SEARCH FOR NEW GAUGE BOSONS AND LEPTOQUARKS AT THE LHC WITH THE CMS DETECTOR

Oana Boeriu
Northeastern University
On behalf of the CMS Collaboration

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  - $W' \rightarrow l\nu$

- **Search for Leptoquarks**

- **Summary**
The CMS Detector

**Tracker:**
\[ \sigma_{p_T}/p_T \approx 1.5 \cdot 10^{-4} \ p_T(\text{GeV}/c) + 0.5\% \]

**ECAL:**
\[ \sigma_{E/E} \approx 2.9%/\sqrt{E(\text{GeV})} + 0.5\% \]

**HCAL:**
\[ \sigma_{E/E} \approx 120%/\sqrt{E(\text{GeV})} + 6.9\% \]

**Muon System:**
\[ \sigma_{p_T}/p_T \approx 5\% \text{ for } 1 \text{ TeV} \mu \]

**Muon System & Tracker:**
- acceptance: \(|\eta|<2.4\)

**Calorimeters:**
- HCAL acceptance: \(|\eta|<5\)
- ECAL acceptance: \(|\eta|<3\)

**Total weight:** 12,500 t
**Overall diameter:** 15 m
**Overall length:** 21.6 m
**Magnetic Field:** 4 Tesla
Beyond the Standard Model:

Z’/W’ bosons are predicted by Grand Unified Theories (GUT):

- $Z_{SSM}$ within the Sequential Standard Model
- $Z_\psi$, $Z_\eta$ and $Z_\chi$: E$_6$ and SO(10) GUT group
- $Z_{LR}$, $W_{LR}$: left-right symmetry model
- $Z_{ALR}$: alternative left-right symmetry model
- $W’/Z’$: Little Higgs Models

All results are based on detailed simulations of the CMS detector with realistic start-up calibrations and alignment conditions, appropriate trigger and pile-up.

Searches concentrate on low luminosities for $\sqrt{s}=14$ TeV.

Methods to extract the background from data are studied.
**Z’->e⁺e⁻ results**

**Signature:**
- two very high $p_T$ oppositely charged electrons

**Event selection:**
- electron trigger applied
- two well isolated electrons with $E_T > 30$ GeV and $|\eta| < 2.5$
- $M_{ll} > 200$ GeV/c²

**Background:**
- SM Drell-Yan
- $t\bar{t}$, QCD, $W$+jets, $\gamma$+jets, $\gamma\gamma$

\[ \sigma(LO) \cdot BR(fb) \text{ and expected number of events with 2 electrons emitted within } |\eta| < 2.5 \text{ for 100pb}^{-1} \text{ (CMS PAS EXO-08-001)} \]

<table>
<thead>
<tr>
<th>SSM $Z'$</th>
<th>M=1000</th>
<th>M=1500</th>
<th>M=2000</th>
<th>M=2500</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma \cdot BR(fb)$ In 100pb$^{-1}$ +2e with $</td>
<td>\eta</td>
<td>&lt; 2.5$</td>
<td>458</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>7.2</td>
<td>1.8</td>
<td>0.54</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DY BG</th>
<th>M&gt;600</th>
<th>M&gt;1100</th>
<th>M&gt;1600</th>
<th>M&gt;2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma \cdot BR(fb)$ In 100pb$^{-1}$ +2e with $</td>
<td>\eta</td>
<td>&lt; 2.5$</td>
<td>50</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>4.0</td>
<td>0.4</td>
<td>0.07</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Signature:
- two very high $p_T$ oppositely charged muons

Event selection:
- muon trigger applied
- at least one pair of oppositely charged isolated muons with $p_T > 20\text{GeV/c}$ and $|\eta| < 2.4$

Background:
- SM Drell-Yan: $pp \rightarrow \gamma^*/Z^0 \rightarrow \mu^+\mu^-$ (irreducible)
- $t\bar{t}$, $Z/\gamma^*$+jets, di-jets

Background and signal expected events after trigger simulation for 100pb$^{-1}$ (CMS AN-2007/038)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Opp.$Q,M_{\mu\mu}&gt;1.0\text{TeV/c}^2$</th>
<th>Same$Q,M_{\mu\mu}&gt;1.0\text{ TeV/c}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drell-Yan</td>
<td>0.57±0.04</td>
<td>0.014±0.007</td>
</tr>
<tr>
<td>QCD jets</td>
<td>0.38±0.18</td>
<td>0.36±0.18</td>
</tr>
<tr>
<td>W+jets</td>
<td>0.23±0.14</td>
<td>0.18±0.13</td>
</tr>
<tr>
<td>$t\bar{t}$+jets</td>
<td>0.24±0.08</td>
<td>0.096±0.048</td>
</tr>
<tr>
<td>$Z_\psi$  M=1TeV/c$^2$</td>
<td>5.4±0.1</td>
<td>0.05±0.01</td>
</tr>
</tbody>
</table>

5$\sigma$ discovery reach plot
Resonances decaying into dijets

- Spin=1 Z' like
- iterative and midpoint cone algorithm used
- highest sensitivity within $|\eta|<1.3$

**Signature:**
- two high $p_T$ jets
- Mass resolution between 9% (0.7 TeV/$c^2$) to 4.5% (5 TeV/$c^2$)

**Selection:**
- High level trigger
- $E/\sum E_T < 0.3$ for unbalanced jet energy deposition rejection

Searches make use of the dijet ratio: $R = N(|\eta|<0.7)/N(0.7<|\eta|<1.3)$
- sensitive to dijet angular distributions

Heaviest dijet resonance in CMS at 5$\sigma$ with 100 pb$^{-1}$: **2.0 TeV/$c^2$**
**W'->ev results**

**Signature:**
- one high $p_T$ electron + missing transverse energy

**Selection:**
- electron trigger applied
- at least one isolated electron with $E_T > 30$ GeV

**Transverse mass reconstruction:**

$$M_T = \sqrt{2p_T e_T(1 - \cos\Delta\phi_e, E_T)}$$

**Background:**
- $W->ev$ from SM
- $t\bar{t}$, multi-jet, $Z\rightarrow e^+e^-$

**Expected number of events after all selection cuts for 100pb$^{-1}$**

(CMS PAS EXO-08-004)

<table>
<thead>
<tr>
<th>Selection</th>
<th>$M_{W'}=1$TeV</th>
<th>$M_{W'}=2$TeV</th>
<th>$M_{W'}=3$TeV</th>
<th>$M_{W'}=4$TeV</th>
<th>$M_{W'}=5$TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>All selection</td>
<td>207</td>
<td>10.81</td>
<td>1.07</td>
<td>0.178</td>
<td>0.036</td>
</tr>
<tr>
<td>All selection+M_T&gt;200GeV</td>
<td>204</td>
<td>10.71</td>
<td>1.06</td>
<td>0.173</td>
<td>0.034</td>
</tr>
<tr>
<td>All selection+M_T&gt;500GeV</td>
<td>176</td>
<td>10.28</td>
<td>1.03</td>
<td>0.162</td>
<td>0.030</td>
</tr>
</tbody>
</table>
**Signature:**
- one high $p_T$ muon + missing transverse energy

**Selection:**
- muon trigger applied
- at least one isolated muon with $E_T > 30$ GeV

**Background:**
- $W\rightarrow\mu\nu$ from SM
- $t\bar{t}$, multi-jet, $Z\rightarrow\mu^+\mu^-$

Integrated luminosity needed for discovery reach or exclusion of $W'$ of certain masses (CMS Note 2006/117).
**Data-Driven Methods for Background Estimation**

**t¯t estimation from data:**
- **b-tagging method:**
  - relation between \( N_{t\bar{t},\text{tot}} \) vs \( N_{b\text{-tag,1jet}} \) and \( N_{b\text{-tag,2jets}} \),
  - once \( n_1, n_2 \) and the geometrical acceptance for one or two b-quarks known, the b-tagging efficiency is known and the total t¯t events can be extracted

Method is robust and solid for 100 pb\(^{-1}\) analysis
- can determine both t¯t events and b-tagging efficiency independent of b-tagging algorithm

**e-µ method:**
- di-lepton events used with different lepton flavors from the two W decays
- event kinematics identical to both W decaying to \( e\mu \)
- \( t\bar{t} \rightarrow e\mu = 2 \cdot t\bar{t} \rightarrow ee \)
- \( ee \) spectrum compared to true \( e\mu \) events -> good agreement
- In 100pb-1 expect \( N_{t\bar{t},ee} = 16 \). which will be determined from an expected sample of 42.5 \( \mu \) events including W+jets production
Leptoquarks

- Predicted by GUT, E\textsubscript{6}, SO(10), SUSY, Technicolor, Superstrings...

**Color triplets, carrying B,L \neq 0:**
- $\lambda_{ij}, \lambda_{kl} = $ Yukawa couplings $\rightarrow$ FCNC, lepton flavor violation
- Scalar & vector leptoquarks

**BRW model:**
- couplings respect $SU(3)\textsubscript{C} \otimes SU(2)\textsubscript{L} \otimes U(1)\textsubscript{Y}$ symmetry
- LQ classified by spin, chiral coupling, weak isospin & electric charge
- 12 different states of scalar and vector LQs
- fixed decay BR = 100% (\textit{lq}) or 50% (\textit{vq})

**LQ pairs favoured in GUT models**

**Signature:**
- two high $p_T$ oppositely charged leptons and two jets

**Background:**
- $t\bar{t}$, $Z/\gamma^*+jets$, $W+jets$

**Selection:**
- 2 high $p_T$ isolated opposite sign muons and 2 jets
- very efficient against the background:

$$S_T = \sum p_{T\mu_1} + p_{T\mu_2} + p_{T\mu_1} + p_{T\mu_2}$$
Good sensitivity with 100pb$^{-1}$ for Z’ and W’ analyses
- Background estimation from data shows good agreement
- Efficiency for electron/muon measurement studied
- Systematic uncertainties investigated

The LHC will break new ground in exploring the TeV scale and hunt for new particles like SUSY, Z’, W’, Leptoquarks,…

CMS IS READY FOR COLLISIONS IN 2009!
Backup Material
First beam in the LHC - accelerating science

Geneva, 10 September 2008. The first beam in the Large Hadron Collider at CERN was successfully steered around the full 27 kilometers of the world's most powerful particle accelerator at 10:28 this morning. This historic event marks a key moment in the transition from over two decades of preparation to a new era of scientific discovery.

Dir. Gen. Robert Aymar

Report on 19th Sept 2008 incident at LHC

Investigations have confirmed that cause of the incident was a faulty electrical connection in a region between two of the accelerator's magnets, which resulted in mechanical damage and release of helium from the magnet cold mass into the tunnel.

Proper safety procedures were in force, the safety systems performed as expected, and no one was put at risk. Sufficient spare components are in hand to ensure that the LHC is able to restart in 2009, and measures to prevent a similar incident in the future are being put in place.

This incident was unforeseen, but I am now confident that we can make the necessary repairs, ensure that a similar incident cannot happen in the future and move forward to achieving our research objectives.

Dir. Gen. Robert Aymar

LHC re-start scheduled for 2009

Geneva, 23 September 2008. The time necessary for the investigation and repairs precludes a restart before CERN's obligatory winter maintenance period, bringing the date for restart of the accelerator complex to early spring 2009. LHC beams will then follow.

Dir. Gen. Robert Aymar
Alignment between tracker and muon system crucial
- mass resolution affected
- 10% at 2TeV

HLT muon:
- ~97% efficiency

Offline reco:
- ~94% efficiency
High energy electrons:
- shower shape, track matching and isolation used
- ~80% efficiency in the barrel
- ~85% in the endcap
Limits from the Tevatron

\[ M_{Z'\rightarrow\mu^+\mu^-} > 680 \text{ GeV/c}^2 \]
\[ M_{Z'\rightarrow e^+e^-} > 780 \text{ GeV/c}^2 \]
\[ M_{Z'\rightarrow q\bar{q}} > 870 \text{ GeV/c}^2 \]
\[ M_{W'_R} > 610 \text{ GeV/c}^2 \]
\[ M_{W'_R} > 630 \text{ GeV/c}^2 \]

\[ M_{LQ\rightarrow \mu^+\mu^- q\bar{q}} > 316 \text{ GeV/c}^2 \]
\[ M_{LQ\rightarrow e^+e^- q\bar{q}} > 292 \text{ GeV/c}^2 \]
Pair Produced Leptoquarks

CMS Leptoquark simulation study

Discovery potential up to 1.5 TeV
Mass resolution 30-40 GeV

Selection cuts:
- 2 isolated same flavour opposite sign leptons with $p_T>40$ GeV, $|\eta|<2.4$
- ≥2 jets with $E_T>60$ GeV, $|\eta|<4.5$
- $M_{ll}>150$ GeV
- $E_{T,\text{miss}}<185$ GeV
- $\Sigma E_T>1700$ GeV
- $E_{T,\text{miss}}/\Sigma E_T<0.041$
- $\Delta M_{lj}<310$ GeV

S.Abdullin, F.Charles, F.Luckel
(CMS Note 1999/027)

A dedicated analysis for first and second generation leptoquarks is underway.