Lightening Top Partner at the LHC

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University of Kansas

based on work in collaboration with

J. Kim, K. Kong and I. Lewis

May, 7th 2018

Top Partner

The Stability of Higgs mass.

Naturalness.

Interaction with SM top-quark.

- Supersymetry: New Scalar.
- Composite Higgs: New Fermion.

Assume Vector Like Quark.

Introduction

Simple Extension to SM with a VLQ: T

Conventionally: $T \to tZ, tH, bW$

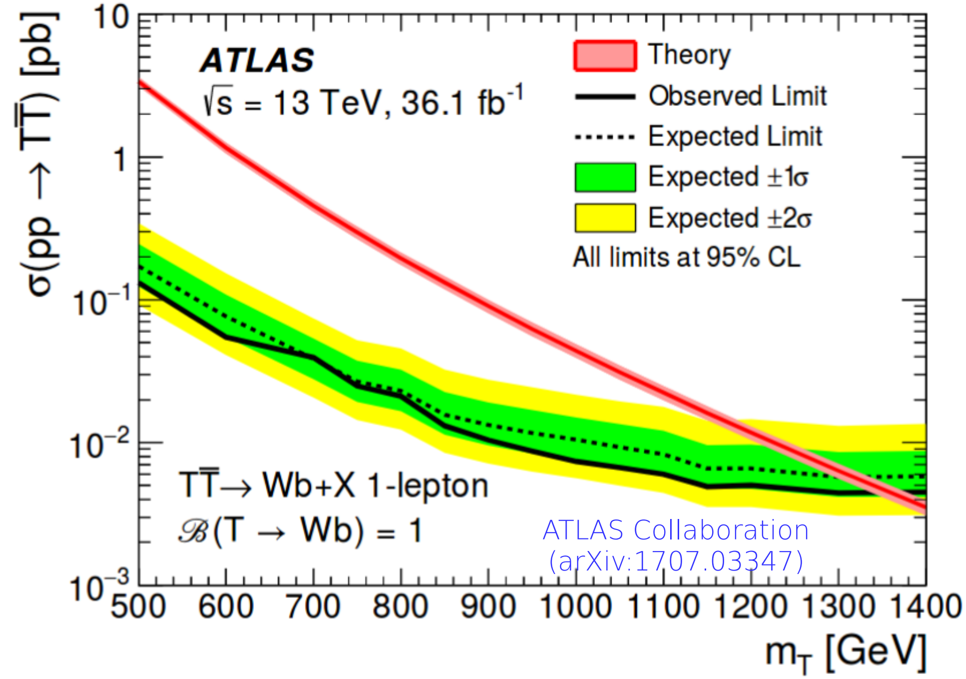
Exp. searches indicate no deviation from the SM.

What if T doesn't decay conventionally?

How about new decay modes?

Radiative decay Modes?

Can we probe this at the LHC?



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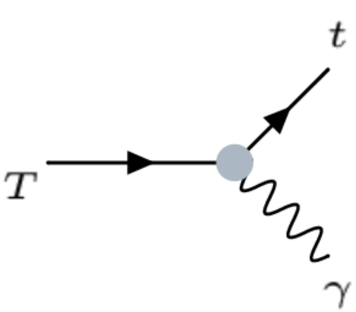

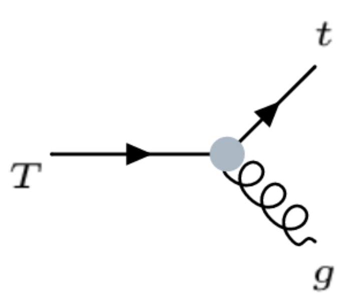

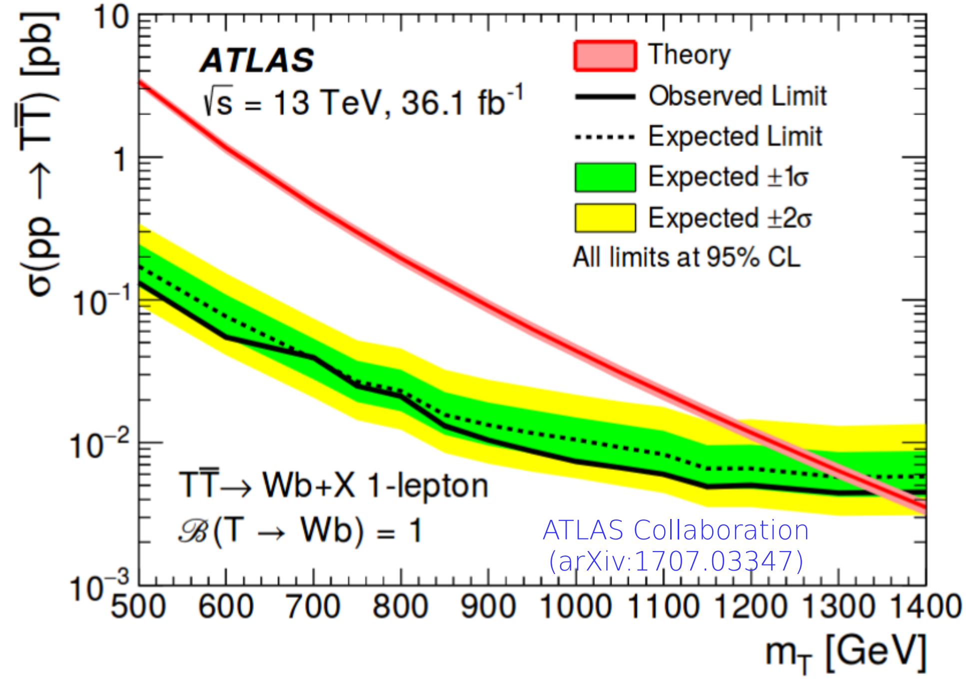

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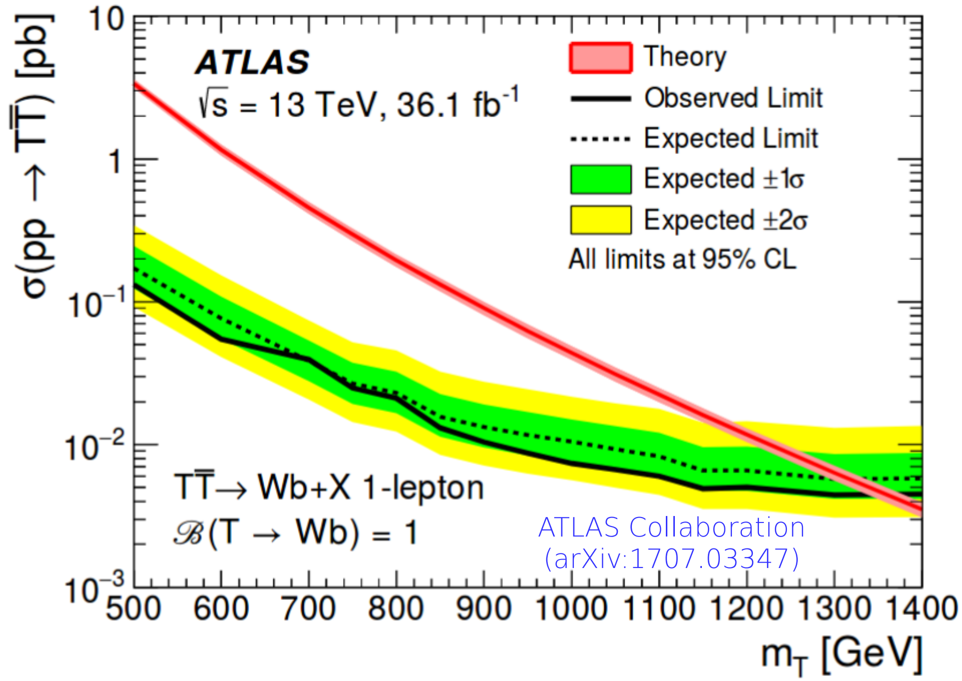

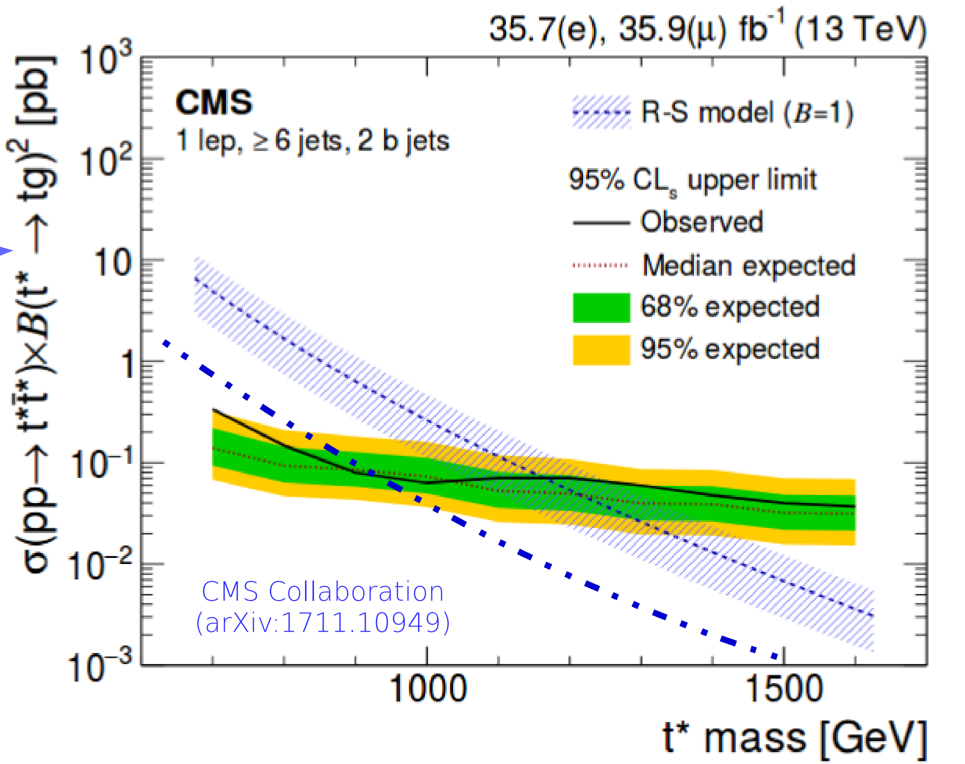

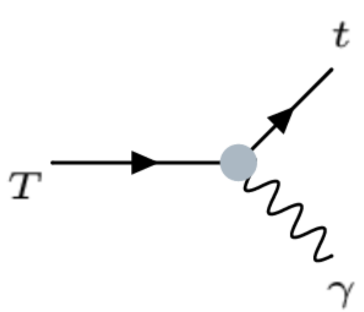

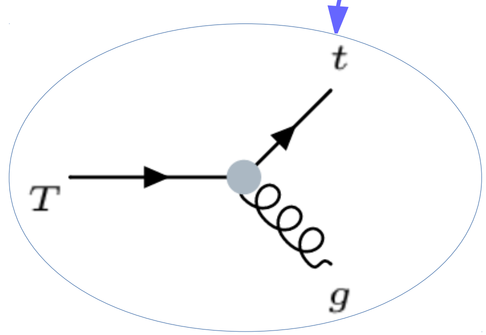

Introduction

Loop Induced Single Top Partner Production and Decay at the LHC

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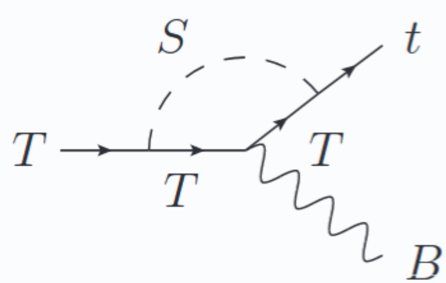
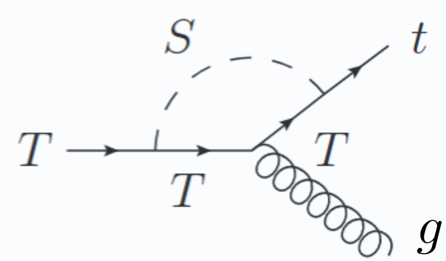
arXiv:1803.06351

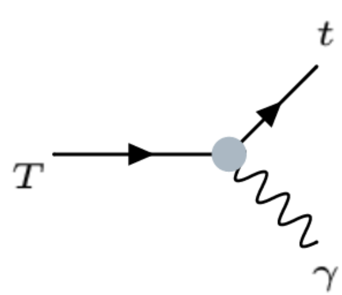
Recent theoretical work → Complete ultraviolet model

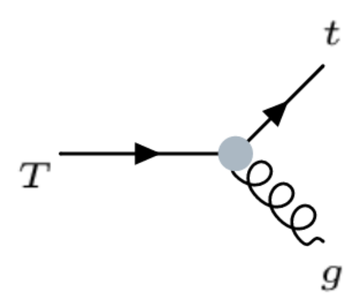
Considers zero mixing angle between SM top and t-prime

Radiative decays are induced by loop processes









The Model

Simple Extension to SM:

SU(3) color triplet and SU(2) Singlet.

Production is fixed by QCD, $\mathcal{L}_{\text{Kinetic}}$.

Effective Lagrangian:

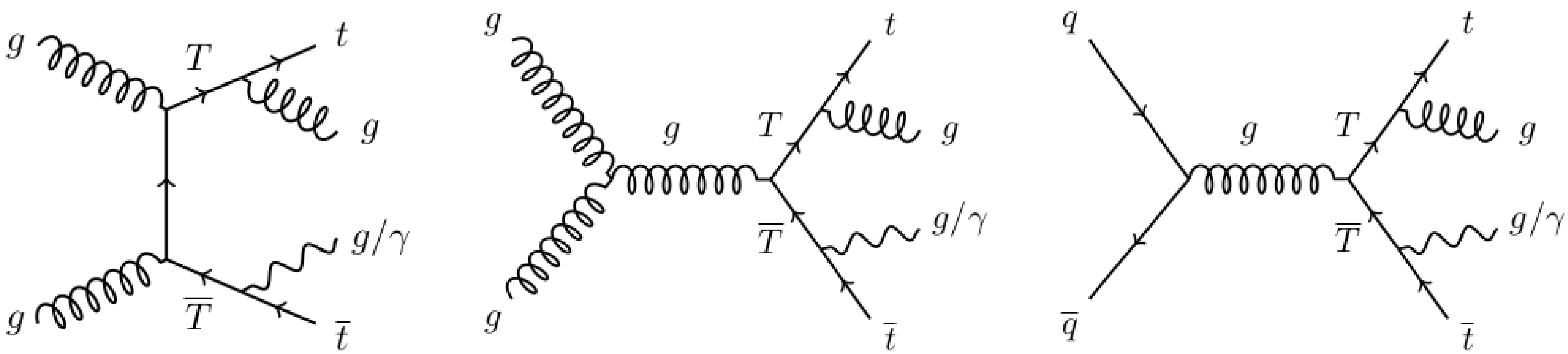
Free Parameters
$\{\mathcal{C}_1, \mathcal{C}_2, m_T\}$

$$\mathcal{L}_{\text{EFT}} = \bar{T}\,\sigma^{\mu\nu}\,\left(\mathcal{C}_1 T^a P_{L/R}\,t\,G^a_{\mu\nu} + \mathcal{C}_2 P_{L/R}\,t\,F_{\mu\nu}\right) + h.c.$$

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{Kinetic}} + \mathcal{L}_{\text{EFT}}.$$

Final States

$pp \to t\bar{t}gg \;/\; t\bar{t}g\gamma$



Benchmark Point:

$$\mathcal{C}_1 = 1.0 \times 10^{-4}$$

$$\mathcal{C}_2 = 0.2 \times 10^{-4}$$

$$m_T = 1.0\ \text{TeV}$$

Branching Fractions:

$$BR(T \to tg) = 0.97$$

$$BR(T \to t\gamma) = 0.03$$

consider semileptonic decay

Semileptonic $t \to bjj$ & $t \to b\bar{l}\nu_l$

1. $t\bar{t}gg$ Final State

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{Kinetic}} + \mathcal{L}_{\text{EFT}}.$$

- Model implementation.
- Signal and Background generation.
- Anti-kT jet clustering.
- TOM for top tagging.
- Detector resolution effect is included (ATLAS parametrization).

2. $t\bar{t}g\gamma$ Final State

- All partons: $p_T > 30\,\text{GeV}$ and $|\eta| < 5$
- Leptons: $p_T^l > 30\,\text{GeV}$ and $|\eta^l| < 2.5$
- Photons: $p_T^\gamma > 300\,\text{GeV}$ and $|\eta^\gamma| < 2.5$
- Additionally: $H_T > 700\,\text{GeV}$

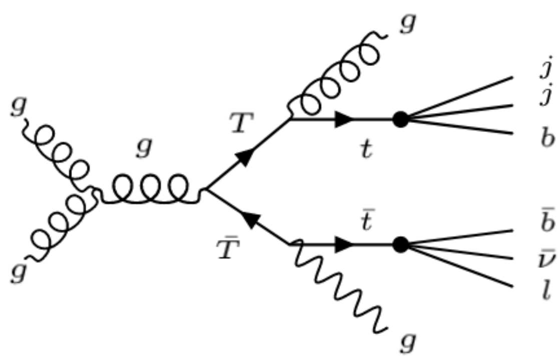
ATLAS Collaboration (arXiv:1407.5063)

Analysis

1. Semileptonic $pp \to T\bar{T} \to t\,g\,\bar{t}\,g$

Consider

$$m_T = 1\,\mathrm{TeV} \implies \sigma^{\mathrm{sig}} \cdot \mathrm{BR} \cdot \varepsilon_{\mathrm{gen}} = 4.4\,\mathrm{fb}$$



CMS: $pp \to t^*\bar{t}^*$

1. at 8 TeV (background) — CMS Collaboration arXiv:1311.5357

2. at 13 TeV (background) — CMS Collaboration arXiv:1711.10949

$t\bar{t}gg$ Final State

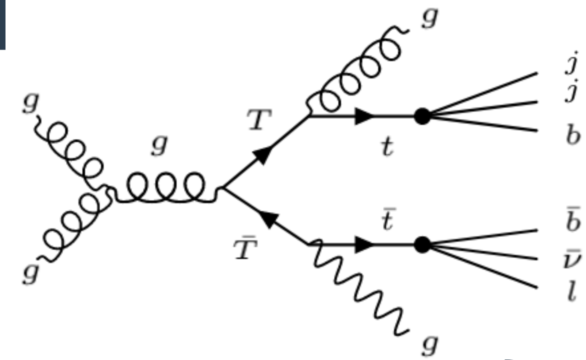
Abbreviations	Backgrounds	Matching	$\sigma \cdot \mathrm{BR} \cdot \varepsilon_{\mathrm{gen}}$
$t\bar{t}$	$t\bar{t}$ + jets	4-flavor	2.9×10^3 fb
Single t	tW + jets	5-flavor	4.1×10^3 fb
	t + jets	4-flavor	77 fb
W	W + jets	5-flavor	5.0×10^3 fb
VV	WW + jets	4-flavor	110 fb
	WZ + jets	4-flavor	44 fb

1. Basic Cuts: { $\not{E}_T > 50\,\mathrm{GeV}$, at least 1 slim jet, at least 1 fat jet and exactly 1 isolated lepton.}

2. Boosted top tagging: {select one fat jet with the best overlap score}

Analysis

1. Semileptonic $p\,p \rightarrow T\,\bar{T} \rightarrow t\,g\,\bar{t}\,g$



$t\bar{t}gg$ Final State

3. Slim jet flavors: {match slim jets to C and B hadrons}

4. Isolated slim jets: {at leas 3 jets are isolated from the fat jet}

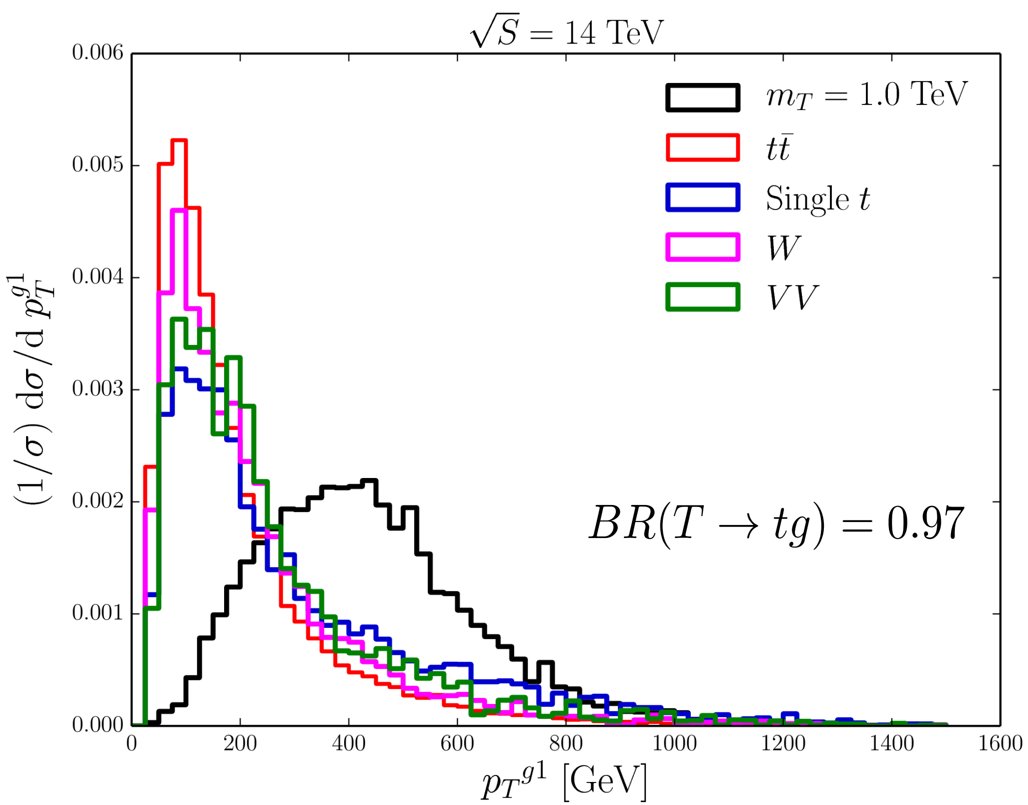
5. b-quark from t-leptonic: { $m_{lj} < m_{lb}^{\max}$ } → $\{\text{jet}\}^{\text{b}}$

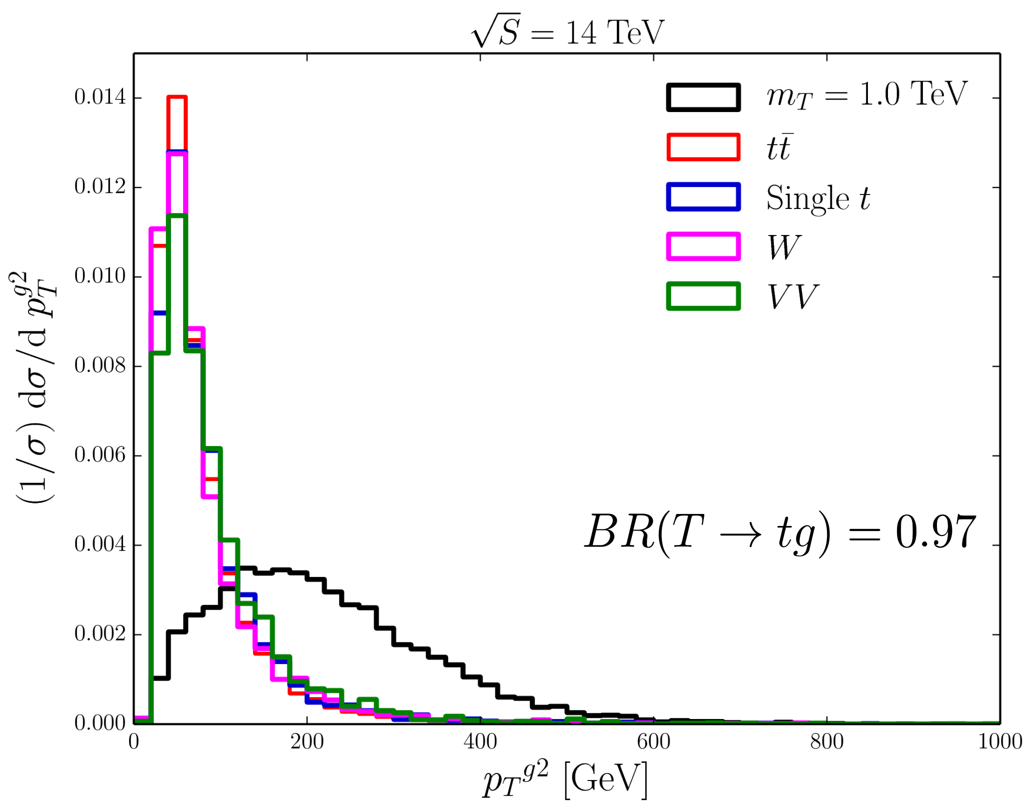
6. Boosted top tagging: { $\not{E}_T + l + \{\text{jet}\}^{\text{b}}$, find the combination with the best overlap results}

7. Realization of g jets: { two highest jets in p_T }

Analysis

1. Semileptonic $pp \to T\bar{T} \to t\,g\,\bar{t}\,g$





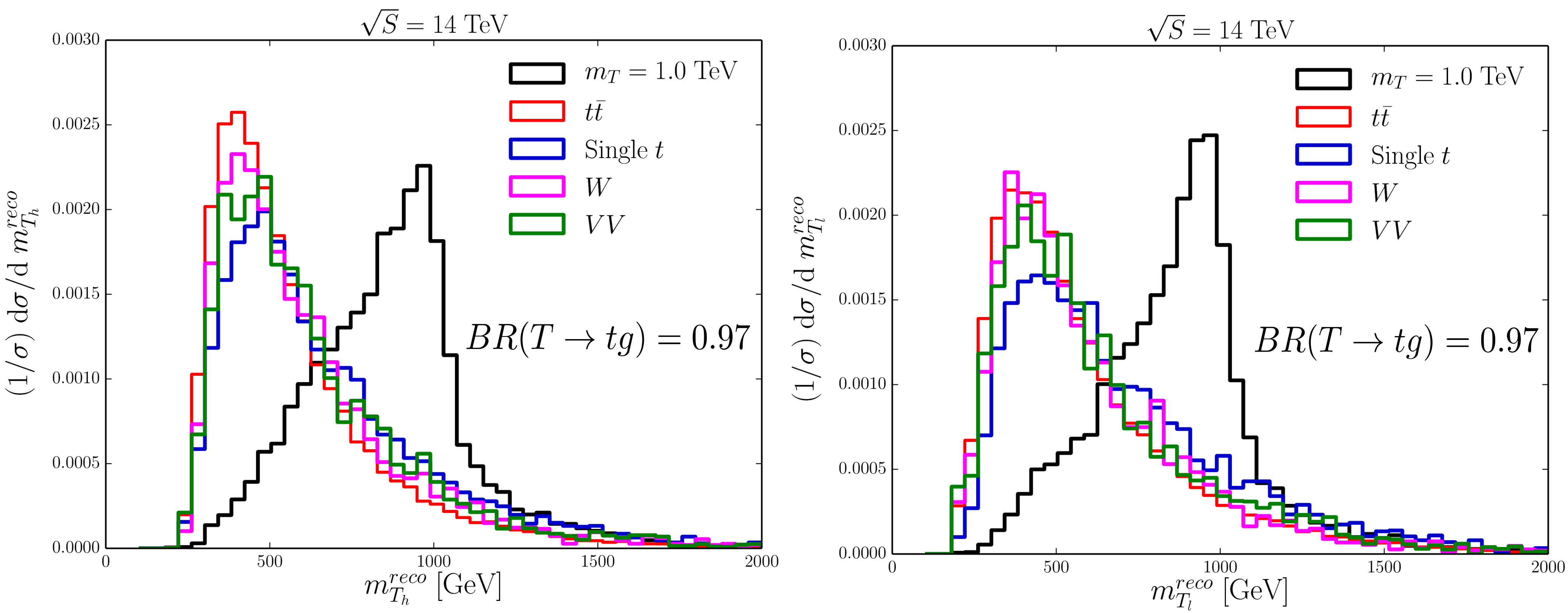
p_T^{g1} : The first hardest gluon jet.

p_T^{g2} : The second hardest gluon jet.

Analysis

1. Semileptonic $pp \to T\bar{T} \to t\,g\,\bar{t}\,g$

mass difference : Δm



$m_{T_h}^{reco}$ hadronic top partner. $m_{T_l}^{reco}$ leptonic top partner.

Analysis

1. Semileptonic $pp \to T\bar{T} \to t\,g\,\bar{t}\,g$

Cut-flow table of tgtg final state

Log likelihood ratio

$H_T^{reco} = p_T^{t_h} + p_T^{t_l} + p_T^{g1} + p_T^{g2}$

cross section in fb

	Signal	tt	t	W	VV	Significance	Exclusion
Basic Cuts	3.0	1100	2600	2100	68	2.14	2.14
t-tagging	0.59	142.8	63.19	32.19	1.83	2.12	2.12
$p_T^{\{g_1,g_2\}} > \{250, 150\}$ GeV	0.35	9.17	4.63	2.48	0.19	4.78	4.76
$H_T^{reco} > 1600$ GeV	0.29	4.86	3.42	1.58	0.12	5.05	5.03
$750 < M_T < 1100$ GeV	0.16	0.84	0.62	0.23	0.017	6.73	6.63
b-tag on t_{had}	0.10	0.51	0.29	5.6×10^{-3}	1.0×10^{-3}	5.90	5.78
b-tag on t_{lep}	0.10	0.49	0.21	0.016	1.7×10^{-4}	6.40	6.26
b-tag on t_{had} & t_{lep}	0.061	0.30	0.084	5.1×10^{-4}	1.0×10^{-5}	5.28	5.15

$BR(T \to tg) = 0.97$

$\text{Luminosity} = 3\ \text{ab}^{-1}$

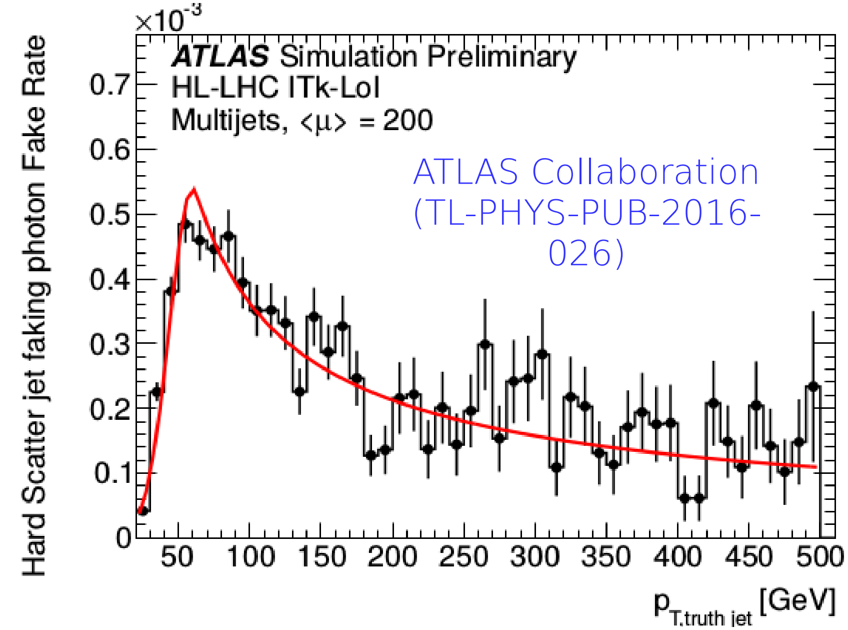
Analysis

2. Semileptonic $pp \to T\bar{T} \to t\,g\,\bar{t}\,\gamma$

Consider

$$m_T = 1\,\text{TeV} \Longrightarrow \sigma^{\text{sig}} \cdot \text{BR} \cdot \varepsilon_{\text{gen}} = 0.22\,\text{fb}$$

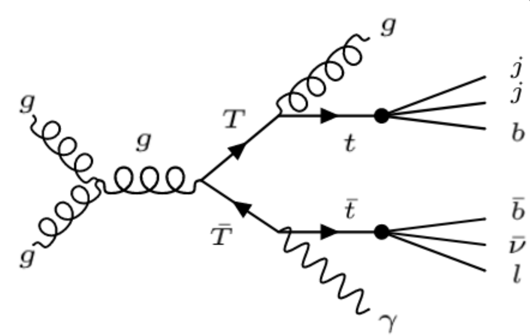
Abbreviations	Backgrounds	Matching	$\sigma \cdot \text{BR} \cdot \varepsilon_{\text{gen}}$
$t\bar{t}\gamma$	$t\bar{t}+\gamma+\text{jets}$	4-flavor	1.0 fb
$t\gamma$	$tW+\gamma+\text{jets}$	5-flavor	1.9 fb
	$t+\gamma+\text{jets}$	4-flavor	0.085 fb
$W\gamma$	$W+\gamma+\text{jets}$	5-flavor	5.4 fb
$VV\gamma$	$WW+\gamma+\text{jets}$	4-flavor	0.17 fb
	$WZ+\gamma+\text{jets}$	4-flavor	0.057 fb



ATLAS Collaboration (TL-PHYS-PUB-2016-026)

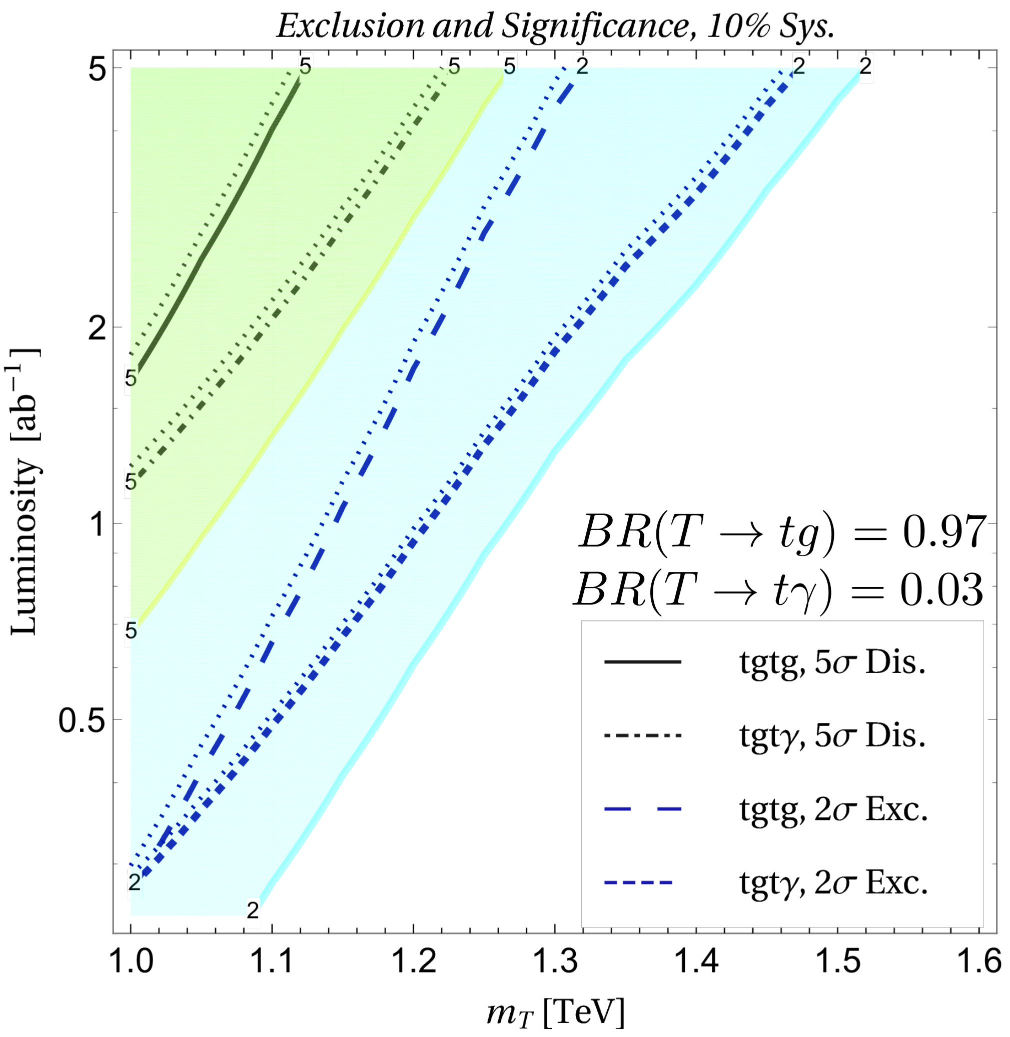
Photon Fake Rate

$$\epsilon_{j\to\gamma} = \begin{cases} 5.3\times 10^{-4}\exp\left(-6.5\left(\frac{p_{T,j}}{60.4\text{GeV}}-1\right)^2\right) & \text{for}\quad p_{T,j} < 65\,\text{GeV}, \\ 0.88\times 10^{-4}\left[\exp\left(-\frac{p_{T,j}}{943\text{GeV}}\right)+\frac{248\text{GeV}}{p_{T,j}}\right] & \text{otherwise,} \end{cases}$$

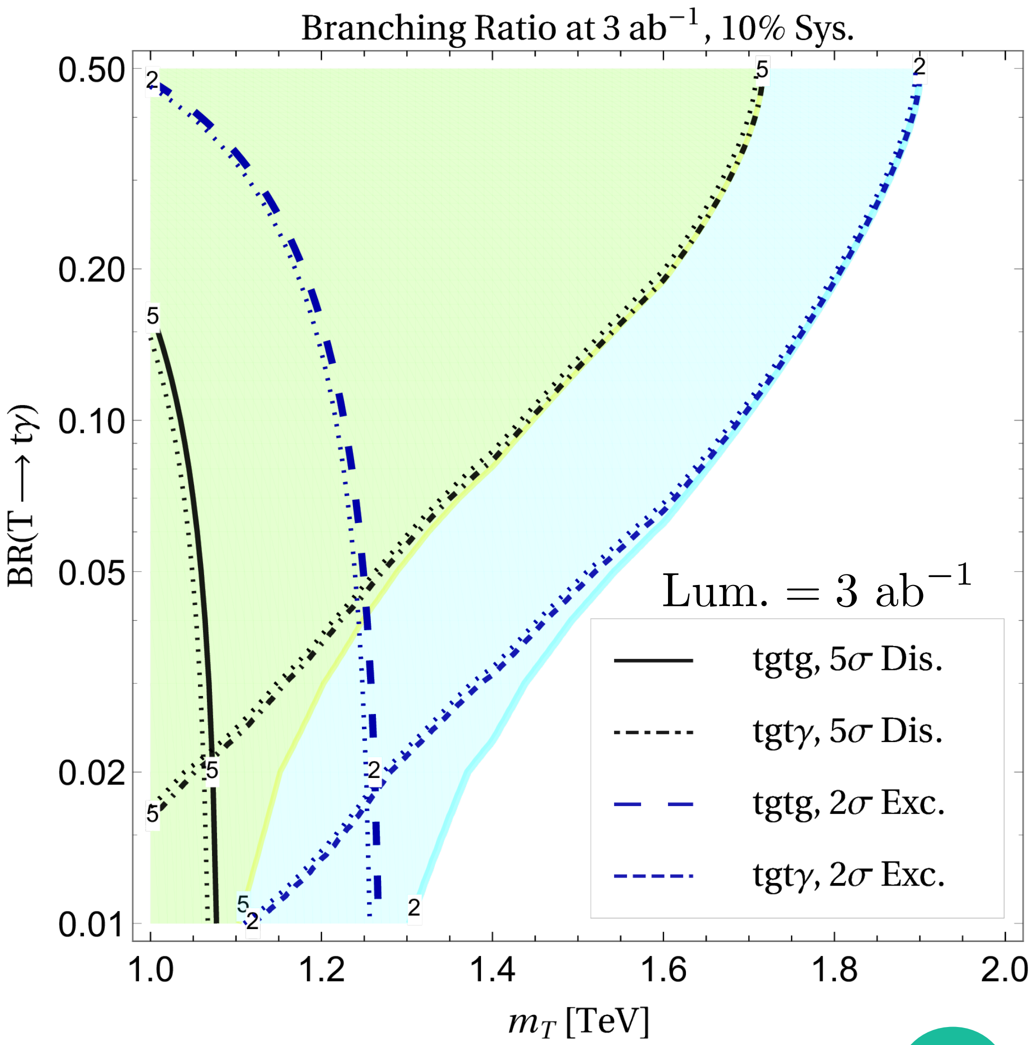


Goncalves, Han, Kling, Plehn, Takeuchi, (arXiv:1802.04319)

Results



Exclusion and Significance, 10% Sys.
Luminosity [ab^{-1}]
m_T [TeV]
$BR(T \to tg) = 0.97$
$BR(T \to t\gamma) = 0.03$
tgtg, 5σ Dis.
tgtγ, 5σ Dis.
tgtg, 2σ Exc.
tgtγ, 2σ Exc.



Branching Ratio at 3 ab^{-1}, 10% Sys.
BR(T ⟶ tγ)
m_T [TeV]
Lum. = 3 ab^{-1}
tgtg, 5σ Dis.
tgtγ, 5σ Dis.
tgtg, 2σ Exc.
tgtγ, 2σ Exc.

Conclusion

$$p\,p \rightarrow T\,\bar{T} \rightarrow t\,g\,\bar{t}\,g \quad \text{and} \quad p\,p \rightarrow T\,\bar{T} \rightarrow t\,g\,\bar{t}\,\gamma$$

- Radiative decay modes serve as a complementary search to the conventional decay modes.
- Radiative decay modes become extremely important when Exp limits are stronger on the conventional decay modes.
- Despite its small BR, photon final state provides better significance and allow exploration of larger part of the parameter space.
- Combining the two final states helps increase the sensitivity.

Questions

Thank You