



The Special One

The top quark is a special player in the SM
 - the heaviest elementary particle
 - coupling with Higgs (y_t) of order 1
 - the only quark not forming bound states.
 Could it be a special player for 'exotic' new physics as well?

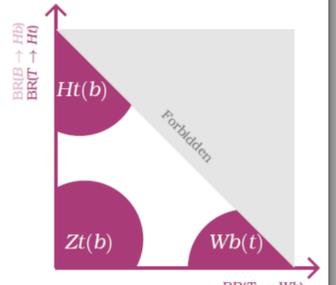
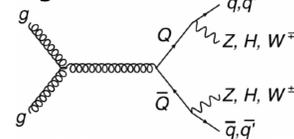
Vector-like Quarks (VLQ)

Vector-like quarks (VLQ) are spin-1/2 but transform as triplets (V coupling instead of V-A).

- Simplest coloured fermions still allowed by experimental data, which exclude 'simple' 4th generation quarks.
- Predicted to appear at the TeV scale by many classes of models (naturalness, partial compositeness...).
- Due to large y_t , sizable mixing with 3rd generation \Rightarrow a way to decay to SM particles:

$$T(+2/3) \leftrightarrow t \rightarrow Wb, Ht, Zt$$

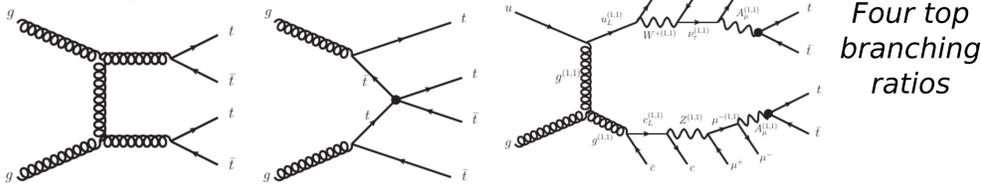
$$B(-1/3) \leftrightarrow b \rightarrow Wt, Hb, Zb$$



Limits on VLQ production placed on 'VLQ triangle(s)'

Four top production

$t\bar{t}\bar{t}$ production in SM is small (~ 9 fb at 13 TeV).
 Production enhanced in BSM scenarios: via effective contact interactions, pair production of resonances decaying to $t\bar{t}$...



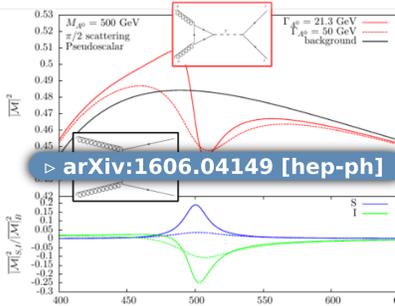
Four top branching ratios

tt resonances and 2HDM

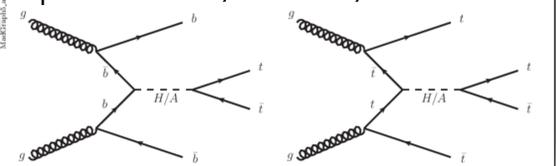
Current experimental constraints in view of Two-Higgs Doublet Models favour heavy neutral Higgs (H or A) $\rightarrow t\bar{t}$: in the 'alignment limit'

H/A couplings with W, Z vanish and high $\tan\beta$ values excluded by $H/A \rightarrow \tau\tau$ searches \Rightarrow for $m_{H/A} > 350$ GeV, $H/A \rightarrow t\bar{t}$ is dominant.

	Type I	Type II
$Y^{H/A}(u)[y_u]$	$1/\tan\beta$	$1/\tan\beta$
$Y^{H/A}(d, \ell)[y_{d, \ell}]$	$1/\tan\beta$	$\tan\beta$



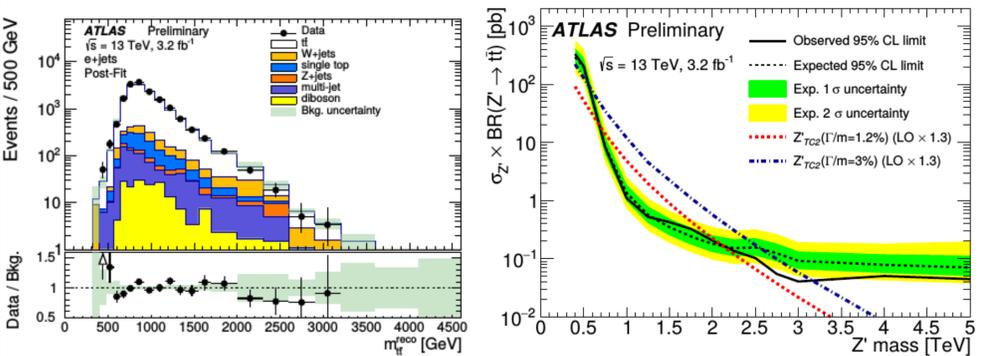
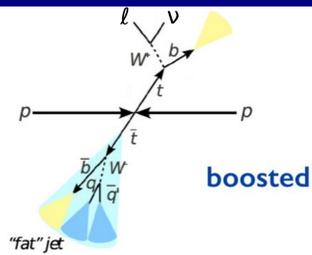
Interference effects $H/A \rightarrow t\bar{t}$ and SM $t\bar{t}$ cause $m_{t\bar{t}}$ peak reduction & distortion \Rightarrow motivation to look at associated production $t\bar{t}H/A$ or $b\bar{b}H/A$:



Search for tt resonances

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Analysis based on $m_{t\bar{t}}$ peak search looking for Z' -like $t\bar{t}$ resonance signals (no interference term).
 ℓ +jets 'boosted' final states selected and final state reconstructed as with top-tagged large-R jet plus leptonic top decay.



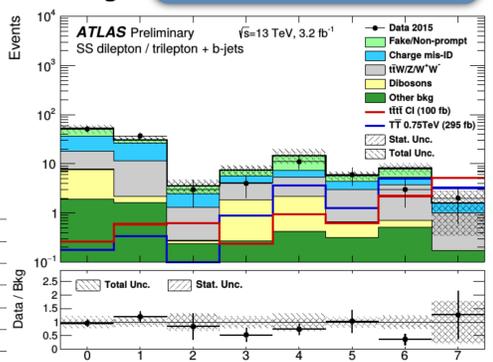
Search for SS-leptons+b-jets

Analysis selecting events with 2 same-sign leptons (e or μ) plus b -jets, to be sensitive to various BSM signals:

- same-sign tops
- VLQ pair production (T and B)
- $t\bar{t}\bar{t}$ events

$$e^+e^+ + e^+\mu^+ + \mu^+\mu^+ + eee + ee\mu + \mu\mu\mu, N_{jets} \geq 2$$

$400 < H_T < 700$ GeV	$N_b = 1$	$E_T^{miss} > 40$ GeV	SR0
	$N_b = 2$		SR1
	$N_b \geq 3$		SR2
$H_T \geq 700$ GeV	$N_b = 1$	$40 < E_T^{miss} < 100$ GeV	SR3
	$N_b = 2$	$E_T^{miss} \geq 100$ GeV	SR4
	$N_b \geq 3$	$E_T^{miss} \geq 100$ GeV	SR6
		$E_T^{miss} > 40$ GeV	SR7

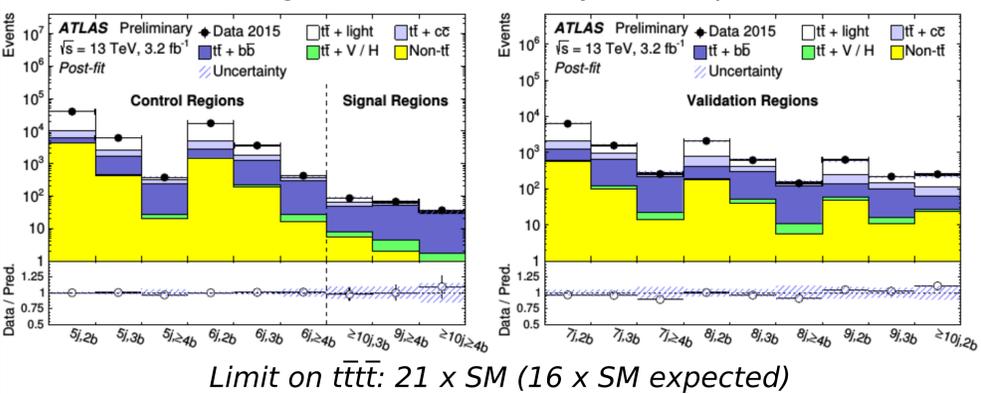


Run I excess not confirmed

Search for 4 tops in l+jets

Analysis targeting $t\bar{t}\bar{t}$ final states in resolved ℓ +jets channel: $1 e/\mu + \geq 10 j, \geq 4 b$.

Large $t\bar{t}+b\bar{b}$ +jets background: hard to model with current theory / MC predictions \Rightarrow simultaneous profile likelihood fit in signal and control regions, use of validation regions to check validity of extrapolation.

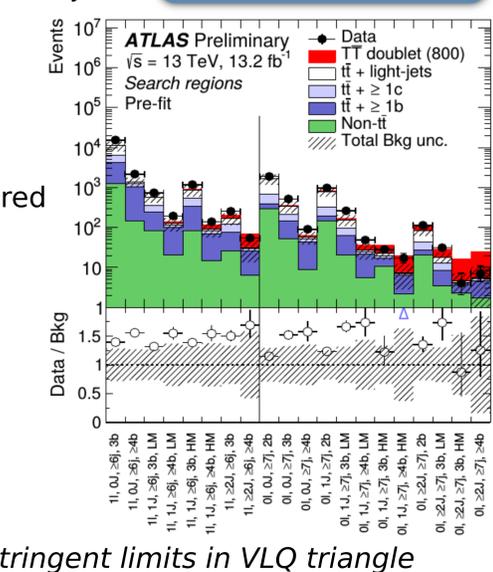
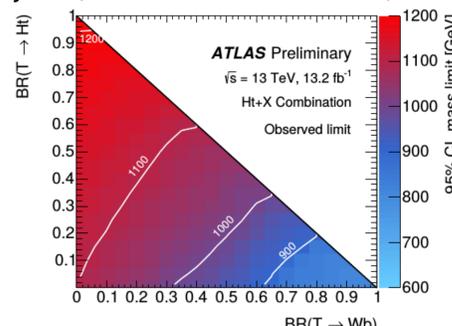


Limit on $t\bar{t}\bar{t}$: $21 \times SM$ ($16 \times SM$ expected)

Search for New Phenomena in tt+bb

Targeting different signals in $0-1\ell+(b)jets$:

VLQ (TT with $T \rightarrow H(bb)t, T \rightarrow Z(\nu\nu)t \dots$), $t\bar{t}\bar{t}$, 2HDM: $t\bar{t}H/A(t\bar{t}), b\bar{b}H/A(t\bar{t}), b\bar{b}H^+(t\bar{b})$.
 Similar analysis strategy as resolved ℓ +jets 4 top search, but selecting high-mass reclustered jets (from boosted t and H).



Stringent limits in VLQ triangle