Search for contact interactions in the di-lepton spectra in pp collisions at center of mass energy of 8 TeV

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*On behalf of the CMS Collaboration*
Introduction

- CI is BSM which is based on the model of quark and lepton compositeness

- Signature can be observed by identifying a deviation from the SM in the dilepton mass spectrum. The production cross section can be observed as:

\[
\frac{d\sigma(\Lambda)}{dM_{l^+l^-}} = \frac{d\sigma(DY)}{dM_{l^+l^-}} - \eta \frac{I}{\Lambda^2} + \eta^2 \frac{C}{\Lambda^4}
\]

where,
- \(M_{l^+l^-}\) = the di-lepton invariant mass
- \(I\) = product of DY and CI amplitudes
- \(C\) = pure CI term.

CI/DY = CI for \(\Lambda \neq \infty\) and pure DY for \(\Lambda = \infty\)

\(\eta\) = +1 and -1 for destructive and constructive interference respectively.

- The production of preons is possible only above the characteristic energy scale \(\Lambda\)
Pythia LLIM model

Constructive interference ($\eta = -1$)

Destructive interference ($\eta = +1$)

Selection criteria used: $P_T > 45$ GeV for each $\mu$, $|\eta|$ of $\mu_1 < 2.1$ and $|\eta|$ of $\mu_2 < 2.4$

$$\frac{d\sigma(\Lambda)}{dM_{\mu\mu}} = \frac{d\sigma(DY)}{dM_{\mu\mu}} - \frac{I}{\Lambda^2} + \eta^2 \frac{C}{\Lambda^4}$$

When $\Lambda \rightarrow \infty$ The spectrum converges to DY production (SM)
Previous Searches

Compositeness model: Left-Left Isoscalar (Currently excluded lower limits at 95% C.L.)

\[ \sqrt{s} = 7 \text{ TeV} \]

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Channel</th>
<th>Luminosity (fb(^{-1}))</th>
<th>Const.</th>
<th>Dest.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS</td>
<td>(\mu^+ \mu^-)</td>
<td>5.3</td>
<td>13.1</td>
<td>9.5</td>
</tr>
<tr>
<td>ATLAS</td>
<td>(\mu^+ \mu^-)</td>
<td>5.0</td>
<td>12.1</td>
<td>9.5</td>
</tr>
<tr>
<td>ATLAS</td>
<td>(e^+ e^-)</td>
<td>4.9</td>
<td>12.9</td>
<td>9.6</td>
</tr>
</tbody>
</table>

Why LLIM?
- Bench mark process (historic)
- Physics is basically similar for rest of the other terms, however, LLIM is implemented in PYTHIA

Other CMS Compositeness Searches

- Search for Contact Interactions using Inclusive Jet Events in pp collisions at $\sqrt{s} = 7$ TeV [CMS-EXO-11-010] Lumi : 5 fb$^{-1}$ $\Lambda = 9.7$ TeV (14.5 TeV) with destructive (constructive) in LLIM

- Measurement of Dijet Angular Distributions and Search for Quark Compositeness in pp Collisions at $\sqrt{s} = 7$ TeV [CMS-QCD-10-016] Lumi : 36 pb$^{-1}$ $\Lambda = 5.6$ TeV ($\Lambda = 6.7$ TeV) for destructive (constructive) interference in LLIM

- Search for Narrow Resonances using the Dijet Mass Spectrum with 19.6 fb$^{-1}$ of pp Collisions at $\sqrt{s} = 8$ TeV [CMS-EXO-12-059] mass of excited quarks = [1.20, 3.50] TeV

- Updated Search for New Physics in Highly Boosted $Z^0$ Decays to Dimuon in pp Collisions at $\sqrt{s} = 7$ TeV Lumi : 5 fb$^{-1}$ [CMS-EXO-11-025] mass of excited quarks < 2.14 TeV

- Search for new physics in the final states with a lepton and missing transverse energy at $\sqrt{s} = 8$ TeV using 20 fb$^{-1}$ [CMS-EXO-12-060] $\Lambda = 13.0$ (10.9) TeV for the electron(muon) channel in Helicity-Non-Conserving-Model
Analysis method

To predict observed events

- Use PYTHIA and POWHEG physics generators with full detector simulation for signal and most backgrounds
- Expected events (SM) = DY + Non DY

- Expected events (CI) = CI/DY(Λ) × QCD K-factor × QED K-factor + Non DY

Single binned counting experiment starting from dilepton minimum mass

(M_{min} = 300 \text{ GeV}, 400 \text{ GeV} \ldots \ldots \, 2000 \text{ GeV})

If data is consistent with SM prediction, set the 95% CL lower limit in Λ

To set the limit on Λ

- Use modified frequentist technique commonly known as CL_s method with a profile-likelihood ratio as a test statistic
- Choose M_{min} where expected limit peaks to get the final limit
Datasets

Data [CMS 2012 at $\sqrt{s} = 8$ TeV ] :

- Di-muon channel (20.6 fb$^{-1}$)
- Single muon trigger with PT $> 40$ GeV and $|\eta| < 2.1$
- Di-electron channel (19.6 fb$^{-1}$)
- Double electron trigger with $E_T > 33$ GeV
Signal:

- CI samples [Pythia 6, LLIM] with different interaction scale parameter $\Lambda$
- $\Lambda$ (in TeV) of 9, 11, 13, 15 (destructive) and additionally 17 and 19 for constructive interference

- 50 k and 25 k events for the samples in low and high mass region respectively

- Use fit functions to estimate the yields for intermediate and higher $\Lambda$ values
## Simulation

### Backgrounds:
- Simulation ($DY, \ttbar, diboson, Z \rightarrow \tau \tau, \text{single top}$)
- Using data ($jets$ backgrounds)

<table>
<thead>
<tr>
<th>Physics process</th>
<th>Generator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drell - Yan</td>
<td>POWHEG</td>
</tr>
<tr>
<td>$TT \text{ bar}$</td>
<td>POWHEG</td>
</tr>
<tr>
<td>Di- boson ($WW, WZ, ZZ$)</td>
<td>PYTHIA</td>
</tr>
<tr>
<td>Single top</td>
<td>POWHEG</td>
</tr>
<tr>
<td>$\gamma +jets$</td>
<td>PYTHIA</td>
</tr>
<tr>
<td>$Z \rightarrow \tau \tau$</td>
<td>POWHEG</td>
</tr>
<tr>
<td>$W +jets$</td>
<td>MADGRAPH</td>
</tr>
<tr>
<td>Incl.-$\mu \ QCD$</td>
<td>PYTHIA</td>
</tr>
</tbody>
</table>
Selection criteria

Muon selection criteria:

- Momentum of muons assigned from a combined track (using tracker tracks and tracks from muon systems)
- $P_T > 45$ GeV

Electron selection criteria:

- Energy from ECAL, cluster matching with tracker, hadronic veto from HCAL
- $E_T > 35$ GeV
NLO corrections

\[ K\text{-factor} = \frac{\sigma^{\text{NLO}}}{\sigma^{\text{LO}}} \]

Since, the Signal is generated using PYTHIA (LO) generator, QCD and QED K-factors are needed for NLO accuracy of the signal.


- QED NLO K-factor is estimated using HORACE 3.1 using DY simulation

- QED K-factor depends upon the di-lepton mass (0.994 at 300 GeV and 0.920 at 2 TeV)
PDF Uncertainty

• Following PDF4LHC recommendations

• PDF uncertainty is estimated from the envelope of the PDF sets CT10, MSTW2008 and NNPDF2.1, using central value of CT10

• POWHEG samples of DY simulation used in both channels

PDF uncertainty shown at 68% CL
# Systematic Uncertainty

## Di-muon Channel:

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDF</td>
<td>13.0</td>
</tr>
<tr>
<td>Trigger and reco efficiency</td>
<td>3.0</td>
</tr>
<tr>
<td>Momentum scale</td>
<td>23.0</td>
</tr>
<tr>
<td>Momentum resolution</td>
<td>6.0</td>
</tr>
<tr>
<td>Alignment</td>
<td>5.0</td>
</tr>
<tr>
<td>QED K-factor</td>
<td>5.0</td>
</tr>
<tr>
<td>QCD NNLO</td>
<td>2.0</td>
</tr>
<tr>
<td>Lumi</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Given at $M_{\mu\mu} = 1.8$ TeV

 CMS-EXO-12-027

## Di-electron Channel:

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDF</td>
<td>12.0</td>
</tr>
<tr>
<td>Identification and reco</td>
<td>5.0</td>
</tr>
<tr>
<td>Energy scale</td>
<td>1.0</td>
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<tr>
<td>DY NLO correction</td>
<td>6.0</td>
</tr>
<tr>
<td>Lumi</td>
<td>4.4</td>
</tr>
</tbody>
</table>

$Given$ at $M_{ee}^{min} = 1.8$ TeV

 CMS-EXO-12-031

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*Systematic uncertainties affecting the limit on $\Lambda$ on this analysis*
Data-MC comparison ($\mu^+ \mu^-$)

- Error bars for data show statistical uncertainty
- Data is consistent with SM expectations
Data -MC comparison \((e^+ e^-)\)
$\mu^+ \mu^- : 95\% \text{ CL lower limit on } \Lambda \text{ at } \sqrt{s} = 7 \text{ TeV}$

CMS-EXO-11-009

Limits from 2011 data at $\sqrt{s} = 7 \text{ TeV}$ in the di-muon channel

Note: Limits from 2012 data at $\sqrt{s} = 8 \text{ TeV}$ are still in preparation
Conclusion

- 8 TeV dimuon and dielectron spectra are consistent with SM
- Procedure for setting 95% CL lower limits on Lambda is demonstrated with 7 TeV dimuon
- At 8 TeV, 95 % CL lower limit is set on \( \Lambda \) in both channels and limits are being prepared
- We expect a significant improvement in the limits in both channels at 8 TeV

THANKS!