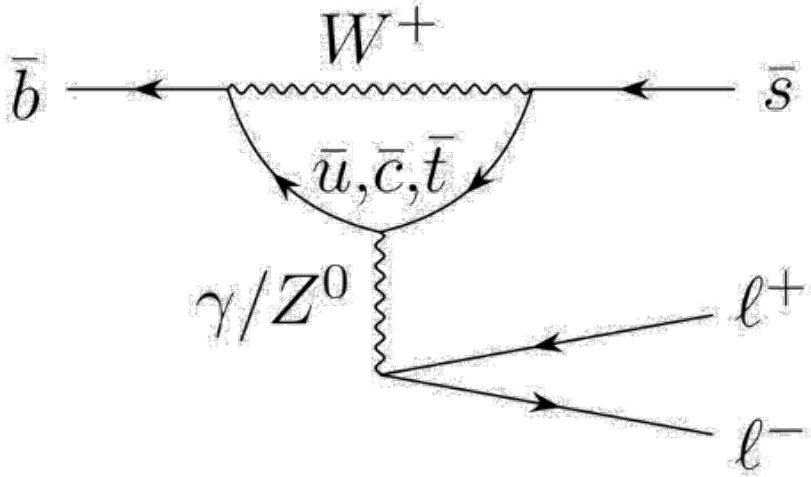
Rare Decays at LHCb

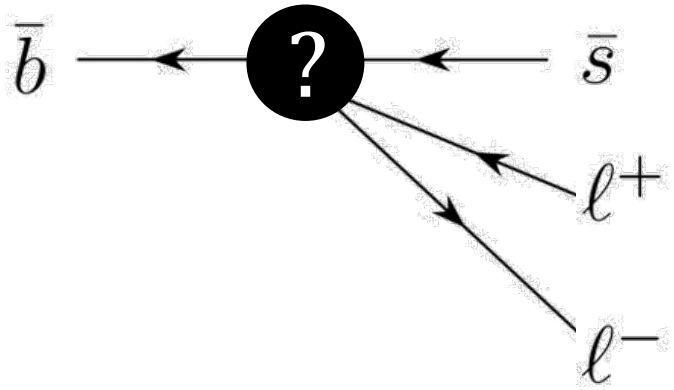
UNIVERSITY OF CAMBRIDGE

Why Rare Beauty Decays?

Standard Model



New Physics



- $b \to s\ell^+\ell^-$ and $b\bar{s} \to \ell^+\ell^-$ transitions, are **flavour-changing neutral current** (FCNC) processes → forbidden at tree level in the Standard Model (SM)
- supressed in SM (branching fractions $\mathcal{O}(10^{-10})$–$\mathcal{O}(10^{-6})$) and sensitive to **New Physics** (NP)
- particles associated with NP quantum fields can have masses above reach of direct searches at LHC

Last Christmas

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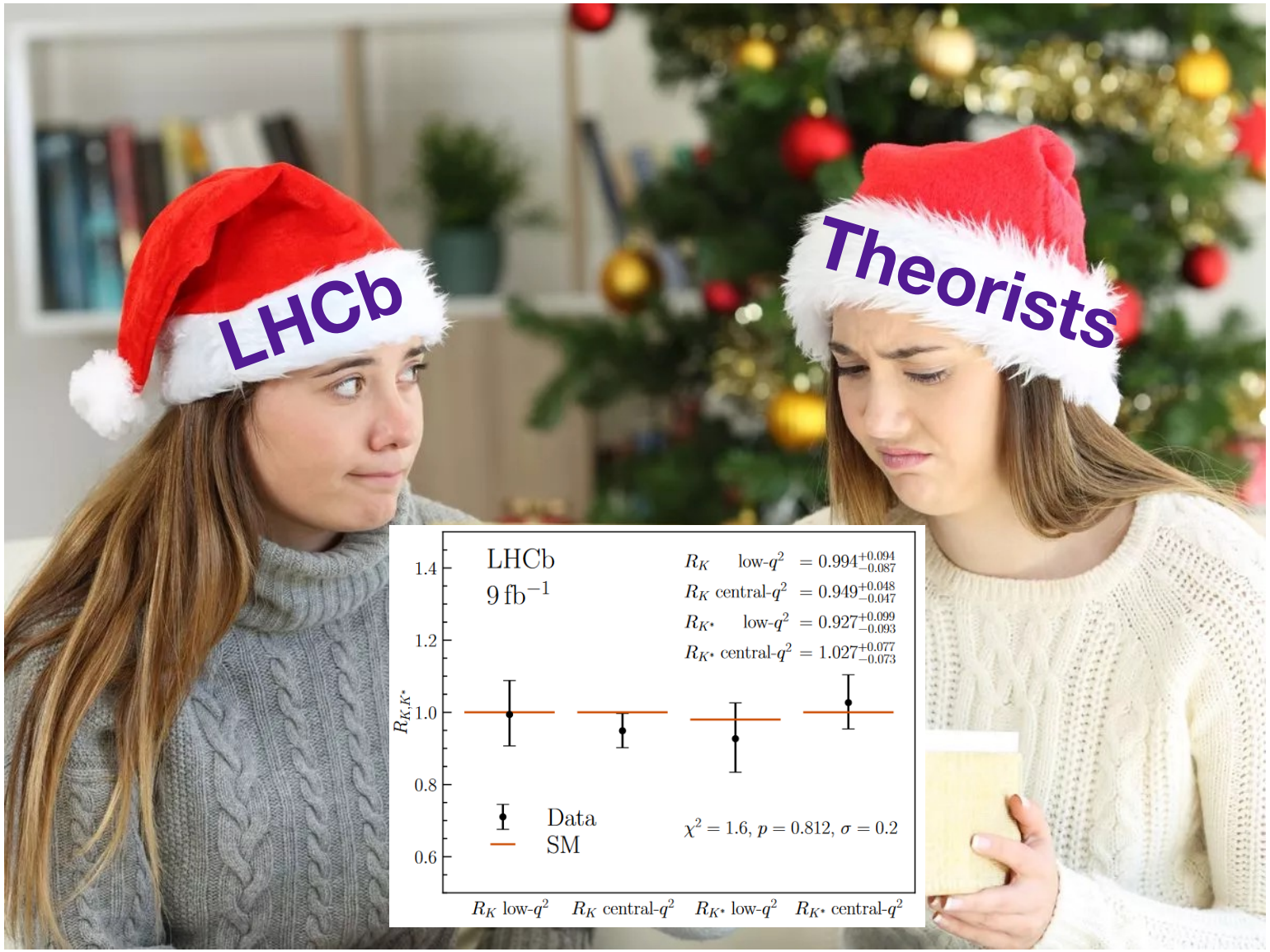
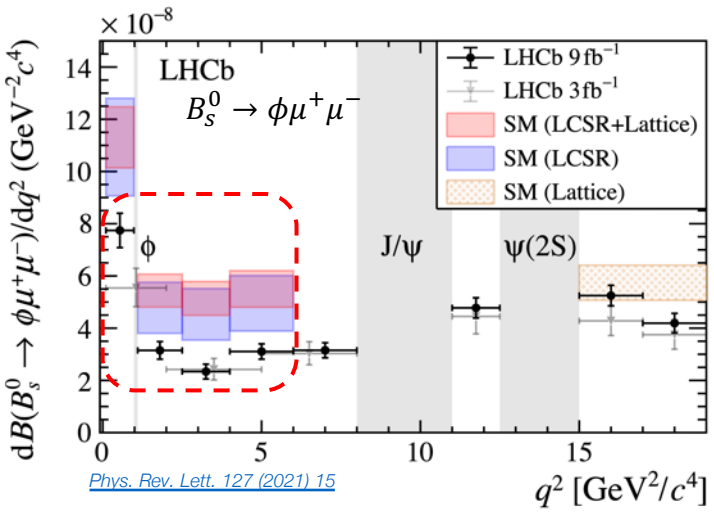
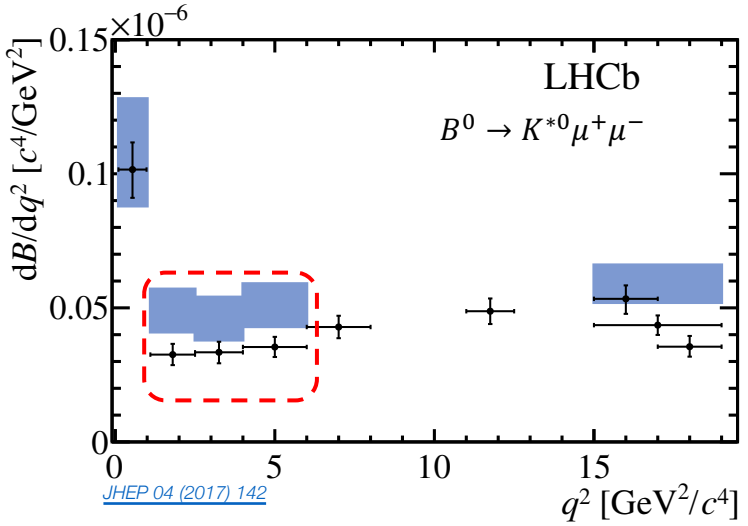


Last Christmas

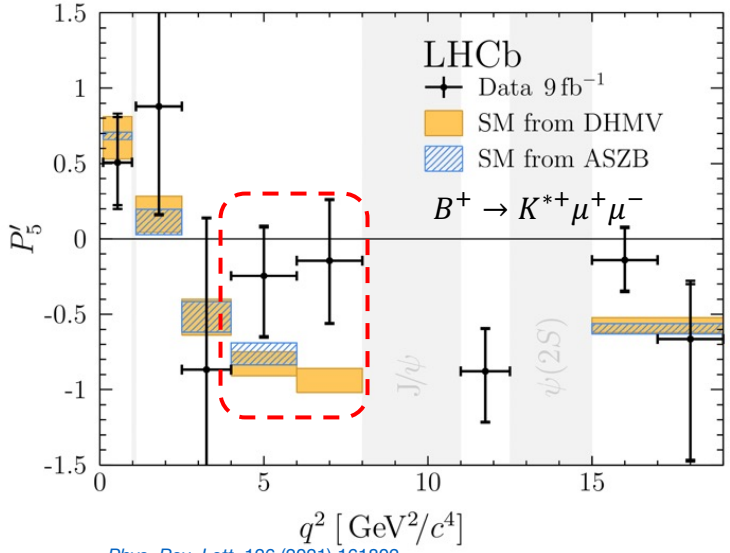
Anomalies



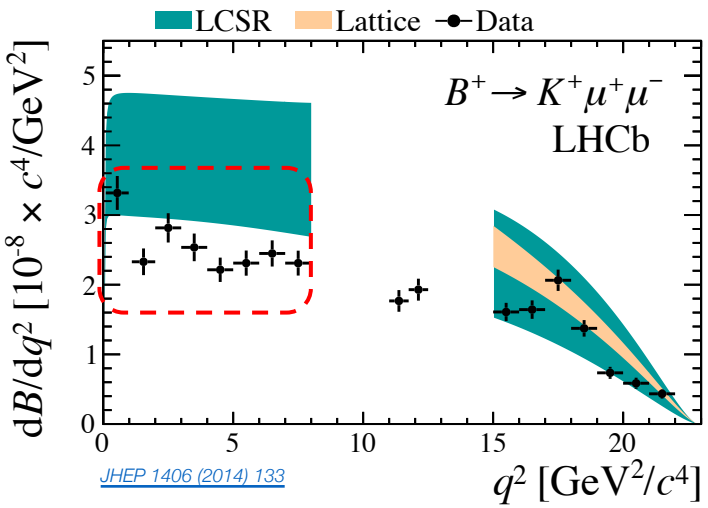
Phys. Rev. Lett. 127 (2021) 15



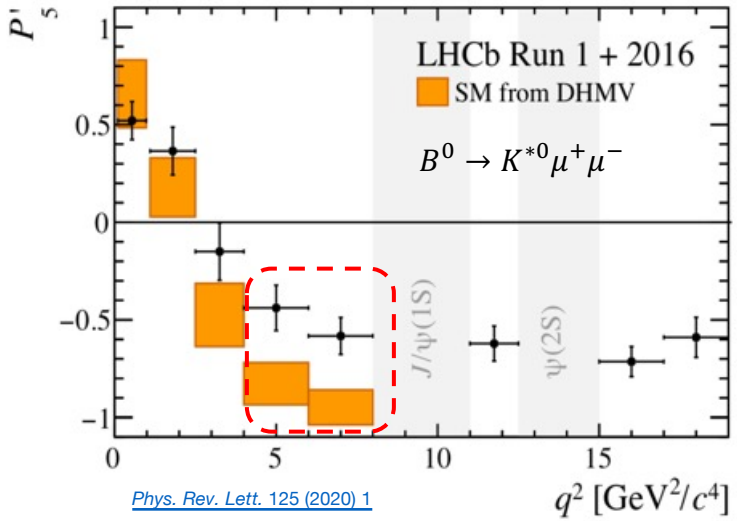
JHEP 04 (2017) 142



Phys. Rev. Lett. 126 (2021) 161802



JHEP 1406 (2014) 133



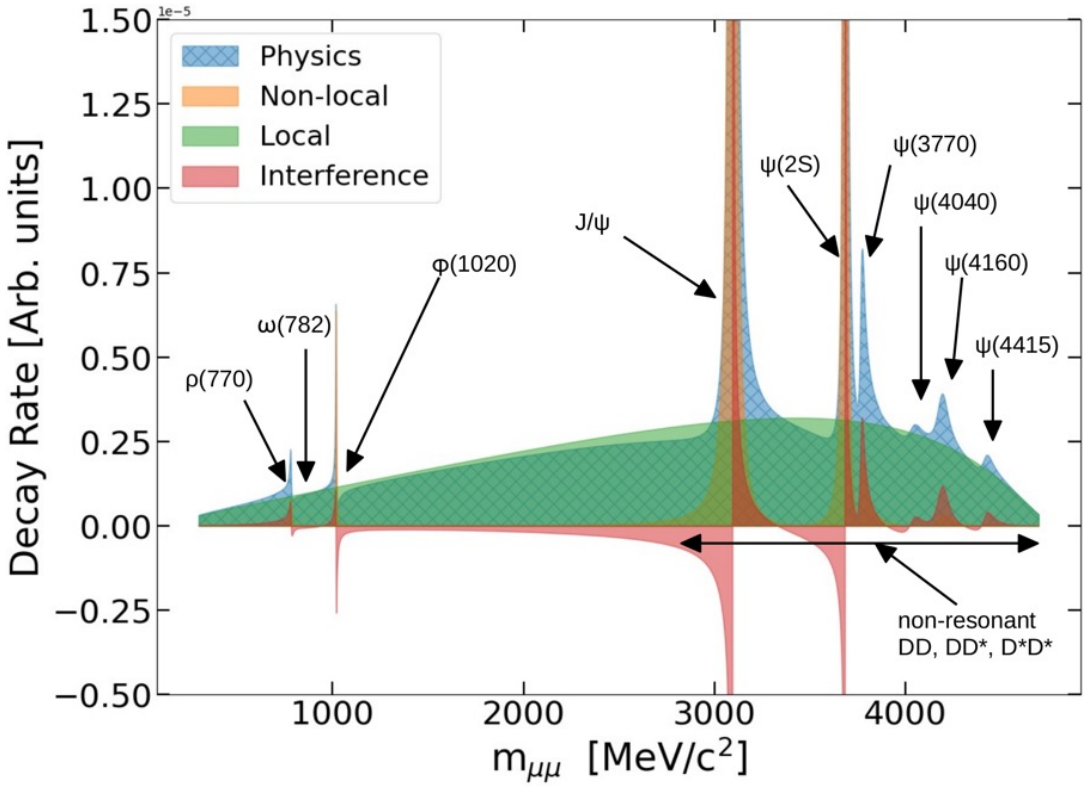
Phys. Rev. Lett. 125 (2020) 1

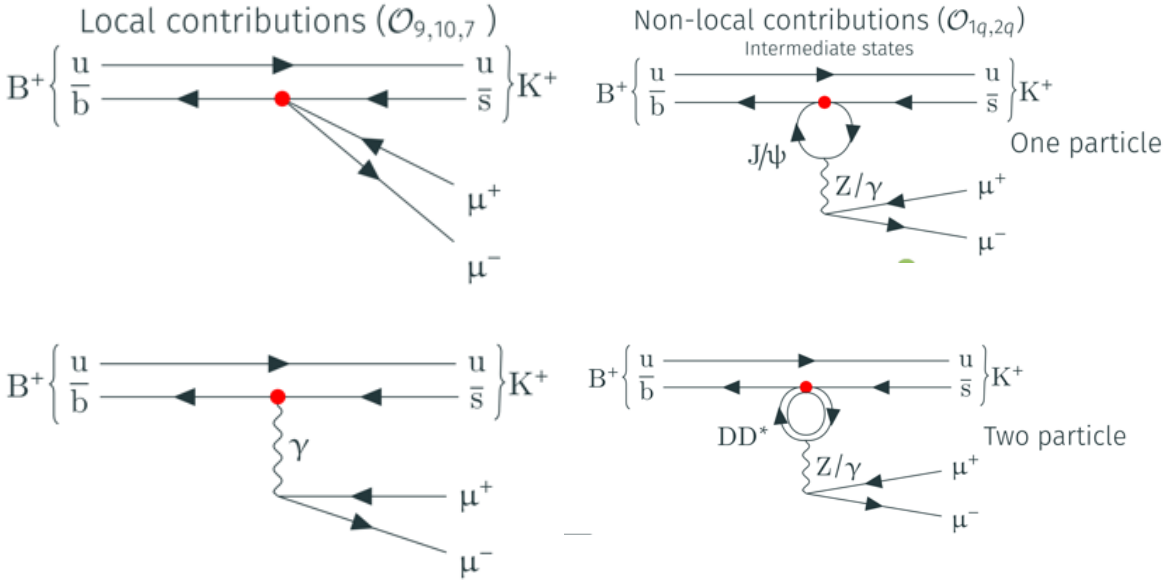

Lakshan Mahdan
LHCb

Analysis of $B^+ \to K^+\mu^+\mu^-$

- The dimuon spectrum of b->sll transition contain both local and non-local (hadronic) contributions
- Underestimated hadronic effect could potentially explain the anomalies seen
- Analysis aims to measure the local SM and NP while accounting for the hadronic effects directly using data in the full dimuon spectrum.
- Sensitive to NP enhanced tau-loop effects to dimuon spectrum

Analysis in Review within LHCb



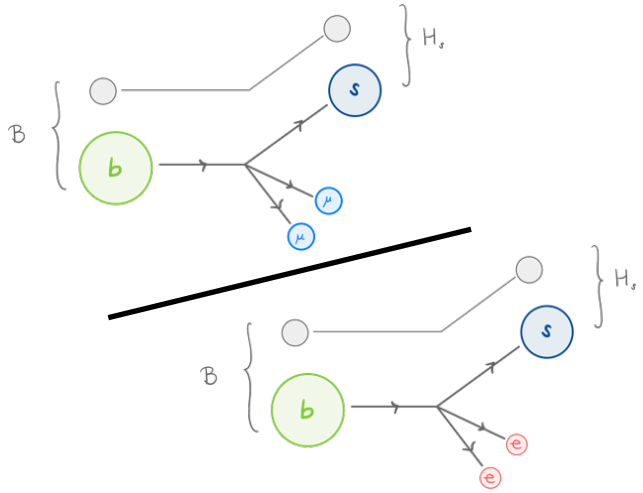



Davide Lancierini

LFU measurements at LHCb: R_K

- $R_{H_s \equiv K}$ measurements compare the branching ratios of $B^+ \to K^+ \ell\ell$ decay to e and μ final states

$$1 \overset{\text{SM}}{=} \frac{\mathcal{B}(B \to K^+ \mu\mu)}{\mathcal{B}(B \to K^+ ee)} \overset{\text{exp}}{=} \frac{N(B \to K^+ \mu\mu)}{N(B \to K^+ ee)} \frac{\varepsilon(B \to K^+ ee)}{\varepsilon(B \to K^+ \mu\mu)}$$



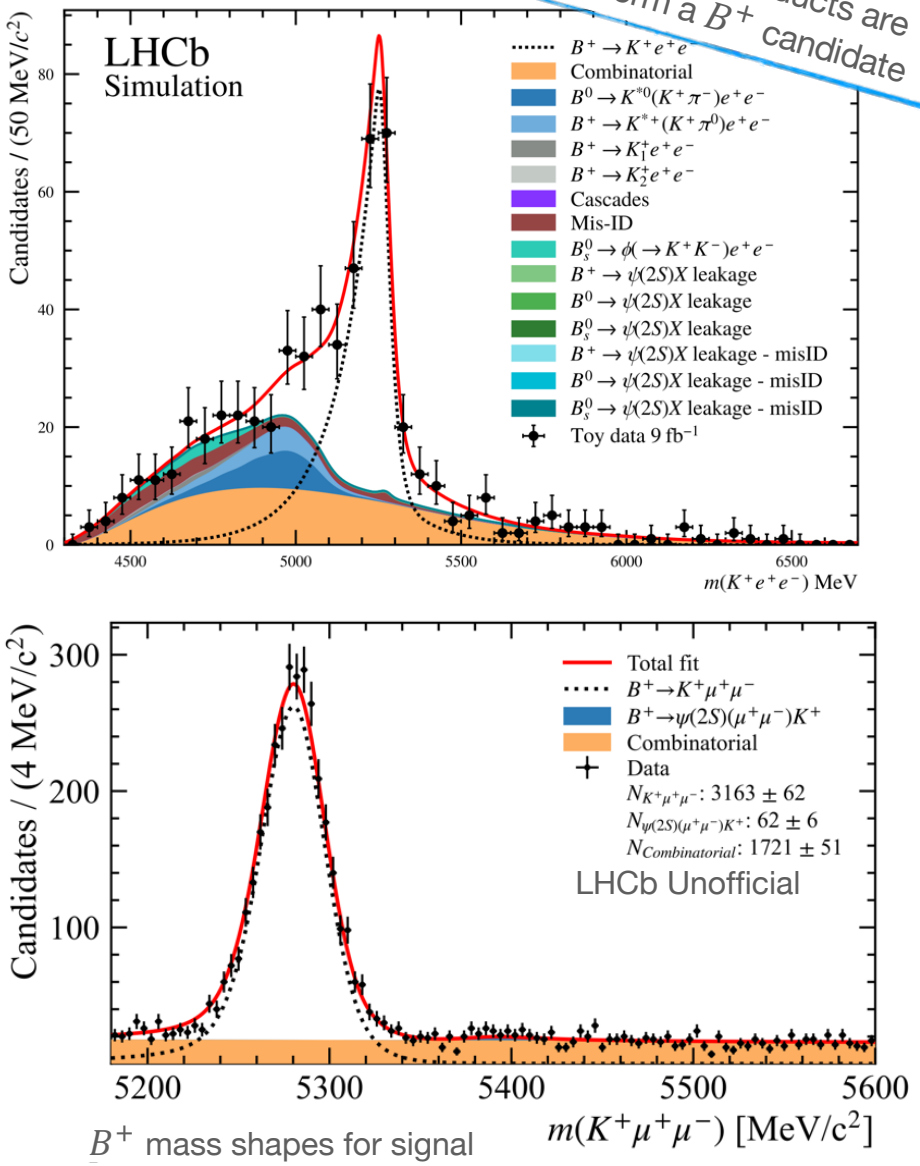
- Challenging as it requires precise knowledge of the signal yield (N) and the selection efficiency (ε) of decays that exploit different sub-detection systems at LHCb
  - Different reconstruction efficiencies, resolution, backgrounds btw e and μ

- We're involved in the measurement of R_K in kinematic region where the dilepton pair carries away most of the B^+ momentum, where existing measurements have big uncertainties ($\sim 18\%$)

R_K at high dilepton invariant mass q^2

Combinatorial background: events polluting the signal region where tracks from different decay products are combined to form a B^+ candidate

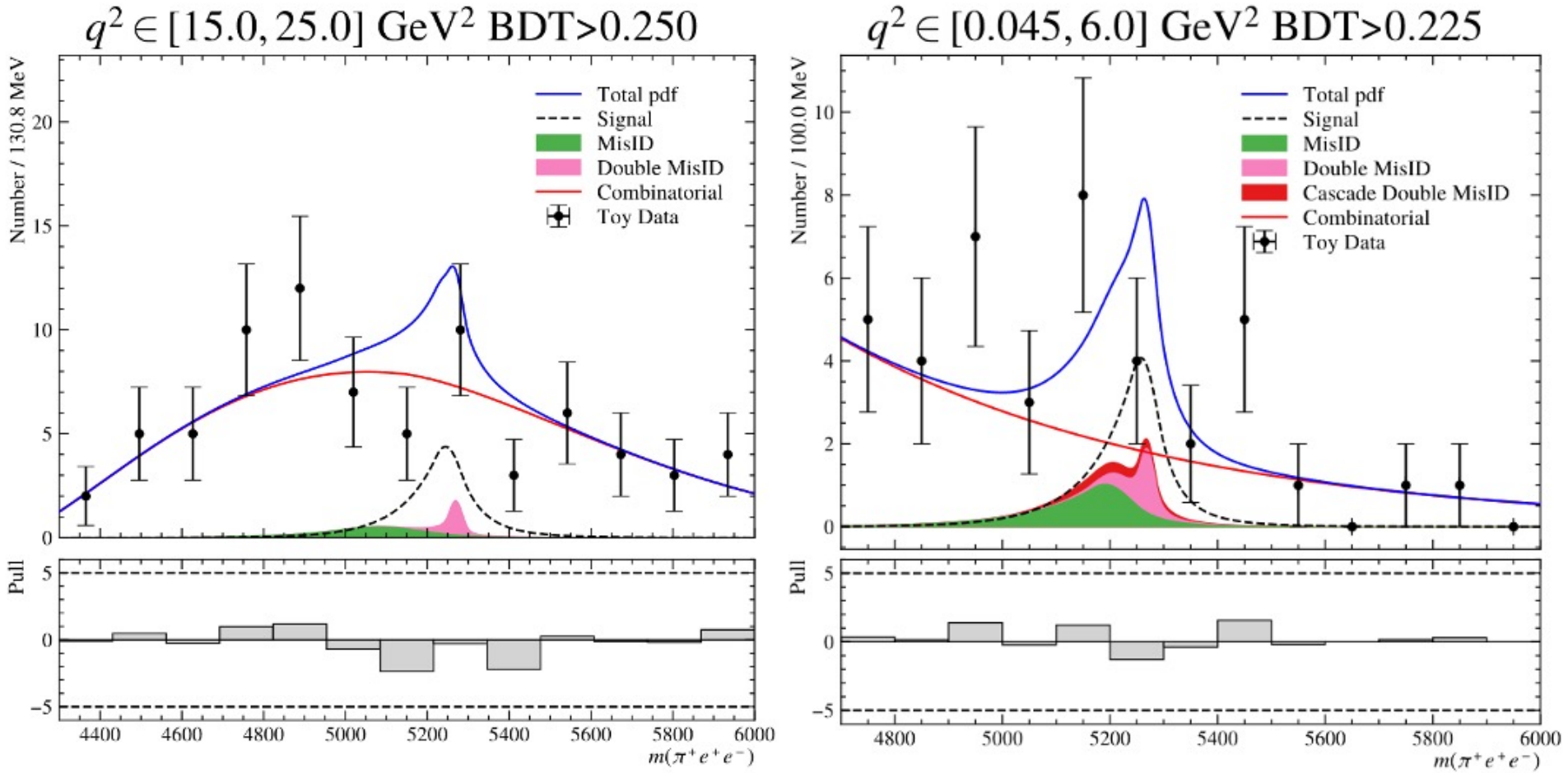
- We extract the signal yield (N) via unbinned maximum likelihood fits to the B^+ mass shape.
- In this kinematic region, lower efficiency and resolution in the electron mode induce a warping of the combinatorial background shape (strong contrast with muons).
- For combinatorial background events, the B^+ mass cannot be arbitrary low and q^2 arbitrary high → B^+ mass shape warping due to phase-space.
- We developed a "physically" inspired model to describe this phase-space cut at low B^+ mass:
  - Allows to minimise the number of parameters needed to describe the combinatorial shape and maximise the sensitivity to R_K at high q^2 (est. ~ 8% tot uncert.)



B^+ mass shapes for signal electrons (top) and muons (bottom)


Richard Williams

Search for $B^+ \to \pi^+ e^+ e^-$



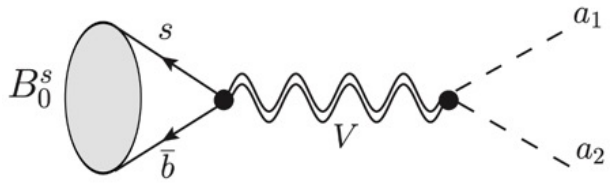
Close to final selection in our search for the as yet unobserved decay, splitting our signal region to help model backgrounds, with 2.2σ expected sensitivity.


Thomas Long

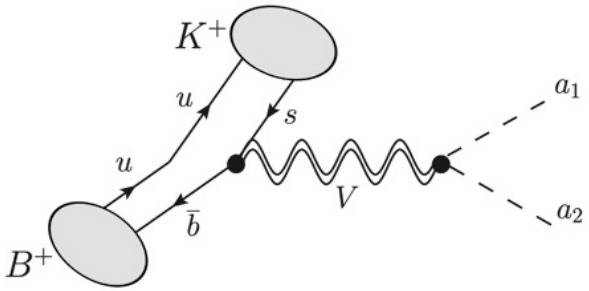
B Decays to Multiple Muons

Motivation

- Enhanced B decays to multiple muons arise naturally in non-minimal composite Higgs models, with flavour-violating heavy vectors (V) and light resonances (a) [arXiv:1902.10156, arXiv:2206.01759].



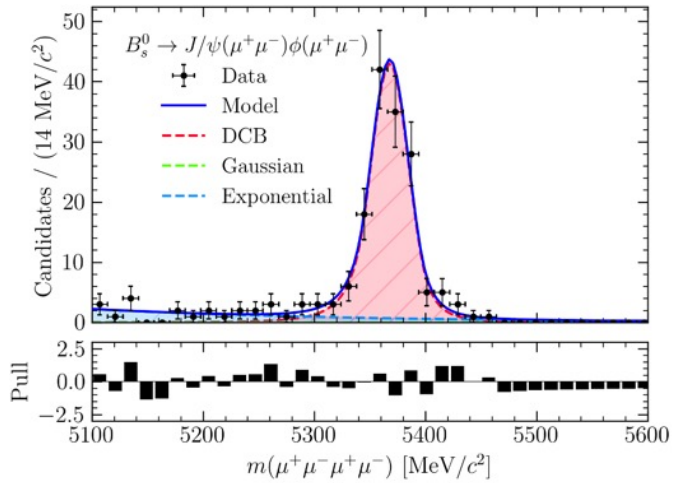
- Depending on the invariant mass of these light resonances, decays of the form $B_s \to a_1 a_2$ and $B^+ \to K^+ a_1 a_2$ could give rise to 4μ or 6μ.



- Small coupling of a to V raises possibility of relatively long-lived intermediates.
- Aim: Measure (or set limits on) BFs for $B_s \to 4\mu/6\mu$ and $B^+ \to K^+ 4\mu/K^+ 6\mu$ (both prompt and long-lived a) relative to $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(\mu^+\mu^-)$ as the normalization mode using Run 2 data.

Progress

- Simulation corrections mainly complete.
- Signal selection and efficiency calculation framework established - complete selection yet to be finalised.
- Yield of normalisation mode $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(\mu^+\mu^-)$ determined from fit to the invariant mass distribution.
- Systematic uncertainties and potential exclusive background sources in signal window to be studied.
- Prepare fitting strategy for signal modes and calculate expected upper limits.



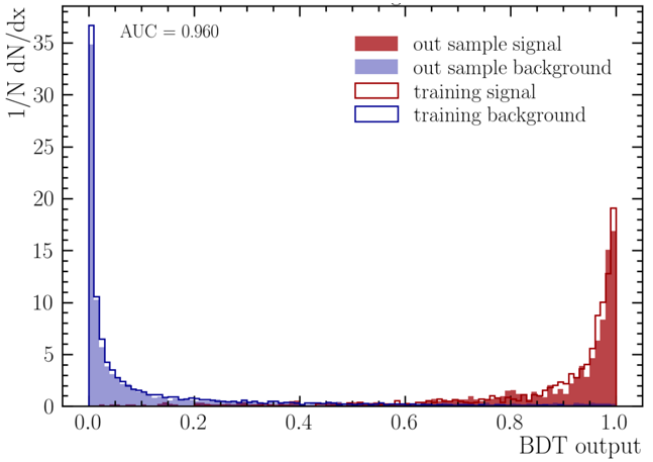
Search for Lepton Flavour Violation with $\Lambda_b \to pK\tau\mu$

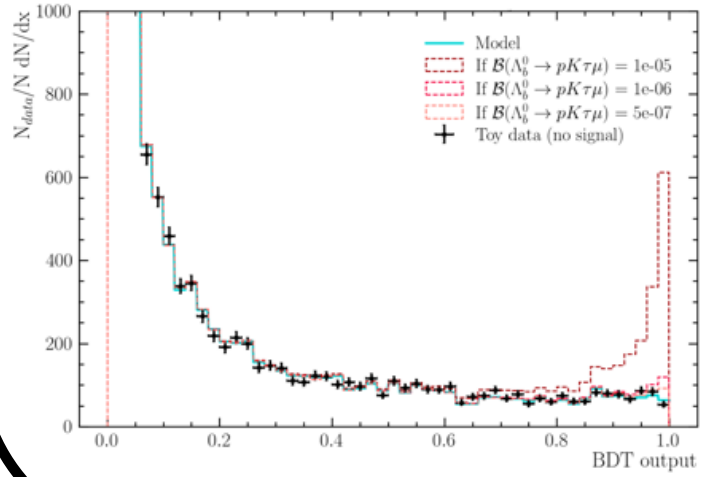
Motivation

- Lepton-flavour violating decays may arise in BSM physics introducing mechanisms breaking LFV, such as leptoquarks [arXiv:1511.01900, 10.1007/JHEP10(2018)148].
- An observation of $\Lambda_b \to pK\tau\mu$ where $\tau \to \mu\nu_\tau\overline{\nu}_\mu$, would constitute a clear sign of NP.
- Large deviations predicted for τ, and current experimental constraints on LFV decays with $\mu\ \tau$ or $e\ \tau$ in the final state are worse than on decays with $e\ \mu$ [10.1007/JHEP06(2023)143, arXiv:2207.04005].
- Aim: Set upper limit on (or measure) $\Lambda_b \to pK\tau\mu$ BF relative to normalisation mode $\Lambda_b^0 \to pK(J/\psi \to \mu^+\mu^-)$ using Run 2 data.
- Energy loss due to unreconstructed neutrinos which means $m(\Lambda_b^0)$ is not suitable for obtaining signal yield.

Progress

- Preliminary studies of physical backgrounds has been completed.
- BDT for discriminating signal from combinatorial background.
- Preliminary fit to normalisation mode.





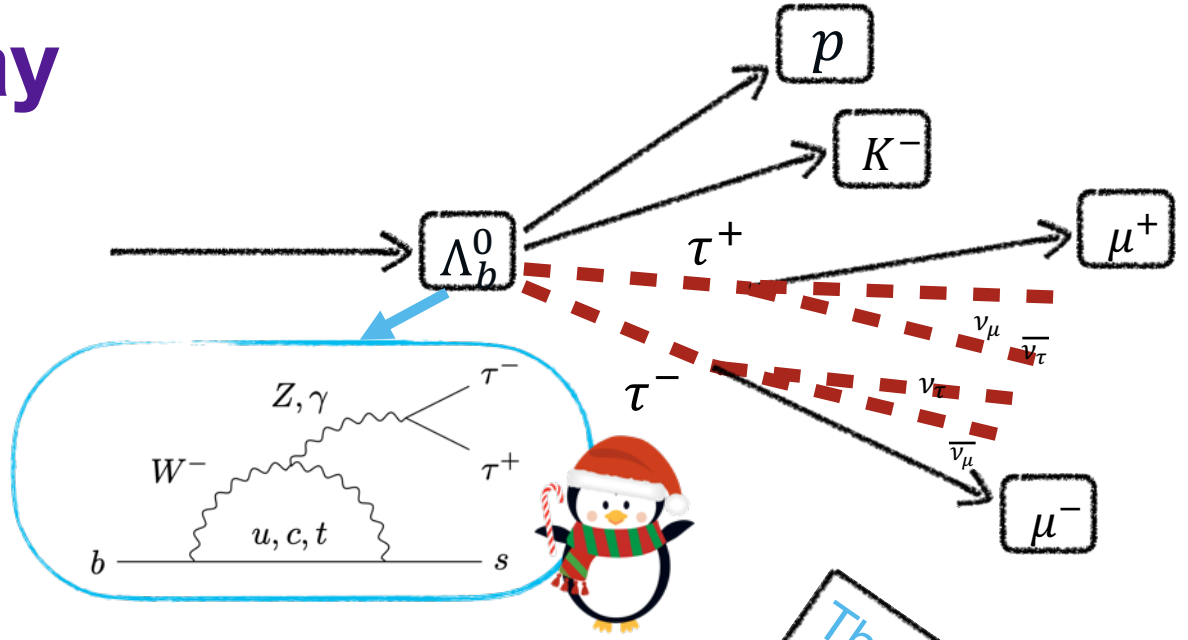
- Investigating template fit to BDT output (toy sample), using the known shapes of the signal and background used for the training.


Josh Bex
Rab

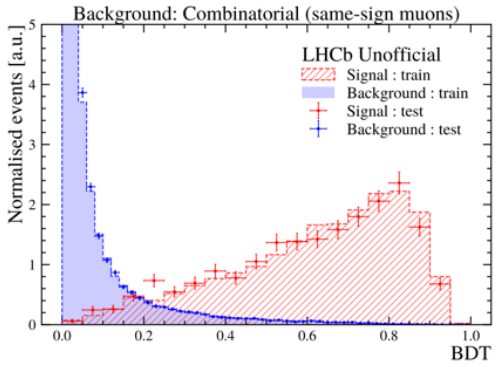
A search for the rare decay $\Lambda_b^0 \to pK^-\tau^+\tau^-$ at LHCb

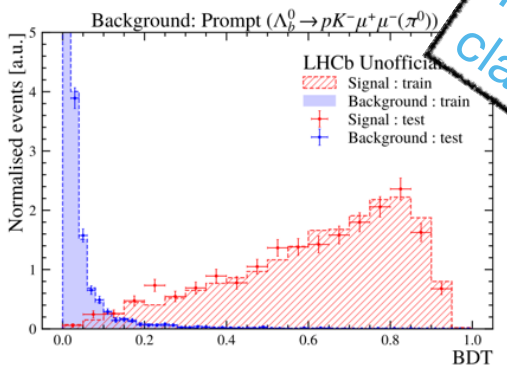
- Motivation?
  - Rare loop level process, sensitive to new physics entering at tree level.
  - Models explaining $R(D) - R(D^*)$ anomalies predict enhanced $b \to s\tau\tau$ branching fractions (expected even for LFU in light lepton generations). [1]

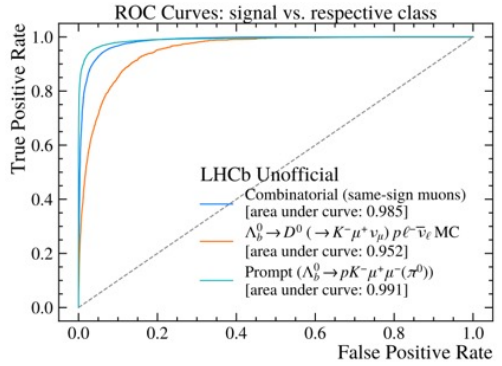
- Progress highlight?
  - Work on selection, for which central feature is BDT to discriminate against combinatorial, prompt, and semi-leptonic background classes.
  - Lack of tau vertex requires many backgrounds to be considered. Most important backgrounds are semi-leptonic, e.g. the background in the bottom right-hand plot:$\Lambda_b^0 \to D^0 p\ell^-\overline{\nu_\ell}, D^0 \to K^-\mu^+\nu_\mu$.

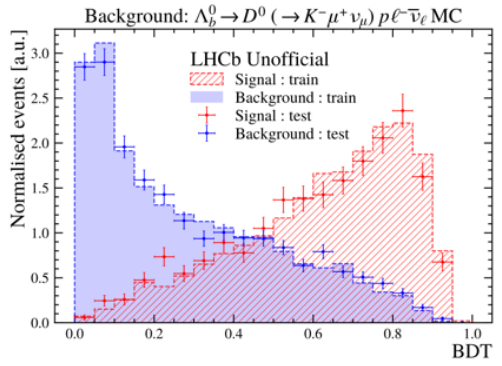


The multi-class BDT





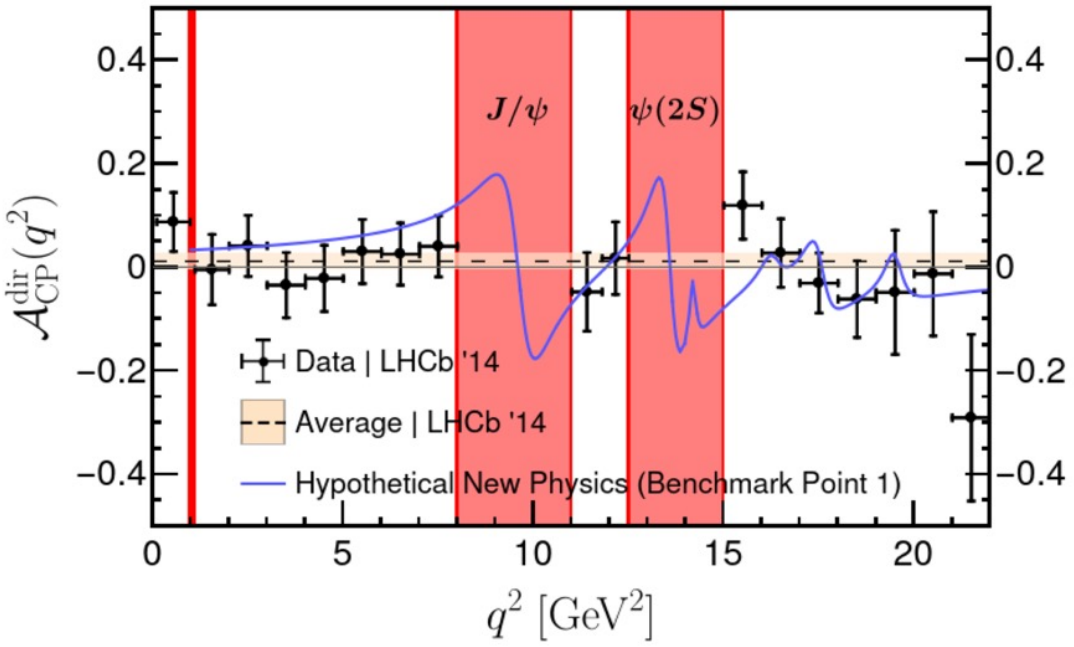


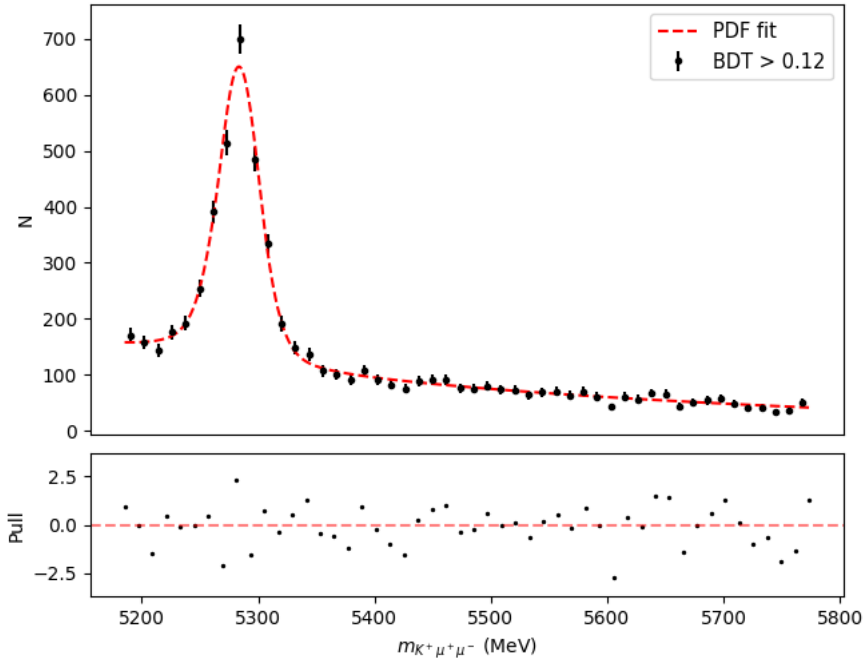


[1] J. Aebischer, G. Isidori, M. Pesut, B. A. Stefanek and F. Wilsch, Eur. Phys. J. C 83 (2023) no.2, 153


Juanjo Castella

A_{CP} in $B^+ \to K^+\mu^+\mu^-$





New physics can induce differences between the CP asymmetries in electronic and muonic decays. Updated measurement of A_{CP} in $B^+ \to K^+\mu^+\mu^-$ decays a first step.