Search for high mass resonances in dilepton, dijet and diboson final states at the Tevatron

Michel Jaffré

on behalf of the CDF and D0 collaborations
Motivations

- Looking for new physics beyond the SM
  - $SU(3)_C \times SU(2)_L \times U(1)_Y$ embedded in a larger gauge group ($SO(10), E_6, ...$) to achieve grand unification, after symmetry breaking, $U(1)$ groups survive $\Rightarrow Z'$
  - L-R symmetry, “little Higgs” models also predicts $Z'$
  - Randall Sundrum model, one extra dimension $\Rightarrow$ excited KK modes $G^*$
  - SUSY with RPV resonant production may occur with lepton pair of same or different flavour decay products

- Common point: narrow resonances with $\Gamma \ll$ detector resolution
  - $Z'$: coupling to $ee, \mu\mu$, or any fermion pair
  - RS ($0.01 < k/M_{Pl} < 0.10$) $\rightarrow ee, \gamma\gamma$
  - $\tilde{\nu} \rightarrow \mu\mu, e\mu, e\tau, \mu\tau$
  - New gauge bosons as well as $G^*$ couple to the SM gauge bosons
    $X(Z', G^*) \rightarrow ZZ; W^+W^- \quad W' \rightarrow WZ$
Outline

Strategy in Tevatron analysis now
try to focus more on signature based searches,
rather than looking for a specific model

- $ee, \mu\mu$ (Z', RS graviton)
- $e\mu$, $e\tau$, $\mu\tau$ (RPV)
- $e$ $E_T \geq 2$ jets (resonant diboson production)
- Di-jet (q*, Z', W', .....)

Z' = Z prime, RS = Randall-Sundrum, RPV = Right-Handed Weak Vector

$E_T$ = transverse energy
Di-electron mass distribution

(2.5 fb⁻¹) PRL 102, 031801 (2009)
1 electron in Central (|η|<1.1), 2nd either Central or Forward (|η|<2)
if both are Central, opposite charge

CDF fluctuation around 240 GeV not confirmed by D0

D0 preliminary result on 3.6 fb⁻¹
(by-product of the FB asymmetry measurement with a tight electron selection)
Central(|η|<1.1) EM clusters with track match only

QCD misid
Z→ττ, WW, WZ, tt

CDF

D0 Run II Preliminary, 3.6 fb⁻¹

M(e⁺e⁻) (GeV/c²)
Events/(10 GeV/c²)

M_{ee} (GeV)
Events/10 GeV

M.Jaffré  EPS 2009 Krakow  July 16-22, 2009
Z' → ee limits

<table>
<thead>
<tr>
<th>Z' model</th>
<th>Z'_{SM}</th>
<th>Z'_{\psi}</th>
<th>Z'_{\chi}</th>
<th>Z'_{\eta}</th>
<th>Z'_{I}</th>
<th>Z'_{sec}</th>
<th>Z'_{N}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp. Lim (GeV)</td>
<td>961</td>
<td>846</td>
<td>857</td>
<td>873</td>
<td>755</td>
<td>788</td>
<td>831</td>
</tr>
<tr>
<td>Obs. Lim (GeV)</td>
<td>963</td>
<td>851</td>
<td>862</td>
<td>877</td>
<td>735</td>
<td>792</td>
<td>837</td>
</tr>
<tr>
<td>Exp. Lim (GeV)</td>
<td>949</td>
<td>817</td>
<td>834</td>
<td>844</td>
<td>732</td>
<td>774</td>
<td>803</td>
</tr>
<tr>
<td>Obs. Lim (GeV)</td>
<td>950</td>
<td>763</td>
<td>800</td>
<td>810</td>
<td>692</td>
<td>719</td>
<td>744</td>
</tr>
</tbody>
</table>
Randall-Sundrum graviton (ee) limits

Narrow resonance for $k/M_{Pl} < 0.1$
- $k^2$: space time curvature in extra dim
- $M_{Pl}$: reduced Planck mass

RS 95% CL limits ($k/M_{Pl}=0.1$)
- CDF Obs. > 848 GeV
- D0 prelim. Obs. (expected) > 786 (826) GeV
$\mu\mu$ mass distribution

2.3 fb$^{-1}$ of data  

PRL 102, 091805 (2009)

Select opposite charged $\mu$ in $|\eta| < 1$

Data – Bckg normalisation

**Almost constant resolution**  > 100 GeV  
$\Delta m^{-1}_{\mu\mu} = 0.17 \text{ TeV}^{-1}$

$\Rightarrow$ A narrow resonance will appear as an excess of events in 3 adjacent bins

**No excess around 240 GeV**

Observation consistent with SM expectation

$\chi = \frac{(\text{Obs} - \text{Bkg})}{\text{Stat. error}}$
μμ: Sneutrino, Z’, RS G* cross section limits

<table>
<thead>
<tr>
<th>( \lambda^2 \times \text{BR} )</th>
<th>Mass Limit, 95% CL (GeV/c^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>866</td>
</tr>
<tr>
<td>0.005</td>
<td>810</td>
</tr>
<tr>
<td>0.002</td>
<td>731</td>
</tr>
<tr>
<td>0.001</td>
<td>662</td>
</tr>
<tr>
<td>0.0005</td>
<td>541</td>
</tr>
<tr>
<td>0.0002</td>
<td>441</td>
</tr>
<tr>
<td>0.0001</td>
<td>397</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Mass Limits, 95% CL (GeV/c^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Z' ) (SM)</td>
<td>1030</td>
</tr>
<tr>
<td>( Z' (\eta) )</td>
<td>904</td>
</tr>
<tr>
<td>( Z' (\chi) )</td>
<td>892</td>
</tr>
<tr>
<td>( Z' (\psi) )</td>
<td>878</td>
</tr>
<tr>
<td>( Z' (N) )</td>
<td>861</td>
</tr>
<tr>
<td>( Z' (\text{sec}) )</td>
<td>821</td>
</tr>
<tr>
<td>( Z' (i) )</td>
<td>789</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Graviton ( k/M_{Pl} )</th>
<th>Mass Limit, 95% CL (GeV/c^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>921</td>
</tr>
<tr>
<td>0.07</td>
<td>824</td>
</tr>
<tr>
<td>0.05</td>
<td>746</td>
</tr>
<tr>
<td>0.035</td>
<td>651</td>
</tr>
<tr>
<td>0.025</td>
<td>493</td>
</tr>
<tr>
<td>0.015</td>
<td>409</td>
</tr>
<tr>
<td>0.01</td>
<td>293</td>
</tr>
</tbody>
</table>
R-parity violating: sneutrino $\rightarrow e\mu$

$\sigma_{e\mu} \propto (\lambda^{'311})^2 (\lambda_{312})^2 \frac{1}{S - M^2 + i\Gamma M}$

Clean topology: 2 isolated leptons with different flavor and charge, no jets, no $E_T$

Main bkgd: physics: $Z/\gamma^* \rightarrow \tau\tau$, WW, WZ, ZZ
MisId W+jet/γ

Good agreement with SM expectation
143 events observed 145 ±4 expected

Final result: RunIIa 1fb$^{-1}$ PRL 100, 241803(2008)
RunIIb 3.1fb$^{-1}$

Limits significantly improved / LEP results
$\lambda^{'311} < 0.12, \lambda_{312} = \lambda_{321} < 0.07$ for $M=100\text{GeV}$
R-parity violating sneutrino $\rightarrow e\mu$, or $e\tau$, or $\mu\tau$

1 fb$^{-1}$ of data but more final states analyzed
Observation of vector boson pairs in a hadronic final state

PRL 102, 161801 (2009)
\[ \mathcal{L} = 1.1 \text{ fb}^{-1} \]
e or \( \mu \), \( \slashed{E}_T \), \( \geq 2 \) jets
WW + WZ

\( \mathcal{L} = 3.5 \text{ fb}^{-1} \)
\( \slashed{E}_T > 60 \text{ GeV} + 2 \) jets
WW+WZ+ZZ

See J. Haley talk
See V. Cavaliere talk

Cross section consistent with SM expectation
$\mathcal{L} = 2.9$ fb$^{-1}$

e + $\nu$ → W (2 solutions)

Dijet mass: W [65,95] Z [70,105]

if 3 jets (pair closest to W/Z mass is chosen)

✓ QCD background estimated from data and normalised to data at small $\not{E}_T$

✓ Other bkgd from MC

$E_T$ cut optimization to get the best expected limit for a given X mass

Electron $E_T$ or $\not{E}_T > 120$ GeV

+ $E_{T,\text{jet}} > 120$ GeV
X → WW/WZ → (ev) + (2 jets) resonance search (II)

<table>
<thead>
<tr>
<th>Exclusions</th>
<th>$G^*(k/M_{Pl}=0.1)$</th>
<th>$Z'$</th>
<th>$W'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed</td>
<td>&lt; 607</td>
<td>247-545</td>
<td>284-515</td>
</tr>
<tr>
<td>Expected</td>
<td>&lt; 632</td>
<td>257-630</td>
<td>381-420</td>
</tr>
</tbody>
</table>
X→ZZ→(ll) (l’l’) or (jet+jet) resonance search

\[ \mathcal{L} = 2.5-2.9 \text{ fb}^{-1} \]

\[ (M_{ll} - 91.2)^2 / (\sigma_{M}^2 + 2.5) < 25 \]

65 < \( M_{jj} \) < 120 GeV

Increase acceptance by loose lepton selection and large \( \eta \) coverage

No evidence for ZZ resonant production

Acceptance from Herwig KK graviton

k/M_{Pl} = 0.1: M_G > 491 GeV
Search for dijet mass resonances (I)

- PRD 79, 112002 (2009)
- Central ($|y|<1$) jets with mid-point algo. $R=0.7$
- Dijet mass spectrum agrees with NLO pQCD predictions
- To search for narrow mass resonances in this spectrum a smooth functional form is fitted

$$\frac{d\sigma}{dm} = p_0 (1-x)^{p_1} / x^{p_2 + p_3 \log(x)}, \quad x = m / \sqrt{s}$$

- A large variety of models: excited quark, $W'$, $Z'$, RS graviton,.....

See T. Nunnemann talk in Higgs + NP session for other searches on dijet topology

No significant indication of resonant structure is observed. $\Rightarrow$ 95% CL limits
Search for dijet mass resonances (II)

<table>
<thead>
<tr>
<th>Model description</th>
<th>Observed mass exclusion range (GeV/c²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W' (SM couplings)</td>
<td>280- 840</td>
</tr>
<tr>
<td>Z' (SM couplings)</td>
<td>320- 740</td>
</tr>
<tr>
<td>RS graviton</td>
<td>No exclusion</td>
</tr>
<tr>
<td>Color octet technirho (top-color-assisted-technicolor (TC2) couplings)</td>
<td>260-1100</td>
</tr>
<tr>
<td>Excited quark ( f=f'=f_s=1)</td>
<td>260- 870</td>
</tr>
<tr>
<td>Axigluon and flavor universal coloron</td>
<td>260-1250</td>
</tr>
<tr>
<td>E6 diquark</td>
<td>290- 630</td>
</tr>
</tbody>
</table>
Summary and outlook

✓ No excess of events over SM expectations in (1- 4.1 fb\(^{-1}\))

✓ Search for sign of new physics will continue at the Tevatron
  > 6 fb\(^{-1}\) of data already recorded
  Expect to collect at least 10 fb\(^{-1}\) of data in the next years

✓ Signature based searches in CDF and D0 take over model specific searches

All CDF and D0 results are available on :

http://www-cdf.fnal.gov/physics/exotic/exotic.html
http://www-d0.fnal.gov/Run2Physics/WWW/results,np.htm
Backup
ee events