Studies of charmless B decays in LHCb

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For the LHCb collaboration
Weak Interactions and Neutrinos 2013, Natal, Brazil

Outline

- Physics case
- LHCb experiment
- Two body modes: $B \to hh(*)$, $B \to p\bar{p}$, ($B \to \phi K^*$)
- Three body modes: : $B \to hhh$, $B \to p\bar{p}h$
- Conclusion

(*) h = π or K

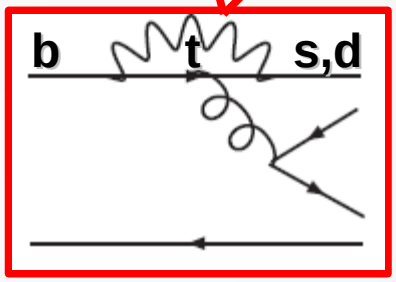
Physics case: why are charmless decays interesting?

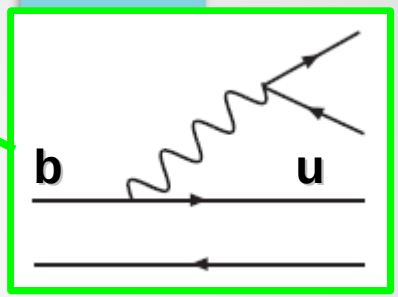
- Charmless = everything that is not b→ c

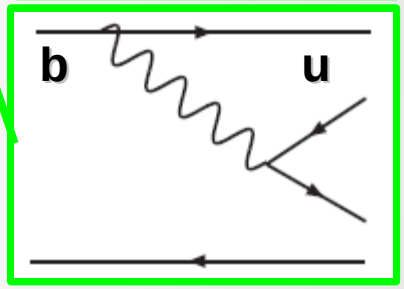
  b → s,d loop (penguin) and b→ u tree transitions

  - Sensitivity to small CKM matrix elements
- Small branching fractions
  - Sensitivity to deviations from SM: new physics (heavy particles in loops)
- CP asymmetries: another probe of NP

CKM	d	s	b
u			T
c			
t	P	P	







$$A_{CP}=\frac{\Gamma\left(B^-\left(\overline{B}^0_{(s)}\right)\to f^-\right)-\Gamma\left(B^+\left(B^0_{(s)}\right)\to f^+\right)}{\Gamma\left(B^-\left(\overline{B}^0_{(s)}\right)\to f^-\right)+\Gamma\left(B^+\left(B^0_{(s)}\right)\to f^+\right)}$$

Direct CP or charge asymmetry
Contribution of at least two amplitudes with different weak and strong phases

$$A_{CP}(t)=\frac{\Gamma\left(\overline{B}\to f_{CP}\right)(t)-\Gamma\left(B\to f_{CP}\right)(t)}{\Gamma\left(\overline{B}\to f_{CP}\right)(t)+\Gamma\left(B\to f_{CP}\right)(t)}=\frac{-C_f\cos\left(\Delta m_{d(s)}t\right)+S_f\sin\left(\Delta m_{d(s)}t\right)}{\cosh\left(\frac{\Delta\Gamma_{d(s)}}{2}t\right)-A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_{d(s)}}{2}t\right)}$$

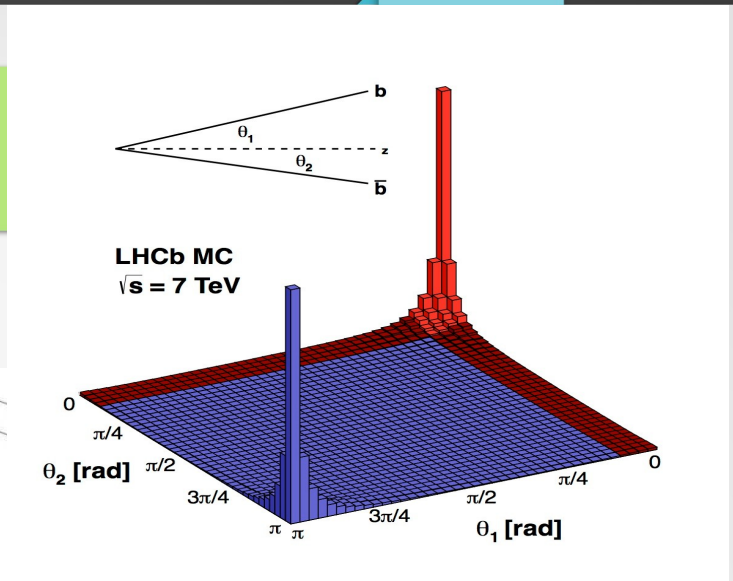
Time-dependent asymmetry
Combines direct and mixing-induced asymmetries

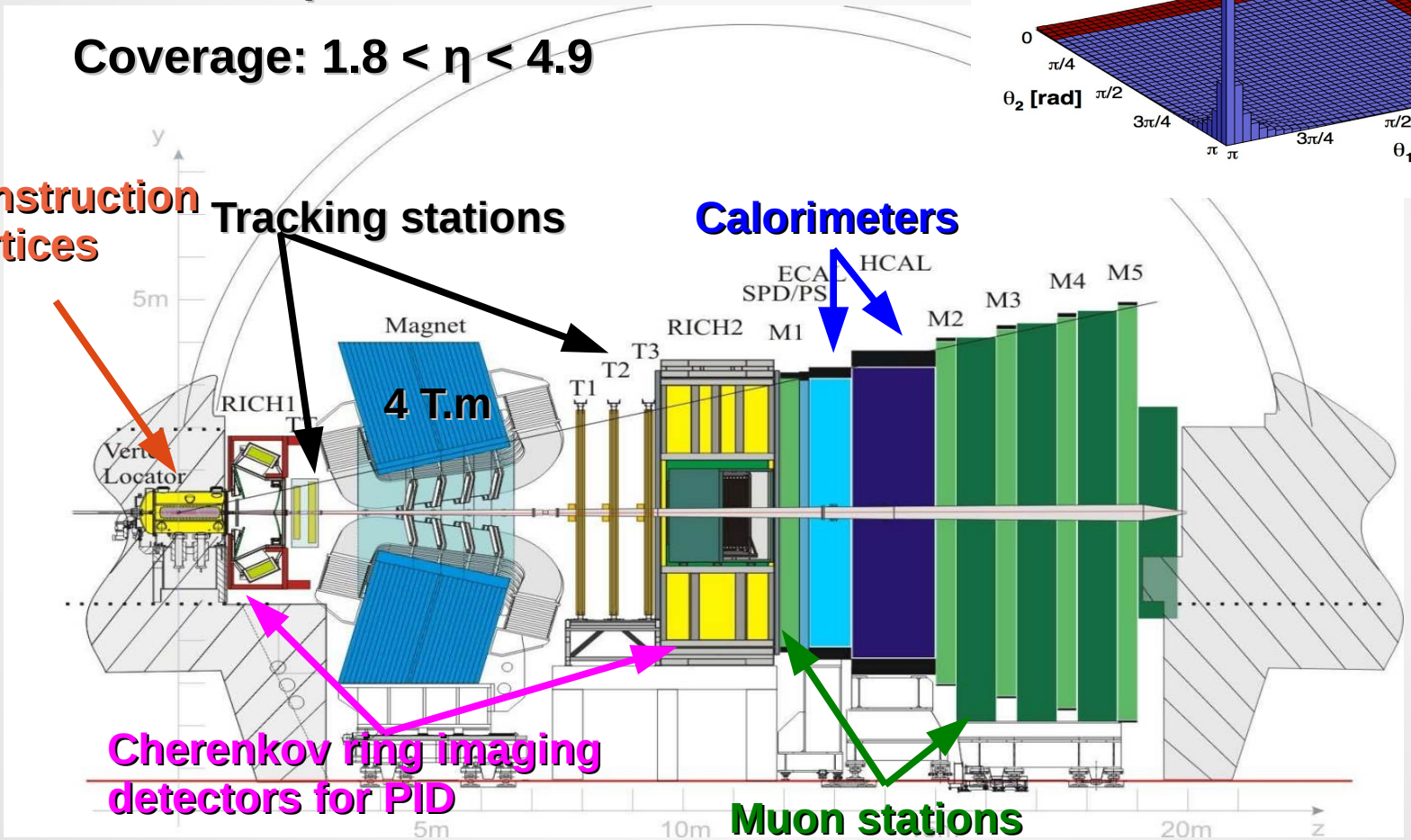
- **Limitation from theoretical hadronic uncertainties due to form factors, etc...: *combine different modes and use (flavour) symmetries*. Studying amplitudes in Dalitz analyses is a plus for disentangling contributions.**

LHCb detector

Forward spectrometer

Coverage: 1.8 < η < 4.9

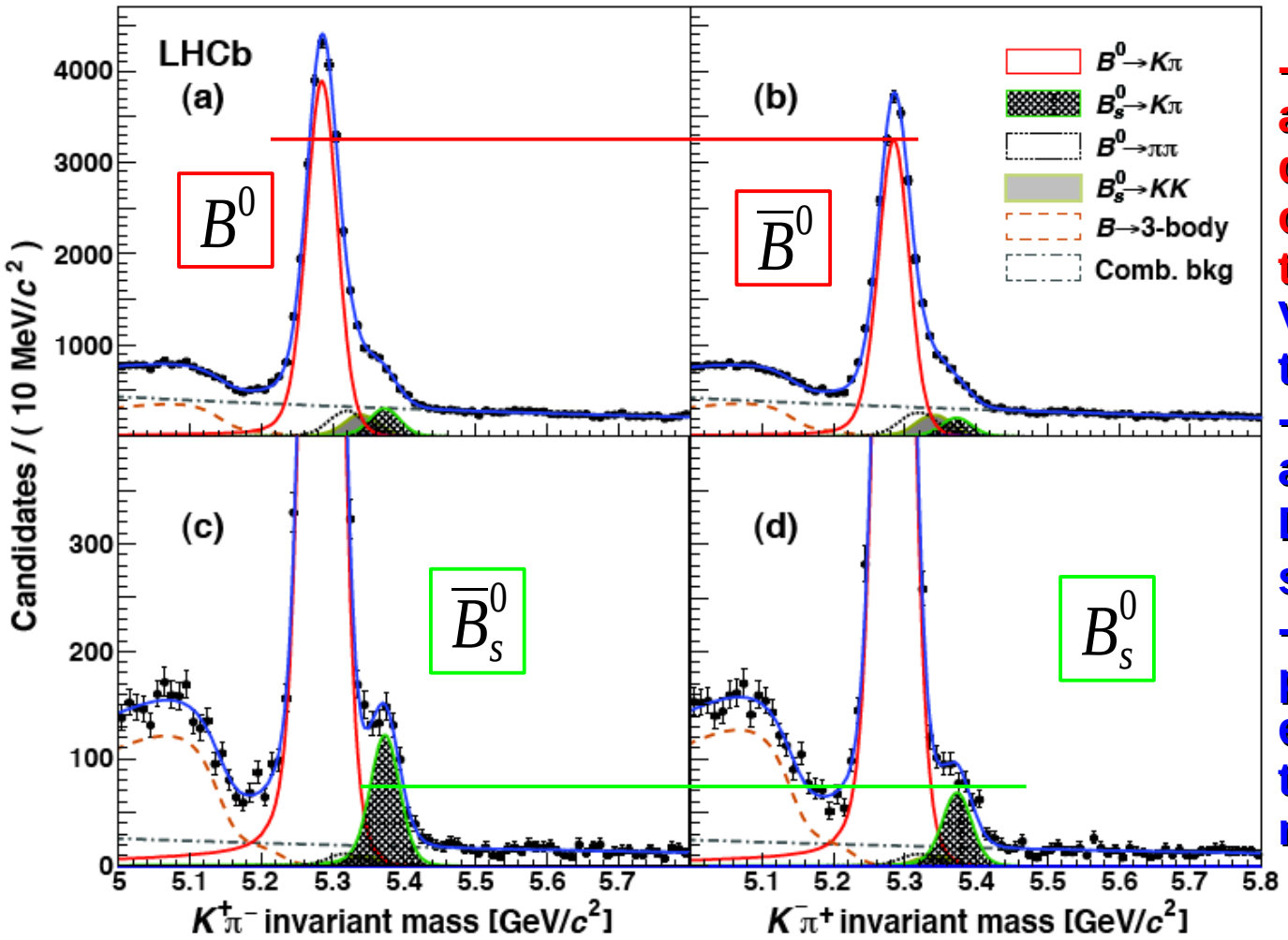




Direct CPV in $B^0 \to K\pi$

$B_d^0 \to K\pi$ and $B_s^0 \to K\pi$ U-spin related

Phys.Rev.Lett.110 (2013) 221601



- Combined fits to signals and cross-feeds. Use of data-based PID calibration to disentangle the contributions

Very carefully corrections to the raw asymmetries:

- Correction for detection asymmetry using $D^* \to D^0(hh)\pi$ control samples in data
- Correction for production asymmetry extracted from study of the time dependence of raw A_{CP}

Main systematics: detection asymmetry and backgrounds

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

Improved

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

First observation of direct CP in Bs system

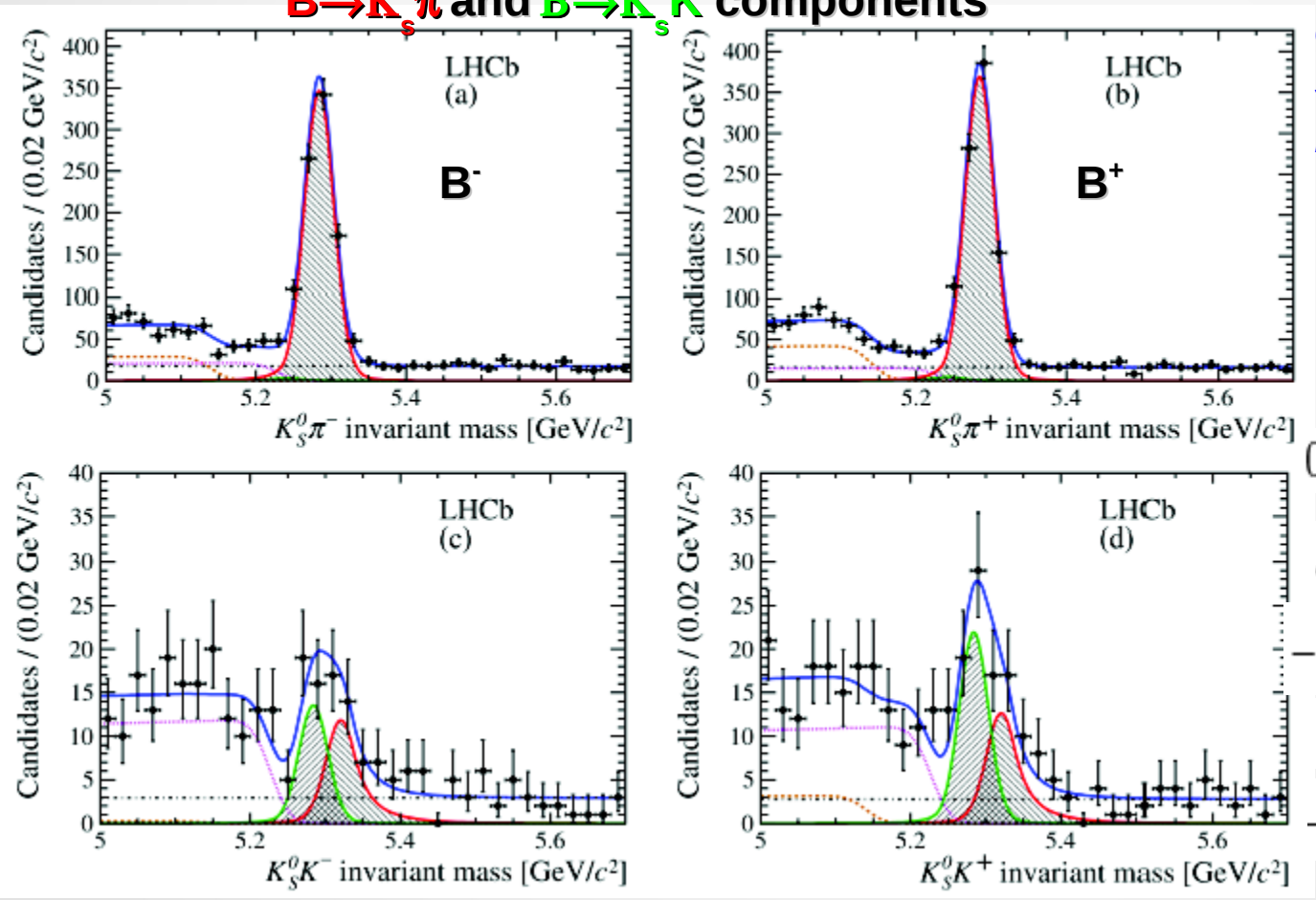
CP asym. and rates in $B^{\pm} \to K_s h^{\pm}$

arXiv:1308.1277

Provides complementary information to $B^0 \to K\pi$ for the extraction of γ angle using U-spin symmetry e.g, R.Fleischer Eur. Phys. J. C52 (2007) 267

For detection and production asymmetries, use $J/\Psi K^{\pm}$ as a control channel, with similar selection + correct for K/π differences

$B \to K_s \pi$ and $B \to K_s K$ components



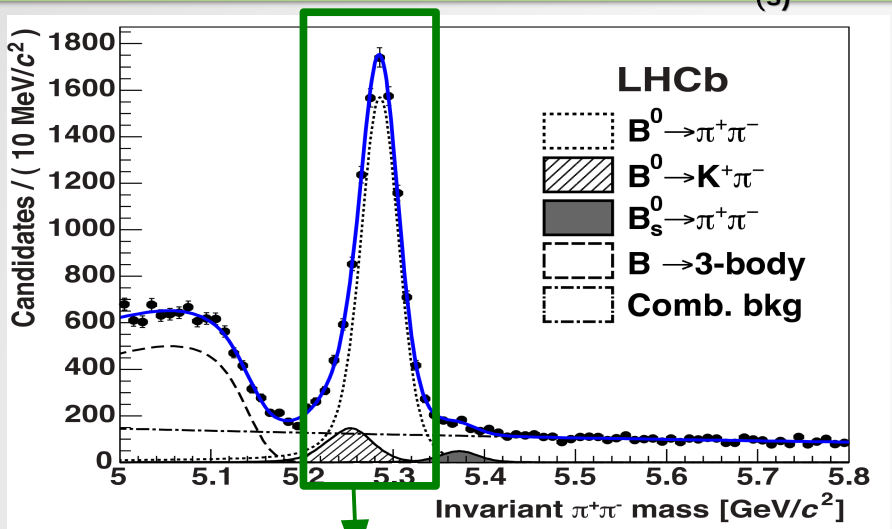
$$\frac{\mathcal{B}(B^+ \to K_s^0 K^+)}{\mathcal{B}(B^+ \to K_s^0 \pi^+)} = 0.064 \pm 0.009\ (\text{stat.}) \pm 0.004\ (\text{syst.})$$

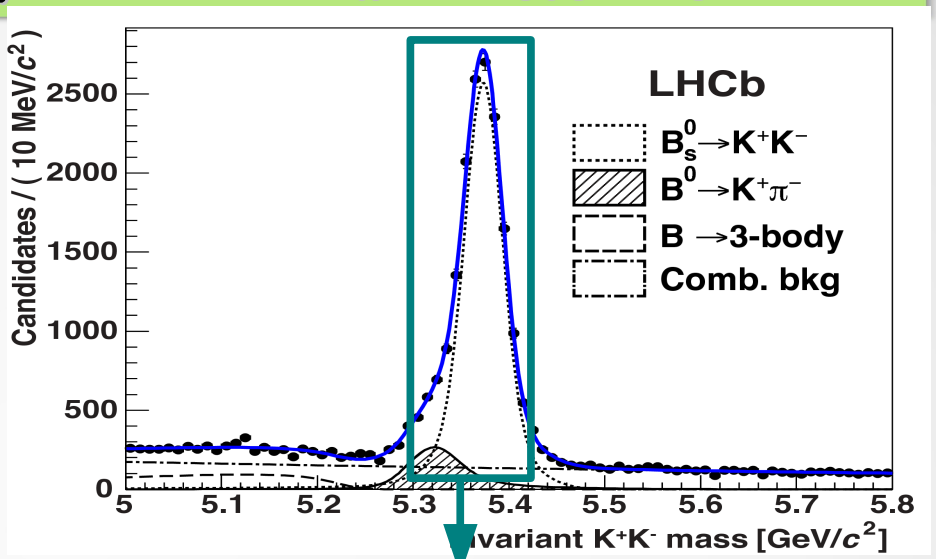
$$\mathcal{A}^{CP}(B^+ \to K_s^0 \pi^+) = -0.022 \pm 0.025\ (\text{stat.}) \pm 0.010\ (\text{syst.})$$

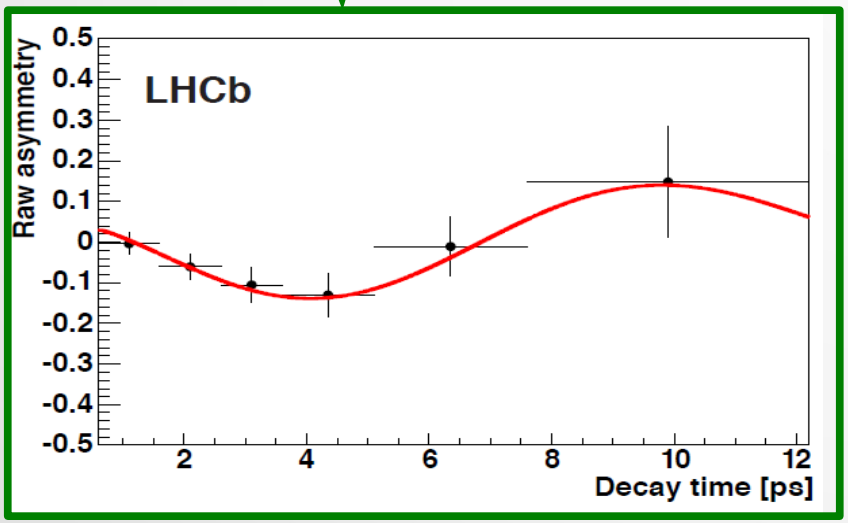
$$\mathcal{A}^{CP}(B^+ \to K_s^0 K^+) = -0.21 \pm 0.14\ (\text{stat.}) \pm 0.01\ (\text{syst.})$$

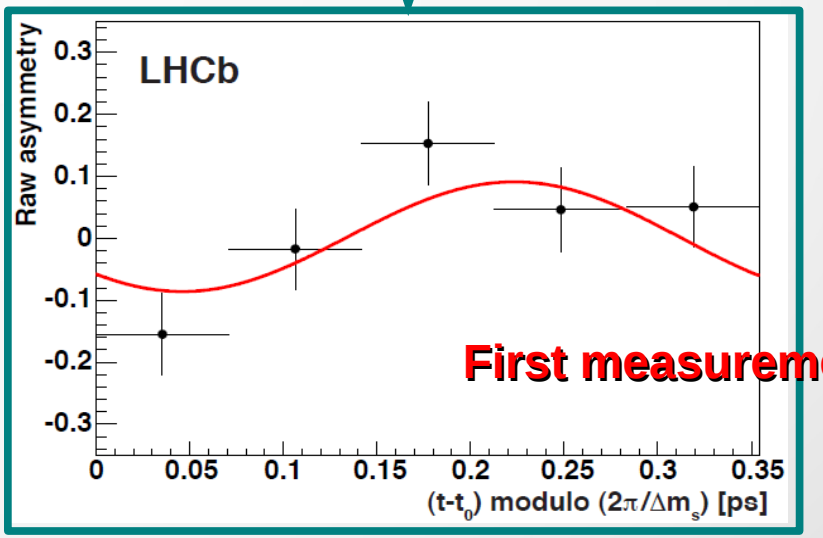
$B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$

Same U-spin interplay as in $B_{(s)}^0 \to K\pi$ ***arXiv:1308.1428***









$C_{\pi\pi}$ = -0.38±0.15 (stat)±0.02 (syst)

$S_{\pi\pi}$ = -0.71±0.13 (stat)±0.02 (syst)

C_{KK} = 0.14±0.11 (stat)±0.03 (syst)

S_{KK} = 0.30±0.12 (stat)±0.04 (syst)

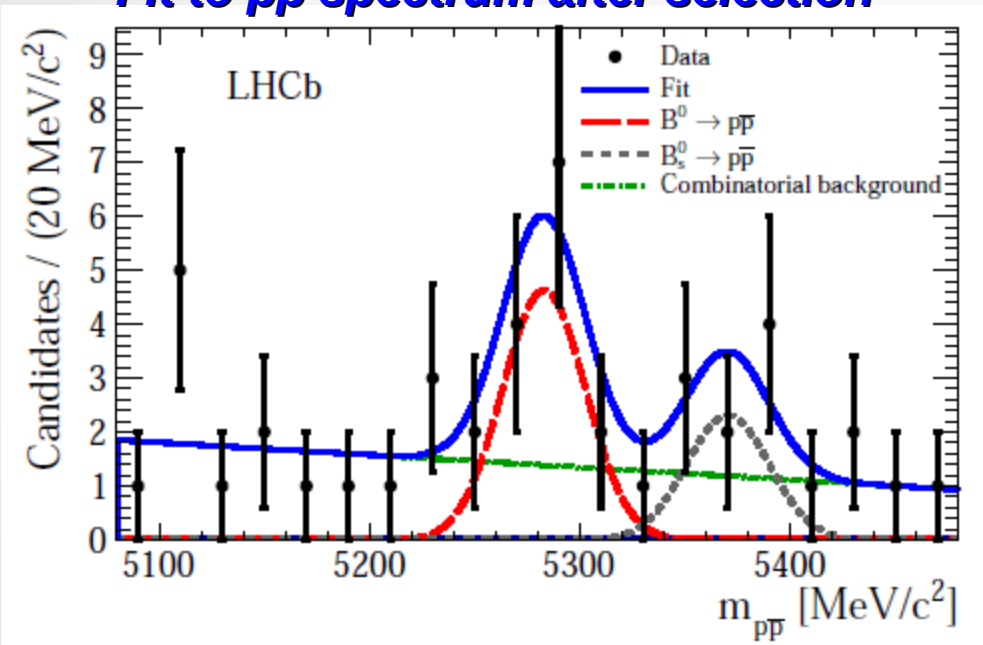
Evidence of $B^0 \to p\bar{p}$

arXiv:1308.0961

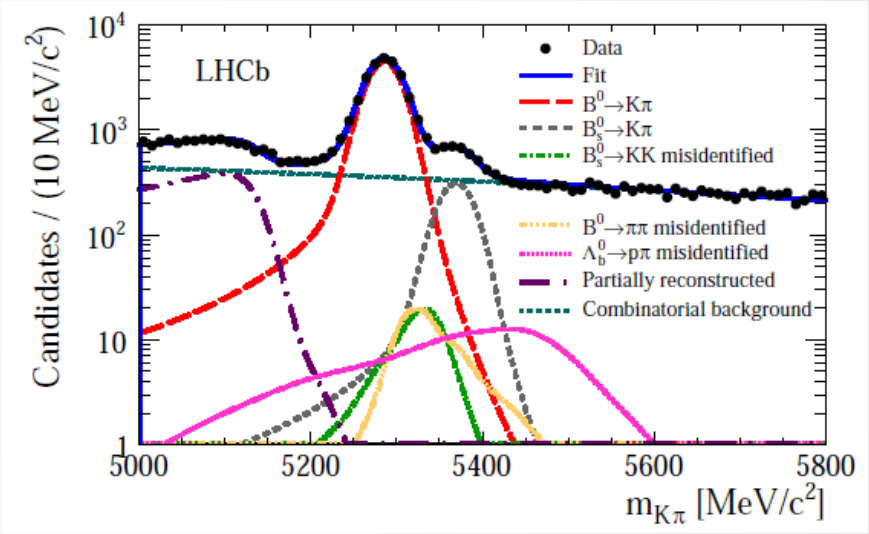
Tree dominated $B^0 \to p\bar{p}$ vs. penguin dominated $B_s^0 \to p\bar{p}$

$B^0 \to K^+\pi^-$ used for normalization
Decision trees used for discrimination. Detailed PID and two-body + three-body backgrounds modeling

Fit to $p\bar{p}$ spectrum after selection



Fit to normalization mode



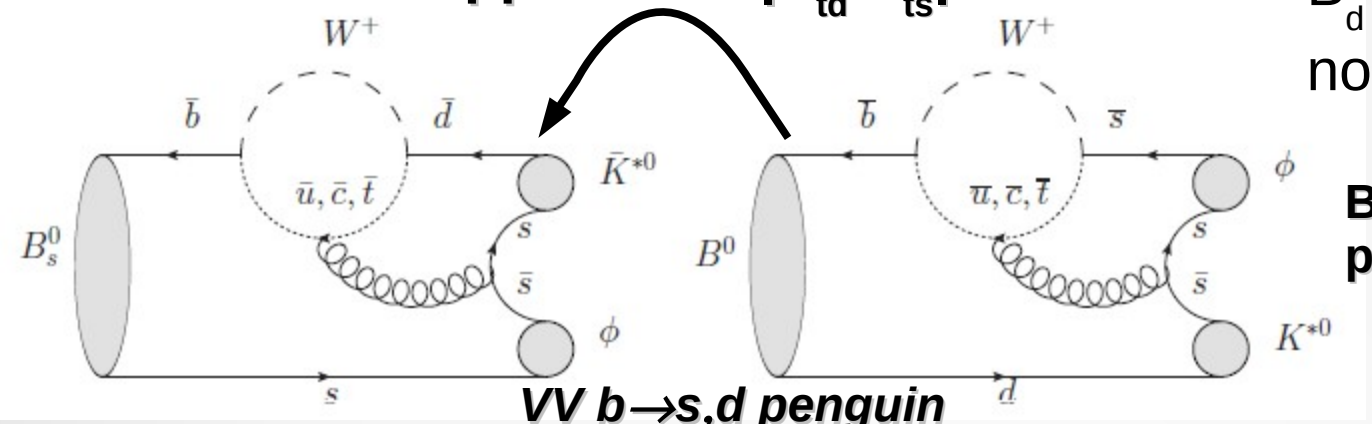
$\Gamma(B^0 \to p\bar{p}) = (1.47\ ^{+0.71}_{-0.53}) \times 10^{-8}$ 3.3σ significance: FIRST EVIDENCE

Nothing significant for $B_s^0 \to p\bar{p}$ (improved limits, though)

First observation of $B_s^0 \to \phi \bar{K}^{*0}$

arXiv:1306.2239

Relative suppression $|V_{td}/V_{ts}|^2$

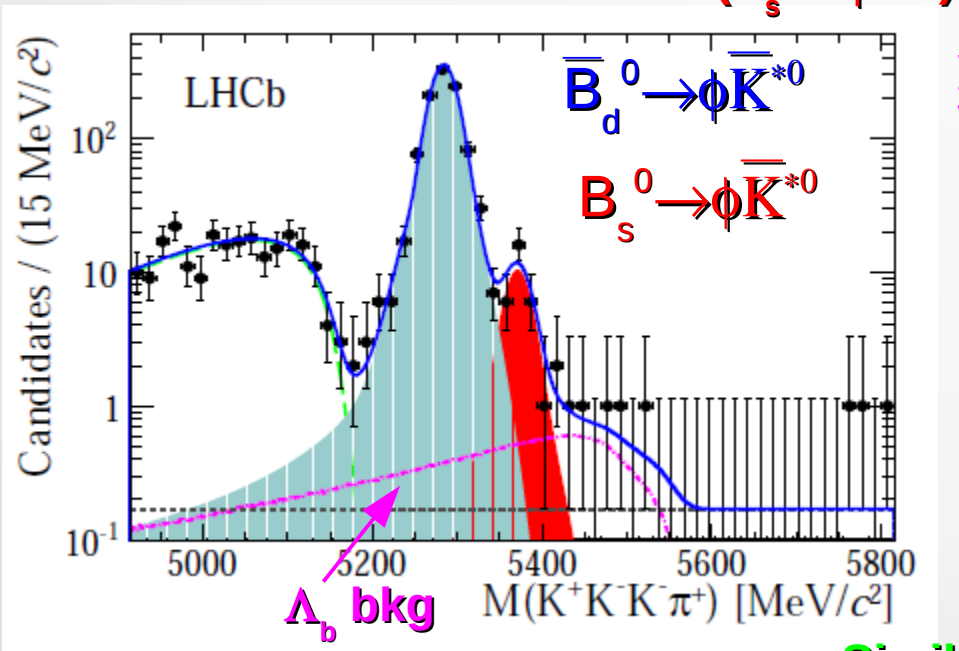


VV b→s,d penguin

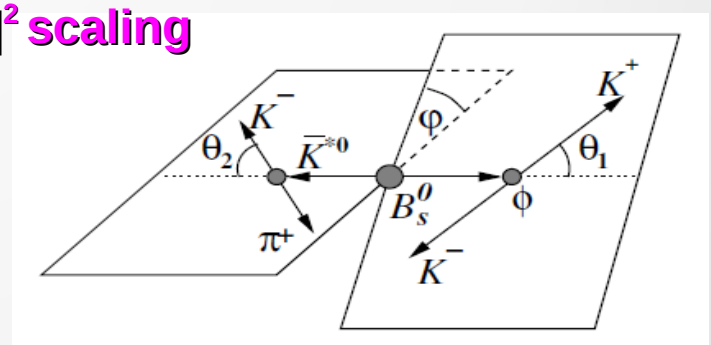
$\bar{B}_d^0 \to \phi \bar{K}^{*0}$ natural normalization channel

Branching fraction and polarization analysis

$\mathcal{B}(B_s^0 \to \phi \bar{K}^{*0}) = (1.10 \pm 0.24(\text{stat}) \pm 0.14(\text{syst}) \pm 0.08(\text{fd/fs}))10^{-6}$



Sig: 6.1σ: first observation!
$3 \times |V_{td}/V_{ts}|^2$ scaling



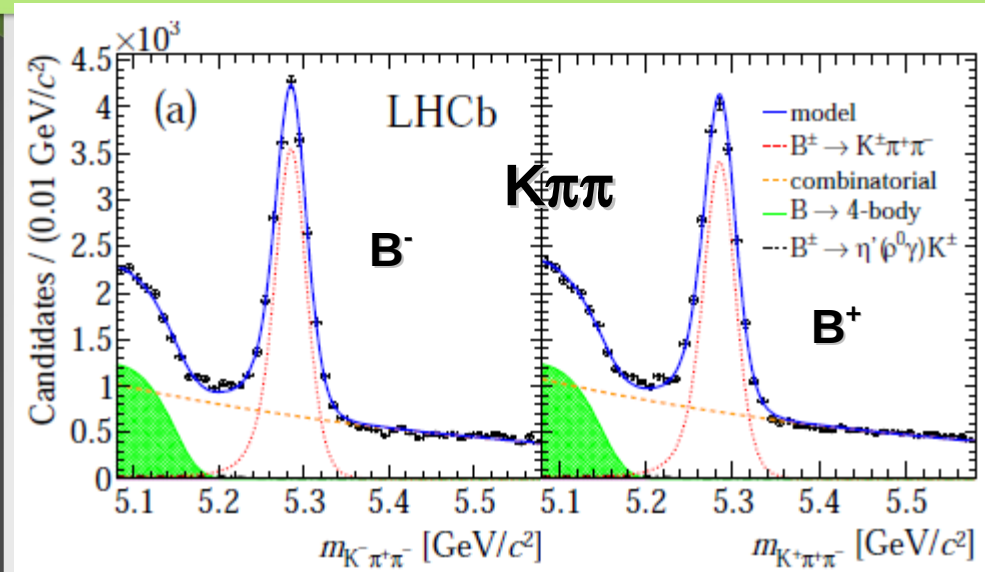
Longitudinal fraction

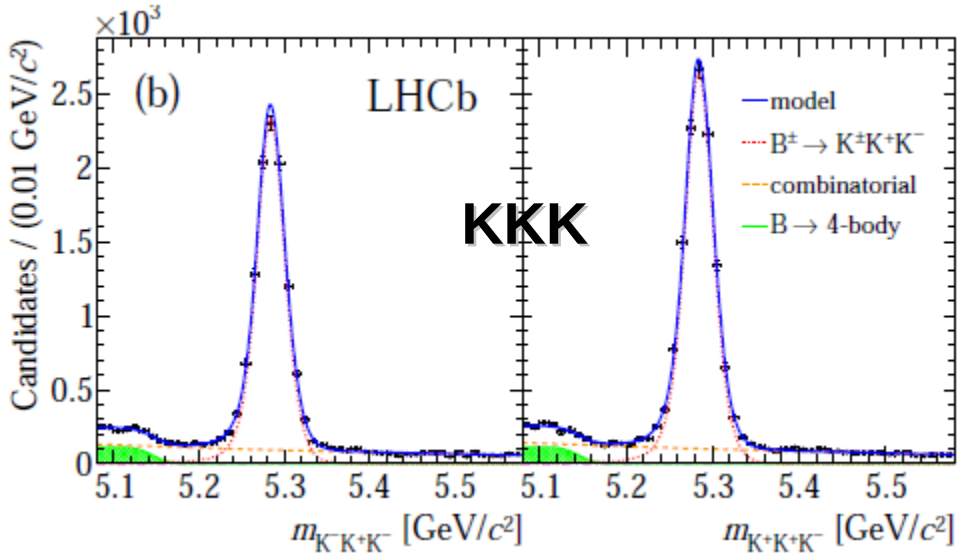
$$f_0 = 0.51 \pm 0.15\,(\text{stat}) \pm 0.07\,(\text{syst})$$

Similar to $\bar{B}_d^0 \to \phi \bar{K}^{*0}$, differs from $\bar{B}_d^0 \to K^{*0} \bar{K}^{*0}$

Direct CPV in $B^{\pm} \to K^{\pm}h^{+}h^{-}$ - inclusive

arXiv:1306.1246
Phys.Rev.Lett.111 (2013) 101801





Partially reconstructed bkg from 4-body decays.
Detection and production asymmetries determined with $B^{\pm} \to J/\Psi(\mu\mu)K^{\pm}$ evts passing same selection
Minor trigger differences accounted for

$$A_{CP} = A_{\rm raw} - A_{\Delta}$$

$$A_{\Delta} = A_{\rm raw}(J/\psi K) - A_{CP}(J/\psi K).$$

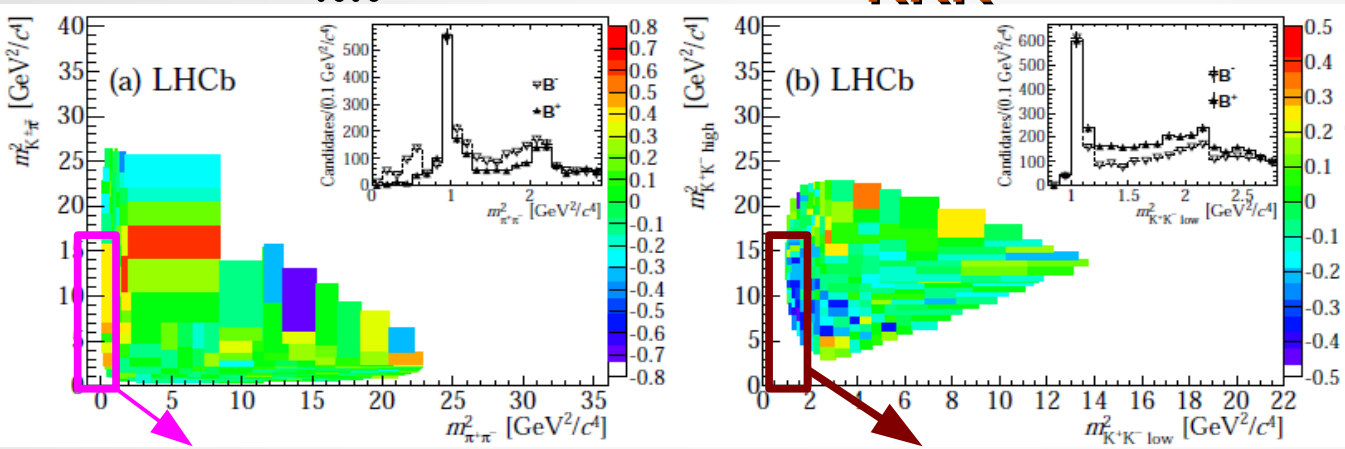
Inclusive asymmetries:

$$A_{CP}(B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}) = 0.032 \pm 0.008 \pm 0.004 \pm 0.007$$ **2.8σ**

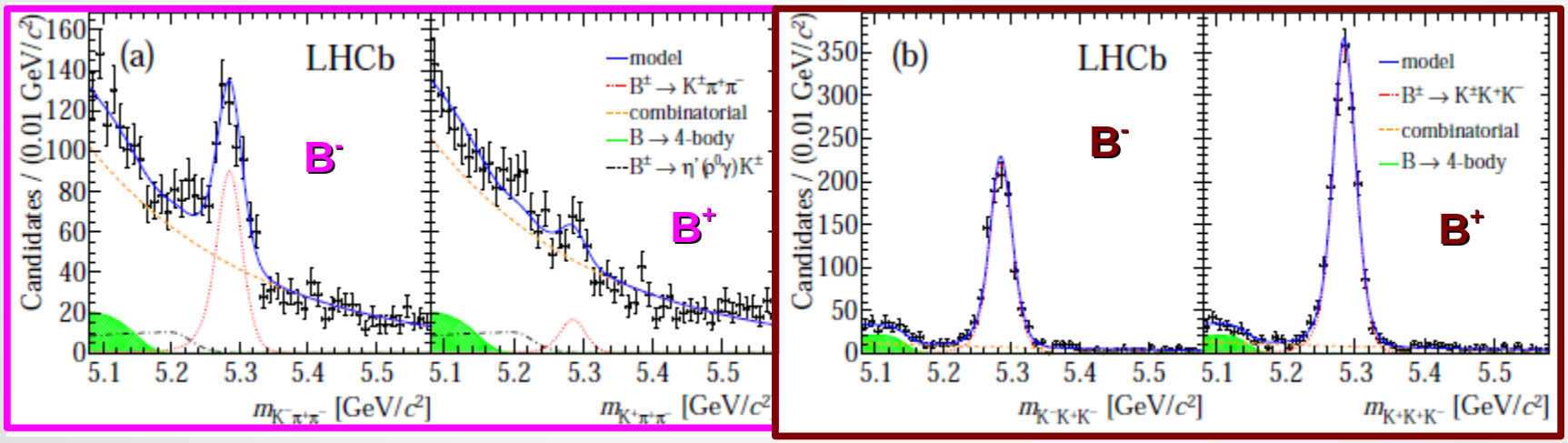
$$A_{CP}(B^{\pm} \to K^{\pm}K^{+}K^{-}) = -0.043 \pm 0.009 \pm 0.003 \pm 0.007$$ **3.7σ**

Direct CPV in $B^{\pm} \to K^{\pm}h^{+}h^{-}$ - regions

Kππ **KKK**



Map of the asymmetry in the Dalitz plane: low ππ and KK-low mass regions exhibit high asymmetries, oppositely correlated. Not clearly related to resonances



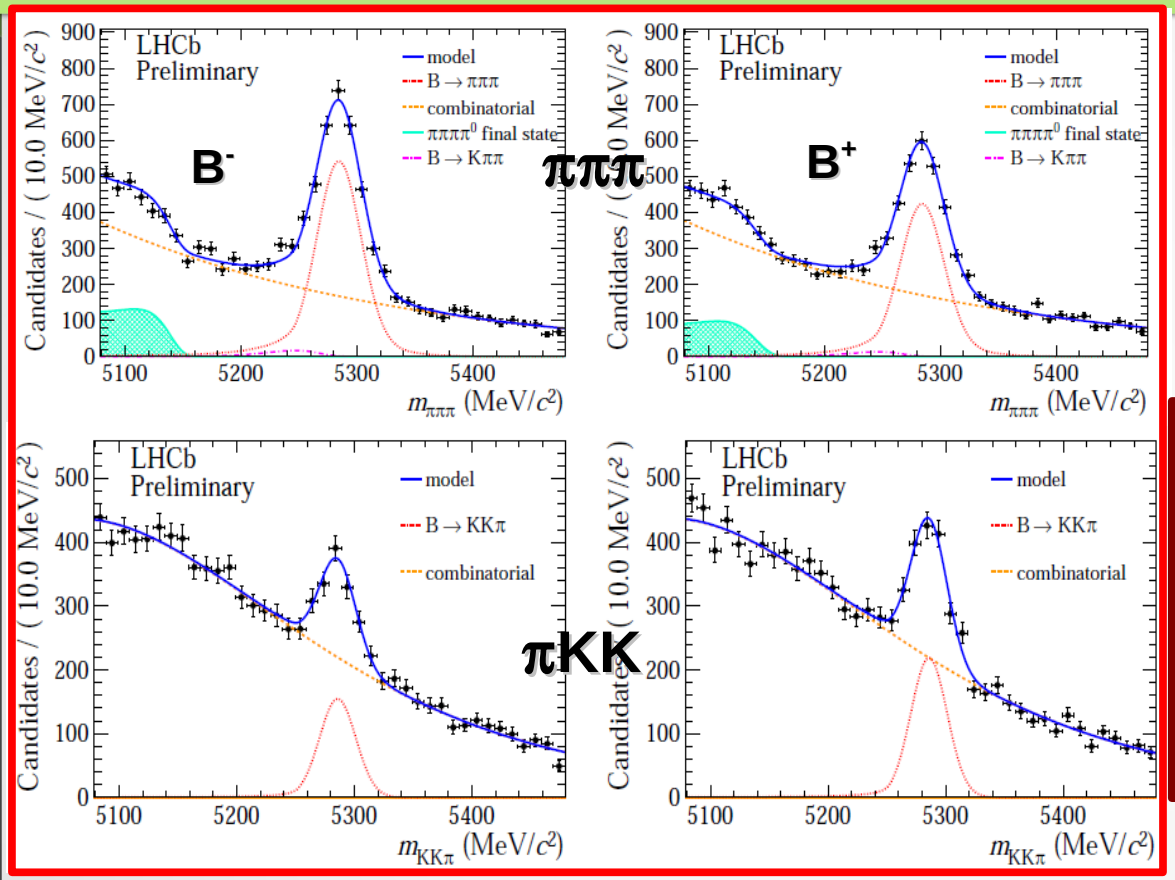
$$A_{CP}^{\rm reg}(K\pi\pi) = 0.678 \pm 0.078 \pm 0.032 \pm 0.007,$$

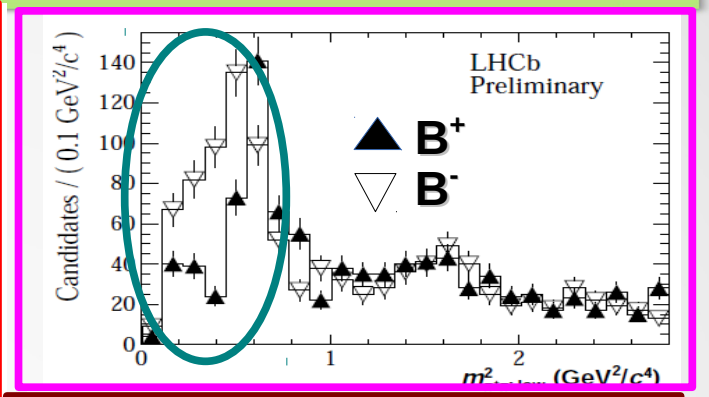
$$A_{CP}^{\rm reg}(KKK) = -0.226 \pm 0.020 \pm 0.004 \pm 0.007$$

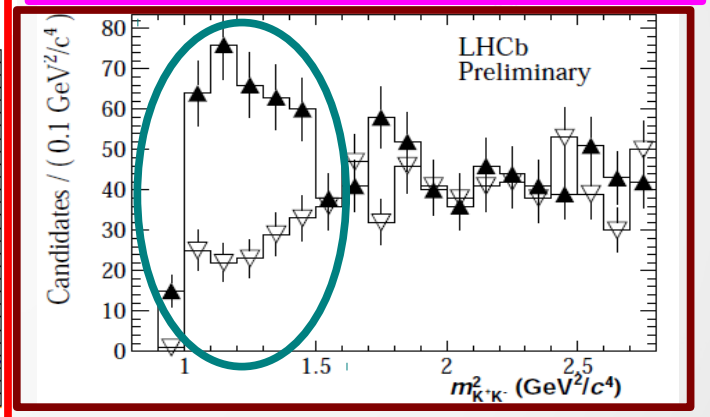
Anti-correlated huge asymmetries
Point to ππ↔KK FSI effects

Direct CPV in $B^{\pm} \to \pi^{\pm} h^{+} h^{-}$ - similar results

LHCb-CONF-2012-028.







Similar anti-correlated huge asymmetries at low ππ and KK mass regions exhibit high asymmetries, oppositely correlated.

Inclusive asymmetries:

$$A_{CP}(B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}) =$$
$$+0.120 \pm 0.020(\text{stat}) \pm 0.019(\text{syst}) \pm 0.007(J/\psi K^{\pm})$$
$$A_{CP}(B^{\pm} \to K^{+}K^{-}\pi^{\pm}) =$$
$$-0.153 \pm 0.046(\text{stat}) \pm 0.019(\text{syst}) \pm 0.007(J/\psi K^{\pm})$$

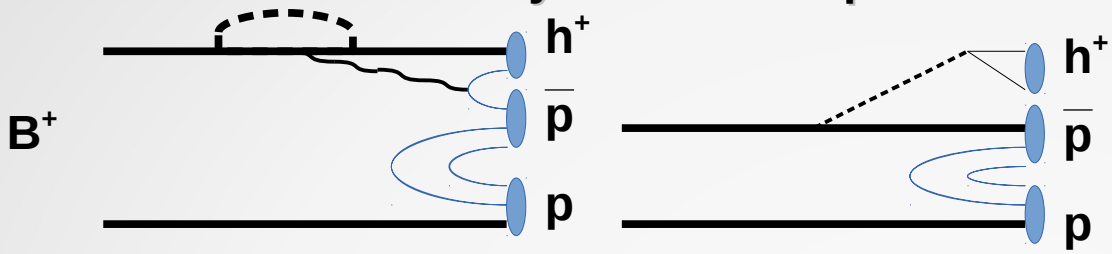
Final results being published

$B^{\pm}\to p\bar{p}h^{\pm}$ dynamics and CP asymmetries

arXiv:1307.6165

PRD accepted

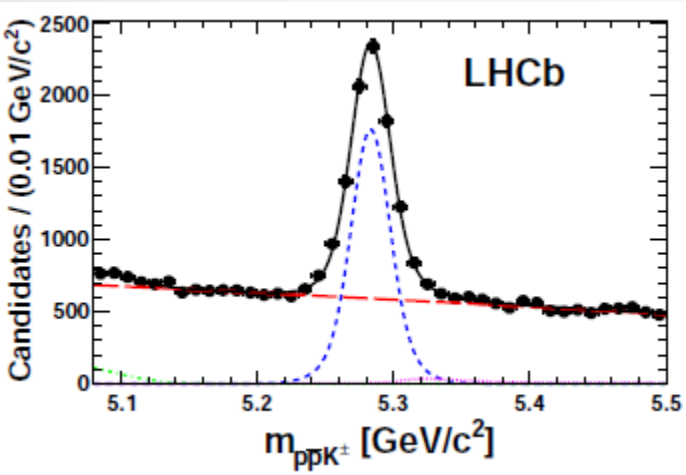
Baryonic counterpart of $B^{\pm}\to h^{+}h^{-}h^{\pm}$

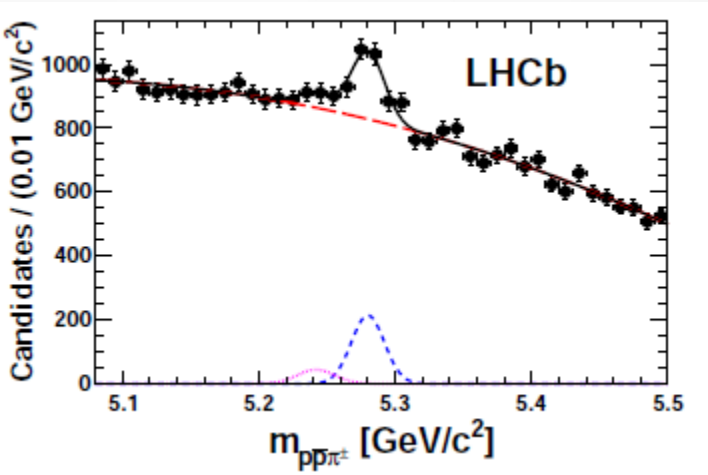


Similar selection to $B^{\pm}\to h^{+}h^{-}h^{\pm}$
Difference in PID only
Background: combinatorial and cross-feed. A small $(p\bar{p})K^{*}$ component part. reco

Inclusive signals

$p\bar{p}K^{\pm}$ **$p\bar{p}\pi^{\pm}$**





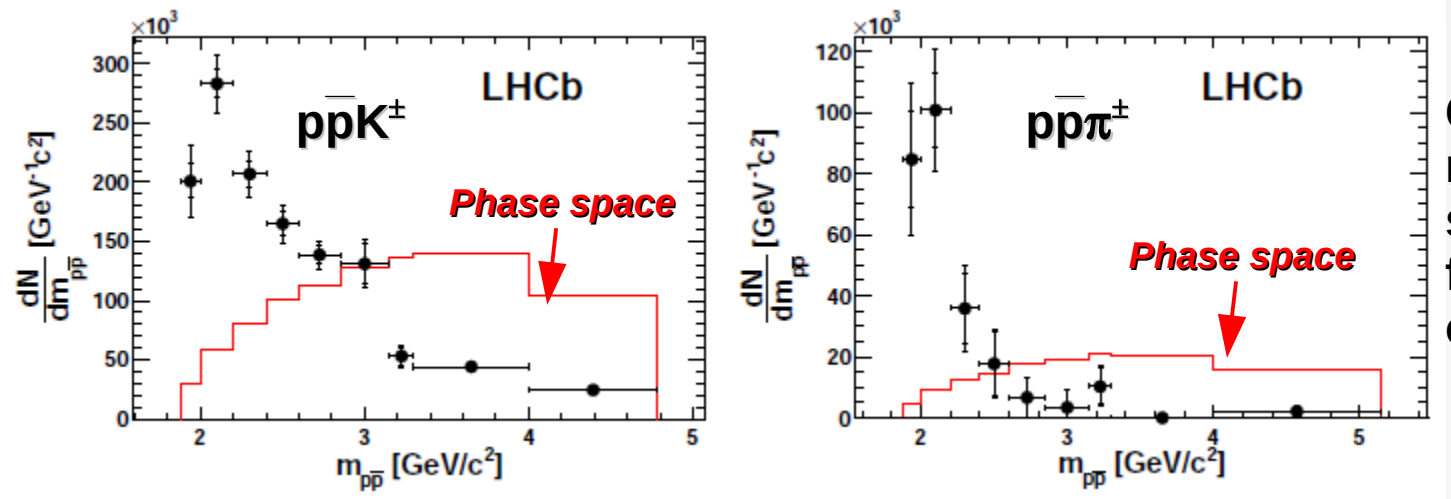
$N(B^{\pm}\to p\bar{p}K^{\pm}) = 7029\pm139$ **$N(B^{\pm}\to p\bar{p}\pi^{\pm}) = 656\pm70$**

- **Study of differential spectra: $p\bar{p}$, neutral Kp masses, cosine of the helicity angle. Chase any peculiar structure**
- **Use of $B^{\pm}\to J/\Psi\,(p\bar{p})K^{\pm}$ as a control channel**
- **Asymmetries for $B^{\pm}\to p\bar{p}K^{\pm}$**

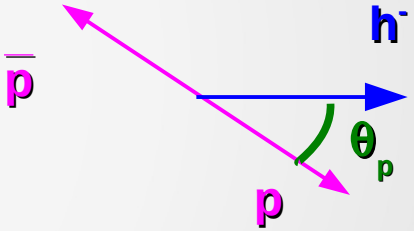
$B^{\pm} \to p\bar{p}h^{\pm}$ spectra

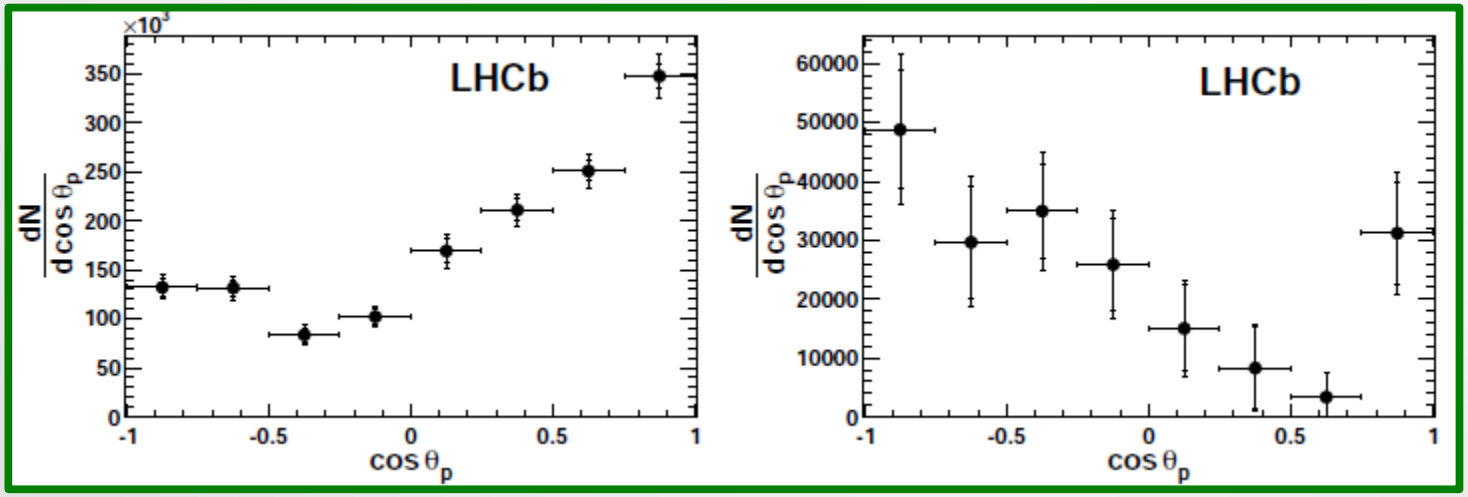
arXiv:1307.6165

$p\bar{p}$ mass spectra derived after removing charmonium contributions



Confirmation of low $m(p\bar{p})$ enhancement seen in B factories for this case and in other contexts





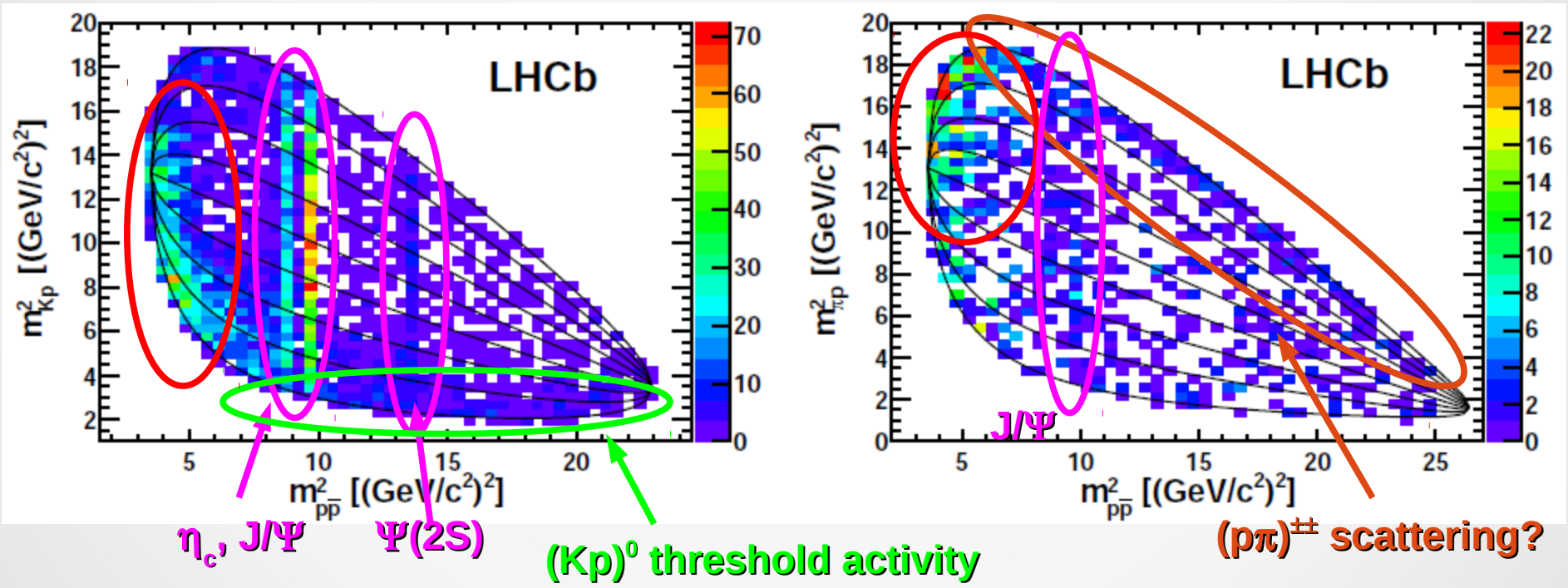
Opposite behaviour for light meson – proton correlations

$p\bar{p}\pi$ obeys to short-distance picture, $p\bar{p}K$ not. Long distance effects?

$B^{\pm}\to p\bar{p}h^{\pm}$ dynamics

Background subtracted Dalitz distributions

$B^{\pm}\to p\bar{p}K^{\pm}$ **$B^{\pm}\to p\bar{p}\pi^{\pm}$**

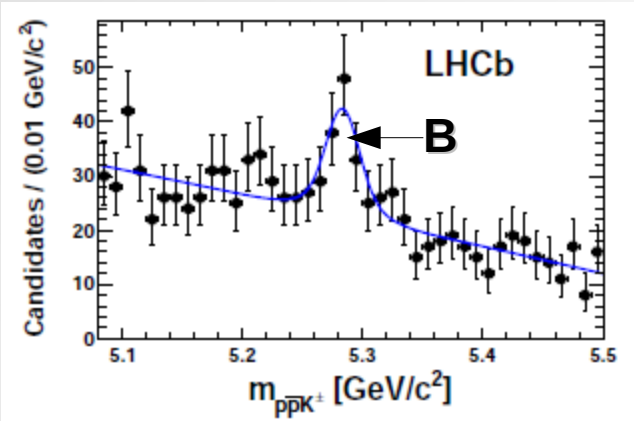


Low $p\bar{p}$ enhancement differently distributed between $p\bar{p}K$ and $p\bar{p}\pi$
Possible $p\bar{p}$ structure near 2 GeV/c^2 for $B^{\pm}\to p\bar{p}K^{\pm}$
Further investigations with more data and upgrade of the analysis

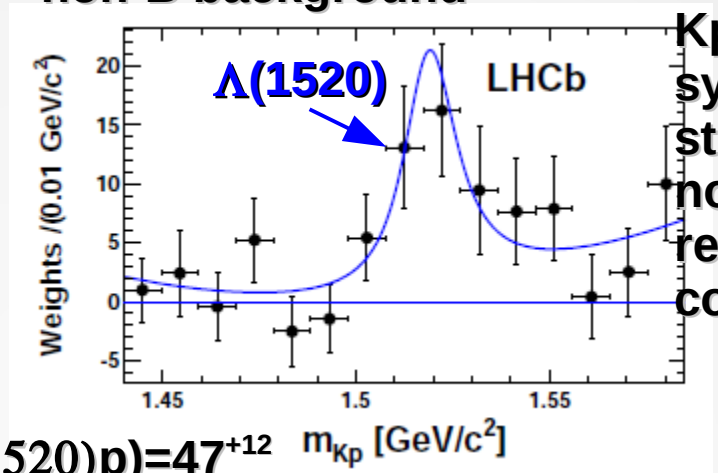
$B^{\pm}\to p\bar{p}K^{\pm}$ Kp resonance...

arXiv:1307.6165

$p\bar{p}K^{\pm}$ spectrum near Kp threshold



Kp distribution after subtraction of non-B background



Kp spectrum systematically studied with non-resonant and resonant components

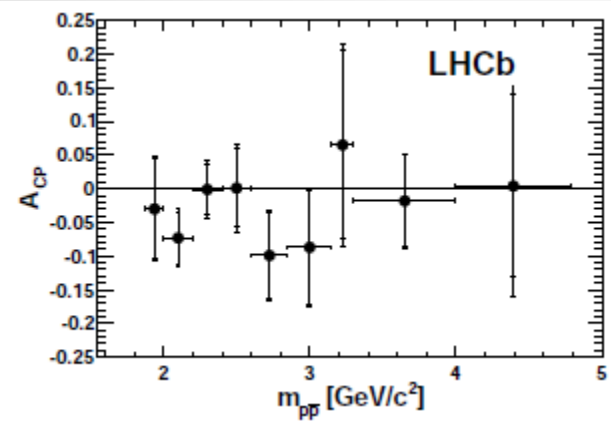
Combined fit gives $N(B^{\pm}\to\Lambda(1520)p)=47^{+12}_{-11}$

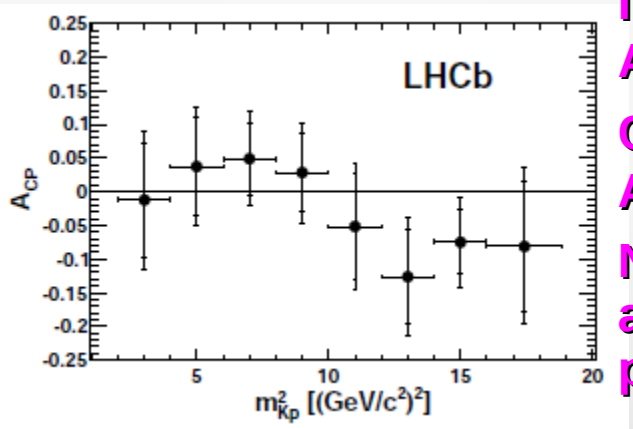
$$\frac{\mathcal{B}(B^+\to\overline{\Lambda}(1520)(\to K^+\overline{p})p)}{\mathcal{B}(B^+\to J/\psi(\to p\overline{p})K^+)}=0.041^{+0.011}_{-0.010}\ (\text{stat})\pm 0.001\ (\text{syst})$$

$$\mathcal{B}(B^+\to\overline{\Lambda}(1520)p)=(3.9^{+1.0}_{-0.9}\ (\text{stat})\pm 0.1\ (\text{syst})\pm 0.3\ (\text{BF}))\times 10^{-7}$$

Combined significance > 5.1σ

First observation of two-body charmless baryonic decay





...and asymmetries

Inclusive asymmetry

$A_{CP}(ppK^{\pm})=-0.022\pm0.031\pm0.007$

Charmless ($m(p\bar{p})<2.85$ GeV/c²)

$A_{CP}(ppK^{\pm})=-0.047\pm0.036\pm0.007$

No significant asymmetry in any projection of the Dalitz plane

$B_{(s)}^0 \to K_s h^+ h'^-$

arXiv:1307.7648

B^0 goes through loop penguins, B_s^0 through suppressed tree

Establish signals, then CP violating angle extraction in the future

Normalization to $B^0 \to K_s \pi^+ \pi^-$

Selection adds the complication of the K_s displaced vertex

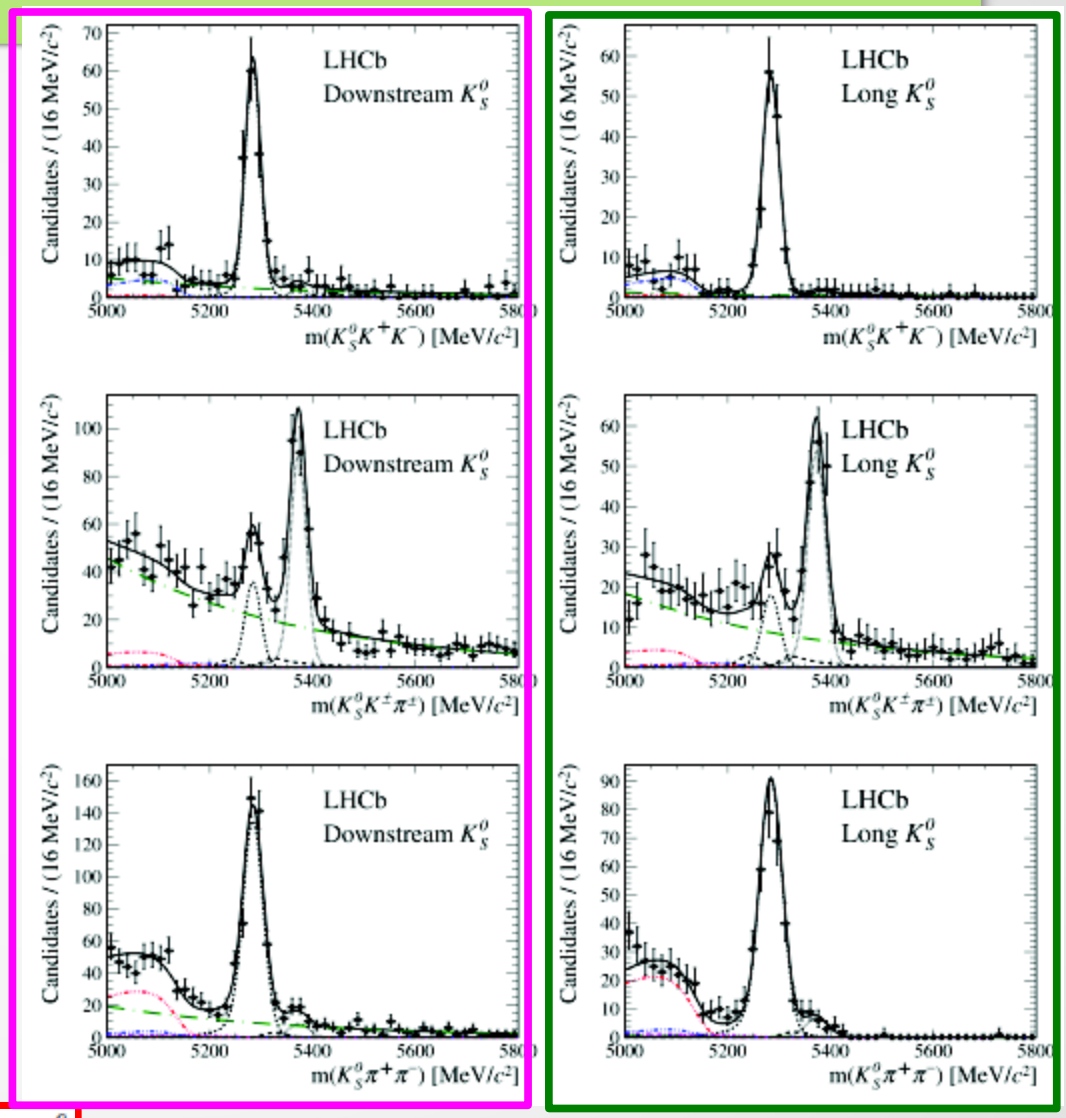
decaying in vertex locator or tracking stations

Veto background from D and charmonium resonances.

- $B^0 \to K_s K^+ \pi^-$ confirmed

- first observation of $B_s^0 \to K_s K^+ \pi^-$

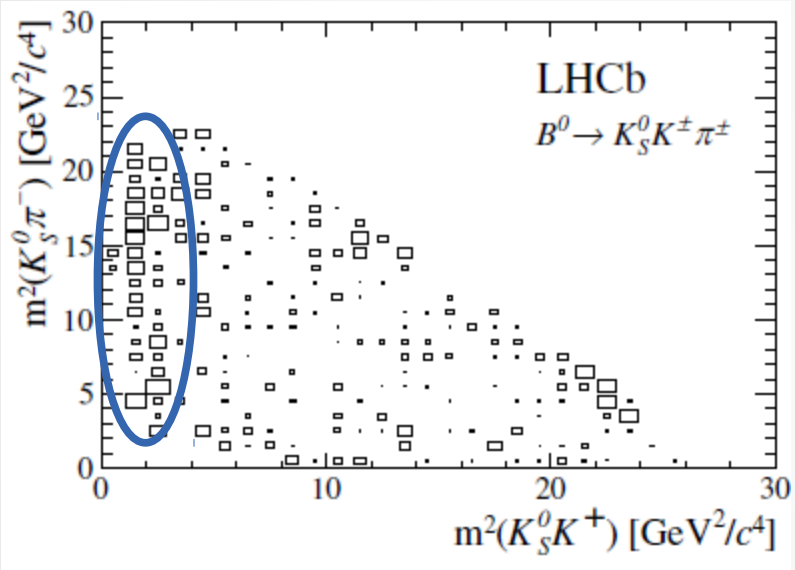
and $B_s^0 \to K_s \pi^+ \pi^-$

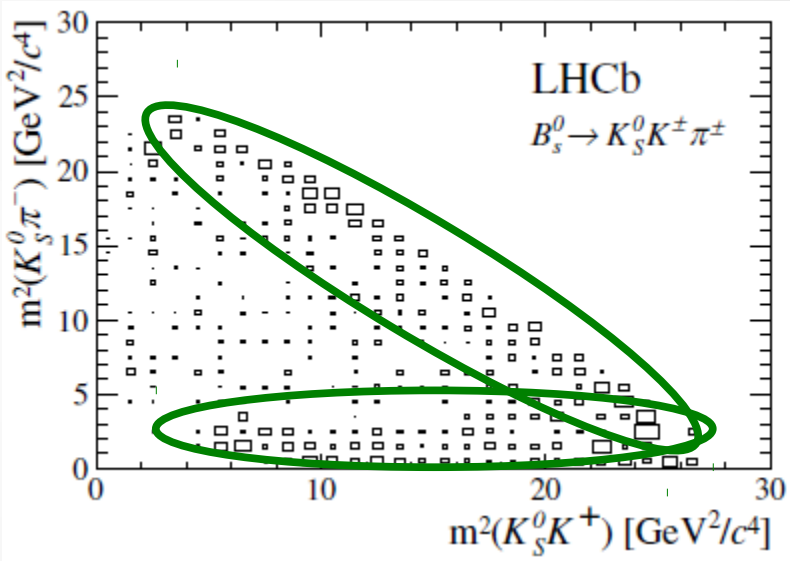


$$\mathcal{B}\left(B_s^0 \to K^0 \pi^+ \pi^-\right) = (14.3 \pm 2.8 \pm 1.8 \pm 0.6) \times 10^{-6}$$
$$\mathcal{B}\left(B_s^0 \to K^0 K^\pm \pi^\mp\right) = (73.6 \pm 5.7 \pm 6.9 \pm 3.0) \times 10^{-6}$$

$B_{(s)}^{0} \to K_s h^+ h'^-$ - dynamics

Differences show up in $B_{(s)}^{0} \to K_s K^+ \pi^-$





Further details will show up with more statistics and full amplitude analysis

Conclusion and outlook

- **Lots of (new) results (all not shown here) on two-body and three-body decays**
  - **Improvements, evidences and observations on branching fractions**
- **Big CP asymmetries showing up, globally and locally**
- **Combined amplitude analyses will help extracting CKM parameters (angles) in the future**
  - **Three-body modes have shown to be an interesting ground for that**
  - **FSI effects could be sized and interpreted with the help of old hh scattering data (e.g arXiv:1307.8164, Bediaga, Frederico, Lourenço)**
- **Charmless baryonics ramping up: B decays, but also other baryons**
  - **e.g: search for $\Lambda_b \to \Lambda\eta'$ decay (LHCb-CONF-2013-010)**
- **Most of the analyses shown are being upgraded (method and/or statistics)**
- **Whether we test (remaining) loosely constrained sectors of SM or probe NP, charmless modes are a privileged tool**