Search for anomalous production of events with same-sign dileptons and b jets in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector

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Motivation

Production of events with two leptons of the same electric charge has a **very low production cross-section** in the Standard Model

$\Rightarrow$ **Potentially large contributions from new theories!**

We study four types of signals that lead to similar final states:

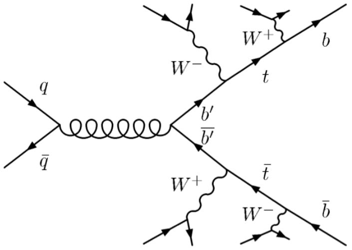
1. Fourth-generation chiral bottom-like quark pair production ($b'\bar{b}'$)
2. Vector-like quark (VLQ) pair production ($B\bar{B}/T\bar{T}$)
3. Same-sign top pair production (tt) from BSM
4. Four top quarks production ($t\bar{t}t\bar{t}$) from BSM (and also SM):
   - Effective model with four-top contact interaction
   - New model with sgluon pair production
   - New model with two universal extra dimensions under real projective plane geometry (2UED/RPP)

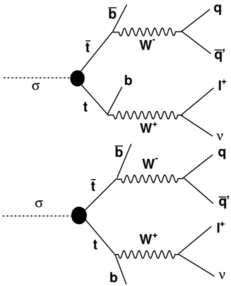
Reduced 8 TeV dataset: 14.3 fb^{-1} **ATLAS-CONF-2013-051**

Signal signature

All signals lead to final states with at least two same-sign leptons, sizable missing transverse momentum (E_T^{miss}), and two or more jets, including b-jets.

The exact final state varies from signal to signal





$b'\bar{b}' \to W^-tW^+\bar{t} \to W^-W^+bW^+W^-\bar{b}$

VLQ pair production can lead to this final state too. But in addition, T/B can also decay to Z boson or Higgs boson, leading to different final states.

$B \to tW/bZ/bH \quad T \to bW/tZ/tH$

Sgluon pair decays to four tops

($t\bar{t}t\bar{t} \to W^+bW^-\bar{b}W^+bW^-\bar{b}$)

More b jets than $b'\bar{b}'$

Event selection

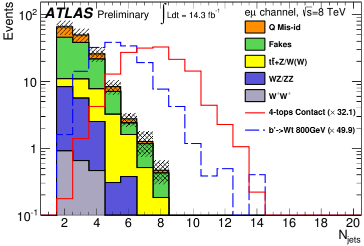
Basic selection criteria for signal region:

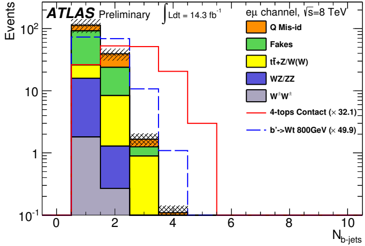
1. At least 1 primary vertex formed with at least 5 tracks
2. Pass either an electron trigger or a muon trigger
3. Exactly 2 isolated leptons ($p_T > 25$ GeV) with same electric charge ($e^{\pm}e^{\pm}/e^{\pm}\mu^{\pm}/\mu^{\pm}\mu^{\pm}$)
4. Z veto for ee and $\mu\mu$ channels: $|M_{ll} - 91| > 10$ GeV and $M_{ll} > 15$ GeV.
5. At least 2 jets ($p_T > 25$ GeV), including at least 1 b-jet.
6. $E_T^{\text{miss}} > 40$ GeV, $H_T > 550$ GeV
   - $H_T = \sum_{jets,e,\mu} p_T$

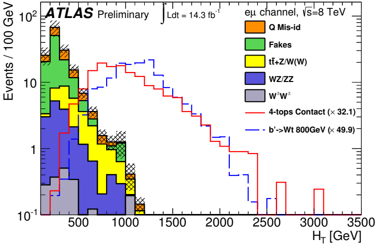
Selection is optimized for each signal using a grid search on:

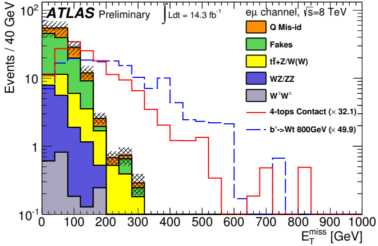
- N_{jets}, N_{bjets}, E_T^{miss}, H_T

Discriminant variables: $e\mu$ channel







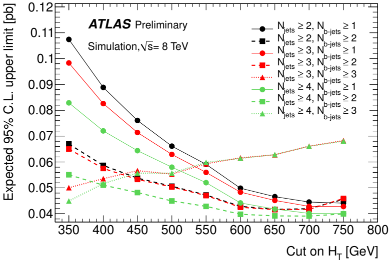


Summary of the selection for the various signals

All signals require:

$N_{jets} \geq 2$, $E_T^{\text{miss}} > 40$ GeV

Variable	b' and VLQ	tt	$t\bar{t}t\bar{t}$
H_T	$> 650GeV$	$> 550GeV$	$> 650GeV$
N_{b-jets}	≥ 1	≥ 1	≥ 2
Charge	$\pm\pm$	$++$	$\pm\pm$



Selection optimization for the four tops signal

Backgrounds

Sources of background:

- **True same-sign dilepton pairs:** physics processes which give same-sign dilepton events
- **False same-sign dilepton pairs:** physics processes which don't give same-sign dilepton events, but are reconstructed/identified as such

True same-sign dilepton pairs ⇒ estimated from Monte Carlo samples:

- WZ + jets
- ZZ + jets
- $W^{\pm}W^{\pm}jj$
- $t\bar{t}Z$+jets
- $t\bar{t}W$+jets
- $t\bar{t}W^{+}W^{-}$

False same-sign dilepton pairs ⇒ estimated from data-driven techniques:

- Fakes: mis-reconstructed leptons (b/c hadrons, π^{0}, photons)
- Charge mis-id: electron charge mis-identification (negligible for muons)
  - Trident electrons produced from hard bremsstrahlung
  - Measurement error induced by slightly curved track

SM processes such as $t\bar{t}$, single top, W+jets will contribute to this background and therefore are not included as Monte Carlo samples

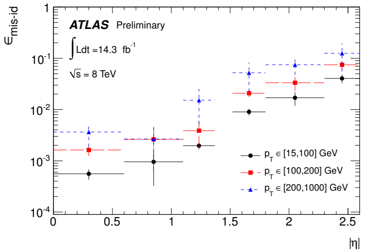
Data-driven background estimation

The fakes background is estimated using a matrix method

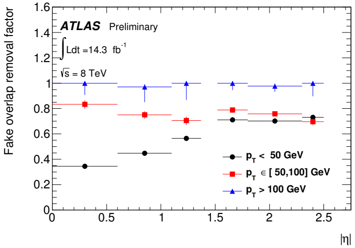
- Real/fake efficiencies measured in single lepton control regions and parametrised with several variables, such as lepton p_T, η, and trigger matching results

The charge mis-id background is estimated using a likelihood method

- Charge mis-identification rate measured in a $Z \to ee$ sample, and corrected using a p_T dependent correction factor computed from MC $t\bar{t}$ events
- Overlap with the fakes removed by applying a correction factor to the rate



Charge mis-identification rate



Correction factor for overlap removal between charge mis-id and fakes

Expected and observed yields in control region

No cut on E_T^{miss}, $100 < H_T < 400$ GeV

Samples	Channel ee	$e\mu$	$\mu\mu$
Charge mis-id	$25.7 \pm 0.7 \pm 6.6$	$30.2 \pm 0.6 \pm 7.9$	—
Fakes	$38.7 \pm 3.7 \pm 11.6$	$73.1 \pm 5.3 \pm 21.9$	$33.4 \pm 8.5 \pm 10.0$
Diboson			
• WZ/ZZ+jets	$3.9 \pm 0.7 \pm 1.3$	$10.9 \pm 1.2 \pm 3.7$	$5.1 \pm 0.8 \pm 1.7$
• $W^{\pm}W^{\pm}$+2 jets	$0.4 \pm 0.2 \pm 0.2$	$1.2 \pm 0.3 \pm 0.6$	$0.8 \pm 0.2 \pm 0.4$
$t\bar{t} + W/Z$			
• $t\bar{t}W$(+jet)	$1.7 \pm 0.1 \pm 0.5$	$6.6 \pm 0.2 \pm 2.0$	$4.3 \pm 0.2 \pm 1.3$
• $t\bar{t}Z$(+jet)	$0.5 \pm 0.1 \pm 0.1$	$1.5 \pm 0.1 \pm 0.5$	$0.8 \pm 0.1 \pm 0.2$
• $t\bar{t}W^+W^-$	0.014 ± 0.002	0.050 ± 0.004	0.029 ± 0.003
Total expected background	$71 \pm 5 \pm 13$	$124 \pm 8 \pm 24$	$44 \pm 11 \pm 10$
Observed	64	97	38
Signal contamination			
• b′ $\to Wt$ (800 GeV)	< 0.003	0.009 ± 0.006	0.002 ± 0.001
• 4 tops contact ($C/\Lambda^2 = -4\pi$ TeV^{-2})	0.009 ± 0.005	0.06 ± 0.02	0.02 ± 0.01

Observed and expected number of events with statistical (first) and systematic (second) uncertainties for the E_T^{miss} control region selection. For the Monte Carlo simulation, the systematic uncertainties include only the production cross section uncertainty

Systematic uncertainties

For MC backgrounds, the largest source of uncertainty is on the calculated cross section. Other leading sources of uncertainty include jet energy scale, b jet identification efficiency, and lepton identification efficiency

	Uncertainty in %					
	650 GeV b'			Background		
Source	ee	$e\mu$	$\mu\mu$	ee	$e\mu$	$\mu\mu$
Cross section	–	–	–	14.4	25.4	32.9
Fakes	–	–	–	9.7	1.4	10.1
Charge mis-ID	–	–	–	7.2	7.1	–
Jet energy scale	4.6	2.5	0.2	3.5	10.2	4.4
ISR/FSR	6.0	6.0	6.0	2.6	4.5	4.0
b jet ID	4.6	3.1	3.0	2.1	4.4	4.0
Lepton ID eff.	5.3	4.9	8.2	2.2	3.6	5.4
Jet energy resolution	0.8	0.9	0.3	0.9	2.7	2.0
Luminosity	3.6	3.6	3.6	1.6	2.7	2.4
Lepton energy scale	0.8	0.4	0.0	1.4	0.9	0.1
JVF selection efficiency	2.5	2.9	2.6	1.1	1.5	1.4

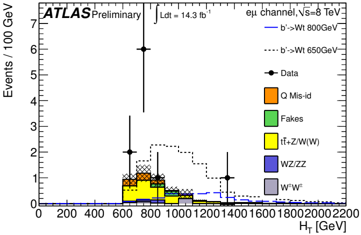
Leading sources of systematic uncertainty on the signal and background estimates for the b'/VLQ selection, and their relative impact on the total background estimate. A b' mass of 650 GeV is assumed

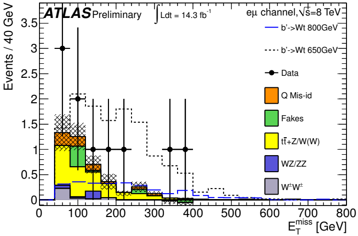
Data/background yields for the b'/VLQ selection

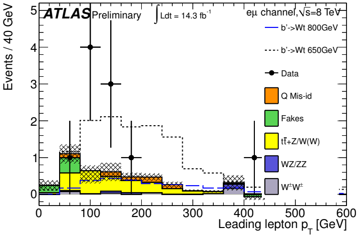
Backgrounds	Channel		
Samples	ee	$e\mu$	$\mu\mu$
Charge mis-id	$0.6 \pm 0.1 \pm 0.2$	$0.9 \pm 0.1 \pm 0.3$	—
Fakes	$0.8 \pm 0.4 \pm 0.3$	$0.2 \pm 0.4 \pm 0.1$	< 1.1
Diboson			
• WZ/ZZ+jets	$0.3 \pm 0.2 \pm 0.1$	$0.3 \pm 0.1^{+0.4}_{-0.2}$	$0.4 \pm 0.2 \pm 0.1$
• $W^{\pm}W^{\pm}$+2 jets	$0.17 \pm 0.09 \pm 0.05$	$0.3 \pm 0.2 \pm 0.1$	$0.2 \pm 0.1 \pm 0.1$
$t\bar{t} + W/Z$			
• $t\bar{t}W$(+jet(s))	$0.6 \pm 0.2 \pm 0.3$	$1.9 \pm 0.2 \pm 0.6$	$1.3 \pm 0.2 \pm 0.4$
• $t\bar{t}Z$(+jet(s))	$0.18 \pm 0.03 \pm 0.06$	$0.66 \pm 0.05 \pm 0.22$	$0.31 \pm 0.04 \pm 0.10$
• $t\bar{t}W^{+}W^{-}$	$0.024 \pm 0.003^{+0.010}_{-0.007}$	$0.072 \pm 0.005^{+0.028}_{-0.020}$	$0.055 \pm 0.004^{+0.022}_{-0.016}$
Total expected background	$2.7 \pm 0.5 \pm 0.4$	$4.4 \pm 0.5^{+0.9}_{-0.7}$	$2.3 \pm 1.2 \pm 0.5$
Observed	3	10	2

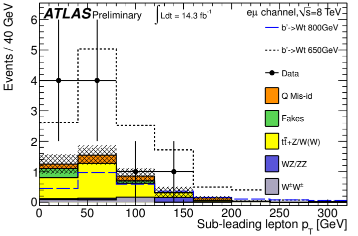
Observed and expected number of events with statistical (first) and systematic (second) uncertainties for the b'/VLQ signal selection

Kinematic distributions after the b'/VLQ selection





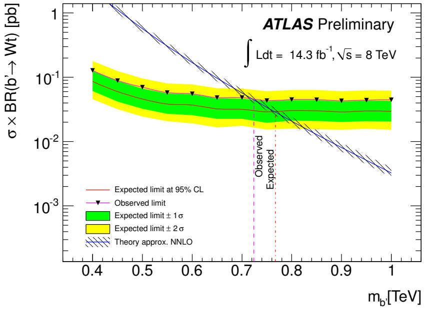




The shaded areas correspond to the total uncertainties on the background. For the Monte Carlo simulated samples, systematic uncertainties include only the production cross section uncertainty

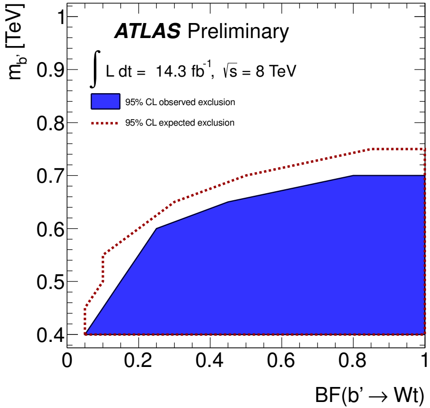
Limits on b'

Left: Limits assuming 100% branching fraction of $b' \to Wt$
Right: Limits set as a function of $b' \to Wt$ branching fraction



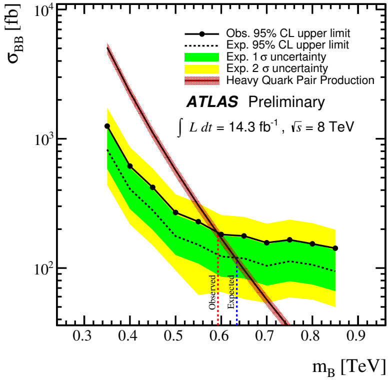
Observed limit: $m_{b'} > 0.72$ TeV

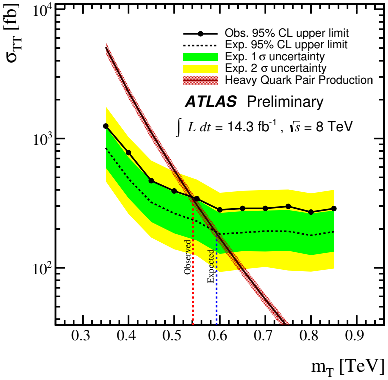
Expected limit: $m_{b'} > 0.77$ TeV



Limits on VLQ

Limits for B/T singlets in a natural scenario (arXiv:0907.3155)





Observed limit: $m_B > 0.59$ TeV

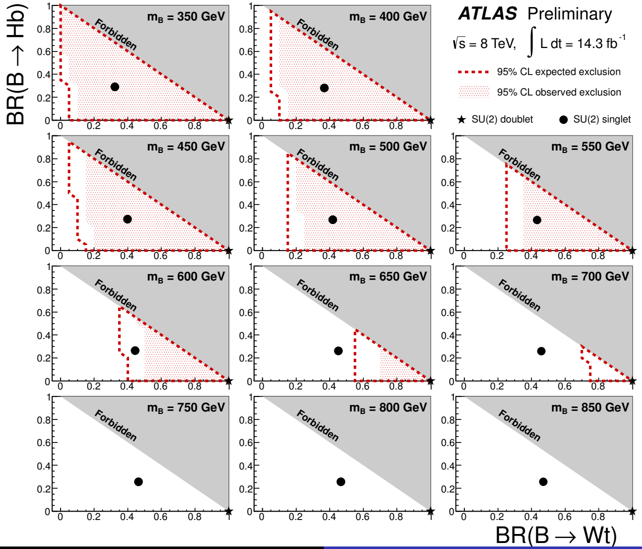
Expected limit: $m_B > 0.63$ TeV

Observed limit: $m_T > 0.54$ TeV

Expected limit: $m_T > 0.59$ TeV

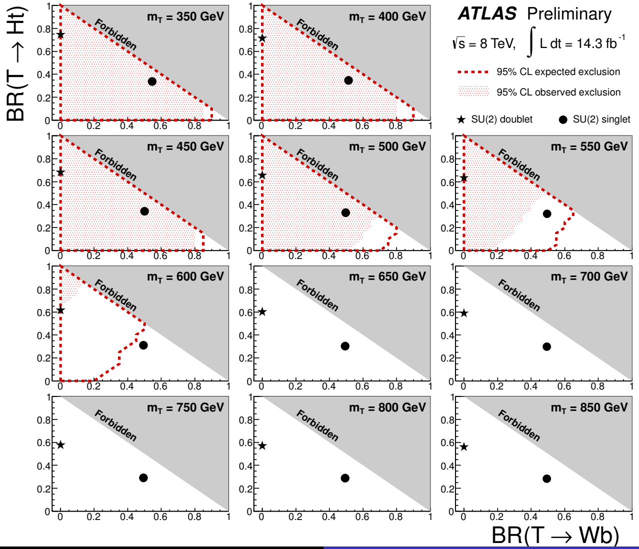
Limits on VLQ

Limits derived for different branching ratios in a 2D plane: B



Limits on VLQ

Limits derived for different branching ratios in a 2D plane: T



Data/background yields for the tt selection

Samples	Channel		
	ee	$e\mu$	$\mu\mu$
Charge mis-id	$0.6 \pm 0.1 \pm 0.2$	$0.5 \pm 0.1 \pm 0.2$	—
Fakes	$0.6 \pm 0.4 \pm 0.2$	$1.0 \pm 0.4 \pm 0.3$	$0.7 \pm 0.7 \pm 0.2$
Diboson			
• WZ/ZZ+jets	$0.2 \pm 0.1 \pm 0.1$	$0.5 \pm 0.3 \pm 0.2$	$0.6 \pm 0.3 \pm 0.2$
• $W^{\pm}W^{\pm}$+2 jets	$0.16 \pm 0.08 \pm 0.04$	$0.3 \pm 0.2 \pm 0.1$	$0.2 \pm 0.1 \pm 0.1$
$t\bar{t} + W/Z$			
• $t\bar{t}W$(+jet(s))	$0.7 \pm 0.1 \pm 0.2$	$2.2 \pm 0.1 \pm 0.7$	$1.5 \pm 0.1 \pm 0.5$
• $t\bar{t}Z$(+jet(s))	$0.18 \pm 0.03 \pm 0.06$	$0.59 \pm 0.05 \pm 0.19$	$0.26 \pm 0.03 \pm 0.09$
• $t\bar{t}W^+W^-$	$0.013 \pm 0.002 \pm 0.005$	$0.053 \pm 0.004 \pm 0.021$	$0.032 \pm 0.003 \pm 0.013$
Total	$2.5 \pm 0.4 \pm 0.4$	$5.1 \pm 0.5 \pm 0.9$	$3.3 \pm 0.8 \pm 0.7$
Observed	3	8	1

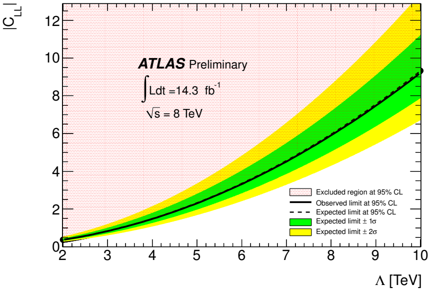
Observed and expected number of events with statistical (first) and systematic (second) uncertainties for the positively-charged top pair signal selection

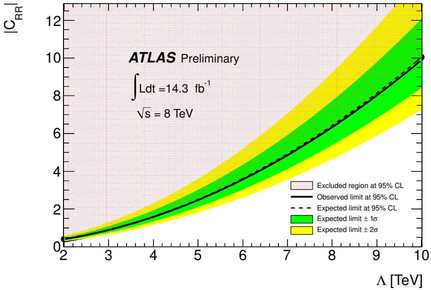
Limits on tt

Limits for an effective four-fermion contact interaction, for three different chirality configurations. The coupling strength is respectively C_{LL}/Λ^2, C_{LR}/Λ^2, and C_{RR}/Λ^2

	95% C.L. upper limit		
	$\sigma(pp \to tt)$ [pb]		$\lvert C\rvert/\Lambda^2$ [TeV^{-2}]
Chirality configuration	Expected 1σ range	Observed	Observed
Left-left	0.14-0.28	0.19	0.092
Right-right	0.15-0.32	0.21	0.099

Expected and observed limits on the positively-charged top quark pair signal



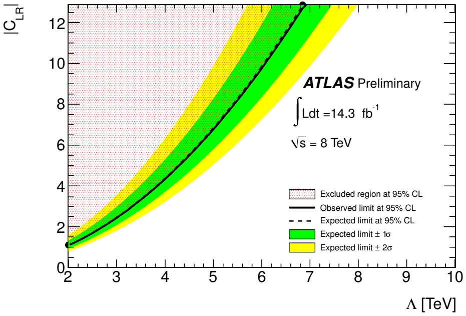


Limits on tt

Limits for an effective four-fermion contact interaction, for three different chirality configurations. The coupling strength is respectively C_{LL}/Λ^2, C_{RR}/Λ^2, and C_{LR}/Λ^2

	95% C.L. upper limit		
	$\sigma(pp \to tt)$ [pb]		$\lvert C\rvert/\Lambda^2$ [TeV^{-2}]
Chirality configuration	Expected 1σ range	Observed	Observed
Left-right	0.15-0.30	0.20	0.271

Expected and observed limits on the positively-charged top quark pair signal



Data/background yields for the four tops selection

Samples	Channel: ee	$e\mu$	$\mu\mu$
Charge mis-id	$0.16 \pm 0.04 \pm 0.05$	$0.41 \pm 0.07 \pm 0.12$	—
Fakes	$0.18 \pm 0.17 \pm 0.05$	$0.07 \pm 0.28 \pm 0.02$	< 1.14
Diboson			
• WZ/ZZ+jets	< 0.1	$0.01 \pm 0.09 \pm 0.01$	< 0.11
• $W^{\pm}W^{\pm}$+2 jets	< 0.03	$0.18 \pm 0.16 \pm 0.07$	< 0.03
$t\bar{t} + W/Z$			
• $t\bar{t}W$(+jet(s))	$0.31 \pm 0.04 \pm 0.12$	$0.93 \pm 0.06 \pm 0.35$	$0.65 \pm 0.06 \pm 0.25$
• $t\bar{t}Z$(+jet(s))	$0.09 \pm 0.02 \pm 0.04$	$0.34 \pm 0.04 \pm 0.14$	$0.14 \pm 0.02 \pm 0.06$
• $t\bar{t}W^{+}W^{-}$	$0.012 \pm 0.002 \pm 0.005$	$0.039 \pm 0.003 \pm 0.016$	$0.024 \pm 0.003 \pm 0.01$
Total	$0.8 \pm 0.2 \pm 0.1$	$2.0 \pm 0.4 \pm 0.4$	$0.8 \pm 1.2 \pm 0.3$
Observed	1	6	1

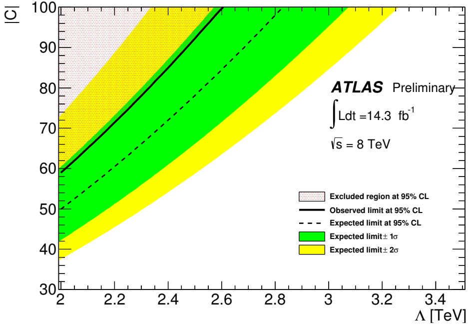
Observed and expected number of events with statistical (first) and systematic (second) uncertainties for the four top quarks signal selection

Limits on $t\bar{t}t\bar{t}$

Limits for SM and a general four-fermion contact interaction with coupling strength C/Λ^2

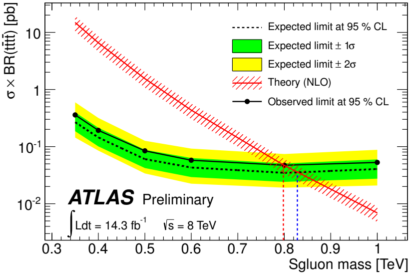
	95% C.L. upper limit		
	$\sigma(pp \to t\bar{t}t\bar{t})$ [fb]		$\lvert C\rvert/\Lambda^2$ [TeV^{-2}]
Model	Expected 1σ range	Observed	Observed
Standard Model	43-89	85	—
Contact interaction	29-61	59	15

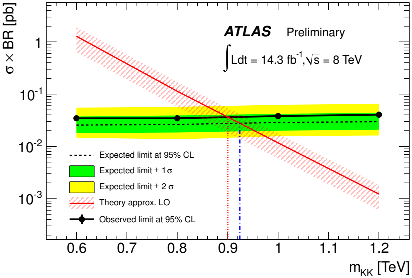
Expected and observed limits on two four top quarks signals



Limits on $t\bar{t}t\bar{t}$

Limits for the two specific models: sgluon pair production, and 2UED/RPP





Observed limit: $m_\sigma > 0.80$ TeV

Expected limit: $m_\sigma > 0.83$ TeV

Observed limit: $m_{KK} > 0.90$ TeV

Expected limit: $m_{KK} > 0.92$ TeV

Conclusions

- Presented a search for new physics using events with same-sign dileptons and b-jets
  - Has the advantage of very low standard model background
- No significant excess of events over background is observed. Therefore 95% C.L. limits have been set for several signals
- We are working towards the publication
  - Will use the full 8 TeV dataset (20.3 fb^{-1})
- Several studies to improve the analysis are under way
  - Adding events with more than two leptons
  - Setting limits with a distribution, instead of cut-and-count
  - Exploring multivariate analysis
  - Better treatment of the systematic uncertainties on the fakes background