Beyond MFV

(SMEFT, FN charges, Leptoquarks, . . .)

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particle **p**hysics **p**henomenology
after the **H**iggs discovery

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Motivation / General Comments:

NP studies with Collider Observables:

- UV-complete SM extensions (e.g. SUSY, GUTs, . . .) ?
- SMEFT ?
- Simplified Models, . . . ?

NP studies with Flavour Observables:

- model-independent studies (low-energy Wilson coefficients)
- flavour assumptions at high energies (for a given NP approach)
  $\rightarrow$ RG running to low scales

Generic Question:

- How to implement flavour assumptions in NP approach:
  (ad-hoc/random ? – symmetry principles ? – pheno insight ?)

Minimal Flavour Violation and Beyond

Benefits of MFV:

- NP flavour coefficients suppressed
  by same CKM and GIM factors as in the SM $\surd$
- Constraints from rare flavour decays, mixing etc.
  can be fulfilled without fine-tuning $\surd$
- Elegant technical implementation:
  Yukawa matrices as Spurions of a broken flavour symmetry $\surd$
  $\rightarrow$ assures that framework is self-consistent under RGE

But: MFV cannot account for present "*B*-Anomalies" **!**

Beyond MFV:

- Introduce new flavour spurions, in addition to SM Yukawa matrices.
- Power-counting for new spurions,
  must obey consistency relations with the SM Yukawas.

In C2b, we have followed one particular path:

- Consider SMEFT framework
- Use pheno insight from leptoquark scenarios explaining the B anomalies
- Consider flavour-specific leptoquark couplings
  as spurions of a broken flavour symmetry
  (in addition to the SM Yukawa spurions)
- Use Froggatt-Nielsen charges for quarks and leptons
  to specify a power counting for flavour coefficients in the EFT

"Effective Theory Approach to New Physics with Flavour:
General Framework and a Leptoquark Example" [Bordone, Cata, Feldmann 2019]

"Constraining flavour patterns of scalar leptoquarks in the EFT"
[Bordone, Cata, Feldmann, Mandal 2020]

Power-counting and consistency relations:

- consider, as an example, a four-fermion operator in SMEFT: ($\to$ LFU violation)

$$\frac{1}{\Lambda^2}\,[\mathcal{C}_{\ell q}]^{ij\alpha\beta}\,(\bar{Q}_i\gamma_\mu Q_j)\,(\bar{L}_\alpha\gamma^\mu L_\beta)$$

- flavour tensor $[\mathcal{C}_{\ell q}]^{ij\alpha\beta}$ introduces 3^4 free real parameters:

generic EFT:	$\mathcal{O}(1)$
MFV:	$\left(\#\delta^{ij} + \#\,(Y_U Y_U^\dagger)^{ij} + \#\,(Y_D Y_D^\dagger)^{ij} + \ldots\right)\,(\delta^{\alpha\beta} + \ldots)$
FN charges:	$\sim \lambda^{\left\|b_Q^i - b_Q^j + b_L^\alpha - b_L^\beta\right\|}$
LQ+FN charges:	$\sim (\Delta_{QL})^{i\beta}(\Delta_{QL}^\dagger)^{\alpha j} + \ldots \sim \lambda^{\left\|b_Q^i - b_L^\beta\right\|}\,\lambda^{\left\|b_L^\alpha - b_Q^j\right\|}$

- exponents in the power-counting fulfill triangle inequalities, like e.g.

$$\left|b_Q^i - b_L^\beta\right| + \left|b_L^\alpha - b_Q^j\right| \quad \geq \quad \left|b_Q^i - b_Q^j + b_L^\alpha - b_L^\beta\right|$$

$\to$ power-counting not violated by higher-orders in spurion expansion $\surd$

Strategy:

- Define leptoquark scenario (e.g. vector leptoquarks, or scalar leptoquarks)
  $\to$ identify flavour coefficients for LQ-couplings as new spurions
- Integrate out heavy LQ fields
  $\to$ identify relevant EFT operators
  $\to$ express Wilson coefficients in terms of LQ spurions
- Define FN charges for quarks, consistent with CKM and Yukawa hierarchies
  $\to$ find different options for leptons' FN charges
  $\to$ determine the corresponding scaling for the LQ spurions

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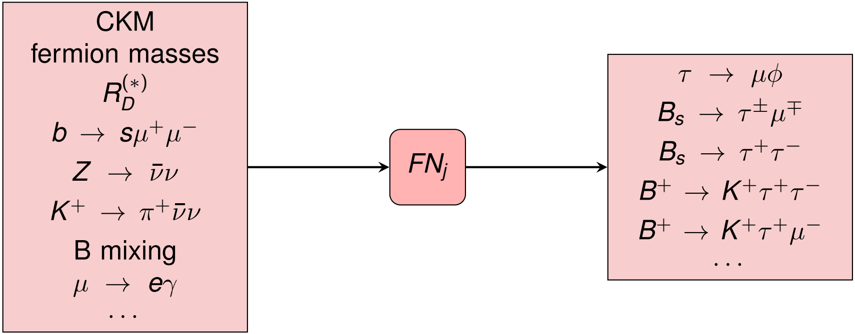
- Apply additional simplifying assumptions on the spurion entries:
  $\to$ further reduction of independent coefficients in the fit
  $\to$ (strong) correlations between different observables in the fit
  $\to$ predictions for NP effects in other observables

Finding the allowed FN charges:



- current pheno input allows for different solutions $FN_j = (b_Q^i, b_U^i, b_D^i; b_L^\alpha, b_E^\alpha)_j$
- remaining tensions with experimental bounds – for a given FN_j – can be reduced by relaxing assumptions on individual spurion entries

Lessons for 2^{nd} Funding Period ?

Pheno beyond MFV:

- NP couplings in collider observables also modify rare flavour observables (i.e. via top-quarks in loops) $(\surd)$

. . . but, rare flavour observables may receive dominant NP contributions from beyond-MFV effects !

- Power-counting for beyond-MFV spurions also fix the order-of-magnitude for flavour non-diagonal collider observables . . .

More implementations of beyond-MFV:

- specific GUT models (e.g. 4321, . . .)
- EFT with light axions, DM, . . .
- Extended Higgs sectors . . .
- . . .

. . . open for dicussion . . .
