Searches for non-Susy new physics at CMS

Blois2011

23rd Rencontres de Blois

Particle Physics and Cosmology

May 29 - June 3, Blois

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on behalf of the CMS collaboration
Outline

• Introduction
  - motivation and general strategy

• CMS in brief

• Searches with high-$p_T$ leptons final state (new heavy resonances)
  - $W', Z', LQ$

• Searches with di-photon final state
  - LED, RS graviton

• New Physics with jets
  - di-jet and multi-jet mass resonances

• Summary
Motivations and strategy

- Many physics theories have been built to extend the SM
- These theories foresee a quantity of new particles

- Left-right symmetry of electroweak interactions
  - Extend the SM gauge group to include right-handed interactions
- Extra dimensions
  - Kaluza-Klein (KK) tower of heavy copies of all SM fields
- General extensions of the SM gauge group
  - e.g. Little Higgs models
- Technicolor
- GUT
- Composite models
  - Higgs not just an elementary particle
- ......

- General strategy:
  - excess in data in the high $P_T/M_T/M_{inv}$ region with respect to the SM expectations (MC)
  - if no excess is observed -> determine the exclusion limit.
- It is crucial to have a good description of the backgrounds
  - accurate shape model
  - accurate normalization

W', Z', RS graviton, LQ, micro black holes, ...
The CMS detector

- Full 2010 dataset used in the analysis presented (~35 pb\(^{-1}\) @ 7 TeV)
High $p_T$ leptons final state

- Detect high-$p_T$ leptons means to optimize reconstruction and identification in order to maximize the efficiency in the high-$p_T$ region

  - Electrons:
    - Electromagnetic clusters with consistent shower shape
    - Spatially matched to a reconstructed track in $\eta$ and $\phi$
    - Isolated in calorimeter and tracker

  - Muons:
    - Tracks in muon system matched to tracks in inner tracking system
    - Isolated in tracking system and calorimeter
    - More than 10 hits in silicon tracker
    - Transverse impact parameter $< 2$mm

- Robust and efficient lepton trigger is needed

- CaloDriven
  - resol gets better with $E$
  - jet background

- TrackerDriven
  - resol gets worse with $p_T$
  - cosmic background (pair)
• Clean signature with 2 high-\(p_T\) leptons in the final state passing the eleId or muId
• Focus on \(Z'\) and RS Graviton models as benchmark
• Complementary searches: lepton univer., different subdet., ...

• Main backgrounds:
  - SM Drell-Yan \(\rightarrow\) irreducible
    - normalized to data
  - \(TT\bar{b}ar + TT\bar{b}ar\)-like \(\rightarrow\) two real leptons (\(tt,WZ,WW,tW,Z\rightarrow\tau\tau\))
  - Jet Background \(\rightarrow\) jet fakes a lepton (\(W+jet,di-jet\))
    - fake rate method
  - Cosmics muons bkg \(\rightarrow\) di-muons from cosmic-rays
    - impact parameter selection
    - 3D angle between the two muons selection

• The bkg with prompt leptons is from MC but cross checked against the e-mu spectrum

<table>
<thead>
<tr>
<th></th>
<th>M&gt;60 GeV/c^2</th>
<th>M&gt;120 GeV/c^2</th>
<th>M&gt;200 GeV/c^2</th>
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<tbody>
<tr>
<td>data</td>
<td>95 ± 10 (stat)</td>
<td>33 ± 6 (stat)</td>
<td>6 ± 2 (stat)</td>
</tr>
<tr>
<td>MC</td>
<td>80.4 ± 2.4 (sys)</td>
<td>27.1 ± 0.8 (sys)</td>
<td>7.0 ± 0.2 (sys)</td>
</tr>
</tbody>
</table>
Final selection and results

• By focusing on the ratio, the uncertainty on the integrated lumi is eliminated

\[ \frac{\sigma \times BR(Z')} {\sigma \times BR(Z^0)} = \frac{N(Z')} {N(Z^0)} \times \frac{A(Z^0)} {A(Z')} \times \frac{\epsilon(Z^0)} {\epsilon(Z')} \]

<table>
<thead>
<tr>
<th>Channel</th>
<th>Channel</th>
<th>Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z_{SSM}</td>
<td>Z_{\Psi}</td>
<td>G_{KK}, k/M_{Pl} = 0.05</td>
</tr>
<tr>
<td>1027 GeV</td>
<td>792 GeV</td>
<td>778 GeV</td>
</tr>
<tr>
<td>958 GeV</td>
<td>731 GeV</td>
<td>729 GeV</td>
</tr>
<tr>
<td>1140 GeV</td>
<td>887 GeV</td>
<td>855 GeV</td>
</tr>
</tbody>
</table>

Exclusion @ 95% C.L.

Published CDF/D0 limits
D0, ee, \gamma\gamma 5.4 fb^{-1}:
M(Z'_{SSM}) > 1023 GeV
M(G_{KK}, k/M_{Pl}=0.1) > 1050 GeV

CDF, \mu\mu, 2.3 fb^{-1}:
M(Z'_{SSM}) > 1030 GeV
M(G_{KK}, k/M_{Pl}=0.05) > 921 GeV

CDF, ee, 2.5 fb^{-1}:
M(Z'_{SSM}) > 963 GeV
M(G_{KK}, k/M_{Pl}=0.05) > 848 GeV
\( W' \rightarrow l \nu \)

- Altarelli reference model tested (carbon copy of SM W boson)
- Signature: single and isolated high-pT lepton + large MET

- Kinematic selections:
  - \( \Delta \phi \) (lepton, MET) > 2.5
  - \( 0.4 < \text{lepton ET} / \text{MET} < 1.5 \)

- Main background: irreducible Standard Model \( W \rightarrow l \nu \)
- Bkg estimate in the high-pT region: two different approaches for electron and muon channels
  - Invert the isolation requirement and use the shape of \( M_T \) from non-isolated electrons
  - Fit data \( E_T / \text{MET} \) distribution with QCD template (from non-iso) + \( W \) template (from MC), leaving the two normalizations as free parameters.
  - \( M_T \) spectra are normalized to the template area in the region \( 0.4 < \text{Et/MET} < 1.5 \)
  - Sideband fit in a region where signal \( \sim 1\% \)
  - Breit-Wigner fit in the range: \( 180 \text{ GeV} < M_T < 350 \text{ GeV} \)
  - Extrapolation in the high-pT region
  - Cross check with MC
Final selection and results

- Good agreement between data and SM prediction
- Exclusion limit up to $M(W') = 1.58$ TeV @ 95% C.L.
- Cut and count method: sliding search window to optimize the limit

$$M_T = \sqrt{2 \cdot E_T^{ele} \cdot E_T^{miss} \cdot (1 - \cos \Delta\phi_{eE_T^{miss}})}$$
Scalar LQ pair -> lljj, lvjj

• Three LQ generations and three signatures
• Characterized by two free parameters
  - $M_{\text{LQ}} = \text{LQ mass}; \quad \lambda = \text{LQ - l - q coupling} < \lambda_{\text{EM}} \approx 0.3$
• Look for an excess in the $S^T$ distribution
  - $S^T = p^T(l_1) + p^T(l_2) + p^T(j_1) + p^T(j_2) > f(M_{\text{LQ}})$

$S^T$ most powerful variable in discr S and B
$M_{lj}$ is affected by combinatorics

[Diagrams of lljj, lvjj, and evjj distribution]
The data are consistent with SM background expectation
- Upper limits on the LQ cross section are set using a Bayesian approach
- The existence of first and second generation LQs with mass below 384 and 394 GeV, respectively, are excluded for $\beta=1$
- Exceed Tavatron limits for almost the entire $\beta$ range

Limits on $\sigma_{\text{prod}}(\text{LQ pair})$ and $M_{\text{LQ}}$

2nd gen LQ: $\mu\mu jj$

1st gen LQ: $e\nu jj + ee jj$

CMS
$\mathcal{L} = 34.0 \text{ pb}^{-1}$

$\int_{200}^{500} M_{\text{LQ}} (\text{GeV})$

$\beta$

CMS
$\sqrt{s} = 7 \text{ TeV}$

$E_{\text{LQQ}} [\text{GeV}]$

$\mathcal{L} = 34.0 \text{ pb}^{-1}$

Expected 95% C.L. limit

Observed 95% C.L. limit

DØ exclusion (1 fb$^{-1}$)

eejj 95% CL limit (obs., 33.2 pb$^{-1}$)

eejj 95% CL limit (exp.)

Combined 95% CL limit (obs.)

Combined 95% CL limit (exp.)

F. De Guio
Di-photon final state: LED, RSG

1. ADD Model
   - Looking for broad excess @ high mass in $\gamma\gamma$ spectrum
   - set limits on $M_S$ vs $n$
   - $M_S$ = UV cut-off in $\sigma$; $n$ = # of extra dimensions

2. RS graviton
   - Looking for narrow resonances @ high mass in $\gamma\gamma$ spectrum
   - set limit on the graviton mass and coupling param

• Main backgrounds:
  - di-photon irreducible (Born+Box)
  - $\gamma$+jet and multijet (photon misidentification)
  - fake rate method from non-iso photons

• $M_{\gamma\gamma}$ and $\eta$ optimized to produce the highest sensitivity
  - $|\eta| < 1.4$ for both the analysis

1. The existence of the RSG is excluded below 371 (945) GeV/c$^2$ for $k/M_P = 0.01$ (0.1)

2. Limit on strength of Extra Dimensions effect/UV cut-off

<table>
<thead>
<tr>
<th></th>
<th>GRW</th>
<th>Hewett</th>
<th></th>
<th></th>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pos.</td>
<td>Neg.</td>
<td>$n_{ED} = 2$</td>
<td>$n_{ED} = 3$</td>
<td>$n_{ED} = 4$</td>
<td>$n_{ED} = 5$</td>
<td>$n_{ED} = 6$</td>
</tr>
<tr>
<td>Full</td>
<td>1.94</td>
<td>1.74</td>
<td>1.89</td>
<td>2.31</td>
<td>1.94</td>
<td>1.76</td>
<td>1.63</td>
</tr>
<tr>
<td>Trunc.</td>
<td>1.84</td>
<td>1.60</td>
<td>1.80</td>
<td>2.23</td>
<td>1.84</td>
<td>1.63</td>
<td>1.46</td>
</tr>
</tbody>
</table>
Di-jet mass resonances

- Look for bumps in dijet mass spectrum
- Select di-jet in event with $|\eta_1, \eta_2| < 2.5$ & $|\Delta \eta| < 1.3$
- Sensitive to the coupling of new massive object to $q$ and $g$
- New model-independent limits on 7 models

- Main Systematics (23-49%)
  - Jet Energy Scale (15 - 38%)
  - Background shape parameterization
    - Alternate 4 parameter fit function
  - Jet Energy Resolution
  - Luminosity (from 11% to 4% recently)

Bayesian approach with flat prior used to set the limit
Three-Jet resonances

- Searching for strongly coupled resonances decaying to $3j$
  - Benchmark model: R-parity violating gluino decays
  - pair-produced + strongly coupled to uds quarks

- Require > 6 jets in the event
- Jet $p_T > 45$ GeV (for each jet)
- Construct $M_{jjj}$ triplets (20 combinations)

- backgrounds from:
  - QCD SM events
  - uncorrelated triplets

![Graph showing $M_{jjj}$ distributions with exponential fit.](image)
Final selection and results

- To reduce the uncorrelated triplets (18 combinations) require each event to pass:
  \[ M_{jjj} < \sum |P_{T\text{jet}}| - \Delta \text{ (offset)} \]

- \( \Delta \text{ offset} \) is adjusted to optimize the signal sensitivity
  - signal triplets \( \rightarrow \) constant mass

- Exponential bkg shape with fixed parameters from the fit of \( N_{\text{jet}} = 4 \) sample

- 95\% CL limit from Bayesian likelihood approach

- Exclusion for gluinos (RPV decay) for masses \( 200 < M < 280 \text{ GeV/c}^2 \)

- 1\textsuperscript{st} limit from pp collisions
Summary

- Good understanding of the detector and backgrounds in a variety of channels
  - validation of data-driven background estimation methods

- Only a small selection of the exotica results from CMS is shown here
  - more than 20 papers already published

- No signals of the new physics observed in the 2010 LHC data yet
  - Analyses of > 400 pb\(^{-1}\) ongoing
  - New results are in the pipe-line. Stay tune!

- In most cases the exclusion limits are world’s best limit

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
Large Extra Dimension (ADD model)

- Hierarchy problem: $M_{Pl} \sim 10^{19}$ GeV, $M_{EW} \sim 10^2$ GeV
- The ADD model solves it
  - “n” extra dimensions in space of size “r”
  - Gravity only propagates through multi-D space
- True Planck scale ($M_D$) lowered to TeV scale
  $\rightarrow$ graviton production possible at LHC

- We have searched for LED in:
  1) Di-photon ($\gamma\gamma$)
  2) Di-muon ($\mu\mu$)
  3) Mono-jet + MET
  4) Microscopic Black Holes

$M^{n+2}_D \propto M^2_{Pl} / r^n$

Standard Model lives in 3+1 D space-time
Overview of main systematics (I)

Systematic uncertainties arise from detector performance and theoretical uncertainties on background and signal modeling

**Luminosity:**
- 11% uncertainty (recently improved to 4%)

**Trigger and lepton reconstruction/identification efficiency**
- use Z Tag&Probe method
- measured within few % uncertainty
- extrapolation with MC for very high $p_T$ range
  - main contribution (8%) to systematic uncertainty on $Z'$ to $Z$ efficiency ratio in the e-channel

**Energy scale/resolution**
- Electrons/photons
  - ECAL scale from $Z \rightarrow ee$ and low mass $\gamma \gamma$ resonances (1%-3% accuracy)
  - extrapolation to high $p_T$ exploiting ECAL linearity, MC, cross-check in data exploiting electron shower shape
- Muons
  - from $Z \rightarrow \mu \mu$
  - cosmics provide validation at high $p_T$
Overview of main systematics (II)

**Missing transverse energy**
- model hadronic recoil from $Z \rightarrow ee/Z \rightarrow \mu\mu$ events
  - along with energy scale and eff. uncertainty affects the bkg estimation in $W' \rightarrow ev$ searches (total $\sim$28% uncertainty for MT $> 500$ GeV)

**Electron/muons/photon fake rates**
- Uncertainty estimated comparing results with different datasets/selections, and applying to control samples. Large uncertainties (25%-50%) but marginal impact in the high mass/pt region

**Theoretical uncertainties**
- PDF uncertainties - reweighting PDF sets
- QCD higher order corrections estimated varying factorization and renormalization scales

**SETTING UPPER LIMITS:**
- Simple **Bayesian approach** to set 95% C.L. Exclusion limit
- Flat prior for signal cross section
- Systematic uncertainties treated as nuisance parameters with log-normal prior distribution
LQs event display
Z' high mass event display

<table>
<thead>
<tr>
<th>Collection</th>
<th>Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>pT</td>
<td>eta</td>
</tr>
<tr>
<td>1</td>
<td>125.0</td>
</tr>
<tr>
<td>2</td>
<td>83.6</td>
</tr>
<tr>
<td>0</td>
<td>8.7</td>
</tr>
</tbody>
</table>
W' event display
A Bayesian tool to calculate the expected and observed 95% C.L. upper limits is used.
Channel combination

- **Extension to two channels**, currently straightforward extension of the implemented Bayesian upper limit for a counting exp.

\[
\Pi_{\text{post}} (\sigma | N_{\text{obs},1}, N_{\text{obs},2}) = \int dL \, d\epsilon_1 \, db_1 \, d\epsilon_2 \, db_2 \, e^{- (\sigma \cdot L \cdot \epsilon_1 + b_1)} \cdot \frac{(\sigma \cdot L \cdot \epsilon_1 + b_1)^{N_{\text{obs},1}}}{N_{\text{obs},1}!} \cdot \frac{(\sigma \cdot L \cdot \epsilon_2 + b_2)^{N_{\text{obs},2}}}{N_{\text{obs},2}!} \cdot e^{- (\sigma \cdot L \cdot \epsilon_2 + b_2)} \cdot \pi (b_1) \cdot \pi (\epsilon_1) \cdot \pi (b_2) \cdot \pi (\epsilon_2) \cdot \pi (L) \cdot \pi_{\text{poi}} (\sigma)
\]

- **Underlying Assumptions:**
  - Identical branching ratio for electron and muon channel
  - Uncertainty on luminosity fully correlated
  - Uncertainties on signal efficiency and background currently fully uncorrelated (also tested fully correlated \(\rightarrow\) same limit)