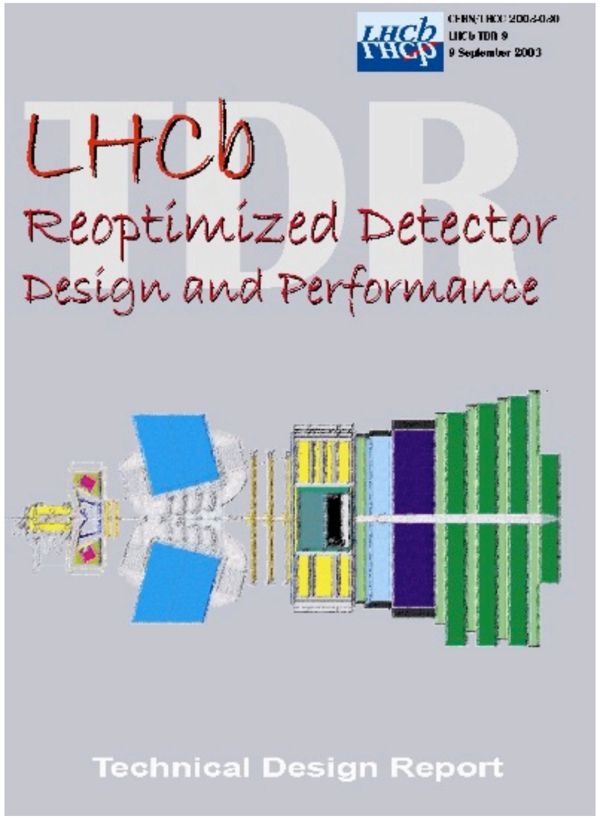
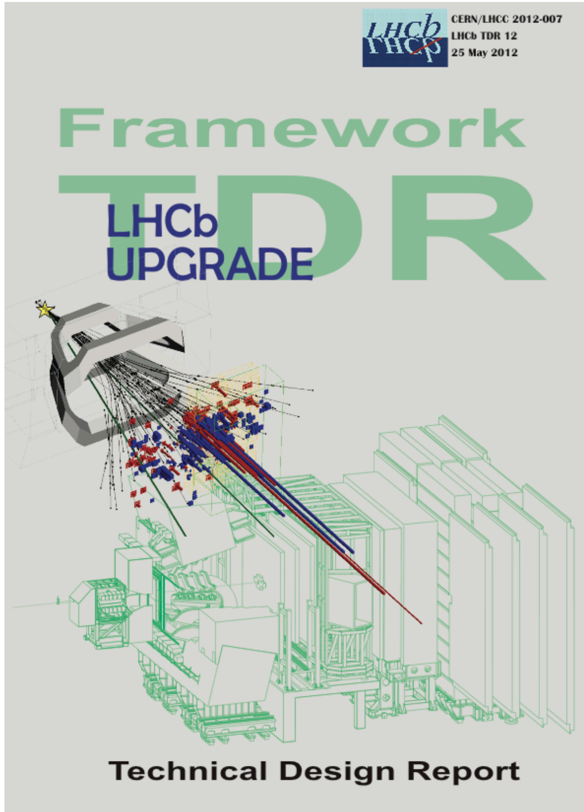
LHCb Prospects





High-energy implications of flavour anomalies, CERN, 24th October 2018

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Introduction

- Have heard extensively about the anomalies that have appeared in measurements of b-decays:
  - Angular observables in $B^0 \to K^{*0}\mu\mu$
  - Branching fractions of several of $b \to sll$ processes
  - Lepton-flavour universality ratios in $b \to sll$ decays
  - Lepton-flavour universality ratios in $b \to cl\nu$ decays

  … and the prospects of high p_T experiments to probe any underlying new physics

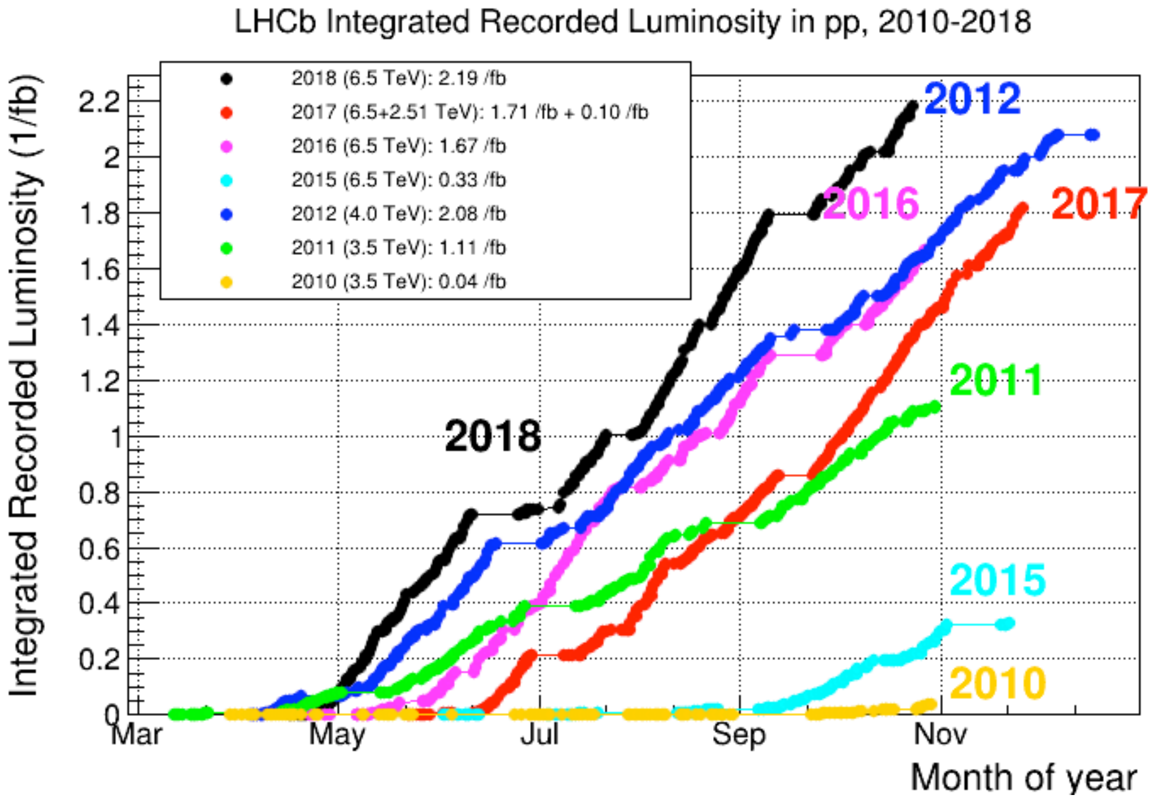
- Will try and say something about the future of the LHCb measurements

- Clear that interplay between theory and experiment will remain critical

Outline

- Short term prospects
- Further into the future – LHCb upgrade phase I (2021-2030)
- Far future – LHCb upgrade phase II (2031...)

Short term prospects



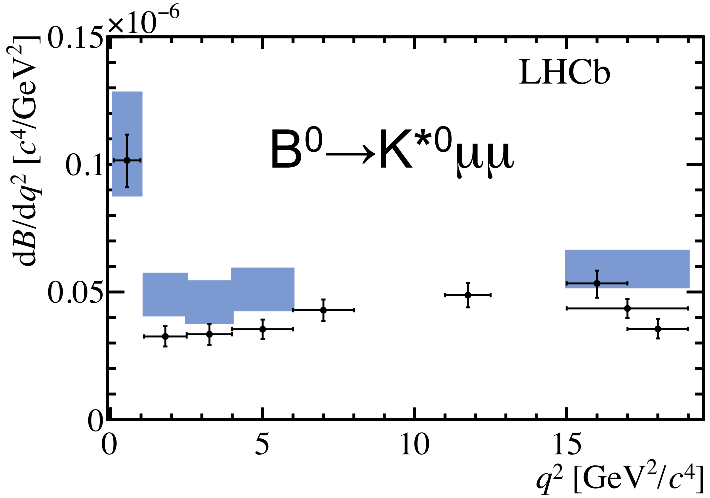
- Near term updates will add part of Run 2 data e.g. Run 1 ($3fb^{-1}$)+ 2015, 2016 ($2fb^{-1}$ but with twice the cross-section)
- Can then expect legacy Run 2 analyses i.e. Run 1 ($3fb^{-1}$) $+(2x\ 2fb^{-1})_{2015/16} + (2x\ 1.8fb^{-1})_{2017} + (2x\ 2.0fb^{-1})_{2018}$ - total equivalent to 5x Run 1 dataset

Angular measurements

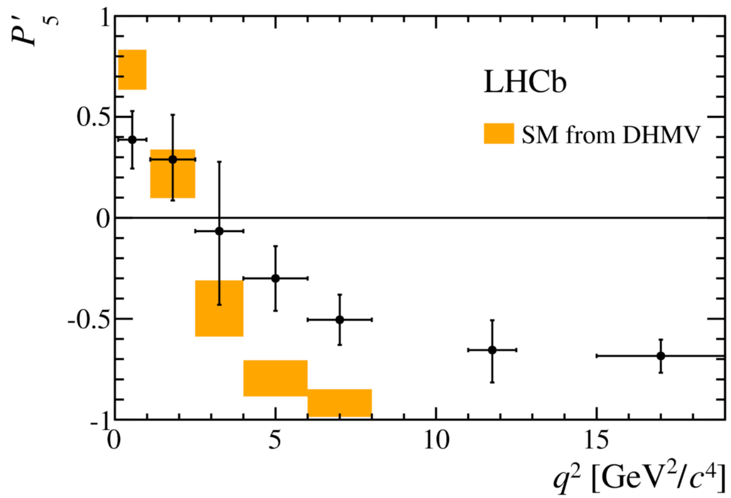
- Updated angular measurements of $B^0 \to K^{*0}\mu\mu$ in progress and will remain statistically limited – can expect at least a ~√2 increase in precision cf Run I results

- Other $\mu\mu$ channels should follow, as should updated branching fraction measurements

- Work on $B^0 \to K^{*0}ee$ also in progress but more challenging



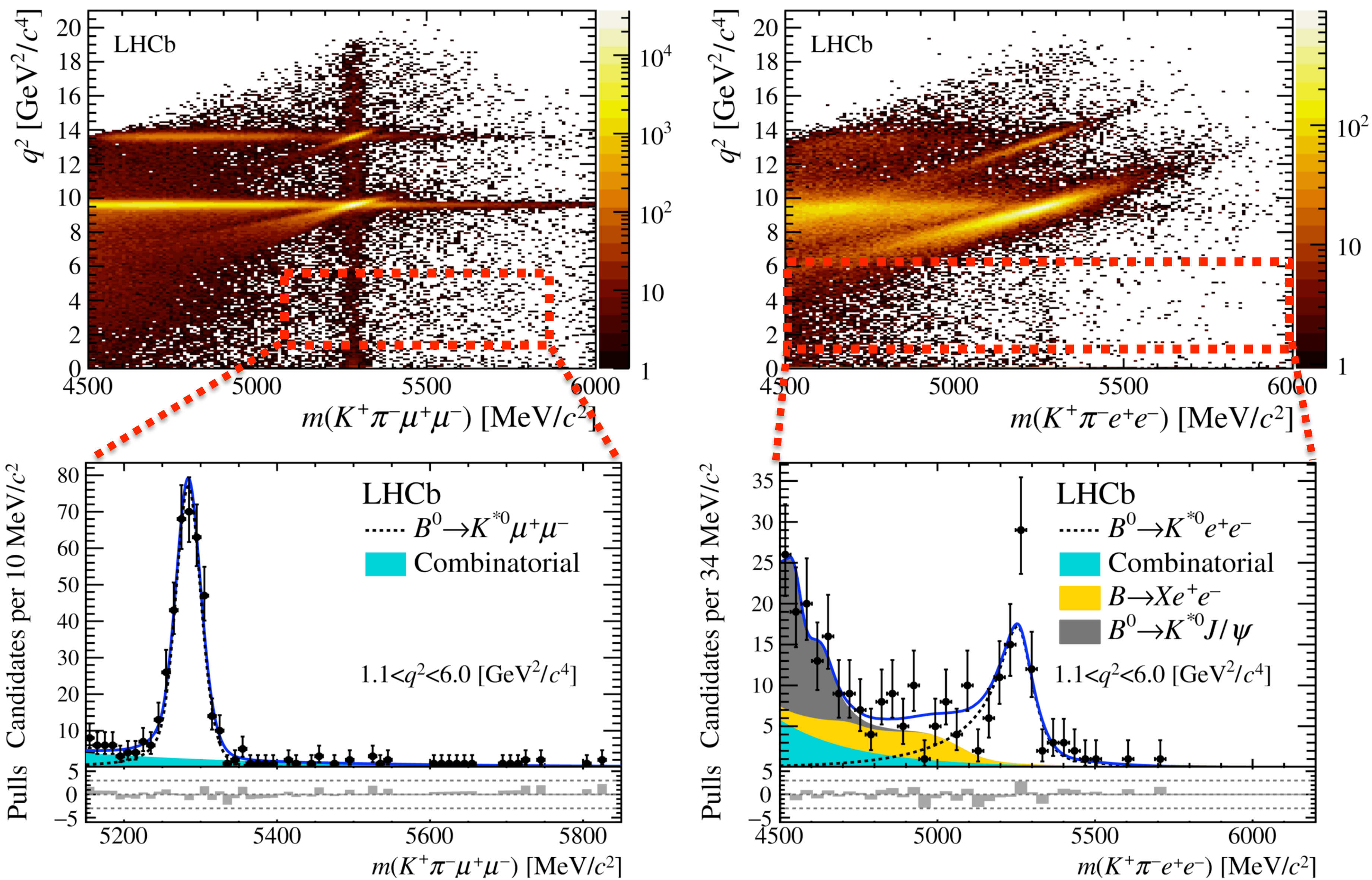
[JHEP 11 (2016) 047, JHEP 04 (2017) 142]



[JHEP 02 (2016) 104]

When will the R_K update be ready?

R_X – experimental challenges

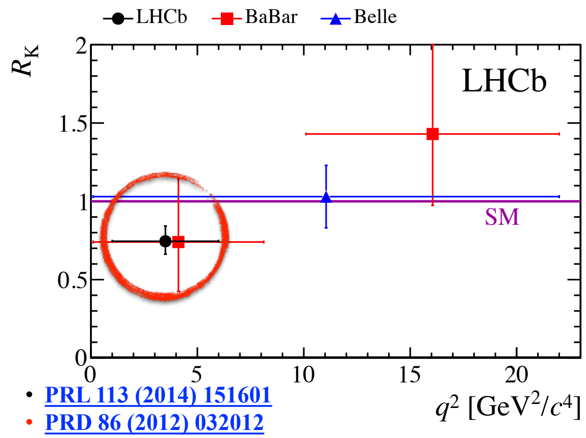


[JHEP 08 (2017) 055]

R_K update – $1.0<q^2<6.0$ GeV^2

- Published R_K analysis used 3fb^{-1} Run-I data and found ~250 $B^+ \to K^+e^+e^-$ candidates in $1.0<q^2<6.0$ GeV^2

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



- PRL 113 (2014) 151601
- PRD 86 (2012) 032012
- PRL 103 (2009) 171801

- Work in progress to update with part of additional data have in-hand
  - Improvements to offline processing
  - Run-II data (2015,16) gives 0.3+1.6 fb^{-1} but, with nearly twice cross-section, and a better trigger : ~250 → ~900 $B^+ \to K^+e^+e^-$ candidates ($1.1<q^2<6.0$ GeV^2) assuming same value of R_K is observed

→ Expect previous error of ~12% to shrink to ~7% *if the central value of R_K remains the same*

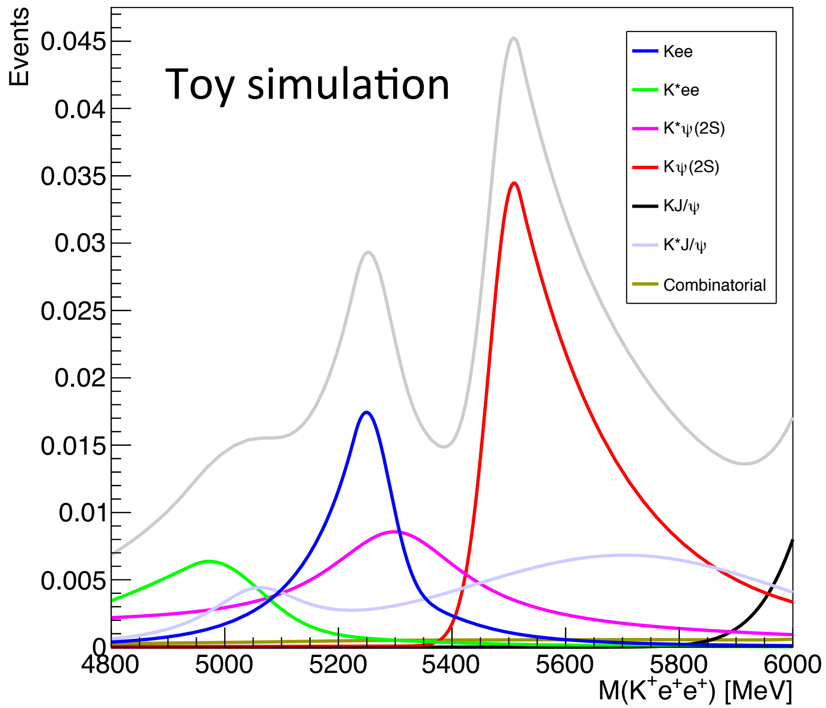
Systematics

- In the main trigger category, systematic effects are presently controlled at the 2-3% level
- Key contributions from
  - Understanding of the trigger efficiency (derived from data)
  - Understanding of the tracking efficiency (working on data-driven methods)

R_K update – other q^2 regions

- (In SM) little $B^+ \to K^+e^+e^-$ signal with $q^2 < 1.0\ GeV^2$

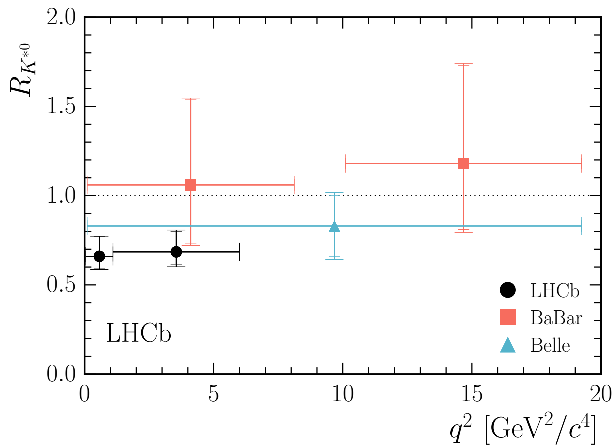
- Can add high q^2 bin – difficulty same for R_K and R_K^*
  - Rare decays with higher K(*) resonances can leak into signal region from below in m_{Kee}
  - $\psi(2S)K^*$ decays can leak into signal region on the upper side
  - Signal sandwiched between these and hence difficult to fit reliably



R_{K^*} update

- $3fb^{-1}$ Run-I analysis found [JHEP 1708 (2017) 055]
  - ~90 $B^0 \to K^{*0} e^+ e^-$ decay in $0.045 < q^2 < 1.1$ GeV^2 and ~110 $B^0 \to K^{*0} e^+ e^-$ decays in $1.1 < q^2 < 6.0$ GeV^2

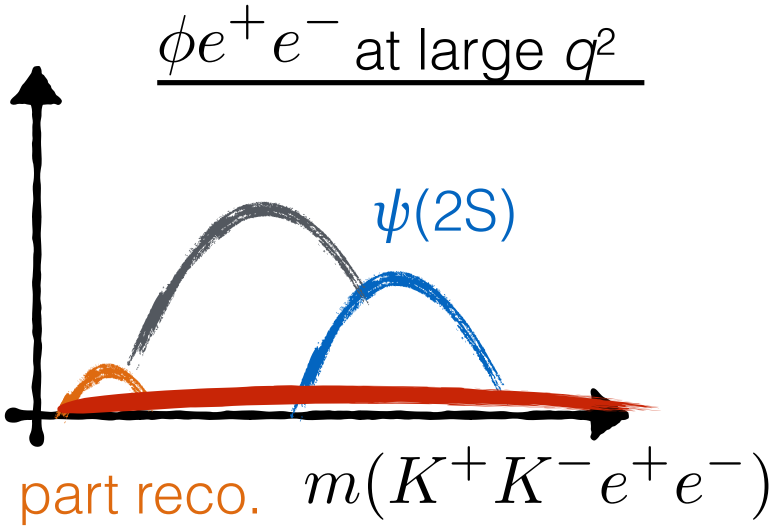
- Analysis being updated with Run-II data
  - Improvements to offline processing already included in most recent result
  - Even with additional data still expect to be stat. limited



R_ϕ

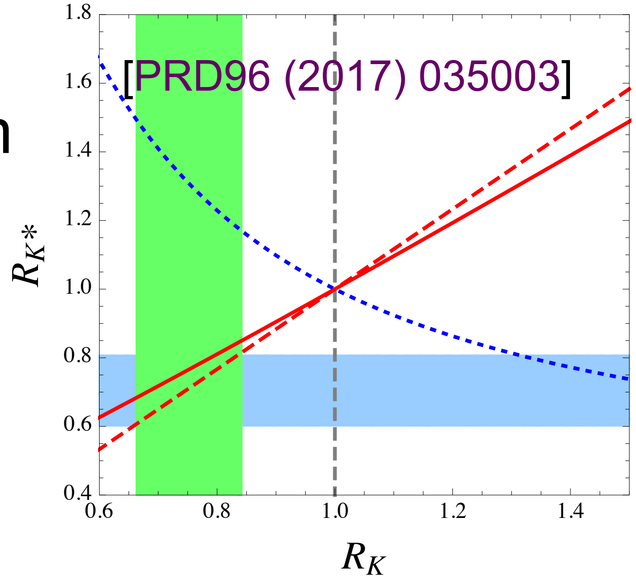
- Can make analogous measurements using $B_s \to \phi l^+ l^-$ decays → R_ϕ

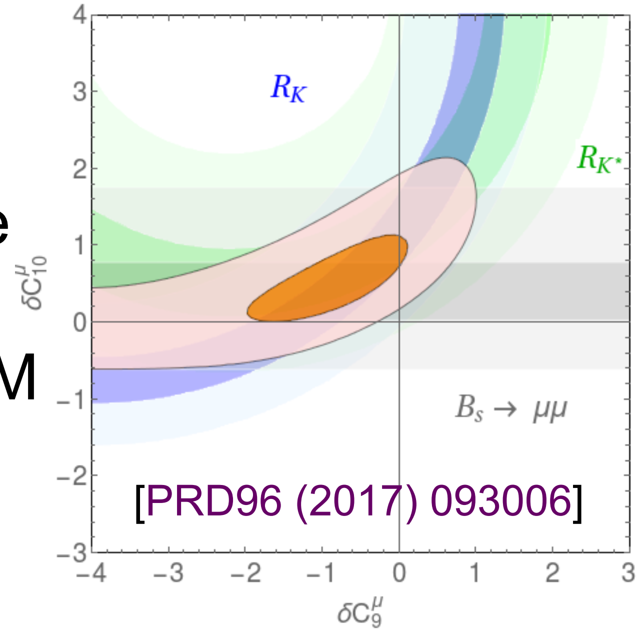
- Signal suppressed by f_s/f_d~0.25 and $B(\phi \to K^+K^-)=½$ but has experimental advantages:
  - Narrow mass helps reduce partially reconstructed bkgrds
  - Absence of higher resonances that decay to $\phi\pi$ suppresses backgrounds – largest involves missing K, rather than missing π in $R_K^{(*)}$ analyses



Can we reach the tipping point?

- Updates should be sufficient to confirm any discrepancy with real significance, indepn of combination with other data
- Expect step change from one or two isolated analyses to a series of related measurements from Run-II dataset
- Even in the absence of direct evidence can get model discrimination and statistically significant indication of BSM physics from channels that are clean





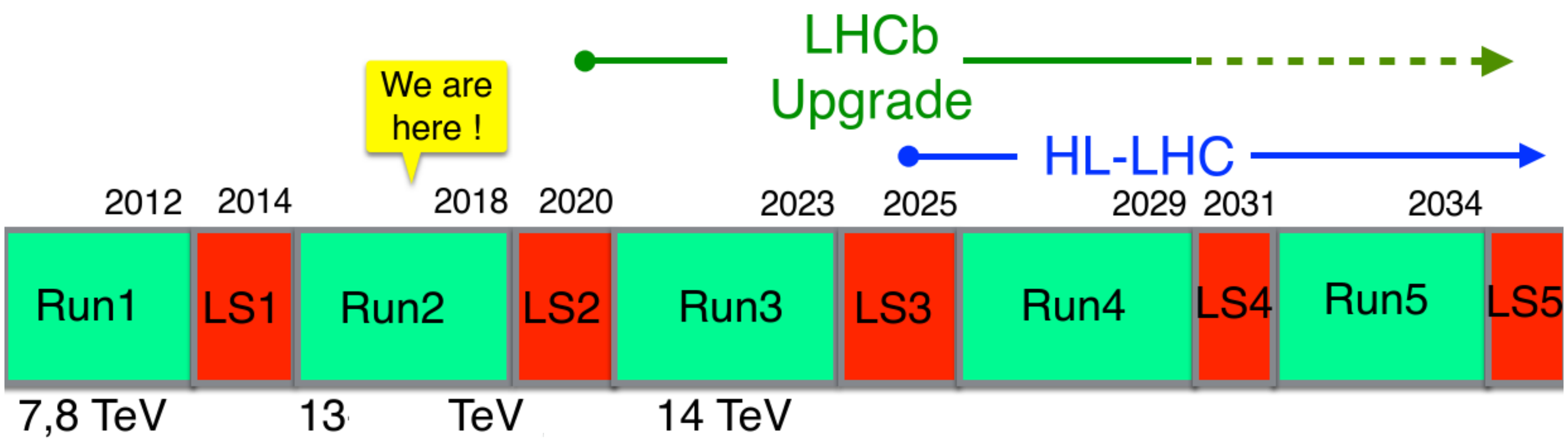
Further experimental input

- CMS have on-tape from 2018 an unbiased sample of 10^{10} B decays
- With an effective low p_T electron reconstruction, should get a very competitive number of e.g. $B^+ \rightarrow K^+ e^+ e^-$ signal candidates
- Expect systematics will be very different to those at LHCb e.g. presumably no trigger effect and very different material distribution (and hence brem effects)

Further into the future

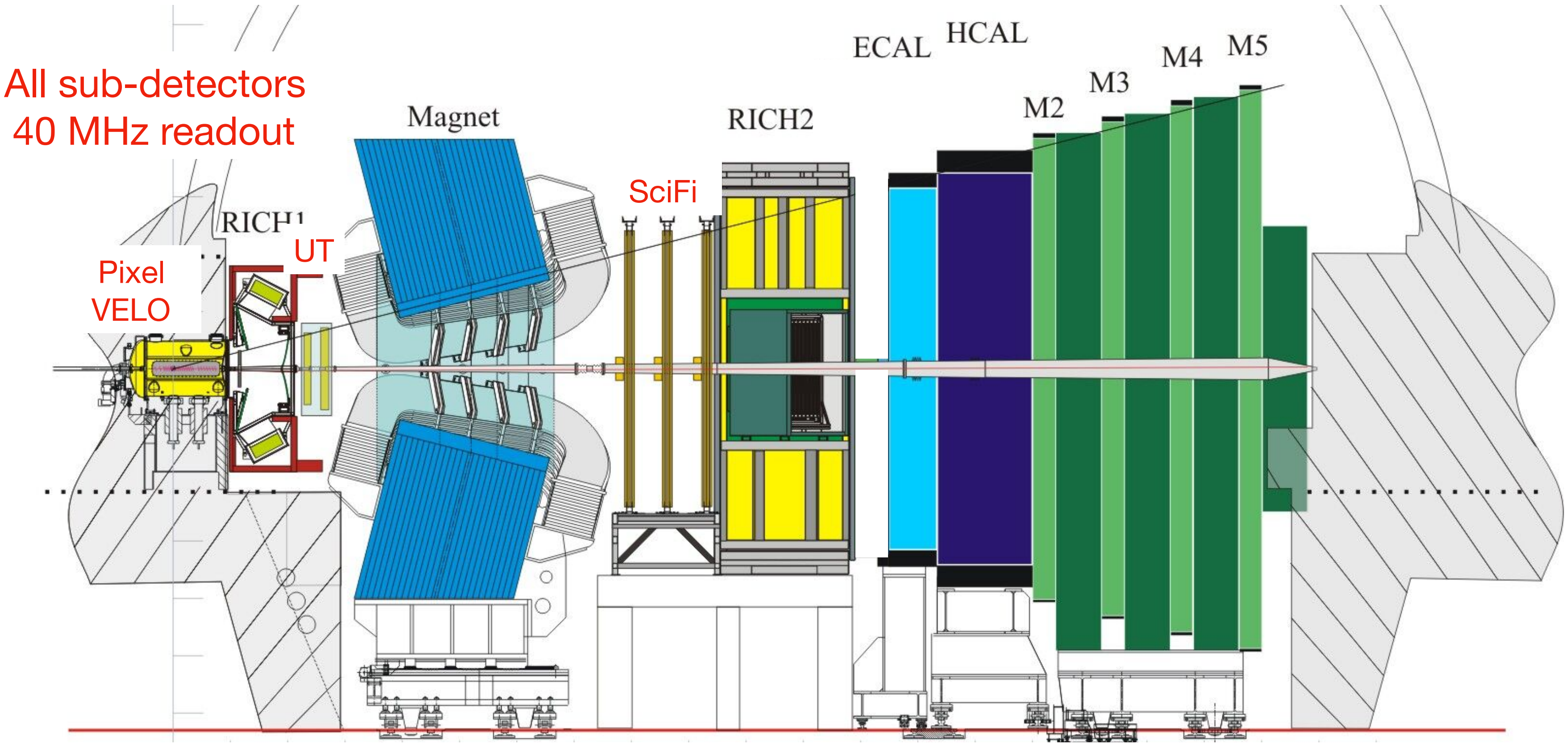
Further into the future

- Final year of Run-II data-taking
- LHC will then have a two year shutdown during which LHCb will install upgraded detector – from 2021-2030 this will allow ~25 fb^{-1} to be accumulated
- On same timescale, Belle2 physics data-taking will start



Phase I Upgrade

- Full software trigger to allow effective operation at higher luminosities with higher efficiency for hadronic decays
- Luminosity to be raised (x5) to $2\text{x}10^{33}$ $\text{cm}^{-2}\text{s}^{-1}$



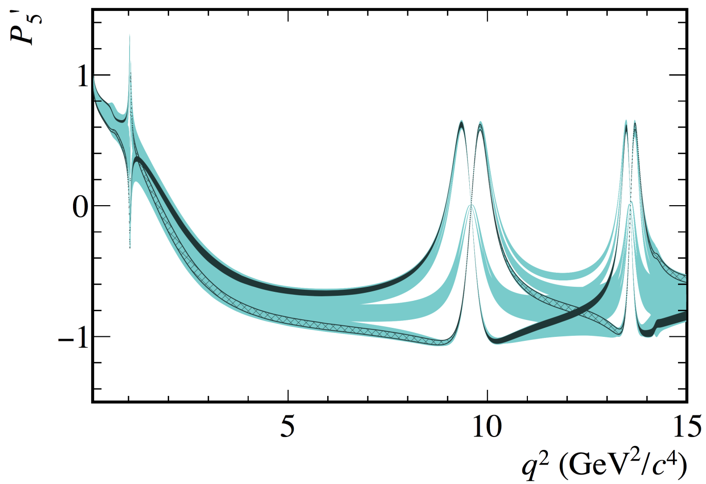
Future angular analysis

- Large dataset will enable us to parameterise and fit for form factors as part of fit to angular distribution, q^2
  - Could then simultaneously constrain BF(*) and angular observables to get Wilson coefficients

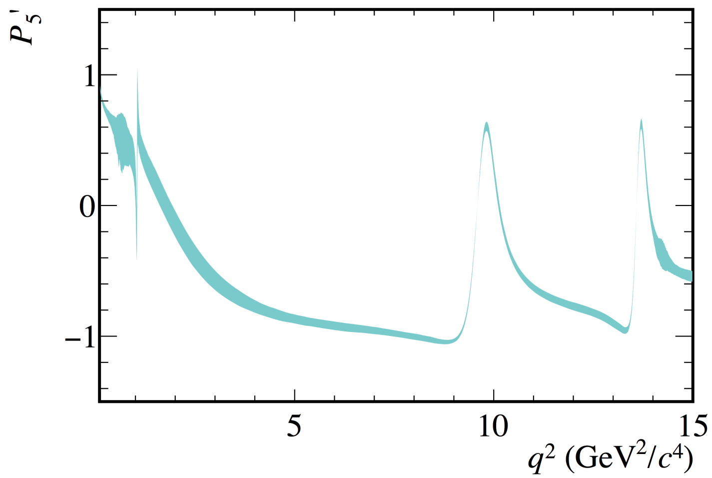
    (*) need Belle2 to improve knowledge of J/ψ normalisation modes

- Can help address residual questions about $c\bar{c}$:

Left: Current theory uncertainty,



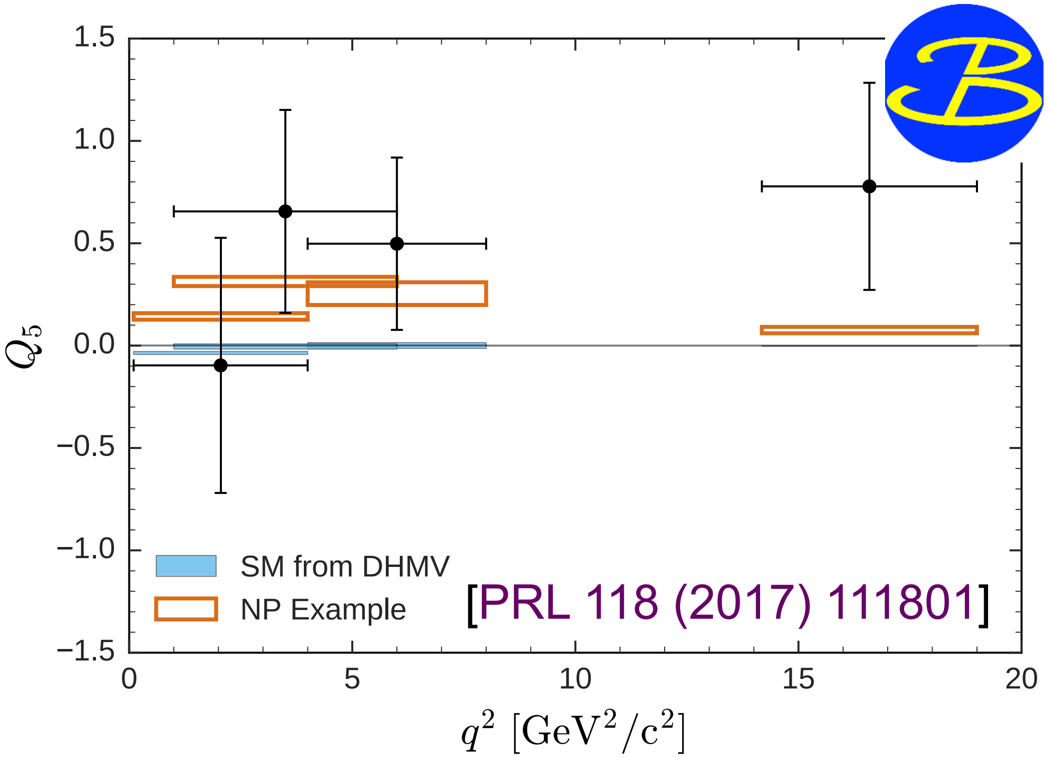
Right: Expected theory uncertainty using data

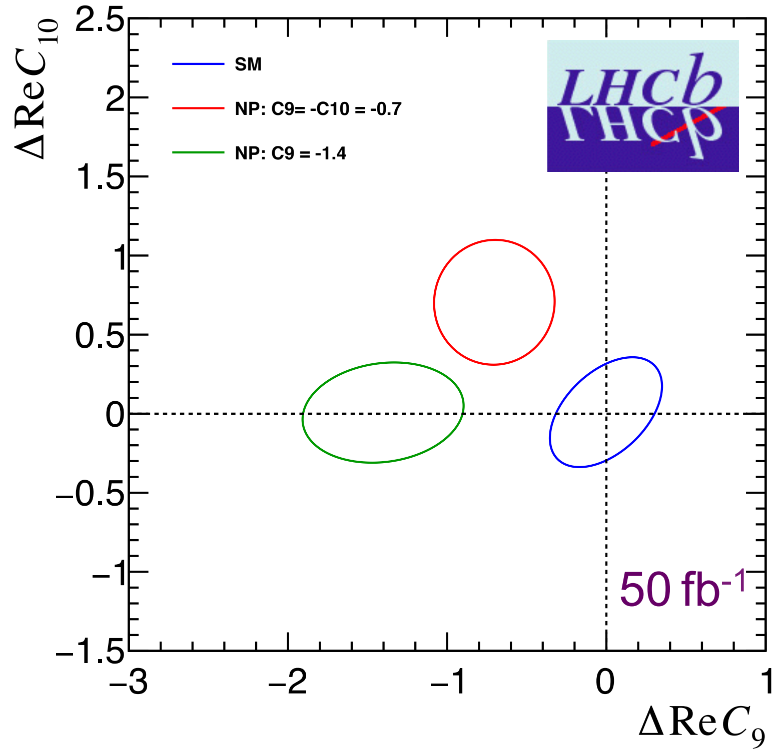


[EPJC (2018) 78: 453]

Future angular analysis

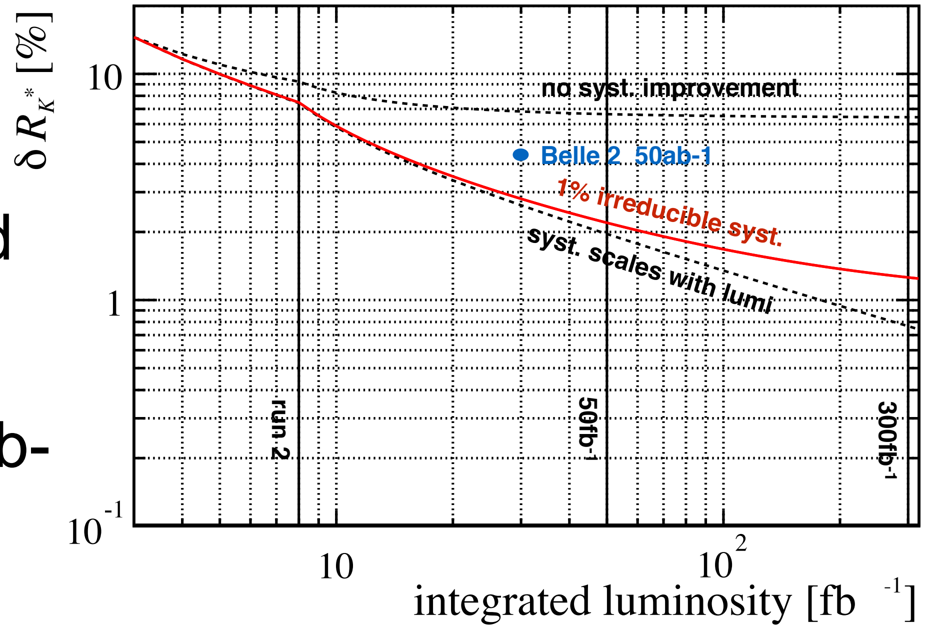
- Can make difference between $P_5'(\mu)$ and $P_5'(e)$ $\rightarrow$ Q_5
- Thus far, only done by Belle – angular analysis of $B^0 \rightarrow K^{*0}ee$ in progress at LHCb





Electron analyses

- Need to drive systematics down to ~1% level to get benefit from upgrade dataset
- Present largest systematic uncertainties will scale with luminosity, ditto data-derived corrections to simulation
- However, have to control sub-dominant uncertainties from e.g. modelling of bremsstrahlung

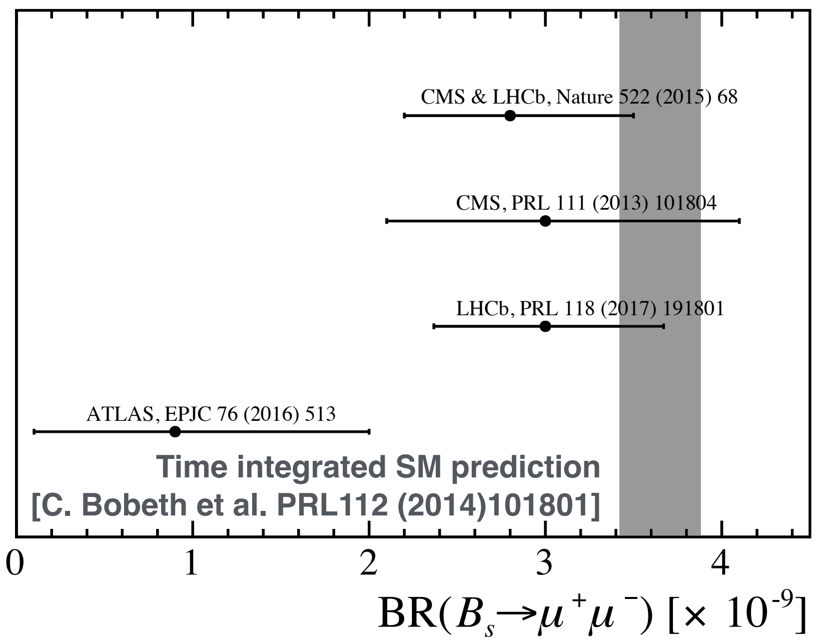


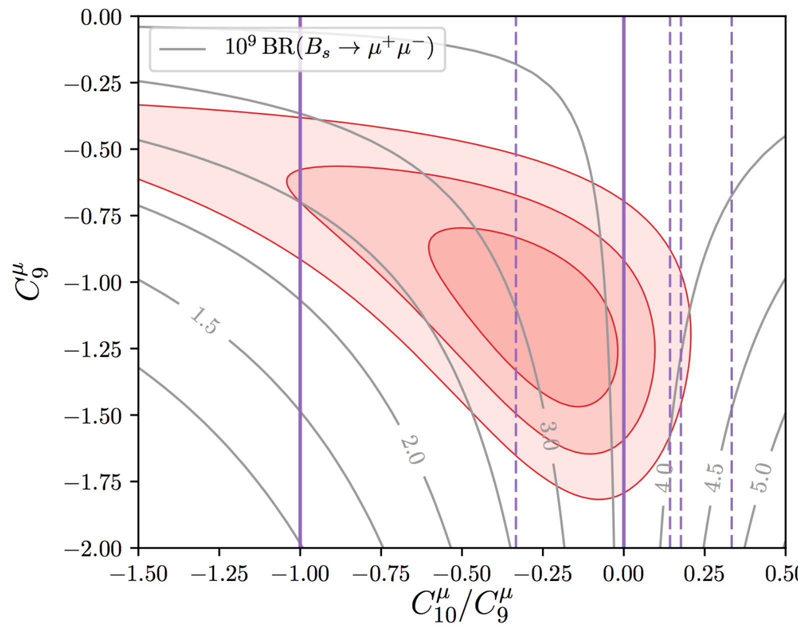
[CERN-LHCC-2018-027]

$B^0_s \to \mu^+\mu^-$ branching fractions

- Can explain anomalies with $C_9^{NP} = -C_{10}^{NP}$
- Would then expect to see an effect in $B(B^0_s \to \mu^+\mu^-)$ decays
- No evidence for any deviation from SM so far…

Recent atlas update ATLAS-CONF-2018-046



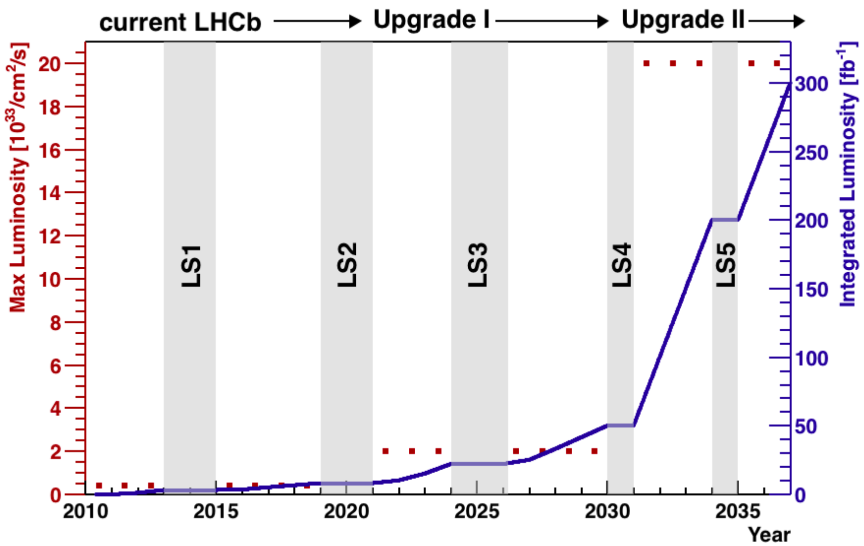


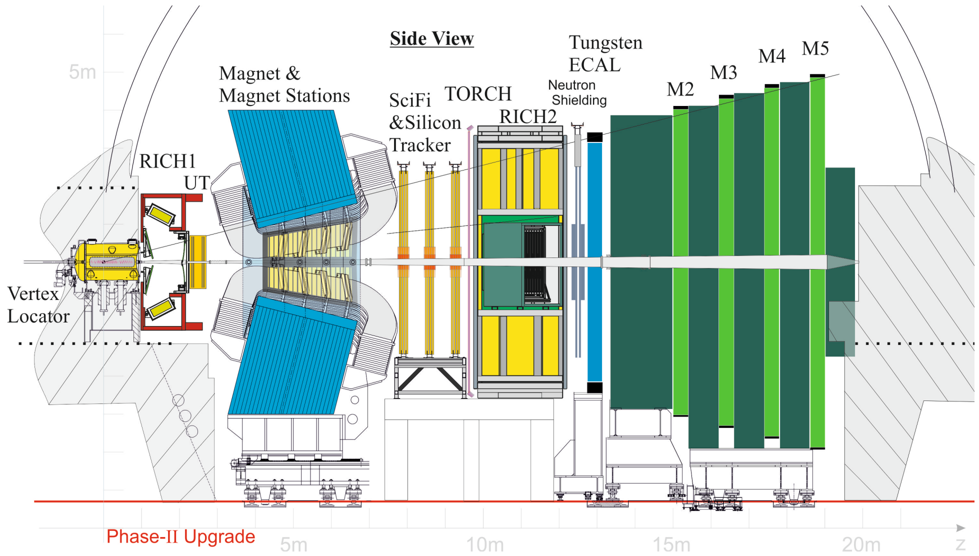
[PRD 96 (2017) 055008]

Far future

Phase-II Upgrade

- Physics case for LHCb phase-II upgrade presented in August, CERN research board have approved to go towards TDRs
- Target 300fb^{-1} in runs 5,6 – requires v. significant upgrade to cope with $2x10^{34}$ cm^{-2}s^{-1}

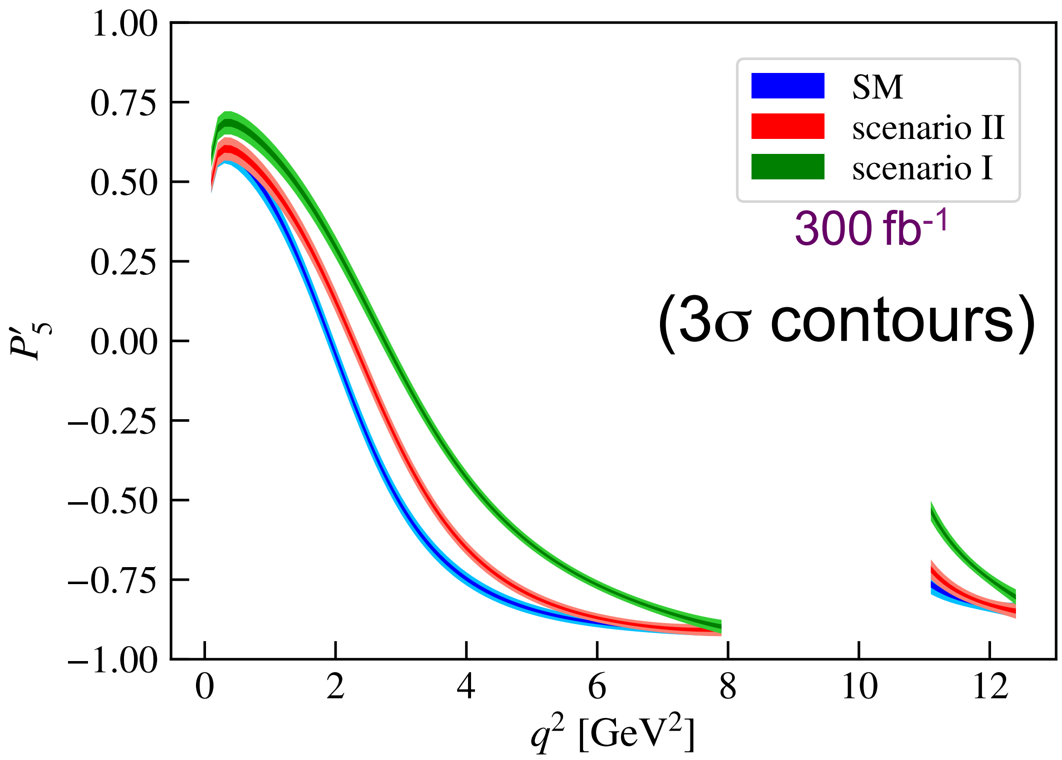




Upgrade projections (stat)

- Improvements in observables will have potential to distinguish between different NP models

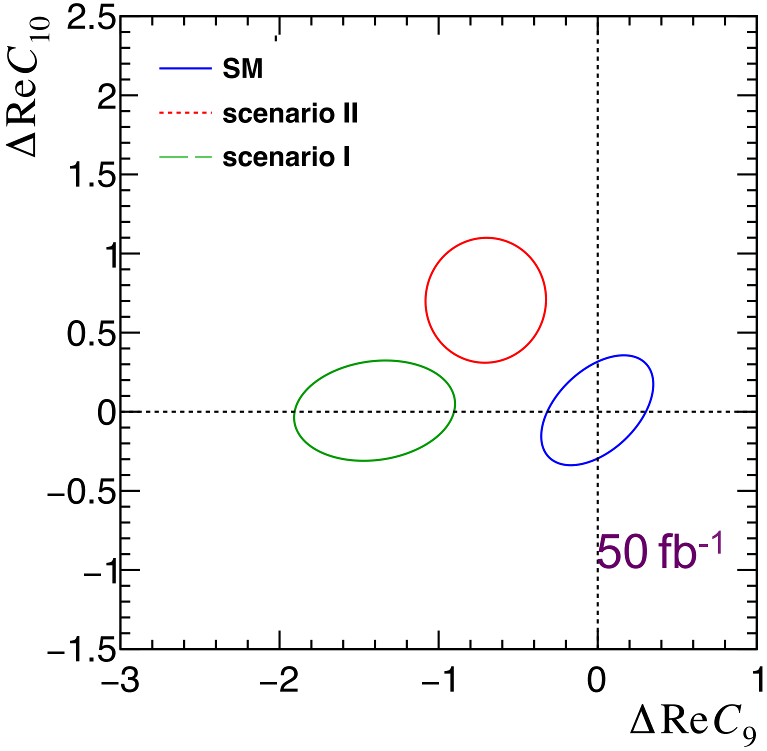
e.g. $\Delta C_9 = -\Delta C_{10} = -0.7$ vs $\Delta C_9 = -1.4$ (SM)

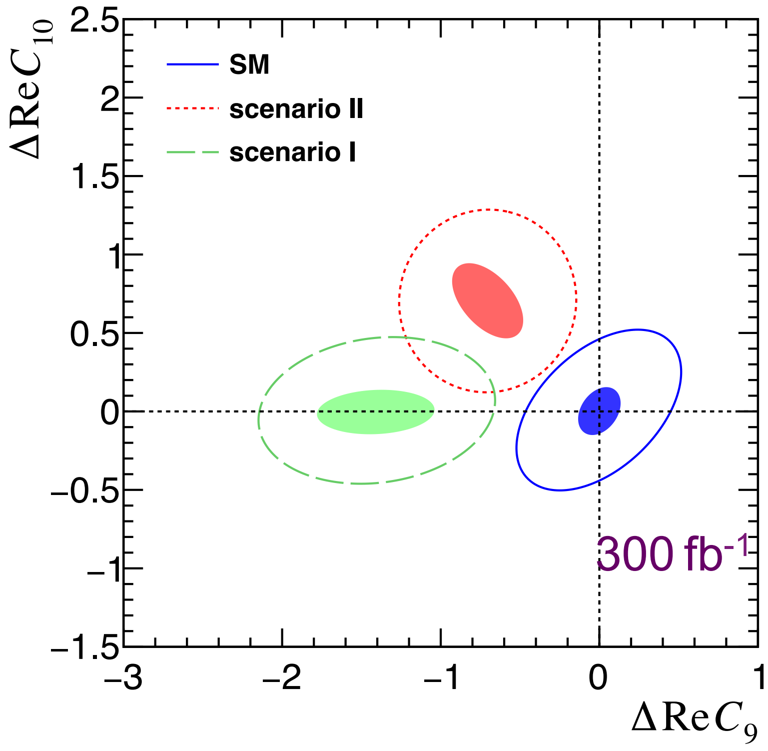


[CERN-LHCC-2018-027]

Upgrade projections (stat)

- Difference between C_9, C_{10} computed in electron and muon modes will discriminate between models

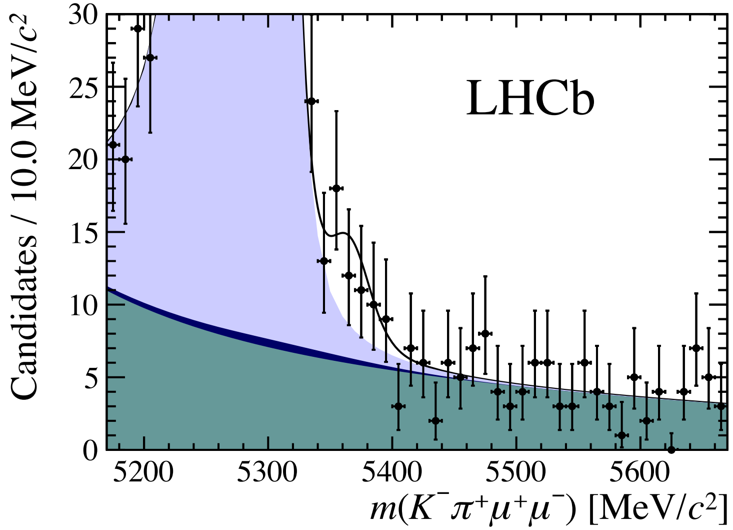


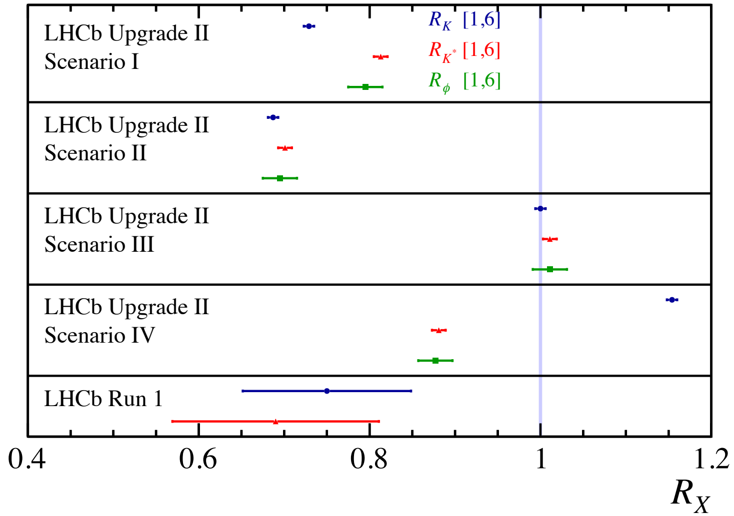


[CERN-LHCC-2018-027]

Upgrade-II measurements

- Step-change in experimental possibilities:
  - Measure b→d transitions with better precision than current b→s
  - e.g. angular analysis of $B_s^0 \to K^{*0}\mu\mu$, expect ~4300 candidates
  - e.g. can measure R_π to a few percent precision
  - Can access V_{ub} equivalents of $R_D(*)$ ratio
  - Can determine $B(B^0 \to \mu^+\mu^-)/B(B_s^0 \to \mu^+\mu^-)$ ratio to 10%
- Plus searches for lepton flavour, number and baryon number violating decays and a wide programme of CKM/mixing/spectroscopy





Conclusions

- Near-term updates should clarify the situation with the anomalies and can help constrain some of the theoretical issues
- Wide range of new measurements will be added to broaden the constraints on the underlying physics
- Phase-I upgrade will give ~25fb^{-1} dataset and a wide range of new measurements on same timescale as Belle2
- LHCb collaboration targeting a further 300fb^{-1} phase-II upgrade beyond this