Searches in dilepton and diphoton final states at the Tevatron

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Experimental motivation

- Diphoton and dilepton searches provide a clean, model-independent probe for new particles
  - Excellent detector resolution
    - CDF dimuon mass resolution: ≈15% at 1 TeV
    - CDF dielectron mass resolution: ≈2% at 1 TeV
  - Unambiguous mass peaks separable from background
    - Primary issue: statistics
    - CDF ee search finds excess at 240 GeV with 2.5σ significance

- Tevatron has best sensitivity to new resonances
  - High-mass resonance searches approaching kinematic limit
  - Improving sensitivity to weakly coupled resonances (α ≤ α_{EW})
Theoretical motivation

- New neutral resonances ubiquitous in models beyond the SM
  - Spin 2 gravitons in models with warped extra dimensions
    - Randall-Sundrum model: metric contains exponential factor as function of extra dimension
    - Predicts tower of graviton resonances with masses and couplings determined by $k/M_{Pl}$
  - Spin 1 gauge bosons in models with new $U(1)$ gauge group
    - Superstring-inspired grand unified theory ($E_8 \times E_8$): couplings determined by one parameter
    - Stueckelberg model where Abelian gauge boson acquires mass without a Higgs mechanism
    - $U(1)$ with flavor-dependent charge
  - Spin 0 Higgs bosons and sneutrinos in supersymmetric models
    - R-parity-violation models allow direct $q$-$q$-sneutrino and $l$-$l$-sneutrino couplings
    - Conserves baryon number, allowing greater suppression of proton decay than R-parity
CDF searches in ee and $\mu\mu$

* CDF search in 2.3 fb$^{-1}$ of $\mu\mu$ data gives best published sensitivity to sneutrino and $Z'$ production

* Uses novel method of fitting $1/m$ distribution, which is $\approx$ constant in resolution

* CDF ee search finds excess at 240 GeV with 2.5σ significance


Phys. Rev. Lett. 102, 031801 (2009)
CDF 4.6 fb$^{-1}$ search in $\mu\mu$

★ New CDF search uses matrix-element-based likelihood to separate $Z'$ signal from Drell-Yan and maximize sensitivity

★ Gains 20% in cross section sensitivity relative to previous search
CDF 4.6 fb$^{-1}$ search in $\mu\mu$

- Determines best fit to data in cross section vs mass plane
- Feldman-Cousins contours account for ‘look elsewhere’ effect by construction

CDF Run II Preliminary, 4.6 fb$^{-1}$

**Best Fit Point:**
- $M_{Z'} = 199$ GeV/c$^2$
- signal frac = 1.3%
- p-value = 0.16

<table>
<thead>
<tr>
<th>Model</th>
<th>Mass Limit (GeV/c$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z'_1$</td>
<td>817</td>
</tr>
<tr>
<td>$Z'_2$</td>
<td>858</td>
</tr>
<tr>
<td>$Z'_3$</td>
<td>900</td>
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<tr>
<td>$Z'_4$</td>
<td>917</td>
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<tr>
<td>$Z'_5$</td>
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<tr>
<td>$Z'_6$</td>
<td>938</td>
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<tr>
<td>$Z'_7$</td>
<td>1071</td>
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</tbody>
</table>

World’s highest direct $Z'$ mass limits
**DØ combined ee/γγ search**

- Graviton branching ratio to photons twice that of electrons
  - Gain sensitivity by separately searching dielectrons and diphotons
  - Most significant excess at mass of 450 GeV in γγ
    - 2.3σ after accounting for mass scan
    - Not confirmed in dielectrons
  - Set world’s highest mass limits on R-S gravitons

**DØ ee search**

- Use dielectron data to probe for $Z'$ bosons
  - $Z'$ with non-universal flavor couplings has higher branching ratio to electrons than muons
  - Test CDF excess at mass of 240 GeV
DØ ee search

* Set limits on gauge coupling in superstring inspired E₆ model as a function of mass

* Also set mass limits for Stueckelberg Z’ bosons with weak coupling to SM

<table>
<thead>
<tr>
<th>Model</th>
<th>Lower Mass Limit (GeV)</th>
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<tbody>
<tr>
<td></td>
<td>Expected</td>
</tr>
<tr>
<td>$Z'_\text{SSM}$</td>
<td>1024</td>
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<tr>
<td>$Z'_H$</td>
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<tr>
<td>$Z'_\lambda$</td>
<td>910</td>
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<tr>
<td>$Z'_\psi$</td>
<td>898</td>
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<td>$Z'_N$</td>
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<tr>
<td>$Z'_{\phi R}$</td>
<td>829</td>
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<tr>
<td>$Z'_I$</td>
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<tr>
<td>$Z'_{\text{SSM}}(\epsilon = 0.06)$</td>
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<td>$Z'_{\text{SSM}}(\epsilon = 0.05)$</td>
<td>414</td>
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<td>$Z'_{\text{SSM}}(\epsilon = 0.04)$</td>
<td>340</td>
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<td>$Z'_{\text{SSM}}(\epsilon = 0.03)$</td>
<td>227</td>
</tr>
<tr>
<td>$Z'_{\text{SSM}}(\epsilon = 0.02)$</td>
<td>—</td>
</tr>
</tbody>
</table>

Preliminary

ICHEP, 24 July 2010

C. Hays, Oxford University
CDF diphoton search

* CDF has updated an earlier diphoton search for R-S gravitons

* Most significant excess at 200 GeV
DØ search in diphoton + $E_T$

Probing diphoton sample with significant energy imbalance sensitive to new class of models

- Pair production of particles decaying to a photon and unidentified particle
  - Neutralino production in gauge-mediated supersymmetry breaking models
    - Neutralino decays to photon and lightest supersymmetric particle
  - Graviton production in models of universal extra dimensions with Kaluza-Klein-parity violating decays
    - Kaluza-Klein photon decays to photon and graviton
Summary

✴ Tevatron searches for dileptons and diphotons continually expanding sensitivity

✴ Resonances with couplings of order of the SM Z are reaching kinematic limit

✴ Results with 5 fb\(^{-1}\) of data per experiment: probing ever weaker couplings

✴ Tevatron continues to pioneer new search techniques and probe new models

✴ Matrix-element provides background separation

✴ For weak couplings searches no longer background-free

✴ Covering many Z' models, general mass vs coupling limits

✴ More ground still to cover with full Tevatron data set