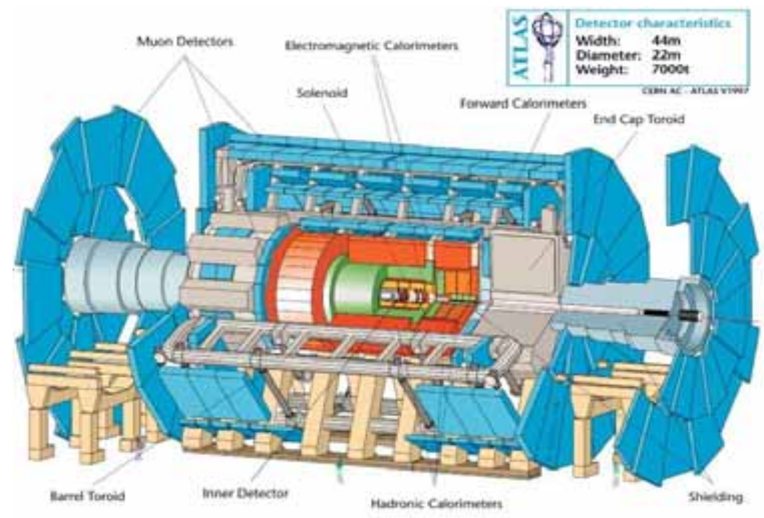
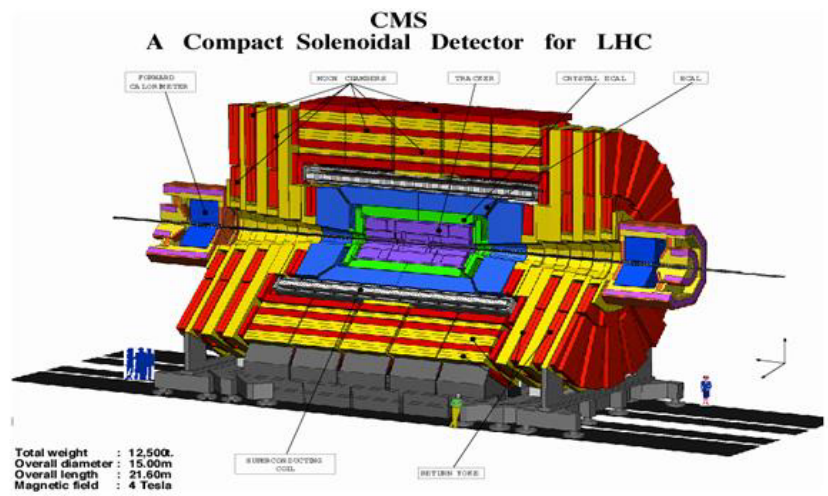
SUSY Without (Much) Prejudice at the LHC





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04/09/2010

Outline

- Motivational & Philosophical Introduction
- Approach for Model Set ‘Generation’
- Some General Properties of Models
- LHC/ATLAS Analysis & Results (ongoing)
- Summary & Conclusions

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

• Analyses generally limited to a specific SUSY scenario(s) such as mSUGRA, GMSB, AMSB,… having few parameters. But there are many ways to break SUSY..some (most?) still unknown.

• But how well do any or all of these reflect the true breadth of the MSSM?? Do we really know the MSSM as well as we think??

• Is there another way to approach this problem & yet remain *more general* ? *Some* set of assumptions are necessary to make any such study practical. But what? 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 the Goals of this Study???

- Prepare a large sample, ~50k, of MSSM models (= parameter space points) satisfying ‘all’ of the experimental constraints based on cuts. A large sample is necessary to get a good feeling for the variety of possibilities. (Done)

- Examine the properties of the models that survive. Do they look like the model points that have been studied up to now? What are the differences? (In progress)

- Do physics analyses with these models for LHC, ILC/CLIC, dark matter, etc. etc. (In progress)

What This Study is Not

Our goal was NOT to find the 'best-fit' model(s) but, e.g., to discover new SUSY spectra & decay scenarios which are different from those seen in the more familiar SUSY breaking frameworks that can lead to possible unexpected surprises at colliders and elsewhere.

How? Perform 2 Random Scans

Linear Priors

10^7 points – emphasizes moderate masses

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

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

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

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

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

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

Log Priors

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

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

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

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

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

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

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

→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.


Successful models
Rare decays and flavor constraints
Direct searches at LEP & Tevatron
Precision data
WMAP & Direct Detection
Spectrum requirements
g-2
GM
214
U. S. COAST GUARD

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: $\Omega h^2 < 0.1210$ → 5yr WMAP data +… 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 & 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 here in how the constraints are used & some require re-evaluation.

Zh, h-> bb, ττ

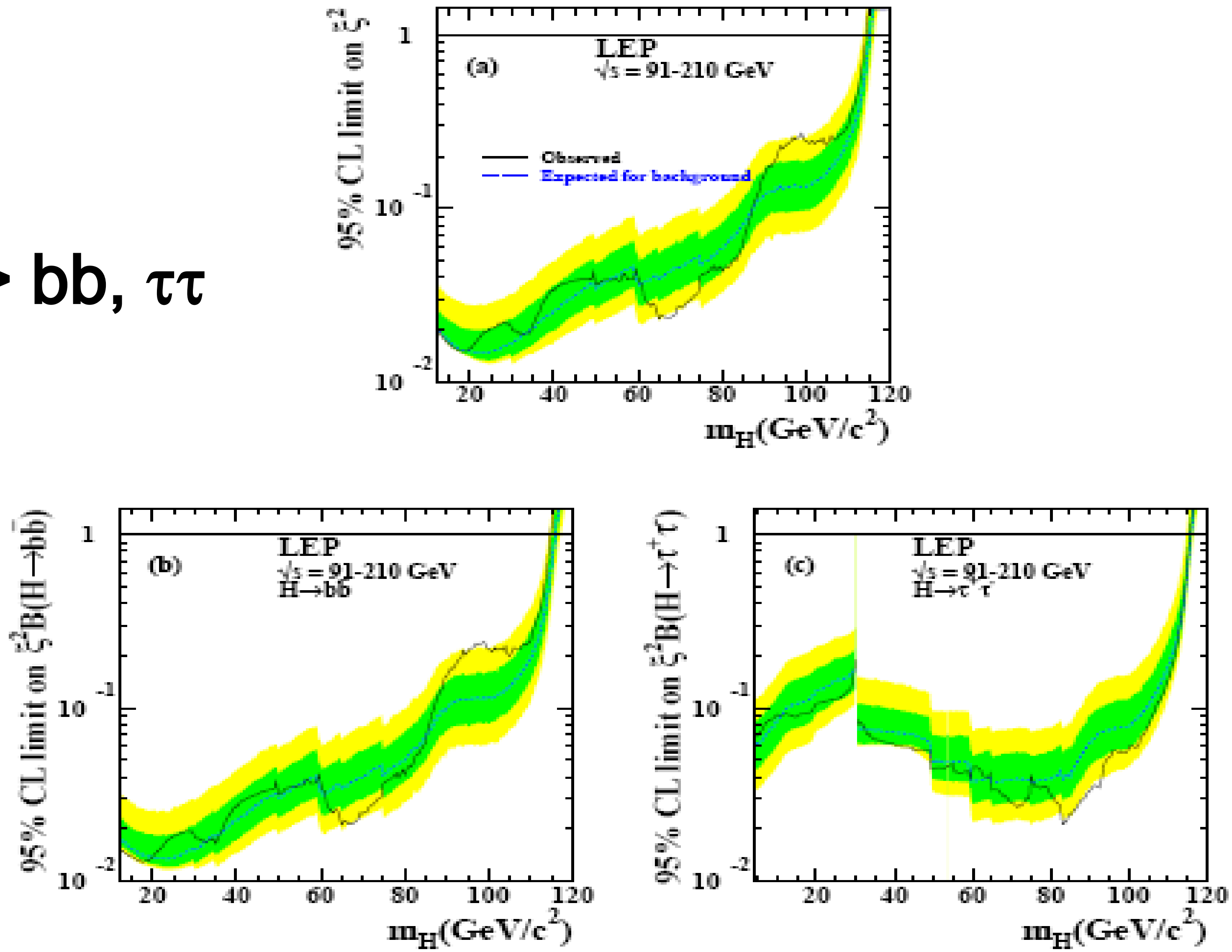
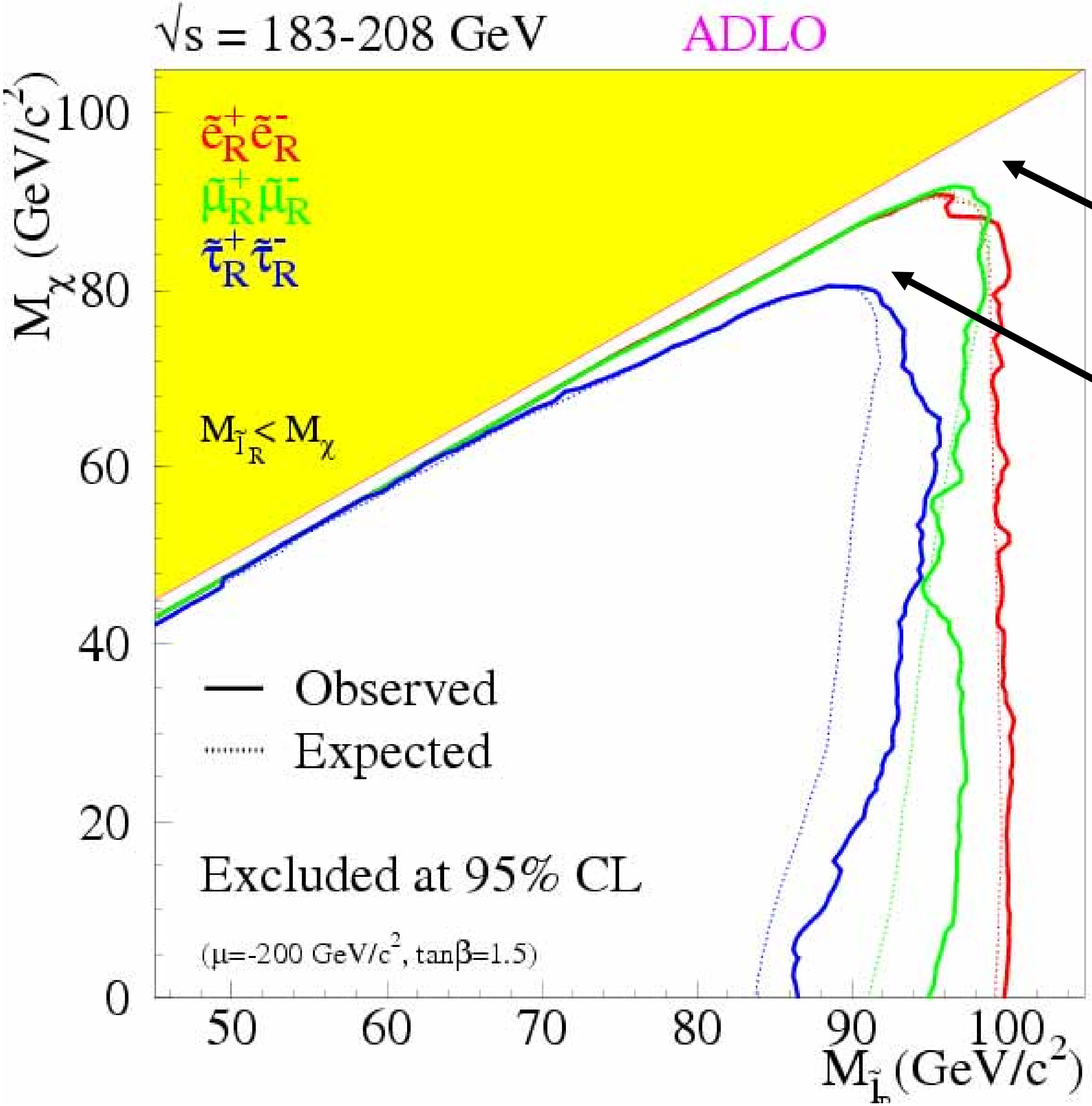


Figure 1: The 95% c.l. upper bound on the coupling ratio $\xi^2 = (g_{\mathrm{HZZ}}/g^{\mathrm{SM}}_{\mathrm{HZZ}})^2$ (see text). The dark (green) and light (yellow) shaded bands around the median expected line correspond to the 68% and 95% probability bands. The horizontal lines correspond to the Standard 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 & also in the squark case when soft jets are possible..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
$\Delta\phi(\not{E}_T, \mathrm{jet}_1)$	$\geq 90°$	$\geq 90°$	$\geq 90°$
$\Delta\phi(\not{E}_T, \mathrm{jet}_2)$	$\geq 50°$	$\geq 50°$	$\geq 50°$
$\Delta\phi_{\min}(\not{E}_T, \text{any jet})$	$\geq 40°$	–	–
H_T	≥ 325	≥ 375	≥ 400
$\not{E}_T$	≥ 225	≥ 175	≥ 100

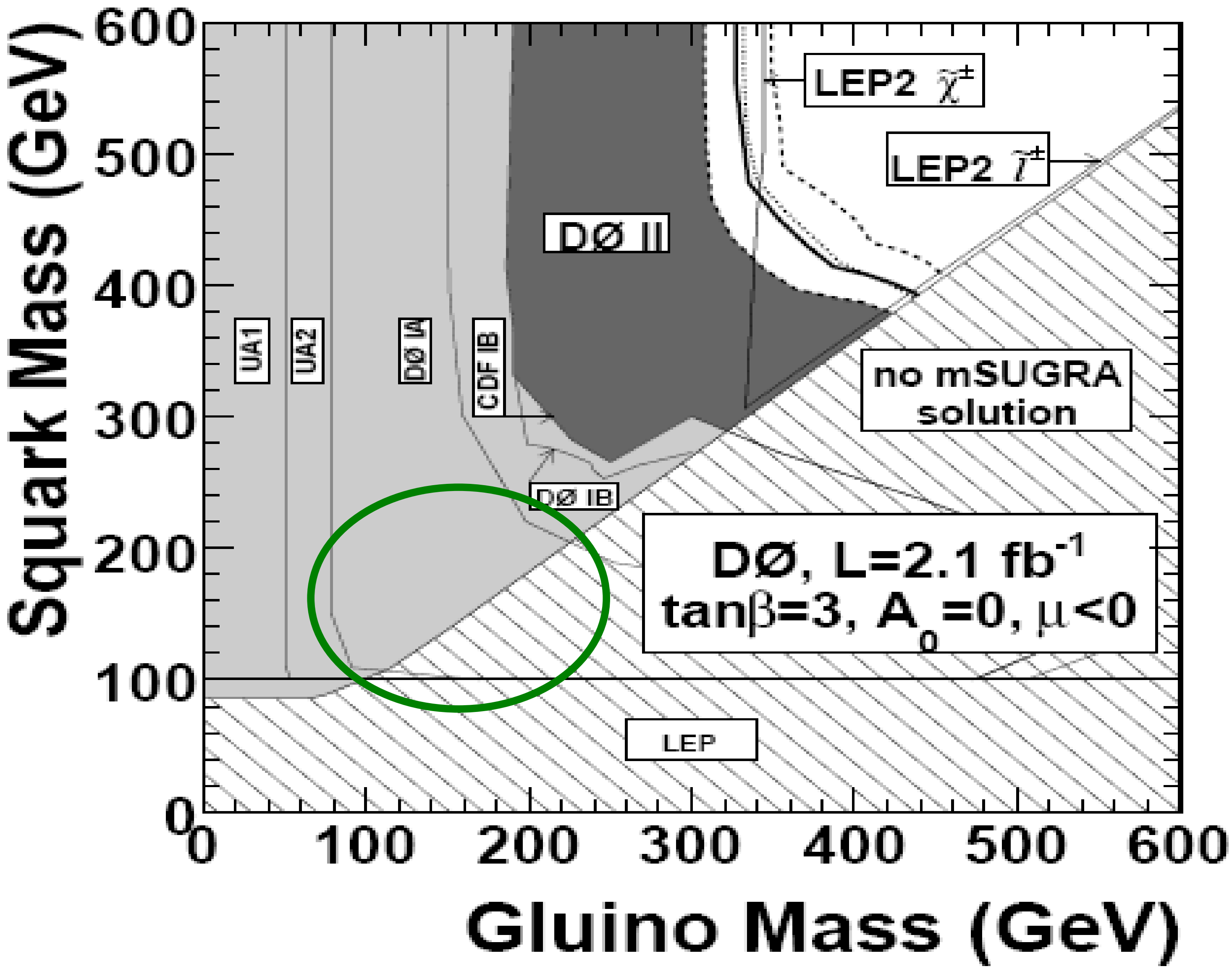
[a] First and second jets are also required to be central ($|\eta_{\rm det}| < 0.8$), with an electromagnetic fraction below 0.95, and to have CPF0 ≥ 0.75.
[b] Third and fourth jets are required to have $|\eta_{\rm det}| < 2.5$, with an electromagnetic fraction below 0.95.

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

This D0 search provides strong constraints in mSUGRA.. squarks & gluinos > 330-400 GeV…our limits can be *much weaker* on both these sparticles !!



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	$17.7 \pm 1.1^{+5.5}_{-3.3}$	$17.0 \pm 1.2^{+3.3}_{-2.9}$	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 ± 0.13(stat) ± 0.29(syst)	0.49 ± 0.04(stat) ± 0.08(syst)	1
2tight,1loose	1.61 ± 0.11(stat) ± 0.21(syst)	0.25 ± 0.03(stat) ± 0.03(syst)	0
1tight,2loose	0.68 ± 0.07(stat) ± 0.09(syst)	0.14 ± 0.02(stat) ± 0.02(syst)	0
Total Trilepton	4.5 ± 0.2(stat) ± 0.6(syst)	0.88 ± 0.05(stat) ± 0.13(syst)	1
2tight,1Track	4.44 ± 0.19(stat) ± 0.58(syst)	3.22 ± 0.48(stat) ± 0.53(syst)	4
1tight,1loose,1Track	2.42 ± 0.14(stat) ± 0.32(syst)	2.28 ± 0.47(stat) ± 0.42(syst)	2
Total Dilepton+Track	6.9 ± 0.2(stat) ± 0.9(syst)	5.5 ± 0.7(stat) ± 0.9(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

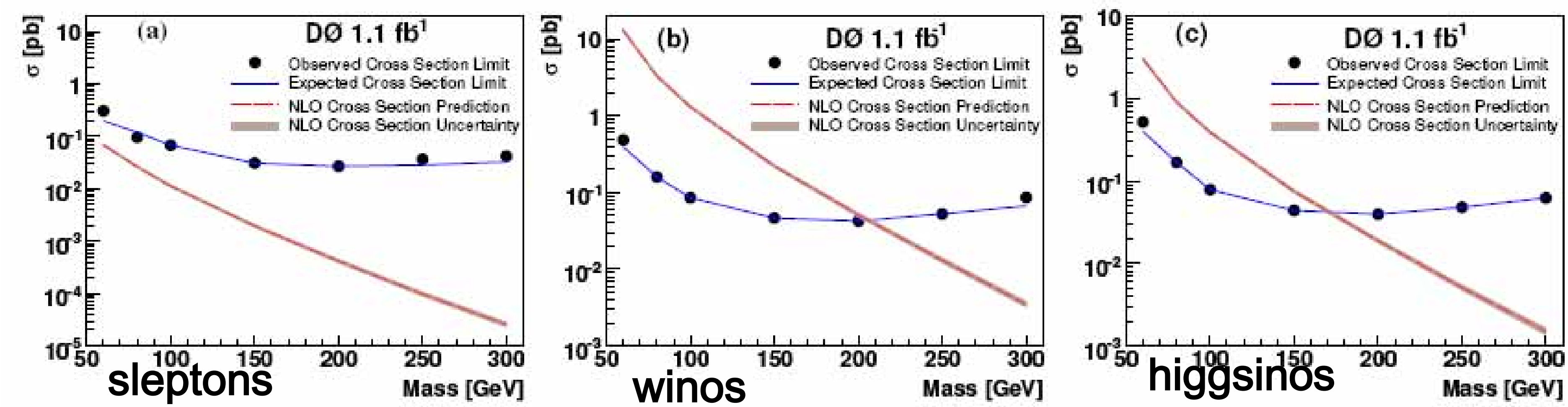


FIG. 2: The observed (dots) and expected (solid line) 95% cross section limits, the NLO production cross section (dashed line), and NLO cross section uncertainty (barely visible shaded band) as a function of (a) stau mass for stau pair production, (b) chargino mass for pair produced gaugino-like charginos,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

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

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

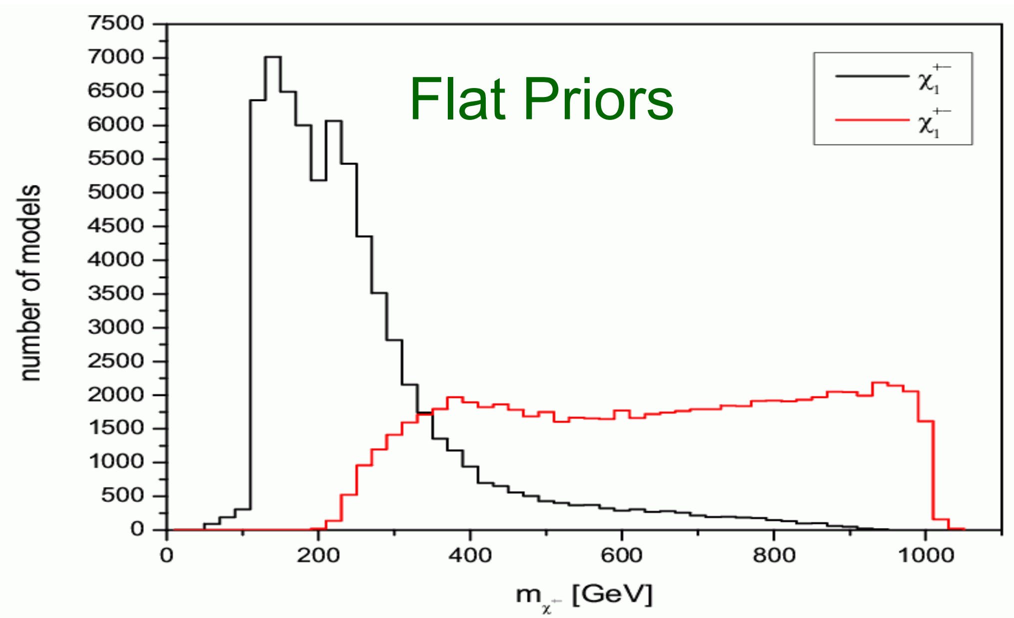
- No applicable bounds on charged sleptons..the cross sections are too small.
- This is the first SUSY analysis to include these constraints

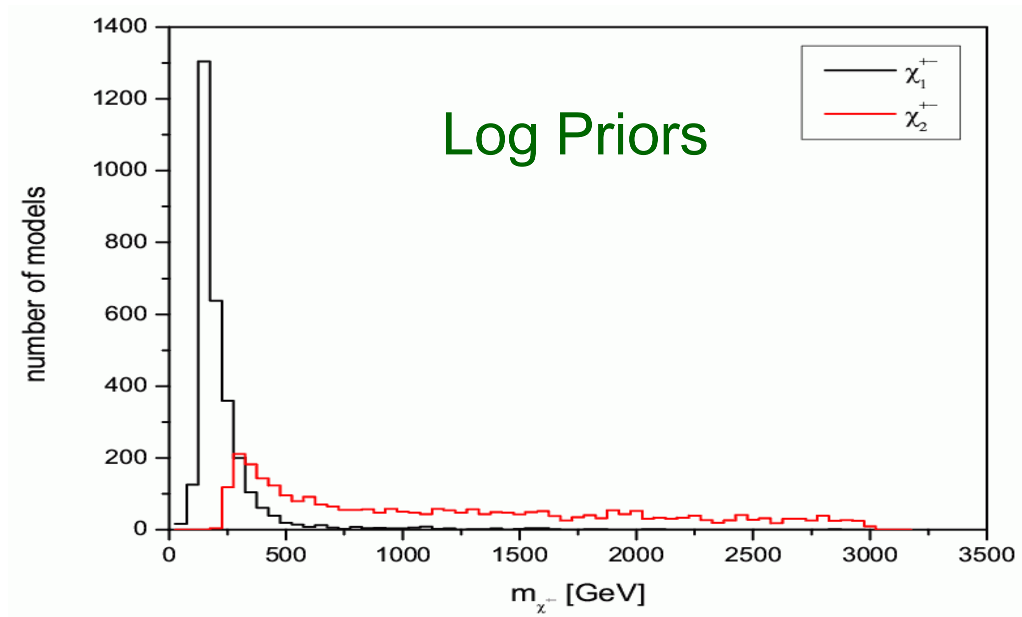
Survival Rates

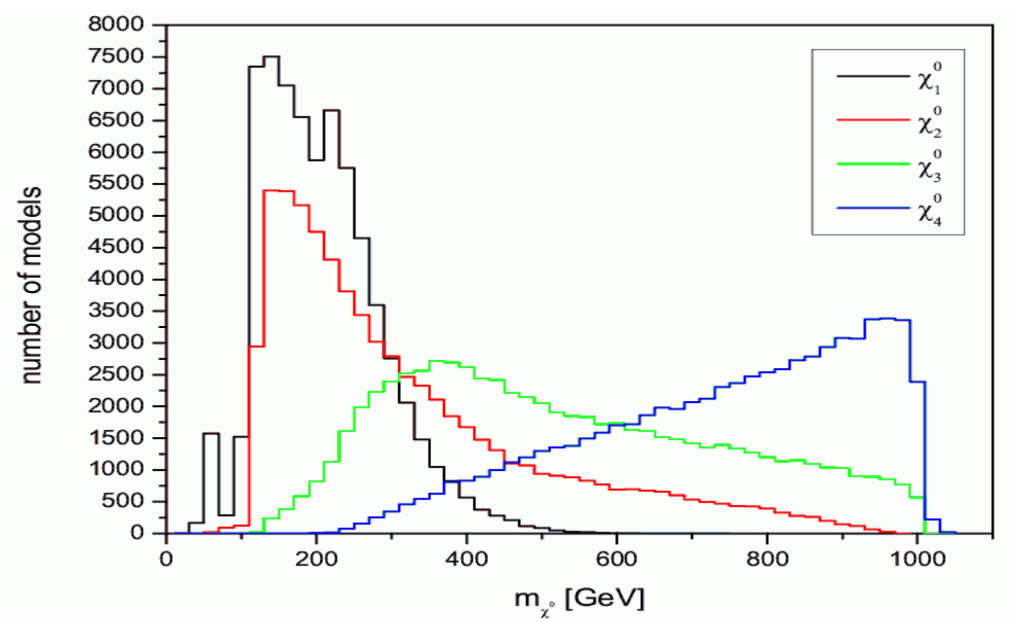
file	Description	Percent of Models Remaining
slha-okay.txt	SuSpect generates SLHA file	99.99 %
error-okay.txt	Spectrum tachyon, other error free	77.29%
lsp-okay.txt	LSP the lightest neutralino	32.70 %
deltaRho-okay.txt	$\Delta\rho$	32.61 %
gMinus2-okay.txt	$g-2$	21.69 %
b2sGamma-okay.txt	$b \longrightarrow s\gamma$	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 %

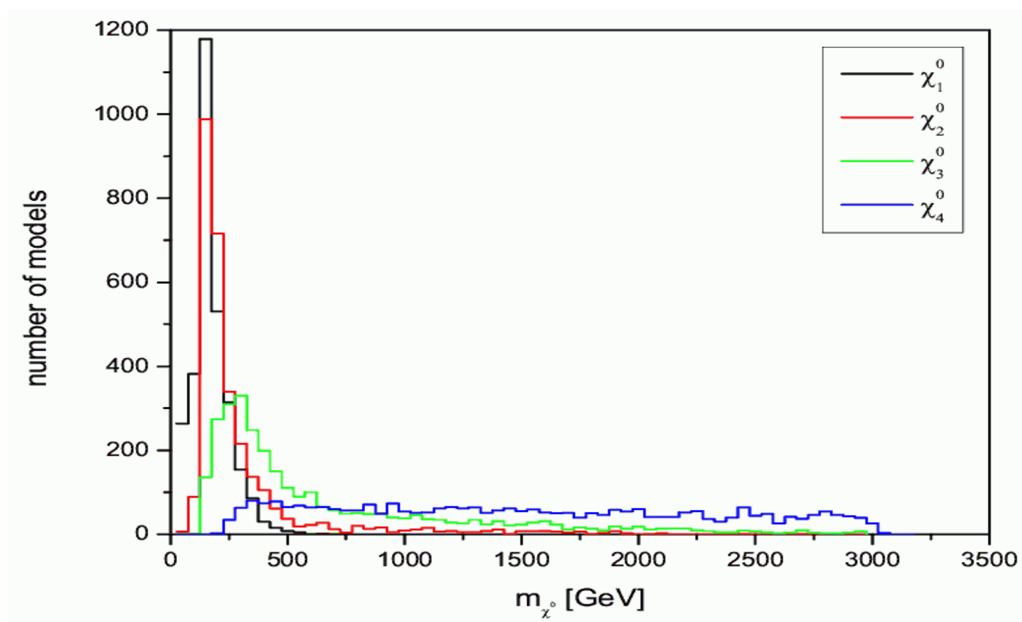
- Flat Priors : 10^7 models scanned , ~ 68.4 K (0.68%) survive
- Log Priors : $2\text{x}10^6$ models scanned , ~ 2.9 K (0.14%) survive

Distribution of Sparticle Masses By Species

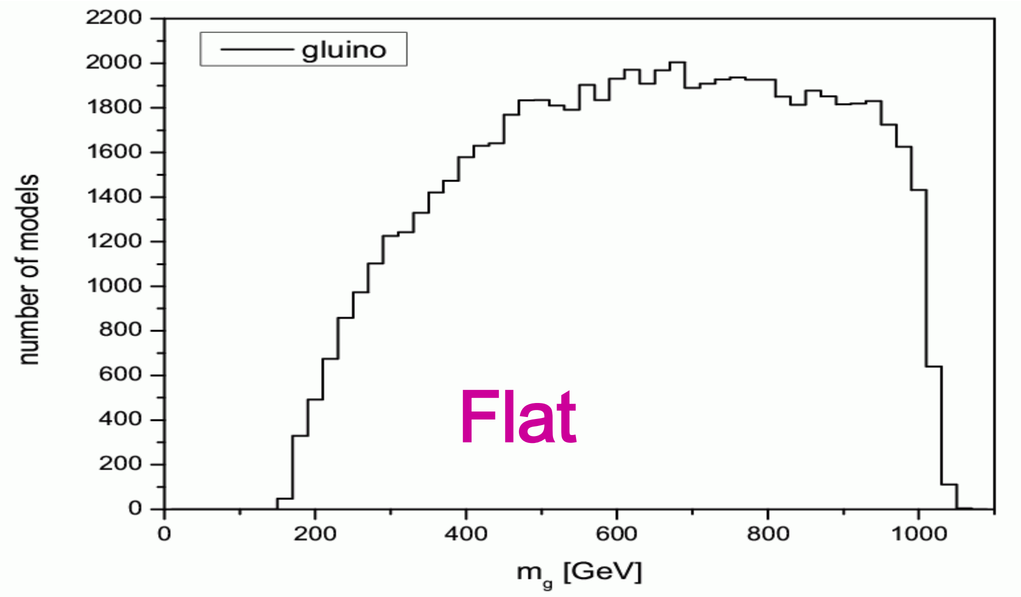


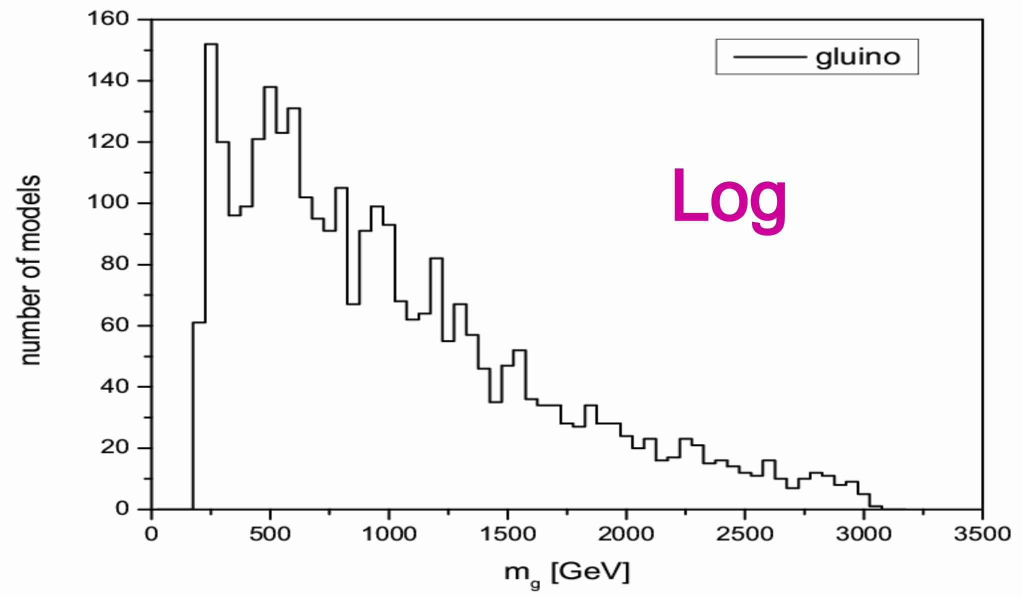


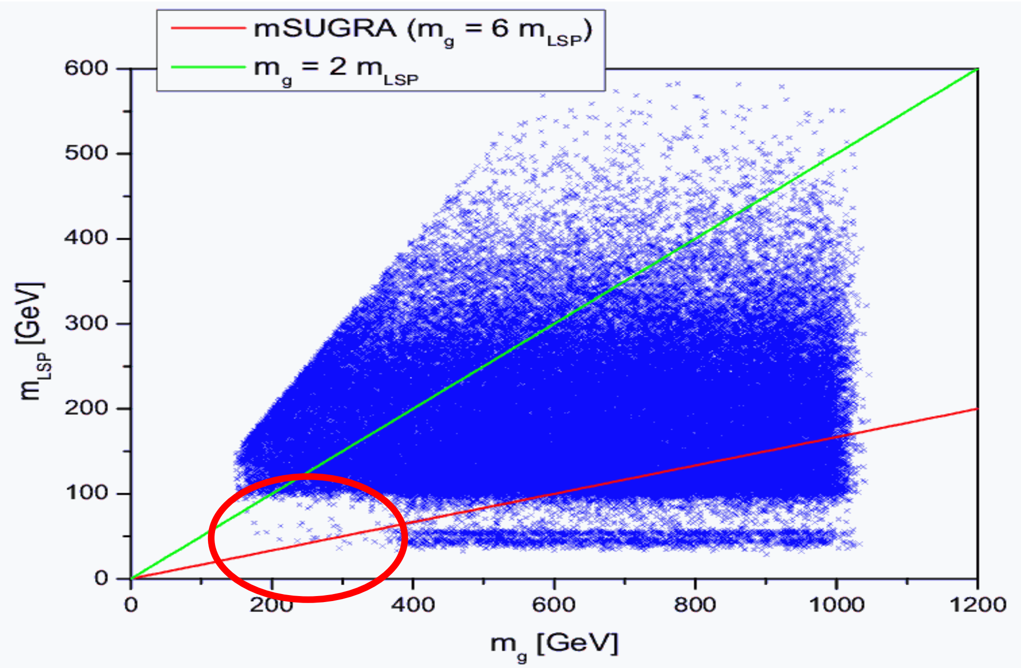


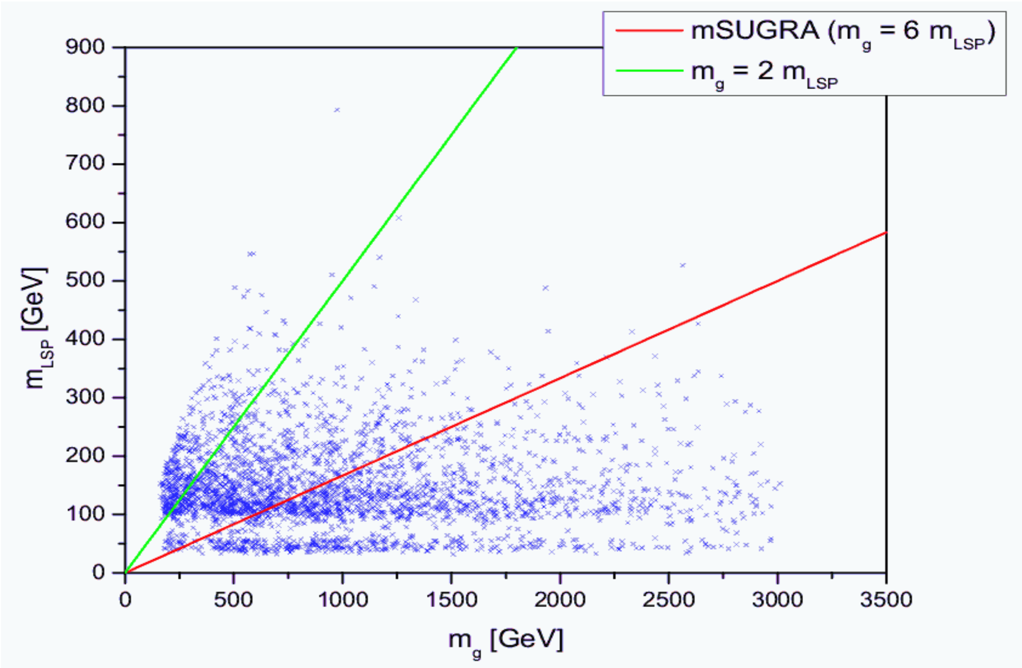


Gluino Can Be Light !!

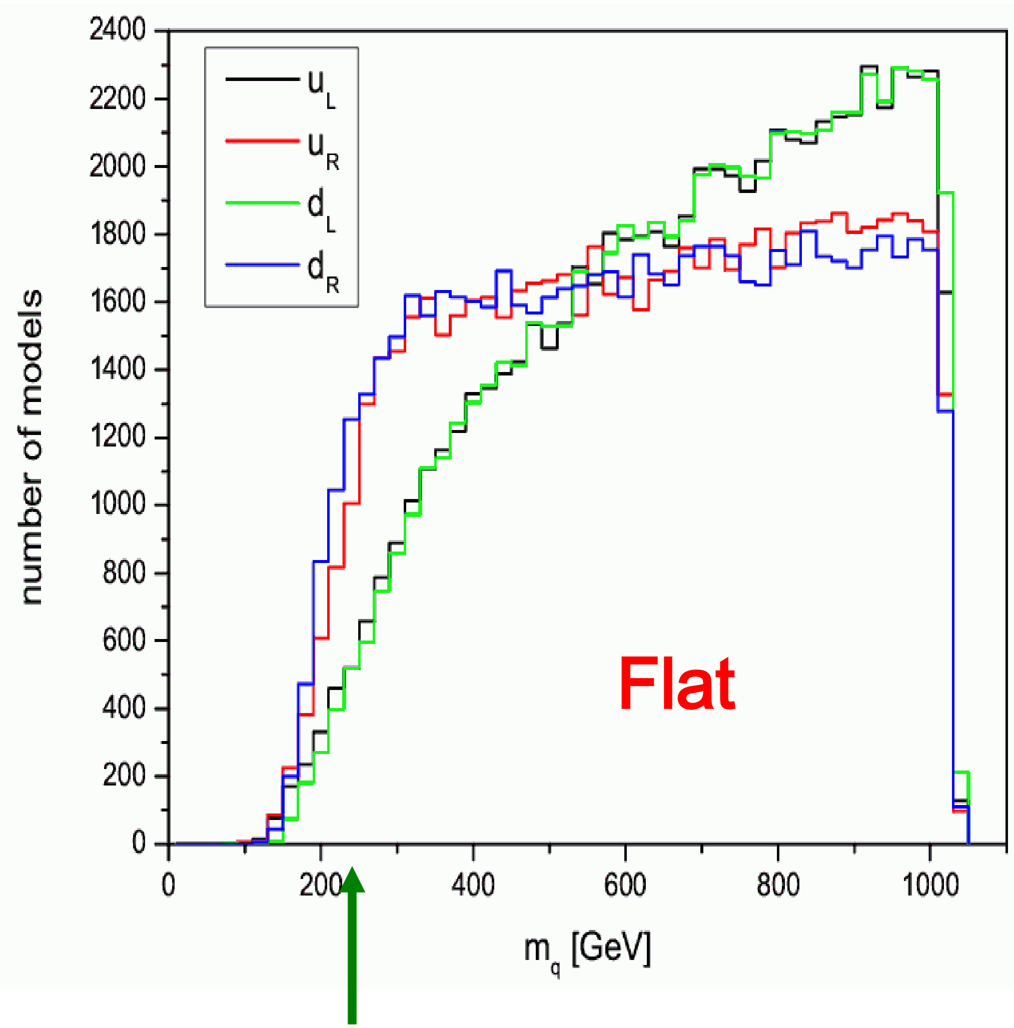


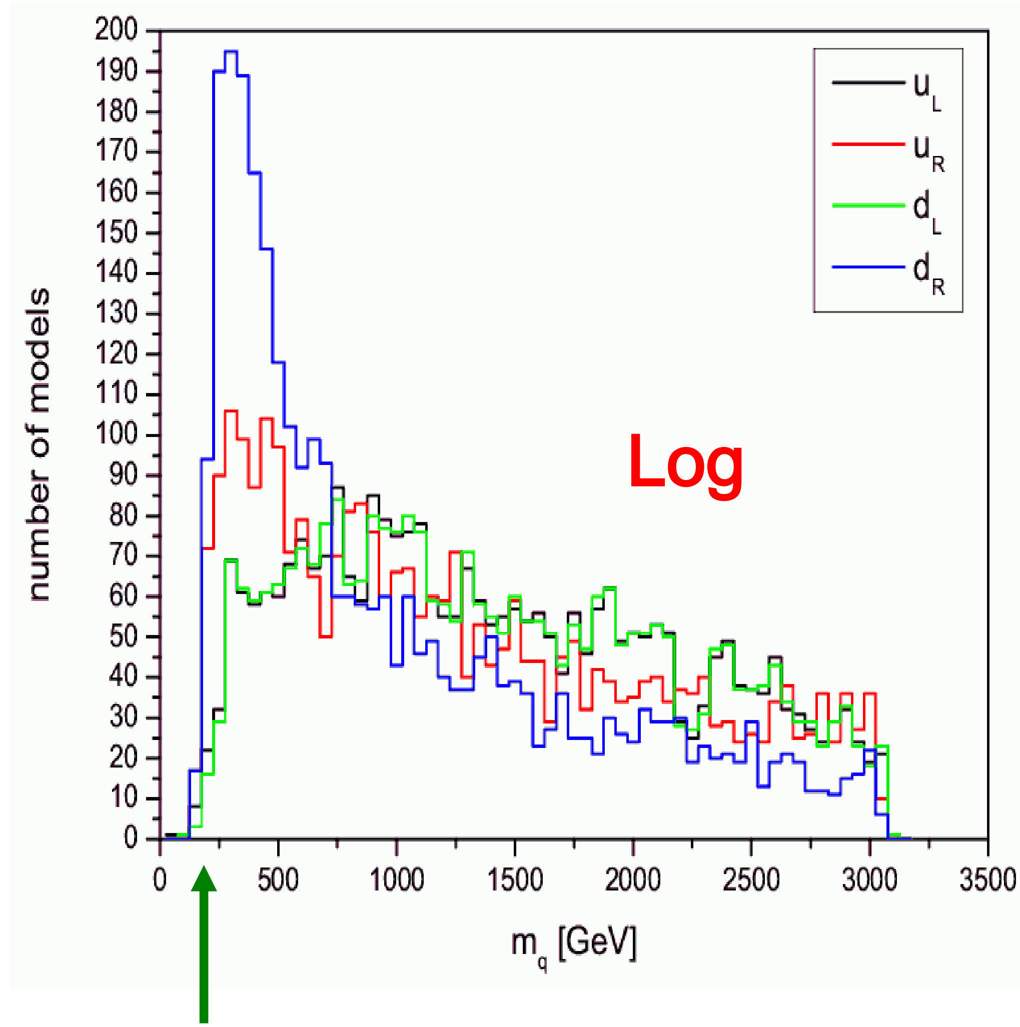






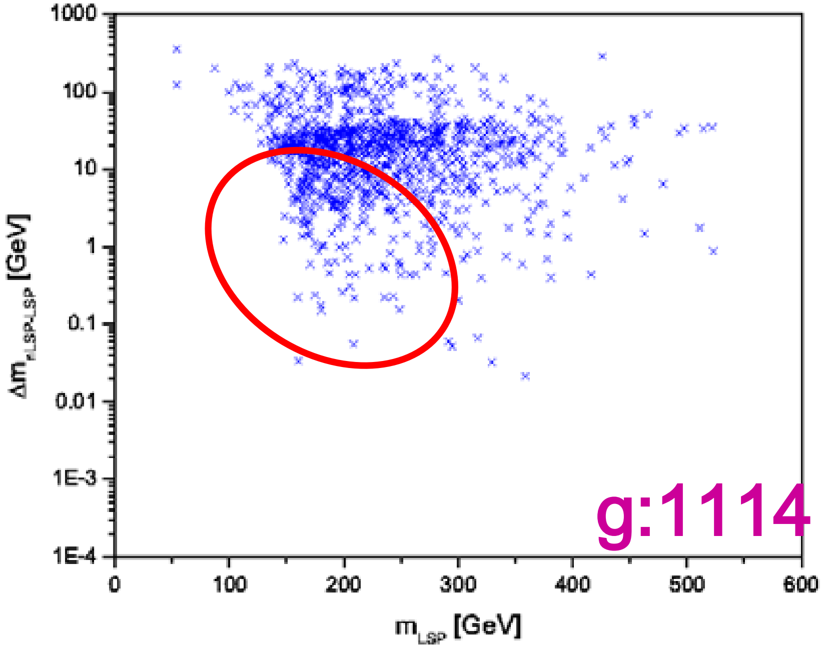
Squarks CAN Be Light !!!



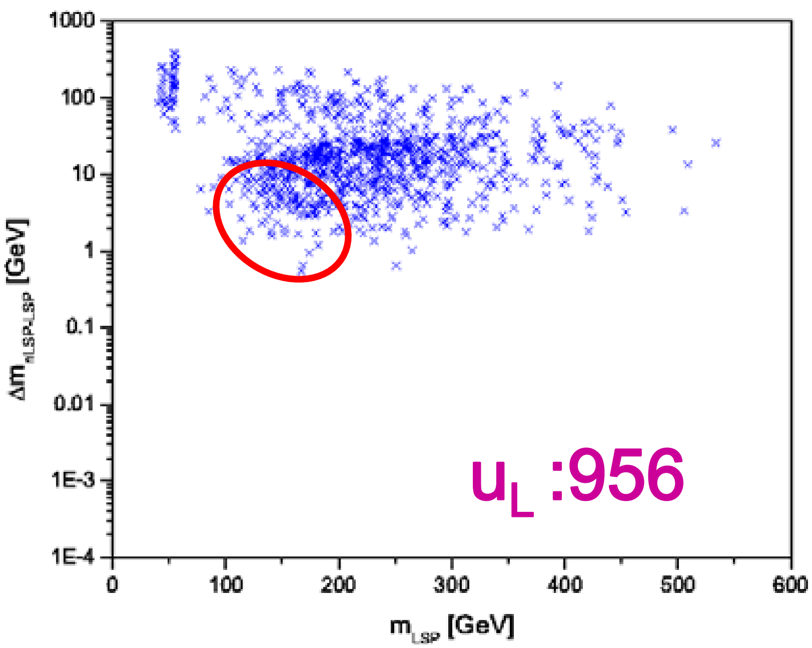


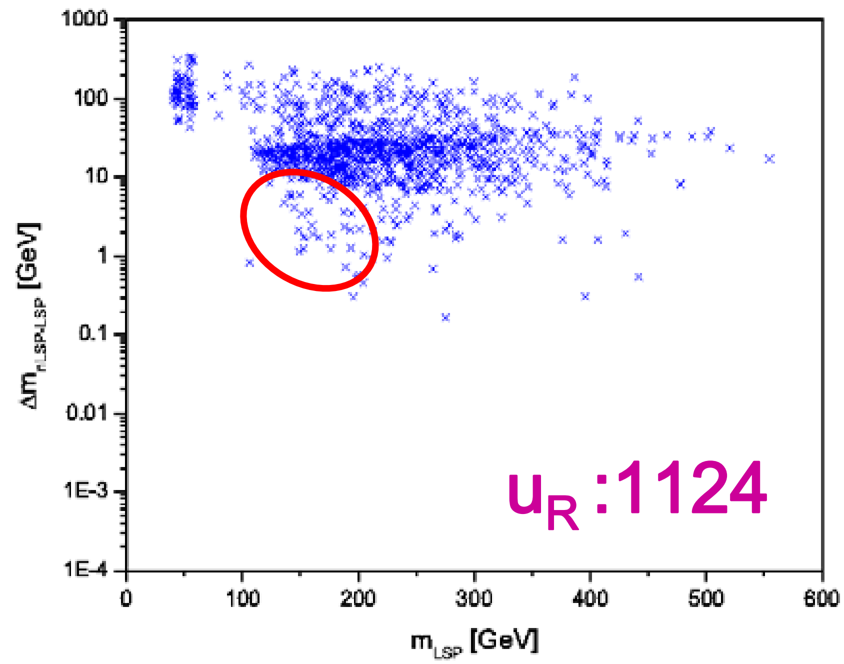
Light squarks can be missed by Tevatron searches for numerous reasons..

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



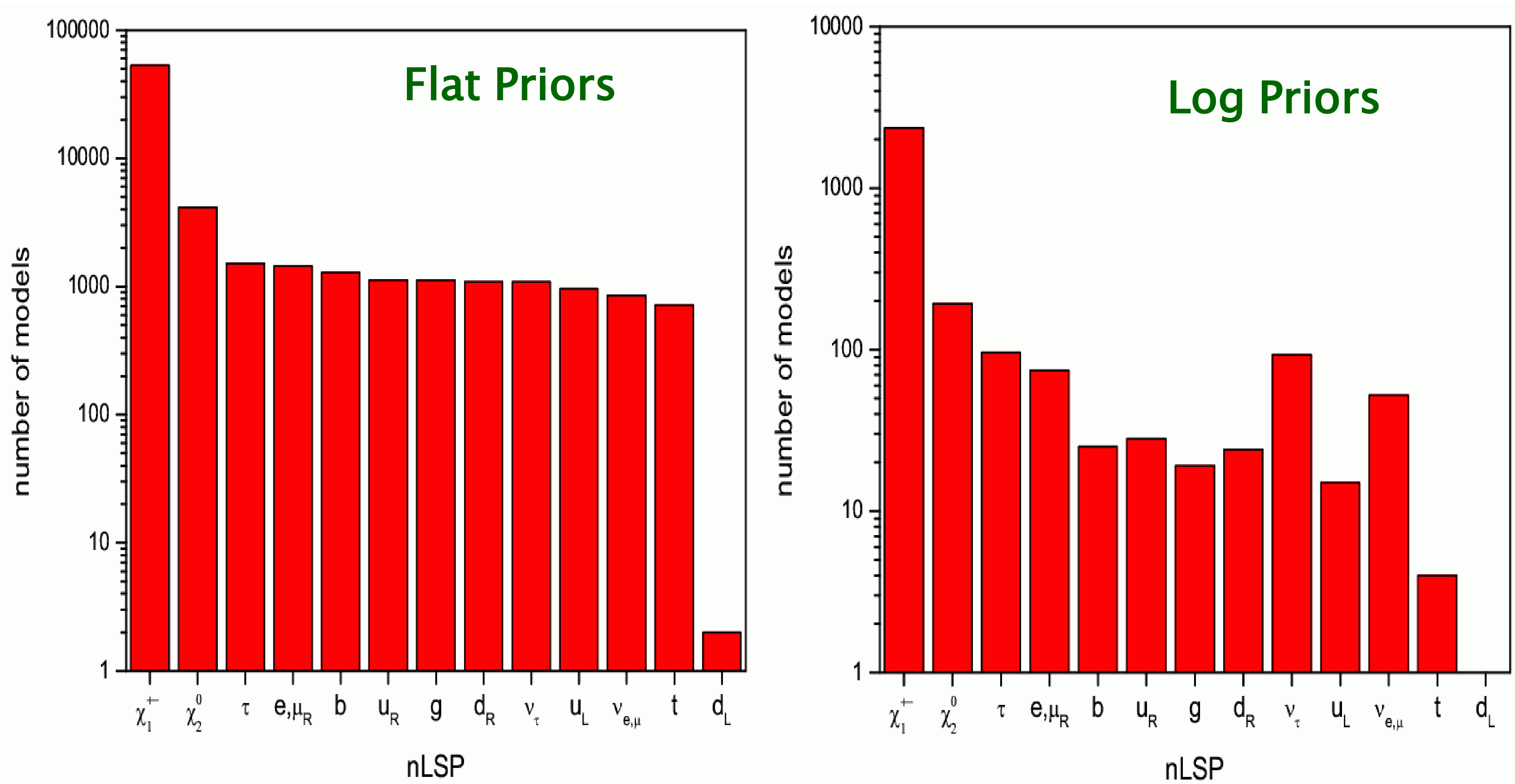
Small mass splittings can lead to soft jets in the final state that have insufficient p_T to pass any SUSY Tevatron search analysis cuts



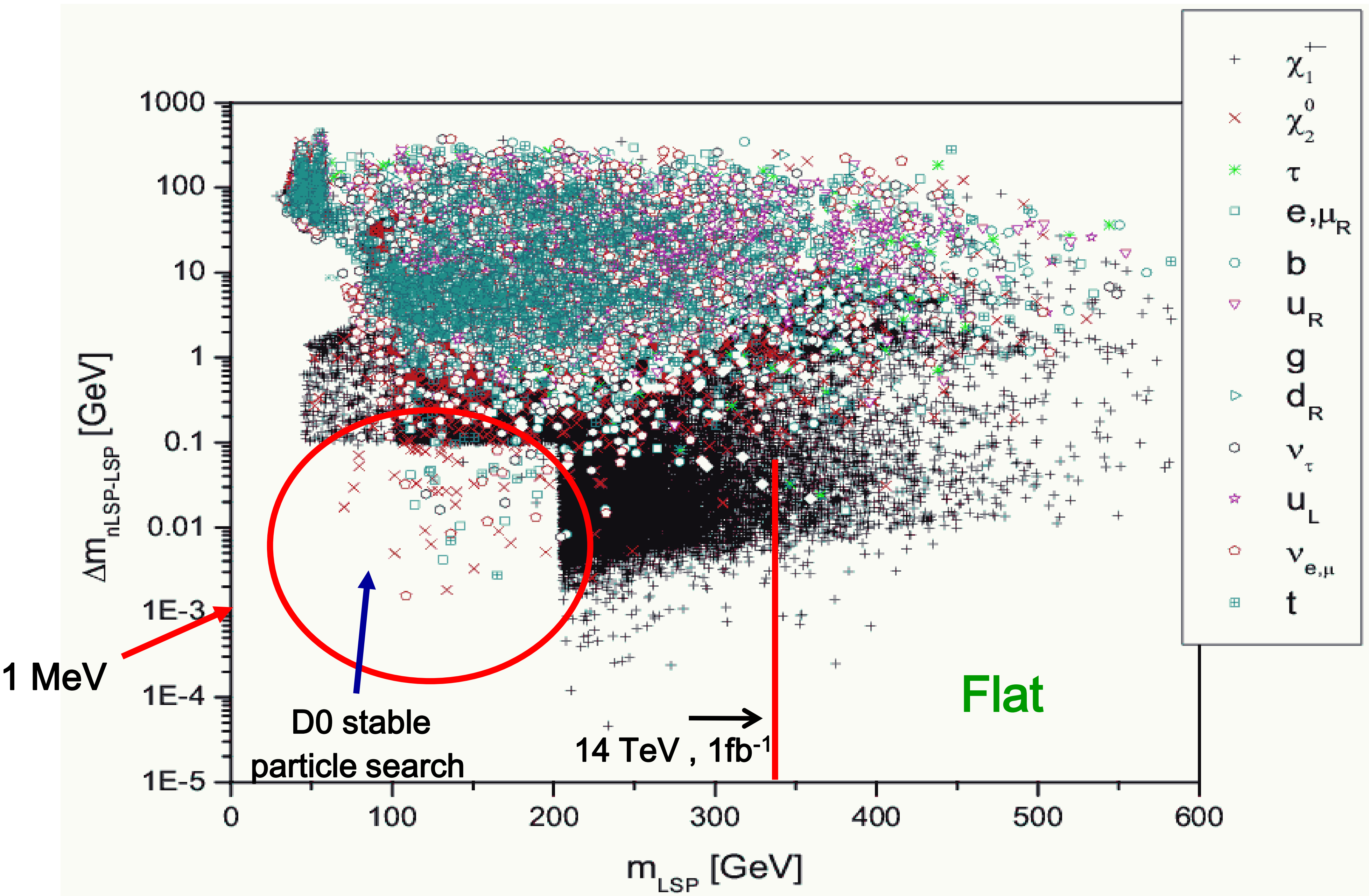


The identity of the nLSP is a critical factor in looking for SUSY signatures..who can play that role here????? Just about

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	$\lvert Z_{11}\rvert^2 > 0.95$	13.94
Mostly Bino	$0.8 < \lvert Z_{11}\rvert^2 \leq 0.95$	3.10
Wino	$\lvert Z_{12}\rvert^2 > 0.95$	14.16
Mostly Wino	$0.8 < \lvert Z_{12}\rvert^2 \leq 0.95$	9.14
Higgsino	$\lvert Z_{13}\rvert^2 + \lvert Z_{14}\rvert^2 > 0.95$	32.19
Mostly Higgsino	$0.8 < \lvert Z_{13}\rvert^2 + \lvert Z_{14}\rvert^2 \leq 0.95$	12.38
All other models		15.09

ATLAS SUSY Analyses w/ a Large Model Set

- We have passed these models through the ATLAS inclusive (14 TeV !) analysis suite, essentially 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 as well as employing their statistical criterion for SUSY 'discovery', etc.

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

- 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 the ATLAS results without including the ATLAS-tuned fast detector simulation fails completely 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 85 processes using PROSPINO** & CTEQ6.6M
Herwig for fragmentation & hadronization	PYTHIA for fragmentation & hadronization
GEANT4 for full detector sim	PGS4-ATLAS for fast detector sim

** version w/ negative K-factor errors corrected

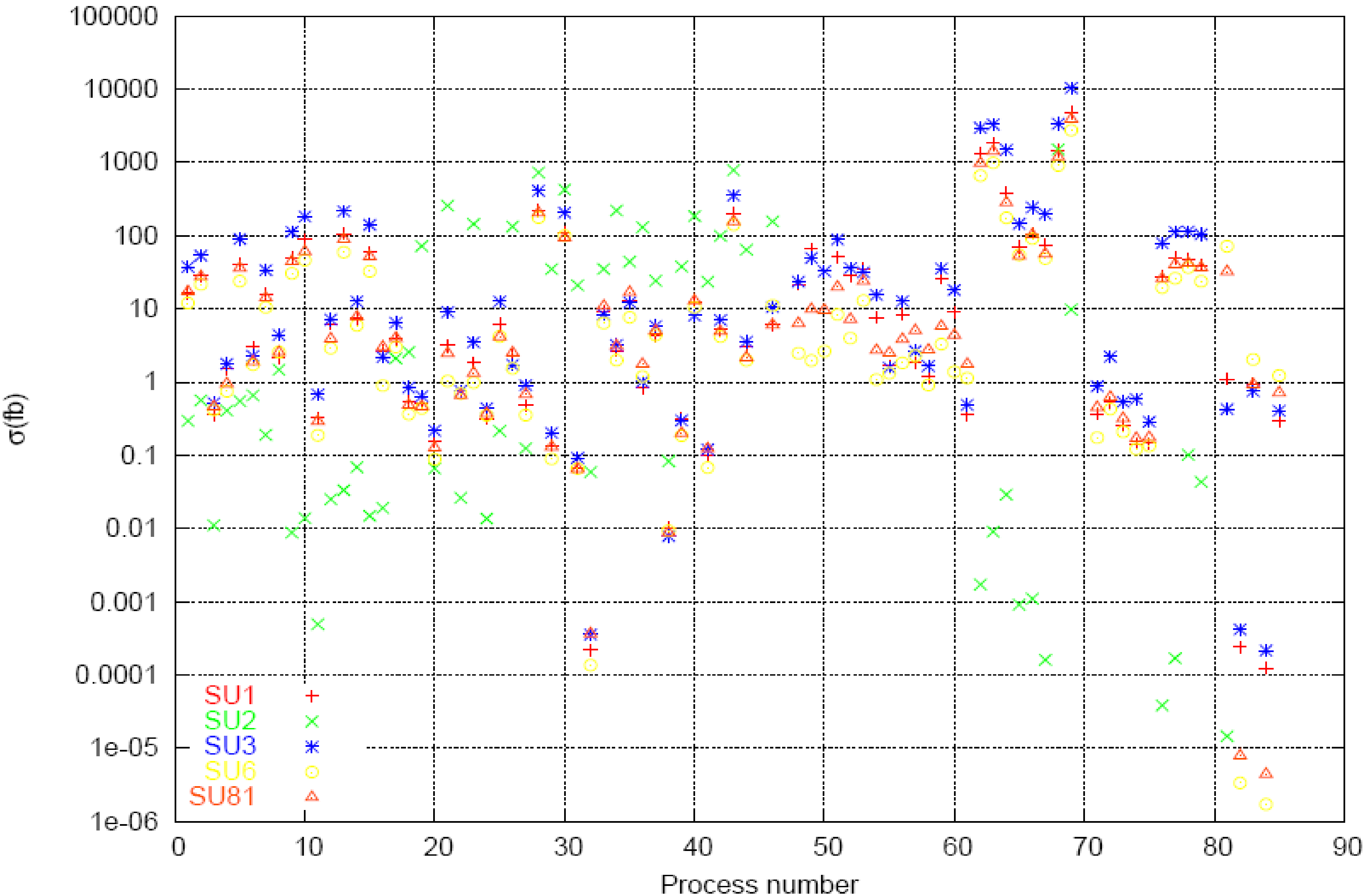
version w/o negative QCD corrections & with 1st & 2nd generation fermion masses included as well as explicit small Δm chargino decays, etc.

The set of inclusive ATLAS analyses is large:

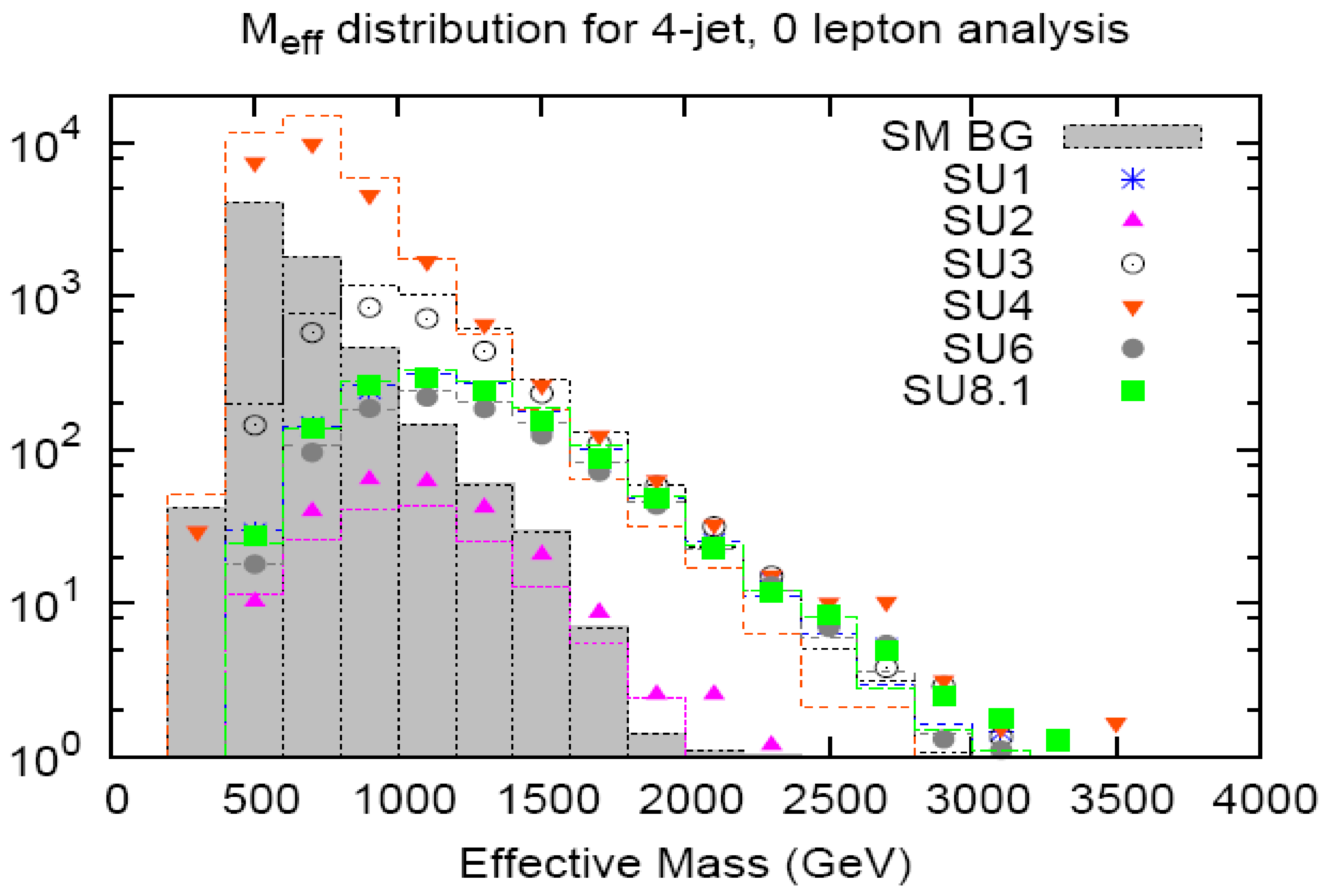
- (2,4)-jet +MET
- 1l+(2,3,4)-jet +MET
- SSDL
- OSDL
- Trileptons + (1-j,X)+MET
- etc.

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

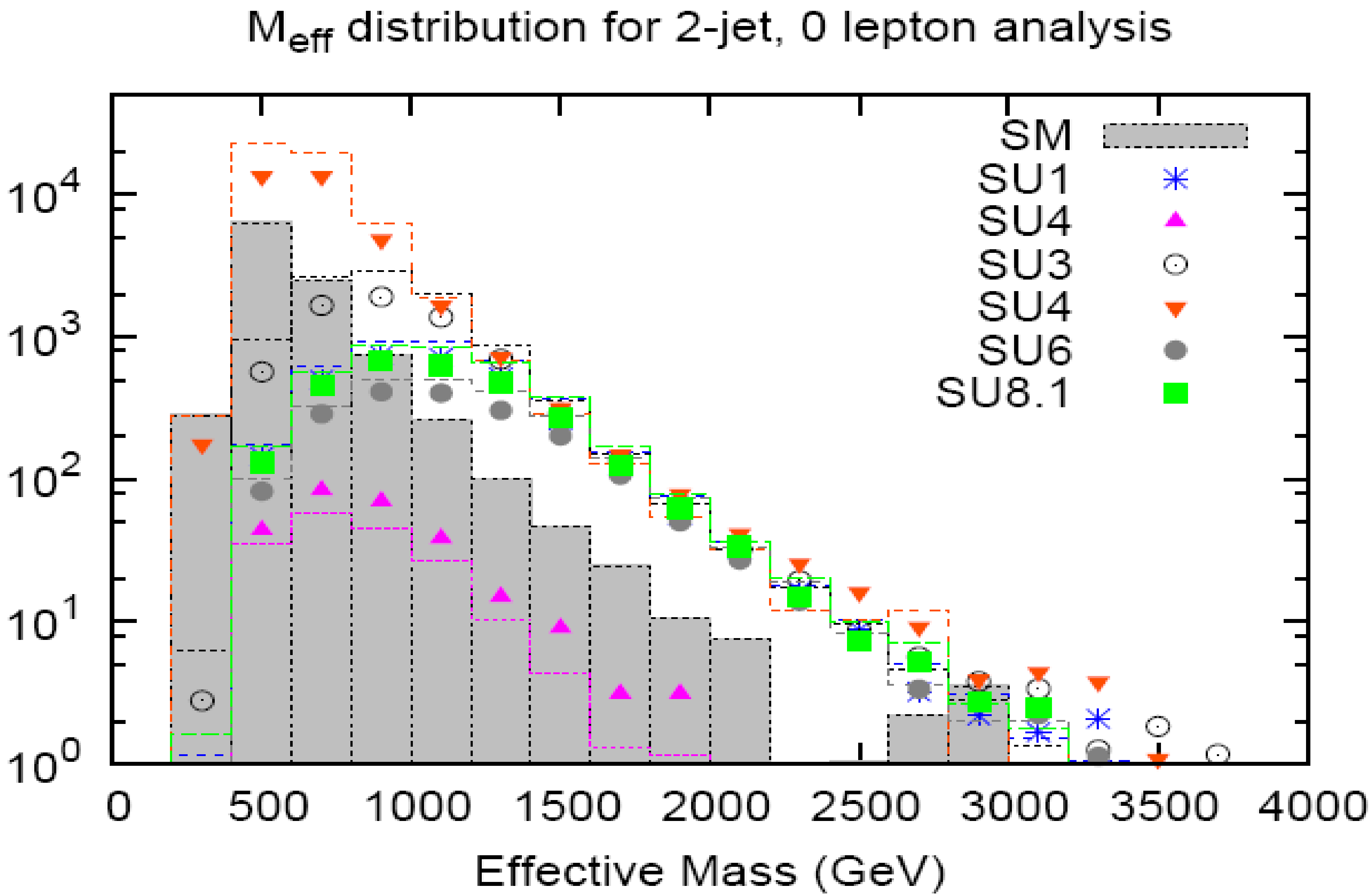
Benchmark Model Process Cross Sections



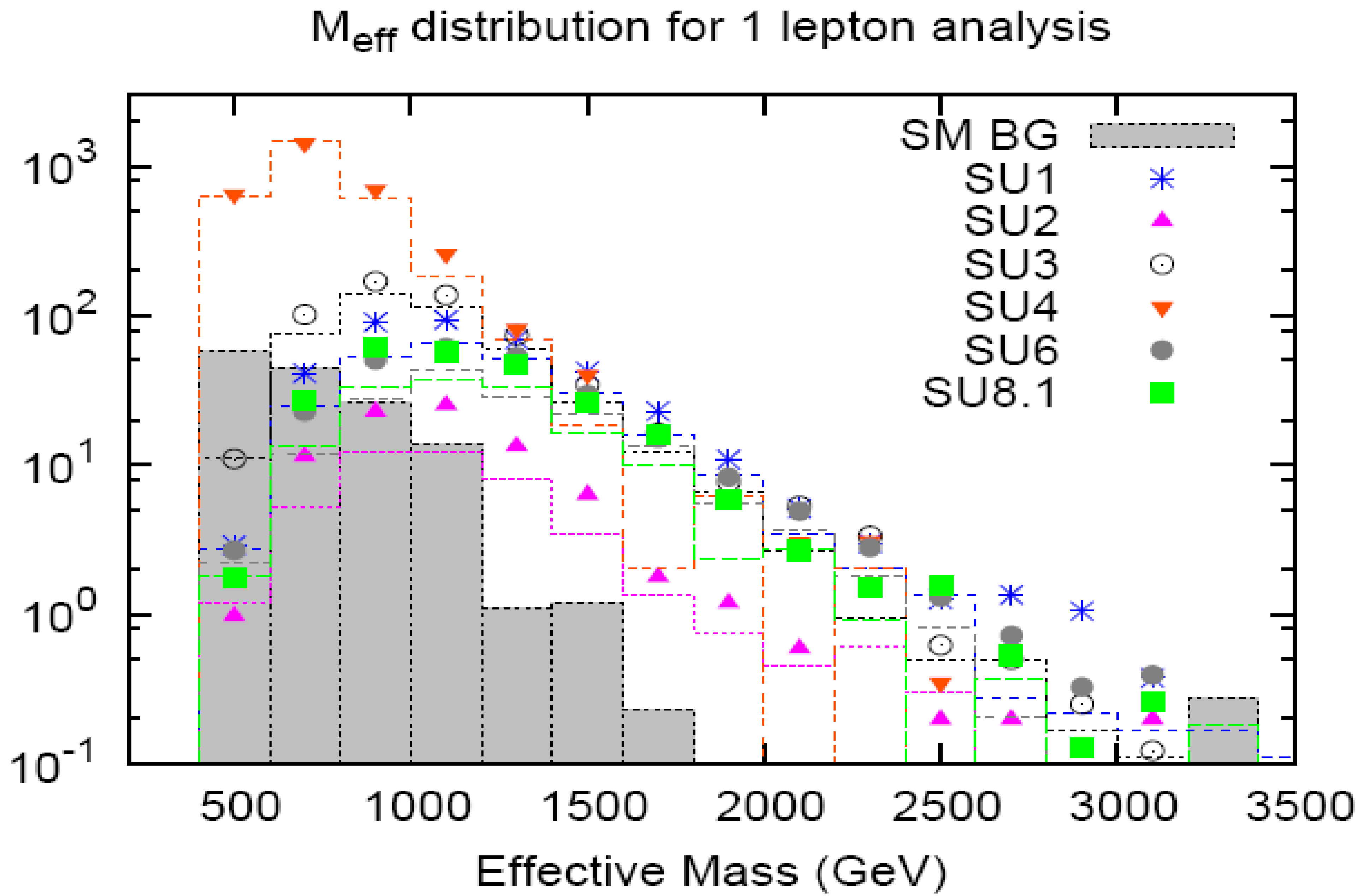
Benchmark Tests: Us vs Them Part I



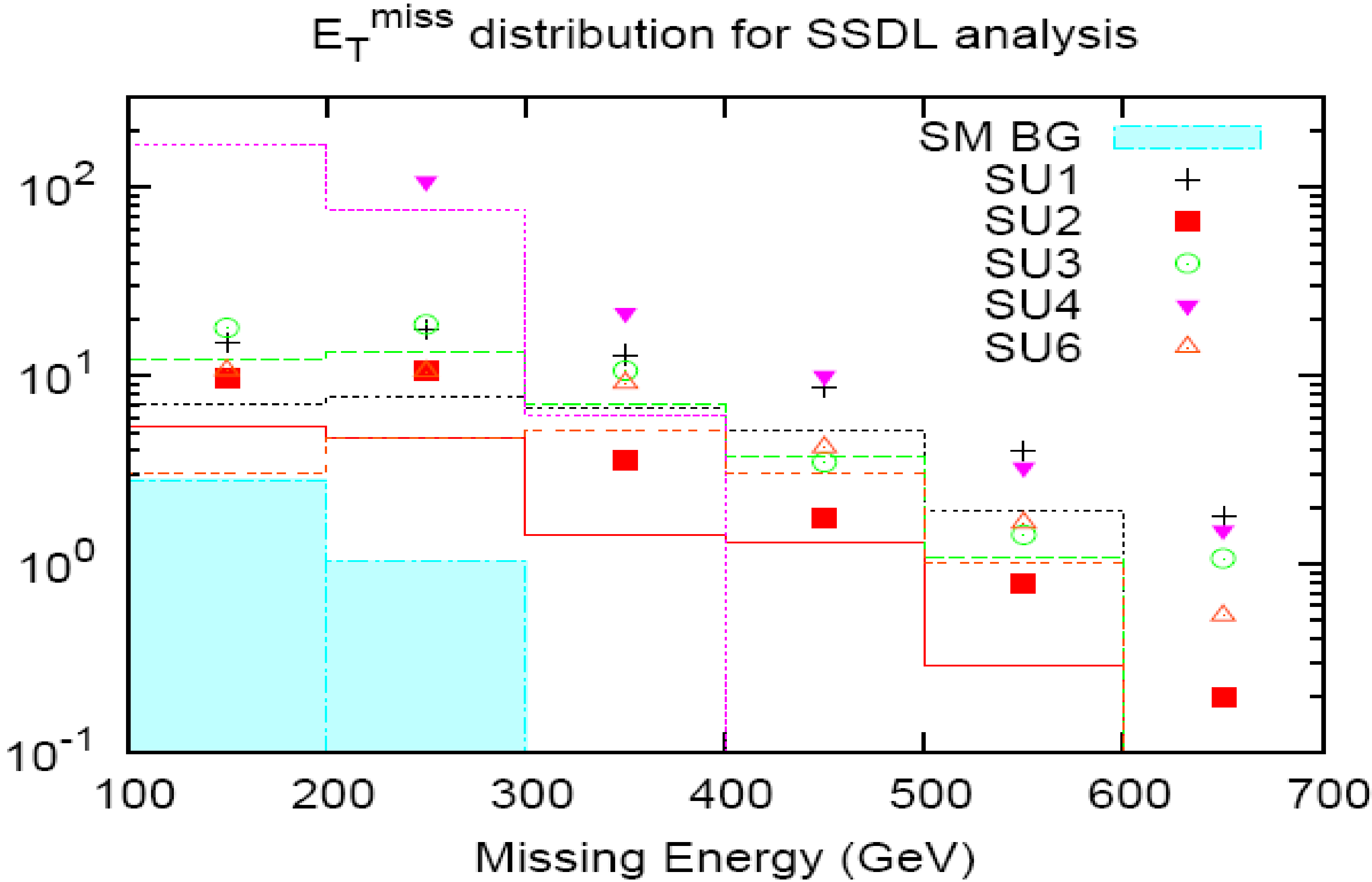
Benchmark Tests: Us vs Them Part II



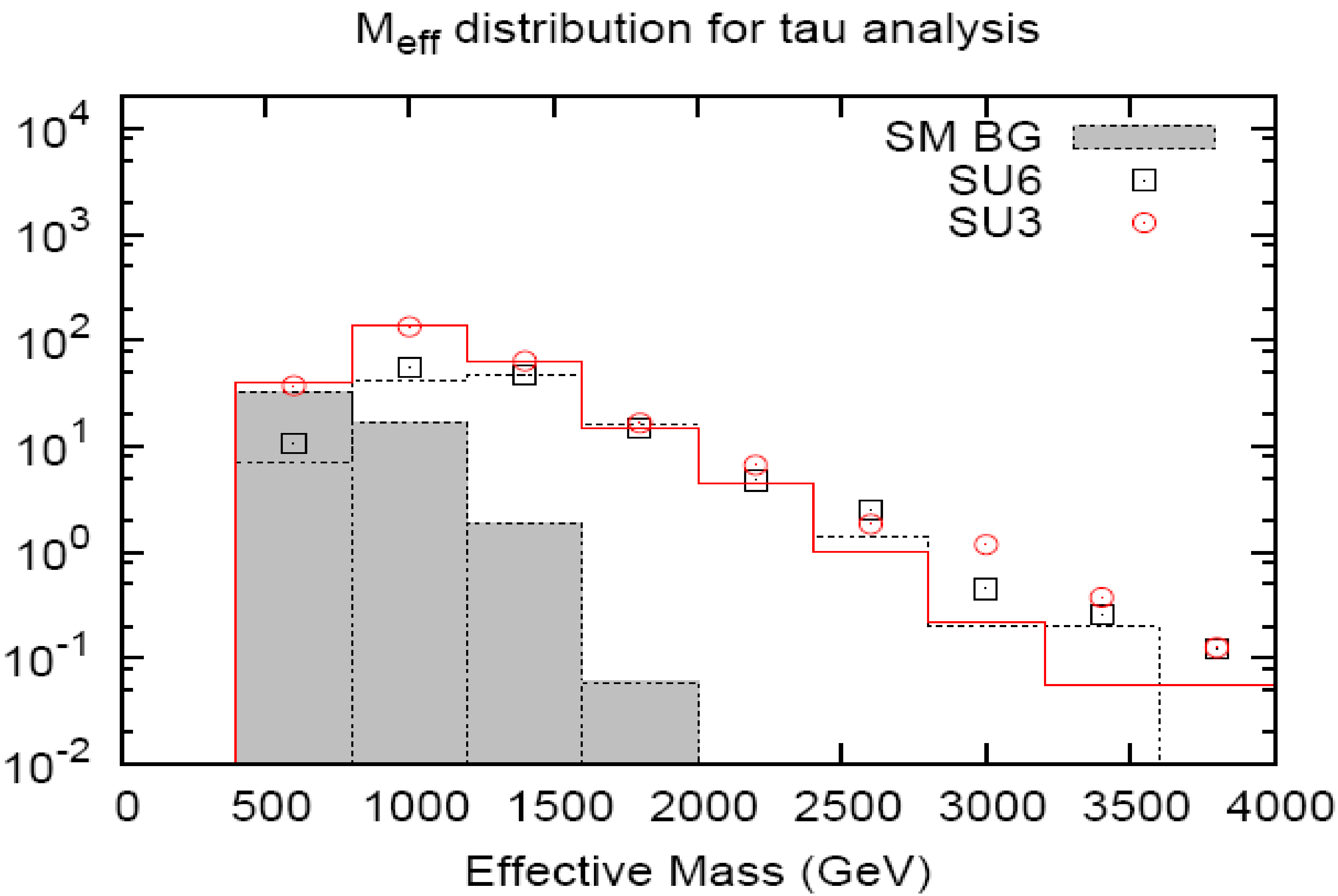
Benchmark Tests: Us vs Them Part III



Benchmark Tests: Us vs Them Part IV



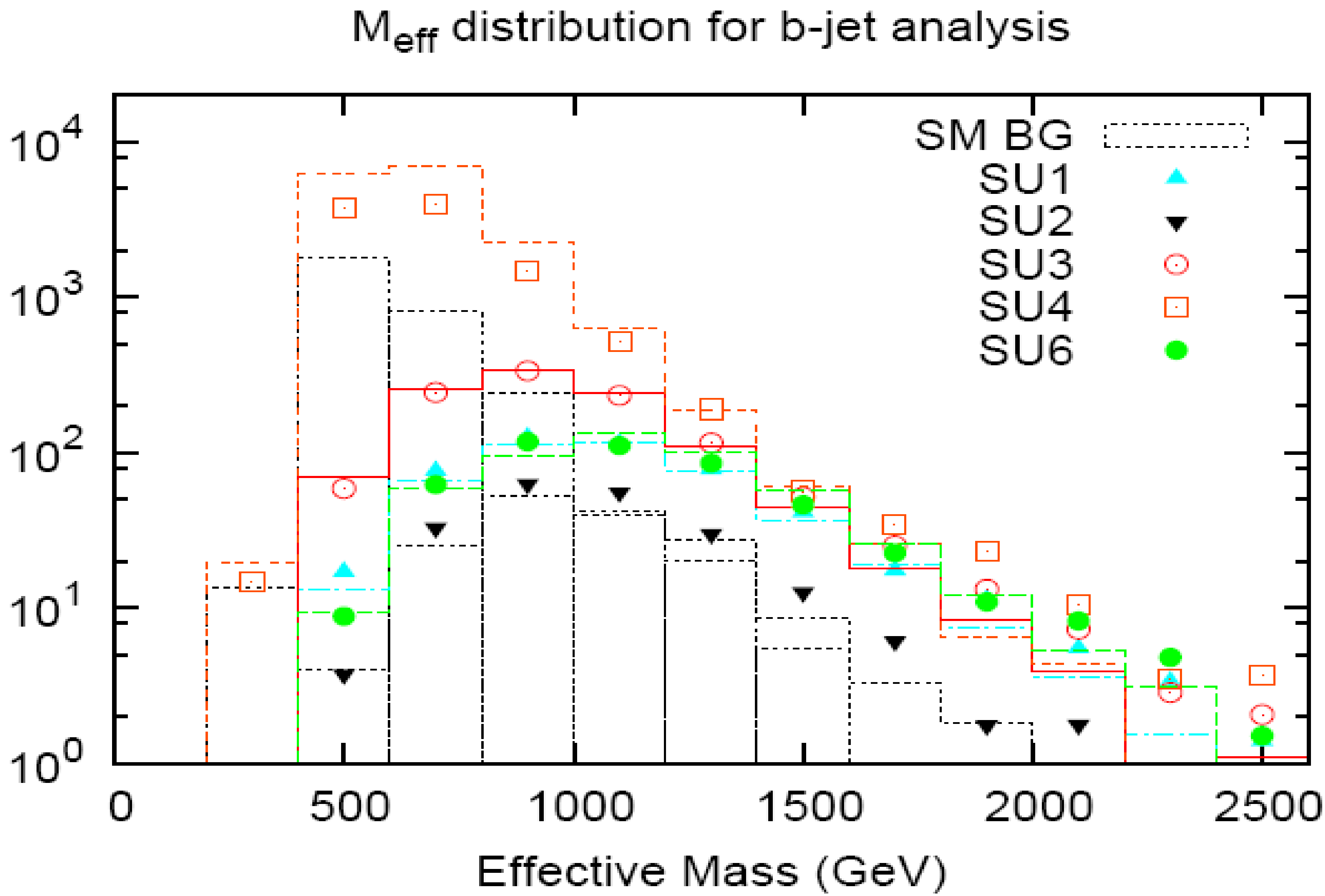
Benchmark Tests: Us vs Them Part V



A Comment:

Although we have reproduced the ATLAS τ analysis results we should be a bit skeptical of PGS4 in this case as it has a low efficiency & a high fake rate for τ's (which we studied in some detail in our analysis) although these seem to approximately compensate ! This *may* lead to this analysis being actually less successful in finding SUSY than the results below will indicate…

Benchmark Tests: Us vs Them Part VI



- We have also reproduced the statistical significance for observability of each of these benchmark points as obtained by ATLAS rather well.

- Hopefully you are now reasonably convinced that we did a respectable job at ‘reproducing’ all of the ATLAS benchmarks points for the various channels given the analysis differences

- Let’s turn now to our model set results… But I can’t show you all these many thousands of tables & figures! One of our problems is the vast amount of information that we have generated. First, some global results..

Aside on Numerics

- FLAT: 68422 models , 38 ‘lost’ due to unreadable event files, (19 ‘NaNs’ in SUSY-HIT) $\rightarrow$ 68384, 1460 w/ $\geq$ 1 PYSTOPs $\rightarrow$ 66294

- LOG: 2908 models , 1 ‘lost’ due to an unreadable event file $\rightarrow$ 2907, 13 w/ $\geq$ 1 PYSTOPs $\rightarrow$ 2894

```
#         PDG            Width
DECAY   1000037                 NAN   # chargino2+ decays
#          BR          NDA       ID1       ID2
              NAN     2     1000002       -1    # BR(~chi_2+ -> ~u_L     db)
              NAN     2     2000002       -1    # BR(~chi_2+ -> ~u_R     db)
              NAN     2    -1000001        2    # BR(~chi_2+ -> ~d_L*    u )
              NAN     2    -2000001        2    # BR(~chi_2+ -> ~d_R*    u )
              NAN     2     1000004       -3    # BR(~chi_2+ -> ~c_L     sb)
              NAN     2     2000004       -3    # BR(~chi_2+ -> ~c_R     sb)
              NAN     2    -1000003        4    # BR(~chi_2+ -> ~s_L*     c )
              NAN     2    -2000003        4    # BR(~chi_2+ -> ~s_R*     c )
              NAN     2     1000006       -5    # BR(~chi_2+ -> ~t_1     bb)
              NAN     2     2000006       -5    # BR(~chi_2+ -> ~t_2     bb)
              NAN     2    -1000005        6    # BR(~chi_2+ -> ~b_1*    t )
              NAN     2    -2000005        6    # BR(~chi_2+ -> ~b_2*    t )
              NAN     2     1000012      -11    # BR(~chi_2+ -> ~nu_eL   e+  )
              NAN     2     1000014      -13    # BR(~chi_2+ -> ~nu_muL mu+ )
              NAN     2     1000016      -15    # BR(~chi_2+ -> ~nu_tau1 tau+)
              NAN     2    -1000011       12    # BR(~chi_2+ -> ~e_L+    nu_e)
              NAN     2    -2000011       12    # BR(~chi_2+ -> ~e_R+    nu_e)
              NAN     2    -1000013       14    # BR(~chi_2+ -> ~mu_L+   nu_mu)
              NAN     2    -2000013       14    # BR(~chi_2+ -> ~mu_R+   nu_mu)
              NAN     2    -1000015       16    # BR(~chi_2+ -> ~tau_1+  nu_tau)
              NAN     2    -2000015       16    # BR(~chi_2+ -> ~tau_2+  nu_tau)
              NAN     2     1000024       23    # BR(~chi_2+ -> ~chi_1+  Z )
              NAN     2     1000022       24    # BR(~chi_2+ -> ~chi_10  W+)
              NAN     2     1000023       24    # BR(~chi_2+ -> ~chi_20  W+)
              NAN     2     1000025       24    # BR(~chi_2+ -> ~chi_30  W+)
              NAN     2     1000035       24    # BR(~chi_2+ -> ~chi_40  W+)
              NAN     2     1000024       25    # BR(~chi_2+ -> ~chi_1+  h )
              NAN     2     1000024       35    # BR(~chi_2+ -> ~chi_1+  H )
              NAN     2     1000024       36    # BR(~chi_2+ -> ~chi_1+  A )
              NAN     2     1000022       37    # BR(~chi_2+ -> ~chi_10  H+)
              NAN     2     1000023       37    # BR(~chi_2+ -> ~chi_20  H+)
              NAN     2     1000025       37    # BR(~chi_2+ -> ~chi_30  H+)
              NAN     2     1000035       37    # BR(~chi_2+ -> ~chi_40  H+)
```

Sample ‘NaN’ SUSY-HIT file for Model 6729

Most common for the 2nd chargino. Why?

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 are LOTS of different decay chains here !

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 luminosity DOES help in many cases… but not always. The most interesting cases will be when it doesn't!

The number of models 'found' by n 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 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 %)

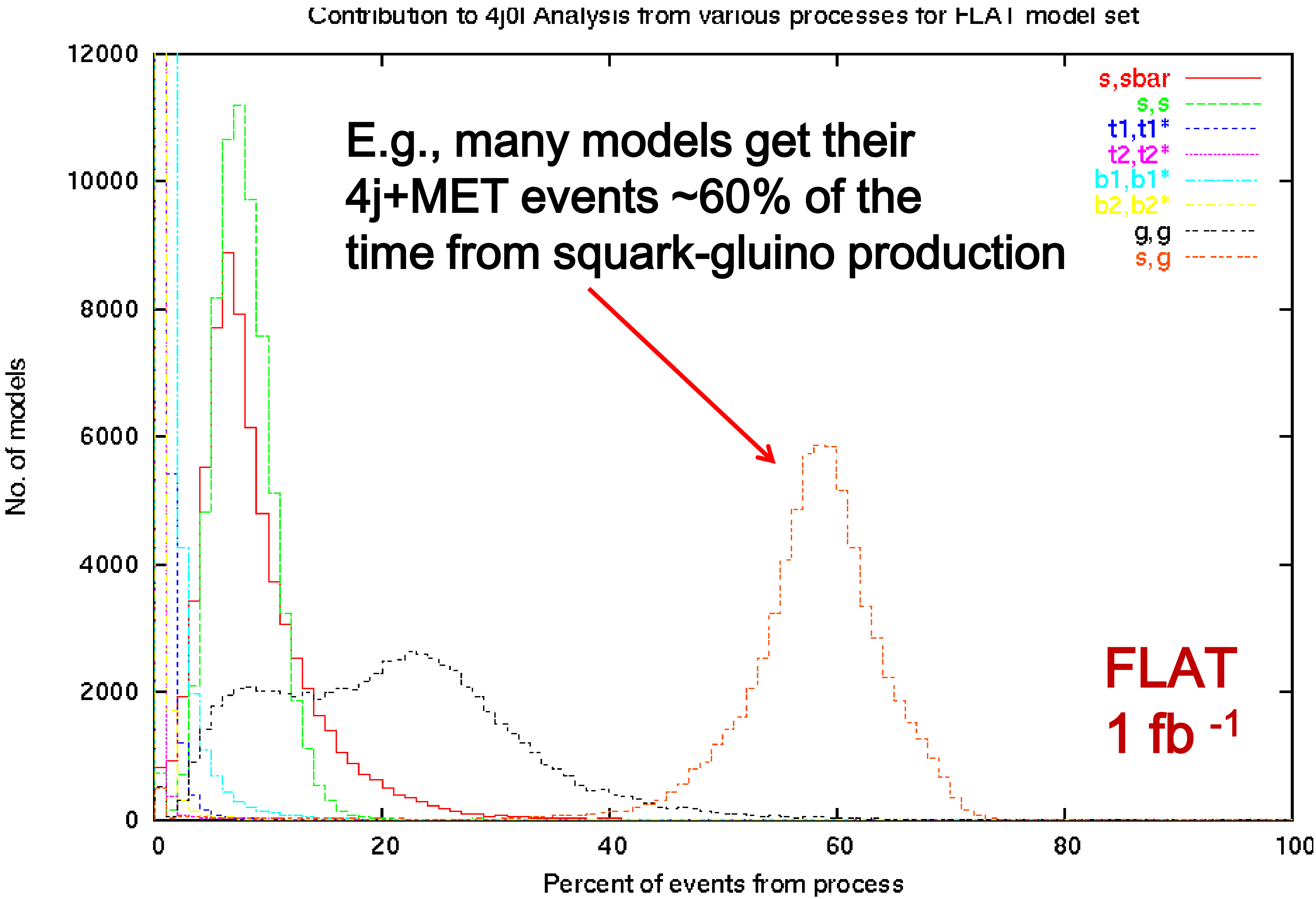
More lumi clearly helps..

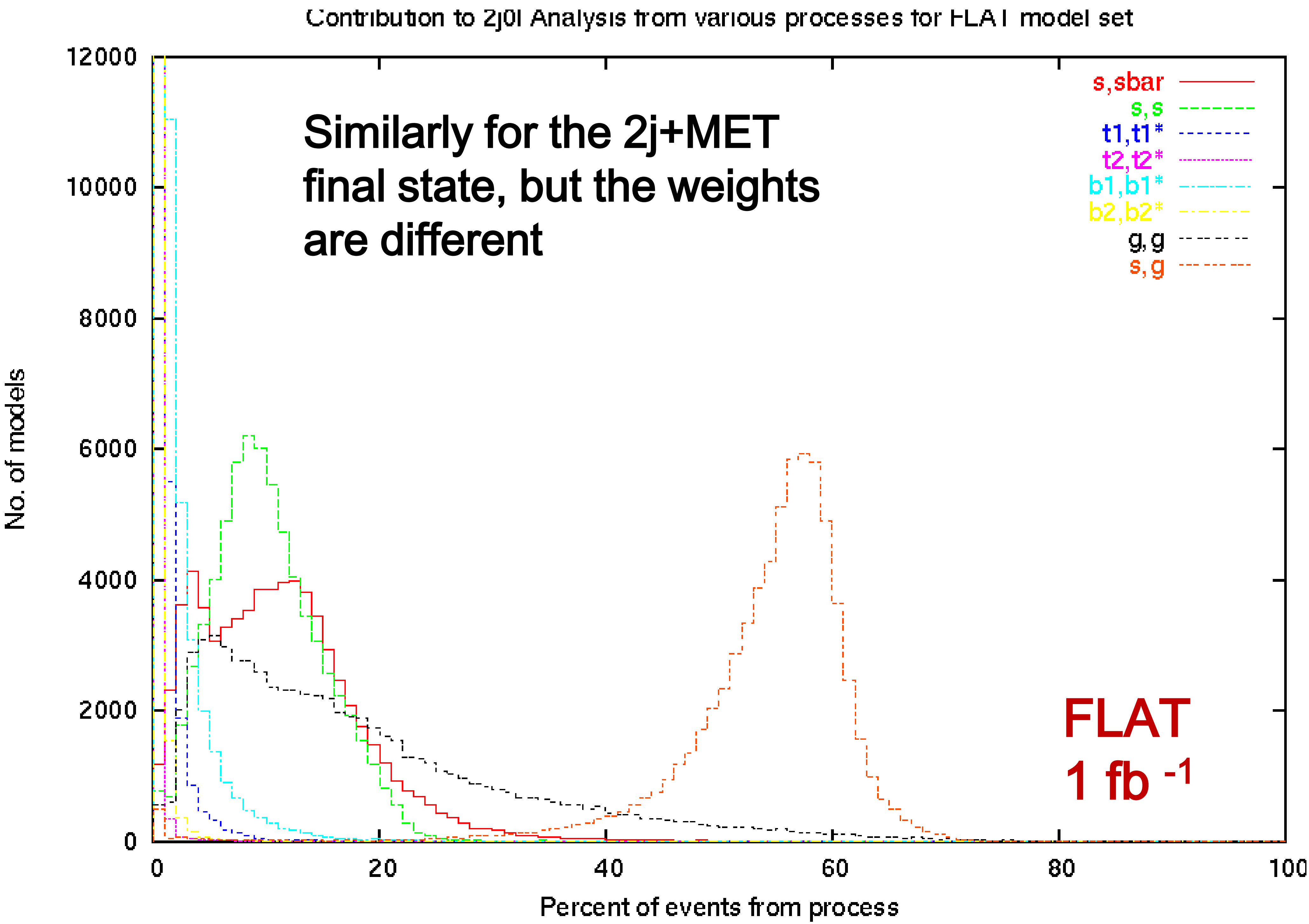
Why Do Models Get Missed by ATLAS?

This is not possible to answer universally but there are some obvious causes…sometimes we just need more luminosity as we saw above…but that's not the only reason. The other reasons are more interesting, of course, & these are being investigated.

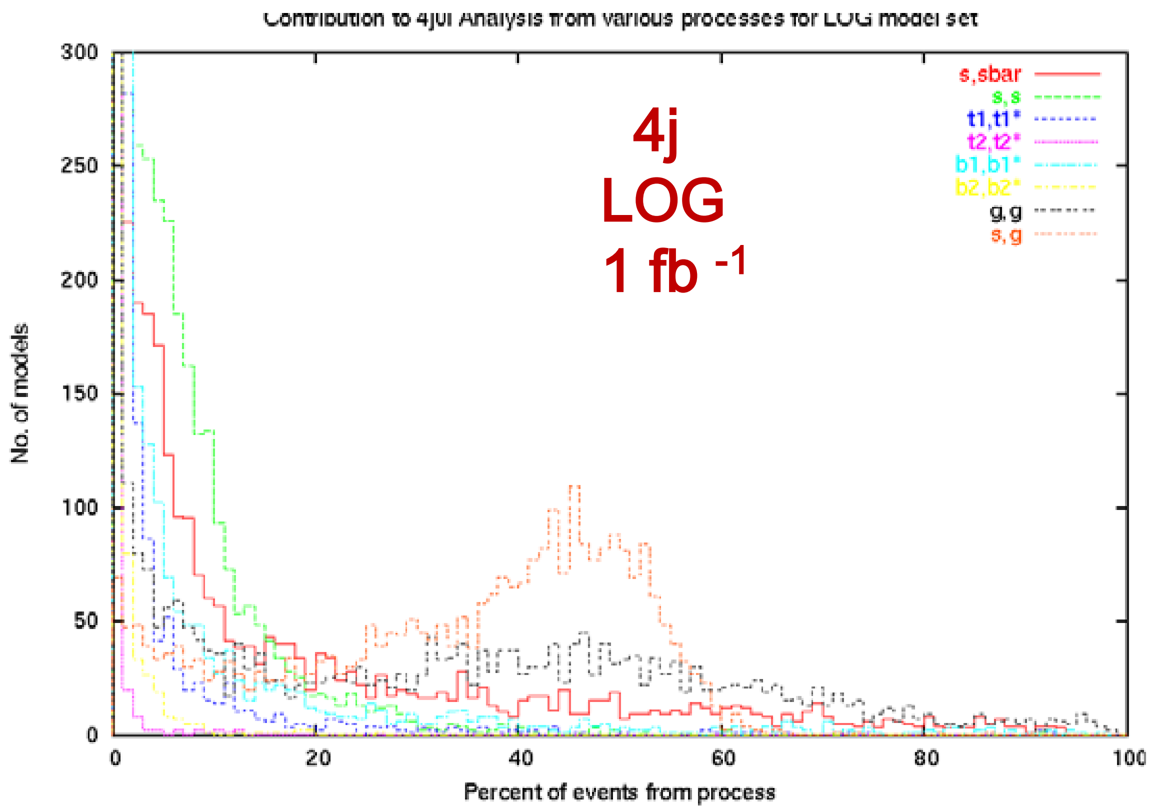
Let's first look at the 2j/4j+MET analyses as examples since they generally have the best reach in the mSUGRA/CMSSM context.

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



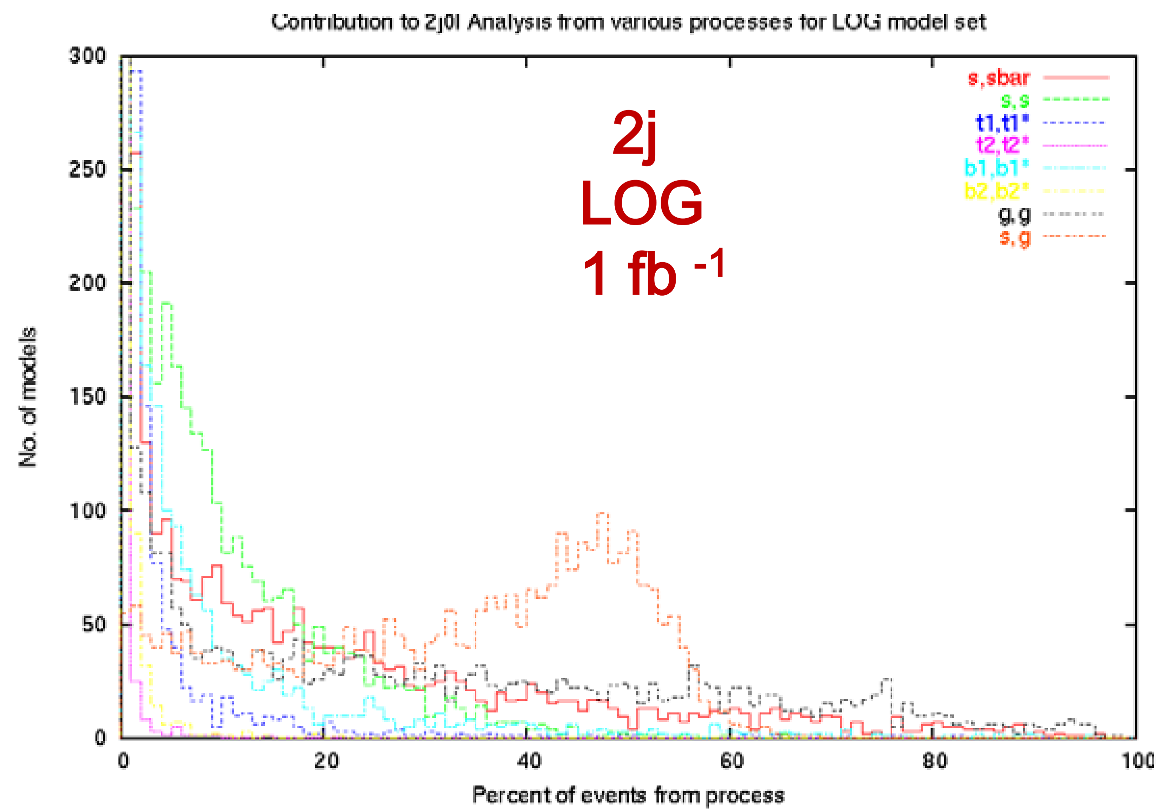


Contribution to 2j0l Analysis from various processes for FLAT model set
Similarly for the 2j+MET final state, but the weights are different
s,sbar
s,s
t1,t1*
t2,t2*
b1,b1*
b2,b2*
g,g
s,g
FLAT
1 fb -1
No. of models
Percent of events from process
0
2000
4000
6000
8000
10000
12000
20
40
60
80
100



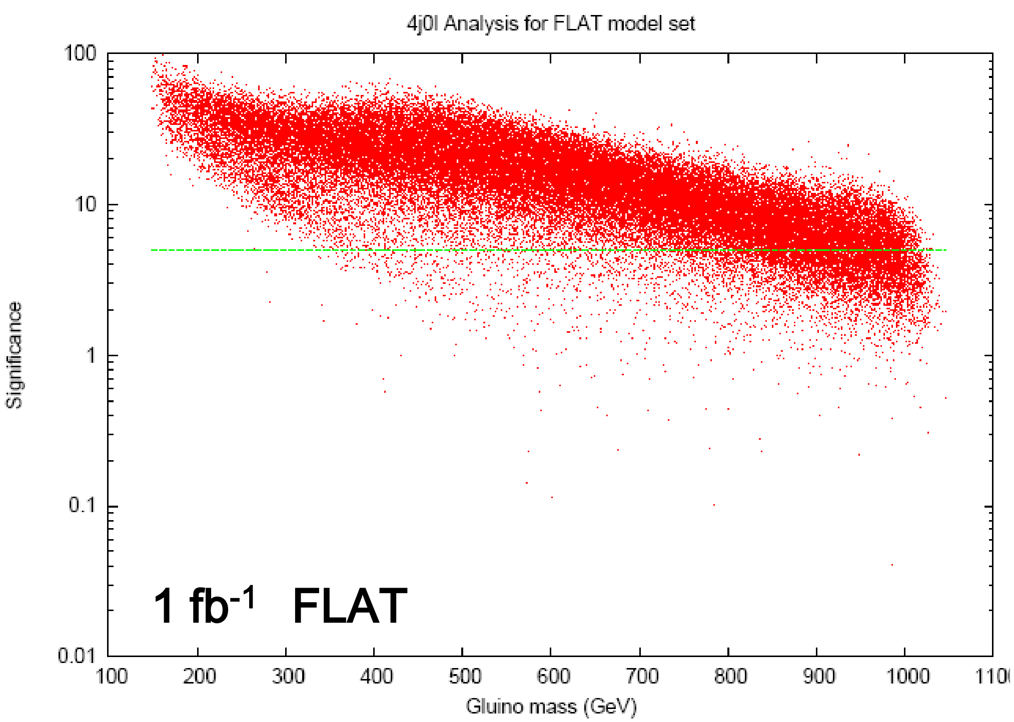
These contributions do change significantly when the LOG prior models are examined…

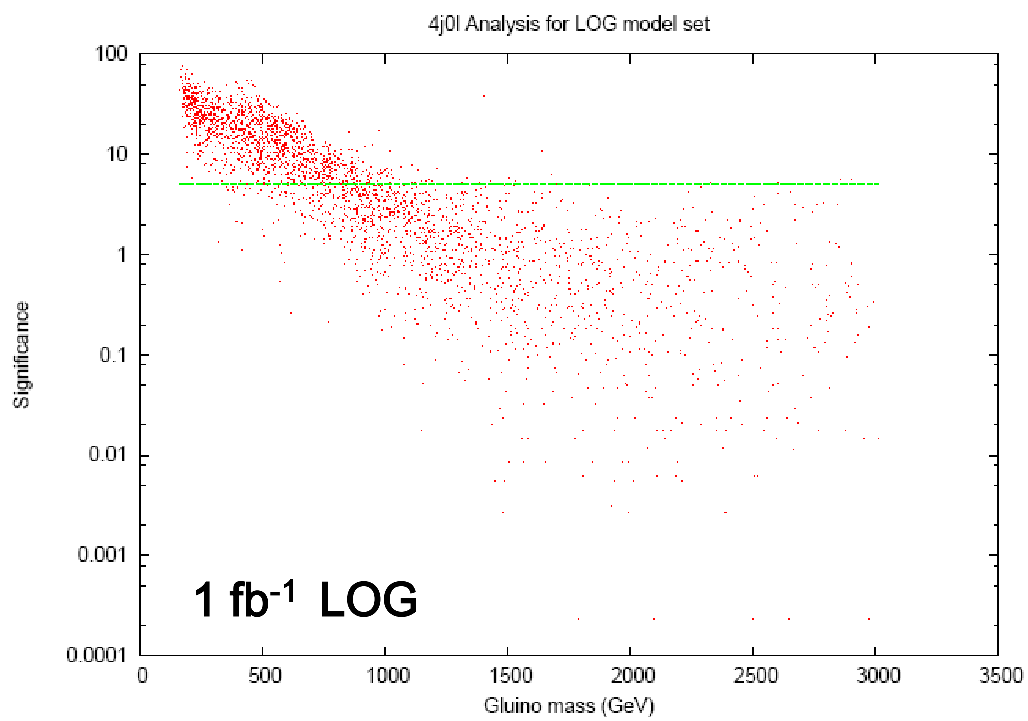
This is likely due to the relative compression in the sparticle mass spectrum in the LOG prior model case



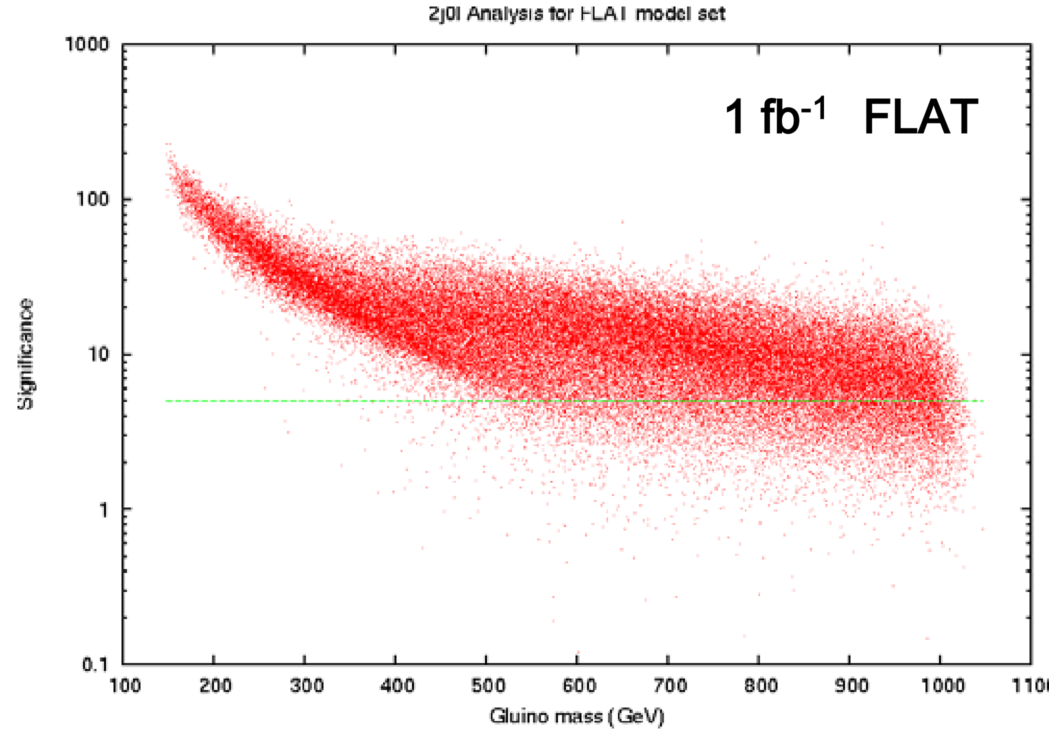
Missed Models: Is it 'just the mass' ??

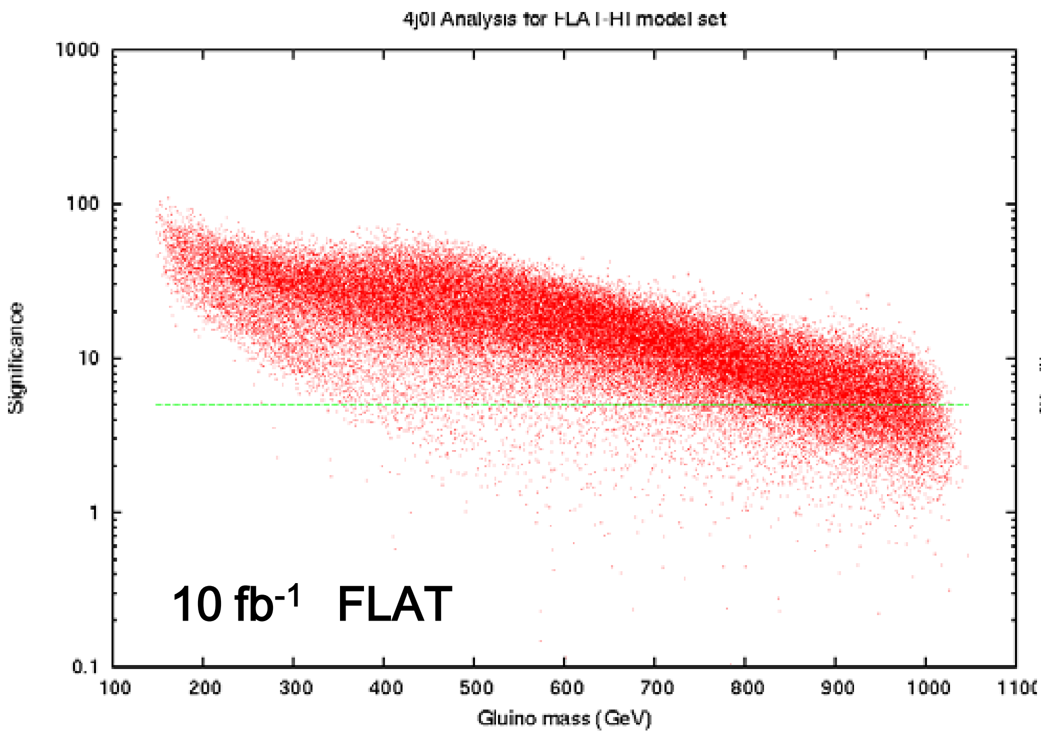
Here we see the significances for the 4j+MET search…there IS a GENERAL reduction in S as the gluino mass increases. BUT we also see that there is quite a spread in significance at any fixed value of the mass.

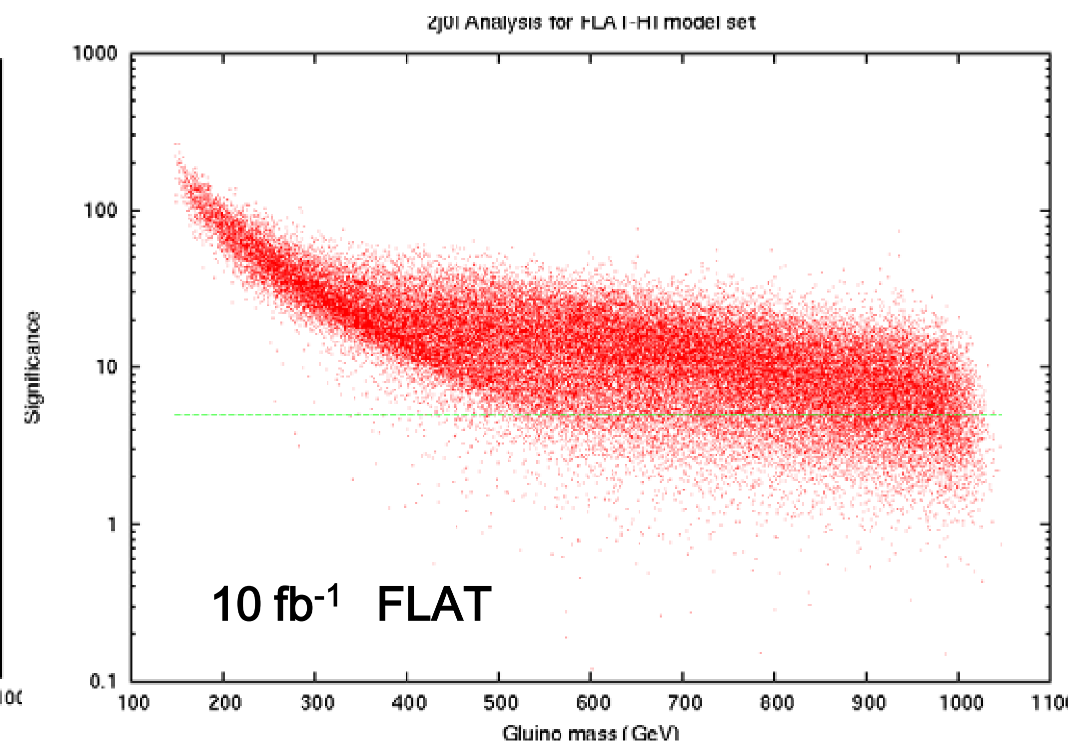


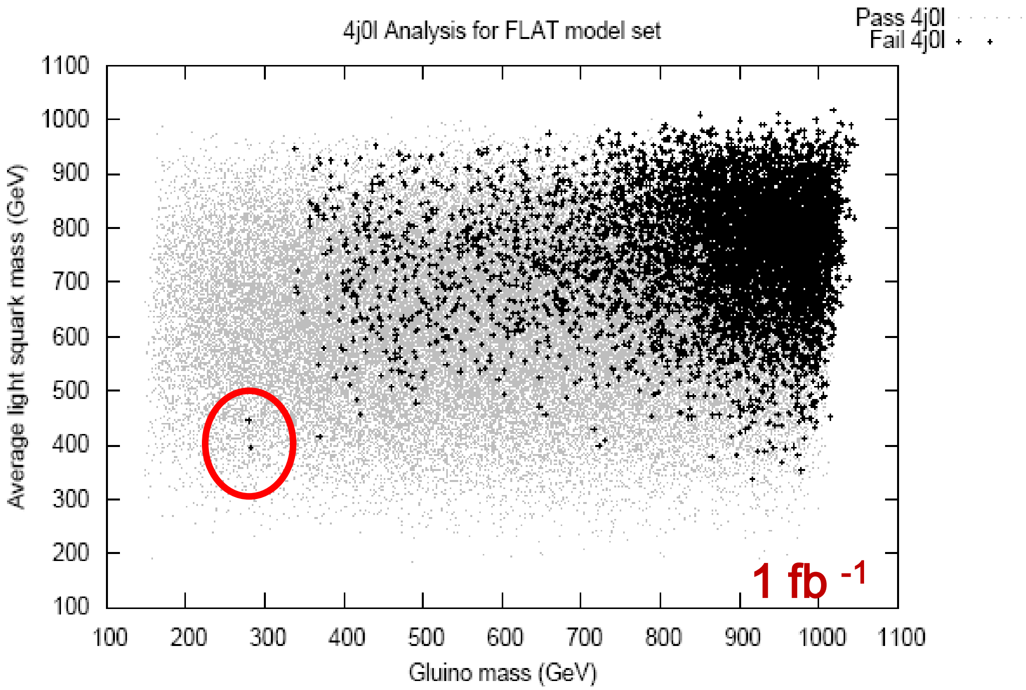


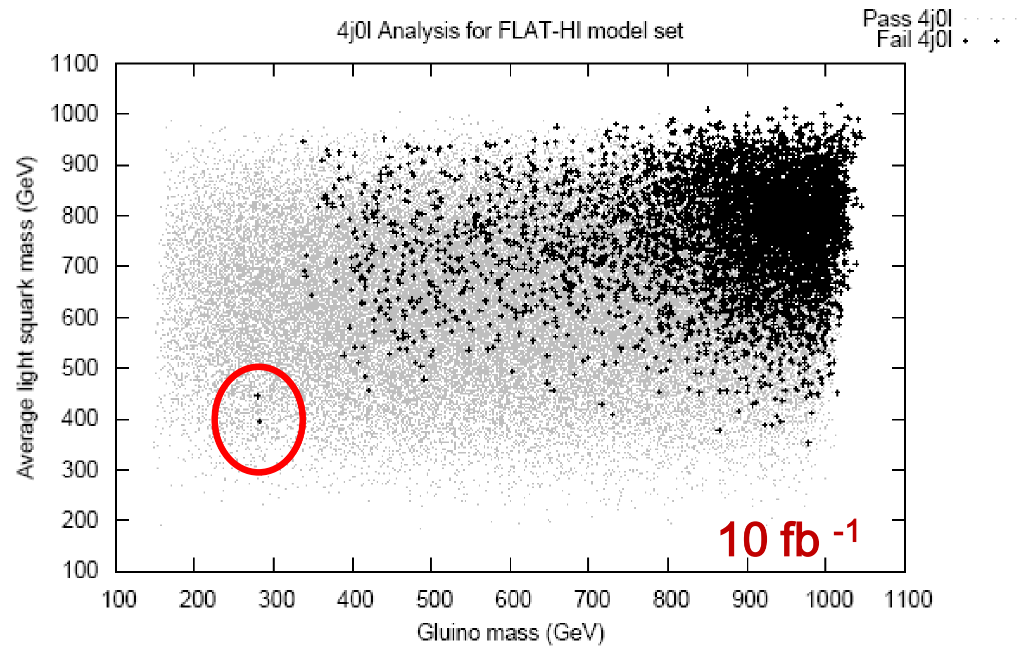
Here are some variations on a theme: the 2j+MET results are similar. Increasing the lumi to 10 fb^{-1} in either case will only raise the overall significance distribution slightly



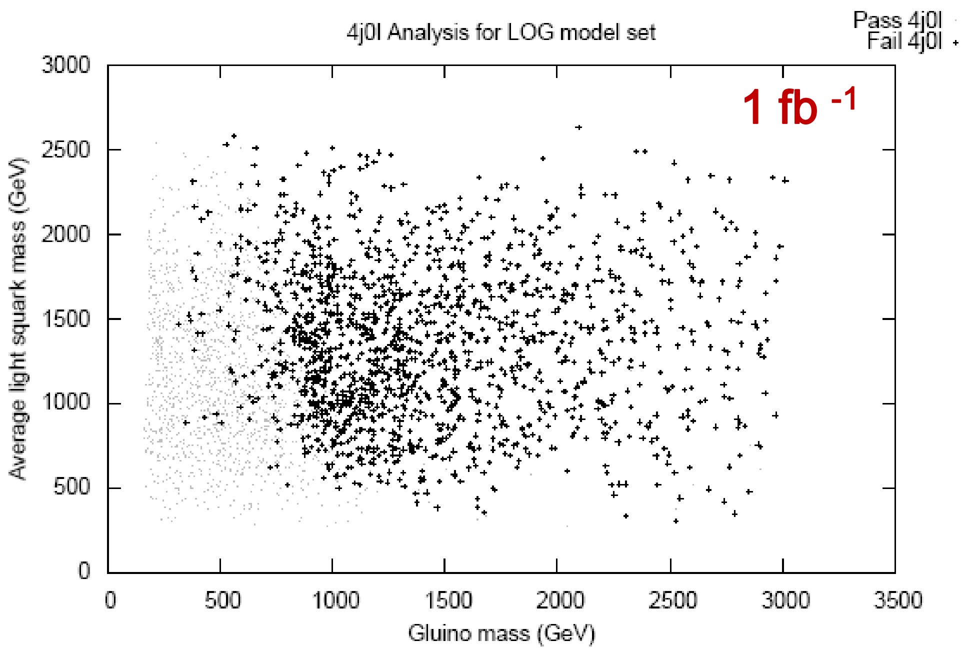


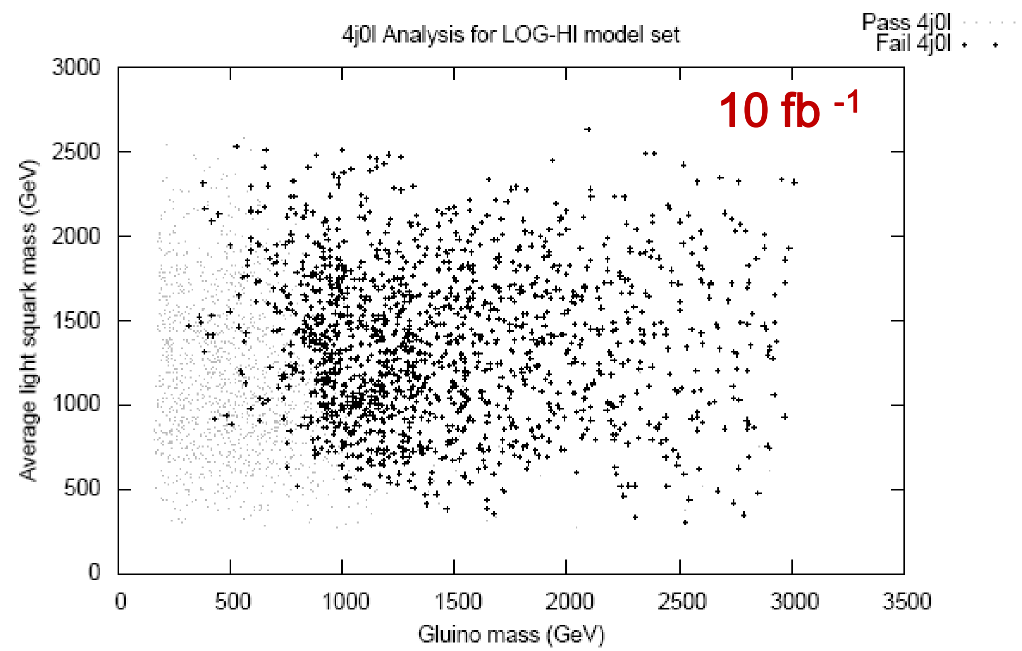


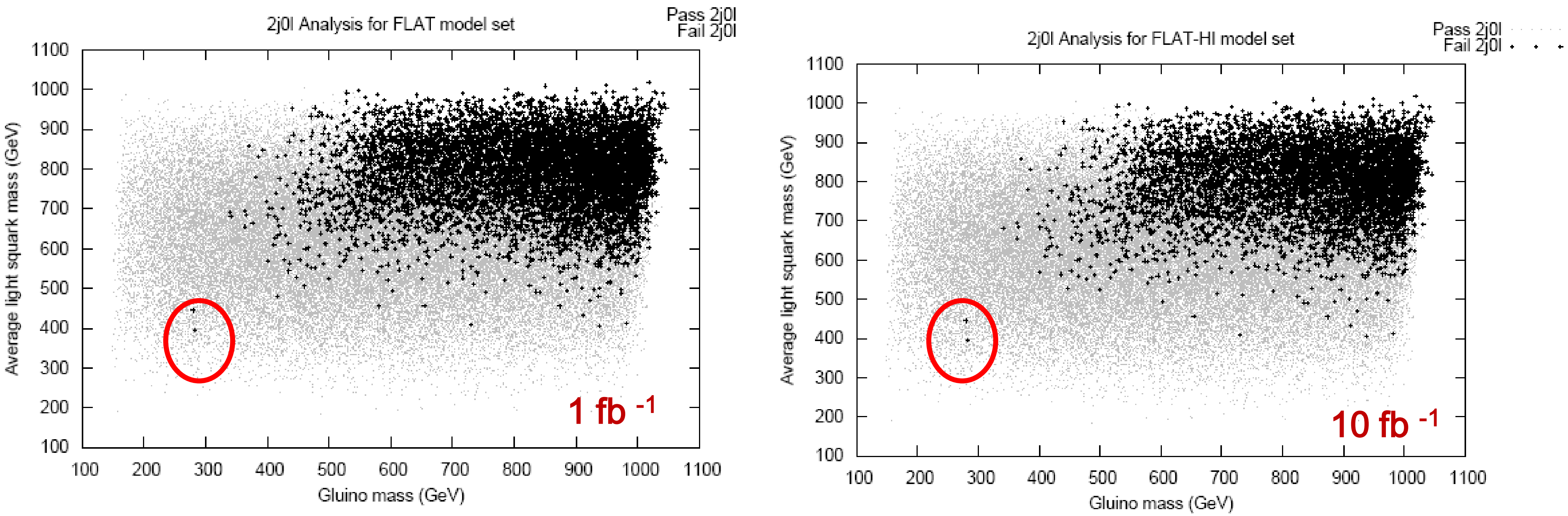




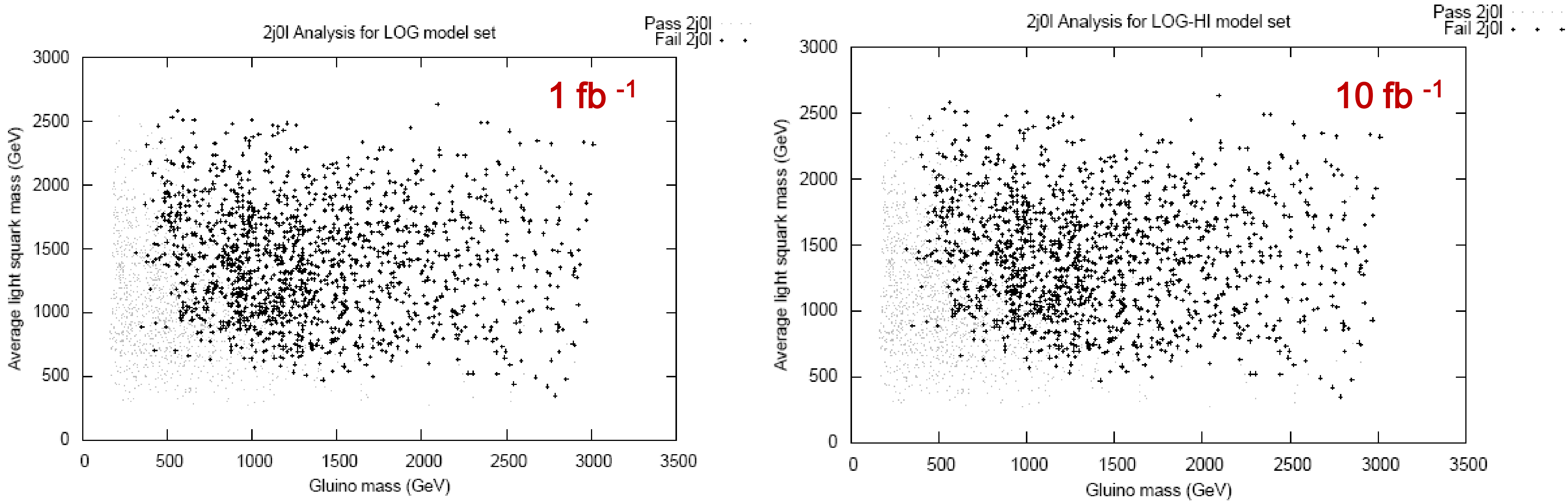
Some models w/ light squarks & gluinos ARE missed here & adding lumi does not necessarily help in all cases





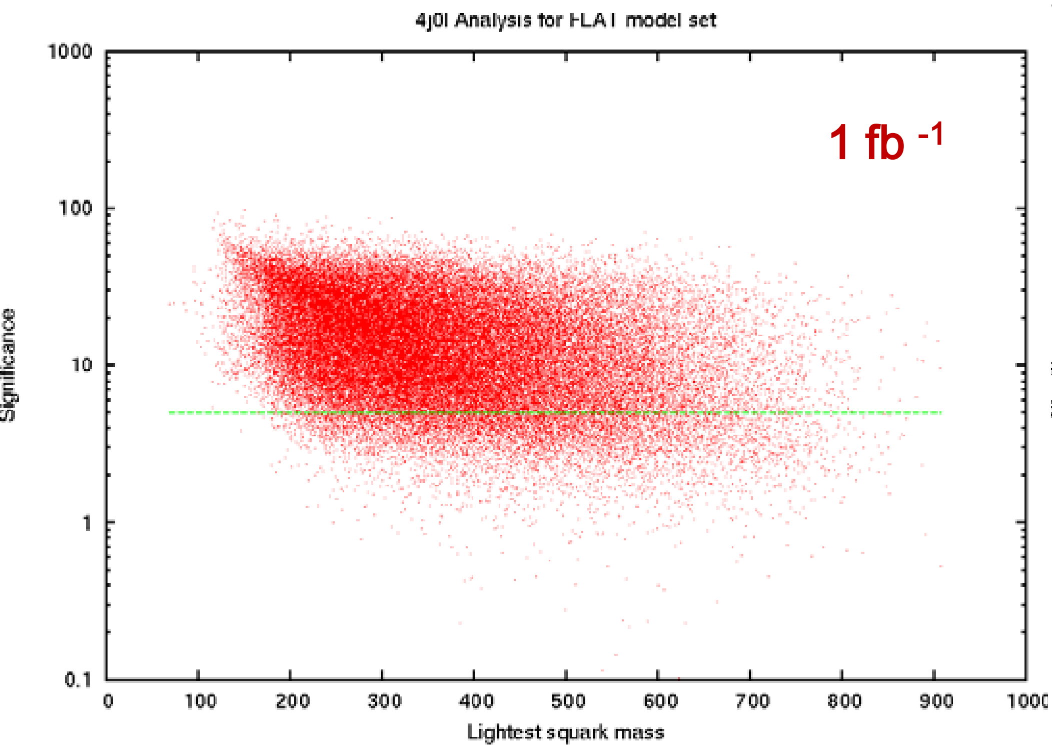


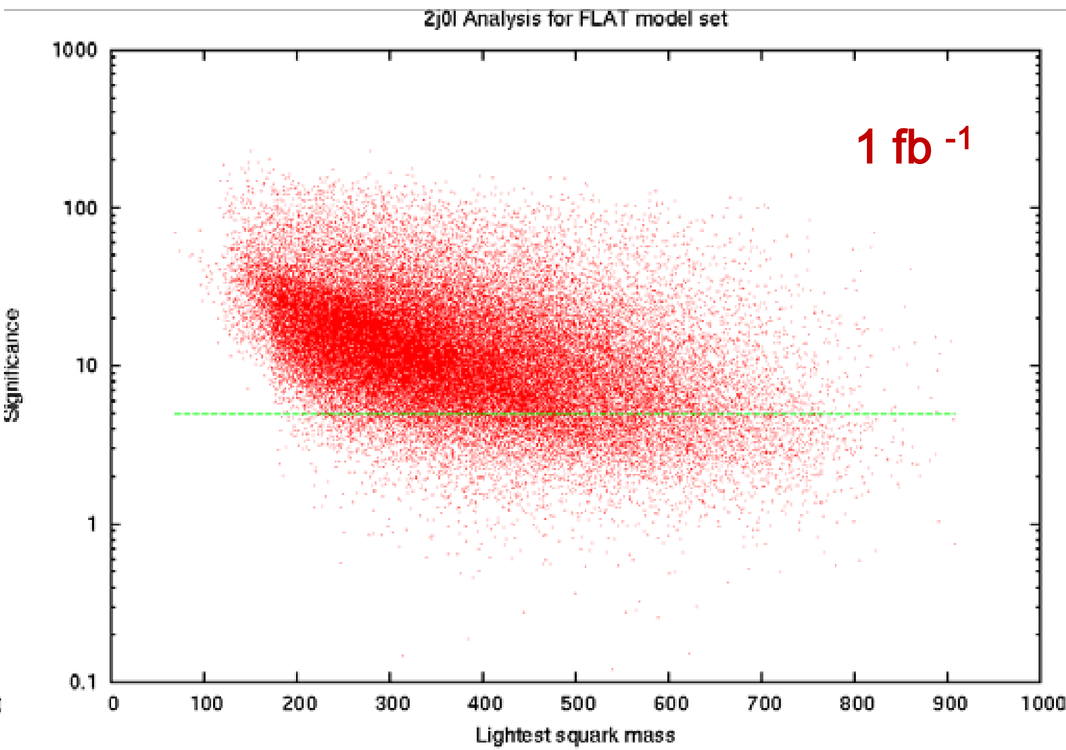
The same holds true for the 2j+MET analysis



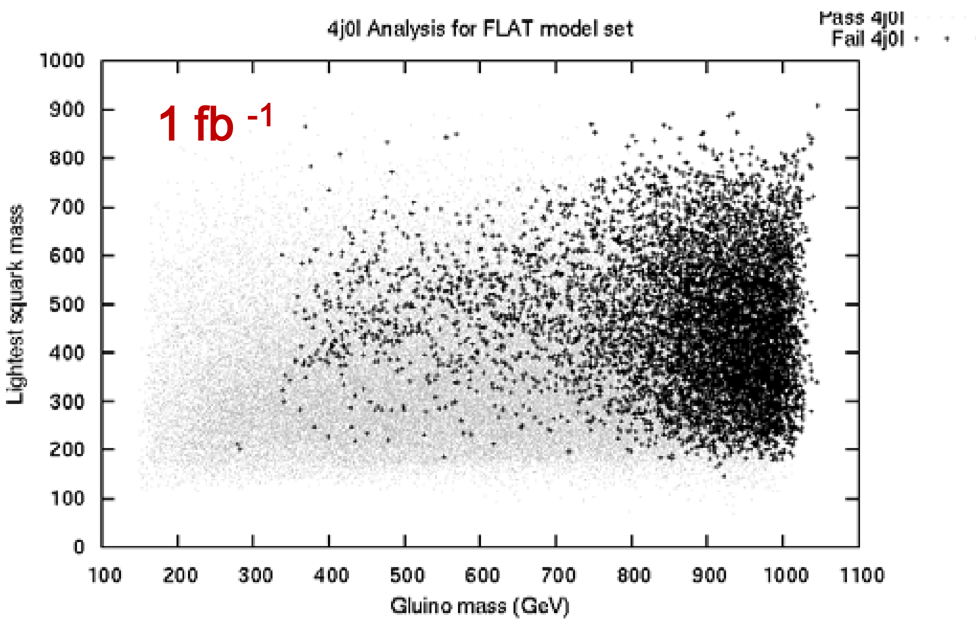
Search Significance Correlations : Dependence on the Lightest Squark Mass

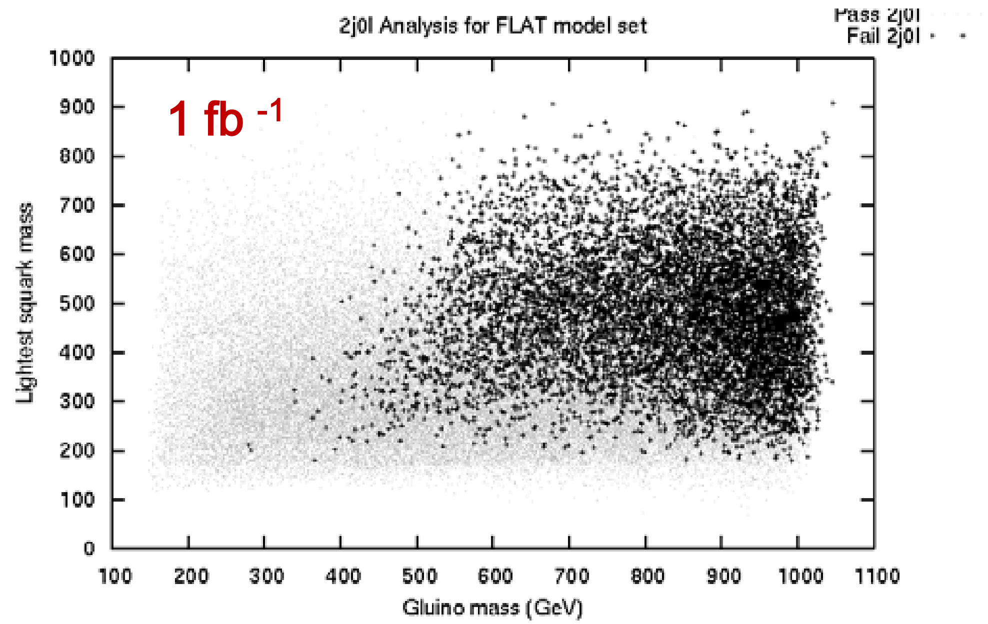
As the lightest of the u,d-squarks get heavier one might expect a qualitative fall off in the signal significance in the 2j &4j+MET searches… here we see that this correlation is rather weak.

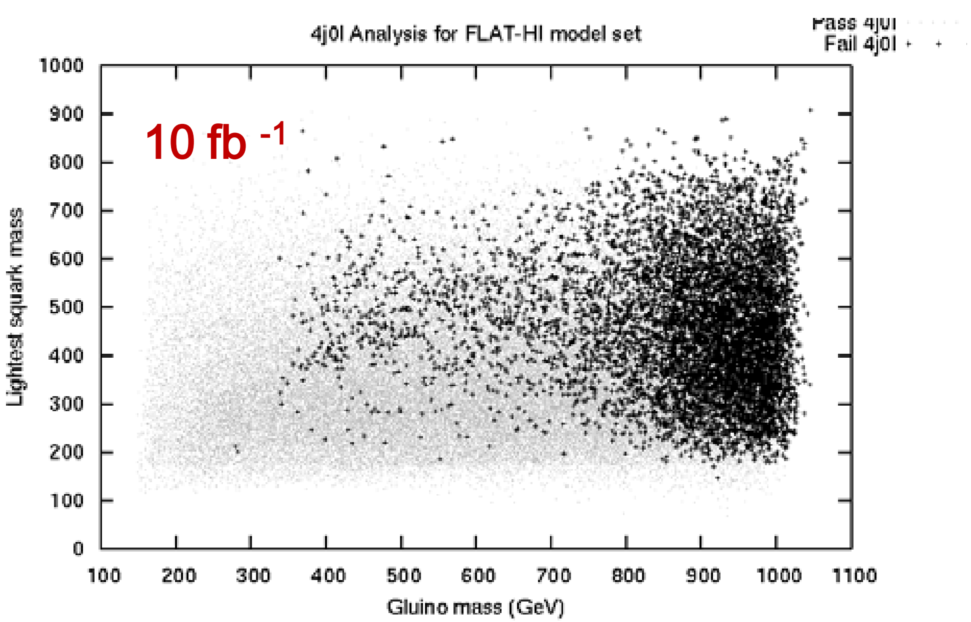


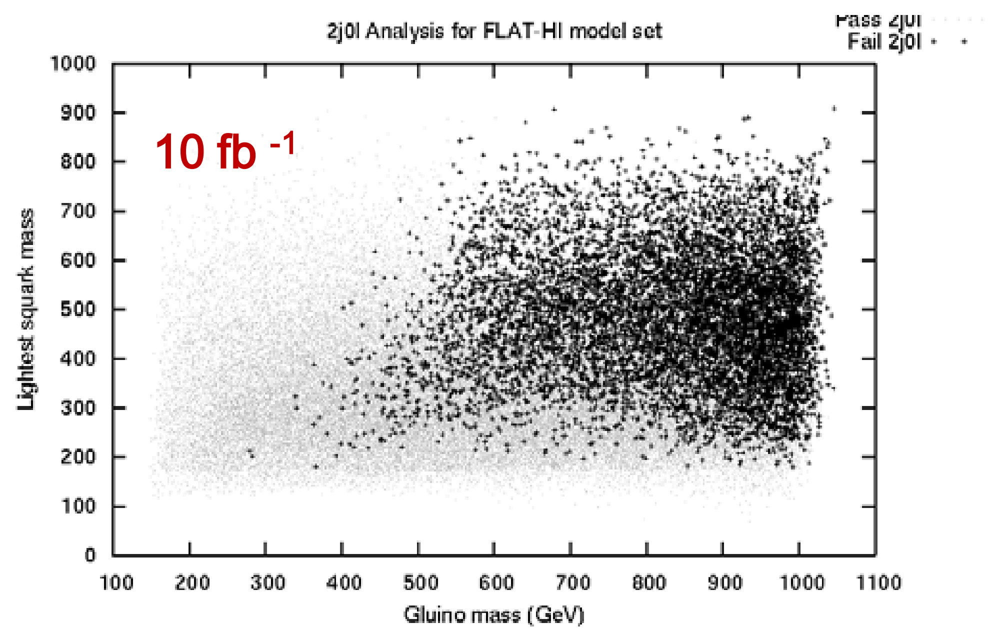


Lightest Squark Mass vs. Gluino Mass

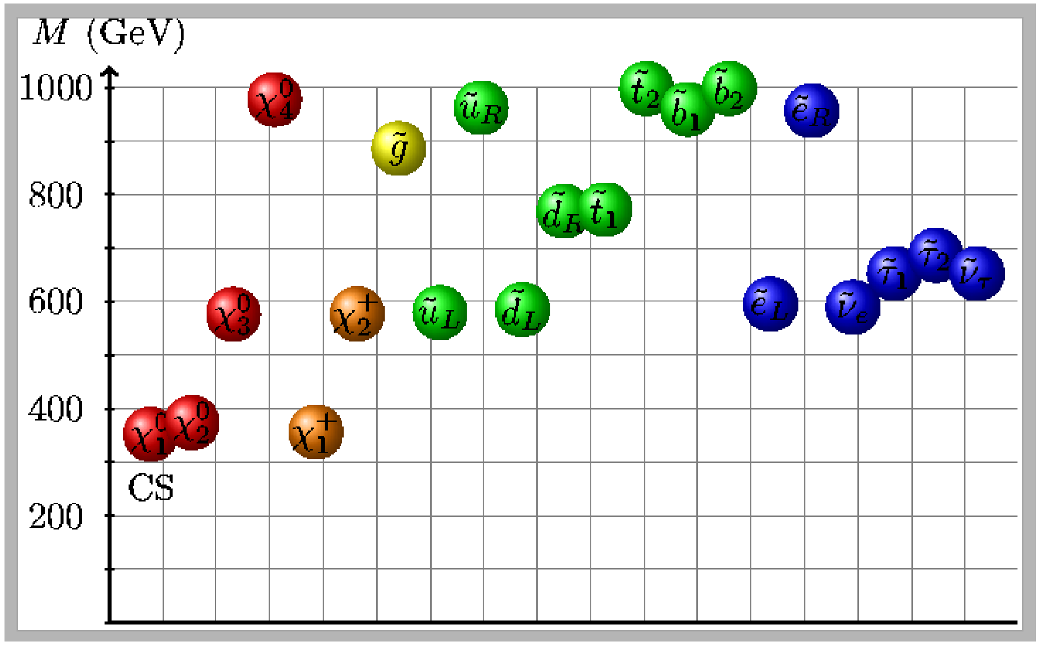








Example: Model 590



gluino(886.1) → $\tilde{u}_L$ (579.3)+j , $\tilde{d}_L$ (584.8)+j, $\tilde{d}_R$ (788.7)+j

$\tilde{u},\tilde{d}_L$ → $\tilde{\chi}_1^{\pm}$ (356.4)+j , (~2/3) $\tilde{\chi}_1^0$ (352.1) +j, (~1/3)

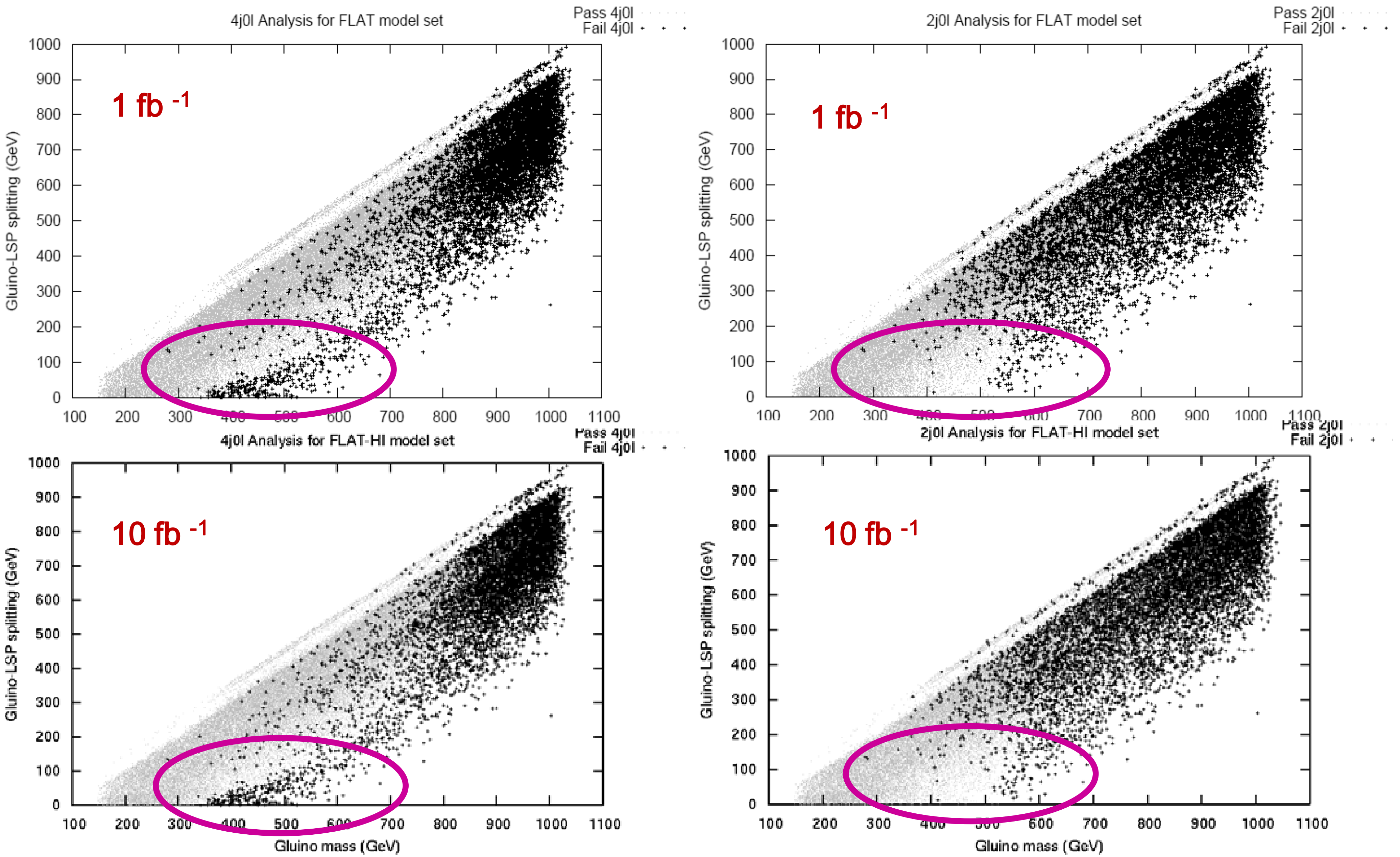
$\tilde{\chi}_1^{\pm}$ → ff' + LSP (Δm=4.2 GeV)

$\tilde{d}_R$ → $\tilde{\chi}_{1,2}^0$ (352.1, 373.6) +j

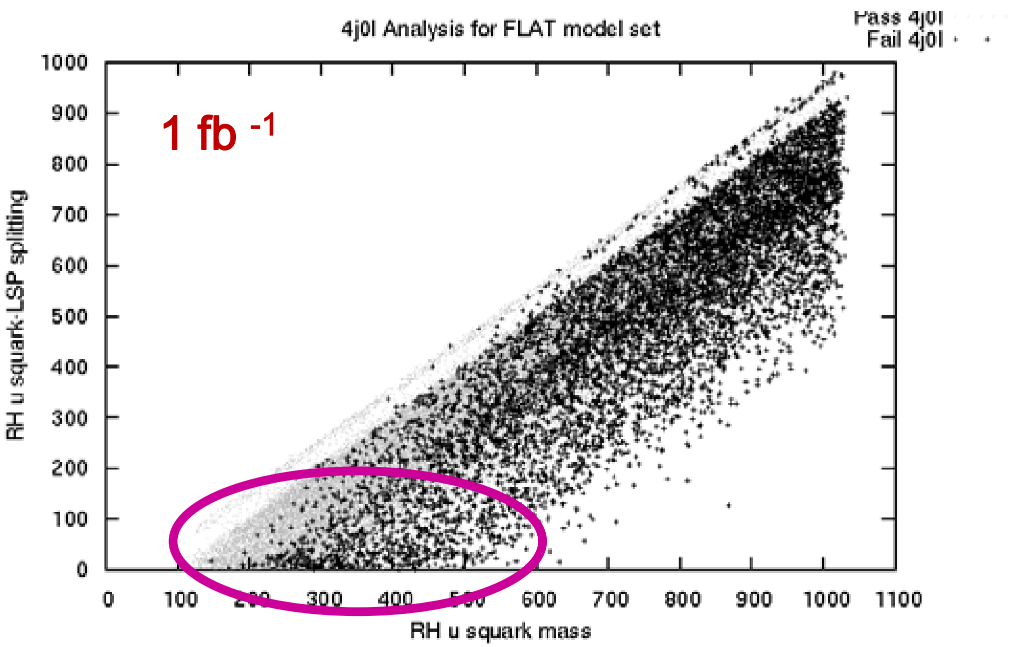
$\tilde{\chi}_2^0$ → $\tilde{\chi}_1^0$ +ff (Δm=21.4 GeV)

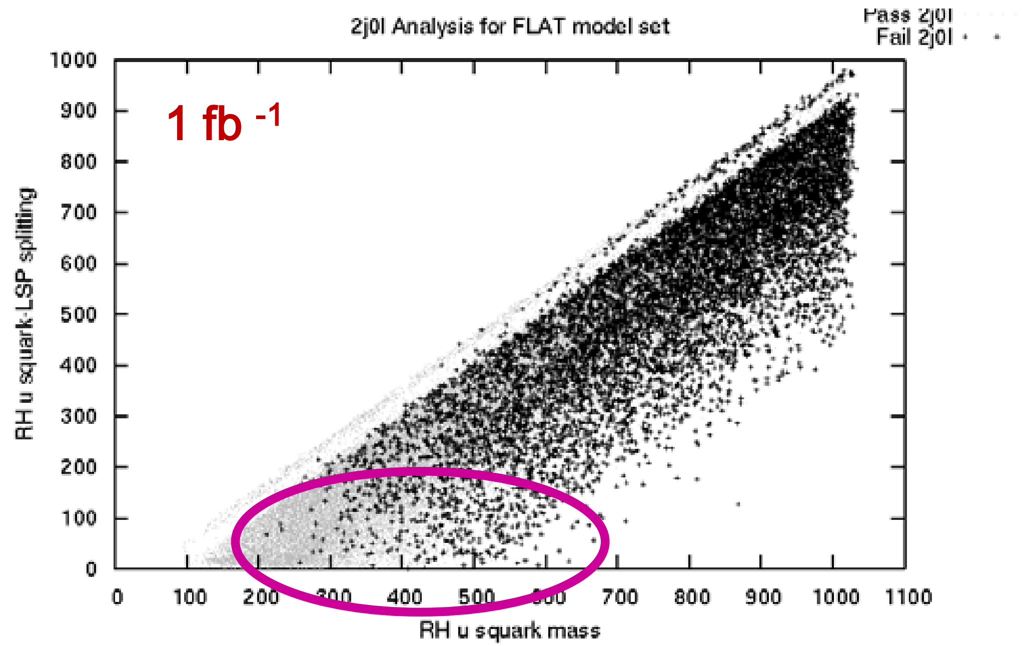
Needs 10 fb^{-1} to have S>5

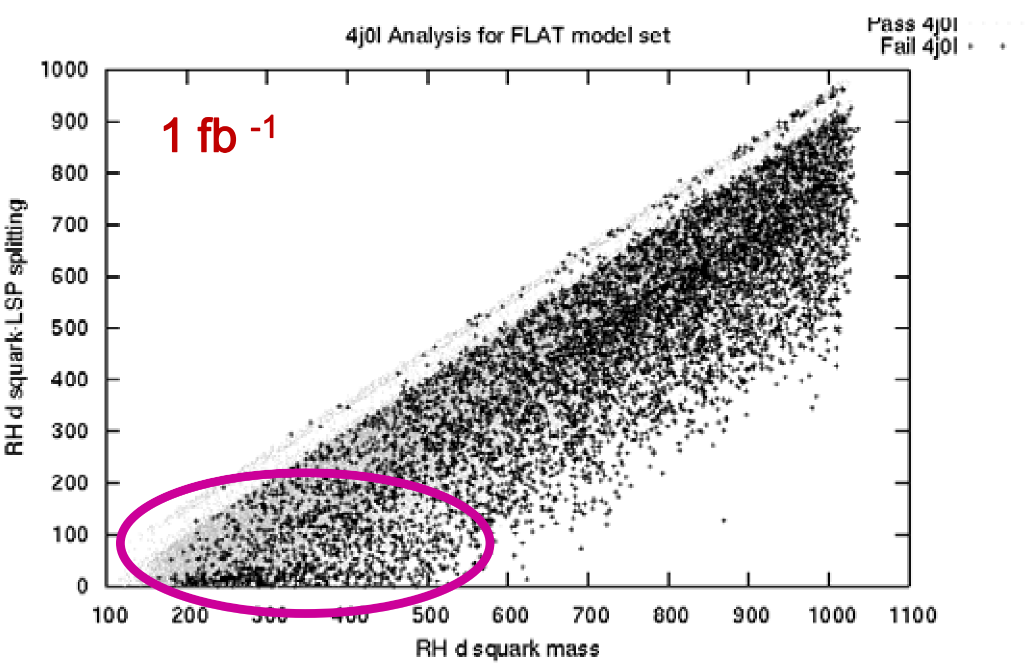
Mass splittings leading to soft jets can be very important.. but that's not all of it either :

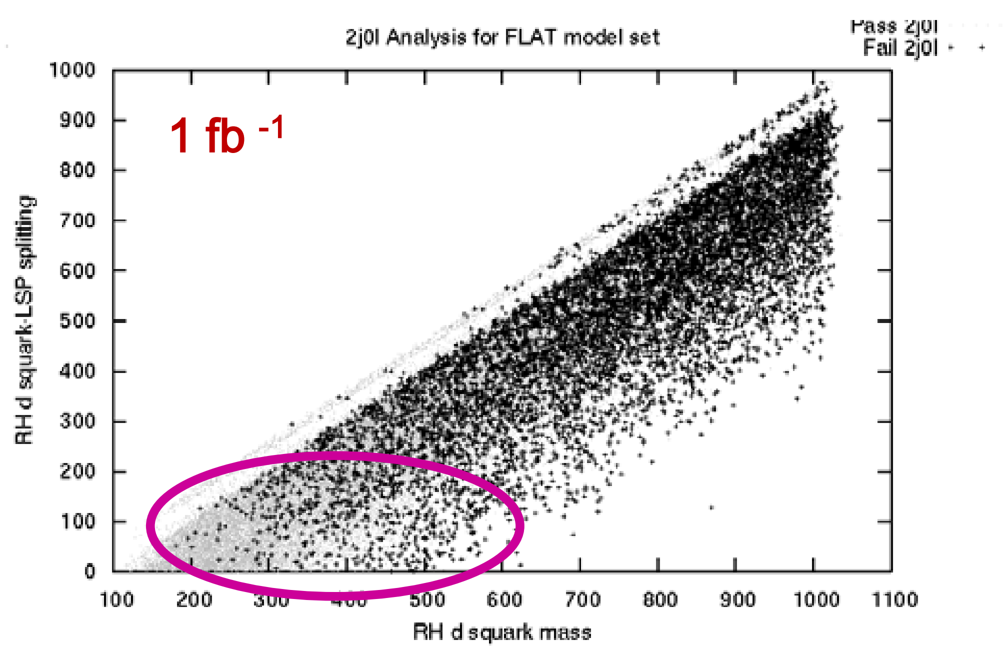


Even weaker correlation for squarks

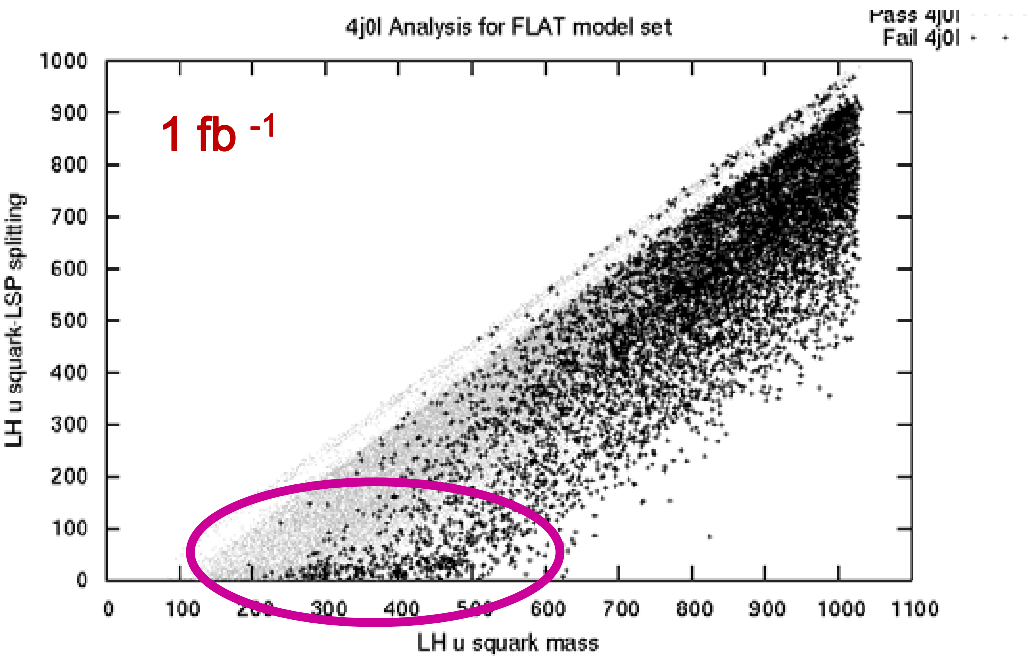


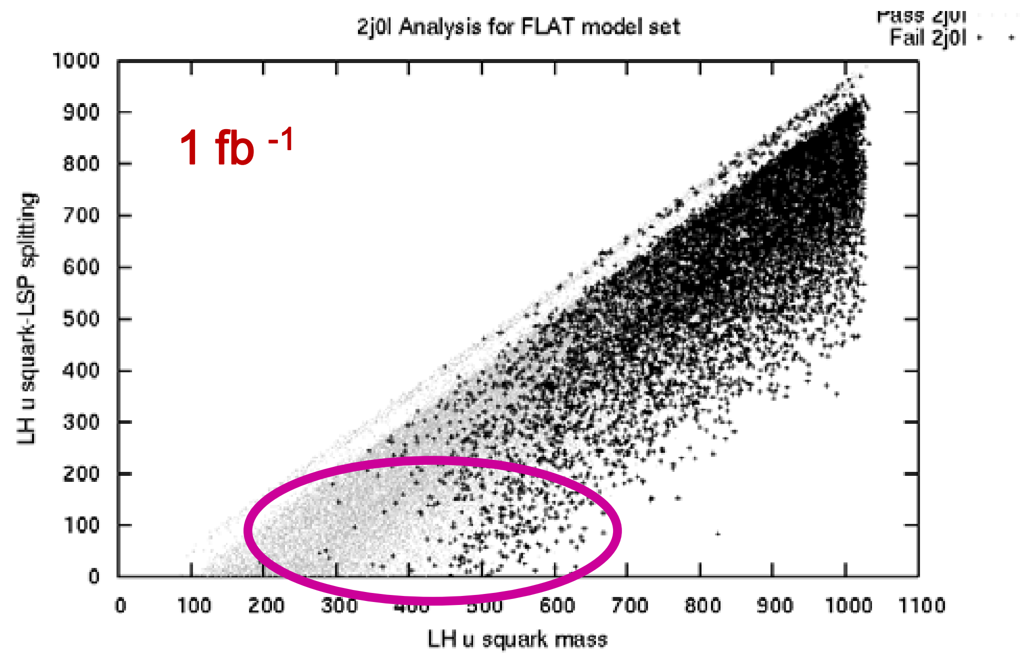


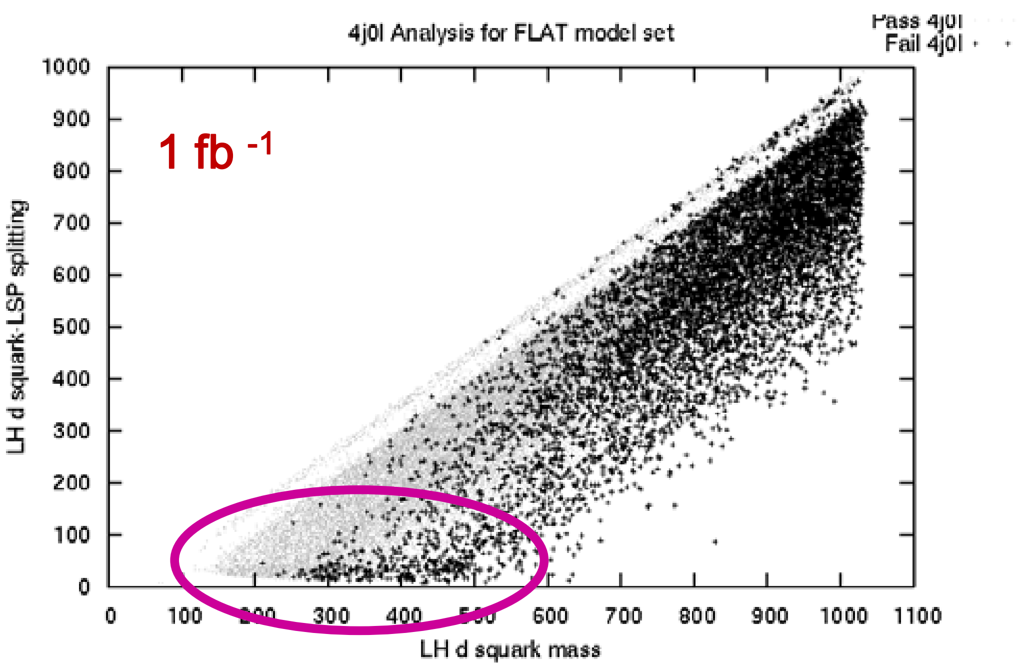


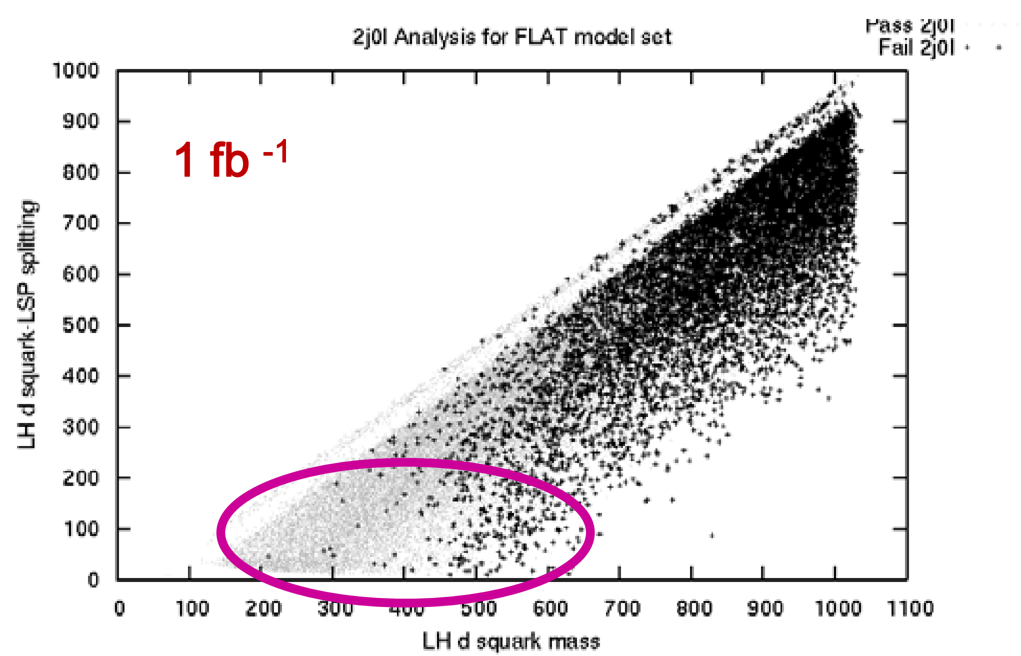


Squark Mass Correlations (cont.)



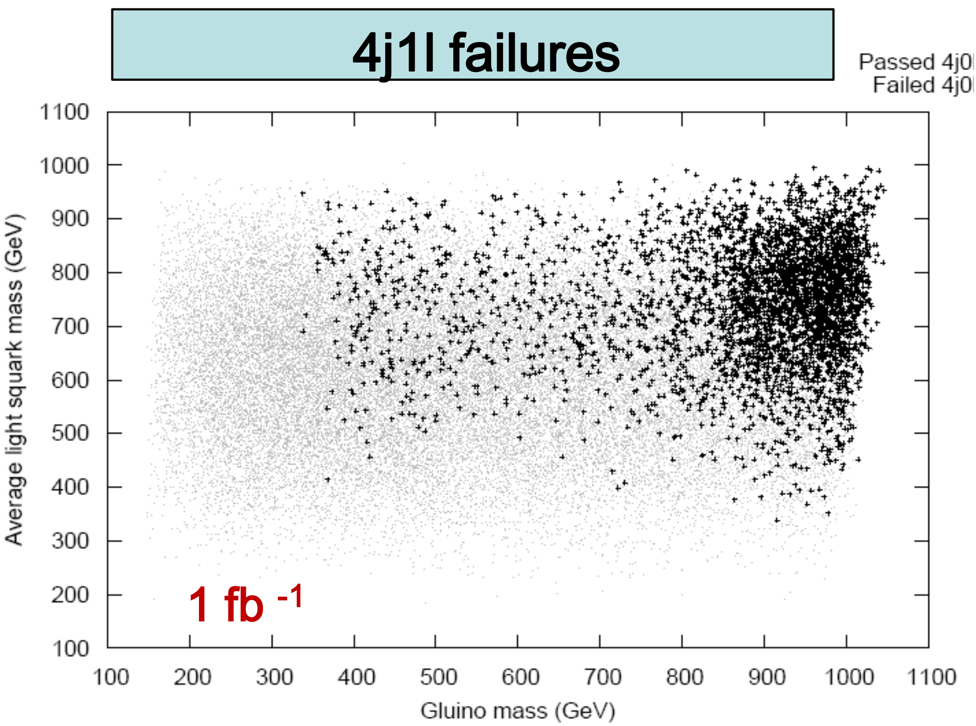


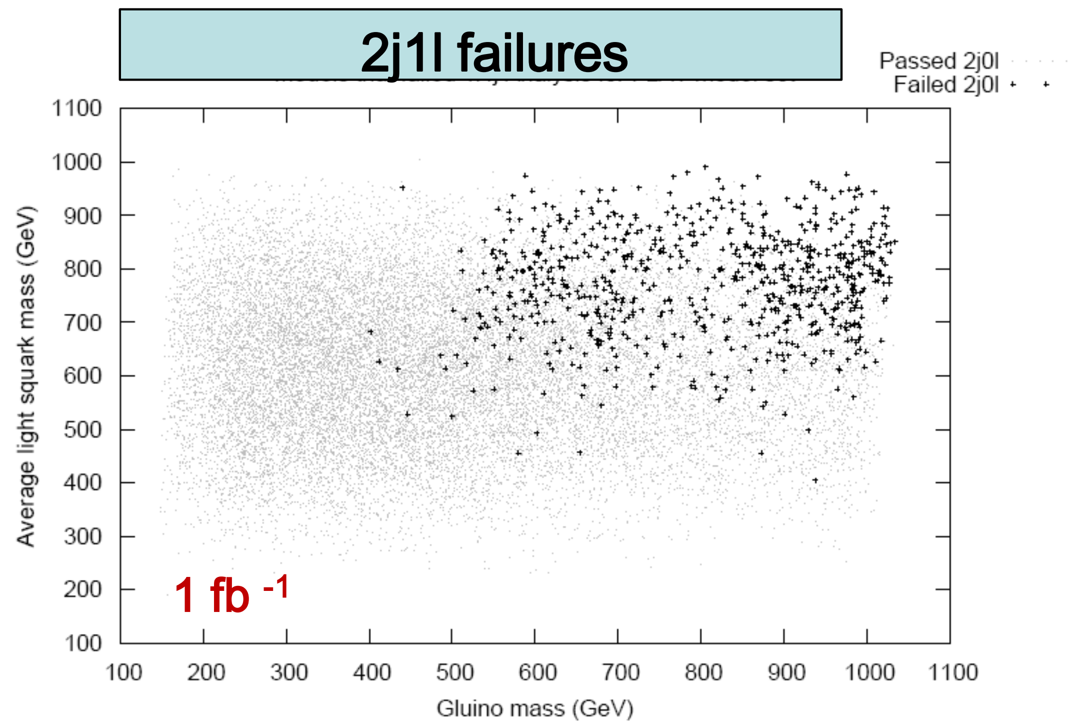




What about the other channels ??

- In the case of (2,4)j+1l 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: $E^T_{\mathrm{miss}} > 0.2 M_{\mathrm{eff}}$	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: $E^T_{\mathrm{miss}} > 0.3 M_{\mathrm{eff}}$	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: $E^T_{\mathrm{miss}} > 0.2 M_{\mathrm{eff}}$ 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: $E^T_{\mathrm{miss}} > 0.25 M_{\mathrm{eff}}$ 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

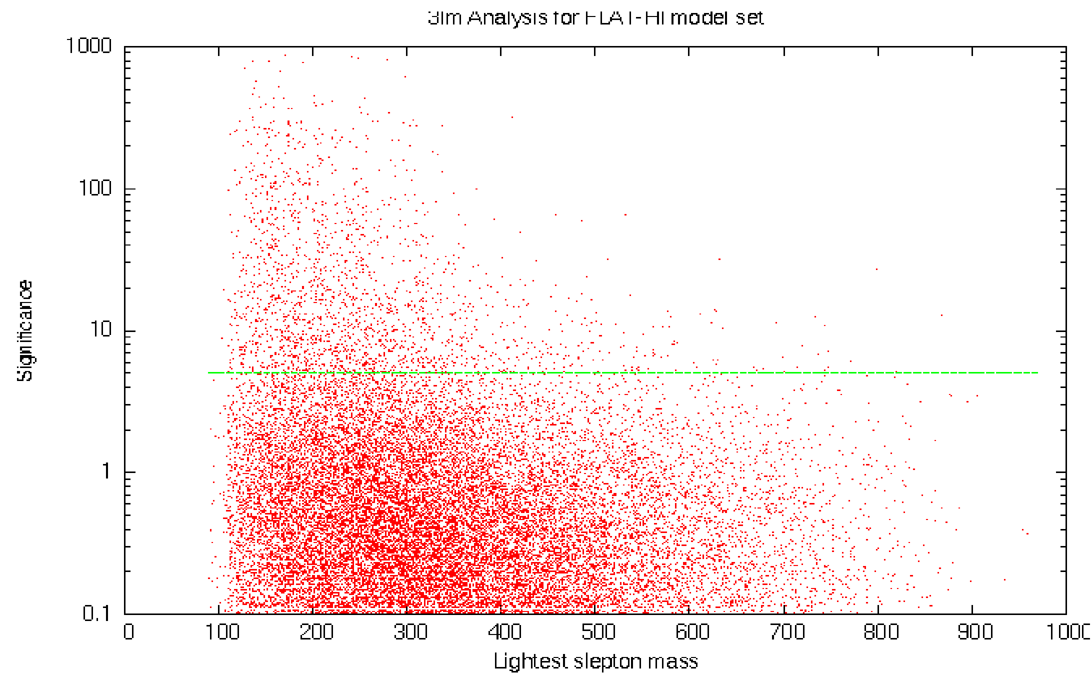
1l2j_1: one isolated lepton	66271 (99.024 %)	67208 (98.28 %)
1l2j_2: no additional leptons	66233 (98.967 %)	67155 (98.203 %)
1l2j_3: two hard jets	62773 (93.797 %)	63329 (92.608 %)
1l2j_4: $E^T_{\rm miss} > 0.3 M_{\rm eff}$ and $E^T_{\rm miss} > 100$	57237 (85.525 %)	57616 (84.254 %)
1l2j_5: trans. sph.	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 %)

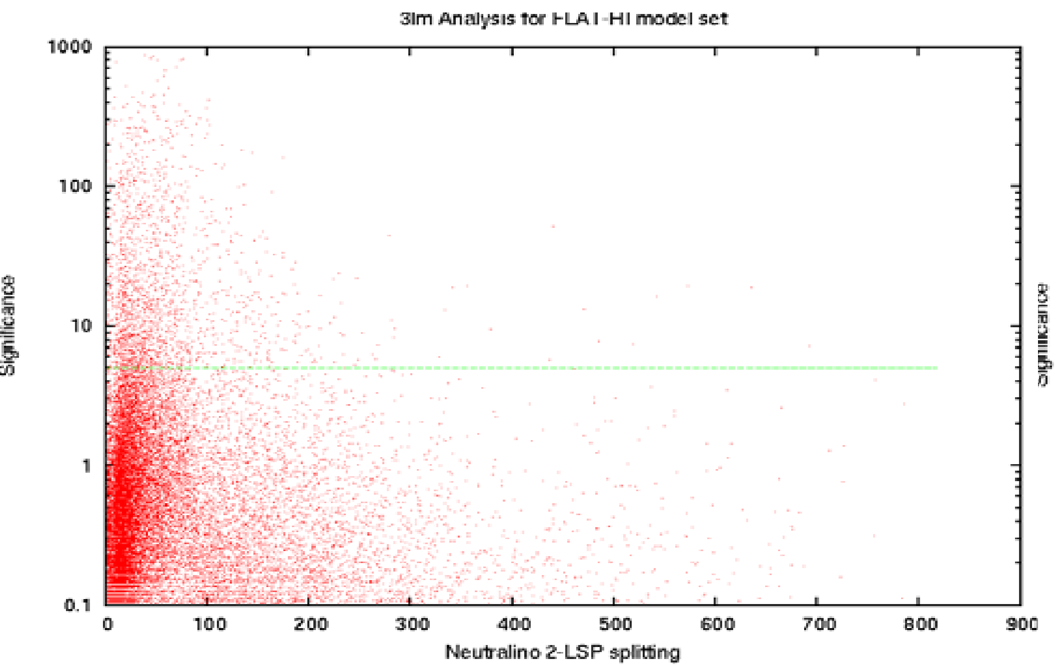
Cut Effectiveness: III

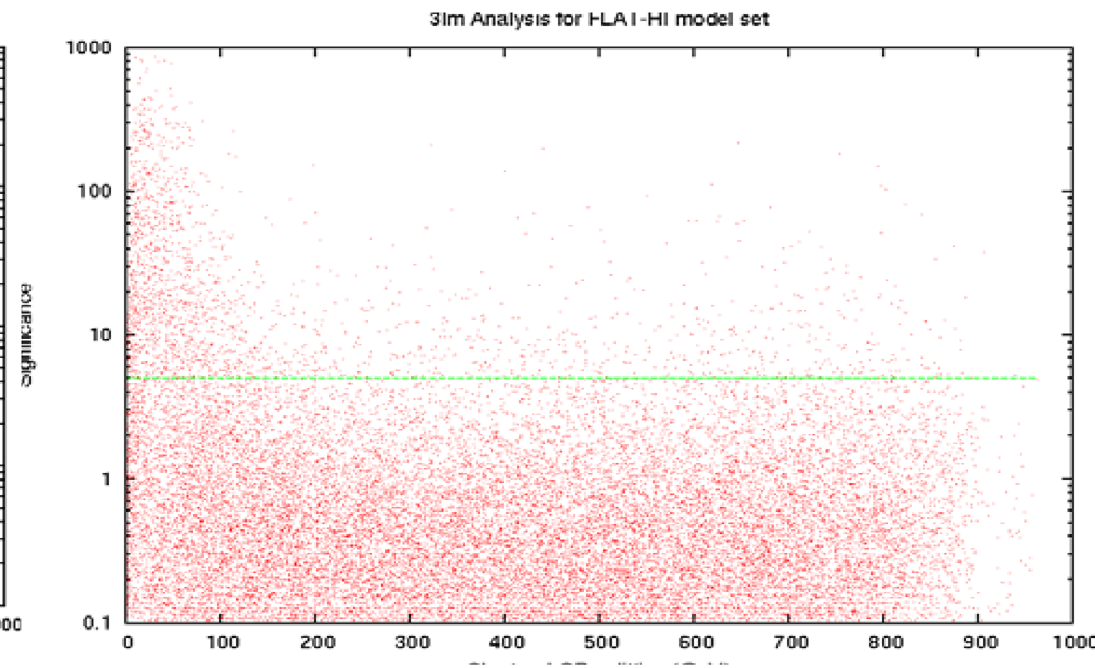
tau_1: four hard jets	66900 (99.964 %)	67568 (98.807 %)
tau_2: $E^T_{\mathrm{miss}} > 100$	66895 (99.957 %)	67524 (98.742 %)
tau_3: jets not near E^T_{\mathrm{miss}}	66883 (99.939 %)	67498 (98.704 %)
tau_4: no lepton	66780 (99.785 %)	67379 (98.53 %)
tau_5: at least one tau	64358 (96.166 %)	64839 (94.816 %)
tau_6: $E^T_{\mathrm{miss}} > 0.2M_{\mathrm{eff}}$	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:	66923 (99.999 %)	67893 (99.282 %)
b_2	66923 (99.999 %)	67892 (99.281 %)
b_3	66923 (99.999 %)	67841 (99.206 %)
b_4	66923 (99.999 %)	67775 (99.109 %)
b_5	66923 (99.999 %)	67669 (98.954 %)
b_6	49760 (74.353 %)	50113 (73.282 %)

3l+X+MET Search Significance : 10 fb $^{-1}$

Clearly this is correlated with the both lightest slepton mass & the mass splitting between the 2nd neutralino & the LSP

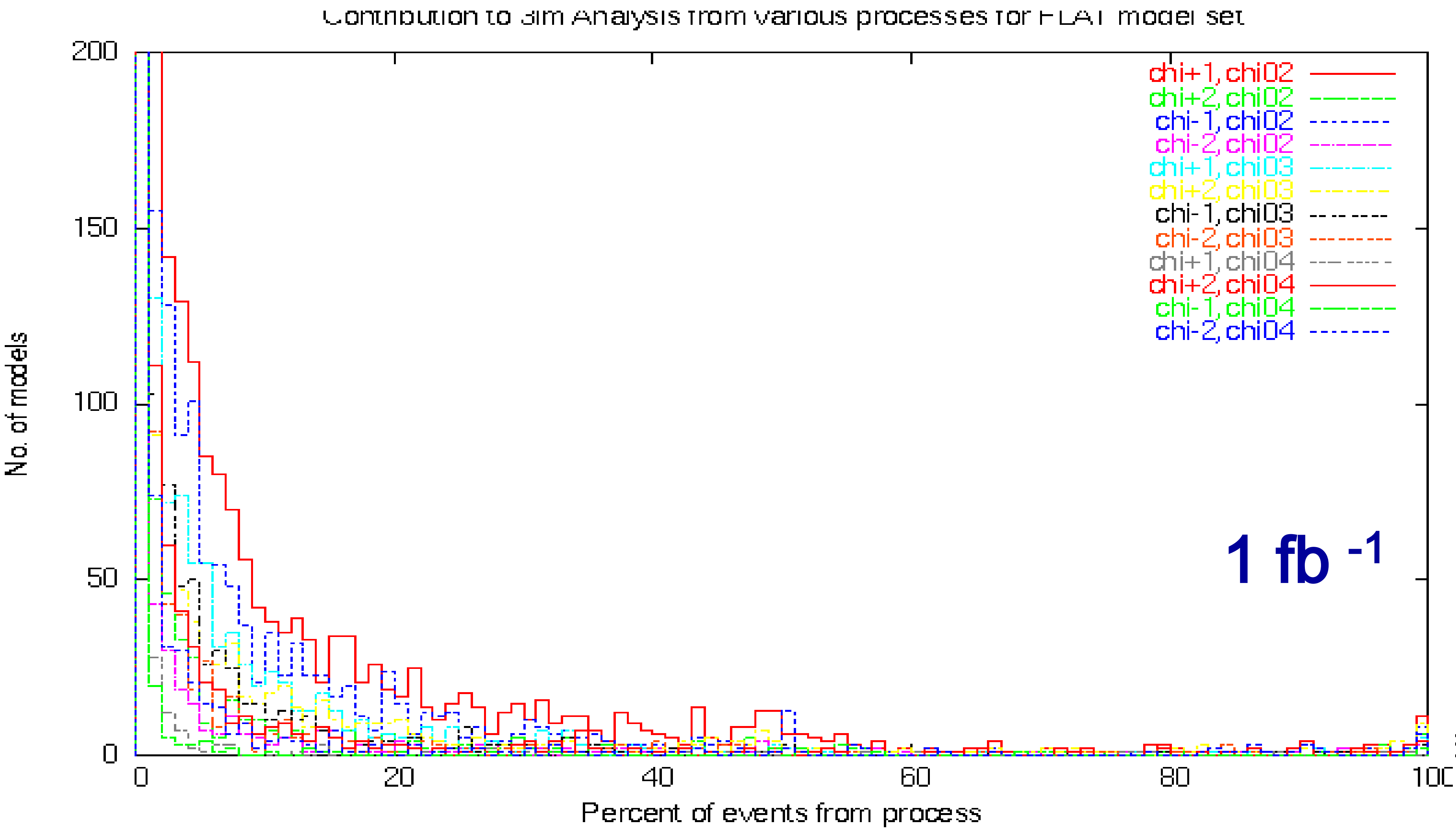


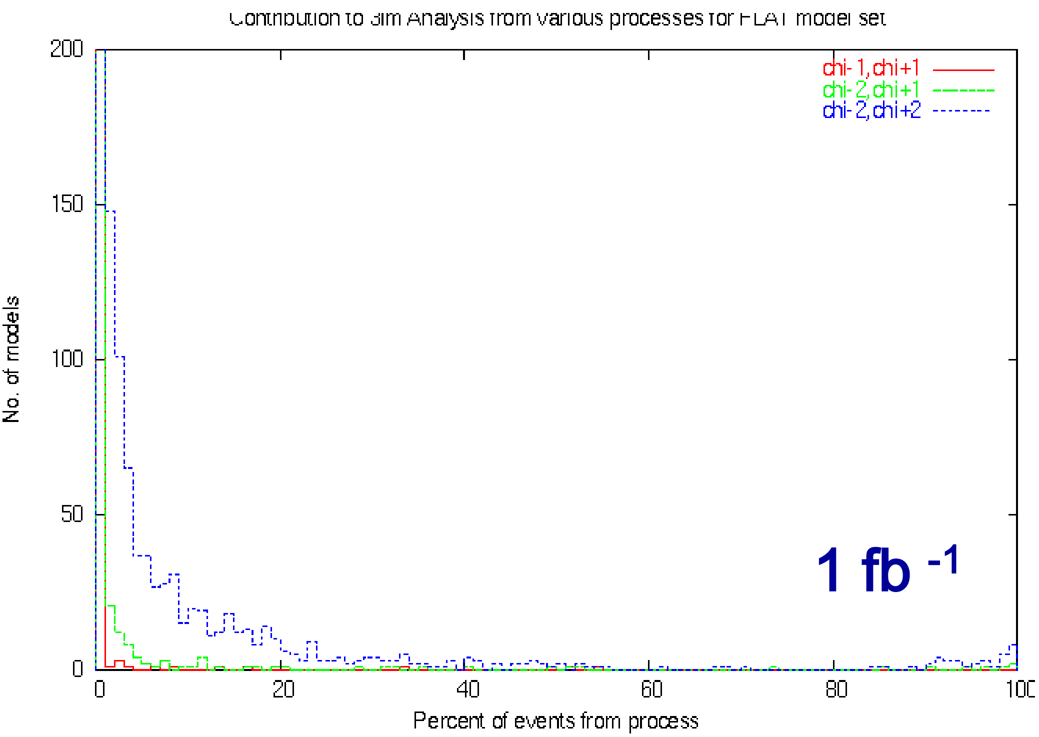


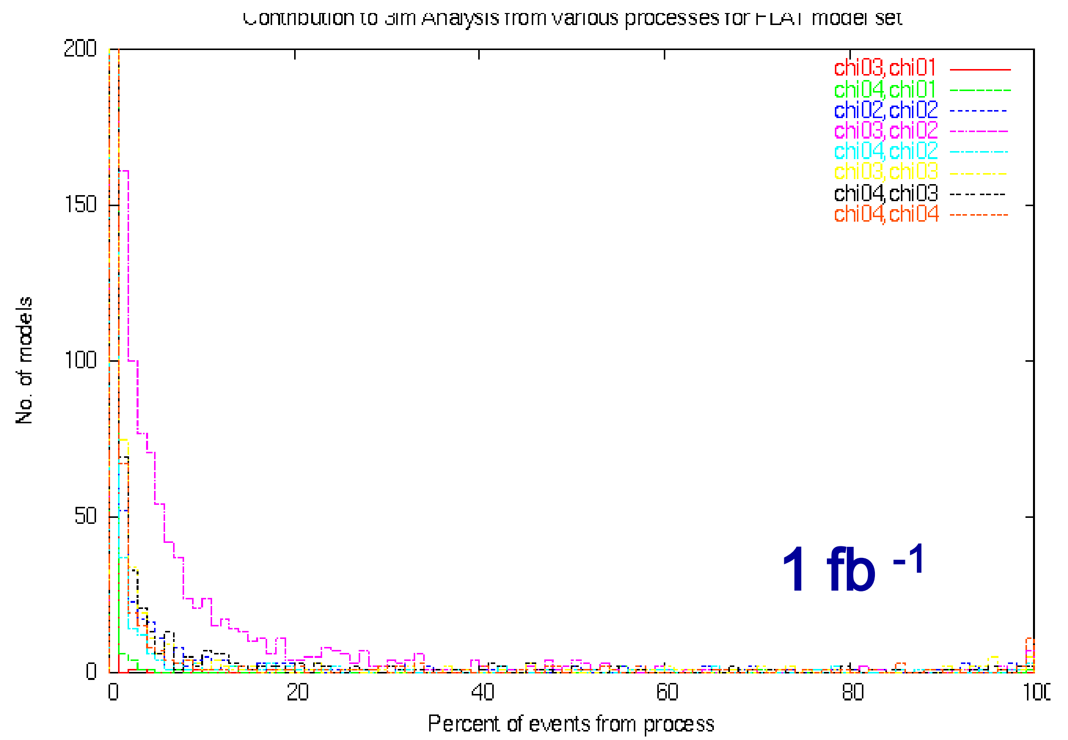


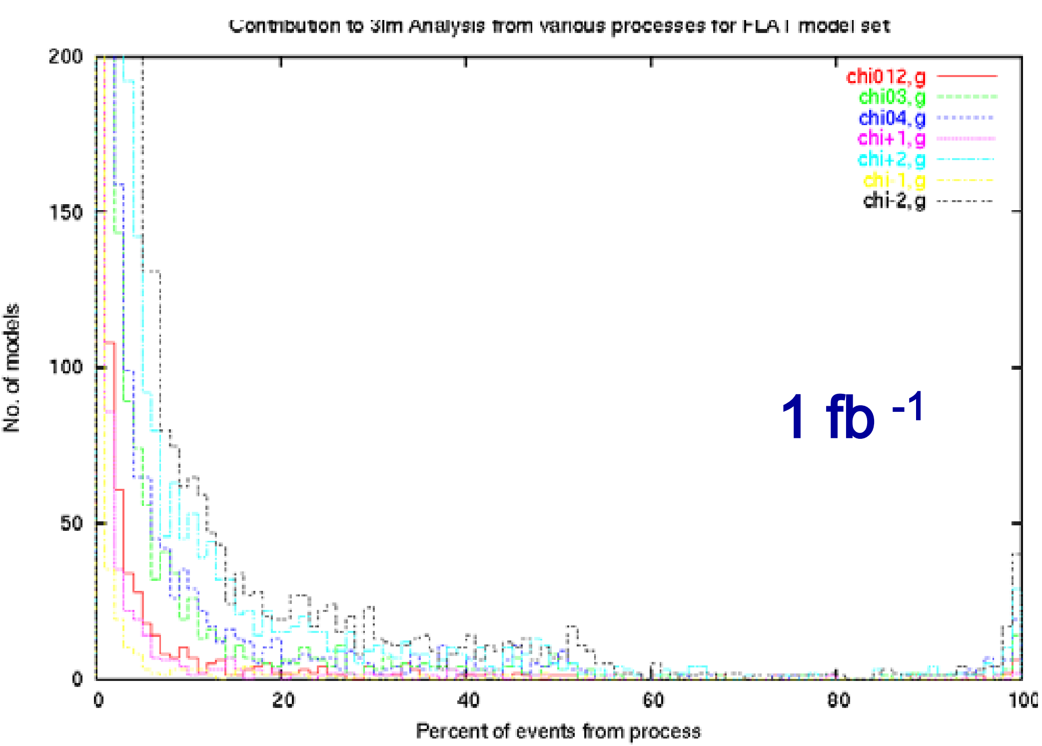
Where do the 3l+X+MET events come from ??

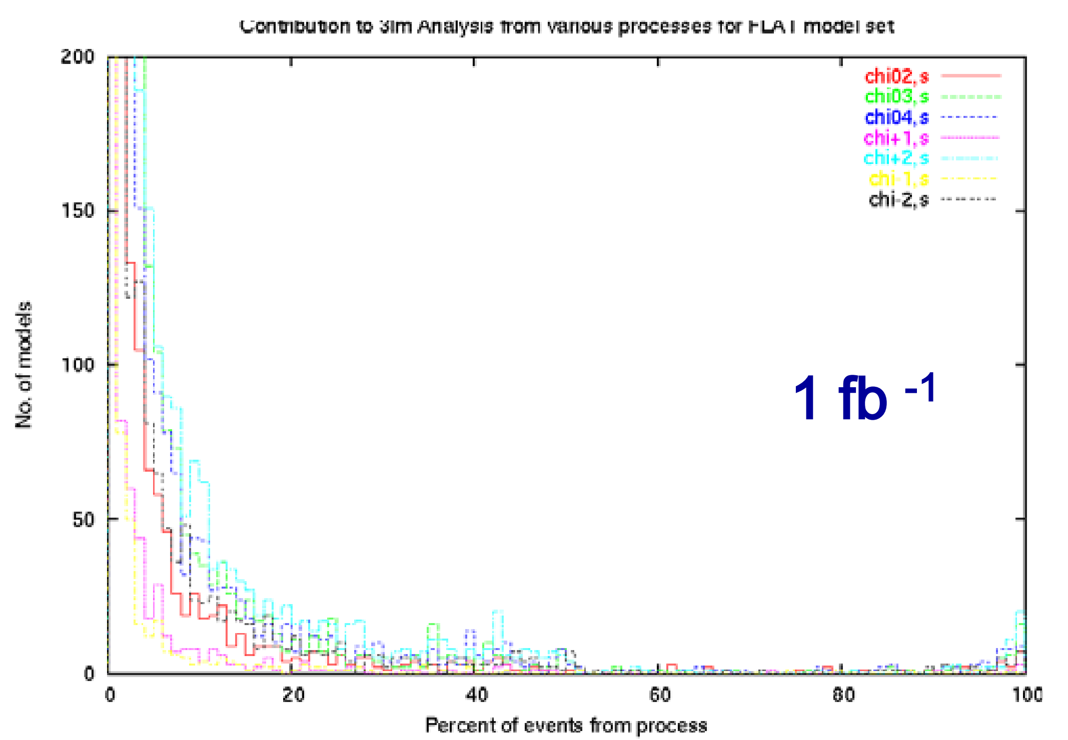
This is what we see from the 'canonical' channels, but there a lot of other contributions too….



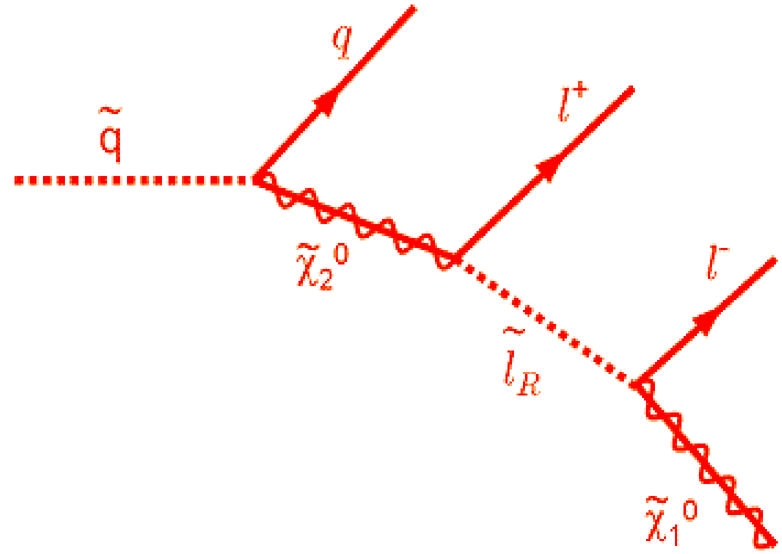

Contribution to 3lm Analysis from various processes for FLAT model set
chi-1,chi+1
chi-2,chi+1
chi-2,chi+2
1 fb -1
No. of models
Percent of events from process
0
50
100
150
200
20
40
60
80
100

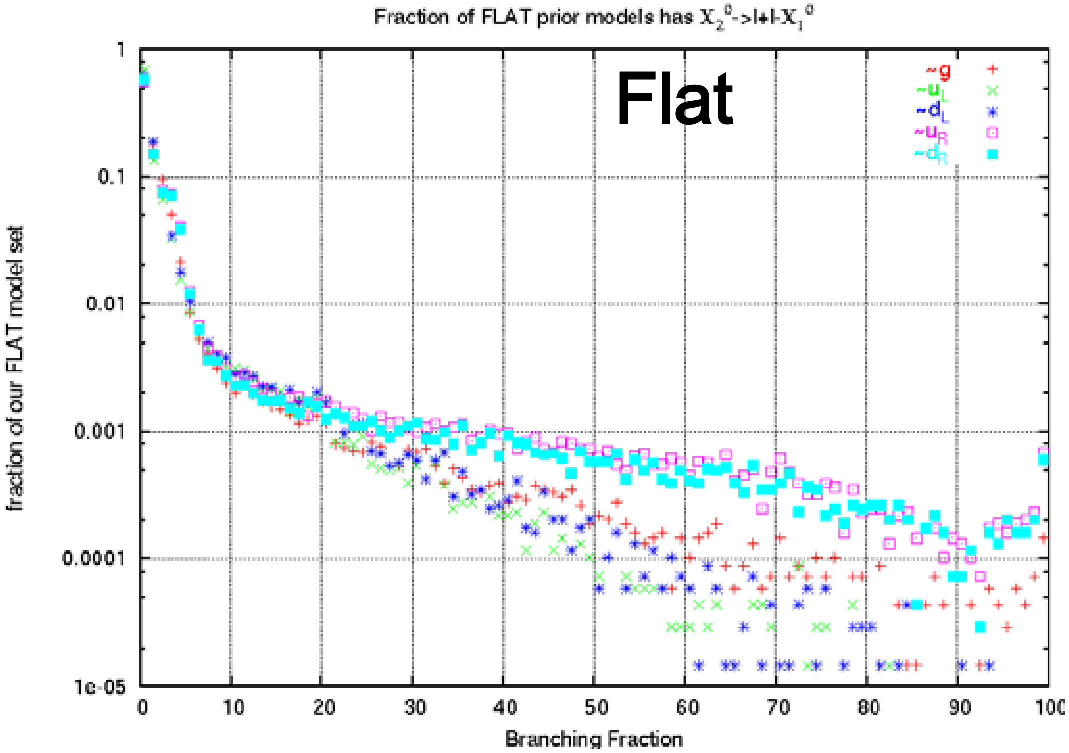

Contribution to 3lm Analysis from various processes for FLAT model set
chi03,chi01
chi04,chi01
chi02,chi02
chi03,chi02
chi04,chi02
chi03,chi03
chi04,chi03
chi04,chi04
1 fb -1
No. of models
Percent of events from process
0
50
100
150
200
20
40
60
80
100


Contribution to 3lm Analysis from various processes for FLAT model set
chi012,g
chi03,g
chi04,g
chi+1,g
chi+2,g
chi-1,g
chi-2,g
1 fb -1
No. of models
Percent of events from process
0
50
100
150
200
20
40
60
80
100

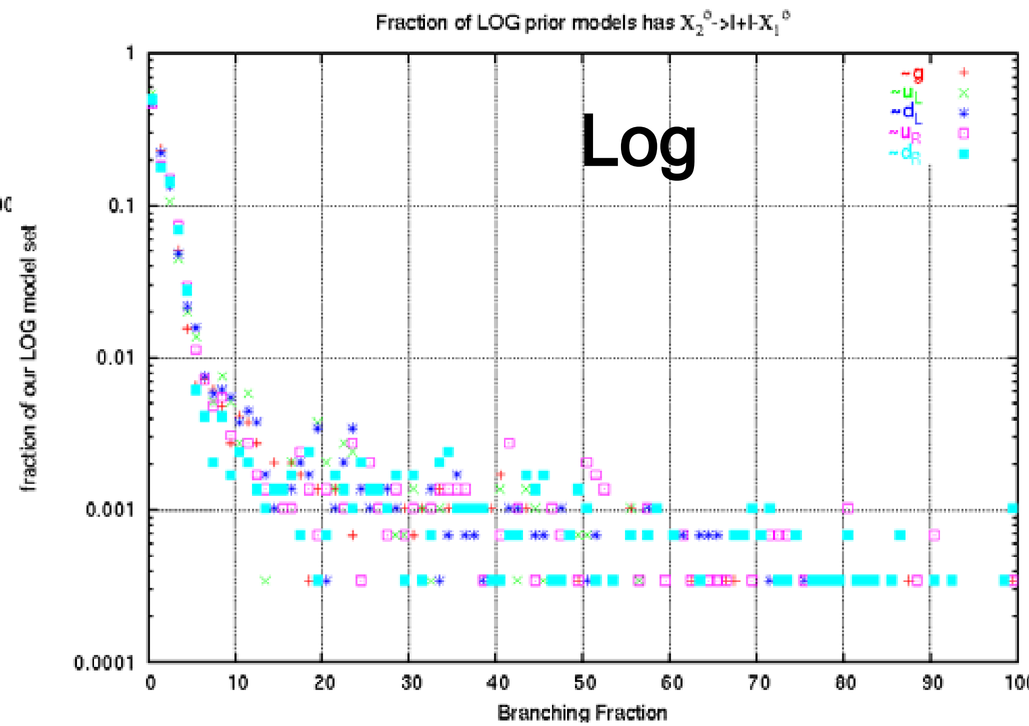

Contribution to 3lm Analysis from various processes for FLAT model set
chi02,s
chi03,s
chi04,s
chi+1,s
chi+2,s
chi-1,s
chi-2,s
1 fb -1
No. of models
Percent of events from process
0
50
100
150
200
20
40
60
80
100

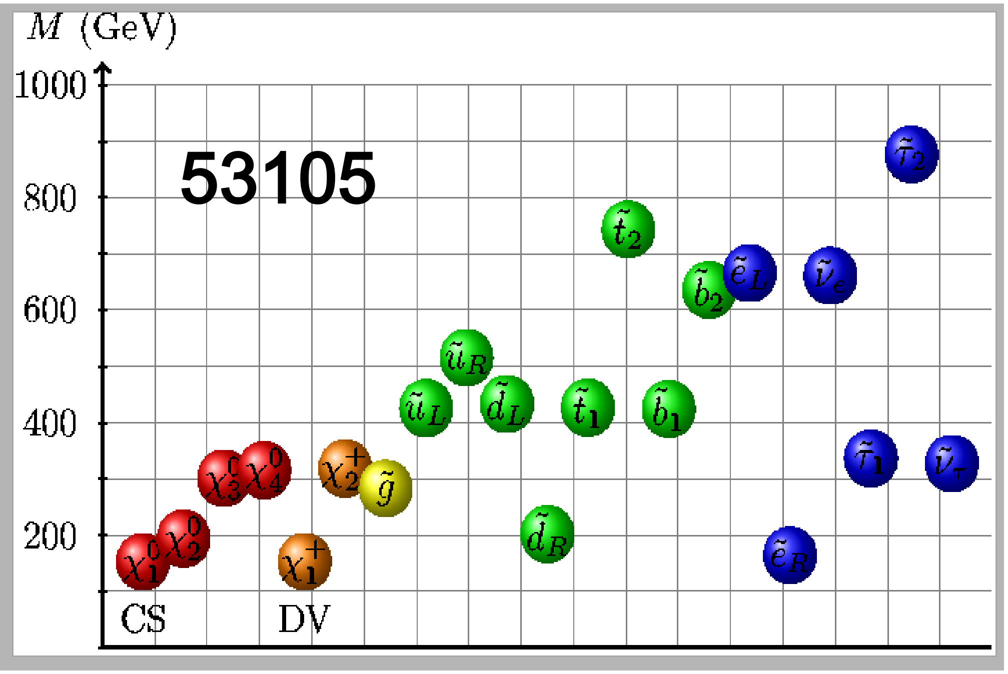
How often do these 'famous' decay chains actually occur??



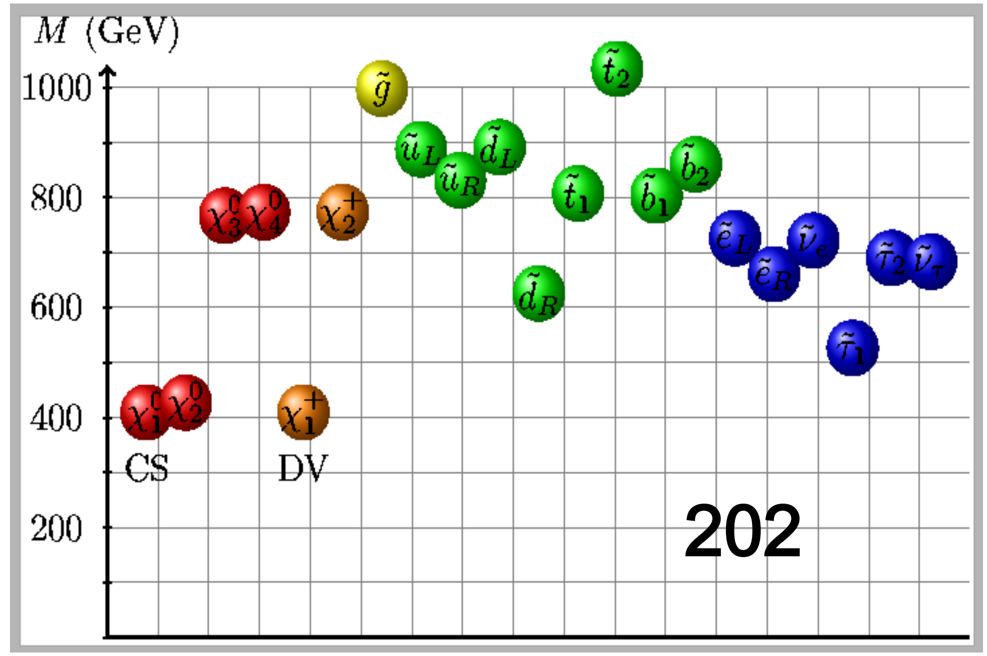


It appears that this is not GENERALLY a common mode

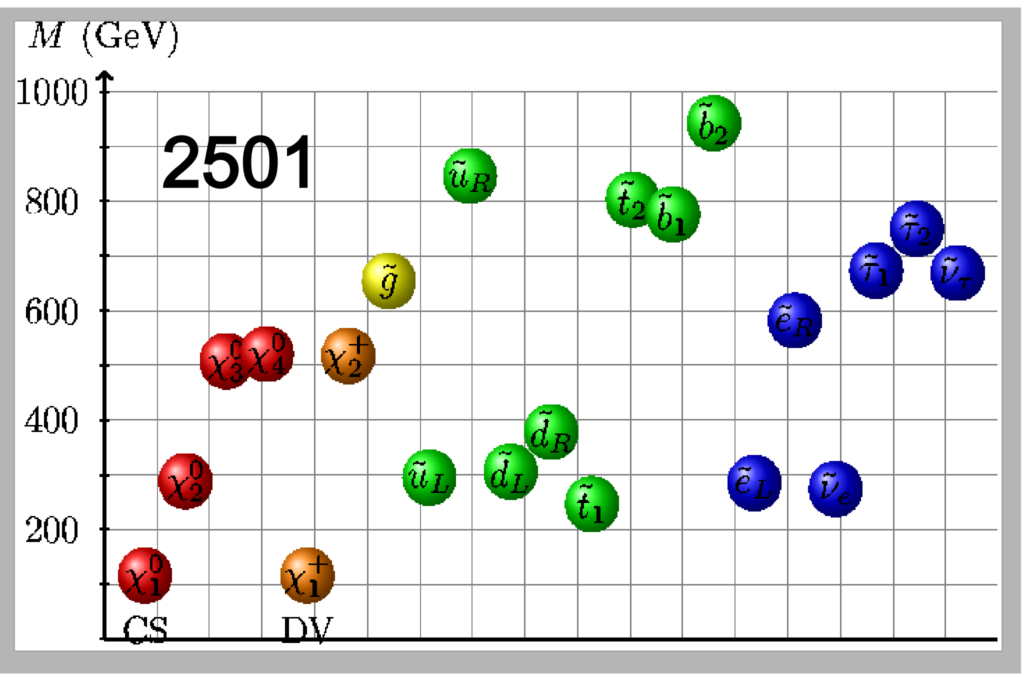




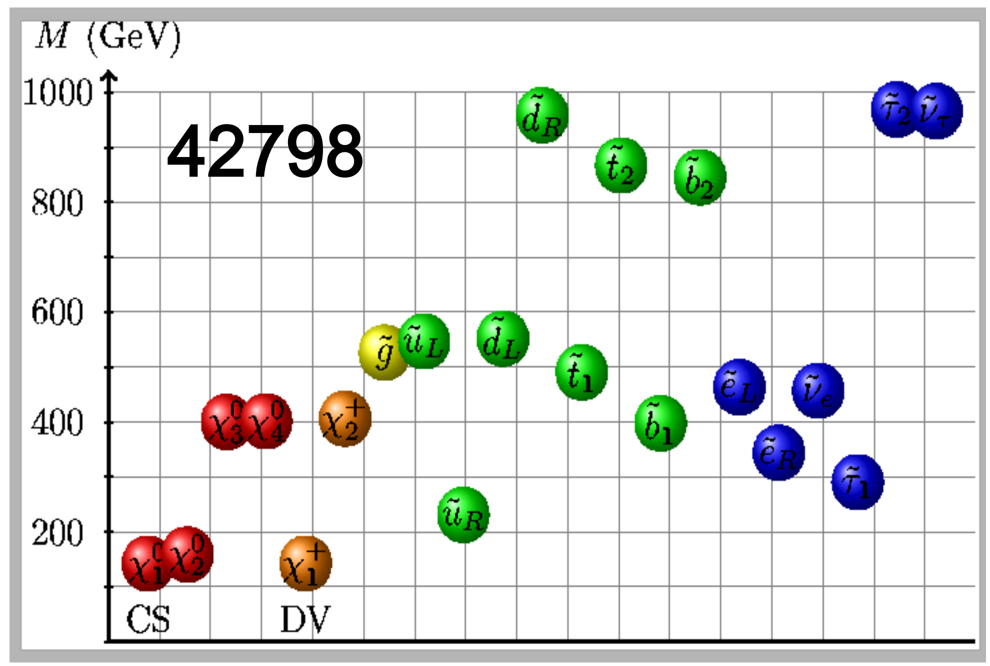
M (GeV)
1000
800
600
400
200
53105
CS
DV



M (GeV)
1000
800
600
400
200
202
CS
DV



M (GeV)
1000
800
600
400
200
2501
CS
DV



M (GeV)
1000
800
600
400
200
42798
CS
DV

Example: Model 53105

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

Model *fails* many ATLAS analysis cuts due to the small mass splittings between the sparticles in this familiar decay chain

→ Sparticles may have ‘commonly discussed’ decay modes yet STILL be missed entirely !

Example: Model 202

gluino(998.0) $\rightarrow \tilde{d}_R$ (625.7) j	~60%	Δm =372.3 GeV
$\tilde{d}_R$ (625.7) $\rightarrow \tilde{\chi}_2^0$ (426.9) j	97%	Δm =198.8 GeV
$\tilde{\chi}_2^0$ (426.9) $\rightarrow \tilde{\chi}_1^\pm$ (409.5) jj	~90%	Δm =25.5 GeV
$\tilde{\chi}_1^\pm$ (409.5) $\rightarrow \pi^\pm$ +MET(409.0)	~90%	Δm = 468 MeV

Note that the existence of a 'long-lived' chargino ($c\tau$ ~1mm) at the end of the decay chain, i.e., the small Δm value, significantly reduces the contribution to the missing p_T

Example: Model 2501

gluino(654.3) $\rightarrow$ u_L (295.2)+j , d_L (305.6)+j, d_R (378.2)+j

u,d_L $\rightarrow$ $\chi_1^{\pm}$ (115.7)+j , ~2/3 χ_1^0 (115.6) +j, ~1/3

$\chi_1^{\pm}$ $\rightarrow$ π + LSP (~90%)

d_R $\rightarrow$ χ_2^0 (288.0) +j (~100%)

χ_2^0 $\rightarrow$ $\chi_1^{\pm}$ W (~2/3), h+χ_1^0 (~1/3)

Small mass splittings at the end of decay chains substantially reduce missing p_T

Example: Model 42798

gluino(526.2) $\rightarrow \tilde{u}_R$ (230.9) j ~90% Δm =296.7 GeV

$\tilde{u}_R$ (230.9) $\rightarrow \tilde{\chi}_2^0$ (158.7) j ~100% Δm =72.2 GeV

$\tilde{\chi}_2^0$ (158.7) $\rightarrow \tilde{\chi}_1^\pm$ (142.2) jj ~70% Δm =16.5 GeV

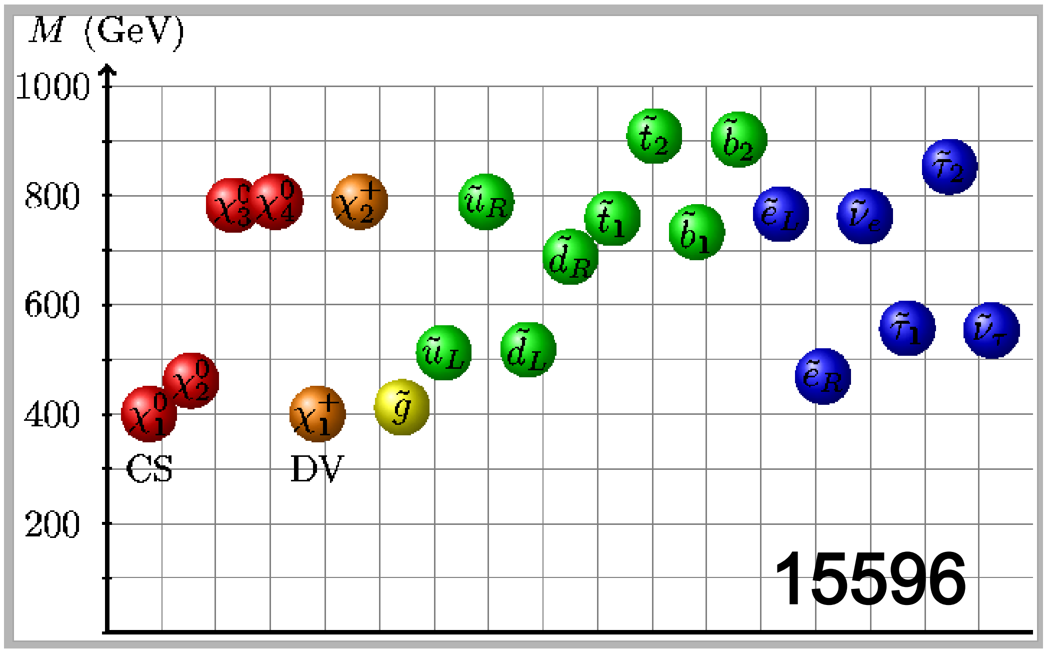
$\tilde{\chi}_1^\pm$ (142.2) $\rightarrow$ $\pi^\pm$ +MET(142.0) ~90% Δm = 201 MeV

Note again the appearance of the small Δm chargino with ($c\tau$ ~1cm) at the end of the decay chain.

Example: Model 15596

gluino(412.7) $\rightarrow \chi_1^0$ (400.2) +jj or $\chi_1^\pm$ (400.3)+jj

$\chi_1^\pm \rightarrow \pi + \chi_1^0$ (~96%) Δm = 142 MeV



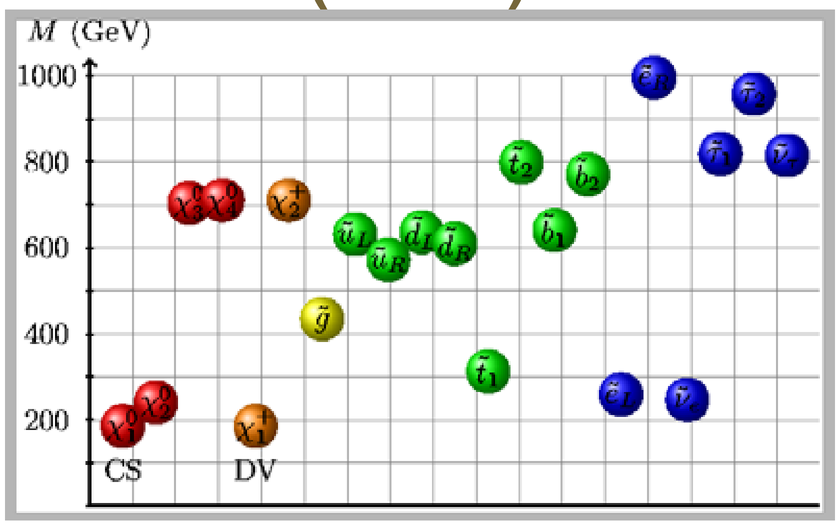
… small mass differences are seen throughout the decay chain here

Example: Model 30661

gluino(434.6) $\rightarrow \tilde{t}_1$ (312.4)+ bW Δm =36.2 GeV

$\tilde{t}_1$ (312.4) $\rightarrow$ $\tilde{\chi}_1^+$ (185.2) b Δm =127.1 GeV

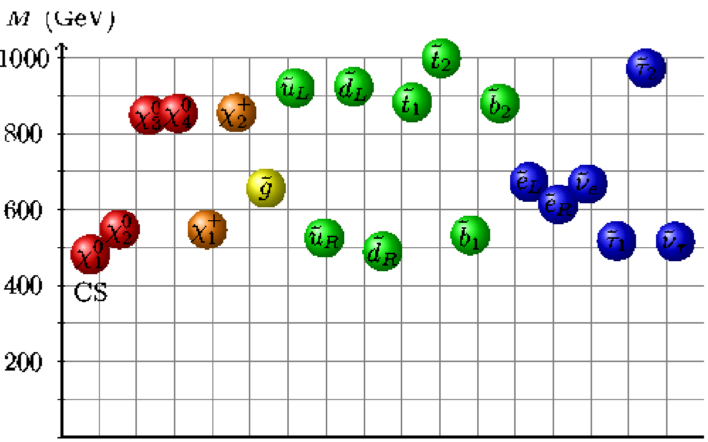
$\tilde{\chi}_1^\pm$ (185.2) $\rightarrow$ $\pi^\pm$ +MET(185.1) Δm = 147 MeV

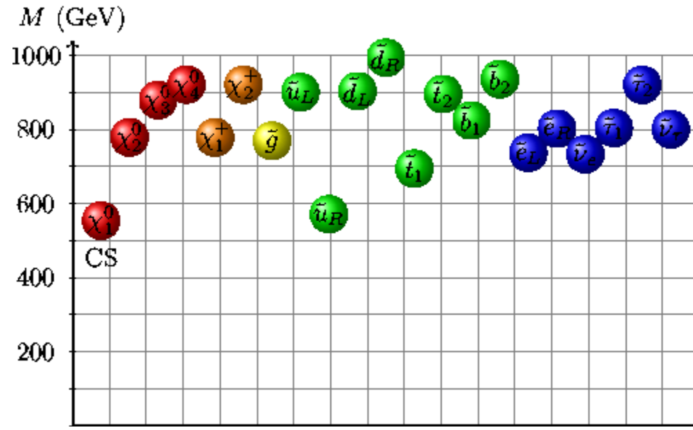


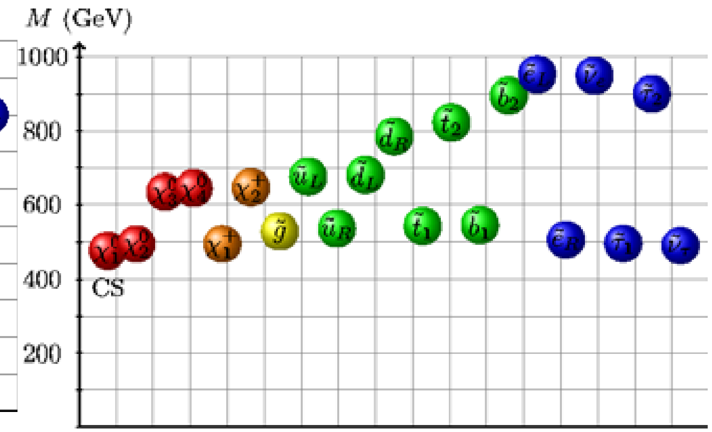
A distinct pattern seems to be emerging… 'long-lived' guys at the end of decay chains signals a reduced missing p_T

This tells us the searches for long-lived states are an important addition to the standard MET inclusive searches

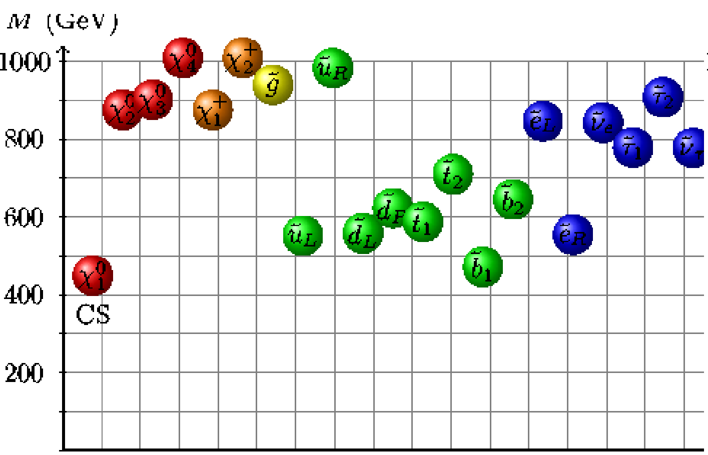
We also have lots of models where the LSP is >90% bino:

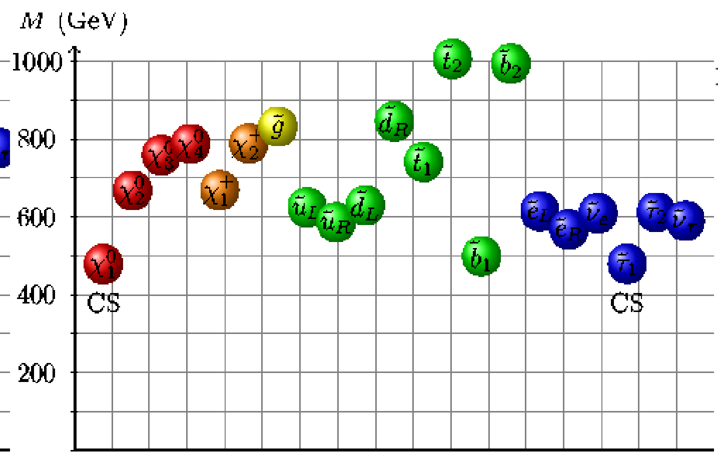


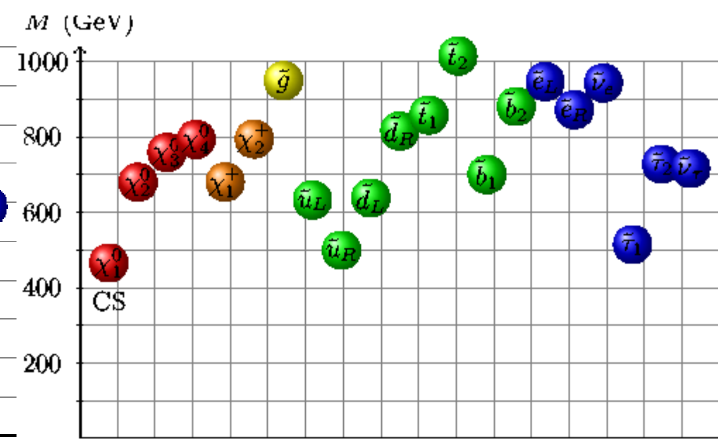




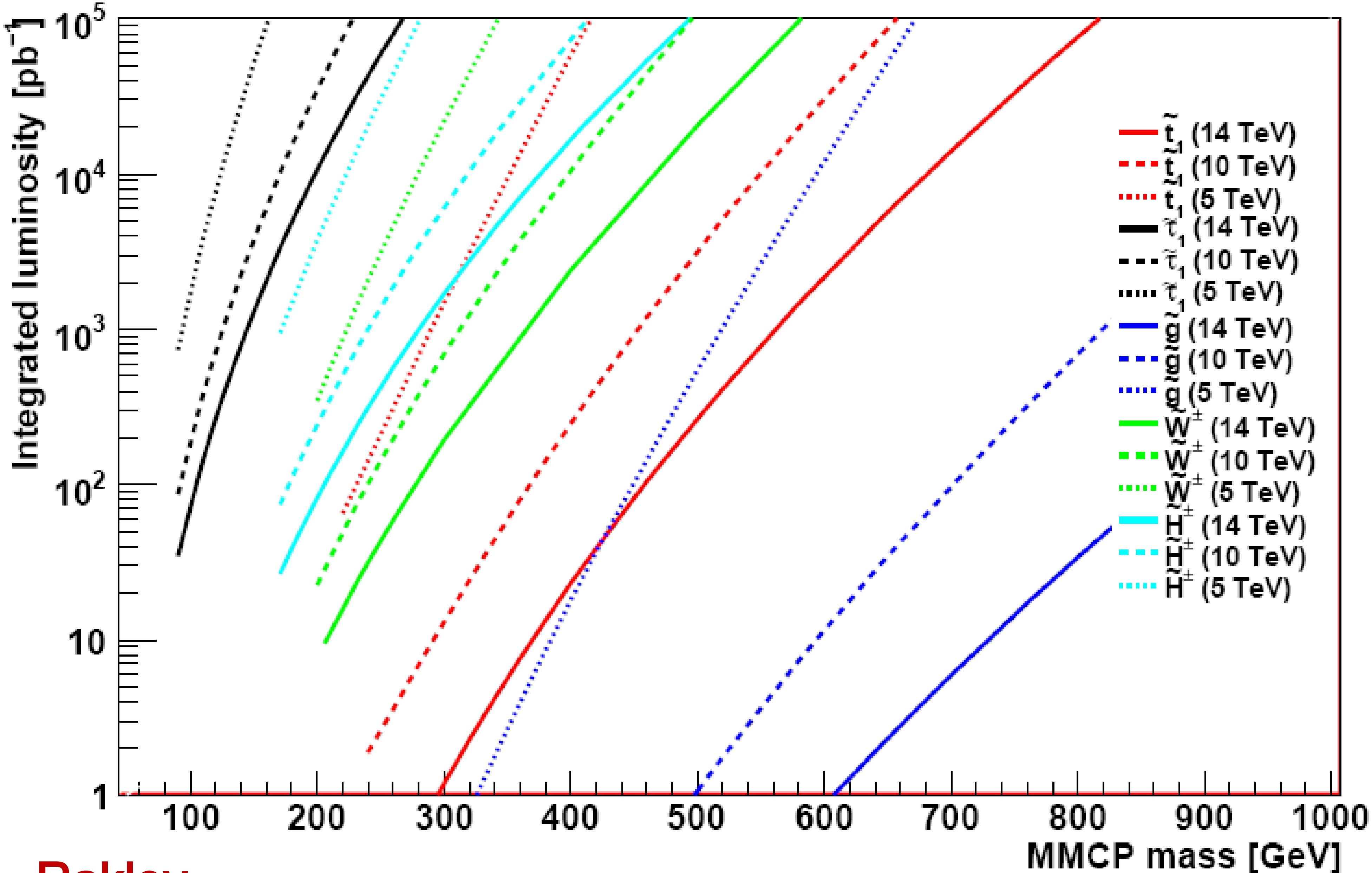
Many of these have relatively heavy & compressed sparticle spectra….







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) !

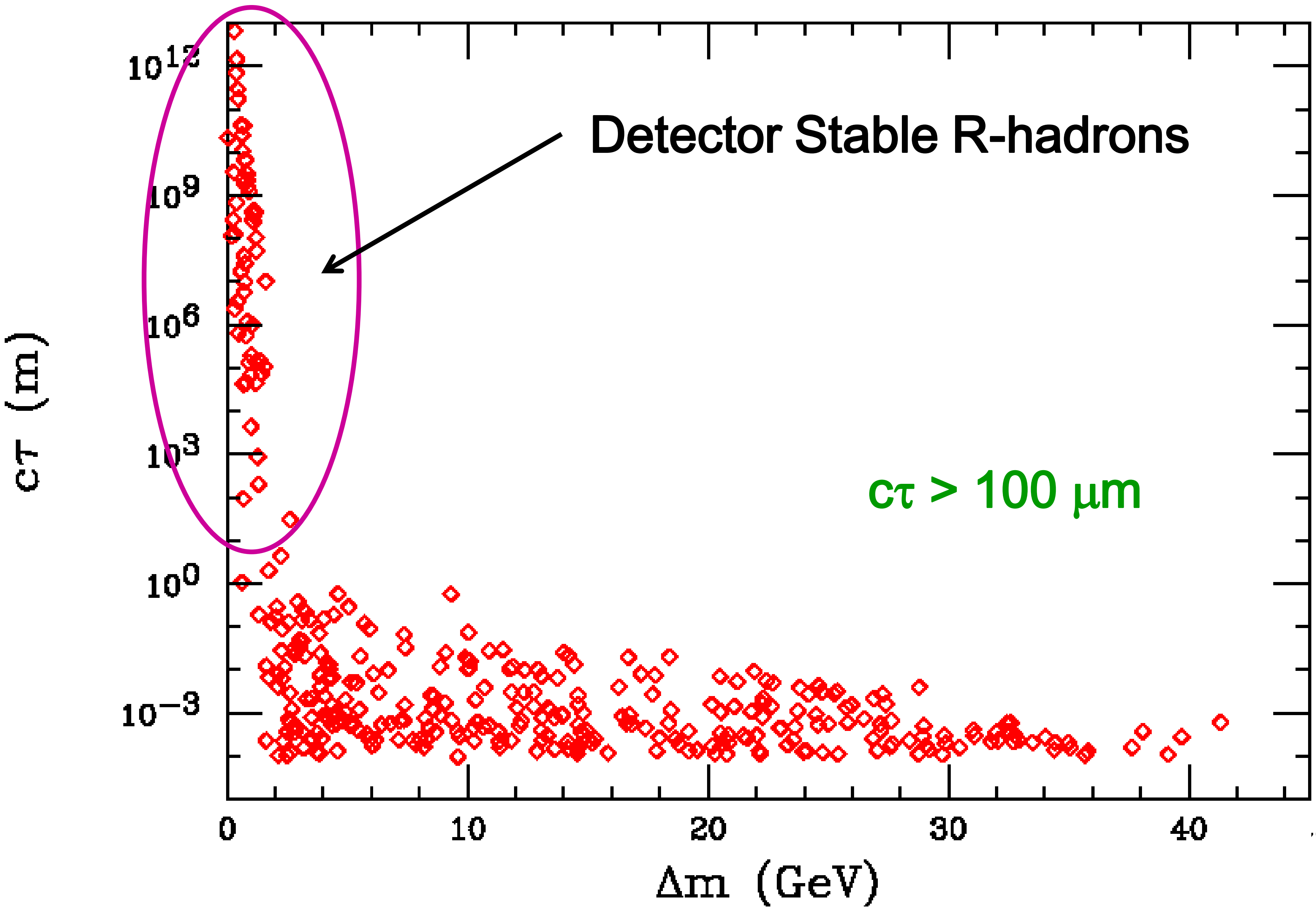
- 8982 are lightest charginos
- 20 are second neutralinos
- 338 are sbottom_1's
- 179 are stau_1's
- 61 are stops
- 5 are gluinos
- 49 are c_R
- 17 are μ_R
- 8 are c_L

etc.

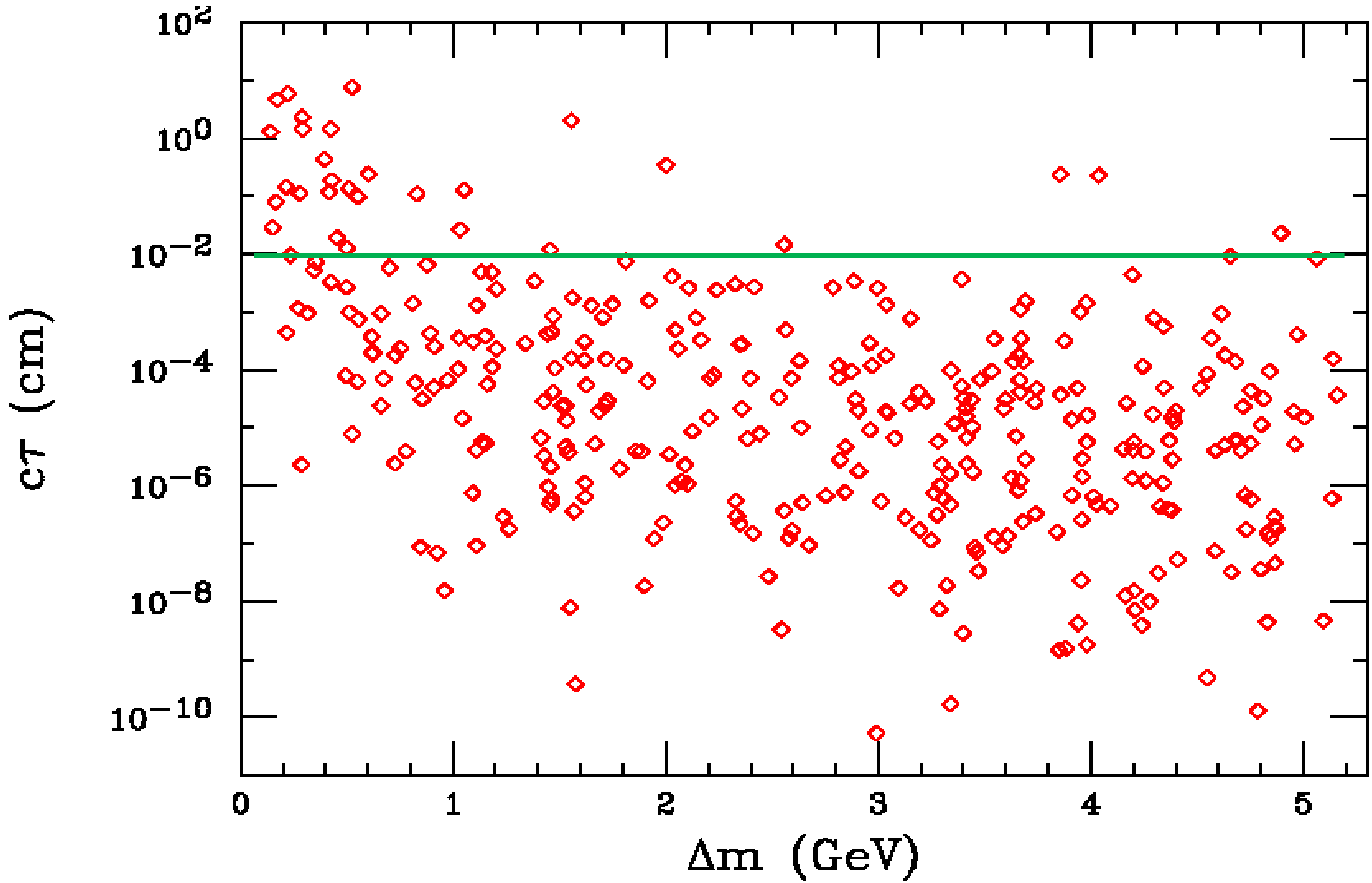
Particles with $c\tau > 20$m will be declared 'detector stable' in our analysis

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

Example: Long-lived stops



$\tilde{b}_1 \to s,d$ + 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.

Semi-Stable Sparticles in the 71k Sample with 200 μm < cτ < 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.

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; we're not even sure of the cuts. It would be nice to do this study soon before too much data is collected at the LHC!
- It may be interesting to do this for other SUSY setups, e.g., the case of gravitino DM or…
- Dark matter analyses are ongoing(e.g., Ice Cube)

Summary

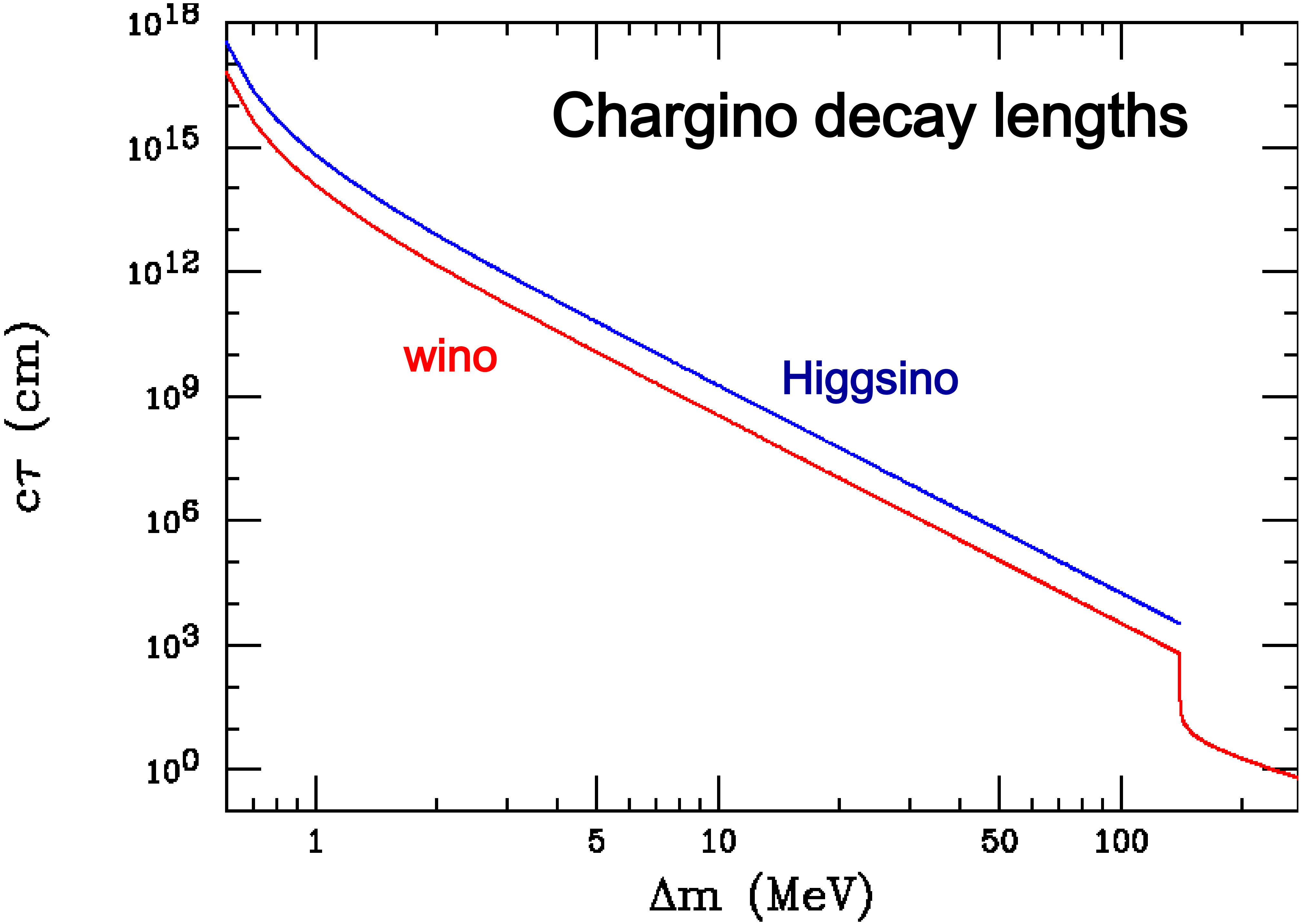
- The pMSSM has a far richer phenomenology than any of the conventional SUSY breaking scenarios. The sparticle properties can be vastly different, e.g., the nLSP can be any other sparticle!

- Light partners may exist which have avoided LEP & Tevatron constraints and may also be difficult to observe at the LHC due to small mass differences or other strange spectra

- Small mass splittings at the end of decay chains substantially reduce the missing p_T significance in many cases BUT this can be helped by long-lived particle searches

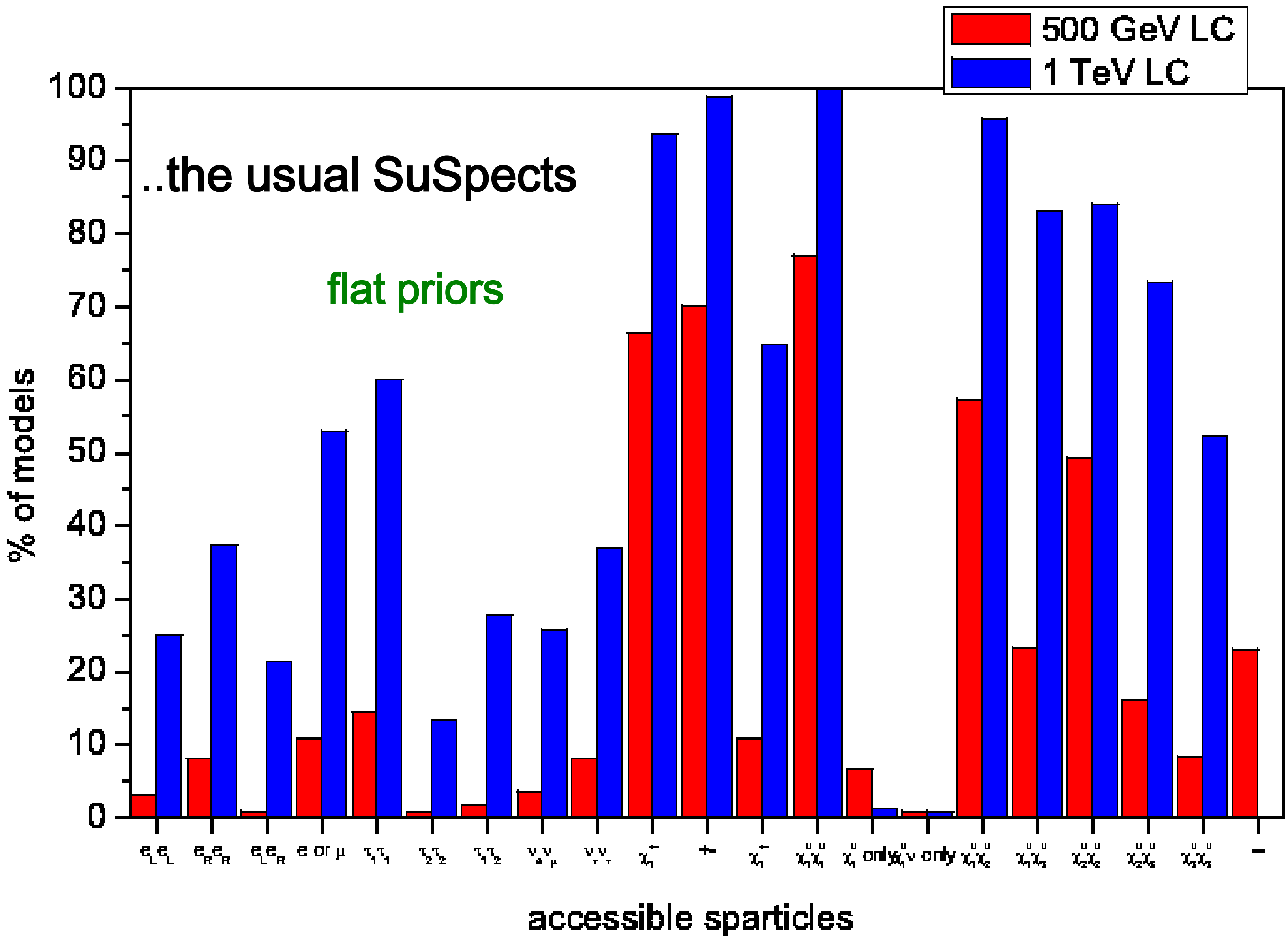
- The study of these complex models is still at early stage..

BACKUP SLIDES



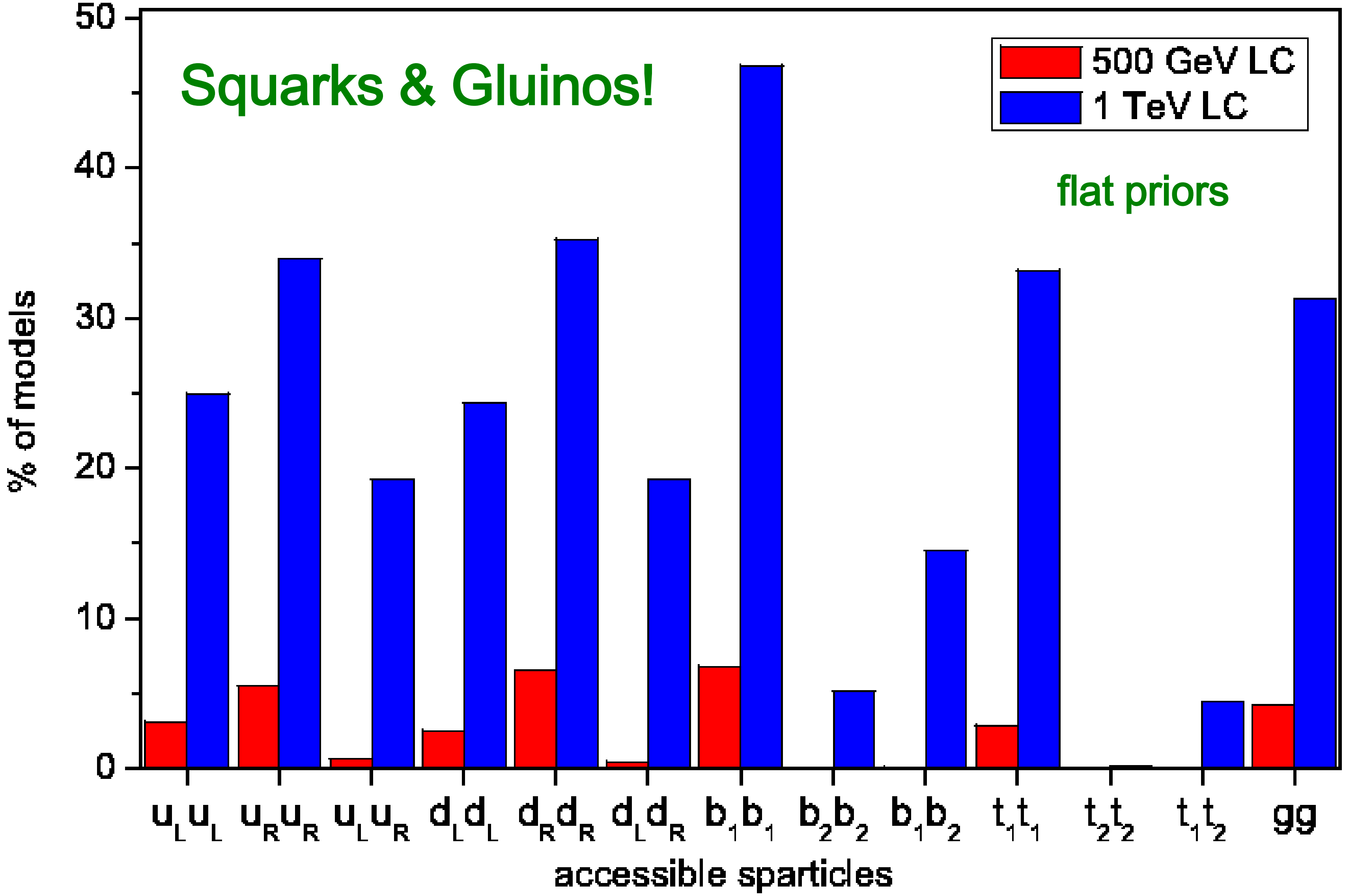
Chargino decay lengths
wino
Higgsino
$c\tau$ (cm)
10^{18}
10^{15}
10^{12}
10^{9}
10^{6}
10^{3}
10^{0}
1
5
10
50
100
Δm (MeV)

Kinematic Accessibility at the ILC : I

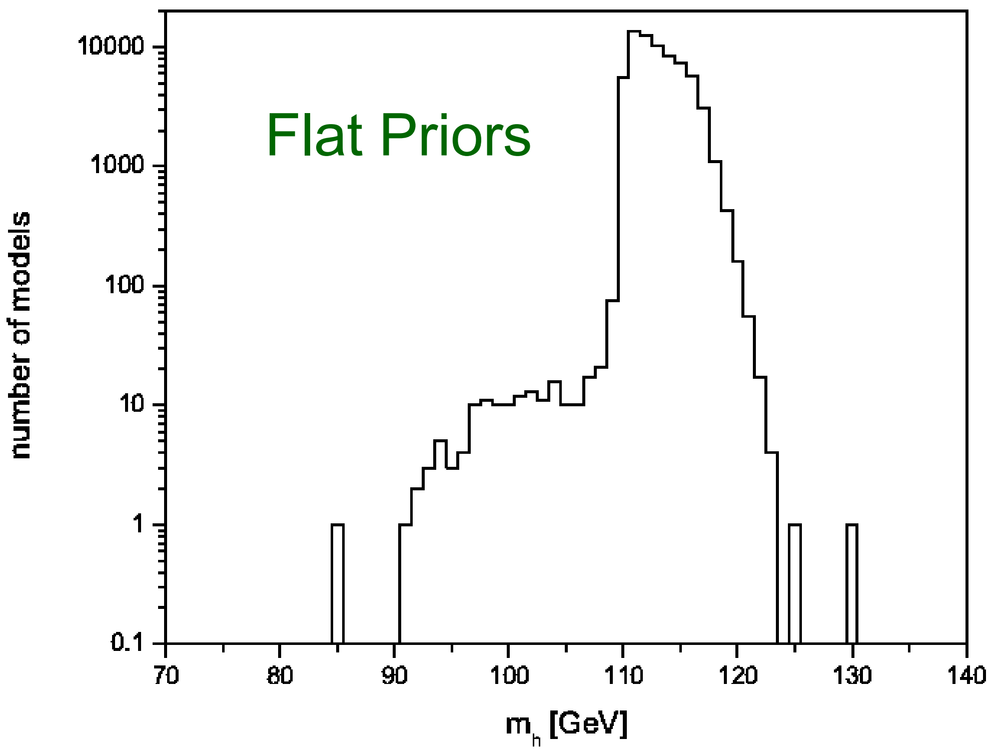


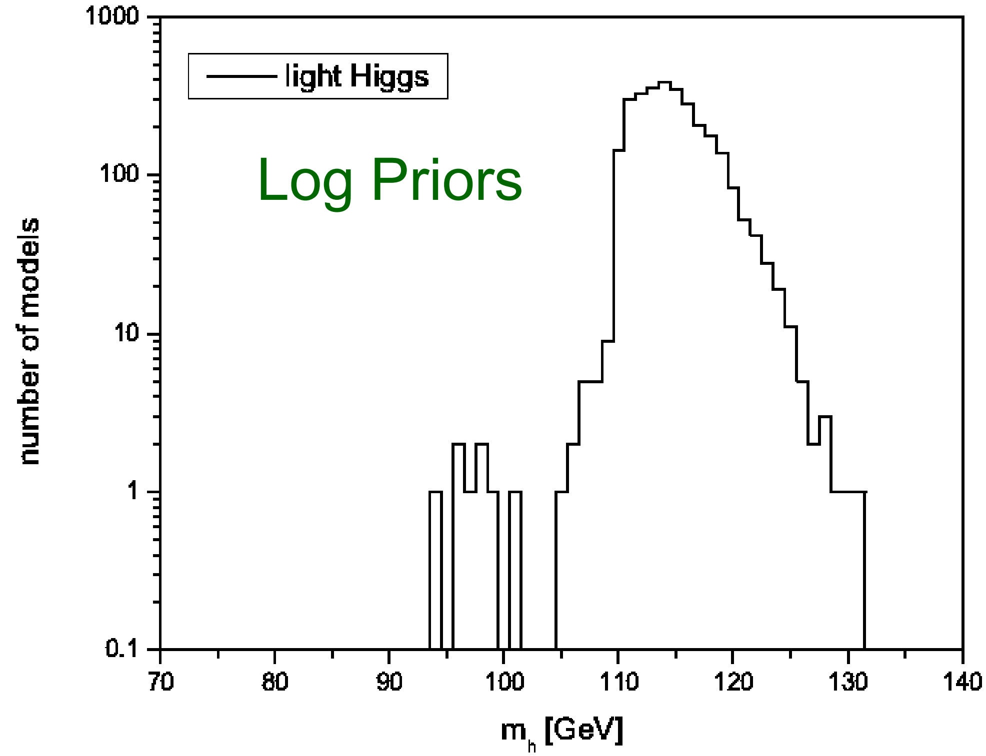
Final State
$\tilde{e}_L^+\tilde{e}_L^-$
$\tilde{e}_R^+\tilde{e}_R^-$
$\tilde{e}_L^\pm\tilde{e}_R^\mp$
$\tilde{\mu}_L^+\tilde{\mu}_L^-$
$\tilde{\mu}_R^+\tilde{\mu}_R^-$
Any selectron or smuon
$\tilde{\tau}_1^+\tilde{\tau}_1^-$
$\tilde{\tau}_2^+\tilde{\tau}_2^-$
$\tilde{\tau}_1^\pm\tilde{\tau}_2^\mp$
$\tilde{\nu}_{e\mu}\tilde{\nu}_{e\mu}^*$
$\tilde{\nu}_\tau\tilde{\nu}_\tau^*$
$\tilde{\chi}_1^+\tilde{\chi}_1^-$
Any charged sparticle
$\tilde{\chi}_1^\pm\tilde{\chi}_2^\mp$
$\tilde{\chi}_1^0\tilde{\chi}_1^0$
$\tilde{\chi}_1^0\tilde{\chi}_1^0$ only
$\tilde{\chi}_1^0+\tilde{\nu}$ only
$\tilde{\chi}_1^0\tilde{\chi}_2^0$
$\tilde{\chi}_1^0\tilde{\chi}_3^0$
$\tilde{\chi}_2^0\tilde{\chi}_2^0$
$\tilde{\chi}_2^0\tilde{\chi}_3^0$
$\tilde{\chi}_3^0\tilde{\chi}_3^0$
Nothing

Kinematic Accessibility at the ILC : III



Light Higgs Mass Predictions

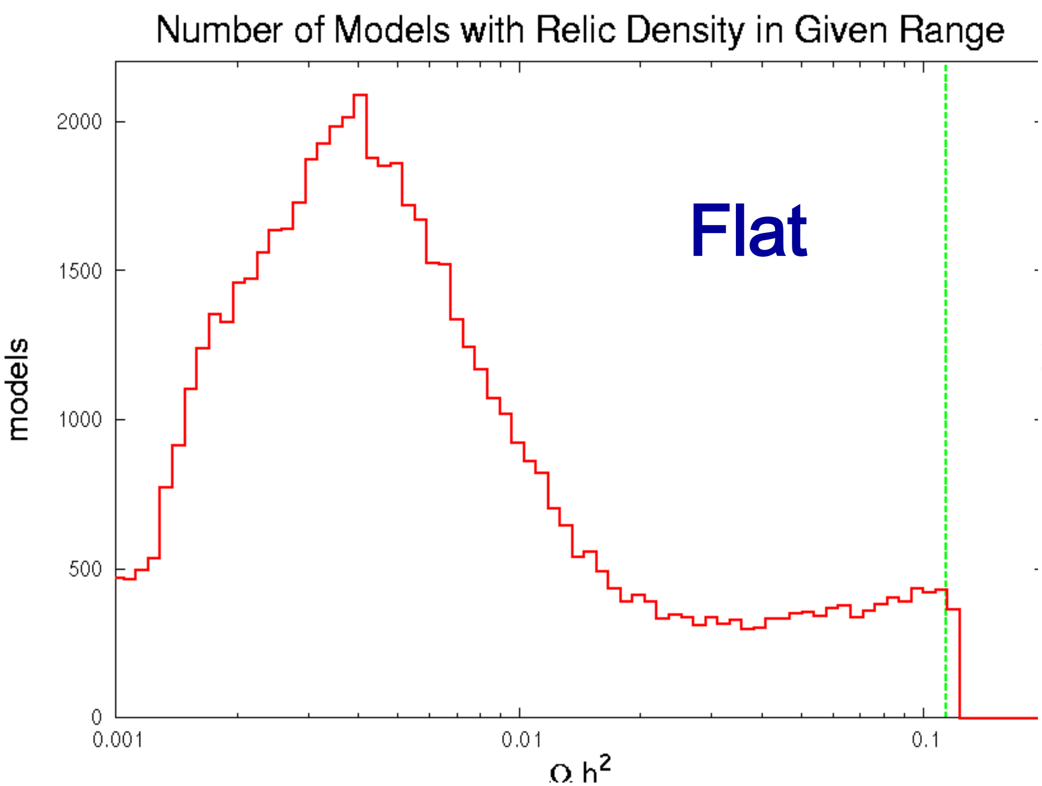


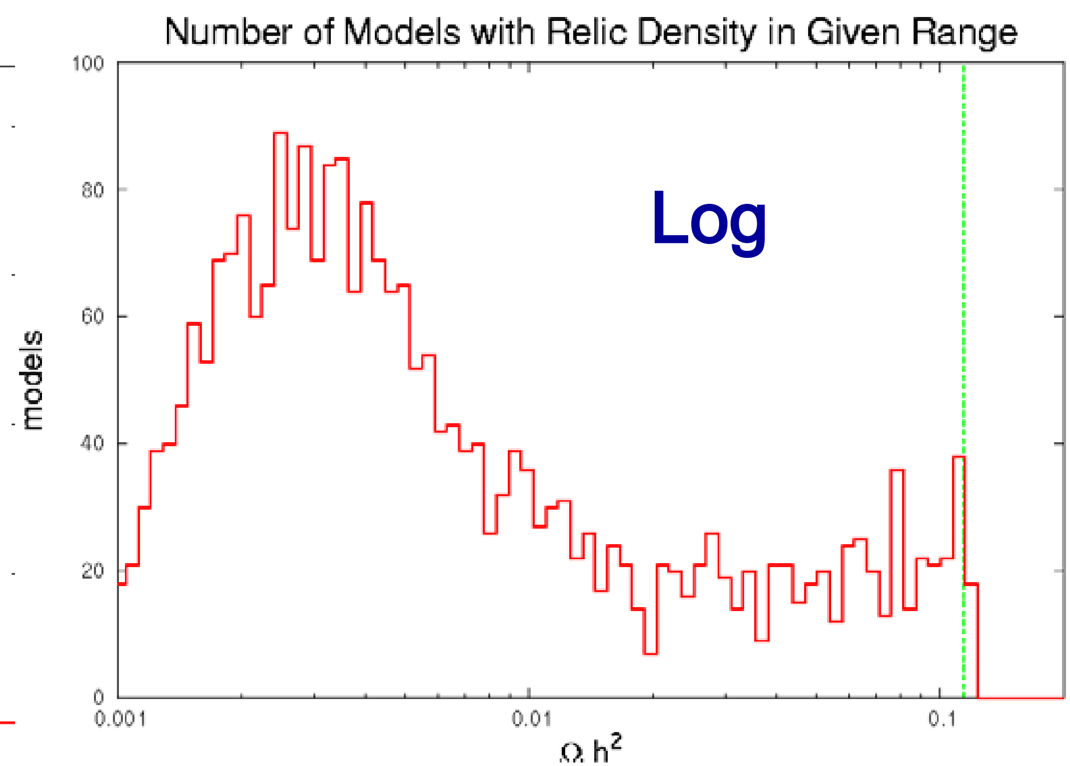


LEP Higgs mass constraints avoided by either reducing the ZZh coupling and/or reducing the, e.g., $h \rightarrow \bar{b}b$ branching fraction by decays to LSP pairs. We have both of these cases in our final model sets.

Predicted Dark Matter Density : Ωh^2

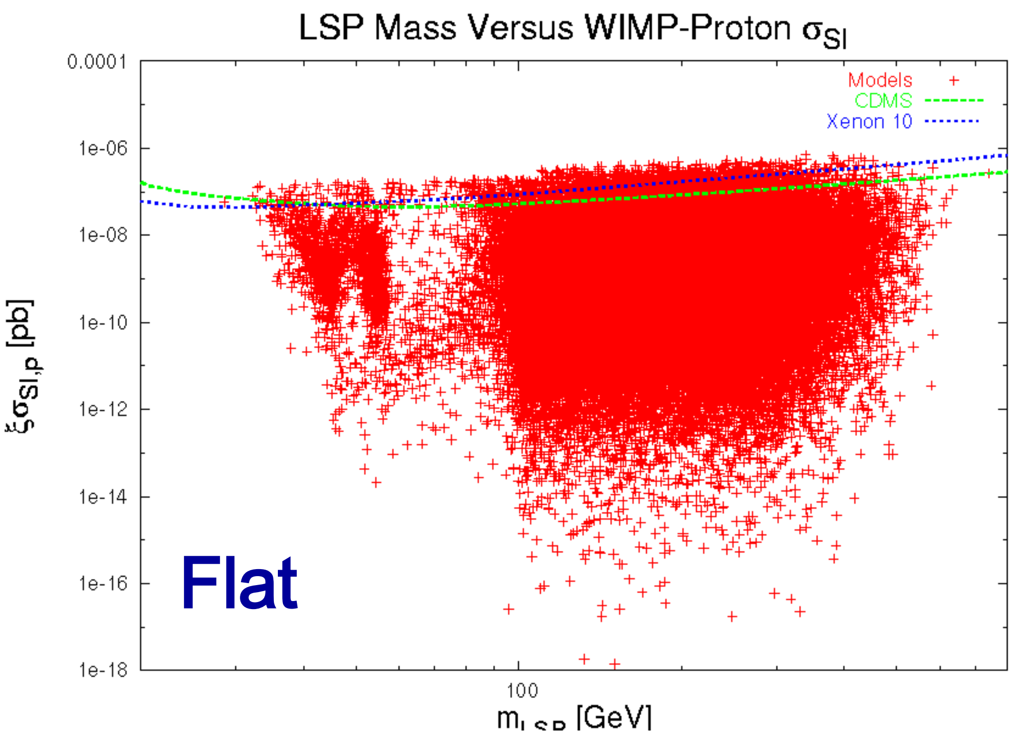
It is not likely that the LSP is the dominant component of dark matter in ‘conventional’ cosmology…but it can be in some model cases.. (1240 + 76)

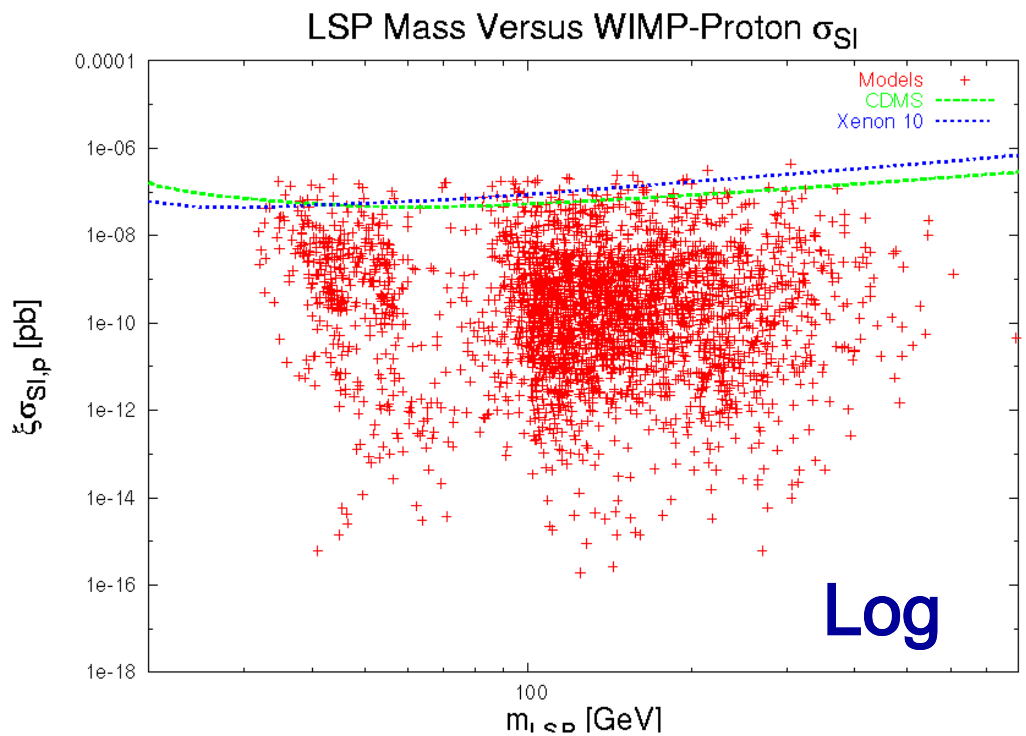




Direct Detection Expectations

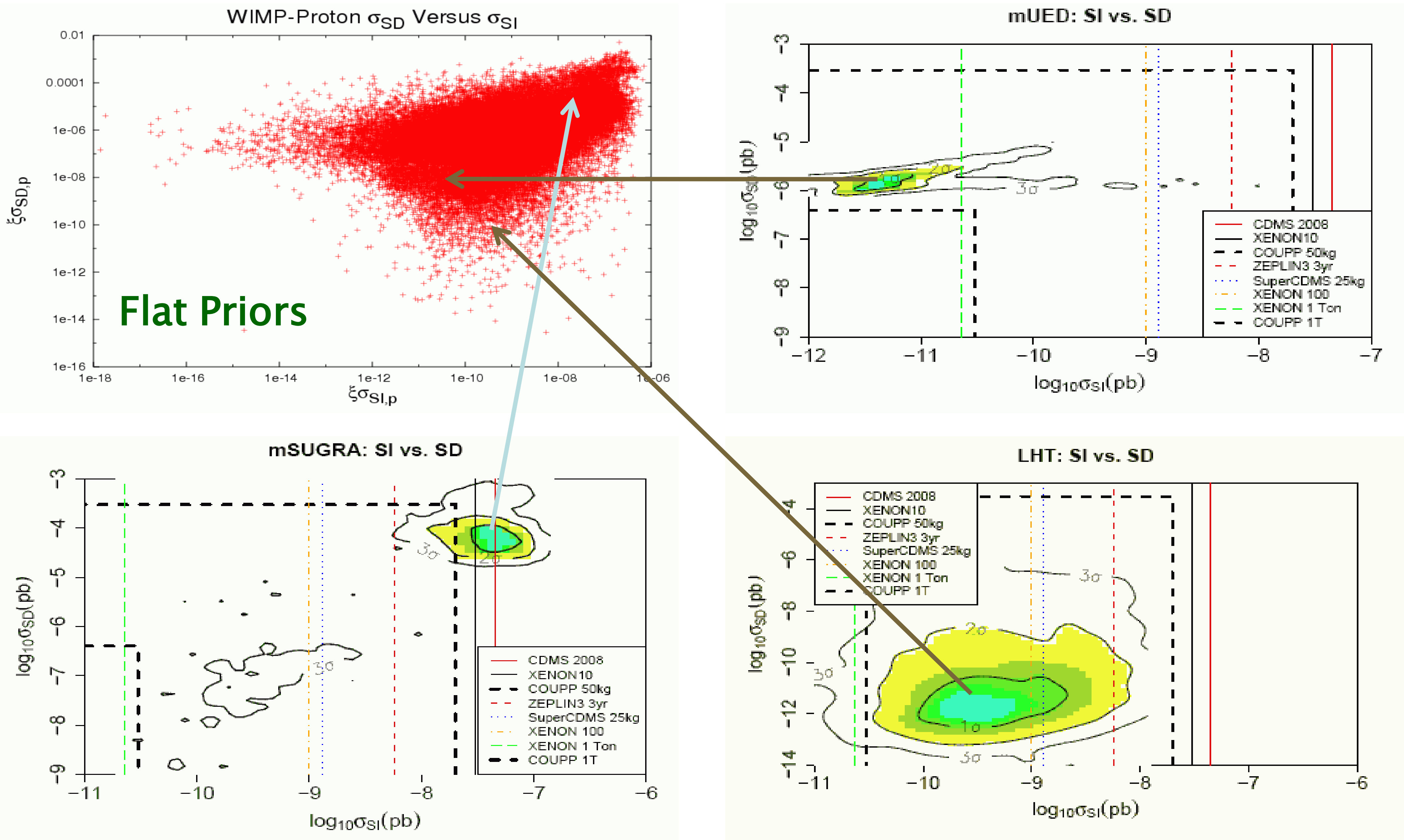
Extremely small cross sections are possible in either the flat or log prior cases…far smaller than expected in, e.g., mSUGRA.…





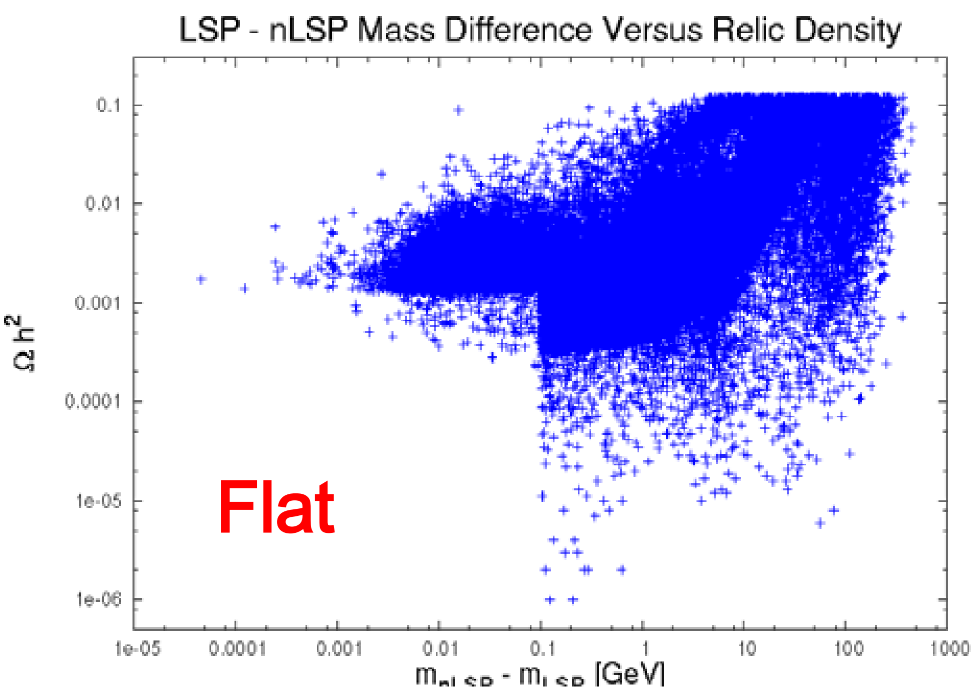
Distinguishing Dark Matter Models

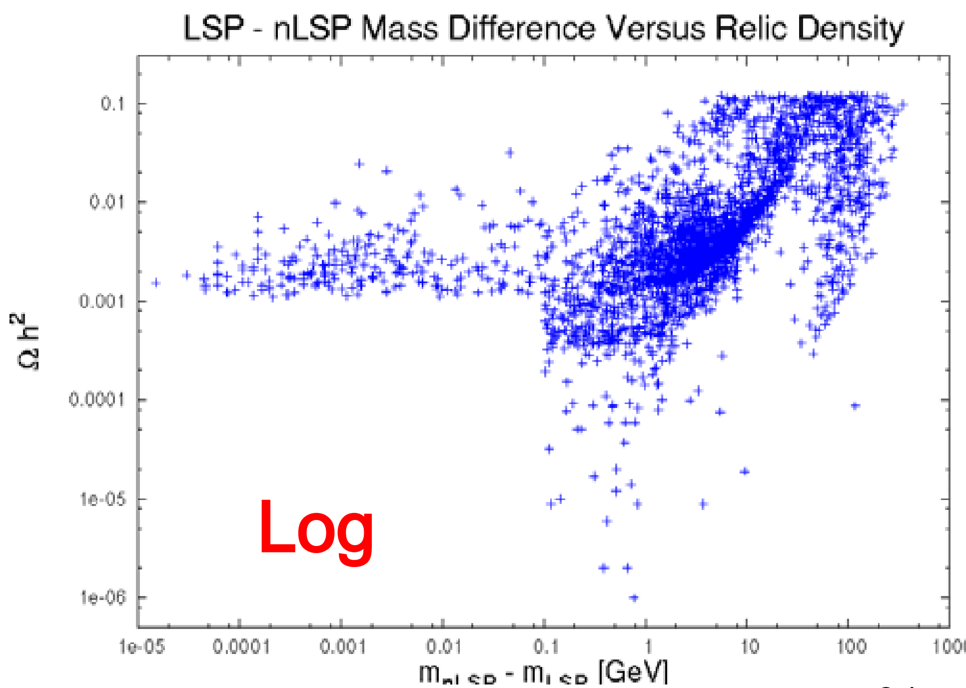
Barger etal



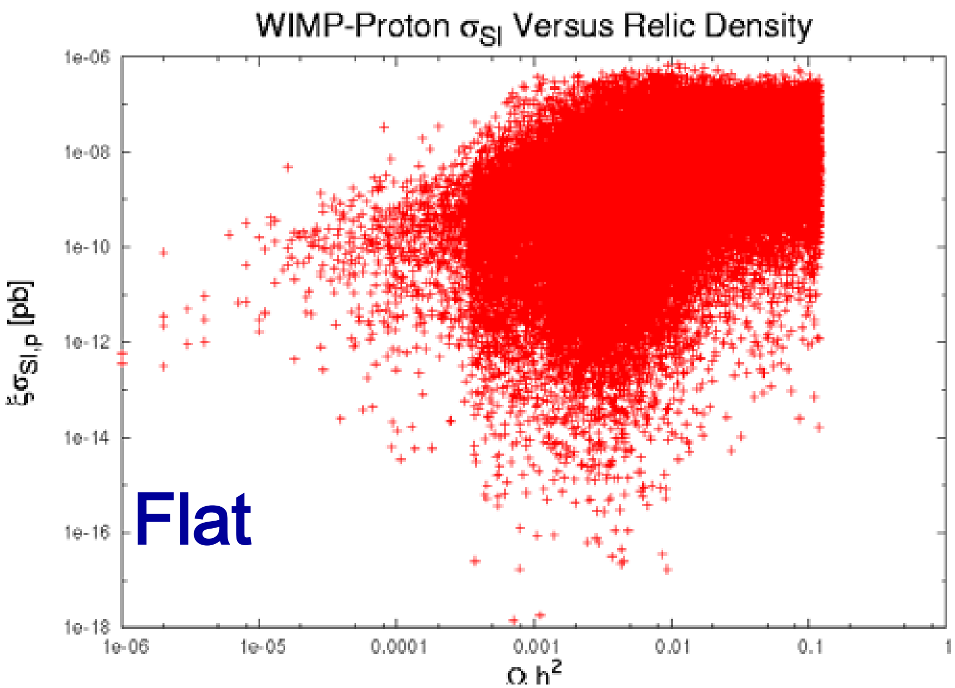
Correlation Between Dark Matter Density & the LSP-nLSP Mass Splitting

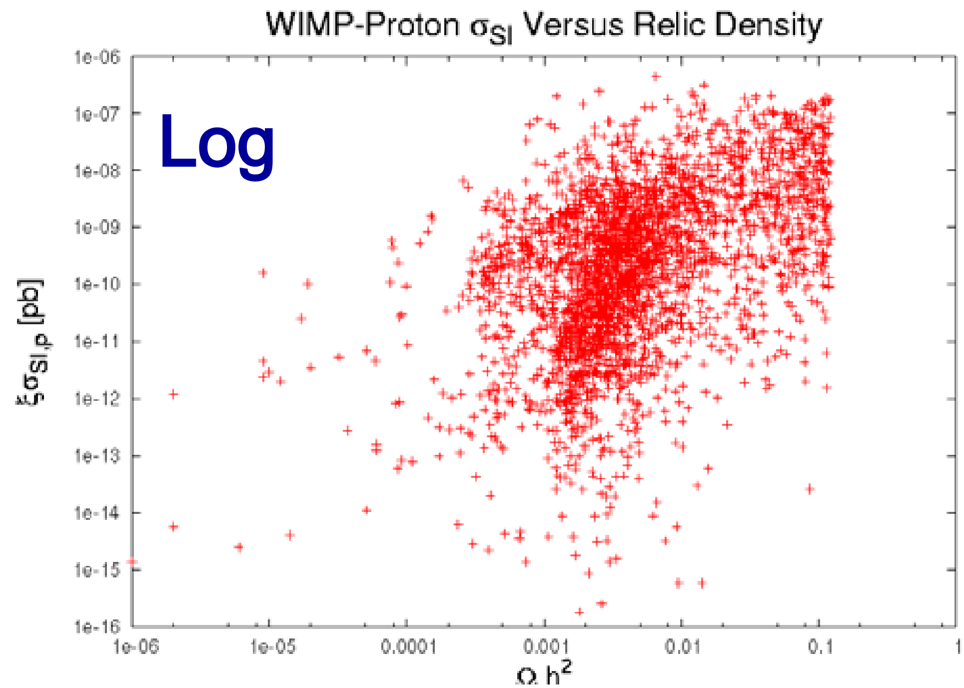
Small mass differences can lead to rapid co-annihilations reducing the dark matter density….





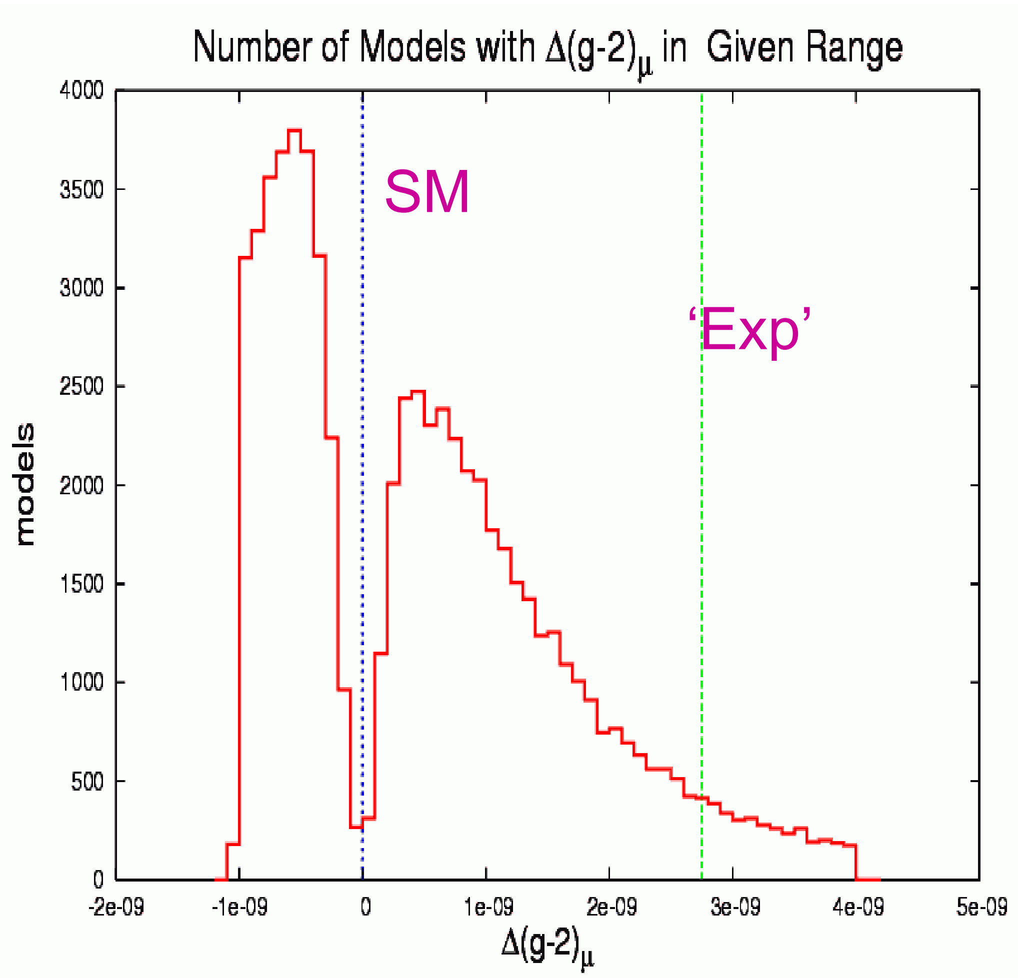
Dark Matter Density Correlation with the Direct Search Cross Section



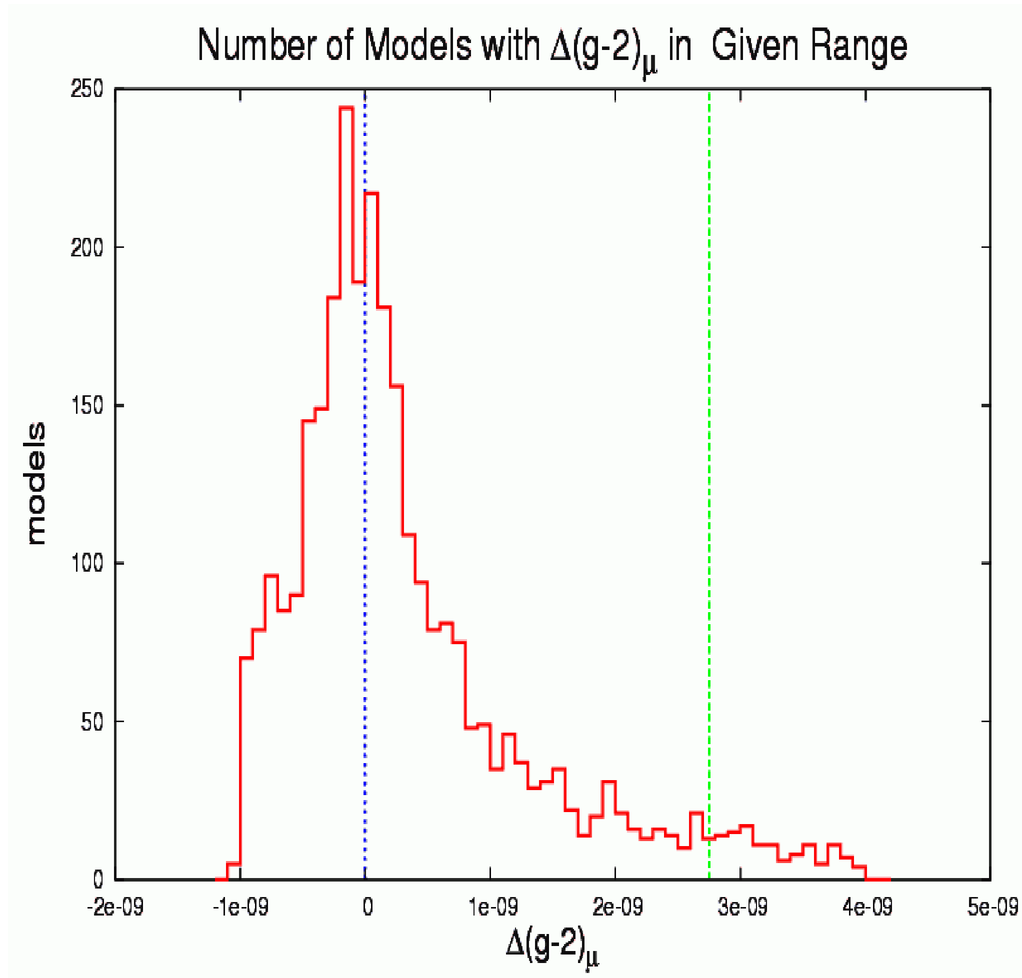


Predictions for $\Delta(g-2)_\mu$

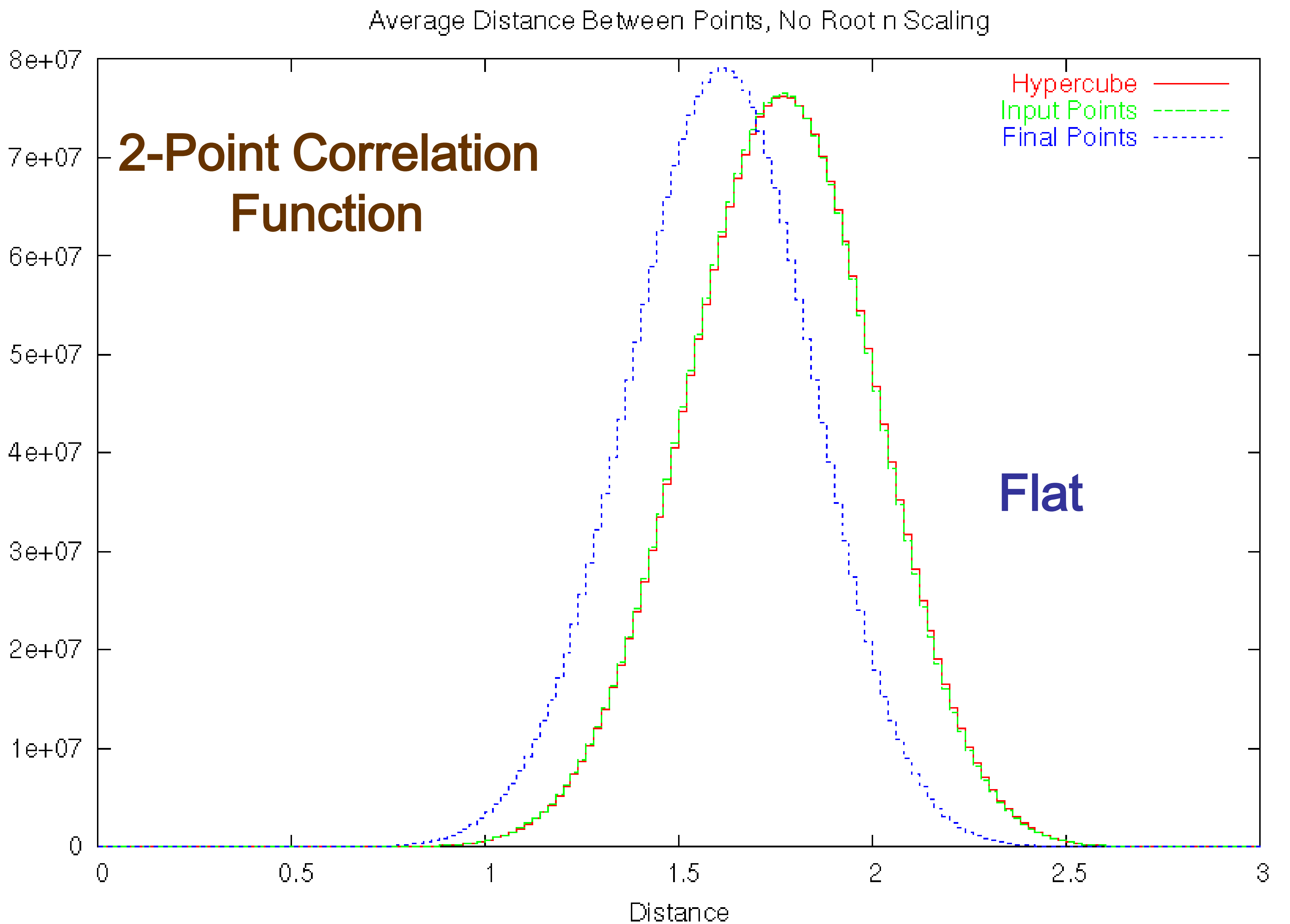
flat

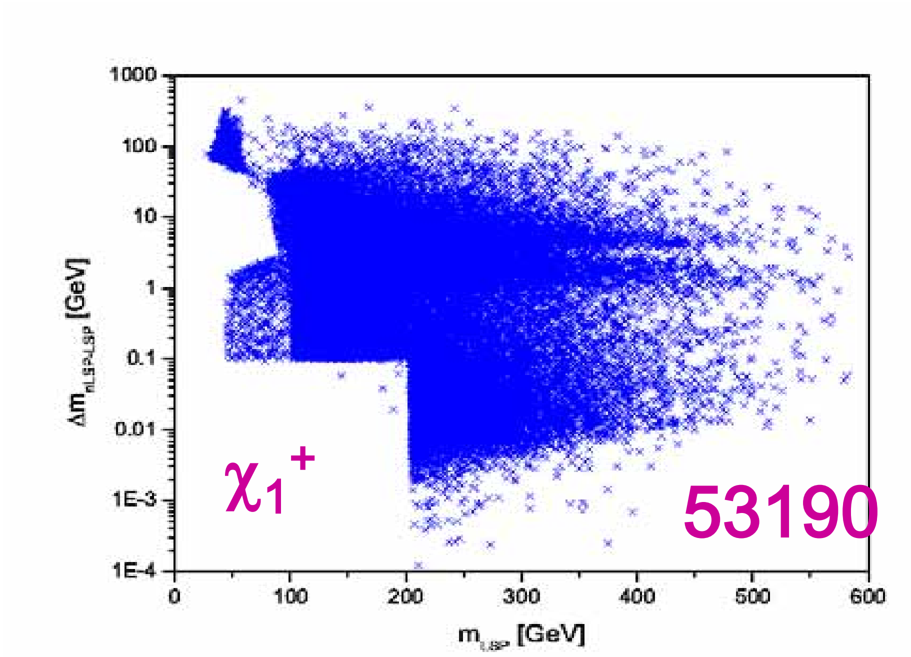


log

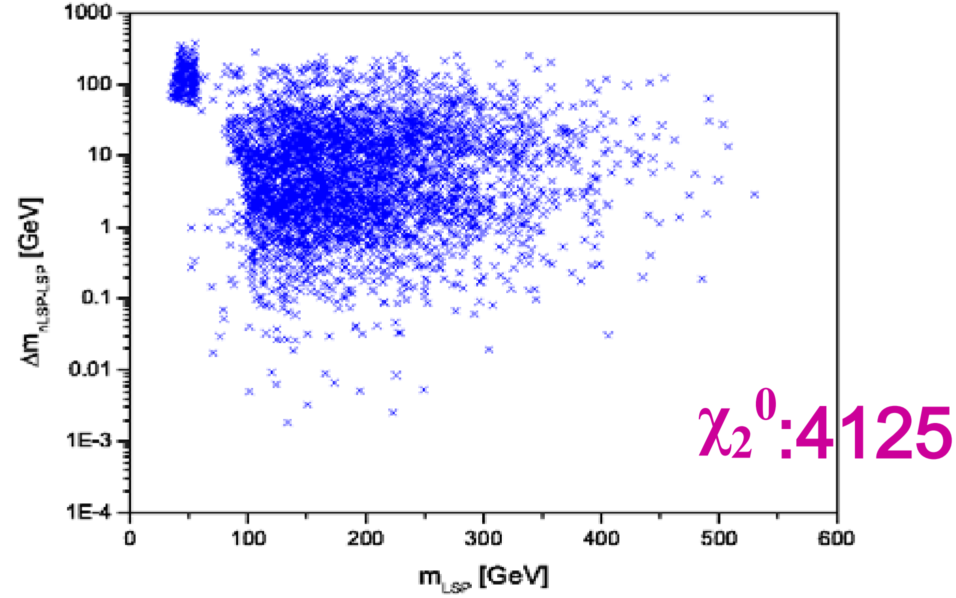


Clustering of Model Points in 19-Dimensional Space

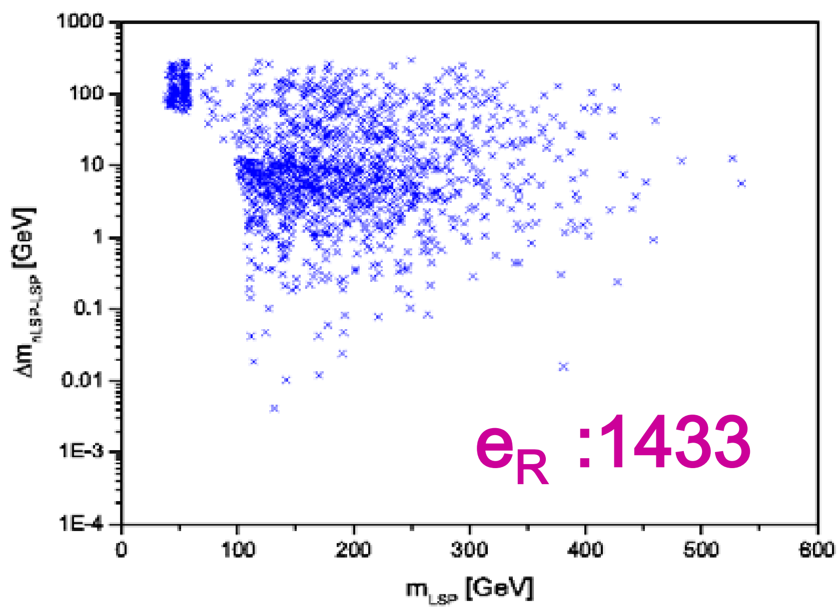




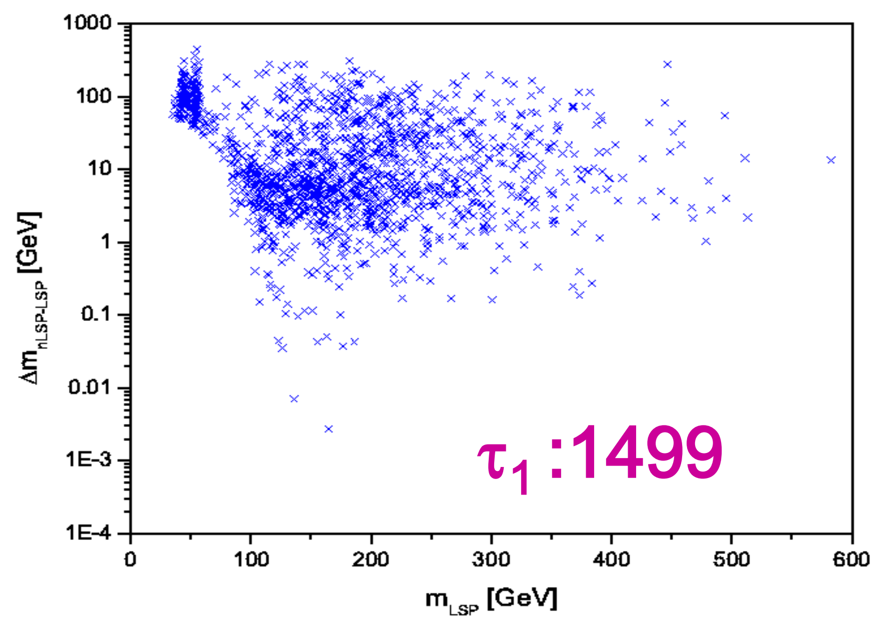
χ_1^+
53190
$\Delta m_{nLSP-LSP}$ [GeV]
m_{LSP} [GeV]
1000
100
10
1
0.1
0.01
1E-3
1E-4
0
100
200
300
400
500
600



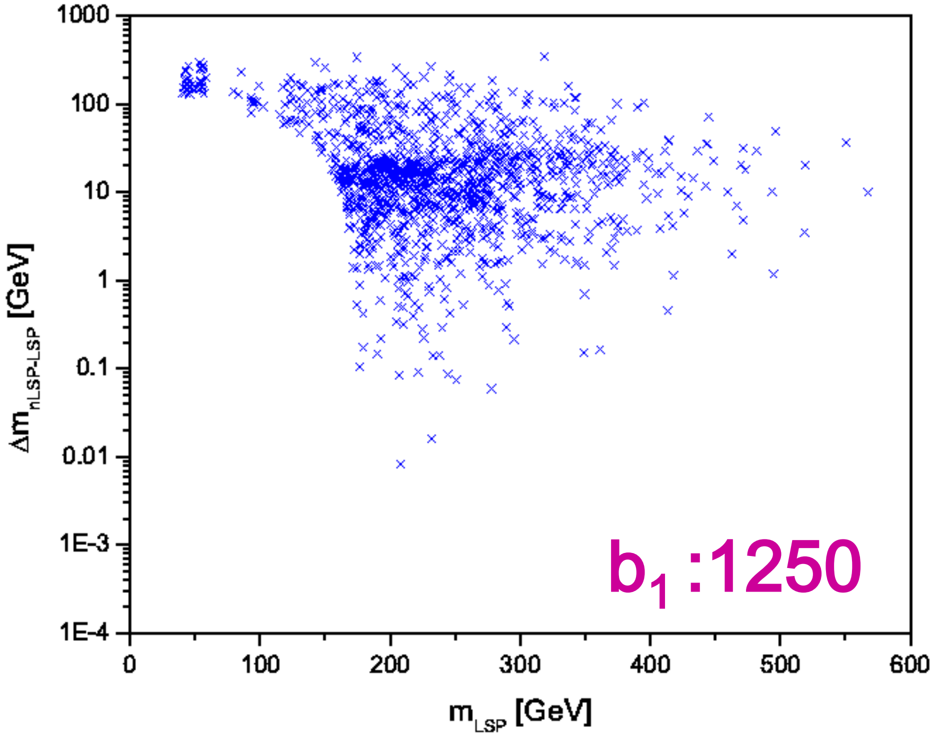
χ_2^0:4125
$\Delta m_{nLSP-LSP}$ [GeV]
m_{LSP} [GeV]
1000
100
10
1
0.1
0.01
1E-3
1E-4
0
100
200
300
400
500
600

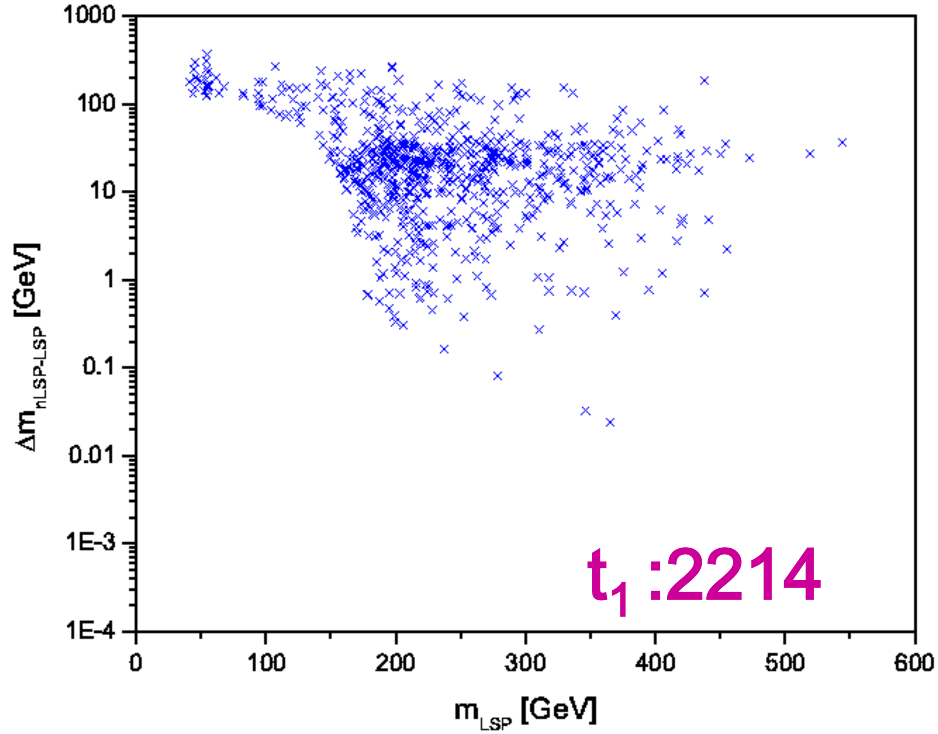


e_R :1433
$\Delta m_{nLSP-LSP}$ [GeV]
m_{LSP} [GeV]
1000
100
10
1
0.1
0.01
1E-3
1E-4
0
100
200
300
400
500
600



τ_1 :1499
$\Delta m_{nLSP-LSP}$ [GeV]
m_{LSP} [GeV]
1000
100
10
1
0.1
0.01
1E-3
1E-4
0
100
200
300
400
500
600

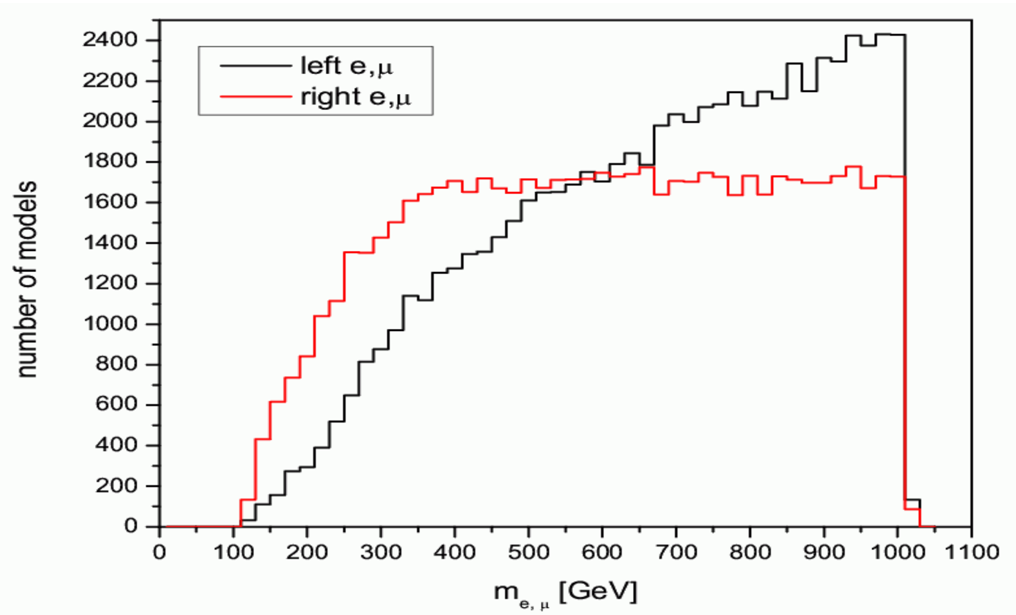

1000
100
10
1
0.1
0.01
1E-3
1E-4
$\Delta m_{nLSP-LSP}$ [GeV]
0
100
200
300
400
500
600
m_{LSP} [GeV]
b_1 :1250

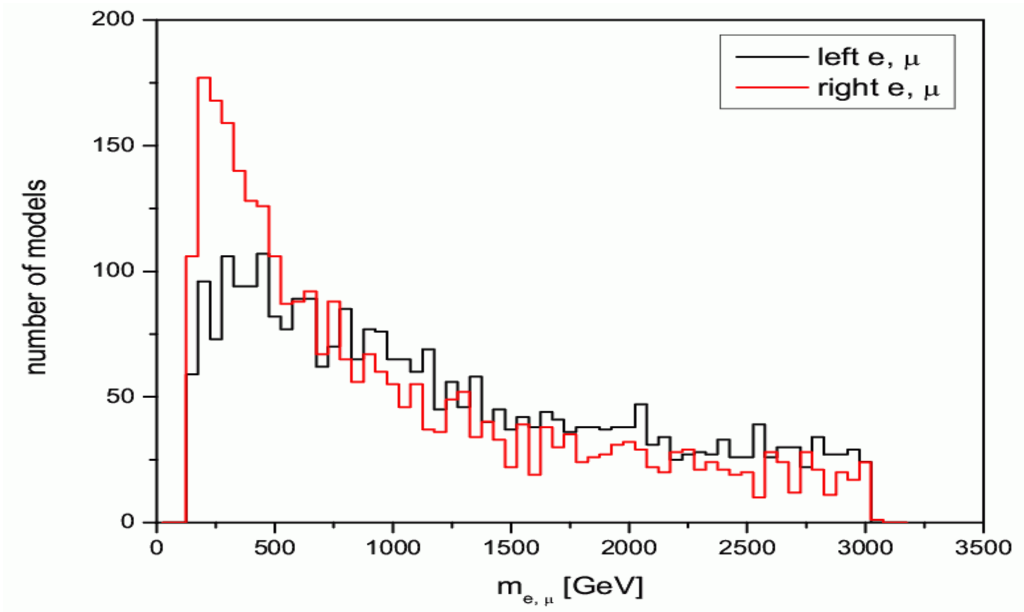

1000
100
10
1
0.1
0.01
1E-3
1E-4
$\Delta m_{nLSP-LSP}$ [GeV]
0
100
200
300
400
500
600
m_{LSP} [GeV]
t_1 :2214

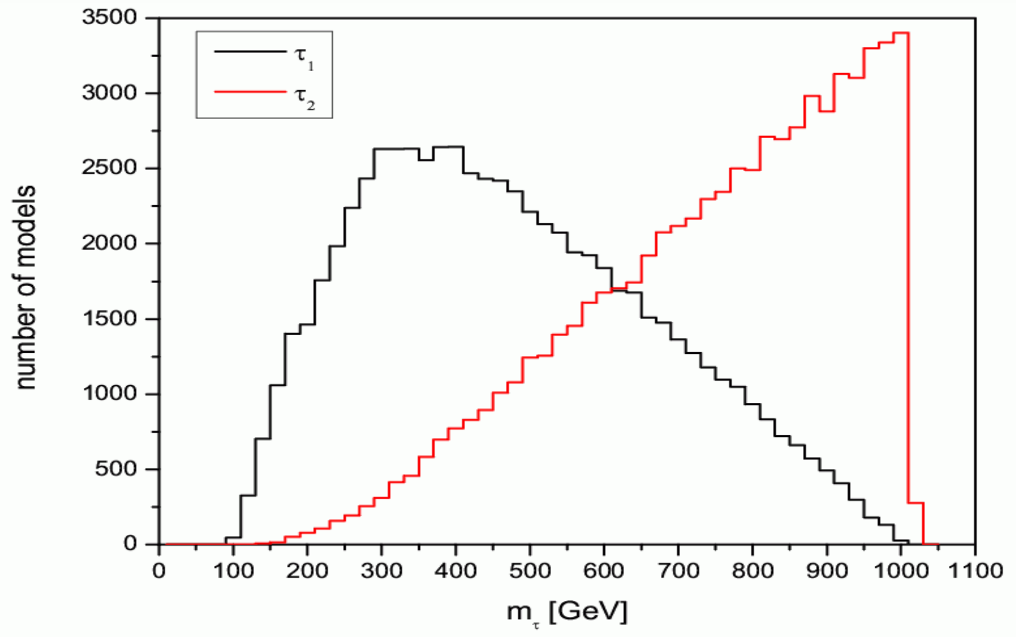
Distribution of Sparticle Masses By Species

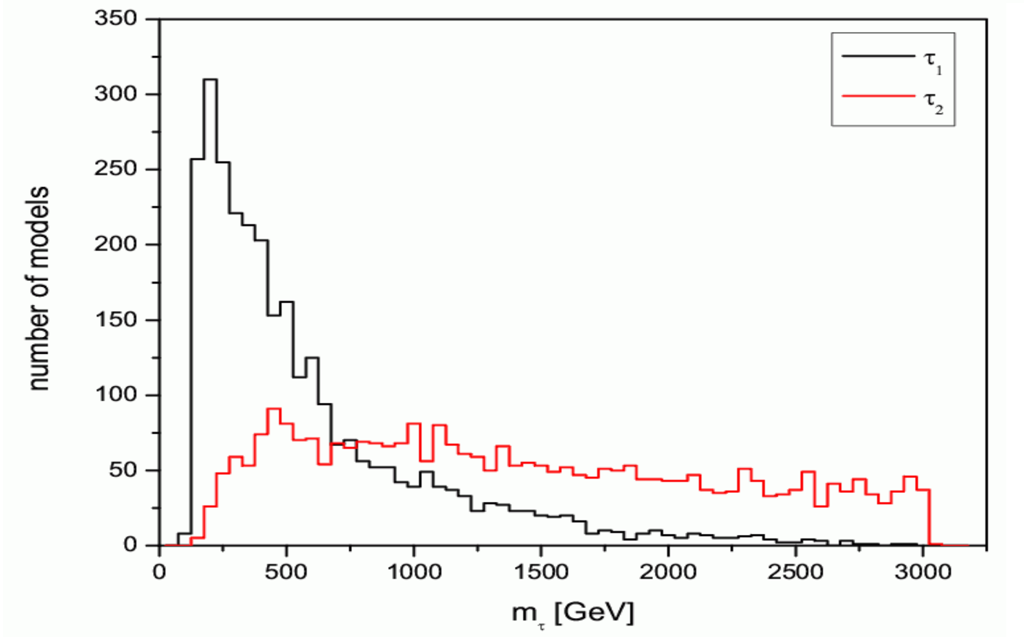
Flat Priors

Log Priors

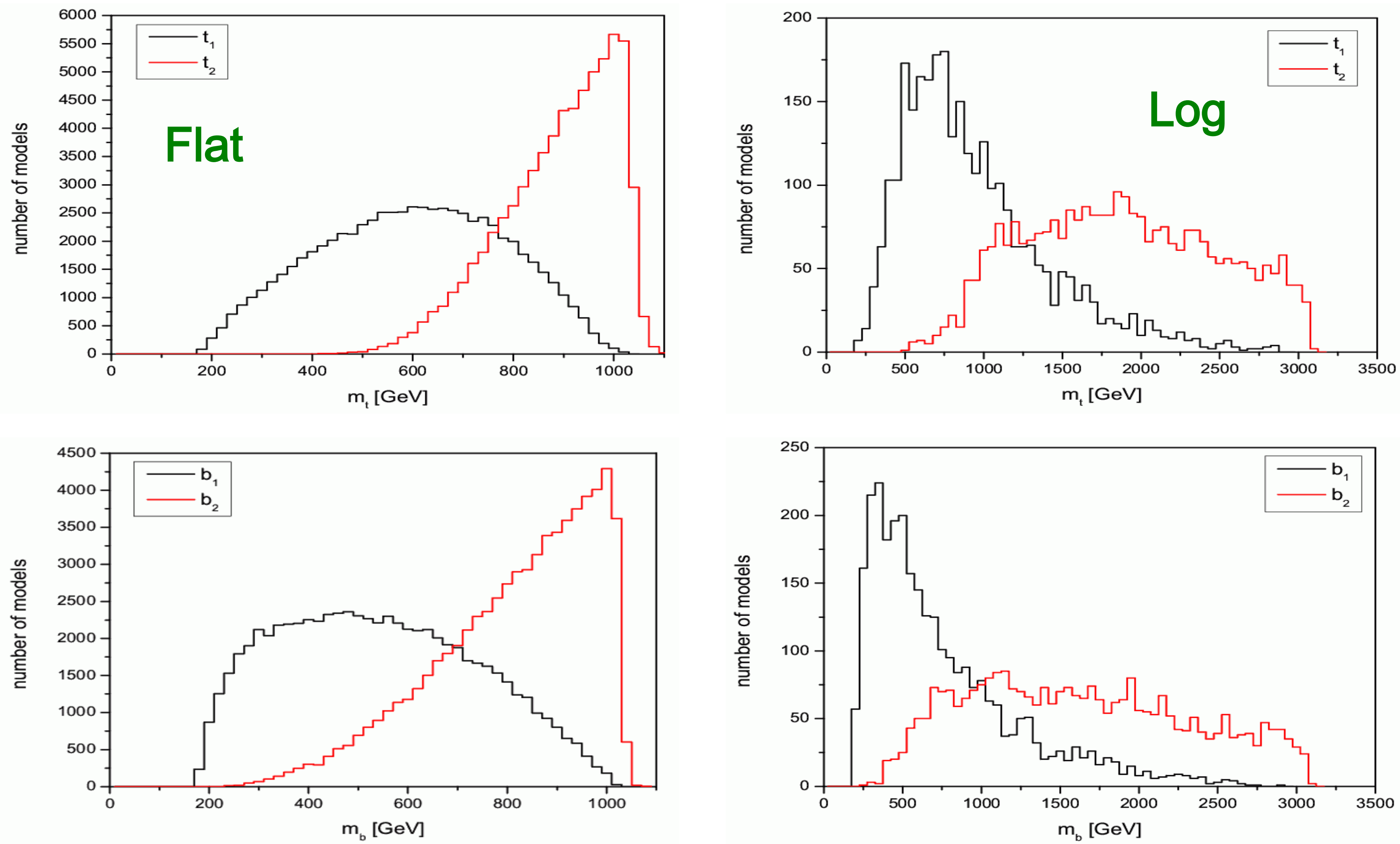






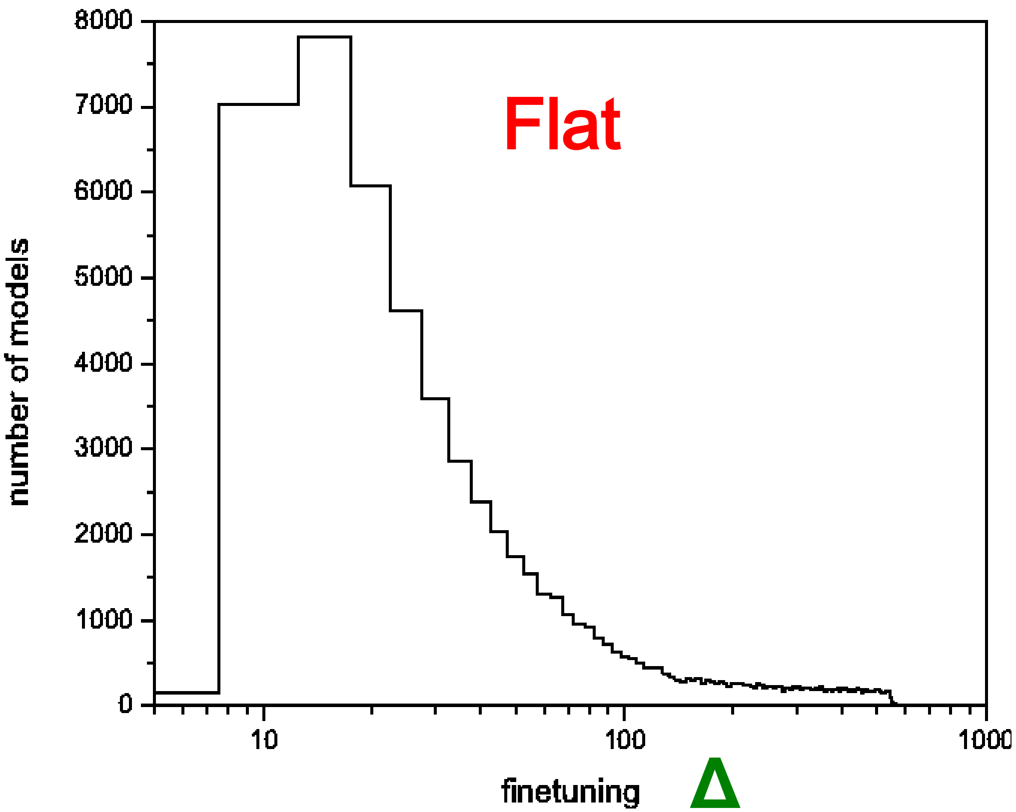


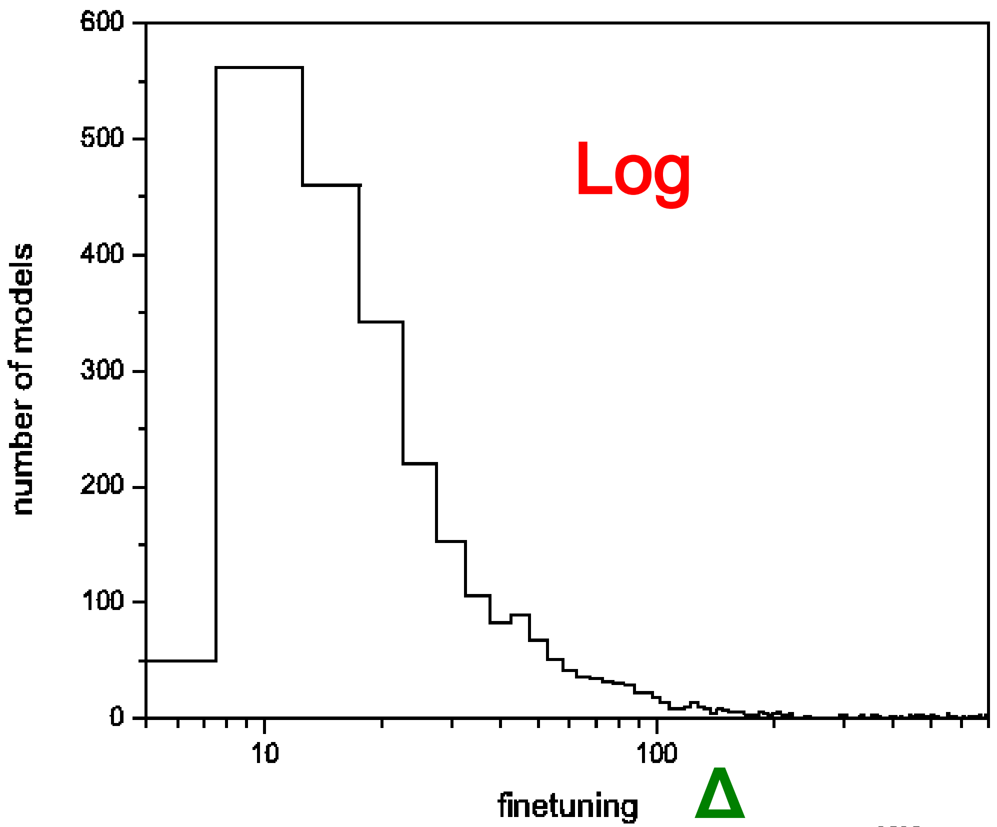
Distribution of Sparticle Masses By Species



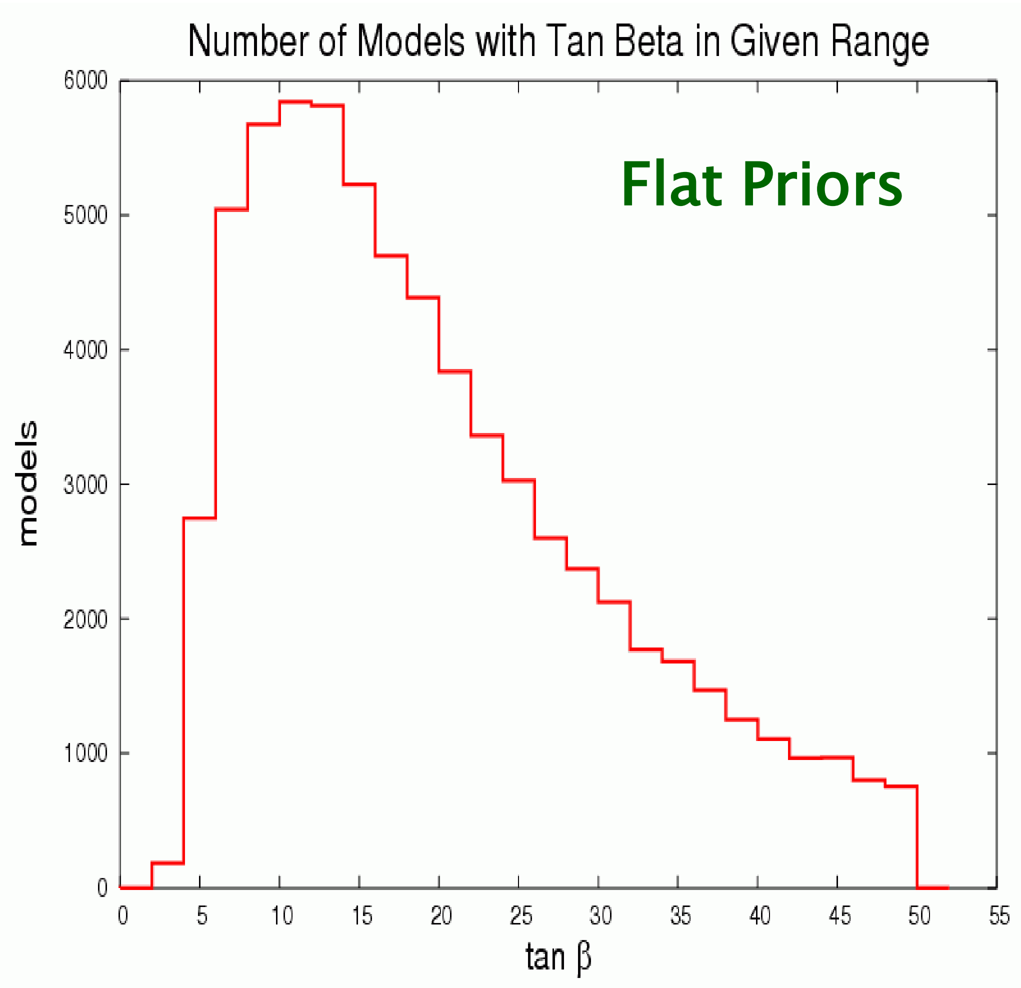
'Fine-Tuning' or Naturalness Criterion

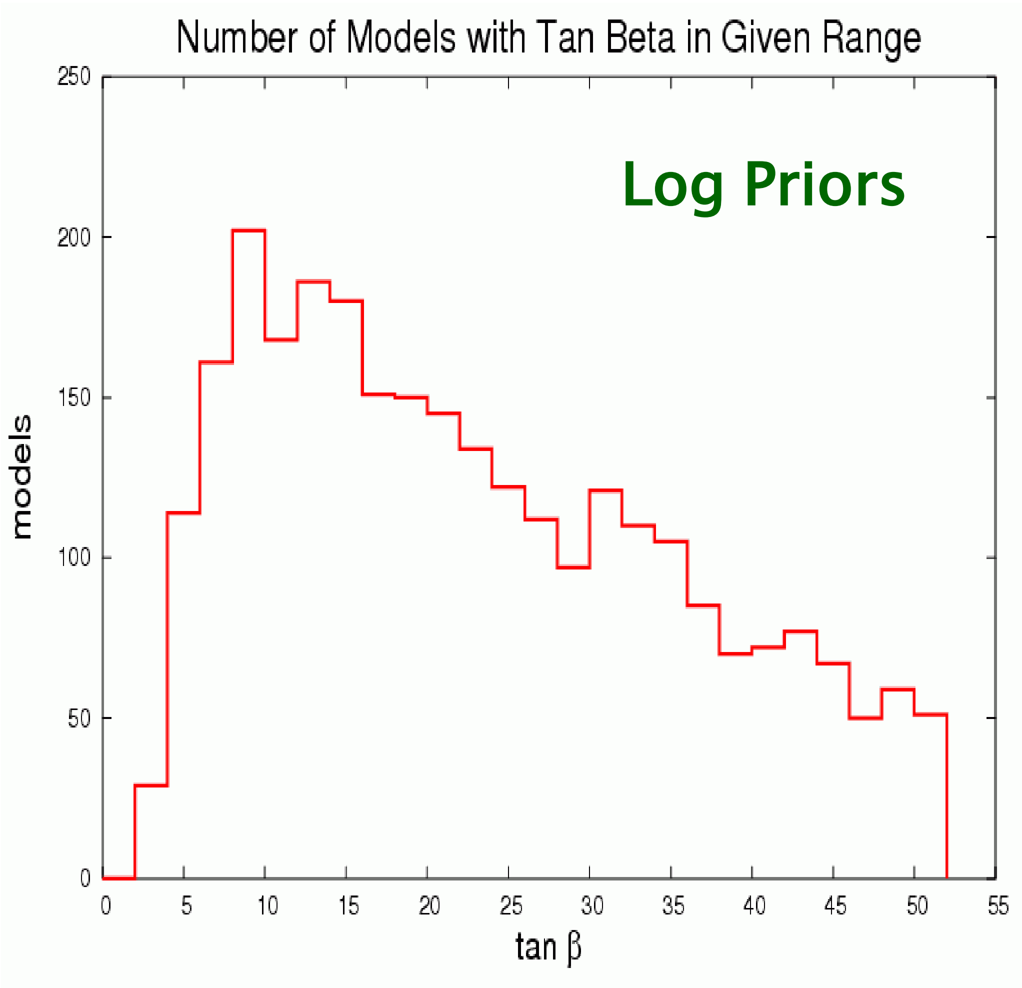
We find that small values of `fine-tuning' are very common !





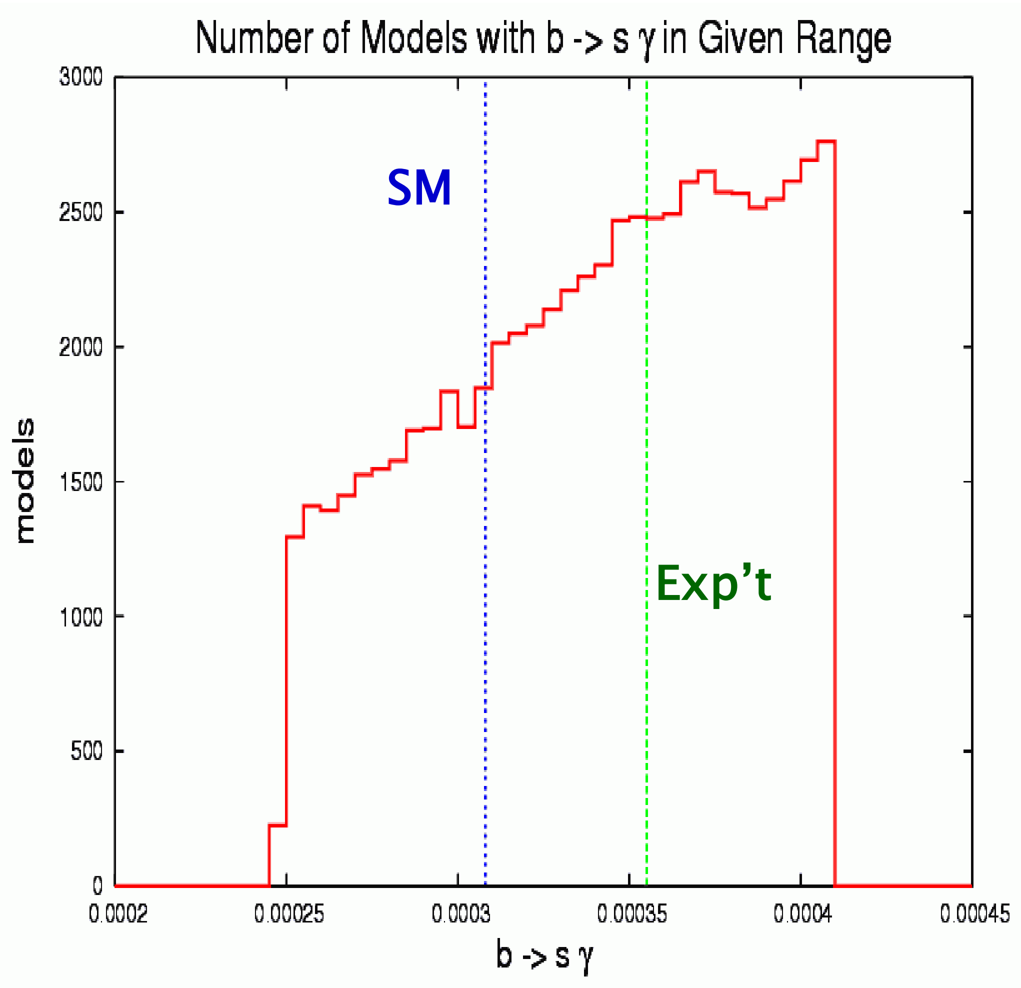
Distribution for tan beta



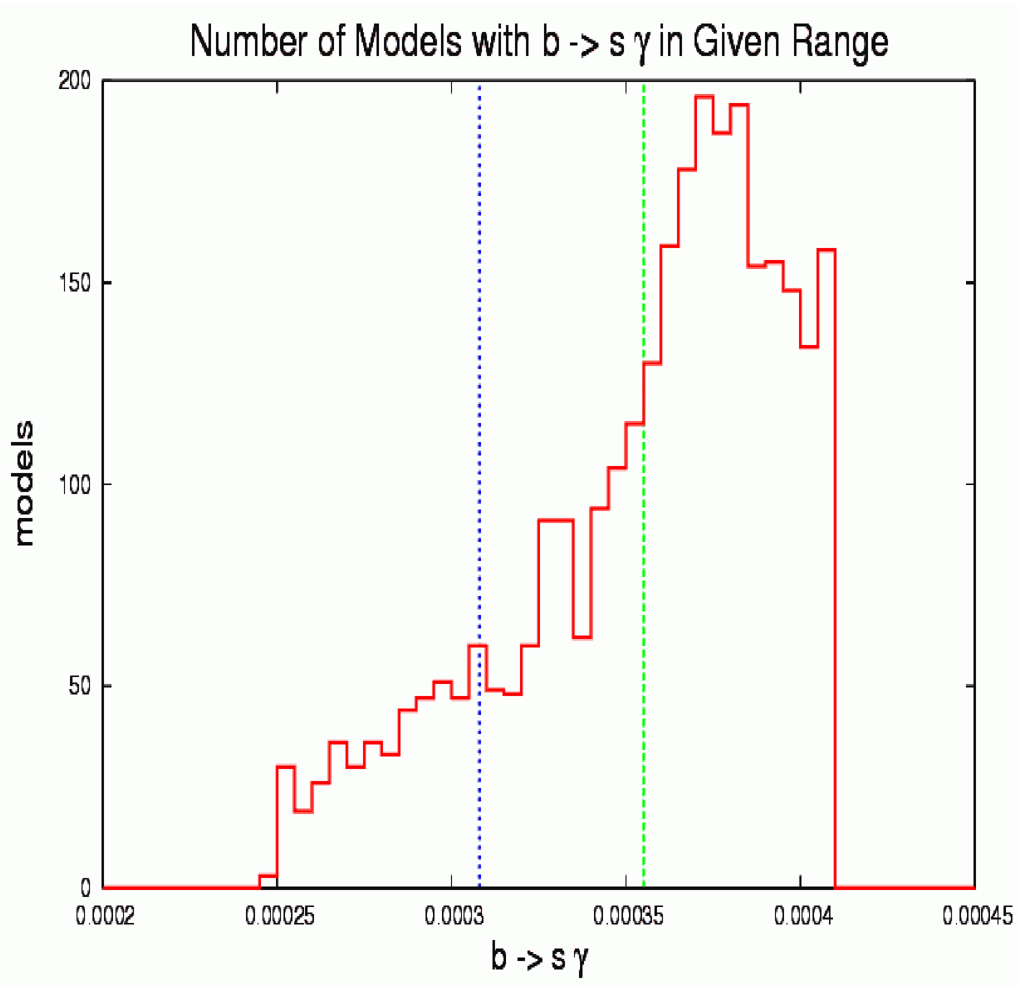


Predictions for b→sγ

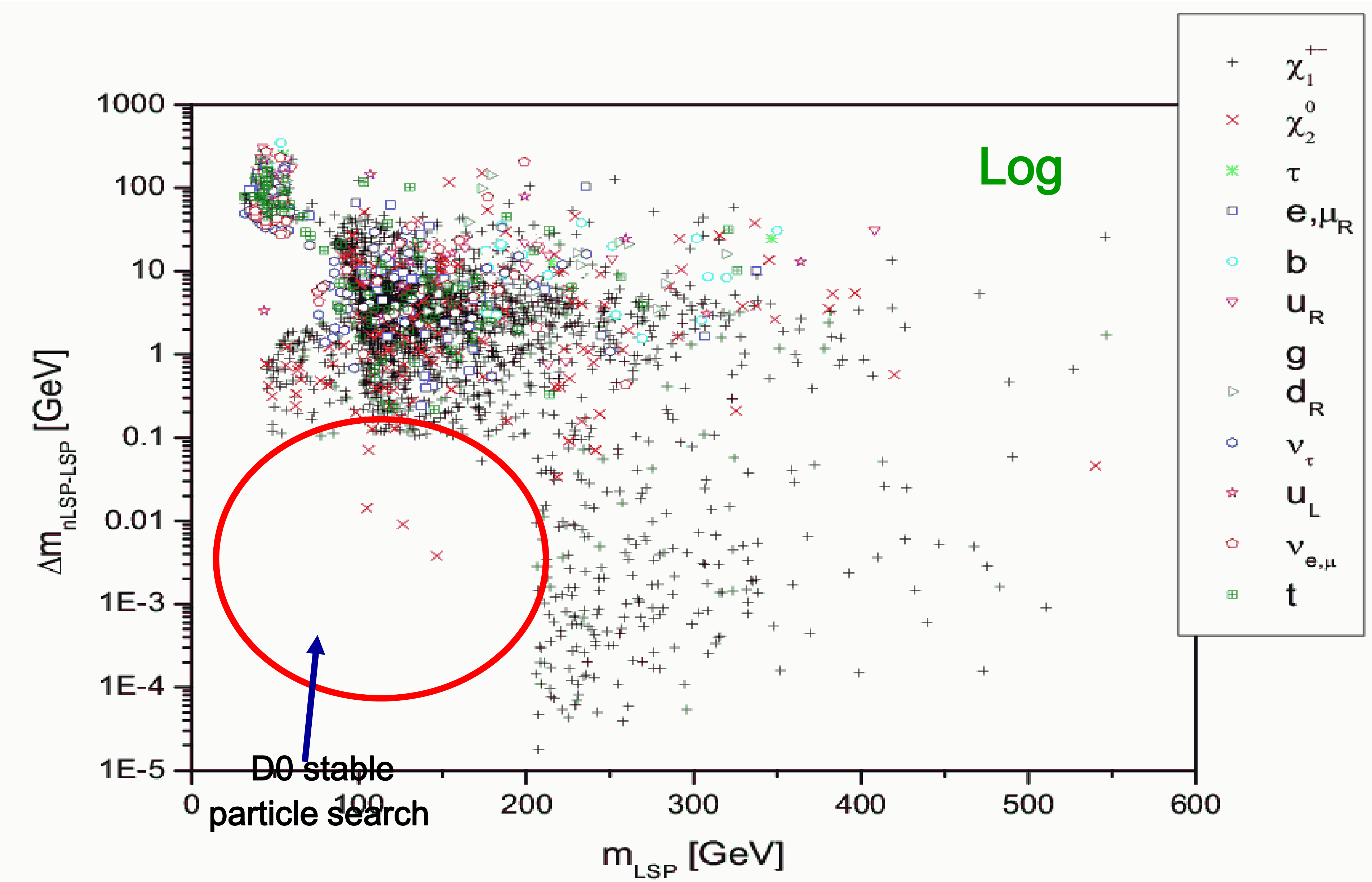
Flat Priors



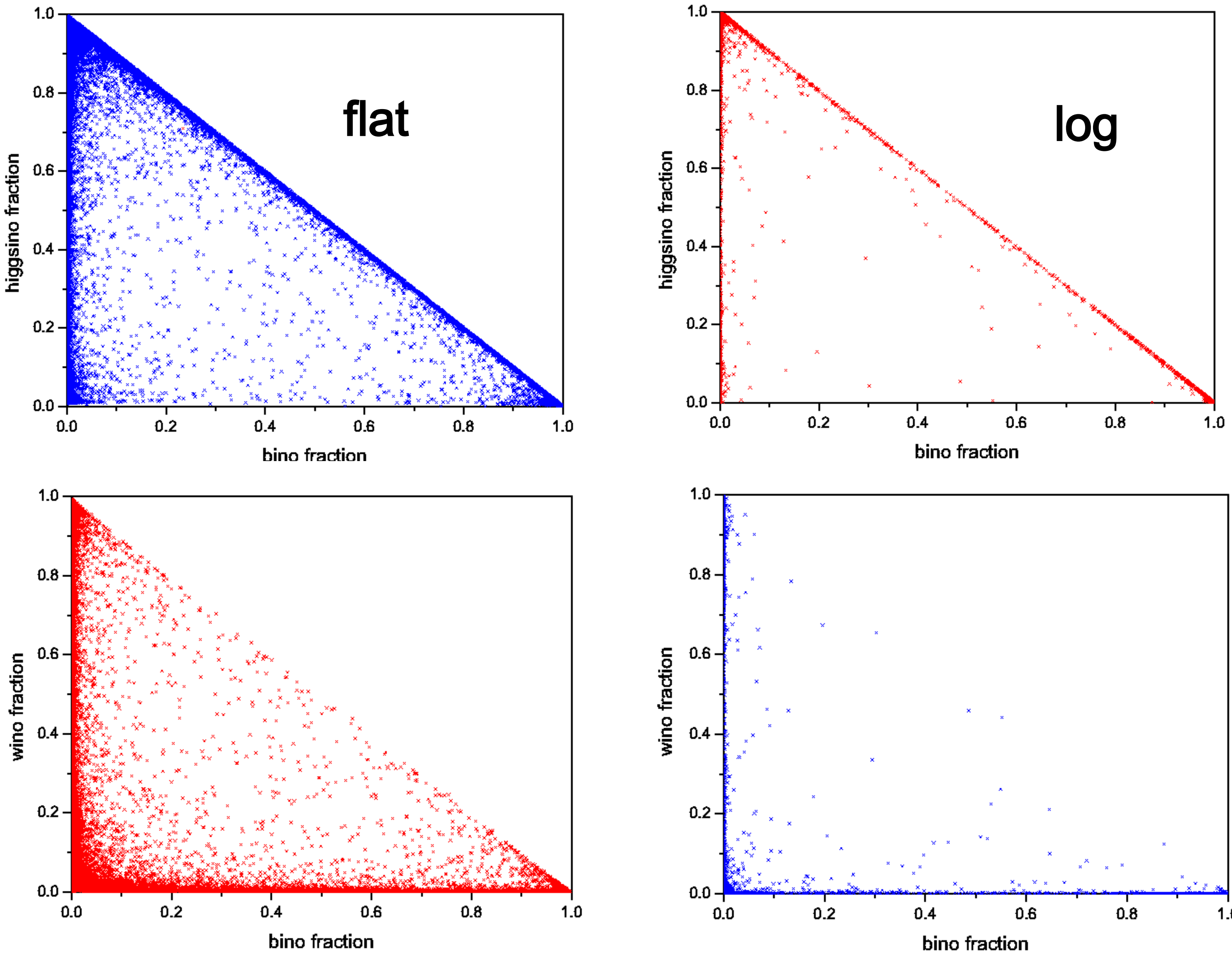
Log Priors



nLSP-LSP Mass Difference



LSP Composition



LEP II: Associated Higgs Production

$Z \to hA \to 4b, 2b2\tau, 4\tau$

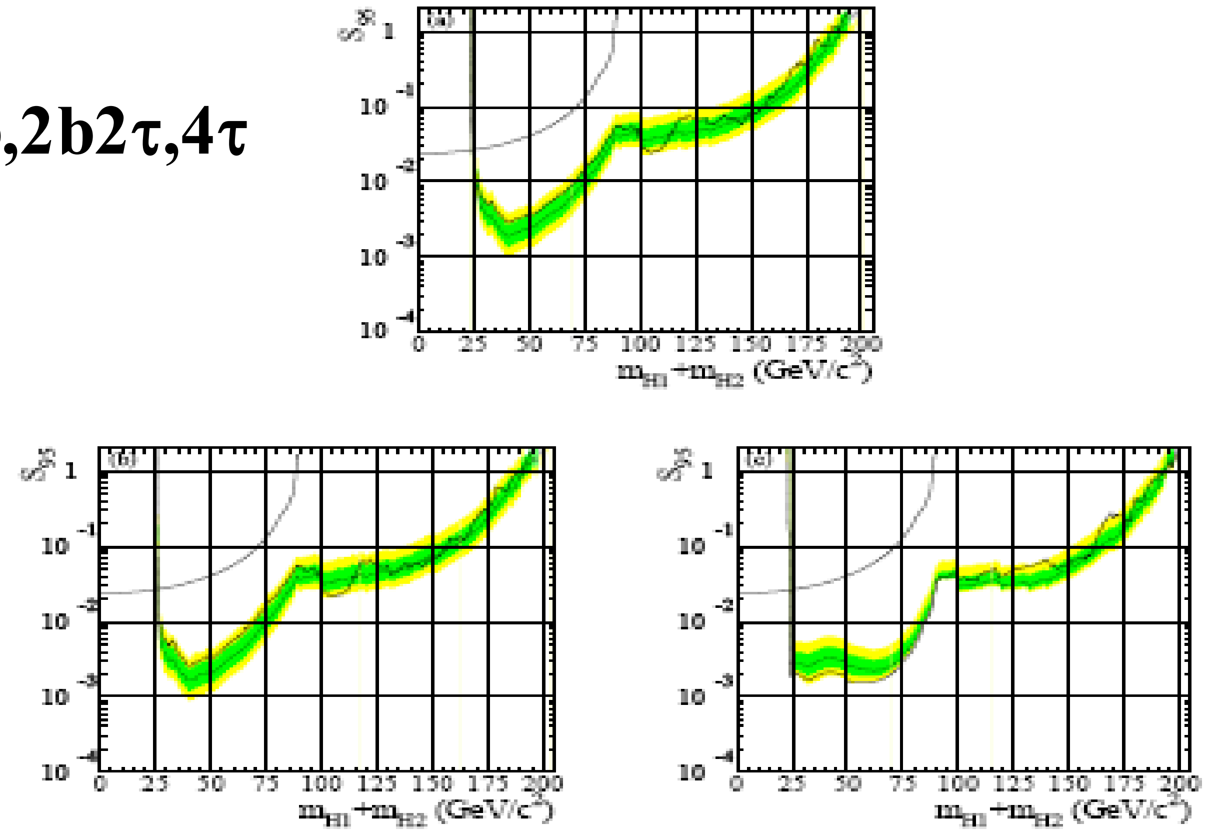
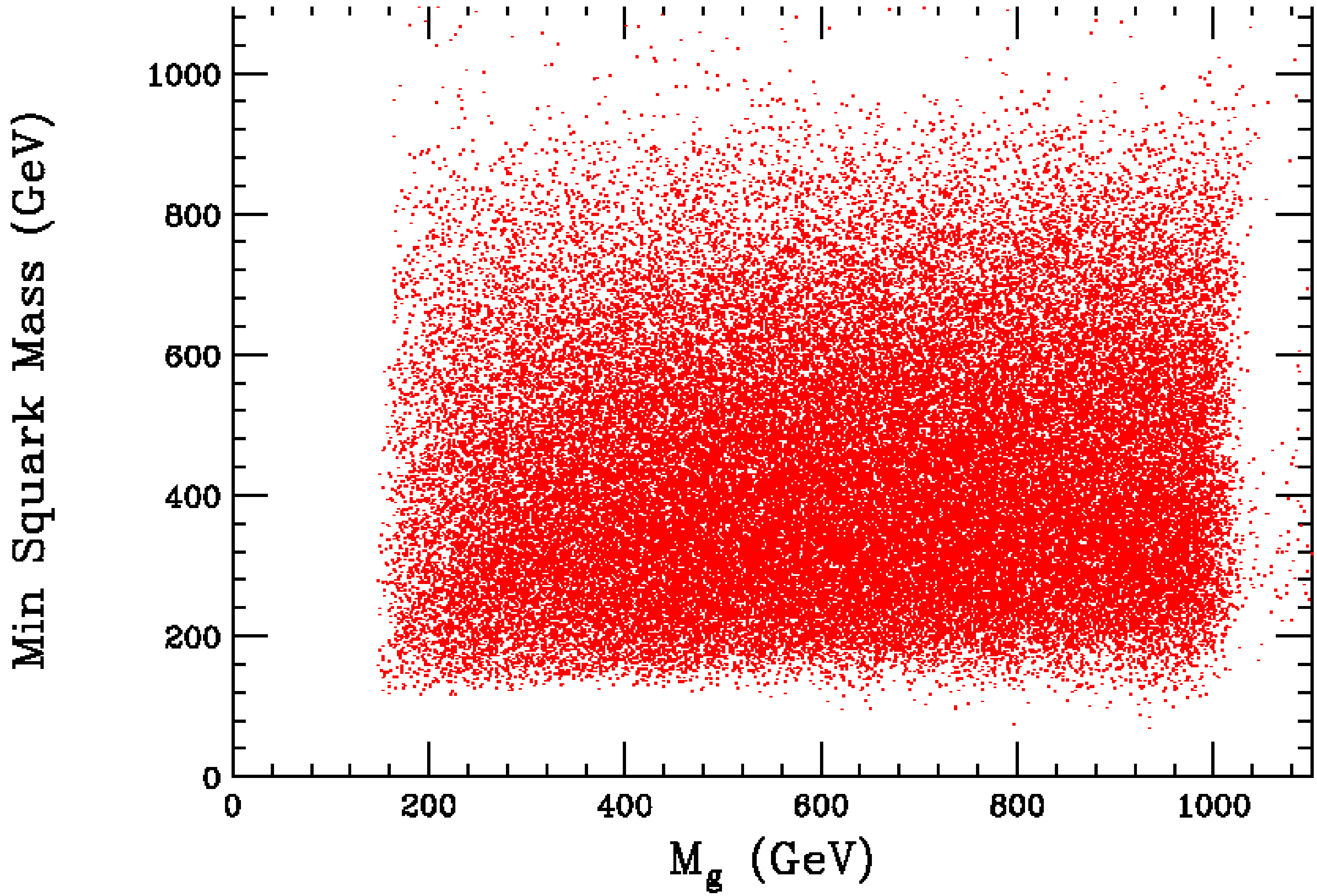


Figure 3: Model-independent 95% c.l. upper bounds, S_{95}, for various topological cross sections motivated by the pair-production process $e^+e^- \to \mathcal{H}_2\mathcal{H}_1$, for the particular case where $m_{\mathcal{H}_2}$ and $m_{\mathcal{H}_1}$ are approximately equal. Such is the case, for example, in the CP-conserving MSSM scenarios for $\tan\beta$ greater than 10. The abscissa represents the sum of the two Higgs boson masses. The full line represents the observed limit. The dark (green) and light (yellow) shaded bands around the median expectation (dashed line) correspond to the 68% and 95% probability bands. The curves which complete the exclusion at low masses are obtained using the constraint from the measured decay width of the Z boson, see Section 3.2. Upper plot: the Higgs boson decay branching ratios correspond to the m_h-max benchmark scenario with $\tan\beta=10$, namely 94% $\mathcal{H}_1 \to b\bar{b}$, 6% $\mathcal{H}_1 \to \tau^+\tau^-$, 92% $\mathcal{H}_2 \to b\bar{b}$ and 8% $\mathcal{H}_2 \to \tau^+\tau^-$; lower left: both Higgs bosons are assumed to decay exclusively to $b\bar{b}$; lower right: the Higgs bosons are assumed to decay, one into $b\bar{b}$ only and the other one into $\tau^+\tau^-$ only. For the case where both Higgs bosons decay to $\tau^+\tau^-$, the corresponding upper bound can be found in Ref. [31], Figure 15.


Min Squark Mass (GeV)
1000
800
600
400
200
0
0
200
400
600
800
1000
M_g (GeV)

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-2009-084
22 July 2009

Cut Effectiveness: IV

log

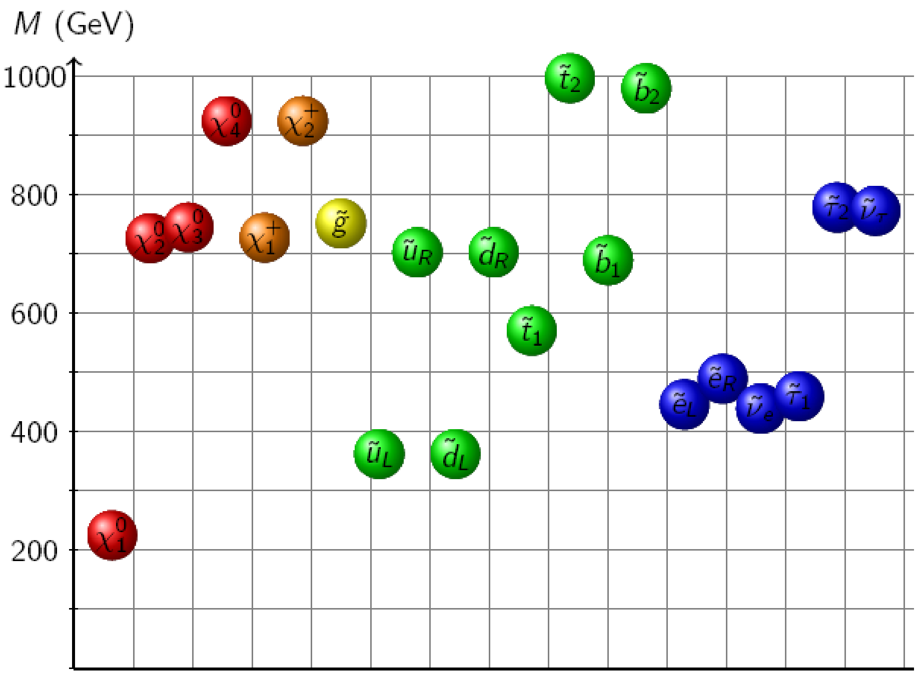
Analysis	# with Zn>5, no pystop	# with Zn>5, incl. pystops
4j0l_1	2034 (70.283 %)	2037 (70.072 %)
4j0l_2	1801 (62.232 %)	1804 (62.057 %)
4j0l_3	1538 (53.144 %)	1539 (52.941 %)
4j0l_4	1488 (51.417 %)	1489 (51.221 %)
4j0l_5	1400 (48.376 %)	1401 (48.194 %)
2j0l_1	1980 (68.417 %)	1983 (68.215 %)
2j0l_2	1570 (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 %)

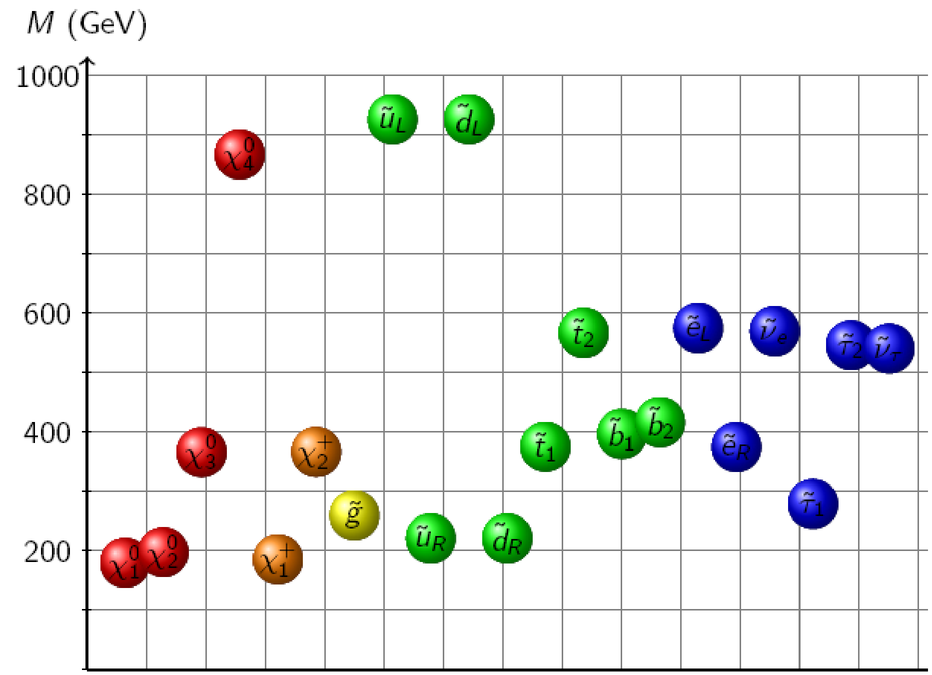
Cut Effectiveness: V

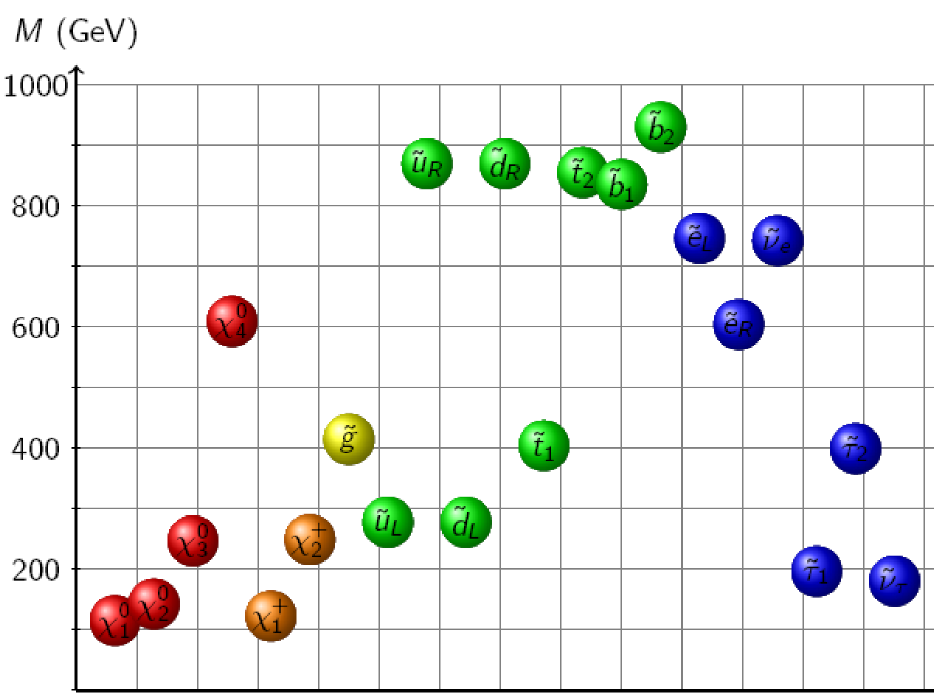
1l2j_1	2681 (92.64 %)	2686 (92.398 %)
1l2j_2	2677 (92.502 %)	2681 (92.226 %)
1l2j_3	2286 (78.991 %)	2287 (78.672 %)
1l2j_4	1823 (62.992 %)	1824 (62.745 %)
1l2j_5	1542 (53.283 %)	1543 (53.079 %)
1l2j_6	1166 (40.29 %)	1167 (40.144 %)
OSDL_1	1133 (39.15 %)	1134 (39.009 %)
OSDL_2	337 (11.645 %)	337 (11.593 %)
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 %)

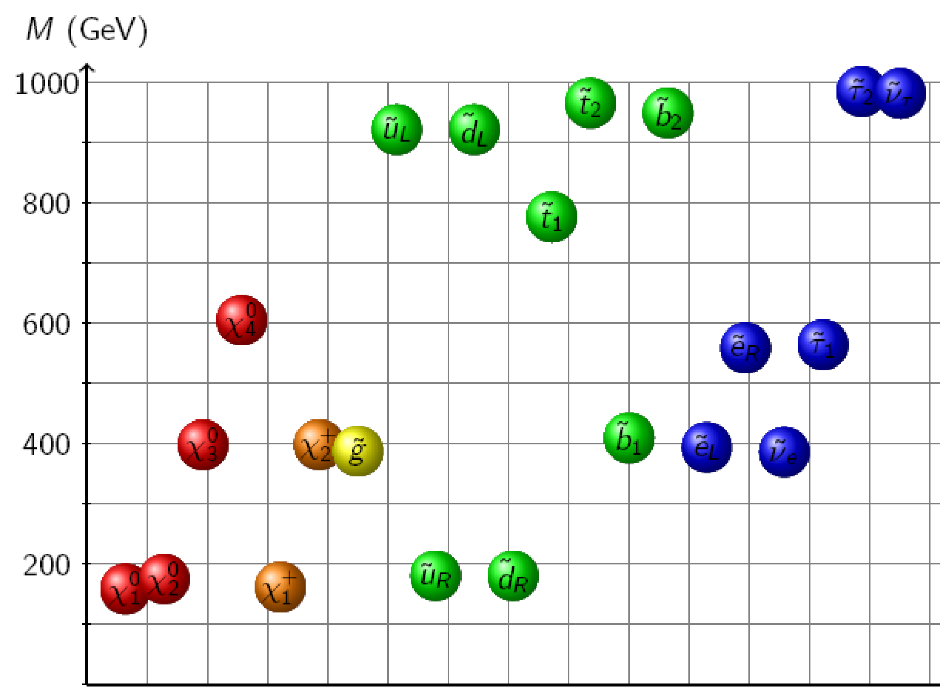
Cut Effectiveness: VI

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 %)


M (GeV)
1000
800
600
400
200
χ_1^0 χ_2^0 χ_3^0 χ_4^0 χ_1^+ χ_2^+ $\tilde{g}$
$\tilde{u}_L$ $\tilde{d}_L$ $\tilde{u}_R$ $\tilde{d}_R$ $\tilde{t}_1$ $\tilde{t}_2$ $\tilde{b}_1$ $\tilde{b}_2$
$\tilde{e}_L$ $\tilde{e}_R$ $\tilde{\nu}_e$ $\tilde{\tau}_1$ $\tilde{\tau}_2$ $\tilde{\nu}_\tau$


M (GeV)
1000
800
600
400
200
χ_1^0 χ_2^0 χ_3^0 χ_4^0 χ_1^+ χ_2^+ $\tilde{g}$
$\tilde{u}_L$ $\tilde{d}_L$ $\tilde{u}_R$ $\tilde{d}_R$ $\tilde{t}_1$ $\tilde{t}_2$ $\tilde{b}_1$ $\tilde{b}_2$
$\tilde{e}_L$ $\tilde{e}_R$ $\tilde{\nu}_e$ $\tilde{\tau}_1$ $\tilde{\tau}_2$ $\tilde{\nu}_\tau$


M (GeV)
1000
800
600
400
200
χ_1^0 χ_2^0 χ_3^0 χ_4^0 χ_1^+ χ_2^+ $\tilde{g}$
$\tilde{u}_L$ $\tilde{d}_L$ $\tilde{u}_R$ $\tilde{d}_R$ $\tilde{t}_1$ $\tilde{t}_2$ $\tilde{b}_1$ $\tilde{b}_2$
$\tilde{e}_L$ $\tilde{e}_R$ $\tilde{\nu}_e$ $\tilde{\tau}_1$ $\tilde{\tau}_2$ $\tilde{\nu}_\tau$


M (GeV)
1000
800
600
400
200
χ_1^0 χ_2^0 χ_3^0 χ_4^0 χ_1^+ χ_2^+ $\tilde{g}$
$\tilde{u}_L$ $\tilde{d}_L$ $\tilde{u}_R$ $\tilde{d}_R$ $\tilde{t}_1$ $\tilde{t}_2$ $\tilde{b}_1$ $\tilde{b}_2$
$\tilde{e}_L$ $\tilde{e}_R$ $\tilde{\nu}_e$ $\tilde{\tau}_1$ $\tilde{\tau}_2$ $\tilde{\nu}_\tau$

Flat Log

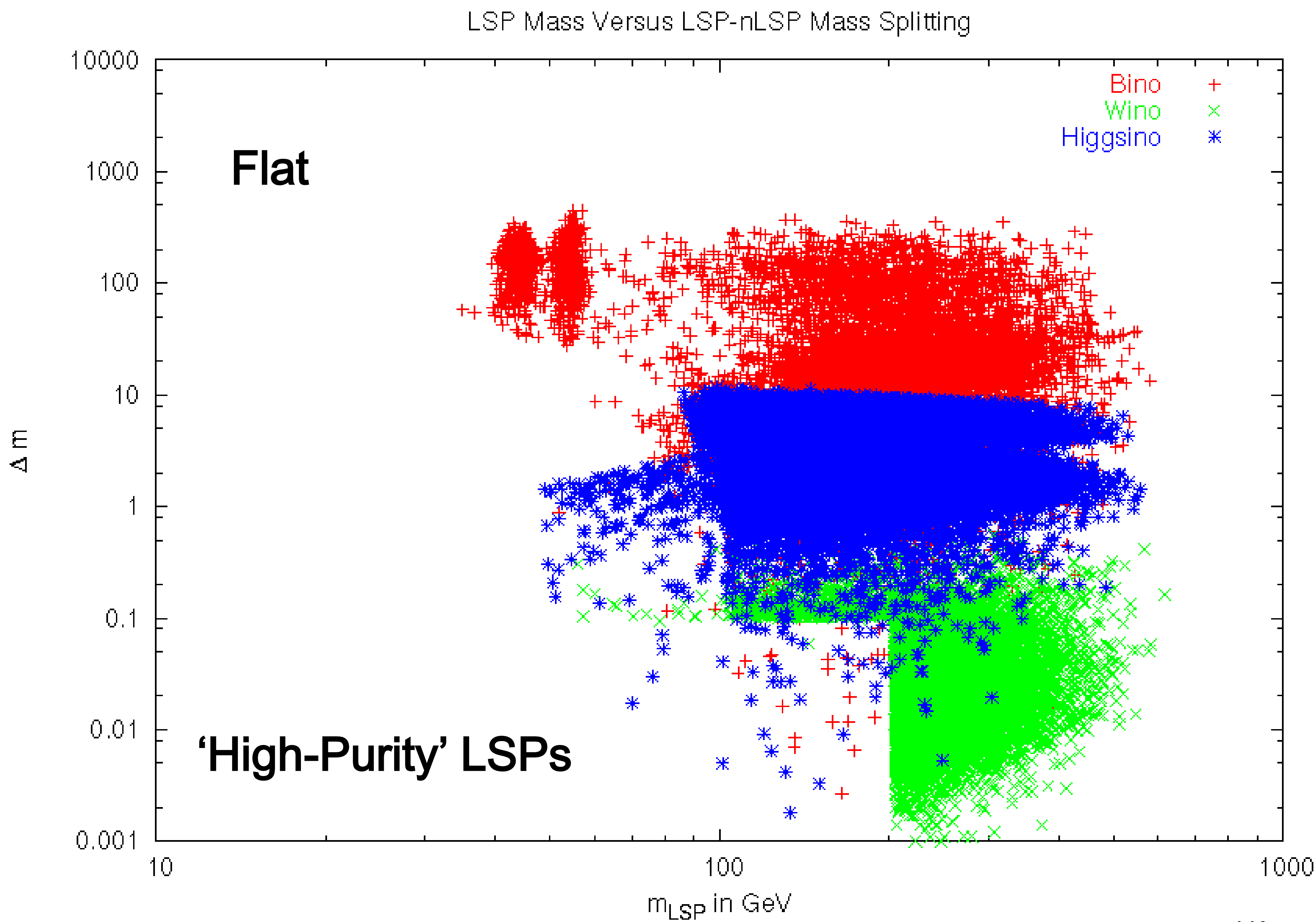
Linear Priors		Log Priors	
Mass Pattern	% of Models	Mass Pattern	% of Models
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde\chi_3^0$	9.82	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde\chi_3^0$	18.59
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde\ell_R$	5.39	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde\nu_\tau$	7.72
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde\tau_1$	5.31	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde\ell_R$	6.67
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde\nu_\tau$	5.02	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde\tau_1$	6.64
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde b_1$	4.89	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde d_R$	5.18
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde d_R$	4.49	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde\nu_\ell$	4.50
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde u_R$	3.82	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde b_1$	3.76
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde g$	2.96	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde g$	3.73
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde\nu_\ell$	2.67	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde u_R$	2.74
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde u_L$	2.35	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\nu_\tau < \tilde\tau_1$	2.27
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\nu_\tau < \tilde\tau_1$	2.19	$\tilde\chi_1^0 < \tilde\chi_2^0 < \tilde\chi_1^\pm < \tilde\chi_3^0$	2.24
$\tilde\chi_1^0 < \tilde\chi_2^0 < \tilde\chi_1^\pm < \tilde\chi_3^0$	2.15	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\ell_R < \tilde\chi_2^0$	1.42
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < A$	2.00	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde u_L$	1.32
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < \tilde t_1$	1.40	$\tilde\chi_1^0 < \tilde\tau_1 < \tilde\chi_1^\pm < \tilde\chi_2^0$	1.22
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\nu_\ell < \tilde\ell_L$	1.37	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\tau_1 < \tilde\chi_2^0$	1.19
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\tau_1 < \tilde\chi_2^0$	1.35	$\tilde\chi_1^0 < \tilde\chi_2^0 < \tilde\chi_1^\pm < \tilde\nu_\tau$	1.15
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\ell_R < \tilde\chi_2^0$	1.32	$\tilde\chi_1^0 < \tilde\ell_R < \tilde\chi_1^\pm < \tilde\chi_2^0$	1.05
$A < H < H^\pm < \tilde\chi_1^0$	1.24	$\tilde\chi_1^0 < \tilde\nu_\tau < \tilde\tau_1 < \tilde\chi_1^\pm$	1.02
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde d_R < \tilde\chi_2^0$	1.03	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\nu_\ell < \tilde\ell_L$	0.95
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde u_L < \tilde d_L$	0.95	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde d_R < \tilde\chi_2^0$	0.71
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde b_1 < \tilde\chi_2^0$	0.89	$\tilde\chi_1^0 < \tilde\nu_\tau < \tilde\chi_1^\pm < \tilde\chi_2^0$	0.68
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde u_R < \tilde\chi_2^0$	0.84	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\chi_2^0 < A$	0.64
$\tilde\chi_1^0 < \tilde\chi_1^\pm < A < H$	0.74	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\nu_\tau < \tilde\chi_2^0$	0.61
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde g < \tilde\chi_2^0$	0.65	$\tilde\chi_1^0 < \tilde\chi_2^0 < \tilde\chi_1^\pm < \tilde d_R$	0.54
$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\tau_1 < \tilde\nu_\tau$	0.51	$\tilde\chi_1^0 < \tilde\chi_1^\pm < \tilde\tau_1 < \tilde\nu_\tau$	0.54

SUSY decay chains are very important…especially the end of the chain at the LHC.

Top 25 most common mass patterns for the 4 lightest SUSY & heavy Higgs particles.

There were 1109 (267) such patterns found for the case of flat (log) priors

Only ~20 are found to occur in mSUGRA!!



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