Missing Energy Look-alikes at the LHC

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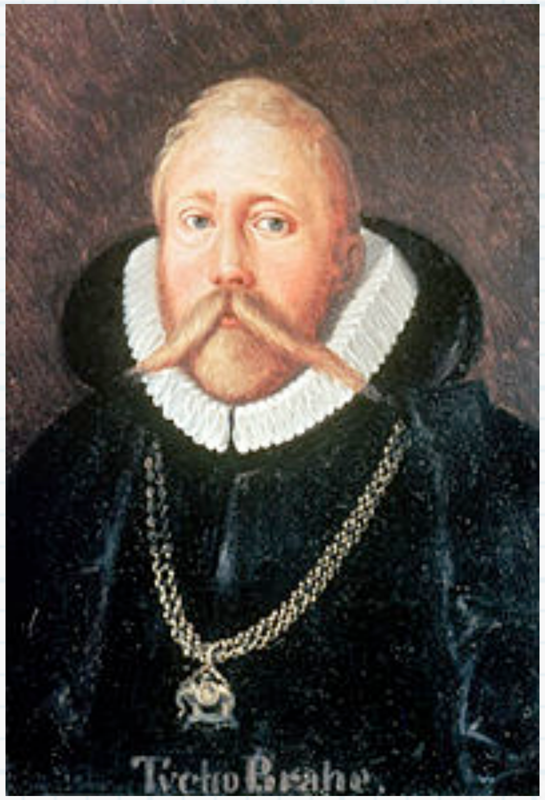
Twenty Questions

* It's an old game
    * one person picks the subject (e.g. Tyco Brahe)
    * rest of players ask yes/no questions
        * is it smaller than a breadbox? - No
        * did he lose part of his nose in a drunken duel with rapiers? - Yes

Is he:  ?

It's an efficient way to go from extremely large N of possibilities to the correct answer with a few **well designed** questions

Twenty questions @ LHC

We begin running the LHC with a very large (pseudo-infinite) number of possible extensions of the SM

Each data "release" gives another step in the game; want order 1/2 (or more) possibilities eliminated each time

Each step (set of analyses) should be designed according to the previous ones, and gain increasing focus

We want to be smart when we create our questions!

Goal: Create a strategy for the "moment of discovery" (perhaps first $100 pb^{-1}$ of data)

Do the most that we can (find powerful model discriminators) taking into account the limitations of what we'll have available with this first small data sample

immature detector simulation

poorly understood systematics

poor understanding of jets

primitive (at best) flavor tagging

Consider this a presentation of a “dry run” of how to manipulate the first signal data

Things will be slightly different once there’s real data to tune det. sim. and Monte Carlo, but we want a strategy ready-in-hand

By keeping as realistic as we can, we bolster our confidence that the strategies we develop will carry over well to the real thing

First "understood" data

* Won't be well understood
* will have some handle on detector response to jets from earlier studies (2008 10 TeV run)
* won't have sophisticated jet corrections (partonic jets), just raw/uncorrected jets
* primitive flavor tagging (enrichment)
* observables that are available will be strongly correlated by both physics and systematics
    * want to keep these errors to a minimum
    * bad time for a global analysis

What can we do?

* $\not{E}_T$ probably comes from exotics
* 1 or more kin. accessible strongly coupled exotics
* leptons in chain that came from exotics (not W's or Z's)
* Indirect spin info! (surprising)

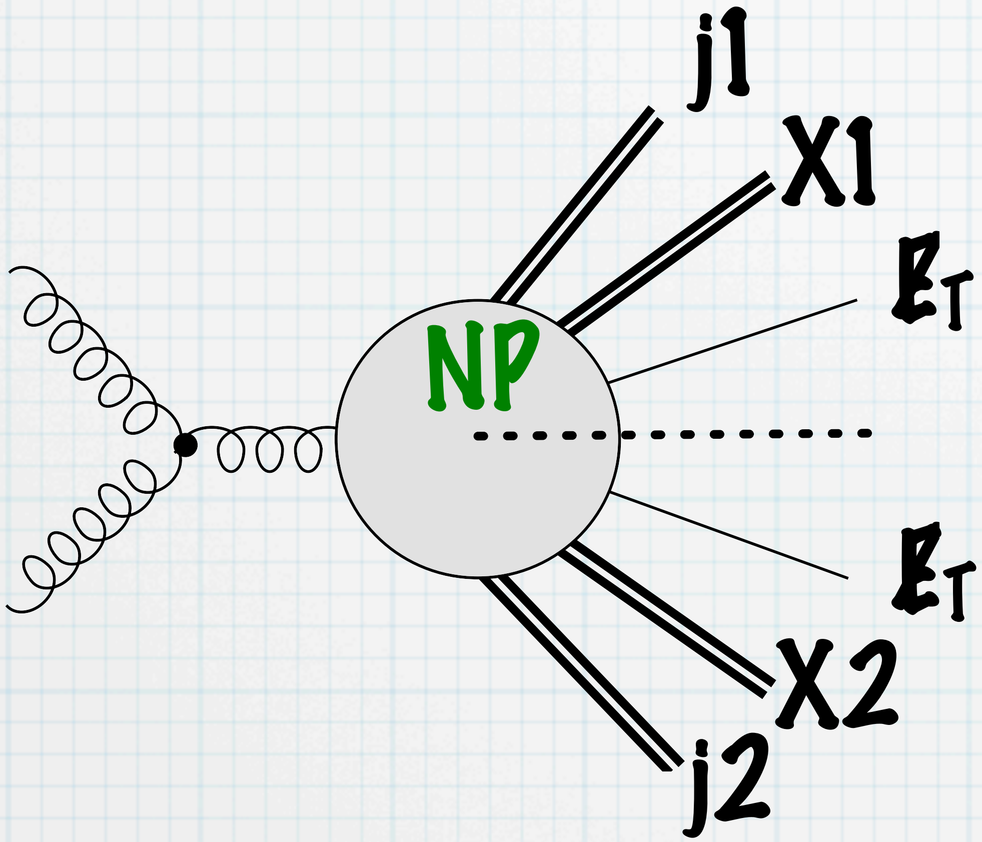
MET + jets @ LHC

WHY?

* Dark matter experimental evidence
* Theoretical prior that hierarchy problem is solved near the TeV scale (top quark is involved)
  * The necessity of conserving certain global symmetries
    * custodial SU(2), baryon #

Compelling case for LHC pair production of strongly coupled exotica decaying to jets + X + E_T(miss)

E_T(miss) + jets @ LHC



- New Physics + Parity
  - SUSY: R-parity (baryon #)
  - Little Higgs: T-parity (cust. SU(2))
  - Universal Extra Dim.: KK-parity

Parities keep protons from decaying, prevent gross violation of flavor constraints, keep M_W consistent with exp., and (if exact) provide dark matter

Starting point

* There is a 5 sigma excess in a MET+jets search with $100pb^{-1}$ (N signal events)
* We don't utilize any other potential search channels (i.e. that don't trigger on MET)

Models

SUSY	Little Higgs
produce squarks + gluinos	produce heavy T-odd quarks
decay to lightest R-odd particle (neutralino)	decay to lightest T-odd particle (neutral vector boson)
Hierarchy problem saved by spin statistics and SUSY coupling relations	Hierarchy problem saved by global symmetries
cancellations with opp. spin	cancellations with same spin

Group 1 and Group 2

We perform two sets of analyses - in each, 1 model plays the role of "data" and the rest are "candidate theories" or "Look-alikes"

Look-alike: model that gives same # of events in E_T(miss) analysis path

Group 1	Group 2
"Data" is SUSY	"Data" is Little Higgs
SUSIC look-alikes	SUSIC look-alikes

Pass all models through a software chain

What data can we get? (CMSPTDR)

* Study of SUSY benchmark scenarios
* series of cleanup/analysis/bkgd rej. cuts on E_T trigger sample
  * up to 25% eff. on signal
* for $\sigma \sim 5$pb, > 5σ discovery in 100pb^{-1}!
* we adopt very similar analysis path (they did bkgds for us!)
* New: we go **beyond** the benchmarks (even non-SUSY) and **refine/develop** the analysis for efficiency in model discrimination

Backgrounds for $\not\!\!E_T$

* ttbar, single top, W+jets, Z+jets, dibosons
  * most have hard lepton in association with neutrino (gives MET)
  * generated by CMS with AlpGen and passed through full det. sim.
* QCD
* beam halo, cosmics, detector noise

CMSPTDR MET analysis path

Cut/Sample	Signal	$t\bar{t}$	$Z(\to \nu\bar{\nu})+$ jets	EWK + jets
All (%)	100	100	100	100
Trigger	92	40	99	57
$E_T^{\text{miss}} > 200$ GeV	54	0.57	54	0.9
PV	53.8	0.56	53	0.9
$N_j \geq 3$	39	0.36	4	0.1
$\lvert\eta_d^{j1}\rvert \geq 1.7$	34	0.30	3	0.07
EEMF ≥ 0.175	34	0.30	3	0.07
ECHF ≥ 0.1	33.5	0.29	3	0.06
QCD angular	26	0.17	2.5	0.04
$Iso^{lead\ trk} = 0$	23	0.09	2.3	0.02
$EMF(j1)$, $EMF(j2) \geq 0.9$	22	0.086	2.2	0.02
$E_{T,1} > 180$ GeV, $E_{T,2} > 110$ GeV	14	0.015	0.5	0.003
$H_T > 500$ GeV	13	0.01	0.4	0.002
events remaining per 1000 pb^{-1}				
	6319	54	48	33

- focuses on 2 WIMP final states ($N_{jets} \geq 2$)
- QCD pileup, radiation often gives a third jet
- efficient for signal, strong reduction of background

Backgrounds

245 evt./fb^{-1} in E_T(miss) analysis path after cuts

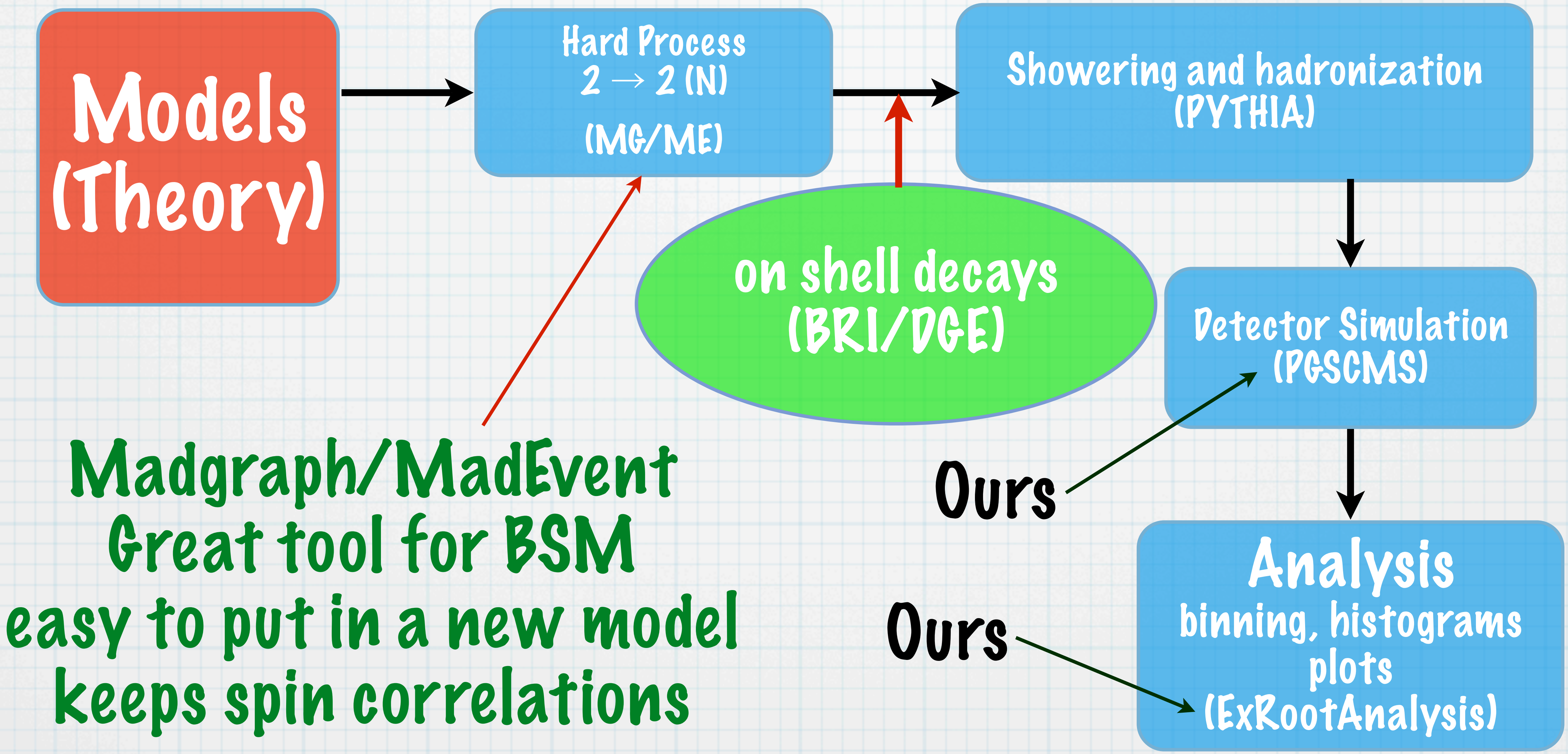
Error: how good is det. sim., how good was CMSPTDR SM cocktail, how well was QCD simulated, PDF's

In models we studied, can **triple** SM background count after cuts, add 15% systematics on signal and still have "discovery" in 100pb^{-1}

Early MET @ LHC

- poor jet resolution fakes missing E_T
- muons contribute (don't deposit all energy)
- plagued by instrumental + spurious bkgds (cosmics, scattering off beam halo) - primary cleanup
- use raw (uncorrected) jets in early running
  - not much like generator level (partonic) missing E_T

Our Toolkit


Models (Theory)
Hard Process
2 → 2 (N)
(MG/ME)
Showering and hadronization
(PYTHIA)
on shell decays
(BRI/DGE)
Detector Simulation
(PGSCMS)
Ours
Ours
Analysis
binning, histograms
plots
(ExRootAnalysis)
Madgraph/MadEvent
Great tool for BSM
easy to put in a new model
keeps spin correlations

PGSCMS + analysis

* needed fast (parametrized) detector simulation
* PGS (pretty good simulation) tuned for CMS detector
* tuned to LM1 study in CMSPTDR
* add pileup, z-vertex, some B-field effects
* agreement good!

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%

Software Chain

Software/Models	Group 1 models	Group 2 models
Spectrum generator	`Isajet v7.69` [30] or or `SUSY-HIT v1.1` [31]	private little Higgs or `SUSY-HIT v1.1`
Matrix element calculator	`Pythia v6.4` [32]	`MadGraph v4` [33]
Event generator	`Pythia v6.4`	`MadEvent v4` [34] with `BRIDGE` [35]
Showering and hadronization	`Pythia v6.4`	`Pythia v6.4`
Detector simulation	`PGSCMS v1.2.5` plus parameterized corrections	`PGSCMS v1.2.5` plus parameterized corrections

Analysis: Specifically designed - ExRootAnalysis (includes jet energy corrections)

η and φ dependent rescaling of jet energies

50 GeV "PGS jet" = 30 GeV uncorrected (raw) jet

Some flaws

* Drop primary cleanup and parts of ILV
  * can't simulate these
* E_T(miss) not quite right - need full sim.
* no electrons - need full sim
  * future study

Modified E_T analysis path

Did not rescale MET - E losses, cal. response, mismeasurements decrease real MET tails while increasing fake MET tails

just raised cut: MET > 220 GeV

in full detector sim, we can avoid this compromise

How does PGSCMS do?

Cut/Software	Full	Fast
Trigger and $E_T^{\text{miss}} > 200$ GeV	53.9%	54.5%
$N_j \geq 3$	72.1%	71.6%
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Biggest disagreement is on QCD angular cuts (we don't accurately reproduce jet mismeasurement effects)

Level of agreement - we expect fast sim. look-alikes to remain look-alikes (or at least be close) with full det. sim.

Observables

* Want to focus on robust objects
  * shapes, distributions, too sensitive to systematics, poor simulation, etc.
    * not good for moment of discovery
* Large bins bring this problem under better control
  * "Boxes"
* Ratios of counts in diff. boxes
  * lower systematics since many are common to all boxes - cancel out

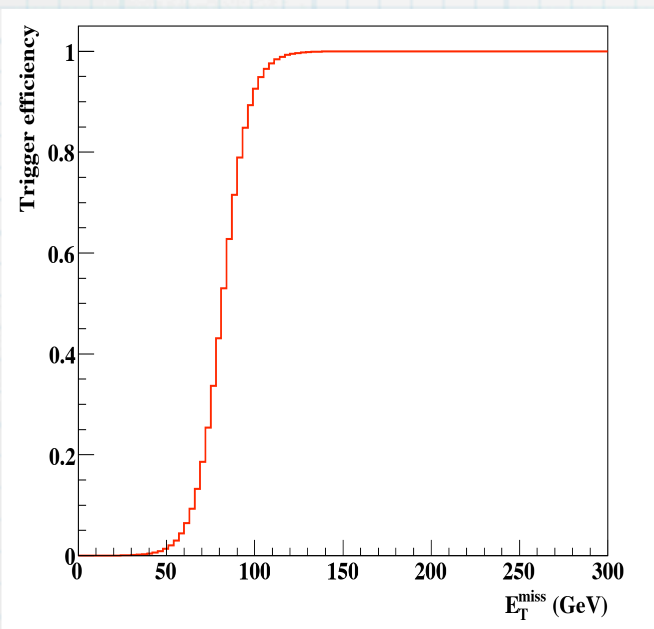
Observables: Ratios

* systematics cancel effectively
  * from about 20% down to about 5%
    * luminosity uncertainty - completely
    * pdf uncertainty - partially
    * higher order corrections - partially

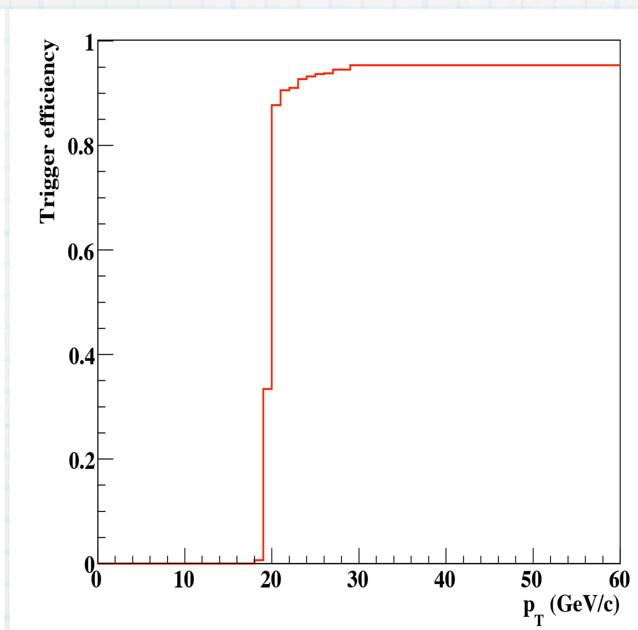
Boxes

Simplest thing: Bin events in analysis path according to other trigger samples (mock-ups of CMS trigger and physics reports)

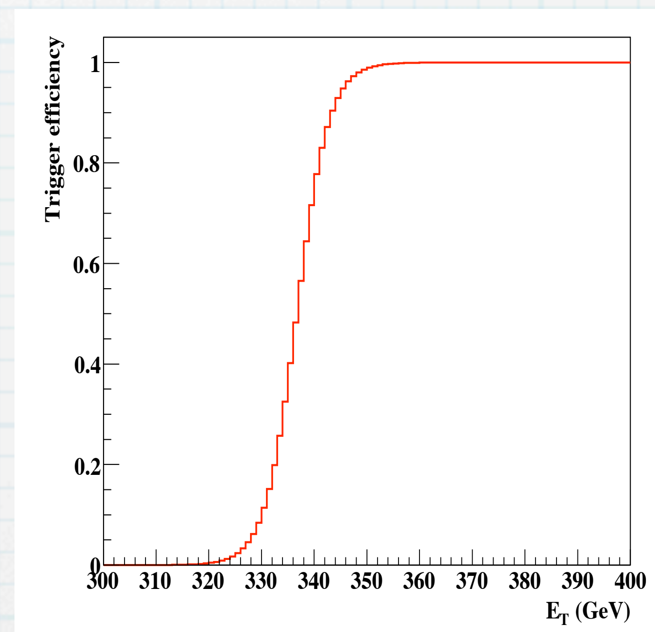
MET (100%)



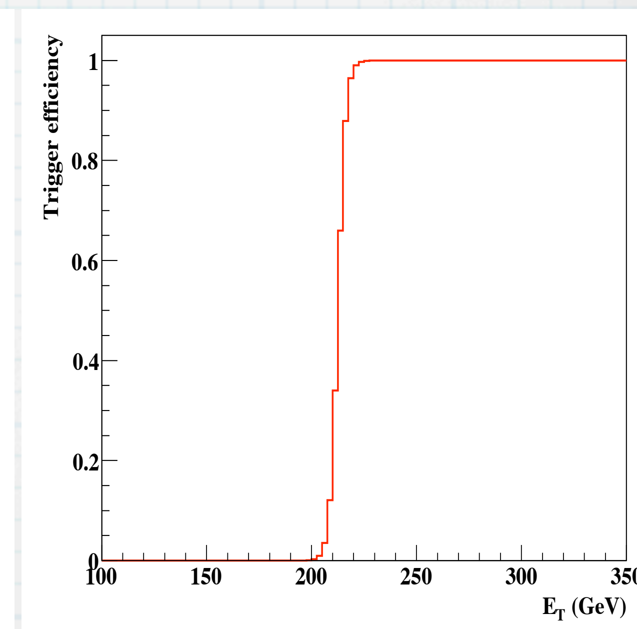
Muon20



DiJet

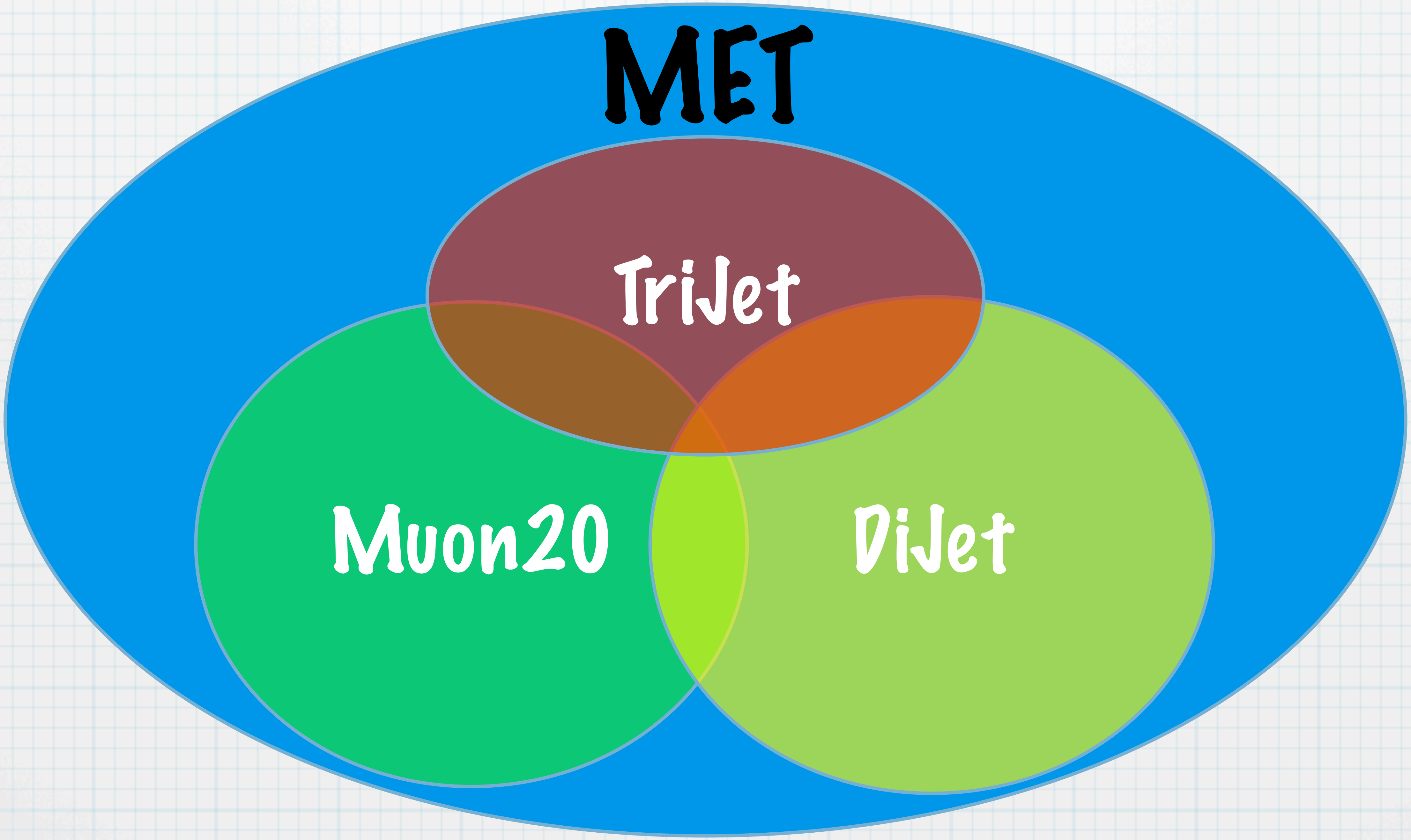


TriJet



Trigger efficiencies - simulate turn-on

Simplest Boxes



M_{eff}

$$M_{\text{eff}} = E_T^{\text{miss}} + \sum_{i=1,4} p_T^j$$

Has often been used to get estimate of mass scale of new physics

Create one new box for events with large M_{eff}

– N(Meff1400)

Stransverse mass (MT2)

* Ignoring neutrinos, assuming perfect hemisphere separation, can construct each set of visible particles into 4-vector
* If know p_T and mass of WIMPs, can reconstruct transverse mass for each hemisphere

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

* But we don't know those things

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

* Kink at m_{dm}(guess) = m_{dm}(actual) !

Won't be able to use this to our advantage for a while, though

Stransverse mass

We don't know WIMP mass except in our candidate explanations of the "data"

Use m_{dm} of candidate theory for both data and MC of candidate

Stransverse mass boxes:

- N(mT2-300) the number of events after selection with $m_{T2} > 300$ GeV/c^2,
- N(mT2-400) the number of events after selection with $m_{T2} > 400$ GeV/c^2,
- N(mT2-500) the number of events after selection with $m_{T2} > 500$ GeV/c^2.
- N(mT2-600) the number of events after selection with $m_{T2} > 600$ GeV/c^2.

Hemispheres and Cones

Event shape: extract info about scattering subprocess and resulting decay chains

Our Signal: pair production of exotics - each event has natural separation into halves (hemispheres)

Each hemisphere (ideally) has 1 wimp and visible decay products of parent exotic (+ neutrinos)

Algorithms: 2 steps - seeding + association

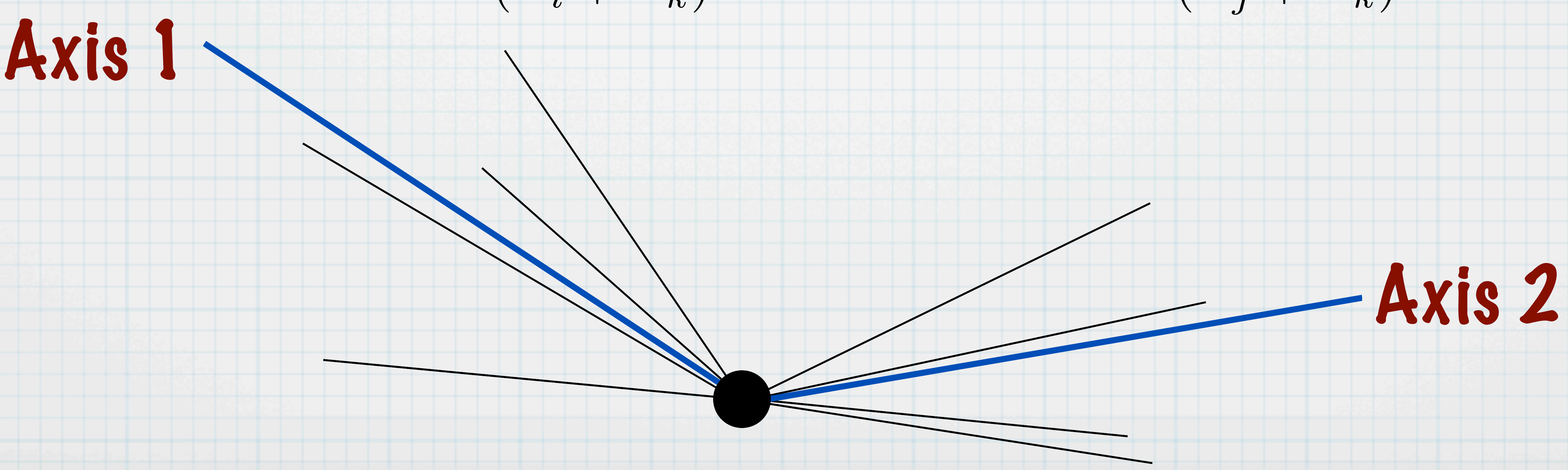
Hemispheres

Moortgat, Pape

Seeding: two hemisphere axes given by angular directions of pair of reconstructed objects with largest invariant mass

Association: reconstructed objects assigned to hemisphere that minimizes the Lund distance

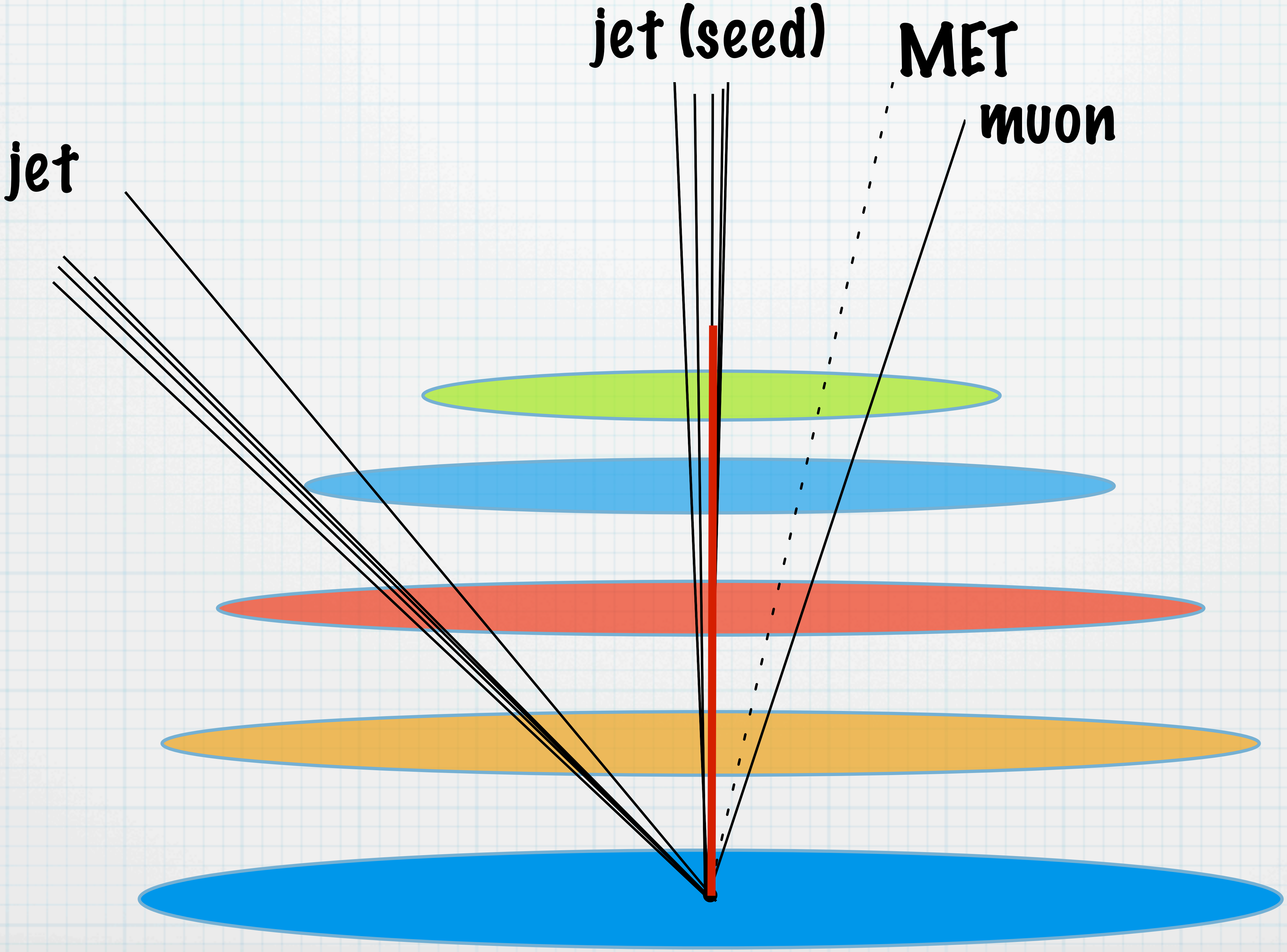
$$(E_i - p_i \cos\theta_{ik})\frac{E_i}{(E_i + E_k)^2} \leq (E_j - p_j \cos\theta_{jk})\frac{E_j}{(E_j + E_k)^2}$$



Cones

* from central axes of hemispheres, generate cones
    * opening angles $2\alpha = 2x(30, 45, 60, 75, 90)$ degrees
* CLEO used them to dist. between QCD bkgd and isotropic decays of B meson

CLEO Cones



Cone observables

How "jet-like" are the decay products?

events w/ n or more tracks in cone of opening angle 2α

$$\mathrm{N(nt\text{-}c}\alpha)$$

events w/ diff. of n or more tracks between cone of opening angle 2α and any other cone

$$\mathrm{N(ntdiff\text{-}c}\alpha)$$

Flavor Enrichment

Very low level “tagging”

* tau enrichment
  * for each jet, .375 cone, count tracks > 2 GeV, if only one, and > 15 GeV, call tau

	LM2p	LM5	LM8	CS4d	CS6
τ jets per fb^{-1}	409	144	171	112	34
tags per fb^{-1}	157	110	122	102	59
correct tags per fb^{-1}	86	25	21	14	5
efficiency	21%	18%	12%	13%	16%
purity	55%	23%	17%	14%	8%

* b enrichment
  * if muon within .2 of jet axis, call b

	LM2p	LM5	LM8	CS4d	CS6
b jets per fb^{-1}	1547	1693	2481	1596	748
tags per fb^{-1}	115	112	148	105	106
correct tags per fb^{-1}	82	81	112	75	41
efficiency	5%	5%	5%	5%	5%
purity	72%	72%	75%	71%	39%

Our Ratios

- r(nj)(3j), with n=4,5
- r(MET320)
- r(MET420)
- r(MET520)
- r(HT900)
- r(Meff1400)
- r(M1400)
- r(M1800)
- r(Hem$j$) with j=1,2,3
- r(2μ-nj)(1μ-nj) with n=3,4
- r(τ-tag)
- r(b-tag)
- r(mT2-300) with the theory LSP mass
- r(mT2-400) with the theory LSP mass
- r(mT2-500) with the theory LSP mass
- r(mT2-600) with the theory LSP mass

- r(DiJet)
- r(TriJet)
- r(Muon20)
- r(mT2-400/300) with the theory LSP mass
- r(mT2-500/300) with the theory LSP mass
- r(mT2-600/300) with the theory LSP mass
- r(nt-cα) for n=10,20,30,40 and α = 30°,45°, 60° 75°, 90°
- r(ntdiff-cα) for for n=10,20,30,40 and α = 30°, 45° 60°, 75°, 90°

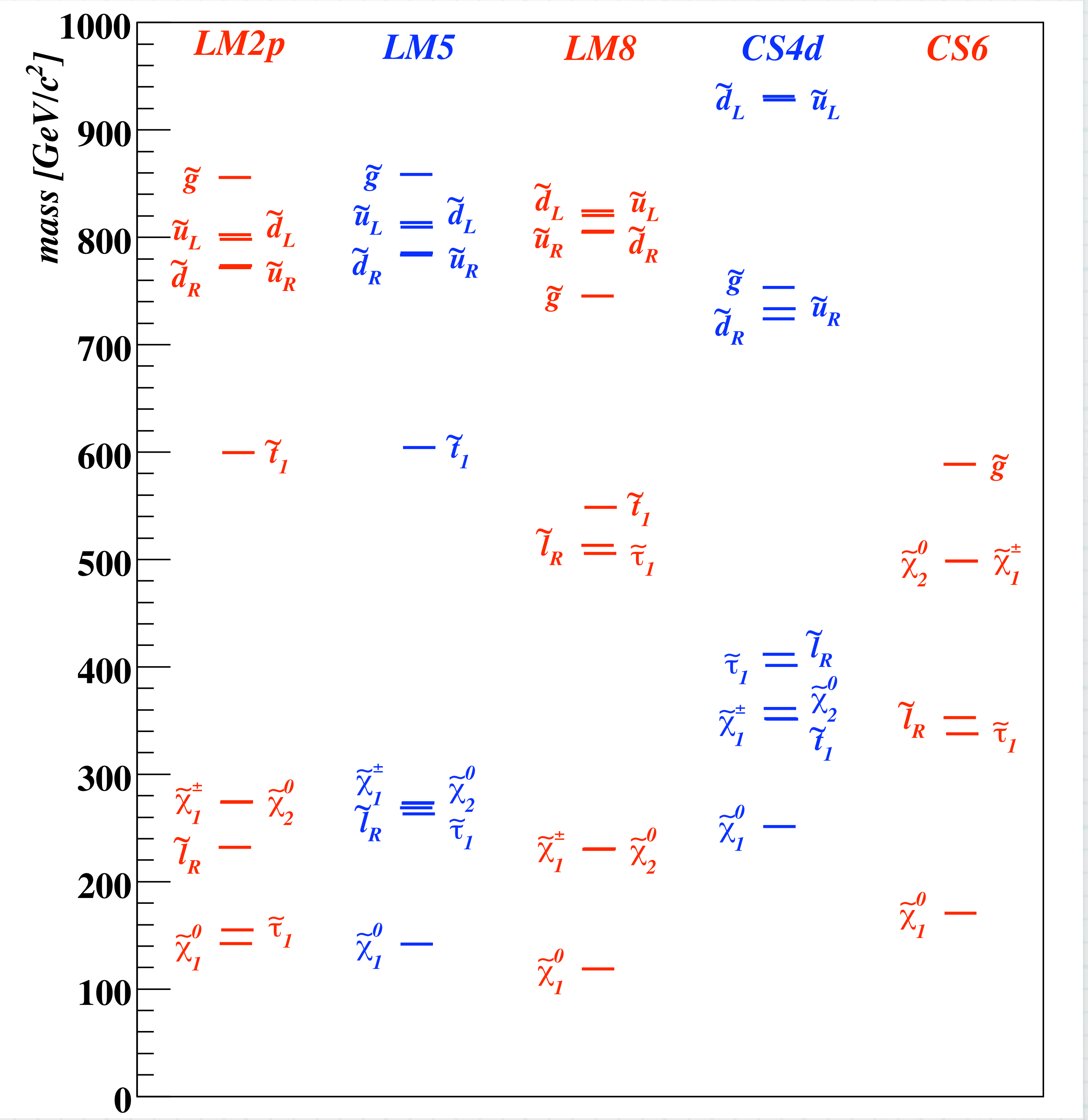
Analysis

Group 1 spectra

"Data" is LM2p

Low mass points and compact SUSY models are candidates

	LM2p	LM5	LM8	CS4d	CS6
$qq\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	57%	61%	34%	38%	98%
$qqq\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	20%	19%	3%	4%	79%
$qqqq\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	1%	1%	1%	1%	77%
$\tau\,\nu_\tau\,q\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	39%	1%	-	-	1%
$\tau\tau\,q\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	25%	1%	-	-	1%
$b\,q\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	30%	25%	33%	69%	19%
$b\,t\,W\,q\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	10%	19%	31%	67%	-
$W\,q\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	25%	52%	56%	93%	-
$h\,q\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	3%	20%	-	-	-
$tt\,q\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	9%	4%	40%	11%	2%
$Z\,q\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	10%	8%	35%	11%	-
$Z\,W\,q\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	2%	6%	23%	6%	-
$bb\,tt\,WW\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	-	-	2%	18%	-



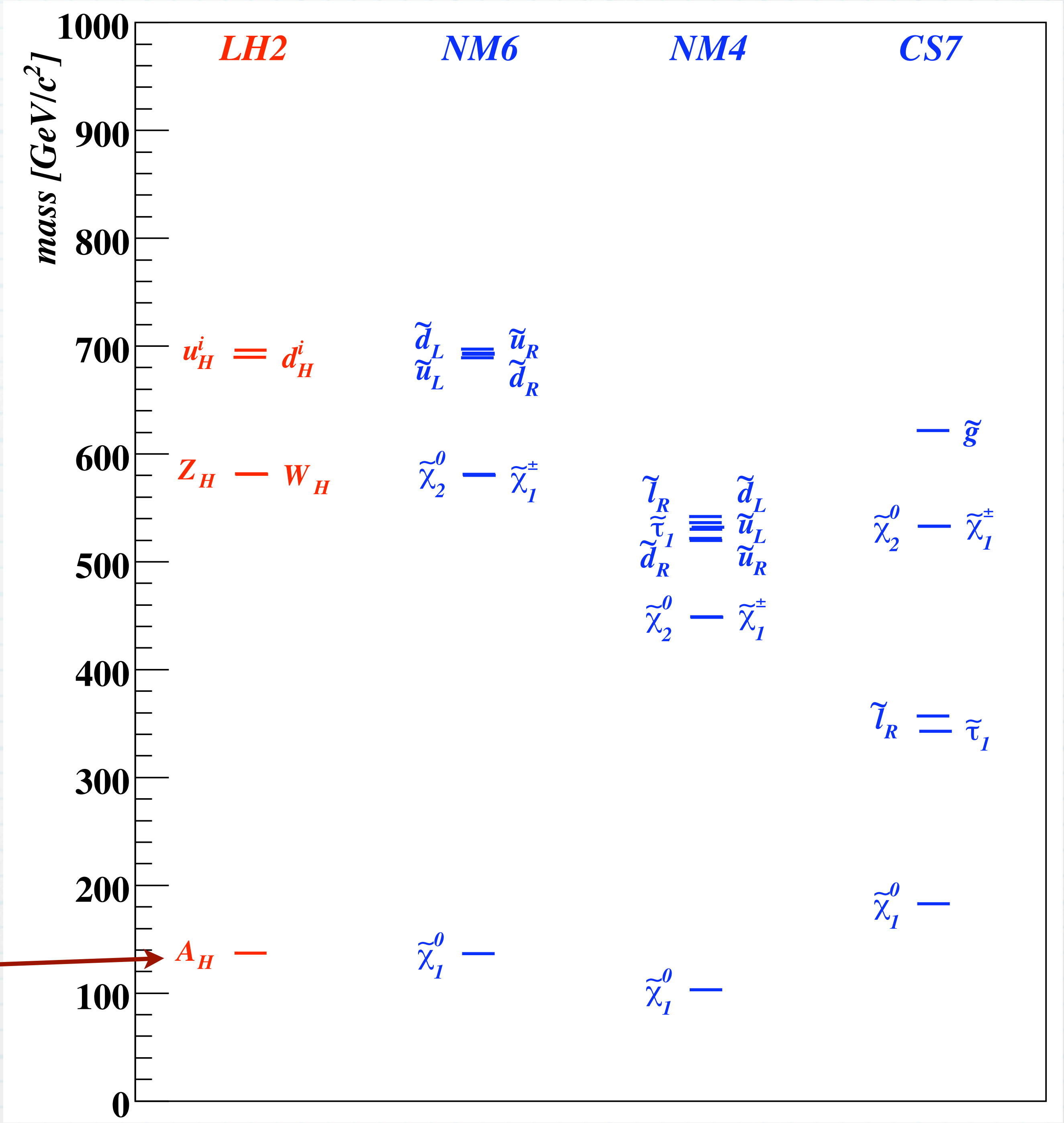
Results (Group 1)

		LM2p		LM5		LM8		CS4d		CS6	
LM2p											
	100			r(5j)(3j)	1.6σ	r(5j)(3j)	4.4σ	r(MET520)	4.1σ	r(mT2-600/300)	11.4σ
				r(mT2-300)	1.4σ	r(MET520)	3.7σ	r(HT900)	3.6σ	r(MET520)	10.6σ
				r(τ-tag)	1.2σ	r(10t-c45)	2.9σ	r(Meff1400)	3.0σ	r(HT900)	6.8σ
	1000			r(τ-tag)	3.1σ	r(MET520)	8.2σ	r(MET520)	9.4σ	r(mT2-600/300)	33.0σ
				r(5j)(3j)	2.8σ	r(mT2-500)	6.7σ	r(HT900)	6.4σ	r(MET520)	26.6σ
				r(mT2-400)	2.6σ	r(5j)(3j)	6.5σ	r(mT2-600)	6.0σ	r(HT900)	14.6σ
LM5											
	100	r(5j(3j)	1.8σ			r(5j)(3j)	2.9σ	r(HT900)	3.6σ	r(mT2-600/300)	11.6σ
		r(mT2-300)	1.5σ			r(MET520)	2.7σ	r(Meff1400)	3.2σ	r(MET520)	9.2σ
		r(10t-c30)	1.4σ			r(Muon20)	2.5σ	r(MET520)	3.1σ	r(HT900)	6.8σ
	1000	r(5j)(4j)	3.4σ			r(MET520)	6.0σ	r(MET520)	7.1σ	r(mT2-600/300)	33.7σ
		r(τ-tag)	2.7σ			r(Muon20)	4.9σ	r(HT900)	6.4σ	r(MET520)	22.9σ
		r(mT2-400)	2.6σ			r(5j)(3j)	4.3σ	r(mT2-600/400)	6.1σ	r(HT900)	14.6σ
LM8											
	100	r(5j)(3j)	5.5σ	r(5j)(3j)	3.3σ			r(5j)(3j)	3.1σ	r(Muon20)	10.1σ
		r(10t-c30)	3.7σ	r(Muon20)	3.1σ			r(mT2-400)	2.2σ	r(mT2500/300)	5.2σ
		r(Muon20)	3.6σ	r(MET520)	2.4σ			r(20t-c45)	2.1σ	r(Hem3)	4.1σ
	1000	r(5j)(3j)	10.1σ	r(Muon20)	7.2σ			r(5j)(3j)	5.4σ	r(Muon20)	25.8σ
		r(Muon20)	8.0σ	r(Hem3)	5.7σ			r(Hem3)	5.3σ	r(mT2-600/300)	20.1σ
		r(Hem3)	7.3σ	r(5j)(3j)	5.6σ			r(Muon20)	4.1σ	r(Hem3)	14.2σ
CS4d											
	100	r(MET520)	3.5σ	r(HT900)	3.0σ	r(5j)(3j)	2.8σ			r(Muon20)	6.8σ
		r(HT900)	3.2σ	r(MET520)	2.7σ	r(mT2-300)	2.1σ			r(MET420)	5.5σ
		r(Meff1400)	2.6σ	r(Meff1400)	2.6σ	r(10t-c30)	1.9σ			r(mT2-500/300)	5.2σ
	1000	r(MET520)	6.5σ	r(MET520)	5.1σ	r(5j)(3j)	4.2σ			r(Muon20)	17.3σ
		r(mT2-600)	5.3σ	r(mT2-600/400)	4.8σ	r(10tdiff-c30)	3.6σ			r(mT2-500)	12.8σ
		r(HT900)	5.2σ	r(HT900)	4.5σ	r(Hem3)	3.6σ			r(MET520)	11.5σ
CS6											
	100	r(MET420)	7.0σ	r(MET420)	6.0σ	r(b-tag)*	6.5σ	r(MET420)	4.3σ		
		r(mT2-500/300)	5.1σ	r(mT2-500/300)	4.6σ	r(Muon20)	5.2σ	r(Muon20)	4.0σ		
		r(HT900)	4.8σ	r(HT900)	4.5σ	r(MET420)	4.0σ	r(mT2-500/300)	2.9σ		
	1000	r(MET520)	11.5σ	r(b-tag)*	11.0σ	r(b-tag)*	15.6σ	r(b-tag)*	14.9σ		
		r(b-tag)*	11.2σ	r(MET520)	10.3σ	r(Muon20)	10.2σ	r(Muon20)	8.4σ		
		r(mT2-500)	10.2σ	r(mT2-500)	9.2σ	r(MET520)	7.6σ	r(MET420)	7.6σ		

Group 2 spectra

* LH2 - little Higgs model
  * "littlest Higgs w/ T-parity"
* NM6 - LH2's susic sister
* NM4 - LH2's susic little sister (look-alike)
* CS7 - No relation (look-alike)

A_H is LH "lightest neutralino"



Group 2 Analysis

LH2 (6.5 pb LO x-sec)

	before cuts	after cuts
$Q_i \bar{Q}_i$	55%	64%
$u_H^i d_H^i$, $u_H^i u_H^i$, $d_H^i d_H^i$	14%	16%
$d_H^i W_H^+$, $u_H^i W_H^-$	12%	7%
$u_H^i Z_H$, $u_H^i A_H$, $d_H^i Z_H$, $d_H^i A_H$	9%	5%
$Q_i \bar{Q}_j$, $i \neq j$	3%	3%
other	7%	5%

No “gluino” in LH models

$qq\ A_H A_H$	64%
$W\ qq\ A_H A_H$	39%
$h\ qq\ A_H A_H$	22%
$bb\ A_H A_H$	14%
$WW\ qq\ A_H A_H$	8%
$hh\ bb\ A_H A_H$	4%
$hh\ qq\ A_H A_H$	3%
$tt\ A_H A_H$	3%

SUSY:

	NM6	NM4	CS7
$qq\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0$	84%	83%	100%
$qqq\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0$	8%	16%	100%
$qqqq\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0$	-	-	95%
$bb\ q\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0$	2%	5%	11%
$W\ qq\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0$	26%	35%	-
$h\ q\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0$	14%	19%	-
$tt\ q\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0$	1%	1%	11%
$Z\ q\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0$	4%	5%	-
$WW\ q\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0$	4%	9%	-

	NM6		NM4		CS7	
LO cross section (pb)	2.3		10.3		5.0	
	before cuts	after cuts	before cuts	after cuts	before cuts	after cuts
$\tilde{q}_i \bar{\tilde{q}}_i$	31%	29%	34%	26%	-	-
$\tilde{u}\tilde{d}$, $\tilde{u}\tilde{u}$, $\tilde{d}\tilde{d}$	32%	28%	29	23%	-	-
squark–gluino	3%	10%	5%	23%	4%	8%
gluino–gluino	-	-	-	-	96%	91%
squark–chargino	2%	2%	3%	1%	-	-
squark–neutralino	4%	1%	4%	-	-	-
$\tilde{q}_i \bar{\tilde{q}}_j$, $i \neq j$	15%	17%	17%	14%	-	-
other	13%	13%	8%	13%	-	-

Results (Group 2)

	LH2		NM4		CS7	
LH2						
100			r(mT2-500)	4.9σ	r(mT2-500)	6.7σ
			r(Meff1400)	3.0σ	r(MET420)	6.5σ
			r(M1400)	2.7σ	r(4j)(3j)	4.0σ
1000			r(mT2-500)	14.1σ	r(mT2-500)	18.9σ
			r(mT2-300) [TriJet]	11.0σ	r(MET420)	16.7σ
			r(mT2-400) [DiJjet]	7.9σ	r(mT2-500) [TriJet]	8.8σ
			r(Meff1400)	7.2σ	r(4j)(3j) [DiJet]	7.3σ
			r(M1400)	6.6σ	r(mT2-300) [DiJet]	6.7σ
NM4						
100	r(Meff1400)	4.2σ			r(Meff1400)	4.3σ
	r(M1400)	4.0σ			r(DiJet)	4.1σ
	r(mT2-400)	3.8σ			r(MET420)	4.0σ
1000	r(Meff1400)	10.8σ			r(Meff1400)	11.2σ
	r(TriJet)	10.4σ			r(MET520)	10.6σ
	r(M1400)	9.8σ			r(DiJet)	10.6σ
	r(DiJet	8.2σ			r(HT900)	9.0σ
	r(HT900)	8.0σ			r(4j)(3j)	6.1σ
CS7						
100	r(MET420)	4.9σ	r(4j)(3j)	4.4σ		
	r(4j)(3j)	4.6σ	r(MET420)	3.3σ		
	r(mT2-400)	4.1σ	r(Hem1)	3.2σ		
1000	r(5j)(3j) [DiJet]	16.8σ	r(4j)(3j)	9.4σ		
	r(TriJet)	10.4σ	r(5j)(3j) [DiJet]	7.4σ		
	r(MET420)	9.6σ	r(Meff1400)	7.4σ		
	r(4j)(3j)	9.5σ	r(DiJet)	6.9σ		
	r(mT2-500)	8.3σ	r(HT900)	6.2σ		

Huh? I thought you couldn't do spin at the LHC...

Spin statistics

Little Higgs vs SUSY

Boson cancels boson
Fermion cancels fermion

Boson cancels fermion
and v.v.

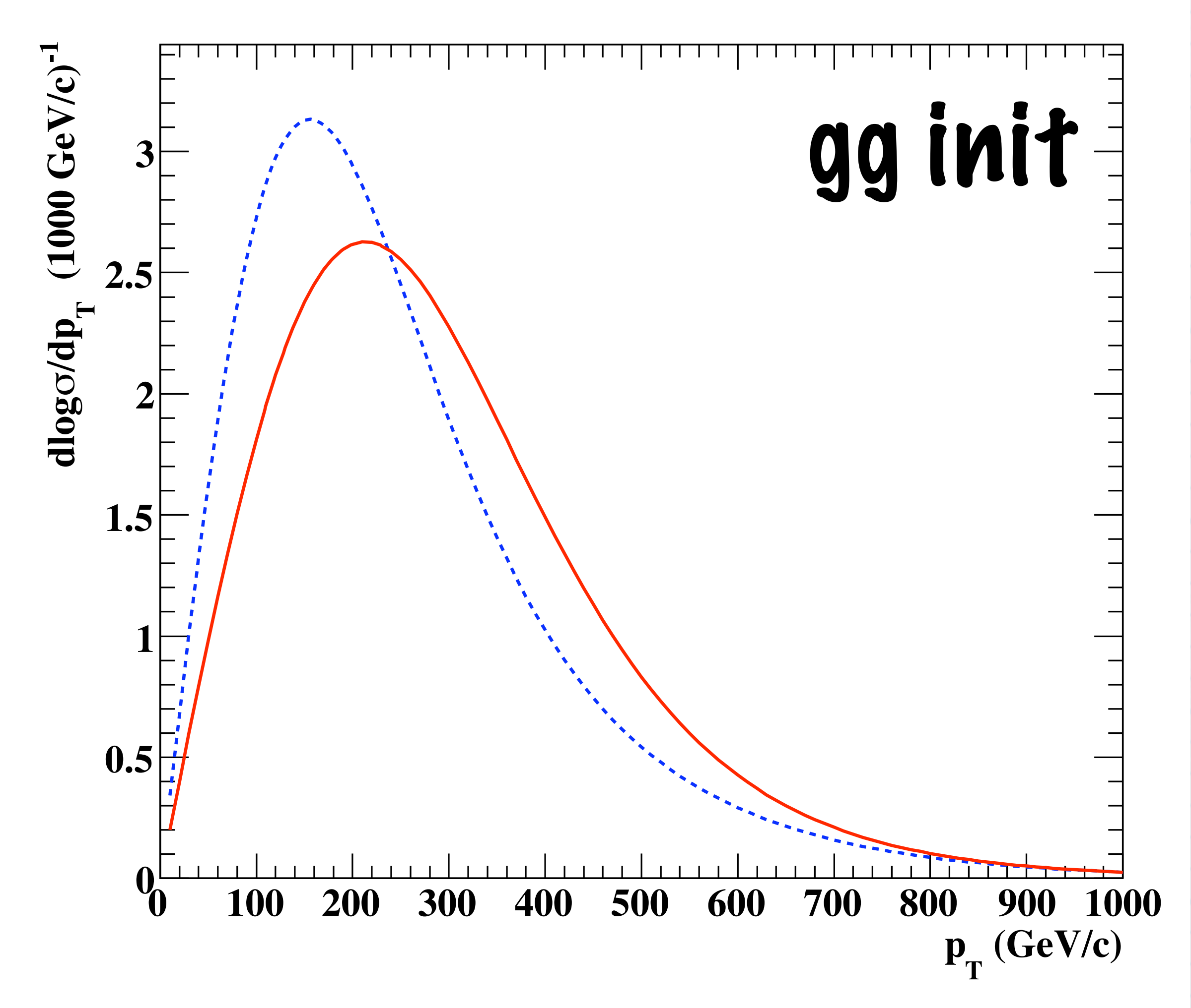
"Ancient wisdom" - models differing only by spin have very different cross sections

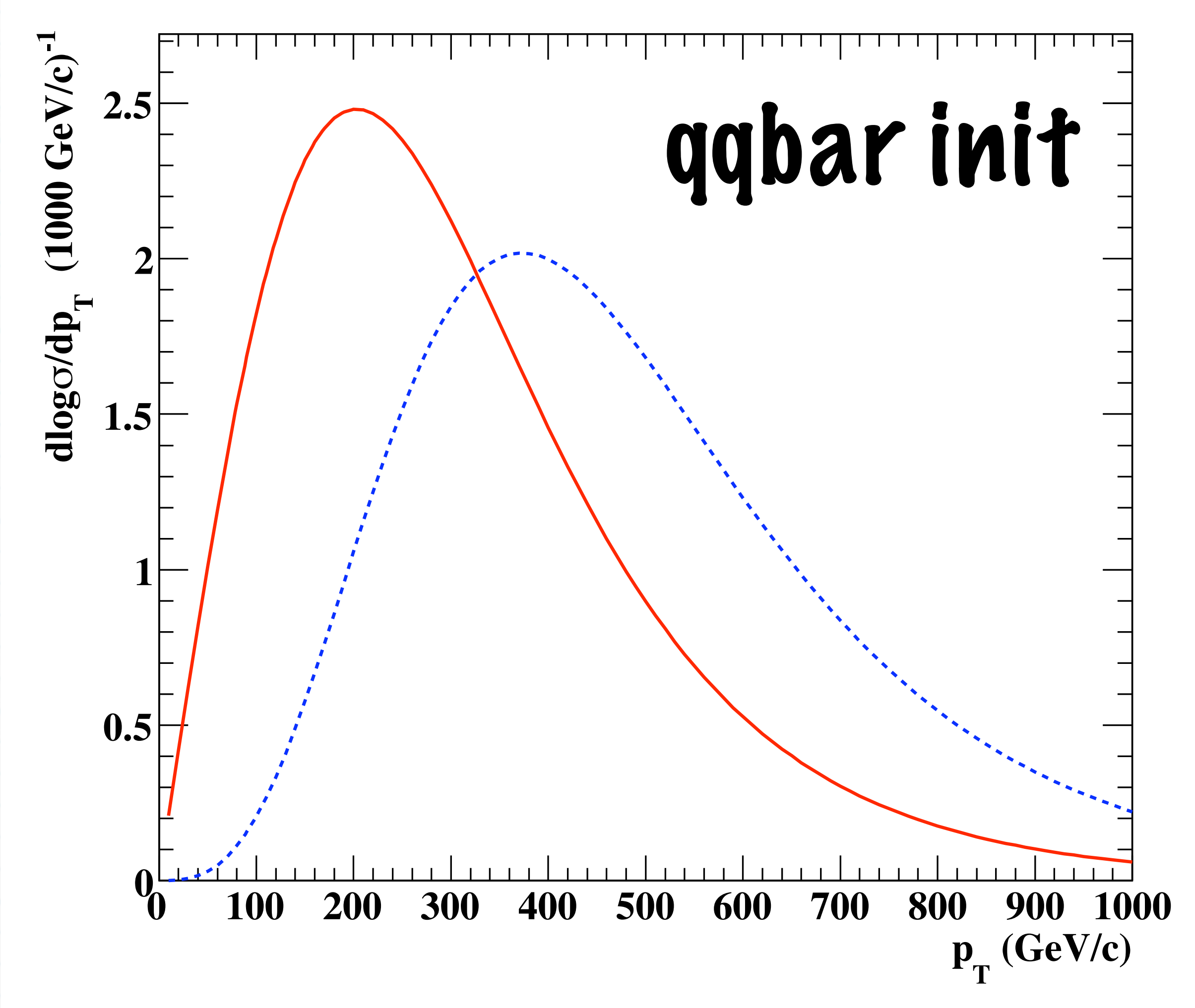
Lesser Known: different p_T spectra!

About spins

Heavy quarks (red solid) vs. colored scalars (blue dashed)

(e.g. T-odd quarks) (e.g. squarks)

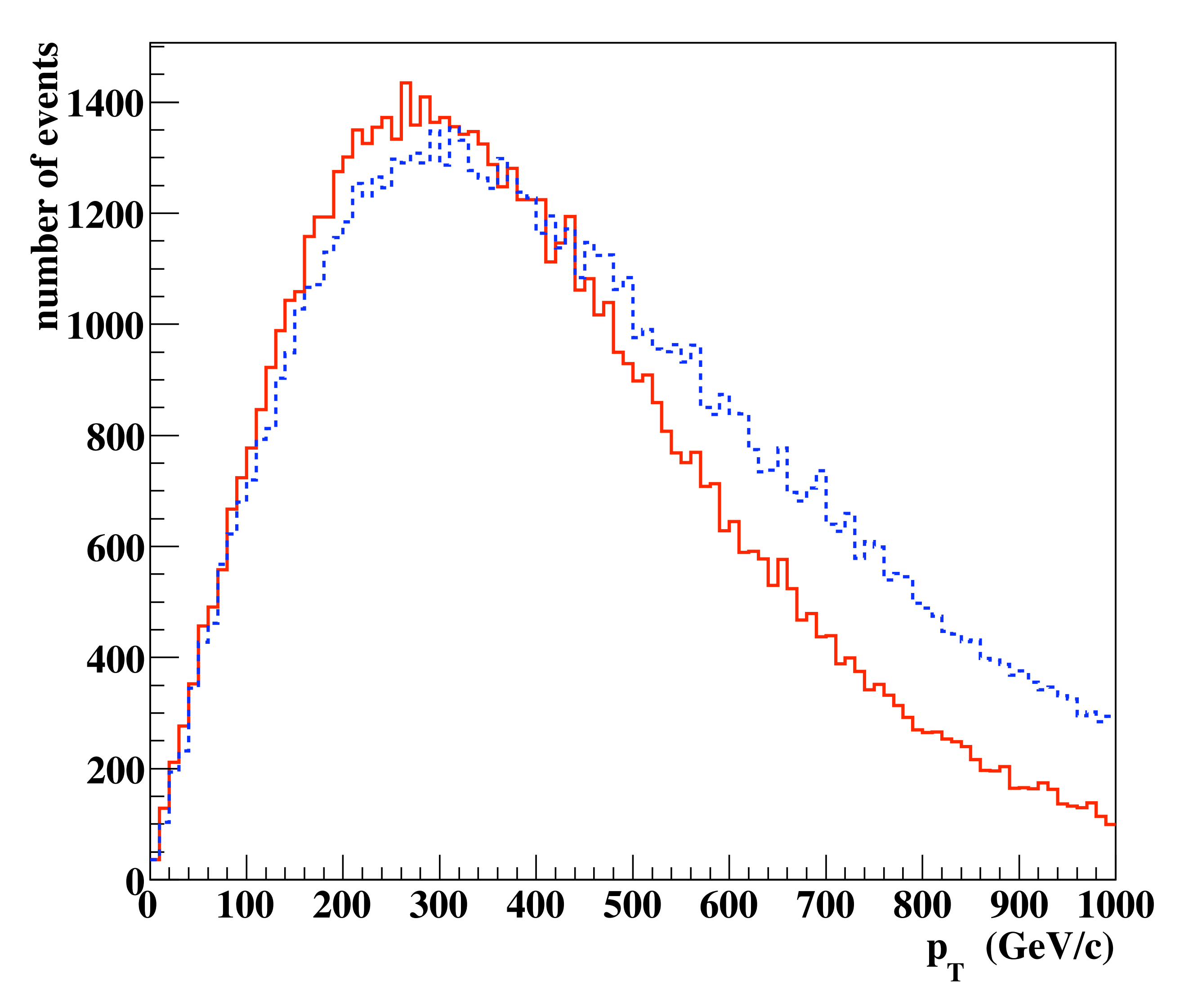




Normalized p_T distributions

Actual Models

LH2 (red) vs susy model NM6 (blue)



Normalized p_T distributions

Distinguish spins:

1) Start with initial sample (analysis path)

2) Create box with higher p_T events

ratio of counts in high p_T box to total # in path should be a discriminating variable

LH2	NM4
6.5pb	10.3pb
14%	9.4%

Lookalikes, but already discriminated at $100pb^{-1}$!

Spin done in first 100pb^{-1}

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

We tried hard to construct a SUSY model that was a closer lookalike, but did not succeed...

MT2 at high p_T strong discriminator

If this holds up under closer examination, will overturn a lot of conventional wisdom

Most techniques rely on detailed shapes of complicated distributions (lots of data)

Future Study

* This was a "dry-run"/exploration of what the best things are to do with the first $100 pb^{-1}$ of data given a signal in the E_T(miss) analysis path
    * primitive sim, left out a few details, but stayed realistic enough to flesh out a grand master plan
* Next:
    * Full sim, including electrons, better E_T(miss), more lookalikes (UED? More LH models?), NLO
    * Spin discrimination in model comparisons
    * what do we learn about dark matter?
    * other analysis paths?

Conclusions

* We will hopefully have 5 sigma discovery by the end of '09 (first 100pb^{-1})
  * we've developed techniques to discriminate models efficiently with this small amount of data
  * set of robust observables (ratios of inclusive counts)
  * "realistic" in that we minimize systematics, and stick to things that are (or should be) achievable in first year
* Compelling evidence for spin discrimination at moment of discovery