Title: Exotic Resonance searches in Atlas data
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Abstract: TBA
Brief Summary of Dijet Searches
Summary of Paper Publications ... and more!

P.O. DeViveiros, S.L. Cheung
University of Toronto
Outline

- **Tools for Dijet Searches:** Jets!
  - The real question: *What is the Jet Energy Scale at ATLAS?*
- **Overview of 2 dijet analyses**
  - First 2 exotics analyses to be published with LHC data!
- **Dijet Angular Distributions @ 3.1 pb⁻¹**
  - Published in PLB, October 21st 2010 [doi:10.1016]
- **Dijet Resonances @ 3.1 pb⁻¹**
  - Published in PRL, October 10th 2010 [ATLAS-CONF-2010-093]
Jets at ATLAS

• The Basics:
  - The anti-$k_T$ algorithm is used
    - Infrared-safe, colinear-safe, robust vs. pile-up, well-defined jet areas, the list goes on...
  - Size parameters 0.4 and 0.6 are 'supported' at ATLAS
    - For dijet topologies, 0.6 is used

• Inputs to jet finding: 'Topoclusters'
  - Noise suppressing 3-dimensional 'nearest neighbor' clustering
  - Uses characterization of the detector noise to group the energy deposits of cells 'single particles'
Jet Energy Scale

- The uncertainty on the measurement of the energy of a jet
  - Reminder: ATLAS calorimeters are non-compensating
- Jet calibration at ATLAS: *Particle* level
  - The jets are calibrated to the energy of the particles (hadrons, etc.) which fall into the jet area
- Simple calibration scheme:
  - $p_T$ and $\eta$ dependent correction factors scale the jet 4-momentum
  - Derived from Monte Carlo samples (*PYTHIA* + ...) by matching *Truth Particle Jets* (jets made from the generator bank of outgoing particles) to *Reco Jets* (jets made from the simulated energy depositions of said particles)
- Why this works: ATLAS has a very sophisticated detector simulation program based on *GEANT4*; describes the energy loss mechanisms of particles in the detector
Jet Energy Calibration

AntiK$_T$, R=0.6 jets
- 0.3 < |$\eta$| < 0.8
- 2.1 < |$\eta$| < 2.8
Jet Energy Scale - How??

- For first data, a conservative procedure:
  - Simulate $X$ Monte Carlo 'variation' samples, with different simulation conditions
  - Each sample represents a *best guess* (conservative) at a possible aspect of the model(s) we may have gotten wrong
  - Use insight from testbeam, and single particle studies, to justify the educated guesses
  - Compare the response of jets between the variation samples and the default to extract an uncertainty

<table>
<thead>
<tr>
<th>Uncertainties: A shopping list!</th>
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<tbody>
<tr>
<td>Shower Models</td>
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<td>EM Scale (!!)</td>
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<td>Noise modeling</td>
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<td>...</td>
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</table>
Jet Energy Scale – How is it??

- The size of this uncertainty will directly affect the sensitivity of searches based on jet signatures!

Just about 6% for central 100 GeV jets...
Dijet Angular Distributions

- We are searching for Quark Compositeness
- Signature is an excess of dijet events at an invariant mass approaching the compositeness scale $\Lambda$ compared to QCD predictions
- Most natural thing to do: Look for deviations in the dijet invariant mass / $p_T$ distribution!
Dijet Angular Distributions

- Alternative approach: Look at the angular distributions of dijet events, which are much less sensitive to the JES uncertainty! Two observables:
  
  \[ \chi = \exp \left| y_1 - y_2 \right| = u / t \quad [\text{in bins of } m_{jj}] \]

- Originally introduced to write the differential cross-sections for QCD processes easily

- \( \frac{d\sigma}{d\chi} \) turns out to be approximately flat for dominant QCD t-channel, but clear deviations from flatness for isotropic processes (quark compositeness)

- \( R_c = \frac{N (|\eta_{1,2}| < 0.7)}{N (0.7 < |\eta_{1,2}| < 1.3)} \) [Centrality Ratio]

- Flat as a function of the invariant mass for QCD, shows 'turn-on' behavior in mass regimes approaching \( \Lambda \) in the case of compositeness

- Allows to probe the angular distributions as a fine function of the invariant mass

- Very 'detector-driven' – Good for early physics!
Philosophy

- Simple kinematic cuts to ensure that the triggers are fully efficient
- No attempt is made to unfold for jet resolution effects: the comparisons between Monte Carlo and data are purely at 'detector level'
- Normalize the distributions to remove any dependencies on theoretical cross-sections and luminosity: 'shape-only'
- Establish agreement between QCD and data with a simple figure of merit
- Set limits using Bayesian & Frequentist methods
Distributions: $R_C$

\[ \int Ldt = 3.1 \text{ pb}^{-1}, \sqrt{s} = 7 \text{ TeV} \]

- QCD
- Theoretical Uncertainties
- Total Systematics

$p$-value: 0.85

'Prefers' $\Lambda = 2.9 \text{ TeV}$

ATLAS
Distributions: $\chi$

$p$-values:
0.54
0.27
0.19
0.11

December 7th 2010
Setting Limits

- Use the highest invariant mass bin in $\chi$
- Collapse all information about the $\chi$ spectrum into a single number, $F$
  - $F_i = \text{Ratio of contents of first 4 bins to total number of events}$
- Use a frequentist Neyman construction

Limits:
- 3.4 TeV [Frequentist]
- 3.3 TeV [Bayesian - Cross-check]
- 2.0 TeV [$R_c$ Bayesian]
- 3.1 TeV [Tevatron]
Distributions: $\chi$

$p$-values:
- 0.54
- 0.27
- 0.19
- 0.11

\[ \chi = e^{\frac{|y_1 - y_2|}{\sqrt{2}}} \]

\[ L dt = 3.1 \text{pb}^{-1}, \sqrt{s} = 7 \ \text{TeV} \]

- $340 < m_1 < 520 \ \text{GeV}$
- $520 < m_1 < 800 \ \text{GeV} (+0.03)$
- $800 < m_1 < 1200 \ \text{GeV} (+0.06)$
- $m_1 > 1200 \ \text{GeV} (+0.09)$

QCD Prediction
Theoretical Uncertainties
Total Systematics

ATLAS

December 7th 2010
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Dijet Resonance: Analysis Overview

- The analysis goal is summarized in the flow chart
  - Any "no" answer will make us worry ... but we haven't been in this situation yet!
- Many exotic models exhibit in the 2-jet resonance signature
  - $q^*$ has been used as the benchmark in this analysis
  - More models are working in progress
- Observable: invariant mass $m_\text{ll}$ of the 2 leading jets

Data Input
- Are the data smooth? No evidences of "bump"?
  - NO
  - YES

Consistent with fit?
- YES

Set limits to exotic models, e.g., excited quark $q^*$

New Physics?

QCD

Equation for $d\sigma/dm_\text{ll}$

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Dijet Resonance:
Data smooth? No "bump"?

- After the event selection, we test the data distribution by fitting a smooth function
  \[ f(x) = p_0 \frac{(1-x)^{p_1}}{x^{p_2+p_3 \ln x}} \]
  where \( x = m^+ \sqrt{s} \)

- This function
  - is continuous and differentiable
  - has a monotonic decreasing property
  - fits QCD very well
  - \( f(1) = 0 \) by the CM energy constraint
  - Also used in CDF [PRD, 79 (2009) 112002]

- The small value of chi2/ndf reflects the smoothness of the data distribution
  - No bumpy feature shows up in the distribution
  - Other alternative forms have been examined, but so far none of them is satisfactory

Scratch our heads ... Bug(s)? Something new?

Are the data smooth? No evidences of "bump"?

Follow PDF fall-off in high x

Imitate QCD matrix element

Consistent with fit?

Set limits to exotic models, e.g., excited quark \( q^* \)
Dijet Resonance: Consistent with fit?

- Pseudo-experiments are then performed with various statistical tests for goodness-of-fit:
  - By measuring statistic of each PE, we examine if the observed data is as typical as any distributions from the PEs
- 6 statistical tests have been employed:
  - Bump Hunter
  - Jeffreys Divergence
  - Kolmogorov-Smirnov
  - \(-\ln L\)
  - Pearson \(\chi^2\)
  - TailHunter
- Large \(p\)-value shows good agreement between the observed data and the fit

Data Input

Are the data smooth? No evidences of “bump”?

Consistent with fit?

Set limits to exotic models, e.g., excited quark \(q^*\)
Dijet Resonance: Set Limit

- We take Bayesian approach and find the number of signal event that can be excluded, at 95% credibility level with a flat prior in signal cross section.
- The following systematics are considered:
  - JES uncertainty (dominant, 6-9%)
  - Fit uncertainty (dominant)
  - Luminosity (11%)
  - JER (negligible)
- These nuisance parameters are convolved in the likelihood calculation:
  - We find the excluded signal events as a function of resonance mass.
  - The mass limit for each model is found by looking for the crossing between the above curve and the theory curve in the mass exclusion plots.

Scratch our heads ... Bug(s)? Something new?

Are the data smooth? No evidences of “bump”?

Consistent with fit?

Set limits to exotic models, e.g., excited quark $q^*$
Dijet Resonance:

$n$ Optimization with MC

$\mathcal{M}_0 < m^{jj} < 1.2 \cdot GeV$

- Select MC events in a specific dijet mass range
- QCD jets are more forward (large $|\Delta \eta|$) while signal jets are more central (small $|\Delta \eta|$)
Dijet Resonance:
Searches with 3.1 pb$^{-1}$

$\sqrt{s} = 7$ TeV
$\int L dt = 3.1$ pb$^{-1}$

ATLAS Preliminary
Dijet Resonance: Optimization with MC

\[ \mathcal{M} \ll m_{jj} \ll 1.2 \text{ GeV} \]

**MC QCD**
- Select MC events in a specific dijet mass range
- QCD jets are more forward (large |\Delta \eta|) while signal jets are more central (small |\Delta \eta|)
Dijet Resonance: Searches with 3.1 pb\(^{-1}\)

\[
\sqrt{s} = 7 \text{ TeV} \quad \int Ldt = 3.1 \text{ pb}^{-1}
\]
Dijet Resonance:
Limits with 3.1 pb⁻¹

0.30 < m(q*) < 1.26 TeV (MC09)

\[ \int L dt = 3.1 \text{ pb}^{-1} \]
\[ \sqrt{s} = 7 \text{ TeV} \]
Dijet Resonance:
Model-independent Search

- Establish a way to provide information for theorists given a resonance model with a signal size
  - Build, e.g., a table of
    - resonance mass | detector-level width | \( \sigma \cdot A \) upper limit
  - For simplicity, assume Gaussian-shape signal
Dijet Resonance:
Example for $m = 1000 \text{ GeV}$ and $\text{width} = 45 \text{ GeV}$

Toy Model
Dijet Resonance:
Example for $m = 1000$ GeV and width = 45 GeV

[Graph showing a decay plot with a log-log scale, labeled as Toy Model]
Dijet Resonance:
Example for $m = 1000$ GeV and width = 45 GeV
Dijet Resonance:
Example for $m = 1000 \text{ GeV}$ and width $= 45 \text{ GeV}$
### Dijet Resonance:

#### Table (example)

<table>
<thead>
<tr>
<th>mass</th>
<th>detector-level width</th>
<th>sigma A upper limit</th>
</tr>
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<tbody>
<tr>
<td>800</td>
<td>16</td>
<td>52.1191</td>
</tr>
<tr>
<td>800</td>
<td>24</td>
<td>52.3828</td>
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Dijet Resonance:
Table Plotting

\begin{align*}
\text{limit (Num. of events)} \\
\sigma / m \\
\end{align*}

\begin{align*}
m &= 600 \text{ GeV} \\
\end{align*}

\begin{align*}
m &= 2000 \text{ GeV} \\
\sigma / m \\
\end{align*}

\begin{align*}
m &= 2200 \text{ GeV} \\
\sigma / m \\
\end{align*}
Summary

• We've shown the results with 3.1 pb$^{-1}$ of data
  • The data shows a good agreement with the predictions
  • The current limits are
    \[ 0.3 < m(q^*) < 1.26 \text{ TeV} \quad [0.87 \text{ TeV at Tevatron}] \]
• More results with other exotic models are underway with full 2010 data
• Model-independent search provides useful communication between us (theorists + experimentalists)
  • Statistical fluctuation only
  • What would make this more useful / practical?
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