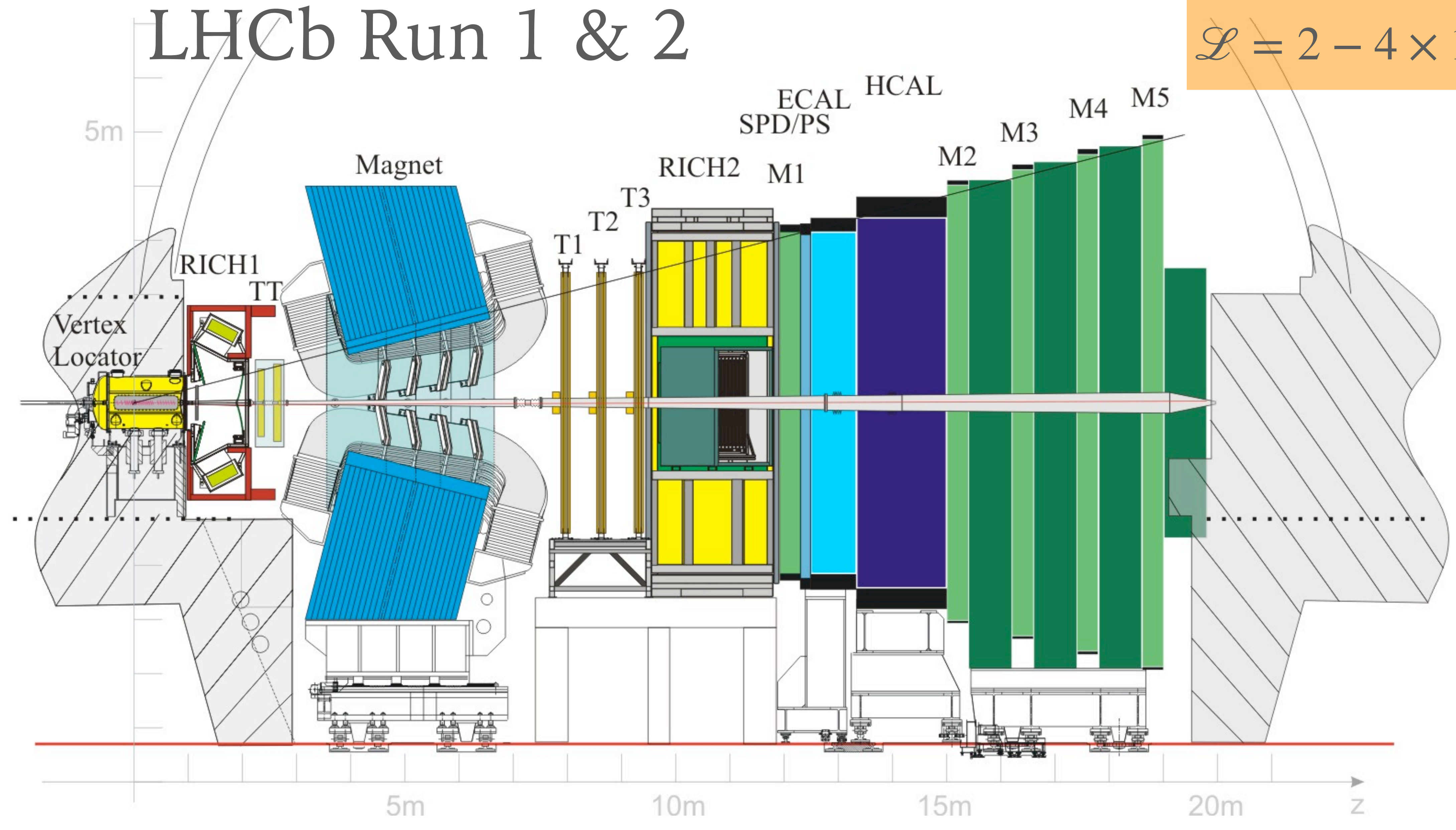
MEASUREMENTS OF CHARMLESS THREE-BODY DECAYS

Renaud Amalric - LPNHE, Paris
On behalf of the LHCb Collaboration

ICHEP - *20/07/2024*

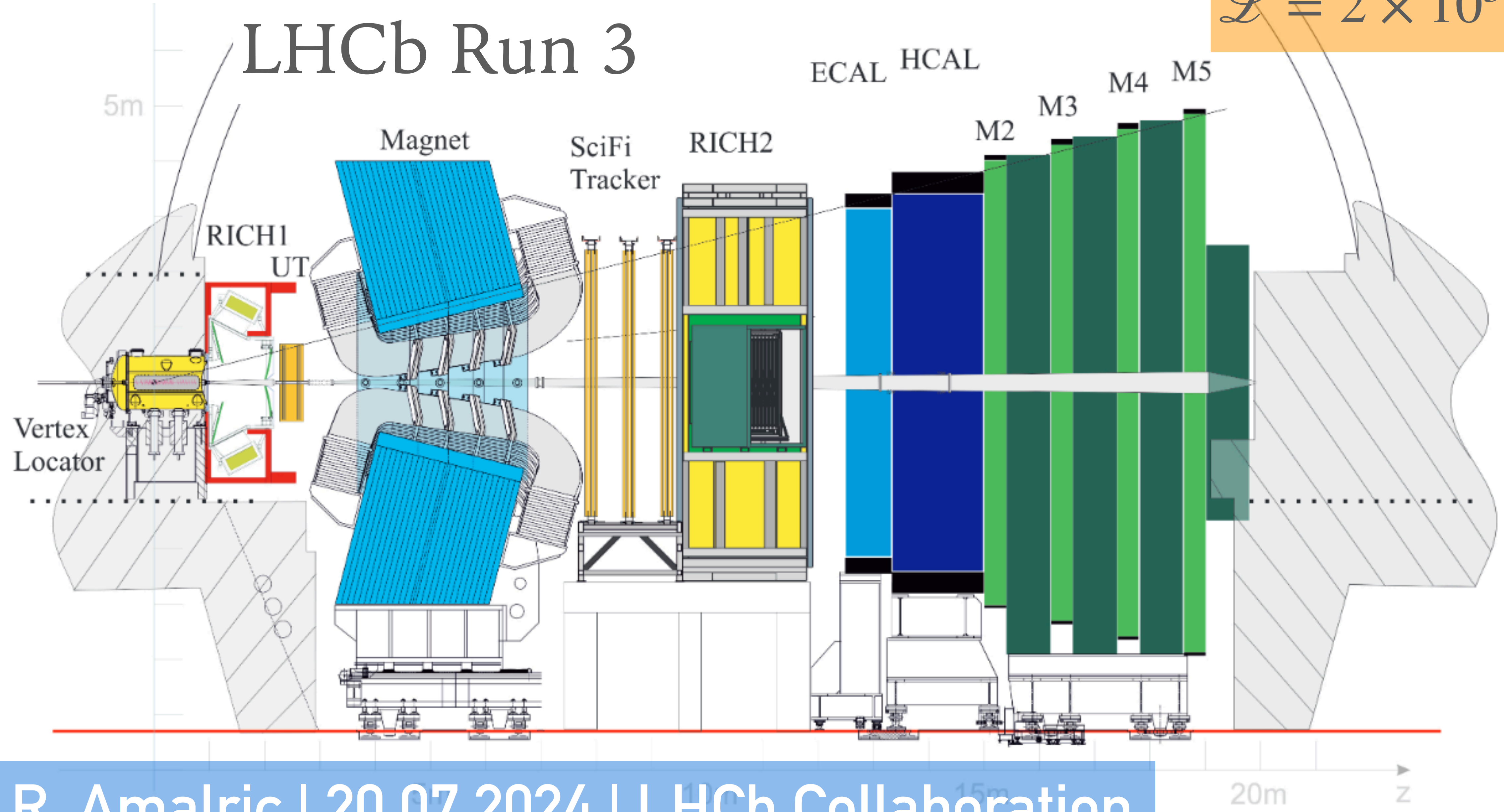
LHCb



$\mathscr{L} = 2-4\times10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

$\times$ 5 the luminosity

$\mathscr{L} = 2\times10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

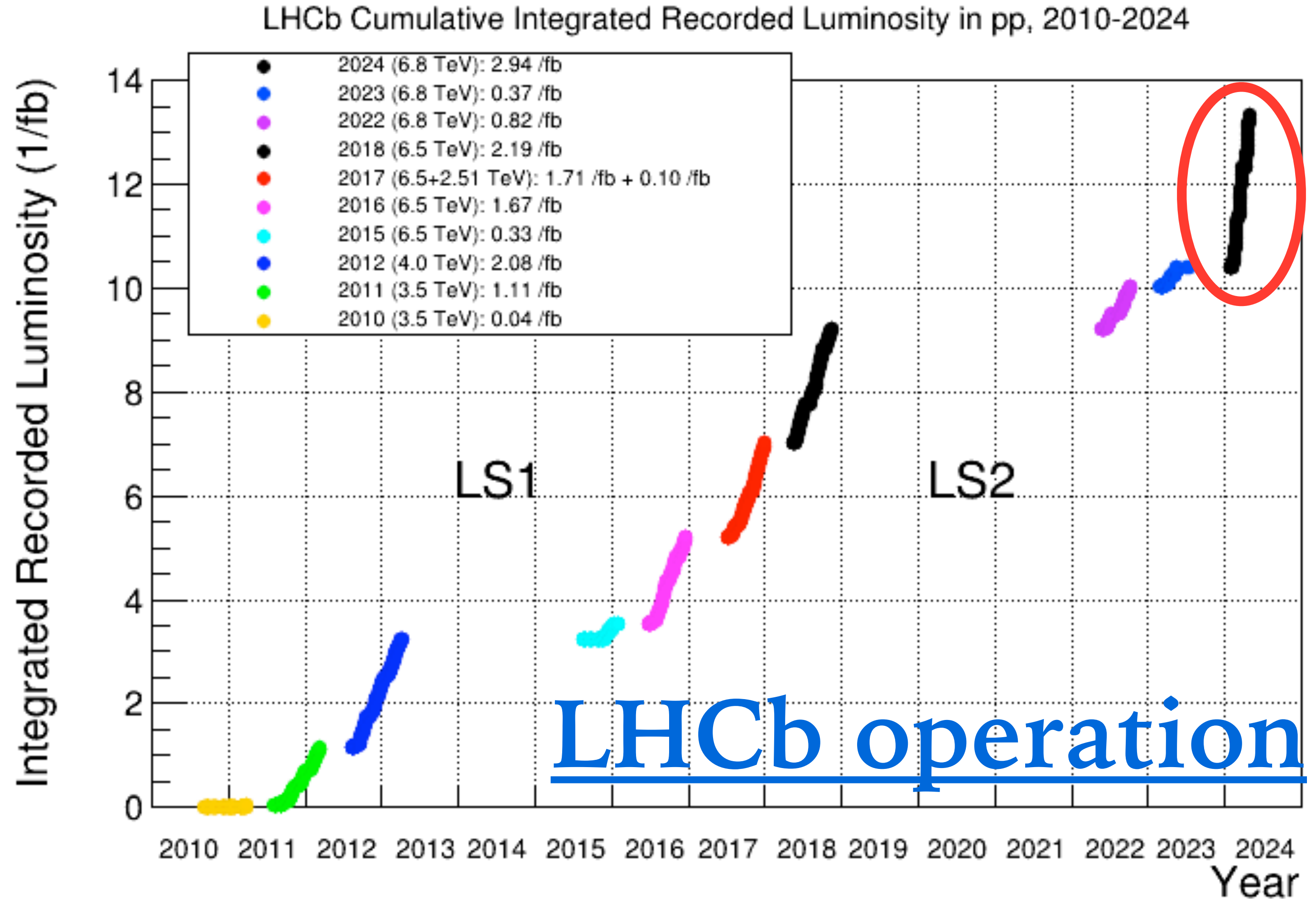


→ **Forward spectrometer**, optimised for the study b and c decays

- $2 < \eta < 5$ acceptance
- Excellent vertexing, tracking and Particle IDentification ($K/\pi/p/\mu/e/\gamma$)

→ **2022-2024 :**

- Commissioning
- Start of Run 3 data-taking



[LHCb operation]

LHCb ——— **LHCb Upgrade1**

Run1 - Run2			STOP	Run3				STOP	Run4			
$\mathscr{L}_{int}\sim 9\mathrm{fb}^{-1}$				$\mathscr{L} = 2\times10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$					$\mathscr{L}_{int}\sim 50\mathrm{fb}^{-1}$			
2010	…	2018	…	2022	2023	2024	2025	…	2029	2030	2031	2032

CP VIOLATION MEASUREMENTS

Direct CP Violation

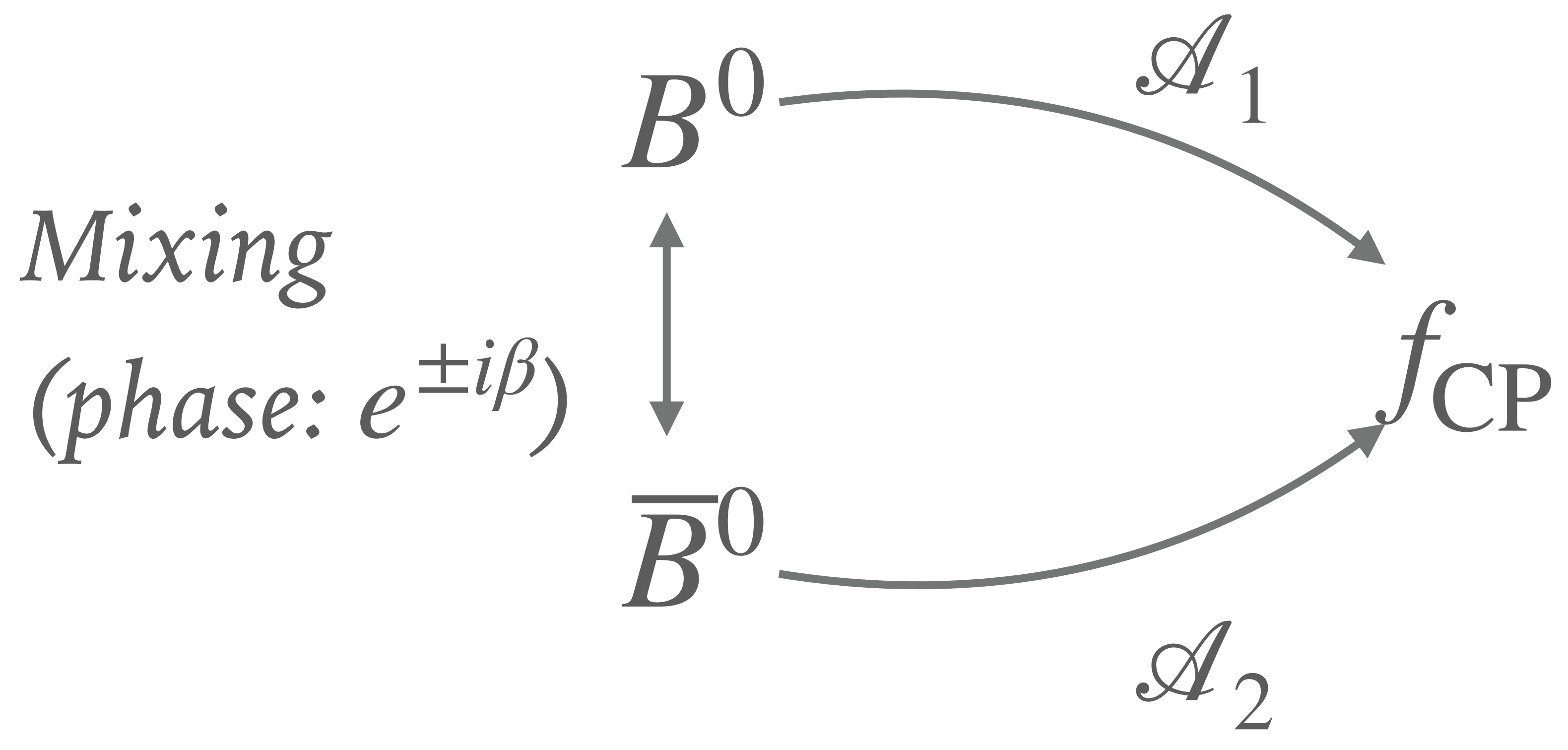
$$\Gamma(B \to f) \neq \Gamma(\bar{B} \to \bar{f})$$

Different rates $\Leftrightarrow$ *CP violation*

$$\mathscr{A}_{\mathrm{CP}} = \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)}$$

CP violation in interferences between decay and mixing

$$\Gamma(B^0 \to f_{\mathrm{CP}}) \neq \Gamma(\bar{B}^0 \to f_{\mathrm{CP}})$$



Branching fraction measurements

- Decay observation
- Branching fraction measurement
- Direct CPV

Time-integrated amplitude analysis

- Study of the decay dynamics
- Resonant structure model
- $\mathcal{A}_{CP}$ in the phase space

Time-dependent tagged amplitude analysis

For neutral mesons

- $\mathcal{A}_{CP}(t)$ measurement
- CKM angles measurement
  - γ: Phys. Rev. D 99, 114011 (2019)
  - β: Phys. Rev. D 85, 112010 (2012)

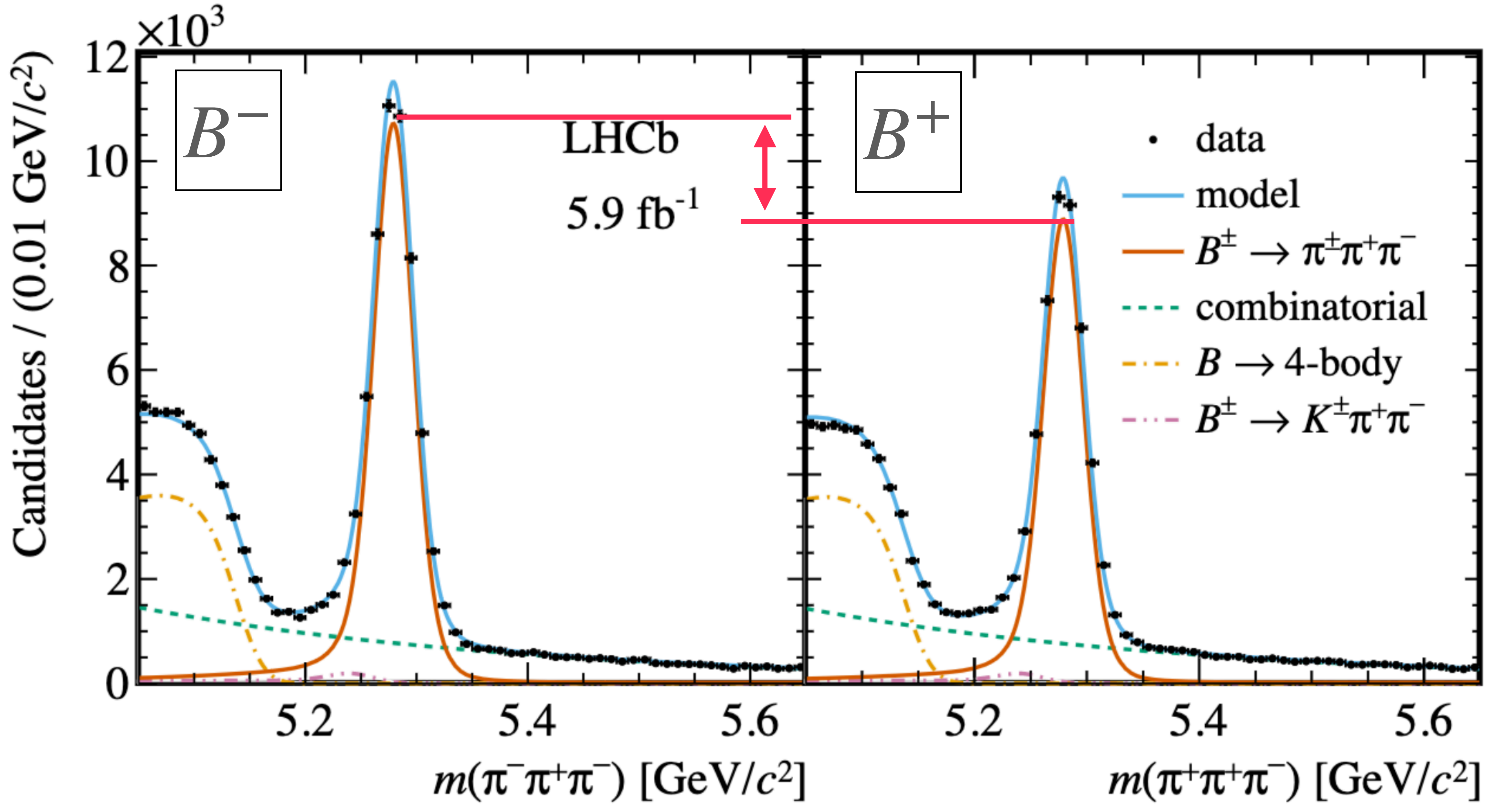
DIRECT CP VIOLATION IN CHARMLESS THREE-BODY DECAYS OF $B^{\pm}$ MESONS

- Four studied channels $B^{\pm} \to h^{\pm}h^{+}h^{-}$:

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

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

- Phase space integrated asymmetries:
  - Observation of CPV in $B^{\pm} \to K^{\pm}K^{+}K^{-}$, $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $B^{\pm} \to \pi^{\pm}K^{+}K^{-}$ confirmed



	Stat.	Syst.	Control channel	
$A_{CP}(B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}) = +0.011$	± 0.002	± 0.003	± 0.003	2.4σ
$A_{CP}(B^{\pm} \to K^{\pm}K^{+}K^{-}) = -0.037$	± 0.002	± 0.002	± 0.003	8.5σ
$A_{CP}(B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}) = +0.080$	± 0.004	± 0.003	± 0.003	14.1σ
$A_{CP}(B^{\pm} \to \pi^{\pm}K^{+}K^{-}) = -0.114$	± 0.007	± 0.003	± 0.003	13.6σ

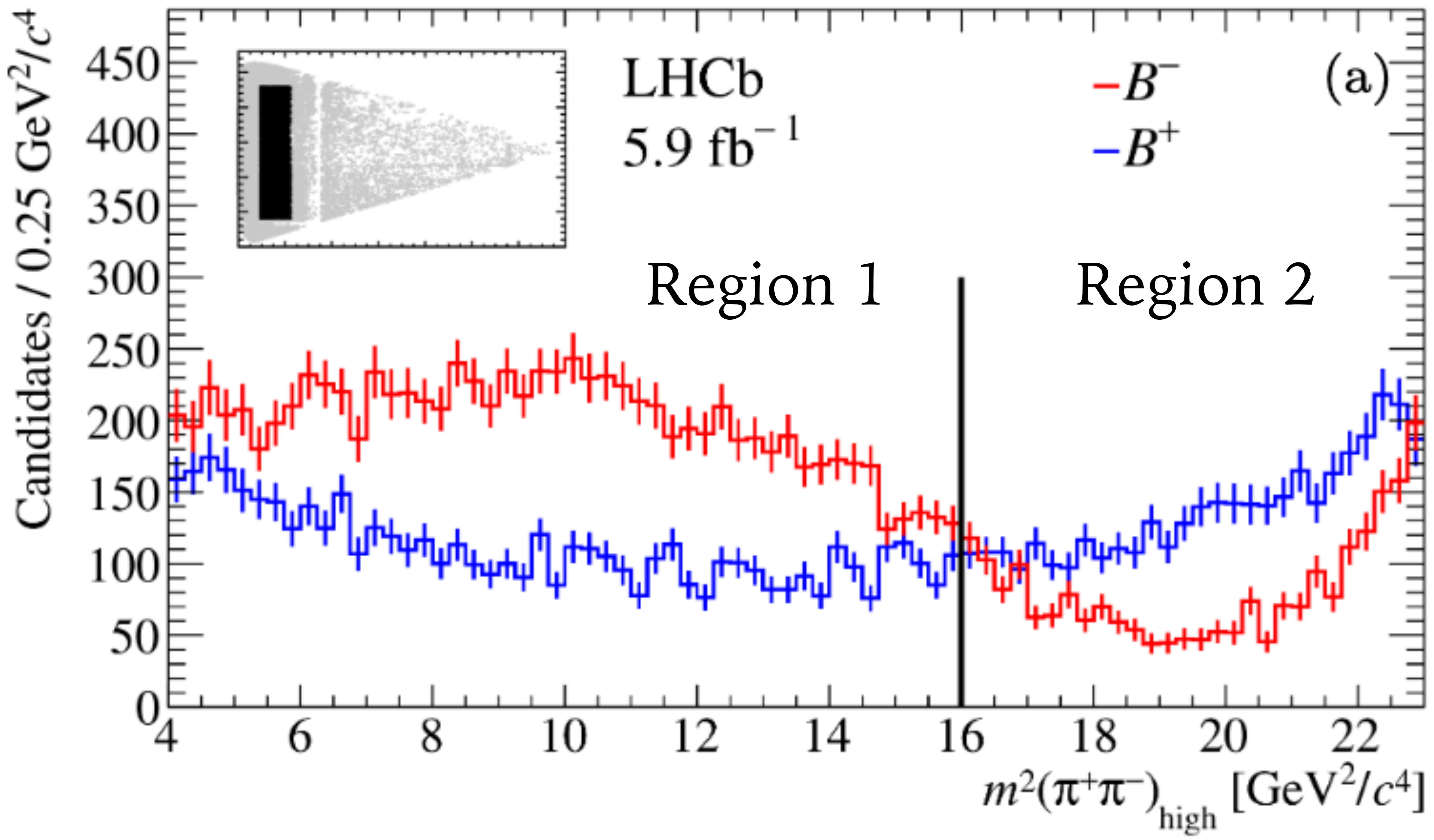
Phys. Rev. D 108, 012008 (2023)

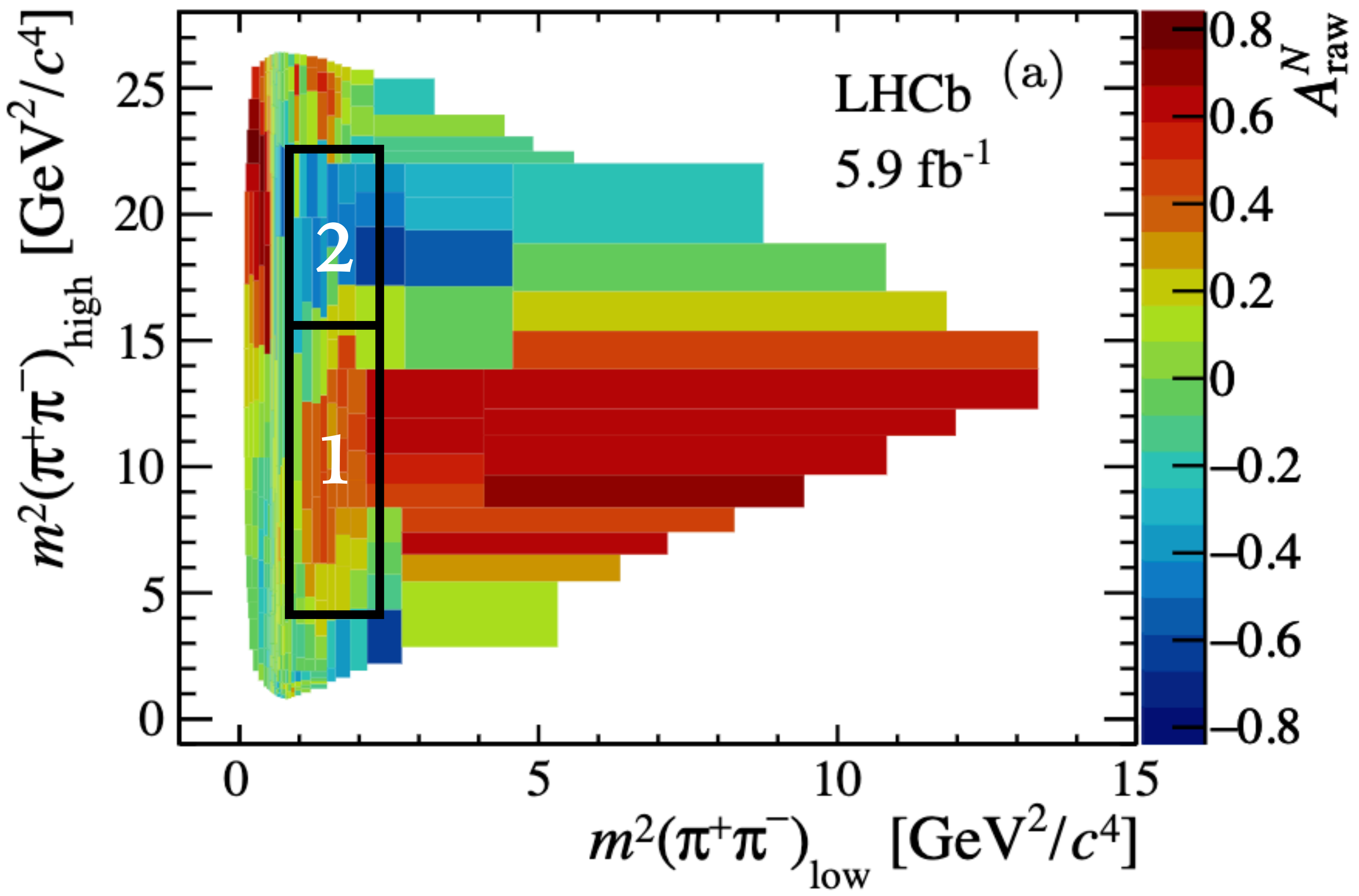
DIRECT CP VIOLATION IN CHARMLESS THREE-BODY DECAYS OF $B^{\pm}$ MESONS

→ Localised ACP studies:

- ➤ Non-uniform asymmetries in the phase space
- ➤ Significant CP violation in the rescattering region
- ➤ Indication of CPV in the region of $\chi_{c0}(1P)$ resonance

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





Phys. Rev. D 108, 012008 (2023)

Presented for the first time

NEW

6 decays of interest:

$$B^0 \to K^0_S \pi^+\pi^- \mid B^0 \to K^0_S K^\pm \pi^\mp \mid B^0 \to K^0_S K^+ K^-$$
$$B^0_s \to K^0_S \pi^+\pi^- \mid B^0_s \to K^0_S K^\pm \pi^\mp \mid B^0_s \to K^0_S K^+ K^-$$

→ Branching fraction measurements allow for:

- ➤ Comparison against theoretical predictions
  → refine approaches such as QCD factorisation or pQCD
- ➤ Evaluation of flavour symmetry breaking: isospin, U-spin and SU(3) Phys. Rev. D 91, 014029 (2015)
- ➤ Extraction of the background-subtracted phase-space distributions (to be used in related amplitude analysis)

BRANCHING FRACTION MEASUREMENTS OF $B^0_{d,s} \to K^0_S h^+ h'^-$

In preparation LHCb-PAPER-2024-029

NEW

→ Previous LHCb analysis, on RunI data ($\sim 3\text{fb}^{1}$)

J. High Energ. Phys. 2017, 27

- All the modes were observed but not $B^0_s \to K^0_S K^+ K^-$ (2.5σ significance)
- Five branching-fraction ratios measured relative to $B^0 \to K^0_S \pi^+ \pi^-$ and compatible with previous results

→ Aims of current analysis:

- Observation of the $B^0_s \to K^0_S K^+ K^-$ decay
- Updating the branching fractions of the other $B^0_{(s)} \to K^0_S h h'$ modes using RunI and RunII data ($\sim 9\text{fb}^{-1}$)

NEW

→ Measurement of each branching fraction done respectively to the branching fraction of $B^0 \to K^0_S \pi^+ \pi^-$ (*the reference mode*):

$$\frac{\mathscr{B}(B^0_{d,s} \to K^0_S h^+ h'^-)}{\mathscr{B}(B^0 \to K^0_S \pi^+ \pi^-)} = \frac{N_{B^0_{d,s} \to K^0_S h^+ h'^-}}{N_{ref}} \frac{\epsilon_{ref}}{\epsilon_{B^0_{d,s} \to K^0_S h^+ h'^-}} \frac{f_d}{f_{d,s}}$$

- $\mathscr{B}$: branching fraction
- N_{decay} : yield of the studied decay
- ϵ_{decay} : overall efficiency of the decay
- $f_{d/s}$: fragmentation fraction of $B^0_{(d/s)}$ mesons
- N_{ref} : the yield of the reference decay ($B^0 \to K^0_S \pi^+ \pi^-$)
- ϵ_{ref} : the overall efficiency of the reference decay

In preparation LHCb-PAPER-2024-029

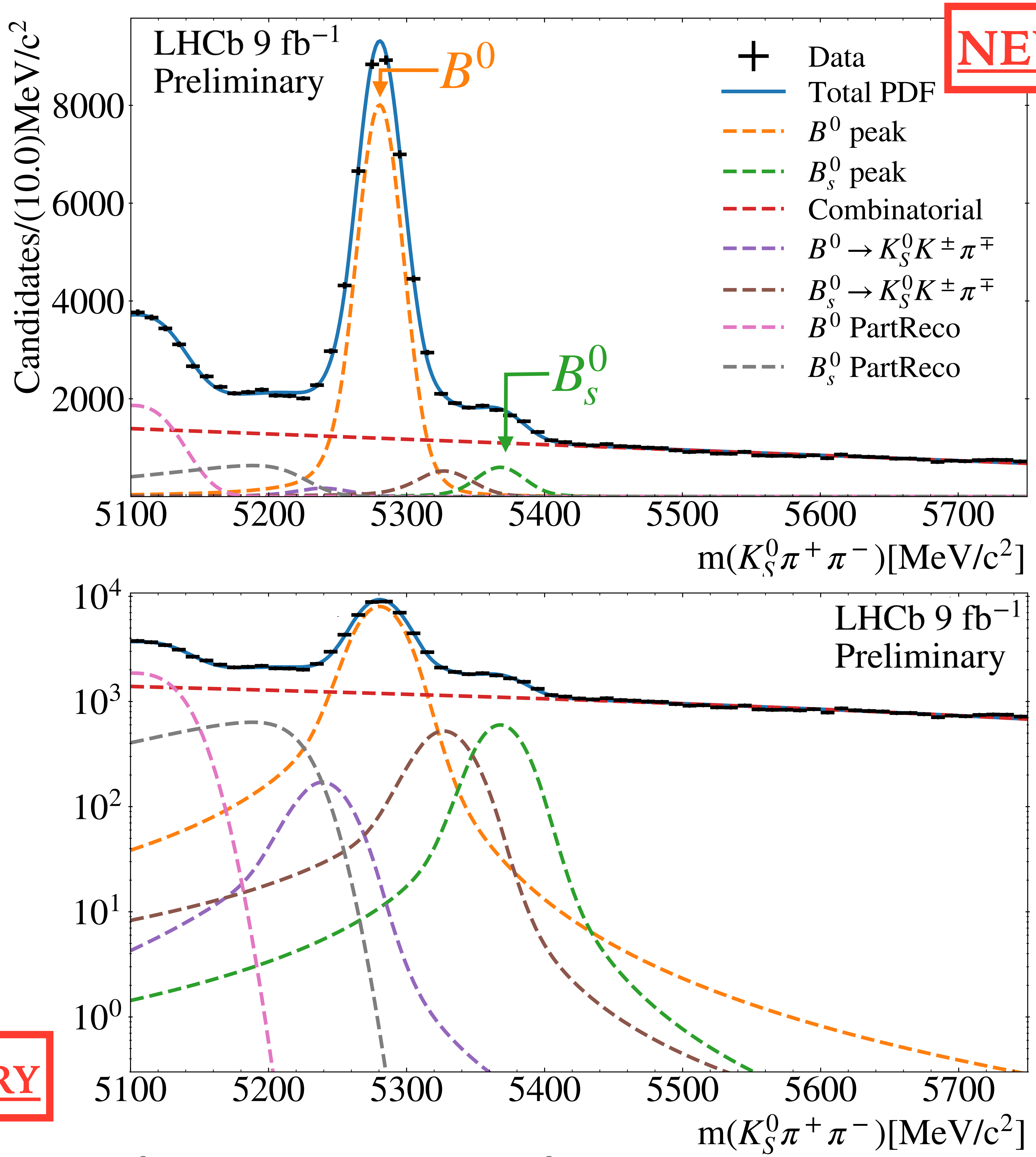
NEW

- **2 optimisations per final state**, one for the study of B^0 decays and one for the study of B^0_s decays
- Fit for 2 signal peaks and 5 sources of background per spectrum

- Simultaneous fits for each data-taking period (2011-2012a-2012b-2015-2016-2017-2018):

4 final states ($\pi\pi, K\pi, \pi K, KK$)
2 K^0_S reconstruction (LL, DD) → **8 spectra fitted simultaneously*

⇒ **56 spectra total (x2 for each optimisation)*



PRELIMINARY

**Mass fits to K^0_S(DD)$\pi^+\pi^-$ 2018 data - B^0 selection*

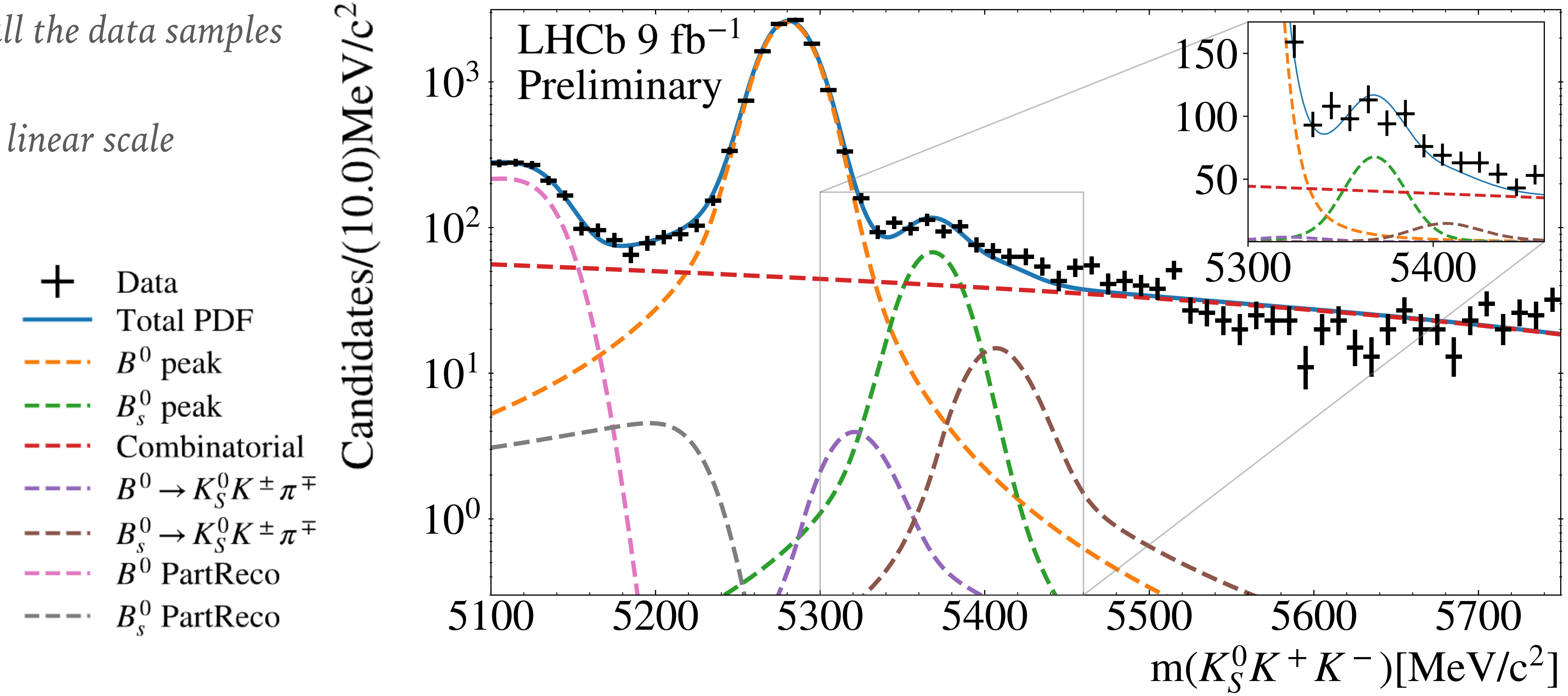
NEW

→ First observation of $B^0_s \to K^0_S K^+ K^-$ at $>10\sigma$ significance (Stat.) and $>6\sigma$ significance (Tot.)

Data fits on the $K^0_S K^+ K^-$ spectrum - sum over all the data samples

SecondaryPeak optimisation

In log scale and zoom on the B^0_s region in linear scale



PRELIMINARY

NEW

- In the Run I results, statistical uncertainties of the same order as the systematic ones
- Systematic uncertainties studies
  - 13 sources from the fit model
  - 10 sources from the efficiency evaluation
- Still the case for the Run I + Run II data set

  ⇒ Systematic and statistic uncertainties of the same order of magnitude

PRELIMINARY

Source [‰]	B^0, K^+K^-	$B^0, K^\pm\pi^\mp$	$B^0_s, \pi^+\pi^-$	B^0_s, K^+K^-	$B^0_s, K^\pm\pi^\mp$
Fit model	8.6	32.5	69.4	88.4	5.5
Tracking	< 0.1	< 0.1	< 0.1	0.2	< 0.1
Hardware trigger	2.9	1.1	0.6	2.2	0.7
PID	2.2	5.8	< 0.1	7.9	1.8
Dalitz plot*	26.4	20.7	37.2	119.2	14.4
Kin. reweighting*	4.6	3.2	4.4	4.4	3.3
Total systematic	28.4	39.1	78.9	148.7	15.8
Statistical	11.5	25.5	45.3	129.6	11.3
f_s/f_d	—	—	17.3	17.8	14.1

NEW

→ Relative branching fractions:

$$\frac{\mathcal{B}(B^0 \to K^0_S K^+ K^-)}{\mathcal{B}(B^0 \to K^0_S \pi^+ \pi^-)} = 0.533 \pm 0.006\,(\text{stat}) \pm 0.015\,(\text{syst})$$

$$\frac{\mathcal{B}(B^0 \to K^0_S K^\pm \pi^\mp)}{\mathcal{B}(B^0 \to K^0_S \pi^+ \pi^-)} = 0.1366 \pm 0.0035\,(\text{stat}) \pm 0.0053\,(\text{syst})$$

$$\frac{\mathcal{B}(B^0_s \to K^0_S \pi^+ \pi^-)}{\mathcal{B}(B^0 \to K^0_S \pi^+ \pi^-)} = 0.276 \pm 0.013\,(\text{stat}) \pm 0.022\,(\text{syst}) \pm 0.005\,(f_s/f_d)$$

$$\frac{\mathcal{B}(B^0_s \to K^0_S K^+ K^-)}{\mathcal{B}(B^0 \to K^0_S \pi^+ \pi^-)} = 0.0341 \pm 0.0044\,(\text{stat}) \pm 0.0051\,(\text{syst}) \pm 0.0006\,(f_s/f_d)$$

$$\frac{\mathcal{B}(B^0_s \to K^0_S K^\pm \pi^\mp)}{\mathcal{B}(B^0 \to K^0_S \pi^+ \pi^-)} = 1.782 \pm 0.020\,(\text{stat}) \pm 0.028\,(\text{syst}) \pm 0.025\,(f_s/f_d)$$

→ Branching fractions (PDG value for $\mathscr{B}(B^0 \to K^0 \pi^+ \pi^-) = [4.97 \pm 0.20] \times 10^{-6}$)

$$\mathcal{B}(B^0 \to K^0 K^+ K^-) = [26.43 \pm 0.30\,(\text{stat}) \pm 0.75\,(\text{syst}) \pm 1.07\,(\mathcal{B})] \times 10^{-6}$$

$$\mathcal{B}(B^0 \to K^0 K^\pm \pi^\mp) = [6.78 \pm 0.17\,(\text{stat}) \pm 0.27\,(\text{syst}) \pm 0.27\,(\mathcal{B})] \times 10^{-6}$$

$$\mathcal{B}(B^0_s \to K^0 \pi^+ \pi^-) = [13.7 \pm 0.6\,(\text{stat}) \pm 1.1\,(\text{syst}) \pm 0.6\,(\mathcal{B})] \times 10^{-6}$$

$$\mathcal{B}(B^0_s \to K^0 K^+ K^-) = [1.69 \pm 0.22\,(\text{stat}) \pm 0.25\,(\text{syst}) \pm 0.07\,(\mathcal{B})] \times 10^{-6}$$

$$\mathcal{B}(B^0_s \to K^0 K^\pm \pi^\mp) = [88.4 \pm 1.0\,(\text{stat}) \pm 1.9\,(\text{syst}) \pm 3.6\,(\mathcal{B})] \times 10^{-6}$$

PRELIMINARY

BRANCHING FRACTION MEASUREMENTS OF $B^0_{d,s} \to K^0_S h^+ h'^-$

In preparation LHCb-PAPER-2024-029

Comparison of the measured ratios of branching fractions (value±stat.±syst.)

NEW

Decay Mode	$B^0 \to K^0_S K^+ K^-$	$B^0 \to K^0_S K^\pm \pi^\mp$	$B^0_s \to K^0_S \pi^+ \pi^-$	$B^0_s \to K^0_S K^\pm \pi^\mp$
$\mathcal{B}_r(X)$ published (Run I)	$0.549 \pm 0.018 \pm 0.033$	$0.123 \pm 0.009 \pm 0.015$	$0.191 \pm 0.027 \pm 0.033$	$1.70 \pm 0.07 \pm 0.15$
$\mathcal{B}_r(X)$ this	$0.533 \pm 0.006 \pm 0.015$	$0.1366 \pm 0.0035 \pm 0.0066$	$0.276 \pm 0.012 \pm 0.022$	$1.782 \pm 0.020 \pm 0.046$

$$\mathcal{B}_r(X) = \frac{\mathcal{B}(X)}{\mathcal{B}(B^0 \to K^0_S \pi^+ \pi^-)}$$

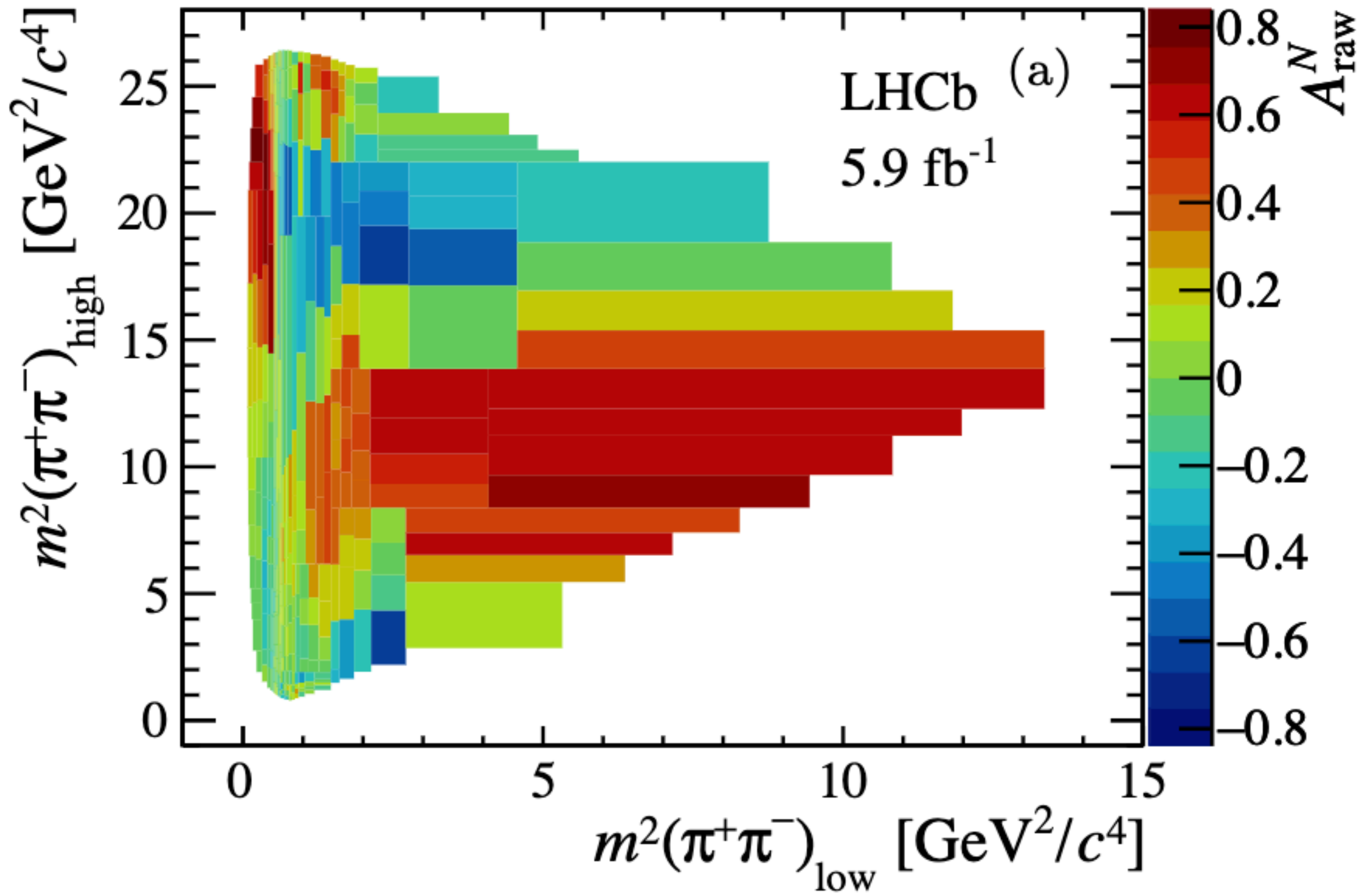
PRELIMINARY

- → Expected improvement in the stat. uncertainties adding the RunII measurements.
- → Improved syst. uncertainties
- → Results compatible
- → Main improvements from the last analysis:
  - ➤ Fit model and background suppression
  - ➤ Improved data-driven corrections

SUMMARY AND PROSPECTS

Phys. Rev. D 108, 012008 (2023)

- Large $\mathscr{A}_{CP}$ found in charmless three-body decays
- [NEW] Branching fraction measurements of $B^0_{d,s} \to K^0_S h^+ h'^-$ analysis soon to be published:
  - First observation of $B^0_s \to K^0_S K^+ K^-$
  - Updated measurements with RunI+RunII samples
  - Improved analysis methods
- Stepping stone for ongoing or planned amplitude analyses of these modes



$$\frac{\mathcal{B}(B^0 \to K^0_S K^+ K^-)}{\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-)} = 0.533 \pm 0.006\,(\text{stat}) \pm 0.015\,(\text{syst})$$

$$\frac{\mathcal{B}(B^0 \to K^0_S K^\pm \pi^\mp)}{\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-)} = 0.1366 \pm 0.0035\,(\text{stat}) \pm 0.0053\,(\text{syst})$$

$$\frac{\mathcal{B}(B^0_s \to K^0_S \pi^+\pi^-)}{\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-)} = 0.276 \pm 0.013\,(\text{stat}) \pm 0.022\,(\text{syst}) \pm 0.005\,(f_s/f_d)$$

$$\frac{\mathcal{B}(B^0_s \to K^0_S K^+ K^-)}{\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-)} = 0.0341 \pm 0.0044\,(\text{stat}) \pm 0.0051\,(\text{syst}) \pm 0.0006\,(f_s/f_d)$$

$$\frac{\mathcal{B}(B^0_s \to K^0_S K^\pm \pi^\mp)}{\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-)} = 1.782 \pm 0.020\,(\text{stat}) \pm 0.028\,(\text{syst}) \pm 0.025\,(f_s/f_d)$$

PRELIMINARY

THANK YOU FOR YOUR ATTENTION

TRACKS IN LHCb