Search for Dilepton and Lepton + MET resonances at high mass with ATLAS Experiment at LHC

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Motivation

- The unification of fundamental interactions as well as some SM deficiencies have motivated the introduction of extended gauge symmetries, featured by several possible extensions of the SM
  - GUTS
  - Superstring-inspired E6 models
  - Extra-dimentions (Kaluza-Klein model)
  - etc...
- $Z'$ and $W'$ are the generic names of the new heavy gauge bosons introduced in those extensions
- ATLAS has studied the dilepton and lepton+MET signatures to search for this particles using 1.21fb-1 of integrated luminosity recorded this summer.
ATLAS Detector

- High energy electrons are detected by the LAr calorimeter, and identified using shower shapes, track matching, etc...

- Muons are detected by the Muon System, and their momenta obtained by a combination with the Inner Detector information
Lepton Resolution

• Electrons
  • Isolated energy deposition in the calorimeter
    \[ \frac{\sigma(E)}{E} = \frac{k_1}{\sqrt{E}} + k_2 \]
  • For high energy electrons, the resolution is dominated by constant term \(k_2\) which is 1.2% in the barrel and 1.8% in the endcap

• Muons
  • At high \(p_T\) curvature resolution dominated by intrinsic/mis-alignment term \(S_2\) which ranges from 0.15/TeV to 0.44/TeV (for \(\eta > 2\))
    \[ \frac{q}{p_T} + \left( \frac{q}{p_{T \text{ ini}}} \right) + S_1 \left( \frac{q}{p_{T \text{ ini}}} \right) + S_2 \]
Introduction

- \( Z'(SSM) \) is a benchmark model with the same couplings constants as the usual \( W \) and \( Z \).

- The neutral gauge boson are produced via the Drell-Yan process: \( pp \rightarrow Z' \rightarrow l^+l^- \) (\( l=\text{e},\mu \)), clean signature.

- The differential cross-section for the lepton-pair production depends on:
  - Center of mass energy
  - \( Z' \) couplings
  - \( Z' \) invariant mass \( M \), its rapidity \( y \)
  - The c.m angle \( \theta^* \)

- If a \( Z' \) is discovered we will be able to measure:
  - Its mass, decay width
  - The total cross-section
  - Its spin and its branching ratios

\[ \frac{d\sigma}{dMdyd(\cos\theta^*)} = \frac{M_{x_A x_B}}{48\pi} \left[ \sum_q \left[ f_q^A(x_A)f_q^B(x_B) + f_q^I(x_A)f_q^I(x_B) \right] S_q(1 + \cos^2 \theta^*) \right. \]

\[ \left. + \sum_q \left[ f_q^A(x_A)f_q^B(x_B) - f_q^I(x_A)f_q^I(x_B) \right] 2A_q \cos \theta^* \right] \]

\( S_q \) and \( A_q \) symmetric and antisymmetric contributions to the cross-section in \( \cos \theta^* \) (\( \theta^* \) is the c.m. angle between negative lepton with respect to the quark direction).

\( f^A \) and \( f^B \) are parton densities depending on the momentum fractions of the quarks.

Electron Selection

- EM clusters with $E_T > 25$ GeV, $|\eta| < 2.47$
- Criteria on the transverse shower shape, the longitudinal leakage into hadronic calorimeter
- Removal of transition region between barrel and endcap
- Association to an inner detector track
- Calorimeter isolation for leading electron $< 0.2$ in cone DR of 0.2
Muon Selection

- Combined muons with $p_T > 25$GeV
- Hit requirements in ID and MS require 3 hits in all 3 muon stations to ensure optimal momentum resolution
- Impact parameter cuts: $d_0$ and $z_0$ wrt PV
- Muons opposite charge
Signal and backgrounds

- Z' signal simulated using Pythia
- Backgrounds simulated used:
  - Pythia (Z/γ*)
  - Alpgen (W+jets)
  - Herwig (WW, WZ, ZZ)
  - MC@NLO (ttbar)
- Higher-order corrections MC cross-sections
- Data driven backgrounds:
  - QCD
  - Cosmics
QCD Backgrounds

- Sources for electron channel
  - Photon conversions
  - Semi-leptonic heavy quark decays
  - Hadrons faking electrons
- Methods estimation
  - Reverse electron identification
  - Isolation fit techniques
  - Fake rates from jet samples
- Source for the muon channel
  - Semi-leptonic decays of b and c quarks
- Estimate from muon isolation variable
  - Found to be negligible
Drell-Yan Background

- \(Z/\gamma^*\) the irreducible background which dominates in the entire search region.
  - Using the Pythia with NNLO multiplicative the K-factor correction was predicted
  - This K-factor was applied to the signal
    - The PDFs uncertainties and higher-order corrections are the dominant uncertainties
Dilepton invariant mass

- Normalization to the Z peak
  \[ \sigma(Z') = \sigma(Z) \frac{N(Z')}{N(Z)} \frac{A(Z)}{A(Z')} \]
- No systematics were applied to the signal
- Resolution systematics is negligible
- Remaining systematics

<table>
<thead>
<tr>
<th>Source</th>
<th>dielectrons</th>
<th>dimuons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>signal</td>
<td>background</td>
</tr>
<tr>
<td>Normalization</td>
<td>5%</td>
<td>NA</td>
</tr>
<tr>
<td>PDFs/(\alpha_S)</td>
<td>NA</td>
<td>10%</td>
</tr>
<tr>
<td>QCD K-factor</td>
<td>NA</td>
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<tr>
<td>Weak K-factor</td>
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</tr>
<tr>
<td>Trigger/Reconstruction</td>
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<td>negligible</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>5%</td>
</tr>
</tbody>
</table>
Z' Limits

- Checking if there is a significant excess in the signal: p-value for electrons 54% and for muons: 24%
- Since there is not evidence, we obtained the 95% C.L limits on $\sigma^* B(Z' \rightarrow ll)$ using the cross-section ratio $Z/Z'$
Introduction

- The heavy gauge charge common denoted by $W'$, is the most easily searched for in a their decay to a charged lepton and neutrino.
- The differential cross-section for the $W'$ depends on:
  - Center of mass energy
  - Its couplings, its mass
  - Its rapidity and the c.m angle $\theta^*$
- The observation of the $W'$ is based on the detection of an excess of a single lepton at high $p_T$ above background, with a sharp upper edge (transverse mass)

T. G. Rizzo, JHEP 0705 (2007)

\[
\frac{d\sigma}{d\tau \ dy \ dz} = K \frac{G_F^2 M_W^4}{48\pi} \sum_{qq'} |V_{qq'}|^2 \left[ S G_{qq'}^+(1 + z^2) + 2 A G_{qq'}^- z \right]
\]

- The coupling strengths for leptons and quarks, the helicity factors and the square of the total collision energy are implicitly in $S$ and $A$
- $V_{qq'}$ is the CKM(unit) matrix; $q(q')$ is a $u(d)$-type quark
- $G_{qq'}^\pm$ are the combinations of the parton distribution functions.
- $z$ in the cos$\theta$, the scattering angle in the c.m. frame defined as that between the incoming u-type quark and the outgoing neutrino.
- $\tau = M^2/s$, where $M^2$ lepton-pair invariant mass and $\sqrt{s}=cme$
Electron Selection

- EM clusters with $E_T > 25$ GeV,
  $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$
- Criteria on the transverse shower shape, the longitudinal leakage into hadronic calorimeter
- Calorimeter isolation for leading electron $< 9$ GeV in cone DR of 0.4
- $(\text{MET or } E_T^{\text{miss}}) > 25$ GeV and $E_T^{\text{miss}}/E_T > 0.6$
- One electron per event.
Muon Selection

- Combined muons with pt>25GeV, $|\eta|<1.0$ or $1.3<|\eta|<2.0$
- Hit requirements in ID and MS require 3 hits in all 3 muon stations to ensure optimal momentum resolution
- Impact parameter cuts: $d0$ and $z0$ wrt PV
- One muon per event and $E_T^{miss}>25\text{GeV}$
Signal and backgrounds

- $W'$ signal simulated using Pythia
- Backgrounds simulated used:
  - Pythia Z/W
  - Alpgen (W+jets)
  - Herwig (WW, WZ, ZZ)
  - MC@NLO (ttbar)
  - Higher-order corrections MC cross-sections
- Data driven backgrounds:
  - QCD
  - Cosmics

<table>
<thead>
<tr>
<th></th>
<th>$\ell\nu$</th>
<th>$\mu\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W \to \ell\nu$</td>
<td>$1.59 \pm 0.13$</td>
<td>$1.36 \pm 0.13$</td>
</tr>
<tr>
<td>$Z \to \ell\ell$</td>
<td>$0.00010 \pm 0.00004$</td>
<td>$0.095 \pm 0.005$</td>
</tr>
<tr>
<td>diboson</td>
<td>$0.08 \pm 0.08$</td>
<td>$0.11 \pm 0.08$</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>$0.08 \pm 0.08$</td>
<td>$0$</td>
</tr>
<tr>
<td>QCD</td>
<td>$0$</td>
<td>$0.01 \pm 0.02$</td>
</tr>
<tr>
<td>Total</td>
<td>$1.75 \pm 0.24$</td>
<td>$1.57 \pm 0.15$</td>
</tr>
</tbody>
</table>
Transverse mass

- Transverse mass definition
  \[ m_T = \sqrt{2p_T E_{T\text{miss}}^\mu (1 - \cos \Delta \phi_{l, E_{T\text{miss}}^\mu})} \]

- Signal and background normalized using calculated cross-section and the integrated luminosity of data.

- Remaining Systematics

<table>
<thead>
<tr>
<th>Source</th>
<th>$\varepsilon_{\text{sig}}$</th>
<th>$N_{\text{bg}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>2.7% 3.9%</td>
<td>2.7% 3.8%</td>
</tr>
<tr>
<td>Energy/momentum resolution</td>
<td>0.3% 2.3%</td>
<td>2.9% 0.6%</td>
</tr>
<tr>
<td>Energy/momentum scale</td>
<td>0.5% 1.3%</td>
<td>5.2% 3.0%</td>
</tr>
<tr>
<td>QCD background</td>
<td>-</td>
<td>10.0% 1.3%</td>
</tr>
<tr>
<td>Monte Carlo statistics</td>
<td>2.5% 3.1%</td>
<td>9.4% 9.9%</td>
</tr>
<tr>
<td>Cross section (shape/level)</td>
<td>3.0% 3.0%</td>
<td>9.5% 9.5%</td>
</tr>
<tr>
<td>All</td>
<td>4.7% 6.3%</td>
<td>18% 15%</td>
</tr>
</tbody>
</table>
W' Limits

- None of the observations for any mass in either channel or the combination has a significance above 3σ.
- 95% C.L exclusion limits on \( \sigma^* B(W' \rightarrow l\nu) \)
ATLAS published its latest results from these final states:


Exclusion limits at 95% C.L.:

- $M(Z'_{SSM}) < 1.83\text{ TeV}$
- $M(W'_{SSM}) < 2.15\text{ TeV}$

ATLAS is still motivated to continue searching for high mass resonances