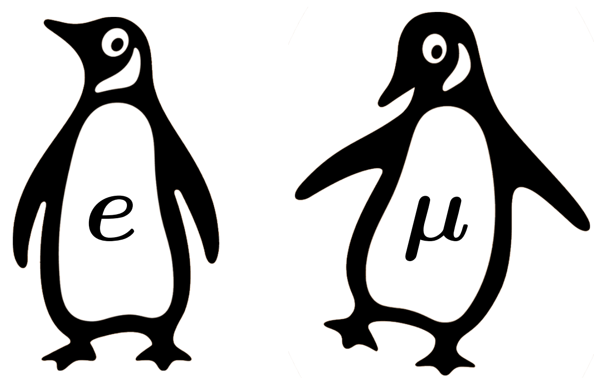
Measurement of $\mathcal{R}_K$ and future plans for LHCb



"Rare B decays in 2015 - experiment and theory"
Edinburgh - 12/05/2015

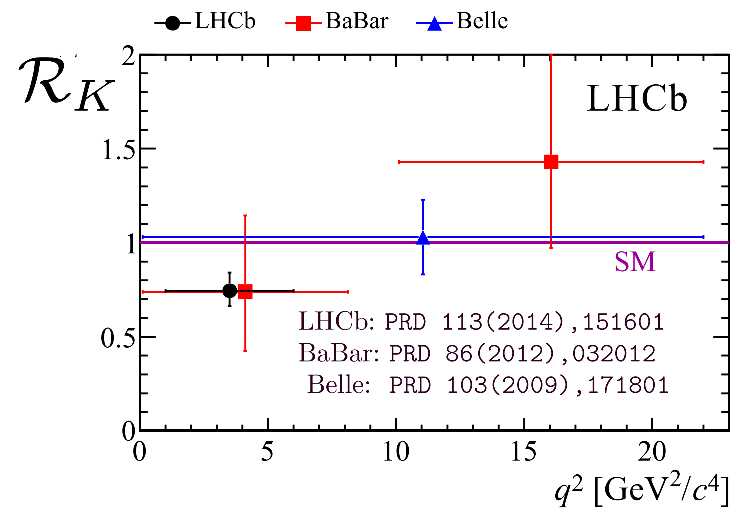
Martino Borsato - LAL (Orsay)

Introduction

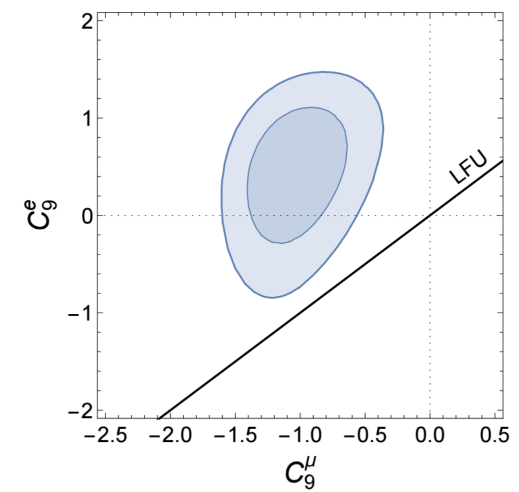
- There's space for BSM giving lepton non-universality in $b \to s\ell\ell$ decays
  $\to$ see talks after lunch
- $\mathcal{R}_K$ showed large deviation from 1, but "only" 2.6 σ significance

$$\mathcal{R}_K = 0.745^{+0.090}_{-0.074} \pm 0.036$$

- impossible to explain with hadronic effects
- it corresponds to the effect one would expect if $B^0 \to K^{*0}\mu^+\mu^-$ tensions were due to NP involving only muons



[Straub - Moriond2015]

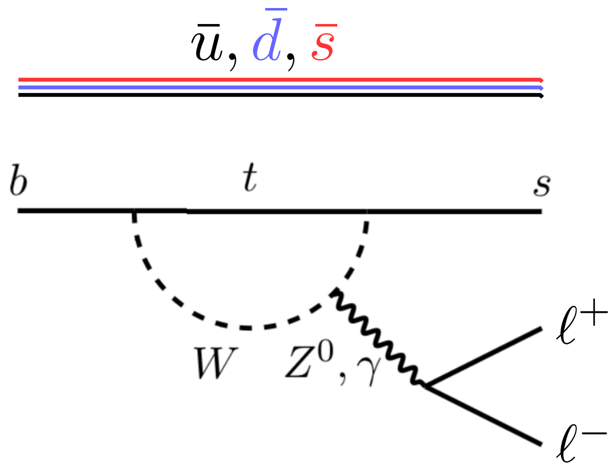


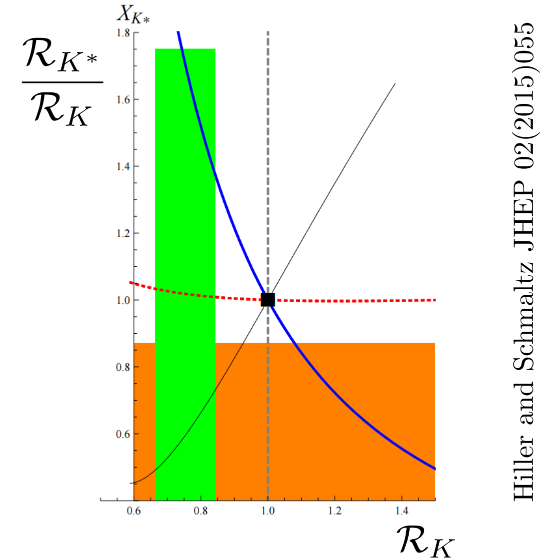
Follow-up measurements

- Other lepton universality tests on bsll can help to clarify the picture
- LHCb plans several follow-up measurements → suggestions and discussion are welcome (main purpose of this talk)
- Vector channels (K^{*0}, ϕ) can help disentangling NP contributions (see talks later)

Becirevic, Fajfer Kosnik arXiv:1503.09024
Hiller and Schmaltz JHEP 02(2015)055

- What about LFU tests with Λ_b baryons?



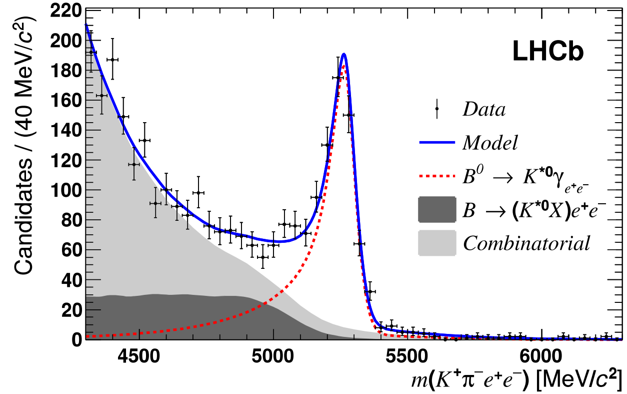


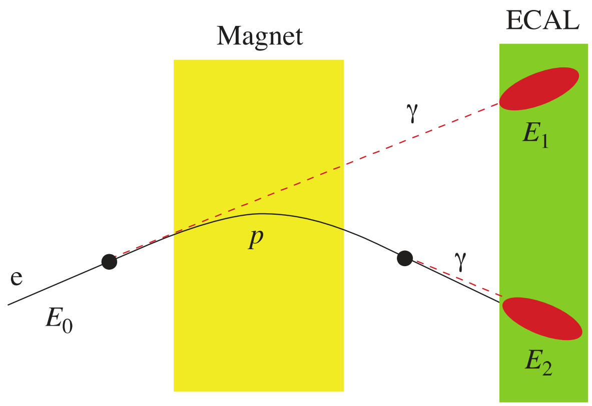
electrons in LHCb

- **LHCb is far better with muons ...**
- **Trigger**, reconstruction, selection and PID are harder with electrons
- Mass resolution affected by very difficult **bremmstrahlung recovery**
- Model mass shape according to number of brem photons recovered

$B^0 \to K^{*0}\gamma$ with conv. to e^+e^-

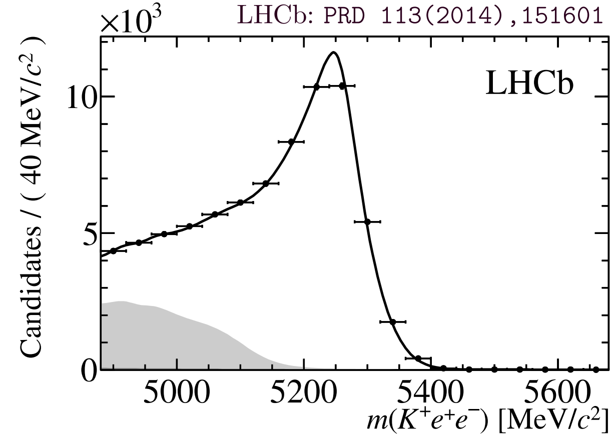
LHCb: JHEP 1504 (2015) 064





$B^0 \to K^{*0} J/\psi$ with $J/\psi \to e^+e^-$

LHCb: PRD 113(2014),151601

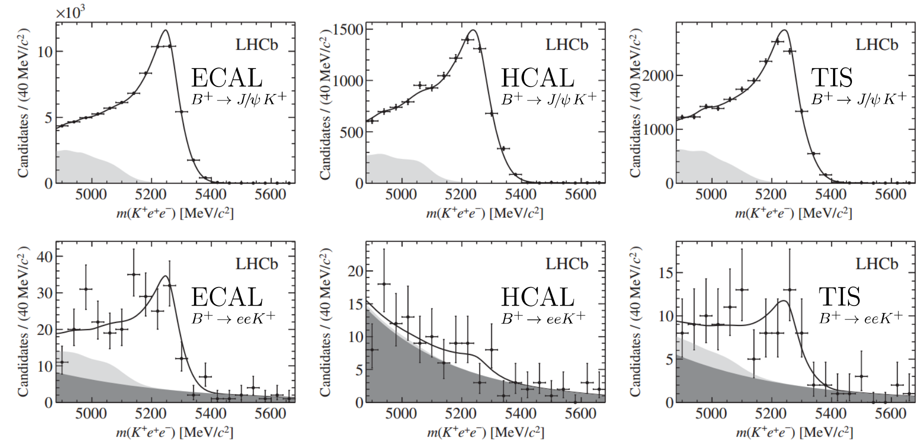


electrons in LHCb

- Complementary way to trigger the event:
  - high p_T electrons on ECAL (high q^2)
  - high p_T hadron on HCAL (low q^2)
  - trigger on other particle (q^2 indep.)

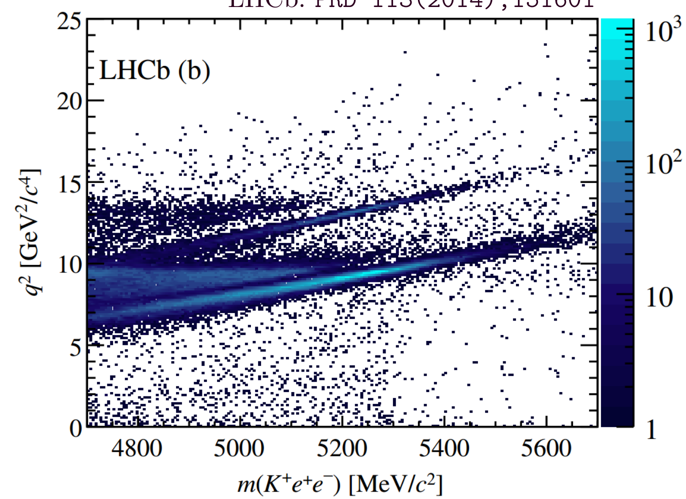
$\Rightarrow$ threated separately in the analysis (different efficiencies and mass shapes)

LHCb: PRD 113(2014).151601



- Bremmstrahlung tail $\Rightarrow$ q^2 definition
  - leakage of resonances at lower q^2 $\to$ cannot go too close
  - q^2 resolution is asymmetric:
    - $*$ correct bin migration ($\mathcal{R}_K$)
    - $*$ define effective bin shifted higher ($B^0 \to K^{*0} e^+ e^-$ ang. ana.)

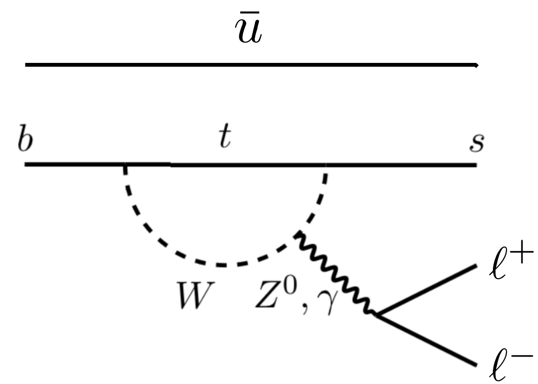
LHCb: PRD 113(2014),151601



$\mathcal{R}_K$ measurement at LHCb

LHCb: PRD 113(2014),151601

$$\mathcal{R}_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to K^+ e^+ e^-)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$



- measurement with $3\,\mathrm{fb}^{-1}$ in bin $[1-6]\,\mathrm{GeV}^2/c^4$
- total $B^+ \to K^+ e^+ e^-$ yield of 264 events
  $\to$ drives the uncertainty on $\mathcal{R}_K$
- Use double ratio : $\mathcal{R}_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to K^+ J/\psi\,(\mu^+ \mu^-))} \frac{\mathcal{B}(B^+ \to K^+ J/\psi\,(e^+ e^-))}{\mathcal{B}(B^+ \to K^+ e^+ e^-)} =$

$$= \frac{N_{K^+\mu^+\mu^-}}{N_{K^+ J/\psi\,(\mu^+\mu^-)}} \frac{N_{K^+ J/\psi\,(e^+e^-)}}{N_{K^+e^+e^-}} \frac{\epsilon_{K^+ J/\psi\,(\mu^+\mu^-)}}{\epsilon_{K^+\mu^+\mu^-}} \frac{\epsilon_{K^+e^+e^-}}{\epsilon_{K^+ J/\psi\,(e^+e^-)}}$$

$\to$ cancel systematics

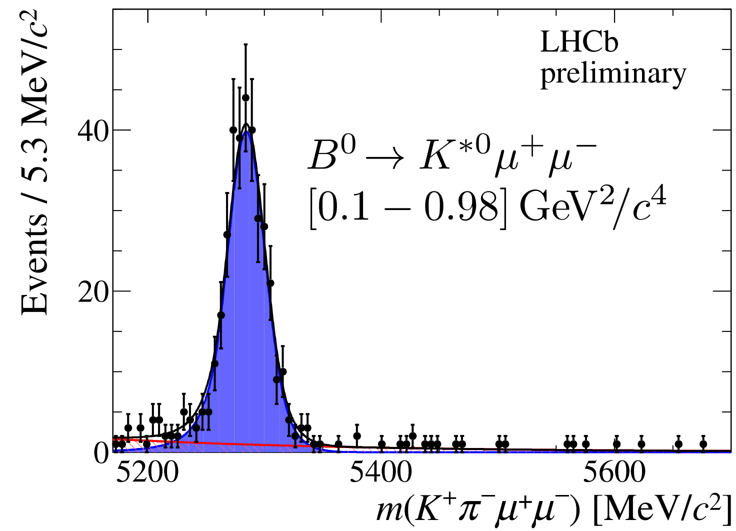
- all efficiencies are cross-checked on proxy $B^+ \to K^+ J/\psi\,(\ell^+ \ell^-)$
- q^2 dependence is modelled with MC (but J/ψ is close)

Future plans: $\mathcal{R}_{K^*}$

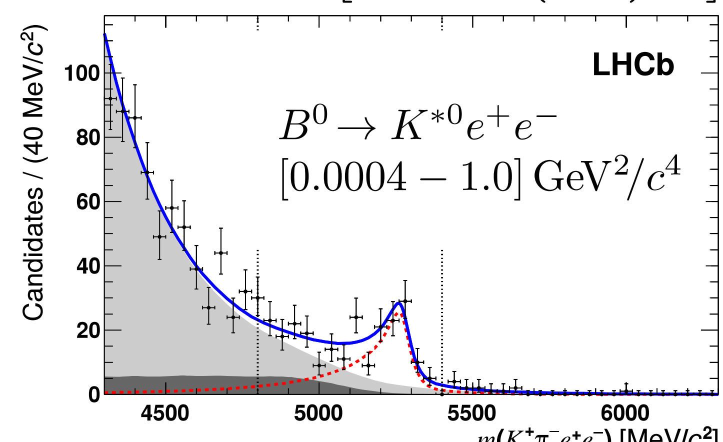
$$\mathcal{R}_{K^*} = \frac{\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{*0}e^+e^-)}$$

- Well-established experimental techniques from previous analyses: trigger, selection, mass fit, backgrounds, double ratio
- Optimized electron pre-selection: $\Rightarrow$ expect roughly same sensitivity as $\mathcal{R}_K$ measurement

[LHCb-CONF-2015-002]



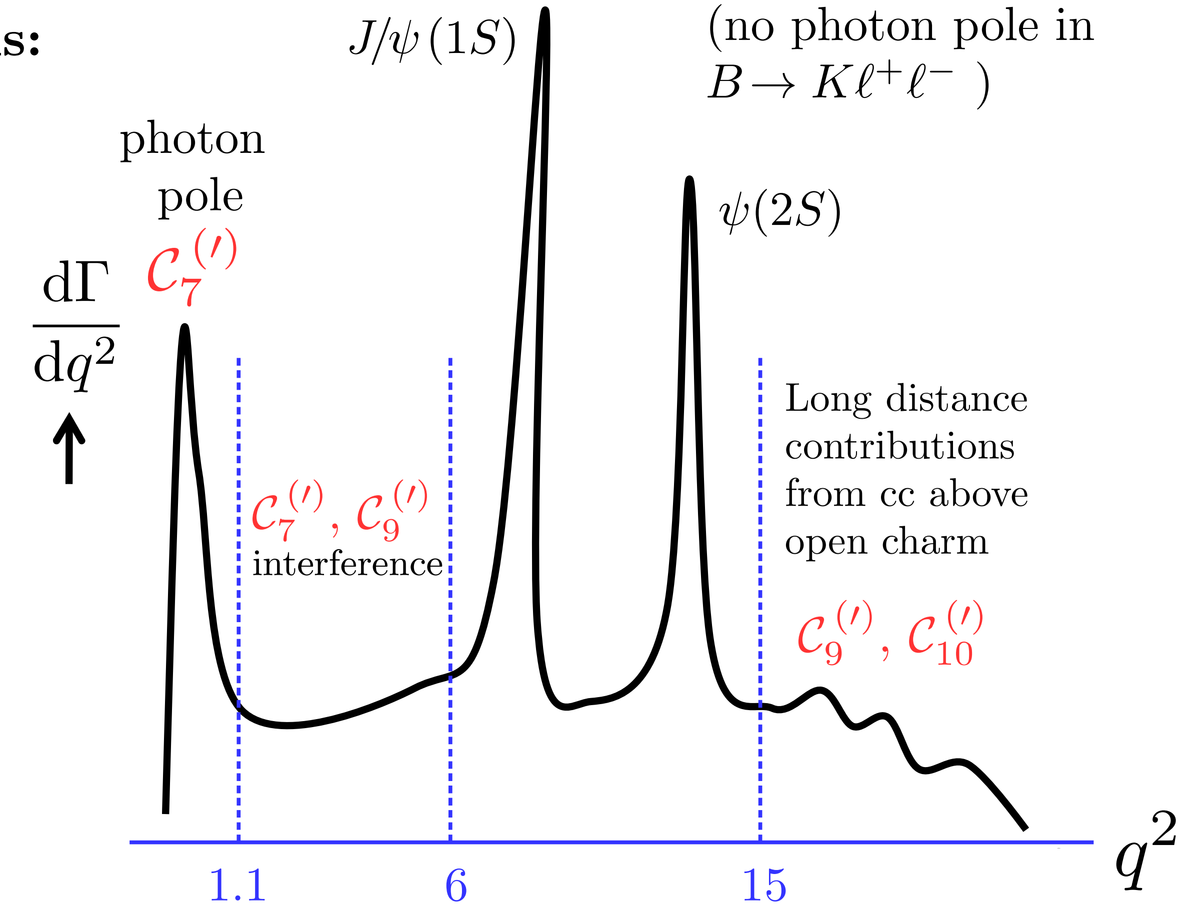
[JHEP 1504(2015)064]



Future plans: $\mathcal{R}_{K^*}$

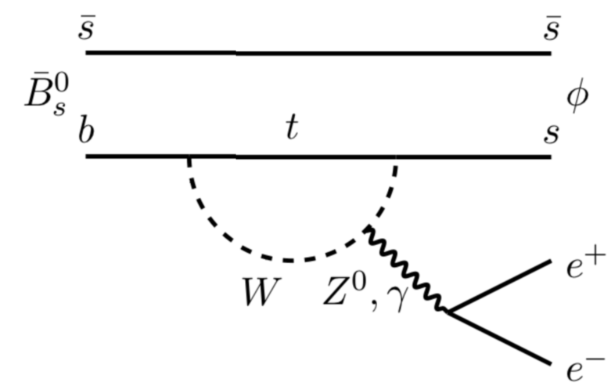
Plan to measure in 3 q^2 bins:

- [1.1-6] **favoured region**
  - Upper bound at 6 to avoid J/ψ radiative tail
- ["0"-1.1] lower q^2 bin
  - threshold for μμ
  - "0.0004" for ee
  - no NP expected here (C_7)
  - crosscheck of q^2 dependence
- [15-19] above charmonia
  - large background
  - large bremmstrahlung
  - have to deal with $\psi(2S)$



Future plans: $\mathcal{R}_\phi$

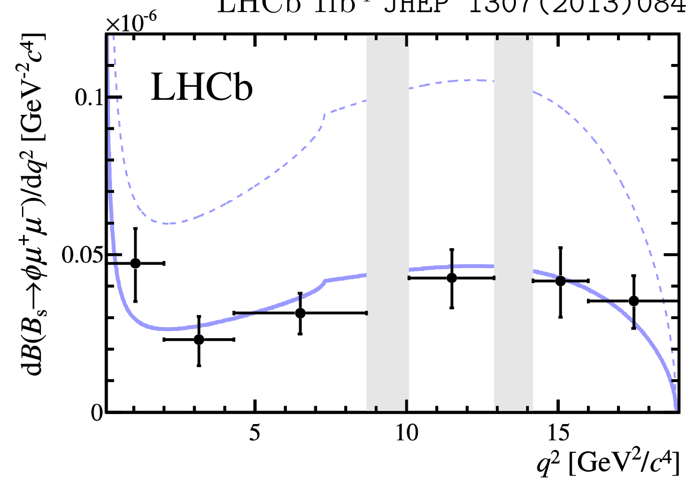
$$\mathcal{R}_\phi = \frac{\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-)}{\mathcal{B}(B_s^0 \to \phi e^+ e^-)}$$



Hiller and Schmaltz
JHEP 02(2015)055

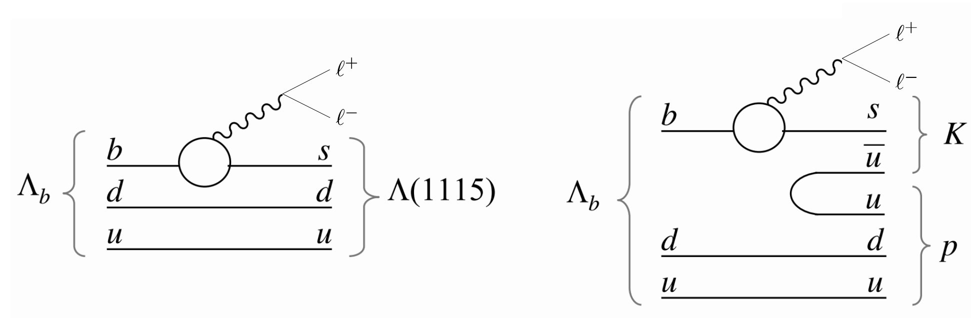
- same as $\mathcal{R}_{K^*}$, but with s-quark as spectator ($\mathcal{R}_{K^*} = \mathcal{R}_\phi$ is true at percent level)
- **pro**: narrow ϕ resonance allows cleaner selection (almost no part. reco. background)
- **con**: lower statistics due to f_s/f_d suppression
- **plan to measure in** $[1-6]\,\mathrm{GeV}^2/c^4$ **bin**
- higher q^2 bin $> 15\,\mathrm{GeV}^2/c^4$ is under discussion
- also considering bin below $1\,\mathrm{GeV}^2/c^4$

LHCb 1fb^{-1} JHEP 1307(2013)084



Future plans: $\mathcal{R}_{\Lambda^{(*)}}$?

$$\mathcal{R}_{\Lambda^{(*)}} = \frac{\mathcal{B}(\Lambda_b \to \Lambda^{(*)} \mu^+ \mu^-)}{\mathcal{B}(\Lambda_b \to \Lambda^{(*)} e^+ e^-)}$$

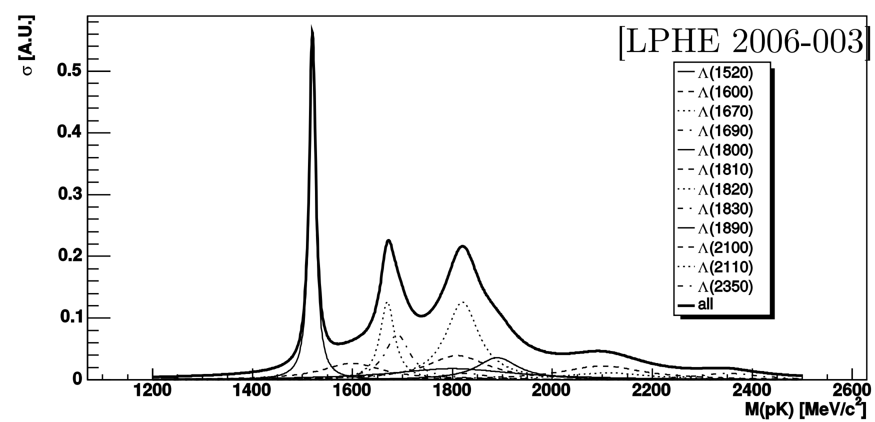


- **extend the lepton universality test to barions?**
- different spin-parity structure $J^P(\Lambda_b) = 1/2^+$
- $\Lambda \mu^+ \mu^-$ with long-lived $\Lambda \to p\pi$

q^2 interval $[\mathrm{GeV}^2/c^4]$	Total signal yield	Significance
$1.1 - 6.0$	9.4 ± 6.3	1.7
$15.0 - 20.0$	276 ± 20	21

LHCb: arXiv:1503.07138

$\Lambda_b \to \Lambda^*(pK)\gamma$ spectrum



- also $\Lambda^* \mu^+ \mu^-$ with prompt $\Lambda^* \to pK$
  - integrate over $m(pK)$?

Summary

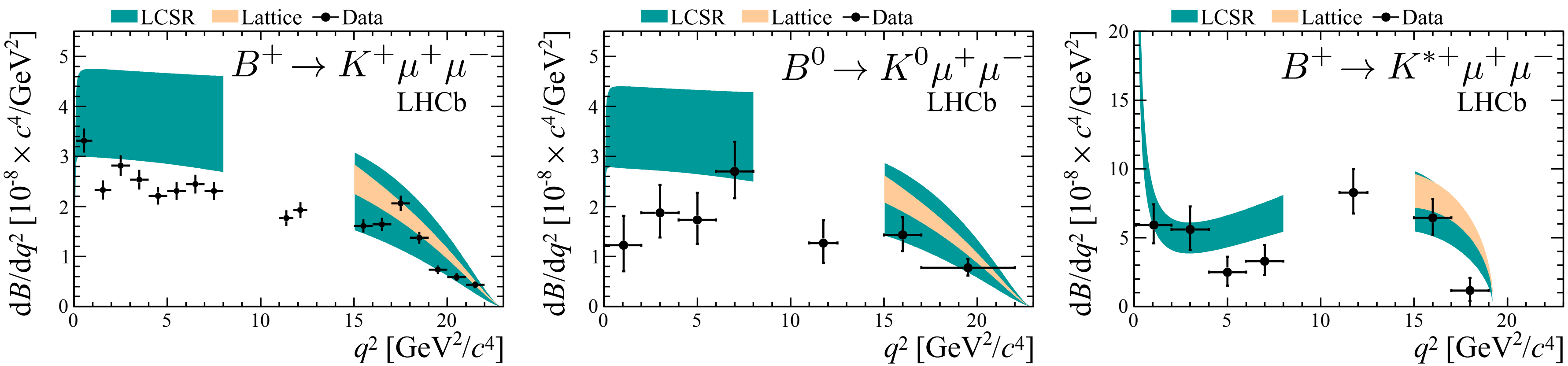
- $\mathcal{R}_K$ result is definitely interesting
- Measurements with electrons at LHCb are challenging
- nonetheless experimental techniques are progressing (and it's fun, after all...)
- LHCb is planning several follow-up measurements ($\mathcal{R}_{K^*,\phi,\Lambda^{(*)}}$)
- did not cover other related measurements like LFV searches
- Efforts ongoing to extract as much information as possible from LHCb Run 1 data with electrons
- more suggestions from theory are welcome

BACKUP

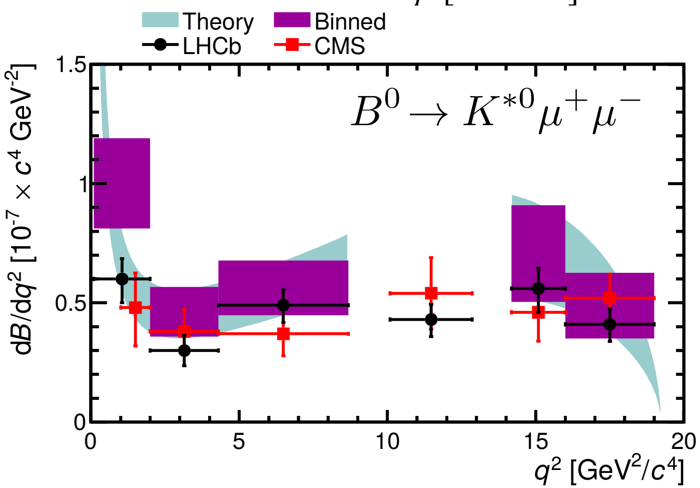
$b \to s\mu\mu$ branching fractions

- Mostly exclusive channels. LHC led to large yield increase
- BRs seem to lie below SM predictions independently of q^2

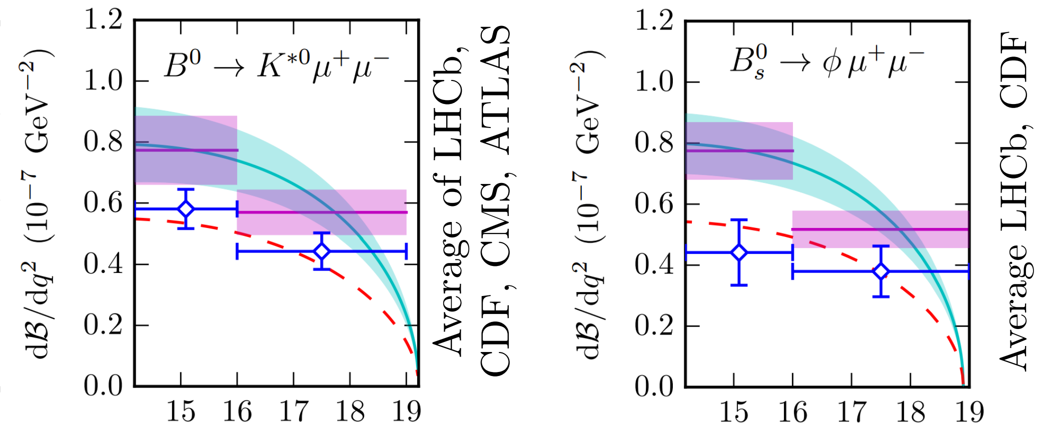
[JHEP 06 (2014) 133]



[JHEP 08 (2013) 131]



[JHEP 07 (2013) 084]



→ 3 fb^{-1} update with S-wave in preparation

Global fit of Wilson coefficients

	Coeff.	best fit	1σ	2σ	$\sqrt{\chi^2_{\text{b.f.}} - \chi^2_{\text{SM}}}$	p [%]
	C_7^{NP}	-0.04	$[-0.07, -0.01]$	$[-0.10, 0.02]$	1.42	2.4
	C_7'	0.01	$[-0.04, 0.07]$	$[-0.10, 0.12]$	0.24	1.8
	C_9^{NP}	-1.07	$[-1.32, -0.81]$	$[-1.54, -0.53]$	3.70	11.3
	C_9'	0.21	$[-0.04, 0.46]$	$[-0.29, 0.70]$	0.84	2.0
	C_{10}^{NP}	0.50	$[0.24, 0.78]$	$[-0.01, 1.08]$	1.97	3.2
	C_{10}'	-0.16	$[-0.34, 0.02]$	$[-0.52, 0.21]$	0.87	2.0
	$C_9^{\text{NP}} = C_{10}^{\text{NP}}$	-0.22	$[-0.44, 0.03]$	$[-0.64, 0.33]$	0.89	2.0
SU(2)_L invariant	$C_9^{\text{NP}} = -C_{10}^{\text{NP}}$	-0.53	$[-0.71, -0.35]$	$[-0.91, -0.18]$	3.13	7.1
	$C_9' = C_{10}'$	-0.10	$[-0.36, 0.17]$	$[-0.64, 0.43]$	0.36	1.8
	$C_9' = -C_{10}'$	0.11	$[-0.01, 0.22]$	$[-0.12, 0.33]$	0.93	2.0

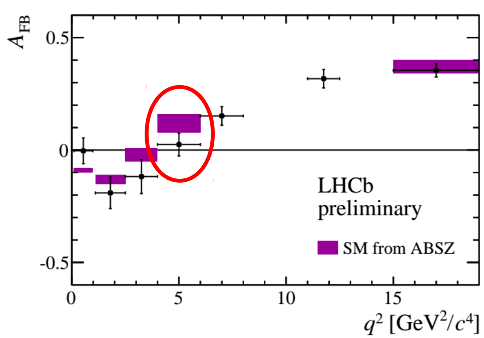
Table 1: Constraints on individual Wilson coefficients, assuming them to be real, in the global fit to 88 $b \to s\mu^+\mu^-$ measurements. The p values in the last column should be compared to the p value of the SM, 2.1%.

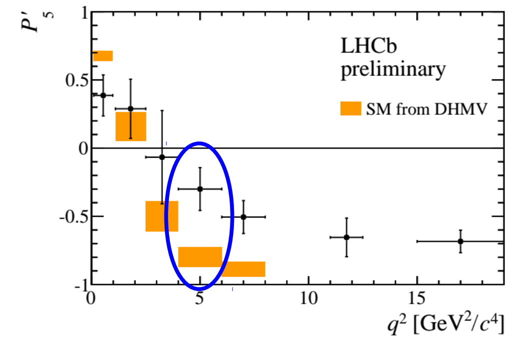
W. Altmannshofer and D, Straub arXiv:1503:06199

Angular analysis of K*ee

- At low q^2 photon pole enhancement + smaller background
- Region 1-6 is hard, above charmonia is even more difficult
- Can gain something in Run II with optimization?
- AFB has systematic from double semileptonic
-

Observable	Ratio of muon vs. electron mode			
	$C_9^{NP} = -1.5$	-1.5	-0.7	-1.3
	$C_9' = 0$	0.8	0	0
	$C_{10}^{NP} = 0$	0	0.7	0.3
$10^7 \frac{dBR}{dq^2}(\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-)_{[1,6]}$	0.83	0.77	0.79	0.81
$10^7 \frac{dBR}{dq^2}(\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-)_{[15,22]}$	0.76	**0.69**	0.76	0.75
$A_{FB}(\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-)_{[4,6]}$	**0.18**	**0.10**	0.75	**0.27**
$S_5(\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-)_{[4,6]}$	**0.66**	**0.66**	0.93	0.71





Global fit including lepton universality

- Assume NP affects only muon modes
  $\rightarrow$ negative $\mathcal{C}_9^{(\mathrm{NP})}$ can explain also $\mathcal{R}_K$ result $\rightarrow$ pull at 4.3 σ

- More observables are needed:
  $\Rightarrow$ next steps at LHCb will be measuring $\mathcal{R}_{K^{*0}}$ and $\mathcal{R}_\phi$
  (will also help to disentangle $\mathcal{C}_9^{(\mathrm{NP})}$ and $\mathcal{C}_{10}^{(\mathrm{NP})}$ effects)
  (Straub, Hiller, Becirevic)

- also useful to search for LFV like $B \rightarrow K^{(*)} e\mu$

- Improved $B_s^0 \rightarrow \mu^+\mu^-$ will help to pin down $\mathcal{C}_{10}^{(\mathrm{NP})}$