Search for new physics in dijet resonant signatures and recent results from Run2 with the CMS experiment

Giulia D’Imperio
Università di Roma La Sapienza – INFN Roma – CERN

On behalf of the CMS collaboration

LHCP2015
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• **Focused on Run 2 analysis and results**
  → just released a public result CMS-PAS-EXO-15-001
• Introduction and motivation
• Jet reconstruction
• Trigger and selection
• Signal shapes
• Background fit and comparison with Run 1
• Upper limits and comparison with Run 1
• Conclusions
Dijet resonance search

- Narrow resonances $X$ decaying in 2 jets $\rightarrow$ bump in the dijet mass spectrum

- Simple and striking signature $\rightarrow$ sensitive to any resonance coupling to quarks/gluons
- LHC collides $pp \ @13$ TeV $\rightarrow$ dijet resonance factory at new energy scale!
- $20$ fb$^{-1}$ of luminosity collected in Run 1 at $\sqrt{s} = 8$ TeV
- $42$ pb$^{-1}$ of luminosity in Run 2 at $\sqrt{s} = 13$ TeV for the results presented in this talk.
Run 2 vs Run 1 sensitivity

- Parton luminosity ratio increase rapidly at high masses
- With much smaller integrated luminosity than Run1 $\rightarrow$ 13 TeV data same sensitivity as 8 TeV

From parton luminosity ratio $\rightarrow$ present dataset @13 TeV more sensitive than Run 1 for masses $> 5$ TeV

http://www.hep.ph.ic.ac.uk/~wstirlin/plots/plots.html
http://collider-reach.web.cern.ch/collider-reach/
Highest* dijet mass event in Run 1

Dijet mass = 5.2 TeV

* for $|\Delta \eta| < 1.3$

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Highest* dijet mass event in Run 2

Dijet mass = 5.4 TeV
Run 2 highest mass event already greater than Run 1

* for $|\Delta \eta| < 1.3$
Wide jet reconstruction

- Wide jets improve dijet mass resolution → include FSR
  - clusters of **PF anti-KT jets** with cone **R=0.5 (Run 1)** or **R=0.4 (Run2)**
  - **Wide jet cone R=1.1**
- Jet identification criteria based on jet energy fractions
- Fiducial region → $|\eta|<2.5$
- Do not use very soft jets → $p_T>30$ GeV

Jet energy corrections from MC + data driven residual correction provided centrally from CMS JetMET group

(wide jet cone R=1.1 is optimal for both 8 and 13 TeV)
Trigger

- Trigger based on the scalar sum of transverse momentum of all jets in the event
  - $HT > 650 \text{ GeV} \ (\text{Run1})$
  - $HT > 800 \text{ GeV} \ (\text{Run2})$

Run 2

Relative efficiency vs. dijet mass
- Reference trigger $HT > 475 \text{ GeV}$
- Reference trigger prescaled by a factor of 100

**Trigger is turned-on completely for dijet masses > 1.1 \text{ TeV}**
Selection

Signal
- Dijet resonance produced in S-channel

\[ \cos \theta^* = \tanh(\Delta \eta/2) \]

\[ \Delta \eta \]

\[ \theta^* \]

Background
- QCD produced in T-channel

\[ \Delta \eta \]

\[ \cos \theta^* \]

- QCD \( \cos \theta^* \) peaks at 1, forward jets
- Dijet resonance \( \cos \theta^* \) depends on the spin, but more flat

Selection
- Suppress QCD (t-channel) and enhance signal (s-channel)
  - \(|\Delta \eta| < 1.3\) (corresponds to \( \cos \theta^* < 0.57 \))
- Avoid bias from trigger inefficiency
  - \( M_{jj} > 890 \text{ GeV} \) (Run1)
  - \( M_{jj} > 1.1 \text{ TeV} \) (Run2)
NEW!
Data-MC comparisons and stability

The measured cross section is stable vs time → good data quality

- Agreement in shape between data and simulation
- MC normalized to data
Angular distribution typical of clean dijet events
- Narrow resonance shapes from simulations of RSGravitons and excited quarks, as in Run 1
  - quark-quark \((qq\rightarrow G\rightarrow qq)\)
  - quark-gluon \((qg\rightarrow q^*\rightarrow qg)\)
  - gluon-gluon \((gg\rightarrow G\rightarrow gg)\)

- Resonance masses up to 7 TeV

- Left tail mostly from FSR for low masses
- Some tail from PDFs at high masses, especially when gluons in final state
Background fit in Run 1

Data are fit with the parametrization

$$\frac{d\sigma}{dm_{jj}} = \frac{p_0 (1-x)^{p_1}}{x^{p_2 + p_5 \ln(x)}} \quad x = \frac{m_j}{8000} \text{GeV}$$

Run 1

- No evidence of dijet resonances: data agree with background fit function
- “excesses” @1.8 TeV and @3.6 TeV ($< \sim 2 \sigma$)
- Run 2 analysis still not as sensitive as Run 1
  - Need $\sim 400 \text{ pb}^{-1}$ for 3.6 TeV
  - Need $\sim 3 \text{ fb}^{-1}$ for 1.8 TeV
Data are fitted with the parametrization:

\[ \frac{d\sigma}{dm_{jj}} = \frac{\rho_0 (1 - x)^p_1}{x^{p_2} + p_3 \ln(x)} \]

\[ x = \frac{M_{jj}}{13000} \text{ GeV} \]

→ proved with Fisher test that p3 not needed to fit Run 2 dataset

Run 2

- Data well described by the background parametrization
  - $\chi^2/\text{ndf}=25/34$ (with empty bins)
  - $\chi^2/\text{ndf}=24/27$ (excluding empty bins)

- $q^*$ resonance signal with mass=4.5 TeV superimposed for illustration
Systematic uncertainties

Sources of uncertainty are the same as in Run 1, more conservative values used for Run 2

- **Jet energy scale (JES)**
  - conservative value 5%
  - → propagated to the search by shifting the dijet resonance shapes by ±5%

- **Jet energy resolution (JER)**
  - same value as in Run 1 of 10%.
  - → propagated to the search by changing the width of the dijet resonance shapes by ±10%

- **Integrated luminosity**
  - estimated at 12%

- **Choice of background parameterization**
  - All 3 background parameters are varied in a correlated fashion along the 3 eigenvectors of the covariance matrix.
**Run 2 exclusion**

- Upper limits @95% CL on the cross section of $qq$, $qg$, and $gg$ resonances
- Comparison to calculations of model cross sections

**Graphs and Tables**

- Gives the following mass limits on models of dijet resonances

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<thead>
<tr>
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<tbody>
<tr>
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<td>$qq$</td>
<td>5.1</td>
<td>5.2</td>
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<tr>
<td>Excited Quark ($q^*$)</td>
<td>$qq$</td>
<td>2.7</td>
<td>2.9</td>
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<td>Scalar Diquark (D)</td>
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<tr>
<td>Color Octet Scalar (s8)</td>
<td>$gg$</td>
<td>2.3</td>
<td>2.0</td>
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Summary of observed limits, model cross sections, and mass limits

**Run 1**

![Graph showing observed limits and model cross sections for Run 1.](image1)

**Run 2**

![Graph showing observed limits and model cross sections for Run 2.](image2)

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CMS-PAS-EXO-15-001
• Presented **first results at $\sqrt{s} = 13$ TeV** and comparison with Run 1

• Dijet mass distribution well modeled by the background parameterization
  
  • **No evidence of dijet resonances... yet**

• New mass limit on string resonances at 5.1 TeV exceeds previous limit of 5.0 TeV

• **CMS now more sensitive to new physics than Run 1 for $M > 5$ TeV**

• Still not as sensitive as Run 1 to lower masses
  
  • Need $\sim$400 pb$^{-1}$ for 3.6 TeV
  
  • Need $\sim$3 fb$^{-1}$ for 1.8 TeV

• **Great potential on discovering new physics with the first few fb$^{-1}$ of data @13 TeV !**
BACKUP
Summary of observed limits, model cross sections, and mass limits

**Run 2**

42 pb⁻¹ (13 TeV)

[Graph showing cross sections and mass limits for various models]

Comparison of exclusion limits for a narrow resonance search

<table>
<thead>
<tr>
<th>Model</th>
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<th>Run 2 (42 pb⁻¹)</th>
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Signal modeling

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- Resonance masses up to 7 TeV

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Extensions of the inclusive analysis

( Run 1 )

Search in 0,1,2 b-tag categories

Wide resonances:
- analysis sensitive to resonances with width/mass ratio up to \sim 30%
Magnet cryogenics issues

- The restart of the CMS magnet after LS1 was more complicated than anticipated due to problems with the cryogenic system in providing liquid Helium.

- Inefficiencies of the oil separation system of the compressors for the warm Helium required several interventions and delayed the start of routine operation of the cryogenic system.

- The data delivered during the first two weeks of LHC re-commissioning with beams at low luminosity have been collected with B=0

- Currently the magnet can be operated, but the continuous up-time is still limited by the performance of the cryogenic system requiring more frequent maintenance than usual.

- A comprehensive program to re-establish its nominal performance is underway. These recovery activities for the cryogenic system will be synchronized with the accelerator schedule in order to run for adequately long periods.

- A consolidation and repair program is being organized for the next short technical stops and the long TS at the end of the year.