

Looking for supersymmetry under the lamppost at the LHC

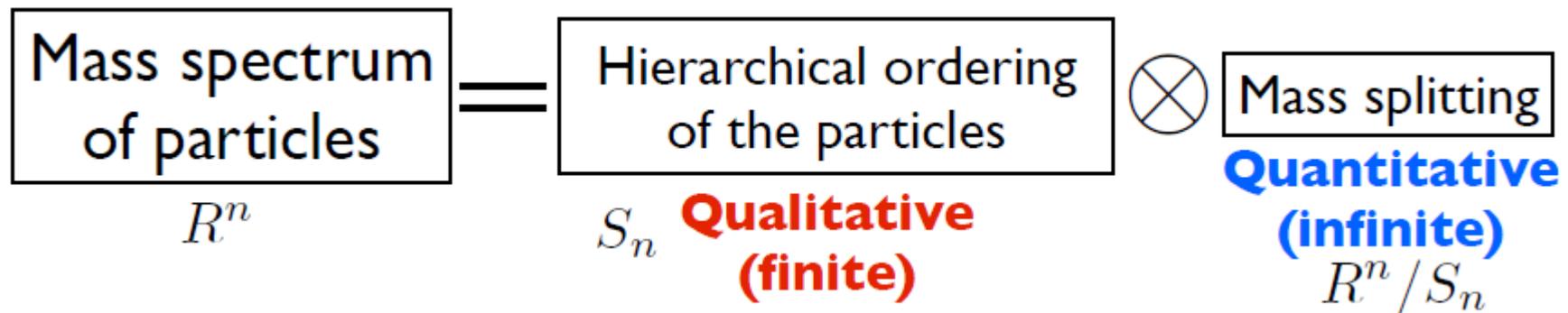
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Tackling the parameter space

- The parameter space is huge.
19 parameters in PMSSM .
- Each mass can vary from 0 to ∞ .



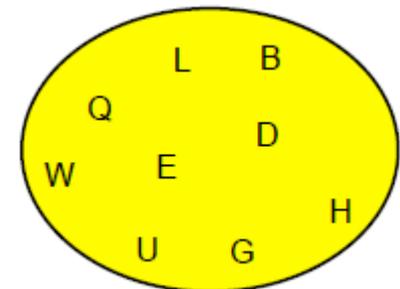
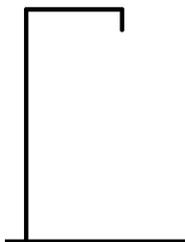
- The **qualitative component** governs the nature of the signature (number of jets, leptons and vector bosons) and the **quantitative component** governs the number of events with that signature.
- We focused on the qualitative (finite) aspect of the parameter space, thus covering all the possible types of signatures.

A closer look at the parameter space we chose

- For simplicity we considered 9 mass parameters (discounting $\tan\beta$, the trilinear couplings, mass of the pseudo-scalar Higgs boson and the 3rd generation sfermion masses).

\tilde{u}_L, \tilde{d}_L	\tilde{u}_R	\tilde{d}_R	$\tilde{e}_L, \tilde{\nu}_L$	\tilde{e}_R	$\tilde{h}^\pm, \tilde{h}_u^0, \tilde{h}_d^0$	\tilde{b}^0	$\tilde{w}^\pm, \tilde{w}^0$	\tilde{g}
Q	U	D	L	E	H	B	W	G
M_Q	M_U	M_D	M_L	M_E	M_H	M_B	M_W	M_G

- Thus there are $9! = 362, 880$ permutations. So, time to start playing hangman.



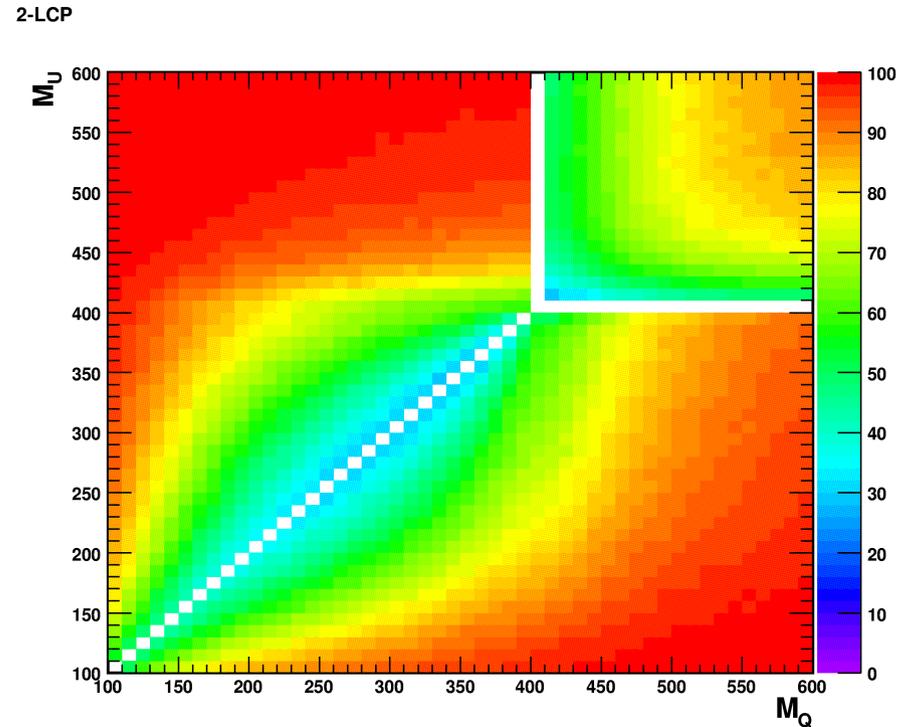
Breaking up the 9! permutations into categories

- Identify the **LSP** (lightest SUSY particle)
 - Charged: **LSP** = {E}, $8! = 40,320$ hierarchies
 - Colored: **LSP** = {G,Q,U,D}, $4 \times 8! = 161,280$ hierarchies
 - Neutral: **LSP** = {L,H,W,B}, $4 \times 8! = 161,280$ hierarchies
- Identify the **LCP** (lightest colored (SUSY) particle), which will be the most abundantly produced SUSY particle at the LHC.
 - G, Q, U or D.
- Identify the particles who live in between (i.e. with masses less than that of the **LCP** and greater than that of the **LSP**).

e.g. in $(x_1 x_2 x_3 \mathbf{C} y_1 y_2 y_3 y_4 \mathbf{L})$, **C** is the **LCP**, **L** is the **LSP** and $y_1 y_2 y_3 y_4$ are the particles who live in between.
- Each of the unique chain starting with a given **C**, we call a “**hierarchy**” and we have 1,040 of such cases.
- Then we ask, “Which is the most optimistic cascade channel for the **LCP** to decay into the **LSP**?”

Percentage of LCP production at the LHC

- We made the assumption that of all the SUSY particles the **LCP** is the most copiously produced one at the LHC.
- The plot here illustrates this point.
- The masses of the left handed and right handed squarks are on the x and y-axis respectively while the mass of the gluino is fixed at 400 GeV.
- On the z-axis (color coded) we have plotted the ratio of the cross-section of production of 2 LCP to the total SUSY cross-section in percentage.



Example of hierarchies

A hierarchy can have one or more different kinds of signatures.

- Example of a hierarchy with 1 signature:

$D > U > W > B > H > E > Q > G > L$: G is the LCP and L is the LSP with no sparticle with mass in between.

Thus, this mass ordering belongs to the hierarchy xxxxxxxGL, where G is most copiously produced SUSY particle at the LHC and it can only decay to L, giving 2 jets and 1 lepton.

Hence, the only signature is $(1, 0, 2) (l, v, j)$

Example of hierarchies

- Next, an example of hierarchy with more than one signature.
 $D > U > G > Q > W > L > B > E > H$: Here, Q is the LCP and H is the LSP. This, mass ordering belongs to the hierarchy xxxQWLBEH
 - ✓ Q is the most copiously produced sparticle at the LHC.
 - ✓ Q can decay into W and B with *similar* suppression.
 - ✓ W can decay into L and H with *similar* suppression.
 - ✓ B can decay into E and H with *similar* suppression.
 - ✓ The L/E produced above will have similar choices for further decays, finally giving us the following decay chains:
 1. $Q \rightarrow W \rightarrow L \rightarrow B \rightarrow E \rightarrow H$ with signature (4, 0, 1)
 2. $Q \rightarrow W \rightarrow H$ with signature (0, 1, 1)
 3. $Q \rightarrow B \rightarrow E \rightarrow H$ with signature (2, 0, 1)
 4. $Q \rightarrow B \rightarrow H$ with signature (0, 1, 1)
- Thus, we have 3 different kinds of signature for this hierarchy.

Signature summary for all the hierarchies

TABLE III: Number of hierarchies for the *maximally leptonic* decay modes of the LCP \mathcal{C} .

n_ℓ	$n_\nu = 0$		$n_\nu = 1$		$n_\nu = 2$	
	$n_j = 1$	$n_j = 2$	$n_j = 1$	$n_j = 2$	$n_j = 1$	$n_j = 2$
0	61488	21168	8310	2550	780	420
1	24150	8310	1278	378	132	72
2	17190	5550	1230	150	0	0
3	4362	1242	312	72	6	6
4	1656	396	66	6	0	0

Hierarchy example:

xxxxxxxGL



Hierarchy example:

xxxQWLBEH



Maximally leptonic
signature

Other
signatures

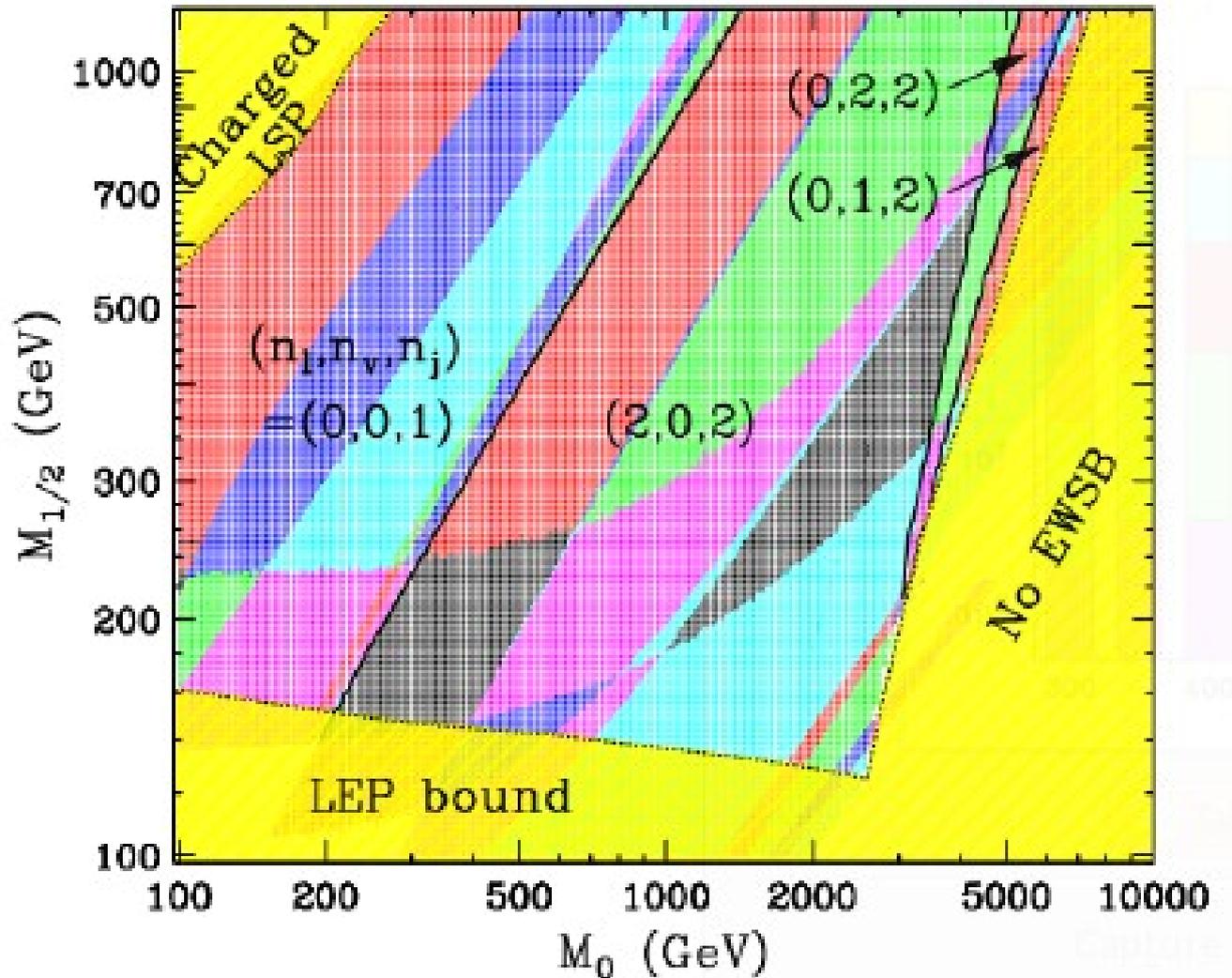
TABLE II: Number of hierarchies for the various dominant decay modes of the LCP \mathcal{C} .

n_ℓ	$n_\nu = 0$		$n_\nu = 1$		$n_\nu = 2$	
	$n_j = 1$	$n_j = 2$	$n_j = 1$	$n_j = 2$	$n_j = 1$	$n_j = 2$
0	79296	26880	12768	3360	1344	672
1	30240	10080	1824	480	192	96
2	19770	6030	1500	180	0	0
3	4656	1296	312	72	6	6
4	1656	396	66	6	0	0

We explore the case of the second hierarchy example with detailed analysis, with the exact hierarchy of

D>U>G>W>L>B>E>H>

mSUGRA parameter space



- Although in mSUGRA many hierarchies are possible (47 in the allowed region to be exact), we only see 4 different kind of signature.
- **Disclaimer:** We have manually set the 3rd generation sfermions to be heavy and when included they may give us more types of signatures

Analysis of the hierarchy: DUG_QWLBEH

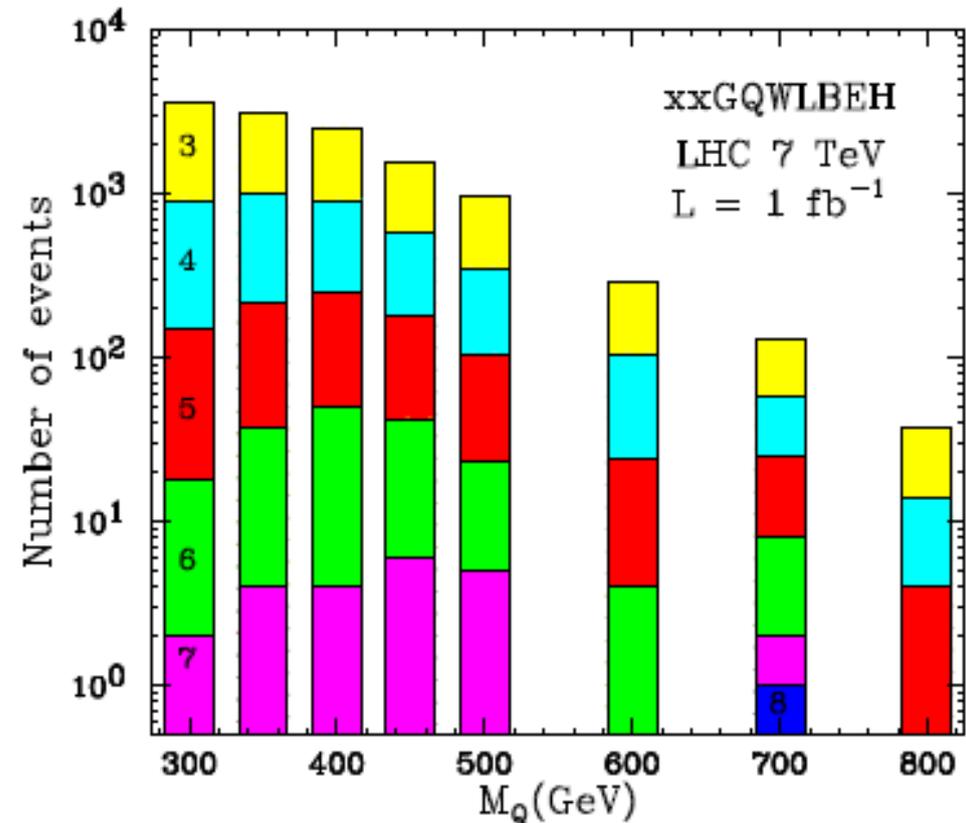
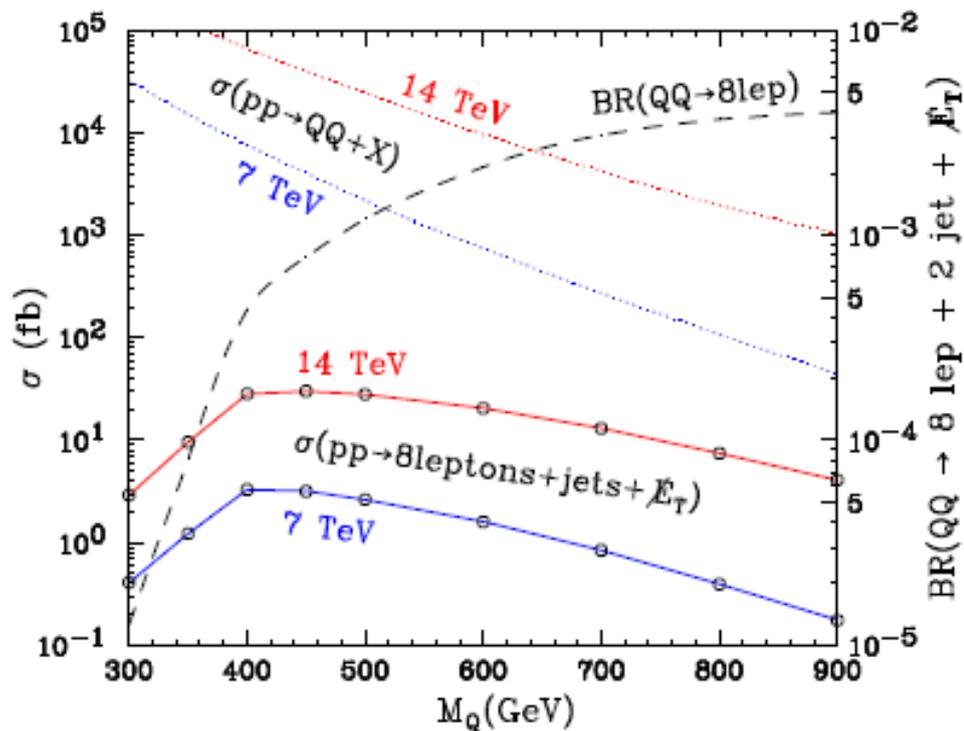
In this example, **8 leptons** in total are produced if two Q's are produced at the LHC which decay via their maximally leptonic cascade decays producing 4 leptons each.

- Thus, the signature is $(8l, 0\nu, 2j)$.
- Once, we fix the hierarchy, the nature of the maximally leptonic signature is fixed.
- Next, we scan the parameter space within this hierarchy to find the mass spectrum of the relevant particles that gives us maximum number of events with such signature.

Soft SUSY mass parameters (in GeV) for DUGQWLBEH

M_G	M_Q	M_W	M_L	M_B	M_E	M_H
400	300	220	190	130	130	130
450	350	280	190	120	120	120
500	400	280	190	120	120	120
550	450	310	200	120	120	120
600	500	350	210	130	120	120
700	600	420	230	150	130	120
800	700	480	250	160	130	120
900	800	500	250	170	130	120
1000	900	510	250	170	130	120

- In this table, we list the soft masses which are optimized (row-wise) to give the maximum branching ratio for the 8 lepton production.
- We use Pythia and PGS to simulate event generation.



Summary and Outlook

- LHC can already start probing SUSY, provided one looks in the right place.
- For this, it's imperative to search for the model hierarchies that are most likely to be discovered first.

In future work we are going to:

- Incorporate the 3rd generation sfermions.
- List all the hierarchies with their respective signatures (maximally leptonic as well as other equally suppressed ones).
- Do analysis for other 8-lepton yielding hierarchies.
- Group all signatures for hierarchies into sets of signature in an attempt to solve the LHC inverse problem.

Back up slide 1: Travelling Salesman

