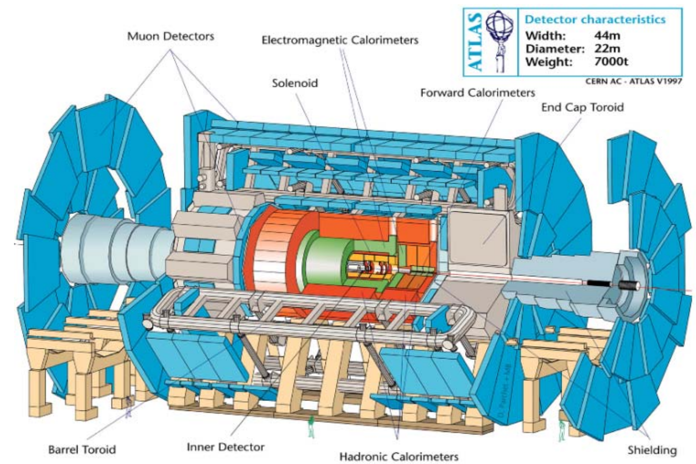
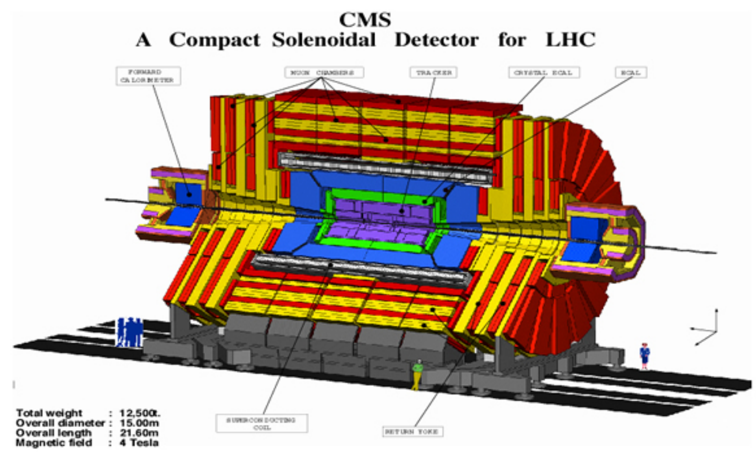
SUSY Without Prejudice: Part I





SLAC NATIONAL ACCELERATOR LABORATORY

C. F. Berger, J.A. Conley, R.C. Cotta, J. S. Gainer,
J. L. Hewett , M.-P. Le & TGR

Jan. 5, 2010

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

- Analyses have been generally limited to a specific SUSY scenario(s) such as mSUGRA, GMSB, AMSB,… having only a few parameters with correspondingly small parameter spaces.

- 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?? Could we be missing something?

- 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. A large sample is necessary to get a good feeling for the variety of possibilities & detailed studies. (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. Are there special space regions? (In progress)

NB : What this study is not

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

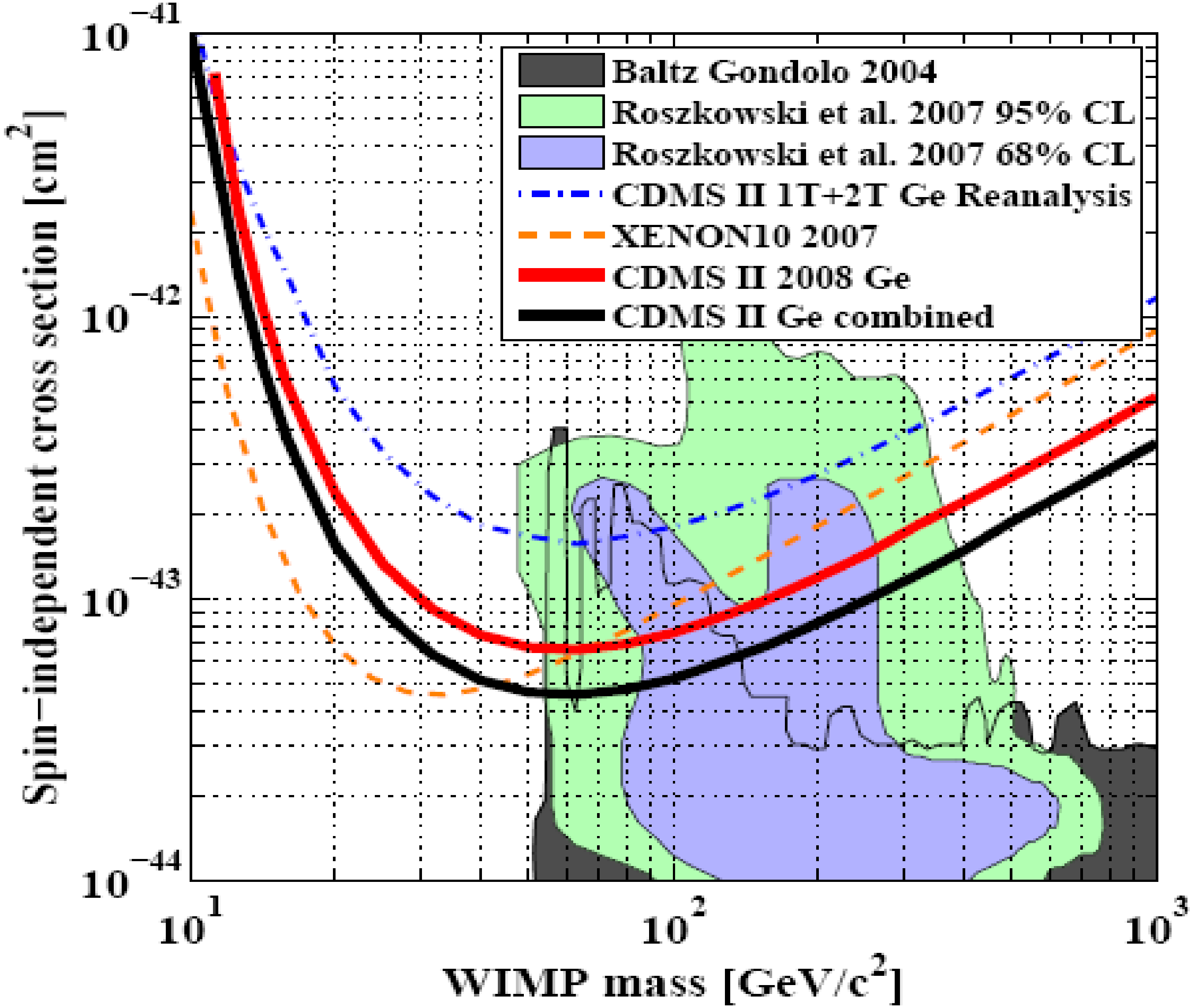
→This analysis required ~ 1 core-century of CPU time…this was the real limitation of this study.

Successful Models

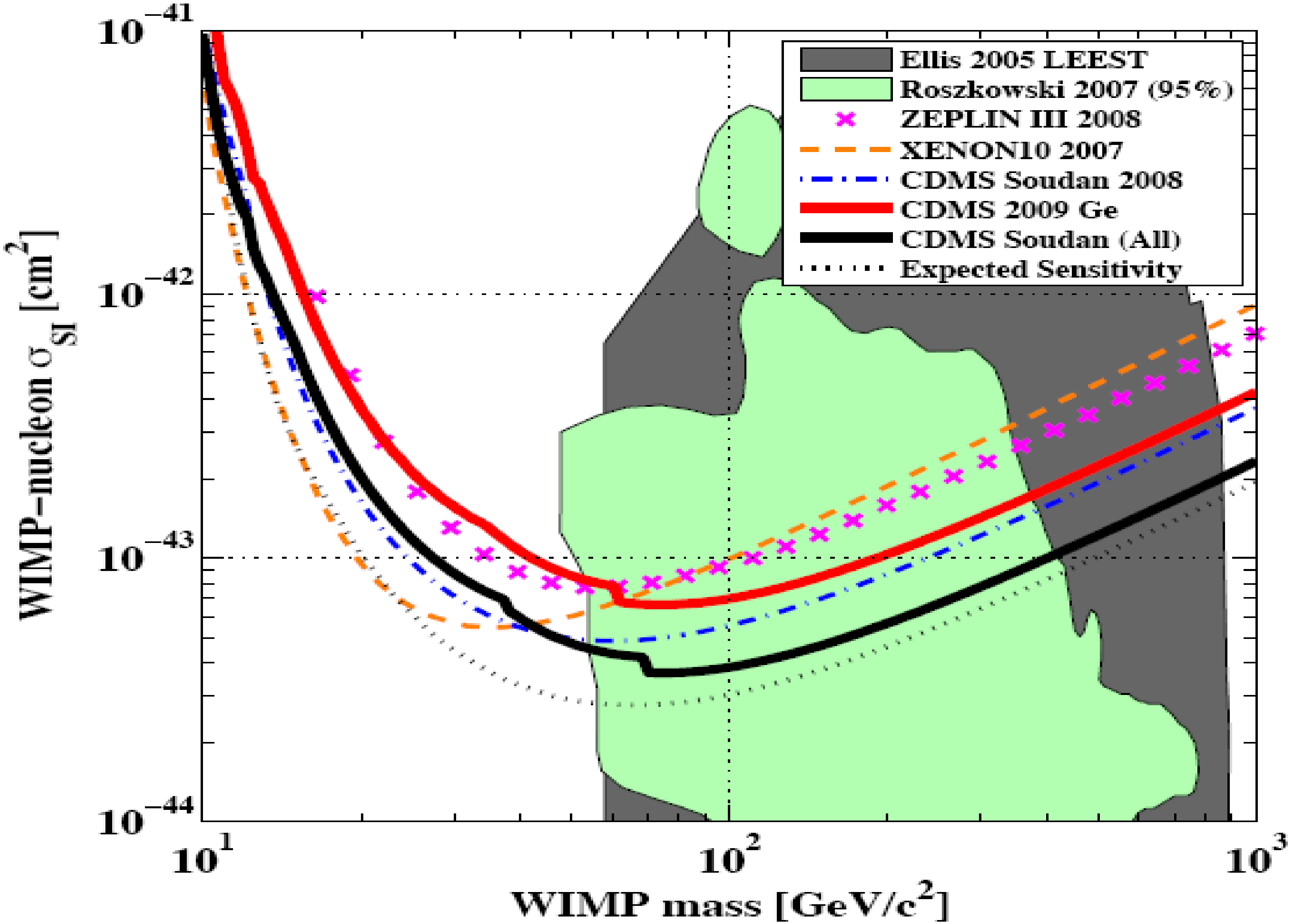
Constraints

- $-0.0007 < \Delta\rho < 0.0026$ [W-mass, etc.] (PDG'08)
- $b \to s\,\gamma$: $B = (2.5 - 4.1) \times 10^{-4}$; (HFAG) + Misiak etal. & Becher & Neubert
- $\Delta(g\text{-}2)_\mu$??? $(30.2 \pm 8.8) \times 10^{-10}$ (0809.4062)
  $(29.5 \pm 7.9) \times 10^{-10}$ (0809.3085)
  $[\sim 14.0 \pm 8.4] \times 10^{-10}$ [Davier/BaBar-Tau08]
  $\to (-10$ to $40) \times 10^{-10}$ to be conservative..
- $\Gamma(Z \to$ invisible$) < 2.0$ MeV (LEPEWWG)
- Meson-Antimeson Mixing $0.2 < R_{13} < 5$
- $B \to \tau\nu$ $B = (55$ to $227) \times 10^{-6}$ 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)

Dark Matter: Direct Searches for WIMPs



The CDMS update is only a very small change



- 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 the, e.g., nuclear physics input parameter 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 & is a thermal relic here

- 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 as many of these have been designed specifically for mSUGRA.

Zh, h-> bb, $\tau\tau$

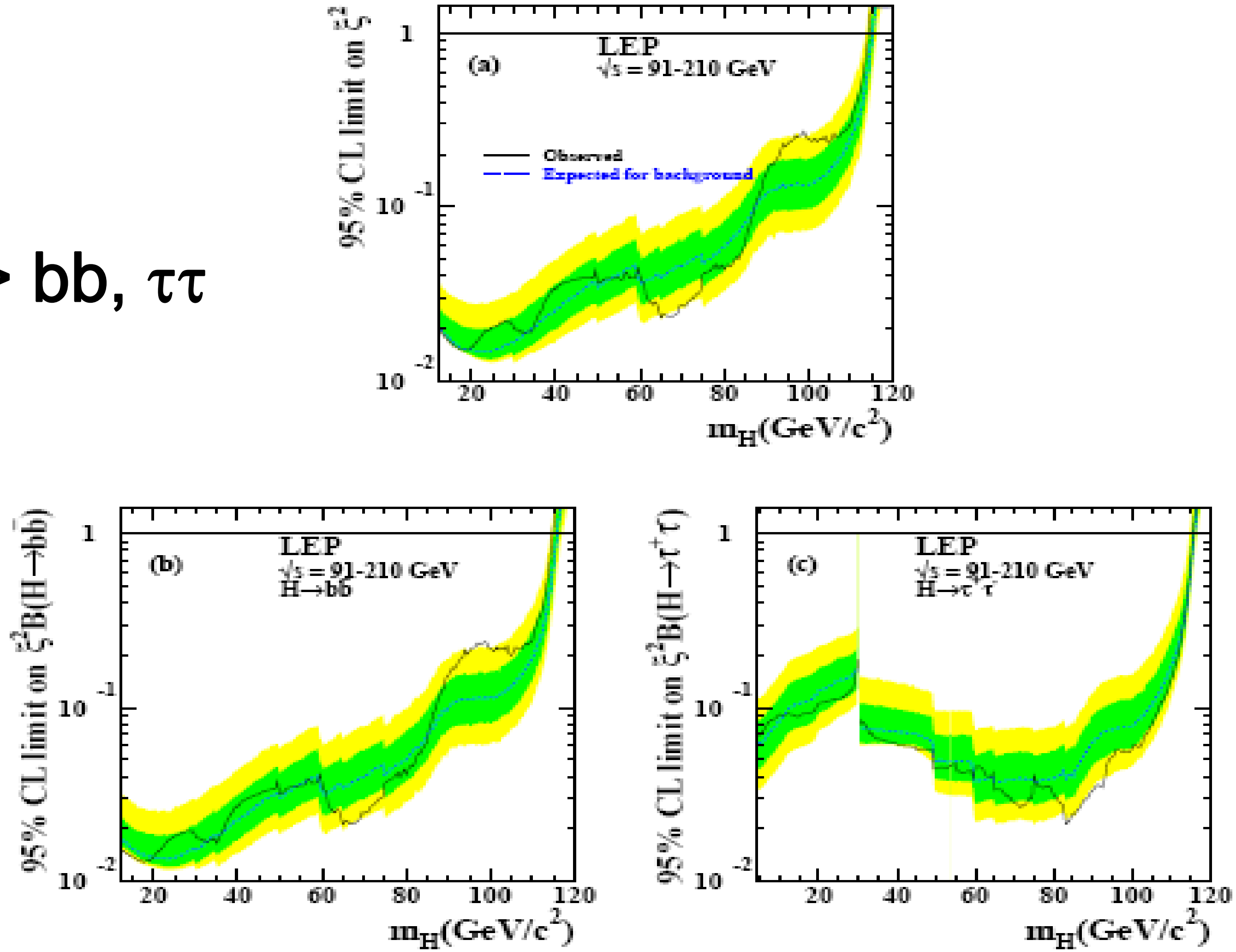


Figure 1: *The 95% c.l. upper bound on the coupling ratio* $\xi^2 = (g_{\rm HZZ}/g^{\rm SM}_{\rm HZZ})^2$ *(see text). The dark (green) and light (yellow) shaded bands around the median expected line correspond to the 68% and 95% probability bands. The horizontal lines correspond to the Standard Model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

LEP II: Associated Higgs Production

Z→ hA →4b,2b2τ,4τ

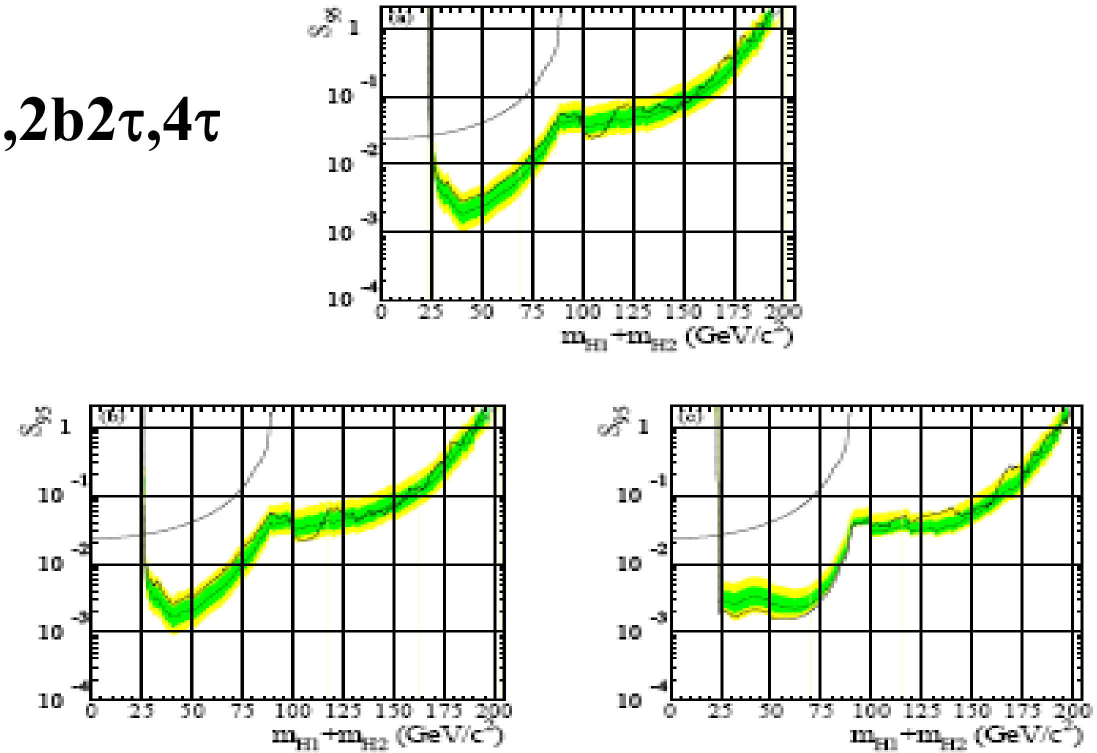
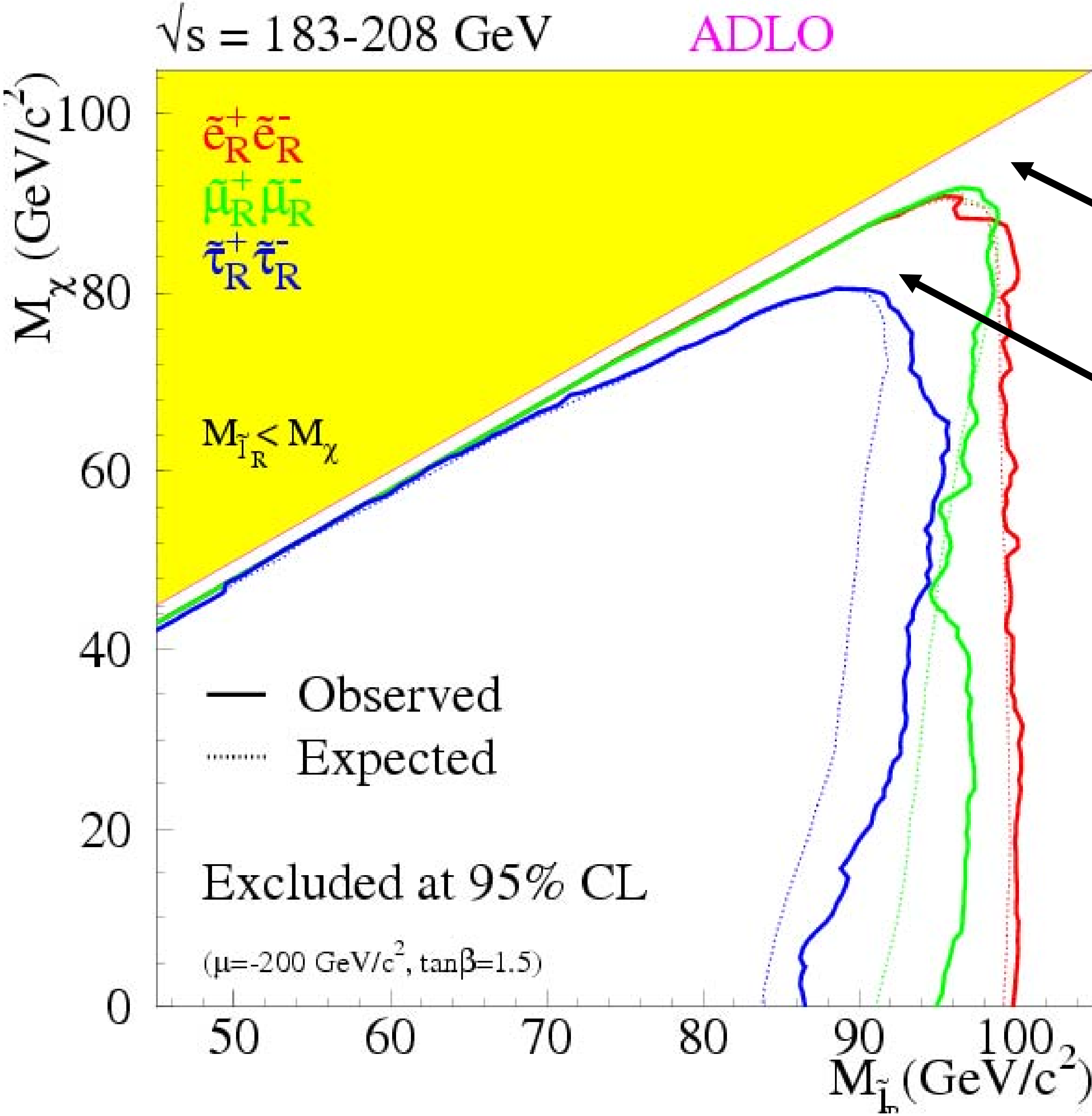


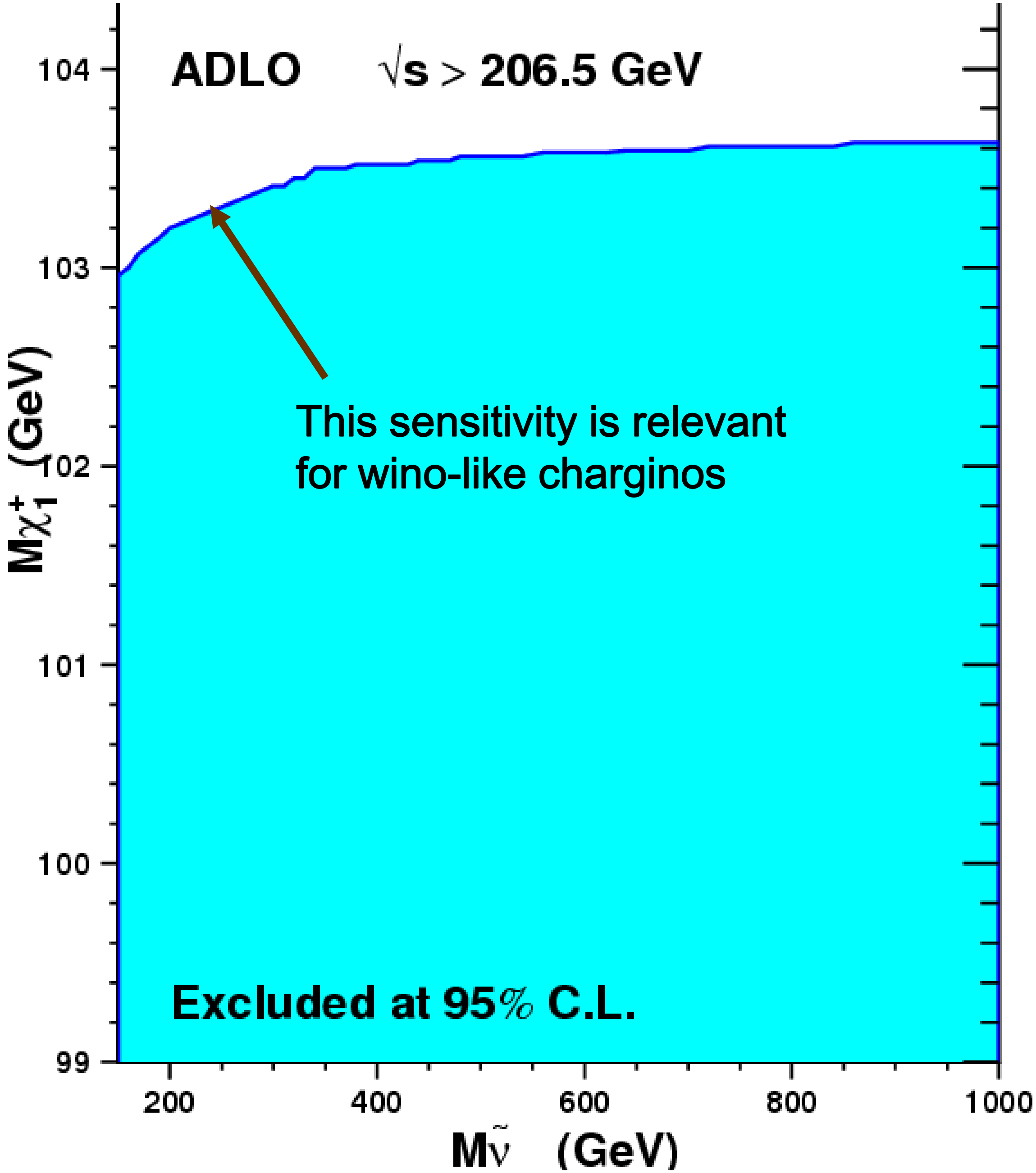
Figure 3: Model-independent 95% c.l. upper bounds, S_{95}, for various topological cross sections motivated by the pair-production process $e^+e^- \rightarrow \mathcal{H}_2\mathcal{H}_1$, for the particular case where $m_{\mathcal{H}_1}$ and $m_{\mathcal{H}_2}$ are approximately equal. Such is the case, 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% $\mathcal{H}_1 \rightarrow b\bar{b}$, 6% $\mathcal{H}_1 \rightarrow \tau^+\tau^-$, 92% $\mathcal{H}_2 \rightarrow b\bar{b}$ and 8% $\mathcal{H}_2 \rightarrow \tau^+\tau^-$; 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.

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



Large mass gap chargino search

Depends on the sneutrino mass in the t-channel if less than ~ 160 GeV due to interference if large wino content

Some 'light' charginos may slip through as search reach is degraded

Tevatron Constraints : I   Squark & Gluino Search

- This is the first & only 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

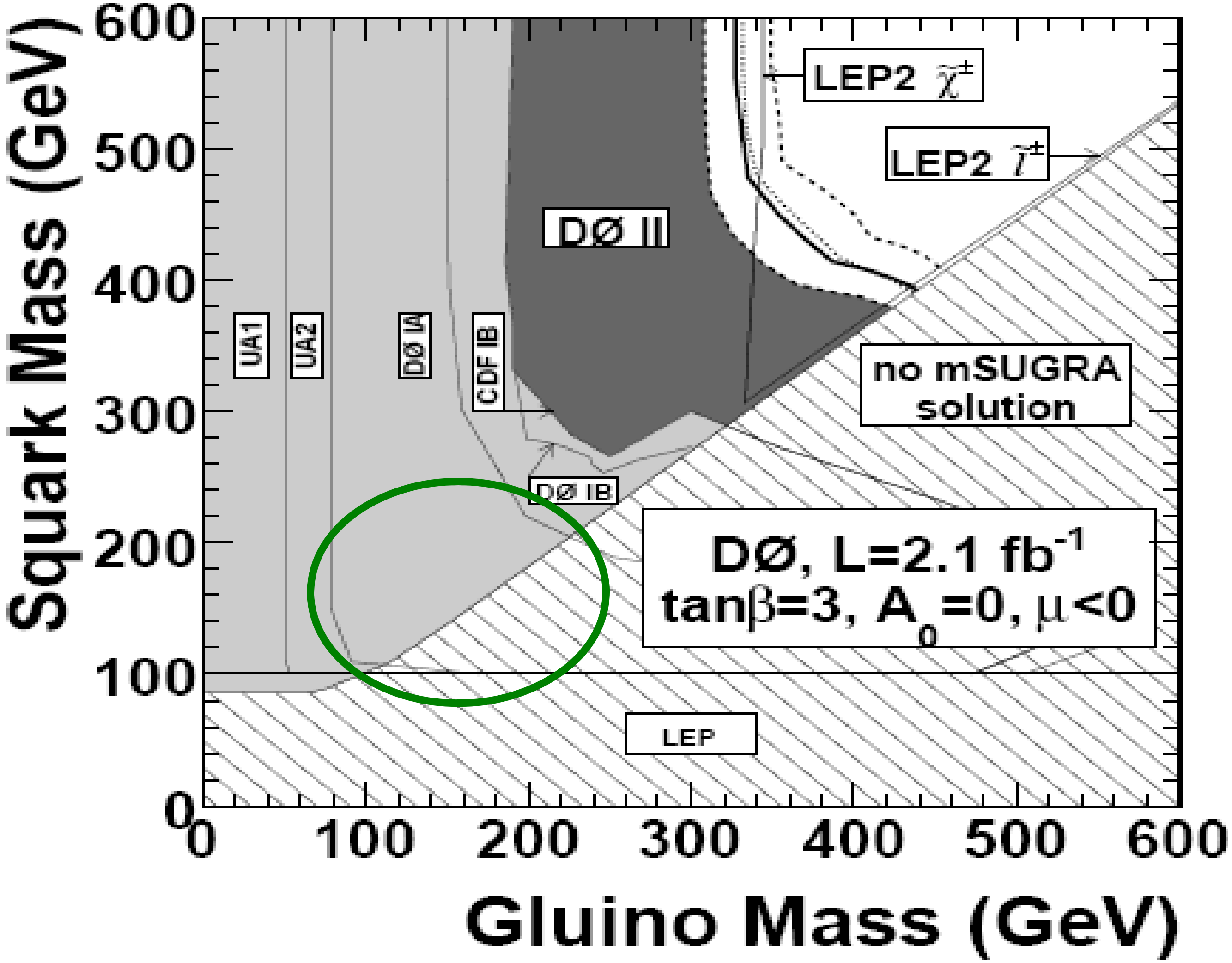
[a] First and second jets are also required to be central ($|\eta_{\rm det}| < 0.8$), with an electromagnetic fraction below 0.95, and to have CPF0 ≥ 0.75.
[b] Third and fourth jets are required to have $|\eta_{\rm det}| < 2.5$, with an electromagnetic fraction below 0.95.

Multiple analyses keyed to look for:

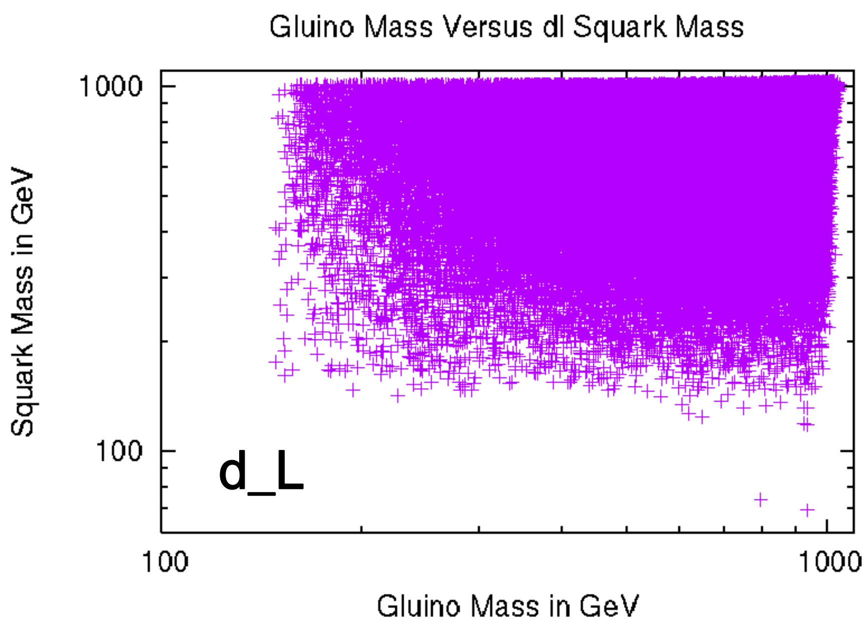
Squarks-> jet +MET
Gluinos -> 2 j + MET

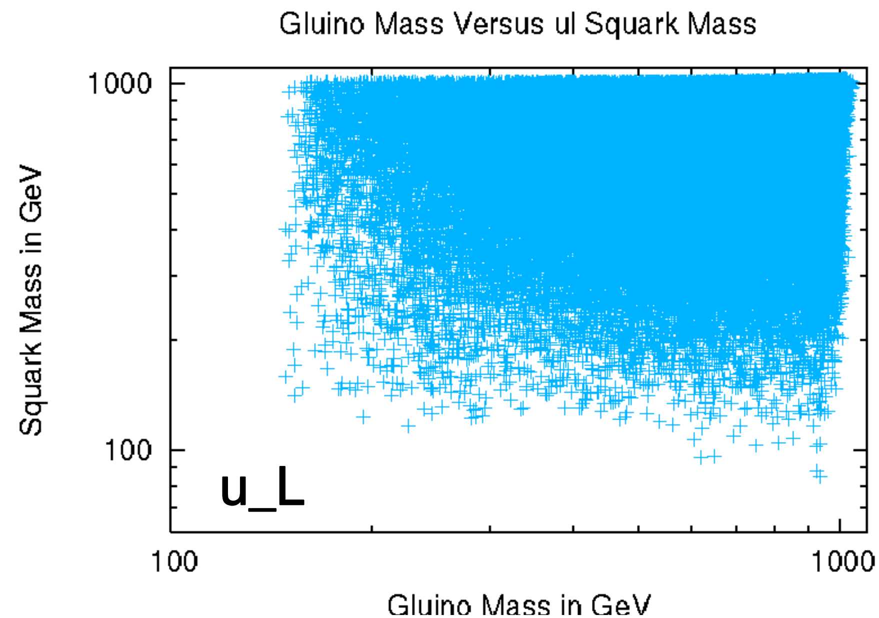
The search is based on mSUGRA type sparticle spectrum assumptions which can be VERY far from our model points

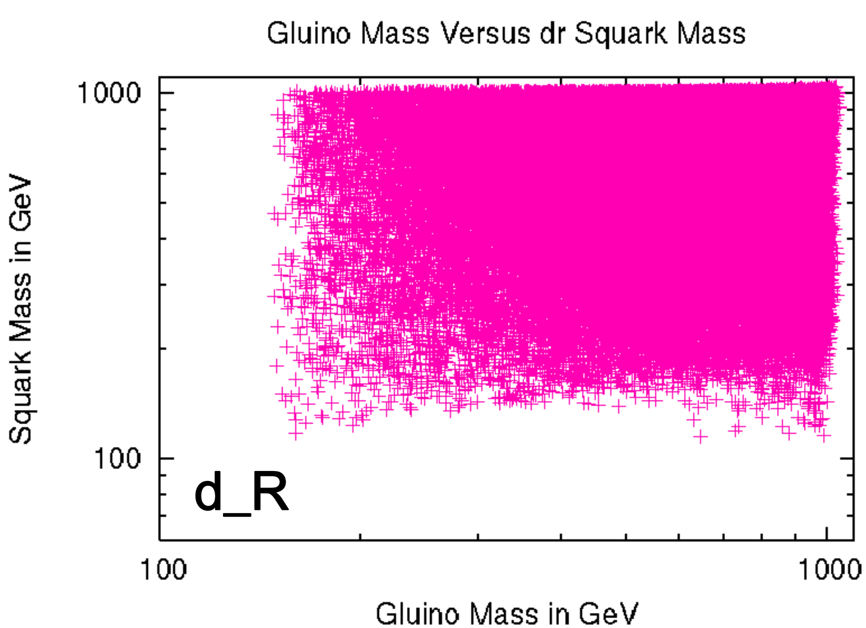
This D0 search provides strong constraints in mSUGRA.. squarks & gluinos > 330-400 GeV…our limits can be *much weaker* on both these sparticles as we'll see !!

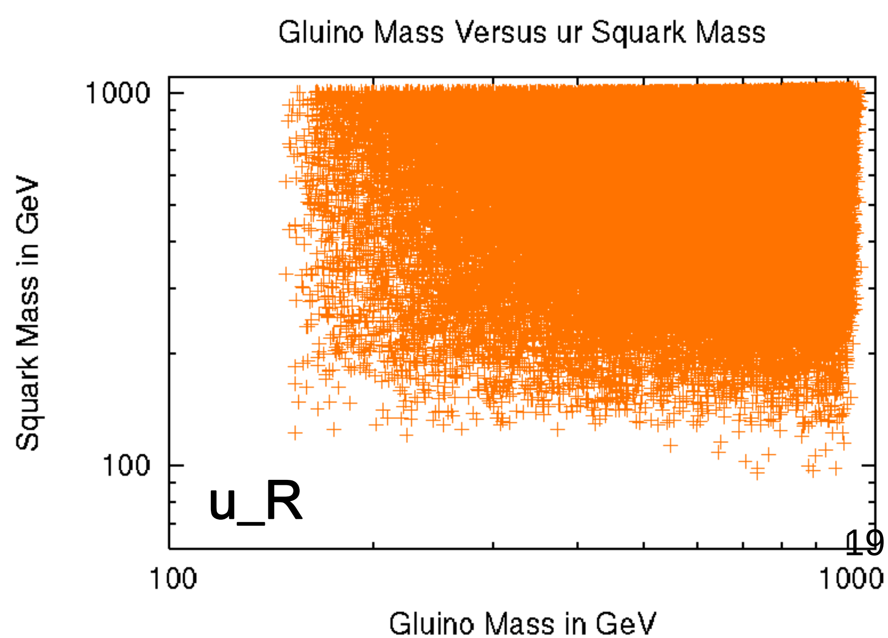


$M_{\tilde{q}}$ > $m_{\tilde{g}}$ and $m_{\tilde{g}}$ > $M_{\tilde{q}}$ are ~ equally likely









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	$17.7 \pm 1.1^{+5.8}_{-3.3}$	$17.0 \pm 1.2^{+3.3}_{-2.9}$	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 & only 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

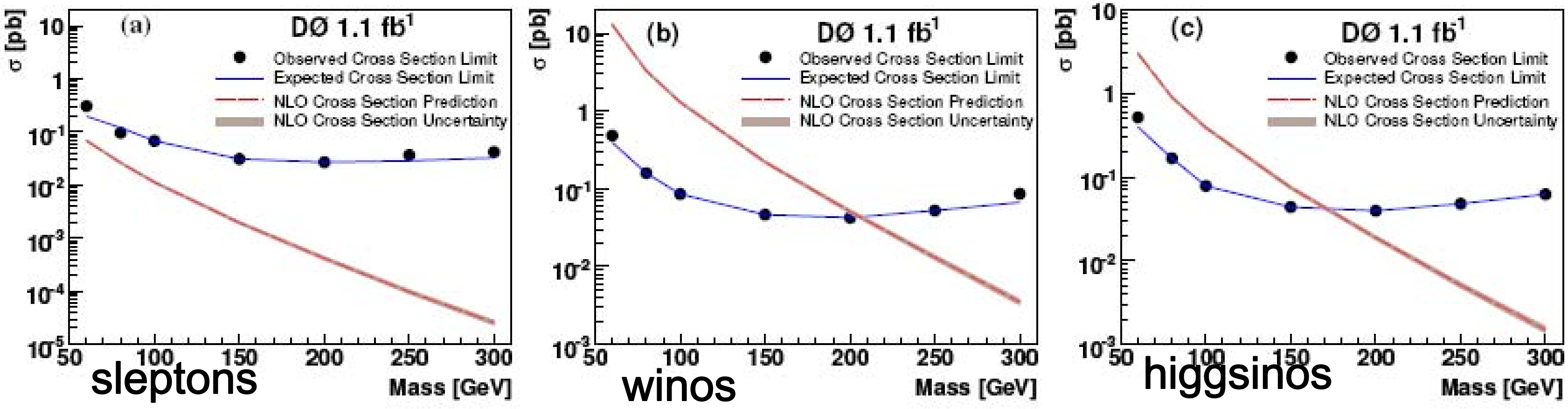


FIG. 2: The observed (dots) and expected (solid line) 95% cross section limits, the NLO production cross section (dashed line), and NLO cross section uncertainty (barely visible shaded band) as a function of (a) stau mass for stau pair production, (b) chargino mass for pair produced gaugino-like charginos, 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 & only 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 , ~ 2.8 K (0.14%) survive

This leaves us a large set of ~ 71.2K models to study !!

ATLAS	SU1	OK
	SU2	killed by LEP
	SU3	killed by Ωh^2
	SU4	killed by $b \rightarrow s\gamma$
	SU8	killed by g-2
CMS	LM1	killed by Higgs
	LM2	killed by g-2
	LM3	killed by $b \rightarrow s\gamma$
	LM4	killed by Ωh^2
	LM5	killed by Ωh^2
	LM6	OK
	LM7	killed by LEP
	LM8	killed by Ωh^2
	LM9	killed by LEP
	LM10	OK
	HM2	killed by Ωh^2
	HM3	killed by Ωh^2
	HM4	killed by Ωh^2

For the curious:

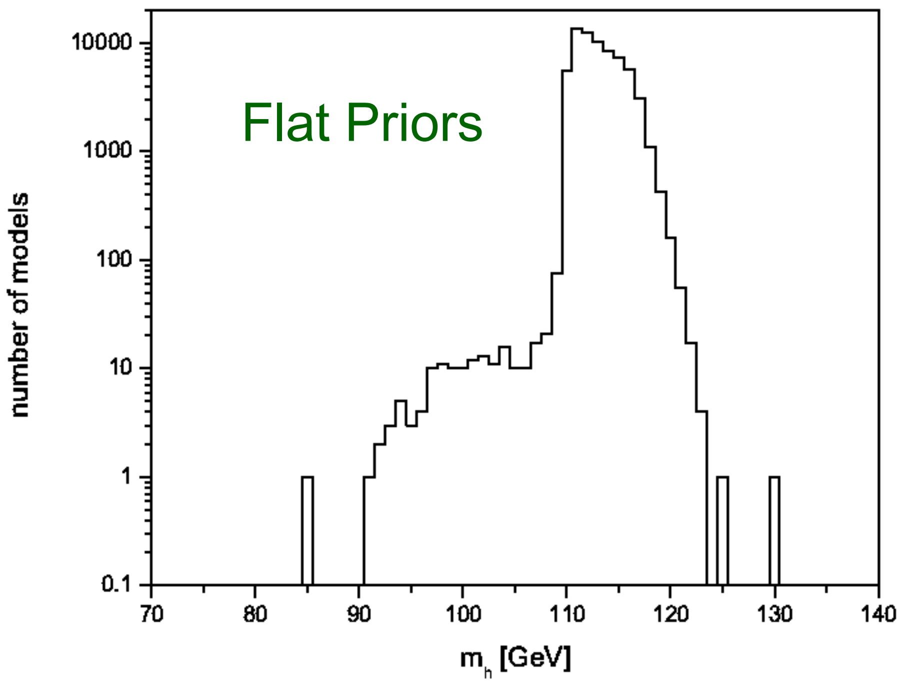
Most well-studied models do not survive confrontation with the latest data.

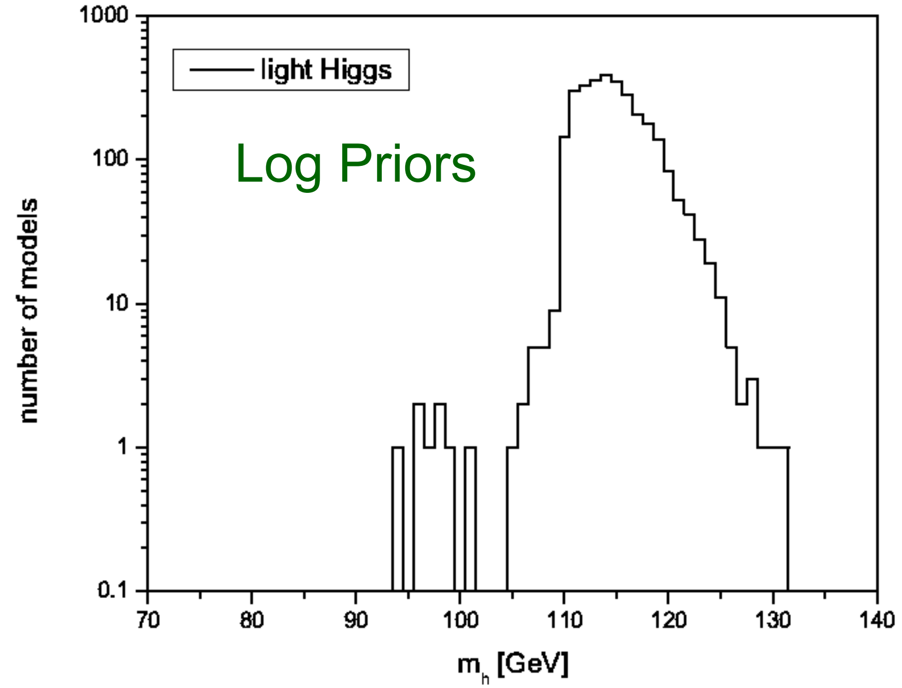
For many models this is not the unique source of failure

Similarly for the SPS Points

SPS1a	killed by $b \to s\gamma$
SPS1a'	OK
SPS1b	killed by $b \to s\gamma$
SPS2	killed by Ωh^2 (GUT) / OK(low)
SPS3	killed by Ωh^2 (low) / OK(GUT)
SPS4	killed by g-2
SPS5	killed by Ωh^2
SPS6	OK
SPS9	killed by Tevatron stable chargino

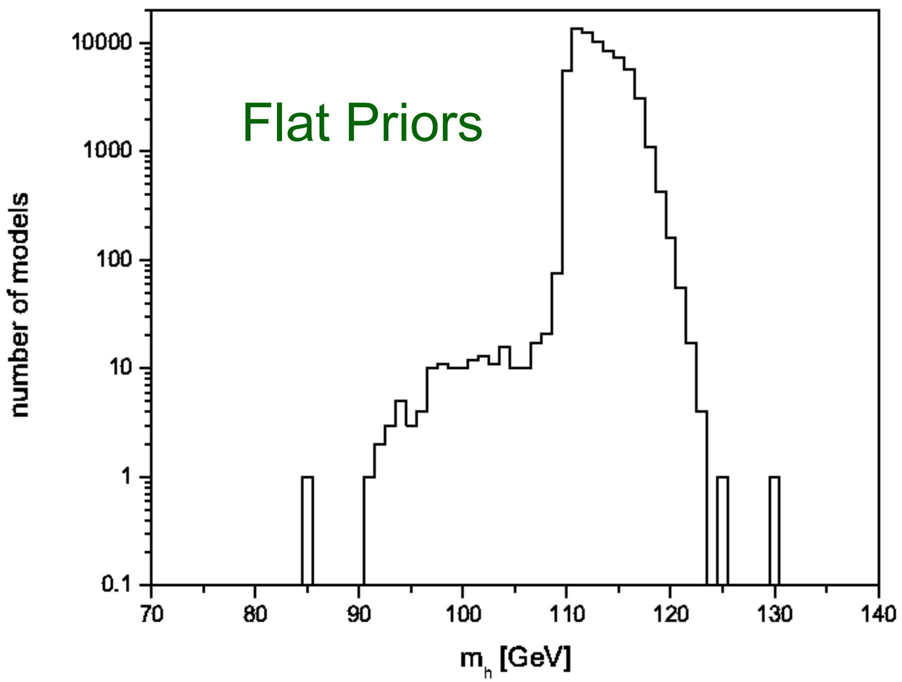
Light Higgs Mass Predictions

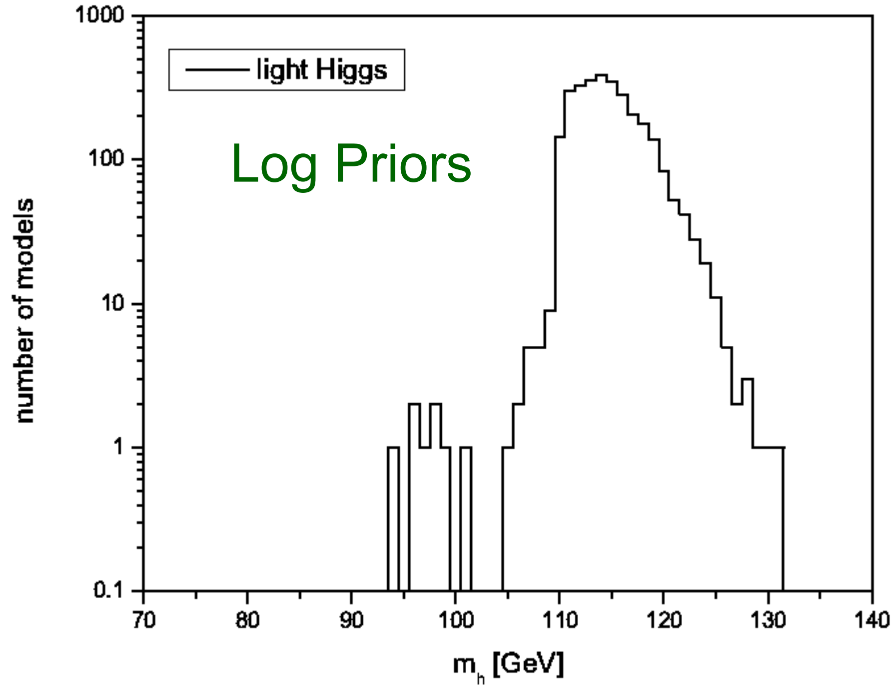




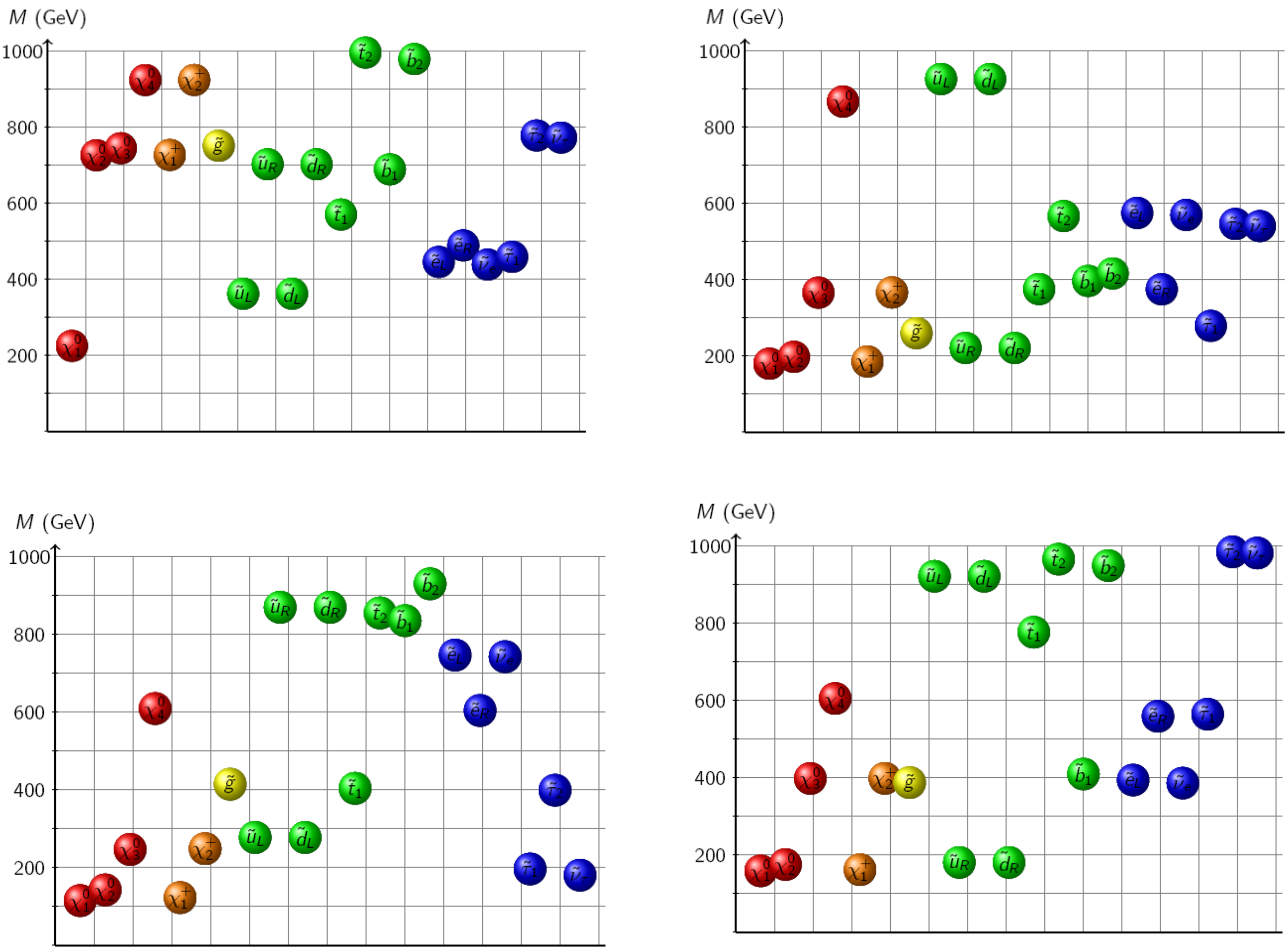
LEP Higgs mass constraints avoided by either reducing the ZZh coupling and/or reducing the, e.g., $h \to \bar{b}b$ branching fraction by decays to LSP pairs. We have both of these cases in our final model sets.

Light Higgs Mass Predictions



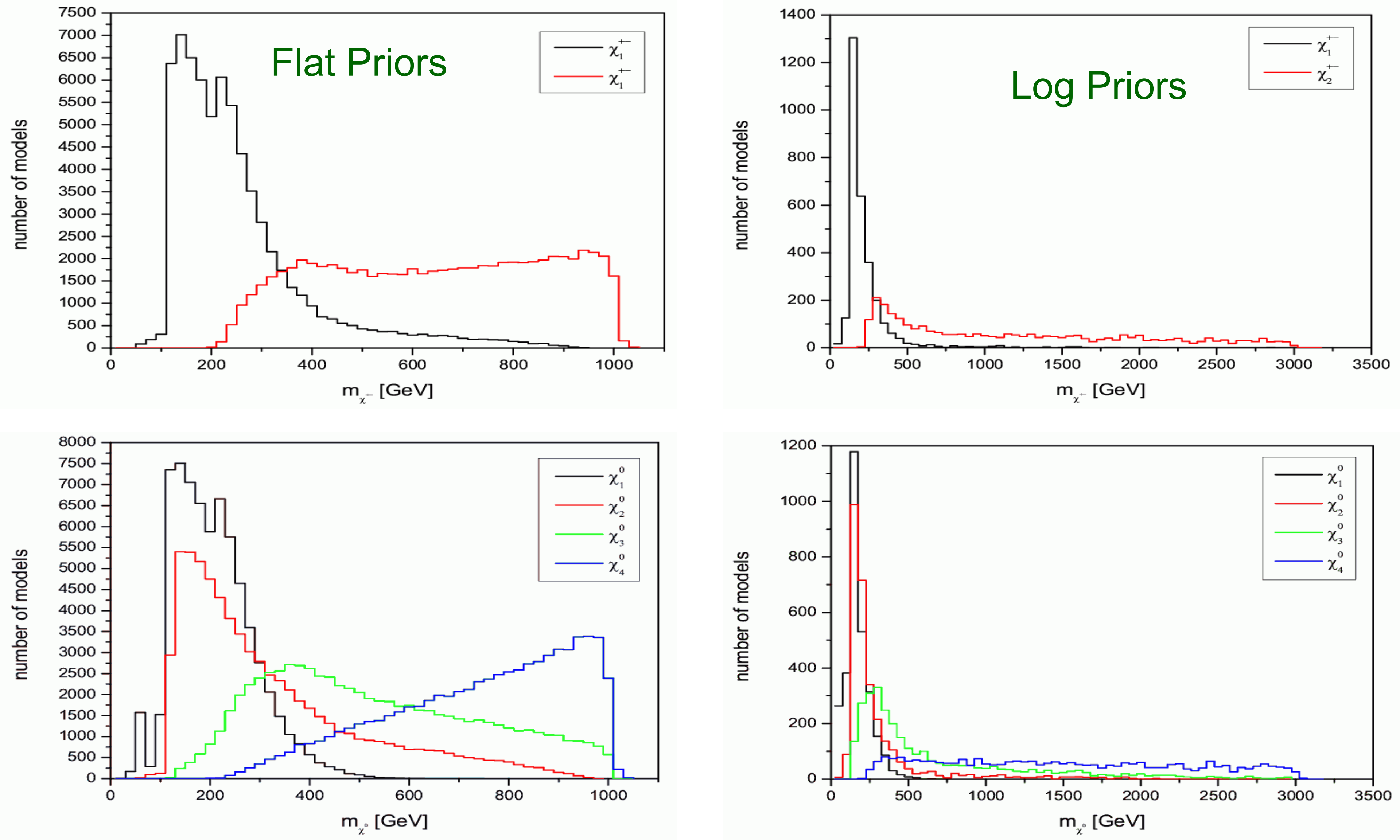


LEP Higgs mass constraints avoided by either reducing the ZZh coupling and/or reducing the, e.g., $h \rightarrow b\bar{b}$ branching fraction by decays to LSP pairs. We have both of these cases in our final model sets.



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

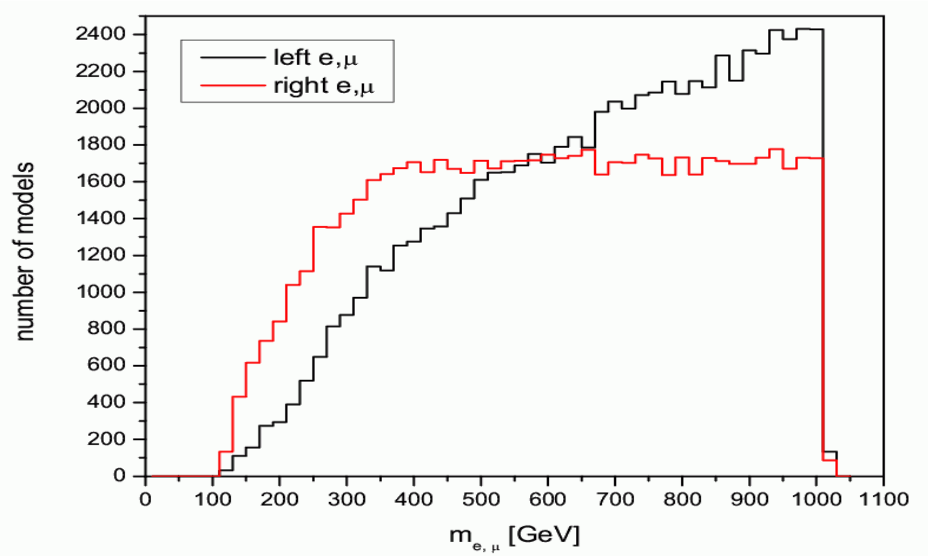
Distribution of Sparticle Masses By Species

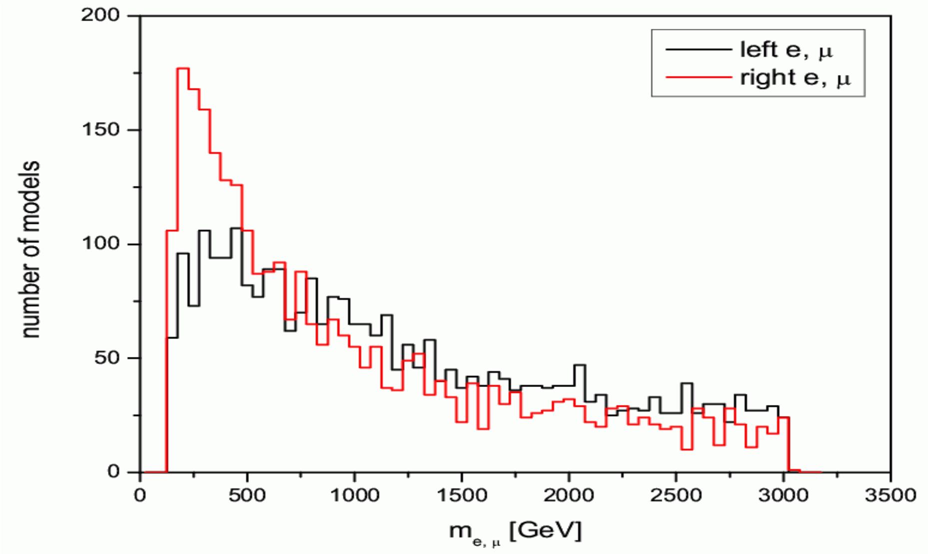


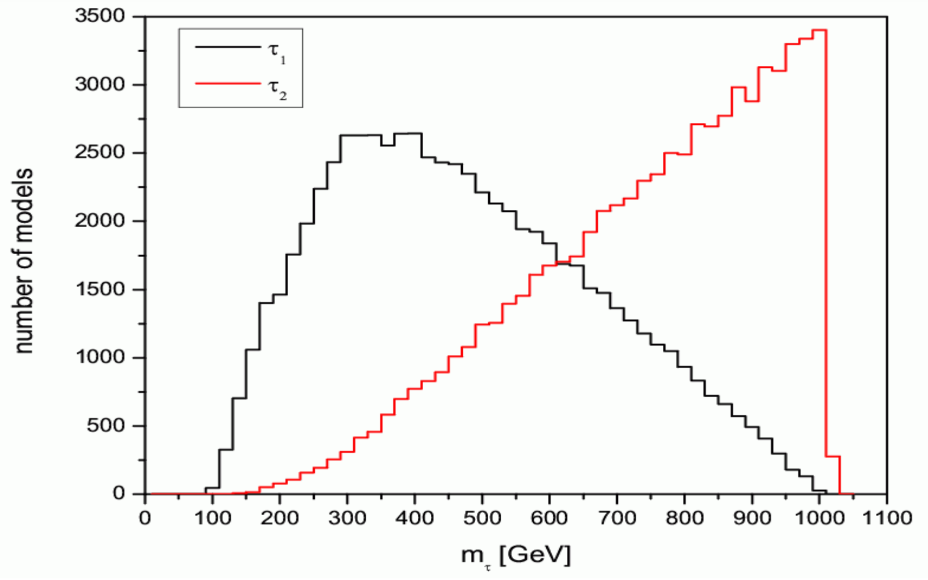
Distribution of Sparticle Masses By Species

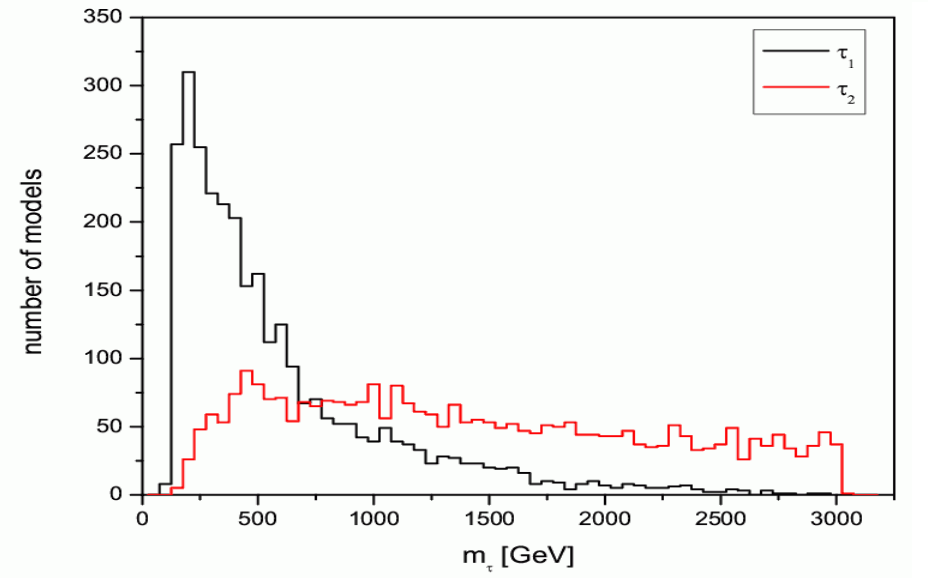
Flat Priors

Log Priors

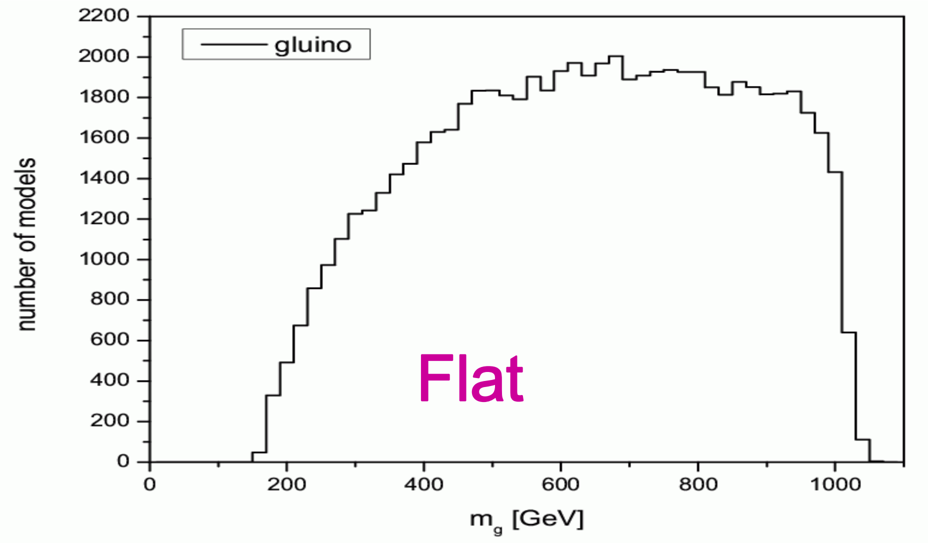


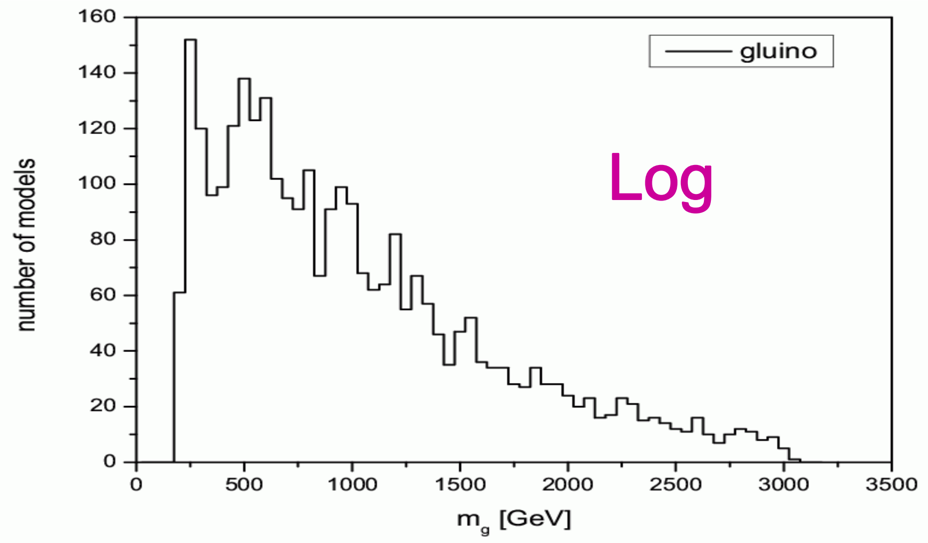


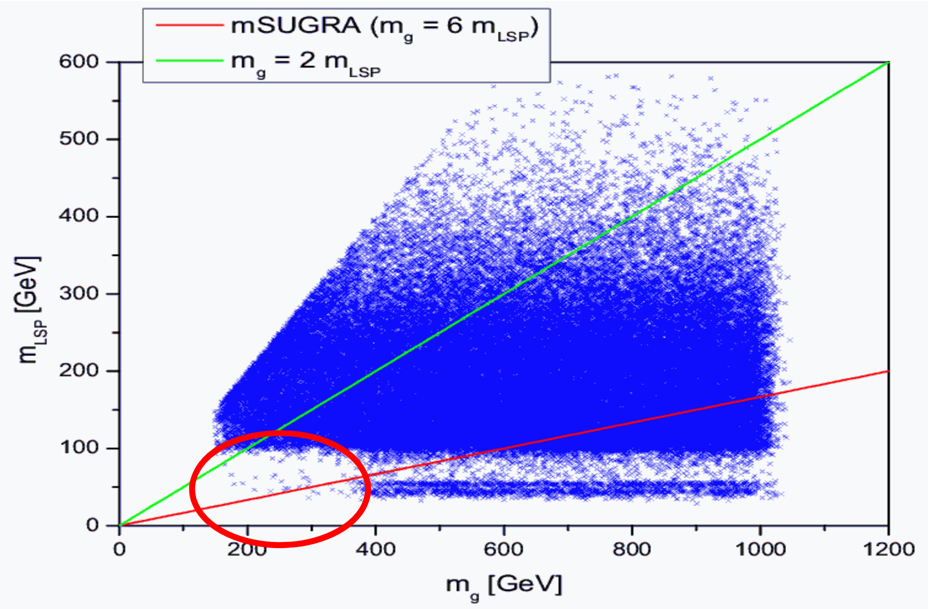


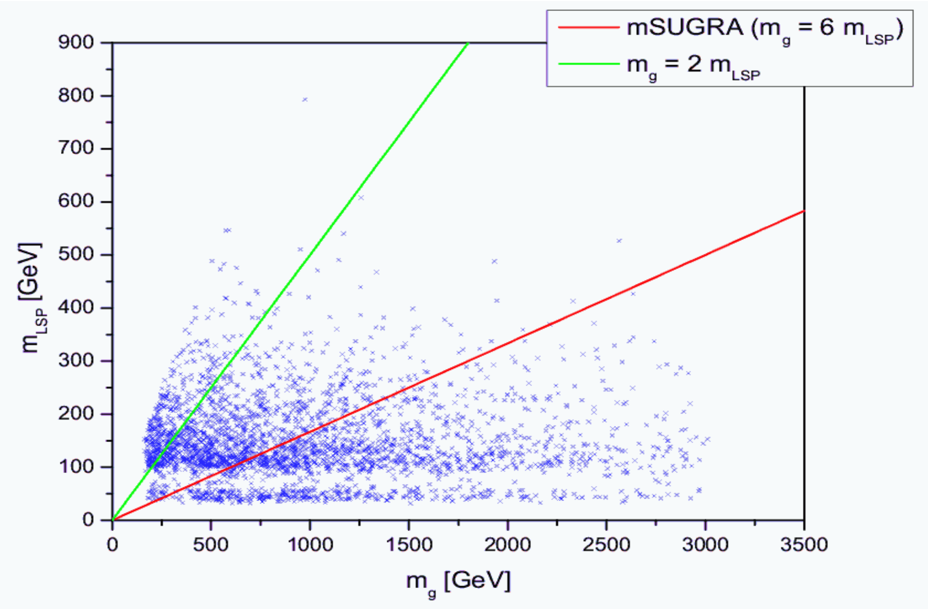


Gluino Can Be Light !!

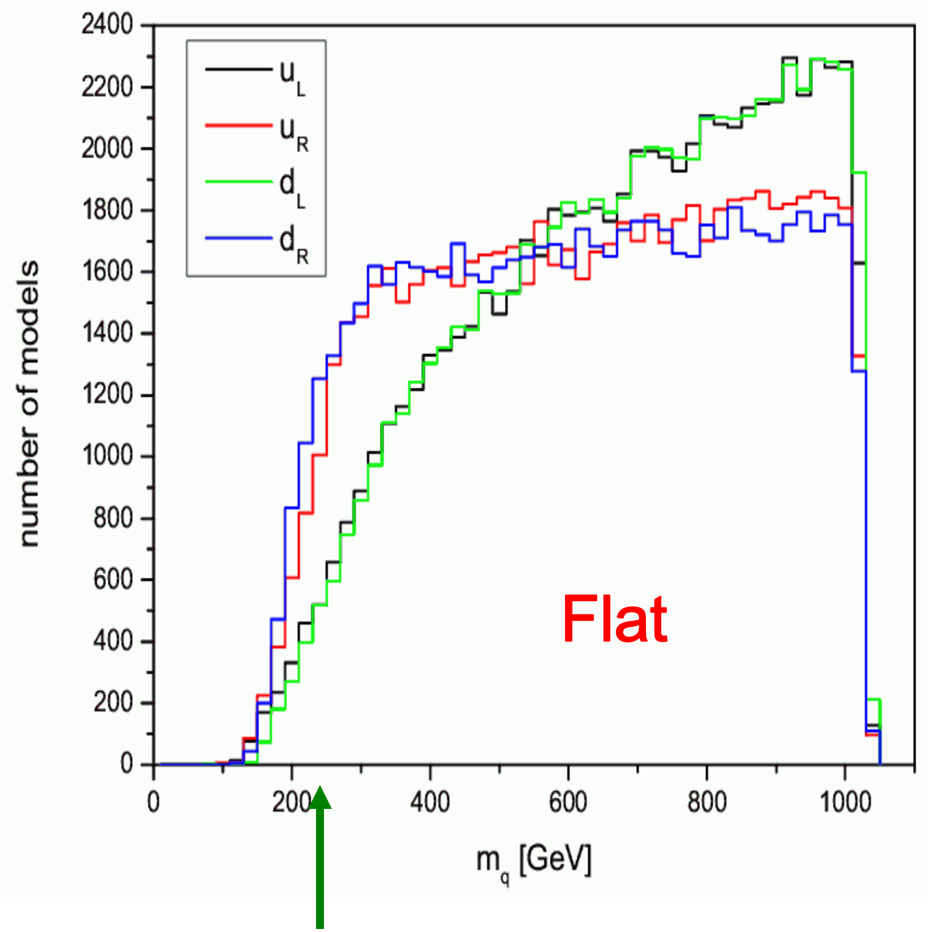


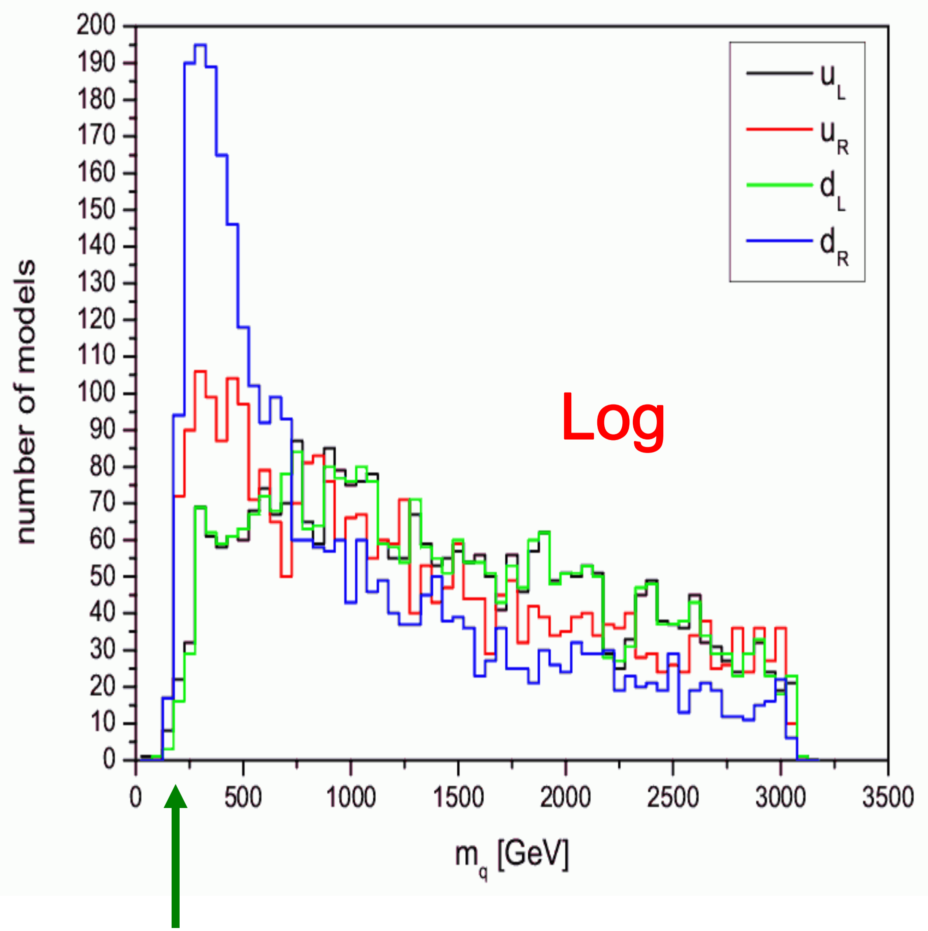






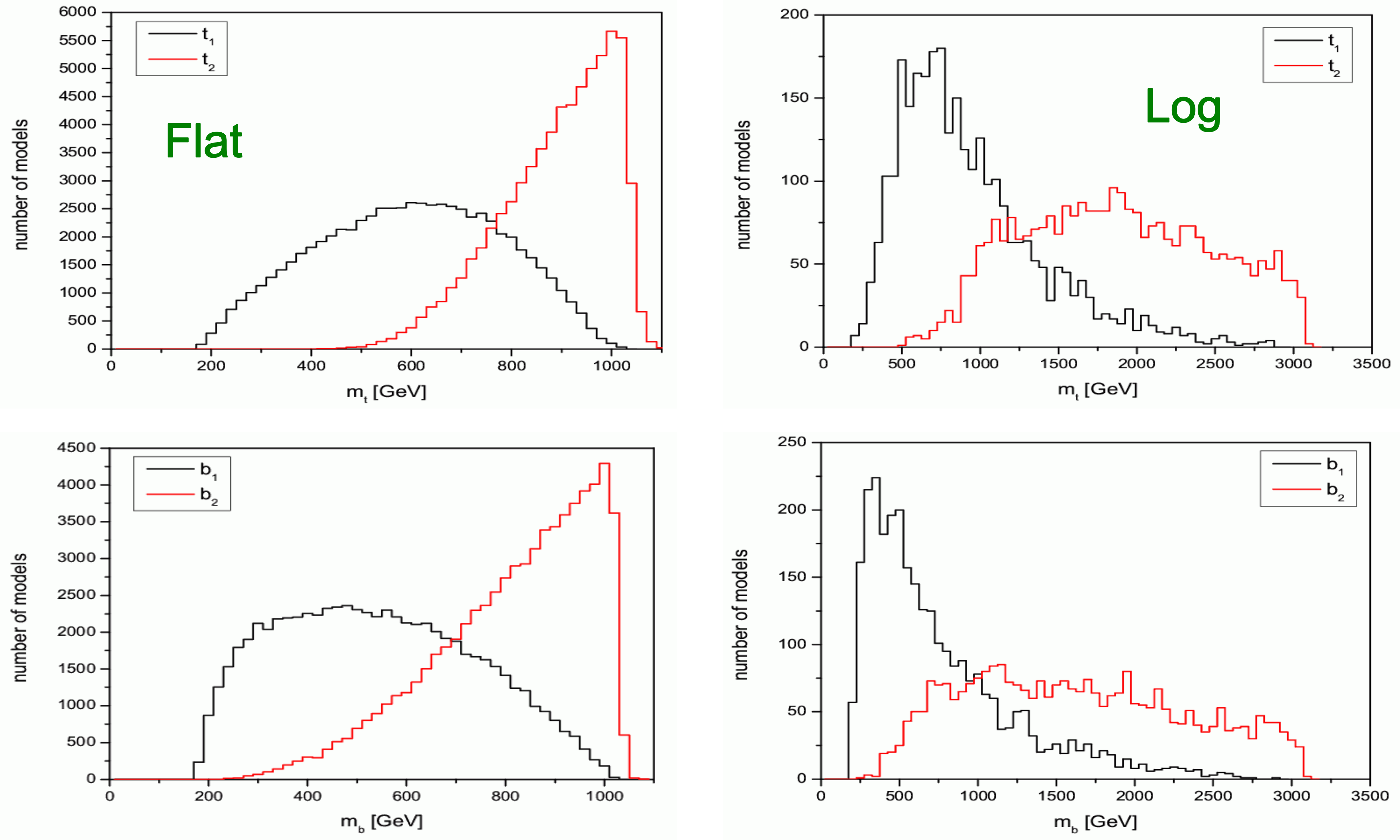
Squarks CAN Be Light !!!



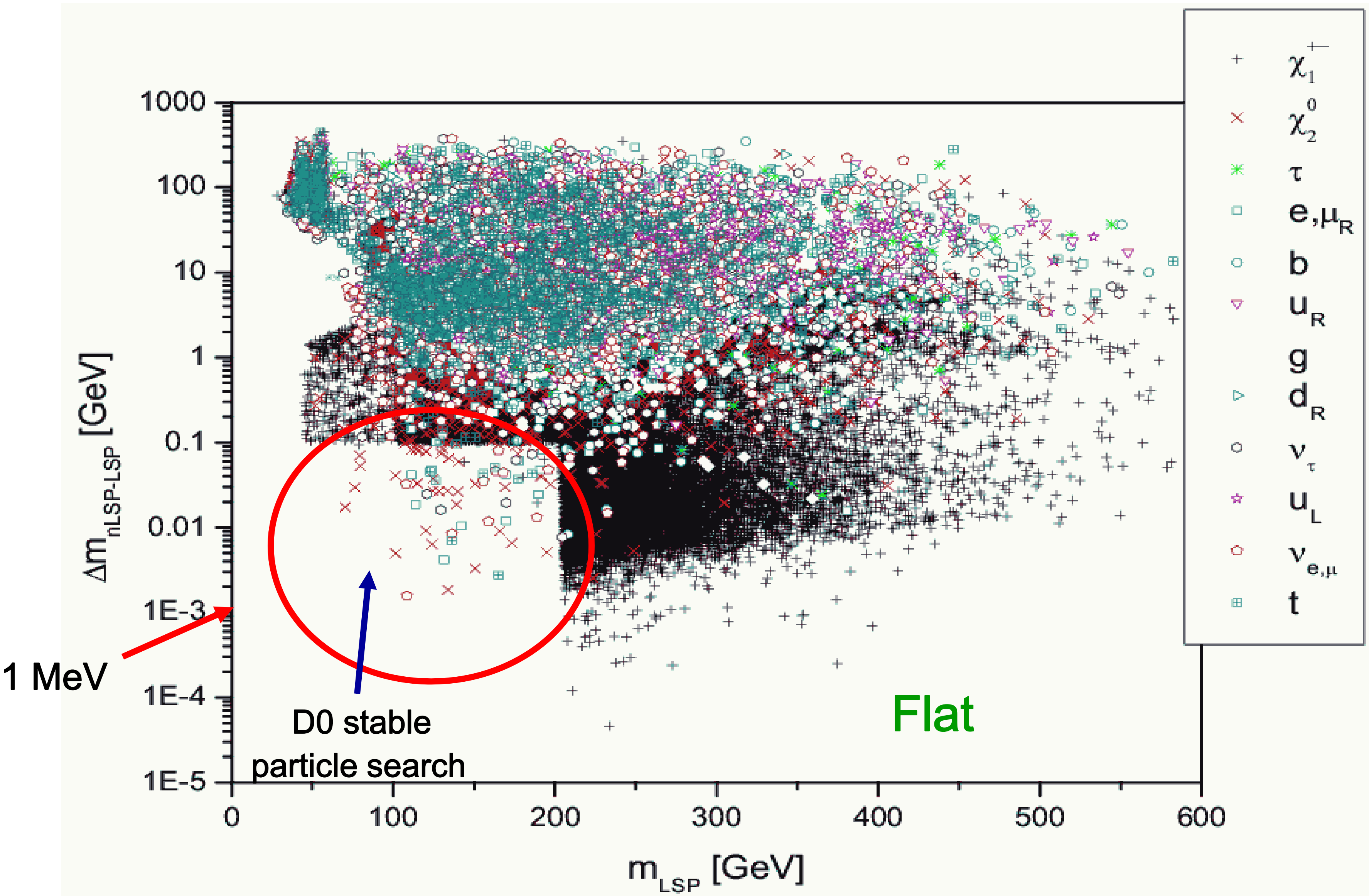


Light squarks can be missed by Tevatron searches for numerous reasons..

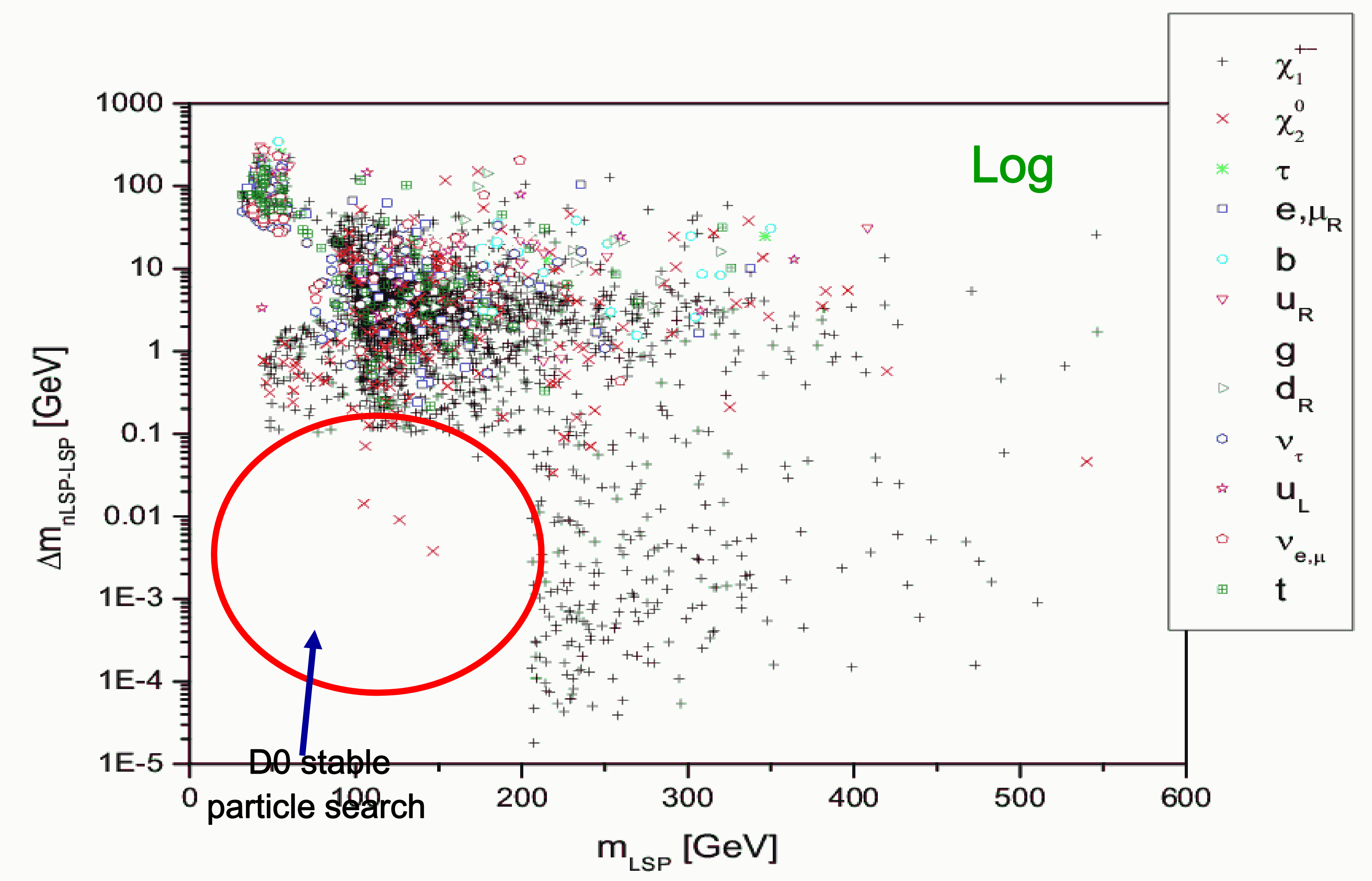
Distribution of Sparticle Masses By Species



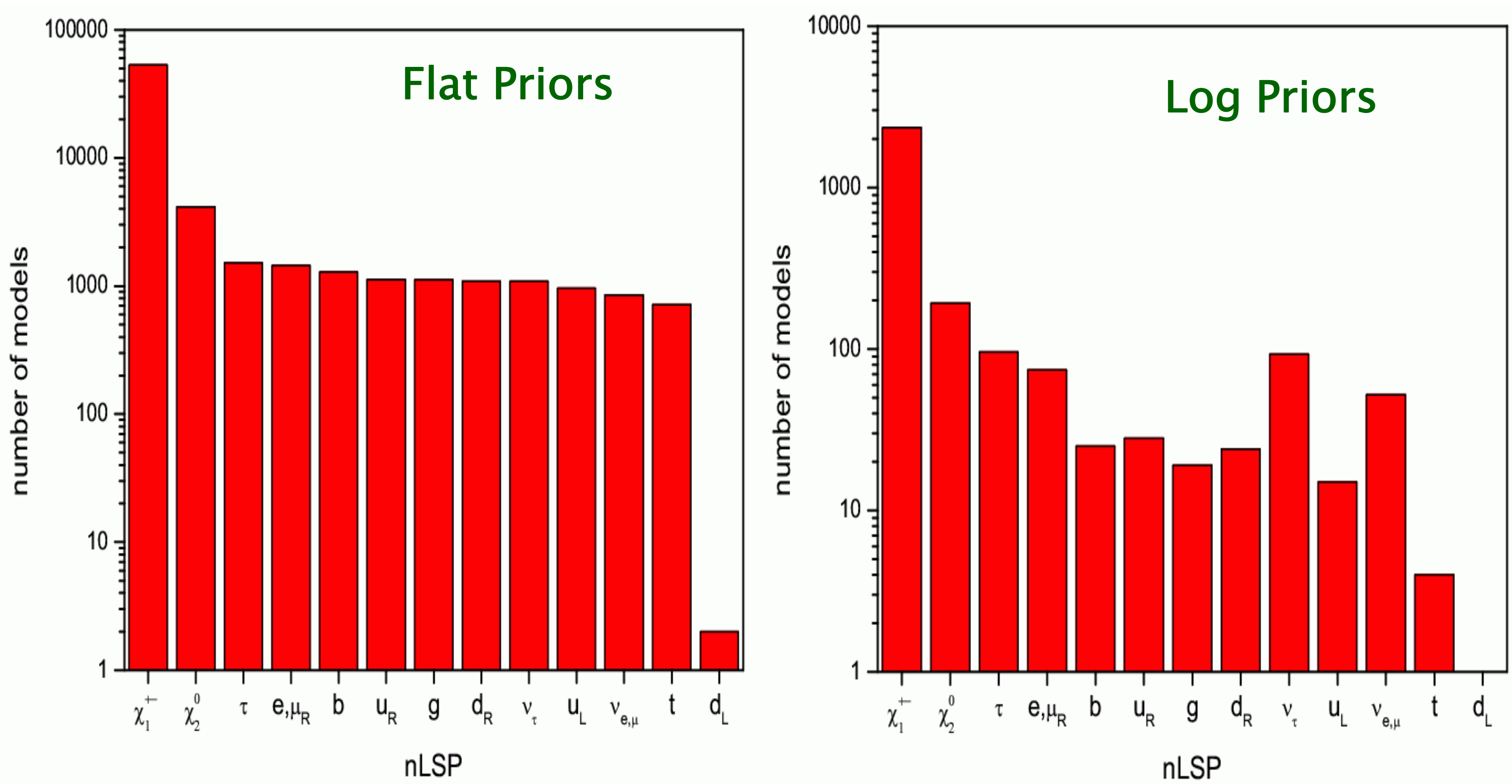
nLSP-LSP Mass Difference



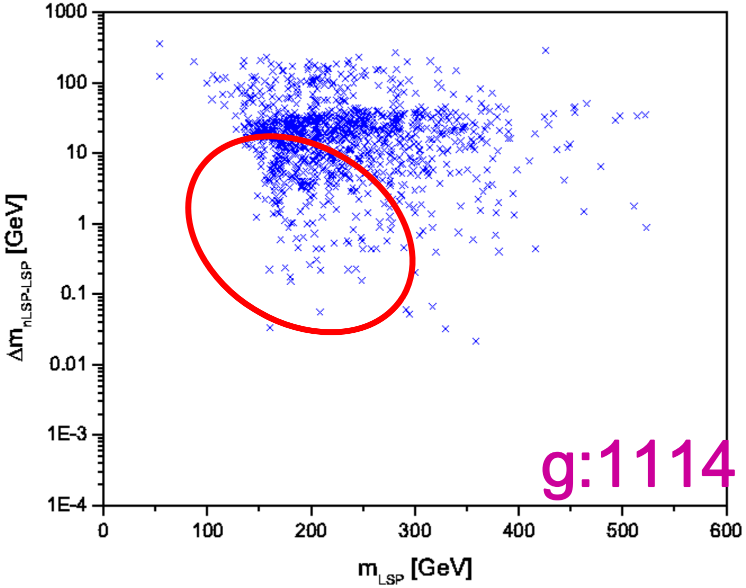
nLSP-LSP Mass Difference



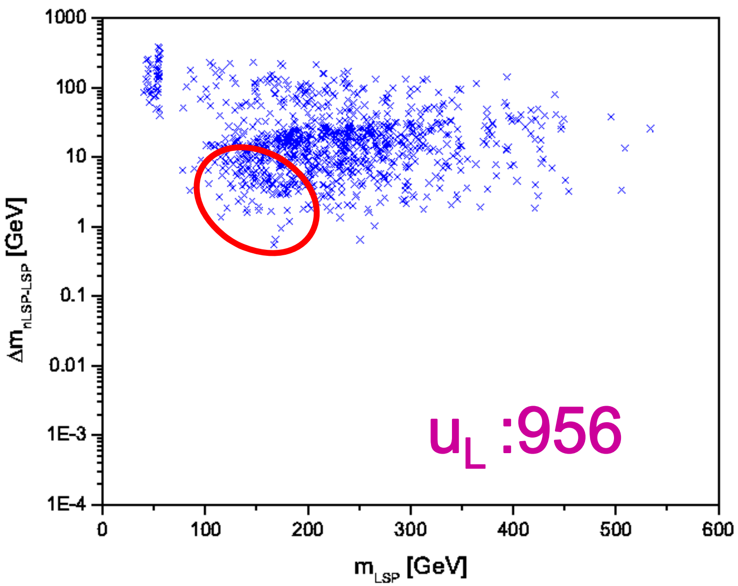
The identity of the nLSP is a critical factor in looking for SUSY signatures..who can play that role here?????   Just about ANY of the 13 possibilities !

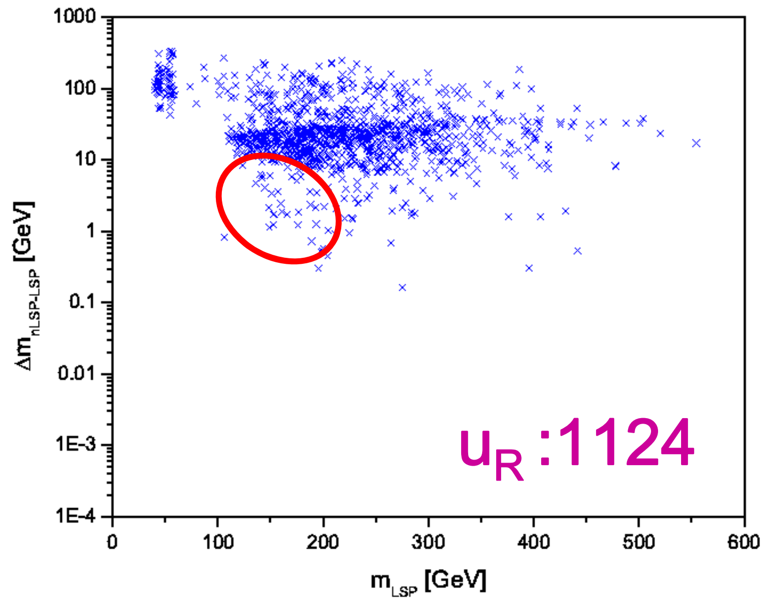


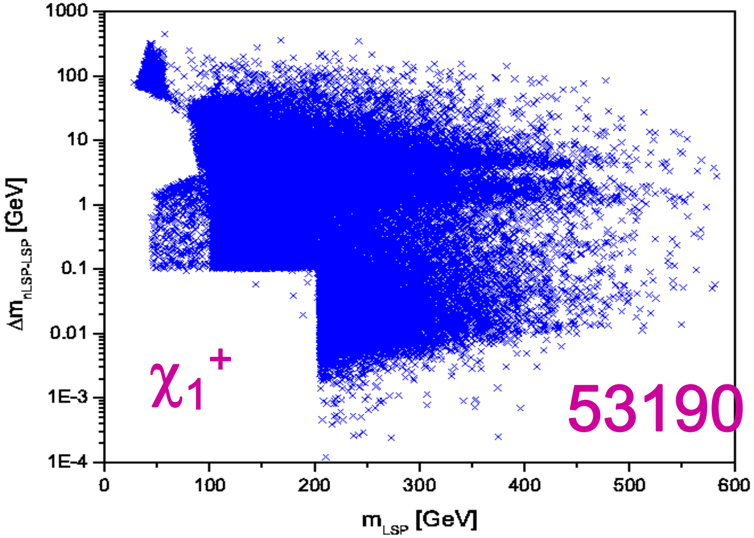
In many cases, but not exclusively, this is due to the small splittings between the squarks and/or gluinos and the LSP…

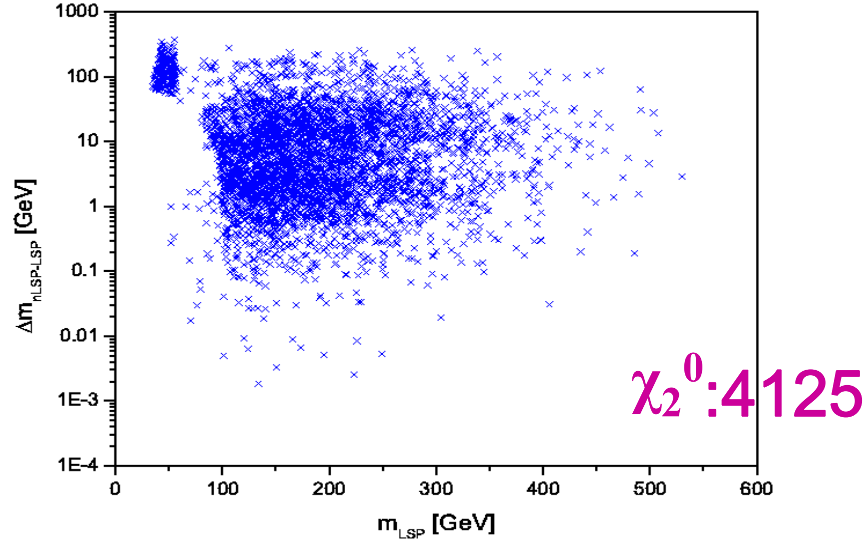


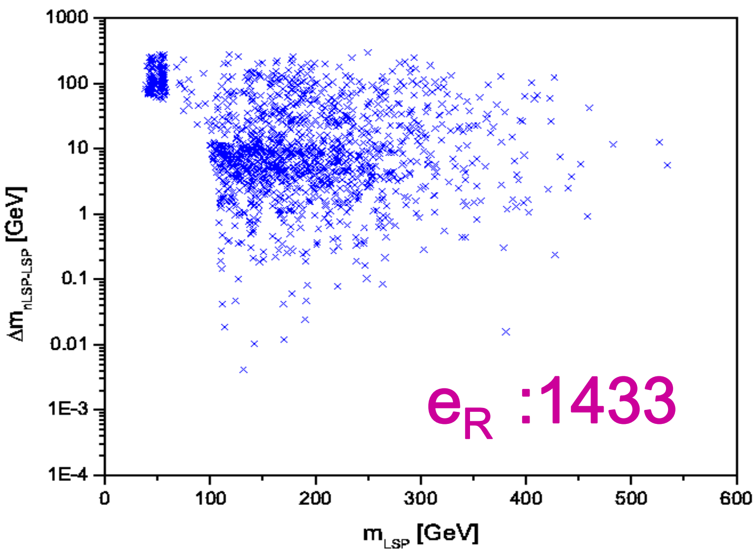
Small mass splittings can lead to soft jets in the final state that have insufficient p_T to pass any SUSY Tevatron search analysis cuts

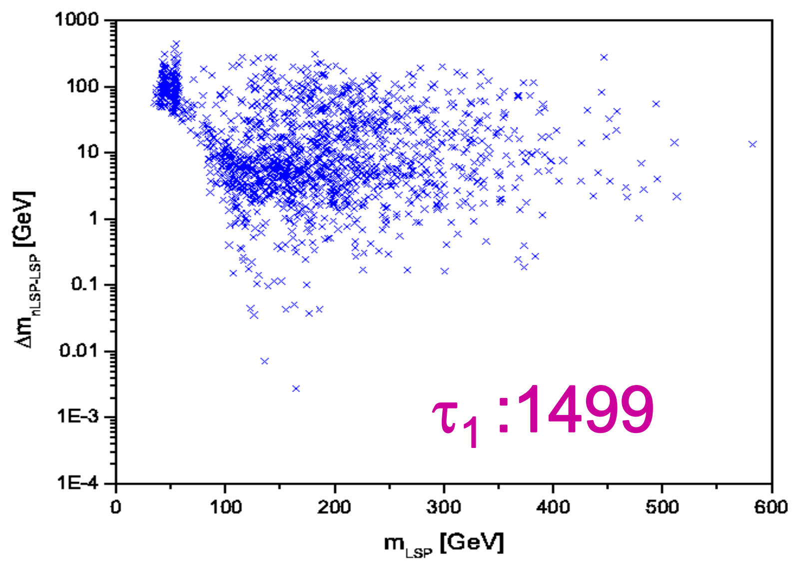


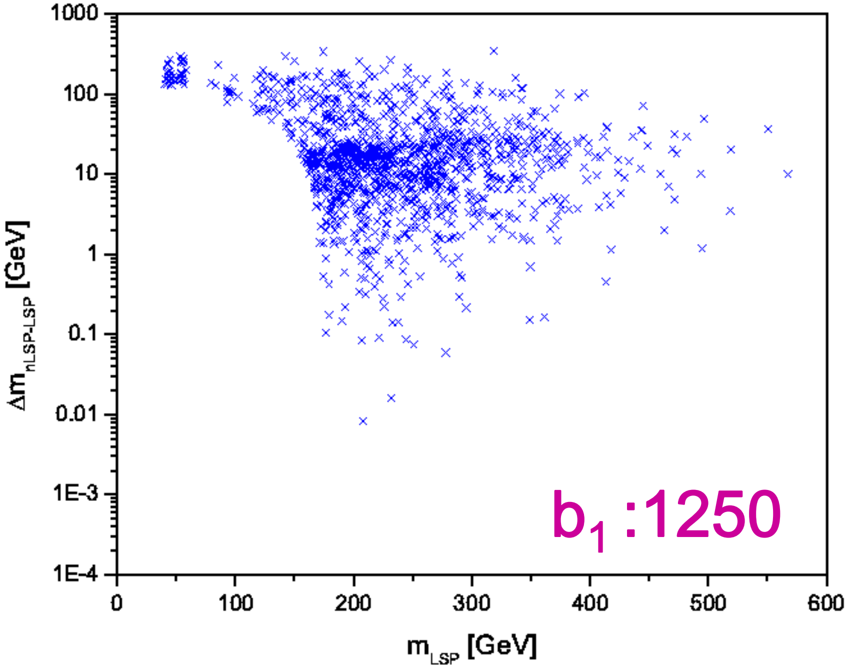


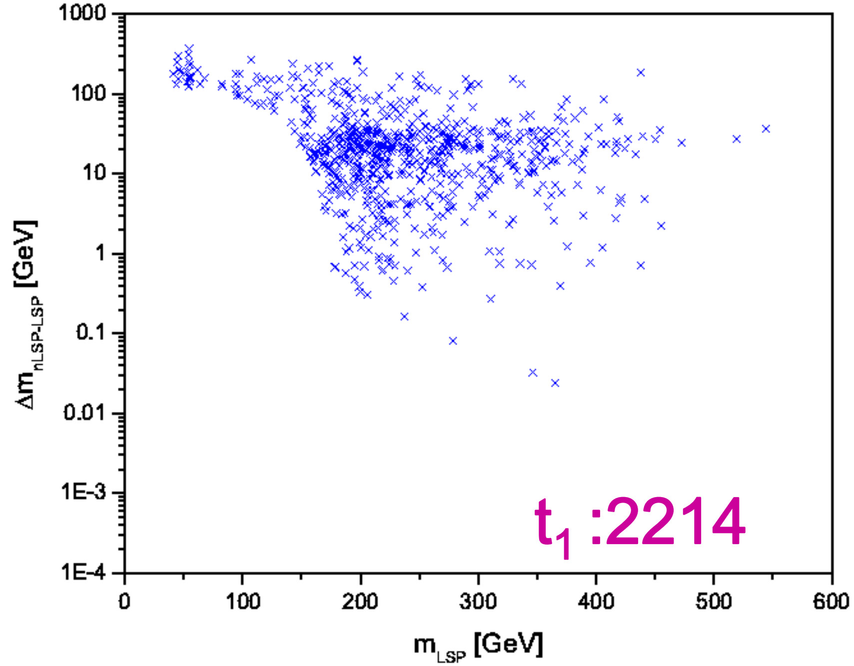

Δm_nLSP-LSP [GeV]
m_LSP [GeV]
χ1+
53190


Δm_nLSP-LSP [GeV]
m_LSP [GeV]
χ20:4125

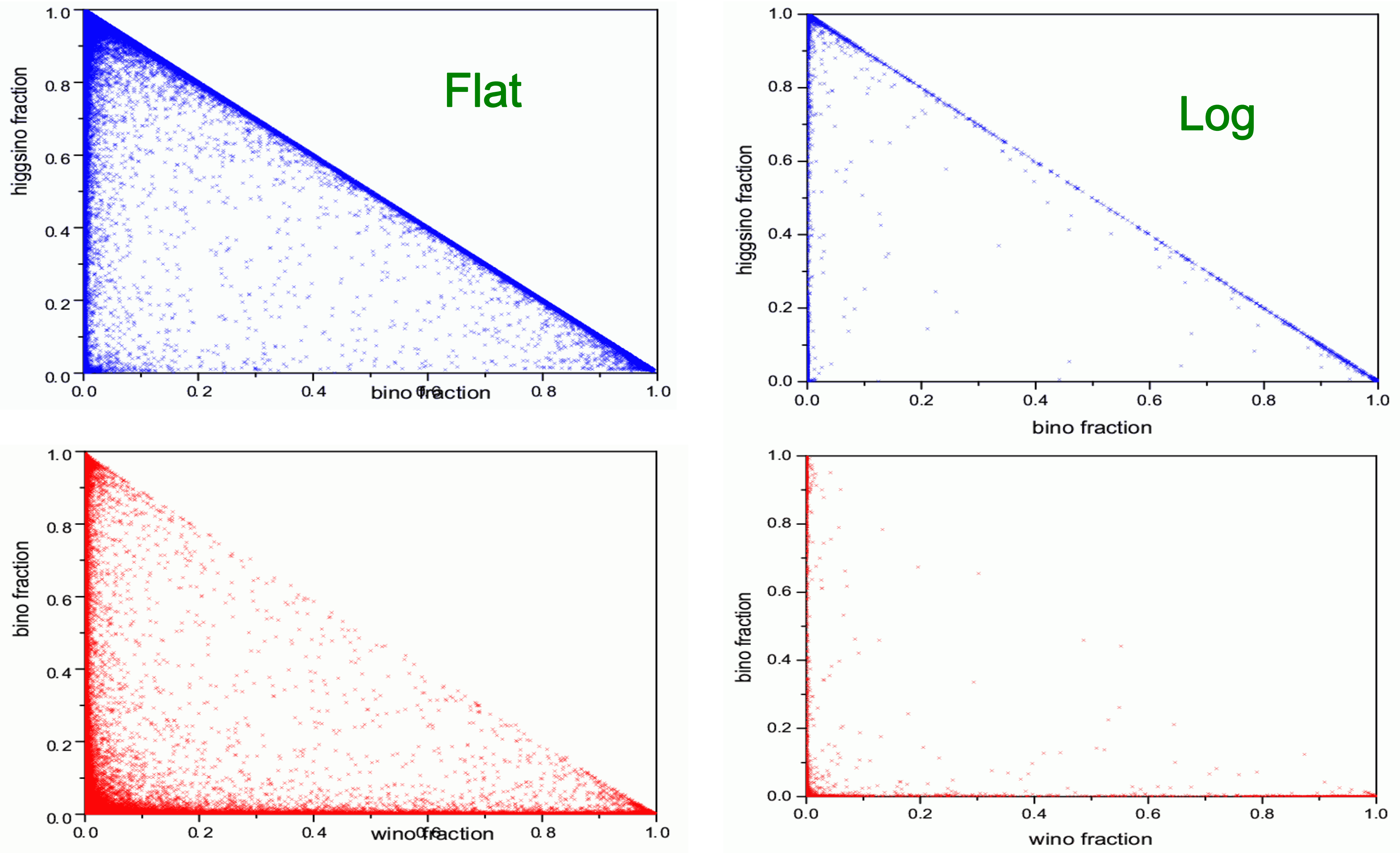

Δm_nLSP-LSP [GeV]
m_LSP [GeV]
eR :1433


Δm_nLSP-LSP [GeV]
m_LSP [GeV]
τ1 :1499


b1 :1250
Δm nLSP-LSP [GeV]
mLSP [GeV]


t1 :2214
Δm nLSP-LSP [GeV]
mLSP [GeV]

LSP Composition

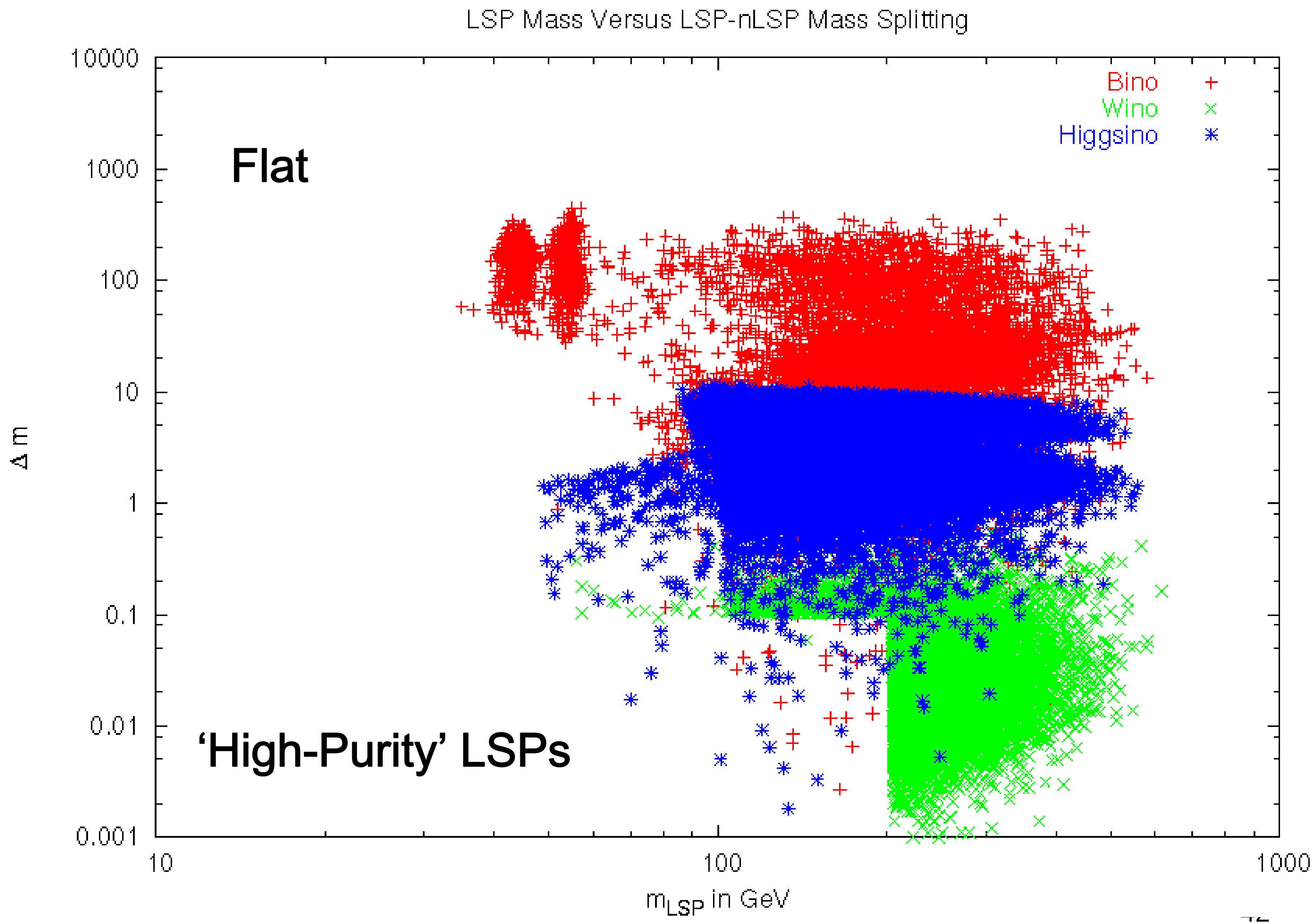


LSP Identity

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


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

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

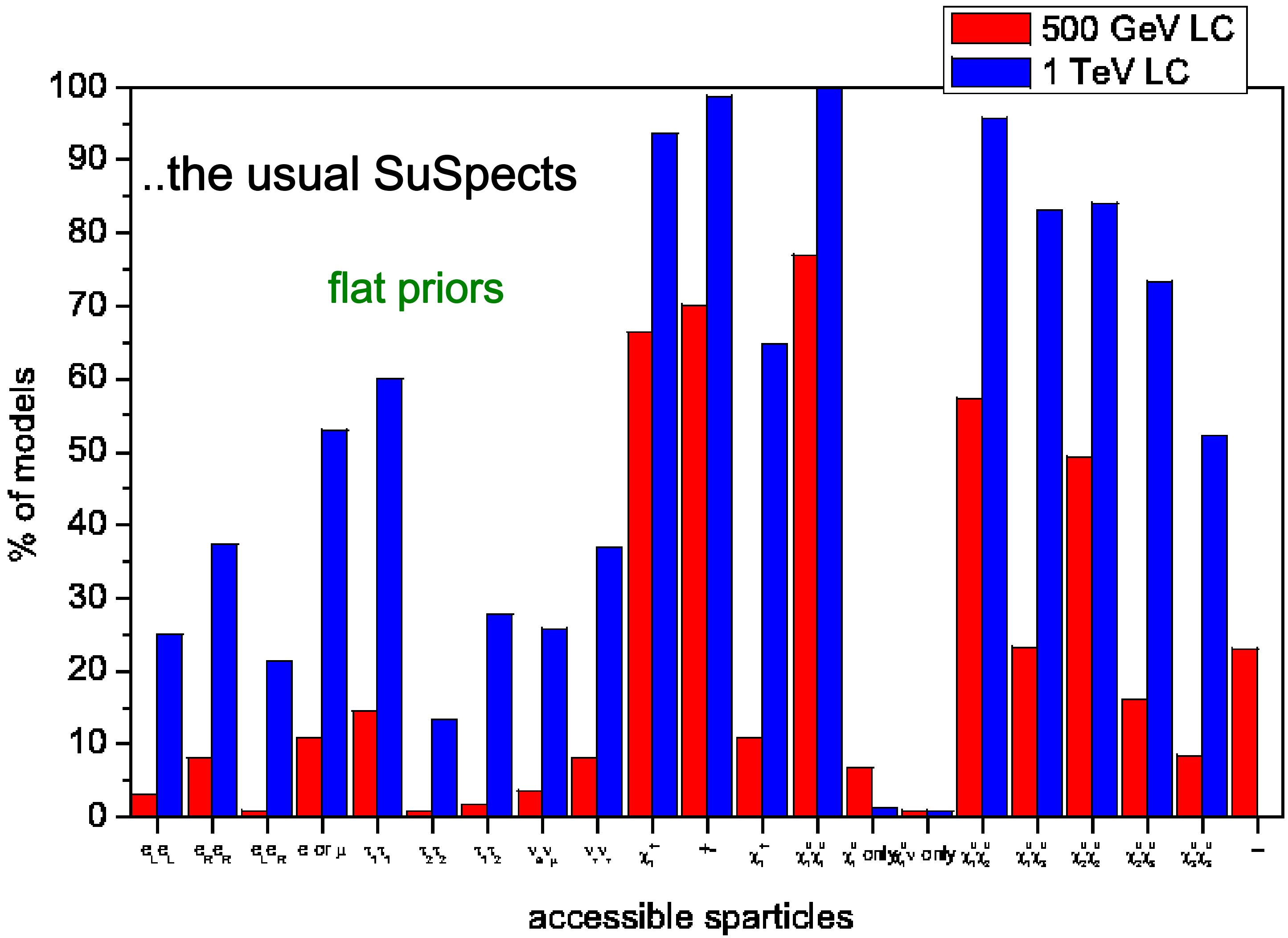
SUSY decay chains are very important…especially the end of the chain at the LHC.

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

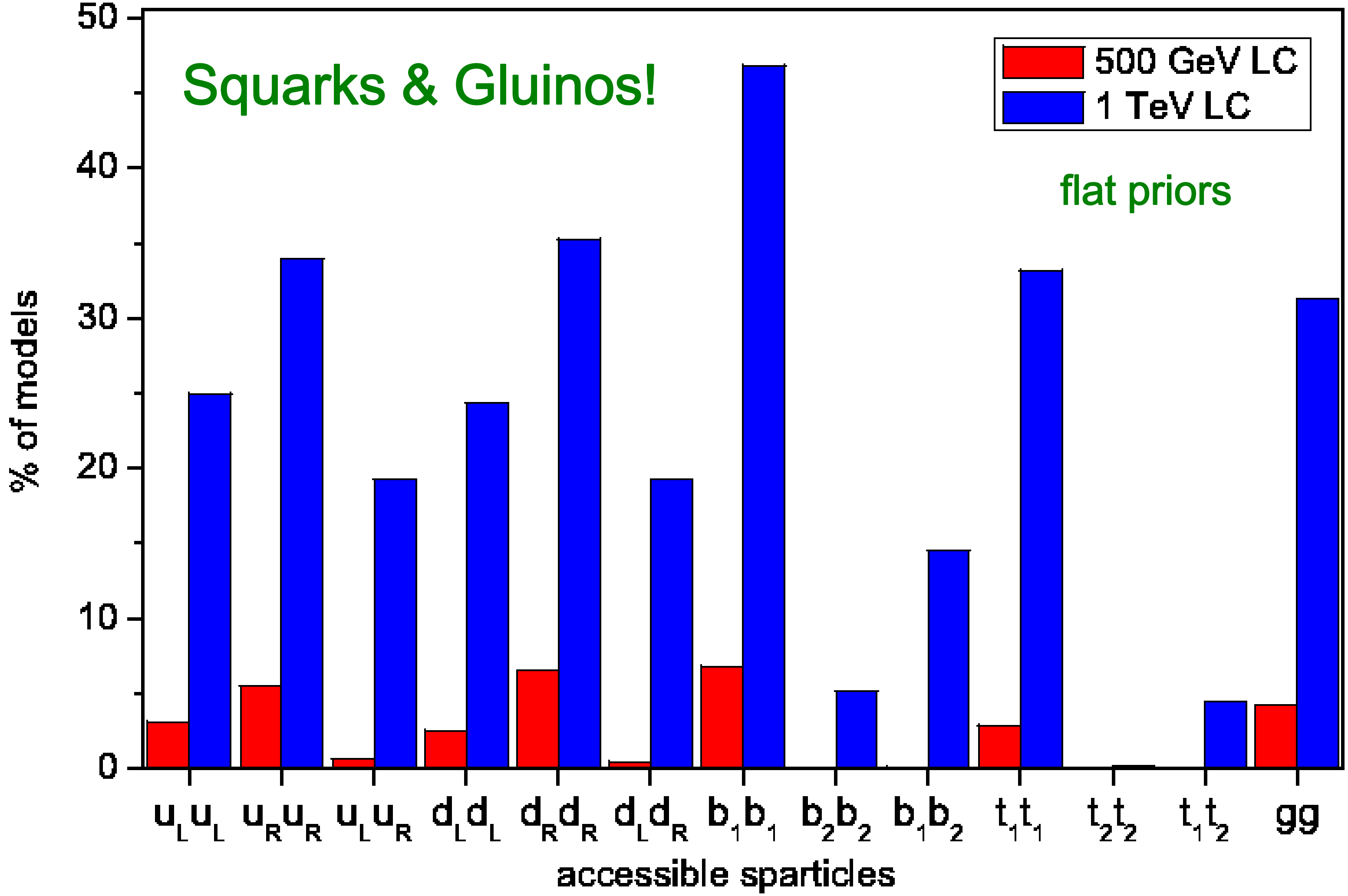
Only ~20 are found to occur in mSUGRA!!

Kinematic Accessibility at the ILC : I

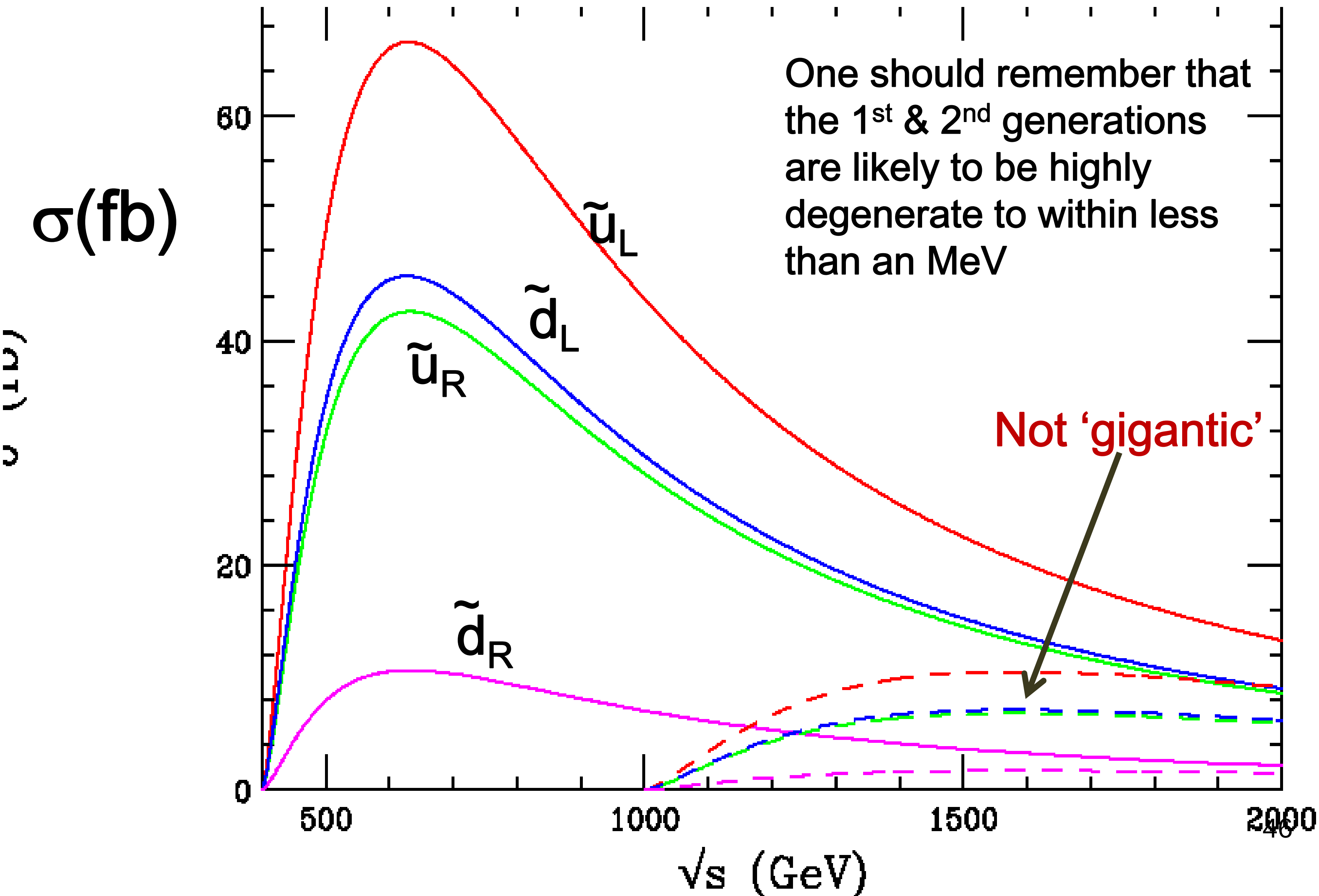


Final State
$\tilde{e}_L^+\tilde{e}_L^-$
$\tilde{e}_R^+\tilde{e}_R^-$
$\tilde{e}_L^\pm\tilde{e}_R^\mp$
$\tilde{\mu}_L^+\tilde{\mu}_L^-$
$\tilde{\mu}_R^+\tilde{\mu}_R^-$
Any selectron or smuon
$\tilde{\tau}_1^+\tilde{\tau}_1^-$
$\tilde{\tau}_2^+\tilde{\tau}_2^-$
$\tilde{\tau}_1^\pm\tilde{\tau}_2^\mp$
$\tilde{\nu}_{e\mu}\tilde{\nu}_{e\mu}^*$
$\tilde{\nu}_\tau\tilde{\nu}_\tau^*$
$\tilde{\chi}_1^+\tilde{\chi}_1^-$
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

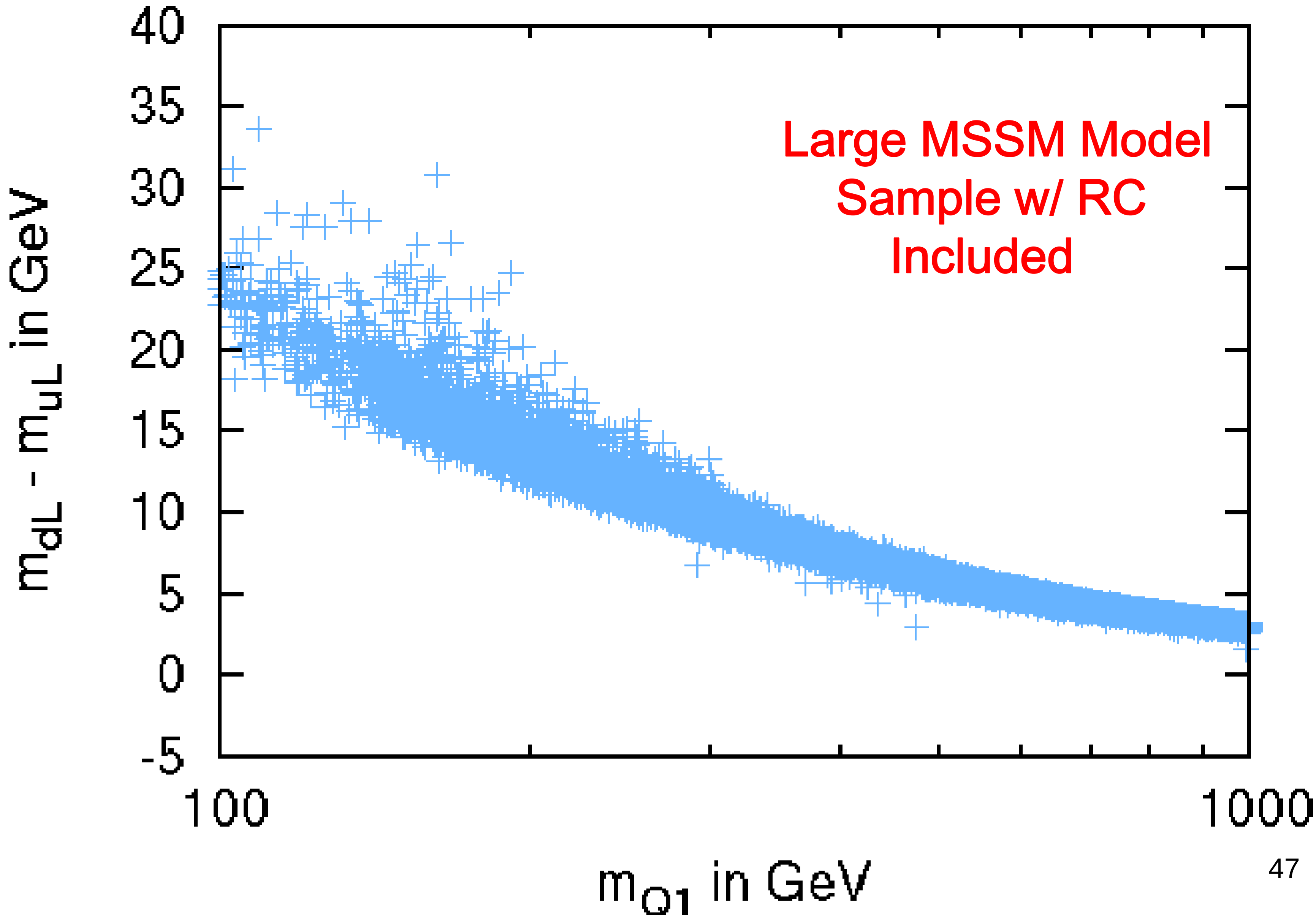
Kinematic Accessibility at the ILC : III



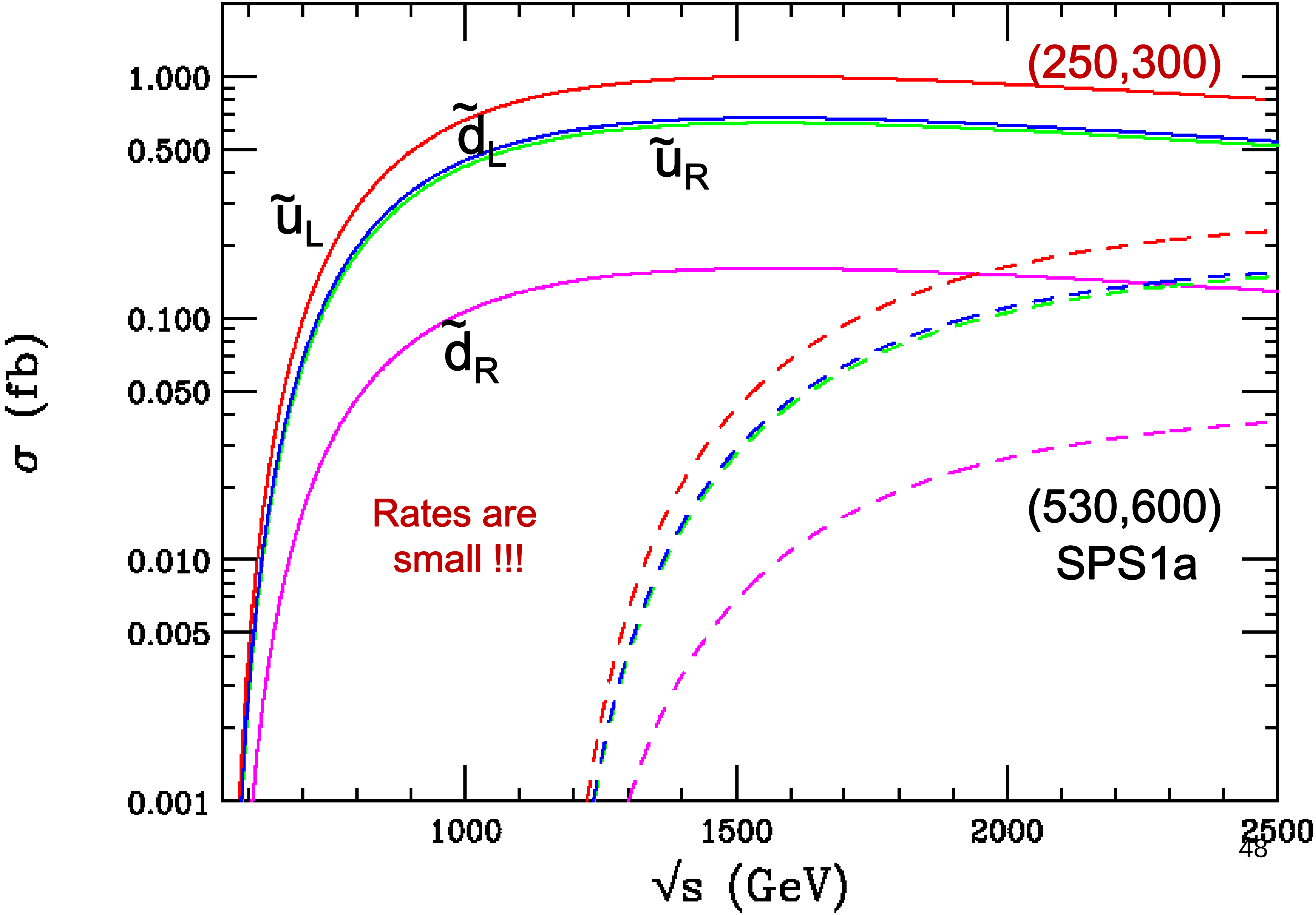
Squark Pair Production in e^+e^-



Squark Mass Splitting

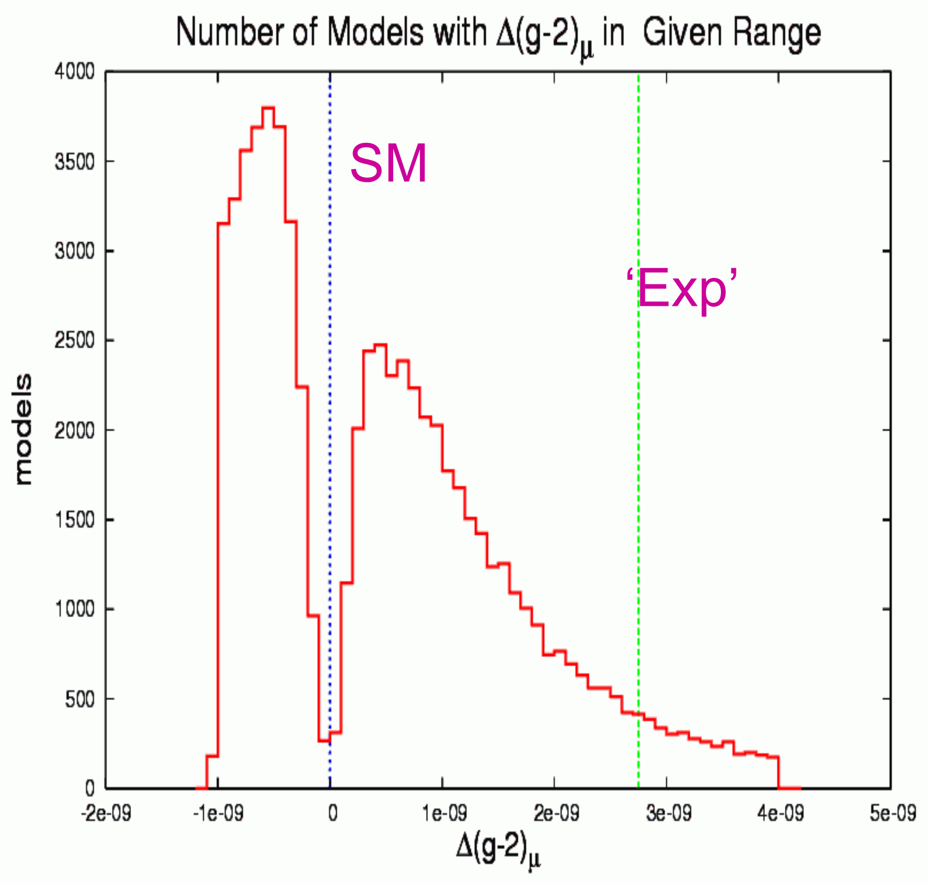


Squark + Gluino Production

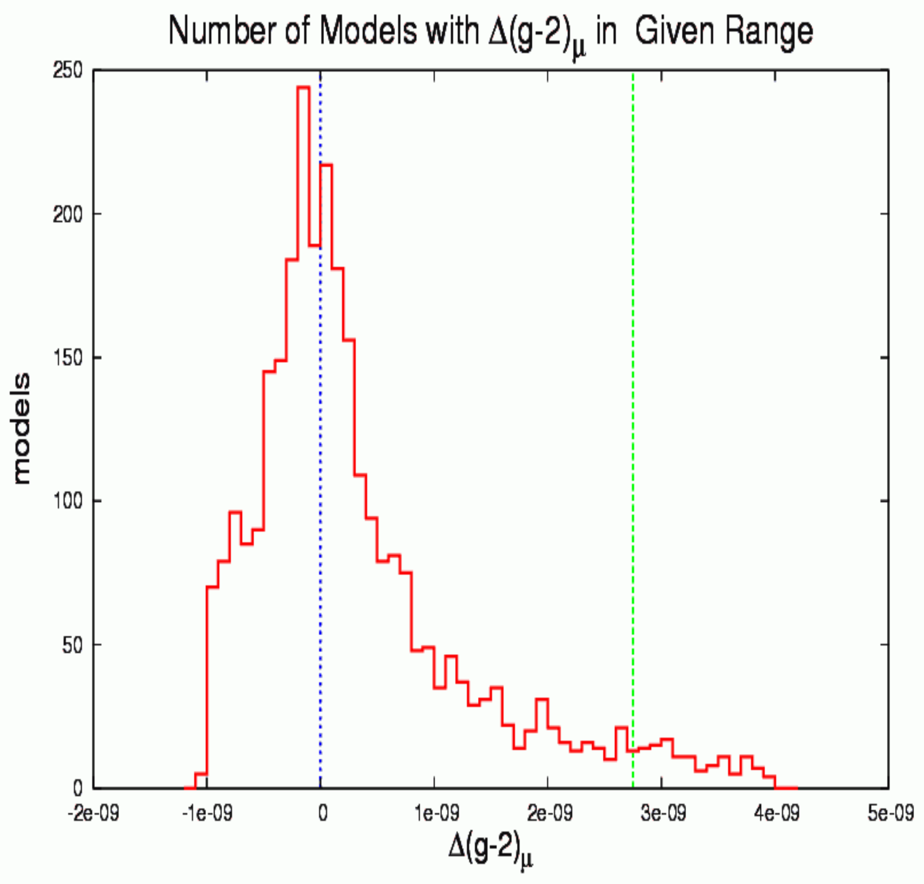


Predictions for $\Delta(g\text{-}2)_\mu$

flat

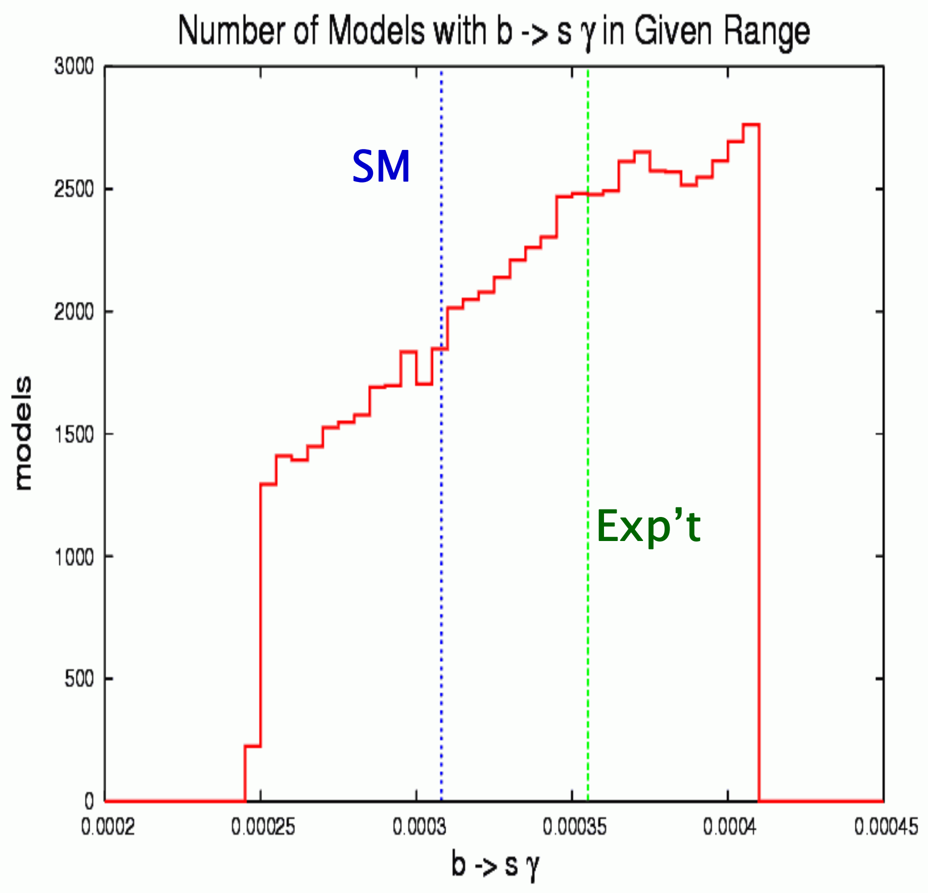


log

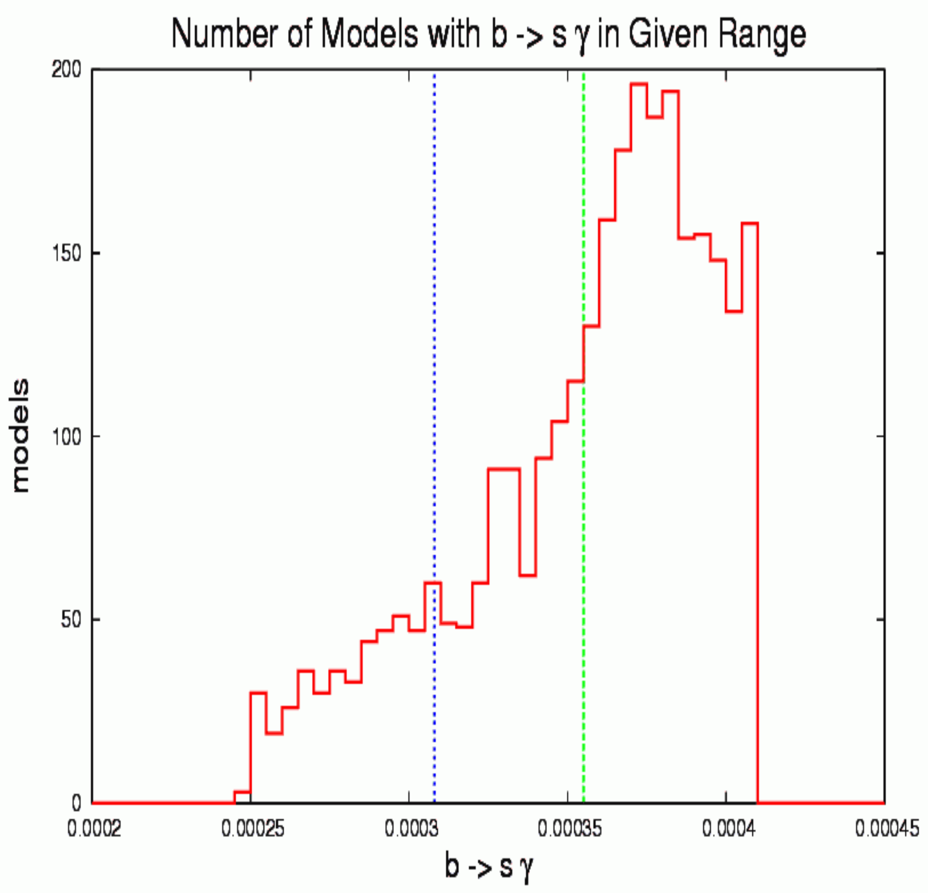


Predictions for b→sγ

Flat Priors

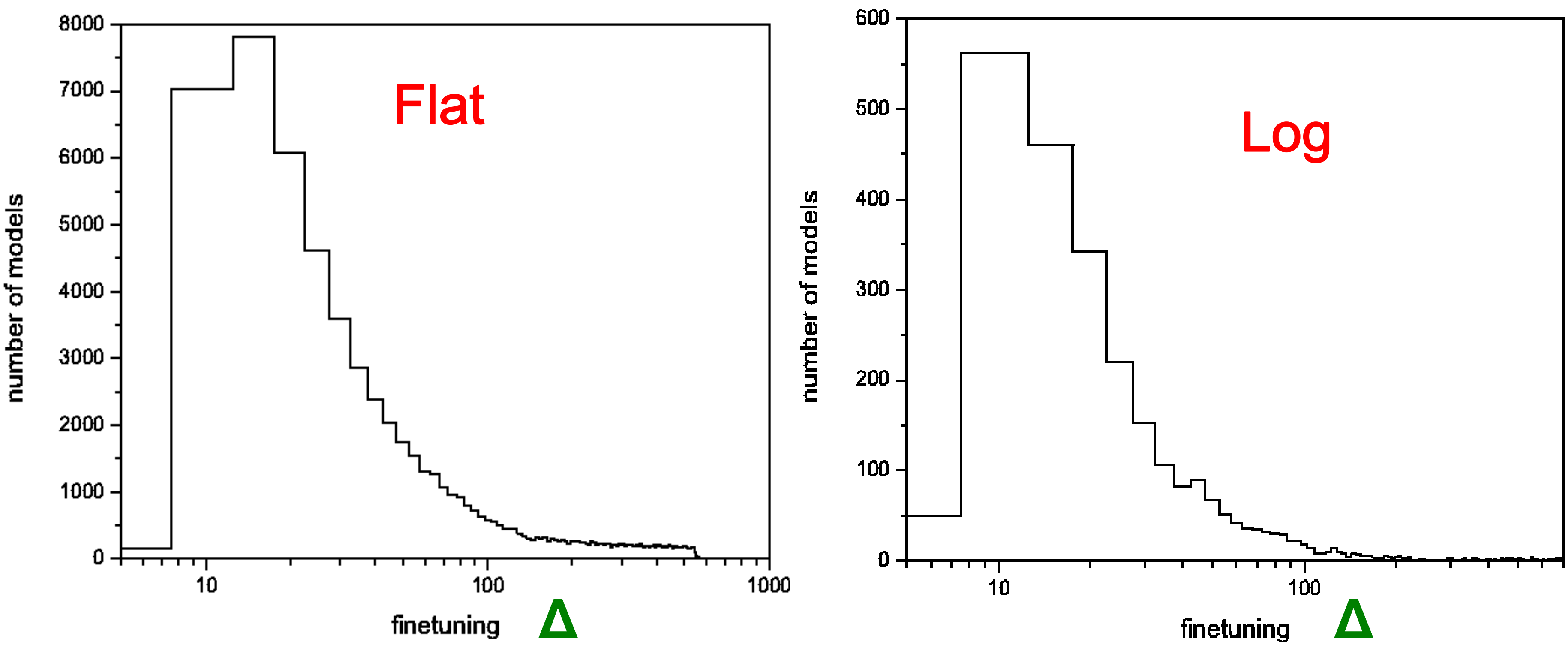


Log Priors



‘Fine-Tuning’ or Naturalness Criterion

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



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 be difficult to observe at the LHC due to rather common small mass differences or strange spectra

- Squarks may exist within the range accessible to a 500 GeV ILC but have not been well studied there.

- With the WMAP constraint employed as a bound the LSP is not likely to be the dominant source of DM…but it can be.

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

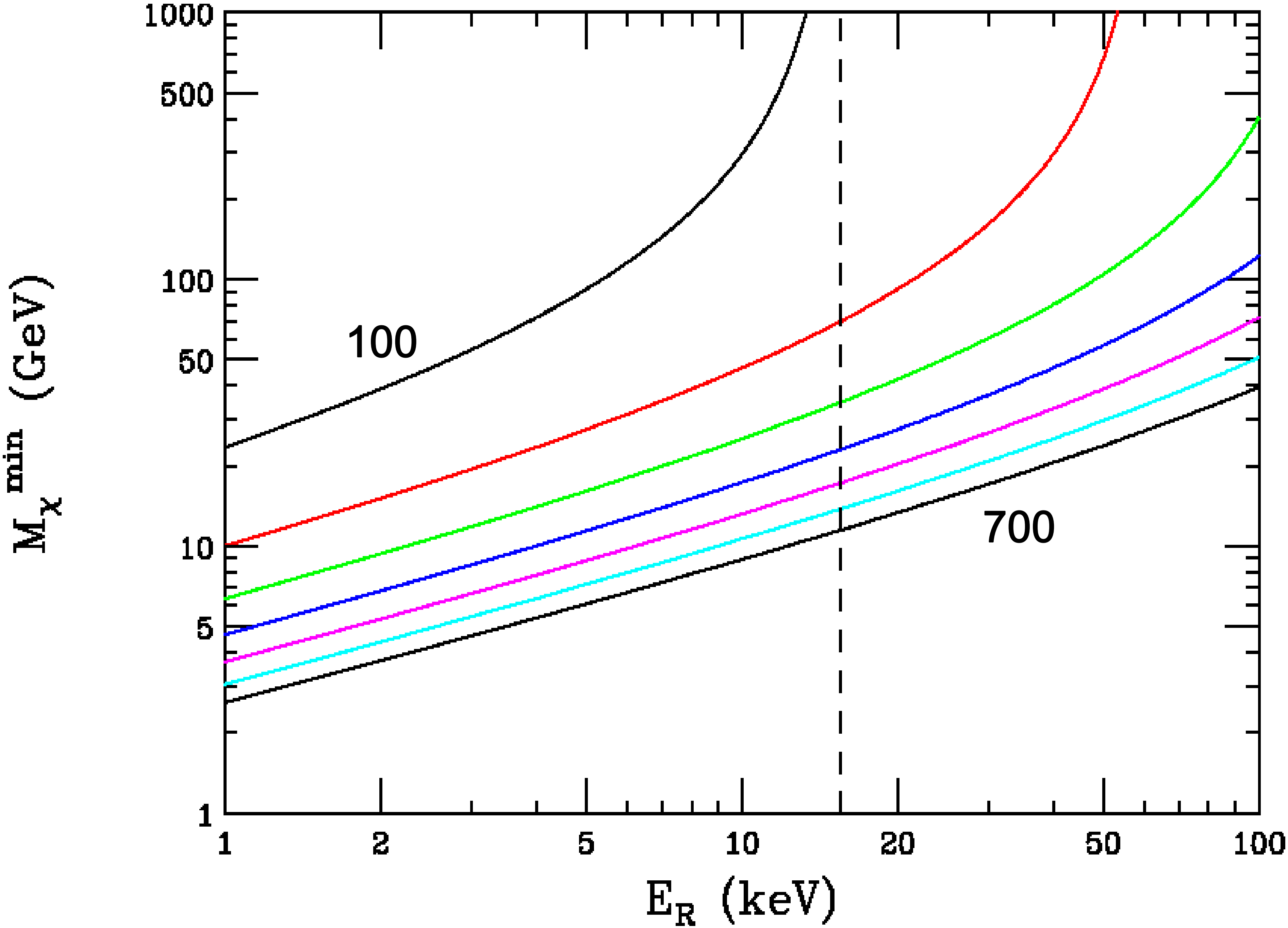
BACKUP SLIDES

Composition of the LSP

	<133 GeV	133-183	133-243	>243 GeV
Class	Quartile 1	Quartile 2	Quartile 3	Quartile 4
$\|Z_{11}\|^2 > 0.95$	373	523	551	384
$0.95 \geq \|Z_{11}\|^2 > 0.8$	308	173	179	161
$\|Z_{12}\|^2 > 0.95$	2	1	41	108
$0.95 \geq \|Z_{12}\|^2 > 0.8$	17	33	52	86
$\|Z_{13}\|^2 + \|Z_{14}\|^2 > 0.95$	81	118	151	124
$0.95 \geq \|Z_{13}\|^2 + \|Z_{14}\|^2 > 0.8$	237	234	238	287
$0.8 \geq \|Z_{11}\|^2 > 0.50$	329	260	193	167
Everything Else	437	442	380	467

$R > x$	$\Omega h^2 > y$	Number of models
4.0	0.0	64
3.0	0.0	295
2.0	0.0	845
1.0	0.0	2217
4.0	0.1	3
3.0	0.1	32
2.0	0.1	91
1.0	0.1	211

Models with Large SI Direct Detection Cross Sections wrt CDMSII



M_χ^{min} (GeV)
E_R (keV)
100
700
1000
500
100
50
10
5
1
1
2
5
10
20
50
100

Squark + Gluino Production