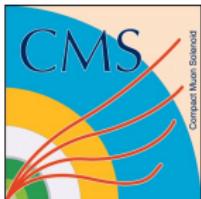


Searches for $t\bar{b}$ resonances at the LHC

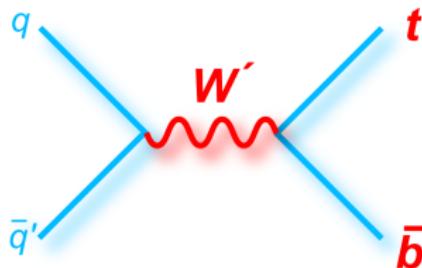
Timothée Theveneaux-Pelzer

Tuesday, April 8th 2014



Motivations

- Massive spin-1 charged bosons - W' - appears in many BSM theories
 - extra-dims : KK excitations of the W
 - technicolor : EWSB without scalars but new bosons
 - L-R symmetry : right-handed counter-part of the W
 - little-Higgs : cancels m_H divergence, several new particles including a W'
- Interesting $t\bar{b}$ decay mode
 - new physics expected to appear in top physics
 - in some BSM theories : stronger coupling to 3rd generation
 - access to models with leptophobic W' - e.g. right-handed ones
 - $t\bar{b}$ final state can be fully reconstructed
 - less hadronic background than $W' \rightarrow jj$



Available results for $W' \rightarrow t\bar{b}$ searches

Experiment	\sqrt{s} [TeV]	$\int \mathcal{L} dt$ [fb^{-1}]	Typical 95% CL limit	Reference
CDF		1.9	820 GeV	Phys. Rev. Lett. 103, 041801 (2009)
D0	1.96	0.9	760 GeV	Phys. Rev. Lett. 100, 211803 (2008)
D0		2.3	880 GeV	Phys. Lett. B 699, 145 (2011)
CMS		5.0	1.8 TeV	Phys. Lett. B 718, 1229 (2013)
ATLAS	7	1.04	1.1 TeV	Phys. Rev. Lett. 109, 081801 (2012)
CMS		19.6	2 TeV	CMS-PAS-B2G-12-010
CMS		19.5	2 TeV	arXiv :1402.2176 [hep-ex]
ATLAS	8	14.3	1.8 TeV	ATLAS-CONF-2013-050
ATLAS		20.3	-	in prep.

⇒ French contributions @LHC : LPC-Clermont leads the 8 TeV ATLAS analyses
G. Gilles (thesis, 2015), J. Donini, T. Theveneaux-Pelzer, H. Liao

W' Effective model

- Generic W' model from Z. Sullivan, used by all experiments

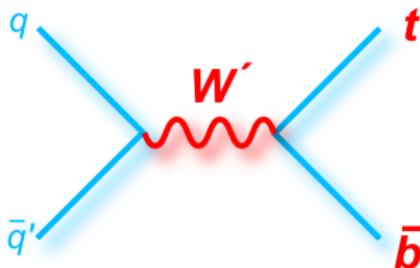
Phys. Rev. D 86, 075018 (2012)

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

- Parameters :

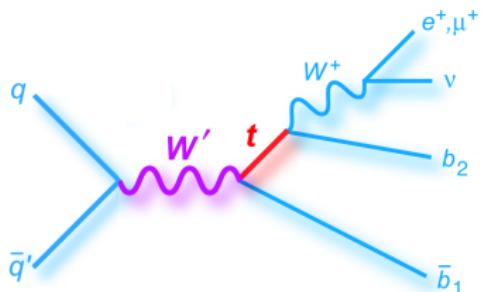
V'_{ij} : CKM (δ_{ij}) matrix for quarks (leptons)
 $g'_L(g'_R)$: coupling to left-(right-) handed fermions

- In this effective model : $m_{W'}$ is independent of g'
- g' can be very different from the SM g
→ model renormalisable up to $g'/g = 5$



Event selection and W' reconstruction

- Using semi-leptonic decays of the top quark
→ final state : 2 bottom quarks, 1 lepton, 1 ν
- $p_T(\nu)$ calculated by fixing $m(W)$
→ reconstruction of W' candidates



ATLAS selection :

- 1 e or μ , $p_T > 30$ GeV, $|\eta| < 2.5$
- 2 or 3 jets, $p_T > 25$ GeV, $|\eta| < 2.5$
- 2 b -tagged jets
- $E_T^{\text{miss}} > 35$ GeV,
 $E_T^{\text{miss}} + m_T(W) > 60$ GeV
- $m(t\bar{b}) > 270$ GeV

CMS selection :

- 1 $e(\mu)$, $p_T > 50$ GeV, $|\eta| < 2.5(2.1)$
- at least 2 jets, $p_T > 30$ GeV, $|\eta| < 2.4$,
 $p_T(j_1) > 120$ GeV, $p_T(j_2) > 40$ GeV
- j_1 or/and j_2 b -tagged
- $E_T^{\text{miss}} > 20$ GeV
- $p_T(t) > 85$ GeV, $p_T(j_1 j_2) > 140$ GeV,
 $130 \text{ GeV} < m(b/\nu) < 210$ GeV

Signal modelling

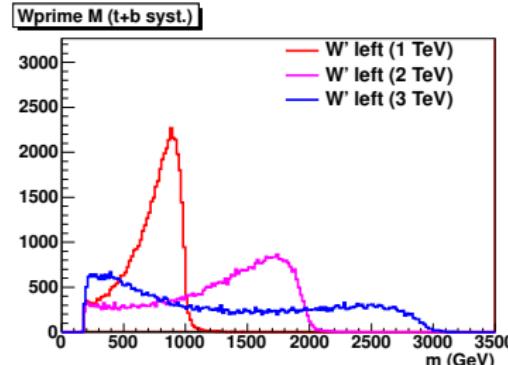
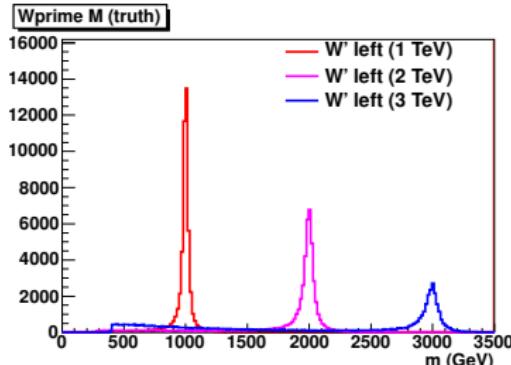
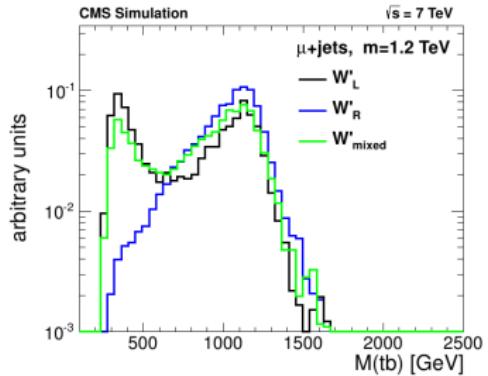
- 3 cases :

$$W'_L : g'_L = 1, g'_R = 0$$

$$W'_R : g'_L = 0, g'_R = 1$$

$$W'_{\text{mixed}} : g'_L = 1, g'_R = 1 \text{ (CMS)}$$

- s-channel SM single-top interference (CMS)
- Effect of FSR and PDF luminosity on $M(t+b)$
- MADGRAPH5 (ATLAS), SINGLETOP (CMS)



Signal cross-sections

- $W'_R \rightarrow l^+ \nu$ allowed only if $m(\nu_R) < m(W'_R)$
 - ATLAS : $m(\nu_R) > m(W'_R)$, hence different BR for L and R
 - CMS : testing $m(\nu_R) > m(W'_R)$ or $m(\nu_R) \ll m(W'_R)$ by changing the BR
- Signal generated with LO generators, applying NLO/LO K-factors
- ATLAS σ .BR values
 - LO from MADGRAPH
 - NLO from Z. Sullivan (following [Phys. Rev. D 86, 075018 \(2012\)](#))

$m(W')$ [GeV]	W'_L			W'_R		
	σ (LO) [pb]	σ (NLO) [pb]	K-factor	σ (LO) [pb]	σ (NLO) [pb]	K-factor
500	17.6	22.6	1.29	12.9	16.9	1.31
1000	1.11	1.36	1.23	0.83	1.03	1.24
1500	0.14	0.17	1.19	0.11	0.13	1.20
2000	0.024	0.028	1.15	0.019	0.022	1.17
2500	0.047	0.053	1.14	0.0038	0.0043	1.16
3000	0.0011	0.0013	1.19	0.00093	0.0011	1.21

- CMS has similar values
 - LO from SINGLETOP
 - K-factor of 1.2

Background modelling

- Dominant backgrounds : $t\bar{t}$, $W+\text{jets}$
- Most background processes estimated with MC
 - normalised to theoretical cross-sections, K-factors
 - data-driven normalisation for $W+\text{jets}$
- QCD/multijets :
 - ATLAS : jet-lepton model normalised on Data (or matrix-method)
 - CMS : neglected (7 TeV analysis : MC template fitted on Data)

Background source	ATLAS	CMS
$t\bar{t}$	Powheg	Madgraph5
Single-top	Powheg (AcerMC)	Powheg
$W+\text{jets}$	Alpgen	Madgraph5
$Z+\text{jets}$	Alpgen	Madgraph5
di-bosons	Herwig	Pythia6

Signal and background separation



- Can be improved with MVA

- event kinematics, angular correlations, top reconstruction
- each experiment tested both approaches

- ATLAS :

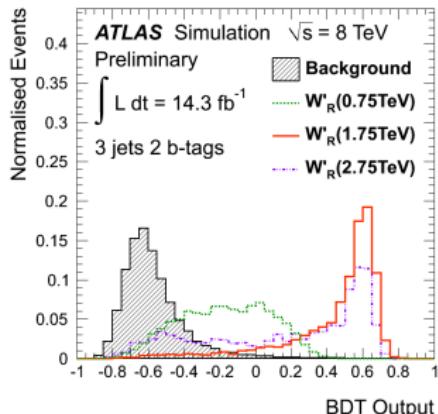
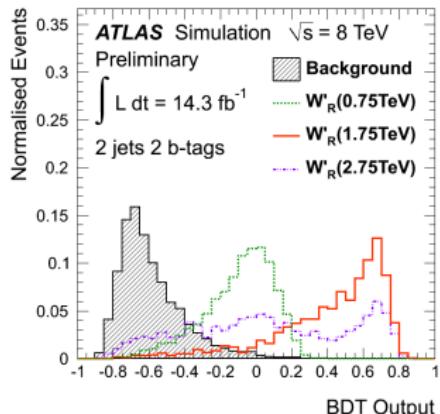
7 TeV : $m(tb)$ only

8 TeV : BDT only (12 variables)

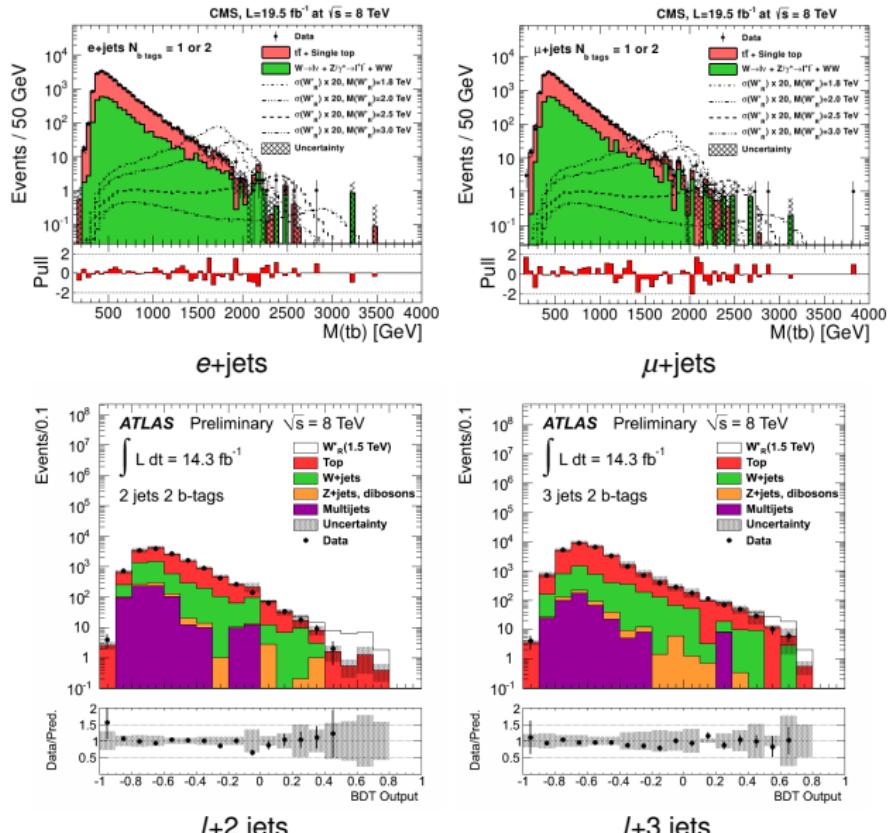
- CMS :

7 TeV : $m(tb)$ or BDT (39 variables)

8 TeV : $m(tb)$ only



No excess seen on data

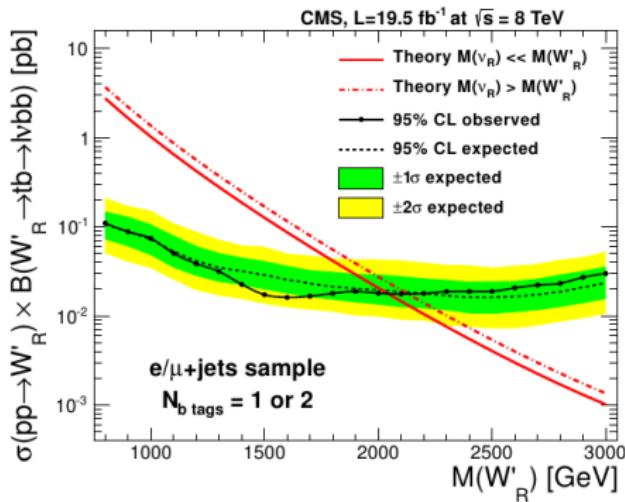


Setting limits on $W' \rightarrow t\bar{b}$ production

- Setting 95% CL limits on production cross-section vs. W' mass
- ATLAS : CLs method (frequentist) - MCLimit package
 - $LLR = -2\ln \frac{\mathcal{L}(\text{data}|H_1)}{\mathcal{L}(\text{data}|H_0)}$
 - \mathcal{L} : product of Poisson distributions in each BDT bin and each channel
 - Gaussian PDFs for systematics
 - no profiling
 - fit of $t\bar{t}$ normalisation
- CMS : bayesian approach - Theta package
- Main systematics : $t\bar{t}$ normalisation (theory), W +jets (data-driven), JES, b -tag

CMS cross-section exclusion

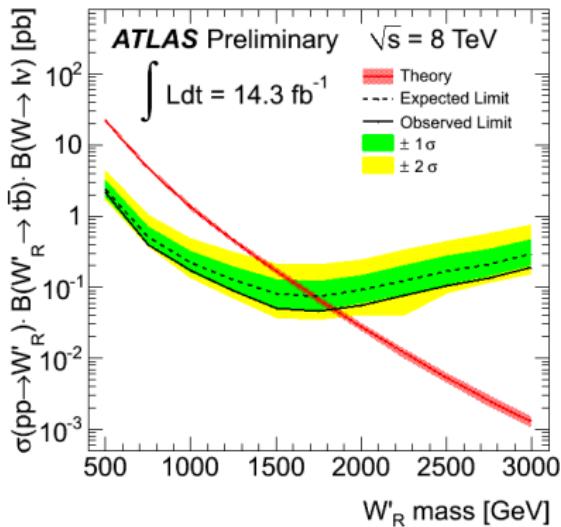
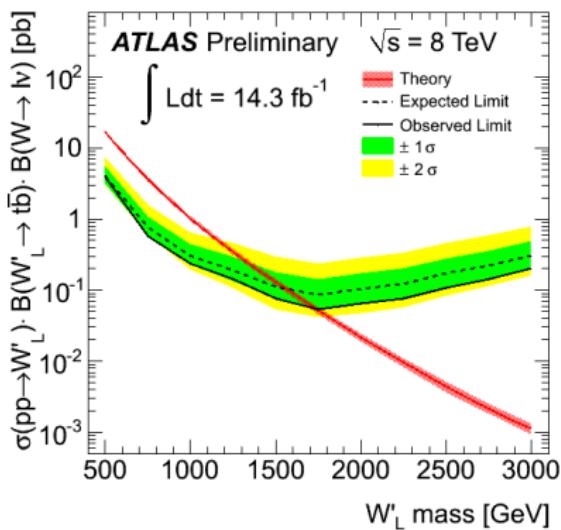
- Obs. (exp.) limits :
 - W'_L w/ interference : 1.84(1.84) TeV
 - W'_R w/ $\ell\nu$ decay : 2.05(2.02) TeV (same as W'_L w/o interference)
 - W'_R w/o $\ell\nu$ decay : 2.13(2.12) TeV



ATLAS cross-section exclusion

- Obs. (exp.) limits :

- W'_L w/o interference : 1.74(1.56) TeV
- W'_R w/o ν decay : 1.84(1.72) TeV

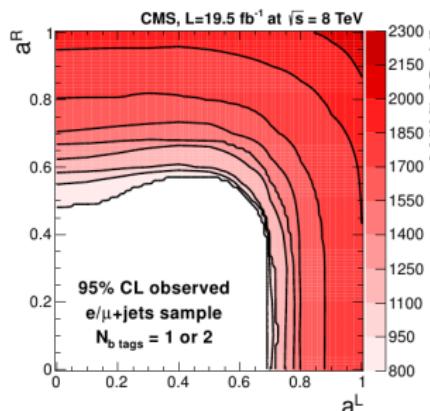


Limit on effective couplings (CMS)

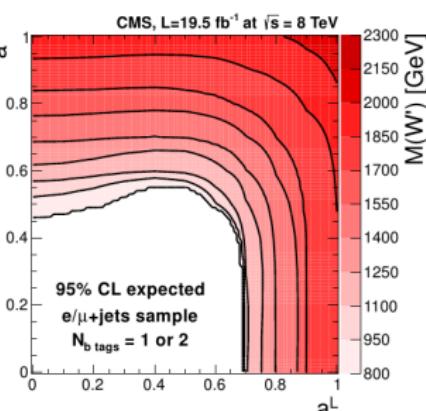
- CMS analyses :
 - L and R mixing
 - interferences with s-channel SM production
- Limit on effective coupling extracted from :

$$\sigma = \sigma_{SM} + a_L^2(\sigma_L - \sigma_R - \sigma_{SM}) + (a_L^4 + a_R^4)\sigma_R + (a_L^2 a_R^2)(\sigma_{LR} - \sigma_L - \sigma_R)$$

$$\rightarrow a_{L,R} = g'_{L,R}/g$$



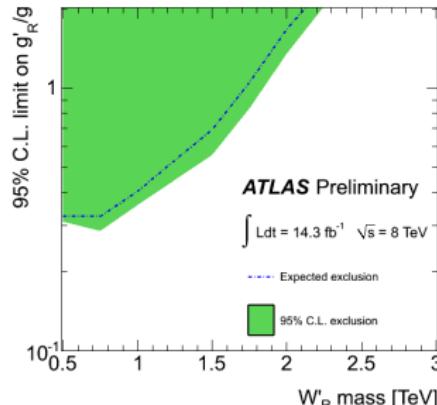
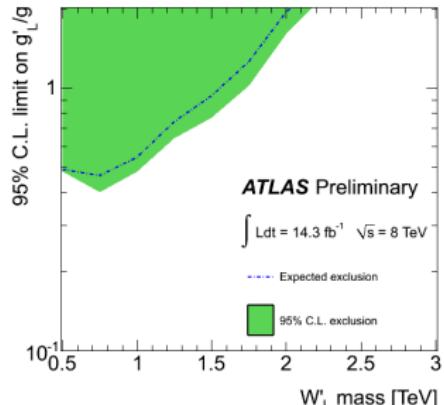
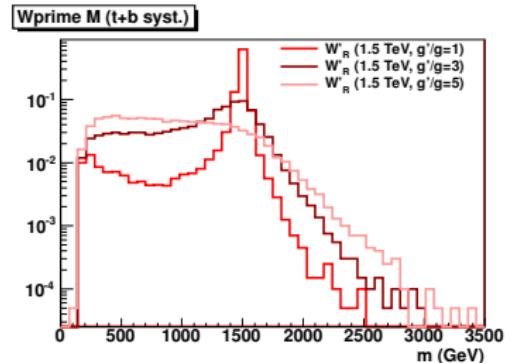
observed



expected

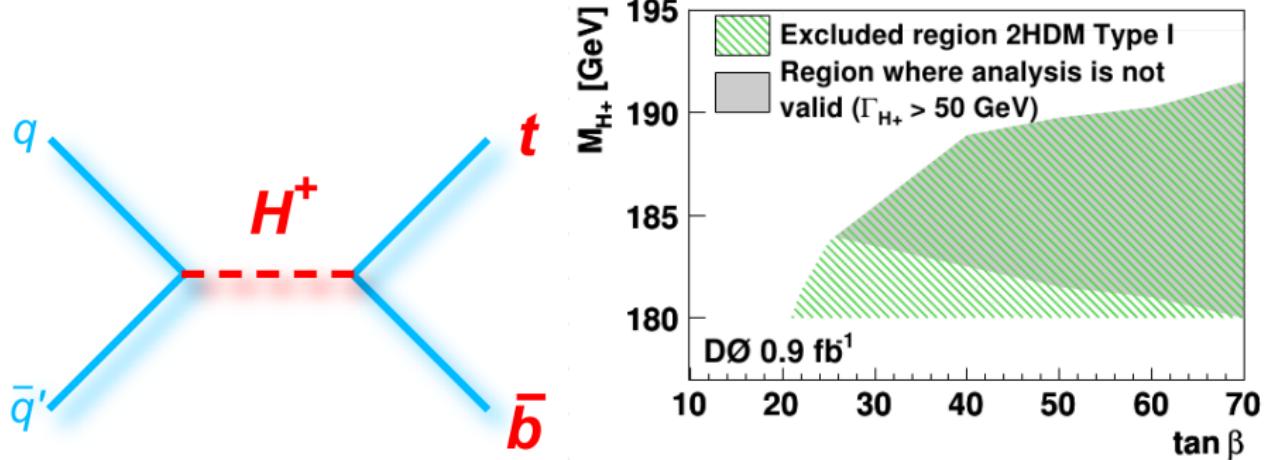
Limit on effective couplings (ATLAS)

- ATLAS analyses :
 - no L and R mixing
 - no interferences with s-channel SM production
 - but probing higher couplings
- $\sigma \propto g'^2$, but :
 - NWA no longer valid for large g'
 - $\Gamma(W')$ as large as detector resolution
 - extrapolation possible up to $g'/g = 2$, otherwise dedicated samples are needed



Other $t\bar{b}$ resonance : H^+

- Spin-0 charged boson
 - appears in 2HDM models, SUSY
- $H^+ \rightarrow t\bar{b}$ allowed if $m(H^+) > m(t) + m(b)$
 - not the best channel to look for it!
- No LHC result yet, but one D0 paper (0.9 fb^{-1}) [Phys. Rev. Lett. 102, 191802 \(2009\)](#)
- Widths effects also to be taken into account



Conclusions

- $W' \rightarrow t\bar{b}$ probe many BSM theories
 - only access to leptophobic W' models
- LHC results excludes W' up to ~ 2 TeV
 - CMS : full 2012 dataset
 - ATLAS : 14.3 fb^{-1} , paper coming with full dataset
- Interpretation in term of couplings depends on the model hypothesis
 - L/R mixing
 - interference with SM s-channel single-top
 - higher couplings than in the SM
- Up to now : only semi-leptonic channel
 - fully-hadronic channel with boosted topology gives access to higher masses
- Other interest : searches for spin-0 $t\bar{b}$ resonance, i.e. H^+