Non-SUSY Exotic Searches at the Tevatron

Qiuguang Liu (Purdue Univ.) on behalf of the CDF and DØ collaborations
Outline

• Tevatron, CDF and DØ

• Standard Model and it’s Extensions

• Exotics Searches at Tevatron (see L. Bellantoni’s talk for the SUSY searches)

• Conclusion
### SUSY 2011 at the “high rise”

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>Highest Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cockcroft Walton</td>
<td>750 KeV</td>
</tr>
<tr>
<td>Linac</td>
<td>400 MeV</td>
</tr>
<tr>
<td>Booster</td>
<td>8 GeV</td>
</tr>
<tr>
<td>Main Injector</td>
<td>150 GeV</td>
</tr>
<tr>
<td>Tevatron ~ 4 miles</td>
<td>980 GeV</td>
</tr>
</tbody>
</table>

Proton → Anti-proton ~ 2 TeV
Two General-purpose Detectors

CDF
60 institutes, 513 members

D∅
72 institutes, 456 members
• **Tracking system**: the silicon detectors for vertex precision, the wire/fiber chamber to measure the charged particle momentum.

• **Calorimeters**: measure the energy of electrons and photons, and sample the energy of hadrons.

• **Muon detector**: improve the muon ID.

• Sophisticated systems behind the curtain: Electronics, Trigger Systems, DAQ, Offline Simulation and Reconstruction, and many others.
Collider Performance

The results showing in this talk are using data about 5~6 fb$^{-1}$
Extension of the Standard Model

- More generations?
- Connections?
- Supersymmetry?
- Grand Unification?
- Extra dimension?
Tevatron Exotics Searches

- Many extensions of Standard Model are proposed.
- New particles are predicted.
- A measurable new particle show itself as elementary particles after decay: $e$, $\mu$, $\tau$, $\Upsilon$, jets (pion, kaon, n, p ...), and neutrino (missing transverse energy).
- If a model doesn’t predict anything measurable, we’re sorry ...

Non-SUSY Exotics
- Leptoquark
- RS Graviton $G$
- SSM $W'$
- 4th gen. neutrino
- $T'$, dark matter
- new resonance

Also see the SUSY talk given by L. Bellantoni
**Background: Standard Model Productions**

- **WW/WZ/ZZ:** Pythia (CDF & D∅)
- **Single top:** MadEvent+Pythia (CDF), COMPHEP(D∅)
- **Top pair:** Pythia (CDF), Alpgen+Pythia (D∅)
- **W/Z + jets:** Alpgen+Pythia (CDF & D∅)
- **QCD multijet:** data-driven

**Signal: exotic particles.**

- mostly Pythia.

*The cross-section is always using the one up to the highest available order*
Leptoquarks (LQ) are predicted to fundamentally couple the leptons and quarks, in each generation.

\[
q + \bar{q} \rightarrow LQ + \overline{LQ}
\]

\[
g + g \rightarrow LQ + \overline{LQ}
\]
Search for the 1st generation scalar leptoquarks

\[ LQLQ \rightarrow eq\nu e q' \]

W+jets is the largest background.

\[ W \rightarrow e\nu, \quad m_{T}^{e\nu} \sim [70, 85] \text{ GeV} \]

\[ S_T = \sum E_{T_j} + E_{T_l} + \not{E}_T \]

arXiv:1107.1849 [hep-ex]
Search for the 1st generation scalar leptoquarks

$LQ \bar{LQ} \rightarrow e \nu_e q'$

Comparing the results

Scanning over samples with $m_{LQ}$ 200–360 GeV.
A lower limit of LQ mass is set at 326 GeV ($\beta=0.5$).

arXiv:1107.1849 [hep-ex]
WW or WZ resonance

Sequential standard model $W'$
Randall-Sundrum model graviton $G$

Two new searches with $\geq 1$ jet and 1- or 2-lepton (5.4 fb$^{-1}$)
Combined with 3-lepton search (4.1 fb$^{-1}$)

\[
p\bar{p} \rightarrow W' \rightarrow WZ (\ell\nu jj, jj\ell\ell, \ell\nu\ell\ell)
p\bar{p} \rightarrow G \rightarrow W^+W^- (\ell\nu jj)
\]

<table>
<thead>
<tr>
<th>Process</th>
<th>Single lepton sample</th>
<th>Dilepton sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z$+jets</td>
<td>$3.6 \pm 0.2$</td>
<td>$7.9 \pm 0.8$</td>
</tr>
<tr>
<td>$W$+jets</td>
<td>$124.5 \pm 20.3$</td>
<td>$&lt; 0.01$</td>
</tr>
<tr>
<td>Top</td>
<td>$22.9 \pm 2.5$</td>
<td>$&lt; 0.01$</td>
</tr>
<tr>
<td>Multijet</td>
<td>$4.6 \pm 0.3$</td>
<td>$&lt; 0.01$</td>
</tr>
<tr>
<td>Diboson</td>
<td>$27.6 \pm 1.4$</td>
<td>$0.8 \pm 0.1$</td>
</tr>
<tr>
<td>Background sum</td>
<td>$183.2 \pm 24.5$</td>
<td>$8.7 \pm 0.8$</td>
</tr>
<tr>
<td>Data</td>
<td>174</td>
<td>8</td>
</tr>
</tbody>
</table>

WW or WZ resonance

Sequential standard model $W'$
Randall-Sundrum model graviton $G$

\[ p\bar{p} \rightarrow W' \rightarrow WZ (|\nu jj, jj|, |\nu|) \]
\[ p\bar{p} \rightarrow G \rightarrow W^+W^- (|\nu jj|) \]

Exclude $W'$ in the mass range $[180, 690] \text{ GeV}$
Exclude RS graviton in $[300, 754] \text{ GeV}$ ($k/M_{pl} = 0.1$)

Search for Randall-Sundrum Graviton in $\mu\mu$ channel

$G \rightarrow \mu\mu, \ ee, \ \gamma\gamma$

Combined with the searches in $ee$ ($5.7 \text{ fb}^{-1}$) and $\Upsilon\Upsilon$ ($5.4 \text{ fb}^{-1}$) channels

The RS graviton mass limit for the coupling $k/M_{pl} = 0.1$ is \textbf{1111 GeV}.

CDF public note 10479

D0: arXiv: 1008.2023 [hep-ex]
In the 4-lepton channel, 4 events observed with $m_{ZZ} \sim 327$ GeV (eeee, eeμμ, 2μμμμ).

The total expected SM ZZ is 5.8, and less than 25% (1.5) of them have $m_{ZZ} > 300$ GeV.

The chance for 4 SM ZZ to cluster around 327 GeV is tiny ($\sim 10^{-4}$).
High Mass Resonance Decaying into ZZ

$G^* \rightarrow ZZ$?

No excess around the expected high mass resonance
In 4-lepton channel, at $m_{ZZ} = 325$ GeV the expected upper limit is $0.7 \text{ pb}$, and the observed is $1.9 \text{ pb}$.

In $\ell\ell\nu\nu$ and $\ell\elljj$ channel, the observed limits are consistent with the Standard Model expected.

Story is not finished yet...
Search for $\Upsilon \Upsilon$ events with large MET

Lightest KK particle in UED model

Update the previous analysis (1.1 fb$^{-1}$)

Improved photon ID utilizing neural network technique

UED: compactification radius $R_c^{-1} < 477$ GeV

Search for 4th gen. neutrino in ZZ+MET

\[ p\bar{p} \rightarrow Z/\gamma^* \rightarrow N_2N_2 \rightarrow N_1Z N_1Z \rightarrow l^+l^- q\bar{q} + E_T \]

Searches for 4th gen. quarks \( t' \), \( b' \) have been performed at Tevatron. Not very much in searching for 4th gen. leptons.

Two eigenstates \( N_1 \), \( N_2 \) for the neutrino.

\( N_2 \rightarrow N_1Z \) dominates in most case.

**Delta Mass Function**

\[ \Delta \text{ Mass Function} = \sqrt{(\frac{m_{jj} - 91.6}{10})^2 + (\frac{m_{jj} - 85.3}{15})^2} \]

Fitted Z mass

Fitted Z width

SM bkgs are either only having one Z or lacking of true MET

CDF public note 10539
Search for New Physics in \( t\bar{t} + \text{MET} \) (all hadronic tops)

\[
p\bar{p} \rightarrow t\bar{t}' \rightarrow t\bar{t}\bar{X} \rightarrow bqq'\bar{b}qq' + \not{E}_{T}
\]

Major bkgs:
Top Pair: all hadronic decay, lack of true MET
QCD: fake MET, small MET\(_{\text{sig}}\)

\[\not{E}_{T}\text{sig} = \not{E}_{T}/\sqrt{\sum E_{T}}\]

Exclude the fourth generation exotic quarks \( t' \) up to 400 GeV for \( m_{X} < 70 \) GeV

Exclusion limits:
\[5.7 \text{ fb}^{-1}\]

CDF lepton analysis: PRL 106, 191801 (2011)

\[\text{arXiv:1107.3574}\]
Dijet Resonance in W+jets

Updated to 7.3 fb\(^{-1}\), the significance of the bump is 4.76

DØ’s result doesn’t favor such a resonance.

Task forces are commanded between CDF and DØ, and internally in these collaborations.
Conclusion

- Many new-physics signatures are explored both at CDF and DØ. Only very recent results are covered in this talk.
- Both experiments are expecting ~11 fb⁻¹ data being finally acquired, which is twice as much the data explored so far. Stay tuned ...
- LHC is delivering many interesting exotic results, wish to hear more in SUSY 2011.
- For more exotic searches at Tevatron:
  - [http://www-d0.fnal.gov/Run2Physics/np/](http://www-d0.fnal.gov/Run2Physics/np/)
A very emotional moment

• Many people have worked on/with CDF and DØ, and loved them.
• But the day just comes.
• Thanks, to the people, and to the machines!
Still hard to have a broad perspective of physics