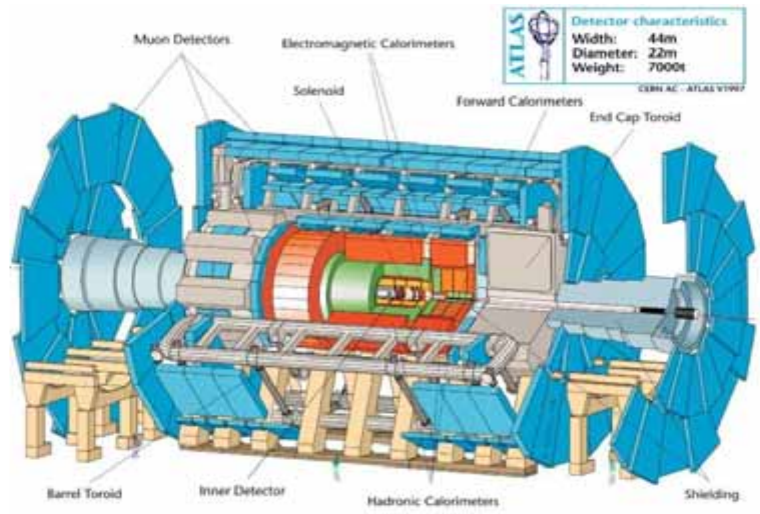
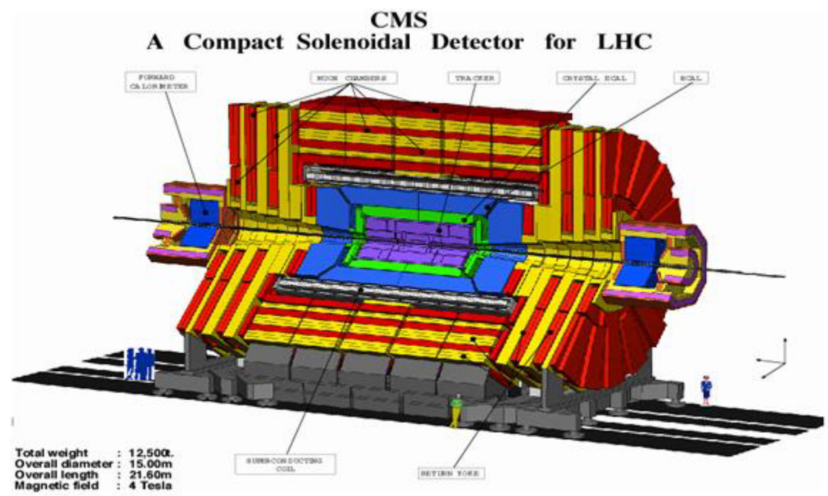
SUSY Without (Much) Prejudice at the LHC





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05/19/2010

Outline

- Motivational & Philosophical Introduction
- Review of Model Set Generation (quickly)
- Some General Properties of Models (quickly)
- LHC/ATLAS Analysis & Preliminary Results
- Summary & Conclusions

Issues:

• The MSSM is very difficult to study due to the very large number of soft SUSY breaking parameters (~ 100).

• Analyses are generally limited to a specific SUSY breaking scenario having few parameters.

• So do we really know the MSSM as well as we think??

• Is there another way to approach this problem & yet remain more general ? There are many possibilities.

FEATURE Analysis Assumptions :

- The most general, CP-conserving MSSM with R-parity
- Minimal Flavor Violation at the TeV scale
- The lightest neutralino is the LSP & a thermal relic.
- The first two sfermion generations are degenerate (sfermion type by sfermion type).
- The first two generations have negligible Yukawa's.
- No assumptions about SUSY-breaking or GUT

This leaves us with the pMSSM:

→ the MSSM with 19 real, TeV/weak-scale parameters…

What are they??

19 pMSSM Parameters

sfermion masses: m_{Q_1}, m_{Q_3}, m_{u_1}, m_{d_1}, m_{u_3}, m_{d_3}, m_{L_1}, m_{L_3}, m_{e_1}, m_{e_3}

gaugino masses: M_1, M_2, M_3

tri-linear couplings: A_b, A_t, A_τ

Higgs/Higgsino: μ, M_A, $\tan\beta$

Note: These are TeV-scale Lagrangian parameters

What are (aren't) the Goals of this Study???

- Prepare a large sample, ~50k, of MSSM models (= parameter space points) satisfying 'all' of the experimental constraints. (Done)

- Examine the properties of the surviving models. Do they look like the model points that have been studied up to now & if not what are the differences? ←

- Do physics analyses with these models. ←

Our goal is NOT to find the 'best-fit' model(s) but to discover new SUSY spectra & decay scenarios different from those seen in the more familiar SUSY breaking frameworks leading to possible unexpected surprises at colliders and elsewhere.

How? Perform 2 Random Scans

Linear Priors

10^7 points – emphasizes moderate masses

$100\ \text{GeV} \leq m_{\text{sfermions}} \leq 1\ \text{TeV}$

$50\ \text{GeV} \leq |M_1, M_2, \mu| \leq 1\ \text{TeV}$

$100\ \text{GeV} \leq M_3 \leq 1\ \text{TeV}$

$\sim 0.5\ M_Z \leq M_A \leq 1\ \text{TeV}$

$1 \leq \tan\beta \leq 50$

$|A_{t,b,\tau}| \leq 1\ \text{TeV}$

Log Priors

$2\text{x}10^6$ points – emphasizes lower masses but extends to higher masses

$100\ \text{GeV} \leq m_{\text{sfermions}} \leq 3\ \text{TeV}$

$10\ \text{GeV} \leq |M_1, M_2, \mu| \leq 3\ \text{TeV}$

$100\ \text{GeV} \leq M_3 \leq 3\ \text{TeV}$

$\sim 0.5\ M_Z \leq M_A \leq 3\ \text{TeV}$

$1 \leq \tan\beta \leq 60$

$10\ \text{GeV} \leq |A_{t,b,\tau}| \leq 3\ \text{TeV}$

→Comparison of these two scans will show the prior sensitivity.

→This analysis required ~ 1 core-century of CPU time...this was the real limitation of this part of the study.

Some Constraints

- $-0.0007 < \Delta\rho < 0.0026$ [W-mass, etc.] (PDG'08)
- $b \to s\, \gamma$: $B = (2.5 - 4.1) \times 10^{-4}$; (HFAG) + Misiak etal. & Becher & Neubert
- $\Delta(g-2)_\mu$??? $(30.2 \pm 8.8) \times 10^{-10}$ (0809.4062)
  $(25.5 \pm 8.0) \times 10^{-10}$ (Malaescu, Moriond '10)
  $[15.7 \pm 8.2] \times 10^{-10}$ [Davier '09, τ's]
  $\to (-10$ to $40) \times 10^{-10}$ to be conservative..
- $\Gamma(Z \to$ invisible$) < 2.0$ MeV (LEPEWWG)
- Meson-Antimeson Mixing $0.2 < R_{13} < 5$
- $B \to \tau\nu$ BaBar/Belle Isidori & Paradisi, hep-ph/0605012 & Erikson etal., 0808.3551 for loop corrections
- $B_s \to \mu\mu$ $B < 4.5 \times 10^{-8}$ (CDF + D0)

- Direct Detection of Dark Matter → Spin-independent limits are completely dominant here. We allow for a factor of 4 variation in the cross section from input uncertainties.

- Dark Matter density: $\Omega h^2 < 0.1210$ → WMAP +SN +BAO+… We treat this only as an *upper bound* on the LSP DM density to allow for multi-component DM, e.g., axions, etc. Recall the lightest neutralino is the LSP & is a thermal relic

- LEP and Tevatron Direct Higgs & SUSY searches : there are *many* of these searches but they are very complicated with many caveats…. We need to be very cautious in how the constraints are used & some require re-evaluation.

Zh, h-> bb, ττ

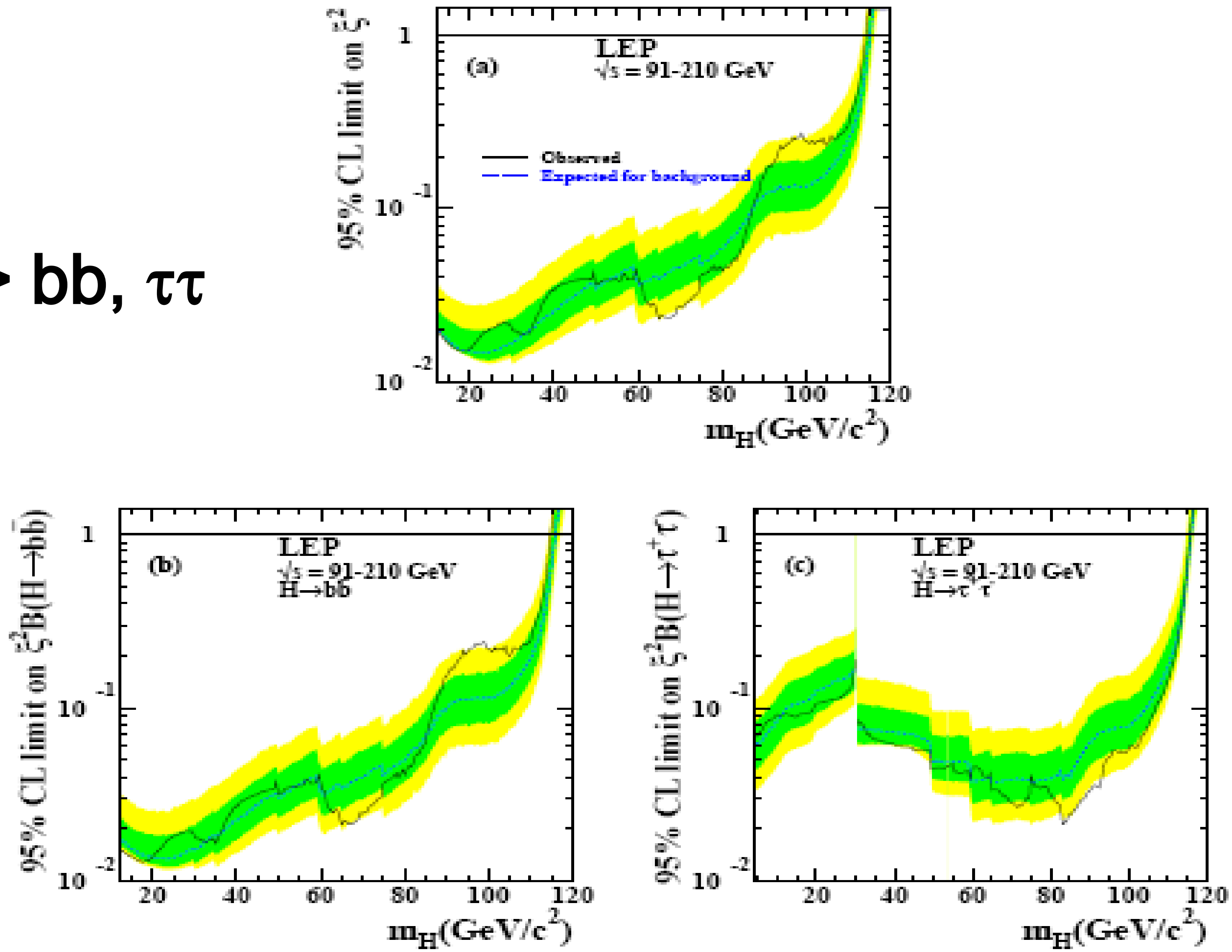
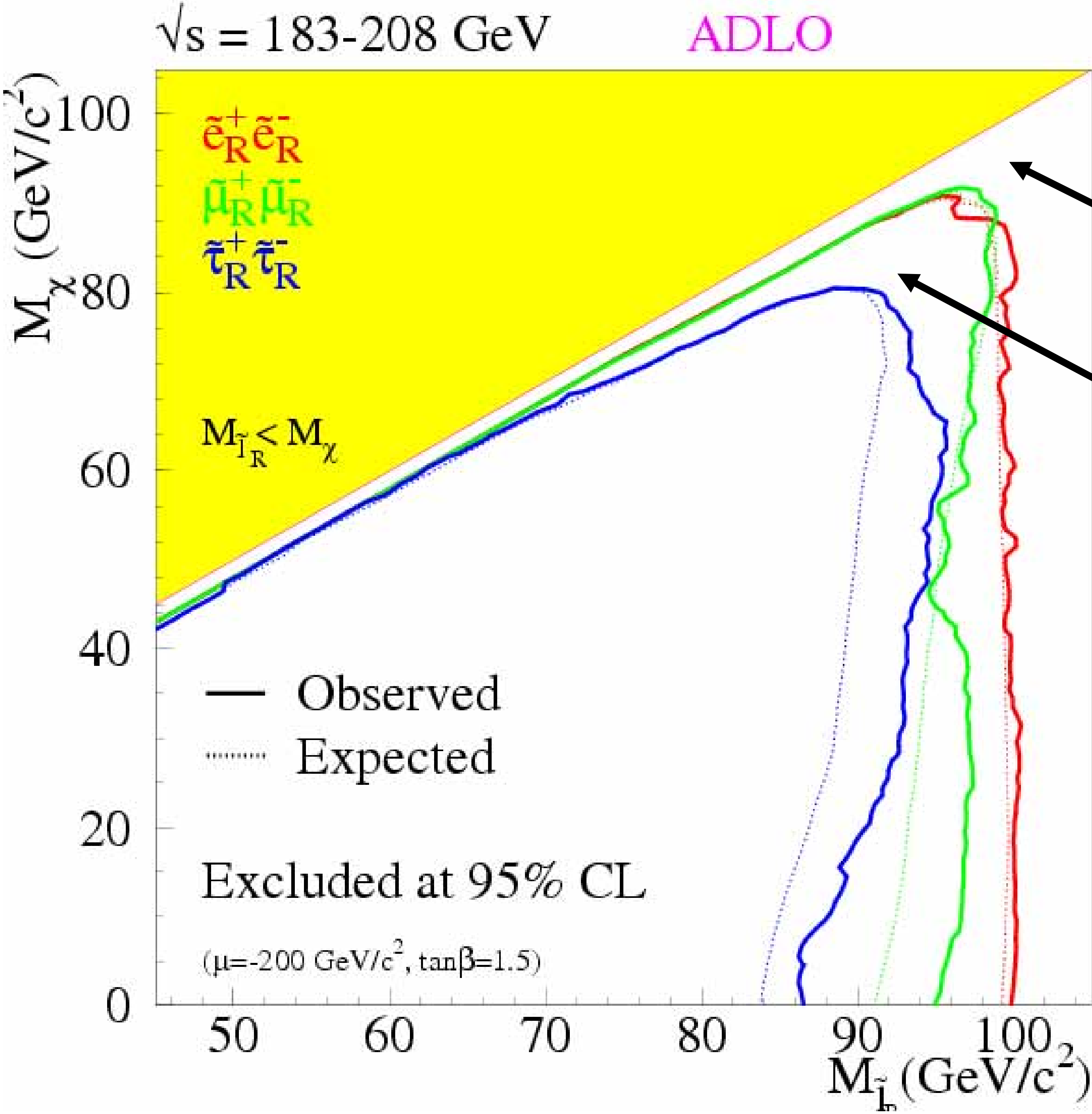


Figure 1: *The 95% c.l. upper bound on the coupling ratio* $\xi^2 = (g_{\mathrm{HZZ}}/g^{\mathrm{SM}}_{\mathrm{HZZ}})^2$ *(see text). The dark (green) and light (yellow) shaded bands around the median expected line correspond to the 68% and 95% probability bands. The horizontal lines correspond to the Standard Model coupling. (a): For Higgs boson decays predicted by the Standard Model; (b): for the Higgs boson decaying exclusively into* $b\bar{b}$ *and (c): into* $\tau^+\tau^-$ *pairs.*

RH Sleptons



Note the holes where the leptons are too soft…

We need to allow for a mass gap w/ the LSP..light guys may slip through !

Tevatron Constraints : I Squark & Gluino Search

- This is the first SUSY analysis to include these constraints

- 2,3,4 Jets + Missing Energy (D0)

TABLE I: Selection criteria for the three analyses (all energies and momenta in GeV); see the text for further details.

Preselection Cut	All Analyses		
$\not{E}_T$	≥ 40		
|Vertex z pos.|	< 60 cm		
Acoplanarity	$< 165°$		
Selection Cut	"dijet"	"3-jets"	"gluino"
Trigger	dijet	multijet	multijet
jet$_1$ p_T[a]	≥ 35	≥ 35	≥ 35
jet$_2$ p_T[a]	≥ 35	≥ 35	≥ 35
jet$_3$ p_T[b]	–	≥ 35	≥ 35
jet$_4$ p_T[b]	–	–	≥ 20
Electron veto	yes	yes	yes
Muon veto	yes	yes	yes
$\Delta\phi(\not{E}_T, \text{jet}_1)$	$\geq 90°$	$\geq 90°$	$\geq 90°$
$\Delta\phi(\not{E}_T, \text{jet}_2)$	$\geq 50°$	$\geq 50°$	$\geq 50°$
$\Delta\phi_{\min}(\not{E}_T, \text{any jet})$	$\geq 40°$	–	–
H_T	≥ 325	≥ 375	≥ 400
$\not{E}_T$	≥ 225	≥ 175	≥ 100

[a]First and second jets are also required to be central ($|\eta_{\text{det}}| < 0.8$), with an electromagnetic fraction below 0.95, and to have CPF0 ≥ 0.75.
[b]Third and fourth jets are required to have $|\eta_{\text{det}}| < 2.5$, with an electromagnetic fraction below 0.95.

Multiple analyses keyed to look for:

Squarks-> jet +MET
Gluinos -> 2 j + MET

The search is based on mSUGRA type sparticle spectrum assumptions which can be VERY far from our model points

D0 benchmarks

TABLE II: For each analysis, information on the signal for which it was optimized (m_0, $m_{1/2}$, $m_{\tilde{g}}$, $m_{\tilde{q}}$, and nominal NLO cross section), signal efficiency, the number of events observed, the number of events expected from SM backgrounds, the number of events expected from signal, and the 95% C.L. signal cross section upper limit. The first uncertainty is statistical and the second is systematic.

Analysis	$(m_0, m_{1/2})$ (GeV)	$(m_{\tilde{g}}, m_{\tilde{q}})$ (GeV)	σ_{nom} (pb)	$\epsilon_{sig.}$ (%)	$N_{obs.}$	$N_{backgrd.}$	$N_{sig.}$	σ_{95} (pb)
"dijet"	(25,175)	(439,396)	0.072	$6.8 \pm 0.4^{+1.2}_{-1.2}$	11	$11.1 \pm 1.2^{+2.9}_{-2.3}$	$10.4 \pm 0.6^{+1.8}_{-1.8}$	0.075
"3-jets"	(197,154)	(400,400)	0.083	$6.8 \pm 0.4^{+1.4}_{-1.3}$	9	$10.7 \pm 0.9^{+3.1}_{-2.1}$	$12.0 \pm 0.7^{+2.5}_{-2.3}$	0.065
"gluino"	(500,110)	(320,551)	0.195	$4.1 \pm 0.3^{+0.8}_{-0.7}$	20	$17.7 \pm 1.1^{+5.6}_{-3.3}$	$17.0 \pm 1.2^{+3.3}_{-2.9}$	0.165

TABLE III: Definition of the analysis combinations, and number of events observed in the data and expected from the SM backgrounds.

Selection	"dijet"	"3-jets"	"gluino"	$N_{obs.}$	$N_{backgrd.}$
Combination 1	yes	no	no	8	9.4 ± 1.2 (stat.) $^{+2.3}_{-1.8}$ (syst.)
Combination 2	no	yes	no	2	4.5 ± 0.6 (stat.) $^{+0.7}_{-0.5}$ (syst.)
Combination 3	no	no	yes	14	12.5 ± 0.9 (stat.) $^{+3.6}_{-1.9}$ (syst.)
Combination 4	yes	yes	no	1	1.1 ± 0.3 (stat.) $^{+0.5}_{-0.3}$ (syst.)
Combination 5	yes	no	yes		kinematically not allowed
Combination 6	no	yes	yes	4	4.5 ± 0.6 (stat.) $^{+1.8}_{-1.3}$ (syst.)
Combination 7	yes	yes	yes	2	0.6 ± 0.2 (stat.) $^{+0.1}_{-0.2}$ (syst.)
At least one selection				31	32.6 ± 1.7 (stat.) $^{+9.0}_{-5.8}$ (syst.)

Combos of the 3 analyses

→ Feldman-Cousins 95% CL Signal limit: 8.34 events

SuSpect -> SUSY-Hit -> PROSPINO -> PYTHIA -> D0-tuned PGS4 fast simulation (to reproduce the benchmark points)…

redo this analysis ~ 10^5 times !

Tevatron II: CDF Tri-lepton Analysis

CDF RUN II Preliminary $\int \mathcal{L}dt = 2.0\ \text{fb}^{-1}$: Search for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$

Channel	Signal	Background	Observed
3tight	$2.25 \pm 0.13(\text{stat}) \pm 0.29(\text{syst})$	$0.49 \pm 0.04(\text{stat}) \pm 0.08(\text{syst})$	1
2tight,1loose	$1.61 \pm 0.11(\text{stat}) \pm 0.21(\text{syst})$	$0.25 \pm 0.03(\text{stat}) \pm 0.03(\text{syst})$	0
1tight,2loose	$0.68 \pm 0.07(\text{stat}) \pm 0.09(\text{syst})$	$0.14 \pm 0.02(\text{stat}) \pm 0.02(\text{syst})$	0
Total Trilepton	$4.5 \pm 0.2(\text{stat}) \pm 0.6(\text{syst})$	$0.88 \pm 0.05(\text{stat}) \pm 0.13(\text{syst})$	1
2tight,1Track	$4.44 \pm 0.19(\text{stat}) \pm 0.58(\text{syst})$	$3.22 \pm 0.48(\text{stat}) \pm 0.53(\text{syst})$	4
1tight,1loose,1Track	$2.42 \pm 0.14(\text{stat}) \pm 0.32(\text{syst})$	$2.28 \pm 0.47(\text{stat}) \pm 0.42(\text{syst})$	2
Total Dilepton+Track	$6.9 \pm 0.2(\text{stat}) \pm 0.9(\text{syst})$	$5.5 \pm 0.7(\text{stat}) \pm 0.9(\text{syst})$	6

Table 3: Number of expected signal and background events and number of observed events in 2 fb^{-1}. Uncertainties are statistical(stat) and full systematics(syst). The signal is for the benchmark point described in section 5.

We need to perform the 3 tight lepton analysis ~ 10^5 times

We perform this analysis using CDF-tuned PGS4, PYTHIA in LO plus a PROSPINO K-factor

→ Feldman-Cousins 95% CL Signal limit: 4.65 events

- This is the first SUSY analysis to include these constraints

The non-‘3-tight’ analyses are not reproducible w/o a better detector simulation

Tevatron III: D0 Stable Particle (= Chargino) Search

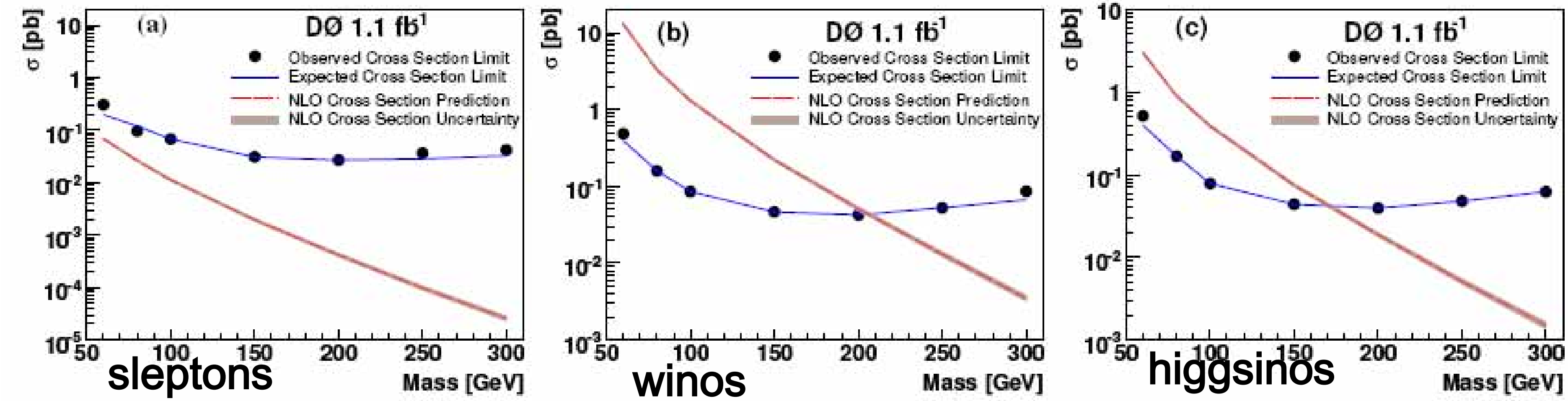


FIG. 2: The observed (dots) and expected (solid line) 95% cross section limits, the NLO production cross section (dashed line), and NLO cross section uncertainty (barely visible shaded band) as a function of (a) stau mass for stau pair production, (b) chargino mass for pair produced gaugino-like charginos, and (c) chargino mass for pair produced higgsino-like charginos.

Interpolation: $M_\chi > 206\ |U_{1w}|^2 + 171\ |U_{1h}|^2$ GeV

This is a powerful constraint on our model set as we have many close mass chargino-neutralino pairs. This search cuts out a huge parameter region as you will see later.

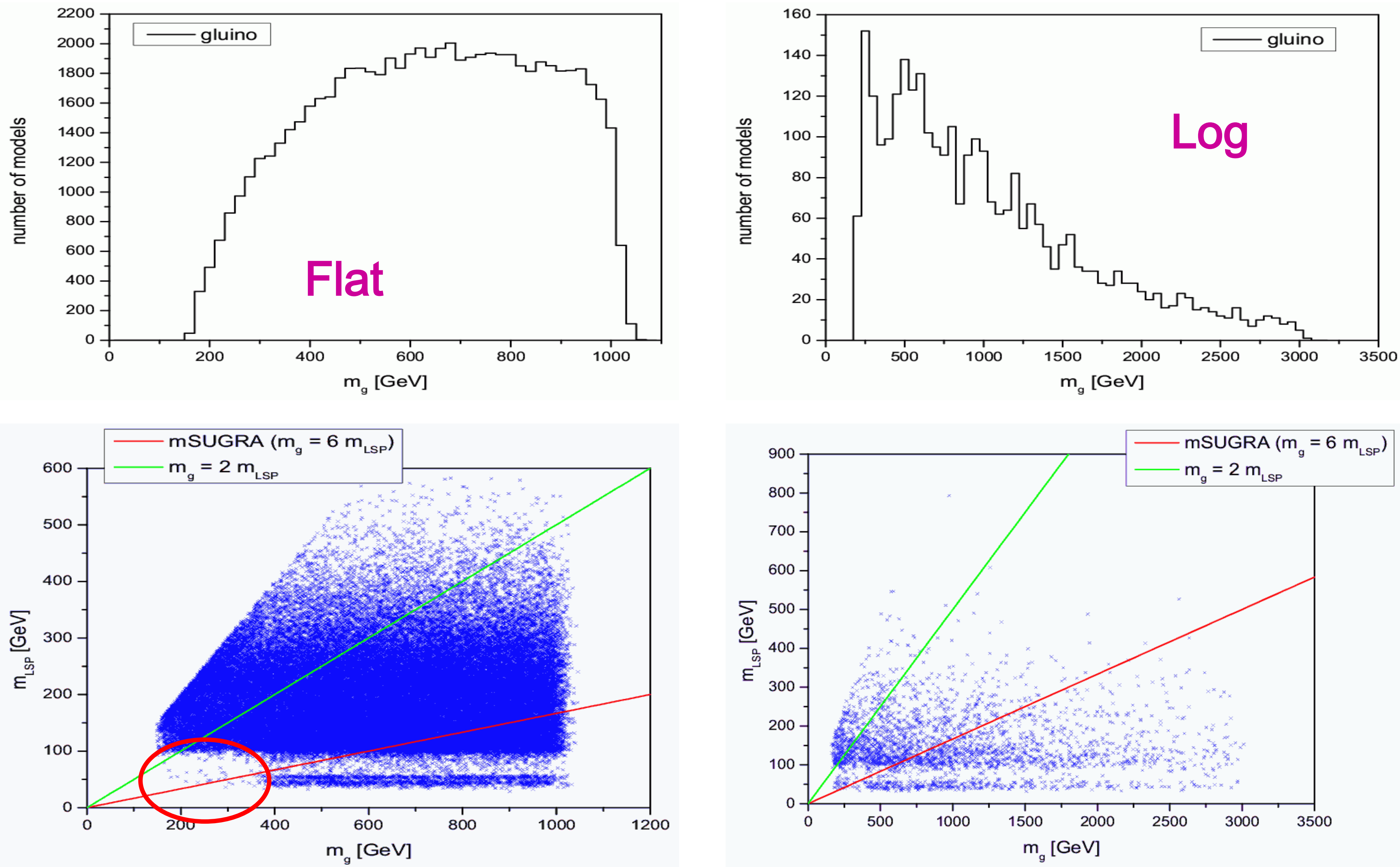
- No applicable bounds on charged sleptons..the cross sections are too small.
- This is the first SUSY analysis to include these constraints

Survival Rates

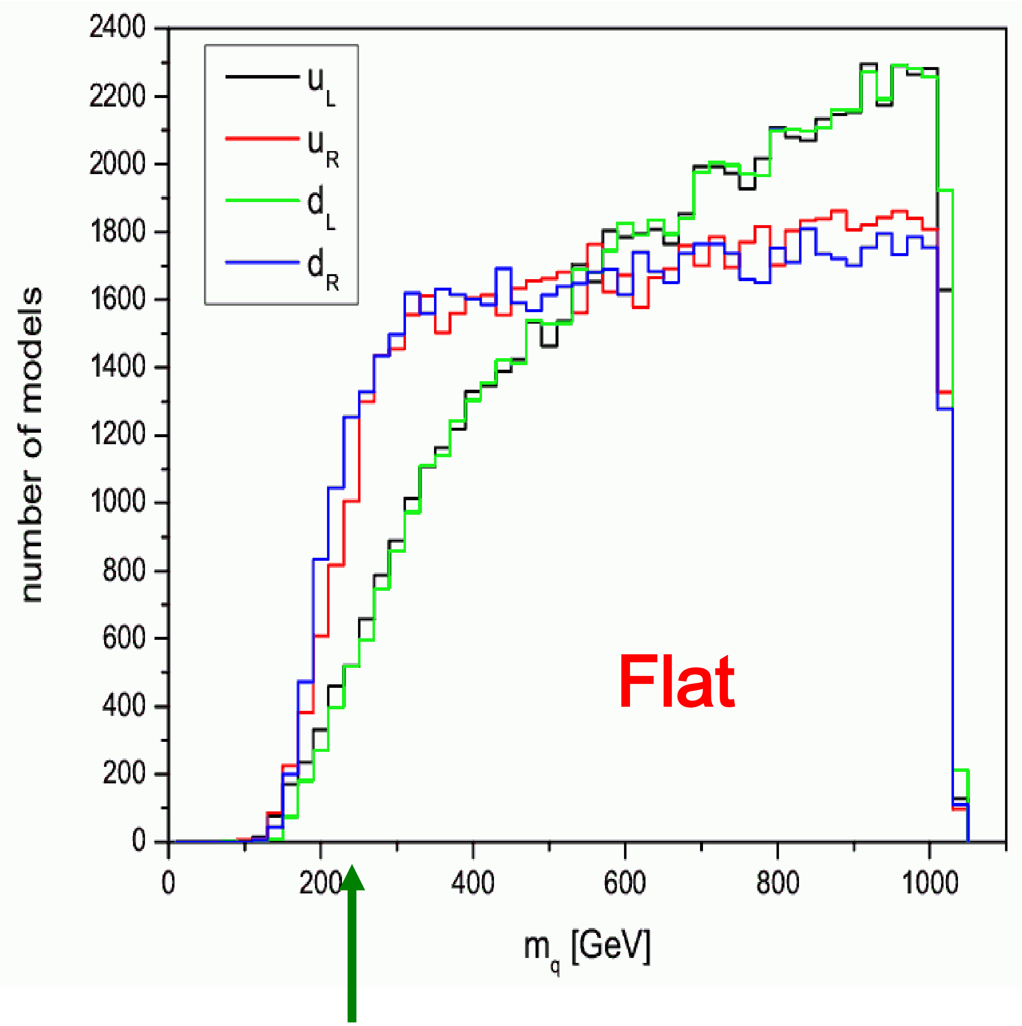
file	Description	Percent of Models Remaining
slha-okay.txt	SuSpect generates SLHA file	99.99 %
error-okay.txt	Spectrum tachyon, other error free	77.29%
lsp-okay.txt	LSP the lightest neutralino	32.70 %
deltaRho-okay.txt	$\Delta\rho$	32.61 %
gMinus2-okay.txt	$g-2$	21.69 %
b2sGamma-okay.txt	$b \longrightarrow s\gamma$	6.17 %
Bs2MuMu-okay.txt	$B \longrightarrow \mu\mu$	5.95 %
vacuum-okay.txt	No CCB, potential not UFB	5.92 %
Bu2TauNu-okay.txt	$B \longrightarrow \tau\nu$	5.83 %
LEP-sparticle-okay.txt	LEP sfermion checks	4.72 %
invisibleWidth-okay.txt	Invisible Width of Z	4.71 %
susyhitProb-okay.txt	Heavy Higgs not problematic for SUSY-HIT	4.69 %
stableParticle-okay.txt	Tevatron stable chargino search	4.19 %
chargedHiggs-okay.txt	LEP/ Tevatron charged Higgs search	4.19 %
neutralHiggs-okay.txt	LEP neutral Higgs search	1.73 %
directDetection-okay.txt	WIMP direct detection	1.55 %
omega-okay.txt	Ωh^2	0.74 %
Bs2MuMu-2-okay.txt	$B \longrightarrow \mu\mu$	0.74 %
stableChargino-2-okay.txt	Tevatron stable chargino search	0.72 %
triLepton-okay.txt	Tevatron trilepton	0.72 %
jetMissing-okay.txt	Tevatron jet plus missing	0.70 %
final-okay.txt	Final after cutting models with e.g. light stop, sbottoms	0.68 %

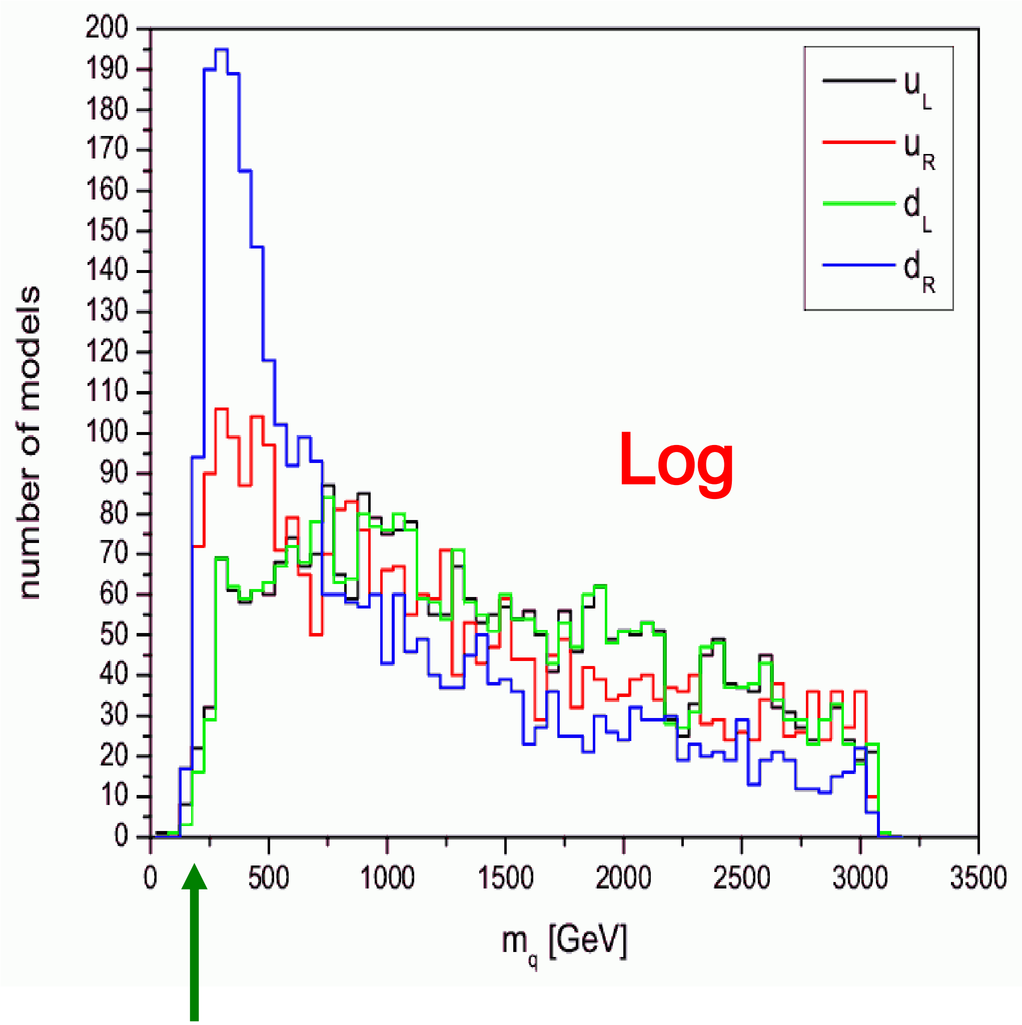
- Flat Priors : 10^7 models scanned , ~ 68.4 K (0.68%) survive
- Log Priors : 2×10^6 models scanned , ~ 2.9 K (0.14%) survive

Gluino Can Be Light !!



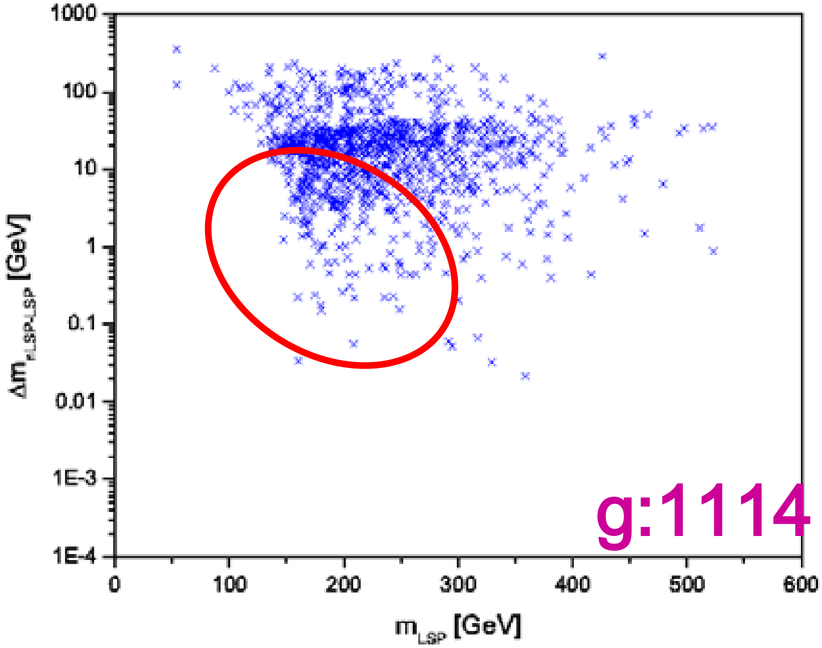
Squarks CAN Be Light !!!



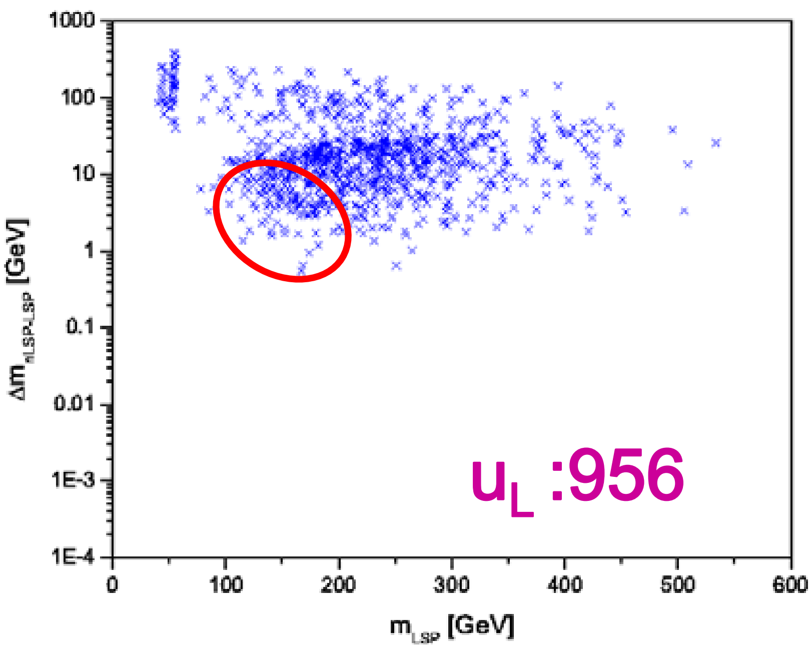


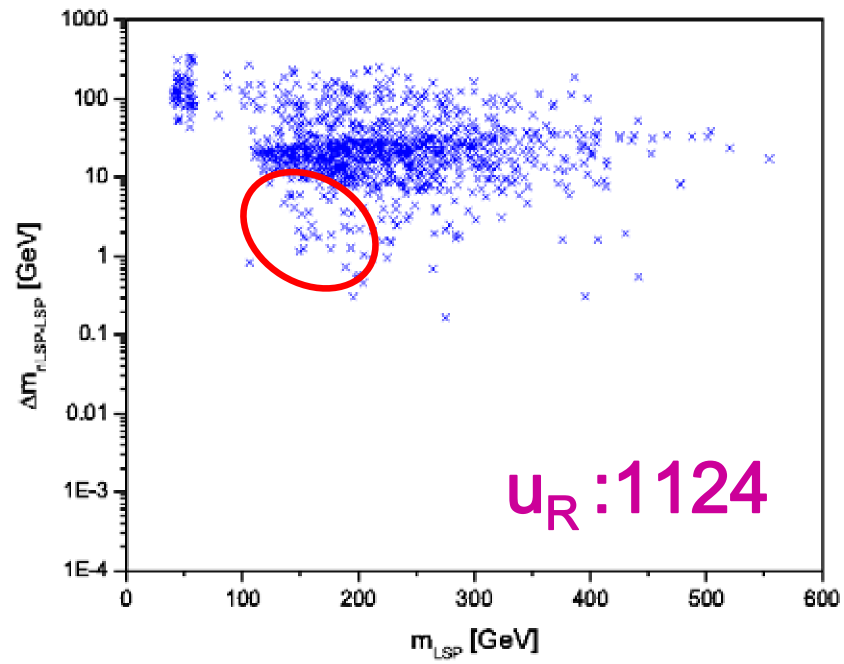
Light squarks can be missed by Tevatron searches for many reasons..

In many cases, but not exclusively, this can be due to the small splittings between the squarks and/or gluinos and other particles in the decay chain or the LSP itself…

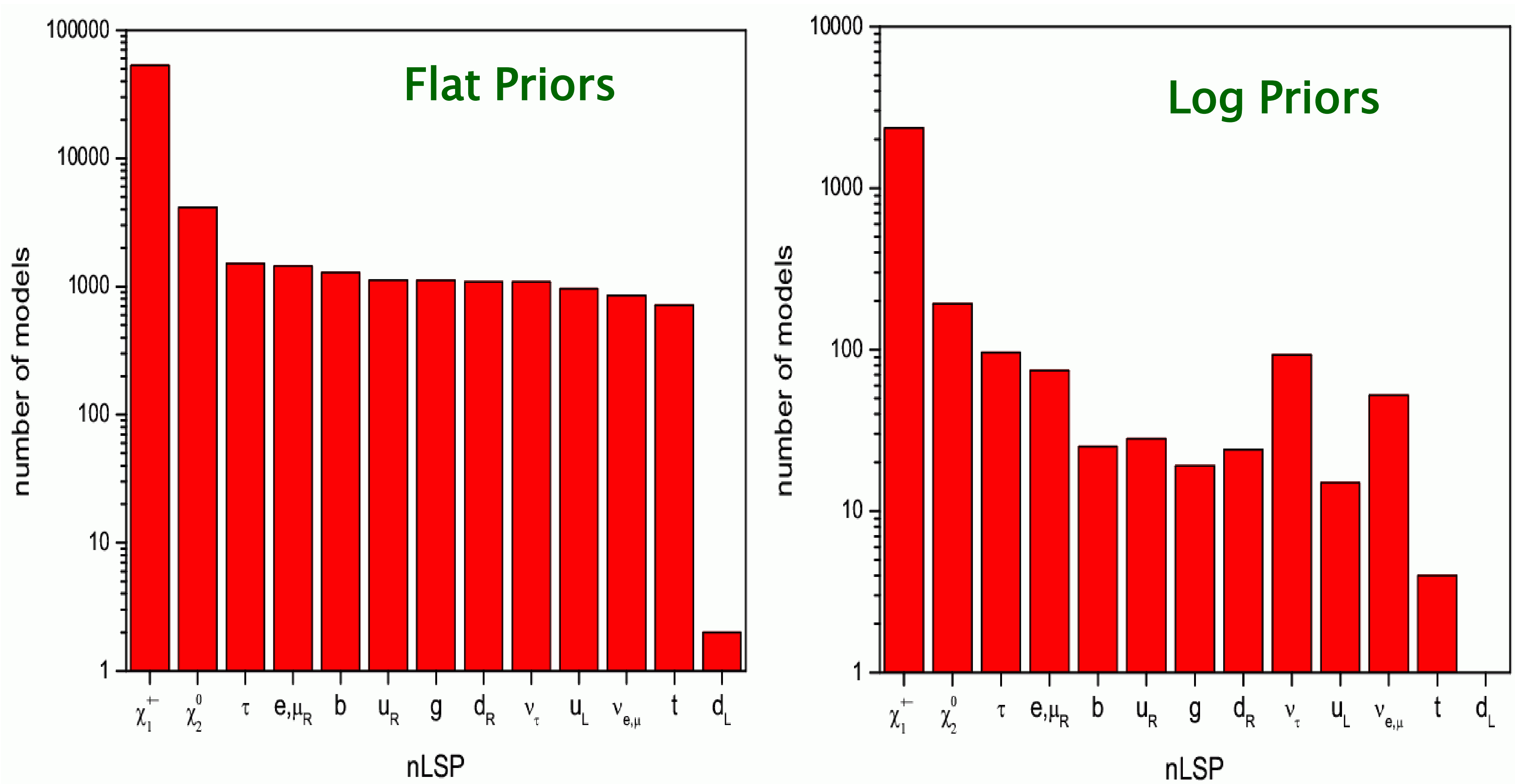


Small mass splittings can lead to soft jets in the final state that have insufficient p_T to pass any SUSY Tevatron search analysis cuts

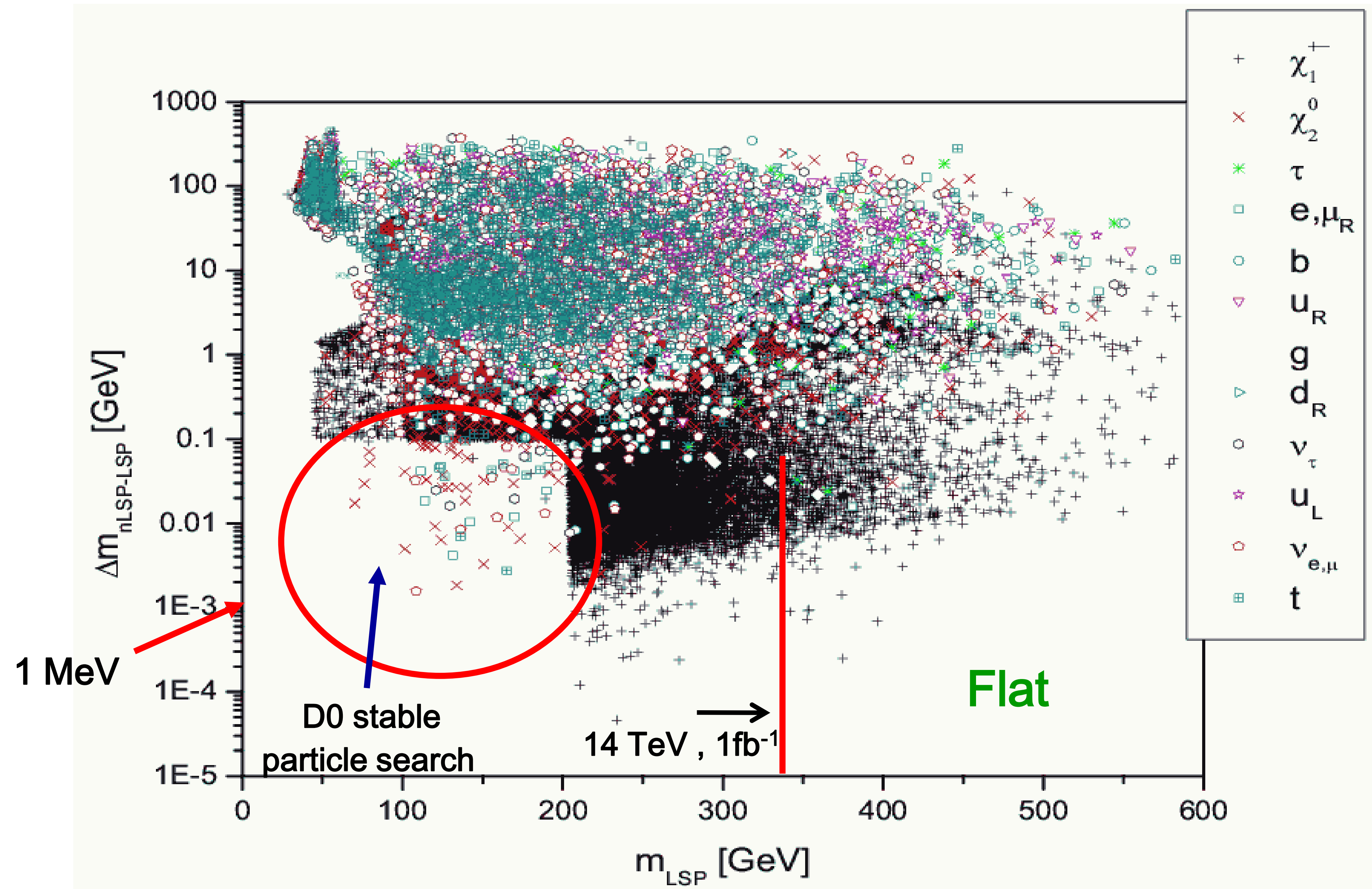




The identity of the nLSP is a critical factor in looking for SUSY signatures..what can plays that role here????? Just about ANY of the 13 possibilities !



nLSP-LSP Mass Difference



LSP Identity

Many models have LSPs which are close to the weak interaction eigenstates…

..e.g., for the flat case:

LSP Type	Definition	Percent of Models
Bino	$\|Z_{11}\|^2 > 0.95$	13.94
Mostly Bino	$0.8 < \|Z_{11}\|^2 \leq 0.95$	3.10
Wino	$\|Z_{12}\|^2 > 0.95$	14.16
Mostly Wino	$0.8 < \|Z_{12}\|^2 \leq 0.95$	9.14
Higgsino	$\|Z_{13}\|^2 + \|Z_{14}\|^2 > 0.95$	32.19
Mostly Higgsino	$0.8 < \|Z_{13}\|^2 + \|Z_{14}\|^2 \leq 0.95$	12.38
All other models		15.09

ATLAS SUSY Analyses w/ a Large Model Set

- We have passed these models through the ATLAS inclusive analysis suite (@14 TeV), designed for mSUGRA , to explore its sensitivity to this far broader class of SUSY models

- We employed ATLAS SM backgrounds (Thanks!!!), their associated systematic errors # & statistical criterion for SUSY 'discovery', etc. No data on background distributions are used in the analyses due to potentially large 'NLO' shape uncertainties.

- We first verified that we can approximately reproduce the ATLAS results for their benchmark mSUGRA models with our analysis techniques for each channel.

We use the exact expressions for Z_n as given by ATLAS with out any approximations causing some numerical differences with the ATLAS public results

- *But*, by necessity there are some differences between the two analyses (as we will soon see) so we shouldn't match *exactly*

- Any attempt to match to the ATLAS results without including the ATLAS-tuned fast detector simulation fails at the level we are working

- This analysis was extremely CPU intensive , e.g., 6M K-factors alone to compute! ..another ~core-century of CPU

- Some problems did arise (associated w/ modifications to public codes to deal w/ more complicated SUSY spectra etc.) & have mostly been dealt with…but not completely.

- A drawback of this procedure is that we CANNOT modify cuts etc. to 'see what happens' as we are, by necessity, following ATLAS very closely.

ATLAS	FEATURE
ISASUGRA generates spectrum & sparticle decays	SuSpect generates spectra with SUSY-HIT# for decays
Partial NLO cross section using PROSPINO & CTEQ6M	NLO cross section for all 85 processes using PROSPINO** & CTEQ6.6M
Herwig for fragmentation & hadronization	PYTHIA for fragmentation & hadronization
GEANT4 for full detector sim	PGS4-ATLAS for fast detector simulation

** version w/ negative K-factor errors corrected

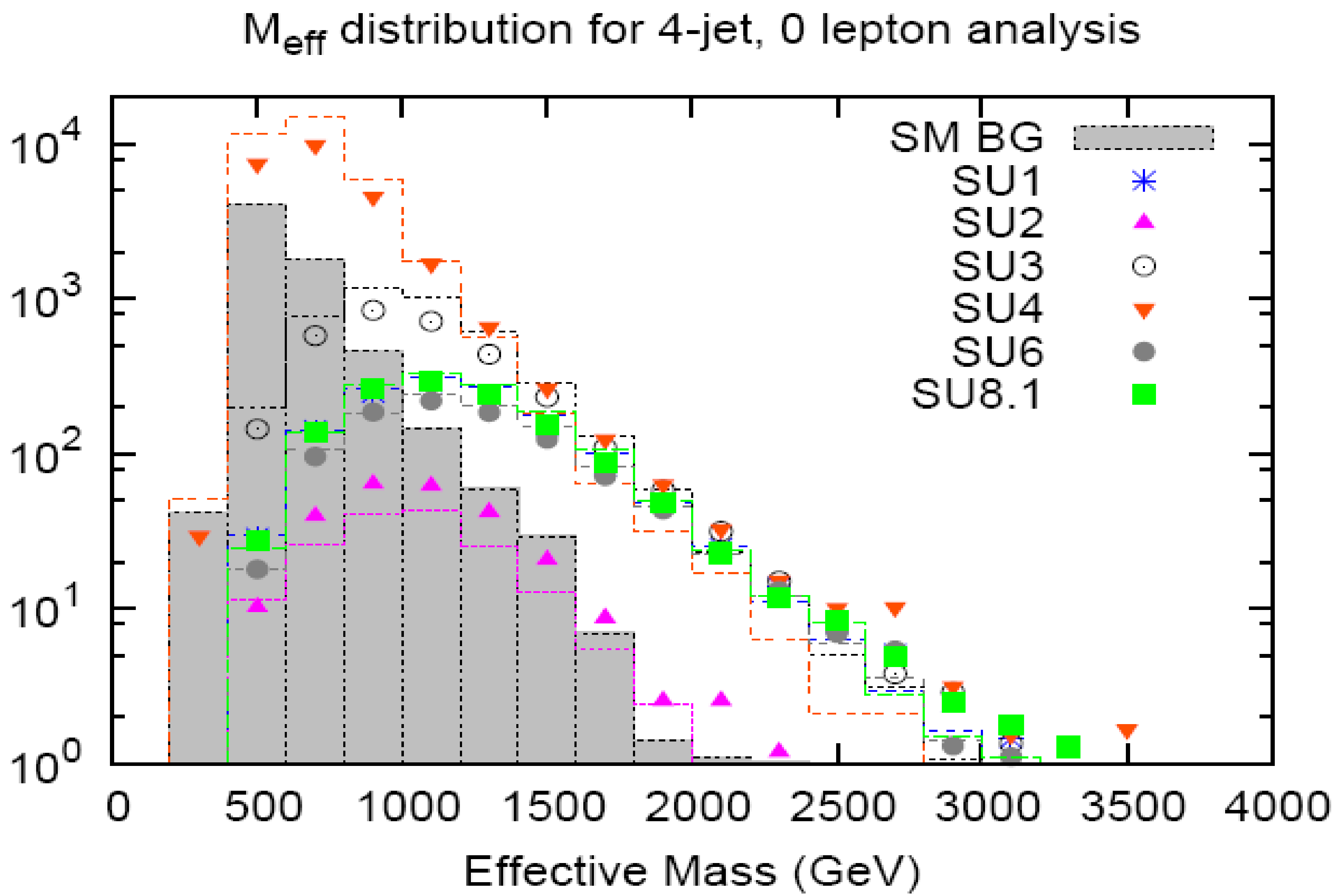
version w/o negative QCD corrections, with 1st & 2nd generation fermion masses & other numerous PS fixes included as well as explicit small Δm chargino decays, etc.

The set of inclusive ATLAS analyses is large:

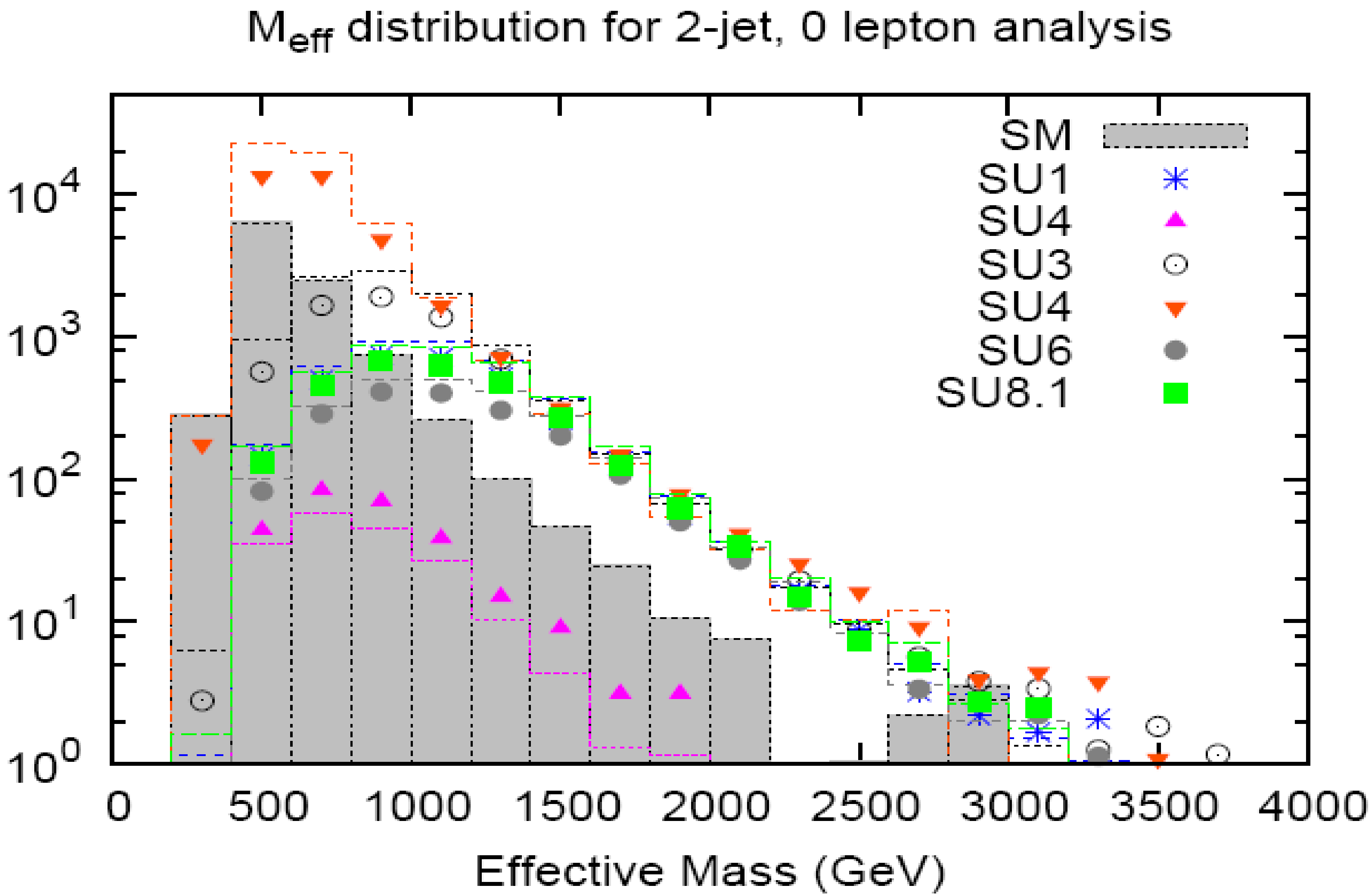
- ≥(2,4)-jet +MET
- 1l+≥(2,3,4)-jet +MET
- SSDL
- OSDL
- Trileptons + (≥1-j,X)+MET

- τ +≥ 4j +MET
- ≥4j w/ ≥ 2btags + MET
- (stable particle search)

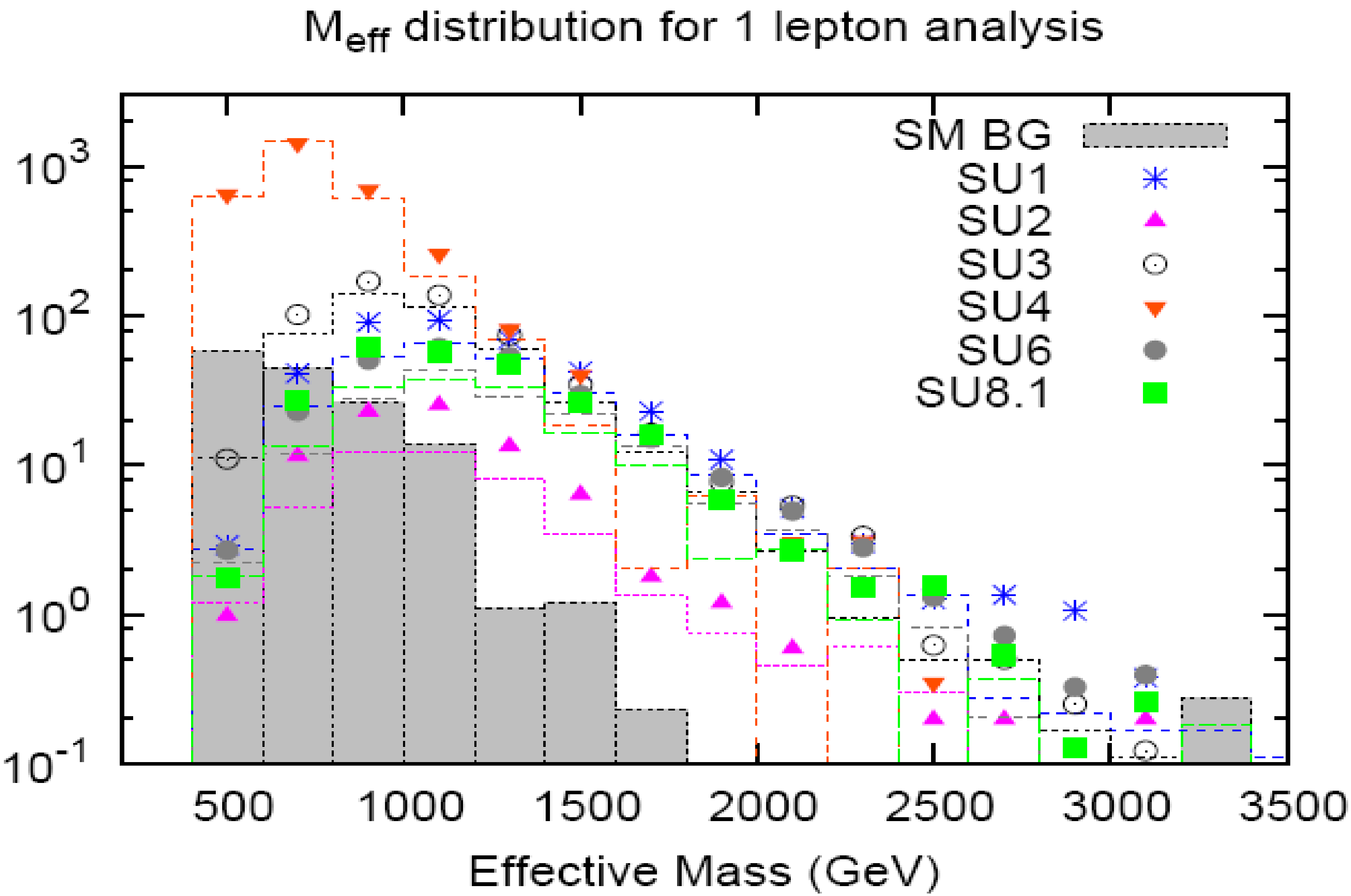
Benchmark Tests: Us vs Them Part I



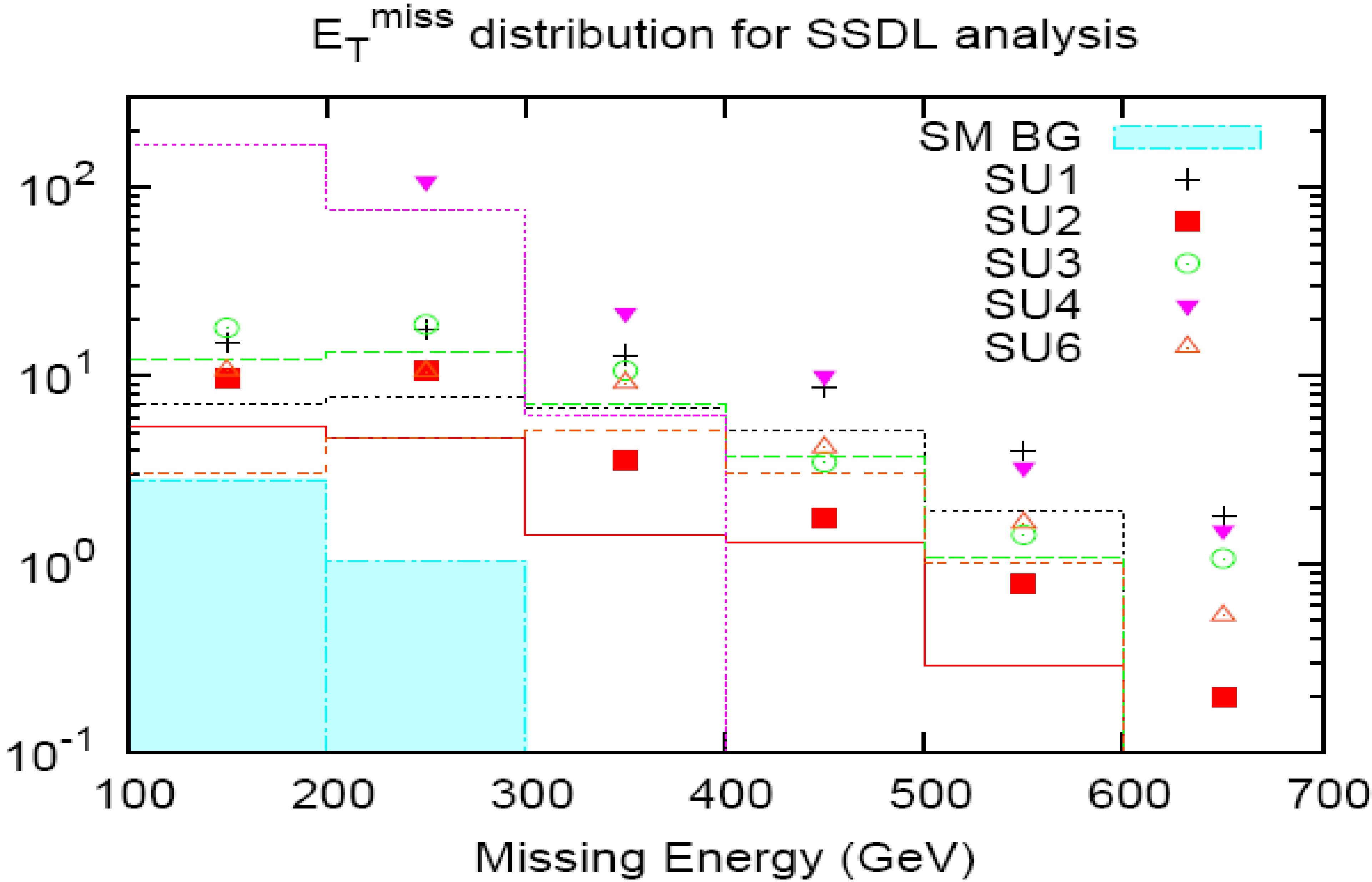
Benchmark Tests: Us vs Them Part II



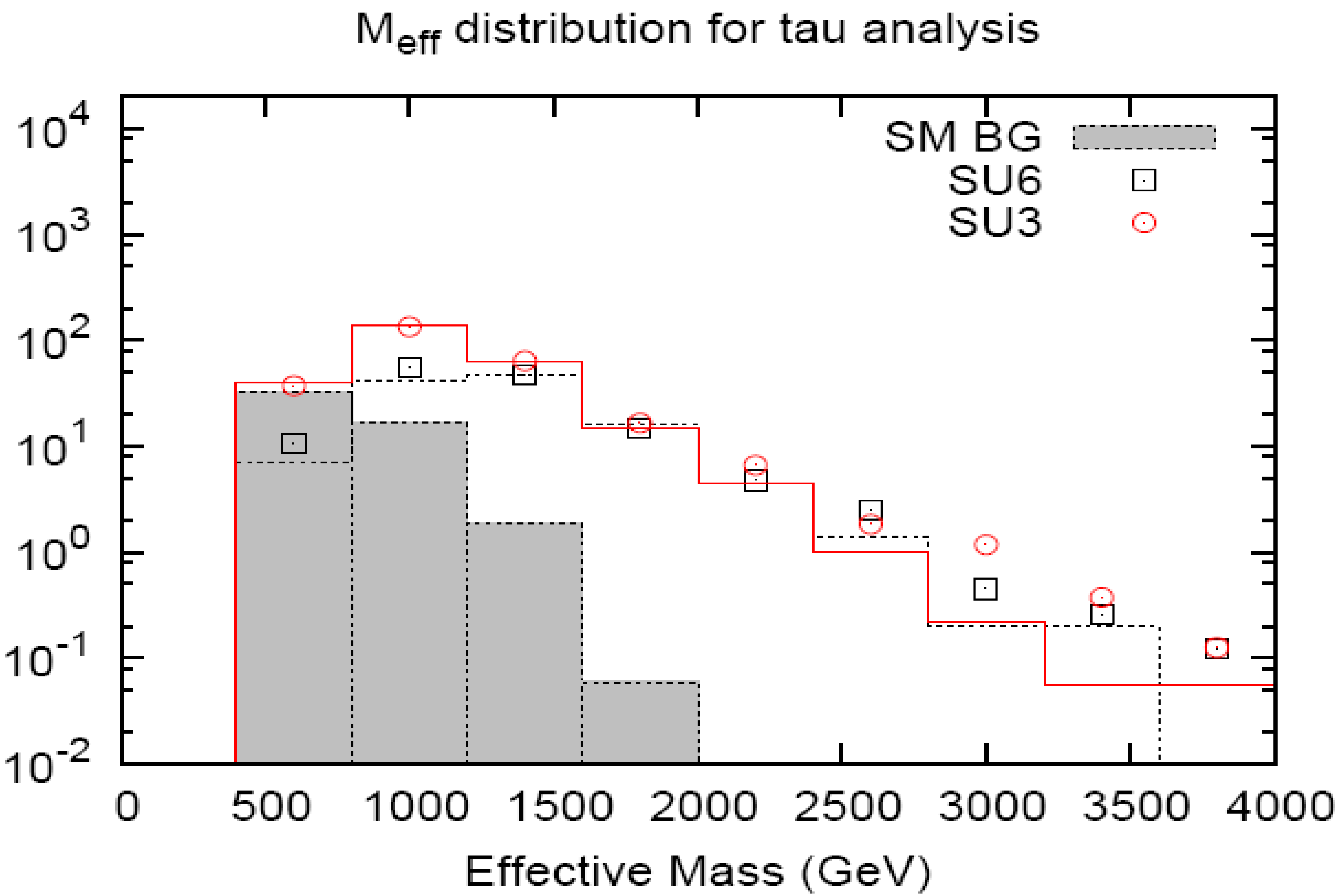
Benchmark Tests: Us vs Them Part III



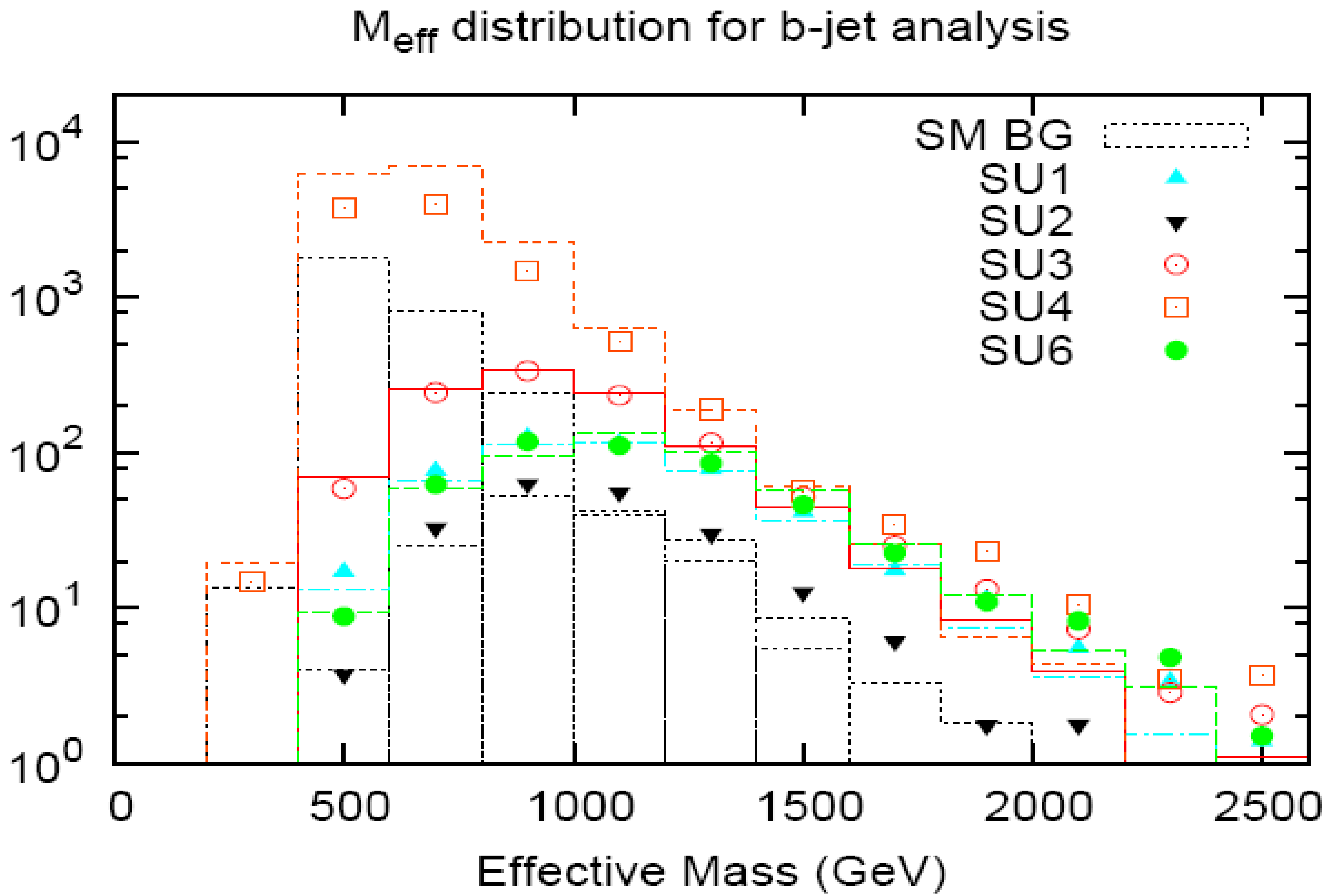
Benchmark Tests: Us vs Them Part IV



Benchmark Tests: Us vs Them Part V



Benchmark Tests: Us vs Them Part VI



Comments

• Although we reproduced the ATLAS τ analysis we should be skeptical of PGS4 as it has a rather low efficiency & a high fake rate for τ's (which we studied in some detail in our analysis) although these approximately compensate for the benchmark points! This *may* lead to this analysis being less successful at finding SUSY than the results below would indicate.

• Hopefully you are convinced that we did a respectable job at 'reproducing' all of the ATLAS benchmarks points for the various channels given the analysis differences

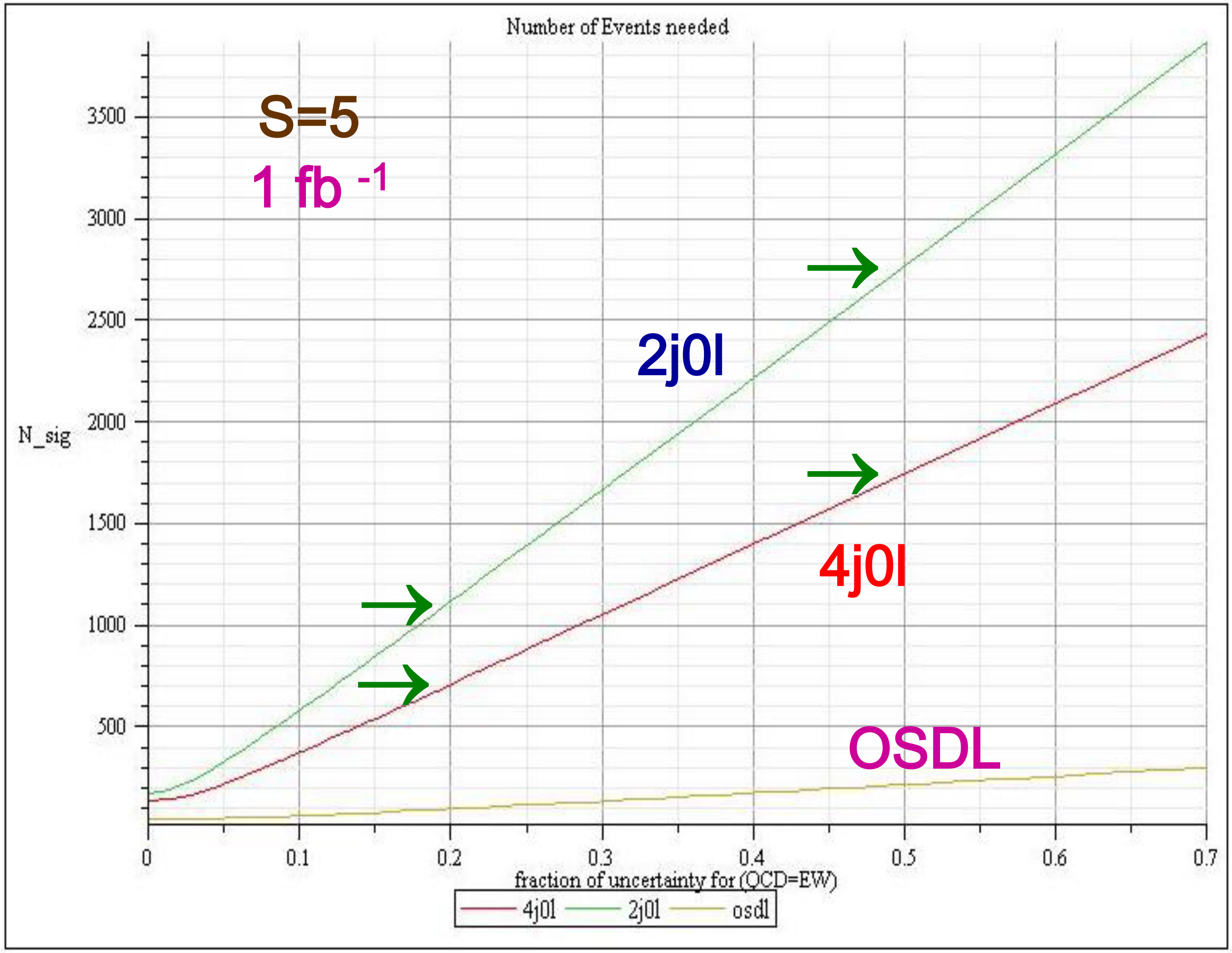
• We now turn to our model set results…One of our problems is the vast amount of information that we have generated. First, some general results..

ATLAS 1fb $^{-1}$ Backgrounds & Target Signal Counts

ANALYSIS	BACKGROUND	S=5, B=50%	B=20%
4j0l	709	1759	721
2j0l	1206	2778	1129
4j1l	41.6	121	62
3j1l	7.2	44	28
2j1l	18.2	61	36
OSDL	84.7	230	108
SSDL	2.3	17	13
3l1j	12	44	28
3lm	72.5	198	94
τ	51	144	72
b	69	178	86

Background systematics are particularly important for both the 4j0l & 2j0l channels .. but not so much for the others:

Required number of signal events for observation



What fraction of models are 'seen' by any of these analyses assuming an integrated luminosity of 1 fb^{-1} ?

Analysis	# with Zn>5, no pystop	# with Zn>5, incl. pystops
4j0l	59537 (88.962 %)	59978 (87.708 %)
2j0l	58719 (87.74 %)	59208 (86.582 %)
1l4j	28560 (42.675 %)	28624 (41.858 %)
1l3j	45228 (67.581 %)	45405 (66.397 %)
1l2j	47011 (70.245 %)	47226 (69.06 %)
OSDL	7360 (10.998 %)	7364 (10.769 %)
SSDL	14280 (21.338 %)	14289 (20.895 %)
3lj	9139 (13.656 %)	9149 (13.379 %)
3lm	1843 (2.7539 %)	1847 (2.7009 %)
tau	57088 (85.303 %)	57483 (84.059 %)
b	49760 (74.353 %)	50113 (73.282 %)

FLAT

Analysis	# with Zn>5, no pystop	# with Zn>5, incl. pystops
4j0l	1400 (48.376 %)	1401 (48.194 %)
2j0l	1380 (47.685 %)	1383 (47.575 %)
1l4j	530 (18.314 %)	530 (18.232 %)
1l3j	1136 (39.254 %)	1136 (39.078 %)
1l2j	1166 (40.29 %)	1167 (40.144 %)
OSDL	201 (6.9454 %)	201 (6.9143 %)
SSDL	362 (12.509 %)	362 (12.453 %)
3lj	257 (8.8804 %)	257 (8.8407 %)
3lm	85 (2.9371 %)	85 (2.924 %)
tau	1306 (45.128 %)	1307 (44.96 %)
b	1218 (42.087 %)	1219 (41.933 %)

LOG

A PYSTOP occurs for a model when PYTHIA cannot properly treat the hadronization in at least one of the decay chains it encounters..there many thousands of different decay chains for every model

What fraction of models are ‘seen’ by any of these analyses assuming an integrated luminosity of 10 fb^{-1} ?

Analysis	# with Zn>5, no pystop	# with Zn>5, incl. pystops
4j0l	59682 (89.179 %)	60125 (87.923 %)
2j0l	58806 (87.87 %)	59296 (86.71 %)
1l4j	30565 (45.671 %)	30638 (44.803 %)
1l3j	49636 (74.168 %)	49878 (72.938 %)
1l2j	49854 (74.493 %)	50108 (73.274 %)
OSDL	7957 (11.89 %)	7961 (11.642 %)
SSDL	21487 (32.107 %)	21531 (31.485 %)
3lj	11702 (17.486 %)	11714 (17.13 %)
3lm	1953 (2.9182 %)	1958 (2.8632 %)
tau	58931 (88.057 %)	59348 (86.786 %)
b	51782 (77.374 %)	52147 (76.256 %)

FLAT

Analysis	# with Zn>5, no pystop	# with Zn>5, incl. pystops
4j0l	1404 (48.514 %)	1405 (48.332 %)
2j0l	1382 (47.754 %)	1385 (47.644 %)
1l4j	579 (20.007 %)	579 (19.917 %)
1l3j	1395 (48.203 %)	1396 (48.022 %)
1l2j	1317 (45.508 %)	1318 (45.339 %)
OSDL	209 (7.2218 %)	209 (7.1895 %)
SSDL	578 (19.972 %)	578 (19.883 %)
3lj	327 (11.299 %)	327 (11.249 %)
3lm	87 (3.0062 %)	87 (2.9928 %)
tau	1369 (47.305 %)	1370 (47.128 %)
b	1261 (43.573 %)	1262 (43.412 %)

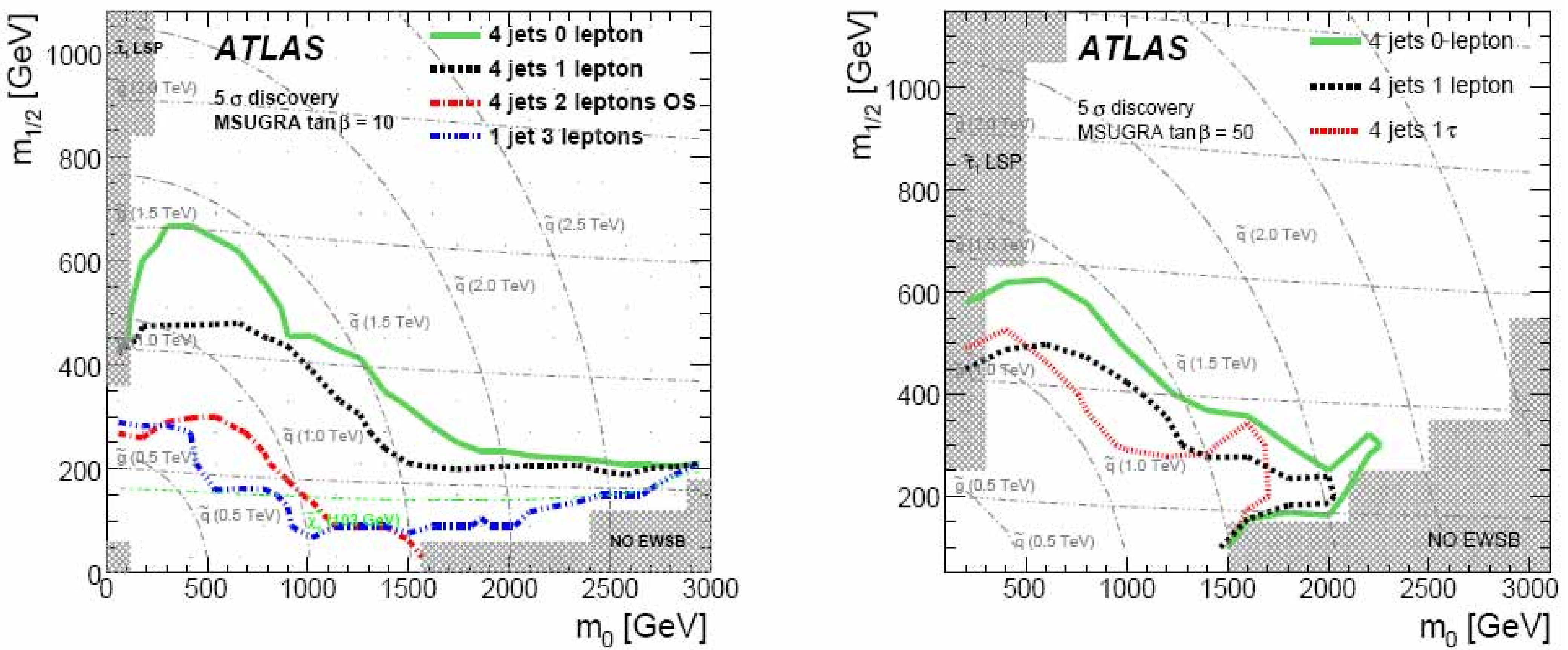
LOG

Clearly, increasing the luminosity DOES help in many cases… especially those with low backgrounds. The most interesting cases will be when it doesn’t!

These results have some similarities to what ATLAS finds for the mSUGRA case but with some important differences:

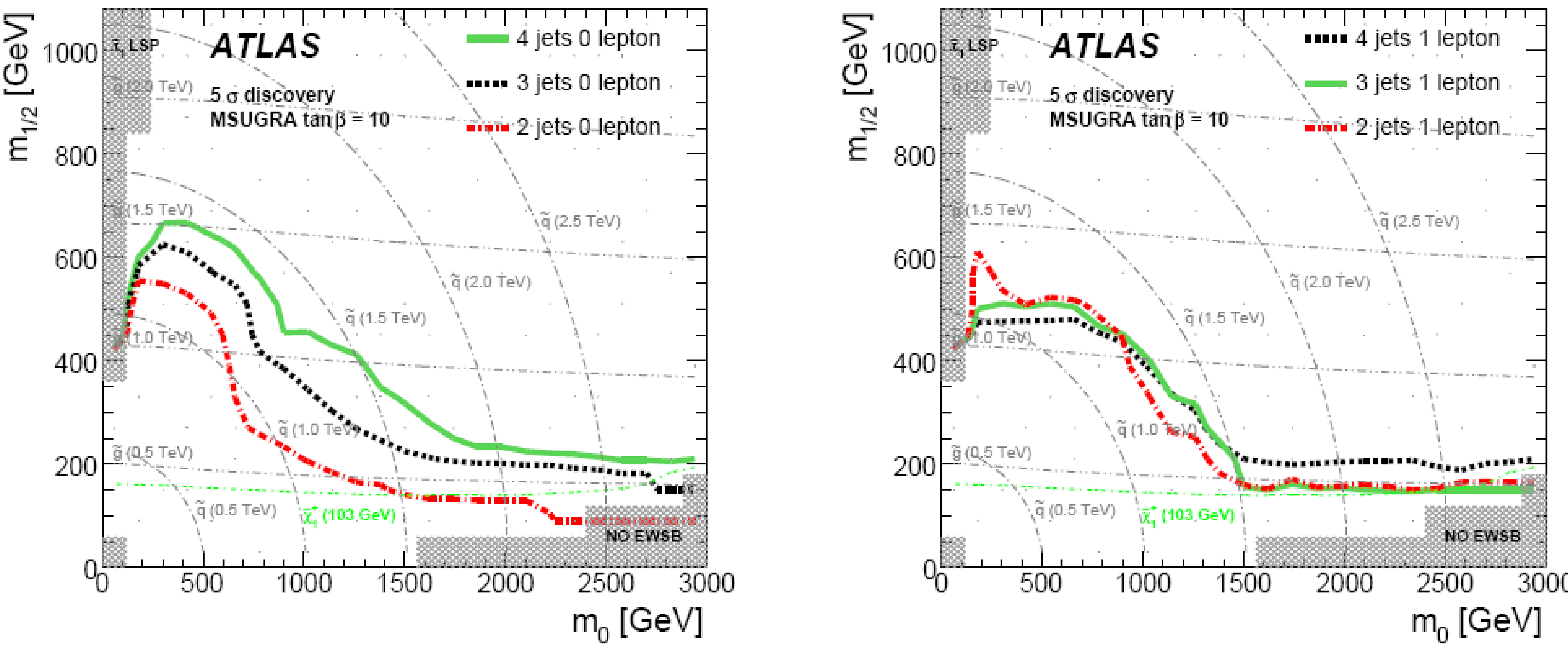
- For mSUGRA, ATLAS finds somewhat comparable power in 4j0l & 4j1l analyses for both high & low tan β…not us

- For us, OSDL are less powerful than in the mSUGRA case



- For us the 4j0l & 2j0l searches give very comparable coverage but not so for the mSUGRA case . Note that <1 TeV gluinos are apparently never missed in mSUGRA

- For mSUGRA comparable reaches are found for (4,3,2)j1l searches..not so for us.



The number of models 'found' by n different analyses

FLAT

# passed	# models no pystop	# models incl. pystops	# models nopy no tau
0	240 (0.35862%)	1135 (1.6597 %)	389 (0.58126%)
1	751 (1.1222 %)	812 (1.1874 %)	957 (1.43 %)
2	2110 (3.1528 %)	2168 (3.1703 %)	8561 (12.792 %)
3	8232 (12.301 %)	8334 (12.187 %)	12055 (18.013 %)
4	12416 (18.552 %)	12608 (18.437 %)	6953 (10.389 %)
5	6962 (10.403 %)	7019 (10.264 %)	12697 (18.972 %)
6	11970 (17.886 %)	12022 (17.58 %)	12290 (18.364 %)
7	11890 (17.766 %)	11925 (17.438 %)	6358 (9.5003 %)
8	6033 (9.0147 %)	6038 (8.8296 %)	3138 (4.6889 %)
9	2898 (4.3303 %)	2900 (4.2408 %)	2714 (4.0553 %)
10	2654 (3.9657 %)	2655 (3.8825 %)	812 (1.2133 %)
11	768 (1.1476 %)	768 (1.1231 %)	0 (0 %)

LOG

# passed	# models no pystop	# models incl. pystops	# models nopy no tau
0	866 (29.924 %)	876 (30.134 %)	887 (30.65 %)
1	182 (6.2889 %)	184 (6.3295 %)	181 (6.2543 %)
2	264 (9.1223 %)	264 (9.0815 %)	442 (15.273 %)
3	317 (10.954 %)	317 (10.905 %)	482 (16.655 %)
4	445 (15.377 %)	445 (15.308 %)	205 (7.0836 %)
5	180 (6.2198 %)	181 (6.2264 %)	262 (9.0532 %)
6	240 (8.293 %)	240 (8.2559 %)	187 (6.4616 %)
7	164 (5.6669 %)	164 (5.6416 %)	107 (3.6973 %)
8	103 (3.5591 %)	103 (3.5432 %)	68 (2.3497 %)
9	63 (2.1769 %)	63 (2.1672 %)	51 (1.7623 %)
10	49 (1.6932 %)	49 (1.6856 %)	22 (0.76019%)
11	21 (0.72564%)	21 (0.72239%)	0 (0 %)

$1\ fb^{-1}$

FLAT

The number of models 'found' by n different analyses

# passed	# models no pystop	# models incl. pystops	# models nopy no tau
0	177 (0.26448%)	1050 (1.5354 %)	286 (0.42735%)
1	565 (0.84424%)	625 (0.91396%)	756 (1.1296 %)
2	1521 (2.2727 %)	1581 (2.3119 %)	6795 (10.153 %)
3	6697 (10.007 %)	6803 (9.9482 %)	10199 (15.24 %)
4	10348 (15.462 %)	10515 (15.376 %)	6688 (9.9934 %)
5	6929 (10.354 %)	6996 (10.23 %)	13714 (20.492 %)
6	13165 (19.672 %)	13235 (19.354 %)	10347 (15.461 %)
7	10140 (15.152 %)	10176 (14.881 %)	9477 (14.161 %)
8	9088 (13.58 %)	9104 (13.313 %)	4146 (6.1951 %)
9	3885 (5.8051 %)	3888 (5.6855 %)	3590 (5.3643 %)
10	3518 (5.2567 %)	3519 (5.1459 %)	926 (1.3837 %)
11	891 (1.3314 %)	892 (1.3044 %)	0 (0 %)

10 fb $^{-1}$

LOG

# passed	# models no pystop	# models incl. pystops	# models nopy no tau
0	741 (25.605 %)	751 (25.834 %)	762 (26.33 %)
1	180 (6.2198 %)	182 (6.2607 %)	185 (6.3925 %)
2	288 (9.9516 %)	288 (9.9071 %)	447 (15.446 %)
3	315 (10.885 %)	315 (10.836 %)	458 (15.826 %)
4	423 (14.616 %)	423 (14.551 %)	232 (8.0166 %)
5	209 (7.2218 %)	209 (7.1895 %)	306 (10.574 %)
6	271 (9.3642 %)	272 (9.3567 %)	185 (6.3925 %)
7	167 (5.7706 %)	167 (5.7448 %)	153 (5.2868 %)
8	141 (4.8721 %)	141 (4.8504 %)	76 (2.6261 %)
9	72 (2.4879 %)	72 (2.4768 %)	61 (2.1078 %)
10	58 (2.0041 %)	58 (1.9952 %)	29 (1.0021 %)
11	29 (1.0021 %)	29 (0.99759%)	0 (0 %)

More lumi clearly helps..

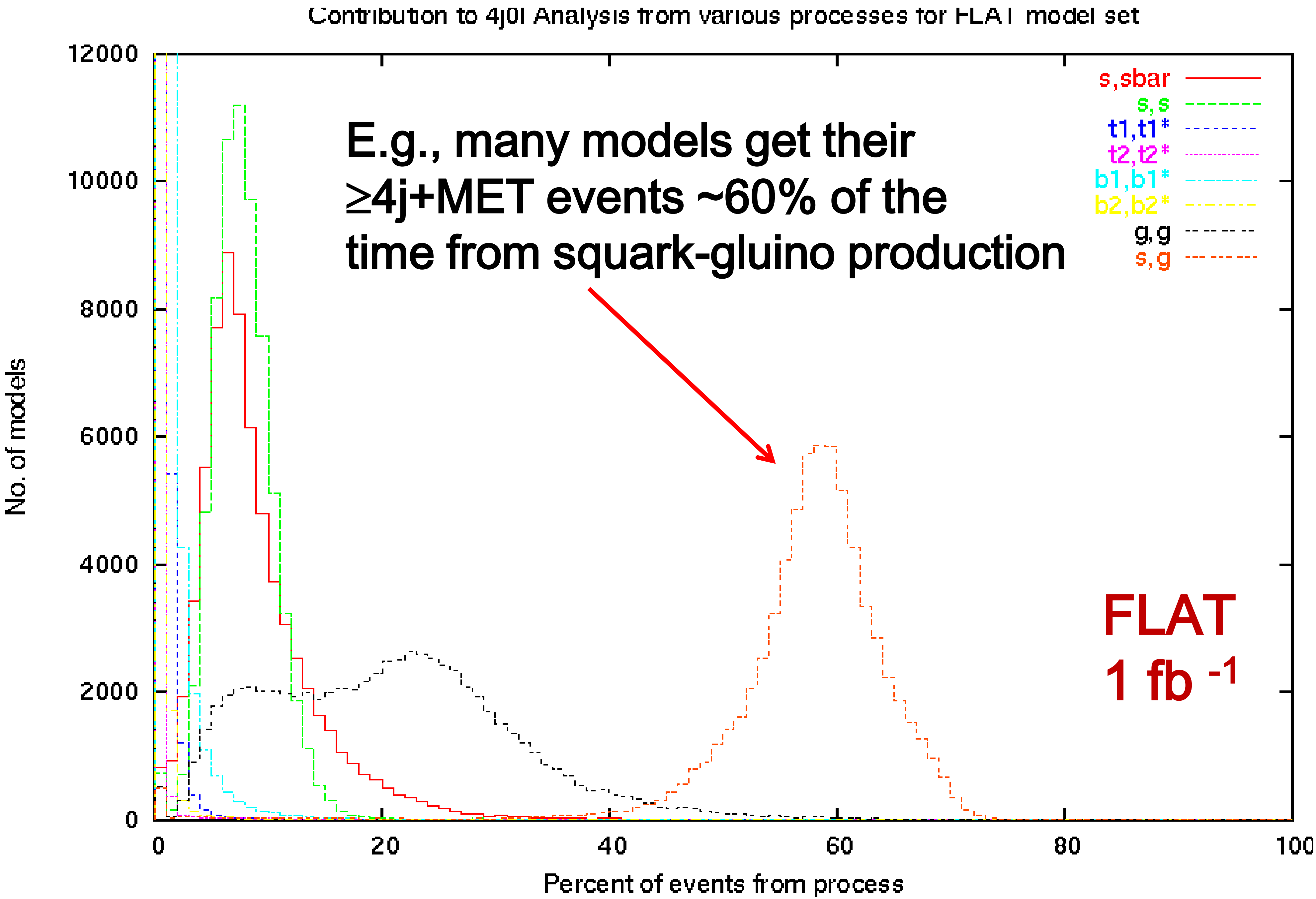
Why Do Models Get Missed by ATLAS?

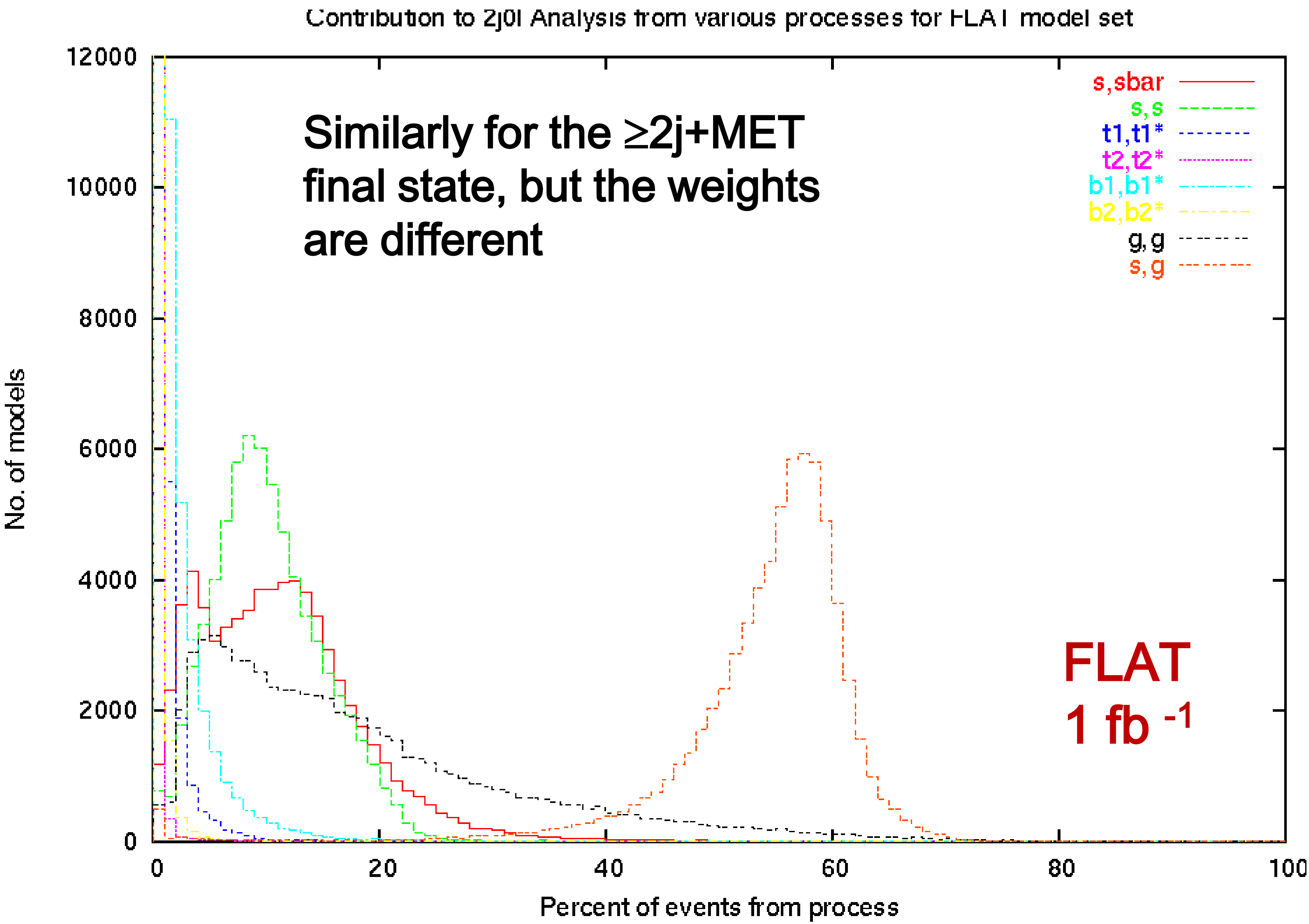
This is not possible to answer universally but there are some obvious causes…sometimes the cross section is just too small & sometimes the background uncertainties are too large…but these are not the only reasons. The other reasons are more interesting.

Let's first look at the 2j/4j+MET analyses as examples since they generally have the best reach in the mSUGRA/CMSSM context & here as well.

Some useful info can come from analyzing the multiple signal sources for the various analysis final states

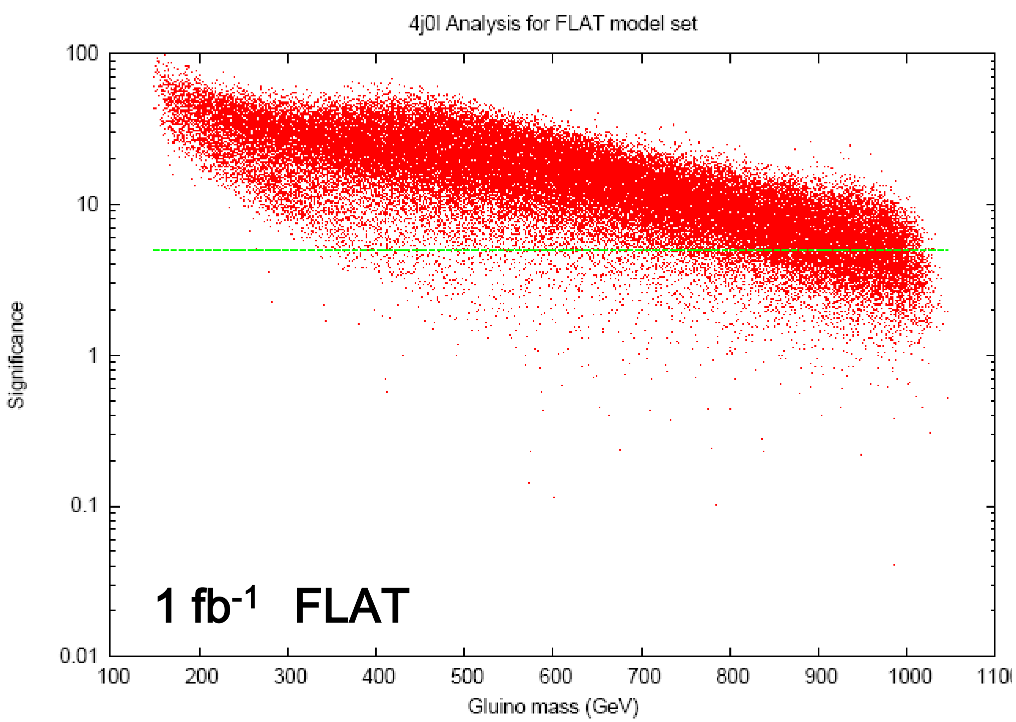
What processes produce the ≥4j/2j+MET events ???

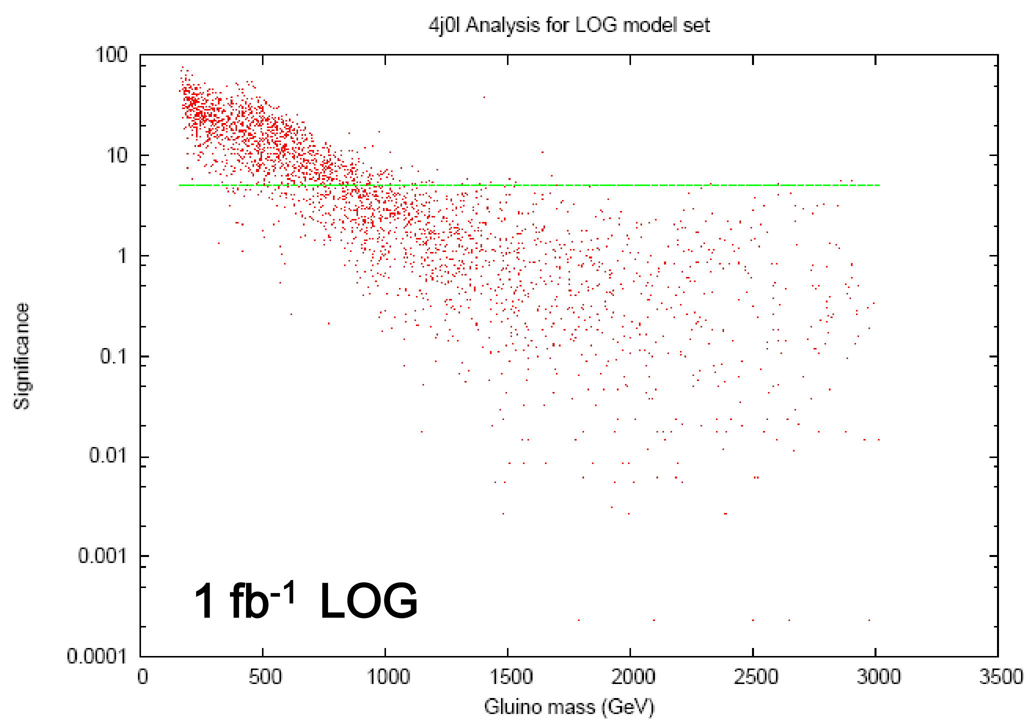



Contribution to 2j0l Analysis from various processes for FLAT model set
Similarly for the ≥2j+MET final state, but the weights are different
s,sbar
s,s
t1,t1*
t2,t2*
b1,b1*
b2,b2*
g,g
s,g
FLAT
1 fb -1
No. of models
Percent of events from process
12000
10000
8000
6000
4000
2000
0
0
20
40
60
80
100

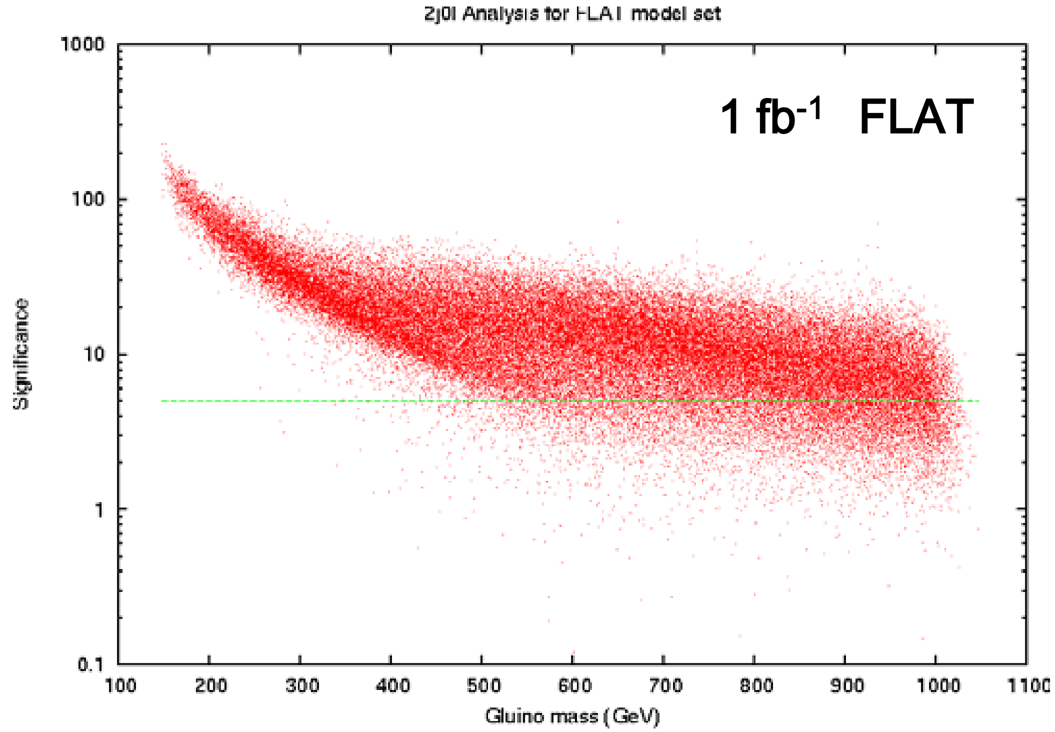
Missed Models: Is it 'just the mass' ??

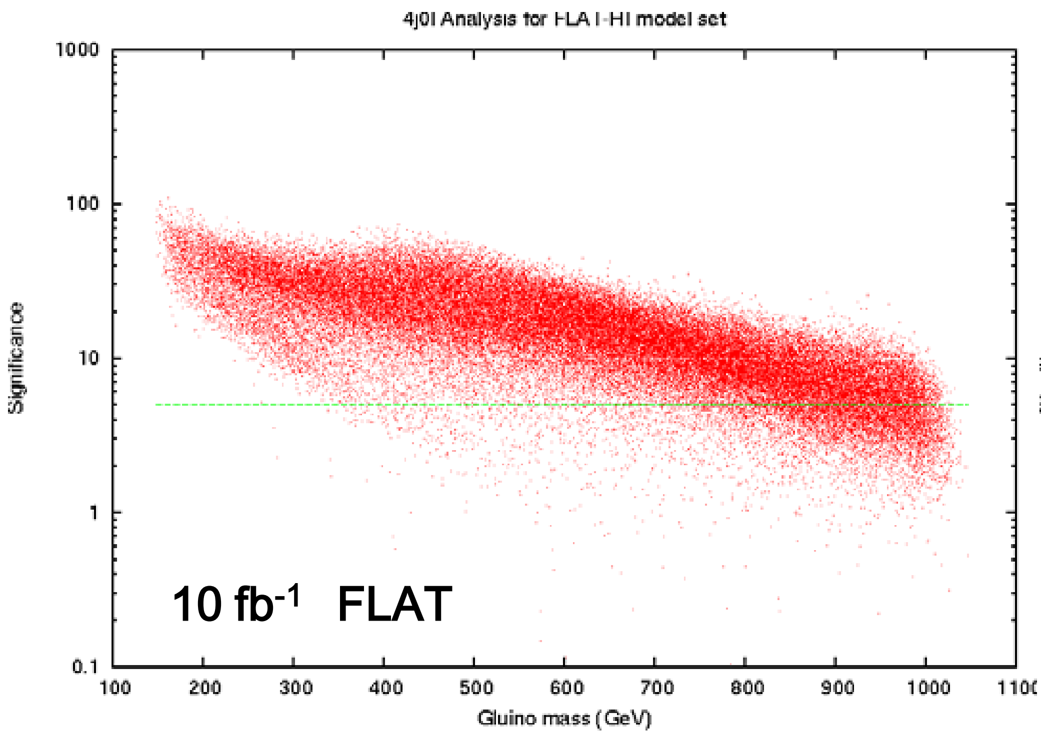
Here we see the significances for the 4j0l search…there IS a GENERAL reduction in S as the gluino mass increases. BUT we also see that there is quite a spread in significance at any fixed value of the mass.

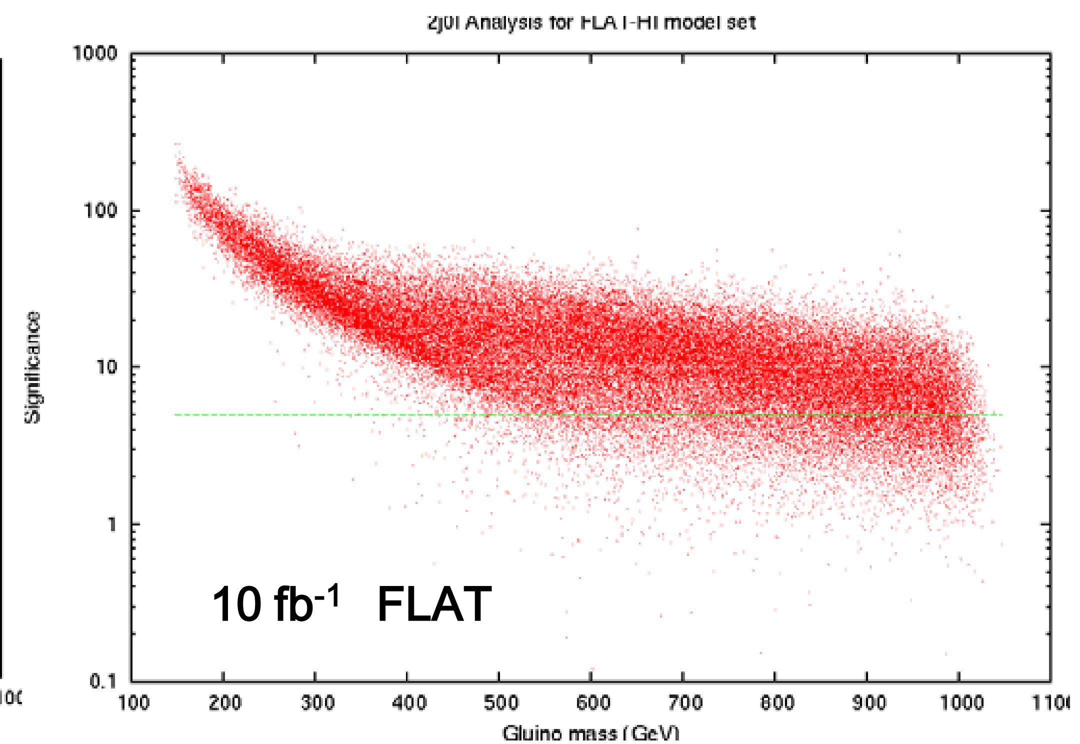




The 2j0l results are similar & increasing the lumi to 10 fb^{-1} in either case will only raise the overall significance distribution very slightly

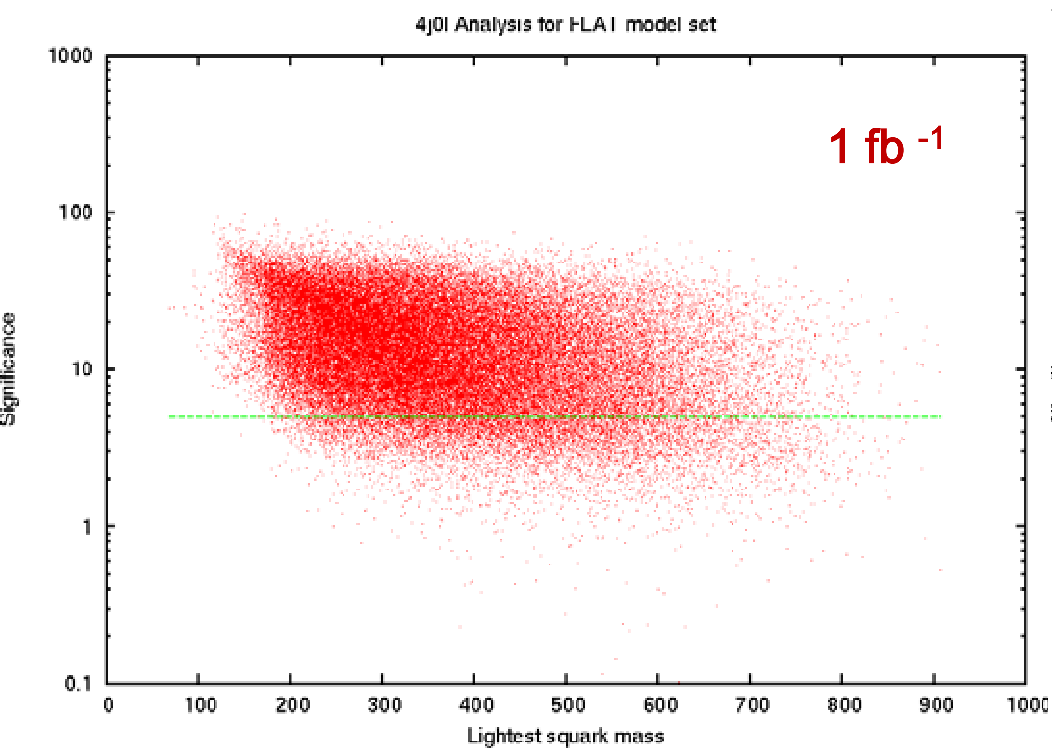


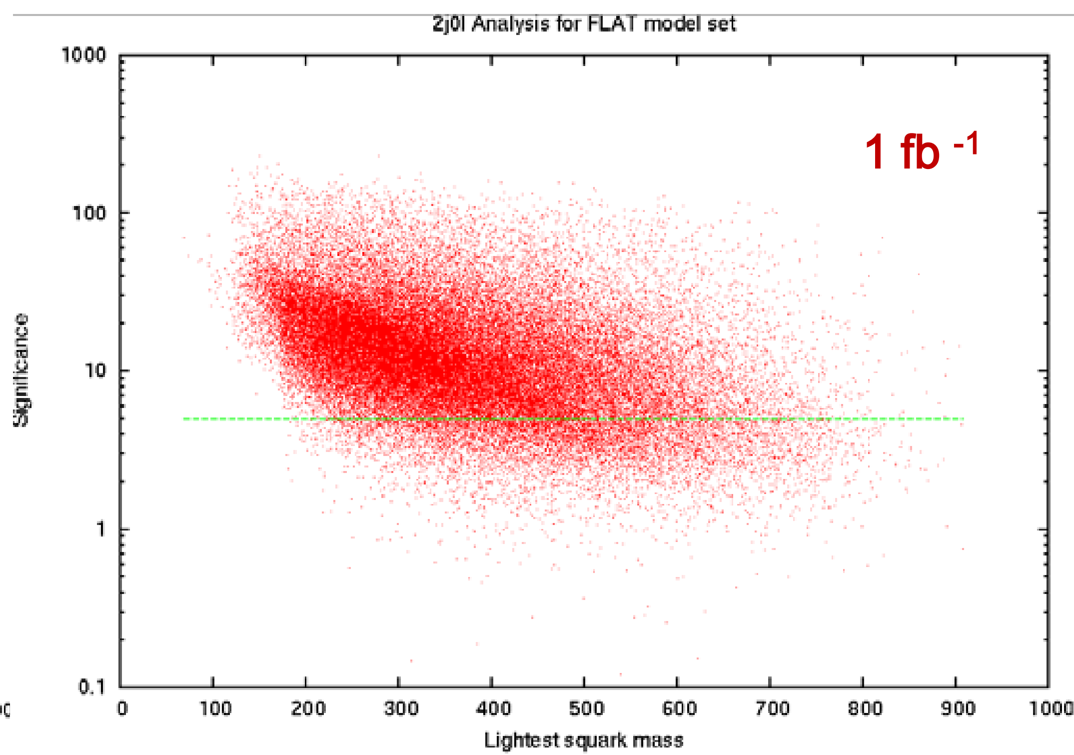




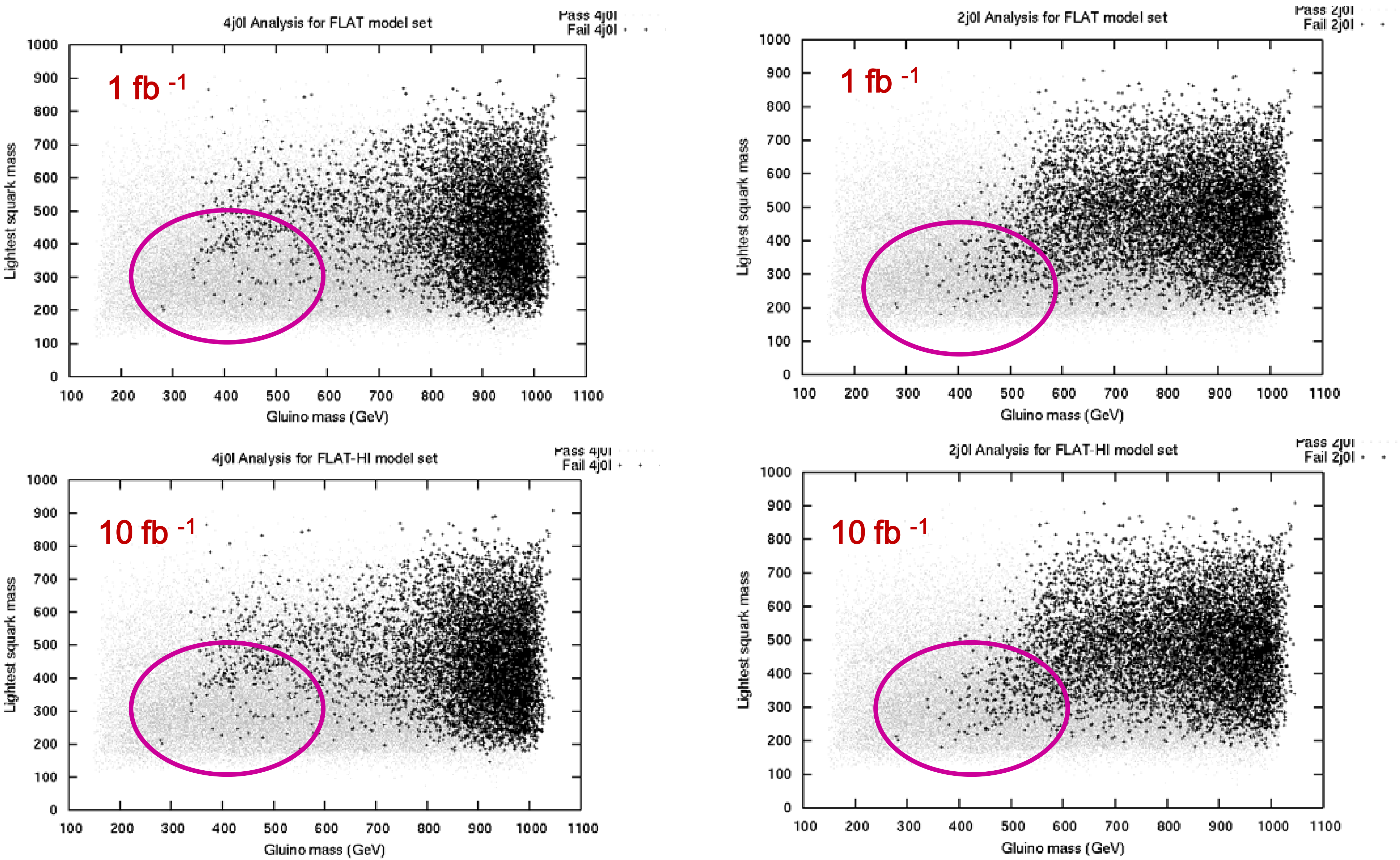
Search Significance Correlations : Dependence on the Lightest Squark Mass

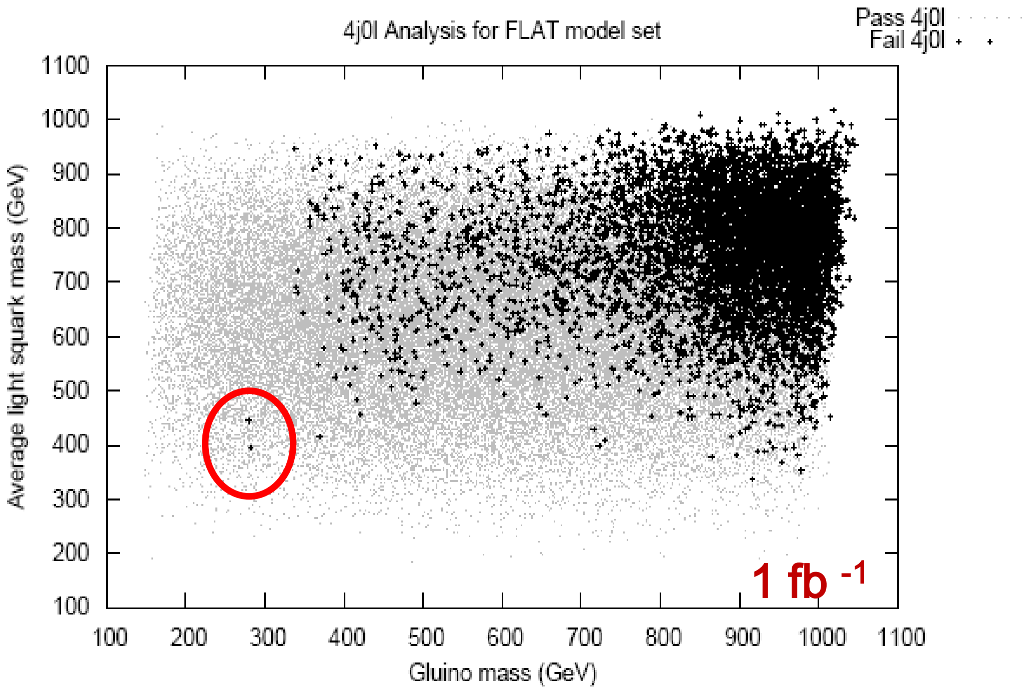
As the lightest of the u,d-squarks get heavier one might expect a qualitative fall off in the signal significance in the 2j0l &4j0l searches… here we see that this correlation is rather weak.

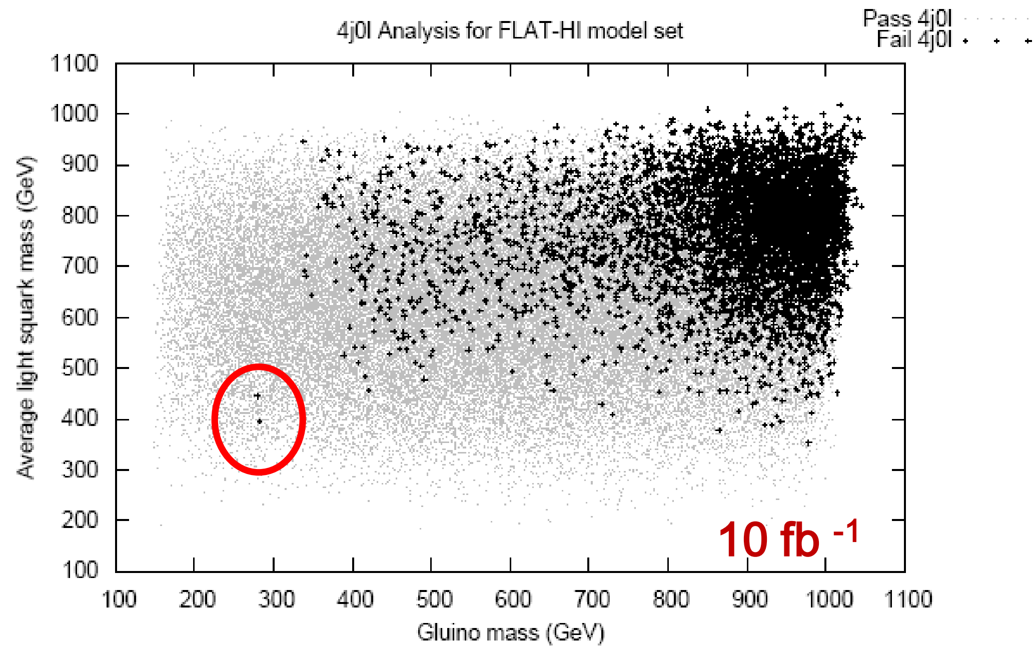




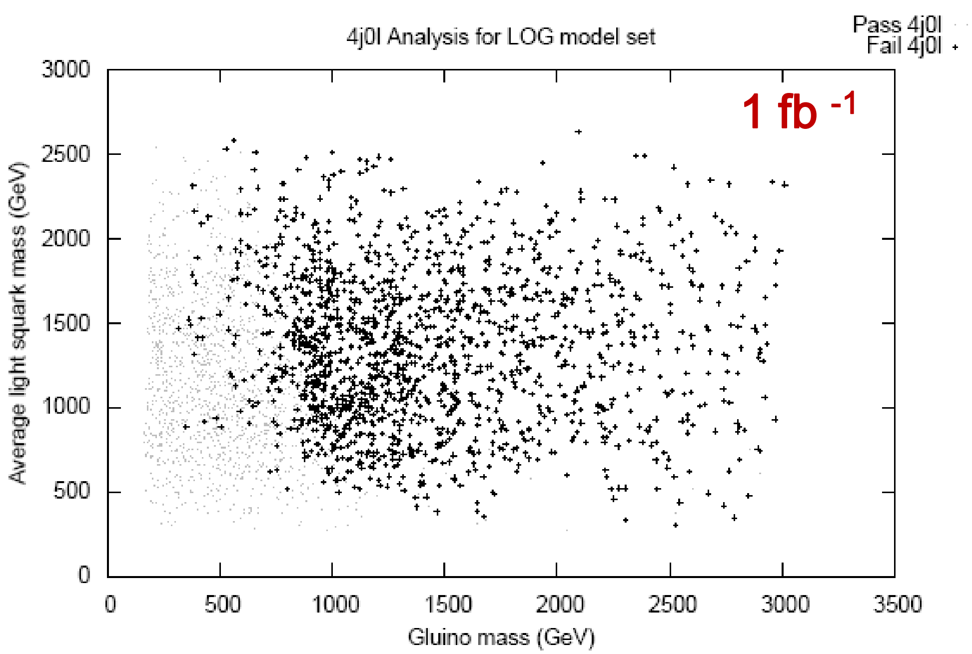
Lightest Squark Mass vs. Gluino Mass

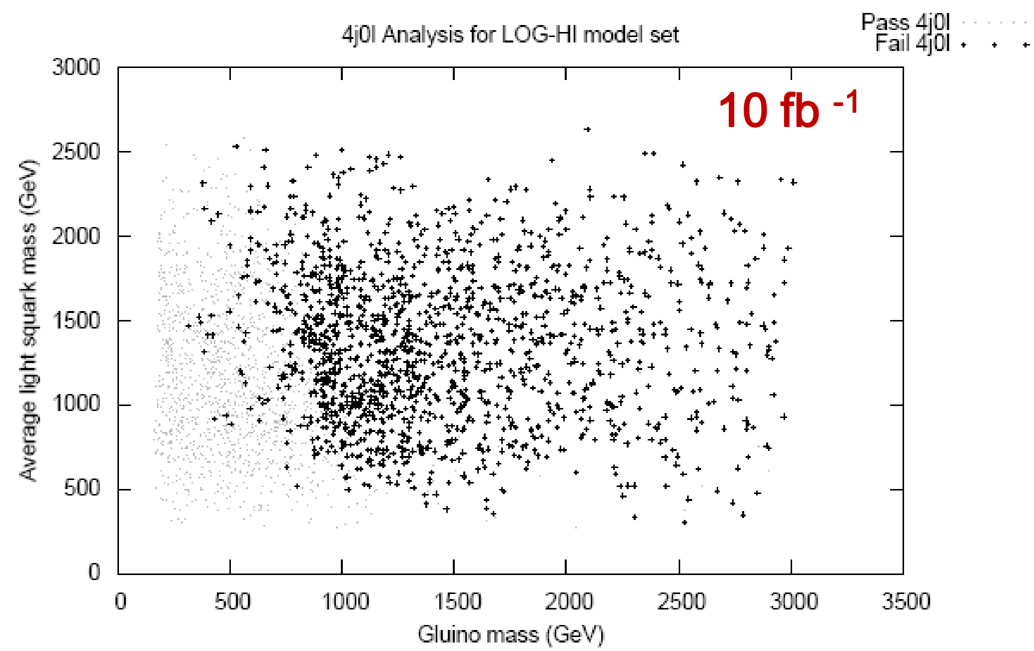


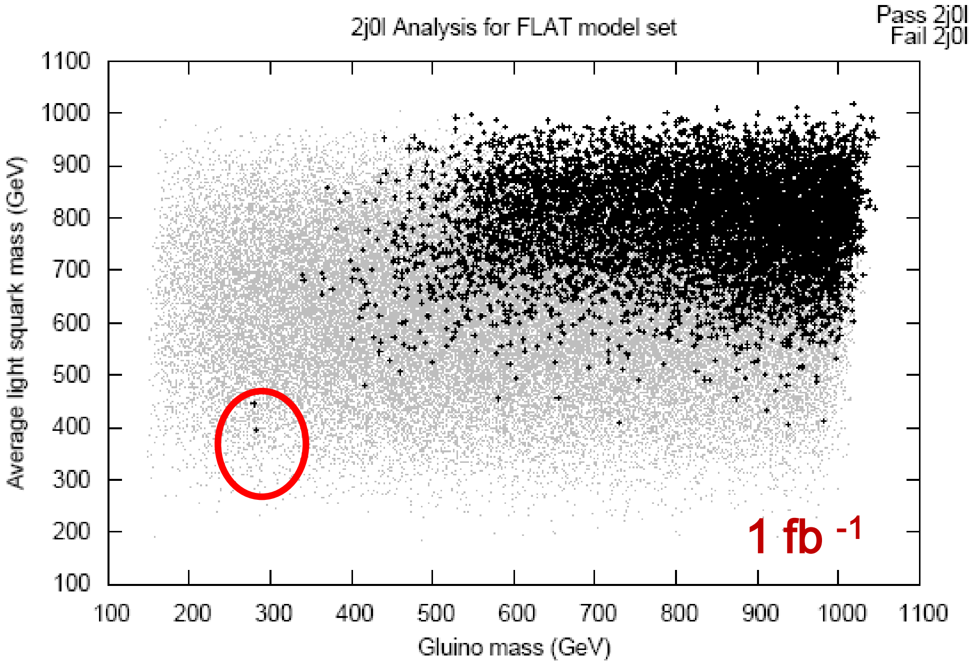


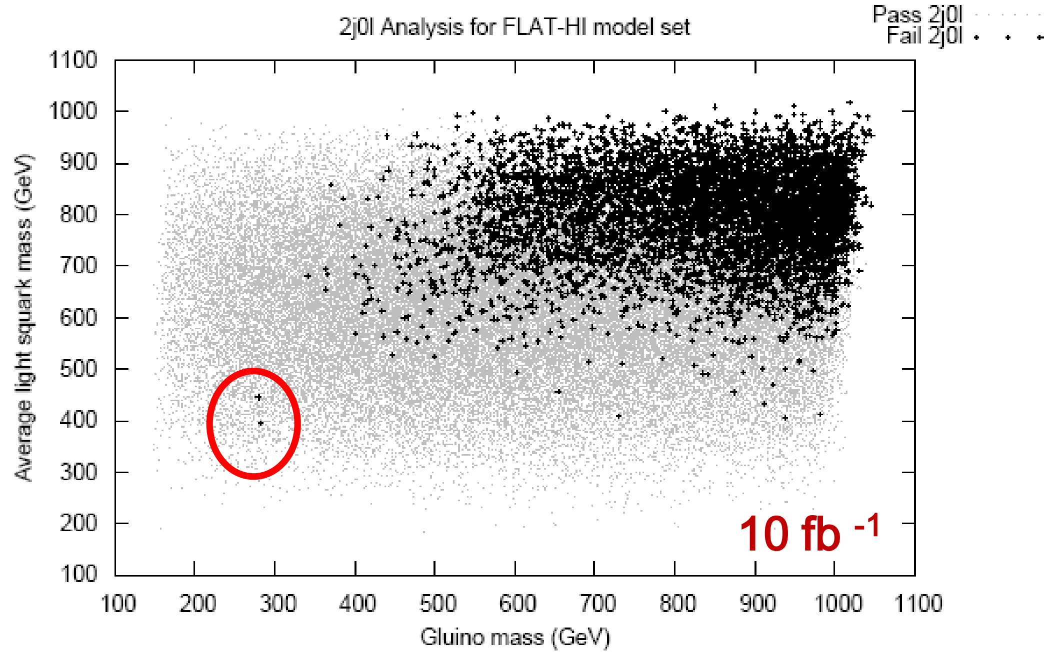


Some models w/ light squarks & gluinos ARE missed here & adding lumi does not necessarily help much in all cases

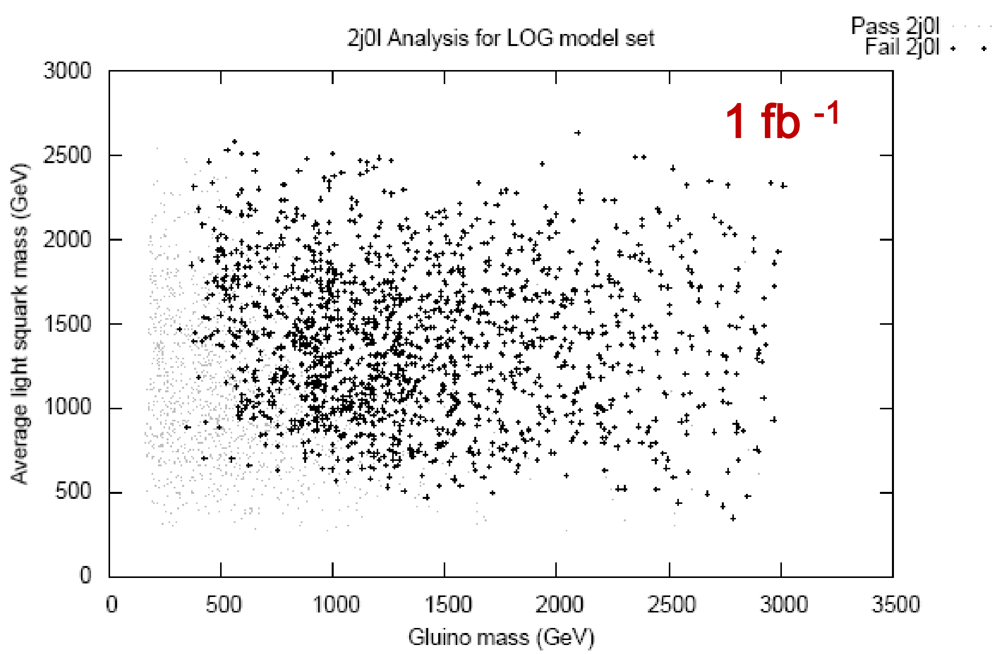


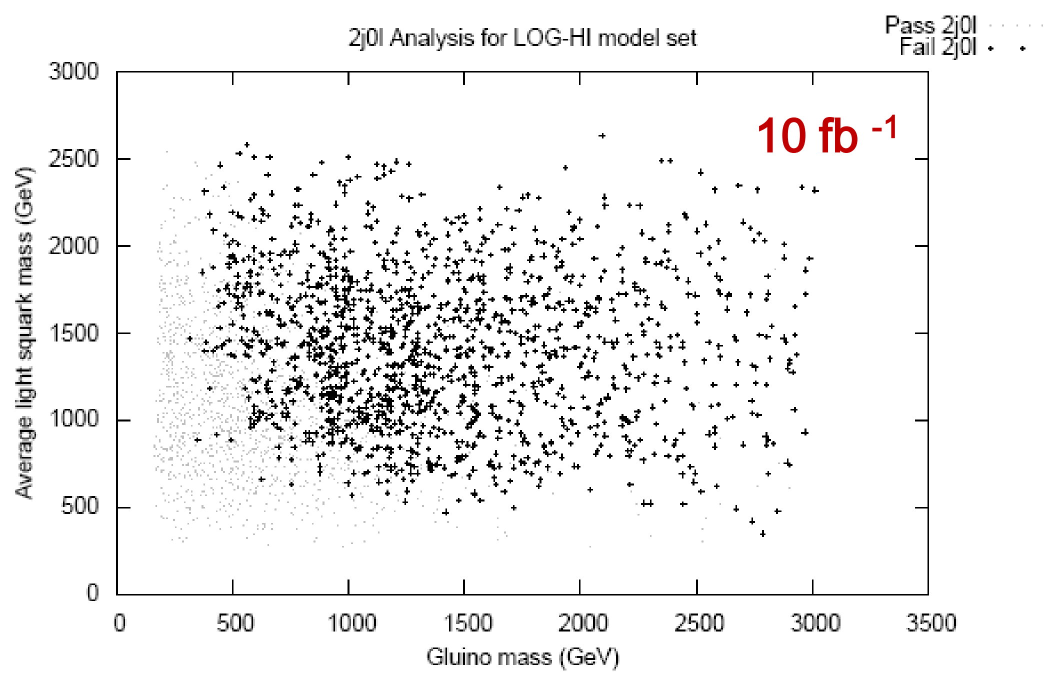


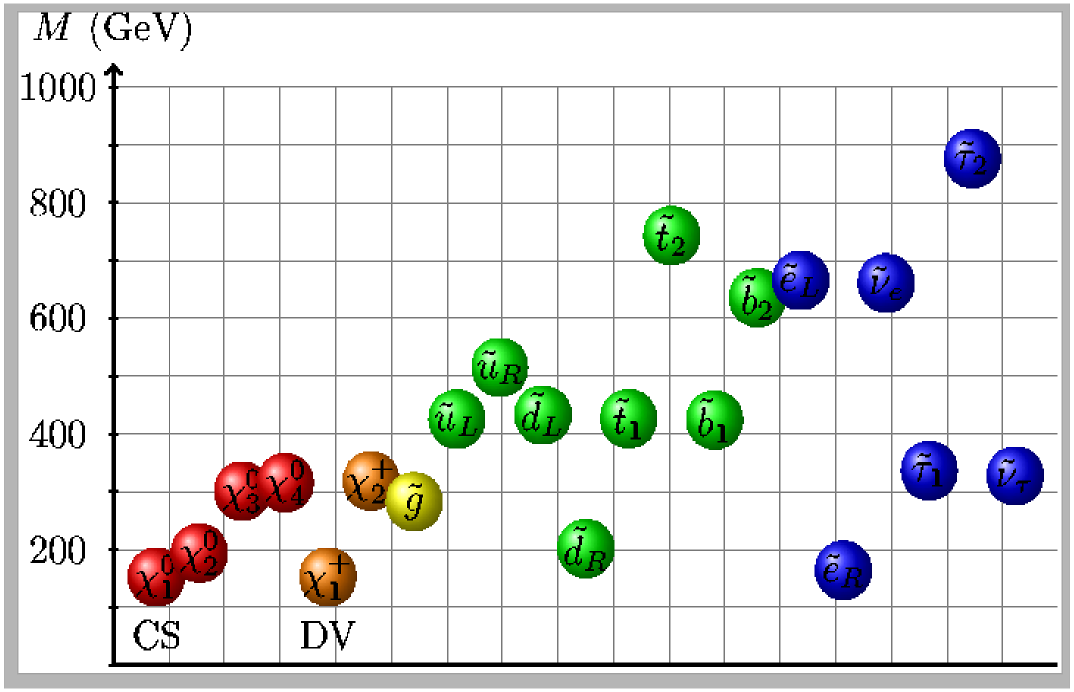




The same holds true for the 2j0l analysis







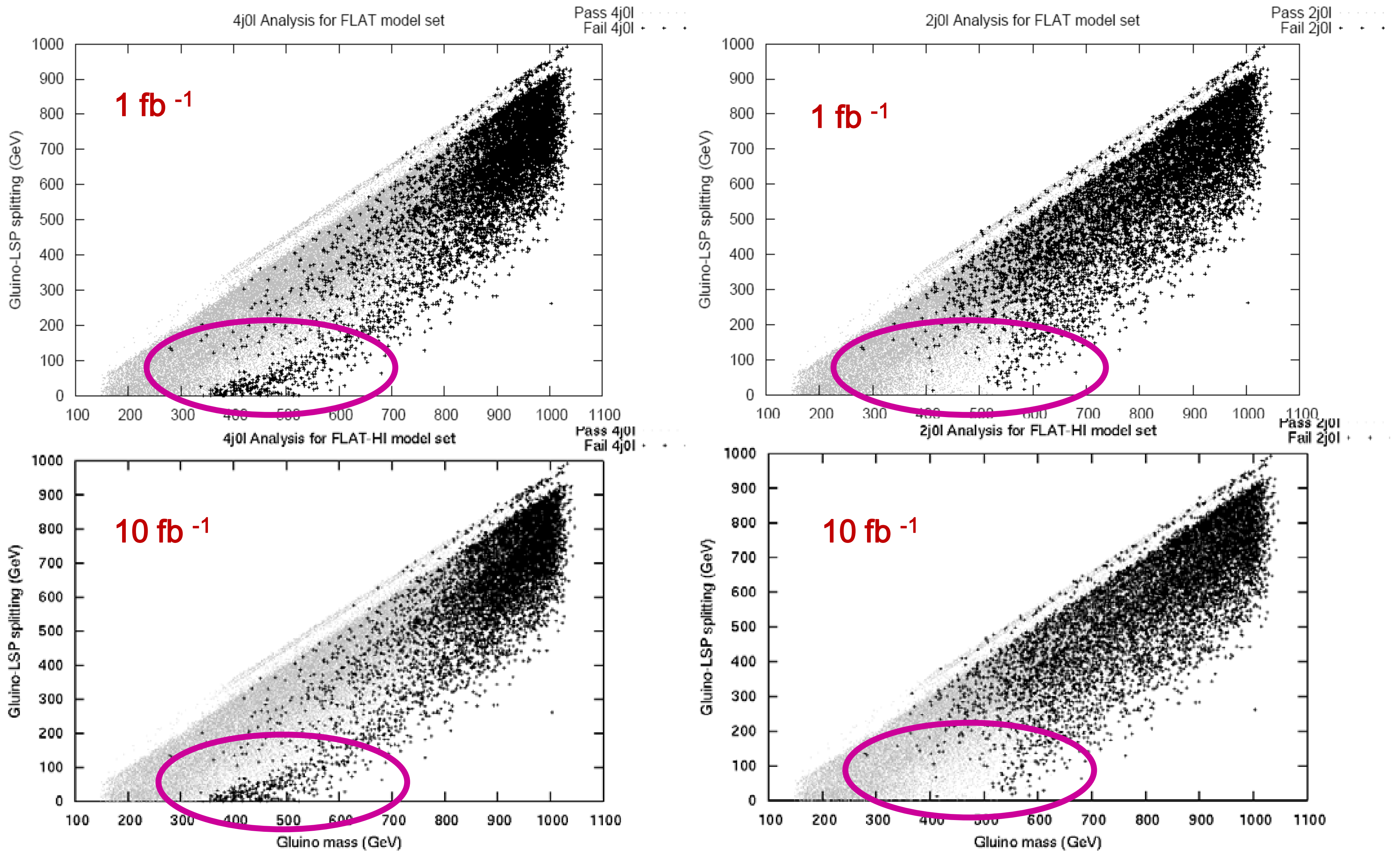
Example: Model 53105

Heavier squarks essentially decay into gluinos + jets & then…

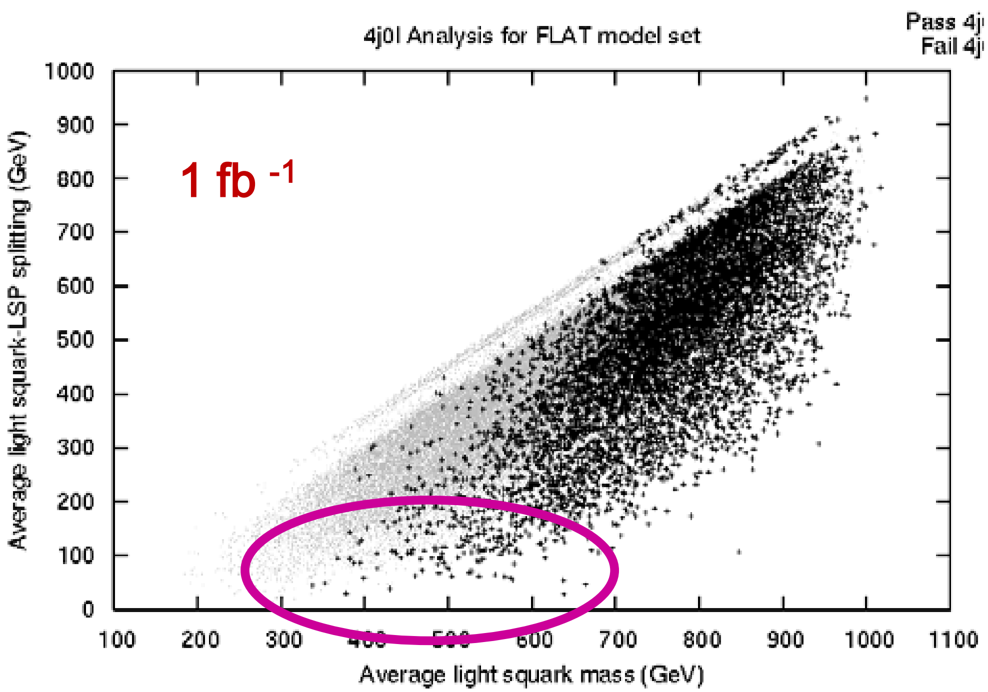
gluino(282.8) → $\tilde{d}_R$ (201.7) j	100%	Δm =81.1 GeV
$\tilde{d}_R$ (201.7) → $\tilde{\chi}_2^0$ (193.8) j	97%	Δm =7.9 GeV
$\tilde{\chi}_2^0$ (193.8) → $\tilde{l}_R^{\pm}$ (163.9) l	100%	Δm =30.0 GeV
$\tilde{l}_R^{\pm}$ (163.9) → $l^{\pm}$ +MET(152.5)	100%	Δm =11.4 GeV

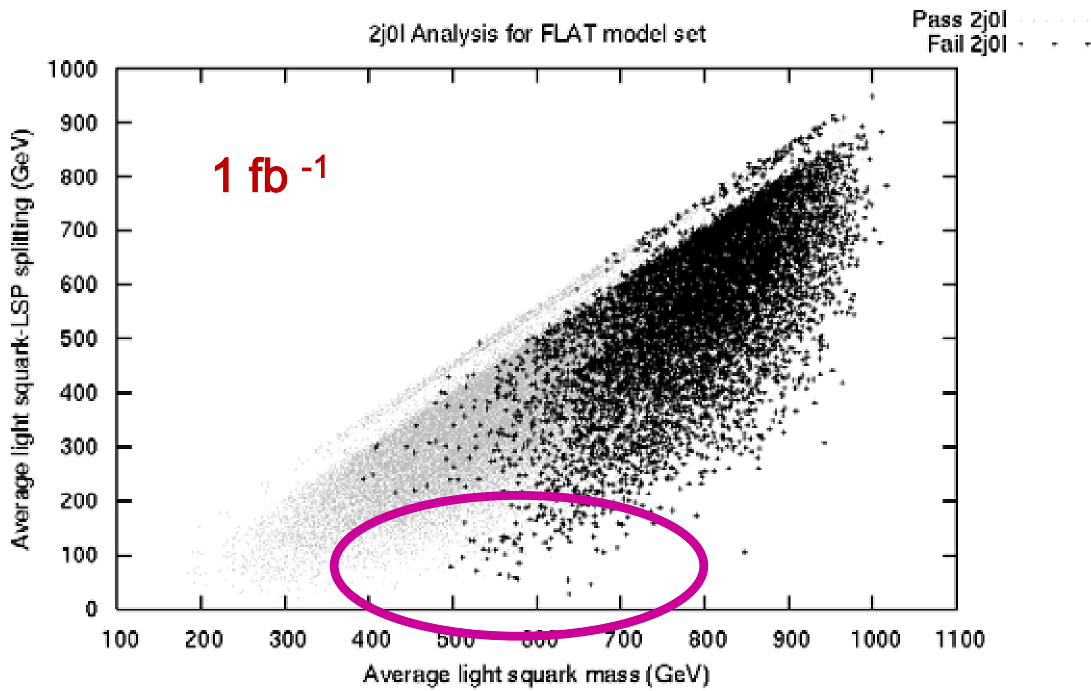
Model *fails* ATLAS (4,2)j0l cuts due to the presence of leptons!

Mass splittings leading to soft jets can be quite important.. but that's not all of it either :



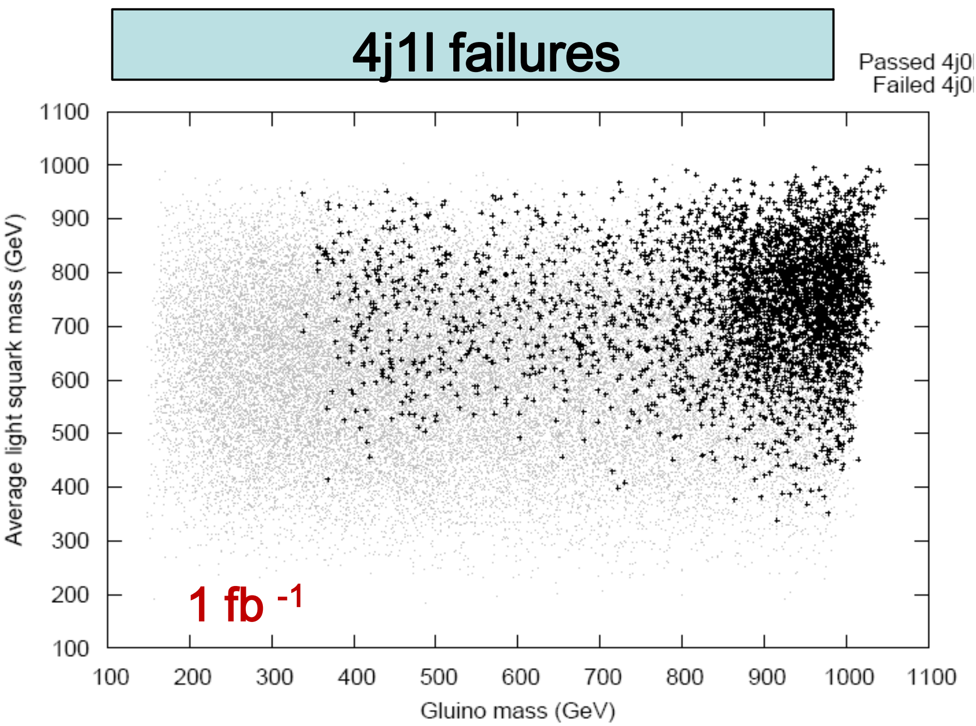
There is an even weaker correlation between small mass splittings for the squarks

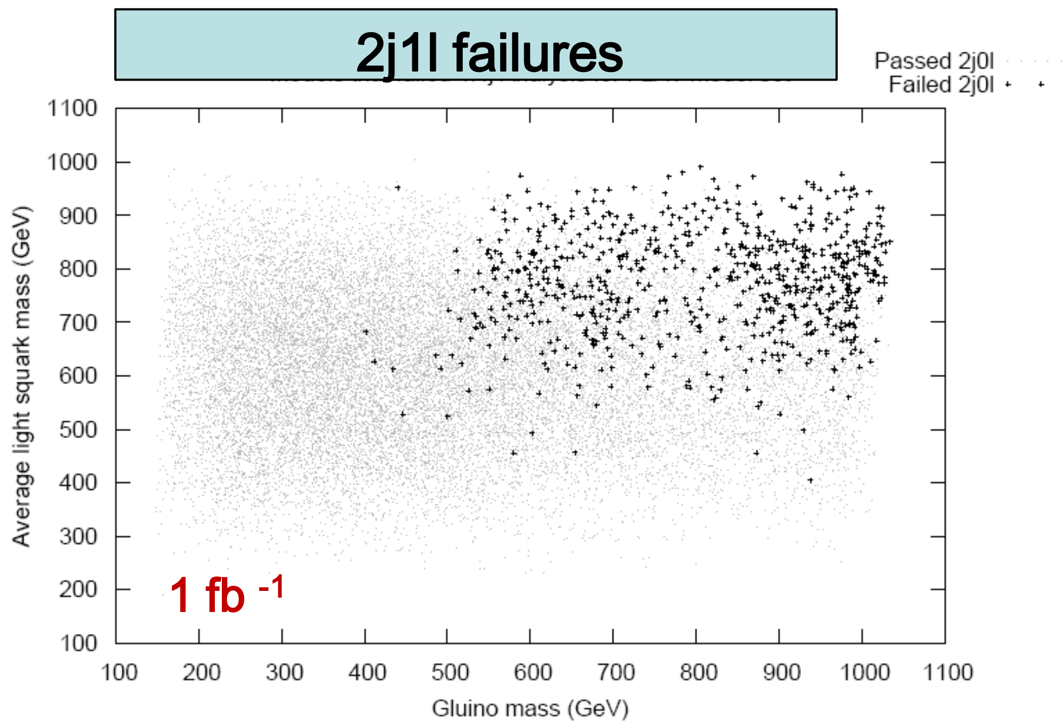




What about the other channels ??

- In the case of (2,4)j1l searches we can ask whether the model fails the ATLAS searches due to the 'hadronic' or the 'leptonic' parts of the cuts…





Cut Effectiveness: I (after M_{eff} cut)

flat

1 fb $^{-1}$

Analysis	# with Zn>5, no pystop	# with Zn>5, incl. pystops
4j0l_1: 4 hard jets	66745 (99.733 %)	67289 (98.399 %)
4j0l_2: $E^T_{\mathrm{miss}} > 0.2M_{\mathrm{eff}}$	66036 (98.673 %)	66556 (97.327 %)
4j0l_3: trans. sph.	63615 (95.056 %)	64071 (93.693 %)
4j0l_4: jets not near E^T_{\mathrm{miss}}	62857 (93.923 %)	63306 (92.574 %)
4j0l_5: no lepton	59537 (88.962 %)	59978 (87.708 %)
2j0l_1: 2 hard jets	66610 (99.531 %)	67173 (98.229 %)
2j0l_2: $E^T_{\mathrm{miss}} > 0.3M_{\mathrm{eff}}$	63573 (94.993 %)	64089 (93.719 %)
2j0l_3: jets not near E^T_{\mathrm{miss}}	63062 (94.229 %)	63568 (92.957 %)
2j0l_4: no lepton	58719 (87.74 %)	59208 (86.582 %)
1l4j_1: one isolated lepton	57665 (86.165 %)	58037 (84.869 %)
1l4j_2: no additional leptons	57374 (85.73 %)	57739 (84.433 %)
1l4j_3: four hard jets	47585 (71.103 %)	47777 (69.866 %)
1l4j_4: $E^T_{\mathrm{miss}} > 0.2M_{\mathrm{eff}}$ and $E^T_{\mathrm{miss}} > 100$	41798 (62.456 %)	41930 (61.316 %)
1l4j_5: trans. sph.	36400 (54.39 %)	36489 (53.359 %)
1l4j_6: $M_T > 100$	28560 (42.675 %)	28624 (41.858 %)
1l3j_1: one isolated lepton	66813 (99.834 %)	67917 (99.317 %)
1l3j_2: no additional leptons	66804 (99.821 %)	67902 (99.295 %)
1l3j_3: three hard jets	60755 (90.782 %)	61204 (89.5 %)
1l3j_4: $E^T_{\mathrm{miss}} > 0.25M_{\mathrm{eff}}$ and $E^T_{\mathrm{miss}} > 100$	54449 (81.359 %)	54763 (80.082 %)
1l3j_5: trans. sph.	51457 (76.889 %)	51714 (75.623 %)
1l3j_6: $M_T > 100$	45228 (67.581 %)	45405 (66.397 %)

Cut Effectiveness: II

1l2j_1: one isolated lepton	66271 (99.024 %)	67208 (98.28 %)
1l2j_2: no additional leptons	66233 (98.967 %)	67155 (98.203 %)
1l2j_3: two hard jets	62773 (93.797 %)	63329 (92.608 %)
1l2j_4: $E^T_{\rm miss} > 0.3 M_{\rm eff}$ and $E^T_{\rm miss} > 100$	57237 (85.525 %)	57616 (84.254 %)
1l2j_5: trans. sph.	53403 (79.796 %)	53696 (78.521 %)
1l2j_6: $M_T > 100$	47011 (70.245 %)	47226 (69.06 %)
OSDL_1: OSDL	33406 (49.916 %)	33513 (49.007 %)
OSDL_2: four hard jets	11993 (17.92 %)	12003 (17.552 %)
OSDL_3: $E^T_{\rm miss} > 0.2 M_{\rm eff}$ and $E^T_{\rm miss} > 100$	9916 (14.817 %)	9922 (14.509 %)
OSDL_4: trans. sph.	7360 (10.998 %)	7364 (10.769 %)
SSDL_1: SSDL	26800 (40.045 %)	26876 (39.302 %)
SSDL_2: four hard jets	14281 (21.339 %)	14290 (20.897 %)
SSDL_3: $E^T_{\rm miss} > 100$	14280 (21.338 %)	14289 (20.895 %)
SSDL_4: $E^T_{\rm miss} > 0.2 M_{\rm eff}$	14280 (21.338 %)	14289 (20.895 %)
3lj_1: at least three leptons	16310 (24.371 %)	16345 (23.902 %)
3lj_2: at least one hard (200 GeV) jet	9139 (13.656 %)	9149 (13.379 %)
3lm_1: at least three leptons	5128 (7.6624 %)	5140 (7.5164 %)
3lm_2: at least one OSSF pair with $M > 20$ GeV	4460 (6.6643 %)	4471 (6.5381 %)
3lm_3: lepton track isolation	4460 (6.6643 %)	4471 (6.5381 %)
3lm_4: $E^T_{\rm miss} > 30$	4306 (6.4342 %)	4315 (6.31 %)
3lm_5: $M < M_Z$ for any OSSF pair	1843 (2.7539 %)	1847 (2.7009 %)

Cut Effectiveness: III

tau_1: four hard jets	66900 (99.964 %)	67568 (98.807 %)
tau_2: $E^T_{\mathrm{miss}} > 100$	66895 (99.957 %)	67524 (98.742 %)
tau_3: jets not near E^T_{\mathrm{miss}}	66883 (99.939 %)	67498 (98.704 %)
tau_4: no lepton	66780 (99.785 %)	67379 (98.53 %)
tau_5: at least one tau	64358 (96.166 %)	64839 (94.816 %)
tau_6: $E^T_{\mathrm{miss}} > 0.2 M_{\mathrm{eff}}$	61618 (92.072 %)	62061 (90.754 %)
tau_7: $M_T > 100$ (of hardest tau and E^T_{miss})	57088 (85.303 %)	57483 (84.059 %)
b_1: 4 hard jets with $p_T > 50$ GeV	66923 (99.999 %)	67893 (99.282 %)
b_2: leading jet with $p_T > 100$ GeV	66923 (99.999 %)	67892 (99.281 %)
b_3: $E^T_{\mathrm{miss}} > 100$ GeV	66923 (99.999 %)	67841 (99.206 %)
b_4: $E^T_{\mathrm{miss}} > 0.2 M_{\mathrm{eff}}$	66923 (99.999 %)	67775 (99.109 %)
b_5: trans sph.	66923 (99.999 %)	67669 (98.954 %)
b_6: at least 2 b-tags	49760 (74.353 %)	50113 (73.282 %)

Reducing Systematics: 50% → 20%

L(fb^{-1})	1	10	1	10
Analysis	50	50*h*	20	20*h*
4j0l	88.962	89.179	99.009	99.093
2j0l	87.74	87.87	98.676	98.754
1l4j	42.675	45.671	57.968	64.074
1l3j	67.58	74.168	72.967	84.116
1l2j	70.244	74.493	79.399	86.972
OSDL	10.997	11.89	23.272	27.446
SSDL	21.337	32.107	25.161	39.138
3lj	13.656	17.486	19.386	28.857
3lm	2.7538	2.9182	4.916	5.8947
tau	85.303	88.057	97.139	98.657
b	74.352	77.374	91.915	94.97

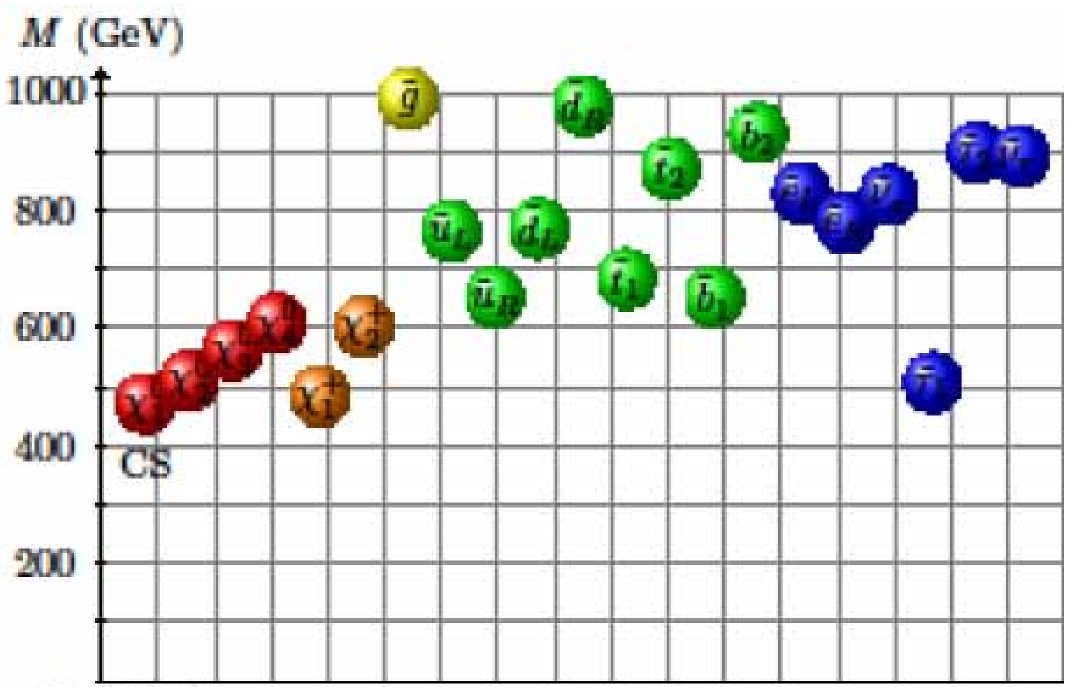
FLAT

This would be a very significant improvement in reach!

Reducing Systematics: 50% $\rightarrow$ 20% (cont.)

Number of analyses	Flat	Flat high-$\mathcal{L}$	Log	Log high-$\mathcal{L}$
0	0.032873	0.025402	17.726	12.025
1	0.071722	0.046321	5.4596	4.9067
2	0.51999	0.20322	7.8093	7.0145
3	4.3302	2.2742	9.3642	7.9475
4	16.018	9.6976	16.966	14.824
5	7.7833	5.9306	7.8438	8.1894
6	14.044	17.512	8.7768	13.407
7	26.452	21.287	10.815	9.8825
8	10.361	14.058	5.5287	7.9475
9	6.9391	8.6217	3.4554	4.8376
10	9.9768	15.67	3.9046	5.8051
11	3.471	4.674	2.3497	3.2135

Sample Failure Analyses



Example: Model 949

ss: 2667
gg: 450.5
sg: 2611

number of events b/f cuts

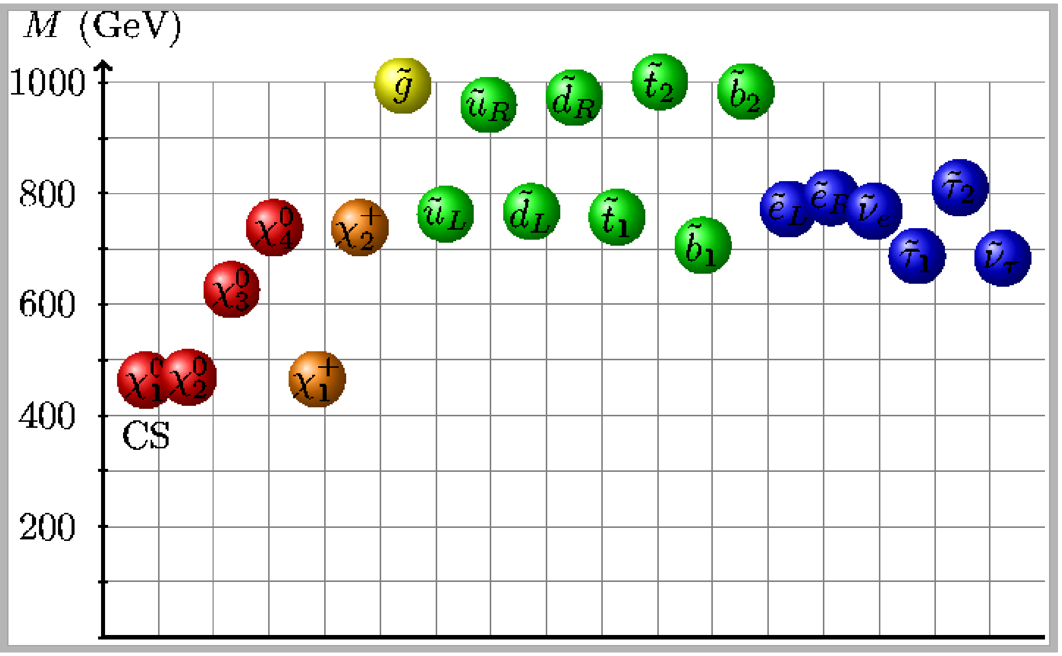
→ gg →ss+2j , gs→ss+j

Signals depend on what squarks do with the highly compressed gaugino spectrum. (Note $\chi^{\pm} \rightarrow$ LSP+W* w/ Δm=11.7 GeV)

•B(s→j + MET) ~0.11-0.37 → (4,2)j0l rates which are too small

•B(s→j + $\chi_{2,3}^{0}$) ~ 0.07-0.68 → ~soft τ's + MET as only staus are accessible → few (B~0.35) soft leptons from tau decays

•B(s→j + $\chi_1^{\pm}$) ~ 0-0.57 → soft jets/leptons + MET



However: Model 56838

is quite similar…BUT.. this model is FOUND !

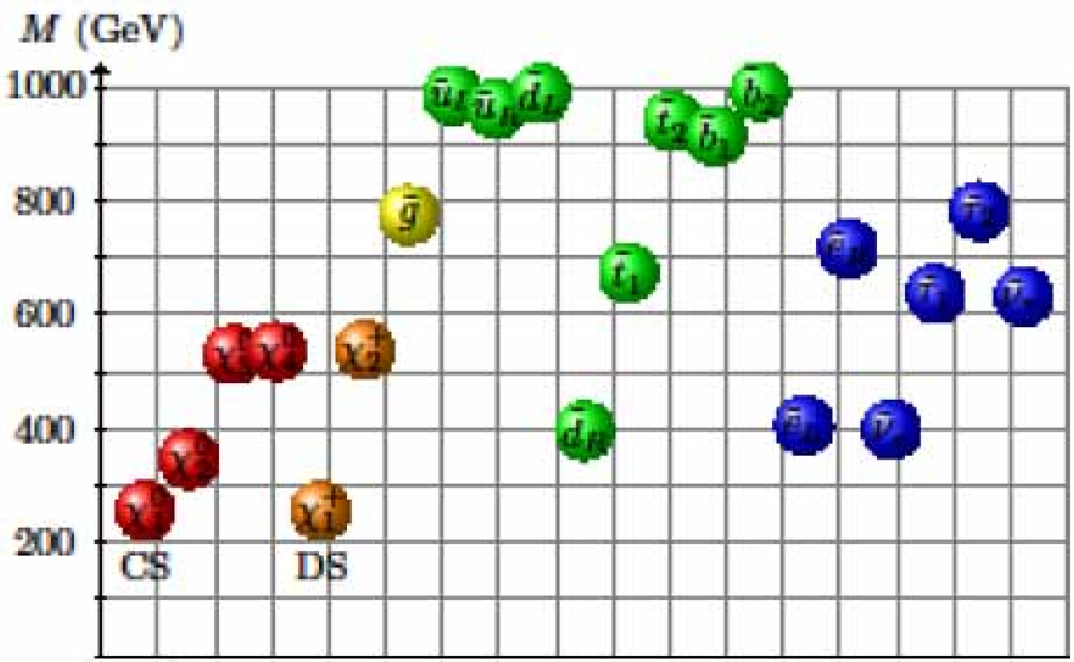
comparable production σ's

→ $gg \to ss+2j$, $gs \to ss+j$

There are more decays of gluinos to sbottoms here.
Signals again depend on what squarks do with the compressed gaugino spectrum. They have BFs to charginos & neutralinos comparable to Model 949.

- However, $\chi_{2,3}^0$ now will decay quite differently with reasonable BFs into final states with significant light leptons !

- 56838 is seen in both the (2,3)j1l analyses



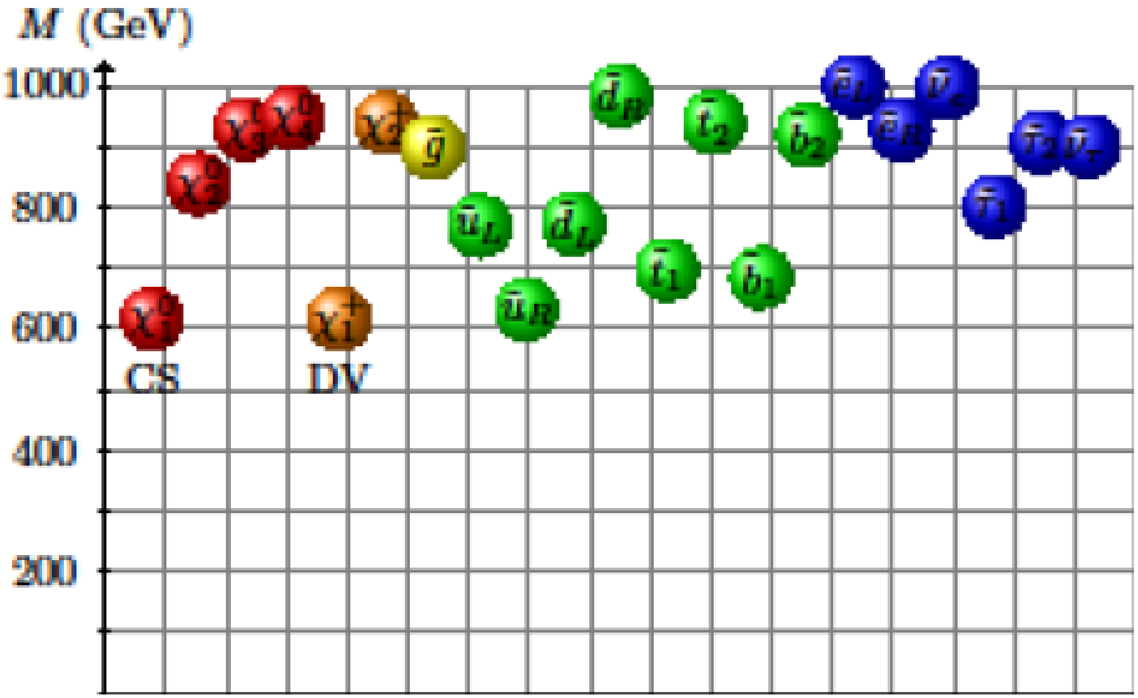
Example: Model 32864

ss: 8029
gg: 2085
sg: 9811

number of events b/f cuts

→ u_R ,(u,d)$_L$ >> g >>> d_R

- $q_L \rightarrow j + \chi_1^0$ (17%), $\chi_1^\pm$ (35%), gluino (46%)
- $u_R \rightarrow j + \chi_2^0$ (18%) , gluino (81%); gluino $\rightarrow$ j+ d_R
- $d_R \rightarrow j + \chi_2^0$; $\chi_2^0 \rightarrow \chi_1^\pm + W$ the chargino is stable
- Most of the decays end up as stable charginos so there is very little MET although there are many jets. No leptons or τ's & few b's



Example: Model 7105

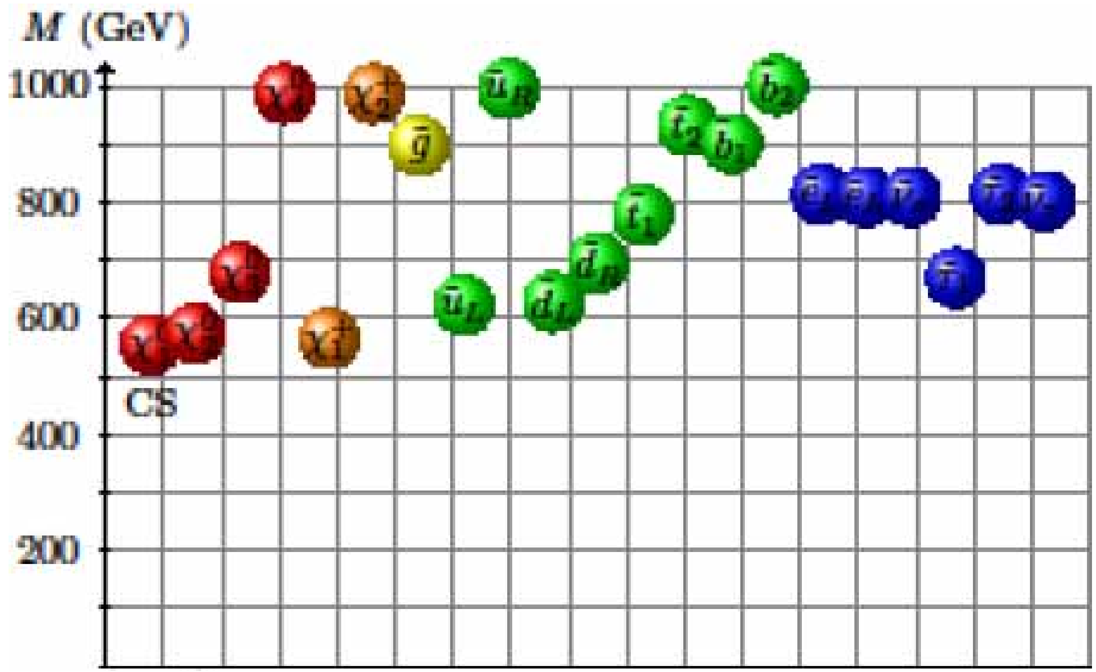
ss: 3391
gg: 777.8
sg: 5720

number of events b/f cuts

→ u_R ,(u,d)$_L$ < g < d_R

- d_R →j + χ_2^0 (2%), gluino (98%) ;
- gluino → j+ u_R (50%), (u,d)$_L$ (28%)
- u_L →j+ χ_1^0 (33%), $\chi_1^\pm$ (67%); d_L →j+ χ_1^0 (34%), $\chi_1^\pm$ (66%);
- u_R →j+ χ_1^0 ; $\chi_1^\pm$ is detector stable ($c\tau$ ~35m)

Long-lived searches in cascades are important !



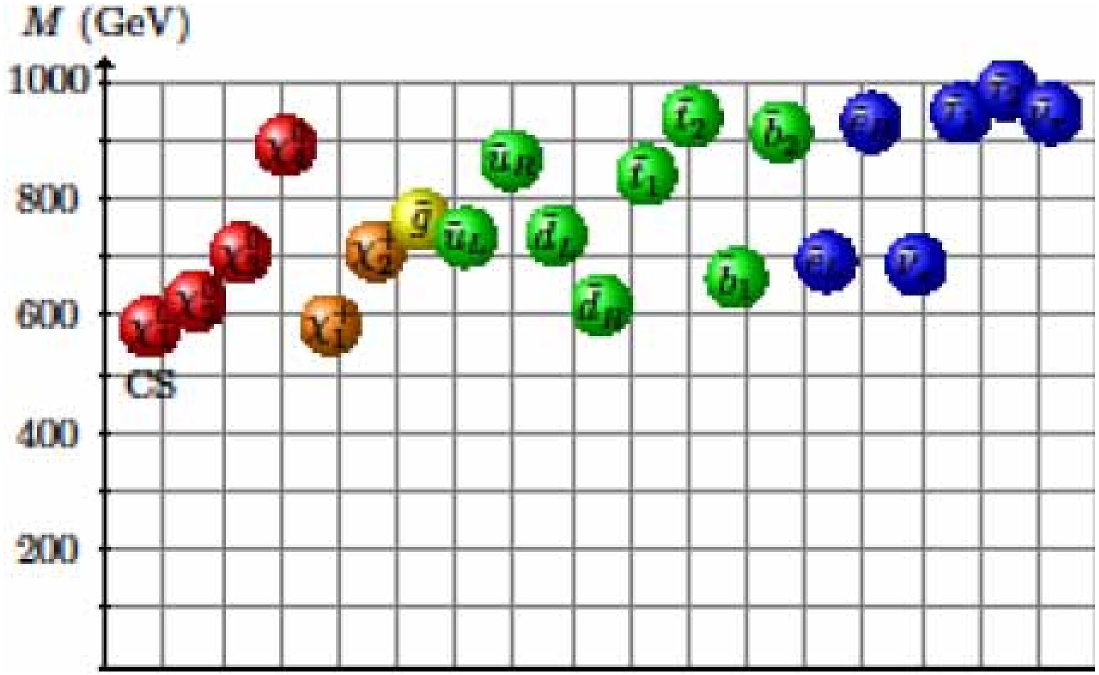
Example: Model 5700

ss: 3972
gg: 848.2
sg: 3840

number of events b/f cuts

→ d_R ,$(u,d)_L$ << g < u_R

- $u_R \rightarrow j + \chi_1^0$ (3%), χ_3^0 (22%), gluino (75%)
- gluino → j+ d_R (23%) , $(u,d)_L$ (76%)
- $u_L \rightarrow j + \chi_1^0$ (12%), $\chi_1^\pm$ (87%); $d_L \rightarrow j + \chi_1^0$ (66%), $\chi_1^\pm$ (32%);
- $d_R \rightarrow j + \chi_1^0$ (81%), χ_3^0 (18%); $\chi_3^0 \rightarrow h\, \chi_1^0$ (21%) , $W\, \chi_1^\pm$ (60%)
- $\chi_1^\pm \rightarrow W^*\, \chi_1^0$ ($\Delta m \sim 10.4$ GeV)



Example: Model 25692

ss: 4117
gg: 2168
sg: 9574

number of events b/f cuts

→ u_R > g > (u,d)$_L$, d_R

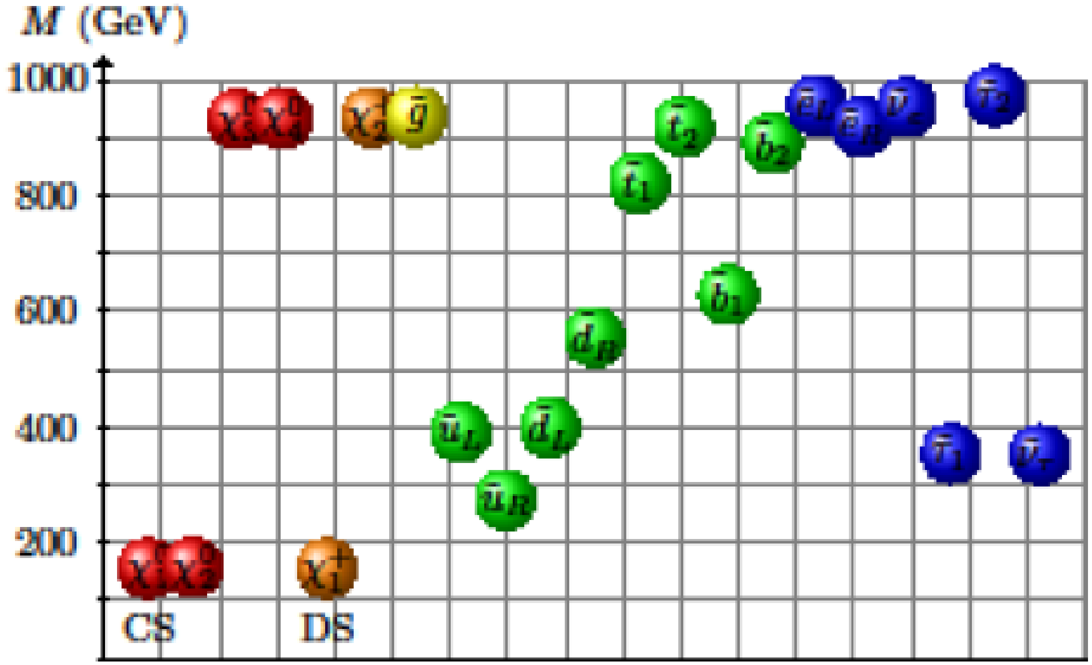
Note the compressed spectrum here leading to softer jets

- u_R (867) →j + gluino(763); gluino → j+ d_R (74%) , (u,d)$_L$ (7%)

- u_L (734) →j+ χ_1^0 (27%), $\chi_1^\pm$ (67%) [581,584] ;
- d_L (738) →j+ χ_1^0 (33%), $\chi_1^\pm$ (57%);

- d_R →j+ χ_1^0 ; $\chi_1^\pm$ → W* χ_1^0 (Δm ~ 3.8 GeV)

Note: Z_n ~4.2 for (2,4) j0l analyses



Example: Model 8829

ss: 5581
gg: 65.2
sg: 1727

number of events b/f cuts

$\rightarrow$ gg $\rightarrow$ss+2j , gs$\rightarrow$ss+j

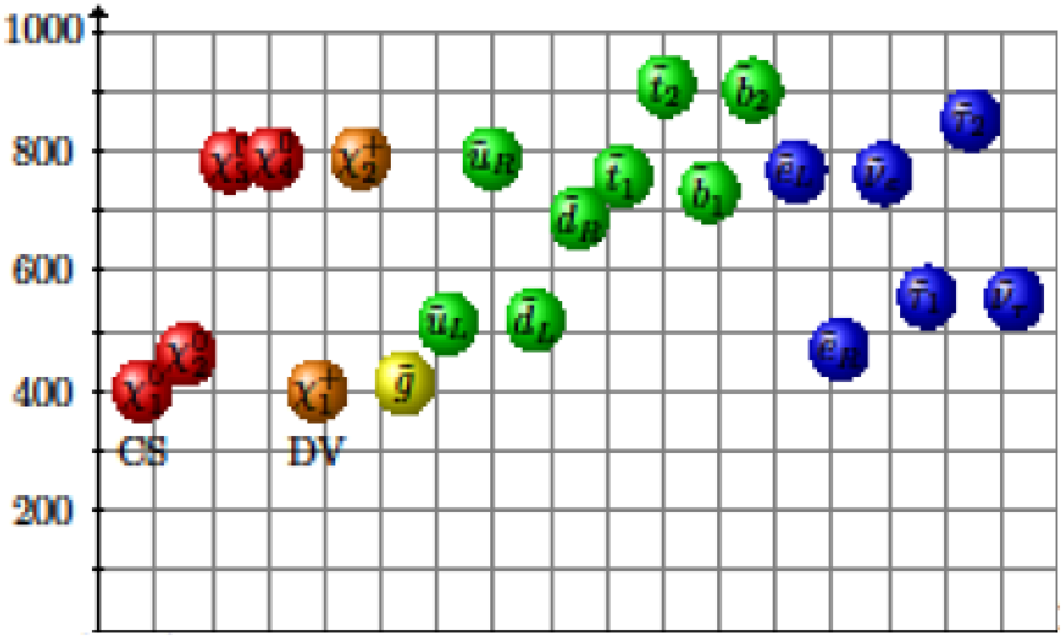
Signals depend on the very light winos & bino in the spectrum.
(Note $\chi^{\pm}_1$ are again detector stable)

•B(s$\rightarrow$j + MET) ~0.07-0.34 $\rightarrow$ (4,2)j0l rates which are too small

•B($s_R\rightarrow$j + χ_2^0) ~ 0.92 $\rightarrow$ χ_2^0 decays inside the detector to $\chi_1^{\pm}$ w/ $c\tau$~1 cm !

•B($s_L\rightarrow$j + $\chi_1^{\pm}$) ~ 0.66 $\rightarrow$ j+stable

Long-lived searches!!



Example: Model 15596

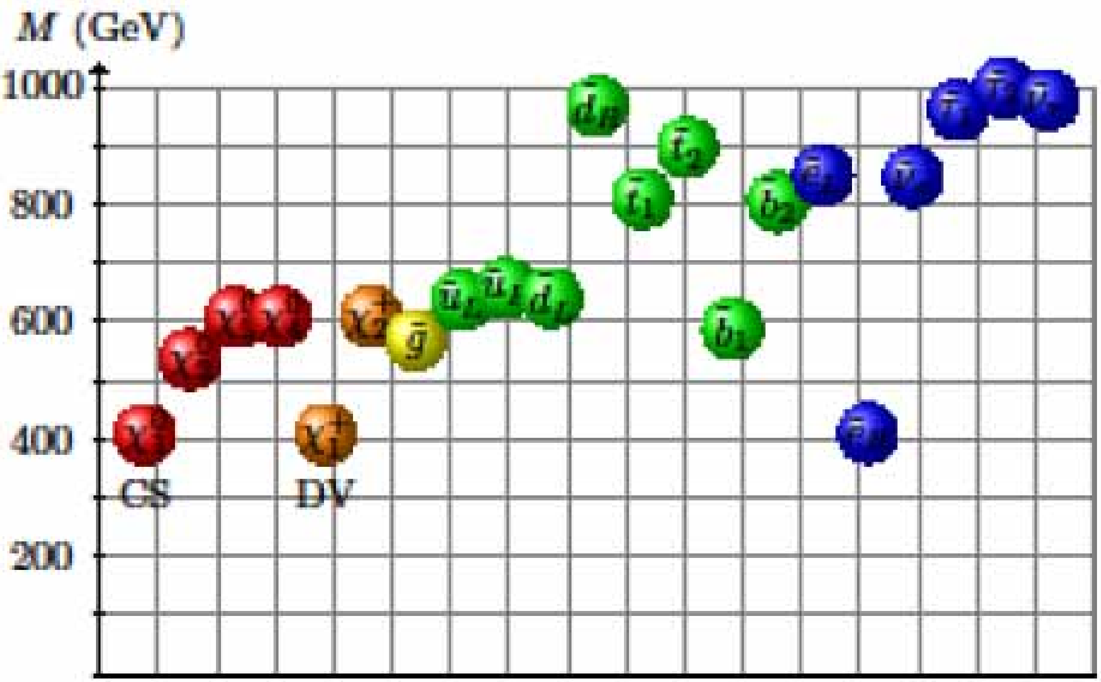
ss: 1823
gg: 13846
sg: 13006

HUGE number of events b/f cuts

→ ss→gg+2j, sg→gg+j

Signals: all squarks decay almost exclusively (~90%) to gluinos, with (~3%) to j + LSP & (~6%) to j + chargino. The squark-gluino mass splittings are in excess of 100 GeV. These generate a smallish 2j0l signal after cuts. Z_n ~4.4 in 2j0l

• The gluinos are nearly degenerate with the LSP , e.g., Δm=12.6 GeV, so their decays to jj+LSP or 'detector stable' charginos are too soft to populate 4j0l . Note that there are no significant sources of leptons, b's or τ's here. Stable particle searches are important in this case .



Example: Model 62828

ss: 914.2
gg: 2120
sg: 4280

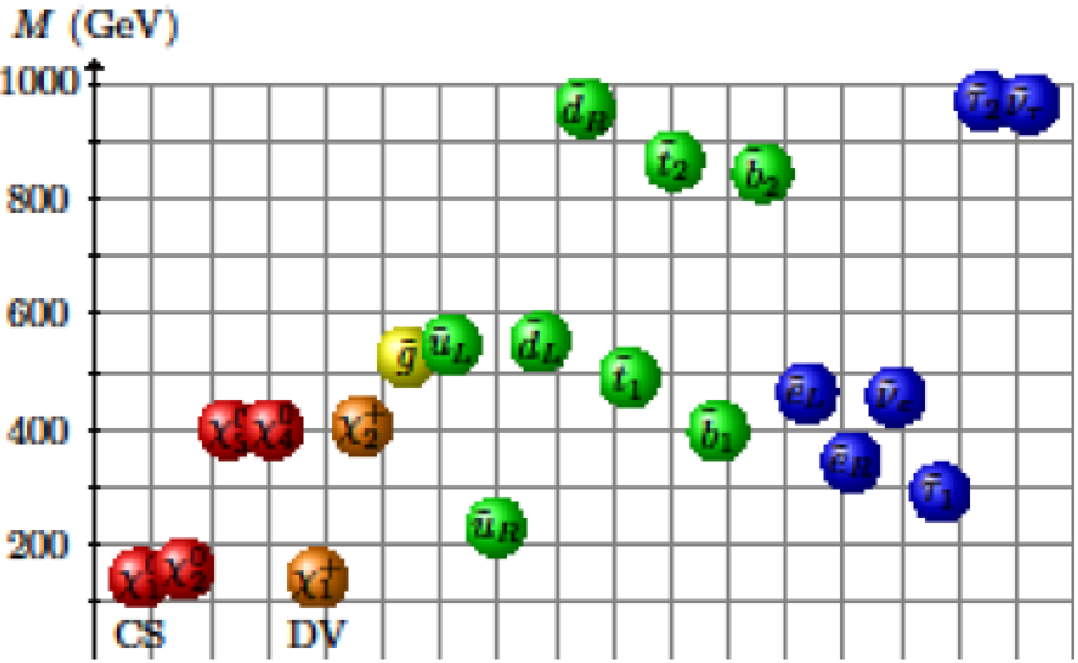
number of events b/f cuts

→ ss →gg+2j , gs→gg+j

Signals depend on the interplay of the gluino and weak gaugino mass spectra. (Note $\chi_1^\pm$ are 'just' detector stable, i.e, cτ ~25m with Δm=141.2 MeV)

- Squark decays to gluinos (B> 0.95 for s_R , ~0.4 for s_L) & somewhat hard jets, i.e., Δm >70 GeV . s_L have B~0.2 for j+MET, too small for (2,4)j0l searches, as well as B~0.4 for j+$\chi_1^\pm$ decays. Few hard b's and very few leptons or τ's.

- B(g→2j + MET) ~0.35, B(g→2j + $\chi_1^\pm$) ~0.65



Example: Model 42798

ss: 4767
gg: 764
sg: 4840

number of events b/f cuts

→ d_R >> $(u,d)_L$ >~ g >> u_R

A bit more complex than most but still killed by BFs

$\Delta m(d_R - g) \sim 420$ GeV, $\Delta m(u_L, d_L - g) \sim 20\text{-}25$ GeV,
$\Delta m(g - u_R) \sim 195$ GeV, $\Delta m(u_R - LSP) \sim 90$ GeV

- $c\tau(\chi_1^{\pm}) \sim 25$m; $\Delta m(\chi_2^0 - LSP) \sim 17$ GeV
- $\chi_2^0 \rightarrow (\gamma, Z^*) + LSP(\sim 5{,}25\%)$, $\rightarrow W^* + \chi_1^{\pm}(\sim 70\%)$

```
        PDG            Width
AY    1000002     6.10464679E+00   # sup_L decays
          BR         NDA      ID1       ID2
   3.04263153E-01    2      1000022         2    # BR(~u_L -> ~chi_10 u)
   1.77955300E-02    2      1000023         2    # BR(~u_L -> ~chi_20 u)
   8.96664783E-04    2      1000025         2    # BR(~u_L -> ~chi_30 u)
   1.99959783E-03    2      1000035         2    # BR(~u_L -> ~chi_40 u)
   6.43930277E-01    2      1000024         1    # BR(~u_L -> ~chi_1+ d)
   5.45923139E-04    2      1000037         1    # BR(~u_L -> ~chi_2+ d)
   3.05688535E-02    2      1000021         2    # BR(~u_L -> ~g      u)

        PDG            Width
AY    2000002     1.46507482E-01   # sup_R decays
          BR         NDA      ID1       ID2
   1.05051938E-03    2      1000022         2    # BR(~u_R -> ~chi_10 u)
   9.98949481E-01    2      1000023         2    # BR(~u_R -> ~chi_20 u)

        PDG            Width
AY    1000001     6.01058767E+00   # sdown_L decays
          BR         NDA      ID1       ID2
   3.19502731E-01    2      1000022         1    # BR(~d_L -> ~chi_10 d)
   5.54071069E-03    2      1000023         1    # BR(~d_L -> ~chi_20 d)
   1.44382012E-03    2      1000025         1    # BR(~d_L -> ~chi_30 d)
   3.35582851E-03    2      1000035         1    # BR(~d_L -> ~chi_40 d)
   6.07976276E-01    2     -1000024         2    # BR(~d_L -> ~chi_1- u)
   1.36988317E-02    2     -1000037         2    # BR(~d_L -> ~chi_2- u)
   4.84818017E-02    2      1000021         1    # BR(~d_L -> ~g      d)

        PDG            Width
AY    2000001     3.05842014E+01   # sdown_R decays
          BR         NDA      ID1       ID2
   1.29360144E-05    2      1000022         1    # BR(~d_R -> ~chi_10 d)
   1.68826930E-02    2      1000023         1    # BR(~d_R -> ~chi_20 d)
   5.06488508E-05    2      1000025         1    # BR(~d_R -> ~chi_30 d)
   1.41365858E-04    2      1000035         1    # BR(~d_R -> ~chi_40 d)
   9.82912356E-01    2      1000021         1    # BR(~d_R -> ~g      d)
```

u_L decays to :

g +j (~3%)

LSP +j (~30%)

$\chi_1^\pm$ +j (~64%)

u_R decays to χ_2^0 +j

d_L decays to :

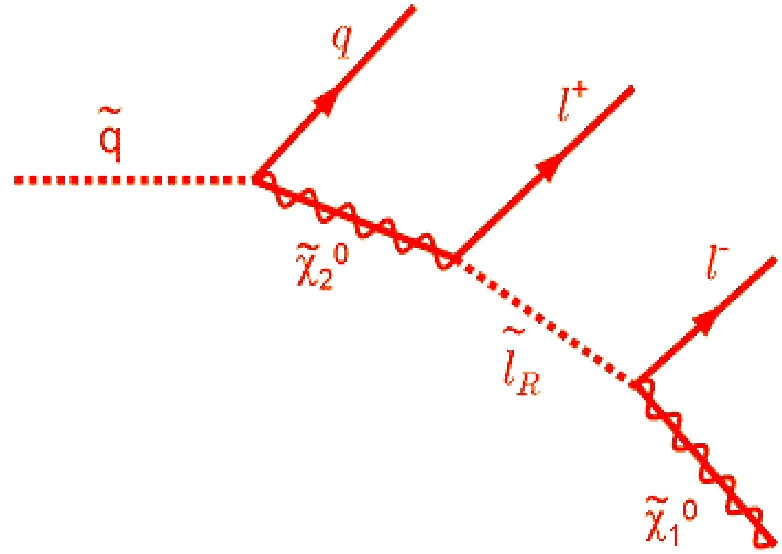
g +j (~5%)

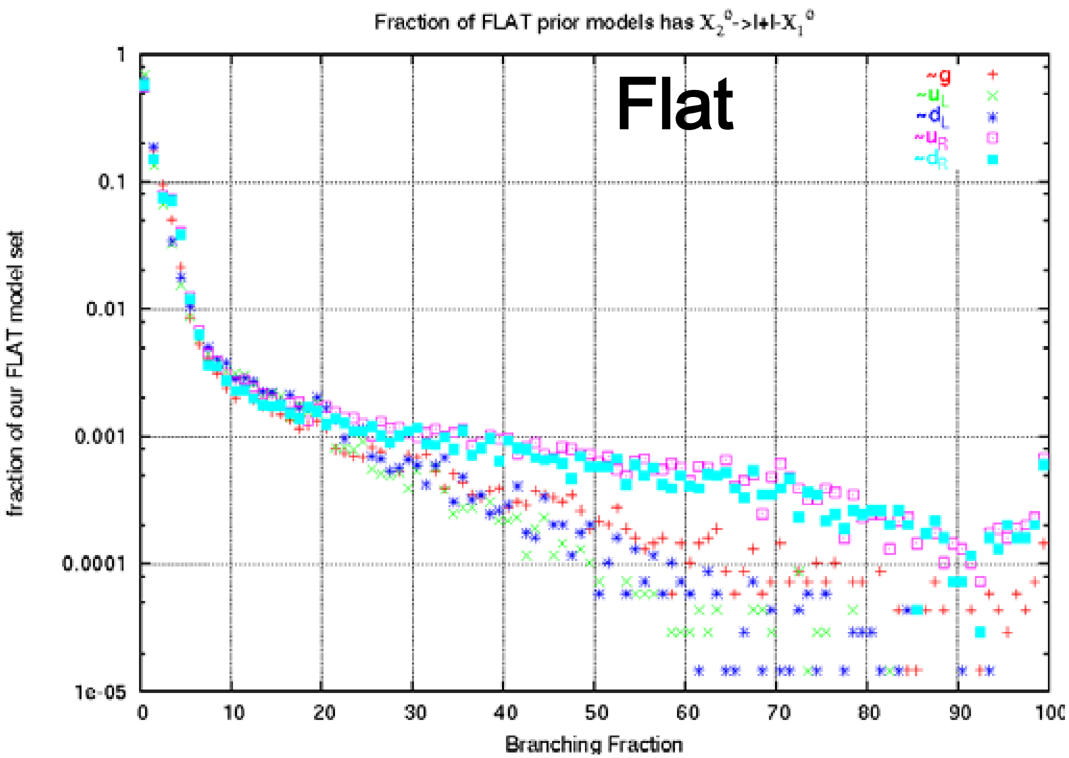
LSP +j (~32%)

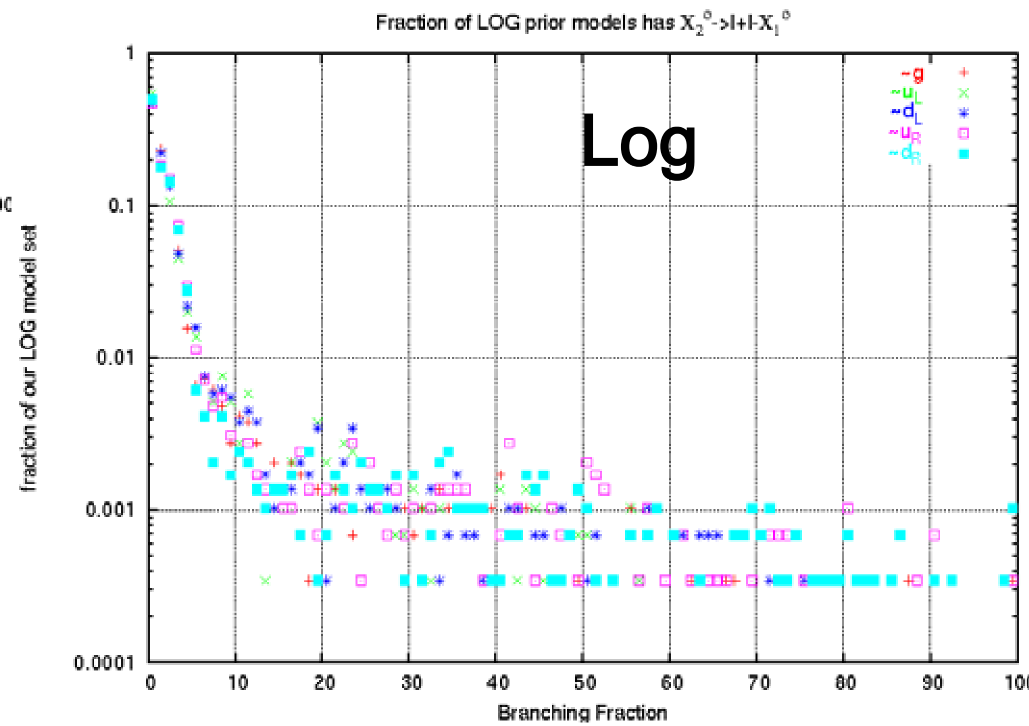
$\chi_1^\pm$ +j (~61%)

d_R decays to g +j

How often do these 'famous' decay chains actually occur??



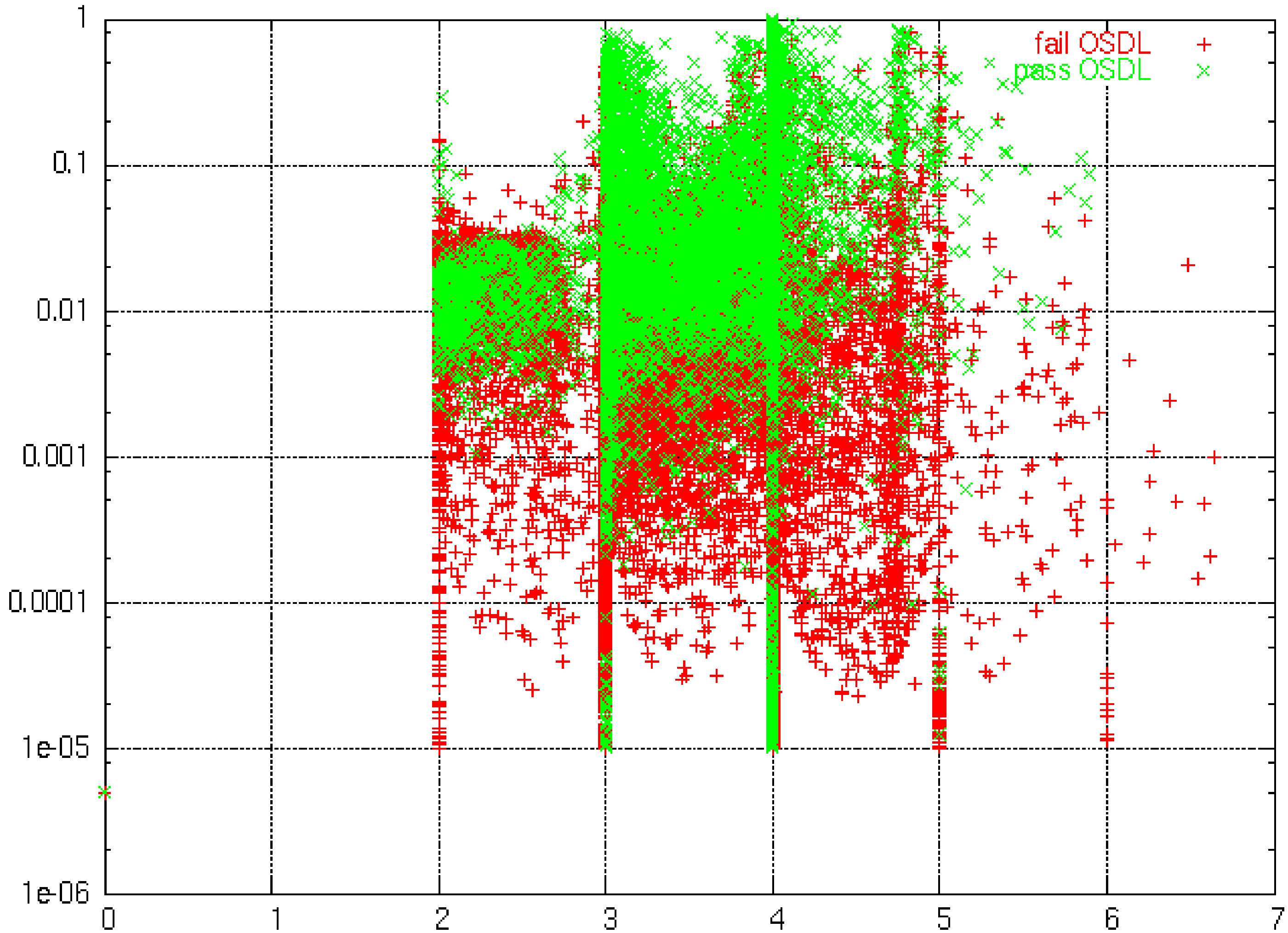




It appears that this is not GENERALLY a common mode

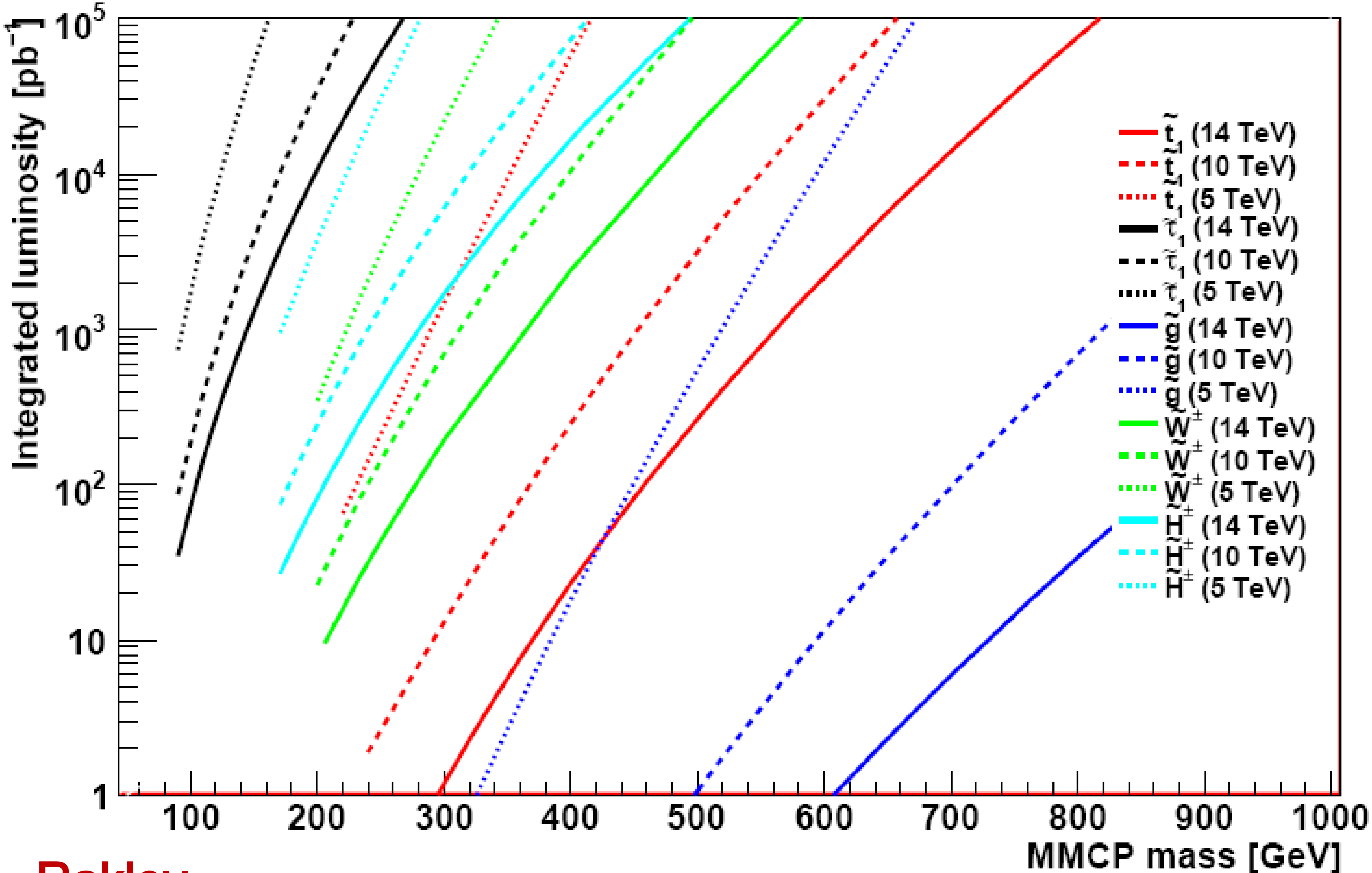
Gluino initiated cascades leading to X $l^+ l^-$ MET

Inclusive Branching fraction



BF-weighted number of steps in decay chain

Stable SUSY Searches at LHC



A. Raklev

Long Lived/Stable Sparticles in the 71k Sample with $c\tau > 20$m

→ 9462 (97,1) models w/ one (2,3) long-lived particle(s) !

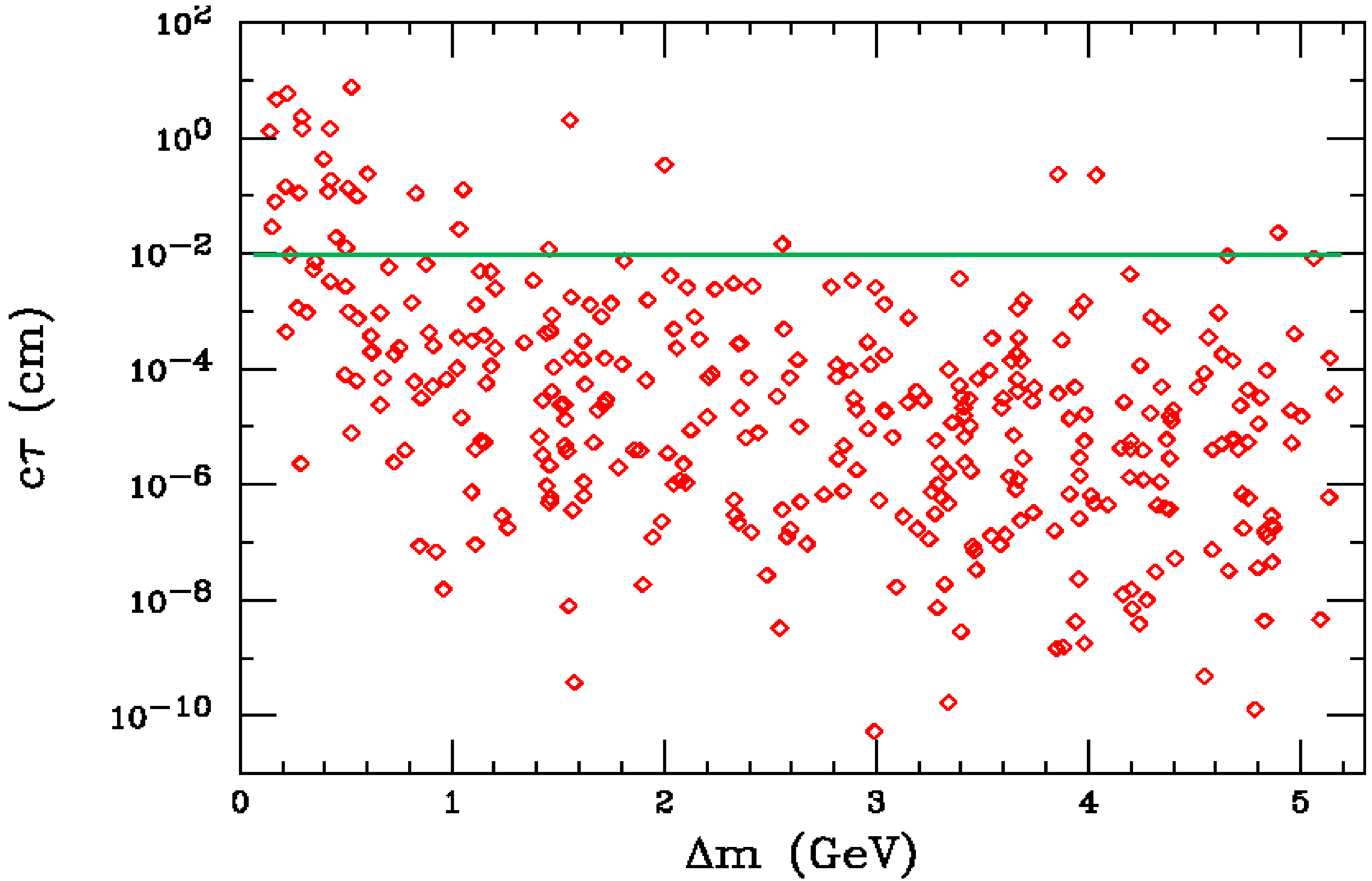
- 8982 are lightest charginos
- 20 are second neutralinos
- 338 are sbottom_1's
- 179 are stau_1's
- 61 are stops
- 5 are gluinos
- 49 are c_R
- 17 are μ_R
- 8 are c_L

etc.

Particles with $c\tau > 20$m will be declared 'detector stable' in our analysis

NB: 4-body & CKM suppressed loop decays, e.g., $\tilde{b}_1 \to b^* (s,d) +$ LSP are missing , i.e., $\Delta m < m_{bottom}$ from SUSY-HIT

$\tilde{b}_1 \rightarrow s,d$ + LSP induced decay lengths for $\Delta m < m_b$



Semi-Stable Sparticles in the 71k Sample with 200 μm < $c\tau$ < 20m

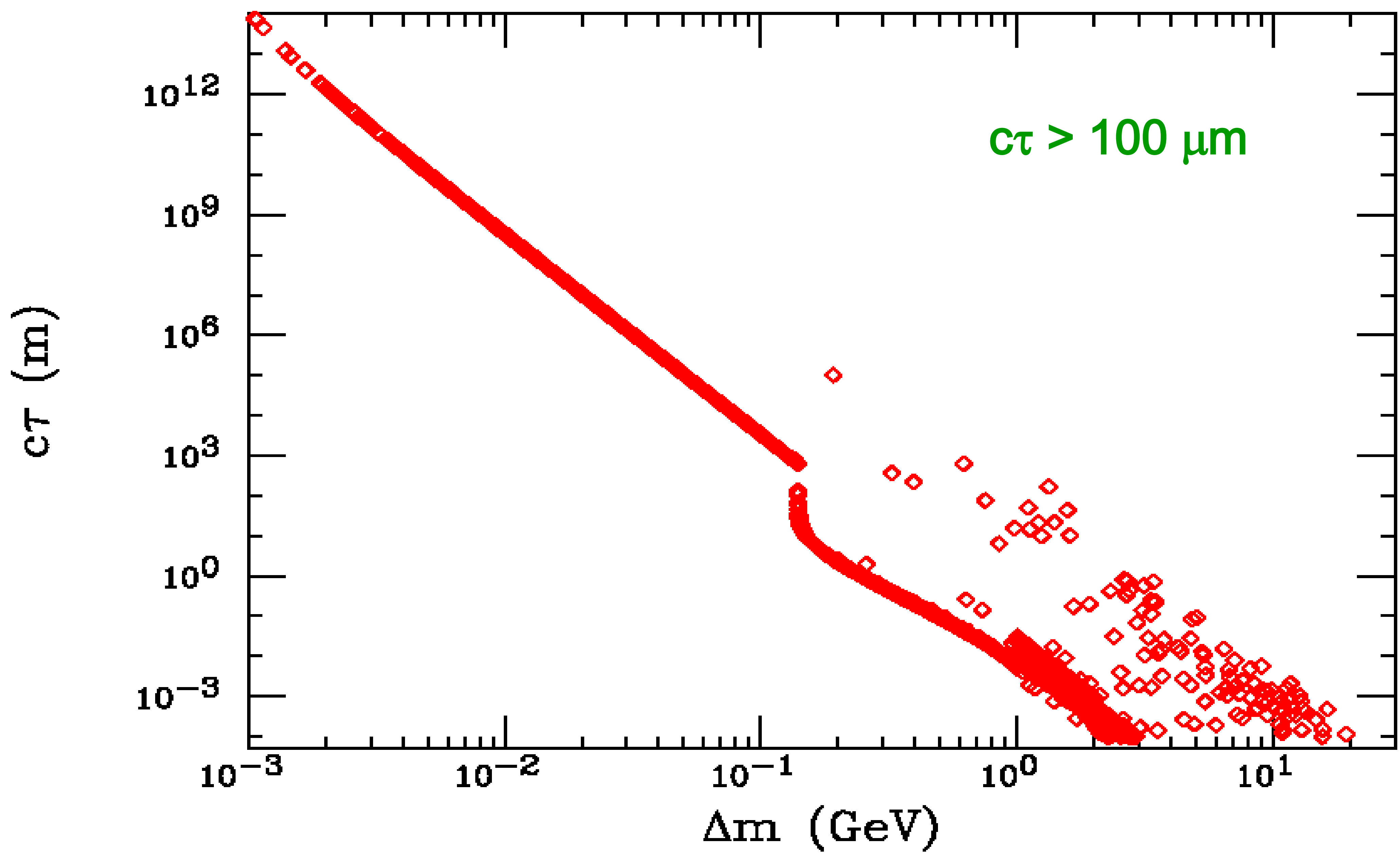
- 8326 models with at least 1 semi-stable state
- 344 (14) have 2 (3) of them

- 8187 are charginos
- 724 are second neutralinos
- 44 are stops
- 90 are gluinos
- 8 are c_L
- 6 are c_R
- 6 are d_R (s_R)

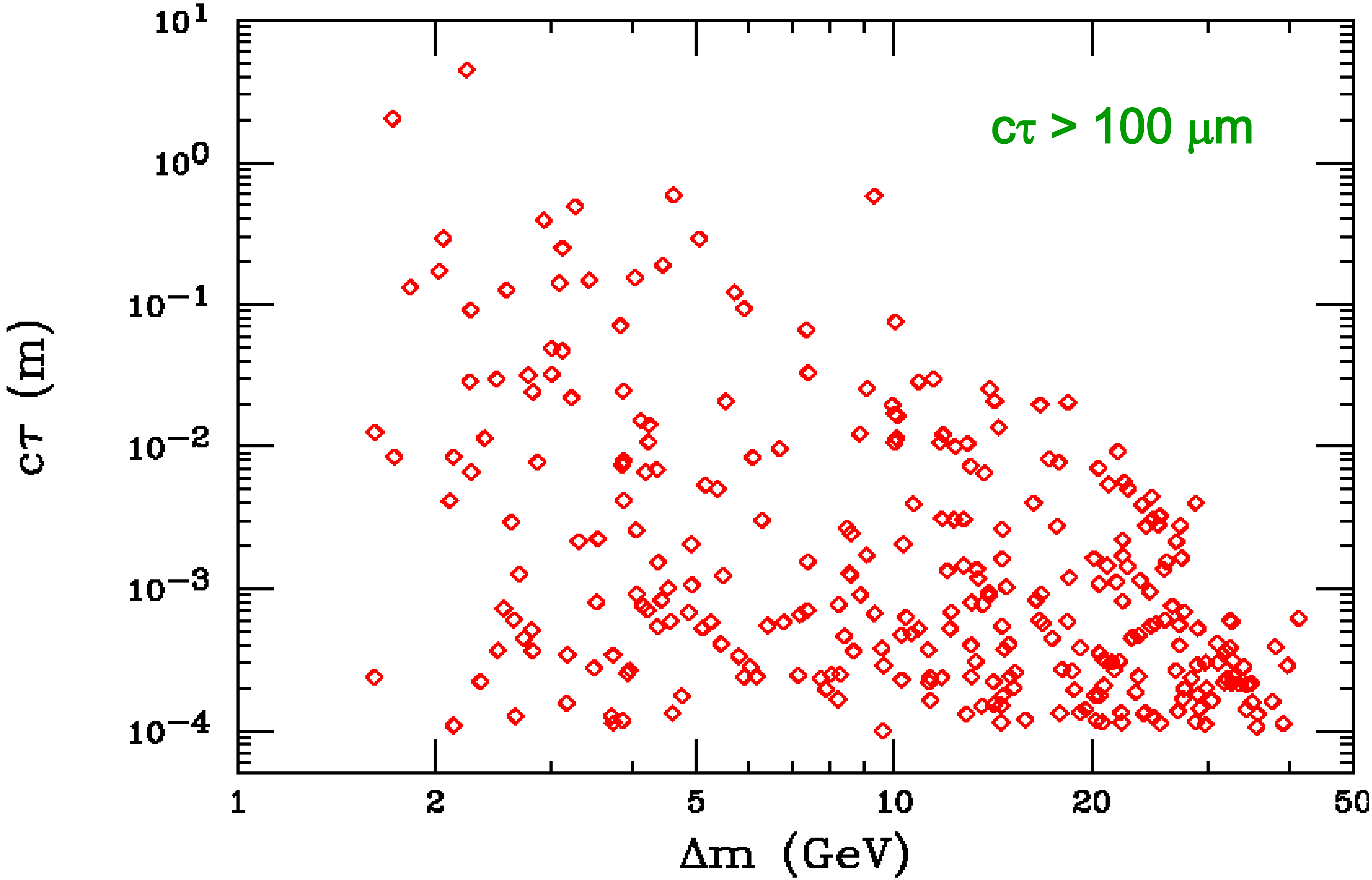
etc.

Particles decaying inside the detector will require some special analyses to study but will likely not be seen by inclusive SUSY searches since their decay products are very soft.

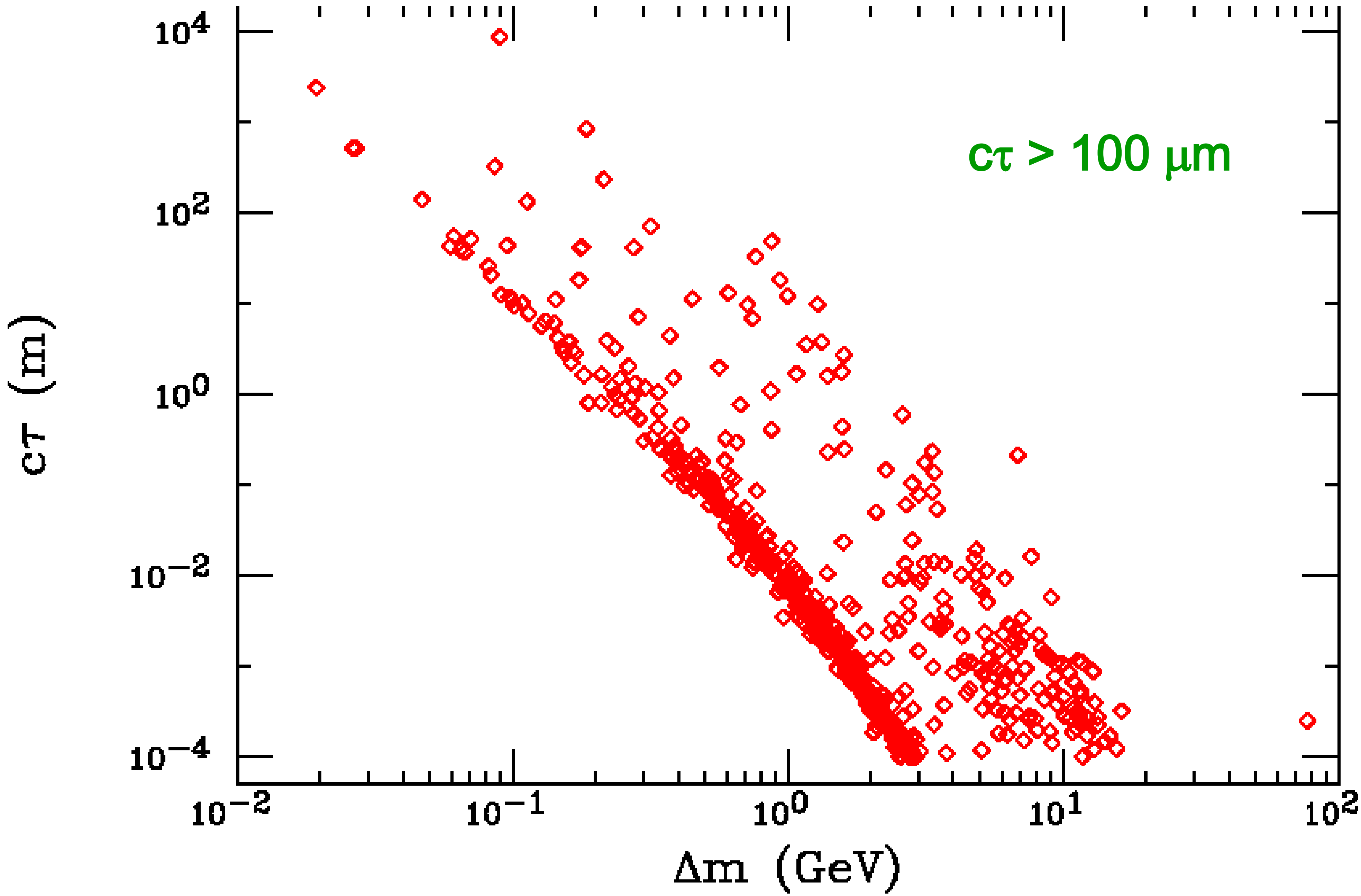
Example: Long-Lived Charginos



Example: Detector Decaying Stops



Example: Long-Lived χ_2^0 s



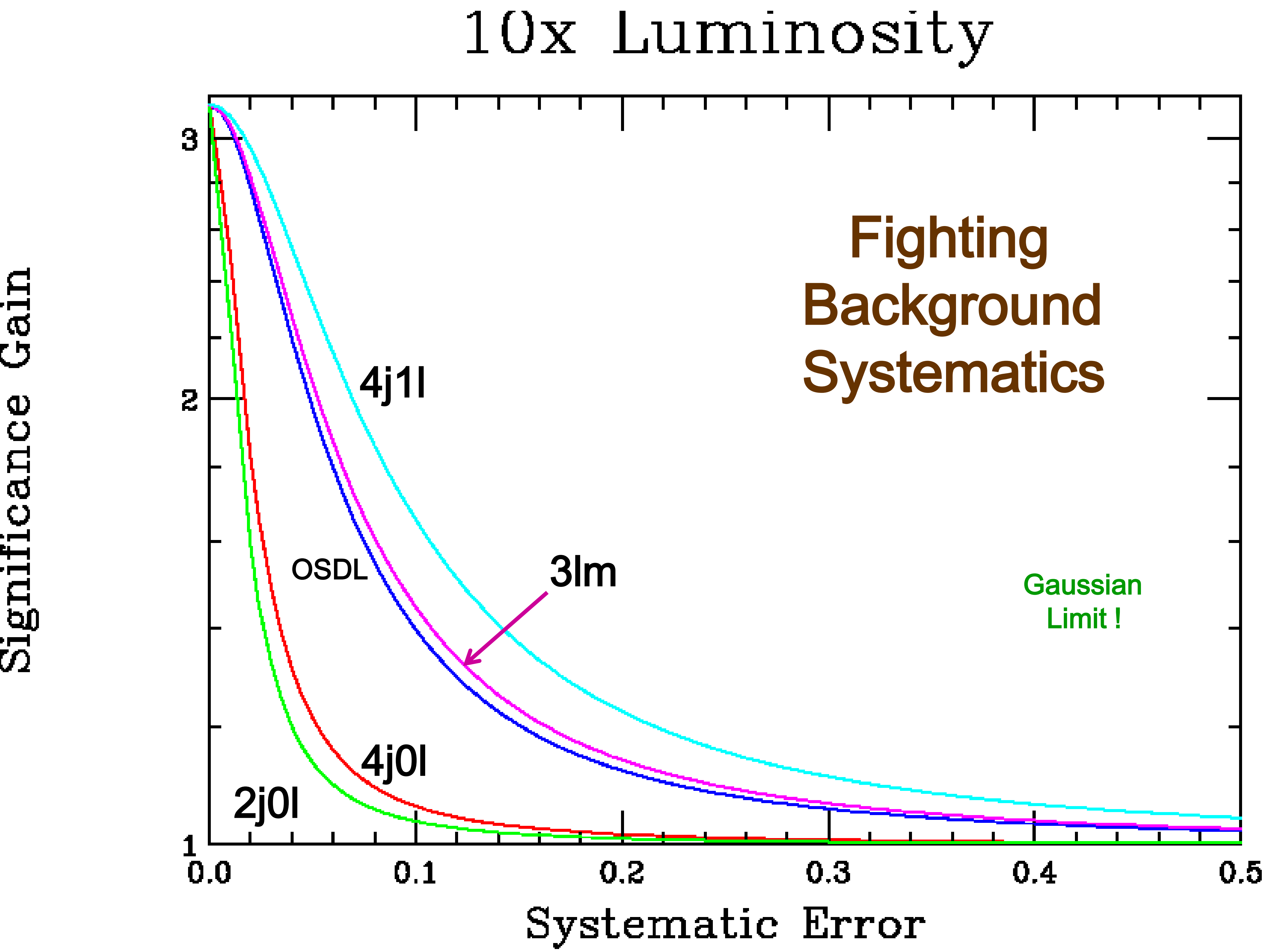
What Next ?

- Obtain & understand more of the details of the 14 TeV case. We have an *enormous* volume of data to look at…
- Examine the 7 TeV case… BUT not yet! While we have the ATLAS background data for 10 TeV, the 7 TeV results are not yet available as they are currently being generated. It would be nice to do this study soon !
- It may be interesting to do a similar analysis to this for other SUSY setups, e.g., the case of the gravitino LSP or…
- Dark matter analyses are ongoing(e.g., Ice Cube)

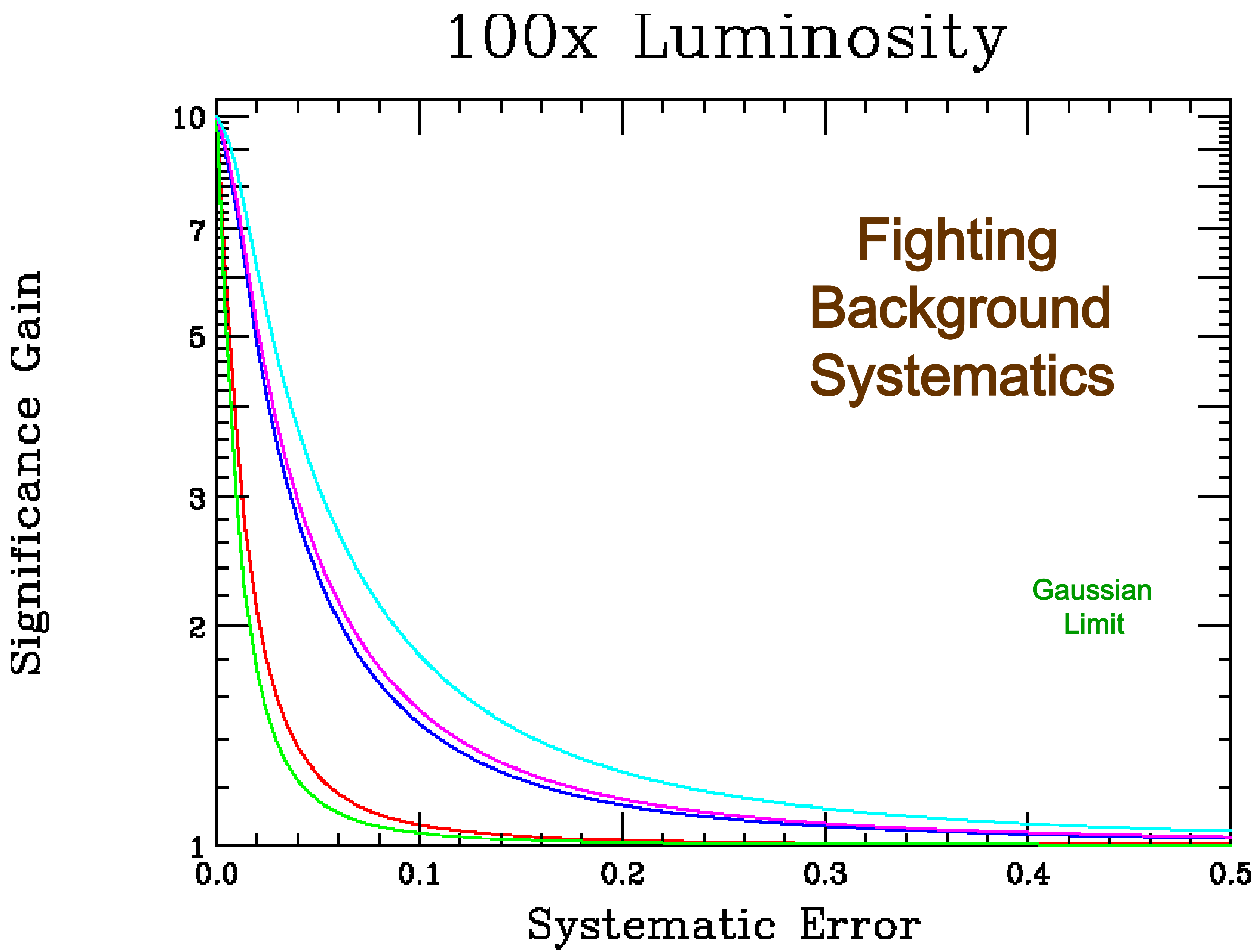
Summary

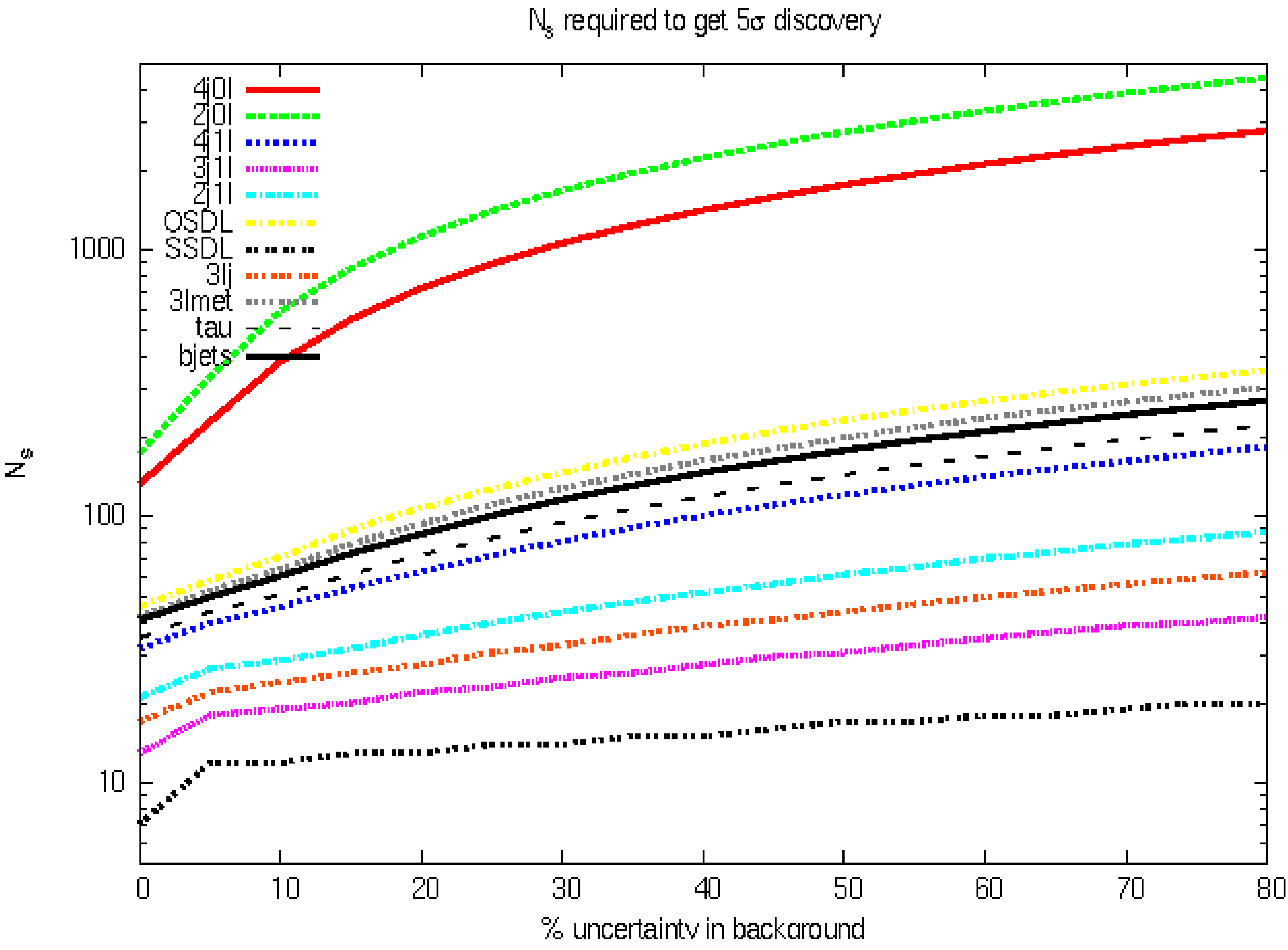
- The pMSSM has a far richer phenomenology than any of the conventional SUSY breaking scenarios. The sparticle properties can be vastly different, e.g., the nLSP can be any other sparticle!
- Light partners can exist which have avoided LEP & Tevatron constraints and may also be difficult to observe at the LHC due to small mass differences or squirky spectra
- Substantial SM background systematics, compressed mass spectra & processes with low signal rates due to unusual decays lead to models being missed by the inclusive analyses.
- Long-lived particle searches are important.
- The study of the complexities of these models is ongoing.

BACKUP SLIDES



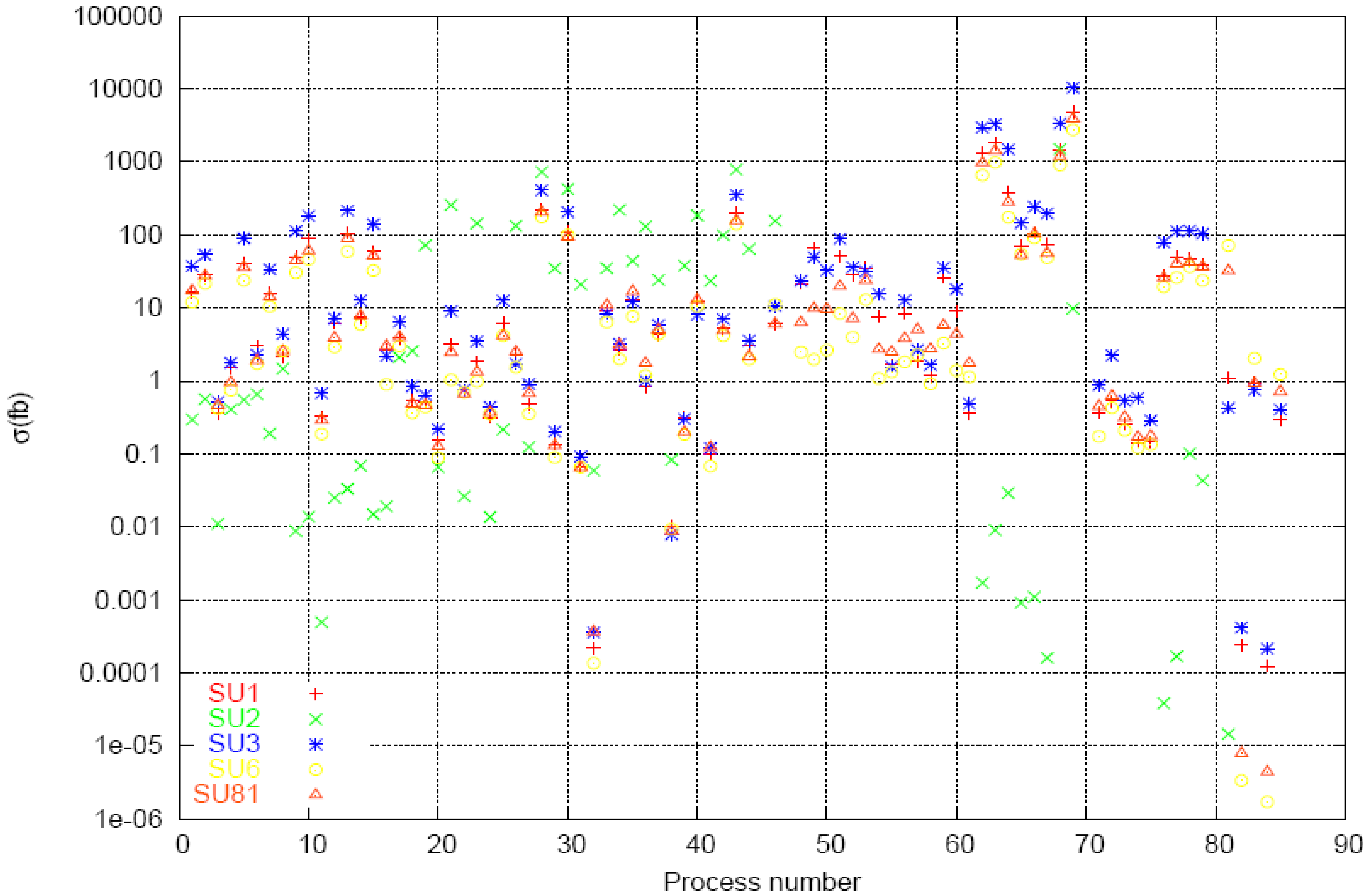
10x Luminosity
Fighting Background Systematics
4j1l
3lm
OSDL
4j0l
2j0l
Gaussian Limit !
Significance Gain
Systematic Error
3
2
1
0.0
0.1
0.2
0.3
0.4
0.5


100x Luminosity
Significance Gain
10
7
5
3
2
1
0.0
0.1
0.2
0.3
0.4
0.5
Systematic Error
Fighting
Background
Systematics
Gaussian
Limit



N_s required to get 5σ discovery
4j0l
2j0l
4j1l
3j1l
2j1l
OSDL
SSDL
3lj
3lmet
tau
bjets
1000
100
10
N_s
0
10
20
30
40
50
60
70
80
% uncertainty in background

Benchmark Model Process Cross Sections



4 jet, 0 lepton analysis

1. At least four jets with $p_T > 50$ GeV, at least one of which must have $p_T > 100$ GeV; and $E_T^{\rm miss} >$ 100 GeV
2. $E_T^{\rm miss} > 0.2 M_{\rm eff}$
3. Transverse sphericity $S_T > 0.2$
4. $\Delta\phi$ between each of three hardest jets and $E_T^{\rm miss}$ must be greater than 0.2
5. Reject events with an electron or muon.

3 jet, 0 lepton analysis

1. At least three jets with $p_T > 100$ GeV, at least one of which must have $p_T > 150$ GeV; and $E_T^{\rm miss} >$ 100 GeV
2. $E_T^{\rm miss} > 0.25 M_{\rm eff}$
3. $\Delta\phi$ between each of three hardest jets and $E_T^{\rm miss}$ must be greater than 0.2
4. Reject events with an electron or muon.

2 jet, 0 lepton analysis

1. At least two jets with $p_T > 100$ GeV, at least one of which must have $p_T > 150$ GeV; and $E_T^{\rm miss} >$ 100 GeV
2. $E_T^{\rm miss} > 0.3 M_{\rm eff}$
3. $\Delta\phi$ between each of two hardest jets and $E_T^{\rm miss}$ must be greater than 0.2
4. Reject events with an electron or muon.

One lepton, 4 jet analysis

1. Exactly one isolated electron or muon.
2. No additional leptons with $p_T > 10$ GeV.
3. At least four jets with $p_T > 50$ GeV, at least one of which must have $p_T > 100$ GeV
4. $E_T^{\text{miss}} >$ 100 GeV and $E_T^{\text{miss}} > 0.2M_{\text{eff}}$
5. Transverse sphericity $S_T > 0.2$
6. Tranverse mass $M_T > 100$ GeV
7. Reject events with an electron or muon.

One lepton, 3 jet analysis

1. Exactly one isolated electron or muon.
2. No additional leptons with $p_T > 10$ GeV.
3. At least three jets with $p_T > 100$ GeV, at least one of which must have $p_T > 150$ GeV
4. $E_T^{\text{miss}} >$ 100 GeV and $E_T^{\text{miss}} > 0.25M_{\text{eff}}$
5. Transverse sphericity $S_T > 0.2$
6. Tranverse mass $M_T > 100$ GeV
7. Reject events with an electron or muon.

One lepton, 2 jet analysis

1. Exactly one isolated electron or muon.
2. No additional leptons with $p_T > 10$ GeV.
3. At least two jets with $p_T > 100$ GeV, at least one of which must have $p_T > 150$ GeV
4. $E_T^{\text{miss}} >$ 100 GeV and $E_T^{\text{miss}} > 0.3M_{\text{eff}}$
5. Transverse sphericity $S_T > 0.2$
6. Tranverse mass $M_T > 100$ GeV
7. Reject events with an electron or muon.

OSDL analysis

1. Two opposite-sign leptons with $p_T > 10$ GeV and $|\eta| < 2.5$; no additional leptons
2. At least four jets with $p_T > 50$ GeV, at least one of which must have $p_T > 100$ GeV
3. $E_T^{\rm miss} >$ 100 GeV and $E_T^{\rm miss} > 0.2 M_{\rm eff}$
4. Transverse sphericity $S_T > 0.2$

SSDL analysis

1. Exactly two same-sign leptons with $p_T > 20$ GeV
2. At least four jets with $p_T > 50$ GeV, at least one of which must have $p_T > 100$ GeV
3. $E_T^{\rm miss} >$ 100 GeV
4. $E_T^{\rm miss} > 0.2 M_{\rm eff}$

Trilepton + jet analysis

1. At least three leptons with $p_T > 10$ GeV
2. At least one jet with $p_T > 200$ GeV

Trilepton + $E_T^{\rm miss}$ analysis

1. At least three leptons with $p_T > 10$ GeV
2. At least one OSSF dilepton pair with $M > 20$ GeV
3. Lepton track isolation: less than 1 (2) GeV maximum p_T of any track within $\Delta R < 0.2$ of a muon (electron).
4. $E_T^{\rm miss} >$ 30 GeV
5. $M < M_Z - 10$ GeV for any OSSF dilepton pair

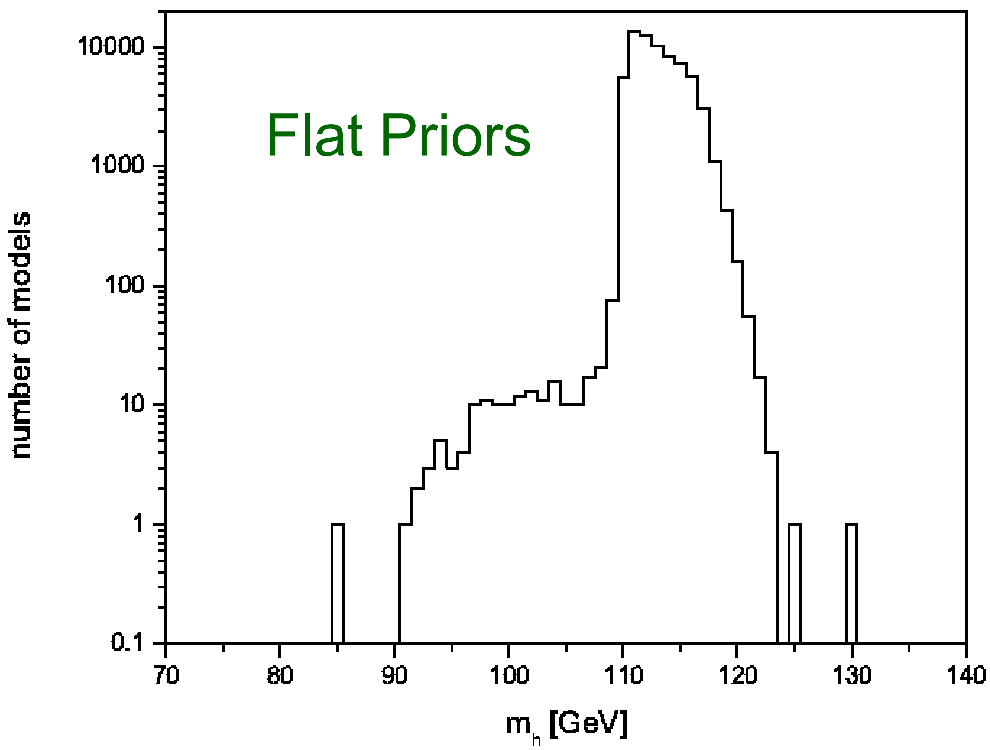
τ analysis

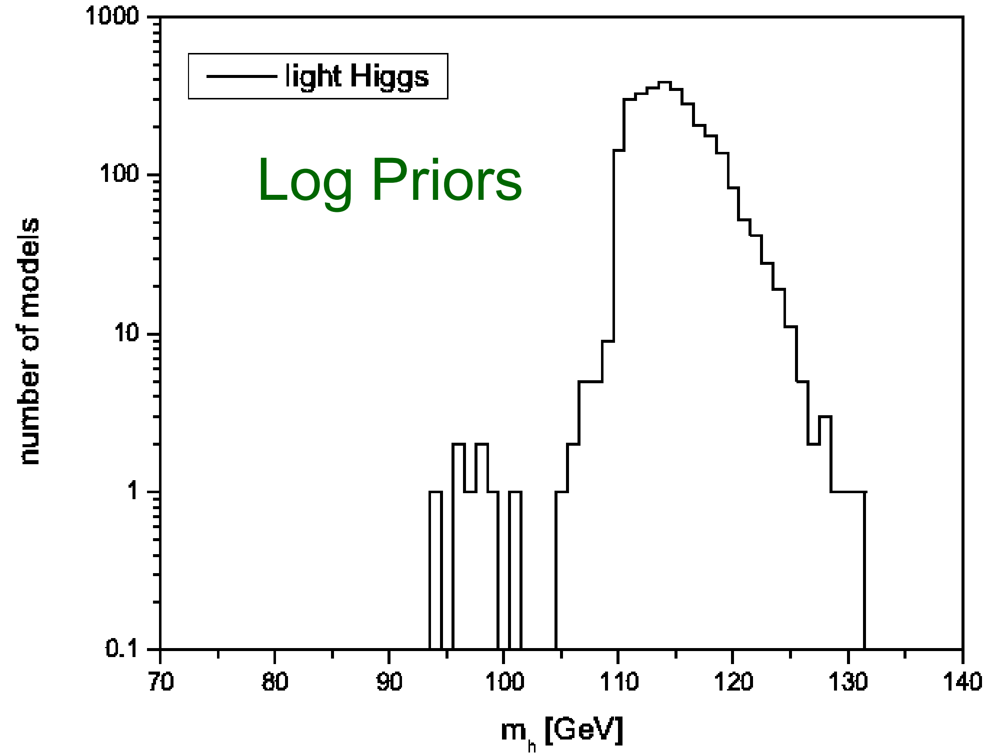
1. At least four jets with $p_T > 50$ GeV, at least one of which must have $p_T > 100$ GeV
2. $E_T^{\rm miss} >$ 100 GeV
3. $\Delta\phi$ between each of three hardest jets and $E_T^{\rm miss}$ must be greater than 0.2
4. Reject events with an electron or muon.
5. At least one τ with $p_T > 40$ GeV and $|\eta| < 2.5$
6. $E_T^{\rm miss} > 0.2 M_{\rm eff}$
7. Tranverse mass $M_T > 100$ GeV, using the hardest τ and $E_T^{\rm miss}$

b -jet analysis

1. At least four jets with $p_T > 50$ GeV
2. at least one of which must have $p_T > 100$ GeV
3. $E_T^{\rm miss} >$ 100 GeV
4. $E_T^{\rm miss} > 0.2 M_{\rm eff}$
5. Transverse sphericity $S_T > 0.2$
6. At least two jets tagged as b -jets

Light Higgs Mass Predictions

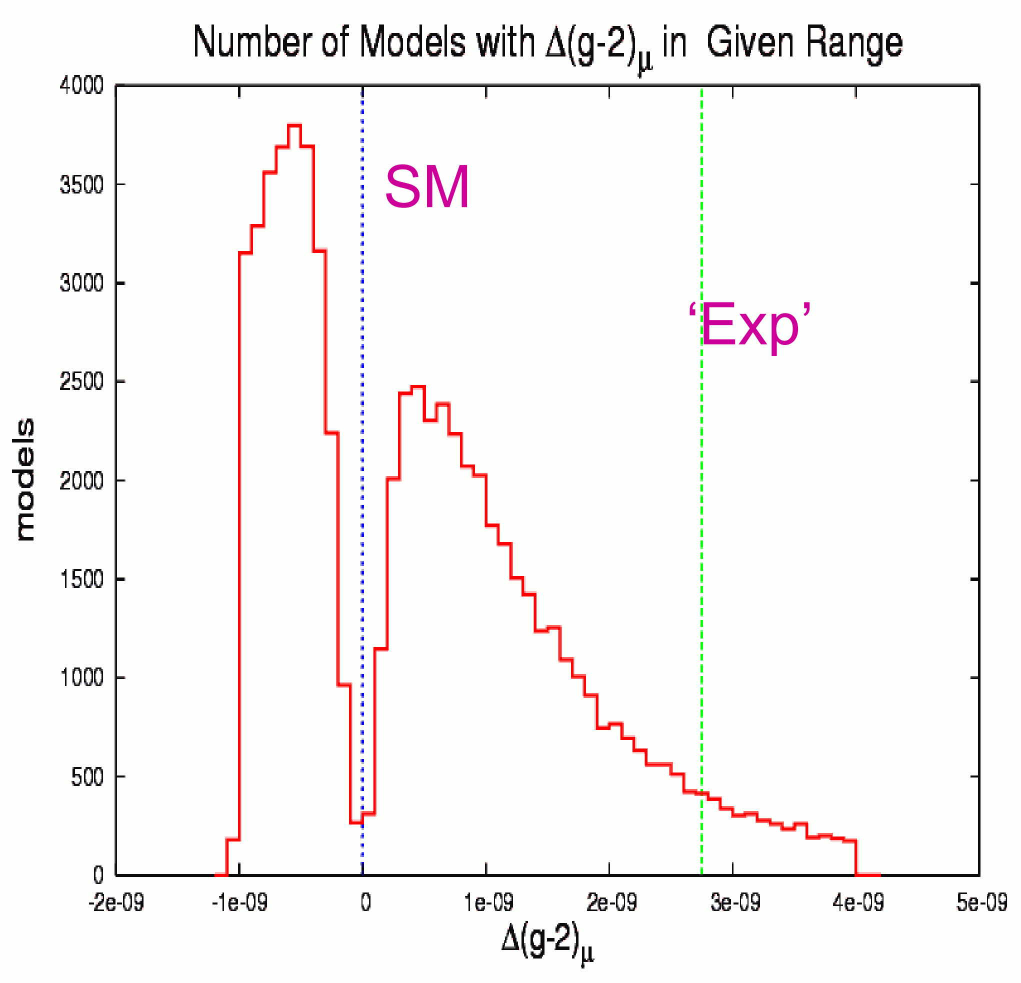




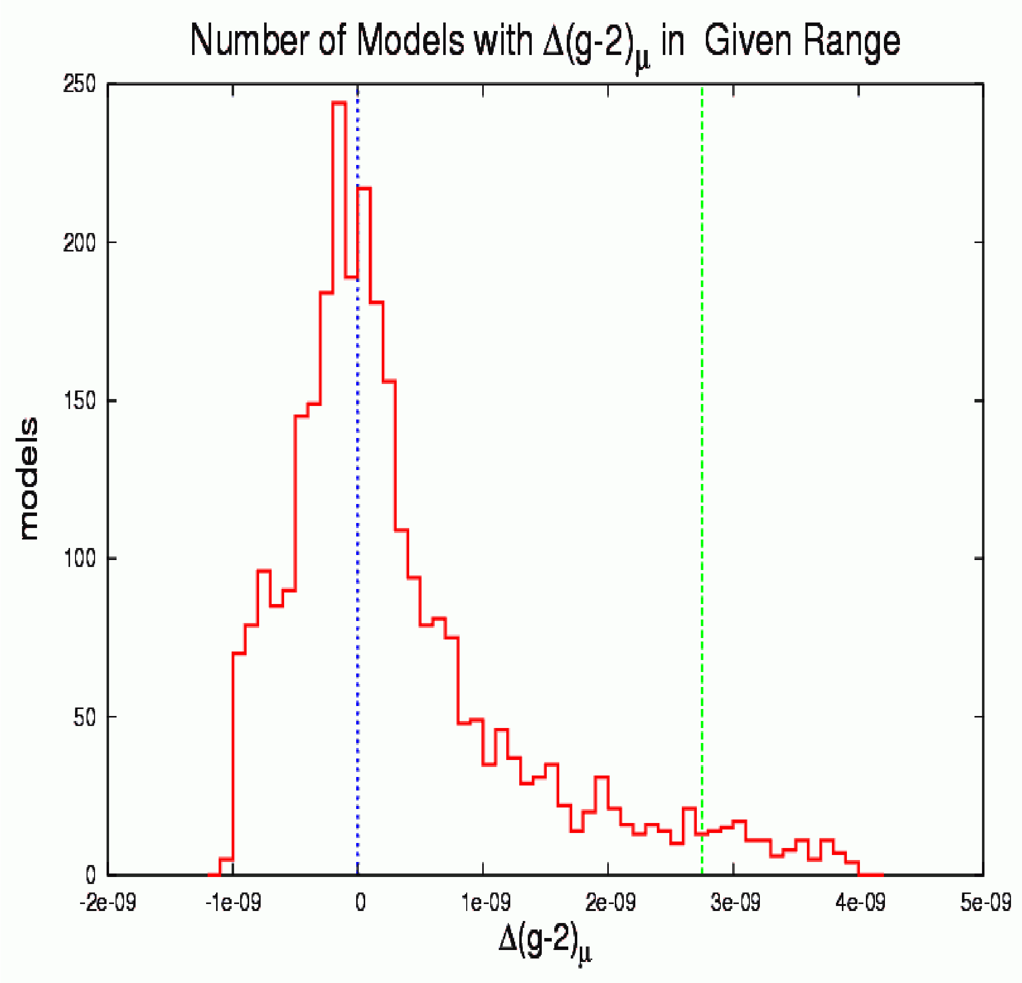
LEP Higgs mass constraints avoided by either reducing the ZZh coupling and/or reducing the, e.g., $h \rightarrow b\bar{b}$ branching fraction by decays to LSP pairs. We have both of these cases in our final model sets.

Predictions for $\Delta(g-2)_\mu$

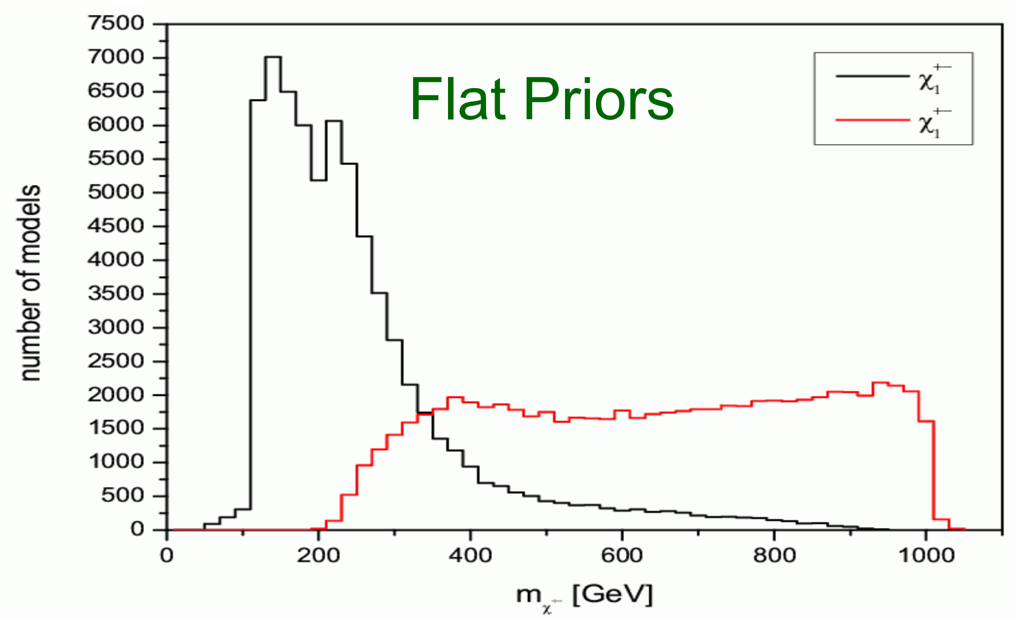
flat

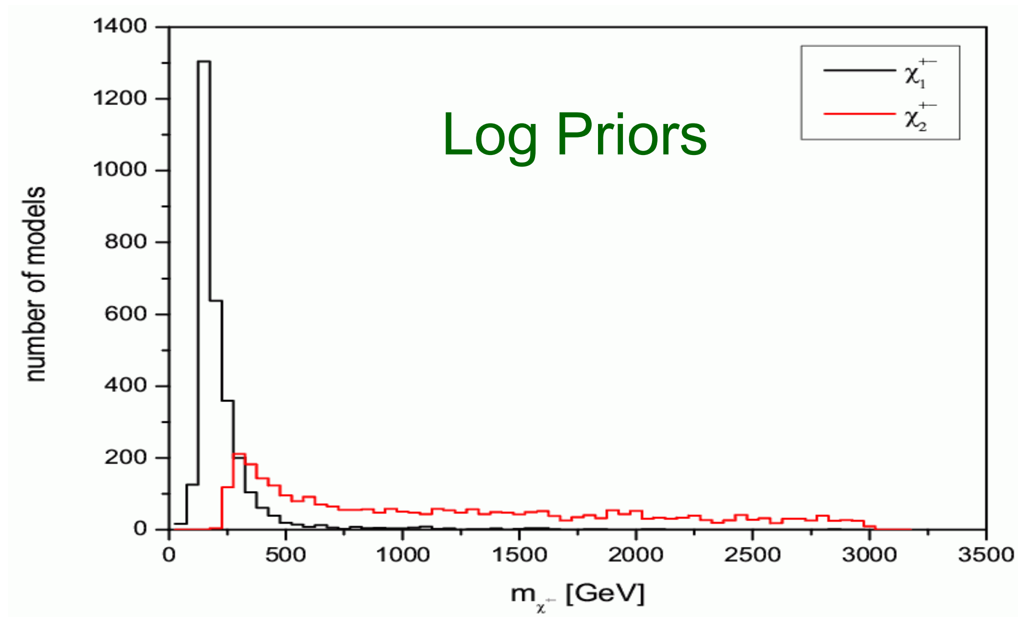


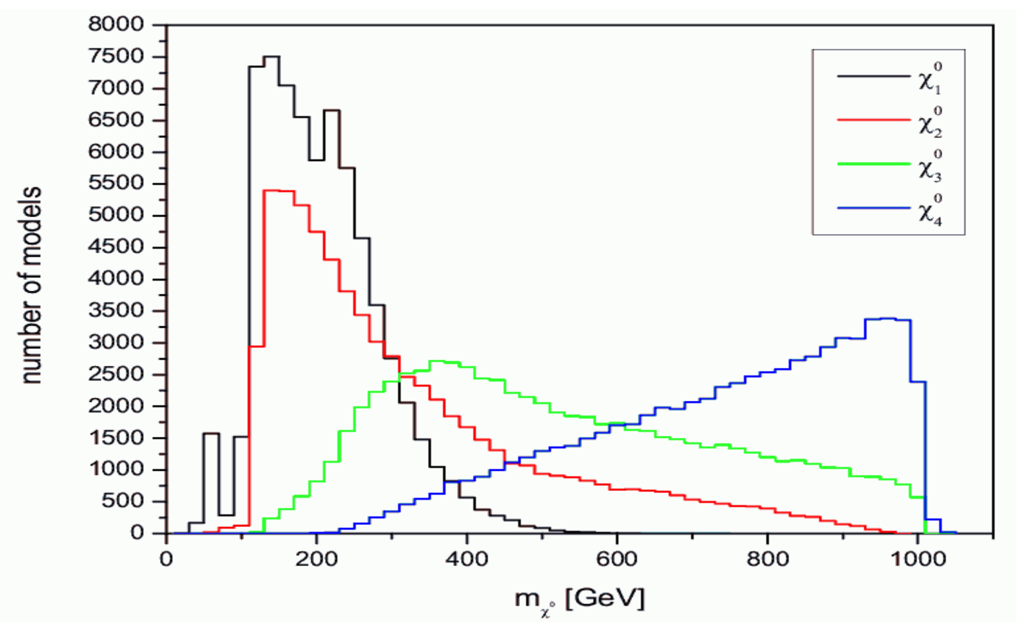
log

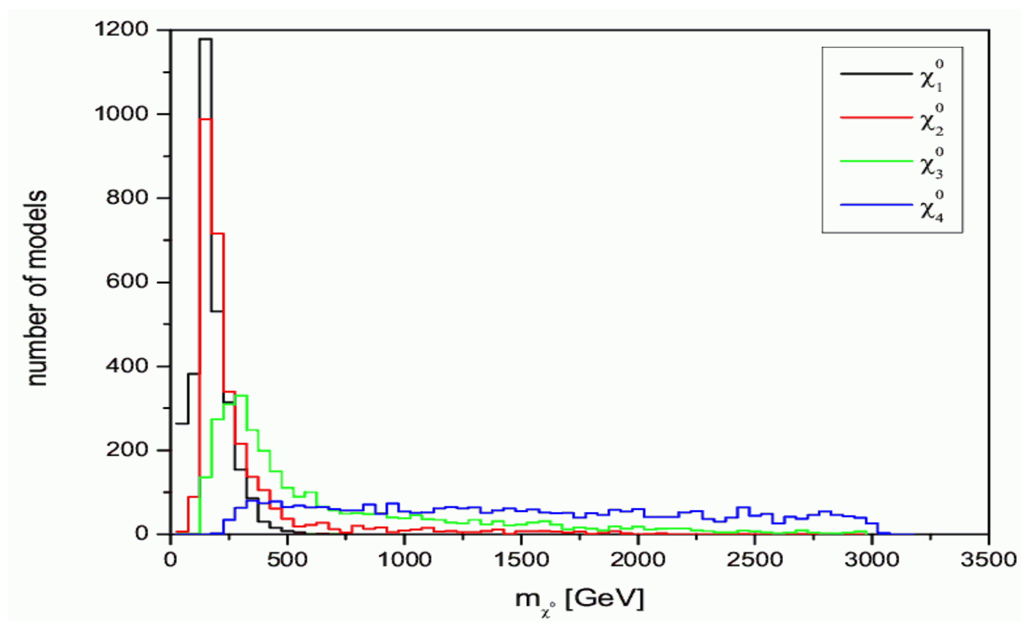


Distribution of Sparticle Masses By Species



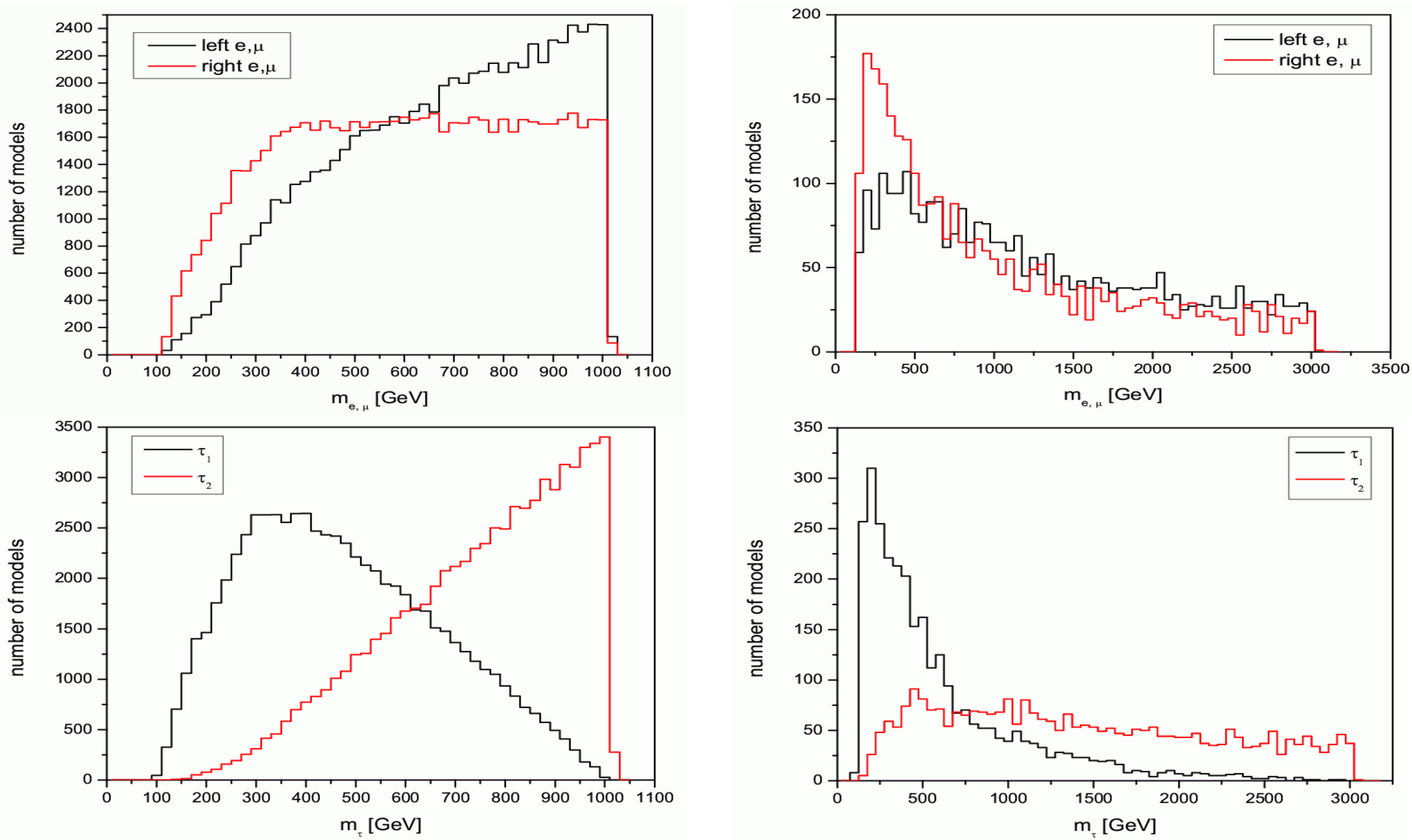




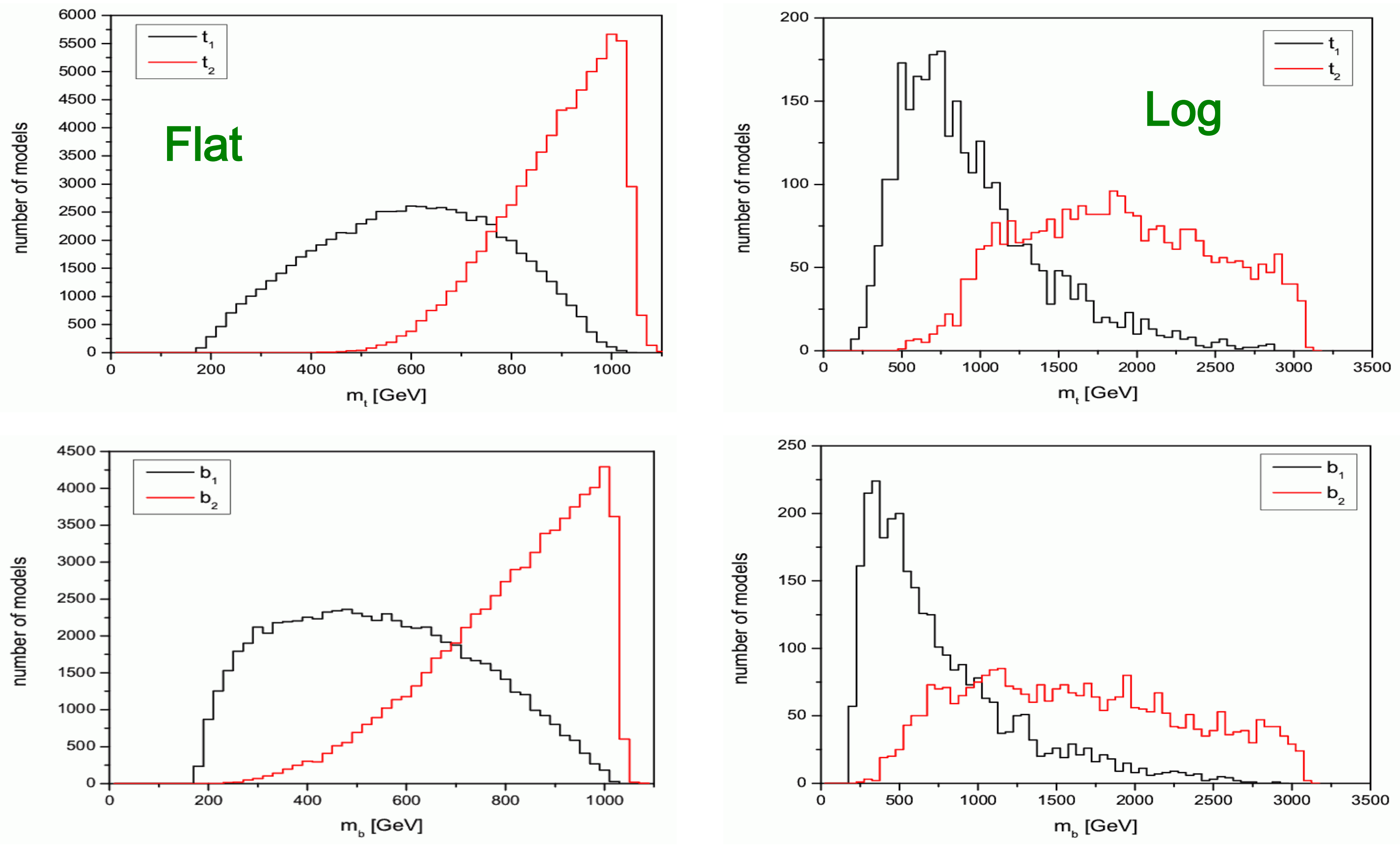


Distribution of Sparticle Masses By Species

Flat Priors / Log Priors

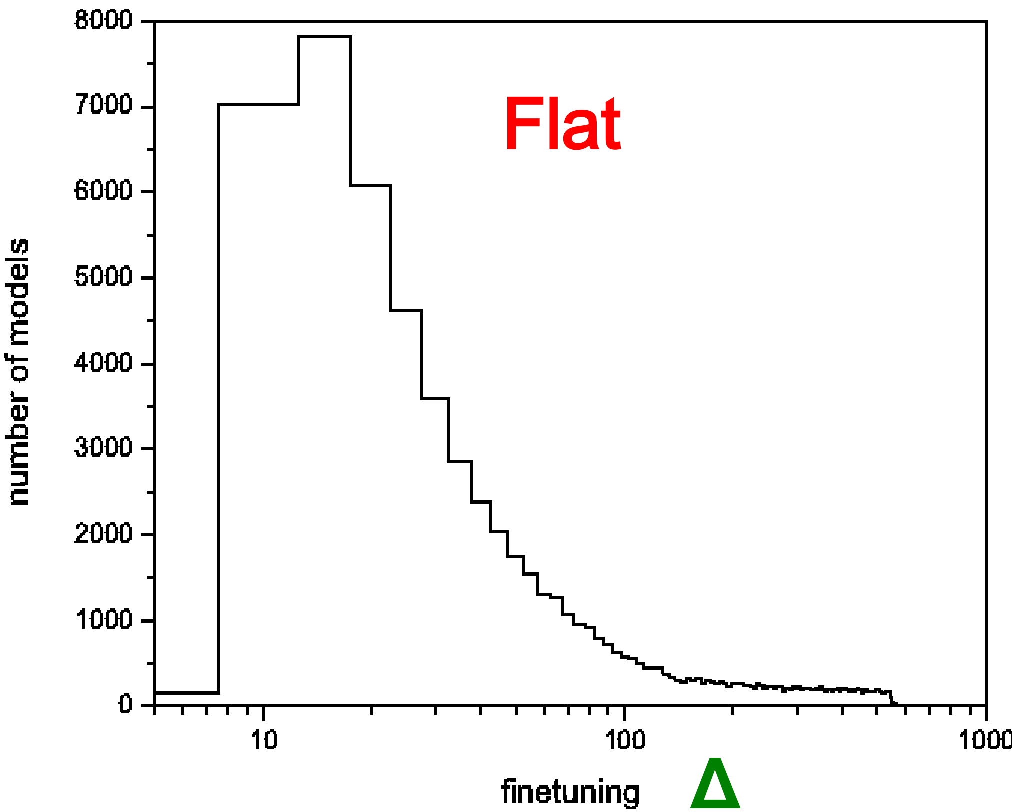


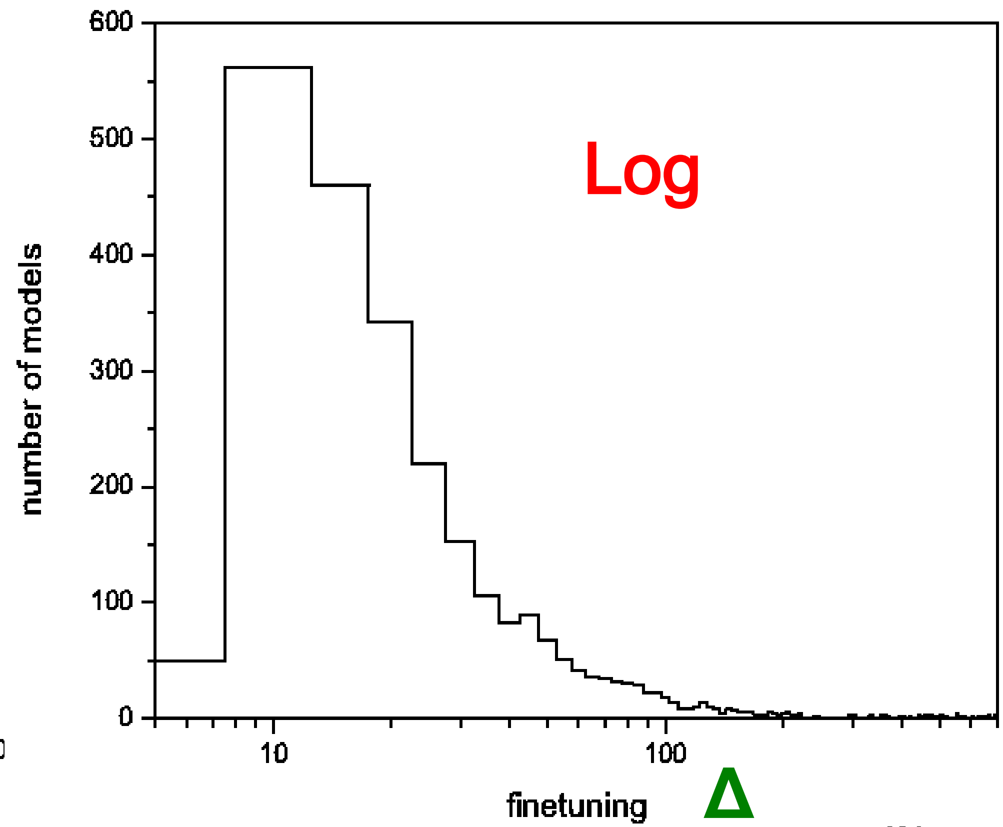
Distribution of Sparticle Masses By Species



'Fine-Tuning' or Naturalness Criterion

We find that small values of `fine-tuning' are very common !





ATLAS has already made use of some of these models!

ATLAS NOTE

ATL-PUB-2009-XXX

July 20, 2009

Prospects for Supersymmetry and Univeral Extra Dimensions discovery based on inclusive searches at a 10 TeV centre-of-mass energy with the ATLAS detector

The ATLAS collaboration

Abstract

This note presents an evaluation of the discovery potential of Supersymmetry and Universal Extra Dimensions for channels with jets, leptons and missing transverse energy. The LHC running scenario at a centre-of-mass energy of 10 TeV, delivering an integrated luminosity of 200 pb^{-1} for the 2009-2010 run is investigated.

ATL-PHYS-PUB-2009-081
22 July 2009

Cut Effectiveness: IV

log

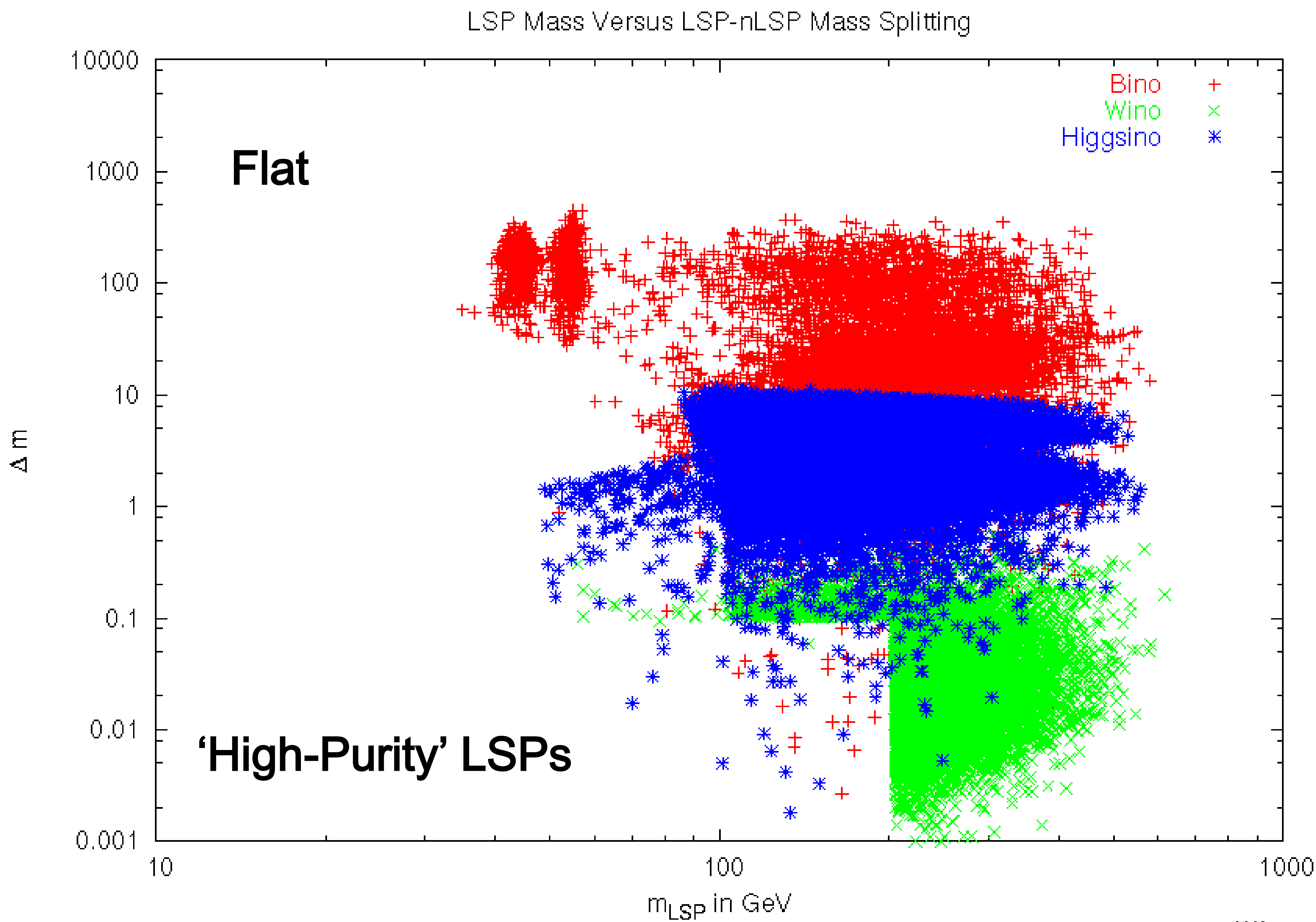
Analysis	# with Zn>5, no pystop	# with Zn>5, incl. pystops
4j0l_1	2034 (70.283 %)	2037 (70.072 %)
4j0l_2	1801 (62.232 %)	1804 (62.057 %)
4j0l_3	1538 (53.144 %)	1539 (52.941 %)
4j0l_4	1488 (51.417 %)	1489 (51.221 %)
4j0l_5	1400 (48.376 %)	1401 (48.194 %)
2j0l_1	1980 (68.417 %)	1983 (68.215 %)
2j0l_2	1570 (54.25 %)	1573 (54.111 %)
2j0l_3	1514 (52.315 %)	1517 (52.184 %)
2j0l_4	1380 (47.685 %)	1383 (47.575 %)
1l4j_1	1878 (64.893 %)	1879 (64.637 %)
1l4j_2	1844 (63.718 %)	1845 (63.467 %)
1l4j_3	1328 (45.888 %)	1329 (45.717 %)
1l4j_4	1002 (34.623 %)	1003 (34.503 %)
1l4j_5	794 (27.436 %)	794 (27.313 %)
1l4j_6	530 (18.314 %)	530 (18.232 %)
1l3j_1	2769 (95.681 %)	2775 (95.459 %)
1l3j_2	2766 (95.577 %)	2772 (95.356 %)
1l3j_3	2194 (75.812 %)	2195 (75.507 %)
1l3j_4	1691 (58.431 %)	1692 (58.204 %)
1l3j_5	1506 (52.039 %)	1507 (51.84 %)
1l3j_6	1136 (39.254 %)	1136 (39.078 %)

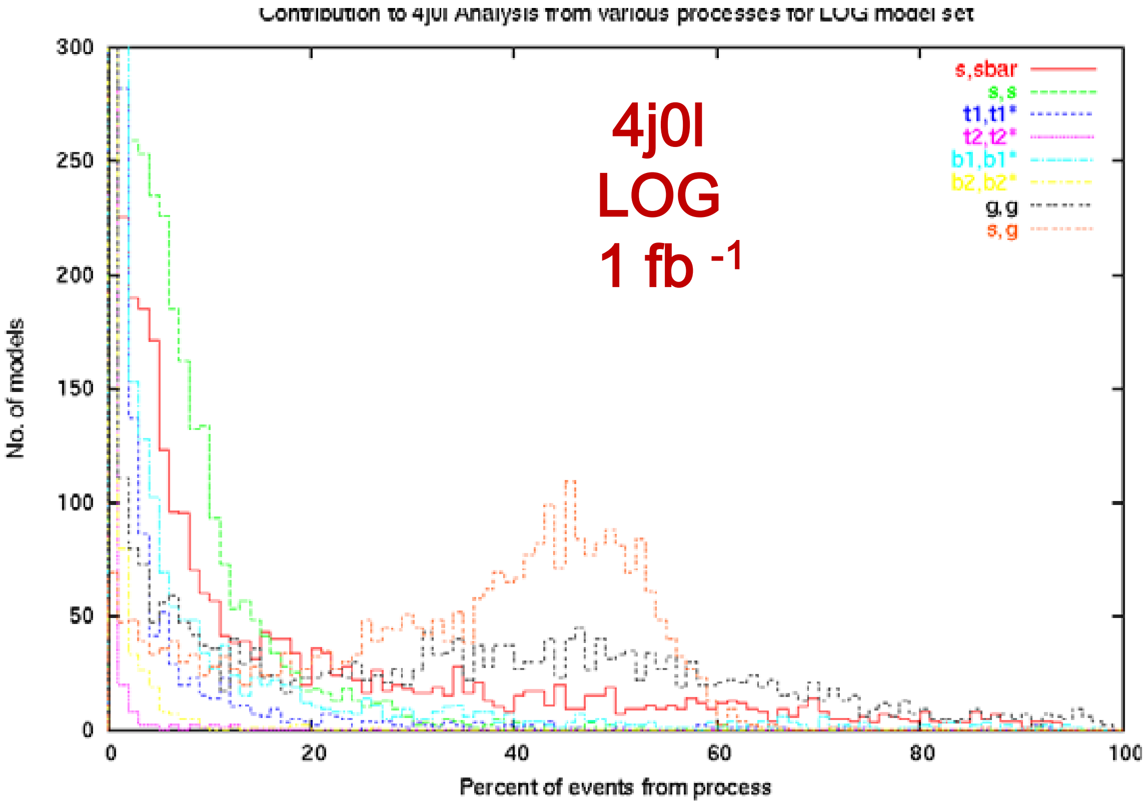
Cut Effectiveness: V

1l2j_1	2681 (92.64 %)	2686 (92.398 %)
1l2j_2	2677 (92.502 %)	2681 (92.226 %)
1l2j_3	2286 (78.991 %)	2287 (78.672 %)
1l2j_4	1823 (62.992 %)	1824 (62.745 %)
1l2j_5	1542 (53.283 %)	1543 (53.079 %)
1l2j_6	1166 (40.29 %)	1167 (40.144 %)
OSDL_1	1133 (39.15 %)	1134 (39.009 %)
OSDL_2	337 (11.645 %)	337 (11.593 %)
OSDL_3	260 (8.9841 %)	260 (8.9439 %)
OSDL_4	201 (6.9454 %)	201 (6.9143 %)
SSDL_1	768 (26.538 %)	768 (26.419 %)
SSDL_2	362 (12.509 %)	362 (12.453 %)
SSDL_3	362 (12.509 %)	362 (12.453 %)
SSDL_4	362 (12.509 %)	362 (12.453 %)
3lj_1	553 (19.109 %)	553 (19.023 %)
3lj_2	257 (8.8804 %)	257 (8.8407 %)
3lm_1	196 (6.7726 %)	196 (6.7423 %)
3lm_2	167 (5.7706 %)	167 (5.7448 %)
3lm_3	167 (5.7706 %)	167 (5.7448 %)
3lm_4	161 (5.5632 %)	161 (5.5384 %)
3lm_5	85 (2.9371 %)	85 (2.924 %)

Cut Effectiveness: VI

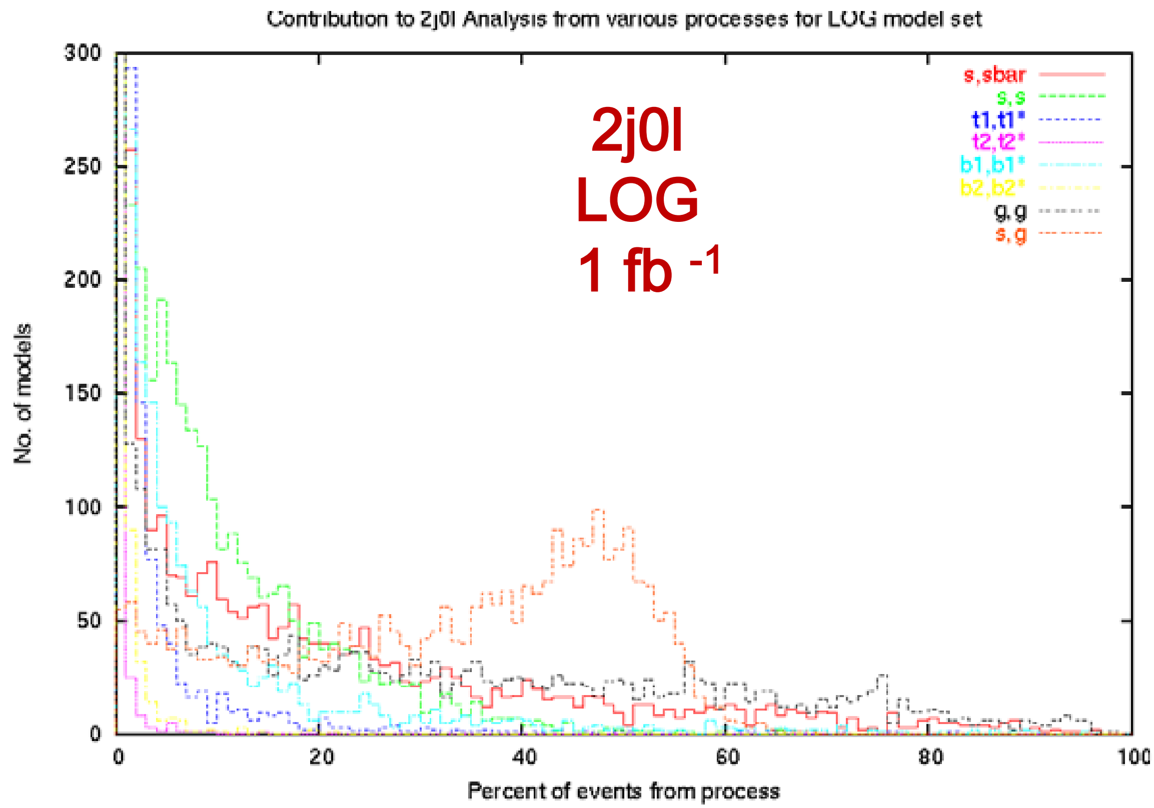
tau_1	2402 (82.999 %)	2405 (82.731 %)
tau_2	2332 (80.581 %)	2335 (80.323 %)
tau_3	2280 (78.784 %)	2283 (78.535 %)
tau_4	2188 (75.605 %)	2191 (75.37 %)
tau_5	1743 (60.228 %)	1745 (60.028 %)
tau_6	1514 (52.315 %)	1515 (52.116 %)
tau_7	1306 (45.128 %)	1307 (44.96 %)
b_1	2743 (94.782 %)	2746 (94.462 %)
b_2	2743 (94.782 %)	2746 (94.462 %)
b_3	2720 (93.988 %)	2723 (93.67 %)
b_4	2657 (91.811 %)	2660 (91.503 %)
b_5	2558 (88.39 %)	2561 (88.098 %)
b_6	1218 (42.087 %)	1219 (41.933 %)


LSP Mass Versus LSP-nLSP Mass Splitting
Flat
'High-Purity' LSPs
Bino
Wino
Higgsino
Δ m
m_LSP in GeV
10000
1000
100
10
1
0.1
0.01
0.001
10
100
1000



These contributions do change significantly when the LOG prior models are examined…

This is likely due to the relative compression in the sparticle mass spectrum in the LOG prior model case



Semi-Stable Sparticles in the 71k Sample with 200 μm < $c\tau$ < 2 cm

- 5381 models with at least 1 semi-stable state
- 283 (13) have 2 (3) of them

- 5316 are charginos
- 552 are second neutralinos
- 38 are stops
- 64 are gluinos
- 5 are d_R (s_R)

etc.