Search for New Physics in 4-tops final states in ATLAS

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Summary

Goal: Find New Physics in events with 4-top quarks ($t\bar{t}t\bar{t}$).

- **New Physics Model:** Low-energy effective field theory.
- **Channel of decay:** two leptons with the same electric charge.

Analysis performed on the **full 2011 data set ($4.7fb^{-1}$) at 7 TeV.**

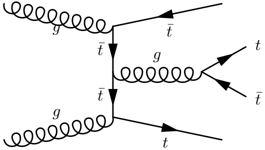
This analysis doesn't test a particular theory, but rather a class of theories where New Physics manifests itself at low energy as a 4 right handed top contact interaction!

All results from ATLAS-CONF-2012-130

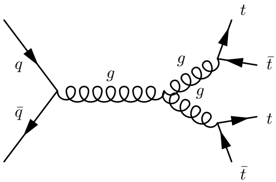
Outline

4-tops production in SM

- $gg \to t\bar{t}t\bar{t}$ (85% at the LHC at 7 TeV)



- $q\bar{q} \to t\bar{t}t\bar{t}$ (15%)



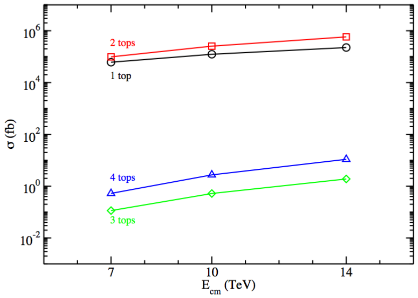
Motivation

- The SM prediction for 4-tops at the LHC is very small:

  $\sigma_{SM} \approx$ **0.5 fb at 7 TeV**

- Some models with New Physics predict an enhancement of the $t\bar{t}t\bar{t}$ production rate at the LHC compared to the SM:

Top composite $\approx 10^3$ **compared to the SM!**



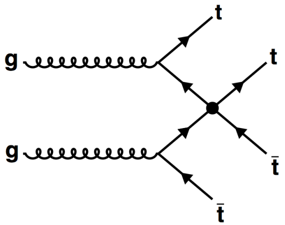
Cross sections for multi-top production in the Standard Model with $m_H = 130 GeV$ (arXiv:1001.0221v3 [hep-ph])

Models with New Physics involving 4-top quarks

Some models can be tested by studying events with 4-top quarks:

- Composite top $\rightarrow$
- Randall-Sundrum.
- Universal Extra Dimensions model.
- SUSY signal.
- ...

- Predicts a 5^{th} fundamental force.



Contribution from a 4-top operator to 4-top production

Models with New Physics involving 4-top quarks

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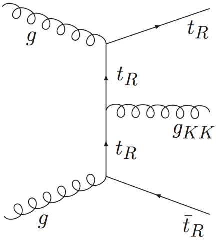
- Predicts a Universe with 5 dimensions.



$g_{KK} \to t\bar{t}$

Models with New Physics involving 4-top quarks

Some models can be tested by studying events with 4-top quarks:

- Composite top.
- Randall-Sundrum.
- Universal Extra Dimensions model $\rightarrow$
- SUSY signal.
- ...

- Predicts a Universe with 6 dimensions.

  Pair production of heavy photons A_μ:

$$A_\mu A_\mu \rightarrow t\bar{t}t\bar{t}$$

- It provides a candidate for dark matter
  arXiv:1107.4616v2 [hep-ph]

Models with New Physics involving 4-top quarks

Some models can be tested by studying events with 4-top quarks:

- Composite top.
- Randall-Sundrum.
- Universal Extra Dimensions model.
- SUSY signal $\rightarrow$
- ...

- Predicts a supersymmetric partner for each SM particle.

  Pair production of gluinos:

$$\tilde{g} \rightarrow t\bar{t}\chi_1^0$$

- It provides a candidate for dark matter
  arXiv:1101.1963v1 [hep-ph]

Analysis: Procedure

1. Generate events for the New Physics signal.
2. Select channel of decay.
3. Estimate background.
4. Determine the final selection of events.
5. Validate the background.
6. Results.

The analysis is performed on the **full 2011 data set (4.7 fb^{-1}) at 7 TeV.**

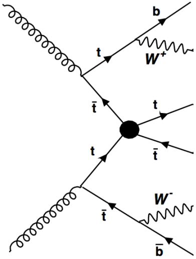
4-tops signal

Model obtained from *"Non-resonant New Physics in Top Pair Production at Hadron Colliders"*, `arXiv:1010.6304`.

- General and model-independent approach: Low-energy effective field theory.

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{c}{\Lambda^2}(t_R \gamma^\mu t_R)(t_R \gamma_\mu t_R)$$

Contact interaction operator



It introduces a new 4-tops contact interaction

4-tops signal

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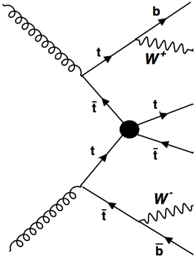
$$\mathcal{L} = \mathcal{L}_{SM} + \frac{c}{\Lambda^2}(t_R\gamma^\mu t_R)(t_R\gamma_\mu t_R)$$

Free parameter to put a limit on

- Only the cross-section depends on c/Λ^2.
- All possible operators with hypotheses:
  - All SM symmetries conserved.
  - Only top-philic new physics.
  - No change in electroweak couplings of top (γ/Z).
  - No change in top decay.

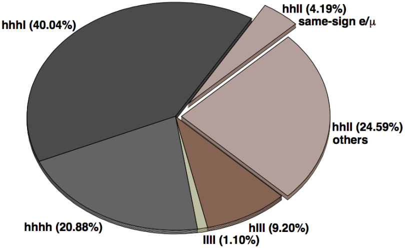


It introduces a new 4-tops contact interaction

Channel of decay

- Most probable decay comes from the 1 lepton + jets!
  → But... 1 lepton can be produced easily by SM.
- Two leptons + jets is more promising.
  → It's less probable in SM.

Branching Ratios



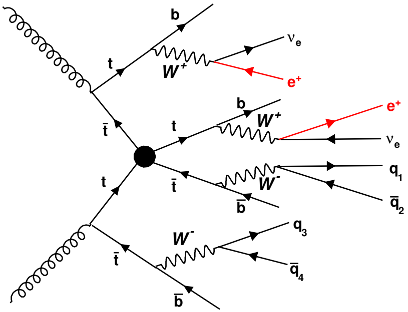
Easiest channel with two leptons with the same electric charge: $hh\ell^{\pm}_{e/\mu}\ell^{\pm}_{e/\mu} \rightarrow 4.2\%$

⇒ Standard Model production very small and potentially large contributions from new theories!

Channel of decay

Channel topology:

- 2 charged leptons (electrons and muons).
- 8 jets, including 4 b-jets.
- Missing Transverse Momentum E_T^{miss} (neutrinos).



Background

Sources of background : Several processes can mimic a final state with 4-top quarks.

- 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 as such.

True same-sign dilepton pairs $\Rightarrow$ estimated from Monte Carlo samples:

- WZ + jets ($\sigma = 1.41$ pb).
- ZZ + jets ($\sigma = 0.86$ pb).
- $W^{\pm}W^{\pm}jj$ ($\sigma = 0.22$ pb).
- $t\bar{t}$ + Z(j) ($\sigma = 0.15$ pb).
- $t\bar{t}$ + W(j) ($\sigma = 0.10$ pb).
- $t\bar{t}WW$ ($\sigma = 0.001$ pb).

Background

Sources of background : Several processes can mimic a final state with 4 top quarks.

- 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 as such.

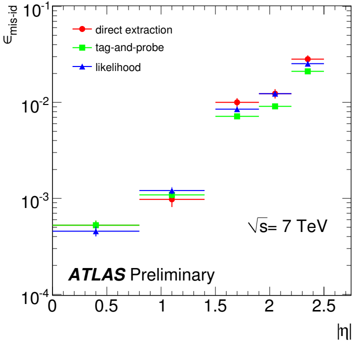
False same-sign dilepton pairs $\Rightarrow$ estimated from data-driven techniques :

- Mis-id $\rightarrow$ electron charge misidentification (for muons is negligible).
- Fakes $\rightarrow$ mis-reconstructed leptons.

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

Electron mis-id estimation

- Estimated by measuring the charge misidentification rate ϵ reconstructing a Z peak using 2 electrons in data.
- ϵ is computed as a function of $|\eta|$ bins for three different methods:
  1. Tag and Probe method.
  2. Direct extraction method.
  3. Likelihood method.
- Closure test gives good results.



Tight lepton fake estimation

At least one of the two leptons in the selected same-sign pair is not a real isolated lepton but has been reconstructed as such!

They could come from:

- Semi-leptonic decay of a *b* or *c* hadron $\rightarrow$ falsely identified as an isolated lepton.
- π^0 or photons $\rightarrow$ mis-reconstructed leptons.

The matrix method is used to determine the magnitude of the mis-reconstructed leptons in the signal region.

Overlap: fakes and mis-id

- Some charge mis-id electrons are also captured as fakes.
- The overlap ($\approx 23\%$) is measured, and this amount is used to rescale the final mis-id estimate.

The fakes were estimated by LPNHE and the Mis-id by Saclay group

Events selection

- Trigger $\rightarrow$ Single isolated lepton.
- At least 2 leptons with the same sign:
  - Leading lepton $p_T > 25$ GeV.
  - If multiple leptons: choose pair with highest p_T (μ: $p_T > 20$ GeV, e: $p_T > 25$ GeV).
- Separate in three samples:
  - $e^{\pm}e^{\pm}$ sample.
  - $\mu^{\pm}\mu^{\pm}$ sample.
  - $e^{\pm}\mu^{\pm}$ sample.
- Z veto $\rightarrow$ ee and $\mu\mu$ events must satisfy $|M_{ll} - 91| > 10$ GeV, and $M_{ll} > 15$ GeV.
- At least 2 jets ($p_T > 20$ GeV), including at least 1 b jet.
- $E_T^{\mathrm{miss}} > 40$ GeV.
- $H_T > 350$ GeV ($H_T = \sum_{jets,e,\mu} p_T$)

Cut optimization

Based on the discriminant variables $\rightarrow$ The following parameters were variated:

- $H_T \in [350, 650]$ per step of 50 GeV.
- Number of all jets $\in [2, 5]$.
- Number of b jets $\in$ [1,3].
- $E_T^{\mathrm{miss}} > 40$, 60 GeV.

Optimization done including full systematics.

$\Rightarrow$ **Try to get the best expected limit.**

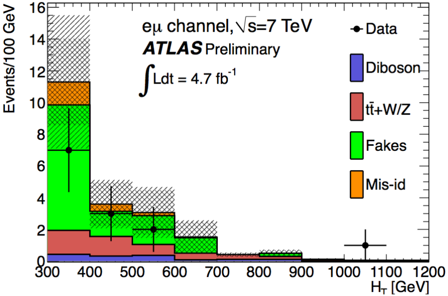
$E_T^{miss} \geq 40$ **GeV,** $H_T > 550$ **GeV,** $N_j \geq 2$ **and** $N_{b-jets} \geq 1$**.**

Background validation: Control Region

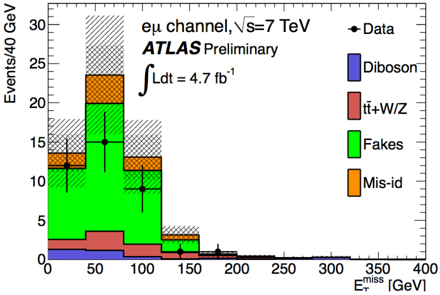
- At least one same-sign pair of leptons and Z veto.
- $H_T \in [100, 500]$ **GeV and no cut on** E_T^{miss}**.**
- $N_{jets} \geq 2$, $N_{b-jets} \geq 1$.

Samples	Channel		
	ee	eμ	$\mu\mu$
False same-sign dilepton pairs			
Mis-id	$5.2 \pm 0.3 \pm 0.6$	$7.9 \pm 0.3 \pm 1.0$	—
Fakes	$10.0 \pm 5.3 \pm 5.0$	$34.0 \pm 5.2 \pm 13.6$	$17.4 \pm 1.8 \pm 5.2$
Diboson			
• WZ/ZZ+jets	$0.69 \pm 0.23 \pm 0.12$	$2.15 \pm 0.36 \pm 0.37$	$2.17 \pm 0.40 \pm 0.44$
• $W^{\pm}W^{\pm}$+2 jets	$0.06 \pm 0.03 \pm 0.03$	$0.27 \pm 0.06 \pm 0.14$	$0.15 \pm 0.04 \pm 0.07$
$t\bar{t} + W/Z$			
• $t\bar{t}W$(+jet)	$0.77 \pm 0.04 \pm 0.17$	$3.34 \pm 0.09 \pm 0.73$	$2.06 \pm 0.07 \pm 0.45$
• $t\bar{t}Z$(+jet)	$0.32 \pm 0.02 \pm 0.12$	$1.33 \pm 0.05 \pm 0.48$	$0.88 \pm 0.04 \pm 0.32$
• $t\bar{t}W^{\pm}W^{\mp}$	$0.008 \pm 0.001 \pm 0.002$	$0.033 \pm 0.001 \pm 0.010$	$0.024 \pm 0.001 \pm 0.007$
Total	$17.0 \pm 5.3 \pm 5.0$	$49.0 \pm 5.2 \pm 13.7$	$22.7 \pm 1.8 \pm 5.2$
Observed	16	34	18
Signal contamination			
• 4 tops ($c/\Lambda^2 = -4\pi\, TeV^{-2}$)	0.012 ± 0.003	0.046 ± 0.005	0.027 ± 0.004

Observed number of events and expected number of background events with statistical (first) and systematic (second) uncertainties for the control region selection.



Final selection with no cut on H_T



Final selection with no cut on E_T^{miss}

Number of events after selection

	Channel		
Samples	ee	$e\mu$	$\mu\mu$
False same-sign dilepton pairs			
Mis-id	$0.13 \pm 0.04 \pm 0.02$	$0.23 \pm 0.04 \pm 0.03$	—
Fakes	$0.52 \pm 1.12 \pm 0.26$	$0.82 \pm 1.05 \pm 0.33$	$0.13 \pm 0.13 \pm 0.04$
Diboson			
• WZ/ZZ+jets	$0.19 \pm 0.20 \pm 0.07$	$0.34 \pm 0.21 \pm 0.13$	$0.28 \pm 0.22 \pm 0.10$
• $W^{\pm}W^{\pm}$+2 jets	$0.06 \pm 0.03 \pm 0.03$	$0.07 \pm 0.03 \pm 0.03$	$0.03 \pm 0.02 \pm 0.03$
$t\bar{t} + W/Z$			
• $t\bar{t}W$(+jet)	$0.23 \pm 0.02 \pm 0.07$	$0.79 \pm 0.04 \pm 0.24$	$0.57 \pm 0.04 \pm 0.18$
• $t\bar{t}Z$(+jet)	$0.17 \pm 0.02 \pm 0.09$	$0.61 \pm 0.03 \pm 0.31$	$0.33 \pm 0.02 \pm 0.17$
• $t\bar{t}W^{\pm}W^{\mp}$	$0.008 \pm 0.001 \pm 0.002$	$0.023 \pm 0.001 \pm 0.007$	$0.016 \pm 0.001 \pm 0.005$
Total Expected	$1.31 \pm 1.14 \pm 0.29$	$2.88 \pm 1.07 \pm 0.53$	$1.36 \pm 0.26 \pm 0.27$
Observed	2	2	0

Observed number of events and expected number of background events with statistical (first) and systematic (second) uncertainties after selection.

Channel		
ee	$e\mu$	$\mu\mu$
0.138 ± 0.010	0.483 ± 0.019	0.343 ± 0.015

Expected number of events after selection for signal ($c/\Lambda^2 = -4\pi\, TeV^{-2}$).

Number of events after selection

Samples	Channel ee	Channel $e\mu$	Channel $\mu\mu$
False same-sign dilepton pairs			
Mis-id	$0.13 \pm 0.04 \pm 0.02$	$0.23 \pm 0.04 \pm 0.03$	—
Fakes	$0.52 \pm 1.12 \pm 0.26$	$0.82 \pm 1.05 \pm 0.33$	$0.13 \pm 0.13 \pm 0.04$
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Expected events: 5.6 ± 1.7

Observed events: 4

Channel ee	Channel $e\mu$	Channel $\mu\mu$
0.138 ± 0.010	0.483 ± 0.019	0.343 ± 0.015

Expected number of events after selection for signal ($c/\Lambda^2 = -4\pi\, TeV^{-2}$).

Number of events after selection

Samples	Channel		
	ee	eμ	$\mu\mu$
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Fakes	$0.52 \pm 1.12 \pm 0.26$	$0.82 \pm 1.05 \pm 0.33$	$0.13 \pm 0.13 \pm 0.04$
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No excess of events has been observed $\Rightarrow \sigma_{t\bar{t}t\bar{t}} < 0.061$ **pb**

Channel		
ee	eμ	$\mu\mu$
0.138 ± 0.010	0.483 ± 0.019	0.343 ± 0.015

Expected number of events after selection for signal $(c/\Lambda^2 = -4\pi\, TeV^{-2})$.

Final limit & conclusions

1. The search for New Physics producing 4-top quarks using same-sign dilepton events has been presented.
2. There are 4 observed events for an expected background of 5.6 ± 1.7 on the full 2011 data set ($4.71\ \text{fb}^{-1}$) at 7 TeV.

   → **No excess of events has been observed**
3. With the final selection an upper limit on the 4-tops production cross section at 95% C.L. has been set:

   $$\sigma_{t\bar{t}t\bar{t}} < 0.061\ \textbf{pb.}$$
4. Studies at 8 TeV are ongoing including 2 new models:
   - Sgluon pair production.
   - 2UED/RPP.

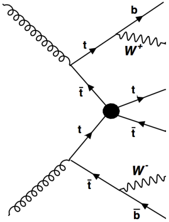
BACKUP

4-tops signal

Event generation with MadGraph 5 at 7 TeV.

4-tops contact interaction introduced by a new colorless vector particle ρ.

- New coupling between t_R and ρ, with g_ρ.
- $m_\rho = 100$ TeV.
- $g_\rho = 100\sqrt{8\pi}$
- Cross-section computed at LO, $\sigma = 12.6$ fb.



Cross section is taken to be a free parameter that we place a limit on.

This analysis doesn't test a particular theory, but rather a class of theories where New Physics manifests itself at low energy as a 4 right handed top contact interaction!

Electron mis-id estimation

The sign of the electric charge of one of the two leptons in the selected same-sign pair has been mis-reconstructed:

True opposite-sign lepton pair reconstructed as a same-sign pair!

They could come from:

- Incorrect measurement of the sign of the track curvature
  $\rightarrow$ dominant effect for high transverse momentum.
- Hard beemsstrahlung producing trident electrons:

$$e^{\pm} \rightarrow e^{\pm}\gamma^{*} \rightarrow e^{\pm}e^{+}e^{-} \quad (1)$$

  Energy cluster assigned to the wrong track!

- Muons are only affected by the sign of the track curvature $\rightarrow$ negligible!

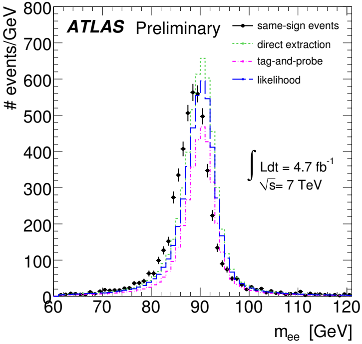
Electron mis-id estimation

- The final same-sign distribution is obtained from $M_{e^+e^-}$ weighted with $\omega(i,j)$.

$$\omega(i,j) = \frac{\epsilon_i + \epsilon_j}{(1-\epsilon_i)(1-\epsilon_j)} \quad (2)$$

ϵ_i is the charge flip rate in the η bin i.

- Method validated by Egamma Working Group.
- Likelihood method is used to extract the event.
- The other two methods are used to compute the systematics.



Likelihood method gives the best fit!

Tight lepton fakes estimation

At least one of the two leptons in the selected same-sign pair is not a real isolated lepton but has been reconstructed as such!

→ They could come from jets of photons.

The matrix method is used to determine the magnitude of the mis-reconstructed leptons in the signal region.

- Two sets of leptons selection criteria are defined: Loose and Tight .
- The probabilities r and f that a real or fake "Loose" lepton pass the "Tight" criteria is measured using purified control regions.

- The composition of the signal samples is extracted by inverting the following matrix:

$$\begin{bmatrix} N_{TT} \\ N_{TA} \\ N_{AT} \\ N_{AA} \end{bmatrix} = \begin{bmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1(1-r_2) & r_1(1-f_2) & f_1(1-r_2) & f_1(1-f_2) \\ (1-r_1)r_2 & (1-r_1)f_2 & (1-f_1)r_2 & (1-f_1)f_2 \\ (1-r_1)(1-r_2) & (1-r_1)(1-f_2) & (1-f_1)(1-r_2) & (1-f_1)(1-f_2) \end{bmatrix} \begin{bmatrix} N^{ll}_{RR} \\ N^{ll}_{RF} \\ N^{ll}_{FR} \\ N^{ll}_{FF} \end{bmatrix}$$

  relating the "true" composition of the sample in terms of real and fake leptons to Tight and Loose leptons.
- The final fake estimation is $N^{fakes}_{TT} = r_1 f_2 N^{ll}_{RF} + f_1 r_2 N^{ll}_{FR} + f_1 f_2 N^{ll}_{FF}$.

Events that tend to have a charge misidentified electron (trident electrons) tend to also be identified as fakes in the matrix method:

$\rightarrow$ The overlap between the charge misidentification and fakes ($\approx 23\%$) is measured, and this amount is used to rescale the final mis-id estimate.

In this moment we are using the Fakes from LPNHE and the Mis-id estimated by Saclay group.

Overlap: Fake-Mis-id

- 90% of the mis-id background comes from trident electrons:

$$e^{\pm} \to e^{\pm}\gamma^{*} \to e^{\pm}e^{+}e^{-} \quad (3)$$

- They also tend to be identified as fakes!

→ The overlap (≈ 23%) is measured, and this amount is used to rescale the final mis-id estimate.

In this moment we are using the Fakes from LPNHE and the Mis-id estimated by Saclay group.

Systematics uncertainties

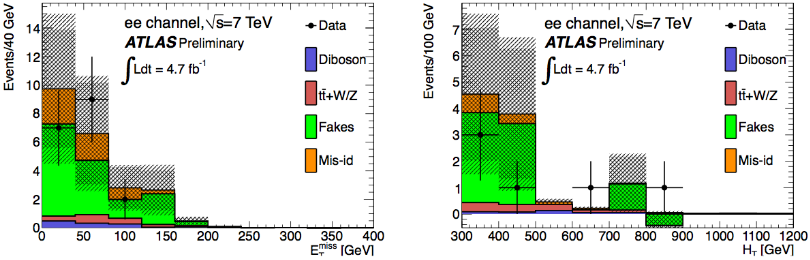
Monte Carlo samples:

- MC cross-section: $t\bar{t}$ + W(j) $\rightarrow$ 30%, $t\bar{t}$ + Z(j) $\rightarrow$ 50%, WZ/ZZ $\rightarrow$ 34.3%, WWjj$\rightarrow$ 50%, $t\bar{t}$+WW $\rightarrow$ +35%/-24%.
- Jets, *e* and μ energy resolution.
- Jets, *e* and μ energy scale.
- Jets, *e* and μ efficiency.
- Jet b-tag efficiency.
- Luminosity: 3.7%.

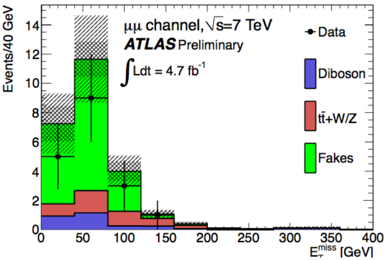
Data-driven background:

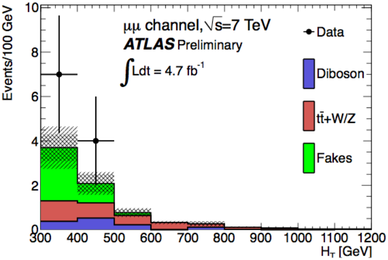
- MisID $\rightarrow$ uncertainties computed as the difference between the 3 methods ($\approx$ 12%).
- Fakes $\rightarrow$ *ee*: 50%, $\mu\mu$: 30%, $e\mu$: 40% (recommended by the Top Group).

Comparison with data: *ee* channel



Comparison with data: $\mu\mu$ channel





McLimit

Limit computed using the tool **McLimit** from Clement Helsens:

- Using test statistic defined as: $LLR = -2\ln\frac{L_{s+b}}{L_b}$
- 50000 pseudoexperiments were generated.
- Correlations of the systematic uncertainties taken into account.
- 95% CL expected limits computed using CL_s.

Limit Combination