Characterizing New Physics at the LHC: CMS Perspective

LPCC Workshop
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On behalf of CMS

Preface

- New Territory
  - LHC will take a few big steps into new territory in coming years.
    - Could/should? see new physics
- What remains to be done to prepare for the trip?
  - Experiments have prepared extensively in similar but independent ways (as seen in preceding talk)
    - Different approaches are good.
  - A few issues could however benefit from a common effort.
- Joint Efforts
  - Typical issues addressed:
    - Comparing apples w/apples
      - Benchmarks, variables, metrics, sensitivity/discovery statistics,…
    - Combination for greater reach
  - These are very important and will be added to the next workshop (early November).
- This workshop:
  - We will start to investigate the new possibility of a joint effort to characterize new physics using simplified model spectra (sms) or "topology sets".

Past versus future discoveries

Past

- W & Z
  - Masses and production rates were predicted
  - Signals stood out "like being hit on the head with a hammer"
  - Interpretation was unambiguous
- Top
  - Signal was hard to dig out and less straightforward to interpret but…
    - We knew it had to be "somewhere"
    - Production and decay properties were predicted

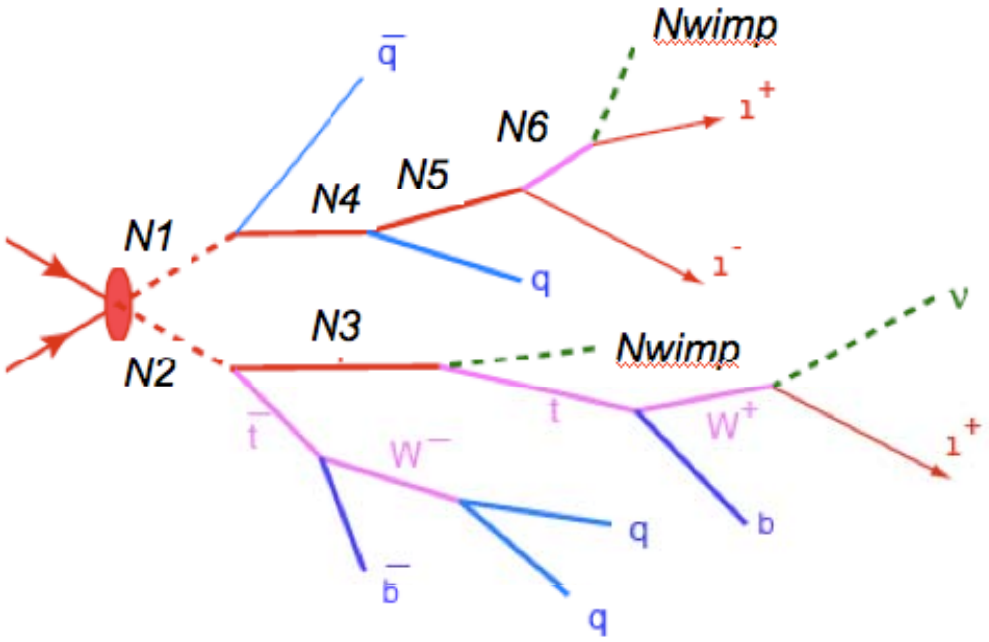
Future

- Higgs
  - Somewhat like top: for a given mass, we know its production and decay properties in the SM and in many alternative models. For some mass ranges, counting experiments would give the first sign.
  - Or like Z – it could appear as a mass peak (e.g. $h \rightarrow \gamma\gamma$, ZZ)
- New Physics (NP)
  - Some of the more compelling possibilities would involve discoveries unlike any we have encountered in (most of) our careers…

SUSY*

- SUSY-like models can solve the gauge hierarchy problem.
  - But, there's no evidence of SUSY from LEP/Tevatron.
  - Reconciled by a discrete symmetry (e.g. R-Parity)
    - New Physics only enters at loop level
    - Et voila' - a dark matter candidate with the right cosmological relic density
  - This a "must do", high priority line of research for the LHC

"SUSY" is an entry point to a more general "Dark Matter Candidate" search.



Missing Energy:
Nwimp - end of the cascade

Multi-Jet:
• from decay of the Ns (possibly via heavy SM particles like top, W/Z)

Multi-Leptons/photons:
• from decay of the N's

*Adapted from: O.Buchmueller (ATLAS+CMS): to LHCC, May 2010

At issue

- If we see evidence of New Physics it will probably not have a unique interpretation.
  - Particularly if it involves a significant spectrum of particles
    - SUSY, UED, Conformal Technicolor, Little Higgs models etc.
      - Many massive particles whose decays cannot all be seen and for those that can be seen, they cannot generally be fully reconstructed.
- Theorists have spent years asking what is beyond the SM
  - They're interested in how results will be communicated to them.
  - Experimentalists will need some guidance if the signals are rich
- This raises a series of questions including
  - How do experiments get the most out of the data?
    - What are the most useful distributions to study?
    - What can we expect to get out of LHC data as it is accumulated?
  - How shall we communicate what we see?
    - Across experiments? With theorists ?

Division of labor

- What is a good division of labor - Experiment vs. Theory?
  - LHC data requires a very significant level of work/expertise to acquire/analyze.
  - There are many multi-parameter models representing vast spaces of possibilities in the current theory landscape.
- If we see evidence of new physics:
  - A spectral/topological characterization of new physics provides experimentalists with a useful, potentially very intuitive perspective.
    - I.e. compare data to expectations for simple models made up of small numbers of particles and their interactions. (covered in more detail in the next talks).
  - The associations of these simple spectral models to any expression of an existing or new model could be very straightforward for theorists.
- If we don't see new physics:
  - We will need to map out what we can exclude.
    - The spectral/topological approach may be just as useful here.
      - Experimentalists would know exactly what "signatures" are impacted.
      - Theorists could again understand the impact on their models.

A common language

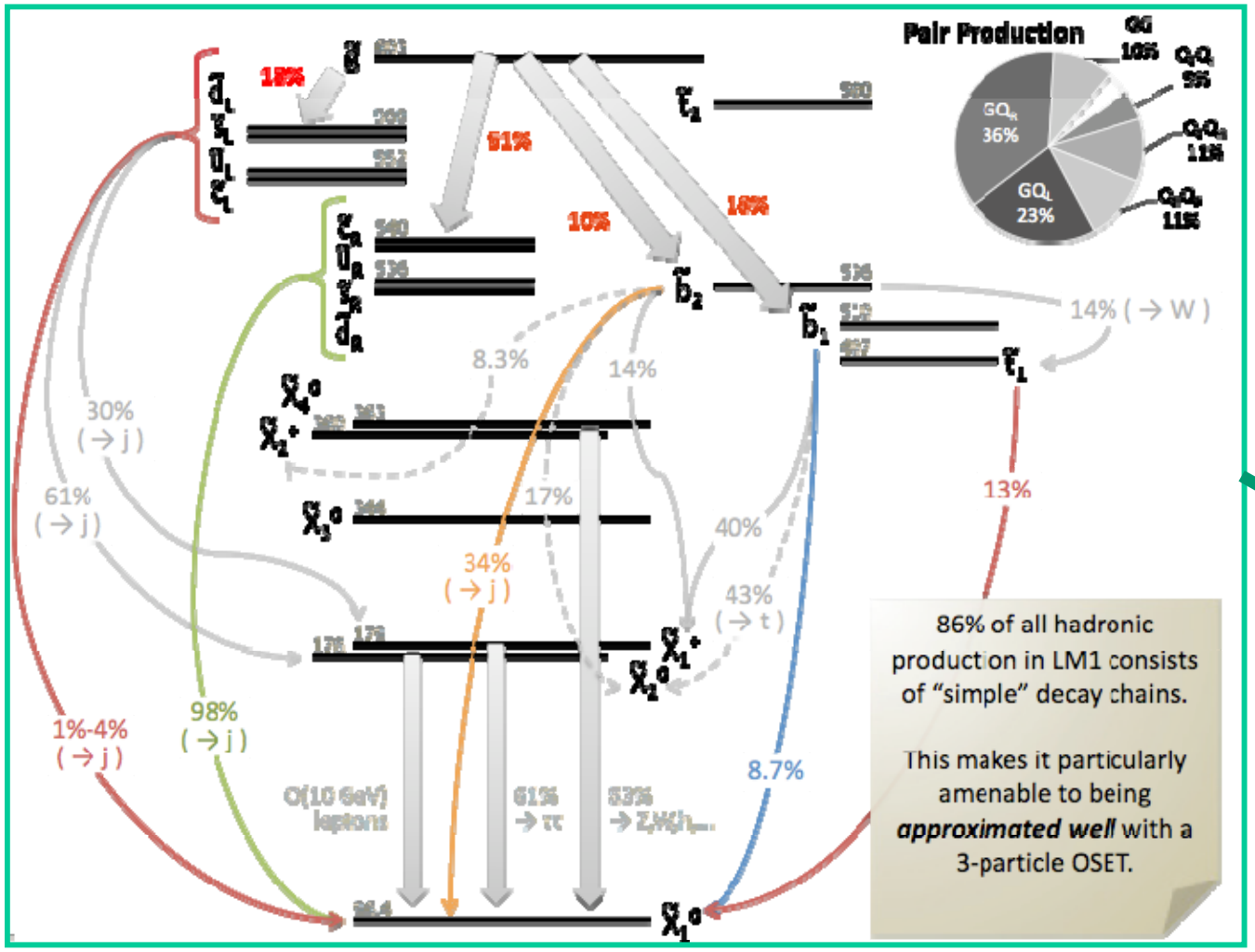
- So… the idea
  - Use topological sets as benchmarks to get a general sense of the spectrum of particles involved.
    - Some of this grew out of work with On Shell Effective Theories (OSETs) but future efforts need not be restricted to this implementation.
- An example of a possible joint effort
  - ATLAS and CMS search groups and theorists
    - Theorists provide benchmark topologies ("Topology sets")
      - Model-inspired but more general
    - Together we agree upon useful distributions, variables.etc. to study
    - Experimentalists find parameters (e.g. masses and rates) that provide the best fit of a given topology set to excesses in data along with a goodness of fit (or set limits on $\sigma \cdot B$ in the absence of excesses).
  - Setup a feedback loop between experiment and theory

Do's and don'ts

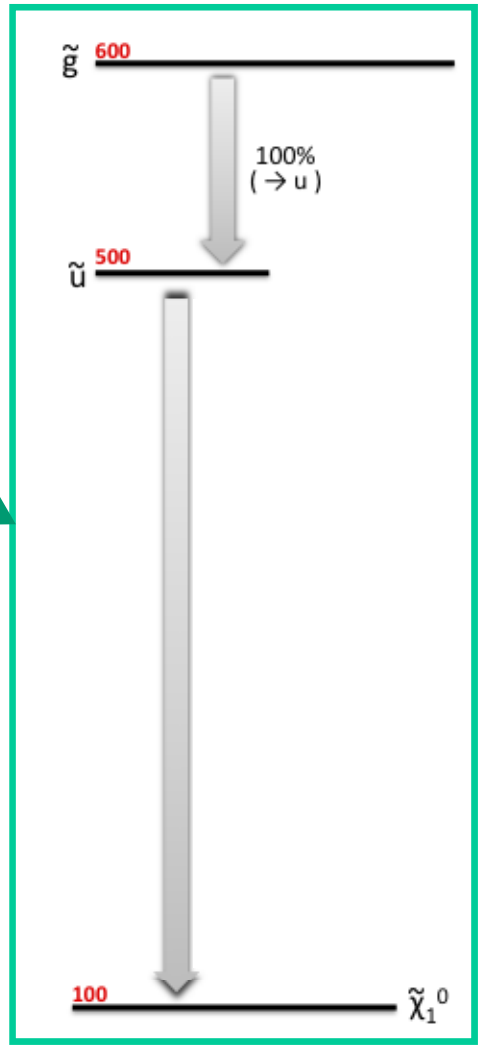
- What this *does not do*:
  - Replace existing studies, model-dependent or model-independent
  - Provide a definitive statement about an underlying theory
- What this *may do*:
  - Provide an a priori array of spectra representing a broad range of physics models to compare to data for:
    - Common ground for comparison
    - A broad, level and somewhat unbiased look at new physics
    - A common language for representing new physics in data that is easily interpreted

Example: mSUGRA-inspired simple model

CMS "LM1" mSUGRA Benchmark point

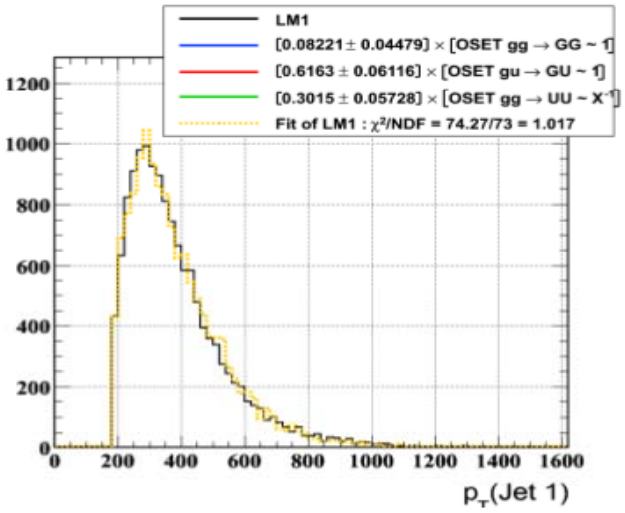


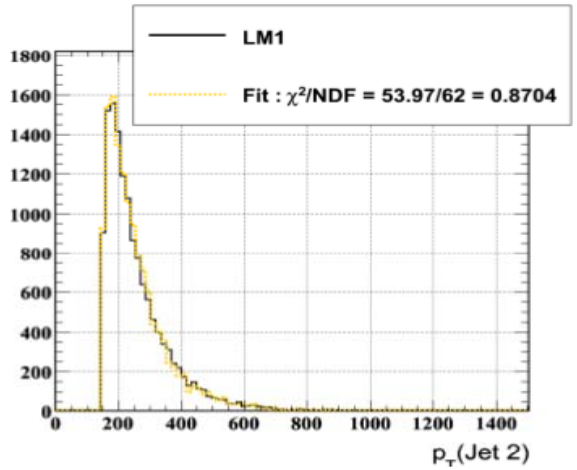
Simplified LM1 for All-hadronic search

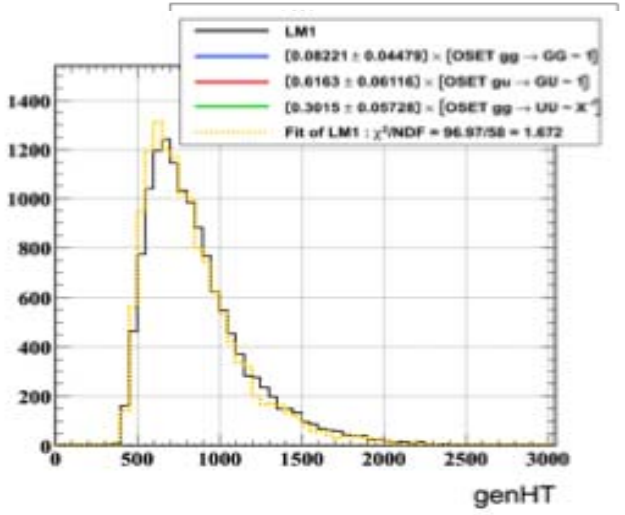


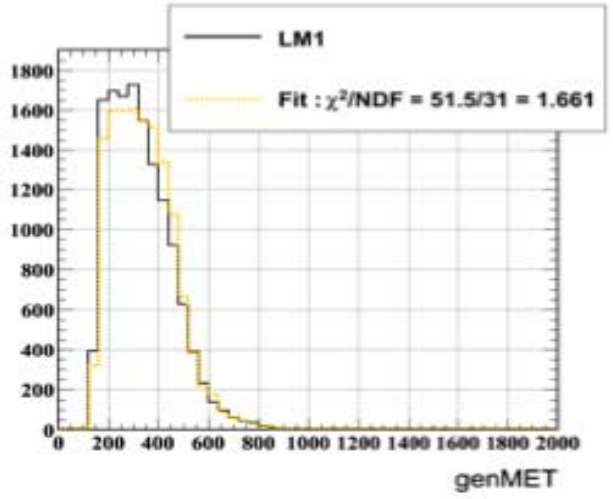
LM1 and a "simplified LM1"
with 3 production modes, 2 decay modes

Performance Comparison







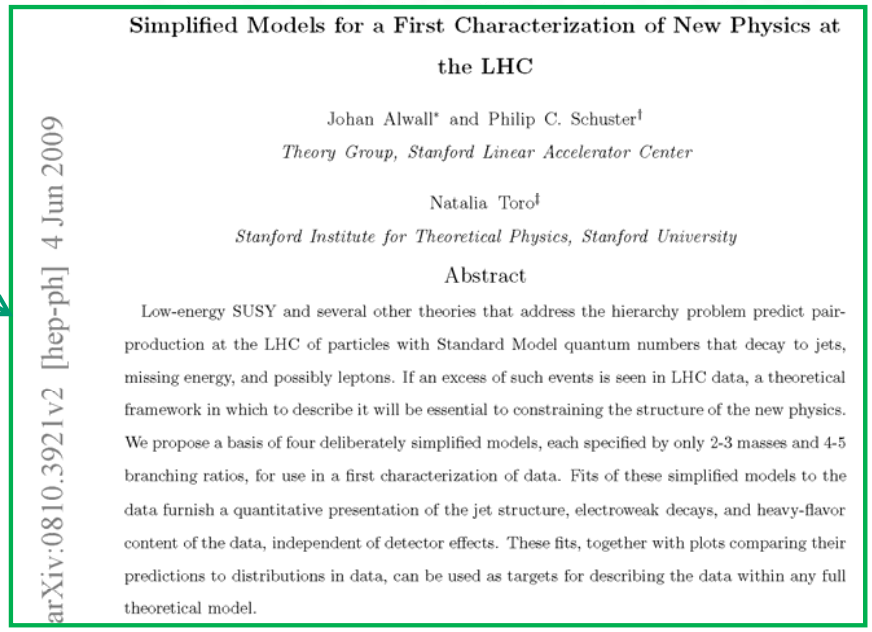


To fully characterize a complicated model like LM1, particularly in the leptonic channels, several simple topology sets must be used. This becomes more important also as more data are accumulated and more details become clear.

Matches are reasonable in key variables even at generator level and with large statistics. Simple topology sets were also found for the single lepton + Missing E_T (MET) channel.

Generalizing

- Some of what has been done
  - Broad set of SUSY-inspired simple model spectra (sms)
  - A framework to generate events[1]
  - Also
    - some rudimentary tools to find best sms parameters and quality of fit
    - can use sms to optimize SUSY searches and go beyond mSUGRA
      - A template sms can populate the whole plane, for instance. (More in talk by Natalia Toro)



Simplified Models for a First Characterization of New Physics at the LHC

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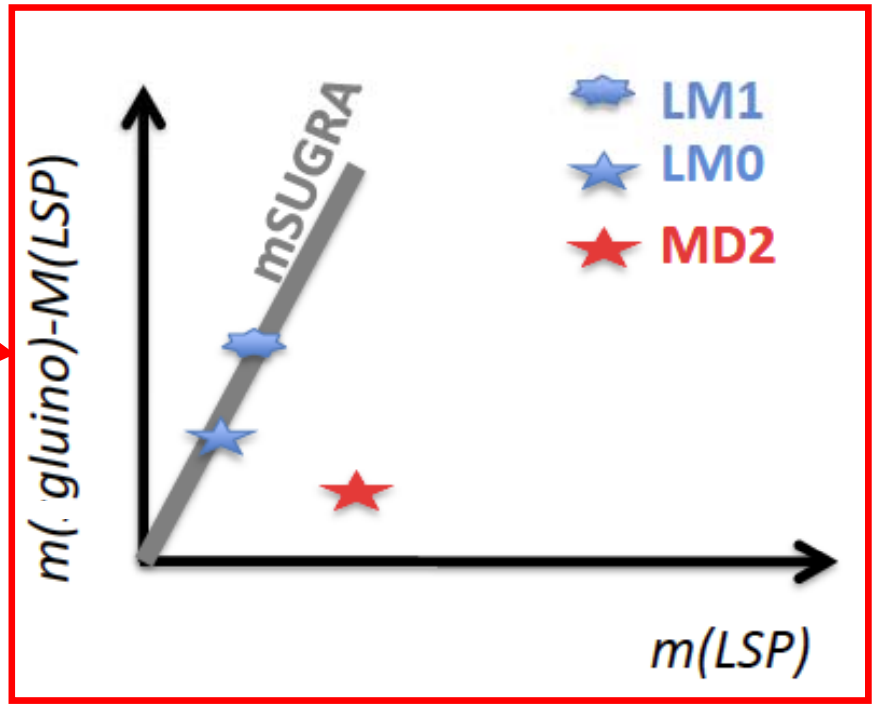
Abstract

Low-energy SUSY and several other theories that address the hierarchy problem predict pair-production at the LHC of particles with Standard Model quantum numbers that decay to jets, missing energy, and possibly leptons. If an excess of such events is seen in LHC data, a theoretical framework in which to describe it will be essential to constraining the structure of the new physics. We propose a basis of four deliberately simplified models, each specified by only 2-3 masses and 4-5 branching ratios, for use in a first characterization of data. Fits of these simplified models to the data furnish a quantitative presentation of the jet structure, electroweak decays, and heavy-flavor content of the data, independent of detector effects. These fits, together with plots comparing their predictions to distributions in data, can be used as targets for describing the data within any full theoretical model.

arXiv:0810.3921v2 [hep-ph] 4 Jun 2009



[1] N.Arkhani-Hamed et al. hep-ph/0703088

What more?

- What more can be done?
  - Theorists with expertise in viable new physics models (including and beyond SUSY) could provide a broad set of sms to be updated as we learn from data.
    - Theorists can also provide tools to model topologies with several generators, different assumptions, etc.
  - Experiments get what they need to optimize searches and even to generalize beyond the models that inspired the sms.

Summary & possible next steps

- Summary
  - It could be useful to form a joint effort of ATLAS, CMS and Theorists to characterize new physics in LHC data
    - A simplified model spectra approach solves many of the problems/constraints faced by experimentalists and is very attractive as an addition to interpreting data in the context of complicated parameter spaces.
- Next steps (a partial list)
  - Fill out the array of topology sets representing viable new physics at the LHC for which this approach makes sense
  - Develop tools to properly confront them to data
  - To agree on common tools, benchmarks, variables, etc. for allowing meaningful comparisons with ATLAS
  - Understand/solve issues associated with communicating results.
    - What goes into publications, what can be exchanged more informally.