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Searches for new physics in multileptons or like-sign leptons with the ATLAS detector

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Events containing several leptons or two like-sign leptons are rarely produced in the Standard Model, but occur with an enhanced rate in many models of new physics. We look for anomalous production of pair of prompt like sign leptons or events with three or more leptons using the data sample recorded in 2011 at $\sqrt{s}$=7 TeV centre-of-mass energy by the ATLAS experiment at the Large Hadron Collider

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1. Introduction

The search for new physics beyond the Standard Model (SM) is one of the main purposes of the ATLAS [1] experiment at the Large Hadron Collider (LHC). Among the many possibilities of how this could be manifested is excess production of multileptons or leptons with the same electric charge. If such signatures are observed they could be the result of the production of new heavy particles, for instance more generations of quarks and leptons, the decays of heavy resonances, supersymmetric particles, and doubly-charged particles. ATLAS is performing both dedicated searches for specific decay chains but also inclusive searches based on a particular signature that is not optimized for any specific model.
The results presented here and at the conference are based on part of or all of the 7 TeV ATLAS dataset. The results have in some cases been updated from preliminary to final status, in those cases references to the most recent results are provided.

2. Inclusive SS search

The search for an excess of leptons[1] with the same electric charge is designed to be sensitive to a broad range of new physics models, such as for instance doubly charged Higgs bosons or heavy neutrinos. The selection is therefore optimized in order to suppress the Standard Model backgrounds as much as possible. In [2] isolated ee and $\mu\mu$ same-sign (SS) pairs are compared in data and Monte Carlo (MC) corresponding to 4.7 fb^{-1} of data after an extensive validation in control regions. The leptons are required to have p_{T} (E_{T}) > 20 GeV (25 GeV for leading electrons) and an invariant mass > 15 GeV. In the $e^{\pm}e^{\pm}$ channel also the mass range $70 < m_{ee} < 110$ GeV is excluded. The preliminary results presented at the conference have now been finalized and published as [3], also including the $e^{\pm}\mu^{\pm}$ channel. The same analysis is also used to set limits on the pair production of doubly charged Higgs bosons [4].
The background is composed of three main components:

a) Real, prompt SS lepton production from diboson production. This is estimated using Sherpa MC normalized to MCFM cross sections.
b) Charge flips, caused by intermediate conversions or charge mismeasurements. The latter is negligible for the energy range explored, but the process of an electron emitting a hard bremstrahlung photon that then converts is very important for electrons. This background is estimated from MC with data-driven corrections, using $Z \rightarrow ee$ decays where the electrons are reconstructed with the same charge.
c) Non-prompt leptons and jets faking leptons. This background is estimated with a data-driven method.

The contributions of each background for the $e^{\pm}e^{\pm}$ and $\mu^{\pm}\mu^{\pm}$ channel can be seen in Figure 1. For the $e^{\pm}e^{\pm}$ channel all three types of backgrounds contribute significantly whereas the diboson background is most important for the $\mu^{\pm}\mu^{\pm}$ channel. The event count for the $e^{\pm}e^{\pm}$ channel is 346 $\pm$ 44 events expected with an observation of 329 events. For the $\mu^{\pm}\mu^{\pm}$ channel the numbers are 247^{+30}_{-29} expected and 264 observed.

[1] In this paper "lepton" refers to electron or muon, not τ lepton

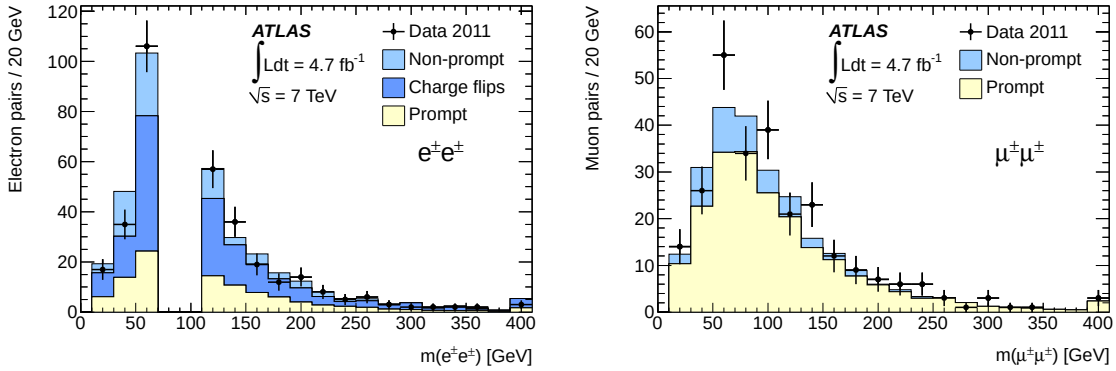

Figure 1: Invariant mass distributions for $e^{\pm}e^{\pm}$ pairs (left) and $\mu^{\pm}\mu^{\pm}$ pairs (right) passing the full event selection [3]. The mass range 70-110 GeV is excluded in the $e^{\pm}e^{\pm}$ analysis due to large backgrounds from Z decays.

No significant excesses were found and the results were used to set limits on the pair production of same-sign leptons. A fiducial region is defined as events passing generator level versions of the offline cuts, including isolation, and the corresponding fraction of these events that pass the full experimental selection is used in the limit calculation. The resulting 95% CL limits are presented in Table 1. To be applicable to a particular model, the acceptance within the fiducial region should be derived and corrected for. Results and limits can also be found in [2] and [3] for the charge-separated cases: e^-e^-, e^+e^+, $\mu^-\mu^-$ and $\mu^+\mu^+$. The largest upward deviation seen corresponds to a p-value of 0.075. This occurs for the $\mu^-\mu^-$ channel in the mass > 100 GeV bin.

Mass range	95% C.L. upper limit [fb]			
	expected	observed	expected	observed
	$e^{\pm}e^{\pm}$		$\mu^{\pm}\mu^{\pm}$	
$M > 15$ GeV	46.0^{+15}_{-12}	42	$24.0^{+8.9}_{-6.0}$	29.8
$M > 100$ GeV	$24.1^{+8.9}_{-6.2}$	23.4	$12.2^{+4.5}_{-3.0}$	15.0
$M > 200$ GeV	$8.8^{+3.4}_{-2.1}$	7.5	$4.3^{+1.8}_{-1.1}$	6.7
$M > 300$ GeV	$4.5^{+1.8}_{-1.3}$	3.9	$2.4^{+0.9}_{-0.7}$	2.6
$M > 400$ GeV	$2.9^{+1.1}_{-0.8}$	2.4	$1.7^{+0.6}_{-0.5}$	1.7

Table 1: Upper limits at 95% C.L. on the fiducial cross section of non-Standard Model physics for $\ell^{\pm}\ell^{\pm}$ pairs taken from [3]. Given are the expected limits and their 1σ uncertainties and the observed limits in data for the ee and $\mu\mu$ final states inclusively and separated by charge.

3. Heavy neutrinos

A model specific search for signatures with SS leptons was performed [5] on events with a like-sign lepton pair and at least one jet in 2 fb^{-1} of data. Two types of models resulting in new heavy neutrinos N are investigated; an effective operator Lagrangian and left-right symmetric

models. This analysis looked at both same-sign and opposite-sign lepton pairs to cover the cases of new Majorana or Dirac neutrinos. Compared to the inclusive analysis, the electron identification cuts are slightly looser and the muon isolation depends on the proximity of jets. Jets are counted if they have $p_{\mathrm{T}} > 20$ GeV and $|\eta| < 2.8$ reconstructed with the anti-k_T algorithm with a radius parameter of 0.4. The main backgrounds are similar to the inclusive same-sign search, and the methods to estimate these are therefore also similar. For the electron charge flip background, however, opposite-sign MC was used due to increased statistics needs.

After testing the predictions in control regions the spectra for reconstructed N and W_R (Figure 2 left) masses are investigated but no signs of new particle production were seen. A total of 268 events were observed in the same-sign signal region compared to 230 ± 52 expected from the Standard Model. In the case of the search for the W_R new gauge boson a requirement that $m(\ell\ell j(j)) \geq 400$ GeV is imposed, and the signal region yield observed is 106 events over a background of 77 ± 21 events. Therefore limits were set on the visible cross section and on the model specific couplings. Limits in the N, W_R mass plane are shown in Figure 2 right. Maximal and minimal mixing here refers to the mixing of the heavy neutrinos N_e and N_μ. For Majorana neutrinos the limit on W_R is m(W_R) > 1.8 (2.3) TeV for Δm(W_R, N) > 0.3 (0.9) TeV.

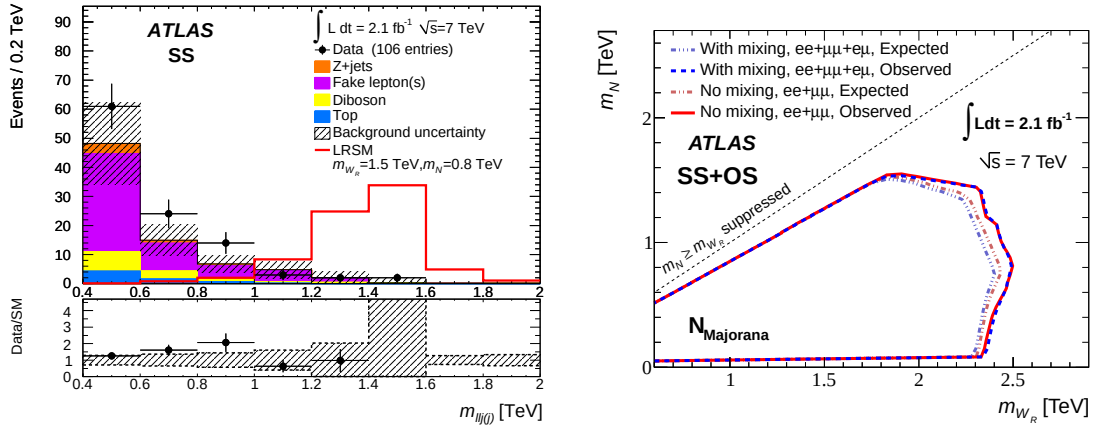

Figure 2: Illustrations from the heavy neutrino search [5]. On the left is shown the reconstructed $m(\ell\ell j(j))$ mass for SS dilepton events with ≥ 1 jets, $m(\ell\ell) > 110$ GeV and $m(\ell\ell j(j)) \geq 400$ GeV. On the right is the resulting 95% C.L. upper limits on the heavy neutrino and W_R masses.

A similar search with 4.7 fb^{-1} is presented in [6].

4. Inclusive multileptons

Also the excess production of multiple (3 or more) charged leptons can be a sign of beyond the Standard Model physics. For the results presented, 1.02 fb^{-1} of data were investigated and documented in [7]. The leptons must pass tight identification cuts, be isolated, and have $p_{\mathrm{T}}(E_{\mathrm{T}}) >$ 20 GeV (25 GeV for the leading lepton). Multilepton events are rejected if they contain a same-flavor, opposite sign lepton pair with an invariant mass consistent with Z boson production, or less than 20 GeV. The main backgrounds come from diboson production and Z / $t\bar{t}$ + a fake lepton. The diboson production is estimated using MC (Herwig) and the Z + jets and $t\bar{t}$ + jets are extracted

from data in control regions. Two signal regions are defined for this analysis: an inclusive region with the cuts mentioned, and a tighter region where p_{T} (E_{T}) > 30 GeV for all leptons, reducing primarily the fake lepton contribution.

The yield in the nominal signal region is 31 events observed with an expected background of 25.9 ± 3.8 (stat) $\pm$ 4.3 (sys) events (see Figure 3 left). For the tighter signal region the observation is 6 events compared to an expectation of $4.9 \pm 1.6 \pm 0.9$.

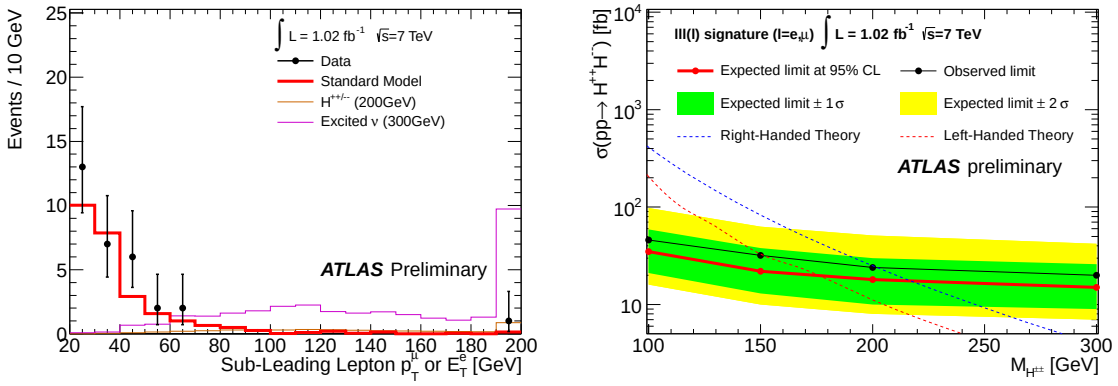

Figure 3: Left: Nominal signal region subleading lepton Pt in trilepton events with SM expectations with models of NP overlaid for both electrons and muons. Right: Tight signal region: Expected and observed cross-section limits on the $H^{++}H^{--}$ model as a function of the doubly-charged Higgs mass. Both plots taken from [7].

With no significant excess limits are set on the production of multileptons. Turning this into fiducial cross-section limits, the nominal signal region observed (expected) 95% CL limit is 38 (28) fb, and for the tighter region, 14 (11) fb. Dedicated models were also investigated and cross section limits on excited ν_e production were set depending on the ν_e* mass: 41 fb for a 200 GeV ν_e* mass and 34 fb if the mass is 300 GeV. In addition this analysis is sensitive to doubly charged Higgs boson production. Figure 3 right shows an example of cross section limits on doubly charged Higgs boson production as a function of mass.

5. Summary

ATLAS has searched for signals of new physics in signatures with multileptons and same-sign dileptons. No evidence for excesses was found and the search continues with more data at 8 TeV center-of-mass energy.

References

[1] ATLAS Collaboration, 2008 JINST 3 S08003

[2] ATLAS Collaboration, ATLAS-CONF-2012-069,
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[3] ATLAS Collaboration, arXiv:1210.4538

[4] ATLAS Collaboration, arXiv:1210.5070

[5] ATLAS Collaboration, Eur.Phys.J. C72 (2012) 2056

[6] ATLAS Collaboration, ATLAS-CONF-2012-139,
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[7] ATLAS Collaboration, ATLAS-CONF-2011-158,
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