Studies of charmless B decays at LHCb

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on behalf of the LHCb collaboration

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LHCb

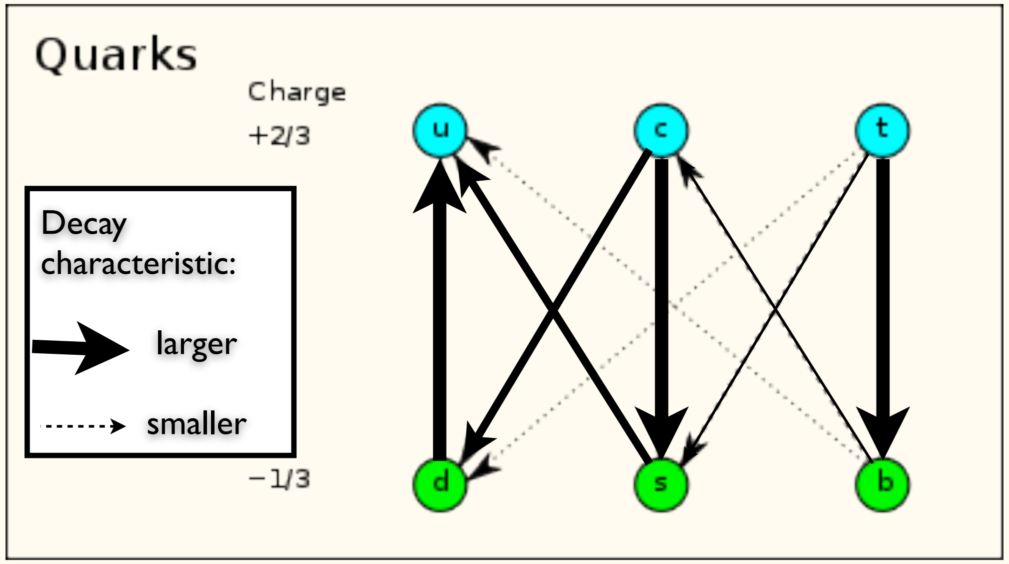
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

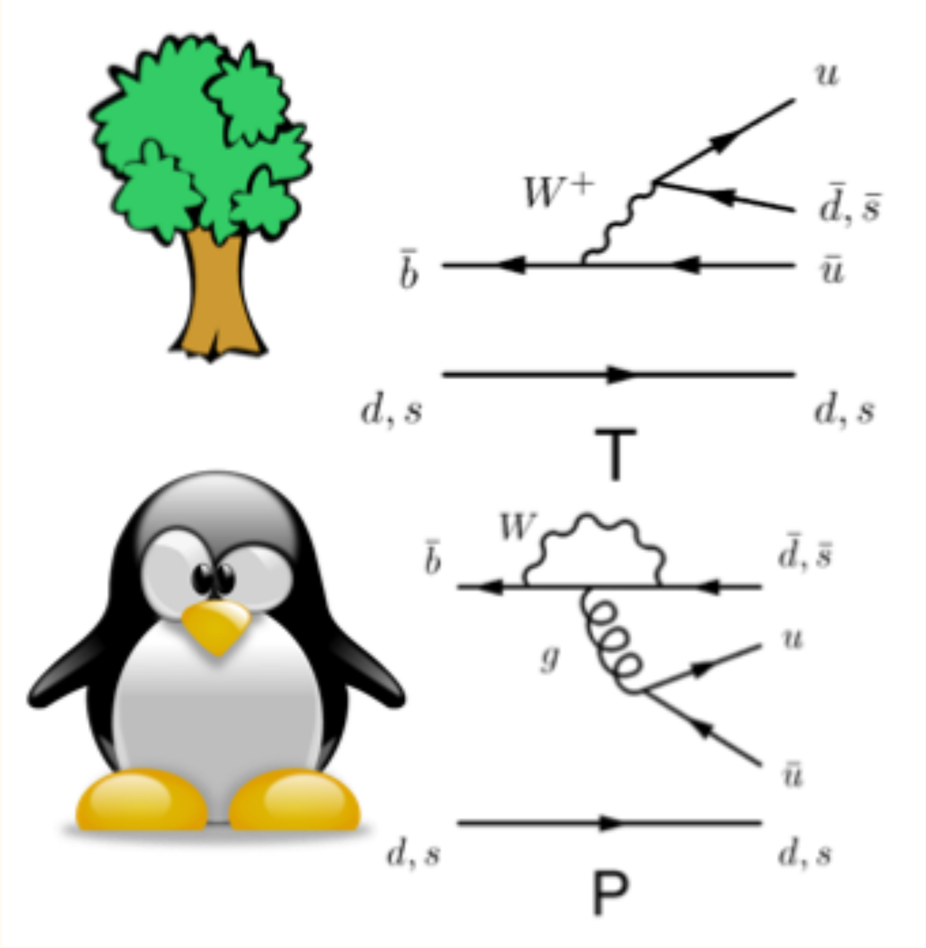
Outline

- Why charmless B decays?
- The LHCb detector
- Two-body final states
  (more charmless results covered in "Measurements of B lifetimes, mixing and CP violation at LHCb" Angelo Carbone talk)
- Three-body final states
- Four-body final states
- Conclusions

Why charmless B decays?

- Sensitive to tiny CKM matrix elements and their phases
- Good probe for New Physics (NP) searches:
  - b →u tree processes. Test the Standard Model (SM) and look for deviations in CKM structure
  - b →s,d loop transitions: NP may appear in the loop

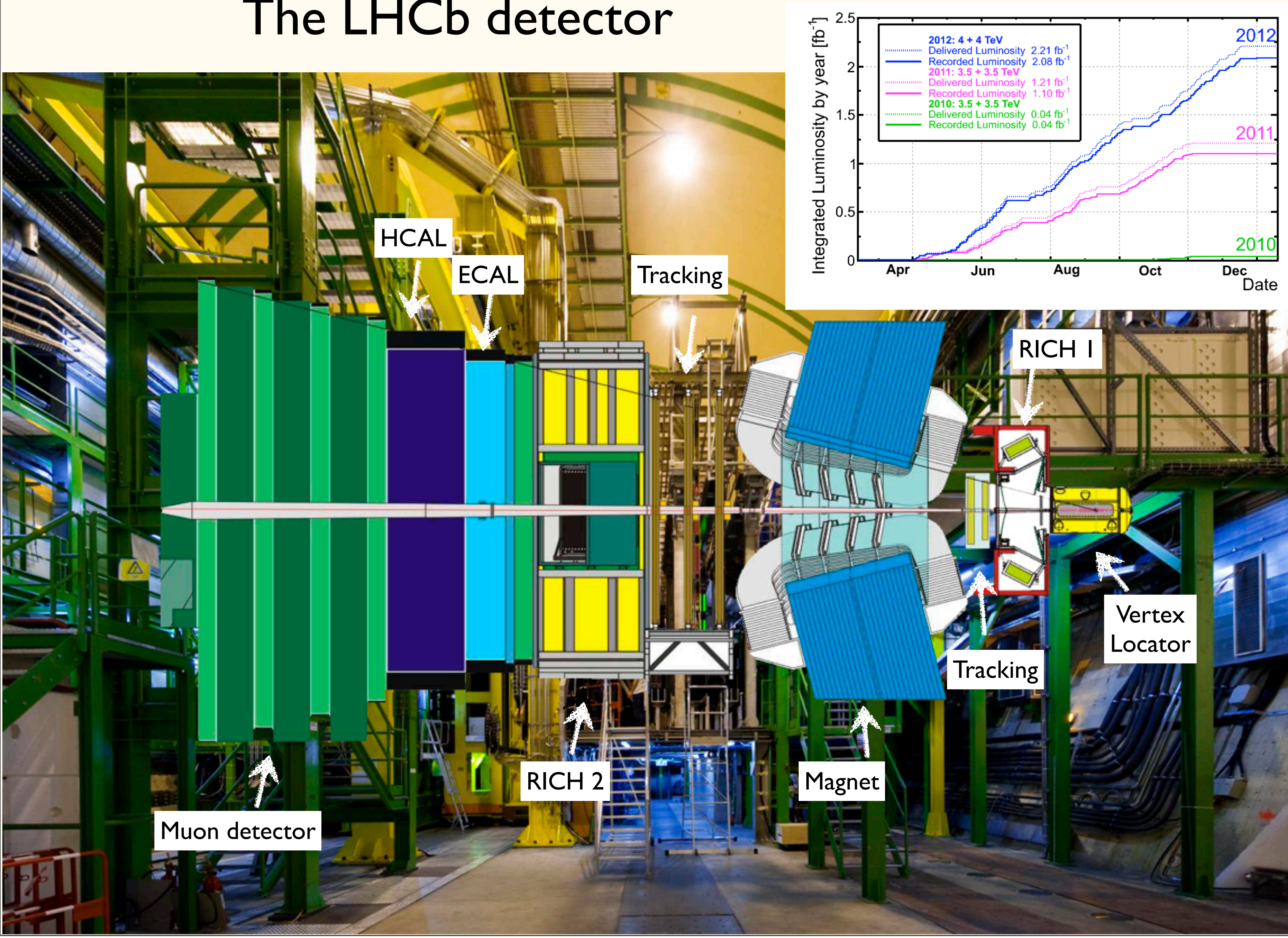




- CP violation measurements:
  - direct CP asymmetry arises from the interference between contributing amplitudes

$$\mathcal{A}_{CP} = \frac{\Gamma_{\bar{B}\to\bar{f}} - \Gamma_{B\to f}}{\Gamma_{\bar{B}\to\bar{f}} + \Gamma_{B\to f}}$$

The LHCb detector

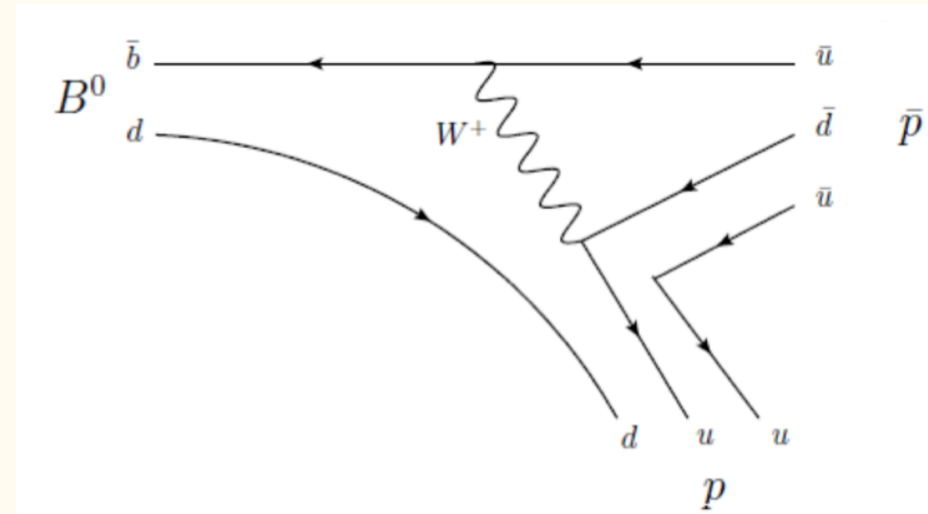


$B^0_{(s)} \rightarrow p\bar{p}$

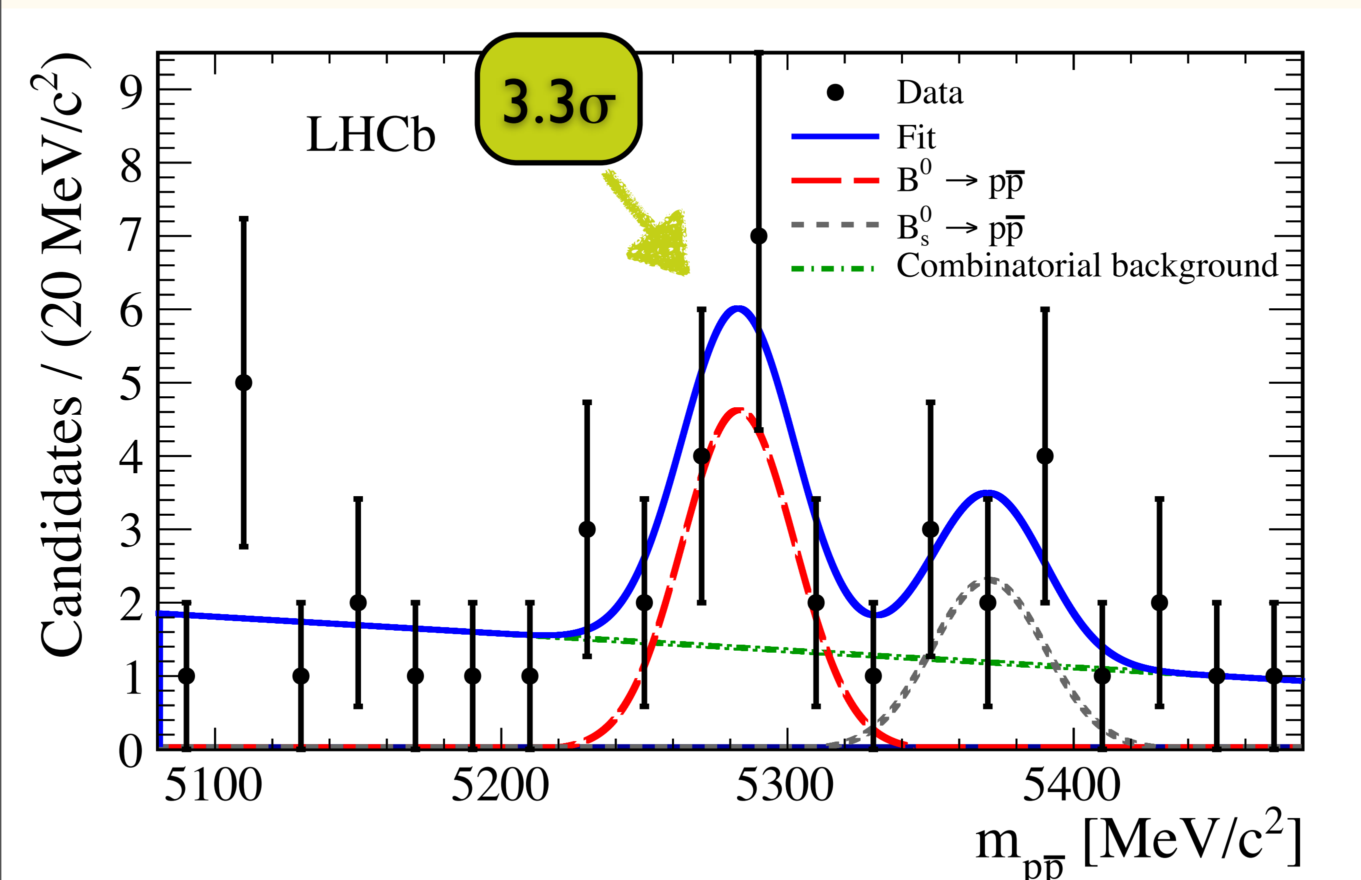
JHEP10(2013)005

- Objective : search for the $B^0_{(s)} \to p\bar{p}$ modes
- Control channel $B^0 \to K^+\pi^-$
- Predicted $B^0 \to p\bar{p}$ branching fraction ~10^{-7}-10^{-6}

  [Phys Rew D66 (2002) 014020, Phys Lett B 237(1990) 513]
- $\mathcal{L}$ = 0.9 fb^{-1} at 7 TeV
- Fit of the $p\bar{p}$ invariant mass



First evidence of $B^0 \to p\bar{p}$!

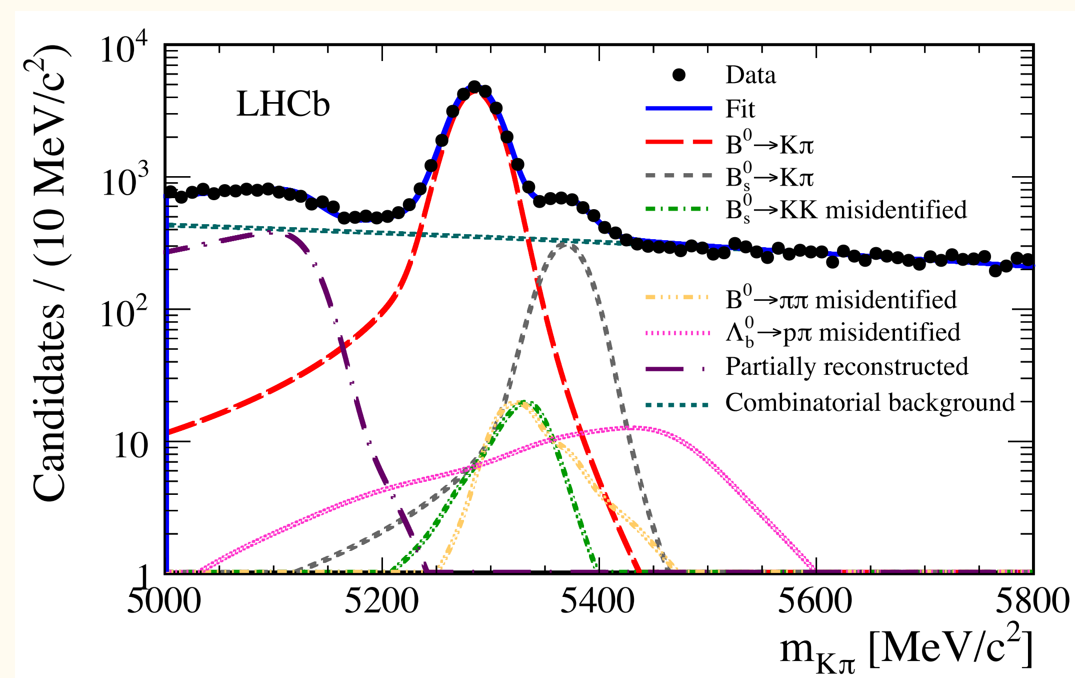


$$N(B^0 \to p\bar{p}) = 11.4^{+4.3}_{-4.1}$$
$$N(B^0_s \to p\bar{p}) = 5.7^{+3.5}_{-3.2}$$

$$\mathcal{B}(B^0 \to p\bar{p}) = (1.47^{+0.62}_{-0.52}{}^{+0.35}_{-0.14}) \times 10^{-8}$$
$$\mathcal{B}(B^0_s \to p\bar{p}) = (2.84^{+2.03}_{-1.68}{}^{+0.85}_{-0.18}) \times 10^{-8}$$

Control channel

$$N(B^0 \to K^+\pi^-) = 24968 \pm 198$$



JHEP10(2013)005

$$B^{\pm} \rightarrow h^{+}h^{-}h^{\pm}$$

$(h = K, \pi)$

PRL111,101801(2013)

arXiv:1310.4740

- Objective: measurement of direct CP violation across the phase space

PRL111,101801(2013)

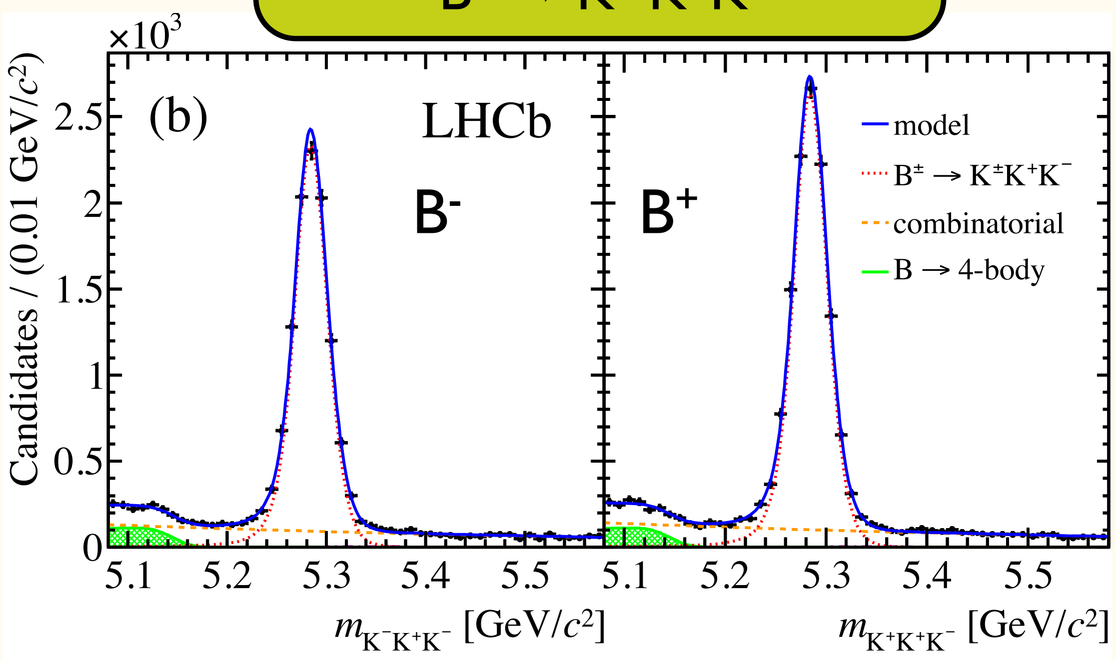
- Two possible sources of CP violation:
  - interference between intermediate states (large strong phase differences)
  - KK ↔ππ rescattering: introduction of additional strong phases which could increase CP asymmetry

Inclusive asymmetries in $B^{\pm} \to K^{\pm} h^{+}h^{-}$ ($\mathcal{L}$ = 1.0 fb^{-1} at 7 TeV):

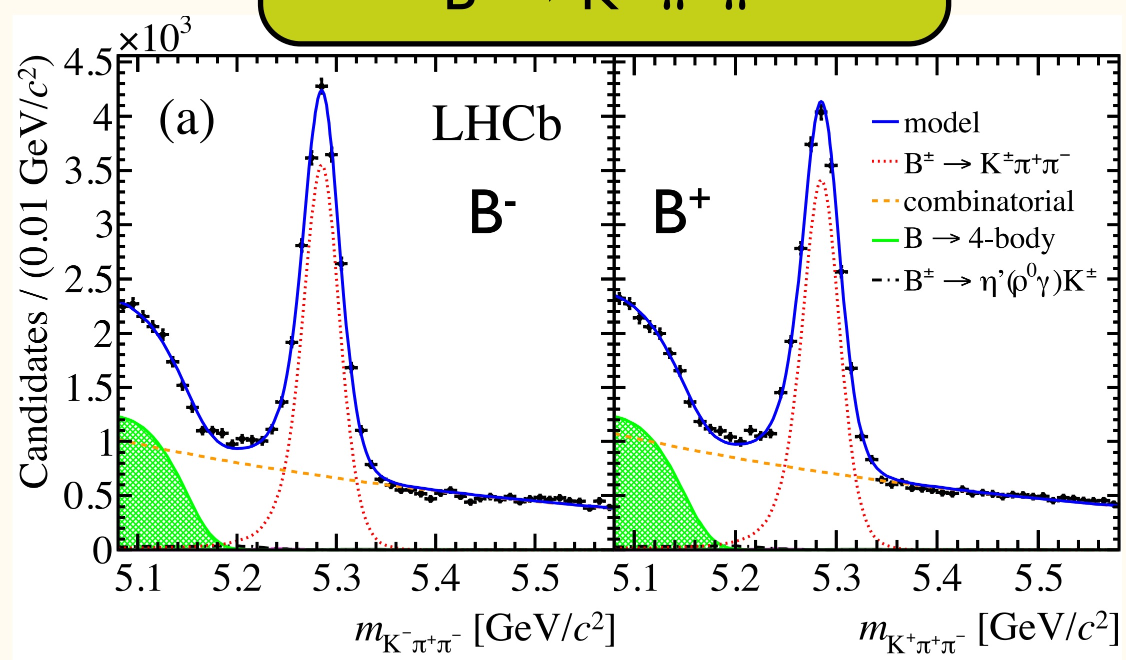
$$\mathcal{A}_{CP} = A_{raw} - A_{Det} - A_{Prod}$$

- A_{Det} + A_{Prod} are extracted from the control channel $B^{\pm} \to J/\psi K^{\pm}$
- A_{raw} extracted from a simultaneous fit of the B^{+} and B^{-} samples

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



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



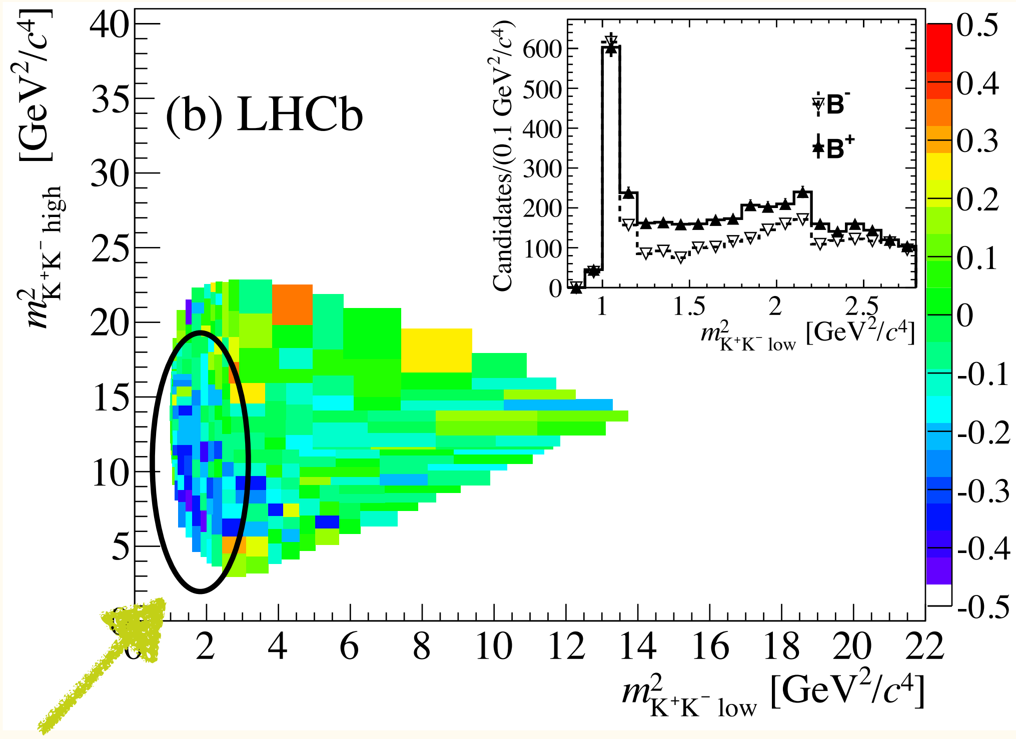
$$\mathcal{A}_{CP}(B^{\pm} \to K^{\pm}K^{+}K^{-}) = -0.043 \pm 0.009\,(stat) \pm 0.003\,(syst) \pm 0.007\,(J/\psi K^{\pm})$$

Evidence at 3.7 σ

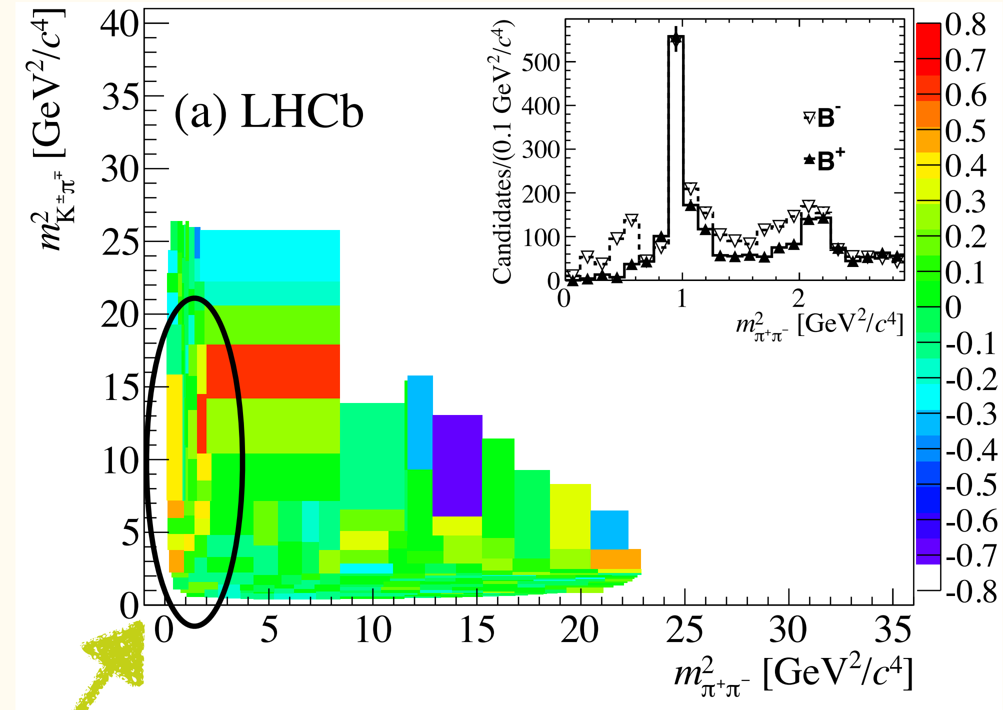
$$\mathcal{A}_{CP}(B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}) = 0.032 \pm 0.008\,(stat) \pm 0.004\,(syst) \pm 0.007\,(J/\psi K^{\pm})$$

2.8 σ

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



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

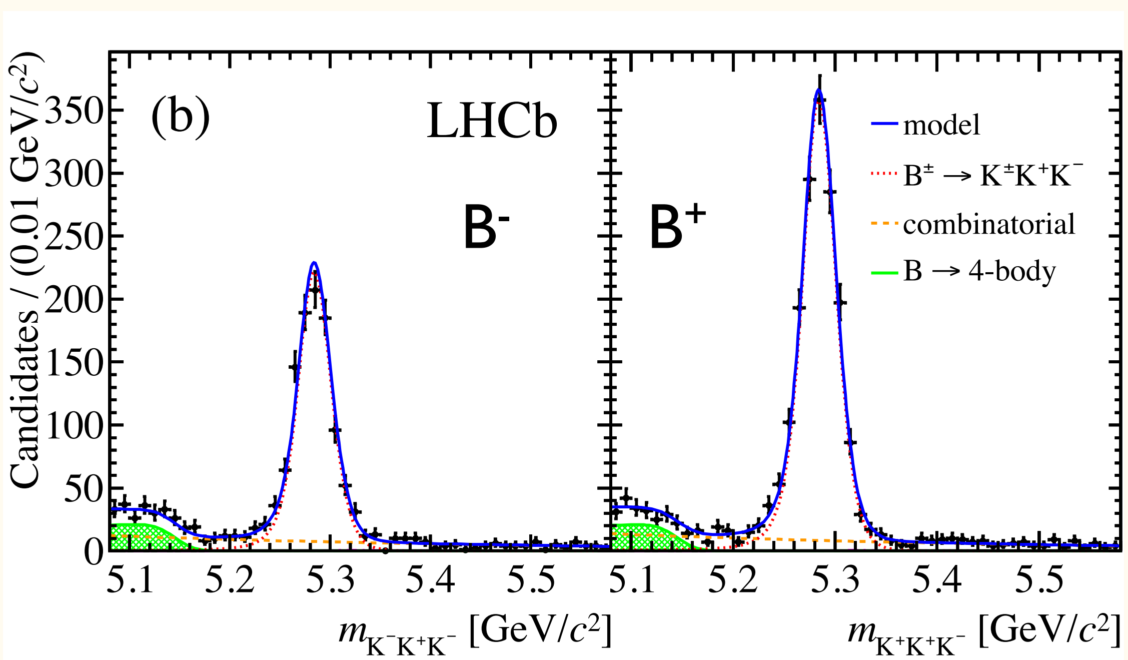


Local asymmetries observed at low $m^2_{\pi\pi}$ and m^2_{KK} with opposite sign.

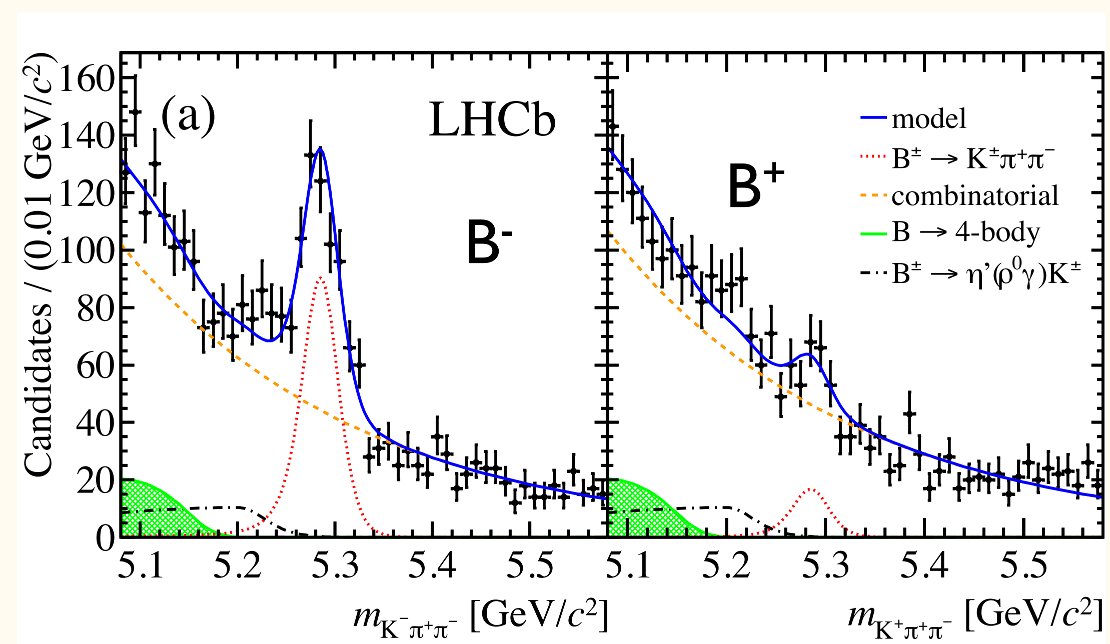
Not clear association with any resonance

PRL111,101801(2013)

$m^2_{K^+K^-high} < 15 GeV^2/c^4$ and $1.2 < m^2_{K^+K^-low} < 2.0 GeV^2/c^4$



$m^2_{K^{\pm}\pi^{\mp}} < 15 GeV^2/c^4$ and $0.08 < m^2_{\pi^+\pi^-} < 0.66\, GeV^2/c^4$



$\mathcal{A}^{reg}_{CP}(B^{\pm} \to K^{\pm}K^{+}K^{-}) = -0.226 \pm 0.020(stat) \pm 0.004(syst) \pm 0.007(J\psi K^{\pm})$

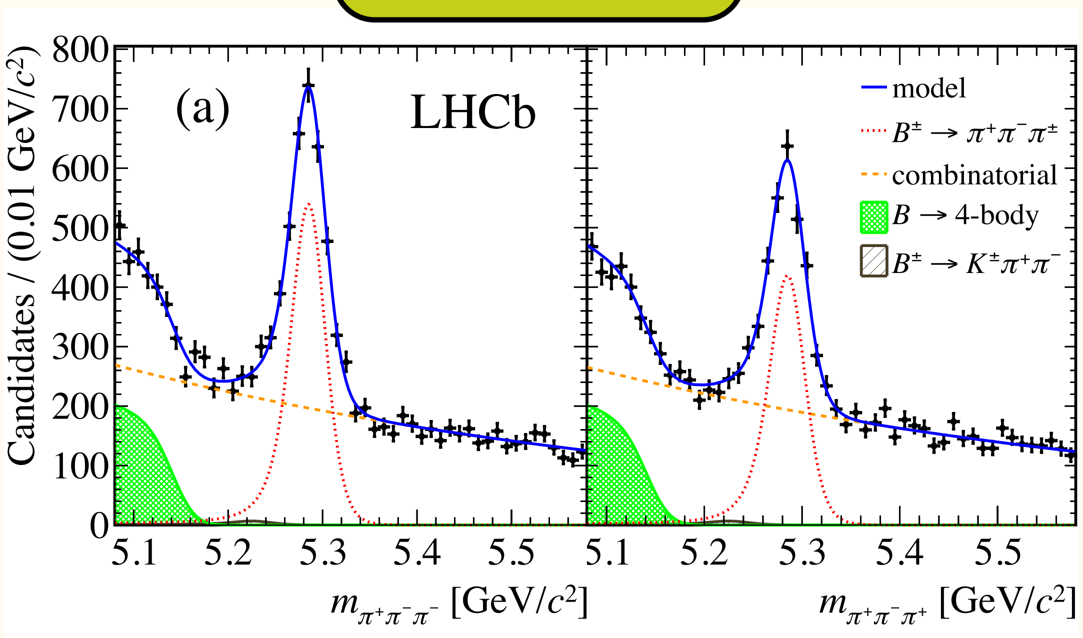
$\mathcal{A}^{reg}_{CP}(B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}) = 0.678 \pm 0.078(stat) \pm 0.032(syst) \pm 0.007(J/\psi K^{\pm})$

Similar analysis in B$^\pm \rightarrow \pi^\pm h^+h^-$:

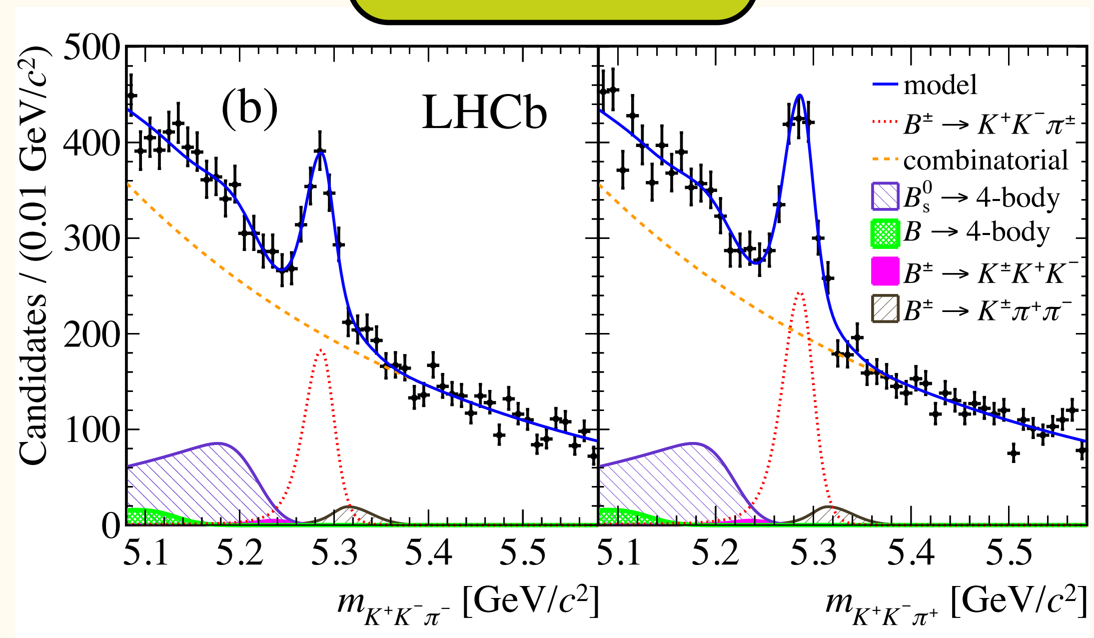
arXiv:1310.4740

Inclusive measurement:

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



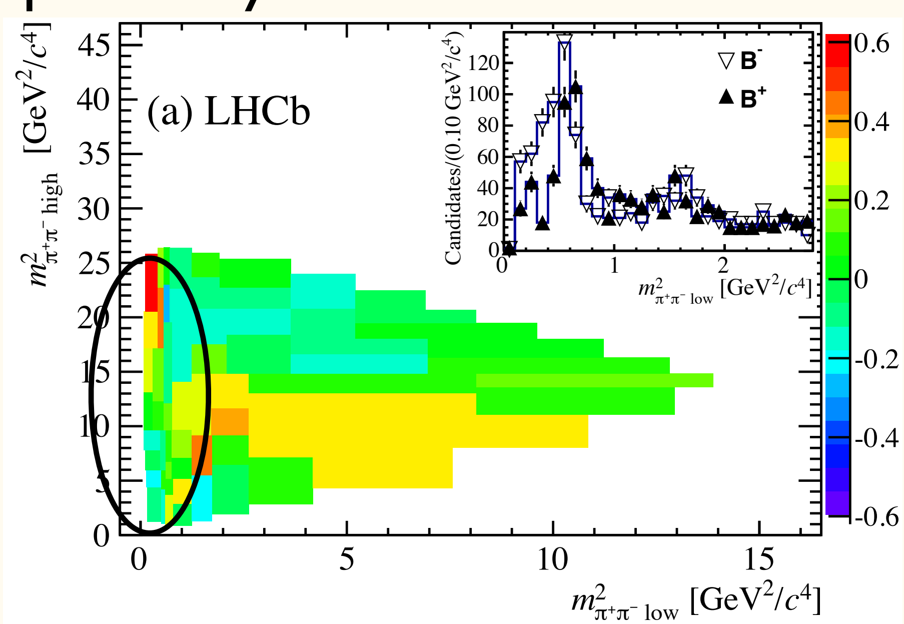
B$^\pm \rightarrow \pi^\pm$ K$^+$K$^-$

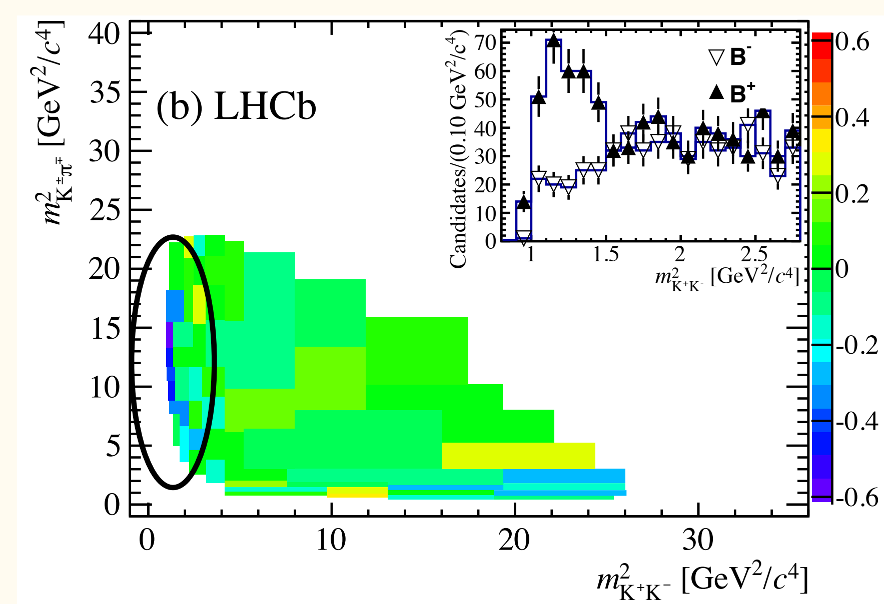


$\mathcal{A}_{CP}(B^\pm \to \pi^\pm\pi^+\pi^-) = 0.117 \pm 0.021(stat) \pm 0.009(syst) \pm 0.007(J/\psi K^\pm)$

$\mathcal{A}_{CP}(B^\pm \to \pi^\pm K^+K^-) = -0.141 \pm 0.040(stat) \pm 0.018(syst) \pm 0.007(J/\psi K^\pm)$

Dalitz plot analysis:





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

$m^2_{K^+K^-} < 1.5 GeV^2/c^4$

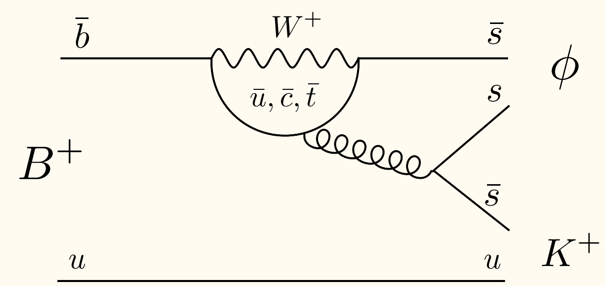
$\mathcal{A}^{reg}_{CP}(B^\pm \to \pi^\pm\pi^+\pi^-) = 0.584 \pm 0.082(stat) \pm 0.027(syst) \pm 0.007(J/\psi K^\pm)$

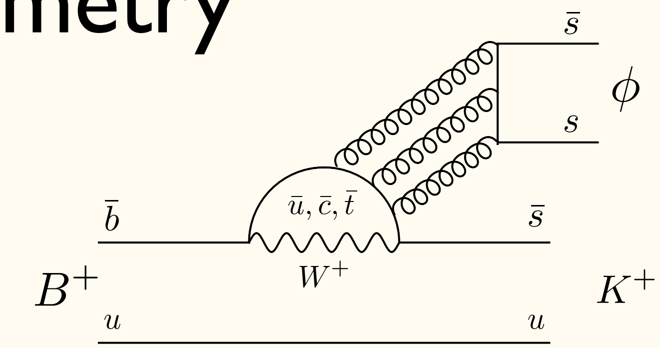
$\mathcal{A}^{reg}_{CP}(B^\pm \to \pi^\pm K^+K^-) = -0.648 \pm 0.070(stat) \pm 0.013(syst) \pm 0.007(J/\psi K^\pm)$

$$B^{\pm} \rightarrow \phi h^{\pm}$$

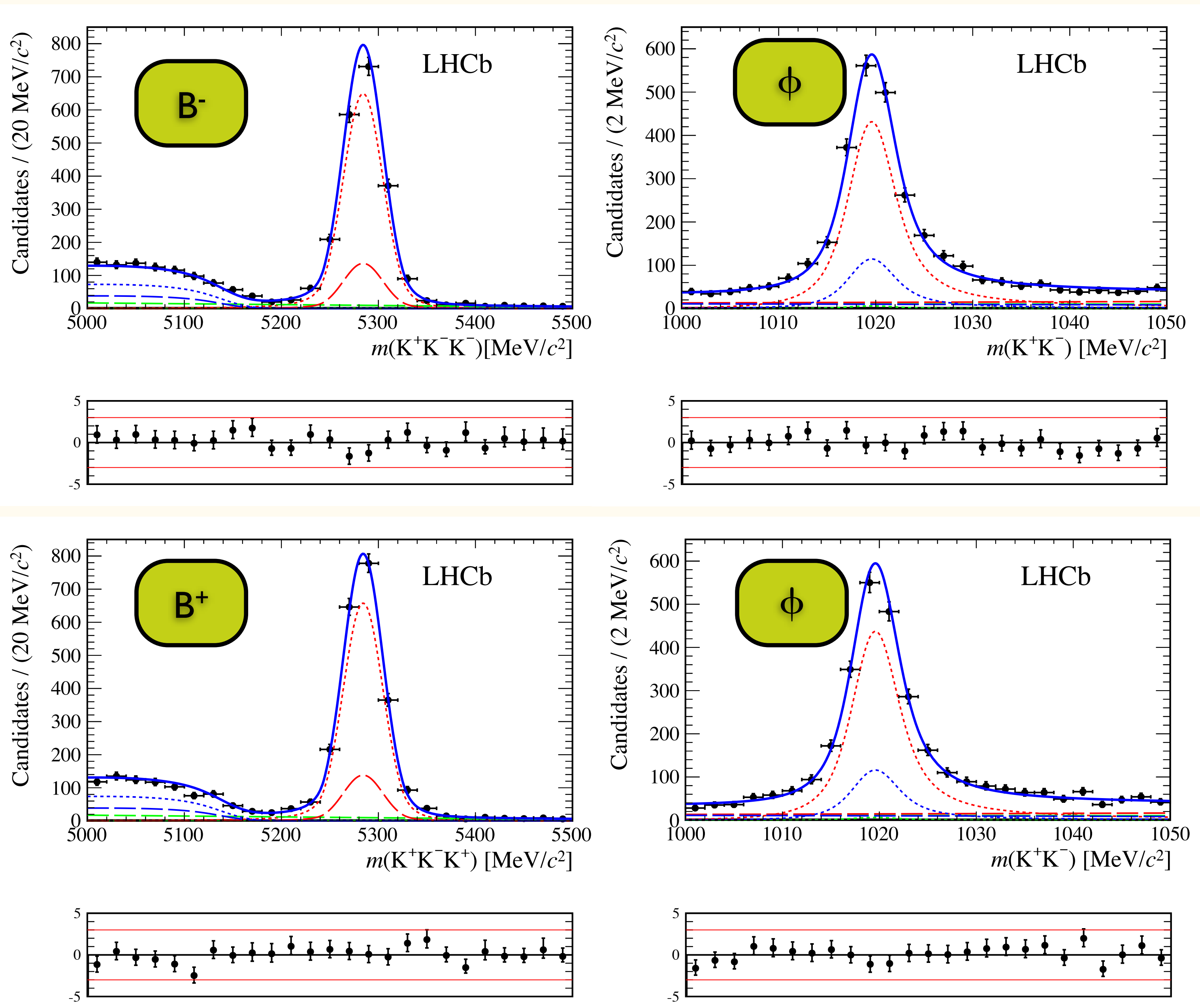
arXiv:1309.3742

Measurement of the $B^\pm \rightarrow \phi K^\pm$ CP asymmetry





- Objective: measurement of the direct CP violation
- Theoretical prediction from the SM : 1-2%
  (Phys. Rev. D74 (2006) 094020, Nucl. Phys. B675 (2003) 333)



arXiv:1309.3742

- $\mathcal{L}$ = 1.0 fb^{-1} at 7 TeV
- Two-dimensional fit of the B mass and ϕ mass spectra
- Simultaneous fit of the B^+ and B^- candidates
- Control channel $B^\pm \rightarrow J/\psi K^\pm$

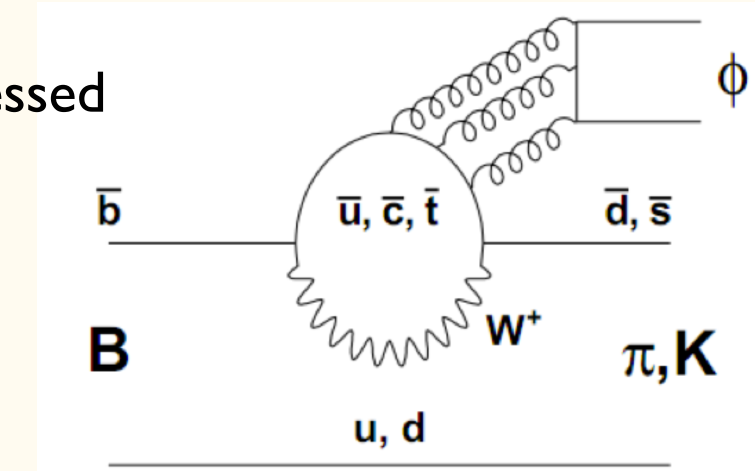
FIT COMPONENTS
Signal
non-resonant B -> KKK
partially reconstructed B -> ϕK*
partially reconstructed B -> KKK*
True ϕ Background
Combinatorial Background

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

Best measurement!

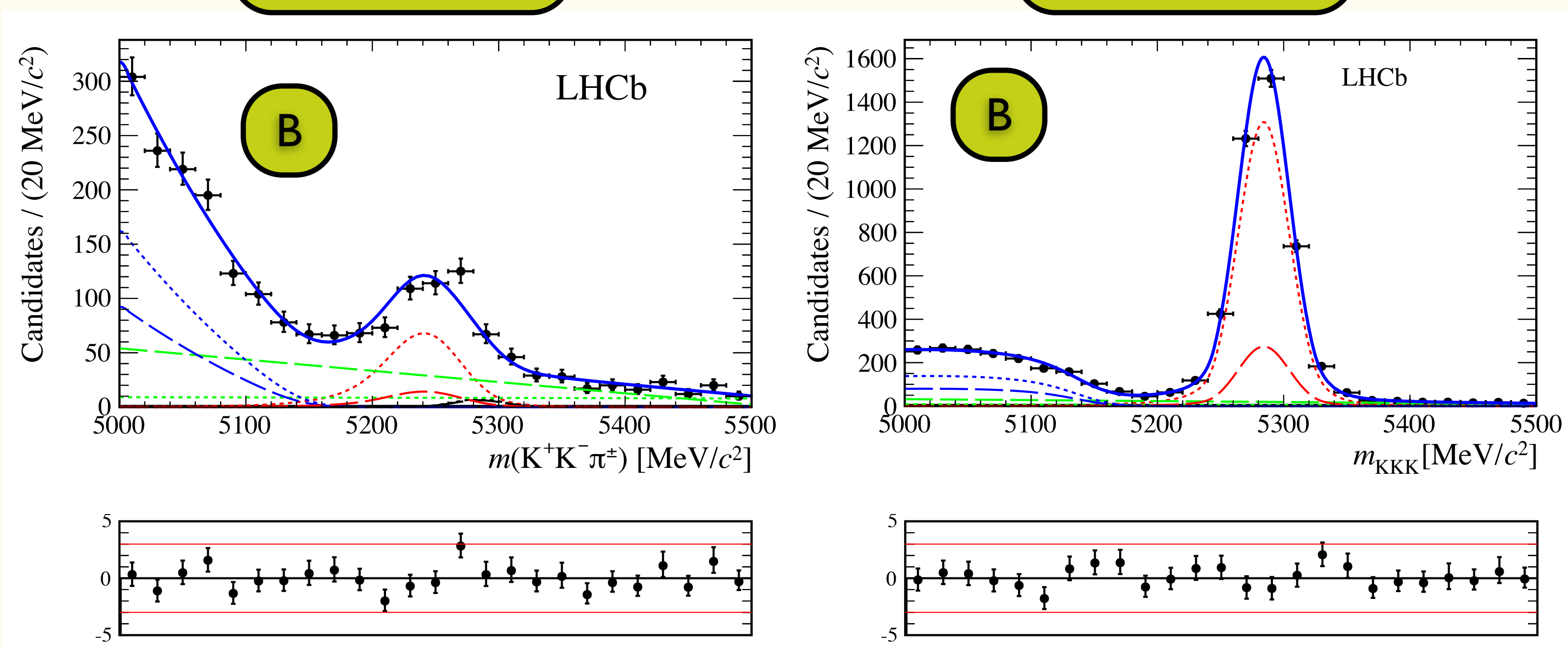
Measurement of the $B^\pm \to \phi\pi^\pm$ branching fraction

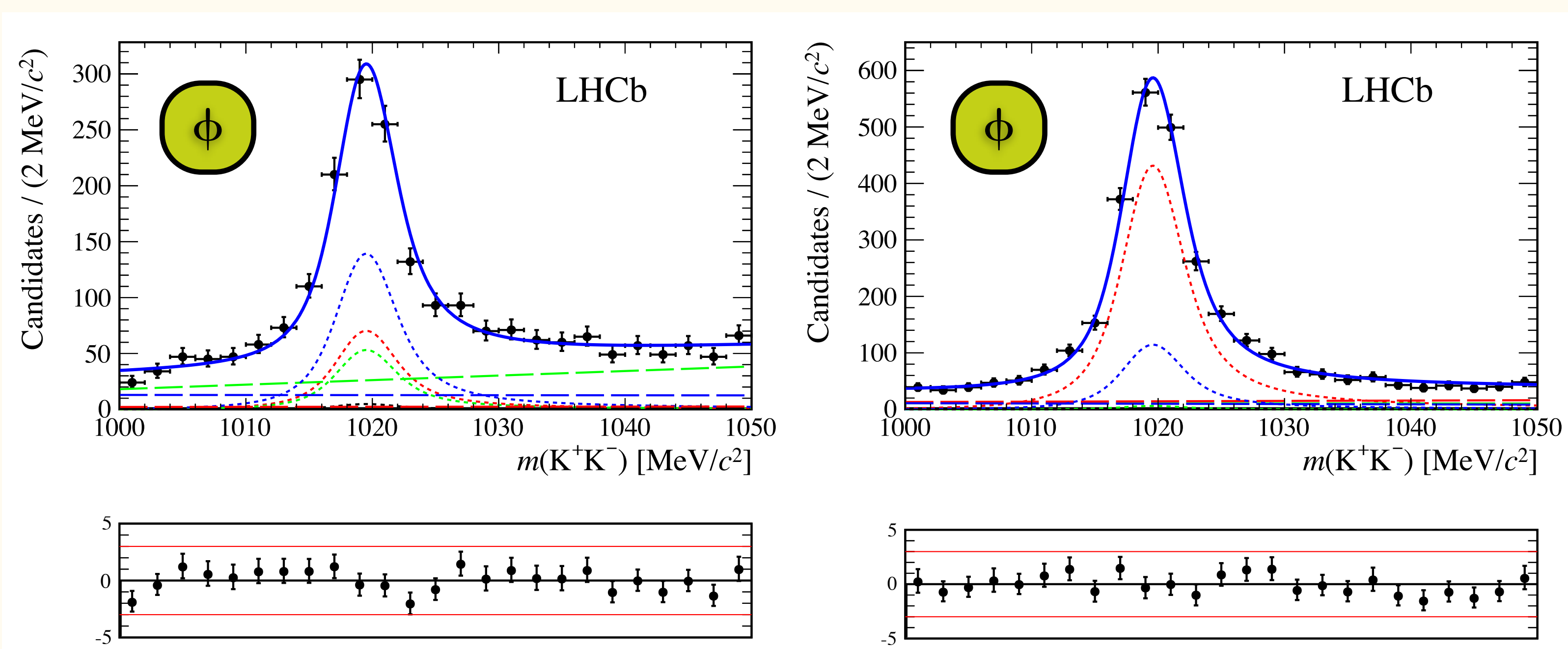
- Rare decay: dominated by $b \to d$ loop penguin transition and OZI suppressed
- SM prediction: 5×10^{-9} - 7×10^{-8} (arXiv:0804.1231v1, PRD 80(2009)014027)
- Useful to study the ω-ϕ mixing



$B^\pm \to \phi\pi^\pm$

$B^\pm \to \phi K^\pm$





- Two dimensional fit of the B mass an the ϕ mass
- Control channel $B^\pm \to \phi K^\pm$
- Simultaneous fit of $B^\pm \to \phi K^\pm$ and $B^\pm \to \phi\pi^\pm$
- $B^\pm \to \phi K^\pm$ sample used to improve sensitivity on $B^\pm \to \phi\pi^\pm$

$$N(\phi\pi^\pm) = 19 \pm 19$$ 1.0 σ

$$\mathcal{B}(B^\pm \to \phi\pi^\pm) < 1.5 \times 10^{-7} \text{ at } 90\% \text{ CL}$$

Best upper limit!

Previous upper limit: BR<2.4×10^{-7} at 90% CL
(BABAR, PRD 74 (2006) 011102)

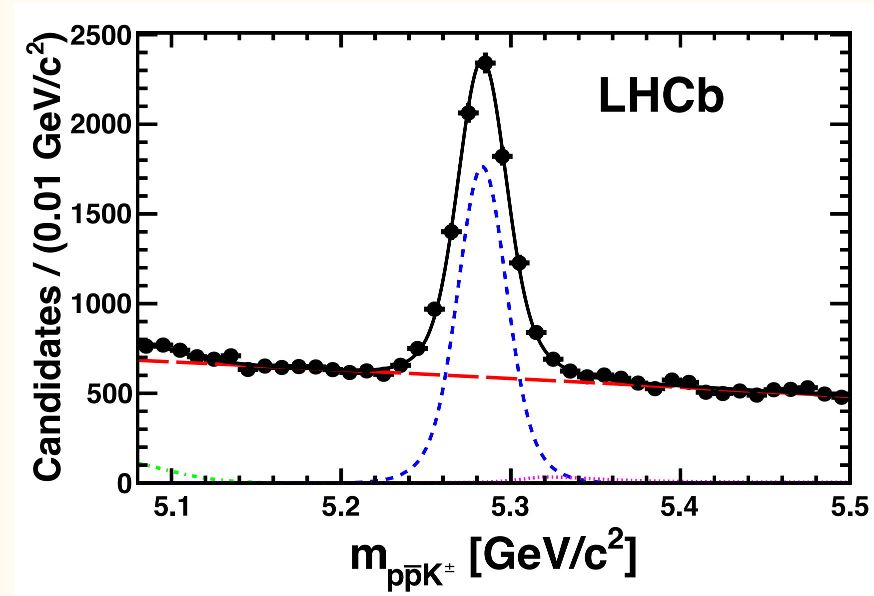
arXiv:1309.3742

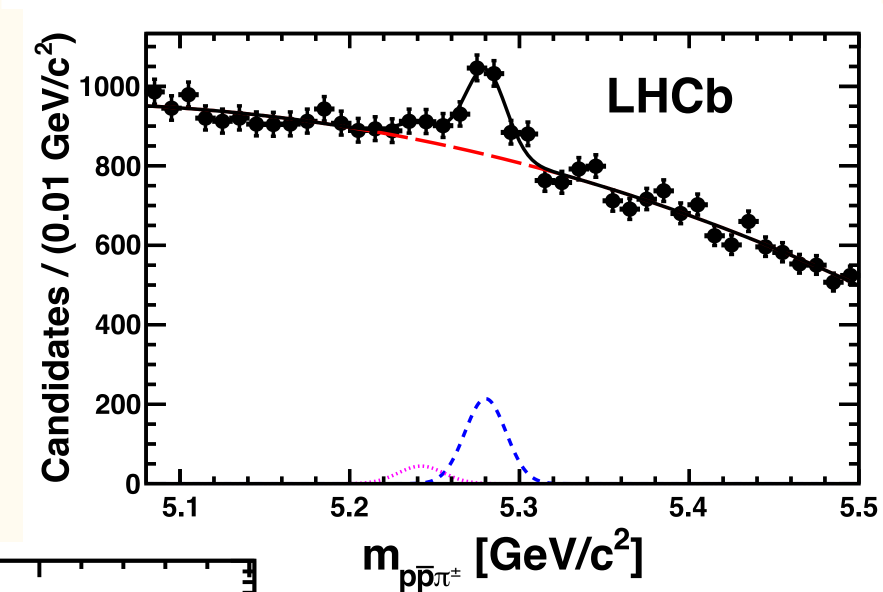
$B^{\pm} \rightarrow p\bar{p}h^{\pm}$

Phys. Rev. D88 052015 (2013)

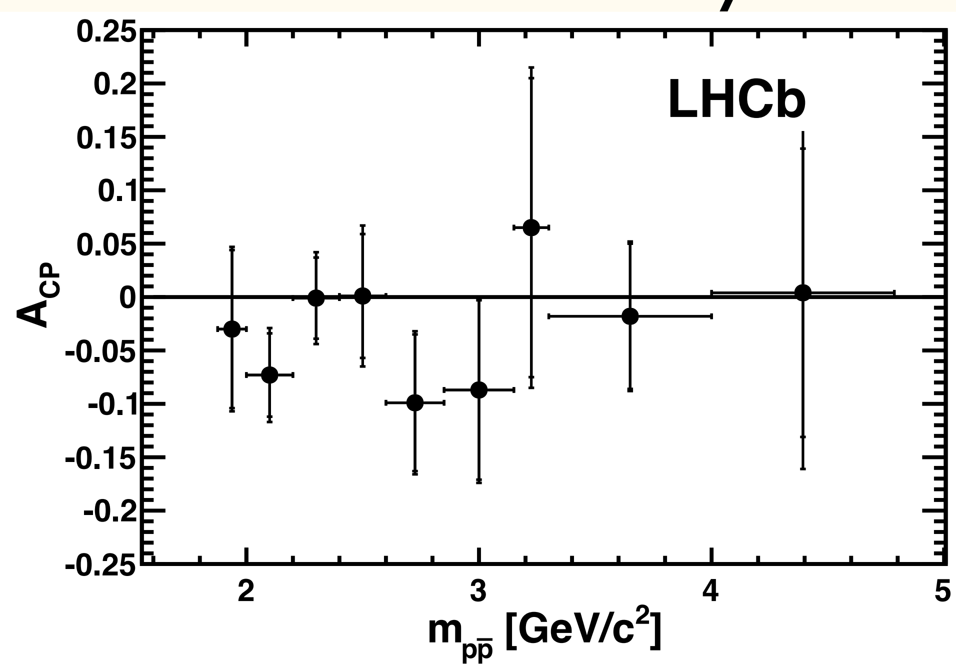
Phys. Rev. D88 052015 (2013)

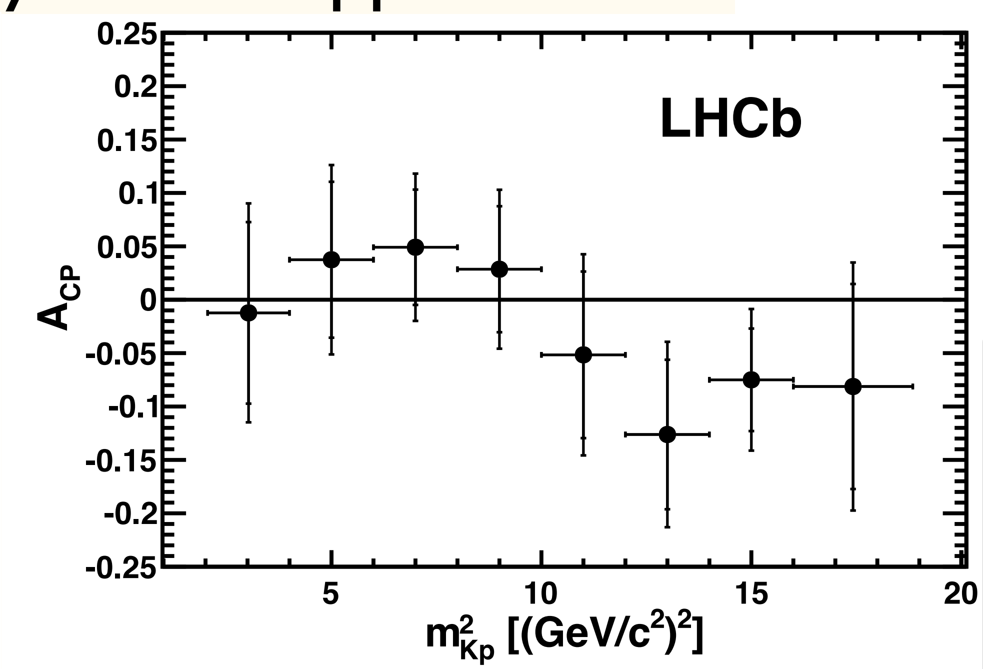
- CP analysis useful to clarify results of B → hhh analysis (same short distance dynamics)
- hh↔$p\bar{p}$ rescattering suppressed
- study of the $B^{\pm} \to p\bar{p}h^{\pm}$ dynamics and CP violation
- $\mathcal{L}$ = 1 fb^{-1} at 7 TeV
- N($p\bar{p}$K)= 7029 ± 139
- N($p\bar{p}\pi$)= 656 ± 70





CP asymmetry in $B^{\pm} \to p\bar{p}K^{\pm}$





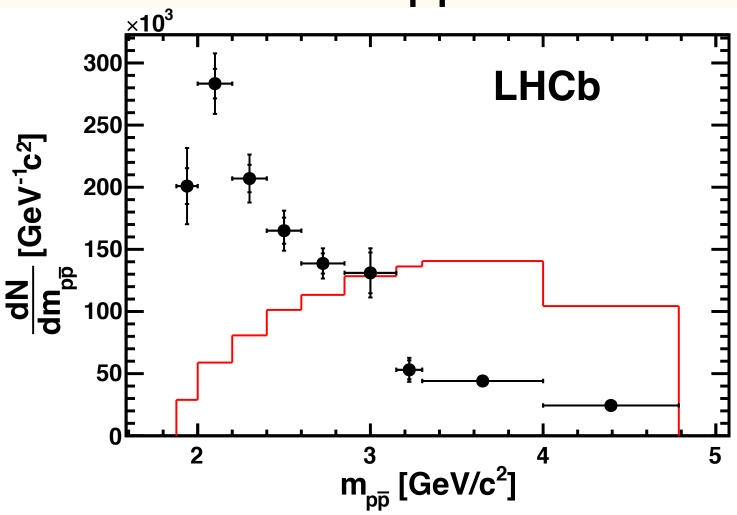
No significant asymmetry in any bin of the Dalitz plot

$$\mathcal{A}_{CP} = -0.022 \pm 0.031(stat) \pm 0.007(syst)$$

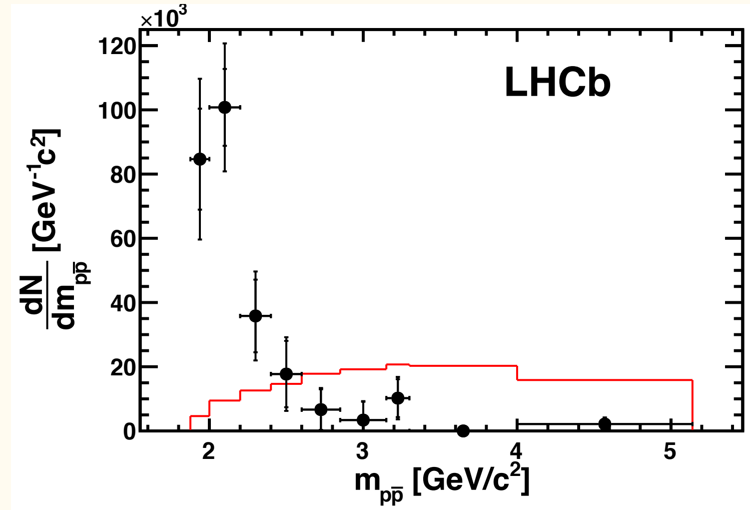
- $B^\pm \rightarrow p\bar{p}h^\pm$ dynamics...

Phys. Rev. D88 052015 (2013)

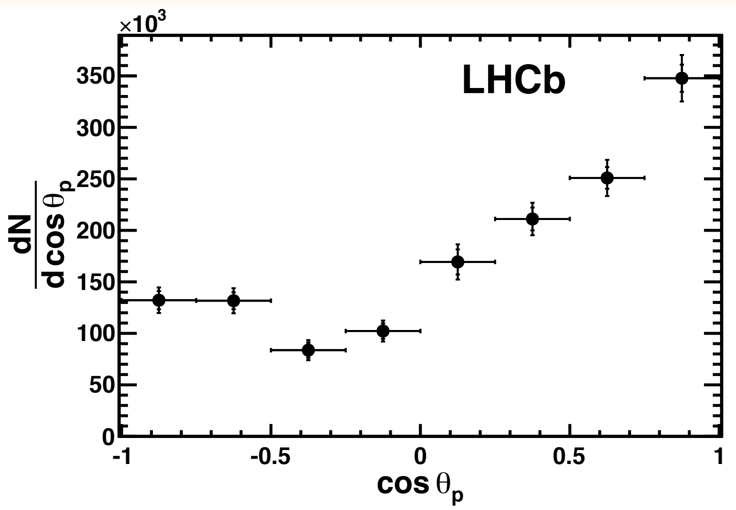
$B^\pm \rightarrow p\bar{p}K^\pm$

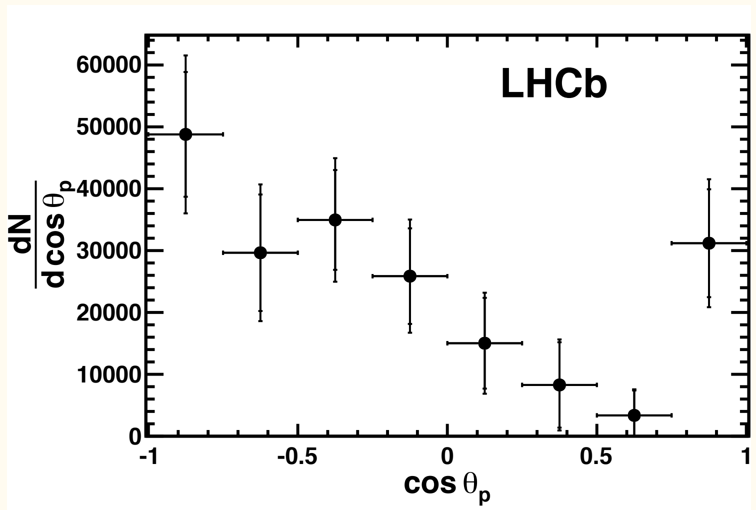


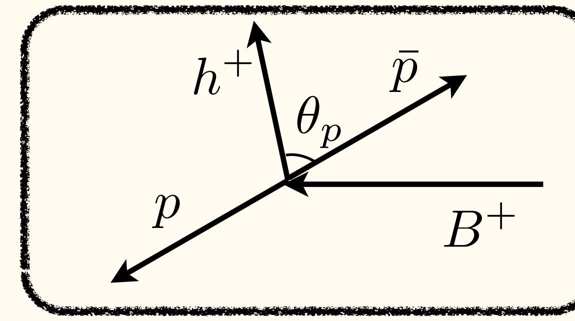
$B^\pm \rightarrow p\bar{p}\pi^\pm$



- differential yield as a function of the $p\bar{p}$ invariant mass compared with theoretical prediction (red)
- accumulation at low mass
  - due to $p\bar{p}$ rescattering

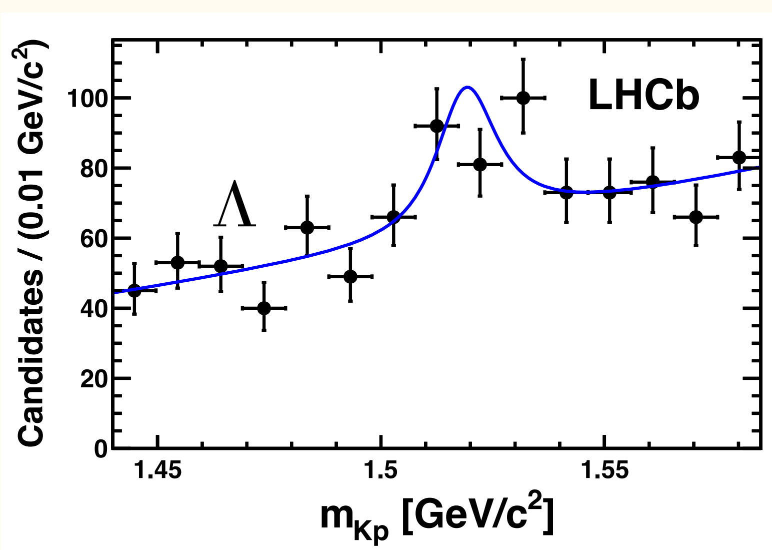


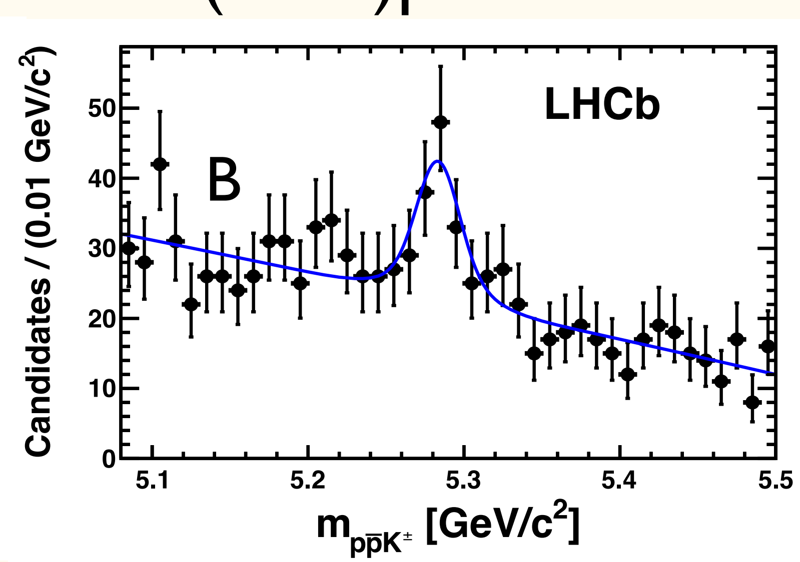




- differential yield as a function of the angle θ_p between the charged meson and the opposite-charge proton, in the $p\bar{p}$ rest frame
- expected behavior for $B^\pm \rightarrow p\bar{p}\pi^\pm$ but not for $B^\pm \rightarrow p\bar{p}K^\pm$

- First observation of $B^+ \rightarrow \bar{\Lambda}(1520)p$





control channel: $B^\pm \rightarrow J/\psi K^\pm$

First observation at 5.1 σ!

$$\mathcal{B}(B^+ \rightarrow \bar{\Lambda}p) = (3.9^{+1.9}_{-0.9}(stat) \pm 0.1(syst) \pm 0.3(J\psi K^\pm)) \times 10^{-7}$$

$B^0_{(s)} \rightarrow K_S h^+ h^-$

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- Objective : measurement of branching fraction
- First step towards a full amplitude analysis and extraction of γ.
- Control channel: $B^0 \rightarrow K^0 \pi^+\pi^-$
- $\mathcal{L}$ = 1 fb^{-1}

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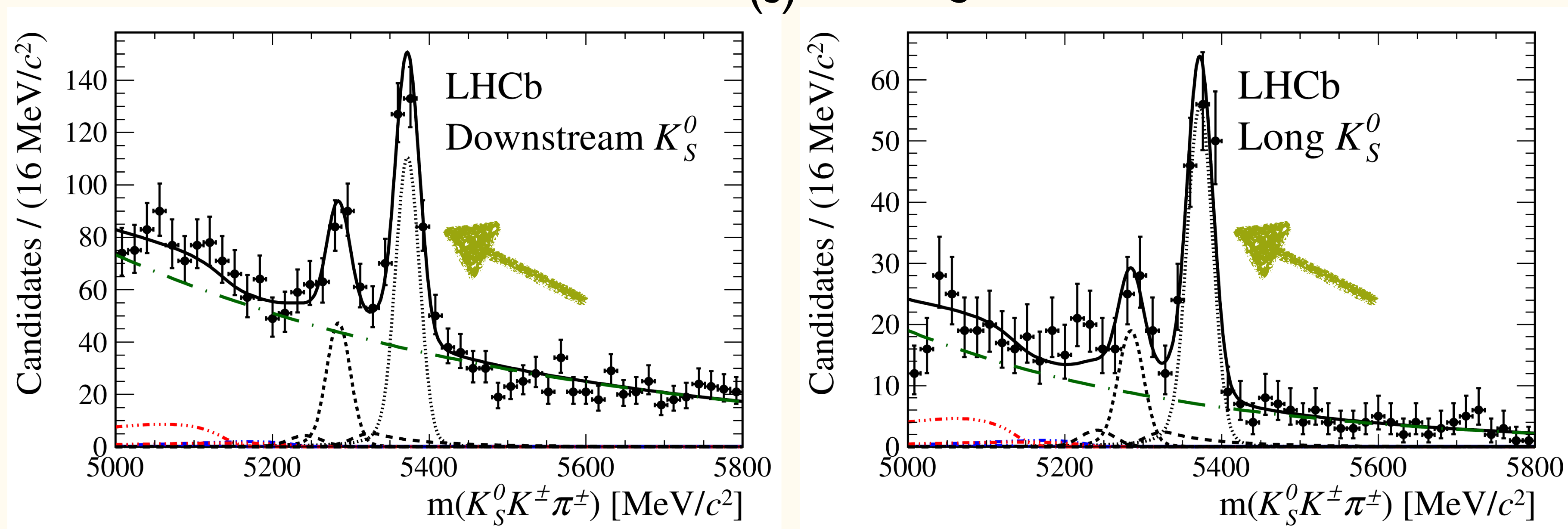
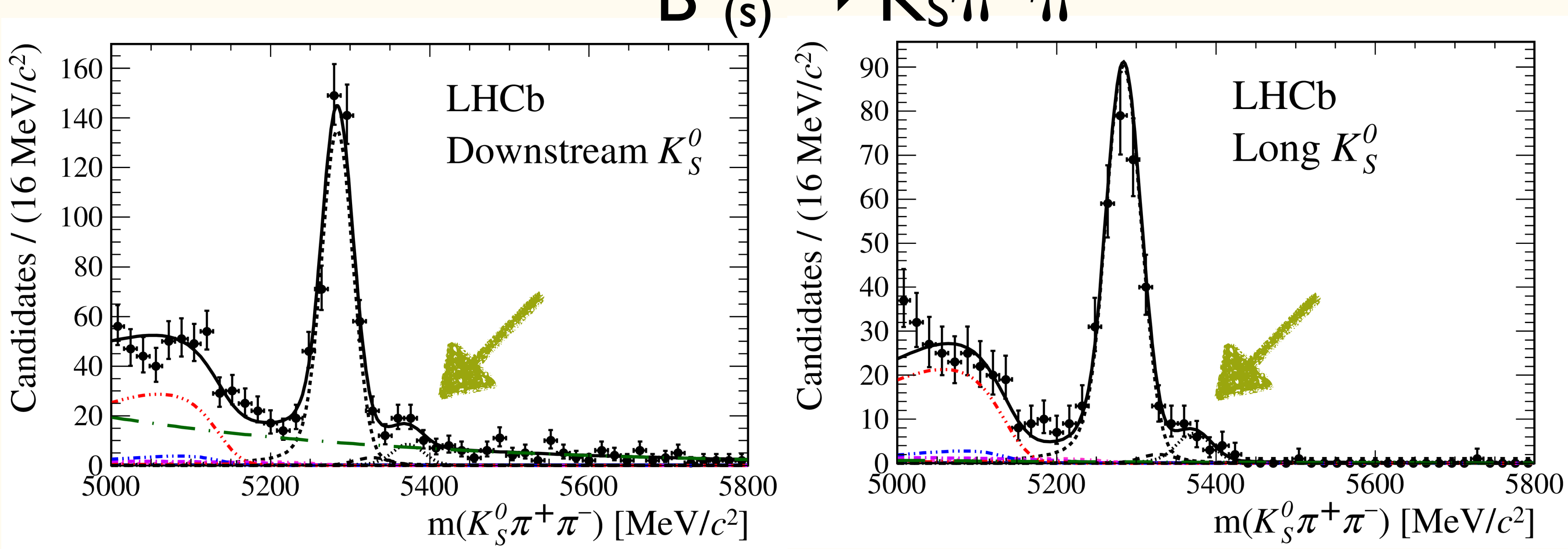
First observation!

$B^0_{(s)} \rightarrow K_S K^+\pi^-$



$$\mathcal{B}(B_s^0 \to K_S K^\pm \pi^\mp) = (73.6 \pm 5.7(stat) \pm 6.9(syst) \pm 3.0\,(B^0 \to K^0\pi^+\pi^-)) \times 10^{-6}$$

$B^0_{(s)} \rightarrow K_S \pi^+\pi^-$



First observation!

5.9 σ

$$\mathcal{B}(B_s^0 \to K_S \pi^\pm \pi^\mp) = (14.3 \pm 2.8(stat) \pm 1.8(syst) \pm 0.6(B^0 \to K^0\pi^+\pi^-)) \times 10^{-6}$$

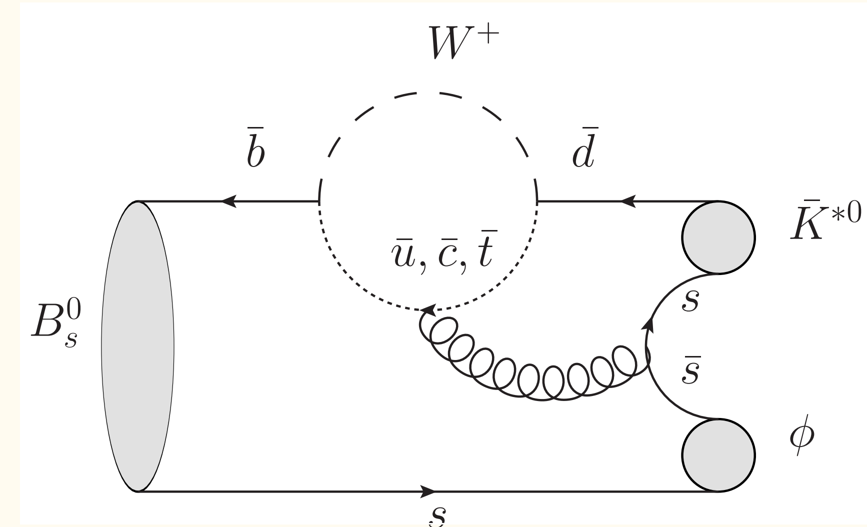
$B^0_s \rightarrow \phi \bar{K}^{*0}$

arXiv:1306.2239

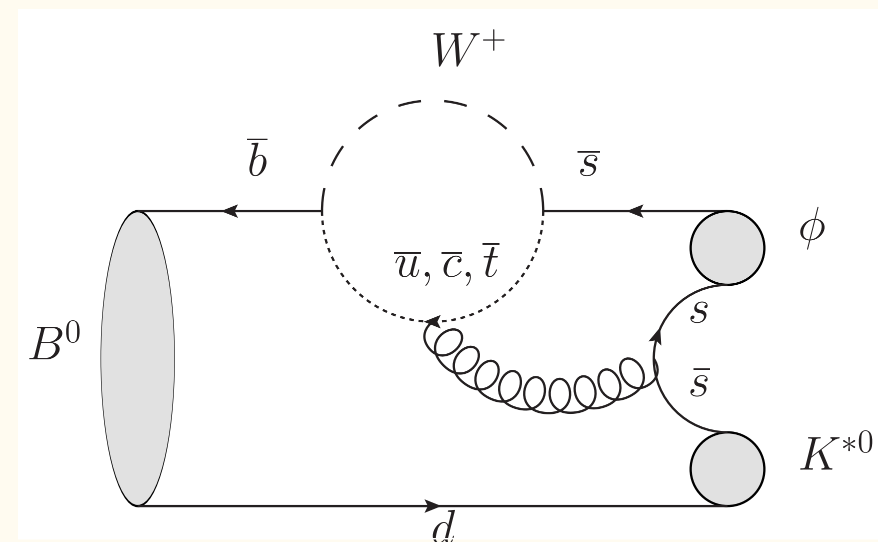
- Objective: observation of the $B^0_s \to \phi \bar{K}^{*0}$ decay

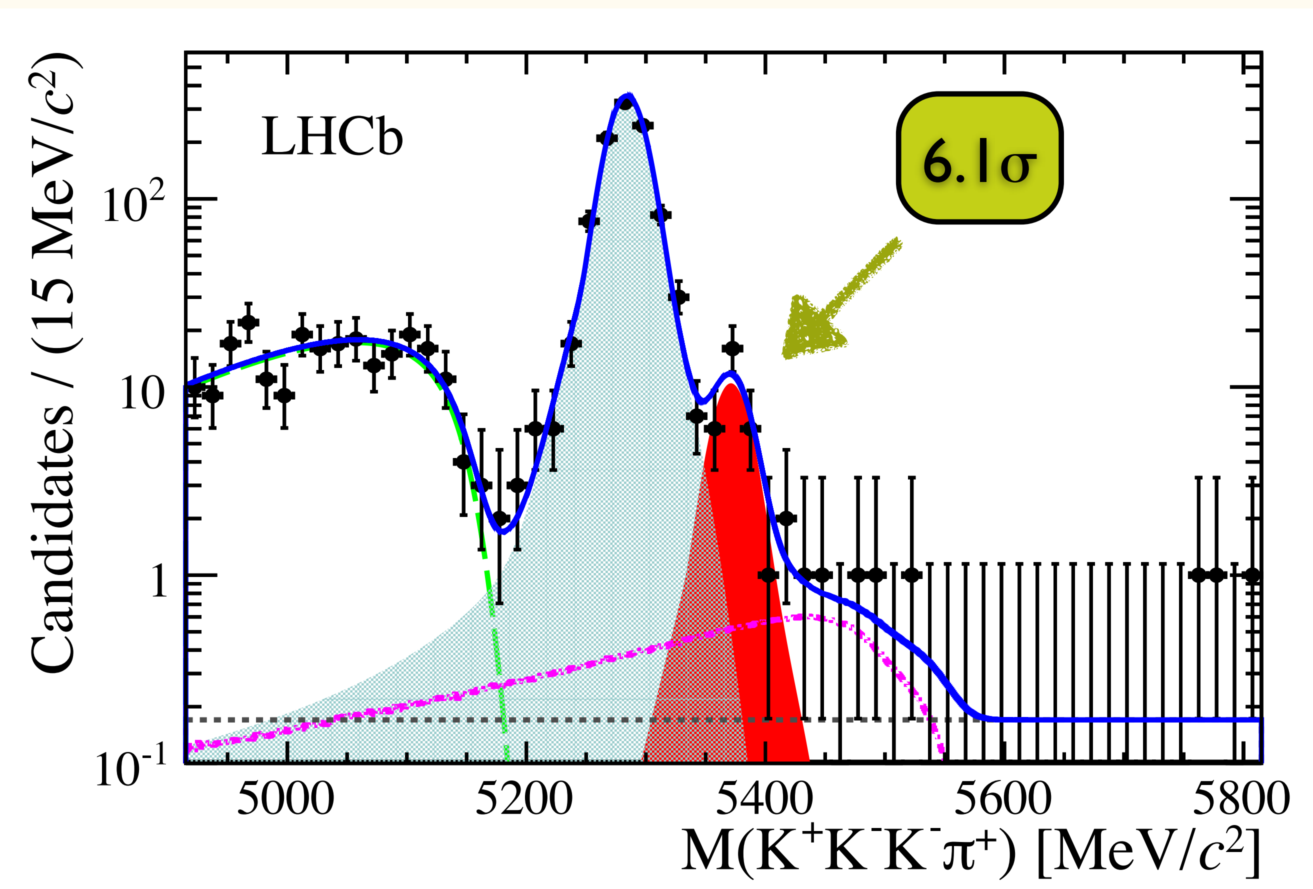
arXiv:1306.2239

- Theoretical prediction:
  - QCD factorization: $(0.4^{+0.5}_{-0.3}) \times 10^{-6}$ (Nucl.Phys.B774(2007)64)
  - perturbative QCD: $(0.65^{+0.33}_{-0.23}) \times 10^{-6}$ (Phys.Rev.D76(2007)074018)
- Essential to understand QCD effects in channels related by d ↔ s exchange symmetry



- Control channel $B^0 \to \phi K^{*0}$



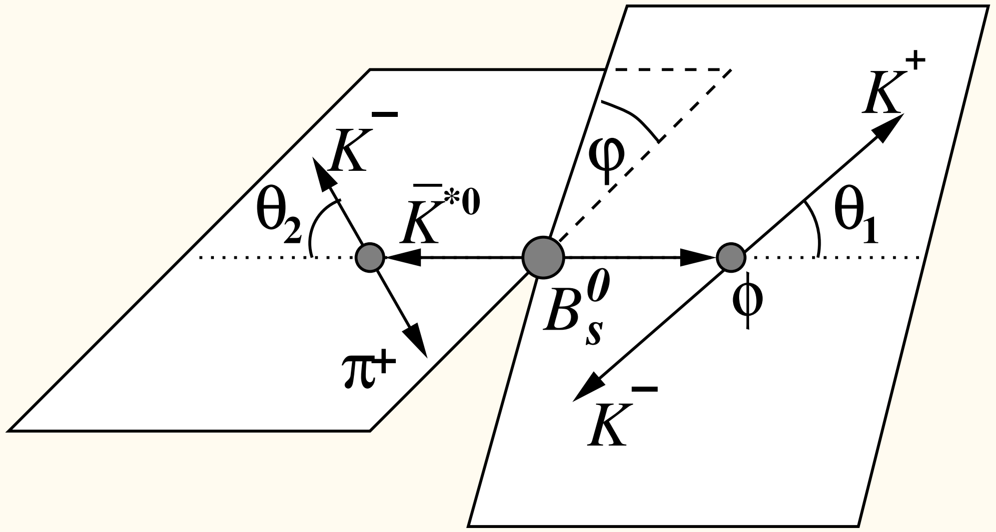


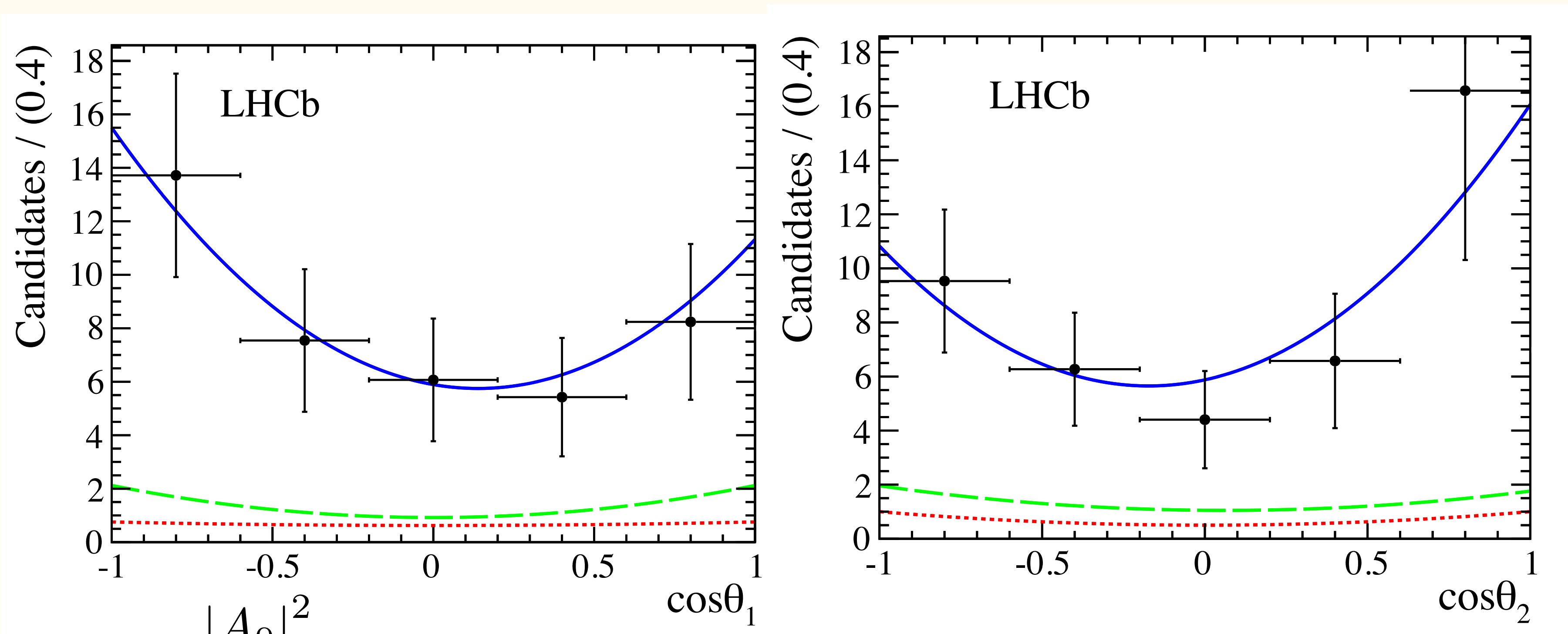
First observation!

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

On the large side of the theoretically expected range

- Objective: Longitudinal polarization in $B^0_s \to \phi \overline{K}^{*0}$ decays
- Theoretical prediction: $f_0 = 0.712^{+0.042}_{-0.048}$ (Phys.Rev.D76(2007)074018)
- $B \to VV$ decays: 3 amplitudes ($A_0, A_\parallel, A_\perp$) that can be extracted from the angular distribution
- Time-integrated polarization analysis performed, assuming no CP violation





$$f_0 = \frac{|A_0|^2}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2} = 0.51 \pm 0.15(stat) \pm 0.07(syst)$$

$$f_\parallel = \frac{|A_\parallel|^2}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2} = 0.21 \pm 0.11(stat) \pm 0.02(syst)$$

$$cos\delta_\parallel = -0.18 \pm 0.52(stat) \pm 0.29(syst)$$ with $\delta_\parallel$ phase difference between A_0, and $A_\parallel$

arXiv:1306.2239

Conclusions

- Charmless B decay: good probe to search for new physics
- Several new results from LHCb in the charmless sector
  - new observations and improvements on branching fraction ($B^+ \to \overline{\Lambda}p$, $B^\pm \to \phi\pi^\pm$, $B^0_{(s)} \to K_s h^+ h^-$, $B^0_s \to \phi K^{*0}$)
  - measurements and improvements of global and local asymmetries ($B^\pm \to \phi K^\pm$, $B^\pm \to h^+ h^- h^\pm$, $B^\pm \to p\overline{p}h^\pm$)

A lot of work still to do...

- Combined amplitude analysis to extract the CKM angles
- Introduction of new techniques to take in account the rescattering
- Larger data samples
- Plenty of charmless channels still to explore