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Search for dilepton and lepton+E_T^{miss} resonances at high mass with ATLAS

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Abstract. We present the discovery potential for a heavy new resonance decaying into lepton pairs, or into a high p_T lepton and missing E_T, using the ATLAS detector at the LHC. The dilepton and lepton+E_T^{miss} final states are robust signatures to look for new physics due to their simplicity. The unprecedented center-of-mass energy (c.m.e.) available allows exploring mass regions that are inaccessible to present colliders. The aim of this work is to study prospects for discovering BSM physics with an integrated luminosity in the range between 100 pb^{-1} and 10 fb^{-1} at 14 TeV c.m.e.

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INTRODUCTION

New heavy gauge bosons are predicted by wider symmetry groups as in GUTs (Grand Unified Theories) or more fundamental theories like Superstring Theories [1], or extra-dimensions (Kaluza-Klein model) which are possible extensions of the Standard Model. ATLAS has studied the dilepton and lepton+E_T^{miss} signatures to search for these particles. All the results presented here correspond to proton-proton collisions at 14 TeV c.m.e.

DILEPTON

The neutral heavy gauge bosons are produced mainly by Drell-Yan process. In the detector the clearest signatures will be a heavy resonance decaying into a pair of muons or electrons. If a high-mass dilepton resonance is discovered, ATLAS will be able to measure its mass, decay width, differential cross-section[1], spin and branching ratios.

Discovery Potential

Several benchmark $Z' \rightarrow \ell^+\ell^-$ models have been analyzed in ATLAS.

In ATLAS, the electron identification efficiency for a 1 TeV Z', obtained by selecting clusters with p_T>50 GeV and $|\eta|$<2.5 is around 80% using the *loose* selection as

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1 $\frac{d\sigma}{dMdyd(\cos\theta^*)} = \frac{Mx_Ax_B}{48\pi}\left[\sum_q \left[f_q^A f_{\bar{q}}^B + f_{\bar{q}}^A f_q^B\right] S_q(1+z^2) + \sum_q \left[f_q^A f_{\bar{q}}^B - f_{\bar{q}}^A f_q^B\right] 2A_q z\right]$. Where $S_q(A_q)$ is the contribution to the cross-section for $q\bar{q} \rightarrow e^+e^-$ which is (anti)symmetric in $z = \cos\theta^*$; f^A and f^B: parton densities depending on the momentum fractions of the quarks in hadrons A and B (x_A and x_B) [2].

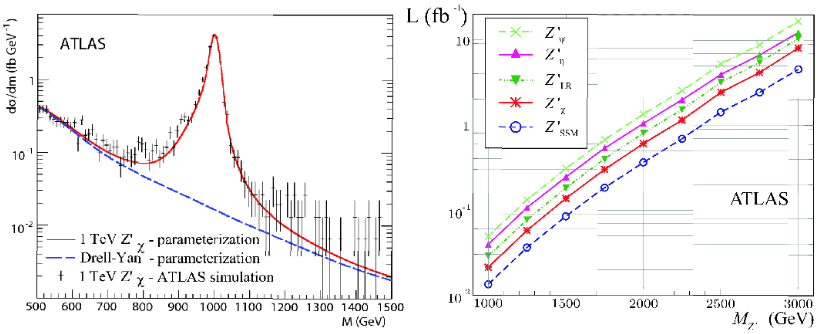

FIGURE 1. Discovery potential of $Z' \to e^+e^-$. Left: Invariant mass of Z'_χ fitted using Breit-Wigner function convoluted with a Gaussian function; Right: 5σ luminosities for several $Z' \to e^+e^-$ models [3].

defined in [3]. For each muon coming from a 1 TeV Z', the reconstruction efficiency is 95% requiring p_{T}>30 GeV and $|\eta|$<2.5. The event selection criteria are the following:

Dielectron Two *loose* electrons with $|\eta|$<2.5 and at least one electron with p_{T}>65 GeV. Events triggered and two electrons with opposite charge (see Fig. 1).

Dimuon Two *combined* muons [3] with $|\eta|$<2.5 and at least one with p_{T}>30 GeV. Events triggered and two oppositely charged muons.

Backgrounds considered were dijets, diphoton, jet+γ, W+jets, Z+jets, Drell-Yan, $W+\gamma$, $Z+\gamma$. After the selection criteria, the main background is Drell-Yan.

Figure 1 (right) shows the 5σ luminosities of the benchmark $Z' \to e^+e^-$ models. To discover a 1 TeV Z', less than 100 pb^{-1} is needed; for a 2 TeV Z', about 1 fb^{-1} is needed, and about 10 fb^{-1} is needed to discover a 3 TeV Z'. The luminosities needed for 5σ discovery for $Z'_{SSM} \to \mu^+\mu^-$ are shown in Fig. 2. About 25 pb^{-1} is needed to discover a 1 TeV Z'_{SSM} and about 3.4 fb^{-1} is needed to discover a 3 TeV Z'_{SSM}. The right plot of Fig. 2 compares the estimated significances by three different methods: number-counting, a fit with fixed mass and a fit with floating Z' mass[2]. The CDF Collaboration has excluded at 95% C.L. masses below 966 GeV and 1030 GeV in the dielectron and dimuon channels, respectively [5].

The theoretical uncertainties (renormalization/factorization scales, PDF's and non perturbative form factor) contribute $\pm$8.5% for 1 TeV Z' and $\pm$14% for 3 TeV Z'. A K-factor (1.26) was applied to the signal and Drell-Yan background as well [3]. The main systematic uncertainties in dielectron channel are the energy resolution and electron energy scale, which increase the luminosity needed for 5σ discovery by 5% and 2.5%, respectively. For high p_{T} muons (>300 GeV) the muon spectrometer alignment is the main contribution to the momentum degradation which increases the 5σ luminosity by 42% when a 300μm misalignment is taken into account (see left plot of the Fig. 2).

For the recontruction of a Z' in the tau decay channel, the final states hadron-hadron, lepton-hadron and lepton-lepton were combined. Events were selected using a combined tau and $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger (see [4]). The reconstructed mass is defined by the collinear ap-

[2] The functional form for the signal was: Breit-Wigner times Landau with a common mean [3]

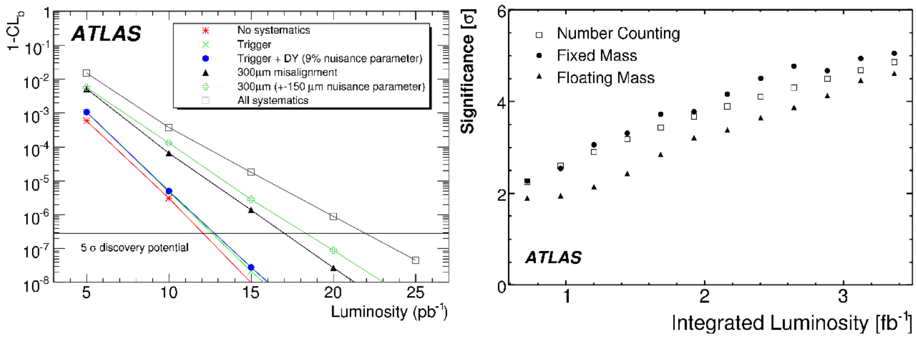

FIGURE 2. Discovery potential for $Z' \to \mu^+\mu^-$. Left: The $1-CL_b$ as a function of integrated luminosity for 1 TeV Z'_{SSM}. Right: The significance as a function of the integrated luminosity for 3 TeV Z'_{SSM} [3].

proximation[3]. Backgrounds were the Drell-Yan, Z+jets, $t\bar{t}$ and QCD. Including 20% of uncertainty[4], a Z' mass around 700 GeV could be observed with 100 pb^{-1} of data [4].

The discovery potential for Gravitons decaying to two electrons has also been studied by ATLAS; here, two back-to-back *loose* electrons were selected without imposing any charge requirements. A K-factor (1.6) was applied to the signal and Drell-Yan background. Taking into account the combined effect of the systematic uncertainties (signal and Drell-Yan background) which increases the 5σ luminosity between 10% and 15%, a 900 GeV Graviton can be discovered with 1 fb^{-1} of data [3].

LEPTON+$E_{\mathrm{T}}^{\mathrm{miss}}$

The heavy gauge charged W' boson [6] corresponds to a symmetry spontaneously broken down to the left-right symmetry [7].

Discovery Potential

The observation of the W' is based on the detection of a a sharp upper edge (see Fig. 3) in the differential cross-section[5] as a function of the transverse mass defined as the combination of the p_{T} of the single lepton in the event, the missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) and the angle between them in the transverse plane:

$$m_T = \sqrt{2p_{\mathrm{T}}E_{\mathrm{T}}^{\mathrm{miss}}(1-\cos(\Delta\phi_{l,E_{\mathrm{T}}^{\mathrm{miss}}}))} \tag{1}$$

[3] $m_{col} = m_{\tau\tau^{vis}}/(x_{\tau_1}x_{\tau_2})^{1/2}$. $m_{\tau\tau^{vis}}$ is the invariant mass of the 2 tau visible decay products and $x_{\tau_1}x_{\tau_2}$ are the fraction of the tau momenta carried by the visible decay daughters.

[4] Systematic uncertainty coming from the luminosity and hadronic tau energy scale [4]

[5] $\frac{d\sigma}{d\tau dy dz} = K\frac{G_F^2 m_W^4}{48\pi}\sum_{qq'}|V_{qq'}|^2\left[SG^+_{qq'}(1+z^2)+2AG^-_{qq'}z\right]$. The coupling strengths, the helicity factors and s^2 are implicit in S and A; $|V_{qq'}|^2$: CKM matrix; $G^{\pm}_{qq'}$: combinations of the PDF; $z=\cos\theta$, with θ c.m. angle between the incoming quark and the outgoing neutrino; $\tau = M^2/s$: M^2 invariant mass of the $\ell\nu$ [8]

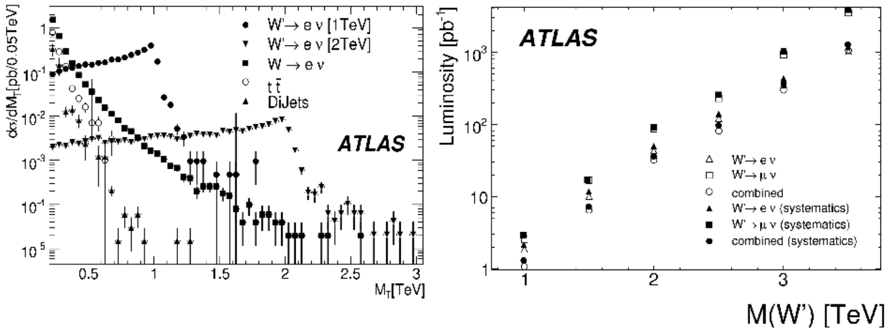

FIGURE 3. Discovery potential of W'. Left: Invariant mass of the W' and W, $t\bar{t}$ and Dijets backgrounds in electron channel. Right: Luminosity needed for 5σ discovery as a function of the W' mass [3].

In ATLAS, the muon reconstruction efficiency is around 93% for a W' in a mass range between 1 TeV and 2 TeV. The average resolutions of $E_{\mathrm{T}}^{\mathrm{miss}}$ for W' are: 18 GeV and 25 GeV for 1 TeV and 2 TeV W' to muon-neutrino and 10 GeV and 14 GeV for 1 TeV and 2 TeV W' to electron-neutrino, respectively.

There is a preselection where events with only one lepton with p_{T}>50 GeV, $|\eta|$<2.5 and $E_{\mathrm{T}}^{\mathrm{miss}}$>50 GeV are kept. The lepton has to be isolated. Then, only events without a high energy track around the lepton trajectory are accepted. Backgrounds for W' were W, $t\bar{t}$ and dijets; the lepton fraction variable, as defined in [3], was used to reduce the dijets and $t\bar{t}$ backgrounds. Figure 3 (right) shows the 5σ luminosities for W'. To discover a 1 TeV W', 10 pb^{-1} is needed; to reach W' masses up to 3 TeV, 1 fb^{-1} is needed[3]. The theoretical uncertainties (renormalization/factorization scales and PDF's) are $\pm$8% on K-factor (1.37) for all W' masses. The effect of all systematic uncertainties (see [3]) on the 5σ luminosity for W' is shown in the right plot of Fig. 3.

CONCLUSIONS

The dilepton and lepton+$E_{\mathrm{T}}^{\mathrm{miss}}$ signatures are promising searches for early data and the ATLAS experiment is ready to explore the new physics beneath them. To discover a 1 TeV Z' in dielectron and dimuon channels, ATLAS needs less than 100 pb^{-1} and about 25 pb^{-1}, respectively. About 100 pb^{-1} is needed to observe $Z' \rightarrow \tau^+\tau^-$ at 700 GeV, and for a 900 GeV Graviton, 1 fb^{-1} is needed. For a 1 TeV W', 10 pb^{-1} is needed in ATLAS.

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