ΔA_{CP} in Charm Decays at LHCb

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On behalf of the LHCb collaboration

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from 31 May 2012 to 05 June 2012 (Europe/Rome)

La Biodola, Isola d'Elba

Why Charm Physics ?

- **Charm Physics is essentially a 2-generation physics: any CPV above O(0.1%) means something new.**

  → *NP, or unexpected strong effects*

- **D-$\overline{\text{D}}$ mixing, CP violating decays and rare decays involve FCNC's that are strongly GIM-suppressed (low mass down-type quarks in the loop)**

  → *NP contributions can have measurable effects (not hidden by SM)*

- **FCNC with down-type quarks in the loop: constrain NP couplings that can't be reached by B/K decays.**

  → *Complementarity with the B-physics program.*

- **Very large samples of charmed particles at hadronic colliders !**

→ *Charm decays are a good place to look for NP and constrain its properties !*

CP Violation in Charm

Two complementary ways to seek CPV (and NP) in Charm Decays

- **D oscillate, so one can look for two manifestations of indirect CPV**

  - CPV in mixing: $\overline{D0} \rightarrow D0 \neq D0 \rightarrow \overline{D0}$

  - CPV in the interplay between mixing and decay

- **$A(\overline{D} \rightarrow f) \neq A(D \rightarrow f)$: direct CPV**

- **Direct CPV is as good an opportunity as indirect**

  - Mixing is slow, strong phases can be large in decays.

  - While indirect CPV is nearly universal, direct depends a lot on the final state. Measuring many brings many complementary clues.

- **CPV is small: ~0.1% to ~1% for direct CPV ⇔ What's SM; What's NP ? Probably an order of magnitude below for indirect CPV.**

Today: direct CPV @ LHCb.

Focus on the current most precise example: Acp(KK)-Acp($\pi\pi$)

LHCb

NP via the precision study of CPV and Flavor Physics

- **Key point: huge b and c production in high E p-p collisions**

  - @ $\sqrt{s}$=7 TeV: $\sigma(pp \rightarrow b\bar{b}+X) = (284 \pm 20 \pm 49)\ \mu b$ *[1]*

  $\sigma(pp \rightarrow c\bar{c}+X) = (6100 \pm 930)\ \mu b$ *[2]*

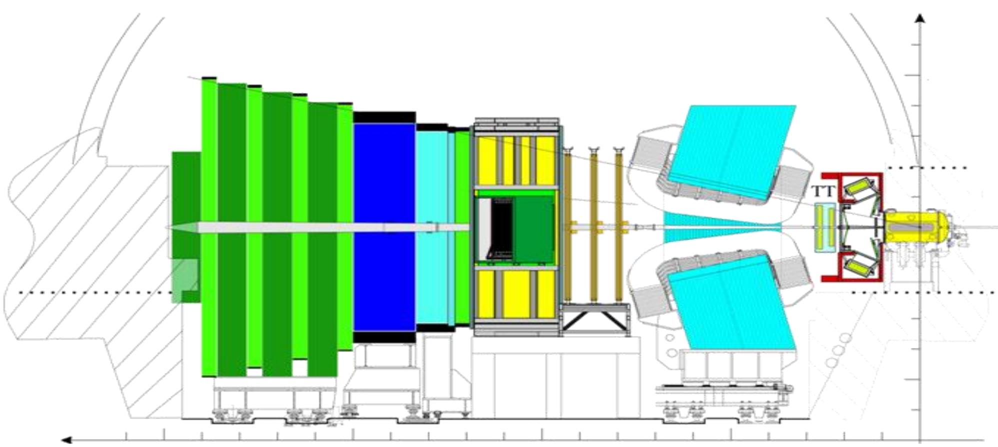
  In 1fb^{-1}: ~10^{12} $c\bar{c}$ pairs in LHCb's acceptance

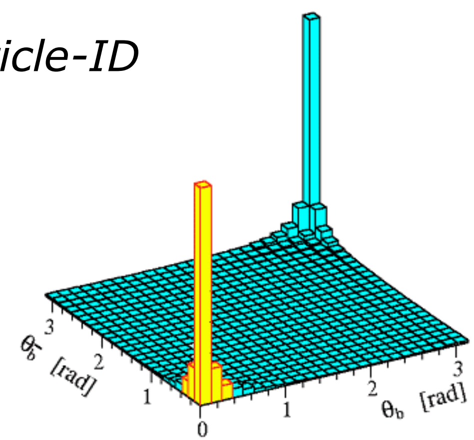
- **Key point: dedicated experiment, optimized for *Flavor Physics* in a *hadronic* environment.**

  - Forward detector

  - Performant vertexing, p and M reconstruction, particle-ID

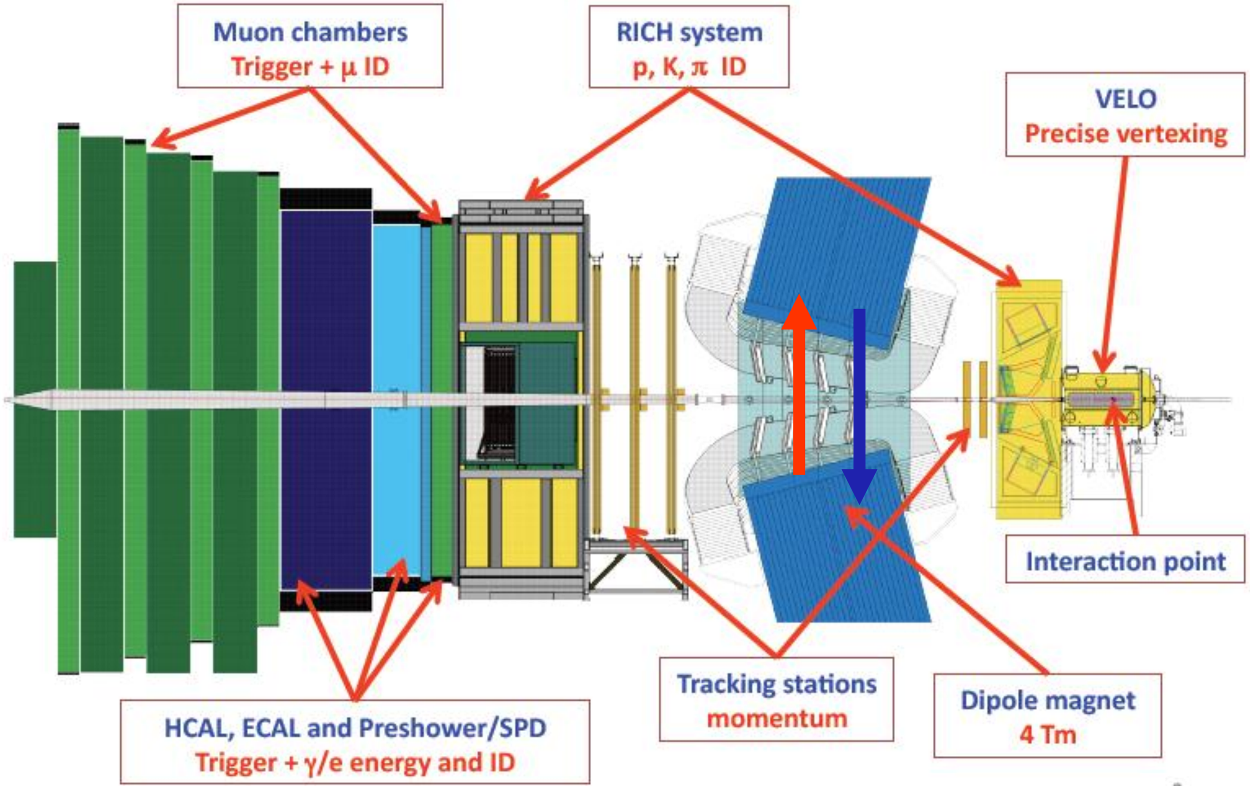
  - Very selective, polyvalent and configurable trigger.





[1] Phys. Lett. B694: 209-216, 2010

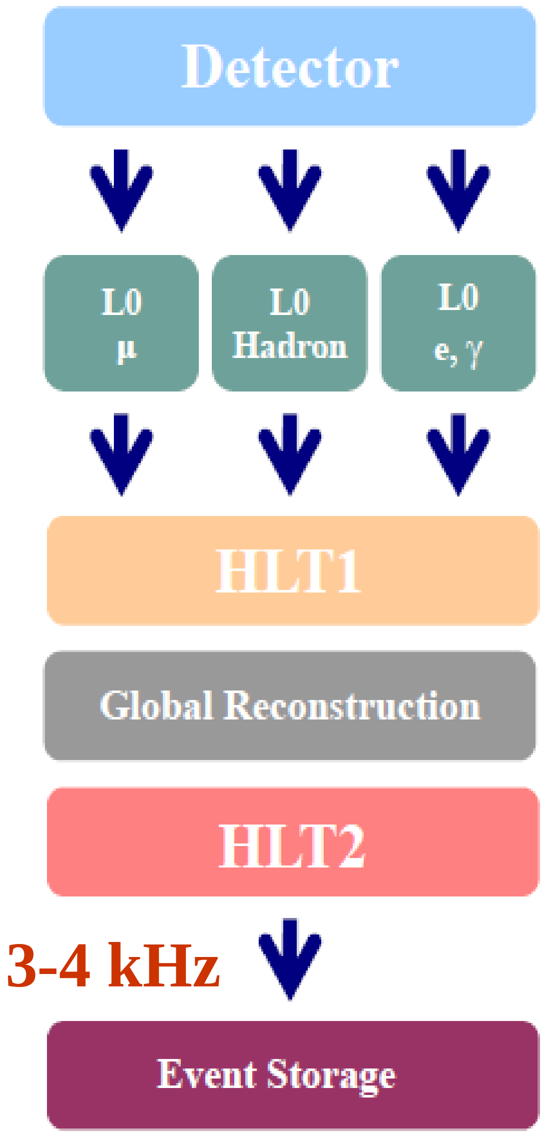
[2] LHCb-CONF-2010-013



B-field polarity can be reversed: ***Up*** *or* ***Down***

- **Typical Performance**
  - *Charged tracks momentum:* $\sigma p/p=0.35\text{-}0.55\%$, $\sigma m=10\text{-}20\ MeV/c^2$
  - *ECAL:* $\sigma E/E=10\%/\sqrt{E} \oplus 1\%$ *(E in GeV)*
  - *muon-ID* $\varepsilon(\mu\to\mu)$ *~95%, mis-ID rate*$(\pi\to\mu)$*~1%*
  - *K-*π *separation* $\varepsilon(K\to K)$ *~95%, mis-ID rate*$(\pi\to K)$*~10%*
  - *Proper time:* σ_t*~ 30-50 fs,* σ_z*~ 60*μ*m (Prim. Vtx)* σ_z*~ 150* μ*m (Secondary Vtx)*

Trigger/DAQ



40 MHz

High PT candidates

1 MHz (max)

High PT displaced tracks matched with L0 objects.

30 kHz

Full reconstruction (ex: lifetimes)
Inclusive/exclusive modes
Highly configurable.
Easy to add/remove/prescale modes.

~50 kB event^{-1}

- **Trigger Efficiency**
  - *~30% for multibody hadronic modes*
  - *~90% for di-muons*

Ex 1/fb :

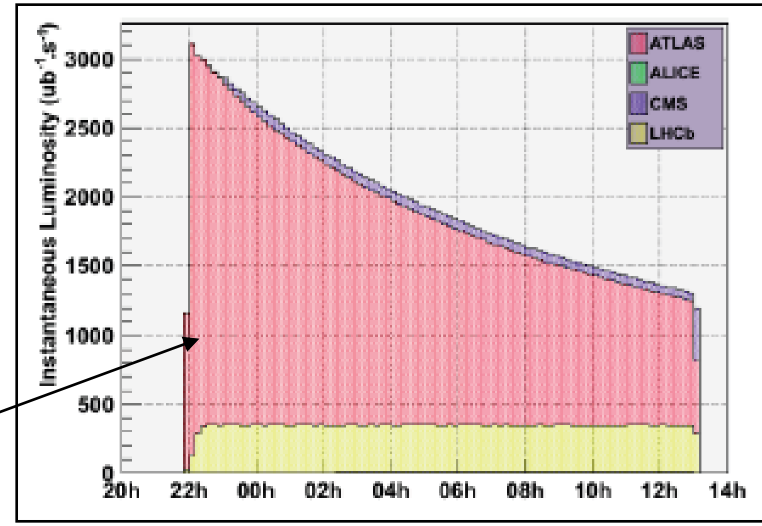
~0.5M $D^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$ *on tape*

- **Output Rate**
  - *3-4 kHz in 2011*
  - *4.5 kHz in 2012*

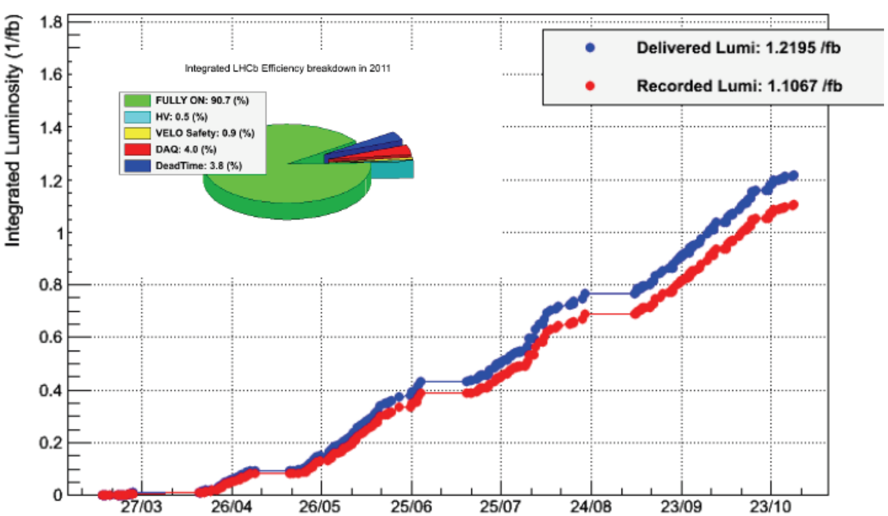
Peak Luminosity

- *2011: 3-4 $10^{32}/cm^2/s$*
- *2012: 4 $10^{32}/cm^2/s$*
- *<#collisions> per bunch crossing ~1.5*

"Luminosity Leveling" to obtained that from LHC's luminosity

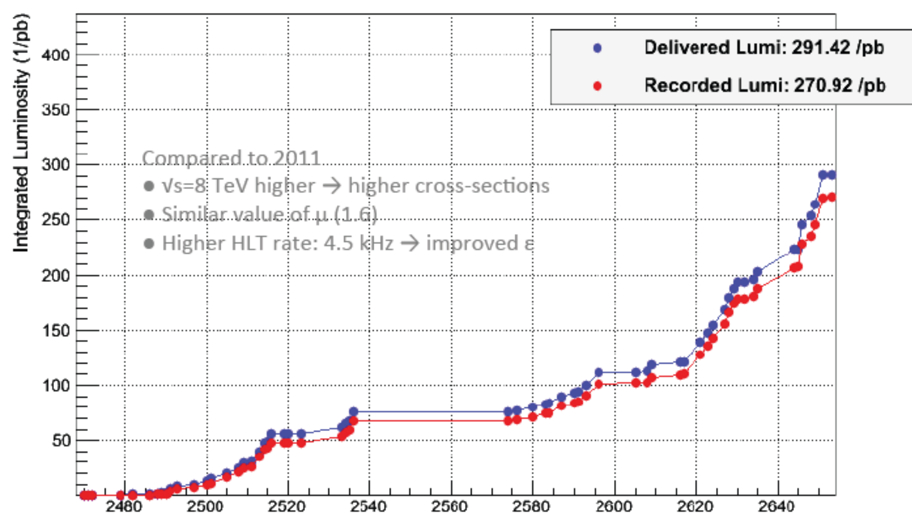


2011



~1.0 fb^{-1} @ $\sqrt{s}$=7 TeV

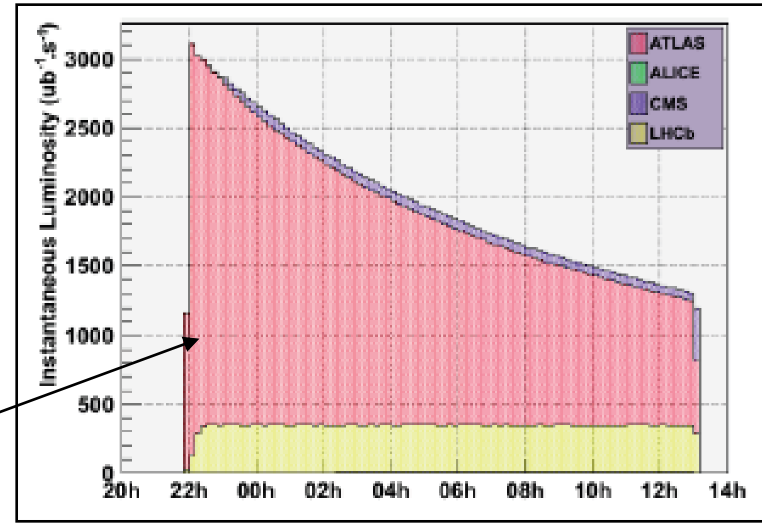
2012



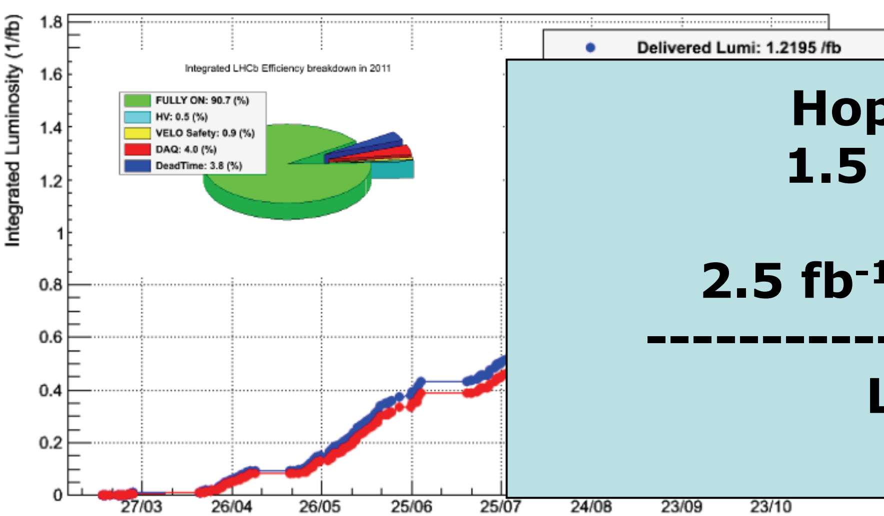
0.3 fb^{-1} @ $\sqrt{s}$=8 TeV

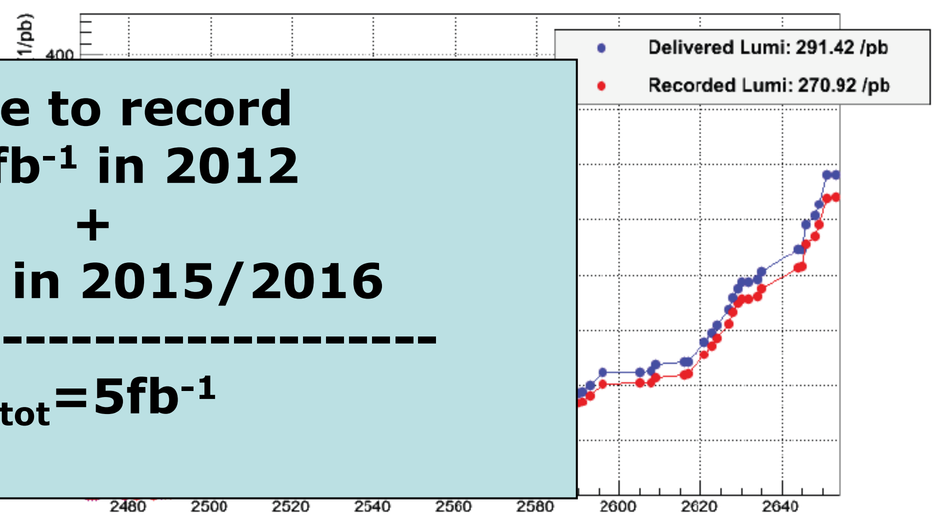
- **Peak Luminosity**
  - *2011: 3-4 $10^{32}/cm^2/s$*
  - *2012: 4 $10^{32}/cm^2/s$*
  - *<#collisions> per bunch crossing ~1.5*

"Luminosity Leveling" to obtained that from LHC's luminosity



2011 **2012**





Hope to record
1.5 fb^{-1} in 2012
+
2.5 fb^{-1} in 2015/2016

L_{tot}=5fb^{-1}

ΔA_{CP}
$=$
$A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$

- $0.6\ fb^{-1}$ (2011)
- Phys.Rev.Lett. 108 (2012) 111602

Analysis Strategy

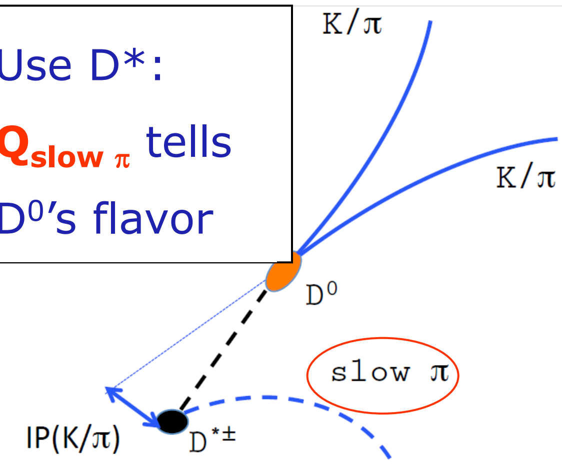
- **Measure a time-integrated asymmetry**

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

Use D*:

$Q_{slow\ \pi}$ tells

D^0's flavor



- **First order Taylor Expansion:**

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

physics CP asymmetry

Detection asymmetry of D^0

Detection asymmetry of soft pion

Production asymmetry

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

When $f=\pi^+\pi^-$ or K^+K^-: no detection asymmetry between D and D

→ $A_D(f)=0$

Similar for $f=\pi^+\pi^-$ and K^+K^-

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

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

- **This rule gives a very robust way to detect a CPV effect**
- **But remember ! It can be broken by**
  - *Large asymmetries (>>1%): Taylor Expansion breaking down*
  - *Dependence of $A_P(D^*)$ and $A_D(\pi_s)$ upon $\varepsilon(KK)/\varepsilon(\pi\pi)$.*

    Ex: $A_D(\pi_s)$ depends upon the π_S phase space, and KK and $\pi\pi$ selections favor a different region.
  - *Different and asymmetric peaking backgrounds.*
- **So the fun in this analysis is to avoid those problems.**

  Main protections:
  - *Measurements in separate bins of P_T and η of D*'s, P of π_S*
  - *Fiducial cuts to remove regions of large asymmetry*
  - *Many checks…*

What does ΔA_{CP} measure exactly ?

- **Time integrated asymmetries: a combination of direct & indirect CPV.**

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

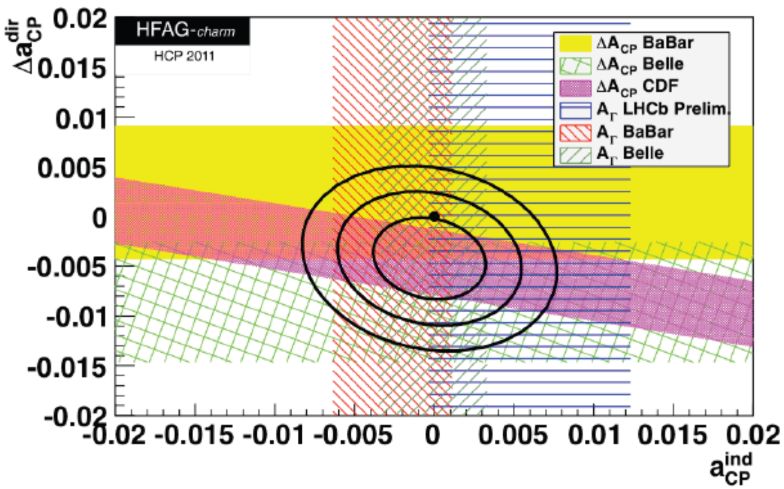
Depends on <t> of the D^0 in the sample (~time given the mixing to interfere).

- **Indirect CPV universal to a very good approximation, but lifetime acceptance can differ between KK and ππ.**

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

→ *Also measure Δ<t> to disentangle each contribution*

- **A year ago…**



HFAG combination

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

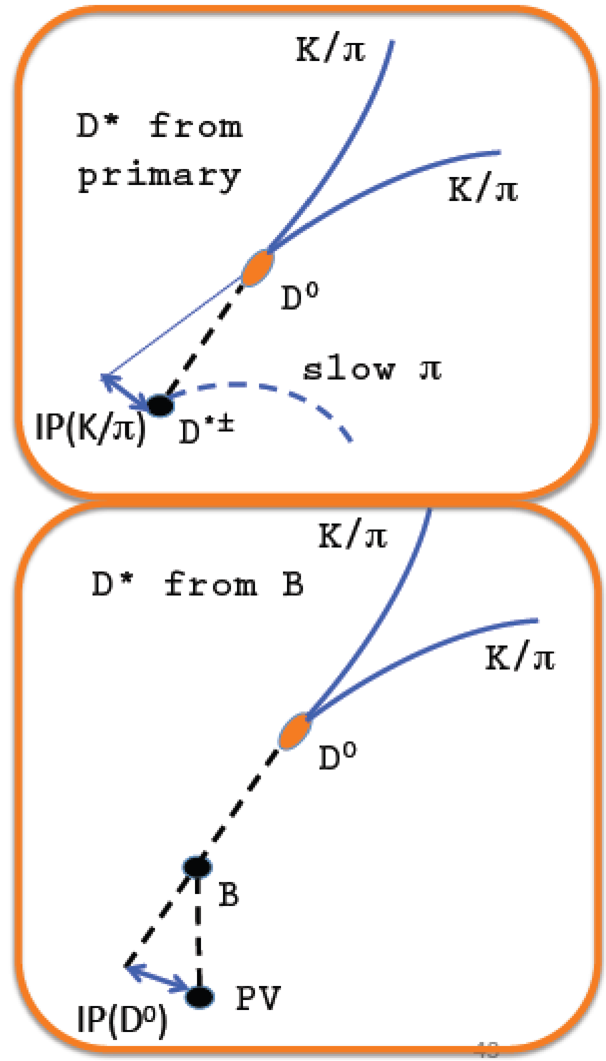
$\Delta a_{CP}^{dir} = (-0.42 \pm 0.27)\%$

Consistency with NO CPV hypothesis: 28%

Selection

Cut-based selection: use the decay topology and kinematics, and LHCb's PID performance.

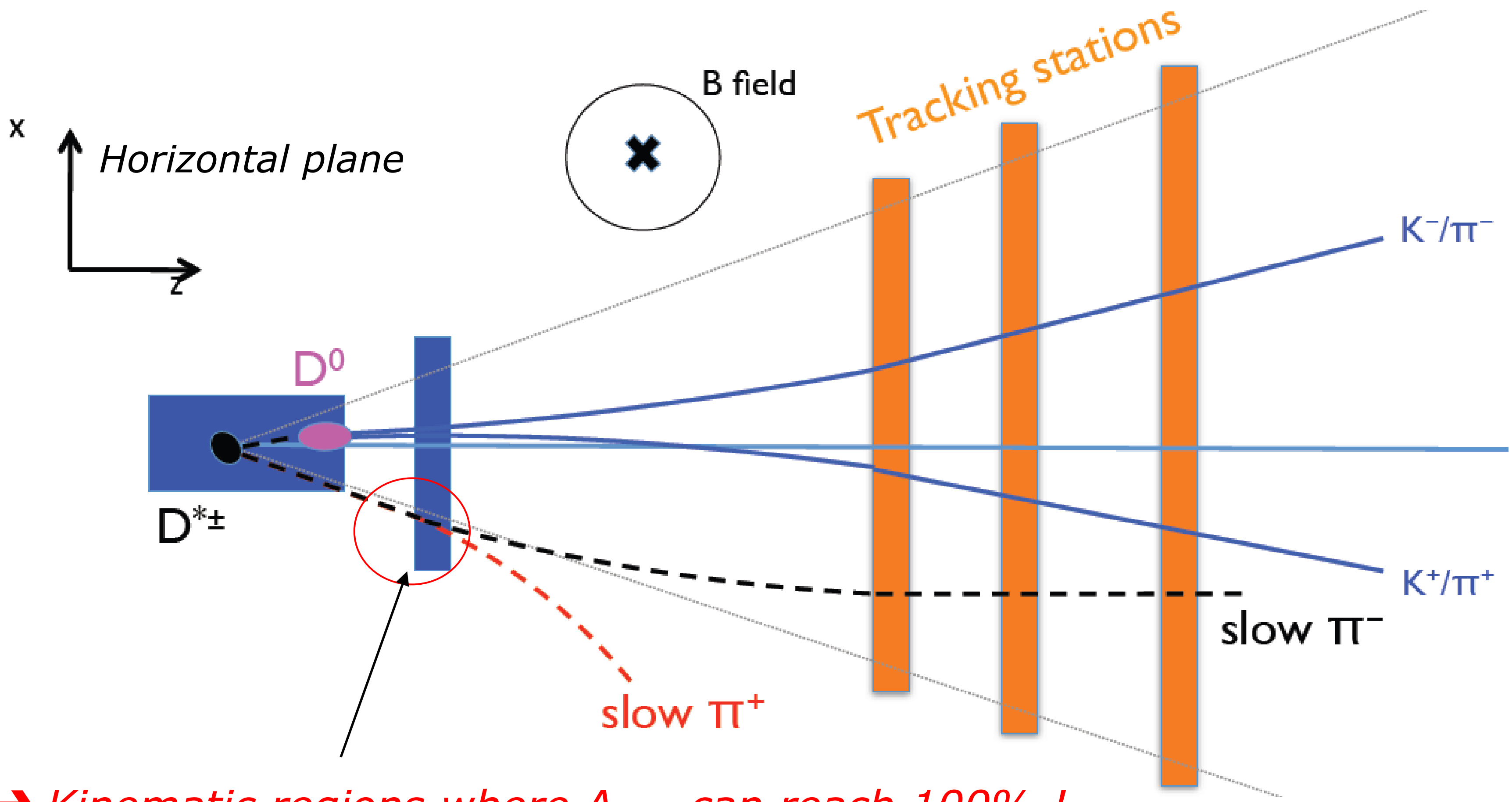
- **Track & Vertex fit quality**
- **Tracks must not come from the primary vertex (PV) & ct(D)>100 μm.**
- **D must come from the PV, to reject D* from B decays**
- **θ between D^0 in lab frame and its daughters in D^0 rest frame: |cosθ|<0.9**
- **Tracks identified as kaon/pions using PID info from the RICH**
- **P_T(D)>2 GeV/c**



N.B. This offline selection applied on candidates that fired a similar (looser) selection in the High Level trigger

Fiducial cuts

The magnetic field breaks the symmetry of the detector



➔ *Kinematic regions where A_{RAW} can reach 100% !*

Borders where $\pi^{+/-}$ are swept out while $\pi^{-/+}$ are swepted in.

(this includes also the beam pipe)

Fiducial cuts

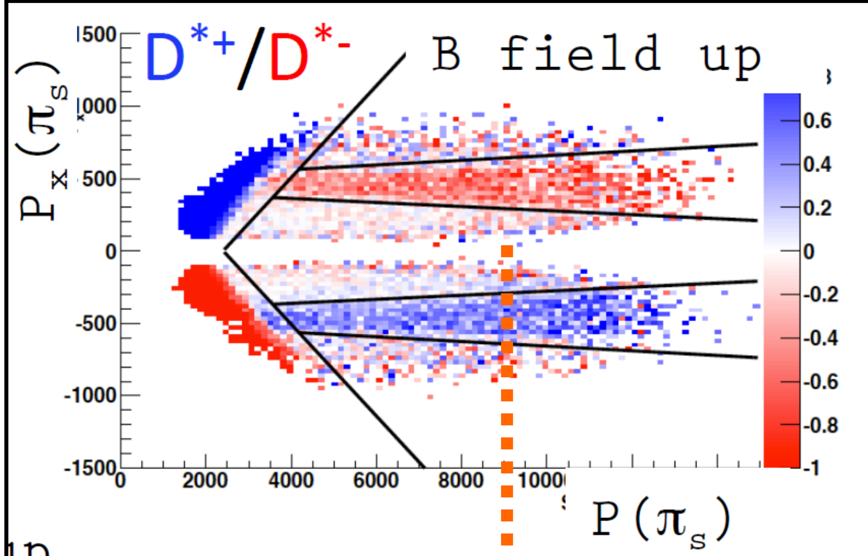
Kinematic regions where A_{RAW} can reach 100% !

- **Breaks the formalism (too large an for a Taylor expansion)**
- **Possible second order effects if the efficiency for being in this region differs between KK and ππ.**
- **Depends more on P_X than on $P_{T,D}$*, η_{D*} or $P_{slow\ \pi}$**

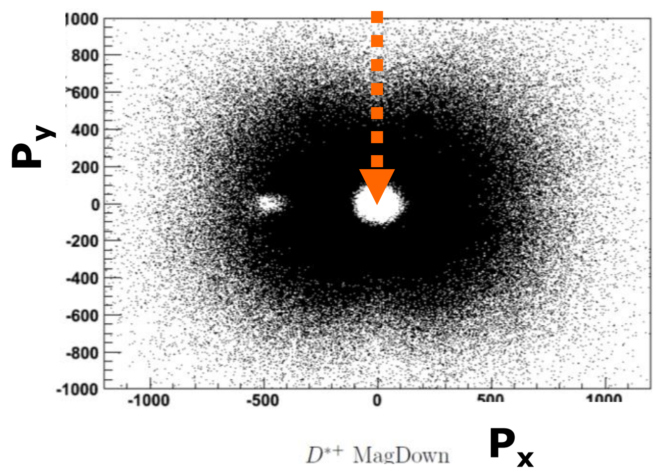
  Thus: not treated perfectly by the kine. binning

- **Left-right binning + the fact that ~1/2 the sample is taken with B-field Up and ~1/2 with B-field Down should limit the overall effect. However, to be more robust, sacrifice 25% of the statistics with Fiducial cuts**

A_{RAW} for |py/pz| $_{slow\ \pi}$ < 0.2. Horizontal plane.



Directly in beam pipe



Fiducial cuts

Kinematic regions where A_{RAW} can reach 100% !

- **Breaks the formalism (too large an for a Taylor expansion)**
- **Possible second order effects if the efficiency for being in this region differs between KK and ππ.**
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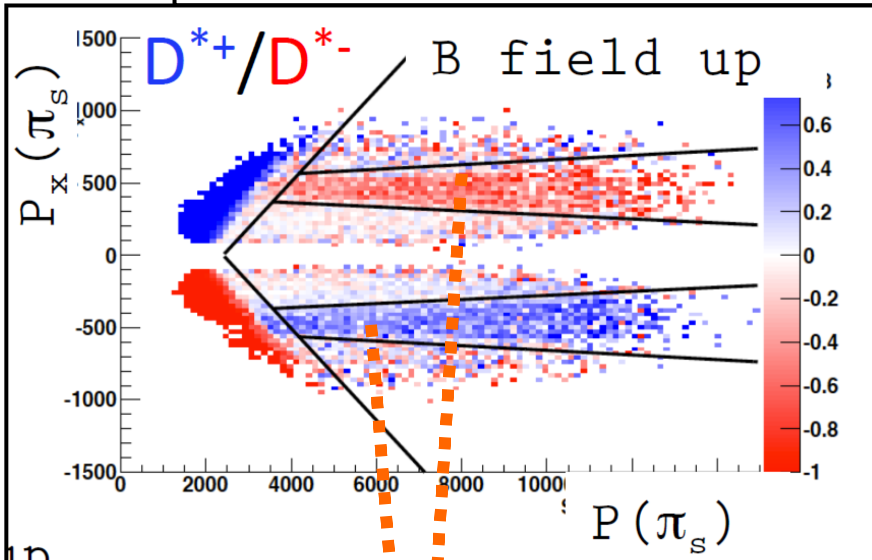
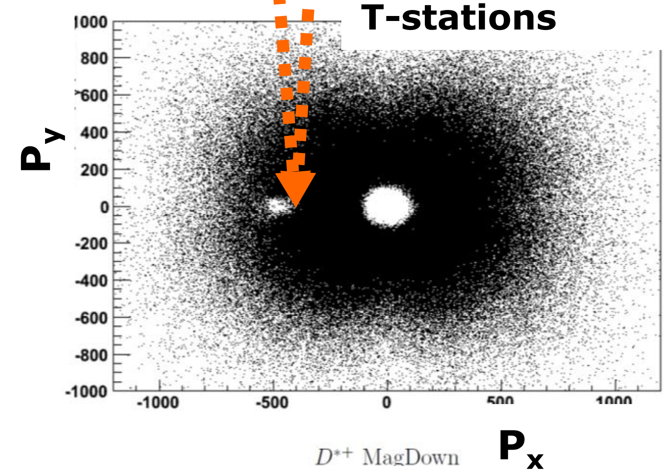
A_{RAW} for $|py/pz|_{slow\ \pi} < 0.2$. Horizontal plane.

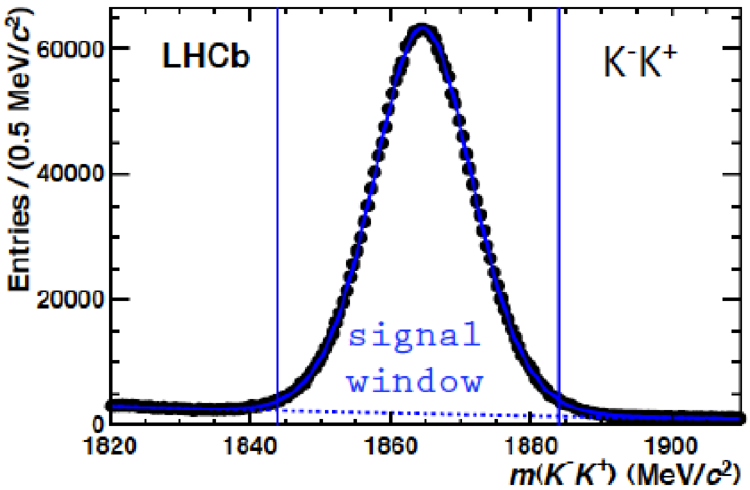


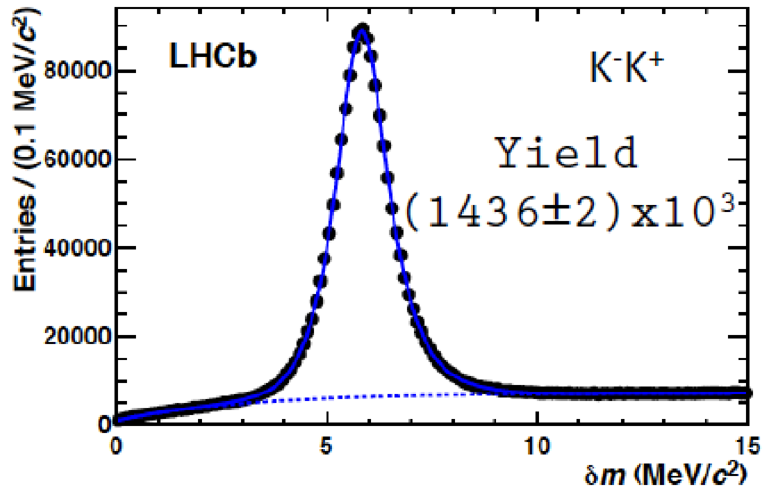
Cross the beam pipe after VELO / before T-stations



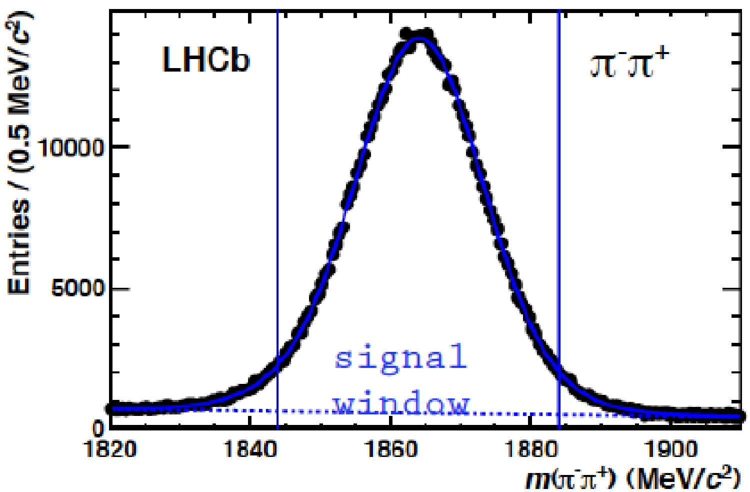
Mass spectra and signal yields

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





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



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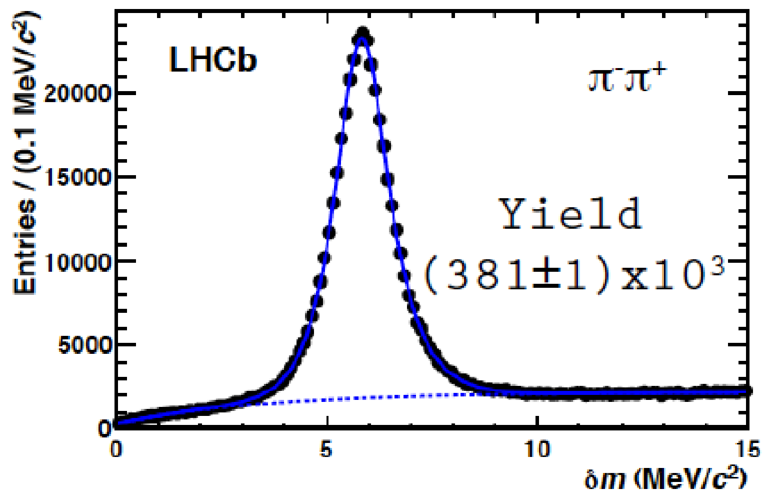
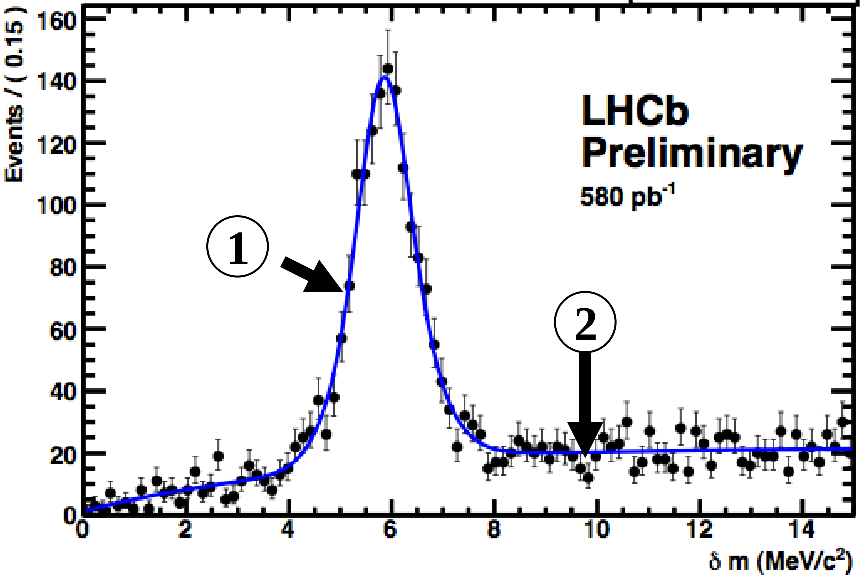


Signal Extraction

1 Bin



- **In 216 bins**

  54 bins in $P_{T,D*} \times \eta_{D*} \times\ P_{slow\,\pi} \times$ left/right

  $\times$ 2 Mag Up / Mag Down

  $\times$ 2 Before/After an LHC technical stop

- **Fit to δm distributions**

  (1) *Signal: double gaussian convolved with a function describing a asymmetric tail.*

  D+ and D*- parameters float separately.*

  (2) *Background: $B[\ 1 - \exp(\ -(\delta m - \delta m_0)/C\ )\ ]$*

- **Finally: A_{RAW} and ΔA_{RAW} in each bin, then weighted average**

$$\Delta A_{CP} = (-0.82 \pm 0.21_{stat})\%$$

(χ^2 / NDF = 211/215)

- **Fit to background subtracted decay time distributions yields:**

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

➔ *This would essentially be a* ***direct*** *CPV*

Systematics

Effect	Uncertainty
ΔA_{CP} with vs. without Fiducial cuts	0.01%
Background peaks (+their asymmetry) from $m(D^0)$ sideband injected into TOYs to check the effect on the fit.	0.04%
ΔA_{CP} with fit vs. sideband subtraction cuts	0.08%
ΔA_{CP} with multiple candidates vs. only one allowed per event	0.06%
ΔA_{CP} with kinematical bins vs. one single bin	0.02%
TOTAL	0.11%

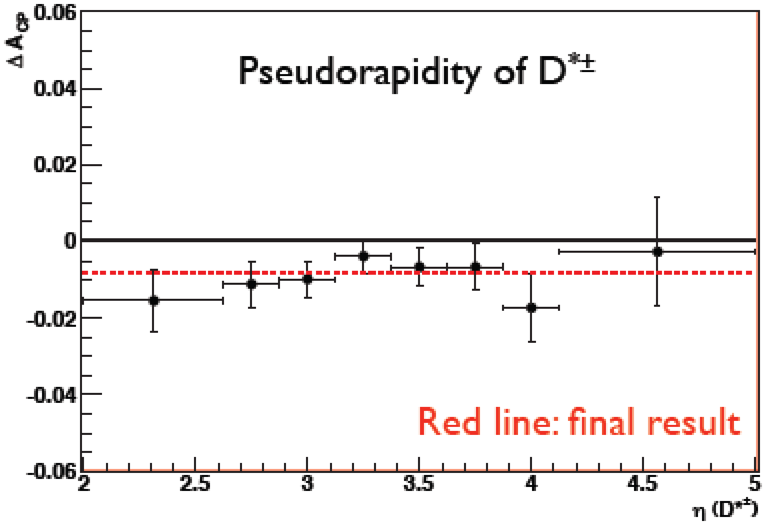
$$\Delta A_{CP} = (-0.82 \pm 0.21_{stat} \pm 0.11)\%$$

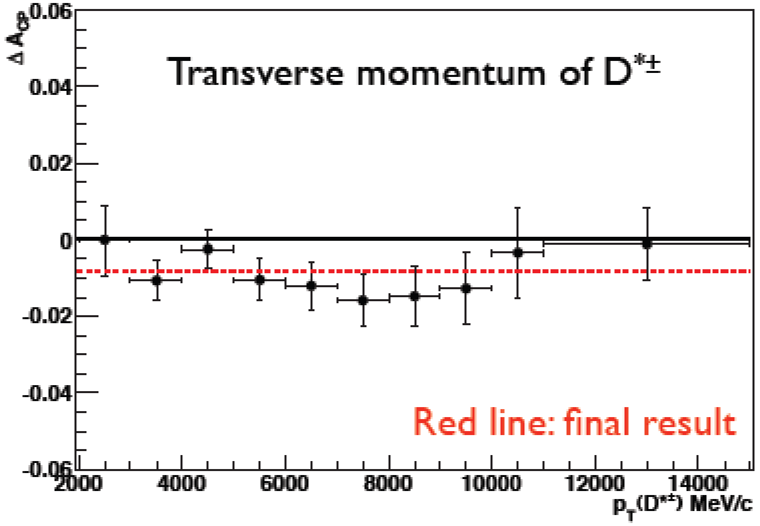
3.5 σ from no CPV.

Cross Checks

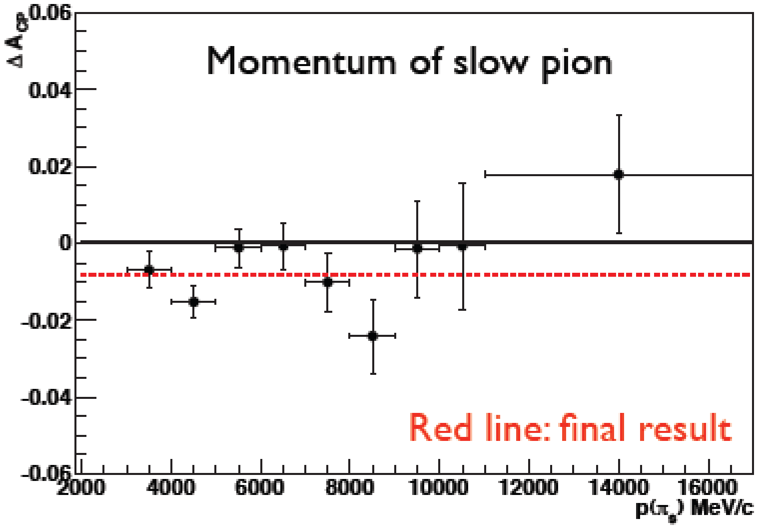
- **Electron and muon vetoes on the soft pion and D^0 daughters**
- **Different kinematic binnings**
- **Stability of result vs data-taking runs**
- **Stability vs kinematic variables**
- **Toy MC studies of fit procedure, statistical errors**
- **Tightening of PID cuts on D^0 daughters**
- **Tightening 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)**

Cross Checks

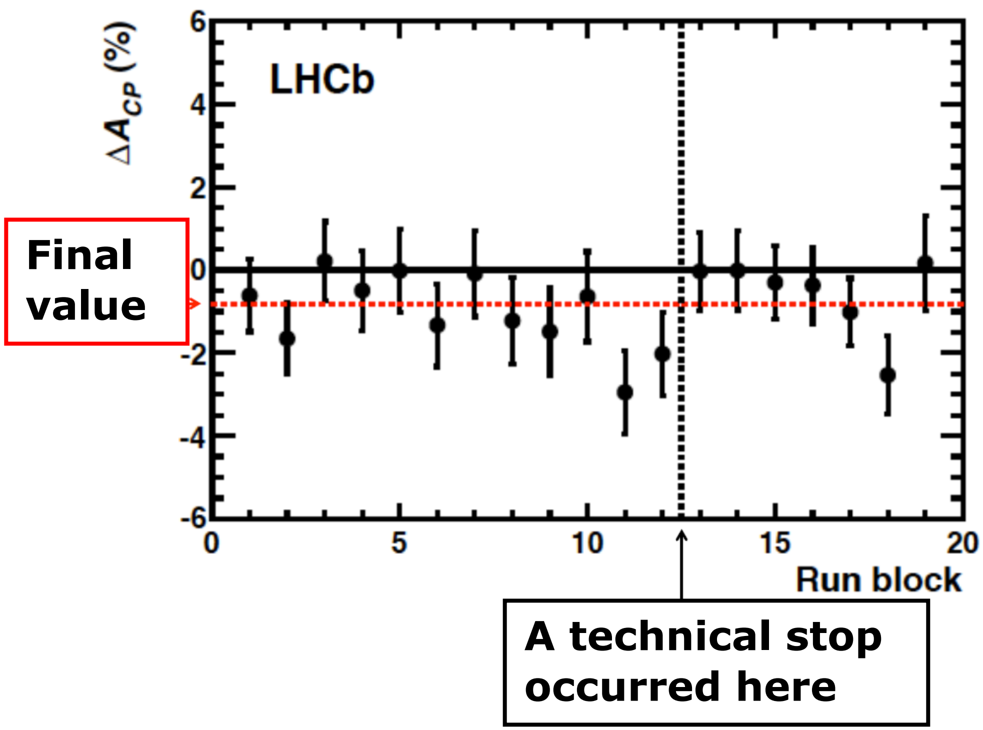




- No evidence of dependence on relevant kinematic variables



Stability with time



Stability wrt PID

No significant variation of ΔA_{CP} when tightening the cut on the hadron PID information provided by the RICH

PID tight+

$\Delta A_{CP} = (-0.88 \pm 0.26_{stat})\%$

PID tight++

$\Delta A_{CP} = (-1.03 \pm 0.31_{stat})\%$

Internal consistency: a closer look

Split the 216 bins into 8 smaller sets and check χ^2 for each, and between them:

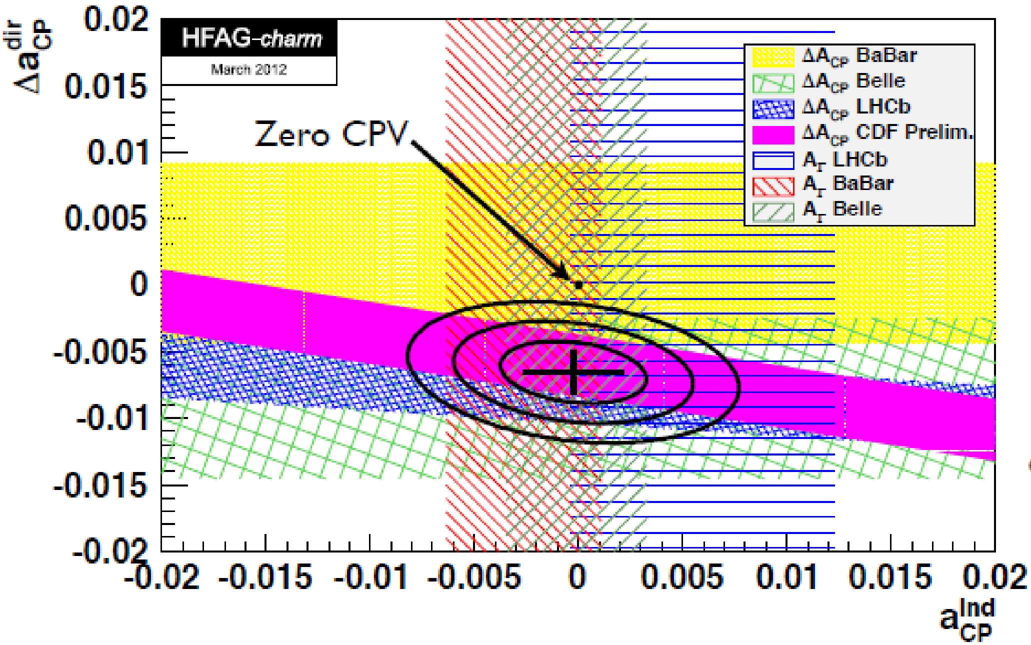
χ^2 / NDF = 6.7/7

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%)

World Wide

Year	Experiment	Results	$\Delta\langle t\rangle/\tau$	$\overline{\langle t\rangle}/\tau$
2007	Belle	$A_\Gamma = (0.01 \pm 0.30\ \text{(stat.)} \pm 0.15\ \text{(syst.)})\%$	-	-
2008	BaBar	$A_\Gamma = (0.26 \pm 0.36\ \text{(stat.)} \pm 0.08\ \text{(syst.)})\%$	-	-
2011	LHCb	$A_\Gamma = (-0.59 \pm 0.59\ \text{(stat.)} \pm 0.21\ \text{(syst.)})\%$	-	-
2008	BaBar	$A_{CP}(KK) = (0.00 \pm 0.34\ \text{(stat.)} \pm 0.13\ \text{(syst.)})\%$ $A_{CP}(\pi\pi) = (-0.24 \pm 0.52\ \text{(stat.)} \pm 0.22\ \text{(syst.)})\%$	0.00	1.00
2008	Belle	$\Delta A_{CP} = (-0.86 \pm 0.60\ \text{(stat.)} \pm 0.07\ \text{(syst.)})\%$	0.00	1.00
2011	LHCb	$\Delta A_{CP} = (-0.82 \pm 0.21\ \text{(stat.)} \pm 0.11\ \text{(syst.)})\%$	0.10	2.08
2012	CDF Prelim.	$\Delta A_{CP} = (-0.62 \pm 0.21\ \text{(stat.)} \pm 0.10\ \text{(syst.)})\%$	0.25	2.58

CDF public note 10784



$$a_{CP}^{\text{ind}} = (-0.025 \pm 0.231)\%$$

$$\Delta a_{CP}^{\text{dir}} = (-0.656 \pm 0.154)\%$$

Agreement with no CPV: 6×10^{-5}

SM or NP ??

- **Predictions are difficult with D mesons**

  - *Too light (heavy) for the techniques that work in B (K) physics*

- **Present consensus**

  - *Difficult for the SM to generate more than O(10^{-4}-10^{-3}) (canonic point of view till 2011)*

  - *But possible: one can think of Hadronic enhancements pushing it up to O(1%)*

  - *Would help: Individual asymmetries*

  - *Would help: Several decay modes should be affected by the same NP, but not the same strong effects: compare A_{CP} measured in each mode to distinguish enhanced contributions of higher order standard model diagrams from NP effects*

Ex: → $D^+_{(S)} \rightarrow K_S h^+;\ \phi h^+$

→ $D^+ \rightarrow K^+ \overline{K}^{*0};\ K^{*+} \overline{K}^0$

→ $D^+ \rightarrow \rho^0 \pi^+;\ \pi^+ \pi^0;\ \pi^+ \eta'$

→ $D_S \rightarrow K^+ \phi,\ K^+ \eta',\ K^{(*)0} \pi^+$

→ $D \rightarrow h^+ h^- h^+;\ h^+ h^- h^+ h^-$

See, e.g.,
Isidori, Kamenik, Ligeti, Perez (arXiv:1111.4987)
Brod, Kagan, Zupan (arXiv:1111.5000)
Cheng, Chaing (arXiv:1201.0785)
Pirtskhalava, Uttayarat (arXiv:1112.5451)
Bhattacharya, Gronau, Rosner (arXiv:1201.2351)
Feldmann, Nandi, Soni (arXiv:1202.3795)
Grossman, Kagan, Zupan (arXiv:1204.3557)

Prospects

Short term (1.1 or 2.5 fb^{-1})

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

  → *σ from 0.25% to ~0.15% may be enough to confirm a 4-5σ effect.*

- **ΔA_{CP} with $D^+_{(S)} \to K_S h^+$ vs. ϕh^+ (work started !)**

  → *Expect ~7M $D^+ \to \phi\pi^+$ and ~3.5M $D+ \to K_S\pi^+$*

  Belle: $\Delta A_{CP}(D^+ \to \phi\pi^+$ vs. $D^+_{(S)} \to \phi\pi^+)$ = (0.51±0.28±0.05)% with 0.238M $D^+ \to \phi\pi^+$

  PRL **108**, 071801 (2012)

  Belle: $A_{CP}(D^+ \to K_S\pi^+)$ = (0.36±0.09±0.07)% with 1.7M events

  CPV due to the kaon

  arXiv:1203.6409

- **Dalitz analyses of $D \to h^+h^-h^-$, $h^+h^+h^-h^-$ modes**

Longer term: LHCb upgrade (2019)

Conclusion

$\Delta A_{CP}(K^+K^- - \pi^+\pi^-) = (-0.82 \pm 0.21_{stat} \pm 0.11)\%$

- **Control of systematic effects: good ex. of precision physics @ pp collider.**
- **Evidence for CPV in charm decays at LHCb**

  → *Mostly a direct CPV*

  → *Not yet a 5σ effect*

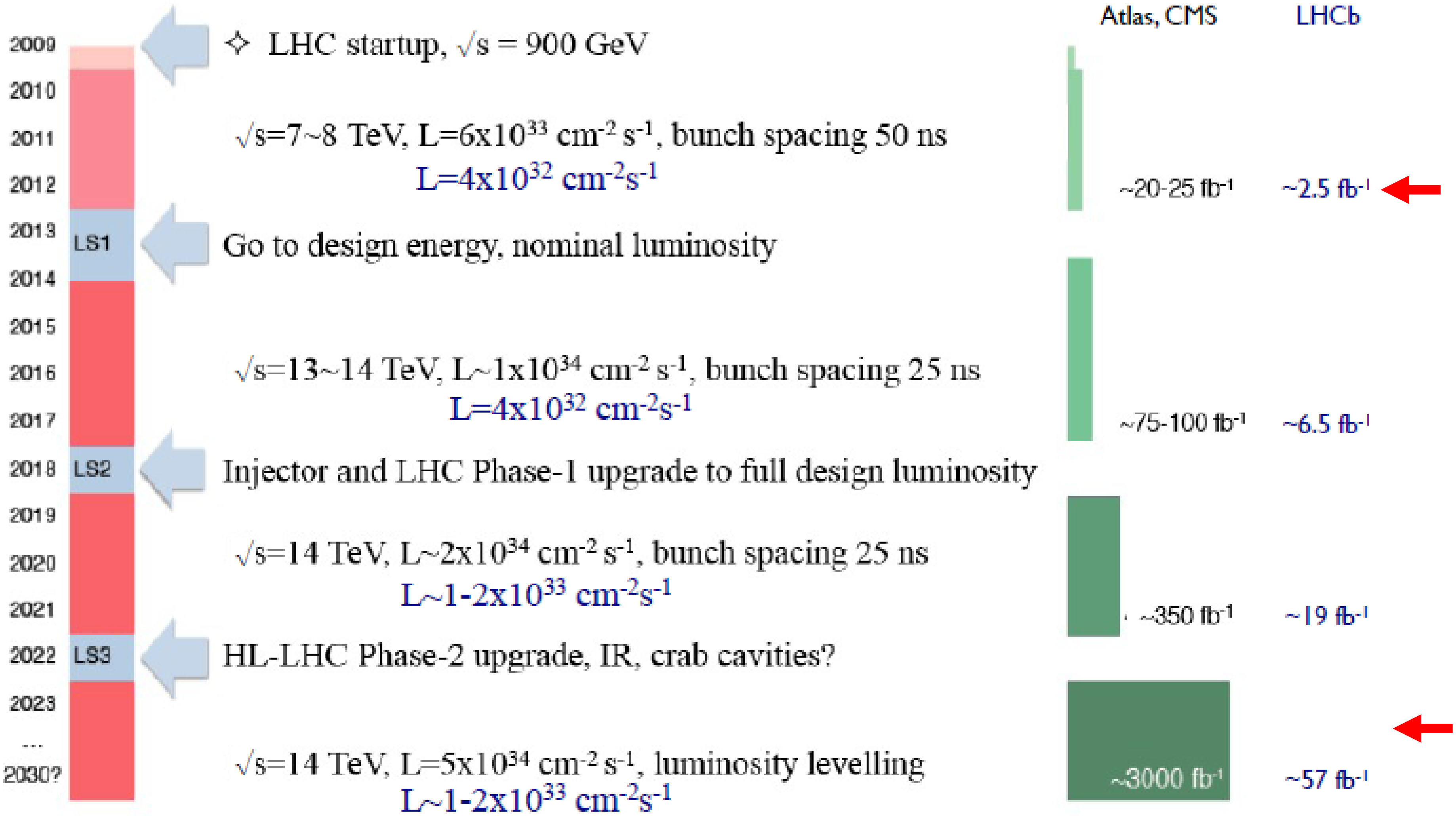
  → *But not far from it when combined with other experiments (4σ)*

- **Could be SM, could be NP, it's anyway very interesting.**
- **There's a large Charm physics programme at LHCb. Other modes will be studied in the future to over-constrain the problem.**
- **And don't forget the LHCb's upgrade !**

→ *Stay tuned (at least for the next 15 years ☺) !*

Back-up

LHC's Schedule



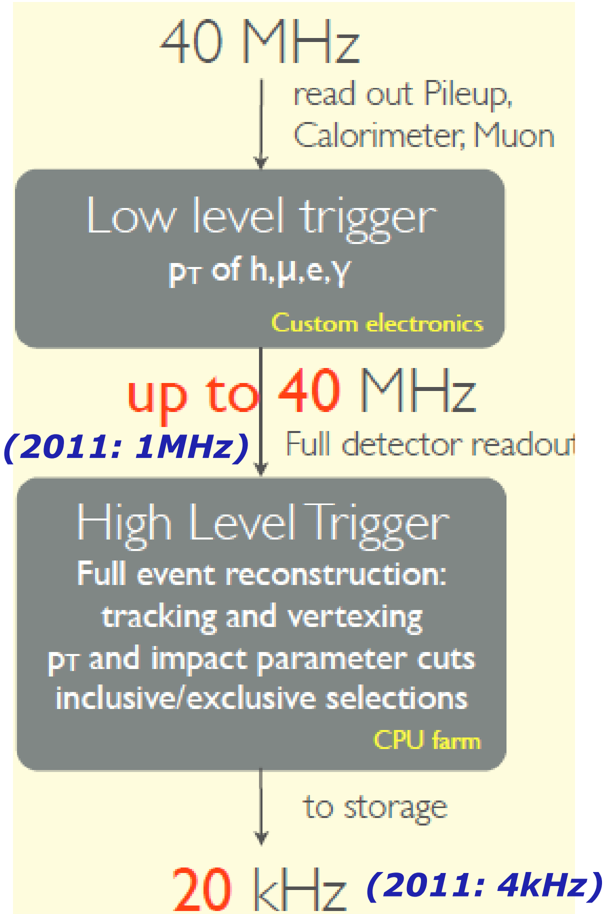
M.Nessi, Chamonix 2012

Upgraded LHCb (start by 2019)

Should bring ~180 times more hadronic charm decays !

- **50 fb^{-1} with L_{peak}=1-2×10^{33} $cm^{-2}s^{-1}$**
- **At $\sqrt{s}$=14 TeV: σ_{cc} ~1.8 times larger**
- **Fully software trigger: Trigger Efficiency on hadronic decays ×2**

(reduce the role the hardware L0 trigger)



-This means ~460M $D^0 \to K^+K^-$ & 130M $D^0 \to \pi^+\pi^-$. Naïve extrapolation: σAcp~0.015%. That's far below the current systematics. A part of the statistic could be sacrificed to improve it.

-Also for decays like $D^+_{(S)} \to K_S h^+$ vs. ϕh^+, will we probably be pushing on the systematics by then.

-And many other things: DCS, precision Dalitz studies, etc…

See e.g. "Workshop on the Implications of of LHCb measurements", CERN, April 16-18, 2012

Mode	2011 yield (kilo events)	50 fb^{-1} yield (mega events)
untagged $D^0 \to K^-\pi^+$	230 000	41 000
$D^{*+} \to D^0\pi^+;\ D^0 \to K^-\pi^+$	39 000	7 020
$D^{*+} \to D^0\pi^+;\ D^0 \to K^+\pi^-$	130	23
$D^0 \to K^-K^+$	25 000	4 600
$D^0 \to \pi^-\pi^+$	6 500	1 200
$D^{*+} \to D^0\pi^+;\ D^0 \to K^-K^+$	4 300	775
$D^{*+} \to D^0\pi^+;\ D^0 \to \pi^-\pi^+$	1 100	200
$D^{*+} \to D^0\pi^+;\ D^0 \to K^0_S\pi^-\pi^+$	290	180
$D^{*+} \to D^0\pi^+;\ D^0 \to K^0_S K^-K^+$	45	30
$D^{*+} \to D^0\pi^+;\ D^0 \to K^-\pi^-\pi^+\pi^+$	7 800	1 400
$D^{*+} \to D^0\pi^+;\ D^0 \to K^-K^+\pi^-\pi^+$	120	22
$D^{*+} \to D^0\pi^+;\ D^0 \to \pi^-\pi^-\pi^+\pi^+$	470	85
$D^{*+} \to D^0\pi^+;\ D^0 \to K^-\mu^+X$	–	4 000
$D^{*+} \to D^0\pi^+;\ D^0 \to K^+\mu^-X$	–	0.1

Mode	2011 yield (kilo events)	50 fb^{-1} yield (mega events)
$D^+ \to K^-\pi^+\pi^+$	60 000	10 800
$D^+ \to K^+\pi^+\pi^-$	210	38
$D^+ \to K^-K^+\pi^+$	6 500	1 170
$D^+ \to \phi\pi^+$	2 825	510
$D^+ \to \pi^-\pi^+\pi^+$	3 200	575
$D^+ \to K^0_S\pi^+$	1 500	945
$D^+ \to K^0_S K^+$	525	330
$D^+ \to K^-K^+K^+$	60	11
$D_S^+ \to K^-K^+\pi^+$	8 900	1 600
$D_S^+ \to \phi\pi^+\ (\phi \to K^-K^+)$	5 350	960
$D_S^+ \to \pi^-\pi^+\pi^+$	2 000	360
$D_S^+ \to K^-\pi^+\pi^+$		
$D_S^+ \to \pi^-K^+\pi^+$	555	100
$D_S^+ \to K^-K^+K^+$	49	9
$D_S^+ \to K^0_S K^+$	413	260
$D_S^+ \to K^0_S\pi^+$	33	21

samples	parameter(s)	precision
WS/RS $K\pi$	(x'^2, y')	$\mathcal{O}[(10^{-5}, 10^{-4})]$
WS/RS $K\mu\nu$	r_M	$\mathcal{O}(5 \times 10^{-7})$
WS/RS $K\mu\nu$	$\lvert p/q \rvert$	$\mathcal{O}(1\%)$
$D^{*+} \to D^0\pi^+;\ D^0 \to K^-K^+,\ \pi^-\pi^+$	$\Delta A_{\rm CP}$	0.015%
$D^{*+} \to D^0\pi^+;\ D^0 \to K^-K^+$	$A_{\rm CP}$	0.010%
$D^{*0} \to D^0\pi^+;\ D^0 \to \pi^-\pi^+$	$A_{\rm CP}$	0.015%
$D^{*0} \to D^0\pi^+;\ D^0 \to K^0_S\pi^-\pi^+$	(x, y)	(0.015%, 0.010%)
$D^{*0} \to D^0\pi^+;\ D^0 \to K^-K^+\ (\pi^-\pi^+)$	$y_{\rm CP}$	0.004% (0.008%)
$D^{*0} \to D^0\pi^+;\ D^0 \to K^-K^+\ (\pi^-\pi^+)$	A_Γ	0.004% (0.008%)
$D^{*0} \to D^0\pi^+;\ D^0 \to K^-K^+\pi^-\pi^+$	$A_{\rm T}$	2.5×10^{-4}
$D^+ \to K^0_S K^+$	PSP-integrated CPV	10^{-4}
$D^+ \to K^-K^+\pi^+$	PSP-integrated CPV	5×10^{-5}
$D^+ \to \pi^-\pi^+\pi^+$	PSP-integrated CPV	8×10^{-5}

Preliminary estimates !

\+

Not everything is solved by increasing the statistics. In some cases, some will be sacrificed to improve systematics.

samples	parameter(s)	precision
WS/RS $K\pi$	(x'^2, y')	$\mathcal{O}[(10^{-5}, 10^{-4})]$
WS/RS $K\mu\nu$	r_M	$\mathcal{O}(5 \times 10^{-7})$
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$D^{*+} \to D^0\pi^+;\ D^0 \to K^-K^+,\ \pi^-\pi^+$	ΔA_{CP}	0.015%
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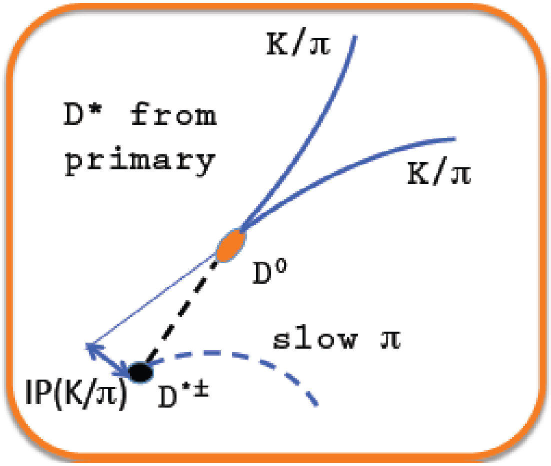
$D^{*0} \to D^0\pi^+;\ D^0 \to \pi^-\pi^+$	A_{CP}	0.015%
$D^{*0} \to D^0\pi^+;\ D^0 \to K_S^0\pi^-\pi^+$	(x, y)	(0.015%, 0.010%)
$D^{*0} \to D^0\pi^+;\ D^0 \to K^-K^+\ (\pi^-\pi^+)$	y_{CP}	0.004% (0.008%)
$D^{*0} \to D^0\pi^+;\ D^0 \to K^-K^+\ (\pi^-\pi^+)$	A_Γ	0.004% (0.008%)
$D^{*0} \to D^0\pi^+;\ D^0 \to K^-K^+\pi^-\pi^+$	A_T	2.5×10^{-4}
$D^+ \to K_S^0K^+$	PSP-integrated CPV	10^{-4}
$D^+ \to K^-K^+\pi^+$	PSP-integrated CPV	5×10^{-5}
$D^+ \to \pi^-\pi^+\pi^+$	PSP-integrated CPV	8×10^{-5}

Fraction of indirect CP

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

- **Δ<t>≠0 since the lifetime acceptance differs between KK and ππ**

  e.g. Smaller KK opening angle: easier to miss cut vetoing tracks from Primary Vertex.



- **Fit to background subtracted decay time distributions yields:**

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

Essentially due to the fraction of D from B decays*

Fraction of indirect CP

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

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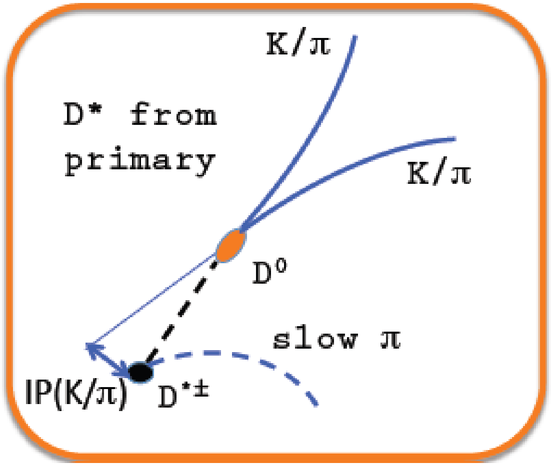

- **Fit to background subtracted decay time distributions yields:**

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

➔ Indirect CPV mostly cancels

Sample	Observable	Sensitivity (1.0 fb^{-1})	Sensitivity (2.5 fb^{-1})
Tagged KK	y_{CP}	6×10^{-4}	4×10^{-4}
Tagged $\pi\pi$	y_{CP}	11×10^{-4}	7×10^{-4}
Tagged KK	A_Γ	6×10^{-4}	4×10^{-4}
Tagged $\pi\pi$	A_Γ	11×10^{-4}	7×10^{-4}
Tagged WS/RS $K\pi$	x'^2	7×10^{-5}	4×10^{-5}
Tagged WS/RS $K\pi$	y'	13×10^{-4}	8×10^{-4}
Tagged $K_S\pi\pi$	x	4×10^{-3}	3×10^{-3}
Tagged $K_S\pi\pi$	y	3×10^{-3}	2×10^{-3}
Tagged $K_S\pi\pi$	$\|q/p\|$	0.4	0.3
Tagged $K_S\pi\pi$	ϕ	25°	15°

Preliminary estimates !

FULL 40 MHz FE READOUT