Search for New Physics in events with 4-top quarks with ATLAS detector at the LHC

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Summary

Goal: Find New Physics in events with 4-top quarks.

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

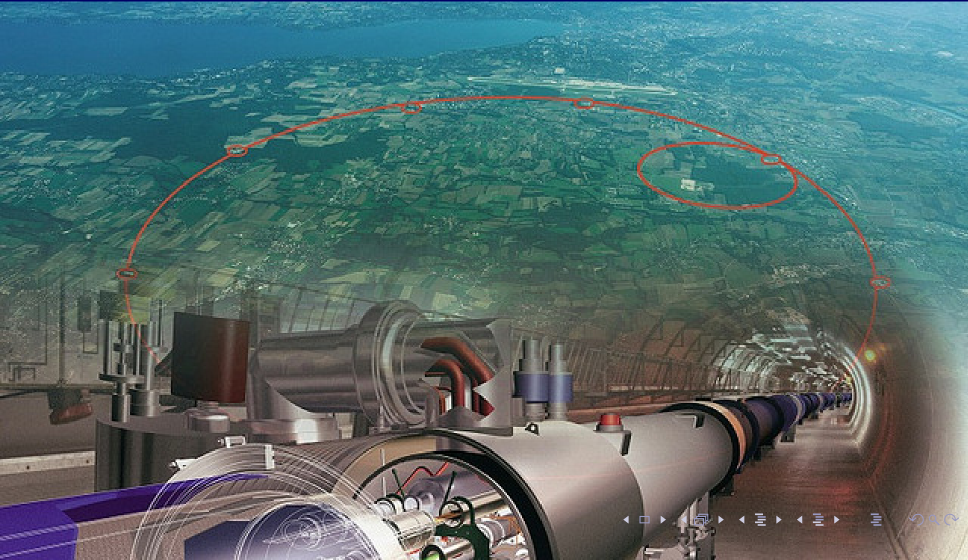
Analysis performed on the **full 2011 data set ($4.7 fb^{-1}$) at 7 TeV.**

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!

Outline

1. Introduction
   - LHC
   - Atlas detector
   - Standard Model
   - Top quark as the most sensitive particle to New Physics
2. 4-tops
   - 4-tops production in SM
   - Top decay & Final states for 4-tops
   - Motivation
   - Models with New Physics involving 4-top quarks
3. Analysis
   - Procedure
   - Signal
   - Channel of decay
   - Background
   - Determining final selection of events
4. Conclusion & Outlooks

Large Hadron Collider



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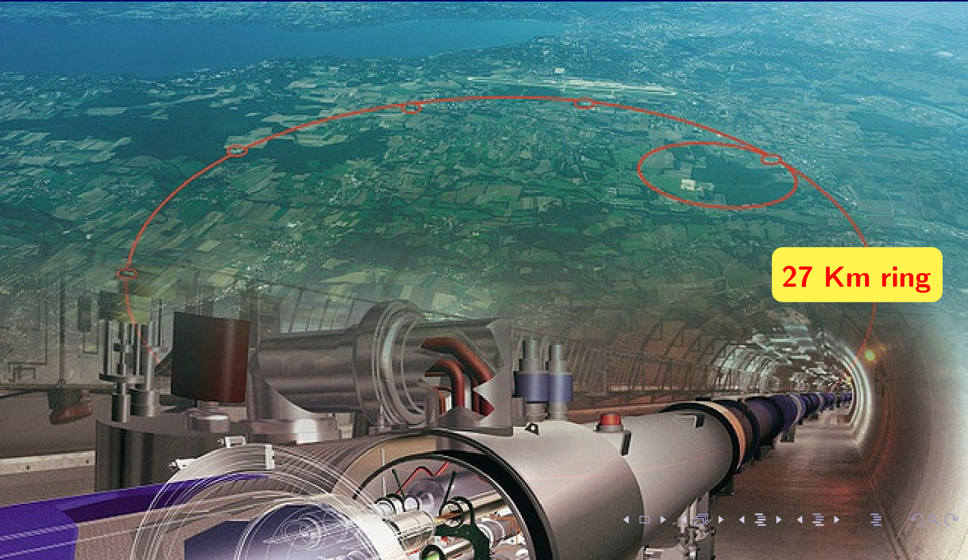

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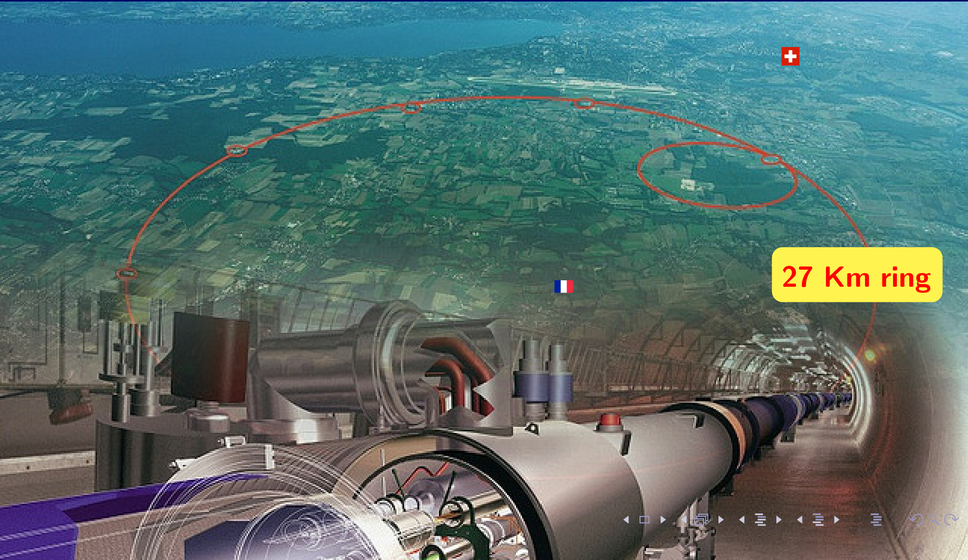

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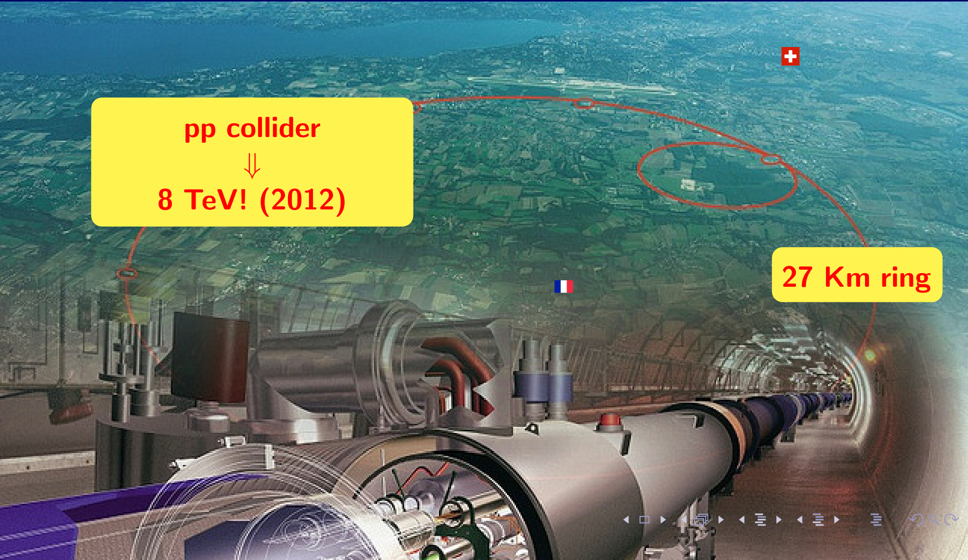

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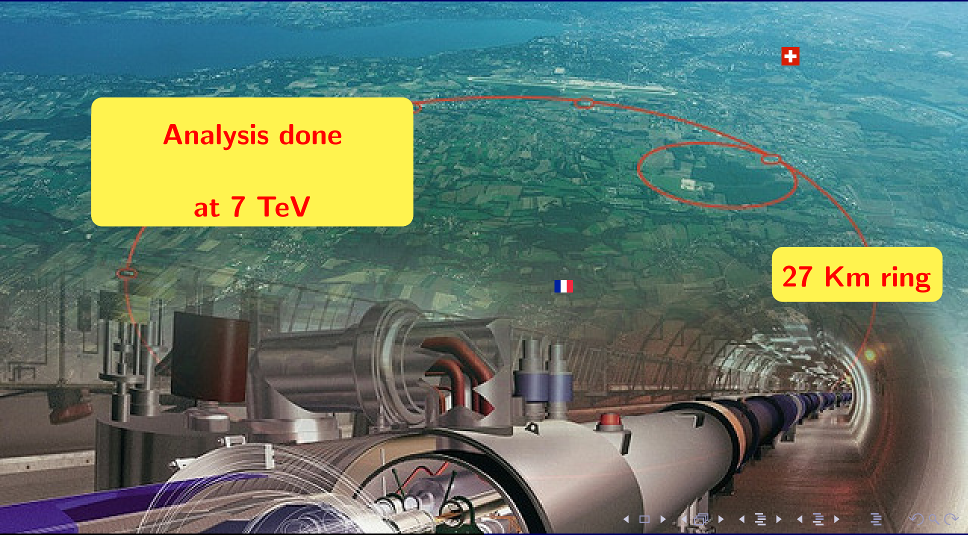

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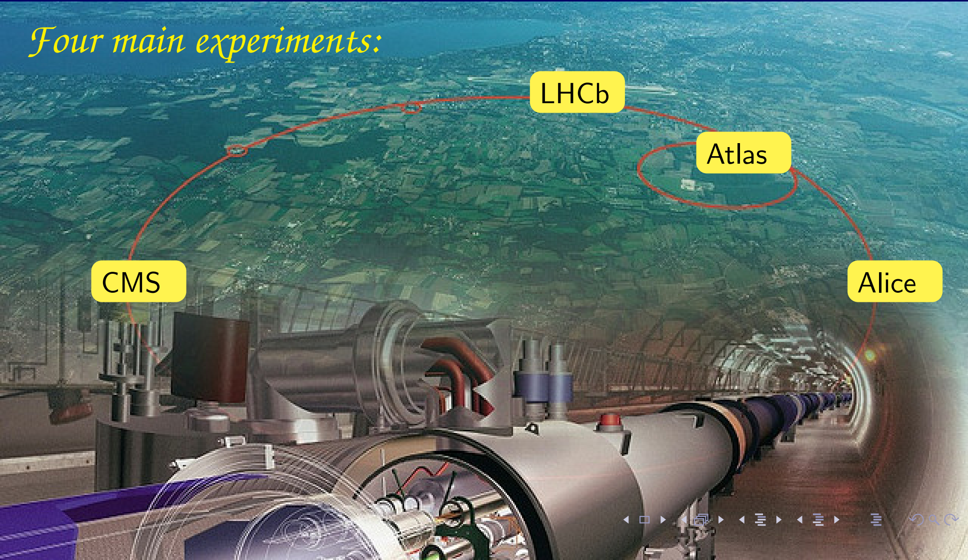

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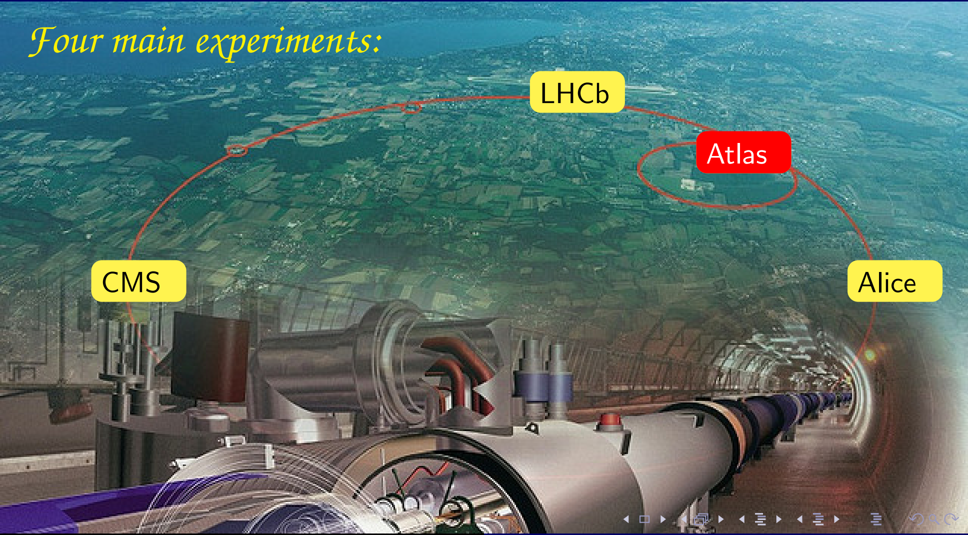
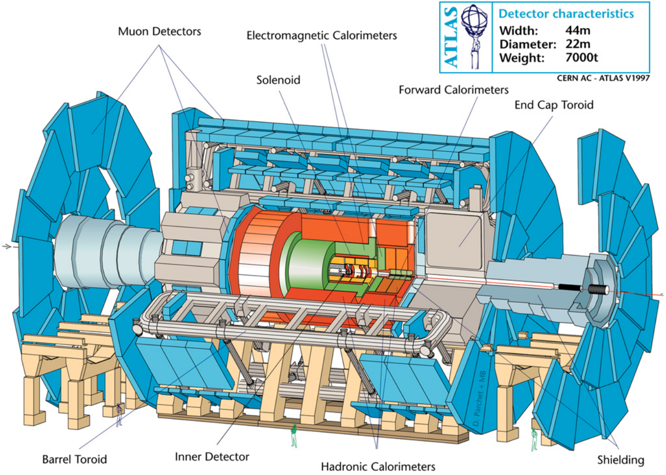


Atlas detector



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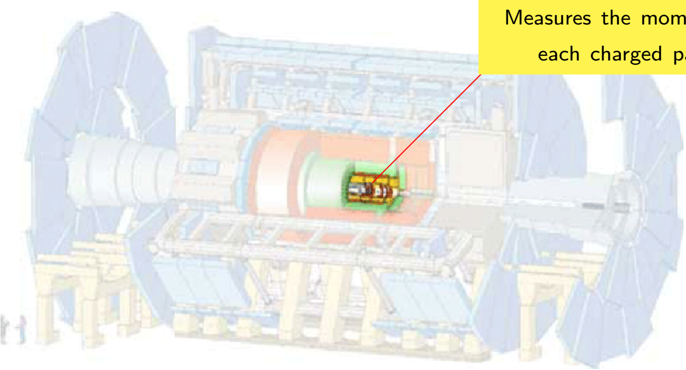


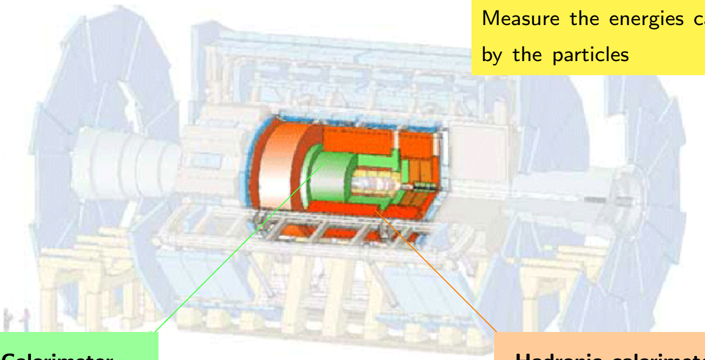
Inner detector

Measures the momentum of each charged particle

Atlas detector

Calorimeters

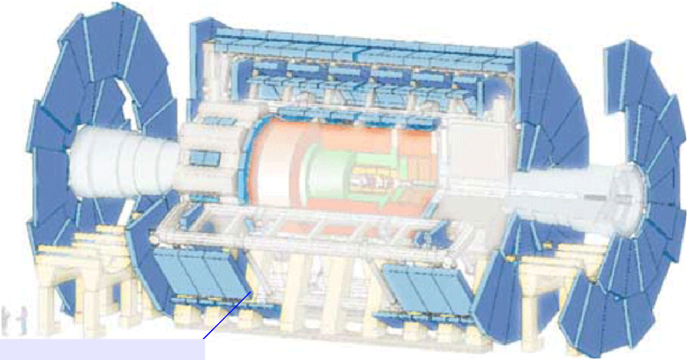
Measure the energies carried by the particles



EM Calorimeter

Hadronic calorimeter

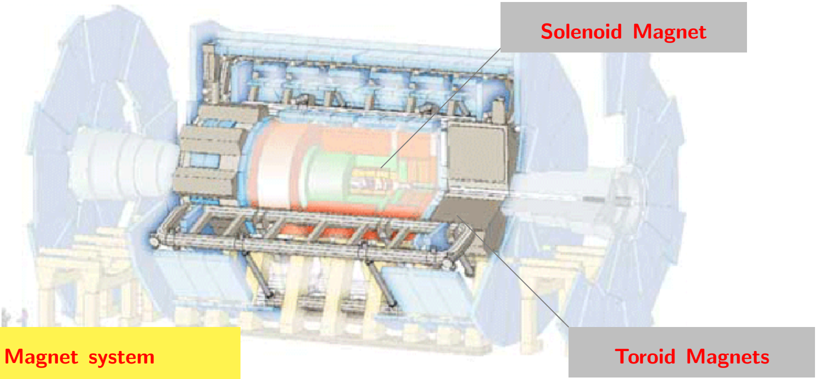
Atlas detector



Muon spectrometer

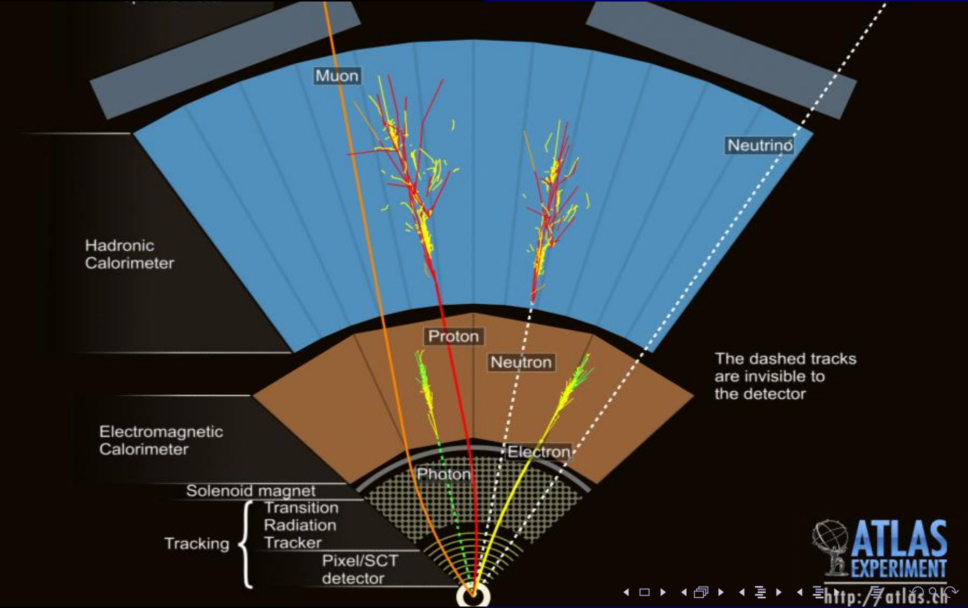
Identifies and measures the momenta of muons

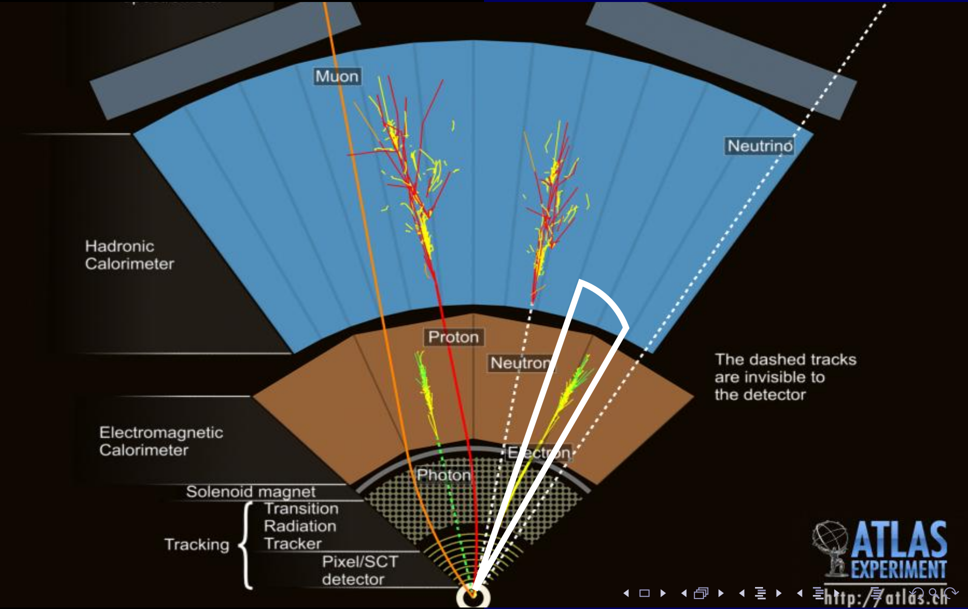
Atlas detector



Magnet system

Bending charged particles for momentum measurement


Muon
Neutrino
Hadronic Calorimeter
Proton
Neutron
The dashed tracks are invisible to the detector
Electromagnetic Calorimeter
Electron
Photon
Solenoid magnet
Transition Radiation Tracker
Tracking
Pixel/SCT detector
ATLAS EXPERIMENT
http://atlas.ch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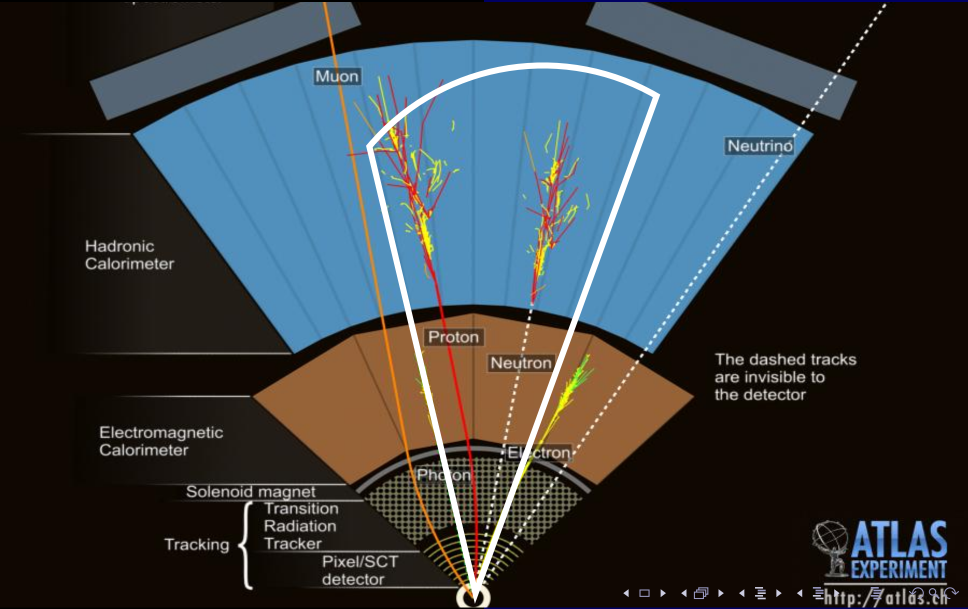
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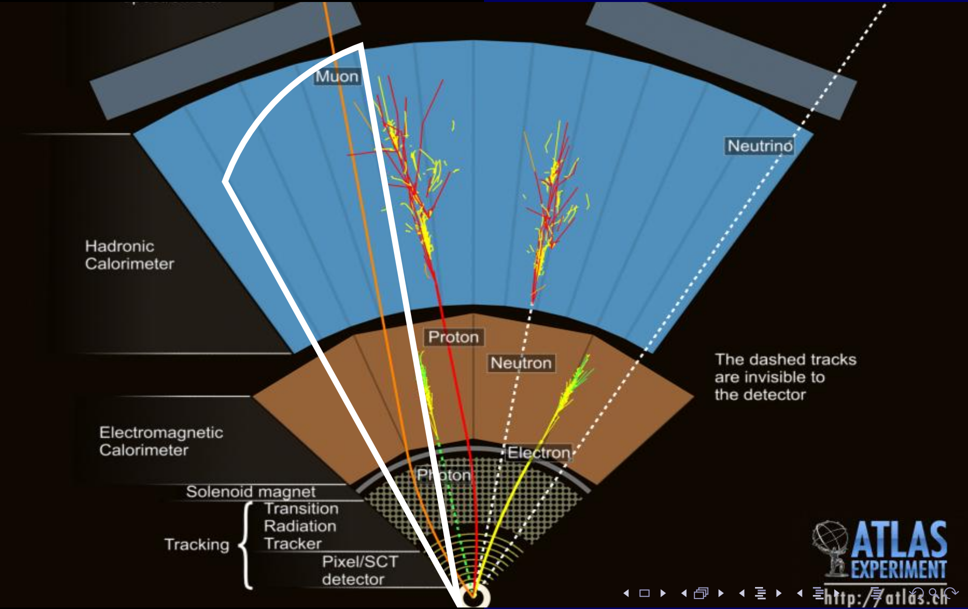
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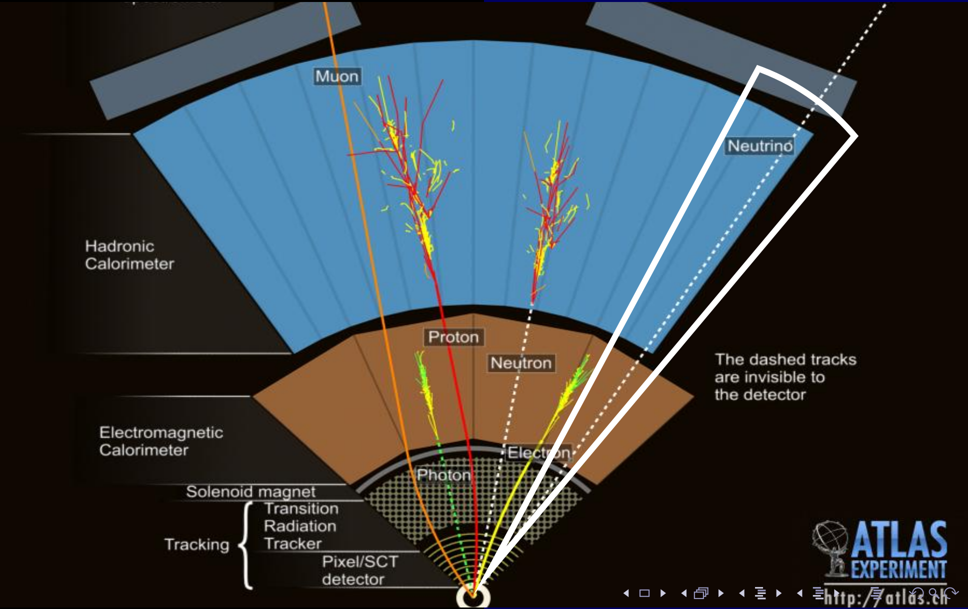
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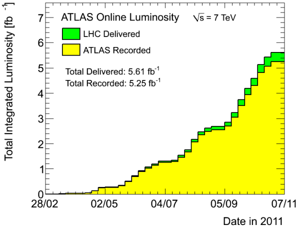
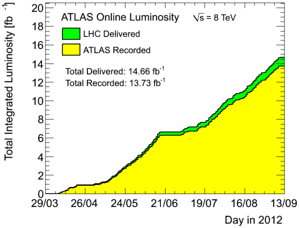
Atlas detector

Atlas detector was designed to:

- Confirm predictions of the Standard Model.
- Improve measurements of the Standard Model.
- Look for New Physics.

- It recorded 5.25 fb^{-1} at 7 TeV.
- It has recorded more than 13 fb^{-1} in 2012!
- Efficiency $\approx 94\%$.

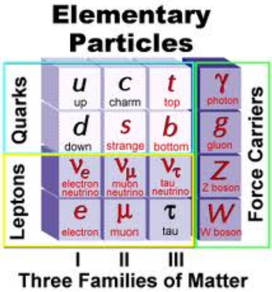




Standard Model

The Standard Model explains all the hundreds of particles and complex interactions only with :

- 6 quarks $\times$3 colors.
- 6 leptons.
- 12 Force carrier particles.
- Higgs boson.



The SM explains the fundamental forces as resulting from matter particles exchanging other particles (force carrier particles).

... but it does not tell the whole story!

Standard Model

- Gravity is not incorporated.
- Generations matter → Why are there three generations of particles?
- Antimatter → Why is there more matter than antimatter in the universe?
- What about the dark matter and dark energy?
- EWSB → Which is its origin? Is the new boson discovered the **SM Higgs particle?**

Top quark as the most sensitive particle to New Physics

In many theories the top quarks plays a special role.

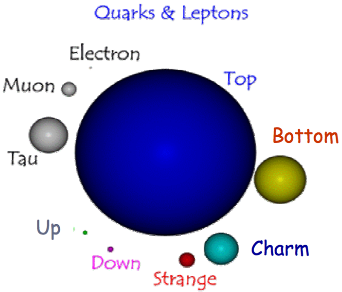
Large mass

$\Downarrow$

Strong coupling to the Higgs

$\Downarrow$

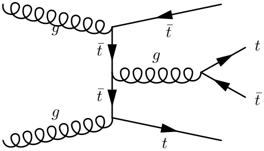
Suggests significant interactions with the New Physics.



Its large mass can be an indication that it is special in some way!

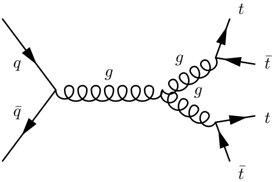
4-tops production in SM

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



76 Feynman diagrams!

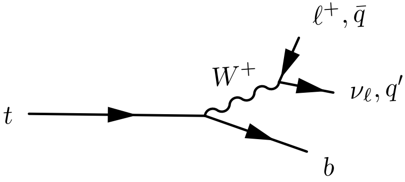
- $q\bar{q} \to t\bar{t}t\bar{t}$ (15%)



28 Feynman diagrams!

Top decay

- Top decay: $t \to Wb$ around 100% times.



Leptonic	Hadronic
$W^+ \to \ell^+\nu$	$W^+ \to q\bar{q}'$
$W^- \to \ell^-\bar{\nu}$	$W^- \to q\bar{q}'$

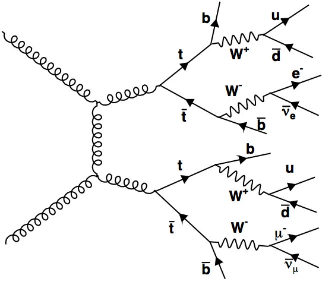
W decay

- How many final states can we obtain from 4-top quarks?

Final states

There are 35 final states from 4-top quarks depending on the W decay (h, e, μ, τ), which are constituted of 5 different classes of channels:

- Full hadronic : $8j + 4b$
- Most hadronic: $1\ell + 6j + 4b + MET$
- Semi leptonic: $2\ell + 4j + 4b + MET$
- Most leptonic: $3\ell + 2j + 4b + MET$
- Full leptonic: $4\ell + 4b + MET$



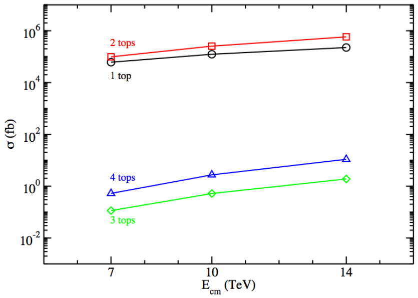
Motivation

- 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!



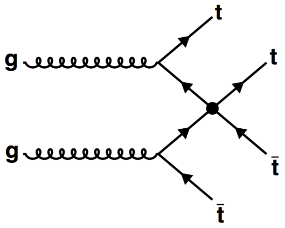
Cross sections for multi-top production in the Standard Model with $m_H = 130 GeV$ (arXiv:1001.0221v3 [hep-ph])

Models with New Physics involving 4-top quarks

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

- Composite top →
- 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

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

- Composite top.
- Randall-Sundrum $\rightarrow$
- Universal Extra Dimensions model.
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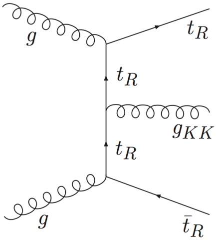
- Predicts a Universe with 5 dimensions.



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

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 →
- 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 supersimetric 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. Determine systematic uncertainties.
6. Validate the background.
7. Results.

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

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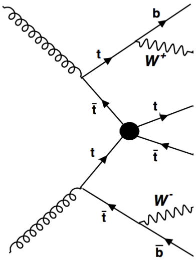
4-tops signal

Model given by C. Degrande *et al.* *"Non-resonant New Physics in Top Pair Production at Hadron Colliders"*, `arXiv:1010.6304`.

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



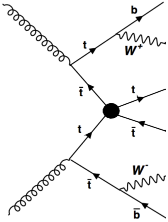
It introduces a new 4-tops contact interaction!

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!

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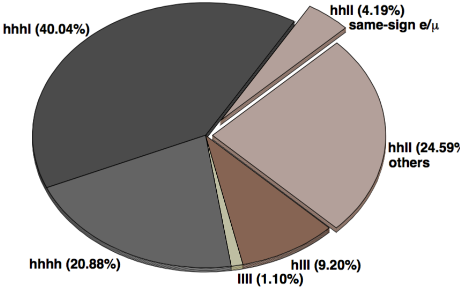
Channel of decay

Easiest channel to select is with two leptons: $hh\ell^{\pm}_{e/\mu}\ell^{\pm}_{e/\mu} \rightarrow BR = 4.15\%$

Why? Production of events with two leptons of the same electric charge have a very low background in the Standard Model.

⇒ Potentially large contributions from new theories!

- 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.

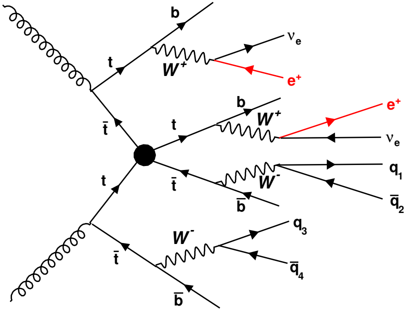


Branching Ratios

Channel of decay

Channel topology:

- 2 charged leptons (electrons and muons).
- 8 jets, including 4 b-jets.
- Missing Transverse Momentum $\not{E}_T$.



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Background

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

- True same-sign dilepton paris: 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 paris $\Rightarrow$ 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

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- 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

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:

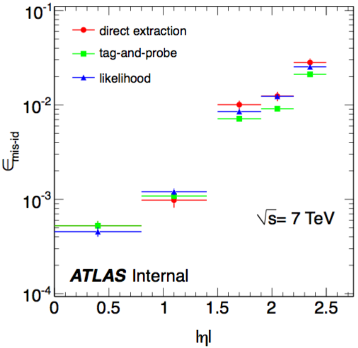
$$e^{\pm} \rightarrow e^{\pm}\gamma^{*} \rightarrow e^{\pm}e^{+}e^{-} \tag{1}$$

  Energy cluster assigned to the wrong track!

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

Electron mis-id estimation

- Estimated by measuring the charge misidentification rate ϵ reconstructing a Z peak using 2 same-sign 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.



Differences on ϵ comes from the kinematic selection

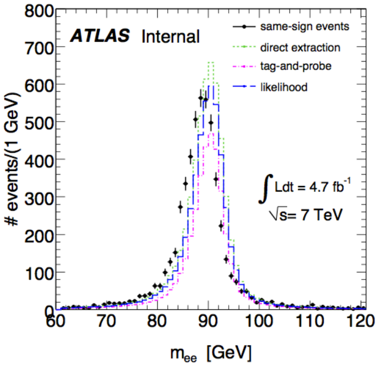
Electron mis-id estimation

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

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

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 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: Fake-Mis-id

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

$$e^{\pm} \rightarrow e^{\pm}\gamma^{*} \rightarrow e^{\pm}e^{+}e^{-} \tag{3}$$

- 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.

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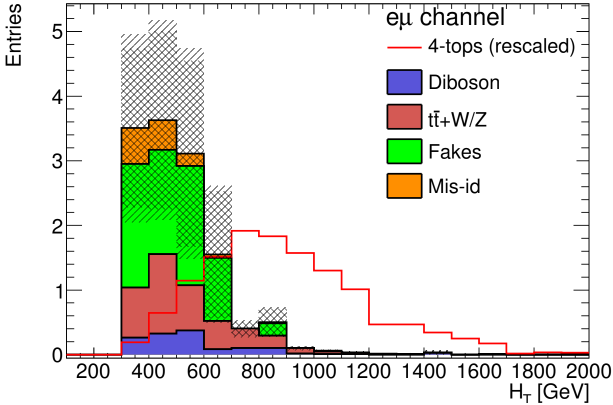
Events selection

- Trigger → 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:
  - ee sample.
  - $\mu\mu$ sample.
  - $e\mu$ sample.
- Z veto → 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).
- $\not{E}_T > 40$ GeV.
- $H_T > 350$ GeV ($H_T = \sum P_T^e + P_T^\mu + P_T^{jets}$)
- At least 1 b jet.

Discriminant variables: Ex. $e\mu$ channel



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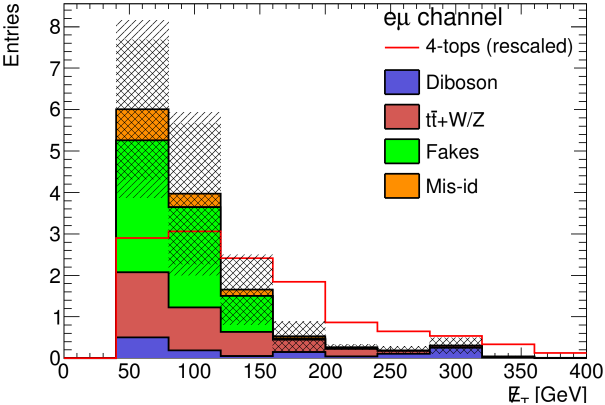
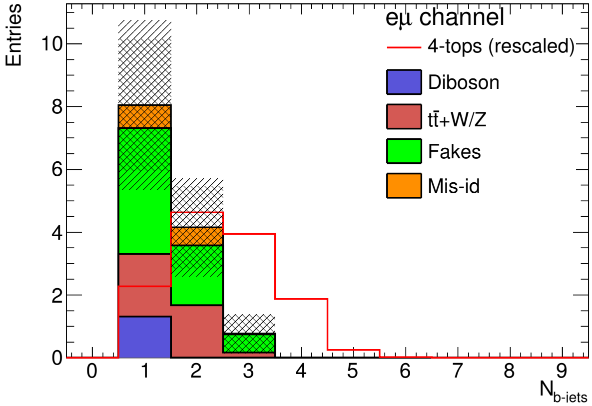
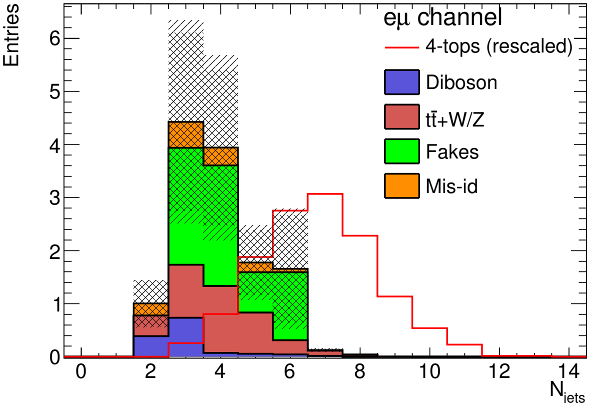


Discriminant variables: Ex. $e\mu$ channel



Discriminant variables: Ex. $e\mu$ channel



Cut optimization

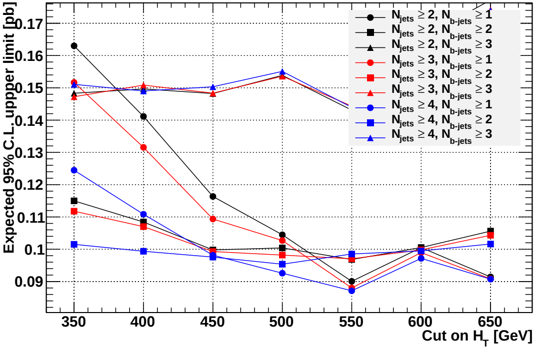
Based on the discriminant variables → The following parameters were variated:

- $H_T \in [350, 650]$ per step of 50 GeV.
- Number of all jets $\in [2, 5]$.
- Number of b jets $\in$ [1,3].
- $\not{E}_T > 40$, 60 GeV.

Optimization done including full systematics (described later)!

GOAL: **Try to get the best expected limit!**

Cut Optimization: $\not{E}_T > 40$ GeV



Choice: $H_T > 550$ **GeV,** $N_j \geq 2$ **and** $N_{b-jets} \geq 1$

Analysis: Procedure

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

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).

Analysis: Procedure

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

Background validation: Control Region

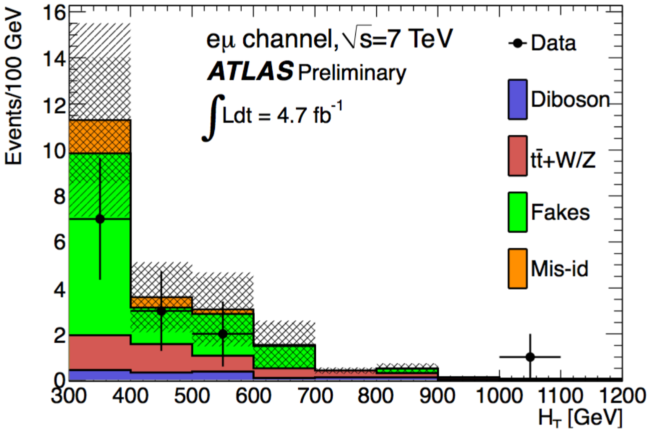
- At least one same-sign pair of leptons.
- $N_{b-jets} \geq 1$.
- Z veto.
- $H_T \in [100, 500]$ **GeV.**
- $N_{jets} \geq 2$.

Background validation: Control Region

Samples	Channel ee	Channel $e\mu$	Channel $\mu\mu$
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	$0.06 \pm 0.03 \pm 0.03$	$0.27 \pm 0.06 \pm 0.14$	$0.15 \pm 0.04 \pm 0.07$
$t\bar{t} + W/Z$			
• $t\bar{t}W(+\text{jet})$	$0.77 \pm 0.04 \pm 0.17$	$3.34 \pm 0.09 \pm 0.73$	$2.06 \pm 0.07 \pm 0.45$
• $t\bar{t}Z(+\text{jet})$	$0.32 \pm 0.02 \pm 0.12$	$1.33 \pm 0.05 \pm 0.48$	$0.88 \pm 0.04 \pm 0.32$
• $t\bar{t}W^{\pm}W^{\mp}$	$0.008 \pm 0.001 \pm 0.002$	$0.033 \pm 0.001 \pm 0.010$	$0.024 \pm 0.001 \pm 0.007$
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 ($\sigma = 12.6$ fb)	0.012 ± 0.003	0.046 ± 0.005	0.027 ± 0.004

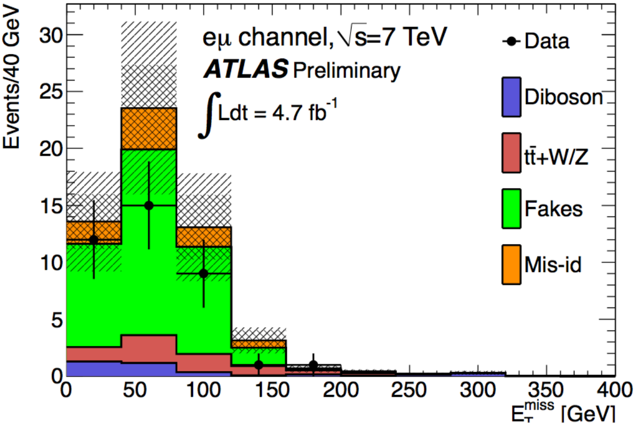
Observed number of events and expected number of background events with statistical (first) and systematic (second) uncertainties for the control region selection.

Comparison with data: $e\mu$ channel



Final selection with no cut on H_T

Comparison with data: $e\mu$ channel



Final selection with no cut on E_T^{miss}

Analysis: Procedure

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

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	$0.52 \pm 1.12 \pm 0.26$	$0.82 \pm 1.05 \pm 0.33$	$0.13 \pm 0.13 \pm 0.04$
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	$0.06 \pm 0.03 \pm 0.03$	$0.07 \pm 0.03 \pm 0.03$	$0.03 \pm 0.02 \pm 0.03$
$t\bar{t} + W/Z$			
• $t\bar{t}W(+\text{jet})$	$0.23 \pm 0.02 \pm 0.07$	$0.79 \pm 0.04 \pm 0.24$	$0.57 \pm 0.04 \pm 0.18$
• $t\bar{t}Z(+\text{jet})$	$0.17 \pm 0.02 \pm 0.09$	$0.61 \pm 0.03 \pm 0.31$	$0.33 \pm 0.02 \pm 0.17$
• $t\bar{t}W^{\pm}W^{\mp}$	$0.008 \pm 0.001 \pm 0.002$	$0.023 \pm 0.001 \pm 0.007$	$0.016 \pm 0.001 \pm 0.005$
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	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 ($\sigma = 12.6$ fb).

Number of events after selection

Samples	Channel: ee	Channel: eμ	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	$0.52 \pm 1.12 \pm 0.26$	$0.82 \pm 1.05 \pm 0.33$	$0.13 \pm 0.13 \pm 0.04$
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)	$0.17 \pm 0.02 \pm 0.09$	$0.61 \pm 0.03 \pm 0.31$	$0.33 \pm 0.02 \pm 0.17$
• $t\bar{t}W^{\pm}W^{\mp}$	$0.008 \pm 0.001 \pm 0.002$	$0.023 \pm 0.001 \pm 0.007$	$0.016 \pm 0.001 \pm 0.005$

Expected events: 5.6 ± 1.7

Observed events: 4

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

Expected number of events after selection for signal ($\sigma = 12.6$ fb).

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	$0.52 \pm 1.12 \pm 0.26$	$0.82 \pm 1.05 \pm 0.33$	$0.13 \pm 0.13 \pm 0.04$
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	$0.06 \pm 0.03 \pm 0.03$	$0.07 \pm 0.03 \pm 0.03$	$0.03 \pm 0.02 \pm 0.03$
$t\bar{t} + W/Z$			
• $t\bar{t}W(+\text{jet})$	$0.23 \pm 0.02 \pm 0.07$	$0.79 \pm 0.04 \pm 0.24$	$0.57 \pm 0.04 \pm 0.18$
• $t\bar{t}Z(+\text{jet})$	$0.17 \pm 0.02 \pm 0.09$	$0.61 \pm 0.03 \pm 0.31$	$0.33 \pm 0.02 \pm 0.17$
• $t\bar{t}W^{\pm}W^{\mp}$	$0.008 \pm 0.001 \pm 0.002$	$0.023 \pm 0.001 \pm 0.007$	$0.016 \pm 0.001 \pm 0.005$

No excess of events has been observed!

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 ($\sigma = 12.6$ fb).

Expected and Observed Limit

Channel	Expected [pb]	Observed [pb]
ee	0.471	0.470
$\mu\mu$	0.150	0.120
$e\mu$	0.147	0.122
Combination	0.090	0.061

Table: **Expected 95% CL. upper limit for all channels and combination.**

Upper limit on the 4-tops production cross section:

$$\sigma_{t\bar{t}t\bar{t}} < 0.061 \textbf{ pb}$$

Conclusion & Outlooks

- There are 4 observed events for an expected background of 5.6 ± 1.7 on the full 2011 data set (4.71 fb^{-1}) at 7 TeV.

  $\rightarrow$ **No excess of events have been observed!**

- It has been set an upper limit on the 4-tops production cross section:

$$\sigma_{t\bar{t}t\bar{t}} < 0.061 \textbf{ pb.}$$

- Results approved to be public yesterday!

  $\rightarrow$ **To be presented at TOP2012.**

Next steps...

- Start to look at 2012 data.
- Do studies for Mis-id background estimation.
- Improve selection.

BACKUP

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:

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

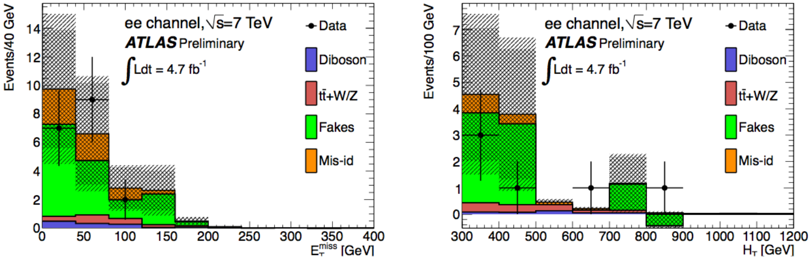
  relating the "true" composition of the sample in terms of real and fake leptons to Tight and Loose leptons.
- The final fake estimation is $N^{fakes}_{TT} = r_1 f_2 N^{ll}_{RF} + f_1 r_2 N^{ll}_{FR} + f_1 f_2 N^{ll}_{FF}$.

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

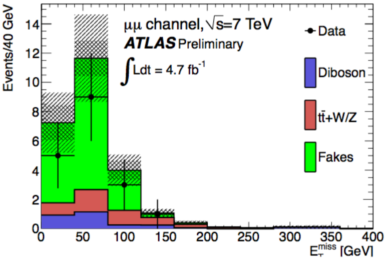
$\rightarrow$ The overlap between the charge misidentification and fakes ($\approx 23\%$) is measured, and this amount is used to rescale the final mis-id estimate.

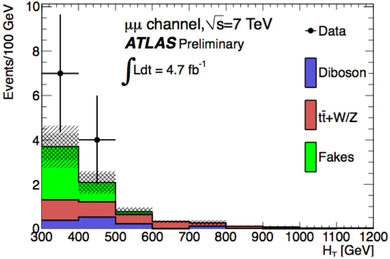
In this moment we are using the Fakes from LPNHE and the Mis-id estimated by Saclay group.

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