Non-SUSY Exotics Searches at the Tevatron

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Overview

- Tevatron, CDF & DØ
- Model-inspired searches
  - Theory driven
  - Standard model and new physics known; optimize for sensitivity.
  - Extra Dimensions, Extra Gauge Bosons (Z’, W’), New quarks (b’), Leptoquarks
- Signature-based searches
  - Final-state driven
  - Standard model is known. Look for any deviations everywhere
  - Because we can
- Today: Emphasis on 1 fb⁻¹ results
- Outlook
Tevatron Performance

- DØ and CDF each have >2 fb\(^{-1}\) recorded; expect 4-8 fb\(^{-1}\) by 2009
- Records: Initial Luminosity: 292.3 \(\times\) 10\(^{30}\) cm\(^{-2}\)s\(^{-1}\)
D0 and CDF Detectors

- Multipurpose Charged Tracking Spectrometers with Microstrip Silicon Vertex Detectors, Electromagnetic and Hadronic Calorimetry and Muon chambers.

- Reconstruct $e, \mu, \tau, \gamma, \text{jets, b-jets}, \text{missing } E_T$ (MET)
Extra Dimensions

Extra dimension models provide a solution to the hierarchy problem

• Arkani-Hamed, Dimopoulos, Dvali (ADD)
  • $n$ compact extra dimensions; $M_{Pl}^2 \sim R^n M_D^{2+n}$
  • Standard Model confined to a 4-dimensional brane
  • Only gravity lives in full 4+n dimensional bulk

• Randall-Sundrum I (RS)
  • Warped extra dimension(s), exponential warp factor solves hierarchy problem
  • Two branes, TeV and Planck. Gravitons live everywhere, SM confined to TeV brane.
  • Signature: High-Mass Graviton Resonances
    • $pp \rightarrow G_n, m_n \sim x_n k/M_{Pl}$

Weakness of gravity due to being diluted by volume of extra dimensions
Search for Large Extra Dimensions: Monojet + Missing $E_{T}$

- Direct production $qq \rightarrow Gg$, $qg \rightarrow Gq$, $gg \rightarrow gG$
- Jet $E_{T} > 150$ GeV, MET $> 120$ GeV
- Backgrounds: $Z \rightarrow \nu\nu$+jets, $W \rightarrow l\nu$+jets, QCD dijet. Measured with data.
- Expected $819 \pm 71$, Observed 779.
Search for Randall Sundrum Gravitons: $G \rightarrow \gamma \gamma$

- Direct search for a bump in $\gamma \gamma$ mass spectrum
- Data-based fake background estimation
- Randall-Sundrum Graviton limits
  - $k/M_{PL}=0.1$, $m_G > 850$ GeV
  - Combination $\gamma \gamma + e^+e^-$
    - $k/M_{PL}=0.1$, $m_G > 889$ GeV

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Search for Randall-Sundrum Gravitons: Combined ee, γγ

- ee and γγ are combined for maximum sensitivity
- Data-based mis-id background estimate
- For $k/M_{Pl} = 0.1$, $m_G < 865$ GeV excluded at 95% CL
Search for New Heavy Particles in $Z^0Z^0$

- RS Graviton Model: for $m_G = 500$ GeV, $k/M_{Pl} = 0.1$ $\sigma = 292$ fb
- Four isolated very loose electrons
- Very clean; almost no background
- Expect 0.02, see 0 events with $M > 500$ GeV

$$\chi^2 = \sum \left( \frac{m_{ee} - m_{Z^0}}{\sigma} \right)^2 \approx 3 \text{ GeV}$$
Search for $Z' \rightarrow ee$

- Many SM extensions introduce additional gauge bosons
- Di-Electron Search in $|\eta| < 3.0$, 1.3 fb$^{-1}$
- Dominant backgrounds from Drell-Yan, QCD
- $Z'_{\text{SM}} > 923$ GeV

<table>
<thead>
<tr>
<th>E$!!!_6Z'$</th>
<th>$Z_1'$</th>
<th>$Z_\psi'$</th>
<th>$Z_\chi'$</th>
<th>$Z_\eta'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Limit (GeV)</td>
<td>729</td>
<td>822</td>
<td>822</td>
<td>891</td>
</tr>
</tbody>
</table>
Search for $W' \rightarrow e\nu$

- Signature: >30 GeV $e^+$, $0.7 < E_T/MET < 1.3$
- Main background is SM W
- Assuming SM Couplings to fermions, exclude $m_{W'} < 965$ GeV (95%CL)
Search for Excited Electrons in $ee\gamma$

- Possible sign of compositeness
- Produced in contact interactions $pp \rightarrow ee' \rightarrow ee\gamma$
- Sets limit $m_{e'} > 756$ GeV (95% CL) for compositeness scale $\Lambda = 1$ TeV
Search for second-generation leptoquarks $\mu \nu qq$

- Signature: $\mu^+$ 2 jets + MET
- Normalizes $W$+jets to data before LQ selection
- Sets limit $m_{LQ} > 214$ GeV (95% CL) for $\beta = 0.5$
Search for b’ in Z+Jets

- Signature: pair-produced b’ \rightarrow bZ, Z \rightarrow \ell \ell
- Signal region: 3 Jets with $E_T > 30$ GeV; discrimination in sum of jet $E_T (J_T)$
- Fit data in $n_{\text{Jet}} < 3$ bins; extrapolate to $n_{\text{Jet}} \geq 3$ signal region
- Method developed with MC
- Background method verified in W+jets by measuring t-tbar cross section

Search for New Particles Decaying to $Z^0_{\text{b'}}$+jets

CDF Run II Preliminary, 1.1 fb

Search for New Particles Decaying to $Z^{\text{b'}}_{\text{b'}}$+jets

CDF Run II Preliminary, 1.1 fb

W+jets Control Sample

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Search for $b'$ in Z+Jets

- Look in data in Z+jets $\geq$ 3 jet bin
- No excess observed; set limit $m_{b'} > 271$ GeV
Signature-Based Search for High-$p_T$ Z

- Sensitive to heavy particles decaying to Z
- Set limits on anomalous Z production versus $p_T$
Signature-Based Search for Dilepton + X

- Search for anomalous production of ll+X, with X = γ, H_T, MET, high E_T jets, lepton
  - Results in eμ and same-sign ee,μμ
  - $H_T = \sum E_T + \text{MET}$

<table>
<thead>
<tr>
<th></th>
<th>$e\mu$</th>
<th>Same sign ee/μμ</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥2 jets SM</td>
<td>2.9±1.5</td>
<td>1.5±0.8</td>
</tr>
<tr>
<td>Data</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

- Applied to BPT heavy quark model, hep-ph 0206116
  - $\sigma < 2.1 \times \sigma_Q$ (90%CL) $\sigma_Q = 0.289\text{pb}$, $m_Q = 300\text{GeV}$
- One event has $H_T = 864\text{ GeV}$; consistent with top dilepton + jets
  - eμjjjjb MET

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- eμjjjjb MET

CDF Run II Preliminary (929 pb⁻¹)

- Data
- W→μν
- Z→ττ
- Z→μμ
- top, Dibosons

Events per 20 GeV

- ≥2 jets
- $e\mu$
- Same sign ee/μμ
- SM: 2.9±1.5, 1.5±0.8
- Data: 2, 0

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Signature-Based Search for $\gamma\gamma + e/\mu/\gamma$/MET

- Motivated by Run I $ee+\gamma\gamma$+MET event
- No significant excess seen
- No $ee+\gamma\gamma$ events seen

$\gamma\gamma\gamma e$ $\gamma\gamma\mu$ $\gamma\gamma\gamma$ $\gamma\gamma+MET$

SM $6.8\pm0.8$ $0.8\pm0.1$ $2.2\pm0.7$ $0.24\pm0.22$

Data $3$ $0$ $4$ $1$
Signature-Based Search for $l\gamma$MET and $ll\gamma$

- Searches for $l\gamma$MET and $ll\gamma$
- Backgrounds from $W\gamma, Z\gamma$
- No significant excess

<table>
<thead>
<tr>
<th></th>
<th>$e\gamma$+MET</th>
<th>$\mu\gamma$+MET</th>
<th>$l\gamma$+MET</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM</td>
<td>95±8</td>
<td>56±7</td>
<td>151±13</td>
</tr>
<tr>
<td>Data</td>
<td>96</td>
<td>67</td>
<td>163</td>
</tr>
<tr>
<td>$ee\gamma$</td>
<td>39±5</td>
<td>26±3</td>
<td>65±8</td>
</tr>
<tr>
<td>$\mu\mu\gamma$</td>
<td>21</td>
<td>2</td>
<td>74</td>
</tr>
<tr>
<td>$ll\gamma$</td>
<td>53</td>
<td>21</td>
<td>74</td>
</tr>
</tbody>
</table>

CDF Run II

- $l\gamma E_{T}$ Data($e+\mu$), 929 pb$^{-1}$
- $W\gamma$
- $Z\gamma$
- $e$ fake $\gamma$
- $Wj$, $\gamma\gamma$, QCD, $Z\gamma\gamma$, $W\gamma\gamma$
Search for Delayed Photons

- Some models predict long-lived particles
  - Conventional searches assume prompt decays
- Use EM Timing system (installed mid Run-II)
  - Signal region $2 < t < 10$ ns.
  - Expect $1.3 \pm 0.7$, Observe 2.

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Search for CHAMPS

- Many extensions of SM predict Charge Massive Stable Particles
- Signature: slow, highly ionizing, penetrating (looks like muon)
- Use time-of-flight (TOF) system to measure particle velocity

Reconstruct mass from $\nu$ and $p$

Model-independent limits: for CHAMP fiducial to TOF, $0.4<\beta<0.9$, $40<p_T<420$,
  - $\sigma<48$ fb if interacts with hadrons
  - $\sigma<10$ fb if no hadronic interactions

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Model-Independent Algorithmic (Vista+Sleuth)

- Classify events by their object content (final state)
- Simulate standard model with Monte Carlo
- Global fit to extract correction factors (luminosity, k-factors, mis-id rates, trigger efficiencies, jet energy scale)
- Look for anomalies in distributions (bulk)
- Look for excesses in high sum $E_T$ distributions
  - Assumes NP will be at high sum $E_T$ and appear as an excess
- Order final states by how discrepant they are
  - Flag interesting states for further study
- Iterative procedure to identify and account for detector effects
- Sensitivity to new physics depends on details of final state
- Provides a safety net to avoid missing the obvious
- 1 fb$^{-1}$ result expected soon
Outlook

- DØ and CDF are searching for many models and signatures of new physics
- No evidence of NP observed yet in Run II
- Both experiments have now recorded 2 fb⁻¹
  - Should soon have results with ~double the data
- Most of expected Run II data still to be collected and analyzed
  - Surprises could be just around the corner
Back-Up
Search for Z’ in ee

CDF Run II Preliminary

Expected Range for Min. Obs. Prob.

3 $\sigma$ evidence level

$\int L \, dt = 1.3 \, fb^{-1}$