technische universität
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Correlating uncertainties within the SMEFT

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In collaboration with C. Grunwald, J. Erdmann, G. Hiller and K. Kröninger
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Introduction

SMEFT approach to BSM physics

- Expect new degrees of freedom much heavier than SM content
- Express BSM physics in effective operators build out of SM fields (consistent with SM gauge symmetries)
- Model-independent studies

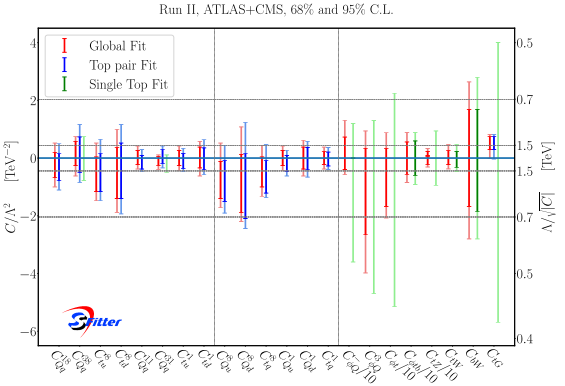
$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \underbrace{\sum_i \frac{C_i^{(5)}}{\Lambda} O_i^{(5)}}_{\text{Majorana masses}} + \underbrace{\sum_i \frac{C_i^{(6)}}{\Lambda^2} O_i^{(6)}}_{\text{Leading contribution}} + \ldots$$

- Lowest order: SM Lagrangian
- Add higher-dimensional operators

Top quark sector of SMEFT

SMEFT approach to BSM physics

- Top physics have entered precision phase
- Deviations in top couplings predicted in many BSM models
- Several studies within the SMEFT framework
- Global fits and uncertainty management key tasks



[Brivio et al. (2019)]

⇒ Correlations between uncertainties play important role

⇒ Quantitative impact of correlations continues to be unknown

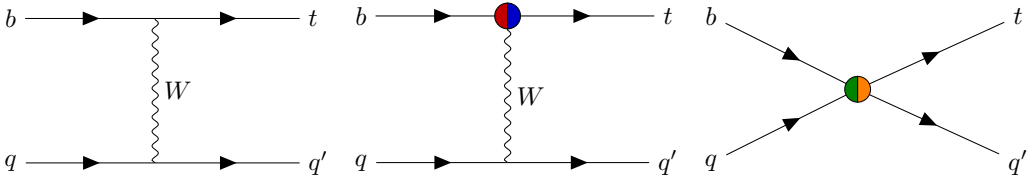
Correlations in SMEFT fits

Operators and degrees of freedom

- Entertain example of t-channel single-top production and top decay
- Four dimension-six operators interfere with SM process

$$O_{\phi q}^{(3)} = i\left(\phi^\dagger \overleftrightarrow{D}^I_\mu \phi\right)\left(\bar{q}_L \gamma^\mu \tau^I q_L\right), \qquad O_{tW} = \left(\bar{q}_L \sigma^{\mu\nu} \tau^I t_R\right)\tilde{\phi} W^I_{\mu\nu},$$

$$O_{qq}^{(1)} = \left(\bar{q}_L \gamma_\mu q_L\right)\left(\bar{q}_L \gamma^\mu q_L\right), \qquad O_{qq}^{(3)} = \left(\bar{q}_L \gamma_\mu \tau^I q_L\right)\left(\bar{q}_L \gamma^\mu \tau^I q_L\right),$$



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$\Rightarrow$ Three parameters in the fit ($\tilde{C}_i = C_i v^2/\Lambda^2$, with $v = 246$ GeV):

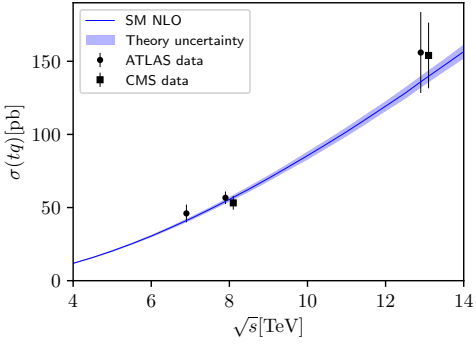
$$\tilde{C}_{\phi q}^{(3)}\,,\ \tilde{C}_{tW}\,,\ \tilde{C}_{qq} = \tilde{C}_{qq}^{(3)1133} + \frac{1}{6}\left(\tilde{C}_{qq}^{(1)1331} - \tilde{C}_{qq}^{(3)1331}\right),$$

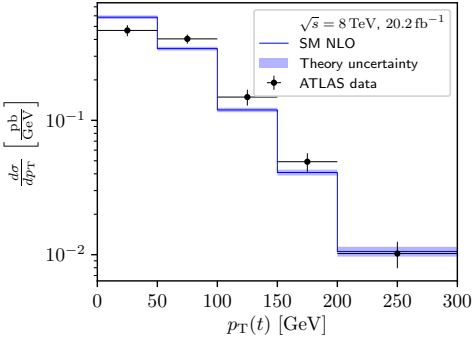
- Observables: Production cross sections, differential distributions, angular observables

Correlations in SMEFT fits

Measurements

- 55 measurements of 41 observables
- Single top production: Total and differential cross sections (ATLAS, CMS @ 7, 8, 13 TeV)





Correlations in SMEFT fits

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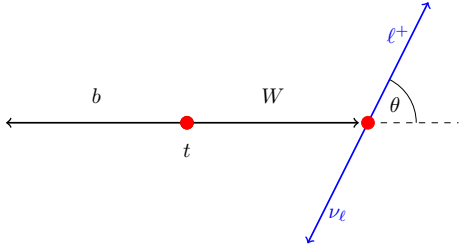

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta} = \frac{3}{4}F_0\sin^2\theta + \frac{3}{8}F_L(1-\cos\theta)^2 + \frac{3}{8}F_R(1+\cos\theta)^2$$

Correlations in SMEFT fits

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Fit setup

- Bayesian ansatz for constraints with EFT*fitter* [Castro et al. (2016)]
- Both linear and quadratic parametrization

$$\sigma_{\text{lin}} = \sigma_{\text{SM}} + \sum_i \tilde{C}_i \sigma_i \,, \quad \sigma_{\text{qua}} = \sigma_{\text{SM}} + \sum_i \tilde{C}_i \sigma_i + \sum_{i \leq j} \tilde{C}_i \tilde{C}_j \sigma_{ij} \,,$$

- Third ansatz with global 'EFT uncertainty' $\delta_{\text{EFT}} \sim v^2/(1\ \text{TeV})^2$:

$$\sigma_{\text{EFT}} = \sigma_{\text{lin}}(1 + \delta_{\text{EFT}})$$

Correlations in SMEFT fits

Correlations of uncertainties

- Correlations of stat. unc. provided by experiment (mostly vanishing)
- Corrleations of syst. and theo. unc. not provided, but could be sizeable [ATLAS, CMS coll. (2019)]
- Simplifying assumptions: consider example of 5 measurements

$$\underbrace{\begin{array}{c} \\ \sigma(tq)^{\mathsf{A}}_7 \\ \sigma(\bar{t}q)^{\mathsf{A}}_7 \\ \sigma(tq)^{\mathsf{A}}_8 \\ \sigma(tq)^{\mathsf{C}}_8 \\ \Gamma_t \end{array} \begin{array}{c} \begin{array}{ccccc} \sigma(tq)^{\mathsf{A}}_7 & \sigma(\bar{t}q)^{\mathsf{A}}_7 & \sigma(tq)^{\mathsf{A}}_8 & \sigma(tq)^{\mathsf{C}}_8 & \Gamma_t \end{array} \\ \begin{pmatrix} 1 & & & & \\ & 1 & & & \\ & & 1 & & \\ & & & 1 & \\ & & & & 1 \end{pmatrix} \end{array}}_{\text{systematic unc.}} , \quad \underbrace{\begin{array}{c} \begin{array}{ccccc} \sigma(tq)^{\mathsf{A}}_7 & \sigma(\bar{t}q)^{\mathsf{A}}_7 & \sigma(tq)^{\mathsf{A}}_8 & \sigma(tq)^{\mathsf{C}}_8 & \Gamma_t \end{array} \\ \begin{pmatrix} 1 & & & & \\ & 1 & & & \\ & & 1 & & \\ & & & 1 & \\ & & & & 1 \end{pmatrix} \end{array}}_{\text{theory unc.}}$$

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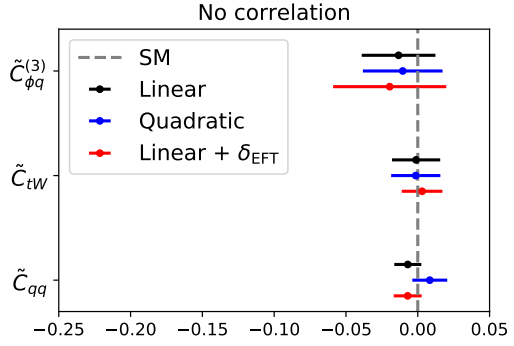
$\Rightarrow$ Two benchmark scenarios: $\rho_i = 0$ ('No Corr.') and $\rho_i = 0.9$ ('Best guess')

Correlations in SMEFT fits

Fits in the benchmark scenarios

- All three coefficients varied independently, constant prior $-1 \leq \tilde{C}_i \leq 1$
- Dots/lines denote global mode/95 % interval



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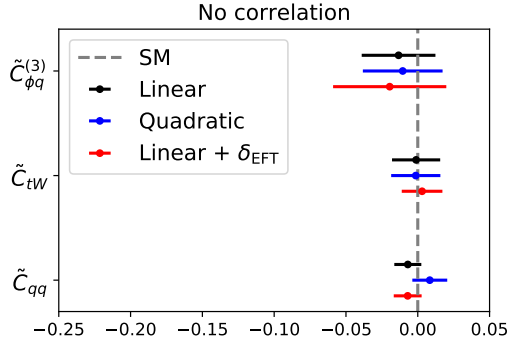
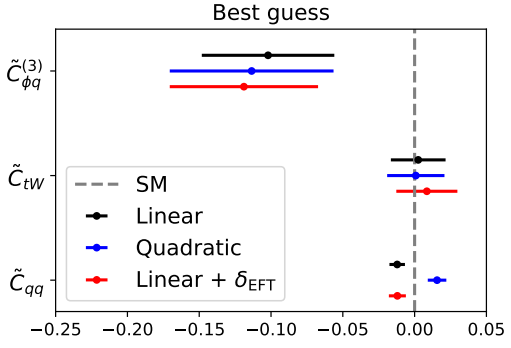




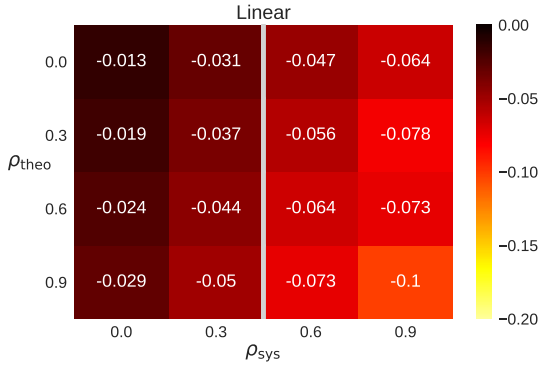
$\Rightarrow$ Deviations from SM in best guess scenario, especially $\tilde{C}_{\phi q}^{(3)}$

$\Rightarrow$ Size of 95 % intervals change

Correlations in SMEFT fits

Comparison of correlation coefficients

- Repeat fit with different values for ρ_{sys}, ρ_{th}
- Special interest: Deviation in $\tilde{C}_{\phi q}^{(3)}$



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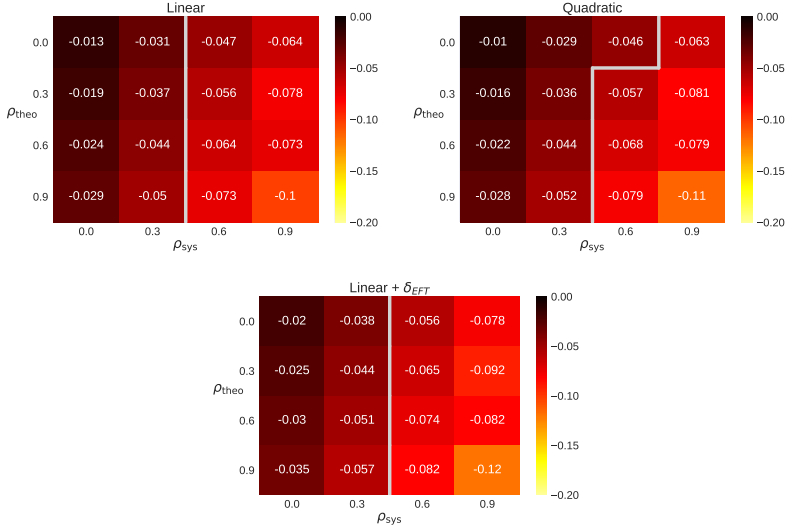
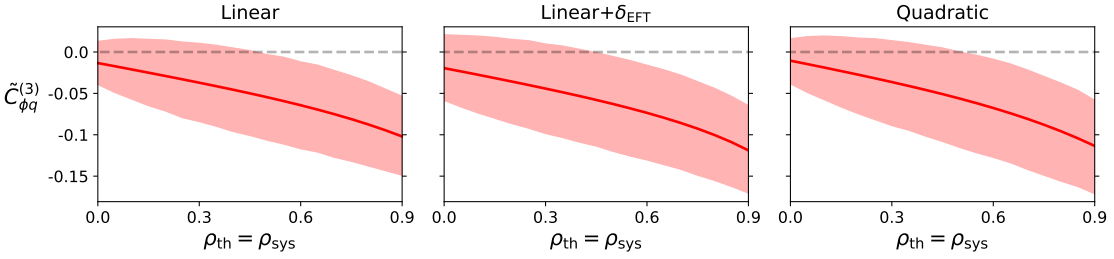


Correlations in SMEFT fits

Stability of the best guess scenario



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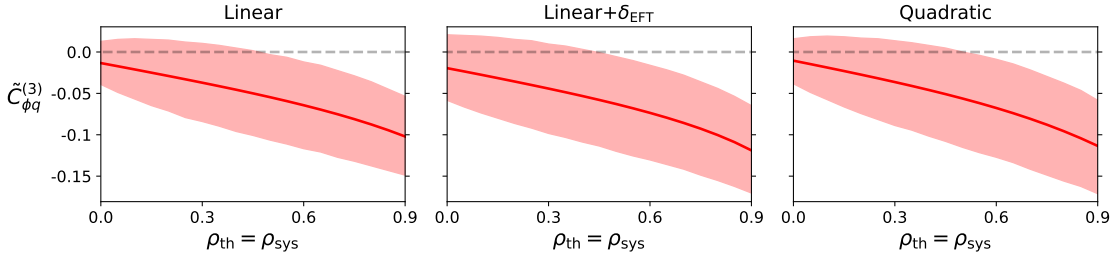
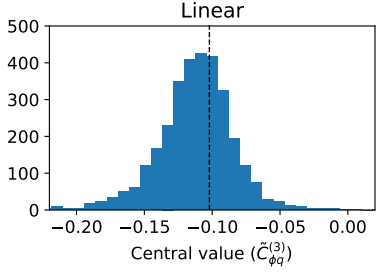


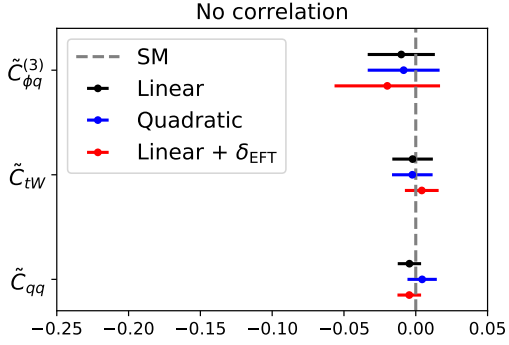
- Repeat fit varying best guess entries randomly (3000 times)
- Add uniformly distributed numbers in interval $[-0.05, 0.05]$
- Matrix required to stay symmetric



Correlations in SMEFT fits

Correlations in the light of future scenarios

- Consider higher integrated luminosity at future experiments
- Scale stat. unc to 300 fb^{-1} (LHC Run 3) [CERN Yellow Rep. (2017)]



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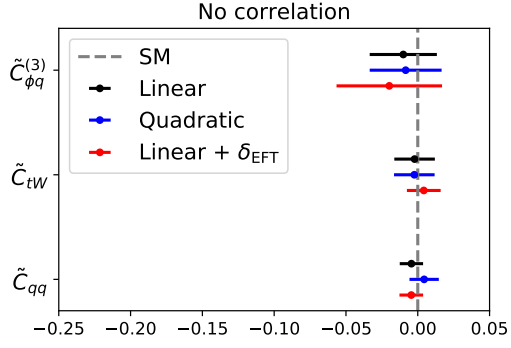
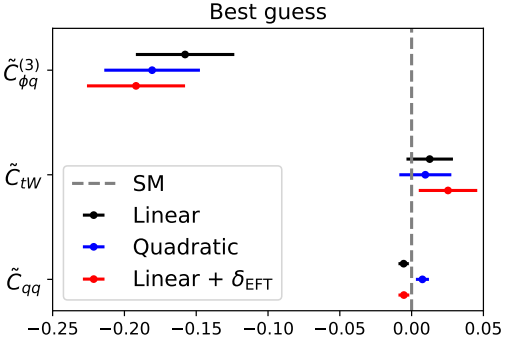
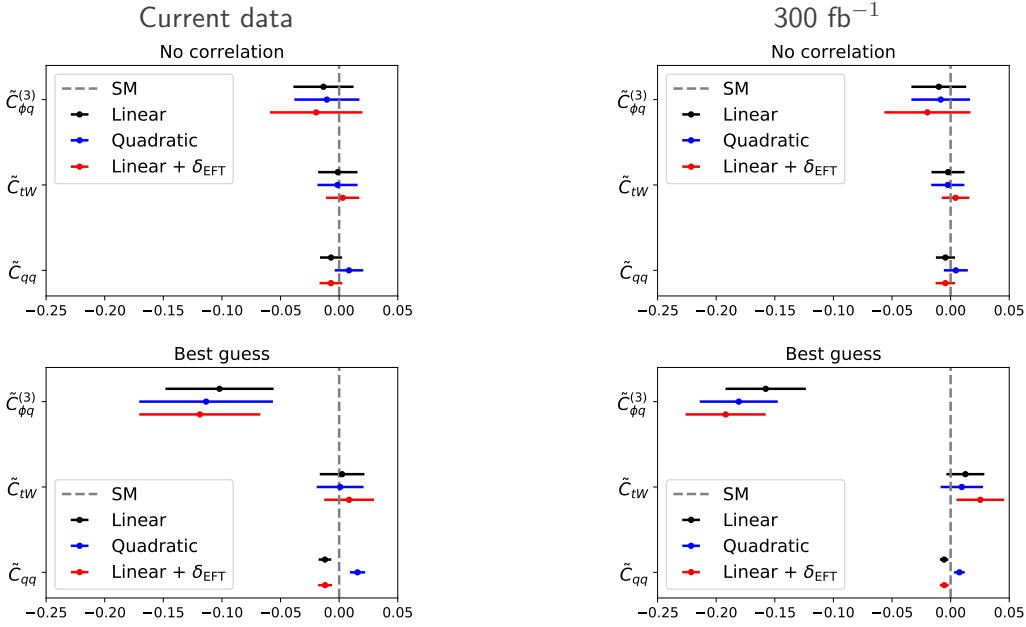




Correlations in SMEFT fits



Conclusion

- Quantitative study of correlations within SMEFT framework
- Overall EFT uncertainty can not cover missing higher orders in Λ^{-2}
- Differences in the two benchmark scenarios 'No Corr.' and 'Best guess':
  - No Corr.: Agreement with SM within 95 % intervals
  - Best guess: Large deviations up to $4.5\ \sigma$ for $\tilde{C}_{\phi q}^{(3)}$, $\tilde{C}_{qq}$
- Constraints show continuous and consistent behavior for rising values of ρ_i
- Stronger correlations $\Rightarrow$ Larger deviations from SM
- Significant deviation $\sim 9\ \sigma$ for $\tilde{C}_{\phi q}^{(3)}$ at 300 fb^{-1} projection
- Suggest to perform global fits with different correlation assumptions
- We encourage studies similar to recent ATLAS and CMS analysis [ATLAS, CMS coll. (2019)]

'Correlations matter, in the future even more'

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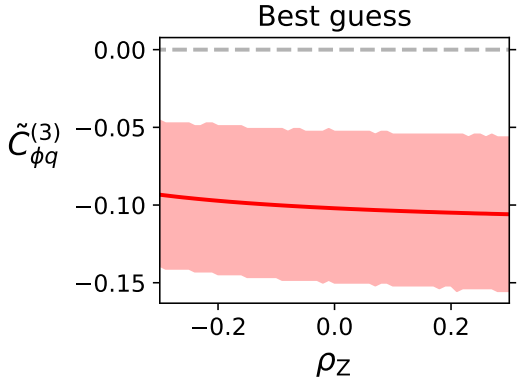
Thank you!

Extra slides

Measurements included

Process	$\sqrt{s}$	Luminosity	Experiment	Observable
Single top	7 TeV	4.59 fb^{-1}	ATLAS[(2014)]	$\sigma(tq)$, $\sigma(\bar{t}q)$, $d\sigma(tq)/dp_T$, $d\sigma(\bar{t}q)/dp_T$
		1.17 fb^{-1}(μ)	CMS [(2012)]	$\sigma(tq+\bar{t}q)$
		1.56 fb^{-1}(e)	CMS [(2012)]	$\sigma(tq+\bar{t}q)$
Single top	8 TeV	20.2 fb^{-1}	ATLAS [(2017)]	$\sigma(tq)$, $\sigma(\bar{t}q)$, $d\sigma(tq)/dp_T$, $d\sigma(\bar{t}q)/dp_T$
		19.7 fb^{-1}	CMS [(2014)], [(2014)]	$\sigma(tq)$, $\sigma(\bar{t}q)$, $\sigma(tq+\bar{t}q)$, $d\sigma/d\lvert y(t/\bar{t})\rvert$
Single top	13 TeV	3.2 fb^{-1}	ATLAS[(2016)]	$\sigma(tq)$, $\sigma(\bar{t}q)$
		2.2 fb^{-1}	CMS[(2016)]	$\sigma(tq)$, $\sigma(\bar{t}q)$, $\sigma(tq+\bar{t}q)$
		2.3 fb^{-1}	CMS[(2016)]	$d\sigma/d\lvert y(t/\bar{t})\rvert$
Top decay	1.96 TeV	2.7 fb^{-1}	CDF[(2010)]	F_0
		8.7 fb^{-1}	CDF[(2013)]	F_0
		5.4 fb^{-1}	D0[(2012)]	F_0
Top decay	7 TeV	1.04 fb^{-1}	ATLAS[(2012)]	F_0, F_L
		5.0 fb^{-1}	CMS[(2013)]	F_0, F_L
Top decay	8 TeV	20.2 fb^{-1}	ATLAS[(2017)]	Γ_t
		20.2 fb^{-1}	ATLAS[(2019)]	F_0, F_L
		19.7 fb^{-1}	CMS[(2015)]	F_0, F_L
Top decay	13 TeV	19.8 fb^{-1}	CMS[(2016)]	F_0, F_L

Correlations at future experiments



- Replace every '0' in correlation matrices by ρ_z
- Vary between -0.3 and 0.3
- Changes $\sim$ few percent

Correlations at future experiments