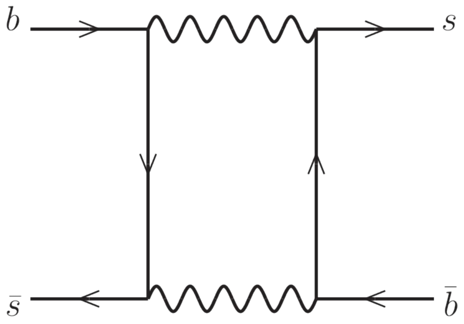
Interplay between ΔM_s and flavour anomalies

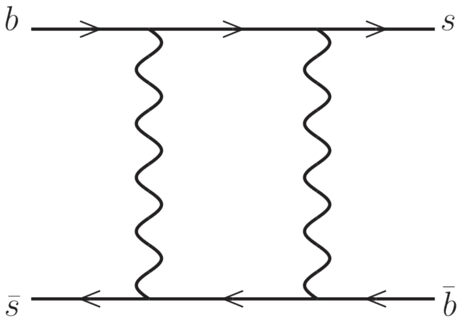
Matthew Kirk

(based on 1909.xxxxx – Di Luzio, MK, Lenz, Rauh)

bsll 2019 – Lyon

Overview of ΔM_s





$$\frac{\partial}{\partial t}\begin{pmatrix} B_s \\ \overline{B}_s \end{pmatrix} = \left(\hat{M} - \frac{i}{2}\hat{\Gamma}\right)\begin{pmatrix} B_s \\ \overline{B}_s \end{pmatrix}$$

Overview of ΔM_s

- $\Delta M_s \equiv M_{B_H} - M_{B_L}$
- Calculated as $2|M_{12}|$
- $M_{12}^q = \frac{G_F^2}{16\pi^2}\lambda_t^2 M_W^2 S_0(x_t)\hat{\eta}_B \frac{\langle \overline{B}_q|Q_1|B_q\rangle}{2M_{B_q}}$
- The matrix element $\langle \overline{B}_q|Q_1|B_q\rangle$ is generally parameterised as $f_B^2 B_Q$, and this is the largest uncertainty.

Linking R_{K^*} and ΔM_s

- There is a generic connection between the two observables for explanations of R_{K^*} (e.g. Z′, LQs)
- Z′: two insertions of bs coupling
- LQ: 1-loop box diagram

Linking R_{K^*} and ΔM_s

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- Z′:
- LC

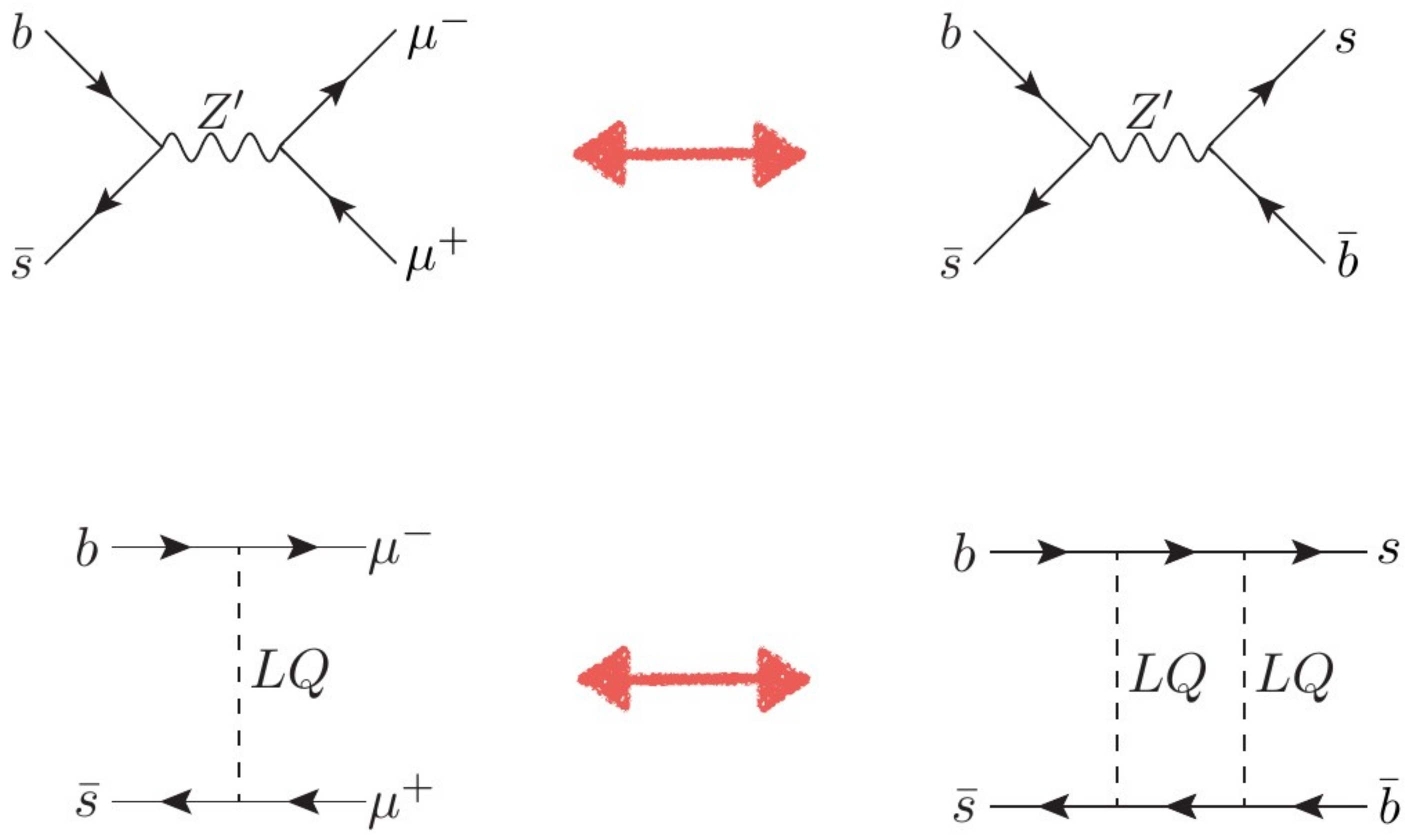
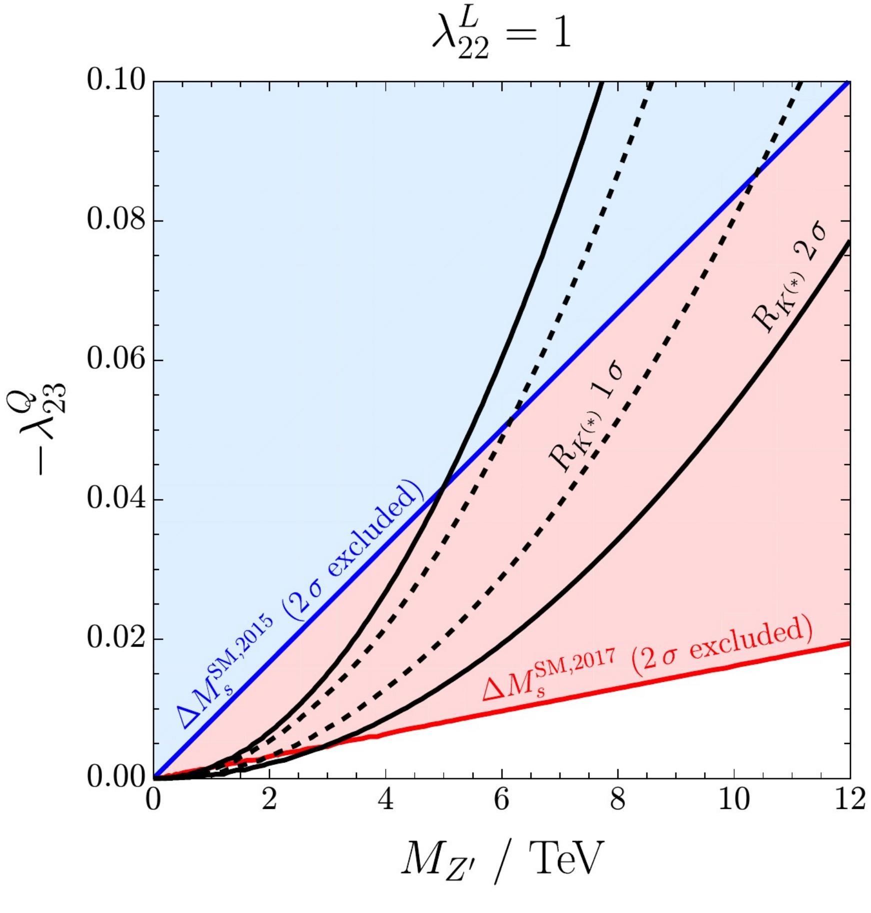


Image: Luca Di Luzio, CKM 2018

Status of ΔM_s

- Exp: (17.757 ± 0.021)ps^{-1}
- SM (FLAG '13): (18.3 ± 2.7)ps^{-1} (from 1511.09466)
- SM (FNAL/MILC): (20.01 ± 1.25)ps^{-1}
- Discussion in "One Constraint to Kill Them All" (1712.06572)

Status of ΔM_s



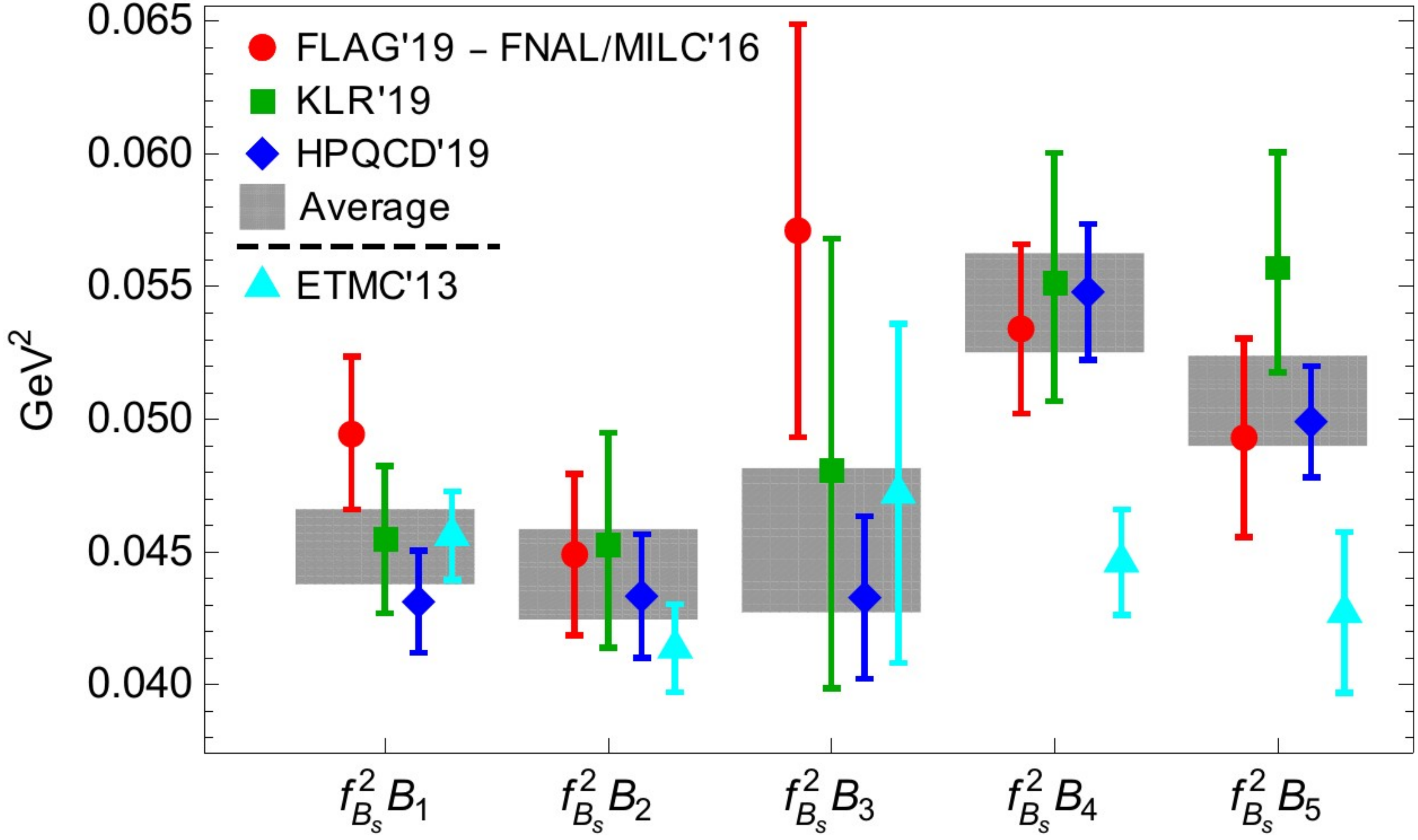
What has happened since?

- Moriond 2019: R_K: $0.75 \pm 0.12 \rightarrow 0.85 \pm 0.06$
- Still $\sim 2.5\,\sigma$
- Currently $R_{K^*} < R_K < 1$
- Favours RH quark currents

New for ΔM_s

- Sum rules calculation of B_s bag parameters (1904.00940 – King, Lenz, Rauh) – based on 1711.02100 (MK, Lenz, Rauh) and 1606.06054 (Seigen)
- HPQCD calculation of B_s bag parameters (1907.01025)

New for ΔM_s



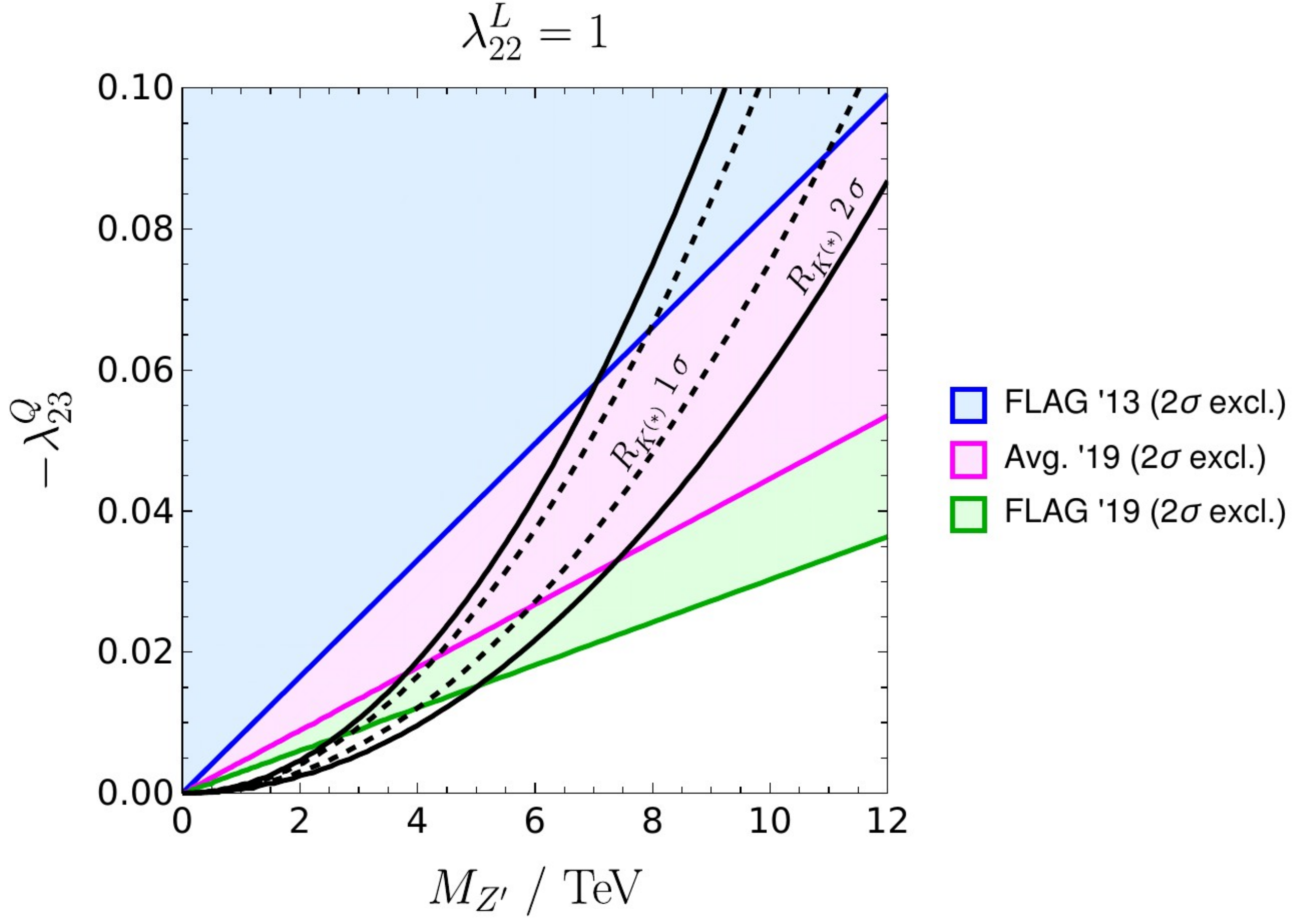
New for ΔM_s

- Also slight updates to CKM fits
  - Between CKMfitter 2016 and 2018 results, error on V_{cb} roughly doubled

Update of ΔM_s

- Using FLAG '19 (~= FNAL/MILC)
  - $\Delta M_s^{\text{FLAG '19}} = \left(20.1^{+1.2}_{-1.6}\right) \text{ps}^{-1}$
- Using average of FNAL/MILC, HPQCD, KLR SR
  - $\Delta M_s^{\text{Avg. '19}} = \left(18.4^{+0.7}_{-1.2}\right) \text{ps}^{-1}$

Update of ΔM_s



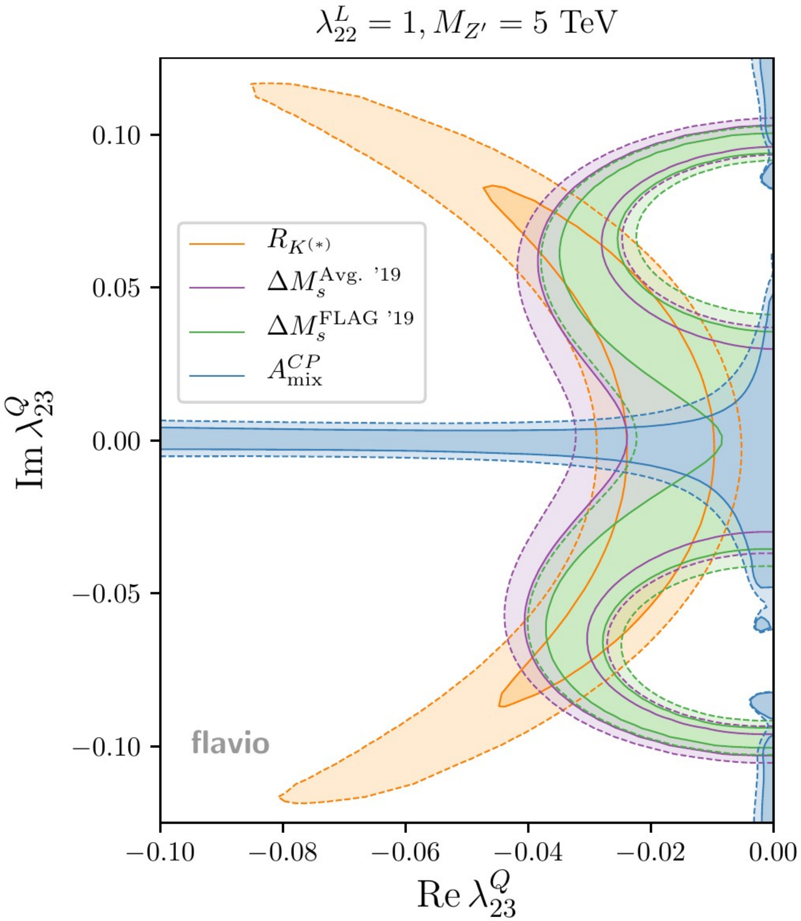
Bounds on Z′ mass

- ΔM_s rules out (at 2σ) Z′ above 5 TeV in the simplest case (only LH quark and lepton coupling, no new phases, lepton coupling = 1)
- What if we relax these restrictions?

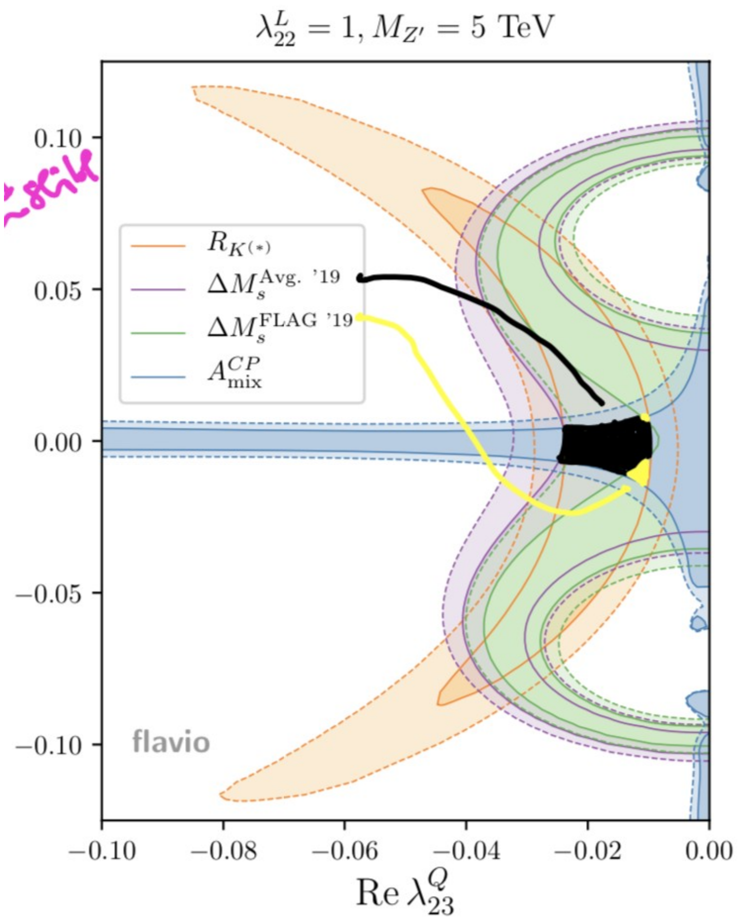
Complex coupling

- $\Delta M_s \sim \Delta M_s^{\mathrm{SM}} \left|1 + g_{\mathrm{NP}}^2\right|$
- So new CP violating phases allow for negative contribution

Complex coupling



Complex coupling

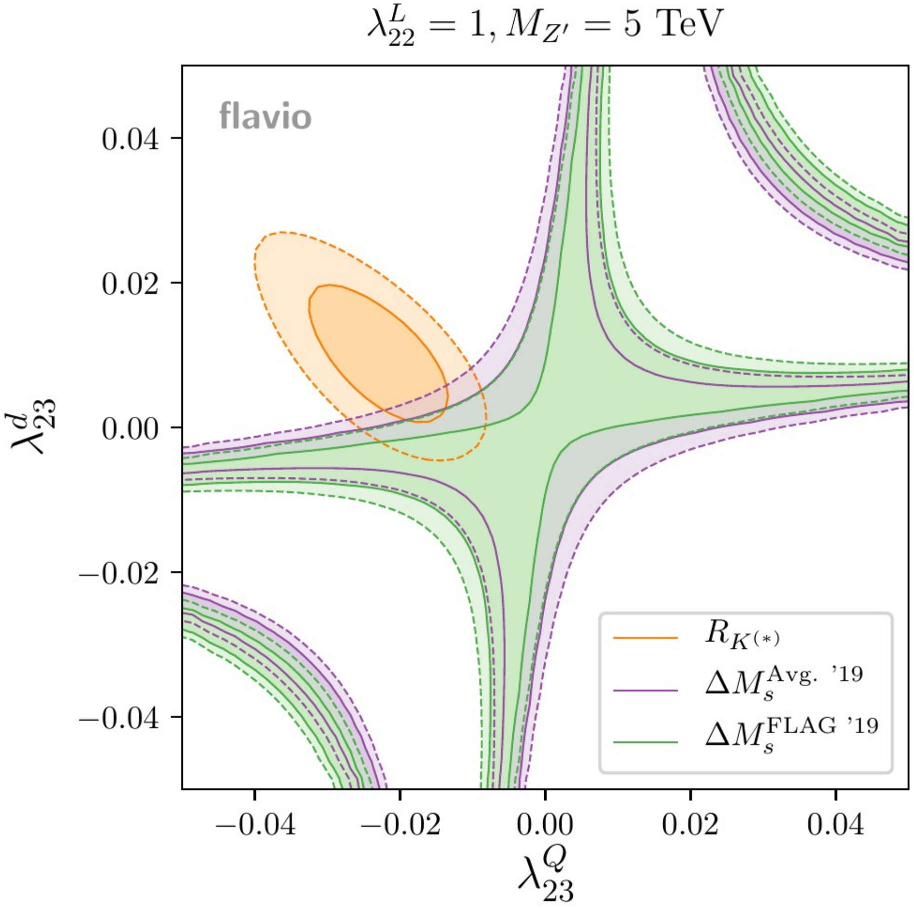


RH quark coupling

- Get interference term with opposite sign

$$\frac{\Delta M_s^{\rm SM+NP}}{\Delta M_s^{\rm SM}} \approx \left| 1 + 200 \left(\frac{5\,{\rm TeV}}{M_{Z'}} \right)^2 \left[\left(\lambda_{23}^Q \right)^2 + \left(\lambda_{23}^d \right)^2 - 9 \lambda_{23}^Q \lambda_{23}^d \right] \right|$$

RH quark coupling



Look to the future

- By 2025, LHCb expects to have much better precision on R_K (down to 0.025) and R_{K^*} (down to 0.031)
- Implies $6\,\sigma$ in R_K, $10\,\sigma$ in R_{K^*}

World of 2025

- What will ΔM_s look like?
- Take matrix element forecasts from LHCb Upgrade II report (1808.08865)
  - Lattice error on matrix element down to 3%
  - We also assume a similar improvement in sum rules
  - Combination at 2%

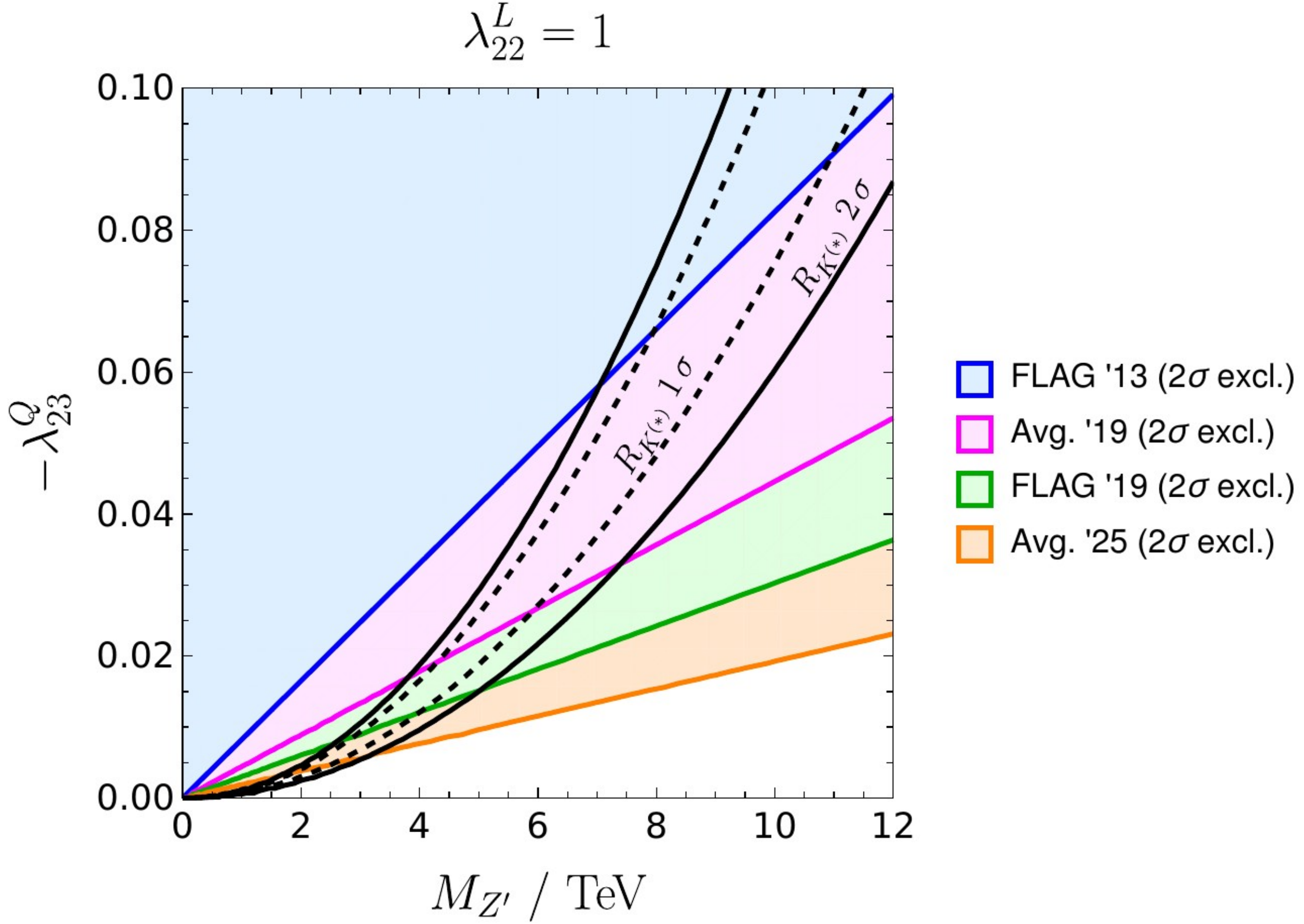
World of 2025

- What will ΔM_s look like?
- Take V_{cb} from Belle II physics book (1808.10567)
- 1% uncertainty (vs ~3% today)
- Everything else the same

World of 2025

- What will ΔM_s look like?
- We expect that the error on ΔM_s can be reduced to $\pm 0.5\,\mathrm{ps}^{-1}$

World of 2025



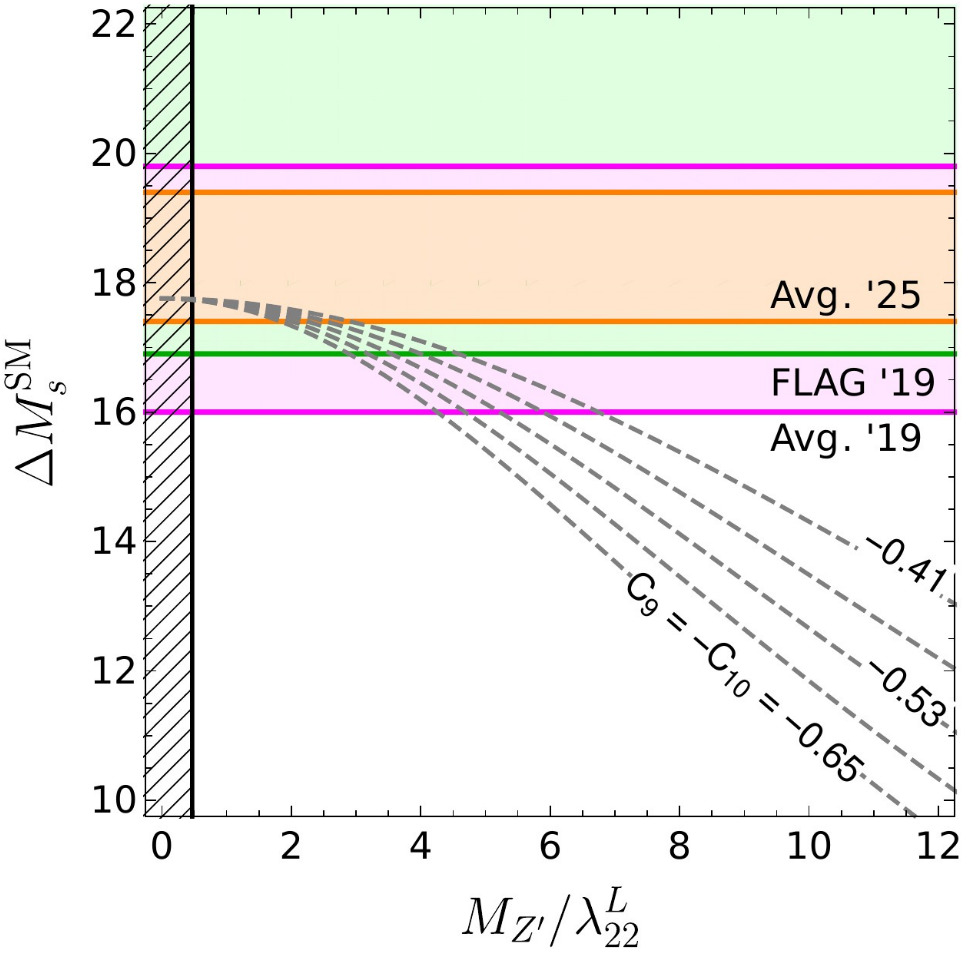
World of 2025

- Lower central value corresponding to current average, with higher precision, is MORE constraining than the FNAL/MILC result is now.
- Entering the age of precision for ΔM_s
- And precision is what kills you (/ your models)

Linking R_{K^*} and ΔM_s

- LHCb expects their data on R_{K^*} alone will be enough to fit C_9 with uncertainty ~ 0.12
- So what ΔM_s value is compatible with a Z′ explanation?

Linking R_{K^*} and ΔM_s



Summary

- New determinations of B_s mixing matrix elements bring us towards precision era of B_s mixing
- CP violating, or right handed quark coupling loopholes don't give a great improvement
- By 2025 precision will be good enough to exceed strong FNAL/MILC constraints from mixing

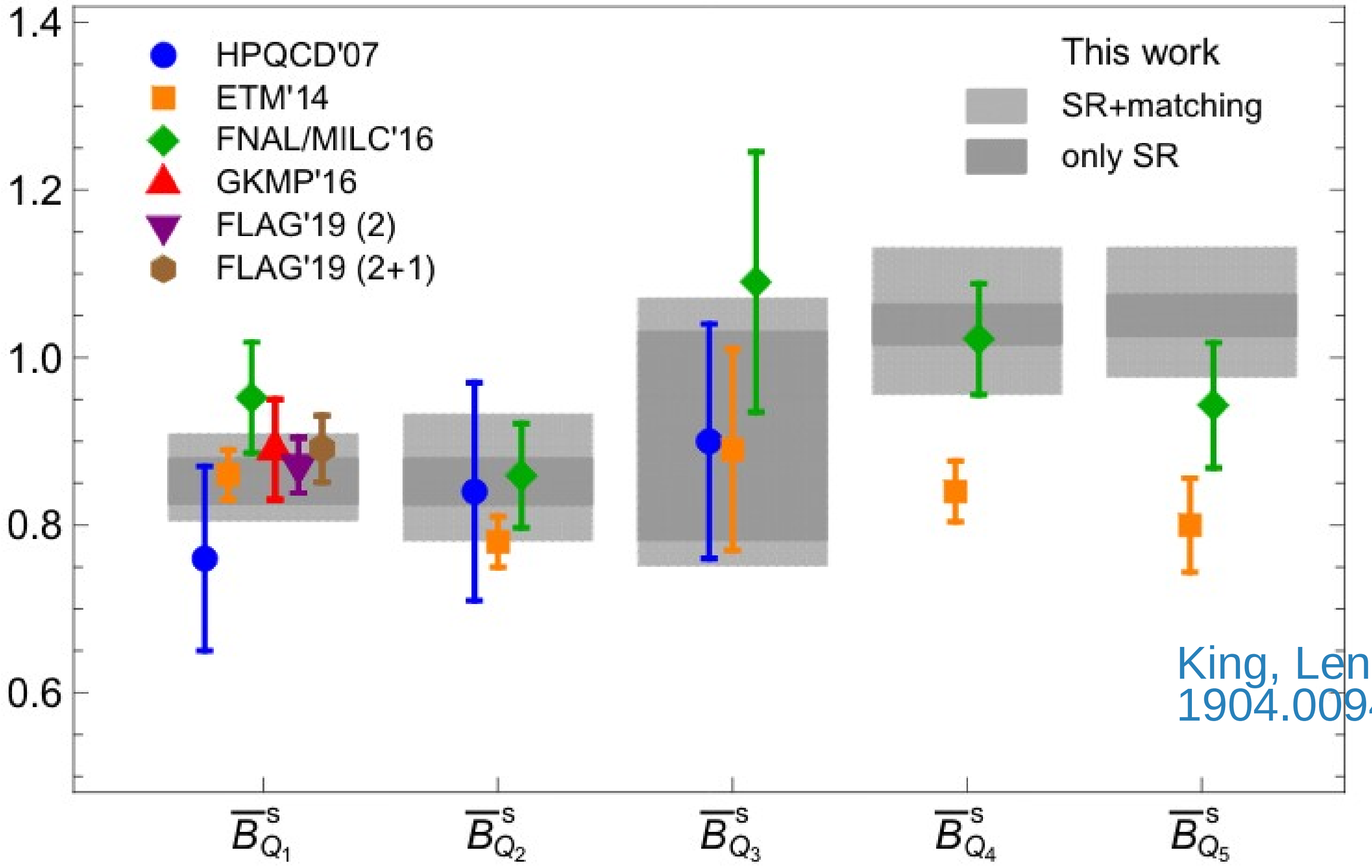
EXTRAS

CKM inputs

- CKMfitter Summer 2018:
  - Vcb = (42.40 +0.30 -1.15)* 10^-3
- CKMfitter tree-only Summer 2018:
  - Vcb = (42.41 +0.40 -1.50)* 10^-3
- CKMlive (excluding ΔM_s and ΔM_d from the fit):

  Vcb = (42.40 +0.40 -1.17)* 10^-3

SR improvement



King, Lenz, Rauh
1904.00940

Neutrino trident

- $\nu \rightarrow \nu \mu^{+} \mu^{-}$
- Assumes SU(2)L invariance of our NP, so muon coupling implies neutrino coupling too
- CCFR data on cross-section can be used to bound Z′ mass / lepton coupling
- Don’t expect much better from DUNE

Linking R_{K^*} and ΔM_s

- R_{K^*} (and other $b \rightarrow s l l$) anomalies require $(\bar{s}\, b)(\bar{l}\, l)$ effective coupling.
- So even at the EFT level, expect $(\bar{s}\, b)(\bar{s}\, b)$ coupling via lepton loop
- (But actually this is totally negligable)