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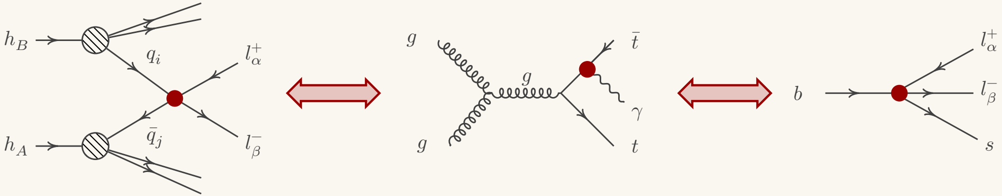

EFT strategies and synergies in global fits

TH-EXP-synergies:

How to efficiently scan SMEFT-couplings in high-dimensional spaces

In collaboration with Cornelius Grunwald, Gudrun Hiller and Kevin Kröninger

Lara Nollen

IAL Kick-Off Meeting 20th March 2024

SMEFT approach to new physics

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_{d=5}^{\infty} \sum_{i} \frac{C_i^{(d)}}{\Lambda^{d-4}} O_i^{(d)}$$

$O_i^{(d)}$: Local operators, IR-sensitive

$C_i^{(d)}$: Wilson coefficients, UV-sensitive

See also e.g. Greljo et al. [JHEP 11 (2020) 080], [JHEP 05 (2023) 087] for global SMEFT fits

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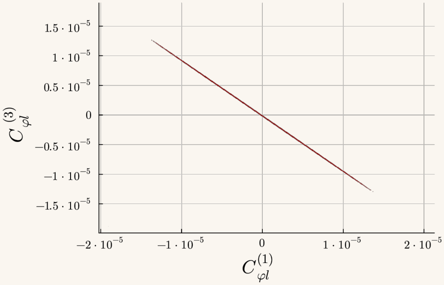
- Typically, only a subset of operators is used (e.g. 14 coefficients in [JHEP 11 (2023) 110])
- Oftentimes: only one operator is fitted at a time

  $\rightarrow$ New physics might hide in other operators or linear combinations, e.g. $C_{\varphi l}^{(\pm)} = C_{\varphi l}^{(1)} \pm C_{\varphi l}^{(3)}$
- **Global fits** are crucial
- Our approach: EFT$fitter$ [arXiv:1605.05585], based on Bayesian Analysis Toolkit - $BAT.jl$ [arXiv:2008.03132]



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Flavor patterns

- Flavor patterns reduce d.o.f. and impose **correlations** among different sectors
- Observation that FCNCs and CP violation are strongly suppressed in the data
  $\rightarrow$ **Minimal Flavor Violation** (MFV)

See also e.g. Bruggisser et al. [arXiv:2212.02532] or Hurth et al. [arXiv:2311.04963] for MFV in SMEFT

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- In the SM: flavor symmetry only broken by the Yukawa couplings $\rightarrow$ spurion expansion

$$\bar{q}_L q_L :\sim a_1 \mathbb{1} + a_2 Y_u Y_u^\dagger + a_3 Y_d Y_d^\dagger + \dots \quad \bar{u}_R u_R :\sim b_1 \mathbb{1} + b_2 Y_u^\dagger Y_u + \dots \quad \bar{d}_R d_R :\sim e_1 \mathbb{1} + e_2 Y_d^\dagger Y_d + \dots$$

$$C\, \bar{q}_L q_L \supset \left[\bar{u}_L \begin{pmatrix} a_1 & 0 & 0 \\ 0 & a_1 & 0 \\ 0 & 0 & a_1 + a_2\, y_t^2 \end{pmatrix} u_L + \bar{d}_L \begin{pmatrix} a_1 + a_2\, |V_{td}|^2\, y_t^2 & a_2\, V_{td}^* V_{ts}\, y_t^2 & a_2\, V_{td}^* V_{tb}\, y_t^2 \\ a_2\, V_{ts}^* V_{td}\, y_t^2 & a_1 + a_2\, |V_{ts}|^2\, y_t^2 & a_2\, V_{ts}^* V_{tb}\, y_t^2 \\ a_2\, V_{tb}^* V_{td}\, y_t^2 & a_2\, V_{tb}^* V_{ts}\, y_t^2 & a_1 + a_2\, |V_{tb}|^2\, y_t^2 \end{pmatrix} d_L \right]$$

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- Alternatives: top-philic approach, motivated by the large top-Yukawa (e.g.[arXiv:2012.10456])
- Frogatt Nielsen models, theoretical approach to flavor hierarchies

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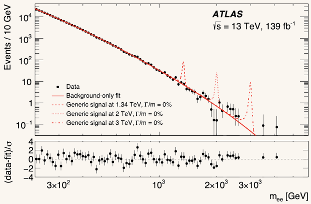
Data and theory predictions

- Huge amount of data from LHC and flavor experiments

  $\Longrightarrow$ **Global fits** to exploit synergies and correlations

- Combine hundreds of observables in a single fit

- Quadratic parameterization:



theory computation

$$\mathcal{M} = \mathcal{M}^{\text{SM}} + \frac{1}{\Lambda^2}\sum_i C_i \mathcal{M}_i^{\text{BSM}} \xrightarrow{\sigma \propto |\mathcal{M}|^2} \sigma = \sigma^{\text{SM}} + \frac{1}{\Lambda^2}\sum_i C_i\, \sigma_i^{\text{int}} + \frac{1}{\Lambda^4}\sum_{i\leq j} C_i C_j \sigma_{ij}^{\text{BSM}}$$

$\sigma_{t\bar{t}}$	$\sigma_{t\bar{t}Z}$	$\sigma_{t\bar{t}\gamma}$	$\sigma_{t\bar{t}W}$
$\sigma_{t\bar{t}H}$	Γ_t	f_0	f_L
R_b	A_{FB}^b	R_c	A_{FB}^c

e^+e^-	$e\nu$
$\mu^+\mu^-$	$\mu\nu$
$\tau^+\tau^-$	$\tau\nu$

$\mathcal{B}_{\bar{B}\to X_s\gamma}$	$\mathcal{B}_{B^0\to K^*\gamma}$	$\mathcal{B}_{B^+\to K^{*+}\gamma}$	$\mathcal{B}_{\bar{B}\to X_s l^+l^-}$	$\mathcal{B}_{\bar{B}\to X_s l^+l^-}$
$\mathcal{B}_{B_s\to\mu^+\mu^-}$	$\mathsf{F}_{L\;B^0\to K^*\mu^+\mu^-}$	$\mathsf{P}^{(\prime)}_{i\;B^0\to K^*\mu^+\mu^-}$	$\mathcal{B}_{B^0\to K\mu^+\mu^-}$	$\mathcal{B}_{B^+\to K^+\mu^+\mu^-}$
$\mathcal{B}_{B^+\to K^{+*}\mu^+\mu^-}$	$\mathsf{F}_{L\;B_s\to\phi\mu^+\mu^-}$	$\mathsf{S}_{i\;B_s\to\phi\mu^+\mu^-}$	$\mathcal{B}_{\Lambda_b\to\Lambda\mu^+\mu^-}$	$\Delta M_{s\;B_s/\bar{B}_s}$

- σ_i^{int}, σ_{ij}^{BSM} $\to$ perturbative as well as non-perturbative computations necessary
- Crucial for flavor observables: hadronic matrix elements and form factors

Collider Observables

- For collider observables: MC simulations (e.g. `MadGraph`, `Sherpa`, `Pythia`)
- Currently: mostly at tree level
- A lot of data is not unfolded $\rightarrow$ need accurate parton shower and detector simulation

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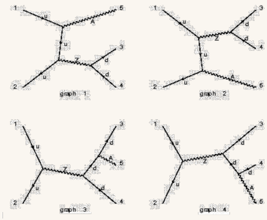
Parton level Monte Carlo — `MadGraph5` [arXiv:1405.0301]



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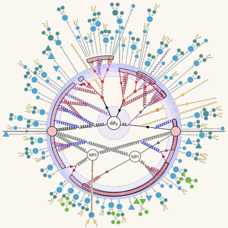

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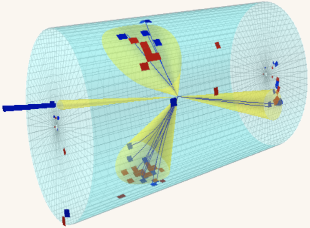
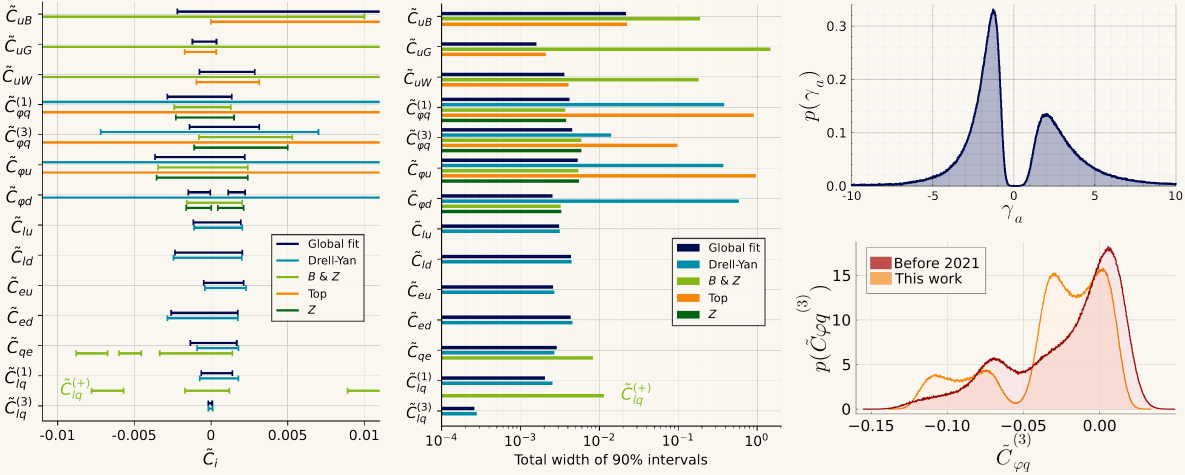
Detector simulation	`Delphes3` [arXiv:1307.6346]



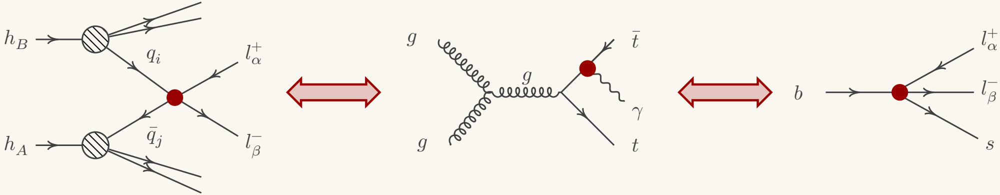
Synergies from Beauty, Top, Z and Drell-Yan



Results from [arXiv:2304.12837]

Challenges and future directions

- **High-dimensional parameter space**
  $\rightarrow$ efficient sampling algorithms, e.g. `BAT`, `EFTFitter` (see also talk by Cornelius Grunwald)
- **Correlations** in the data can have a significant impact ([arXiv:1912.06090])
- **PDFs** can mask NP effects $\rightarrow$ ideally a combined fit of PDFs and SMEFT
- **Dimension 8 operators** are also relevant
- With the growing precision of data, theory predictions need to be improved



See e.g. [arXiv:2104.02723] for PDFs in SMEFT, [arXiv:2207.01703] for dimension 8 SMEFT fits