# Searches for DM in association with a single top quark

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# Overview

# Dark Matter and Simplified Models

- Dark Matter makes up $\sim 25\%$ of our universe
- Simplified models provide a framework for general DM searches
- They assume some mediation between DM sector and SM
- Useful assumption: Yukawa-like couplings
  $\longrightarrow$ top quarks have leading contribution **Arina et al. 1605.09242**

# The Model

$$\mathcal{L}_S \supset g_S^\chi \left(\bar{\chi}\chi\right) S + g_S^t \frac{m_t}{v} \left(\bar{t}t\right) S$$

$$\mathcal{L}_P \supset i g_P^\chi \left(\bar{\chi}\gamma_5\chi\right) P + i g_P^t \frac{m_t}{v} \left(\bar{t}\gamma_5 t\right) P$$

Things to notice:

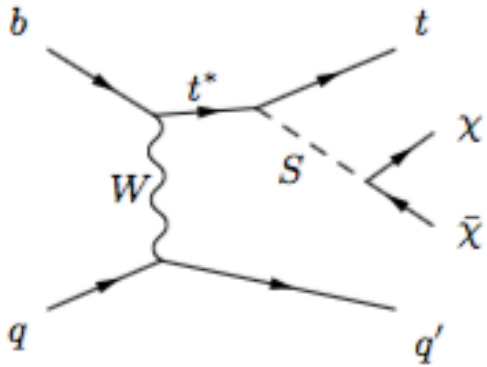
- spin-0 mediators
- coupling to top quarks
- fermionic Dirac DM particles

# single top in $t\bar{t}$+DM searches

- Search channels:
  $\longrightarrow$ $t\bar{t}$+DM **e.g. Haisch, Pani and Polesello 1611.09841**
  $\longrightarrow$ $j$+DM **e.g. Haisch and Re 1503.00691**
- $t\bar{t}$+DM searches are sensitive to $tj$+DM: **see Pinna et al. 1701.05195**
  $\longrightarrow$ 30%-90% improvement in sensitivity
- Our question - can we use single top to search?

# signal

- Extra jet is useful for a dedicated $tj$+DM search channel
- Consider on-shell mediator production
- Benchmark: $M_{S/P} = 300$ GeV, $g^{\chi}_{S/P} = g^{t}_{S/P} = 1$, $m_{\chi} = 1$ GeV



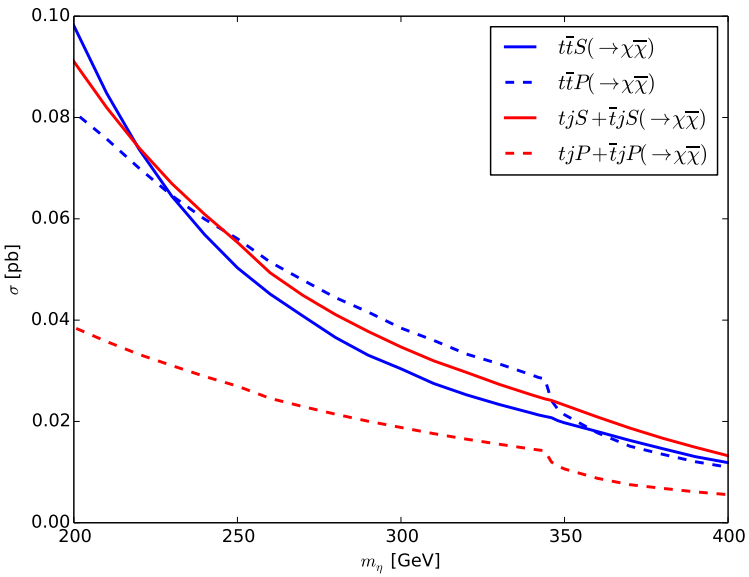

NOTE: $tW$ can also be a nice search channel for extended Higgs sectors/charged mediators: **Pani and Polesello 1712.03874**

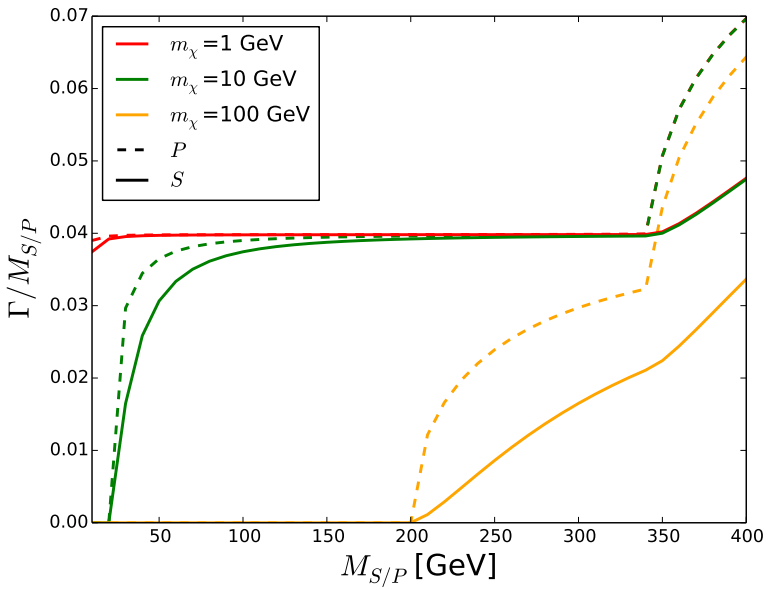
# Mediator Widths

$$\frac{\Gamma_S}{m_S} = \frac{1}{8\pi}\left[(g_S^\chi)^2\left(1-\frac{4m_\chi^2}{m_S^2}\right)^{3/2} + 3(g_S^t)^2\frac{m_t^2}{v^2}\left(1-\frac{4m_t^2}{m_S^2}\right)^{3/2}\Theta(m_S-2m_t)\right]$$

$$\frac{\Gamma_P}{m_P} = \frac{1}{8\pi}\left[(g_P^\chi)^2\left(1-\frac{4m_\chi^2}{m_P^2}\right)^{1/2} + 3(g_P^t)^2\frac{m_t^2}{v^2}\left(1-\frac{4m_t^2}{m_P^2}\right)^{1/2}\Theta(m_P-2m_t)\right]$$

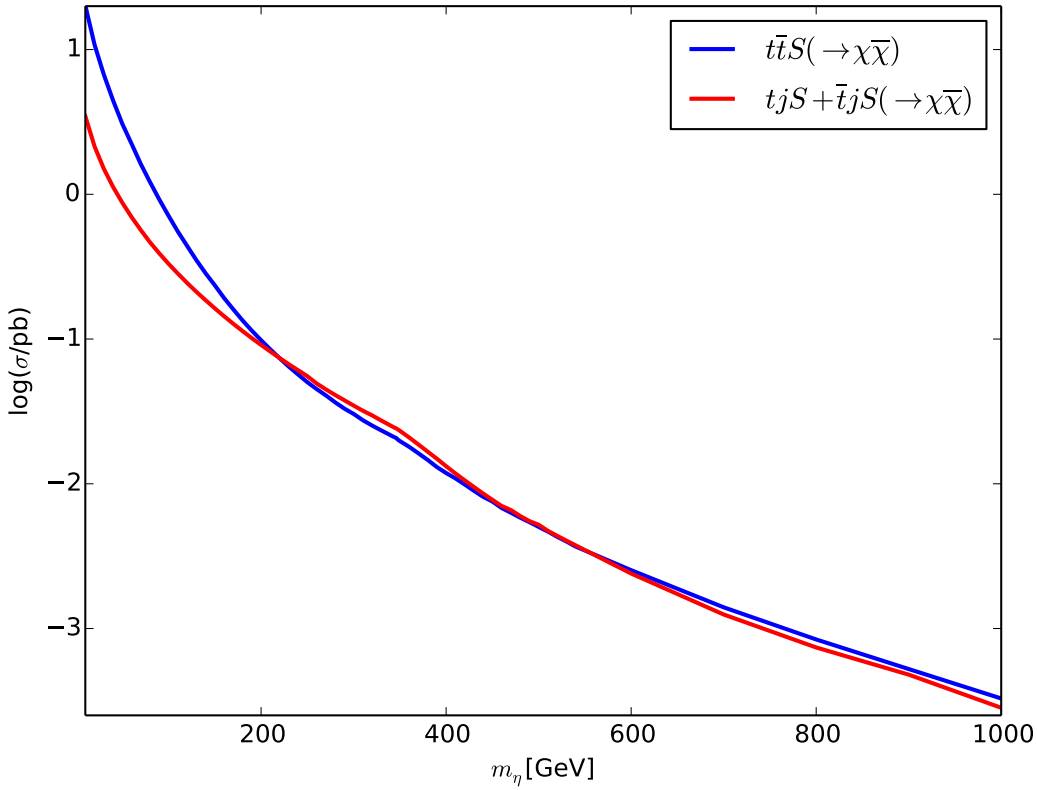
# Signal total cross sections




$\longrightarrow \sigma_{tj\text{DM}} \sim \sigma_{t\bar{t}\text{DM}}$, exact values dependent on peturbative order and scale choice

# Scalar total cross secions



# Event Selection

- 13 TeV LHC
- Leptonic top decays
- Sherpa
  $\longrightarrow$ LO merged samples
- Delphes for fast detector simulation
- BDT analysis

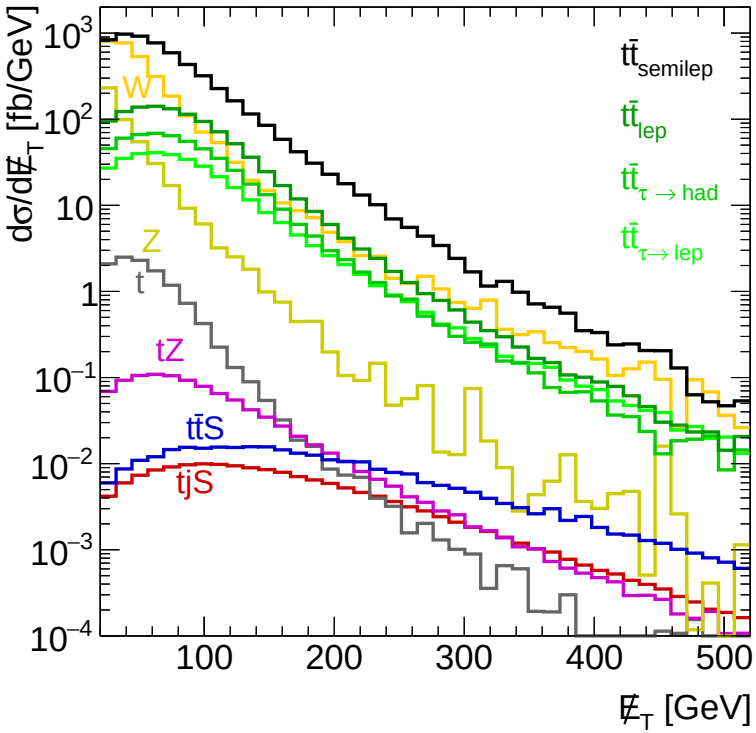
| Observable | Cut |
|---|---|
| $N_b$ | 1 |
| $N_{\text{lep}}$ | 1 |
| $N_j$ | $\geq$1 |
| $p_{Tj}$ | 20 |
| $E_T^{\text{miss}}$ | $>$ 100 GeV |
| $m_T$ | $>$ 85 GeV |

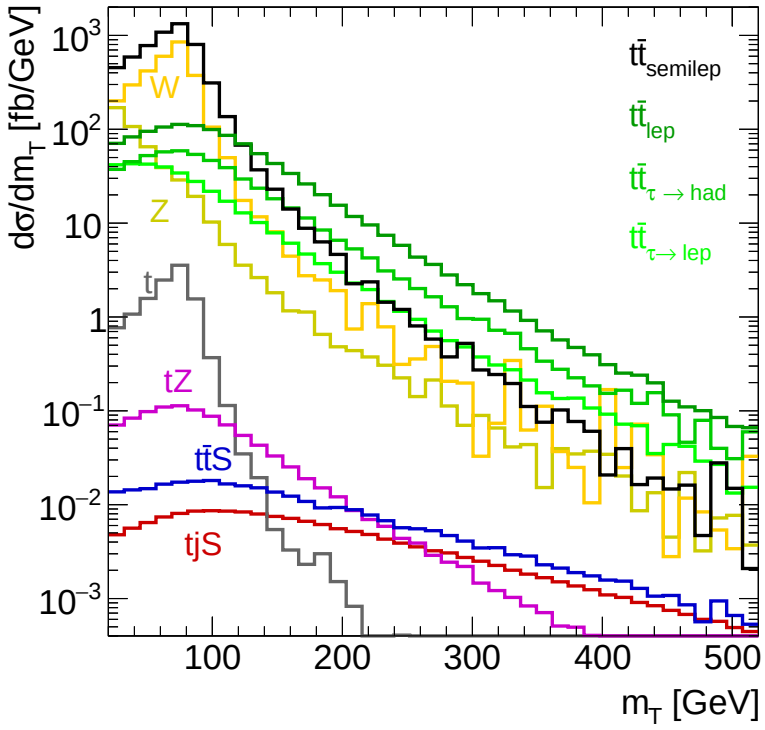
# Backgrounds

In order of importance

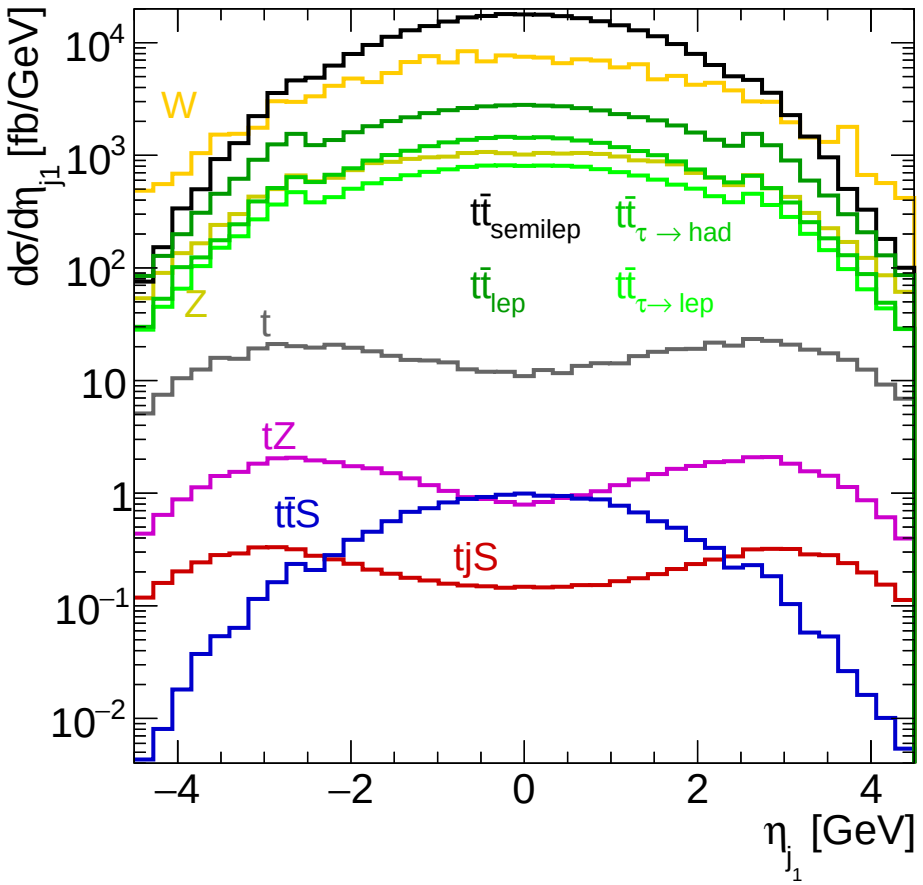
- $t\bar{t}$, of course:
  1. $t\bar{t} \to \ell^+\ell^-\nu\overline{\nu}$
  2. $t\bar{t} \to \overline{\nu_\tau}\tau(\to \text{had})\ell^+\nu$
  3. $t\bar{t} \to \overline{\nu_\tau}\tau(\to \ell\overline{\nu})\ell^+\nu$
  4. $t\bar{t} \to \ell\overline{\nu}+\text{had}$
- $tj$
- $tZj$
- $V+\text{jets}$
- $t\bar{t}+\text{DM}$

# signal kinematics

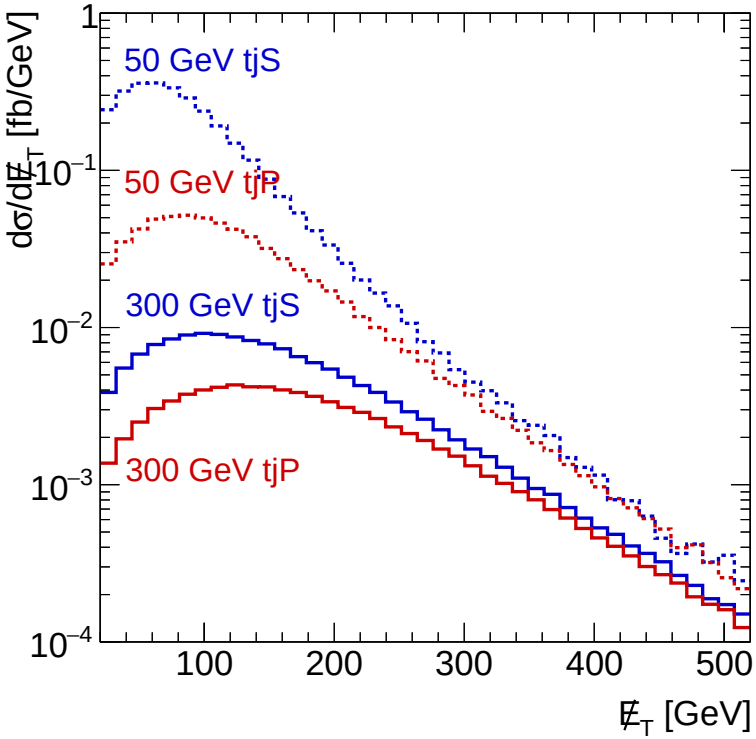


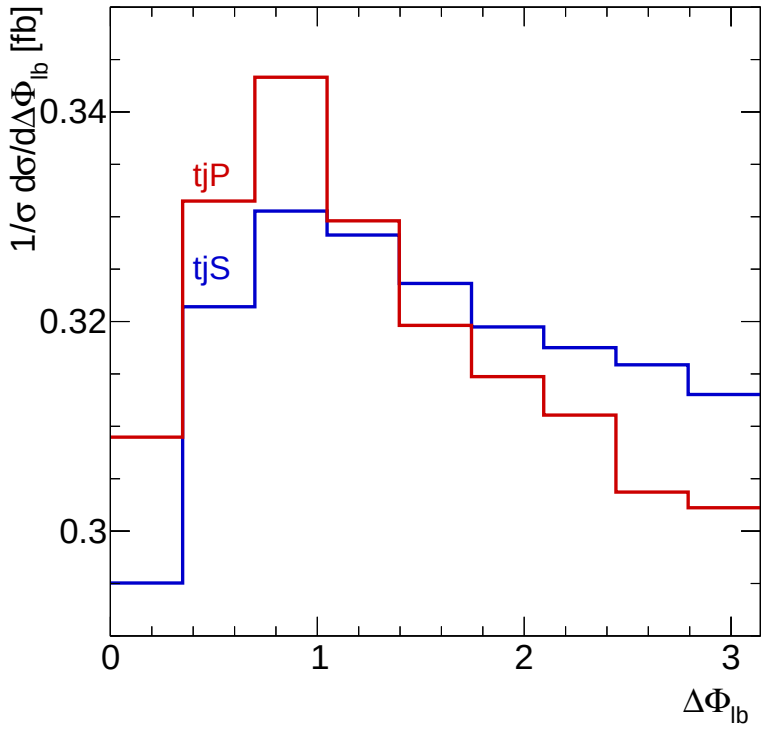



# hardest jet


dσ/dη_j1 [fb/GeV]
10^4
10^3
10^2
10
1
10^−1
10^−2
W
Z
t
tZ
tt̄S
tjS
tt̄_semilep
tt̄_τ→had
tt̄_lep
tt̄_τ→lep
−4
−2
0
2
4
η_j1 [GeV]

# Pseudo Vs. Scalar



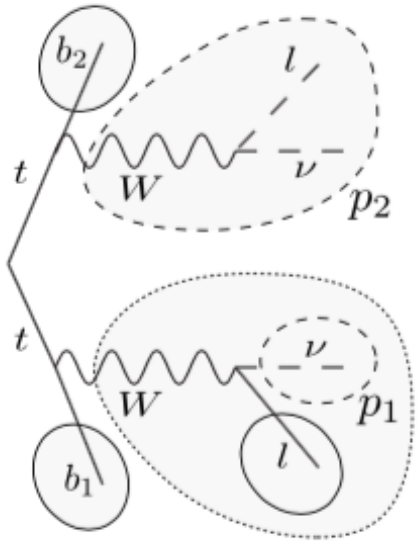



# BDT for scalar mediator

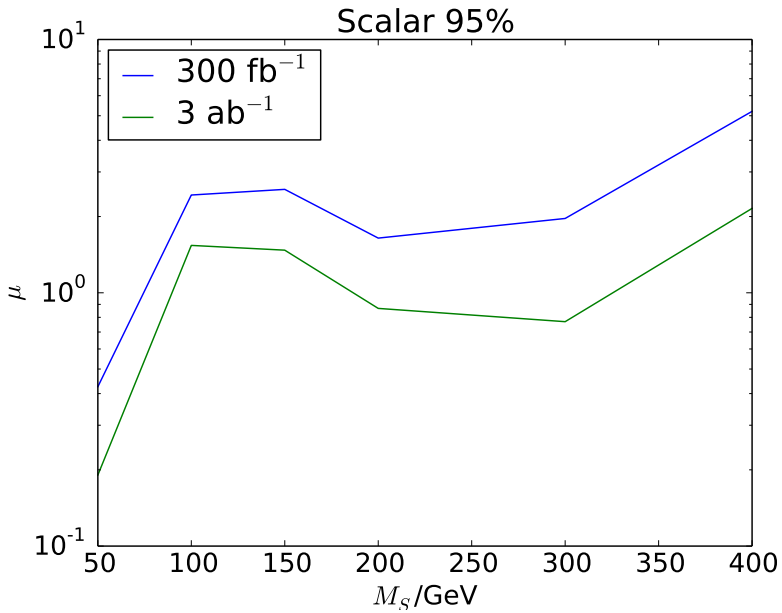
**Bai et al. 1203.4813**

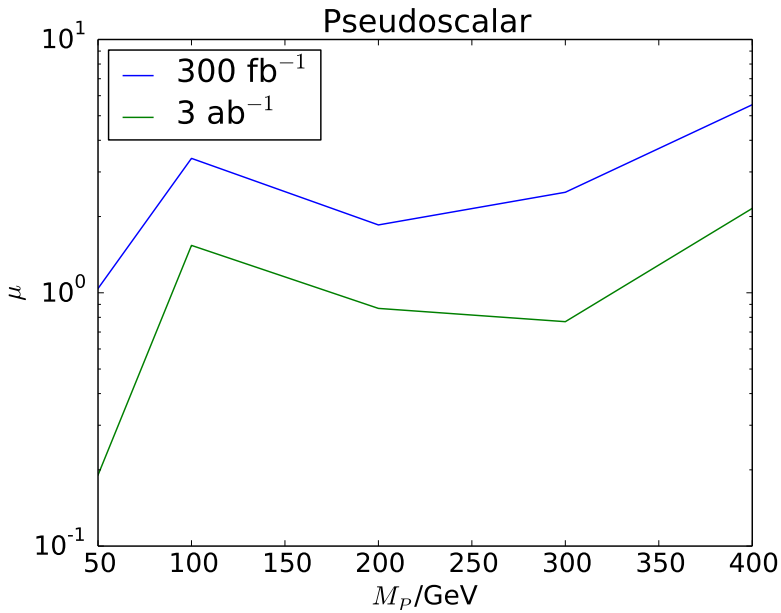
$$\{p_{T,\ell}, \eta_\ell,\ p_{T,b}, \eta_b,\ p_{T,j_1}, \eta_{j_1},\ E_T^{\text{miss}},\ \phi_{\ell,b}, \phi_{\ell,j_1}, \phi_{j_1,b}, \phi_{\ell,E_T^{\text{miss}}},$$
$$\phi_{j_1,E_T^{\text{miss}}}, \phi_{b,E_T^{\text{miss}}},\ m_T, M_{T2}^W, m_{bj_1},\ N_{\text{jets}}\}.$$

- $t\bar{t}$ backgrounds are dominant: need good control
- assume 3% systematic uncertainty



# Preliminary CLs limits




$\longrightarrow$ signal strength $\mu$

$\longrightarrow$ relative to all couplings=1

# Conclusions

- Single top+DM can be useful search channel at the LHC
- Characteristic forward jet and $m_T$ useful for suppressing backgrounds
- $\sigma_{tj\text{DM}} \sim \sigma_{t\bar{t}+\text{DM}}$ for large mediator masses
- Similar sensitivity to $t\bar{t}$+DM searches
- Relies on a good understanding of $t\bar{t}$ backgrounds