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Plan

- EFT introduction
- Top examples (with EFT)
- Top fit
- PDF and EFT
- Summary

Indirect detection of NP

• Assumption : NP scale >> energy probed in experiments E

Effective field theory

Model independent searches for new physics

Ex: Fermi theory
$$
\frac{G_F}{Sqrt[2]} J^{\mu} J_{\mu}, \quad J_{\mu} = J_{\mu}^{l} + J_{\mu}^{h}, \quad J_{\mu}^{l} = \nu_l \gamma_{\mu} (1 - \gamma_5) l
$$

Resonances

C. Degrande

Model independent searches for new physics

Expansion of the Lagrangian

$$
L^{NP} = -\frac{1}{4}V^{\mu\nu}V_{\mu\nu} + M^2V^{\mu}V_{\mu} + \sum_{i} g_i V_{\mu}J^{\mu}_i + h.c.
$$

• if V is very heavy -1 4 $V^{\mu\nu}V_{\mu\nu} \sim 0$

• and the EOM is $V^{\mu} = -\frac{1}{M}$ $\overline{M^2}$ $\overline{}$ *i* $g_i J_i^{\mu}$ $\frac{d}{dt}$ + h . c .

$$
L_{EFT}^{NP} = -\frac{\left(\sum_{i} g_i J_i^{\mu}\right) \left(\sum_{i} g_i J_{\mu_i}\right)^{\dagger}}{M^2}
$$
 C. Degrande

in a smaller number of parameters can be obtained for any heavy new physics model using

far, the size of the f ^V

$\mathcal{L} = \mathcal{L}_{SM} + \sum$ $d > 4$ \sum \boldsymbol{i} C_i $\frac{C_i}{\Lambda^{d-4}}$ \mathcal{O}_i^d SM fields & sym.

EFT is unknown. They have been also contained or estimated or estimated or estimated or estimated or estimated or for some extensions of the SM \blacksquare \blacksquare \blacksquare as well as the size as well as the interval as the interval as well as the interval as well as the

in a smaller number of parameters can be obtained for any heavy new physics model using

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Exametrize any NP but an ∞ number of coefficients

$$
\mathcal{L} = \mathcal{L}_{SM} + \sum_{d>4} \sum_{i} \frac{C_i}{\Lambda^{d-4}} \mathcal{O}_i^d
$$
 = SM fields & sym.
\n• Assumption: $E_{exp} \ll \Lambda$
\n
$$
\mathcal{L} = \mathcal{L}_{SM} + \sum_{i} \frac{C_i}{\Lambda^2} \mathcal{O}_i^6
$$
 a finite number of coefficients
\n=Predictive!

- Model independent (i.e. parametrize a large class of models) : any HEAVY NP
- SM is the leading term : EFT for precision physics

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in a smaller number of parameters can be obtained for any heavy new physics model using

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Exametrize any NP but an ∞ number of coefficients

$$
\mathcal{L} = \mathcal{L}_{SM} + \sum_{d>4} \sum_{i} \frac{C_i}{\Lambda^{d-4}} \mathcal{O}_i^d \blacktriangleleft \text{ SM fields & sym.}
$$
\n• Assumption: $E_{\text{exp}} \ll \Lambda$ \n
$$
\mathcal{L} = \mathcal{L}_{SM} + \sum_{i} \frac{C_i}{\Lambda^2} \mathcal{O}_i^6
$$
\n
$$
\text{measure only } C_i/\Lambda^2
$$
\n
$$
= \text{Predictive!}
$$

- Model independent (i.e. parametrize a large class of models) : any HEAVY NP
- SM is the leading term : EFT for precision physics

Interference

$$
|M(x)|^2 = |M_{SM}(x)|^2 + 2\Re(M_{SM}(x)M_{d6}^*(x)) + |M_{d6}(x)|^2 + \cdots
$$

\n
$$
\Lambda^0
$$
\n
$$
\Lambda^{-2}
$$
\n

Observable dependent

EFT & scales

EFT & scales

Top operators no restriction is imposed on this imposed on the third-generation bilinears. This assumption simplifies four-f
This assumption simplifies for the third-generation simplifies for the third-generation simplifies four-fermio operators but does not aect third-generation two-fermion ones. Compared to flavour diagonality, $3, \ldots, 3$, which would just force quarks and antiquarks and antiquarks and antiquarks to appear in same-flavour pairs, α *U*(2)*^q* ◊ *U*(2)*^u* ◊ *U*(2)*^d* eectively imposes the following additional requirements:

³, which would just force quarks and antiquarks to appear in same-flavour pairs,

operators but does not aect third-generation two-fermion ones. Compared to flavour diagonality,

alently, a *U*(2)*^q* ◊*U*(2)*u*◊*U*(2)*^d* symmetry is assumed between the first two quark generations and

Assume (*Io be checked)* that all the operators without top are 2. the chirality-flipping bilinears of the first generations (*qu*¯ , *qd*¯) are forbidden, 2. the constrained by other processes (*i* e not involving the fon) Assume (To be checked) that all the **operators without top** are better **constrained** by other processes (i.e. not involving the top)

 $U(2)_a \times U(2)_u \times U(2)_d$ flavour symmetry

The *U*(2)*^q* ◊*U*(2)*^u* ◊*U*(2)*^d* flavour symmetry assumption is used by default in this note where not $F = \mathsf{W} \mathsf{P} \mathsf{V}$ with all F massiess out t, b $-NIEN$ with all F maccless but the following T =MFV with all F massless but t,b

C. Degrande

four heavy quarks two light and two heavy quarks 14 two light and two heavy quarks 14 two heavy quarks and bosons $9+6$ CPV two heavy quarks and two leptons $11 + 2$ CPV $(8 + 3 \text{ CPV}) \times 3$ lepton flavours

Finally, a more restrictive variant of this *U*(2)*^q* ◊*U*(2)*^u* ◊*U*(2)*^d* scenario would retain only the

Warsaw-basis operator coecients. 1802.07237 s_{0} and s_{0} and s_{1} to s_{0} and s_{1} to s_{0} to s_{0} to s_{0} to s_{0} and s_{0} to s_{0} Warsawa basis operator coecients. Coecients was considered and coecients. The coefficients of the coefficients of the coefficients of the coefficients of the coefficients. The coefficients of the coefficients of the coeffi

i.e. [*U*(1)*q*+*u*+*d*]

i.e. [*U*(1)*q*+*u*+*d*]

top pair production *qu* = (¯*qi"µT ^Aq^j*)(¯*uk"µT ^Aul*)*,* (4) *uu* [≠2*.*92*,* 2*.*80] (*Ecut* = 3 TeV) [44] ² *^C*3(*i*33*i*) *qq* [≠3*.*13*,* 3*.*15] [44] \bullet **u**op pair prod

qu [≠8*.*13*,* 4*.*05] [44]

Two-light-two-heavy (14 d.o.f.) 8[*I*] *<u>Two-light-two-heavy (14 d.o.f.)</u>*

$$
\begin{array}{llll} \overline{c_{Qq}^{3,1}} & \equiv C_{qq}^{3(ii33)} + \frac{1}{6}(C_{qq}^{1(i33i)} - C_{qq}^{3(i33i)}) \\ \overline{c_{Qq}^{3,8}} & \equiv C_{qq}^{1(i33i)} - C_{qq}^{3(i33i)} \\ \overline{c_{Qq}^{1,1}} & \equiv C_{qq}^{1(i33i)} + \frac{1}{6}C_{qq}^{1(i33i)} + \frac{1}{2}C_{qq}^{3(i33i)} \\ \overline{c_{Qq}^{1,1}} & \equiv C_{qq}^{1(i33i)} + 3C_{qq}^{3(i33i)} \\ \overline{c_{Qu}^{1}} & \equiv C_{qu}^{1(33ii)} \\ \overline{c_{Qu}^{1}} & \equiv C_{qu}^{1(33ii)} \\ \overline{c_{Qu}^{1}} & \equiv C_{qu}^{1(33ii)} \\ \overline{c_{Qd}^{1}} & \equiv C_{qu}^{1(33ii)} \\ \overline{c_{Qd}^{1}} & \equiv C_{qu}^{1(i33i)} \\ \overline{c_{Qd}^{1}} & \equiv C_{qu}^{2(i33i)} \\ \overline{c_{Qd}^{1}} & \equiv C_{qu}^{2(i33i)} \\ \overline{c_{u}^{1}} & \equiv C_{qu}^{2(i33i)} \\ \overline{c_{u}^{1}} & \equiv C_{uu}^{2(i33i)} \\ \overline{c_{u}^{1}} & \equiv C_{uu}^{2(i33i)} \\ \overline{c_{u}^{1}} & \equiv C_{u}^{2(i33i)} \\ \overline{c_{u}^{1}}
$$

$T \sim 1$ d.o.f. [*I*] Two -heavy Re *{*≠*s^W ^C*(33) [*I*]

8[*I*]

tb © *^C*8(3333)

*c*8

*c*8

^t^Ï © [Im] Re *{C*(33) *uÏ }* $c_{tG}^{[1]}$ = $\frac{[Im]}{[Re]}$ { $C_{uG}^{(33)}$ } *^Ï^q c*¹ *c*3 *^Ï^q* [≠4*.*1*,* 2*.*0] [45], [≠8*.*6*,* 8*.*3] [46] $\begin{bmatrix} I \end{bmatrix}$ $\begin{bmatrix} I_{\rm m} \end{bmatrix}$ (33) $\epsilon_{tG} = \frac{1}{\text{Re}} \{C_{uG} \}$ *^Ï^q c*¹ *^Ï^q* [≠3*.*1*,* 3*.*1] [45], [≠8*.*3*,* 8*.*6] [46] **c bww.com**
With the contract of Re *{C*(33) $c_{tG}^{[I]}$ = $_{\rm Re}^{[\rm Im]}$ {*C*_{*uG*}⁽³³⁾} $\{aG\}$ } **c** Two-heavy-two-lepton (8+3 CPV d.o.f. ⁸2 lepton flavours)
Two-lepton flavours)

From the Warsaw hasis matrices; *^T ^A* © *[⁄]^A/*² where *[⁄]^A* are Gell-Mann matrices. *O*8(*ijkl*) *qd* = (¯*qi"µ^T ^Aq^j*)(¯ *dk"µT ^Adl*)*,* (6) From the Warsaw basis

$$
O_{qq}^{1(ijkl)} = (\bar{q}_i \gamma^\mu q_j)(\bar{q}_k \gamma_\mu q_l),
$$

\n
$$
O_{qq}^{3(ijkl)} = (\bar{q}_i \gamma^\mu \tau^I q_j)(\bar{q}_k \gamma_\mu \tau^I q_l),
$$

\n
$$
O_{qu}^{1(ijkl)} = (\bar{q}_i \gamma^\mu q_j)(\bar{u}_k \gamma_\mu u_l),
$$

\n
$$
O_{qu}^{8(ijkl)} = (\bar{q}_i \gamma^\mu T^A q_j)(\bar{u}_k \gamma_\mu T^A u_l),
$$

\n
$$
O_{qd}^{1(ijkl)} = (\bar{q}_i \gamma^\mu q_j)(\bar{d}_k \gamma_\mu d_l),
$$

\n
$$
O_{qd}^{8(ijkl)} = (\bar{q}_i \gamma^\mu T^A q_j)(\bar{d}_k \gamma_\mu T^A d_l),
$$

\n
$$
O_{uu}^{(ijkl)} = (\bar{u}_i \gamma^\mu u_j)(\bar{u}_k \gamma_\mu u_l),
$$

\n
$$
O_{ud}^{1(ijkl)} = (\bar{u}_i \gamma^\mu u_j)(\bar{d}_k \gamma_\mu d_l),
$$

\n
$$
O_{ud}^{8(ijkl)} = (\bar{u}_i \gamma^\mu T^A u_j)(\bar{d}_k \gamma_\mu T^A d_l),
$$

 $^\ddagger O^{(ij)}_{uG} = (\bar q_i \sigma^{\mu\nu} T^A u_j)\ \tilde\varphi G^A_{\mu\nu},$ Ωæ*^D ^µÏ*)(¯*qi"^µq^j*)*,* (13) $\frac{A}{\mu\nu}$,

> C. Degrande <u>Cantanda</u> *^Ïud* = (˜*Ï†iDµÏ*)(¯*ui"^µd^j*)*,* (16) *lu* = (¯*li"^µl^j*)(¯*uk"^µul*)*,* (23)

qu = (¯*qi"µq^j*)(¯*uk"µul*)*,* (3)

dk"µdl)*,* (5)

top pair production

4F interfere only with qq

uu is **Top operators** *ud* [≠4*.*95*,* 5*.*04] [44] *uu* [≠8*.*05*,* 4*.*75] [44]

Two-quark operators: $T_{\rm eff}$ two-lepton operators: $\sigma_{\rm eff}$ two-lepton operators: $\sigma_{\rm eff}$ Two-heavy $(9+6$ CPV d.o.f.) $c^{[I]}_{t\varphi}$ $\begin{bmatrix} 1 & 1 \ t \varphi \end{bmatrix} \equiv \frac{[\text{Im}]}{\text{Re}} \{ C^{(33)}_{u\varphi} \}$ c_{φ}^+ $\frac{1}{\varphi q}$ $\equiv C_{\varphi q}^{1(33)} - C_{\varphi q}^{3(33)}$ c_{φ}^3 $\frac{3}{\varphi Q}$ $\equiv C_{\varphi q}^{3(33)}$ \overline{I} ³⁽³³⁾ $O_{\infty}^{3(i)}$ $c_{\varphi t}$ \equiv $C_{\varphi u}^{(33)}$ $\overline{\mathbf{F}}_{q}^{(33)}$ **i** $\overline{\mathbf{F}}_{q}^{(33)}$ **i** $\overline{\mathbf{F}}_{q}^{(43)}$ $c_{\text{tot}}^{[I]}$ $\begin{bmatrix} 1 \\ \varphi tb \end{bmatrix} \equiv \frac{[\text{Im}]}{\text{Re}} \{ C^{(33)}_{\varphi ud} \}$ $c_{tW}^{\left[I\right] }$ $\frac{1}{t}$ *W* $\equiv \frac{[\text{Im}]}{\text{Re}} \{C_{uW}^{(33)}\}$ $\mathbf{u}^{(33)}$, $\mathbf{u}^{(34)}$, $\mathbf{u}^{(45)}$, $\mathbf{u}^{(46)}$, $\mathbf{u}^{(47)}$ $\mathbf{u}^{(48)}$, $\mathbf{u}^{(49)}$ $c^{[I]}_{tZ}$ $\frac{1}{2}$ $\frac{1}{2}$ $\equiv \frac{[Im]}{Re} \{-s_W C^{(33)}_{uB} + c_W C^{(33)}_{uW}\}$ $\begin{bmatrix} 1 & 3 & 3 \ 0 & u \end{bmatrix}$ [46⁷] **c**
 c_{*uW*} = (1*i*) [47*.* 7*.*6*ii*) [47] [47. 1*.* 1*.* 2*.* 1*.* 2*.* 1*.* 2*.* 1*.* 2*.* 1*.* 2*.* 1*.* 2*.* 1*.* 2*.* 1*.* 2*.* 1*.* 2*.* 1*.* 2*.* 1*.* 2*.* 1*.* 2*.* 2*.* 2*.* $c_{tZ}^{[I]}$ = _{Re}
 $c_{bW}^{[I]}$ = $_{\rm Re}^{[{\rm Im}]}$ $\begin{bmatrix} \partial^{\{I\}} \\ \partial^{\{I\}} \\ \partial^{\{I\}} \end{bmatrix} \equiv \frac{[\text{Im}]}{\text{Re}} \{ C_{dW}^{(33)} \}$ $c_{tG}^{[I]}$ ${}_{tG}^{[1]}$ $\equiv \text{F}_{\text{Re}}^{[\text{Im}]} \{C_{uG}^{(33)}\}$ $\{aG \}$ } Two-heavy-two-lepton $(8+3 \text{ CPV})$ $\overline{a^{3(\ell)}}$ $\frac{3(\ell)}{Ql_{q}} \equiv C_{lq}^{3(\ell \ell 33)}$ $\frac{Q}{c}(\ell)$ $\frac{C(\ell)}{Ql}$ = $C_{lq}^{1(\ell \ell 33)} - C_{lq}^{3(\ell \ell 33)}$ $c_{\Omega}^{(\ell)}$ Q_e $\equiv C_{eq}^{(\ell \ell 33)}$ $c_{t}^{(\ell)}$ $\begin{array}{lll} \n\ell^{(l)} & \equiv C_{lu}^{(\ell \ell 33)} \n\end{array}$ $c_{te}^{(\ell)}$ $\frac{d^{(k)}}{d^{(l)}} \equiv C_{eu}^{(\ell \ell 33)}$ $c_t^{S[I](\ell)} \equiv \frac{[\text{Im}]}{\text{Re}} \{ C_{lequ}^{1(\ell \ell 33)} \}$ $c_t^{T[I](\ell)} \equiv \frac{[\text{Im}]}{\text{Re}} \{ C_{lequ}^{3(\ell \ell 33)} \}$ $c_b^{S[I](\ell)} \equiv \frac{[\text{Im}]}{\text{Re}} \{ C_{ledq}^{(\ell \ell 33)} \}$ $Two-heavv$ $(9+6$ CPV $d \circ f$) $\frac{1}{\sqrt{1-\frac{1$ *c* τ σ^2 = $C^{1(33)}$ *u*¹ *c*[≠] $\frac{6}{9}$ ⁹
 $\frac{6}{9}$ $\frac{6}{9}$ $\frac{6}{9}$ $\frac{6}{9}$ $\frac{6}{9}$ σ *q* σ $\sigma_{\varphi q}^{(z)}$ \sim $\begin{bmatrix} \varphi \varphi & \varphi q \\ \vdots & \vdots & \vdots \\ \varphi q \varphi & \varphi q \end{bmatrix}$ *√*_{*γq*} (33)</sub> [∪**p** *(x*₁*s*) *i*⁹*.6,* 8*.i*³*.i*³*.i*³*.i*</sub>*.i*³*.i*³.*i*</sup> $\frac{C\varphi}{I}$ $\frac{C\varphi}{I}$ $\int_{\mathbb{Z}_{\varphi u}^{(33)}}^{\mathbb{Z}_{\varphi u}^{(33)}}$ **leptonic** $c_{\varphi tb}^{t}$ $\equiv \frac{1}{Re}$
 $\begin{bmatrix} I \end{bmatrix}$ $\begin{bmatrix} I_{\text{in}} \end{bmatrix}$ (33) c_{tW}^{t} $\equiv \frac{1}{Re}$
 *I*_l $R_e V^U uV$ $\frac{1}{2}$ c_{tZ} ^{$\frac{1}{I}$} $\frac{1}{2}$ Re $\left(\frac{-sW}{uB} + cW\right)$ \bigcirc ¹W *}* \bigcirc \bigcirc ¹W_{^{*xW*}} c_{bV}^{L} $\frac{dV}{dr}$ c_{tC} ^{\lvert} \tilde{t}_t \tilde{G} \equiv $\frac{1}{R}$ $\{C_{uG}$ *c*^{*u*}*uG* [}] *f c*_{*uG*} $\frac{1}{2}$ $c_{OL}^{3(\ell)}$ $c_{Ql}^{-(\ell)}$ $c^{(\ell)}_{Oe}$ $c_{t l}^{(\ell)}$ $c_{te}^{(\ell)}$) 0 if $m_b=0$ Top decay

ud [≠11*.*8*,* 9*.*31] [44]

ud [≠4*.*95*,* 5*.*04] [44]

*c*8

td © *^C*8(33*ii*)

td © *^C*1(33*ii*)

From the Warsaw basis

*‡O*1(*ijkl*)

 $^\ddagger O^{(ij)}_{u\varphi} = \bar q_i u_j \tilde \varphi \, (\varphi^\dagger \varphi),$ $O_{\varphi q}^{1(ij)} = (\varphi^{\dagger}\overleftrightarrow{iD}_{\mu}\varphi)(\bar{q}_{i}\gamma^{\mu}q_{j}),$ $O_{\varphi q}^{3(ij)} = (\varphi^\dagger i\!\overleftrightarrow{D}_\mu^I \varphi) (\bar{q}_i \gamma^\mu \tau^I q_j),$ $O_{\varphi u}^{(ij)} = (\varphi^\dagger i\!\overleftrightarrow{D}_\mu \varphi) (\bar{u}_i \gamma^\mu u_j),$ $^\ddagger O^{(ij)}_{\varphi ud} = (\tilde{\varphi}^\dagger i D_\mu \varphi) (\bar{u}_i \gamma^\mu d_j),$ ${}^{\ddagger}O^{(ij)}_{uW}=\left(\bar{q}_i\sigma^{\mu\nu}\tau^I u_j\right)\tilde{\varphi}W^I_{\mu\nu}$ *u*_{*µν*}, ${}^{\ddagger}O_{dW}^{(ij)}= (\bar q_i \sigma^{\mu\nu} \tau^I d_j)\ \varphi W_{\mu\nu}^I$ *u*_{*µν*}, $^\ddagger O^{(ij)}_{uB} = (\bar q_i \sigma^{\mu\nu} u_j) \quad \ \tilde \varphi B_{\mu\nu},$ ${}^{\ddagger}O_{uG}^{(ij)} = (\bar{q}_{i}\sigma^{\mu\nu}T^{A}u_{j})\ \tilde{\varphi}G^{A}_{\mu\nu}$ A _{$\mu\nu$}, $O_{lq}^{(i,j,k)} = (l_i \gamma^{\mu} l_j)(\bar{q}_k \gamma^{\mu} q_l),$ $O_{lq}^{(i,j,k)} = (l_i \gamma^{\mu} \tau^{\mu} l_j)(q_k \gamma^{\mu} \tau^{\mu} q_l),$ O_{lu} ^{*iu*} $Q_{lu}^{i} = (l_i \gamma^{i} l_j)(u_k \gamma^{i} u_l),$
 $Q(iikl) = (l_i \gamma^{i} l_j)(u_k \gamma^{i} u_l),$ O_{eq} e_q = (e_i / e_j)(q_k / q_l),
 $e^{i k k l}$ / $e^{i k l}$ / $e^{i k l}$ / q_l \overline{C}_{eu} $(\overline{C}_l \cap C_j)(\overline{u}_{k} \cap u_l),$
 $(\overline{C}_{qu}) \cap (\overline{C}_{qu})$ $\mathcal{L}_{lequ} = (i_{l}\mathcal{L}_{j}) \subset (q_{k}u_{l}),$
 $\mathcal{L}_{1} = \mathcal{L}_{1}$ \mathcal{I} *dequ* $(i\ell^c)^{r}$ *c*_{*j*} $(i\ell^c)^{r}$ *d_k*^{*x*}_{*H*}^{*x*_{*a*}}*i*, *n*^{*n*}</sup> *uÏ* $O_{\varphi q}^{1(ij)} = (\varphi^{\dagger} \overleftrightarrow{iD}_{\mu} \varphi)(\bar{q}_i \gamma^{\mu} q_j),$ *^µ‹,* (17) *^µ‹,* (18) $Q_{uG}^{(ij)} = (\bar{q}_i \sigma^{\mu \nu} T^A u_j) \ \tilde{\varphi} G_{uJ}^A$ *^µ‹,* (20) $O_{lq}^{1(ijkl)} = (\bar{l}_i \gamma^\mu l_j)(\bar{q}_k \gamma^\mu q_l),$ $O_{lq}^{3(ijkl)} = (\bar{l}_i \gamma^\mu \tau^I l_j)(\bar{q}_k \gamma^\mu \tau^I q_l),$ $O_{lu}^{(ijkl)} = (\bar{l}_i \gamma^\mu l_j)(\bar{u}_k \gamma^\mu u_l),$ $O_{eq}^{(ijkl)} = (\bar{e}_i \gamma^\mu e_j)(\bar{q}_k \gamma^\mu q_l),$ $O_{eu}^{(ijkl)} = (\bar{e}_i \gamma^\mu e_j)(\bar{u}_k \gamma^\mu u_l),$ ${}^{\ddagger}O_{lequ}^{1(ijkl)} = (\bar{l}_i e_j) \varepsilon (\bar{q}_k u_l),$ ${}^{\ddagger}O_{lequ}^{3(ijkl)} = (\bar{l}_i \sigma^{\mu\nu} e_j) \varepsilon (\bar{q}_k \sigma_{\mu\nu} u_l),$ ${}^{\ddagger}O_{ledq}^{(ijkl)} = (\bar{l}_ie_j)(\bar{d}_kq_l),$ (C. Degrande)

C. Degrande *dedq* $\left(\begin{array}{cc} \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{array} \right)$, Degiande

uu = (¯*ui"^µu^j*)(¯*uk"µul*)*,* (7)

uu = (¯*ui"^µu^j*)(¯*uk"µul*)*,* (7)

quqd = (¯*qiu^j*) *Á* (¯*qkdl*)*,* (10)

quqd = (¯*qiu^j*) *Á* (¯*qkdl*)*,* (10)

dk"µdl)*,* (8)

dk"µdl)*,* (8)

dk"µT ^Adl)*,* (6)

dk"µT ^Adl)*,* (9)

dk"µT ^Adl)*,* (9)

(SM-like) Top decay

$$
\begin{array}{|l|l|} \hline t\rightarrow bW & \mathcal{O}_{\phi q}^{(3)}=i\left(\phi^{\dagger}\tau^{i}D_{\mu}\phi\right)\left(\bar{Q}\gamma^{\mu}\tau^{i}Q\right)+h.c.\\ \hline \mathcal{O}_{tW}=\bar{Q}\sigma_{\mu\nu}\tau^{i}t\tilde{\phi}W_{i}^{\mu\nu}.\hspace{1.5cm}\\ \hline \mathbb{O}^{\dagger M}=\mathbb{O}^{\text{nm}}\bot_{i}\text{R}\text{M} & \text{C. Zhang, S willenbrock, PRD83, 034008} \\ \hline \end{array}
$$

$$
t\rightarrow bl\nu_{l} \qquad \mathcal{O}_{ql}^{(3)}=\left(\bar{Q}\gamma^{\mu}\tau^{i}Q\right)\left(\bar{l}\gamma_{\mu}\tau^{i}l\right) \qquad \qquad \text{J.A. Aguilar-Saavedra, NPB843, 683}
$$

+ one four-fermion operator for the hadronic decay

$$
\begin{array}{lll} \displaystyle \frac{1}{2}\Sigma|M|^{2}&=&\displaystyle \frac{V_{tb}^{2}g^{4}u(m_{t}^{2}-u)}{2(s-m_{W}^{2})^{2}}\left(1+2\frac{C_{\phi q}^{(3)}v^{2}}{V_{tb}\Lambda^{2}}\right)+\displaystyle \frac{4\sqrt{2}\textrm{Re}C_{tW}V_{tb}m_{t}m_{W}}{\Lambda^{2}}\frac{g^{2}su}{(s-m_{W}^{2})^{2}}\\&+\displaystyle \frac{4C_{q^{\prime}}^{(3)}}{\Lambda^{2}}\frac{g^{2}u(m_{t}^{2}-u)}{s-m_{W}^{2}}+\mathcal{O}\left(\Lambda^{-4}\right) \end{array}
$$

Width, W helicities and … *W* 22 **22**
W 22 **22**
W 22 **22**
W 22 **22**
W 22 **22**
W 22 **22** *g*²*u*(*m*² *^t u*) " "

$$
\frac{\Gamma\left(t\to b e^+\nu_e\right)}{GeV}=0.1541+\left[0.019\frac{C^{(3)}_{\phi q}}{\Lambda^2}+0.026\frac{C_{tW}}{\Lambda^2}+0\frac{C^{(3)}_{q l}}{\Lambda^2}\right]\text{TeV}^2
$$

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

*s m*²

W

1

²⇥*|M[|]*

Single top

The top quark is

- one of the least known particle
- more sensitive to many dim-6 operators due to its mass

 $A_l = A_d = 1, A_u = A_v = -0.31$

$$
\mathcal{L}_{\text{eff}} = \frac{1}{\Lambda^2} \left[C_{qq} (\bar{t}_L \gamma^\mu b_L) (\bar{d}_L \gamma_\mu u_L) + C_{du} (\bar{t}_R \gamma^\mu b_R) (\bar{d}_R \gamma_\mu u_R) + C_{qu} (\bar{t}_R b_L) (\bar{d}_L u_R) \right. \\ \left. + C_{qd} (\bar{t}_L b_R) (\bar{d}_R u_L) - C_{qu} d_R (\bar{t}_R b_L) (\bar{d}_R u_L) - C_{qu} d_L (\bar{t}_L b_R) (\bar{d}_L u_R) \right] + \text{h.c.}
$$

polarisation *P^z* ' 0*.*9 in the direction ˆ*z* of the spectator jet in the top quark rest frame [17],

J.A. Aguilar-Saavedra, C. D. and S. Khatibi, PLB769 (2017) 498-502

C. Degrande operator contributions, which as seen in Eq. (6) only involve *u*, *d*, *t* and *b* fields. $\mathcal{L}_{\mathcal{A}}$

Interference *†*d.1 *pp* ! *Hjjj* p p > h j j j QED=1 [QCD] ²*.*⁵¹⁹ *[±]* ⁰*.*⁰⁰⁵ +75*.*1% 39*.*8% +0*.*6% 0*.*6% [62] ?d.2 *pp* ! *HHjj* p p > h h j j QED=1 [QCD] ¹*.*⁰⁸⁵ *[±]* ⁰*.*⁰⁰² *·* ¹⁰² +62*.*1% +1*.*2% have a quark-antiquark-antiquark-antiquark-antiquark-antiquark initial state prevents in the contributions from four-fermion operators. In this work we start from the known observation

+1*.*4%

$$
|M(x)|^2 = \frac{|M_{SM}(x)|^2}{\Lambda^0} + \frac{2\Re(M_{SM}(x)M_{d6}^*(x))}{\Lambda^{-2}} + \frac{|M_{d6}(x)|^2 + ...}{\mathcal{O}(\Lambda^{-4})}
$$

$$
\approx l = 0 \Longrightarrow \approx l = 0 \Longrightarrow \approx l = 0 \Longrightarrow \approx l = 0
$$

Ex : FCNC such as tt F_{11} **FCNC** augh 20.¹¹ LA . I VIVU SUUI QS II

5, 6, 7], including those affecting AF B. At the LHC, the low probability to

that this issue is avoided for same sign top pair production and we perform

Selected ² ! ⁴ ^p*^s* ⁼ 13 TeV

JHEP 1510 (2015) 146

C. Degrande

SM $4.045 \pm 0.007 \cdot 10^{-15}$ $_{-0.8\%}^{+0.2\%}$ $_{-1.0\%}^{+0.9\%}$ **pb** $-0.8\% -1.0\%$ SM $4.045 \pm 0.007 \cdot 10^{-15}$ $+0.2\%$ $+0.9\%$ pb at 13 TeV Any operator contributing to same sign top pair $\mathsf{J}\mathsf{F}$ $\mathcal{O}_{RR} \;\; = \;\; \left[\bar{t}_R \gamma^\mu u_R \right] \left[\bar{t}_R \gamma_\mu u_R \right]$ O(1) up to 0.5 pb

Table 7. Inclusive cross-sections for various 2 $\mathsf{Phys} \mathsf{L}$ Phys.Lett. B703 (2011) 306-309

tation in the current framework is possible and is left for α NG WORK. In calculations at N calculations at N in \mathcal{N} and \mathcal{N} are not \mathcal{N} and \mathcal{N} are not \mathcal{N} evant for constraining new physics in the Higgs sector. \blacksquare Finally, we stress that four-fermion operators should also be shown operators should also be shown in be taken into account for a complete phenomenological \mathbf{T}_{max} field, the Higgs field, they are also related they are also related they are also related to relate evant for constraining new physics in the Higgs sector. Finally, we stress that four-fermion operators should also \mathbf{r} tween different operators. The Higgs boson rapidity different operators. The SM, FCN interactions can be seen o
PDFs. In the SM, FCN interactions can be seen on the SM, FCN interactions can be seen on the SM, FCN interacti T,top tribution in pp → the form in pp → th for tune turns in the form in the form induced production in the form in
The form in the form in th as proposed in Ref. [39], because c and g have similar similar similar similar similar similar similar similar μ possibly extracting top-quark FCN couplings at the LHC. be generated at one loop, yet they turn out to be sup-dimension-six operators [19, 20] or dimension-four and parametrized using either fully gauge-symmetric

priate UV counterterms have to be implemented in the

uG , veto 0.799 ± 0.739 , veto 0.799 ± 0.739 , 0.799 ± 0.739 , 0.799 ± 0.739

uB = 1.9 152 +10.6% -9.6% 258 +6.8% -6.0%

 $u_{\rm eff} = 0.09$, $u_{\rm eff} = 0.09$

relevant operators together with their operator mixing

effects need to be considered simultaneously, and appro-

priate UV counterterms have to be implemented in the

calculation. Our method and its implementation are fully

general and can cover arbitrary NLO calculations in the

calculation. Our method and its implementation are fully

general and can cover arbitrary NLO calculations in the

complete dimension-six Lagrangian of the SM.

complete dimension-six Lagrangian of the SM.

V. DIFFERENTIAL CROSS SECTIONS

be taken into account for a complete phenomenological phenomenologic study of FCN interactions, see Ref. [?]. Their implemen-

be used to discriminate between uth and cth couplings, $\mathcal{L}_{\mathcal{A}}$ and $\mathcal{L}_{\mathcal{A}}$

The FCN couplings of the top quark can be top quark can be top quark can be top quark can be top quark can be

dimension-five operators in the electroweak broken

are found to be large, order 30% and to 80% μ 30% and to 80% and to 10% and 10% and 10% and 10% and 10% and

to considerable reductions of the residual theoretical un-

certainties. Both aspects are important in bounding and

possibly extracting top-quark FCN couplings at the LHC.

C. Degrande light groups. U.S. fields. under the single and CD , F. Maltoni, J. Wang which is that when you and the top-top-to-top-to-top-to-top-to-top-to-top-to-topperforming its renormalization at \mathbf{p} renormalization at one loop, and then then \mathbf{p} $s = 0$ is equal behanded. In the energy set ϵ and ϵ ang, G. Zhang, r RD91 (2013) 034024 $\hbox{\bf C}$. Degrande $\hbox{\bf C}$

Data

04. (2049) 100 e Only one distribution per measurement (correlation) considered in the present analysis to constrain the Constraints of the SMEFT dimension-6 operators of the SMEFT dimension-N.P. Hartland, F.Maltoni, E. R. Nocera, J. Rojo, E. Slade, E. Vryonidou and C.~Zhang,JHEP 1904 (2019) 100

Data

Global top Fit

 M ara less constrained than ind wary. 1999 Sonotramod than ma.
C. Degre Marg. less constrained than ind.

C. Degrande $\zeta_{\rm eff} = \zeta_{\rm eff}$ and in the individual fit cases, with the LHC Top WG EFT note $\zeta_{\rm eff}$

EFT and PDF

EFT and PDF See EFT and \blacksquare to the traditional approach where P approach where P are kept fixed. Approach where P are kept fixed. Approach where P

1905.05215 with S. Carrazza, S. Iranipour, J. Rojo and M. Ubiali

$$
\mathcal{O}_{lq} = (\bar{l}_R \gamma^{\mu} l_R) (\bar{q}_R \gamma_{\mu} q_R) , \ q = u, d, s, c ,
$$

 $\mathbf{H} = \mathbf{H} \mathbf{H} \mathbf{H}$

Here we will study the impact of operators of operators of the impact of the form of the form of the form of the form σ

coecients are modified in this joint fit as compared in this joint fit as compared in this joint fit as compared in \mathcal{C}

C. Degrande

 \overline{a}

EFT and PDF See EFT and \blacksquare to the traditional approach where P approach where P are kept fixed. Approach where P are kept fixed. Approach where P

1905.05215 with S. Carrazza, S. Iranipour, J. Rojo and M. Ubiali

$$
\mathcal{O}_{lq} = (\bar{l}_R \gamma^{\mu} l_R) (\bar{q}_R \gamma_{\mu} q_R) , \ q = u, d, s, c ,
$$

 $\mathbf{H} = \mathbf{H} \mathbf{H} \mathbf{H}$

⇣ ⌘

Here we will study the impact of operators of operators of the impact of the form of the form of the form of the form σ

coecients are modified in this joint fit as compared in this joint fit as compared in this joint fit as compared in \mathcal{C}

EFT and PDF

 \mathcal{F}_1 and \mathcal{F}_2 are divisors in 2: The divisors in 2: The divisors in 2: The divisors in 2: The divisors in 2:

One finds that the most stringent bounds are obtained

for *au*, followed by *ad*, and then *a^c* and *as*. This is con-

sistent with the fact that the SMEFT corrections pro-

portional to *a^q* are weighted by the corresponding PDFs

in Eq. (3), and that in the HERA region one has the

NNPDF3.1 DIS-only, $Q = 10$ GeV

tot with respect to the SM in the SM in

EFT and PDF

 a_u

C. Degrande $\mathsf C$

Looking for new physics

- EFT provide guidance (which observable)
- Check the validity of the single EFT assumption
- EFT is multi-channel/observable : correlation
- Global fit with a large number of parameters
- Distinguish PDF and EFT

Summary

