not-SUSY

first steps after an LHC discovery

Joseph Lykken

Fermilab

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theorists are trouble

outline

- interpreting a discovery
- dark matter at the LHC
- missing energy look-alikes
- discriminating look-alikes at the moment of discovery
- case study: discriminating SUSY from not-SUSY
- mT2 on steroids
- what about neutrinos?

interpreting a discovery

- much detailed work has been done on the zeroeth order characterization of new physics
- and on the second order characterization of new physics
- not enough has been done on the first order characterization
- i.e. how much can you say about the new underlying theory at, or close to, the moment of discovery?

the LHC look-alike problem

"lots of models now, most will be Dead On Arrival after the first data" (Ian Hinchliffe)

- any signal in the first data ->many possible explanations
- dataset+analysis ->signal-> a set of "look-alike" models
- our initial job, post-discovery, is to begin discriminating these look-alikes

“20 questions” at the LHC

- if there are N models in the theory space, do we need N-1 successful binary comparisons to find the true model?

- as the game “20 questions” illustrates, a reasonably clever person can find the true answer with of order Log(N) comparisons

- to do this efficiently at the LHC, we will need to know a lot about both the theory space and the data

- as in the game “20 questions”, the answers to the first few questions determines what questions you ask later

- design the first few questions!!

what is the LHC for?

- the LHC was designed to find the Higgs boson and look for other new TeV scale physics like supersymmetry

- however dark matter has become as important a part of the LHC physics program as the Higgs

- in particular, we hope to use the LHC to manufacture dark matter particles from high energy collisions, and thus to study their properties as we do ordinary elementary particles

Triumph of the WIMP?

- one possibility is that dark matter particles are WIMPs (Michael S. Turner)
- this would explain why they are cold and dark
- we can say more by assuming that the WIMPs were produced thermally from a standard Big Bang cosmology:

Michael S. Turner (actual size)

By integrating the Boltzmann equation for the WIMP density through this era of 'freeze-out', it is possible to work out how much WIMP matter is left over:

$$\Omega_W = \frac{s_0}{\rho_c} \left(\frac{45}{\pi g_*} \right)^{1/2} \frac{x_f}{m_{\rm Pl}} \frac{1}{\langle \sigma v \rangle}$$

We know the parameters. Put in the numbers:

The cross section for WIMP annihilation is

$$\langle \sigma v \rangle = 1 \text{ pb} = \frac{\pi \alpha^2}{8 m^2} \quad \text{for m = 100 GeV}$$

This points to the length scale of weak interactions.

this is a completely independent cosmological argument for the LHC!

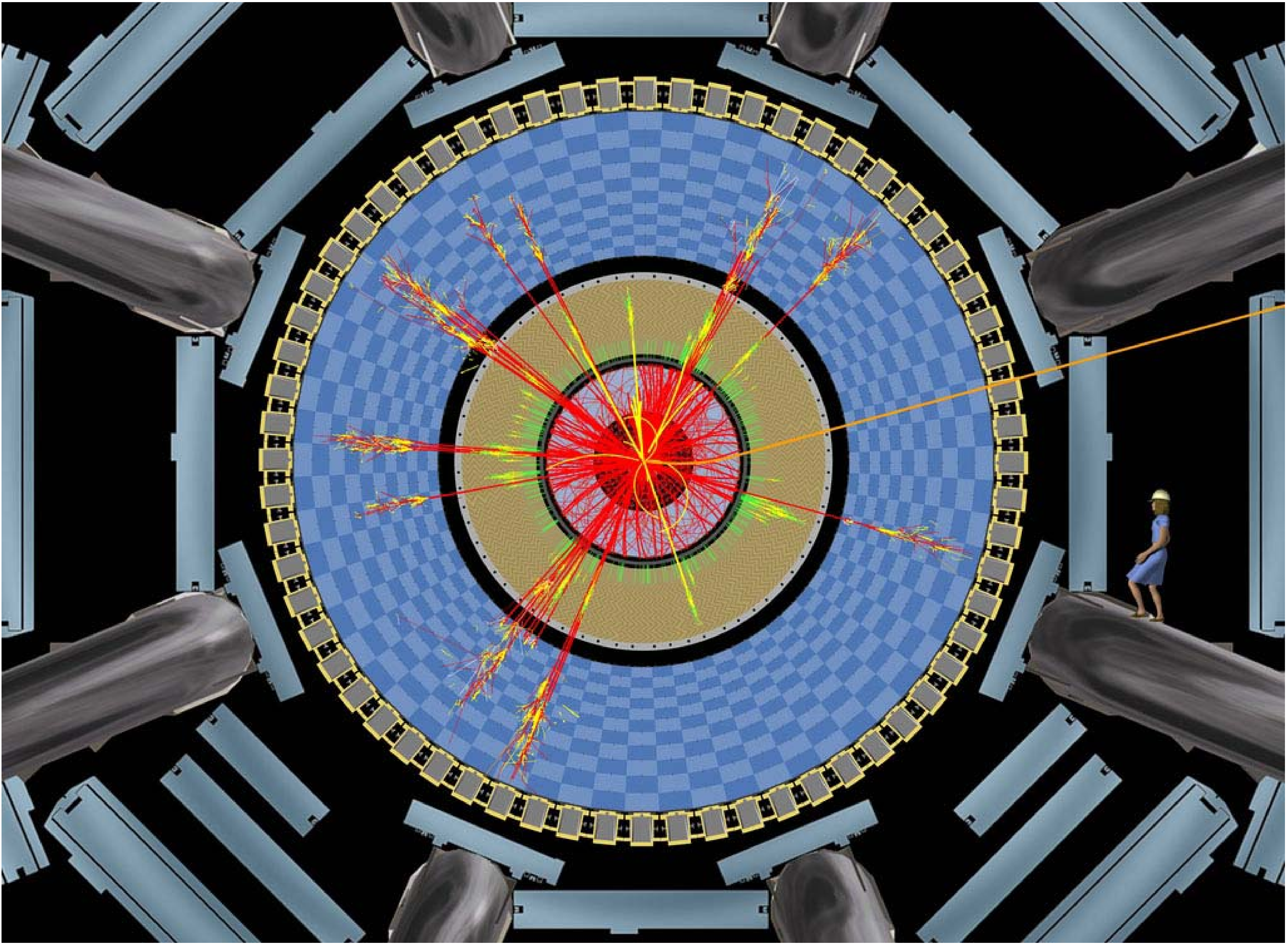
producing dark matter at LHC

- WIMP dark matter particles are the lightest particles carrying some (new) conserved quantum number
- this means that at LHC you will always produce dark matter particles in pairs
- probably the LHC will produce heavier unstable relatives of the dark matter particles, that decay into them
- study it all to figure out the role of dark matter in the bigger picture of particle physics and the big bang

- this opportunity for the LHC is largely independent of the underlying theory for the dark matter particles
- could be some form of SUSY
- or it could be an extra dimensional model
- or it could be a “little” Higgs or composite Higgs model
- or ...

missing energy

- one small problem: even if you produce WIMP dark matter particles as the LHC, they won’t interact with the LHC detectors
- in this sense they are like neutrinos in collider experiments, whose presence is inferred by measuring the visible products of the collision
- the smoking gun of WIMP dark matter particles at the LHC is collisions with large missing transverse energy



first questions for a missing energy signal

- how many invisible particles per event?
- are they massive or nearly massless?
- are they associated with top, W, or Z decays?
- how many kinds of parent particles?
- how many kinds of decay chains?

missing energy from SUSY

• SUSY models already provide too many possibilities

• several choices for the WIMP LSP: bino, wino, higgsino, singlino, the spin 3/2 gravitino, or a spin 0 sneutrino

• at the LHC, an invisibly decaying or long-lived NLSP can be mistaken for an LSP

• with R-parity breaking, can still get a missing energy signal from neutrinos

missing energy from not-SUSY

many not-SUSY models also have WIMPs, stabilized by the same discrete symmetry that suppresses tree level contributions to precision electroweak and flavor-changing processes

- Little Higgs: the dark matter candidate is a spin 1 vector boson partner stabilized by T parity;

- 5-dimensional Universal Extra Dimensions: the dark matter candidate is a spin 1 vector boson partner stabilized by KK parity

- 6-dimensional UED: the dark matter candidate is a spin 0 vector boson partner stabilized by KK parity

more missing energy from not-SUSY

• models with large extra dimensions produce missing energy from single emission of a massive graviton

• hidden valley or unparticle models can produce missing energy from multiple hidden sector particles

• models with new heavy particles decaying to neutrinos, either directly or via top quarks, W's or Z's

missing energy look-alikes

• a discovery plan for the LHC should include strategies to begin discriminating missing energy look-alikes

• “look-alike” is defined by a particular experimental analysis, not by comparing lagrangians or mass spectra

• direct measurements of spins, charges, and couplings at the LHC can definitively resolve most look-alike questions, but these could come roughly a decade later, as they did e.g. for top quarks

• the “20 questions” process will not wait around for these measurements!

discriminating look-alikes at the moment of discovery

- our recent study indicates that, at the moment of an early missing energy discovery at the LHC, it will be possible to discriminate many SUSY from not-SUSY look-alikes

J. Hubisz, JL, M. Pierini, M. Spiropulu, arXiv:0805:2398

- this will not provide a definitive answer to “is it SUSY?”, but it can provide essential early guidance

- since other look-alikes may not be immediately eliminated, better measurements and more clever strategies will certainly be called for

missing energy discovery scenario with ~100 pb-1

- we will assume that a >5 sigma excess is observed in an inclusive missing transverse energy (MET) analysis with the first 100 pb-1 or less of understood LHC data

- this should be the case if there is a BSM source of large missing energy + energetic jets with a cross section of at least a few pb.

- we want to design a strategy to rapidly narrow the list of candidate theories at, or close to, the moment of discovery

- we want to do this taking into account uncertainties of the LHC experiments during the 100 pb-1 era

Table 4.2: The $E_{\mathrm{T}}^{\mathrm{miss}}$ + multi-jet SUSY search analysis path

Requirement	Remark
Level 1	Level-1 trigger eff. parameter.
HLT, $E_T^{miss} > 200\,\mathrm{GeV}$	trigger/signal signature
primary vertex ≥ 1	primary cleanup
$F_{em} \geq 0.175$, $F_{ch} \geq 0.1$	primary cleanup
$N_j \geq 3$,$\lvert\eta_d^{1j}\rvert < 1.7$	signal signature
$\delta\phi_{min}(E_T^{miss} - jet) \geq 0.3$ rad, $R1, R2 > 0.5$ rad, $\delta\phi(E_T^{miss} - j(2)) > 20°$	QCD rejection
$Iso^{ltrk} = 0$	ILV (I) $W/Z/t\bar{t}$ rejection
$f_{em(j(1))},\ f_{em(j(2))} < 0.9$	ILV (II), $W/Z/t\bar{t}$ rejection
$E_{T,j(1)} > 180\,\mathrm{GeV}$,$E_{T,j(2)} > 110\,\mathrm{GeV}$	signal/background optimisation
$H_T > 500\,\mathrm{GeV}$	signal/background optimisation
SUSY LM1 signal efficiency 13%	

CMS Physics TDR Vol. II, CERN/LHCC 2006-021

- **we will assume that the discovery is made with this analysis; the look-alike analysis depends on the form of the discovery analysis**
- **the signature is large MET plus >= 3 jets; no leptons are required**

Table 3. All-hadronic selected low mass SUSY and Standard Model background events for 1 fb^{-1} from CMS

Signal (LM1)	6319
$t\bar{t}$/single t	56.5
$Z(\rightarrow \nu\bar{\nu})$+ jets	48
$(W/Z,WW/ZZ/ZW)$ + jets	33
QCD	107

- **having assumed this analysis we can also use this estimate of the residual SM backgrounds after all cuts**
- **these backgrounds and the background rejection are in line with what was actually observed at the Tevatron**

detector simulation

- the results shown here used a parametrized generator-level simulation tuned to reproduce the published cut-by-cut signal efficiencies in the CMS Physics TDR

Cut/Software	Full	Fast
Trigger and $E_T^{\text{miss}} > 200$ GeV	53.9%	54.5%
$N_j \geq 3$	72.1%	71.6%
$\lvert\eta_d^{j1}\rvert \geq 1.7$	88.1%	90.0%
QCD angular	75.6%	77.6%
$Iso^{lead\ trk} = 0$	85.3%	85.5%
$E_{T,1} > 180$ GeV, $E_{T,2} > 110$ GeV	63.0%	63.0%
$H_T > 500$ GeV	92.8%	93.9%
Total efficiency	12.9%	13.8%

reconstructed objects

Look-alike studies designed for LHC after 10, 100, or 1000 fb-1 have the luxury of assuming that everything in an event is reconstructable. This may not realistic for the 100 pb-1 era.

We will assume the robust availability only of those physics objects necessary for the discovery itself:

- MET, in the range roughly 200 GeV <~ MET <~ 700 GeV
- jets, with uncorrected ET>30 GeV and |eta| < 3
- muons, not necessarily isolated but with pT > 20 GeV

Multi-lepton techniques will give powerful handles on the underlying physics; we are intentionally orthogonalizing from these to look at the most difficult case

populating the theory space

- ideally, the look-alike models should be drawn from a sampling of the entire volume of theory space relevant to an early LHC missing energy discovery

- we don’t really know how to do this!

- a practical approach is to draw from as many different classes of models as we can, limited by the available event generators for our study we used three classes of models

- the CMS mSUGRA benchmarks generated by Isajet 7.69 + Pythia 6.4

- general low scale MSSM models generated by Suspect 2.3.4 + MadGraph 4.2 + Pythia 6.4

- Little Higgs with T parity implemented in MadGraph 4.2 + Pythia 6.4

defining the look-alikes

We define a look-alike by first defining:

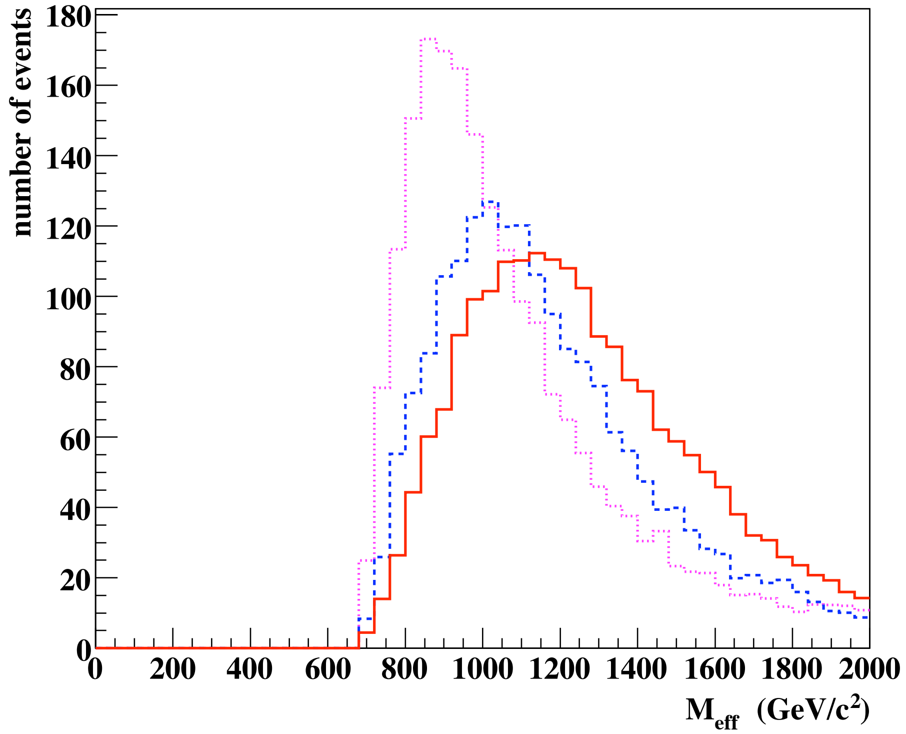
- an inclusive signature or, more simply, a trigger sample
- a set of analysis cuts
- an integrated luminosity
- a detector in which all this is happening
- estimated backgrounds + systematics for this analysis
- Two models that give the same signal (within 2 sigma) are defined to be look-alikes

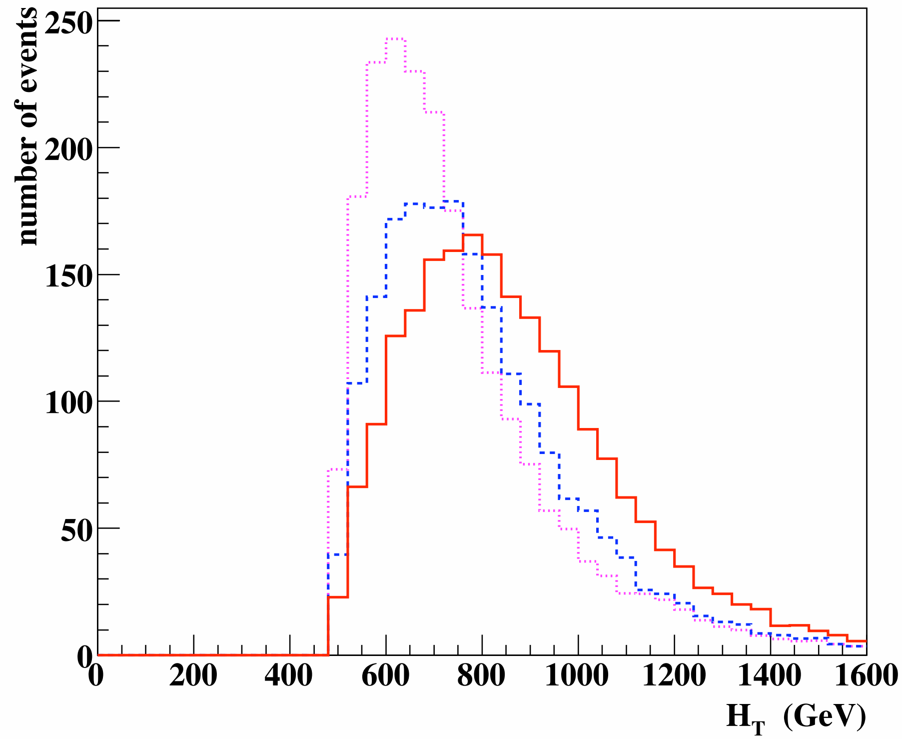
what are the discriminating observables?

•we want to identify experimental observables that are the best and most robust discriminators of a group of look-alikes

• we tried out a large number of observables, but required that all of them be defined as ratios of inclusive counts, e.g.

r(4j)(3j) = ratio of the number of events (after selection) with at least 4 jets to the number of events with at least 3 jets



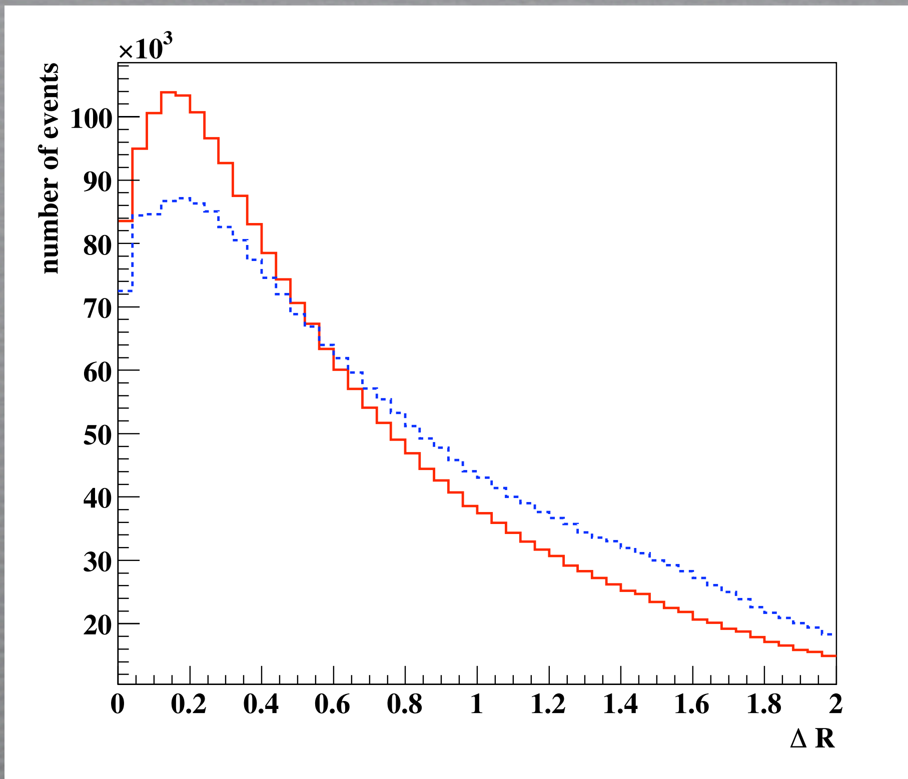


•kinematic distributions like Meff and HT have peaks and tails, but the details of theses shapes have uncertainties that are hard to estimate

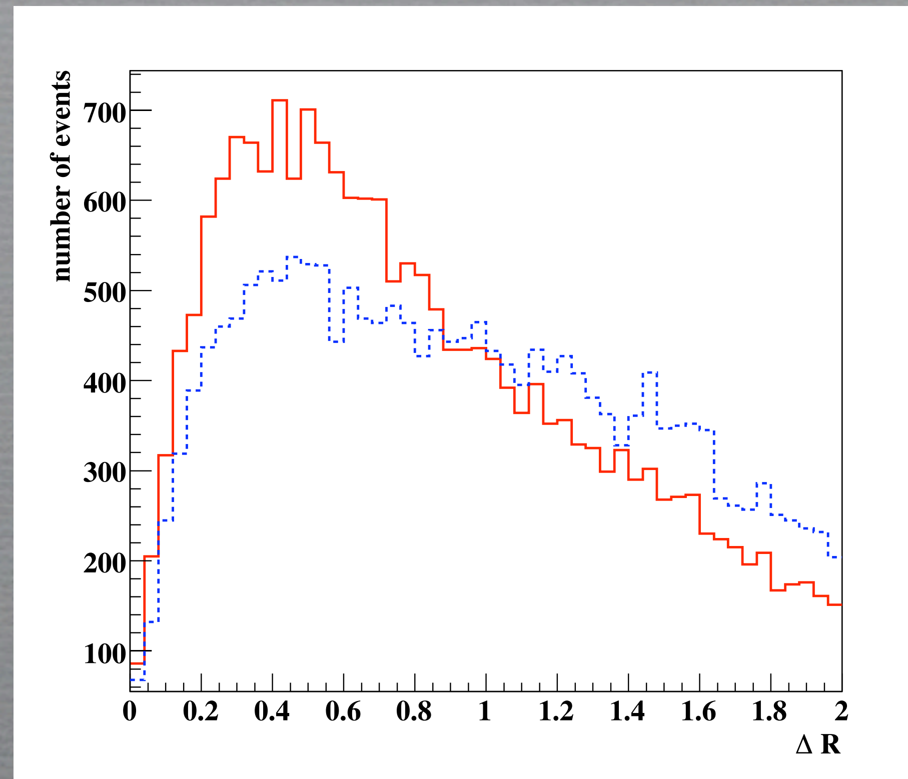
•so we divide these up into a few bins, and define ratios:

r(Meff1400) = ratio of the number of events (after selection) with Meff>1400 GeV to the total number of events (after selection)

hemisphere separation



unselected ttbar

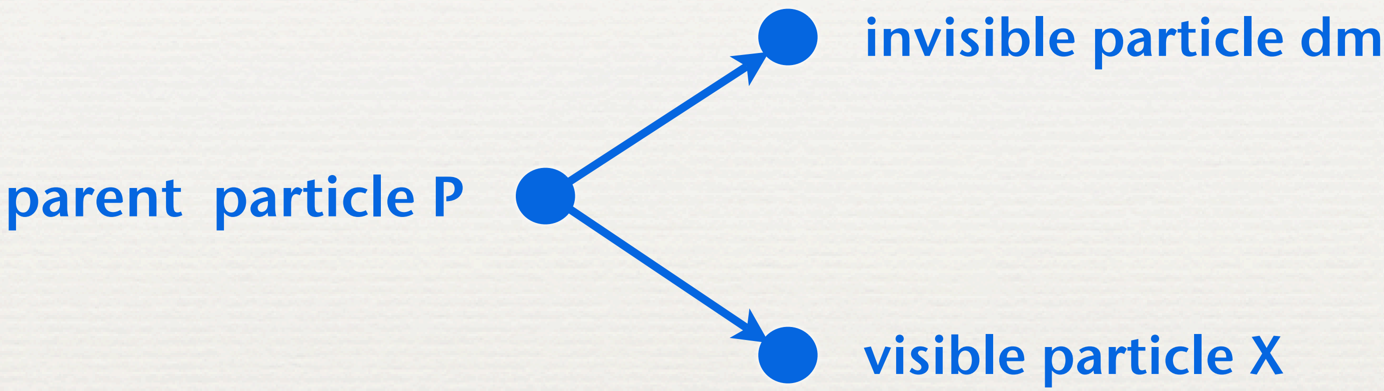


SUSY model LM5 after selection

- we use an algorithm that attempts to separate the reconstructed objects into two hemispheres, corresponding to the two heavy particles produced in the event and their decay products

the stransverse mass mT2

A. Barr, C. Lester, D. Summers, P. Stephens

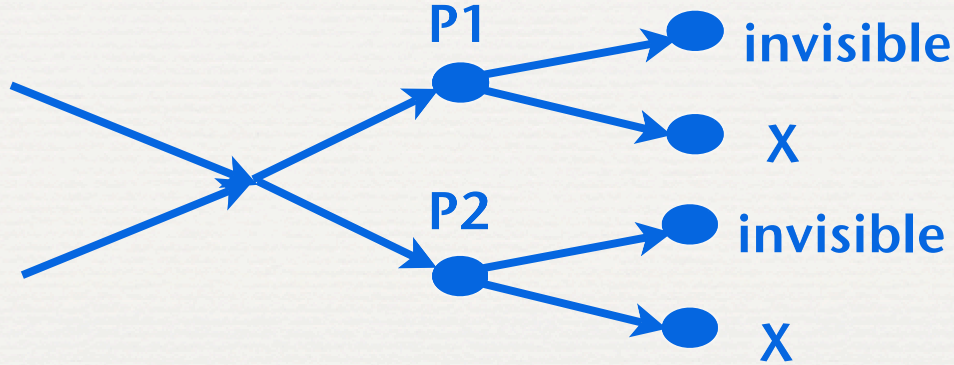


$$m_{\mathrm{P}}^2 = m_{\mathrm{dm}}^2 + m_X^2 + 2\left(E_T^X E_T^{\mathrm{dm}} \cosh(\Delta y) - \mathbf{p}_T^X \cdot \mathbf{p}_T^{\mathrm{dm}}\right)$$

$$m_T^2 = m_{\mathrm{dm}}^2 + m_X^2 + 2\left(E_T^X E_T^{\mathrm{dm}} - \mathbf{p}_T^X \cdot \mathbf{p}_T^{\mathrm{dm}}\right)$$

$$\boxed{m_T \leq m_{\mathrm{P}}}$$

- in a 2-body decay, the transverse mass is bounded from above by the mass of the parent particle



- pair-produce parent particles of the same mass

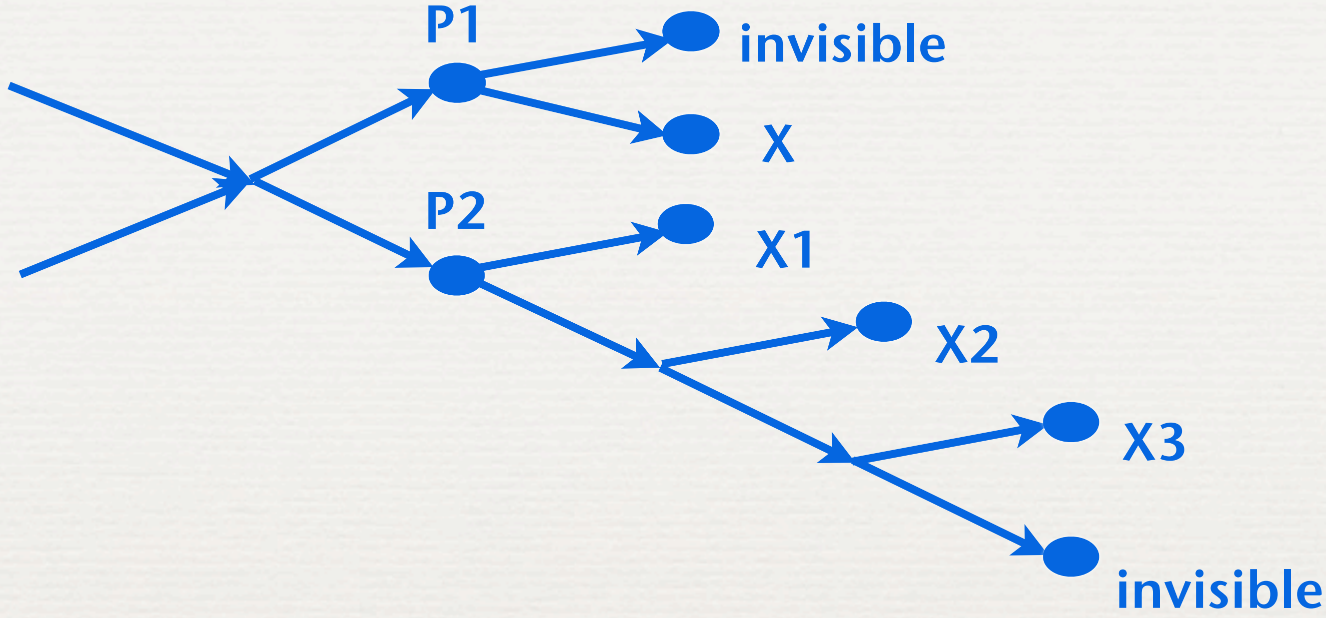
- if we could measure everything, then we would get two m_T's per event; both would be bounded by m_{P}, so $\max(m_T^1, m_T^2)$ is also bounded above

- suppose we don't know the pT of each dm particle separately, but we measure p_T^{miss} = the sum of the two dm particle pT's

- consider all possible decompositions of p_T^{miss} into two pT's; one of these decompositions is the correct one. now define:

$$m_{T2}^2 = \min_{p_T^{(1)} + p_T^{(2)} = p_T^{\mathrm{miss}}} \left[\max\left[m_T^2(m_{\mathrm{dm}}; p_T^{(1)}), m_T^2(m_{\mathrm{dm}}; p_T^{(2)})\right]\right]$$

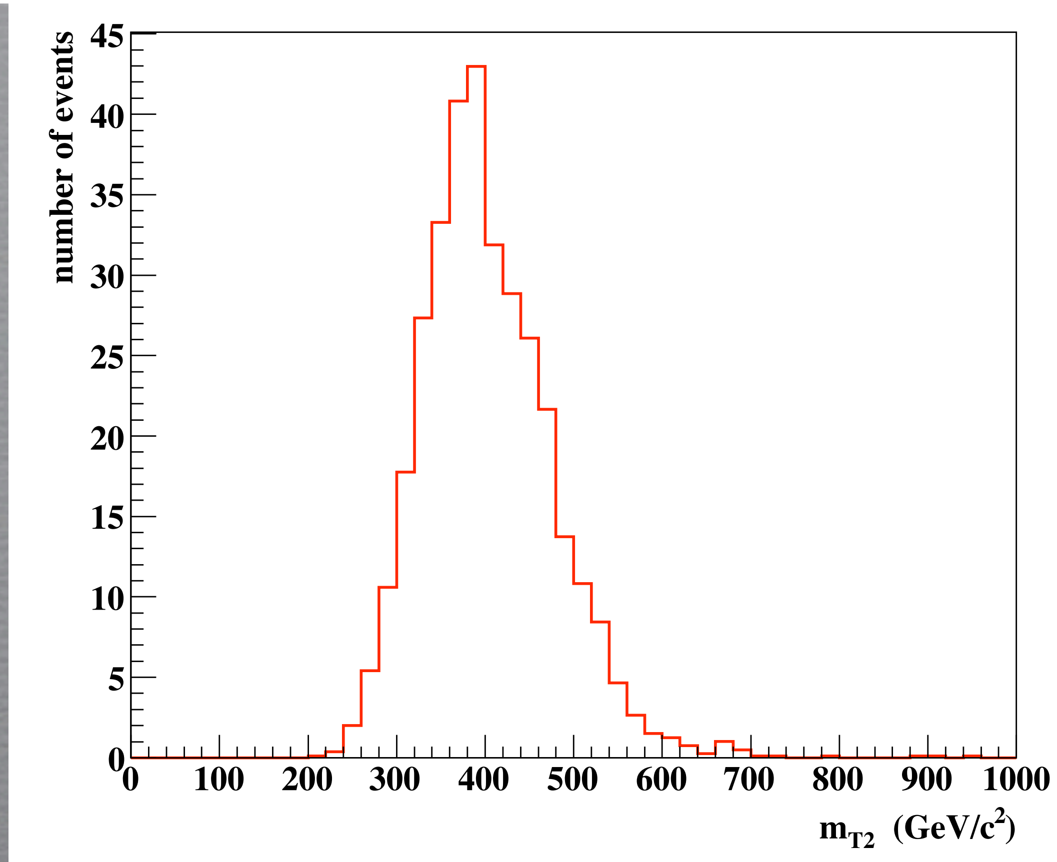
so $\boxed{m_{T2} \leq m_{\mathrm{P}}}$



• we can just as well apply mT2 to cascade decays, adding up all the 4-vectors of the visible particles

• however this assumes we know which visible particle goes with which parent particle decay chain, i.e. perfect “hemisphere” separation

• we also need to input a value for the invisible particle mass



- the upper endpoint is around the parent particle mass, 589 GeV here

- the endpoint is not sharp because of imperfect hemisphere separation, initial state radiation, the underlying event, finite decay widths, and detector resolution

- also, with 100 pb-1 we don't populate the endpoint well enough to extract it directly

uncertainties

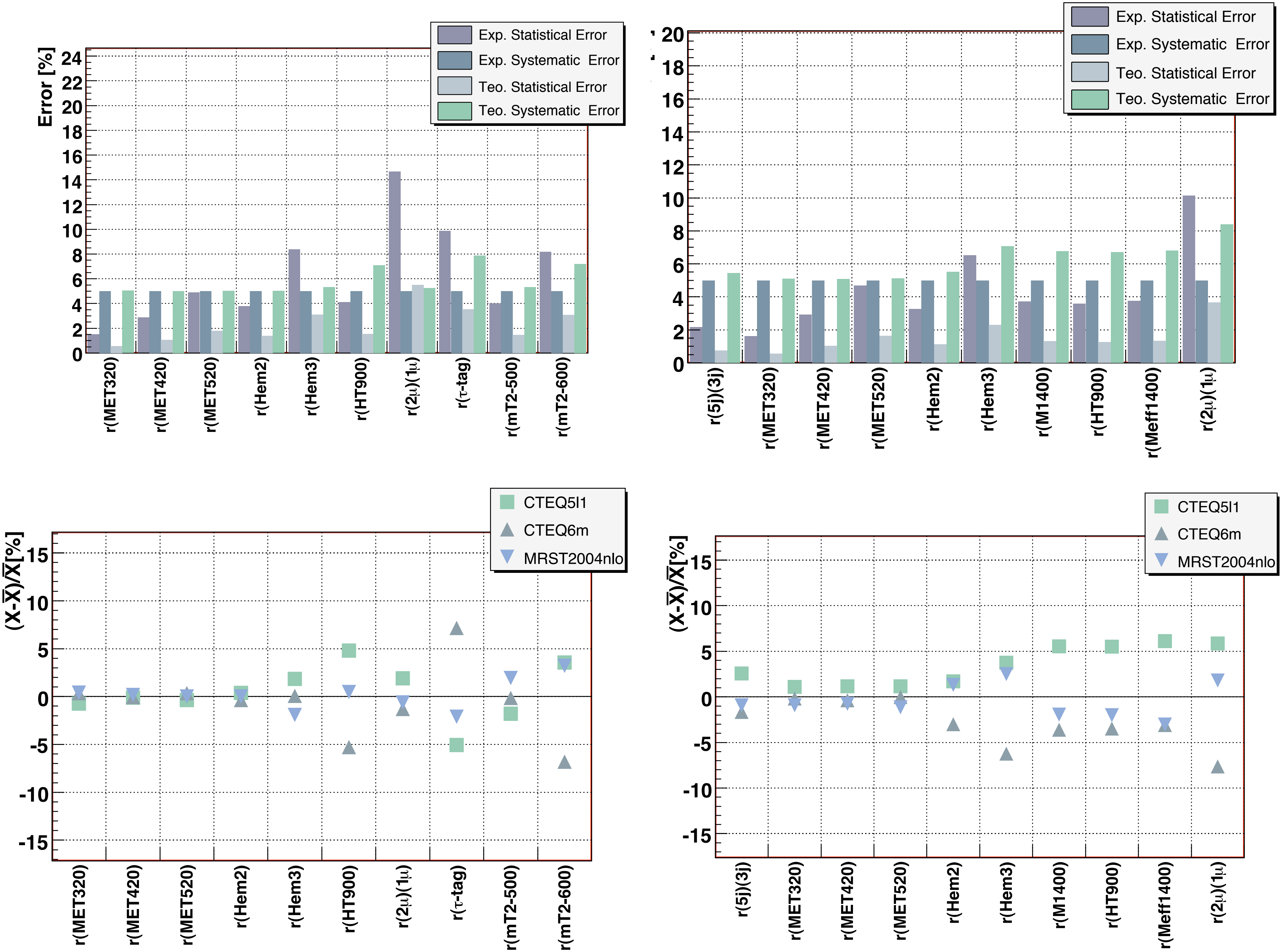
Since we don’t have data we take one model as the “data” and compare it pairwise to look-alike “theory” models

- experimental statistical uncertainty:
the Poissonian error on the number of “events” in the inclusive counts that define a given ratio, after rescaling to 100 pb-1

- theoretical statistical uncertainty (small)

- experimental systematic uncertainty:
from detector effects that only partly cancel in the ratios

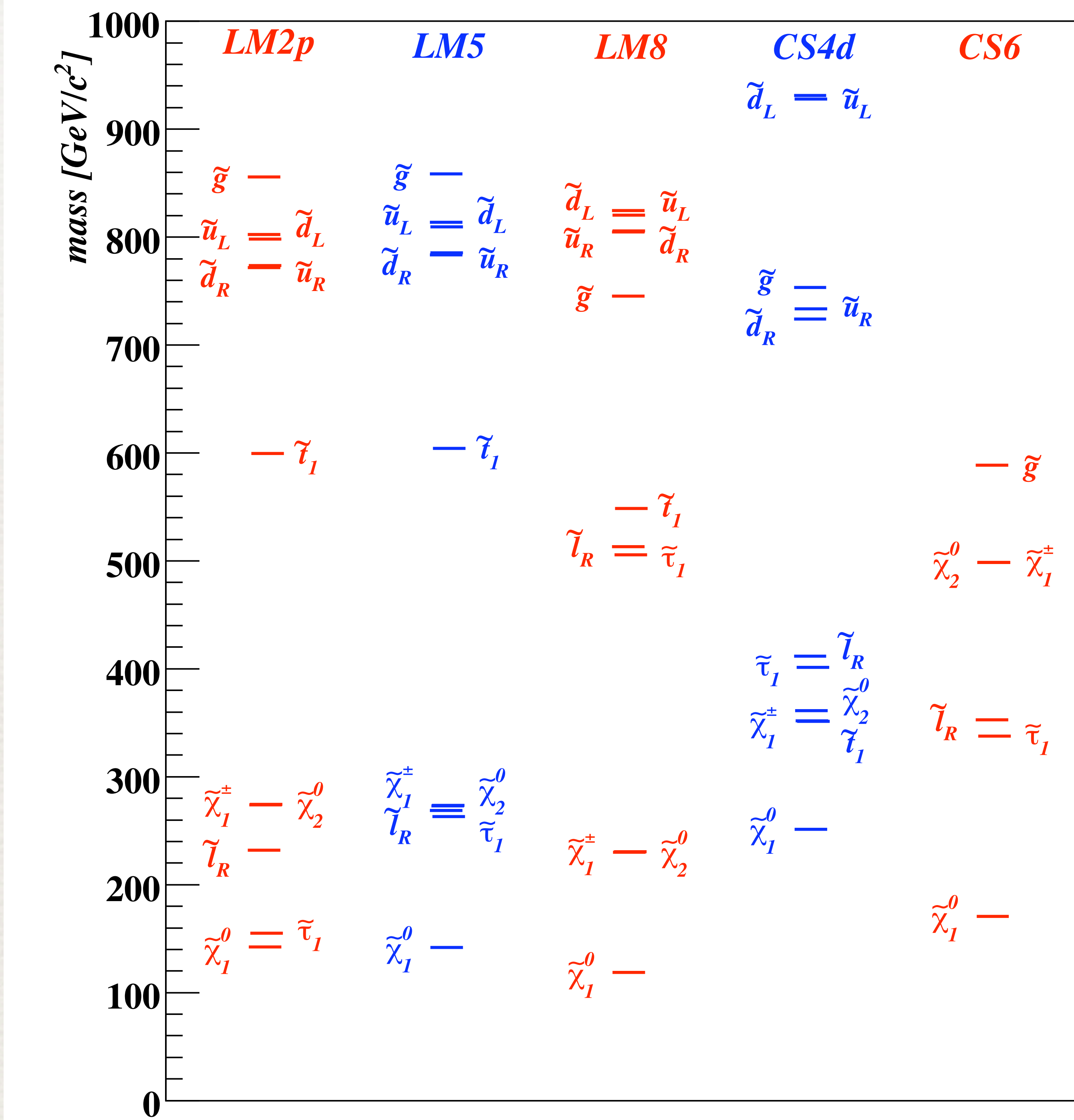
- theoretical systematic uncertainty:
pdf errors crudely estimated directly for each observable by using three different pdfs; QCD scale uncertainty in the ratios



Exp. Statistical Error
Exp. Systematic Error
Teo. Statistical Error
Teo. Systematic Error
Error [%]
0 2 4 6 8 10 12 14 16 18 20 22 24
r(MET320) r(MET420) r(MET520) r(Hem2) r(Hem3) r(HT900) r(2μ)(1μ) r(τ-tag) r(mT2-500) r(mT2-600)
0 2 4 6 8 10 12 14 16 18 20
r(5j)(3j) r(MET320) r(MET420) r(MET520) r(Hem2) r(Hem3) r(M1400) r(HT900) r(Meff1400) r(2μ)(1μ)
CTEQ5l1
CTEQ6m
MRST2004nlo
(X-X̄)/X̄[%]
-15 -10 -5 0 5 10 15

Models

- Group 1 consists of 6 SUSY models
- all 6 models are look-alikes of our MET analysis, producing ~200 signal events in 100 pb-1
- the first three are mSUGRA SUSY models
- CS4d is a “compressed SUSY” model S. Martin
- CS6 is a general MSSM model with a light gluino and heavy squarks



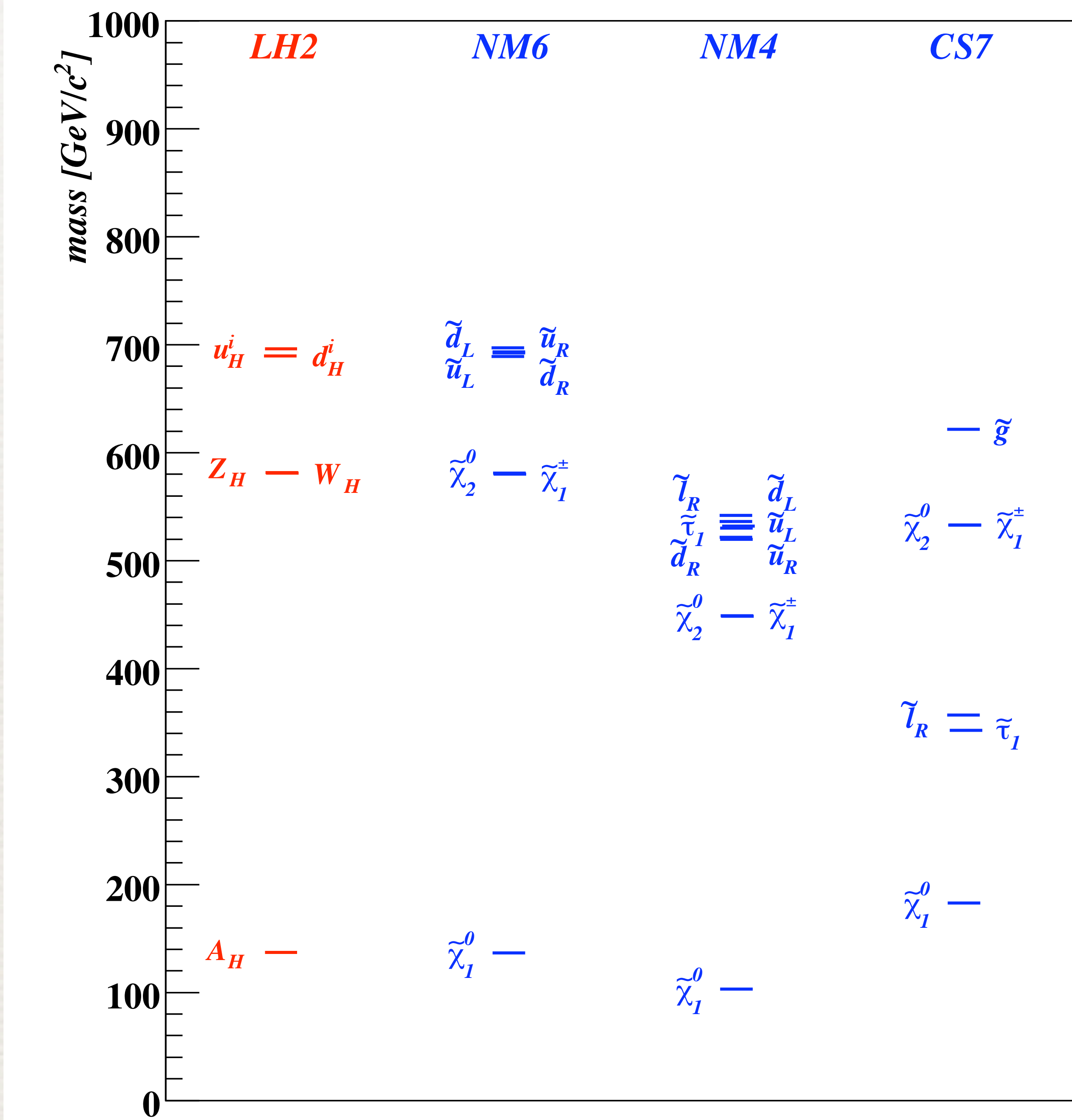
Models

•Group 2 consists of 3 SUSY models and one not-SUSY

•LH2 is a Little Higgs with T-parity model

•SUSY model NM6 has the same spectrum as non-SUSY LH2, modulo a 2 TeV gluino

•however NM6 turns out NOT to be a look-alike of LH2 in our analysis

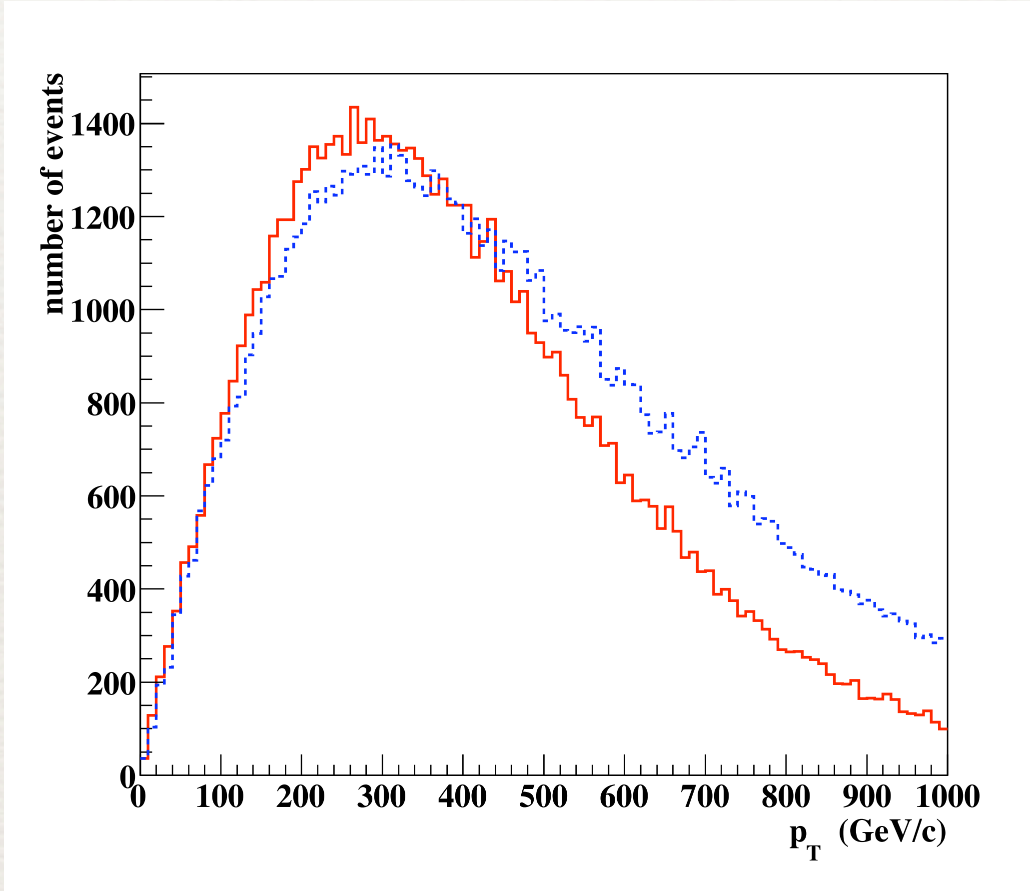


Little Higgs model LH2: LO cross section = 6.5 pb
SUSY model NM6: LO cross section = 2.3 pb

model LH2: signal efficiency after our MET selection = 14%
model NM6: signal efficiency after our MET selection = 19%

- red line = pT distribution of parent heavy quark partners in LH2

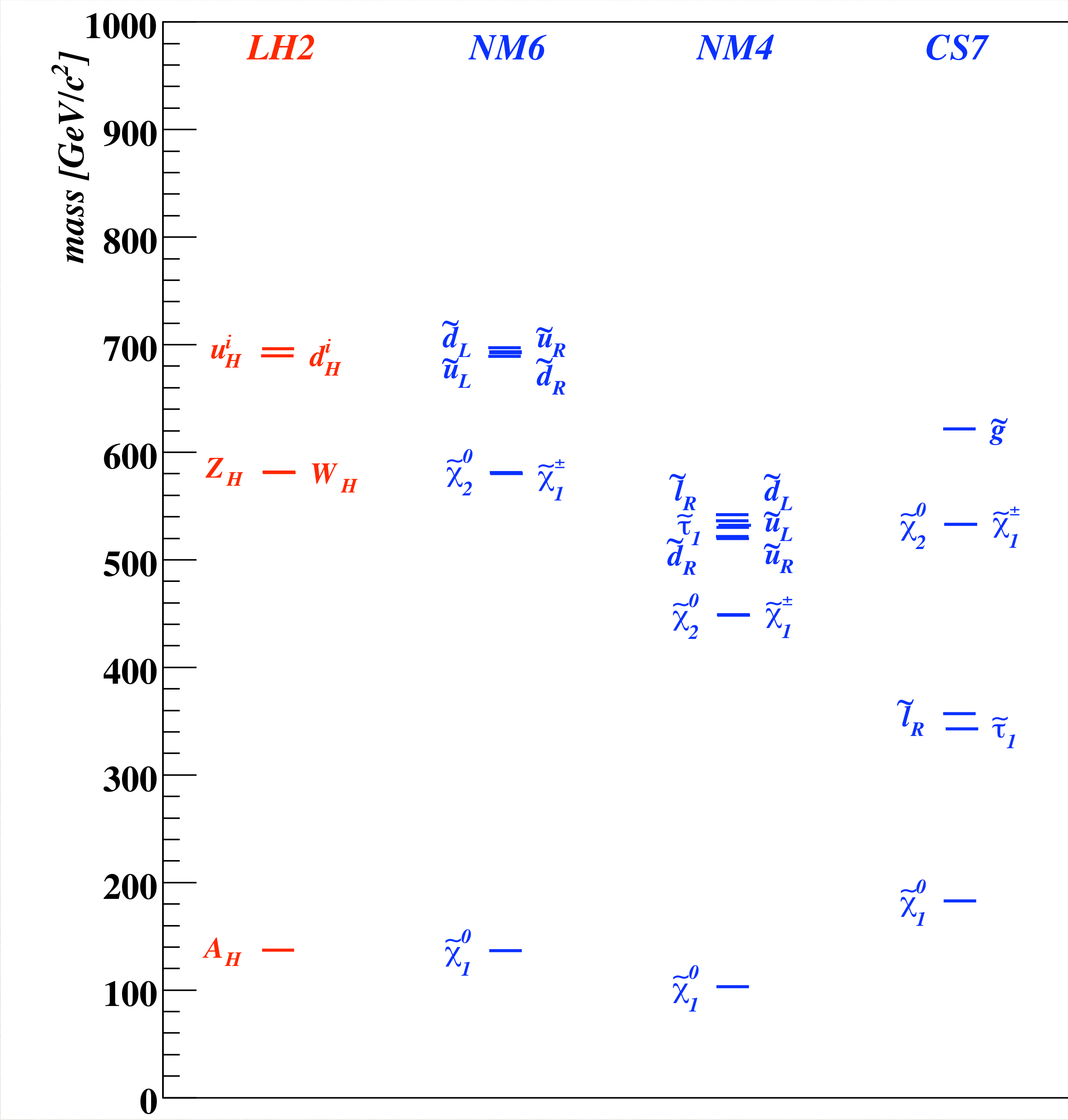
- blue line = pT distribution of parent squarks in NM6



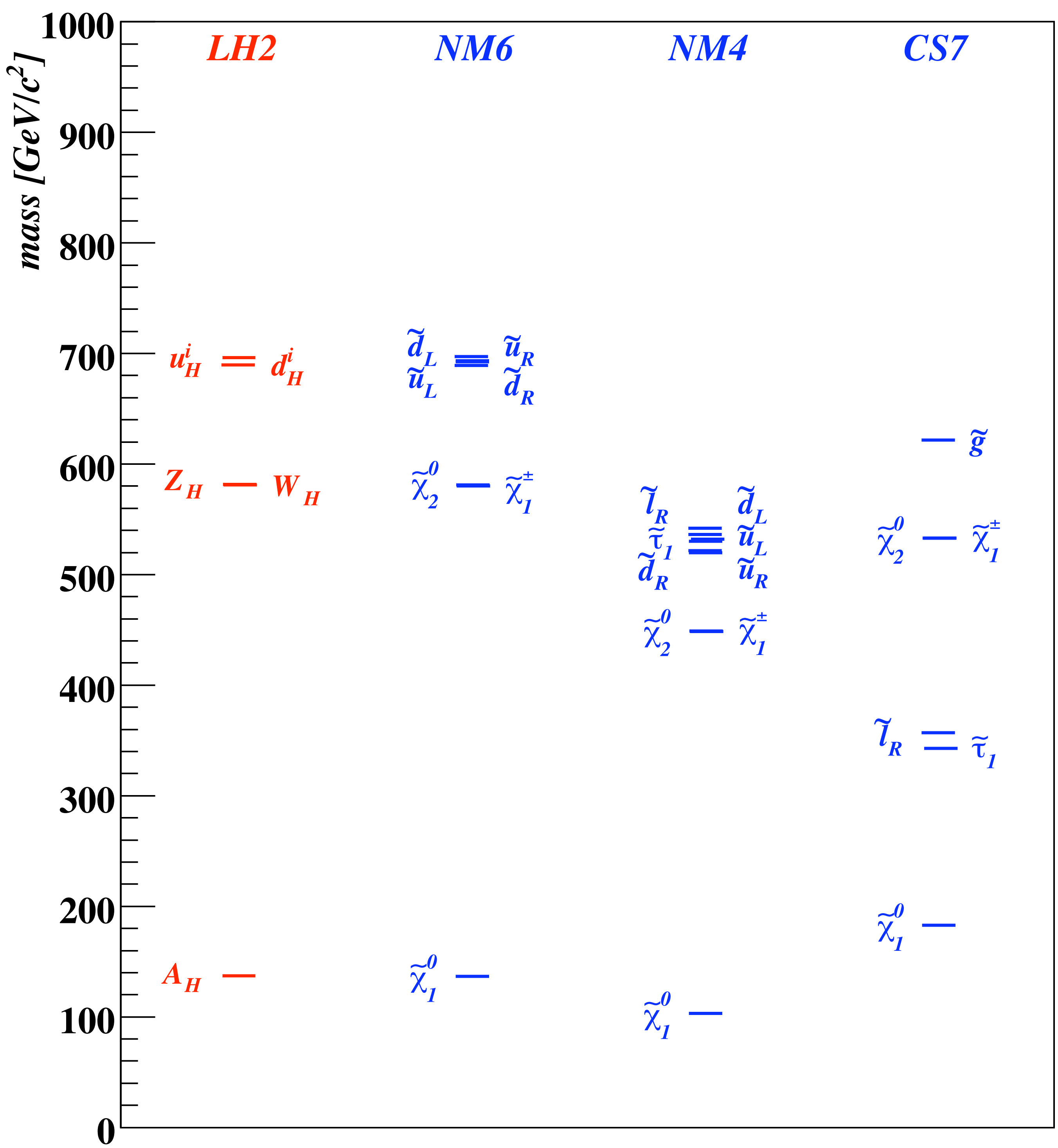
Lesson: cross sections and signal efficiencies depend on the matrix elements, and the matrix elements depend on masses, charges, *and spins* of the parent particles

Models

•LH2, NM4, and CS7 are look-alikes of our MET analysis, producing ~100 signal events in 100 pb-1



results: SUSY versus not-SUSY



results: SUSY versus not-SUSY

Take not-SUSY model LH2 as the "data", compare to the SUSY look-alike NM4:

LH2 vs. NM4 [100 pb^{-1}]			
Variable	LH2	NM4	Separation
MET			
r(mT2-500)	0.16	0.05	4.87
r(mT2-400)	0.44	0.21	4.84
r(mT2-300)	0.75	0.54	3.49
r(Meff1400)	0.11	0.25	2.99
r(mT2-500/300)	0.21	0.09	2.98
r(M1400)	0.07	0.19	2.69
r(mT2-400/300)	0.58	0.40	2.48
r(HT900)	0.13	0.24	2.34
r(MET420)	0.48	0.37	2.00
r(mT2-500/400)	0.36	0.22	1.47

Table 21. Best discriminating ratios in the MET box, with separations in units of σ, for the comparison of LH2 vs.NM4, taking LH2 as the "data", assuming an integrated luminosity of 100 pb^{-1}.

LH2 vs. NM4 [1000 pb^{-1}]			
Variable	LH2	NM4	Separation
MET			
r(mT2-500)	0.16	0.05	14.11
r(mT2-400)	0.44	0.21	11.13
r(mT2-500/300)	0.21	0.09	8.52
r(Meff1400)	0.11	0.25	7.24
r(M1400)	0.07	0.19	6.57
r(mT2-300)	0.75	0.54	6.26
r(mT2-400/300)	0.58	0.40	5.77
r(HT900)	0.13	0.24	5.67
r(M1800)	0.02	0.07	4.82
r(MET420)	0.48	0.37	4.32

Table 36. Best discriminating ratios in the MET box, with separations in units of σ, for the comparison of LH2 vs.NM4, taking LH2 as the "data", assuming an integrated luminosity of 1000 pb^{-1}.

the mT2 ratios for LH2 are larger, reflecting the fact that the parent particles in LH2 are ~700 GeV vs ~550 GeV in NM4

however the Meff and HT ratios in LH2 are smaller; this is from the spin differences in the matrix elements, and enhanced production in NM4 from t-channel exchange of the very heavy gluino

LH2 vs. NM4 [100 pb^{-1}]			
Variable	LH2	NM4	Separation
MET			
r(mT2-500)	0.16	0.05	4.87
r(mT2-400)	0.44	0.21	4.84
r(mT2-300)	0.75	0.54	3.49
r(Meff1400)	0.11	0.25	2.99
r(mT2-500/300)	0.21	0.09	2.98
r(M1400)	0.07	0.19	2.69
r(mT2-400/300)	0.58	0.40	2.48
r(HT900)	0.13	0.24	2.34
r(MET420)	0.48	0.37	2.00
r(mT2-500/400)	0.36	0.22	1.47

Table 21. Best discriminating ratios in the MET box, with separations in units of σ, for the comparison of LH2 vs.NM4, taking LH2 as the "data", assuming an integrated luminosity of 100 pb^{-1}.

LH2 vs. NM4 [1000 pb^{-1}]			
Variable	LH2	NM4	Separation
MET			
r(mT2-500)	0.16	0.05	14.11
r(mT2-400)	0.44	0.21	11.13
r(mT2-500/300)	0.21	0.09	8.52
r(Meff1400)	0.11	0.25	7.24
r(M1400)	0.07	0.19	6.57
r(mT2-300)	0.75	0.54	6.26
r(mT2-400/300)	0.58	0.40	5.77
r(HT900)	0.13	0.24	5.67
r(M1800)	0.02	0.07	4.82
r(MET420)	0.48	0.37	4.32

Table 36. Best discriminating ratios in the MET box, with separations in units of σ, for the comparison of LH2 vs.NM4, taking LH2 as the "data", assuming an integrated luminosity of 1000 pb^{-1}.

LH2 versus CS7: though a look-alike of LH2, CS7 is almost 100% gluino pair production, which is qualitatively quite different

Meff and HT do not discriminate, but mT2 does; also the CS7 gluino events have higher jet multiplicity and are more symmetrical between hemispheres than the LH2 "data"

LH2 vs. CS7 [100 pb^{-1}]			
Variable	LH2	CS7	Separation
	MET		
r(mT2-500)	0.27	0.08	6.68
r(MET420)	0.48	0.20	6.49
r(MET520)	0.21	0.07	5.06
r(MET320)	0.78	0.53	4.29
r(mT2-500/300)	0.32	0.12	4.24
r(4j)(3j)	0.36	0.61	4.04
r(mT2-400)	0.63	0.40	4.00
r(mT2-300)	0.85	0.62	3.55
r(mT2-500/400)	0.43	0.19	3.52
r(Hem1)	0.79	0.63	2.59

Table 22. Best discriminating ratios in the MET box, with separations in units of σ, for the comparison of LH2 vs.CS7, taking LH2 as the "data", assuming an integrated luminosity of 100 pb^{-1}.

LH2 vs. CS7 [1000 pb^{-1}]			
Variable	LH2	CS7	Separation
	MET		
r(mT2-500)	0.27	0.08	18.87
r(MET420)	0.48	0.20	16.73
r(MET520)	0.21	0.07	14.49
r(mT2-600)	0.05	0.01	14.11
r(mT2-500/300)	0.32	0.12	11.17
r(mT2-500/400)	0.43	0.19	9.77
r(mT2-600/300)	0.06	0.01	9.77
r(mT2-400)	0.63	0.40	8.46
r(MET320)	0.78	0.53	8.17

Table 38. Best discriminating ratios in the MET box, with separations in units of σ, for the comparison of LH2 vs.CS7, taking LH2 as the "data", assuming an integrated luminosity of 1000 pb^{-1}.

did we prove that the signal was non-SUSY?

- no

- but we got clues about the underlying theory model at, or close to, the moment of discovery

- part of this guidance traces back to the spins of the parent partners in the 2->2 process

- mT2 is very helpful is this regard, because to first approximation the mT2 ratios don't care about the spin of the parents, while the other kinematic observables do care

ongoing improvements

- mT2 on steroids
- mapping theory space
- what about those neutrinos?
- NLO signals
- the LHC background look-alike problem

mT2 on steroids

- many improvements of mT2
- the mT2 upper endpoint as a function of m_dm has a “kink”at the true value of m_dm

W.S Cho, K. Choi, Y.G Kim, C.B. Park, arXiv:0709.0288

- can generalize mT2 to intermediate particles in sub-decay chains

M. Burns, KC Kong, K. Matchev, M. Park, arXiv:0810.5576

- can find new mT2-like observables, e.g. shat_min

P. Konar, KC Kong, K. Matchev, arXiv:0812.1042

mapping theory space

- don’t know how to parametrize the theory space of viable BSM models that can produce missing energy signals at the LHC

- but at LHC startup the problem is much easier, because we can coarse-grain the theory space

- not crazy to try to simulate all known possibilities on a unified platform, e.g. Madgraph

mapping theory space

G. Hallenbeck, M. Perelstein, C. Spethmann, J. Thom, J. Vaughan, arXiv:0812.3135

- the Cornell group improved on our look-alike analysis by doing a scan over Little Higgs models
- they get worse results
- however most of the difference could be because they didn't use mT2 in their analysis

mapping theory space

J. Alwall, P. Schuster, N. Toro, arXiv:0810.3921

- another approach is to introduce a stripped-down set of simplified models, “OSETs”, characterized by just a couple of masses and branching ratios

- this is certainly simple, and an event generator exists

- but it is a shame to give up the matrix element information, even at LHC startup

what about those neutrinos?

S. Chang and A. de Gouvea, arXiv:0901.4796

- Chang and de Gouvea have constucted a number of models with new pair-produced heavy particles whose dominant decay modes have large missing energy...
- ...but all the missing energy is from neutrinos

$$\lambda_d X_d d^c L$$

S. Chang and A. de Gouvea, arXiv:0901.4796

- a simple not-SUSY example is a leptoquark doublet
- assume that the -1/3 LQ is lighter than the +2/3 LQ
- EWPT want the mass difference to be <~ 50 GeV
- if the coupling is small enough, the +2/3 LQ decays primarily to the -1/3 LQ + W*
- and the -1/3 LQ decays to a d and an antineutrino

S. Chang and A. de Gouvea, arXiv:0901.4796

- they also have SUSY versions with R-parity violation, right-handed neutrinos, low scale see-saw, etc
- these are all models in which neutrinos fake the "smoking gun" signature of WIMP dark matter
- can we tell that the missing energy comes from pairs of (nearly) massless neutrinos?

S. Chang and A. de Gouvea, arXiv:0901.4796

- mT2 on steroids is the obvious way to do this
- a good warm-up is to look at ttbar production: what upper bound can we put on the neutrino masses in ttbar dilepton samples?
- in a simulation, Chang and de Gouvea got 17 GeV
- increase the top mass to 400 GeV and the upper bound gets worse: 46 GeV

NLO signals

- NLO corrections have a strong effect on the signal cross sections; for SUSY, included already in Group 1 using Prospino2; for LH, can fake it using MCFM

- affects the shapes of the squark/gluino/heavy quark pT distributions, but the effects are pretty small; probably OK to just determine the error bar

e.g. W. Beenakker, R. Hopker, M. Spira, P. Zerwas
S. Dawson, RK Ellis, P. Nason

- needed for correct modeling of extra hard jet emission

J. Alwall, M-P Le, M. Lisanti, J. Wacker et al, arXiv:0809.3264

the LHC background look-alike problem

- in order to make a missing energy discovery at LHC, we first have to sort out the relevant SM backgrounds
- ttbar, Z+jets, W+jets, and QCD
- need to calibrate these without normalizing away any possible signals
- this is a complicated bootstrapping problem

beginning

- we are at the beginning of a new era
- new ideas for understanding the LHC data are coming from all directions
- expect the unexpected