Searches for NP

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Disclaimer

• Not a comprehensive review of results.

• Selected results (mostly) shown to make some (pedagogical? interesting?) point

• Only CMS and Atlas

• Skewed towards CMS

• Not representing CMS (or Atlas)
New Physics?
2018 LHC extreme views

1. There is no new physics, we are doomed.

2. LHC has only taken a few % of full dataset, we have only scratched the surface! Exciting!!!
Pre-LHC NP expectations quickly met reality

**Figure 33:** (a) Prediction of [126] at 68% and 95% confidence of the unified supersymmetry-breaking parameters \((m_0, m_{1/2})\) of the constrained Minimal Supersymmetric Standard Model. (b) 95% confidence exclusion region in the parameters \((m_0, m_{1/2})\) in the \(\alpha_T\) search for supersymmetry presented by CMS at LP11 [127].
The steep fall of the production cross-sections of new particles with mass drives the pessimism. It is hard to make progress with luminosity alone. Worth reviewing for a few minutes why that is and some consequences.
• Parton-parton x-section, i+j \rightarrow X:
  \[ \hat{\sigma}_{ij}(\hat{s}) \text{ at } E_{CM} = \sqrt{\hat{s}} \]

• \( \sigma \) for \( pp \rightarrow X \):
  \[ \sigma = \sum \int dx_i dx_j f_i(x_i) f_j(x_j) \hat{\sigma}_{ij} \]
  \[ \hat{s} = x_i x_j s \text{ and } \tau \equiv \frac{s}{\hat{s}} \]

• Rewrite it as:

  \[
  \sigma(s) = \sum \int_{\tau_0}^{1} \frac{d\tau}{\tau} \cdot \frac{\tau}{\hat{s}} \frac{dL_{ij}}{d\tau} \cdot [\hat{s}\hat{\sigma}_{ij}(\hat{s})]
  \]

  \[
  \frac{dL_{ij}}{d\tau} \equiv \frac{1}{1 + \delta_{ij}} \int_{\tau}^{1} \frac{dx}{x} [f_i(x) f_j(\frac{\tau}{x}) + f_j(x) f_i(\frac{\tau}{x})]
  \]

Luminosity for parton-parton collisions.
Dimensionless, function of parton-parton shat
Multiply by \((\tau/\hat{\tau})=(1/s)\) to get in units of \(1/E^2\), ie area, ie, nb, pb, fb...
CTEQ6L1: gg

CTEQ6L1: qq
As a consequence, most of the production is near threshold. Keep it in mind when you think about your own search!
New Physics Searches

3 + 1 ingredients

0. Detector and machine

1. **Trigger:** *If you didn't trigger on it, it never happened*
   - Will mostly not talk about it

2. **Backgrounds:** *It's the background, stupid*
   - Need to understand SM and instrumental backgrounds

3. **Ideas (or luck):** *If you look for something, you may not find it. But if you don't look, you will never find it*
   - Model independent vs model dependent searches
Roadmap for a search

• A search is most often an analysis of BG
• Decide what to look for (!)
  • Pay attention to theory guidance, but don’t go overboard
• Define trigger/event selection
  • Most often with MC of signal and BG
  • May need to develop new tools (fun)
• Do not overtune on particular signal model
  • Unless you are looking for very specific signal
• Keep it simple
  • Esp. if the 1st time and/or “next year” you get more data
• Think carefully about BG estimate at every step
  • Avoid blind use of MC.
Roadmap for a search (cont.)

- Don’t forget very rare (maybe never seen?) SM processes. They can add up.
  - UA1 “found” SUSY in 1984 because of this (!)
  - Here sometimes all you have is MC

- If it is a mass peak it sounds easy (!)

- If you can separate, use control region plus MC or other tricks to extrapolate
  - If counting instead of fitting, careful about sig. contamination

- If on top of each other, difficult
  - Need good control of shape and/or normalization of SM

- Blind analysis
Some of these looked really easy

From some pre-LHC MC studies
Did not quite work out that way
Not all that glitters is gold
SUSY

• The most popular BSM model at LHC turn-on
  • Maybe still is?
• It is not a model. It is a family of models

Figure 1: Full spectrum of STC8 and decay modes with a branching fraction of at least 10% (a). The lower part of the spectrum of the STC scenarios, which features $M_{\tilde{\tau}_1} - M_{\chi^0_1} \approx 10$ GeV (b).
This way of presenting the results was soon abandoned in favor of “Simplified Models”.

It is not just a matter of presenting results in a different, more “down to earth” way.

It also enabled a wider variety of searches with less prejudice.
Simplified Models

- Production of SUSY particles with well defined x-sections
- Almost always 100% BR
- Almost always neglecting spin factors, matrix element dynamics in decay
Simplified Models

• Production of SUSY particles with well defined x-sections
• Almost always 100% BR
• Almost always neglecting spin factors, matrix element dynamic in decay

• Unrealistic
• But helps to zero-in on the mass-shell physics
• Better motivation of searches
• Colorful plots
SUSY searches

• Many different final states
  • 0L, 1L, 2LSS, 2LOS, Multilepton
  • Different $N_{\text{jets}}, N_{b}, \text{MET} H_T, M_{\text{eff}}$ ..... 
  • Many bins

• Most searches are “generic” enough that they are sensitive to broad range of NP possibilities

• Started with strong production, moving to EWK production
### ATLAS SUSY Searches\* - 95% CL Lower Limits

#### Model

<table>
<thead>
<tr>
<th>Model</th>
<th>(\ell\ell\tau\gamma) Jets</th>
<th>2 (\ell\ell) Jets</th>
<th>Mass limit</th>
<th>Reference</th>
</tr>
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<td>(\tilde{q}_1, \tilde{q}_2, \tilde{\ell})</td>
<td>0</td>
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<td>Yes</td>
<td>36.1</td>
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<tr>
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<td>2-6 jets</td>
<td>Yes</td>
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#### Inclusive Searches

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#### EW Direct

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#### Long-lived Particles

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<tr>
<td></td>
<td>(\tilde{b}_1, \tilde{b}_2, \tilde{\ell})</td>
<td>Multiple</td>
<td>Yes</td>
<td>36.1</td>
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<tr>
<td></td>
<td>(\tilde{b}_1, \tilde{b}_2, \tilde{\ell})</td>
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<td>Yes</td>
<td>36.1</td>
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<td>(\tilde{b}_1, \tilde{b}_2, \tilde{\ell})</td>
<td>Multiple</td>
<td>Yes</td>
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<tr>
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<td>(\tilde{b}_1, \tilde{b}_2, \tilde{\ell})</td>
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<td>Yes</td>
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<tr>
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<td>(\tilde{b}_1, \tilde{b}_2, \tilde{\ell})</td>
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<td>Yes</td>
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<td>(\tilde{b}_1, \tilde{b}_2, \tilde{\ell})</td>
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#### RPV

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<th>Mass limit</th>
<th>Reference</th>
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<td>36.1</td>
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<tr>
<td></td>
<td>(\tilde{b}_1, \tilde{b}_2, \tilde{\ell})</td>
<td>Multiple</td>
<td>Yes</td>
<td>36.1</td>
</tr>
<tr>
<td></td>
<td>(\tilde{b}_1, \tilde{b}_2, \tilde{\ell})</td>
<td>Multiple</td>
<td>Yes</td>
<td>36.1</td>
</tr>
<tr>
<td></td>
<td>(\tilde{b}_1, \tilde{b}_2, \tilde{\ell})</td>
<td>Multiple</td>
<td>Yes</td>
<td>36.1</td>
</tr>
</tbody>
</table>

\*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.
Example of results of a SUSY search
pp → \tilde{g} \tilde{g}, \tilde{g} → q \bar{q} \tilde{\chi}_1^0 \text{ NLO+NLL exclusion}

- Observed ± 1 \sigma_{\text{theory}}
- Expected ± 1 \sigma_{\text{experiment}}

CMS 35.9 fb⁻¹ (13 TeV)

m_{\tilde{\chi}_1^0} [GeV]

m_{\tilde{g}} [GeV]

95% CL upper limit on cross section [pb]
$m_{\tilde{g}}$ [GeV] vs. $m_{\tilde{\chi}_1^0}$

$pp \rightarrow \tilde{g} \tilde{g}, \tilde{g} \rightarrow q \bar{q} \tilde{\chi}_1^0$

CMS Supplementary arXiv:1704.07781

35.9 fb$^{-1}$ (13 TeV)
More Shortcomings of Simplified Models

- No di-squark, squark-gluon production
- Cross-sections calculated in decoupling limit
- How good are the mass limits then?
pMSSM study (8 TeV, Atlas)

• Generate MC for many “full” R-parity conserving models consistent with Dark matter and other constraints
• Feed them through 22 Atlas searches
• Look at SUSY masses of excluded vs. allowed models
EWK SUSY

Low cross-section

NLO + NLL, pp, \( \sqrt{s} = 13 \) TeV

S. Strandberg
ICHEP 2018
$\tilde{\chi}_1^{\pm} \tilde{\chi}_2^0$

$\tilde{\chi}_1^0$

$\Delta m$

$\tilde{\chi}_2^0$

$\tilde{\chi}_1^{\pm}$

$\tilde{\chi}_1^0$

Wino-like cross-sections

Higgsino-like cross-sections
Sleptons

$\tilde{e}, \tilde{\mu}$

$\tilde{\tau}$
End of Lecture 1
# ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

**Status:** July 2018

### Model

<table>
<thead>
<tr>
<th>Model</th>
<th>(L, \chi)</th>
<th>Jets†</th>
<th>(\sqrt{s})</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADD (G_{\chi})</td>
<td>0 (e, \mu), 1 - 4</td>
<td>Yes</td>
<td>36.1</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>ADD non-resonant (\gamma\gamma)</td>
<td>2 (\gamma)</td>
<td>—</td>
<td>36.7</td>
<td>(M_{\gamma})</td>
</tr>
<tr>
<td>ADD BH high (\Sigma_{T})</td>
<td>(\geq 1) (e, \mu), (\geq 2)</td>
<td>Yes</td>
<td>3.2</td>
<td>(M_{\Sigma_{T}})</td>
</tr>
<tr>
<td>ADD BH multiplet</td>
<td>(\geq 3)</td>
<td>Yes</td>
<td>3.6</td>
<td>(M_{\Sigma_{T}})</td>
</tr>
<tr>
<td>RS1 (G_{\chi}) (\rightarrow) (\gamma\gamma)</td>
<td>2 (\gamma)</td>
<td>—</td>
<td>36.7</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>Bulk RS (G_{\chi}) (\rightarrow) (WW) / (ZZ)</td>
<td>multi-channel</td>
<td>36.1</td>
<td>(</td>
<td>G_{W})</td>
</tr>
<tr>
<td>Bulk RS (G_{\chi}) (\rightarrow) (t\bar{t})</td>
<td>1 (e, \mu), (\geq 1) (b), (\geq 1) (J/\psi)</td>
<td>Yes</td>
<td>2.3 TeV</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>2HED / RPP</td>
<td>1 (e, \mu), (\geq 2) (b), (\geq 3)</td>
<td>Yes</td>
<td>36.1</td>
<td>(M_{\chi})</td>
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### Gauge bosons

<table>
<thead>
<tr>
<th>Model</th>
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<th>Jets†</th>
<th>(\sqrt{s})</th>
<th>Limit</th>
</tr>
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<tbody>
<tr>
<td>SSM (Z') (\rightarrow) (\ell\ell)</td>
<td>2 (\ell)</td>
<td>—</td>
<td>36.1</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>SSM (Z') (\rightarrow) (\tau\tau)</td>
<td>2 (\tau)</td>
<td>—</td>
<td>36.1</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>Leptophobic (Z') (\rightarrow) (bb)</td>
<td>2 (b)</td>
<td>—</td>
<td>36.1</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>Leptophobic (Z') (\rightarrow) (\tau\tau)</td>
<td>1 (e, \mu), (\geq 1) (b), (\geq 1) (J/\psi)</td>
<td>Yes</td>
<td>3.0 TeV</td>
<td>(M_{\chi})</td>
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<tr>
<td>SSM (W') (\rightarrow) (\ell\ell)</td>
<td>1 (e, \mu)</td>
<td>—</td>
<td>79.8</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>SSM (W') (\rightarrow) (\tau\tau)</td>
<td>1 (\tau)</td>
<td>—</td>
<td>36.1</td>
<td>(M_{\chi})</td>
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<tr>
<td>HVT (W') (\rightarrow) (WW) (m_{\chi}) model</td>
<td>0 (e, \mu), (\geq 1) (b), (\geq 2)</td>
<td>Yes</td>
<td>4.1 TeV</td>
<td>(M_{\chi})</td>
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<td>HVT (Y') (\rightarrow) (WH) (2H) model</td>
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<td>36.1</td>
<td>(\sqrt{s})</td>
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<td>URSM (W') (\rightarrow) (tb)</td>
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### DM

<table>
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<th>Jets†</th>
<th>(\sqrt{s})</th>
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</thead>
<tbody>
<tr>
<td>Axial-vector mediator (Dirac DM)</td>
<td>0 (e, \mu), (\leq 1) (J/\psi)</td>
<td>Yes</td>
<td>36.1</td>
<td>(m_{\chi})</td>
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<td>Colored scalar mediator (Dirac DM)</td>
<td>0 (e, \mu), (\leq 1) (J/\psi)</td>
<td>Yes</td>
<td>3.2</td>
<td>(m_{\chi})</td>
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<td>Scalar LQ 1\textsuperscript{st} gen</td>
<td>2 (e, \mu)</td>
<td>—</td>
<td>3.2</td>
<td>(M_{\chi})</td>
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<td>Scalar LQ 2\textsuperscript{nd} gen</td>
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<td>—</td>
<td>3.2</td>
<td>(M_{\chi})</td>
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<tr>
<td>Scalar LQ 3\textsuperscript{rd} gen</td>
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<td>3.2</td>
<td>(M_{\chi})</td>
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### LQ

<table>
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<th>Jets†</th>
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<tbody>
<tr>
<td>VLO TT (\rightarrow) (H_{1}Z_{1}W_{b}+X)</td>
<td>multi-channel</td>
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<td>(\sqrt{s})</td>
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<td>VLO BB (\rightarrow) (W_{1}Z_{2}+X)</td>
<td>multi-channel</td>
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<td>(\sqrt{s})</td>
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<td>VLO TC1 (\rightarrow) (W_{1}Z_{2}+X)</td>
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<td>36.1</td>
<td>(\sqrt{s})</td>
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<td>1 (e, \mu), (\geq 1) (b), (\geq 1) (J/\psi)</td>
<td>Yes</td>
<td>3.2</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>VLO (q') (\rightarrow) (H_{b}+X)</td>
<td>0 (e, \mu), (2) (\gamma) (\geq 1) (b), (\geq 1) (J/\psi)</td>
<td>Yes</td>
<td>79.8</td>
<td>(M_{\chi})</td>
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<tr>
<td>VLO (Q_{3}) (q') (\rightarrow) (W_{b}q'q')</td>
<td>1 (e, \mu) (\geq 1) (b), (\geq 1) (J/\psi)</td>
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<td>6.6 TeV</td>
<td>(M_{\chi})</td>
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<tr>
<td>Excited quark (q') (\rightarrow) (qq)</td>
<td>2 (\gamma)</td>
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<td>36.7</td>
<td>(M_{\chi})</td>
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<tr>
<td>Excited quark (q') (\rightarrow) (qq)</td>
<td>1 (\gamma) (\leq 1)</td>
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<td>36.7</td>
<td>(M_{\chi})</td>
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<td>Excited quark (b') (\rightarrow) (bg)</td>
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<td>Yes</td>
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<td>(M_{\chi})</td>
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<td>Excited lepton (l')</td>
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<td>Excited lepton (v')</td>
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### Other

<table>
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<tr>
<td>Type II Seesaw</td>
<td>1 (e, \mu), (\geq 2)</td>
<td>Yes</td>
<td>79.8</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>URM Majarana</td>
<td>2 (e, \mu), (\geq 1)</td>
<td>—</td>
<td>20.3</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>Higgs triplet (H_{i}^{2} \rightarrow \ell\ell)</td>
<td>2,3,4 (e, \mu, \mu) (SS)</td>
<td>—</td>
<td>36.1</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>Higgs triplet (H_{i}^{2} \rightarrow \ell\ell)</td>
<td>3 (e, \mu, \tau)</td>
<td>—</td>
<td>20.3</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>Monotop (non-res prod)</td>
<td>1 (e, \mu), (\geq 1)</td>
<td>Yes</td>
<td>20.3</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>Multi-charged particles</td>
<td>—</td>
<td>—</td>
<td>20.3</td>
<td>(M_{\chi})</td>
</tr>
<tr>
<td>Magnetic monopoles</td>
<td>—</td>
<td>—</td>
<td>7.0</td>
<td>(M_{\chi})</td>
</tr>
</tbody>
</table>

### References

*Only a selection of the available mass limits on new states or phenomena is shown.
†Small-radius (large-radius) jets are denoted by the letter \(J\) (\(J\)).
New technique: boosted objects

(OK, maybe not so new anymore)

• All sorts of neat tricks

• Enables new type of searches
  • $X \rightarrow VV, VH(bb), qq$ (with ISR)
  • $H(bb)$ in SUSY cascades
  • $X \rightarrow tt$
  • High $P_T$ tops in SUSY
  • .....
Semileptonic t\bar{t} bar events – ATLAS-CONF 2013-084
CMS

35.9 fb\(^{-1}\) (13 TeV)

- Data
- W(qq)+jets (×3)
- Z(qq)+jets (×3)
- Multijet pred.
- t/\bar{t}(qq)+jets (×3)
- Z'(qq), \( g'_q = 0.17, m_{Z'} = 135 \) GeV

\( p_T \): 500-600 GeV

Data/Prediction

\[ \begin{array}{c|c|c|c|c|}
\text{m}_{SD} (\text{GeV}) & 50 & 100 & 150 & \\
\hline
\text{Data/Prediction} & 1.0 & 1.0 & 1.0 &
\end{array} \]

JHEP01(2018)097
(a) $WW + WZ$ signal region for HVT model

(b) $WW + ZZ$ signal region for bulk RS model
A new frontier: machine learning?
Dark Matter Searches

• These have become very popular as they potentially connect with the direct DM searches
• A new industry....
Simplified Models (again)

In addition to $\chi$ they introduce other new particles ($V, \phi, a, \ldots$) and interactions
DM Simplified Models (cont.)

• More ad-hoc than SUSY simplified models as they need to introduce new particles and interactions (more parameters)

• In some cases the final states are ~ same as in SUSY models, and the analysis can be ~ same (but they aren’t)
• In other cases the final states look the same but are really different.
• This is “jets + MET” a classic SUSY final state

\[
\begin{align*}
\text{vs.}
\end{align*}
\]
SUSY searches operate in the tails of MET

DM searches are in the bulk of SM MET
Requires fine control of SM prediction
CMS

Vector med, Dirac DM, $g_q = 0.25$, $g_{DM} = 1$

- Median expected 95\% CL
- $\pm 1\sigma_{\text{experiment}}$

- Observed 95\% CL
- Observed $\pm$ theory unc.

$\Omega_c h^2 \geq 0.12$

$35.9 \text{ fb}^{-1}$ (13 TeV)
Some mediators are made through quark couplings. So instead of decay to $\chi\chi$ they could decay to dijets.

**MEDIATOR SEARCHES AND DM: SPIN-1**

- By fixing couplings limits on mediators cross section translated into DM production cross section

\[ \sigma = K' \frac{g_q^2 g_{DM}^2}{M^4 \Gamma_{med}} \]

- $g_q =$ coupling to SM
- $g_{DM} =$ coupling to DM
- $M =$ mediator mass
- $\Gamma_{med} =$ mediator width
Vector mediator, Dirac DM
\[ g_q = 0.25, \ g_l = 0, \ g_{DM} = 1 \]
ATLAS limits at 95% CL, direct detection limits at 90% CL
Long Lived and other weirdness

Searches for long-lived particles at the LHC: Second workshop of the LHC LLP Community

17 Oct 2017, 16:00 → 20 Oct 2017, 18:00, Europe/Zurich
Giambiagi Lecture Hall (CTP, Trieste, Italy)
Albert De Roeck (ESRF), Bobby Samir Acharya (Abdu Salam Int. Cent. Theor. Phys. (Tri)), Brian Shuve (SLAC National Accelerator Laboratory), James Beacham (Ohio State University (US)), Xabier Cid Vidal (Universidade de Santiago de Compostela)

Building upon the groundwork laid by the LHC Long-Lived Particle (LLP) Workshop in April of 2017 – and continuing the robust and rich tradition defined by prior workshops such as "LHC Searches for Long-Lived BSM Particles: Theory Meets Experiment", at U. Mass, Amherst, in November of 2016; "Experimental Challenges for the LHC Run I", at the Kavli Institute for Theoretical Physics in May of 2016; and the "LHC Long-Lived Particles Mini-Workshop" at CERN in May of 2016 – the LHC LLP Community – composed of members of the CMS, LHCb, and ATLAS collaborations as well as theorists, phenomenologists and those interested in LLP searches with dedicated LHC detectors such as MINER, MoEDAL, and MATHUSLA – convenes again to finalize the community white paper and assess the state of LLP searches at the LHC.

This workshop is the second of two workshops devoted to producing an LHC LLP white paper that proposes a set of simplified models for LLP searches; contains an enumeration of gaps in the coverage of classes of BSM models that can produce LLPs; proposes recommendations for new triggering strategies for LLPs in ATLAS, CMS, and LHCb; lists ideas for new searches for LLPs; and proposes a set of recommendations for the presentation of search results to ensure future reinterpretation and recasting.

We will have three days of talks and breakout working sessions that will be geared toward finalizing the white paper and discussing the results produced by the working groups / chapter groups over the summer.
One example

• There is a “dark” QCD sector
• There is a TeV-scale mediator (X) that couples to dark quarks (Q) and ”our” quarks (q)
• The dark quarks make GeV-scale dark pions ($\pi_d$)
• The dark pions have long lifetimes (mm $\to$ m)
• Mediators are pair-produced, then $X \to Qq$
• Get four jets
  • Two “normal” jets
  • Two emerging jets, with many displaced tracks
    • Maybe even decaying outside tracker (MET)
CMS Preliminary

$m_{\pi_d} = 1$ GeV

- Expected limit
- Expected limit ± 1σ
- Observed limit

95% C.L. upper limit on cross section [fb]
Comments

- The search is very cool
  - Two standard jets, two weird jets
- Model not very compelling
  - But it motivated a cool search
- Why do we need (crazy) models to motivate cool searches?
- Why isn’t there a search for e.g. Z + two weird jets
  - Because there is no model?
- Sociological reality: without model search does not start
  - Also: how to make pretty colorful plots without a model?
What are we missing?

• What are we missing in the trigger?

• What are we missing by not looking?
This huge signal had been in various data sets for many years.

- Nobody had ever looked
- Why?
This huge signal had been in various data sets for many years.
- Nobody had ever looked
- Why?

Don’t believe theorists too much!
Trigger issues

• New clever triggers are being developed all the time
  • Very important

• Even more possibilities at HL-LHC
  • Track triggers, etc

• Fundamentally we are limited by 1-2 kHz output rate

• A colleague suggested that in Run 3 we should prescale by (say) factor 2 the “standard” triggers on which the high $P_T$ searches have been based. Give the bandwidth to other stuff
  • Just a bit crazy?
Delayed reco. & Real Time Analysis

- The ~ 1 kHz limit is not determined by DAQ hardware but by rate at which data can be reconstructed
- Read out more data that can be processed and set some of it aside for later reconstruction
  - Lower priority analyses
  - Data Parking, Delayed Stream
- Reasonably straightforward
  - In some cases move much of the analysis to HLT
- Write out data in reduced format (smaller events)
  - Scouting, Trigger Level Object Analysis
- Challenges with calibrations, etc.
  - Demonstrated
  - Dijet mass searches
Communicating results

• Important to communicate results of searches so that they can be re-used to challenge new models or ideas
  ➔ Make it possible for outsiders to reinterpret results

• Seems obvious, but
  • A bit controversial inside experiments at the beginning of LHC
  • Confusion with many tools/approaches on the market
Some people never liked the emphasis on models.....

**Return to Rationale(s)**

1. Have a robust and predictive hypothesis to test- the Standard Model- testing it is classic science.

2. Emphasis should be on understanding **and improving** the detector performance on SM predictions- time spent elsewhere is very costly (**zero sum game for time and $**)

3. Exptl papers dependent on a model do not age well- 20 years later one could use the data, but the comparisons with models are junk, and diminish the paper (**e.g Trion-ProtoDynamics**)

4. Particle theorists do it better- experimentalists should concentrate on communicating results to them and working together

5. Students learn the wrong lessons from poorly-motivated limit setting- complacency on $,time

Frisch, Pheno09
Simplified likelihood for the re-interpretation of public CMS results

**CMS SUSY Results: Objects Efficiency**

- Light Leptons Selection Efficiency
- Hadronic Tau identification efficiency
- B-tagging Efficiency
- Photon Selection Efficiency

**Moriond 2017**

In the following the representative object selection efficiencies for the SUSY 2016 analyses presented at Moriond2017 are reported.
Digging Deeper for New Physics in the LHC Data

Pouya Asadi, Matthew R. Buckley, Anthony DiFranzo,
Angelo Monteux and David Shih

NHETC, Dept. of Physics and Astronomy
Rutgers, The State University of NJ
Piscataway, NJ 08854 USA

Abstract

In this paper, we describe a novel, model-independent technique of “rectangular aggregations” for mining the LHC data for hints of new physics. A typical (CMS) search now has hundreds of signal regions, which can obscure potentially interesting anomalies. Applying our technique to the two CMS jets+MET SUSY searches, we identify a set of previously overlooked $\sim 3\sigma$ excesses. Among these, four excesses survive tests of inter- and intra-search compatibility, and two are especially interesting: they are largely overlapping between the jets+MET searches and are characterized by low jet multiplicity, zero $b$-jets, and low MET and $H_T$. We find that resonant color-triplet production decaying to a quark plus an invisible particle provides an excellent fit to these two excesses and all other data – including the ATLAS jets+MET search, which actually sees a correlated excess. We discuss the additional constraints coming from dijet resonance searches, monojet searches and pair production. Based on these results, we believe the wide-spread view that the LHC data contains no interesting excesses is greatly exaggerated.
The future?
Predicting the future is hard

“In 50 years, every street in London will be buried under nine feet of manure.”

Times of London, 1894

The great horse manure crisis of 1894
Run 1  Run 2  Run 3  High Luminosity LHC
Future of Searches

• Only ~ ¼ of the Run 2 dataset has been analyzed
• “Standard” searches will be updated with full Run 2 data and then Run 3
  • Limits will improve somewhat, discovery unlikely
• Clever ideas, new searches to be developed
  • Unexplored corners of phase space
  • New (crazy?) signatures
  • Need your creativity!
• HL-LHC will push out further
• Projections are being developed
  • Don’t take them too seriously, qualitatively ~ OK
  • Experience is that we (mostly) do better than projections
    • People get smarter when they get their hands on the data
Prediction power of the common sense: \( \tilde{t} \) example

extrapolation with \( \approx 0 \) background in the highest mass excluded point works very well

L. Shutska, Moriond 17
Region of ~ 0 BG...Here things improve
“Compressed” region with lots of BG. Here things don’t change much. Probably pessimistic.
Note that the 300 fb$^{-1}$ exclusion on paper precludes the 5$\sigma$ discovery....
Conclusions

• The LHC has been working very well, and has given us a wonderful gift: the Higgs boson

• But Nature is toying with us
  • The conventional wisdom on NP at the TeV scale has failed
Theorists are confused

The trouble is that it’s not clear when to give up on supersymmetry. True, as more data arrives from the LHC with no sign of superpartners, the heavier they would have to be if they existed, and the less they solve the problem. But there’s no obvious point at which one says ‘ah well, that’s it – now supersymmetry is dead’. Everyone has their own biased point in time at which they stop believing, at least enough to stop working on it. The LHC is still going and there’s still plenty of effort going into the search for superpartners, but many of my colleagues have moved on to new research topics. For the first 20 years of my scientific career, I cut my teeth on figuring out ways to detect the presence of superpartners in LHC data. Now I’ve all but dropped it as a research topic.

Ben Allanach, Cambridge
Conclusions

• The LHC has been working very well, and has given us a wonderful gift: the Higgs boson

• But Nature is toying with us
  • The conventional wisdom on NP at the TeV scale has failed

• We do not have a lot of theoretical guidance
  • But we know that the SM is not the end of the story
When I began my physical studies [in Munich in 1874] and sought advice from my venerable teacher Philipp von Jolly...he portrayed to me physics as a highly developed, almost fully matured science...Possibly in one or another nook there would perhaps be a dust particle or a small bubble to be examined and classified, but the system as a whole stood there fairly secured, and theoretical physics approached visibly that degree of perfection which, for example, geometry has had already for centuries.

Max Planck
Conclusions

• The LHC has been working very well. It has given us a wonderful gift: the Higgs boson

• But Nature is toying with us
  • The conventional wisdom on NP at the TeV scale has failed

• We do not have a lot of theoretical guidance
  • But we know that the SM is not the end of the story

• As experimentalists we’ll keep looking