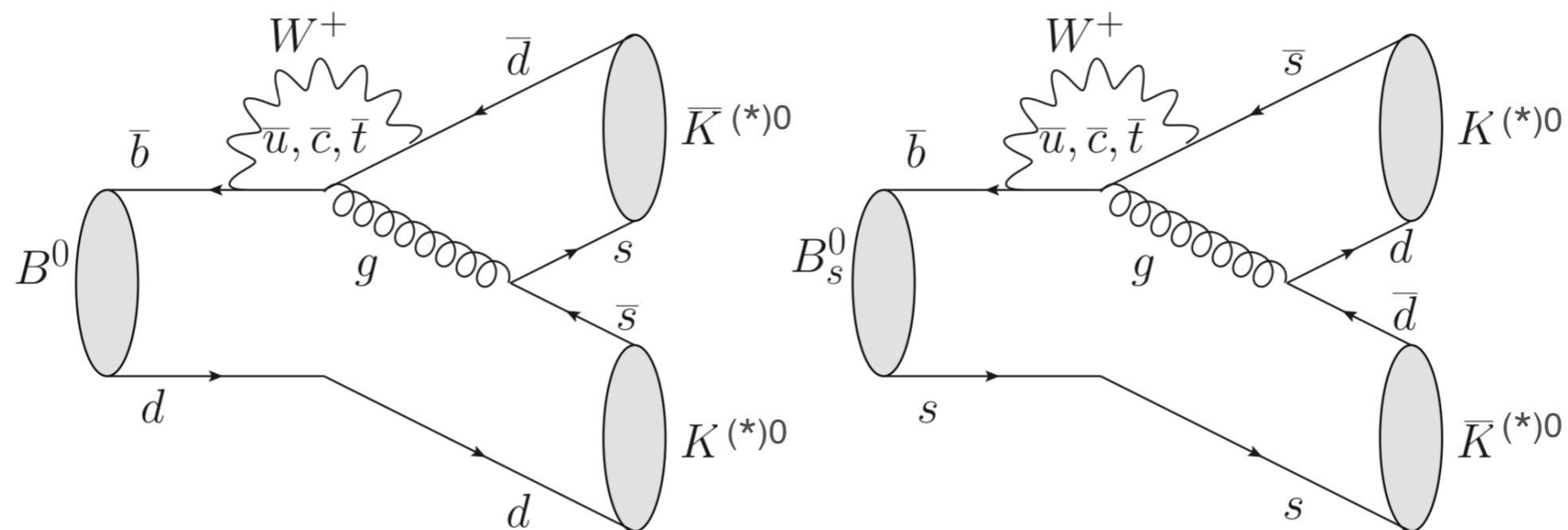


# Experimental perspective on $B_{(s)} \rightarrow K^{(*)0} \bar{K}^{(*)0}$ decays



Julián García Pardiñas



CERN (Switzerland)

**1. Introduction**

**2. History of  
the puzzle**

**3. The “crossed”  
modes**

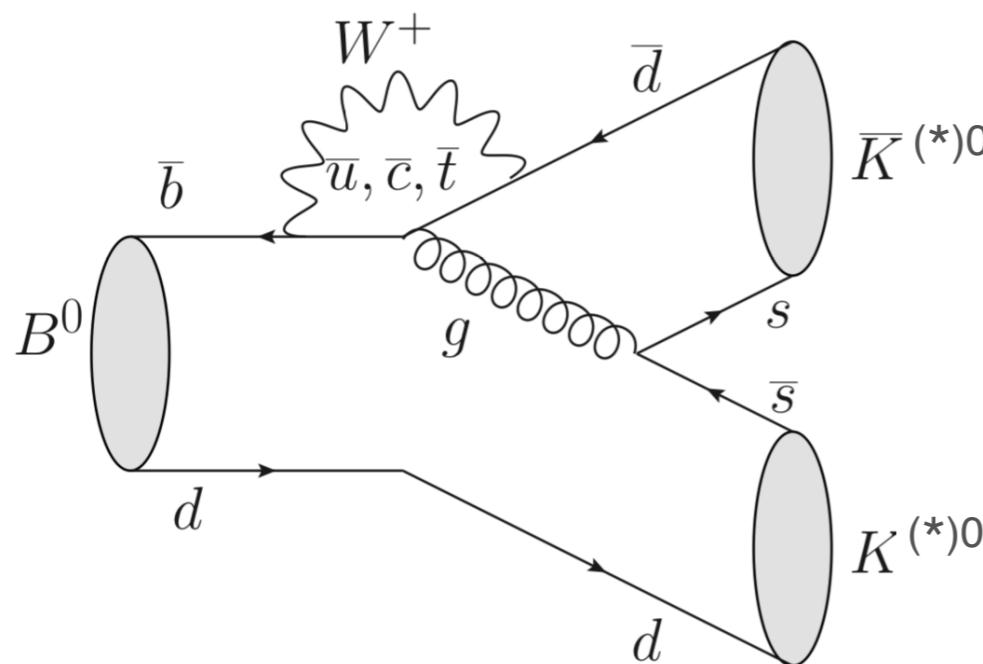
**5. Conclusions**

# Original motivation: CPV measurements with $B_{(s)}^0 \rightarrow K^{(*)0} \bar{K}^{(*)0}$

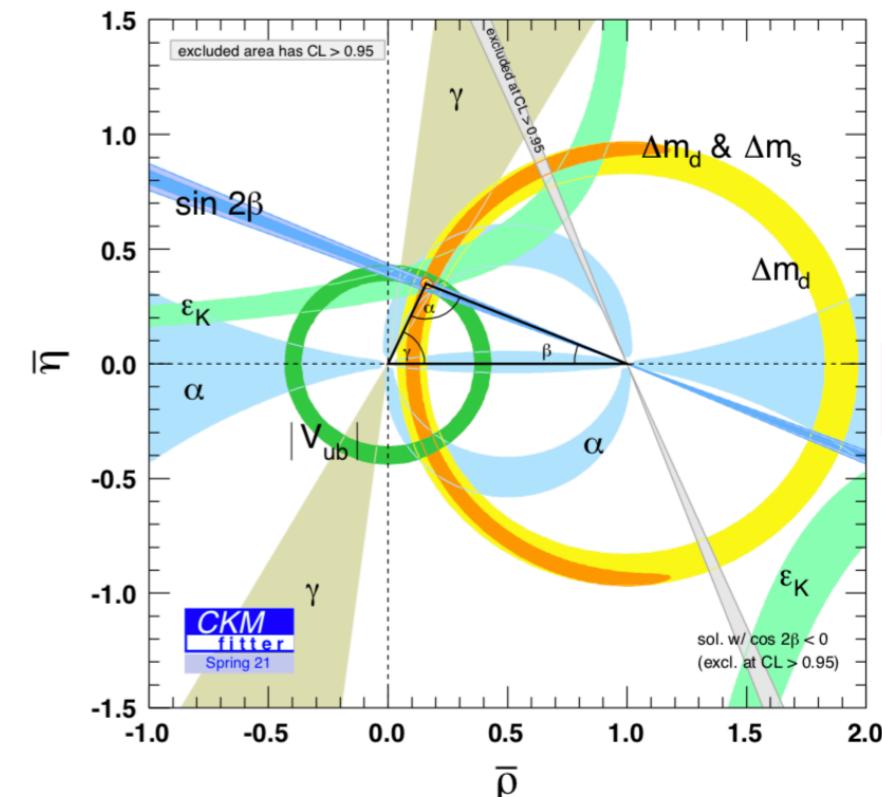
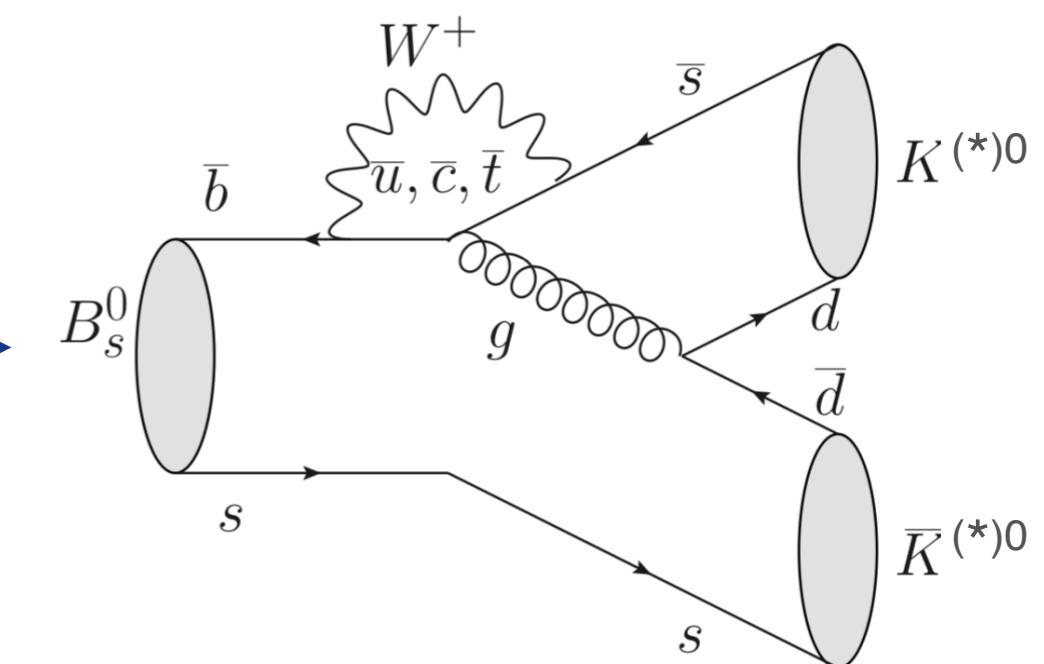
Flavour changing neutral currents → **Loop-level transitions in the SM, potentially enhanced sensitivity to NP contributions.**

Sensitivity to the **CKM phases  $\beta$  and  $\beta_s$** , through the interference between mixing and decay.

Leading order diagrams in the SM:



**U-spin transformation  
(exchange of s and d quarks)**



# Experimental situation

---

The analysis of these modes is typically done in **increases steps of difficulty and required statistical power:**

1. BR measurement.
2. Amplitude analysis (when needed).
3. Measurement of time-integrated CPV parameters.
4. Measurement of time-dependent CPV parameters using flavour tagging.

## Experiments involved:

**B factories:** mostly studied B decays. Some  $B_s$  studies through the  $\Upsilon(5S)$  production.

**LHCb:** study both B and  $B_s$  modes.

**Disclaimer:** I'm going to focus mostly on LHCb measurements.

# Experimental situation: challenges

---

The analysis of these modes is typically challenging due to the low signal rate and statistical power:

1. BR measurement.
  2. Amplitude analysis (when needed).
  3. Measurement of time-integrated CPV parameters.
  4. Measurement of time-dependent CPV parameters using flavour tagging.
- At LHCb,  $K^0$  accessible through  $K_S \rightarrow \pi^+ \pi^-$ .  
 $K_S$ : Long lived particle.  
→ Around 2/3 of  $K_S$  decay outside the VELO. →  
**Challenging efficiency and resolution.**

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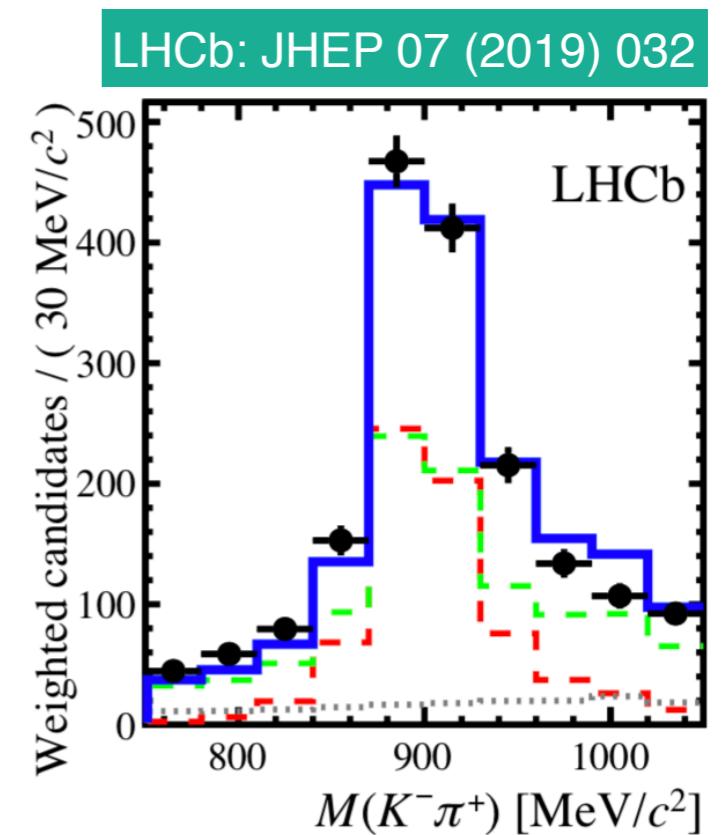
→ Around 2/3 of  $K_S$  decay outside the VELO. →  
**Challenging efficiency and resolution.**

At LHCb,  $K^{*0}$  reconstructed in the  $K^+ \pi^-$  final state.

$K^{*0}$ : Wide resonance.

→ S-wave ( $K_0^*(800)$ ,  $K_0^*(1430)$ , non-resonant, ...) in the same  $K^+ \pi^-$  mass region as the  $K^{*0}$ .  
→ **The amount and shape of the S-wave needs to be determined.**

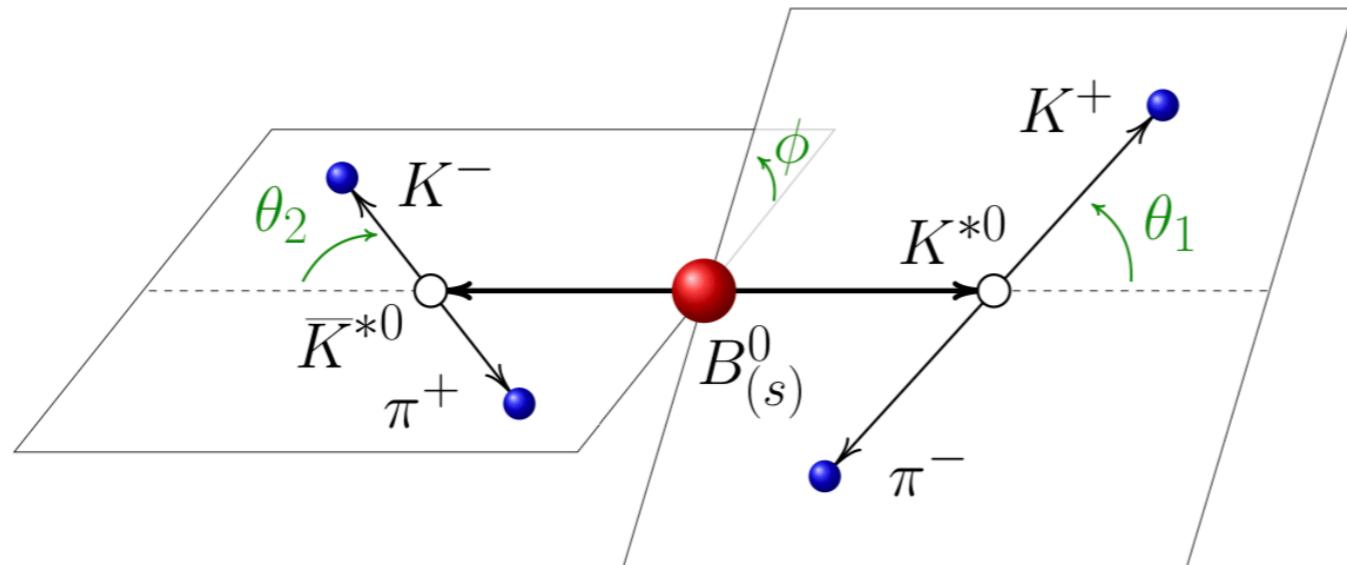
- Data
- Total PDF
- - - VV
- - SV+VS
- ..... SS



# Experimental situation: challenges

The analysis of these modes are typically done in **increases stages of difficulty and statistics required:**

1. BR measurement.
2. Amplitude analysis (when needed).
3. Measurement of time-integrated CPV parameters.



$B^0, B_s$ : P

$K^{*0}$ : V

$K_S$ : P

$K^+\pi^-$  S-wave: P

**Longitudinal polarization fraction,  $f_L$ .**

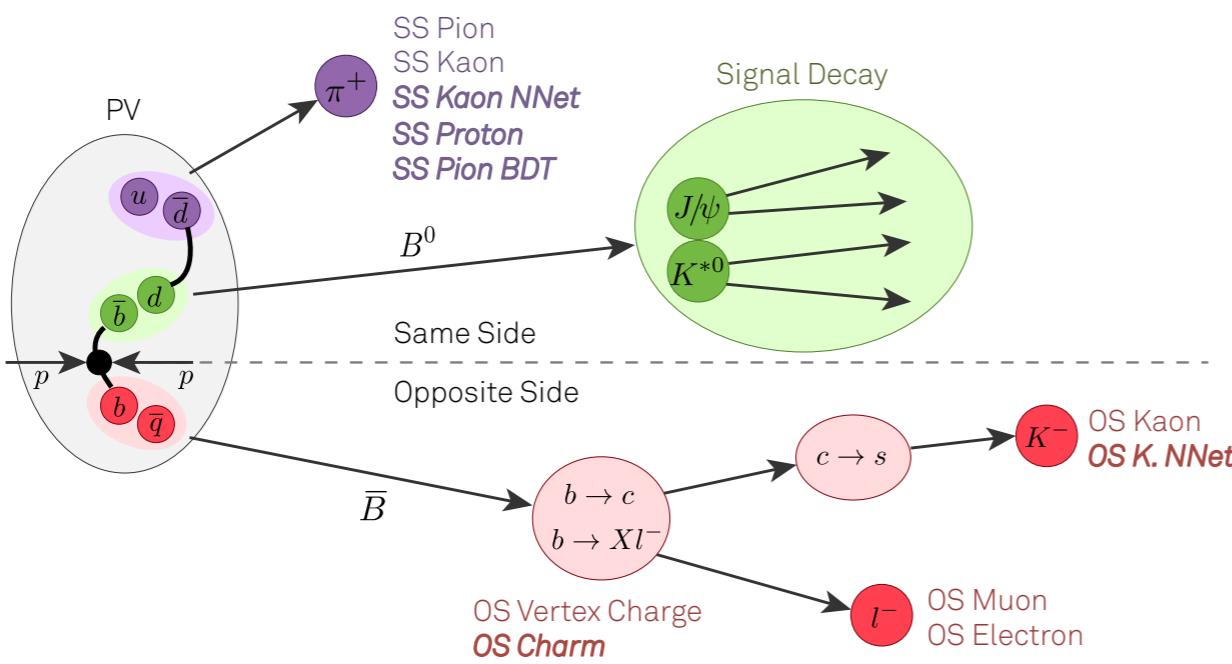
$P \rightarrow VV$  decays:

3 polarisation amplitudes: L, ||, ⊥

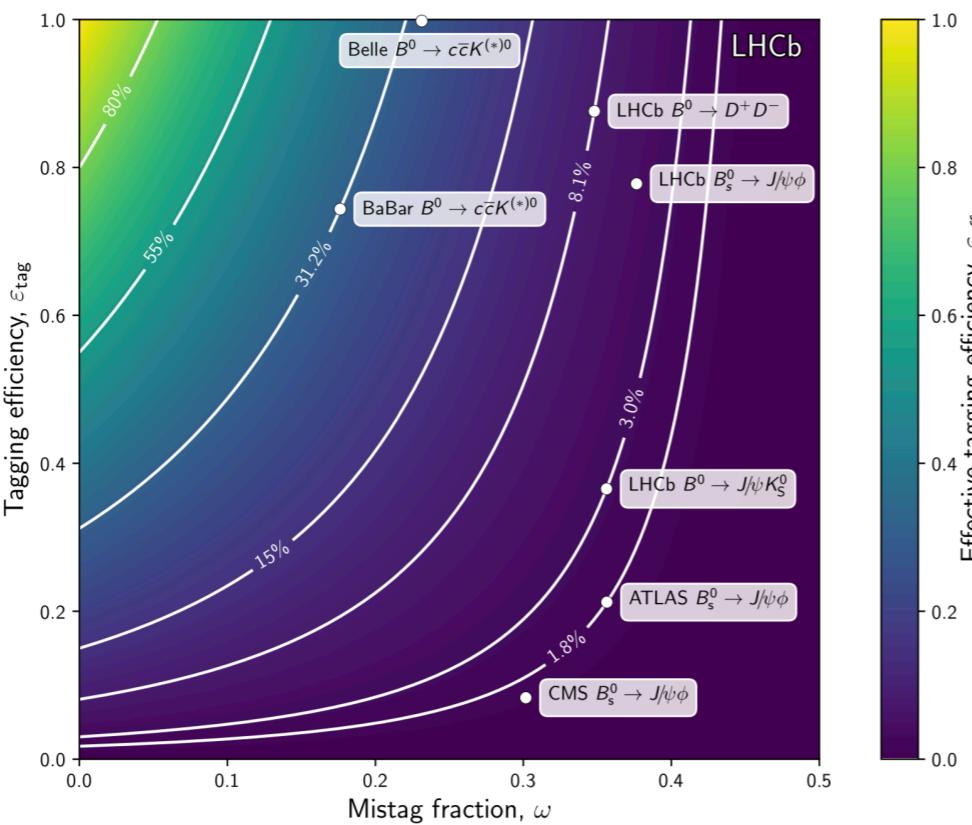
$P \rightarrow PP, P \rightarrow VP, P \rightarrow PV$

1 polarisation amplitude

# Experimental situation: challenges



LHCb-FIGURE-2020-002



es of difficulty and

using flavour tagging.

**Note:** additional challenges when including the decay time for CPV measurements.  
 Not discussed here as not directly relevant to the puzzle.

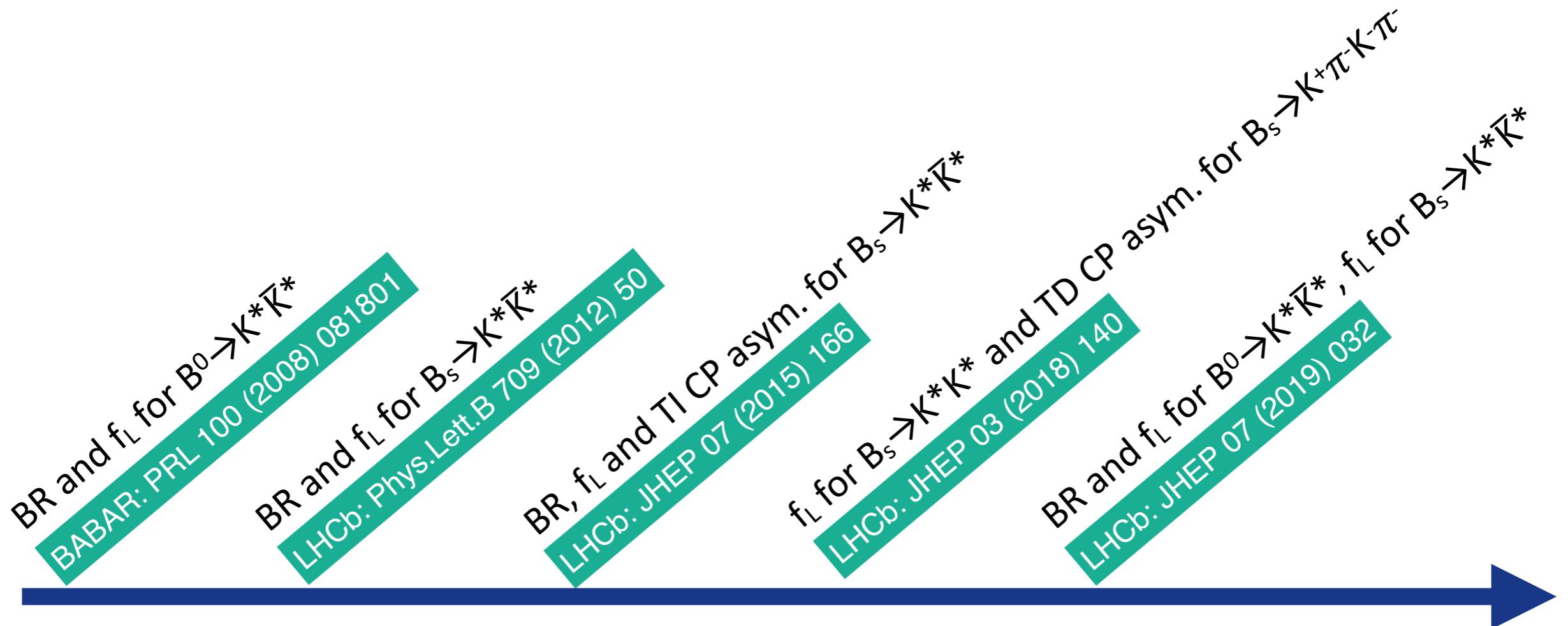
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# Measurements of $B_{(s)}^0 \rightarrow K^{*(0)}\bar{K}^{*(0)}$



QCDF predictions

Nucl.Phys.B774:64-101,2007

**$B^0$  mode**

$$f_L = 0.69^{+0.16}_{-0.20}$$

**$B_s$  mode**

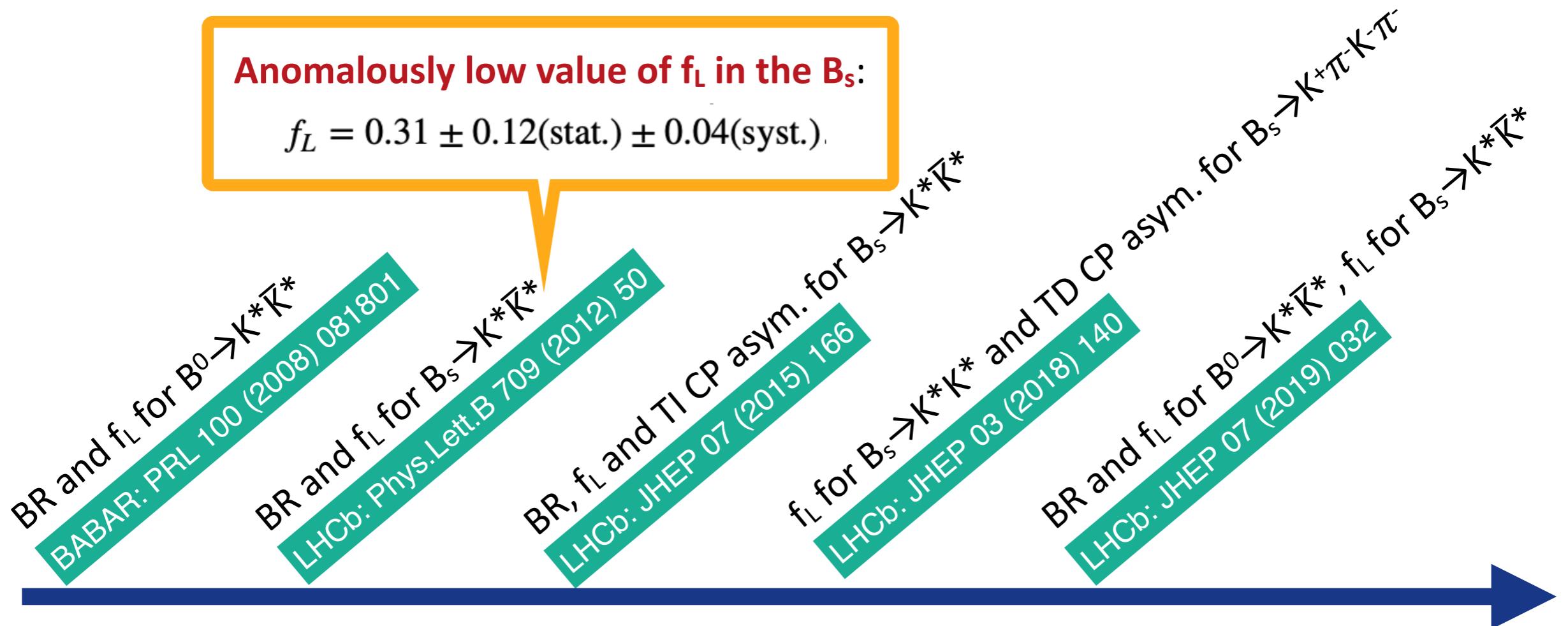
$$f_L = 0.72^{+0.16}_{-0.21}$$

Similar behavior for both modes also expected naively from **U-spin symmetry**.

# Measurements of $B_{(s)}^0 \rightarrow K^{(*)0} \bar{K}^{(*)0}$

**Anomalously low value of  $f_L$  in the  $B_s$ :**

$$f_L = 0.31 \pm 0.12(\text{stat.}) \pm 0.04(\text{syst.})$$



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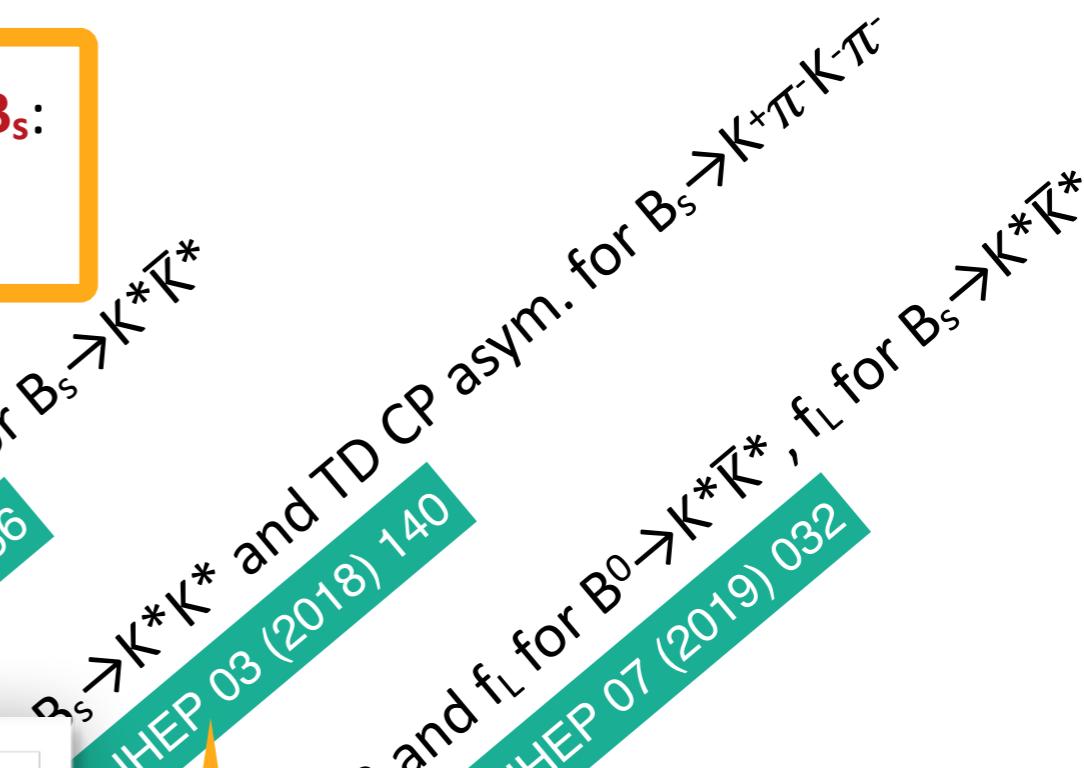
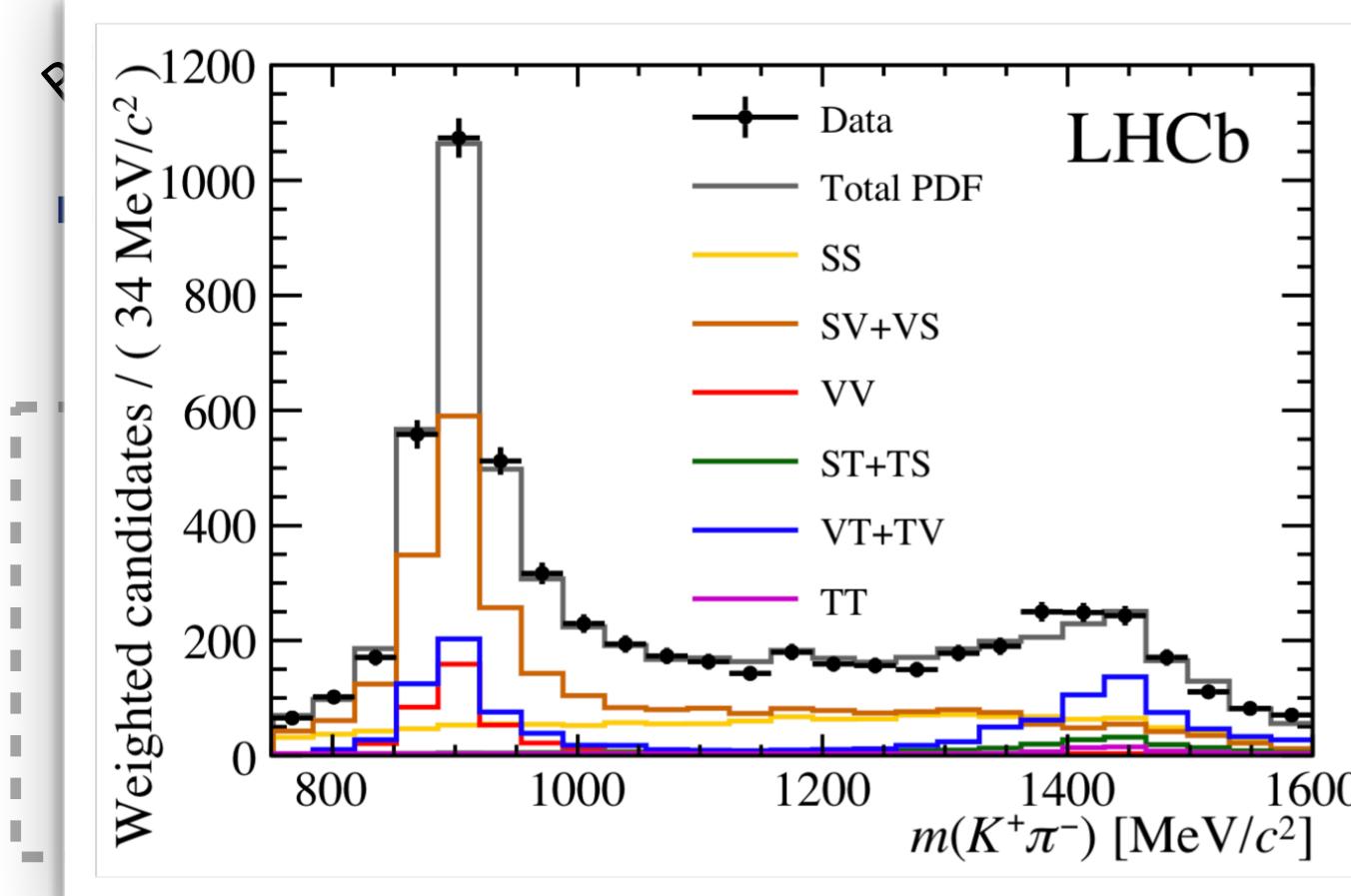
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**Analysis in a large  $K^+\pi^-$  mass window, with a lot of spectroscopy work (19 polarization amplitudes, with scalar, vector and tensor components), six-dimensional fit.**  
 $f_L$  consistent with previous experimental results:

$$f_L = 0.208 \pm 0.032 \pm 0.046$$

# Measurements of $B_{(s)}^0 \rightarrow K^{(*)0} \bar{K}^{(*)0}$

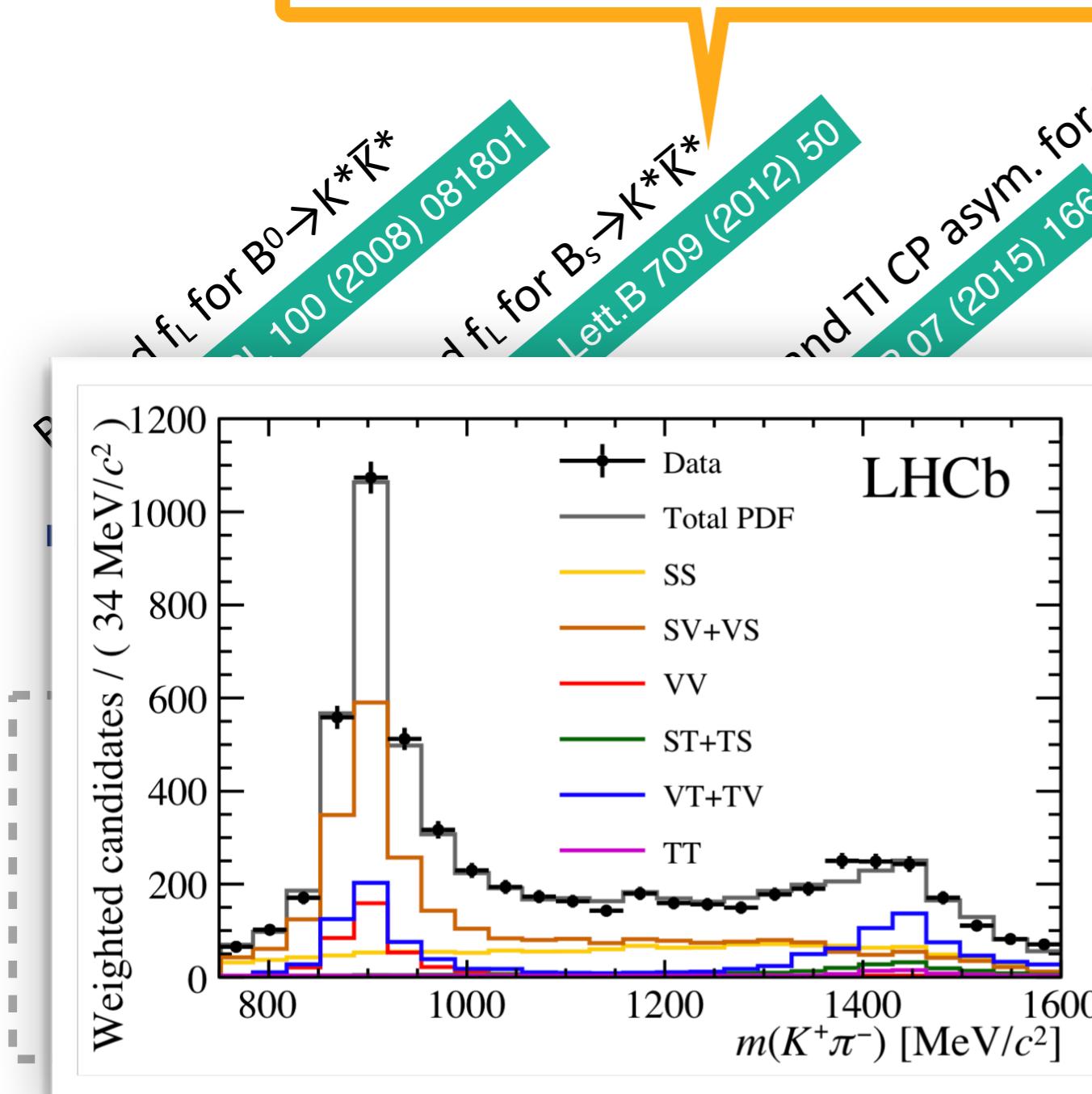
Anomalously low value of  $f_L$  in the  $B_s$ :

$$f_L = 0.31 \pm 0.12(\text{stat.}) \pm 0.04(\text{syst.})$$

**Comparative study  $B^0$  vs.  $B_s$**

The  $B^0$  mode is consistent with the SM prediction:

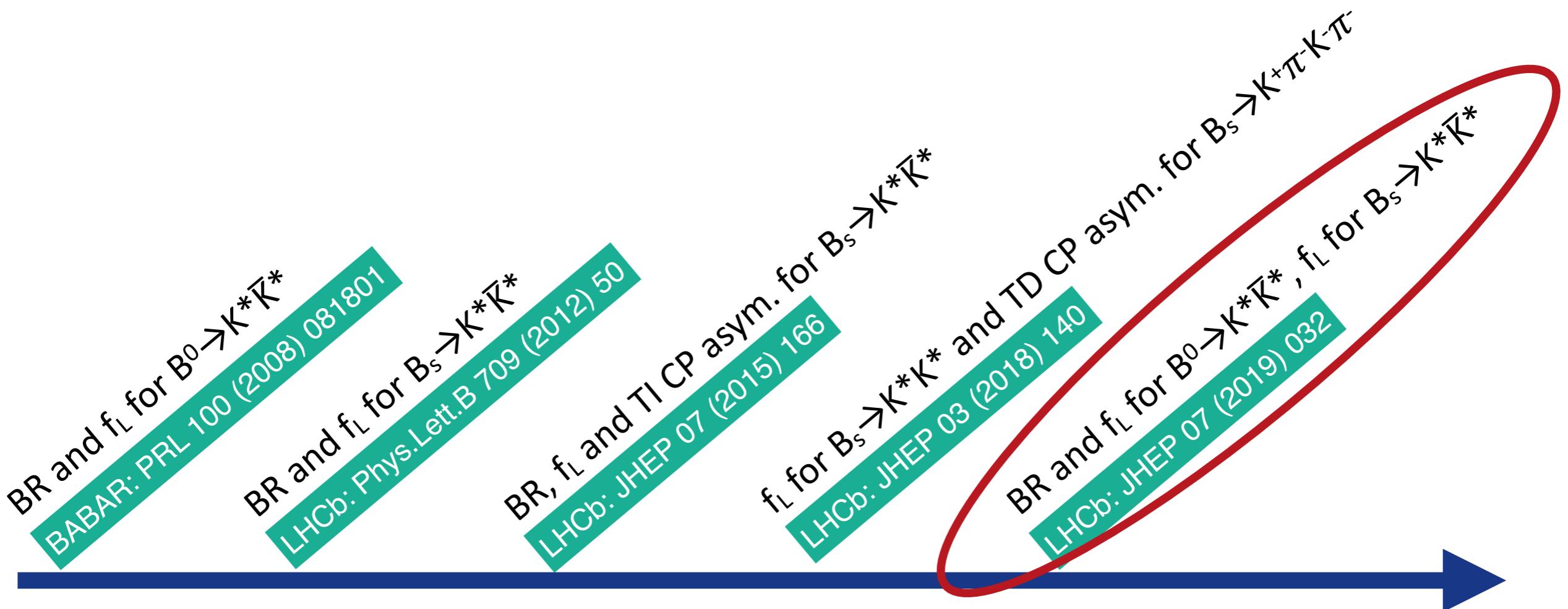
$$f_L = 0.724 \pm 0.051 (\text{stat}) \pm 0.016 (\text{syst})$$



Analysis in a large  $K^+\pi^-$  mass window, with a lot of spectroscopy work (19 polarization amplitudes, with scalar, vector and tensor components), six-dimensional fit.  
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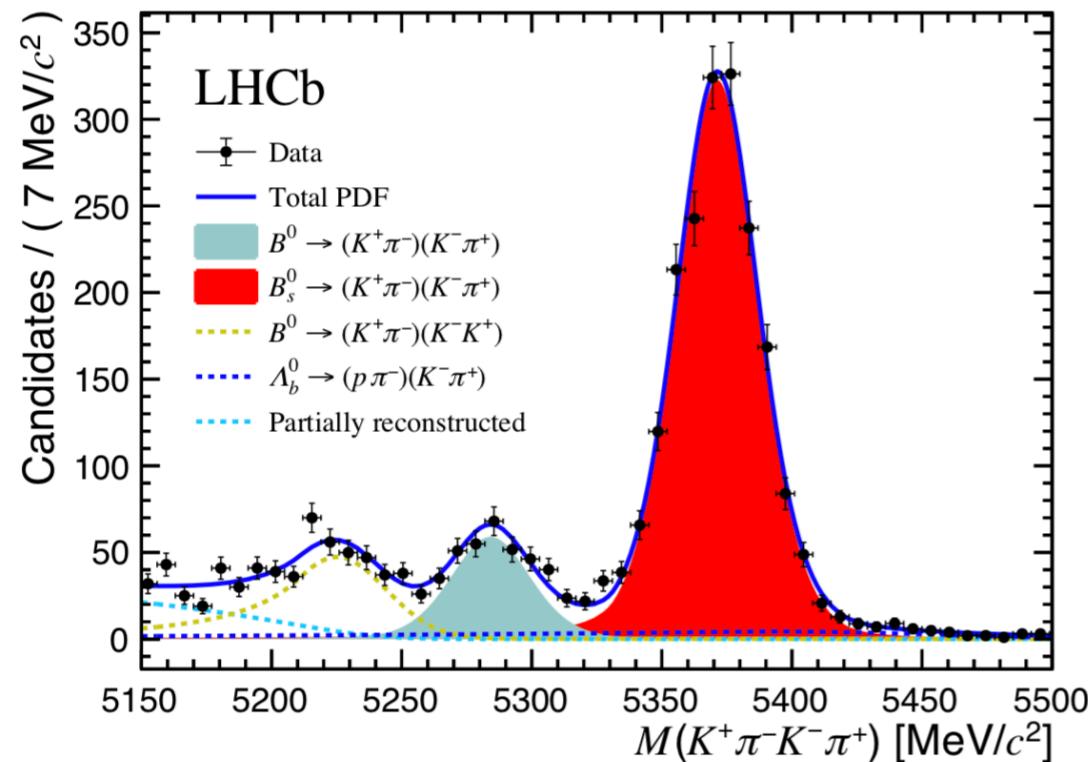
**$B_s$  mode**

$$f_L = 0.72^{+0.16}_{-0.21}$$

# Measurement of BR and $f_L$ for $B^0 \rightarrow K^{*0}\bar{K}^{*0}$ , $f_L$ for $B_s^0 \rightarrow K^{*0}\bar{K}^{*0}$

LHCb: JHEP 07 (2019) 032

Run 1 data



## Analysis method:

- Filter data, 4-body mass fit and sWeights to remove backgrounds.
- Amplitude analysis separately for the  $B^0$  and the  $B_s$  to measure the amplitude parameters.
- Combine the previous numbers together to measure the BR.

Clean peaks for the  $B^0$  and the  $B_s$ .

Six contributing amplitudes for each mode: VV (3 pols.), PV, VP and PP.

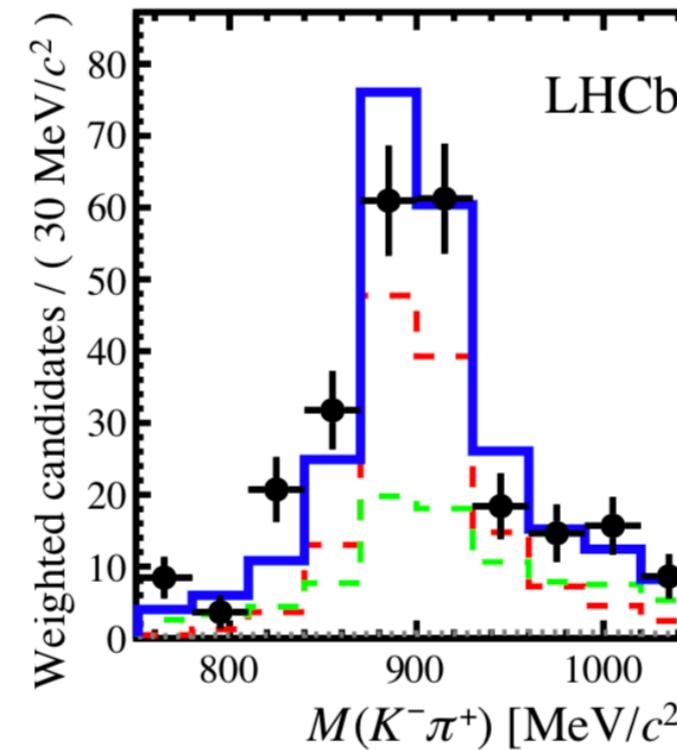
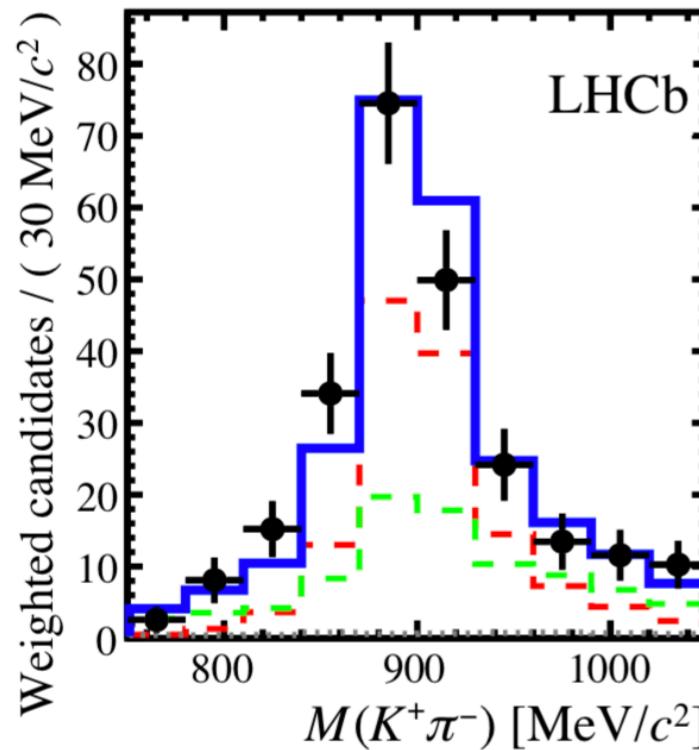
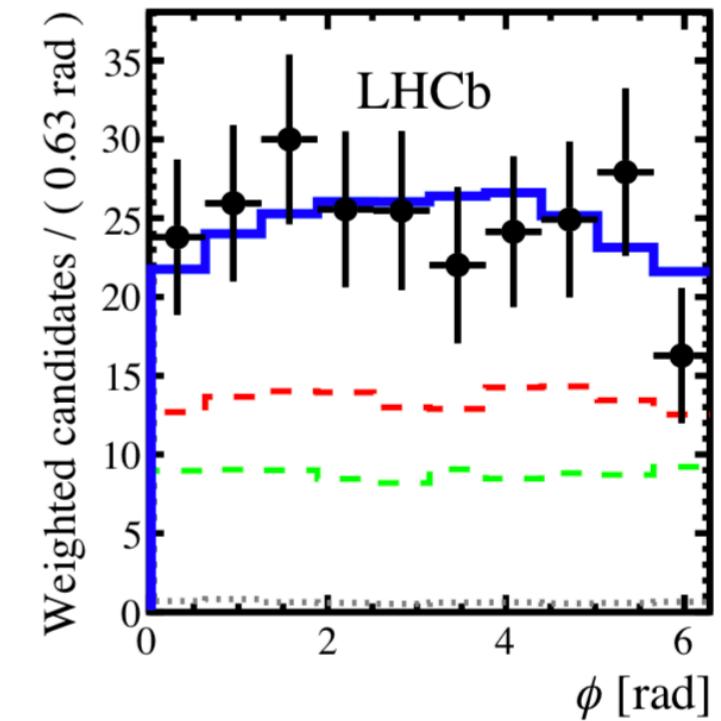
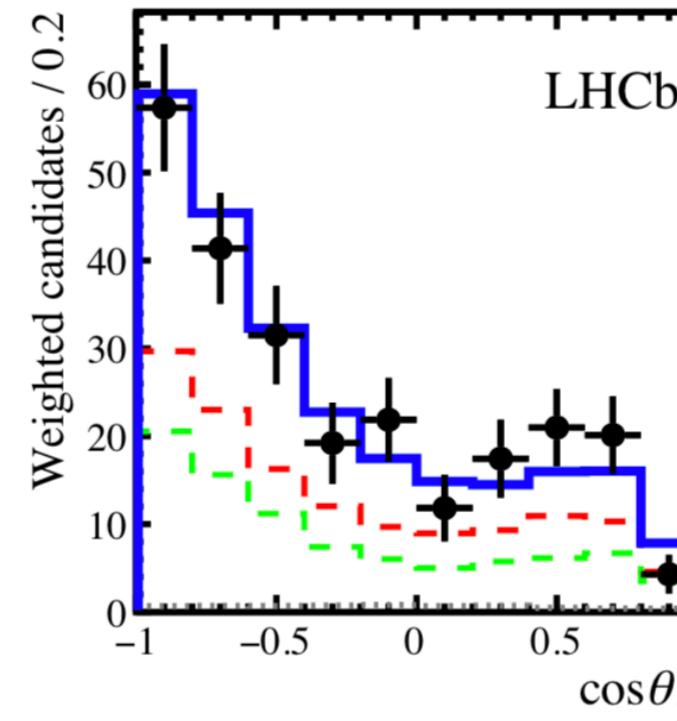
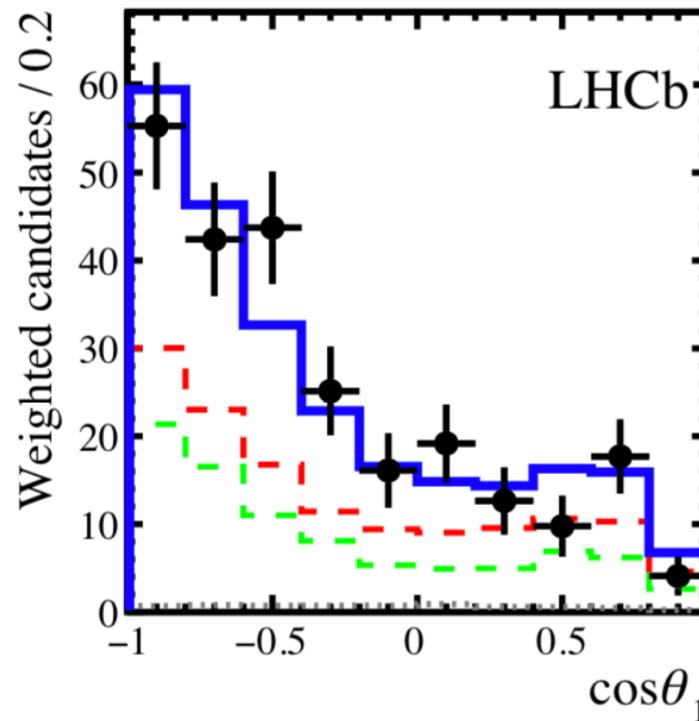
$i$	$A_i$	$\eta_i$	$g_i(m_1, m_2, \theta_1, \theta_2, \phi)$
1	$A_0$	1	$\cos \theta_1 \cos \theta_2 \mathcal{M}_1(m_1) \mathcal{M}_1(m_2)$
2	$A_{\parallel}$	1	$\frac{1}{\sqrt{2}} \sin \theta_1 \sin \theta_2 \cos \phi \mathcal{M}_1(m_1) \mathcal{M}_1(m_2)$
3	$A_{\perp}$	-1	$\frac{i}{\sqrt{2}} \sin \theta_1 \sin \theta_2 \sin \phi \mathcal{M}_1(m_1) \mathcal{M}_1(m_2)$
4	$A_S^+$	-1	$-\frac{1}{\sqrt{6}} (\cos \theta_1 \mathcal{M}_1(m_1) \mathcal{M}_0(m_2) - \cos \theta_2 \mathcal{M}_0(m_1) \mathcal{M}_1(m_2))$
5	$A_S^-$	1	$-\frac{1}{\sqrt{6}} (\cos \theta_1 \mathcal{M}_1(m_1) \mathcal{M}_0(m_2) + \cos \theta_2 \mathcal{M}_0(m_1) \mathcal{M}_1(m_2))$
6	$A_{SS}$	1	$-\frac{1}{3} \mathcal{M}_0(m_1) \mathcal{M}_0(m_2)$

# Measurement of BR and $f_L$ for $B^0 \rightarrow K^{*0}\bar{K}^{*0}$ , $f_L$ for $B_s^0 \rightarrow K^{*0}\bar{K}^{*0}$

Fit projections for the  $B^0$

LHCb: JHEP 07 (2019) 032

Run 1 data



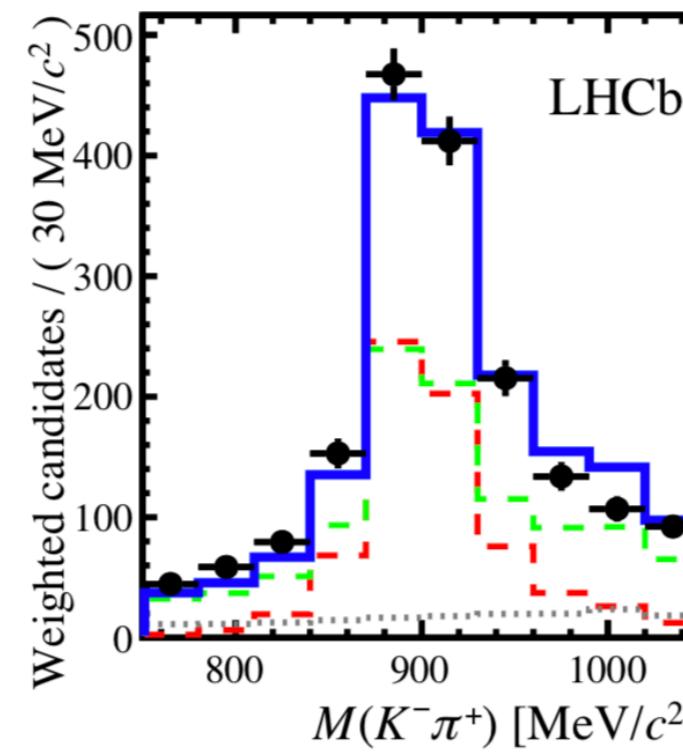
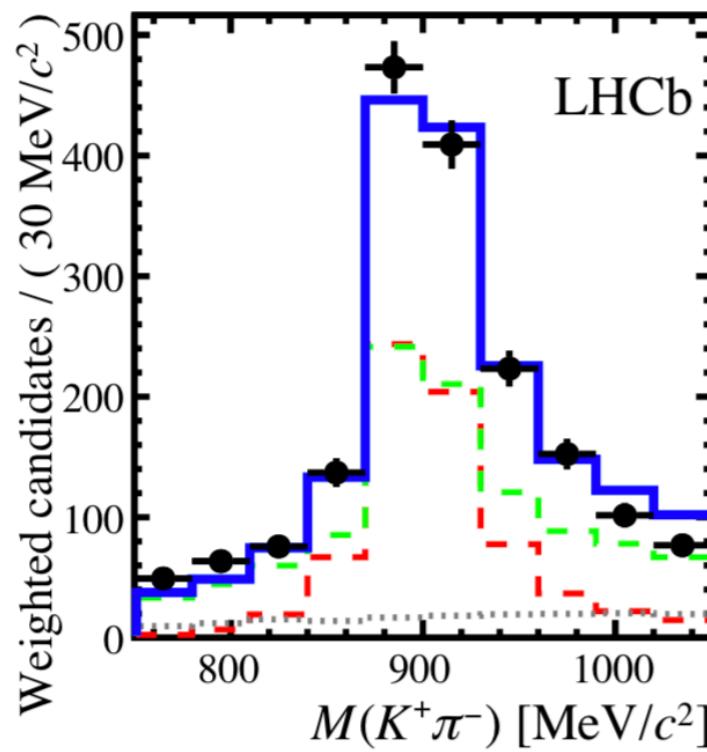
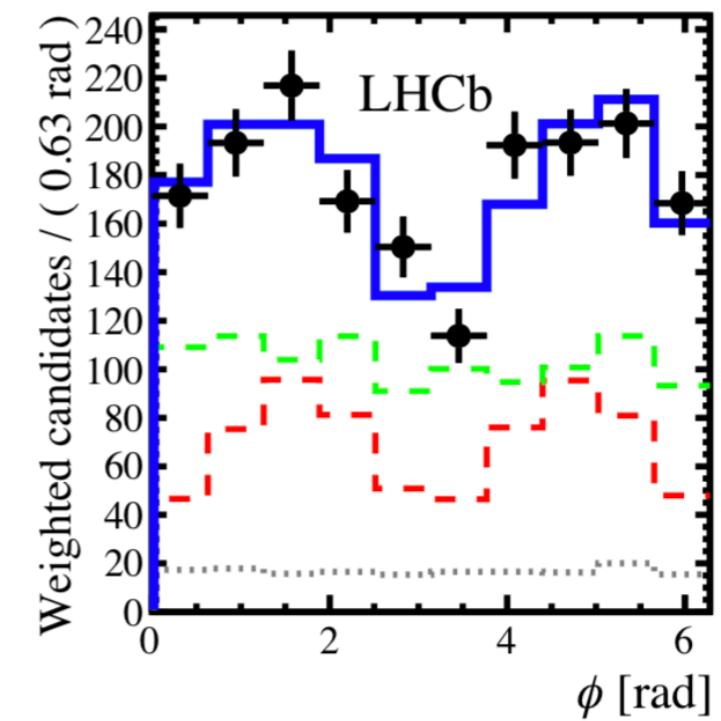
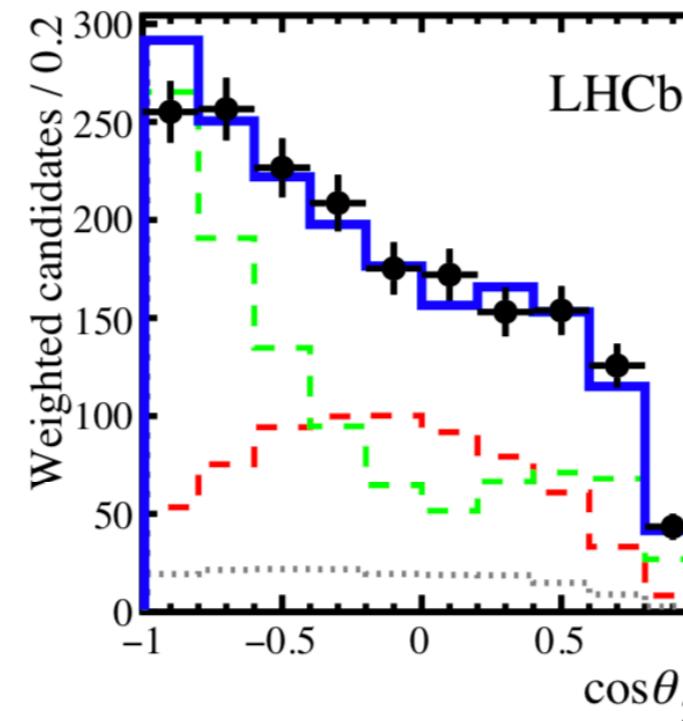
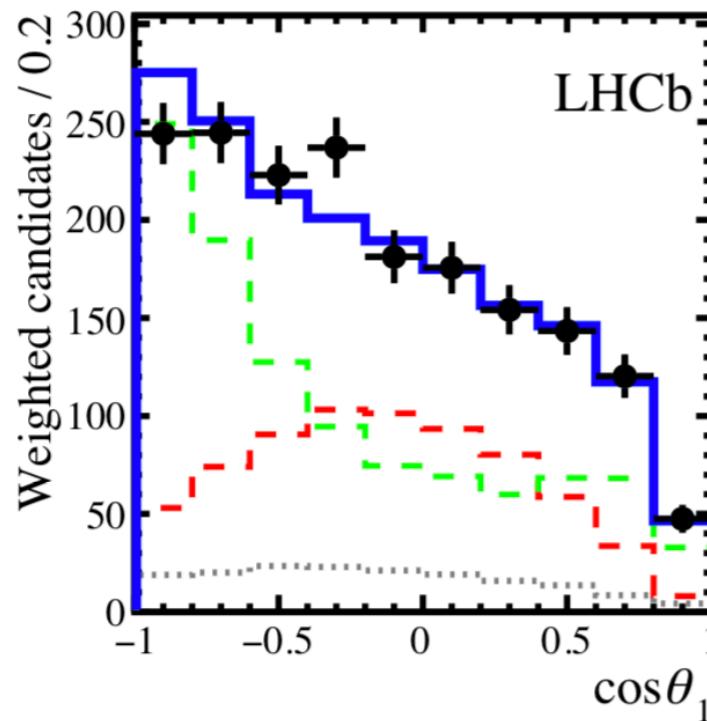
- **Data**
- **Total PDF**
- -  **$VV$**
- -  **$SV+VS$**
- ....  **$SS$**

# Measurement of BR and $f_L$ for $B^0 \rightarrow K^{*0}\bar{K}^{*0}$ , $f_L$ for $B_s^0 \rightarrow K^{*0}\bar{K}^{*0}$

Fit projections for the  $B_s$

LHCb: JHEP 07 (2019) 032

Run 1 data



- Data
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- - VV
- - SV+VS
- .... SS

# Measurement of BR and $f_L$ for $B^0 \rightarrow K^{*0}\bar{K}^{*0}$ , $f_L$ for $B_s^0 \rightarrow K^{*0}\bar{K}^{*0}$

LHCb: JHEP 07 (2019) 032

Run 1 data

Parameter	$B^0 \rightarrow K^{*0}\bar{K}^{*0}$	$B_s^0 \rightarrow K^{*0}\bar{K}^{*0}$
$f_L$	$0.724 \pm 0.051 \pm 0.016$	$0.240 \pm 0.031 \pm 0.025$
S-wave fraction	$0.408 \pm 0.050 \pm 0.017$	$0.694 \pm 0.016 \pm 0.010$

## Systematic uncertainties for the $B^0$

Decay mode	
Parameter	$f_L$
Bias data-simulation	0.001
Fit method	0.007
Kinematic acceptance	0.005
Resolution	0.007
P-wave mass model	0.001
S-wave mass model	0.007
Differences data-simulation	0.004
Background subtraction	0.002
Peaking backgrounds	0.009
Total systematic unc.	0.016

(Simulation  
sample size)

## Systematic uncertainties for the $B_s$

Decay mode	
Parameter	$f_L$
Bias data-simulation	0.004
Fit method	0.001
Kinematic acceptance	0.011
Resolution	0.002
P-wave mass model	0.001
S-wave mass model	0.021
Differences data-simulation	0.002
Background subtraction	0.000
Peaking backgrounds	0.003
Time acceptance	0.008
Total systematic unc.	0.025

# Measurement of BR and $f_L$ for $B^0 \rightarrow K^{*0}\bar{K}^{*0}$ , $f_L$ for $B_s^0 \rightarrow K^{*0}\bar{K}^{*0}$

LHCb: JHEP 07 (2019) 032

Run 1 data

$$\frac{\mathcal{B}(B^0 \rightarrow K^{*0}\bar{K}^{*0})}{\mathcal{B}(B_s^0 \rightarrow K^{*0}\bar{K}^{*0})} = \frac{\varepsilon_{B_s^0}}{\varepsilon_{B^0}} \times \frac{\lambda_{B_s^0}^{f_L}}{\lambda_{B^0}^{f_L}} \times \frac{N_{B^0} \times f_{B^0}^D}{N_{B_s^0} \times f_{B_s^0}^D} \times \frac{f_s}{f_d}$$

$$\kappa_{B_{(s)}^0}^k \equiv \frac{\lambda_{B_{(s)}^0}^{f_L}}{f_{B_{(s)}^0}^D} = \frac{\sum_{i=1}^6 \sum_{j \geq i}^6 \text{Re}[A_i A_j^* \left( \frac{1-\eta_i}{\Gamma_H} + \frac{1+\eta_i}{\Gamma_L} \right) \omega_{ij}^k]}{(1 - |A_S^-|^2 - |A_S^+|^2 - |A_{SS}|^2) \sum_{i=1}^3 \sum_{j \geq i}^3 \text{Re}[A_i^{\text{sim}} A_j^{\text{sim}*} \left( \frac{1-\eta_i}{\Gamma_H} + \frac{1+\eta_i}{\Gamma_L} \right) \omega_{ij}^k]},$$

The **polarisation parameters** (because of the efficiency computation) and **S-wave fraction** are **inputs to the BR computation**.

$$\frac{\mathcal{B}(B^0 \rightarrow K^{*0}\bar{K}^{*0})}{\mathcal{B}(B_s^0 \rightarrow K^{*0}\bar{K}^{*0})} = 0.0758 \pm 0.0057 \text{ (stat)} \pm 0.0025 \text{ (syst)} \pm 0.0016 \left( \frac{f_s}{f_d} \right)$$

Using previous measurements of the  $B_s$  BR:

$$\mathcal{B}(B^0 \rightarrow K^{*0}\bar{K}^{*0}) = (8.0 \pm 0.9 \text{ (stat)} \pm 0.4 \text{ (syst)}) \times 10^{-7}$$

# Measurement of BR and $f_L$ for $B^0 \rightarrow K^{*0}\bar{K}^{*0}$ , $f_L$ for $B_s^0 \rightarrow K^{*0}\bar{K}^{*0}$

LHCb: JHEP 07 (2019) 032

Run 1 data

$$\frac{\mathcal{B}(B^0 \rightarrow K^{*0}\bar{K}^{*0})}{\mathcal{B}(B_s^0 \rightarrow K^{*0}\bar{K}^{*0})} = \frac{\varepsilon_{B_s^0}}{\varepsilon_{B^0}} \times \frac{\lambda_{B_s^0}^{f_L}}{\lambda_{B^0}^{f_L}} \times \frac{N_{B^0} \times f_{B^0}^D}{N_{B_s^0} \times f_{B_s^0}^D} \times \frac{f_s}{f_d}$$

Smaller value than the one measured by BaBar, due to the S-wave been included in the LHCb analysis:

$$\mathcal{B}(B^0 \rightarrow K^{*0}\bar{K}^{*0}) = [1.28_{-0.30}^{+0.35} \pm 0.11] \times 10^{-6} \quad \text{BABAR: PRL 100 (2008) 081801}$$

$$\frac{\mathcal{B}(B^0 \rightarrow K^{*0}\bar{K}^{*0})}{\mathcal{B}(B_s^0 \rightarrow K^{*0}\bar{K}^{*0})} = 0.0758 \pm 0.005 \quad (\text{stat}) \pm 0.0025 \text{ (syst)} \pm 0.0016 \left( \frac{f_s}{f_d} \right)$$

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LHCb: JHEP 07 (2019) 032

Run 1 data

arXiv:2301.10542

Optimised observable from a theory point of view:

$$L_{K^*\bar{K}^*} = \rho(m_{K^{*0}}, m_{K^{*0}}) \frac{\mathcal{B}(\bar{B}_s \rightarrow K^{*0}\bar{K}^{*0})}{\mathcal{B}(\bar{B}_d \rightarrow K^{*0}\bar{K}^{*0})} \frac{f_L^{B_s}}{f_L^{B_d}}$$

$$L_{K^*\bar{K}^*}^{\text{SM}} = 19.53^{+9.14}_{-6.64} \quad \xleftrightarrow{2.6 \sigma} \quad L_{K^*\bar{K}^*}^{\text{exp}} = 4.43 \pm 0.92$$

using previous measurements of the  $B_s$  BR.

$$\mathcal{B}(B^0 \rightarrow K^{*0}\bar{K}^{*0}) = (8.0 \pm 0.9 \text{ (stat)} \pm 0.4 \text{ (syst)}) \times 10^{-7}$$

# Measurements of $B_{(s)}^0 \rightarrow K^0 \bar{K}^0$

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# Measurements of $B_{(s)}^0 \rightarrow K^0 \bar{K}^0$

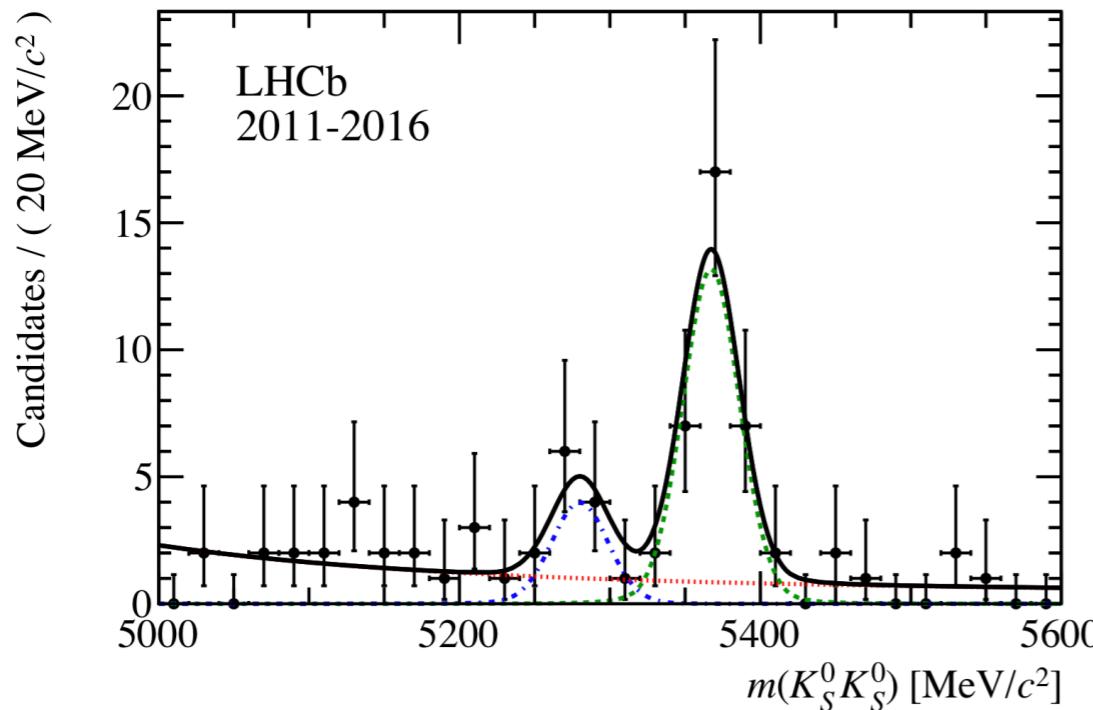
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# Measurement of BR for $B_{(s)}^0 \rightarrow K^0 \bar{K}^0$

LHCb: PRD 102 (2020) 1, 012011

Run 1 + 2015&2016 data



## Analysis method:

- Measure yields and efficiencies for the **signal mode(s)** and the **normalization one**.
- No need for amplitude analysis.

Normalisation mode:  $B^0 \rightarrow \phi K_S^0$

$$\mathcal{B}(B_s^0 \rightarrow K_S^0 K_S^0) = [8.3 \pm 1.6 \text{ (stat)} \pm 0.9 \text{ (syst)} \pm 0.8 \text{ (norm)} \pm 0.3 (f_s/f_d)] \times 10^{-6}$$

If directly normalising the  $B^0 \rightarrow K_S \bar{K}_S$  to the  $B_s \rightarrow K_S \bar{K}_S$ :

$$\frac{\mathcal{B}(B^0 \rightarrow K_S^0 K_S^0)}{\mathcal{B}(B_s^0 \rightarrow K_S^0 K_S^0)} = [7.5 \pm 3.1 \text{ (stat)} \pm 0.5 \text{ (syst)} \pm 0.3 (f_s/f_d)] \times 10^{-2}$$

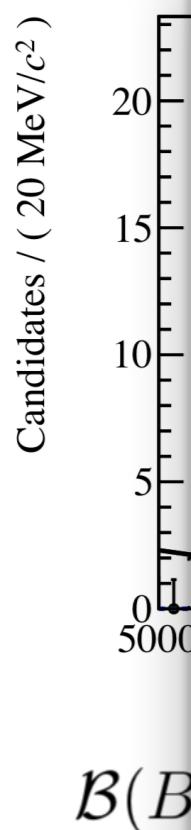
- Several **systematic uncertainties cancel in the ratio** (including a dominant one from data/simulation differences in the trigger).
- **The result is statistically dominated.**

# Measurement of BR for $B_{(s)}^0 \rightarrow K^0 \bar{K}^0$

LHCb: PRD 102 (2020) 1, 012011

Run 1 + 2015&2016 data

arXiv:2301.10542



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$$L_{K\bar{K}} = \rho(m_{K^0}, m_{K^0}) \frac{\mathcal{B}(\bar{B}_s \rightarrow K^0 \bar{K}^0)}{\mathcal{B}(\bar{B}_d \rightarrow K^0 \bar{K}^0)}$$

If direc-

$$L_{K\bar{K}}^{\text{SM}} = 26.00^{+3.88}_{-3.59} \quad \xrightarrow{2.4 \sigma} \quad L_{K\bar{K}}^{\text{exp}} = 14.58 \pm 3.37$$

- Several systematic uncertainties cancel in the ratio (including a dominant one from data/simulation differences in the trigger).
- The result is statistically dominated.

**1. Introduction**

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the puzzle**

**3. The “crossed”  
modes**

**5. Conclusions**

# Connecting modes: Week Effective Theory

arXiv:2301.10542

$$H_{\text{eff}} = \frac{G_F}{\sqrt{2}} \sum_{p=c,u} \lambda_p^{(q)} \left( \mathcal{C}_{1s}^p Q_{1s}^p + \mathcal{C}_{2s}^p Q_{2s}^p + \sum_{i=3\dots 10} \mathcal{C}_{is} Q_{is} + \mathcal{C}_{7\gamma s} Q_{7\gamma s} + \mathcal{C}_{8gs} Q_{8gs} \right)$$

$$Q_{1s}^p = (\bar{p}b)_{V-A}(\bar{s}p)_{V-A},$$

$$Q_{2s}^p = (\bar{p}_i b_j)_{V-A}(\bar{s}_j p_i)_{V-A},$$

$$Q_{3s} = (\bar{s}b)_{V-A} \sum_q (\bar{q}q)_{V-A},$$

$$Q_{4s} = (\bar{s}_i b_j)_{V-A} \sum_q (\bar{q}_j q_i)_{V-A},$$

$$Q_{5s} = (\bar{s}b)_{V-A} \sum_q (\bar{q}q)_{V+A},$$

$$Q_{6s} = (\bar{s}_i b_j)_{V-A} \sum_q (\bar{q}_j q_i)_{V+A},$$

$$Q_{7s} = (\bar{s}b)_{V-A} \sum_q \frac{3}{2} e_q (\bar{q}q)_{V+A},$$

$$Q_{8s} = (\bar{s}_i b_j)_{V-A} \sum_q \frac{3}{2} e_q (\bar{q}_j q_i)_{V+A},$$

$$Q_{9s} = (\bar{s}b)_{V-A} \sum_q \frac{3}{2} e_q (\bar{q}q)_{V-A},$$

$$Q_{10s} = (\bar{s}_i b_j)_{V-A} \sum_q \frac{3}{2} e_q (\bar{q}_j q_i)_{V-A},$$

$$Q_{7\gamma s} = \frac{-e}{8\pi^2} m_b \bar{s} \sigma_{\mu\nu} (1 + \gamma_5) F^{\mu\nu} b,$$

$$Q_{8gs} = \frac{-g_s}{8\pi^2} m_b \bar{s} \sigma_{\mu\nu} (1 + \gamma_5) G^{\mu\nu} b,$$

**Both deviations can be consistently explained by NP contributions to Wilson coefficients.**

# The “crossed” modes: $B_{(s)}^0 \rightarrow K^{*0} \bar{K}^0$ and $B_{(s)}^0 \rightarrow K^0 \bar{K}^{*0}$

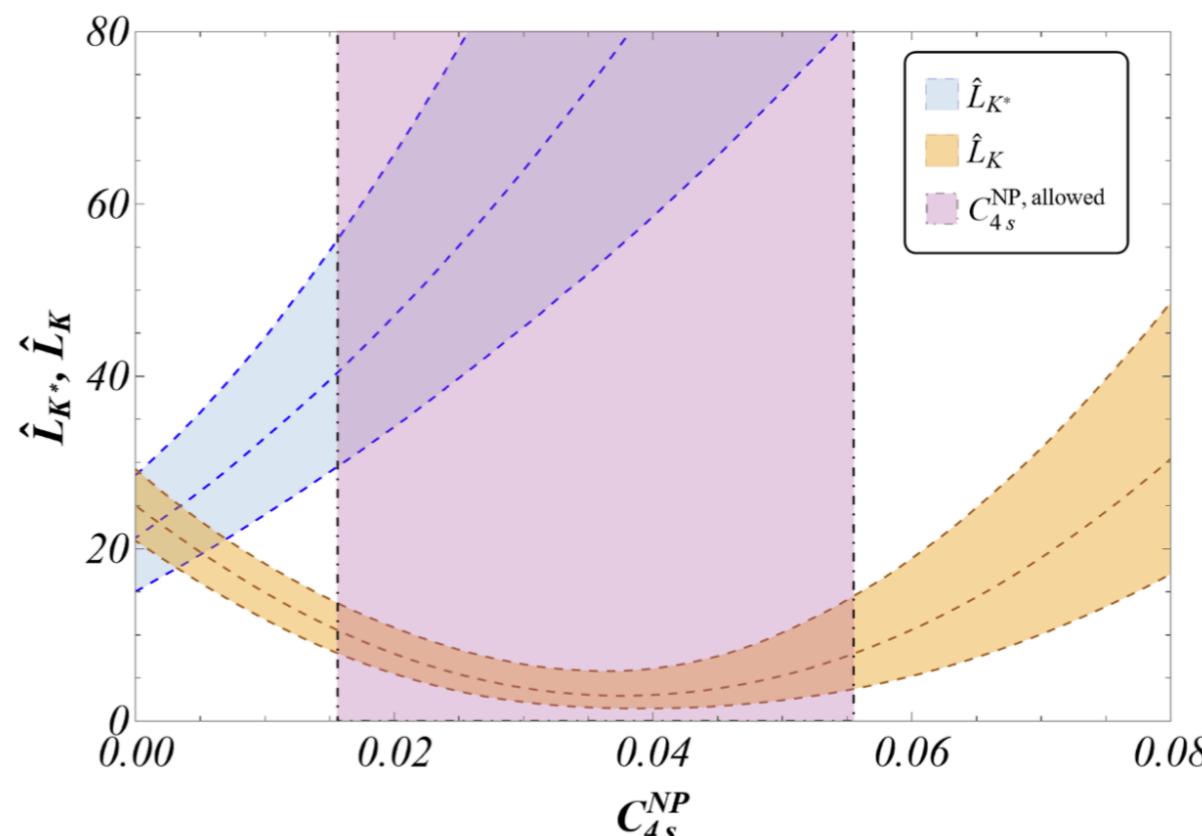
arXiv:2301.10542

If the previous anomalies come from NP, large deviations predicted for the “crossed modes”.

Two observables can be defined, depending on whether the spectator quark ends up in a P or a V meson:

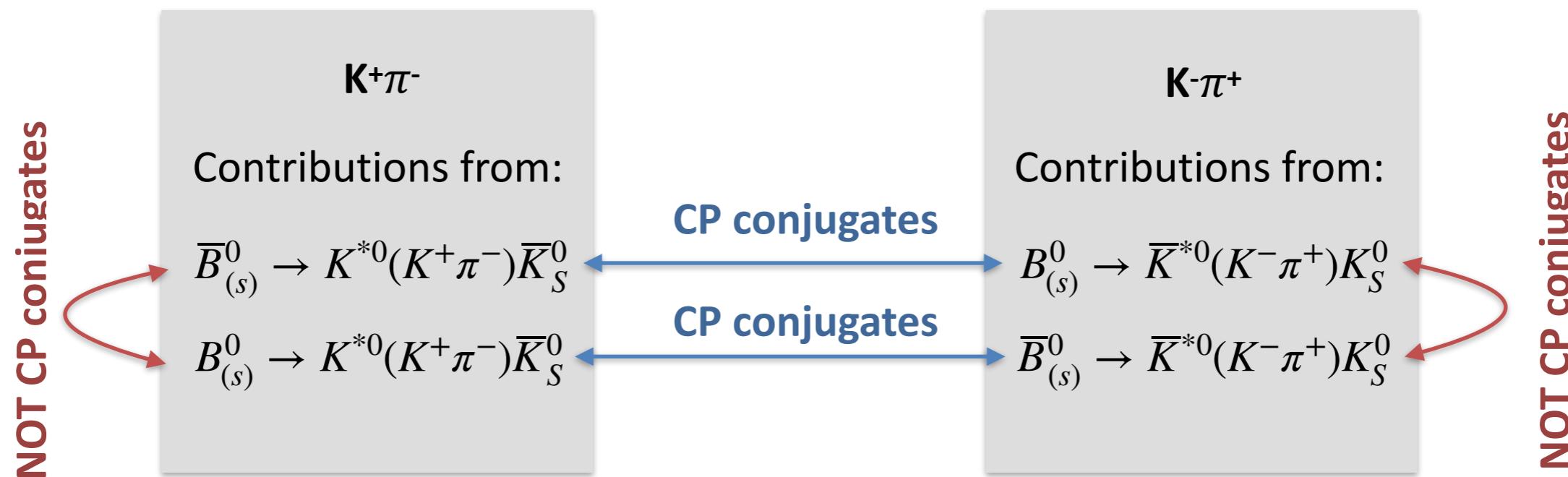
$$\hat{L}_{K^*} = \rho(m_{K^0}, m_{K^{*0}}) \frac{\mathcal{B}(\bar{B}_s \rightarrow K^{*0} \bar{K}^0)}{\mathcal{B}(\bar{B}_d \rightarrow \bar{K}^{*0} K^0)}$$

$$\hat{L}_K = \rho(m_{K^0}, m_{K^{*0}}) \frac{\mathcal{B}(\bar{B}_s \rightarrow K^0 \bar{K}^{*0})}{\mathcal{B}(\bar{B}_d \rightarrow \bar{K}^0 K^{*0})}$$



# Experimental note: this needs flavour tagging

Visible final states at LHCb:



Measuring the previous observables requires **splitting the contributions, which can only be done with FT in both the  $B_s$  and  $B^0$  modes.**

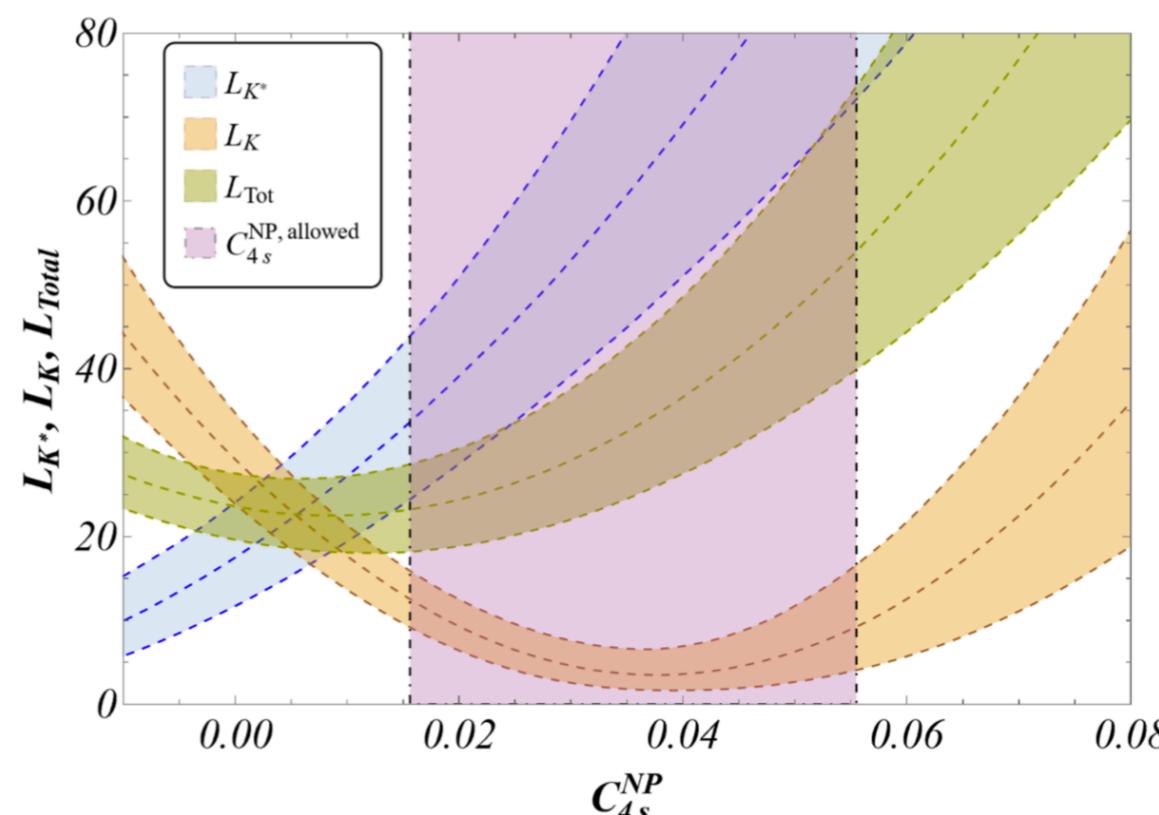
# More-friendly (but less sensitive) observables

arXiv:2301.10542

$$L_{K^*} = 2 \rho(m_{K^0}, m_{K^{*0}}) \frac{\mathcal{B}(\bar{B}_s \rightarrow K^{*0} \bar{K}^0)}{\mathcal{B}(\bar{B}_d \rightarrow \bar{K}^{*0} K^0) + \mathcal{B}(\bar{B}_d \rightarrow \bar{K}^0 K^{*0})}$$

$$L_K = 2 \rho(m_{K^0}, m_{K^{*0}}) \frac{\mathcal{B}(\bar{B}_s \rightarrow K^0 \bar{K}^{*0})}{\mathcal{B}(\bar{B}_d \rightarrow \bar{K}^{*0} K^0) + \mathcal{B}(\bar{B}_d \rightarrow \bar{K}^0 K^{*0})}$$

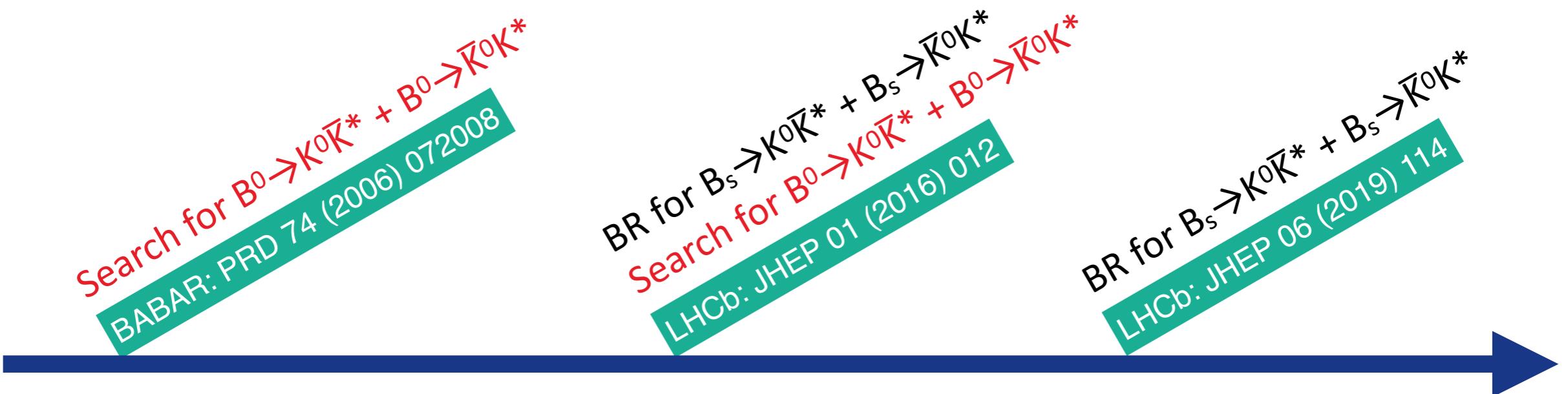
$$L_{\text{total}} = \rho(m_{K^0}, m_{K^{*0}}) \left( \frac{\mathcal{B}(\bar{B}_s \rightarrow K^{*0} \bar{K}^0) + \mathcal{B}(\bar{B}_s \rightarrow K^0 \bar{K}^{*0})}{\mathcal{B}(\bar{B}_d \rightarrow \bar{K}^{*0} K^0) + \mathcal{B}(\bar{B}_d \rightarrow \bar{K}^0 K^{*0})} \right) \rightarrow \text{No FT required.}$$



FT required  
only on the  $B_s$ .

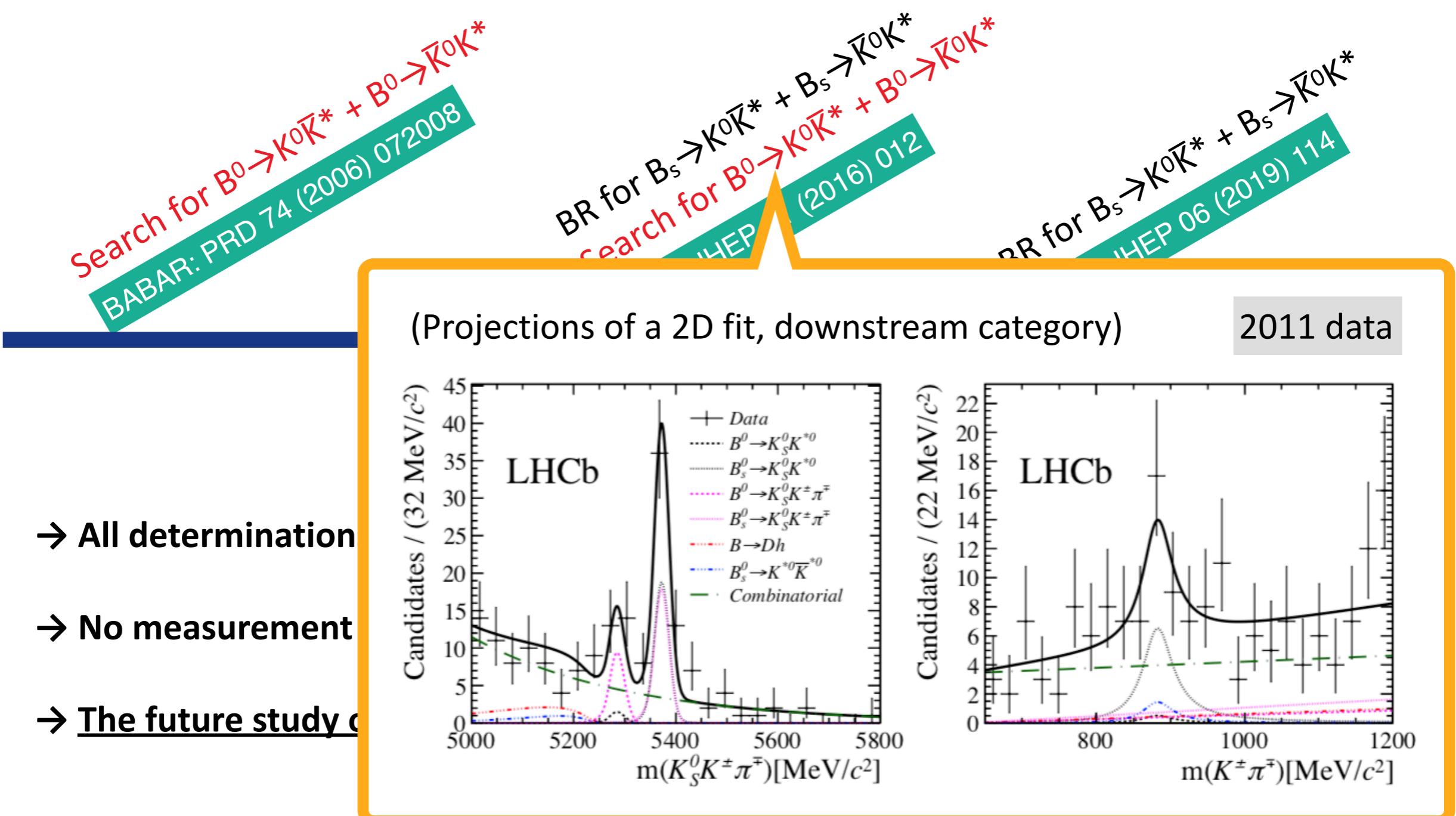
# Measurements of the crossed modes

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- All determinations up to now refer to the average.
- No measurement for the  $B^0$  yet.
- The future study of these modes can help clarifying the non-leptonic puzzle.

# Measurements of the crossed modes



**1. Introduction**

**2. History of  
the puzzle**

**3. The “crossed”  
modes**

**5. Conclusions**

# Conclusions

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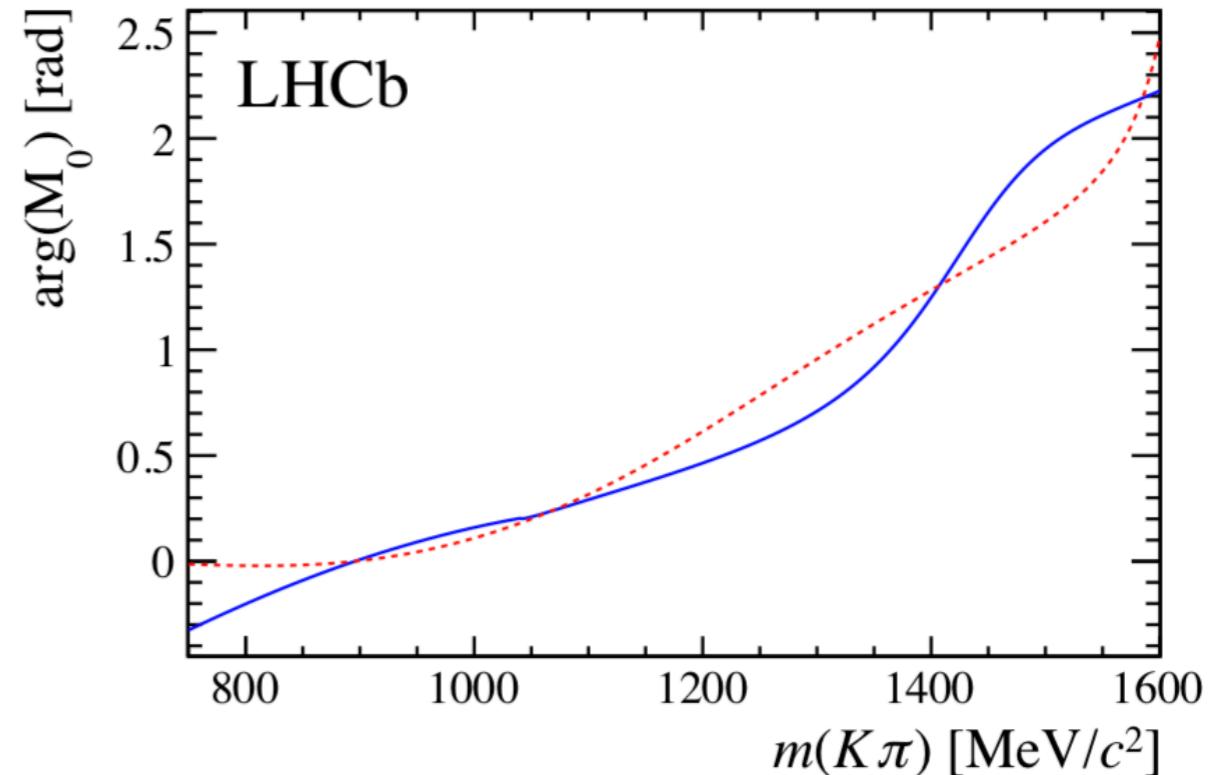
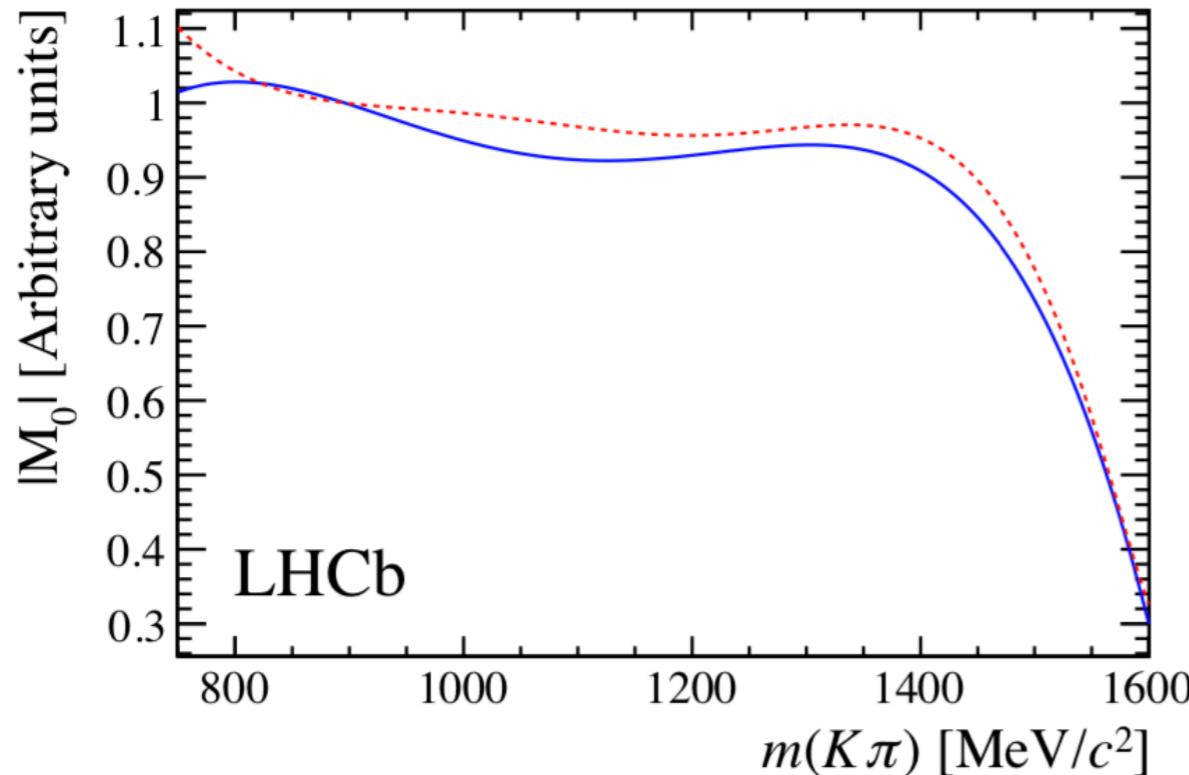
- The  $B_{(s)}^0 \rightarrow K^{(*)0} \bar{K}^{(*)0}$  decays are loop-level transitions in the SM.  $\rightarrow$  NP contributions can be sizable.
  - ➡ Modes originally studied for the measurement of CPV parameters.
- Long standing tension for  $f_L$  in  $B_s^0 \rightarrow K^{*0} \bar{K}^{*0}$ , while  $f_L$  in  $B^0 \rightarrow K^{*0} \bar{K}^{*0}$  is as expected.
  - ➡ **2.6  $\sigma$  tension in the associated optimized observable  $L_{K^*\bar{K}^*}$ .**
- Additional tension in the relative BR between  $B_s^0 \rightarrow K^0 \bar{K}^0$  and  $B^0 \rightarrow K^0 \bar{K}^0$ .
  - ➡ **2.4  $\sigma$  tension in the associated optimized observable  $L_{K\bar{K}}$ .**
- **Different experimental signatures** for the two types of decays, but phenomenological connection at the Week Effective Theory level.
- Future measurements from LHCb and Belle II can help clarify the situation.
  - ➡ **The “crossed” modes**, with or without flavour tagging.
  - ➡ Updates of the previous measurements (which are statistically dominated).
  - ➡ ...

**Stay tuned!**

# **Backup slides**

# S-wave model in $B_s^0 \rightarrow (K^+ \pi^-)(K^- \pi^+)$

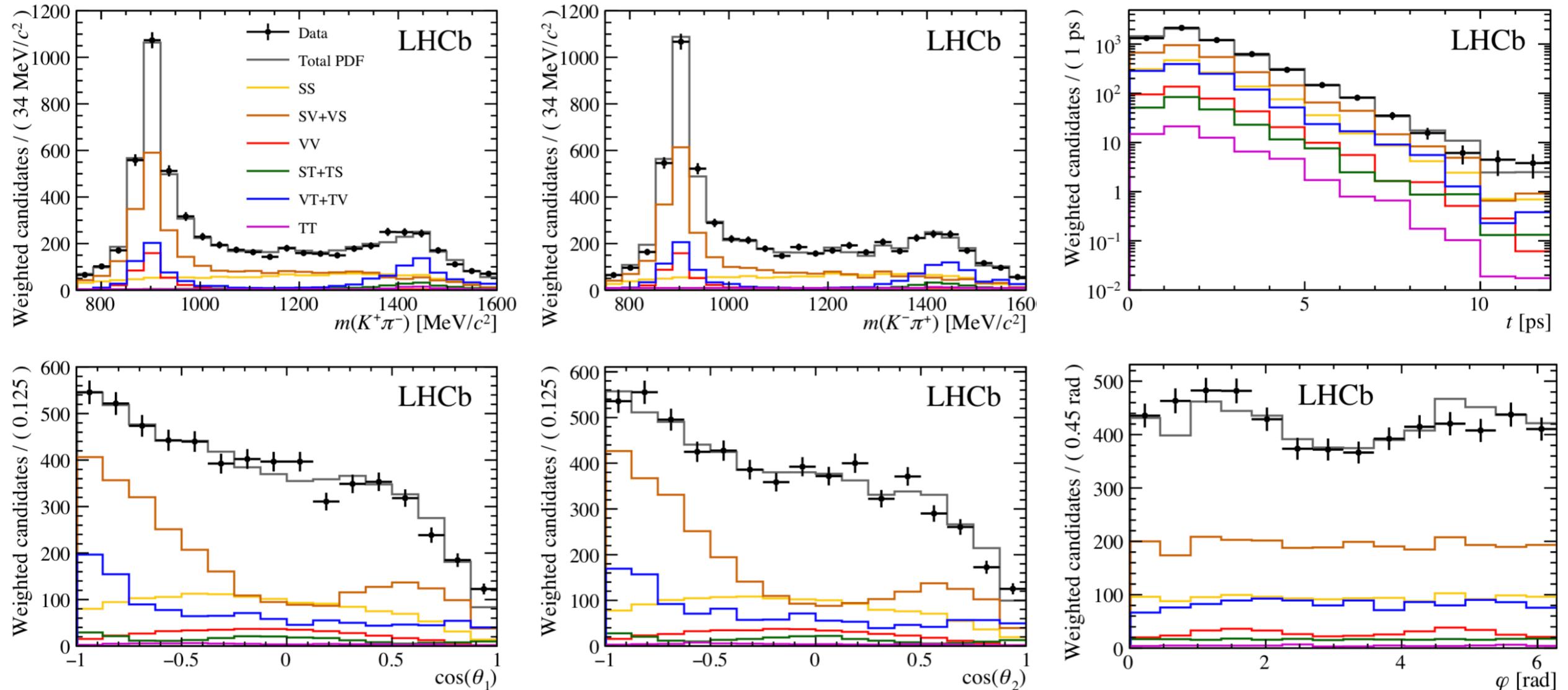
LHCb: JHEP 03 (2018) 140



**In blue:** pheno. (scattering) model for the phase and polynomial for the modulus.  
**In red:** fully model independent, polynomials for real and imaginary parts.

# Analysis of $B_s^0 \rightarrow (K^+\pi^-)(K^-\pi^+)$

LHCb: JHEP 03 (2018) 140



# Systematic uncertainties on the analysis of $B_s^0 \rightarrow (K^+ \pi^-)(K^- \pi^+)$

LHCb: JHEP 03 (2018) 140

Parameter	$\phi_s^{d\bar{d}}$ [rad]	$ \lambda $	$f^{VV}$	$f_L^{VV}$	$f_{  }^{VV}$	$\delta_{  }^{VV}$	$\delta_{\perp}^{VV}$	$f^{SV}$	$f^{VS}$	$\delta^{SV}$	$\delta^{VS}$	$f^{SS}$	$\delta^{SS}$			
Yield and shape of mass model	0.012	0.001	0.001	0.004	0.004	0.011	0.020	0.002	0.003	0.023	0.023	0.004	0.012			
Signal weights of mass model	0.012	0.007	0.002	0.006	0.005	0.024	0.112	0.004	0.005	0.049	0.022	0.005	0.047			
Decay-time-dependent fit procedure	0.006	0.002	0.001	0.006	0.002	0.007	0.017	0.003	0.002	0.007	0.027	0.001	0.009			
Decay-time-dependent fit parameterisation	0.049	0.013	0.021	0.025	0.026	0.187	0.202	0.042	0.029	0.159	0.234	0.064	0.227			
Acceptance weights (simulated sample size)	0.106	0.078	0.004	0.031	0.029	0.236	0.564	0.037	0.039	0.250	0.290	0.015	0.256			
Other acceptance and resolution effects	0.063	0.008	0.005	0.018	0.005	0.136	0.149	0.006	0.004	0.167	0.124	0.017	0.194			
Production asymmetry	0.002	0.002	0.000	0.000	0.001	0.017		0.002	0.002	0.002	0.008	0.000	0.002			
Total	0.141	0.089	0.024	0.046	0.042	0.333	0.641	0.071	0.065	0.346	0.405	0.069	0.399			
Parameter	$f^{ST}$	$f^{TS}$	$\delta^{ST}$	$\delta^{TS}$	$f^{VT}$	$f_L^{VT}$	$f_{  }^{VT}$	$f^{TV}$	$f_L^{TV}$	$f_{  }^{TV}$	$\delta_0^{VT}$	$\delta_{  }^{VT}$	$\delta_{\perp}^{VT}$	$\delta_0^{TV}$	$\delta_{  }^{TV}$	$\delta_{\perp}^{TV}$
Yield and shape of mass model	0.002	0.004	0.111	0.023	0.001	0.003	0.001	0.001	0.043	0.025	0.023	0.055	0.110	0.053	0.018	0.065
Signal weights of mass model	0.004	0.006	0.151	0.105	0.002	0.003	0.001	0.001	0.043	0.029	0.025	0.131	0.126	0.080	0.073	0.150
Decay-time-dependent fit procedure	0.001	0.002	0.248	0.017	0.002	0.004	0.002	0.002	0.008	0.005	0.012	0.069	0.025	0.062	0.017	0.030
Decay-time-dependent fit parameterisation	0.006	0.017	0.736	0.247	0.011	0.053	0.019	0.008	0.080	0.048	0.286	0.308	0.260	0.260	0.228	0.405
Acceptance weights (simulated sample size)	0.014	0.015	1.463	0.719	0.026	0.145	0.054	0.027	0.199	0.102	1.117	1.080	0.888	0.712	0.417	0.947
Other acceptance and resolution effects	0.002	0.003	0.184	0.226	0.015	0.024	0.004	0.005	0.045	0.017	0.163	0.168	0.191	0.229	0.246	0.171
Production asymmetry	0.001	0.001	0.037	0.026	0.001	0.003	0.001	0.002	0.012	0.006	0.015	0.030	0.018	0.003	0.007	0.041
Total	0.031	0.033	1.688	0.817	0.049	0.165	0.063	0.048	0.252	0.143	1.171	1.159	0.970	0.802	0.546	1.076
Parameter	$f^{TT}$	$f_L^{TT}$	$f_{  }^{TT}$	$f_{\perp}^{TT}$	$f_{  }^{TT}$	$\delta_0^{TT}$	$\delta_{  }^{TT}$	$\delta_{\perp}^{TT}$	$\delta_{  }^{TT}$	$\delta_{\perp}^{TT}$	$\delta_{  }^{TT}$	$\delta_{\perp}^{TT}$	$\delta_{  }^{TT}$	$\delta_{\perp}^{TT}$	$\delta_{  }^{TT}$	$\delta_{\perp}^{TT}$
Yield and shape of mass model	0.000	0.045	0.019	0.037	0.002	0.038	0.027	0.009	0.079	0.114						
Signal weights of mass model	0.000	0.066	0.025	0.024	0.002	0.147	0.046	0.112	0.123	0.215						
Decay-time-dependent fit procedure	0.001	0.022	0.022	0.014	0.004	0.127	0.036	0.068	0.058	0.040						
Decay-time-dependent fit parameterisation	0.005	0.051	0.071	0.113	0.038	1.213	0.199	0.685	0.820	0.476						
Acceptance weights (simulated sample size)	0.003	0.135	0.110	0.127	0.077	1.328	0.454	1.348	1.443	1.161						
Other acceptance and resolution effects	0.002	0.031	0.028	0.056	0.024	0.226	0.275	0.156	0.343	0.301						
Production asymmetry	0.000	0.002	0.001	0.008	0.003	0.005	0.002	0.062	0.015	0.043						
Total	0.007	0.176	0.142	0.205	0.107	1.825	0.573	1.546	1.706	1.330						

# Summary of measurements and SM computations

arXiv:2301.10542

$\mathcal{B}(\bar{B}_d \rightarrow K^0 \bar{K}^0) [10^{-6}]$	
SM (QCDF)	Experiment
$1.09^{+0.29}_{-0.20}$	$1.21 \pm 0.16$ [24, 27, 28]

$\mathcal{B}(\bar{B}_s \rightarrow K^0 \bar{K}^0) [10^{-5}]$	
SM (QCDF)	Experiment
$2.80^{+0.89}_{-0.62}$	$1.76 \pm 0.33$ [24, 29, 30]

Measured longitudinal polarisation fractions	
$f_L(\bar{B}_d \rightarrow K^{0*} \bar{K}^{0*})$	$f_L(\bar{B}_s \rightarrow K^{0*} \bar{K}^{0*})$
$0.73 \pm 0.05$ [17, 35, 36]	$0.240 \pm 0.040$ [37]

Measured branching ratios (all polarisations included)	
$\mathcal{B}(\bar{B}_d \rightarrow K^{*0} \bar{K}^{*0})_{\text{all pol}}$	$\mathcal{B}(\bar{B}_s \rightarrow K^{*0} \bar{K}^{*0})_{\text{all pol}}$
$(0.83 \pm 0.24) \times 10^{-6}$ [24]	$(1.11 \pm 0.28) \times 10^{-5}$ [24]

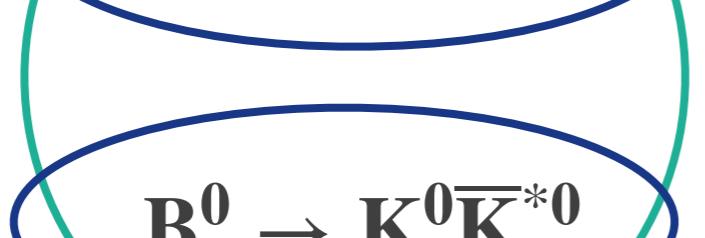
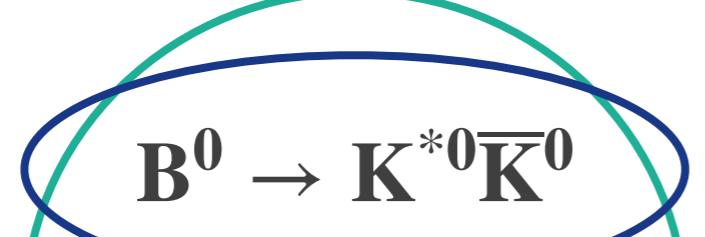
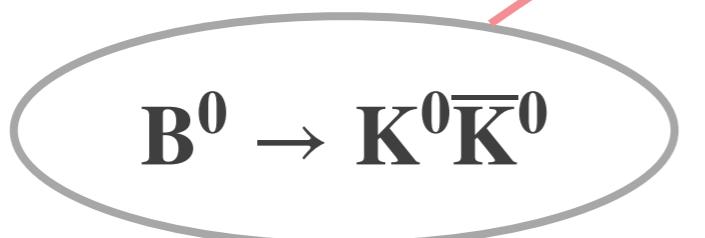
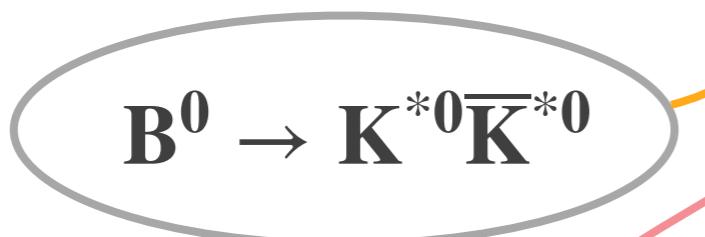
Longitudinal $\mathcal{B}(\bar{B}_d \rightarrow K^{*0} \bar{K}^{*0}) [10^{-7}]$	
SM (QCDF)	Experiment
$2.27^{+0.98}_{-0.74}$	$6.04^{+1.81}_{-1.78}$

Longitudinal $\mathcal{B}(\bar{B}_s \rightarrow K^{*0} \bar{K}^{*0}) [10^{-6}]$	
SM (QCDF)	Experiment
$4.36^{+2.23}_{-1.65}$	$2.62^{+0.85}_{-0.75}$

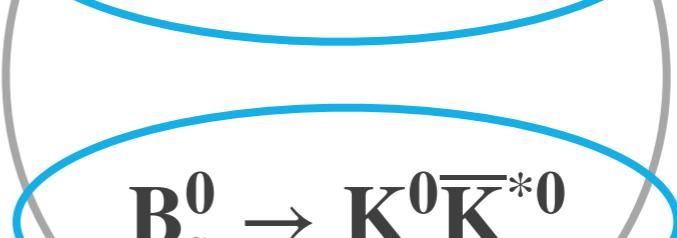
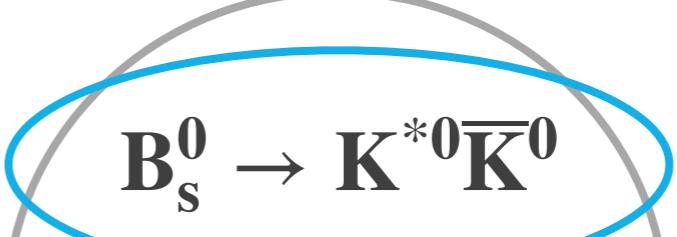
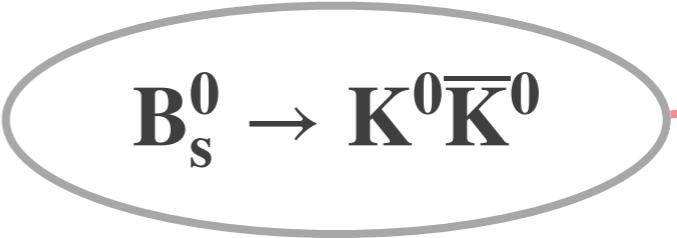
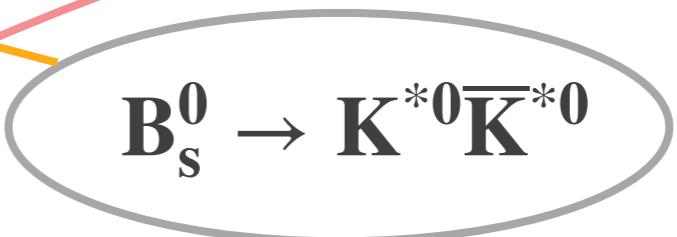
# Possible future opportunities

Already measured  
in gray

LHCb Run 1 only,  
Full Run 2 data available



LHCb Run 1 + 2015&2016 only,  
2017&2018 data available



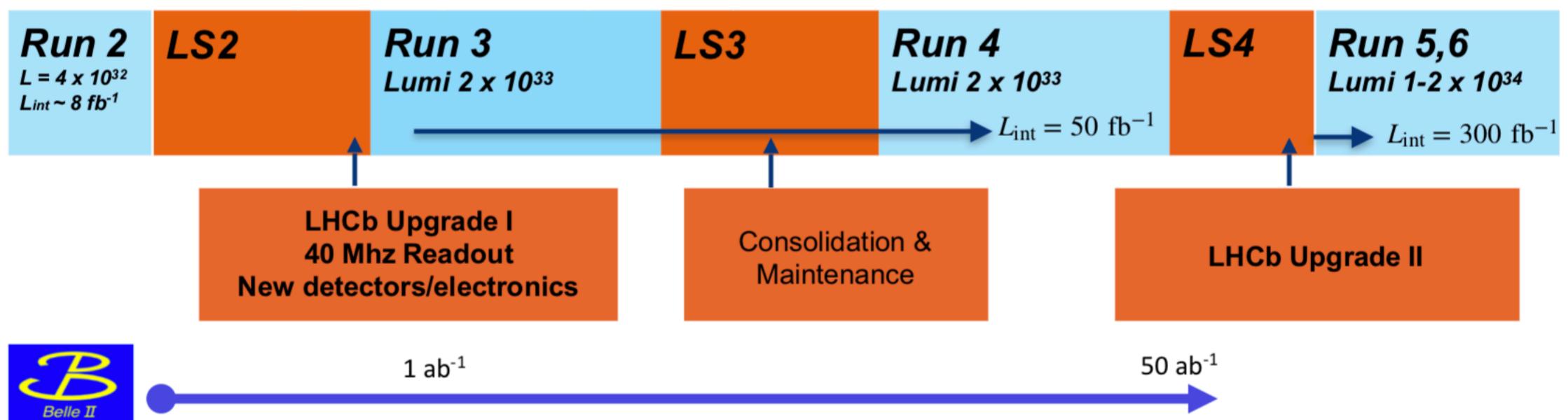
Higher difficulty for LHCb

Easier for LHCb

Medium difficulty for LHCb

# Possible future opportunities

A lot more data to be collected by LHCb in the future.



Important complementary information from Belle II.