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

Carsten Magass

on behalf of the DØ Collaboration

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Overview

• Introduction

• Experimental Setup

• Featured Analyses:
  
  1. Search for Randall-Sundrum Gravitons in dielectron and diphoton final states
  
  2. Search for a $W'$ Boson in electron + MET final state

• Conclusion & Outlook

most recent Run IIa DØ results

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

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

- Data Selection
- Backgrounds
- Result
- 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?
Extension (I) : Extra Dimensions (ED)

Hierarchy problem:
EW scale $\ll$ GUT scale $\ll$ Planck scale ($\sim 10^2$ GeV $\ll$ $\sim 10^{16}$ GeV $\ll$ $\sim 10^{19}$ GeV)

Idea:
1 fundamental scale ($\sim$ tens TeV) with $1 + 3 + \delta$ time-space structure

Randall-Sundrum Extra Dimensions (RS ED)

- one (5th) extra dimension ($\delta = 1$)
- 2 branes: Planck ($y = 0$) and TeV/SM ($y = \pi r_C$)
- 'warped' metric $ds^2 = e^{-2k|y|} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$
- SM brane $\Lambda_{\pi} = M_{\text{Planck}} e^{-k\pi r_C} \sim 1$ TeV $\Rightarrow kr_C \sim 11$ ('natural')
- KK gravitons $m_n = x_n k e^{-k\pi r_C} = x_n \cdot \Lambda_{\pi} \cdot \frac{k}{M_{\text{Planck}}} \sim O(\text{GeV}) - O(\text{TeV})$

$x_0 = 0; x_1 = 3.83\ldots$
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, ...
Extension (II) : Heavy Gauge Bosons

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

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:

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

$m_{W'} < 180 \text{ GeV} : \Gamma_{W'} = \frac{m_{W'}}{3} \cdot \Gamma_{W}$

$\Rightarrow$ width $\sim$ mass

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

Decay $tb$ allowed
Signatures

Look for resonances in diEM spectrum

Look for high $E_T$ objects (electron & MET)

1.5 TeV Graviton + tower states

LHC

Davoudiasl, Hewett, Rizzo
PRD 63, 075004 (2001)

$k/M_{\text{Planck}} = 1; 0.5; 0.1; 0.05; 0.01$

Tevatron

$W$, $W'$ (500 GeV)
Tevatron & DØ

Main Injector & "Recycler" circumference ~ 3.2 km
Tevatron circumference ~ 6.4 km

Run IIa (2001 - 2006): ~1.3 fb\(^{-1}\)

CDF

DØ
RS ED : Data Selection

Note: \( \text{Br}(G \rightarrow \gamma \gamma) = 2 \text{Br}(G \rightarrow e e) \)

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

Data taken from 2002 – 2006 : 1.1 fb\(^{-1}\)

Event selection:
• triggered by electron or dielectron triggers
• 2 electromagnetic objects (diEM) in the DØ Calorimeter
  without any contraints to the tracking system (\(\gamma \) !!!)
  - 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

\(\Rightarrow 50354\) Events
RS ED: Backgrounds

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>
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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, NNLO K

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
Data Selection

Data taken from 2002 - 2006 : 0.9 fb⁻¹

Event selection:
- triggered by inclusive single electron triggers
- missing transverse energy MET > 30 GeV
- contains 1 electron candidate
  - energy deposition patterns consistent with electromagnetic showers (isolation, shape, ...)
  - in central calorimeter : |η| < 1.1
  - E_T > 30 GeV
  - track match in z and φ 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

**Transverse Mass $m_T$**

Good agreement between data and sum of backgrounds

**MET**

- $W \rightarrow e \nu$
- QCD (from Data)
- $W \rightarrow \tau \nu$
- $Z/\gamma' \rightarrow e e$
- $Z/\gamma' \rightarrow \tau\tau$
- WW incl.
- $t\bar{t}$ incl.
- WZ incl.
- ZZ incl.
- Data

**Results**

- $150 \text{ GeV}$: $630 \pm 18 \text{ (stat)} \pm 79 \text{ (sys)}$
- $200 \text{ GeV}$: $199 \pm 9 \text{ (stat)} \pm 28 \text{ (sys)}$
- $300 \text{ GeV}$: $31 \pm 2 \text{ (stat)} \pm 6 \text{ (sys)}$
- $400 \text{ GeV}$: $8 \pm 1 \text{ (stat)} \pm 2 \text{ (sys)}$
- $500 \text{ GeV}$: $2 \pm 1 \text{ (stat)} \pm 1 \text{ (sys)}$

**Figure Notes**

- DØ Run II Preliminary 900 pb$^{-1}$
Limit: 
Use $m_T$ distribution ($m_T > 150$ GeV) 
→ shape information

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

~ 15%

Assuming SM couplings and no mixing with new gauge groups the mass limit is 965 GeV
$m_T = 530 \text{ GeV}$

$H_T = 265 \text{ GeV}$

$E_T^{el} = 265 \text{ GeV}$

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

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

- interesting signatures to look for at the Tevatron
- presented 2 new analyses:
  - Search for Randall-Sundrum Gravitons in diEM spectrum
  - Search for $W'$ in electron + MET final state
- in 1 fb$^{-1}$ no evidence for 'New Physics' found
- both analyses give very restrictive limits

- For $k\sqrt{8\pi}/M_{Planck}=0.1$ mass limit on RS Graviton is 865 GeV
- Mass limit for $W'$ is 965 GeV (SM couplings, no mixing)

Run IIb has just started with improved accelerator & detector

→ Reveal 'New physics' with higher luminosity ??
Backup
Performance

Run IIa (2001 - 2006): ~1.3 fb⁻¹

End of Run IIa
RS ED : CDF & DØ

**Figure:**

- **Title:** k/Mₚ vs RS Graviton Mass Exclusion
- **Legend:**
  - Blue line: CDF: γγ + e⁺e⁻ (0.8-1.2 fb⁻¹)
  - Red line: D0: γγ + e⁺e⁻ (1.1fb⁻¹)
- **Graph:**
  - x-axis: Graviton Mass (Gev/c²)
  - y-axis: k/Mₚ
  - Excluded region

**Notes:**

- Tevatron Run II Preliminary

**Contact:**

P. Savard
ICHHEP 2006
RS Graviton 95% Confidence Limits

CDF Run II Preliminary

$\sigma(B_{RS} \rightarrow 1 \gamma') (pb)$

- $e^+e^-$ limits
- $\gamma\gamma$ limits
- $\gamma\gamma + e^+e^-$ limits
- LO $\sigma . Br \times 1.3$

$\int L dt = 0.8 - 1.2 fb^{-1}$

$M_G (GeV/c^2)$

$k/M_{pl} = 0.1$

$k/M_{pl} = 0.05$

$k/M_{pl} = 0.025$

For $k\sqrt{8\pi} / M_{Planck} = 0.1(0.01)$ mass limit on RS Graviton is 875 (242) GeV