8%
D_s^+ window	88.9%	15.5%	34.4%
Upper sideband	1.3%	50.7%	26.5%

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



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



LHCb Preliminary	
Magnet Up	6.0%
Magnet Down	28.5%
Combined	12.7%

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

Measurement of A_Γ

[LHCb-CONF-2011-046]

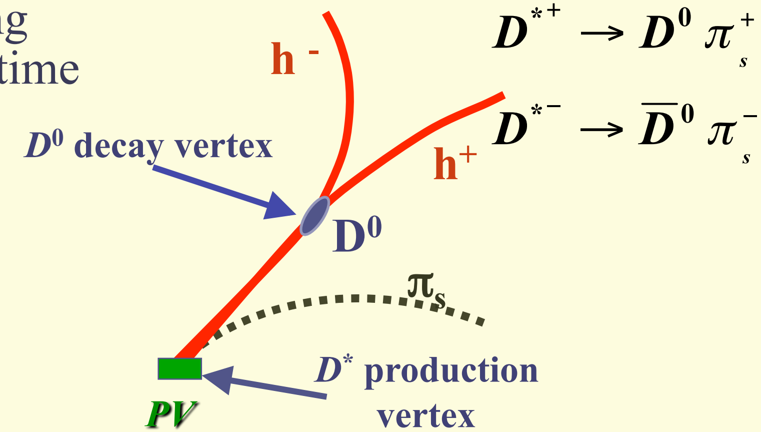
A_Γ measurement

- A direct measurement of CP violation in D^0 mixing can be evaluated by the asymmetry of the proper-time of flavour-tagged decays:

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

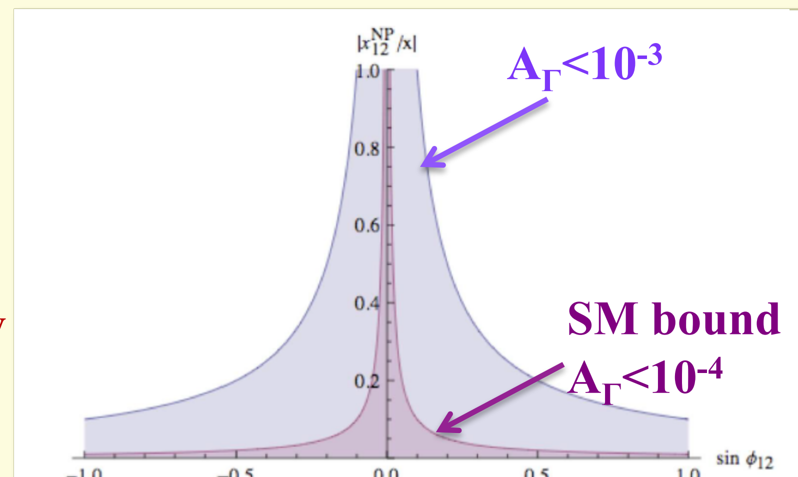
$$\approx \frac{A_M}{2} y\cos\phi - x\sin\phi$$

where the flavour of D^0 is determined by the sign of the charged pion.



- Control mode: $D^0 \to K\pi$

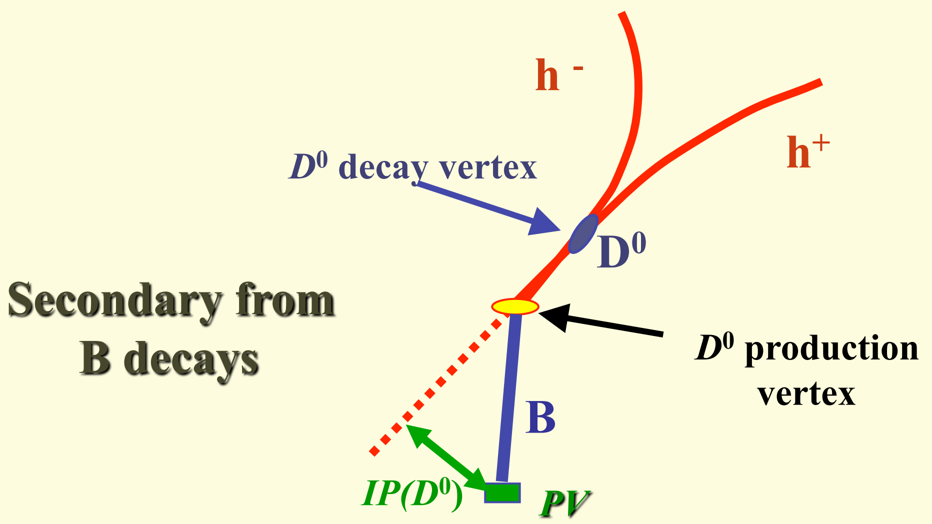
➔ A non-zero value of A_Γ would be a direct measurement of CP violation and a sign of new physics contribution.

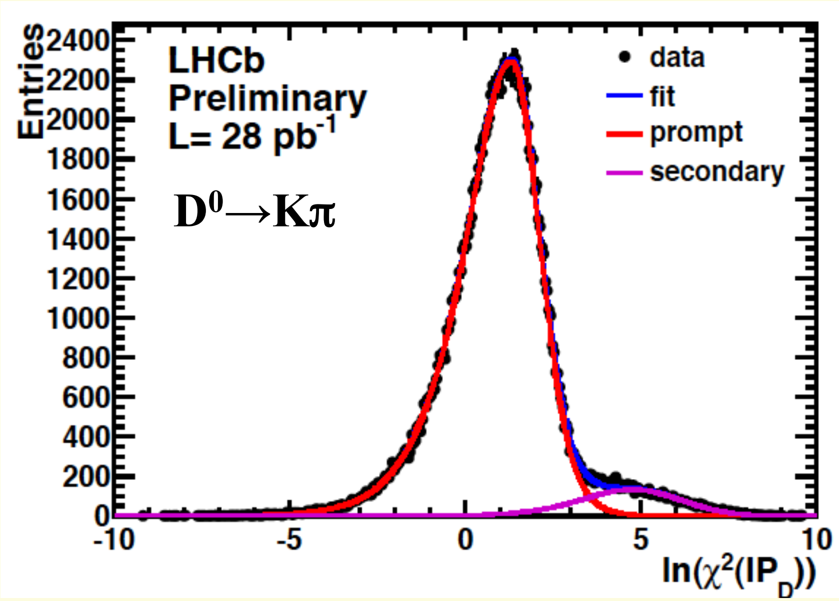


[Kagan, FPCP 2011]

A_Γ measurement: Method

- Unbinned likelihood fit m_{D0} for the determination of signal yield
- Main background due to secondary D^0
  - Not distinguishable by the invariant mass distribution
  - Difference direction: large IP wrt PV and large angle between p_{D0} and dir. pointing to PV
  - Need statistical separation by $\ln(\chi^2_{IP})$
- Simultaneous fit of proper time and $\ln(\chi^2_{IP})$ to distinguish between prompt and secondary
- Evaluation of the mis-tag rate from $\Delta m(D^* - D^0(hh))$



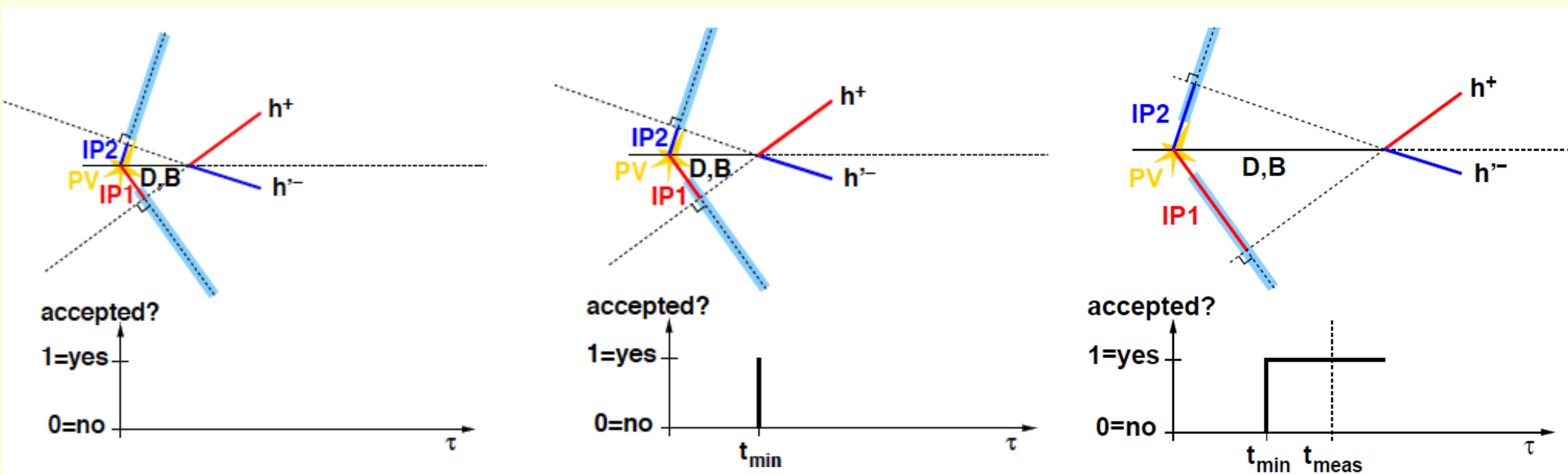


Acceptance evaluation

- Determine trigger & selection acceptance on an event-by-event basis, the so called ‘Swimming method’
- Evaluate the event acceptance as function of lifetime:

move the PV along the D^0 momentum

Evaluate the trigger & selection decision: accepted or not accepted



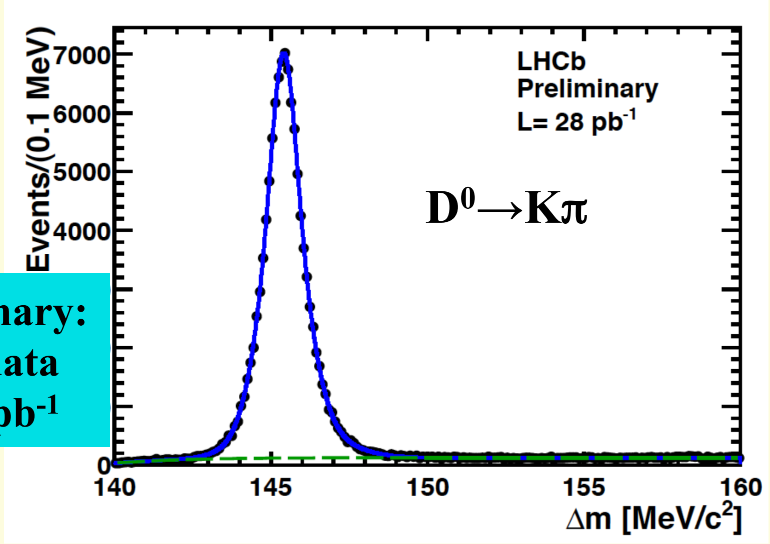
Control channel $D^0 \rightarrow K\pi$

- Proof of principle: apply same procedure to $D^0 \rightarrow K\pi$
  - ~110k candidates of each flavour tag

$A_\Gamma^{Kpi}=(-0.9 \pm 2.2 \pm 1.6)\ 10^{-3}$

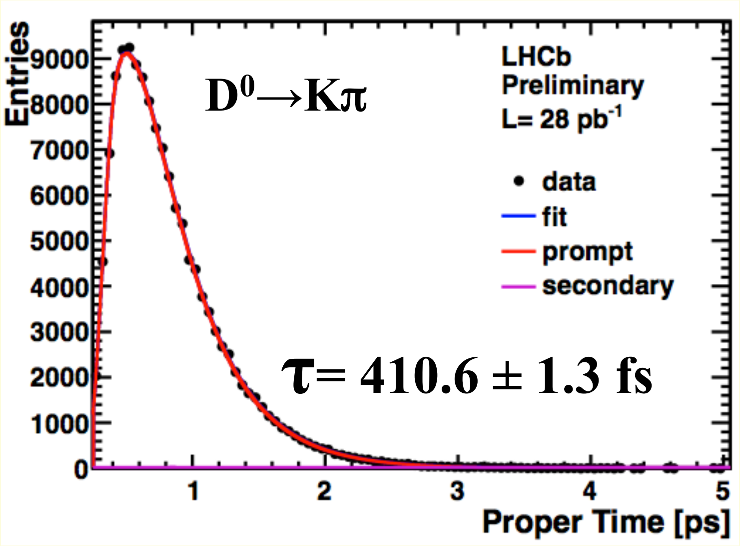
Preliminary: 2010 data L=28 pb^{-1}

Consistent with 0 as expected!



- Lifetimes consistent with PDG average: 410.1 ± 1.5 fs

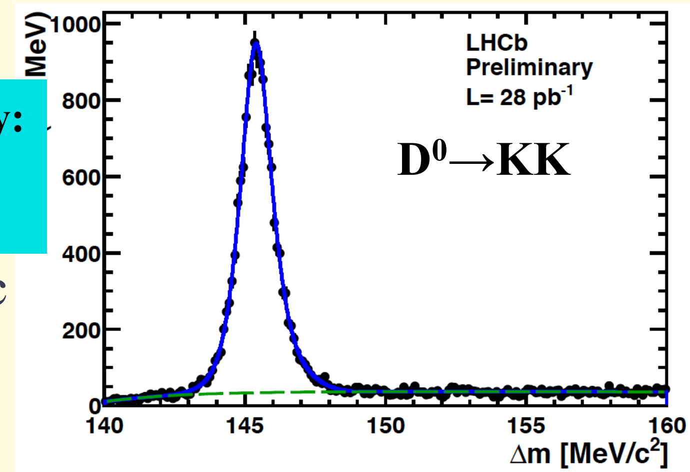
- Acceptance well modelled by 'Swimming'

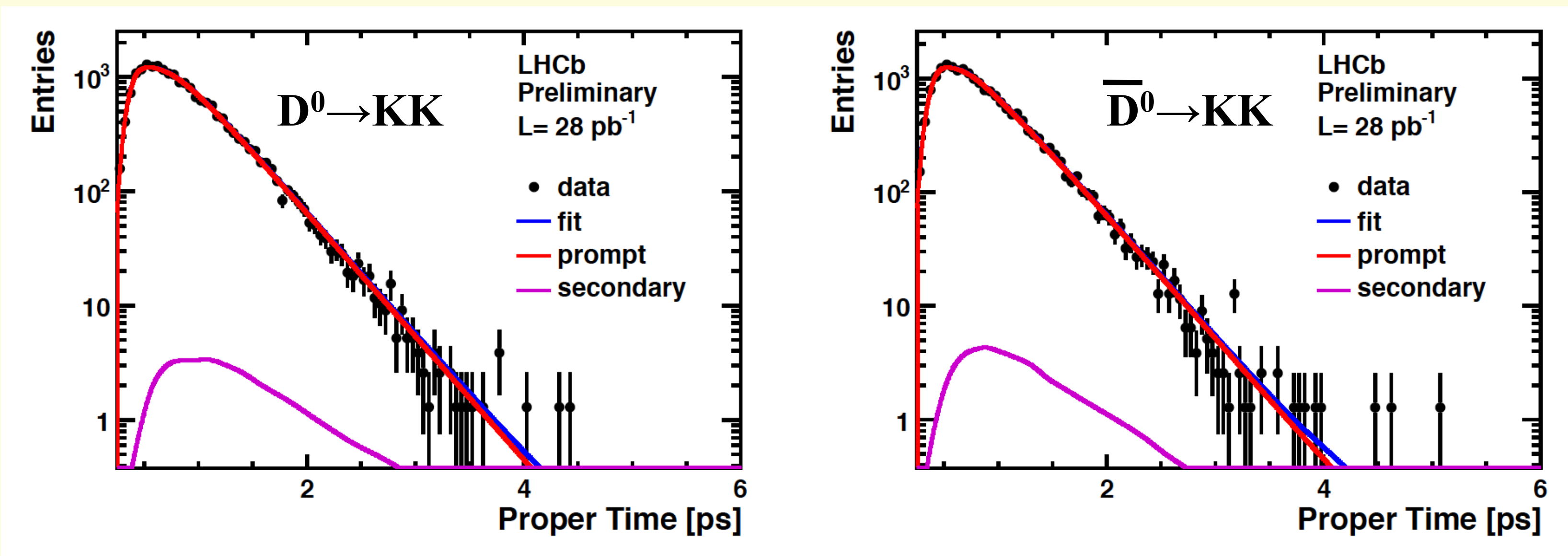


A_Γ measurement

- Data sample of D0 → KK:
  ~15k events of each flavour tag.
- **A_Γ=(-0.59 ± 0.59 ± 0.21) %**
  where 1st error is statistical and 2nd systematic
- The main systematic is due to the secondary and the combinatorial background

Preliminary: 2010 data L=28 pb^{-1}





Measurement of ΔA_{CP} ($D^0 \rightarrow K^-K^+$ - $D^0 \rightarrow \pi^-\pi^+$)

[LHCb-CONF-2011-023]

Measurement of ΔA_{CP} ($D^0 \rightarrow K^-K^+$ - $D^0 \rightarrow \pi^-\pi^+$)

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

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

Physics CP asymmetry **Production asymmetry**

Detection asymmetry of D^0 and of soft pion

- Taking $A_{RAW}(f)^*$ - $A_{RAW}(f')^*$ the production and soft pion detection asymmetries will cancel.
- Detection asymmetry for self-conjugate final states is 0

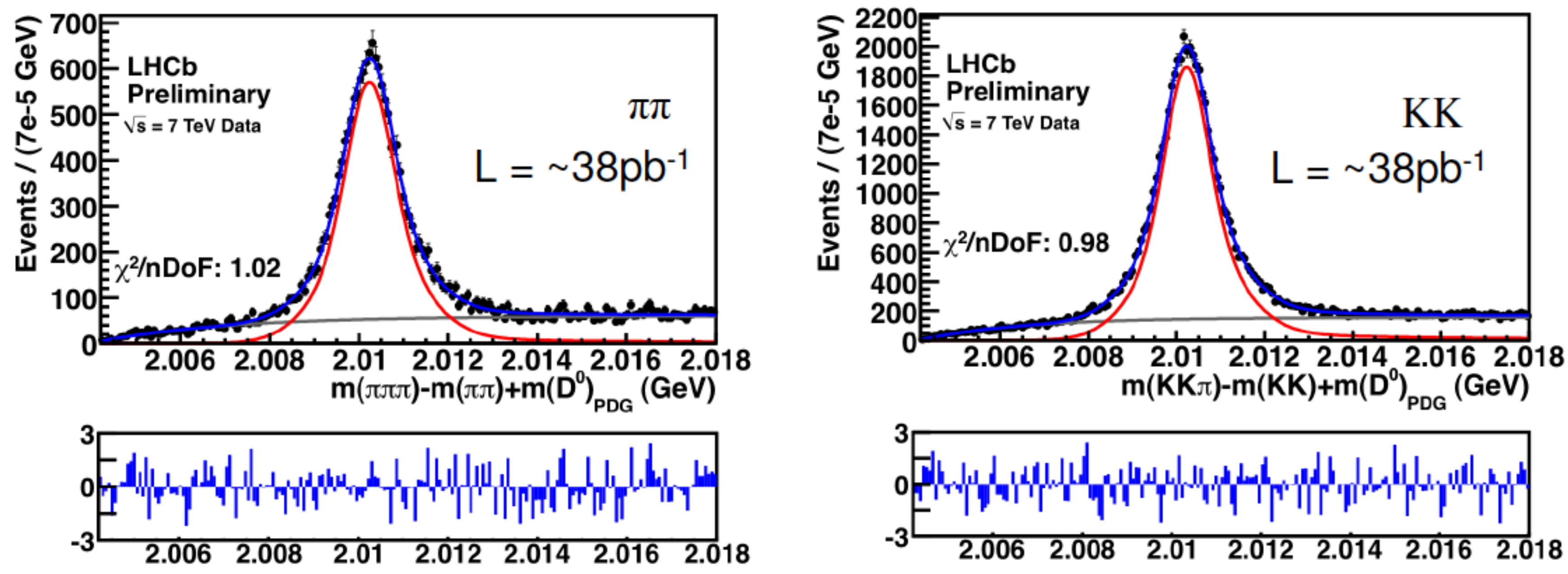
$$A_{RAW}(K^-K^+)^* - A_{RAW}(\pi^-\pi^+)^* = A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+) \equiv \Delta A_{CP}$$

➠ All the D^* related production and detection effects cancel

➠ CP asymmetry difference very robust against systematics

Measurement of ΔA_{CP} ($D^0 \rightarrow K^-K^+$ - $D^0 \rightarrow \pi^-\pi^+$)

Fit the $\Delta m = m(D^*) - m(D^0)$



- Total signal yield: 116k tagged $D^0 \rightarrow K^-K^+$ and 36k tagged $D^0 \rightarrow \pi^-\pi^+$

$\Delta A_{CP} = A_{CP}(K^- K^+) - A_{CP}(\pi^- \pi^+) = (-0.28 \pm 0.70 \pm 0.25)\%$

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

- Note: already competitive with the B-factories!
  - Statistical error for BABAR 0.62%, Belle 0.60%, but for CDF 0.33%
- Expect systematic error to scale well with integrated luminosity
  - Estimates very conservative with large statistical component

Interpretation

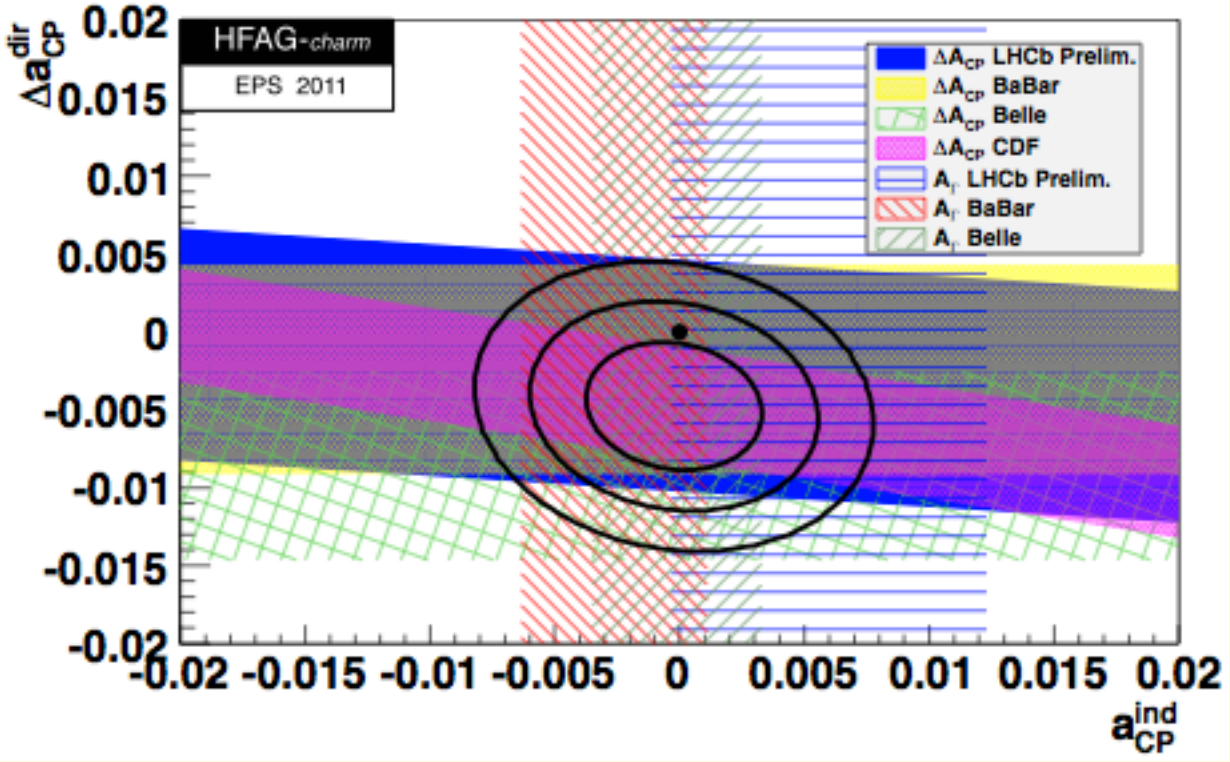
- Combination of direct and indirect CPV measurement

$$\Delta A_{CP} = \Delta a_{CP}^{dir} + \Delta\langle t\rangle/\tau \; a_{CP}^{ind} \quad \text{and} \quad A_{\Gamma} = -a_{CP}^{ind}$$

where $\Delta\langle t\rangle$ is the difference of the average proper time of KK and $\pi\pi$

- Slope in LHCb result due to small KK/$\pi\pi$ lifetime acceptance diff.: $\Delta\langle t\rangle/\tau = 0.10 \pm 0.01$

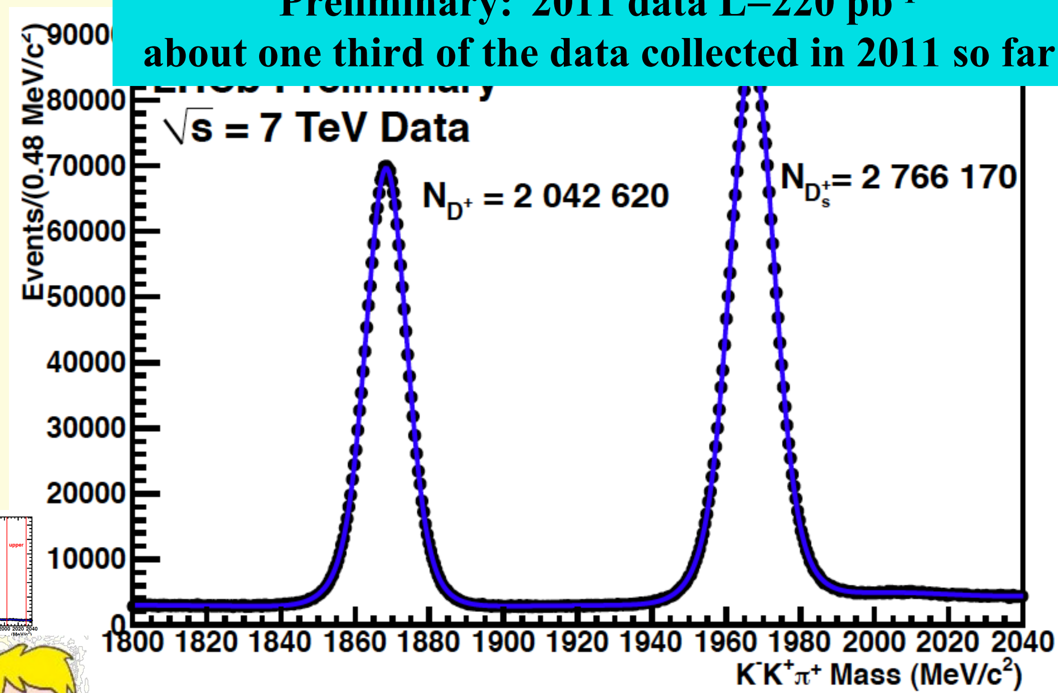
➔ **Agreement with no CP violation CL = 20%**



Expected more results soon

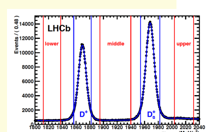
- Other charm analysis ongoing:
  - Time-dependent measurements of mixing parameters
  - Spectroscopy and production measurements
  - Searches of the rare D decays

Preliminary: 2011 data L=220 pb^{-1}
about one third of the data collected in 2011 so far

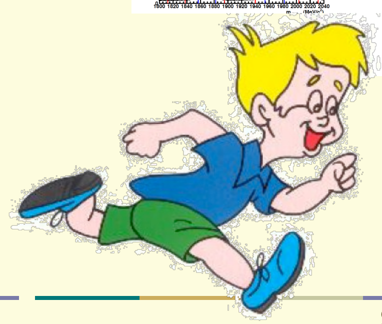


But this are only the first steps…

2010 data



… we are running



towards many new results

Conclusion

Preliminary: 2010 data

- LHCb produces its first charm physics results on 2010 data (total L ~38 pb^{-1}):
  - Search of CPV in $D^+ \rightarrow \mathbf{K^-K^+\pi^+}$ [LHCb paper in preparation]
  - Measurement of $A_{CP}(K^- K^+) - A_{CP}(\pi^- \pi^+)$ = **(-0.28 ± 0.70 ± 0.25) %** [LHCb-CONF-2011-023]
  - Measurement of A_Γ = **(-0.59 ± 0.59 ± 0.21) %** [LHCb-CONF-2011-046]

  Even 2010 data interesting: with 38 pb^{-1}, already competitive with B-factories

- The data collected in 2011 so far are an order magnitude higher statistiscs (more than 621 pb^{-1})
  - Precision searches for CP violation to really probe new physics in many key areas!

Backup

Acceptance evaluation

- Determine trigger & selection acceptance on an event-by-event basis, the so called ‘Swimming method’.
  - Evaluate the event acceptance for many different lifetimes by moving the PV along the D^0 momentum
  - In events with multiple PV ➔ more turning points