Studies of charmless B decays at LHCb

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on behalf of the LHCb collaboration

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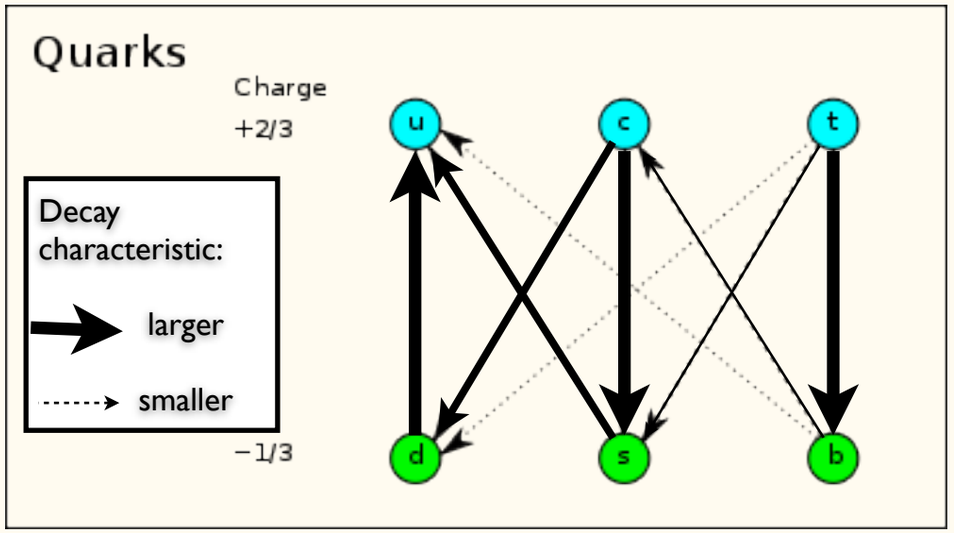
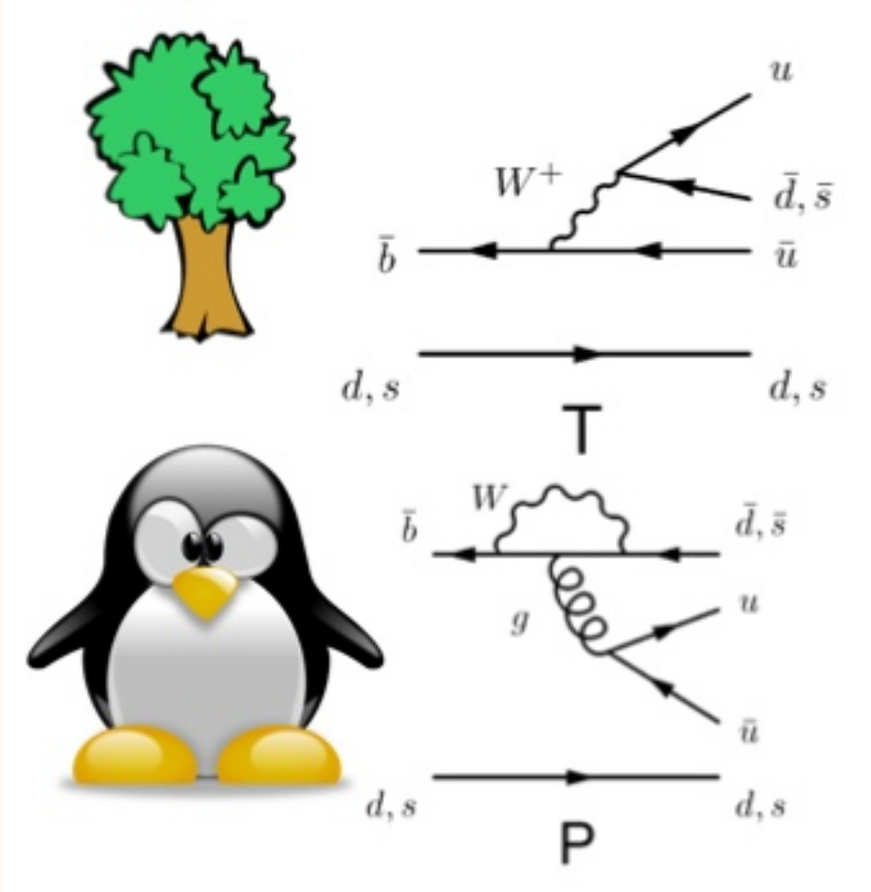
Why charmless B decays?

- Sensitive to suppressed CKM matrix elements and their phases

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

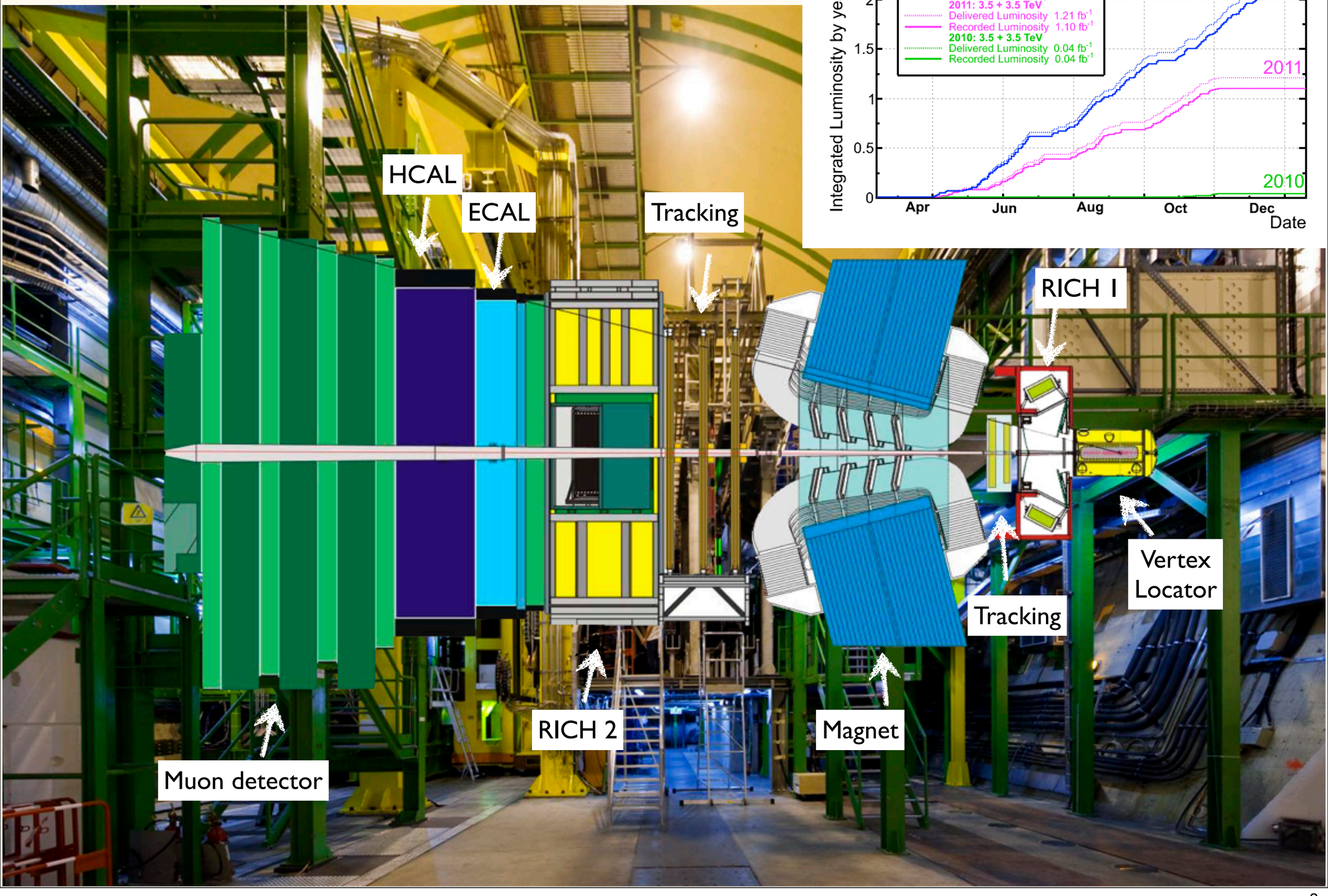


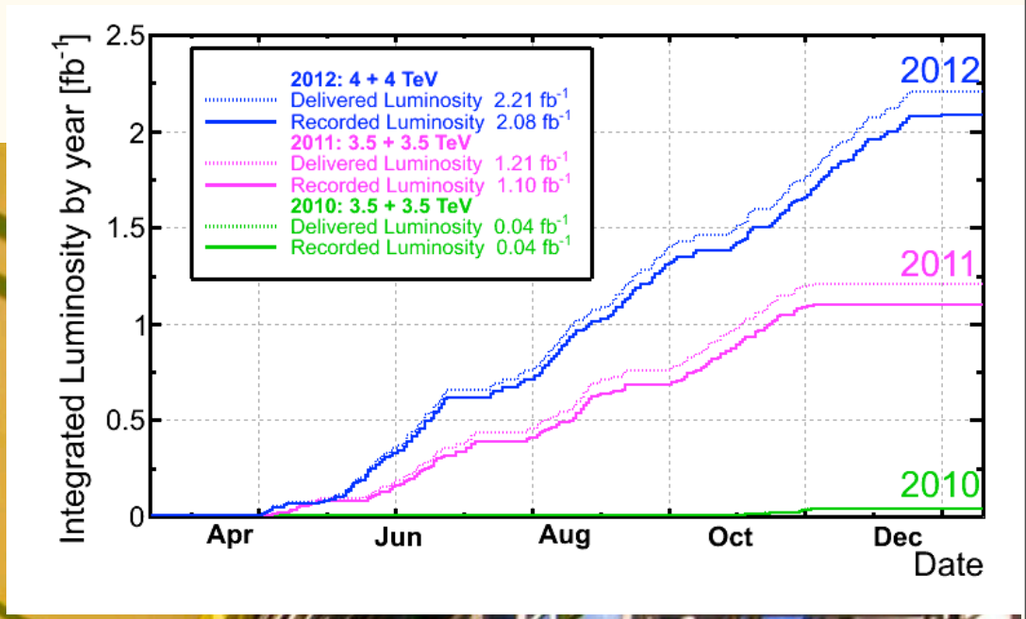


- Direct CP violation in time-integrated measurements: arises from the interference between contributing amplitudes

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

The LHCb detector





$$\Lambda^0_b, \Xi^0_b \rightarrow \bar{K}^0_s p h^-$$

$$(h = K, \pi)$$

JHEP04(2014)087

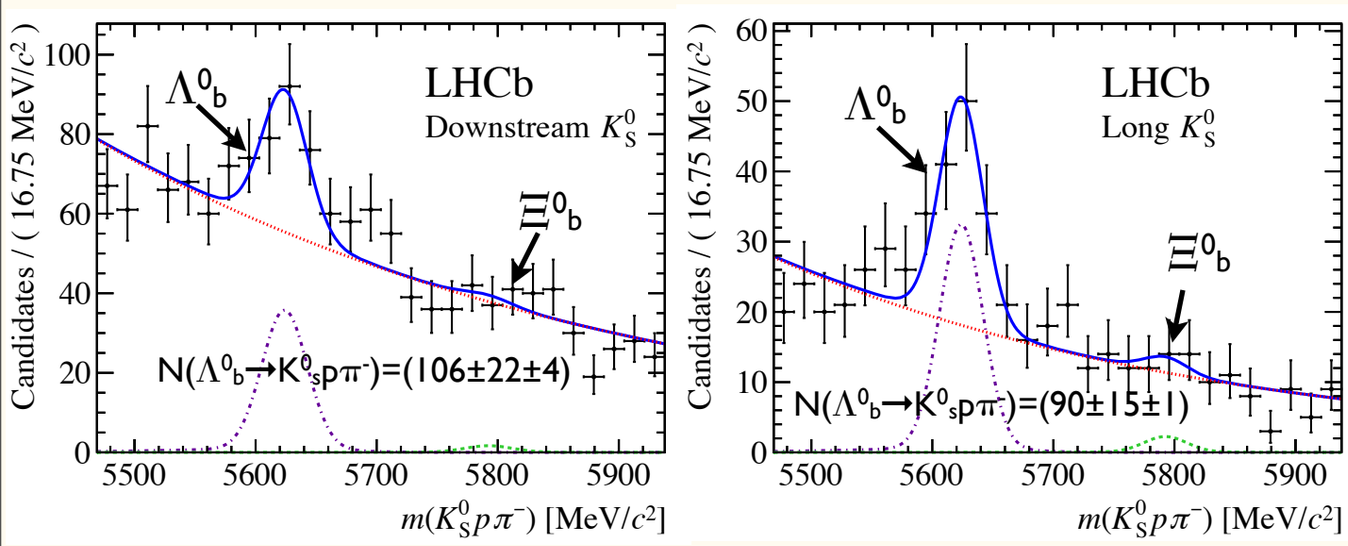
Motivation

- no b-baryon charmless three-body decays had yet been observed
- possibility of direct CP violation searches (no mixing)

Objectives

- search for $\Lambda^0_b, \Xi^0_b \to K^0_s p h^-$ decays
- measurement of branching fractions (or set upper limits)
- normalization channel $B^0 \to K^0_s \pi^+ \pi^-$
- CP violation measurement for the observed $\Lambda^0_b \to K^0_s p \pi^-$ decay

$\Lambda^0_b, \Xi^0_b \to K^0_s p\pi^-$



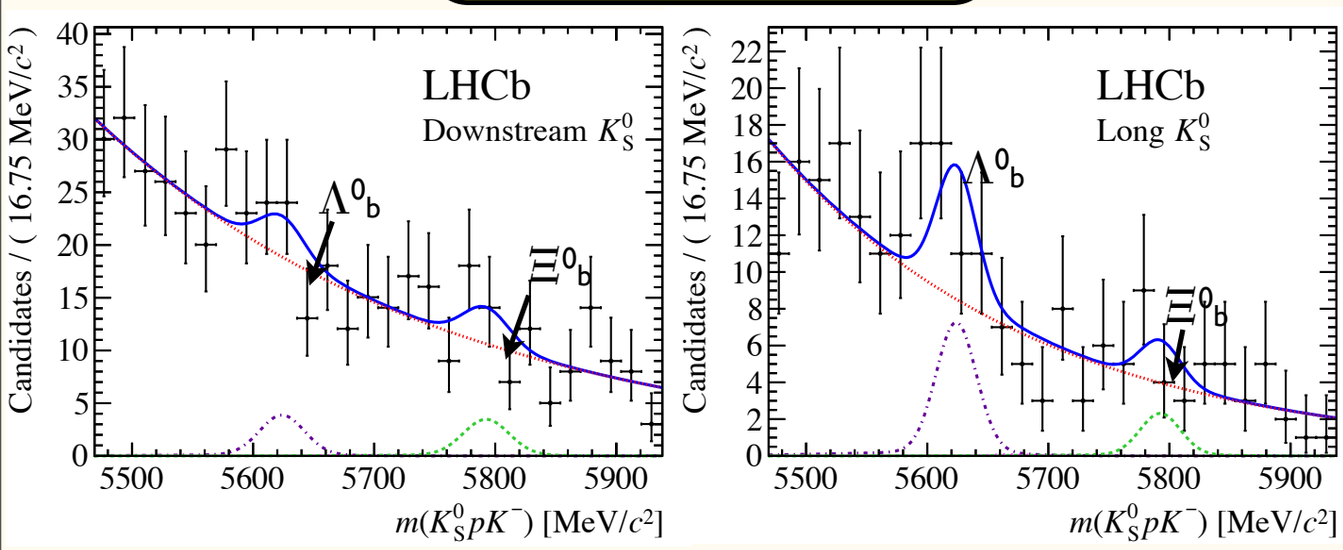
$\Lambda^0_b, \Xi^0_b \to K^0_s p h^-$

$$\mathcal{B}(\Lambda^0_b \to \overline{K}^0 p\pi^-) =$$
$$= (1.26 \pm 0.19 \pm 0.09 \pm 0.34 \pm 0.05) \times 10^{-5}$$

First observation (8.6 σ)!

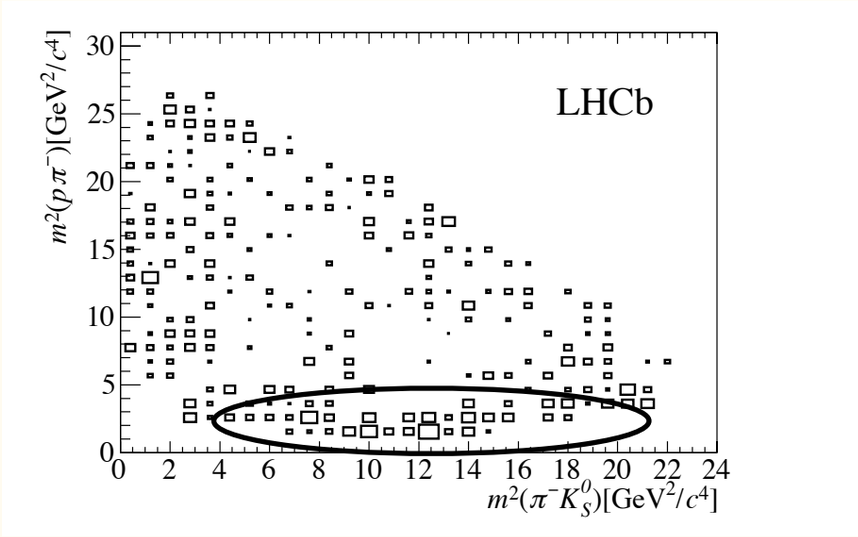
$$f_{\Xi^0_b}/f_d \times \mathcal{B}(\Xi^0_b \to \overline{K}^0 p\pi^-) < 1.6(1.8) \times 10^{-6}$$
at 90% (95%) CL

$\Lambda^0_b, \Xi^0_b \to K^0_s p K^-$



$$\mathcal{B}(\Lambda^0_b \to K^0 pK^-) < 3.5(4.0) \times 10^{-6}$$
$$f_{\Xi^0_b}/f_d \times \mathcal{B}(\Xi^0_b \to \overline{K}^0 pK^-) < 1.1(1.2) \times 10^{-6}$$
at 90% (95%) CL

Dalitz plot $\Lambda^0_b \to K^0_s p\pi^-$



structure at low $p\pi^-$ invariant mass

CP Asymmetry

$$\mathcal{A}_{CP}(\Lambda^0_b \to K^0 p\pi^-) = 0.22 \pm 0.13(stat) \pm 0.04(syst)$$

- phase space integrated measurement

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

$(h = K, \pi)$

LHCb-PAPER-2014-011

Objectives

- $B^0_s \rightarrow K^+K^-$ decay: CP even final state (decay consists almost entirely of the light mass eigenstate).
- Small CP violation predicted in SM

$$A_{\Delta\Gamma}(B_s^0 \rightarrow K^+K^-) = \frac{-2Re(\lambda)}{(1+|\lambda|^2)} = -0.97^{+0.014}_{-0.009}$$

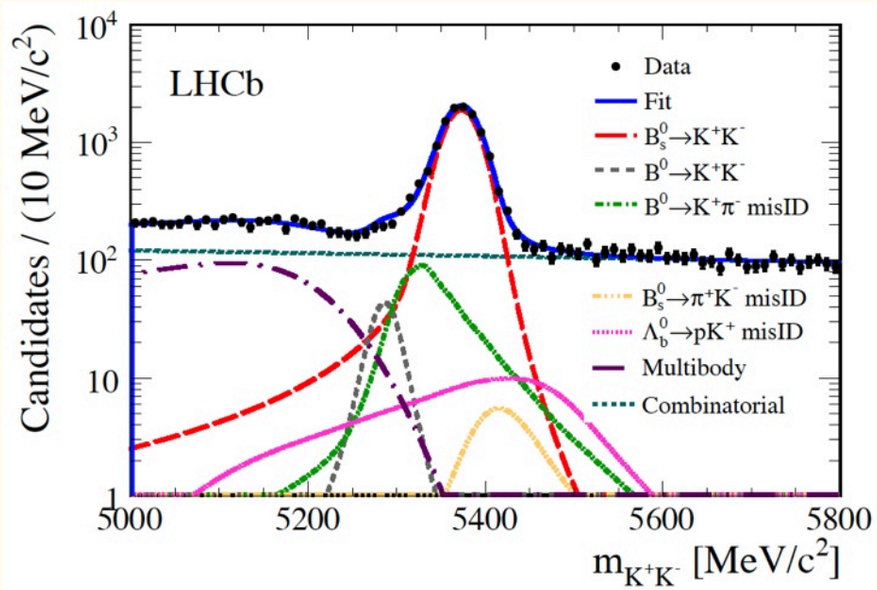
- Measure the $B^0_s \rightarrow K^+K^-$ effective lifetime: useful to constrain the B_s mixing phase and the CP violation parameter $A_{\Delta\Gamma s}$

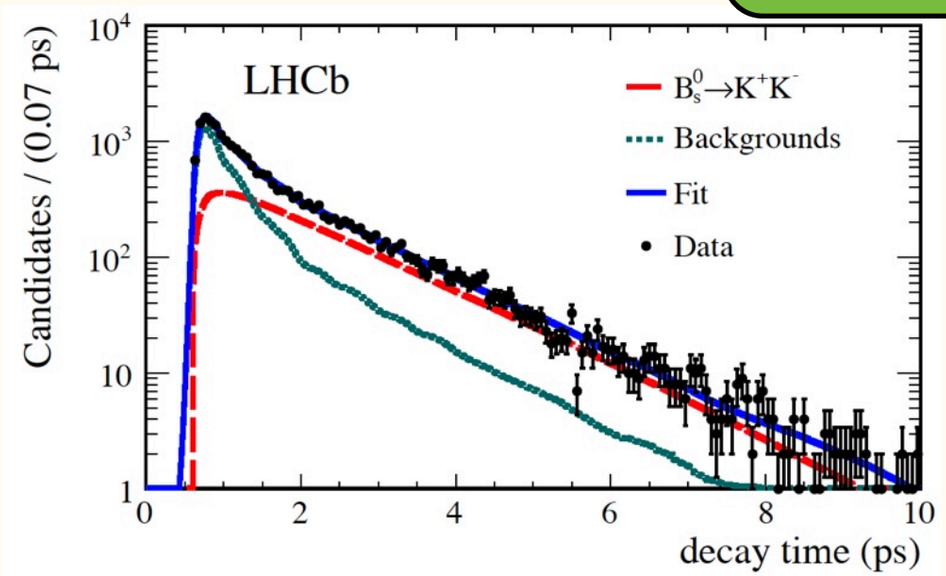
$$\tau_{K^+K^-} \approx \Gamma_s^{-1}(1 + \frac{A_{\Delta\Gamma_s}\Delta\Gamma_s}{2\Gamma_s})$$

where $\Gamma_s = \frac{\Gamma_H + \Gamma_L}{2}$ and $\Delta\Gamma_s = 2\,|\Gamma_{12}|\,cos\Phi_{M/\Gamma}$

- Measure the $B^0 \rightarrow K^+\pi^-$ and $B^0_s \rightarrow K^-\pi^+$ lifetimes: contribute to the world average of $\tau(B^0)$ and $\tau(B^0_s)$.
- Analysis performed with 1 fb^{-1}

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





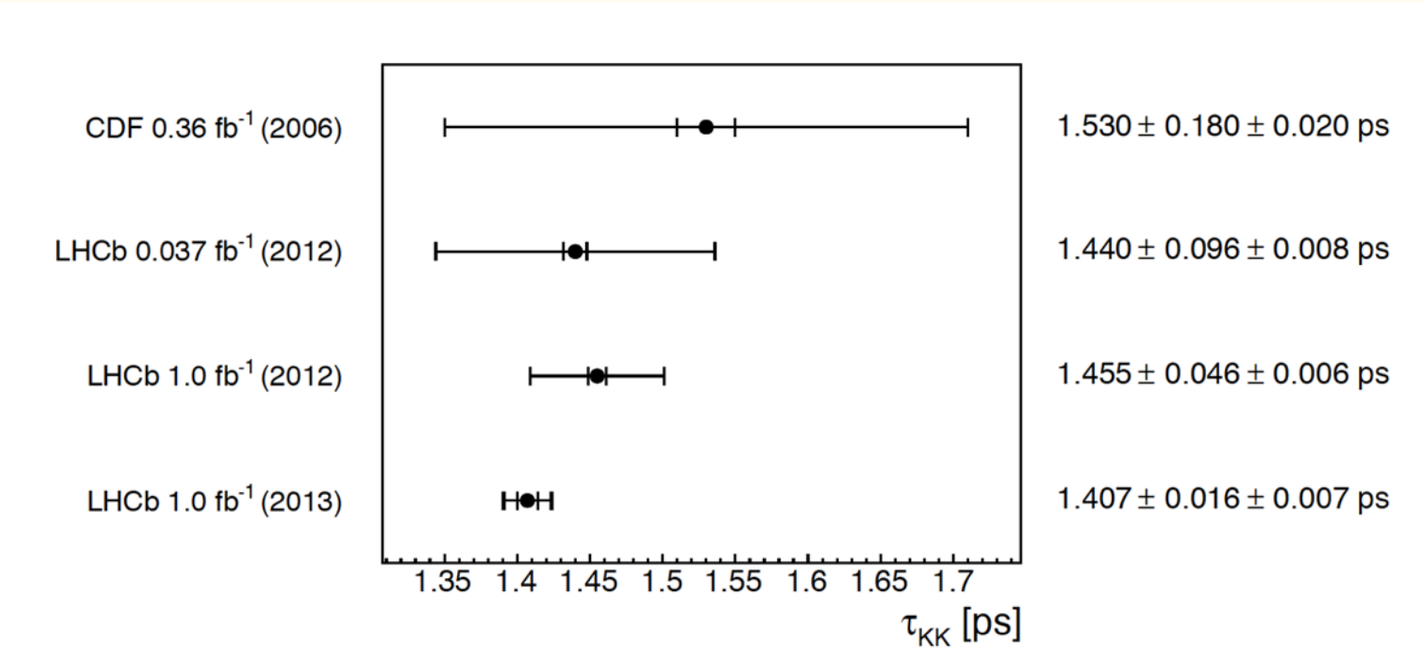
$$\tau_{B^0_s \rightarrow K^+K^-} = 1.407 \pm 0.016\,(stat) \pm 0.007\,(syst)\ \text{ps}$$

Best measurement!

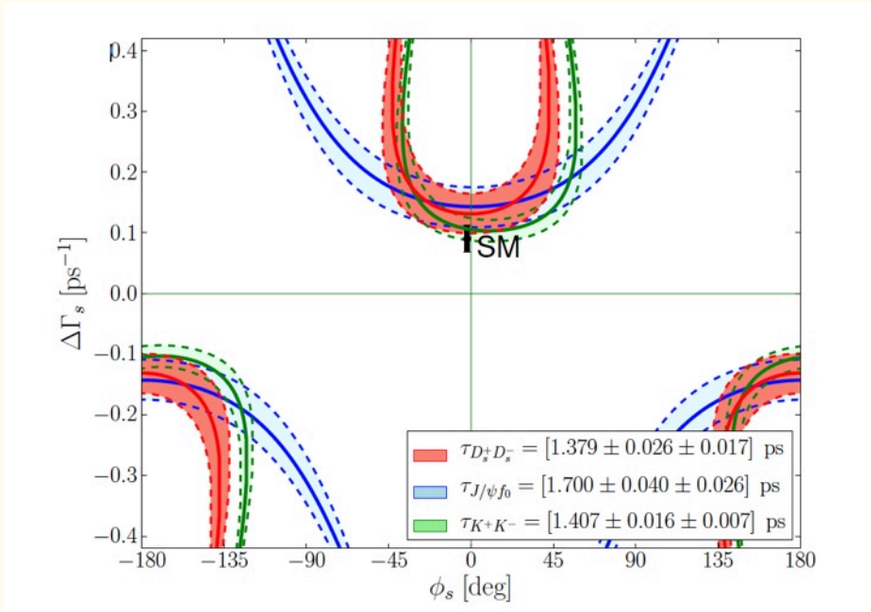
- Data driven method to determine the decay time acceptance function
- Mass and lifetime assumed uncorrelated

$$\tau_{B^0 \rightarrow K^+\pi^-} = 1.524 \pm 0.011\,(stat) \pm 0.004\,(syst)\ \text{ps}$$
$$\tau_{B^0_s \rightarrow \pi^+K^-} = 1.56 \pm 0.06\,(stat) \pm 0.01\,(syst)\ \text{ps}$$

$B^0_s \rightarrow K^+K^-$ lifetime measurements



Constraints on ϕ_s and Γ_s



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

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.. from $B^{\pm} \to h^{+}h^{-}h^{\pm}$ (h= K,π)

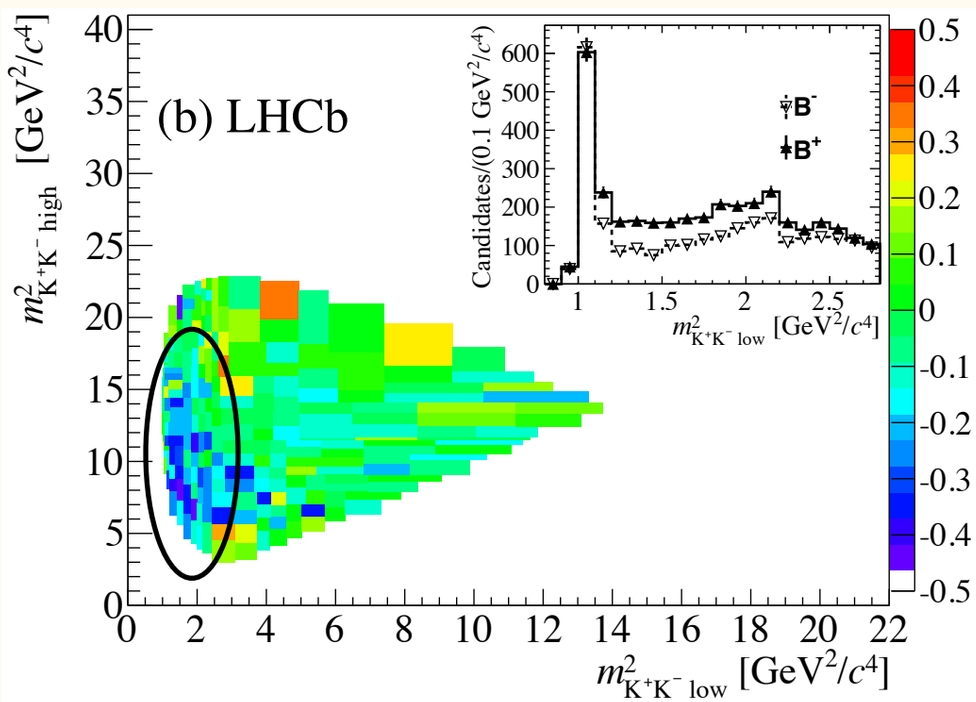
PRL111,101801(2013)

Objective: CP asymmetry in $B^{\pm} \to K^{\pm} K^{+}K^{-}$ Dalitz plot.

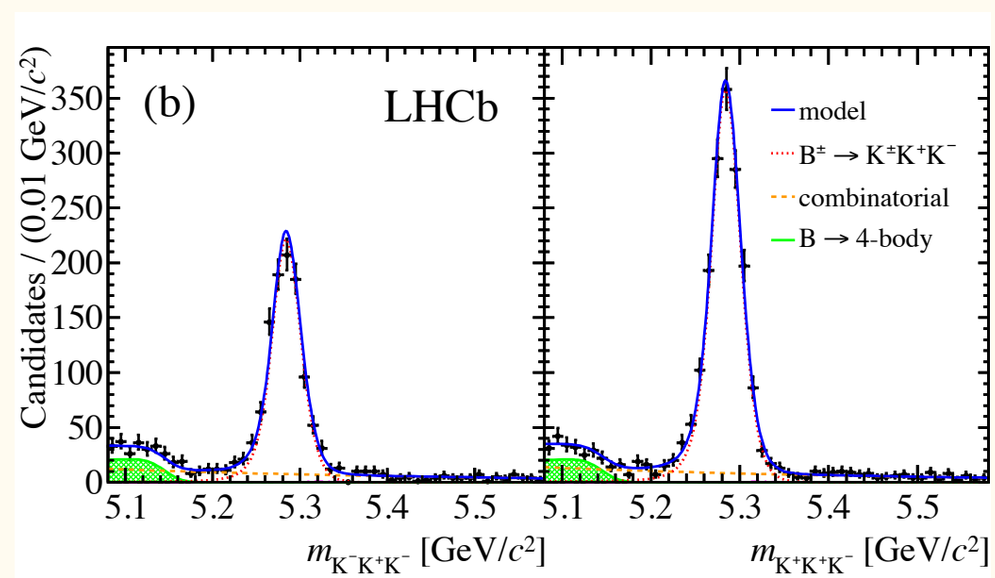
- Two possible sources of CP violation:
  - interference between intermediate states (large strong phase differences)
  - KK ↔ππ rescattering: introduction of additional strong phases which could increase CP asymmetry

Local asymmetries observed at low m^2_{KK} (just above the ϕ resonance).

No clear association with any resonance



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



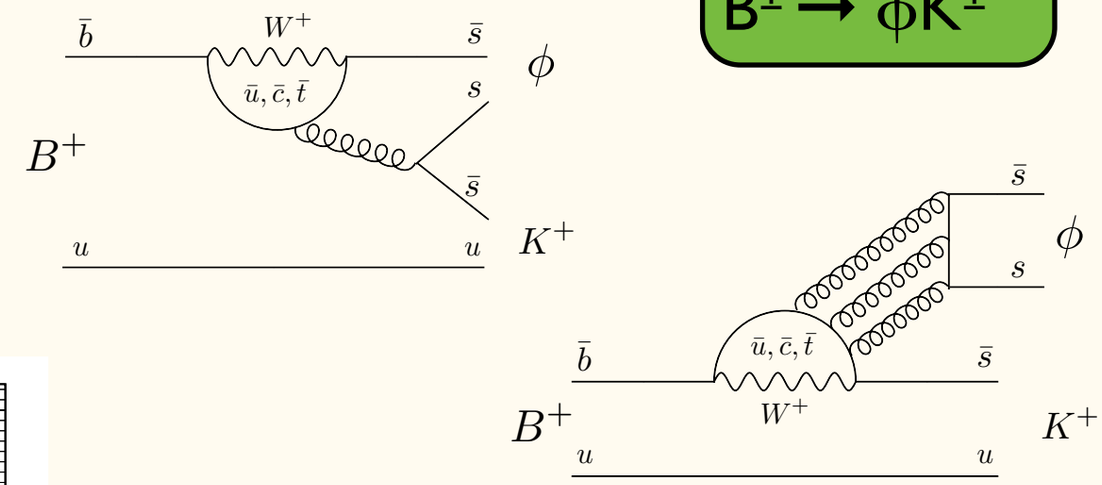
$$\mathcal{A}^{reg}_{CP}(B^{\pm} \to K^{\pm}K^{+}K^{-}) = -0.226 \pm 0.020(stat) \pm 0.004(syst) \pm 0.007(J\psi K^{\pm})$$

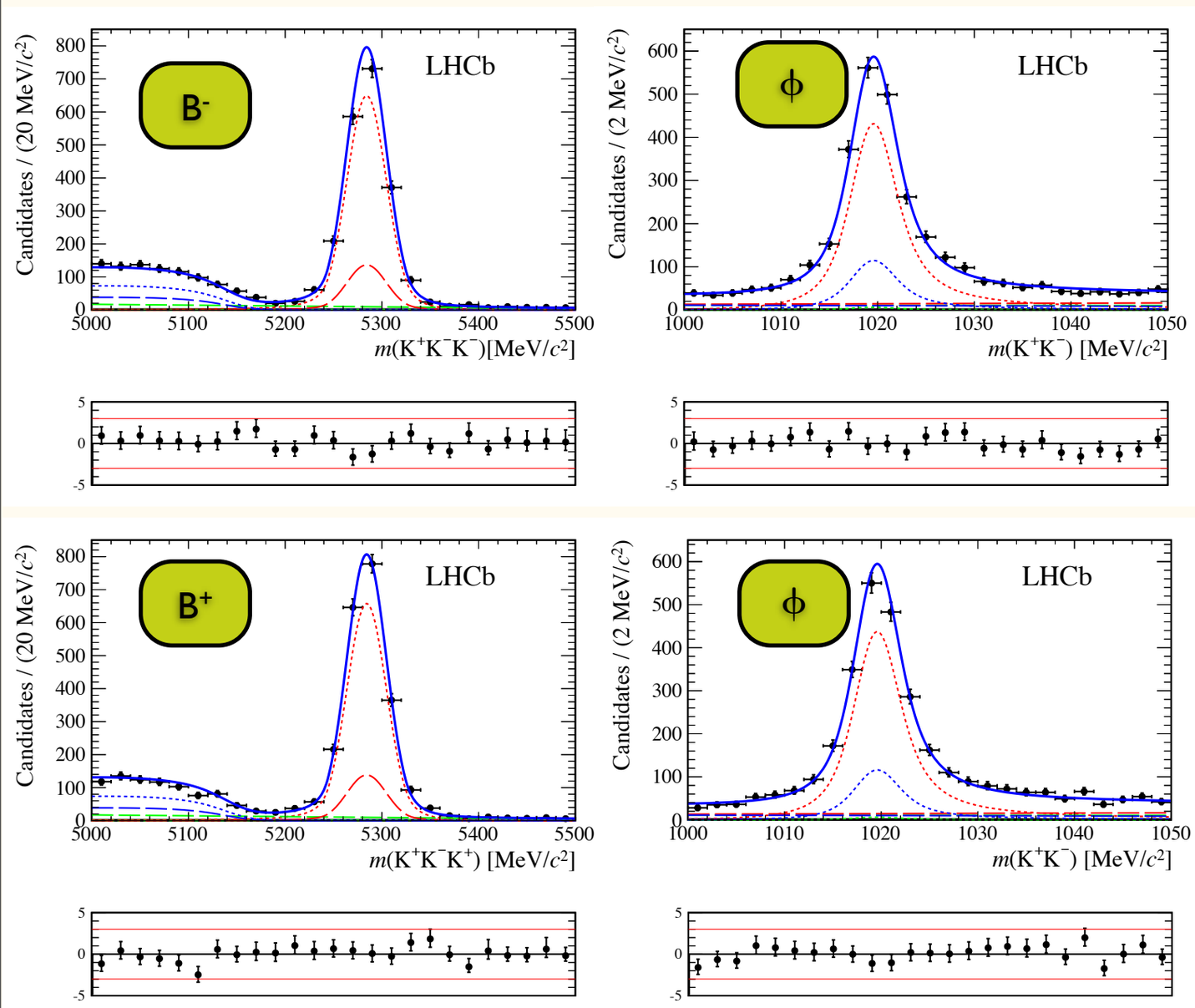
- Similar results in other $B^{\pm} \to h^{\pm} h^{+}h^{-}$ modes

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

- Objective measurement of the CP asymmetry,
- Theoretical prediction from the SM : 1-2%

(Phys. Rev. D74 (2006) 094020, Nucl. Phys. B675 (2003) 333)





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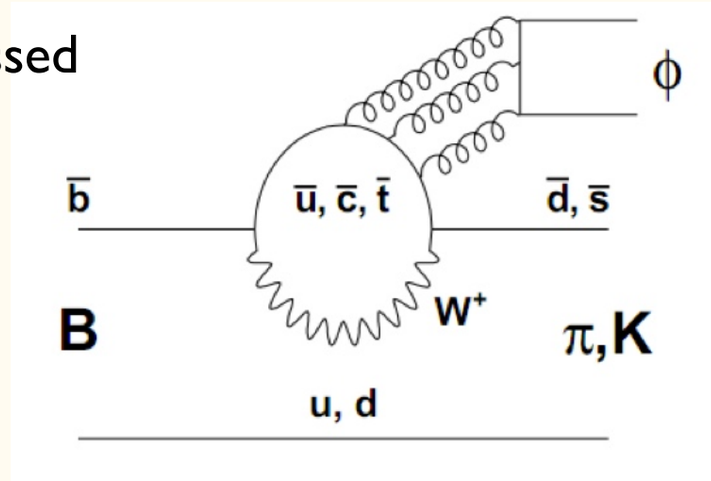
- $\mathcal{L}$ = 1.0 fb^{-1} at 7 TeV
- Two-dimensional fit of the B mass and ϕ mass spectra
- Simultaneous fit of the B^+ and B^- candidates
- Control channel $B^{\pm} \rightarrow J/\psi K^{\pm}$, to measure the production and detection asymmetry

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

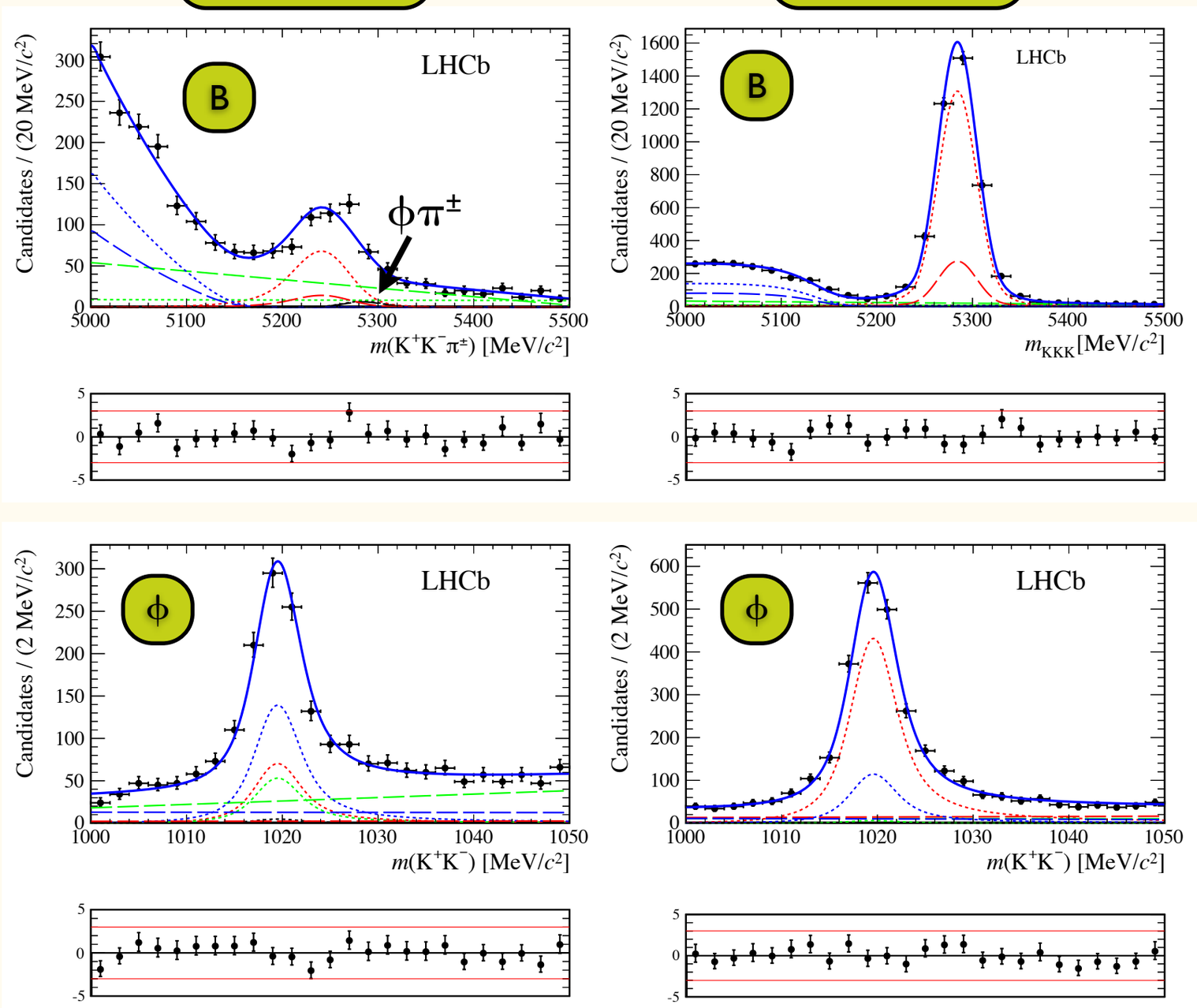
Best measurement!

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

- Objective : search for the decay
- Rare decay: dominated by b → 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
- 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 $B^{\pm} \to \phi\pi^{\pm}$

$$N(\phi\pi^{\pm}) = 19 \pm 19$$

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

Best upper limit!

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

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

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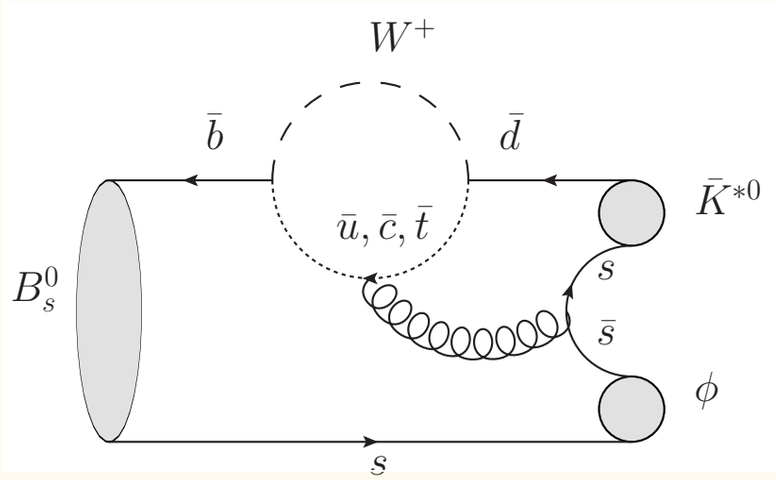
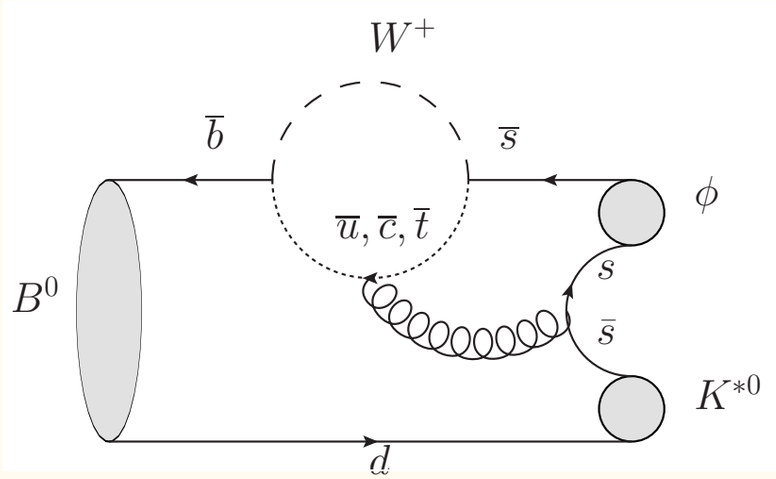
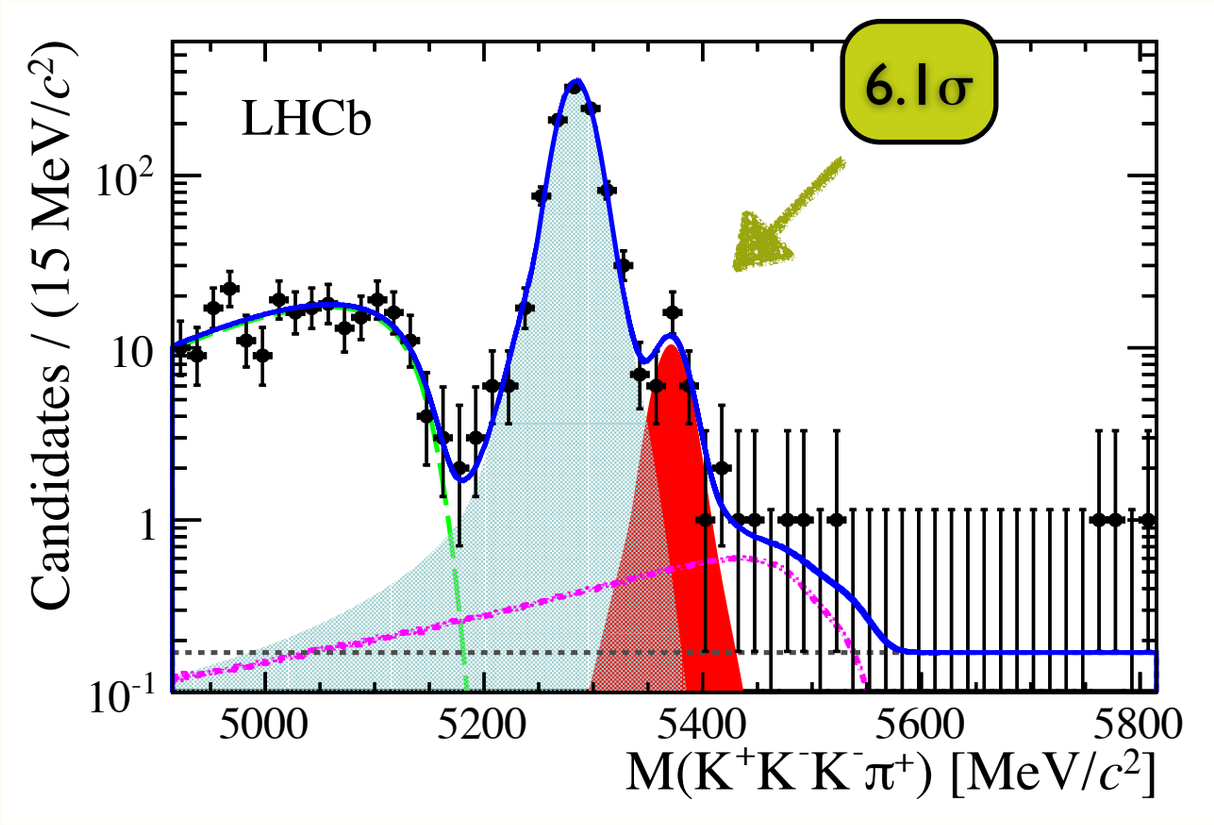
$B^0_s \to \phi \bar{K}^{*0}$

- Objective: search for the $B^0_s \to \phi \bar{K}^{*0}$ decay. New physics may appear in the loop
- 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 $B^0 \to \phi K^{*0}$ (same final state, polarization fraction expected to be similar)







$$N(B^0_s \to \phi \bar{K}^{*0}) = 30 \pm 6$$

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 high side of the theoretically expected range

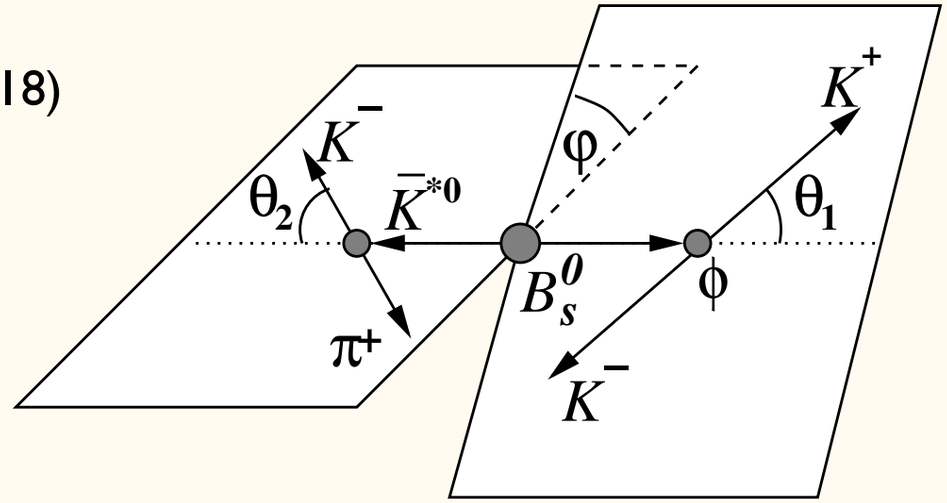
$B^0_s \to \phi \overline{K}^{*0}$

- Objective: measurement of longitudinal polarization in $B^0_s \to \phi \overline{K}^{*0}$ decays

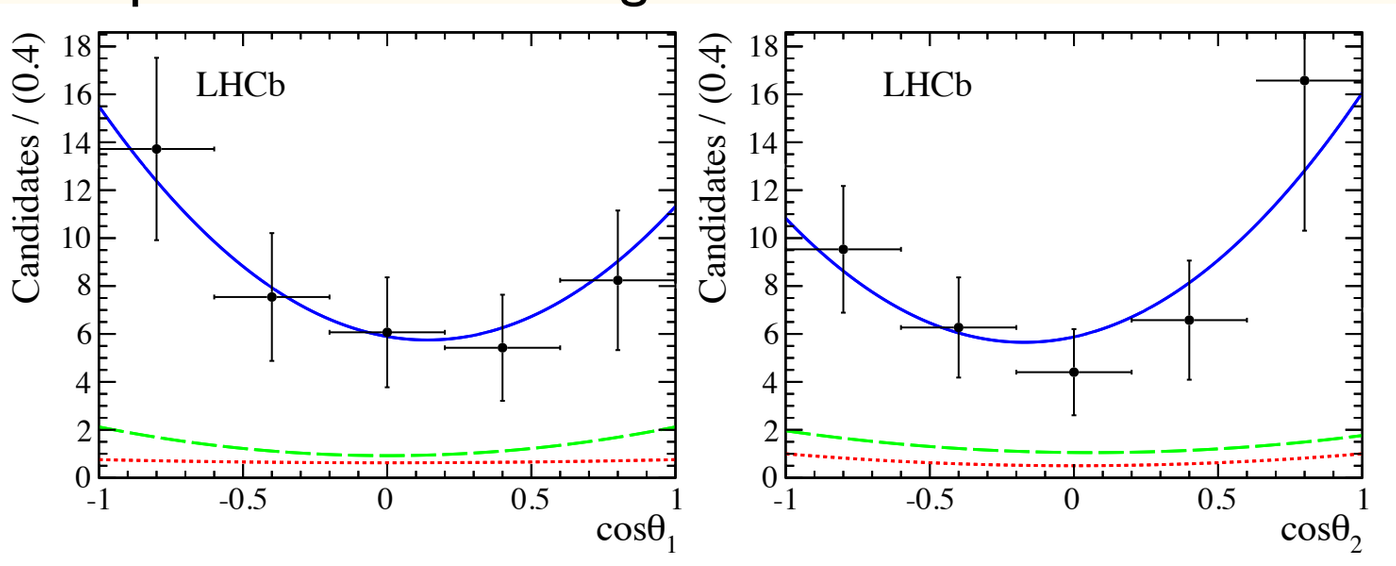
- Theoretical prediction: $f_0 = 0.712^{+0.042}_{-0.048}$ (Phys.Rev.D76(2007)074018)

- Lower f_0 compared to prediction measured in $b \to s$ transition.

- $f_0 = 0.80^{+0.12}_{-0.13}$ measured in $B^0 \to K^{*0} \overline{K}^{*0}$



Acceptance corrected angular distribution:



- $B \to VV$ 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 $A_\parallel$

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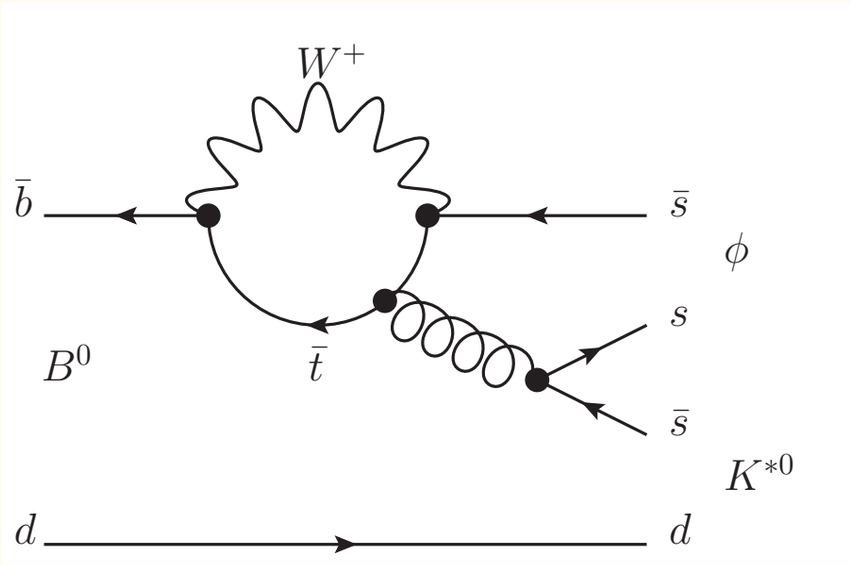
$B^0 \to \phi K^{*0}$

arXiv:1403.2888

$B^0 \to \phi K^{*0}$

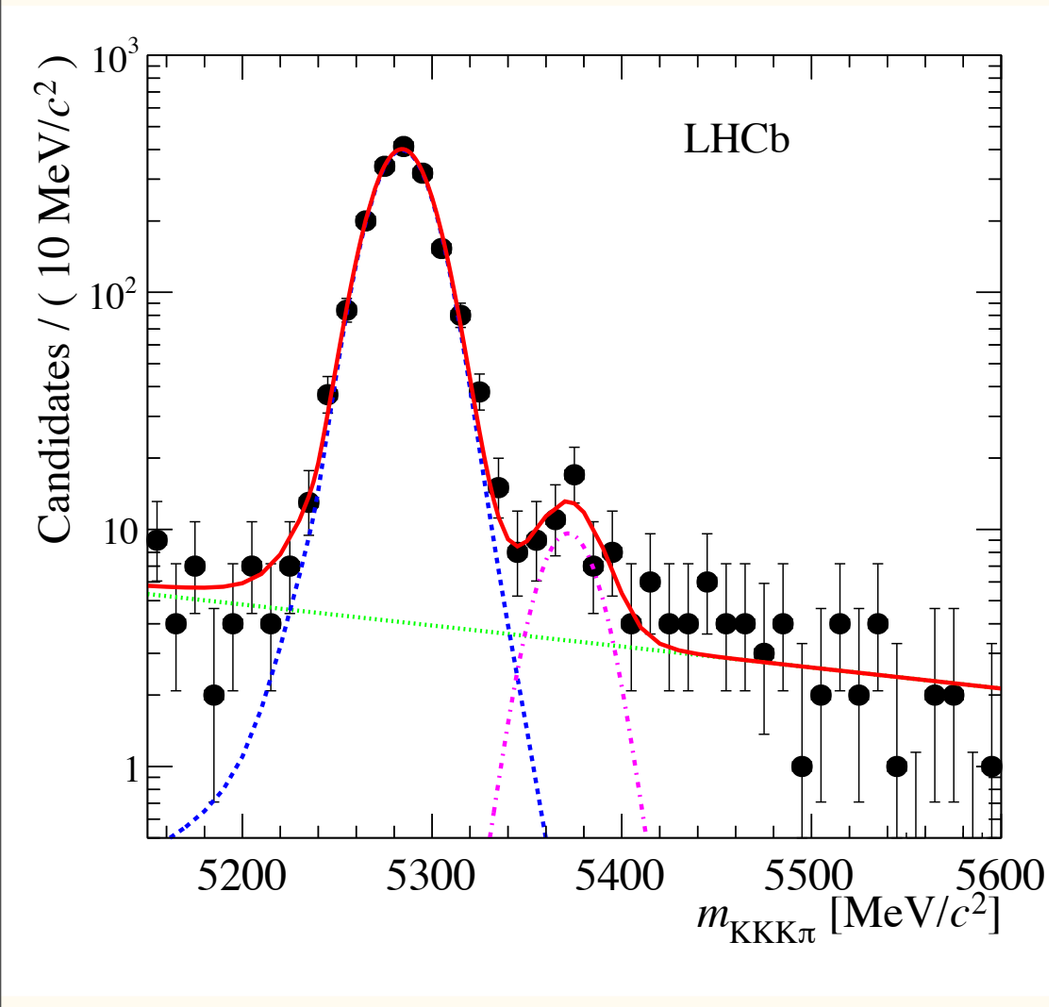
- FCNC process ($b \to s\bar{s}s$)
- gluonic penguin diagram: new physics may appear in the loop
- f_L predicted to be ~0.8. From measurement $f_L \sim 0.5$

(BaBar PRD 78(2008),092008; Belle PRD88(2013)072004)



What did we measure ?

- direct CP asymmetry
- time-integrated polarization amplitude



- Analysis performed with 1 fb^{-1}
- 1655±42 B^0 signal candidates

Direct CP asymmetry:

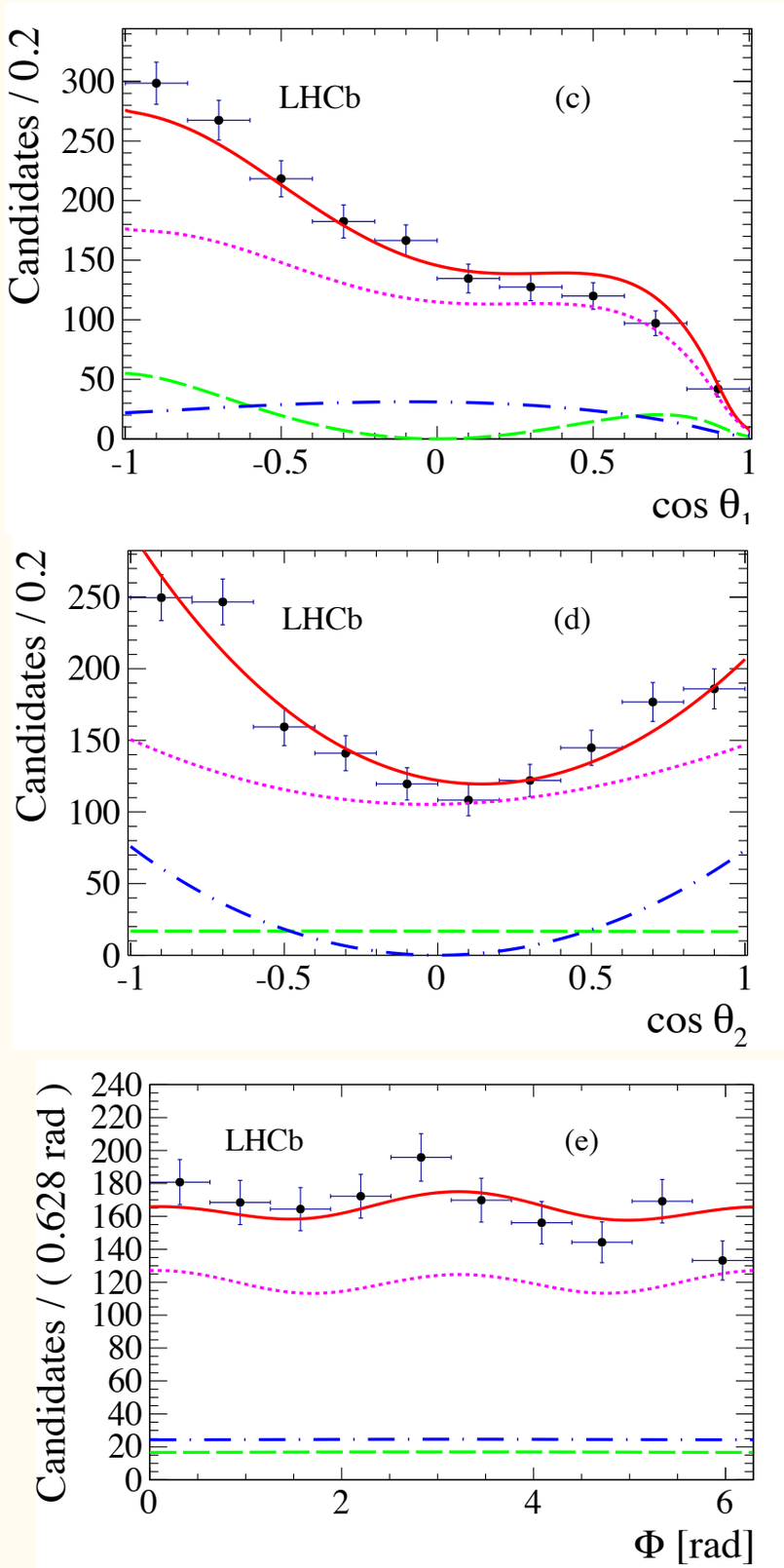
$$\mathcal{A}_{CP}(B^0 \to \phi K^{*0}) = (1.5 \pm 3.2 \pm 0.5)\%$$

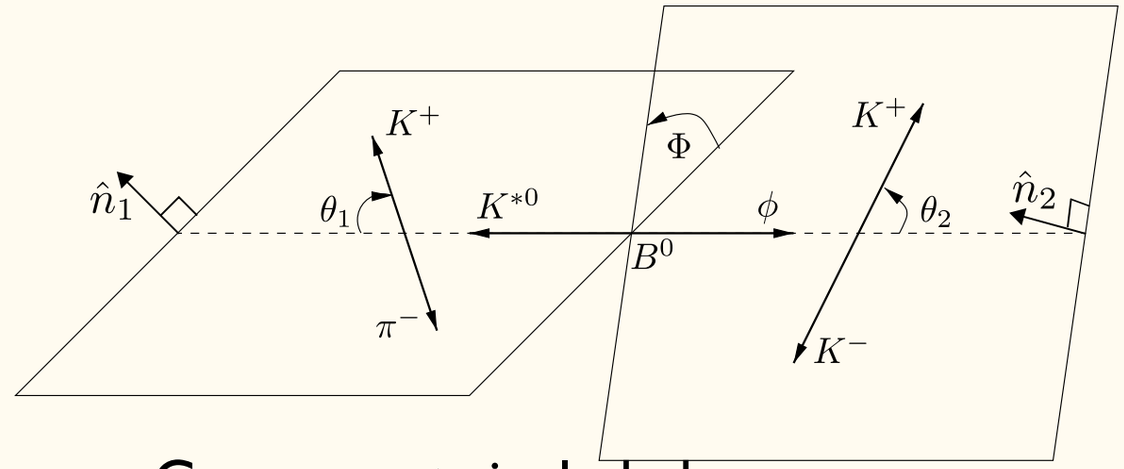
- reference channel $B^0 \to J/\psi K^{*0}$
- No CP violation observed

Best measurement!

Angular analysis:

$B^0 \to \phi K^{*0}$





Components included:

- P-wave contributions: f_L, $f_\perp$, $f_{/\!/}$ ($f_{/\!/}$ = 1-f_L-$f_\perp$)+ strong phases $\delta_\perp$, $\delta_{/\!/}$

-Two s-wave amplitudes taken in account ($A_s^{K\pi}$, A_s^{KK}) + two phases ($\delta_s^{K\pi}$, δ_s^{KK}) from $B^0 \to \phi K\pi$ and $B^0 \to K^*KK$

$$f_L = 0.497 \pm 0.019 \pm 0.015$$
$$f_\perp = 0.221 \pm 0.016 \pm 0.013$$
$$f_S(K\pi) = 0.143 \pm 0.013 \pm 0.012$$
$$f_S(KK) = 0.122 \pm 0.013 \pm 0.008$$

- No dominant longitudinal component
- Results in agreement with BaBar (PRD 78(2008)092008) and Belle (PRD 88(2013)072004) measurements

Conclusions

- Charmless b-flavoured hadron decays are a good probe to search for new physics
- Several new results from LHCb in the charmless sector

  - new observations and improvements on branching fractions (Λ^0_b, $\Xi^0_b \to K^0_s p h^-$ $B^\pm \to \phi\pi^\pm$, $B^0_s \to \phi K^{*0}$)

  - lifetime measurements ($B^0_{(s)} \to h^+h^-$)

  - measurements and improvements of global and local asymmetries ($B^\pm \to \phi K^\pm$, $B^\pm \to h^+h^-h^\pm$)

  - angular analyses

A lot of work still to do...

- Combined amplitude analysis to extract the CKM angles
- Larger data samples (~9fb^{-1} expected by 2018)
- Plenty of charmless channels still to explore