Test of lepton flavour universality
in $B^+ \rightarrow K^+ l^+ l^-$ decays
in high dilepton invariant mass squared region

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Ratio of $B^+ \rightarrow K^+ l^+ l^-$ branching fractions (a theoretically clean observable):

$$ R_K = \frac{\int_{q_{\min}^2}^{q_{\max}^2} \frac{d\mathcal{B}(B^+ \rightarrow K^+ \mu^+\mu^-)}{dq^2} dq^2}{\int_{q_{\min}^2}^{q_{\max}^2} \frac{d\mathcal{B}(B^+ \rightarrow K^+ e^+e^-)}{dq^2} dq^2}, \quad q^2 \equiv \text{dilepton invariant mass squared} $$

In the Standard Model (SM) coupling of gauge bosons to leptons are independent of lepton flavour:

$$ R_K \approx 1 $$

Any significant deviation — hint of New Physics (NP):

- Latest results show $3.1\sigma$ tension with SM \[\text{arXiv:2103.11769}\]
'Central $q^2$' measurements ($q^2 \in [1.1 \, \text{GeV}^2, 6.0 \, \text{GeV}^2]$), see Davide’s talk before:

- **3.1 $\sigma$ tension** with the Standard Model

LHCb measurements ($R_K$) and $q^2$ distribution.
Only have measurements from the $B$-factory experiments at high $q^2$

**Question:** Why hasn’t LHCb made measurements of $R_K$ at high $q^2$?
‘High $q^2$’ measurements:

- Statistically independent measurements with a large yield;

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**Question:** Why hasn’t LHCb made measurements of $R_K$ at high $q^2$?

**Answer:** Bremsstrahlung effects are large thus the analysis become more difficult to perform.
Bremsstrahlung recovery

Even after Bremsstrahlung recovery, we see large differences between dielectron and dimuon final states:

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Due to imperfect Bremsstrahlung recovery signal is ‘washed out’ for electron channel.
Bremsstrahlung recovery

Narrow charmonium resonances have larger tails for the electron channel due to the imperfect Bremsstrahlung recovery and the energy resolution of the ECAL.
Bremsstrahlung recovery

Partially reconstructed backgrounds are not well separated from the signal for the electron case.
Bremsstrahlung recovery

Combinatorial and partially reconstructed backgrounds are **distorted** by the available phase space.
Dielectron final state is difficult due to the $\psi(2S)$ resonance leakage (Bremsstrahlung recovery smears out resonances)

Dimuon final state is less problematic
High $q^2$ problem

- ‘Central $q^2$’ measurements
  
  LHCb [arXiv:2103.11769]

- ‘High $q^2$’ measurements:
  
  It becomes challenging to statistically separate signal from background.

It becomes challenging to statistically separate signal from background.

LHCb [arXiv:2103.11769]

part-reco. background

signal

ψ(2S)K

combinatorial background

T. Blake talk
Resonances are smeared due to the **wrong** Bremsstrahlung recovery.
Since resonances are smeared due to the wrong Bremsstrahlung recovery:

\[ \frac{q^2}{\text{no Brem.}} \equiv \text{dilepton invariant mass (without adding Bremsstrahlung photons) squared} \]
Since resonances are smeared due to the wrong Bremsstrahlung recovery:

$q^2_{\text{no Brems}}$ is used in order to get rid of the resonance(s)
$q^2_{no\ Brem.}$ cut based signal selection:

Loose $\sim 50\%$ of signal compared to $q^2$ cut.

High $q^2$ solution

$q^2_{no\ Brem}$

$q^2$

$\frac{31/08/2020}{\text{Joint Annual Meeting of ÖPG and SPS 2021 | Test of LFU in } B^+ \to K^{+}\ell^+\ell^- \text{ decays in high } q^2 \text{ region | Vadym Denysenko}}$
**Purpose:** Recover signal (discriminate against $\psi(2S)$)
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- Signal sample ($B \rightarrow Ke$):
  - $q_{\text{no Brems}}^2 < 14$ GeV$^2$
  - $q_{\text{true}}^2 > 14$ GeV$^2$
  - $q^2 > 10$ GeV$^2$

- Background sample:
  - $B \rightarrow \psi(2S)( \rightarrow ee)K$

- Variables:
  - $q^2$, $q_{\text{no Brems}}^2$
  - Lepton momenta
  - Investigating addition of other variables
**Status:** Starting to put different components together

Expect around 800 signal (~ ½ of Central $q^2$)

- **Signal:** sum of 3 DCBs
  - Signal shape parameters fixed from simulation
  - Brem. fractions are gaussian constrained to the fraction observed in MC
  - Mean shift and scales are fixed from simulation
- **Part. Reco.: KDE**
- **Comb.: Exponential** (shape to be studied)

Total model obtained by summing the PDFs with the relative fraction obtained from simulation

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**Electron Sensitivity studies**

Fit to toy model. Run1 + Run2 stats (9 fb⁻¹).

- Total
- Signal
- Partially reconstructed
- Combinatorial

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Preliminary

- Full selection and $q_{no\text{ Brem.}}^2 > 14$ GeV²
- Hlt and L0 eTOS
- PID cut corrected with weights (DLLe > 4)
- Combinatorial BDT cut and fit range

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Joint Annual Meeting of ÖPG and SPS 2021 | Test of LFU in $B^+ \rightarrow K^+ l^+ l^-$ decays in high $q^2$ region | Vadym Denysenko
First evidence of LFU violation in $B^+ \rightarrow K^+ l^+ l^-$ decays has been seen by LHCb with $3.1\sigma$ deviation from Standard Model. To further investigate the problem more studies are required.

Measurement of the LFU ratio $R_K$ in ‘high $q^2$’ region:
- first LHCb measurement;
- using the full available dataset (9 fb$^{-1}$);
- statistically independent result;
- high yield;
- complementary phase space;

Work in progress. Stay tuned for further updates :)
Thanks for your attention