Inclusive signatures and 2008 discoveries

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papers: hep-ph/07xxxxx

LHC discoveries with 1 fb-1

- many discoveries (and false positives) will be possible with the 2008 data set.

- this talk will focus on missing energy signatures since, next to Higgs, these have the best theoretical motivation.

- missing energy channels will be very challenging for the experiments (see talk by Maria Spiropulu).

- but I am optimistic that unambiguous signals can be obtained with ~ 1 fb-1 assuming that the heavy partners are strongly produced with cross sections >~ 1 pb.

what this talk is about

- after heroic efforts ATLAS and CMS establish a missing energy signal based on the 2008 data set.
- now what?
- what are the very next questions that you ask, and what are the very next steps that you take.
- how much can you learn about the signal with the original 1 fb-1 of data? how do you prepare to do better with the next ~5 fb-1 of data?

what this has to do with theorists

- if you are a theorist and your name is not Rick Field, you probably do not have the requisite skill set for analyzing real LHC data.

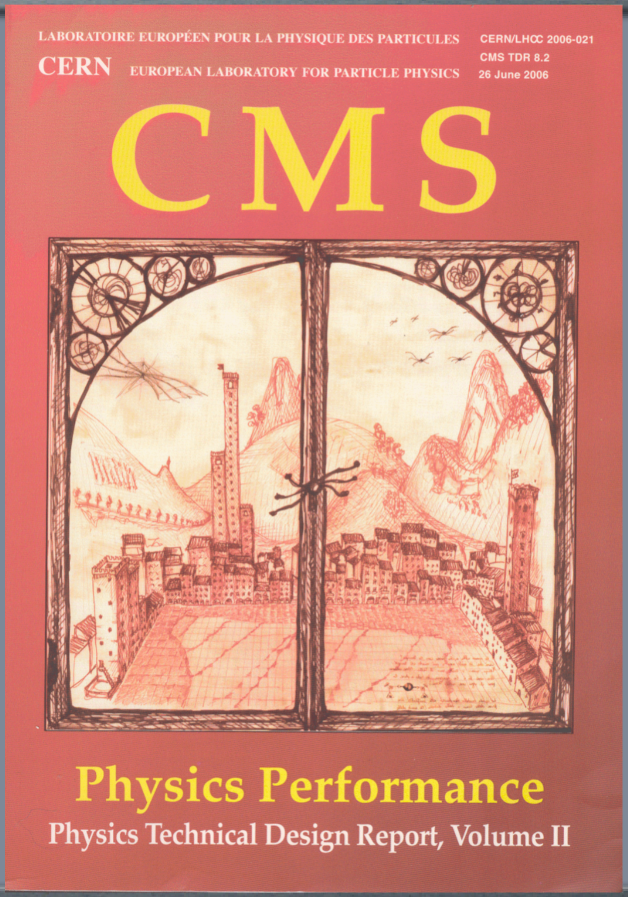
- however theorists are good at asking simple questions, suggesting creative strategies, implementing and understanding event generators.

- thus some theorists can make valuable contributions, but only if they are sufficiently up to speed on the (sobering) realities of the actual data analysis.

The CMS PHYSICS TDR of 2006 gives a snapshot of what the physics groups were thinking for the real 2008 analyses.

The PTDR Vol II contains a large number of analysis studies using full GEANT based simulation of the CMS detector, with most/all Standard Model backgrounds included.

Our strategy is to follow these analyses as closely as possible, focusing on missing energy signatures



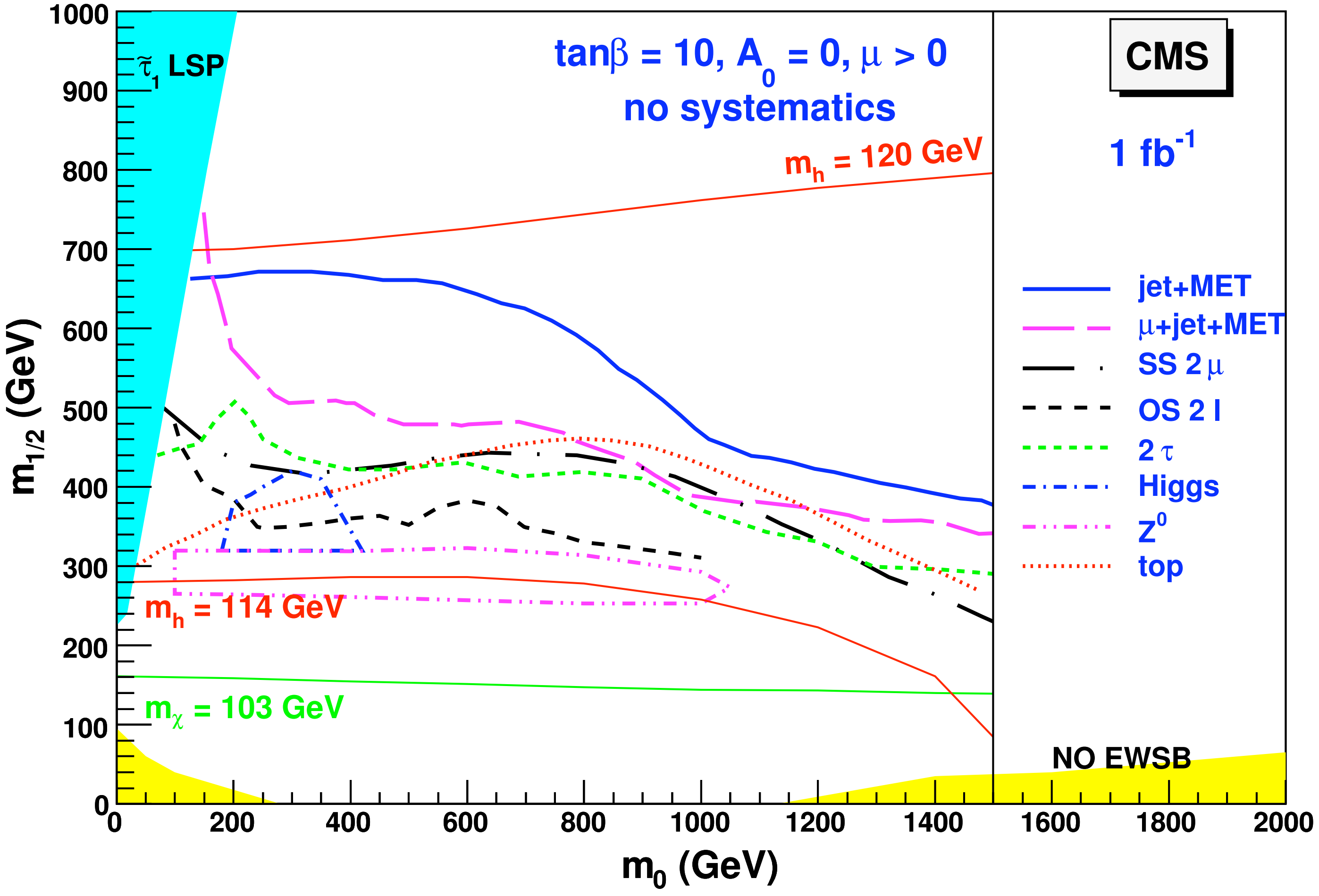
LABORATOIRE EUROPÉEN POUR LA PHYSIQUE DES PARTICULES
CERN EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CERN/LHCC 2006-021
CMS TDR 8.2
26 June 2006

CMS

Physics Performance
Physics Technical Design Report, Volume II

what the three most relevant missing energy channels for 2008 discovery?



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

- not surprisingly, the channels which are the most inclusive are projected to have the best reach.
- I will refer to these channels as:
    - jetmet = all hadronic jets + missing energy
    - muon+jetmet = isolated muon + jets + met
    - SS dimuon = same-sign dimuons + jets + met
- OS dimuon is also interesting because of the possibility of seeing a kinematic edge.
- theorists have already thought a lot about these channels and how correlated signals distinguish the underlying new physics.
- see e.g. A. Datta, G. Kane, M. Toharia, hep-ph/0510204 and references therein.

- what is new here is that we a trying to follow the exact steps of (the rehearsal for) the real analyses.

- this is important because there is actually no such thing as an inclusive signature at LHC.

- this should have been obvious already from Maria’s talk.

- let me remind you of what the most inclusive analysis, jetmet, actually looked like:

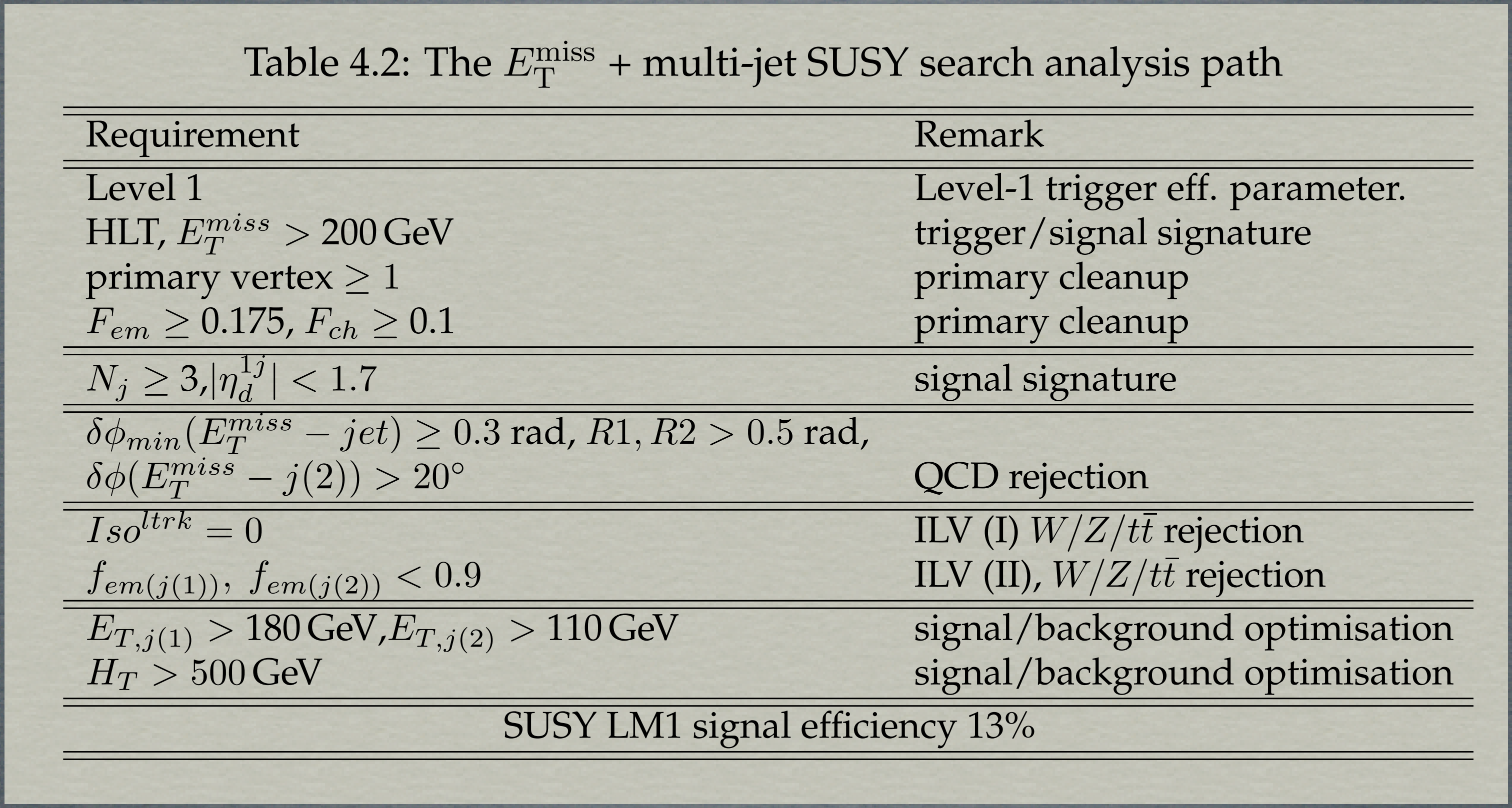


Table 4.2: The $E_{\mathrm{T}}^{\mathrm{miss}}$ + multi-jet SUSY search analysis path

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,	
$\delta\phi(E_T^{miss} - j(2)) > 20^\circ$	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%	

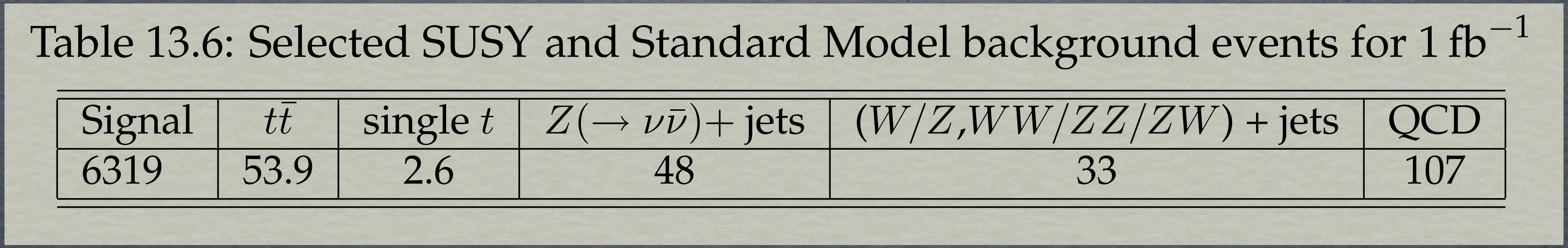


Table 13.6: Selected SUSY and Standard Model background events for 1 fb^{-1}

Signal	$t\bar{t}$	single t	$Z(\rightarrow \nu\bar{\nu})$+ jets	$(W/Z,WW/ZZ/ZW)$ + jets	QCD
6319	53.9	2.6	48	33	107

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

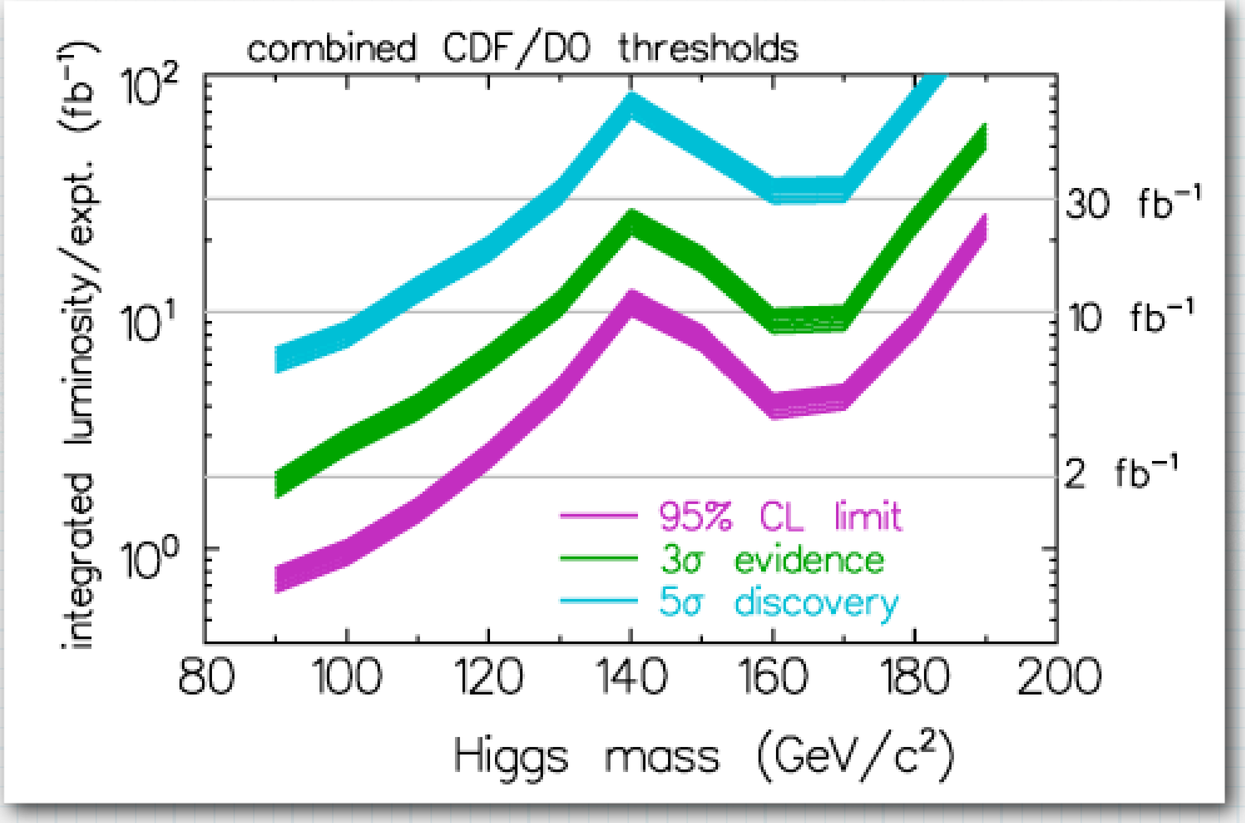
detector simulation

- an adequate analysis of the SM backgrounds requires (at least) full detector simulation.
- because we are copying the existing studies, we don’t have to repeat the background analysis.
- however we do need some kind of detector simulation for looking at SUSY or other kind of signals.
- the full simulation CMSSW is very slow; the fast simulation FAMOS is also slow.
- can we use a faster parametrized simulation like PGS?

Origin of PGS

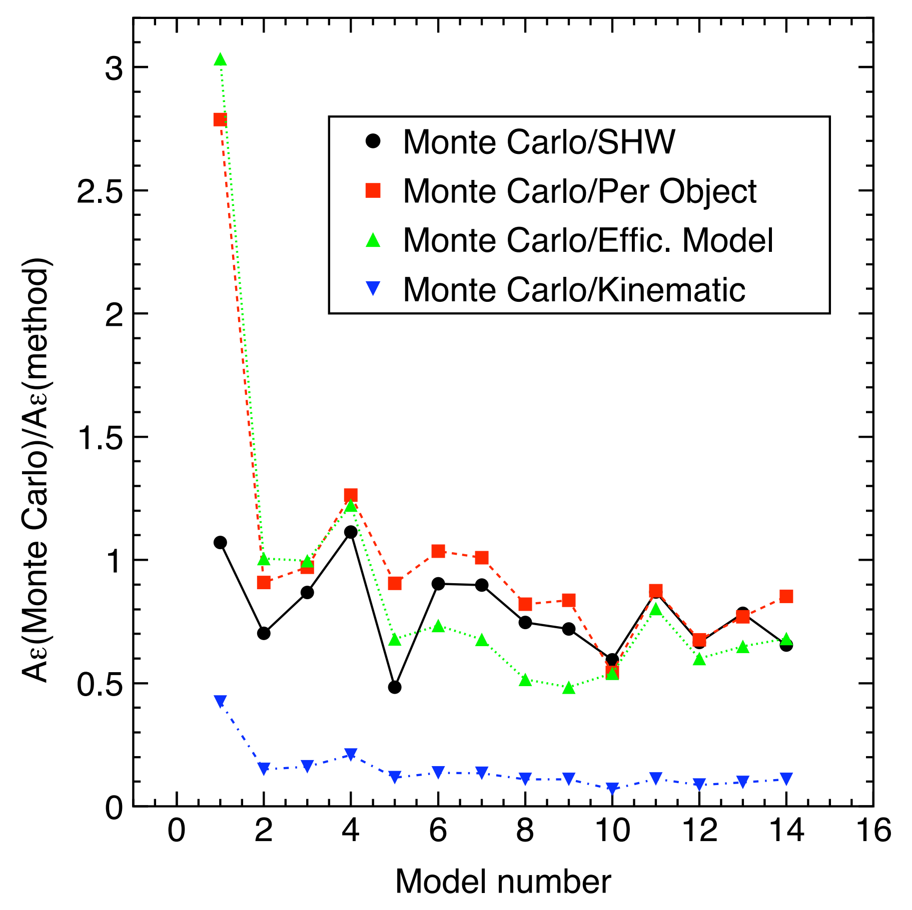
- March 1998: kickoff of the Tevatron Run 2 SUSY/Higgs Workshop
- no Run 2 CDF/D0 simulations available then
- developed “SHW” simulation as average of CDF/D0
- published SHW Higgs report: hep-ph/0010338
- still a reliable resource for Tevatron Higgs reach!
- SHW -> PGS for Snowmass 2001
- used for VLHC, LHC, LC, Tevatron comparisons, especially by theorists

Tevatron SM Higgs: SHW

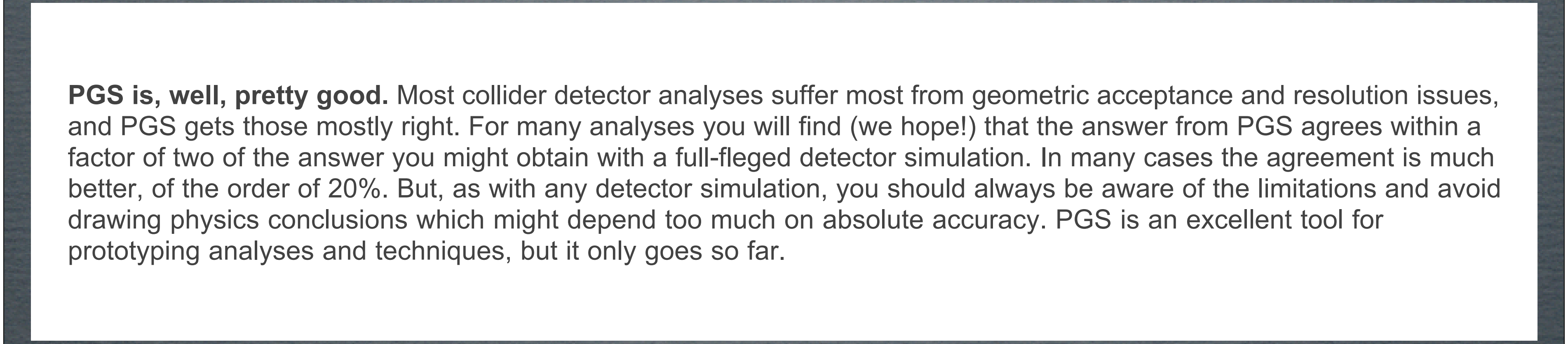


Famous result from the 1998 Tevatron Run 2 Susy/Higgs Workshop: from SHW simulation!

John Conway, talk at the 3rd LHCO



Ray Culbertson et al, hep-ex/0106012


PGS is, well, pretty good. Most collider detector analyses suffer most from geometric acceptance and resolution issues, and PGS gets those mostly right. For many analyses you will find (we hope!) that the answer from PGS agrees within a factor of two of the answer you might obtain with a full-fleged detector simulation. In many cases the agreement is much better, of the order of 20%. But, as with any detector simulation, you should always be aware of the limitations and avoid drawing physics conclusions which might depend too much on absolute accuracy. PGS is an excellent tool for prototyping analyses and techniques, but it only goes so far.

it is not obvious that PGS is good enough for the kind of detailed LHC signal analysis that we are interested in.

PGS-CMS

- our strategy is to assume that a parametrized detector simulation like PGS is not hopeless for extracting the main features of central high pT signals like SUSY.

- the next step is to improve/tune PGS to make it act more like the real CMS detector for SUSY-like signals.

- we have a version of this working that we call PGS-CMS.

- PGS-CMS was developed by putting more of the physics of the real CMS detector into PGS, then tweaking it to get the best fit, cut by cut, to the 3 benchmark SUSY studies in the PTDR.

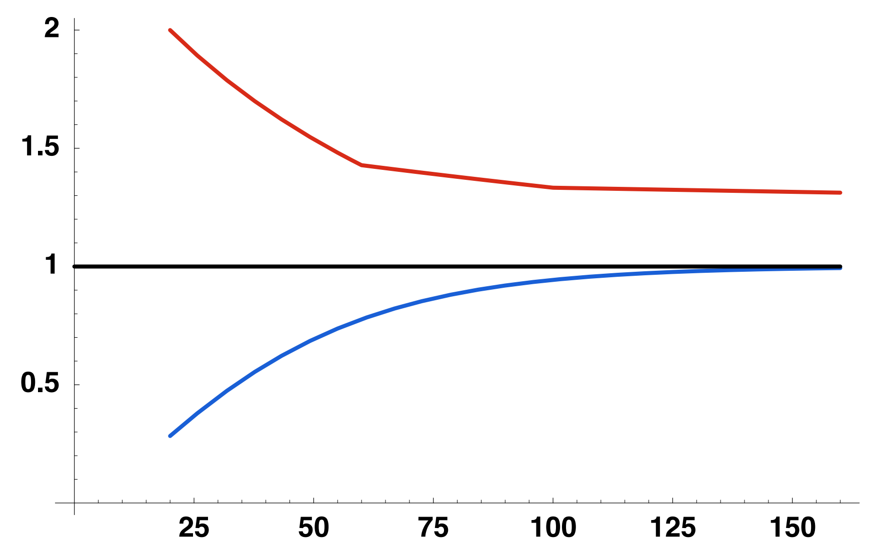
	PGS-CMS	PGS
raw jets?	yes	no
corrected jets?	yes	no
B field?	yes	only trk smear
z vertex?	yes	no
realistic muon reco eff?	yes	no
realistic tau reco?	yes	yes
charged hadron track reco?	yes	no
realistic cal and track isolation?	yes	no
brem effects?	partially	no
realistic triggering?	no	no
pileup and multiple interactions?	implement in Pythia	“

PGS jets

- the main difference between the output of PGS and PGS-CMS is in the properties of jets.

- the CMS studies that we copy use both “raw jets” and “corrected jets”; the former is basically just what you see from towers in the calorimeter while the latter is an attempt to correct back to something close to the parton level.

- what kind of jets do you get out of vanilla PGS?



Answer: vanilla PGS gives jets which are intermediate between CMS raw jets and CMS corrected jets.

in PGS-CMS we believe that we have a rough approximation to either CMS raw jets (used in the jetmet study) or CMS corrected jets (used in the muon+jetmet and SS dimuon studies).

PGS

Event 1

muon:	-0.77555	3.7240	44.052
jet:	-1.16510	6.2412	196.759
jet:	0.21522	0.2520	179.586
jet:	1.37564	2.4204	36.614
MET:		3.1851	407.571

Event 2

photon:	1.13097	4.7595	6.673
muon:	0.46886	2.7614	4.282
muon:	1.20407	2.6583	14.795
jet:	-1.06580	2.3848	81.465
jet:	-1.04471	4.0310	45.261
jet:	0.32781	2.7650	60.518
jet:	-0.52758	0.9956	48.930
jet:	0.44550	5.0371	31.612
MET:		4.9581	156.979

Event 3

photon:	-0.37699	3.0945	22.997
electron:	0.93496	0.5188	5.587
photon:	1.06814	0.4869	8.610
photon:	1.19380	2.2777	9.687
muon:	1.60418	1.9217	14.935
jet:	1.14699	5.1260	341.055
jet:	0.78540	2.9374	34.538
jet:	-0.32488	3.0305	124.186
jet:	-0.39767	0.9554	45.115
jet:	1.05585	0.5097	31.141
MET:		1.2517	233.073

PGS-CMS

Event 1

muon:	-0.77555	3.7413	44.130
jet:	-1.22758	6.2237	138.192
jet:	0.16871	0.3161	194.663
MET:		3.3071	359.070

Event 2

muon:	0.46886	2.9401	4.282
jet:	-1.03309	2.3566	92.761
jet:	0.44874	2.9640	98.260
jet:	0.58518	4.4407	35.746
MET:		5.8191	125.354

Event 3

photon:	-0.43633	3.0980	6.321
muon:	1.60418	1.9727	14.943
muon:	-0.42769	2.9494	5.846
jet:	1.07804	5.0974	337.040
jet:	-0.44801	2.9387	95.573
jet:	-0.54962	1.0083	34.331
MET:		1.7325	240.897

how well does PGS-CMS do in matching the 3 PTDR analyses, cut by cut?

- make the comparison for the CMS benchmark SUSY model LM1.

- this is an msugra model generated with Isajet v7.69, with events generated by Pythia and run through PGS-CMS.

- the model has 600 GeV gluinos, 550 GeV squarks, and a 95 GeV LSP.

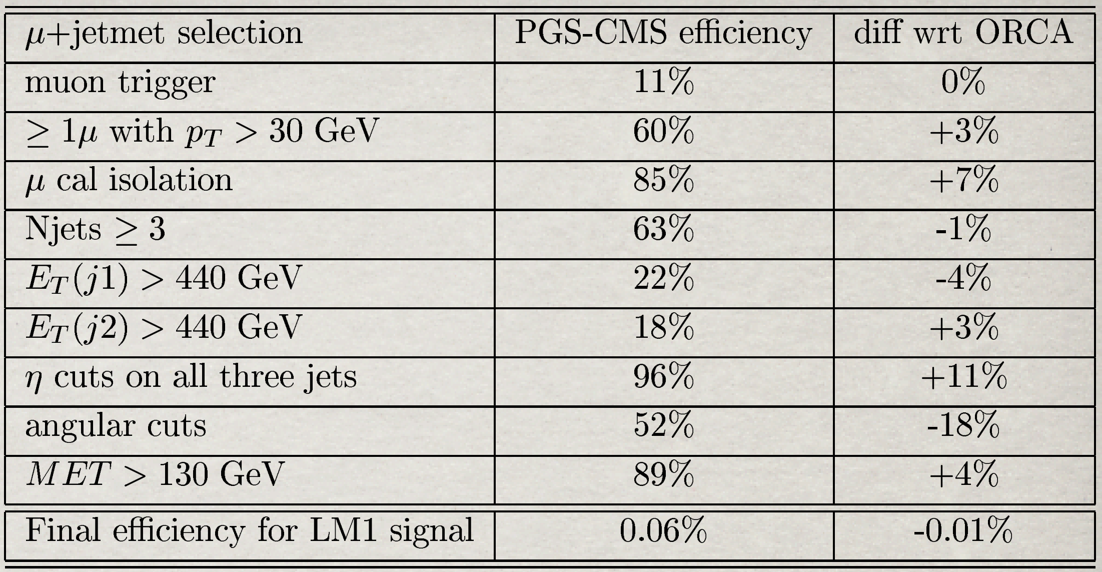
- the NLO cross section from Prospino 2 is 53.3 pb.

- 51% of production is squark-gluino, 15% is gluino pairs, almost all of the rest is squark pairs.

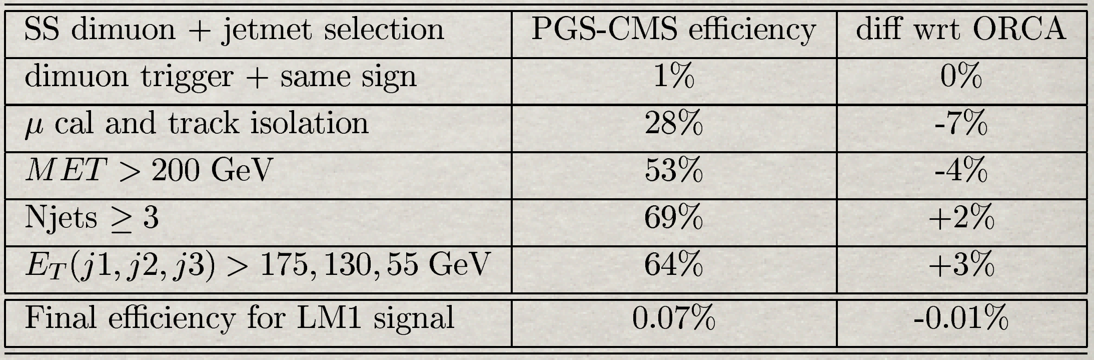
jetmet selection	PGS-CMS efficiency	diff wrt ORCA
trigger, $MET > 200$ GeV + central jet	54.2%	+0.3%
Njets ≥ 3	72.3%	+0.2%
$\lvert\eta_d\rvert < 1.7$ for leading jet	93.5%	+5.4%
Event Charged Fraction ≥ 0.175	98.6%	+0.7%
angular cuts: $\delta\phi_{\min}$, $\delta\phi_{MET-j2}$, $R1$, $R2$	78.8%	+1.5%
Indirect Lepton Veto	81.5%	-3.8%
$E_T(j1) > 180$ GeV, $E_T(j2) > 110$ GeV	62.8%	-0.2%
$H_T > 500$ GeV	91.9%	-0.9%
Final efficiency for LM1 signal	13.4%	+0.5%

- **excellent agreement.**
- **+5.4% discrepancy is really a trigger issue.**
- **-3.8% discrepancy involves modeling electrons faking raw jets.**

- good agreement.
- because you are cutting so hard, have to model the tails of the signal, as you do for the background.



μ+jetmet selection	PGS-CMS efficiency	diff wrt ORCA
muon trigger	11%	0%
$\geq 1\mu$ with $p_T > 30$ GeV	60%	+3%
μ cal isolation	85%	+7%
Njets ≥ 3	63%	-1%
$E_T(j1) > 440$ GeV	22%	-4%
$E_T(j2) > 440$ GeV	18%	+3%
η cuts on all three jets	96%	+11%
angular cuts	52%	-18%
$MET > 130$ GeV	89%	+4%
Final efficiency for LM1 signal	0.06%	-0.01%



SS dimuon + jetmet selection	PGS-CMS efficiency	diff wrt ORCA
dimuon trigger + same sign	1%	0%
μ cal and track isolation	28%	-7%
$MET > 200$ GeV	53%	-4%
Njets ≥ 3	69%	+2%
$E_T(j1, j2, j3) > 175, 130, 55$ GeV	64%	+3%
Final efficiency for LM1 signal	0.07%	-0.01%

what if you use PGS instead of PGS-CMS?

- with vanilla PGS, the total efficiency for the LM1 signal is too high by about 30%.

- the biggest differences are in the trigger and jet counting, which are both sensitive to the difference between PGS jets and CMS raw jets.

- individual distributions from vanilla PGS peak at values that disagree by as much as a factor of two with CMS ORCA.

- so Conway's disclaimer was correct!

what have you discovered?

- suppose we repeat these 3 analyses with the first fb-1 of physics-quality CMS data.
- suppose that we observe the following excesses:
    - 7136 events in the jetmet channel
    - 31 events in the muon+jetmet channel
    - 38 events in the SS dimuon channel
- with small remaining backgrounds and a 15-20% systematic
- now what?

what have you discovered?

- by construction, this signal could have been produced by the CMS benchmark SUSY model LM1, i.e. a sugra model with 600 GeV gluinos, 550 GeV squarks, a 180 GeV chargino and a 100 GeV LSP.

- for LM1, the NLO cross section from Prospino 2 is 53.3 pb, 51% of production is squark-gluino, 15% is gluino pairs, almost all of the rest is squark pairs.

- what else could this signal be?

what have you discovered?

- as a first step, ask what other sugra models, if any, are consistent with these excesses.

- without trying very hard, we have found two other possibilities:

three SUSY models

- model LM1 has 600 GeV gluinos and 550 GeV squarks, with a NLO cross section of 53 pb. 51% of production is squark-gluino, 15% is gluino pairs, almost all of the rest is squark pairs.

- model NM1 has 350 GeV gluinos and 1200 GeV squarks, with a NLO cross section of 232 pb. 95% of production is gluino pairs.

- model NM2 has 450 GeV gluinos, 550 GeV squarks, but the lightest stop is 190 GeV. The NLO cross section is 233 pb. 20% of production is gluino pairs, about 30% is squark-gluino, and 40% is stop pairs.

SUSY model LM1:

$$\mathbf{pp} \rightarrow \tilde{\mathbf{q}}\,\tilde{\mathbf{g}}$$
$$\hookrightarrow \tilde{\mathbf{q}}\,\mathbf{q}$$
$$\hookrightarrow \tilde{\chi}^{\pm}_{\mathbf{1}}\,\mathbf{q}$$
$$\hookrightarrow \tilde{\tau}_{\mathbf{1}}\,\tau$$
$$\hookrightarrow \tilde{\chi}^{\mathbf{0}}_{\mathbf{1}}\,\tau$$

SUSY model NM1:

$$\mathbf{pp} \rightarrow \tilde{\mathbf{g}}\,\tilde{\mathbf{g}}$$
$$\hookrightarrow \tilde{\chi}^{\pm}_{\mathbf{1}}\,\mathbf{q}\,\mathbf{q}$$
$$\hookrightarrow \tilde{\chi}^{\mathbf{0}}_{\mathbf{1}}\,\mathbf{q}\,\mathbf{q}$$

SUSY model NM2:

$$\mathbf{pp} \rightarrow \tilde{\mathbf{g}}\,\tilde{\mathbf{g}}$$
$$\hookrightarrow \tilde{\mathbf{t}}_{\mathbf{1}}\,\mathbf{t}$$
$$\hookrightarrow \tilde{\chi}^{\pm}_{\mathbf{1}}\,\mathbf{b}$$
$$\hookrightarrow \tilde{\chi}^{\mathbf{0}}_{\mathbf{1}}\,\mathbf{q}\,\mathbf{q}$$

identical signals within errors

SUSY model LM1:

- jetmet events after all cuts: 7133

SUSY model NM1:

- jetmet events after all cuts: 6657 -7%

SUSY model NM2:

- jetmet events after all cuts: 7933 +11%

the muon channels help a lot

SUSY model LM1:

jetmet events after all cuts:	7133
muon+jetmet events after all cuts:	31
SS dimuon events after all cuts:	38

SUSY model NM1:

jetmet events after all cuts:	6657	-7%
muon+jetmet events after all cuts:	22	-29%
SS dimuon events after all cuts:	16	-58%

SUSY model NM2:

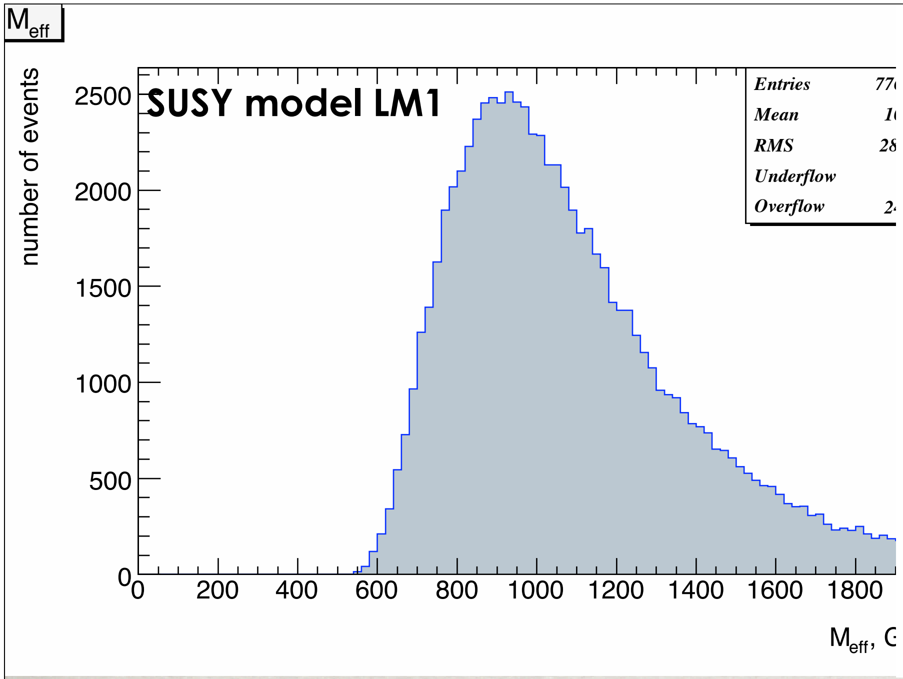
jetmet events after all cuts:	7933	+11%
muon+jetmet events after all cuts:	43	+39%
SS dimuon events after all cuts:	95	+250%

What other observables discriminate between these 3 models?

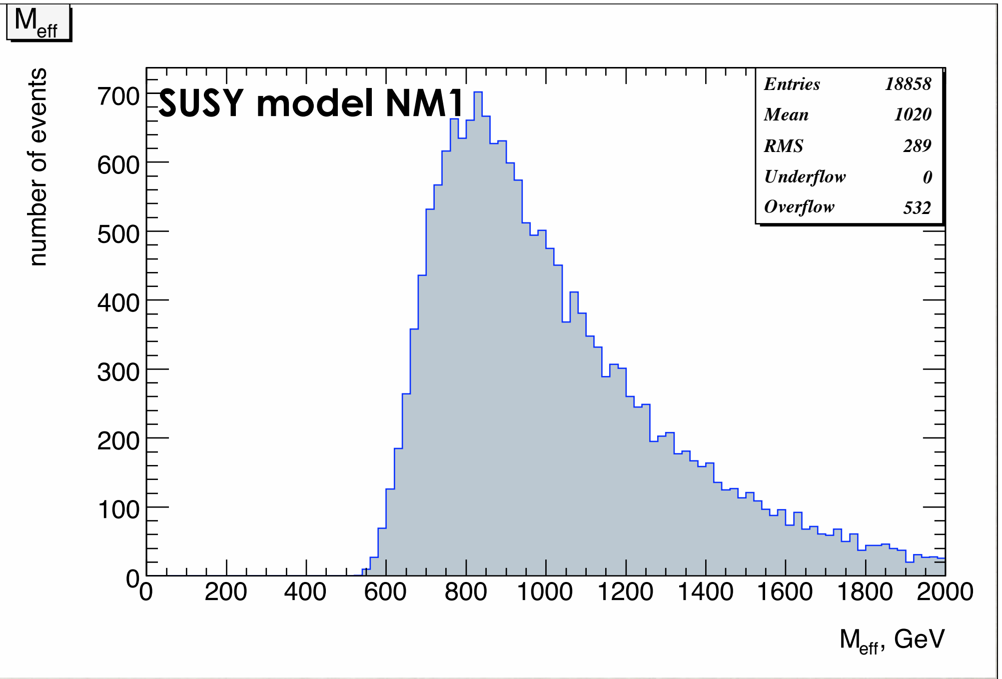
- standard SUSY mythology says that the very first plot you should make with your putative SUSY signal is the effective mass plot.

- this is supposed to measure the overall SUSY scale, meaning roughly the gluino mass times some factor.

- so this should easily discriminate between models LM1 and NM1, which have gluino mass 600 GeV and 350 GeV, right???

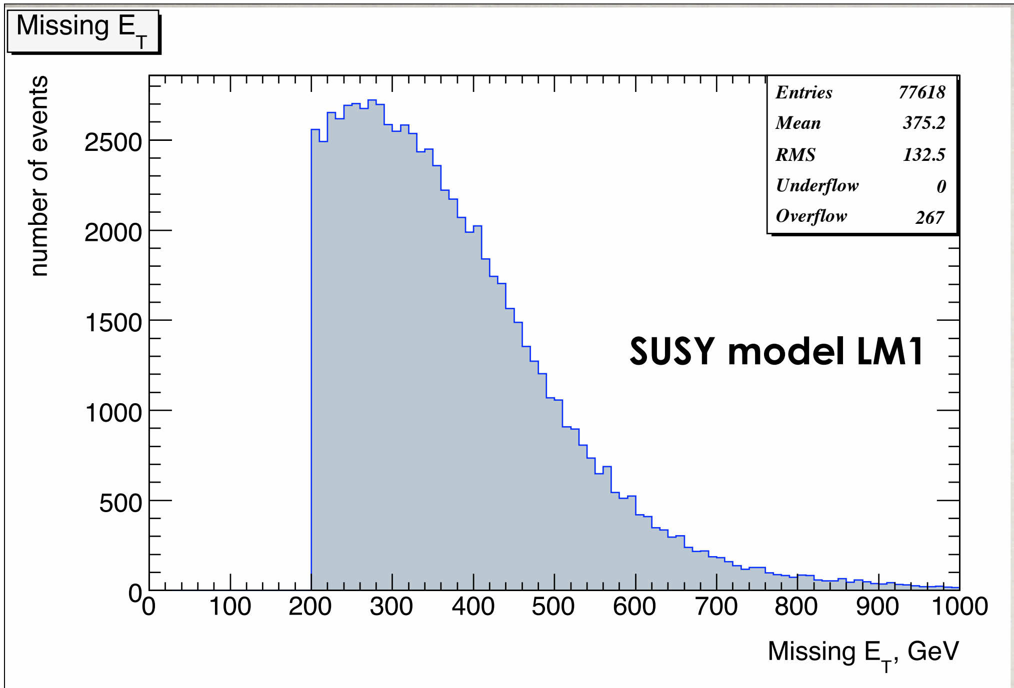


M_{eff}
SUSY model LM1
number of events
Entries 77
Mean 1
RMS 28
Underflow
Overflow 2
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
1400
1600
1800
M_{eff}, G

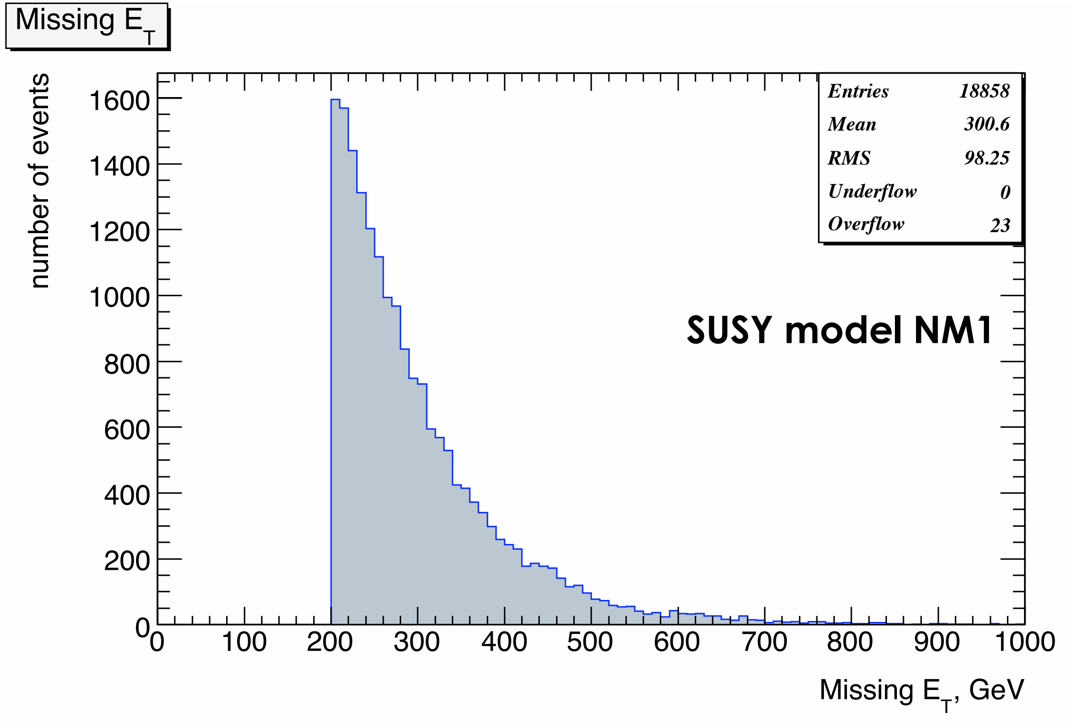


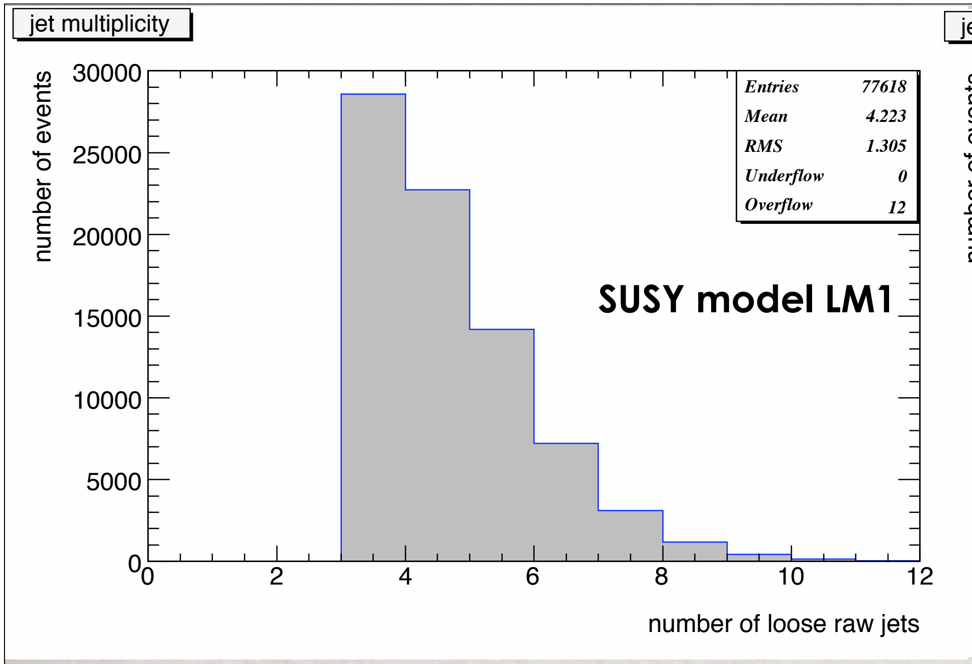
M_{eff}
SUSY model NM1
number of events
Entries 18858
Mean 1020
RMS 289
Underflow 0
Overflow 532
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
M_{eff}, GeV

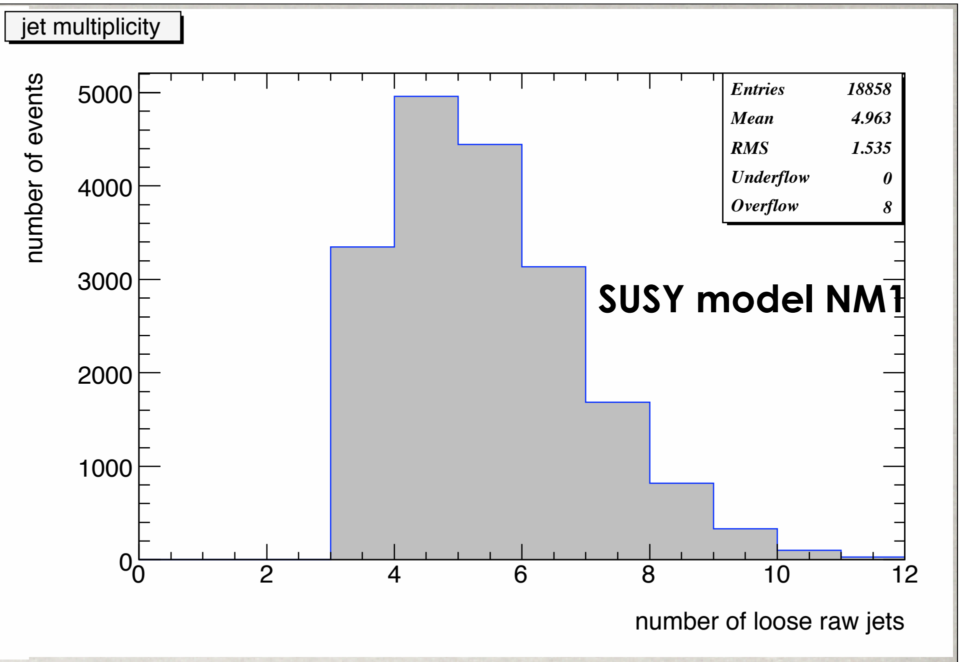
useless!



the missing transverse energy above the cut is much better







compute the ratio of the number of events with >3 jets to the number of events with 3 jets, after all cuts except the final HT cut:

SUSY model LM1:	**1.7**
SUSY model NM1:	**4.6**
SUSY model NM2:	**6.3**

work in progress

- systematic expanded analysis with more general SUSY models + non-SUSY models + ...

- have a look at the backgrounds, triggers, ...

- guided by these interesting results, repeat with full CMSSW simulation.

- ATLAS?

HCPSS : 2007

Applications are now open for the

2nd CERN-Fermilab Hadron Collider Physics Summer School

June 6-15, 2007

CERN

The school web site is

http://cern.ch/hcpss

with links to the academic program and application procedure.

The **APPLICATION DEADLINE IS MARCH 9, 2007**. The results of the selection process will be announced shortly thereafter. The goal of the CERN-Fermilab Hadron Collider Physics Summer Schools is to offer students and young researchers in high energy physics a concentrated syllabus on the theory and experimental challenges of hadron collider physics. The first school in the series, held last summer at Fermilab, covered extensively the physics at the Tevatron collider experiments. The second school to be held at CERN, will focus on the technology and physics of the LHC experiments. Emphasis will be given on the first years of data-taking at the LHC and on the discovery potential of the programme. The series of lectures will be supported by in-depth discussion sessions and will include the theory and phenomenology of hadron collisions, discovery physics topics, detector and analysis techniques and tools, as well as the preparatory strategies of the experiments towards readiness for first collisions at the LHC.

Students from around the world attending classes at the first CERN-Fermilab Hadron Collider Physics Summer School in 2006 at Fermilab. The 2007 School will be held at CERN, home of the Large Hadron Collider.

The poster of the School is available at
http://hcpss.web.cern.ch/hcpss/images/poster.pdf
Further inquiries should be directed to

cern-fnal-school-sec@cern.ch

On behalf of the Local Organizing Committee,

Maria Spiropulu
CERN, December 19 2006