PROCEEDINGS OF SCIENCE

Searches for new physics with leptons in ATLAS

Xin Chen[*†]
Department of Physics, University of Wisconsin, Madison, WI 53706, U.S.A.
E-mail: xin.chen@cern.ch

Leptonic final states are rare and have relatively small backgrounds at a hadron collider. Many models of beyond the Standard Model physics predict new particles which may decay into high p_T leptons and/or anomalously large missing transverse energy. A number of exotic signatures, such as W', Z', SUSY, Leptoquarks, LRSM Majorana neutrinos and diboson resonances, are being searched for by ATLAS. The prospects and results of some of these searches with the early data collected by ATLAS in 2010, are presented here.

Workshop on Discovery Physics at the LHC -Kruger 2010
December 05-10, 2010
Kruger National Park, Mpumalanga, South Africa

[*]Speaker.
[†]On behalf of the ATLAS Collaboration.

PoS(Kruger 2010)036

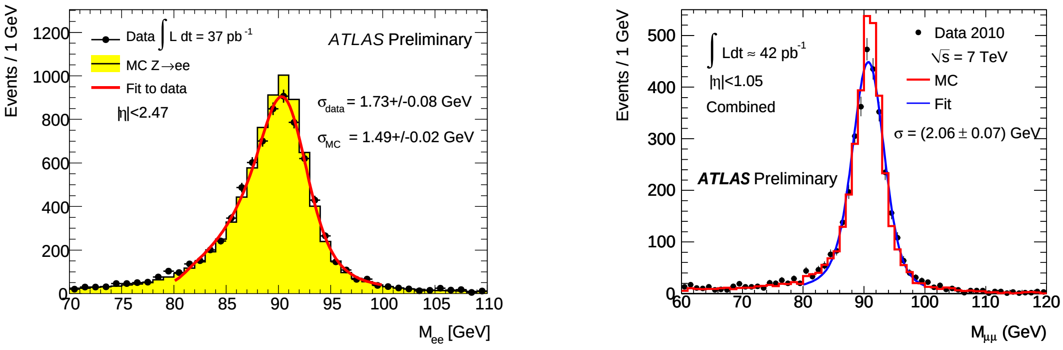

Figure 1: Left: the $Z \to ee$ invariant mass for dielectron pairs. Right: invariant mass distribution for oppositely charged and isolated barrel dimuon pairs.

1. Introduction

Although the Standard Model (SM) has remarkable predictive powers for the known particle physics phenomena, some theoretical problems, such as the need for fine-tuning radiative corrections to the Higgs mass, have led physicists to search for new physics beyond the SM. In some of these models, new particles are predicted from extended gauge symmetries. These new particles can decay into high momentum leptons. Many models[1] predict the existence of new heavy gauge bosons: W' and Z'. These are similar to the SM W and Z gauge bosons but with much heavier masses and undetermined coupling. In the Left-Right Symmetry model (LRSM), the W' may decay into a right-handed Majorana neutrino, which then decays and leads to the possible observation of two same-sign leptons. Leptons can be also found in the cascade decays of the supersymmetric (SUSY) particles such as gluinos and sqarks, whose final state is characterized by leptons + jets + missing transverse energy ($\not{E}_T$). The observed symmetry between leptons and quarks has motivated the search for leptoquarks, hypothetical bosons carrying both lepton and quark quantum numbers, and decay into a lepton and a quark in the same generation. In the absence of a light Higgs, various models predict diboson resonances that can be produced via WW scattering, and which decay into one or more leptons.

ATLAS recorded about 45 pb^{-1} of integrated luminosity of pp collisions at $\sqrt{s} = 7$ TeV in 2010. The detector has performed very well according to the design goals. Fig. 1 shows the dielectron and dimuon invariant mass distributions. Good agreement between data and MC in terms of Z mass peak and resolution is observed. Leptons (electrons, muons and taus that decay leptonically) are efficiently triggered[1]. For $p_T > 20$ GeV, the fake lepton rejection factor is, roughly speaking, 10^2-10^3 (10^3) for the electrons (muons). Analyses searching for new physics involving leptons with the very first data of ATLAS are presented here. For the ones with no available data results yet, prospects based on $\sqrt{s} = 7$ TeV or 14 TeV Monte Carlo (MC) results are given.

[1]The L1 trigger efficiency is about 75-95% (>99%) for muons (electrons).

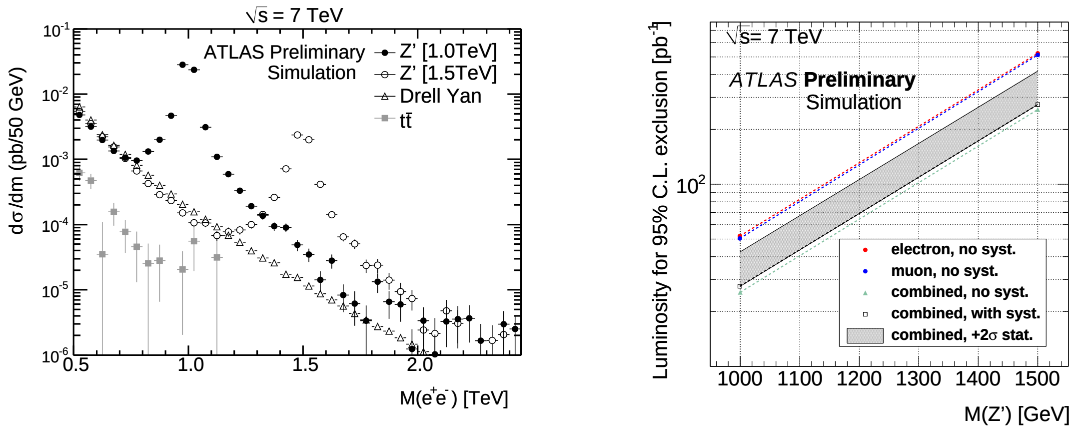

Figure 2: Right: dielectron invariant mass spectra after all cuts. Right: integrated luminosity expected to allow a 95% CL exclusion of the SSM Z' model, as a function of Z' mass.

2. $Z' \to ee, \mu\mu$

To search for a $Z' \to ee$ or $Z' \to \mu\mu$ signature, events with two good leptons with $p_T > 20$ GeV, $|\eta| < 2.5$ and $\sum_{\Delta R<0.3} p_T^{tracks}/p_T^{lepton} < 0.05$ are selected. The single lepton trigger efficiencies are about 98% for events that pass the final cuts. The dielectron invariant mass after all cuts and the exclusion sensitivity for the two channels are shown in Fig. 2, for Z' masses of 1.0 and 1.5 TeV in the Sequential Standard Models (SSM) [2] with SM-like couplings. The Z' resolution in the dimuon channel is worse than in the dielectron channel, since the muon p_T resolution deteriorates to about 10% (barrel) at 1 TeV, whereas the electron one stays around 1% owing to the EM calorimeter. Under the Z' peak, the main SM backgrounds are the Drell-Yan process ($Z/\gamma^* \to ee, \mu\mu$) and $t\bar{t}$. A 1.5 TeV Z' in SSM can be excluded with about 400 pb^{-1} of data including systematics, while the current CDF limit is around 1 TeV[3]. It is worth noting that Z' can also be searched for in the $\tau\tau$ and $t\bar{t}$ decays mode if Z' prefers to couple to the third generation, but these channels are more difficult to reconstruct and need higher luminosity to observe.

3. $W' \to e\nu, \mu\nu$

To search for $W' \to e\nu$ in data, ATLAS selects events with (1) at least one primary vertex with at least 3 associated tracks, (2) no jets with large calorimeter noise, (3) exactly one medium electron with $p_T > 20$ GeV within the tracking acceptance and well isolated, (4) $\not{E}_T > 25$ GeV to reject low $\not{E}_T$ events such as QCD multijet. Fig. 3 shows the transverse mass (m_T) distribution after all cuts and the W' exclusion limits by counting the events in the $m_T > 0.7 m_{W'}$ region. Very good agreement between the m_T distributions in data and SM prediction is observed. The main backgrounds left after all cuts are W/Z and QCD multijet, which are small compared to the signal. A 465 GeV W' in the SSM is excluded at 95% CL with 0.317 pb^{-1} of data in the $e\nu$ channel alone, which is consistent with the limit of 1 TeV from D0 [4]. A similar sensitivity is expected in the $W' \to \mu\nu$ channel. With about 500 pb^{-1} of data, a 2 TeV W' (SSM) can be excluded at 95% CL with the $e\nu$ and $\mu\nu$ channels combined.

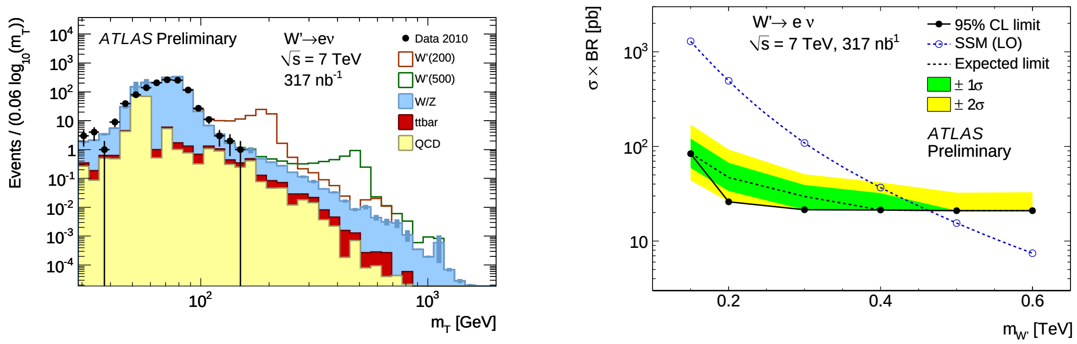

Figure 3: Left: m_T spectrum after the final cuts. Right: Limits on W' production as a function of W' mass with 317 nb^{-1} of data.

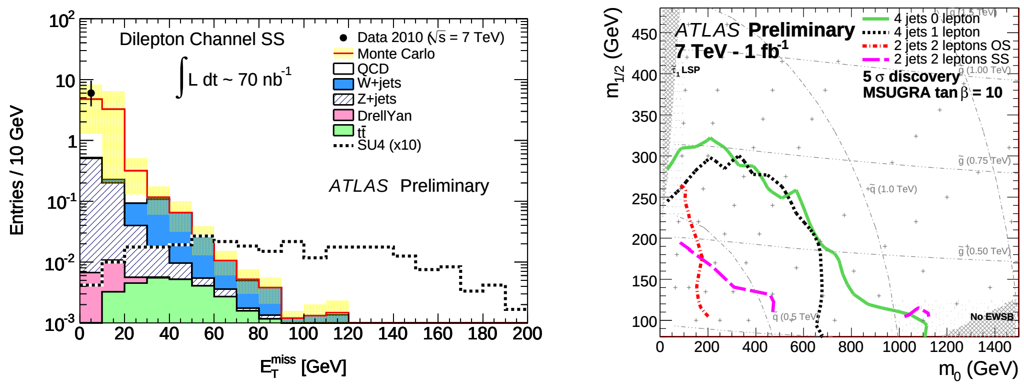

Figure 4: Left: the $\not{E}_T$ distribution for dilepton events with equal lepton charge. Right: 5σ discovery reach as a function of m_0 and $m_{1/2}$ in the mSUGRA model.

4. SUSY leptonic decay modes

SUSY introduces a new symmetry between the bosons and fermions, protects the SM Higgs mass, allows a unification of the electroweak and strong forces, and many models of SUSY provide a dark matter candidate. If SUSY exists, gluino/squark pairs can be copiously produced (subject to the mass scale) at LHC, and one or more leptons can be found in the cascade decays of the super particles, together with multiple jets and large $\not{E}_T$. The $\not{E}_T$ distribution in the same-sign 2-lepton channel and the 5σ discovery reach in the mSUGRA [5] model are shown in Fig. 4. It is expected that with 1 fb^{-1} of data, a large corner of parameter space in the mSUGRA model can be discovered, which corresponds to gluino and squark masses of up to about 700 GeV.

5. Leptoquarks

Leptoquark (LQ) can be pair-produced via QCD and LQ-lep-LQ couplings at LHC. The selection requires at least 2 leptons and 2 jets, large p_T sum of leptons and jets ($\gtrsim$500 GeV), large

PoS(Kruger 2010)036

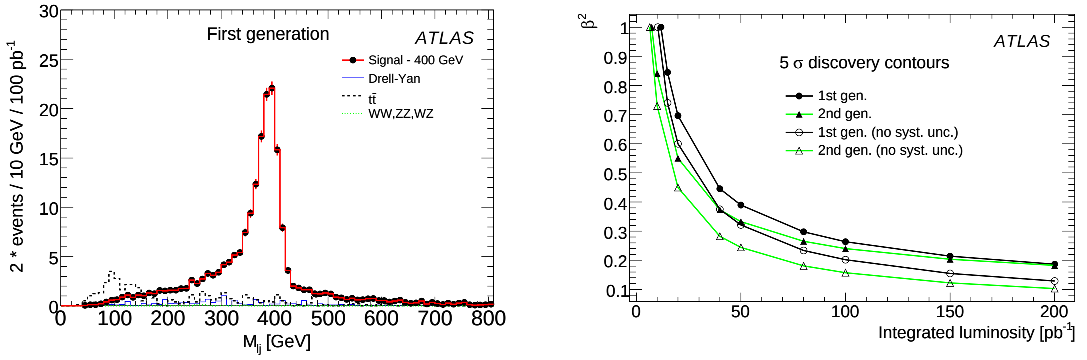

Figure 5: Left: electron-jet invariant mass for the 1st generation LQ with $m_{LQ} = 400$ GeV after all cuts and normalized to 100 pb^{-1}. Right: 5σ discovery potential for 1st and 2nd generation LQs with $m_{LQ} = 400$ GeV.

dilepton mass ($m_{ll} \gtrsim$120 GeV). Lepton-jet pair ambiguity is resolved by minimizing the mass difference of such two pairs. The dominant backgrounds after all cuts are Drell-Yan/Z and $t\bar{t}$. For $\beta = BR(LQ \to lq) = 1$, D0 limit on the LQ mass is around 250 GeV [6]-[7]. The electron-quark pair invariant mass and the ATLAS 5σ discovery potential (at $\sqrt{s} = 14$ TeV) are shown in Fig. 5.

6. $W_R \to 2l + 2j$ in LRSM

In the LRSM, the W' couples to right-handed fermions (thus denoted as W_R). It can decay into a lepton and a heavy neutrino N_R, which then decays into a lepton and two quarks. Due to the Majorana nature of N_R, these two leptons can have the same charge, which leads to the observation of lepton number violation ($\Delta L = 2$) with no $\not{E}_T$. In the analysis, at least 2 leptons and 2 jets are required, with large p_T sum of leptons and jets (>700 GeV) and large dilepton mass (>300 GeV). The lepton+2jets combination ambiguity for N_R is resolved by taking the one with the smaller mass. The current D0 limit on W_R is about 750 GeV [8] in the decay mode of $W' \to tb$. Fig. 6 shows the $e+$2jets invariant mass distribution and the 5σ discovery contour for two signal samples with no flavor mixing (at $\sqrt{s} = 14$ TeV): (1) $m_{W_R} = 1800$ GeV, $m_{N_R} = 300$ GeV; (2) $m_{W_R} = 1500$ GeV, $m_{N_R} = 500$ GeV.

7. Diboson resonaces

In the absence of a light Higgs with $m_H \lesssim 700$ GeV, new physics must exist at some high energy scale based on the arguments of vector boson scattering unitarity [9], possibly in the form of diboson resonances. To search for them, diboson resonance signals are generated with an effective Chiral Lagrangian. Two forward tagging jets plus central jet veto are required for the analysis. The main backgrounds are W/Z+4jets and diboson+2jets. Signals can be reconstructed in the subchannels of $WW/WZ \to l\nu jj$, $WZ \to jjll/l\nu ll$ and $ZZ \to \nu\nu ll$. However, to establish a discovery of these subchannels, about 55-235 fb^{-1} of data (at $\sqrt{s} = 14$ TeV) is needed.

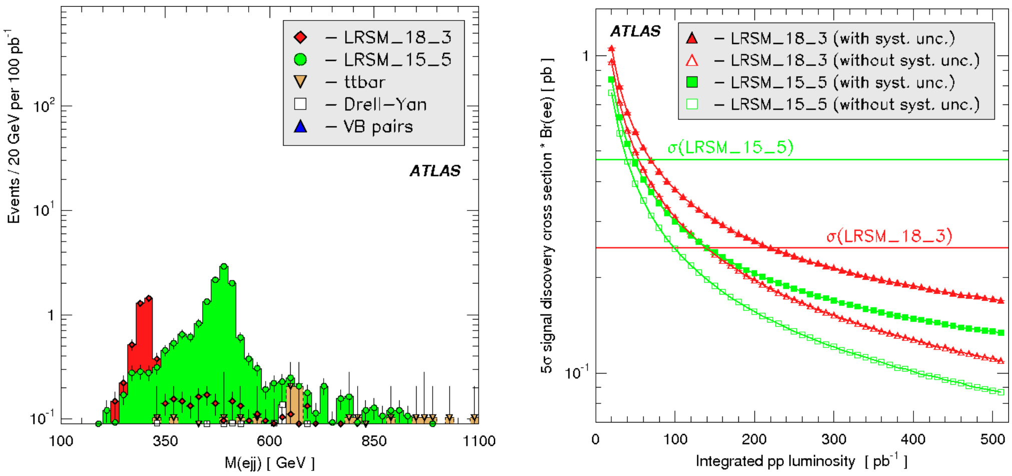

Figure 6: Left: the ejj invariant mass for N_R candidates after the background suppression cuts in the dielectron channel (normalized to 100 pb^{-1}). Right: the necessary signal $\sigma \times$BR for a 5σ discovery as a function of integrated luminosity in the dielectron channel.

8. Conclusions and outlooks

Many new physics models include leptons in the final state, which can be efficiently triggered and cleanly reconstructed by ATLAS. The early data of SM W/Z benchmarks is available to calibrate the leptons and check against the MC prediction and detector simulation. In general, the ATLAS MC is well tuned and agrees with data. A W' with SM coupling and mass of 465 GeV is excluded at 95% CL by 0.317 pb^{-1} of initial ATLAS data collected in 2010. Distributions of SUSY-sensitive variables show no evidence of SUSY based on 70 nb^{-1} of data. Prospects and expected sensitivities of searches for W', Z', SUSY, Leptoquark, W_R and Majorana neutrinos in LRSM, and diboson resonances are also summarized in this note. Data results based on higher luminosities have yet to come, but the sensitivities will surpass Tevatron in many new physics search channels as new data continues to be collected in year 2011 and onwards.

References

[1] C. Amsler *et al.*, *Reviews on W′ and Z′*, Phys. Lett. **B 667** (2008) 1.

[2] G. Altarelli, B. Mele, M.Ruiz-Altaba, Z. Phys. **C 45** (1989) 109.

[3] T. Aaltonen *et al.*, Phys. Rev. Lett. **102** (2009) 091805.

[4] V. M. Abazov *et al.*, Phys. Rev. Lett. **100** (2008) 031804.

[5] A.H. Chamseddine, R. Arnowitt, Pran Nath, Phys. Rev. Lett. **49** (1982) 970.

[6] V. M. Abazov *et al.*, Phys. Lett. **B 636** (2006) 183.

[7] V. M. Abazov *et al.*, Phys. Rev. **D 71** (2005) 071104.

[8] V. M. Abazov *et al.*, Phys. Rev. Lett. **100** (2008) 211803.

[9] B.W. Lee, C. Quigg, H.B. Thacker, Phys. Rev. Lett. **38** (1977) 883.