Tests of Lepton Universality at LHCb

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Physics 290E

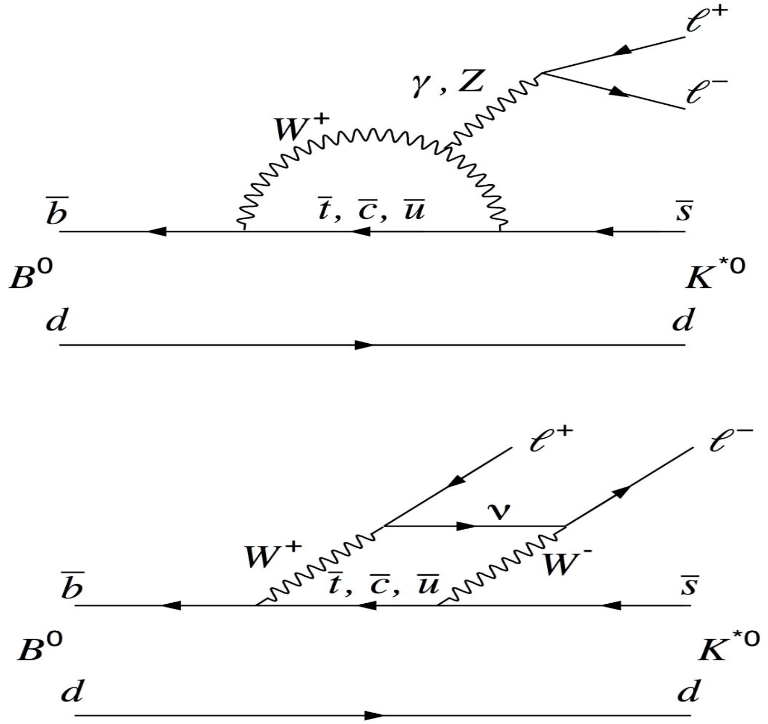
April 03, 2019

https://arxiv.org/pdf/1705.05802.pdf

Overview

- Theory considerations
- Background on LHCb
- Experimental approach
- Recent results

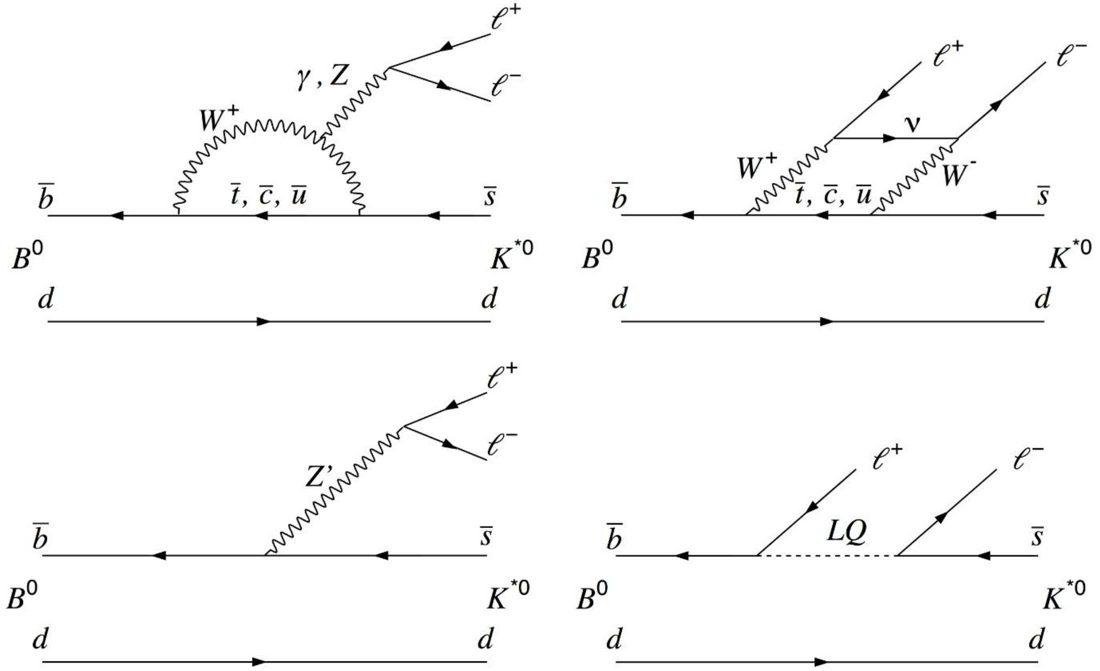
What Do Quark Interactions Have to Do With Leptons?



- B mesons explored extensively at lepton and hadron colliders
- Weak decays (below bb threshold)
- Clean way to look at loop processes involving leptons
- Precision test of the Standard Model
- In particular:

$$B^0 \to K^{*0}\mu^+\mu^- \text{ and } B^0 \to K^{*0}e^+e^-$$

To Infinity and Beyond (the Standard Model)



- Z’ and Leptoquark models could appear at tree level
- In SM, EW lepton couplings are all the same
- Possible BSM processes break that universality

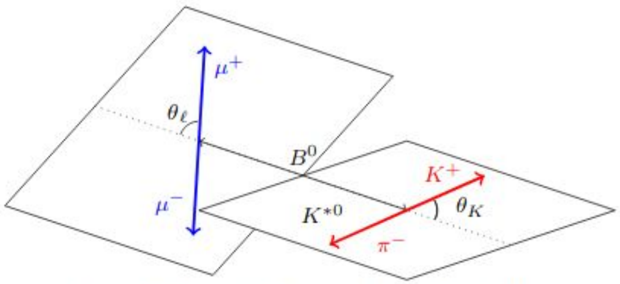
What Quantities Can We Measure?

- How do we determine if this universality hold?
- Easy way and complicated way
- Ratios! →
- H is a hadron containing a strange quark
- But to help reduce systematics, take double ratios

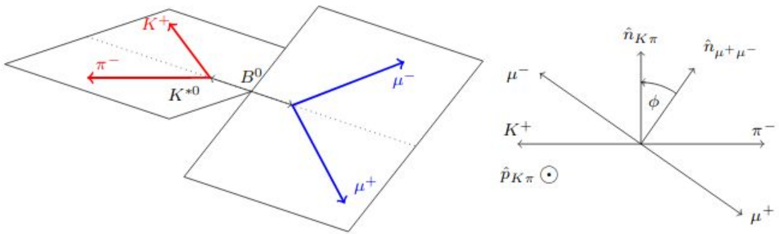
$$R_H = \frac{\int \frac{d\Gamma(B \to H \mu^+ \mu^-)}{dq^2} dq^2}{\int \frac{d\Gamma(B \to H e^+ e^-)}{dq^2} dq^2}$$

$$R_{K^{*0}} = \frac{\mathcal{B}(B^0 \to K^{*0} \mu^+ \mu^-)}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to \mu^+ \mu^-))} \Bigg/ \frac{\mathcal{B}(B^0 \to K^{*0} e^+ e^-)}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to e^+ e^-))}$$

More Complicated: Angular Distributions



(a) θ_K and θ_ℓ definitions for the B^0 decay



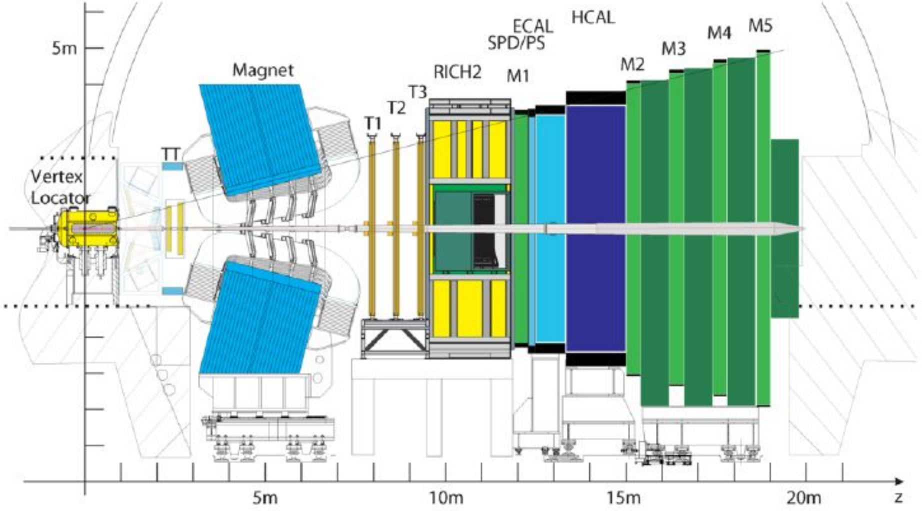
(b) ϕ definition for the B^0 decay

- Differential decay rates with respect to three angles
- Decay rates are sum of angular observables times function of angles
- Observables are in turn functions of 6 bilinears of amplitudes
- And on and on….
- Complicated but also shows interesting results also (more later)

https://arxiv.org/pdf/1304.6325.pdf

The LHCb Experiment

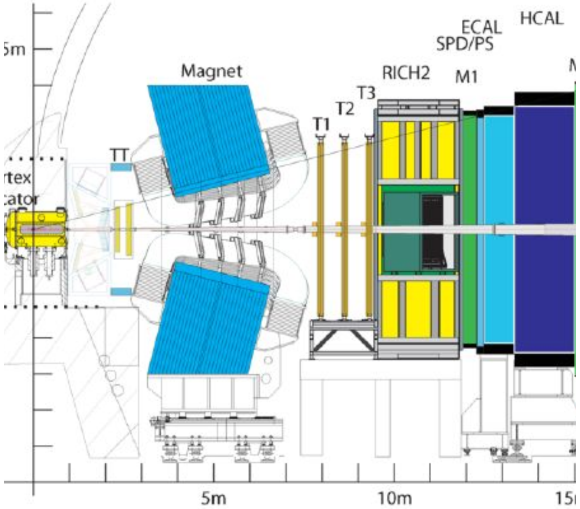
- Forward detector
- Strong vetexing
    - Si pixels and strips + Drift tubes
- Excellent particle ID
    - Two RICH Detectors
- Calorimetry
    - Hadronic and EM
- Muon System



LHCb Detector

Electron Reconstruction Issues

- Muons: Clean, easy, unique signature
- Electrons: the opposite
- Brem before or after magnet
    - After magnet: all energy in 1 Calo cell
    - Before magnet: combine cells
- Additional issues from adding cells
    - background contamination, loss of signal, decreased mass resolution

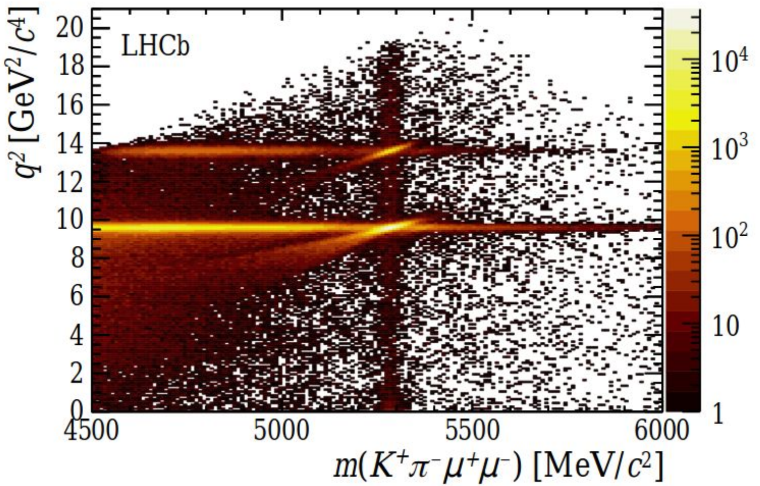


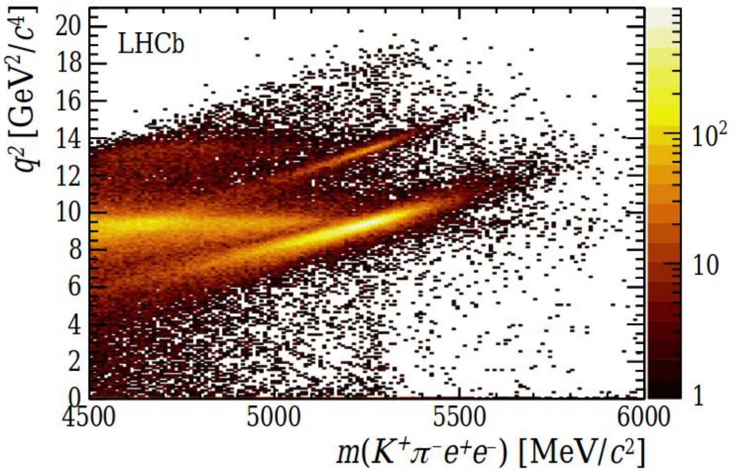
Event Selection

Def: M = inv. Mass of system

q = inv. Mass of leptons

- Common vertex
- ee(**$\mu\mu$**) p_T > 500 (800) MeV
- $K^+\pi^-$ p_T > 250 MeV
  - M within 100 MeV of K^{*0}
- Displaced vertex
- Collinear p with decay





Backgrounds: Combinatorial and Exclusive

Combinatorial

- Discrimination by neural network classifier
- Trained on simulation (with corrections to conform to data)
- Every momentum, angle, vertex fit used as input

Exclusive

- Misreconstructed charmonium resonances
  - Small enough to neglect
- B^0 mesons to light vector mesons
  - Mass restriction on hadron + muon
- $B^0 \longrightarrow D^- l^+ \nu \longrightarrow K^{*0} l^- \nu$
  - Rejected using dilepton angles

Fits to the Spectrum and Yields

	$B^0 \to K^{*0}\ell^+\ell^-$		$B^0 \to K^{*0}J/\psi\,(\to \ell^+\ell^-)$
	low-q^2	central-q^2	
$\mu^+\mu^-$	$285\,^{+\,18}_{-\,18}$	$353\,^{+\,21}_{-\,21}$	$274416\,^{+\,602}_{-\,654}$
e^+e^- (L0E)	$55\,^{+\,9}_{-\,8}$	$67\,^{+\,10}_{-\,10}$	$43468\,^{+\,222}_{-\,221}$
e^+e^- (L0H)	$13\,^{+\,5}_{-\,5}$	$19\,^{+\,6}_{-\,5}$	$3388\,^{+\,62}_{-\,61}$
e^+e^- (L0I)	$21\,^{+\,5}_{-\,4}$	$25\,^{+\,7}_{-\,6}$	$11505\,^{+\,115}_{-\,114}$

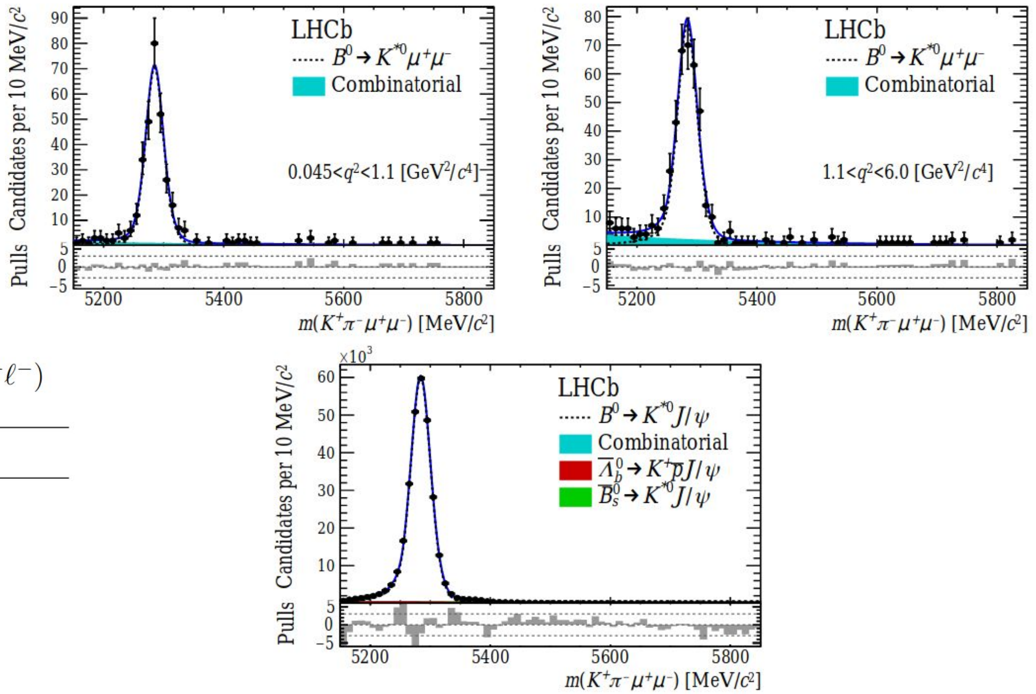


Figure 6: Fit to the $m(K^+\pi^-\mu^+\mu^-)$ invariant mass of (top) $B^0 \to K^{*0}\mu^+\mu^-$ in the low- and central-q^2 bins and (bottom) $B^0 \to K^{*0}J/\psi\,(\to \mu^+\mu^-)$ candidates. The dashed line is the signal PDF, the shaded shapes are the background PDFs and the solid line is the total PDF. The fit residuals normalised to the data uncertainty are shown at the bottom of each distribution.

Cross Checks

Of two kinds

- Not subject to cancellation

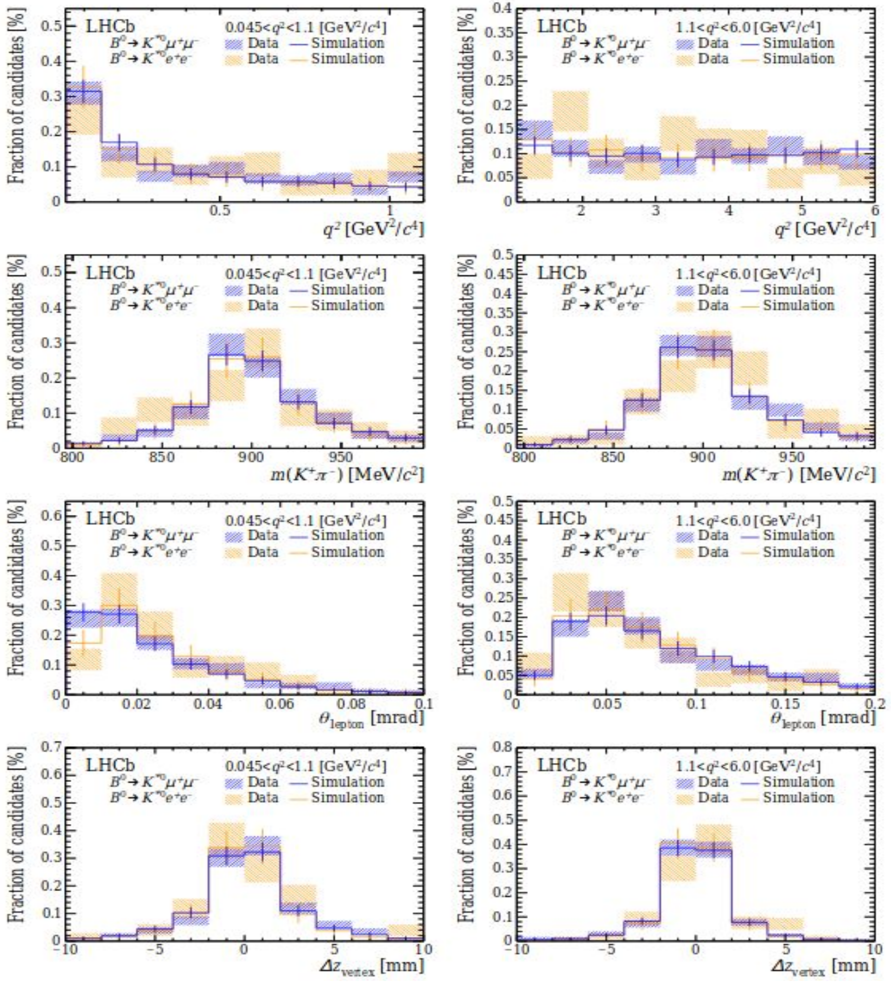
$$r_{J/\psi} = \frac{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to \mu^+\mu^-))}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to e^+e^-))}$$

= ~1

- Subject to the cancellation

$R_{\psi(2S)}$ (ratio of ψ(2S) to J/ψ) =~1

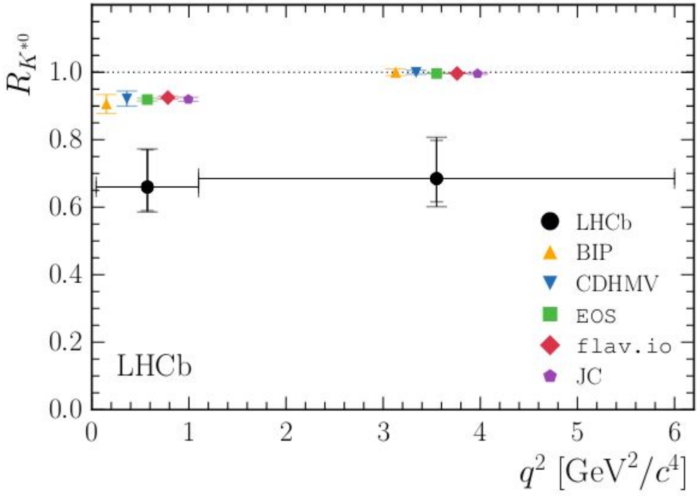
- Additional Kinematics checks
- Etc.

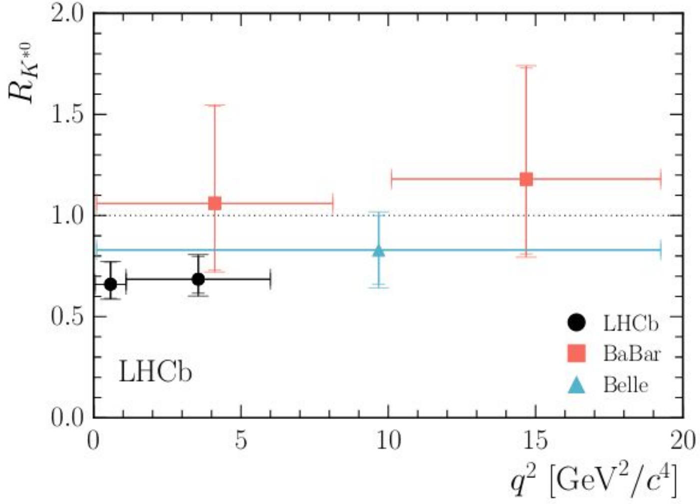


Results: 2017

	low-q^2	central-q^2
$R_{K^{*0}}$	$0.66\ ^{+\ 0.11}_{-\ 0.07} \pm 0.03$	$0.69\ ^{+\ 0.11}_{-\ 0.07} \pm 0.05$
95.4% CL	$[0.52, 0.89]$	$[0.53, 0.94]$
99.7% CL	$[0.45, 1.04]$	$[0.46, 1.10]$

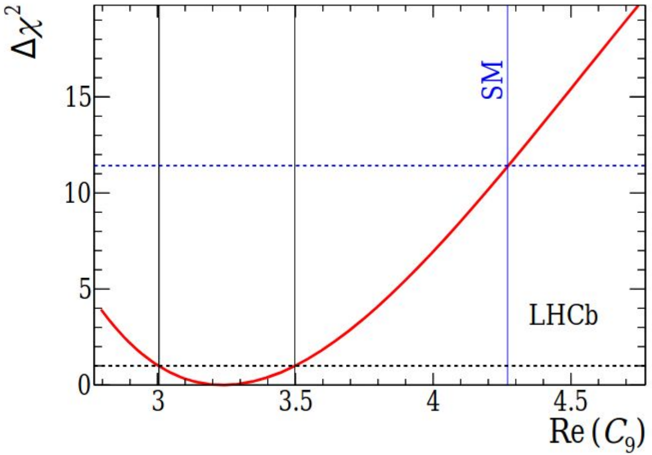
Big If True!

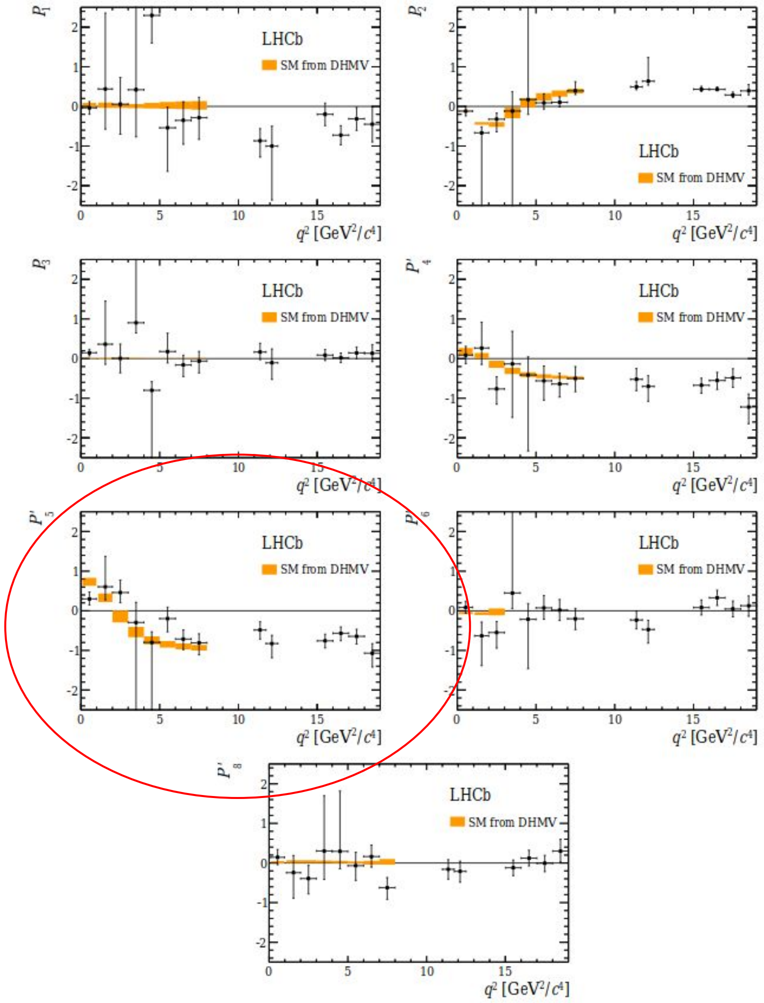




Angular Analysis Results

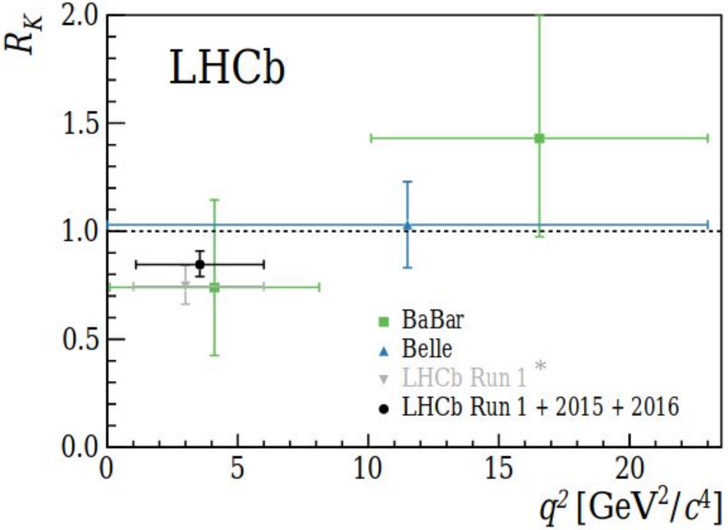
- See paper for full details:
  - https://arxiv.org/pdf/1304.6325.pdf
- Discrepancy in P'_5: 3.4σ
- Possible Unexpectedly large hadronic effect … or BSM





Other Results as of 2019

- When do we celebrate the BSM era?
- Look at results in other, similar channels
- $B \rightarrow K^+ l^+ l^-$ done in 2014 and 2019
- Shows a similar tension



2014 Result:

$$R_K = 0.745 \,^{+0.090}_{-0.074}\,(\text{stat}) \,\pm 0.036\,(\text{syst})$$

2019 Result:

$$R_K = 0.846 \,^{+0.060}_{-0.054}\,^{+0.016}_{-0.014}$$

Conclusions

- Lots of interesting results that merit further study
- Questions about hadronic uncertainties remain
- Bad: Deviation from SM goes down with more data
- Good: Different measurements across different channels show same sign discrepancy
- Bad: Possibility of systematic, experiment wide issue
- Good: Stringent cross checks
- Inconclusive, worth following