Constraining New Physics through Standard Model Effective Theory

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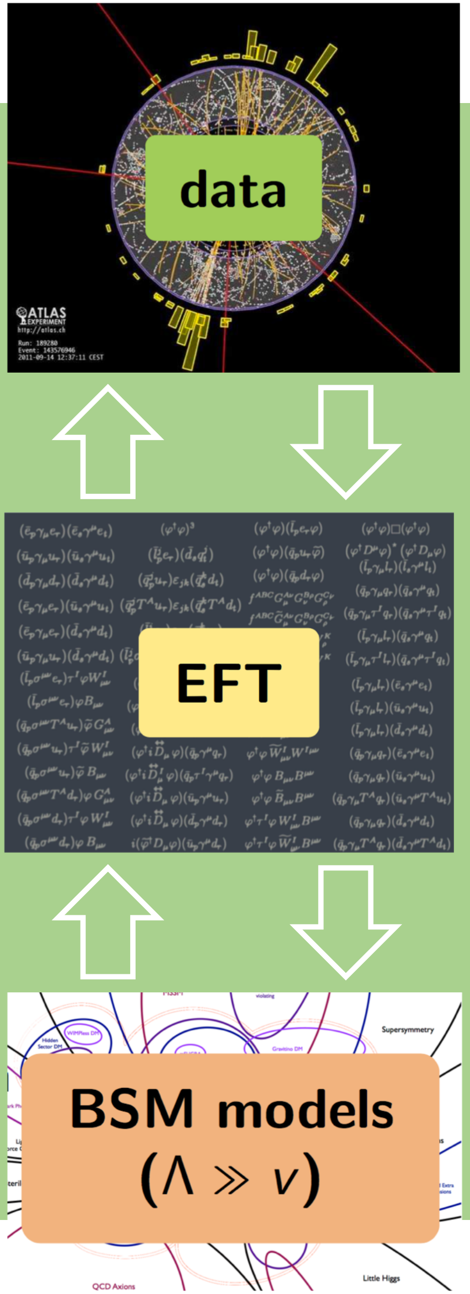
Fig. 1 A multi-loop corrected tree

Based on work with:

R. Boughezal, F. Petriello, C. Chen

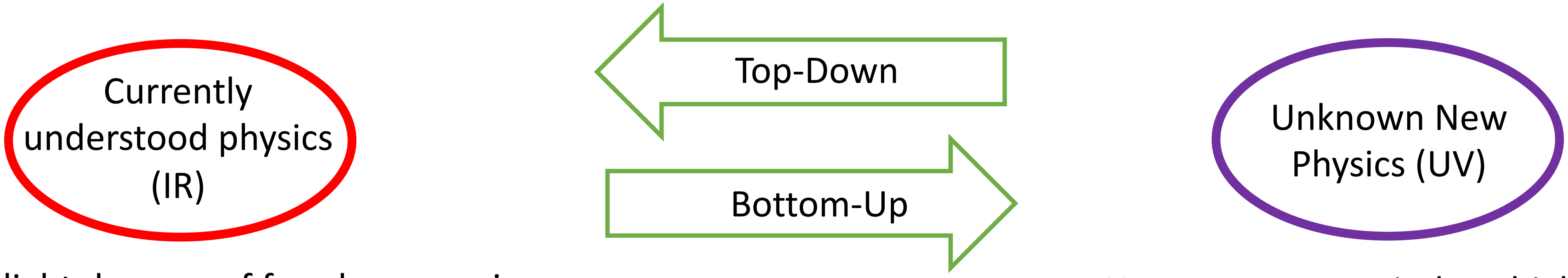
the What, the Why and the How



- the What
  - SMEFT is an attractive framework to constrain **new physics**
  - **Radiative Corrections** important for stability/precision/operator mixing!
- the Why
  - Analysis is **universally** applicable/model independent
  - Nifty way to keep track of data
  - Plenty of progress/active field
- the How
  - Basic Philosophy of SMEFT
  - Where are we standing now?
  - Tools of the trade

SMEFT – Basic Idea

The obligatory historic example (Fermi 1933)



Only light degrees of freedom remain

Heavy new states induce higher dim operators

SMEFT – Basic Idea

The obligatory historic example (Fermi 1933)

Currently understood physics (IR)

Top-Down

Bottom-Up

Unknown New Physics (UV)

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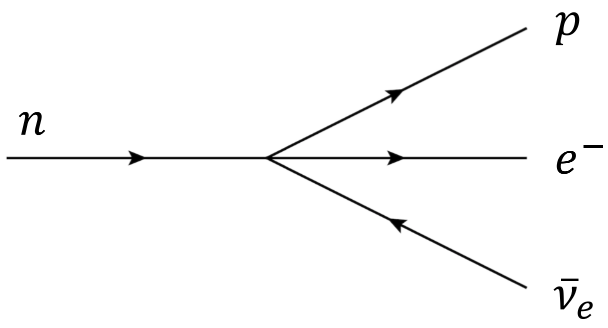
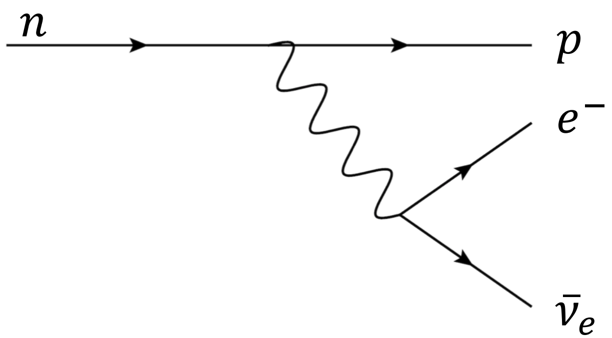


Energies $\ll \Lambda$



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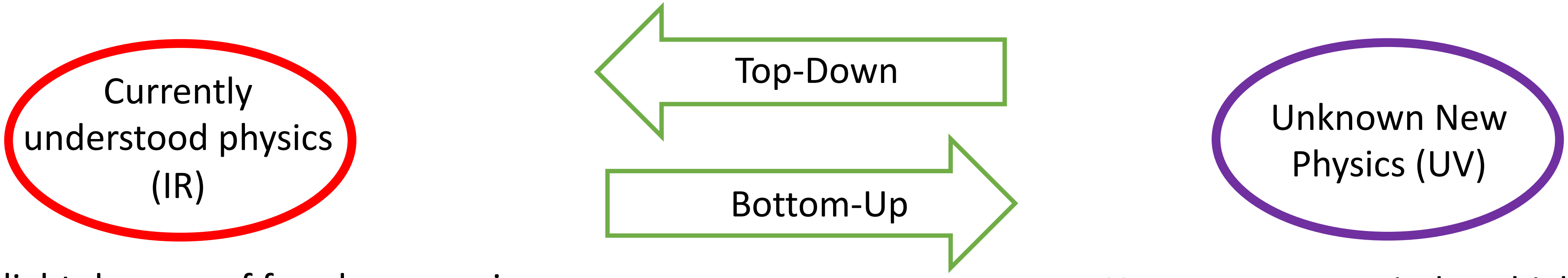

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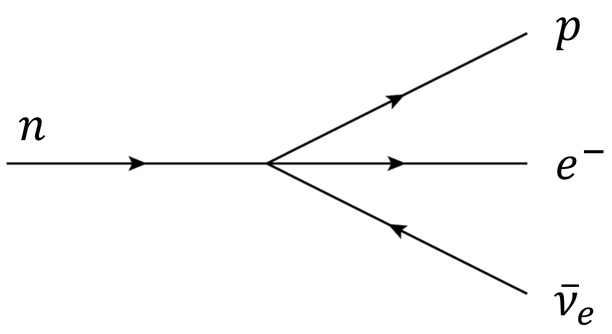

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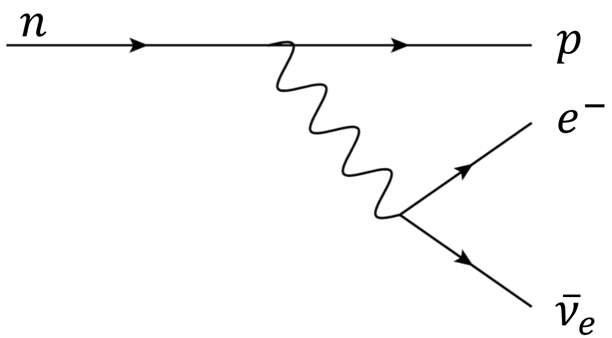

Write down all possible IR operators...

$$\frac{S_{\pm\pm}}{\Lambda^2}(\bar{p}\mathcal{P}_\pm n)(\bar{e}\mathcal{P}_\pm \nu_e) \quad \frac{T_{\pm\pm}}{\Lambda^2}(\bar{p}\sigma^{\mu\nu}\mathcal{P}_\pm n)(\bar{e}\sigma^{\mu\nu}\mathcal{P}_\pm \nu_e) \quad \frac{V_{\pm\pm}}{\Lambda^2}(\bar{p}\gamma^{\mu}\mathcal{P}_\pm n)(\bar{e}\gamma^{\mu}\mathcal{P}_\pm \nu_e)$$

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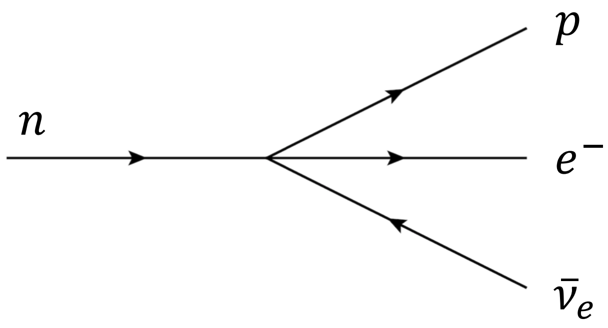

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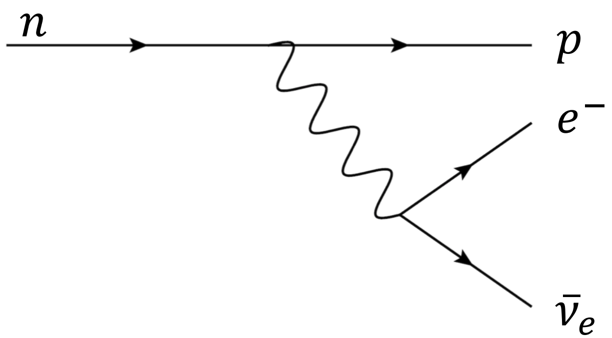

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... and start measuring!

V-A Structure: $G_F(\bar{p}\gamma^{\mu}\mathcal{P}_- n)(\bar{e}\gamma^{\mu}\mathcal{P}_- \nu_e)$ ⟹ G_F suggests $\Lambda \sim \mathcal{O}(100\text{GeV})$

Technical details (I)

Write down all possible operators that new physics could induce

- Stay consistent with SM **symmetries**! $(\delta B \neq 0?, \delta L \neq 0?)$
- Build from SM field content!

$$\mathcal{L}_{SMEFT} \supset \mathcal{L}_{SM} + \frac{C_5}{\Lambda}\mathcal{O}^5 + \frac{C_6^i}{\Lambda^2}\mathcal{O}_i^6 + \frac{C_7^i}{\Lambda^3}\mathcal{O}_i^7 + \cdots$$

*Weinberg (Phys. Rev. Lett. **43**, 1566)*
Grzadkowski, Iskrzynski, Misiak, Rosiek (1008.4884)
Henning, Lu, Meila, Murayama (1512.03433)
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Renormalizability remains intact if consistent truncation in Λ

Counterterms: Introduce $\overline{MS}$ renormalized operators through $C_i = \mathcal{Z}_{ij}\tilde{C}^j$ (**Operator Mixing** with tree-level)

Leads to running coefficients: $$\frac{dC_i}{d\log\mu} = \frac{\delta Z_{ij}}{16\pi^2}C^j$$

Complete RGE at 1-loop known

Alonso, Jenkins, Manohar, Trott (1312.2014)

Technical details (II)

$1: X^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
Q_W	$\epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$
$Q_{\widetilde{W}}$	$\epsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$

$2: H^6$	
Q_H	$(H^\dagger H)^3$

$3: H^4 D^2$	
$Q_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$
Q_{HD}	$\left(H^\dagger D_\mu H\right)^* \left(H^\dagger D_\mu H\right)$

$5: \psi^2 H^3 + \text{h.c.}$	
Q_{eH}	$(H^\dagger H)(\bar{l}_p e_r H)$
Q_{uH}	$(H^\dagger H)(\bar{q}_p u_r \widetilde{H})$
Q_{dH}	$(H^\dagger H)(\bar{q}_p d_r H)$

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$6: \psi^2 X H + \text{h.c.}$	
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Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{H}\, G^A_{\mu\nu}$
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Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) H\, G^A_{\mu\nu}$
Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I H\, W^I_{\mu\nu}$
Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) H\, B_{\mu\nu}$

$7: \psi^2 H^2 D$	
$Q_{Hl}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{l}_p \gamma^\mu l_r)$
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Q_{He}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{e}_p \gamma^\mu e_r)$
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Fig. 2 the 59 operators of the Warsaw basis

Complete non-redundant operator base in unbroken phase (**Warsaw base**)

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(NB: ghosts receive dim-6 contribution from field redefinitions)

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Automate in a number of computational frameworks (FeynArts/MadGraph/Rosetta/…)

Here Feynman-Rules in R_ξ gauge:

Dedes, Materkowska, Paraskevas, Rosiek, Suxhoa (2017)

What has been done?

This list is incomplete; you can help by expanding it.

Higgs Physics
- *Dawson, Giardino (1801.01136)*
- *Dawson, Ismail (1808.05948)*
- *Englert, Freitas, Muhlleiter, Plehn, Rauch, Spira (1403.7191)*
- *Pomarol, Riva (1308.2803)*

Electroweak-LHC
- *Falkowski, Gonzalez-Alonso, Greljo, Marzocca, Son (1609.06312)*
- *Hartmann, Shepherd, Trott (1611.09879)*
- *Farina, Panico, Pappadopulo, Ruderman, Torre, Wulzer (1609.08157)*

Low-Energy Electroweak
- *Falkowski, Gonzalez-Alonso, Mimouni (1706.03783)*
- *Jenkins, Manohar, Stoffer (1709.04486)*

QCD/Jets
- *Kraus, Kuttimalai, Plehn (1611.00767)*
- *Maltoni, Pagani, Tsinikos (1507.05640)*

Also Reviews:
- *Brivio, Trott (1706.08945)*
- *Passarino, Trott (1610.08356)*

⇒ Tons of LO and plenty NLO analysis

Top Decay

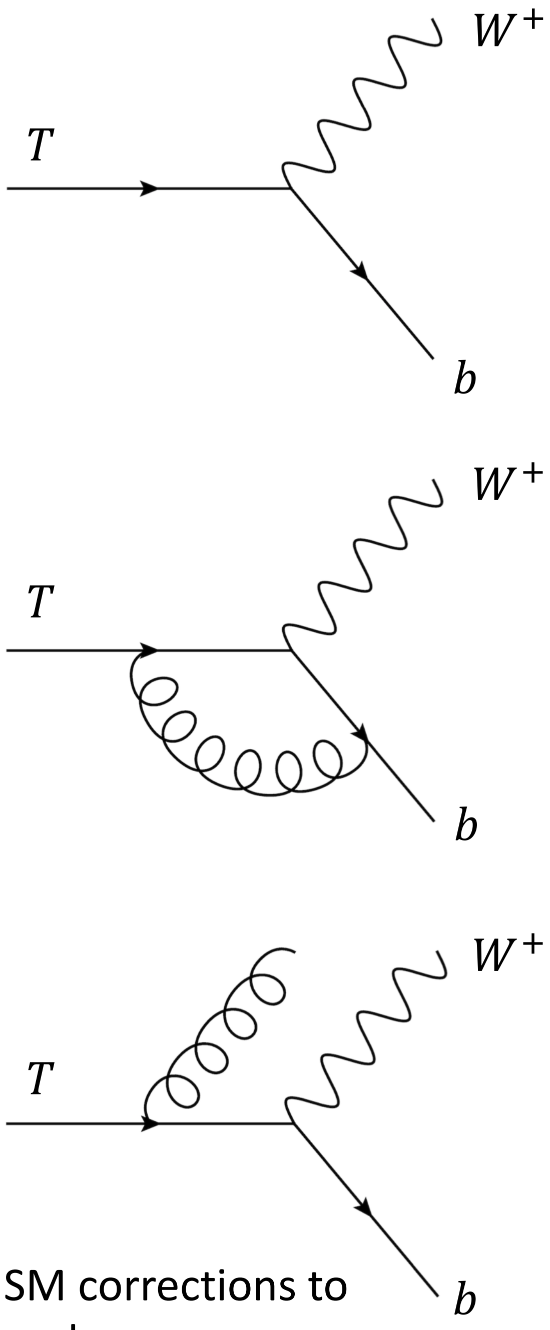


Fig. 3 QCD SM corrections to Top decay

Start with a simple process to get the machinery set up:

Top decay **helicity fractions** very well measured:

$$\frac{\Gamma_L}{\Gamma} = 0.72 \qquad \frac{\Gamma_+}{\Gamma} = 0.28 \qquad \frac{\Gamma_-}{\Gamma} \sim 0$$

SM predictions known to NNLO QCD – strong SMEFT constraints?

Czarecki, Körner, Piclum (1005.2625)

Top Decay

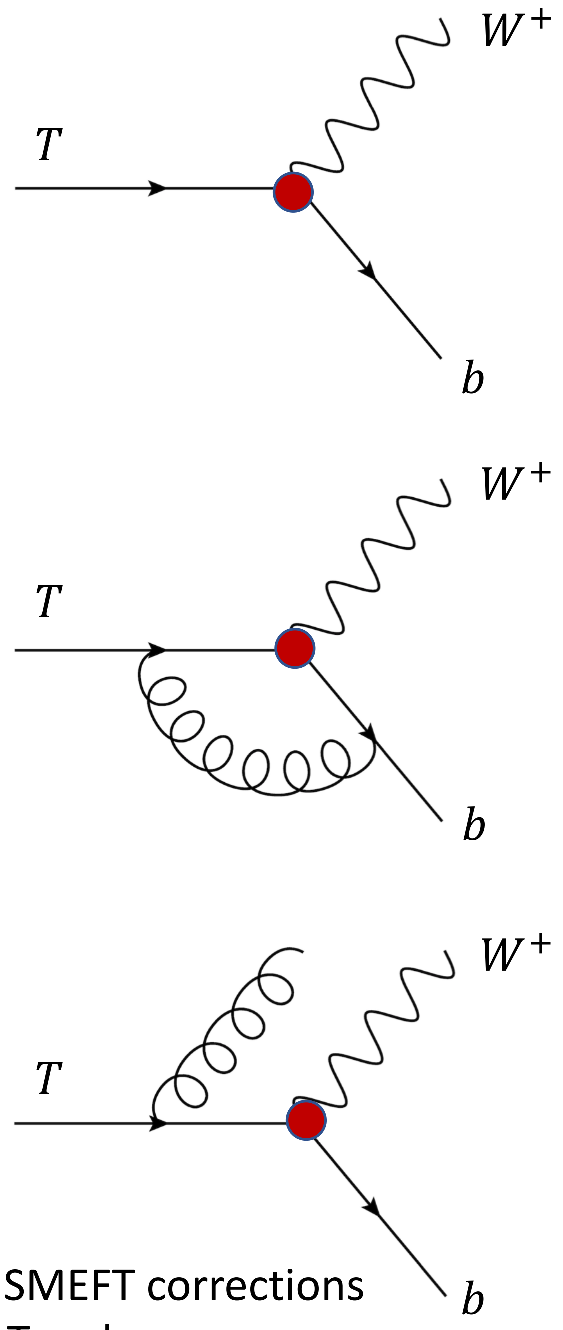


Fig. 3 QCD SMEFT corrections to Top decay

Start with a simple process to get the machinery set up:

Top decay **helicity fractions** very well measured:

$$\frac{\Gamma_L}{\Gamma} = 0.72 \qquad \frac{\Gamma_+}{\Gamma} = 0.28 \qquad \frac{\Gamma_-}{\Gamma} \sim 0$$

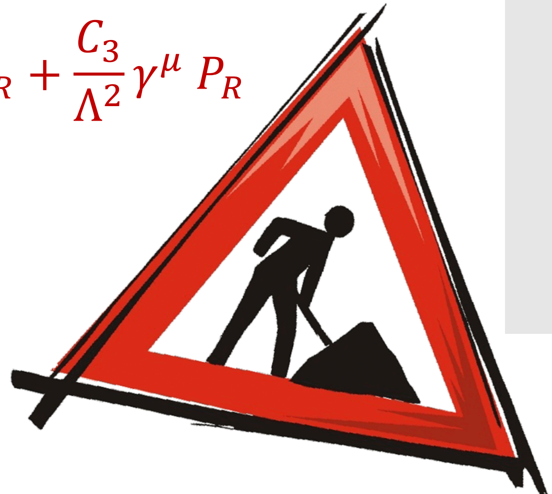
SM predictions known to NNLO QCD – strong SMEFT constraints?

Czarecki, Körner, Piclum (1005.2625)

⇨ Now switch on dimension six operators:

$\bar{b}Wt$-Vertex $\quad \frac{ie}{s_w}\gamma^\mu P_L + \frac{C_1}{\Lambda^2}\sigma^{\mu\upsilon}p_\upsilon P_L + \frac{C_2}{\Lambda^2}\sigma^{\mu\upsilon}p_\upsilon P_R + \frac{C_3}{\Lambda^2}\gamma^\mu\, P_R$

$\bar{q}Gq$-Vertex $\quad ig_s\gamma^\mu$



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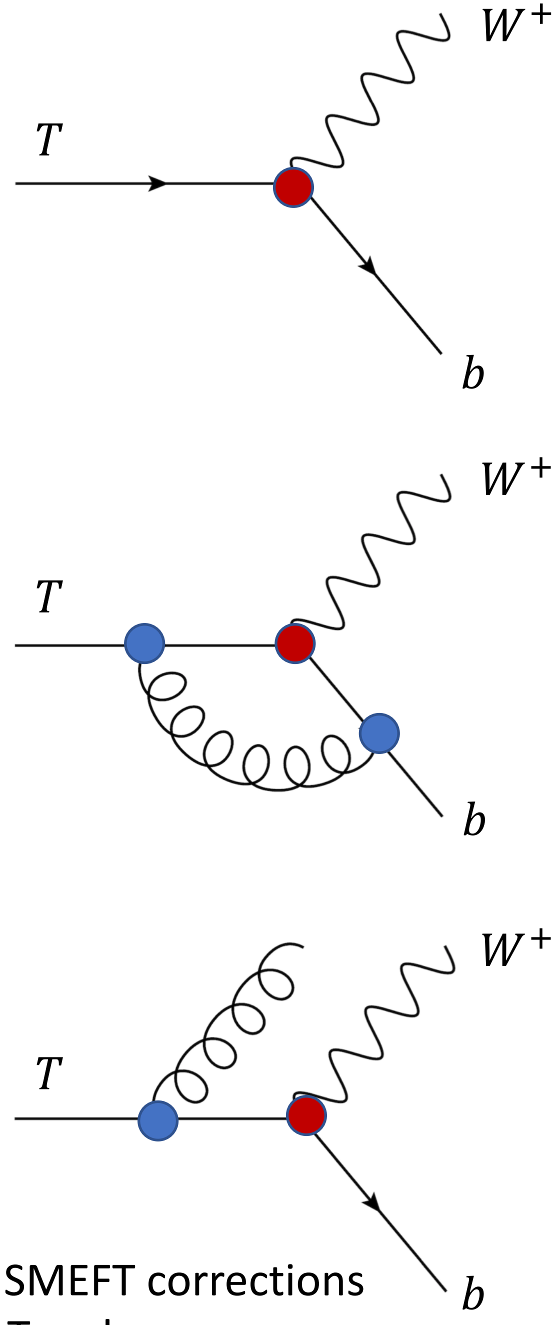

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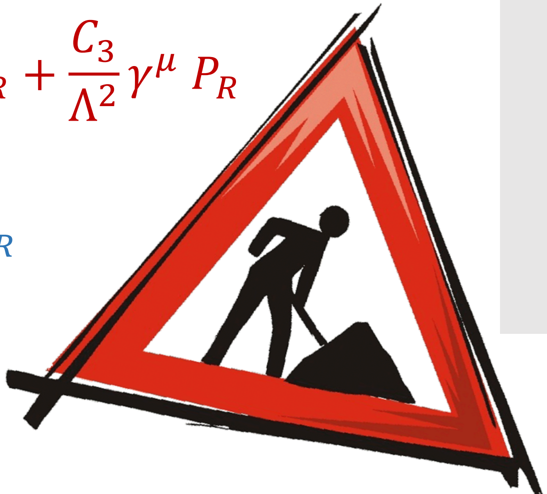


Setting Bounds

The Born-level already gives a taste what bounds to expect:

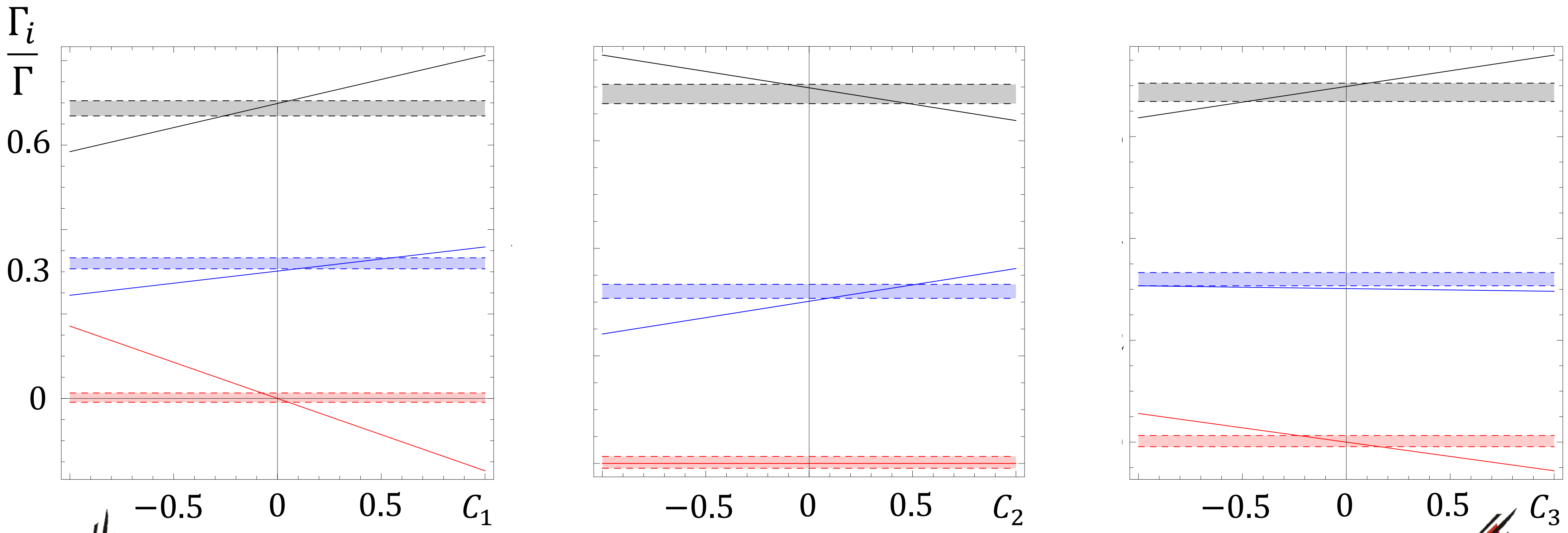
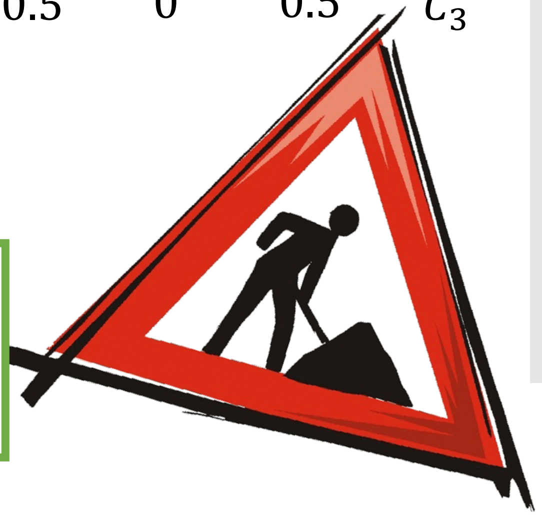


Fig. 3 Bounds on the electroweak Wilson coefficients at LO ($\Lambda = 100\text{GeV}$)



1) NLO QCD is work in progress – stay tuned!
2) EW corrections might or might not be important

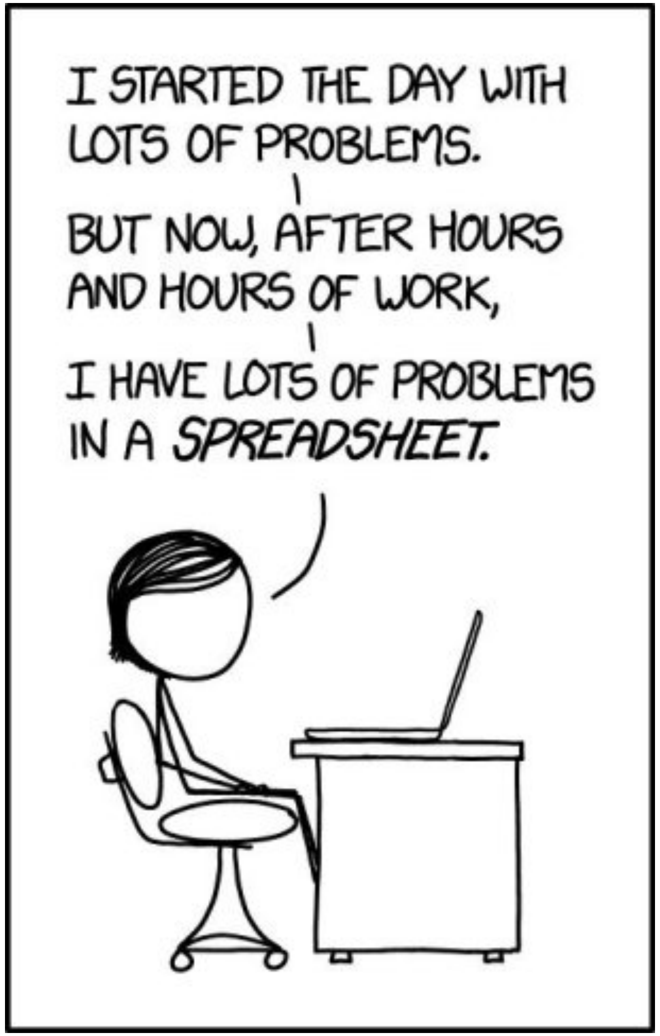
… and now what?

SMEFT has been the framework to go about constraining new physics!

- Systematic way to evaluate data/link seemingly unrelated results
- Parametrize new physics data in **model-independent** way
- Active field with plenty to do!

- Where to go from here?

  - More involved Top processes?
    (larger topology – more constraints
    – more difficult)
  - Low-energy electroweak observables?
    (less LHC – less sexy)



Thanks!