Searches for new fermions and gauge interactions with ATLAS

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on behalf of the ATLAS collaboration

Implications of LHC Results for TeV-Scale Physics, CERN
30 August 2011
Introduction

Standard Model describes data very well, but is only low energy effective theory

New Physics is needed at the weak scale ~1TeV

Searching for New Physics:
- New Gauge Interactions:
  - W-like gauge bosons
  - Z-like gauge bosons
  - Contact Interactions (µµ, di-jet)
- New particles:
  - Doubly Charged Higgs
  - LeptoQuarks
  - lvjj spectrum
  - Di-jet spectrum

- 2010: 45 pb⁻¹ recorded
- 2011 (till 26/08): 2.55 fb⁻¹ recorded
- Peak Lumi of 2.37 \(10^{33}\) cm⁻²s⁻¹
- 6 interactions per BC on average
New Heavy Gauge Bosons
Search for Right-Handed W boson

- Benchmark: Left-Right Symmetric Model
- New gauge boson $W_R$ and Heavy neutrinos (N)
  - $qq\bar{q} \rightarrow W_R \rightarrow lN$, $N \rightarrow lW^*_R \rightarrow l\text{jetjet}$
  - Non-Majorana N: only $l^+l^-$ (OS) final state
  - Majorana N: both $l\pm\pm$ (SS) and $l^+l^-$ (OS) final states
    - Neutrino masses explained via sea-saw mechanism
  - N can mix if masses are different both no-mixing and 100% mixing cases considered
- Data consistent with SM predictions
Search for New Heavy Charged Boson

- Benchmark Signal: $W' \rightarrow l\nu$
- Observable
  $$M_T = \sqrt{2p_T^l E_{\text{T}}^{\text{miss}} (1 - \cos \Delta \phi_{l,E_{\text{T}}^{\text{miss}}})}$$
- Data consistent with SM prediction
- Limit @ 95% CL mass of SSM $W' > 2.15$ TeV (2.08 TeV $e$ & 1.98 TeV $\mu$)

**Search for New Heavy Neutral Gauge Boson**

- **Benchmark Signal:** $Z' \rightarrow l^+l^-$

- Data consistent with DY predictions
- **Limit:** 1.83 TeV @ 95% CL for SSM $Z'$ (1.69 TeV $ee$ and 1.60 TeV $\mu\mu$)
- Limits @ 95% CL on E$_6$ Model $Z'(\text{TeV})$

<table>
<thead>
<tr>
<th>$Z'_\psi$</th>
<th>$Z'_N$</th>
<th>$Z'_\eta$</th>
<th>$Z'_I$</th>
<th>$Z'_S$</th>
<th>$Z'_X$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.50</td>
<td>1.52</td>
<td>1.54</td>
<td>1.56</td>
<td>1.60</td>
<td>1.64</td>
</tr>
</tbody>
</table>

Search for New Heavy Boson with anomalous magnetic type couplings

- $W^* \rightarrow l\nu$ and $Z^* \rightarrow ll$ (same analysis as $W'/Z'$)
- Assume quark-lepton universality gives similar $Z^*/Z'$ width
- At LHC acceptances are also similar thus limits are closely related
- Only $\sim 40$ pb$^{-1}$ of data used so far
- Data consistent with SM predictions
- Limits @ 95% CL with 36 pb$^{-1}$ $M(W^*) > 1470$ GeV (1380 e, 1210 $\mu$)

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<tbody>
<tr>
<td>$Z^* \rightarrow e^+e^-$</td>
<td>1.058</td>
<td>1.062</td>
<td>0.149</td>
<td>0.143</td>
</tr>
<tr>
<td>$Z^* \rightarrow \mu^+\mu^-$</td>
<td>0.946</td>
<td>0.995</td>
<td>0.265</td>
<td>0.199</td>
</tr>
<tr>
<td>$Z^* \rightarrow \ell^+\ell^-$</td>
<td>1.152</td>
<td>1.185</td>
<td>0.089</td>
<td>0.080</td>
</tr>
</tbody>
</table>

W' and Z' limits Expected Evolution

ATLAS Preliminary (simulation)

95\%CL Limit Z' → ee,μμ

Luminosity [pb]

\( m_{Z'} \text{ Mass [TeV]} \)

\( m_{W'} \text{ Mass [TeV]} \)

\( \sigma_{\text{limit}}/\sigma_{\text{SSM}} \)

ATLAS-PHYS-PUB-2011-002

ATLAS Preliminary (simulation)

95\%CL Limit W' → eν,μν

Luminosity [pb]

\( m_{W'} \text{ Mass [GeV]} \)

\( m_{Z'} \text{ Mass [TeV]} \)

\( \sigma_{\text{limit}}/\sigma_{\text{SSM}} \)

CDF 2010

ATLAS 2010

ATLAS Preliminary

\( W' \rightarrow lν \text{ (2011)} \)

\( \sqrt{s} = 7 \text{ TeV} \)

\( \int L \, dt = 1.04 \, \text{fb}^{-1} \)
Other Models of New Interactions
Quark-lepton compositeness can be described as four-fermion contact interaction (CI) at low energy limit.

**Benchmark: left-left isoscalar model**

\[
\frac{d\sigma}{dm_{\mu\mu}} = \frac{d\sigma_{DY}}{dm_{\mu\mu}} - \eta_{LL} \frac{F_I(m_{\mu\mu})}{\Lambda^2} + \frac{F_C(m_{\mu\mu})}{\Lambda^4}
\]

- $F_{I(C)}$ is interference (CI) term, $\eta_{LL}=\pm 1$
- $\Lambda$ is the energy scale below which fermion constituents are bound

- No excess, limits at 95% CL:
  - $\Lambda^{-} > 4.9\,\text{TeV}$ for constructive interference
  - $\Lambda^{+} > 4.5\,\text{TeV}$ for destructive interference

*arxiv:1104.4398* accepted by PRD
If quarks have substructure which it will appear at compositeness scale $\Lambda$ 

$$\chi = \exp(|y_1 - y_2|) = \frac{1 + |\cos \theta^*|}{1 - |\cos \theta^*|}$$

$y_{(2)}$ (sub)leading jet rapidity, $\theta^*$ angle between two jets

Flat distribution for SM processes, excess at low $\chi$ for signal

$F_\chi$ is ratio of events in the first four $\chi$ bins to full $\chi$ distribution
More Searches for Compositeness

If quarks have substructure which it will appear at compositeness scale $\Lambda$

$$\chi = \exp(|y_1 - y_2|) = \frac{1 + |\cos \theta^*|}{1 - |\cos \theta^*|}$$  

$y_{(2)}$ (sub)leading jet rapidity, $\theta^*$ angle between two jets

Flat distribution for SM processes, excess at low $\chi$ for signal

Data $>2$TeV below SM prediction. Exclude $\Lambda < 6.7$TeV (bayesian method), expected limit $\Lambda < 5.7$TeV
New Particles Searches
Search for doubly charged Higgs →μμ

• Models: Left-Right Symmetric (LRSM), Higgs triplet, Little Higgs
• Pair production: pp→H^++H^-
• H/μμ Coupling ≈ 10^{-5}-0.5 considered to have lifetime <10μm and Γ/M<1%
• In LRSM 2σ(H^{++}_R)≈2σ(H^{++}_L)

In LRSM with 1.6fb^{-1} &
BR(H^{++}→μμ)=100%
M(H^{++}_R/L)<295/375GeV @95%CL
BR(H^{++}→μμ)=33%
M(H^{++}_R/L)<210/268GeV @95%CL

World best limits on H^{++}
Search for Leptoquarks

- Benchmark model: pair production of leptoquarks (LQ)
- Particles with both lepton and baryon quantum numbers
- Consider 2 lepton + 2 jets and lepton + 2 jets + $E_T^{\text{Miss}}$ final states

Average $l_j$ invariant mass

At $\sqrt{s} = 7$ TeV
\[ \int L \, dt = 35 \text{ pb}^{-1} \]

95% CL exclusion region

$\beta = B(\text{LQ} \to e\mu)$

arxiv:1104.4481, accepted by PRD
Search for $l\nu jj$ resonance

- CDF has reported an excess of $4.1\sigma$ at $\sim 145\text{GeV}$ in $jj$ mass distribution in $l\nu jj$ channel with 7.3fb$^{-1}$ of data
- This channel is not optimal at LHC with $W$+jet bkg 20 times higher, but this can be model dependent
- Selection: $p_T^j > 30\text{GeV}$, $p_T^e > 25\text{GeV}$, $p_T^\mu > 20\text{GeV}$, $p_T^{jj} > 40\text{GeV}$, $E_T^{\text{Miss}} > 25\text{GeV}$, $M_T > 40\text{GeV}$, $|\Delta\eta| < 2.5$, $|\Delta\phi^{jj,ETMiss}| > 0.4\text{GeV}$
- Looked at $N_j=2$ (shown) and $N_j \geq 2$ (in backup)

No significant excess over Standard Model processes seen in 1.02fb$^{-1}$ of data

ATL-CONF-2011-097
Searches for a di-jet resonance

Looked for di-jet resonance in the measured $M_{jj}$ distribution → spectrum compatible with a smooth monotonic function → no bumps
More ATLAS exotics results to be shown...

- **Top, Top-like BSM & Boosted Objects**
  - Talk by **J. Ferrando**, Wed pm
  - Includes: $Z'\rightarrow tt\bar{t}$, Heavy top partner in $tt\bar{t} + E_T^{\text{Miss}}$ channel, $4^{\text{th}}$ generation light quark searches ($u_4$ & $d_4$)

- **Extra dimension signatures**
  - Talk by **F. Ruehr**, Thu am

- **Long-Lived particles and other weird things**
  - Talk by **D. Milstead**, Thu am

- **ATLAS Review of BSM signatures w/o $E_T^{\text{Miss}}$**
  - Talk by **E. Etzion**, Wed am

- **ATLAS overview of $E_T^{\text{Miss}}$ signatures**
  - Talk by **R. Bruneliere**, Tue am
Conclusion

• LHC is working very well
• ATLAS detector is efficiently collecting data
• Have not found any New Physics yet
  – A lot of limits are reaching ~1-2TeV range

We already have more than 2fb\(^{-1}\) of data, more exciting results from ATLAS to come...
Backup Slides
More on $l\nu jj$ channel (backup)

- CDF has reported an excess of $4.1\sigma$ at $\sim145\text{GeV}$ in $jj$ mass distribution in $l\nu jj$ channel with $7.3\text{fb}^{-1}$ of data.
- This channel is not optimal at LHC with $W+$jet bkg 20 times higher, but this can be model dependent.
- Selection: $p_T^{j}>30\text{GeV}$, $p_T^{e}>25\text{GeV}$, $p_T^{\mu}>20\text{GeV}$, $p_T^{jj}>40\text{GeV}$, $E_T^{\text{Miss}}>25\text{GeV}$, $M_T^{W}>40\text{GeV}$, $|\Delta\eta|<2.5$, $|\Delta\phi^{j1,\text{MET}}|>0.4\text{GeV}$
- Looked at $N_j=2$ (shown) and $N_j\geq2$ (in backup)

No significant excess over Standard Model processes seen in $1.02\text{fb}^{-1}$ of data.
Search for New Physics in lljj channel

- Benchmark: Left-Right Symmetric Model
- New gauge boson $W_R$
- Heavy neutrinos (N):
  - $q\bar{q} \rightarrow W_R \rightarrow lN, N \rightarrow lW^*_R \rightarrow ljejet$
  - Non-Majorana N: only $l^+l^-$ (OS)
  - Majorana N: both $l^\pm l^\mp$ (SS) and $l^+l^-$ (OS)
  - N can mix if masses are different both no-mixing and 100% mixing cases considered
- Data consistent with SM predictions
Search for New Physics in Diphotons

- Benchmark Signal RS Gravitons (G)
- 5-D space-time bound by two 3+1D branes with SM particles localized on one and gravity on the other
- Only G propagate in bulk resulting in massive spin-2 Kaluza-Klein (KK) excitations
- Narrow intrinsic width if $k/M_{Pl} < 0.1$ ($k$ is space-time curvature in ED)
- Graviton decays to SM fermions or bosons: Diphoton branching fraction is twice higher than dilepton one
- Data consistent with SM predictions
- Limit @ 95% CL >920(545) GeV for $k/M_{Pl} = 0.1(0.02)$

See poster by X. Anduaga for more details

ATLAS-CONF-2011-044
Search for New Physics in Dileptons

Benchmark signal: RS G* → l⁺l⁻
Same spectrum at for Z’, no excess
UL @95% CL on M(G*)

<table>
<thead>
<tr>
<th>Coupling(k/M_{Pl})</th>
<th>0.01</th>
<th>0.03</th>
<th>0.05</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL@95%CL(TeV)</td>
<td>0.70</td>
<td>1.03</td>
<td>1.33</td>
<td>1.63</td>
</tr>
</tbody>
</table>

Search for doubly charged Higgs $\rightarrow \mu\mu$
Searches for New Physics in Dijets

![Graphs showing ATLAS Preliminary results for excited-quark and axigluon models and color octet scalar model.](image)

(a) Excited-quark and axigluon models.

(b) Color octet scalar model.

ATLAS-CONF-2011-095