LHCb Physics Highlights 2020/2021

Stephen Farry

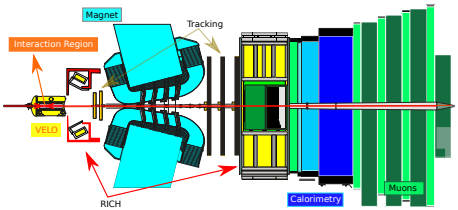
on behalf of the Liverpool LHCb group

HEP Christmas Meeting Part II

April 28, 2021

UNIVERSITY OF LIVERPOOL

The (current) LHCb detector



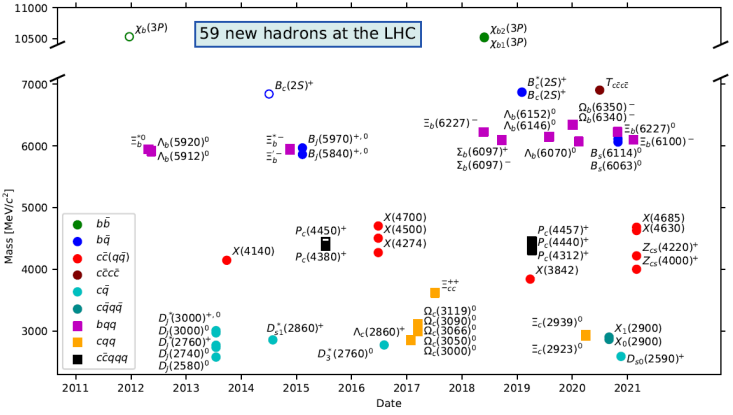
- Dedicated heavy flavour experiment at the LHC
- Collected 9 fb^{-1} in Runs I and II ($>$ 1 trillion B hadrons)

Liverpool Physics Roles

S. Farry	LHCb representative on LHC Top working group
	co-convener of LHC EW jets and Boson group
	QEE WG convener (to March 2020)
E. Rodrigues	coordinator of Data Processing and Analysis (DPA) project
T. Shears	LHCb representative on LHC Electroweak group (to September 2020)
L. Yeomans	Trigger liaison for Rare Decays working group

Plenty of physics highlights in 2020/2021!

Spectroscopy

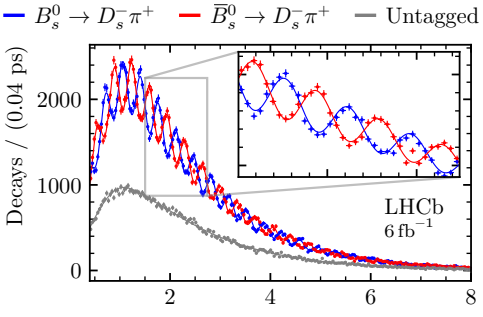


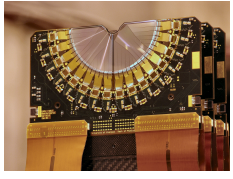
- Abundance of new hadrons discovered at the LHC, a massive contribution from LHCb
- In the last year at LHCb, new beauty baryons and six new tetraquarks

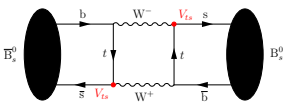
$\mathbf{B_s^0}$ oscillations

[2104.04421 [hep-ex]]

"Never measure anything but frequency!" - Arthur Schawlow



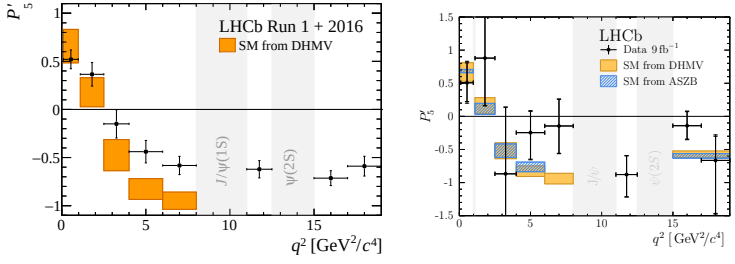




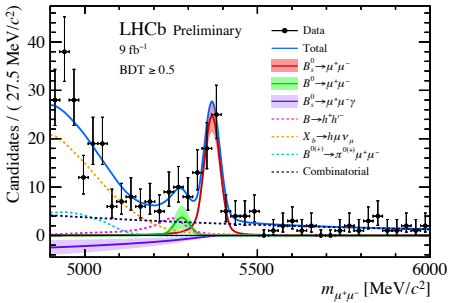
- Precise determination of the B_s^0 oscillation frequency - a flagship measurement that LHCb was designed for
- No anomalies here, but a demonstration of the power of the VELO
- $\Delta m_s = 17.7656 \pm 0.0057 \text{ps}^{-1}$
- Frequency of $\sim$ 3 THz!
- Precision of 0.03%, improvement by a factor of two over previous measurements

[*Phys. Rev. Lett.* (2020) 125:p. 011802], [*Phys. Rev. Lett.* (2021) 126:p. 161802]

- **What is $\mathbf{P'_5}$?**
  - The P_i variables are a derived set of optimised angular observables designed to be minimally sensitive to poorly understood hadronic effects
  - One of LHCb's longest standing discrepancies has been in one specific observable, P'_5



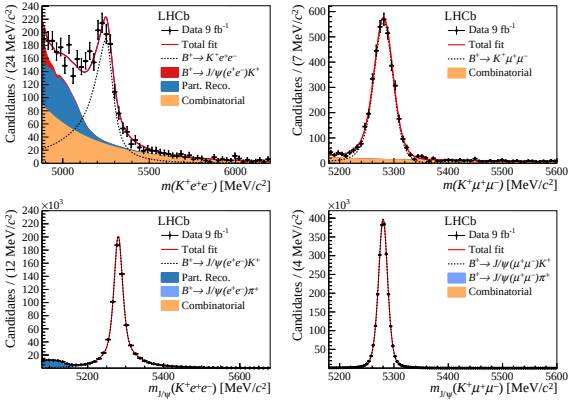
- This year, LHCb has updated its measurements in the $B^0 \to K^{*0}\mu^+\mu^-$ channel as well adding a new measurement in the $B^+ \to K^{*+}\mu^+\mu^+$ channel
  - Discrepancy persists in K^{*0} channel and similar pattern seen in K^{*+} channel

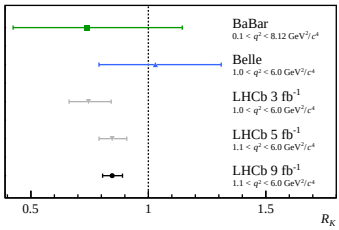


- Legacy measurement of $B_s^0 \to \mu^+\mu^-$ using full Run 1 and Run 2 dataset is an important milestone for LHCb
  - Also now including first limit on $B_s^0 \to \mu^+\mu^-\gamma$ at high invariant mass (complementary physics sensitivity)
- 10σ observation of $B_s^0 \to \mu^+\mu^-$, $B^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-\gamma$ consistent with background only hypothesis at 1.8 and 1.5σ
  - $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.09^{+0.46+0.15}_{-0.43-0.11}) \times 10^{-9}$, $\mathcal{B}(B^0 \to \mu^+\mu^-) < 2.6 \times 10^{-10}$

Lepton Flavour Universality - $\mathbf{R_K}$

[2103.11769 [hep-ex]]



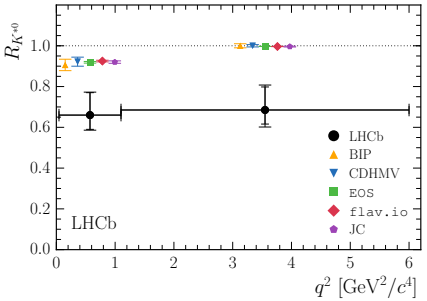


$$R_K = \mathcal{B}(B^+ \to K^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+e^+e^-)$$

- Double ratio performed with with respect to J/ψ modes
- Updated measurement of lepton flavour universality in $B^+ \to K^+\ell^+\ell^-$ mode using full Run 2 data
- Discrepancy between muons and electrons persists and now reaches 3.1σ

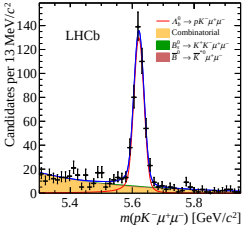
Lepton Flavour Universality $\mathbf{R_{K^*}}$, $\mathbf{R_{pK}}$

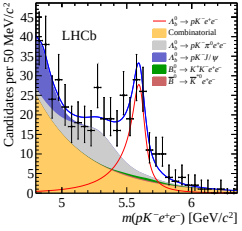
[*JHEP* (2020) 05:p. 040], [*JHEP* (2017) 08:p. 055]



- ...and R_K is not the only muon/electron deviation

  $\mathbf{B^0 \to K^{*0} \ell^+ \ell^-}$
- R_{K^*} shows discrepancies of $\sim 2\sigma$ in two bins of q^2
- Measurement only performed with Run 1 data so far, full update in the works



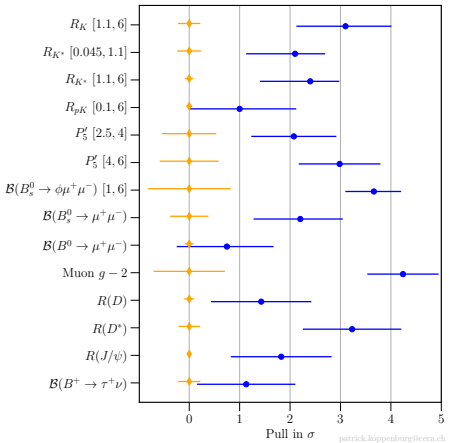


- First measurement of LFU in a baryonic mode (D. Hutchcroft, V. Franco Lima)

  $\mathbf{\Lambda_b^0 \to pK^- \ell^+ \ell-}$

  $R_{pK}^{-1} = 1.17^{+0.18}_{-0.16} \pm 0.07$
- A factor of two more data available now, looking forward to update with more statistics

The Flavour Anomalies



- LHCb is seeing a consistent pattern of deviations from the Standard Model (with a guest appearance by $g-2$)
  - The chief culprit appears to be muons
- Global fits show significant deviations from the SM in a number of different scenarios [2104.08921 [hep-ph]]. **The key is fitting it all together**

"We show that the new LHCb data corroborate the emerging pattern of a new, predominantly left-handed, semileptonic current-current interaction" [2103.16558 [hep-ph]]

"A combination of the clean observables R_K, R_{K*}, and $B_s \to \mu\mu$ alone results in a discrepancy with the Standard Model at 4.0σ.... One-parameter scenarios with purely left-handed or with purely axial coupling to muons fit the data well and exclude the Standard Model at $\sim 5\sigma$ level" [2103.12738 [hep-ph]]

"Our main conclusion is that in the context of a simple theory for quark-lepton unification proposed in Ref. [6] one can explain simultaneously the recent experimental results for R_K and $(g-2)_\mu$." [2104.11229 [hep-ph]]

"a thermal DM candidate can naturally provide a simultaneous explanation of the muon $g-2$ ... and the B-physics anomalies, while evading present bounds from collider and DM searches." [2104.03228 [hep-ph]]

Other Highlights

Things I didn't mention...

- V_{ub}/V_{cb} [*Phys. Rev. Lett.* (2021) 126:p. 081804]
- Time dependent $\mathcal{CP}$ violation in B_s^0 meson decays [*JHEP* (2021) 03:p. 075]
- Precise measurements of the CKM angle γ [*JHEP* (2021) 02:p. 169], [*JHEP* (2021) 03:p. 137],

and we soon expect other new results

- Update of R_{K*} with full dataset
- Precision EWK measurements, W mass, Low mass Drell-Yan, A_{FB} as well as top physics measurements
- First search for purely baryonic decays at LHCb [*Sci. Rep.* (2019) 9:p. 1358]

Plenty of physics yet to be done with current dataset!

Conclusions

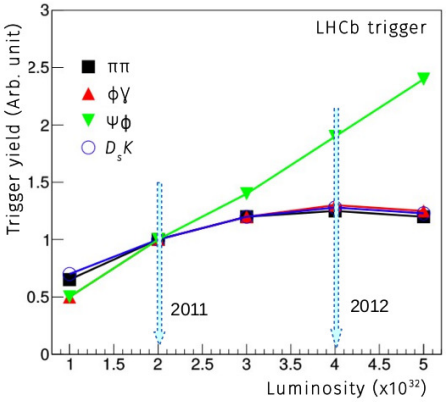
- We are a little bit further away from the Standard Model than we were at the last Christmas meeting
- No doubt the most promising hints from new physics at the LHC are coming from LHCb
  - Many searches for new physics at ATLAS/CMS are now motivated by the LHCb results
- The focus for the experiment is to complete legacy measurements ahead of the upgrade (see Themis' talk)
  - The extra statistics at the upgrade will unravel some of these mysteries
- Other experiments (e.g. Belle II) will also have their say!

backup

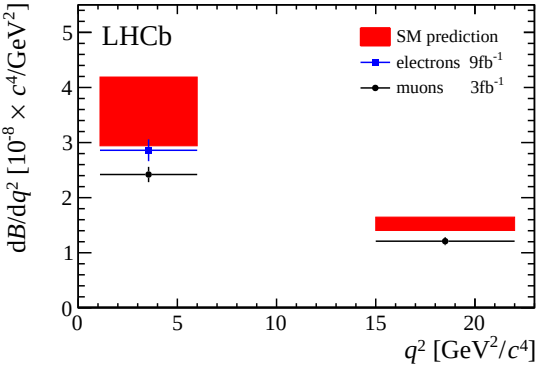
upgrade running conditions

- aim to collect a factor of ten more data than Runs I and II
  - $\geq 50\,\text{fb}^{-1}$
- run at instantaneous luminosity of 2 x $10^{33}\text{cm}^{-2}\text{s}^{-1}$
  - 7.4 interactions per bunch crossing
- yield in hadronic final states saturates at higher intensities
- an effective trigger will require information from all subdetectors
- improvements to counter expected degradation in physics performance

  $\rightarrow$ replacement of a number of subdetectors



electron and muon branching ratios



- electrons appear more standard-model like than muons

new physics contributions