Search for heavy resonances in dielectron, diphoton, electron + photon and electron + MET final states

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on behalf of the DØ Collaboration

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Supported by
Overview

• Introduction

• Featured Analyses:
  
  most recent Run IIa DØ results

  (1) Search for Randall-Sundrum Gravitons in dielectron and diphoton final states

  (2) Search for excited electrons $e^*$ in the electron + photon final state

  (3) Search for a $W'$ Boson in electron + MET final state

• Conclusion & Outlook
  
  o Data Selection
  o Backgrounds
  o Result
  o Limit
Introduction

Standard Model

Describes the fundamental fermions and their interactions

Prediction of
- $W$, $Z$ production cross section
- top quark
- $\Delta m_s$

... But it is not considered to be a complete theory

What about
- number of fermion families?
- hierarchy of fermion masses?
- fine tuning?
**Tevatron & DØ**

- **Circumference**
  - Tevatron: ~ 6.4 km
  - Main Injector & "Recycler": ~ 3.2 km

- **Energy**
  - 1.96 TeV

- **Luminosity**
  - Recorded Luminosity during Run IIa (2001 - 2006): 1.3 fb⁻¹
Extension (I) : Extra Dimensions (ED)

Hierarchy problem:
EW scale ≪ GUT scale ≪ Planck scale (∼10^2 GeV ≪ ∼10^{16} GeV ≪ ∼10^{19} GeV)

Idea:
1 fundamental scale (∼ tens TeV) with 1 + 3 + δ time-space structure

Randall-Sundrum Extra Dimensions (RS ED)

- one (5th) extra dimension (δ = 1)
- 2 branes: Planck (y = 0) and TeV/SM (y = πr_C)
- ‘warped’ metric \( ds^2 = e^{-2k|y|} \eta_{\mu \nu} dx^\mu dx^\nu - dy^2 \)
- SM brane \( \Lambda_\pi = M_{\text{Planck}} e^{-kr_C} \sim 1 \text{ TeV} \Rightarrow kr_C \sim 11 \) (‘natural’)
- KK gravitons \( m_n = x_n k e^{-kr_C} = x_n \cdot \Lambda_\pi \cdot \frac{k}{M_{\text{Planck}}} \sim O(\text{GeV}) - O(\text{TeV}) \)
  \( x_0 = 0; \ x_1 = 3.83 \ldots \)
Extension (I) : Extra Dimensions (ED)

2 free parameters: mass of lightest KK excitation $m_1$ and $k/M_{\text{Planck}}$

5d curvature scalar in $\text{AdS}_5$:

\[ R_5 = -20k^2 \]

5d Planck scale:

\[ M_5^3 \approx kM_{\text{Planck}}^2 \]

Many other types of ED: Large ED, TeV$^{-1}$ ED, ...
**RS ED : Data Selection**

**Event selection:**
- triggered by EM or diEM triggers
- 2 electromagnetic objects (diEM) in the DØ Calorimeter
  - no track match required ($\gamma !!!$)
  - energy deposition patterns consistent with electromagnetic showers (isolation, shape, ...)
  - both in central calorimeter: $|\eta| < 1.1$
  - $E_T > 25$ GeV
  - $m_{\text{diEM}} > 50$ GeV

**Note:** $\text{Br}(G \rightarrow \gamma \gamma) = 2 \text{Br}(G \rightarrow \text{ee})$

**Idea:** do not distinguish in final state between electrons and photons

$\Rightarrow 50354 \text{ Events}$
Backgrounds:
- physics: Drell-Yan / Z & direct diphoton from Pythia MC
- instrumental: from Data

Select diEM objects failing the tight shower criteria -> gives an estimate for the shape of misidentified electrons/photons
-> fit the invariant mass distribution around the Z peak with sum of physics and instrumental background

Fit: $60 \text{ GeV} < m_{\text{diEM}} < 140 \text{ GeV}$
RS ED : Result

For different Graviton masses we make use of an optimized mass window in invariant mass distribution

Some Examples:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>240</td>
<td>230 - 250</td>
<td>53</td>
<td>47.0 ± 6.1</td>
</tr>
<tr>
<td>330</td>
<td>310 - 350</td>
<td>23</td>
<td>15.9 ± 3.2</td>
</tr>
<tr>
<td>400</td>
<td>370 - 430</td>
<td>12</td>
<td>7.0 ± 1.2</td>
</tr>
<tr>
<td>500</td>
<td>460 - 540</td>
<td>3</td>
<td>3.38 ± 0.76</td>
</tr>
<tr>
<td>600</td>
<td>550 - 650</td>
<td>0</td>
<td>0.78 ± 0.10</td>
</tr>
<tr>
<td>700</td>
<td>630 - 770</td>
<td>1</td>
<td>0.76 ± 0.33</td>
</tr>
<tr>
<td>800</td>
<td>710 - 890</td>
<td>0</td>
<td>0.15 ± 0.03</td>
</tr>
<tr>
<td>900</td>
<td>790 - 1010</td>
<td>0</td>
<td>0.08 ± 0.02</td>
</tr>
</tbody>
</table>

Uncertainties:
Cross sections, efficiency corrections, PDF, acceptance

Good agreement between data and sum of backgrounds

~ 10%
RS ED : Limit

- Bayesian approach with a flat prior
- Systematic uncertainties are represented by Gaussian priors

For $k \sqrt{8\pi} / M_{\text{Planck}} = 0.1(0.01)$ mass limit on RS Graviton is 865 (240) GeV
Extension (II) : Excited Electrons \( e^* \)

Possible explanation for \textbf{hierarchical} structure of fermions:

Substructure of fermions ??

observable : \textbf{radiative decays}

Production :

\begin{itemize}
  \item EW (here: neglected)
  \item Contact Interaction CI
\end{itemize}

Decay :

\begin{align*}
\ell^* &\rightarrow \nu W \quad \text{(EW)} \\
\ell^- &\rightarrow \ell Z \\
\ell^* &\rightarrow f f \ell \quad \text{(CI)}
\end{align*}

Effective theory :

\[ \mathcal{L} = \frac{4\pi}{2\Lambda^2} j^\mu j_\mu \]

„Compositeness Scale \( \Lambda " \)

Parameters :

\begin{align*}
\text{Mass } m(\ell^*) \\
\text{Scale } \Lambda
\end{align*}
e* : Data Selection (ee)

Event selection:
- triggered by EM or diEM triggers
- 2 electromagnetic objects in the DØ Calorimeter
  - energy deposition patterns consistent with EM showers
  - associated tracks
  - \( E_T(e_1) > 25 \text{ GeV} \)
  - \( E_T(e_2) > 15 \text{ GeV} \)
  - \(|\eta| < 1.1 \) or \( 1.5 < |\eta| < 2.5 \)
  - separated \( \Delta R > 0.4 \)

Data:
62930

Background:
61560 ± 120 (stat) ± 6553 (sys)
**e* : Data Selection (eeγ)**

**Photon Identification**
- electromagnetic object in the DØ Calorimeter
- energy deposition patterns consistent with EM showers
- no associated track, isolated
- $E_T > 15$ GeV and $|\eta| < 1.1$ or $1.5 < |\eta| < 2.5$

**Data:** 259
**Background:** 232 ± 3 (stat) ± 29 (sys)

Good agreement between data and background
Optimize cut on $m(e\gamma)$ wrt the expected limit

How to combine electron and photon??

For $m(e^*) < 300$ GeV: $e^2 + \gamma$

For $m(e^*) \geq 300$ GeV: Combination closest to $m(e^*)$

$\Delta R (e_2, \gamma) < 1.8$

**Data:**
- Background: $0.31 \pm 0.09$

**Data:**
- Background: $0.28 \pm 0.10$

$m_{e^*} = 100$ GeV
$\Lambda = 1$ TeV

$m_{e^*} = 300$ GeV
$\Lambda = 1$ TeV
**e* : Result**

**Uncertainties:**
Efficiency corrections, cross sections, PDF luminosity, misID, QCD

Neglect decays via Contact Interaction:

\[ m_{e^*} > 946 \text{ GeV} \]

\[ \Lambda = m_{e^*} \]

\[ m_{e^*} > 756 \text{ GeV} \]

\[ \Lambda = 1 \text{ TeV} \]

CDF II (202 pb\(^{-1}\)):
\[ m(e^*) > 879 \text{ GeV} \]
\( m(e_2, \gamma) = 195 \text{ GeV} \)

\( m(e_1, e_2) = 90.1 \text{ GeV} \rightarrow Z + \gamma \)
Extension (III) : Heavy Gauge Bosons

Additional gauge bosons ($W'$, $Z'$) are introduced in many extensions to the SM: $SU(5), SO(10), E_6, \ldots$

Parameters:
- mass, width

In addition:
- mixing (mass eigenstates $\neq$ group eigenstates) $\xi$
- new fermion - boson - couplings $g'$
- new CKM - Matrix $U'$

Make assumptions to reduce number of parameters:

$\Rightarrow \xi = 0$, $g' = g_{SM}$, $U' = U_{SM}$

$m_{W'} < 180 \text{ GeV} : \Gamma_{W'} = \frac{m_{W'}}{m_w} \cdot \Gamma_w$

$\Rightarrow$ width $\sim$ mass

$m_{W'} > 180 \text{ GeV} : \Gamma_{W'} = \frac{4}{3} \cdot \frac{m_{W'}}{m_w} \cdot \Gamma_w$

Decay $t \bar{b}$ allowed
**W' : Data Selection**

**Event selection:**
- triggered by inclusive single EM triggers
- missing transverse energy MET $> 30$ GeV
- contains 1 electron candidate
  - energy deposition patterns consistent with electromagnetic showers (isolation, shape, ...)
  - in central calorimeter: $|\eta| < 1.1$
  - $E_T > 30$ GeV
  - track match in $z$ and $\phi$ direction (no $E/p$)

**Further cleaning cuts:**
- $0.7 < E_T/MET < 1.3$
- no jet activity in opposite direction of electron/MET

-> Reject fake MET
W': Backgrounds

Backgrounds:
- dominant: W from Pythia MC
- minor: WW, ZZ, WZ, Z from Pythia MC
- QCD multijet from Data ('fake electrons')

Method similar to diEM analysis:
- electron candidate failing tight shower criteria
- scale to data + SM PYTHIA MC in low $m_T$ region
W' : Result

Good agreement between data and sum of backgrounds
Assuming SM couplings and no mixing with new gauge groups, the mass limit is 965 GeV.

Limit:
Use $m_T$ distribution ($m_T > 150$ GeV)
→ shape information

Uncertainties:
Cross sections, normalization, QCD scaling, efficiency corrections, PDF, electron energy scale

~ 15%

95% CL Limit

$\sigma_{W'} B(W' \rightarrow e v)$ [pb]
$m_T = 530 \text{ GeV}$

$E_T = 265 \text{ GeV}$

$E_{T}^{el} = 265 \text{ GeV}$

$z_{vtx} = -38.36 \text{ cm}$

$|z_{vtx} - z_{e}| = 0.04 \text{ cm}$
Conclusion and Outlook

- interesting signatures to look for at the Tevatron
- presented 3 new analyses:
  - Search for Randall-Sundrum Gravitons in diEM spectrum
  - Search for excited electrons
  - Search for W' in electron + MET final state
- in 1 fb\(^{-1}\) no evidence for 'New Physics' found \implies new restrictive limits

\begin{itemize}
  \item For \(k\sqrt{8\pi}/M_{Planck} = 0.1\) mass limit on RS Graviton is 865 GeV
  \item For \(\Lambda = 1\) TeV the mass limit on e* is 756 GeV
  \item Mass limit for W' is 965 GeV (SM couplings, no mixing)
\end{itemize}

Run IIb ongoing with improved accelerator & detector

\(\rightarrow\) Reveal 'New physics' with higher luminosity ???
Performance

Run IIa (2001 - 2006): ~1.3 fb⁻¹

End of Run IIa

Delivered
Recorded
RS ED : CDF & DØ

**k/M_{pl} vs RS Graviton Mass Exclusion**

**Tevatron Run II Preliminary**

- CDF: $\gamma\gamma + e^+e^- (0.8-1.2 \text{ fb}^{-1})$
- D0: $\gamma\gamma + e^+e^- (1.1 \text{ fb}^{-1})$

excluded region

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[Image: Graph showing k/M_{pl} vs RS Graviton Mass Exclusion]
For $k\sqrt{8\pi} / M_{Planck} = 0.1(0.01)$ mass limit on RS Graviton is $875 (242) \text{ GeV}$
Extension (II): Excited Electrons e*

Lepton required for trigger, clean final state

→ check BR für leptonic decays of W and Z

→ 70% of e* → lepton + X decays into 'golden' channel e* → eγ
\[ \mathcal{L}_{GM} = \frac{1}{2\Lambda} \tilde{F}^* R \sigma_{\mu\nu} \left[ g f \frac{\tau^a}{2} W^a_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\chi^a}{2} G^a_{\mu\nu} \right] F_L \]

**Excited Electron Searches (f = + f')**

- **H1 HERA I** (120 pb\(^{-1}\))
- **CDF Run II** (202 pb\(^{-1}\))
- **D0 Run II** (1 fb\(^{-1}\)) (prelim.)
- **H1 HERA I+II** (435 pb\(^{-1}\)) (prelim.)
- **LEP** (direct, indirect)

**Note:**
Contact Interaction contribution here neglected
Tevatron: CI \sim 100 * GM

Thanks to E. Sauvan and A. Meyer  
**e**\(^*\) Mass [ GeV ]