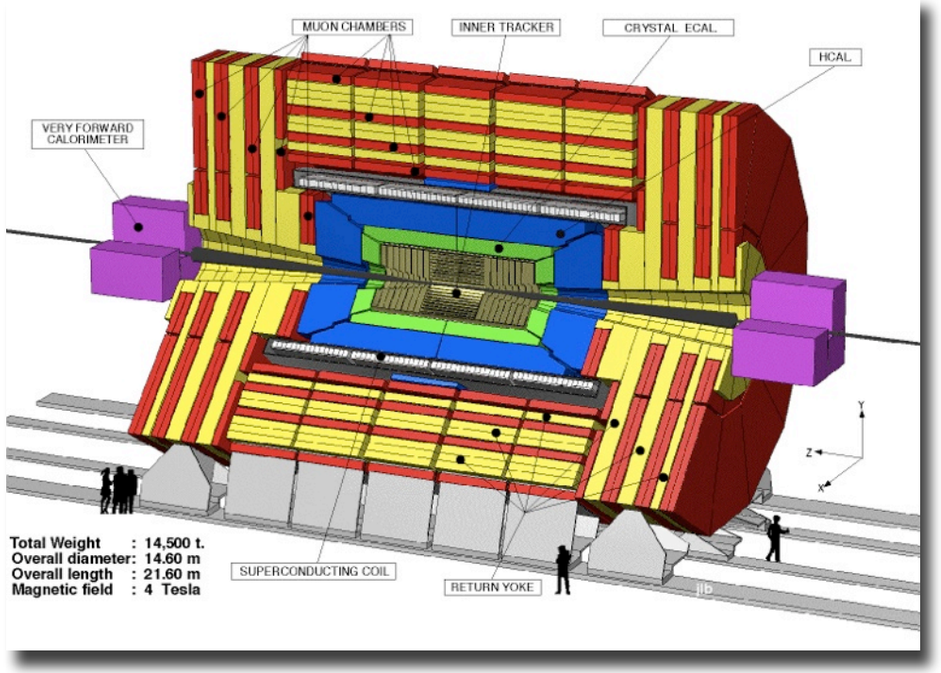
Searches for New Physics at CMS



2nd Workshop on Characterization of New Physics at the LHC

CERN, Nov. 5-6, 2010

F.Ratnikov
Karlsruhe Institute of Technology
on behalf of CMS

Karlsruhe Institute of Technology

CMS Compact Muon Solenoid

Outline

- Signatures CMS is looking at
- Experimental results interpretation
- Simplified models approach

- Referred documents are all available from
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults
  - or may be searched in http://cdsweb.cern.ch/search?cc=CMS

Signatures for Narrow Resonance Searches

Signature	Interpretation	Reference	7 TeV Result
2×jet	generic contact interaction	arXiv:1010.0203 arXiv:1010.4439	✔
2×μ	$Z' \rightarrow \mu^+\mu^-$, RS G	SBM-07-002	
2×e	$Z' \rightarrow e^+e^-$, RS G	EXO-09-006	
t tbar (jets)	$Z' \rightarrow$ t tbar	EXO-09-002	
t tbar (μ+jets)	$Z' \rightarrow$ t tbar	EXO-09-008	
eγ, μγ	excited leptons		

- and few more signatures

Heavy Stable Charged Particles

Signature	Interpretation	Reference	7 TeV Result
Anomalous High Ionization	long living gluino, stop, ...	EXO-10-004	✔
Calorimeter Clusters Beyond Collisions	long living gluino, stop, ...	EXO-10-003	✔

Basic SUSY Signatures

Signature	Interpretation	Reference
3×jet + MET	mSUGRA	CMS-NOTE-10-008
(e,μ) + 3×jet + MET	mSUGRA	CMS Physics TDR
$\mu^{\pm}\mu^{\pm}$, $e^{\pm}e^{\pm}$, $\mu^{\pm}e^{\pm}$	mSUGRA	CMS-NOTE-10-008
($\mu^{\pm}\mu$, $e^{\pm}e$, $e^{\pm}\mu$) + 3×jet + MET	mSUGRA	SUS-09-002
2×γ + MET	GMSB	SUS-09-004
multileptons	mSUGRA	CMS Physics TDR

- The current plan is evolving: we are looking into more universal approaches in addition to mSUGRA reference.
  - see presentations from
  - Mariarosaria D'Alfonso
  - Sanjay Padhi
  - Sue Ann Koay
  - Sunil Somalwar

More Counting Signatures

Signature	Interpretation	Reference	7 TeV Result
2×e + 2×jet + $\not{S}_T$	leptoquarks	EXO-10-005	✔
2×μ + 2×jet + $\not{S}_T$	leptoquarks	EXO-09-010	
$\mu^{\pm}\mu^{\pm}$ + 2×jet	Majorana ν	EXO-09-003	
2×γ	extra dimensions graviton unparticles	EXO-09-004 EXO-09-009 EXO-09-011	
3×lepton (WZ)	technicolor	EXO-09-007	
multileptons + jet	b'	EXO-09-012	
jet,γ + MET	extra dimensions	EXO-09-013 EXO-09-014	

Remarks on Signatures

- ONLY BSM searches are listed, no QCD, EWK, Top, Higgs special signatures
  - there are few more signatures currently under study, but the full list is not too long
  - It takes time (~1 year by interested people) to commission a new search signature for the experiment
- Signature is more than just list of objects - phase space counts
  - Multileptons
    - Exotica: leptons are assumed from W/Z - high momentum
      - techniques are well established with EWK measurements
    - SUSY: leptons are from cascades - recover low momentum is crucial for efficiency
      - need special techniques for recovering reconstruction efficiency and for backgrounds estimations
  - Multileptons in SUSY and Exotica are different signatures

a Bit on Statistics Techniques

- Counting experiments
  - Raw result is model independent
    - Most common for early searches
- Search for resonances
  - assumptions about resonance width/shape
    - assume narrow resonances for early searches
    - Detailed discussion in Jim Hirschauer's presentation
- More sophisticated analysis
  - assumptions about particular distribution details
    - usually needs more efforts to justify in early searches

Confidence Intervals

- Different ways of building intervals in absence of systematics
  - Frequentist (a.k.a. Neyman's confidence belt)
  - Bayesian
  - Likelihood ratio variation
- Different ways of treating systematics
  - Bayesian - integrate over nuisances
  - Re-maximizing Likelihood (a.k.a. profile likelihood)
- Work around downward fluctuations
  - CLs, etc.

- The approach actually used to build Confidence Interval for the particular analysis is some combination depending from
  - details of the search
  - details of statistics
  - (presence of signal)
  - personal preferences
- 95% C.L. results are not directly combinable! - systematics need unfolding
- 95% C.L. results obtained in different approaches are not directly comparable!
  - procedural details should be taken into account when comparing or combining results
  - on practice however all (reasonable) approaches produce similar numbers
    - No signal evidence → similar limits
    - Signal evidence → similar intervals
    - Grey area → speculative anyway
- Note PHYSAT'2011 workshop Jan. 17-20, 2011 @ CERN

Experimental Results Interpretation

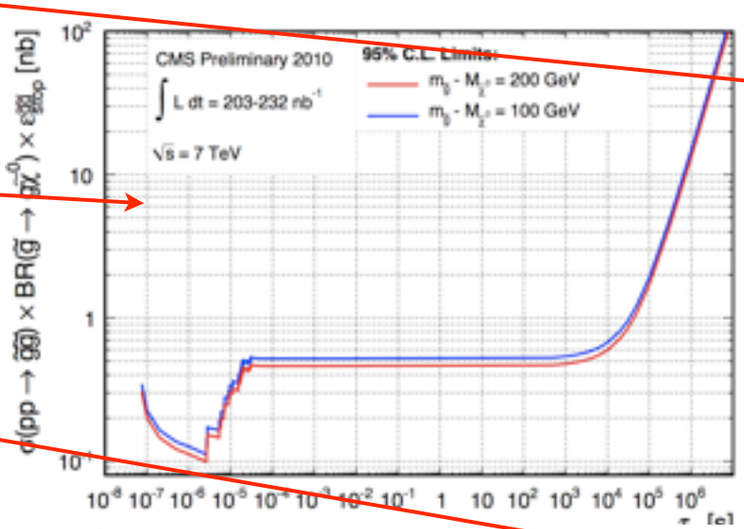
Credits to F. Würthwein who elaborated this topic on the SLAC workshop

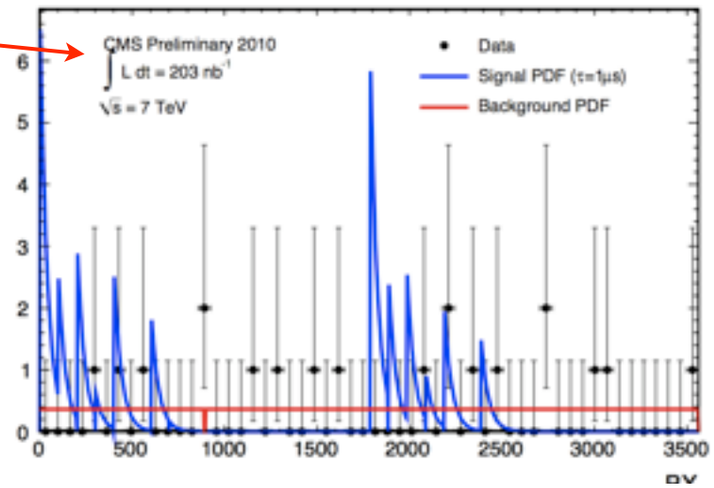
- Consider Stopped Gluino search as a study case (EXO-10-003)
  - Signature
    - energy cluster in the calorimeter E>50GeV
    - at time when no collisions and other activity is expected in the detector
  - Backgrounds
    - long story taking 80% of the search description
      - cosmics muons
      - beam halo muons
      - beam-gas interactions
      - trigger pre-fires
      - instrumental noise

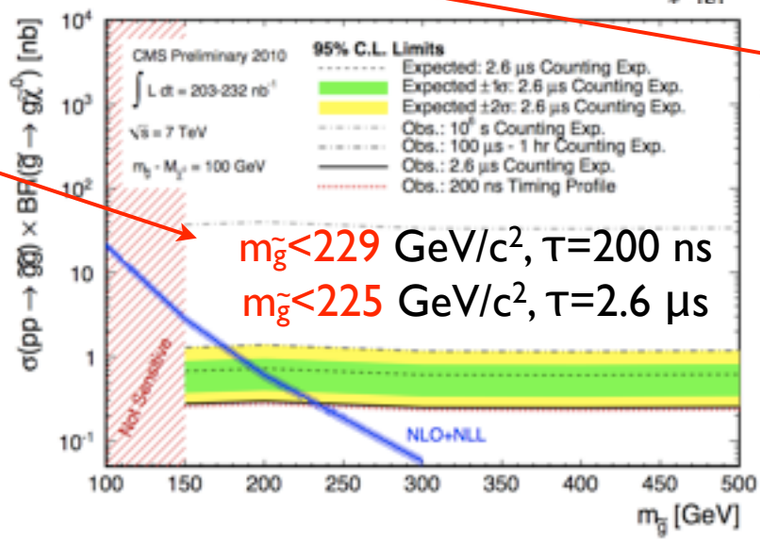
Add Model Dependency: Step by Step

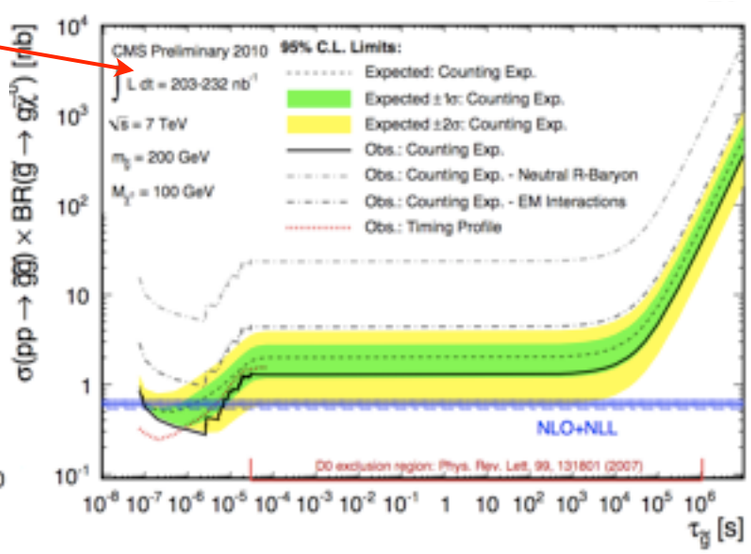
- no dependency - raw numbers
- lifetime
- decay mode, energy deposited
- R-hadrons mass spectra, interaction with material
- gluino production cross section, decay branching
- Ironically, two last, most model dependent results are usually advertised

Lifetime [s]	Expected Background ($\pm$ stat $\pm$ syst)	Observed
1e-07	$0.15 \pm 0.04 \pm 0.05$	0
1e-06	$1.8 \pm 0.5 \pm 0.5$	0
1e-05	$11.7 \pm 3.2 \pm 3.5$	8
1e-04	$28.3 \pm 7.8 \pm 8.5$	19
1e-03	$28.3 \pm 7.8 \pm 8.5$	19
1e+03	$28.3 \pm 7.8 \pm 8.5$	19
1e+04	$28.3 \pm 7.8 \pm 8.5$	19
1e+05	$28.3 \pm 7.8 \pm 8.5$	19
1e+06	$28.3 \pm 7.8 \pm 8.5$	19







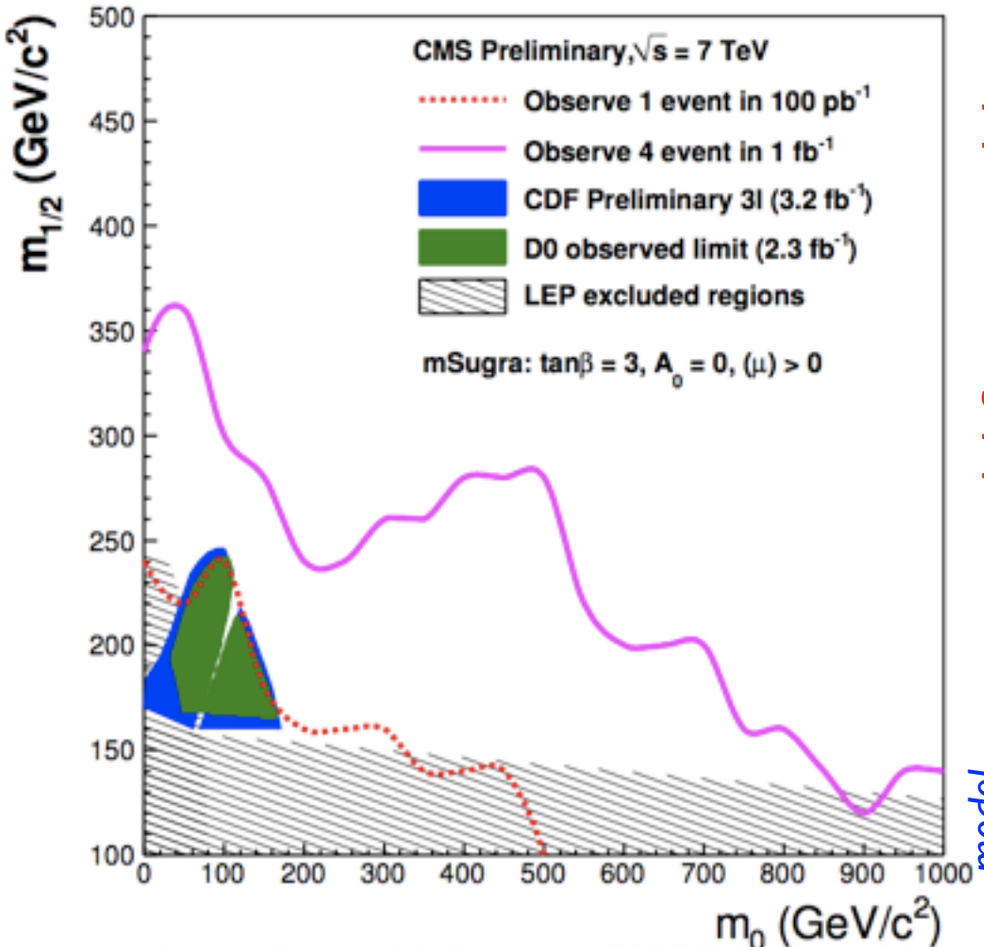


Reference Models

- Experimentalists attempt to present results in different formats:
  - From: most model independent, but hardly usable raw results
  - To: easy understandable, but very model dependent “physics” results
- To compare results of different experiments need “reference” model
  - e.g. gluino for “stopped HSCP” search
  - e.g. mSUGRA for SUSY searches
- We expect the theory community to advise us which reference model for every signature is the most usable for further interpretation
  - This could also set a reference to compare and combine results of different experiments

Importance of Backgrounds

- 95% (or even more) of experimental efforts on measurement of the particular signature is taken by reliable background estimations, efficiencies calculations, systematics studies, etc.
  - Mostly irrelevant to the model producing the signature under study
    - Providing the signature covers model signal with reasonable efficiency



projected sensitivity to mSUGRA signal in same-sign di-leptons signature (MC)

- Example: SUSY scan for counting experiment

generic, valid for any models

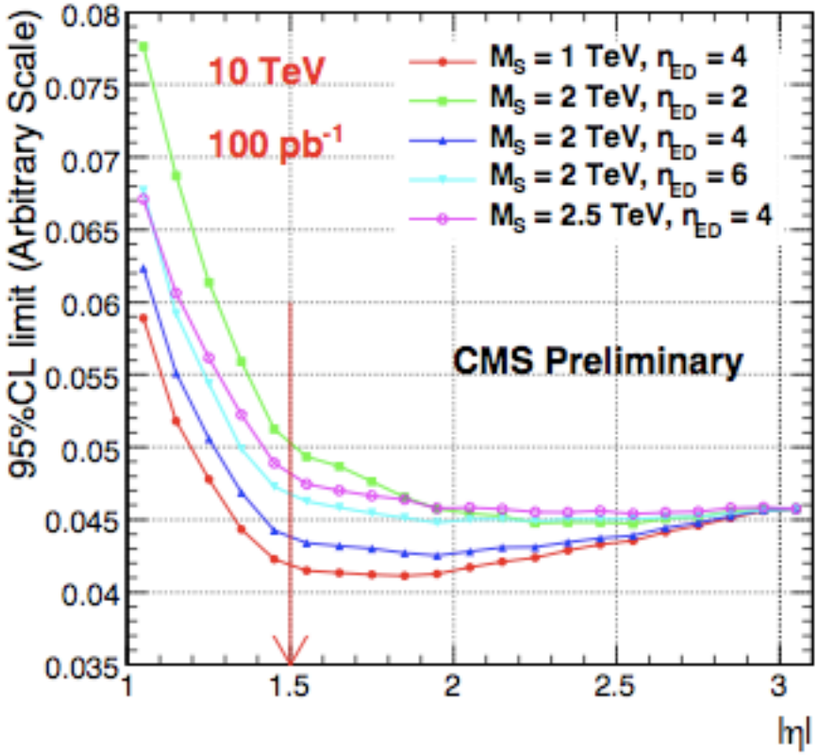
- Select signature and reference model
- Develop selection with reasonable efficiency to the reference signal, and good SM and other backgrounds suppression
- Measure signature efficiency
- Measure expected backgrounds
- Count observed events, compare with expected background
  - If consistent, set upper limit on $\sigma \times L_{int} \times \varepsilon$
  - If inconsistent
    - double, triple cross checks
    - low limit on $\sigma \times L_{int} \times \varepsilon$ (a.k.a. discovery)

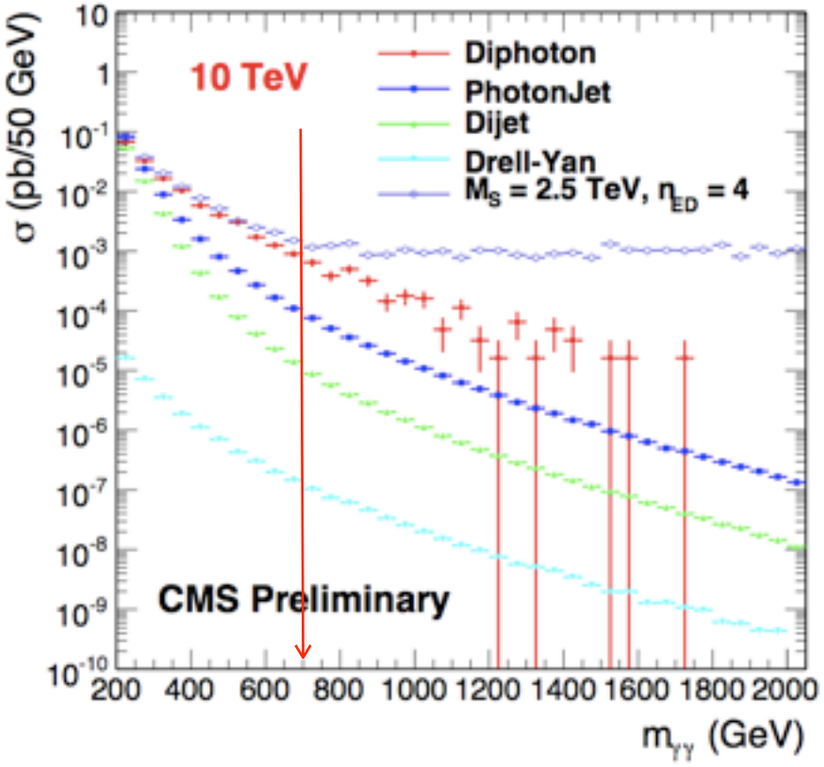
model dependent

- Run parameters scan, get $\sigma \times \varepsilon$ for different parameters of the model
- Draw exclusion curve corresponding to generic $\sigma \times L_{int} \times \varepsilon$ and model dependent $\sigma \times \varepsilon$

Measurement Interpretation

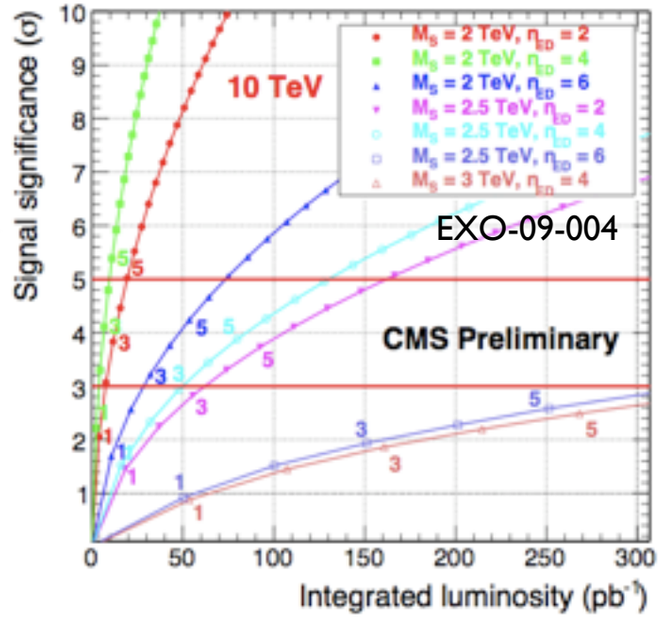
- E.g. di-photon signature, EXO-09-004
  - Counting of photon pairs with big invariant mass
  - Selection optimized for Large Extra Dimensions search

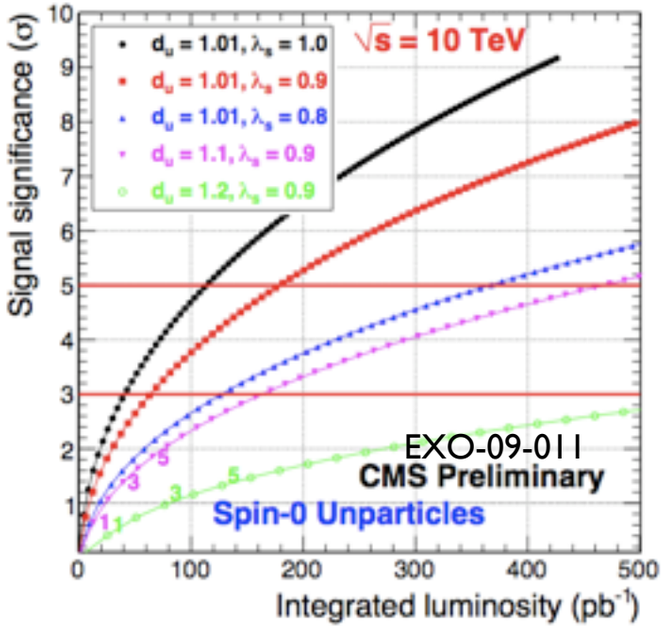


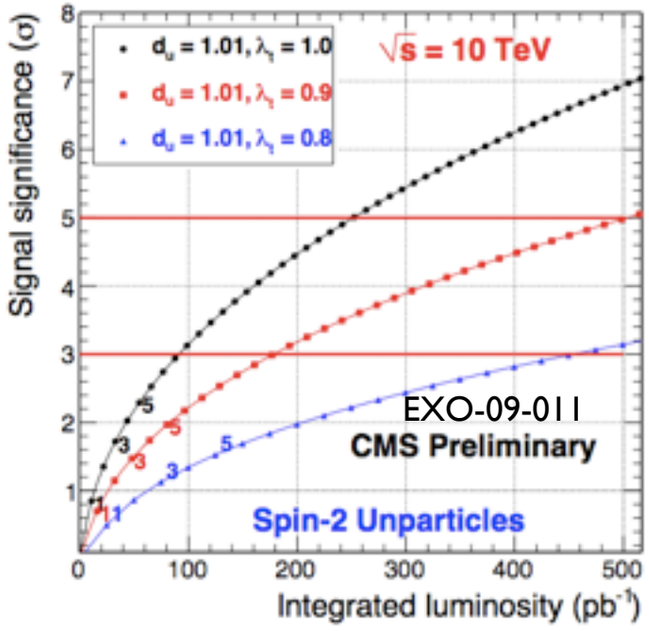


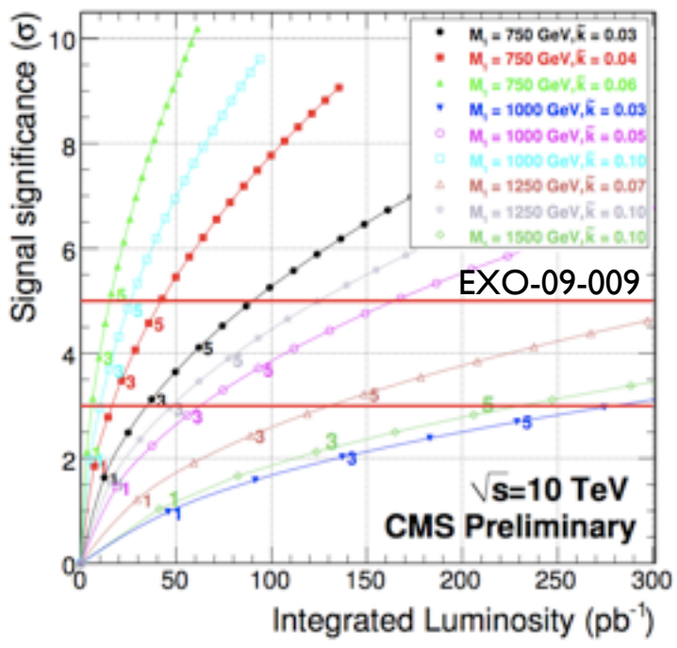
Physics Interpretation of 2γ Signal

- Large Extra Dimensions
- Randall-Sandrum Graviton
- Scalar and Tensor Unparticles



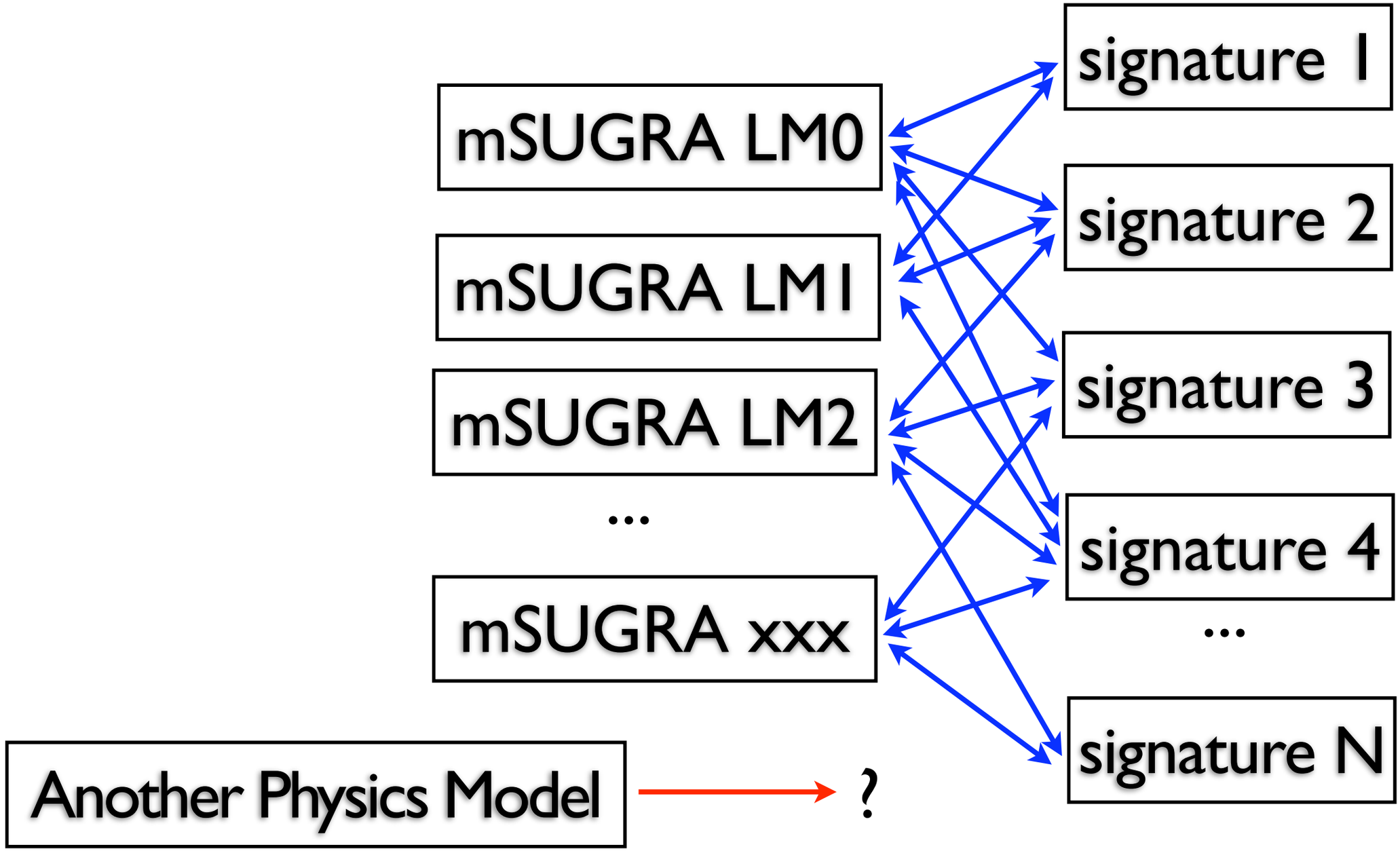






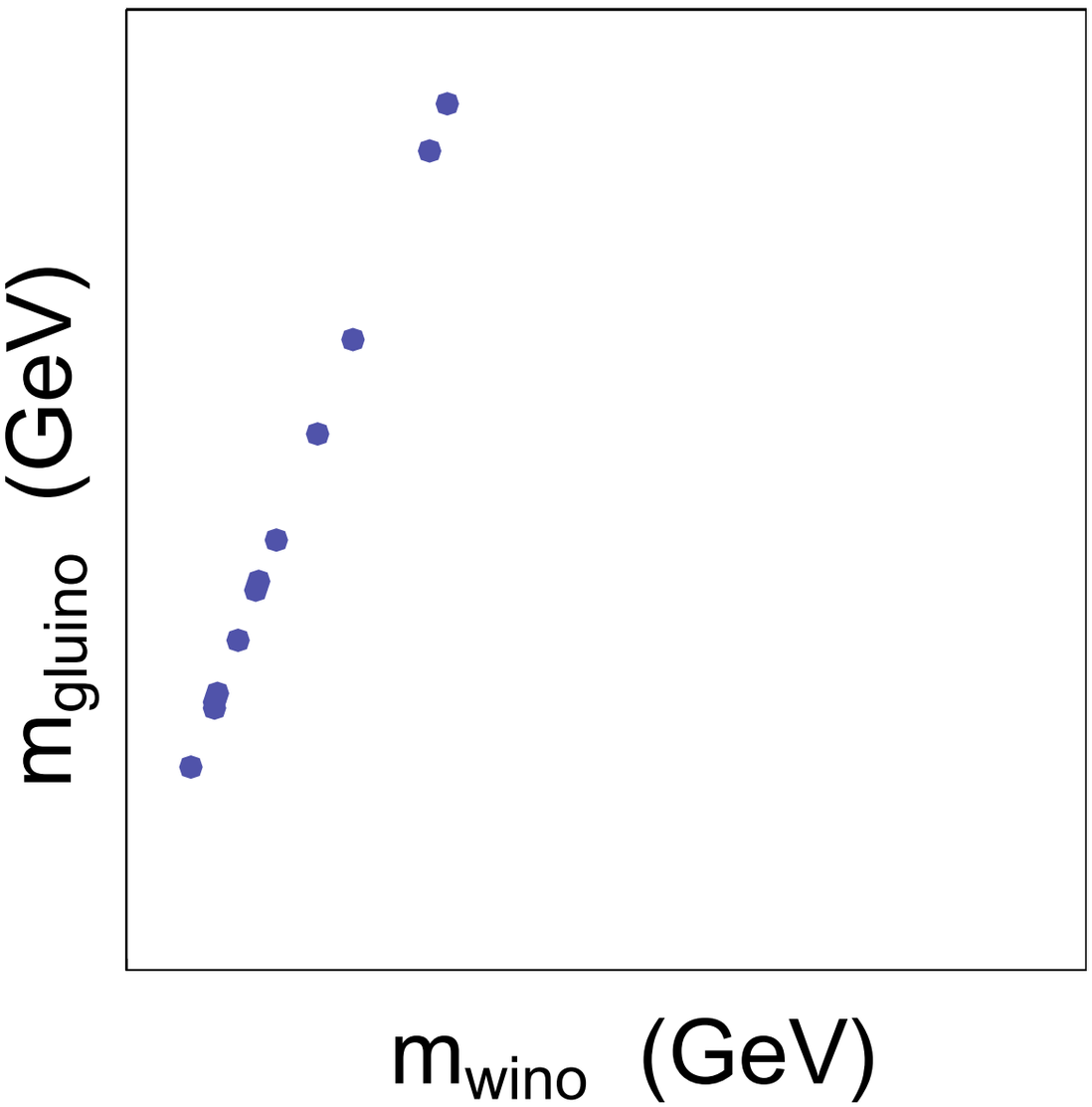
- One measurement produces limits on several specific models
  - Using simplified di-photon model would generalize them all

Current Physics Model Approach in SUSY searches



- signatures to study are inspired by reference mSUGRA models
- measurements are treated in terms of mSUGRA model parameters

CMS SUSY Reference Models

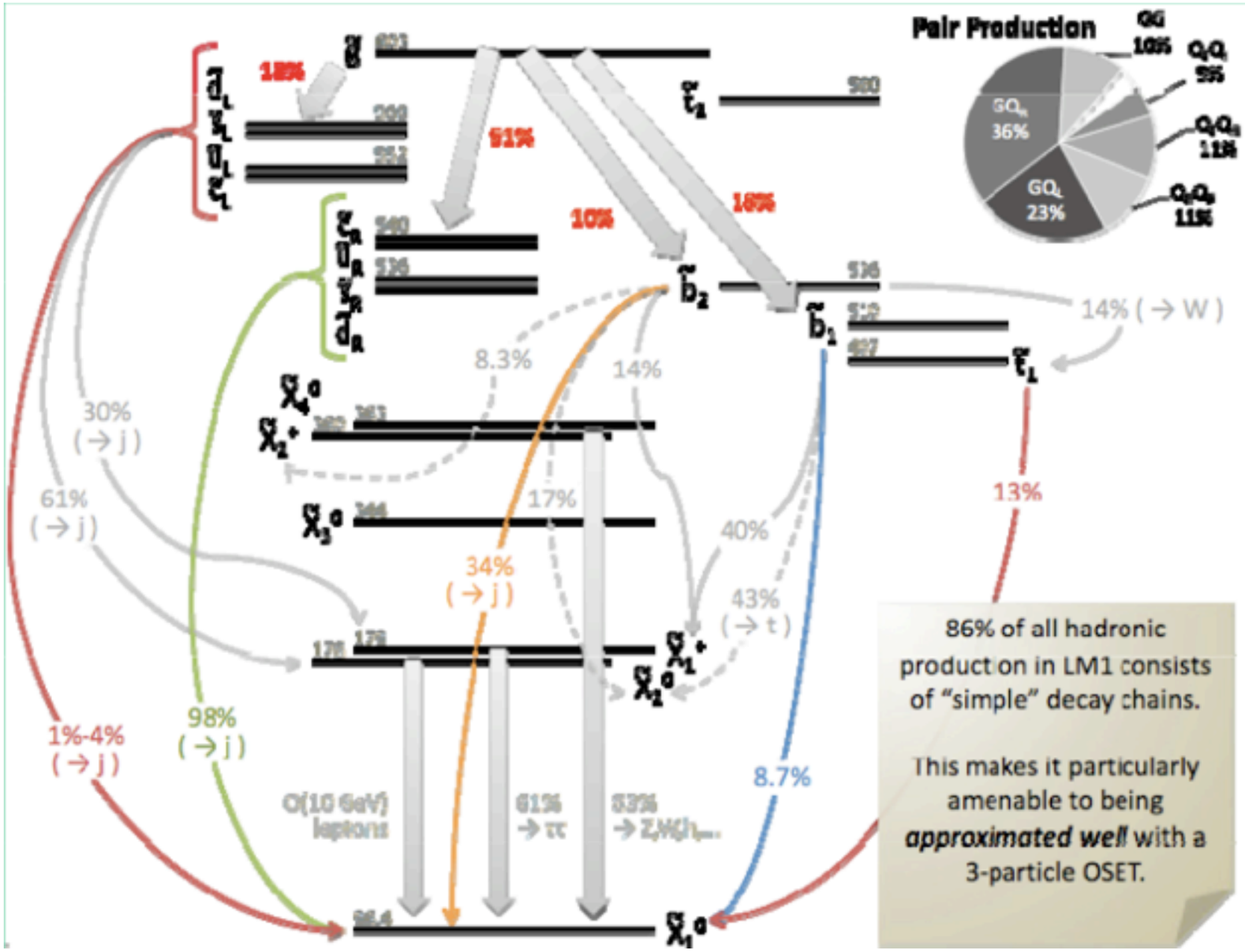


- Set of mSUGRA Reference Models poorly covers full space of different Physics Models

Simplified Models

- Represent the most pronouncing features of the signatures
- Contain minimal set of most relevant parameters
- If we see no excess in the signature
  - Specifies which features of Physics Models are excluded
- If we see new physics
  - Specifies effective parameters for Physics Model

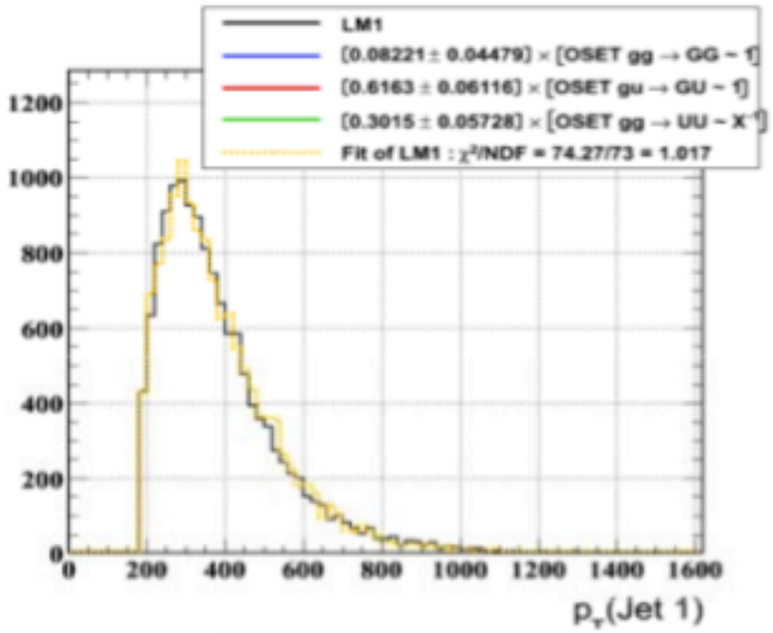
Example: All Hadronic Decays @ LM1*

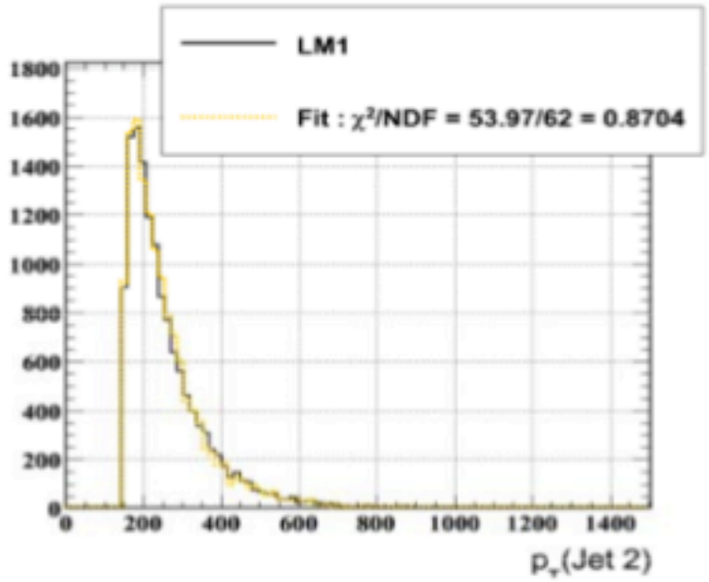


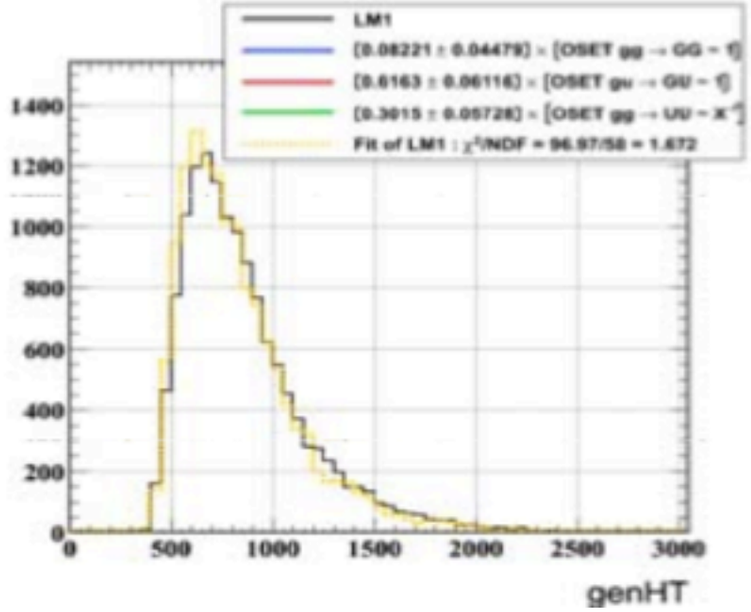
- 3 essential parameters: M(gluino) drives the cross section, two mass differences drive spectra

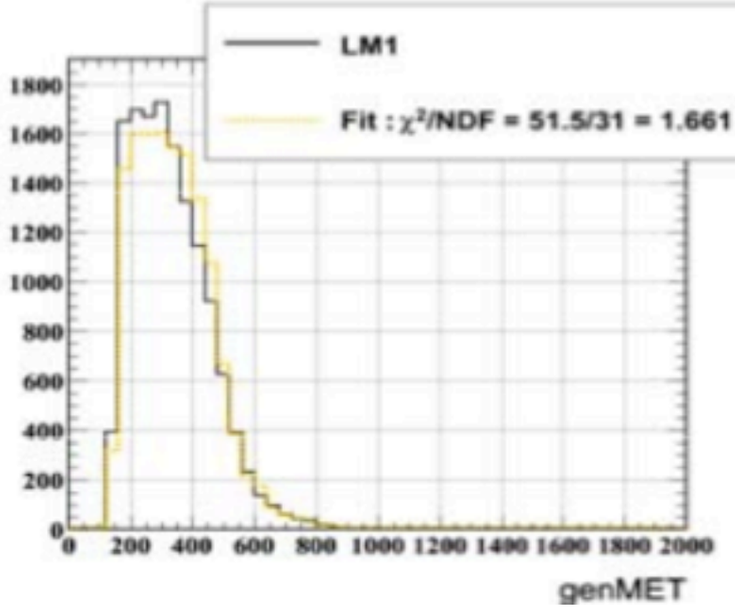
*LM1 = one of reference points in mSUGRA parameter space

Simplified vs mSUGRA@LM1



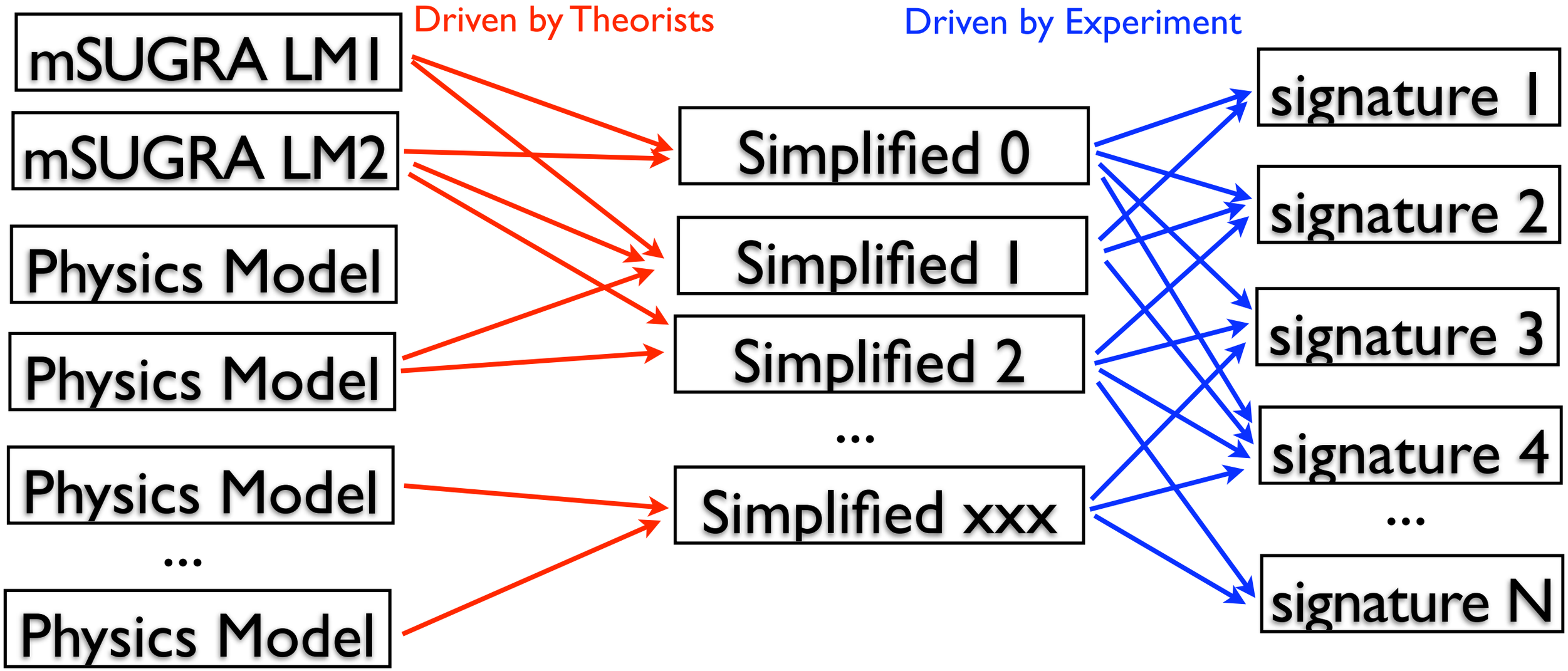






- Pretty good agreement on Generator level and with high statistics
  - Instrumental effects and actual statistics fluctuation will smear distributions

Simplified Models Approach



- Simplified Models are inspired by Physics Models
- Measurements are treated in terms of Simplified Models by the experiment
- Results for Simplified Models are projected to the Physics Model by the theorist
- Exclusive list of Simplified Models provides comprehensive basis in space of possible Physics Models
  - Does such basis set of Simplified Models exist?

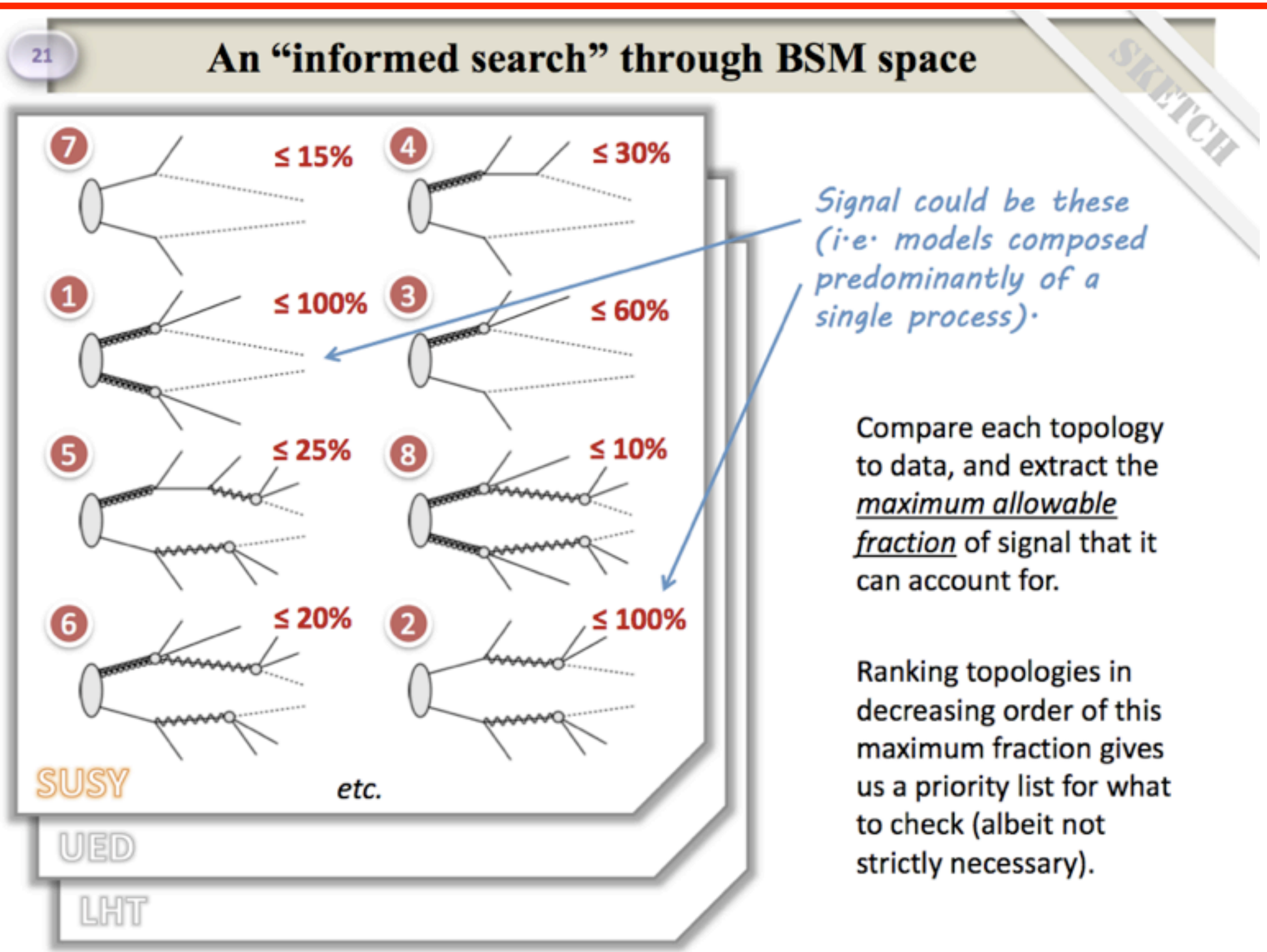
What Is It Useful For?

- With any Reference Models set
  - Experiments can convert raw measurements into parameters for standard set of reference models
  - Theorists can approximately extrapolate parameters from evaluated Reference models to particular Physics Model
    - Precise combining Physics Model from several Reference Models requires unfolding of correlated backgrounds and systematic uncertainties
      - This can be correctly done only by experiments
  - ... or can not, if intersection between Reference and Physics models is small
- Reference Models set combined from Simplified Models is special
  - the number of models in the set is minimal, and covers the maximum phase space of considered Physics Models
- The choice of Reference Models set may be driven by the Theory Community
  - Such set needs to be explicit and of limited size

Ongoing studies

- Just list those to be presented on the workshop

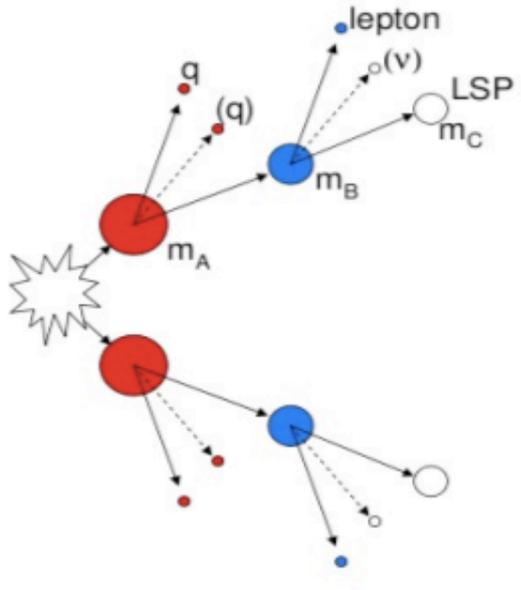
Characterization of BSM Signals



- In Sue Ann's talk later today

Direct model parameters ↔ observables relation

Simplified Models for early searches



m_A drives cross section

Δm_{AB} drives HT

Δm_{BC} drives lepton's p_T

MET is large as long as Δm_{AC} is large

Represent limits based on:

- m_A Vs m_c - Sensitive to strong production scale
- m_A Vs m_B - Sensitive to strong (m_A) and electroweak (m_B) scales
- m_A Vs Δm_{AB} – Sensitive to reconstructed quantities like HT (SumJetPT)
- m_A Vs Δm_{BC} – Sensitive to reconstructed quantities like lepton(s) p_T(s)

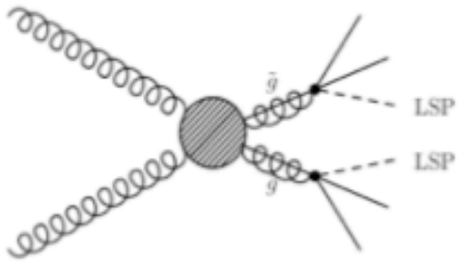
Nov. 5th 2010, *Characterization of new physics at the LHC, II*. CERN 12 Sanjay Padhi

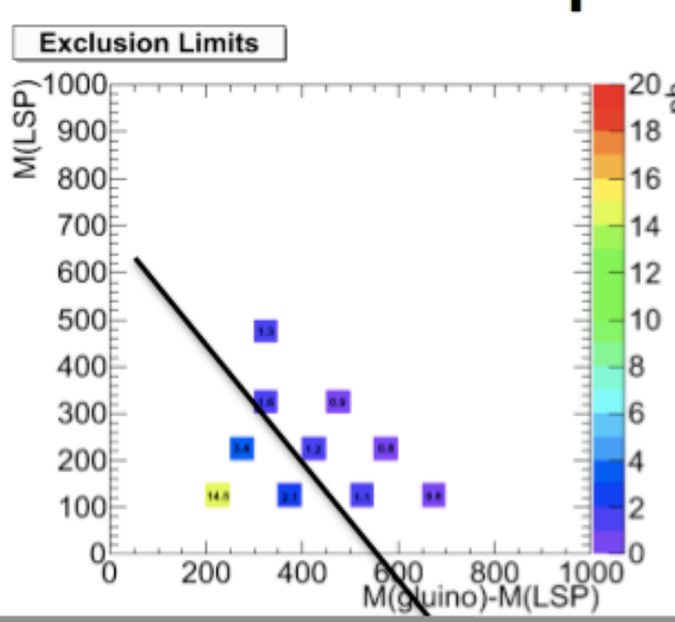
- This and more discussions in Sanjay's talk later today

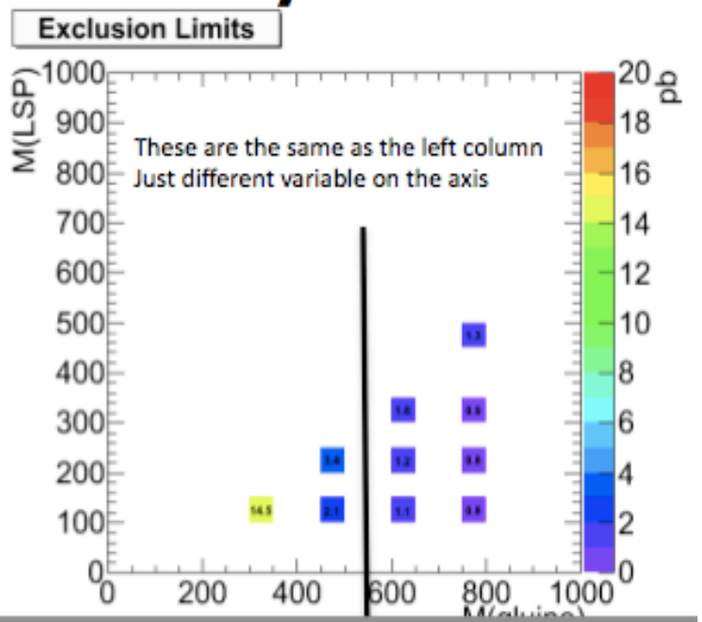
Practical Exercise with Simplified Models

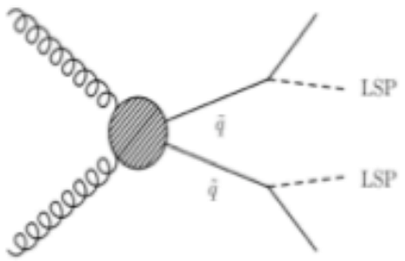
Limits for simple decay

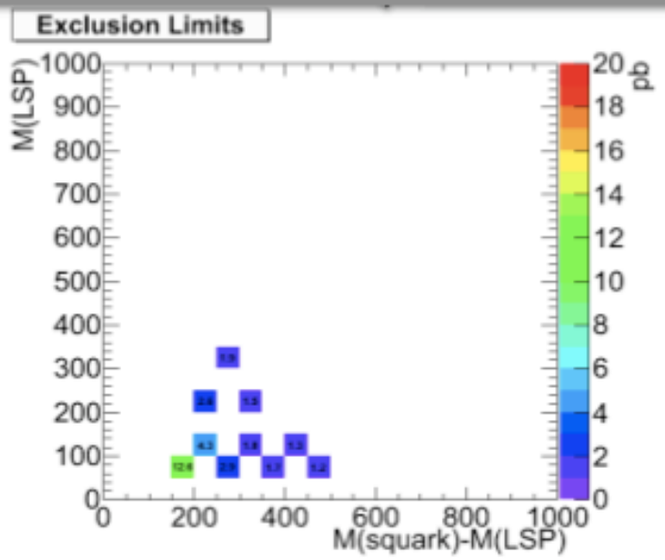
highMHT

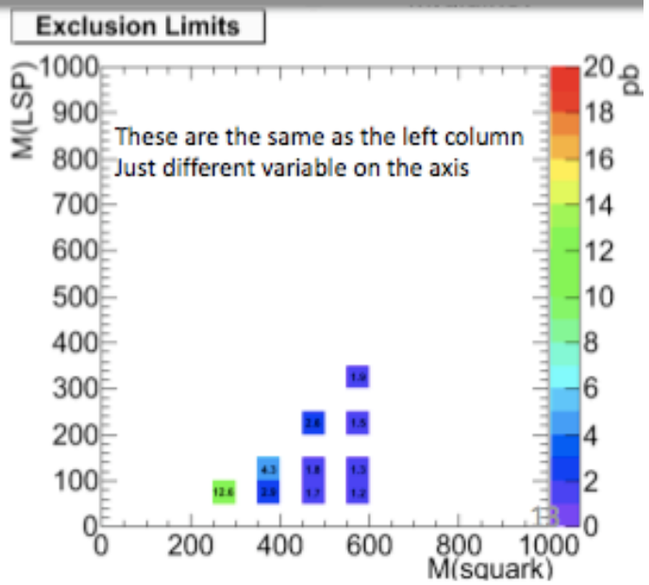












- This and more results in Mariarosaria's talk tomorrow 9 am
  - Wake up early, don't be late!

Summary

- Exciting time for experimentalists: start pushing the boundaries
- Exciting time for theorists: moment of truth for various models
- CMS is looking on exclusive list of different signatures
- Need unified reference models for those signatures
  - deliver results for further interpretations
  - compare results, combining results
- Different models with signatures already being analyzed may be tested with not much extra efforts from the experiment
  - Simplified Models approach extends rather than substitutes the current Physics Models approach