Searches for New Physics in Multijet Events at CMS

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On behalf of the CMS Collaboration

LHCP2014: Large Hadron Collider Physics
Columbia University, New York, NY
June 2nd-7th, 2014
Outline

- Why multijets? Broad range of searches!
  - Many New Phenomena (NP) signals couple strongly (directly)
  - Some models predict NP to decay to vector bosons, which decay to jets
  - Boost statistics – jets are abundant at the LHC

- Latest results in multijet final states at 8 TeV:
  - Heavy resonances in the W/Z-tagged dijet events
  - Light- and heavy-flavor three-jet resonances
  - Dark matter, extra dimensions, unparticles in monojet events
  - Jet extinction

- Conclusions
proton-proton collider with $\sqrt{s} = 8$ TeV (circa 2012)

7.67e33 cm$^{-2}$s$^{-1}$ peak instantaneous luminosity

23.3 fb$^{-1}$ delivered to the CMS experiment (Thanks LHC!!)
Search for W/Z-Tagged Dijet Resonances
Models and Selection

- Models: \( q^* \rightarrow qW, qZ; \) \( G_{RS} \) or \( G_{Bulk} \rightarrow WW, ZZ; W' \rightarrow WZ \) (\( W, Z \rightarrow jj \))
- Selection: CA (\( R = 0.8 \)) Particle Flow (PF) jets with \( p_T > 30 \) GeV, \( |\eta| < 2.5 \)
- QCD background suppressed by two highest \( p_T \) jets \( |\Delta \eta_{jj}| < 1.3 \)
- Prune jets and tag vector bosons based on \( N \)-subjettiness ratio \( \tau_{21} \) (\( \tau_2/\tau_1 \) - measure of consistency that a jet has \( N \) subjets)

Pruned jet mass window (70-100) to become a tag

Submitted to JHEP

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Classify events by high (low) purity tag with \( \tau_{21} \leq 0.5 \) (0.5 < \( \tau_{21} < 0.75 \)) and number of W/Z-tags (single or double):

- Double-tagged events must have at least one high-purity tag.
• Inspect dijet events for bumps (resonances) with mass above 890 GeV
  • Background is data-driven, fit to a smooth function
  • No excess of data over prediction observed

Distributions

CMS, $L = 19.7 \text{ fb}^{-1}$, $\sqrt{s} = 8 \text{ TeV}$

- Low-purity singly W/Z-tagged data
- $q^* \rightarrow qW$ (3.0 TeV)

CMS, $L = 19.7 \text{ fb}^{-1}$, $\sqrt{s} = 8 \text{ TeV}$

- High-purity doubly W/Z-tagged data
- $G_{RS} \rightarrow WW$ (1.5 TeV)

Set stringent upper limits on cross section times branching ratio

**Results**

<table>
<thead>
<tr>
<th>Process</th>
<th>Observed excluded mass limit (TeV)</th>
<th>Expected excluded mass limit (TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q^* \rightarrow qW$</td>
<td>3.2</td>
<td>3.0</td>
</tr>
<tr>
<td>$q^* \rightarrow qZ$</td>
<td>2.9</td>
<td>2.6</td>
</tr>
<tr>
<td>$W' \rightarrow WZ$</td>
<td>1.7</td>
<td>1.6</td>
</tr>
<tr>
<td>$G_{RS} \rightarrow WW$</td>
<td>1.2</td>
<td>1.3</td>
</tr>
</tbody>
</table>

All exclusion limits are best to date

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Search for Light- and Heavy-Flavor Three-Jet Resonances
Pair produced RPV gluinos:

- Case 1: light-flavor, gluino → uds
- Case 2: heavy-flavor, gluino → udb or csb

Select $\geq 6$ PF jets, $4^{\text{th}}$ ($6^{\text{th}}$) jet $p_T > 80$ (60) GeV

- High mass search ($> 600$ GeV): $6^{\text{th}}$ jet $p_T > 110$ GeV
- Use sphericity $> 0.4$ to reduce SM multijet background at high mass

CMS, $L = 19.4$ fb$^{-1}$ at $\sqrt{s} = 8$ TeV
- 20 unique triplets per event with 6 jets:
  - Can only be two correctly assigned triplets
  - Large combinatorial background
- Select triplets with $M(ijk) < \sum |p_T(ijk)| - \Delta$ to suppress uncorrelated triplets; set $\Delta = 110$ GeV
- Inspect triplet mass spectrum for deviations

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Case 1: fully data-driven background estimate

Fit data to a smooth function

No significant excess observed

Set lower limit on gluino ($\rightarrow qqq$) mass at 650 GeV
Case 2 – extra selection: ≥ 1 b tag in triplet
Combined MC and data-driven background estimate
Low-mass region (200 – 600 GeV)
- Background estimated from ttbar MC and b-jet control region in data
High-mass region (> 600 GeV) – fit data to a smooth function
Case 2 – extra selection: \( \geq 1 \) b tag in triplet

Combined MC and data-driven background estimate

Low-mass region (200 – 600 GeV)

- Background estimated from ttbar MC and b-jet control region in data

High-mass region (> 600 GeV) – fit data to a smooth function

Exclude gluinos \((\rightarrow qqb)\) with masses below 835 GeV

First search (gluino \(\rightarrow qqb\)) of this kind. Best limit to date
Search for Dark Matter in Monojet Final State
Generic signature - a jet and missing energy:
- Used to constrain many new scenarios – dark matter production, extra dimensions, unparticles

Selection:
- At least one jet with $p_T > 110$ GeV, $|\eta| < 2.4$
- 2$^{nd}$ jet with $p_T > 30$, $|\eta| < 4.5$, $|\Delta \phi_{jj}| < 2.5$
- Isolated lepton veto
- Seven inclusive MET bins: MET > 250, 300, 350, 400, 450, 500, and 550 GeV

Largest backgrounds – data driven:
- $Z(\nu \nu) + \text{jets}$ – estimated from $Z(\mu \mu) + \text{jets}$ control data sample
- $W(l \nu) + \text{jets}$ – from $W(\mu \nu) + \text{jets}$ control sample
Good agreement between observed data and expected background
Stringent constraints on dark matter candidate mass for broad range of extra dimensions

Model-independent limits

$\int L \, dt = 19.5 \, fb^{-1}, \sqrt{s} = 8 \, TeV$

- Can be used to constrain any model with the same final state

$M_D$ limits as a function of $\delta$

Stringent constraints on dark matter candidate mass for broad range of extra dimensions
90% CL upper limits on nucleon cross section vs. DM mass

- Spin dependent: best limits up to ~300 GeV
- Spin independent: best limits up to ~3.5 GeV

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Search for Jet Extinction
- Search for terascale gravity in inclusive jet $p_T$ spectrum (18 bins)

- Expect suppression of high-$p_T$ jets above certain threshold – extinction scale $M$ (2, 3, and 4 TeV probed)

- Selection: anti-$k_T$ ($R = 0.7$) PF jets with $p_T > 592$ GeV, $|\eta| < 1.5$

- Compare data to NLO calculation with CT10 PDFs:
  - NLOJet++ within fastNLO
  - Non-perturbative corrections derived from Pythia
  - Corrected jet $p_T$ spectra are convolved with detector response
Perform $C_{L_s}$ scan as a function of $\beta \equiv M^{-2}$ (as $\beta \to 0$ the extinction model approaches SM prediction):

- Systematic uncertainties take into account bin-to-bin correlations and migrations between jet $p_T$ bins.

- Limit on the extinction scale $M = 3.3$ TeV ($\beta = 0.090$ TeV$^{-2}$) for CT10 PDF ($\sim 10\%$ higher for MSTW2008).

Submitted to PRD
Conclusions

- All these searches made possible by the LHC – thanks for high-quality data!
- Rich program of searches for NP in multijets:
  - No evidence for new physics yet
  - Many interesting results on LHC data have been obtained
  - Many give best limits to date
  - Public pages:
    - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
- Stay tuned for LHC Run2
“Search for massive resonances in dijet systems containing jets tagged as W or Z boson decays pp collisions at $\sqrt{s} = 8$ TeV”
- CMS-PAPER-EXO-12-024: [http://cds.cern.ch/record/1700394](http://cds.cern.ch/record/1700394)

“Search for new physics in monojet events in pp collisions at $\sqrt{s} = 8$ TeV”
- CMS-PAS-EXO-12-048: [http://cds.cern.ch/record/1525585](http://cds.cern.ch/record/1525585)

“Search for light- and heavy-flavor three-jet resonances in pp collisions at $\sqrt{s} = 8$ TeV”
- CMS-PAS-EXO-12-049: [http://cds.cern.ch/record/1563139](http://cds.cern.ch/record/1563139)

“Search for jet extinction in the inclusive jet-$p_T$ spectrum from proton-proton collisions at $\sqrt{s} = 8$ TeV”
- CMS-PAPER-EXO-12-051: [http://cds.cern.ch/record/1704979](http://cds.cern.ch/record/1704979)
Thanks!

- Thanks to my colleagues for the results I've shown today

- Thanks to LHCP2014 Organizers!