Looking for SUSY under the lamppost (with 8-12 lepton events)

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With: P. Konar, K. Matchev, G. Sarangi

arXiv:1008.2483 [hep-ph]

Workshop on Topologies for Early LHC Searches
SLAC National Accelerator Laboratory

Looking for SUSY

- Minimal SUSY (MSSM) has O(100) parameters.
- We can study benchmark points in SUSY models with fewer parameters, for example MSUGRA, GMSB...
  - Benchmark approach is too restrictive.
  - What are we missing ?
- Consider more general models.
  - e.g. pMSSM with 19 parameters relevant for collider phenomenology, scan parameter space.

Conley, Gainer, Hewett, Le, Rizzo, 2010

- We are focusing on a different approach.
  - The qualitative features of the spectrum as defined by the mass ordering of the superpartners.

Different view of Searches

Quantitative Searches

Benchmark points / Scanned parameters

↓

30^9 = 19,683,000,000,000

100 GeV - 3TeV by ΔM= 100GeV = 30 points

Mass spectrum of sparticles

↓

Distributions of kinematic variables

Qualitative Searches

Hierarchical ordering of the sparticles

↓

9! = 362,880

Number/Type of visible particles

Our goal

- The parameter scanning is infinite but the total number of all hierarchical orderings (permutation) is finite and we exhaust all possibilities. Thus it would be good to study all permutations first.

$\tilde{u}_L, \tilde{d}_L$	$\tilde{u}_R$	$\tilde{d}_R$	$\tilde{e}_L, \tilde{\nu}_L$	$\tilde{e}_R$	$\tilde{h}^{\pm}, \tilde{h}^0_u, \tilde{h}^0_d$	$\tilde{b}^0$	$\tilde{w}^{\pm}, \tilde{w}^0$	$\tilde{g}$
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

- Our question: What is the list of all possible signatures for SUSY and what are the corresponding mass hierarchies for each signature ?

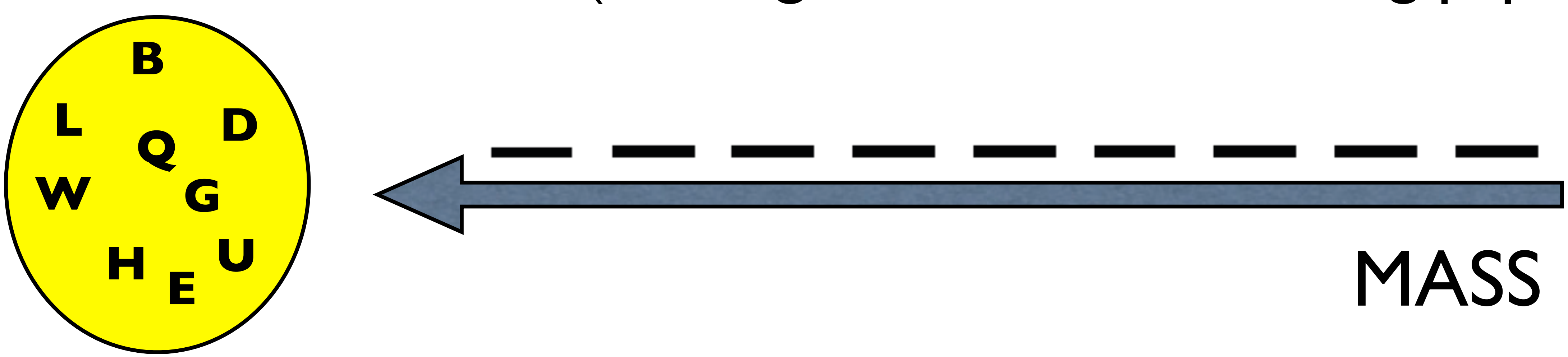
Hierarchical ordering of the SUSY particles

- Mass terms in SUSY

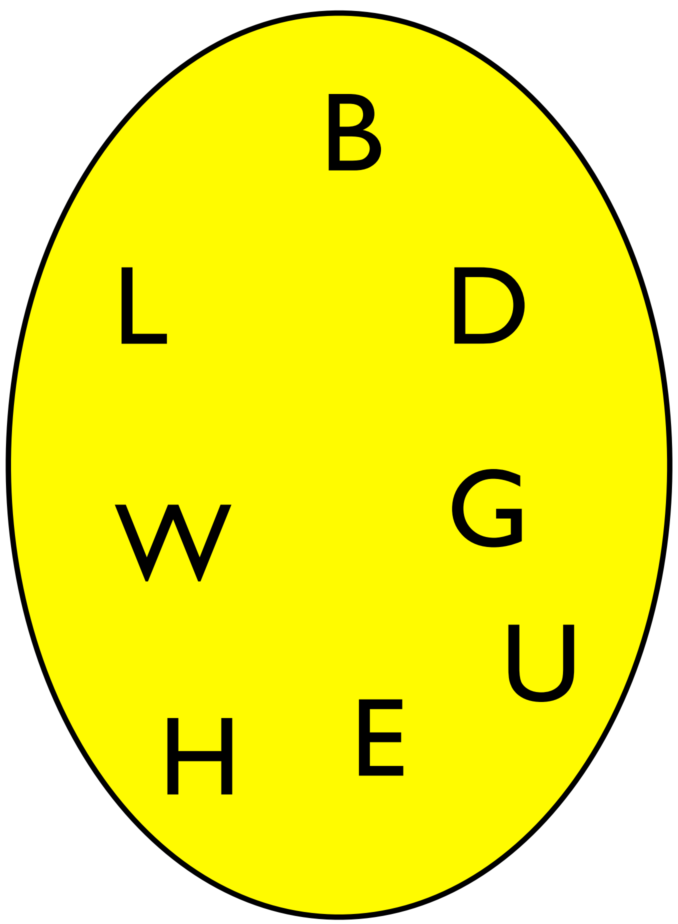
$\tilde{u}_L,\, \tilde{d}_L$	$\tilde{u}_R$	$\tilde{d}_R$	$\tilde{e}_L,\, \tilde{\nu}_L$	$\tilde{e}_R$	$\tilde{h}^{\pm},\, \tilde{h}^0_u,\, \tilde{h}^0_d$	$\tilde{b}^0$	$\tilde{w}^{\pm}, \tilde{w}^0$	$\tilde{g}$
Q	U	D	L	E	H	B	W	G
M_Q	M_U	M_D	M_L	M_E	M_H	M_B	M_W	M_G

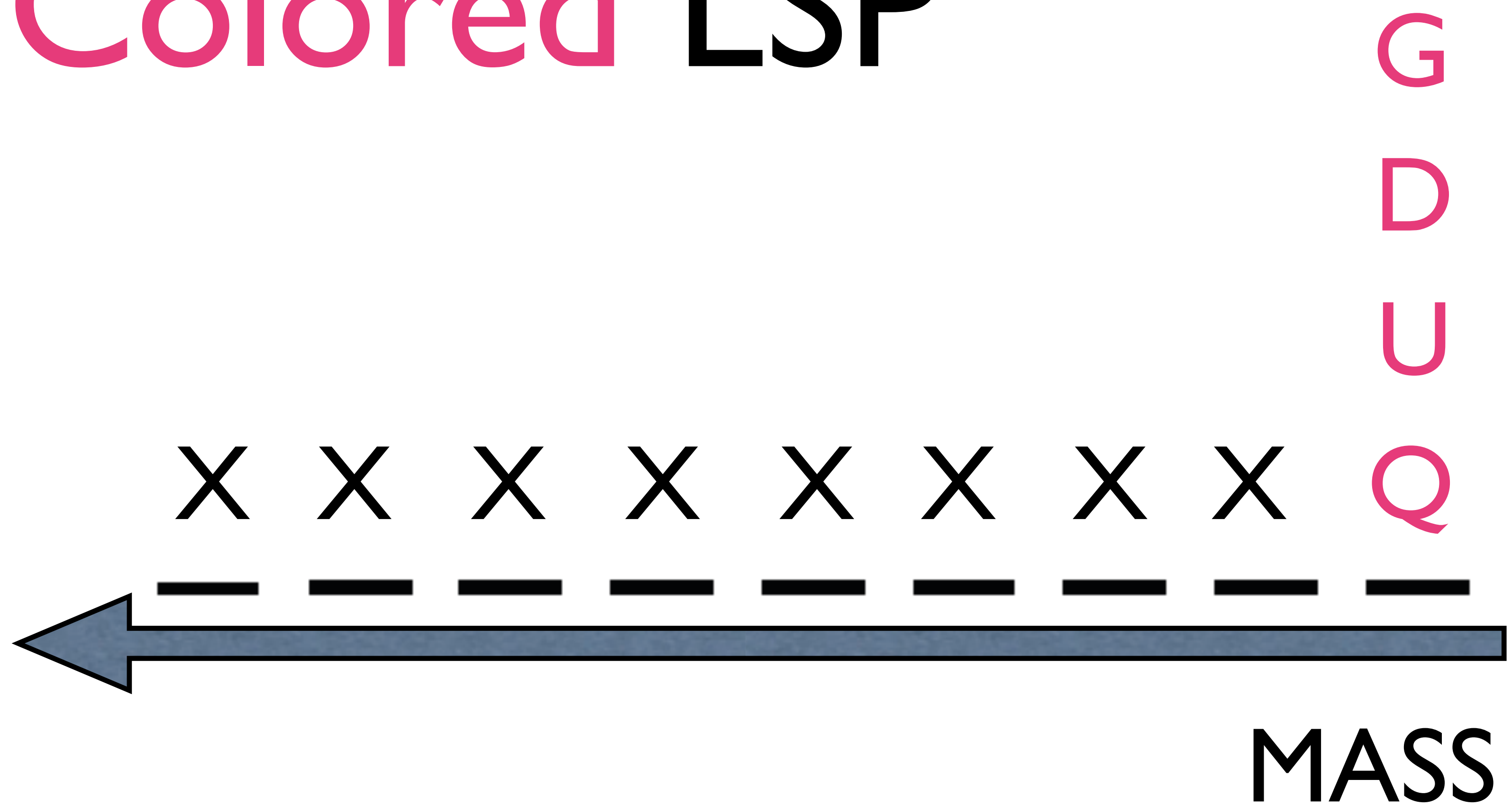
- We consider all possible orderings of susy mass terms at the electroweak scale.

- We have nine parameters and total possibilities are 9! = 362,880 cases. (Third generation left for long paper.)



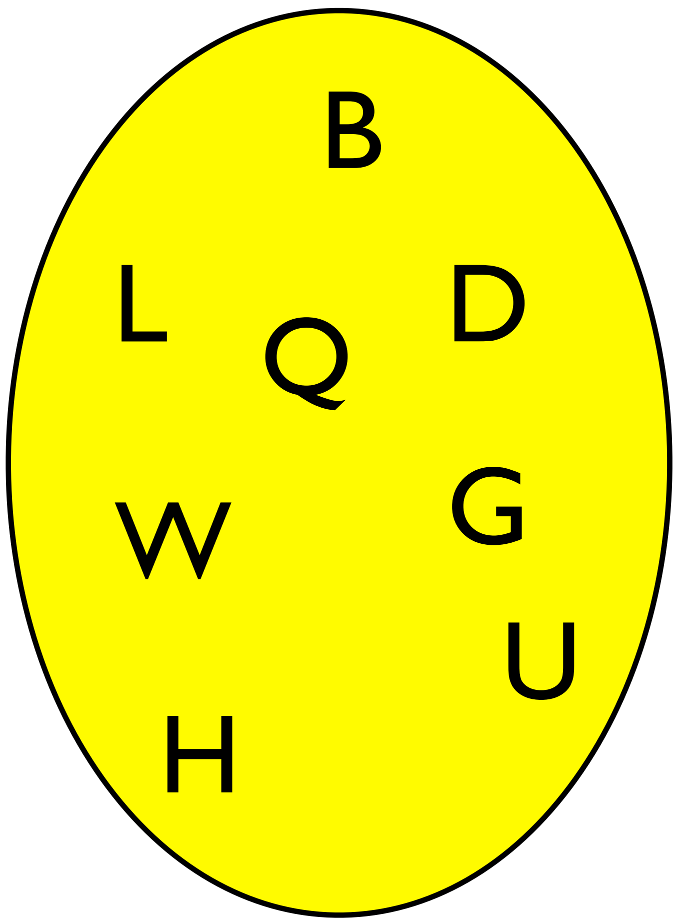
Colored LSP

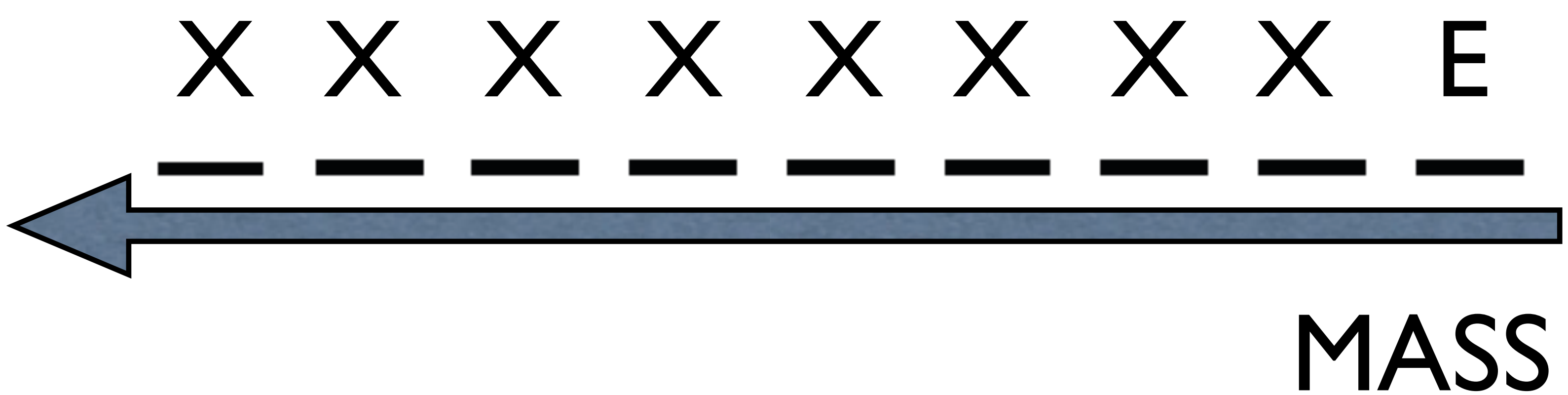




Number of hierarchies : 4x8! = 161,280
(candidate for colored LSP : Q,U,D,G)

Charged LSP





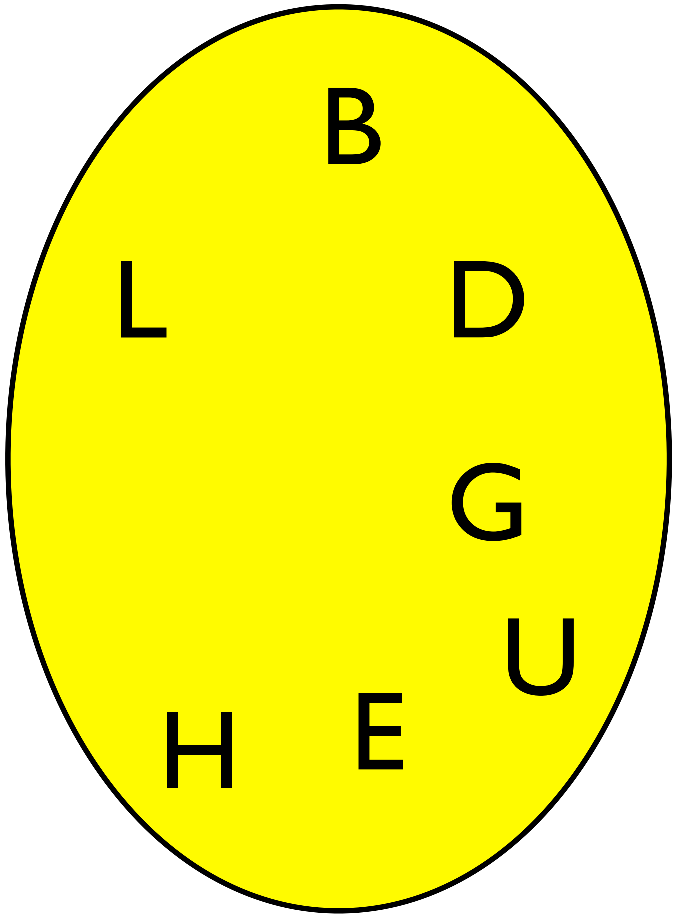
Number of hierarchies : 8! = 40,320
(candidate for charged LSP : E)

Neutral LSP (Missing energy)

L
H
B

X X X X X X X Q W

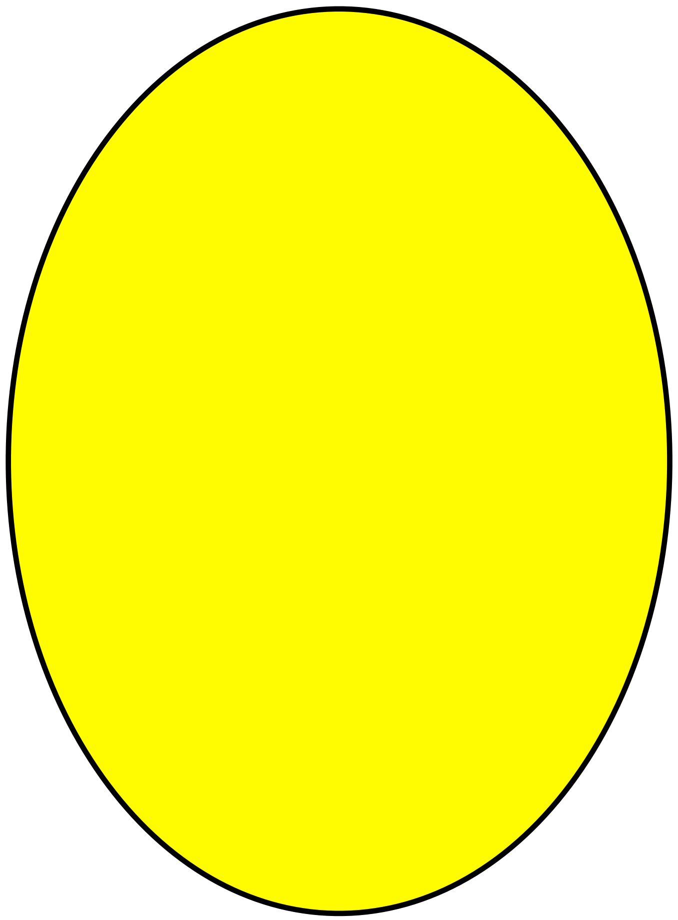
MASS 4x8! = 161,280

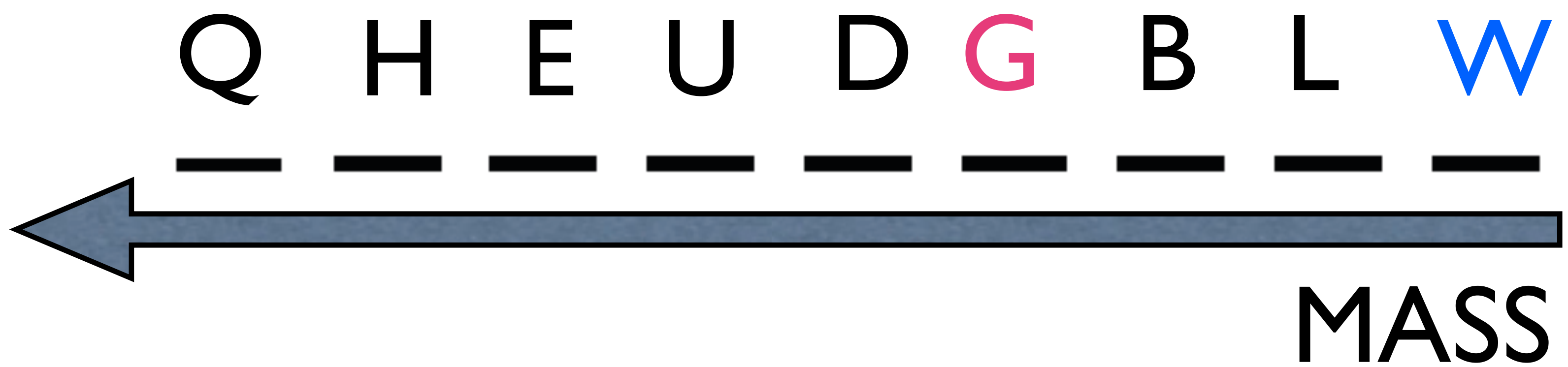


- Lightest Colored Particle (**LCP**)
  - Most abundantly produced at hadron collider

Decay Mode	Signals			Suppression
	lep	vec	jet	
Q→W	0	0	1	None

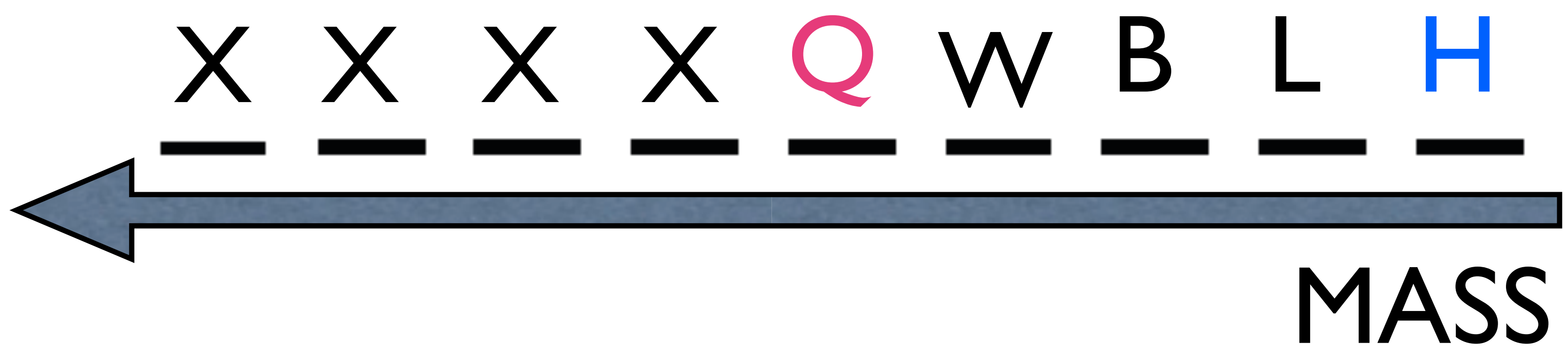
Neutral LSP: Examples

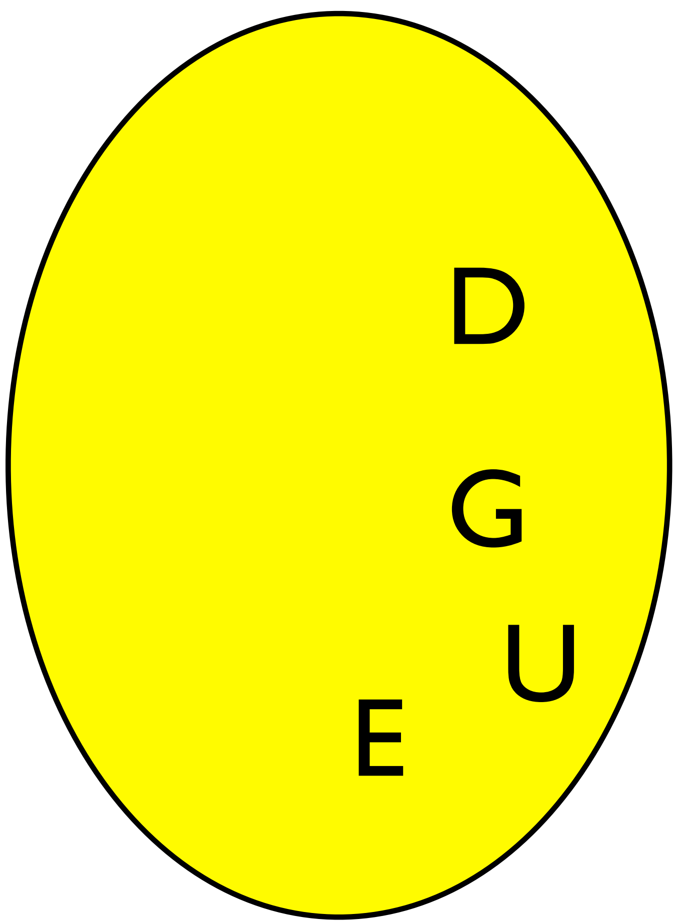




Decay Mode	Signals			Suppression
	lep	vec	jet	
G→W	0	0	2	Offshell
G→L→W	2	0	2	Four-body
G→B→W	0	1	2	Offshell,Mixing
G→B→L→W	2	0	2	Offshell

Neutral LSP: Examples

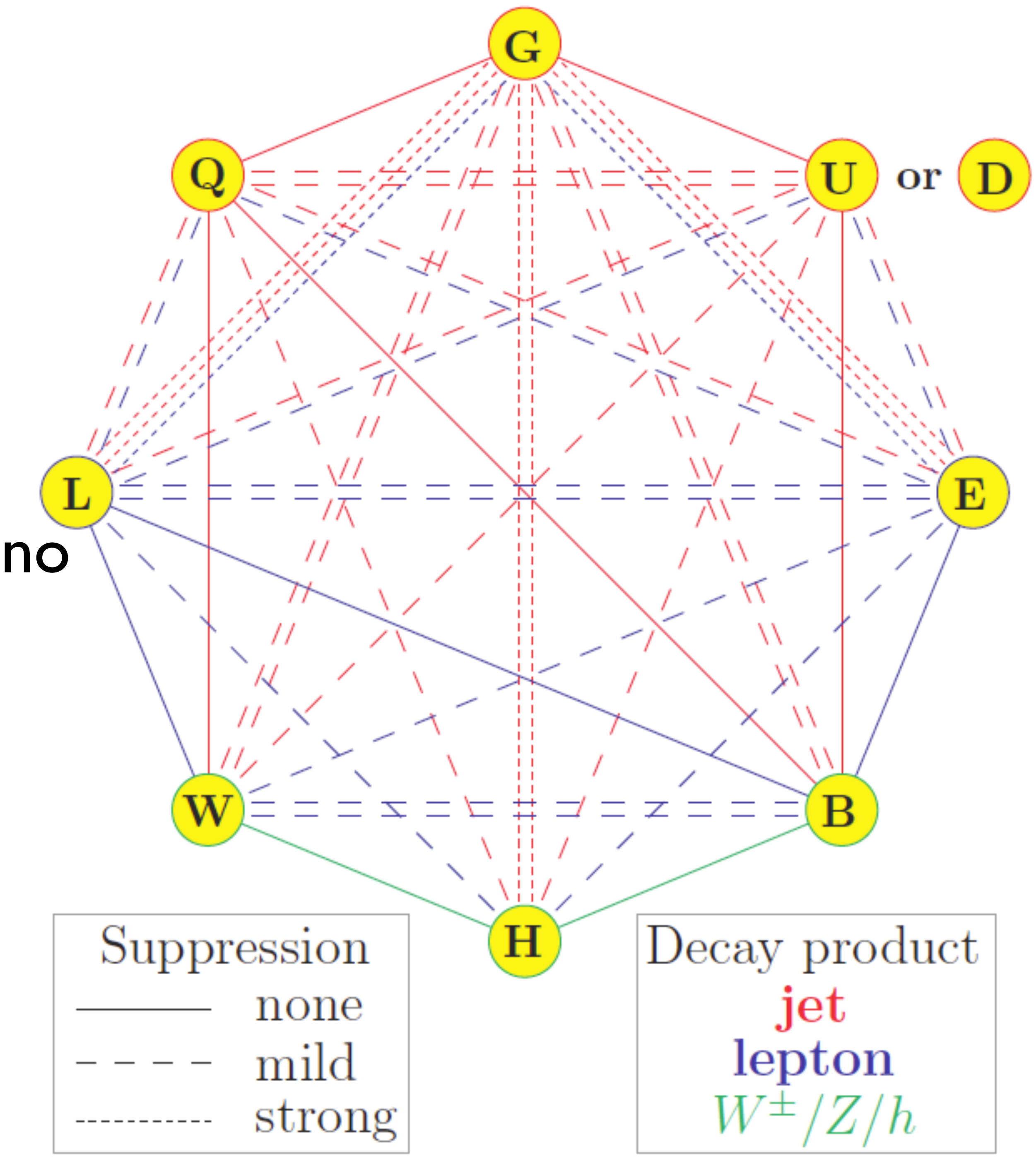




Decay Mode	Signals			Suppression
	lep	vec	jet	
Q→H	0	0	1	Mixing
Q→L→H	2	0	1	Offshell, Mixing
Q→B→H	0	1	1	-
Q→B→L→H	2	0	1	-
Q→W→H	0	1	1	-
Q→W→L→H	2	0	1	-
Q→W→B→H	0	2	1	Mixing
Q→W→B→L→H	2	1	1	Mixing

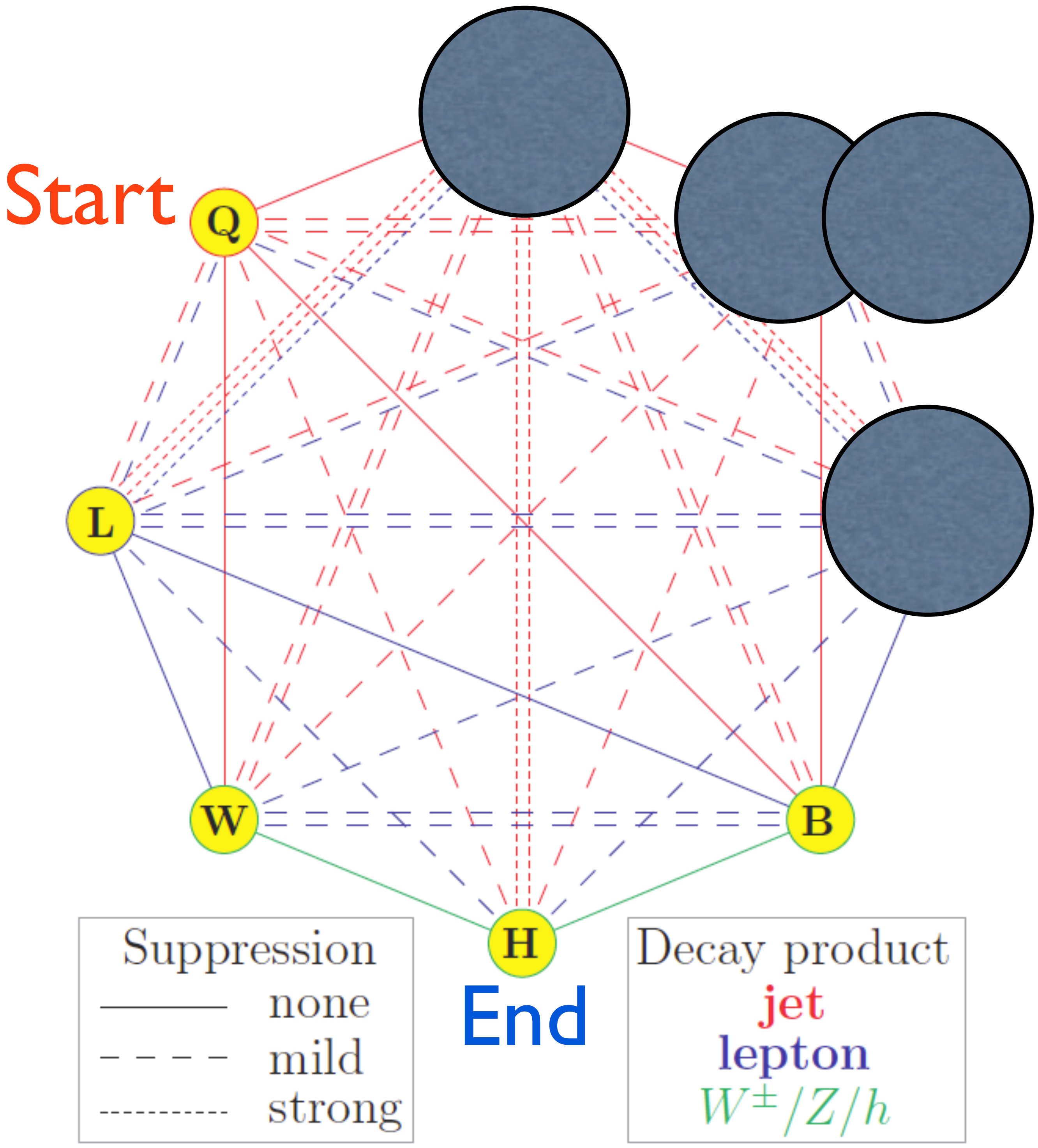
Traveling Salesman

- LCP decays : A variation of traveling salesman problem.
  - count suppression by multibody phase space
  - count suppression from neutralino mixing angles
  - squark$_{LR}$ and slepton$_{LR}$ mixing angles are negligible.



Traveling Salesman

- LCP decays : A variation of traveling salesman problem.
- Example : G>U>D>E>**Q**>W>B>L>**H**



Traveling Salesman

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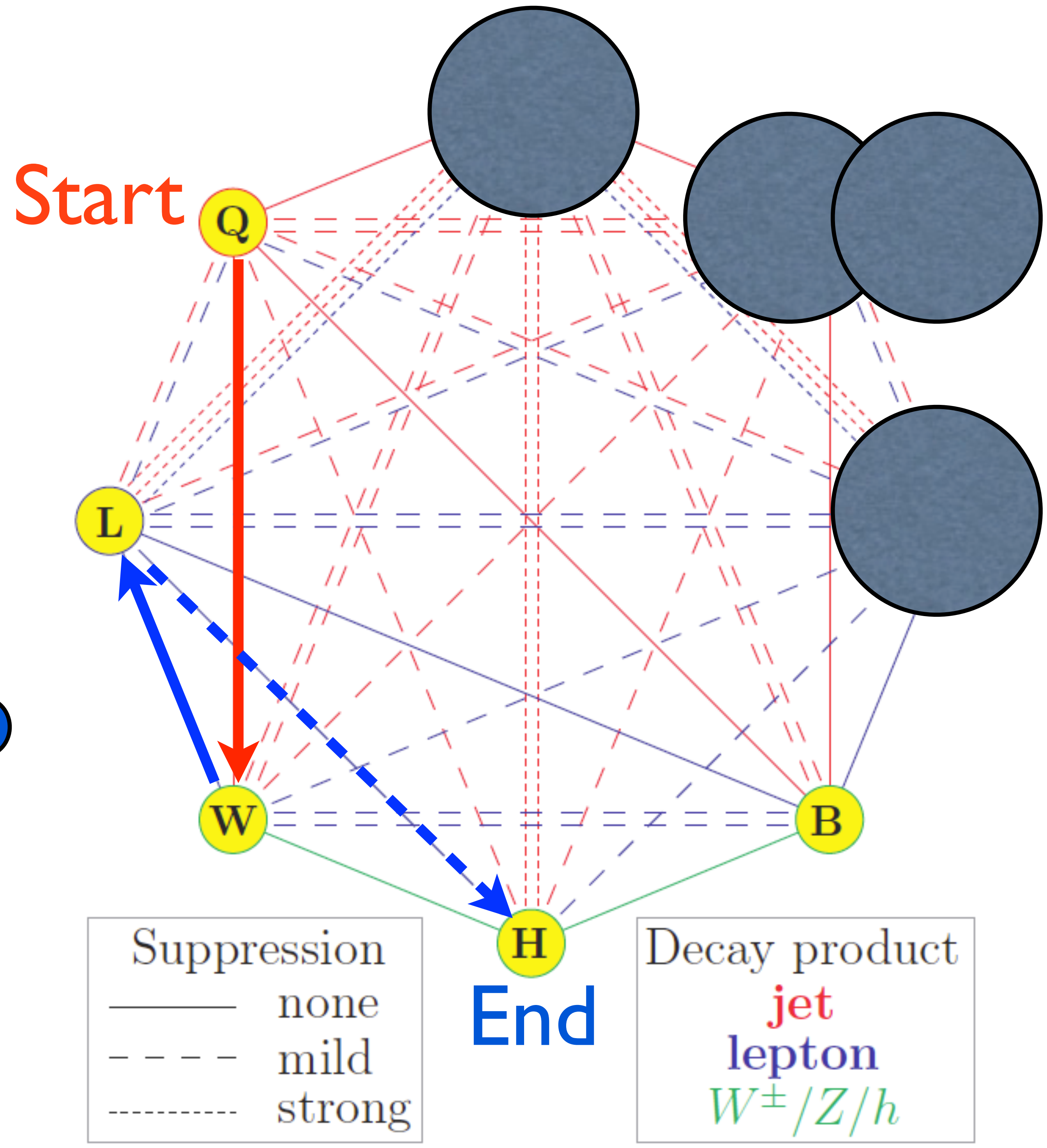
- Example : G>U>D>E>**Q**>W>B>L>**H**
  1) **Q→W→L→H**



Traveling Salesman

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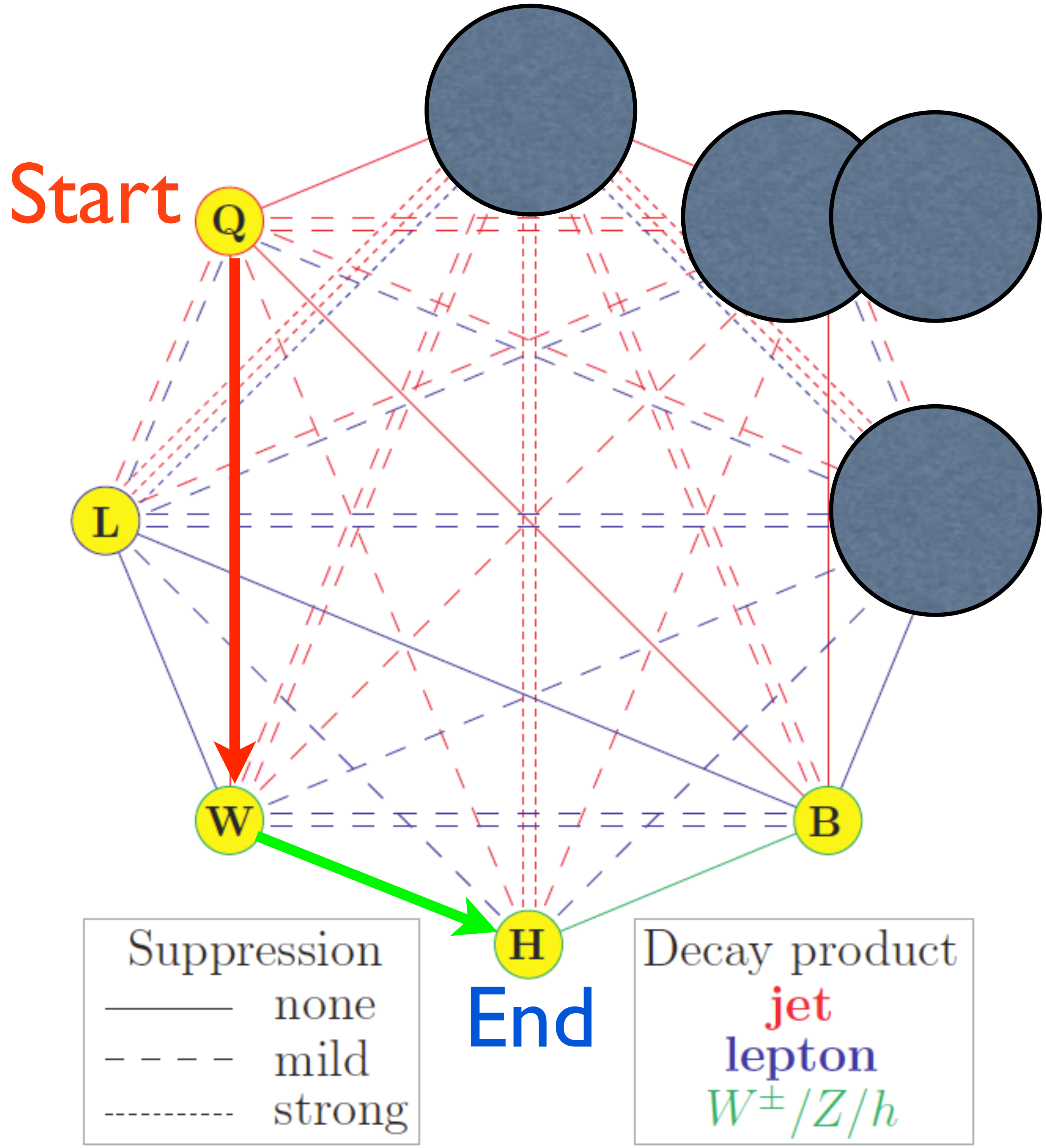
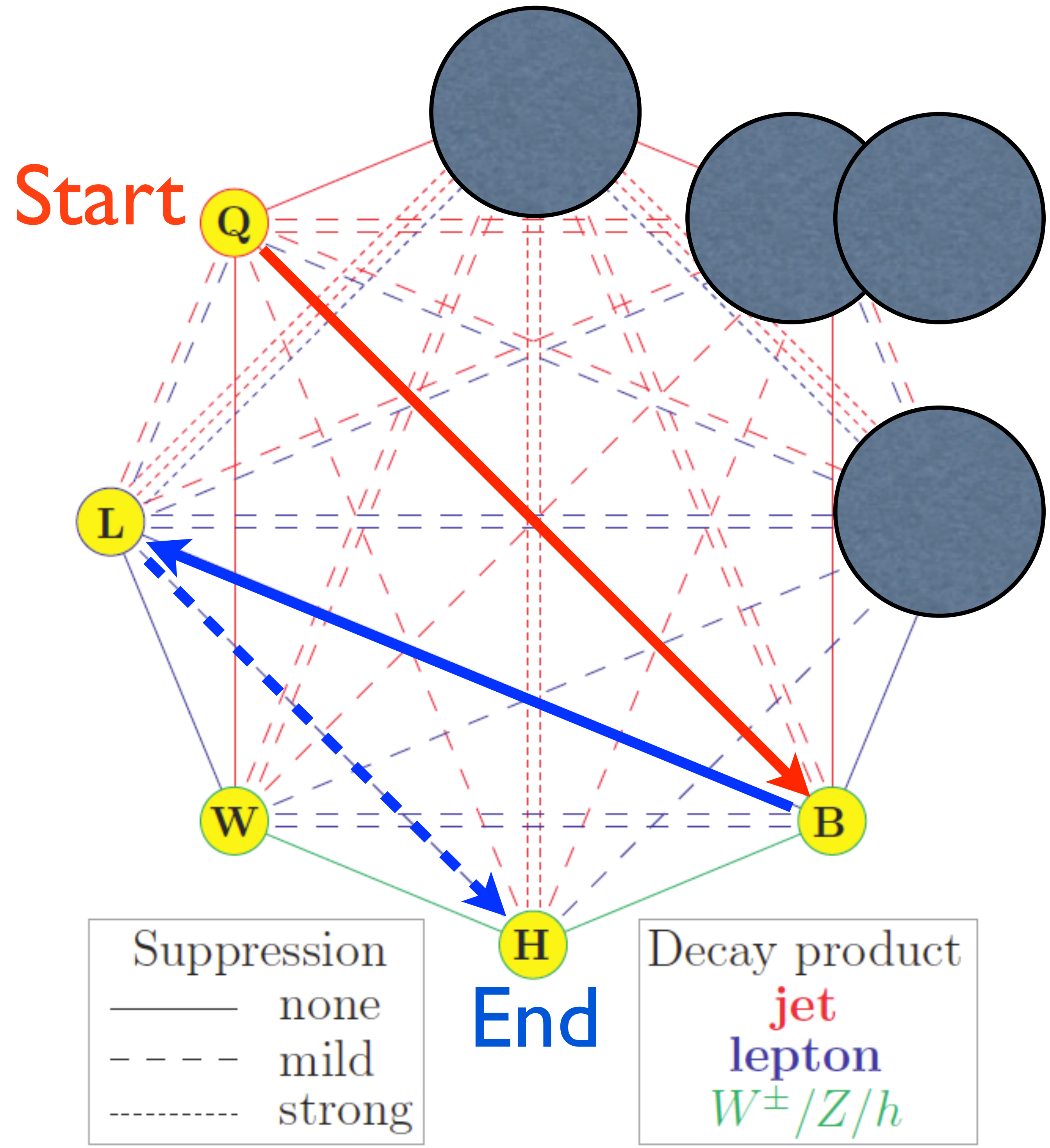
- Example :
  G>U>D>E>**Q**>W>B>L>**H**
  1) Q→W→L→H
  2) **Q→W→H**



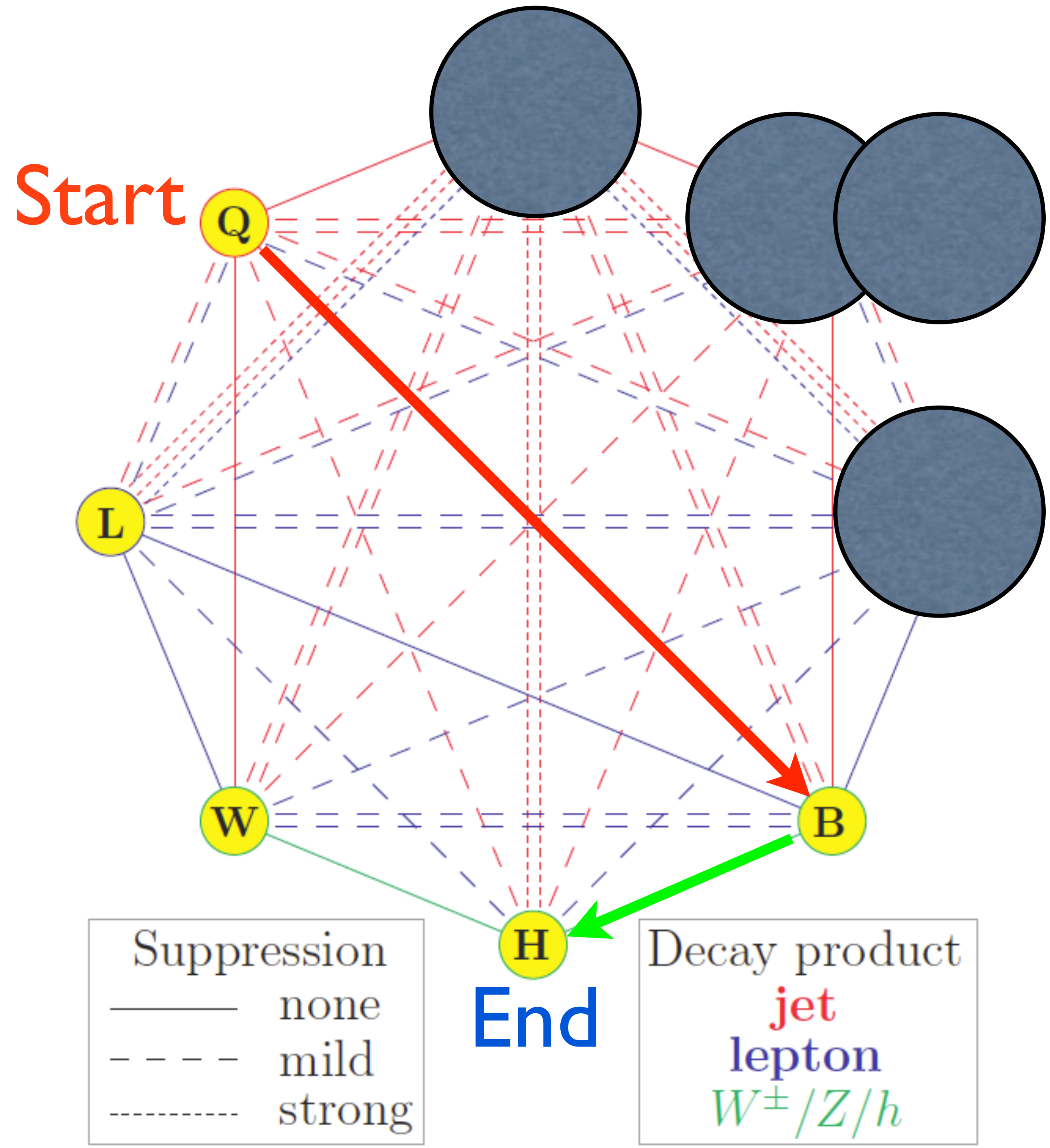
Traveling Salesman

- LCP decays : A variation of traveling salesman problem.
- Example :
  G>U>D>E>**Q**>W>B>L>**H**
  1) Q→W→L→H
  2) Q→W→H
  3) **Q→B→L→H**



Traveling Salesman

- LCP decays : A variation of traveling salesman problem.
- Example :
  G>U>D>E>**Q**>W>B>L>**H**
  1) Q→W→L→H
  2) Q→W→H
  3) Q→B→L→H
  4) **Q→B→H**



Counting signatures

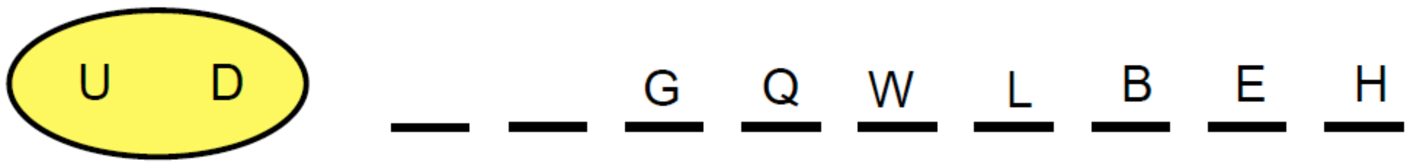
- Counting all possible dominant LCP decay

	$n_v = 0$		$n_v = 1$		$n_v = 2$	
n_ℓ	$n_j = 1$	$n_j = 2$	$n_j = 1$	$n_j = 2$	$n_j = 1$	$n_j = 2$
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

x2= 8 ~ 12 leptons

- Within R-parity conservation, we can have up to 8 leptons from cascade decay channel + (Up to 2 more leptons from V) , in total, we can have up to 12 leptons
- With lepton number violating R-parity violation, (e.g. LLE) we can have up to 16 leptons

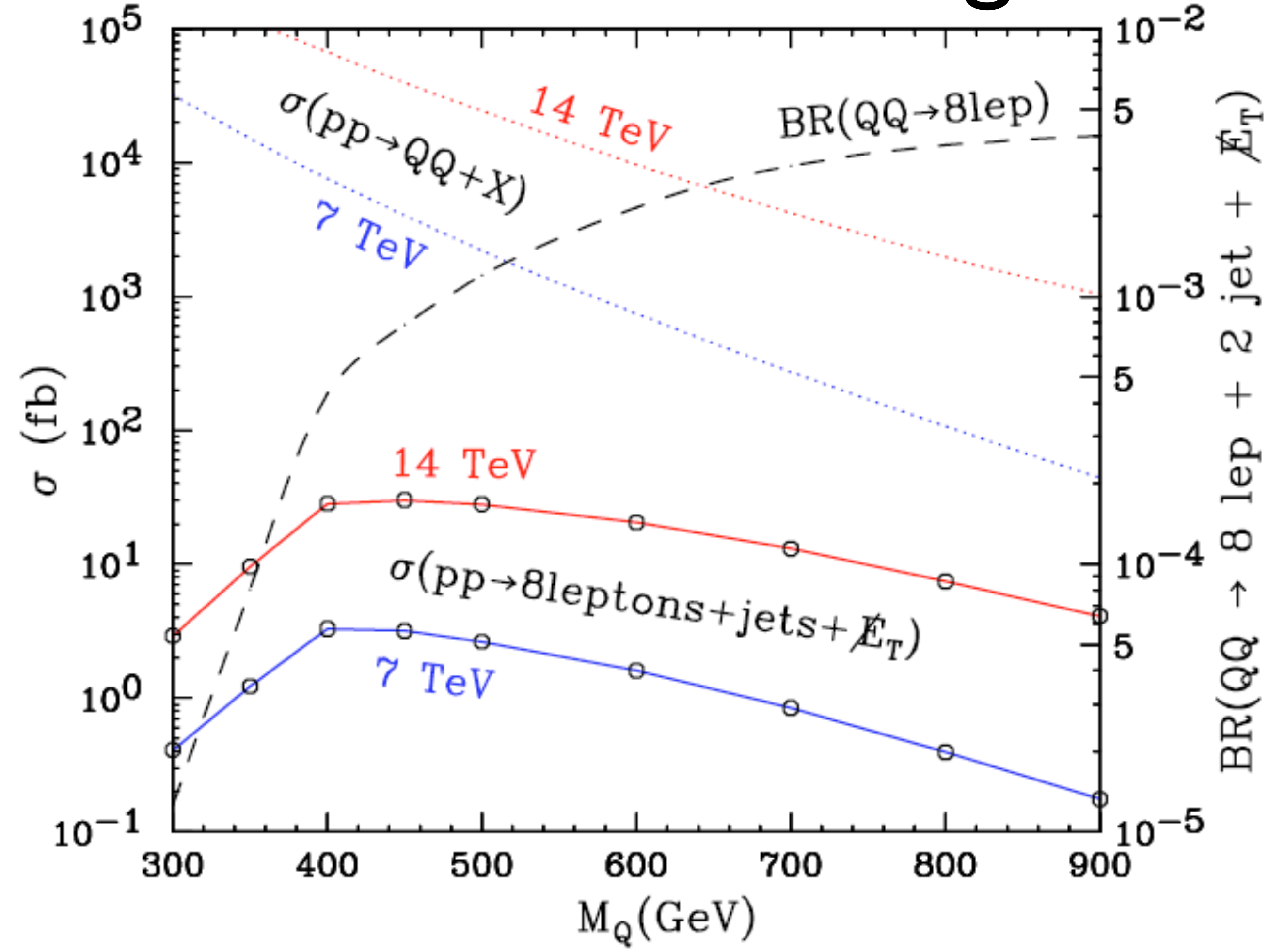
One 8-lepton hierarchy example



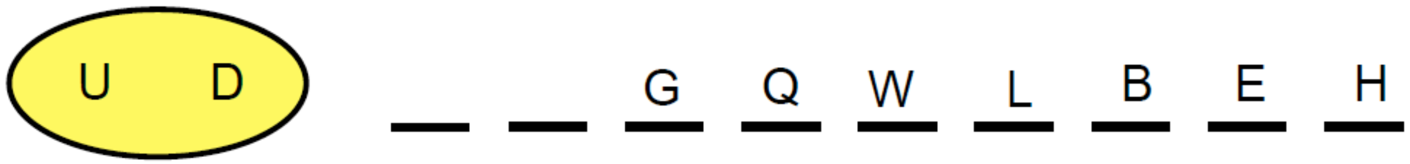
- For the given Q, we scanned the W, L, B, E and H mass terms.

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

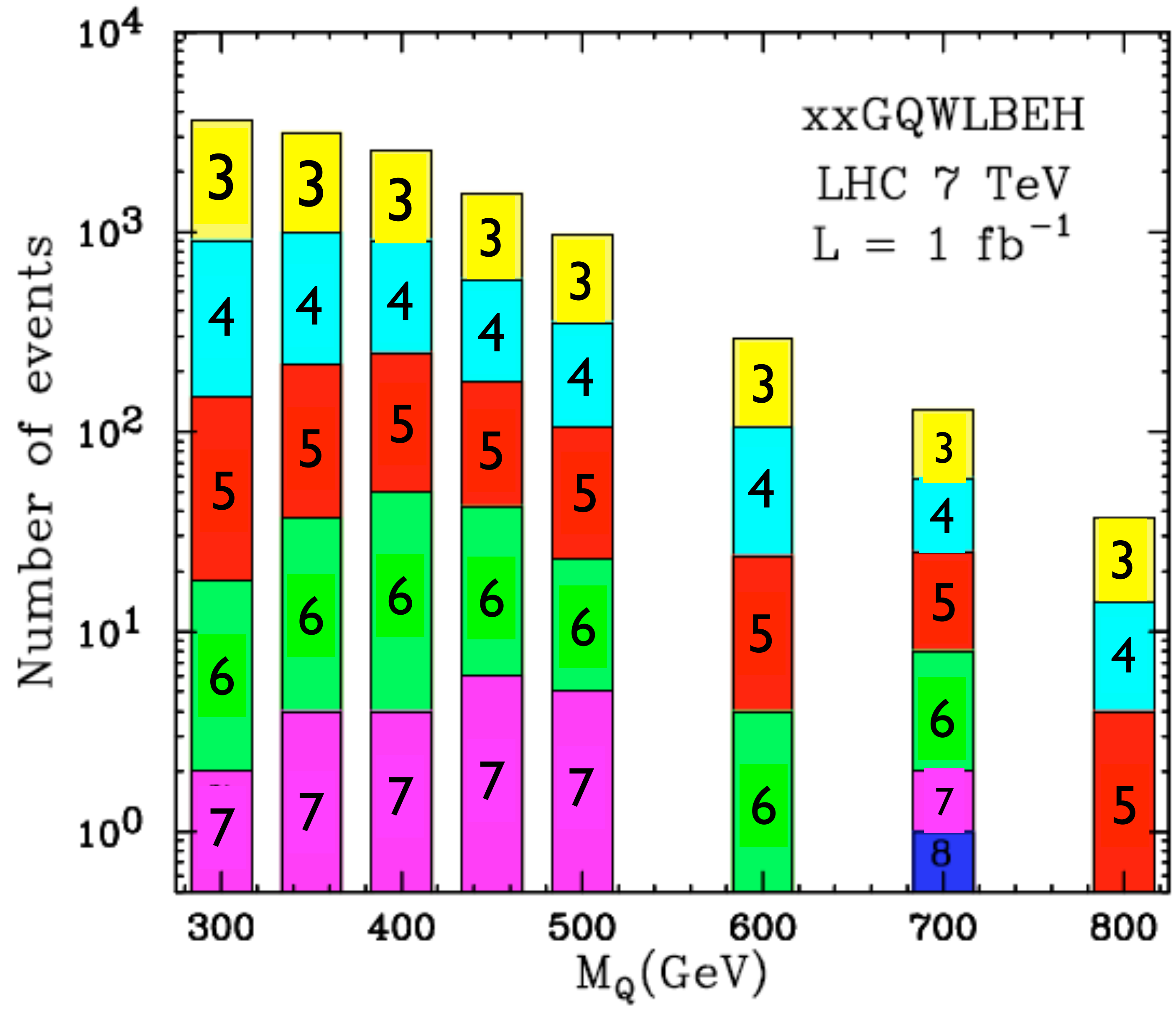
Optimistic, optimistic:
How soon can we get ?



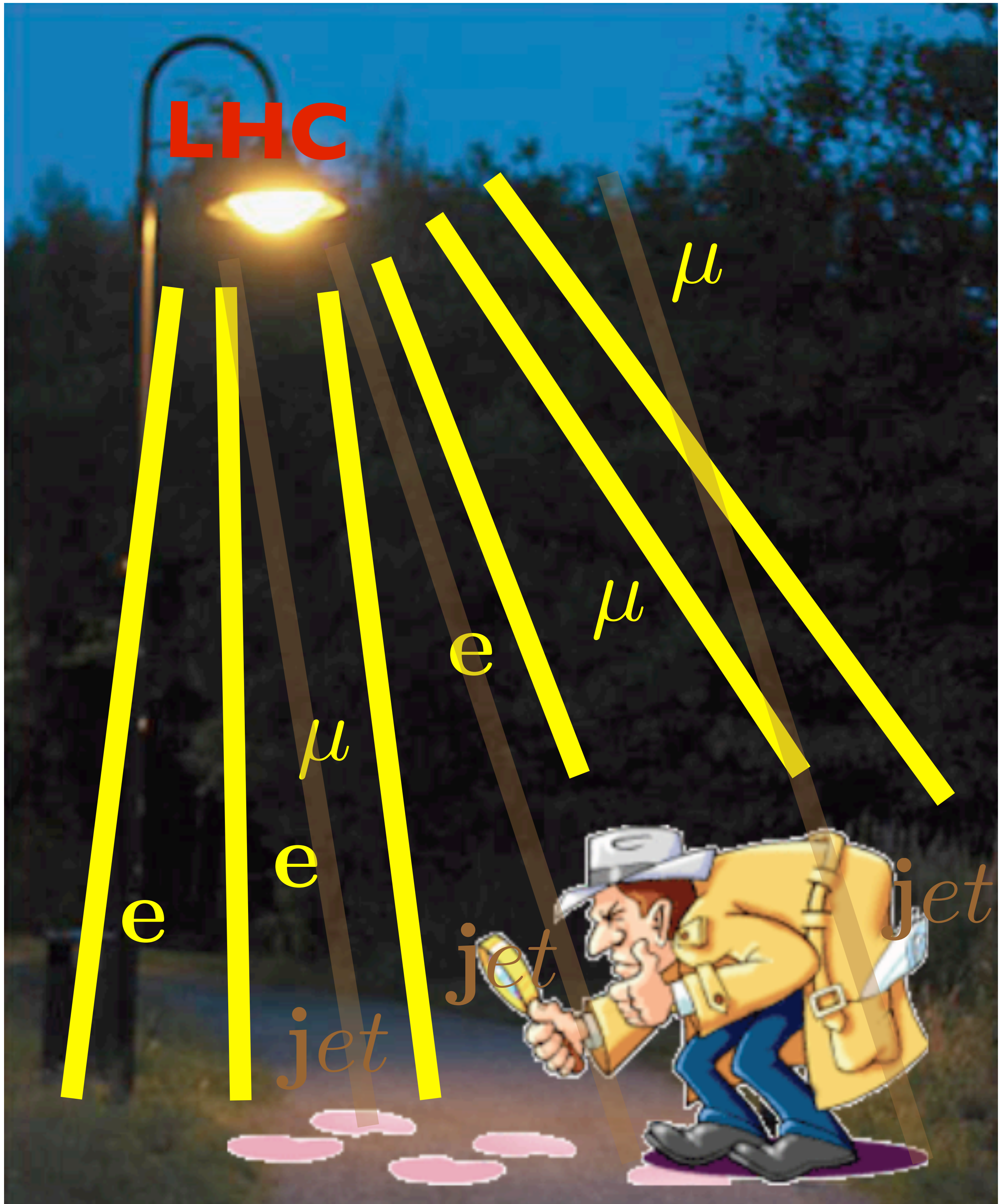
Study one 8-lepton hierarchy



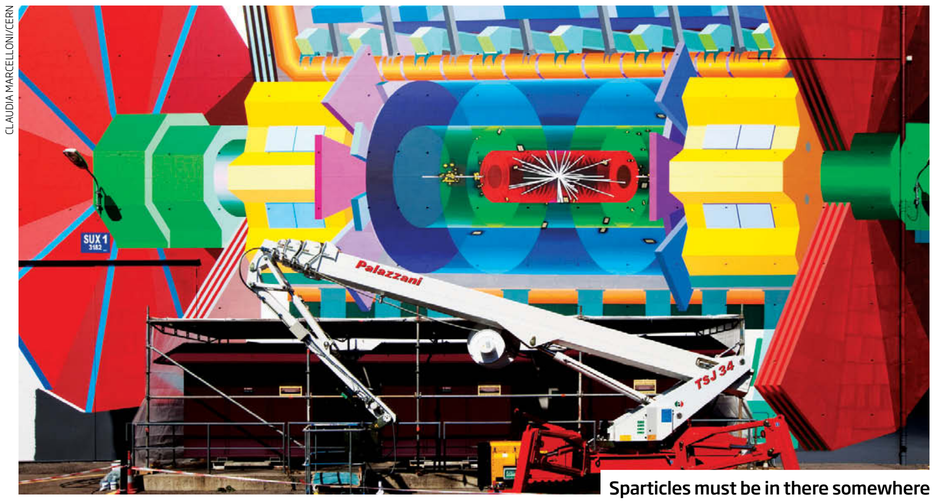
- Simulation : PYTHIA + PGS
- Count isolated leptons with P_T cut : electron 10 GeV
  muon 3 GeV



Summary



THIS WEEK


CLAUDIA MARCELLONI/CERN

Sparticles must be in there somewhere

LHC could hit the jackpot this year

Kate McAlpine

THE world's most powerful particle smasher could start making major discoveries sooner than we thought.

Evidence of supersymmetry (SUSY), a theory that helps solve several cosmological mysteries, as well as exotic new types of matter may emerge at the Large Hadron Collider (LHC) at CERN near Geneva, Switzerland, by the end of the year. That is if certain particles can decay into lighter ones via newly discovered pathways that are relatively easy to spot.

The assumption had been that the LHC would not have smashed enough particles together by December to see clear evidence of (SUSY). This theory, which suggests that every known particle has a "superpartner" or sparticle, could smooth the way for a "grand unified theory" that brings together the fundamental forces of nature. It could also provide an explanation for dark matter.

To find evidence for SUSY, the LHC needs time to amass enough data to see sparticles decaying unambiguously. So the earliest evidence for SUSY was not expected until mid-2011.

Now Konstantin Matchev of the University of Florida in Gainesville and colleagues say we may not need to wait that long.

Typical SUSY models assume heavy superpartners for the gluon and quarks, and a light neutral particle as a candidate for dark matter. But since the true masses of sparticles are uncertain, Matchev's team considered hundreds of possible masses for them, and worked out the routes by which they could decay into lighter objects.

The team found that if the gluon's superpartner, the gluino, or the lightest super-quarks require at least five steps to decay to the lightest sparticle, then they should ultimately produce up to eight electrons or muons, which are both examples of a family of particles called leptons.

Decays that produce leptons are prized because these particles leave clear tracks in detectors and their energies can be accurately measured. The team calculates that eight leptons would produce a signal clear enough to disentangle even from the meagre LHC data available at the end of this year (arxiv.org/abs/1008.2483v1). "It's so striking," says Matchev.

> "Decays that produce leptons are prized as they leave clear tracks and their energies can be measured"

It is not known whether the masses considered by Matchev's team are correct, so the results come with a big pinch of salt. In fact, just 1 per cent of all the mass combinations they looked at will produce the eight-lepton signal.

Sparticles aren't the only exotic particles that could turn up before the year is out: diquarks and leptoquarks could also be on the menu, say Jesse Thaler of the Massachusetts Institute of Technology and colleagues. These particles appear in grand unified theories, in which the strong, electromagnetic and weak forces merge at high energies.

Thaler describes the diquark as a single particle that has twice the "quarkness" of a single quark. A leptoquark would allow quarks and leptons to transform in ways that have never been observed and that are forbidden under the standard model of particle physics, which accounts for all particles known to date.

Thaler says that because the LHC collides quark-containing protons with each other, it should be particularly adept at creating diquarks. His team has calculated that both the diquark and leptoquark could show up at the LHC this year (*Physics Letters B*, DOI: 10.1016/j.physletb.2010.05.032). ■

IS THE HIGGS SET FOR A SURPRISE APPEARANCE?

The Higgs boson, thought to give all other particles mass, tops the Large Hadron Collider's most-wanted list. It is unlikely to be seen before 2013 according to the standard model of particle physics, but exotic physics could allow it to arrive sooner.

Modifications to the LHC will require it to be shut down for all of 2012. By then it will have enough data to see a Higgs with a mass between 160 and 180 gigaelectronvolts – except that results from the Tevatron collider in Batavia, Illinois, combined with the standard model, have already ruled out a Higgs mass above about 160 GeV.

But the LHC could be in luck if there are particles and forces outside the standard model. Then the Higgs could be heavier than 160 GeV and emerge in the early data.

What's more, if heavy "fourth generation" quarks – hints of which have shown up at the Tevatron – exist, the LHC could detect a Higgs with a mass of up to 300 GeV before 2012 (*Physical Review D*, DOI: 10.1103/PhysRevD.76.075016).

The Higgs might also be seen by then if it is lighter than 130 GeV. This could be the case if another particle outside the standard model, the Z-prime, exists as some string theory models predict (*Physical Review D*, DOI: 10.1103/PhysRevD.78.055002).

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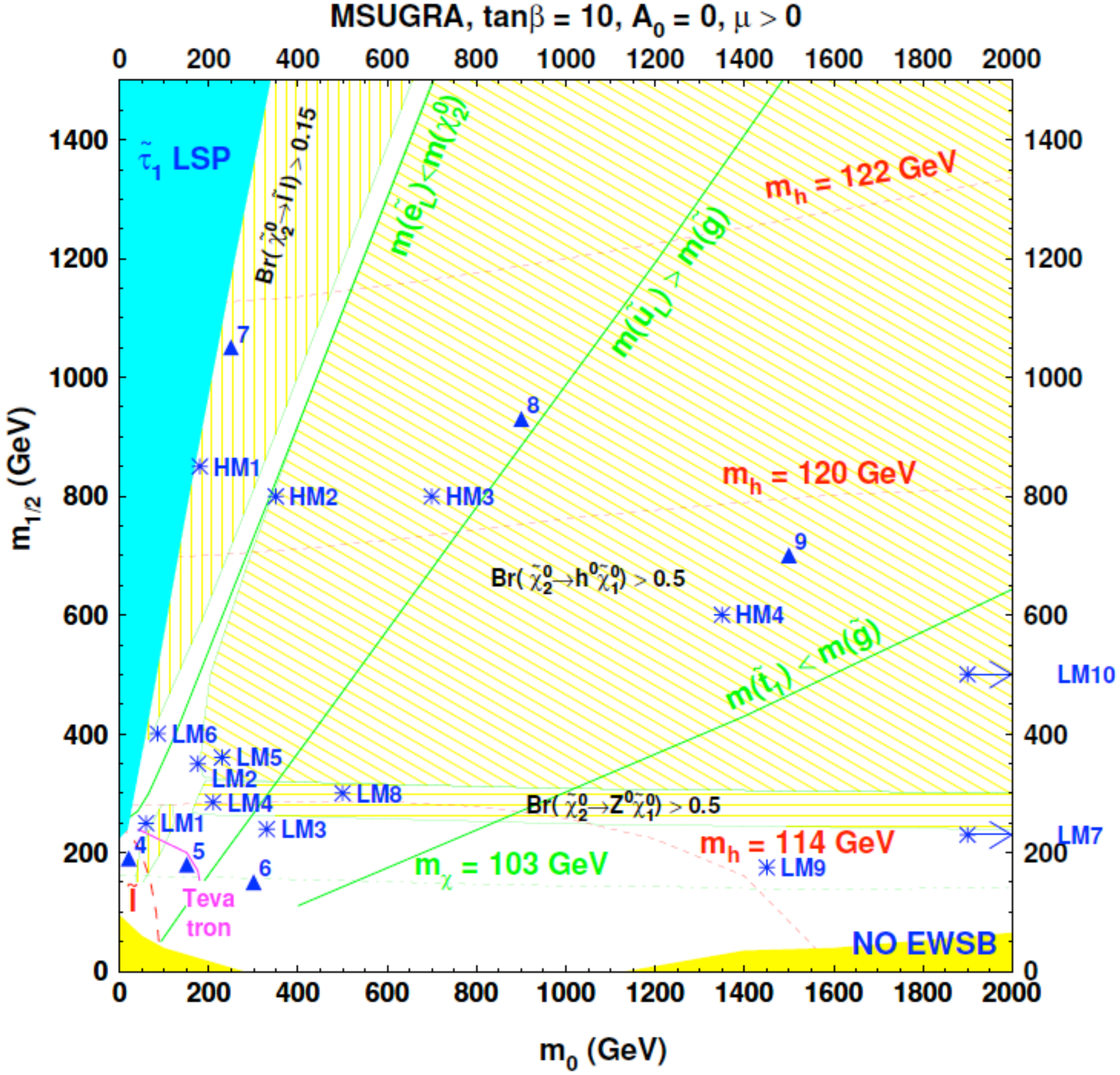
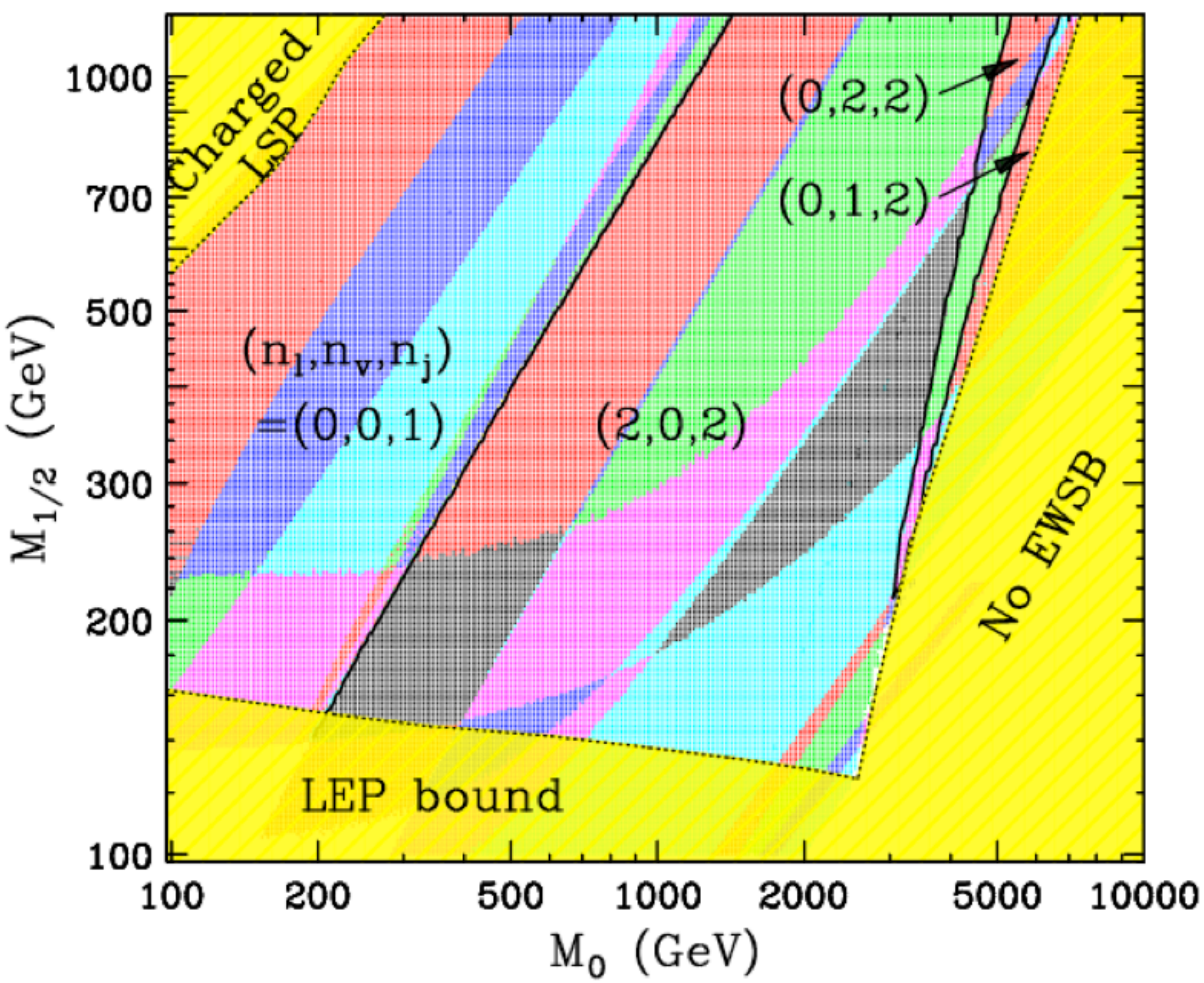
Back up

MSUGRA result

- Only 47 out of the 161,280 possible hierarchies
- Only 4 out of the 26 possible decay channels.





MSUGRA result

- CMS groups are looking for multi-leptonic channels: example : LM6 study point

```
     M_0       M_1/2       A_0    Tan(beta)    Sgn(mu)    M_t
    85.00     400.00      0.00      10.00         1     175.00

  ISASUGRA Output:
  ----------------
  EW scale masses:
           ~u        ~d        ~s        ~c        ~b      ~b(12)      ~t      ~t(12)
   L     859.05    862.96    862.96    859.05    756.81    789.49    756.81    653.82
   R     830.29    827.76    827.76    830.30    782.01    816.17    655.11    836.90

           ~e        ~mu      ~tau     ~tau(12)   ~nu_e     ~nu_mu    ~nu_tau
   L     291.23    291.23    281.00    169.40    275.58    275.58    274.76
   R     176.62    176.62    167.61    292.60

           ~g      ~chi_10   ~chi_20   ~chi_30   ~chi_40   ~chi_1+   ~chi_2+
         939.78    158.18    305.23   -524.77    540.48    304.01    540.36

           h0        H0        A0        H+
         116.72    580.91    580.60    586.10

  Mixing structure:
                |    ~B    |   ~W_3   |   ~H_1   |   ~H_2   |
       ~chi_10  |   0.994  |  -0.024  |   0.095  |  -0.038  |
       ~chi_20  |  -0.049  |  -0.965  |   0.216  |  -0.138  |
       ~chi_30  |   0.039  |  -0.058  |  -0.702  |  -0.709  |
       ~chi_40  |  -0.084  |   0.254  |   0.672  |  -0.691  |

           L    |    ~W    |    ~H    |               R    |    ~W    |    ~H    |
       ~chi_1+  |  -0.946  |   0.323  |          ~chi_1+   |  -0.979  |   0.206  |
       ~chi_2+  |  -0.323  |  -0.946  |          ~chi_2+   |  -0.206  |  -0.979  |
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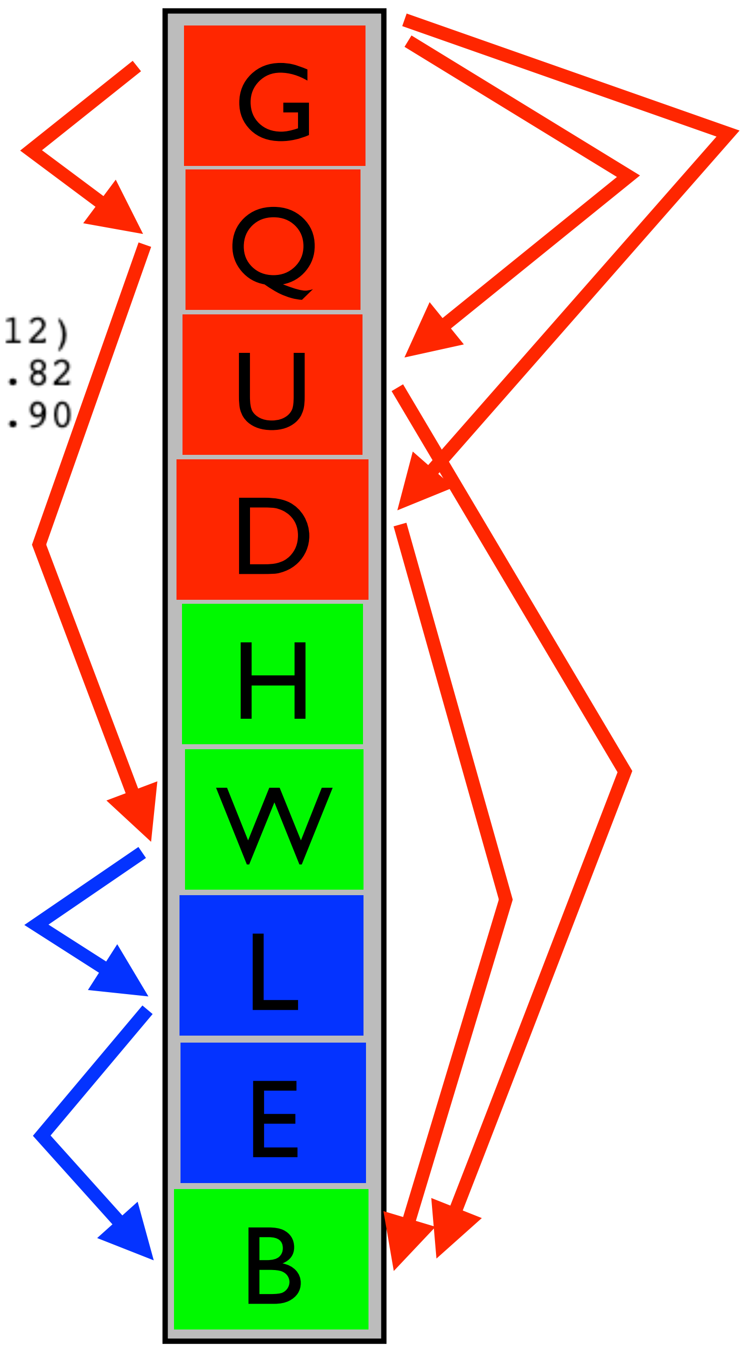

MSUGRA result

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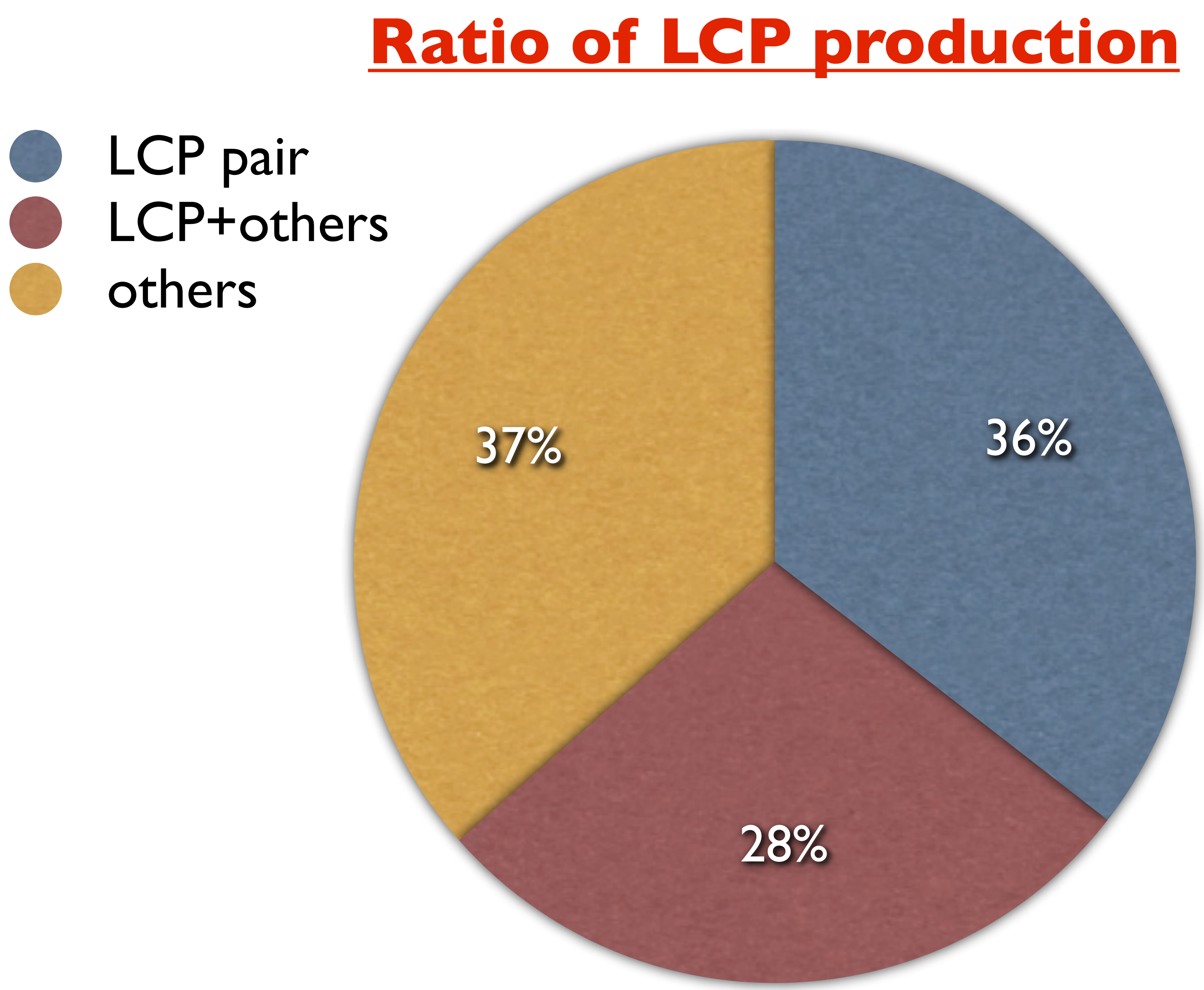
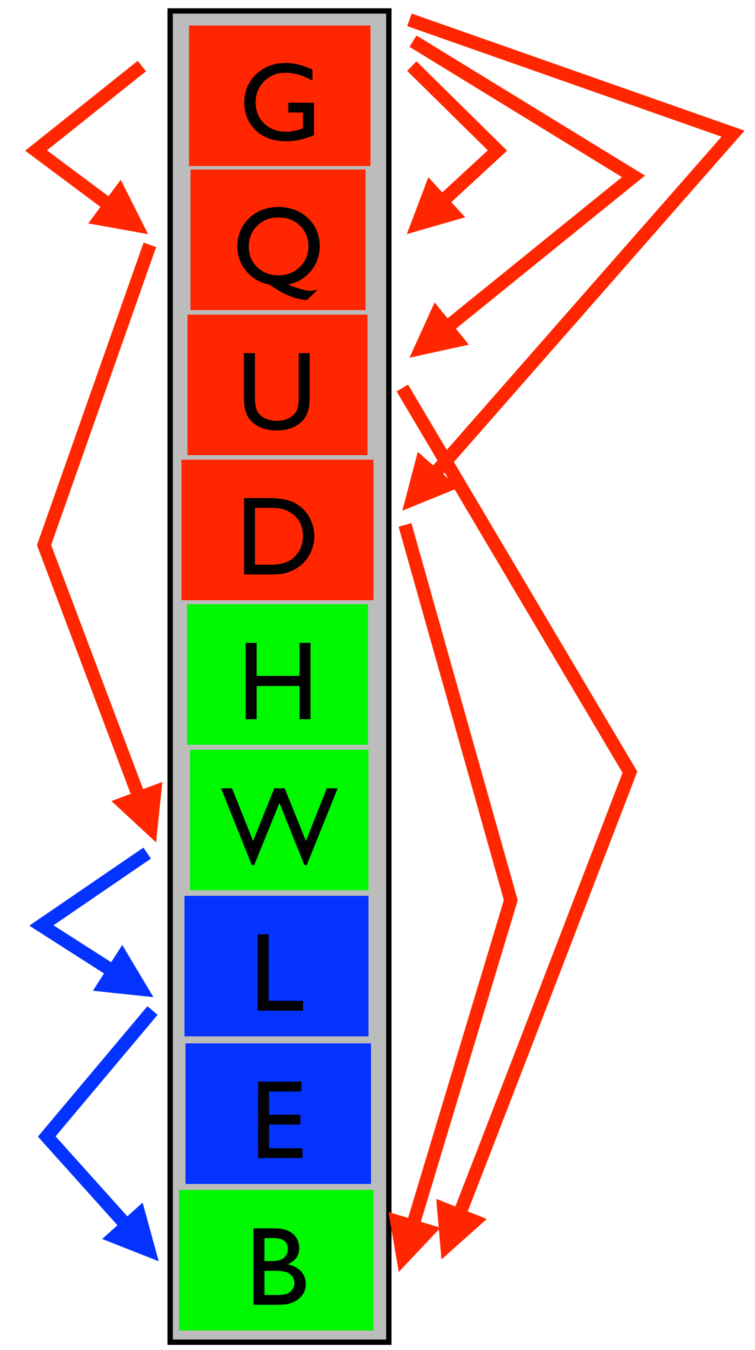
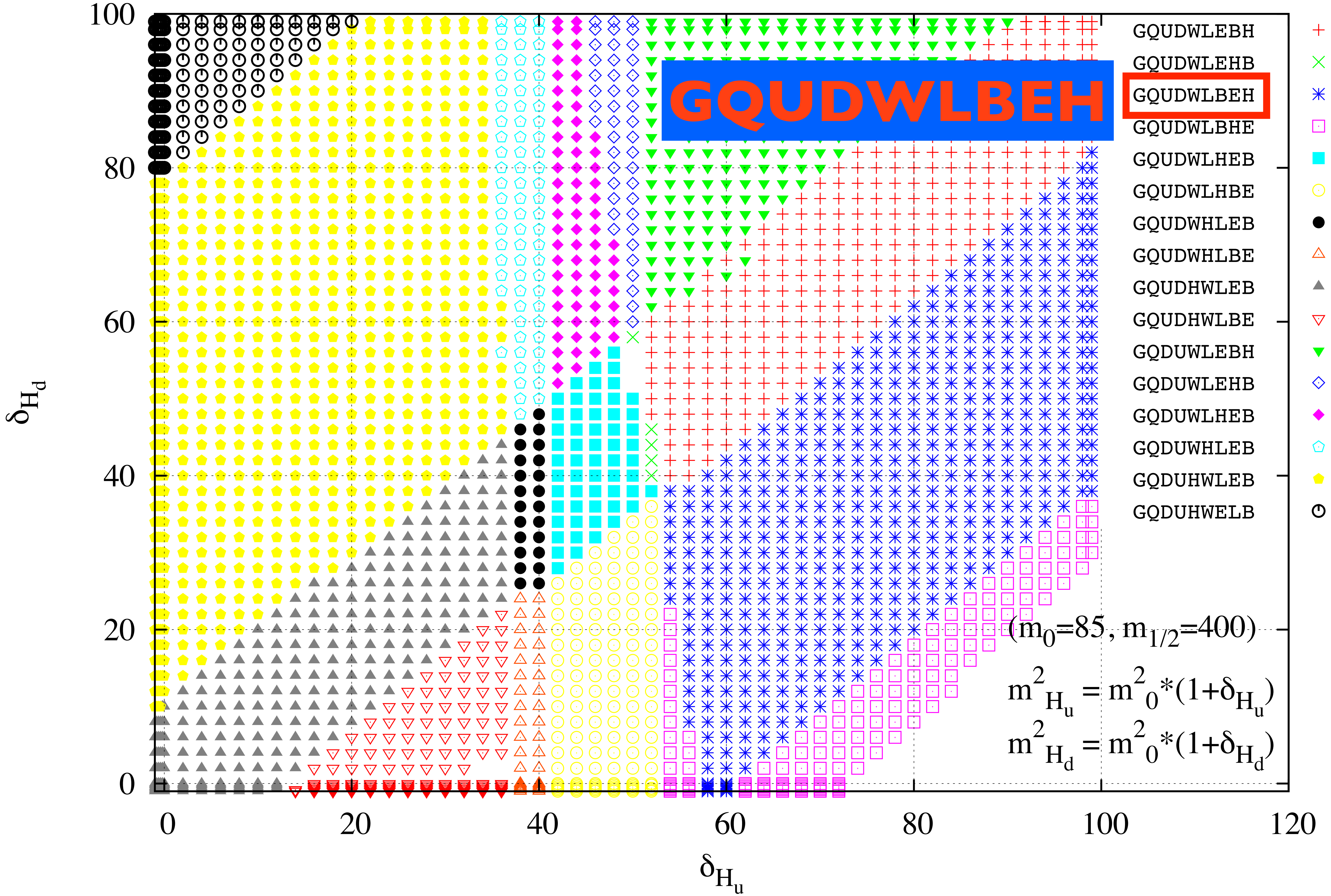




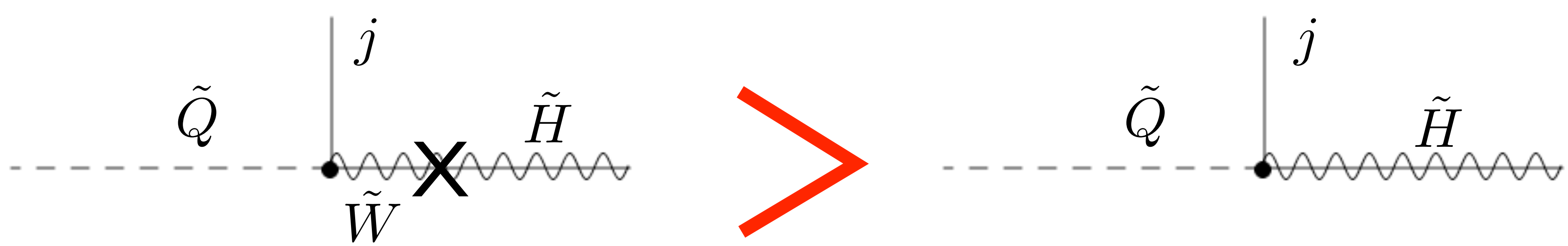
Extension of MSUGRA



Relations between sparticles

- Degree of Suppression for Decaying channels:
  - Three body decaying suppression ~ Mixing suppression > Yukawa int.
  eg 1) $M_{\tilde{L}} > M_{\tilde{W}} > M_{\tilde{B}}$

  eg 2) $\tilde{Q} \rightarrow \tilde{H} + j$



- If the suppression degrees are same, we take the leptons > Vector > Jet