"Current Trends in Flavor Physics" - *March 29 2017*

Lepton flavour universality tests at LHCb

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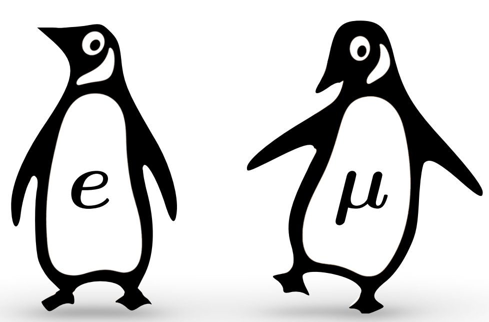
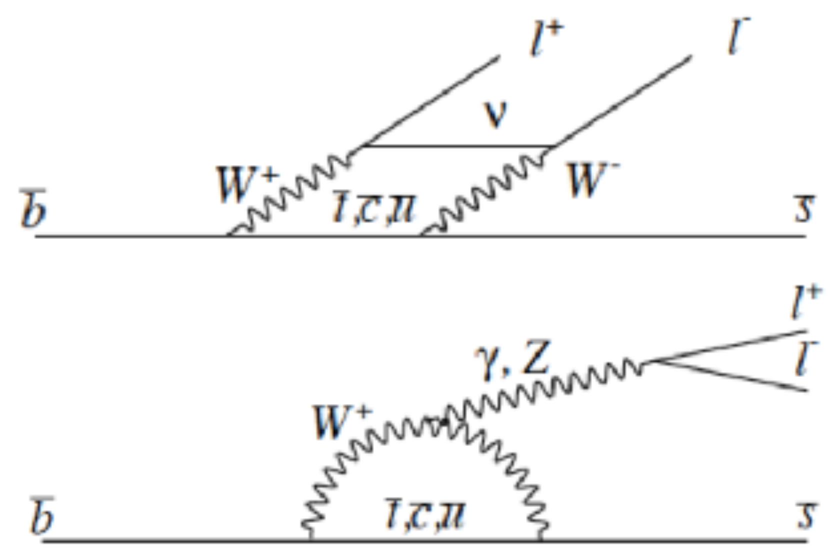
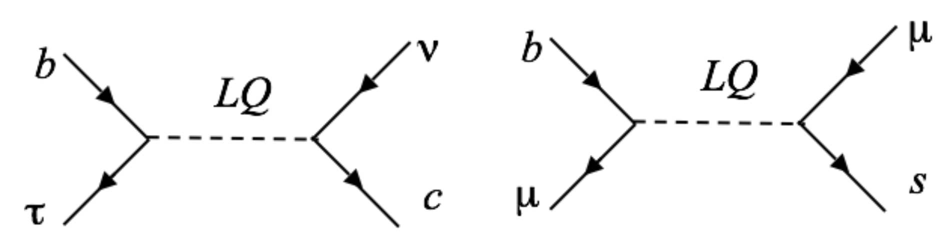


Testing LFU with $b\to s\ell\ell$

- $b\to s\ell\ell$ is a good probe:
  - No tree level, CKM suppressed
  - Sensitive to various types of BSM
  - Up to very high masses
- Good to test NP **structure**
  - ex: does NP share LFU couplings?
    - Can get smoking guns at low energy!
    - Predicted in various models such as leptoquarks or Z'

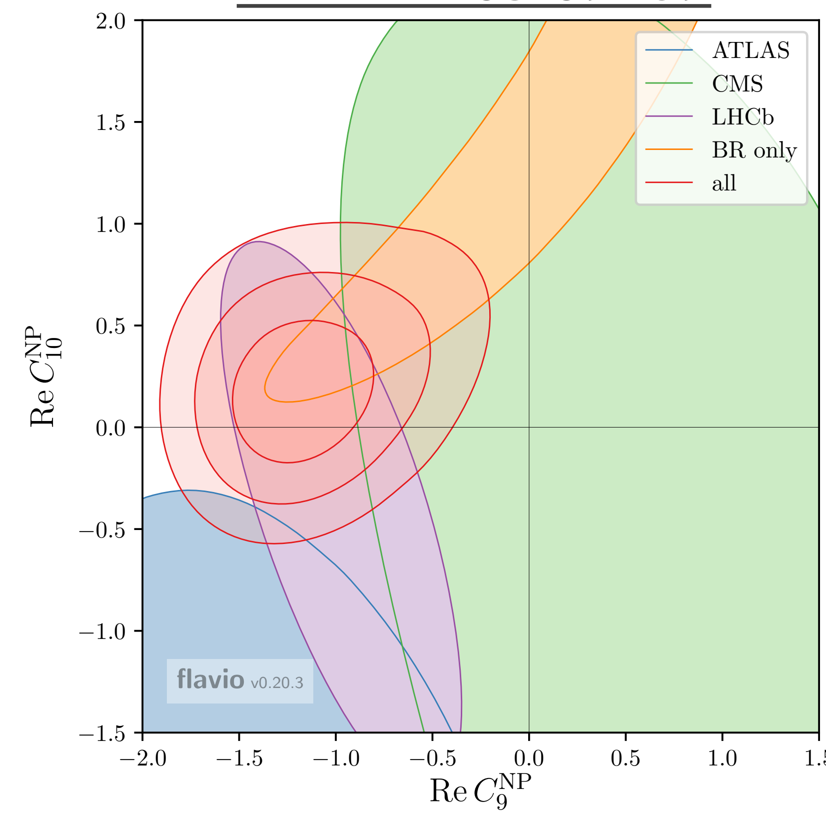


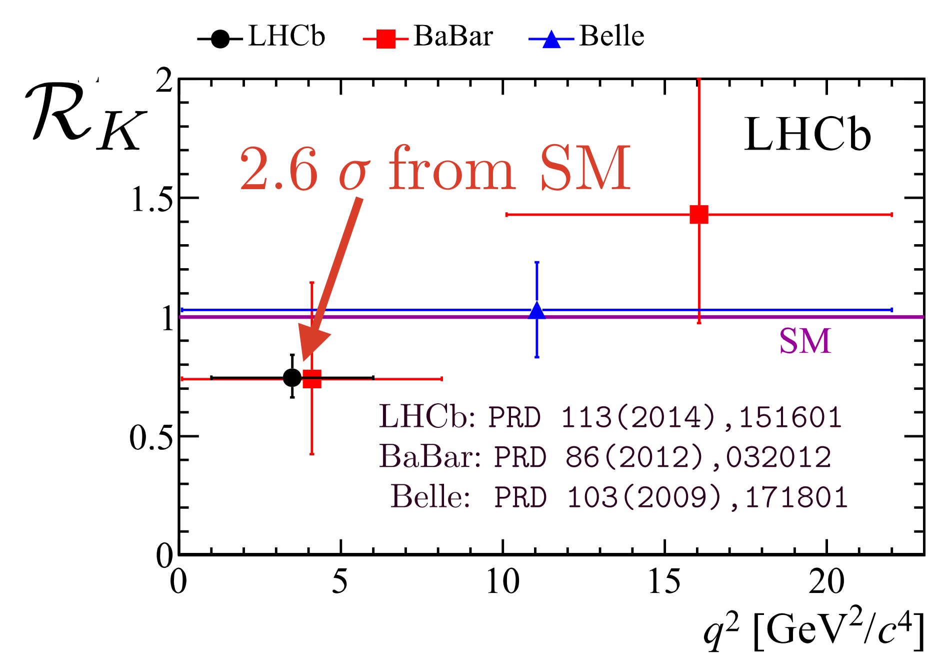


Dream scenario

- Hints of new dynamics in $b \to s\mu\mu$
  - Branching ratios
  - Angular distributions
  - *Need to deal with QCD*
- **Dream scenario**:
  - It's NP, not QCD
  - NP also violates LFU (e vs. μ)
    ➡ **can study NP "safely" by comparing $b \to s\mu\mu$ and $b \to see$**
  - *Example:*
    - *~20%* SM uncert. on BR($K\mu\mu$)
    - *< 1%* SM uncert. on R_K=BR($K\mu\mu$)/BR(Kee)
- Hints in R_K in right direction,
  - Only 2.6 sigma, need more channels/data

arXiv:1703.09189





Experimentally

Not a dream scenario experimentally:

➜ $b \to s e^+ e^-$ is challenging at LHCb:

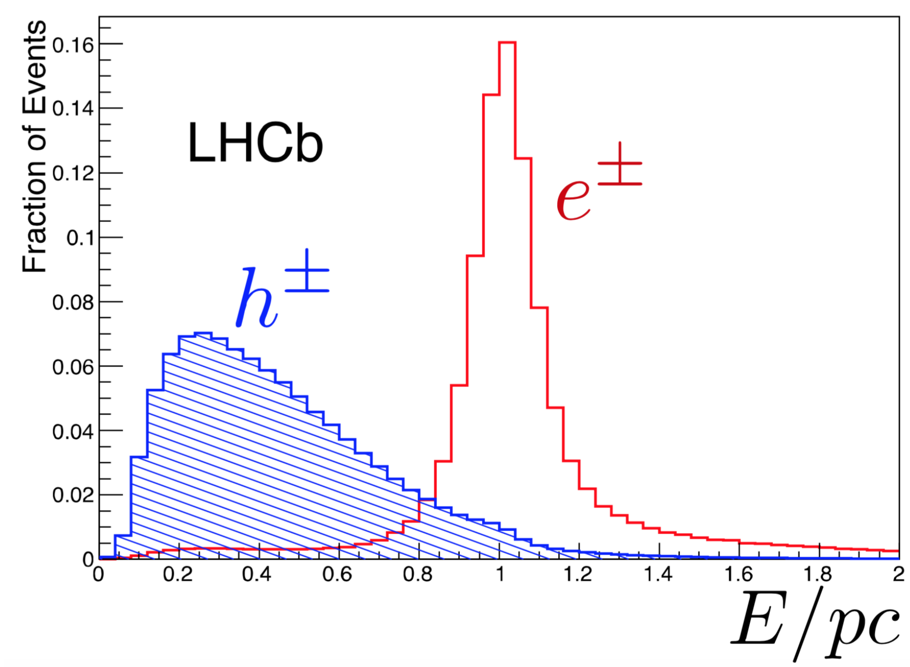
- Trigger on large p_T $e^\pm / h^\pm$ deposit on calorimeters
  (or on track from other B)
- Electron ID relies on calorimeter
- Important combinatorial background: MVA selection
- From R_K paper:

$$\frac{N(B^0 \to K^+ J/\psi\,(e^+ e^-))}{N(B^0 \to K^+ J/\psi\,(\mu^+ \mu^-))} \sim \frac{1}{7}$$

Level-0 trigger at LHCb

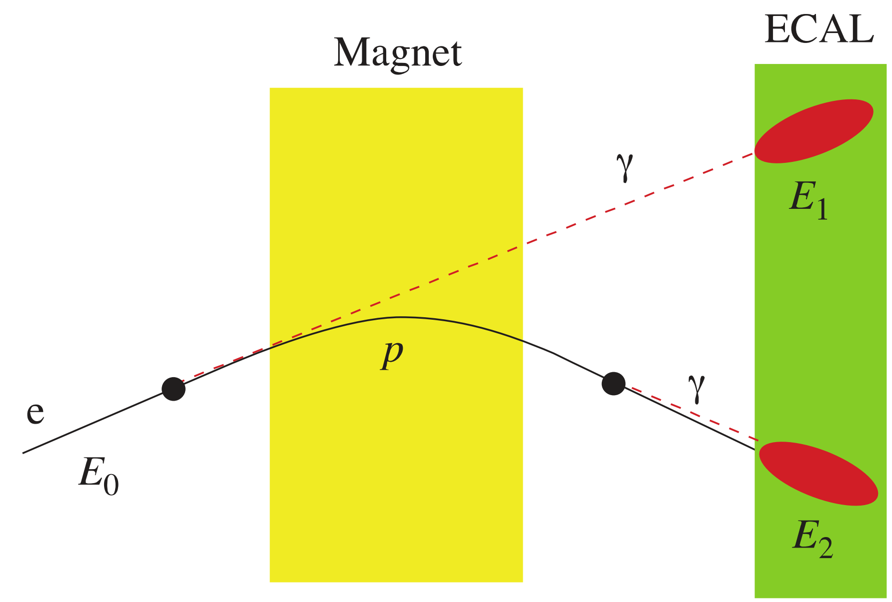
	p_T or E_T 2011	p_T or E_T 2012
single muon	1.48 GeV/c	1.76 GeV/c
dimuon $p_{T1} \times p_{T2}$	$(1.30\,\text{GeV}/c)^2$	$(1.60\,\text{GeV}/c)^2$
hadron	3.50 GeV	3.50-3.74 GeV
electron	2.50 GeV	2.72-2.96 GeV
photon	2.50 GeV	2.72-2.96 GeV

Electron ID at LHCb



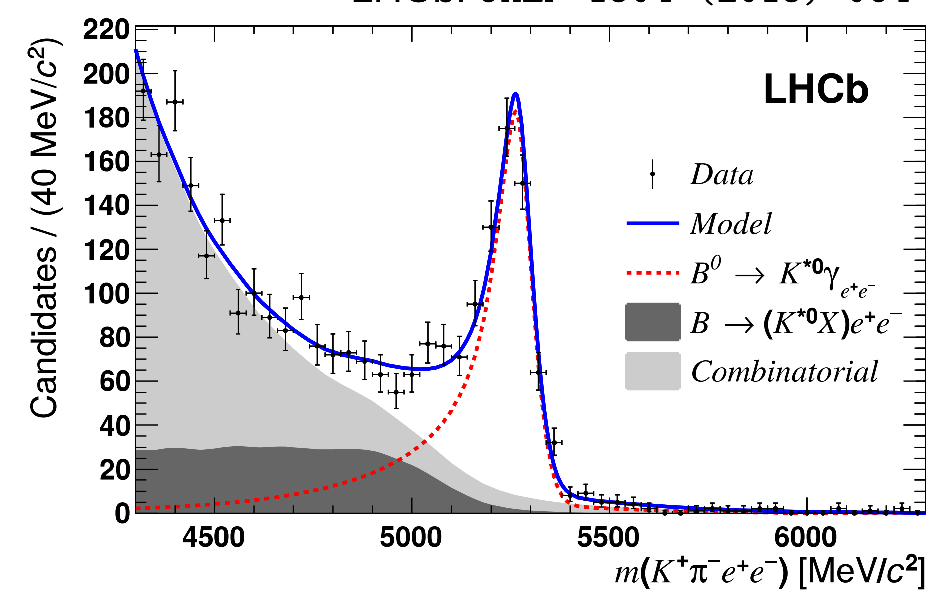
Experimentally

- Large $p \to$ large bremsstrahlung
  - Recover with calorimeter:
    - Inefficiency causes B mass tail
    - Mass resolution degraded by photon energy measured by calorimeter
- Fight backgrounds from:
  - Combinatorial tracks
  - Semileptonic cascade (missing neutrinos)
  - Partially reconstructed rare decay

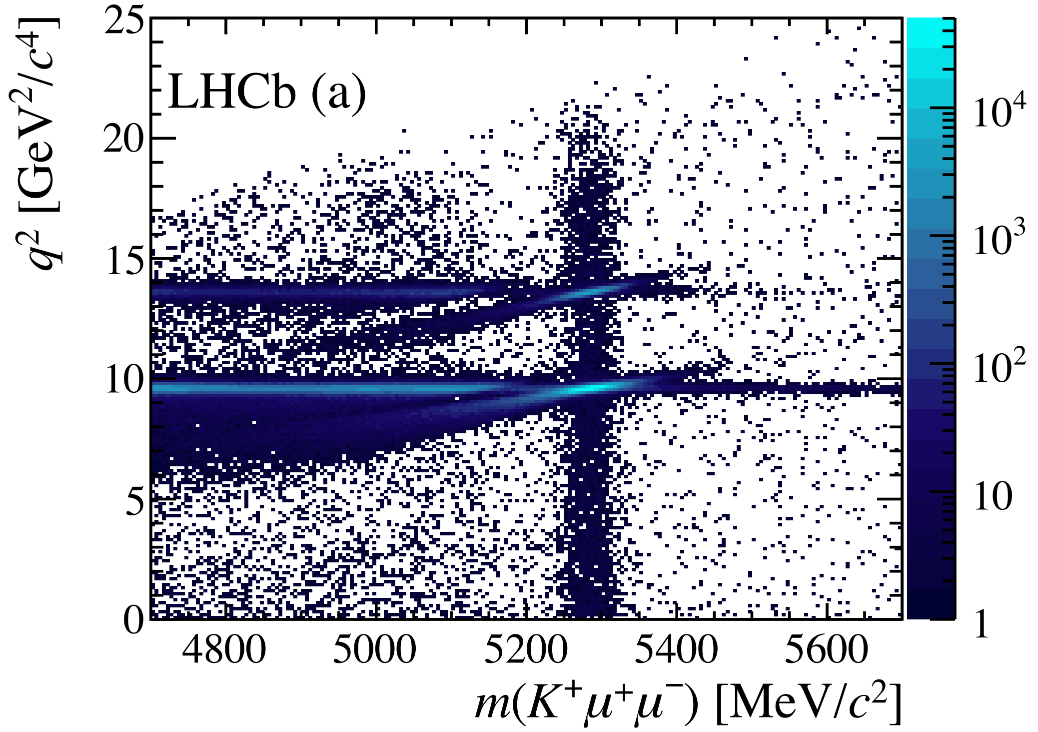


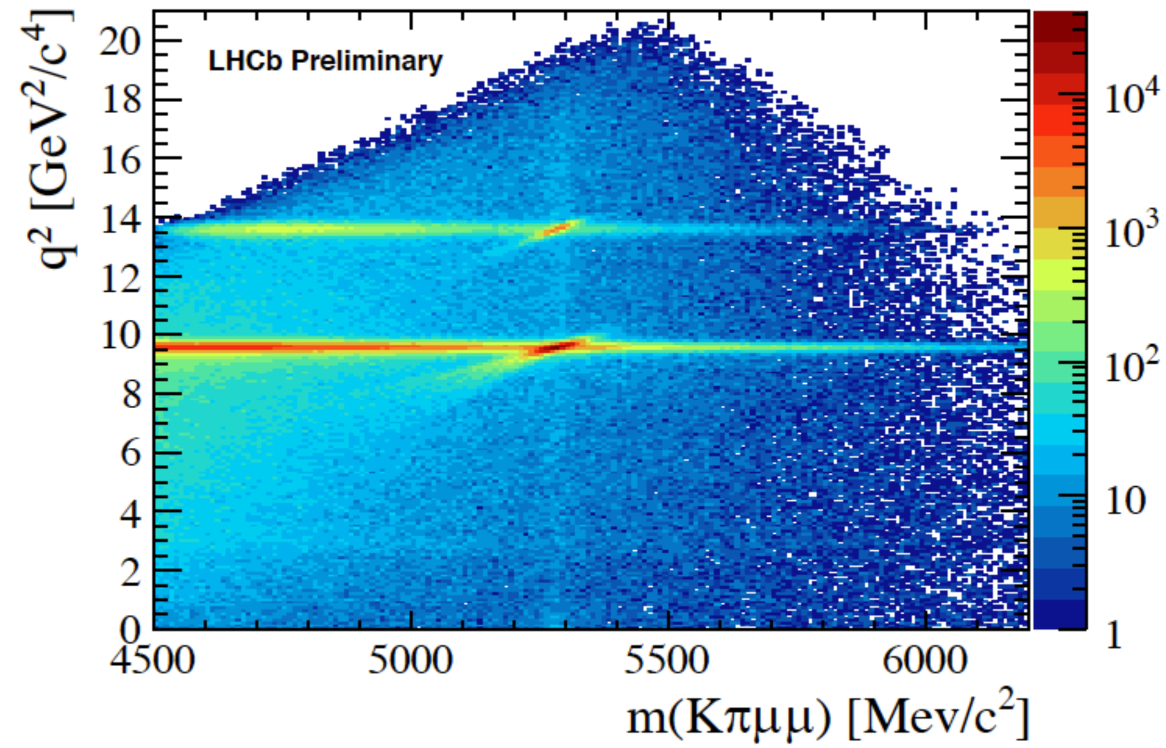
$B^0 \to K^{*0}\gamma$ with conv. to e^+e^-

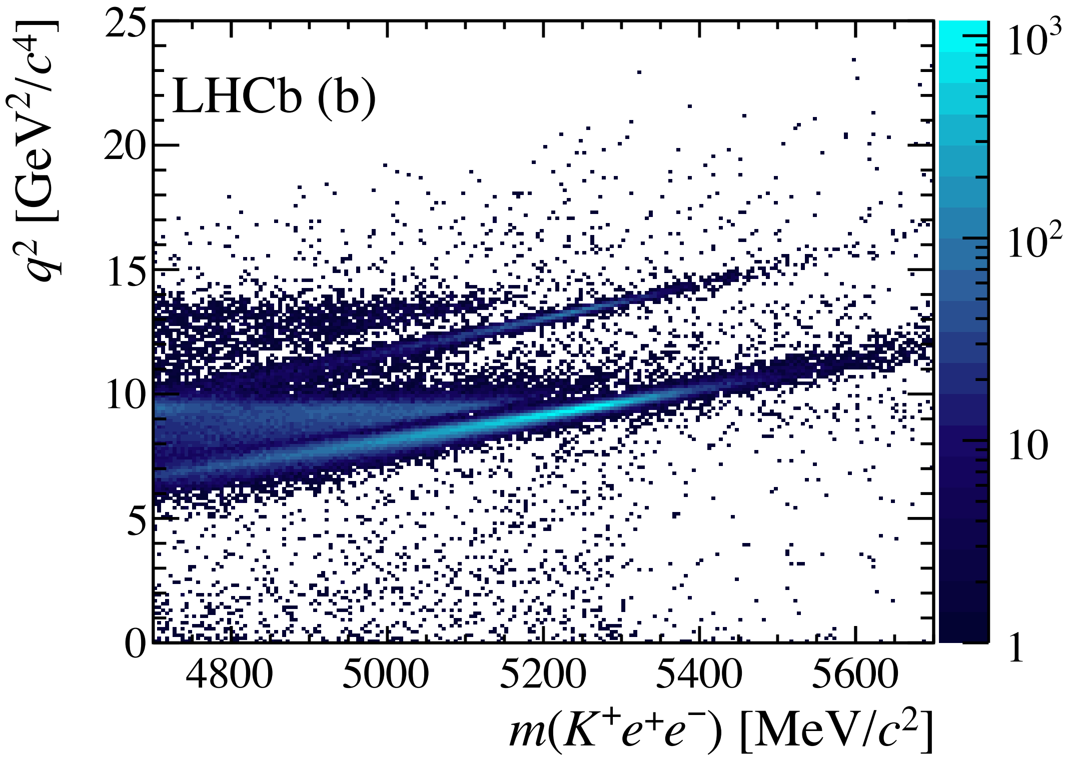
LHCb: JHEP 1504 (2015) 064

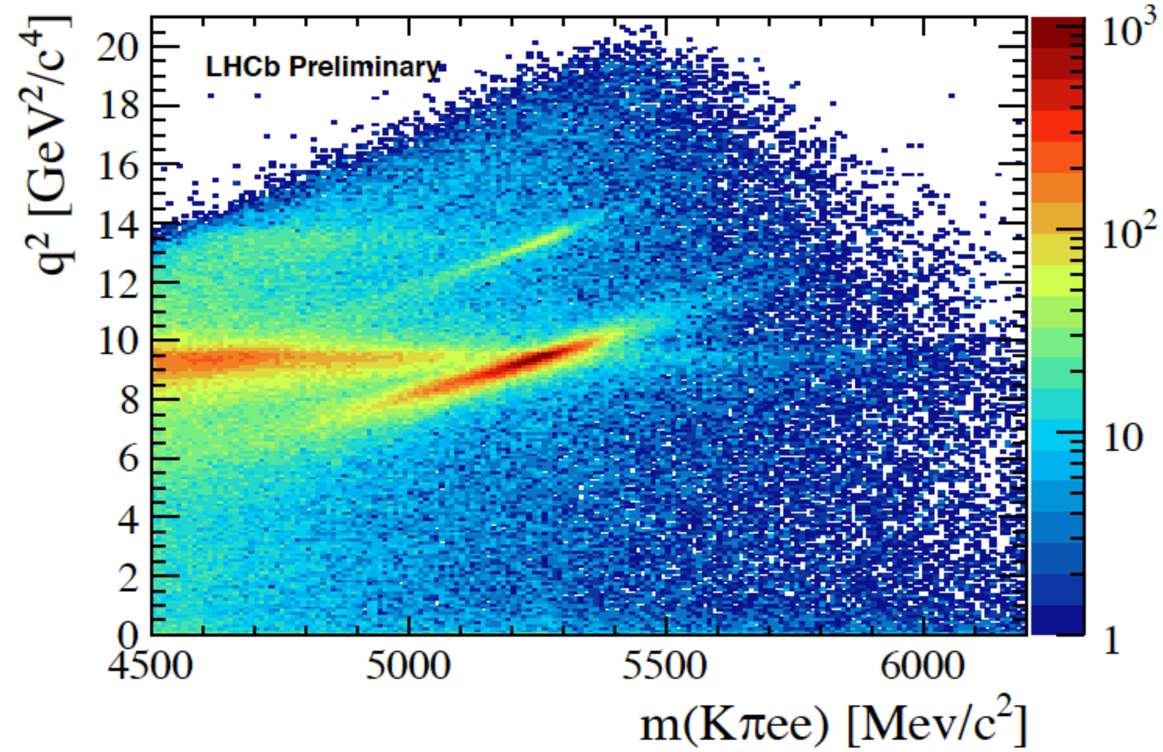


q^2 versus B mass









Experimental challenges

- Use **double ratio:**

$$\mathcal{R}_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to K^+ J/\psi\,(\mu^+ \mu^-))} \frac{\mathcal{B}(B^+ \to K^+ J/\psi\,(e^+ e^-))}{\mathcal{B}(B^+ \to K^+ e^+ e^-)} =$$

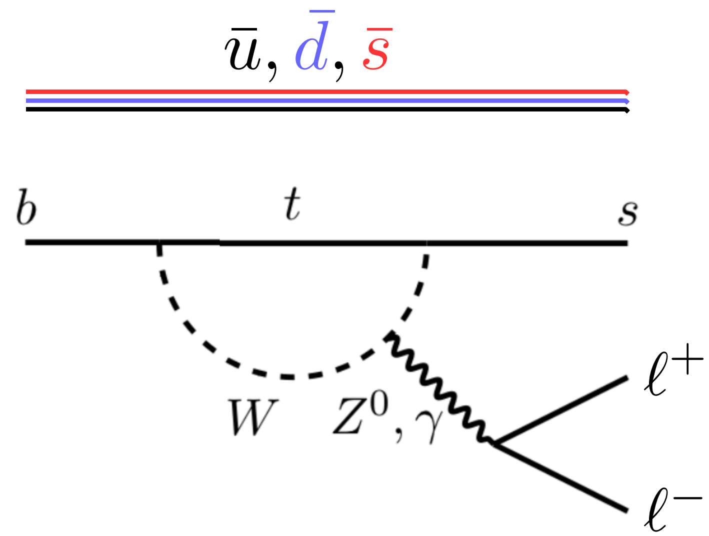
$$= \frac{N_{K^+ \mu^+ \mu^-}}{N_{K^+ J/\psi\,(\mu^+ \mu^-)}} \frac{N_{K^+ J/\psi\,(e^+ e^-)}}{N_{K^+ e^+ e^-}} \boxed{\frac{\epsilon_{K^+ J/\psi\,(\mu^+ \mu^-)}}{\epsilon_{K^+ \mu^+ \mu^-}}} \boxed{\frac{\epsilon_{K^+ e^+ e^-}}{\epsilon_{K^+ J/\psi\,(e^+ e^-)}}}$$

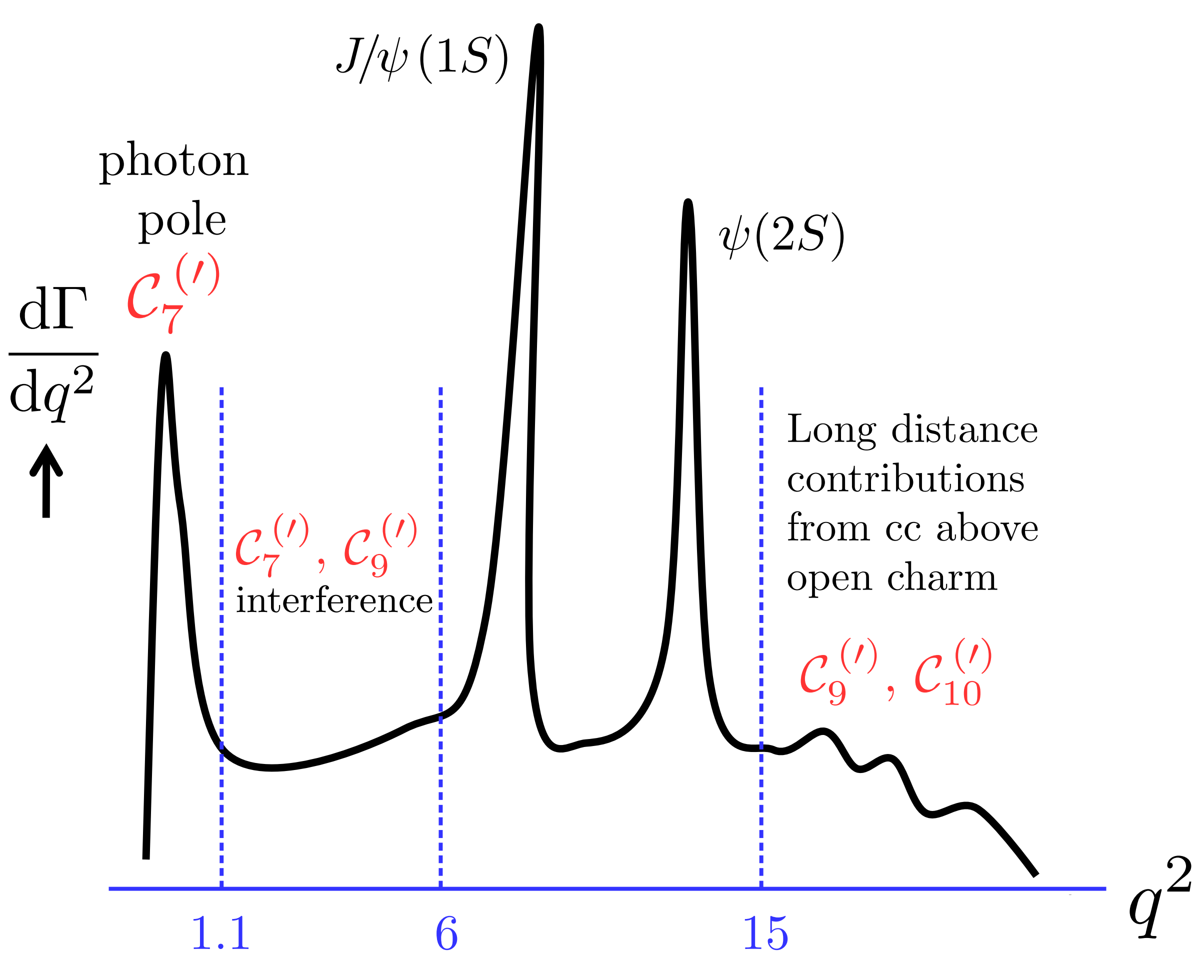
$\rightarrow$ cancel systematics

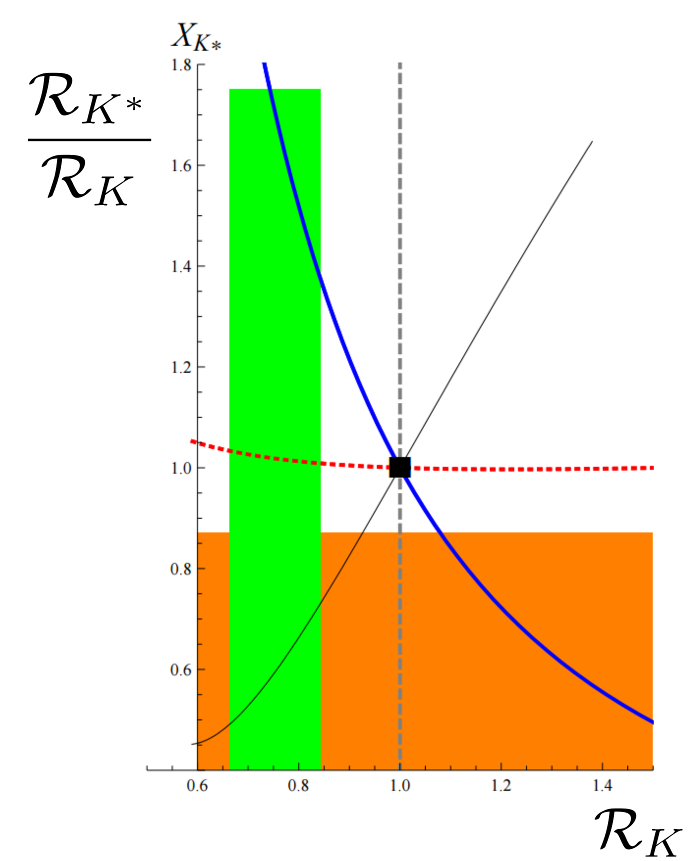
- Need to model correctly q^2 dependence
  - Cross-check MC / data agreement of q^2 dependent variables on resonant J/ψ decays
- Can also check that $R_{K^{(*)}}$ on the $\psi(2S)$ is 1
- R_K had yield of ~250 $B^+ \to K^+ ee$ events (versus ~1200 $\mu\mu$)
  - Electron yield is driving the total uncertainty

Additional probes

- Change spectator quark
  a.k.a. number of K/π in final state
- Vector channels (K^*, ϕ) could help to clarify the picture





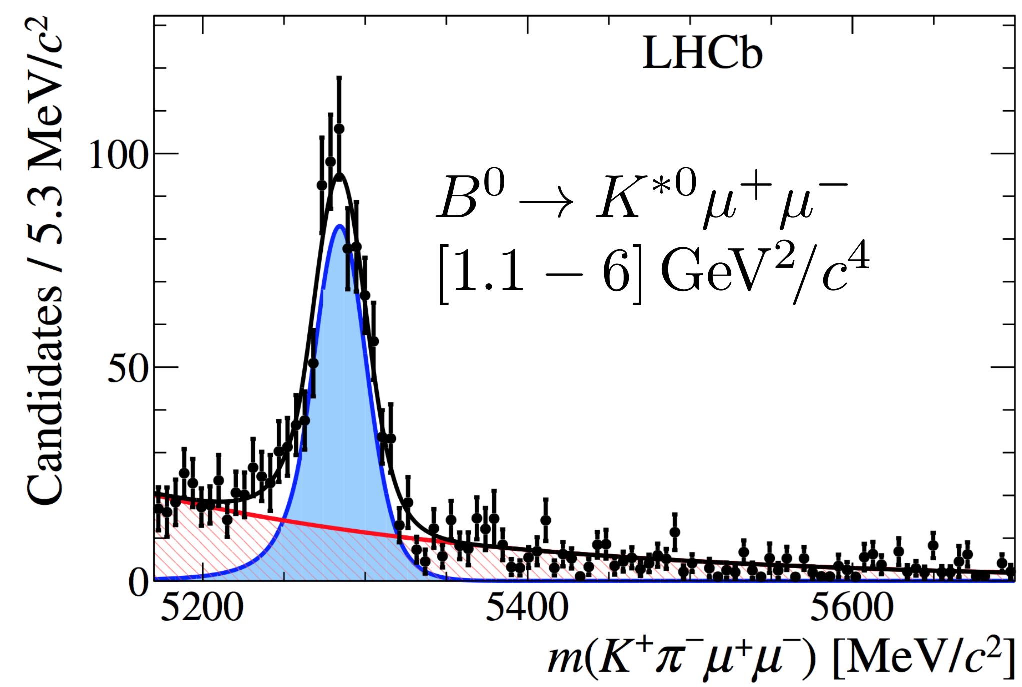


Hiller and Schmaltz JHEP 02(2015)055

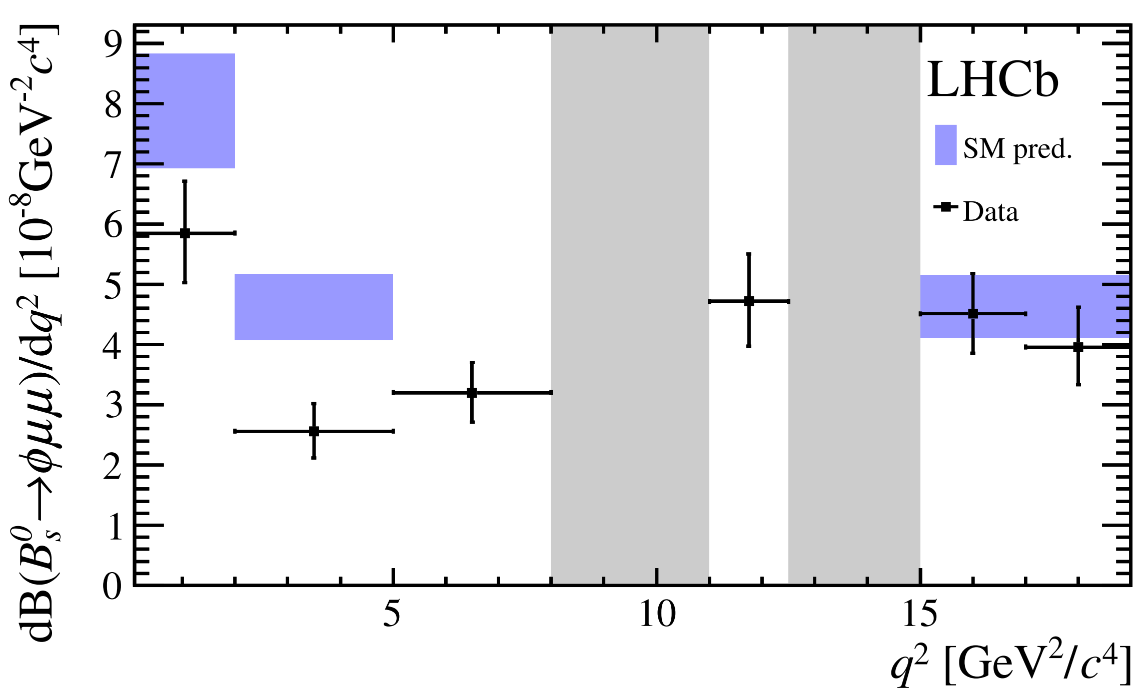
Additional probes

- R_{K^*} : obvious followup of R_K
- R_ϕ : lower yield (due to f_s/f_d) but cleaner sample (narrow ϕ)
- Lots of activity in LHCb…

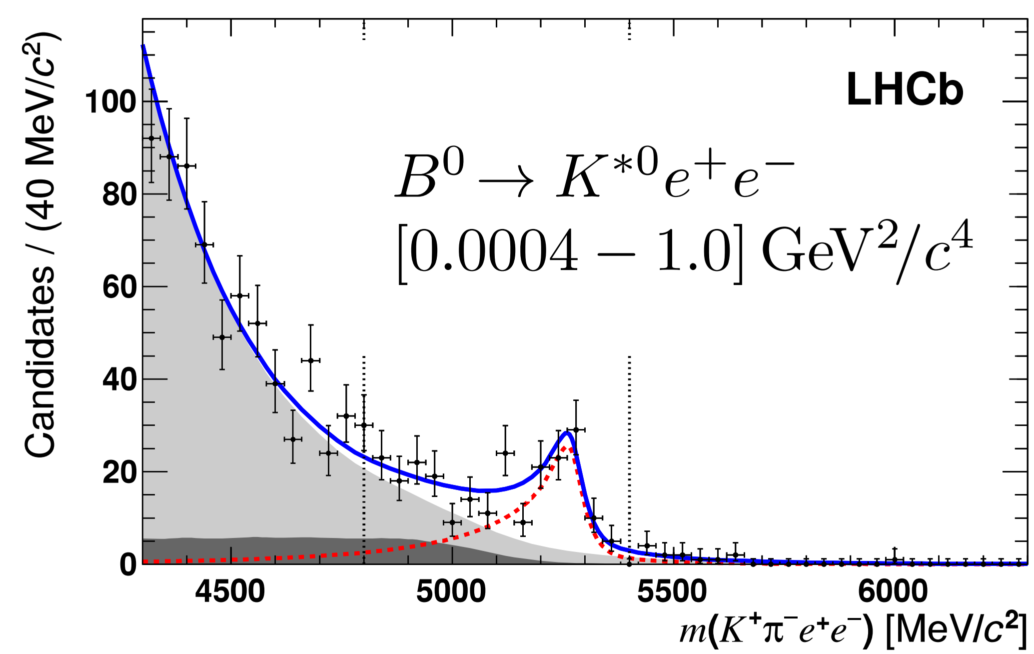
[JHEP 02 (2016) 104]



[JHEP 09 (2015) 179]



[JHEP 04 (2015) 064]

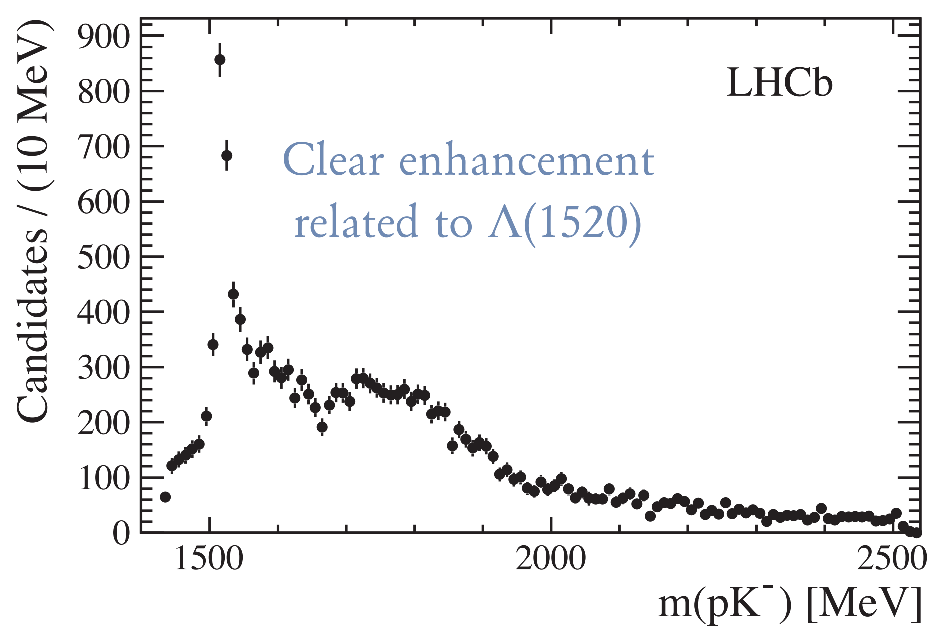


Additional probes

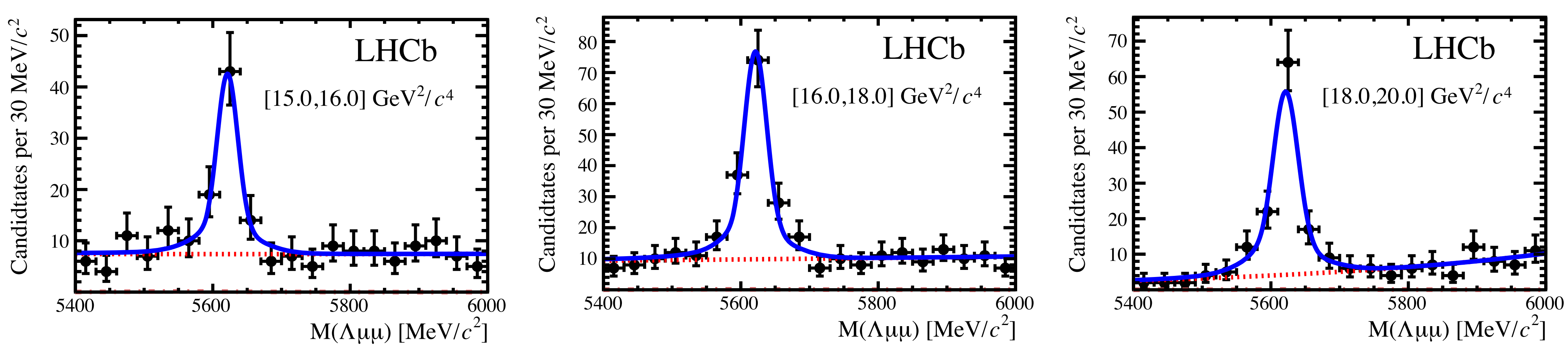
Can also look at $\Lambda_b \to \Lambda^{(*)} \ell \ell$:

- R_{Λ^*} ongoing. Prompt $\Lambda^* \to pK$
- $\Lambda_b \to \Lambda \mu\mu$ in LHCb Run 1 dataset yield is: 276 ± 16 for $q^2 \in [15.0, 20.0]$ GeV^2/c^4
- 5-10 times less events expected in electrons
- Need to combine Run1 and Run2

[PRL 111 102003 (2013)]



[JHEP 01 (2015) 155]

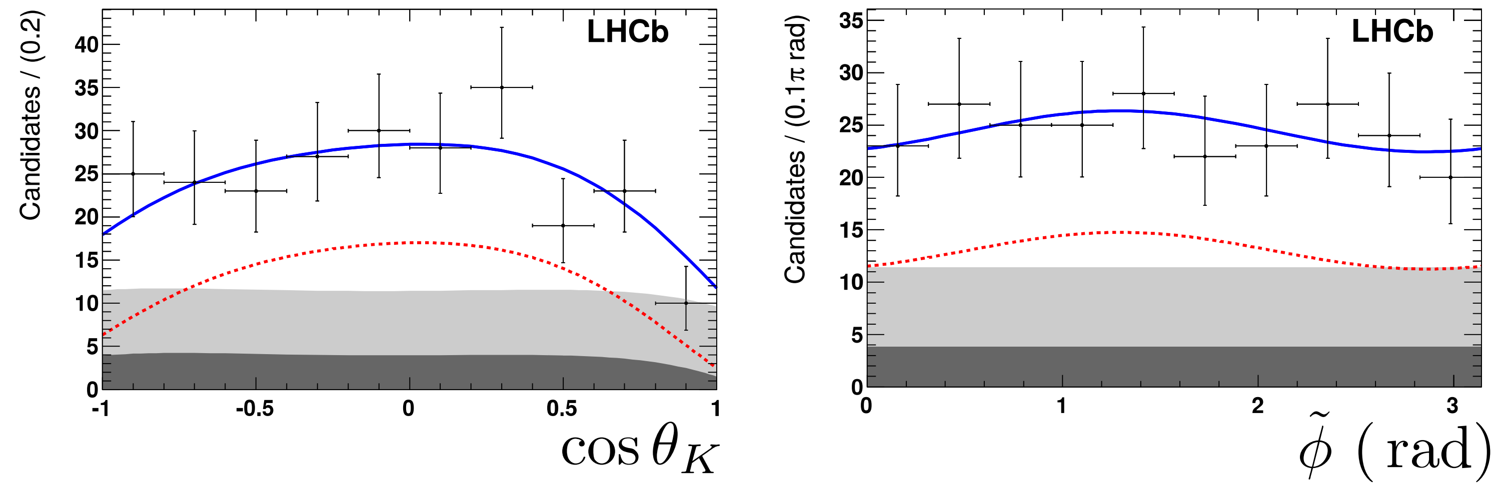


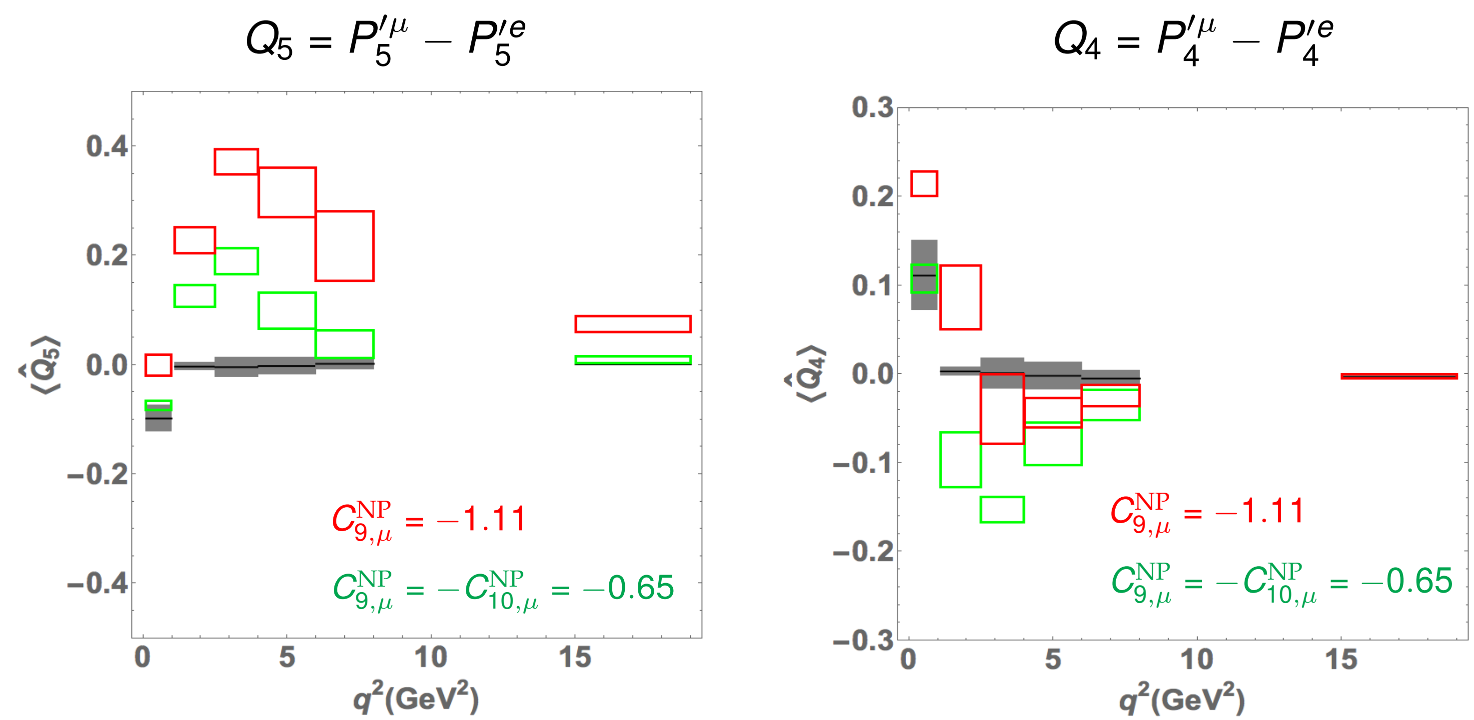
Additional probes

Can look at **angular differences** as well

- Challenging experimentally
  - angular modelling of K*ee background
- More C_9/C_{10} disentangling:
  - could be important in the future

[JHEP 04 (2015) 064]





[Q.Matias @MoriondEW2017]

Need for data

- All measurements are statistically limited
- Run 2 data being collected
- High-luminosity run:
  - somewhat more challenging for electrons

Run (years)	Run 1 (2010-2012)	Run 2 (2015-2018)	Run 3 (2021-2023)	Run 4 (2027-2029)
Integrated luminosity	3 fb^{-1}	8 fb^{-1}	25 fb^{-1}	50 fb^{-1}
Instantaneous luminosity	4×10^{32} $cm^{-2}s^{-1}$		2×10^{33} $cm^{-2}s^{-1}$	

Current LHCb → | Upgraded LHCb →

channel	Run 1	Run 2	Run 3,4 (50fb^{-1})
$B^0 \to K^{*0}(K^+\pi^-)\mu^+\mu^-$	2,400	9,000	80,000
$B^0 \to K^{*+}(K^0_S\pi^+)\mu^+\mu^-$	160	600	5,500
$B^0 \to K^0_S\mu^+\mu^-$	180	650	5,500
$B^+ \to K^+\mu^+\mu^-$	4,700	17,500	150,000
$\Lambda_b \to \Lambda\mu^+\mu^-$	370	1500	10,000
$B^+ \to \pi^+\mu^+\mu^-$	93	350	3,000
$B^0_s \to \mu^+\mu^-$	15	60	500
$B^0 \to K^{*0}e^+e^-$ (low q^2)	150	550	5,000
$B_s \to \phi\gamma$	4,000	15,000	150,000

Naively scaling with luminosity and linear scaling of $\sigma_{b\bar{b}}$ with $\sqrt{s}$.

Conclusions

- R_K result is intriguing ⇒ dream scenario
  - that doesn't increase the number of sigma (2.6)
- Many follow-up measurements in the oven:
  - In particular R_{K^*}, R_ϕ, R_{Λ^*}, …
- Time to look also at angular observables differences
- Increasing interest in LHCb
- Increasing amount of data being collected
- Stay tuned!