Large Extra Dimension Searches at 8 TeV

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Introduction

• Theoretical Motivation

• ATLAS and the LHC

• Signal & Background Estimates

• Electron Event Selection

• Search Strategy

• Statistical Interpretation

• Results

Motivation – Large Extra Dimensions (LEDs)

- Arkani-Hamed, Dimpoulos and Dvali (ADD) proposed n large flat extra dimensions of size $R$ to solve the hierarchy problem;

$$M_{Pl} \sim 10^{16} \text{TeV} \gg M_{EW} \sim \text{TeV}.$$  

- “Fundamental” Planck scale $M_D$ (related to search parameter $M_S$) can be modified from $M_{Pl}$ through;

$$M_{Pl} \sim M_D^{n+2} R^n. \quad M_S = 2\sqrt{\pi} [\Gamma(n/2)]^{1/(n+2)} M_D$$

- Gravitons propagate in these Extra Dimension resulting in a series of mass states with splitting $\sim 1/R$ – observable as broad excess above Drell-Yan.

$$\sigma_{\text{tot}} = \sigma_{\text{DY}} + \mathcal{F} \frac{F_{\text{int}}}{M_S^4} + \mathcal{F}^2 \frac{F_G}{M_S^8},$$
Searching for LEDs - ATLAS

Electron Identification;
- Inner Detector
- Electromagnetic Calorimeter
Backgrounds and Signal

**Signal:**
- ADD gravitons

**Irreducible backgrounds:**
- Drell-Yan
- Photon-Induced

**Reducible backgrounds:**
- Top \([ttbar+Wt]\)
- Diboson \([WW, ZZ, WZ]\)
- Multi Jets \& W+jets (data driven)
Electron Event Selection

Event requirements
- Pass high $p_T$ 2 object e/gamma trigger (35 & 25 GeV)
- At least one primary vertex with more than 2 tracks

Electron requirements
- $|\eta| < 2.47$, excluding $1.37 < |\eta| < 1.52$
- $p_T > 40$ (30) GeV leading (sub-leading)
- Isolated electrons
- Opposite sign charges
- Invariant mass > 80 GeV

Signal Efficiency = 67% at 2TeV

Discriminating variable – Invariant mass

\[ \text{ee: } \int L \, dt = 20.3 \, \text{fb}^{-1} \]

\[ \sqrt{s} = 8 \, \text{TeV} \]

ATLAS

Data 2012
- \( Z/\gamma^* \)
- Photon-Induced
- Top
- Multi-Jet & W+Jets
- Diboson

\[ m_{ee} = 3.0 \, \text{TeV (GRW)} \]
\[ m_{ee} = 3.5 \, \text{TeV (GRW)} \]
\[ m_{ee} = 4.0 \, \text{TeV (GRW)} \]
Single bin counting experiment

The likelihood of observing \( n \) events given the new physics parameter \( \Theta \) (\( 1/M_s^4 \) or \( 1/M_s^8 \)) and nuisance parameters \( \Omega \):

\[
L(n|\Theta, \bar{\Omega}) = \frac{\mu^n e^{-\mu}}{n!}
\]

where \( \mu = n_s(\Theta, \bar{\Omega}) + n_b(\bar{\Omega}) \)

the posterior probability for the parameter \( \Theta \), given \( n \) observed events, is then

\[
P(\Theta | n) = \frac{1}{\mathcal{Z}} \mathcal{L}_M(n | \Theta)P(\Theta)
\]

Use two separate priors, flat in \( 1/M_s^4 \) or \( 1/M_s^8 \).

The 95\% C.L. limit is then obtained by solving;

\[
\int_0^{\Theta_{\text{lim}}} P(\Theta | n) d\Theta = 0.95
\]
Parameterisations

Counting events in each search bin is only possible for the generated discrete samples of $M_S$ values.

Instead use function of number of expected events vs parameter of interest ($1/M_S^4$ or $1/M_S^8$).

$$N_{exp}(M_S) = c_0 + \frac{c_1}{M_S^4} + \frac{c_2}{M_S^8}$$

$c_0$ = DY estimate

$c_1$ & $c_2$ determined through fitting
Search Bin Optimisation

The minimum mass of the search bin is optimised using the strongest expected limit.

The strongest mean limit from the Pseudo Experiment distribution determines the optimal binning and the median is extracted as the limit value.

**Strongest expected limit found at 1.9TeV**
Good agreement is found between data and SM – proceed to set limits on $M_S$

95% CL lower limits

Prior: $1/M_S^8$

$\int L \, dt = 20.3 \, fb^{-1}$

$\sqrt{s} = 8 \, TeV$

$\sigma_{1\pm1 \sigma}$

$\sigma_{2\pm2 \sigma}$

$5 \, fb^{-1}, \sqrt{s} = 7 \, TeV$

ATLAS Work in Progress
Dilepton Results

Combining with the dimuon channel.

\begin{align*}
\text{ATLAS} & \quad ee/\mu\mu: \int L \, dt = 20.5 \text{ fb}^{-1} \\
\sqrt{s} & = 8 \text{ TeV}
\end{align*}

\text{Prior: } 1/M_s^8 \quad \text{ADD LO}

\begin{align*}
\text{95\% C.L. lower limits} & \\
\text{Observed} & \\
\text{Expected} & \pm 1 \sigma \\
\text{Expected} & \pm 2 \sigma \\
5 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV}
\end{align*}
Summary

Searching for ADD LEDs which would solve hierarchy problem

Well isolated high $p_T$ electrons of opposite charge selected

Invariant mass used as discriminating variable

High mass bin cut and count experiment to determine any excess

Limits presented in the dielectron and combined dielectron + dimuon channels

Looking forward to Run 2 where this will be an early search using $\sim 2 \mathrm{fb}^{-1}$ of data to surpass current limits.
Thank-you

Questions?
\[ F = 1, \quad \text{(GRW)} \]

\[ F = \begin{cases} 
\log \left( \frac{M_S^2}{m_{\ell\ell}^2} \right), & (n = 2) \\
\frac{2}{n-2}, & (n > 2)
\end{cases}, \quad \text{(HLZ)} \]

\[ F = \frac{2\lambda}{\pi} = \frac{\pm 2}{\pi}, \quad \text{(Hewett)} \]
## Samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Estimated using</th>
<th>Generation Order</th>
<th>kFactor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drell-Yan</td>
<td>Powheg+Pythia8 (CT10)</td>
<td>NLO</td>
<td>NNLO FEWZ QCD +EW kF</td>
</tr>
<tr>
<td>Photon-Induced</td>
<td>Pythia 8 (MRST2004QED)</td>
<td>LO</td>
<td>taken at LO</td>
</tr>
<tr>
<td>Diboson</td>
<td>Herwig (CTEQ6L1)</td>
<td>LO</td>
<td>NLO mass independent kF</td>
</tr>
<tr>
<td>Top</td>
<td>MC@NLO (CT10)</td>
<td>NLO</td>
<td>NNLO mass independent kF</td>
</tr>
<tr>
<td>Djet &amp; W +jets</td>
<td>Data-Driven</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADD signal</td>
<td>Sherpa (CT10)</td>
<td>LO</td>
<td>LO</td>
</tr>
</tbody>
</table>
## Event selections

<table>
<thead>
<tr>
<th>Cut</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dielectron</strong> Event Level Selection Criteria</td>
<td></td>
</tr>
<tr>
<td>Trigger</td>
<td>EF_g35_loose_g25_loose</td>
</tr>
<tr>
<td>Primary Vertex</td>
<td>$\geq$ 1 PV with $&gt; 2$ Trks</td>
</tr>
<tr>
<td><strong>Electron Level Selection Criteria</strong></td>
<td></td>
</tr>
<tr>
<td>Author</td>
<td>Calo/Trk Reco</td>
</tr>
<tr>
<td>$E_T$ lead (sub)</td>
<td>$E_T &gt; 40$ (30) GeV</td>
</tr>
<tr>
<td>$\eta$</td>
<td>$</td>
</tr>
<tr>
<td>Object Quality</td>
<td>Quality and LAr Error Check</td>
</tr>
<tr>
<td>Electron ID</td>
<td>Medium++</td>
</tr>
<tr>
<td>Highest $p_T$ Electron Pair Criteria</td>
<td></td>
</tr>
<tr>
<td>Leading Isolation</td>
<td>$E_T(\Delta R &lt; 0.2)_{p_T/NPV} &lt; (0.007 E_T + 5.0)$ GeV</td>
</tr>
<tr>
<td>Sub Isolation</td>
<td>$E_T(\Delta R &lt; 0.2)_{p_T/NPV} &lt; (0.022 E_T + 60)$ GeV</td>
</tr>
<tr>
<td>Charge</td>
<td>Pair of Opposite-Sign Charge</td>
</tr>
<tr>
<td>Invariant Mass</td>
<td>$M_{ee} &gt; 80$ GeV</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
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<th>Comment</th>
</tr>
</thead>
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<tr>
<td><strong>Dimuon</strong> Event Level Selection Criteria</td>
<td></td>
</tr>
<tr>
<td>Trigger</td>
<td>EF_mu24i_tight</td>
</tr>
<tr>
<td>Primary Vertex</td>
<td>$\geq$ 1 PV with $&gt; 2$ Trks</td>
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<tr>
<td><strong>Muon Level Selection Criteria</strong></td>
<td></td>
</tr>
<tr>
<td>MuID</td>
<td>$\geq$ 2 combined MuID muons</td>
</tr>
<tr>
<td>$p_T$</td>
<td>$p_T &gt; 25$ GeV</td>
</tr>
<tr>
<td>ID Hits</td>
<td>Hit cuts prescribed by MCP</td>
</tr>
<tr>
<td><strong>MS Hits (3 Station only)</strong></td>
<td></td>
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<tr>
<td>Trk Parameters</td>
<td>$</td>
</tr>
<tr>
<td>Isolation</td>
<td>$\sum p_T(\Delta R &lt; 0.3) / p_T &lt; 0.05$</td>
</tr>
<tr>
<td>Highest $\sum p_T$ Muon pair</td>
<td></td>
</tr>
<tr>
<td>Charge</td>
<td>Opposite-Sign Charge</td>
</tr>
<tr>
<td>Invariant Mass</td>
<td>$M_{\mu\mu} &gt; 80$ GeV</td>
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