Searches for resonant and non-resonant new phenomena in CMS

This talk will not cover:
- Search for NP in multilepton final states (see Shilpi Jain’s talk)
- Search for NP in diboson final states (see Viviana Cavaliere’s talk)
- Search for top/bottom partners and top/bottom pair signatures (see Ivan Marchesini’s talk)

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Overview

1) **RUN1 results from CMS**
Results based on 2012 datasets, luminosity about 20 fb\(^{-1}\)
Focus on new preliminary results or newly published final results

Searches for narrow or broad resonances and searches for an excess in the tail of mass or transverse momentum distributions in final states:
- Di-jets and mutijet mass spectra
- Di-lepton (ee, µµ, ττ) mass spectra
- Di-photon mass spectrum
- lepton+MET final states

2) **First look at the CMS RUN2 data – PRELIMINARY results**
- Di-jet invariant mass spectrum
- Displays of the highest di-lepton and (lepton+MET) mass events
• Search for hint of new physics in the di-jet mass spectra / narrow and wide resonances
• Provide a model independent upper limits on $\sigma_{\text{max}}$BR

CMS

\begin{align*}
    p_T(j) &> 30 \text{ GeV} \\
    |\eta(j)| &< 2.5 \text{ and } |\Delta\eta_{jj}| < 1.3 \\
    m(jj) &> 890 \text{ GeV to remove trigger bias}
\end{align*}

• The Particle Flow candidates clustered into jets using the anti-kT algorithm with DR = 0.5
• Geometrically close jets (DR<1.1) combined into “wide jets”, which are used to measure $m_{jj}$
• Also: spectrum divided in categories: 0, 1, 2-btag jets

• Highest di-jet mass event at 5.15 TeV
• Dominant systematic uncertainties: jet energy scale, jet energy resolution, luminosity

PRD 91, 052009, arXiv:1501.05603
Di-jet resonances

Observed limits on gg, qg and qq narrow resonances compared to LO predictions for several models.

**Mass exclusion results for narrow resonances:**
- String resonances < 5.0 TeV
- Excited quarks < 3.5 TeV
- Scalar di-quarks < 4.7 TeV
- W' (SSM) bosons < 2.2 TeV
- Z' (SSM) bosons < 1.7 TeV
- RS Gravitons (c=0.1) < 1.6 TeV

**Wide resonances:** width to mass ratio up to 30%
- Axigluons and colorons < 3.6 TeV
- Color-octets scalars < 2.5 TeV

**Mass of quantum black holes:**
- Lower bounds between 5.0 and 6.3 TeV
Di-jet angular distributions

Search for quark contact interactions and extra spatial dimensions in di-jet angular distributions

- Red line: prediction for SM+Cl with $\Lambda_{LL}^+ (NLO)=10$ TeV
- Blue dashed line: prediction for SM +ADD with $\Lambda_T (GRW)=7$ TeV
- SM prediction: perturbative NLO QCD prediction + EWK NLO corrections

$\chi(\text{dijet}) = \exp(|y_1 - y_2|)$; $y_1,y_2=$rapidities of the jets

For the scattering of massless partons, $\chi(\text{dijet})$ is related to the polar scattering angle $\theta^*$ in the partonic CMF by $\chi(\text{dijet}) = (1 + |\cos \theta^*|)/(1 - |\cos \theta^*|)$
Muti-jet resonances

- Pair produced resonances decaying to jets: $X \rightarrow YY, Y \rightarrow jj$

- Resonances with three-jet final states: $X \rightarrow ZZ, Z \rightarrow jjj$

Exclude top squark masses for RPV decays to light (heavy) jets in range: $200 < m(jj) < 350 \ (385) \ GeV$

Exclude gluino masses for RPV decays to light (heavy) jets in range: $0 \ (200) < m(jjj) < 350 \ (835) \ GeV$

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Di-lepton (ee and μμ) mass spectrum

- Simple final states, low backgrounds
- Main backgrounds: Drell-Yan, top-antitop, WW, and multijet from QCD processes (for the electron channel)
- Highest mass event: 1.79 TeV (ee channel) and 1.87 TeV (μμ channel)

### Selection

| ee | $E_T > 35, 35$ GeV  
|    | $|\eta| < 1.442$ or $1.56 < |\eta| < 2.5$  
|    | ID and isolation criteria  
| μμ | $p_T > 45, 45$ GeV  
|    | $|\eta| < 2.4$ ($|\eta| < 2.1$ for triggering muon)  
|    | ID and isolation criteria  

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Di-lepton (ee and $\mu\mu$) resonances

$m(Z'_{SSM}) > 2.90$ TeV
$m(Z'_{\psi}) > 2.57$ TeV

$m(G_{RS}) > 2.73, 2.35,$ and $1.27$ TeV
for coupling $c = 0.1, 0.05,$ and $0.01$

Interpretation in 2 non-resonant analyses: large extra dimension model (ADD) and compositeness model (CI)

Observed limits on $M_S$ scale as a function of the number of extra spatial dimensions $n_{ED}$
Di-tau resonances

CMS consider $\tau^e-\tau^\mu$ final states (e$\mu$ channel)
Test a possible non-universal coupling
Main backgrounds: top-antitop, diboson production, Drell-Yan, multijet from QCD

- Limits on ADD model: parameter $\Lambda$ up to 2800 GeV

Kinematics cuts

<table>
<thead>
<tr>
<th></th>
<th>(e)</th>
<th>(\mu)</th>
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<tbody>
<tr>
<td>(E_T(e))</td>
<td>$&gt; 20$ GeV</td>
<td>$&gt; 20$ GeV</td>
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<tr>
<td>(</td>
<td>\eta(e)</td>
<td>)</td>
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</table>

\[m(Z'_{SSM}) > 1300 \text{ GeV}\]
\[m(Z'_{\psi}) > 810 \text{ GeV}\]
Di-photon resonances

- Simple final state, large background
- Background from SM processes (box and born diagrams), and from photon + jet or di-jet processes where one or two jets produce a fake photon signature

Kinematics selection

- $p_T > 80$ GeV
- $|\eta| < 1.4442$
- $m(\gamma\gamma) > 300$ GeV

Limits for $k/M_{Pl} = 0.1$: $m(G_{RS}) > 2.78$ TeV
Searches for $W' \rightarrow l\nu$

Search for $W' \rightarrow e\nu$ and $W' \rightarrow \mu\nu$

$M_T$ distribution for the $e\nu$ channel:

Interpretation in various models:
- heavy $W'$, split universal extra dimension,
- $W'(KK)$ as well as dark matter and compositness

Mass limits of $W'(SSM) > 3.28$ TeV

Search for $W' \rightarrow \tau\nu$

Test a possible non-universal coupling

Consider hadronic decay of the $\tau$-lepton

Distribution of the cumulative $M_T$ variable:

Mass limits of $W'(SSM) > 2.7$ TeV

Summary: Run 1 results

- A large number of analyses
- Mix of simple and complex final states
- Run1 legacy papers with a wide range of model interpretation

All CMS EXOTICA public results at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G
CMS Run 2 dataset

- Run2 started in June 3, 2015, pp collision at 13 TeV! - 50 ns bunch crossing spacing
- Cumulative luminosity delivered by LHC and recorded by CMS during stable beam
- Integrated luminosity delivered and recorded per day
- CMS B = 3.8 T from 06/07
- Date: June 3, up to July 20
  - Total delivered: 106 pb⁻¹
  - Total recorded: 83.5 pb⁻¹
  - Total recorded at 3.8 T: 61.8 pb⁻¹
  - Results @EPS presented up to 43 pb⁻¹
- More information/control plots in the Kerstin Borras’s plenary talk next Monday
CMS Run 2 – dijet analysis

- Dataset $L = 37 \text{ pb}^{-1}$
- Similar selection as for 2012 data analysis for the wide jets reconstruction

**Di-jet $\Delta \Phi$ distribution**

Jet 1: $p_T > 60 \text{ GeV}$, $|\eta| < 2.5$
Jet 2: $p_T > 30 \text{ GeV}$, $|\eta| < 2.5$
$|\Delta \eta_{jj}| < 1.3$  \quad $M(jj) > 1.1 \text{ TeV}$

**Di-jet $\Delta \eta$ distribution**
CMS Run 2 – dijet mass spectrum

• Mass spectrum fitted using a 4 parameter function:

\[
p_0 \left( 1 - \frac{m}{13000} \right)^{p_1} \left( \frac{m}{13000} \right)^{p_2} + p_3 \log \left( \frac{m}{13000} \right)
\]

• For illustration purposes: In blue : signal of a \( q^* \to qg \) resonance at \( M = 4.5 \) TeV

• Highest dijet mass event : \( M = 5 \) TeV
CMS Run 2 – highest dijet mass event

Di-jet event $M=5$ TeV

$Pt(1)= 2.41$ TeV

$pt(2)= 2.36$ TeV

CMS 2015 data
Run = 251562,
date=12Jul 09:52
CMS Run 2 – highest $\Pi\Pi$ mass event

Di-electron event: $M = 999$ GeV

CMS 2015 data
Run = 251562, date=12Jul 10:33
Pt(1) = 377 GeV, pt(2) = 371 GeV

MET = 9.2 GeV

3.5 events expected with $m > 500$ GeV for the luminosity analyzed, and 3 events observed
CMS Run 2 – highest (l+MET) mass events

(single μ + MET) event : $M_T = 1.1 \text{ TeV}$

Run = 251251, date=8Jul 23:50
pt(μ) = 0.53 TeV, MET = 0.61 TeV
$\Delta\Phi (\mu, \text{MET}) = 3.0$

1 event expected
with $m_T > 700 \text{ GeV}$ for the luminosity analyzed
Summary – Run 2

• LHC Run 2 has just started - at the highest energy ever!
• First results are shown on di-jet final state analysis
• Highest dilepton and lepton+MET mass events shown
• Number of high mass events compatible with SM expectation

• Much more to come in the near future
• Fingers crossed for seeing hints for new physics at LHC Run 2 soon!
Searches for $W'\rightarrow tb$

- CMS investigated $W'$ boson decaying to $tb$ final state
- Dedicated algorithms for top-tagged jets and $W'$ candidates

- Dominant systematic uncertainties: t-tbar production, top-tagging
- Limits: $m(W')_{\text{right handed}} > 2.15$ TeV
Searches for Leptoquarks: Gen 1 and 2

Consider both lvjj and lljj final states

The m(e-jet) distribution for evjj preselection

$\beta = BF$ of a LQ to a charged lepton and a quark

$M_{LQ} > 1005$ (845) GeV for $\beta=1(0.5)$

$M_{LQ} > 1070$ (785) GeV for $\beta=1(0.5)$
Searches for single production of scalar leptoquarks

Single production of first and second generation scalar LQ:
In both eejet and μμjet final states

**eej channel**

Lepton-jet invariant mass with eej final selection for a LQ of 1 TeV

- $M_{\text{LQ1}} > 1730$ GeV for $\lambda, \beta = 1$
- $M_{\text{LQ2}} > 530$ GeV for $\lambda, \beta = 1$

$\lambda$ = Yukawa coupling at the LQ-lepton-quark vertex

Because the initial state possesses quark flavor, single LQ prod. beyond the first GEN is suppressed
Searches for Leptoquarks in $t\tau$

- CMS investigate leptoquarks decaying to a $t\tau$ final state
- Two categories A (B) on right:
- $S_T$ is scalar sum of $p_T$ in the event

- Limits: $m(LQ \rightarrow t\tau) > 685$ GeV
- Dominant systematic: $t$ reco, pileup, background estimation

**Category A (B)**

<table>
<thead>
<tr>
<th>Lepton</th>
<th>Limit</th>
<th>Category A (B)</th>
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<tbody>
<tr>
<td>$t_{\text{had}}$</td>
<td>$p_T(t_{\text{had}}) &gt; 20$ (35) GeV</td>
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<td>\eta(t_{\text{had}})</td>
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<td>$e$</td>
<td>$E_T(e) &gt; 15$ (35) GeV</td>
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<tr>
<td>$\mu$</td>
<td>$p_T(\mu) &gt; 25$ (30) GeV</td>
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<tr>
<td>jet</td>
<td>$p_T(j) &gt; 40$ (30) GeV</td>
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<td></td>
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<td>\eta(\mu)</td>
</tr>
<tr>
<td>$E_T^{\text{Miss}}$</td>
<td>No selection ($&gt;50$ GeV)</td>
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<tr>
<td>$S_T$</td>
<td>Optimised by mass ($S_T &gt; 1000$ GeV)</td>
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<tr>
<td>$p_T(t_{\text{had}})$</td>
<td>Optimised by mass ($p_T(t_{\text{had}}) &gt; 20$ GeV)</td>
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<tr>
<td>Leptons</td>
<td>Same sign $\mu t_{\text{had}}$ ($\mu t_{\text{had}}$ or $e t_{\text{had}}$)</td>
<td></td>
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</tbody>
</table>

CMS Run 2 – performance plots – Z peak

Di-muon mass spectrum $L=43 \text{ pb}^{-1}$

Di-electron mass spectra $L=21.3 \text{ pb}^{-1}$

Di-tau mass spectrum $L=5.6 \text{ pb}^{-1}$