

Isospin extrapolation as a method to study inclusive $b \rightarrow s \ell \ell$ decays

Offshell-21 virtual HEP conference

Isospin extrapolation as a method to study inclusive $\bar{B} \rightarrow X_s \ell^+ \ell^-$ decays

Yasmine Amhis, Patrick Owen

A novel approach to reconstruct inclusive $\bar{B} \rightarrow X_s \ell^+ \ell^-$ decays is presented. The method relies on isospin symmetry to extrapolate the semi-inclusive signature $X_b \rightarrow K^+ \ell^+ \ell^- X$ to the fully inclusive rate in B^+ and B^0 decays. We investigate the possibility to measure branching fractions and other observables such as lepton universality ratios and CP asymmetries. As a proof of concept, fast simulation is used to compare the $X_b \rightarrow K^+ \ell^+ \ell^- X$ signature with a fully inclusive approach. Several experimental advantages are seen which have the potential to make measurements of inclusive $\bar{B} \rightarrow X_s \ell^+ \ell^-$ decays tractable at a hadron collider.

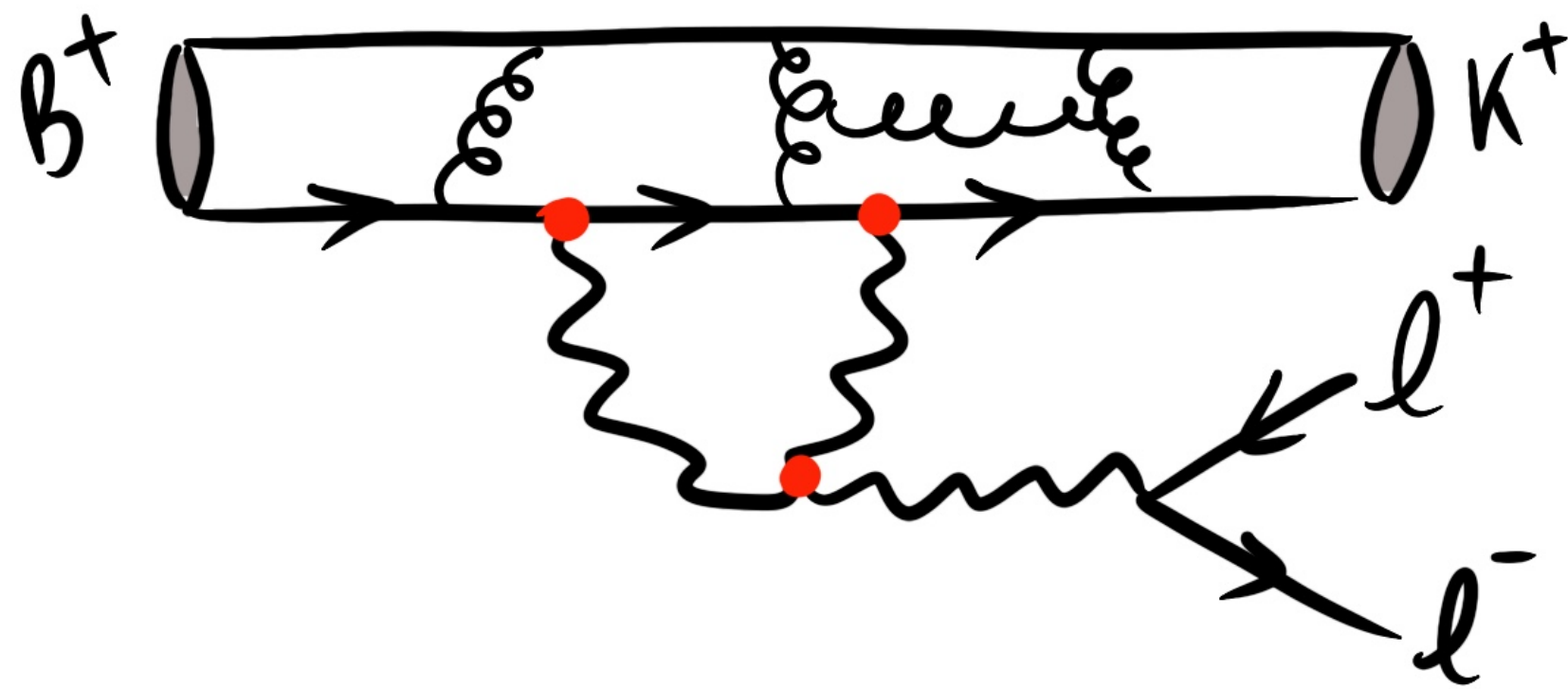
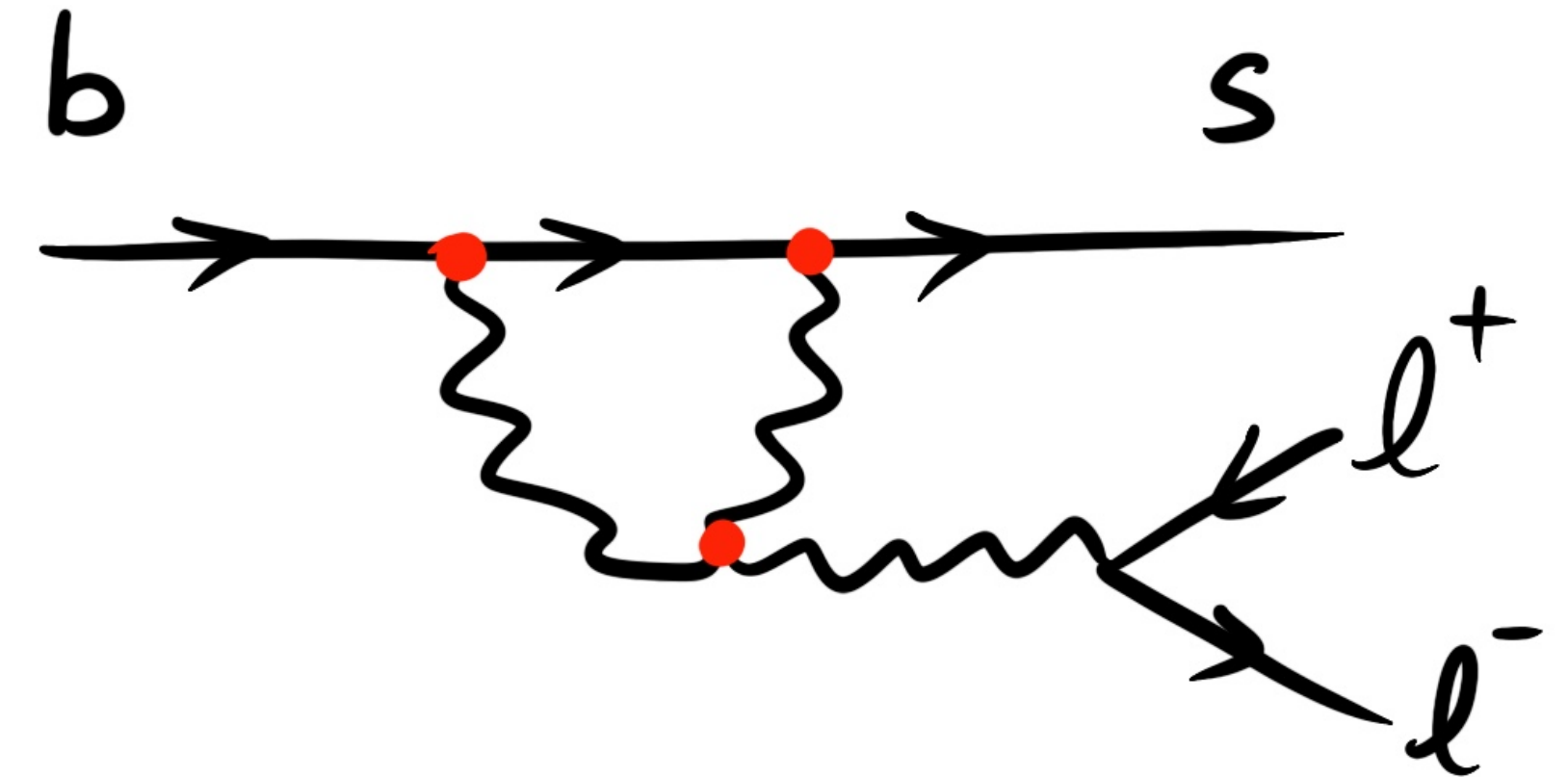
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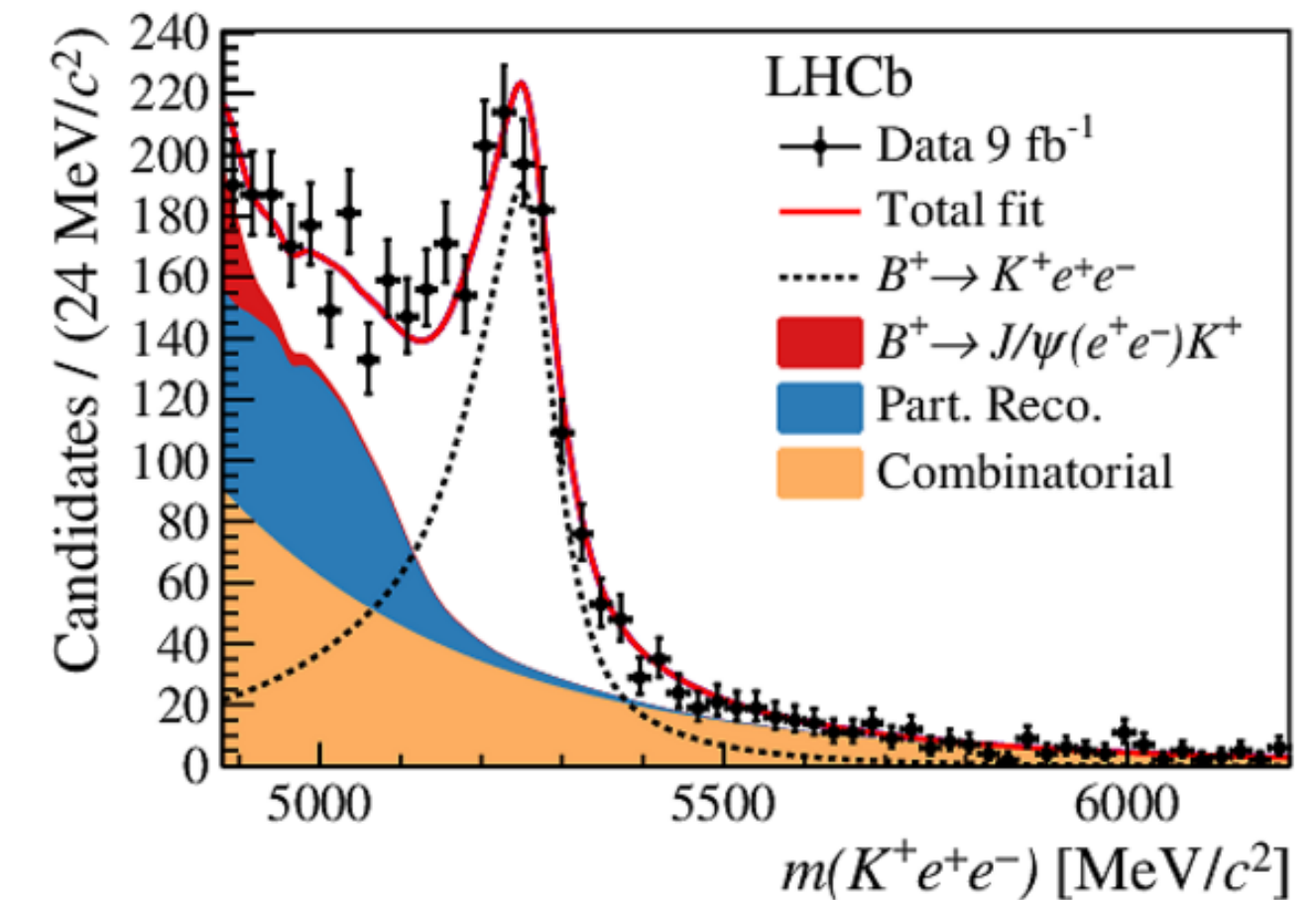
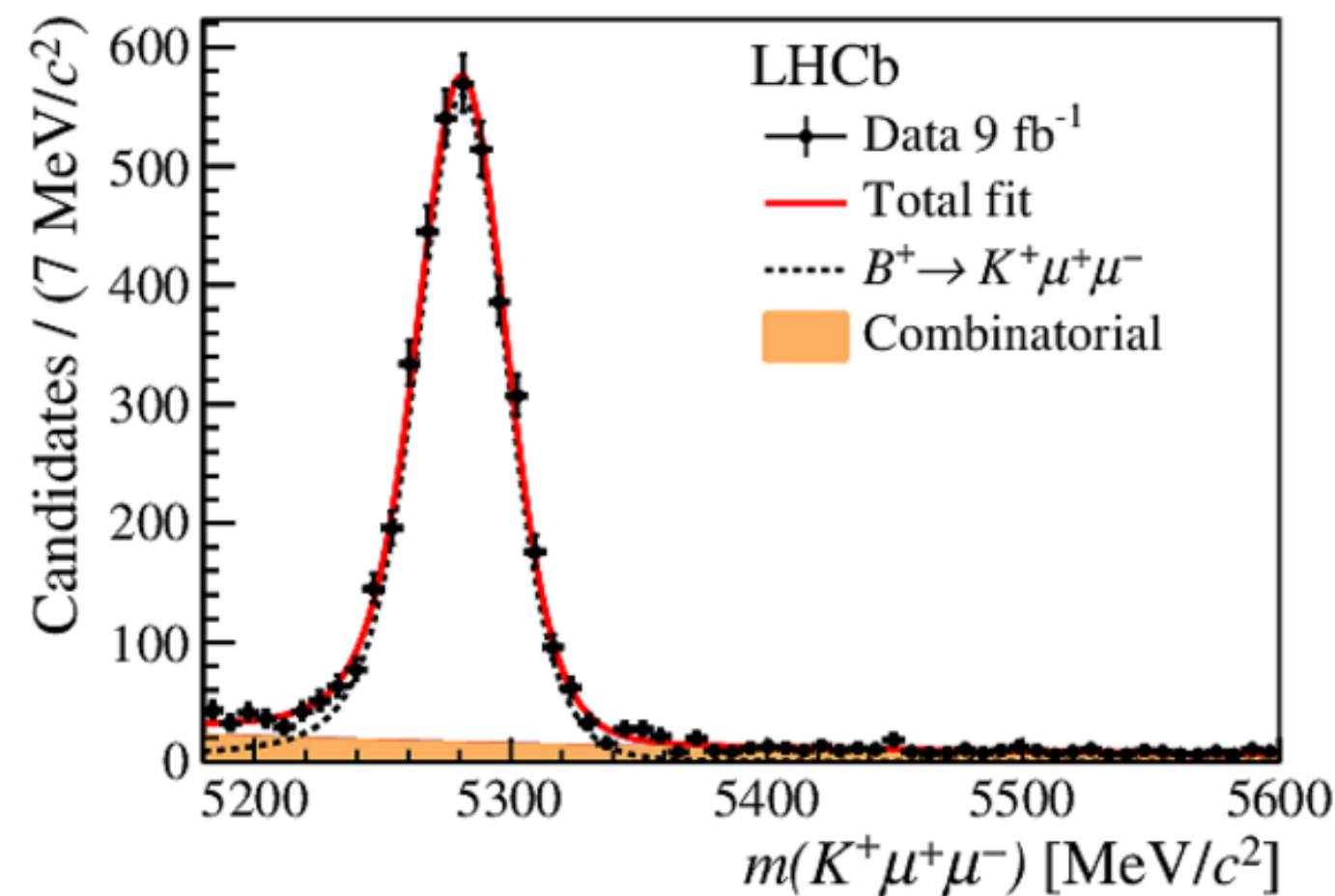


$b \rightarrow s \ell \ell$ decays

- $b \rightarrow s \ell \ell$ decays are loop suppressed semileptonic decays. Their loop suppression allows for NP sensitivity up to $\sim 50 \text{ TeV}$.
- They have been part of LHCb's core program for years.
- Focus has been on exclusive decays, whereby the strange quark hadronises into a specific final state.



[LHCb-PAPER-2021-004](#)



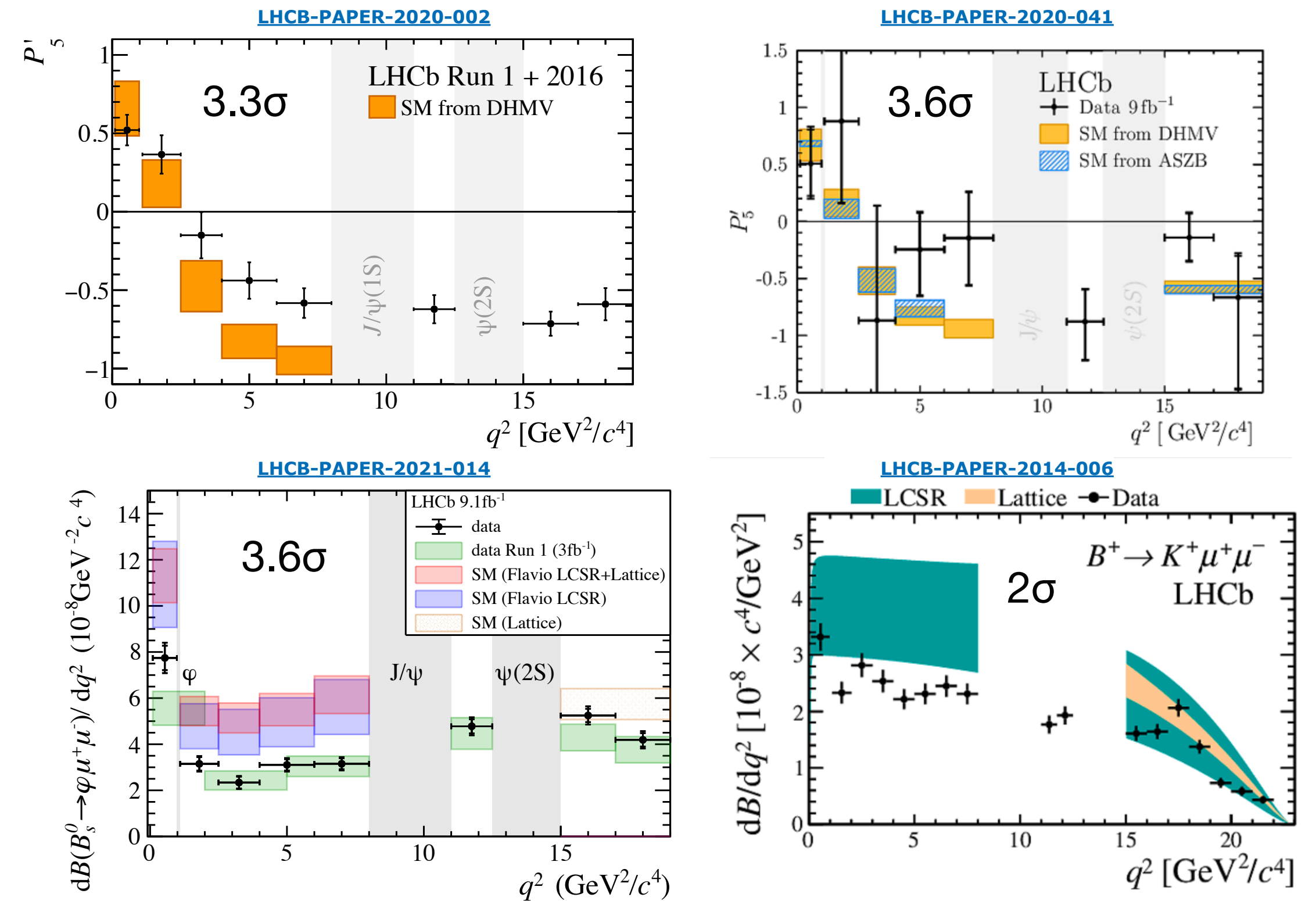
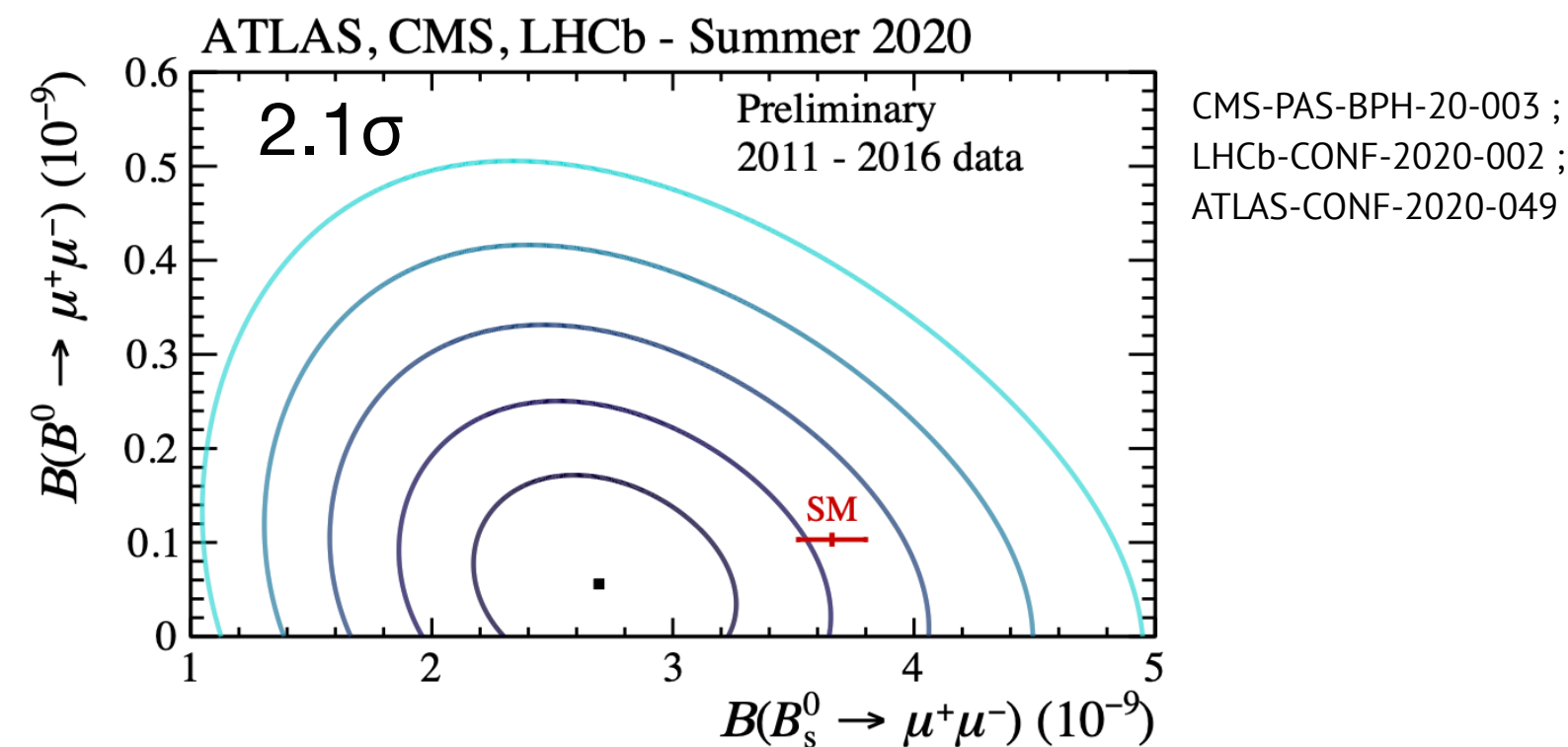
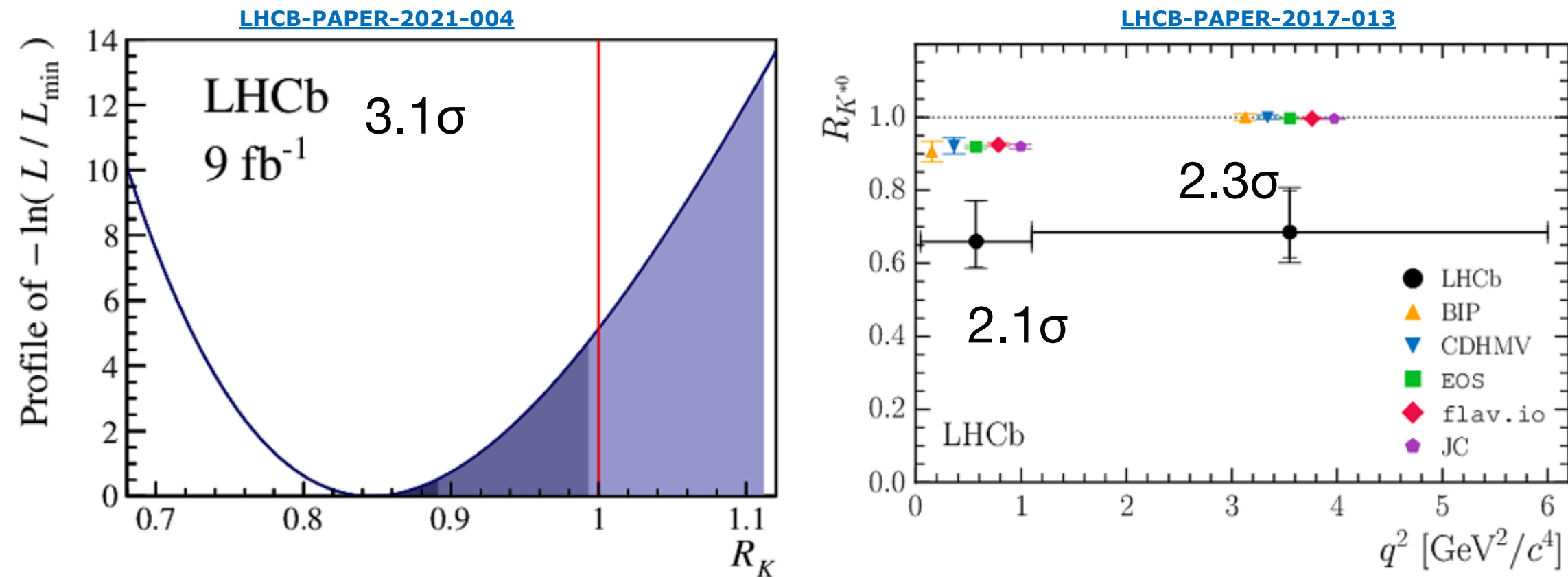
- Exclusive decays are fully reconstructed \rightarrow signal peaks at the B mass.

Where are we

- Two sets of deviations with the interpretation limited either by theory or statistics.

Limited by statistical uncertainties.

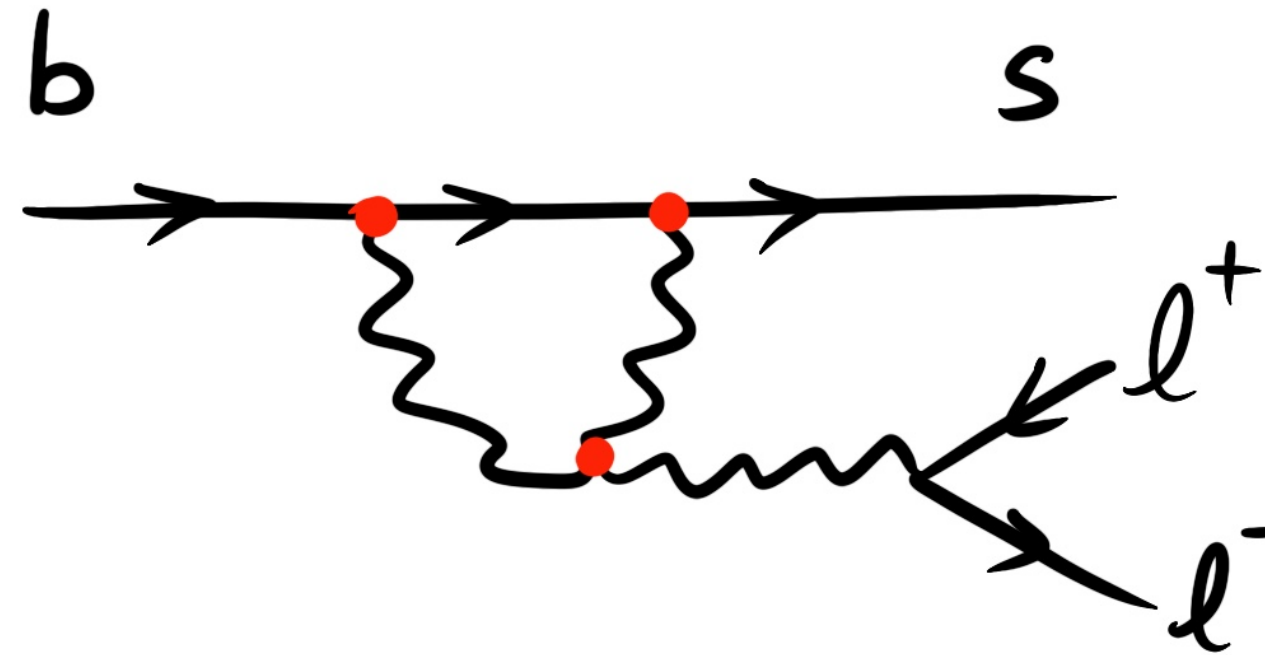
Limited by theoretical interpretation



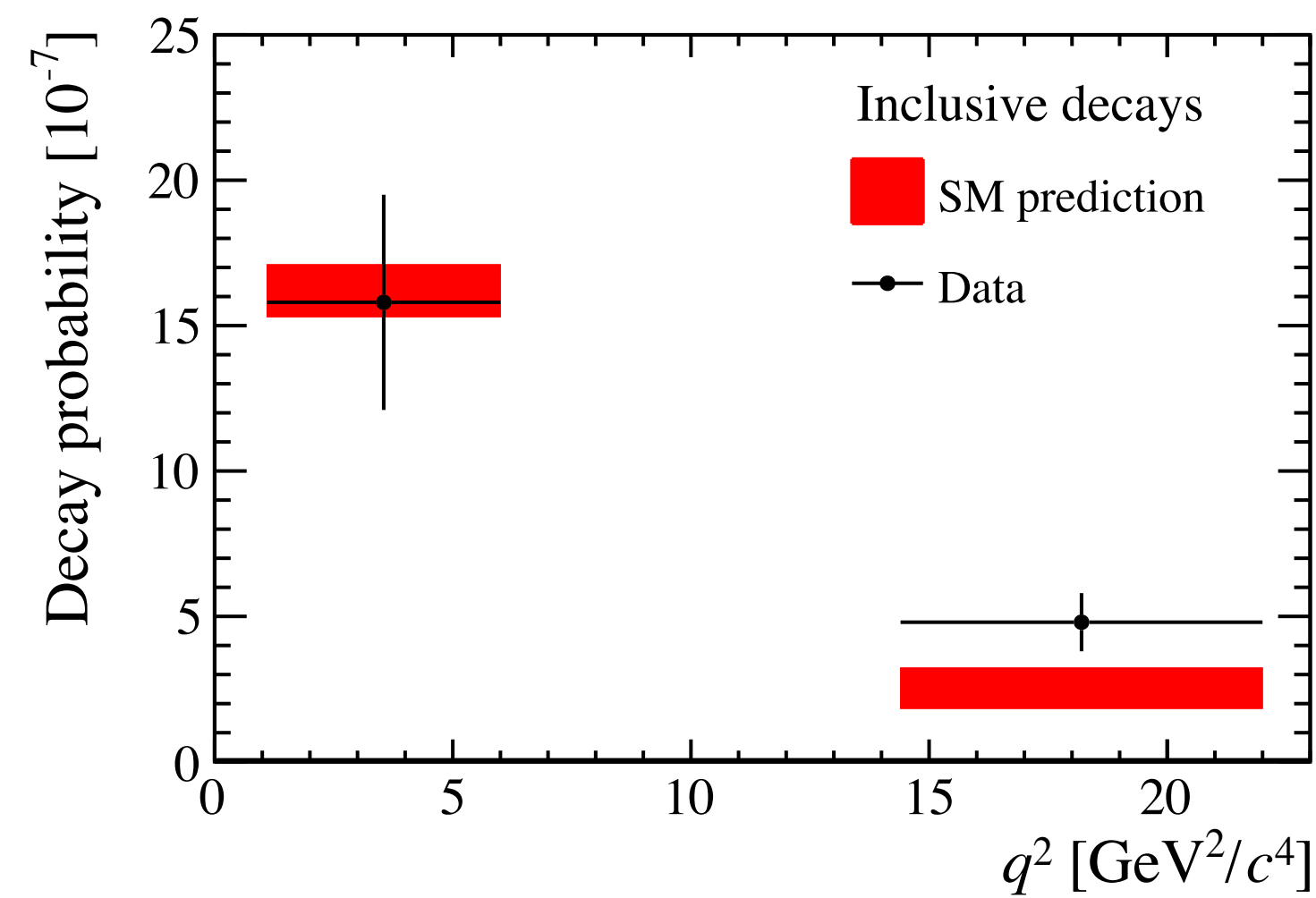
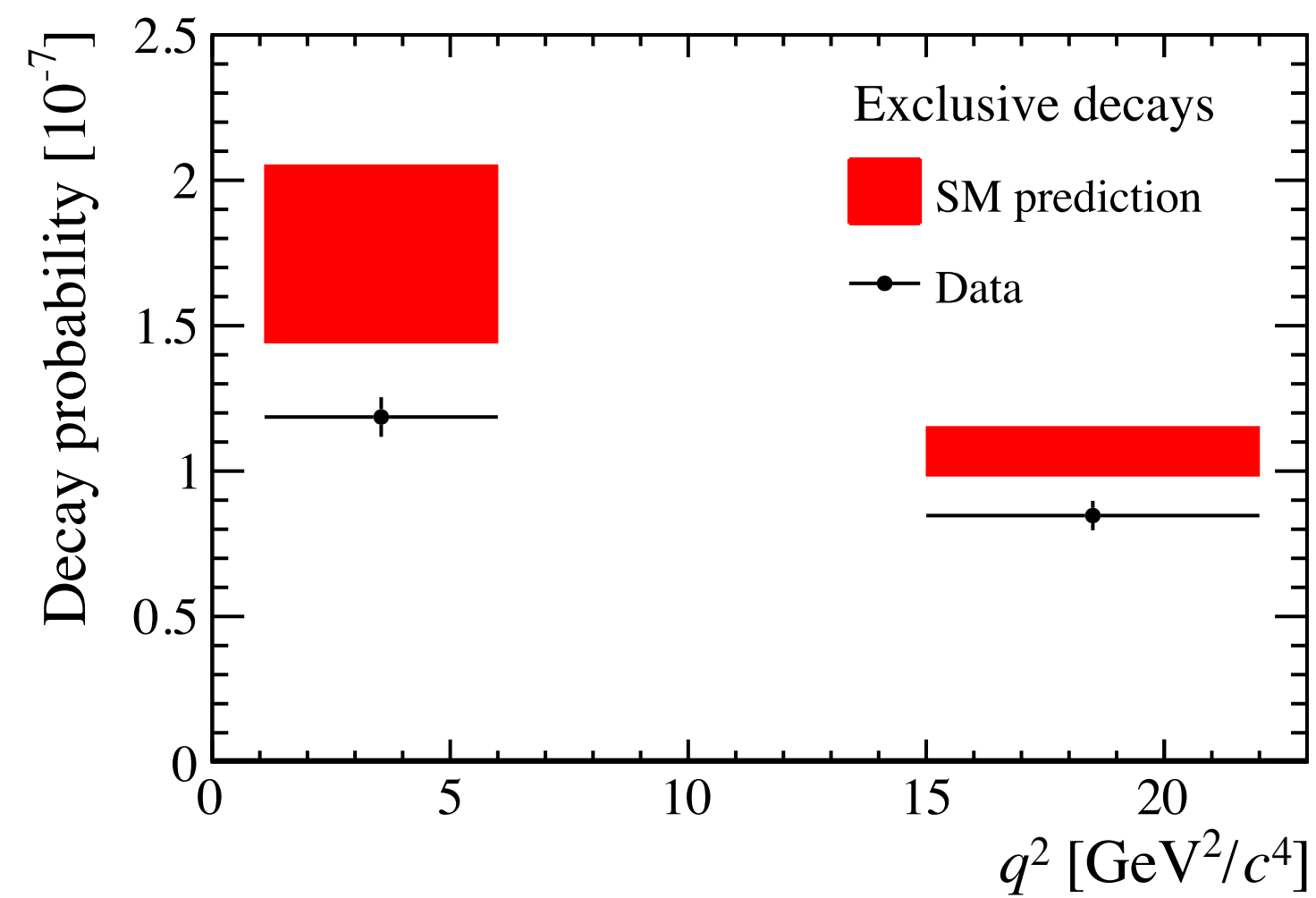
- Inclusive $b \rightarrow sll$ measurements offer a way forward for both these limitations.

Inclusive $b \rightarrow sll$ decays

- Instead of reconstructing a specific hadronic final state, allow the strange quark to hadronise whatever it likes



- Inclusive decays have complementary (and generally more precise) theoretical uncertainties compared to exclusive ones.



- For the branching fraction, uncertainty saturated by experimental uncertainties rather than theoretical ones.

Methods to study inclusive $b \rightarrow sll$ decays

- Inclusive $b \rightarrow sll$ decays have been the domain of the B-factories.
- They employ a sum-of-exclusives approach:
 - Reconstruct as many exclusive final states as possible (typically 50% coverage).
 - Extrapolate missing modes using a hadronisation model (e.g. with JETSET).

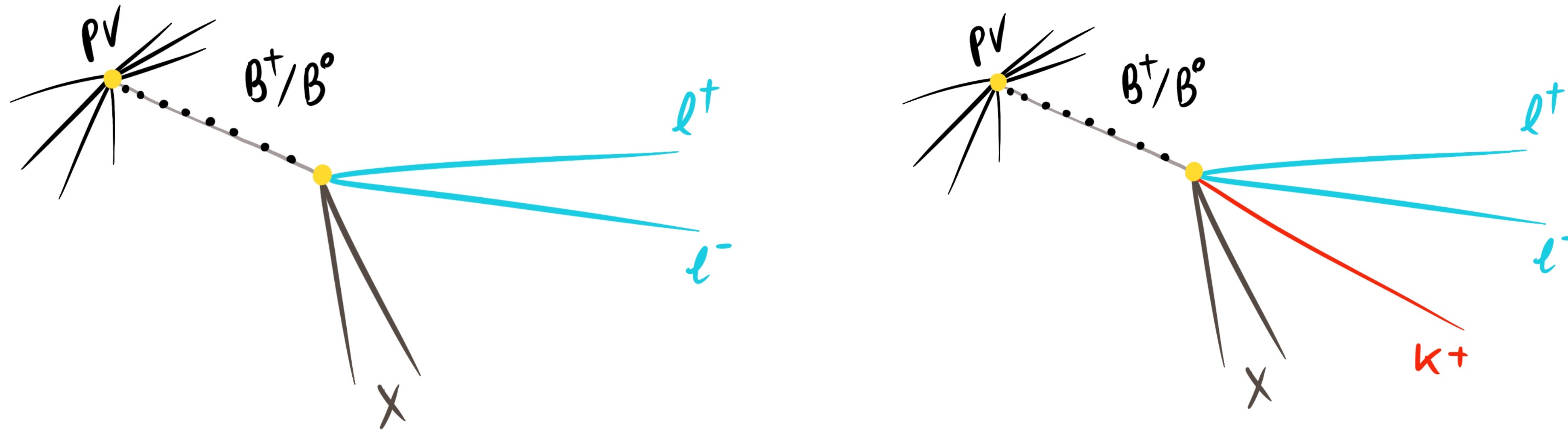
Belle, Phys. Rev. D 93, 032008 (2016)

\bar{B}^0 decays		B^- decays	
$K^- \pi^+$	(K_S^0)	K^-	
$K^- \pi^+ \pi^0$	$(K_S^0 \pi^0)$	$K^- \pi^0$	$K_S^0 \pi^-$
$K^- \pi^+ \pi^- \pi^+$	$(K_S^0 \pi^- \pi^+)$	$K^- \pi^+ \pi^-$	$K_S^0 \pi^- \pi^0$
	$(K_S^0 \pi^- \pi^+ \pi^0)$	$K^- \pi^+ \pi^- \pi^0$	$K_S^0 \pi^- \pi^+ \pi^-$
$(K^- \pi^+ \pi^- \pi^+ \pi^0)$	$(K_S^0 \pi^- \pi^+ \pi^- \pi^+)$	$(K^- \pi^+ \pi^- \pi^+ \pi^-)$	$(K_S^0 \pi^- \pi^+ \pi^- \pi^0)$

- For Belle-II a fully inclusive approach, whereby only the two leptons are reconstructed, is also foreseen.
- This has no systematic uncertainty associated with the extrapolation, but suffers from larger background.

Our approach

- Our approach is to reconstruct an additional charged kaon in addition to the two leptons.



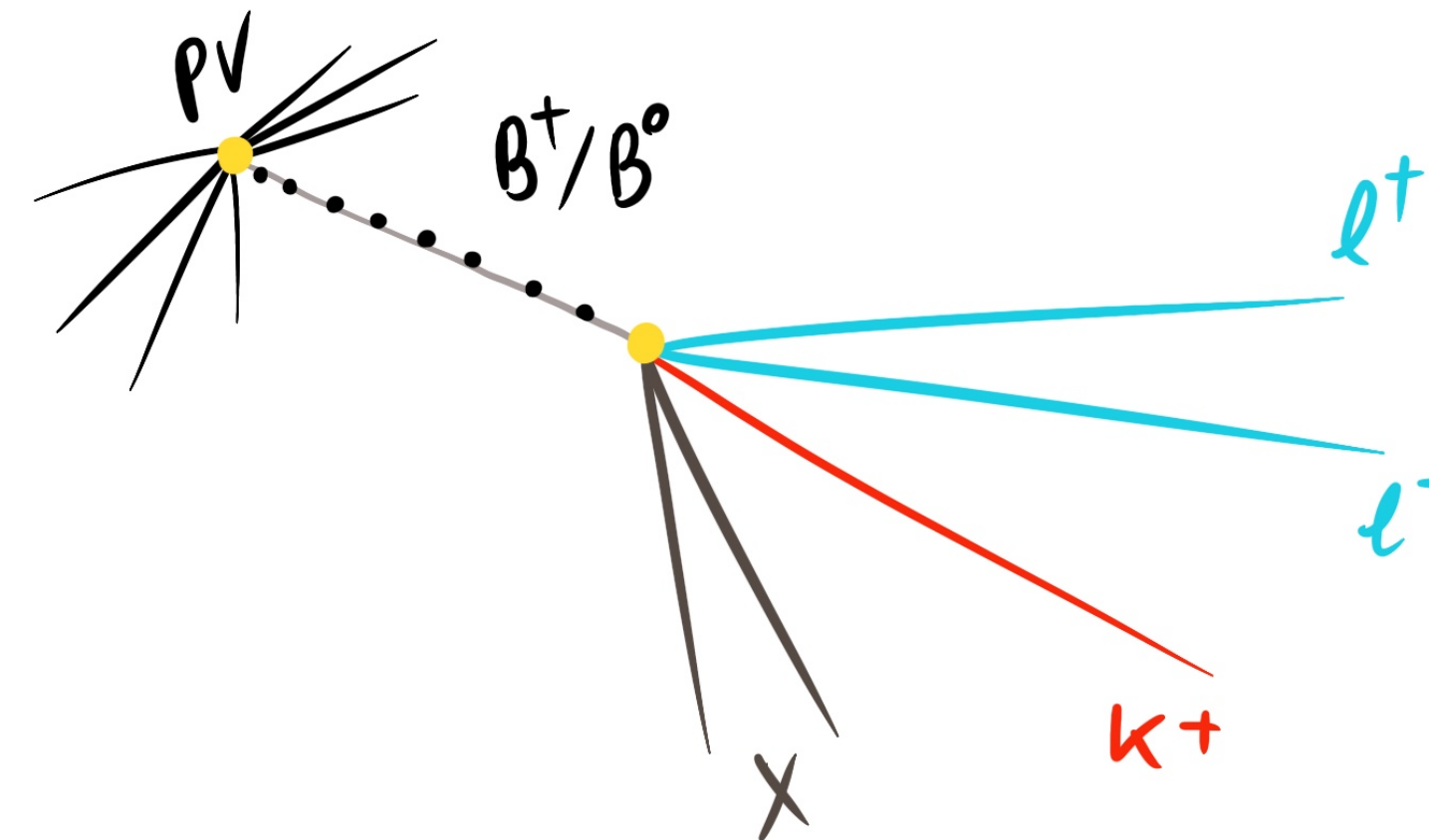
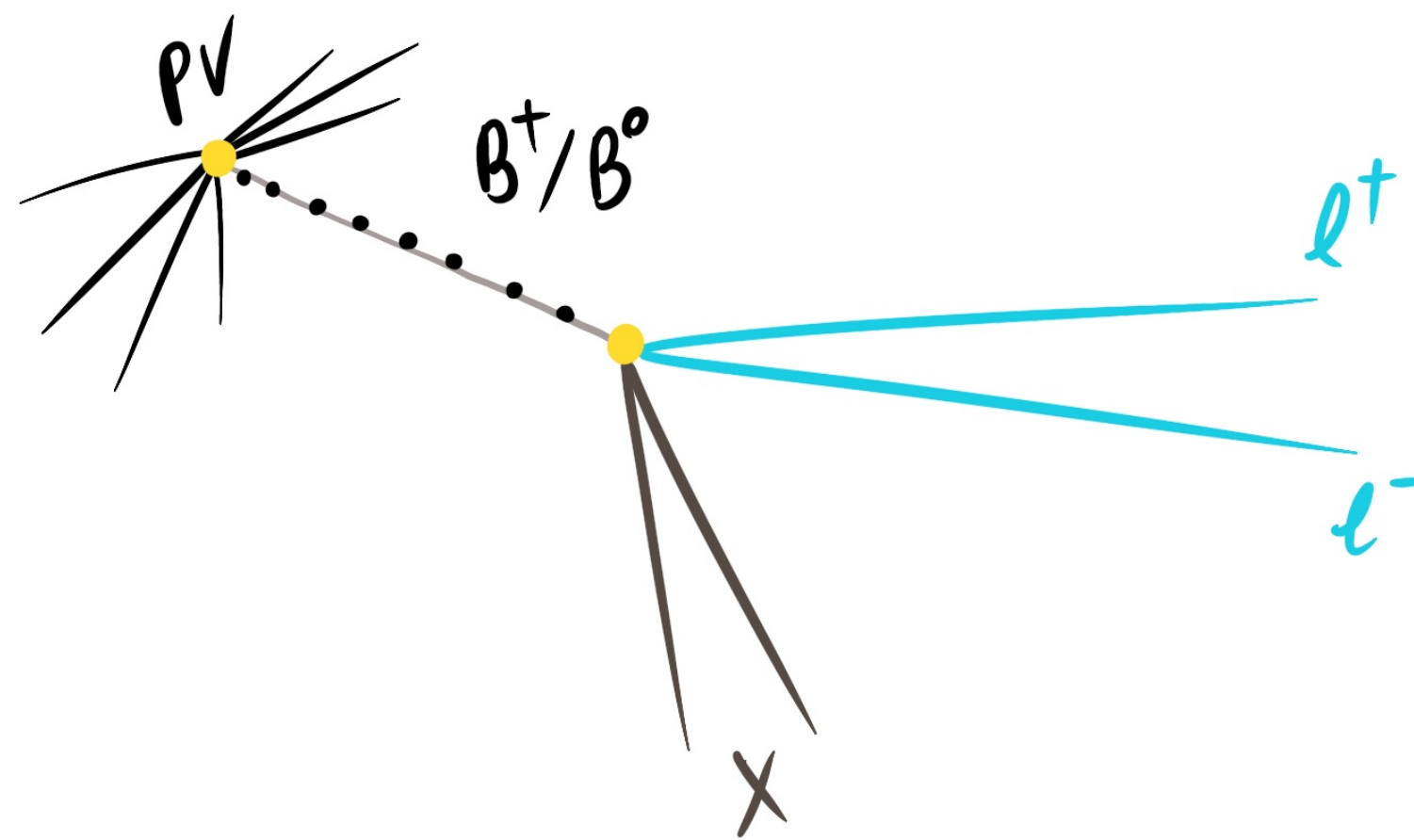
- This can be seen as a hybrid of the fully inclusive and sum-of-exclusives modes.
 - Still needs an extrapolation, but hopefully cleaner (or at least complementary) than from a sum-of-exclusives method.
- We are not claiming to have invented isospin extrapolation here. This has been used to fill in some gaps in the sum-of-exclusives method. We instead promote this to the main extrapolation of the analysis.

Fast simulation

- To explore some experimental advantages, generate some fast simulation with RapidSim. [arXiv:1612.07489](https://arxiv.org/abs/1612.07489)
 - B-hadrons produced with kinematics expected within the LHCb acceptance.
 - Smearing to account for reconstruction.
- We generate two exclusive channels as a proxy for inclusive decays.
 - $B^+ \rightarrow K^+ \pi^- \pi^+ \mu^+ \mu^-$
 - $B^+ \rightarrow K^+ \pi^- \mu^+ \mu^-$
- In both cases the pions are missing from the visible signature.
- Apply μ $p_T > 300$ MeV/c to account for trigger effects in run II.

Background to these decays

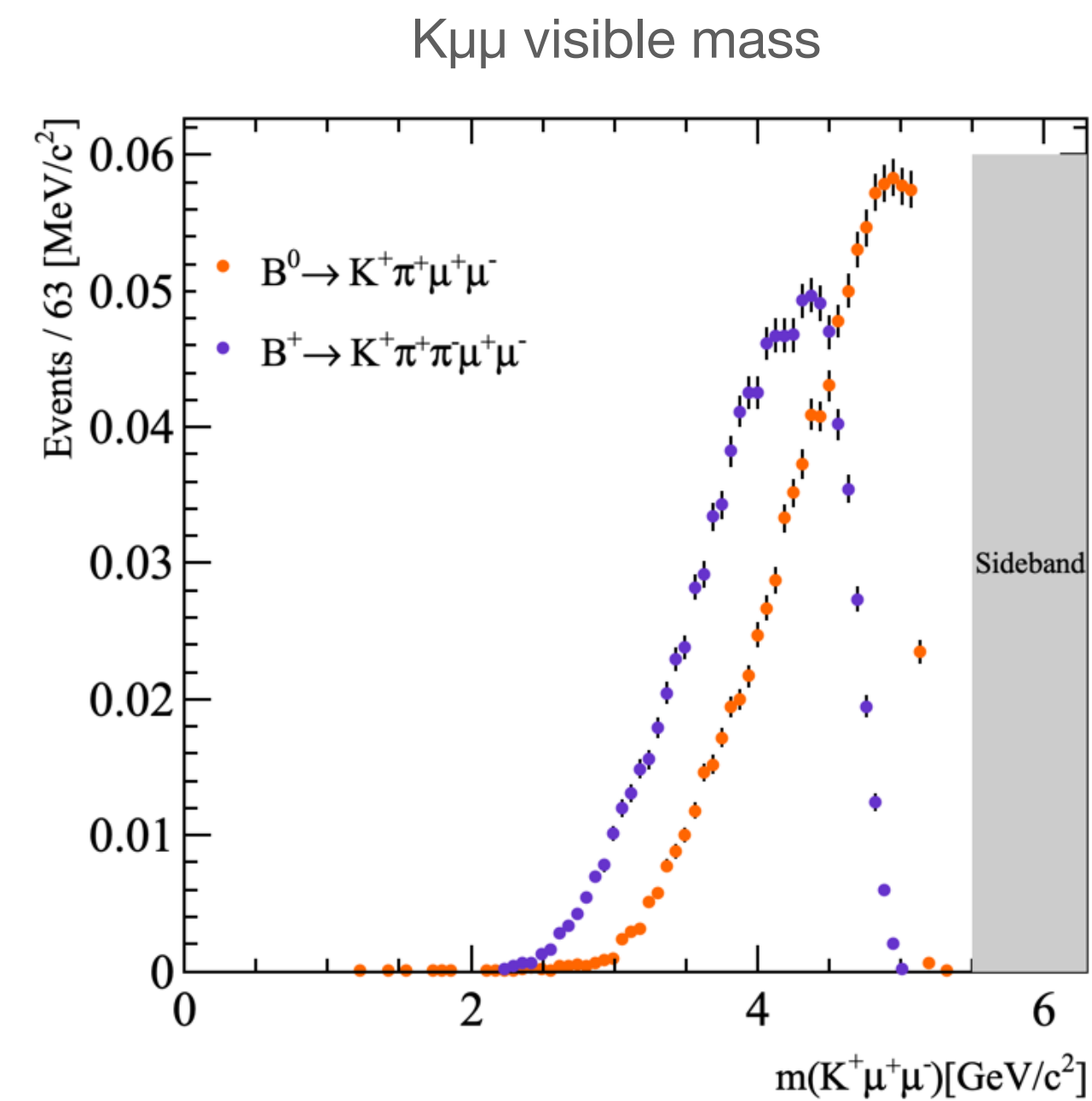
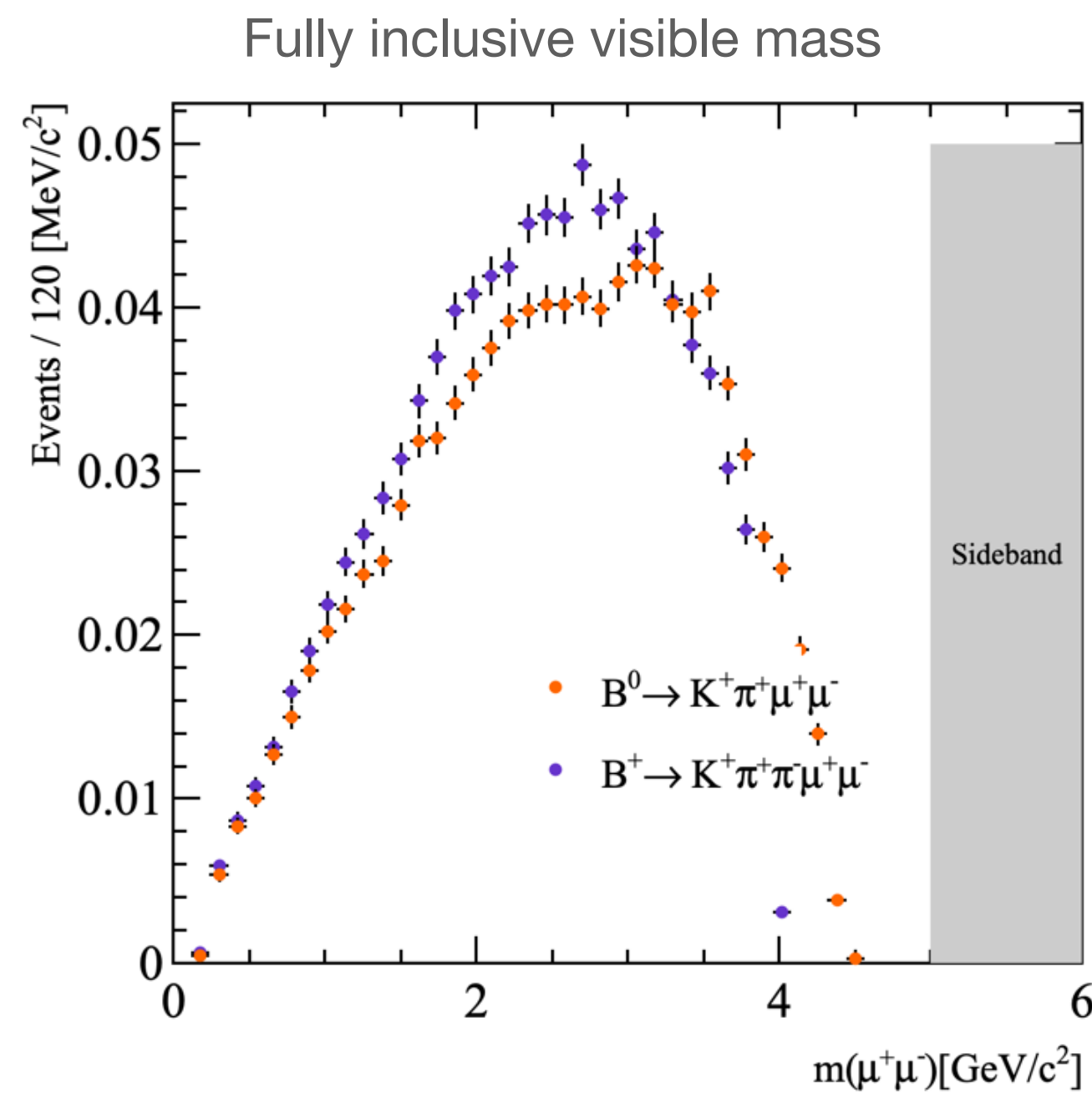
- There are two main backgrounds to an inclusive analysis:
 - Combinatorial, whereby accidental combinations of different B/D decays are made.
 - Double-semileptonic: $B \rightarrow (D \rightarrow K^- \ell^+ \nu_\ell X) \ell^- \nu_\ell X$



- Combinatorial is easier to distinguish but less well understood.

The sideband

- Combinatorial background is extrapolation into signal region using a sideband (above the B mass).

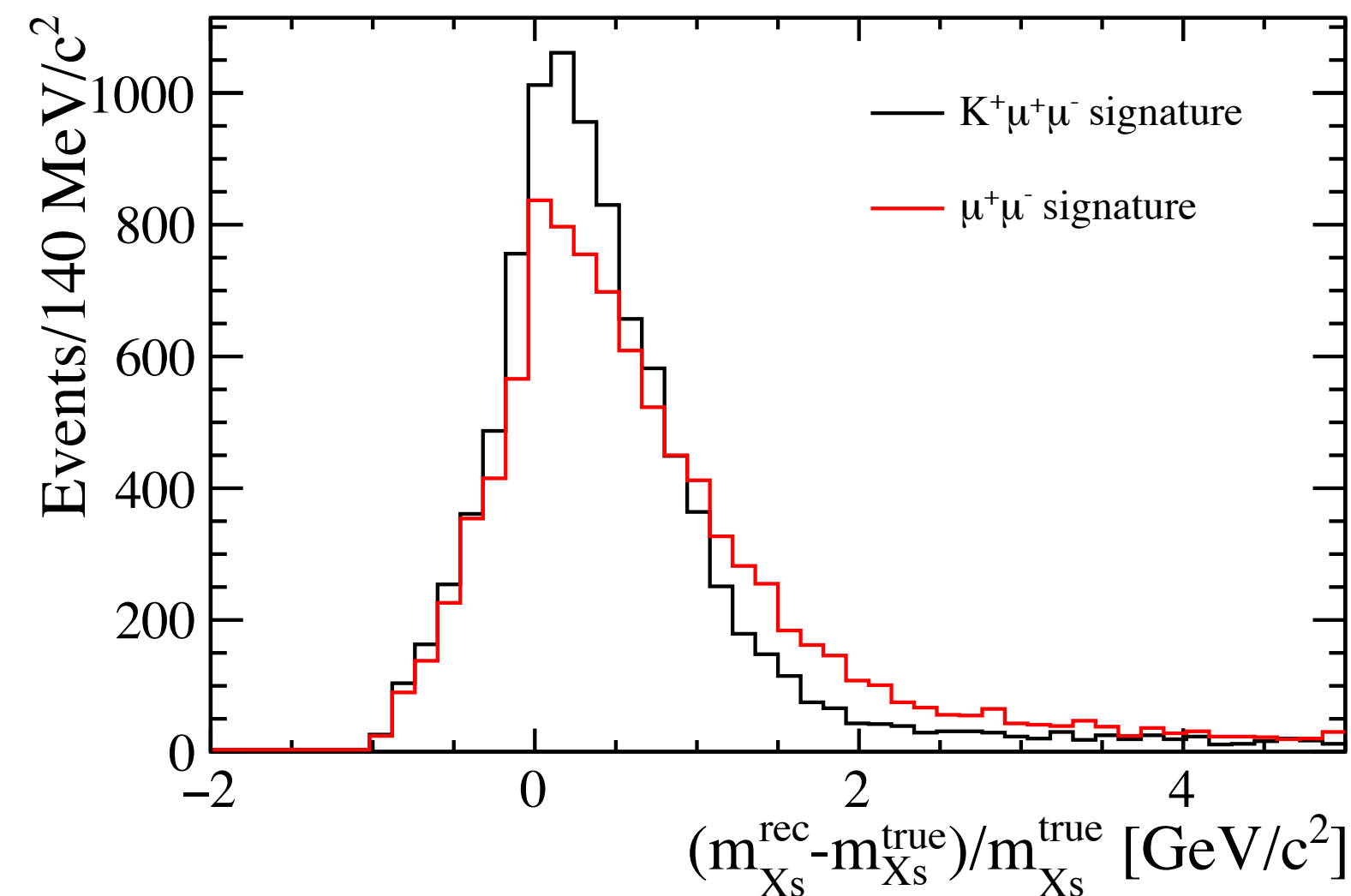


- Signals are substantially closer to the sideband than in a fully inclusive approach.

The mass of the strange hadron, m_{X_s}

- An important discriminating variable is the mass of the strange hadron.
 - Also selected to reduce background in sum-of-exclusives analyses.
- If we use the rest frame approximation [1] to calculate m_{X_s} , see an improvement

$$(p_B)_z = \frac{m_B}{m_{\text{reco}}} (p_{\text{reco}})_z$$

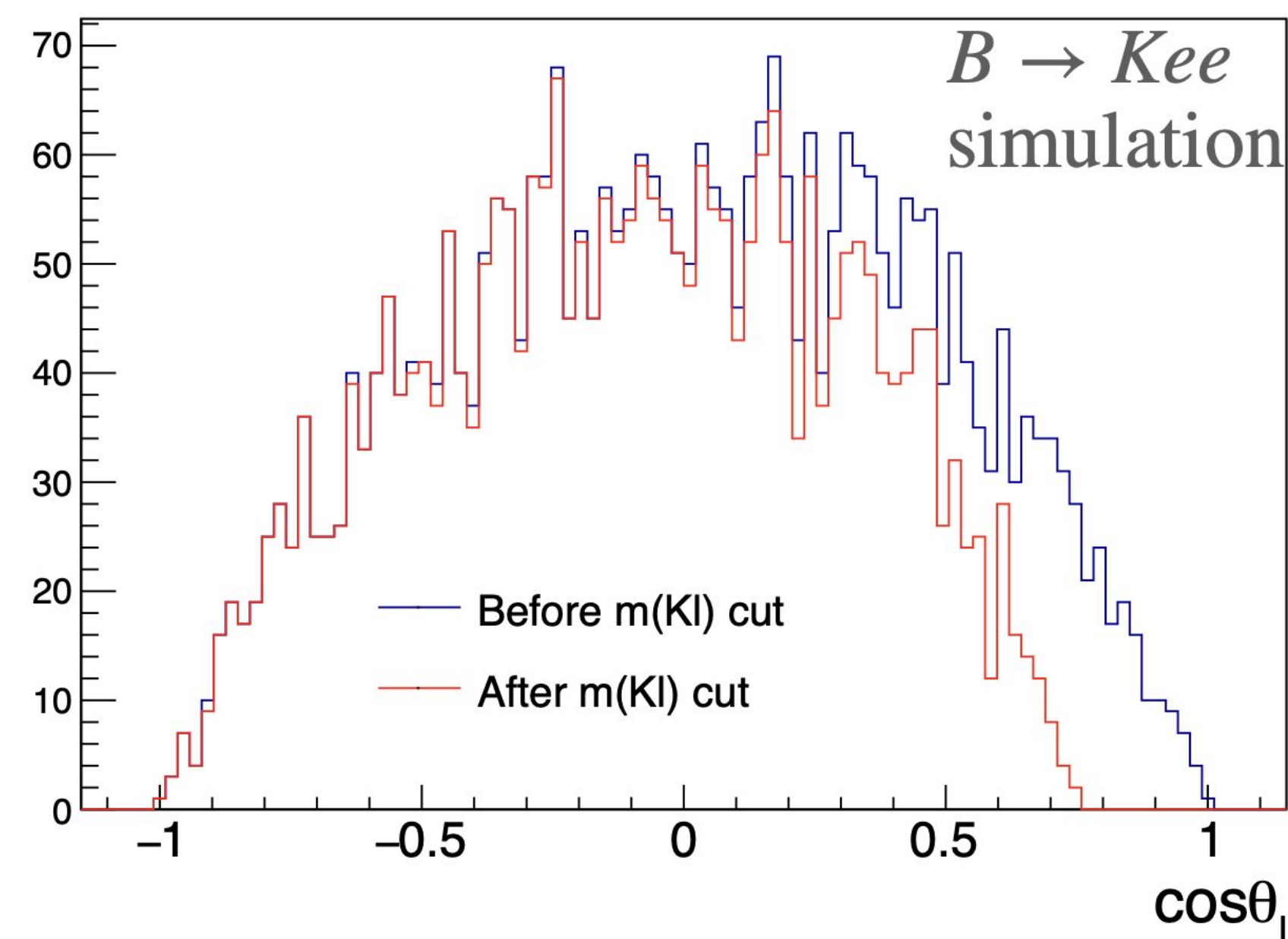


- Kll signature has better resolution on the mass c.f. fully inclusive approach.

Other advantages

- Other advantages include:
 - A better defined vertex (three tracks instead of two).
 - Flavour tagged for A_{CP}/A_{FB} measurements.
 - Access to opposite sign m_{KI} combination.

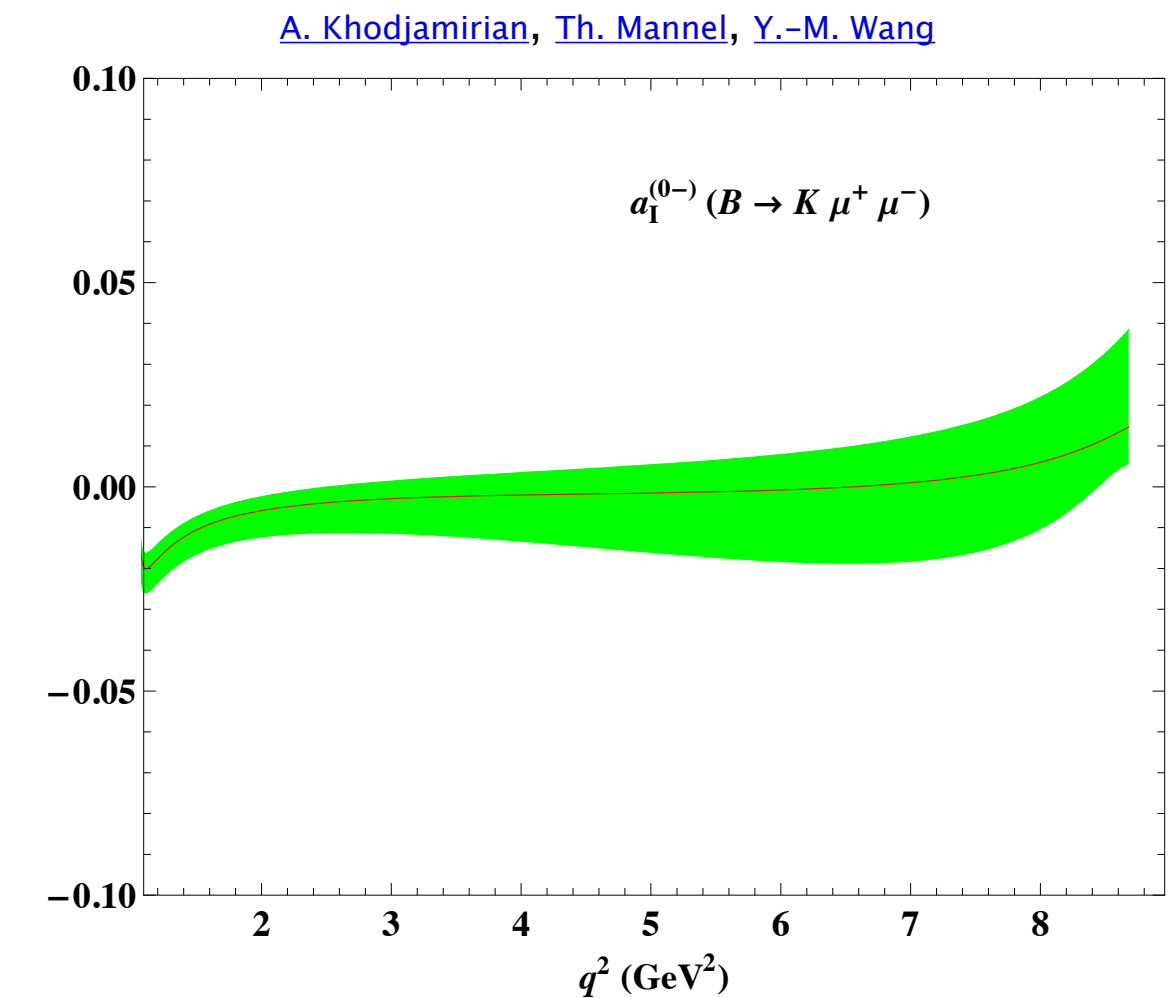
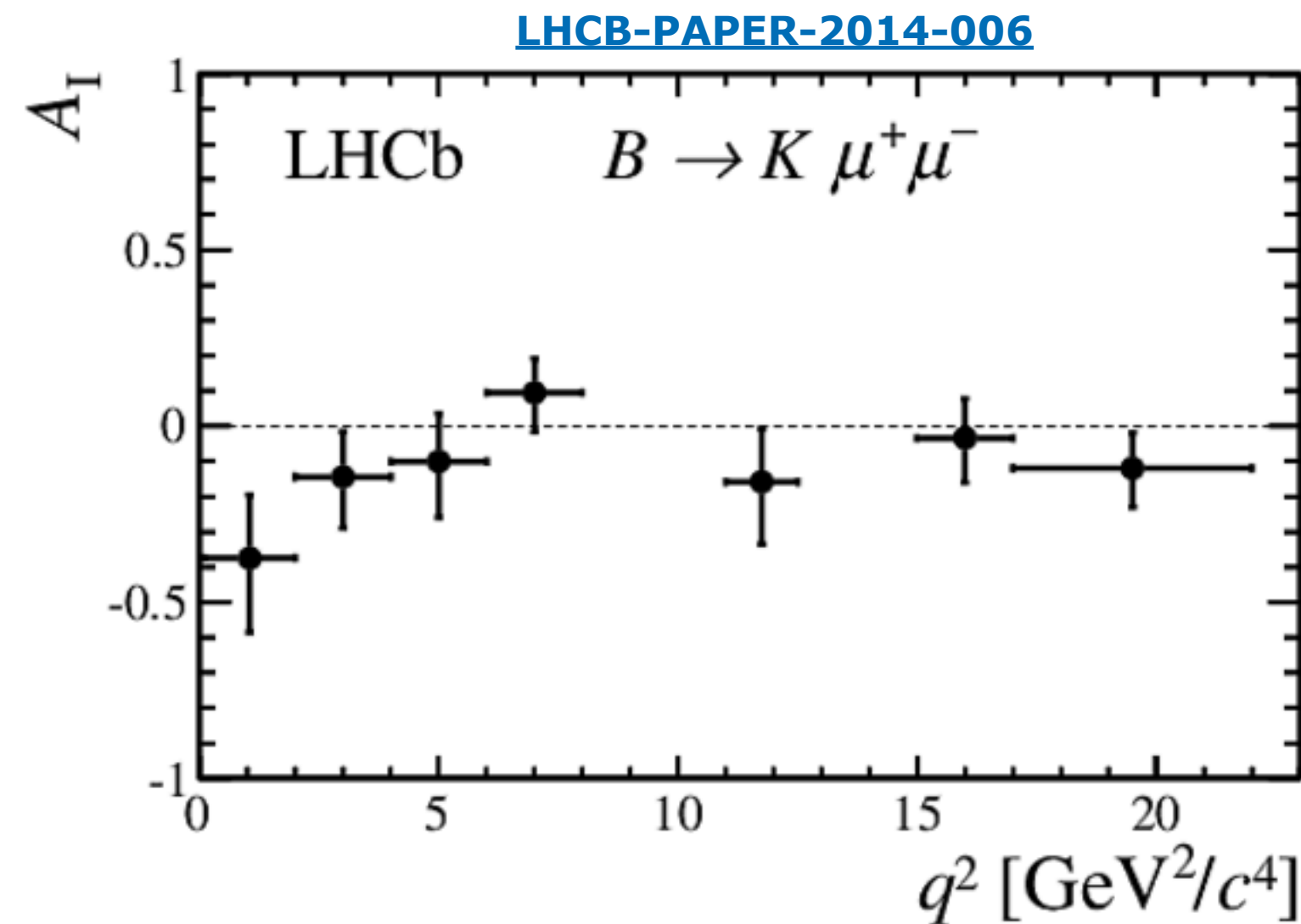
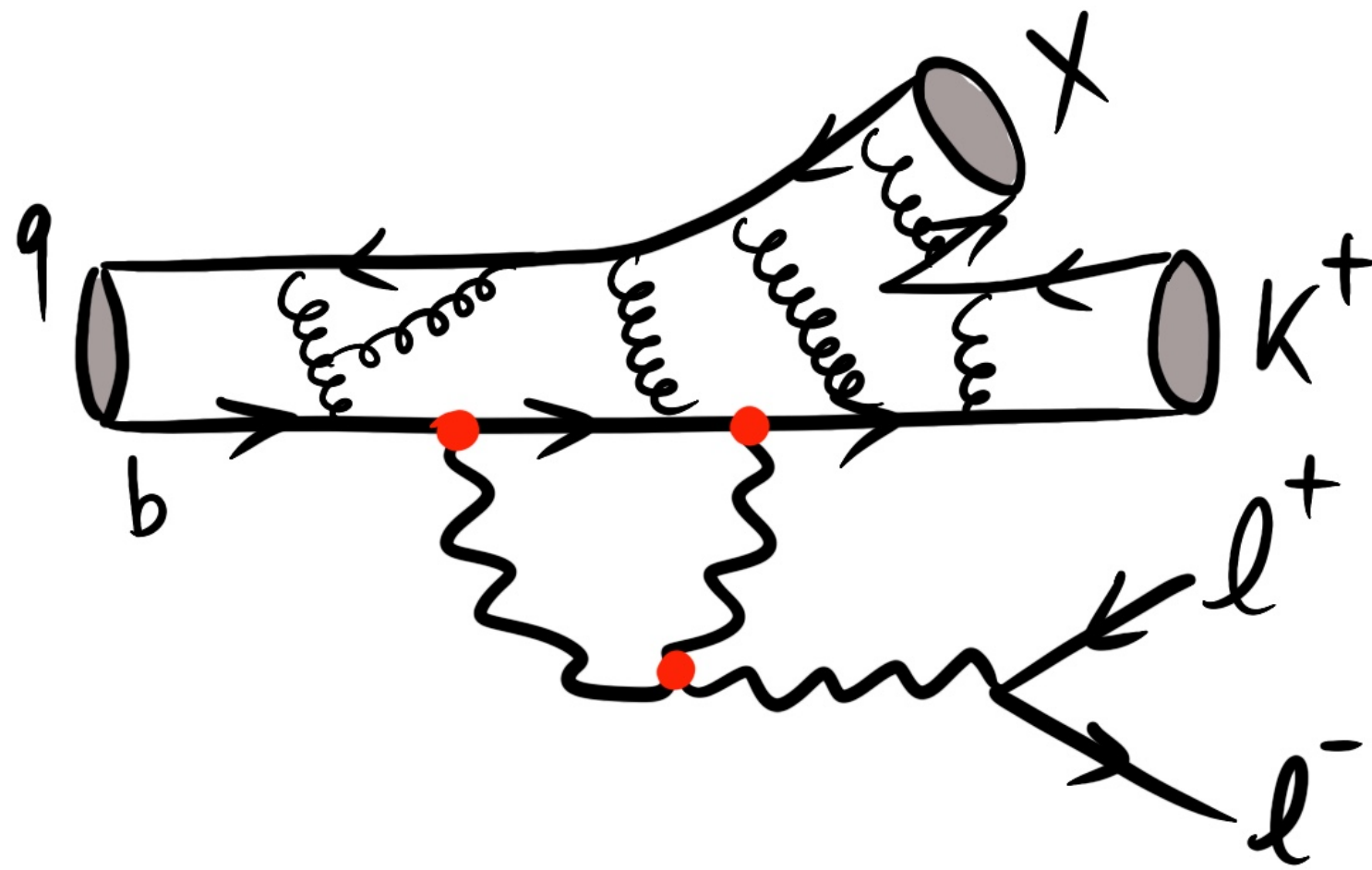
P. Alvarez-Cartelle, W. Altmannshofer, Beyond the flavour anomalies II workshop



- In order to fully understand the advantages and remaining level of background, a detailed study with full simulation would be required (beyond the scope of the paper).

Comments on the extrapolation

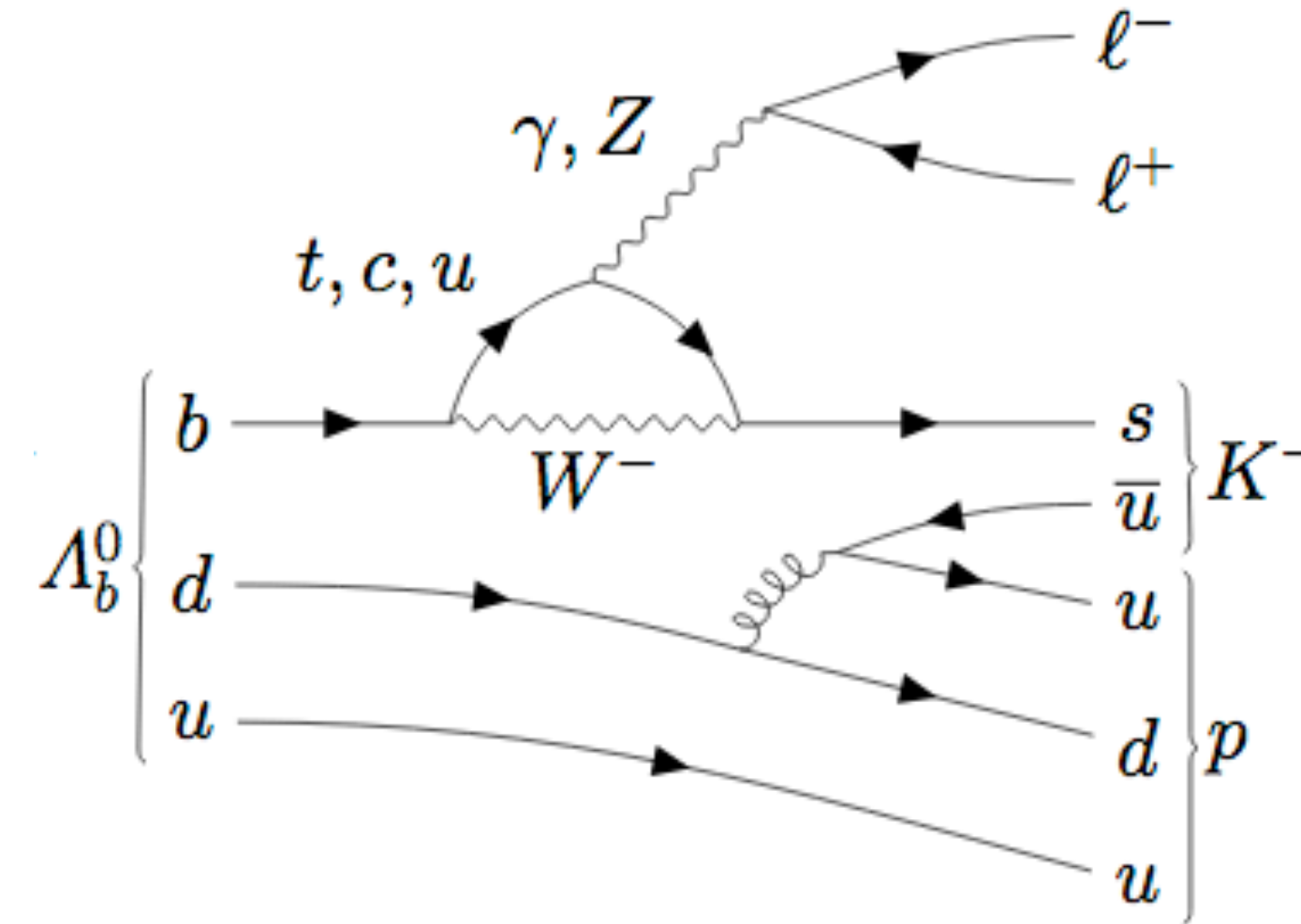
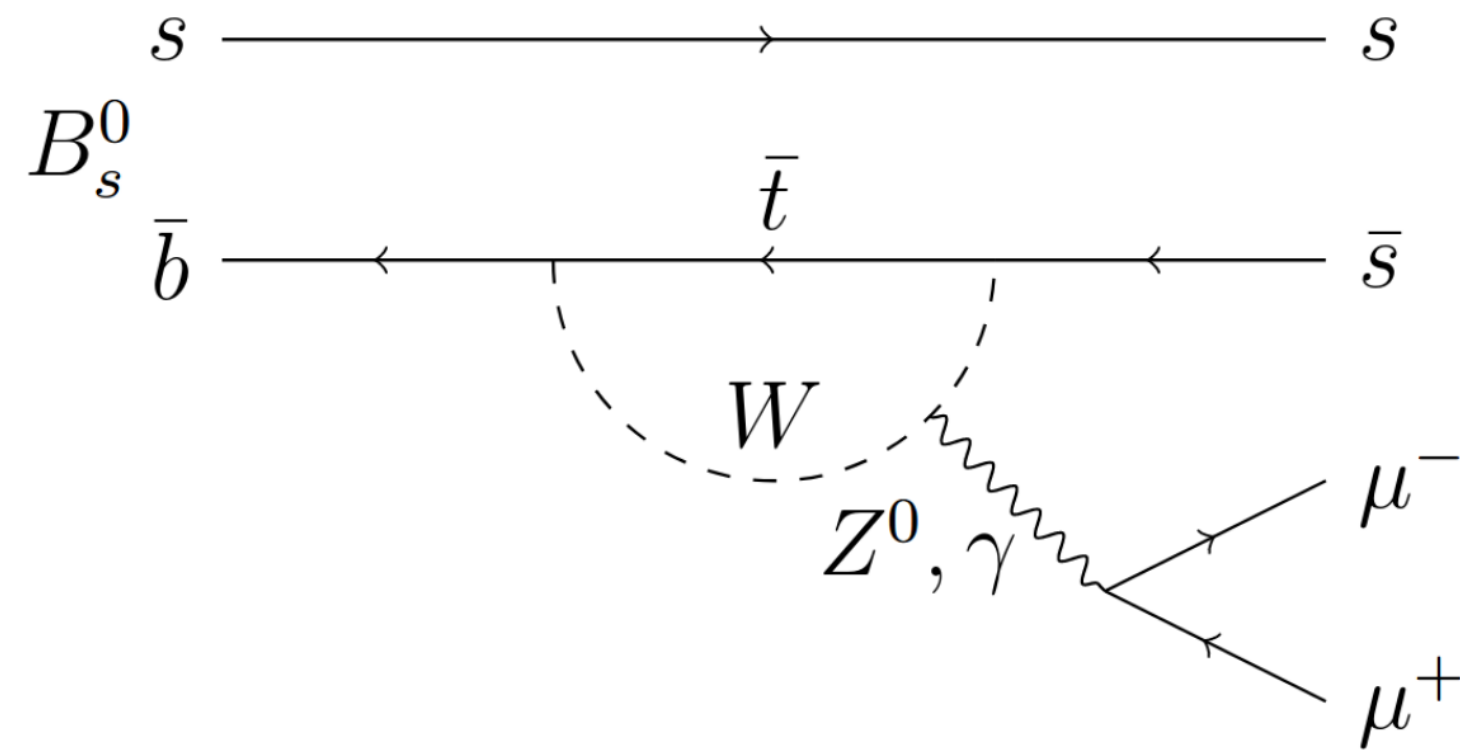
- The extrapolation boils down to calculating the fraction of inclusive $b \rightarrow sll$ that produce a charged kaon.



- For B^0 and B^+ decays, each $b \rightarrow sll$ decay is expected to either a charged or neutral kaon.
 - Extrapolation is then done using isospin rules (naively expected to be around 50%).
- Of course, we do not only produce B^0 and B^+ mesons at the LHC..

The complication from B_s^0 and Λ_b^0 hadrons

- Naively, isospin extrapolation should account for neutral kaons nicely for both B_s^0 and Λ_b^0 hadrons.



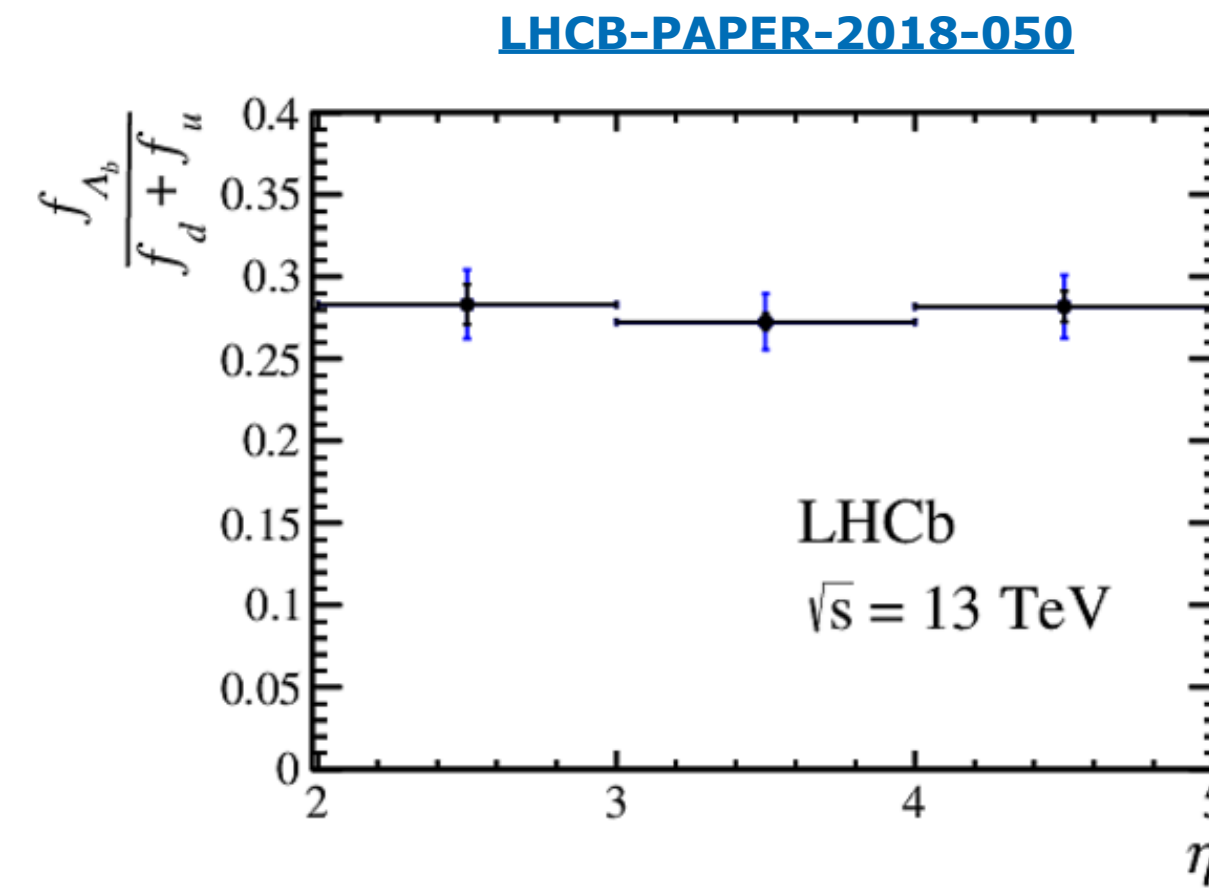
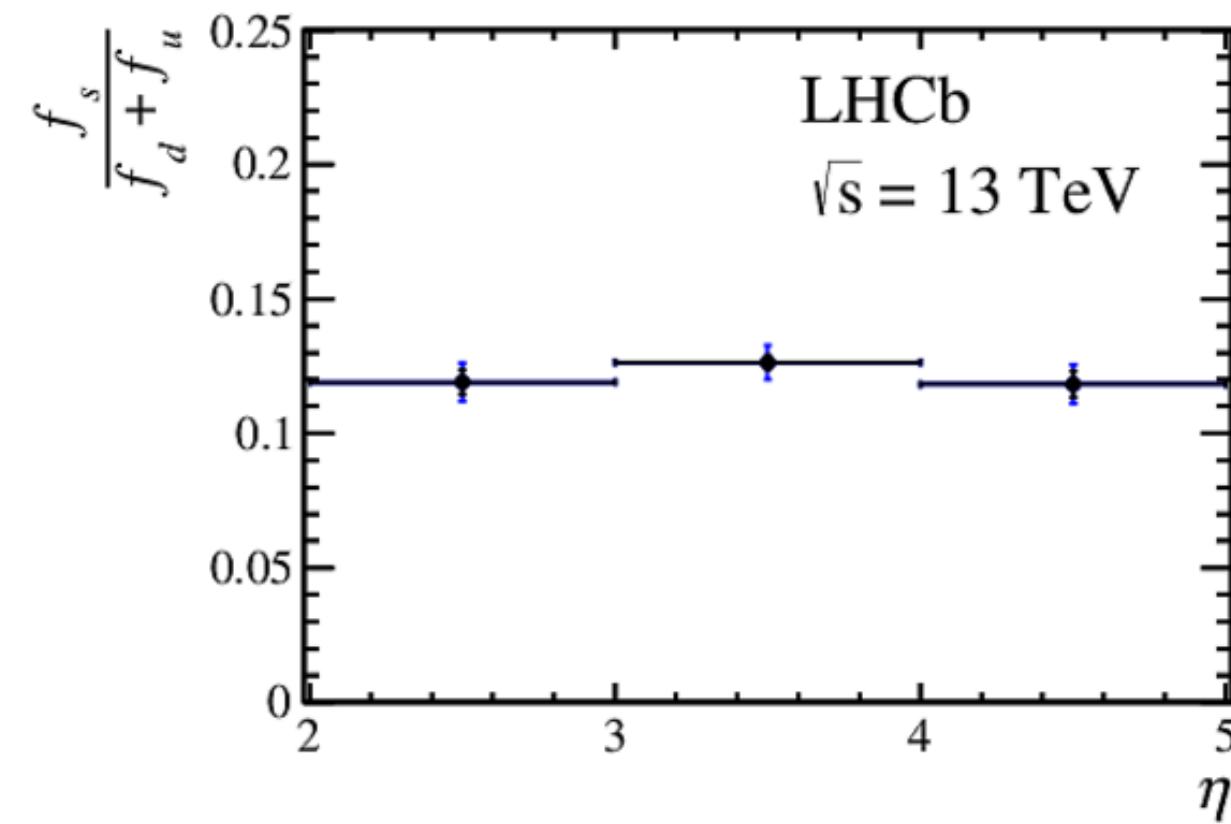
- Problem is that there is a fraction of inclusive B_s^0 and Λ_b^0 decays which do not produce kaons. This fraction is unknown and extrapolation appears difficult.

B_s^0 $I(J^P) = 0(0^-)$		
Γ_{51}	$J/\psi(1S)\phi$	$(1.08 \pm 0.08) \times 10^{-3}$
Γ_{52}	$J/\psi(1S)\phi\phi$	$(1.24^{+0.17}_{-0.19}) \times 10^{-5}$
Γ_{53}	$J/\psi(1S)\pi^0$	$< 1.2 \times 10^{-3}$
Γ_{54}	$J/\psi(1S)\eta$	$(4.0 \pm 0.7) \times 10^{-4}$
Γ_{55}	$J/\psi(1S)K_S^0$	$(1.92 \pm 0.14) \times 10^{-5}$
Γ_{56}	$J/\psi(1S)\bar{K}^*(892)^0$	$(4.1 \pm 0.4) \times 10^{-5}$
Γ_{57}	$J/\psi(1S)\eta'$	$(3.3 \pm 0.4) \times 10^{-4}$
Γ_{58}	$J/\psi(1S)\pi^+\pi^-$	$(2.09 \pm 0.23) \times 10^{-4}$

$\Lambda(1690)$ $I(J^P) = 0(3/2^-)$			
Decay Modes			
Mode		Fraction (Γ_i / Γ)	Scale Factor/ Conf. Level P (MeV/c)
Γ_1	$N\bar{K}$	20–30%	433
Γ_2	$\Sigma\pi$	20–40%	410
Γ_3	$\Lambda\sigma$	$(5.0 \pm 2.0)\%$	
Γ_4	$\Lambda\pi\pi$	$\sim 25\%$	419

B_s^0 and Λ_b^0 hadron decays as background

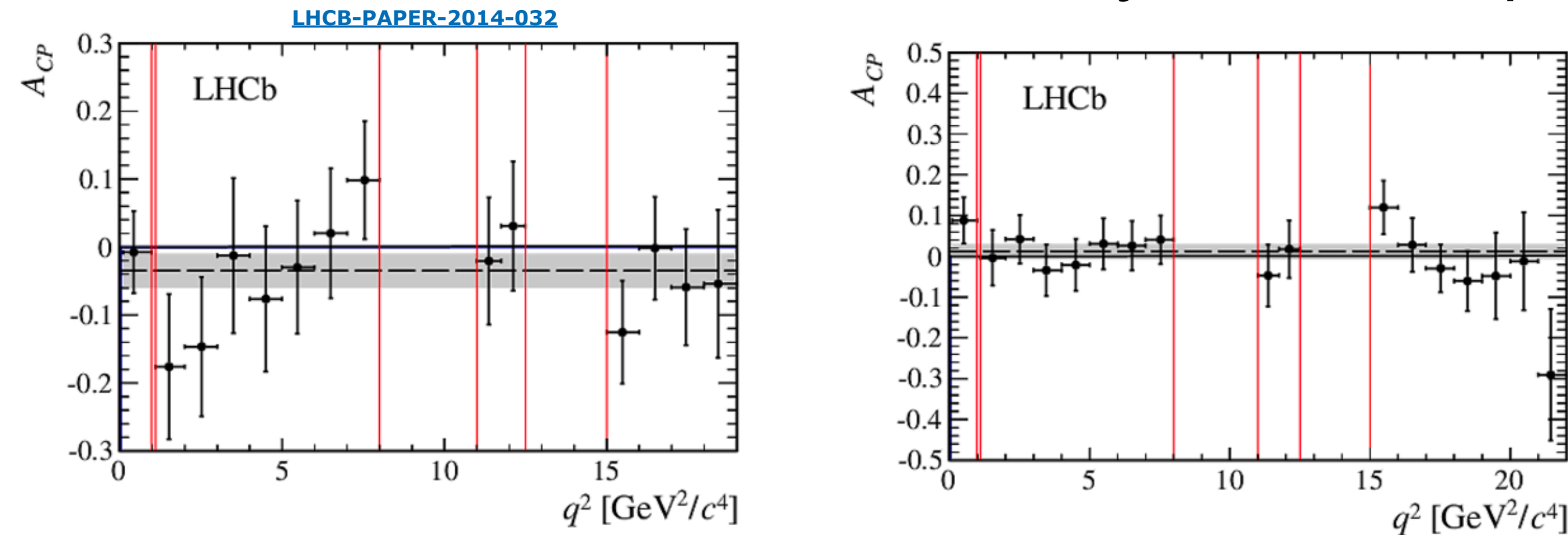
- These decays have smaller production and branching fractions than the B^+ and B^0 decays.



- We therefore propose to treat them as background and subtract them for the branching fraction.
- Dedicated auxiliary measurements can be useful:
 - For B_s : $\mathcal{B}(B_s \rightarrow K^+ K^- X \ell^+ \ell^-)$
 - For Λ_b : $\mathcal{B}(\Lambda_b^0 \rightarrow p K^- X \ell^+ \ell^-)$
- It is clear that a resulting systematic uncertainty will arise from this.

Prospects for theoretically precise observables

- Of course none of these matters for observables which are either reliably zero in the SM (A_{CP}) or hadronic uncertainties cancel (LFU ratios).
- In this case, missing an unknown fraction of the inclusive decay does not spoil the comparison with the SM.



- Here we note the fact that the inclusive BF is around order of magnitude higher than exclusive channels.
- By the end of run III, we expect around 1M $X_b \rightarrow K^+ X \ell^+ \ell^-$ candidates(!!).
- Due to the low reconstruction efficiency at LHCb, expect any LFU/ A_{CP} measurements to be statistically independent than exclusive ones (e.g. R_K).
- Can afford to be brutal with the selection and still have a large signal yield.

Summary

- We propose to use the signature $X_b \rightarrow K^+ X \ell^+ \ell^-$ as a proxy for inclusive $b \rightarrow s \ell \ell$ decays.
- Several experimental advantages are expected with respect to a fully inclusive approach.
 - Sideband closer to the signal - easier extrapolation for combinatorial background.
- Extrapolation complicated at LHC by presence of B_s and Λ_b^0 hadrons - propose to treat them as background.
- Expect the largest sample of self-tagged $b \rightarrow s \ell \ell$ decays in the world with this method - could provide statistically independent measurements of clean observables.