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Angular Analysis of $B^0 \to K^{*0}\mu^+\mu^-$ at LHCb

Felix Kress, on behalf of the LHCb collaboration

IoP joint HEPP and APP annual conference 2019

9th of April 2019

Rare Decays of b hadrons: $b \to s\ell^+\ell^-$

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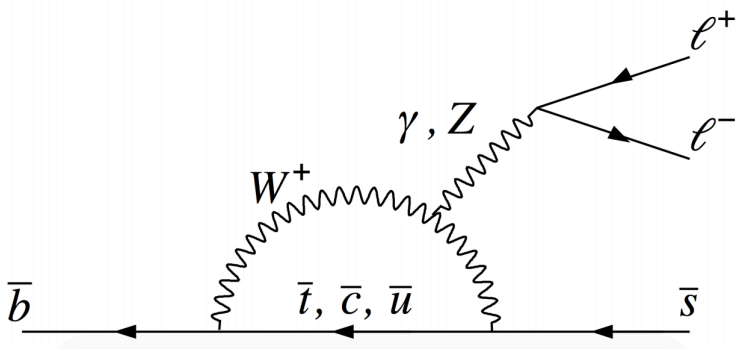
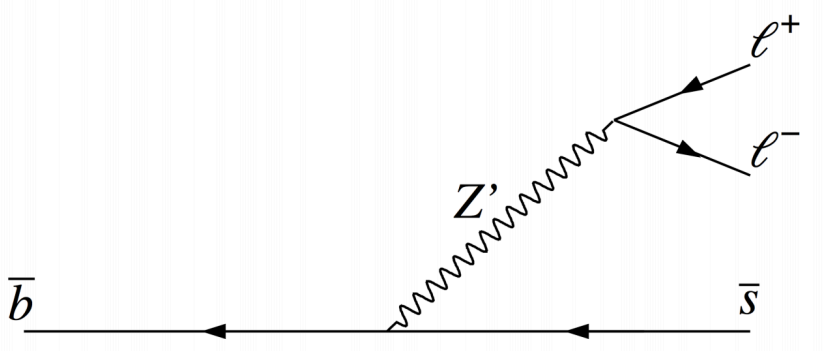
- Proceeds via a flavour changing neutral current transition
- Forbidden at tree level in the SM
- Can only occur at lowest order via electroweak penguin and box diagrams
- New Physics could already appear at tree level
- Sensitive to new particles at higher energy scales than direct searches



SM loop level diagram

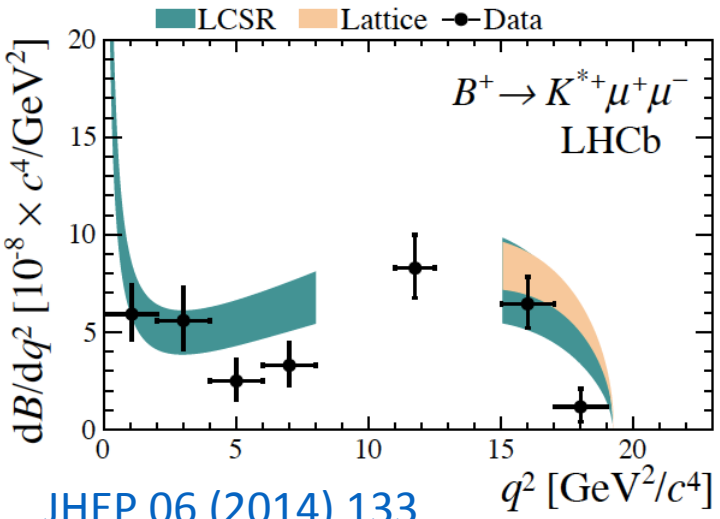


New Physics tree level diagram

Experimental status of $b \to s\ell^+\ell^-$

Three different types of measurements:

1.) Branching fractions: suffer from form factor and hadronic uncertainties



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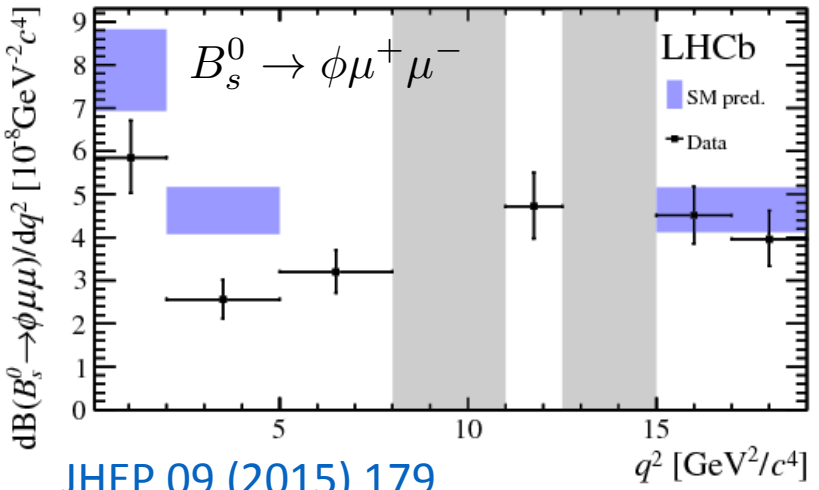

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2.) Angular analysis:

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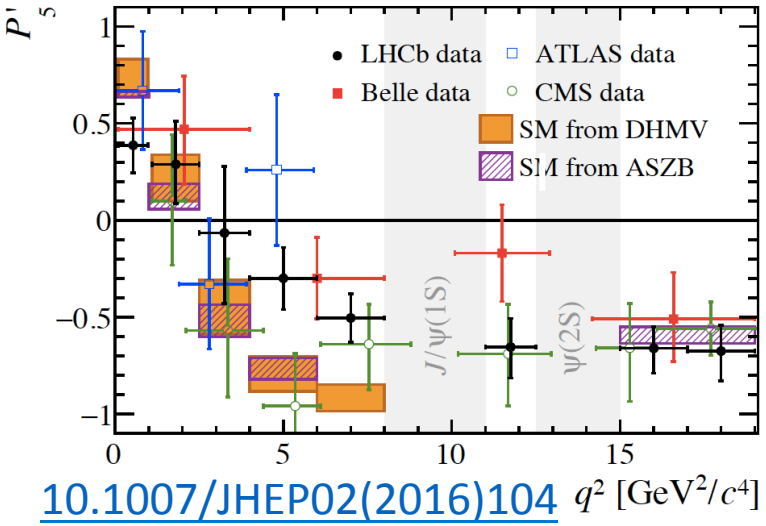
- local tensions of 2.8σ and 3.0σ observed in 4th and 5th q^2 bins
- vigorous debate about theory control of hadronic uncertainties (see Malte Hecker's talk)



10.1007/JHEP02(2016)104

Experimental status of $b \to s\ell^+\ell^-$

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3.) Branching fraction ratios: theoretically pristine, all hadronic effects cancel

$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)} \overset{\text{SM}}{=} 1.0$$

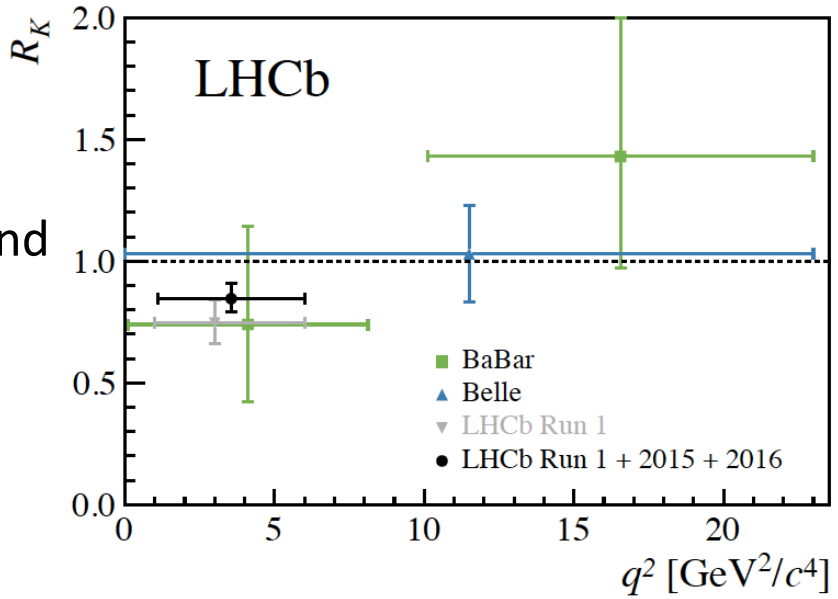
Any statistically significant deviation of these ratios from 1 is a sign of New Physics

LHCb: https://arxiv.org/abs/1903.09252
Belle: PRL103(2009)171801
BaBar: PRD86(2012)032012

Most recent LHCb result presented at Moriond EW including Run 1 + 2015 + 2016 data:

$$\boldsymbol{R_K = 0.846\ ^{+0.060}_{-0.054}(\text{stat.})\ ^{+0.016}_{-0.014}(\text{syst.})}$$

$1.0 < q^2 < 6.0\ \text{GeV}^2 \sim \mathbf{2.5}\,\boldsymbol{\sigma}$ from SM.



Discrepancy at the level of 2σ also present for R_{K^*} (driven by LHCb result JHEP08(2017)055)

Most recent result by Belle (https://arxiv.org/abs/1904.02440)

Theoretical interpretation of $b \to s\ell^+\ell^-$

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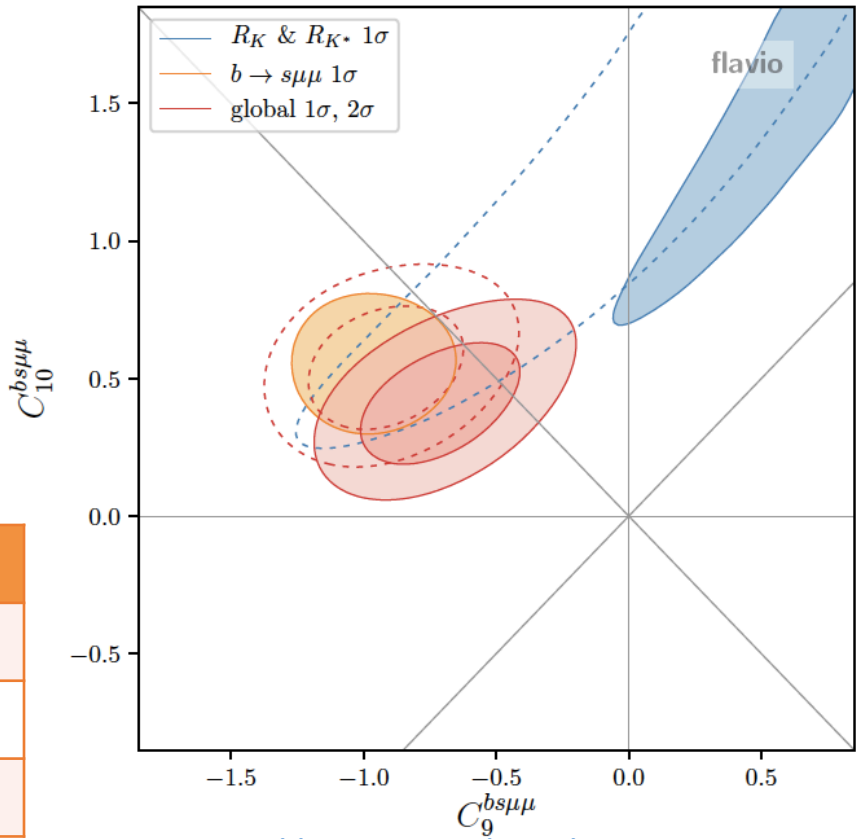
- Model independent description: Operator Product Expansion

$$H_{eff} \propto \sum_i \left(C_i^{SM} + C_i^{NP} \right) \cdot O_i$$

- Wilson coefficients (C_i) are extracted from global fits to data
- Any deviations from SM calculations would point to New Physics effects

- C_9: vector coupling
- C_{10}: axial vector coupling
- Plot shows one of the most recent global fits to data
- $b \to s\ell^+\ell^-$ experimental results can be interpreted in a coherent way



https://arxiv.org/pdf/1703.09189.pdf

Coeff. varied	Best fit	Pull from SM
$C_9^{NP} = -C_{10}^{NP}$	-0.53	6.5 σ
C_9^{NP}	-0.95	5.8 σ
C_{10}^{NP}	+0.73	5.6 σ

Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

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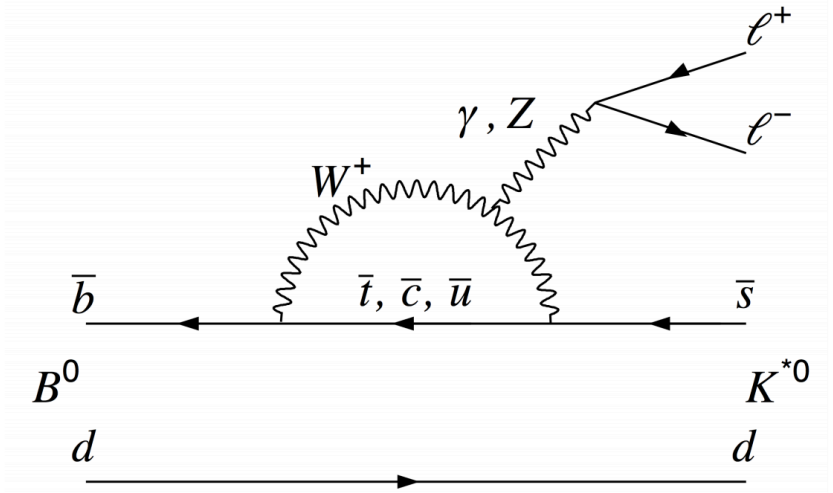
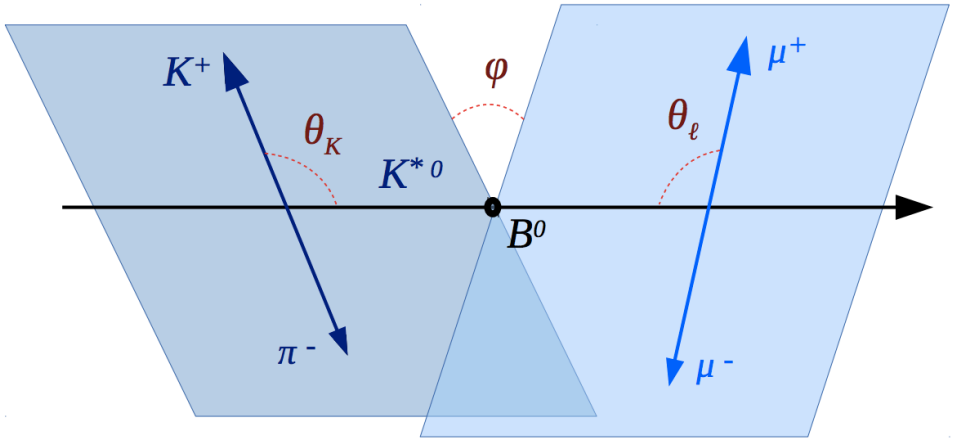
- Angular distribution is a function of q^2, the invariant mass squared of the dimuon system and $\vec{\Omega} = (\cos(\theta_l), \cos(\theta_K), \phi)$





$$\frac{\mathrm{d}^4\bar{\Gamma}[B^0 \to K^{*0}\mu^+\mu^-]}{\mathrm{d}q^2\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\sum_i \bar{I}_i(q^2) f_i(\vec{\Omega})$$

- In order to extract the angular observables a fit to the three angles, $m_{K\pi\mu\mu}$ and $m_{K\pi}$ is performed in bins of q^2

Update Strategy

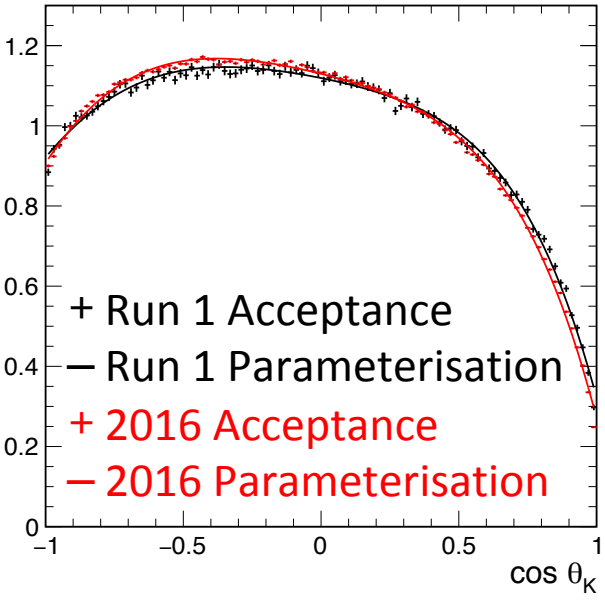
- Use 3 fb^{-1} of Run 1 data + add 1.7 fb^{-1} of 2016 data:
  ≈ double the events
- As in last analysis, use maximum likelihood fit to extract observables in bins of q^2
- Perform simultaneous fit to Run 1 and 2016
- Use corrected simulation to model efficiencies

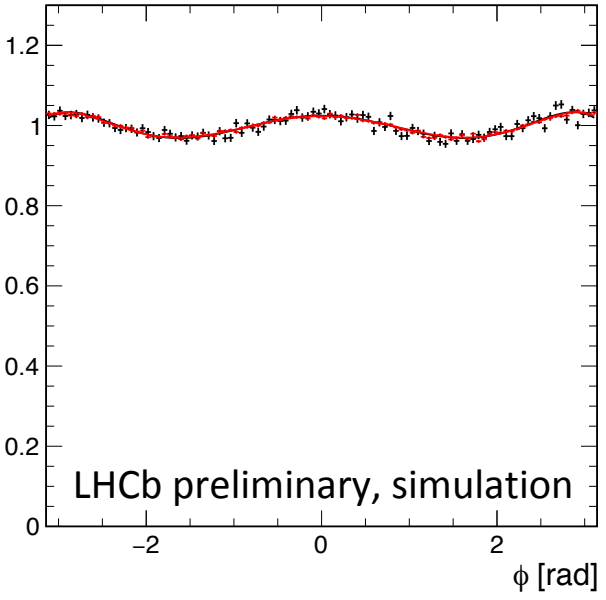
Acceptance

- Angular distribution is distorted due to detector effects, reconstruction and selection − acceptance effects

$$\frac{\mathrm{d}^4\bar{\Gamma}[B^0 \to K^{*0}\mu^+\mu^-]}{\mathrm{d}q^2\mathrm{d}\vec{\Omega}}(\text{observed}) = \varepsilon \frac{\mathrm{d}^4\bar{\Gamma}[B^0 \to K^{*0}\mu^+\mu^-]}{\mathrm{d}q^2\mathrm{d}\vec{\Omega}}(\text{physical})$$

- Use simulation to model efficiency correctly:
  1.) Simulation needs to model data correctly
  2.) Parameterise efficiency to implement in fit





Expected sensitivity & status of analysis

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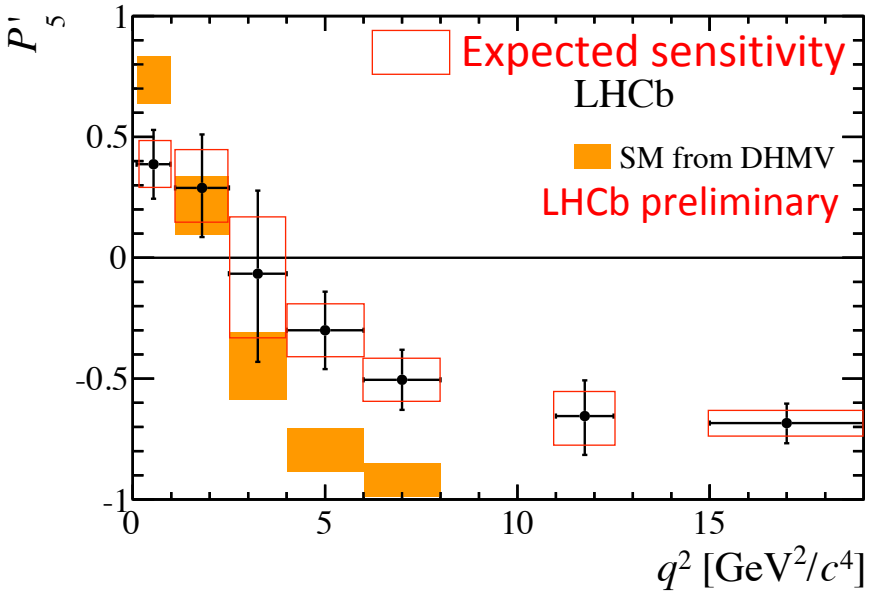
- Adding 2016 data to Run 1 results in doubling the events: expected reduction of uncertainty ≈ √2 (measurement statistically dominated + reduction in systematics)



- Currently results are still blinded
- Used the control channel $B^0 \to K^* J/\psi$ to perform main cross checks
- Validated simultaneous fit using the control channel, as well as performing toy studies for $B^0 \to K^{*0}\mu^+\mu^-$
- Main systematic studies have been performed, dominant uncertainty will still be statistical

Conclusion and Outlook

- $b \to s\ell^+\ell^-$ decays hint at discrepancies with predictions of the SM
- Observations can be interpreted in a coherent way in New Physics models by introducing a new (axial-)vector particle such as a Z' or a leptoquark
- It is extremely important to update the $B^0 \to K^{*0}\mu^+\mu^-$ experimental results in order to establish clarity
- The update of the binned angular analysis with a simultaneous fit to Run 1 and 2016 data is in a very good state
- Stay tuned for updated results!

Backup

q^2 bins

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Bin	q^2 range $[\mathrm{GeV}^2/c^4]$
1	$[0.1, 0.98]$
2	$[1.1, 2.5]$
3	$[2.5, 4.0]$
4	$[4.0, 6.0]$
5	$[6.0, 8.0]$
6	$[11.0, 12.5]$
7	$[15.0, 17.0]$
8	$[17.0, 19.0]$
9	$[1.1, 6.0]$
10	$[15.0, 19.0]$

Experimental status of $b \to s\ell^+\ell^-$

3.) Branching fraction ratios: theoretically pristine, all hadronic effects cancel

$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)} \overset{\text{SM}}{=} 1.0$$

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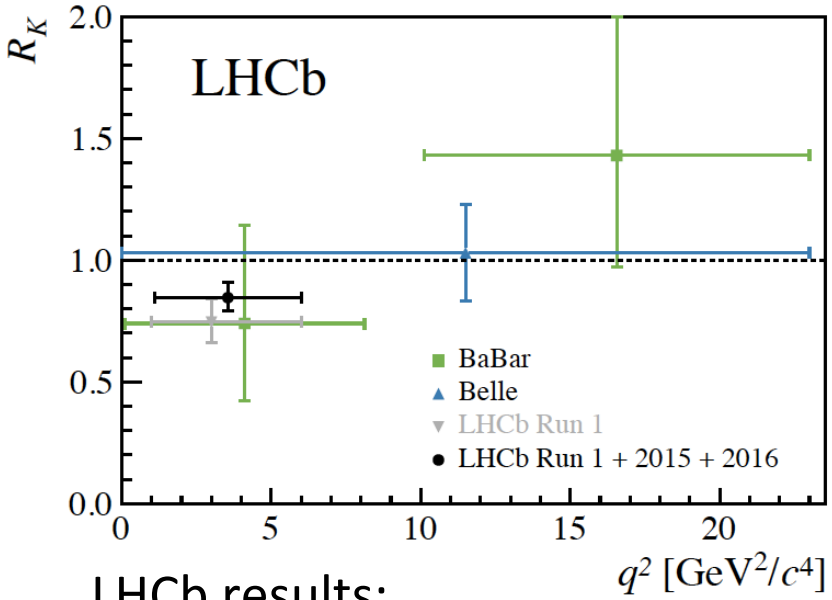

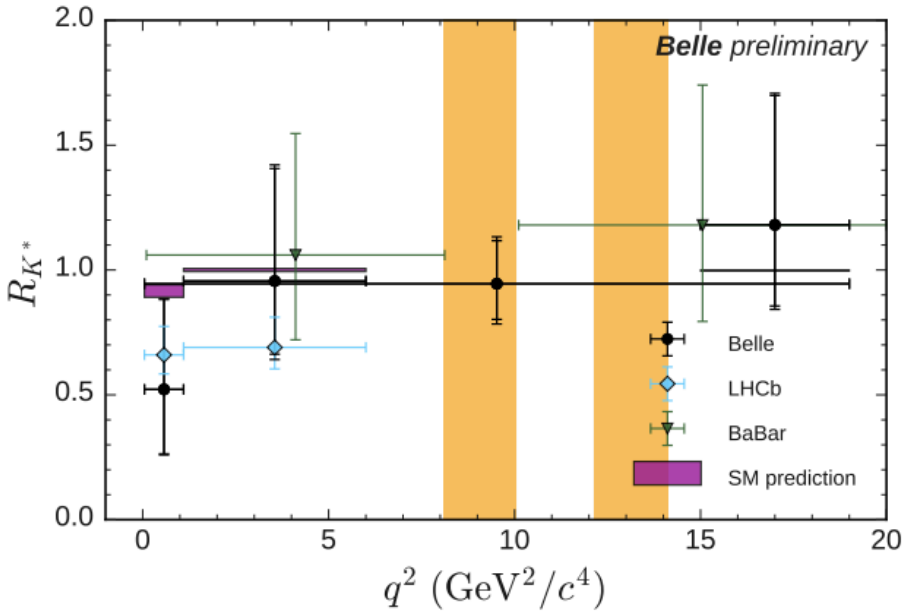

LHCb results:

$R_{K^*} = 0.66^{+0.11}_{-0.07} \pm 0.03$ for $0.045 < q^2 < 1.1$ GeV^2, $\sim 2.2\,\sigma$ from SM;

$R_{K^*} = 0.69^{+0.11}_{-0.07} \pm 0.05$ for $1.1 < q^2 < 6.0$ GeV^2, $\sim 2.4\,\sigma$ from SM;

Most recent result presented at EW Moriond including Run 1 + 2015 + 2016 data:

$$\boldsymbol{R_K = 0.846}\ ^{+0.060}_{-0.054}(\text{stat.})\ ^{+0.016}_{-0.014}(\text{syst.})$$

$1.0 < q^2 < 6.0$ GeV^2

$\sim \mathbf{2.5}\,\boldsymbol{\sigma}$ from SM.

Slide from Thibaud's talk at Moriond EW

Branching fractions and other results LHCb-Paper-2019-009

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If instead the Run 1 and Run 2 were fitted separately:

$$R^{\text{new}}_{K\ \text{Run 1}} = 0.717^{+0.083+0.017}_{-0.071-0.016}, \qquad R_{K\ \text{Run 2}} = 0.928^{+0.089+0.020}_{-0.076-0.017},$$
$$R^{\text{old}}_{K\ \text{Run 1}} = 0.745^{+0.090}_{-0.074} \pm 0.036 \quad \text{(PRL113(2014)151601)},$$

Compatibility taking correlations into account:

- Previous Run 1 result vs. this Run 1 result (new reconstruction selection): $< 1\ \sigma$;
- Run 1 result vs. Run 2 result: $1.9\ \sigma$.

$B^+ \to K^+\mu^+\mu^-$ branching fraction:

- Compatible with previous result (JHEP06(2014)133) at $< 1\ \sigma$;
- Run 1 and Run 2 results compatible at $< 1\ \sigma$.

$B^+ \to K^+e^+e^-$ branching fraction:

$$\frac{\mathrm{d}\mathcal{B}(B^+ \to K^+e^+e^-)}{\mathrm{d}q^2}(1.1 < q^2 < 6.0\ \text{GeV}^2) = (28.6^{+2.0}_{-1.7} \pm 1.4) \times 10^{-9}\ \text{GeV}^{-2}$$

http://moriond.in2p3.fr/2019/EW/Program.html

Experimental status of $b \to s\ell^+\ell^-$

Three different types of measurements:

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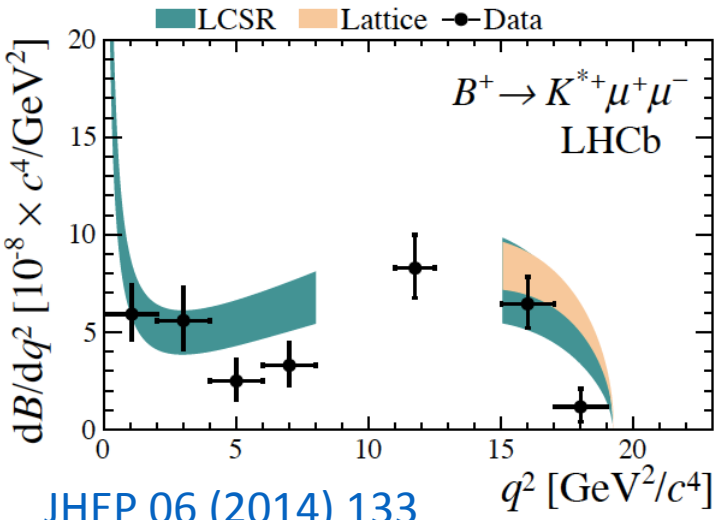

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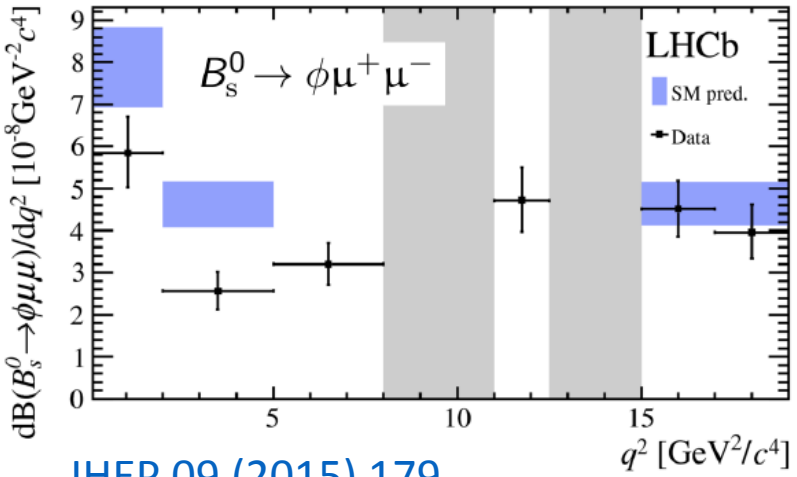

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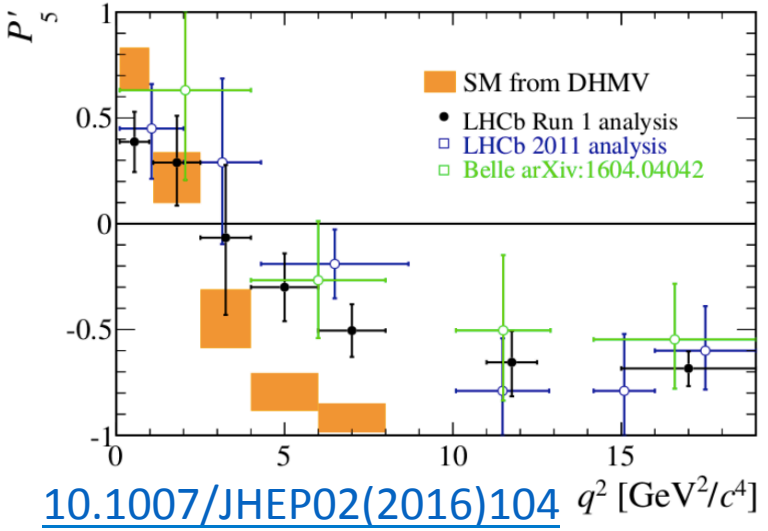

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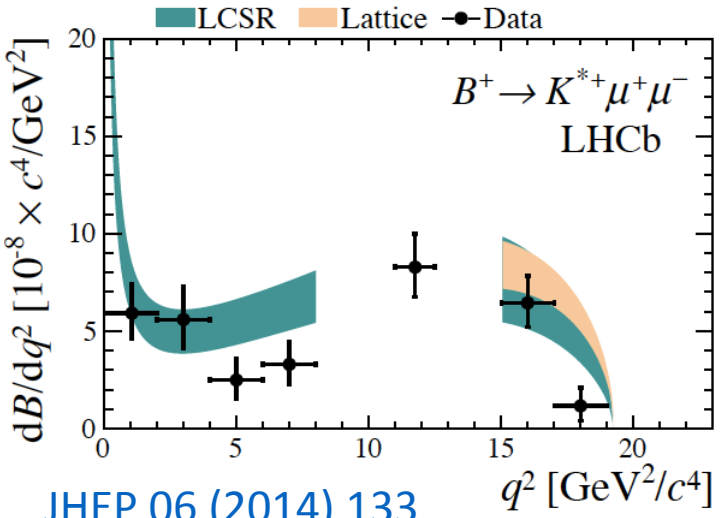

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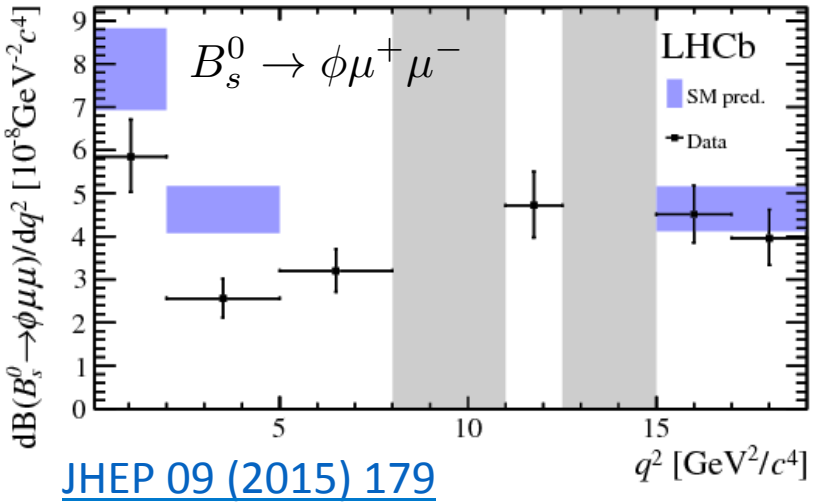

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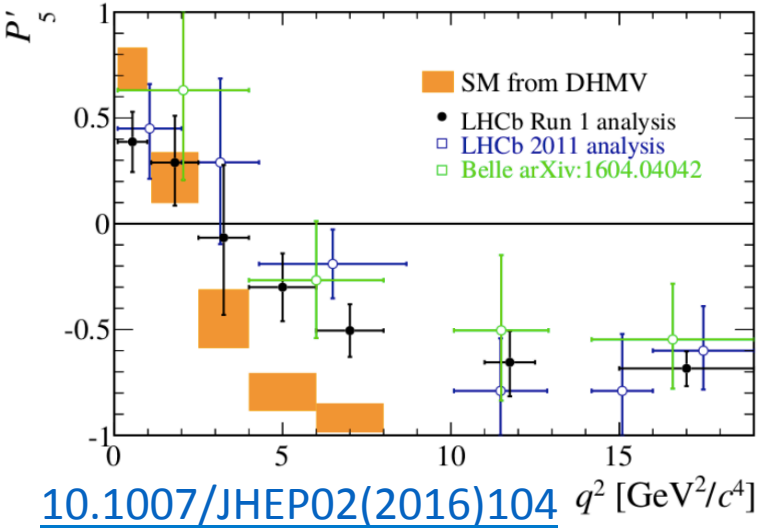

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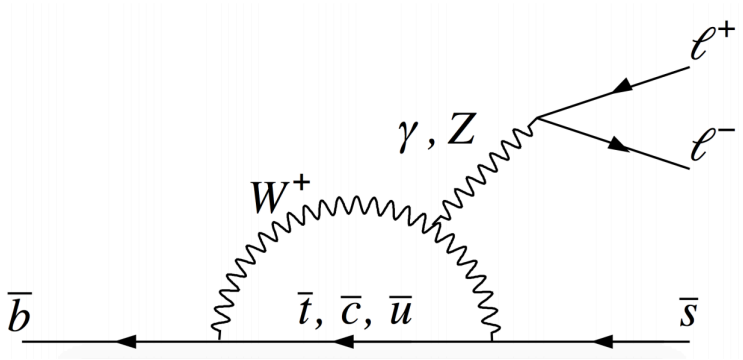

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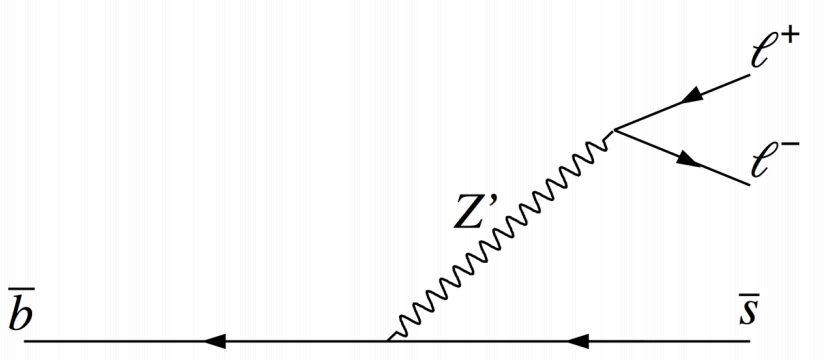

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