Future prospects for LHCb and complementarity with Belle II

LIO International Conference on Flavour Physics, Lyon, 19th April 2018

Mitesh Patel (Imperial College London)
on behalf of the LHCb collaboration

Imperial College London

Introduction

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

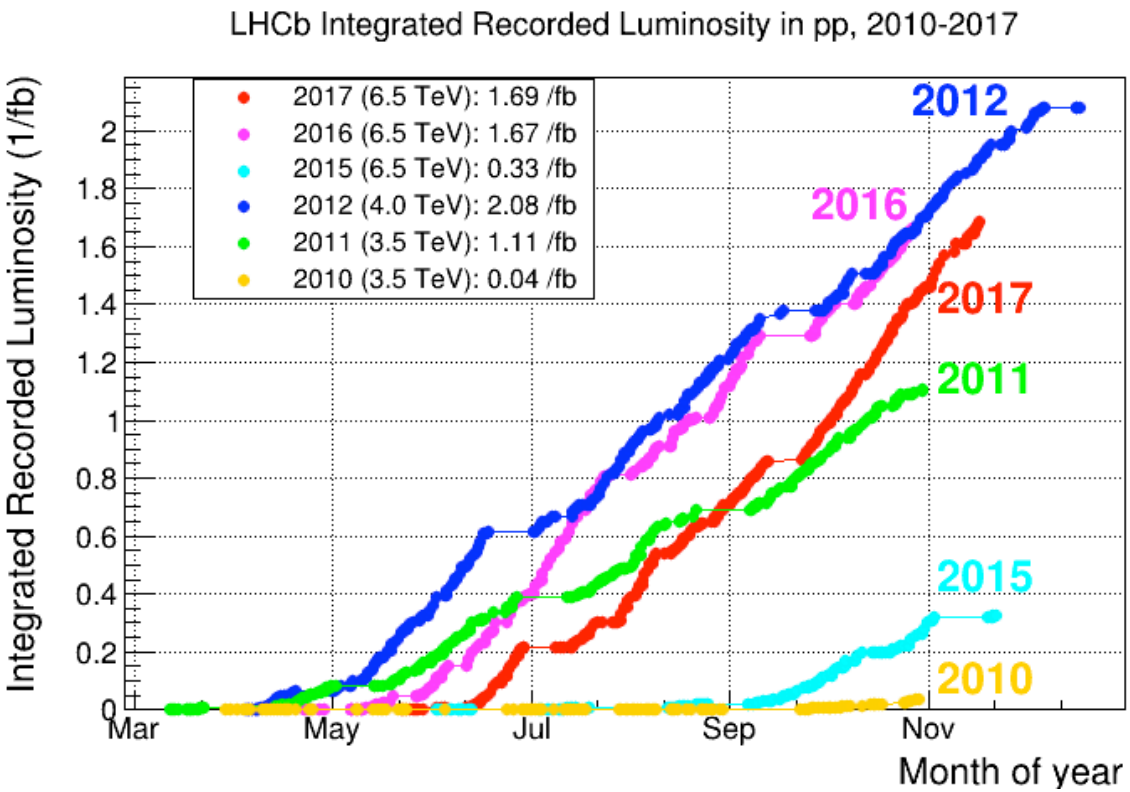
- Will try and say something about the future of these measurements

- Extent of discrepancies depends on several theoretical issues – will try and highlight where experiment can provide some future input into these issues

Outline

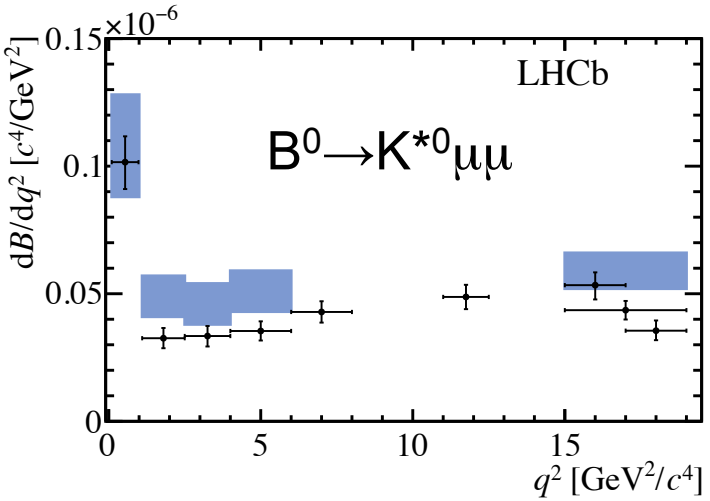
- Short term prospects
- Further into the future – LHCb upgrade phase I (2021-2030)
- Far future – LHCb upgrade phase II (2031...)

Short term prospects

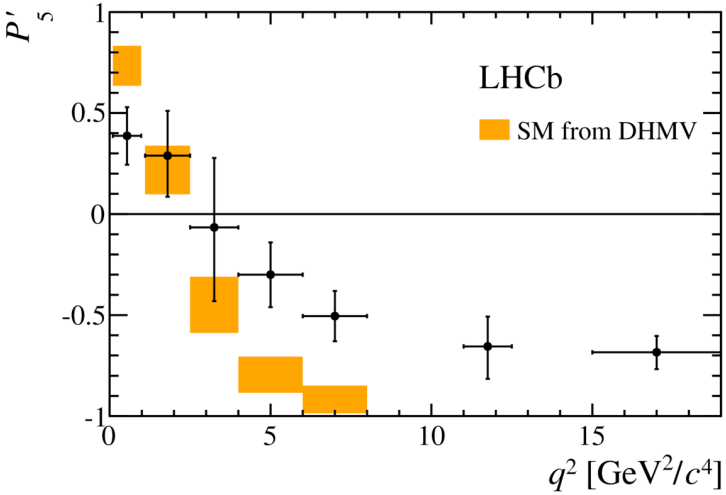


Angular measurements

- Updated angular measurements of $B^0 \to K^{*0}\mu\mu$ in progress and will remain statistically limited – can expect a ~$\sqrt{2}$ 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

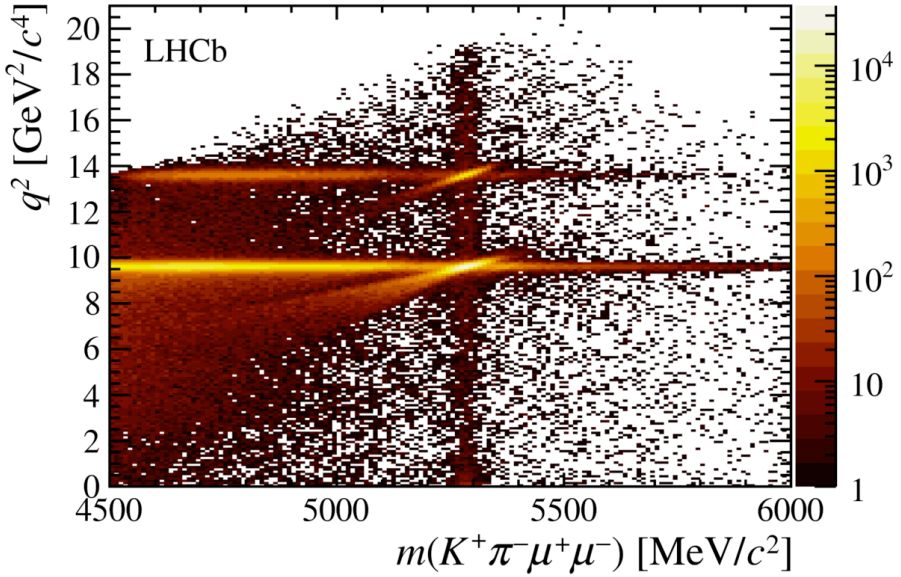


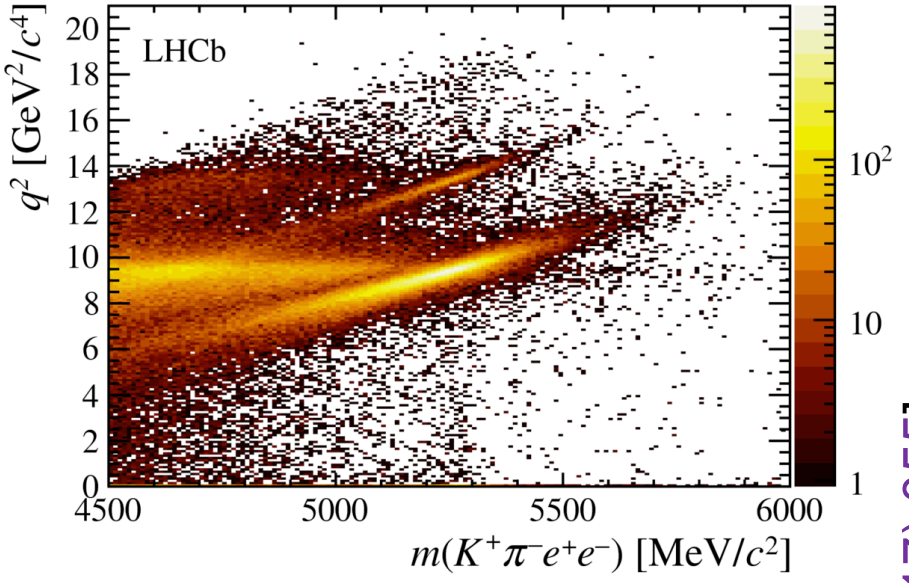
[JHEP 11 (2016) 047, JHEP 04 (2017) 142]

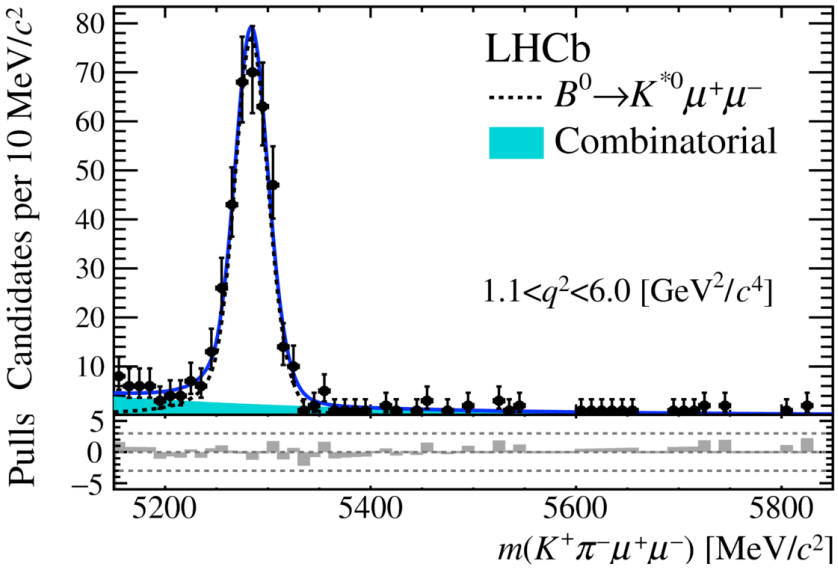


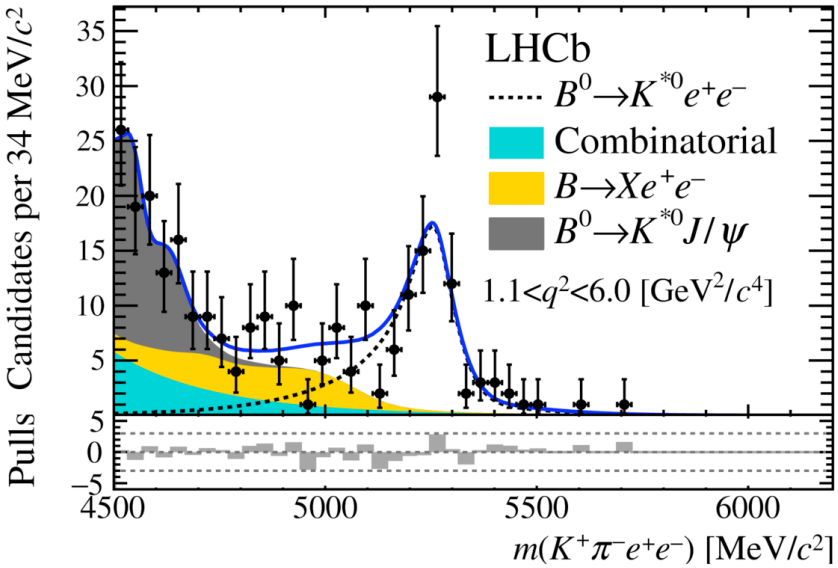
[JHEP 02 (2016) 104]

R_X – experimental issues







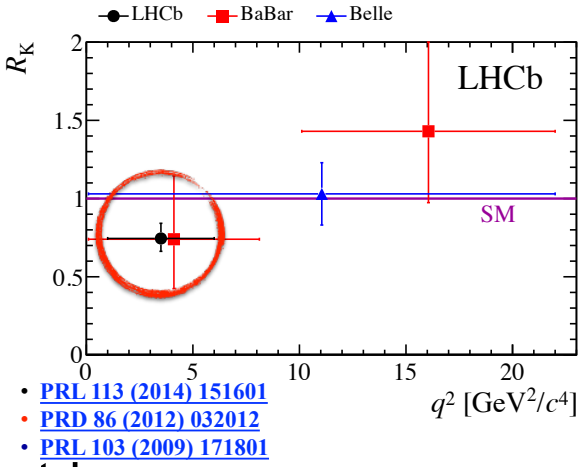


[JHEP 08 (2017) 055]

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

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



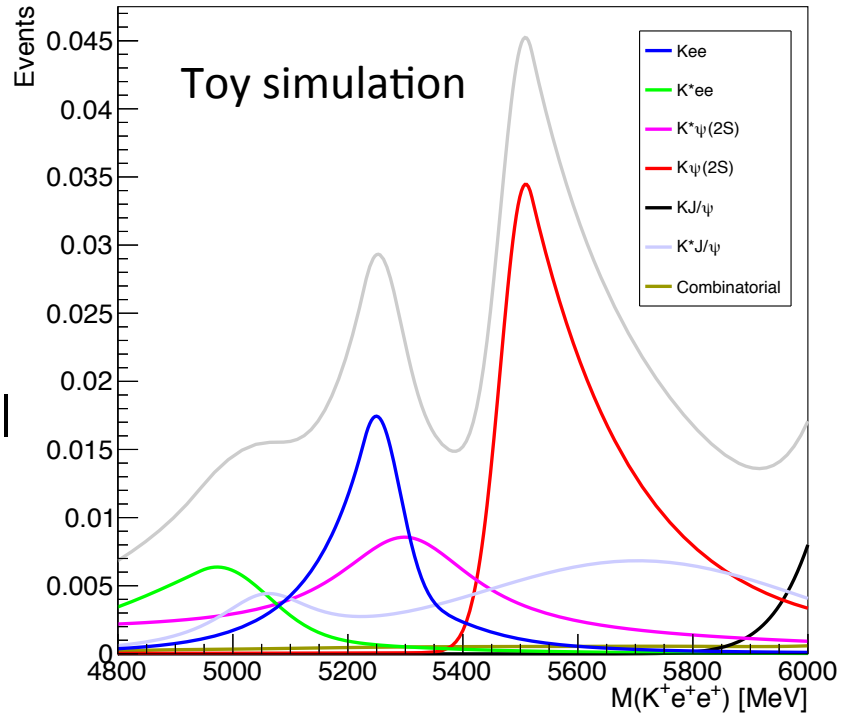
- Work in progress to update with part of additional data already have in-hand
  - Improvements to offline processing
  - Run-II data (2015,16) gives 0.3+1.6 fb^{-1} but, with nearly twice cross-section, slightly better trigger : ~250 → ~800 $B^+ \to K^+e^+e^-$ candidates ($1.0<q^2<6.0$ GeV^2)

→ Can expect stat. error on R_K to go down a factor ~1.8

- Systematics likely to differ but expect to be data-driven
- Also have (in-hand) further 1.7fb^{-1} from 2017

R_K update – other q^2 regions

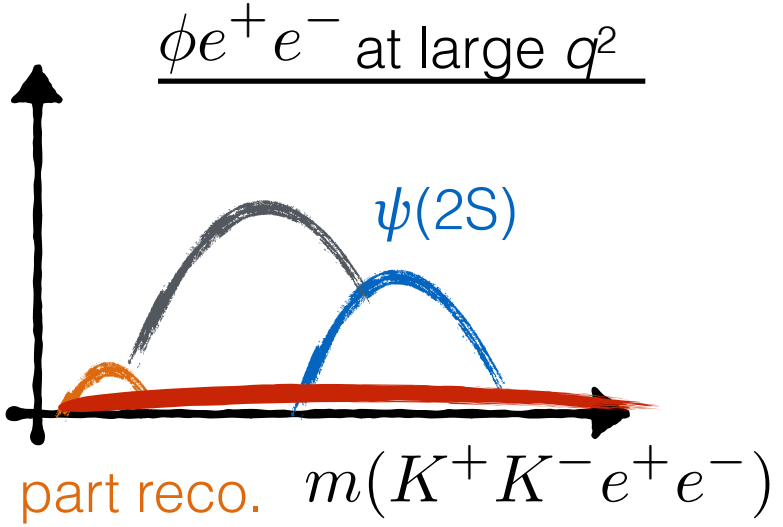
- Little signal with $q^2<1.0$ GeV^2 (no photon pole)
- Can add high q^2 bin – difficulty same for R_K and R_K*
  - Rare decays with higher K(*) resonances can leak into signal region from below
  - ψ(2S)K* decays can leak into signal region on the upper side
  - Signal sandwiched between these and hence difficult to fit reliably



R_ϕ

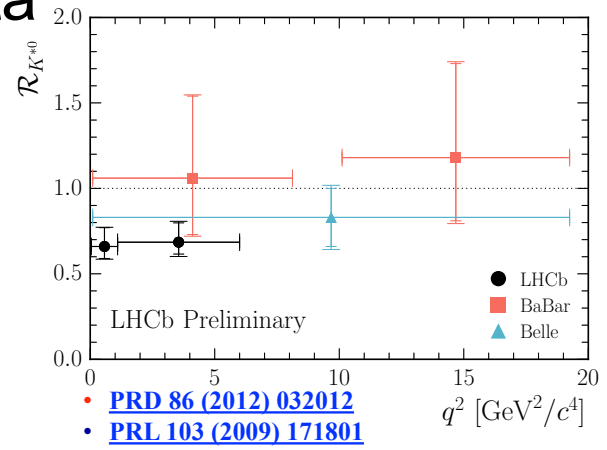
- Can make analogous measurements using $B_s \to \phi l^+ l^-$ decays $\rightarrow R_\phi$

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



R_K^* update

- 3fb^{-1} Run-I analysis found
  - ~90 $B^0 \to K^{*0} e^+ e^-$ candidates in $0.045 < q^2 < 1.1$ GeV^2 and ~110 $B^0 \to K^{*0} e^+ e^-$ candidates in $1.1 < q^2 < 6.0$ GeV^2
- Analysis will be updated with Run-II data
  - Improvements to offline processing already included in most recent result
  - Can expect to gain from further 0.3+1.6(+1.7) fb^{-1} data (at twice cross-section)
  - Again, expect to be stat. limited



- → Can expect existing errors to go down a factor ~1.5

Further R_X analyses

- Updates should be sufficient to confirm any discrepancy with real significance, independent of (very important) combination with angular, muon mode BF data etc.

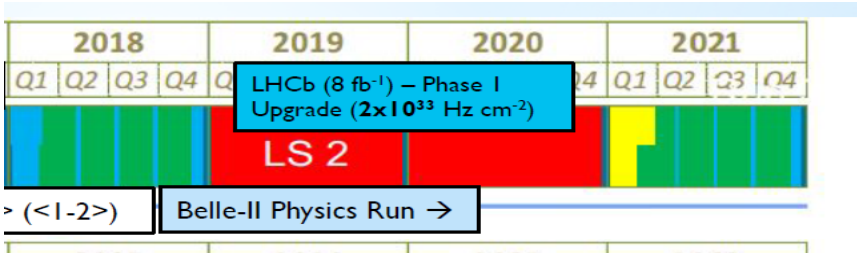
- Several additional final states are under study : pK, $K\pi\pi$, higher K* resonances, K_S and K^{*+} and will follow
  - Run I statistics *in muon modes*:

$pK\mu\mu$	~600
$K\pi\pi\mu\mu$	~360
$K^{**}\mu\mu$	~230
$K_S\mu\mu$	~30
$K^{*+}\mu\mu$	~40

Further into the future

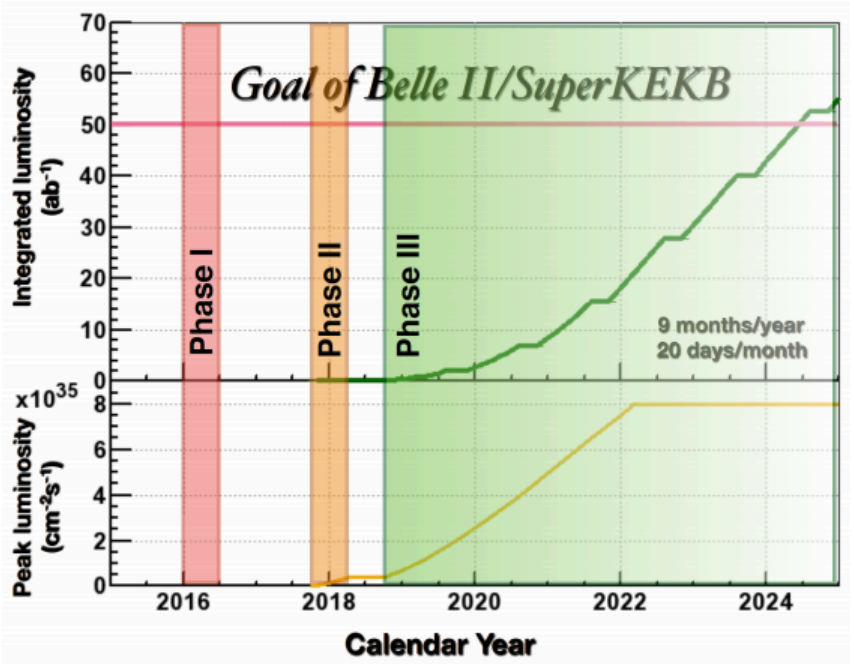
Further into the future

- Final yr of Run-II data-taking is just starting in earnest:
  - https://lbevent.cern.ch/EventDisplay/index.html



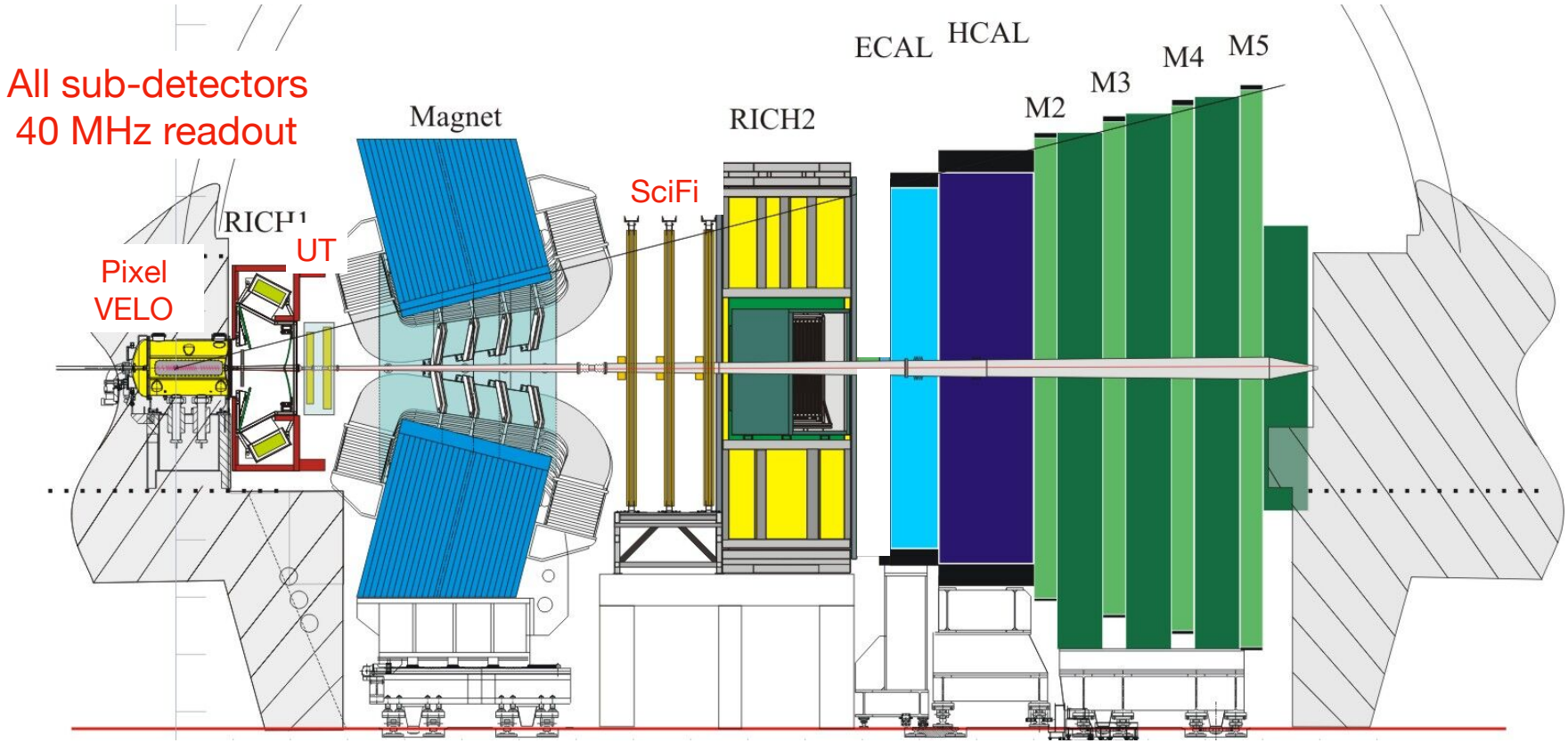
- LHC will then have a two year shutdown during which LHCb will install upgraded detector – from 2021-2030 this will allow 50fb^{-1} to be accumulated

- On same timescale, Belle2 physics data-taking will start



Phase I Upgrade

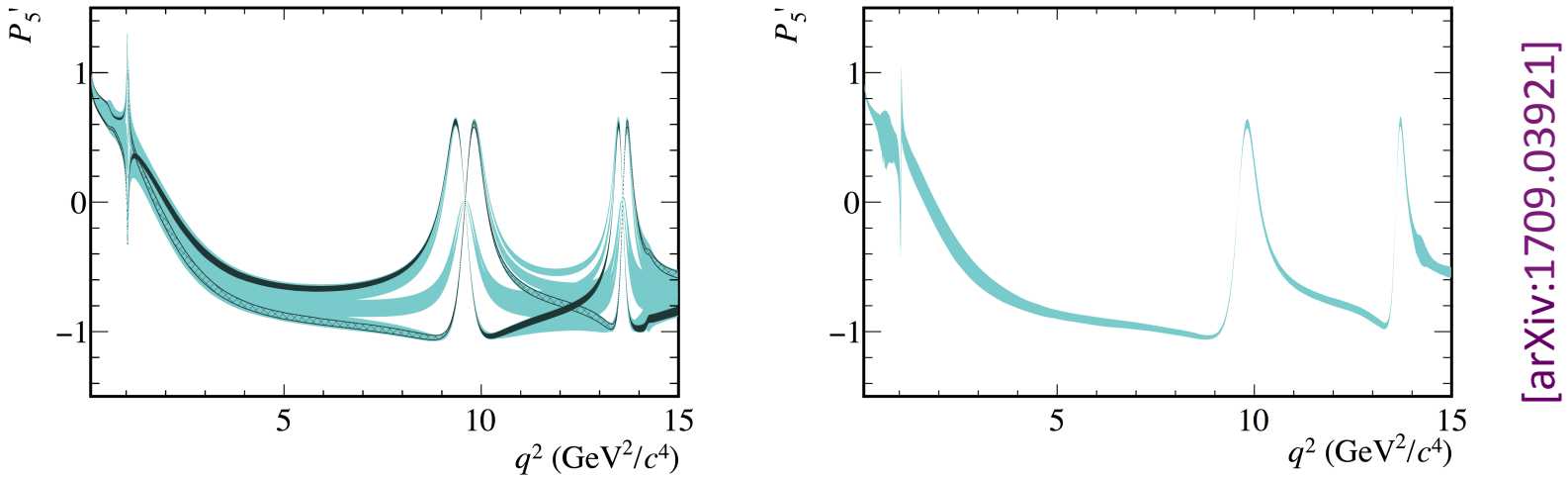
- Full software trigger to allow effective operation at higher luminosities with higher efficiency for hadronic decays
- Luminosity to be raised (x5) to 2×10^{33} $cm^{-2}s^{-1}$



Future angular analysis

- Large dataset would 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 normaln modes
- Will help address residual questions about $c\bar{c}$:

Left: Current theory uncertainty, Right: Expected theory uncertainty using data

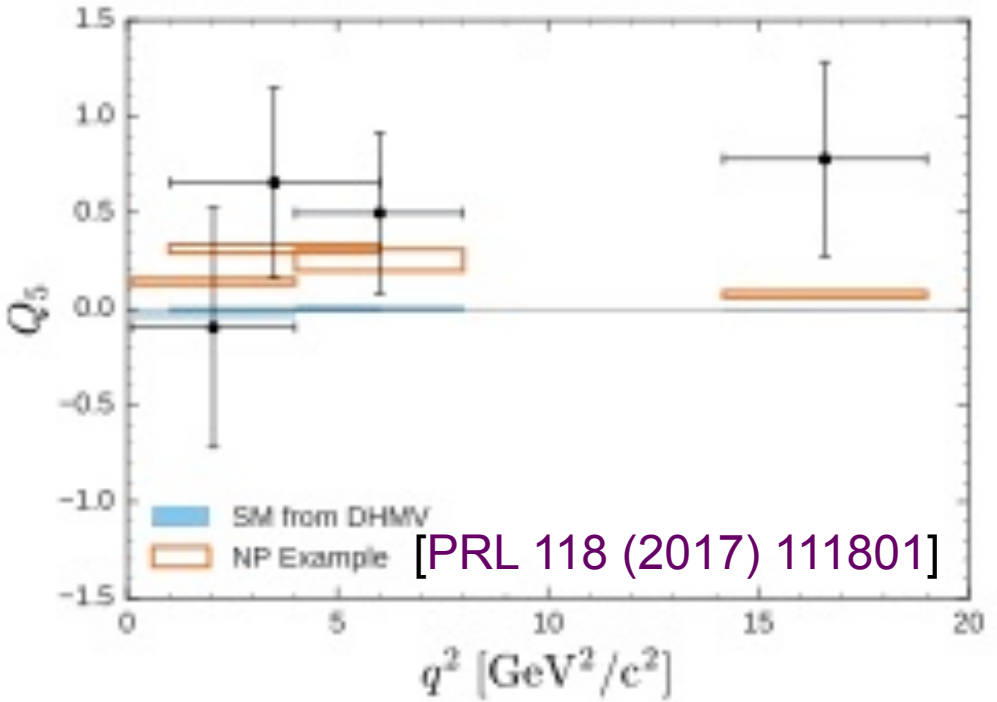


[arXiv:1709.03921]

Future angular analysis

- Can make difference between $P_5'(e)$ and $P_5'(\mu)$ → Q_5

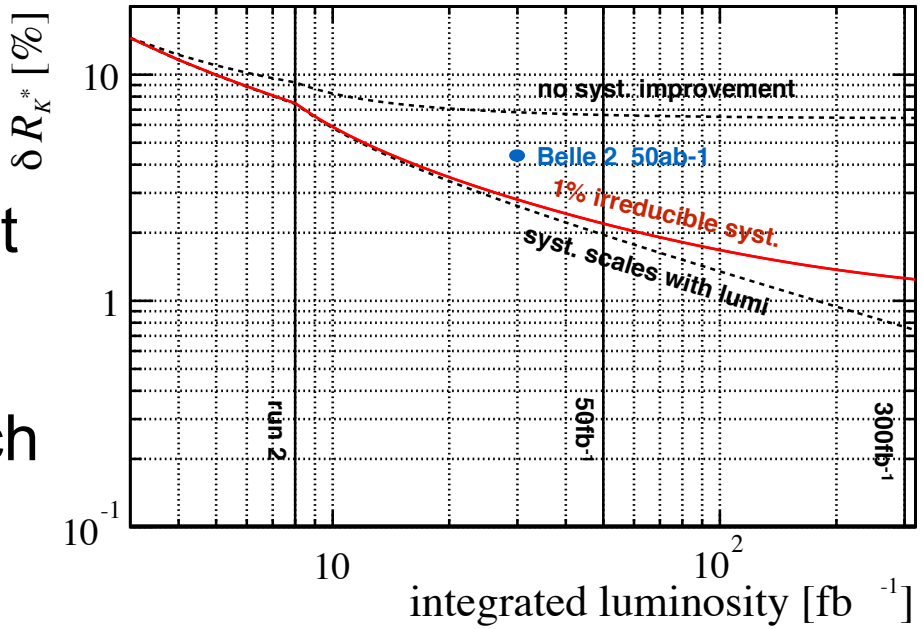
- Thus far, only done by Belle – full angular analysis of $B^0 \to K^{*0} ee$ in progress at LHCb

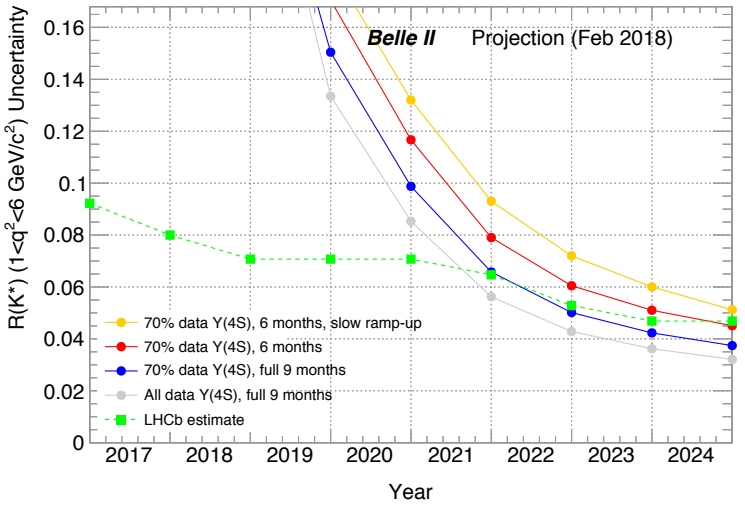


[PRL 118 (2017) 111801]

Electron analyses

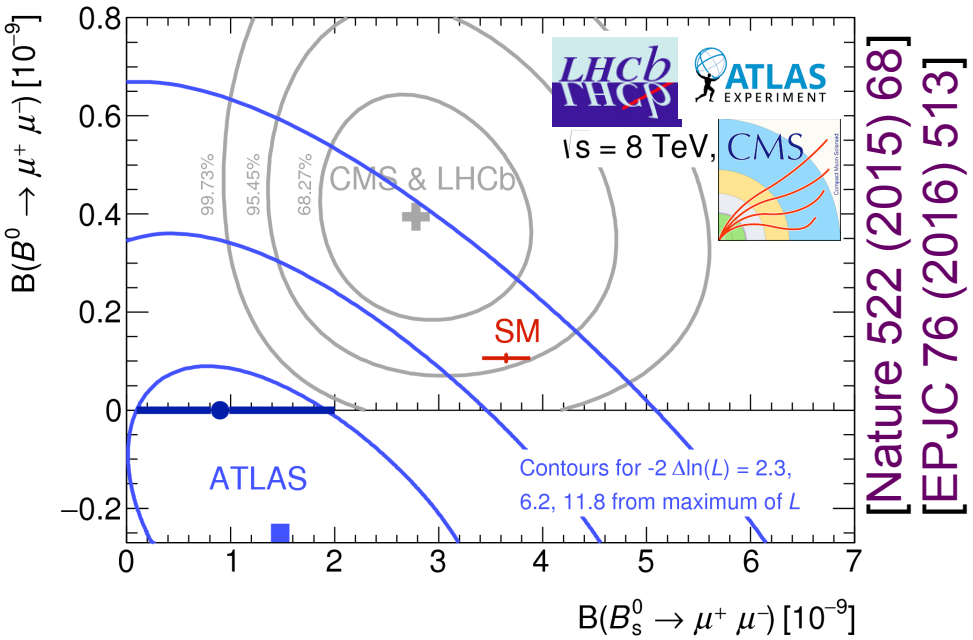
- Need to drive systematics down to ~1% level to get benefit from upgrade dataset
- Large uncertainty from modelling backgrounds which can study with data and hence will scale with luminosity, ditto data-derived corrections to simulation
- However, sub-dominant uncertainties from e.g. modelling of bremsstrahlung



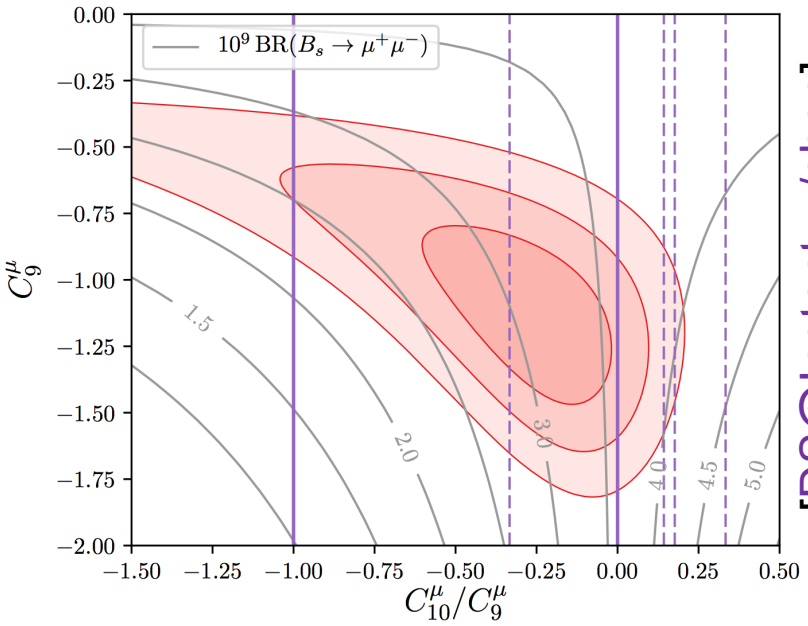


$B^0 \to \mu^+\mu^-$ branching fractions

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



[Nature 522 (2015) 68]
[EPJC 76 (2016) 513]

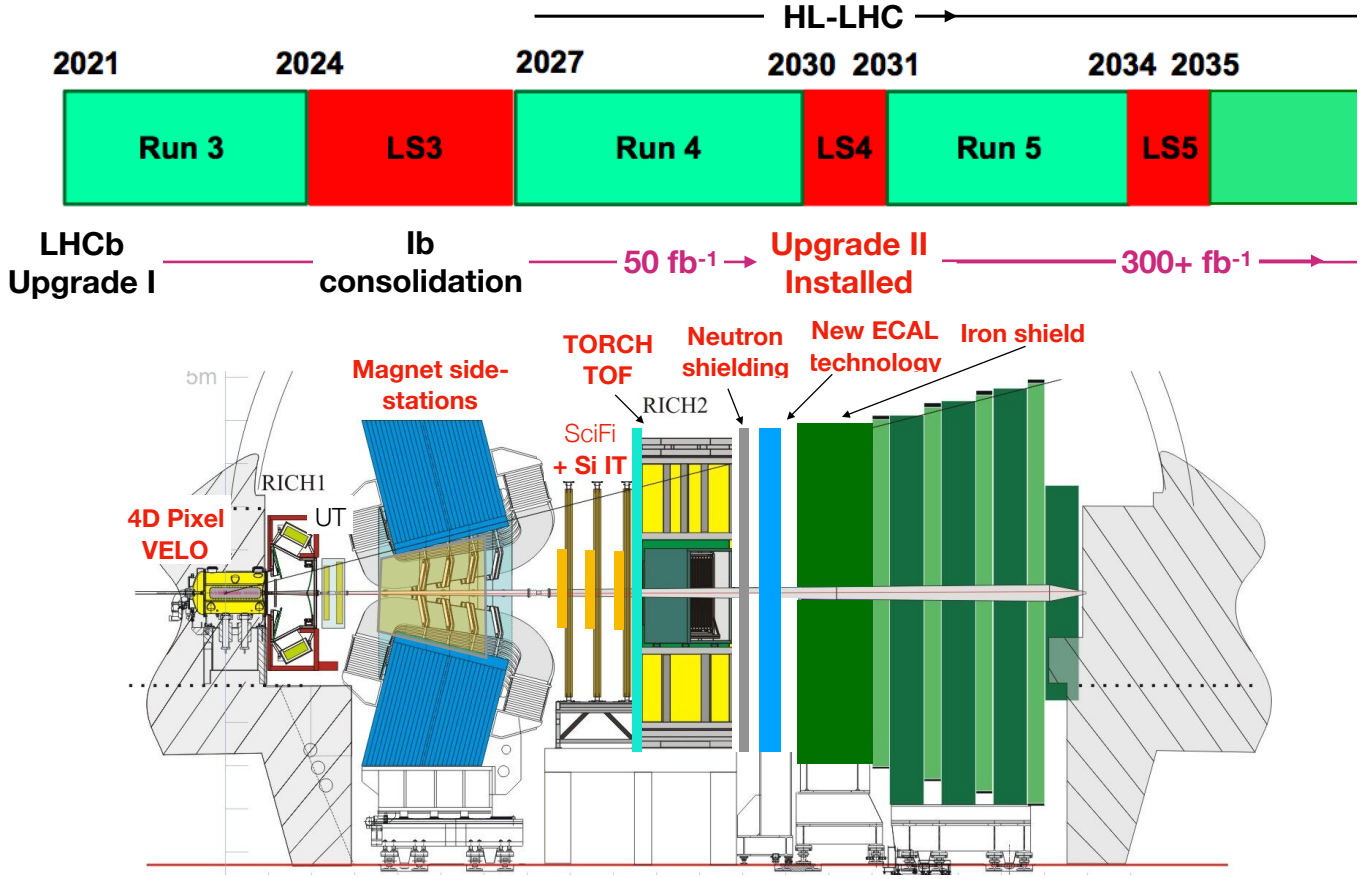


[DS@Instant w/shop]

Far future

Phase-II Upgrade

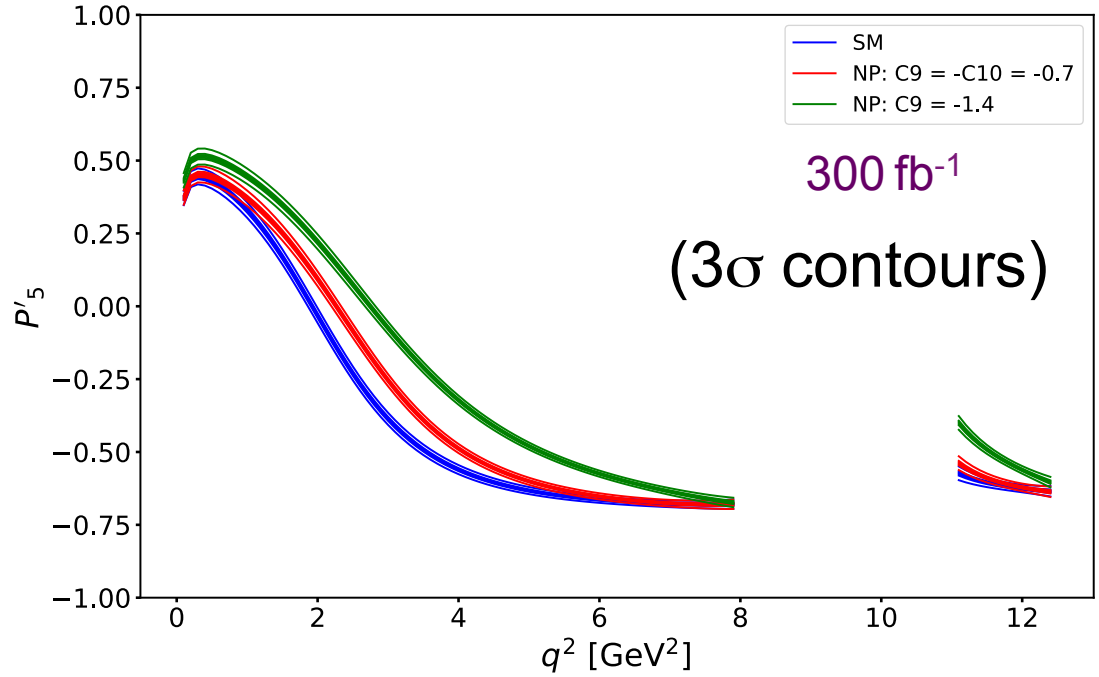
- Expression of interest for LHCb phase-II upgrade submitted to the LHCC in February 2017
- Target 300fb^{-1} in runs 5,6 – requires v. significant upgrade



Upgrade projections (stat)

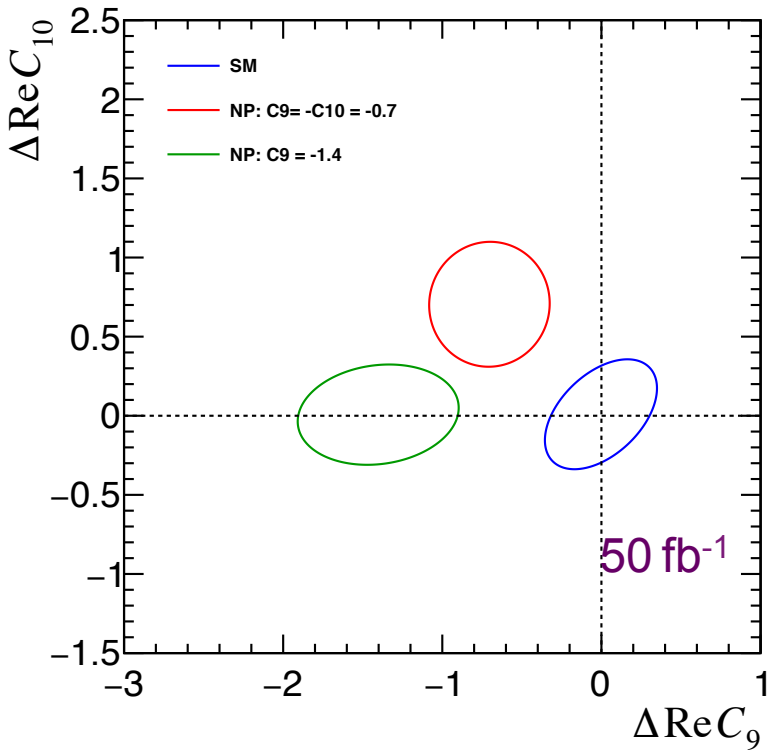
- Improvements in observables will have potential to distinguish between different NP models

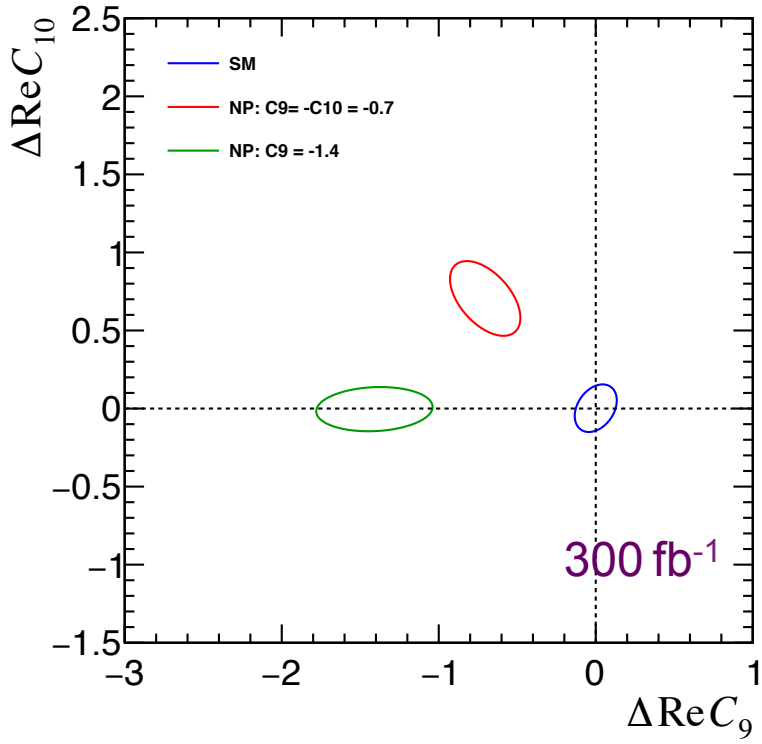
  e.g. $\Delta C_9 = -\Delta C_{10} = -0.7$ vs $\Delta C_9 = -1.4$ (SM)



Upgrade projections (stat)

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

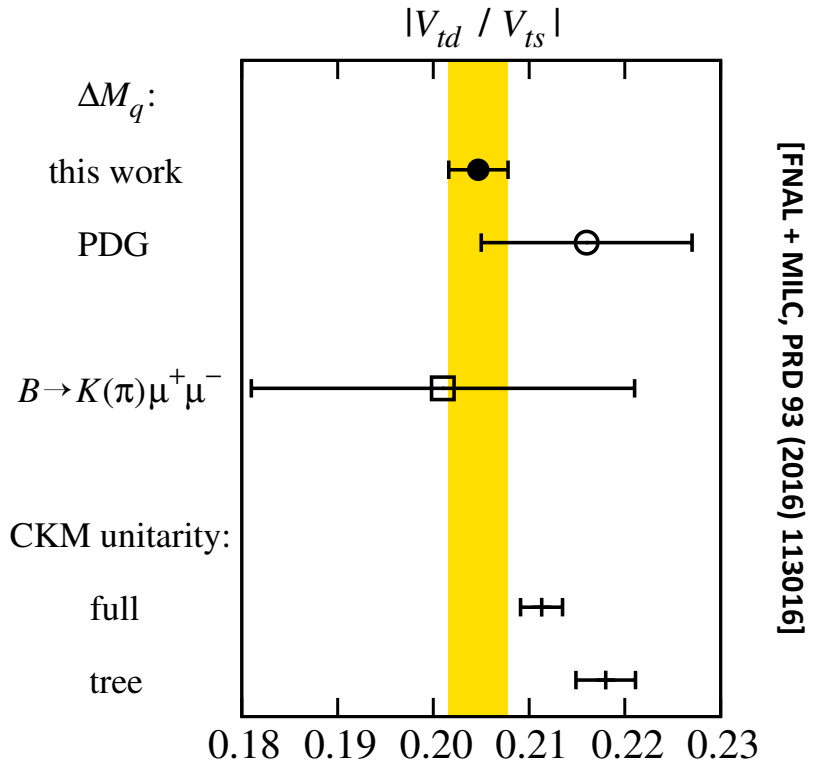




(3σ contours)

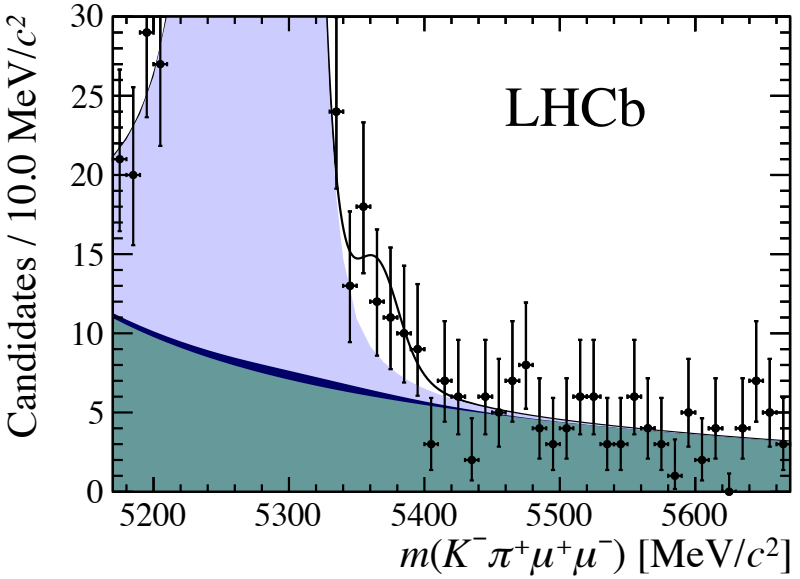
Testing MFV with b→dll

- BF($B^+ \to \pi^+ ll$) / BF($B^+ \to K^+ ll$) and lattice input → $|V_{td}/V_{ts}|^2$
  - 300fb^{-1} will give order of magnitude smaller experimental error but need improvement in lattice also
- B^0 equivalent involves $\rho^0 \mu\mu$, complicated by multiple $\pi\pi$ resonances
- B^0_s equivalent involves $K^{(*)0} \mu\mu$



Testing MFV with b→dll

- CKM suppressed $B_s^0 \to K^{*0}\mu\mu$ will enable full angular analysis with comparable precision to Run-1 $B^0 \to K^{*0}\mu\mu$
  - Simultaneous fit of B^0 mode will help separate B_s^0 and B^0 angular observables but improved mass resolution would clearly help



- $B^0 \to \rho^0\mu\mu$ requires flavour tag., also multiple $\pi\pi$ resonances
  - $B^+ \to \rho^+\mu\mu$ – would avoid flavour tagging but gives π^0
  - $\Lambda_b \to p\pi\mu\mu$ – would similarly suffer from (many) $p\pi$ resonances

Conclusions

- Interesting set of anomalies observed in B decays
- Near-term updates should clarify the situation 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 50fb^{-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