Constraining four-fermion operators in rare top decays

Mikael Chala (UGR & IPPP)

Based on **MC**, Jose Santiago and Michael Spannowsky, *1809.09624;*

Shankha Banerjee, **MC** and Michael Spannowsky, *1806.02836;*

Julien Alcaide, Shankha Banerjee, **MC** and Arsenii Titov, ~~in progress~~. 1905.11375

1. The SMEFT **operators that can be generated at tree level** by weakly-coupled UV completions are naturally sizable.

2. These include **four-fermion operators**: *qqqq* [Domenech, Pomarol, Serra, 1201.6510], *qqll* [Carpentier, Davidson, 1008.0280; Cirigliano, Gonzalez-Alonso, Graesser, 1210.4553; Blas, **MC**, Santiago, 1307.5068; Farina, Panico, Pappadopulo, Ruderman, Torre, Wulzer, 1609.08157], *llll* [Aguila, **MC**, Santiago, Yamamoto, 1505.00799; Falkowski, Mimouni, 1511.07434; Falkowski, Gonzalez-Alonso, Mimouni, 1706.03783; Falkowski, Grilli di Cortona, Tabrizi, 1802.08296], *ttll* from RGEs [Blas, MC, Santiago, 1507.00757], *tttt* [Degrande, Gerard, Grojean, Maltoni, Servant, 1010.6304] and *ttbb* [D'Hont, Mariotti, Mimasu, Moorgart, Zhang, 1807.02130].

Name	$\mathcal{S}$	$\mathcal{S}_1$	$\mathcal{S}_2$	φ	Ξ	Ξ_1	Θ_1	Θ_3
Irrep	$(1,1)_0$	$(1,1)_1$	$(1,1)_2$	$(1,2)_{\frac{1}{2}}$	$(1,3)_0$	$(1,3)_1$	$(1,4)_{\frac{1}{2}}$	$(1,4)_{\frac{3}{2}}$

Name	ω_1	ω_2	ω_4	Π_1	Π_7	ζ
Irrep	$(3,1)_{-\frac{1}{3}}$	$(3,1)_{\frac{2}{3}}$	$(3,1)_{-\frac{4}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{\frac{7}{6}}$	$(3,3)_{-\frac{1}{3}}$

Name	Ω_1	Ω_2	Ω_4	Υ	Φ
Irrep	$(6,1)_{\frac{1}{3}}$	$(6,1)_{-\frac{2}{3}}$	$(6,1)_{\frac{4}{3}}$	$(6,3)_{\frac{1}{3}}$	$(8,2)_{\frac{1}{2}}$

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Name	$\cancel{\mathcal{S}}$	$\mathcal{S}_1$	$\mathcal{S}_2$	φ	$\cancel{\Xi}$	Ξ_1	$\cancel{\Theta_1}$	$\cancel{\Theta_3}$
Irrep	$\cancel{(1,1)_0}$	$(1,1)_1$	$(1,1)_2$	$(1,2)_{\frac{1}{2}}$	$\cancel{(1,3)_0}$	$(1,3)_1$	$\cancel{(1,4)_{\frac{1}{2}}}$	$\cancel{(1,4)_{\frac{3}{2}}}$

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Blas et al.

[1412.8480]

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Name	$\mathcal{B}$	$\mathcal{B}_1$	$\mathcal{W}$	$\mathcal{W}_1$	$\mathcal{G}$	$\mathcal{G}_1$	$\mathcal{H}$	$\mathcal{L}_1$
Irrep	$(1,1)_0$	$(1,1)_1$	$(1,3)_0$	$(1,3)_1$	$(8,1)_0$	$(8,1)_1$	$(8,3)_0$	$(1,2)_{\frac{1}{2}}$

Name	$\mathcal{L}_3$	$\mathcal{U}_2$	$\mathcal{U}_5$	$\mathcal{Q}_1$	$\mathcal{Q}_5$	$\mathcal{X}$	$\mathcal{Y}_1$	$\mathcal{Y}_5$
Irrep	$(1,2)_{-\frac{3}{2}}$	$(3,1)_{\frac{2}{3}}$	$(3,1)_{\frac{5}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,3)_{\frac{2}{3}}$	$(\bar{6},2)_{\frac{1}{6}}$	$(\bar{6},2)_{-\frac{5}{6}}$

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in general, they also induce other operators

Blas et al. [1711.10391]

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Irrep	$(1,1)_0$	$(1,1)_1$	$(1,3)_0$	$(1,3)_1$	$(8,1)_0$	$(8,1)_1$	$(8,3)_0$	$(1,2)_{\frac{1}{2}}$

Name	$\mathcal{L}_3$	$\mathcal{U}_2$	$\mathcal{U}_5$	$\mathcal{Q}_1$	$\mathcal{Q}_5$	$\mathcal{X}$	$\mathcal{Y}_1$	$\mathcal{Y}_5$
Irrep	$(1,2)_{-\frac{3}{2}}$	$(3,1)_{\frac{2}{3}}$	$(3,1)_{\frac{5}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,3)_{\frac{2}{3}}$	$(\bar{6},2)_{\frac{1}{6}}$	$(\bar{6},2)_{-\frac{5}{6}}$

1. There are, however, **very few studies of four fermion operators with one top and light quarks or leptons** *[Aguilar-Saavedra, 1008.3562; Fox, Ligeti, Papucci, Perez, Schwartz, 0704.1482, Drobnak, Fajfer, Kamenik, 0812.0294; Durieux, Maltoni, Zhang, 1412.7166; Kamenik, Katz, Stolarski, 1808.00864]*. In fact, no dedicated searches have been performed, with the exception of LFV *[Gottardo, 1809.09048]*. The reach of HL-LHC has not been estimated either.

2. **We recast searches for top to *Zq*** *[ATLAS Collaboration, 1803.09923]* to set bounds on flavour-violating top operators decaying non-resonantly to *llq:*

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Irrep	$(1,1)_0$	$(1,1)_1$	$(1,3)_0$	$(1,3)_1$	$(8,1)_0$	$(8,1)_1$	$(8,3)_0$	$(1,2)_{\frac{1}{2}}$

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Irrep	$(1,2)_{-\frac{3}{2}}$	$(3,1)_{\frac{2}{3}}$	$(3,1)_{\frac{5}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,3)_{\frac{2}{3}}$	$(\bar{6},2)_{\frac{1}{6}}$	$(\bar{6},2)_{-\frac{5}{6}}$

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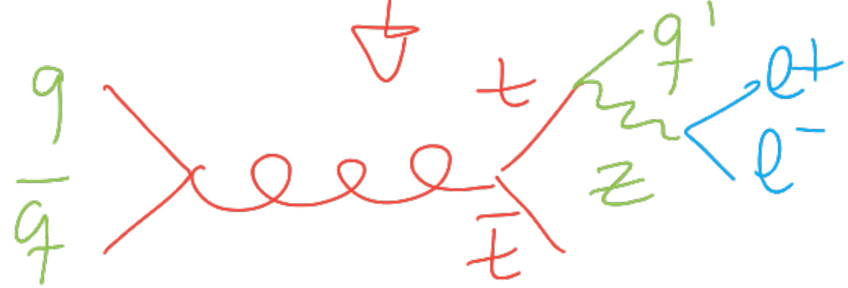

Name	$\mathcal{B}$	$\mathcal{B}_1$	$\mathcal{W}$	$\mathcal{W}_1$	$\mathcal{G}$	$\mathcal{G}_1$	$\mathcal{H}$	$\mathcal{L}_1$
Irrep	$(1,1)_0$	$(1,1)_1$	$(1,3)_0$	$(1,3)_1$	$(8,1)_0$	$(8,1)_1$	$(8,3)_0$	$(1,2)_{\frac{1}{2}}$

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1. The number of signal events is given by

$$s = 2 \times \sigma(pp \to t\bar{t}) \times \frac{\Gamma(t \to \ell^+\ell^- q)}{\Gamma_t} \times \epsilon \times \mathcal{L}$$

$$(\bar{e}^j_R \gamma_\mu l^i_L)(\bar{q}^k_L \gamma^\mu q^3_L)$$

$$\Gamma(t \to \ell_i^+ \ell_j^- u_k) = \frac{m_t}{6144\pi^3}\left(\frac{m_t}{\Lambda}\right)^4 \Big\{ 4|c_{lq}^{-(jik3)}|^2 + 4|c_{eq}^{(jik3)}|^2 + 4|c_{lu}^{(jik3)}|^2 + 4|c_{eu}^{(jik3)}|^2$$
$$+|c_{lequ}^{1\,(jik3)}|^2 + |c_{lequ}^{1\,(ij3k)}|^2 + 48|c_{lequ}^{3\,(jik3)}|^2 + 48|c_{lequ}^{3\,(ij3k)}|^2 \Big\}.$$

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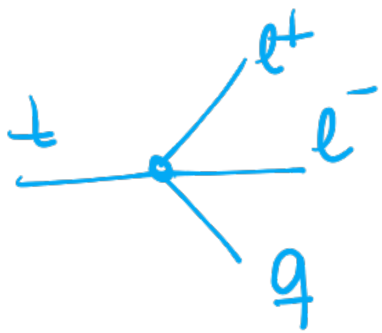
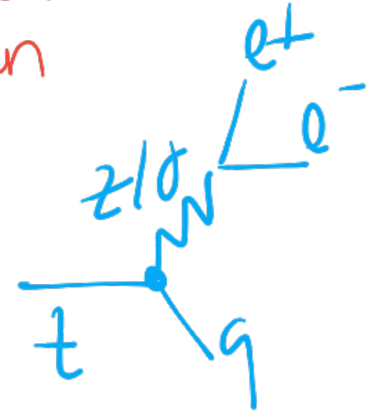
analysis dependent

a priori, interference between



and



but this is loop suppressed

no interference among themselves

[nor with the SM]

$$\Gamma(t \to \ell_i^+ \ell_j^- u_k) = \frac{m_t}{6144\pi^3} \left(\frac{m_t}{\Lambda}\right)^4 \Big\{ 4|c_{lq}^{-(jik3)}|^2 + 4|c_{eq}^{(jik3)}|^2 + 4|c_{lu}^{(jik3)}|^2 + 4|c_{eu}^{(jik3)}|^2$$
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1. In short terms, this analysis demands three light leptons, two of them SFOS, as well as exactly one b-tagged jet and at least two more light jets.

2. **The two SFOS leptons with invariant mass closest to the Z pole** are considered the Z boson candidate.

3. Further observables are computed: the invariant mass of the W boson, and the invariant mass of each top, obtained upon minimization of:

$$\chi^2 = \frac{(m_{\ell^+\ell^- j} - m_{t_{\mathrm{FCNC}}})^2}{\sigma^2_{t_{\mathrm{FCNC}}}} + \frac{(m_{\ell^\pm b\nu} - m_{t_{\mathrm{SM}}})^2}{\sigma_{t_{\mathrm{SM}}}} + \frac{(m_{\ell^\pm\nu} - m_W)^2}{\sigma_W}$$

	$\alpha_{lq}^{-(2223)}$	$\alpha_{eq}^{(2223)}$	$\alpha_{lu}^{(2223)}$	$\alpha_{eu}^{(2223)}$	$\alpha_{lequ}^{1(2223)}$	$\alpha_{lequ}^{1(2232)}$	$\alpha_{lequ}^{3(2223)}$	$\alpha_{lequ}^{3(2232)}$
CR1	2.0	2.0	2.0	2.0	0.44	0.44	26.0	26.0
NEW	1.8	1.8	1.8	1.8	0.37	0.37	23.0	23.0

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→ # signal events/100 for $\alpha = 1$, $\Lambda = 1$ TeV

	$\alpha_{lq}^{-(2223)}$	$\alpha_{eq}^{(2223)}$	$\alpha_{lu}^{(2223)}$	$\alpha_{eu}^{(2223)}$	$\alpha_{lequ}^{1(2223)}$	$\alpha_{lequ}^{1(2232)}$	$\alpha_{lequ}^{3(2223)}$	$\alpha_{lequ}^{3(2232)}$
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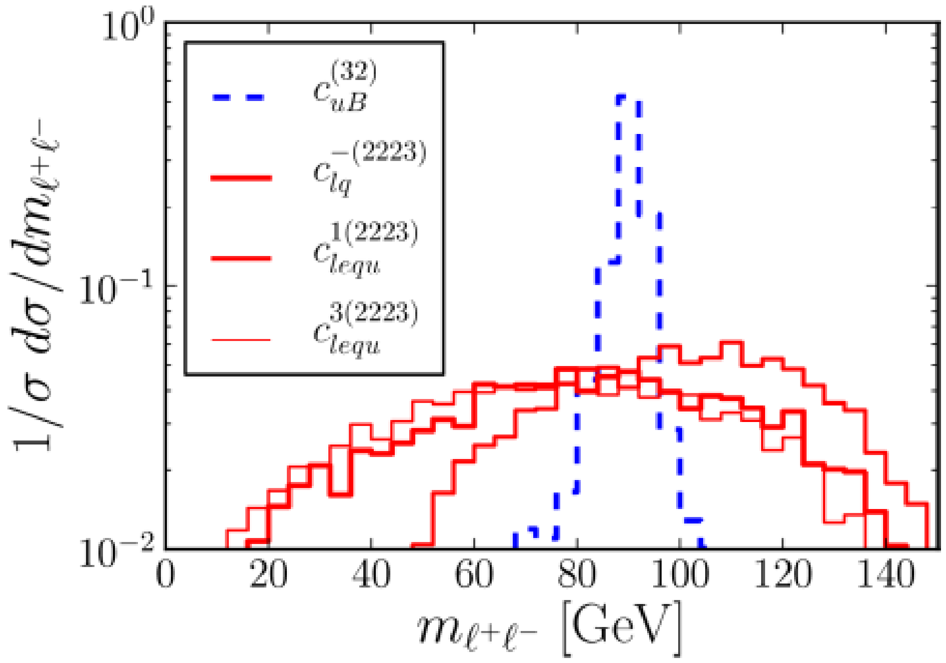
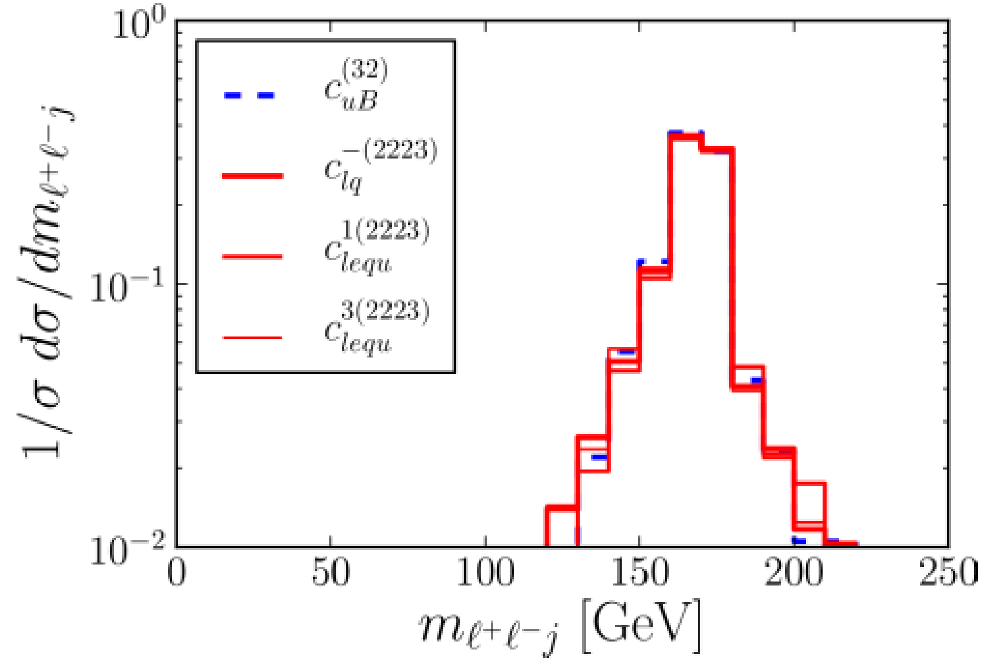
1. The di-lepton invariant mass is different in the Zq and contact interaction cases. (Caution with signal bias.)

2. Numbers for the signal region are given after fit assuming no signal in the control region. We therefore **use raw data from the control regions**.





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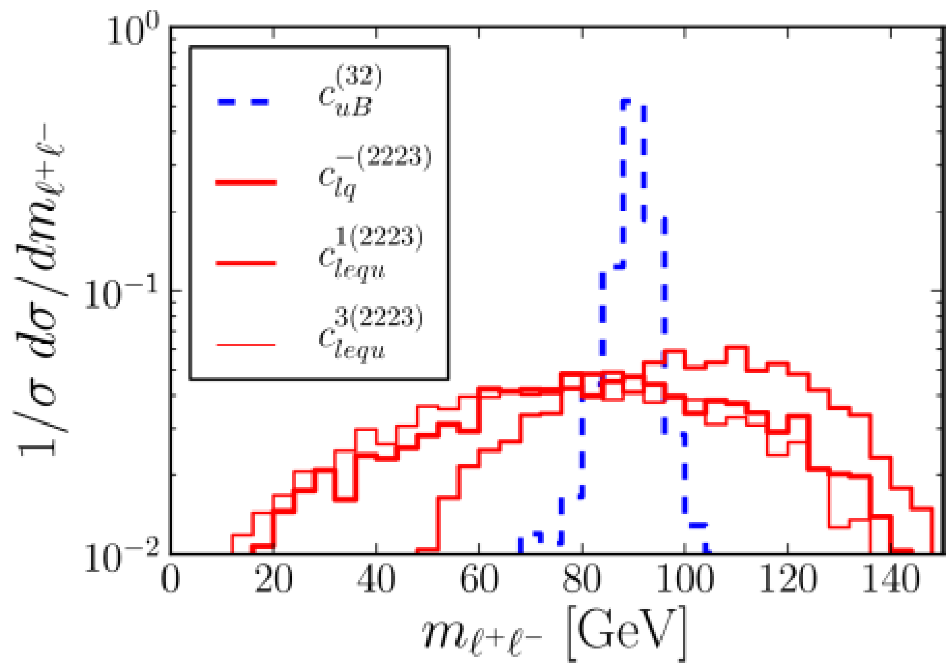
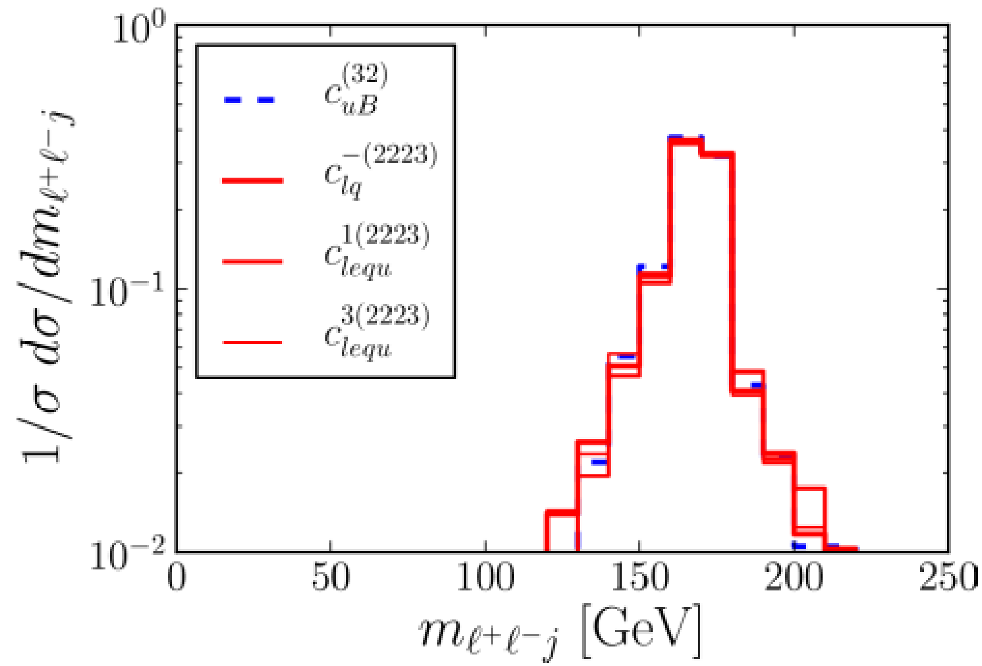
SRA	CR1	New
$m_{\ell\ell} \sim m_Z$	$m_{\ell\ell} \neq m_Z$	$m_{\ell\ell} \neq m_Z$
$m_{t_{1/2}} \sim 172.5$ GeV	—	$m_{t_{1/2}} \sim 172.5$ GeV





1. The TeV scale is already tested in some cases.

2. **Bounds from flavour physics** are more stringent for operators involving LH quarks, since b-s transitions arise at tree level. The contribution of RH operators is instead chirality and loop suppressed.

	$c_{lq}^{-(2223)}$	$c_{eq}^{(2223)}$	$c_{lu}^{(2223)}$	$c_{eu}^{(2223)}$	$c_{lequ}^{1(2223)}$	$c_{lequ}^{1(2232)}$	$c_{lequ}^{3(2223)}$	$c_{lequ}^{3(2232)}$
CR1	**8.4** (1.2)	**8.4** (1.2)	**8.4** (1.2)	**8.4** (1.2)	**18** (2.7)	**18** (2.7)	**2.3** (0.35)	**2.3** (0.35)
NEW	3.1 (1.0)	3.1 (1.0)	3.1 (1.0)	3.1 (1.0)	6.8 (2.2)	6.8 (2.2)	0.87 (0.28)	0.87 (0.28)

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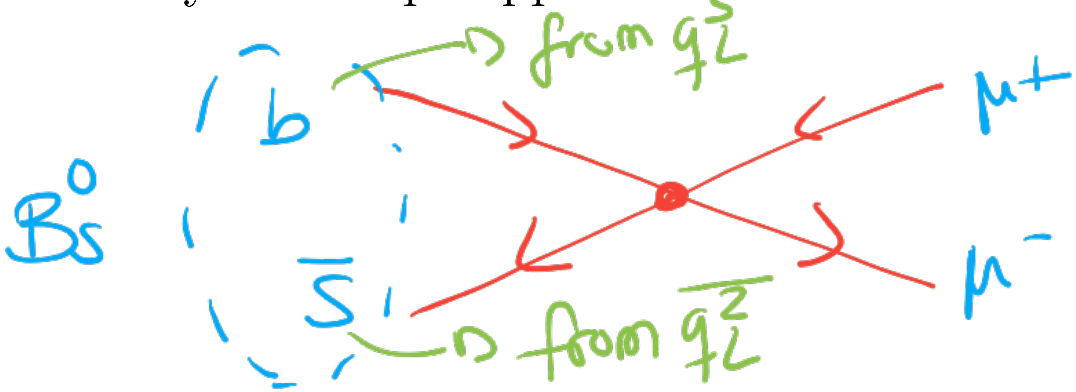

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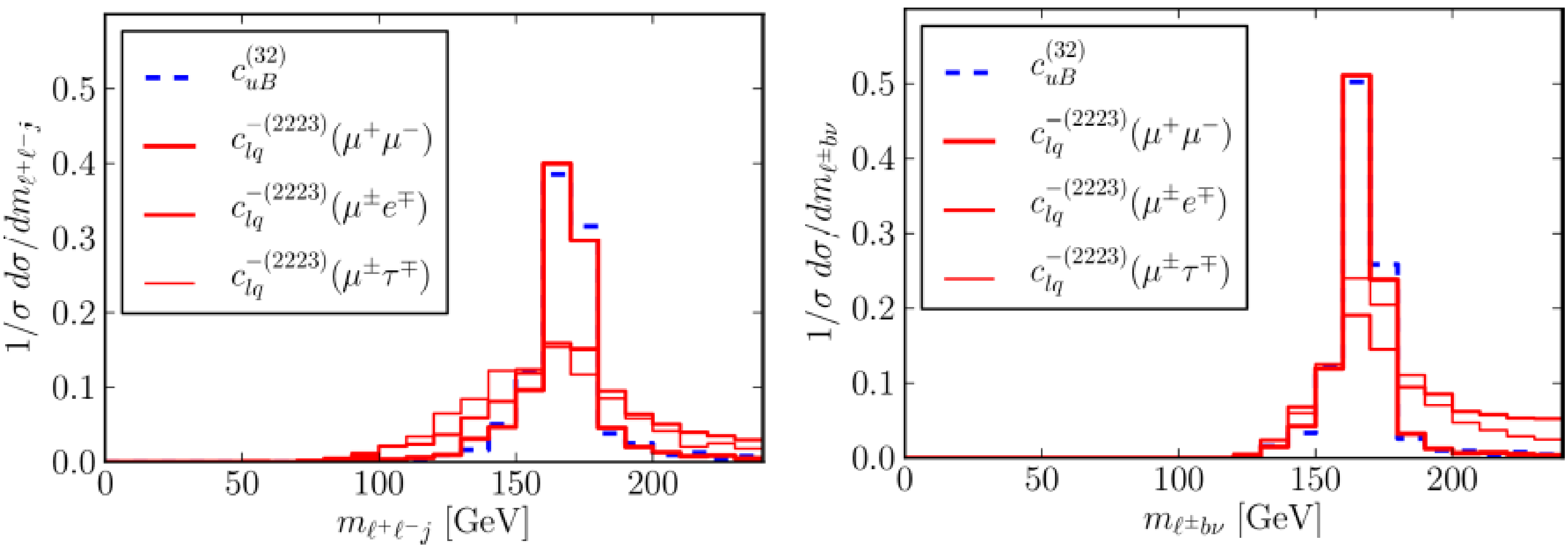
1. **If LFV decays are allowed, the experimental sensitivity changes**. (See distributions below.)

2. Also, efficiency for detecting electrons is smaller than four muons. More importantly, leptonic tau decay has a small branching ratio.



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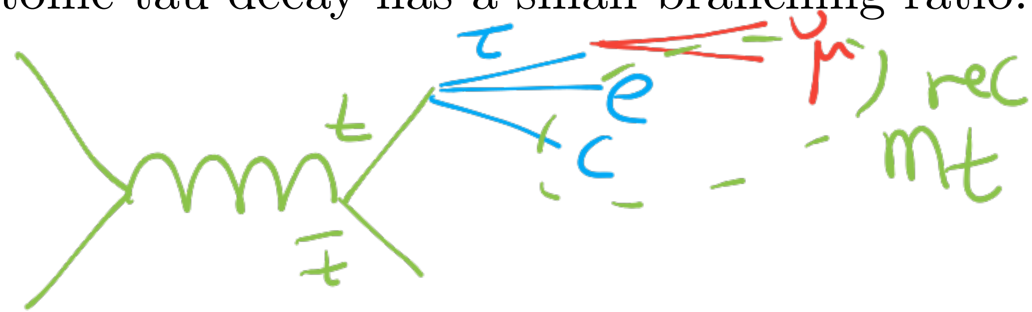

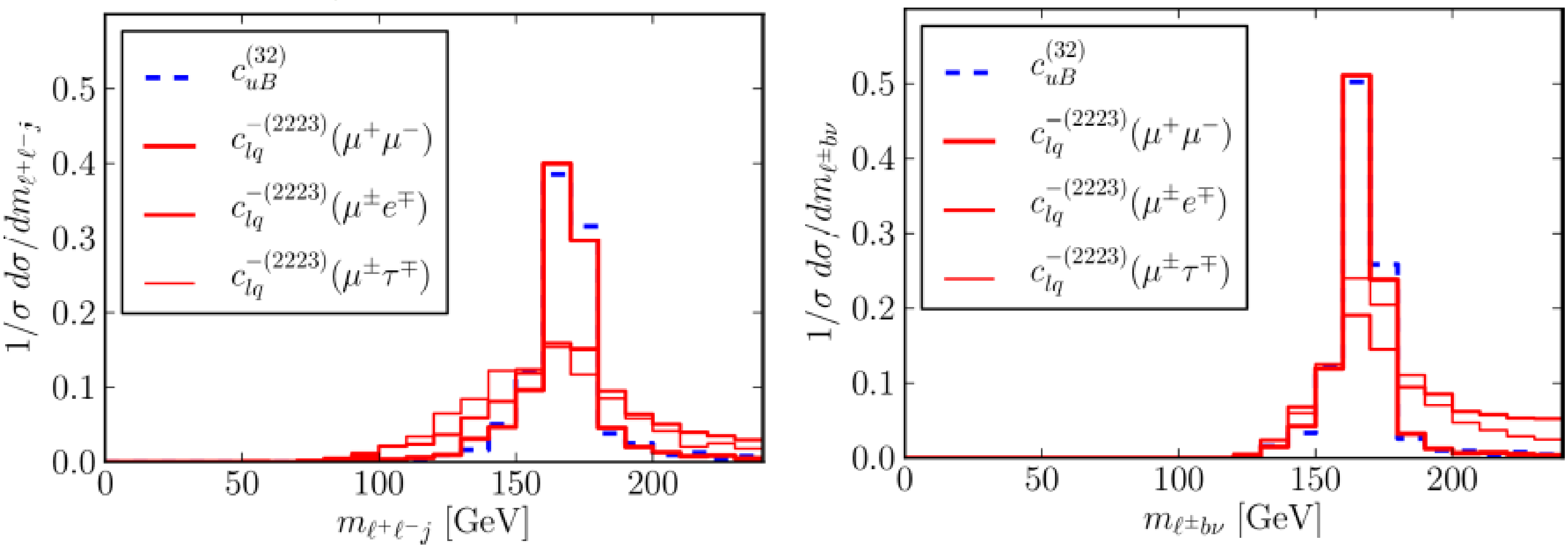

1. In summary, bounds on decays into electrons get a factor of 1.2 smaller. For the case of taus, bounds are weakened by a factor of about 2.

2. Most of the operators do not renormalize photon operators and therefore are safe from constraints from $\mu(\tau) \to e\gamma$

3. **Bounds for q = *up* (instead of q = *charm*) are instead stronger due to the smaller misstag rate for b-tagging.**

	$C_{lq}^{-(ij23)}$	$C_{eq}^{(ij23)}$	$C_{lu}^{(ij23)}$	$C_{eu}^{(ij23)}$	$C_{lequ}^{1(ij23)}$	$C_{lequ}^{1(ij32)}$	$C_{lequ}^{3(ij23)}$	$C_{lequ}^{3(ij32)}$
$\mu^+\mu^-$	8.4 (1.0)	8.4 (1.0)	8.4 (1.0)	8.4 (1.0)	18.0 (2.2)	18.0 (2.2)	2.3 (0.28)	2.3 (0.28)
$\mu^\pm e^\mp$	6.3 (1.1)	6.3 (1.1)	6.3 (1.1)	6.3 (1.1)	13.0 (2.4)	13.0 (2.4)	1.7 (0.3)	1.7 (0.3)
$\mu^\pm \tau^\mp$	14.0 (2.0)	14.0 (2.0)	14.0 (2.0)	14.0 (2.0)	29.0 (4.3)	29.0 (4.3)	3.7 (0.55)	3.7 (0.55)
e^+e^-	10.0 (1.2)	10.0 (1.2)	10.0 (1.2)	10.0 (1.2)	22.0 (2.7)	22.0 (2.7)	2.8 (0.34)	2.8 (0.34)
$e^\pm \tau^\mp$	15.0 (2.1)	15.0 (2.1)	15.0 (2.1)	15.0 (2.1)	32.0 (4.7)	32.0 (4.7)	4.1 (0.6)	4.1 (0.6)

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3. **Bounds for q = *up* (instead of q = *charm*) are instead stronger due to the smaller misstag rate for b-tagging.** corresponds to BR $\leq 2\times10^{-5}$
[to be compared with ATLAS BR $< 7\times10^{-6}$]

	$c_{lq}^{-(ij23)}$	$c_{eq}^{(ij23)}$	$c_{lu}^{(ij23)}$	$c_{eu}^{(ij23)}$	$c_{lequ}^{1(ij23)}$	$c_{lequ}^{1(ij32)}$	$c_{lequ}^{3(ij23)}$	$c_{lequ}^{3(ij32)}$
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$\mu^\pm \tau^\mp$	14.0 (2.0)	14.0 (2.0)	14.0 (2.0)	14.0 (2.0)	29.0 (4.3)	29.0 (4.3)	3.7 (0.55)	3.7 (0.55)
e^+e^-	10.0 (1.2)	10.0 (1.2)	10.0 (1.2)	10.0 (1.2)	22.0 (2.7)	22.0 (2.7)	2.8 (0.34)	2.8 (0.34)
$e^\pm \tau^\mp$	15.0 (2.1)	15.0 (2.1)	15.0 (2.1)	15.0 (2.1)	32.0 (4.7)	32.0 (4.7)	4.1 (0.6)	4.1 (0.6)

1. We also explore the possibility of bounding **four-fermion operators contributing to non resonant top decays into bbq**. There are no dedicated searches for this channel yet.

$$\Gamma(t \to b\bar{b}u_i) = \frac{m_t}{2048\pi^3}\left(\frac{m_t}{\Lambda}\right)^4 \Bigg\{ 4\Big[|c_{qq}^{1(33i3)}|^2 + |c_{qu}^{1(33i3)}|^2 + |c_{qd}^{1(i333)}|^2 + |c_{ud}^{1(i333)}|^2\Big]$$
$$+ \frac{8}{9}\Big[\frac{33}{2}|c_{qq}^{3(33i3)}|^2 + |c_{qu}^{8(33i3)}|^2 + |c_{qd}^{8(i333)}|^2 + |c_{ud}^{8(i333)}|^2\Big]$$
$$- \frac{8}{3}\mathrm{Re}[(c_{qq}^{1(33i3)})(c_{qq}^{3(33i3)})^*]$$
$$+ |c_{quqd}^{1(i333)}|^2 + |c_{quqd}^{1(33i3)}|^2 + \frac{7}{3}|c_{quqd}^{1(3i33)}|^2$$
$$+ \frac{2}{9}\left(|c_{quqd}^{8(i333)}|^2 + |c_{quqd}^{8(33i3)}|^2\right) + \frac{10}{27}|c_{quqd}^{8(3i33)}|^2$$
$$+ \frac{1}{3}\mathrm{Re}[(c_{quqd}^{1(i333)})(c_{quqd}^{1(33i3)})^*] - \frac{2}{27}\mathrm{Re}[(c_{quqd}^{8(i333)})(c_{quqd}^{8(33i3)})^*]$$
$$+ \frac{4}{9}\mathrm{Re}[(c_{quqd}^{1(i333)})(c_{quqd}^{8(33i3)})^*] + \frac{4}{9}\mathrm{Re}[(c_{quqd}^{8(i333)})(c_{quqd}^{1(33i3)})^*]$$
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\end{aligned}
$$

negligible interference with the SM

1. We require exactly one isolated lepton and four jets, three of them must be b-tagged.

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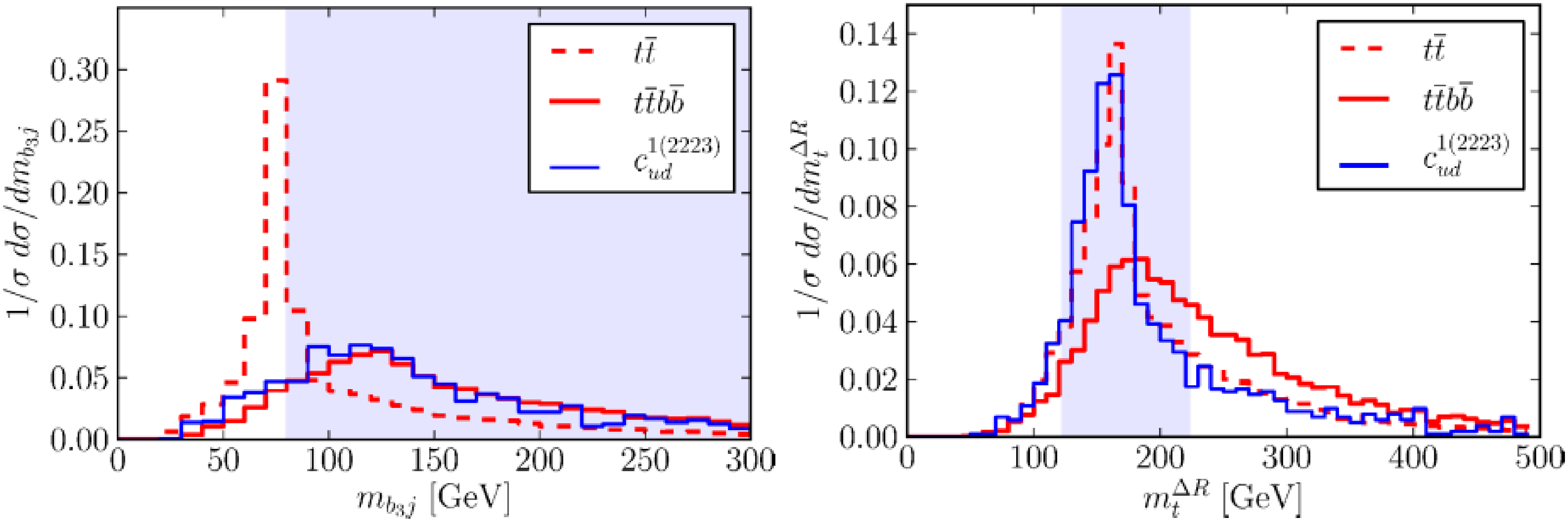

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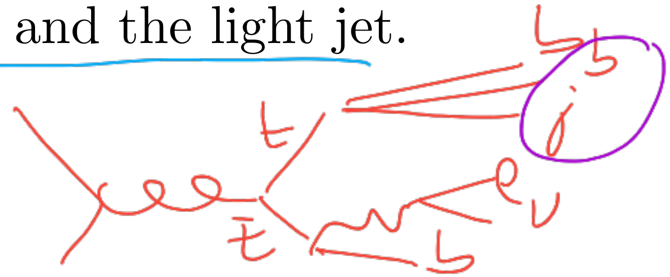
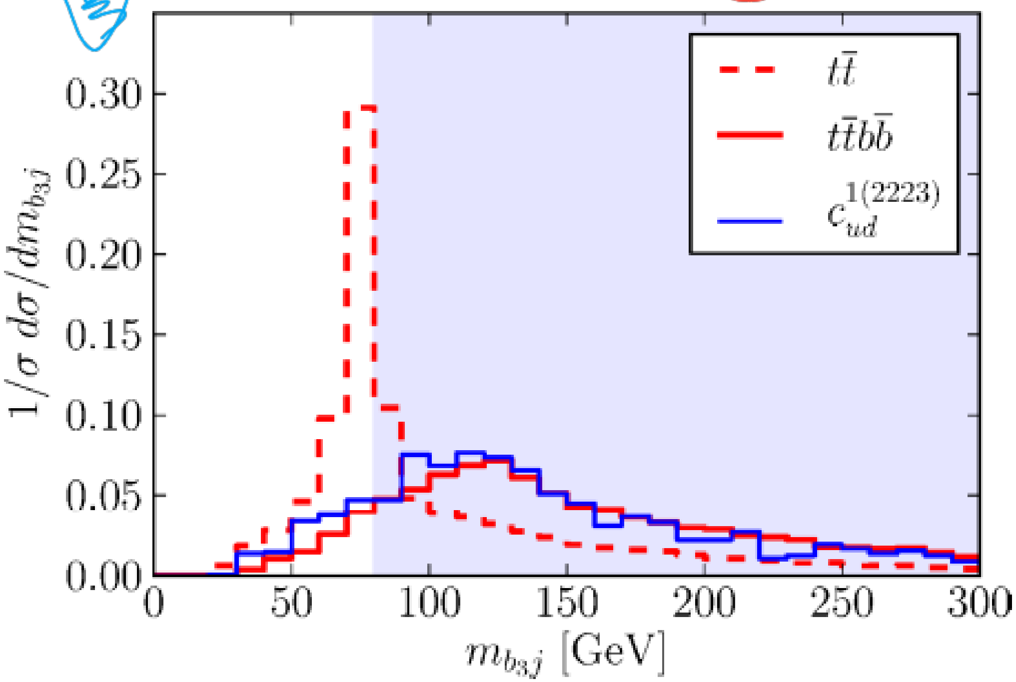
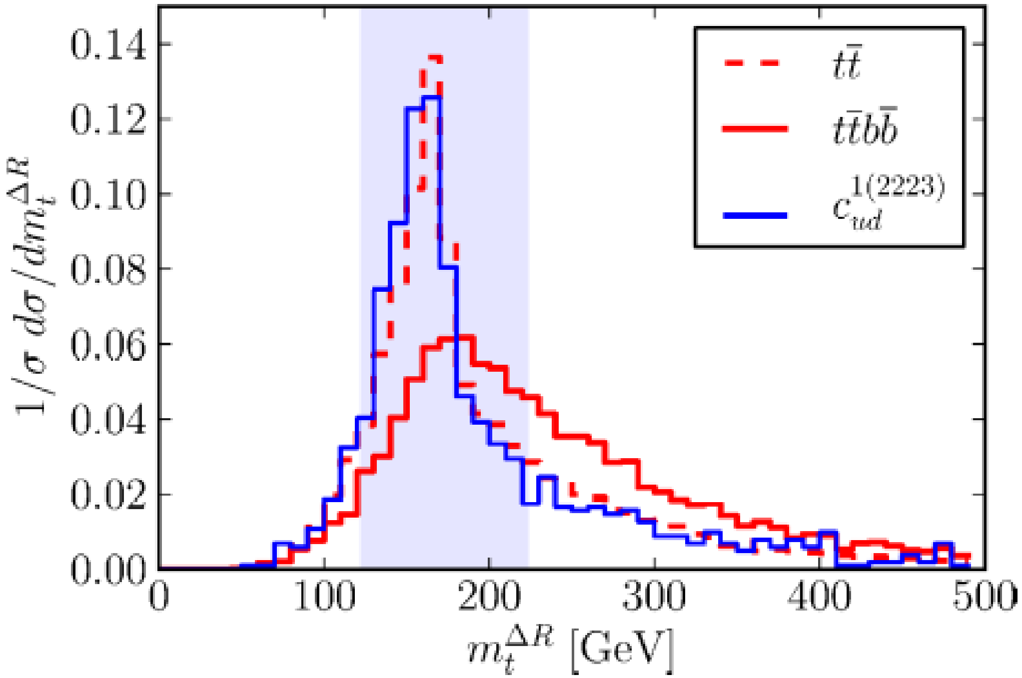


in the SM, they come from a W





1. These **bounds get a factor of 7 larger if systematic uncertainties of 10%** are taken into account.

2. Searches for single top production might improve on these bounds.

	$c_{qq}^{1(3323)}$	$c_{qq}^{3(3323)}$	$c_{qu}^{1(3323)}$	$c_{qu}^{8(3323)}$	$c_{qd}^{1(2333)}$	$c_{qd}^{8(2333)}$	$c_{ud}^{1(2333)}$	$c_{ud}^{8(2333)}$
Bound	2.7	1.4	2.7	5.8	2.7	5.8	2.7	5.8

	$c_{quqd}^{1(3233)}$	$c_{quqd}^{1(3323)}$	$c_{quqd}^{1(2333)}$	$c_{quqd}^{8(3233)}$	$c_{quqd}^{8(3323)}$	$c_{quqd}^{8(2333)}$
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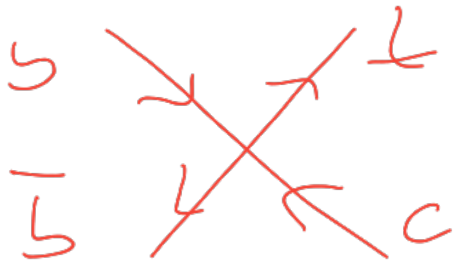

$\sigma(pp \to t\bar{b}(\bar{t}b)) =$
$4.8 \pm 0.8\,(\mathrm{stat}) \pm 1.6\,(\mathrm{syst})$
at 8 TeV

	$C_{qq}^{1(3323)}$	$C_{qq}^{3(3323)}$	$C_{qu}^{1(3323)}$	$C_{qu}^{8(3323)}$	$C_{qd}^{1(2333)}$	$C_{qd}^{8(2333)}$	$C_{ud}^{1(2333)}$	$C_{ud}^{8(2333)}$
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bounded by $\Delta m_{b/d}$

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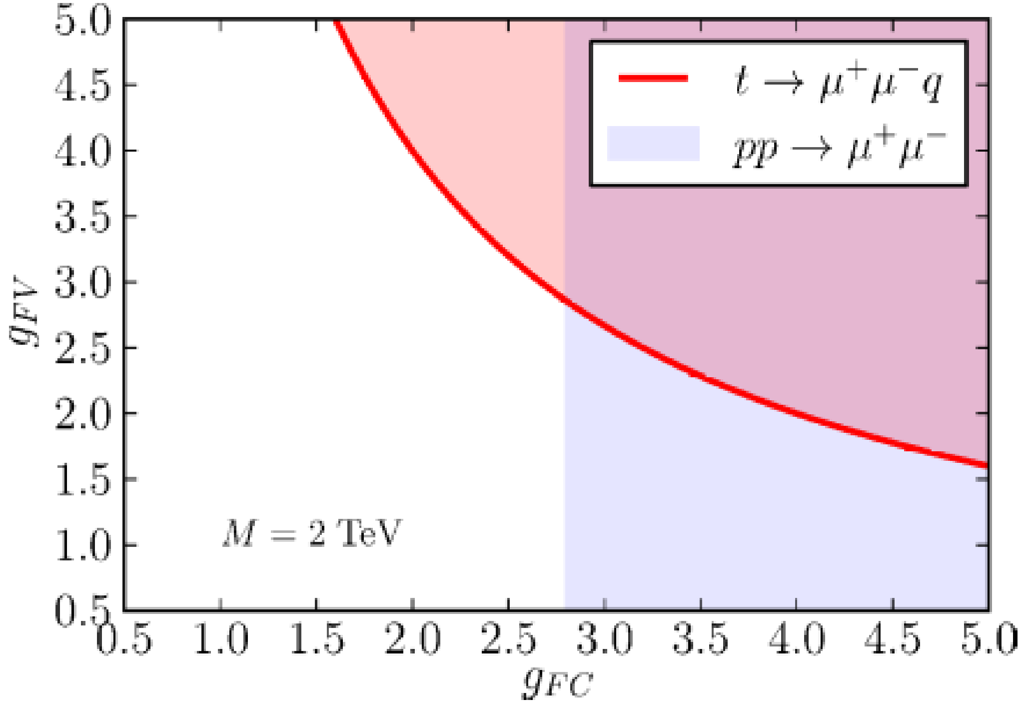

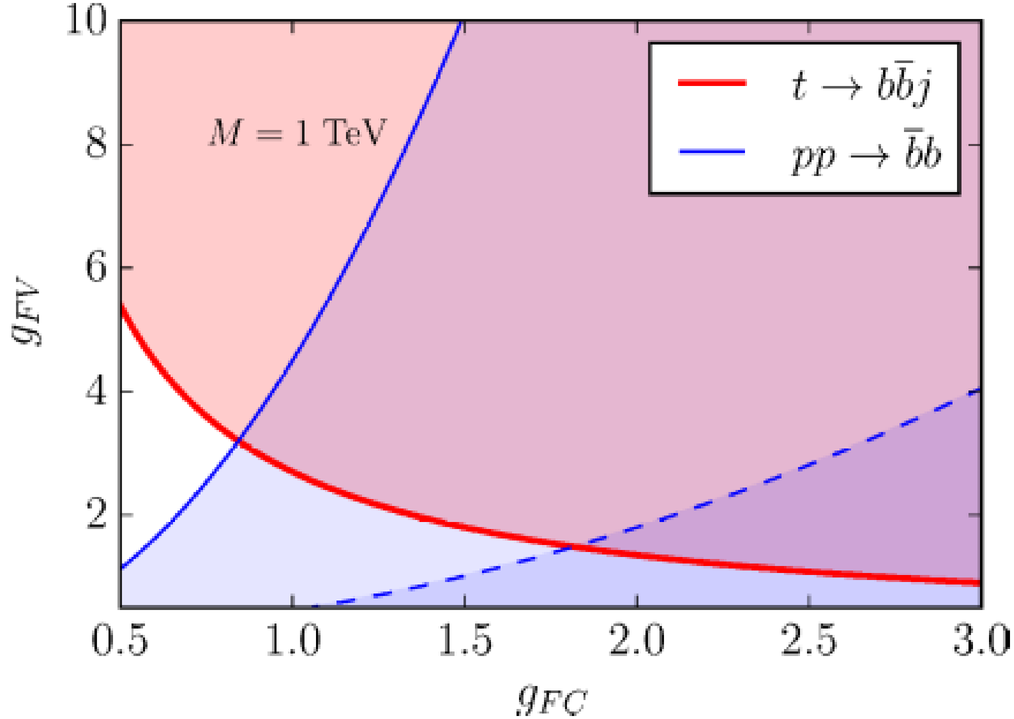

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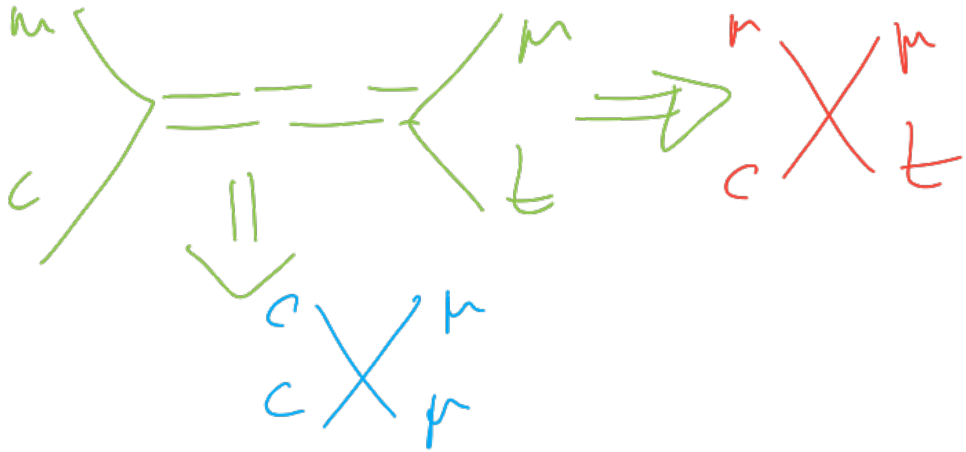

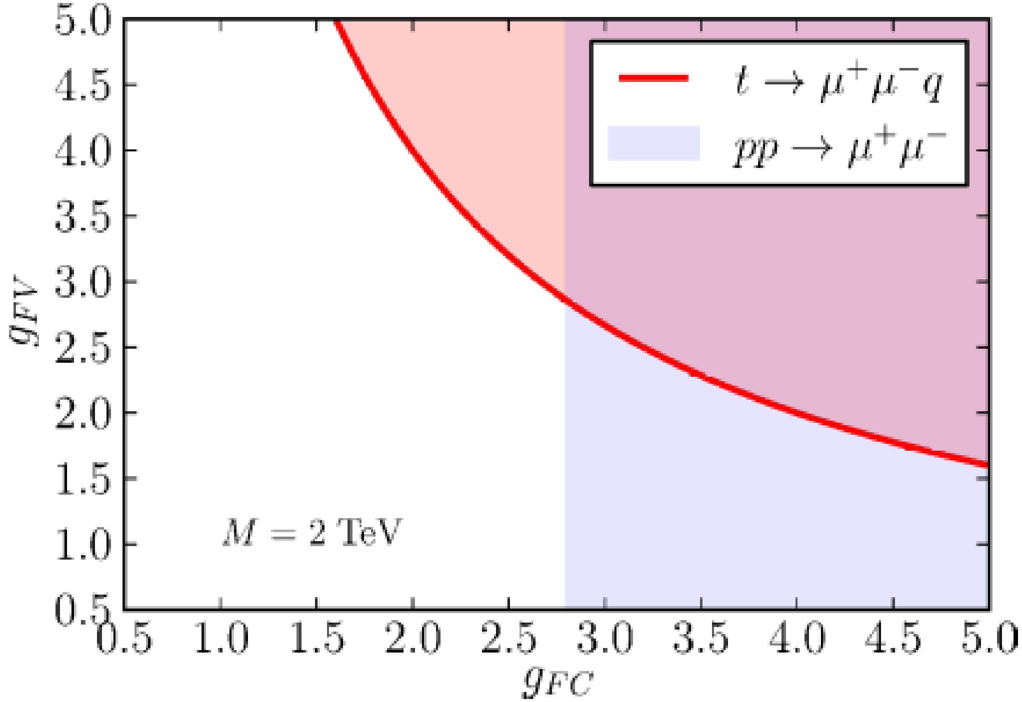

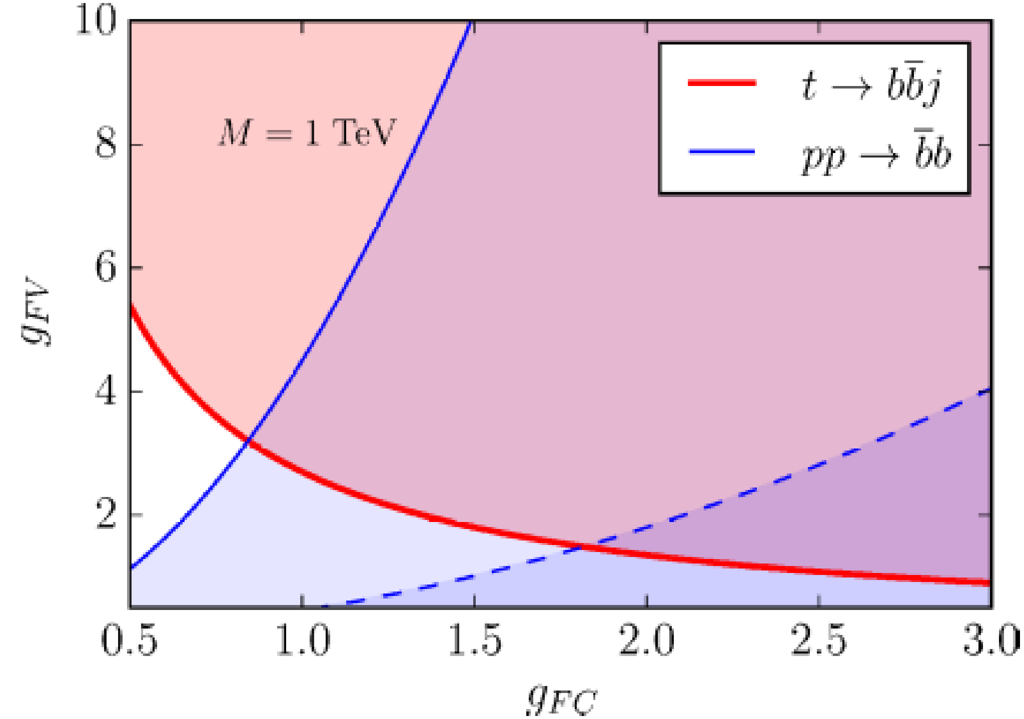

1. **There can be degrees of freedom beyond the SM below the electroweak scale**. Scalar singlets are good candidates. (Interestingly help to solve *e.g.* electroweak baryogenesis, etc.)

2. They are quite unconstrained, since they only couple to the SM via the Higgs boson at the renormalizable level.

3. They can induce FCNCs larger than those mediated by the Higgs boson.

4. Reasons: *(i)* the corresponding interaction is suppressed by one less power of *1/f*; *(ii)* in principle, the scalar singlet can have larger decay rates into clear final states; *(iii)* In several models, Higgs mediated FCNCs are forbidden in first approximation *[Agashe, Contino, 0906.1542]* (*Y'* aligned with Y.)

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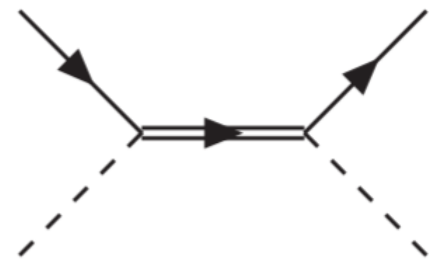
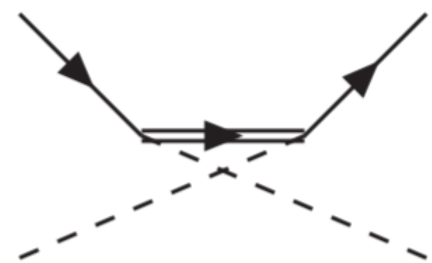
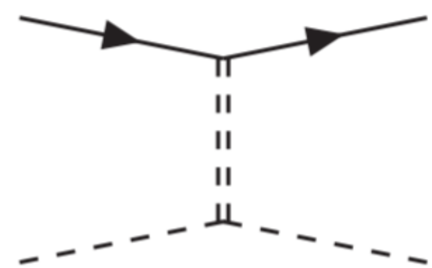
1. Scalars singlets are predicted in different well-motivated extensions of the SM, including the **NMSSM** and **CHMs**, *e.g.* $SO(6)/SO(5)$.

Field	Relevant Lagrangian	Diagram	$\tilde{\mathbf{Y}}_{ij}/f^2$
$Q = (1,2)_{1/6}$	$L_Q = -m_Q \overline{Q} Q + (\alpha_i^Q \overline{Q} S q_L^i$ $+ \tilde{\alpha}_j^Q \overline{Q} \tilde{H} u_R^j + \text{h.c.})$		$\dfrac{\alpha_i^Q \tilde{\alpha}_j^Q}{m_Q}$
$U = (1,1)_{2/3}$	$L_U = -m_U \overline{U} U + (\alpha_i^U \overline{U} H q_L^i$ $+ \tilde{\alpha}_j^U \overline{U} S u_R^j + \text{h.c.})$		$\dfrac{\alpha_i^U \tilde{\alpha}_j^U}{m_U}$
$\Phi = (1,2)_{1/2}$	$L_\Phi = -\frac{1}{2} m_\Phi^2 \Phi^2 + (\alpha_{ij}^\Phi \overline{q_L^i} \tilde{\Phi} u_R^j$ $+ \kappa S \Phi^\dagger H + \text{h.c.})$		$\dfrac{\alpha_{ij}^\Phi \kappa}{m_\Phi^2}$

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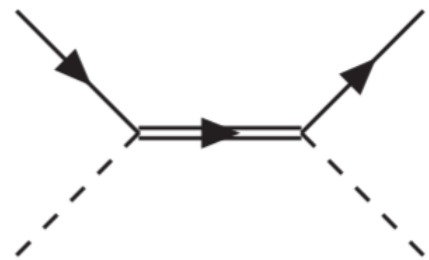
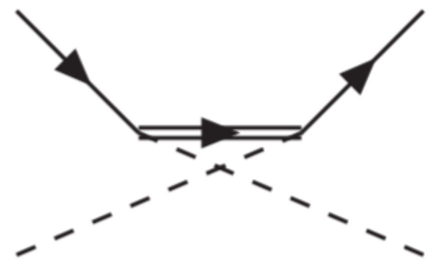
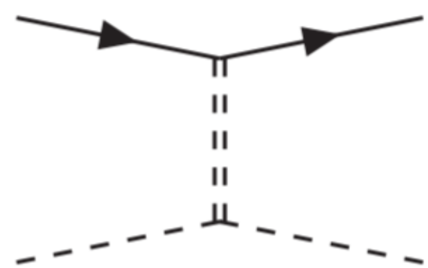
$Q=(1,2)_{1/6}$	$L_Q = -m_Q\overline{Q}Q + (\alpha_i^Q\overline{Q}Sq_L^i + \tilde{\alpha}_j^Q\overline{Q}\tilde{H}u_R^j + \mathrm{h.c.})$		$\dfrac{\alpha_i^Q\tilde{\alpha}_j^Q}{m_Q}$
$U=(1,1)_{2/3}$	$L_U = -m_U\overline{U}U + (\alpha_i^U\overline{U}Hq_L^i + \tilde{\alpha}_j^U\overline{U}Su_R^j + \mathrm{h.c.})$		$\dfrac{\alpha_i^U\tilde{\alpha}_j^U}{m_U}$
$\Phi=(1,2)_{1/2}$	$L_\Phi = -\frac{1}{2}m_\Phi^2\Phi^2 + (\alpha_{ij}^\Phi\overline{q_L^i}\tilde{\Phi}u_R^j + \kappa S\Phi^\dagger H + \mathrm{h.c.})$		$\dfrac{\alpha_{ij}^\Phi\kappa}{m_\Phi^2}$

1. We require at least four jets, three of them b-tagged as well as exactly one isolated lepton.

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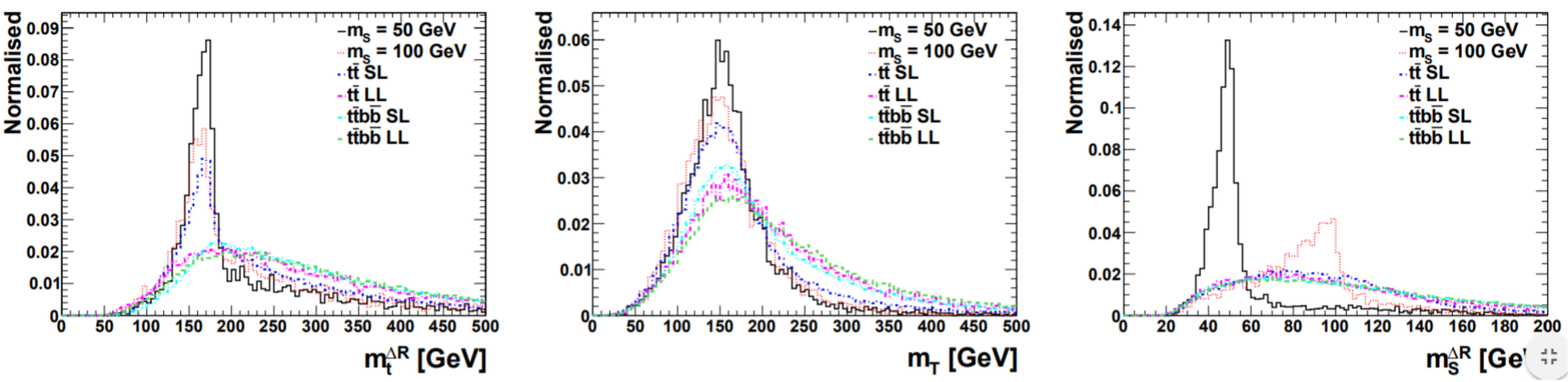

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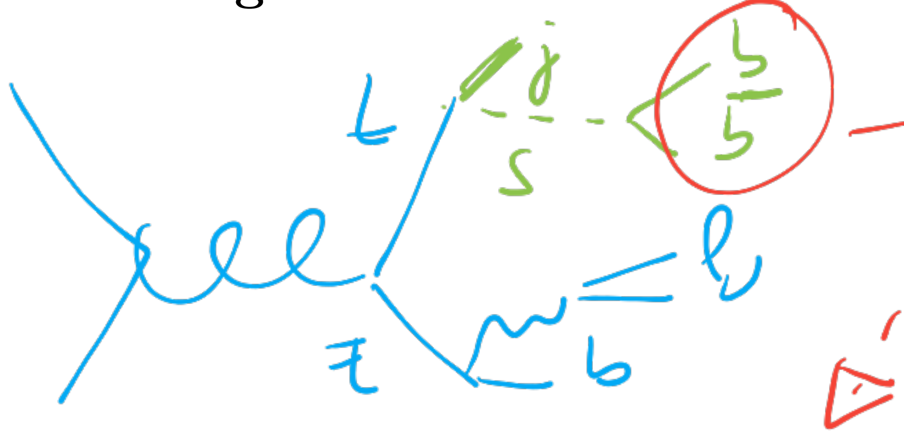

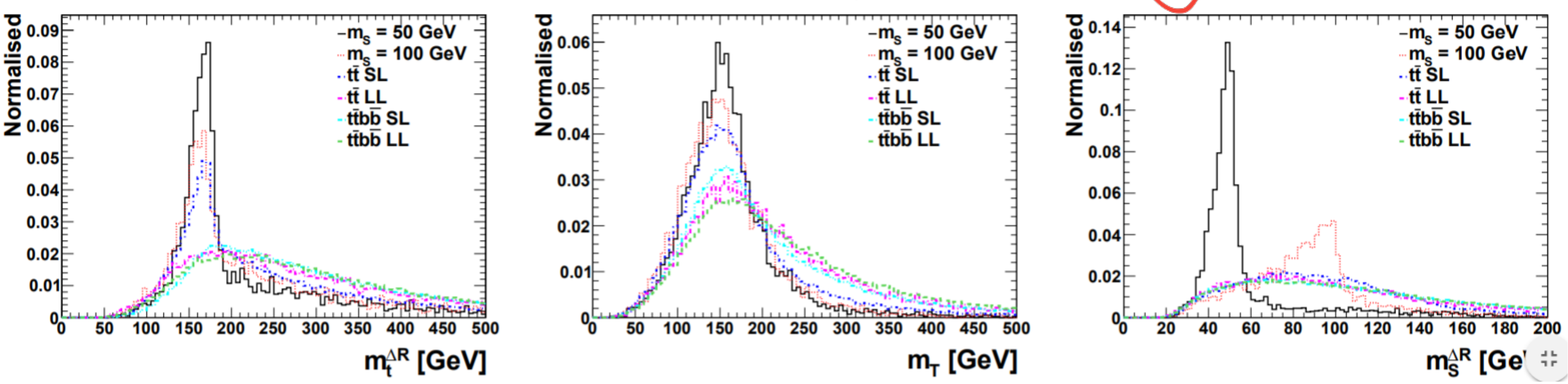

1. Highest reach for about *80* GeV, for which one can probe a BR of order *1E-4* at the LHC with $L = 3/ab$. The reach goes down for low masses because the b-jets coming from S can not always be resolved independently.

2. For higher masses, the sensitivity goes down because the invariant mass of the closest b-jets does not always peak around the singlet mass.

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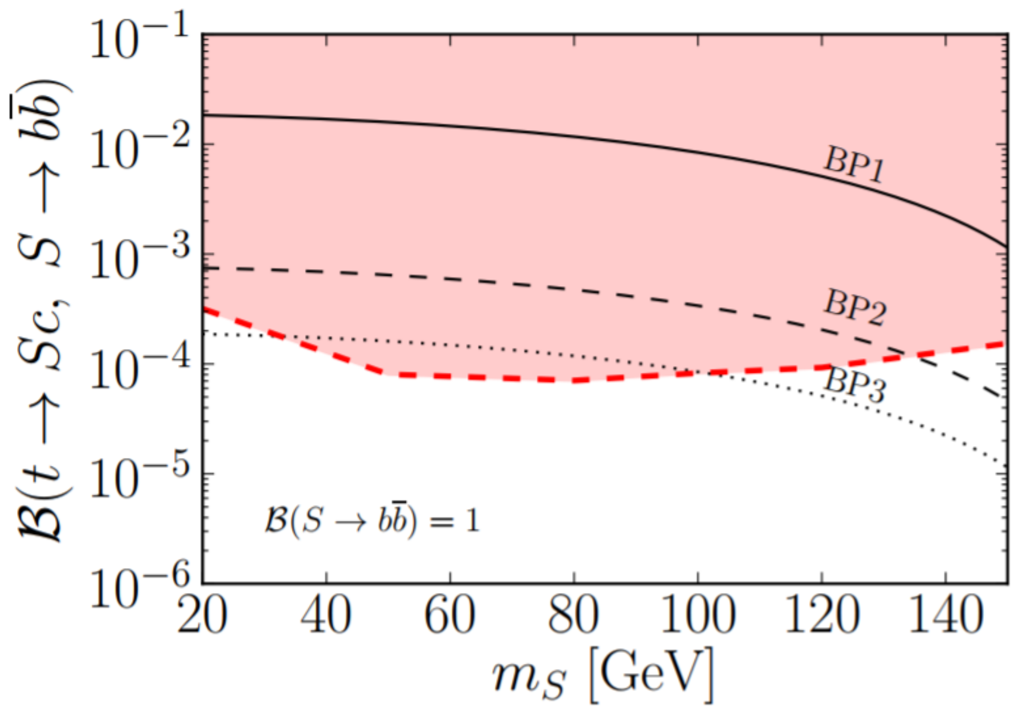

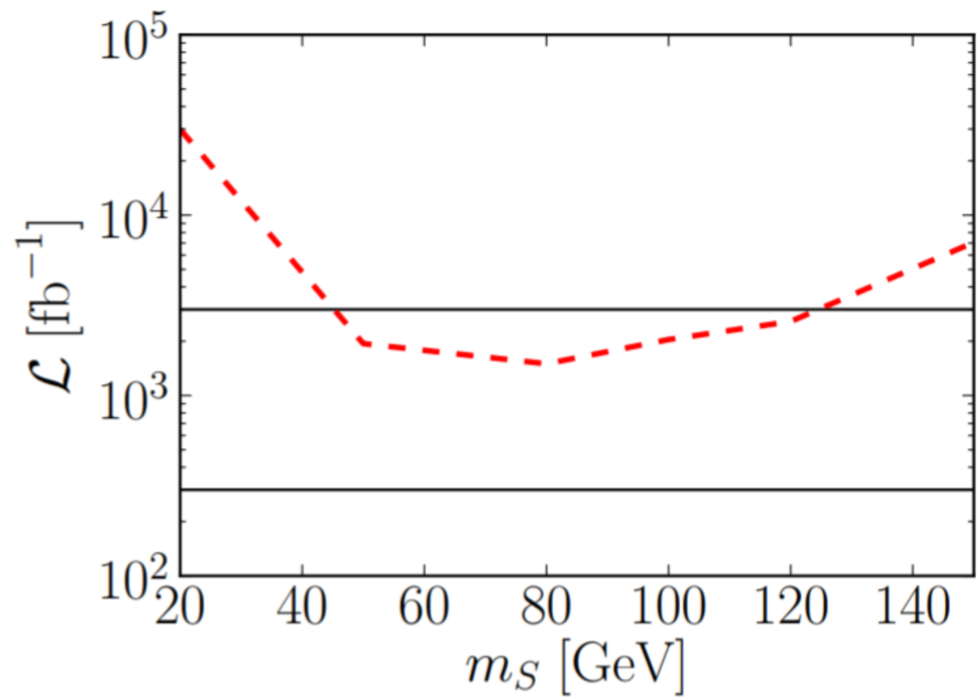

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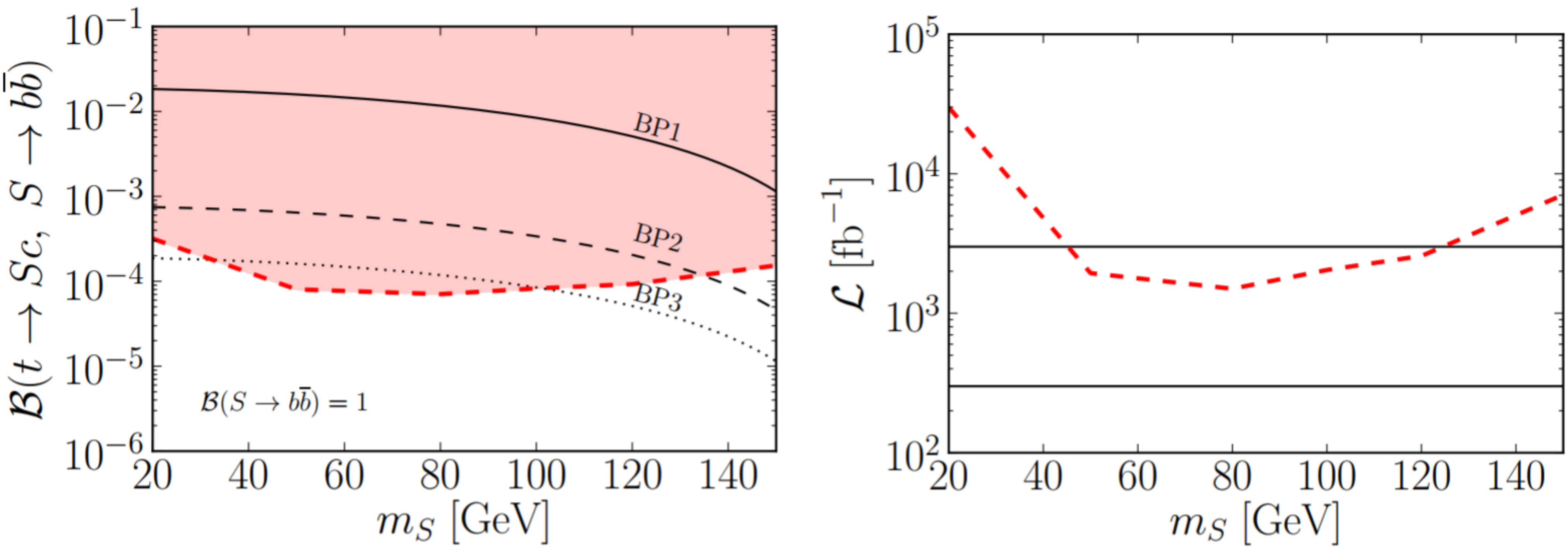

1. **An even simpler extension of the usual SMEFT is that in which the neutrino is Dirac**. (Also if the Majorana neutrino giving mass to the SM one is light enough and longlived.)

2. Contrary to the SM case, some of the operators can be only probed in rare top decays with missing energy.

	Operator	Notation	Operator	Notation
SF	$(\overline{l_L}N)\tilde{H}(H^\dagger H)$	$\mathcal{O}_{lNH}$ (+h.c.)		
	$(\overline{N}\gamma^\mu N)(H^\dagger i\overleftrightarrow{D}_\mu H)$	$\mathcal{O}_{HN}$	$(\overline{N}\gamma^\mu e_R)(\tilde{H}^\dagger iD_\mu H)$	$\mathcal{O}_{HNe}$ (+h.c.)
	$(\overline{l_L}\sigma_{\mu\nu}N)\tilde{H}B^{\mu\nu}$	$\mathcal{O}_{NB}$ (+h.c.)	$(\overline{l_L}\sigma_{\mu\nu}N)\sigma_I\tilde{H}W^{I\mu\nu}$	$\mathcal{O}_{NW}$ (+h.c.)
RRRR	$(\overline{N}\gamma_\mu N)(\overline{N}\gamma^\mu N)$	$\mathcal{O}_{NN}$		
	$(\overline{e_R}\gamma_\mu e_R)(\overline{N}\gamma^\mu N)$	$\mathcal{O}_{eN}$	$(\overline{u_R}\gamma_\mu u_R)(\overline{N}\gamma^\mu N)$	$\mathcal{O}_{uN}$
	$(\overline{d_R}\gamma_\mu d_R)(\overline{N}\gamma^\mu N)$	$\mathcal{O}_{dN}$	$(\overline{d_R}\gamma_\mu u_R)(\overline{N}\gamma^\mu e_R)$	$\mathcal{O}_{duNe}$ (+h.c.)
LLRR	$(\overline{l_L}\gamma_\mu l_L)(\overline{N}\gamma^\mu N)$	$\mathcal{O}_{lN}$	$(\overline{q_L}\gamma_\mu q_L)(\overline{N}\gamma^\mu N)$	$\mathcal{O}_{qN}$
LRRL	$(\overline{l_L}N)\epsilon(\overline{l_L}e_R)$	$\mathcal{O}_{lNle}$ (+h.c.)	$(\overline{l_L}N)\epsilon(\overline{q_L}d_R)$	$\mathcal{O}_{lNqd}$ (+h.c.)
	$(\overline{l_L}d_R)\epsilon(\overline{q_L}N)$	$\mathcal{O}_{ldqN}$ (+h.c.)	$(\overline{q_L}u_R)(\overline{N}l_L)$	$\mathcal{O}_{quNl}$ (+h.c.)

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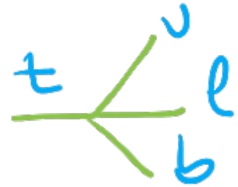

[only]

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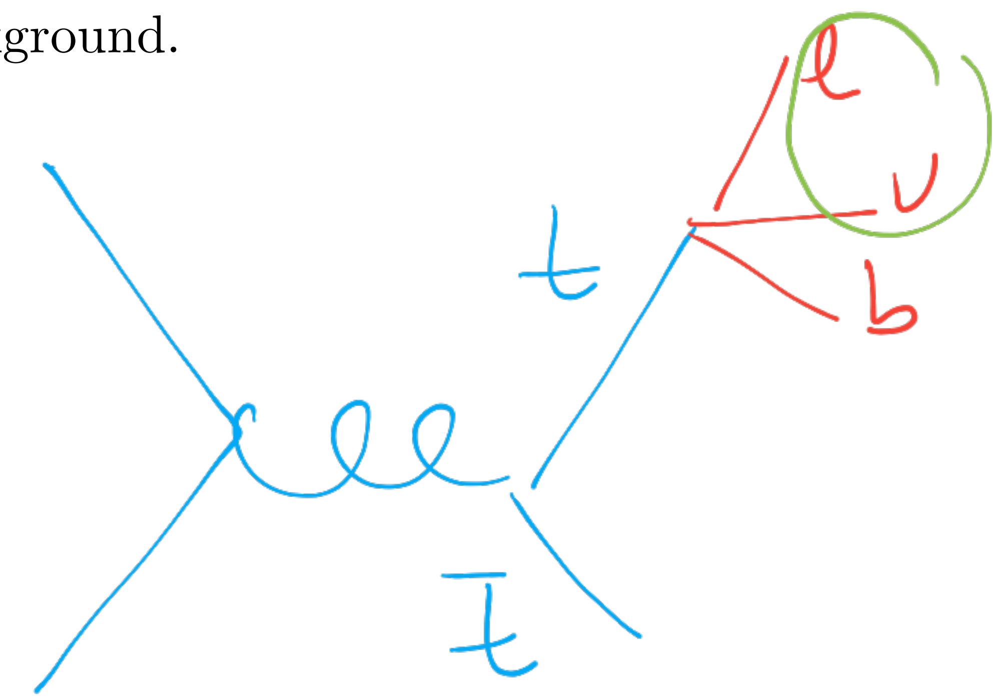

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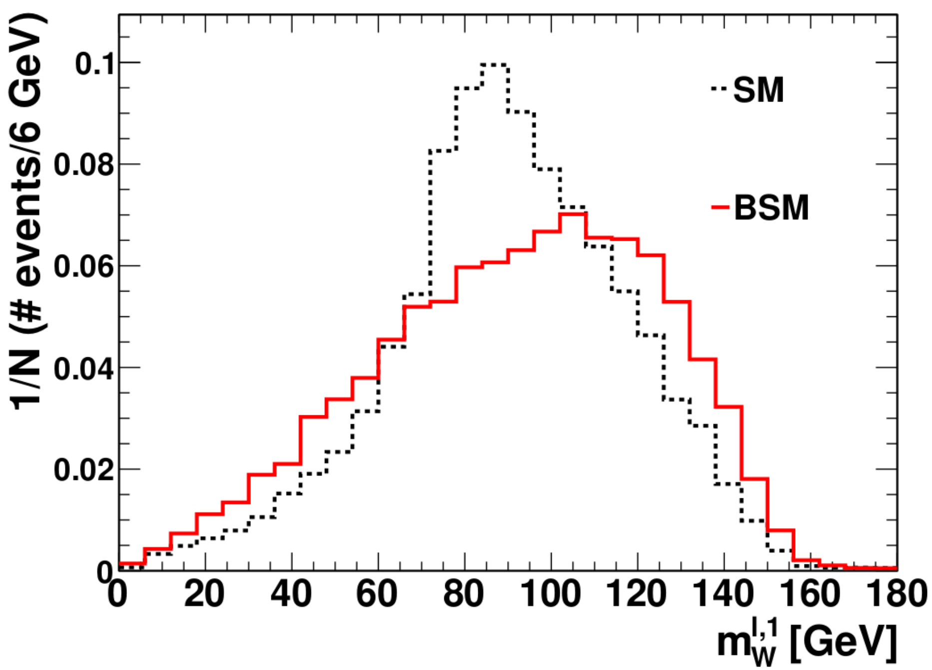
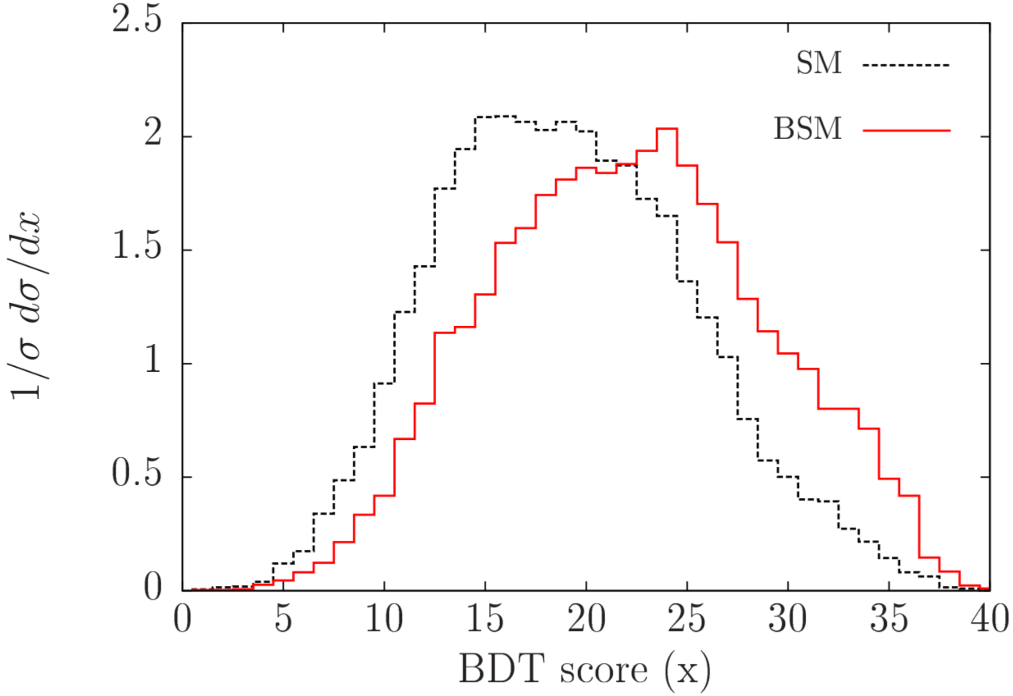


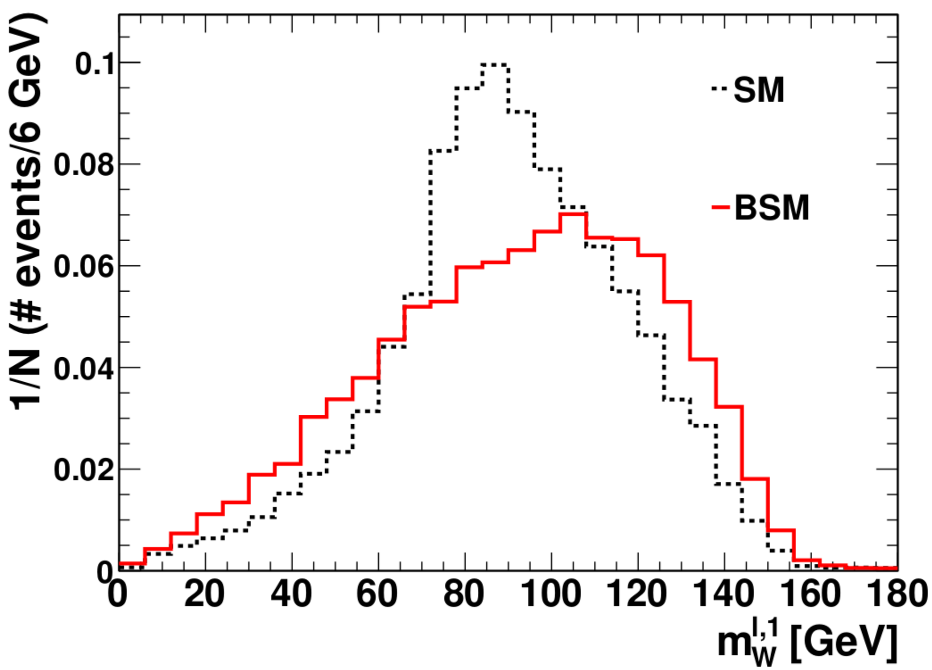


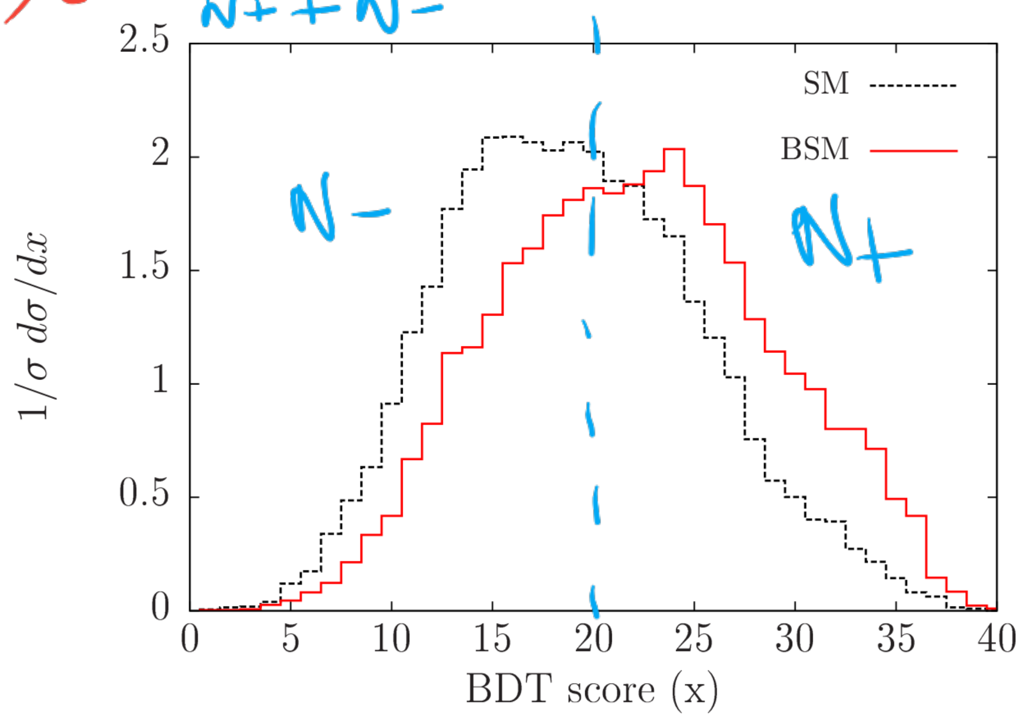
1. We require exactly two b-tagged jets, one isolated lepton and at least two light jets.

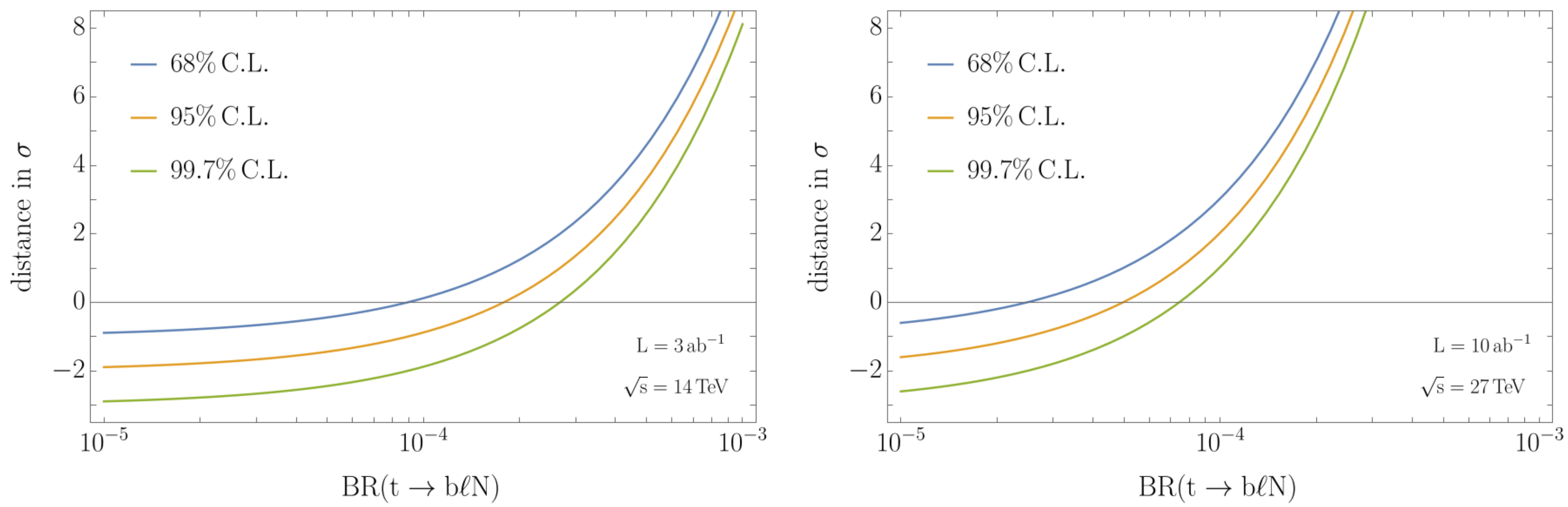
2. We construct the hadronic top (using the b-tagged jet giving the invariant mass closest to the measured top mass). The longitudinal momentum of the neutrino is obtained from the leptonic top mass.

3. We subsequently reconstruct **the invariant mass of the lepton and the neutrino**. This **provides the main discriminant** (input to a BDT) between signal and background.

$$A = \frac{N_+ - N_-}{N_+ + N_-}$$







roughly $\Lambda \sim 1$ TeV [assuming 3 ν_R and both e^+ and μ^+].

Conclusions

1. The **large number of top quarks produced at the LHC** and possible future hadron colliders allows to study rare decays of this particle.

2. These can be used to constrain several operators of the SMEFT, often improving over flavour bounds.

3. Top decays into unconstrained non-SM degrees of freedom are also possible; scalar singlets giving the most promising signals at the LHC.

4. Top operators in the vSMEFT are much harder to constrain, because they give rise to SM-like signatures. New analyses are welcome.

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thank you!