# Charmless B decays
## including CP violation effects

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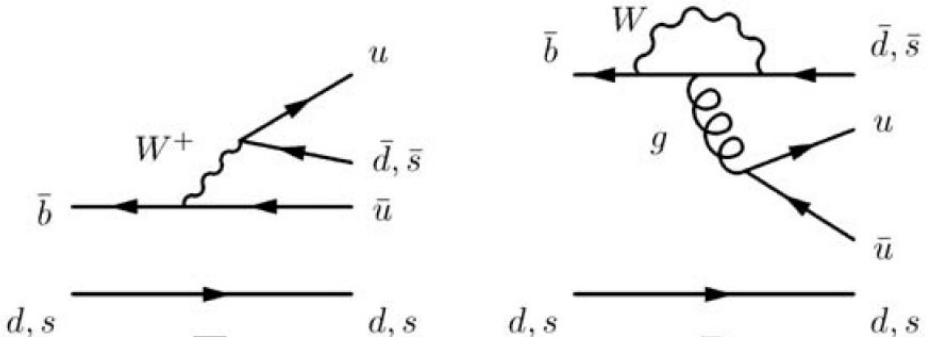
On behalf of the LHCb collaboration, including results from Belle and BaBar

Flavour Physics and CP Violation
Búzios, Brazil, 20 May 2013

# Outline

- Charmless two-body $B_{(s)}^{0}$ decays (LHCb):
  - First observation of direct CP violation in $B_s^0 \to K^+\pi^-$.
  - Measurement of direct CP violation in $B^0 \to K^+\pi^-$.
- Charmless three-body $B$ decays:
  - Direct CP violation in $B^\pm \to K^\pm\pi^+\pi^-$ and $B^\pm \to K^\pm K^+K^-$ (LHCb NEW).
  - $B^\pm \to K^\pm K^+K^-$ comparison between LHCb and BaBar (BaBar NEW).
  - Direct CP violation in $B^\pm \to K^+K^-\pi^\pm$ and $B^\pm \to \pi^+\pi^-\pi^\pm$ (LHCb).
  - First evidence for the decay $B^0 \to K^+K^-\pi^0$ (Belle NEW).
  - Branching ratios of $B^\pm \to p\bar{p}K^\pm$ modes (LHCb).
- First observation of the decay $B_s^0 \to \phi\overline{K}^*$ (LHCb).

# Charmless two-body *B* decays




- Decay amplitudes have contributions from tree and penguin (strong and electroweak) diagrams.
- Sensitive to $V_{ub}$ phase, CKM angle $\gamma$.
- New Physics can contribute to penguin loop.
- Tree-penguin interference allows to look for direct CP violation in $B^0_{(d,s)} \to K^-\pi^+$.

# $B^0_{(d,s)} \to K^-\pi^+$

arXiv:1304.6173
Accepted by PRL

• Measurements of direct CP violation in $B^0_{(d,s)} \to K^-\pi^+$ with 2011 LHCb data (1.0 $fb^{-1}$).

$$A_{CP} = \frac{(N_{\bar{B}\to\bar{f}} - N_{B\to f})}{(N_{\bar{B}\to\bar{f}} + N_{B\to f})} \qquad B \to f = \begin{cases} B^0 \to K^+\pi^- \\ B_s \to \pi^+K^- \end{cases}$$

• Offline selections with two different sets of cuts, optimised for $A_{CP}(B^0 \to K^+\pi^-)$ and $A_{CP}(B_s \to K^-\pi^+)$.

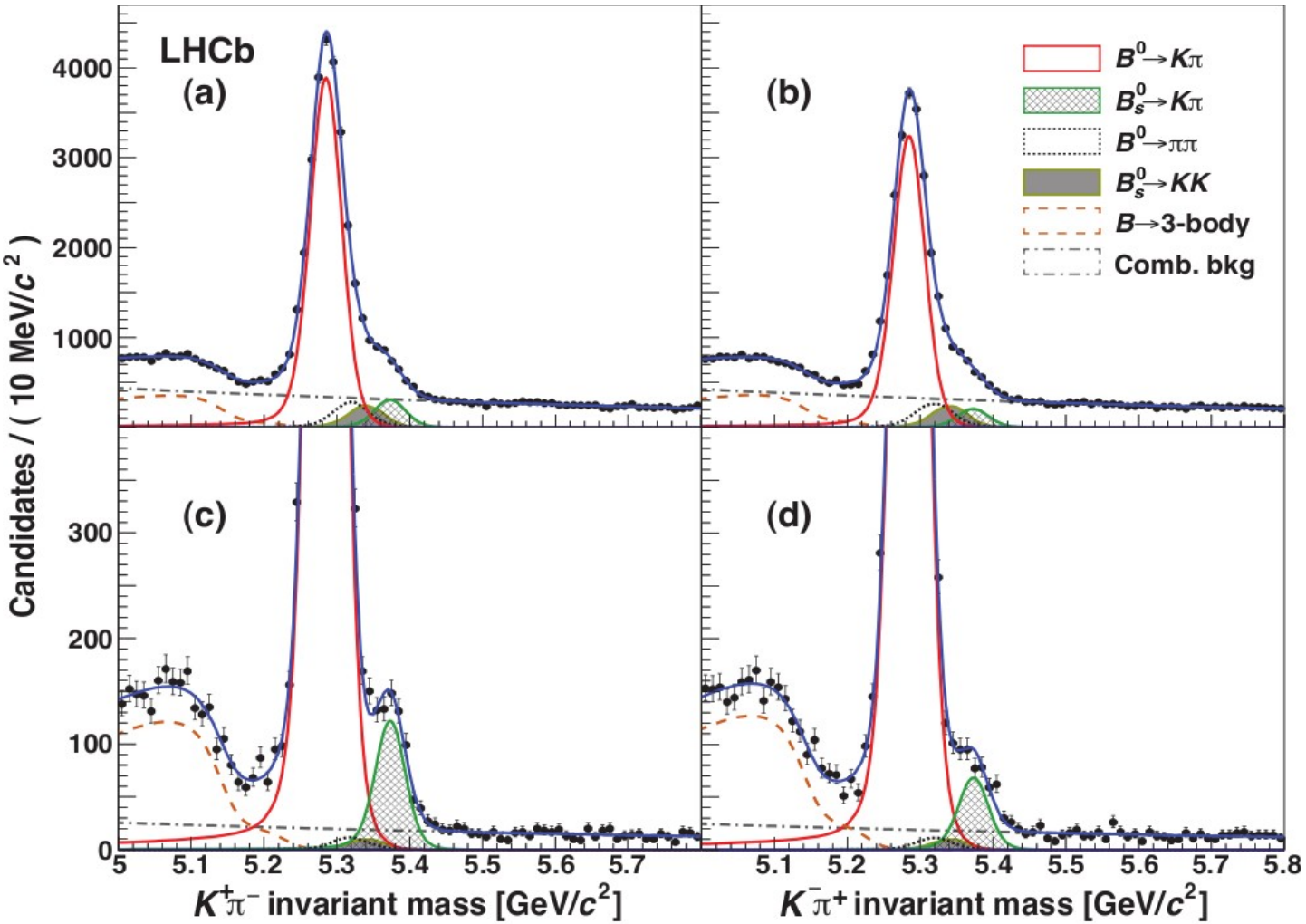
• Use particle ID to identify the subsamples for each mass hypothesis: $\pi^+\pi^-$, $K^+\pi^-$, $K^-\pi^+$, $K^-K^+$.

• Determine PID efficiencies and misid rates from large samples of calibration data: $D^{*+} \to D^0\pi^+ \to (K^-\pi^+)\pi^+$, $\Lambda \to p\pi^-$.

• Raw asymmetries from maximum likelihood fits to the invariant mass spectra.

# $B^0_{(d,s)} \to K^-\pi^+$ raw asymmetries

arXiv:1304.6173
Accepted by PRL




**$B^0 \to K\pi$**

$N_{sig}$ = 41420 ± 300

$A_{raw}$ = –0.091 ± 0.006

**$B^0_s \to K\pi$**

$N_{sig}$ = 1065 ± 55

$A_{raw}$ = 0.28 ± 0.04

# Direct CP violation in $B_{(d,s)} \to K^-\pi^+$

arXiv:1304.6173
Accepted by PRL

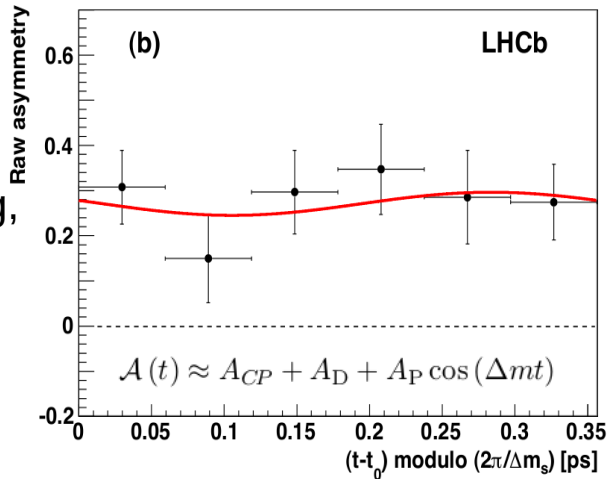
- Raw asymmetry is corrected for instrumental and production asymmetries.

$$A_{CP}(K\pi) = A_{raw}(K\pi) - (A_D^K + \kappa A_P) = A_{raw}(K\pi) - \Delta A$$

Instrumental asymmetry
$A_D$ from charm control samples: $D^{*+} \to D^0(K^-\pi^+)\pi^+$, $D^{*+} \to D^0(K^+K^-)\pi^+$.

Production asymmetry
$\kappa$: dilution of $A_P$ due to mixing, lifetime and acceptance: $\kappa(B^0) \sim 0.3$, $\kappa(B_s) \sim -0.03$

- $A_P$ from time-dependence.




$A_{CP}(B^0) = -0.080 \pm 0.007(stat) \pm 0.003(syst)$ — $10.5\sigma$

$A_{CP}(B^0_S) = 0.27 \pm 0.04(stat) \pm 0.01(syst)$ — $6.5\sigma$

- First observation of direct CP violation in the $B_S$ system.
- Most precise measurement of $A_{CP}(B^0 \to K^-\pi^+)$.
- Agreement with the SM:

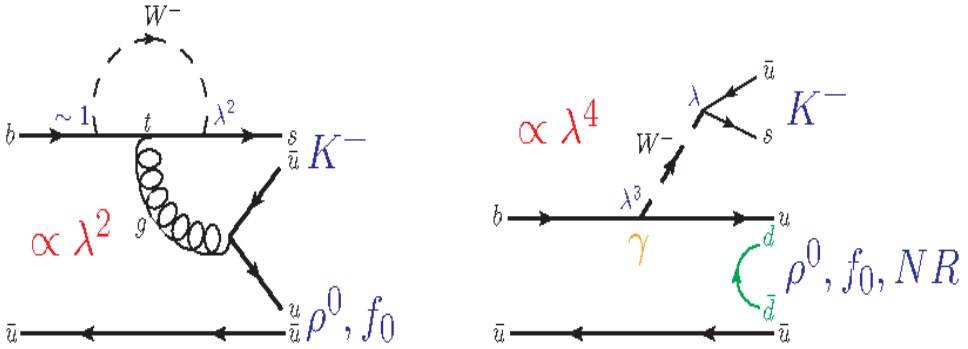
$$\Delta = \frac{A_{CP}(B^0 \to K^+\pi^-)}{A_{CP}(B_s^0 \to K^-\pi^+)} + \frac{\mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(B^0 \to K^+\pi^-)} \frac{\tau_d}{\tau_s} = 0$$

H.J. Lipkin, PL**B621** (2005) 126

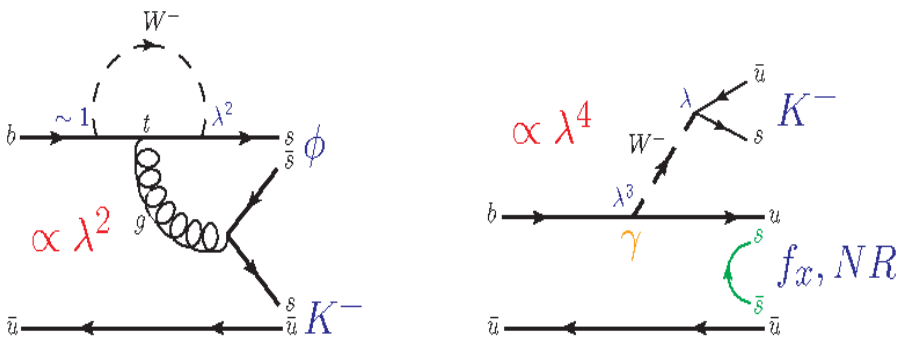
$$\Delta = -0.02 \pm 0.05 \pm 0.04$$

# Charmless $B^{\pm} \to h^{+}h^{-}h^{\pm}$ decays

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




$B^{\pm} \to K^{\pm}K^{+}K^{-}$

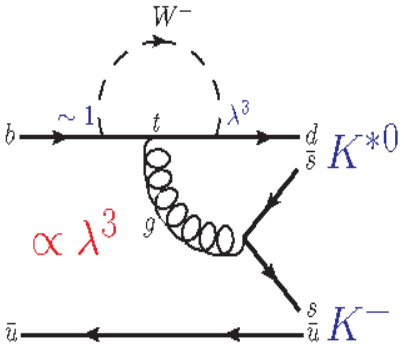


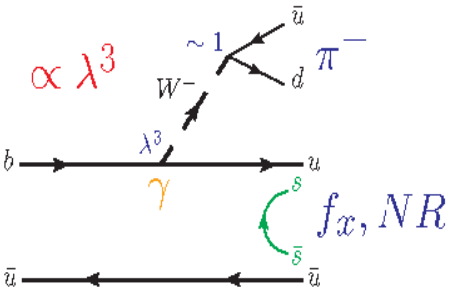

**$B \to K\pi\pi$ and $B \to KKK$:**

- Strangeness = 1.
- Contributions from penguin ($b \to s$) and tree ($b \to u$) transitions.
- CPV expected from interference between tree and penguin diagrams.
- CPV expected from intermediate two-body resonant states.
  - Evidence of CPV in $B^{\pm} \to \rho K^{\pm}$ ($K\pi\pi$ final state). Belle: PRL **96**, (2006) 251803 BaBar: PR **D78**, (2008) 012004
  - Evidence of CPV in $B^{\pm} \to \phi K^{\pm}$ (KKK final state). BaBar: PR **D85**, (2012) 112010
- CPT connection implies possibility of "compound" CPV ($KK \to \pi\pi$ rescattering).
- CPT imposes that the sum of the partial decay widths, for all channels with the same quantum numbers, be equal for charge-conjugated decays. Cheng, Chua, Soni, PR **D71** (2005) 014030

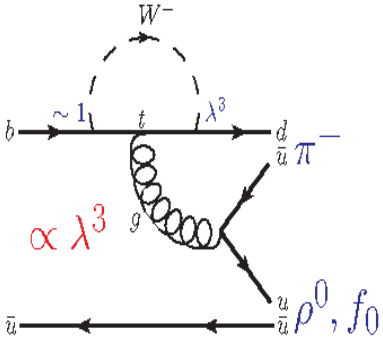
# Charmless $B^{\pm} \to h^{+}h^{-}h^{\pm}$ decays

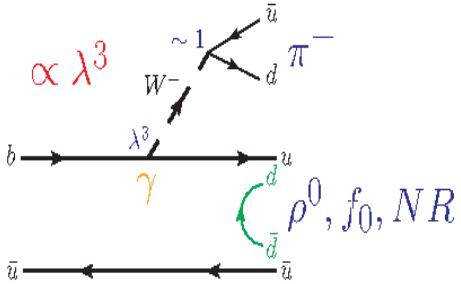
$B^{\pm} \to \pi^{\pm}K^{+}K^{-}$




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




**$B \to KK\pi$ and $B \to \pi\pi\pi$:**

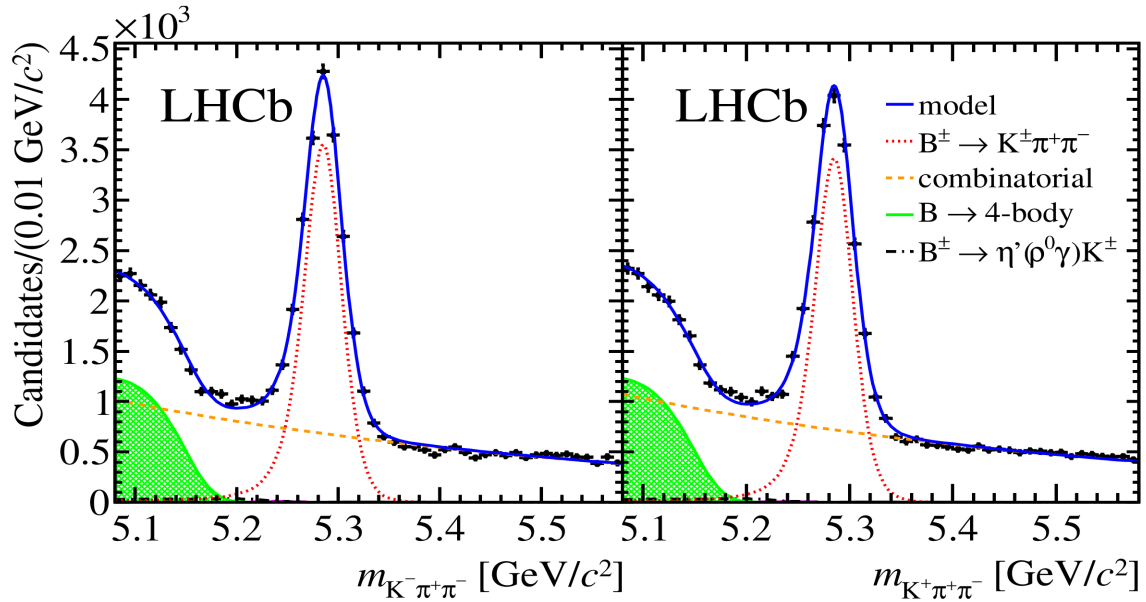
- Strangeness = 0.
- Contributions from penguin ($b \to d$) and tree ($b \to u$) transitions.
- CPV expected from interference between tree and penguin diagrams.
- CPV expected from intermediate two-body resonant states.
  - ➔ Not observed at B factories.
- CPT connection implies possibility of "compound" CPV ($KK \to \pi\pi$ rescattering).
- CPT imposes that the sum of the partial decay widths, for all channels with the same quantum numbers, be equal for charge-conjugated decays.

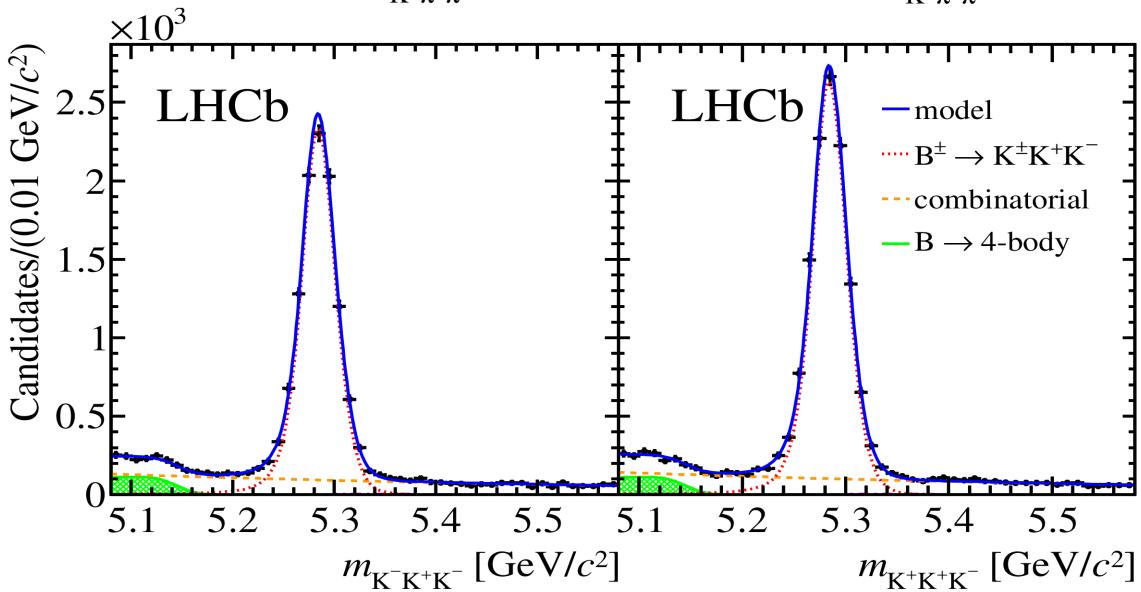
Cheng, Chua, Soni, PR **D71** (2005) 014030

# $B^{\pm} \to h^{+}h^{-}K^{\pm}$ raw asymmetries

LHCb-PAPER-2013-027
In preparation

NEW!




- 1.0 fb$^{-1}$ of 2011 LHCb data.

### $B \to K\pi\pi$

$N_{sig}$ = 35901 ± 327

$A_{raw}$ = 0.020 ± 0.007

### $B \to KKK$

$N_{sig}$ = 22119 ± 164

$A_{raw}$ = –0.060 ± 0.007

# CPV in $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$ and $B^{\pm} \to K^{\pm}K^{+}K^{-}$

LHCb-PAPER-2013-027
In preparation

NEW!

- The inclusive CP asymmetry is obtained from the raw asymmetry:

$$A_{CP}(Khh) = A_{raw}(Khh) - (A_D^K + A_P) = A_{raw}(Khh) - \Delta A$$

$K^{\pm}$ detection asymmetry

$B^{\pm}$ production asymmetry

- The correction factor is measured from $B^{\pm} \to J/\psi\, K^{\pm}$ decays

$$\Delta A = A_{raw}(J/\psi K) - A_{CP}(J/\psi K)\ , \qquad A_{CP}(J/\psi K) = (0.001 \pm 0.007)$$ PDG

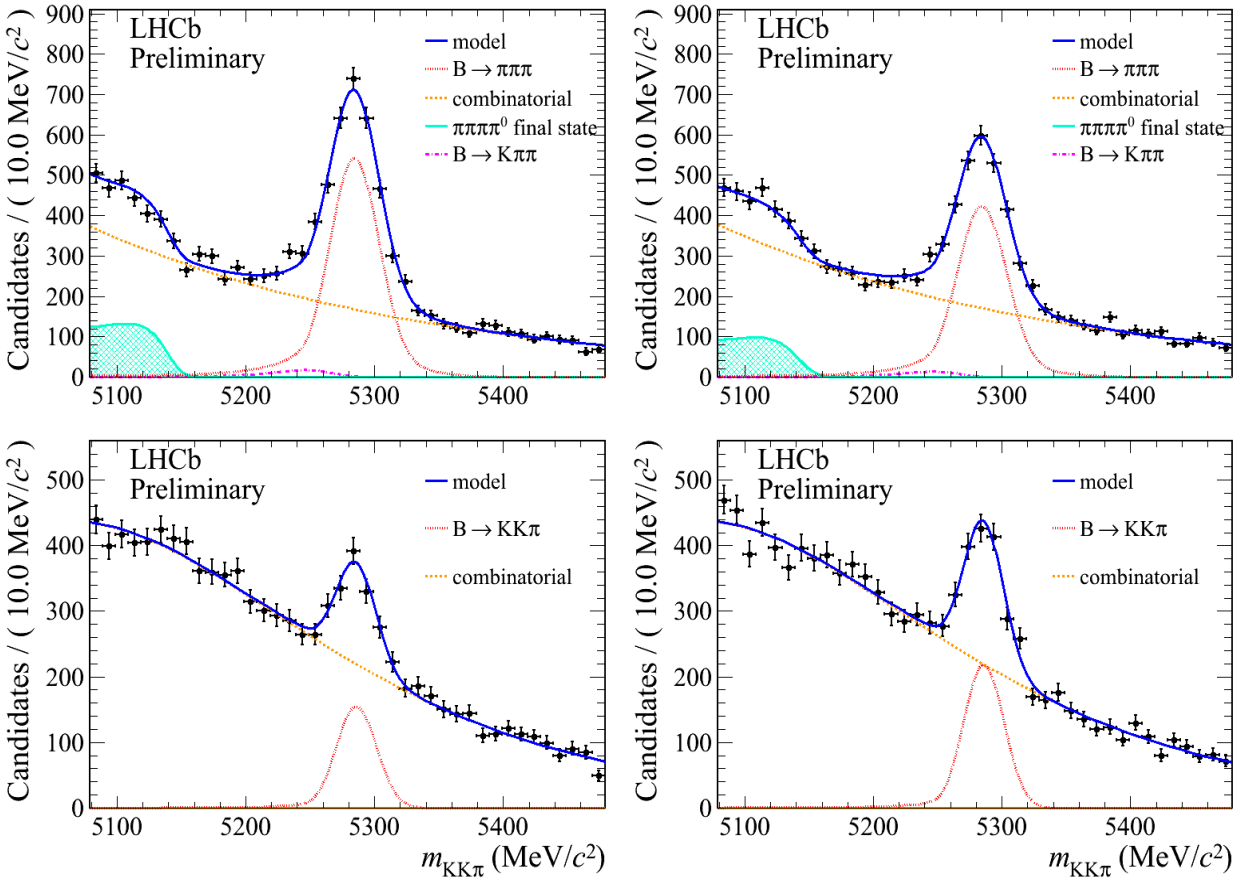
- Raw asymmetries are corrected for variation of acceptance in phase space.
- The samples are divided in two depending on the trigger decision.
- Dominant systematic uncertainties are due to the trigger selection and acceptance correction uncertainty.

$$A_{CP}(K\pi\pi) = 0.032 \pm 0.008(stat) \pm 0.004(syst) \pm 0.007(J/\psi K) \quad 2.8\sigma$$

$$A_{CP}(KKK) = -0.043 \pm 0.009(stat) \pm 0.003(syst) \pm 0.007(J/\psi K) \quad 3.7\sigma$$

- First evidence of an inclusive CP asymmetry in charmless three-body B decays.

# CPV in $B^{\pm} \to K^{+}K^{-}\pi^{\pm}$ and $B^{\pm} \to \pi^{+}\pi^{-}\pi^{\pm}$




LHCb-CONF-2012-028
Preliminary

- 1.0 fb$^{-1}$ of 2011 LHCb data.

***B → πππ***

$N_{sig}$ = 4829 ± 97

***B → KKπ***

$N_{sig}$ = 1494 ± 69

- Production ($A_P$) and detection ($A_D^K$, $A_D^\pi$) asymmetries from previous analyses.

LHCb-CONF-2012-018.
PRL **108**, (2012) 201601.
PL**B713**, (2012) 186.

$A_{CP}(\pi\pi\pi) = 0.120 \pm 0.020(\text{stat}) \pm 0.019(\text{syst}) \pm 0.007(J/\psi K)$ 4.2σ

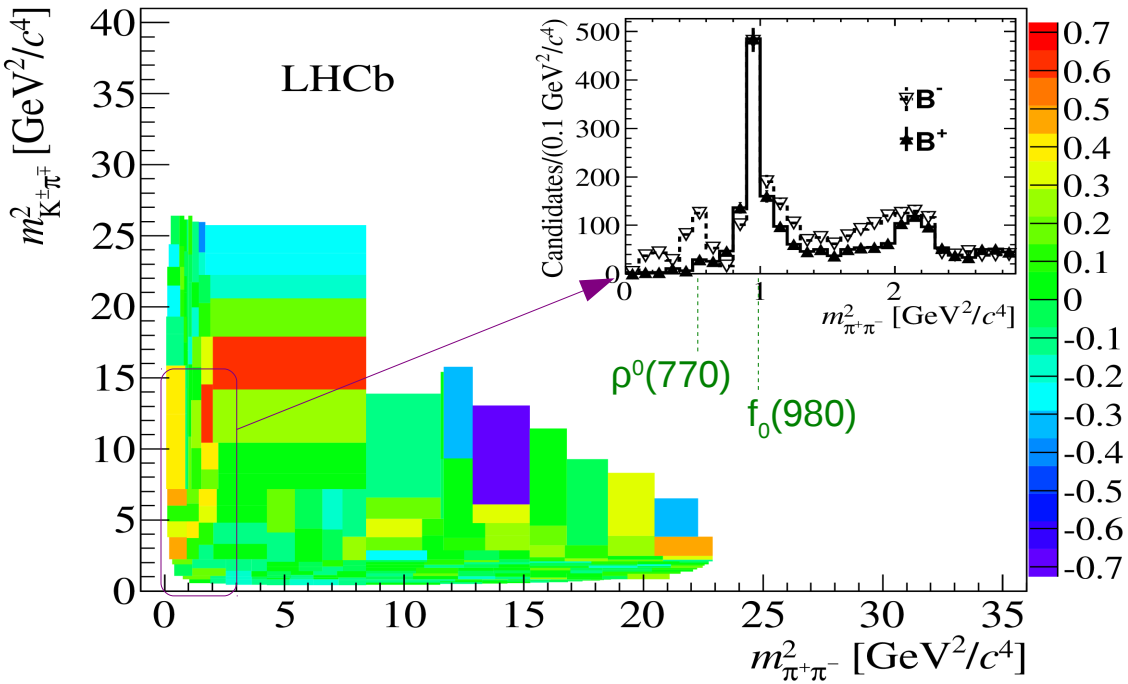
$A_{CP}(KK\pi) = -0.153 \pm 0.046(\text{stat}) \pm 0.019(\text{syst}) \pm 0.007(J/\psi K)$ 3.0σ

- First evidences of an inclusive CP asymmetry in these decays.

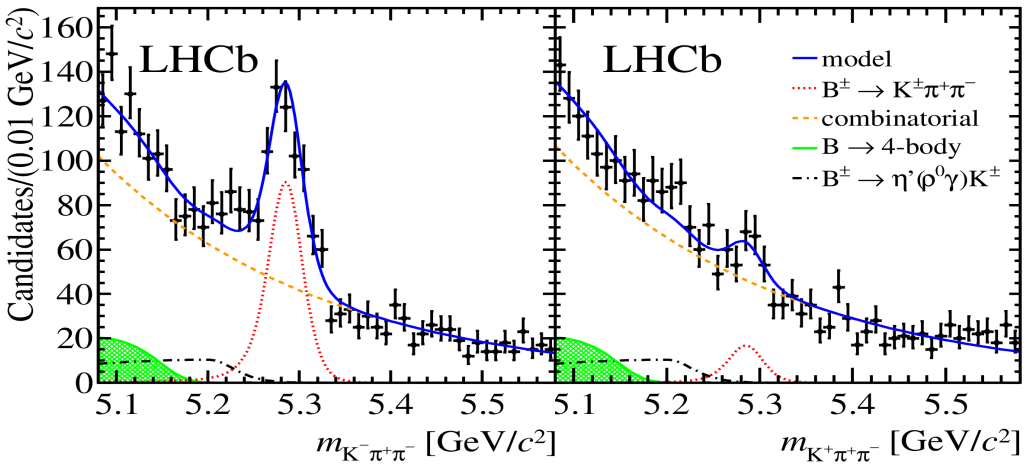
# $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$ phase space

LHCb-PAPER-2013-027
In preparation

NEW!




- Asymmetries in bins of the background-subtracted Dalitz plot.
- Positive asymmetry at low $m_{\pi\pi}$, near the $\rho^0(770)$ and above the $f_0(980)$ resonances.
- No significant asymmetry in $m_{K\pi}$.




- Measured the CP asymmetry in the region $m_{\pi\pi}^2 < 0.66$ GeV$^2$/$c^4$ and $m_{K\pi}^2 < 15$ GeV$^2$/$c^4$:

$N_{sig} = 552 \pm 47$

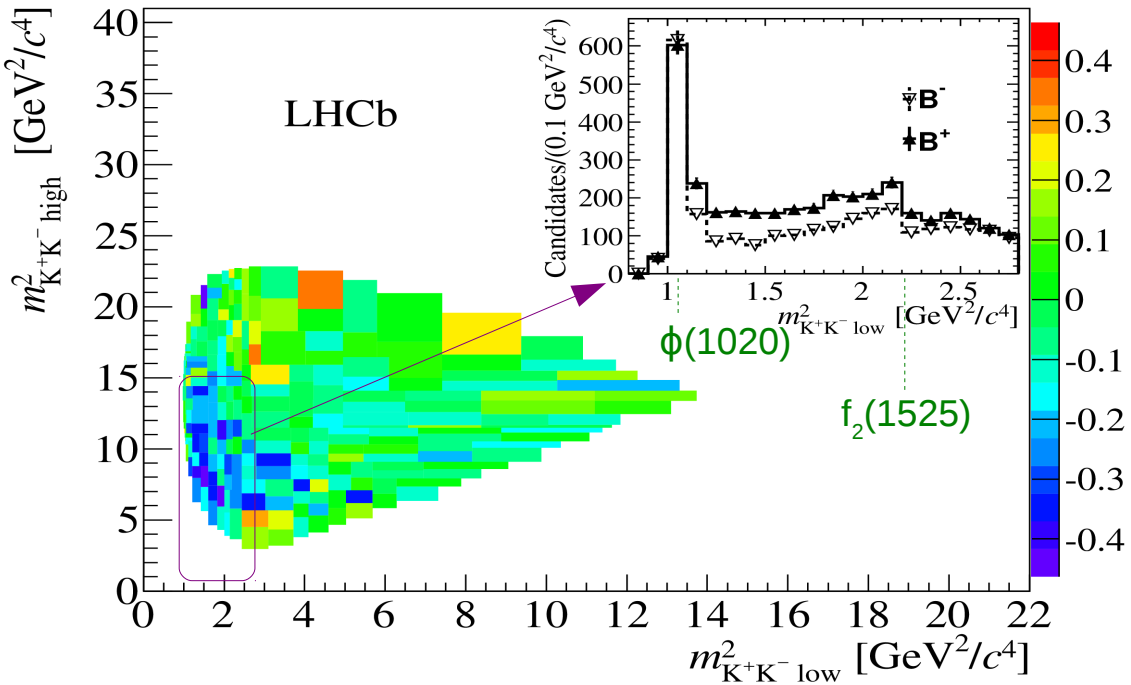
$A_{CP}(K\pi\pi) = 0.678 \pm 0.078 \pm 0.032 \pm 0.007$

$8.0\sigma$

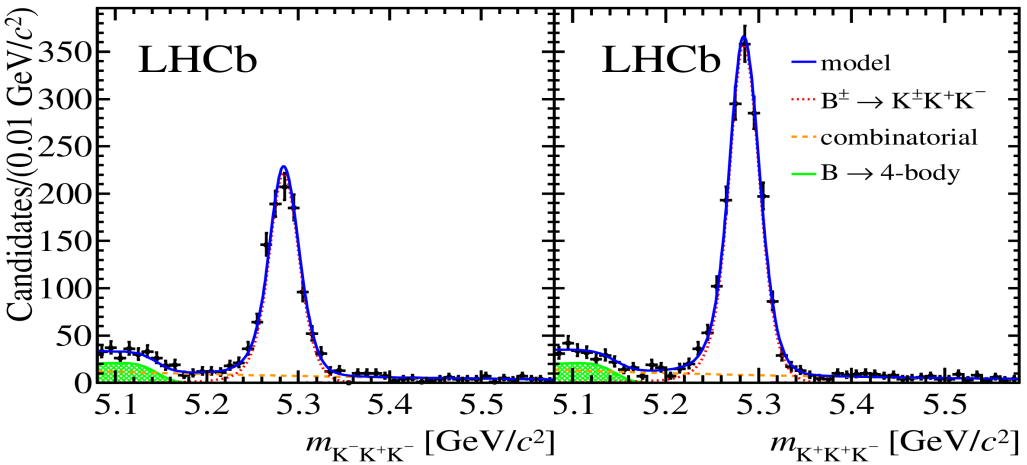
# $B^{\pm} \to K^{\pm}K^{+}K^{-}$ phase space

LHCb-PAPER-2013-027
In preparation

NEW!




- Asymmetries in bins of the background-subtracted Dalitz plot.
- Negative asymmetry at low values of $m_{KK\,low}$ and $m_{KK\,high}$, not obviously associated to resonances.
- No significant asymmetry in the $\phi(1020)$ resonance.




- Measured the CP asymmetry in the region $1.2 < m_{KK\,low}{}^2 < 2.0$ GeV$^2$/$c^4$ and $m_{KK\,high}{}^2 < 15$ GeV$^2$/$c^4$:

$N_{sig} = 2581 \pm 55$

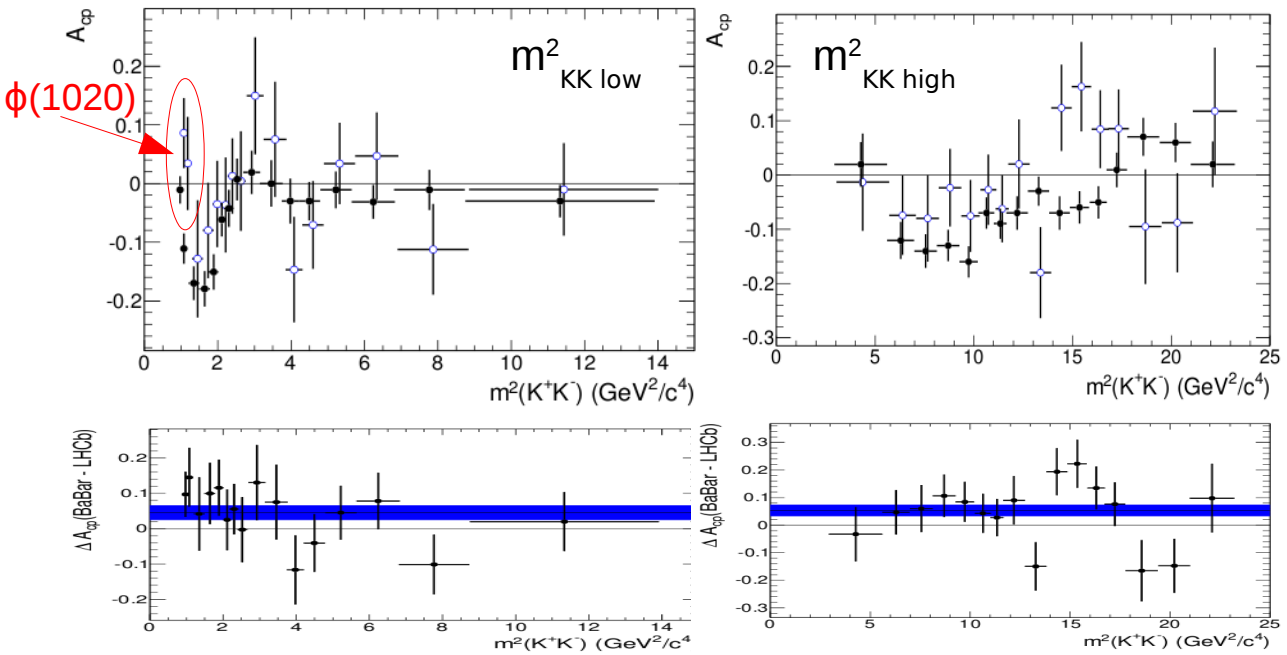
$A_{CP}(KKK) = -0.226 \pm 0.020 \pm 0.004 \pm 0.007$

$10.5\sigma$

# $B^{\pm} \to K^{\pm}K^{+}K^{-}$ comparison

SLAC-PUB-15451

- A follow up to the BaBar amplitude analysis of $B^{\pm} \to K^{\pm}K^{+}K^{-}$. PR **D85**, (2012) 112010 NEW!
- Invariant-mass dependence of the CP asymmetry, comparison with the LHCb results: LHCb-CONF-2012-018



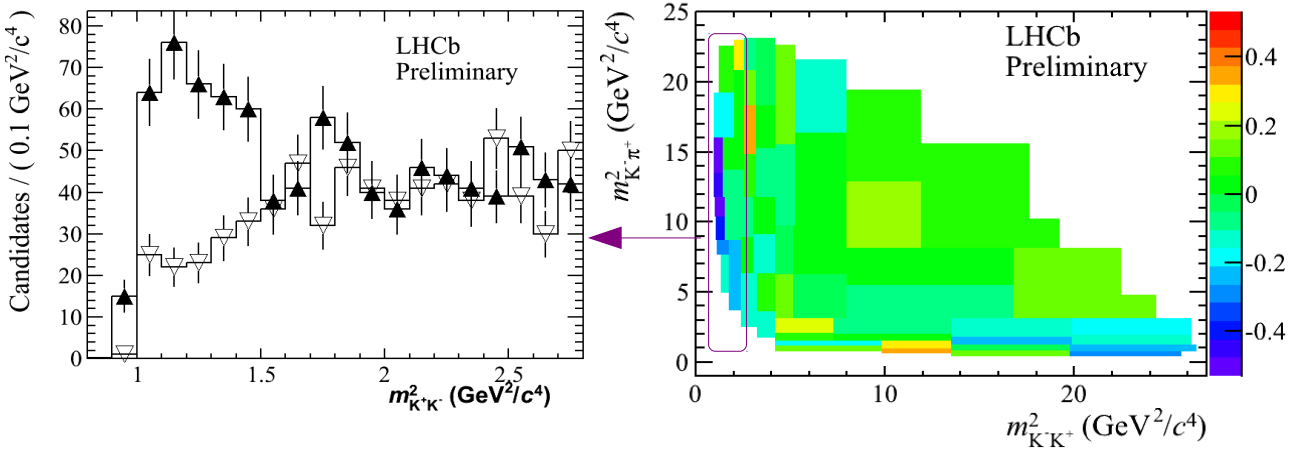

- BaBar $A_{CP}$ from sPlots.
- LHCb $A_{raw}$ from fits in bins (no acceptance corrections; no corrections for detection and production asymmetry~–1.4%).

$\Delta = 0.045 \pm 0.021$ in $m_{KK\ low}$

$\Delta = 0.053 \pm 0.021$ in $m_{KK\ high}$

- Similar patterns in the asymmetries.
- Apparent shift between BaBar and LHCb results (less than 2 sigma) is consistent with the difference in inclusive asymmetries.
- BaBar measure a 2.8σ positive asymmetry in ϕ(1020); not seen by LHCb.
- Further investigation is needed to pin down the source of CP violation.

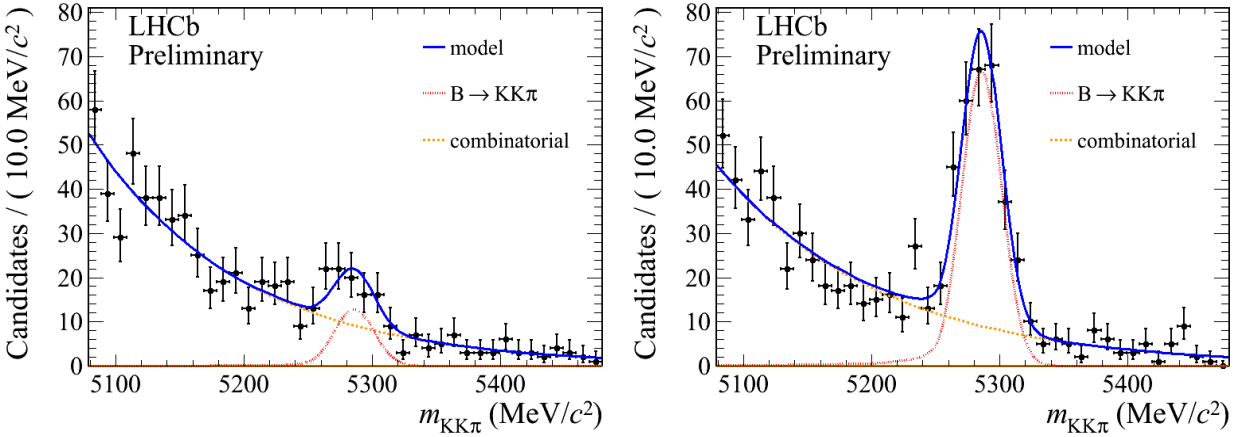
# $B^{\pm} \to K^{+}K^{-}\pi^{\pm}$ phase space




LHCb-CONF-2012-028
Preliminary

- Asymmetries in bins of the Dalitz plot (not background-subtracted).

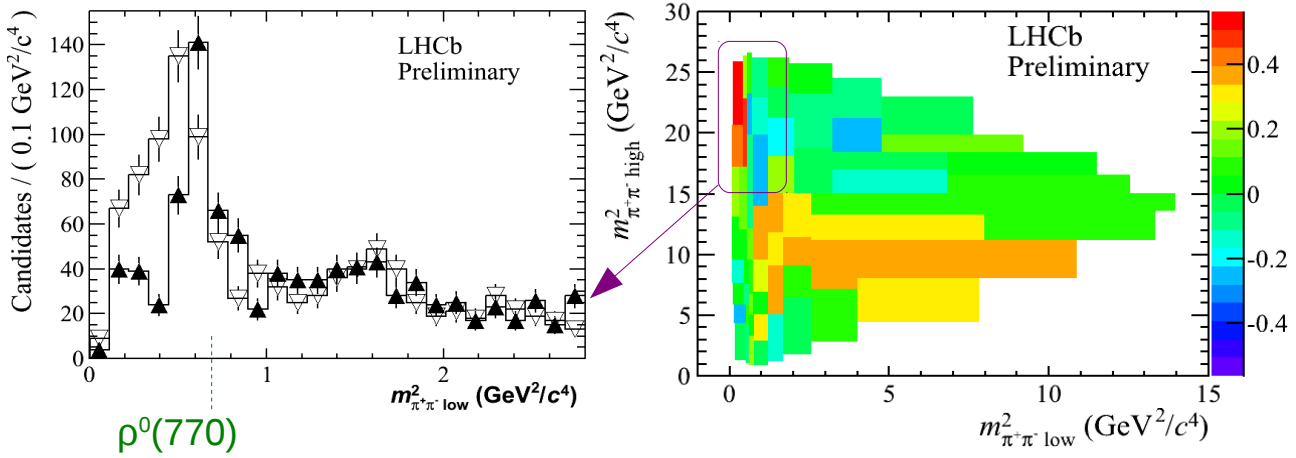
- Large negative asymmetry at low $m_{KK}$, in a region not associated to resonances.
- No ϕ(1020) signature.
- Low mass structure as seen by BaBar. PRL 99 (2007) 221801




- Measured the CP asymmetry in the region $m_{KK}^2 < 1.5$ GeV²/c⁴:

$A_{CP}(KK\pi) = -0.671 \pm 0.067 \pm 0.028 \pm 0.007$ 9.2σ

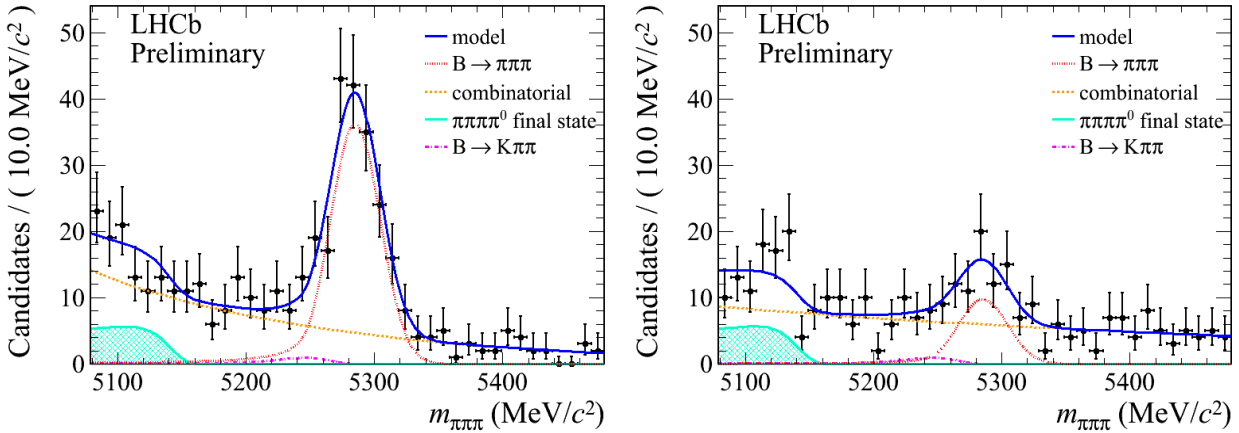
# $B^{\pm} \to \pi^+\pi^-\pi^{\pm}$ phase space




LHCb-CONF-2012-028
Preliminary

- Asymmetries in bins of the Dalitz plot (not background-subtracted).

- Large positive asymmetry at low $m_{\pi\pi}$, in a region below the $\rho^0(770)$ resonance.



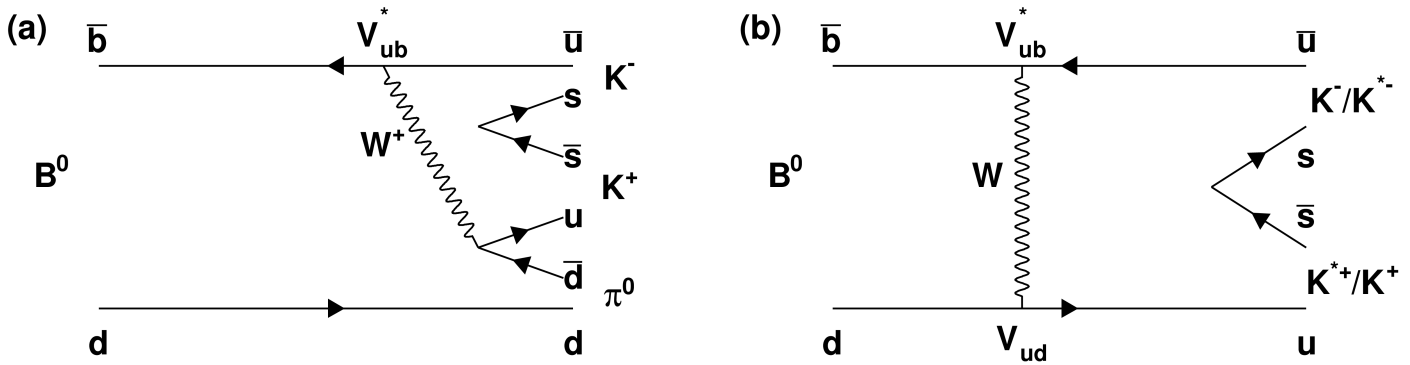

- Measured the CP asymmetry in the region $m_{\pi\pi}^2 < 0.4$ GeV²/c⁴ and $m_{K\pi}^2 > 15$ GeV²/c⁴:

$A_{CP}(\pi\pi\pi) = 0.622 \pm 0.075 \pm 0.032 \pm 0.007$ $7.6\sigma$

# Search for $B^0 \to K^+K^-\pi^0$ decay

arXiv:1304.5312
Accepted by PRD

NEW!



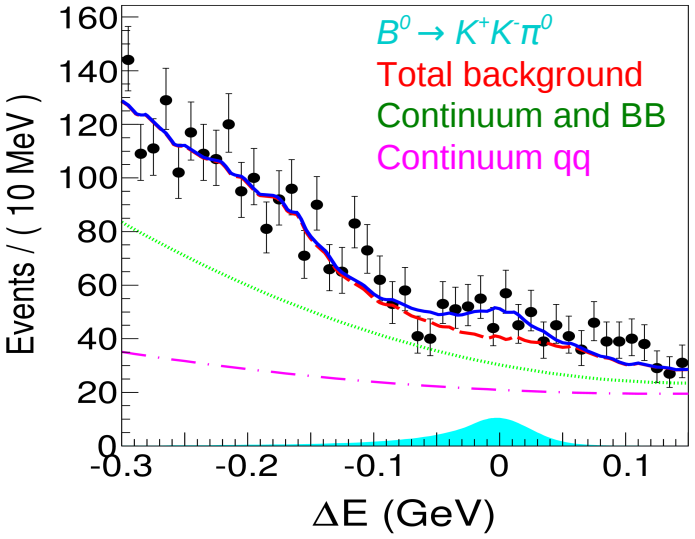

- Previously unobserved decay and suppressed in the SM.
- Contributions from colour- and Cabibbo-suppressed tree ($b \to u$) and internal $W$ exchange transitions.
- No experimental information for potential resonance modes.
- Look for the unexpected structure at low $K^+K^-$ mass seen by BaBar and LHCb in $B^\pm \to K^+K^-\pi^\pm$.

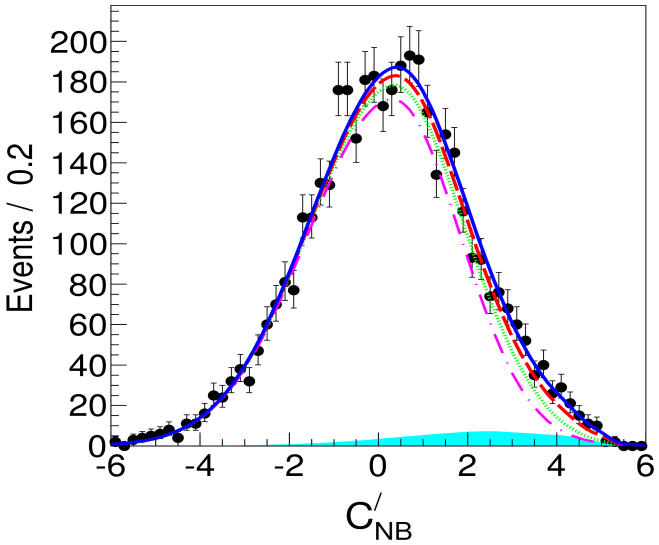
# First evidence for $B^0 \to K^+K^-\pi^0$ decay

arXiv:1304.5312
Accepted by PRD

- 711 fb$^{-1}$ of Belle data (772 x 10$^6$ BBbar pairs) at the Υ(4S) resonance.
- Candidates selected using a neural network.
- Selected ±3σ around the nominal *B* mass in $M_{bc}$.
- Two-dimensional fit in ΔE and the neural network output $C'_{NB}$.

NEW!




$n_{sig} = 299 \pm 83$

3.8σ

- First evidence for $B^0 \to K^+K^-\pi^0$ decay.
- Decay branching fraction:

$$\mathcal{B}(B^0 \to K^+K^-\pi^0) = [2.17 \pm 0.60 \pm 0.24] \times 10^{-6}$$

$$\mathcal{B}(B^0 \to K^+K^-\pi^0) = \frac{n_{\rm sig}}{N_{B\bar{B}} \times \varepsilon_{\rm rec} \times r_{K/\pi}}$$

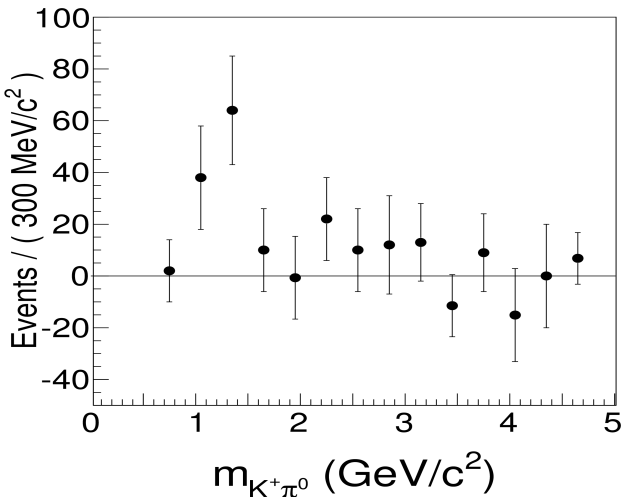
Reconstruction efficiency

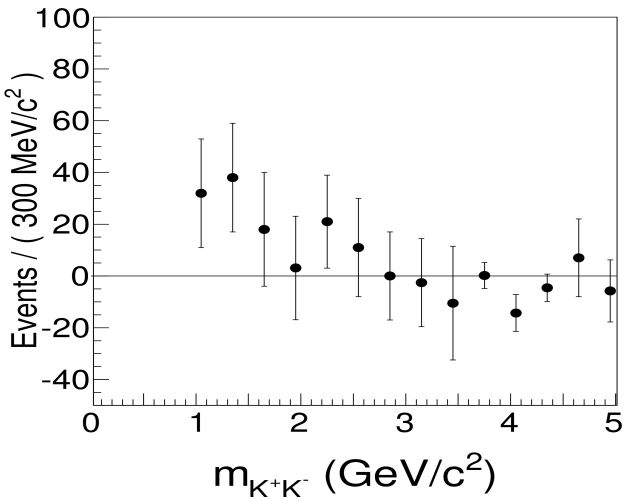
Correction for data/MC difference in PID

# Two-body spectra of $B^0 \to K^+K^-\pi^0$

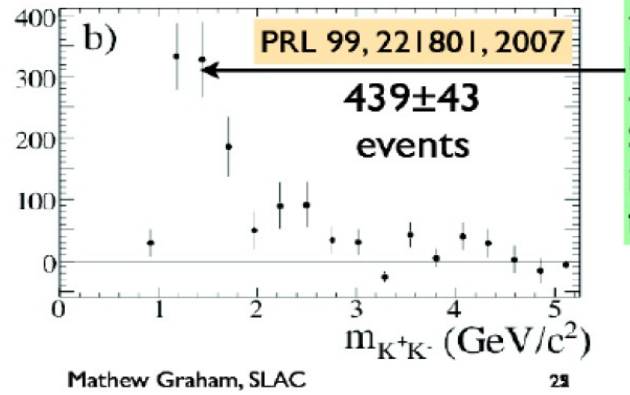
arXiv:1304.5312
Accepted by PRD

NEW!




- Yields from fits in bins of $m_{K\pi}$ and $m_{KK}$.
- Excess of events around $m_{K\pi}$ = 1.4 GeV/$c^2$, needs an amplitude analysis.
- No definitive statement about the low-mass structure seen by BaBar and LHCb:

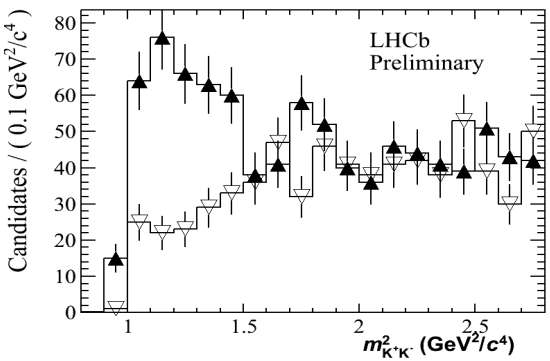



~ 1/2 of the events seen at low $K^+K^-$ mass; structure at ~1.5GeV?
Similar broad structures seen in $K^+K^-K^+/K^+K^-K_S$ and $\pi^+\pi^-K^+/\pi^+\pi^-K_S$

What about $K_SK_S\pi^+$?

Matt Graham
SLAC
on behalf of the BaBar Collaboration
February 12, 2009
Aspen Winter Conference

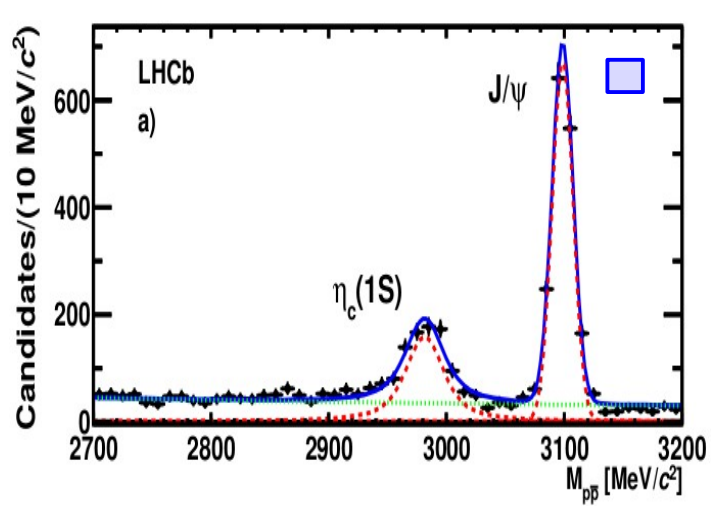
LHCb-CONF-2012-028

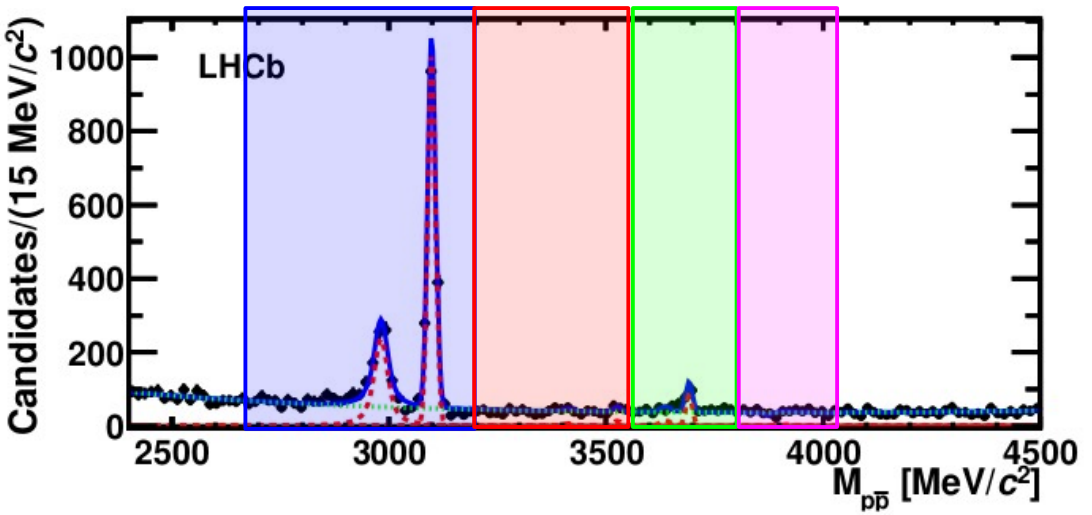


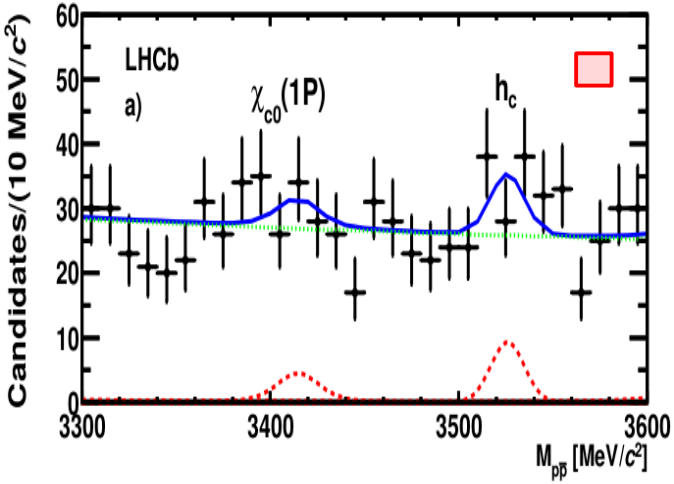
# BR of $B^{\pm} \to p\bar{p}K^{\pm}$ decays

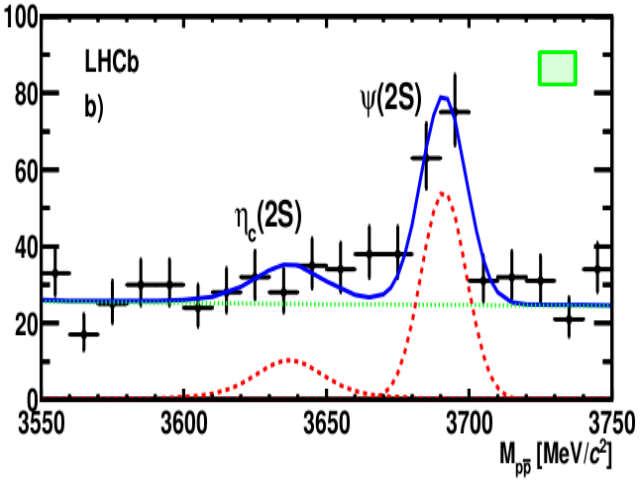
arXiv:1303.7133
Submitted to EPJC

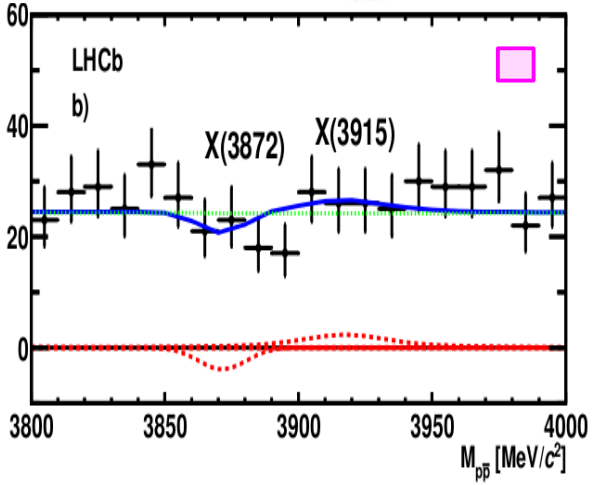
- Measurement of the relative BR of $B \to p\bar{p}K$ modes normalised to $B \to J/\psi(pp)K$:



# BR of $B^{\pm} \to p\bar{p}K^{\pm}$ decays

arXiv:1303.7133
Submitted to EPJC

- Yields:

| $B^+$ decay mode | Signal yield | Upper limit (95% CL) |
|---|---|---|
| $p\bar{p}K^+$ [total] | $6951 \pm 176$ | |
| $p\bar{p}K^+$ [$M_{p\bar{p}} < 2.85\,\mathrm{GeV}/c^2$] | $3238 \pm 122$ | |
| $J/\psi\,K^+$ | $1458 \pm 42$ | |
| $\eta_c(1S)K^+$ | $856 \pm 46$ | |
| $\psi(2S)K^+$ | $107 \pm 16$ | |
| $\eta_c(2S)K^+$ | $39 \pm 15$ | $< 65.4$ |
| $\chi_{c0}(1P)K^+$ | $15 \pm 13$ | $< 38.1$ |
| $h_c(1P)K^+$ | $21 \pm 11$ | $< 40.2$ |
| $X(3872)K^+$ | $-9 \pm 8$ | $< 10.3$ |
| $X(3915)K^+$ | $13 \pm 17$ | $< 42.1$ |

- Relative branching fractions and upper limits on $\eta_c(2S)$ and X(3872):

$$\mathcal{R}(\mathrm{mode}) = \frac{\mathcal{B}(B^+ \to \mathrm{mode} \to p\bar{p}K^+)}{\mathcal{B}(B^+ \to J/\psi K^+ \to p\bar{p}K^+)} = \frac{N_{\mathrm{mode}}}{N_{J/\psi}} \times \frac{\epsilon_{J/\psi}}{\epsilon_{\mathrm{mode}}}$$

$$\frac{\mathcal{B}(B^+ \to p\bar{p}K^+)_{\mathrm{total}}}{\mathcal{B}(B^+ \to J/\psi K^+ \to p\bar{p}K^+)} = 4.91 \pm 0.19\,(\mathrm{stat}) \pm 0.14\,(\mathrm{syst}),$$

$$\frac{\mathcal{B}(B^+ \to p\bar{p}K^+)_{M_{p\bar{p}}<2.85\,\mathrm{GeV}/c^2}}{\mathcal{B}(B^+ \to J/\psi K^+ \to p\bar{p}K^+)} = 2.02 \pm 0.10\,(\mathrm{stat}) \pm 0.08\,(\mathrm{syst}),$$

$$\frac{\mathcal{B}(B^+ \to \eta_c(1S)K^+ \to p\bar{p}K^+)}{\mathcal{B}(B^+ \to J/\psi K^+ \to p\bar{p}K^+)} = 0.578 \pm 0.035\,(\mathrm{stat}) \pm 0.025\,(\mathrm{syst}),$$

$$\frac{\mathcal{B}(B^+ \to \psi(2S)K^+ \to p\bar{p}K^+)}{\mathcal{B}(B^+ \to J/\psi K^+ \to p\bar{p}K^+)} = 0.080 \pm 0.012\,(\mathrm{stat}) \pm 0.009\,(\mathrm{syst}).$$

$$\frac{\mathcal{B}(\eta_c(2S) \to p\bar{p})}{\mathcal{B}(\eta_c(2S) \to K\bar{K}\pi)} < 3.1 \times 10^{-2}$$

$$\frac{\mathcal{B}(X(3872) \to p\bar{p})}{\mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-)} < 2.0 \times 10^{-3}$$

# First observation of $B^0_s \to \phi \bar{K}^{*0}$ decay

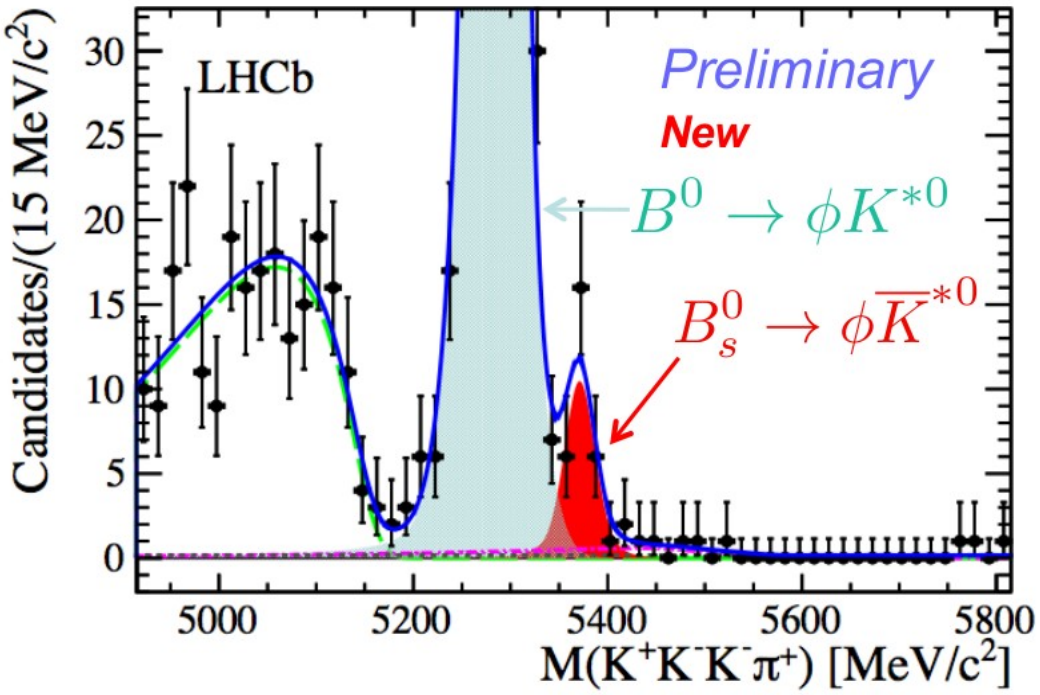
LHCb-PAPER-2013-012
In preparation

- Last undiscovered B → VV penguin decay.
- Reconstructed $\phi(K^+K^-)\bar{K}^{*0}(K\pi)$.

$N_{sig} = 30 \pm 6$ $6.1\sigma$

- First observation of $B^0_s \to \phi\bar{K}^{*0}$.

- BR measurement using $B^0 \to \phi K^{*0}$ as normalisation.
- Main systematical uncertainties due to fit model and $B^0$ purity.



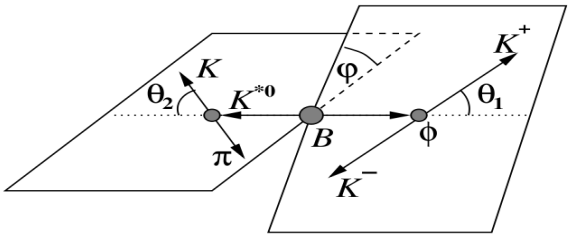

$$\mathcal{B}(B^0_s \to \phi\bar{K}^{*0}) = \left(1.10 \pm 0.24\,(\text{stat}) \pm 0.14\,(\text{syst}) \pm 0.08\left(\frac{f_d}{f_s}\right)\right) \times 10^{-6}$$

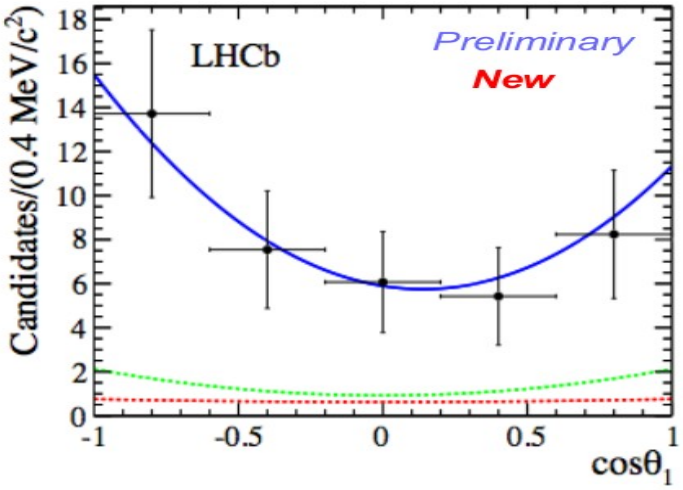
- 3x theory prediction: $(0.4^{+0.1\ +0.5}_{-0.1\ -0.3}) \times 10^{-6}$ NPB 774 64
- 3x naive scaling: $\mathcal{B}(B^0 \to \phi K^{*0}) \times |V_{td}|^2/|V_{ts}|^2$

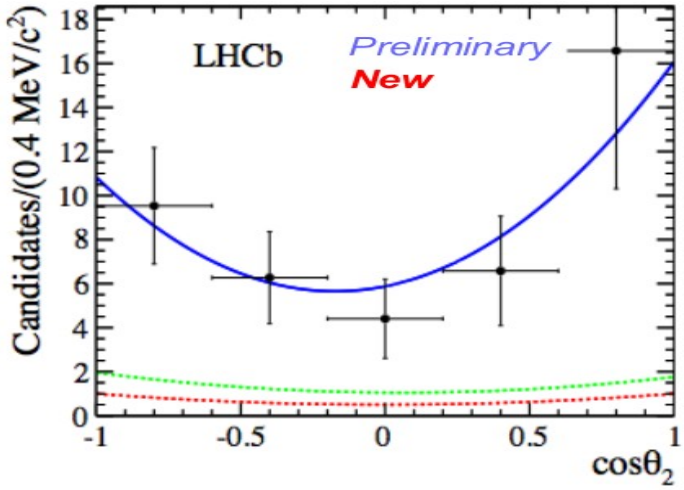
# $B^0_s \to \phi \bar{K}^{*0}$ polarisation

LHCb-PAPER-2013-012
In preparation

- Untagged time-integrated angular analysis.
  - $B^0_s \to \phi \bar{K}^{*0}$ P-wave.
  - S-wave contribution.
  - $B^0 \to \phi K^{*0}$ cross-feed.
  - Combinatorial background.




$$f_0 = 0.51 \pm 0.15\,(\text{stat}) \pm 0.07\,(\text{syst}),$$
$$f_\parallel = 0.21 \pm 0.11\,(\text{stat}) \pm 0.02\,(\text{syst}),$$
$$\cos\delta_\parallel = -0.18 \pm 0.52\,(\text{stat}) \pm 0.29\,(\text{syst}).$$

Longitudinal polarisation fraction agrees with other $b \to s$ penguins.

# Conclusions

- First observation of direct CP violation in $B_S$ mesons.
- CP violation in charged charmless three-body B decays:
  - First evidence of an inclusive CP asymmetry.
  - Large local asymmetries in regions not associated to resonances.
  - Partial agreement between LHCb and BaBar results.
  - Apparent correlations could be due to compound CP violation.
  - Future amplitude analysis needs to include hadron rescattering.
- New decay channels and measurements:
  - Measurement of the relative BR of $B \to ppK$ modes.
  - First evidence of $B^0 \to K^+K^-\pi^0$ decay.
  - First observation of $B^0_S \to \phi\overline{K}^{*0}$ decay.
- LHCb results based on 1.0 $fb^{-1}$ of 2011 data. The 2012 dataset of ~2 $fb^{-1}$ is under study.

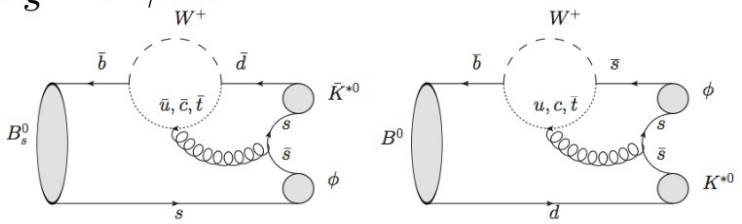
# Back up

# First observation of $B^0_s \to \phi K^{*0}$ decay

$B^0 \to \phi\phi$

$B^0_s \to K^{*0}\overline{K}^{*0}$ $\quad$ $B^0 \to K^{*0}\overline{K}^{*0}$

$B^0_s \to \phi\overline{K}^{*0}$ $\quad$ $B^0 \to \phi K^{*0}$




$$\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_1\,\mathrm{d}\cos\theta_2\,\mathrm{d}\varphi} \propto \frac{|A_0|^2}{\Gamma_\mathrm{L}}\cos^2\theta_1\cos^2\theta_2 + \frac{|A_\parallel|^2}{\Gamma_\mathrm{L}}\frac{1}{2}\sin^2\theta_1\sin^2\theta_2\cos^2\varphi + \frac{|A_\perp|^2}{\Gamma_\mathrm{H}}\frac{1}{2}\sin^2\theta_1\sin^2\theta_2\sin^2\varphi + \frac{|A_0||A_\parallel|}{\Gamma_\mathrm{L}}\cos\delta_\parallel\frac{1}{2\sqrt{2}}\sin 2\theta_1\sin 2\theta_2\cos\varphi.$$

Table 4: Systematic uncertainties of the angular parameters.

| Effect | $\Delta f_0$ | $\Delta f_\parallel$ | $\Delta\cos\delta_\parallel$ |
|---|---|---|---|
| S–wave | 0.07 | 0.02 | 0.29 |
| Acceptance | 0.007 | 0.005 | 0.00 |
| Combinatorial background | 0.02 | 0.01 | 0.01 |
| Total | 0.07 | 0.02 | 0.29 |