Charm Mixing and CPV measurements at Hadron Colliders

Walter M. Bonivento

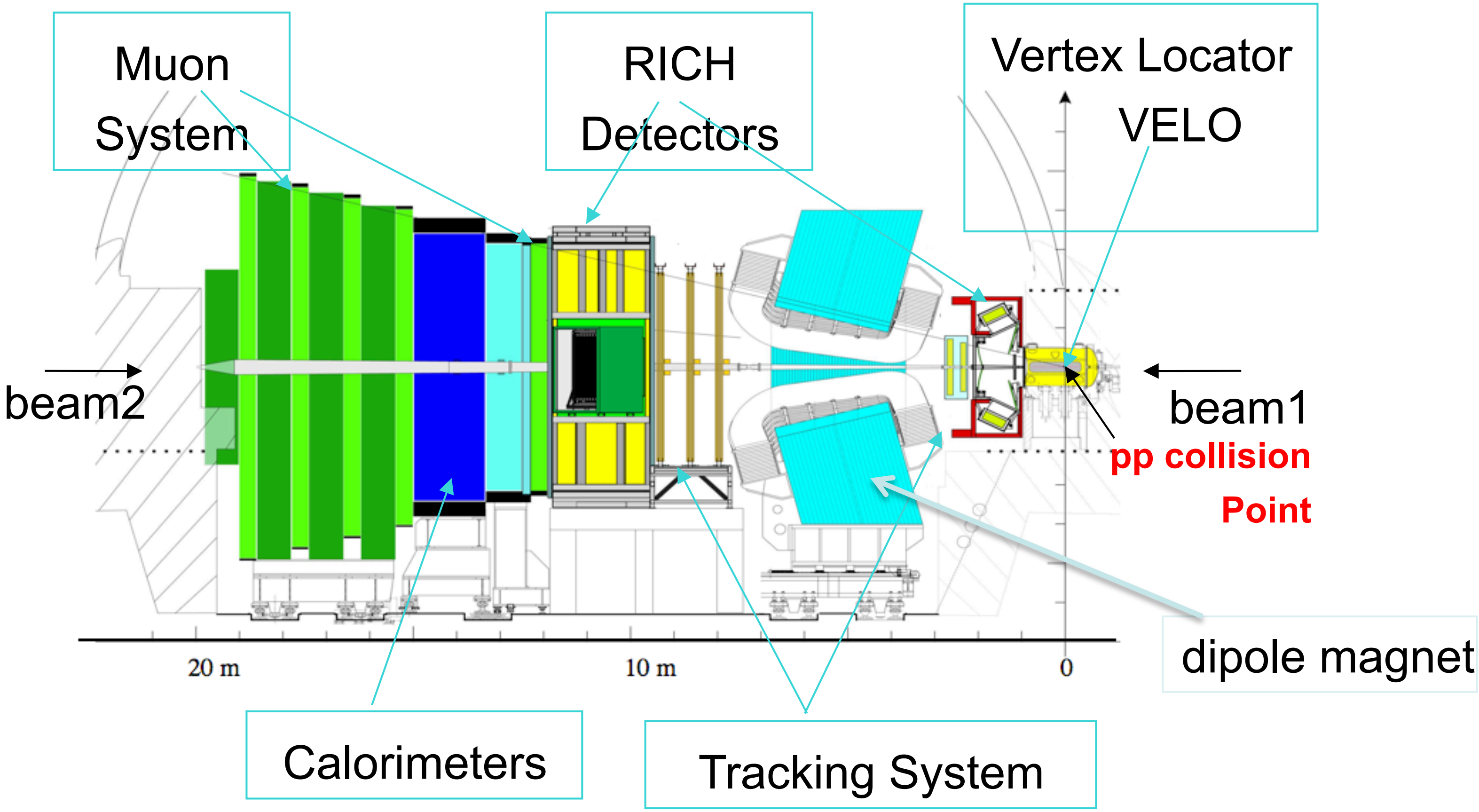
INFN Cagliari

1. Experimental challenges of charm in HC (LHCb)
2. Mixing and indirect CPV
3. Direct CPV → **evidence at 3.5σ in $\Delta A_{CP}(KK/\pi\pi)$**
4. What's next in the line

Intro

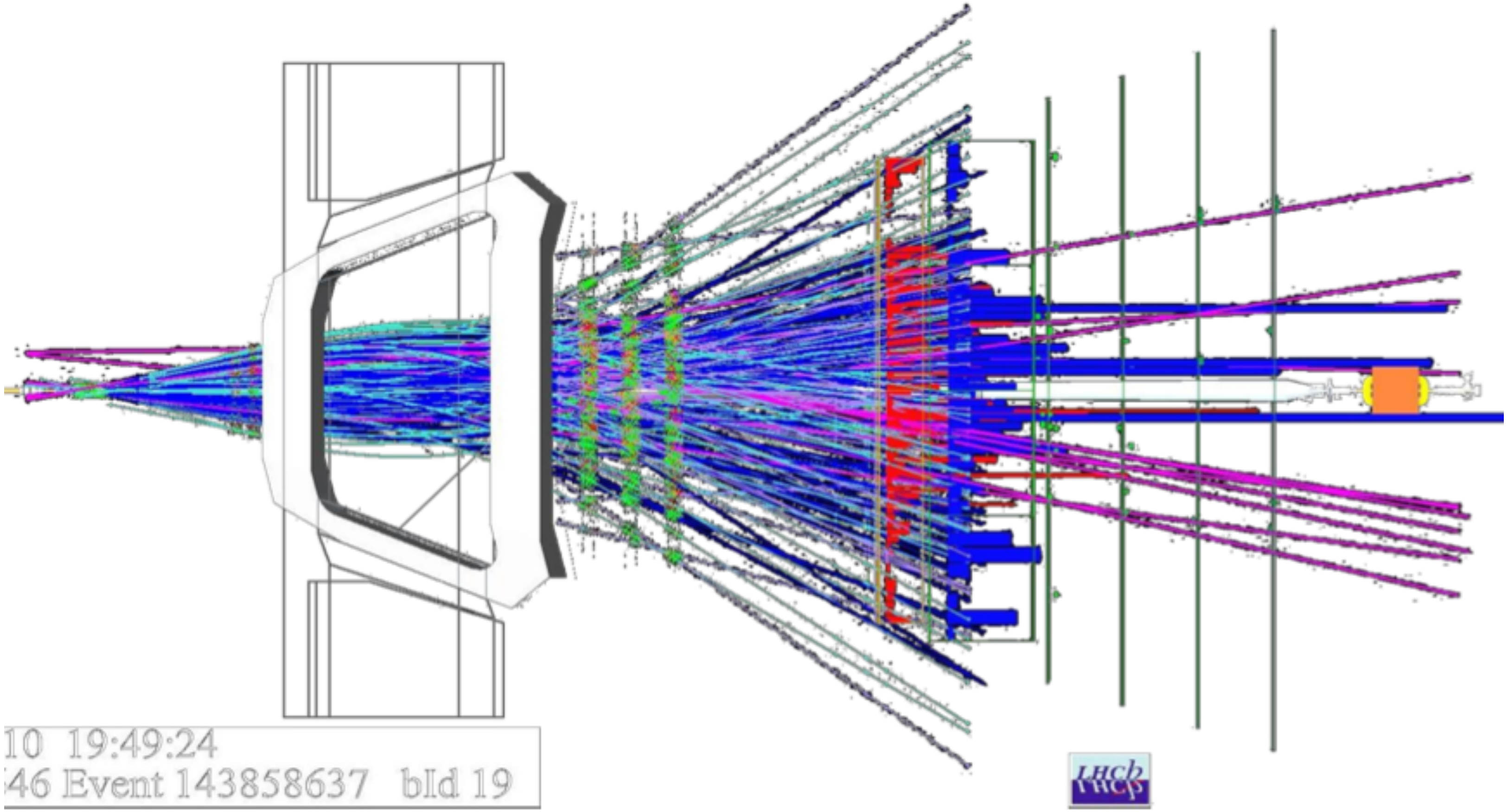
- Hadron colliders we may talk about in charm physics are of course Tevatron and LHC
- But for charm mixing and CPV LHC means LHCb
- LHCb already presented some very interesting results
- LHC is taking over Tevatron for all measurement; by the end of this year we will make public all results on mixing and CPV both time dependent and time integrated with a sensitivity 10x Tevatron
- Tevatron is unfortunately not taking data anymore
- So I will mostly talk about LHCb (but add some reference to Tevatron results)

The LHCb detector



CERN LHC: pp machine with √s=7TeV (due to the 2008 accident)
Pseudo-rapidity coverage → 1.9-4.9
Originally designed for b physics, but now is pursuing a wide charm physics program

A typical event!



Challenges and goodies of charm physics (in LHCb)

the indirect search for NP in B and K decays probe only down-quark couplings

charm decays probe up-quark couplings: we of course do not know where NP might (if any) show up. Studying charm at LHCb would perform a more comprehensive search for NP

- at 7 TeV:
  - σ(ccbar) ≈ 6mb
  - σ(bbar) ≈ 0.3mb
  - σ(pp inelastic)≈60mb
- → **huge σ(ccbar) cross section**
  - background from secondary charm from b already low from the start of the selection
  - and very favorable ratio to inelastic σ (only a factor of 10!)

→ high purity selections with few and soft IP, displaced vertex and p_T cuts

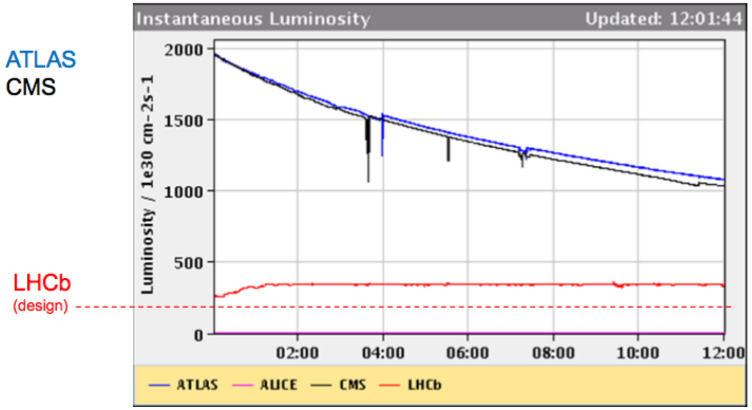
→ very large yields (the highest on the market)

- however due to lower D meson daughter p_T and IP wrt B mesons, trigger thresholds have to be kept low

  → tough requirements for trigger, tracking, online and offline reconstruction, both for bandwidth and timing, and last but not least storage!
- we mostly concentrate on channels with charged tracks in the final state

The LHCb running conditions

2010 was a “learning phase” year with fast varying running conditions and luminosity at the end of it we collected 37pb^{-1} and we were running at a pile-up of up to 2.5 in average (with the design being 0.4) but we coped well with it!



2011

In 2011 we’ve been running with more steady conditions with

- -pile-up of ≈1.5
- -with up to L=4•10^{-32} cm^{-1}s^{-1} (2x the design value but at 0.5xσ) with luminosity leveling

Overall we collected up to more than 1fb^{-1} (while GPE collected about 5pb^{-1})

The trigger and charm physics

hardware

LHC rate ~ 10 MHz

cc fraction ~ 10%

L0 E_T trigger ~ 1 MHz

cc fraction ~ 50%

After the hardware trigger have ~ 500 kHz of cc events

No possibility of an inclusive charm trigger!

Use exclusive triggers tuned for the needs of specific analyses to deliver high signal efficiency and purity

software

High P_T, IP track ~ 50 kHz (50% eff.)

Exclusive D->hh/3h/4h ~ 1 kHz (50-90% eff.)

out for 3kHz total

Already at trigger level selections very similar to offline (S/B about 1)!!!

Then we write down to disk at 200Hz rate (stripping)

at $L=3.5 \cdot 10^{-32}$ $cm^{-1}s^{-1}$ we collect:

$5 * 10^3$ tagged $D^{*\pm} \rightarrow (D0 \rightarrow K^{\pm}K^{\mp})\ \pi^{\pm}$

$3 * 10^5$ untagged $D^0 \rightarrow K^-\pi^+$ per pb^{-1} (now we have $>1fb^{-1}$) !!

We are analyzing the 1fb^{-1} sample (which allows us to have the largest c-meson and baryons sample of history) and we already got one surprise!!!!

Mixing

Time evolution of flavor states in the presence of strong and weak interaction with flavor changing interactions:

$$i\frac{\partial}{\partial t}\begin{pmatrix}a\\b\end{pmatrix}=H\begin{pmatrix}a\\b\end{pmatrix}=\begin{pmatrix}M_{11}-\frac{i}{2}\Gamma_{11} & M_{12}-\frac{i}{2}\Gamma_{12}\\ M_{12}^{*}-\frac{i}{2}\Gamma_{12}^{*} & M_{22}-\frac{i}{2}\Gamma_{22}\end{pmatrix}\begin{pmatrix}a\\b\end{pmatrix}$$

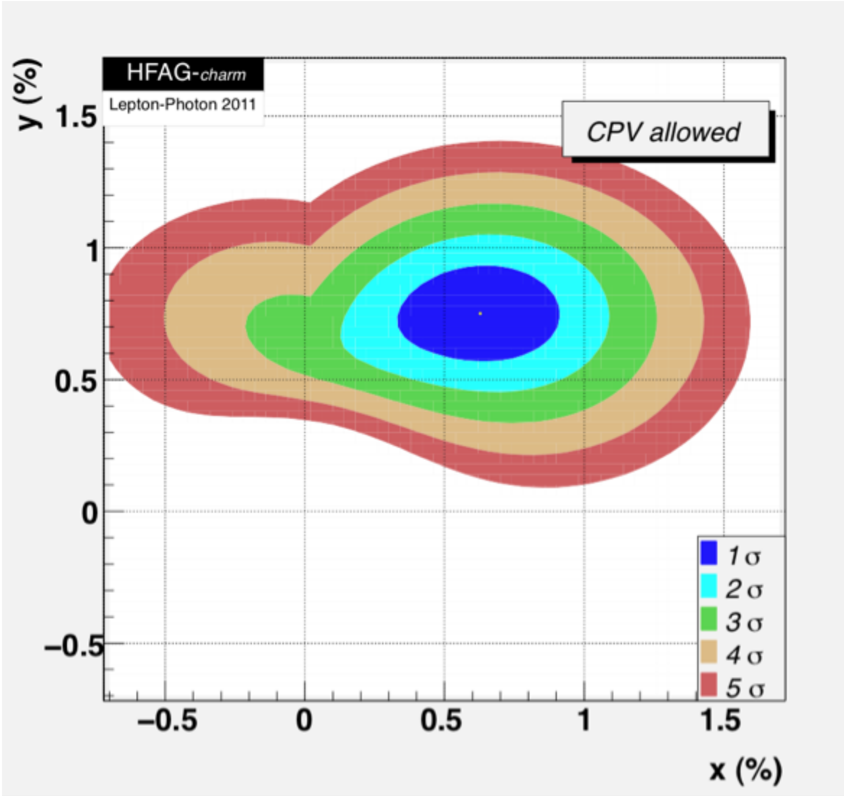
eigenstates of H are $|B_{L,H}\rangle = p|B^0\rangle \pm q|\overline{B^0}\rangle$ with $\frac{q}{p}=\sqrt{\frac{M_{12}^{*}-\frac{i}{2}\Gamma_{12}^{*}}{M_{12}-\frac{i}{2}\Gamma_{12}}}$

$x \equiv \frac{\Delta m}{\Gamma}$ $\quad y \equiv \frac{\Delta\Gamma}{2\Gamma}$ $\quad P(N^0 \to \overline{N^0}) = \frac{1}{2}\left|\frac{q}{p}\right|^2 e^{-T}(\cosh yT - \cos xT)$ $\quad T \equiv \Gamma t$

	$K^0/\overline{K^0}$	$D^0/\overline{D^0}$	$B_d^0/\overline{B_d^0}$	$B_s^0/\overline{B_s^0}$
τ (ps)	89.58 ± 0.05, 51160 ± 200	0.4101 ± 0.0015	1.530 ± 0.009	1.470 ± 0.027
Γ (s^{-1})	5.59×10^9	2.4×10^{12}	6.5×10^{11}	6.8×10^{11}
x	0.946 ± 0.002	0.0097 ± 0.0028	0.776 ± 0.008	26.1 ± 0.5
y	-0.9965	0.0078 ± 0.0019	$\|y\| < 0.04$, 90% C.L.	$[0.09, -0.03]$, 95% C.L.
	K_S, K_L	slow mixing		fast mixing

x→frequency y→amplitude

Experimental status: mixing



no mixing point excluded at 10.1σ
x differs from 0 by 2.7σ
y differs from 0 by 5.9σ

Theory: mixing

SM contribution expected to be dominated by long range non-perturbative effects: up to x and y to $O(10^{-2})$ possible. Slight preference for $|y|<|x|$ ($x=\Delta m/\Gamma$ and $y=\Delta\Gamma/2\Gamma$)

NP can enhance short range box diagram contribution (which is 10^{-5} in SM)

Observables for mixing measurements:

1) $$y_{CP} = \frac{\hat{\Gamma}(D^0 \to K^+K^-)}{\hat{\Gamma}(D^0 \to K^-\pi^+)} - 1$$ in absence of CPV is equivalent to y

2) time dependent ratio of WS/RS $D^0 \to K\pi$ decays → yields x'^2 and y' (rotated to x and y by the strong phase δ between RS and WS)

Year	Exper.	y' (%)	$x'^{\,2}$ ($\times 10^{-3}$)
2007	CDF [14]	0.85 ± 0.76	-0.12 ± 0.35

3) time dependent Dalitz to self conjugated final states $D^0 \to K_S\pi\pi$ → yield x and y

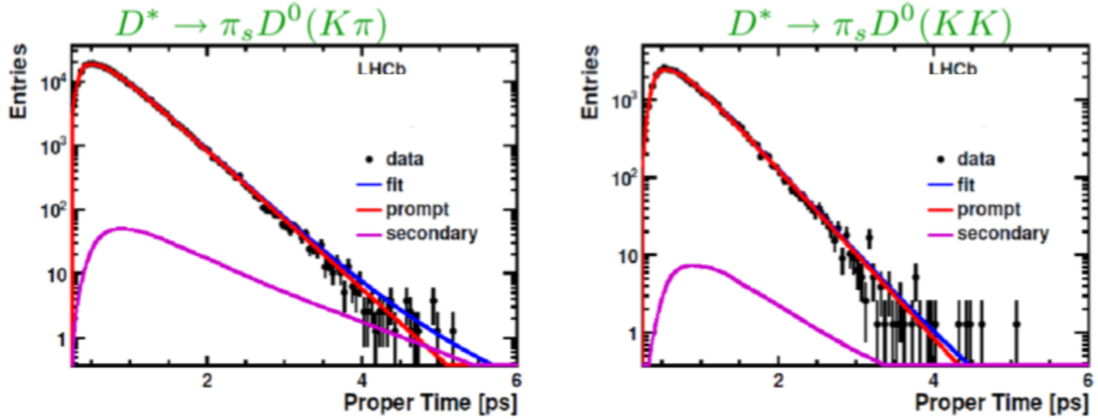
4) WS/RS BR ($D^0 \to K^+ l\nu$) → yields x^2+y^2

5) correlated $\psi(3770)$ decays → yield y,(x^2+y^2) and δ

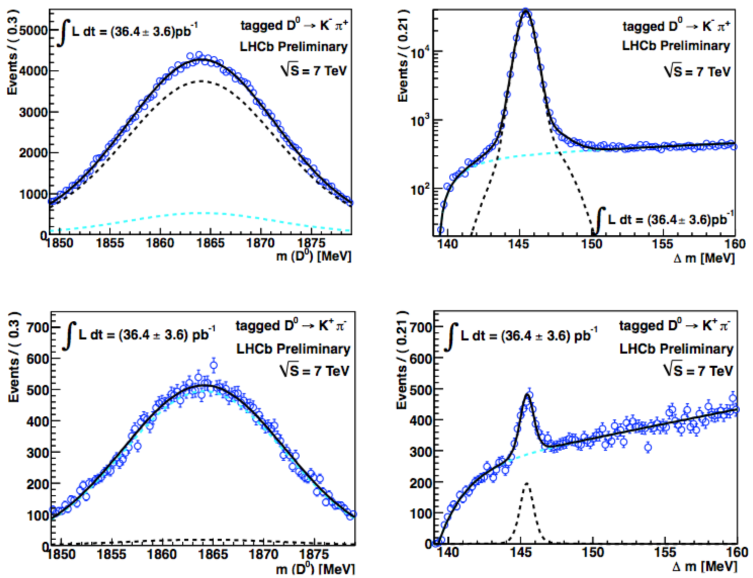
Mixing measurements in LHCb

Measurement of y_{CP}
with 2010 data L=28pb^{-1}
arXiv:1112.4698

y_{CP}=y cosΦ-R_Mx sinΦ



$y_{CP} = (0.55 \pm 0.63\,(stat)\ \pm 0.41\,(syst))\%$



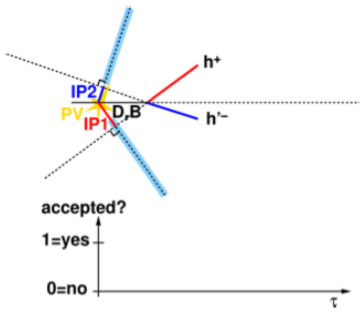
	WS/RS of $D \to K\pi$ decays (%)
$R_{measured}$	$0.442 \pm 0.033\ (stat.)\ \pm 0.042\ (sys.)$
$R_{acc\,cor}$	$0.409 \pm 0.031\ (stat.)\ \pm 0.039 (sys.)\ ^{+0.028}_{-0.020}\ (sys.\ mixing)$
$R(PDG)$	0.380 ± 0.018

in preparation to the measurement of mixing with wrong sign $D^0 \to K\pi$:
with 2010 data only time-integrated measurement

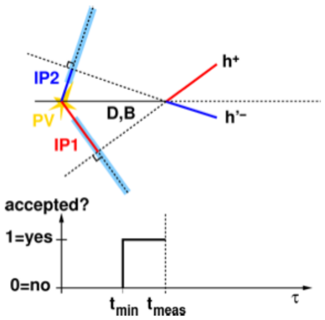
At present no 5σ measurement of mixing ≠0; for sure we expect to do it with LHCb: scaling of $\sigma_{stat}(y_{CP})$=0.03-0.04% with 5fb^{-1}

Two main experimental issues

- **Need to determine lifetime acceptance in real data**
  - Key ingredient to the method is an event by event based lifetime acceptance which takes trigger and selection into account: this is possible in LHCb since the lifetime bias is in the software trigger
  - results are used in the normalization of the PDF in the fitting procedure

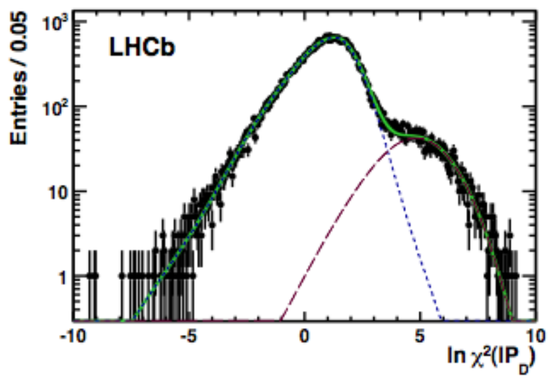


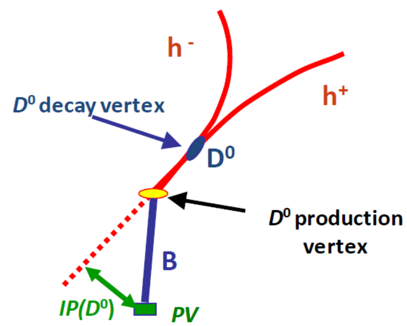
swiming method



idea from CDF…

•prompt-secondary separation





Types of CPV

CP violation if $\boxed{\Gamma_f \neq \overline{\Gamma}_f}$ $\quad A_f = \langle f|H|B^0\rangle \quad \overline{A}_f = \langle f|H|\overline{B^0}\rangle$

CPV in Decay

Direct CP Violation

$$\boxed{\left|\frac{\overline{A}_{\overline{f}}}{A_f}\right| \neq 1}$$

CPV in Mixing

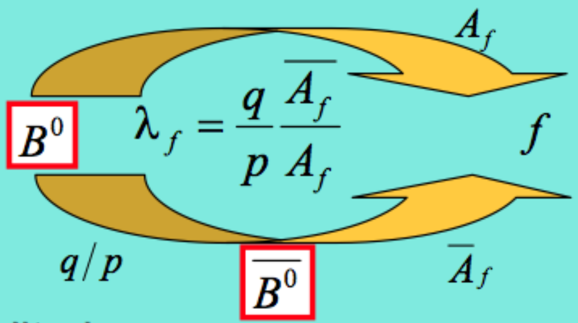
Indirect CP Violation

$$\boxed{\left|\frac{q}{p}\right| \neq 1} \qquad \boxed{\mathrm{Im}\{\Gamma_{12}^* M_{12}\} \neq 0}$$

CPV in Interference between mixing and decay

Indirect CP Violation

$$\boxed{|\lambda_f| = 1, \quad \mathrm{Im}\{\lambda_f\} \neq 0}$$



$$\boxed{A_f^{CP}(t) = \frac{\Gamma_f(t) - \overline{\Gamma}_f(t)}{\Gamma_f(t) + \overline{\Gamma}_f(t)} = \frac{-C_f \cos(\Delta m t) + S_f \sin(\Delta m t)}{\cosh(\Delta\Gamma t/2) + \Omega_f \sinh(\Delta\Gamma t/2)}}$$

Golden case: CP final state and single dominating amplitude

$$\boxed{A_{f_{CP}}^{CP}(t) = \mathrm{Im}\,\lambda_{f_{CP}} \sin(\Delta m t)}$$

CP Violation

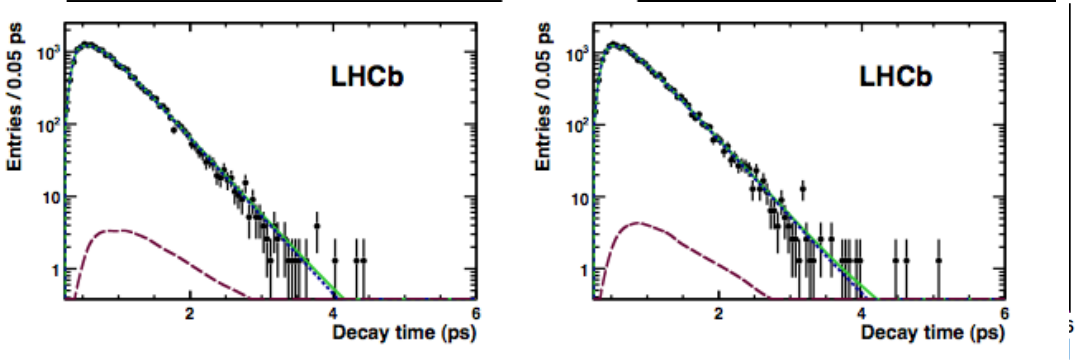
- **In the SM, indirect CP violation in charm is expected to be very small and universal between CP eigenstates**
  - Exactly how small is a matter of debate... but <few 10^{-4} looks as a reasonable recent estimate
- Direct CP violation can be larger in SM, very dependent on final state (therefore we must search wherever we can)
  - in singly-Cabibbo-suppressed modes O (few 10^{-3}) possible (in particular as a post-diction now)
- Both can be enhanced by NP, in principle up to O(%)
- **In LHCb we have now the statistics to make O(0.1-0.2%) measurements!**

Measurement of indirect CPV

Measurement using 28 pb^{-1} of 2010 data, arXiv:1112.4698
using $D^* \to D^0\pi$, $D^0 \to K^+K^-$ decays.

$$A_\Gamma = \frac{\Gamma(D^0 \to KK) - \Gamma(\overline{D^0} \to KK)}{\Gamma(D^0 \to KK) + \Gamma(\overline{D^0} \to KK)} = \frac{1}{2} R_M y \cos\Phi - x \sin\Phi$$

$D^{*+} \to \pi_s^+ D^0(K^-K^+)$ $\quad$ $D^{*-} \to \pi_s^- D^0(K^-K^+)$



$A_\Gamma = (-\,5.9 \pm 5.9 \;\pm 2.1) \times 10^{-3}$

WA_{HFAG} $A_\Gamma = (0.12 \pm 0.25)\%$
(w/o LHCb)

220k $D^0 \to K\pi$ events used to determine D^0 lifetime $\tau = (410.3 \pm 0.9)$ fs, PDG:(410.1±1.5) fs

Expected precision with 5fb^{-1} $\rightarrow$ $2 {*} 10^{-4}$

Experimental issues with time integrated CPV in LHCb

- **Experimentally, we have to cope with fake asymmetries**:
  - production asymmetries (pp collider)
  - detection asymmetries (different K+/K- interaction lengths, soft pion efficiency asymmetry)
  - backgrounds
- **Moreover the dipole magnet makes the detector left-right asymmetric for + charge and – charge particles**
  - a localized detector inefficiency translates into a fake CPV asymmetry

1) **we developed robust observables**:

- Miranda technique for SCS decay $D^+ \rightarrow K^+K^-\pi^-$
- difference of two CPV asymmetries in SCS decays into CP eigenstates $D^0 \rightarrow KK$ and $D^0 \rightarrow \pi\pi$
- develop fiducial cuts to exclude kinematic zones leading to potentially high systematics effects

2) **swap the magnetic field from time to time**

- signal purity is a must → excellent detector performance

D->KKπ: the method

- **Model-independent search for CPV in Dalitz plot distribution**
- **Compare binned, normalized Dalitz plots for D^+ and D^-**
  - Production asymmetry cancels completely after normalization.
  - Efficiency asymmetries that are flat across Dalitz plot also cancel.
- Method based on asymmetry significance (*)

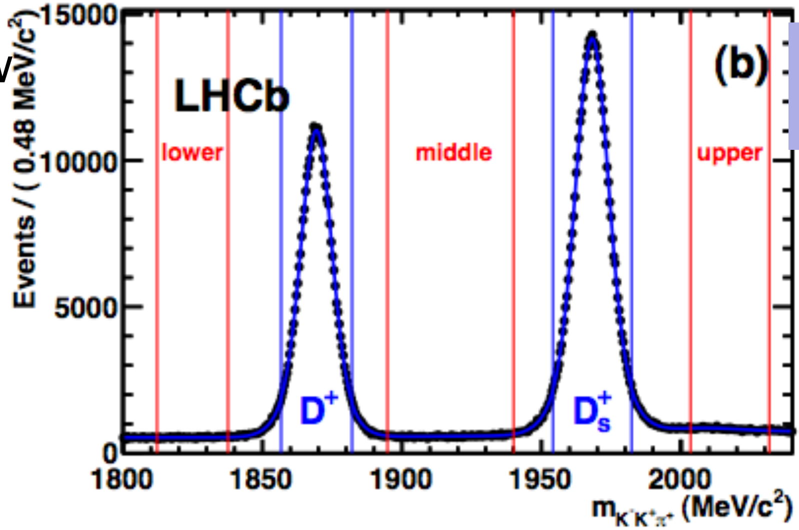
$$\mathcal{S}^i_{CP} = \frac{N^i(D^+) - \alpha N^i(D^-)}{\sqrt{N^i(D^+) + \alpha^2 N^i(D^-)}}, \qquad \alpha = \frac{N_{\mathrm{tot}}(D^+)}{N_{\mathrm{tot}}(D^-)}$$

  - In absence of asymmetry, values distributed as Gaussian (μ=0, σ=1)
  - Figure of merit for statistical test: sum of squares of S^i_{CP} is a $\chi 2$

(*) Phys. Rev. D80 (2009) 096006
See also BaBar: Phys.Rev. D78:051102 (2008); our 2010 dataset contains 10x more events, and is of comparable size of Belle analysis of D→φπ:(arXiv: 0807.4545)
(2011 is another x30 !!)

D→KKπ: mass and Dalitz plot

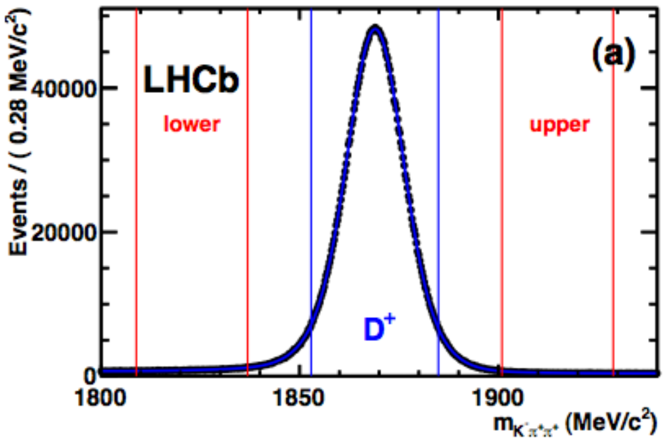
Yield of 400k in window
Purity of ≈91%



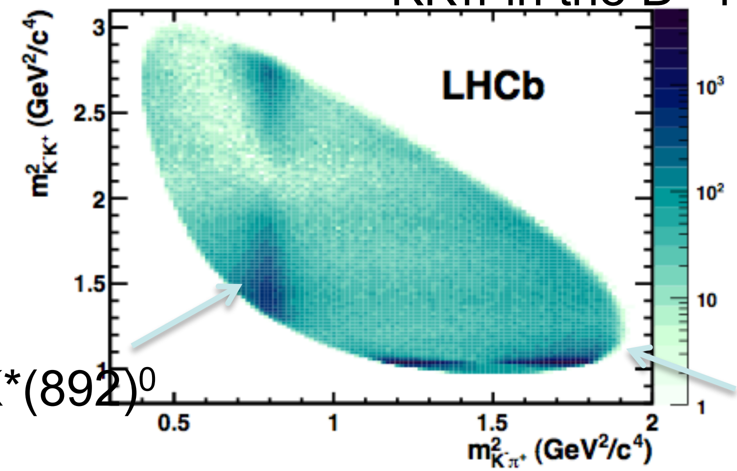
Phys. Rev. D 84, 112008 (2011)
LHCb 35pb^{-1}

KKπ signal (D^+)
and control mode
(D_s^+)

Kππ control mode (D^+)
purity ~ 98%



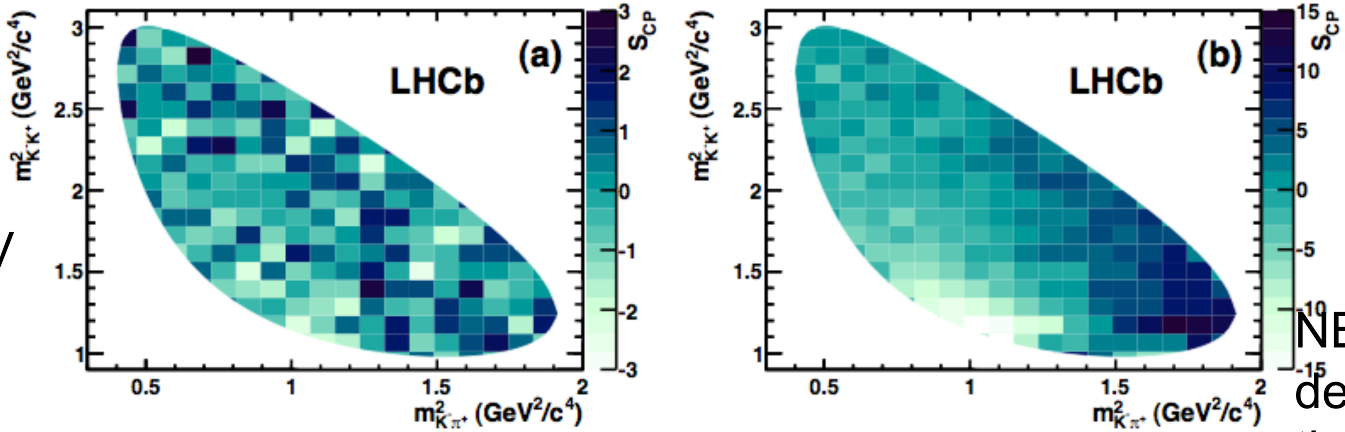
KKπ in the D+ mass window



K*(892)^0
φ(1020)

Sensitivity to NP

no CPV
p=5%



4^o in φ phase
p=10^{-100}!!

NB: on the total decay asymmetry the effect would be 0.1%!!

toys using
CLEO-c model

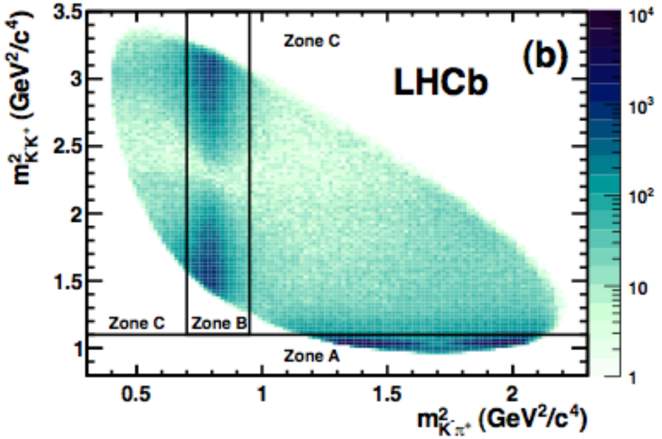
CPV	Adaptive I		Adaptive II	
	$p(3\sigma)$	$\langle S\rangle$	$p(3\sigma)$	$\langle S\rangle$
no CPV	0	0.84σ	1%	0.84σ
6° in $\phi(1020)$ phase	99%	7.0σ	98%	5.2σ
5° in $\phi(1020)$ phase	97%	5.5σ	79%	3.8σ
4° in $\phi(1020)$ phase	76%	3.8σ	41%	2.7σ
3° in $\phi(1020)$ phase	38%	2.8σ	12%	1.9σ
2° in $\phi(1020)$ phase	5%	1.6σ	2%	1.2σ
6.3% in $\kappa(800)$ magnitude	16%	1.9σ	24%	2.2σ
11% in $\kappa(800)$ magnitude	83%	4.2σ	95%	5.6σ

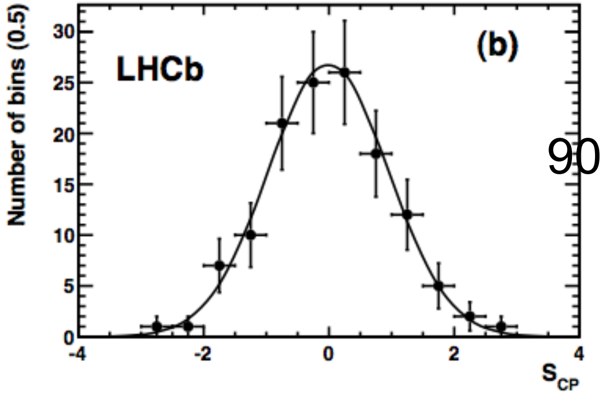
- With no CPV, method does not produce a signal (good!)
- If we do see a signal, it will mean big CPV and thus new physics.

$D_s \to KK\pi$ control mode

LHCb 35pb^{-1}

CF mode → expect no CPV





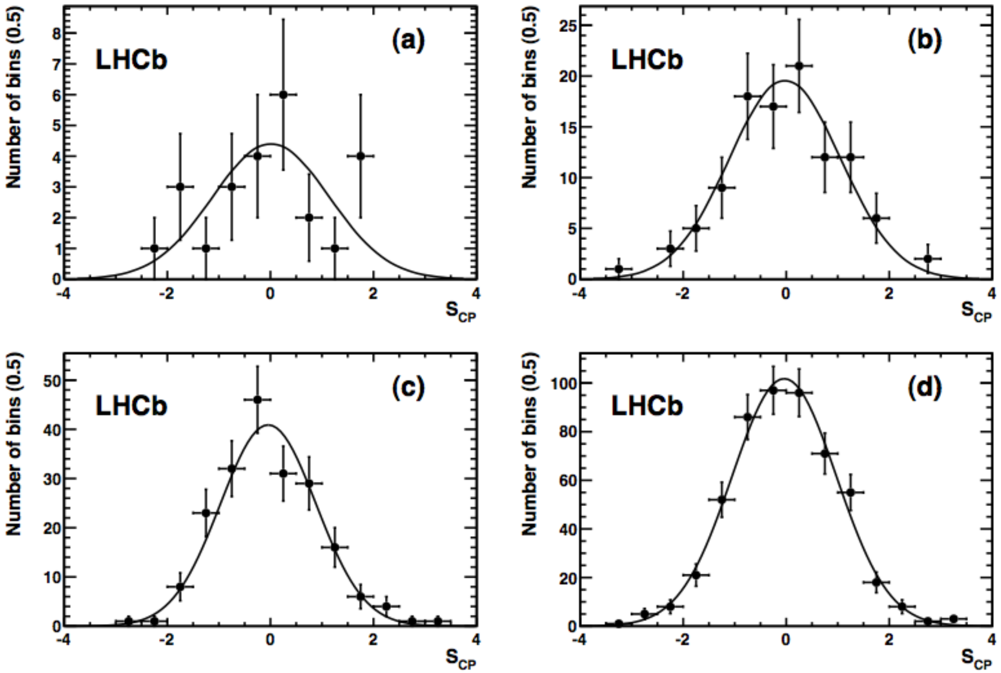
900 uniform bins

bins	Zone A	Zone B	Zone C
300	20.1	25.3	14.5
100	41.7	84.6	89.5
30	66.0	62.5	24.6

p-Values

Results for D→KKπ

Binning	Fitted mean	Fitted width	χ^2/ndf	p-value (%)
Adaptive I	0.01 ± 0.23	1.13 ± 0.16	32.0/24	12.7
Adaptive II	-0.024 ± 0.010	1.078 ± 0.074	123.4/105	10.6
Uniform I	-0.043 ± 0.073	0.929 ± 0.051	191.3/198	82.1
Uniform II	-0.039 ± 0.045	1.011 ± 0.034	519.5/529	60.5



No evidence for CP violation in the 2010 dataset

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$A_{CP}(D^0 \rightarrow KK)$ and $A_{CP}(D^0 \rightarrow \pi\pi)$

- Most precise measurement of CDF
- From A.Di Canto talk at Beauty 2011"
  - " World's largest sample of D0 → h+h′− decays"

Combine the "raw" asymmetries of three different event samples to minimize systematic errors caused by the detector induced asymmetries:

✓ $D^\star \rightarrow D^0\pi_s \rightarrow [h\,h]\,\pi_s$ $\quad A(hh^\star) = A_{CP}(hh) + \delta(\pi_s)$

cancel asymmetry due to π_s^+/π_s^-
different reconstruction efficiencies

✓ $D^\star \rightarrow D^0\pi_s \rightarrow [K\pi]\,\pi_s$ $\quad A(K\pi^\star) = A_{CP}(K\pi) + \delta(\pi_s) + \delta(K\pi)$

cancel asymmetry due to K^+/K^-
different interaction with matter
+
possible CPV
in $D^0 \rightarrow K\pi$

✓ $D^0 \rightarrow [K\pi]$ $\quad A(K\pi) = A_{CP}(K\pi) + \delta(K\pi)$

The physical A_{CP} could be extracted through the combination:

$$A_{CP}(hh) = A(hh^\star) - A(K\pi^\star) + A(K\pi)$$

$A_{CP}(D^0 \rightarrow \pi^+\pi^-)$ $\quad [+0.22 \pm 0.24\ (stat.) \pm 0.11\ (syst.)]\%$ $\quad A_{CP}(D^0 \rightarrow K^+K^-)$ $\quad [-0.24 \pm 0.22\ (stat.) \pm 0.10\ (syst.)]\%$

$\Delta A_{CP} = A_{CP}(D^0 \rightarrow KK) - A_{CP}(D^0 \rightarrow \pi\pi)$

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

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

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

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

physics CP asymmetry

Detection asymmetry of D^0

Detection asymmetry of soft pion

Production asymmetry

For a two-body decay of a spin-0 particle to a self-conjugate final state, no D^0 detector efficiency asymmetry, $A(K^-K^+) = A(\pi^-\pi^+) = 0$

Look at difference in CP asymmetry between KK and ππ: very robust against systematics

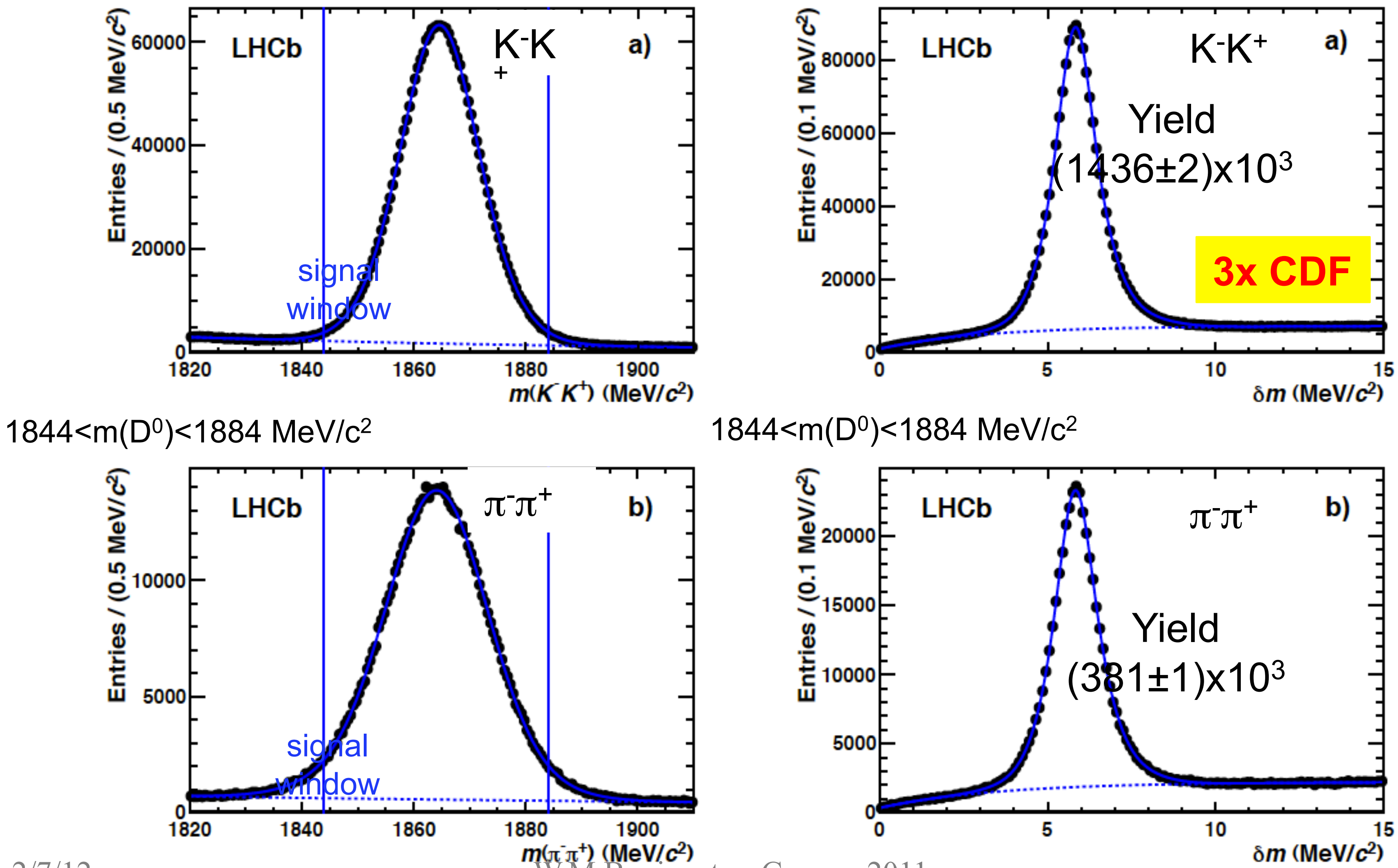
$$A_{RAW}(K^-K^+)^* - A_{RAW}(\pi^-\pi^+)^* = A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+)$$

$A_{CP}(KK)$ and $A_{CP}(\pi\pi)$ receive contributions from both indirect CPV (universal) and direct CPV (final state dependent) → taking the difference we are sensitive (almost) only to the direct CPV contribution

Mass spectra

http://arxiv.org/abs/1112.0938
LHCb 620pb^{-1}

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



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Kinematic binning

- **Kinematic binning needed to suppress second-order effects** of correlated asymmetries e.g. correlated variation of A_P and A_D with kinematics (pt, η of soft π)
  - Divide data into kinematic bins of (pT of D*+, η of D*+, p of soft pion, left/right hemisphere) -- 54 bins
  - Along similar lines:
    - split by magnet polarity (field pointing up, pointing down)
    - split into two run groups (before & after technical stop)
  - Fit final states $D^0 \to K^+ K^-$ and $\pi^+ \pi^-$ separately => 432 independent fits.

Result

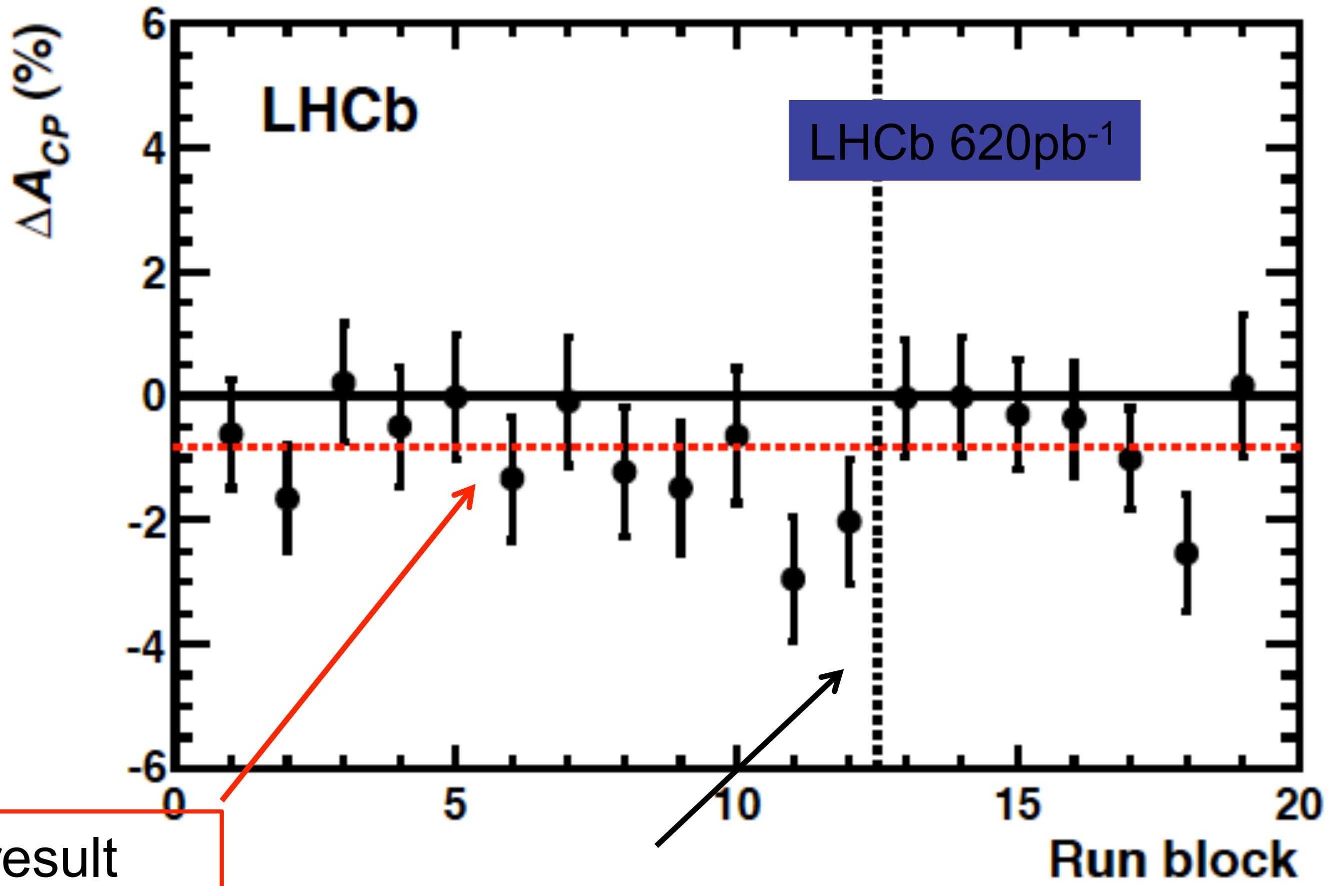
$$\Delta A_{CP} = [-0.82 \pm 0.21(\text{stat.}) \pm 0.11(\text{sys.})]\,\%$$

significance 3.5σ

LHCb 620pb^{-1}

expected stat error with 5fb^{-1} → 4×10^{-4}

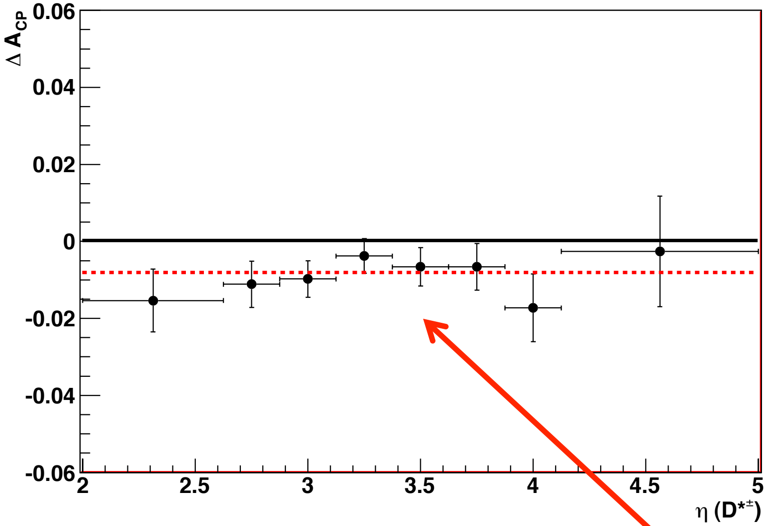
Stability of result vs data-taking runs

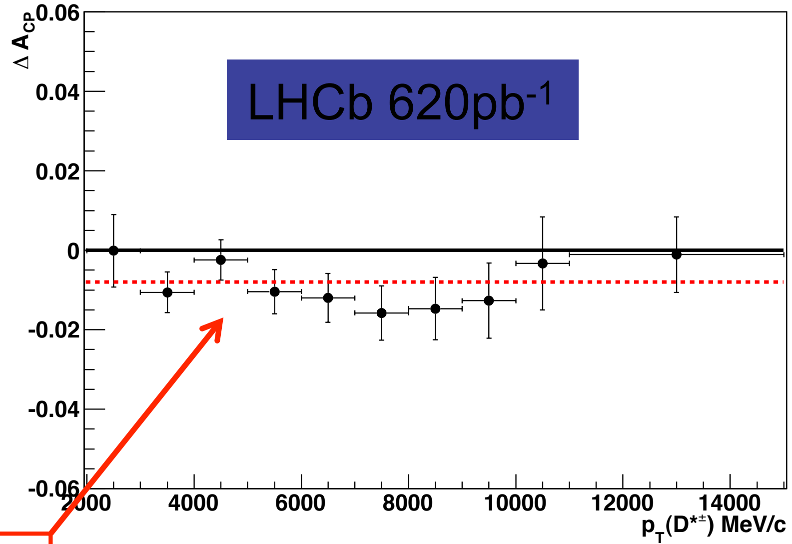


Final result (dashed line)

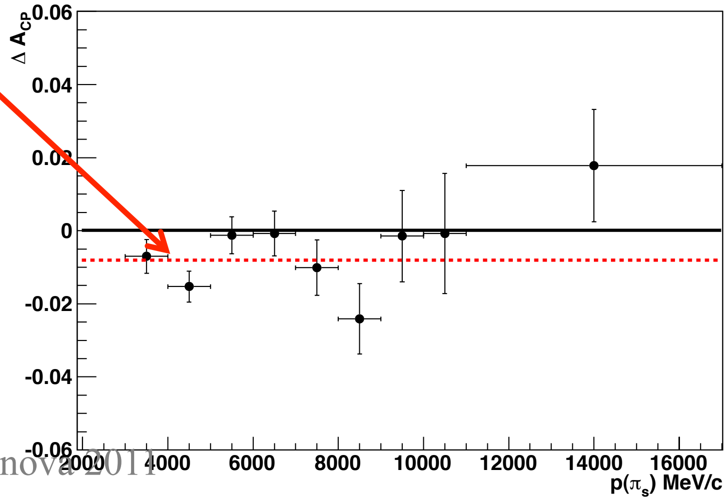
Before and after a technical stop

Stability of result on relevant kinematic variables





Final result(dashed line)



No evidence of dependence on relevant kinematic variables

Interpretation

- The discussion on weather this is NP or SM we leave it to theoreticians
- Papers appeared in arXiv since then…

- Direct CP violation in charm and flavor mixing beyond the SM, Gian Francesco Giudice, Gino Isidori, Paride Paradisi, http://arxiv.org/pdf/1201.6204v1

- LHCb ΔA_{CP} of D meson and R-Parity Violation, Xue Chang, Ming-Kai Du, Chun Liu, Jia-Shu Lu, Shuo Yang arXiv:1201.2565v1

- CP asymmetries in singly-Cabibbo-suppressed D decays to two pseudoscalar mesons,Bhubanjyoti Bhattacharya, Michael Gronau, Jonathan L. Rosner arXiv:1201.2351v1

- Direct CP violation in two-body hadronic charmed meson decays, Hai-Yang Cheng, Cheng-Wei Chiang arXiv:1201.0785v1

- CP Violation and Flavor SU(3) Breaking in D-meson Decays, David Pirtskhalava, Patipan Uttayarat arXiv:1112.5451v1

- Relating direct CP violation in D decays and the forward-backward asymmetry in $t\bar t$ production, Yonit Hochberg, Yosef Nir arXiv:1112.5268v1

- On the size of direct CP violation in singly Cabibbo-suppressed D decays, Brod, Kagan, Zupan, _arXiv:1111.5000v2

- Implications of the LHCb Evidence for Charm CP Violation, Isidori, Kamenik, Ligeti, Perez _arXiv:1111.4987v1

-Can Up FCNC solve the $ΔA_{CP}$ puzzle?, Kai Wang, Guohuai Zhu arxiv:1111.5196v1

-(ΔA_{CP})_{LHCb} and the fourth generation,A. N. Rozanov, M. I. Vysotsky arxiv:1111.6949v1

Interpretation

- A_{CP} of each final state may be written at first order as

$$A_{CP} \approx a_{CP}^{dir}\left(1 + y\cos\phi\frac{\langle t\rangle}{\tau}\right) + a_{CP}^{ind}\frac{\langle t\rangle}{\tau}$$

- where $\langle t\rangle$ is the average decay time (experiment dependent) and τ is the D^0 lifetime
- To good approximation the indirect asymmetry is universal, i.e. independent of the final state.
- ΔA_{CP} may be written as

$$\Delta A_{CP} \approx \Delta a_{CP}^{dir}\left(1 + y\cos\phi\frac{\overline{\langle t\rangle}}{\tau}\right) + \left(a_{CP}^{ind} + \overline{a_{CP}^{dir}}\, y\cos\phi\right)\frac{\Delta\langle t\rangle}{\tau}$$

$$\Delta X \equiv X\left(K^+K^-\right) - X\left(\pi^+\pi^-\right) \quad \text{and} \quad \overline{X} \equiv \frac{X\left(K^+K^-\right) + X\left(\pi^+\pi^-\right)}{2}$$

- Interpretation of ΔA_{CP} depends on the experiment

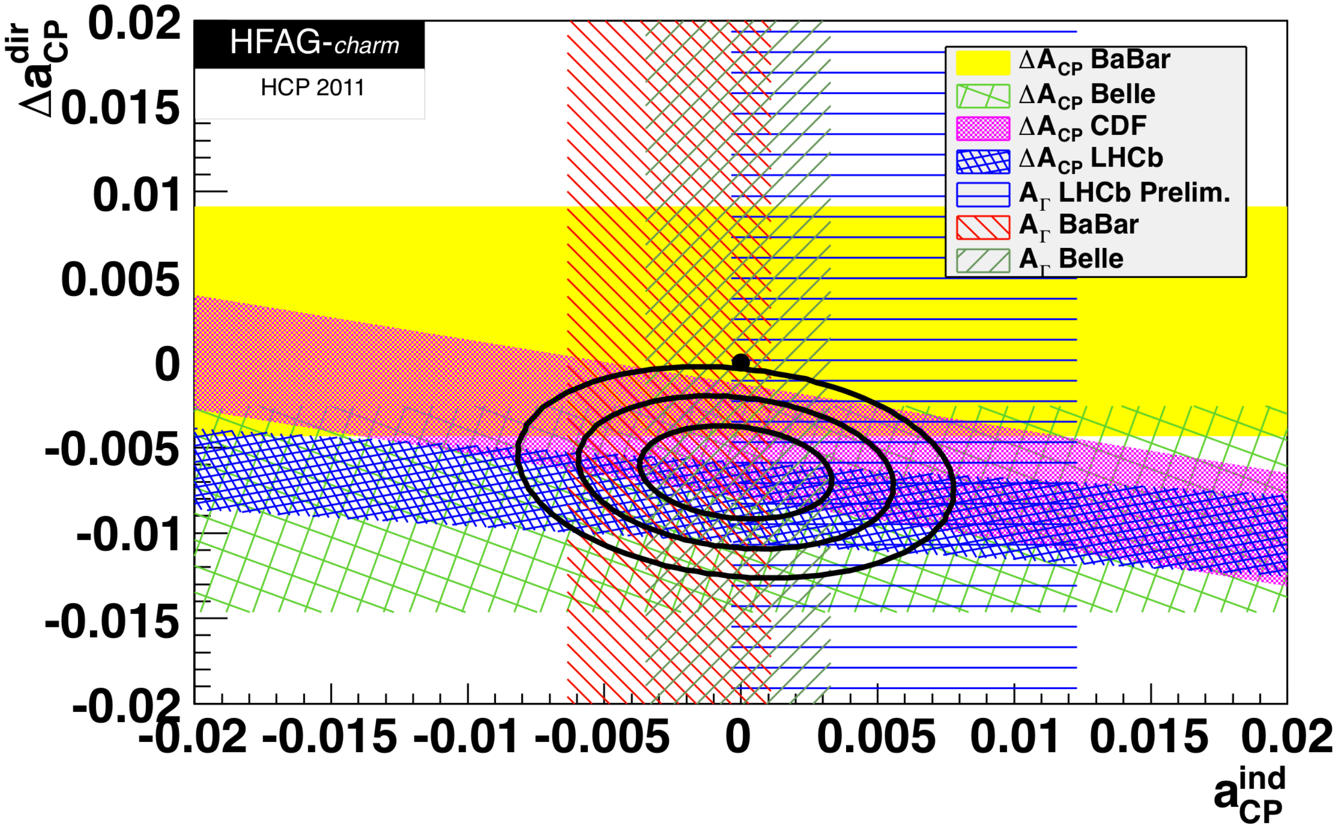
Lifetime aceptance

- Lifetime acceptance differs between D0→K-K+ and D0→π-π+
  - e.g. smaller opening angle → short-lived D0→K-K+ more likely to fail cut requiring daughters not to point to PV than D0→π-π+
- Background-subtracted average decay time of D0 candidates passing the selection is measured for each final state, and the fractional difference with respect to world average D0 lifetime is obtained:

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

- indirect CP violation contribution to ΔACP mostly cancel

New HFAG combination (with LHCb result)



$a_{CP}^{ind} = (-0.019 \pm 0.232)\%$ and $\Delta a_{CP}^{dir} = (-0.645 \pm 0.180)\%$

Consistency with NO CP violation: 0.13%

(the slanted bands due to lifetime acceptances)

Other channels under study

- Beyond updating with 2011 statistics (>30x 2010) the above mentioned analyses of 2010 data and updating to the $1fb^{-1}$ statistics the ΔA_{CP} analysis, we have under study:
  - Direct CPV in $D^+ \rightarrow K^0_S h$
  - Direct CPV in Dalitz plot with $D^0 \rightarrow \pi\pi\pi\pi$
  - T-odd correlations in $D^0 \rightarrow KK\pi\pi$
  - Direct CPV in Dalitz plot in other 3-body Singly-Cabibbo-Suppressed D+ and D_s^+ decays
  - The golden channel: Mixing and CPV with time dependent Dalitz analysis $D^0 \rightarrow K^0_S hh$
  - ΔA_{CP} with D^0 from semi-leptonic b decays
  - Direct CPV $\Lambda_c \rightarrow p\pi\pi$
  - CPV in $\Lambda_c \rightarrow \Lambda\pi$, ΛK
- Main limitation: manpower…!
- + rare decays + spectroscopy (search for new resonances)

Conclusion

- LHCb has a very rich charm physics program ranging from mixing/CPV to rare decays and spectroscopy, mostly with decays to charged particles in the final state and is continuing the pioneering work done by CDF in the charm sector.
- **With 2011 data (1fb^{-1}) we already have the world highest statistics in many channels**
- We expect to collect 5fb^{-1} up to 2017 (phase 1) and 50fb^{-1} (2019-2029?) with the upgrade
- **For many years to come, at least until 2018, LHCb will be (together with BES3) the leading experiment in the field**: statistical sensitivity to many observables such to rule out NP contributions (e.g. some channels sensitive direct CPV)
- Still systematics such as production asymmetries in CPV and lifetime acceptance have to be treated with care and more new ideas on that need to be developed
- In general, we have not tried yet to address channels with neutrals in the final state but things are starting, though it is not guaranteed it will be competitive.
- **Most channels with neutrinos and π^0's remain peculiar to the e^+e^- machines**