

Search for $W' \rightarrow t\bar{b}$ with the ATLAS detector at
LHC

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Beyond the Standard Model

The Standard Model (SM)

successful 😊

- 12 fundamental fermions
- 3 fundamental interactions
- Higgs boson

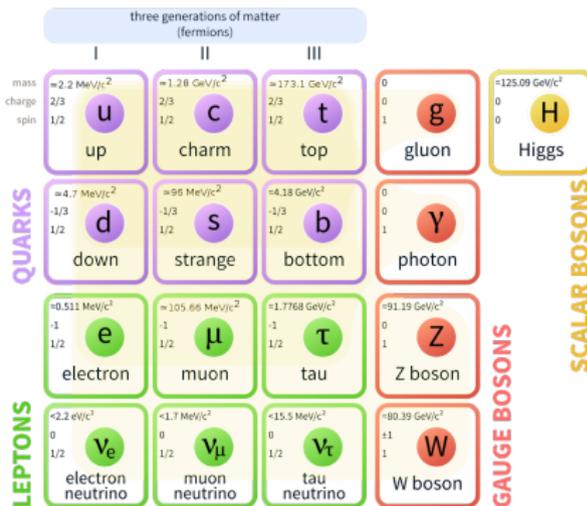
some limitations 😞

- Gravity
- Dark matter
- Neutrino masses
- Baryon asymmetry
- ...

Low energy approximation of a more fundamental theory?

Beyond the SM requires some new physics: *new particles?*
new interactions?

Standard Model of Elementary Particles



New heavy charged gauge bosons beyond the SM

Various *theories BSM* introduce extra vector-boson resonances, such as W'^{\pm}

- Universal extra-dimensions:
 - Kaluza-Klein excitations of the W boson
- Extended symmetries of the SM:
 - massive right-handed counterparts of the W boson
- ...

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$W' \rightarrow t\bar{b}$ search

- Explores models potentially inaccessible to $W' \rightarrow \ell\nu$
For instance: $W'_R \rightarrow \ell\nu_R$ **forbidden** if $\text{mass}(\nu_R) > \text{mass}(W'_R)$
- Expected to couple more strongly to 3rd generation of quarks (**t, b**)

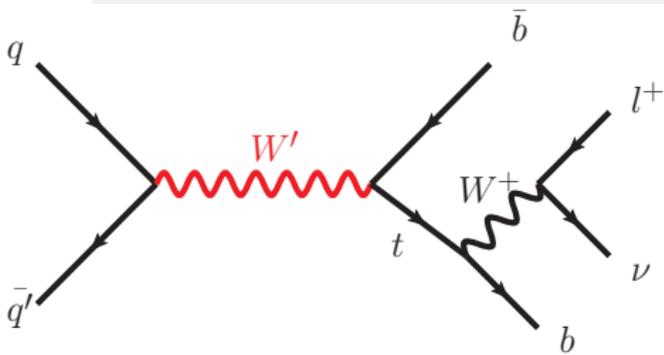
We search for $W'_R \rightarrow t\bar{b}$ in final states with lepton+jets

Status: $W'_R \rightarrow t\bar{b} \rightarrow \ell + \text{jets}$ search

Experiment	\sqrt{s}	Int. lumi.	95% CL Limit	Ref.
CDF D0	1.96 TeV	1.9 fb ⁻¹ 2.3 fb ⁻¹	800 GeV 885 GeV	Phys. Rev. Lett. 103, 041801 (2009) Phys. Lett. B 699, 145 (2011)
ATLAS CMS	7 TeV	1.04 fb ⁻¹ 5.0 fb ⁻¹	1.13 TeV 1.85 TeV	Phys. Rev. Lett. 109, 081801 (2012) Phys. Lett. B 718, 1229 (2013)
ATLAS CMS	8 TeV	20.3 fb ⁻¹ 19.7 fb ⁻¹	1.76 TeV 2.05 TeV	Eur. Phys. J. C 75 165 (2015) JHEP02 12 (2016)
ATLAS CMS	13 TeV	36.1 fb⁻¹ 35.9 fb ⁻¹	3.15 TeV 3.6 TeV	Phys. Lett. B 788 347 (2019) Phys. Lett. B 777 39–63 (2018)
ATLAS CMS	14 TeV	3000 fb⁻¹	4.9 TeV 4 TeV	ATL-PHYS-PUB-2018-044 CMS-PAS-FTR-16-005

Covered in this talk

Signature



- 1 isolated b-jet
- 1 lepton: electron or muon
- 1 Neutrino
- 1 b-jet from top decay

Dominant backgrounds : $t\bar{t}$, W +jets production

Subdominant backgrounds : single top (s-, t-channel, Wt), Z +jets, diboson, multijet production

$W' \rightarrow t\bar{b} \rightarrow \ell\nu b\bar{b}$ search @ LHC with ATLAS detector

2015+2016 data ($\sqrt{s} = 13$ TeV, 36.1 fb^{-1})

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Event selection

- trigger based on single lepton
- exactly one charged lepton:
 - e^\pm or μ^\pm with $p_T > 25$ GeV
 - both e and μ isolated
- $E_T^{\text{miss}} > 30$ GeV
 - $p_T(\nu)$ assumed to be E_T^{miss}
- Two to four anti- k_t jets ($R=0.4$) with $p_T > 25$ GeV

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Top and W' reconstruction

$p_z(\nu)$ calculated from E_T^{miss} and
 W -boson mass constraint

- ▷ Find **jet** that gives
 $\text{mass}(\ell\nu\text{jet})$ closest to
 $\text{mass}(\text{top})$, $\text{jet} \mapsto \text{b}_2$
- ▷ Assign highest p_T remaining
jet to W' decay, $\text{jet} \mapsto \text{b}_1$
- ▷ $W' \leftrightarrow (\text{top}, \text{b}_1)$

discriminating variable: $m(\text{tb})$

Signal and validation regions

- To reduce background tighter selections are applied

$$p_T(\ell) > 50 \text{ GeV}, p_T(b_1) > 200 \text{ GeV}, p_T(\text{top}) > 200 \text{ GeV}$$
$$E_T^{\text{miss}}(e \text{ channel}) > 80 \text{ GeV}, m_T^W + E_T^{\text{miss}} > 100 \text{ GeV}$$

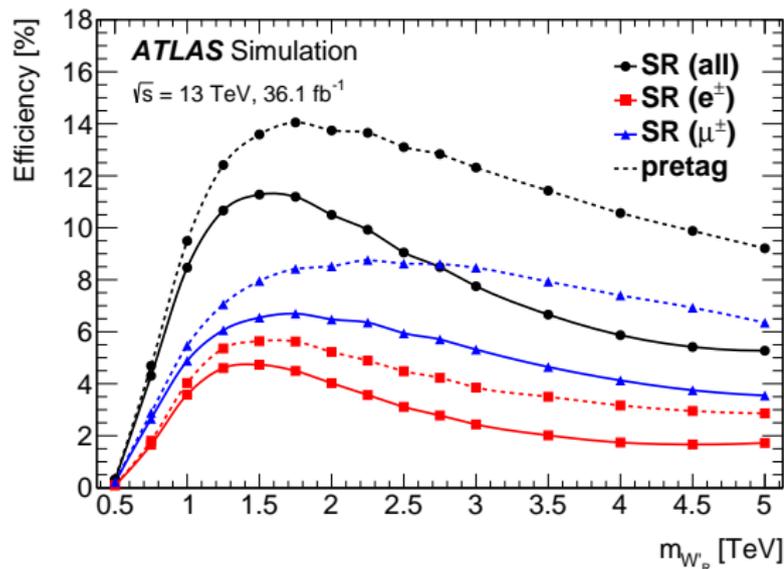
- 8 signal regions (SR) are used for the fits: 2 channels, e and μ
- 3 validation regions (VR) to check background modelling

SR	VR _{W+jets}	VR _{t\bar{t}}	VR _{HF}
2 or 3 jets 1 or 2 b-tag $\Delta R(\ell, b_2) < 1.0$ $m_{tb} > 500 \text{ GeV}$	2 or 3 jets ≥ 0 b-tag (pretag)	4 jets 1 or 2 b-tag	2 or 3 jets 1 b-tag $\Delta R(\ell, b_2) > 2.0$ $\Delta R(b_1, b_2) > 1.5$

$$m_T^W = \sqrt{2p_T^\ell p_T^\nu [1 - \cos \Delta\phi(p_T^\ell, p_T^\nu)]}$$

Signal selection efficiency

$$\text{Efficiency} = \frac{\text{Nb. of } W' \rightarrow t\bar{b} \rightarrow l\nu b\bar{b} \text{ simulated events} \mid \text{SR}}{\text{Nb. of } W' \rightarrow t\bar{b} \rightarrow l\nu b\bar{b} \text{ simulated events} \mid \text{All}}$$



High mass regime
→

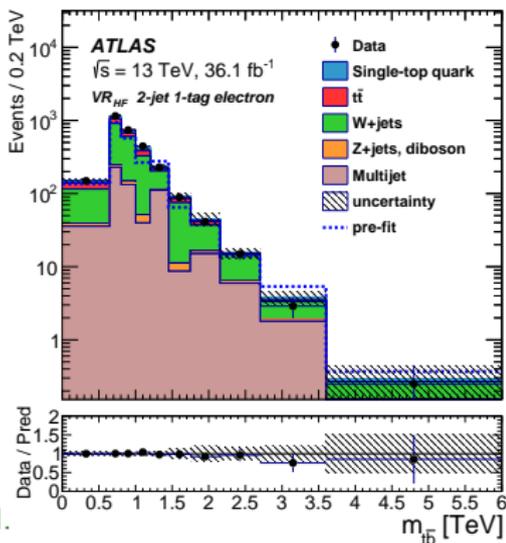
- low stats
- high p_T b -tagging
- electrons close to jets

$W' \rightarrow t\bar{b} \rightarrow l\nu b\bar{b}$ samples simulated using Madgraph5+Pythia8

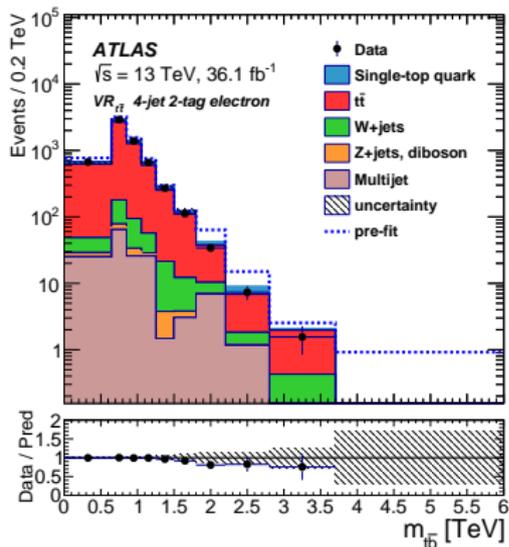
Background estimation

MC simulation	:	single top & $t\bar{t}$ (Powheg+Pythia) W+jets & Z+jets (Sherpa) dibosons (Powheg+Pythia)
Data-driven approach	:	multijets (matrix method)

VR(HF): 2-jet 1-tag e^\pm



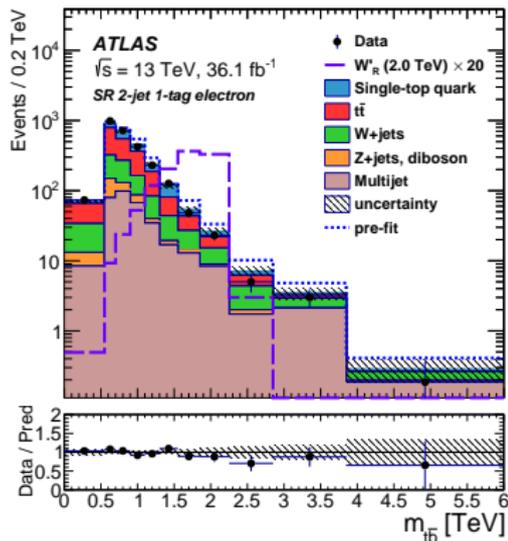
VR($t\bar{t}$): 4-jet 2-tag e^\pm



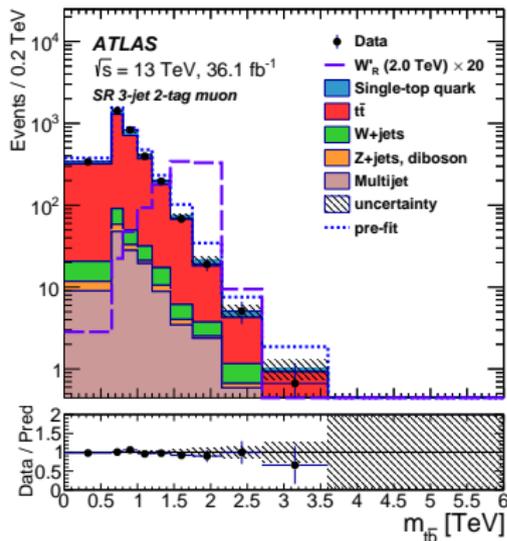
- Simultaneous fit of the $t\bar{b}$ invariant mass distribution in the **8 SRs**
- Normalisation of $t\bar{t}$ and W +jets backgrounds are free parameters: found to be 0.98 ± 0.04 and 0.78 ± 0.19 respectively
- Main systematic uncertainties:
 - b-tagging efficiency
 - jet energy scale
 - $t\bar{t}$ background modelling (MC generator choice)

Reconstructed invariant mass after the fit

SR: 2-jet 1-tag e^\pm



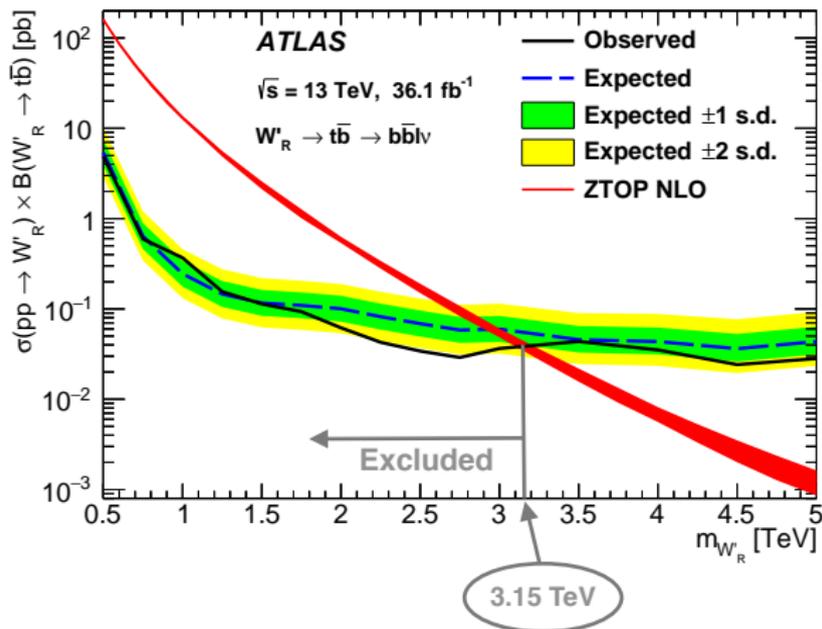
SR: 3-jet 2-tag μ^\pm



Data agree with the SM expectation

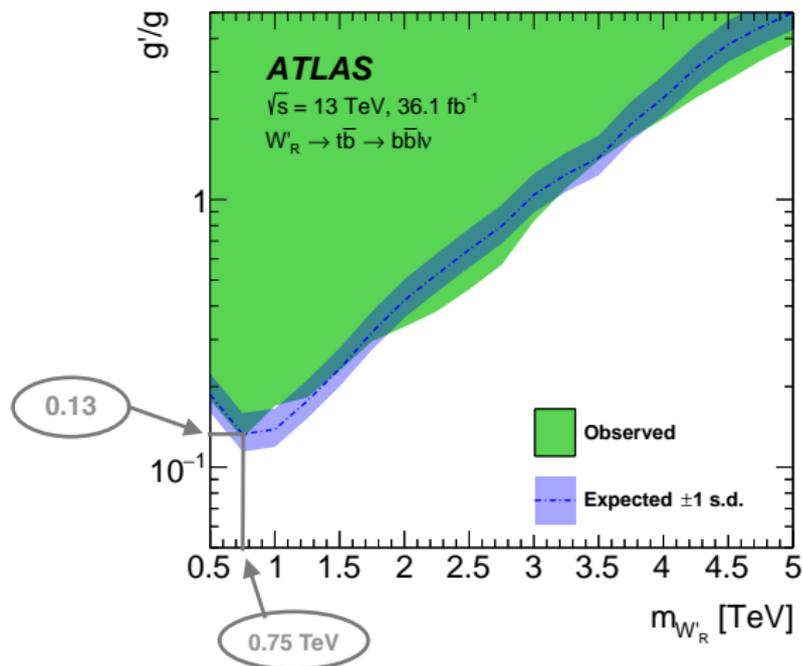
Exclusion limits

Limits at 95% CL on cross-section times branching ratio to $t\bar{b}$ assuming $g'/g = 1$



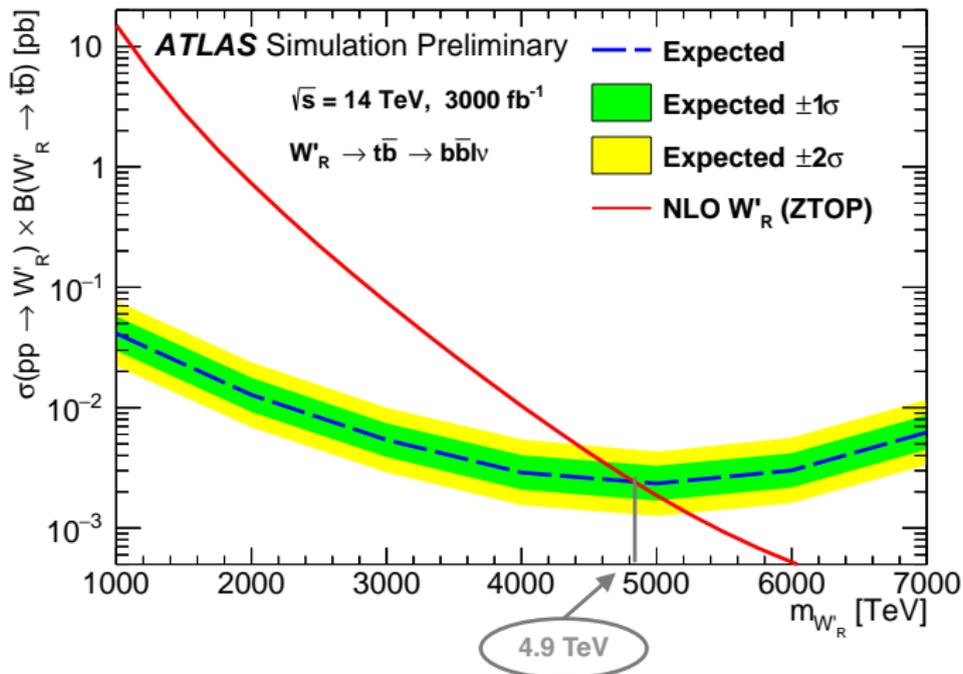
g' : coupling of W' to fermions, g : SM $SU(2)_L$ coupling

Limits on g'/g



W' width dependency on the coupling value for $g'/g > 1$ is taken into account.

Prospects at HL LHC: MC based studies



Background: $t\bar{t}$, W +jets, single top, Z +jets, diboson

Large syst. uncertainties: b -tagging efficiency, $t\bar{t}$ modelling

Conclusions

- Search for $pp \rightarrow W'_R \rightarrow t\bar{b}$ ($\sqrt{s} = 13$ TeV, 36.1 fb^{-1}) [1]
- No significant excess of data events above SM prediction
- Masses below 3.15 TeV are excluded
- Lowest observed limit on g'/g , obtained for a W'_R mass of 0.75 TeV, is 0.13.
- Prospects at HL LHC ($\sqrt{s} = 14$ TeV, 3000 fb^{-1}) [2]
- In case of no discovery, W' masses can be excluded up to 4.9 TeV

[1] [Phys. Lett. B 788 \(2019\) 347](#)

[2] [ATL-PHYS-PUB-2018-044](#)

Backup

Effective model describing the **couplings of the W' boson to fermions**, from D. Duffy and Z. Sullivan [arXiv:1208.4858](#)

$$\mathcal{L} = \frac{V'_{ij}}{2\sqrt{2}} g \bar{f}_i \gamma_\mu [g'_R(1 + \gamma^5) + g'_L(1 - \gamma^5)] W'^\mu f_j + h.c.$$

Parameters

- V'_{ij} : CKM(δ_{ij}) matrix for quarks(leptons)
- $g'_R(g'_L)$: coupling to left-(right-) handed fermions
- g : $SU(2)_L$ coupling

If $g'_L \neq 0$, one must take into account interference with the SM W boson