Searches for Exotica at the LHC

Moriond QCD 2013

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Rutgers University

Monday, March 11th, 2013
Outlines:

**Exclusive focus on new 8 TeV (~9-20/fb) results from the LHC!**

- **8 TeV Results**
  - Dijets Resonances (CMS+ATLAS)
  - Top Partners (CMS)
  - T-Prime (ATLAS)
  - B-Prime (CMS)
**Dijet Resonances**

- Generic search for new physics in the dijet spectrum
  - Look for **central** resonances (ATLAS: $|\Delta y|<1.2$; CMS: $|\Delta \eta|<1.3$)
  - CMS separates searches by final state (qq, qg, gg)
  - ATLAS provides simplified Gaussian models ($\sigma/M=0.07, 0.10, 0.15$)

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**Diagram**

- Normalized yield/GeV
- Dijet Mass (GeV)
- Quark-Quark, Quark-Gluon, Gluon-Gluon
- CMS Simulation Preliminary
- $\sqrt{s}=8$ TeV, WideJets
- $|\eta| < 2.5 & |\Delta \eta| < 1.3$

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**Graph**

- [CMS-EXO-12-059]

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**Table**

<table>
<thead>
<tr>
<th>$\sqrt{s}$ = 8 TeV, $\int L dt = 13.0$ fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>[data - fit] / fit</td>
</tr>
<tr>
<td>q$^*$ PYTHIA 8 (1500)</td>
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<tr>
<td>q$^*$ PYTHIA 8 (2500)</td>
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<tr>
<td>q$^*$ PYTHIA 8 (3000)</td>
</tr>
<tr>
<td>q$^*$ PYTHIA 8 (3750)</td>
</tr>
</tbody>
</table>

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**ATLAS Preliminary**

- [ATLAS-CONF-2012-148]
• CMS uses an FSR-recovery technique by combining anti-$k_T$ 0.5 jets within $\Delta R<1.1$
• CMS and ATLAS fit to a smooth, steeply falling function

\[ \frac{d\sigma}{dm_{jj}} = \frac{P_0(1 - x)^{P_1}}{xP_2 + P_3 \ln(x)} ; \quad x \equiv \frac{m_{jj}}{\sqrt{s}} \]

[CMS-EXO-12-059] [ATLAS-CONF-2012-148]
**Dijet Limits**

- **Exclusions**
  - CMS excludes e.g. SSM Z' [1.20 TeV, 1.68 TeV] (+ many more)
  - ATLAS excludes excited quark [1.50 TeV, 3.84 TeV]
**TOP PARTNERS**

- Search for pair production of charge $\frac{5}{3}$ top partner decaying 100% to $Wt$
  - Final state signature: **same-sign leptons** outside Z window + $H_T>900$ GeV
  - Require $\geq5$ “constituents” in addition to two SS leptons
    - constituent=lepton, jet, V-tagged jet (2), or top-tagged jet (3)

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CMS Preliminary
19.6 fb$^{-1}$ at $\sqrt{s} = 8$ TeV

SS+$\geq2$ jets

[CMS-B2G-12-012]

reconstructed $T_{\frac{5}{3}}$ mass (not final selection)

[CMS-B2G-12-012]
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• In final selection, observe 11 events against 6.6±2.0 expected
  • Exclude 5/3 Top Partners with masses up to 770 GeV
**Vector-Like T-Prime Search**

- Inclusive search for pair production of T’
  - consider decays to Wb, Zt, and Ht
  - =1 lepton + ≥6 jets + MET + M_T
  - bin in number of b-tags

- Use control (H_T<700 GeV) regions to fit for ttbar+LF and ttbar+HF

(\text{N.B. ATLAS } H_T = \sum p_T (\text{of all objects})

[ATLAS-CONF-2013-018]
T-Prime Limits

- Set limits on weak-isospin double and singlet models
  - specific BRs to Wb, Zt, and Ht as a function of mass
  - Exclude T' < 790 (640) GeV for a doublet (singlet)
T-PRIME LIMITS BY BRANCHING RATIO

ATLAS Preliminary
\( \sqrt{s} = 8 \text{ TeV}, \int L \, dt = 14.3 \text{ fb}^{-1} \)

- 95% CL expected exclusion
- 95% CL observed exclusion

- SU(2) doublet  
- SU(2) singlet


[ATLAS-CONF-2013-018]
• Re-interpret search for RPV SUSY with \( \geq 3 \) leptons as search for vector-like \( B' \)
  • RPV SUSY search considers 100’s of bins
    • \( S_T = H_T + L_T + \text{MET} \)
    • number of leptons
    • number of taus
    • number of b tags
    • # of opposite-sign same flavor lepton pairs
    • on/off shell Z

[B'-Prime Search with Multileptons]

CMS Preliminary
\[ \sqrt{s} = 8 \text{ TeV}, L_{\text{int}} = 9.2 \text{ fb}^{-1} \]

4-leptons + OSSF2 + on-Z + no taus + at least 1 b-jet

\[ B'B' \rightarrow bZbZ \]

CMS Preliminary
\[ \sqrt{s} = 8 \text{ TeV}, L_{\text{int}} = 9.2 \text{ fb}^{-1} \]

3-leptons + OSSF1 + high-Z + no taus + at least 1 b-jet

\[ B'B' \rightarrow tWtW \]
**B-Prime Limits**

- Exclude $B'$ with 100% BR to $bZ$
  - $m_{B'} > 660 \text{ GeV} \ @ \ 95\% \ CL$
- Exclude $B'$ with 100% BR to $tW$
  - $m_{B'} > 760 \text{ GeV} \ @ \ 95\% \ CL$
- Exclude $B'$ with 50% BR to $bZ$
  - $m_{B'} > 715 \text{ GeV} \ @ \ 95\% \ CL$

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**CMS Preliminary**

- $\sqrt{s} = 8 \text{ TeV, } L_{int} = 9.2 \text{ fb}^{-1}$

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**[CMS-SUS-12-027]**
CONCLUSIONS

• LHC has completed its first run

• We’ve found something BEHGHK-like, but the search for New Physics has just begun
  • CMS and ATLAS have only just begun exploring and exploiting the full 8 TeV dataset
  • We’ve learned a lot about where New Physics isn’t, and where it still could be

• Lots of places new physics could still be hiding
  • Long-lived particles, multijet final states, top-like final states, etc.
  • Be prepared for many more results in the coming months

• Stay tuned!
Backup
### ATLAS Exotics Searches* - 95% CL Lower Limits (Status: HCP 2012)

#### ATLAS Preliminary

\[ \int Ldt = (1.0 - 13.0) \text{ fb}^{-1} \]

\[ \mathcal{L} = 7, 8 \text{ TeV} \]

*Only a selection of the available mass limits on new states or phenomena shown*

### Other

#### Major. neutr. (LRSμ, no mixing): 2-lep + jets

- \( W_R \) (LRSμ, no mixing): 2-lep + jets
- \( H^{±±} (DY prod., BR(H^{±±}\rightarrow l\nu_l)=1): SS ee (μμ), m = \) 1.08 TeV
- \( H_L^{±+} (DY prod., BR(H_L^{±+}\rightarrow e\nu_l)=1): SS e\mu, m = \) 1.23 TeV
- Color octet scalar: dijet resonance, \( m = \)

### Techni-hadrons (LSTC)

- WZ resonance (νll, \( m = \)) 2.2 GeV
- WZ resonance (νll, \( m = \)) 1.3 GeV
- White Kaluza-Klein modes (9, 9 TeV)
- Techni-hadrons (LSTC): WZ resonance (νll, \( m = \)) 2.2 GeV
- Techni-hadrons (LSTC): WZ resonance (νll, \( m = \)) 1.3 GeV
- White Kaluza-Klein modes (9, 9 TeV)

### Excited fermions

- Excited quarks: dijet resonance, \( m = \)
- Excited quarks: dijet resonance, \( m = \)
- Excited lepton: π resonance, \( m = \)

### Techni-hadrons (LSTC)

- dijet resonance, \( m = \)
- White Kaluza-Klein modes (9, 9 TeV)

### Other

- Major. neutr. (LRSμ, no mixing): 2-lep + jets
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<th>Mass scale [TeV]</th>
<th>( 10^{-1} )</th>
<th>1</th>
<th>10</th>
<th>100</th>
<th>1000</th>
</tr>
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<tr>
<td>( M_D ) (h=2)</td>
<td>4.7 TeV</td>
<td>4.18 TeV</td>
<td>1.93 TeV</td>
<td>4.37 TeV</td>
<td>4.7 TeV</td>
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<td>( M_S ) (H LZ h=3, NLO)</td>
<td>1.41 TeV</td>
<td>4.47 TeV</td>
<td>2.23 TeV</td>
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Heavy Resonances

- Z’S (ee, μμ)
- Z’S (ττ)
- Z’ (tt hadronic) width=1.2%
- Z’ (dijet)
- Z’ (tt lep+jet) width=1.2%
- Z’S (ll llqq) fbb=0.2
- G (dijet)
- G (tbar hadronic)
- G (jet+MET) k/M = 0.2
- G (γγ) k/M = 0.1
- G (ZllZllqq) k/M = 0.1
- W’ (ll)
- W’ (dijet)
- W’ (td)
- W’ → WZ(lep)
- WR’ (tb)
- WR, MNR=MWR/2
- WKK μ = 10 TeV
- pTC, πTC > 700 GeV
- String Resonances (qg)
- s8 Resonance (qg)
- E6 diquarks (qq)
- Axigluon/Coloron (qgbar)
- gluino, 3jet, RPV
- gluino, Stopped Gluino stop, HSCP
- stau, Stopped Gluino stau, HSCP, GMSB
- hyper-K, hyper-μ=1.2 TeV neutrino, cτ<50cm

Compositeness

- q* (qg), dijet
- q* (qW)
- q* (qZ)
- q* , dijet pair
- q* , boosted Z
- e* , Λ = 2 TeV
- μ* , Λ = 2 TeV

Long Lived

- Z’SSM (ee, μμ)
- Z’SSM (ττ)
- Z’ (tt hadronic) width=1.2%
- Z’ (dijet)
- Z’ (tt lep+jet) width=1.2%
- Z’S (ll llqq) fbb=0.2
- G (dijet)
- G (tbar hadronic)
- G (jet+MET) k/M = 0.2
- G (γγ) k/M = 0.1
- G (ZllZllqq) k/M = 0.1
- W’ (ll)
- W’ (dijet)
- W’ (td)
- W’ → WZ(lep)
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- WR, MNR=MWR/2
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- gluino, Stopped Gluino stop, HSCP
- stau, Stopped Gluino stau, HSCP, GMSB
- hyper-K, hyper-μ=1.2 TeV neutrino, cτ<50cm

LeptoQuarks

- b’ → tW, (3l, 2l) + b-jet
- q’, b'/t' degenerate, Vtb=1
  - b’ → tW, l+jets
  - B’ → bZ (100%)
  - T’ → TZ (100%)
  - t’ → bW (100%), l+jets
  - t’ → bW (100%), l+l

4th Generation

- C.I. Λ , X analysis, Λ+ LL/RR
- C.I. Λ , X analysis, Λ- LL/RR
- C.I., μμ, destructive LLIM
- C.I., μμ, constructive LLIM
- C.I., single e (HnCM)
- C.I., single μ (HnCM)
- C.I., incl. jet, destructive
- C.I., incl. jet, constructive

Contact Interactions

- Ms, γγ, HLZ, nED = 3
- Ms, ll, HLZ, nED = 3
- Ms, γγ, HLZ, nED = 6
- Ms, ll, HLZ, nED = 6
- MD, monojet, ADD, nED = 3
- MD, monojet, ADD, nED = 6
- MD, mono-γ, ADD, nED = 3
- MD, mono-γ, ADD, nED = 6
- BH, rotating, MD=3TeV, nED = 2
- BH, non-rot, MD=3TeV, nED = 2
- BH, rotating, loss, MD=3TeV, nED = 2
- BH, boil. remn., MD=3TeV, nED = 2
- BH, stable remn., MD=3TeV, nED = 2

Extra Dimensions & Black Holes

- Sh. Rahatlou

CMS Exotica 95% CL Exclusion Limits (TeV)

LQ1, β=0.5
LQ1, β=1.0
LQ2, β=0.5
LQ2, β=1.0
LQ3 (bv), Q=±1/3, β=1.0
LQ3 (bt), Q=±2/3, ±4/3, β=1.0
stop (bt)