Measurements with b→sll and b→dll

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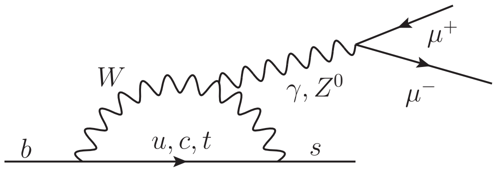
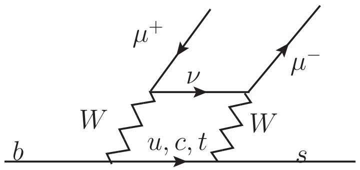
LHCb

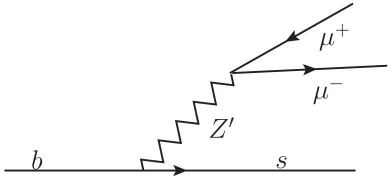
Introduction

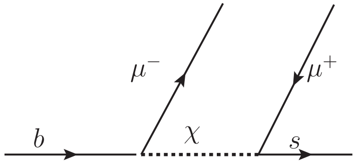
- Rare b→(s,d)ll decays sensitive to NP in O_7, O_9 and O_{10} operators

- Can measure amount of these different kinds of couplings to different quarks e.g. b→s vs b→d; and different leptons b→qee vs b→qμμ (b→qττ?)





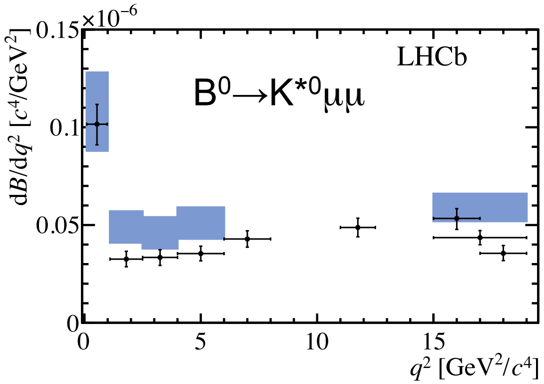




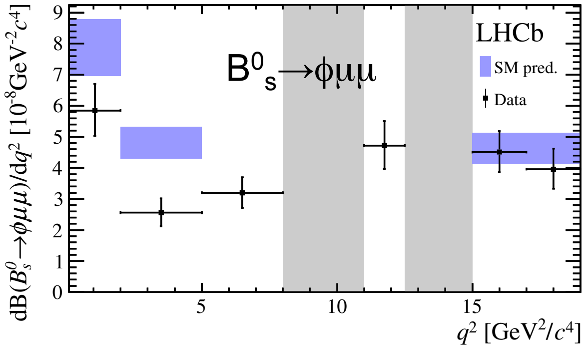
Branching Fractions

- Dominant theory uncertainties from form factors
  - BF *already* have comparable theory/experimental errors
  - Lattice will improve at high q^2 but not a revolution

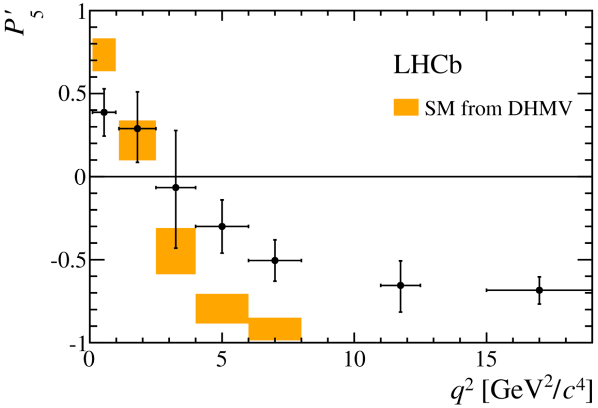
- To go beyond this, measure angular observables
  - Construct observables where form factors cancel to some greater or less extent e.g. the infamous P_5'



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



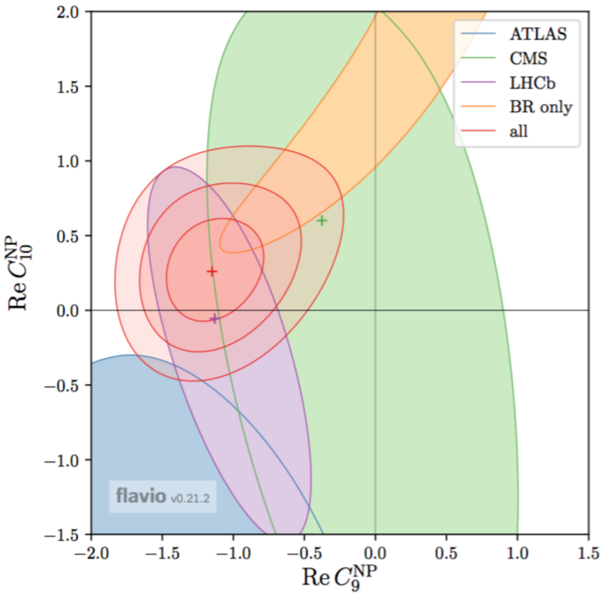
[JHEP 09 (2015) 179]

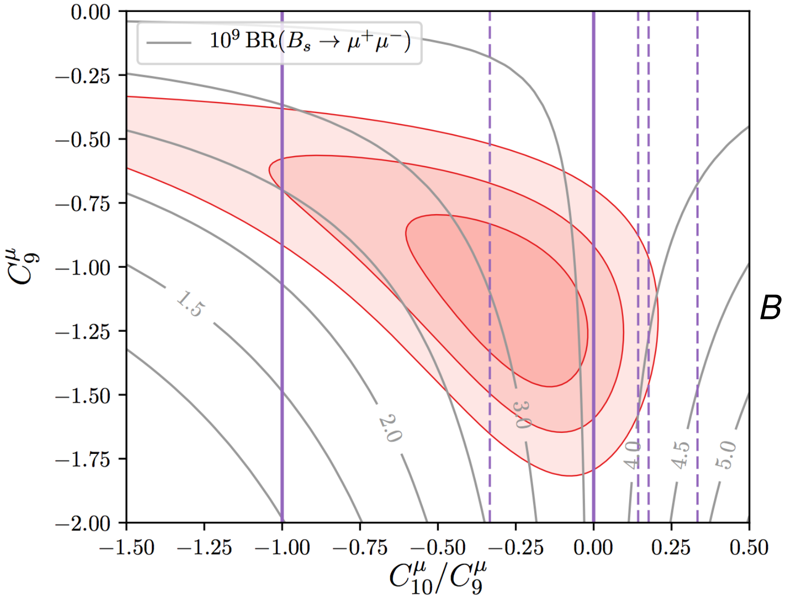


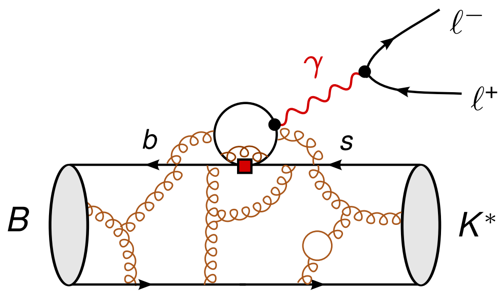
[JHEP 02 (2016) 104]

Reminder – present status

- Existing discrepancies serve to illustrate power - constrain mass-coupling plane of NP models e.g. with LQ
  - explanations with only on b-s coupling → O(TeV) LQ;
  - with full couplings can have O(30TeV) LQ
- Tensions observed have exposed theory limitations e.g. ΔC_9 effect from $c\bar{c}$ loops



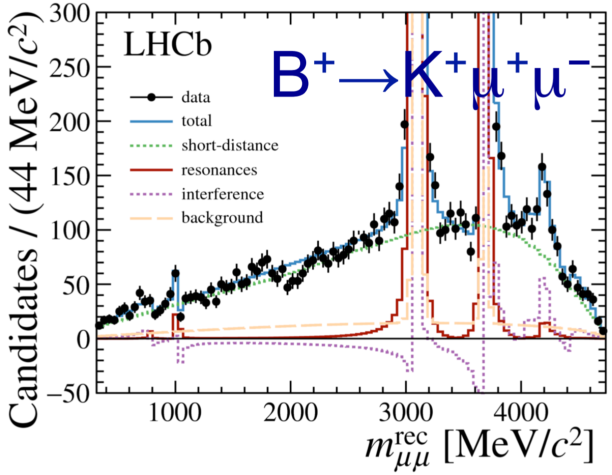




Analysis in the upgrade era

- 50 (300) fb^{-1} 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

- Similarly, if can agree modelling with theory community, fit of interference resonances/rare decay will tackle $c\bar{c}$ loop issue



$B^+ \to K^+\mu^+\mu^-$

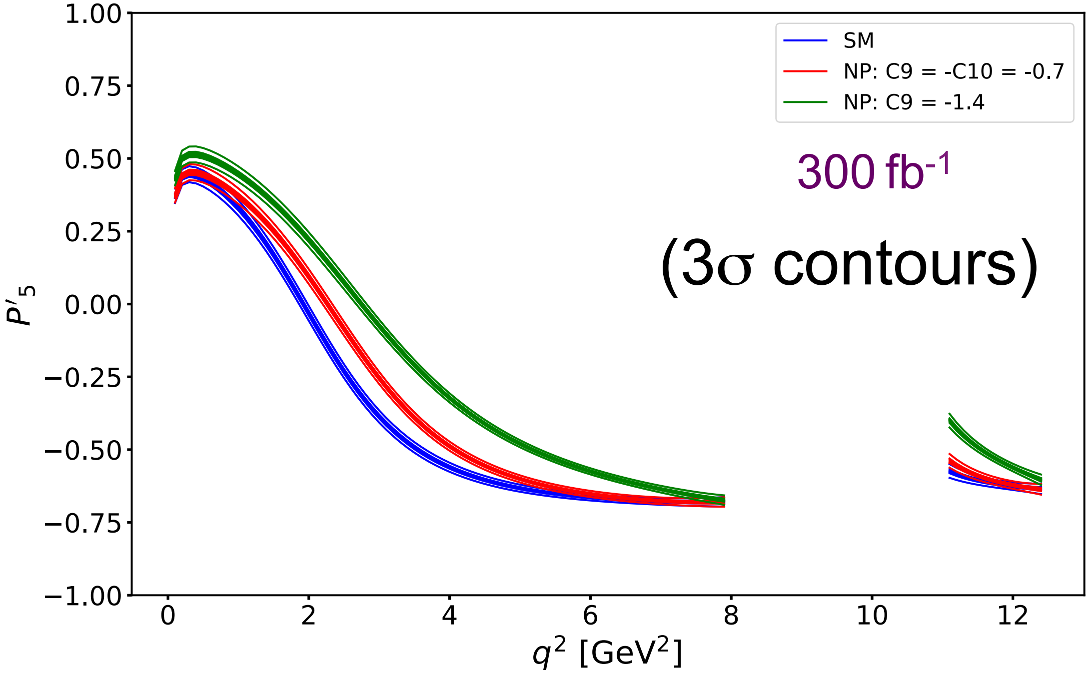
[EJPC (2017) 77:161]

- For μ channels, detector considerations are as might expect - maintain PID performance and mass resolution; vertex isoln important for rejecting cascade backgrounds

Upgrade projections (stat)

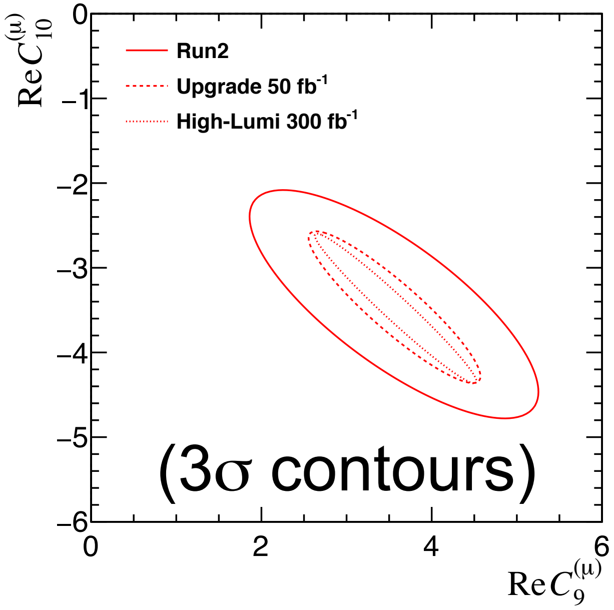
- [If can control syst. (…) and detector performance maintained] improvements in observables will distinguish between different NP models

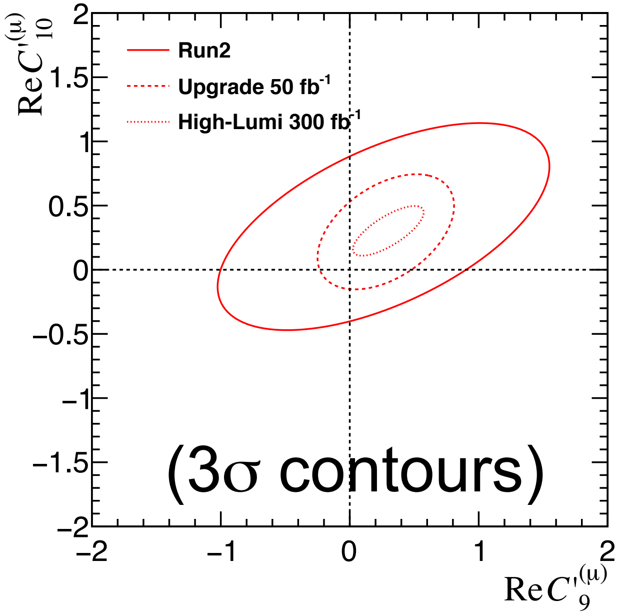
e.g. $\Delta C_9 = -\Delta C_{10} = -0.7$ vs $\Delta C_9 = -1.4$ (SM)



Upgrade projections (stat)

- Even with parametric approach, form factor uncertainties cause some saturation in extraction C_9, C_{10} after ~30 fb^{-1} – need improvements from theory-side to go further

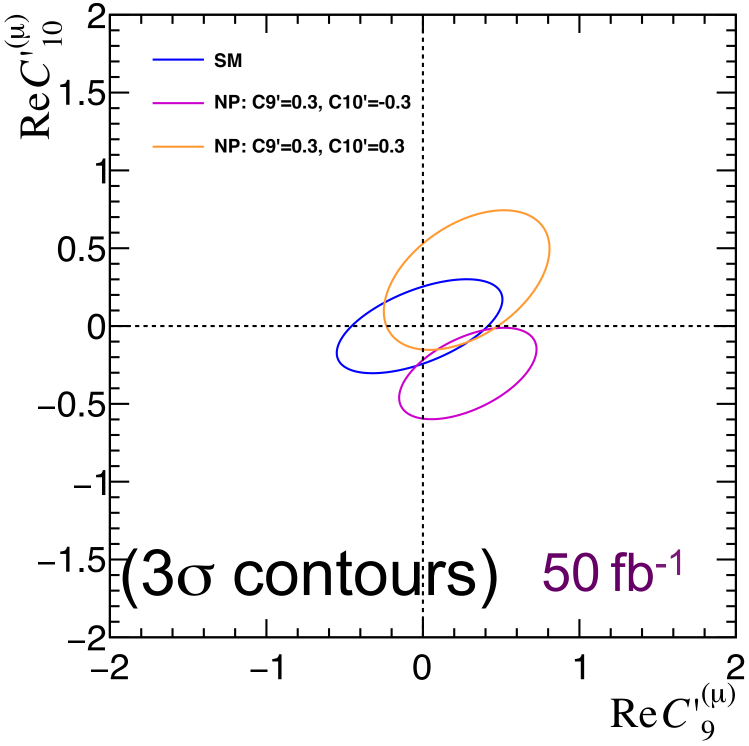


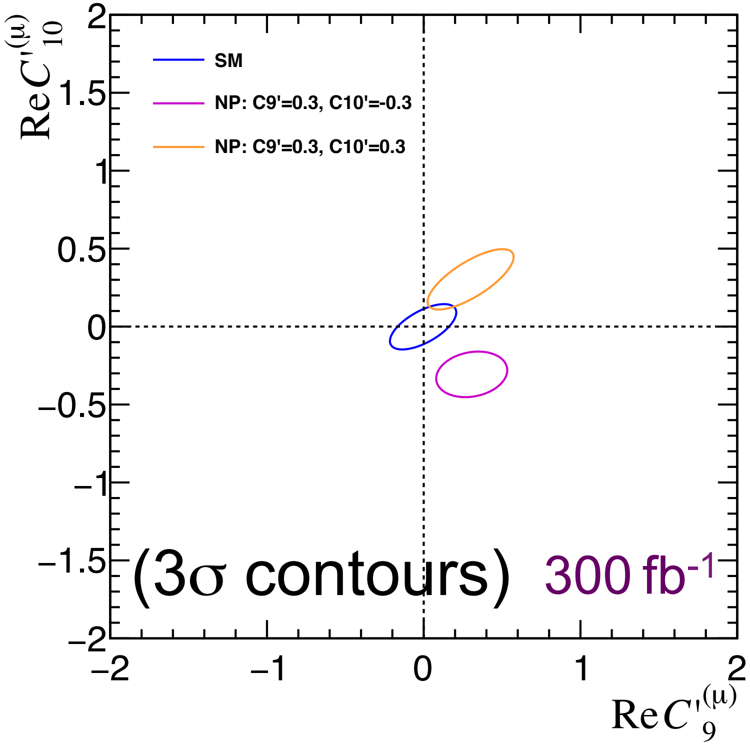


- However, will be able to probe C_9’, C_{10}’, which are essentially unconstrained at the moment – important for real models! [Still need to evaluate potential with $C_7^{(')}$]

Upgrade projections (stat)

- Again C_9', C_{10}' probes will discriminate between models



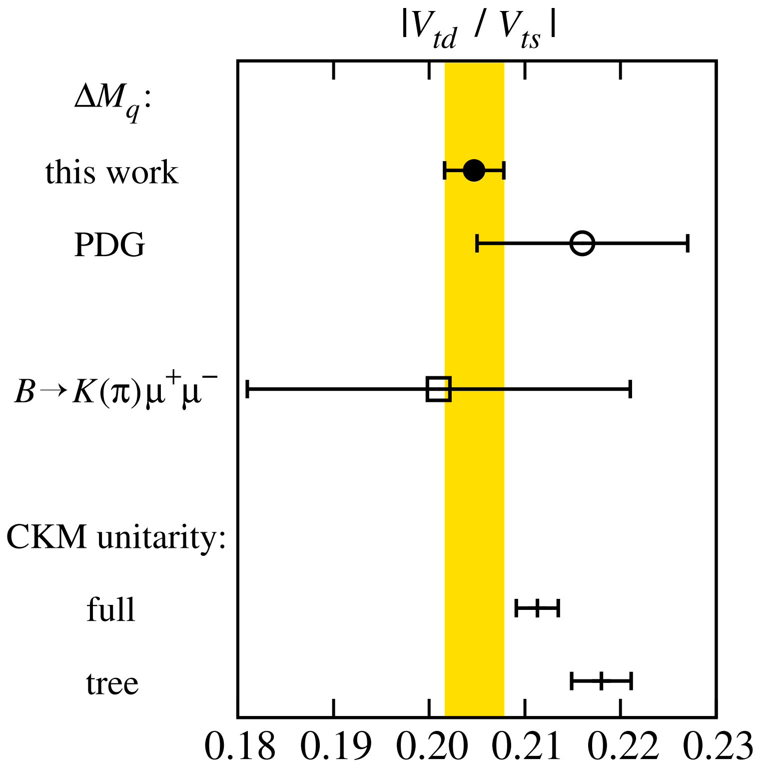


Upgrade projections (syst)

- Stat. uncertainties will become increasingly irrelevant - key issue systematics
- Assumptions from modelling of resonances, parameterisation of form factors likely to be major sources
- Present syst: angular acceptance modelling of detector
  - will require enormous stats to drive this down (fast MC)
  - Stability of trigger/detector, data-taking important to ease calcn.
- Angular distribution of bkgrds can also give rise to syst.
  - Mitigate by improving separation (mass resoln, PID, vertex isoln)
  - Study directly with data - need to be able to access wide range of related channels

Testing MFV with b→dll

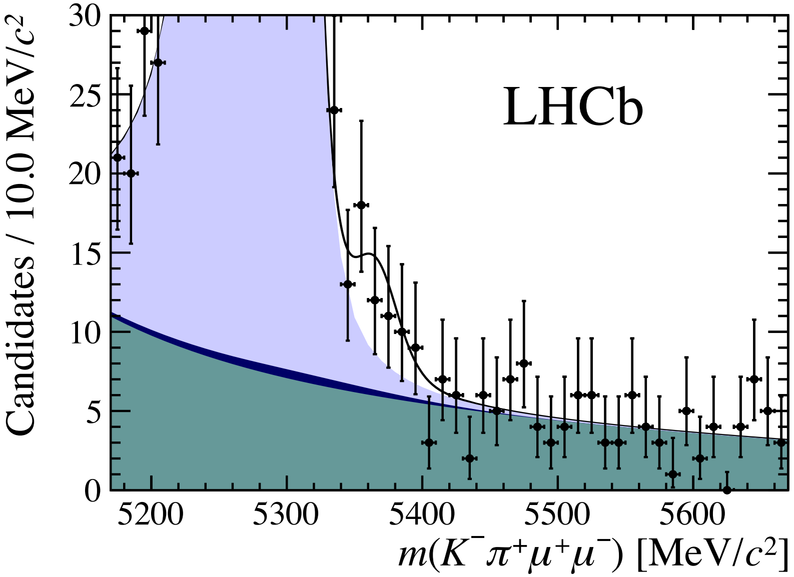
- BF($B^+ \to \pi^+ ll$) / BF($B^+ \to K^+ ll$) and lattice input → $|V_{td}/V_{ts}|^2$
  - 300fb^{-1} will give order of magnitude smaller experimental error but need improvement in lattice also
- B^0 equivalent involves $\rho^0\mu\mu$, complicated by multiple ππ resonances
- B^0_s equivalent involves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



[FNAL + MILC, PRD 93 (2016) 113016]

Testing MFV with $b \to dll$

- 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

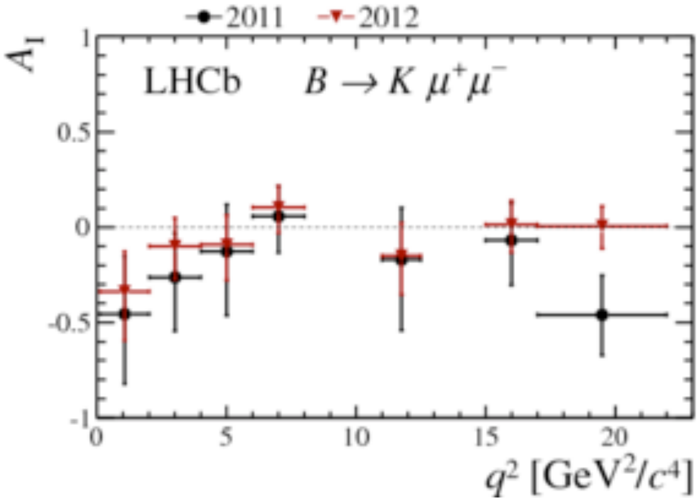


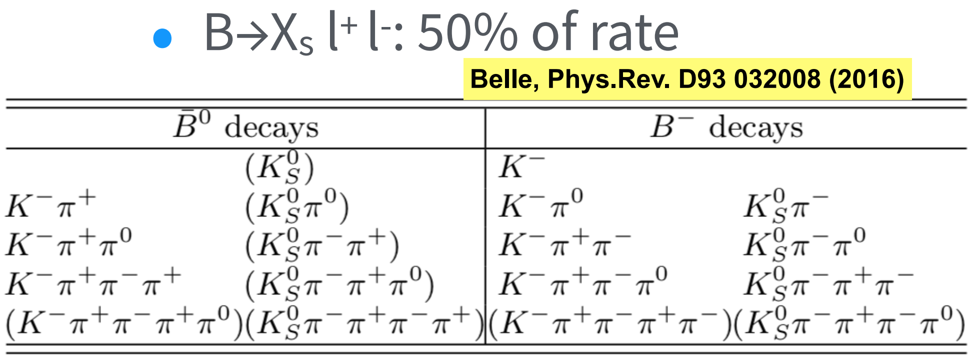
- $B^0 \to \rho^0\mu\mu$ requires flavour tag., also multiple $\pi\pi$ resonances
  - $B^+ \to \rho^+\mu\mu$ – would avoid flavour tagging but gives π^0 – good channel to consider in detector optimisation?
  - $\Lambda_b \to p\pi\mu\mu$ – would similarly suffer from (many) $p\pi$ resonances

Other measurements

- Still something significant to understand in our isospin measurements
- With 300fb^{-1}, a sum of exclusive modes as a proxy for $B \to X_s ll$ will become possible (but not theoretically clean): e.g. even one of worst modes for us that was used at Belle, $K_S\pi\pi\pi\pi^0$ would give ~200 candidates

[JHEP 06 (2014) 133]





- $B \to X_s\, l^+ l^-$: 50% of rate

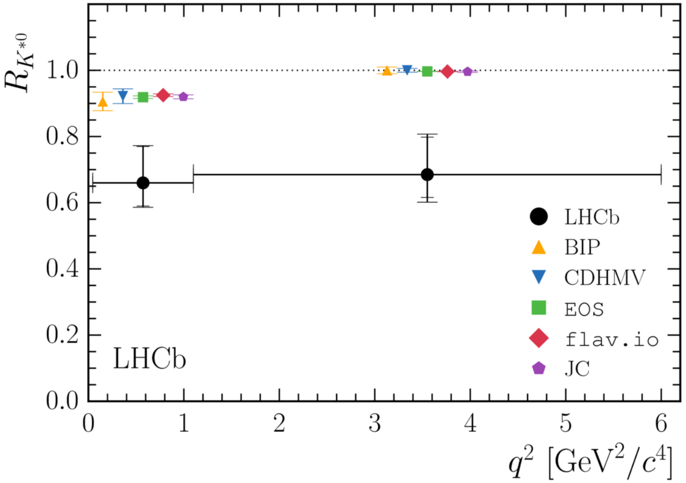
Belle, Phys.Rev. D93 032008 (2016)

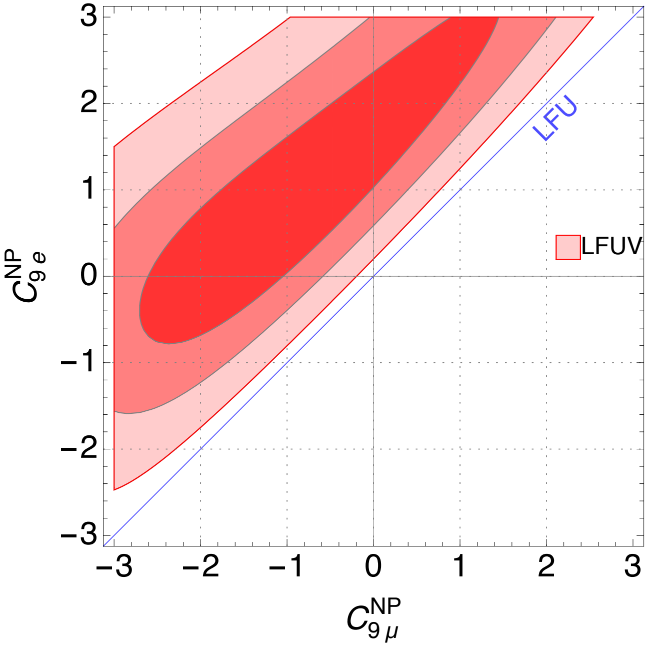
$\bar{B}^0$ decays		B^- decays	
	(K_S^0)	K^-	
$K^-\pi^+$	$(K_S^0\pi^0)$	$K^-\pi^0$	$K_S^0\pi^-$
$K^-\pi^+\pi^0$	$(K_S^0\pi^-\pi^+)$	$K^-\pi^+\pi^-$	$K_S^0\pi^-\pi^0$
$K^-\pi^+\pi^-\pi^+$	$(K_S^0\pi^-\pi^+\pi^0)$	$K^-\pi^+\pi^-\pi^0$	$K_S^0\pi^-\pi^+\pi^-$
$(K^-\pi^+\pi^-\pi^+\pi^0)$	$(K_S^0\pi^-\pi^+\pi^-\pi^+)$	$(K^-\pi^+\pi^-\pi^+\pi^-)$	$(K_S^0\pi^-\pi^+\pi^-\pi^0)$

LFU observables

- Ratios of BF’s between different flavours of leptons e.g. R_{K^*}, R_K, or differences between angular observables e.g. $D_i=S_i^e-S_i^\mu$, theoretically pristine
  - Precision dictated by electron modes – while again expect substantial yields, projections based on extrapolating current performance forward (…)

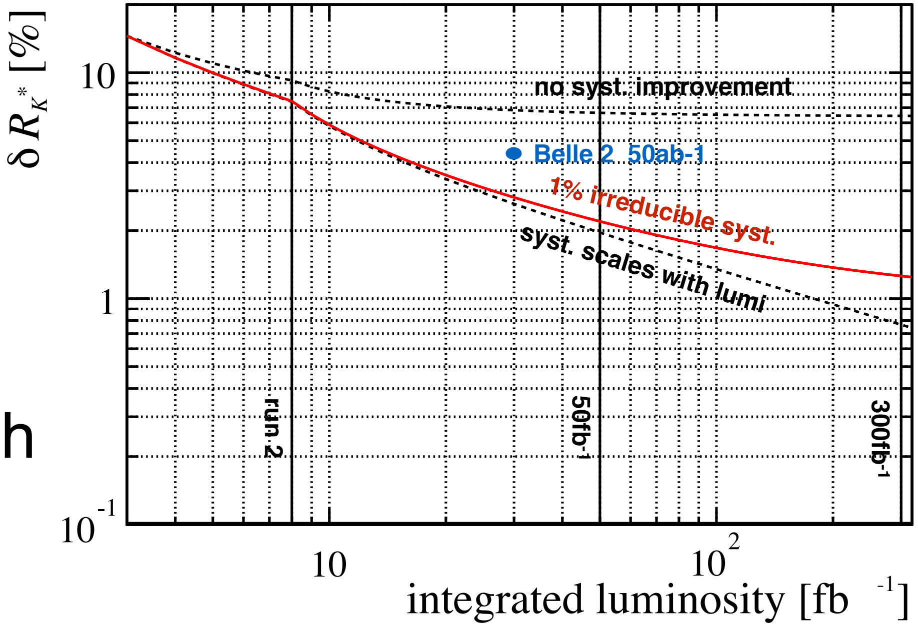
- Will have statistics to measure CKM sup. versions e.g. R_π and many new channels R_ϕ, R_Λ etc.

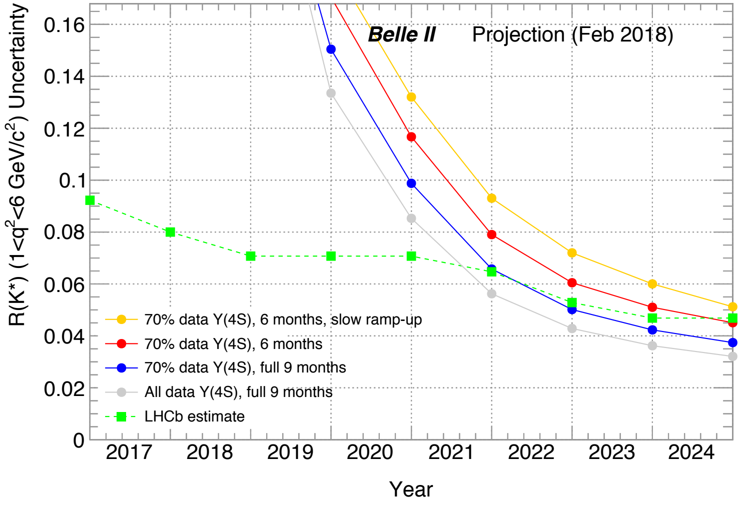




Electron analyses with 300fb^{-1}

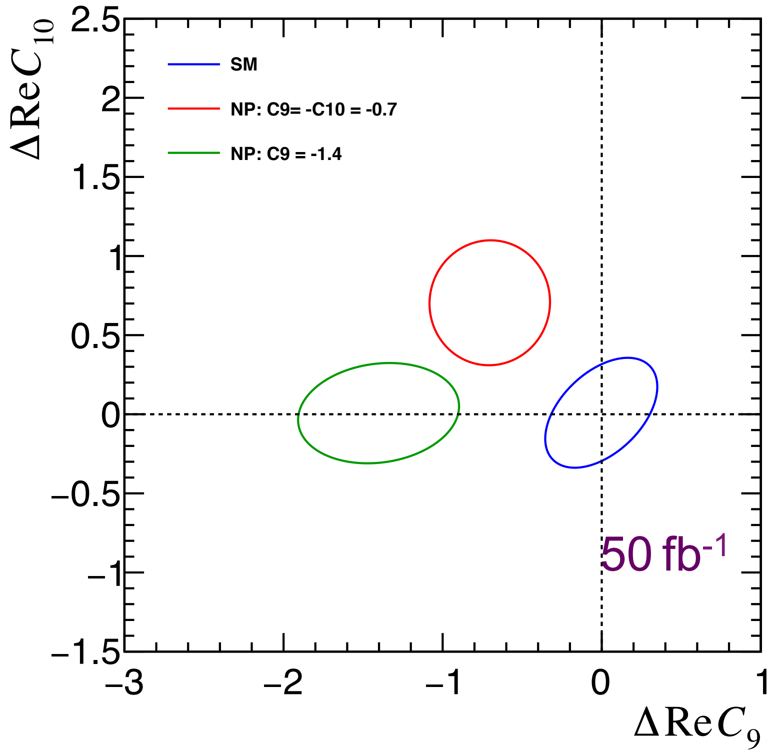
- Need to drive systematics down to <1% level to get benefit from 300fb^{-1} data
- Large uncertainty from modelling backgrounds which can study with data and hence will scale with luminosity, ditto data-derived corrections to simulation
- However, sub-dominant uncertainties from e.g. modelling of bremsstrahlung

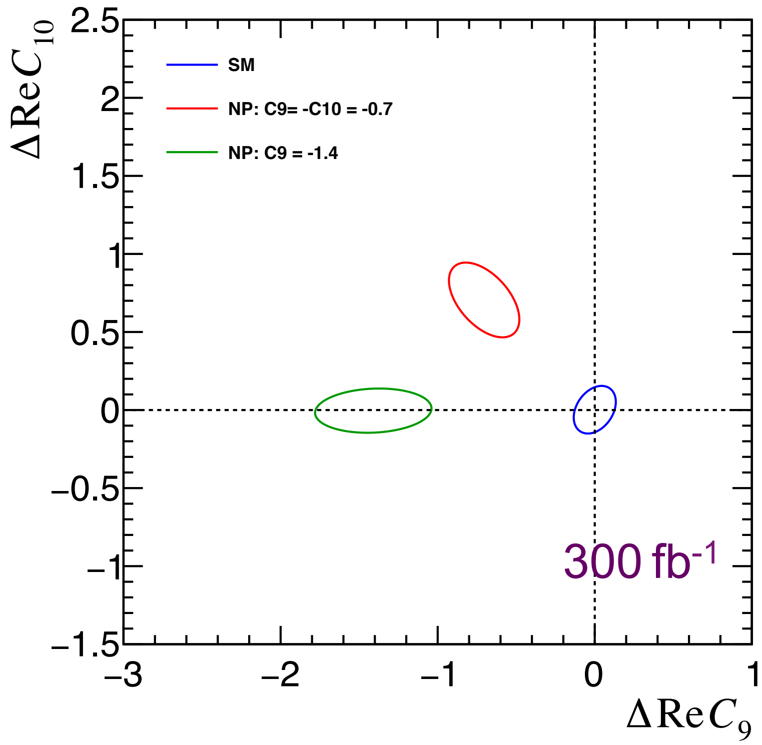




Upgrade projections (stat)

- Difference between C_9, C_{10} computed in electron and muon modes is free of theory uncertainties and will discriminate between models





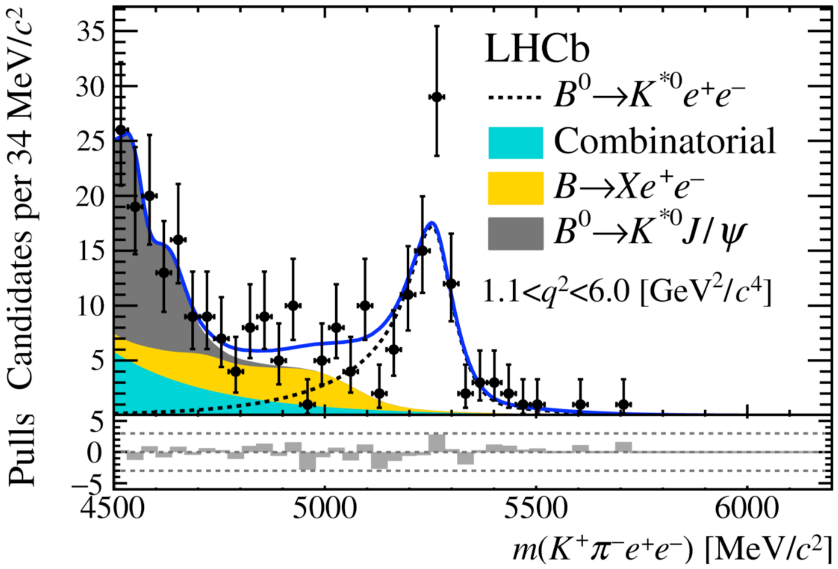
(3σ contours)

Upgrade projections (syst)

- C_i projections based on stat. extrapolation but not detailed bkgrd, acceptance, angular resolution in new upgrade/HL environment
  - Each will be much bigger effects for us than for Belle2
  - Belle2 will also access additional channels which will add to their sensitivity substantially

Future detector considerations

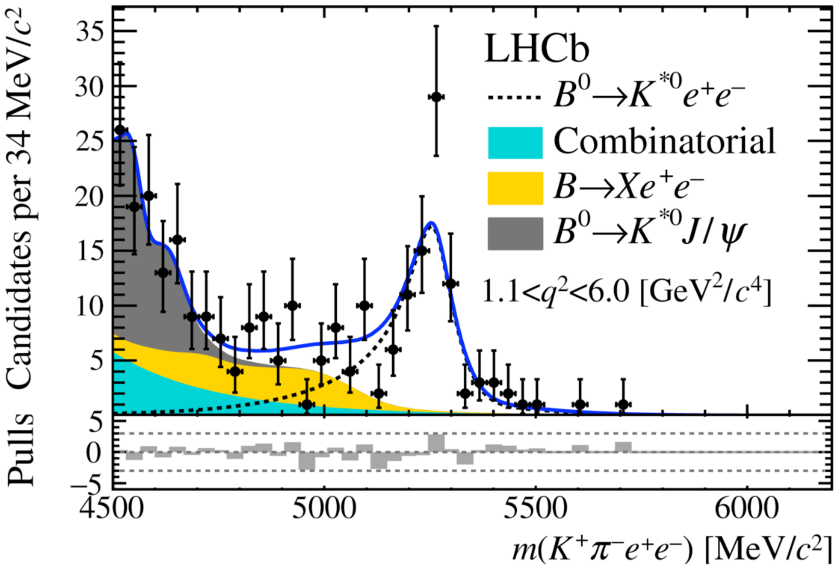
- Width of mass peak → ability to recover brem. before magnet
  - affects ability to reconstruct signal and to reject bkgrds that we otherwise need to model



- Can we maintain existing ability to reconstruct brem photons? To improve need to *reduce* material in front of the magnet?
  - Phase-I VELO will have better vertex/IP resoln but how much material?

Future detector considerations

- Technologically conceivable to have directionality in ECAL st can distinguish PV of neutral object – could this be to the extent we could improve the brem. matching based on this directionality?



- To maintain electron-hadron separation need *longitudinal* segmentation of ECAL that effectively have with PS in Run1,2 and will lose for Phase I

- Bkgrds from K* and higher resonances – critical issue ability to veto additional charged track

- Could tolerate factor increase in combinatorial

Connection to other areas

- (Atm) mixing constraints squeeze out most of parameter space for Z' explanation of anomalies
- FLAG update of parameters give some tension in Δm_s:
  - $\Delta m_s^{SM} > \Delta m_s^{expt}$ [theory limited]
  - need negative NP contribution → possible with some new phase - best constraints come from $A_{mix}(B_s \rightarrow J/\psi\varphi) = \sin(\Delta\varphi - 2\beta_s)$
  - However, phase can spoil interference SM and NP contribution to e.g. R_{K^*} - clear that there is a subtle interplay to disentangle

Conclusions

- Existing discrepancies illustrate the power of $b \to qll$ decays as probes of NP, this will continue in the upgrade/HL era
- With upgrade/HL datasets will be able to discriminate between different C_9, C_{10} NP models and probe e.g. V_{td}/V_{ts}
- Even with a parametric approach, our ability to probe these WC's will start to saturate due to theory uncertainties
- New observables C_9', C_{10}' and ΔC_9, ΔC_{10} will remain compelling
- Need to think about detector that will allow us to access and control systematics for these observables

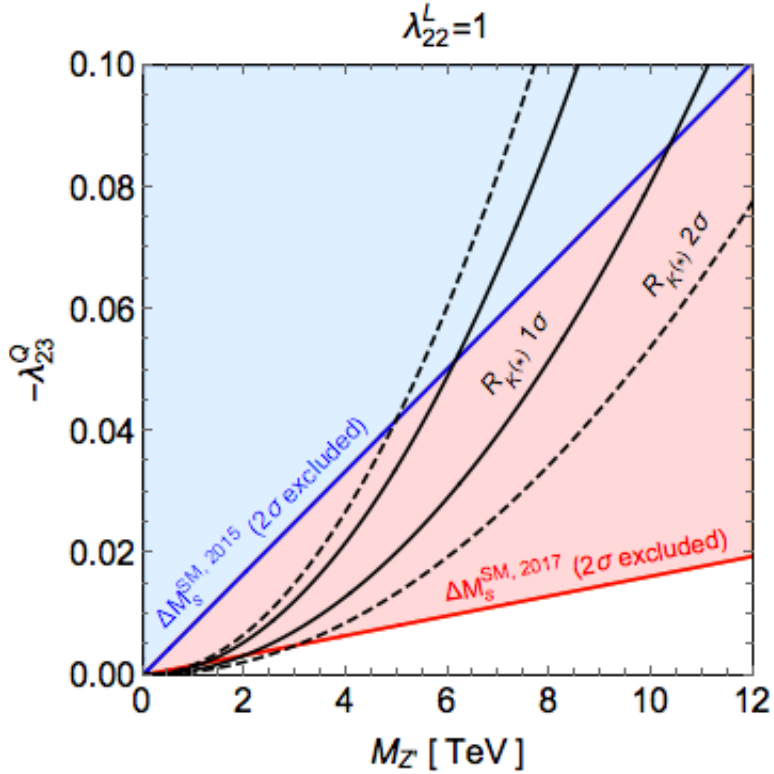


Figure 2: Bounds from B_s-mixing on the parameter space of the simplified Z' model of Eq. (20), for real λ_{23}^Q and $\lambda_{22}^L = 1$. The blue and red shaded areas correspond respectively to the 2σ exclusions from $\Delta M_s^{\text{SM, 2015}}$ and $\Delta M_s^{\text{SM, 2017}}$, while the solid (dashed) black curves encompass the 1σ (2σ) best-fit region from $R_{K^{(*)}}$.

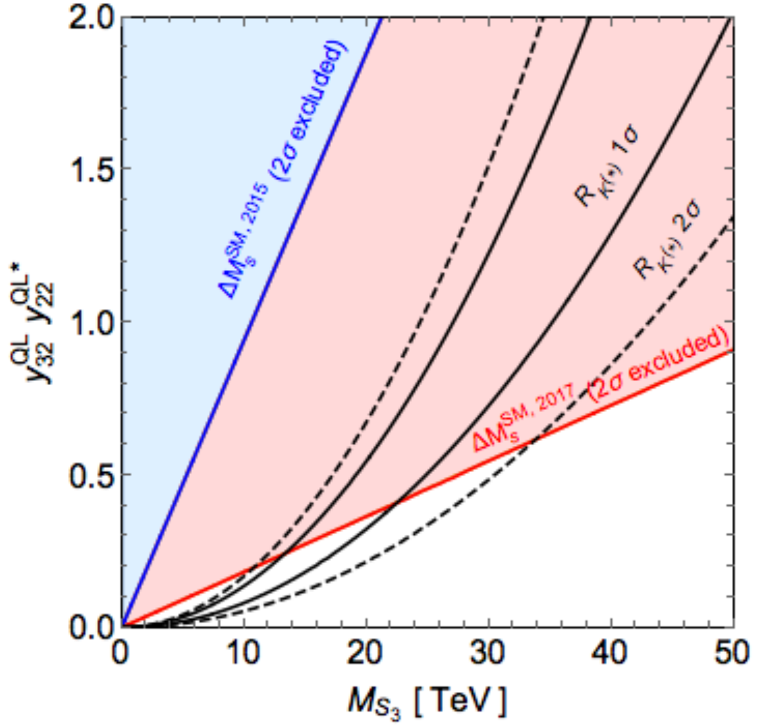


Figure 3: Bounds from B_s-mixing on the parameter space of the scalar leptoquark model of Eq. (24), for real $y_{32}^{QL} y_{22}^{QL*}$ couplings. Meaning of shaded areas and curves as in Fig. 2.

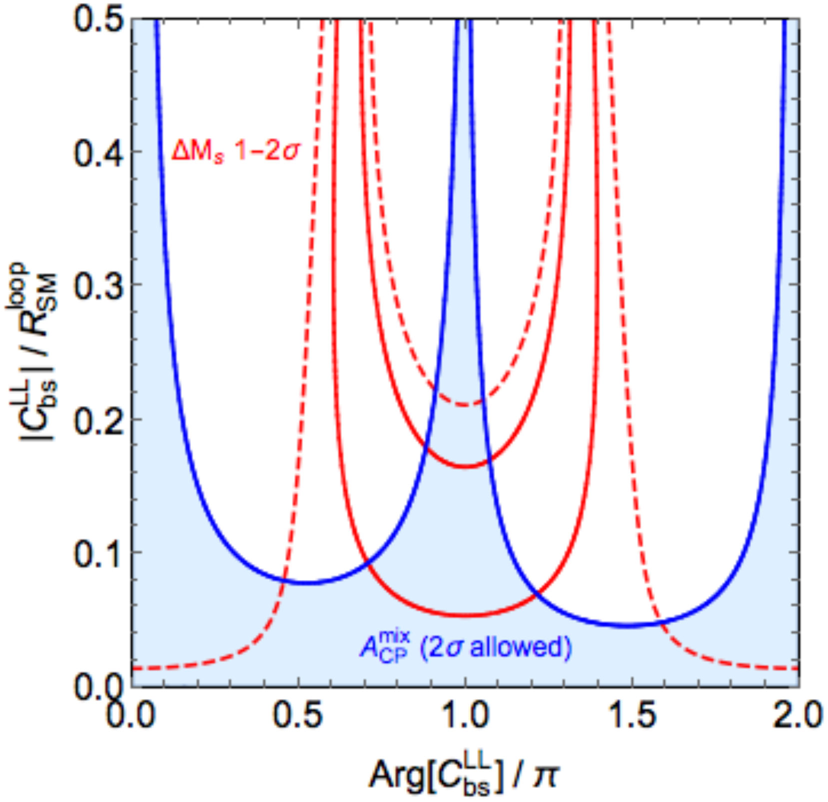


Figure 4: Combined constraints on the complex Wilson coefficient C_{bs}^{LL}. The blue shaded area is the 2σ allowed region from $A_{\rm CP}^{\rm mix}$, while the solid (dashed) red curves enclose the 1σ (2σ) regions from $\Delta M_s^{\rm SM,\,2017}$.