

Study of charmless b –hadron decays with the LHCb spectrometer

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Outline

1. Research project

- Scientific context
- Progress and main results

2. Professional project

3. Doctoral School and complementary activities

4. Outlook

- Planning for 2026-2027
- Documentation

5. Questions and discussion

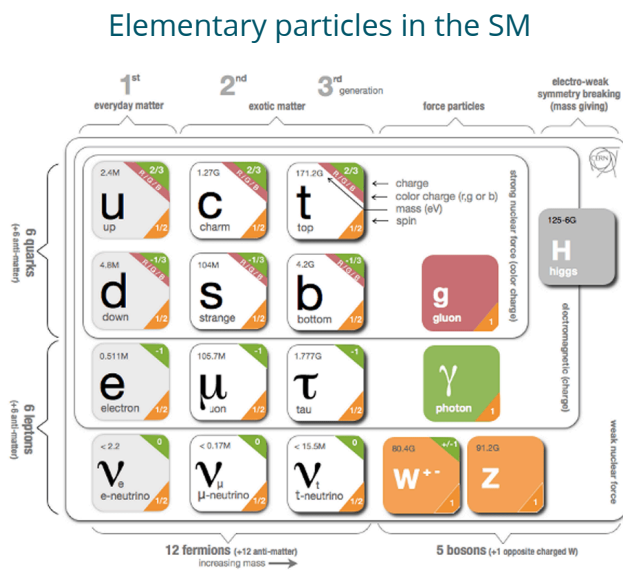


Research project

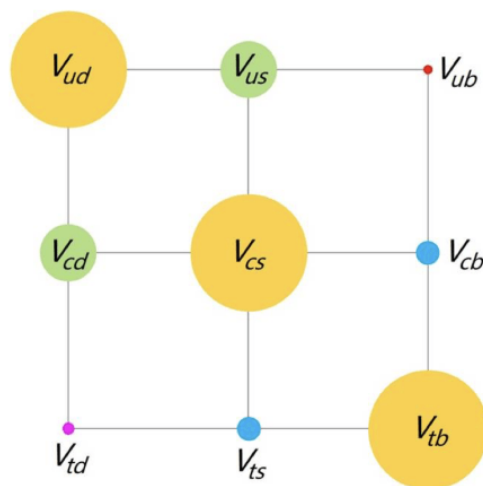
Standard model and flavour physics

Flavour physics studies how quarks change flavour — and tests the Standard Model with high precision

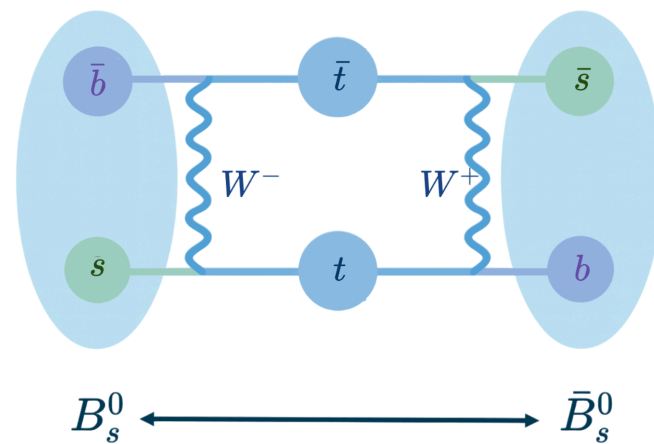
- The Standard Model (SM) is the quantum field theory which describes strong and electroweak interactions
 - Based on: local gauge invariance $SU(3)_C \times SU(2)_L \times U(1)_Y$ and spontaneous symmetry breaking
- Flavour physics relates to the existence of different families of quarks and how they couple to each other.
- In the SM, quark mixing arises through charged weak currents mediated by the $W^\pm$ bosons and is quantified by the Cabbibo-Kobayashi-Maskawa (CKM) matrix



Quark mixing (CKM)



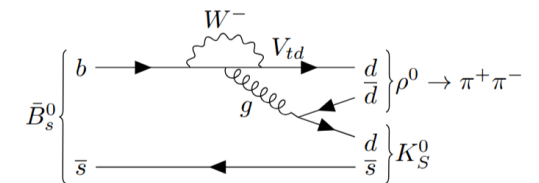
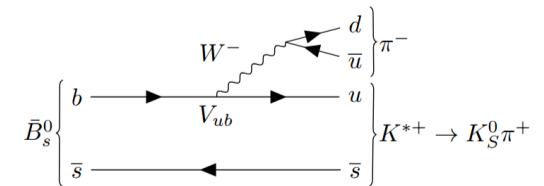
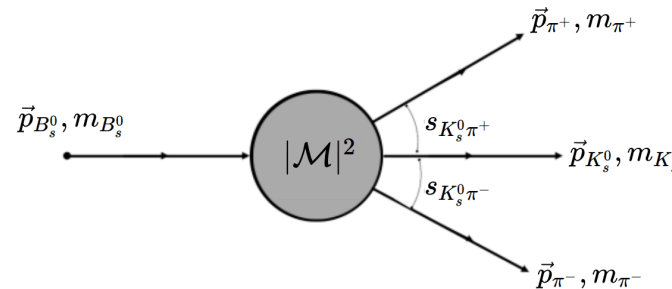
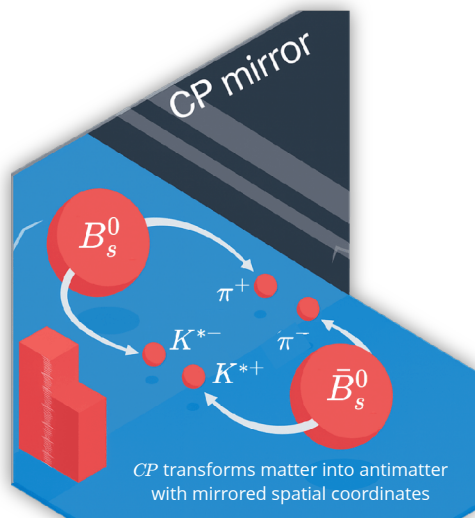
Neutral meson oscillations



CP violation in three-body charmless B decays

Three-body $B_{(s)}^0$ decays turn CP violation into interference patterns of interference across phase space

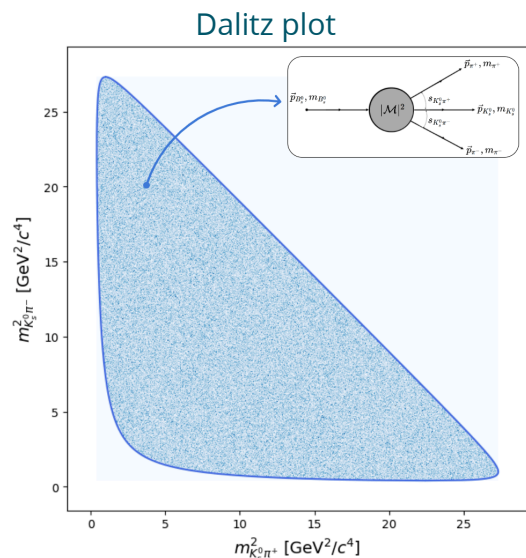
- CP symmetry is the combination of charge (C) and parity (P) conjugations.
 - In the SM, it arises solely from a non-zero complex phase in the CKM matrix $\Rightarrow V_{ij} \neq V_{ij}^*$
- Observable CP asymmetries arise from the interference of decay amplitudes with different weak and strong phases.
- Charmless three-body B decays, such as $B_{(s)}^0 \rightarrow K_s^0 \pi^+ \pi^-$, provide many interfering decay pathways.
 - Resonant intermediate states produce a rich structure across phase space, making them excellent laboratories for CP -violation studies



Amplitude Analysis of $B_{(s)}^0 \rightarrow K_S^0 \pi^+ \pi^-$ decays

Amplitude analysis turns interference patterns across the Dalitz plot into measurements of resonant dynamics and CP violation

- Dalitz plot (DP) $\Rightarrow$ Two-dimensional representation of the phase space of three-body decays.
- Intermediate resonances appear as characteristic structures across this phase space.
 - Isobar model (IM) $\Rightarrow$ Parameterization of the decay amplitude $\mathcal{A}$.
 - Coherent sum of a non-resonant (NR) component and resonant amplitudes.
- By fitting the interference pattern, we determine the magnitude and phase of each contribution.
 - Comparing the amplitudes of $B_{(s)}^0$ and $\bar{B}_{(s)}^0$ decays gives access to CP -violating observables.



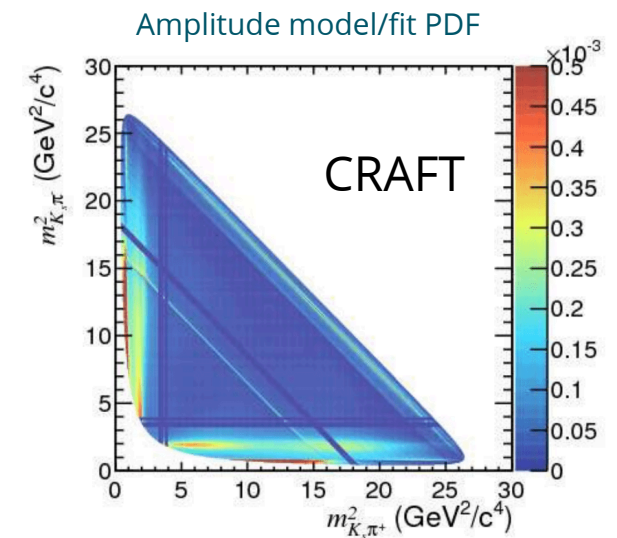
$$|\mathcal{A}(s_+, s_-)|^2 = \left| \sum_j a_j e^{i\phi_j} F_j(s_+, s_-) \right|^2$$

Isobar amplitudes

$$c_k = a_k e^{i\phi_k} = x_k + iy_k$$

CP asymmetry observable

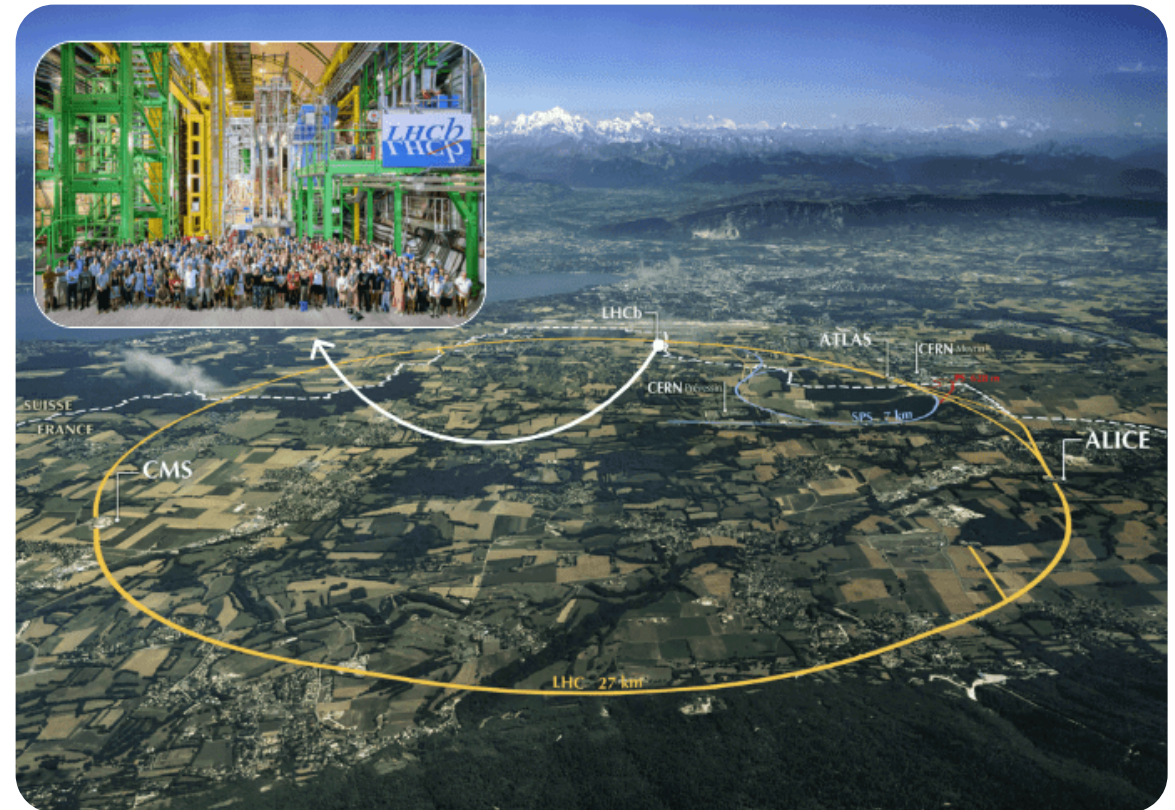
$$\mathcal{A}_{\text{dir}}^{CP} = \frac{|\bar{c}_k|^2 - |c_k|^2}{|\bar{c}_k|^2 + |c_k|^2}.$$



The experimental environment: LHC and LHCb

The LHC produces heavy-flavour particles in abundance — LHCb is designed to study how they decay

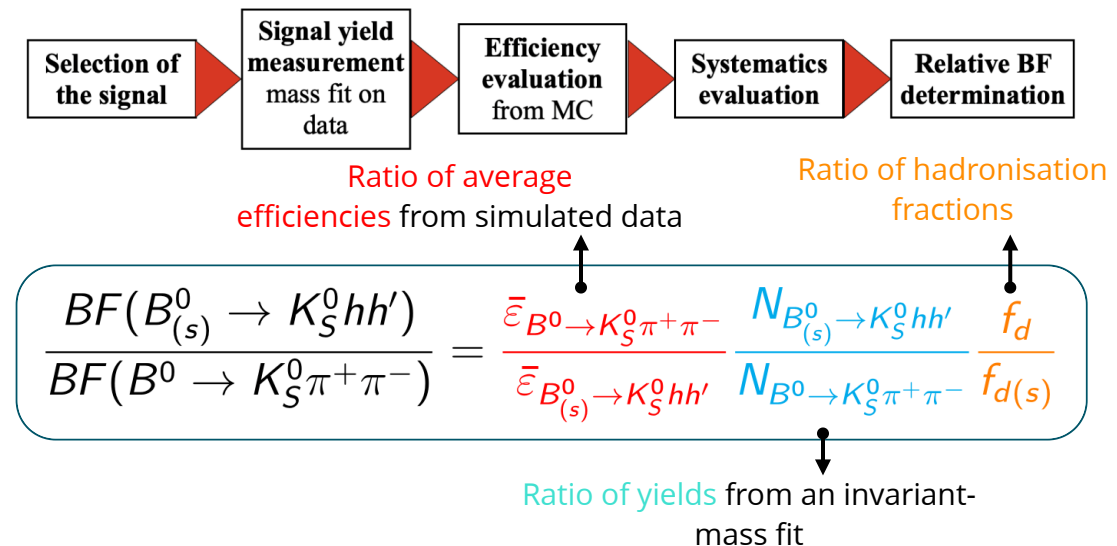
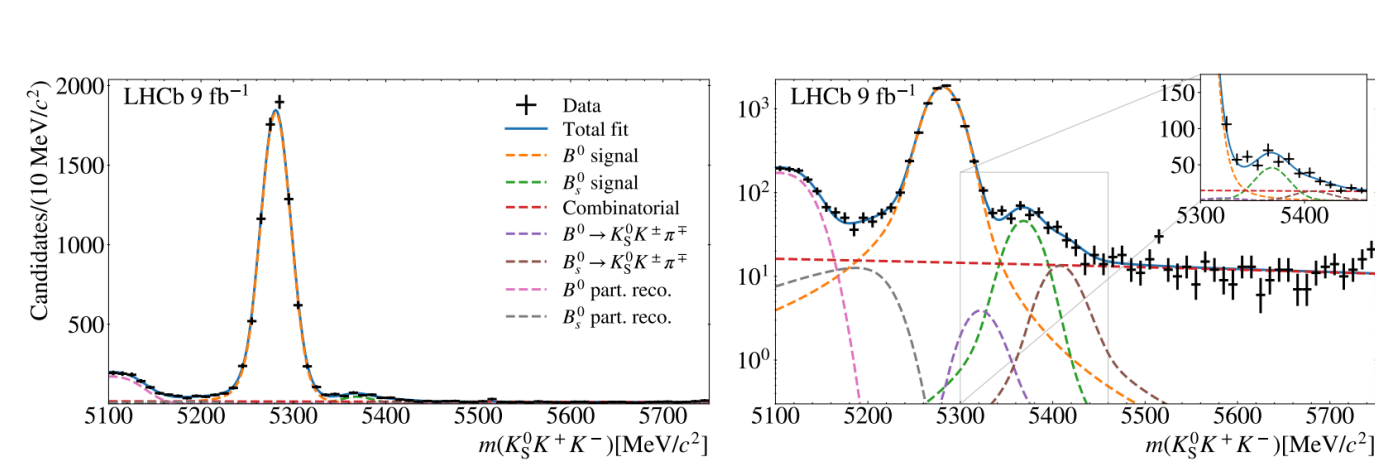
- The LHC collides protons at very high energies, producing large samples of b - and c - hadrons.
 - LHCb is one of the four major LHC experiments and is specialised in heavy-flavour physics.
 - Precise reconstruction of decay vertices, particle trajectories and particle identities.
 - This thesis uses $B_{(s)}^0 \rightarrow K_s^0 \pi^+ \pi^-$ candidates from pp collisions recorded by LHCb during: 2011 & 2012 (Run 1) and 2015-2018 (Run 2)
-
- LHCb studies the subtle differences between matter and antimatter through heavy-flavour decays.
 - CP violation searches
 - Rare decays
 - HF production and spectroscopy



Branching Fraction measurement of $B_{(s)}^0 \rightarrow K_S^0 h^+ h^-$ decays

Analysis finally completed and published $\Rightarrow$ This will be a chapter of my thesis!

- Measurement of Branching Fractions of $B_{(s)}^0 \rightarrow K_S^0 hh'$ (6 modes) using Run 1 and Run 2 data
 - This analysis was performed in collaboration with LPNHE and the U. of Warwick $\Rightarrow$ B(s)->Kshh' μ -group
 - Previous measurement done with Run 1 data only
 - Main result: Observation of the $B_s^0 \rightarrow K_S^0 K^+ K^-$ decay
- Contributed to the re-computation of the efficiencies and validation of the fit model, as well as to the review process within the collaboration and the journal.
- This work is the starter point towards Amplitude Analysis $\Rightarrow$ My thesis



Time integrated Amplitude Analysis of $B_s^0 \rightarrow K_S^0 \pi^+ \pi^-$

Physics motivation

The charmless decay $B_s^0 \rightarrow K_S^0 \pi^+ \pi^-$ will provide access to:

- Search of direct CP asymmetries of the Q2B decays with an untagged time-integrated (TI) Dalitz analysis:
 - Flavour specific: $\bar{B}_s^0 \rightarrow K_0^{*+}(1430)\pi^-$, $\bar{B}_s^0 \rightarrow K^{*+}(892)\pi^-$
 - CP -eigenstate: $B_s^0 \rightarrow \rho^0 K_S^0$
- Establishment of fit Fractions of the different amplitudes contributing to the decay.

Precedents

- This analysis follows a similar strategy to that of the $B_d^0 \rightarrow K_S^0 \pi^+ \pi^-$ amplitude analysis with Run I data.
 - We use our own fitter: CRAFT (Clermont Roofit-based Amplitude Fitter Tool)

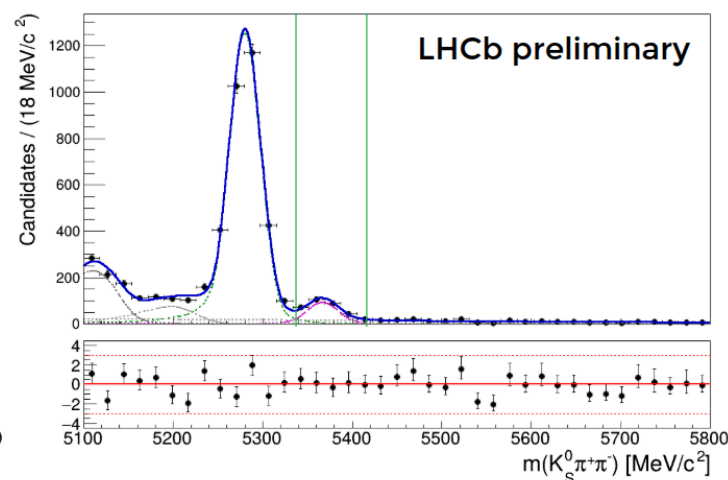
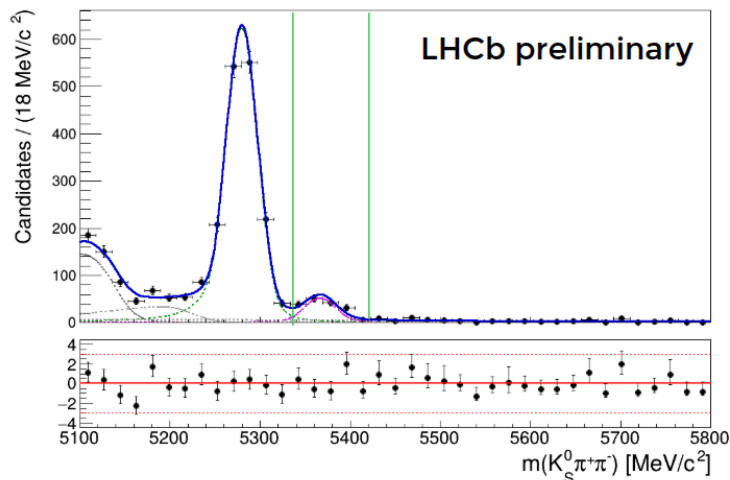
Data samples

- This analysis inherits samples and selections from the B2KShh' Branching Fraction Analysis.
 - 14 samples: Run 1 (2011, 2012a, 2012b), Run 2 (2015-2018). Two K_S^0 reco categories: DD and LL.
 - The selection is optimized with a tight optimization targeting $B_s^0 \rightarrow K_S^0 \pi^+ \pi^-$ signal candidates.

Time integrated Amplitude Analysis of $B_s^0 \rightarrow K_S^0 \pi^+ \pi^-$

Analysis strategy

- Stages:
 - Selection of $B_s^0 \rightarrow K_S^0 \pi^+ \pi^-$ signal candidates
 - Fit the invariant-mass spectrum $K_S^0 \pi^+ \pi^-$, define a signal window around B_s^0 signal peak, and determine the fraction of signal and bkg. (both combinatorial and $B_d^0 \rightarrow K_S^0 \pi^+ \pi^-$)
 - Obtain the spline histogram of the efficiency variation across the DP, evaluated from signal MC.
 - Determine a model for the different background components .
 - Fit simultaneously the different samples and educate the final model.



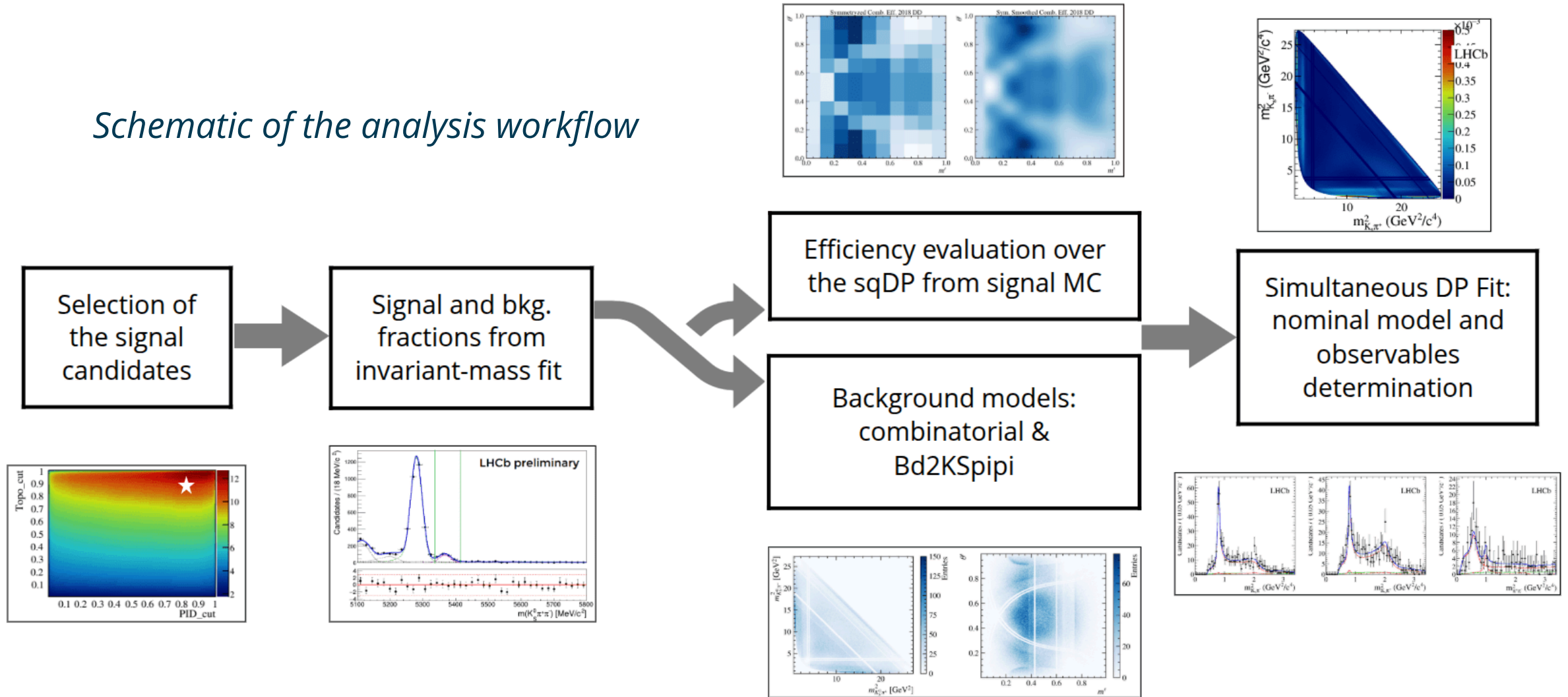
The approx. number of $B_s^0 \rightarrow K_S^0 \pi^+ \pi^-$ candidates in the signal window and hence entering the DP fit is **1.02K**

- Total: ~1.2K signal candidates
- Run 1:
 - Total: ~186
 - DD: ~116
 - LL: ~70
- Run 2:
 - Total: ~1K
 - DD: ~637
 - LL: ~365

The vertical green lines indicate the selected signal window around the B_s^0 peak.

Time integrated Amplitude Analysis of $B_s^0 \rightarrow K_S^0 \pi^+ \pi^-$

Schematic of the analysis workflow



Time integrated Amplitude Analysis of $B_s^0 \rightarrow K_S^0 \pi^+ \pi^-$

Model building

- A preliminary DP fit on data is conducted using a **Baseline model**.
- The model parameterizes the signal amplitude as the **isobar** sum of four resonances plus a non-resonant (NR) contribution.

$$|\mathcal{A}(s_+, s_-)|^2 = \left| \sum_j a_j e^{i\phi_j} F_j(s_+, s_-) \right|^2$$

a_j and ϕ_j (x_j, y_j in cartesian) describe the relative magnitude and phase. **Floating parameters in the fit.**



$$\mathcal{S}(s_+, s_-) \propto |\mathcal{A}(s_+, s_-)|^2 + |\bar{\mathcal{A}}(s_+, s_-)|^2$$

Untagged time-integrated Dalitz signal PDF.



$$\mathcal{P}(s_+, s_-) = f_{\text{sig}} \frac{\epsilon(s_+, s_-) \mathcal{S}(s_+, s_-)}{N_{\text{sig}}} + \sum_i f_{\text{bkg}_i} \frac{\mathcal{B}_i(s_+, s_-)}{N_{\text{bkg}_i}}$$

Total Dalitz PDF

- Relevant additional contributions have been tested, one by one, and accepted according to a defined algorithm.

Nominal model

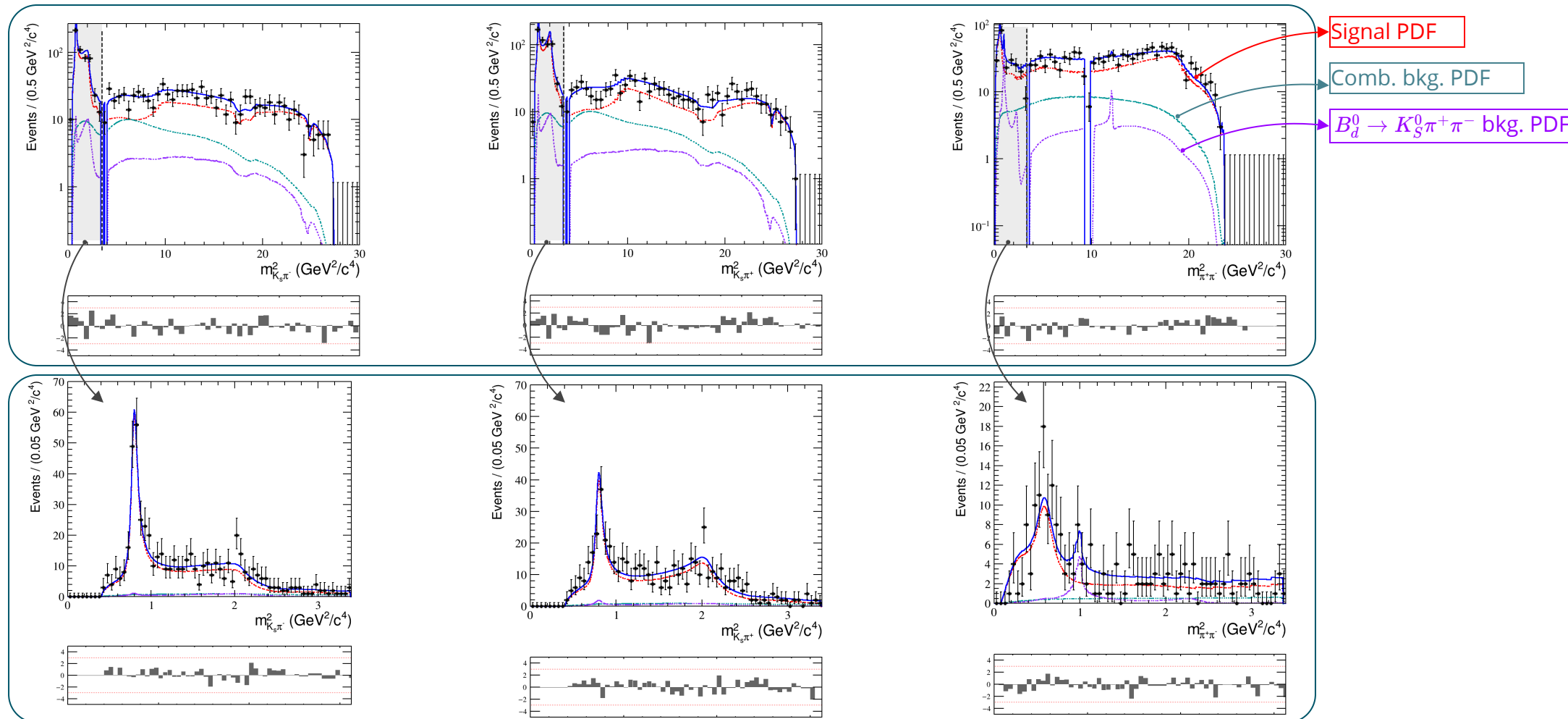
Resonance	Parameters	Lineshape
NR		Flat
S-wave		
	$\text{Re}(c_0) = 0.204 \pm 0.103$	
$(K\pi)_0^{*\pm}$	$\Im(c_0) = 0$ $\text{Re}(c_1) = 1$ $\Im(c_1) = 0$	EFKLLM
$f_0(500)$	$m_0 = 513 \pm 32$ $\Gamma_0 = 335 \pm 67$ $\kappa = 0$	Red. K-Matrix
$f_0(1370)$	$m_0 = 1380 \pm 70$ $\Gamma_0 = 220 \pm 80$	T-Matrix pole
P-wave		
$K^{*\pm}(892)$	$m_0 = 891.66 \pm 0.26$ $\Gamma_0 = 50.8 \pm 0.9$	RBW
$\rho^0(770)$	$m_0 = 775.26 \pm 0.25$ $\Gamma_0 = 149.8 \pm 0.8$	GS
$K^{*\pm}(1680)$	$m_0 = 1717 \pm 27$ $\Gamma_0 = 332 \pm 110$	Flatté
D-wave		
$K_2^{*\pm}(1430)$	$m_0 = 1425.6 \pm 1.5$ $\Gamma_0 = 98.5 \pm 2.7$	RBW

Time integrated Amplitude Analysis of $B_s^0 \rightarrow K_S^0 \pi^+ \pi^-$

Fit results with the nominal model

All 14 sub-samples (7 data-taking periods x 2 K_S^0 reconstruction categories) are combined in the plots below.

Dalitz plot projections in the full spectrum: $K_S^0 \pi^+$, $K_S^0 \pi^-$ and $\pi^- \pi^+$



Zoomed projections: $K_S^0 \pi^+$, $K_S^0 \pi^-$ and $\pi^- \pi^+$

Time integrated Amplitude Analysis of $B_s^0 \rightarrow K_S^0 \pi^+ \pi^-$

Fit results with the nominal model

- The results of the fit with the nominal model are gathered below, in terms of :
 - Complex amplitudes (isobar parameters).
 - Fit fractions and raw CP asymmetries.
 - Interference fit fractions

	x_j	y_j	a_j	ϕ_j
Resonance	Real part	Imaginary part	Magnitude	Phase ($^\circ$)
NR	-1.76 ± 0.27	0.28 ± 0.27	1.78 ± 0.28	$171.1^{+11.4}_{-12.3}$
$(K\pi)_0^{*+}$	-2.81 ± 0.22	-1.10 ± 0.30	3.02 ± 0.21	$-158.7^{+6.9}_{-7.4}$
$(K\pi)_0^{*-}$	-2.61 ± 0.19	-0.07 ± 0.33	2.61 ± 0.19	$-178.4^{+8.0}_{-8.1}$
$f_0(500)$	0.14 ± 0.48	0.52 ± 0.15	0.54 ± 0.18	$75.4^{+61.1}_{-60.9}$
$f_0(1370)$	-0.31 ± 0.38	-0.83 ± 0.21	0.89 ± 0.15	$-110.2^{+28.5}_{-44.1}$
$K^{*+}(892)$	1.71 ± 0.13	0.00	1.71 ± 0.13	0.0 ± 0.0
$K^{*-}(892)$	-2.00	0.00	2.00	180.0
$\rho^0(770)$	-0.47 ± 0.55	1.13 ± 0.29	1.22 ± 0.13	$112.7^{+30.4}_{-28.6}$
$K^{*+}(1680)$	0.17 ± 0.34	1.07 ± 0.20	1.08 ± 0.20	$81.1^{+25.4}_{-21.5}$
$K^{*-}(1680)$	0.15 ± 0.48	-1.07 ± 0.21	1.08 ± 0.21	$-82.2^{+30.7}_{-30.5}$
$K_2^{*+}(1430)$	1.16 ± 0.18	0.14 ± 0.22	1.17 ± 0.17	$6.8^{+11.7}_{-12.9}$
$K_2^{*-}(1430)$	0.56 ± 0.17	-0.72 ± 0.22	0.91 ± 0.20	$-52.1^{+14.3}_{-13.0}$

Isobar parameters

Resonance	Fit fraction (%)	Raw CP asymm.
$K^*(892)$	$21.87^{+1.91}_{-1.56}$	0.158 ± 0.075
$(K\pi)_0^*$	$50.46^{+4.68}_{-4.45}$	-0.143 ± 0.065
$K_2^*(1430)$	$6.95^{+1.94}_{-1.64}$	-0.247 ± 0.232
$K^*(1680)$	$7.39^{+1.78}_{-1.74}$	-0.002 ± 0.276
$\rho^0(770)$	$9.47^{+1.72}_{-1.90}$	—
$f_0(500)$	$1.84^{+2.10}_{-0.99}$	—
$f_0(1370)$	$4.97^{+2.46}_{-2.00}$	—
NR	$20.16^{+6.92}_{-6.42}$	—

Fit fractions and direct CP asymmetries

Resonance	$K^*(892)$	$(K\pi)_0^*$	K_2^*	$K^*(1680)$	ρ^0	$f_0(500)$	$f_0(1370)$	NR
$K^*(892)$	21.87	0.00	0.70	1.82	0.12	-0.02	0.56	0.00
$(K\pi)_0^*$		50.46	2.15	0.00	1.28	0.14	1.49	-21.15
K_2^*			6.95	0.29	-0.42	-0.25	0.63	-4.45
$K^*(1680)$				7.39	-0.87	-0.67	0.53	0.00
ρ^0					9.47	0.00	0.00	0.00
$f_0(500)$						1.84	0.16	2.34
$f_0(1370)$							4.97	-7.48
NR								20.16

Interference fit fractions

Time integrated Amplitude Analysis of $B_s^0 \rightarrow K_S^0 \pi^+ \pi^-$

Summary

- The analysis is in an advanced status with most of the pieces in place: Optimized selection for signal candidates $\Rightarrow$ Invariant-mass fits to the $K_S^0 \pi^+ \pi^-$ spectrum $\Rightarrow$ Models for the remaining backgrounds and efficiency maps across the phase space $\Rightarrow$ Simultaneous Dalitz plot fit and nominal model.
- Results from the nominal model have been presented, including: isobar parameters, fit fractions and interference fit fractions and the raw CP asymmetry.
- Most of the systematic uncertainties have been already computed.

Outlook

- The remaining systematic uncertainties are work in progress and are expected to be estimated in the following weeks.
- Following two previous talks in the BnoC/B2CC working group (WG), the analysis will enter the WG review as soon as the syst. unc. are completed $\Rightarrow$ End of this month/beginning next month
- Depending on the internal review process, a publication could be foreseen by the end of this year or the beginning of the next one.
- The TF flavour-tagged analysis is proceeding concurrently.

Professional project

Prospects for life after PhD

- During the first two years of my PhD I have:
 - Confirmed that I enjoy research and I would see myself in the mid-term pursuing a career in Academia
 - I will look for a PostDoc position
 - Become more aware of the difficulties in Academia in the long-term
 - In practice, the chances of finding a position seem to be low (even at the PostDoc level).

- In an scenario in which Academia does not go well for me in the short/mid or long term, I would contemplate:
 - Move to industry $\Rightarrow$ "Data science" related
 - Look for positions related to education
 - Including high school level
 - Others $\Rightarrow$ To be planned

~~What are people's~~
people think their
 chances in Academia **are?**

+

what they probably are?

Ivan Polyakov & ECGD office of LHCb



Conclusions 2

- Probability for turning from PhD into Senior seem to be **<20%** (probably ~15%)
- While expectation of fresh PhDs is **>40%**
- Expectations of **30-35%** of PostDocs seem to be reasonable
- People more often leave academia between 5-9 years of career
if tracking by publications
- For those who remained for 15+ years in academia:
 - **65%** of those trained in LHCb remained
 - **3.4(0.6)%** of those trained in CMS/ATLAS/ALICE come to LHCb (and stay)
- This study can and should be improved.
 Under mandate of ECGD / LHC-ECSF / ...

Ivan Polyakov

Chances in Academia talk -116th LHCb week

Doctoral School and complementary activities

Doctoral School Modules

French Module

Learning French for Foreign PhD Students

(2/2) ED Specialty Modules

- Neural networks and artificial intelligence
- Statistical data analysis and Machine learning

(0/2) Communication Modules

- International Conference
- Scientific days ED

Ethics in Research and Scientific Integrity

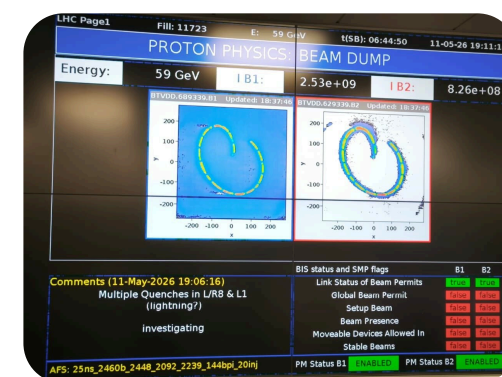
Complementary activities

Outreach



Contributed to science communication initiatives, including the international Masterclass organized by the IPPOG.

Service to the collaboration



- Acted as **Data Manager** and **SciFi piquet** during the last data taking period of the Run 3
- I've been appointed as the **Flavour Tagging liaison** for the BnoC/B2CC WG (02/2026-01/2028).

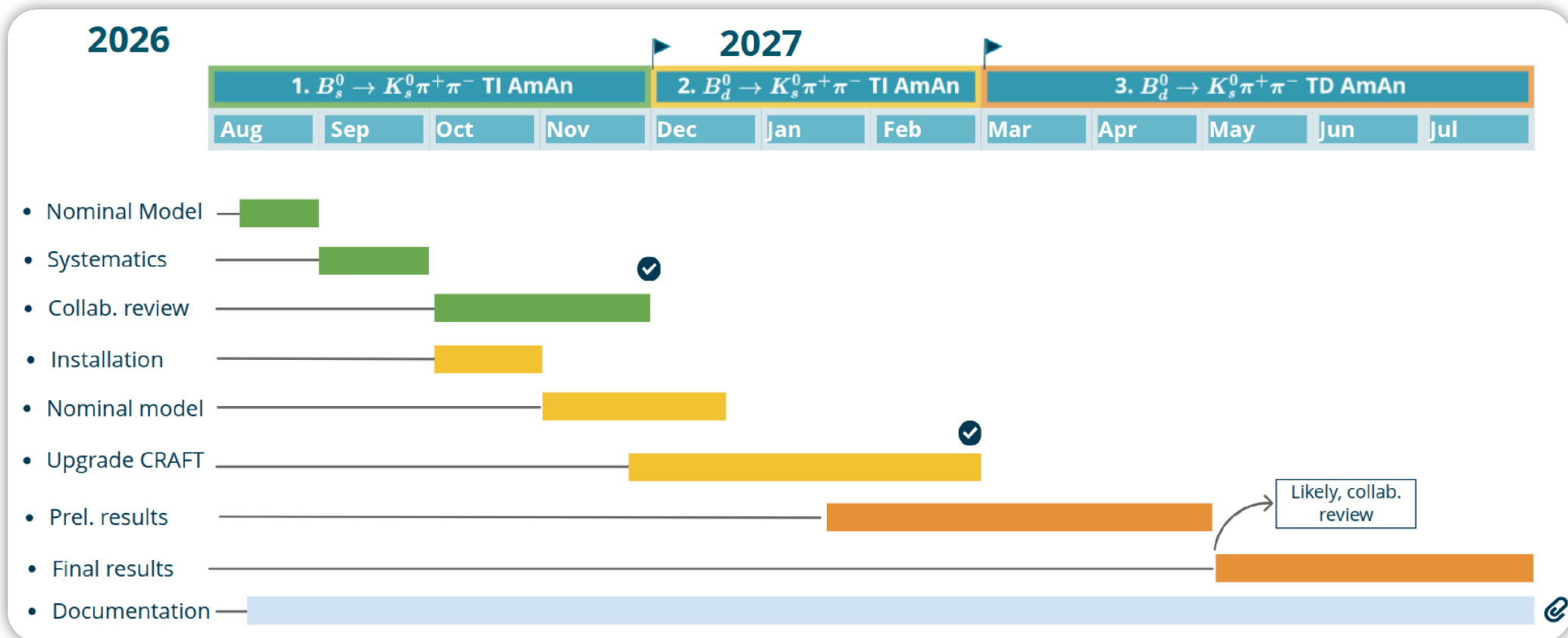
Academic events

- As part of my PhD education, I've attended two schools related to my research interests:
 - **Trans-European School of High Energy Physics** (11-19 Jul 2025, Stara Lesna, Slovakia)
 - Experimental Particle Physics, Standard Model and Beyond, Neutrino physics, etc
 - **Flavour physics at LHC School** (15-19 Jun 2026, CERN)
 - Training in the physics and tools of relevance to the flavour programme of the LHC
- Also, attended my first collaboration week: **119th LHCb Week** (23-27 Feb 2026, CERN)

Outlook

Timeline

1. Complete the Time Integrated Amplitude Analysis of the $B_s^0 \rightarrow K_s^0 \pi^+ \pi^-$ decay
2. Carry out an upgraded Time Integrated AmAn of the $B^0 \rightarrow K_s^0 \pi^+ \pi^-$ using Run 1 and Run 2 data
3. Perform the Time Dependent AmAn of the $B^0 \rightarrow K_s^0 \pi^+ \pi^-$ decay



Papers and internal notes

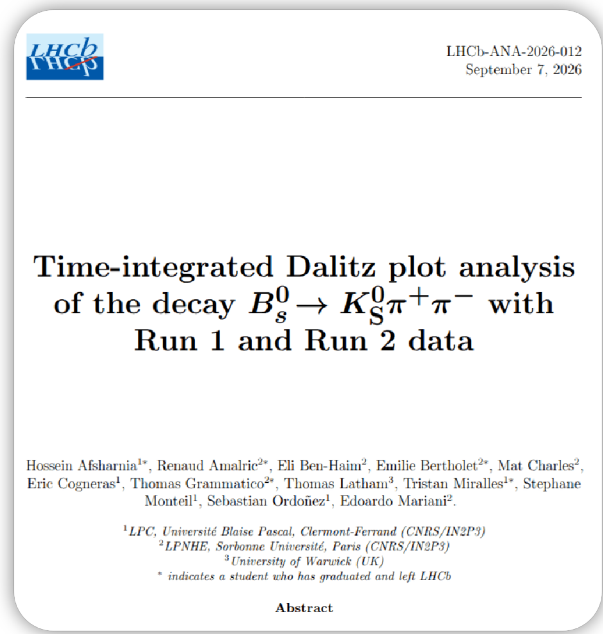
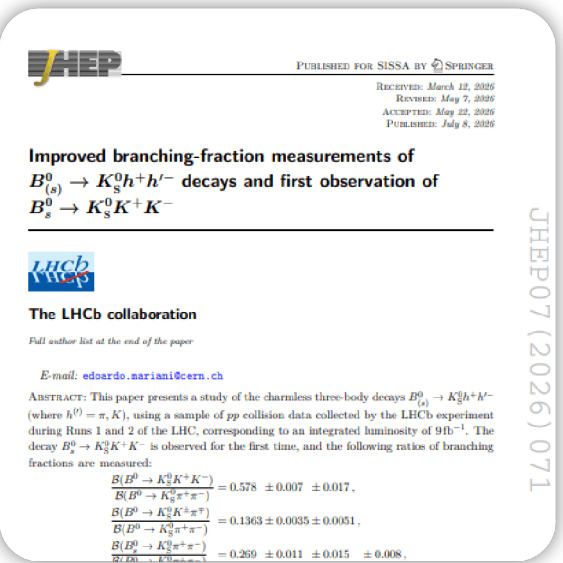
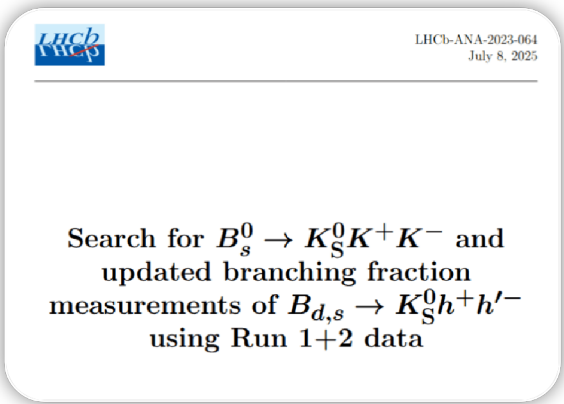
The work presented here is either already documented or currently being documented in parallel with the progress of the analysis.

Branching Fraction Analysis

- Internal documentation:
 - Analysis Note: [LHCb-ANA-2023-064](#)
 - Paper: [LHCb-PAPER-2024-029](#)
- Paper published:
 - [JHEP](#) (July 8, 2026).
 - [Arxiv](#) (Mar 9, 2026)

Time Integrated Amplitude Analysis

- Two updates presented to the BnoC group
- Internal note written in parallel and currently under review by the LPCA team.



Thank you!

Questions and discussion