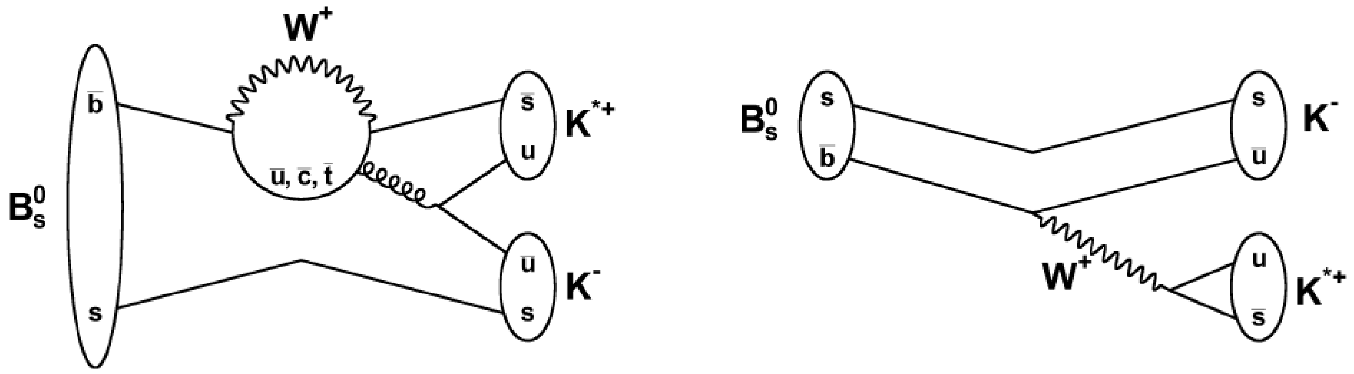
Charmless B Decays at LHCb

David Dossett on behalf of the LHCb collaboration

BEACH 2014, Birmingham University, 23rd July

Physics motivation

- Charmless decays can proceed via both tree and penguin diagrams.
- Particles in the loops make them sensitive to new physics.



- The diagrams may have different weak and strong phases.
- Comparable amplitudes of the diagrams allows the interference to be large.
- Leads to measurable CP-Violation.

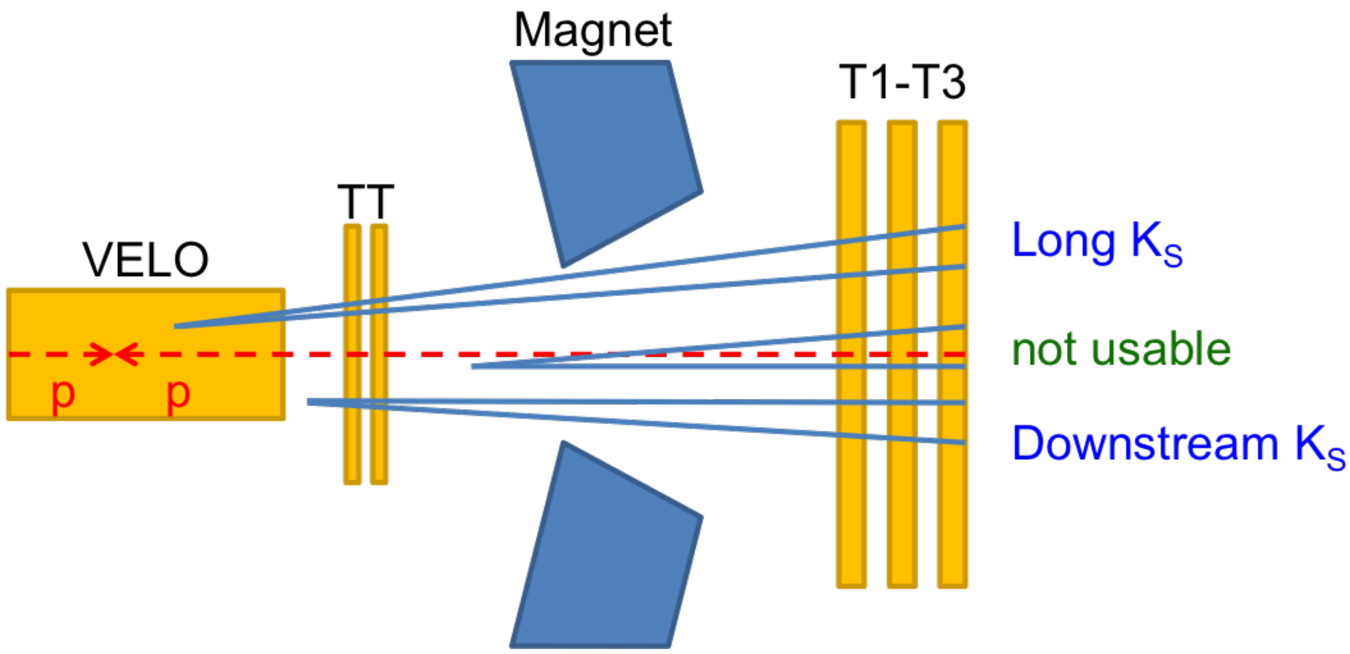
$B \to K^{*\pm} h^{\mp}$ decays

LHCb-PAPER-2014-043

- $B^0_{d,s} \to K^{*\pm} h^{\mp}$ charmless vector-pseudoscalar (VP) modes
  - K^* will always refer to the $K^*(892)$ resonance.
  - Final states are $K^0_S \pi^{\pm} h^{\mp}$ ($h = \pi, K$)
- Useful modes for U-spin symmetry and SM tests
  - e.g. Amplitudes and relative phase between $B^0_d \to K^{*+}\pi^-$ and $B^0_d \to K^0_S \rho^0$.
- Full Dalitz plot analysis required to get relative phases, but a quasi-two-body approach can provide branching fraction results faster and with much smaller data samples.
- The $B^0_d \to K^{*+}\pi^-$ mode has been previously measured, but the B_s modes and suppressed $B^0_d \to K^{*\pm}K^{\mp}$ are unobserved.

Data selection overview

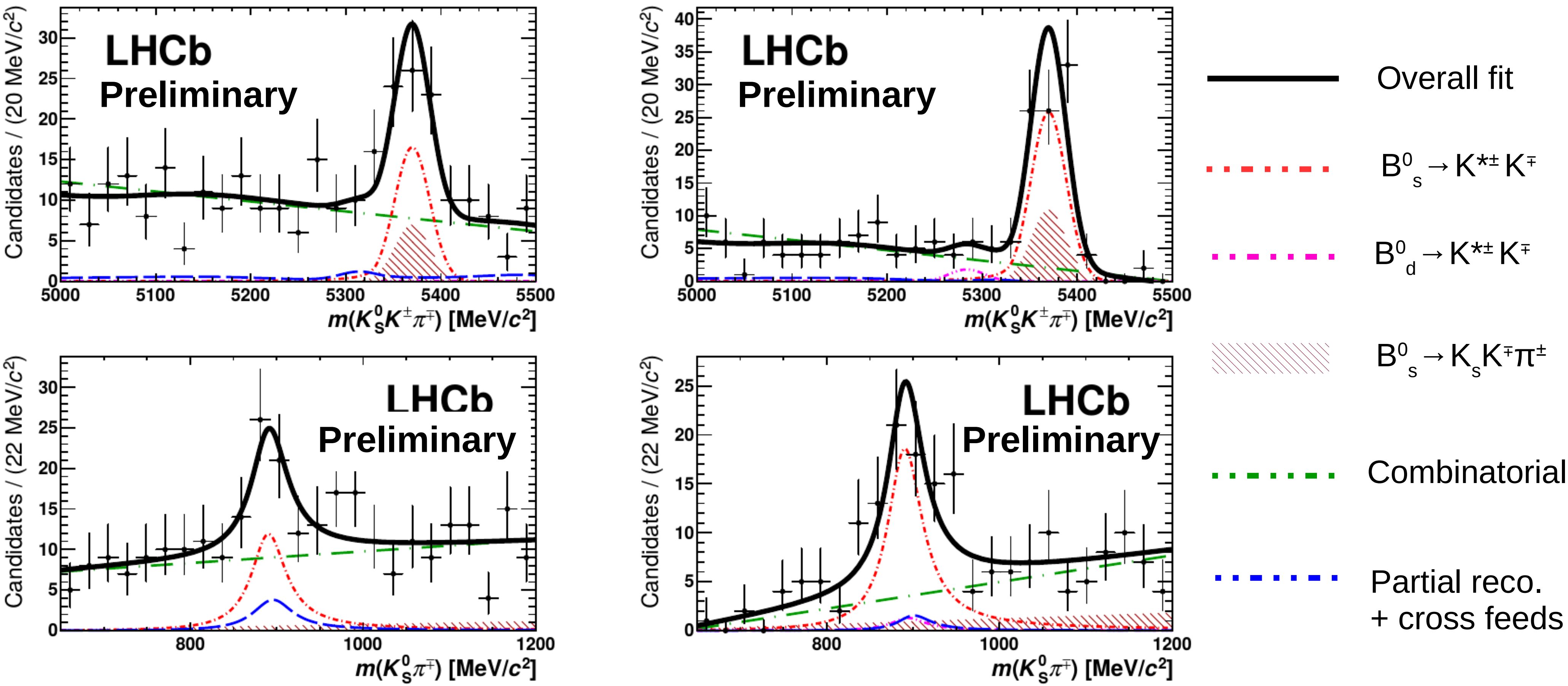
- Uses 1.0fb^{-1} from 2011 data sample.
- Tracks are combined to form K^0_s candidates and then B candidates.
- Two separate samples of K^0_s called Long and Downstream.
  - Long use tracks that have hits in the VELO subdetector to make the K^0_s candidates, Downstream do not.



$B \to K^{*\pm} K^{\mp}$ mass spectra

- 2D extended unbinned maximum likelihood fit of candidates.
- Simultaneous fit to candidates with both K^0_s categories.

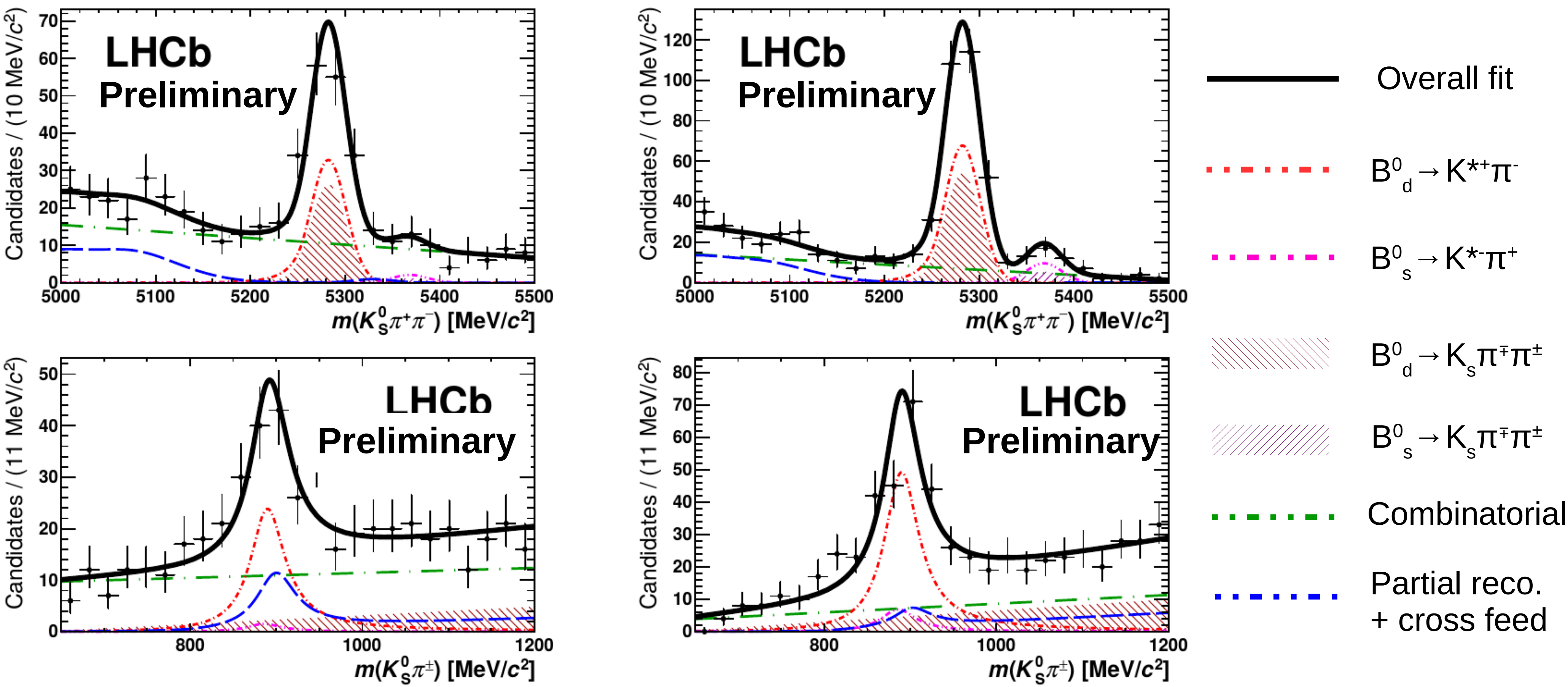
Long category **Downstream category**



$B \rightarrow K^{*\pm} \pi^{\mp}$ mass spectra

- 2D extended unbinned maximum likelihood fit of candidates.
- Simultaneous fit to candidates with both K^0_s categories.

Long category | **Downstream category**



Results

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Preliminary

- With systematic uncertainties included the yields give:
  - $B^0_s \to K^{*\pm} K^{\mp}$ = 7.8σ observation
  - $B^0_s \to K^{*-} \pi^{+}$ = 3.4σ evidence
  - $B^0_d \to K^{*\pm} K^{\mp}$ < 2σ unobserved
- Measuring branching fraction relative to known $B^0_d \to K^{*+} \pi^{-}$.

$$\mathcal{B}\left(B^0 \to K^{*+}\pi^-\right) = (8.5 \pm 0.7) \times 10^{-6}$$ HFAG arXiv:1207.1158

$$\mathcal{B}\left(B^0_s \to K^{*\pm}K^{\mp}\right) = (12.7 \pm 1.9\,(\text{stat}) \pm 1.9\,(\text{syst})) \times 10^{-6}$$

$$\begin{aligned}\mathcal{B}\left(B^0 \to K^{*\pm}K^{\mp}\right) &= (0.17 \pm 0.15\,(\text{stat}) \pm 0.05\,(\text{syst})) \times 10^{-6} \\ &< 0.4\ (0.5) \times 10^{-6} \text{ at } 90\,\%\ (95\,\%)\ \text{CL}\end{aligned}$$

$$\mathcal{B}\left(B^0_s \to K^{*-}\pi^{+}\right) = (3.3 \pm 1.1\,(\text{stat}) \pm 0.5\,(\text{syst})) \times 10^{-6}$$

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

LHCb-PAPER-2014-044

- First measurements of direct CPV with $1.0 fb^{-1}$.

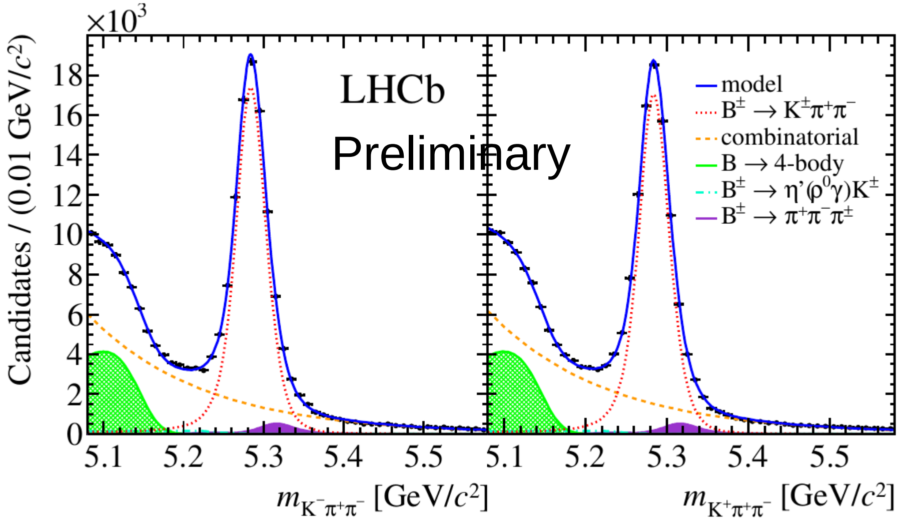
  PRL 111 (2013) 101810
  PRL 112 (2014) 011801

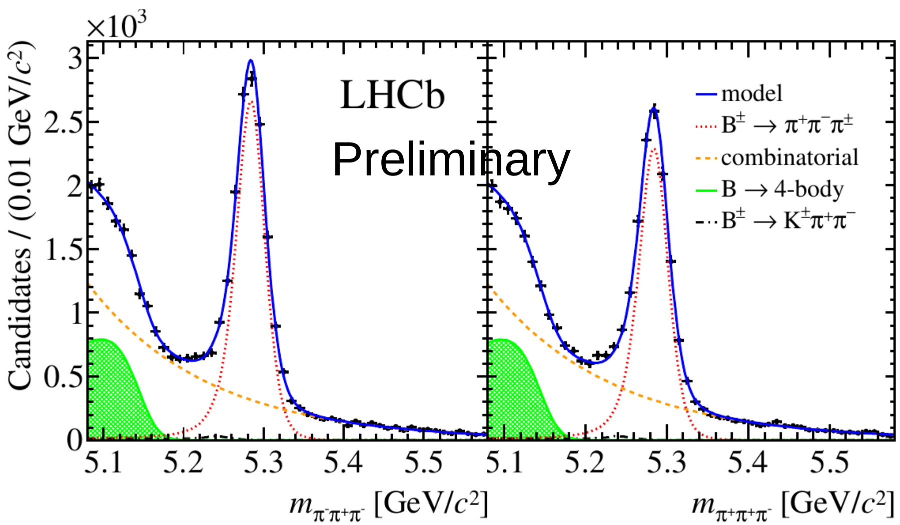
- Strong phase difference could be from several sources:
  - Timelike gluons in penguin loop.
  - Interference betweeen intermediate states.
  - $KK \leftrightarrow \pi\pi$ rescattering.
- Here presenting update with $3.0 fb^{-1}$ from 2011 and 2012 and better selection → allowing investigation of CP asymmetry in the phase space.
- Improved algorithms for particle identification and suppression of the combinatorial background.

B mass spectra

B$^-$ (left) B$^+$ (right)

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

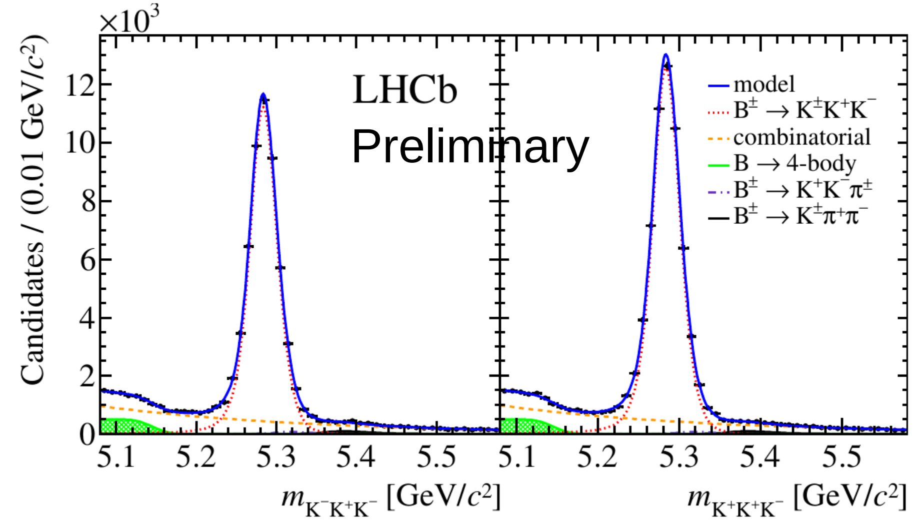


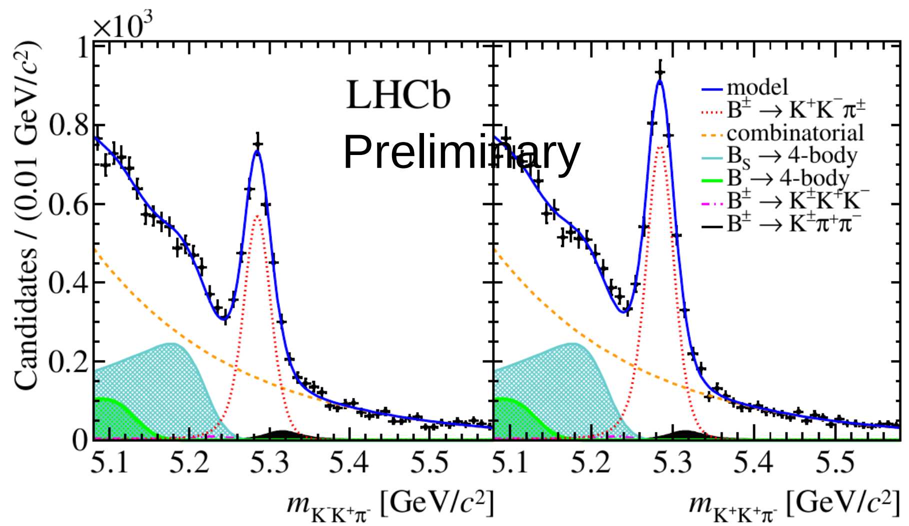


$B^\pm \rightarrow \pi^\pm \pi^+\pi^-$

B$^-$ (left) B$^+$ (right)

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





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

Inclusive CP asymmetry

- Raw asymmetry comes from the fitted yields. $A_{\rm RAW} \equiv \frac{N_{B^-} - N_{B^+}}{N_{B^-} + N_{B^+}}$
- Must be corrected by detector and production asymmetries. When small, the asymmetries have this relation.

$$A_{\rm RAW} \approx A_{CP} + A_{\rm P} + A_{\rm D}^{h'}$$

$$A_{CP}(hh\pi) = A_{\rm RAW}(hh\pi) - A_{\rm D}^{\pi} - A_{\rm P}$$

- Different detector asymmetries for $hh\pi^\pm$ and $hhK^\pm$ decays.
  - A_P and A_D^K from $B^\pm \to J/\psi K^\pm$ collision data studies.
  - A_D^π previously measured from prompt D^+. PLB 713 (2012) 186
- Acceptance correction for non-uniform efficiencies across the Dalitz plot, from simulated data.

Inclusive asymmetry results

Preliminary

$$A_{CP}(B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}) = +0.025 \pm 0.004\,(\text{stat}) \pm 0.004\,(\text{syst}) \pm 0.007(J/\psi\, K^{\pm})$$ **2.8σ**

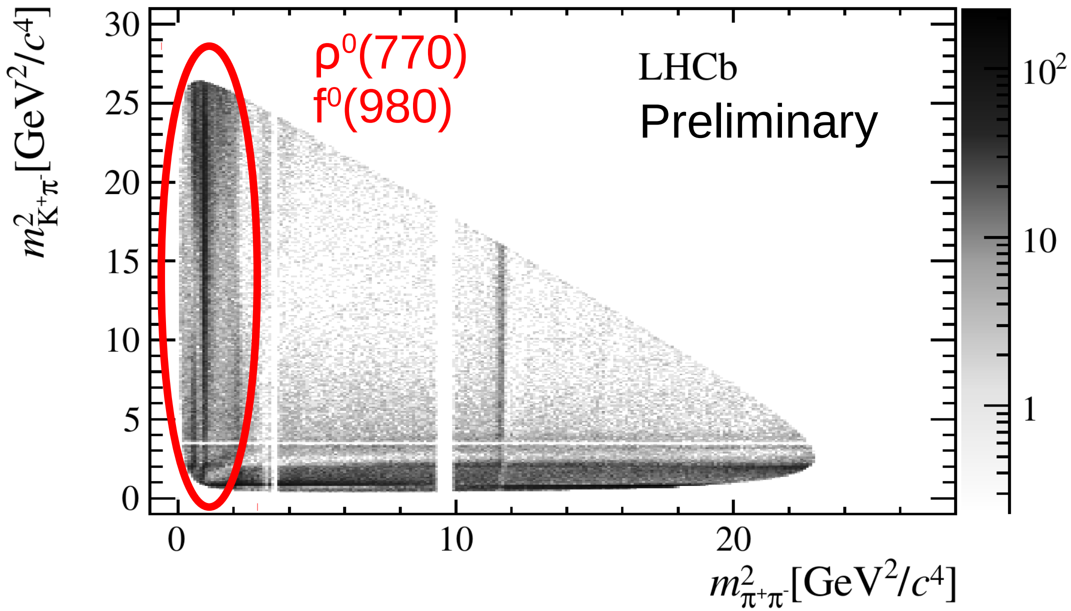
$$A_{CP}(B^{\pm} \to K^{\pm}K^{+}K^{-}) = -0.036 \pm 0.004\,(\text{stat}) \pm 0.002\,(\text{syst}) \pm 0.007(J/\psi\, K^{\pm})$$ **4.3σ**

$$A_{CP}(B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}) = +0.058 \pm 0.008\,(\text{stat}) \pm 0.009\,(\text{syst}) \pm 0.007(J/\psi\, K^{\pm})$$ **4.2σ**

$$A_{CP}(B^{\pm} \to \pi^{\pm}K^{+}K^{-}) = -0.123 \pm 0.017\,(\text{stat}) \pm 0.012\,(\text{syst}) \pm 0.007(J/\psi\, K^{\pm})$$ **5.6σ**

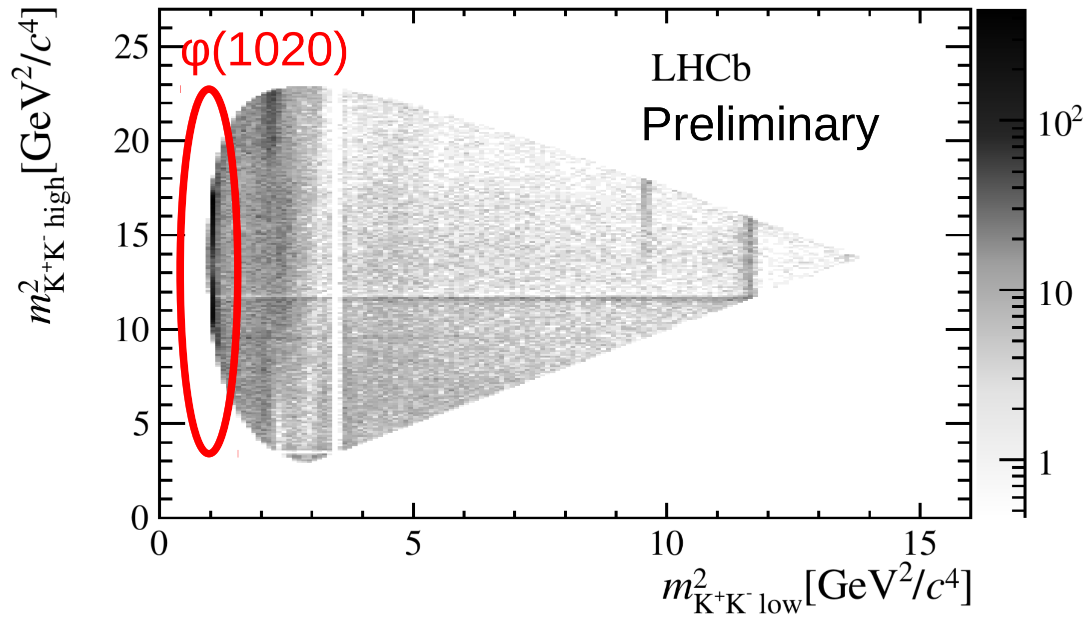
- These supersede previous LHCb results.

Dalitz plots



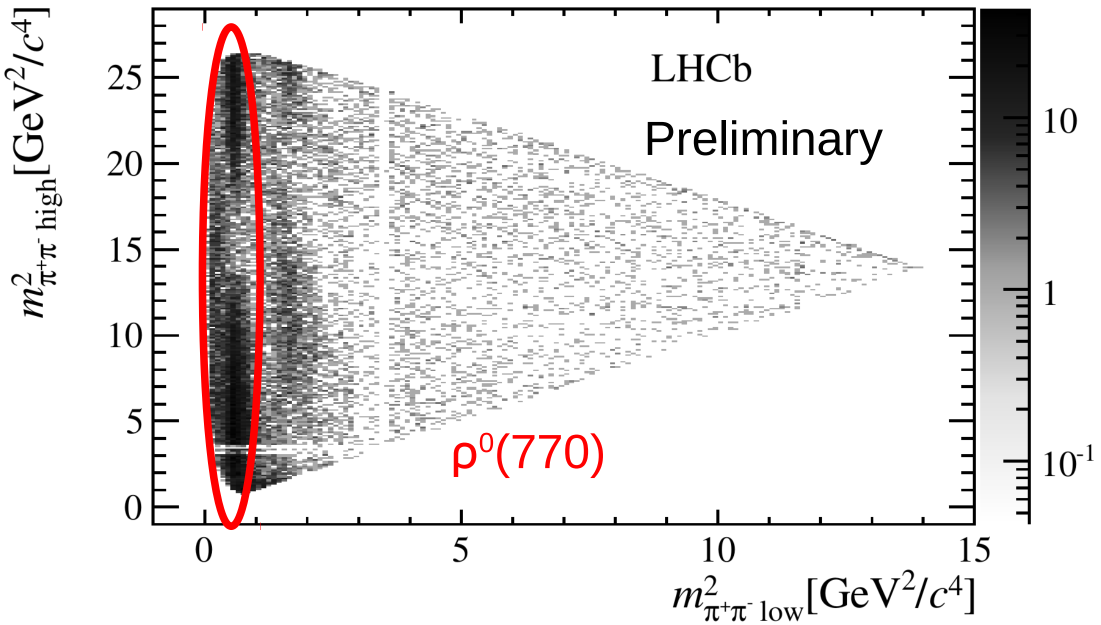
$B^{\pm} \rightarrow K^{\pm} \pi^{+}\pi^{-}$

Dalitz plots for
the signal regions



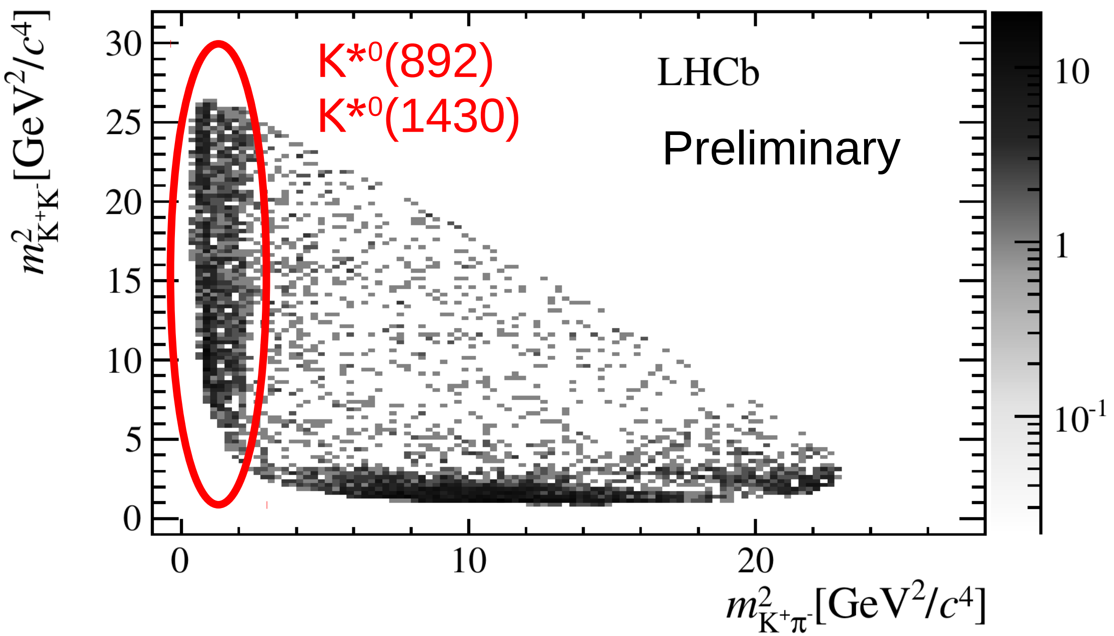
$B^{\pm} \rightarrow K^{\pm} K^{+}K^{-}$

Dalitz plots



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

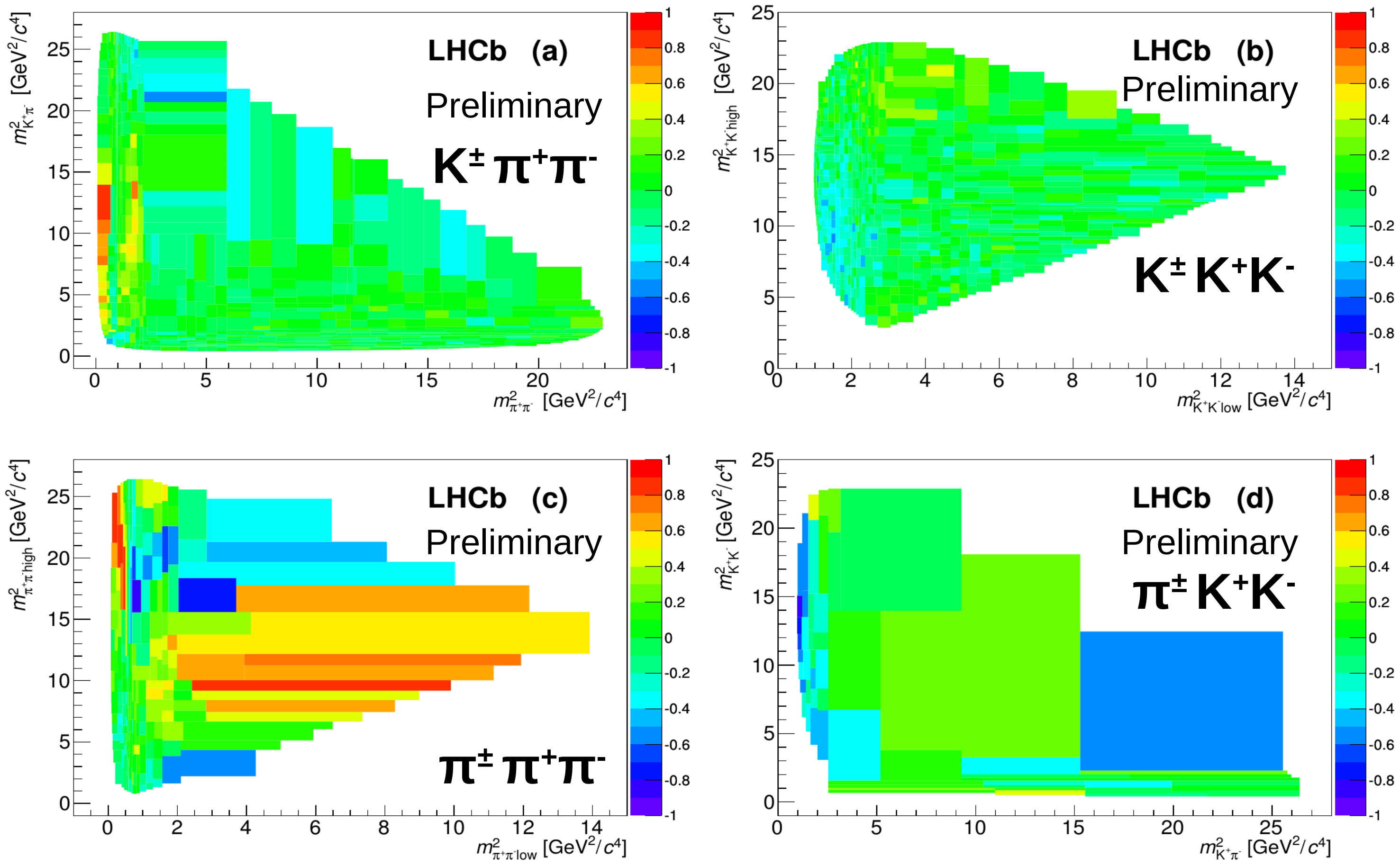
Dalitz plots for the signal regions



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

Asymmetries in phase space

- Adaptive binning keeps total events in each bin approximately constant.

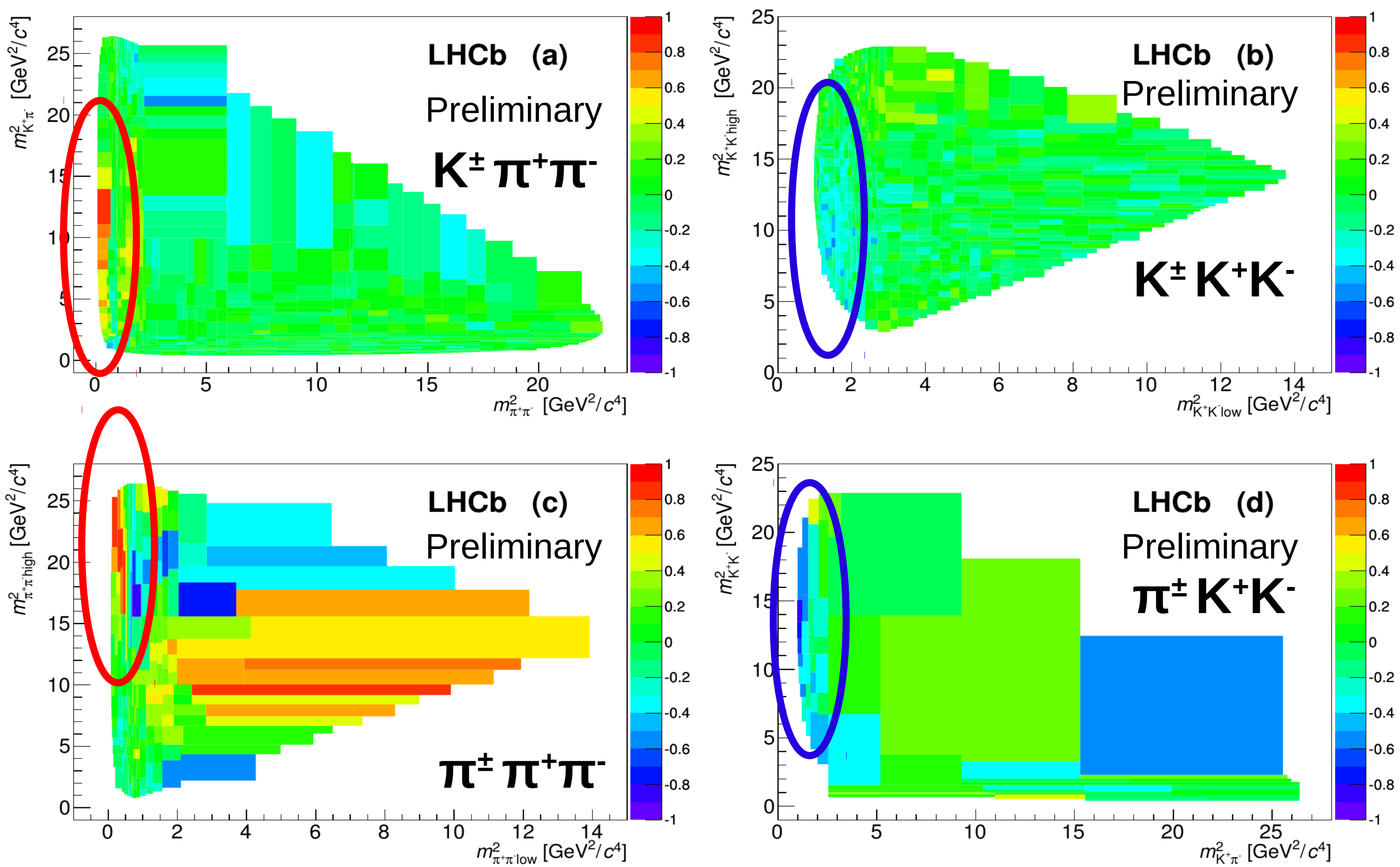


- Backgrounds are subtracted.
- Efficiencies corrected.

Asymmetries in phase space

Large positive asymmetries at low $m^2_{\pi\pi}$

Large negative asymmetries at low m^2_{KK}



- Could be accounted for by KK ↔ ππ rescattering and interference between P and S-waves.

Rescattering effects

- Study of 1.0 – 1.5 GeV/c^2 m^2_{hh} regions show large asymmetry.
- Opposite signs for ππ and KK suggesting rescattering is an important contribution.

Preliminary

Decay	N_s	$A_{CP} \pm \sigma_{(stat)} \pm \sigma_{(syst)} \pm \sigma_{(J/\psi K^{\pm})}$
$B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$	15562 ± 165	$+0.121 \pm 0.012 \pm 0.017 \pm 0.007$
$B^{\pm} \to K^{\pm}K^{+}K^{-}$	16992 ± 142	$-0.211 \pm 0.011 \pm 0.004 \pm 0.007$
$B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$	4329 ± 76	$+0.172 \pm 0.021 \pm 0.015 \pm 0.007$
$B^{\pm} \to \pi^{\pm}K^{+}K^{-}$	2500 ± 57	$-0.328 \pm 0.028 \pm 0.029 \pm 0.007$

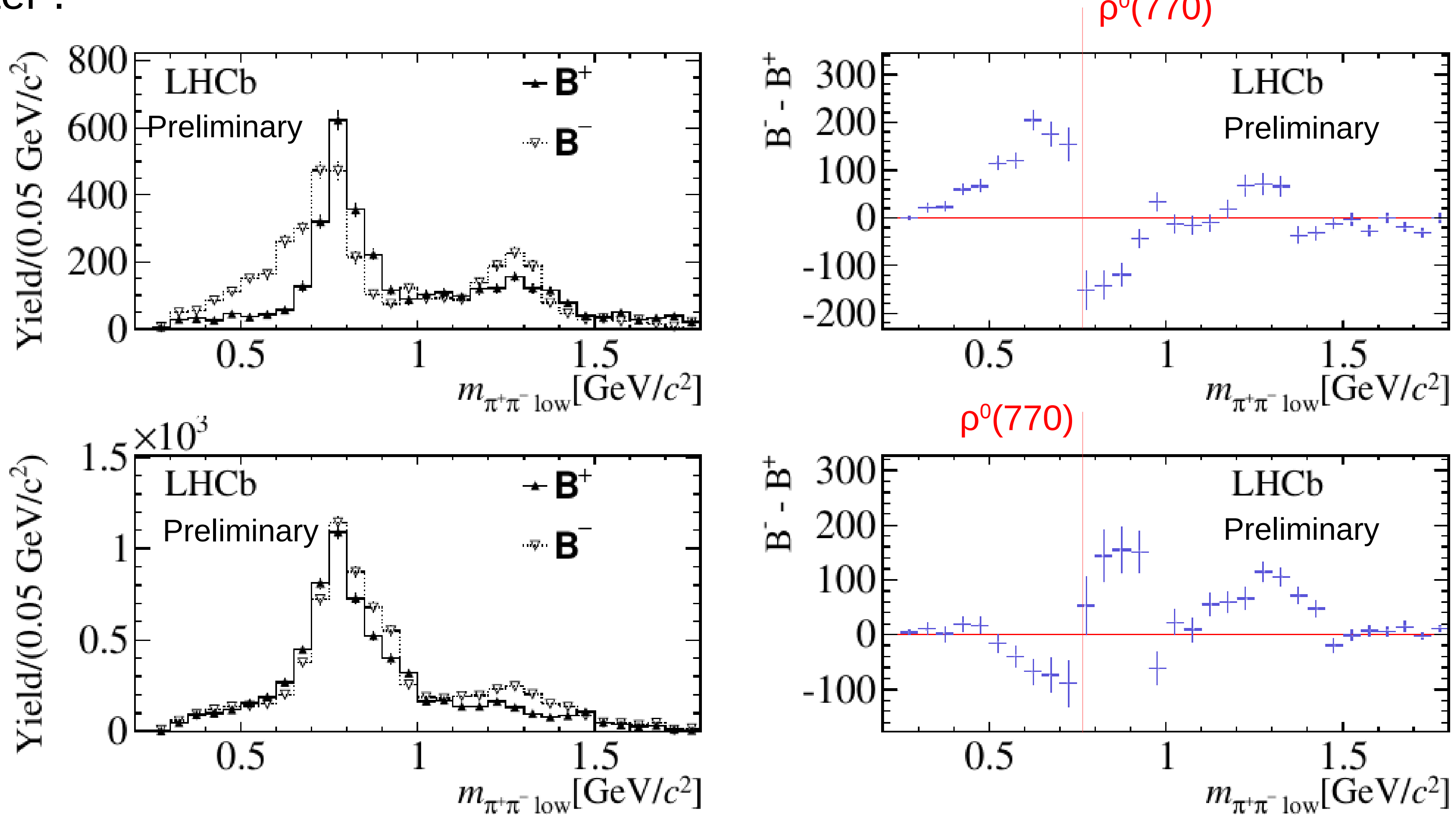
All > 5σ

S and P-wave interference

- $\rho^0(770)$ region shows interesting CP trends depending on $m_{\pi\pi}$ and cosθ.
- The angle (θ) is between the unpaired hadron and the same sign resonance daughter .

cos θ < 0

cos θ > 0



CPV from interference

- CP asymmetries around some vector resonances.

Decay mode	Resonance	Sector	N_s	$A_{CP} \pm \sigma_{(stat)} \pm \sigma_{(syst)} \pm \sigma_{(J/\psi K^\pm)}$
$B^\pm \to K^\pm \pi^+ \pi^-$	ρ	I	2909 ± 80	$-0.052 \pm 0.032 \pm 0.047 \pm 0.007$
		II	6136 ± 100	$+0.140 \pm 0.018 \pm 0.034 \pm 0.007$
		III	2856 ± 86	$+0.598 \pm 0.036 \pm 0.079 \pm 0.007$
		IV	2107 ± 55	$-0.208 \pm 0.043 \pm 0.042 \pm 0.007$
$B^\pm \to K^\pm \pi^+ \pi^-$	K^*	I	11095 ± 115	$+0.002 \pm 0.013 \pm 0.011 \pm 0.007$
		II	7159 ± 89	$+0.007 \pm 0.016 \pm 0.005 \pm 0.007$
		III	2427 ± 65	$-0.009 \pm 0.031 \pm 0.054 \pm 0.007$
		IV	9861 ± 124	$-0.020 \pm 0.015 \pm 0.010 \pm 0.007$
$B^\pm \to \pi^\pm \pi^+ \pi^-$	ρ	I	2629 ± 59	$+0.302 \pm 0.026 \pm 0.015 \pm 0.007$
		II	1653 ± 46	$-0.244 \pm 0.034 \pm 0.019 \pm 0.007$
		III	5204 ± 79	$-0.076 \pm 0.019 \pm 0.007 \pm 0.007$
		IV	4476 ± 72	$+0.055 \pm 0.020 \pm 0.013 \pm 0.007$
$B^\pm \to K^\pm K^+ K^-$	ϕ	I	3082 ± 56	$-0.018 \pm 0.024 \pm 0.008 \pm 0.007$
		II	4119 ± 64	$-0.008 \pm 0.021 \pm 0.004 \pm 0.007$
		III	1546 ± 39	$+0.066 \pm 0.034 \pm 0.010 \pm 0.007$
		IV	2719 ± 53	$+0.015 \pm 0.026 \pm 0.002 \pm 0.007$

Preliminary

- Significant asymmetry for $\rho^0(770)$ resonances.

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

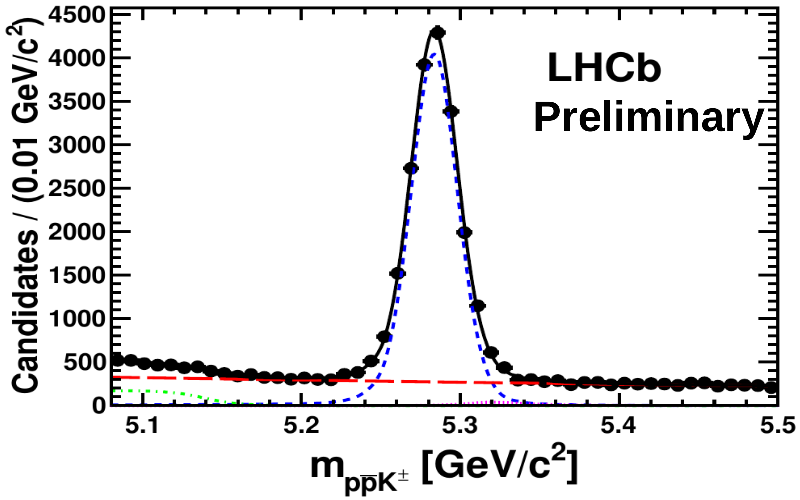
LHCb-PAPER-2014-034

- While large CPV seen in $B^{\pm} \to h^{\pm} h^{+} h^{-}$ decays, expect smaller amount here.
- Due to smaller expected rescattering of $hh \leftrightarrow pp$.
- Here presenting update to PRD 88 (2013) 052015, with the $3.0 fb^{-1}$ data sample.
- Measure:
  - Branching fraction of $B^{+} \to \bar{\Lambda}(1520)p$ $(\bar{\Lambda} \to \bar{p}K)$.
  - Forward-backward asymmetry.
  - CPV in phase space of decay.

Branching fraction $B^+ \to \overline{\Lambda}(1520)p$ ($\overline{\Lambda} \to \overline{p}K$)

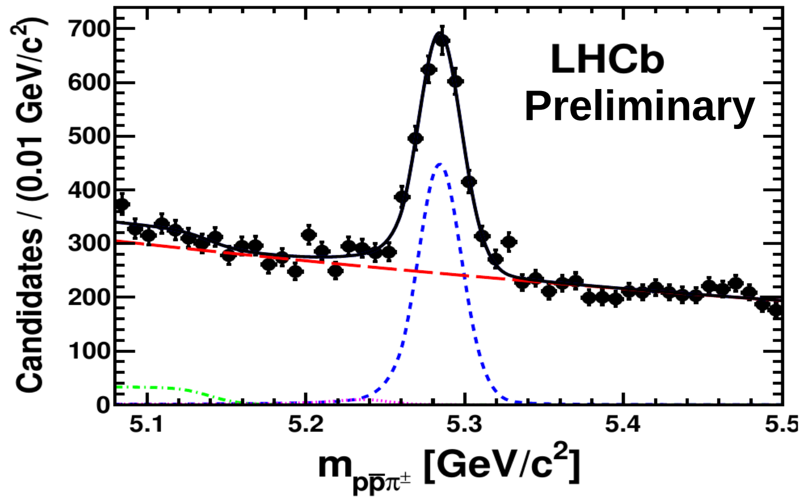
- Inclusive yields for both modes extracted.

$B^\pm \to K^\pm p\overline{p}$



$N = 18721 \pm 142$

$B^\pm \to \pi^\pm p\overline{p}$



$N = 1988 \pm 74$

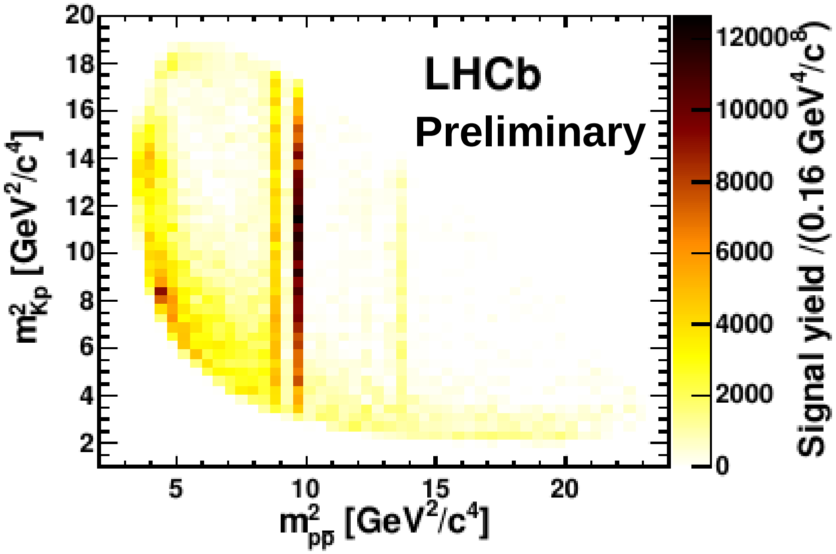
- 2D fit to $h^\pm p\overline{p}$ and $p\overline{p}$ or $K^+\overline{p}$ mass combinations to extract resonance yields.
- Measure relative to the $B^+ \to J/\psi(\to p\overline{p})\, h^+$ modes and use previous measurements to give absolute B.F.

$$\mathcal{B}(B^+ \to \overline{\Lambda}(1520)p) = (3.15 \pm 0.48\ (\text{stat}) \pm 0.07\ (\text{syst}) \pm 0.26\ (\text{BF})) \times 10^{-7}$$

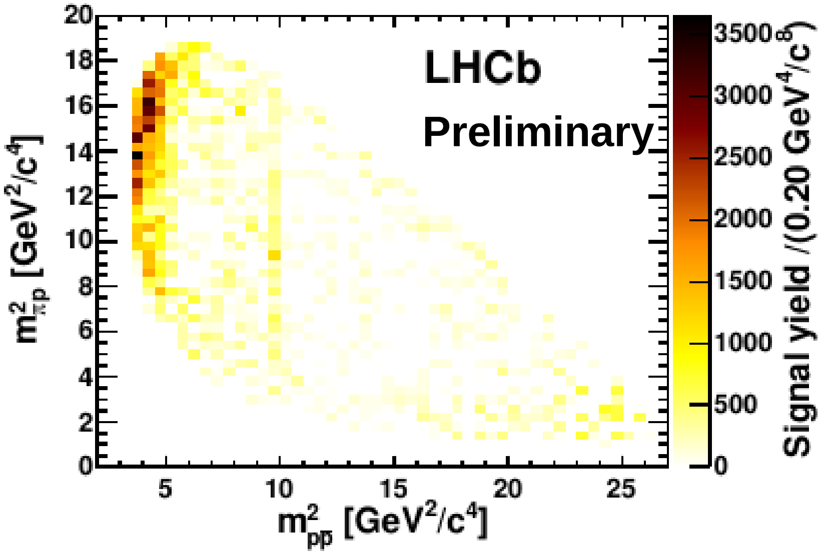
Dalitz plots

- Background subtracted and efficiency corrected.

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



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



- Charmonium bands clearly visible e.g. J/ψ, ψ(2S)
- Charmless events cluster around low m^2_{pp}.
  - Different helicity (θ_p) distributions between π and K modes.

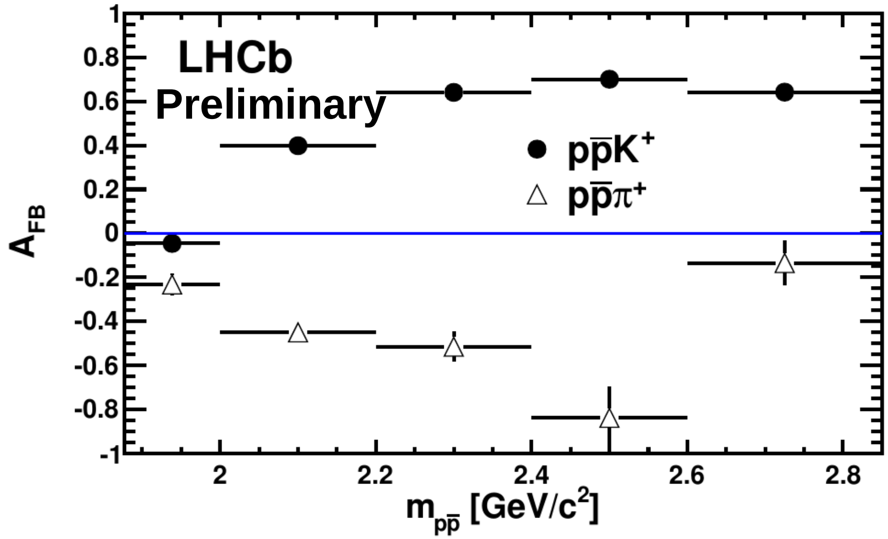
Forward-backward asymmetry

- Forward-backward asymmetry defined as $$A_{\mathrm{FB}} = \frac{N_{\mathrm{pos}} - N_{\mathrm{neg}}}{N_{\mathrm{pos}} + N_{\mathrm{neg}}}$$

- N_{neg} and N_{pos} refer to the efficiency corrected yields for $\cos\theta_p > 0$ or < 0.

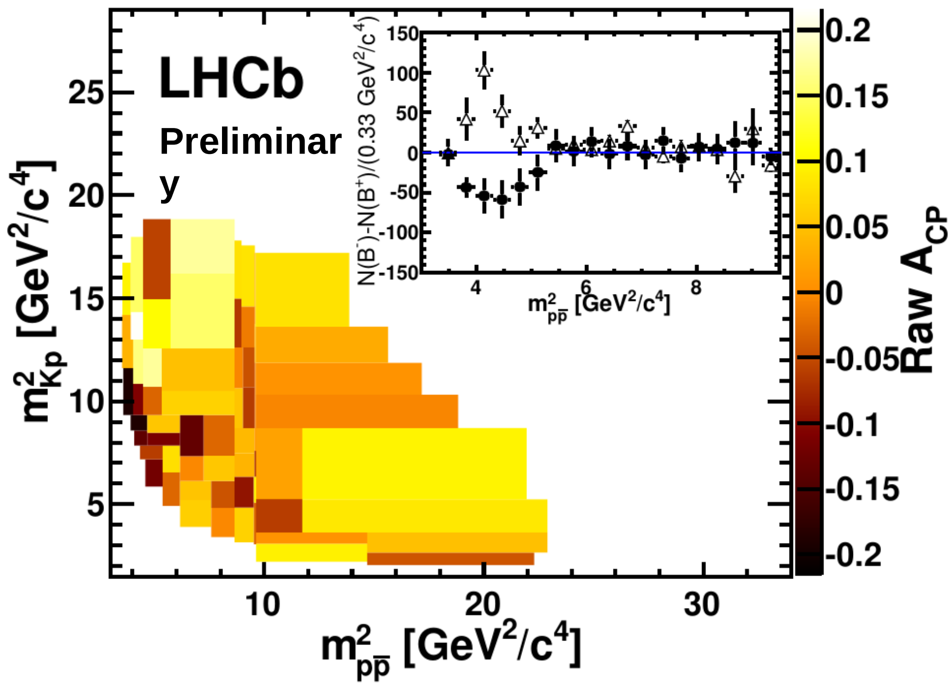
- Results: $$A_{\mathrm{FB}}(p\bar{p}K^+,\ m_{p\bar{p}} < 2.85\,\mathrm{GeV}/c^2) = 0.495 \pm 0.012\ (\mathrm{stat}) \pm 0.007\ (\mathrm{syst})$$
$$A_{\mathrm{FB}}(p\bar{p}\pi^+,\ m_{p\bar{p}} < 2.85\,\mathrm{GeV}/c^2) = -0.409 \pm 0.033\ (\mathrm{stat}) \pm 0.006\ (\mathrm{syst})$$

- Value of A_{FB} is strongly dependent on $m_{p\bar{p}}$



CP asymmetry

- Only enough events to analyse $B^{\pm} \rightarrow K^{\pm} p\bar{p}$.
- Adaptive binning algorthm again, raw A_{CP} here plotted.
- Sign flip between low and high values of m_{Kp} at low $m_{p\bar{p}}$.
  - Equivalent to flip across cosθ >0 and <0.



CP asymmetry results

- Raw asymmetries are corrected (similar to before) to give A_{CP}.

Preliminary

Mode/region	A_{CP}	
$\eta_c(\to p\bar{p})K^{\pm}$	0.040 ± 0.034 (stat)±0.004 (syst)	
$\psi(2S)(\to p\bar{p})K^{\pm}$	0.092 ± 0.058 (stat)±0.004 (syst)	
$p\bar{p}K^{\pm},\ m_{p\bar{p}} < 2.85\,\mathrm{GeV}/c^2$	0.021 ± 0.020 (stat)±0.004 (syst)	
$p\bar{p}K^{\pm},\ m_{p\bar{p}} < 2.85\,\mathrm{GeV}/c^2,\ m^2_{Kp} < 10\,\mathrm{GeV}^2/c^4$	-0.036 ± 0.023 (stat)±0.004 (syst)	
$p\bar{p}K^{\pm},\ m_{p\bar{p}} < 2.85\,\mathrm{GeV}/c^2,\ m^2_{Kp} > 10\,\mathrm{GeV}^2/c^4$	0.096 ± 0.024 (stat)±0.004 (syst)	**4σ**
$p\bar{p}\pi^{\pm},\ m_{p\bar{p}} < 2.85\,\mathrm{GeV}/c^2$	-0.041 ± 0.039 (stat)±0.005 (syst)	

- First evidence of CPV in baryonic B decays.
- Systematics dominated by measurement of $A_{CP}(B^+ \to J/\psi K^{\pm})$

Summary

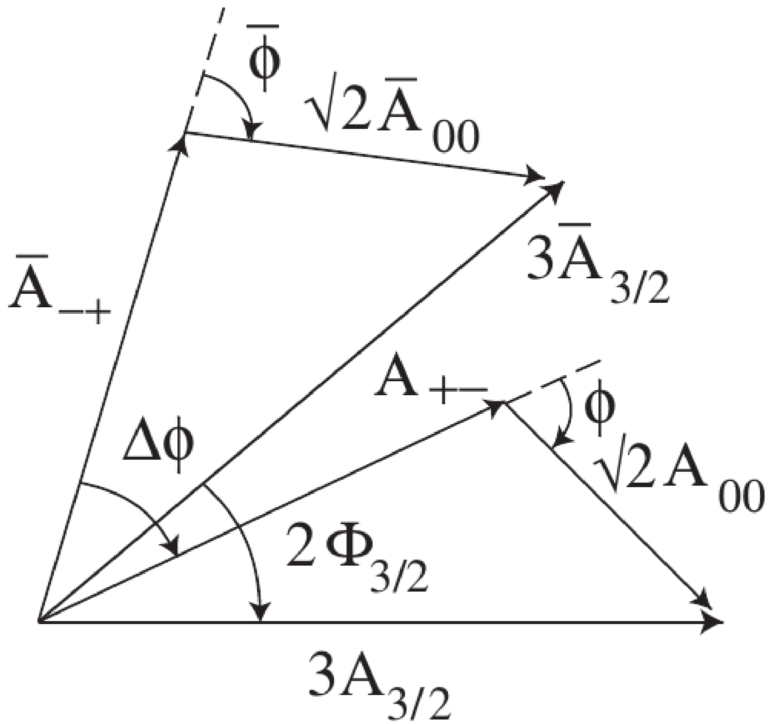
- $B^0_{d,s} \to K^{*\pm} K^{\mp}$ decays
  - First observation of $B^0_s \to K^{*\pm} K^{\mp}$ and evidence for $B^0_s \to K^{*-}\pi^+$.
  - Limits placed on $B^0_d \to K^{*\pm} K^{\mp}$ branching fractions.
- $B^\pm \to h^\pm h^+ h^-$ decays
  - CP asymmetries are not uniform in phase space.
  - $\pi\pi \leftrightarrow KK$ rescattering is apparent.
  - P/S-wave interference effects seem important around the $\rho^0(770)$ resonance.
- $B^\pm \to h^\pm p\bar{p}$ decays
  - First evidence of CPV in baryonic B decays in $B^\pm \to K^\pm p\bar{p}$.
  - Improved measurement of B.F. of $B^+ \to \bar{\Lambda}(1520)p$ ($\bar{\Lambda} \to \bar{p}K$) decay.
- Full amplitude analysis should reduce some systematics and determine the exact reasons for the non-uniform CP asymmetries.

Backup

SM tests

$$\mathcal{B}\left(B_s^0 \to K^{*+}K^-\right) \approx \mathcal{B}\left(B^0 \to \rho^+ K^-\right)$$
$$\mathcal{B}\left(B_s^0 \to K^{*-}K^+\right) \approx \mathcal{B}\left(B^0 \to K^{*-}\pi^+\right)$$

$$3A_{3/2} = A(B^0 \to K^{*+}\pi^-) + \sqrt{2}A(B^0 \to K^{*0}\pi^0)$$



$$\gamma = \Phi_{3/2} \equiv -\frac{1}{2}\arg\left(\frac{\bar{A}_{3/2}}{A_{3/2}}\right)$$

$K_s$pipi and Kpipi^0

$B \to K^*K$ yields

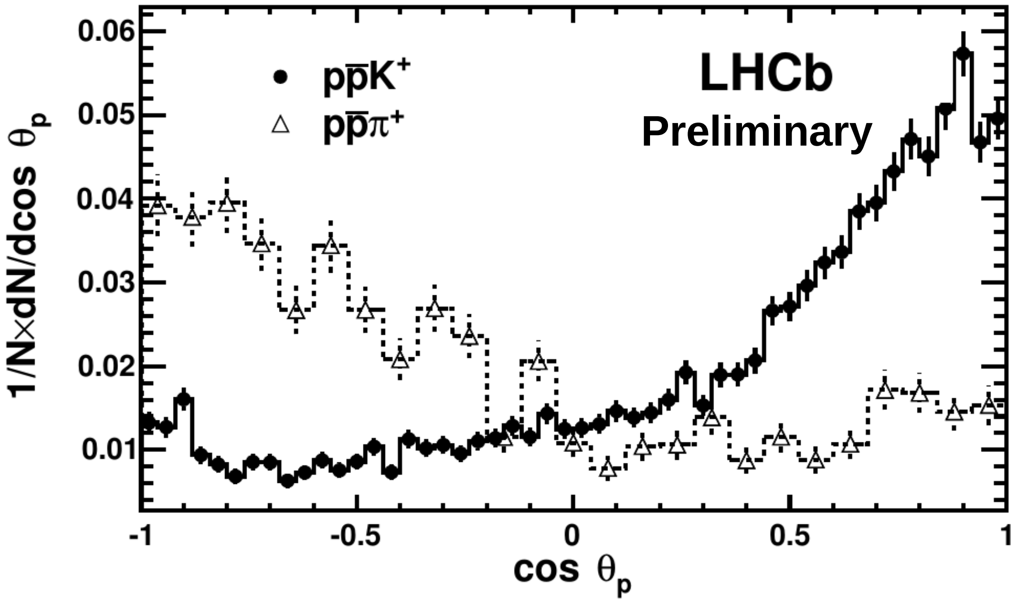
	B^0		B_s^0	
	long	downstream	long	downstream
$K^{*\pm}K^{\mp}$	0 ± 4	4 ± 3	40 ± 8	62 ± 10
$K^{*\pm}\pi^{\mp}$	80 ± 10	165 ± 16	5 ± 4	23 ± 8

CP asymmetry formula

$$A_{\mathrm{RAW}} = \frac{A_{CP} + A_{\mathrm{P}} + A_{\mathrm{D}}^{h'} + A_{CP}A_{\mathrm{P}}A_{\mathrm{D}}^{h'}}{1 + A_{CP}A_{\mathrm{P}} + A_{CP}A_{\mathrm{D}}^{h'} + A_{\mathrm{P}}A_{\mathrm{D}}^{h'}}$$

Helicity angle

- Looking at the charmless region $m_{p\bar{p}} < 2.85 GeV/c^2$.
- θ_p is the helicity angle of the $p\bar{p}$ system.
- Acceptance corrected and normalised distributions.



- Opposite behaviour between the two modes.