Topological Approach to New physics

Myeonghun Park
with P. Konar, K. T. Matchev and G. K. Sarangi

1. How to look for supersymmetry under the lamppost at the LHC.
   with P. Konar, K. T. Matchev, G. K. Sarangi,
2. Follow up paper with P. Konar, K. T. Matchev, G. K. Sarangi

SUSY Recast 2011
University of California Davis
Different view of Searches

• Problem: Every model has (large) parameter space.
  - Especially MSSM: lots of particles

• (Mass) Parameter space: each mass from 0 to $\infty$

<table>
<thead>
<tr>
<th>Mass spectrum of particles $R^n$</th>
<th>Hierarchical ordering of the particles $S_n$</th>
<th>Qualitative (finite)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass splitting</td>
<td>$R^n / S_n$</td>
<td>Quantitative (infinite)</td>
</tr>
</tbody>
</table>

• We focused on the finite structure of the parameter space. This approach enables us to cover all possible scenarios.
Topological approach

- Model with 9 particles motivated by Supersymmetry
  - We ignore the mass splitting within a multiplet.

<table>
<thead>
<tr>
<th>$\tilde{u}_L, \tilde{d}_L$</th>
<th>$\tilde{u}_R$</th>
<th>$\tilde{d}_R$</th>
<th>$\tilde{e}_L, \tilde{\nu}_L$</th>
<th>$\tilde{e}_R$</th>
<th>$\tilde{h}^\pm, \tilde{h}_u^0, \tilde{h}_d^0$</th>
<th>$\tilde{b}^0$</th>
<th>$\tilde{\omega}^\pm, \tilde{\omega}^0$</th>
<th>$\tilde{g}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q$</td>
<td>$U$</td>
<td>$D$</td>
<td>$L$</td>
<td>$E$</td>
<td>$H$</td>
<td>$B$</td>
<td>$W$</td>
<td>$G$</td>
</tr>
<tr>
<td>$M_Q$</td>
<td>$M_U$</td>
<td>$M_D$</td>
<td>$M_L$</td>
<td>$M_E$</td>
<td>$M_H$</td>
<td>$M_B$</td>
<td>$M_W$</td>
<td>$M_G$</td>
</tr>
</tbody>
</table>

- There are $9! = 362,880$ possible permutations.
Analyzing hierarchies

• First: who is the **LSP** (lightest stable particle)
  – CHAMP ($8! = 40,320$) if LSP=E
  – R-hadron ($4 	imes 8! = 161,280$) if LSP=G, Q, U or D
  – Missing energy ($4 	imes 8! = 161,280$) if LSP=L, H, W or B

• Second: who is the **LCP** (lightest colored particle): G, Q, U, or D
  – most abundantly produced at hadron colliders

• Total number of distinct hierarchies, starting from LCP
  \((x_1 x_2 x_3 c y_1 y_2 y_3 y_4 L)\) Possible cases = **1,040**.

• For a given hierarchy, how does the LCP decay into LSP?
How do particles decay into each other?
- Dominant decay: ________ unsuppressed two body decay
- Mild suppression: " " suppression by multibody phase space
  suppression from mixing angle
- Strong suppression: " "

What are the standard model decay products? Jet, lepton, W/Z/h

SUSY-like framework

Suppression

- none
- mild
- strong

Decay product

jet

lepton

W±/Z/h
Traveling Salesman

- Example:
  \[ G \succ U \succ D \succ E \succ Q \succ W \succ B \succ L \succ H \]
  - start from Q
  - go to H
  - in all possible ways

- Then ask: what is the best way?
Traveling Salesman

Example:
G>U>D>E>Q>W>B>L>H

1) Q→W→L→H

Suppression

----- none
- - - - mild
--------- strong

Decay product
jet
lepton
W±/Z/h
Traveling Salesman

- Example:
  
  G→U→D→E→Q→W→B→L→H
  
  1) Q→W→L→H
  2) Q→W→H

Start → Q → W → H → B → End

Suppression
- none
- mild
- strong

Decay product
- jet
- lepton
- W+/Z/h
Traveling Salesman

• Example:
  \[ G > U > D > E > Q > W > B > L > H \]

1) \[ Q \rightarrow W \rightarrow L \rightarrow H \]
2) \[ Q \rightarrow W \rightarrow H \]
3) \[ Q \rightarrow B \rightarrow L \rightarrow H \]
Traveling Salesman

- Example:
  \[ G \rightarrow U \rightarrow D \rightarrow E \rightarrow Q \rightarrow W \rightarrow B \rightarrow L \rightarrow H \]
  1) \( Q \rightarrow W \rightarrow L \rightarrow H \)
  2) \( Q \rightarrow W \rightarrow H \)
  3) \( Q \rightarrow B \rightarrow L \rightarrow H \)
  4) \( Q \rightarrow B \rightarrow H \)

- This given hierarchy has two equally dominant decay modes,
  1. One jet + Two leptons
  2. One jet + One Vector boson

Suppression

- none
- mild
- strong

Decay product

- jet
- lepton
- \( W^\pm / Z / h \)
Checking all possibilities

- 1,040 theory model hierarchies from LCP to LSP
- Within our SUSY-like framework, there are 26 experimental channels (LCP decay modes)
- Obviously the inverse map will not be unique (?)

<table>
<thead>
<tr>
<th>Hierarchies</th>
<th>Channels of the LCP decay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C₁</td>
</tr>
<tr>
<td>H₁</td>
<td>V</td>
</tr>
<tr>
<td>H₂</td>
<td>V</td>
</tr>
<tr>
<td>H₃</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>H_{1040}</td>
<td>V</td>
</tr>
<tr>
<td>Allowed theory Models</td>
<td>C₁</td>
</tr>
<tr>
<td>----------------------</td>
<td>----</td>
</tr>
<tr>
<td>H₁</td>
<td>V</td>
</tr>
<tr>
<td>H₂</td>
<td>V</td>
</tr>
<tr>
<td>H₃</td>
<td></td>
</tr>
<tr>
<td>H₄</td>
<td>V</td>
</tr>
<tr>
<td>H₅</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>H₁₀₃₇</td>
<td>V</td>
</tr>
<tr>
<td>H₁₀₃₈</td>
<td></td>
</tr>
<tr>
<td>H₁₀₃₉</td>
<td></td>
</tr>
<tr>
<td>H₁₀₄₀</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>C₁</td>
</tr>
<tr>
<td>------</td>
<td>----</td>
</tr>
<tr>
<td><strong>H₁</strong></td>
<td>V</td>
</tr>
<tr>
<td><strong>H₂</strong></td>
<td>V</td>
</tr>
<tr>
<td><strong>H₃</strong></td>
<td></td>
</tr>
<tr>
<td><strong>H₄</strong></td>
<td>V</td>
</tr>
<tr>
<td><strong>H₅</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V</td>
</tr>
<tr>
<td><strong>H₁₀³₇</strong></td>
<td>V</td>
</tr>
<tr>
<td><strong>H₁₀³₈</strong></td>
<td></td>
</tr>
<tr>
<td><strong>H₁₀³⁹</strong></td>
<td>V</td>
</tr>
<tr>
<td><strong>H₁₀⁴₀</strong></td>
<td>V</td>
</tr>
</tbody>
</table>

**Allowed theory Models**

**LHC experiments (ATLAS / CMS)**
The LHC inverse problem

- This procedure is very generic and covers all possibilities in a model-independent way.
- We form groups of hierarchies which share the same set of channels.
  - We find 64 groups.
- Any group may contain one or many hierarchies.
  (As many as 167)
- The size of a group characterizes the uniqueness of inverse mapping.
  - Large group has more ambiguities.
  - Small group is more unique.
More details

• A group of \((H_2, H_{1040})\) has 3 channels.
  - The maximum of leptons in this group: 4
  - The number of channels in this group: 3
Solution of inverse problem

Number of hierarchies which share same set of channels

Unique solution

Maximum number of leptons in a given group

0 leptons
2 leptons
4 leptons
6 leptons
8 leptons
Solution of inverse problem

Number of hierarchies which share same set of channels

Number of groups

1 channel
2 channels
3 channels
4 channels
5 channels
Let's take an example.

Triplet solution with 4 channels.
Example of triplet

G > B > E > H > W
G > B > L > E > H > W
G > L > B > E > H > W

(leptons, W/Z/H, jets)
(2, 1, 2)
(2, 0, 2)
(0, 2, 2)
(0, 0, 2)

GBEHW
GBLEHW
GLBEHW
Example: Two leptons + (# jets) channels

<table>
<thead>
<tr>
<th>Hierarchy</th>
<th>≤ 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>93 HIERARCHIES</td>
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</table>

<table>
<thead>
<tr>
<th>Hierarchy</th>
<th>= 2</th>
</tr>
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<tbody>
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<td>21 HIERARCHIES</td>
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</table>

<table>
<thead>
<tr>
<th>Hierarchy</th>
<th>= 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 HIERARCHIES</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hierarchy</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>18 HIERARCHIES</td>
<td></td>
</tr>
</tbody>
</table>

- Length of hierarchy: number of particles from LCP to LSP
- Starting with G

6 HIERARCHIES

(G,L), (Q,L), (U/D, L)
Conclusion

• By focusing on the finite structure of parameter space, we can cover all possible scenarios.

• We found the inverse map from the signature space to the theory space.
  - We identify the unique solutions.
  - We identify duplicated solutions.

• We provide the relevant topologies to the “simplified model approach” systematically.
Thank you! / BACK UP

Real GATOR passing by a road next to our physics department in UF. This photo was taken by Michael Burns in 2008.
Checking all possibilities

- By focusing on finite structure of parameter space, we can cover all possible scenario.

<table>
<thead>
<tr>
<th>$n_\ell$</th>
<th>$n_j = 1$</th>
<th>$n_j = 2$</th>
<th>$n_j = 1$</th>
<th>$n_j = 2$</th>
<th>$n_j = 1$</th>
<th>$n_j = 2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_v = 0$</td>
<td>79296</td>
<td>26880</td>
<td>12768</td>
<td>3360</td>
<td>1344</td>
<td>672</td>
</tr>
<tr>
<td>1</td>
<td>30240</td>
<td>10080</td>
<td>1824</td>
<td>480</td>
<td>192</td>
<td>96</td>
</tr>
<tr>
<td>2</td>
<td>19770</td>
<td>6030</td>
<td>1500</td>
<td>180</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>4656</td>
<td>1296</td>
<td>312</td>
<td>72</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>1656</td>
<td>396</td>
<td>66</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Relations for transitions

No suppression

a) 2-body decays, no MAS

b) 2-body decays, with MAS

c) 3-body decays, no MAS

Strong suppression

d) 3-body decays, with MAS

e) 4-body decays, no MAS

Summary

Suppression
- none
- mild
- strong

Decay product
- jet
- lepton
- $W^{\pm}/Z/h$
Rate of LCP production

- In MSSM with gaugino unification by fixing $(M_B, M_W, M_G) \sim (100, 200, 400) \text{ GeV}$
A group of length 167

This group corresponds to two jets channel.
Solution of inverse problem

- Inclusive search (disregard number of jets, only consider leptons and vector-bosons)
Solution of inverse problem

- Inclusive search (disregard number of jets. only consider leptons and vector-bosons)

In this histogram, we treat U/D are the same. Thus, there are 8 generic particles.