Rencontres de Physique de la Vallee d'Aoste
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CP violation in the B and D systems

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On behalf of the LHCb Collaboration

Outline

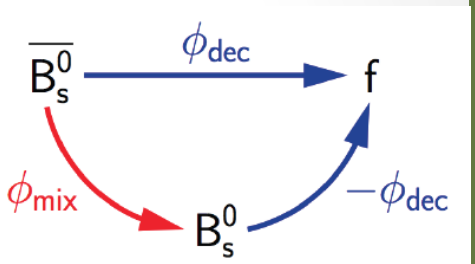
Highlights of LHCb results on CPV in B and D systems

- CPV in B^0_s mixing and decay
- CPV in $B^0 \rightarrow \phi K^{*0}$
- Direct CPV in $B^{\pm} \rightarrow h^+h^-h^{\pm}$

- D^0 mixing and CPV in $D^0 \rightarrow K\pi$
- Search for CPV in mixing in $D^0 \rightarrow KK, D^0 \rightarrow \pi\pi$
- Direct CPV in $D^+ \rightarrow \pi^-\pi^+\pi^+$

CPV in B^0_s mixing and decay

- A weak phase ϕ_s is arising from interference between B^0_s decays w and w/o mixing to a final state CP eigenstates.



- Precise prediction in SM for $b \to c\bar{c}s$ transitions, eg. $B^0_s \to J/\psi\phi$ (neglecting penguins contributions):

$$\phi_s^{SM} = \phi_{mix} - 2\,\phi_{dec} = -2\arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$$
$$\approx (-0.0363 \pm 0.0016)\ \text{rad}$$

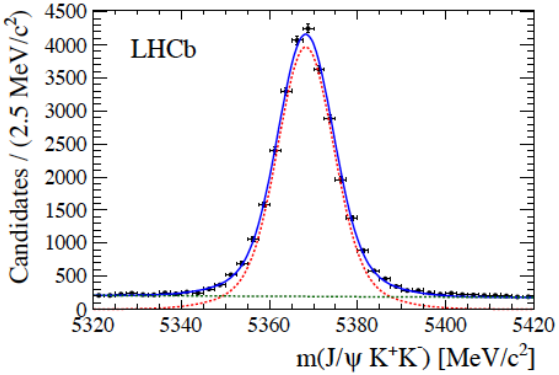
CKMfitter
PRD 84 (2011) 033005

- New Physics might add large phases $\phi_s = \phi_s^{SM} + \phi_s^{NP}$
- A precise measurement of ϕ_s is a sensitive test of NP in the B^0_s sector.

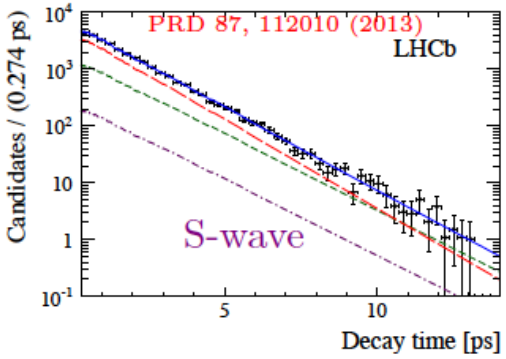
ϕ_s from $B^0_s \rightarrow J/\psi\, K^+K^-$

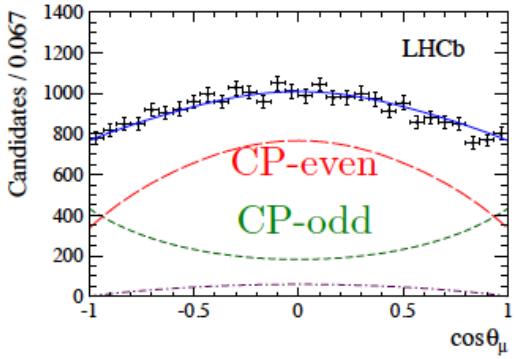
- P→VV decay with CP-even and CP-odd components (P-wave, S-wave)
- Fit to invariant mass, decay time and angular distributions of flavour tagged events.
- 1 fb^{-1} data set

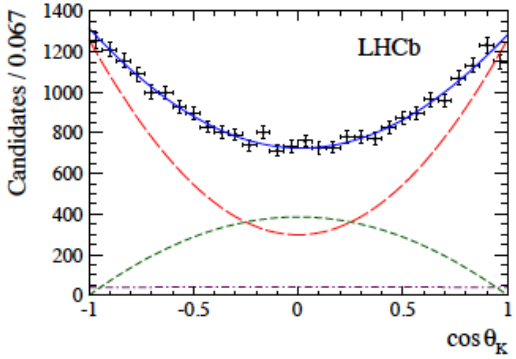
  27617 ± 115 events

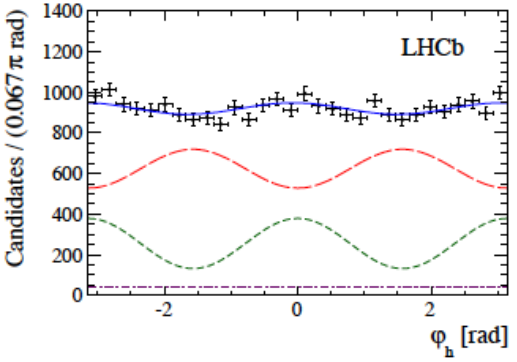


[PRD 87, 112010 (2013)]

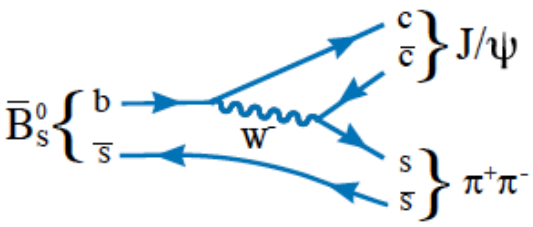


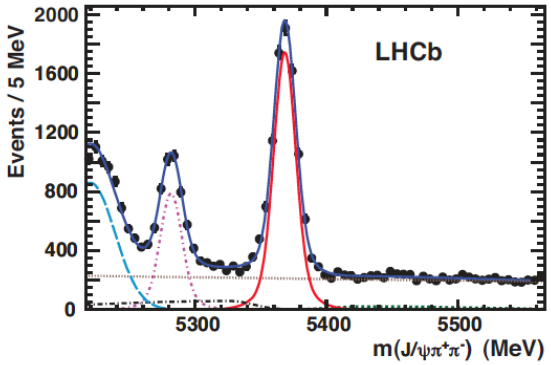


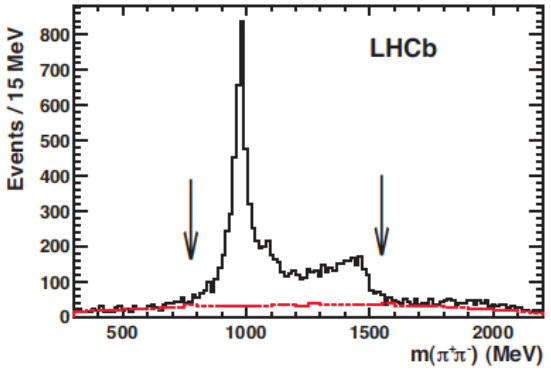




$B^0_s \rightarrow J/\psi\, \pi^+\pi^-$



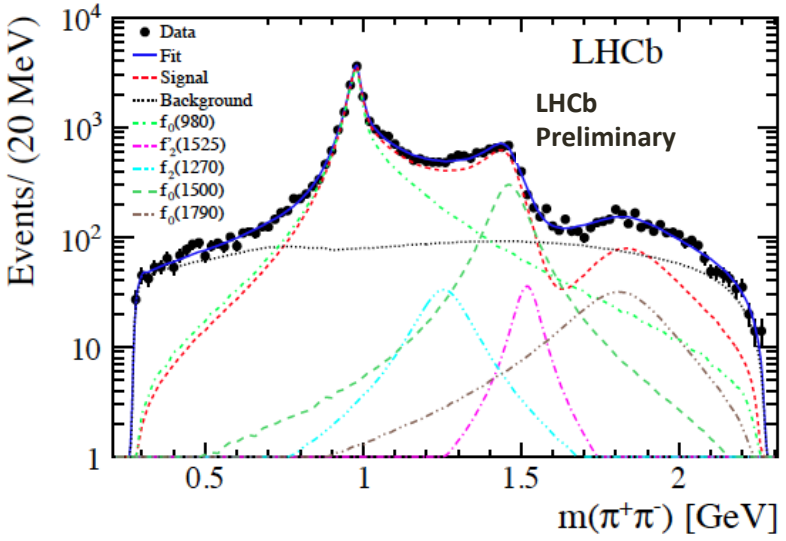




- Final state >97.7% CP-odd at 95%CL, no angular analysis required.
- With $1fb^{-1}$: $\phi_s = -0.14^{+0.17}_{-0.16} \pm 0.01$ rad PLB 713 (2012) 378.

- New amplitude analysis with $3fb^{-1}$ precise study of CP content
- Five interfering states required to describe the decay: $f_0(980)$, $f_0(1500)$, $f_0(1790)$, $f_0(1270)$, $f'_0(980)$
- CP-odd > 97.7% confirmed.

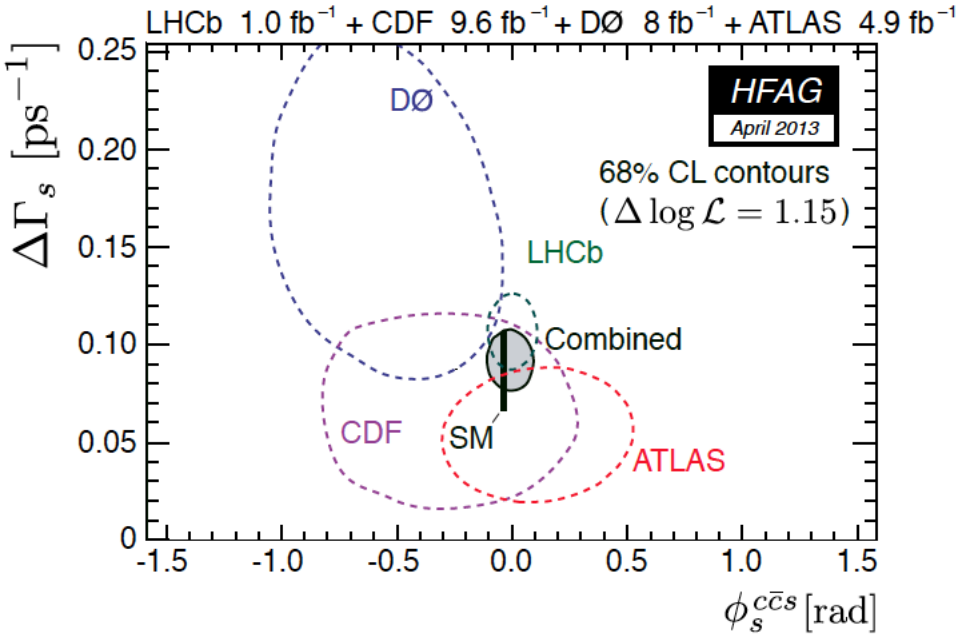
LHCb-PAPER-2013-069 in preparation.



Precise measurement of ϕ_s

- Combined fit to $B^0_s \to J/\psi KK$ and $B^0_s \to J/\psi\pi\pi$ ($1fb^{-1}$) [PRD 87, 112010 (2013)]

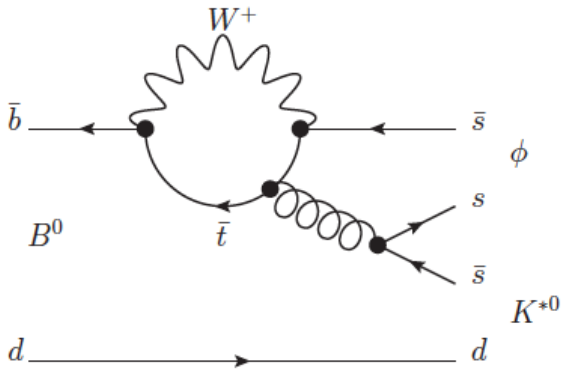
$$
\begin{aligned}
\phi_s &= 0.01 \pm 0.07\ (\text{stat}) \pm 0.01\ (\text{syst})\ \text{rad}, \\
\Gamma_s \equiv (\Gamma_L + \Gamma_H)/2 &= 0.661 \pm 0.004\ (\text{stat}) \pm 0.006\ (\text{syst})\ \text{ps}^{-1}, \\
\Delta\Gamma_s \equiv \Gamma_L - \Gamma_H &= 0.106 \pm 0.011\ (\text{stat}) \pm 0.007\ (\text{syst})\ \text{ps}^{-1},
\end{aligned}
$$

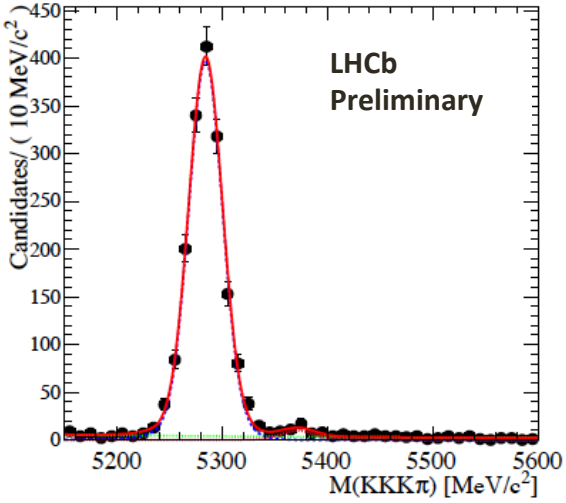


- In agreement with SM.
- Constrains NP contributions to B^0_s mixing <30% at 3σ (A.Lentz arXiv:1203.0238v2)
- Update with $3fb^{-1}$ imminent.

Polarization amplitudes and CP asymmetries in $B^0 \rightarrow \phi K^{*0}$

- $b \rightarrow s\bar{s}s$ FCNC decay, gluonic penguin in SM. Sensitive to NP contributions in the loop
- New LHCb analysis, $1fb^{-1}$, 1655±42 signal events

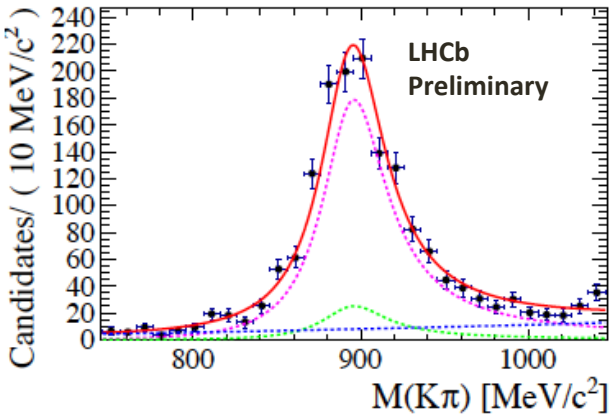


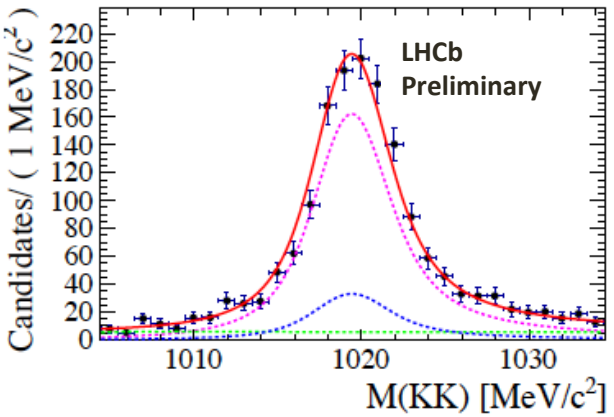


- Angular analysis of time-integrated decay rates to disentangle helicity structure of the P→VV decay
  - P-wave contributions: longitudinal f_L, parallel $f_{||}$ and perpendicular $f_\perp$ fractions $f_{||} = 1 - f_L - f_\perp$
  - S-wave contributions: $B^0 \rightarrow \phi K^+\pi^-$, $B^0 \rightarrow K^*(892)^0 K^-K^+$

(LHCb-PAPER-2014-005 in preparation)

$B^0 \rightarrow \phi K^{*0}$ polarization amplitudes





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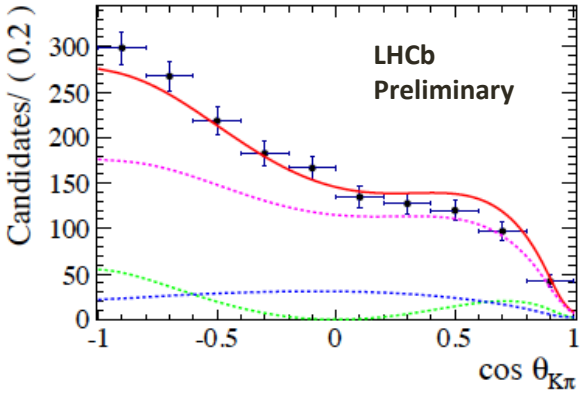
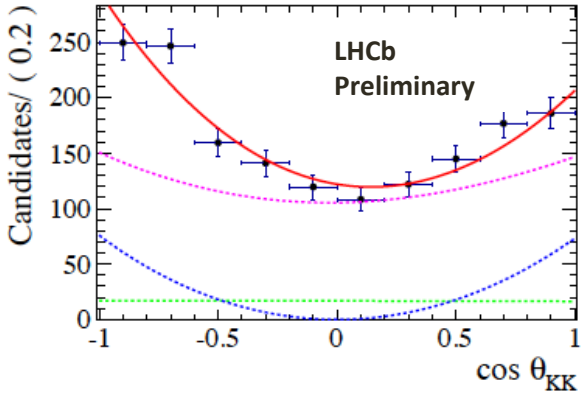
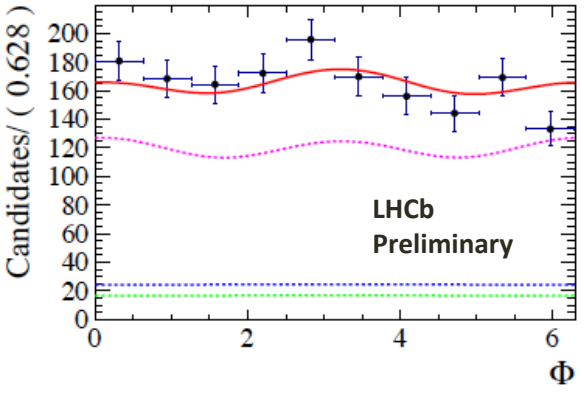






M.Calvi- La Thuile 2014

$f_{\rm L}$	$0.497 \pm 0.019 \pm 0.015$
$f_{\perp}$	$0.221 \pm 0.016 \pm 0.013$
$f_{\rm S}(K\pi)$	$0.143 \pm 0.013 \pm 0.012$
$f_{\rm S}(KK)$	$0.122 \pm 0.013 \pm 0.008$

Preliminary

- Large component of longitudinal polarization, in agreement with BaBar (PRD 78(2008)092008) and Belle (PRD 88(2013)072004)
- Significant S-wave contribution

Direct CP asymmetry in $B^0 \rightarrow \phi K^{*0}$

- Final state tagged by $K^{0*} \rightarrow K^+\pi^-$ decay.
- Raw asymmetry measured from integrated rates

$$A = \frac{N(\overline{B}^0 \rightarrow \phi \overline{K}^*(892)^0) - N(B^0 \rightarrow \phi K^*(892)^0)}{N(\overline{B}^0 \rightarrow \phi \overline{K}^*(892)^0) + N(B^0 \rightarrow \phi K^*(892)^0)}$$

- Correcting for production and detection asymmetries (determined on the $B^0 \rightarrow J/\psi K^{*0}$ control channel)

$$A_{CP}(\phi K^{*0}) = (+1.5 \pm 3.2_{\text{stat}} \pm 0.5_{\text{syst}})\%$$

LHCb-PAPER-2014-005
in preparation

- No CP asymmetry in agreement with (and a factor 2 more precise than) Babar and Belle.

Direct CPV in charmless B decays

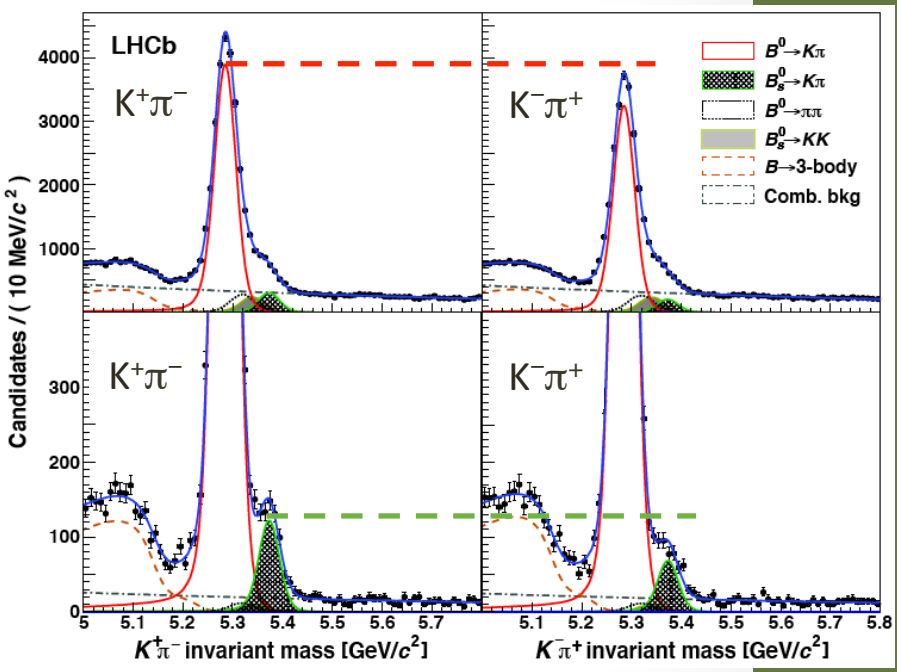
- CPV measured in two-body charmless B decays PRL 110 (2013) 22601

$$A_{CP} \equiv \frac{\Gamma(\overline{B} \to \overline{f}) - \Gamma(B \to f)}{\Gamma(\overline{B} \to \overline{f}) + \Gamma(B \to f)}$$

$A_{CP}(B^0 \to K^+\pi^-) = -0.080 \pm 0.007 \pm 0.003$

$A_{CP}(B_s^0 \to K^-\pi^+) = 0.27 \pm 0.04 \pm 0.01$

First observation of CPV in B^0_s decays (6.5 σ)



- Test of SM expectation, using U-spin (Lipkin PLB 621 (2005) 126)

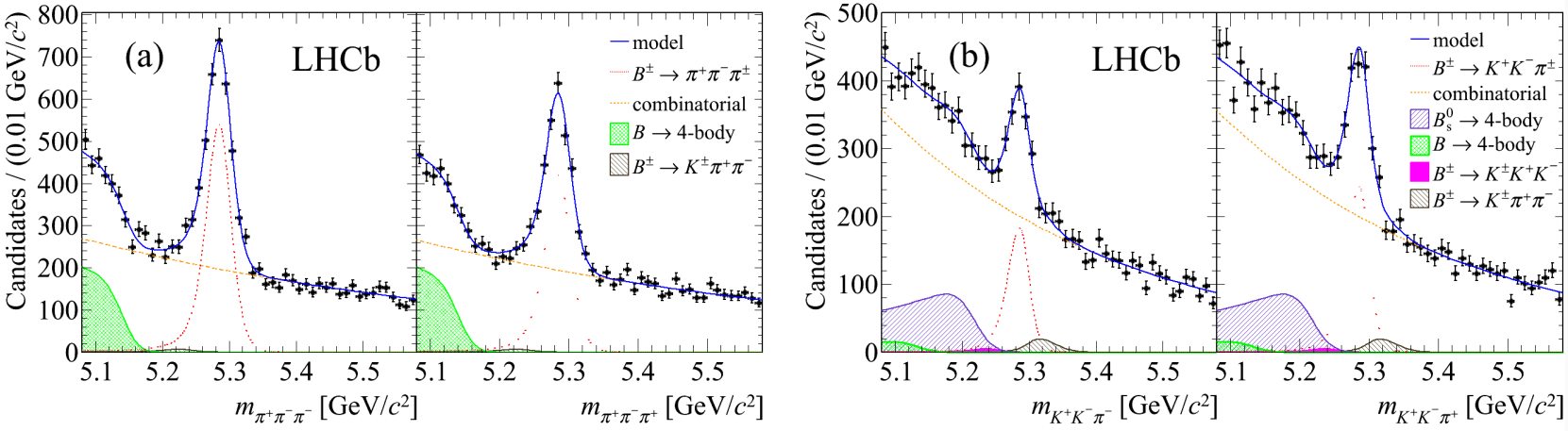
$$\Delta = \frac{A_{CP}(B^0 \to K^+\pi^-)}{A_{CP}(B_s^0 \to K^-\pi^+)} + \frac{\mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(B^0 \to K^+\pi^-)} \frac{\tau_d}{\tau_s} = 0$$

- Using LHCb measurement of branching ratios (JHEP 10 (2012) 037)

$\Delta = -0.2 \pm 0.05 \pm 0.04$ in agreement with SM.

Direct CPV in 3-body charmless B decays

- CP asymmetries measured on $B^{\pm}$ charmless three-body decays
  $B^{\pm} \rightarrow K^+K^-K^{\pm}$, $\pi^+\pi^-K^{\pm}$, $K^+K^-\pi^{\pm}$, $\pi^+\pi^-\pi^{\pm}$ PRL 112,011801 (2014) , PRL 111,101801 (2013)



$$A_{CP}(B^{\pm} \to K^{\pm}\pi^+\pi^-) = 0.032 \pm 0.008 \pm 0.004 \pm 0.007,$$

$$A_{CP}(B^{\pm} \to K^{\pm}K^+K^-) = -0.043 \pm 0.009 \pm 0.003 \pm 0.007,$$

$$A_{CP}(B^{\pm} \to K^+K^-\pi^{\pm}) = -0.141 \pm 0.040 \pm 0.018 \pm 0.007,$$

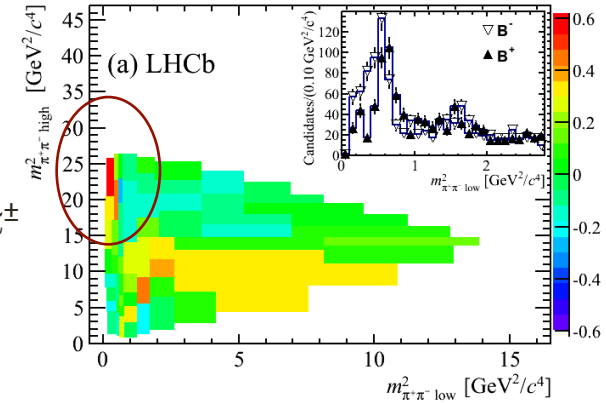
$$A_{CP}(B^{\pm} \to \pi^+\pi^-\pi^{\pm}) = 0.117 \pm 0.021 \pm 0.009 \pm 0.007,$$

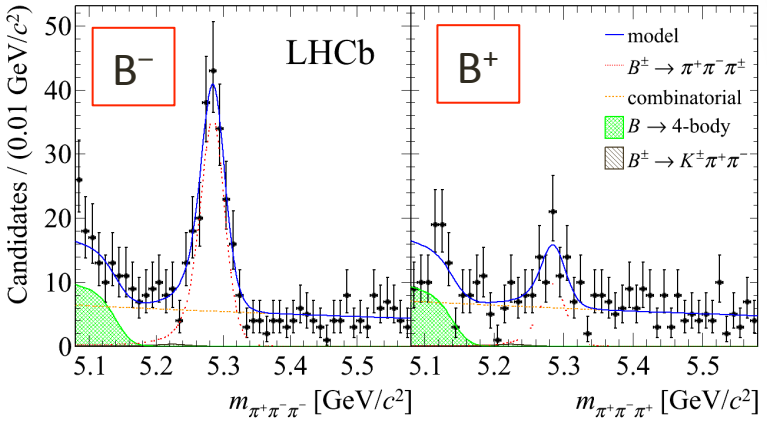
- First evidence of inclusive CP asymmetries in B→3h ($3\sigma - 5\sigma$)

CPV in phase space of $B^+ \to h^+h^-h^+ (h=\pi,K)$

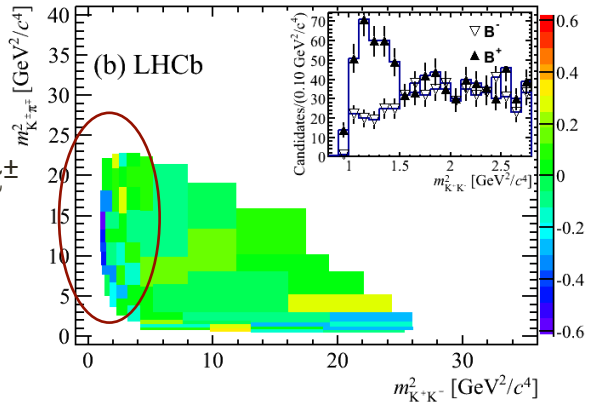
- Study of asymmetries on Dalitz plot shows large asymmetries in localized regions of phase space, outside resonances.

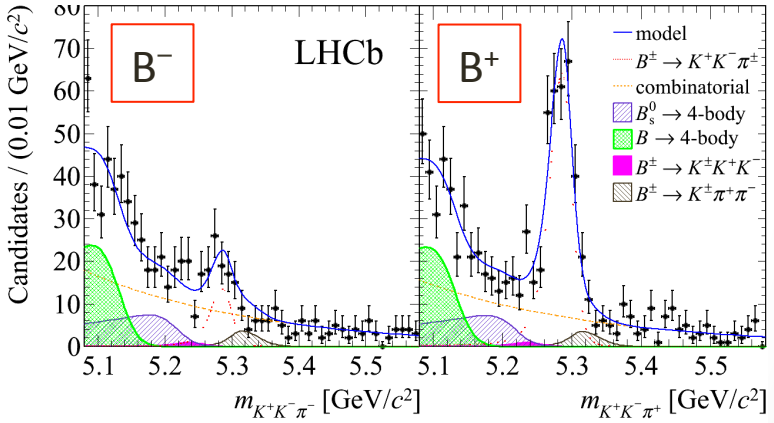
$B^\pm \to \pi^+\pi^-\pi^\pm$





$B^\pm \to K^+K^-\pi^\pm$





PRL 112,011801 (2014)

$$m^2_{\pi^+\pi^-high} > 15 GeV^2/c^4$$
$$m^2_{\pi^+\pi^-low} < 0.4 GeV^2/c^4$$
$$m^2_{K^+K^-} < 1.5 GeV^2/c^4$$

$$A_{CP}^{\mathrm{reg}}(B^\pm \to K^+K^-\pi^\pm) = -0.648 \pm 0.070 \pm 0.013 \pm 0.007,$$
$$A_{CP}^{\mathrm{reg}}(B^\pm \to \pi^+\pi^-\pi^\pm) = 0.584 \pm 0.082 \pm 0.027 \pm 0.007,$$

Mixing and CPV with $D^0 \to K\pi$

- Charm is the only "up" quark allowing mixing studies. Small CPV expected in SM: good probe for NP.

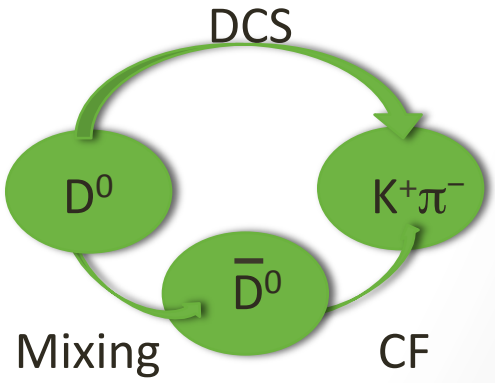
  But long-distance effects not easily calculable.

- LHCb with $1fb^{-1}$ of data $>5\sigma$ observation of D^0 mixing (PRL110,101802)
- Update with $3fb^{-1}$ and search for CPV in mixing. PRL111,251801(2013)

- Use prompt $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$, flavour tagged by slow π^+
- Measure time dependent decay rate of Right Sign and Wrong Sign

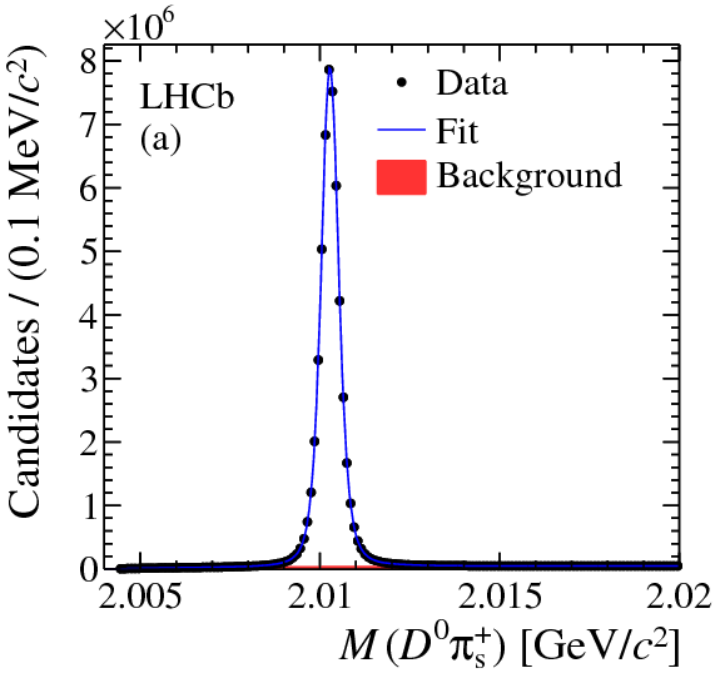
  RS = $D^0 \to K^-\pi^+$ CF decays

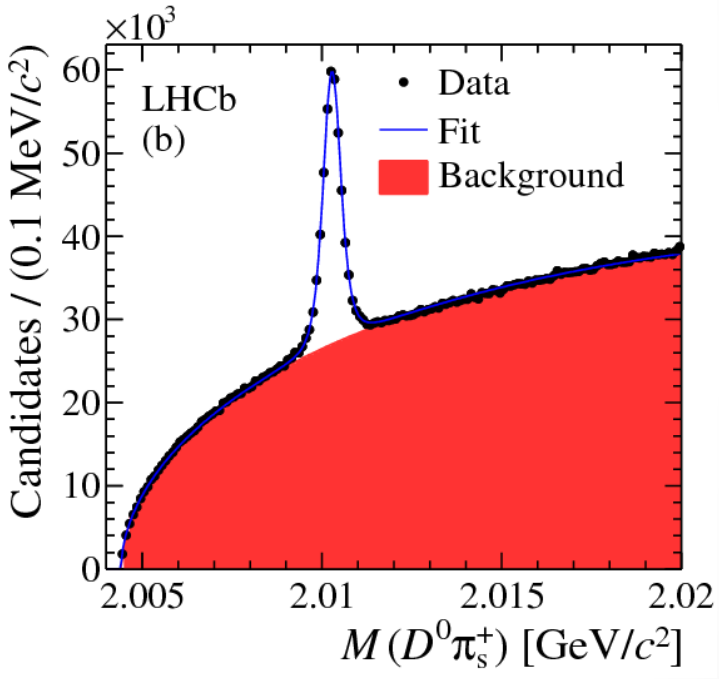
  WS = $D^0 \to K^-\pi^+$ DCS or oscillations



$D^0 \rightarrow K\pi$

- 5.4M RS and 230k WS signal events





Time-dependent rate of $D^0 \to K\pi$

- Time-dependent ratio of WS to RS decay rates

$$R(t) = \frac{N_{\mathrm{WS}}(t)}{N_{\mathrm{RS}}(t)} \approx R_D + \sqrt{R_D}\, y' \frac{t}{\tau} + \frac{x'^2 + y'^2}{4}\left(\frac{t}{\tau}\right)^2$$

$$\left|D_{1,2}\right\rangle = p\left|D^0\right\rangle \pm q\left|\overline{D}^0\right\rangle \quad |p|^2 + |q|^2 = 1 \quad x \equiv \frac{\Delta m}{\Gamma} \quad y \equiv \frac{\Delta\Gamma}{2\Gamma}$$

$$x' = x\cos\delta + y\sin\delta$$
$$y' = y\cos\delta - x\sin\delta$$

R_D= ratio suppressed/ favoured decay rates

δ = strong phase difference

- For CPV study use two sets of parameters for initially produced $D^0, \overline{D}^0$
  - Direct CPV: $R_D^+ \neq R_D^-$
  - CPV in mixing or interference: $(x'^{2+}, y'^{2+}) \neq (x'^{2-}, y'^{2-})$

CPV in WS $D^0 \to K\pi$

- Mixing parameters

$R_D = (0.3568 \pm 0.066) \times 10^{-3}$

$x'^2 = (5.5 \pm 4.9) \times 10^{-5}$

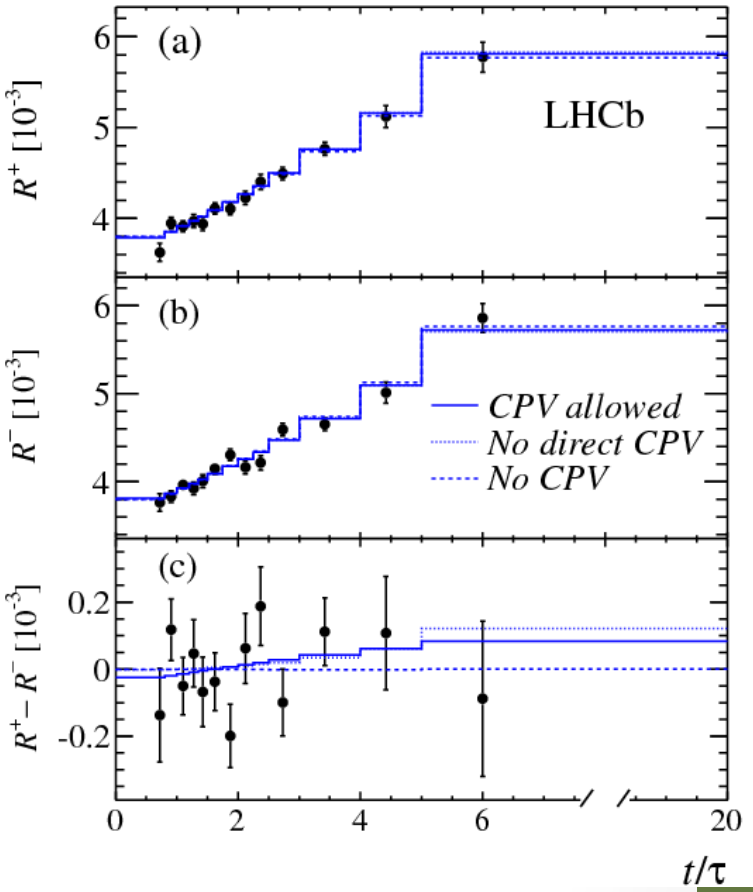
$y' = (4.8 \pm 1.0) \times 10^{-3}$

world best determination

- No evidence for CP violation

$$\left(R_D^+ - R_D^-\right) / \left(R_D^+ + R_D^-\right) = (-0.7 \pm 1.9)\%$$

$0.75 < |q/p| < 1.2$ at 68% CL



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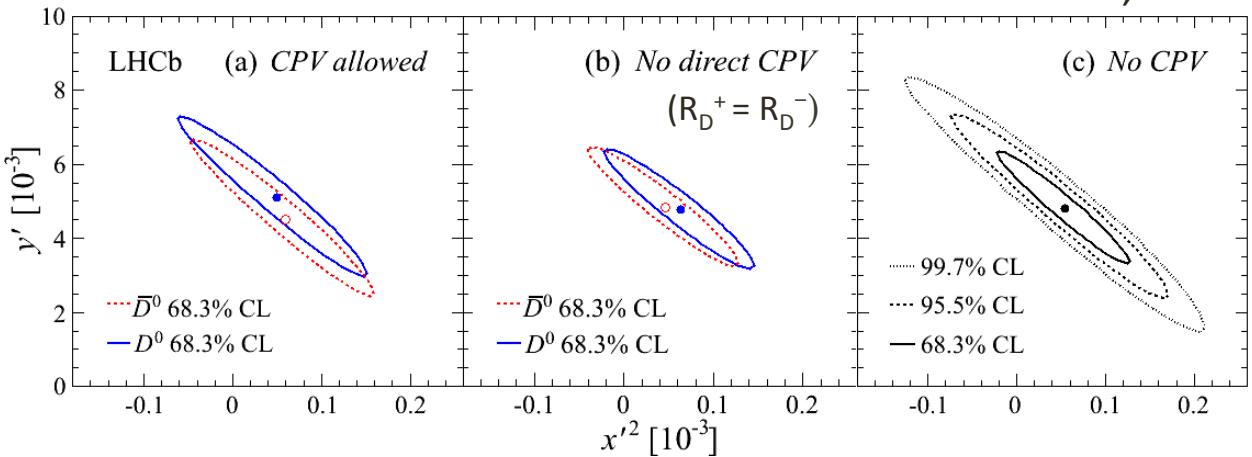


Indirect CPV in $D^0 \to K^+K^-$, $D^0 \to \pi^+\pi^-$

- Measure asymmetry of the effective lifetimes of D^0 decays to CP-even eigenstates.

$$A_\Gamma \equiv \frac{\hat{\tau}(\overline{D}^0) - \hat{\tau}(D^0)}{\hat{\tau}(\overline{D}^0) + \hat{\tau}(D^0)} \approx \eta_{CP}\left(\frac{A_m + A_d}{2} y\cos\phi - x\sin\phi\right)$$

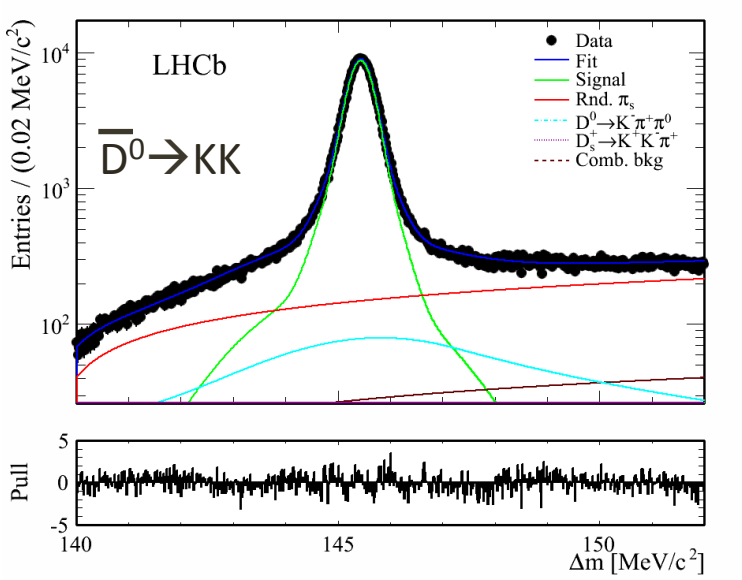
$$A_m \equiv \frac{|q/p|^2 - |p/q|^2}{|q/p|^2 + |p/q|^2} \qquad A_d \equiv \frac{|A_f|^2 - |\overline{A}_f|^2}{|A_f|^2 + |\overline{A}_f|^2} \qquad \lambda_f \equiv \frac{q\overline{A}_f}{pA_f} = -\eta_{CP}\left|\frac{q}{p}\right|\left|\frac{\overline{A}_f}{A_f}\right| e^{i\phi}$$

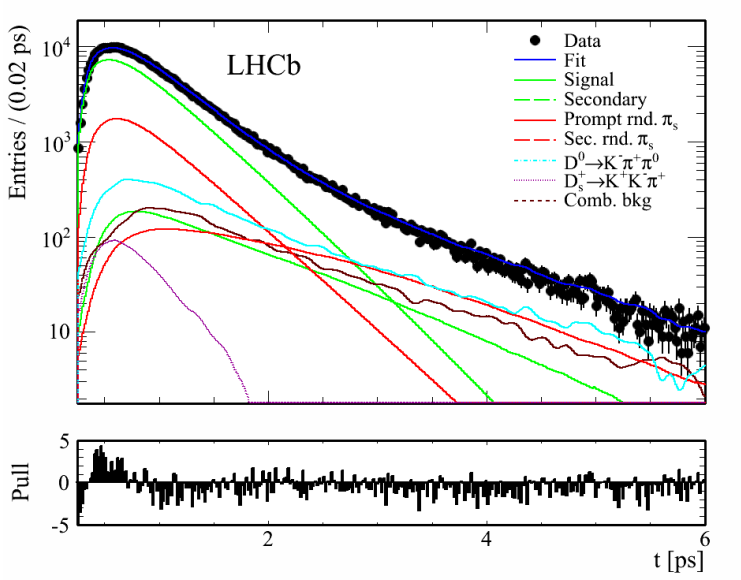
- Sensitive to CPV in mixing, small contribution of direct CPV A_d
- In SM ϕ is final state independent and zero if CP conserved.

- 3.1×10^6 $D^0 \to KK$ and 1.03×10^6 $D^0 \to \pi\pi$ signal candidates, flavour tagged by $D^{*+} \to D^0\pi$, in $1fb^{-1}$ data sample.

Effective lifetimes in $D^0 \to KK, \pi\pi$

- Two-stage unbinned maximum likelihood fits:
  - Join fit to m(KK) and Δm separates signal from background and determines D^0, $\overline{D}^0$ yields
  - Join fit to D^0 decay time and D^0 pointing determines lifetimes and discriminates against (small) $b \to D^0$ component



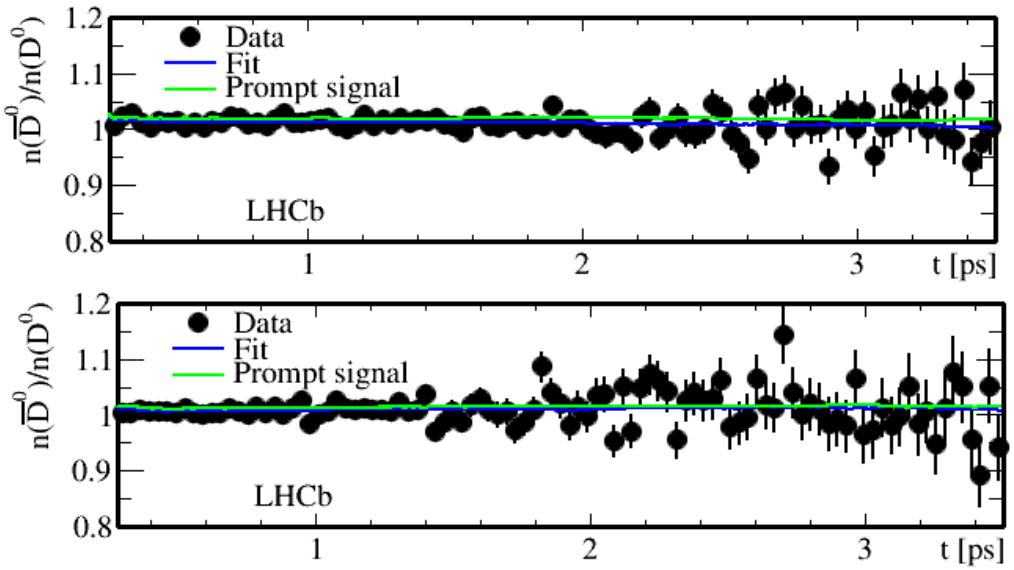


PRL112,041801 (2014)

Effective lifetimes in $D^0 \to KK, \pi\pi$

$D^0 \to KK$

$D^0 \to \pi\pi$



PRL 112,041801 (2014)

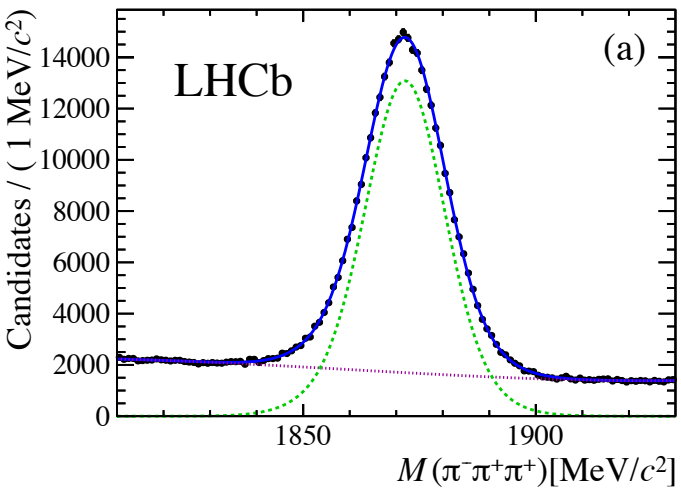
$$A_\Gamma(KK) = (-0.35 \pm 0.62 \pm 0.12) \times 10^{-3}$$

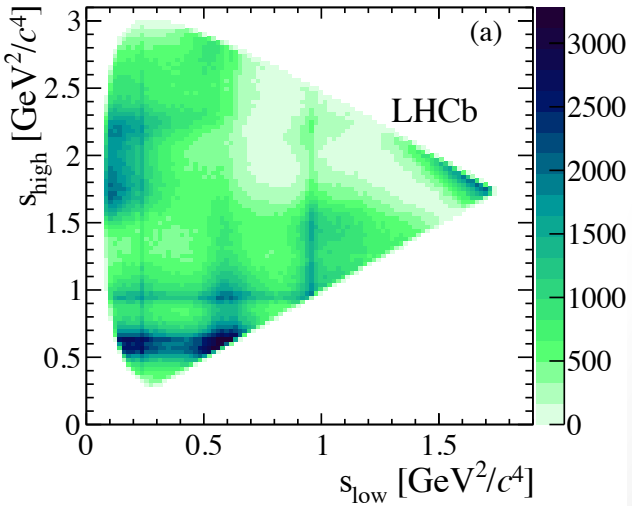
$$A_\Gamma(\pi\pi) = (0.33 \pm 1.06 \pm 0.14) \times 10^{-3}$$

- No evidence of indirect CPV and no significant difference among the two final states.
- World's best result with $1 fb^{-1}$.

Search for direct CPV in $D^+ \to \pi^-\pi^+\pi^+$

- Measure asymmetry between $D^+ \to \pi^-\pi^+\pi^+$ and $D^- \to \pi^-\pi^+\pi^-$ time integrated decay rates. CS decay sensitive to NP contributions.
- Exploit multi-body dynamics to seek for charge asymmetries localized in phase space regions. Can bring additional info on nature of CPV.
  - Similar strategy used already in D→4body PLB B 726 (2013), 623
  - Use CF $D_s^+ \to \pi^-\pi^+\pi^+$ decay to control possible asymmetries from production or detector effects.
- 2.7M signal candidates (and 2.7M in control channel).

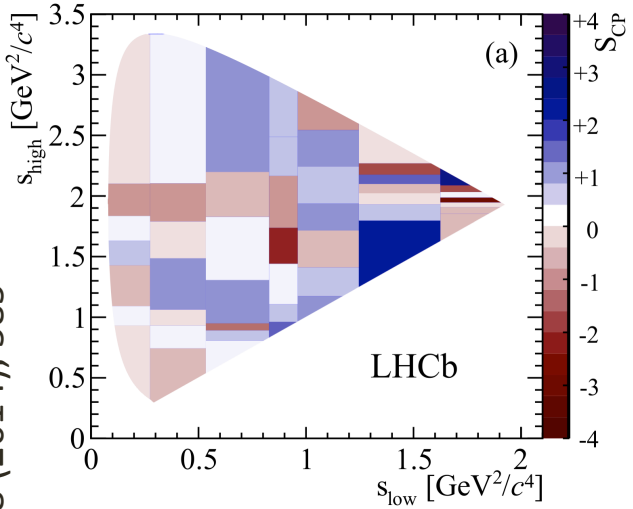




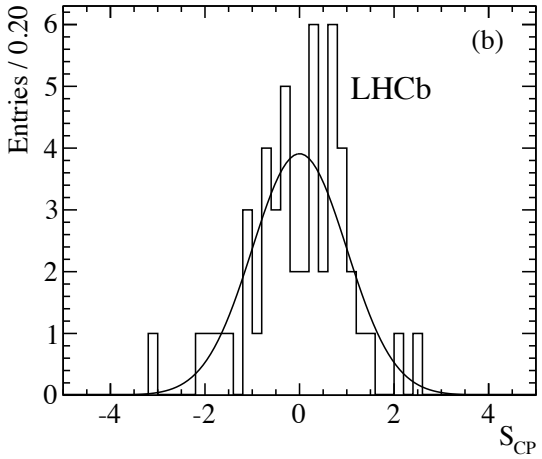
PLB B 728 (2014), 585

Direct CPV in $D^+ \to \pi^-\pi^+\pi^+$

- Model-independent technique. Compare D^+ and D^- Dalitz plots with a χ^2 test . Calculate a significance per bin and then average



PLB B 728 (2014), 585



$$\mathcal{S}^i_{CP} \equiv \frac{N_i^+ - \alpha N_i^-}{\sqrt{\alpha(N_i^+ + N_i^-)}}, \quad \alpha \equiv \frac{N^+}{N^-}$$

$$\chi^2 = \sum_i (\mathcal{S}^i_{CP})^2$$

- p-values for null CPV hypothesis all >50%
- Similar results for adaptive binning, uniform grid of bins (20-100) and unbinned search.
- No evidence of localized CPV in $D^+ \to \pi^-\pi^+\pi^+$

Conclusions

- Large variety of measurements of CPV in the B sector coming from LHCb, persisting agreement with SM.
  - Large CP asymmetries in $B^{\pm} \rightarrow 3h$, in localized region of phase space.

- LHCb contribution to charm physics steadily growing, world best results in mixing and indirect CPV measurements.
- No evidence of CP violation in charm sector.

- Some measurements still on partial data sample.
  3 fb^{-1} on tape , full update coming soon.

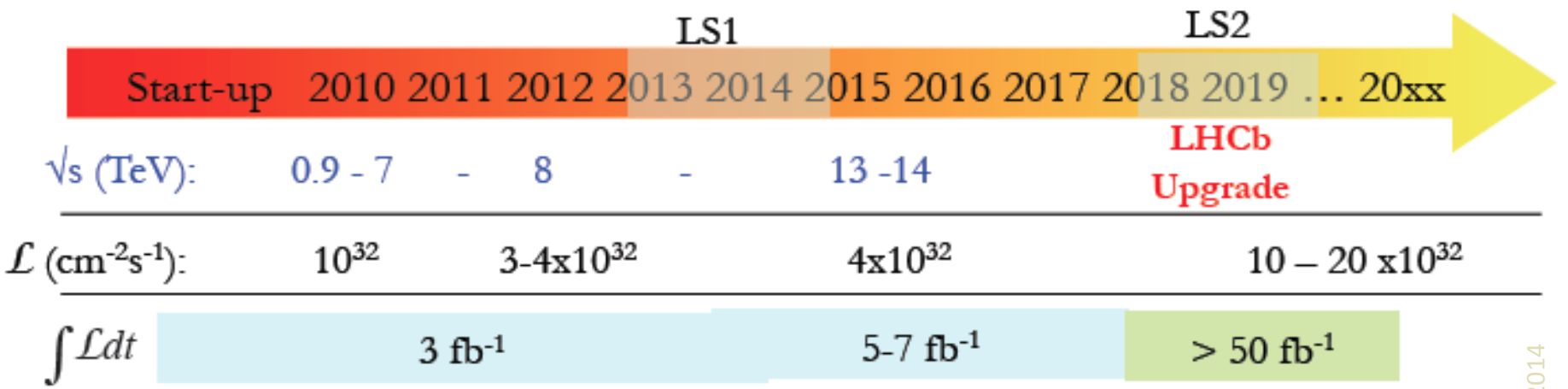
backup

LHCb upgrade: statistical sensitivity to key observables

EPJ C (2013) 73:2373

Type	Observable	Current precision	LHCb 2018	**Upgrade** (50 fb^{-1})	Theory uncertainty
B_s^0 mixing	$2\beta_s(B_s^0 \to J/\psi\phi)$	0.10 [139]	0.025	0.008	~0.003
	$2\beta_s(B_s^0 \to J/\psi f_0(980))$	0.17 [219]	0.045	0.014	~0.01
	$a_{\rm sl}^s$	6.4×10^{-3} [44]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\rm eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\rm eff}(B_s^0 \to K^{*0}\overline{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\rm eff}(B^0 \to \phi K_S^0)$	0.17 [44]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\rm eff}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	<0.01
	$\tau^{\rm eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\ {\rm GeV}^2/c^4)$	0.08 [68]	0.025	0.008	0.02
	$s_0 A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [68]	6 %	2 %	7 %
	$A_{\rm I}(K\mu^+\mu^-; 1 < q^2 < 6\ {\rm GeV}^2/c^4)$	0.25 [77]	0.08	0.025	~0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [86]	8 %	2.5 %	~10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [13]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~100 %	~35 %	~5 %
Unitarity triangle angles	$\gamma(B \to D^{(*)}K^{(*)})$	~10–12° [252, 266]	4°	0.9°	negligible
	$\gamma(B_s^0 \to D_s K)$	–	11°	2.0°	negligible
	$\beta(B^0 \to J/\psi K_S^0)$	0.8° [44]	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	2.3×10^{-3} [44]	0.40×10^{-3}	0.07×10^{-3}	–
	$\Delta\mathcal{A}_{CP}$	2.1×10^{-3} [18]	0.65×10^{-3}	0.12×10^{-3}	–

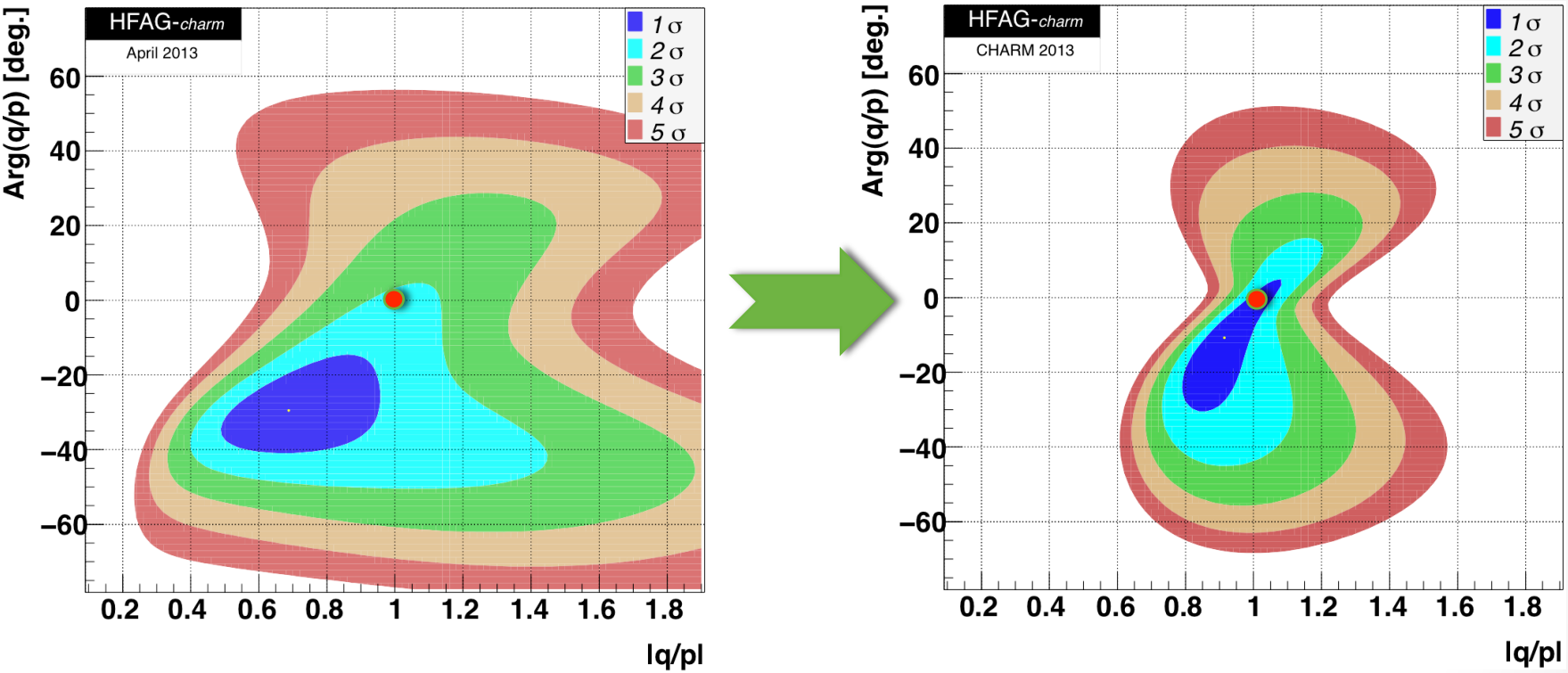
LHCb upgrade



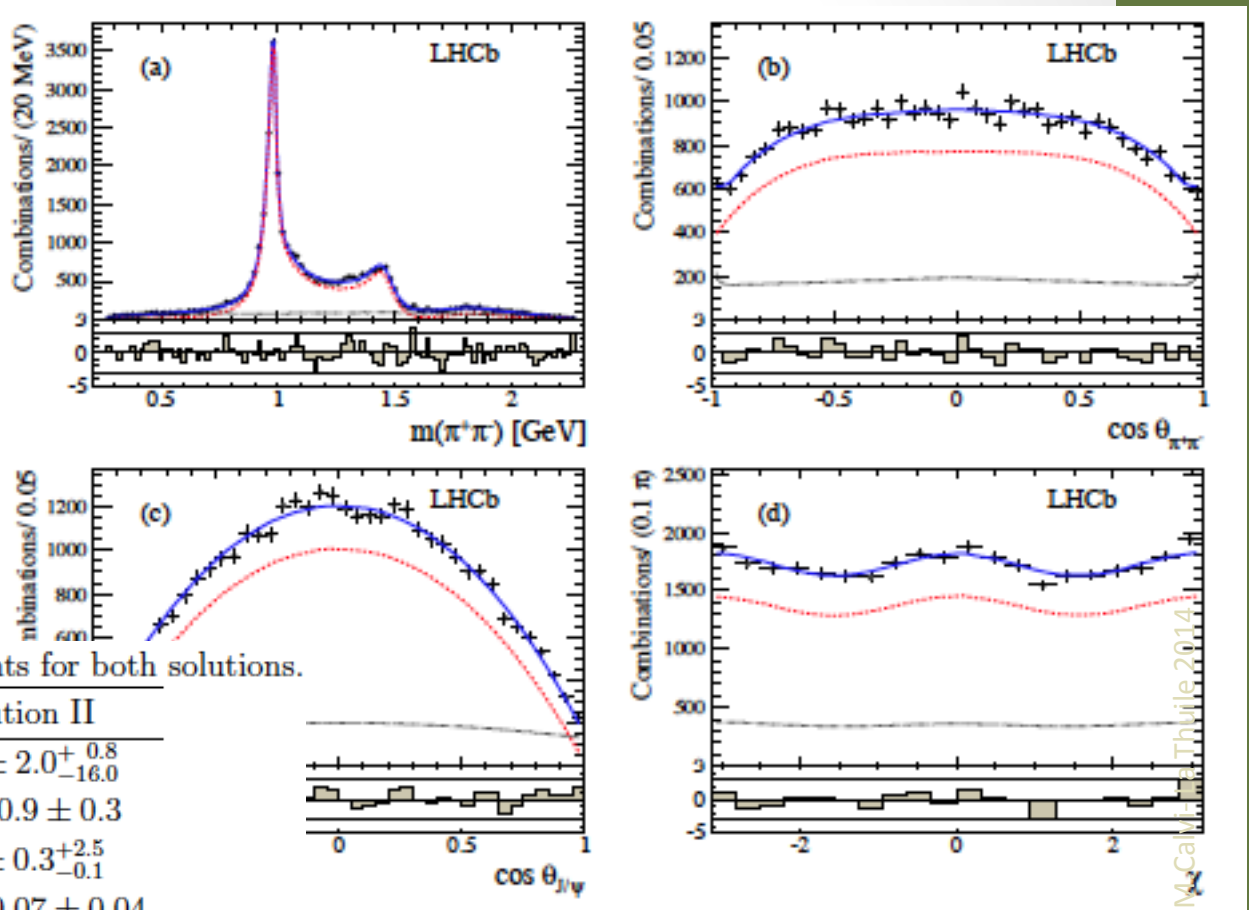
$D^0 \to K\pi$ mixing and CPV

Direct and indirect *CP* violation	
R_D^+ (10^{-3})	$3.545 \pm 0.082 \pm 0.048$
y'^+ (10^{-3})	$5.1 \pm 1.2 \pm 0.7$
x'^{2+} (10^{-5})	$4.9 \pm 6.0 \pm 3.6$
R_D^- (10^{-3})	$3.591 \pm 0.081 \pm 0.048$
y'^- (10^{-3})	$4.5 \pm 1.2 \pm 0.7$
x'^{2-} (10^{-5})	$6.0 \pm 5.8 \pm 3.6$
χ^2/ndf	85.9/98
No direct *CP* violation	
R_D (10^{-3})	$3.568 \pm 0.058 \pm 0.033$
y'^+ (10^{-3})	$4.8 \pm 0.9 \pm 0.6$
x'^{2+} (10^{-5})	$6.4 \pm 4.7 \pm 3.0$
y'^- (10^{-3})	$4.8 \pm 0.9 \pm 0.6$
x'^{2-} (10^{-5})	$4.6 \pm 4.6 \pm 3.0$
χ^2/ndf	86.0/99
No *CP* violation	
R_D (10^{-3})	$3.568 \pm 0.058 \pm 0.033$
y' (10^{-3})	$4.8 \pm 0.8 \pm 0.5$
x'^2 (10^{-5})	$5.5 \pm 4.2 \pm 2.6$
χ^2/ndf	86.4/101

Impact on WA


HFAG-charm
April 2013
1 σ
2 σ
3 σ
4 σ
5 σ
Arg(q/p) [deg.]
60
40
20
0
−20
−40
−60
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
|q/p|
HFAG-charm
CHARM 2013
1 σ
2 σ
3 σ
4 σ
5 σ
Arg(q/p) [deg.]
60
40
20
0
−20
−40
−60
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
|q/p|

$B^0_s \rightarrow J/\psi\, \pi^+\pi^-$



Fit fractions (%) of contributing components for both solutions.

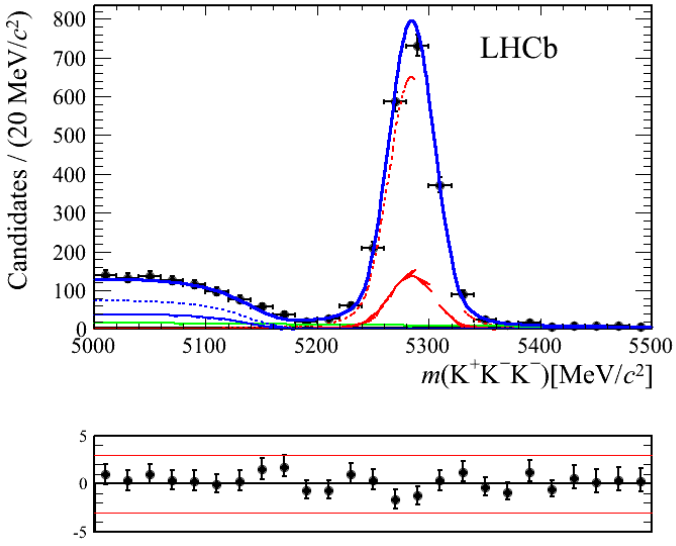
Component	Solution I	Solution II
$f_0(980)$	$70.3 \pm 1.5^{+0.4}_{-5.1}$	$92.4 \pm 2.0^{+\ 0.8}_{-16.0}$
$f_0(1500)$	$10.1 \pm 0.8^{+1.1}_{-0.3}$	$9.1 \pm 0.9 \pm 0.3$
$f_0(1790)$	$2.4 \pm 0.4^{+5.0}_{-0.2}$	$0.9 \pm 0.3^{+2.5}_{-0.1}$
$f_2(1270)_0$	$0.36 \pm 0.07 \pm 0.03$	$0.42 \pm 0.07 \pm 0.04$
$f_2(1270)_\parallel$	$0.52 \pm 0.15^{+0.05}_{-0.02}$	$0.42 \pm 0.13^{+0.11}_{-0.02}$
$f_2(1270)_\perp$	$0.63 \pm 0.34^{+0.16}_{-0.08}$	$0.60 \pm 0.36^{+0.12}_{-0.09}$
$f_2'(1525)_0$	$0.51 \pm 0.09^{+0.05}_{-0.04}$	$0.52 \pm 0.09^{+0.05}_{-0.04}$
$f_2'(1525)_\parallel$	$0.06^{+0.13}_{-0.04} \pm 0.01$	$0.11^{+0.16+0.03}_{-0.07-0.04}$
$f_2'(1525)_\perp$	$0.26 \pm 0.18^{+0.06}_{-0.04}$	$0.26 \pm 0.22^{+0.06}_{-0.05}$
NR	-	$5.9 \pm 1.4^{+0.7}_{-4.6}$
Sum	85.2	110.6
$-\ln\mathcal{L}$	−93738	−93739
χ^2/ndf	2005/1822	2008/1820

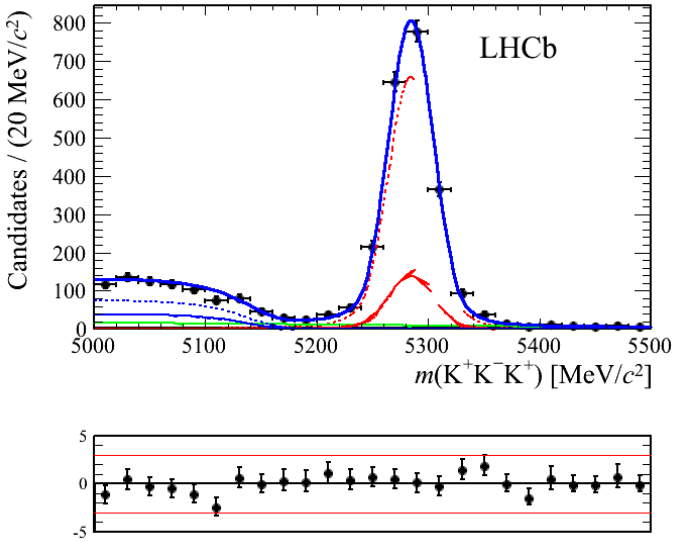
LHCb-PAPER-2013-069 in preparation.

Direct CP asymmetry in $B^+ \rightarrow \phi K^+$

- $B^+ \rightarrow \phi K^+$ from loop diagrams only, SM predicts A_{CP}~0 with few %. Sensitive to NP contributions.

$$\mathcal{A}_{CP}(B^{\pm} \to \phi K^{\pm}) \equiv \frac{\mathcal{B}(B^- \to \phi K^-) - \mathcal{B}(B^+ \to \phi K^+)}{\mathcal{B}(B^- \to \phi K^-) + \mathcal{B}(B^+ \to \phi K^+)}$$





- Measurement relative to $B^+ \rightarrow J/\psi K^+$. $A_{CP}(B^+ \rightarrow J/\psi K^+) = 0.003 \pm 0.006$

$$\mathcal{A}_{CP}(B^{\pm} \to \phi K^{\pm}) = 0.022 \pm 0.021 \pm 0.009$$