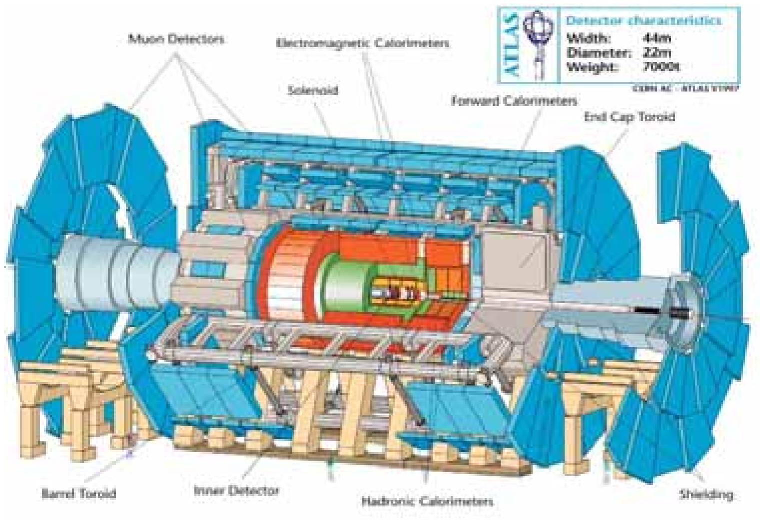
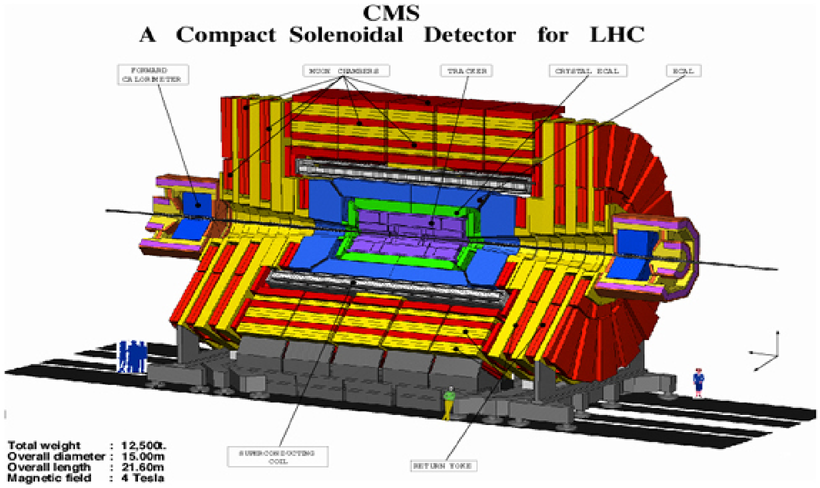
Supersymmetry Without Prejudice





SLAC NATIONAL ACCELERATOR LABORATORY

C. F. Berger, J. G. Cogan, J.A. Conley, R.C. Cotta, J. S. Gainer,
J. L. Hewett & TGR

06/12/2009

The MSSM has many nice features but is very difficult to study in any detailed, model-independent manner due to the very large number of soft SUSY breaking parameters (~ 100).

To circumvent this issue, authors generally limit their analyses to a specific SUSY breaking scenario(s) such as mSUGRA, GMSB, AMSB,… which determines the sparticle (e.g., the LSP's) couplings & signatures in terms of a few parameters.

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.
- 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…

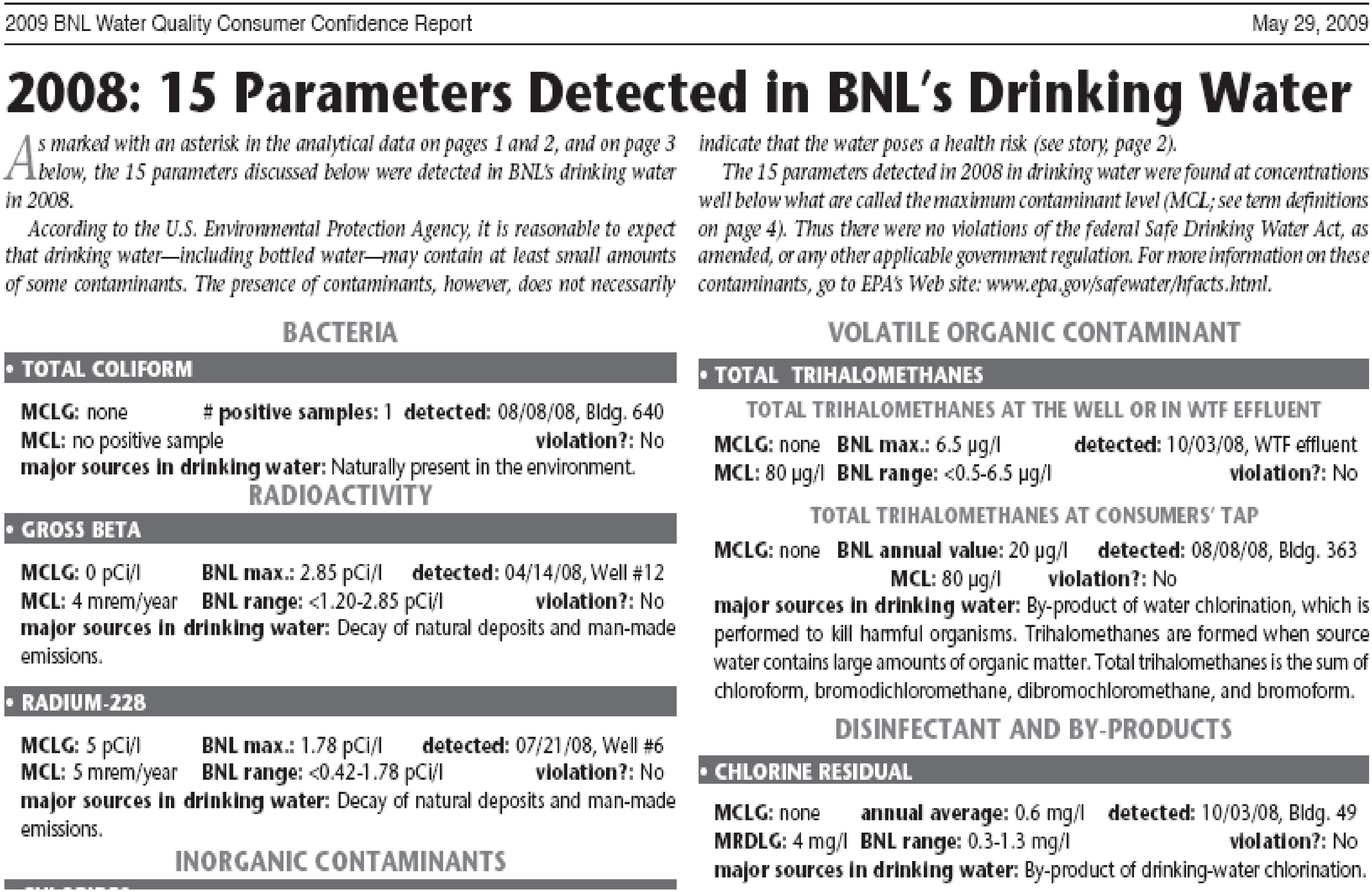
What are they??

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



2009 BNL Water Quality Consumer Confidence Report May 29, 2009

2008: 15 Parameters Detected in BNL's Drinking Water

As marked with an asterisk in the analytical data on pages 1 and 2, and on page 3 below, the 15 parameters discussed below were detected in BNL's drinking water in 2008.

According to the U.S. Environmental Protection Agency, it is reasonable to expect that drinking water—including bottled water—may contain at least small amounts of some contaminants. The presence of contaminants, however, does not necessarily indicate that the water poses a health risk (see story, page 2).

The 15 parameters detected in 2008 in drinking water were found at concentrations well below what are called the maximum contaminant level (MCL; see term definitions on page 4). Thus there were no violations of the federal Safe Drinking Water Act, as amended, or any other applicable government regulation. For more information on these contaminants, go to EPA's Web site: www.epa.gov/safewater/hfacts.html.

BACTERIA

• TOTAL COLIFORM

MCLG: none **# positive samples:** 1 **detected:** 08/08/08, Bldg. 640
MCL: no positive sample **violation?:** No
major sources in drinking water: Naturally present in the environment.

RADIOACTIVITY

• GROSS BETA

MCLG: 0 pCi/l **BNL max.:** 2.85 pCi/l **detected:** 04/14/08, Well #12
MCL: 4 mrem/year **BNL range:** <1.20-2.85 pCi/l **violation?:** No
major sources in drinking water: Decay of natural deposits and man-made emissions.

• RADIUM-228

MCLG: 5 pCi/l **BNL max.:** 1.78 pCi/l **detected:** 07/21/08, Well #6
MCL: 5 mrem/year **BNL range:** <0.42-1.78 pCi/l **violation?:** No
major sources in drinking water: Decay of natural deposits and man-made emissions.

INORGANIC CONTAMINANTS

VOLATILE ORGANIC CONTAMINANT

• TOTAL TRIHALOMETHANES

TOTAL TRIHALOMETHANES AT THE WELL OR IN WTF EFFLUENT

MCLG: none **BNL max.:** 6.5 µg/l **detected:** 10/03/08, WTF effluent
MCL: 80 µg/l **BNL range:** <0.5-6.5 µg/l **violation?:** No

TOTAL TRIHALOMETHANES AT CONSUMERS' TAP

MCLG: none **BNL annual value:** 20 µg/l **detected:** 08/08/08, Bldg. 363
MCL: 80 µg/l **violation?:** No
major sources in drinking water: By-product of water chlorination, which is performed to kill harmful organisms. Trihalomethanes are formed when source water contains large amounts of organic matter. Total trihalomethanes is the sum of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

DISINFECTANT AND BY-PRODUCTS

• CHLORINE RESIDUAL

MCLG: none **annual average:** 0.6 mg/l **detected:** 10/03/08, Bldg. 49
MRDLG: 4 mg/l **BNL range:** 0.3-1.3 mg/l **violation?:** No
major sources in drinking water: By-product of drinking-water chlorination.

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. (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. – all your favorites! Are there, e.g., models which give ‘unusual’ and/or particularly ‘difficult’ signatures at the LHC?? (In progress)

NB :

Our goal is 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 unexpected surprises at colliders and elsewhere.

How? Perform 2 Random Scans

Linear Priors

10^7 points – emphasizes moderate masses

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

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

100 GeV $\leq M_3 \leq$ 1 TeV

~0.5 $M_Z \leq M_A \leq$ 1 TeV

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

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

Log Priors

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

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

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

100 GeV $\leq M_3 \leq$ 3 TeV

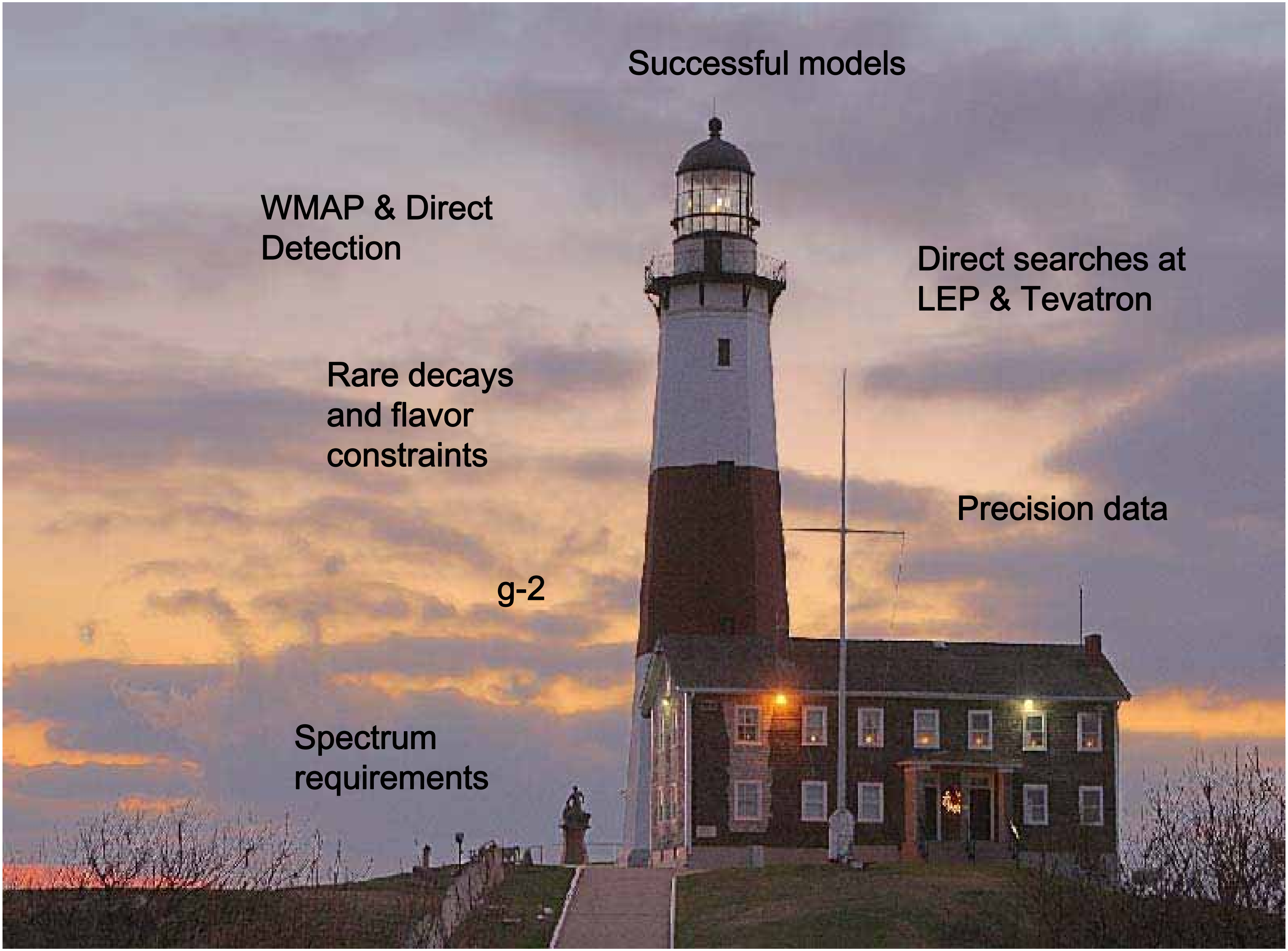
~0.5 $M_Z \leq M_A \leq$ 3 TeV

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

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

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

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



Successful models

WMAP & Direct
Detection

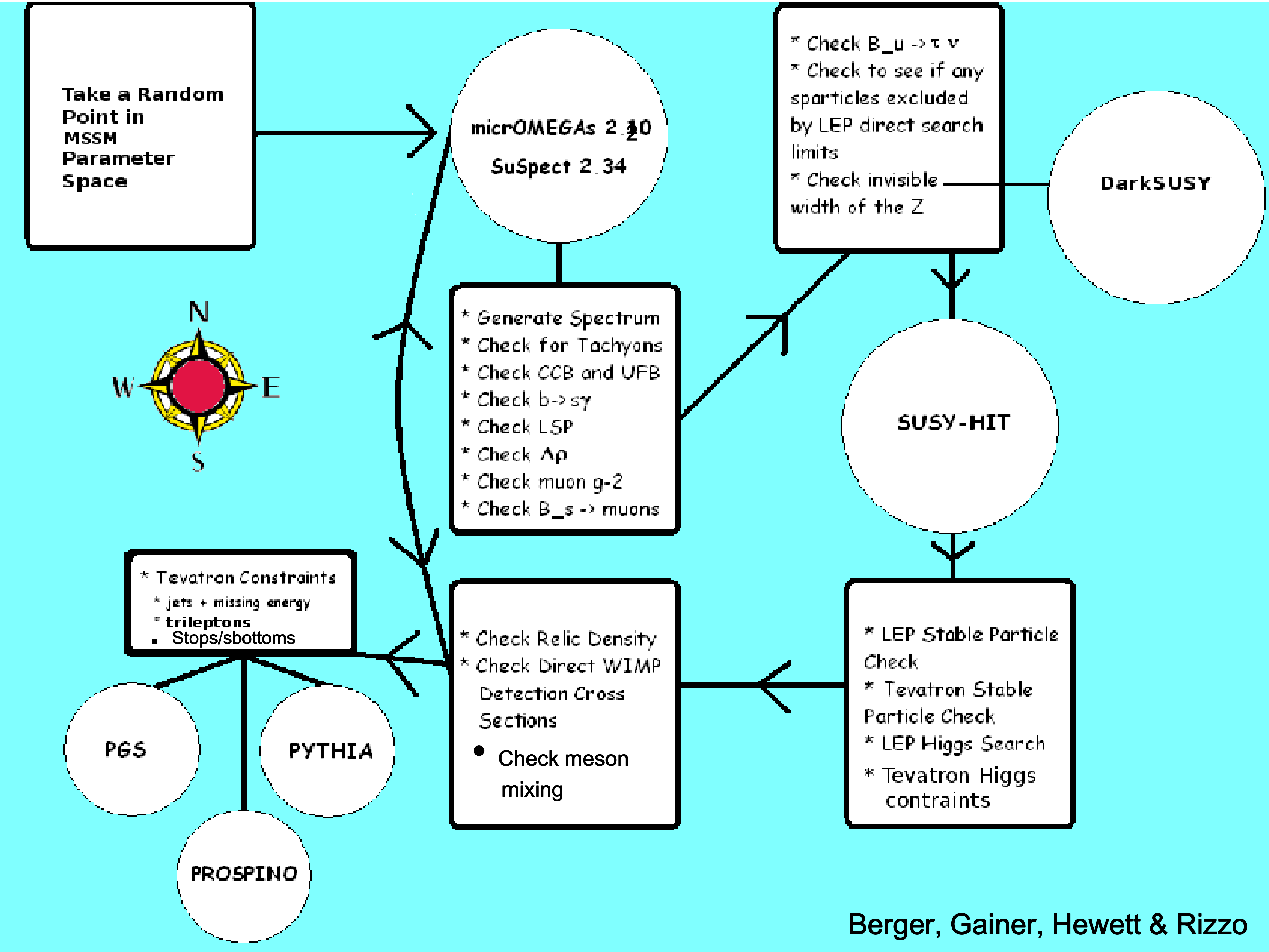
Direct searches at
LEP & Tevatron

Rare decays
and flavor
constraints

Precision data

g-2

Spectrum
requirements



Take a Random Point in MSSM Parameter Space

micrOMEGAs 2.10

SuSpect 2.34

- Generate Spectrum
- Check for Tachyons
- Check CCB and UFB
- Check b->sγ
- Check LSP
- Check Δρ
- Check muon g-2
- Check B_s -> muons

- Check B_u -> τ ν
- Check to see if any sparticles excluded by LEP direct search limits
- Check invisible width of the Z

DarkSUSY

SUSY-HIT

- LEP Stable Particle Check
- Tevatron Stable Particle Check
- LEP Higgs Search
- Tevatron Higgs contraints

- Check Relic Density
- Check Direct WIMP Detection Cross Sections
- Check meson mixing

- Tevatron Constraints
  - jets + missing energy
  - **trileptons**
  - Stops/sbottoms

PGS

PYTHIA

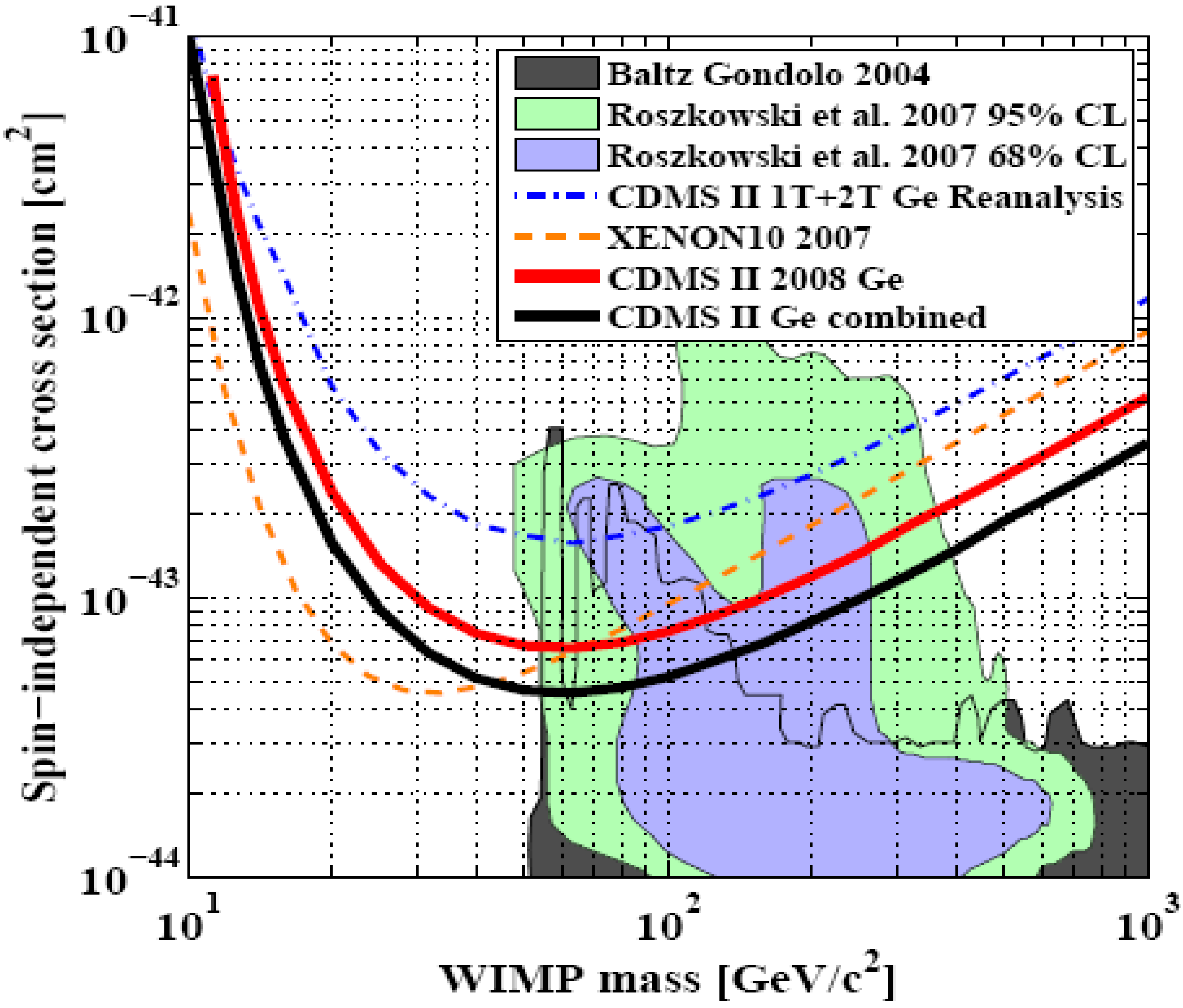
PROSPINO

Berger, Gainer, Hewett & Rizzo

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)
  $(29.5 \pm 7.9) \times 10^{-10}$ (0809.3085)
  $[\sim 14.0 \pm 8.4] \times 10^{-10}$ [Davier/BaBar-Tau08]
  → $(-10 \text{ to } 40) \times 10^{-10}$ to be conservative..
- $\Gamma(Z \to \text{invisible}) < 2.0$ MeV (LEPEWWG)
- Meson-Antimeson Mixing $0.2 < R_{13} < 5$
- $B \to \tau\nu$ $B = (55 \text{ to } 227) \times 10^{-6}$ 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



- Direct Detection of Dark Matter → We find a factor of ~ 4 uncertainty in the nuclear matrix elements. This factor was obtained from studying several benchmark points in detail & so we allow cross sections 4x larger than the usually quoted limits. Spin-independent limits are completely dominant here.

- 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 cautious here in how the constraints are used.

Zh, h-> bb, ττ

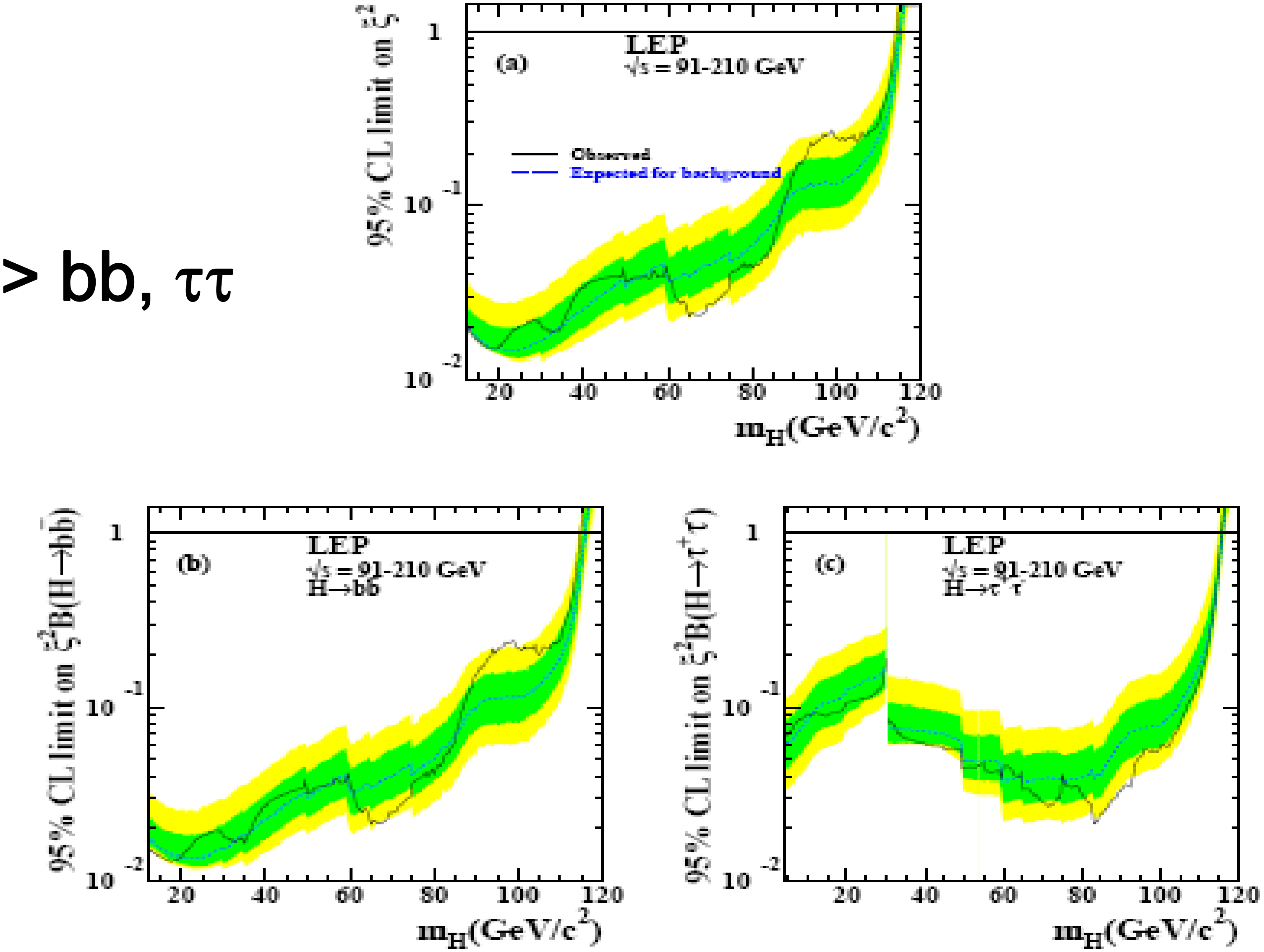


Figure 1: The 95% c.l. upper bound on the coupling ratio $\xi^2 = (g_{\mathrm{HZZ}}/g^{\mathrm{SM}}_{\mathrm{HZZ}})^2$ (see text). The dark (green) and light (yellow) shaded bands around the median expected line correspond to the 68% and 95% probability bands. The horizontal lines correspond to the Standard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

LEP II: Associated Higgs Production

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

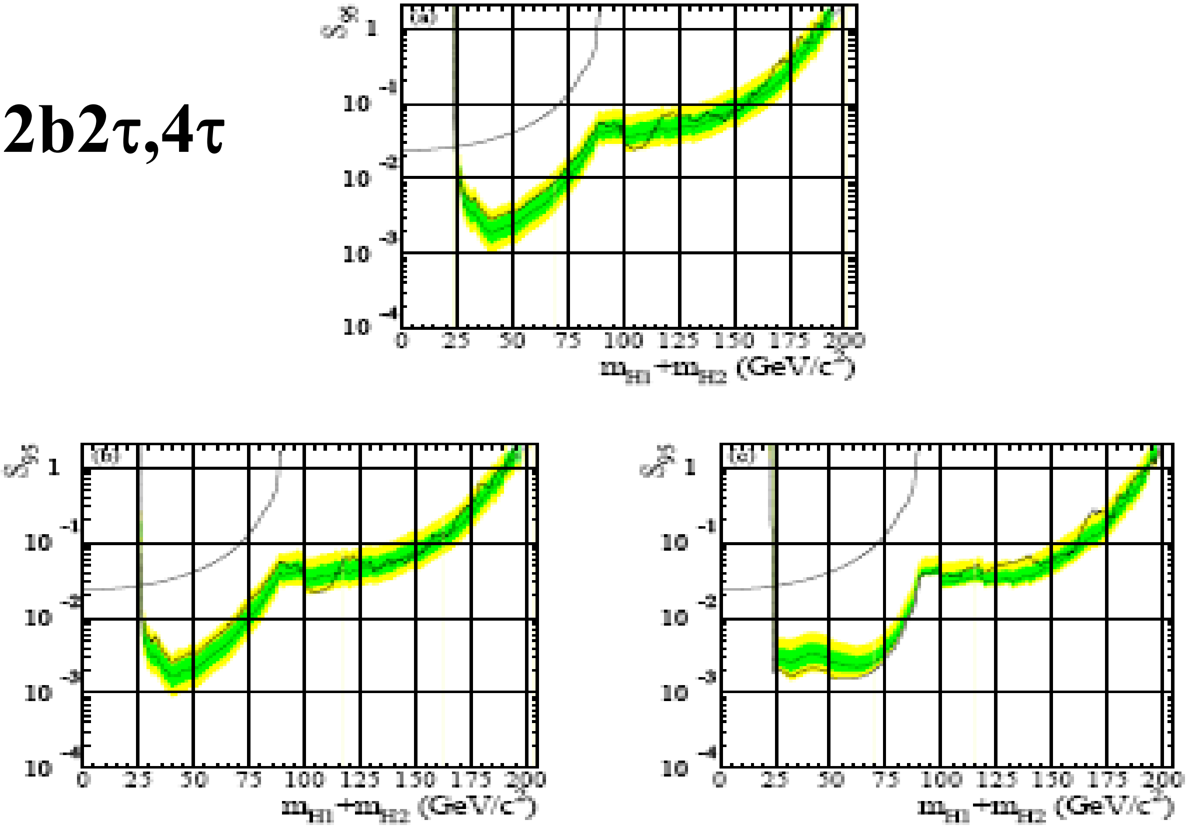
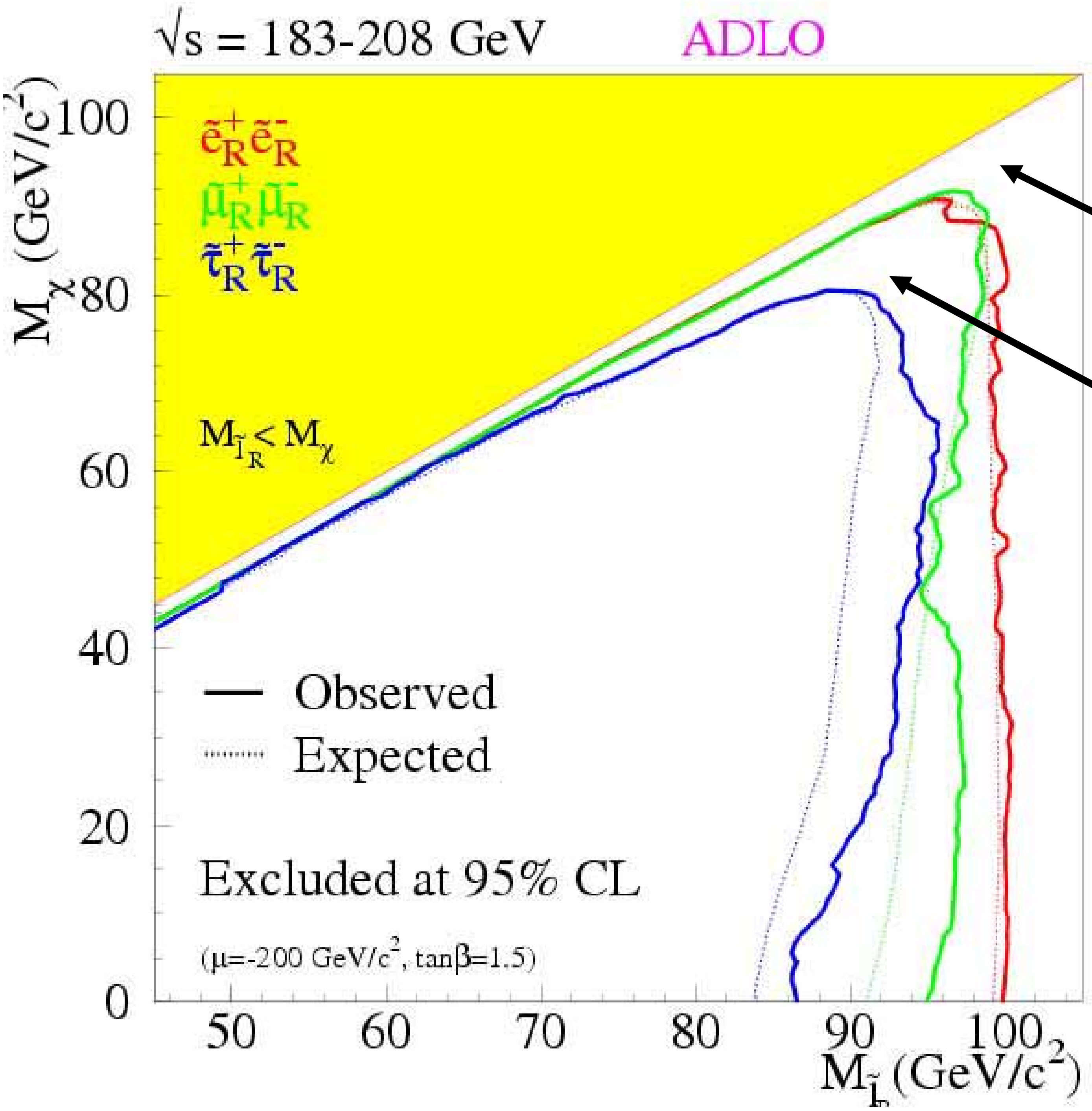


Figure 3: *Model-independent 95% c.l. upper bounds, S_{95}, for various topological cross sections motivated by the pair-production process $e^+e^- \rightarrow \mathcal{H}_2\mathcal{H}_1$, for the particular case where $m_{\mathcal{H}_1}$ and $m_{\mathcal{H}_2}$ are approximately equal. Such is the case,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

Tevatron Constraints : I Squark & Gluino Search

- This is the first SUSY analysis to include these constraints

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

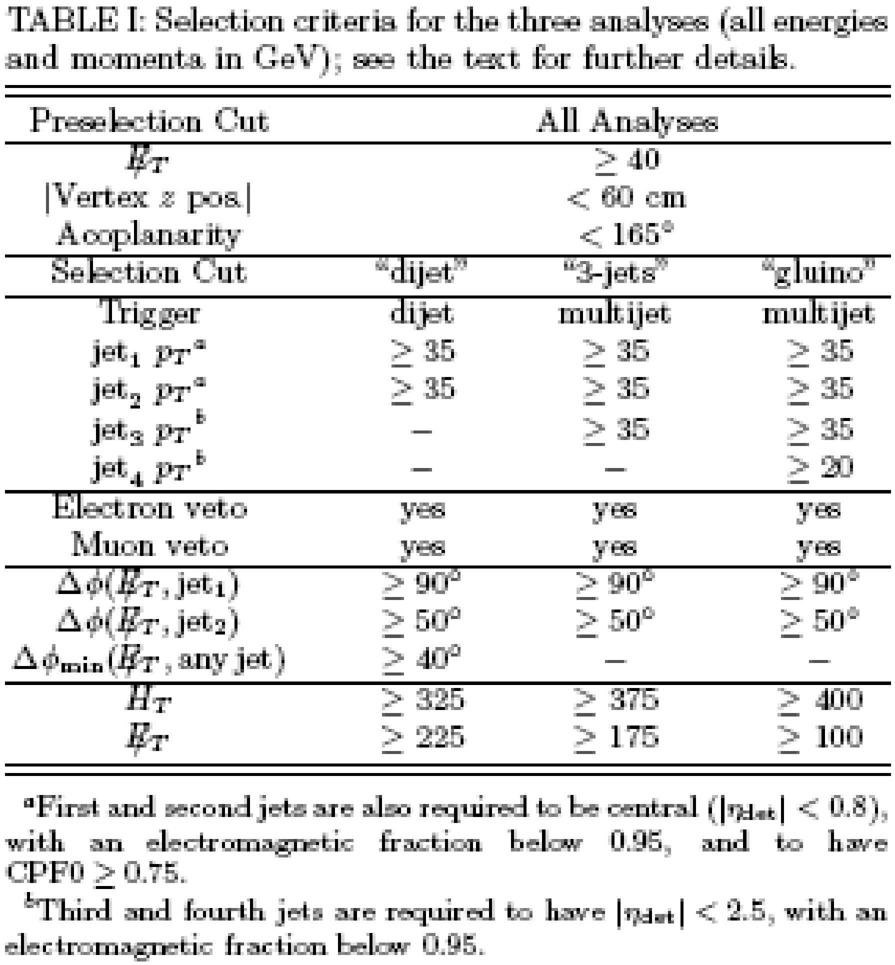


TABLE I: Selection criteria for the three analyses (all energies and momenta in GeV); see the text for further details.

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

[a] First and second jets are also required to be central ($|\eta_{\rm det}| < 0.8$), 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.

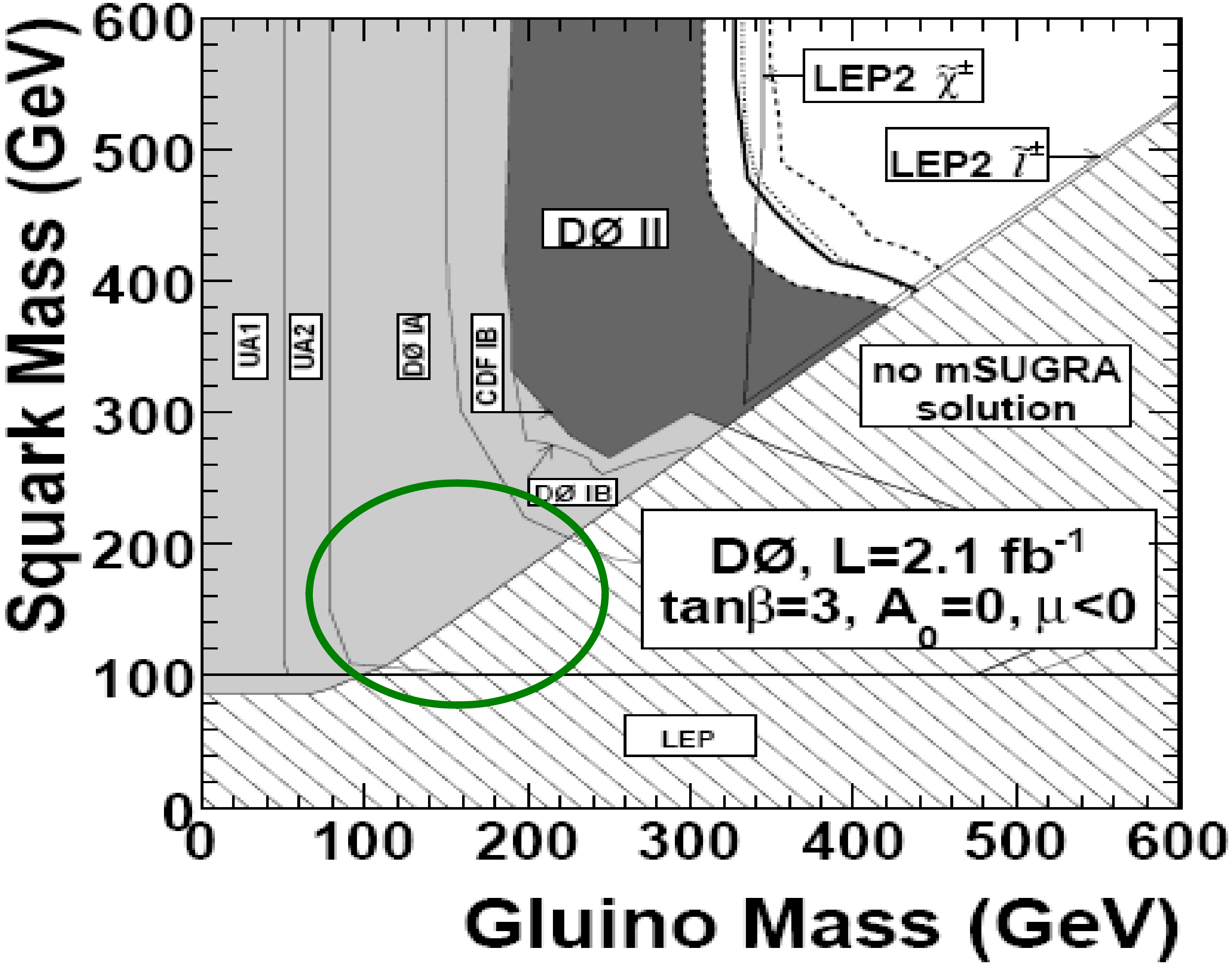
Multiple analyses keyed to look for:

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 !!



D0 benchmarks

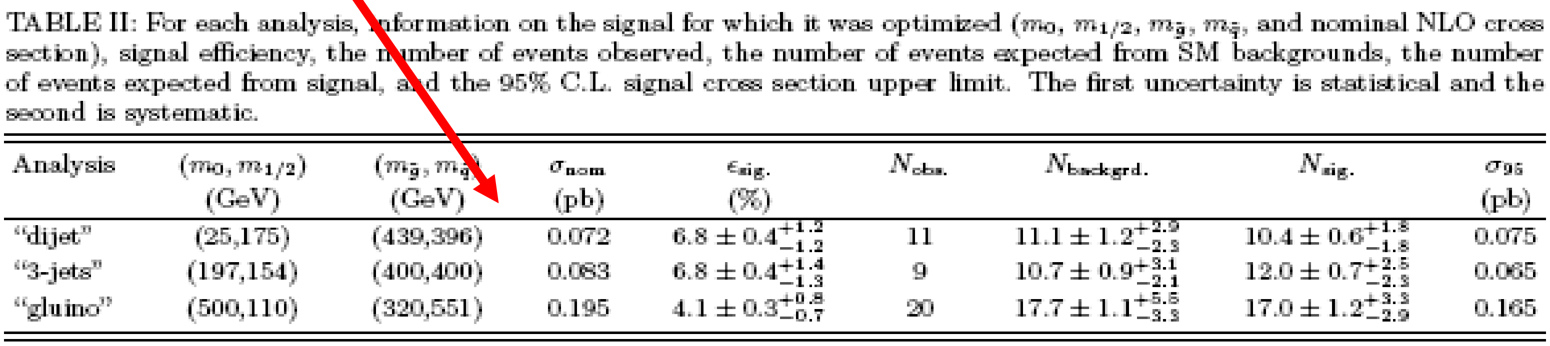


TABLE II: For each analysis, information on the signal for which it was optimized (m_0, $m_{1/2}$, $m_{\tilde g}$, $m_{\tilde q}$, and nominal NLO cross section), signal efficiency, the number of events observed, the number of events expected from SM backgrounds, the number of events expected from signal, 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

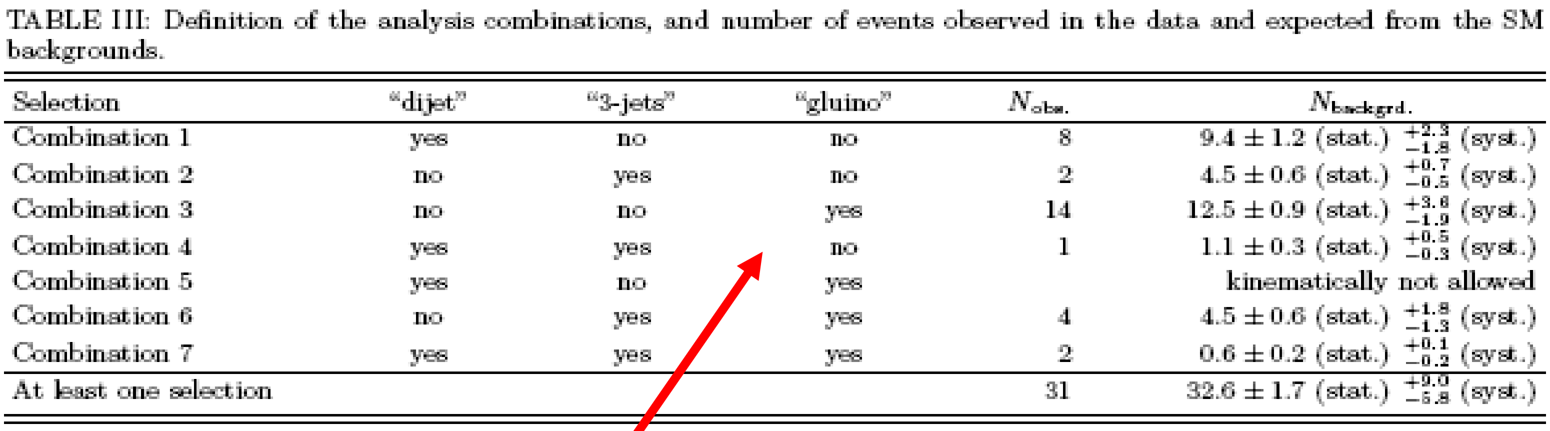


TABLE III: Definition of the analysis combinations, and number of events observed in the data and expected from the SM backgrounds.

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.)

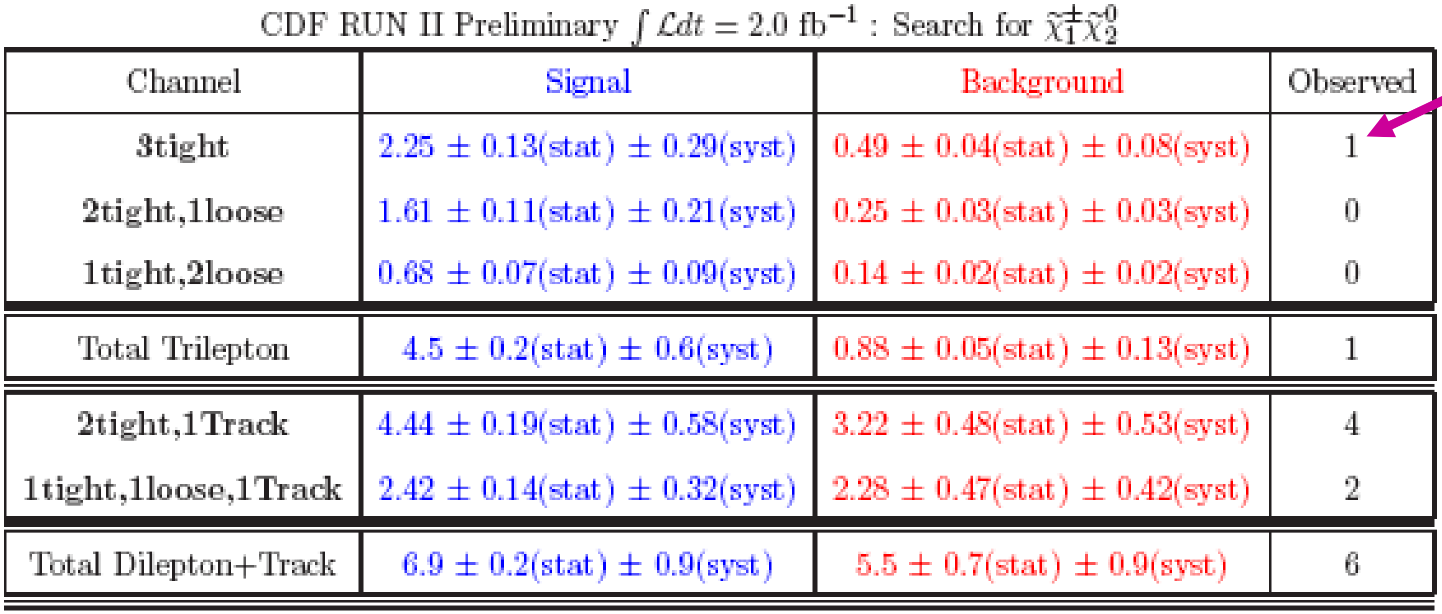
Combos of the 3 analyses

→ 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 $\int \mathcal{L}dt = 2.0\ \mathrm{fb}^{-1}$: 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

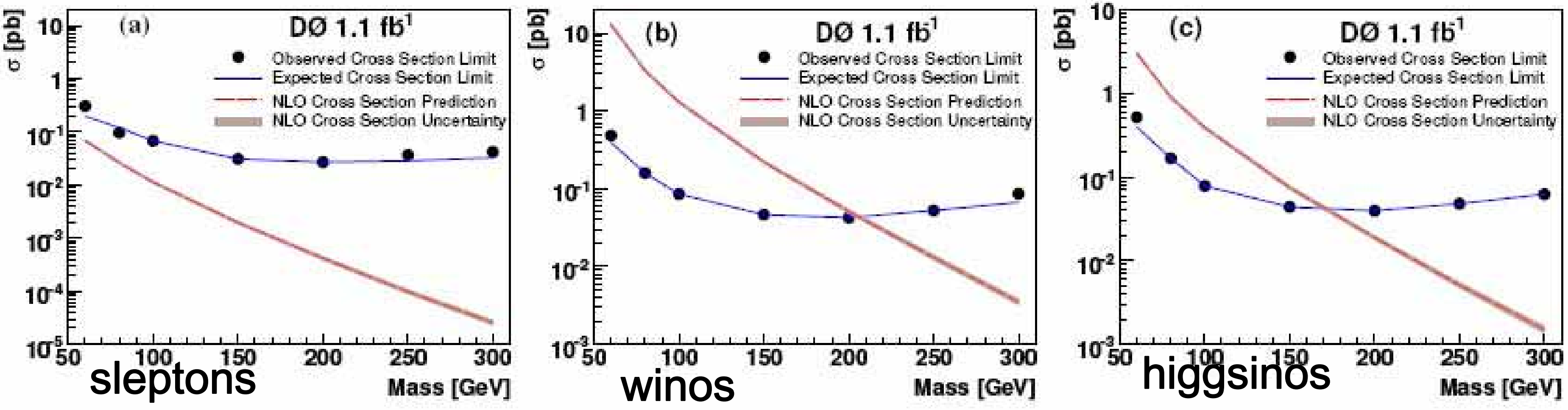


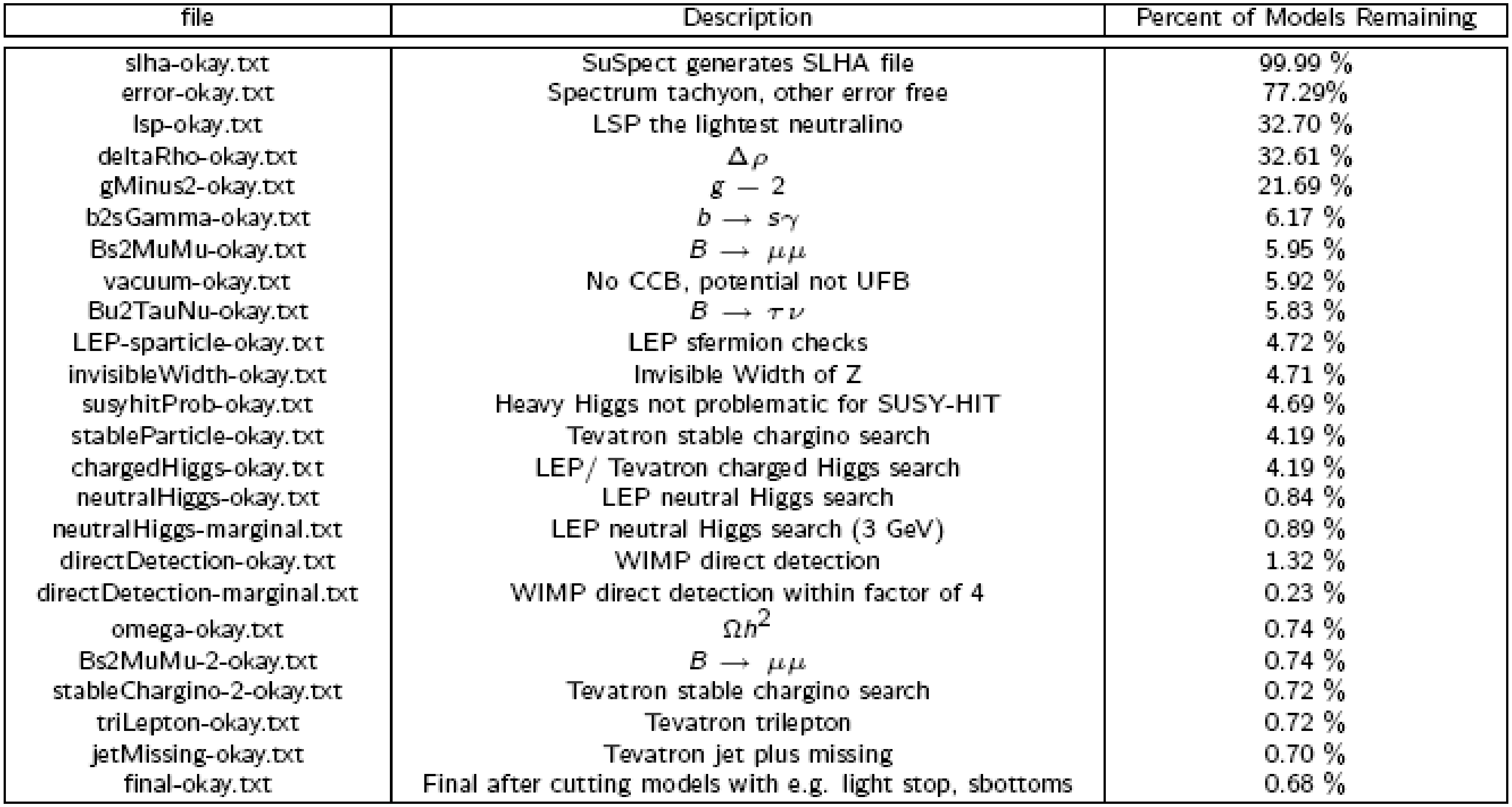
FIG. 2: The observed (dots) and expected (solid line) 95% cross section limits, the NLO production cross section (dashed line), and NLO cross section uncertainty (barely visible shaded band) as a function of (a) stau mass for stau pair production, (b) chargino mass for pair produced gaugino-like charginos,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

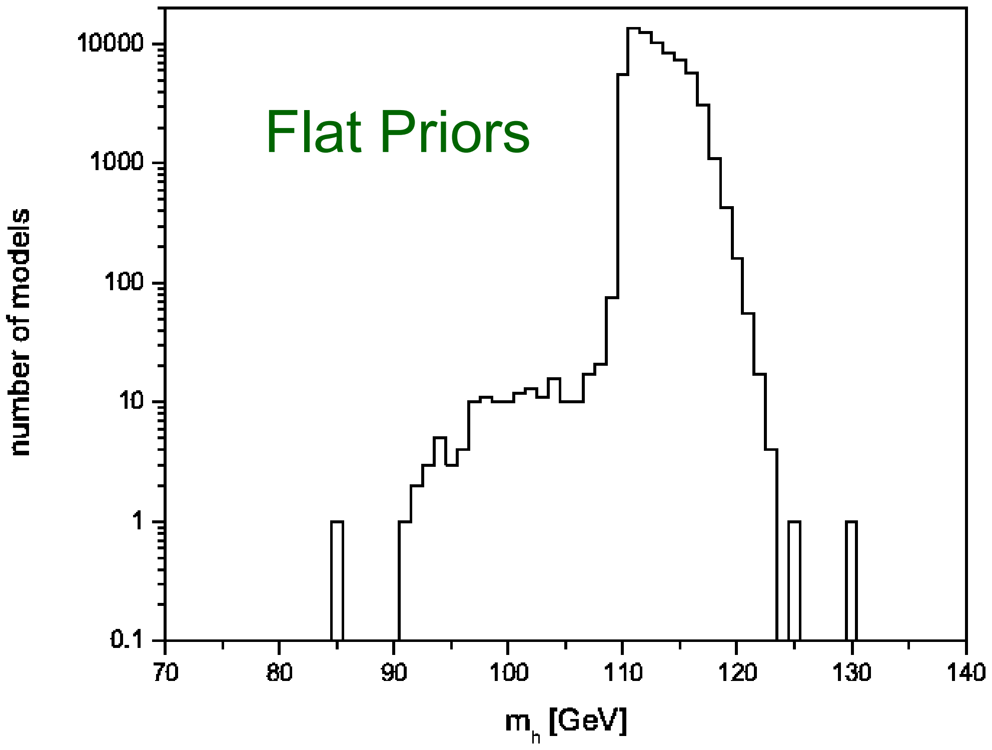
Survival Rates

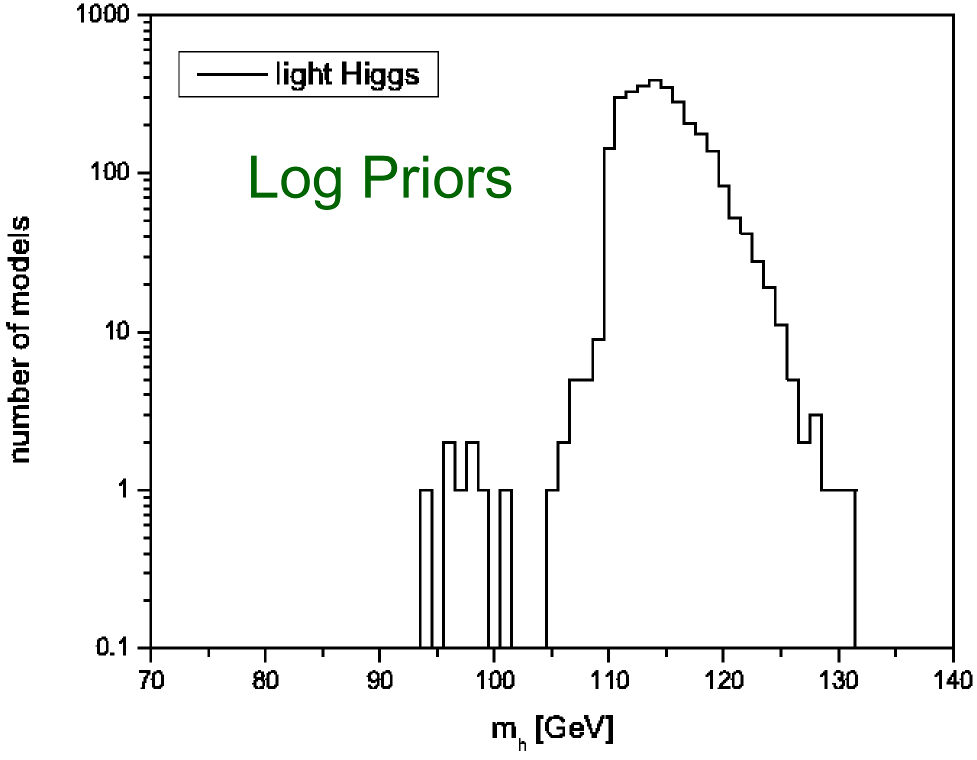


file	Description	Percent of Models Remaining
slha-okay.txt	SuSpect generates SLHA file	99.99 %
error-okay.txt	Spectrum tachyon, other error free	77.29%
lsp-okay.txt	LSP the lightest neutralino	32.70 %
deltaRho-okay.txt	$\Delta\rho$	32.61 %
gMinus2-okay.txt	$g-2$	21.69 %
b2sGamma-okay.txt	$b \longrightarrow s\gamma$	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	0.84 %
neutralHiggs-marginal.txt	LEP neutral Higgs search (3 GeV)	0.89 %
directDetection-okay.txt	WIMP direct detection	1.32 %
directDetection-marginal.txt	WIMP direct detection within factor of 4	0.23 %
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 , ~ 68.5 k (0.68%) survive
- Log Priors : $2\mathrm{x}10^6$ models scanned , ~ 2.8 k (0.14%) survive

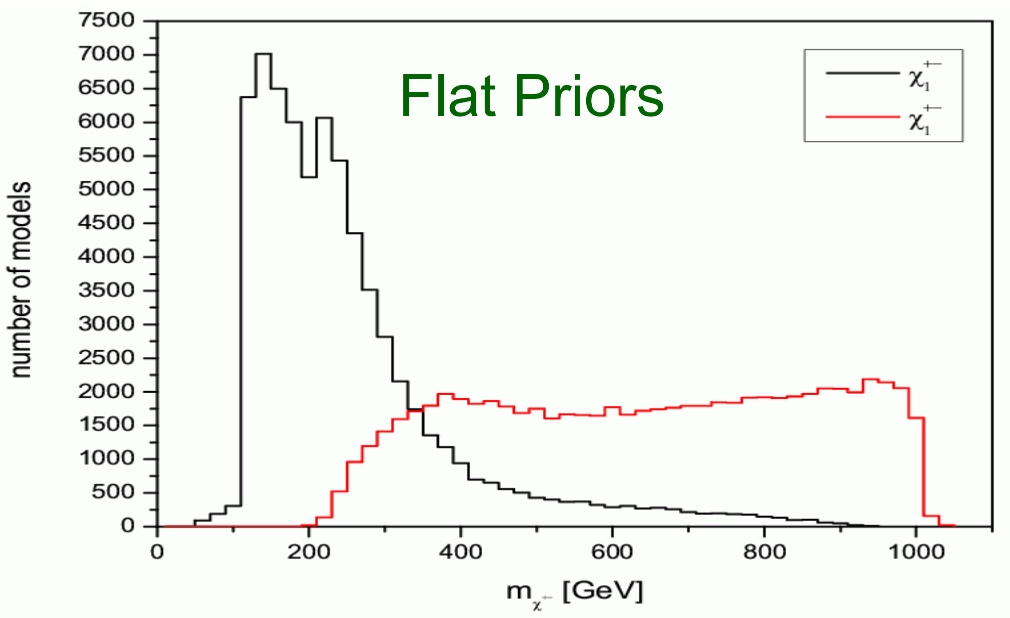
Light Higgs Mass Predictions

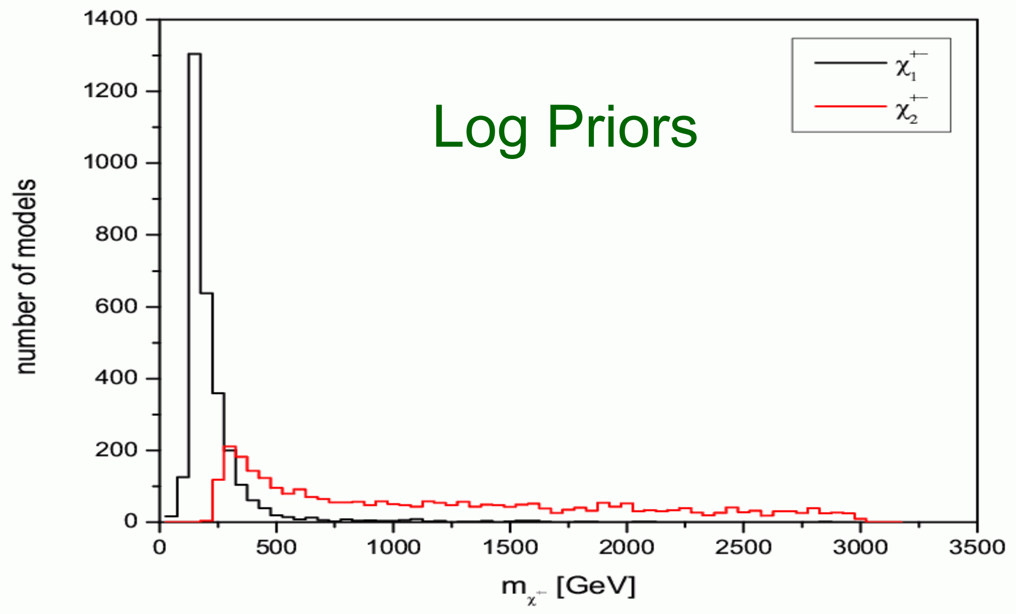


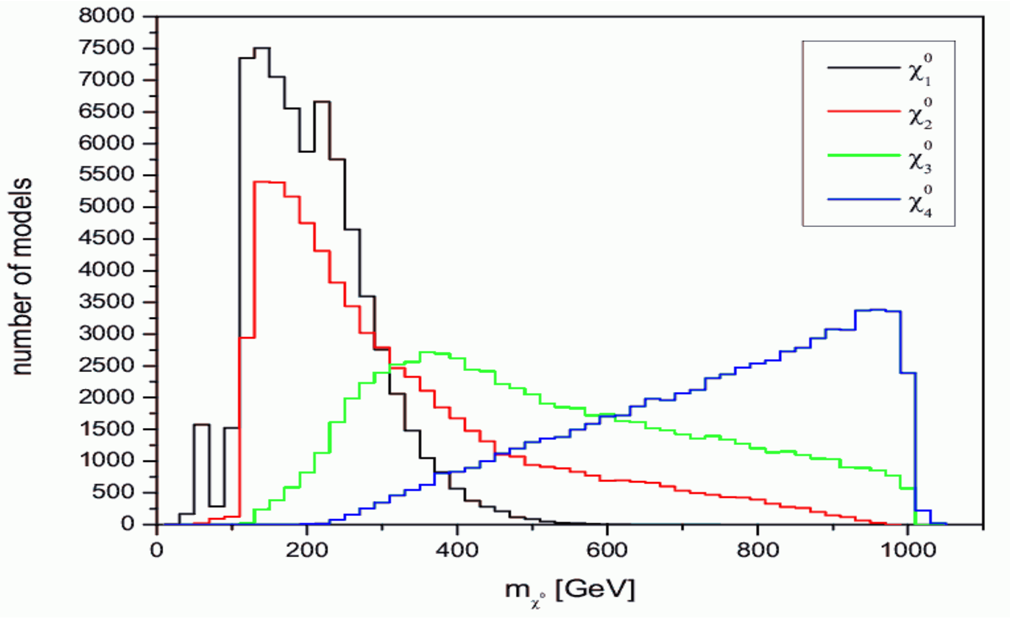


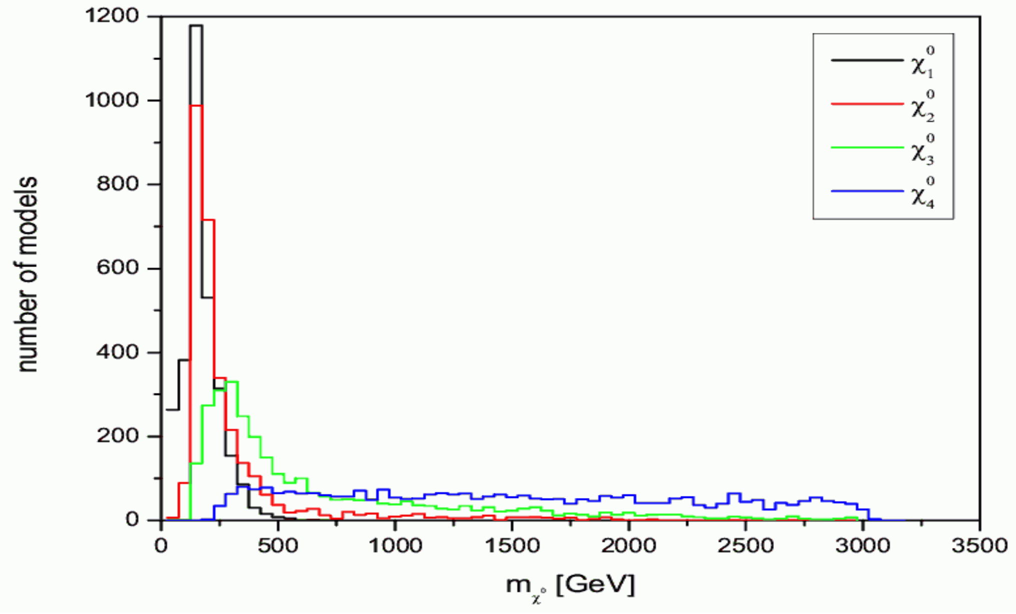
LEP Higgs mass constraints avoided by either reducing the ZZh coupling and/or reducing the, e.g., h →$\bar{b}b$ branching fraction by decays to LSP pairs. We have both of these cases in our final model sets.

Distribution of Sparticle Masses By Species



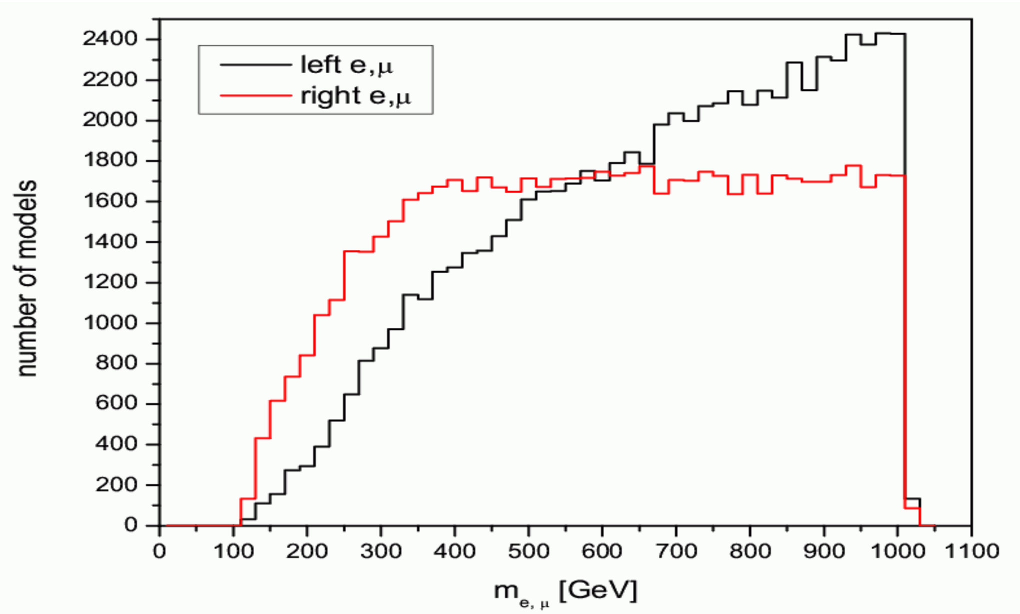


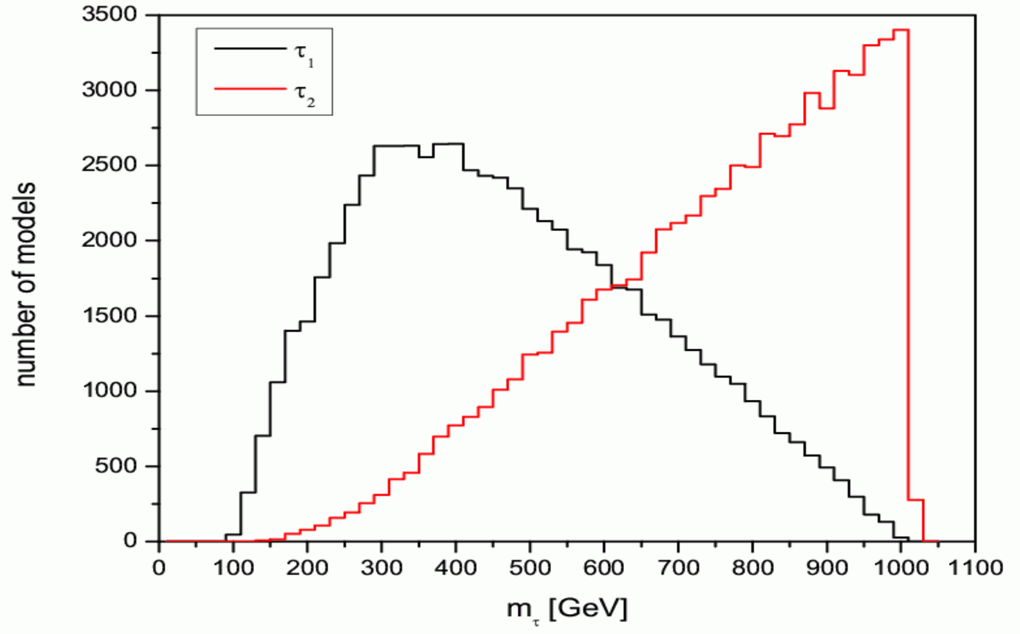




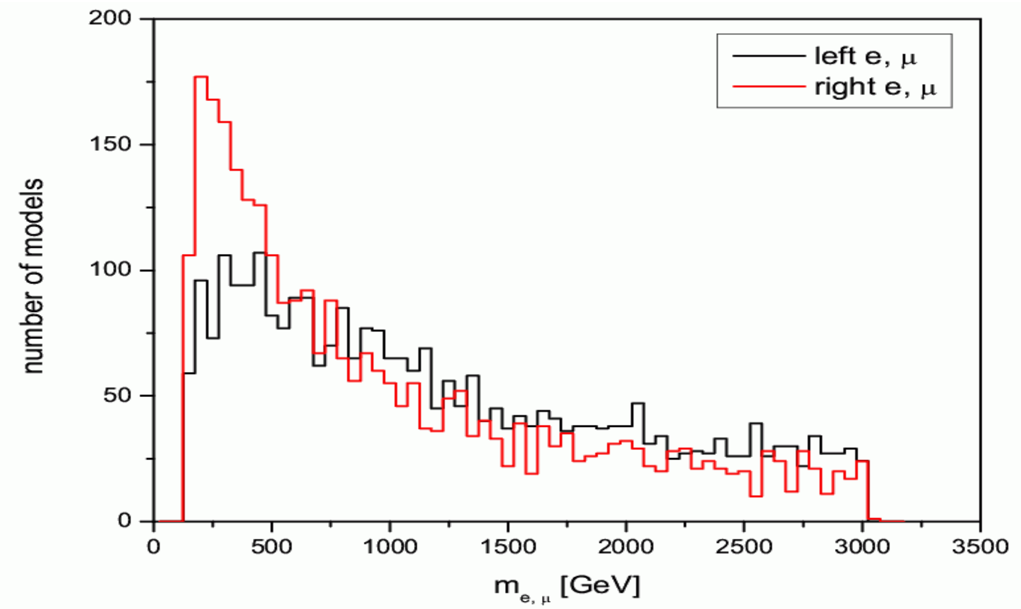
Distribution of Sparticle Masses By Species

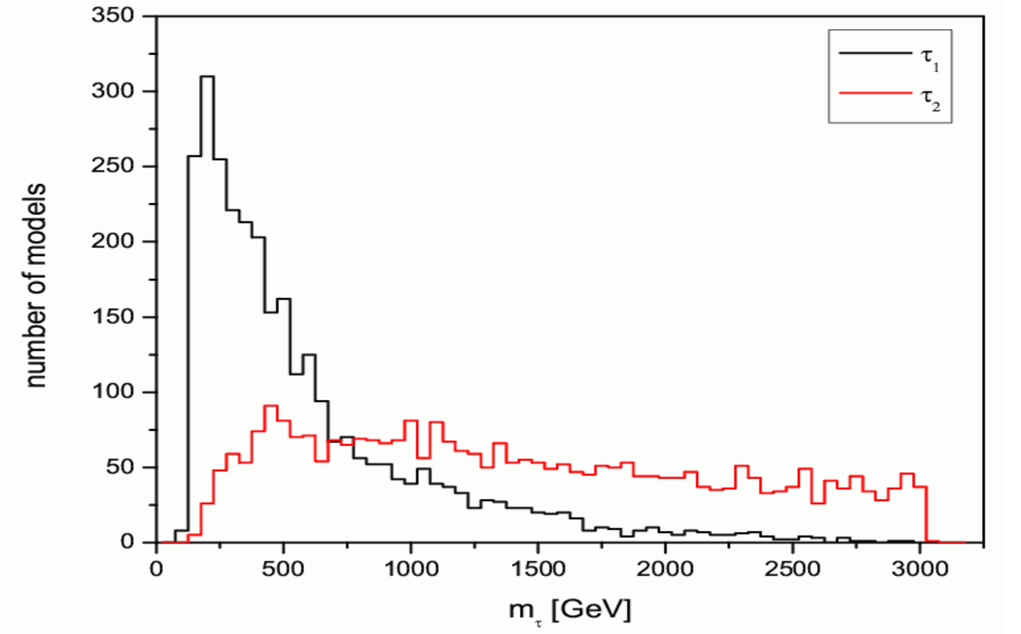
Flat Priors



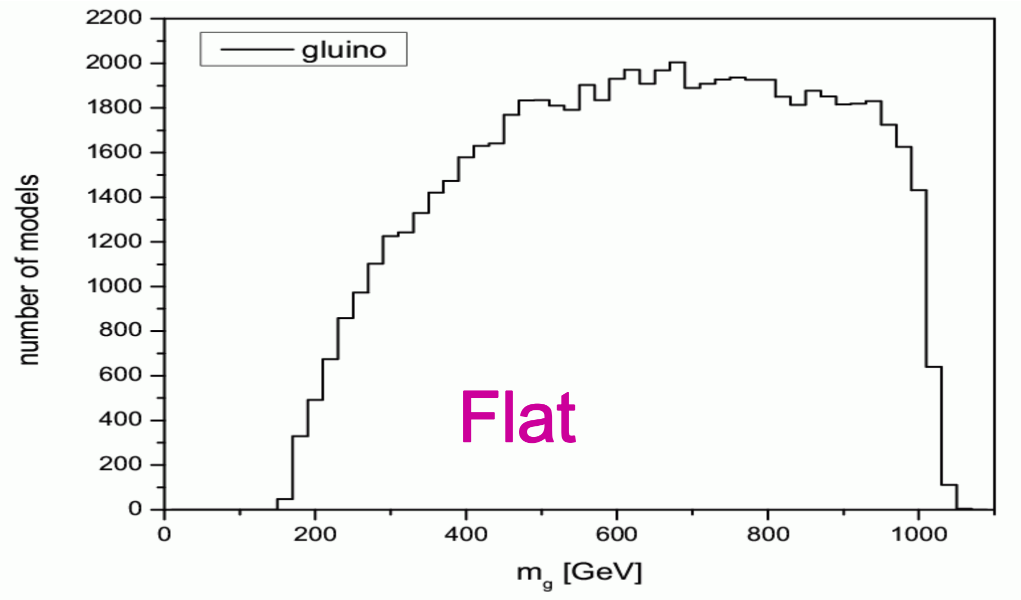


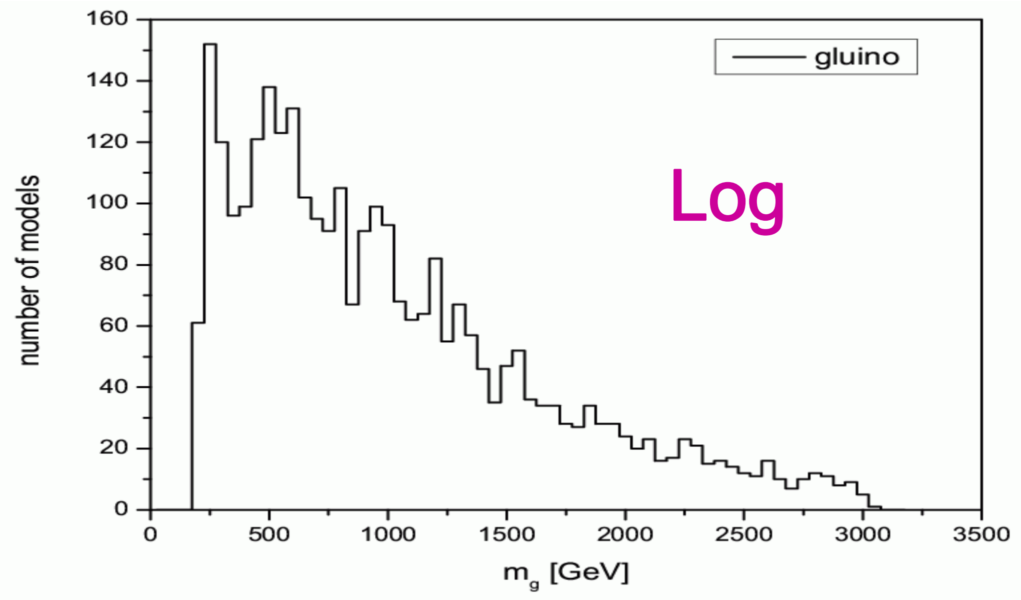
Log Priors

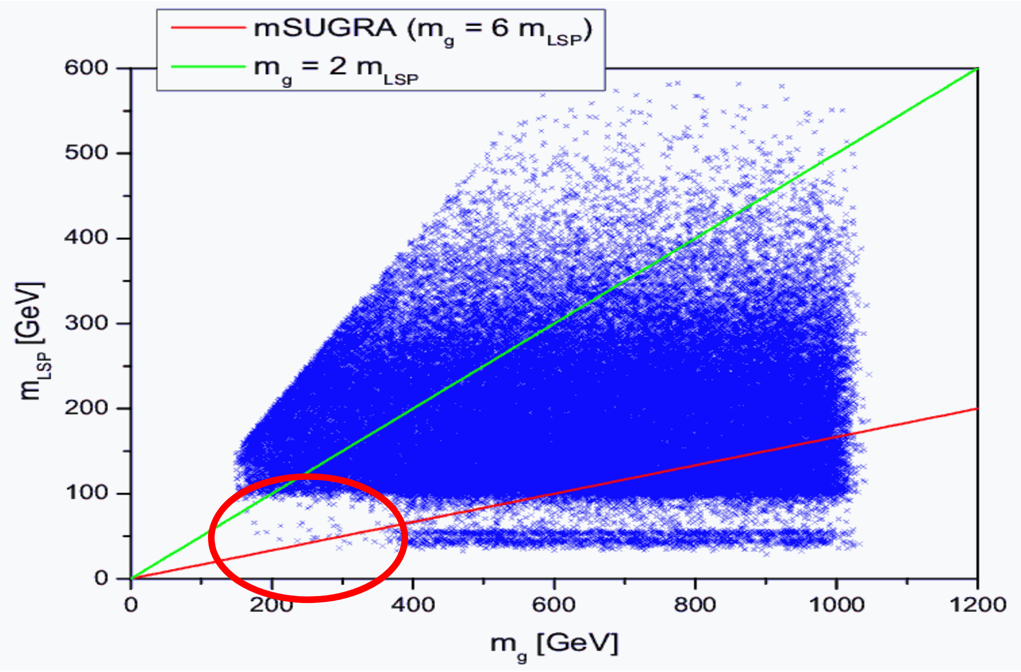


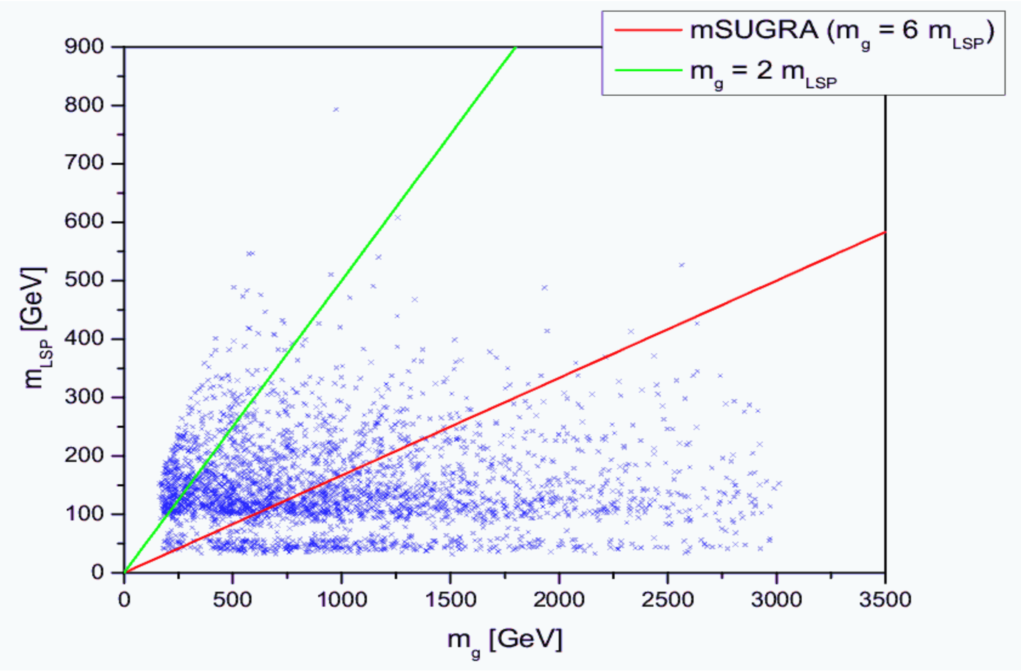


Gluino Can Be Light !!

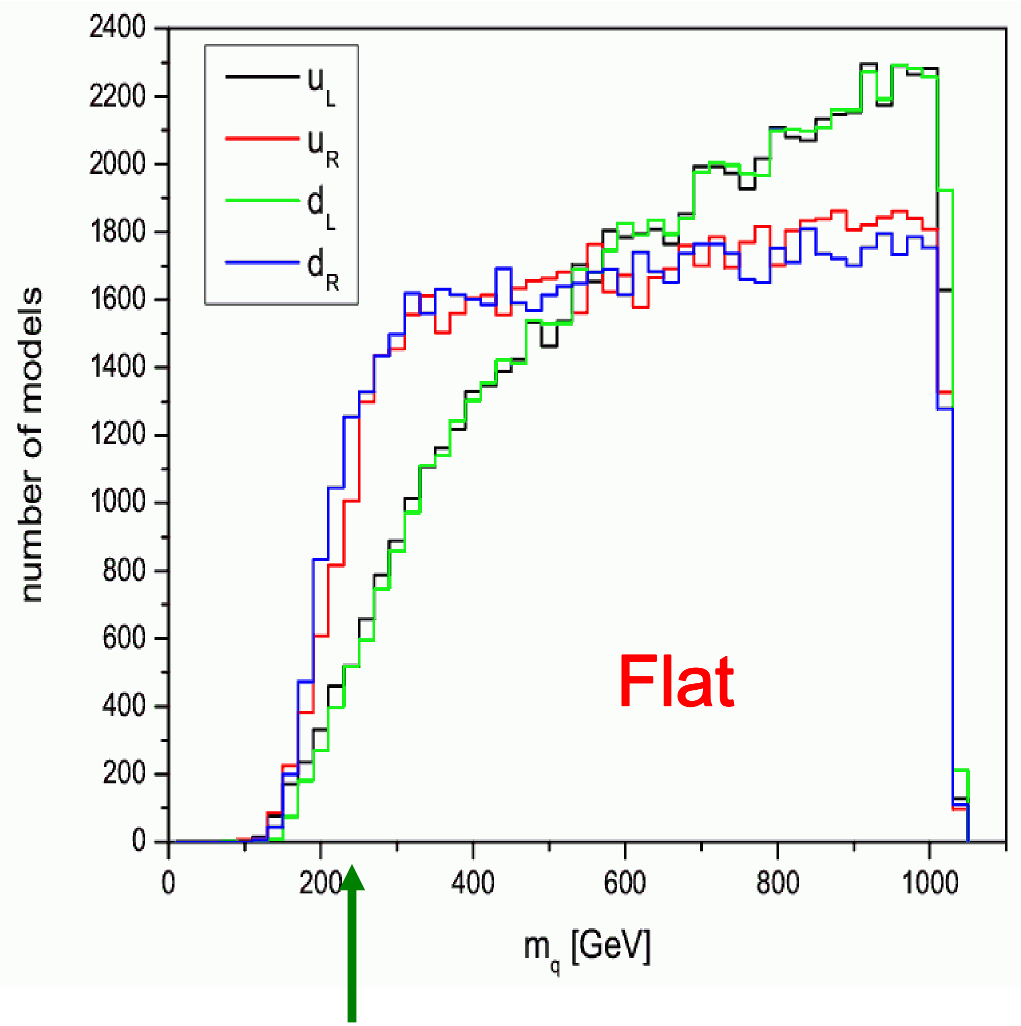


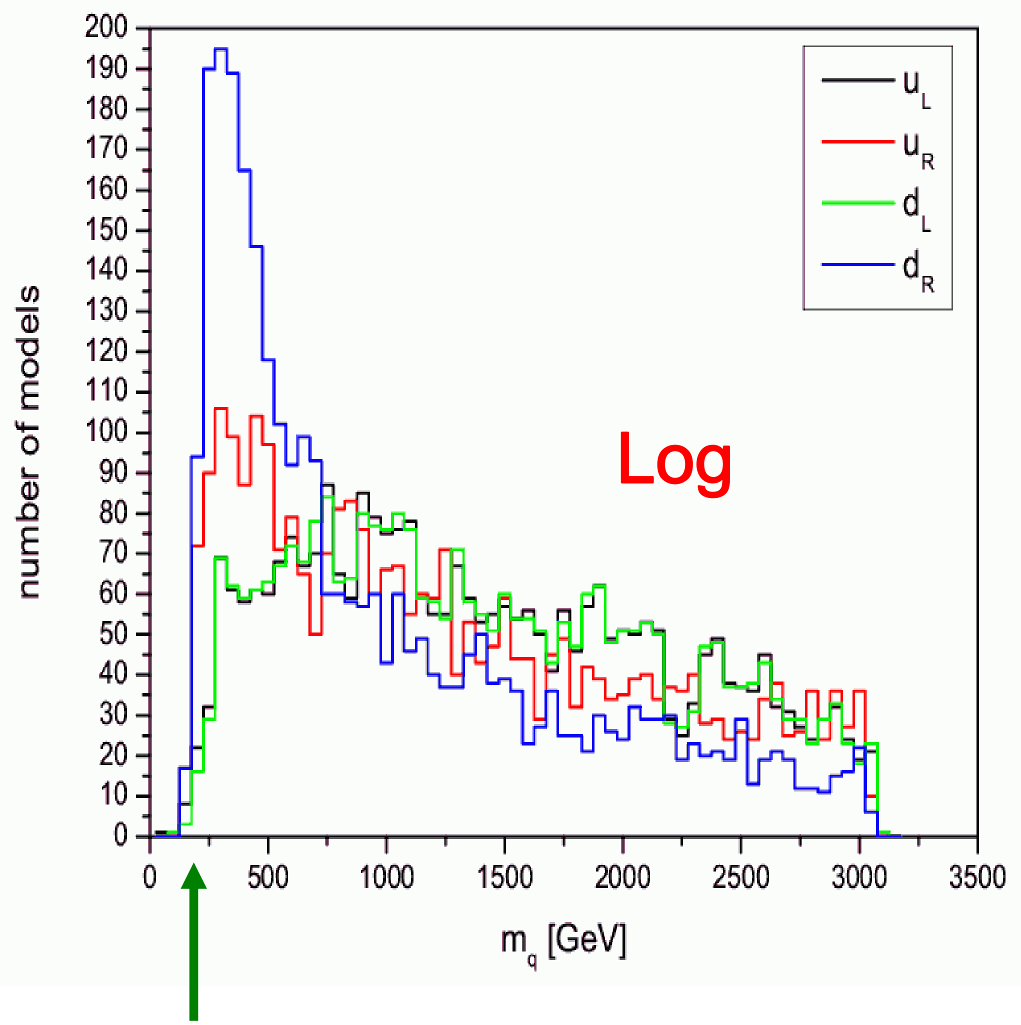






Squarks CAN Be Light !!!

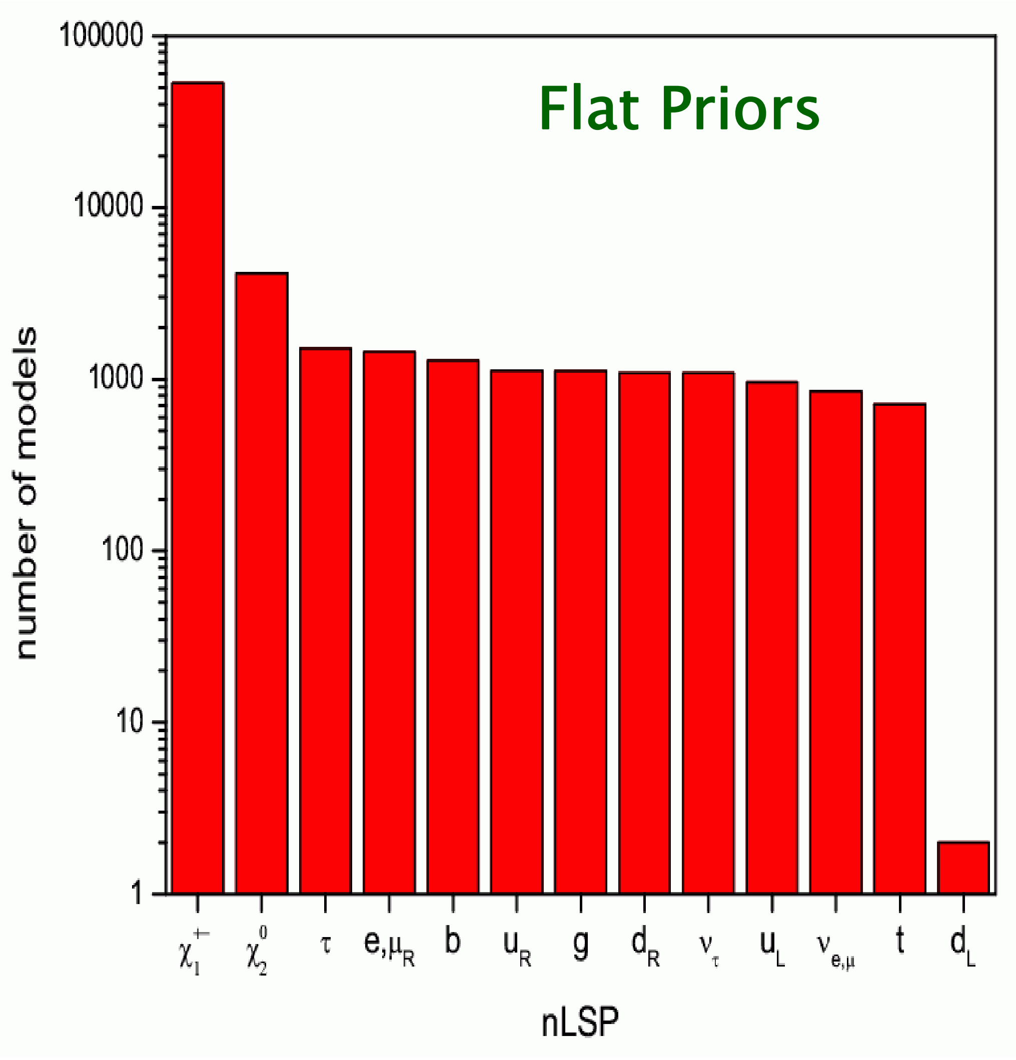


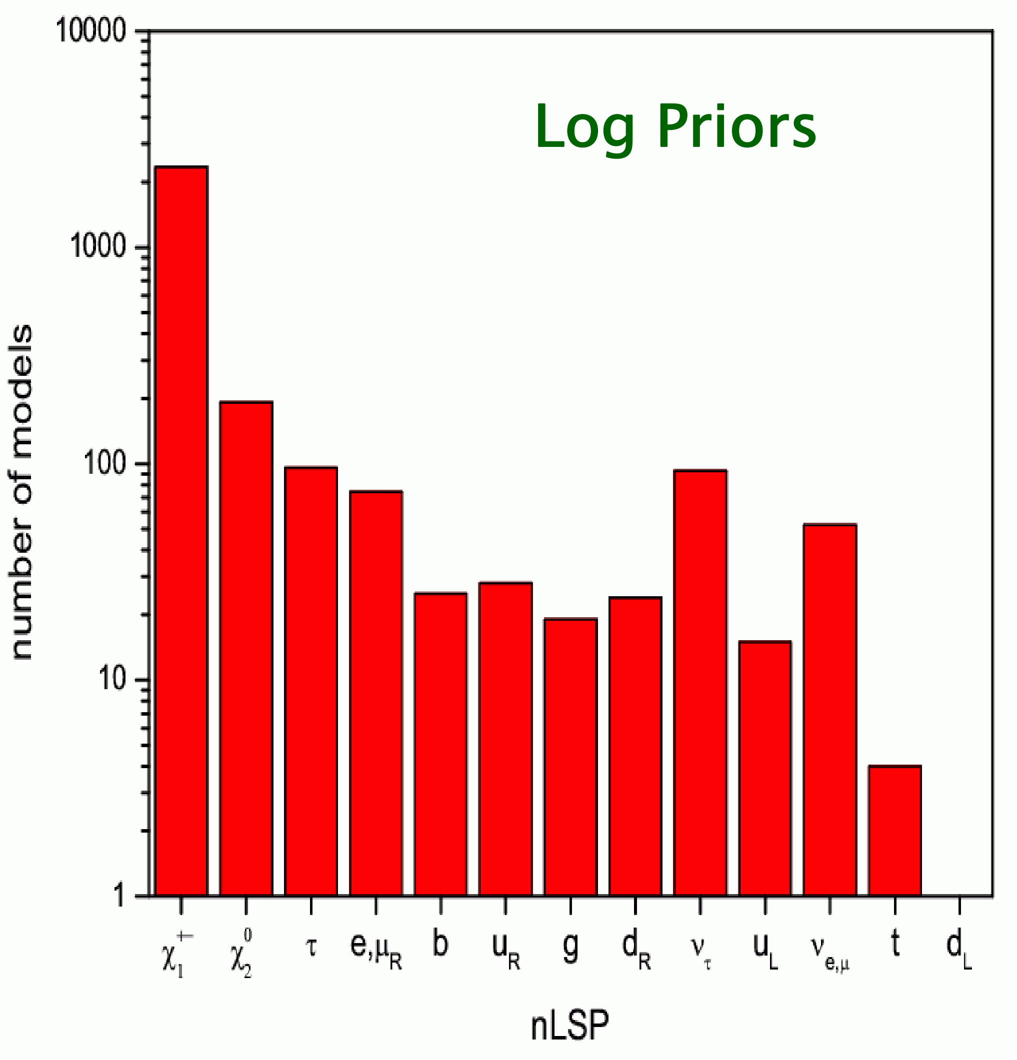


Light squarks can be missed by Tevatron searches for numerous reasons..

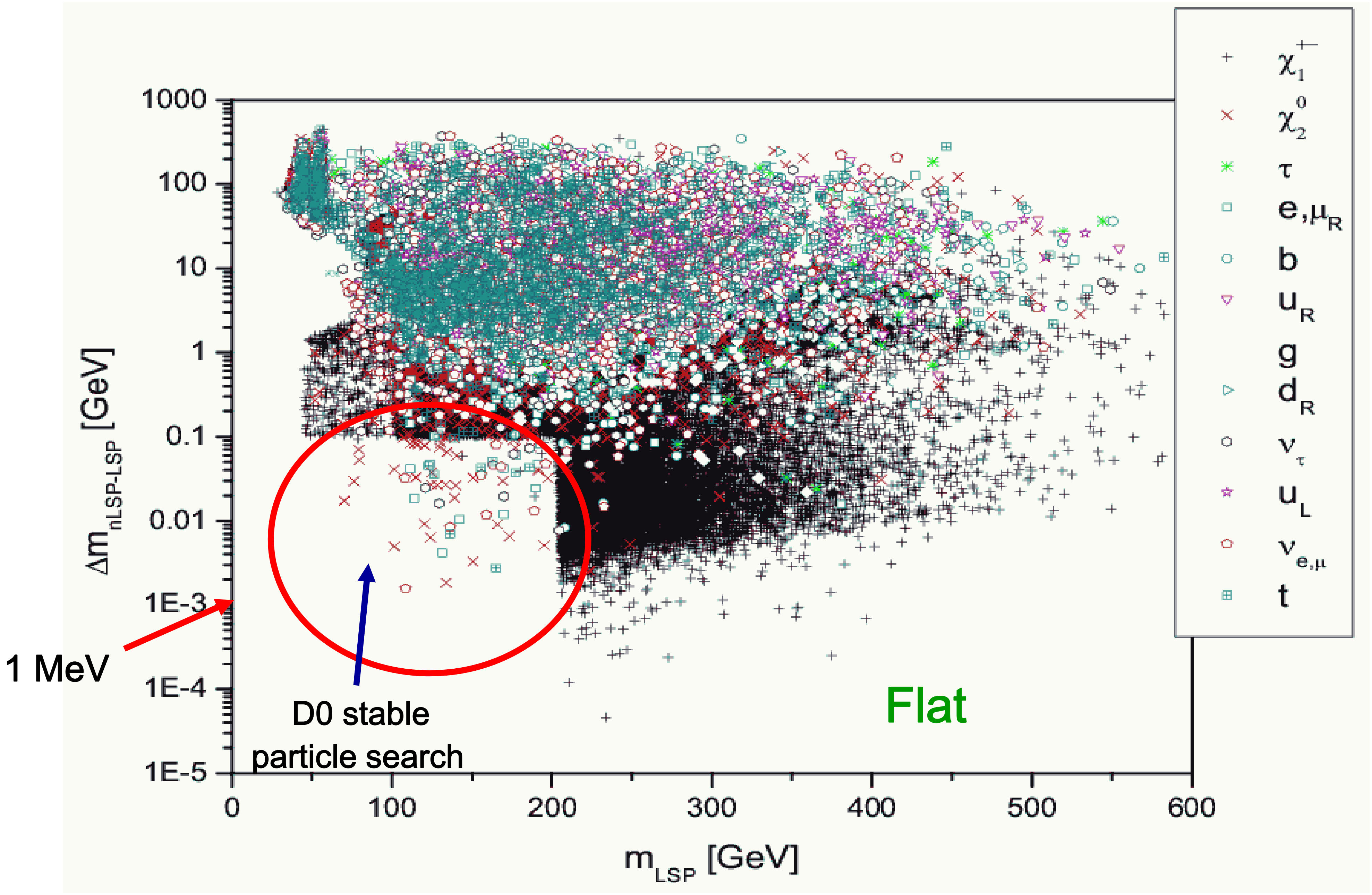
The identity of the nLSP is a critical factor in looking for SUSY signatures..who can play that role here????? Just about

ANY of the 13 possibilities !





nLSP-LSP Mass Difference

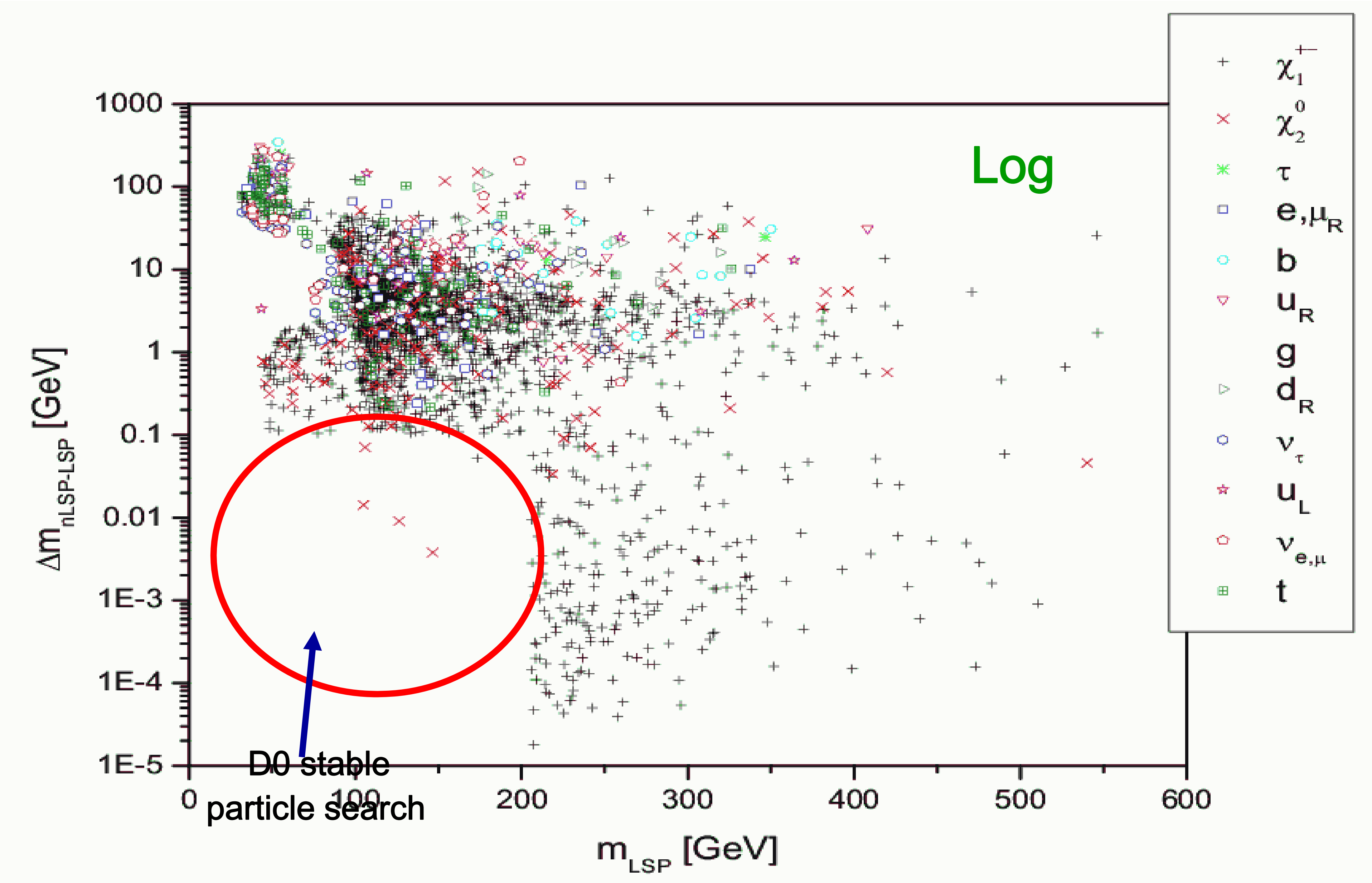


1 MeV

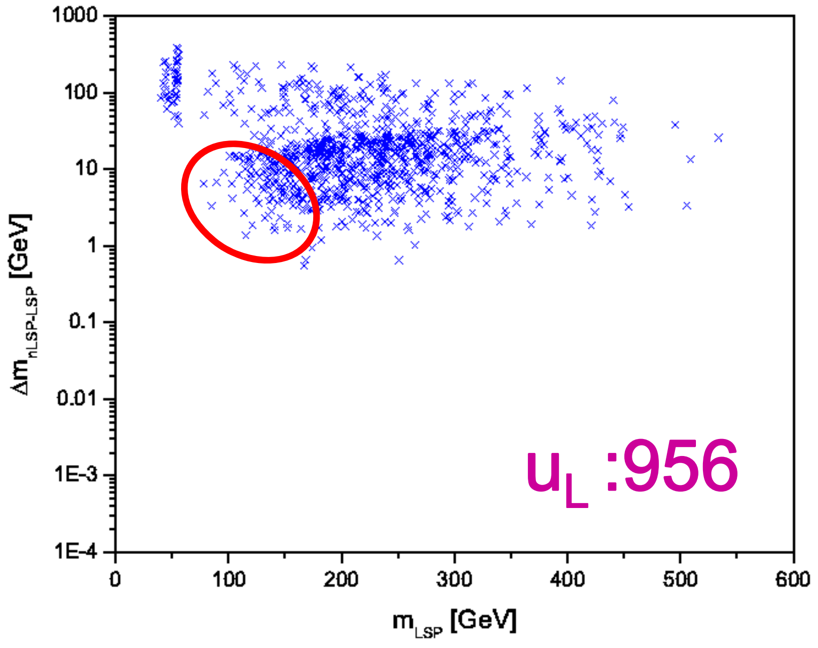
D0 stable particle search

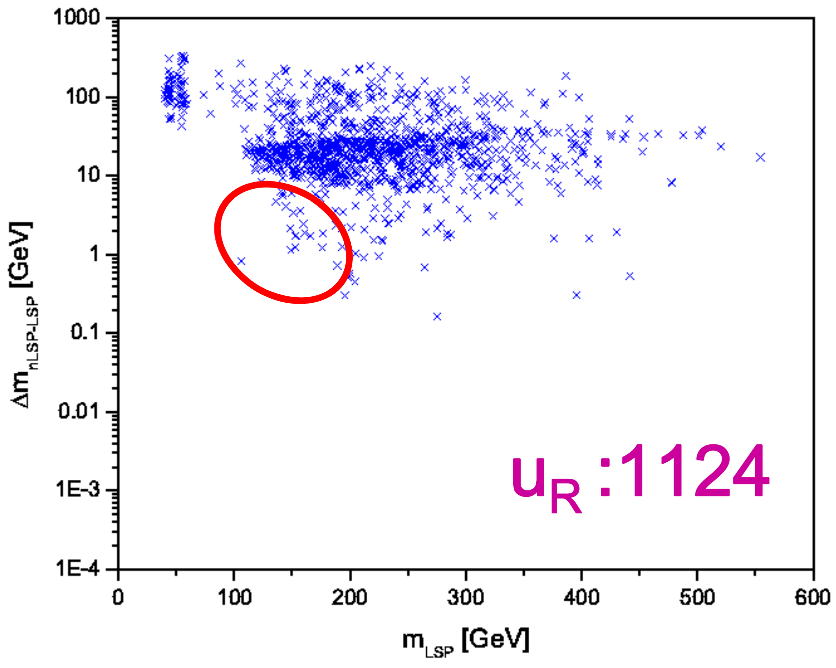
Flat

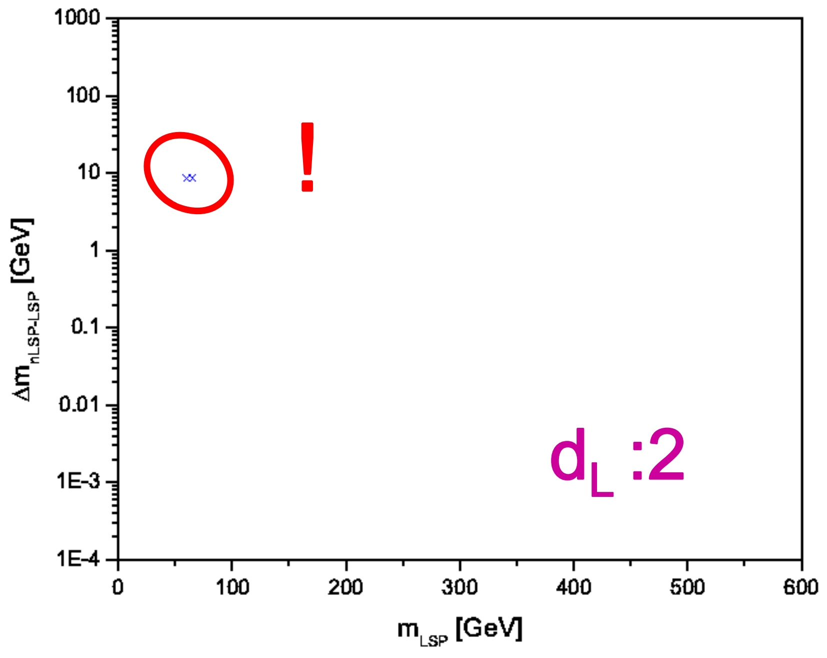
nLSP-LSP Mass Difference

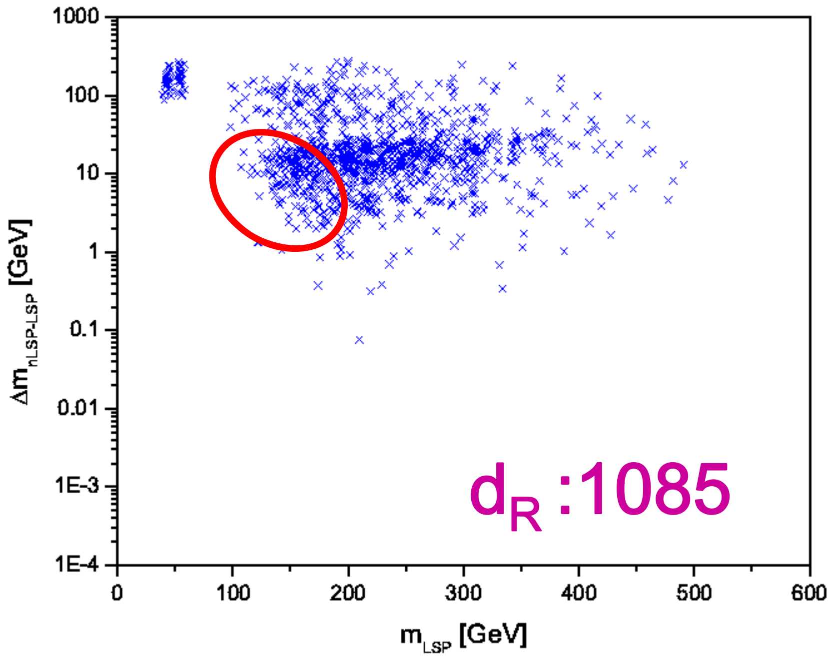


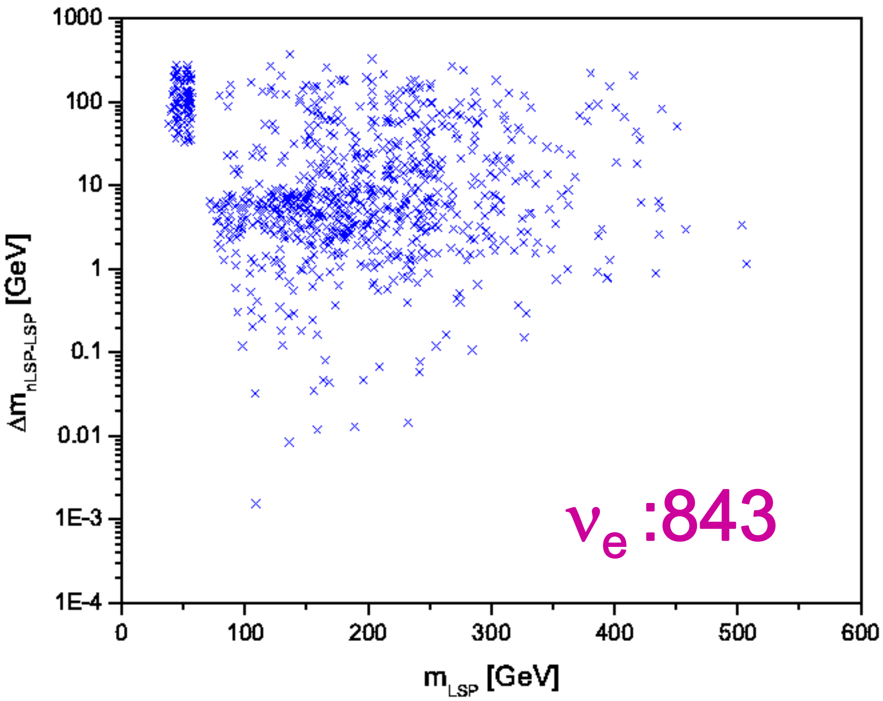
D0 stable particle search

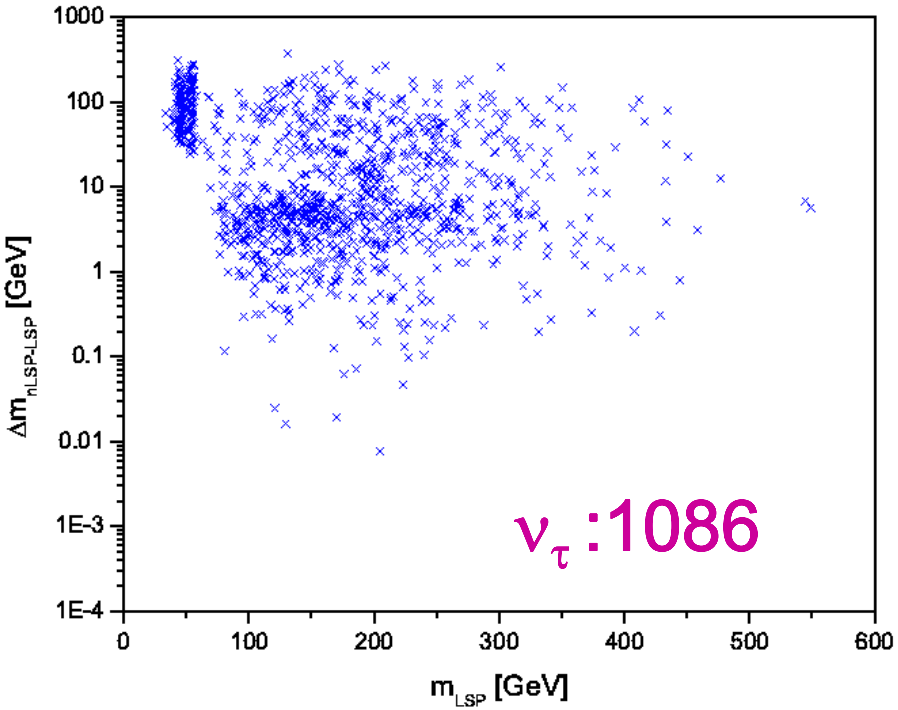

1000
100
10
1
0.1
0.01
1E-3
1E-4
0
100
200
300
400
500
600
Δm_nLSP-LSP [GeV]
m_LSP [GeV]
u_L :956

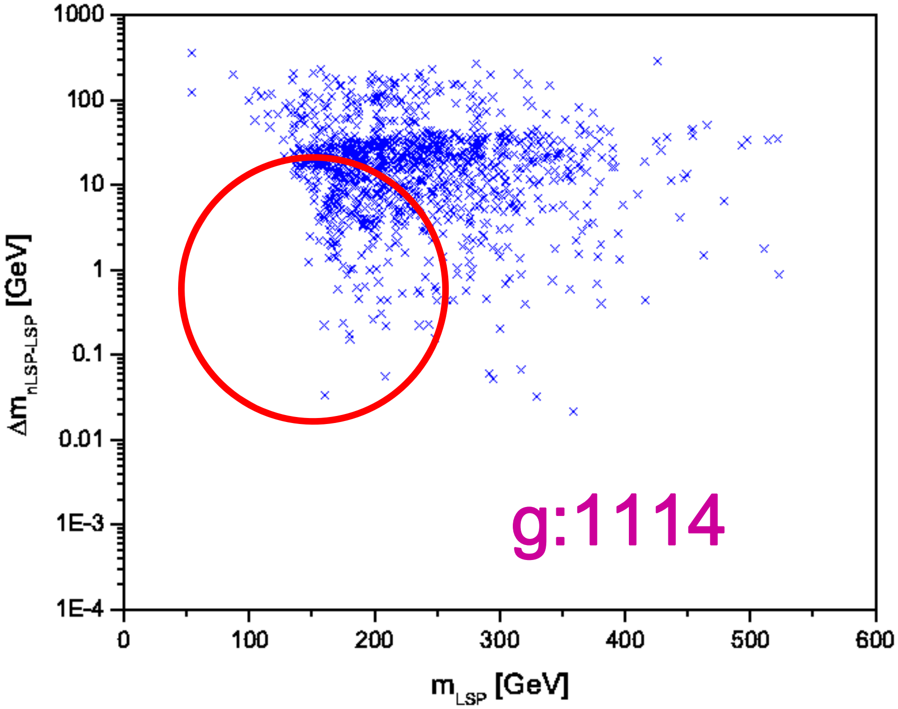

1000
100
10
1
0.1
0.01
1E-3
1E-4
0
100
200
300
400
500
600
Δm_nLSP-LSP [GeV]
m_LSP [GeV]
u_R :1124


1000
100
10
1
0.1
0.01
1E-3
1E-4
0
100
200
300
400
500
600
Δm_nLSP-LSP [GeV]
m_LSP [GeV]
!
d_L :2

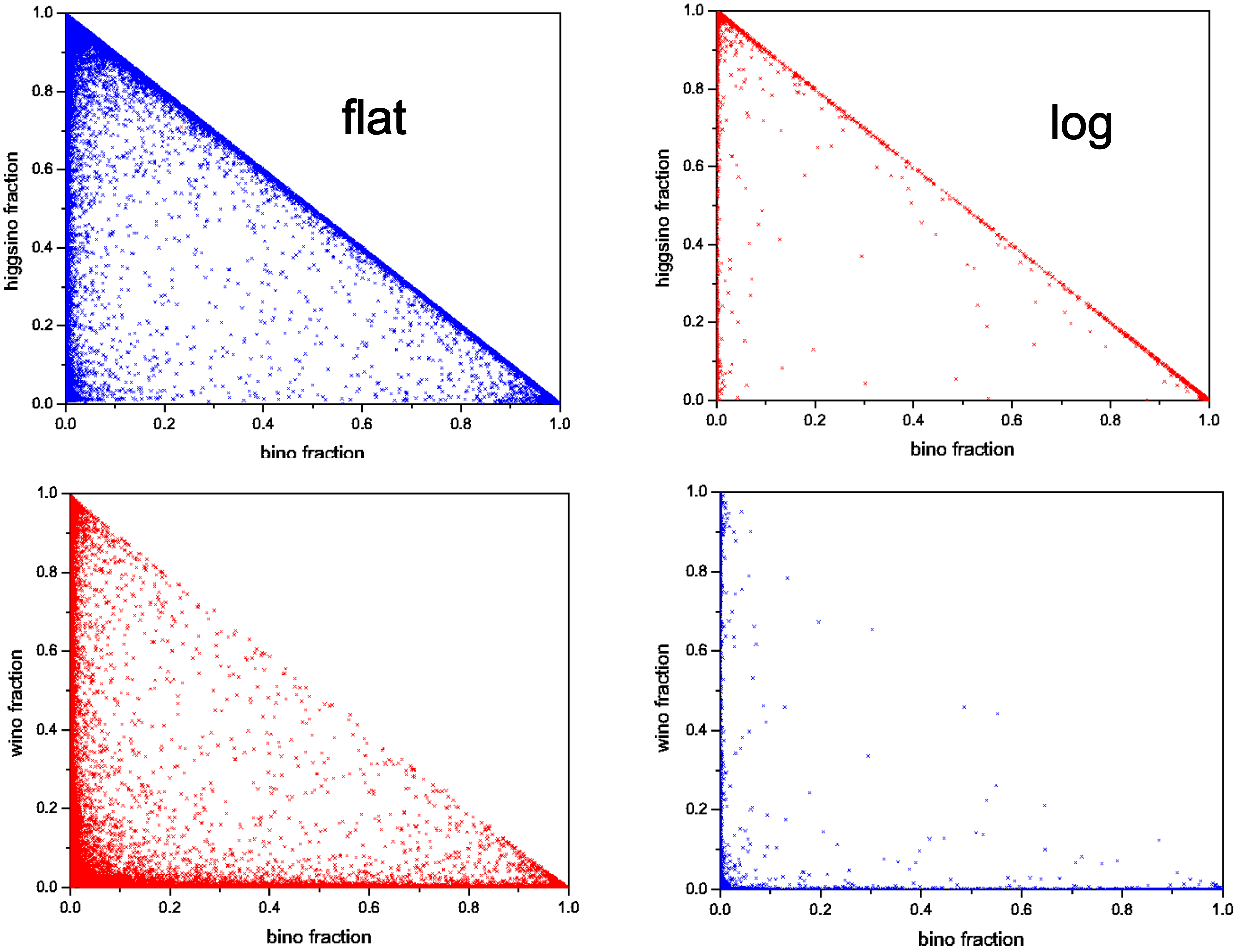

1000
100
10
1
0.1
0.01
1E-3
1E-4
0
100
200
300
400
500
600
Δm_nLSP-LSP [GeV]
m_LSP [GeV]
d_R :1085


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]
ν_e :843


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]
ν_τ :1086


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]
g:1114

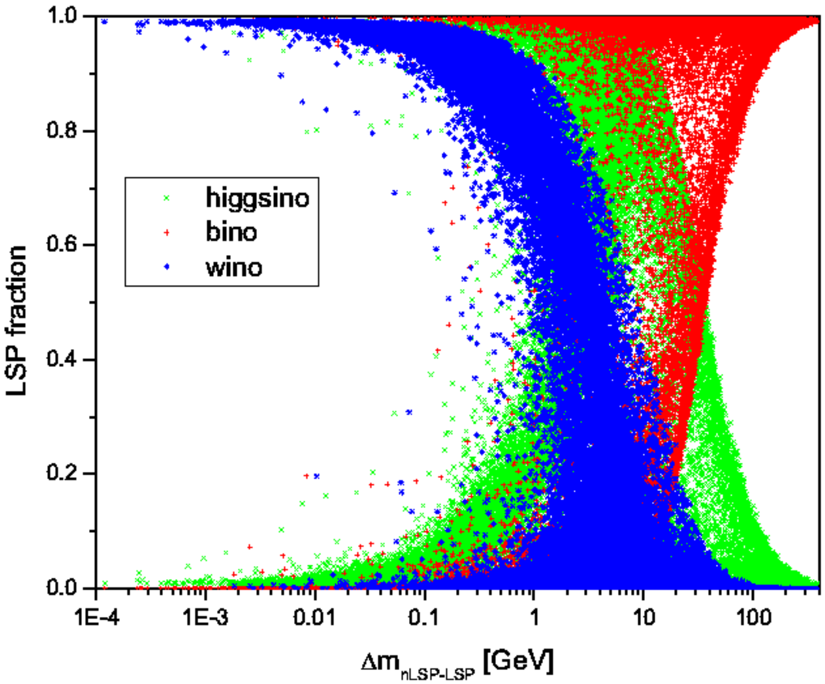
LSP Composition



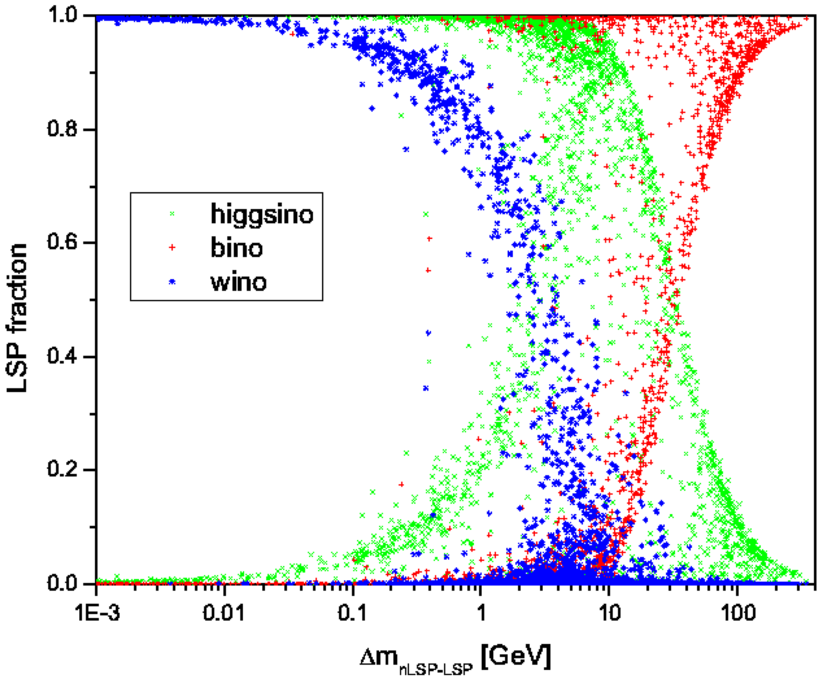
LSP Composition

The LSP composition is found to be both mass dependent as well as (no surprise) sensitive to the nLSP-LSP mass splitting…models with 'large' mass splittings have LSPs which are bino-like but VERY small mass splittings produce wino-like LSPs. Higgsino-like LSPs have 'intermediate' splittings.

Flat

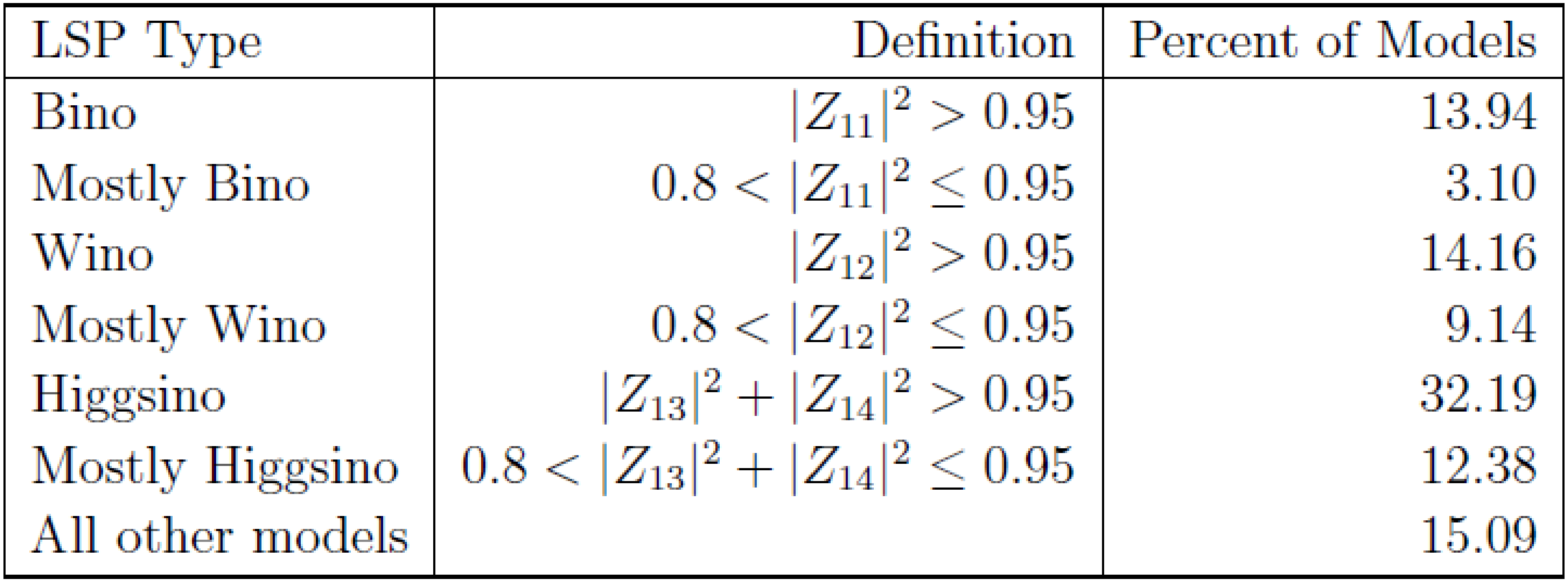


Log

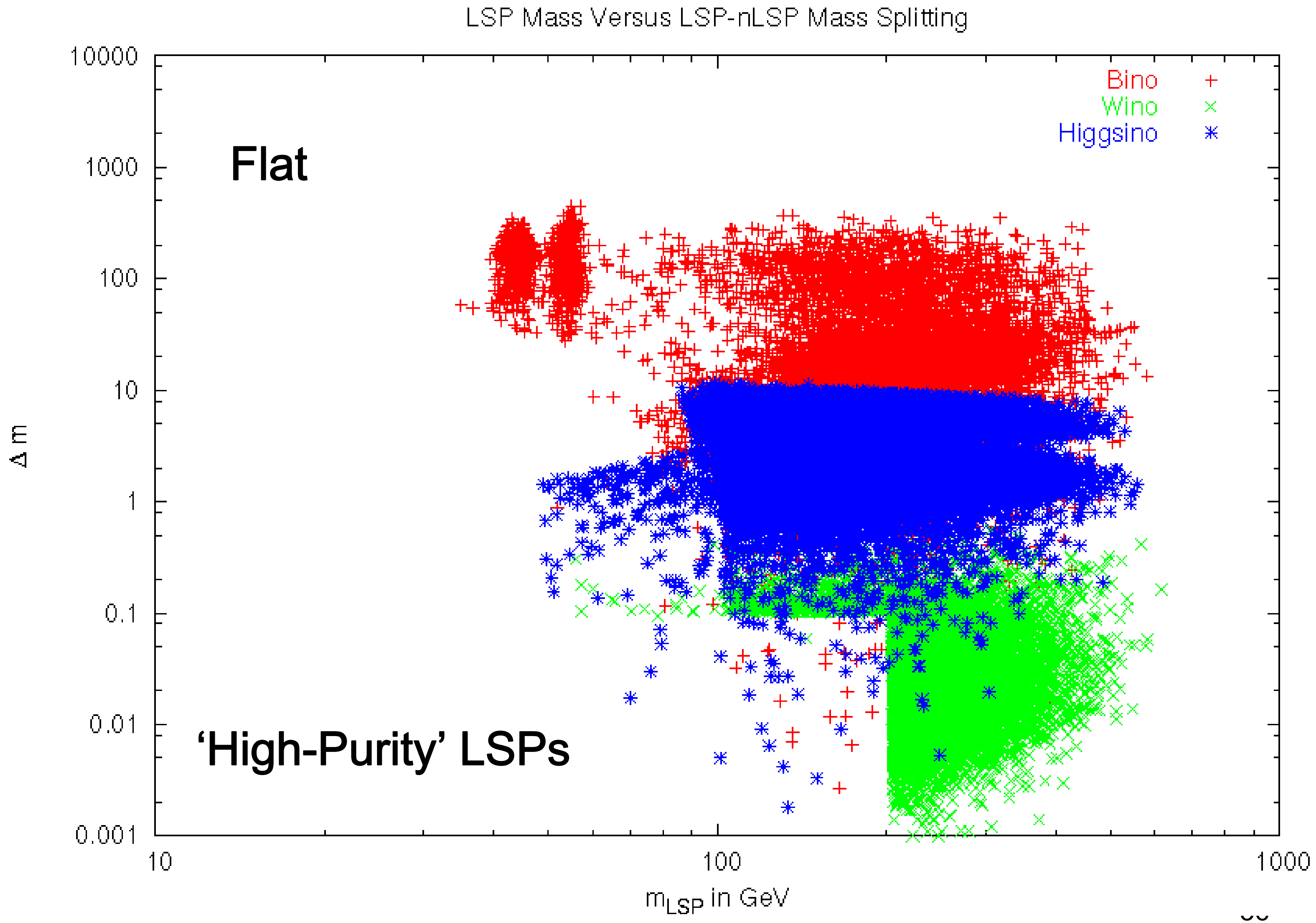


Another way to see this is to just count states with various constrained admixtures of the three weak eigenstates…

..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

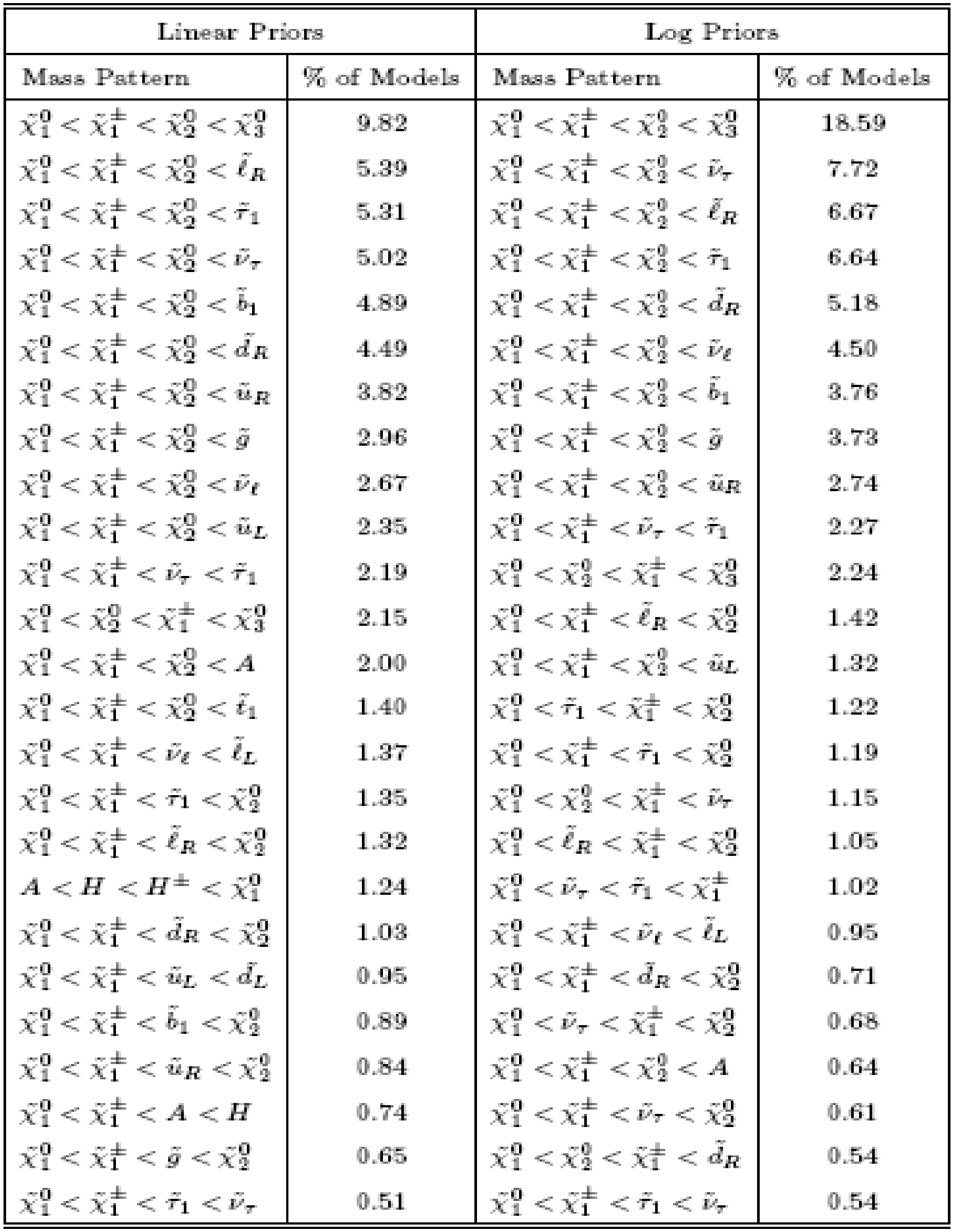


Flat

‘High-Purity’ LSPs

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!!

ATLAS SUSY Analyses w/ a Large Model Set

- We are running our ~71k MSSM models through the ATLAS SUSY (14 TeV) CSC analysis suite, essentially designed for mSUGRA , to explore its sensitivity to this far broader class of SUSY models employing the ATLAS background estimates

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

- We have begun our study with the multi-jet + MET analyses

- By necessity there are some differences between the two analyses as we will soon see….

- This is extremely CPU intensive , e.g., 7M K-factors to compute

ATLAS	FEATURE
ISASUGRA generates spectrum & sparticle decays	SuSpect generates spectra with SUSY-HIT[#] for decays
NLO cross section using PROSPINO & CTEQ6M	NLO cross section for ~85-90 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

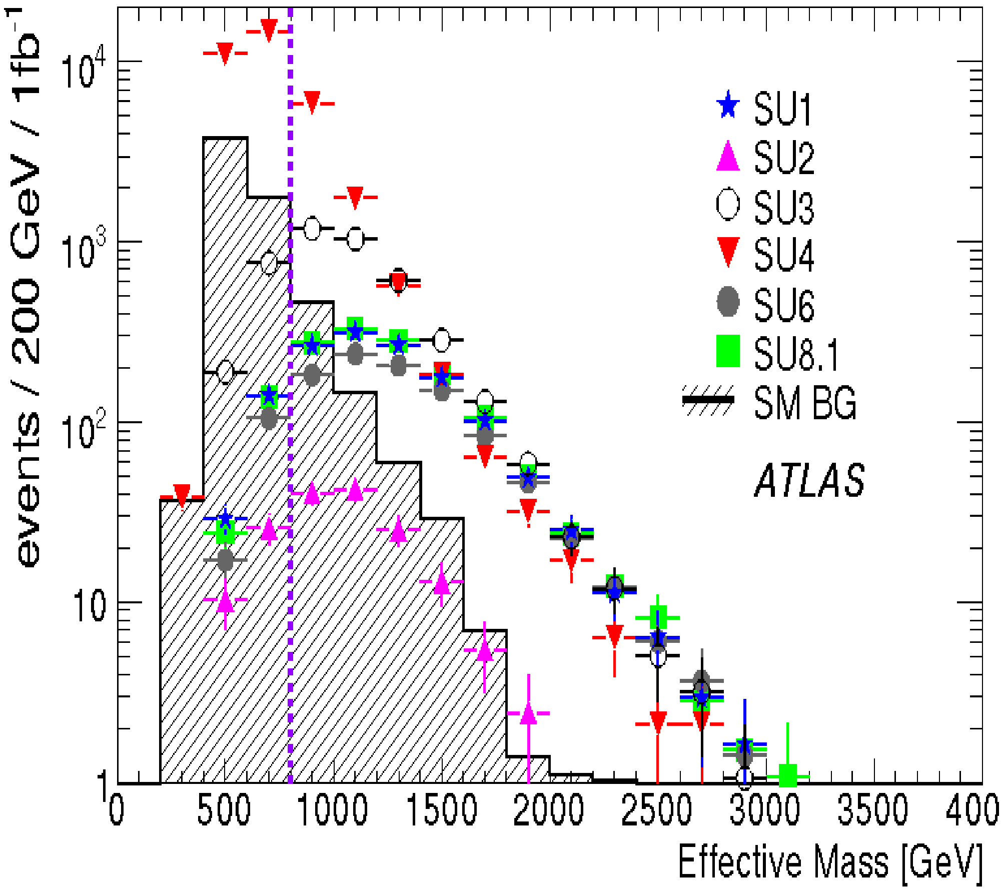
[#] version w/o negative QCD corrections

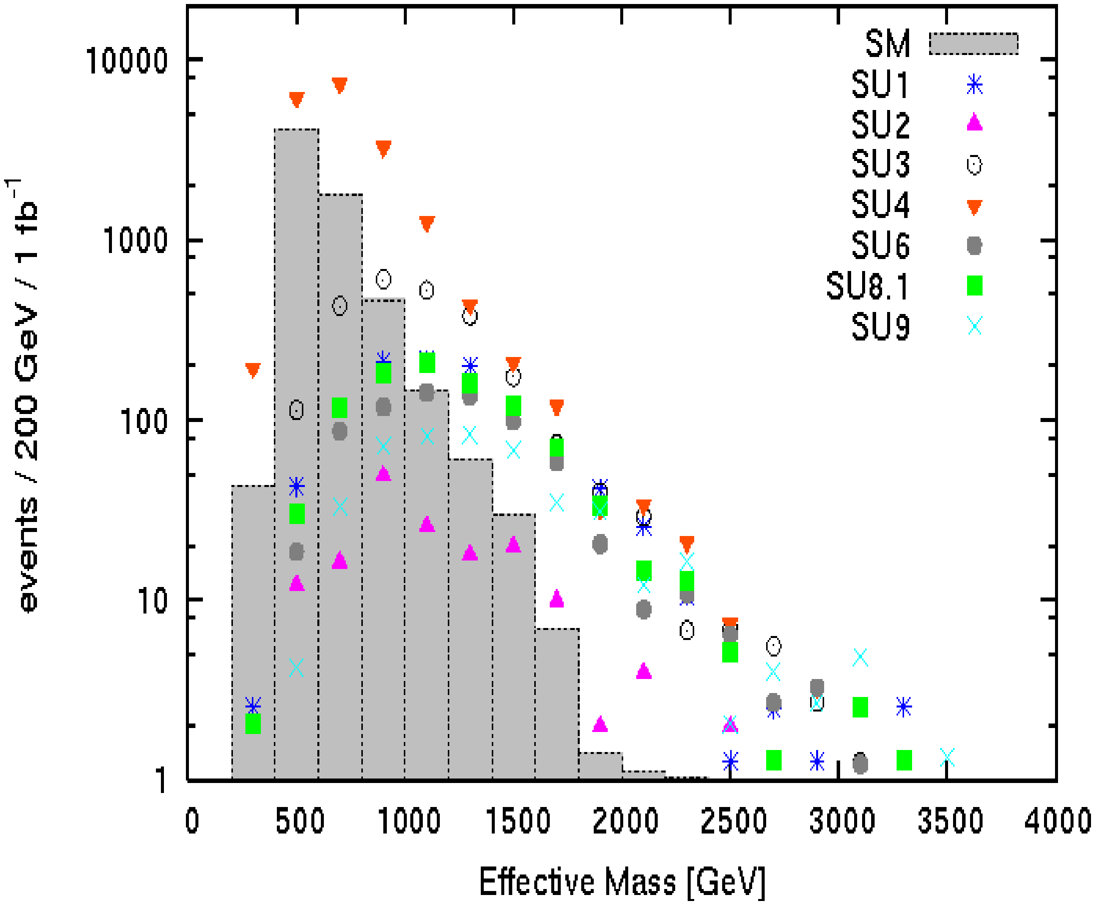
The set of ATLAS SUSY analyses is large:

- 2,3,4-jet +MET
- 1–l, ≥4-jet +MET
- SSDL
- OSDL
- Trileptons + (0,1)-j +MET
- etc.

- τ +≥ 4j +MET
- ≥4j w/ ≥ 2btags + MET
- Stable particle search

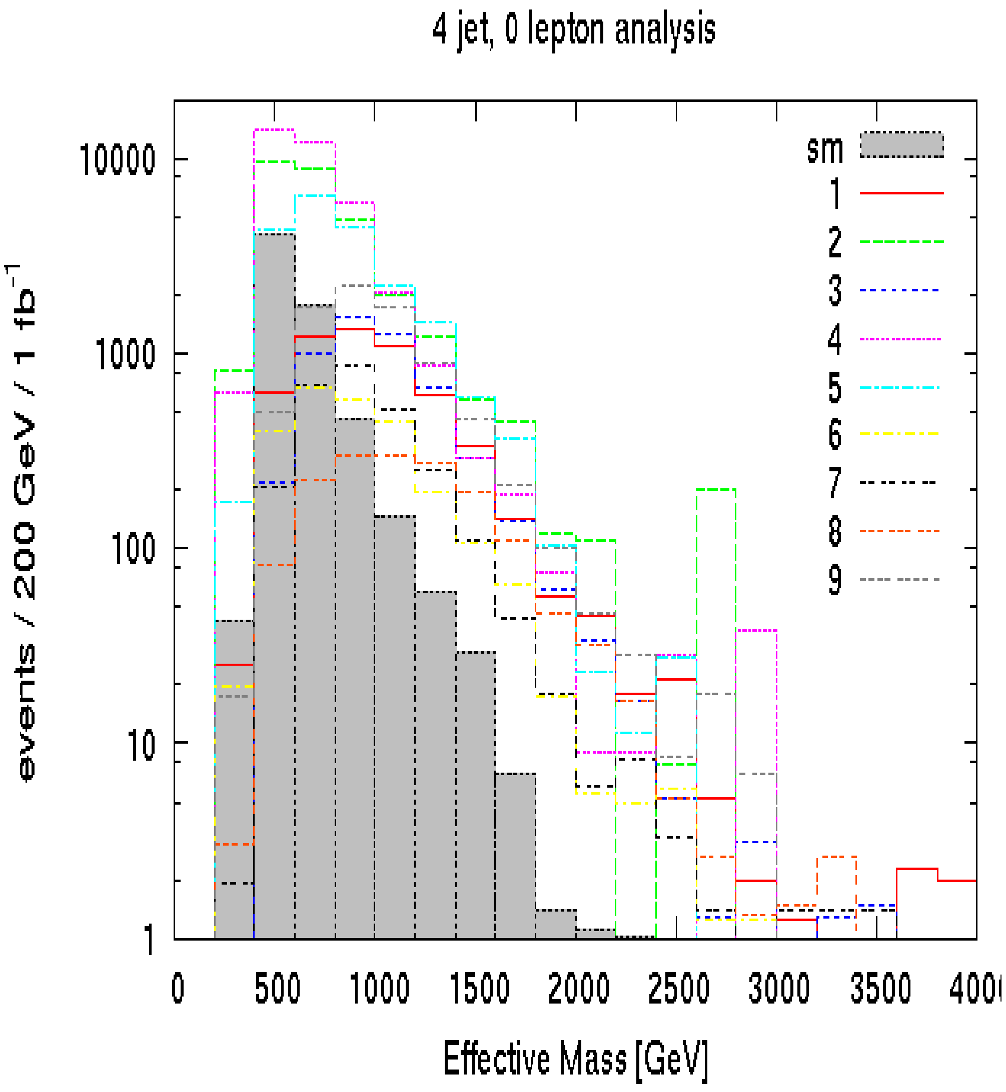
4-jet +MET

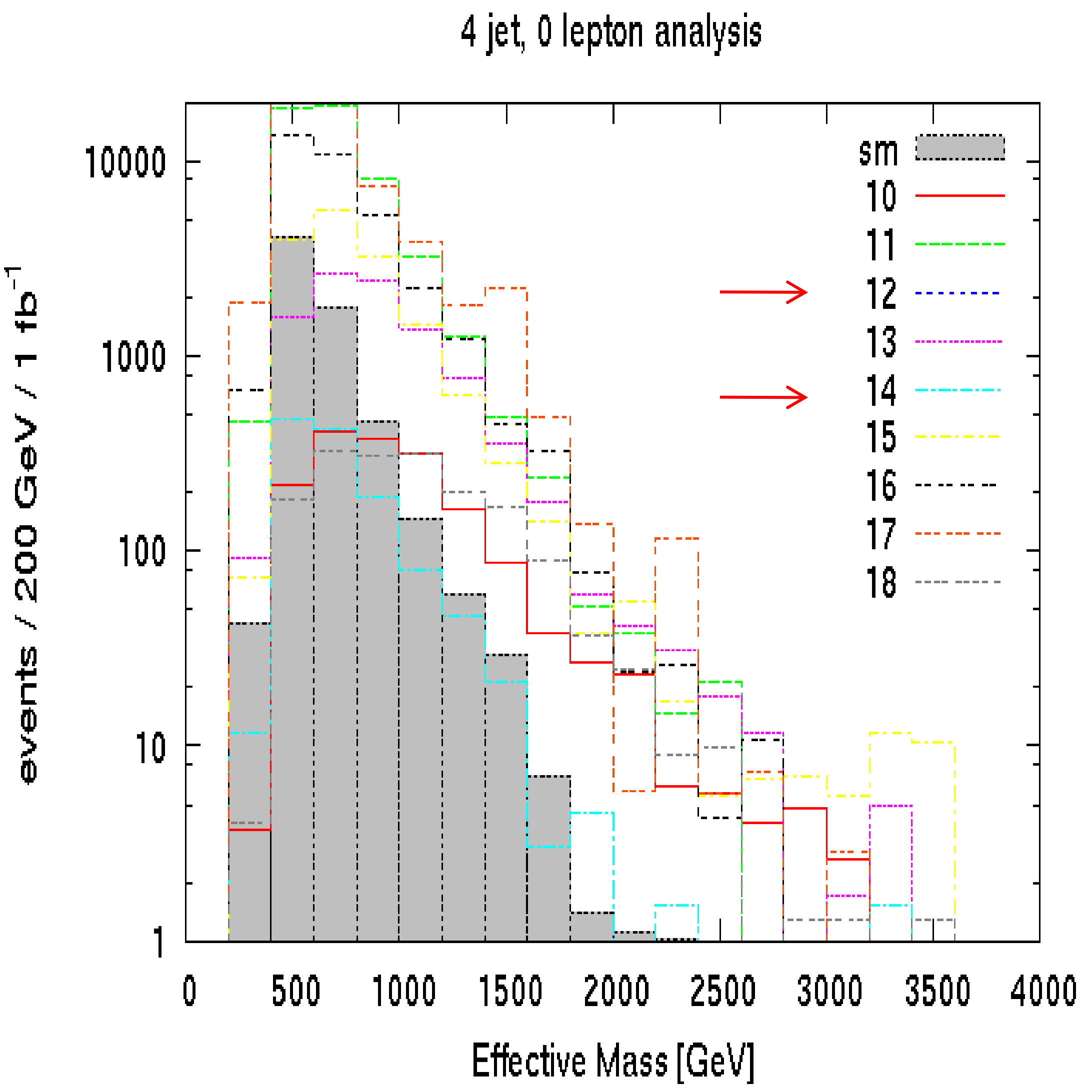




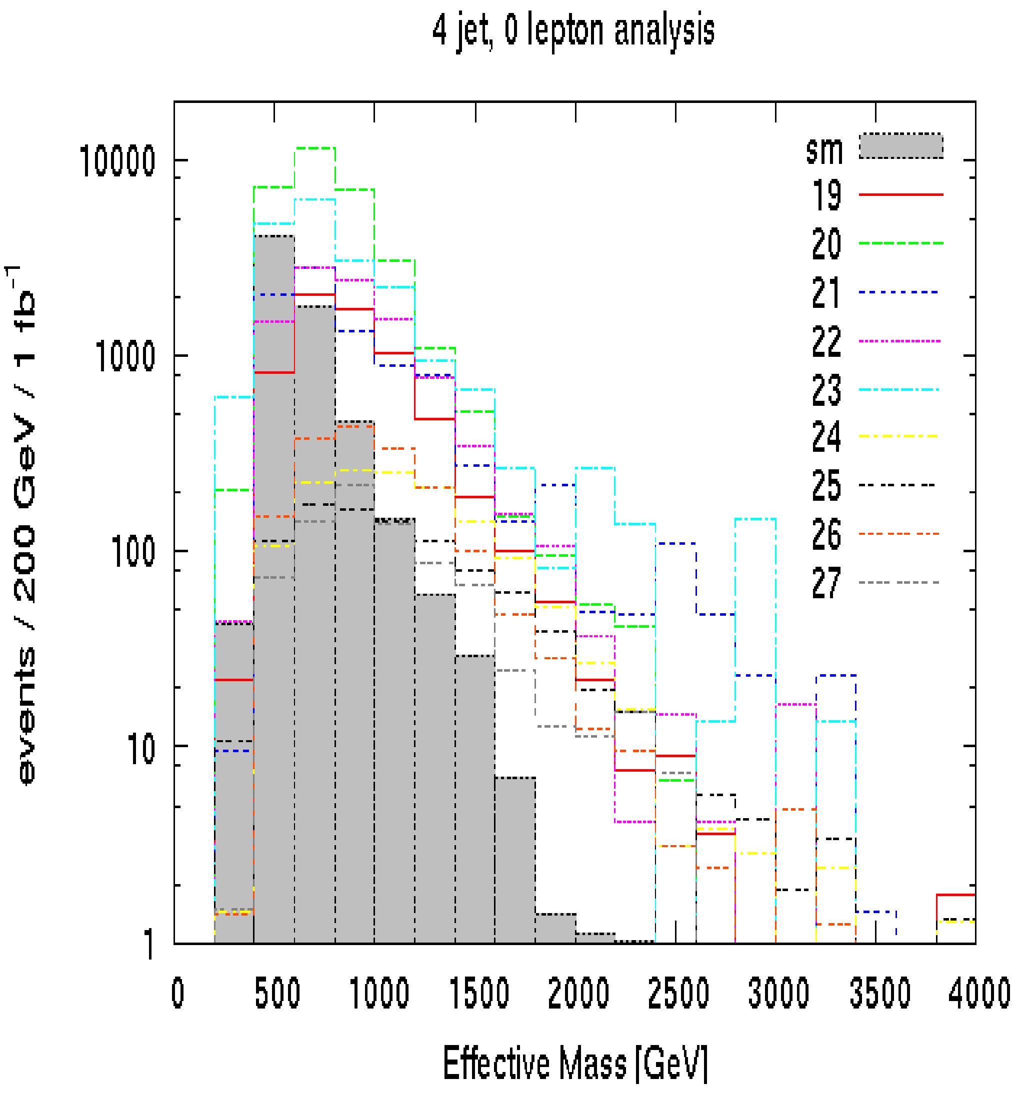
We do a good job at reproducing the mSUGRA benchmarks in this channel . If anything, our rates are a bit LOWER than are those obtained by ATLAS.

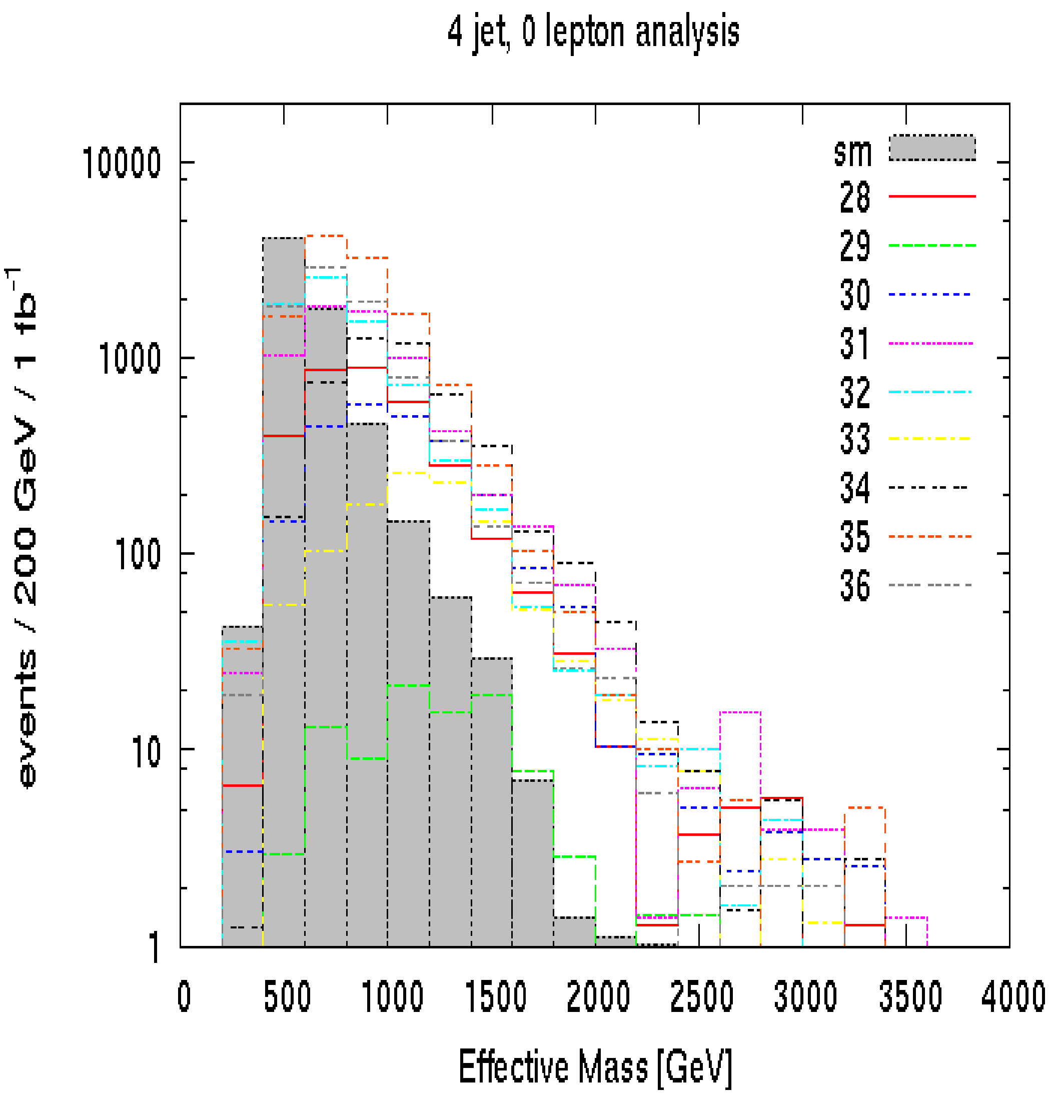
Sample Model Results



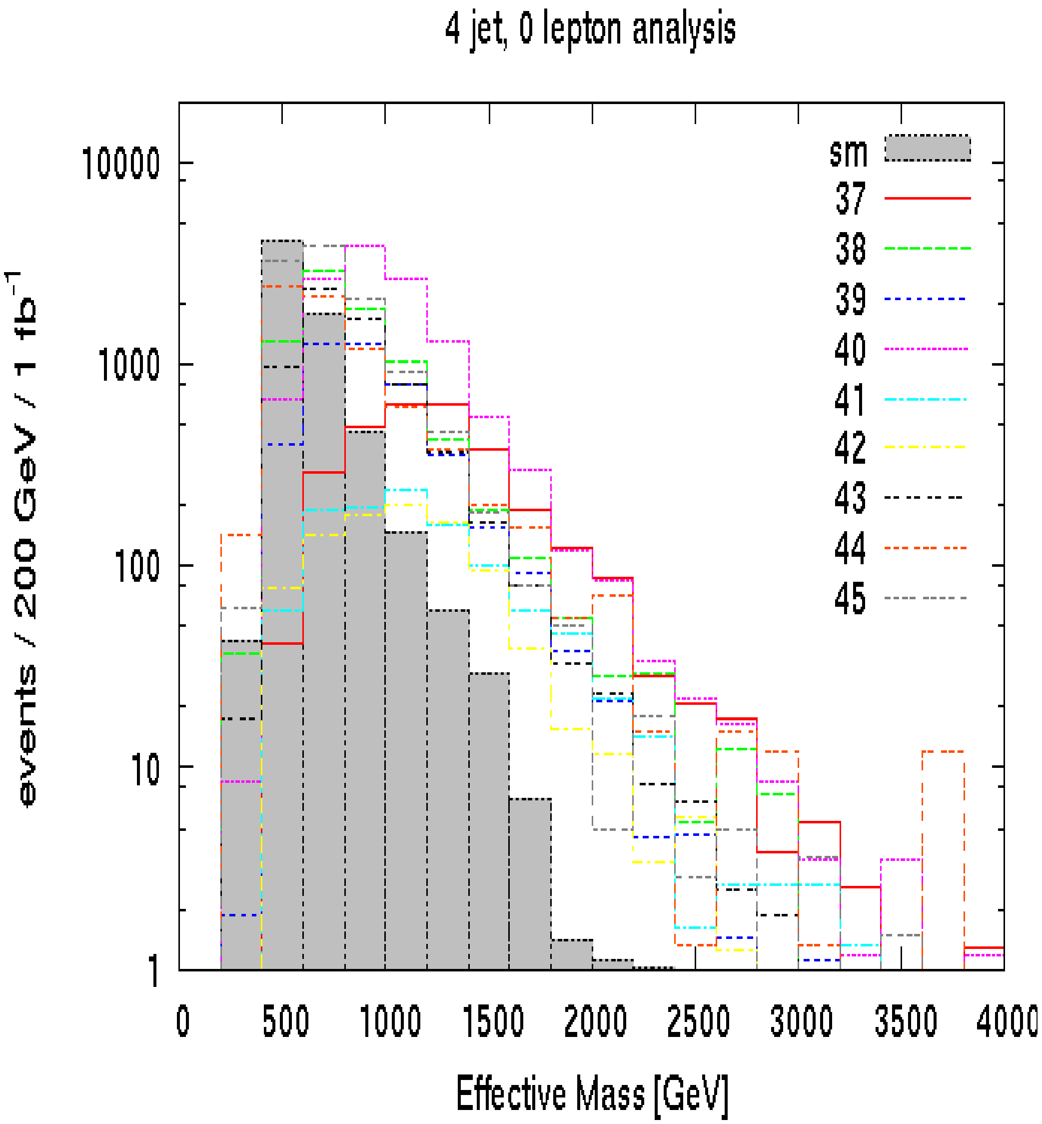


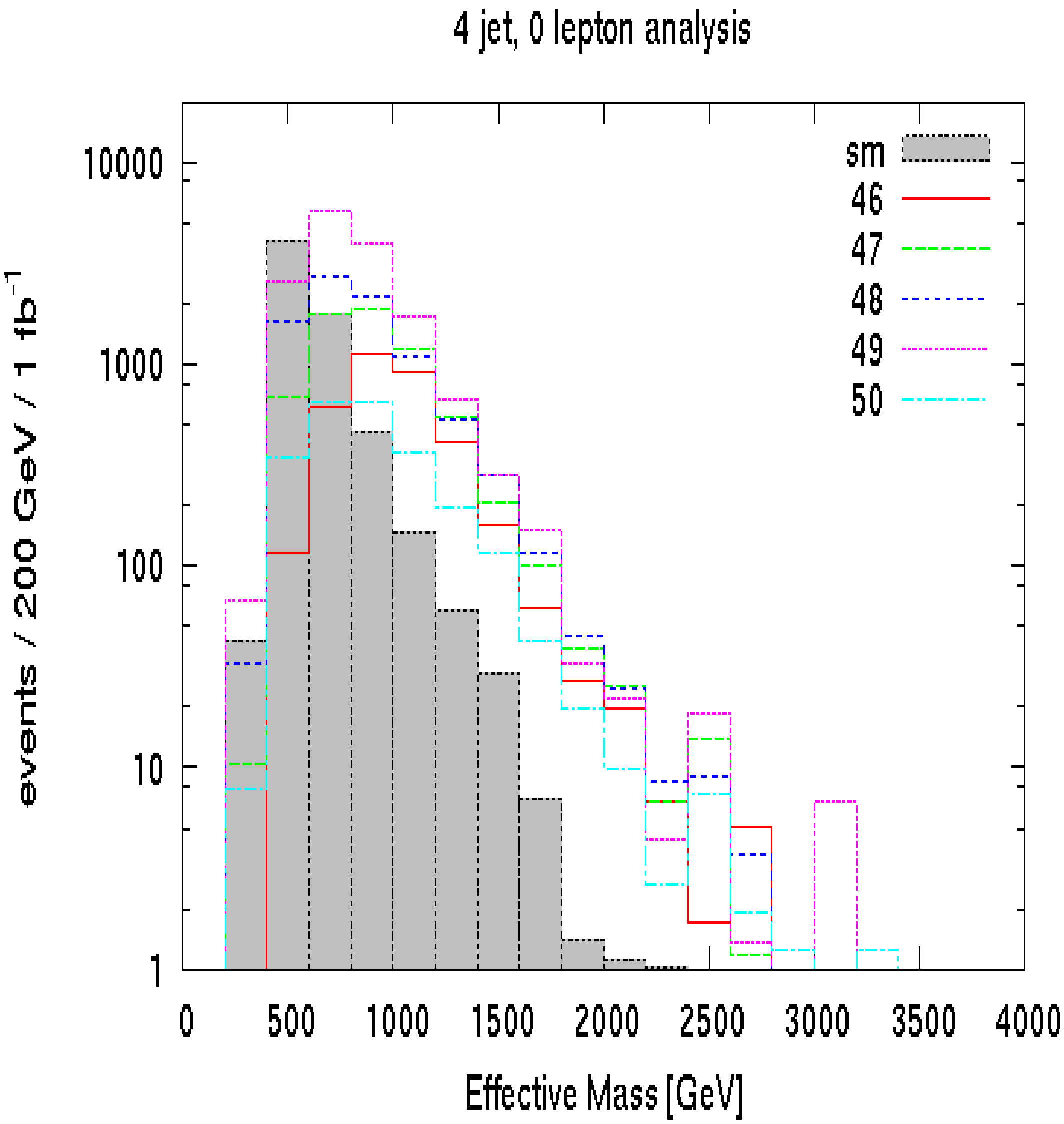
Sample Model Results (cont.)



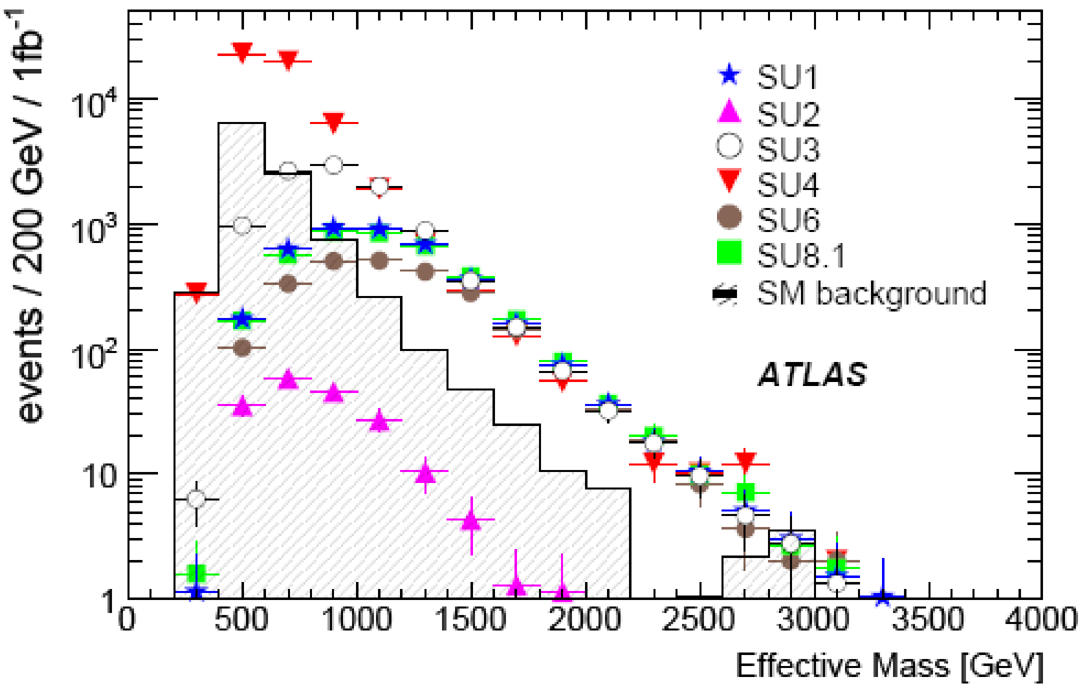


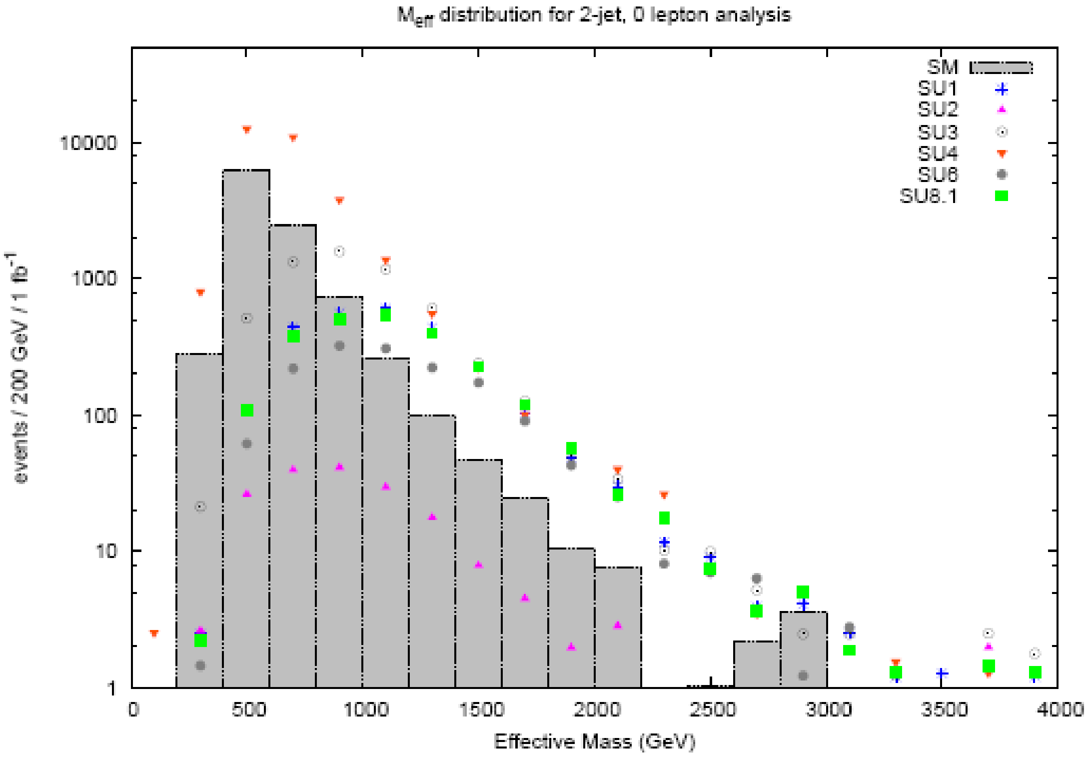
Sample Model Results (cont.)





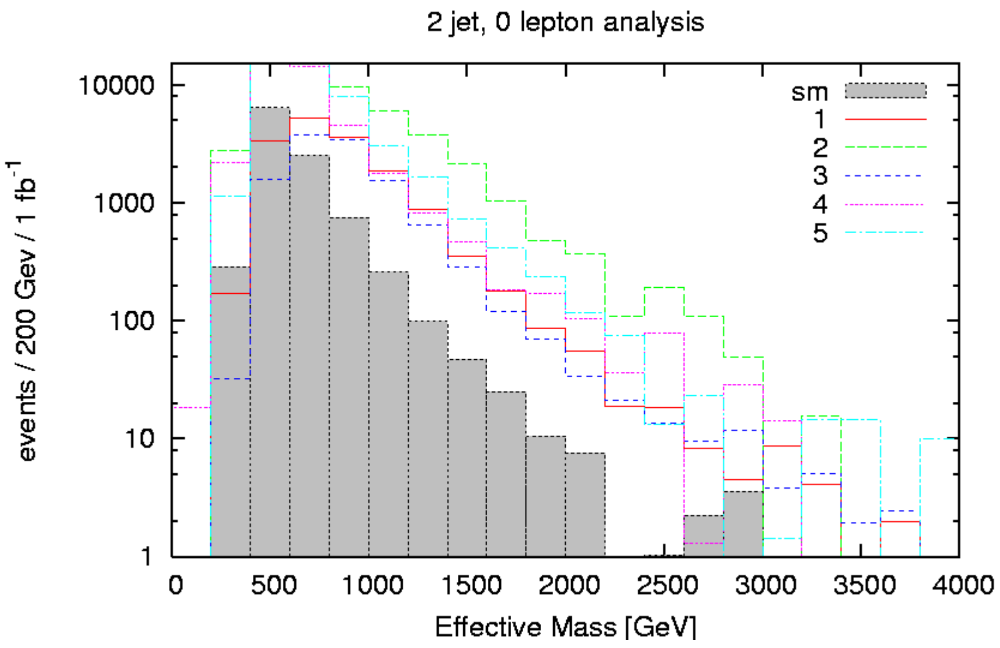
2j +MET

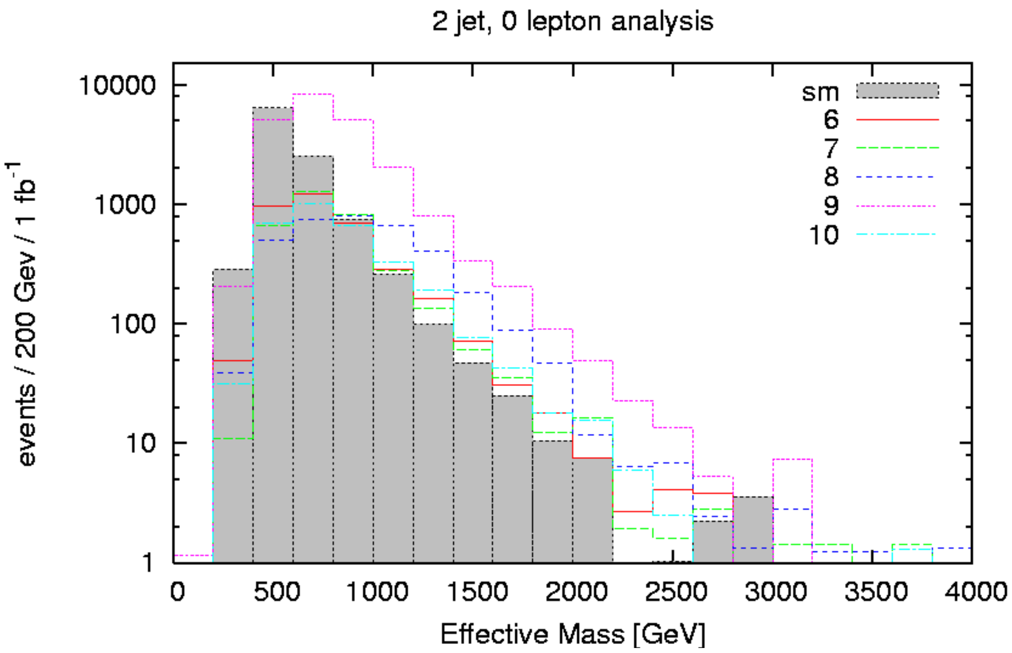


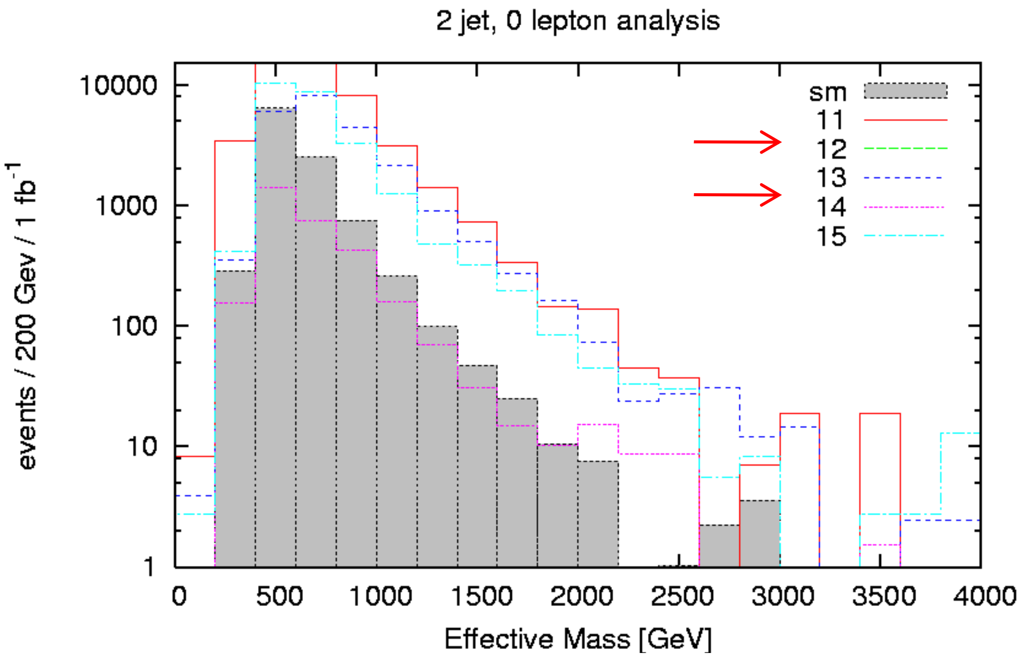


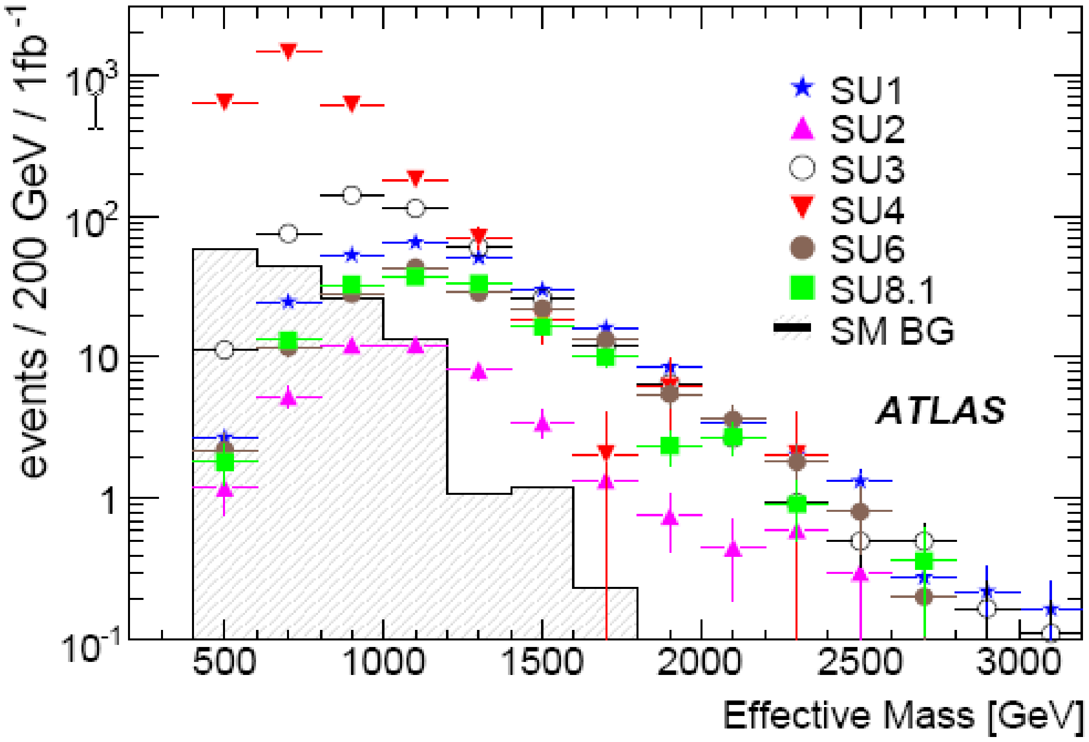
Looks good !

2j+MET Analysis

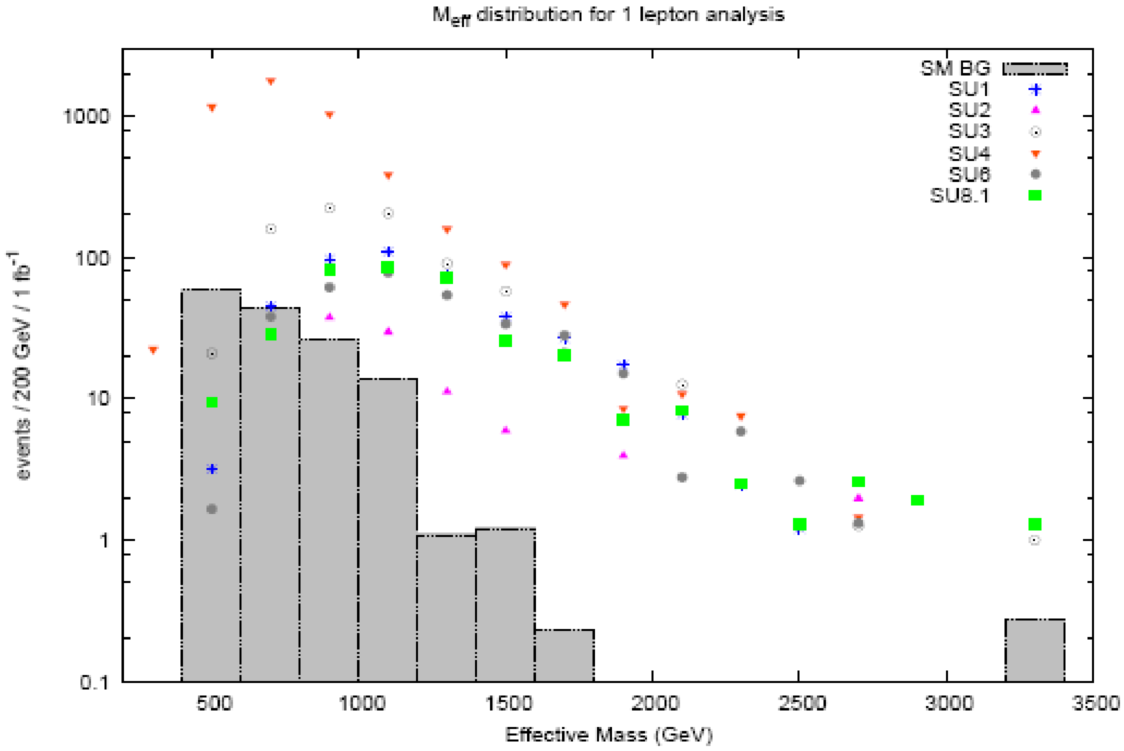






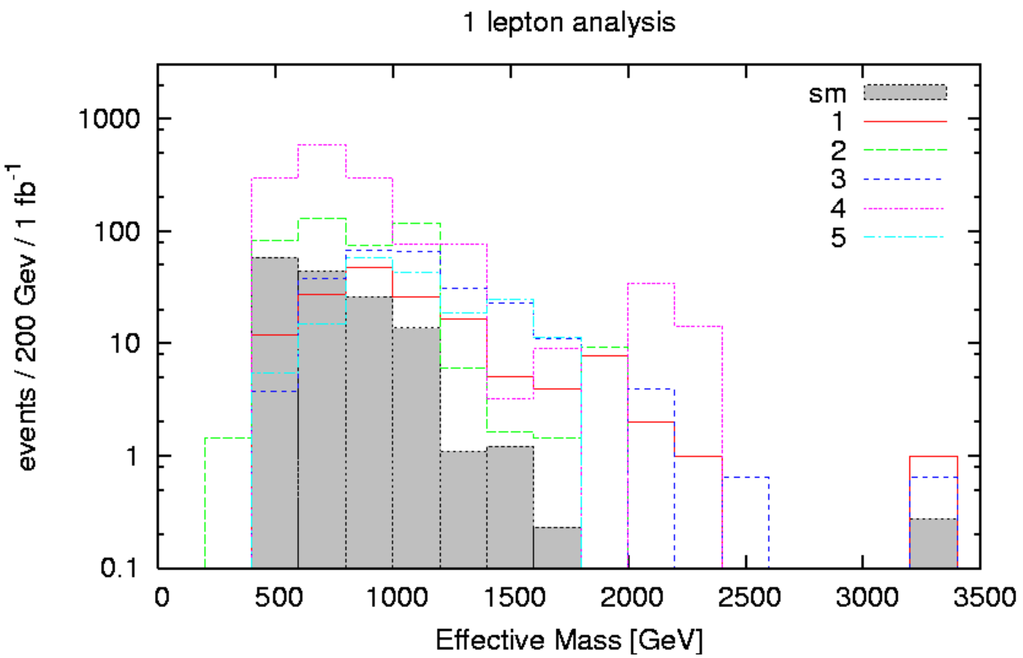


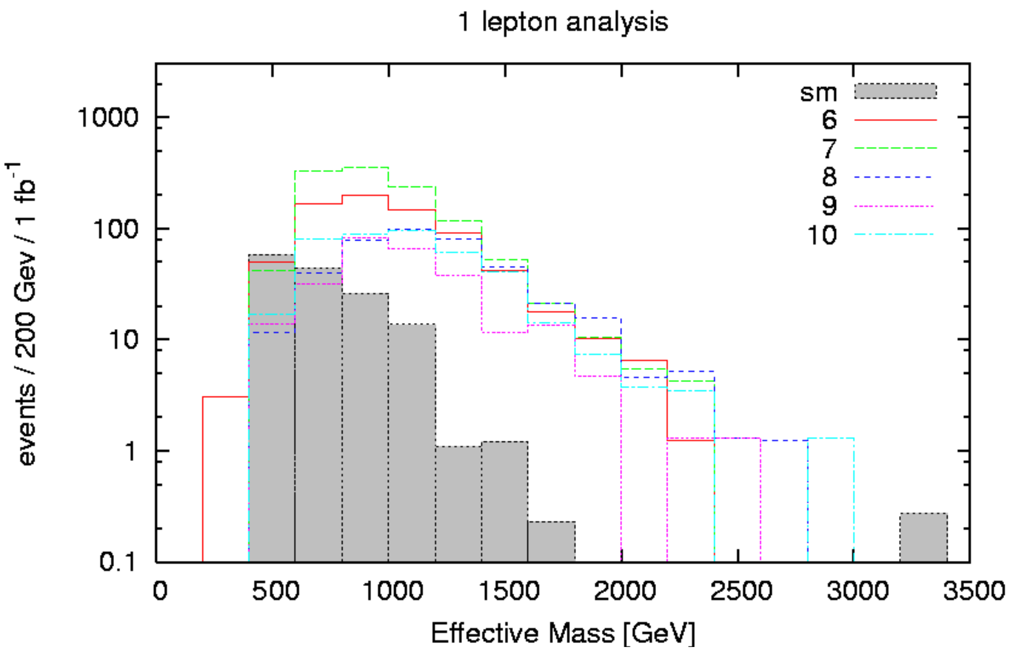
1l+4j+MET

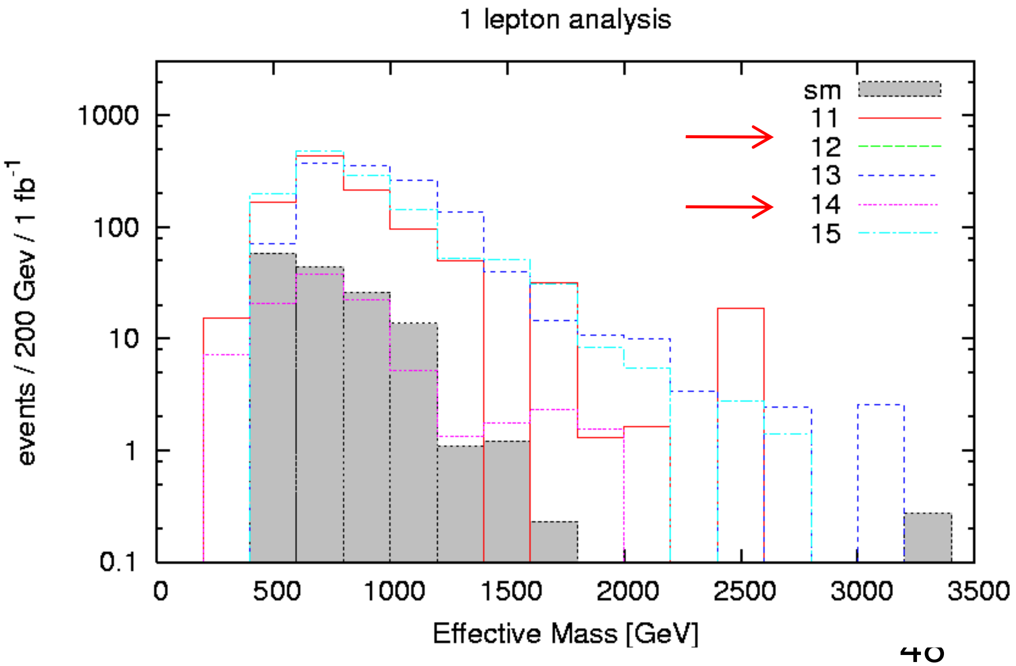


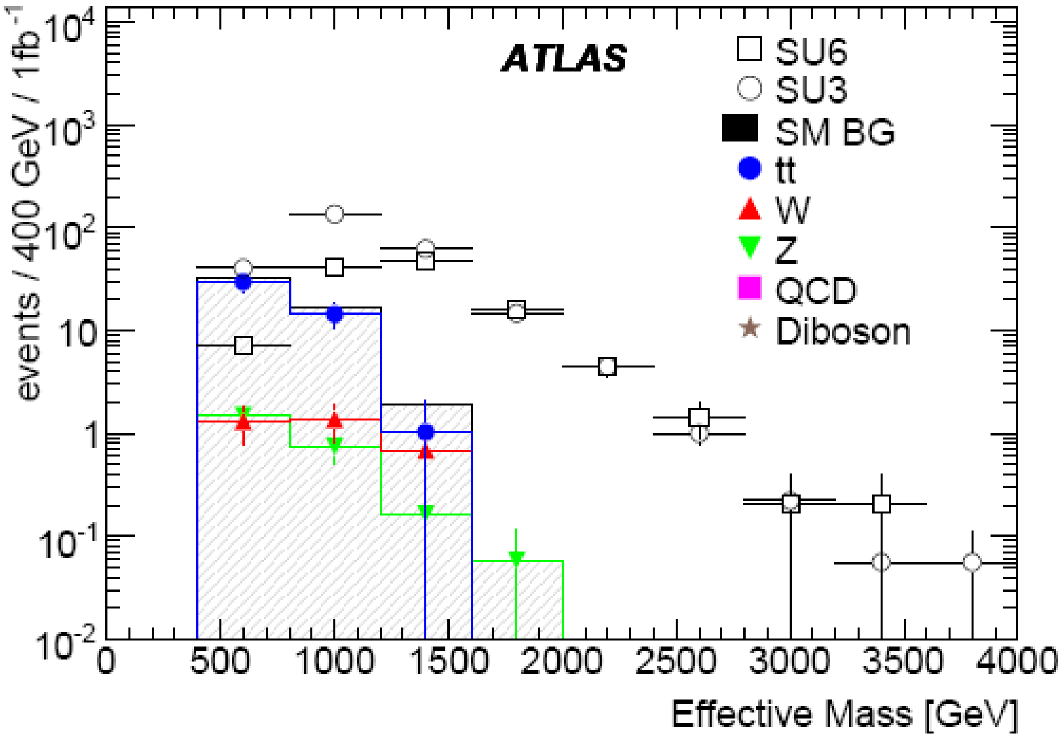
Great !

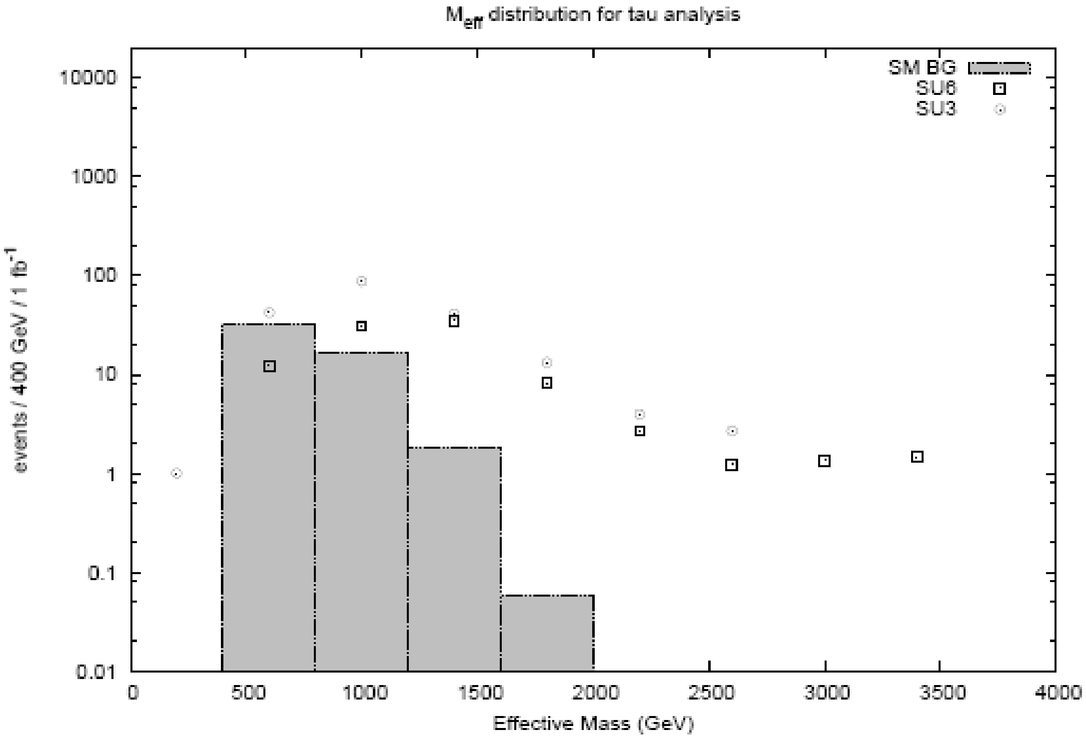
Single Lepton Analysis







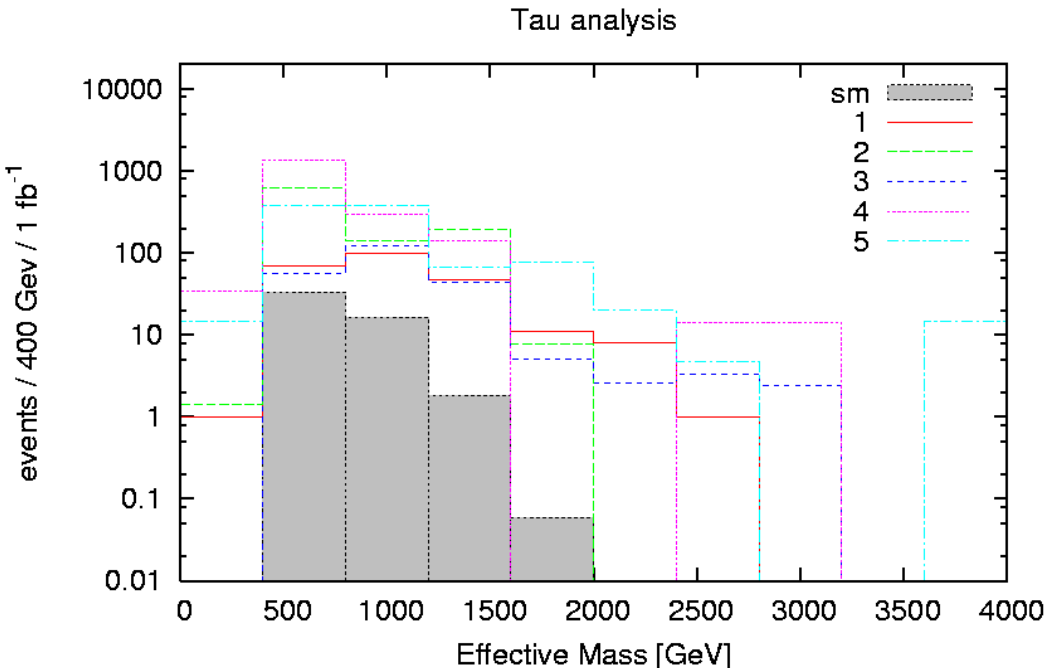


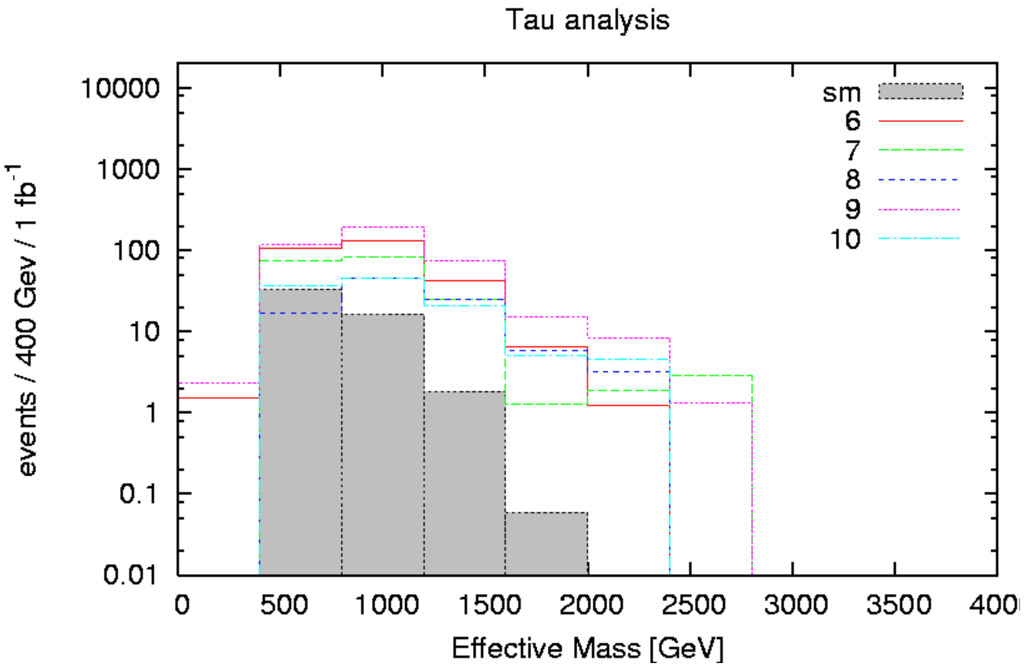

M_{eff} distribution for tau analysis

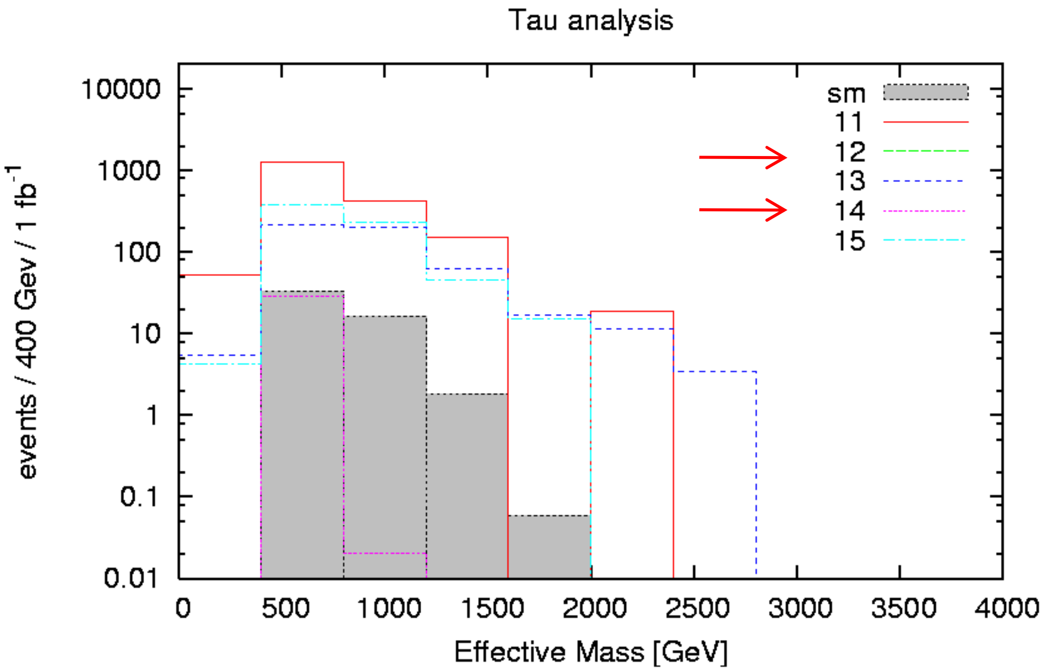
τ-analysis

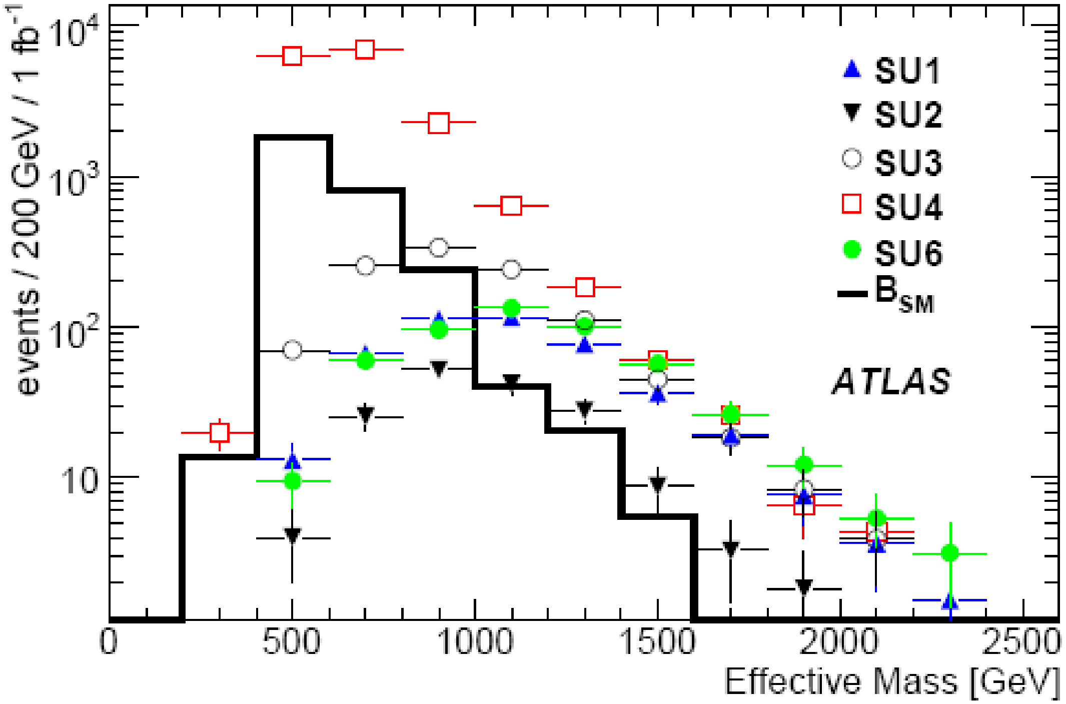
Looks OK except at the high end where the statistics are poor..

τ-analysis

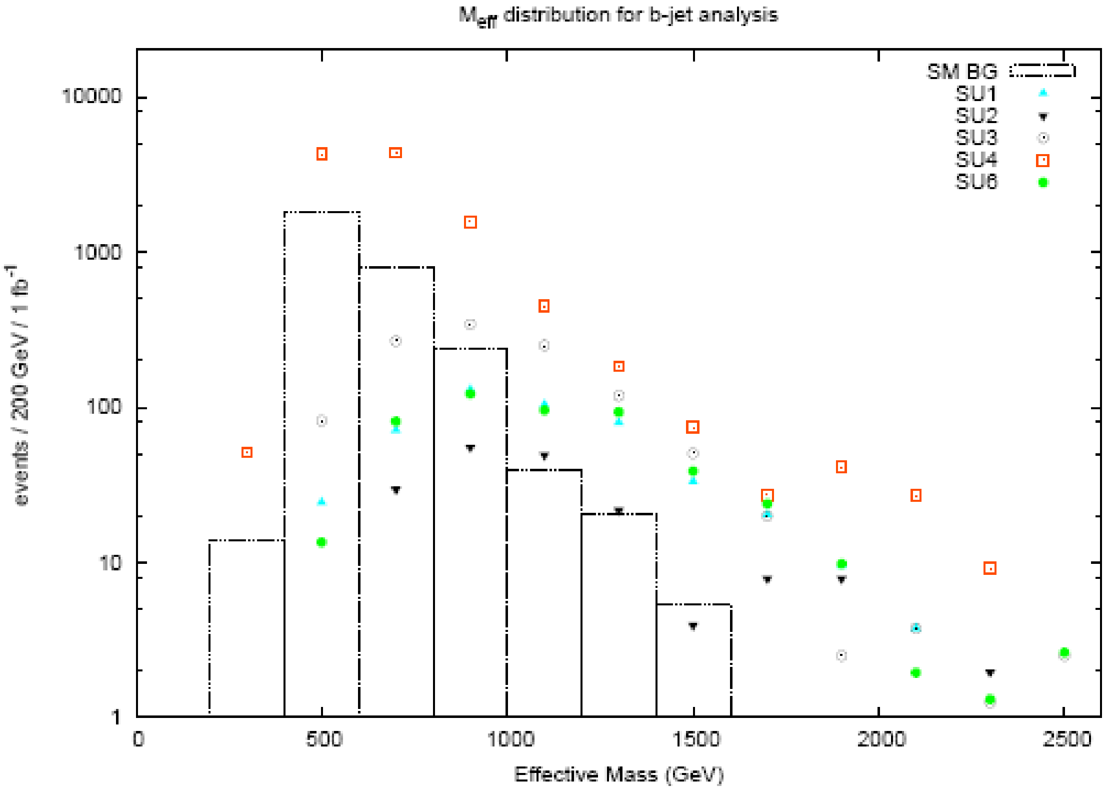

Tau analysis
events / 400 Gev / 1 fb^{-1}
10000
1000
100
10
1
0.1
0.01
0
500
1000
1500
2000
2500
3000
3500
4000
Effective Mass [GeV]
sm
1
2
3
4
5


Tau analysis
events / 400 Gev / 1 fb^{-1}
10000
1000
100
10
1
0.1
0.01
0
500
1000
1500
2000
2500
3000
3500
400
Effective Mass [GeV]
sm
6
7
8
9
10


Tau analysis
events / 400 Gev / 1 fb^{-1}
10000
1000
100
10
1
0.1
0.01
0
500
1000
1500
2000
2500
3000
3500
4000
Effective Mass [GeV]
sm
11
12
13
14
15

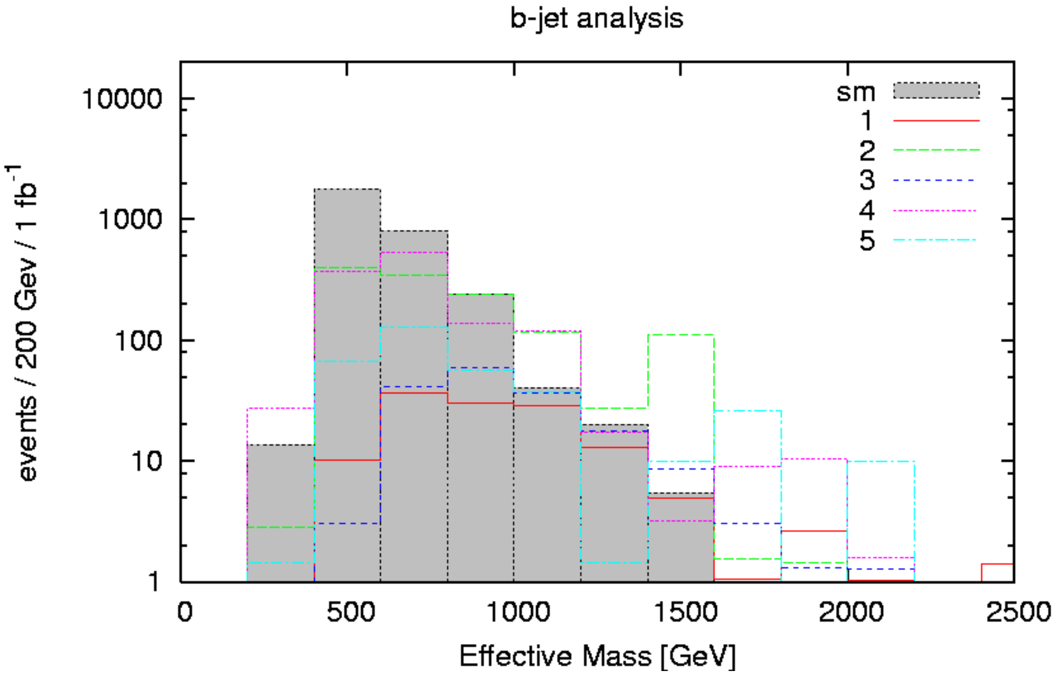


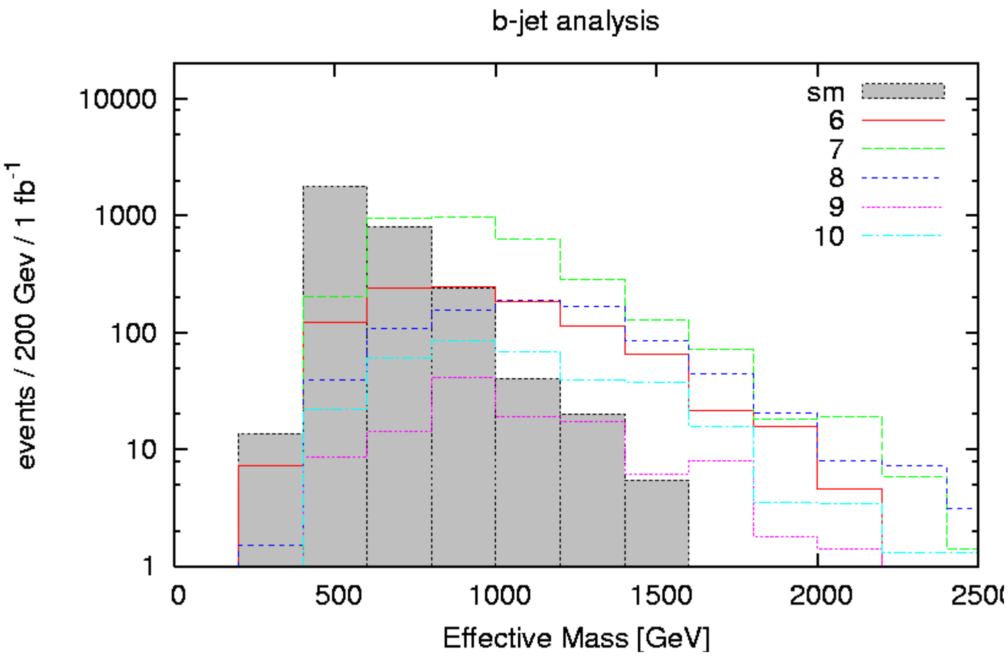
b-jet analysis

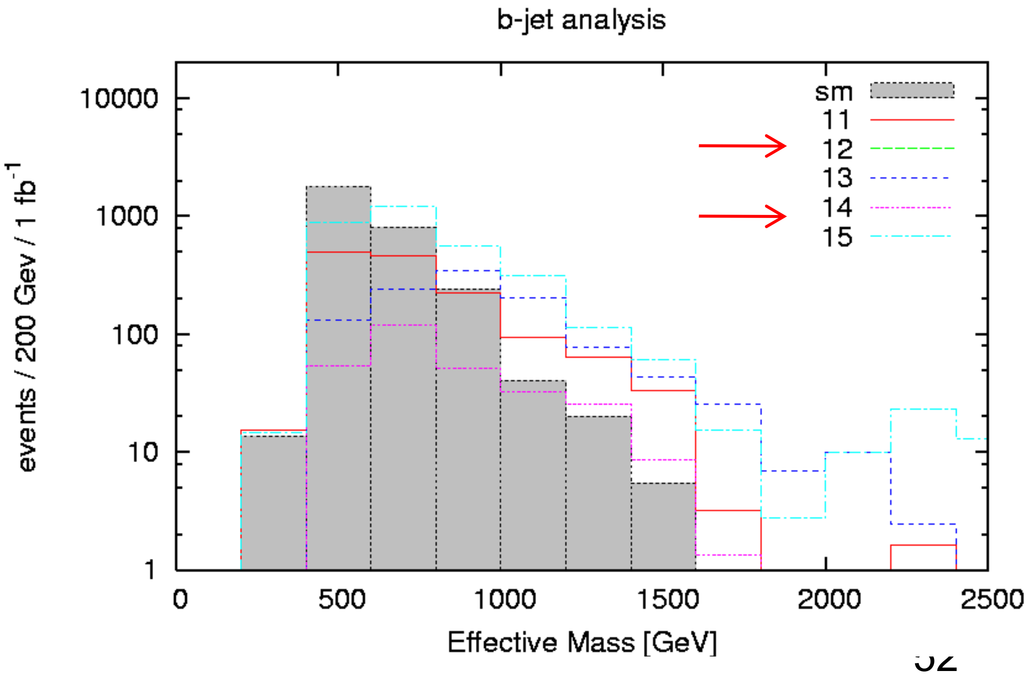


Great !

b-jet analysis







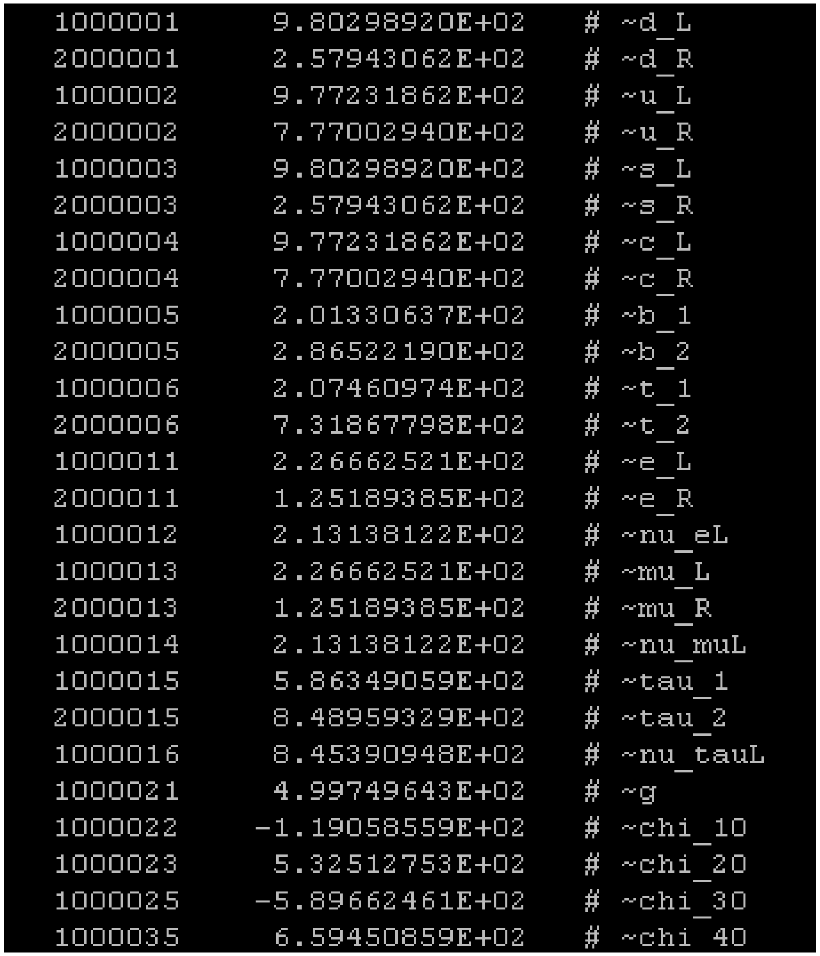
What can we conclude from this ???

There are many models which will show a respectable signal in these specific channels but some will --*not* -- like models 12 & 14. We will need to understand why models ‘fail’ on a case by case basis and how analyses would need to be modified (cuts, etc.) to cover them. However, what we have completed so far is only a VERY SMALL subset ..we have finished only ~0.02-0.07% of the entire model set.

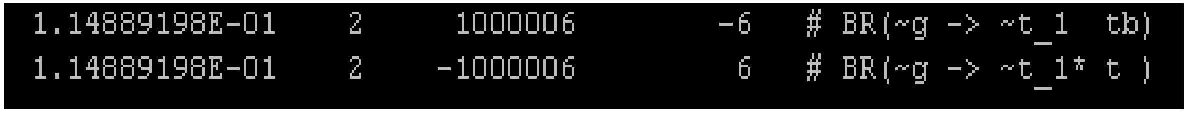
More work is needed to reach final results and it will take some reasonable time to run all ~71k models through the analysis chain. BUT there is every reason to believe that some thousands of model will be ‘in trouble’ requiring new/different analyses.

We will also run the corresponding 10 TeV SUSY chain once the backgrounds become publically available

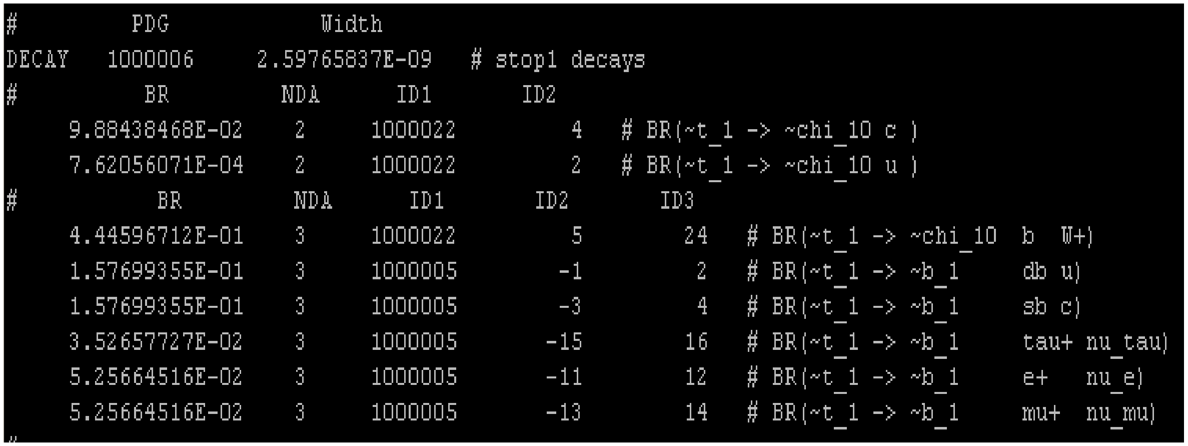
Model 14



```
   1000001     9.80298920E+02   # ~d_L
   2000001     2.57943062E+02   # ~d_R
   1000002     9.77231862E+02   # ~u_L
   2000002     7.77002940E+02   # ~u_R
   1000003     9.80298920E+02   # ~s_L
   2000003     2.57943062E+02   # ~s_R
   1000004     9.77231862E+02   # ~c_L
   2000004     7.77002940E+02   # ~c_R
   1000005     2.01330637E+02   # ~b_1
   2000005     2.86522190E+02   # ~b_2
   1000006     2.07460974E+02   # ~t_1
   2000006     7.31867798E+02   # ~t_2
   1000011     2.26662521E+02   # ~e_L
   2000011     1.25189385E+02   # ~e_R
   1000012     2.13138122E+02   # ~nu_eL
   1000013     2.26662521E+02   # ~mu_L
   2000013     1.25189385E+02   # ~mu_R
   1000014     2.13138122E+02   # ~nu_muL
   1000015     5.86349059E+02   # ~tau_1
   2000015     8.48959329E+02   # ~tau_2
   1000016     8.45390948E+02   # ~nu_tauL
   1000021     4.99749643E+02   # ~g
   1000022    -1.19058559E+02   # ~chi_10
   1000023     5.32512753E+02   # ~chi_20
   1000025    -5.89662461E+02   # ~chi_30
   1000035     6.59450859E+02   # ~chi_40
```



```
  1.14889198E-01    2      1000006         -6   # BR(~g -> ~t_1  tb)
  1.14889198E-01    2     -1000006          6   # BR(~g -> ~t_1* t )
```

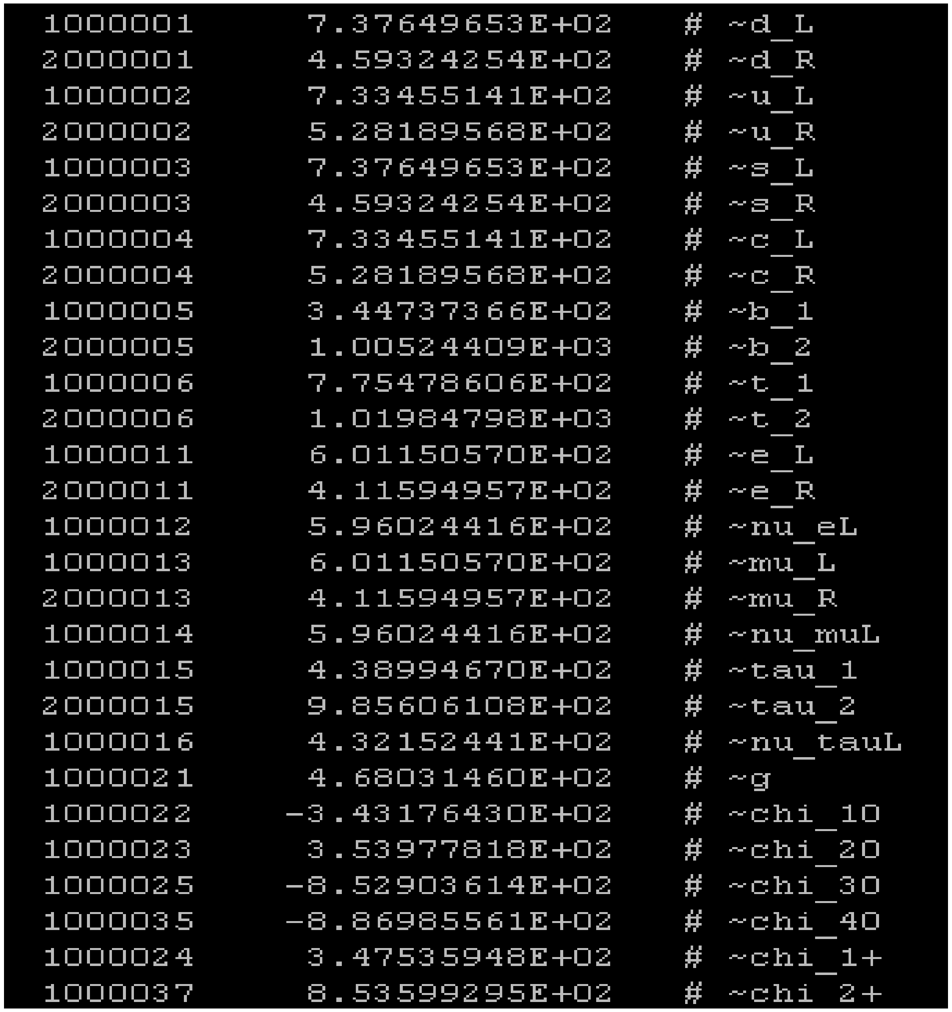


```
#         PDG           Width
DECAY   1000006     2.59765837E-09   # stop1 decays
#          BR         NDA      ID1       ID2
     9.88438468E-02    2     1000022          4   # BR(~t_1 -> ~chi_10 c )
     7.62056071E-04    2     1000022          2   # BR(~t_1 -> ~chi_10 u )
#           BR         NDA      ID1       ID2       ID3
     4.44596712E-01    3     1000022          5         24   # BR(~t_1 -> ~chi_10  b  W+)
     1.57699355E-01    3     1000005         -1          2   # BR(~t_1 -> ~b_1     db u)
     1.57699355E-01    3     1000005         -3          4   # BR(~t_1 -> ~b_1     sb c)
     3.52657727E-02    3     1000005        -15         16   # BR(~t_1 -> ~b_1     tau+ nu_tau)
     5.25664516E-02    3     1000005        -11         12   # BR(~t_1 -> ~b_1     e+   nu_e)
     5.25664516E-02    3     1000005        -13         14   # BR(~t_1 -> ~b_1     mu+  nu_mu)
```

First two generation of squarks are heavy; gluinos -> stop + top
The stop hadronizes first & then decays as: stop-> bW+ LSP
w/ Q=4 GeV so b-jet is soft & MET is small

Model 12

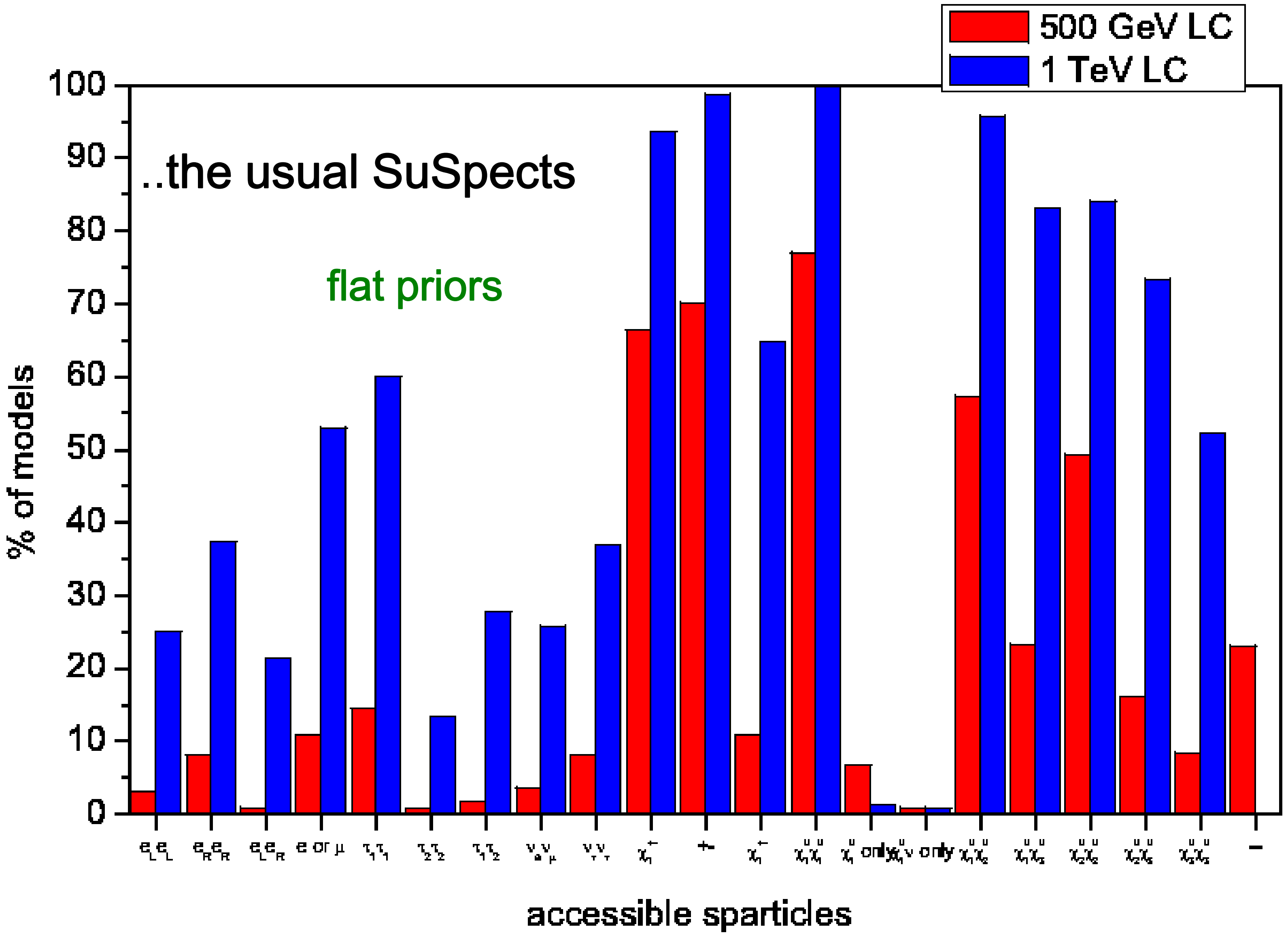
This case is even more unusual as it didn't even show up in any of the histograms ! Here sbottom_1 is the nLSP with a mass splitting of only ~1.5 GeV so we get lots of soft jets + MET only. The other squarks are rather heavy:



```
   1000001     7.37649653E+02   # ~d_L
   2000001     4.59324254E+02   # ~d_R
   1000002     7.33455141E+02   # ~u_L
   2000002     5.28189568E+02   # ~u_R
   1000003     7.37649653E+02   # ~s_L
   2000003     4.59324254E+02   # ~s_R
   1000004     7.33455141E+02   # ~c_L
   2000004     5.28189568E+02   # ~c_R
   1000005     3.44737366E+02   # ~b_1
   2000005     1.00524409E+03   # ~b_2
   1000006     7.75478606E+02   # ~t_1
   2000006     1.01984798E+03   # ~t_2
   1000011     6.01150570E+02   # ~e_L
   2000011     4.11594957E+02   # ~e_R
   1000012     5.96024416E+02   # ~nu_eL
   1000013     6.01150570E+02   # ~mu_L
   2000013     4.11594957E+02   # ~mu_R
   1000014     5.96024416E+02   # ~nu_muL
   1000015     4.38994670E+02   # ~tau_1
   2000015     9.85606108E+02   # ~tau_2
   1000016     4.32152441E+02   # ~nu_tauL
   1000021     4.68031460E+02   # ~g
   1000022    -3.43176430E+02   # ~chi_10
   1000023     3.53977818E+02   # ~chi_20
   1000025    -8.52903614E+02   # ~chi_30
   1000035    -8.86985561E+02   # ~chi_40
   1000024     3.47535948E+02   # ~chi_1+
   1000037     8.53599295E+02   # ~chi_2+
```

Note that SDECAY treats the sbottom in this case as stable but really an R-hadron forms which then undergoes a 4-body decay or a 1-loop suppressed decay with a $c\tau$ ~10-100 μm

Kinematic Accessibility at the ILC : I

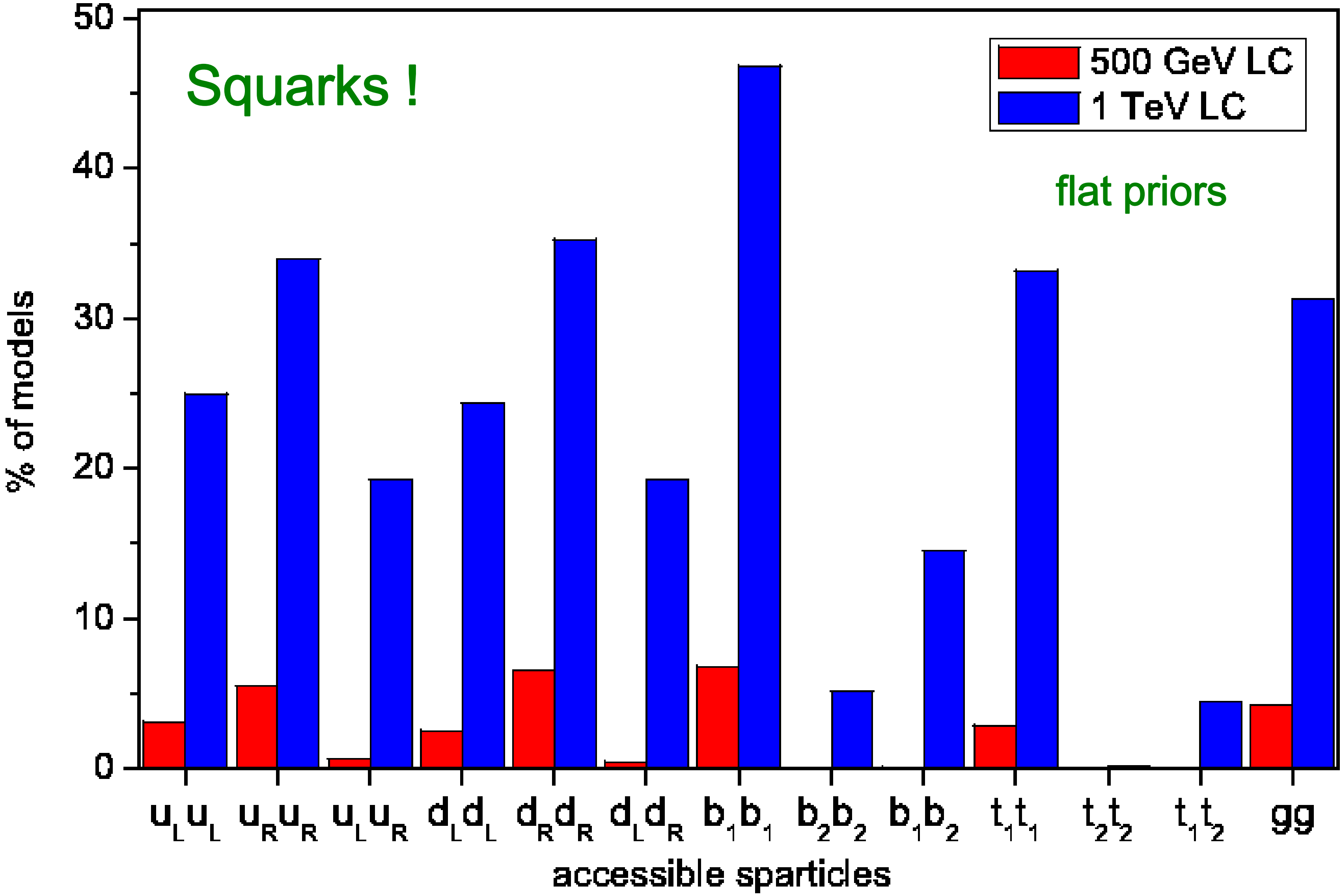


..the usual SuSpects

flat priors

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 : II



Dark Matter Challenge

Can we find models (out of our ~71k model sample) that ALSO

- saturate the WMAP dark matter constraint (1240+76 models)
- can reproduce the positron flux seen at PAMELA with 'low' χ^2 & a 'small' boost factor
- can avoid the PAMELA anti-proton constraints with the *same* boost factor (though this need not be the case!)
- and can still satisfy the data from FERMI

as we might hope since we have such a large parameter space?

??? This work is in progress ???

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!

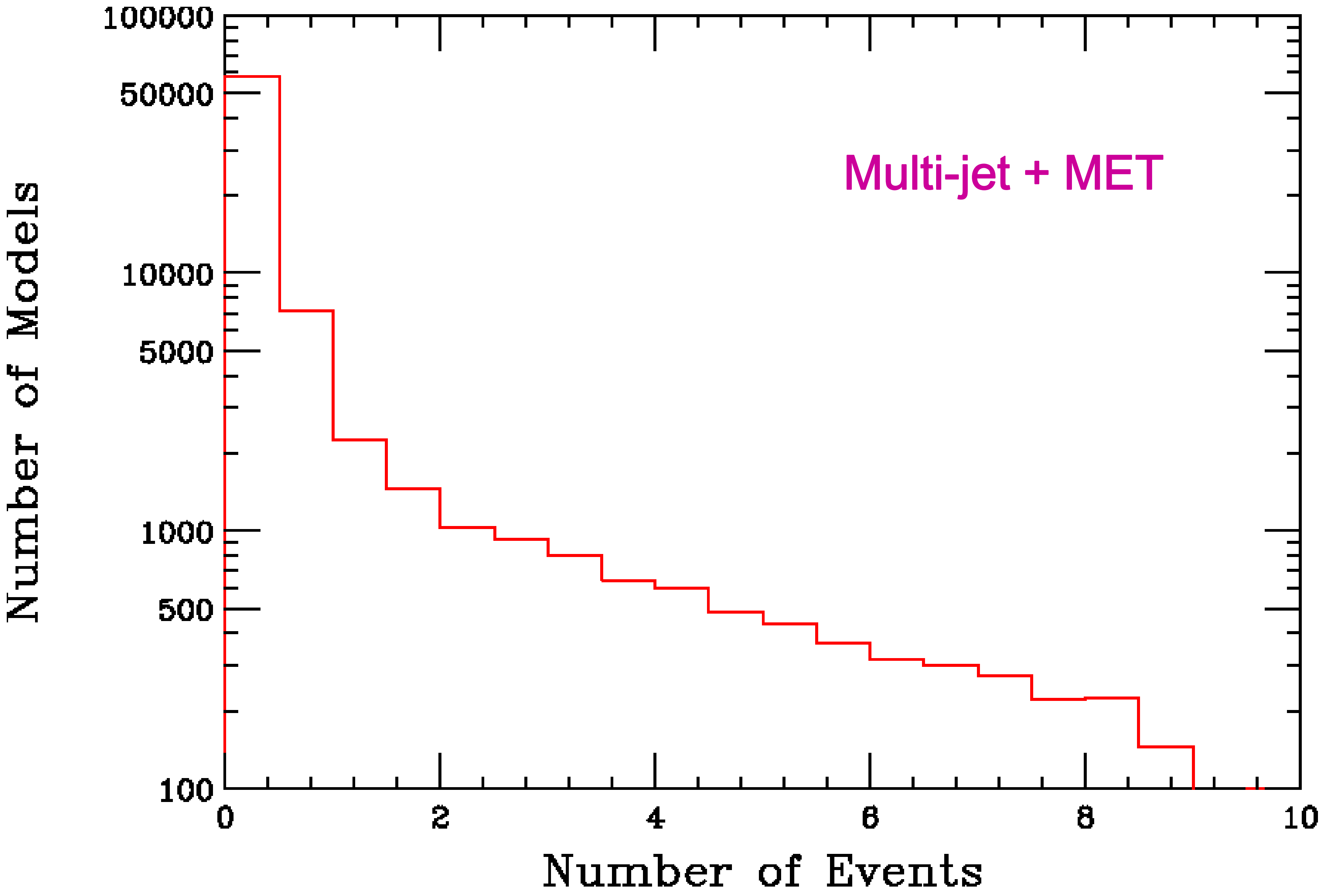
- Light partners may exist which have avoided LEP & Tevatron constraints and may be difficult to observe at the LHC due to rather common small mass differences or strange spectra

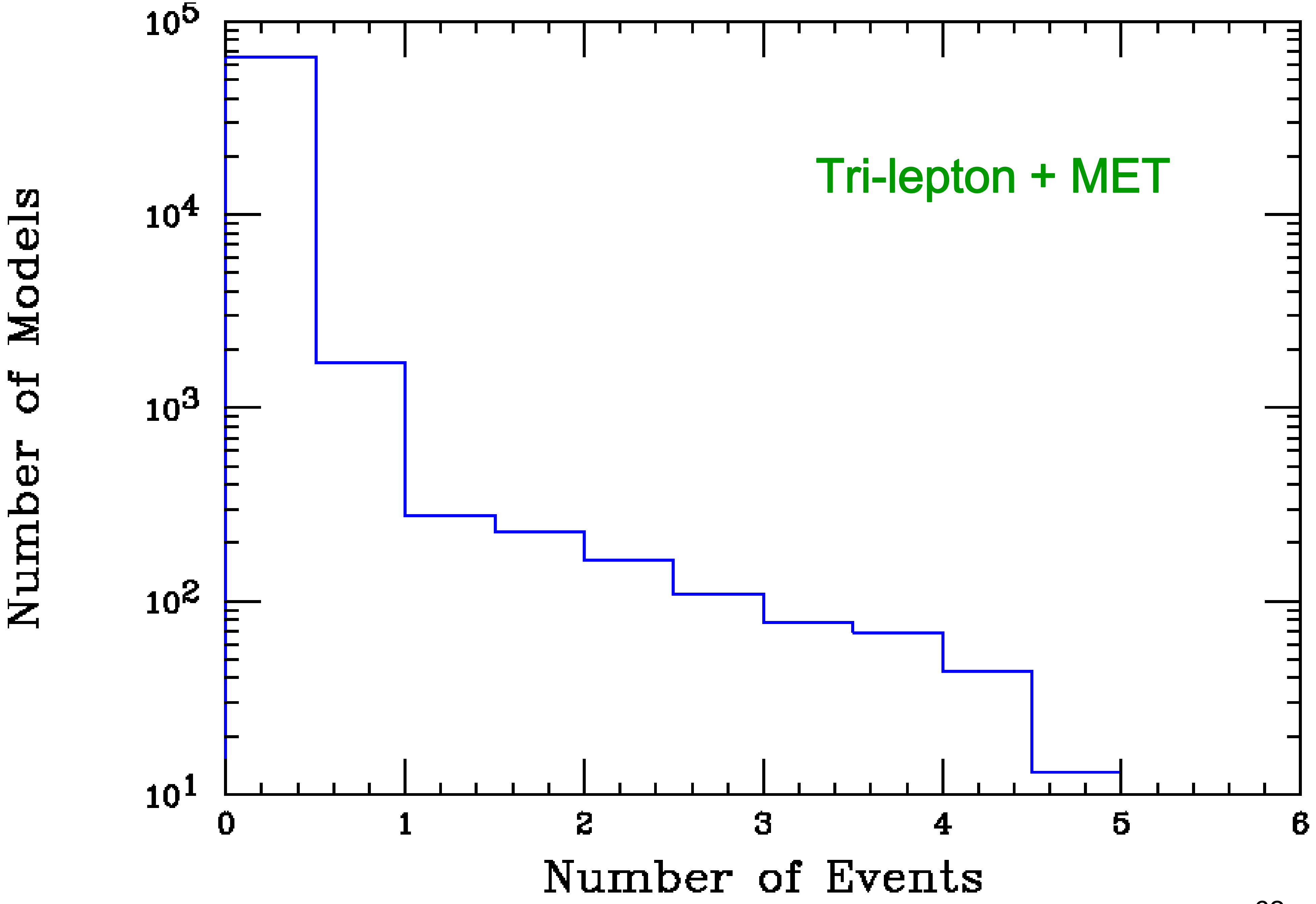
- Squarks may exist within the range accessible to a 500 GeV ILC but have not been well studied there.

- 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..

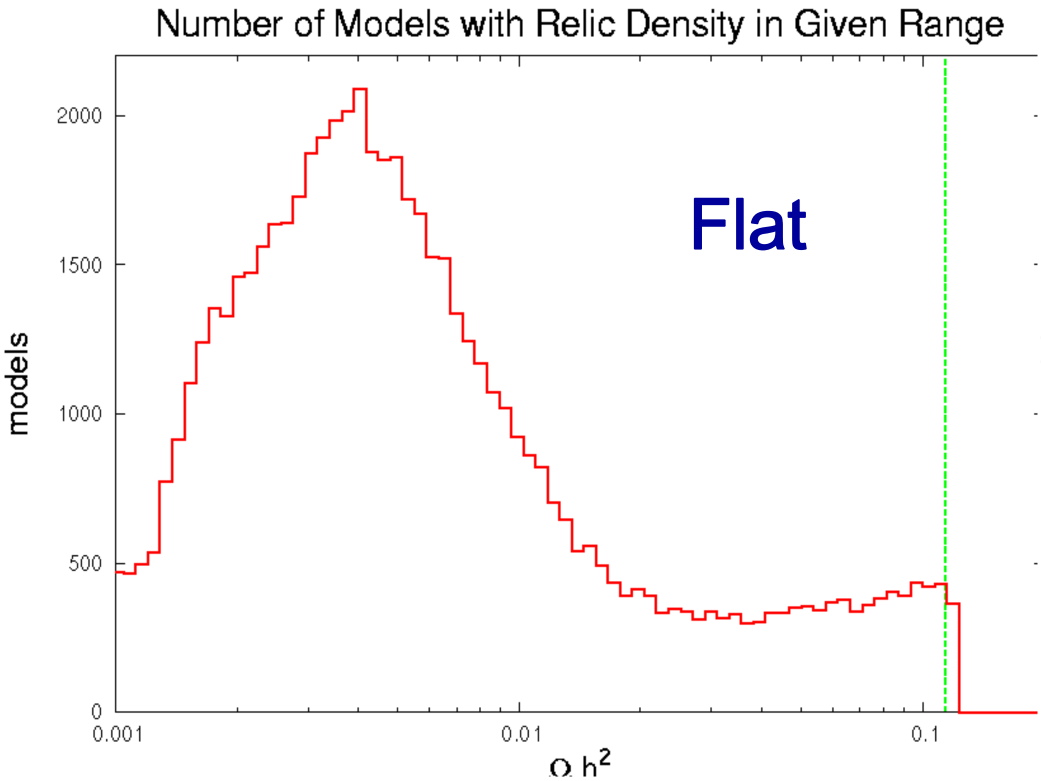
BACKUP SLIDES

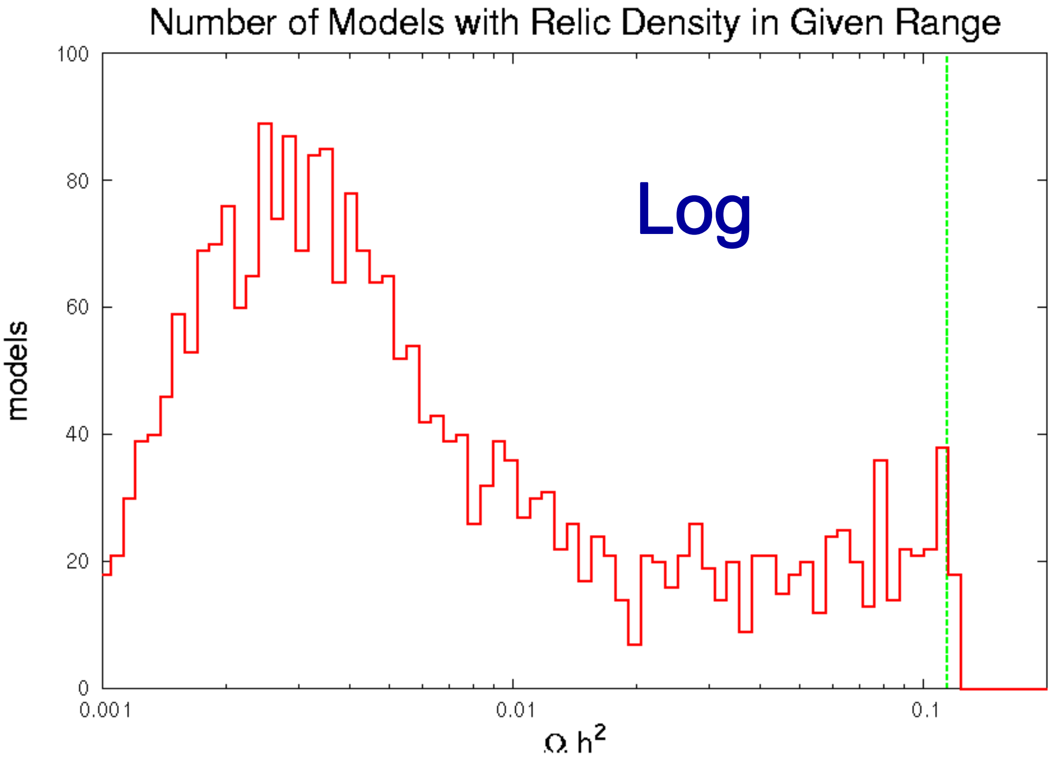

Multi-jet + MET
Number of Models
Number of Events
100000
50000
10000
5000
1000
500
100
0
2
4
6
8
10


Tri-lepton + MET
Number of Models
Number of Events
10^5
10^4
10^3
10^2
10^1
0
1
2
3
4
5
6

Predicted Dark Matter Density : Ωh^2

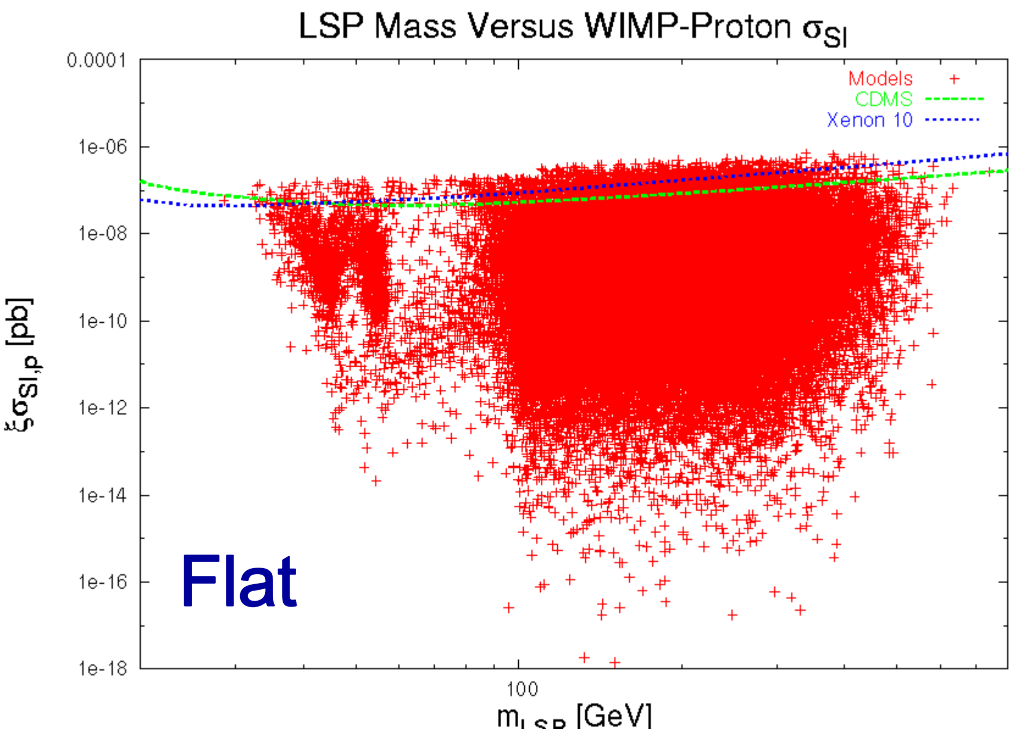
It is not likely that the LSP is the dominant component of dark matter in ‘conventional’ cosmology…but it can be in some model cases.. (1240 + 76)

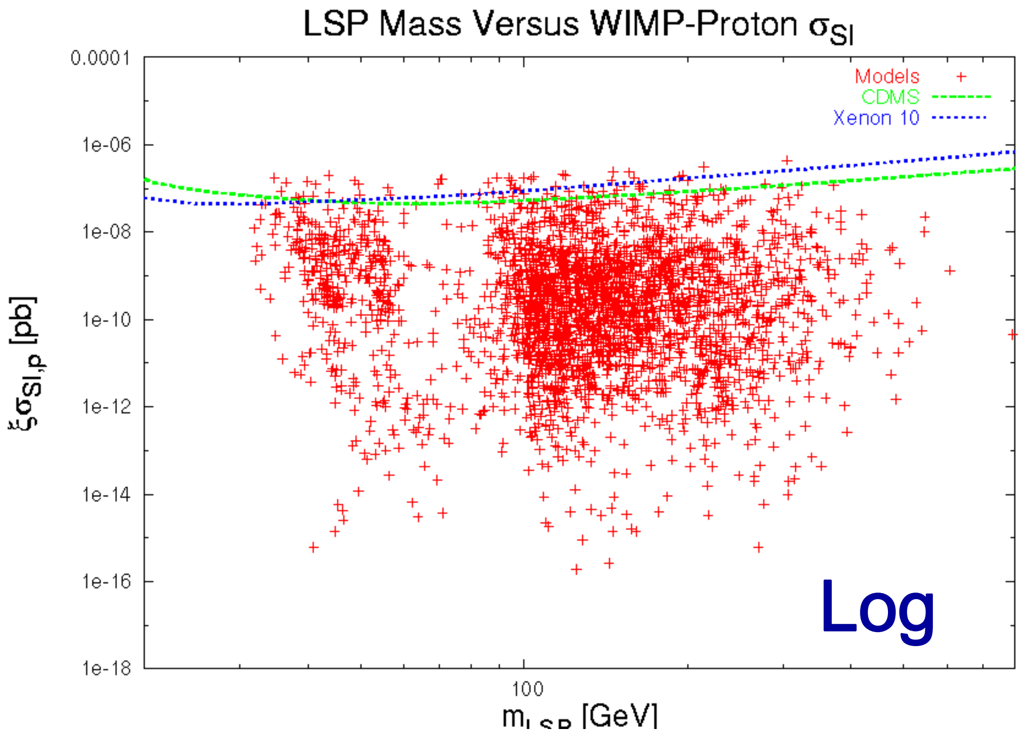

Number of Models with Relic Density in Given Range


Number of Models with Relic Density in Given Range

Direct Detection Expectations

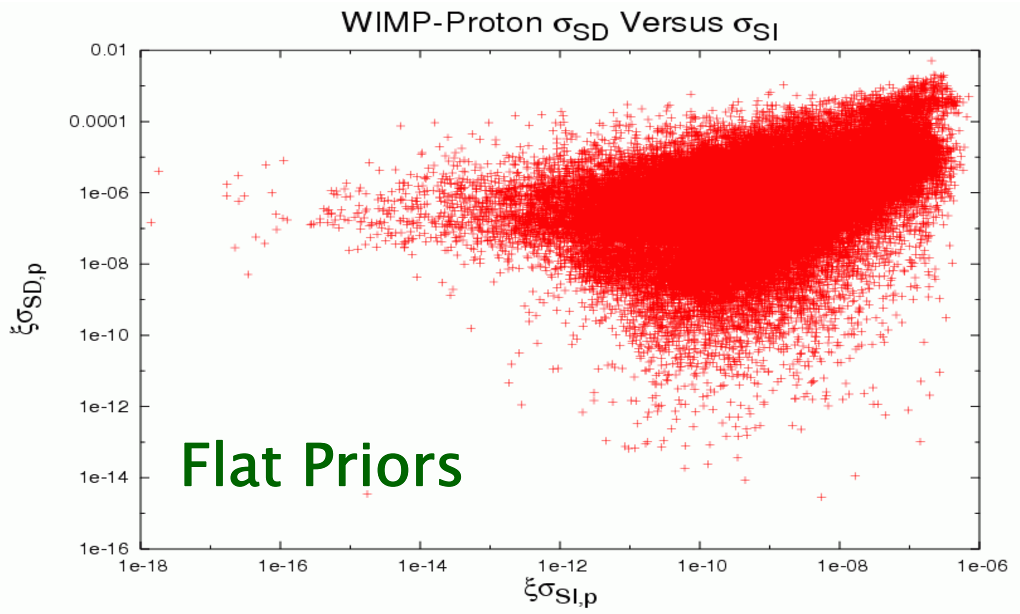
Extremely small cross sections are possible in either the flat or log prior cases…far smaller than expected in, e.g., mSUGRA….



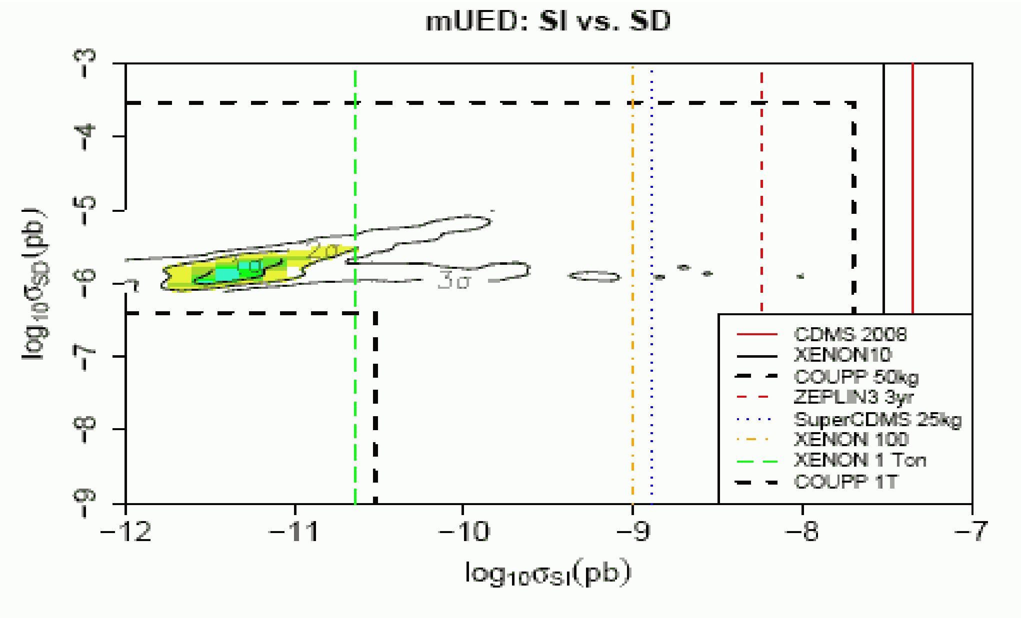


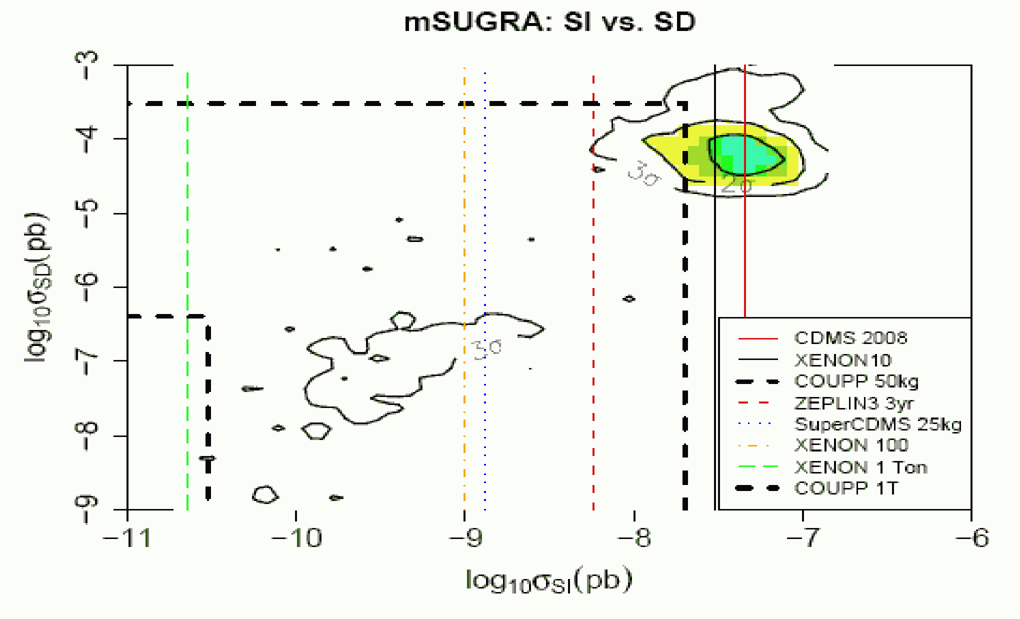
Distinguishing Dark Matter Models

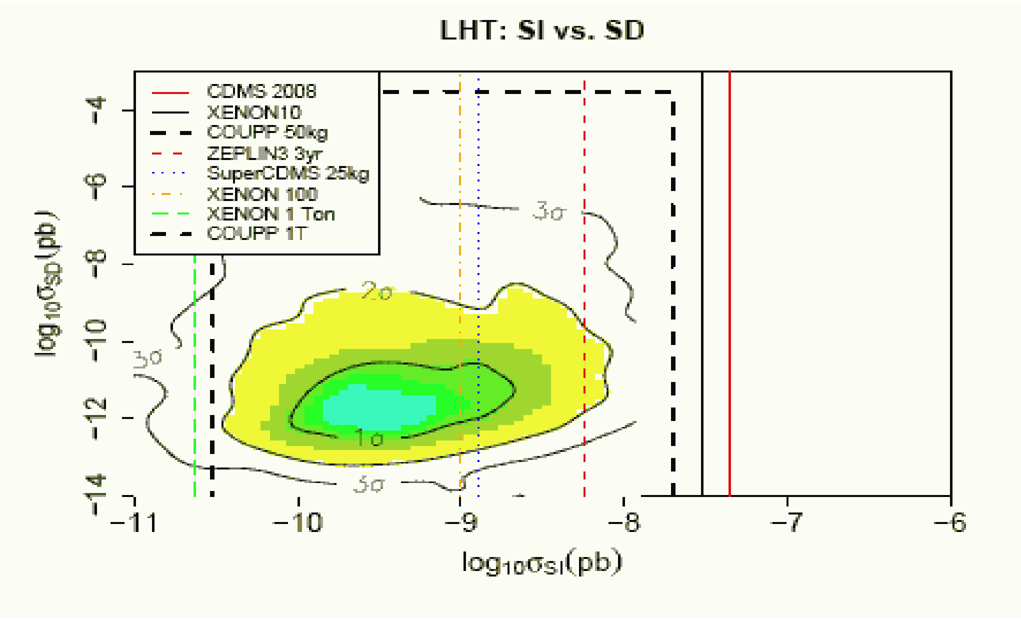
Barger etal



Flat Priors

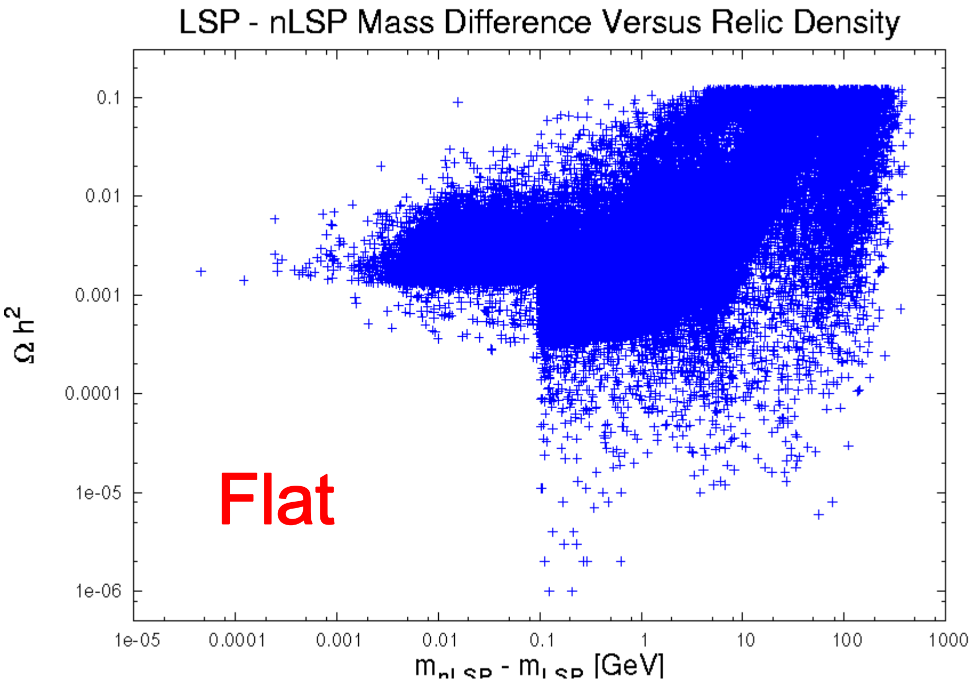


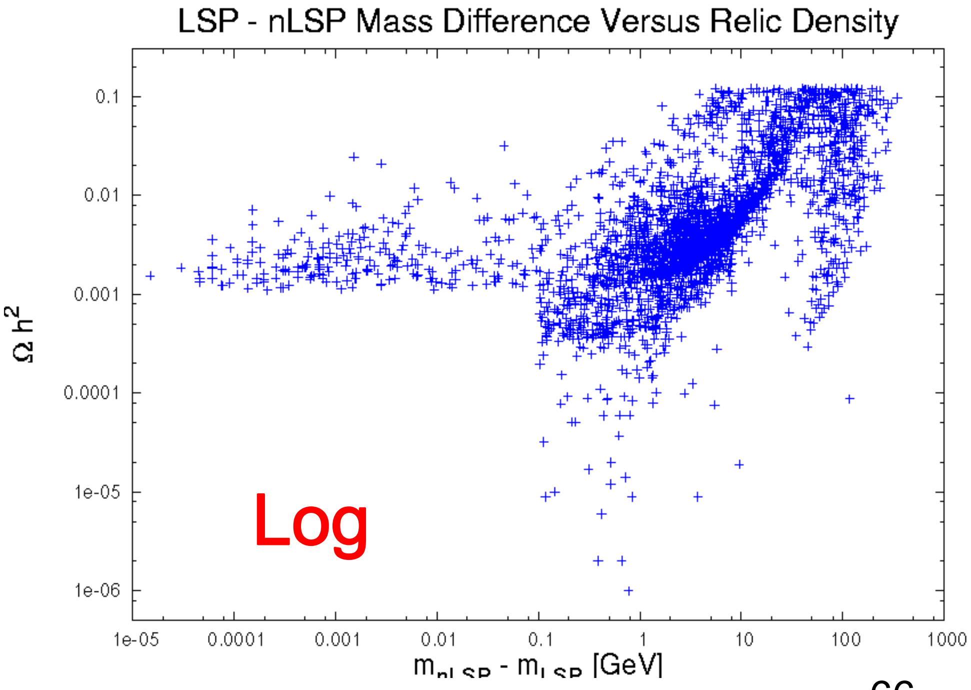




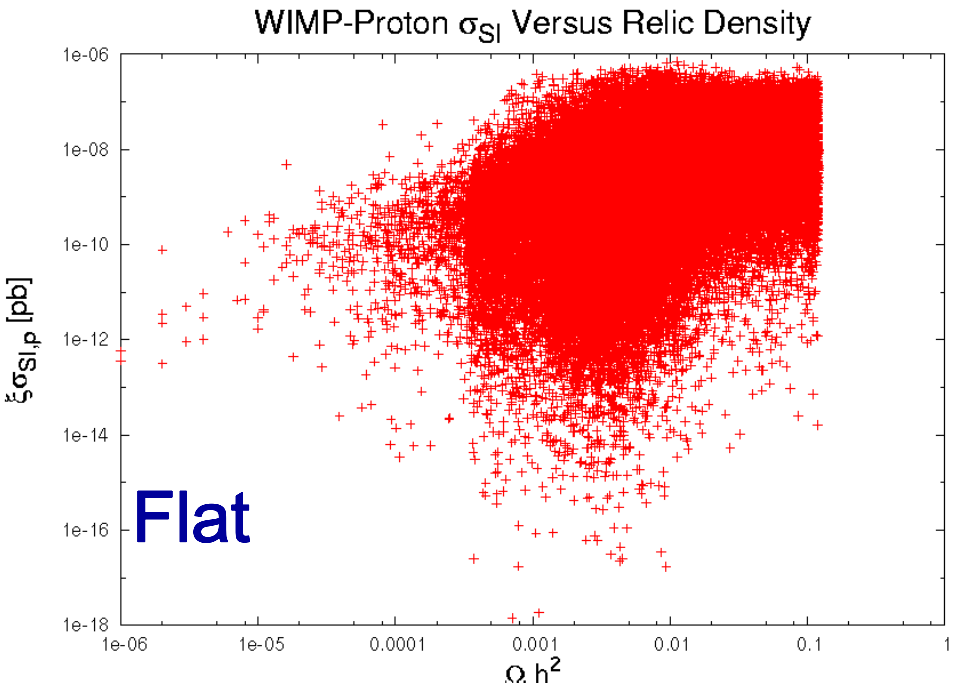
Correlation Between Dark Matter Density & the LSP-nLSP Mass Splitting

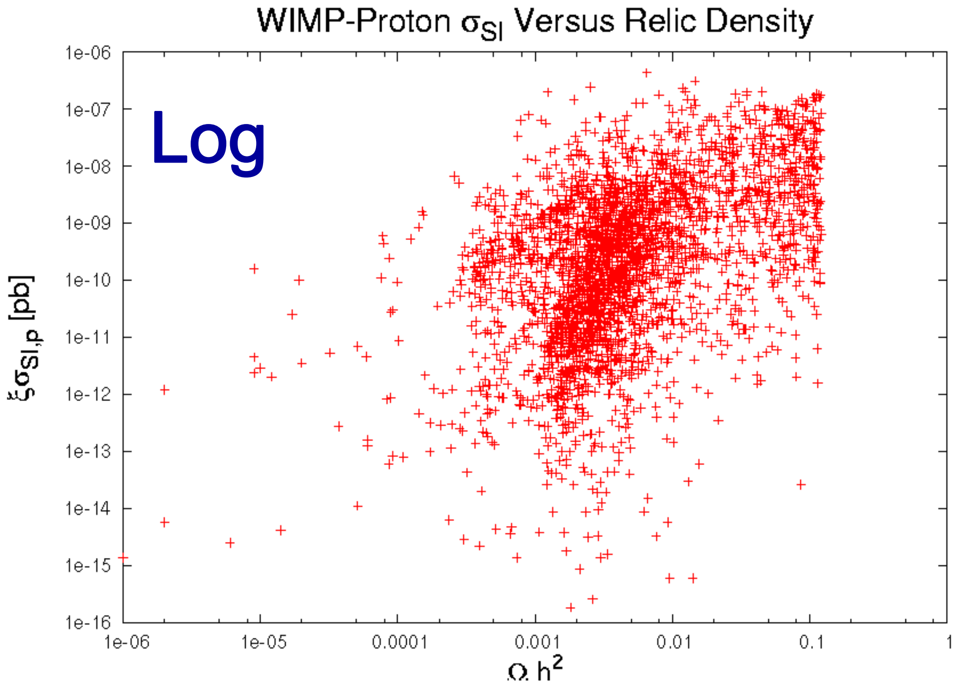
Small mass differences can lead to rapid co-annihilations reducing the dark matter density….



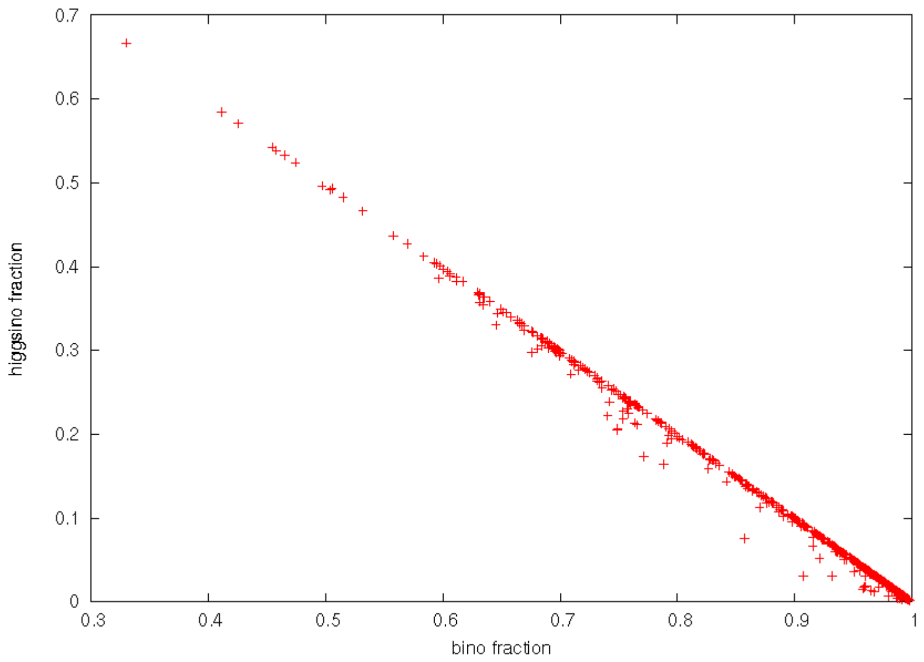


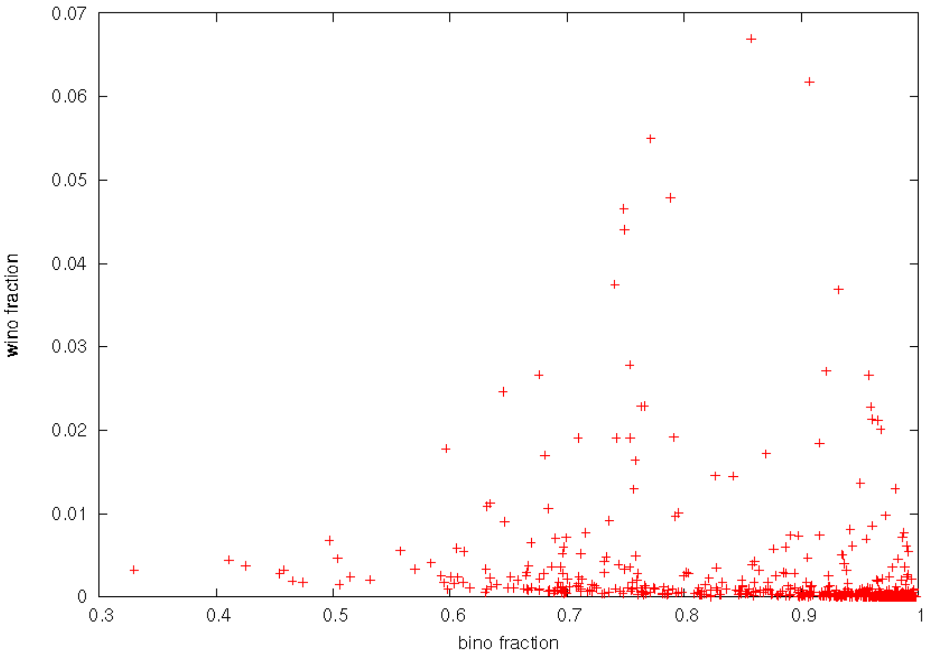
Dark Matter Density Correlation with the Direct Search Cross Section

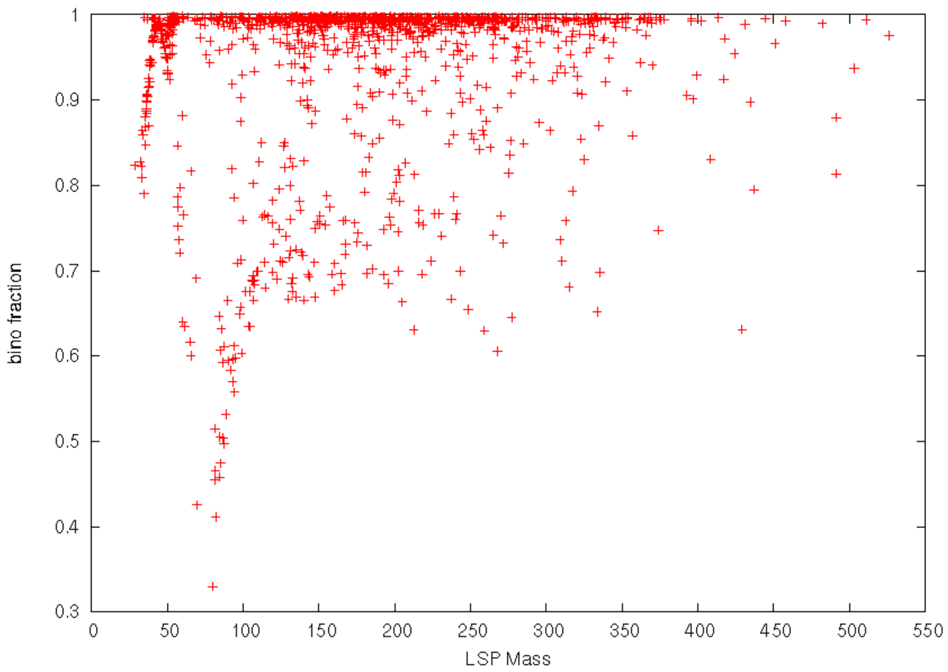


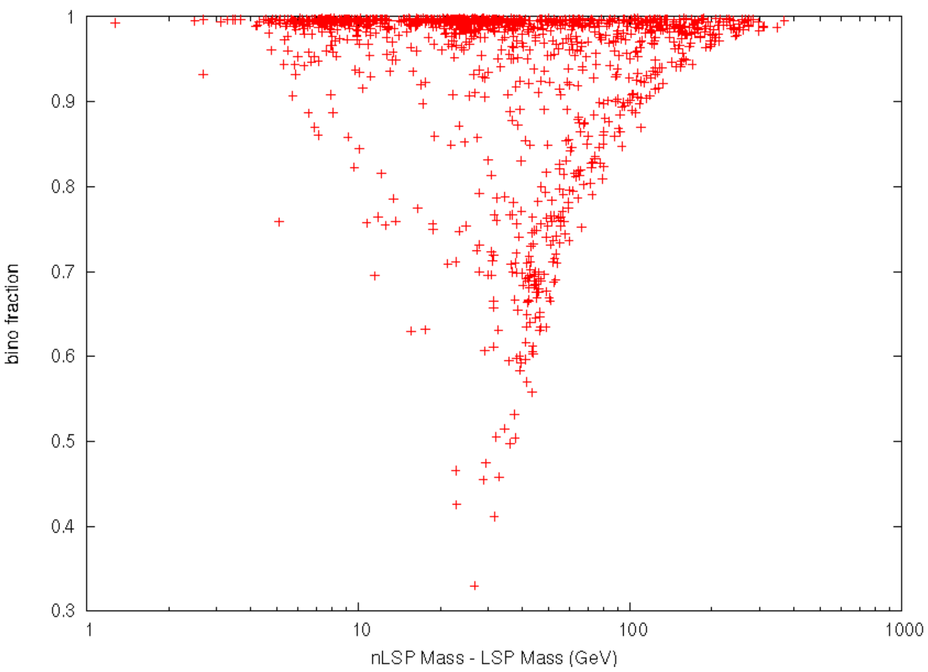


Properties of Models With WMAP Values of Ωh^2

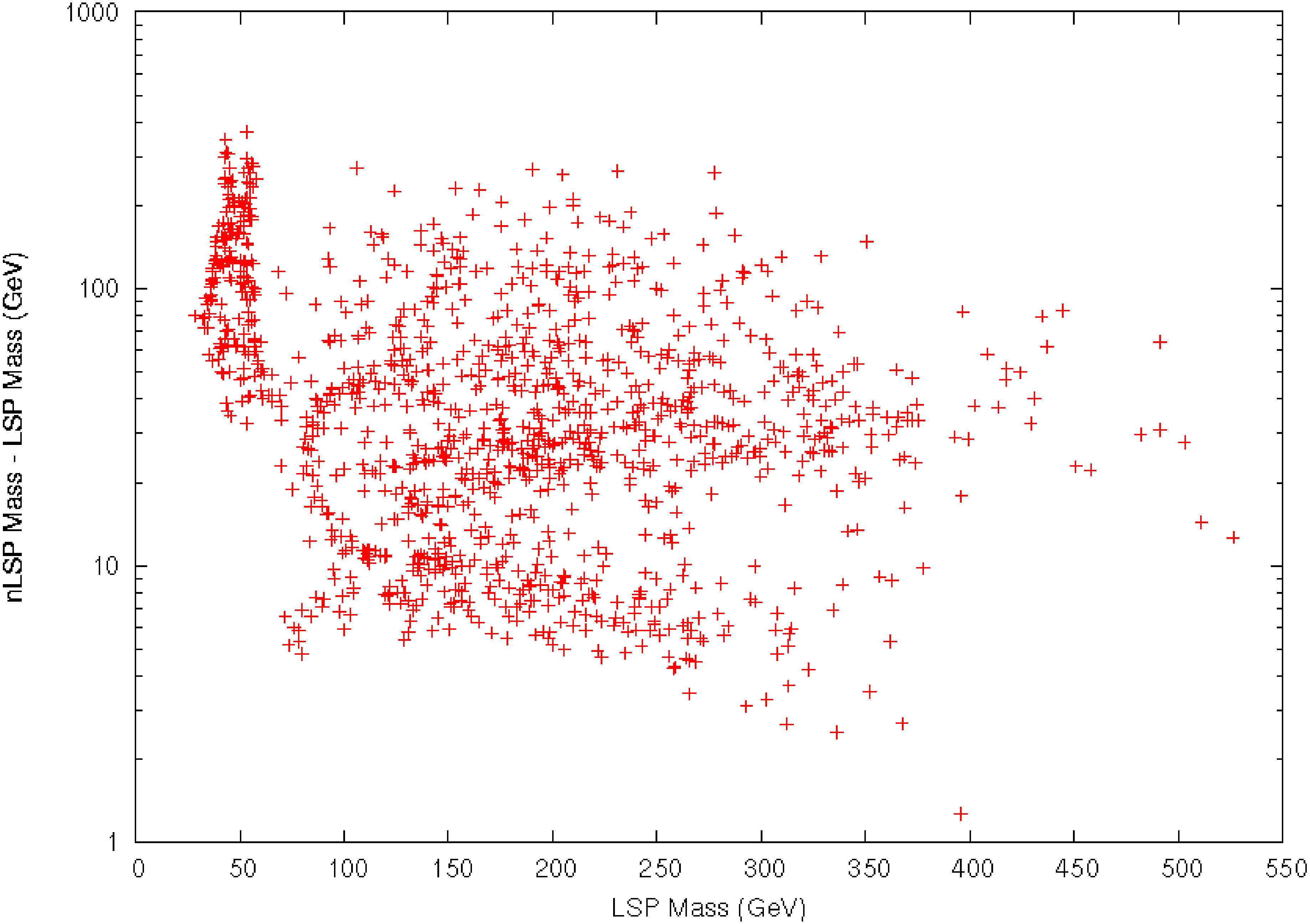








Properties of Models With WMAP Values of Ωh^2



ATLAS	SU1	OK
	SU2	killed by LEP
	SU3	killed by Ωh^2
	SU4	killed by $b \to s\gamma$
	SU8	killed by g-2
CMS	LM1	killed by Higgs
	LM2	killed by g-2
	LM3	killed by $b \to s\gamma$
	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.

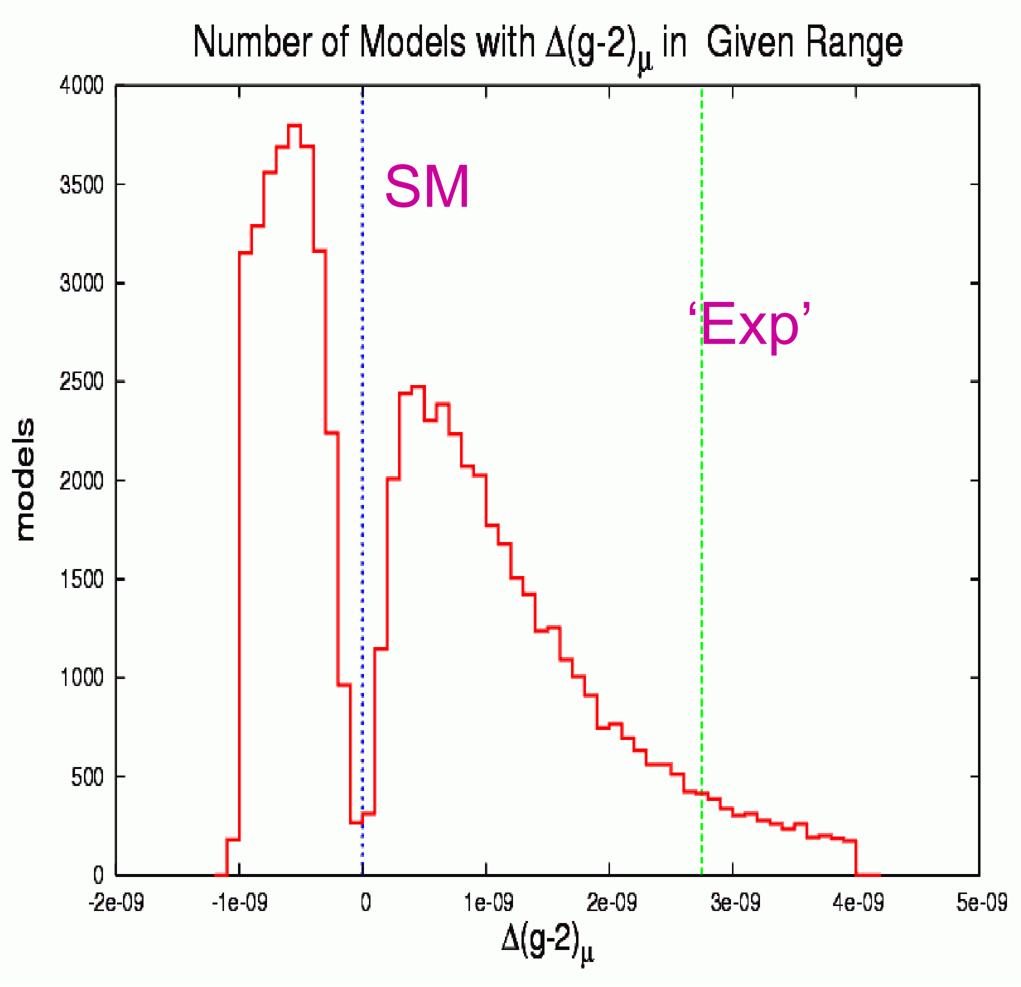
For many models this is not the unique source of failure

Similarly for the SPS Points

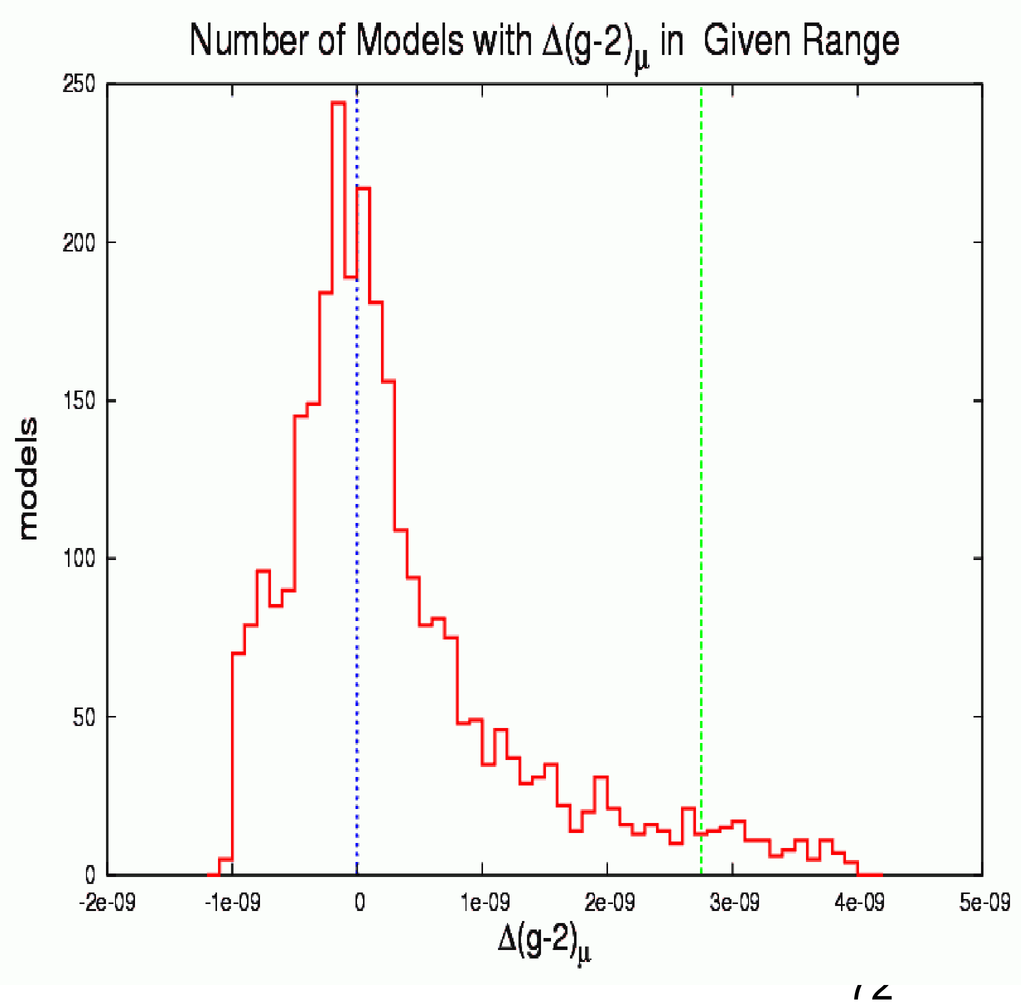
SPS1a	killed by b $\rightarrow s\gamma$
SPS1a’	OK
SPS1b	killed by b $\rightarrow s\gamma$
SPS2	killed by Ωh^2 (GUT) / OK(low)
SPS3	killed by Ωh^2 (low) / OK(GUT)
SPS4	killed by g-2
SPS5	killed by Ωh^2
SPS6	OK
SPS9	killed by Tevatron stable chargino

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

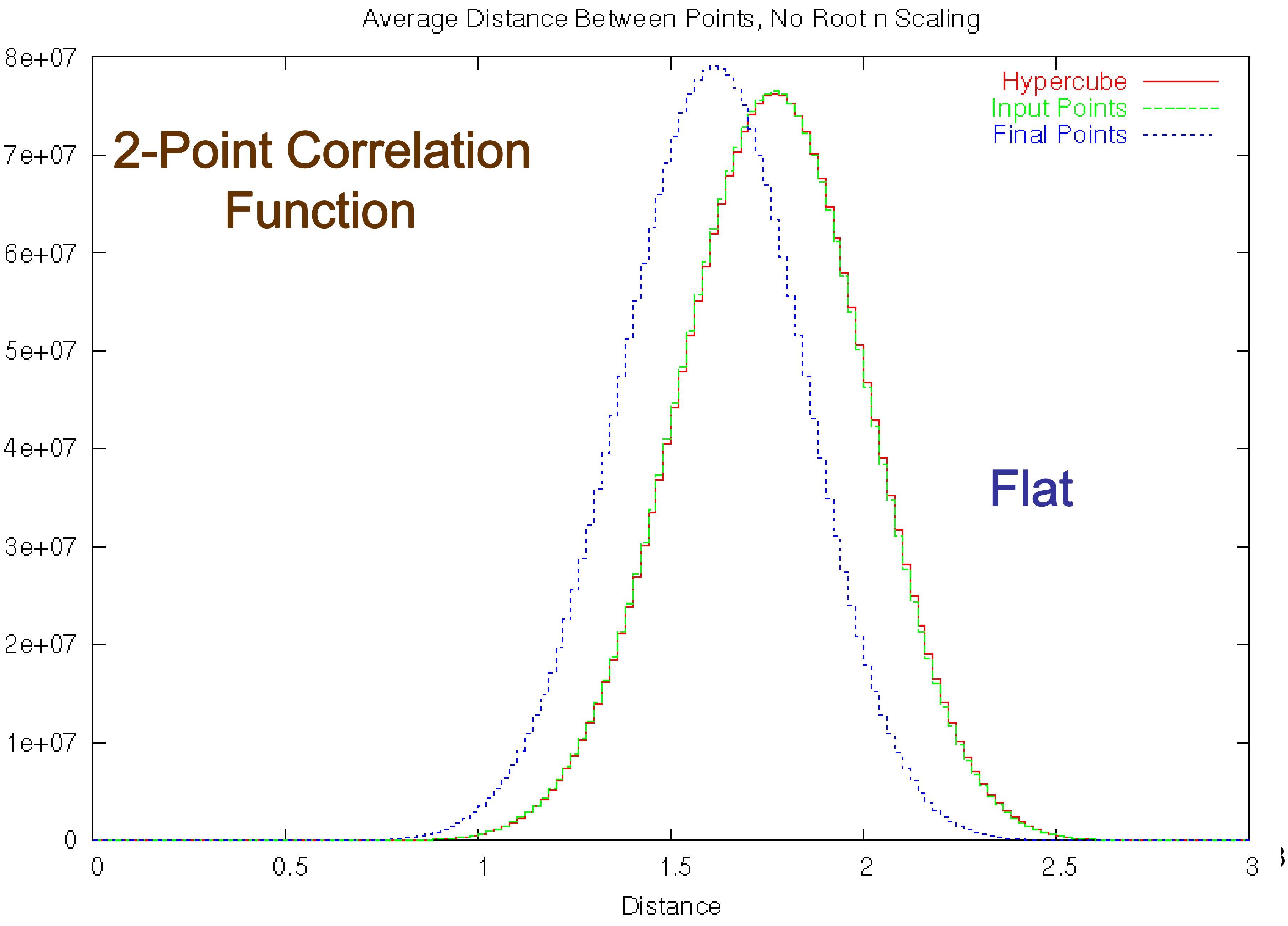
flat



log

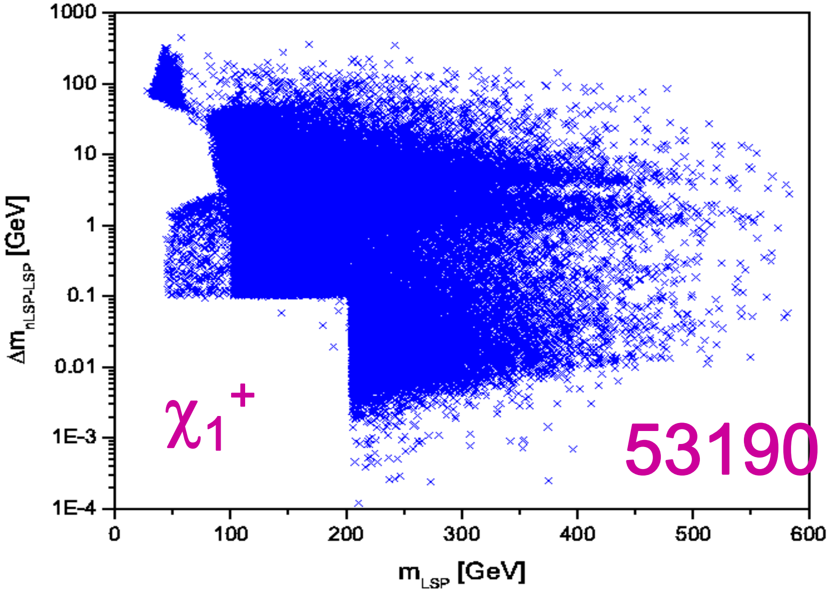


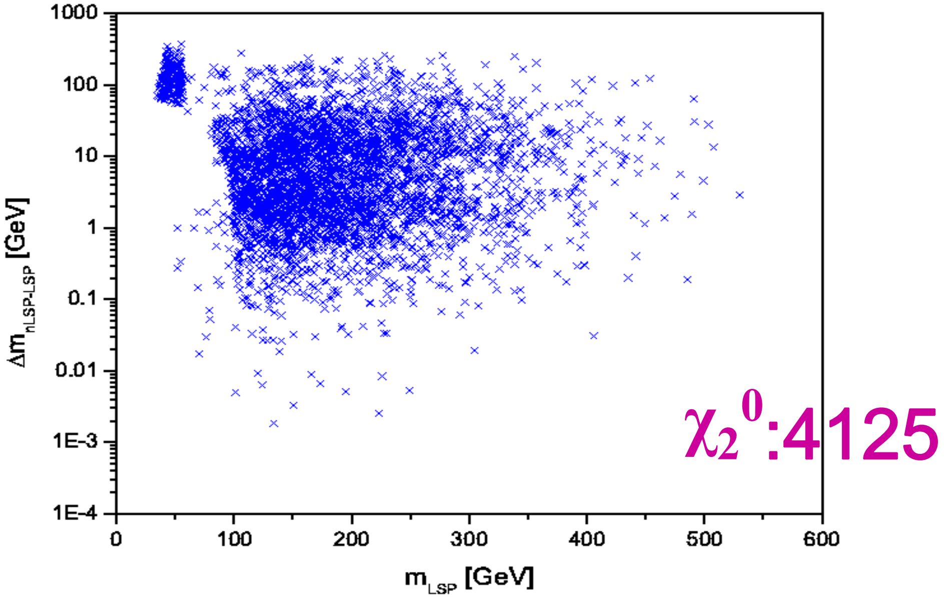
Clustering of Model Points in 19-Dimensional Space

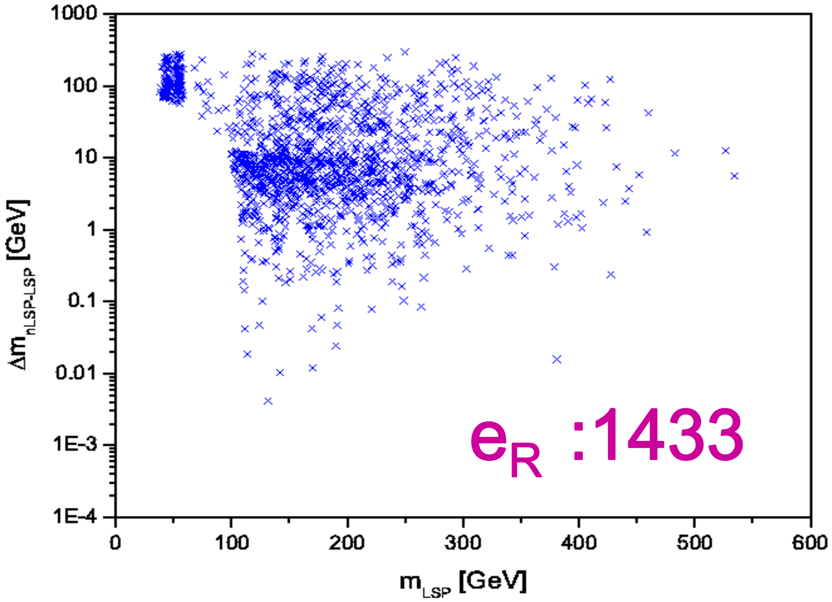


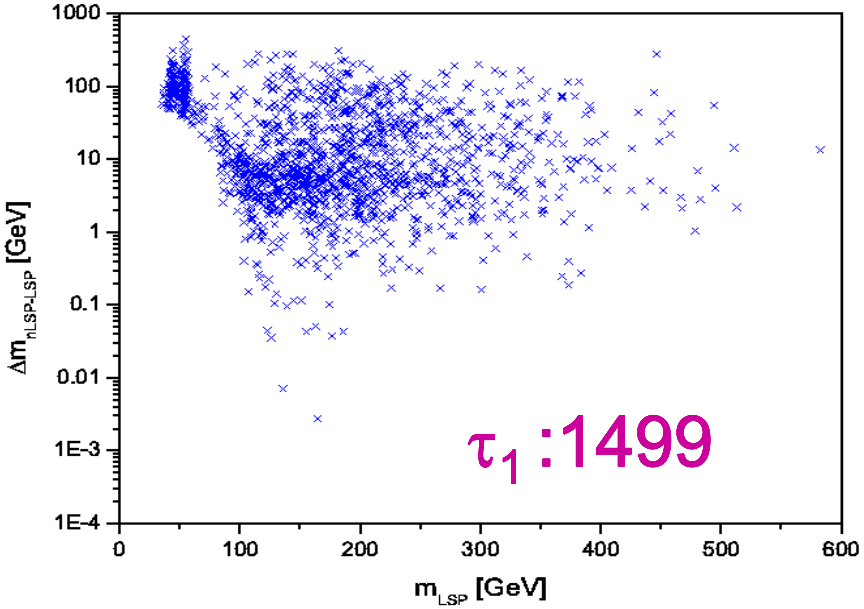
2-Point Correlation Function

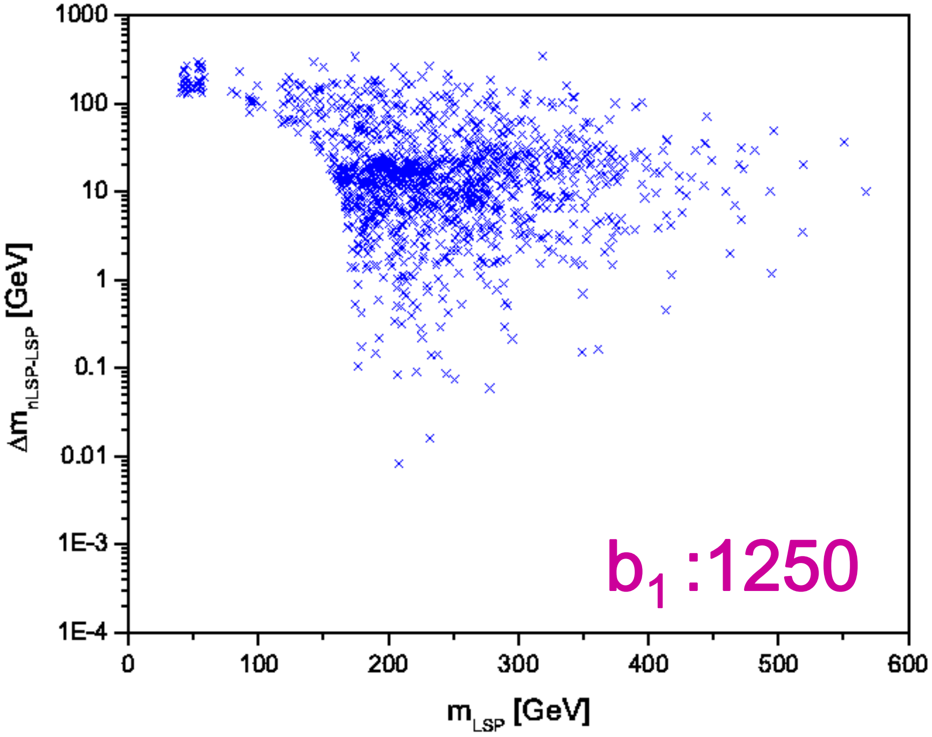
Flat

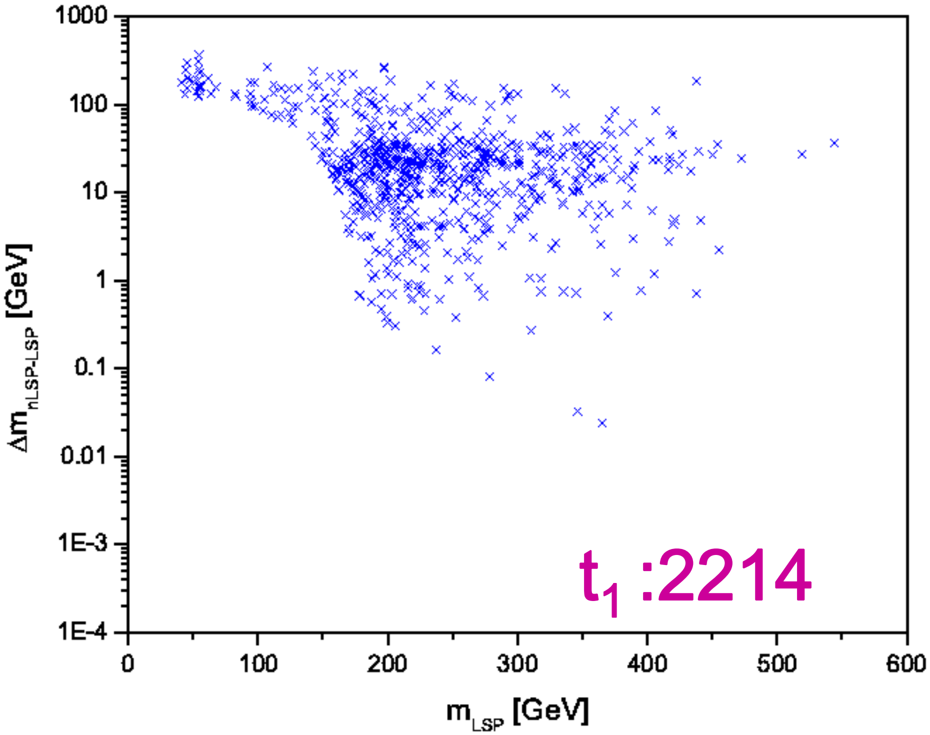

χ_1^+
53190
$\Delta m_{nLSP-LSP}$ [GeV]
m_{LSP} [GeV]
1000
100
10
1
0.1
0.01
1E-3
1E-4
0
100
200
300
400
500
600

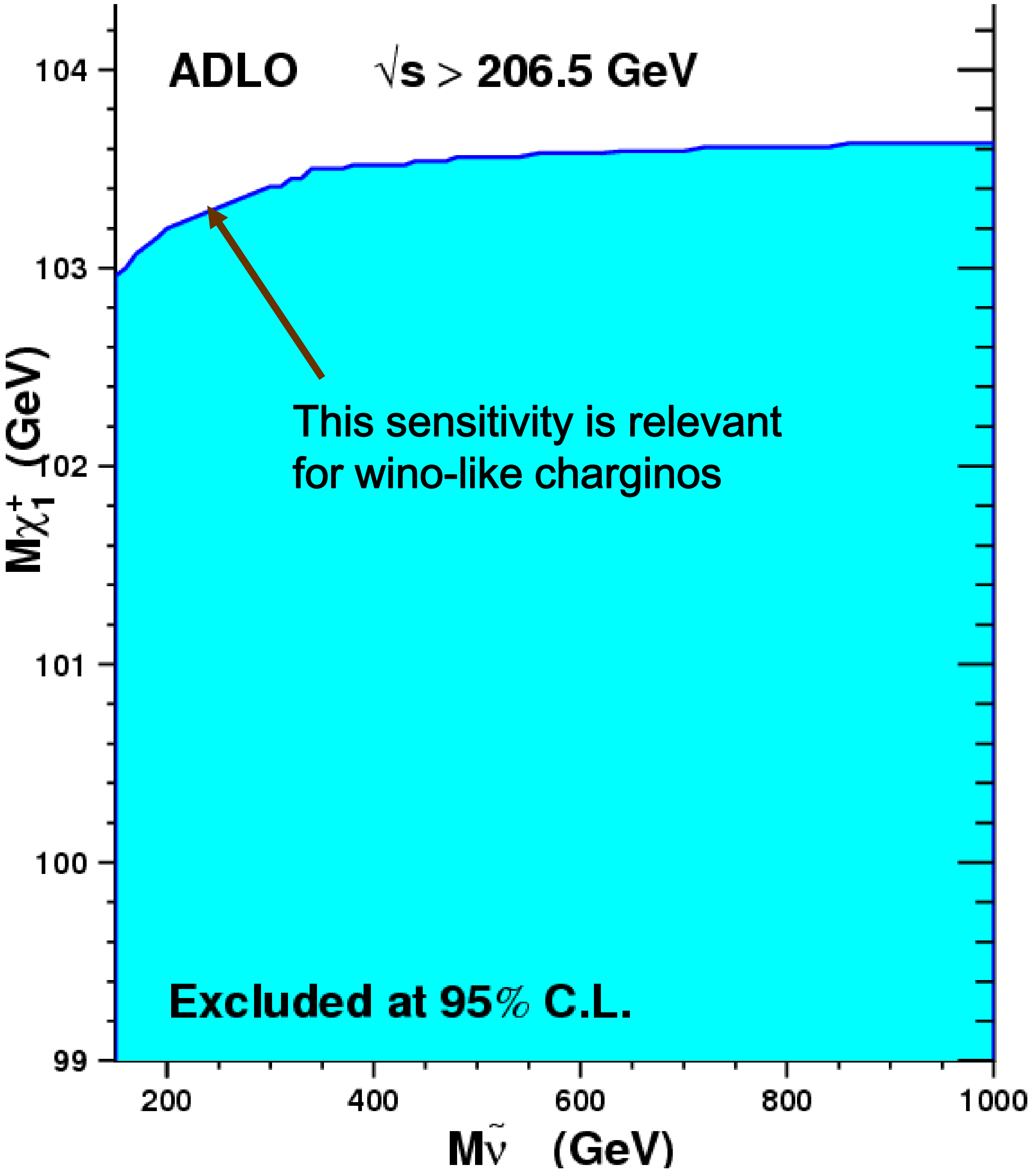

χ_2^0:4125
$\Delta m_{nLSP-LSP}$ [GeV]
m_{LSP} [GeV]
1000
100
10
1
0.1
0.01
1E-3
1E-4
0
100
200
300
400
500
600


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


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


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

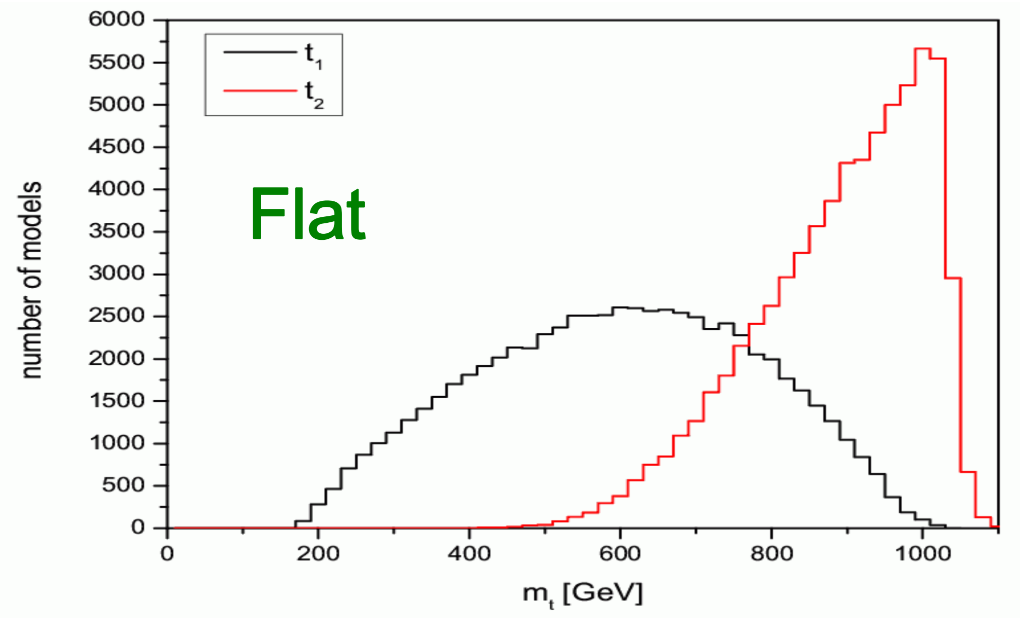


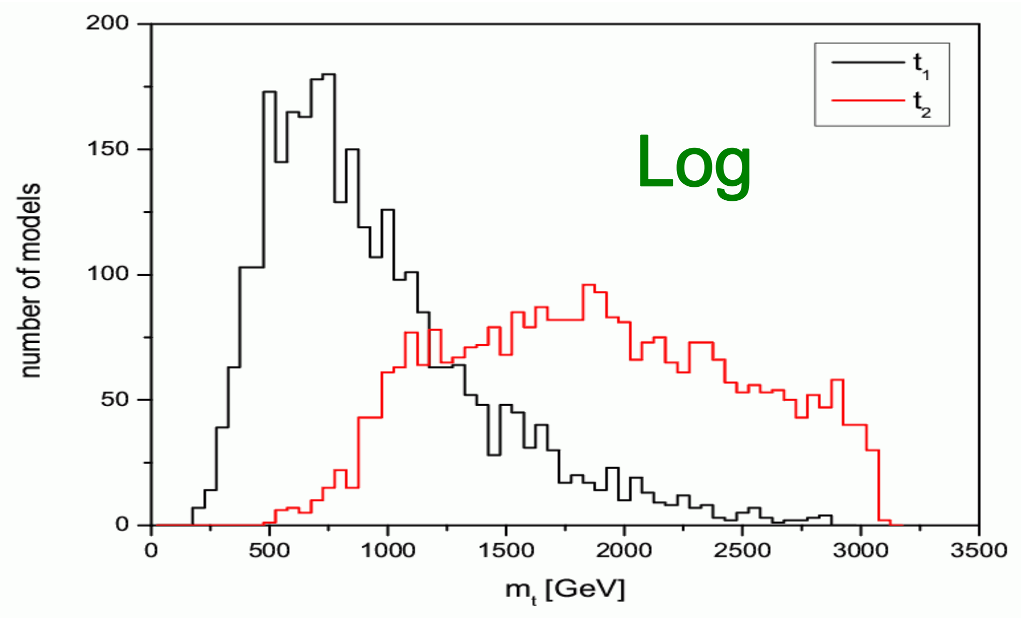
Large mass gap chargino search

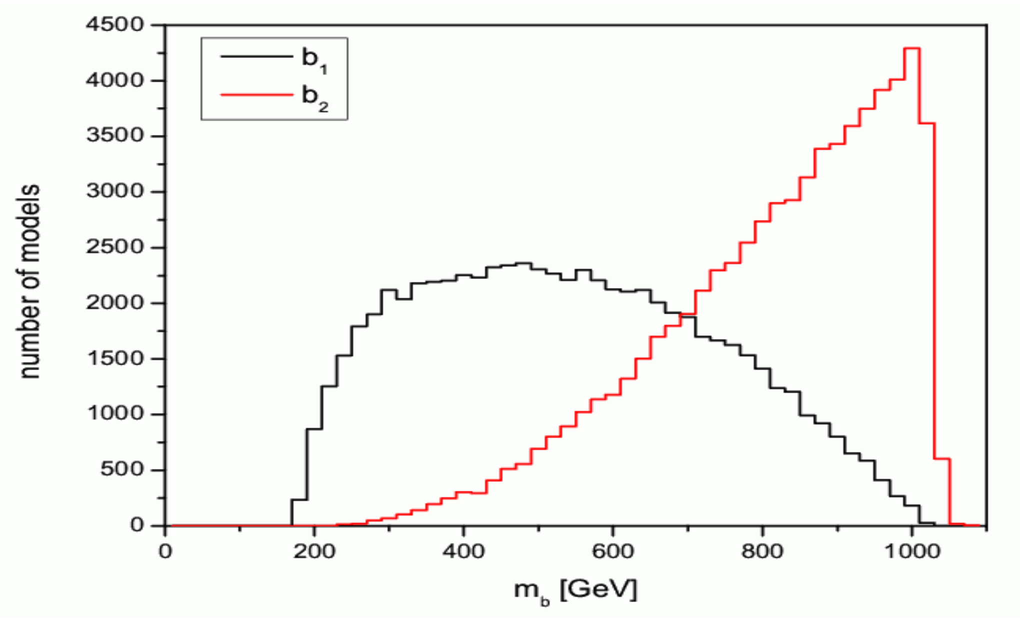
Depends on the sneutrino mass in the t-channel if less than ~ 160 GeV due to interference if large wino content

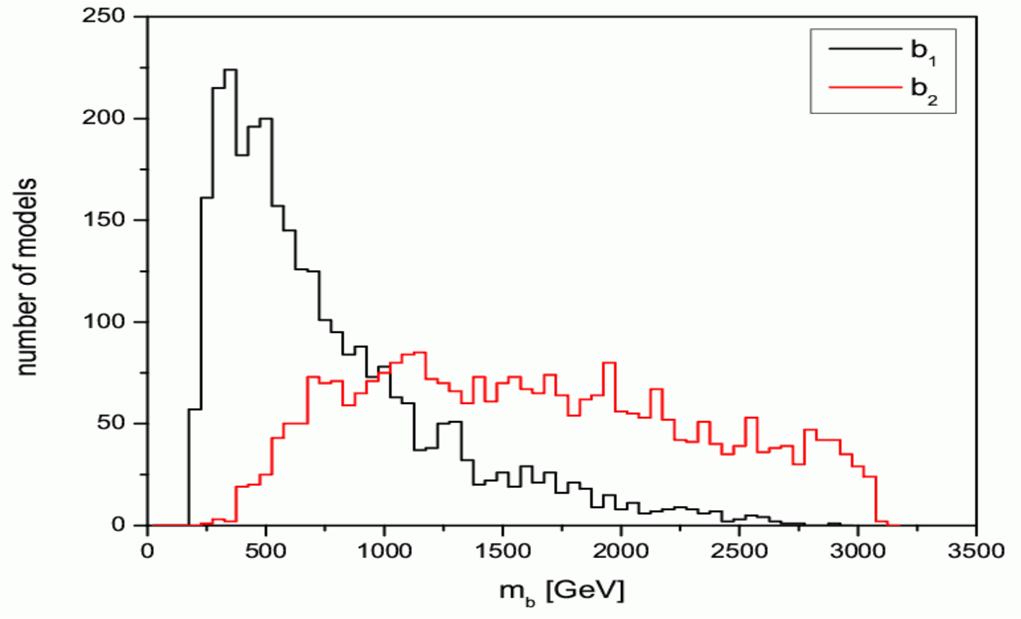
Some 'light' charginos may slip through as search reach is degraded

Distribution of Sparticle Masses By Species









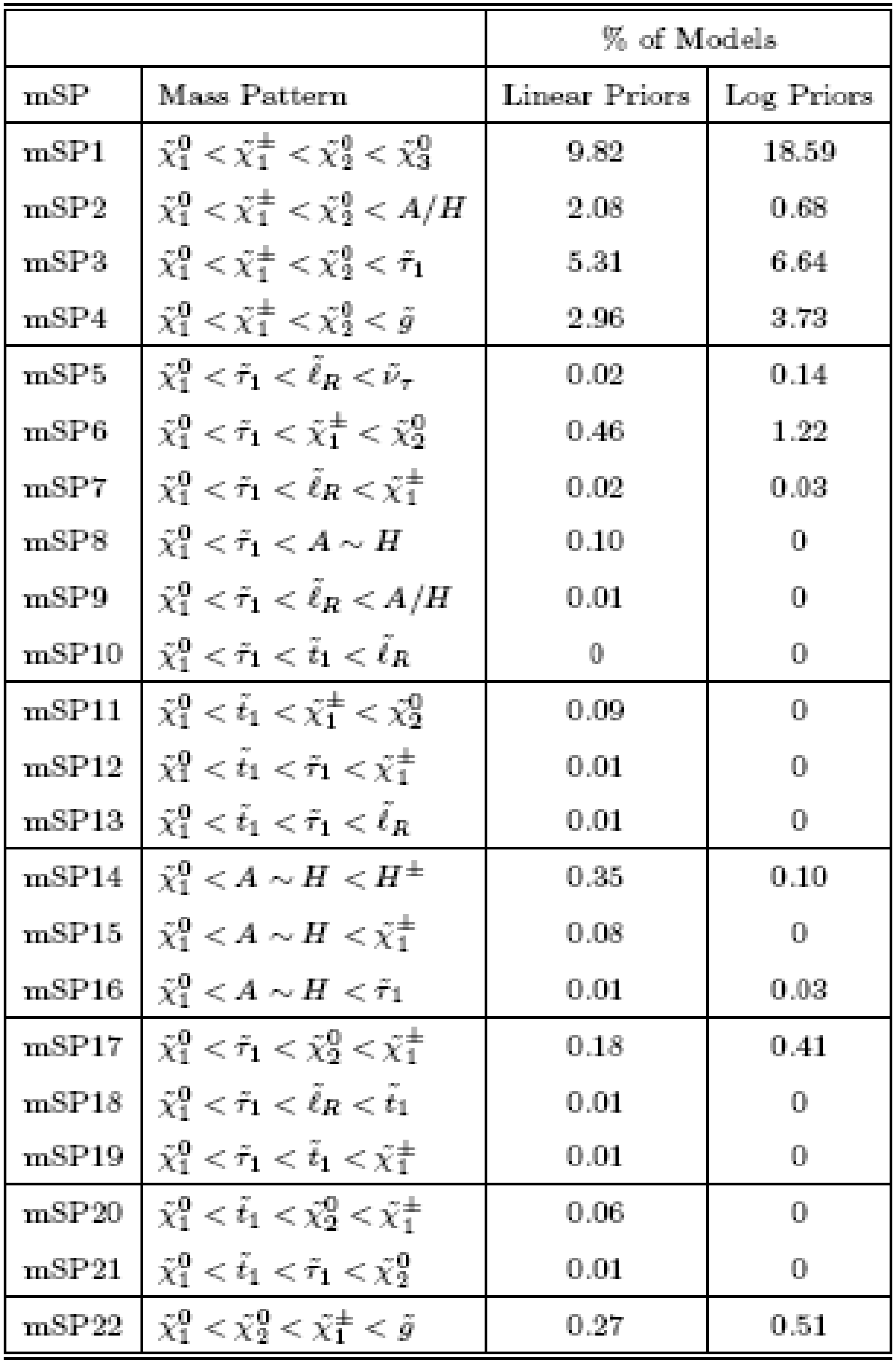
Cascade Failure: Typical Analyses May Require Changes

$$\tilde{g} \rightarrow q'\bar{q}\tilde{\chi}_1^{\pm}\,, \quad \tilde{\chi}_1^{\pm} \rightarrow W^{\pm}\tilde{\chi}_1^{0} \rightarrow l^{\pm}\,\nu\tilde{\chi}_1^{0}$$

This is a typical mSUGRA cascade leading to 2l+4j+MET from gluino pair production. But in many of our models the W will be far off-shell & the resulting lepton will be too soft. This will then appear as 4j+MET unless the chargino is long-lived in which case we observe 4j +2 long-lived charged particles with no MET.

Something similar happens when the 2nd neutralino is close in mass to the LSP as the 2nd neutralino decay products may all be missed since they can be very soft; this looks like 4j+MET

$$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_2^{0}\,, \quad \tilde{\chi}_2^{0} \rightarrow Z\tilde{\chi}_1^{0} \rightarrow l^{+}l^{-}\,\nu\tilde{\chi}_1^{0}$$



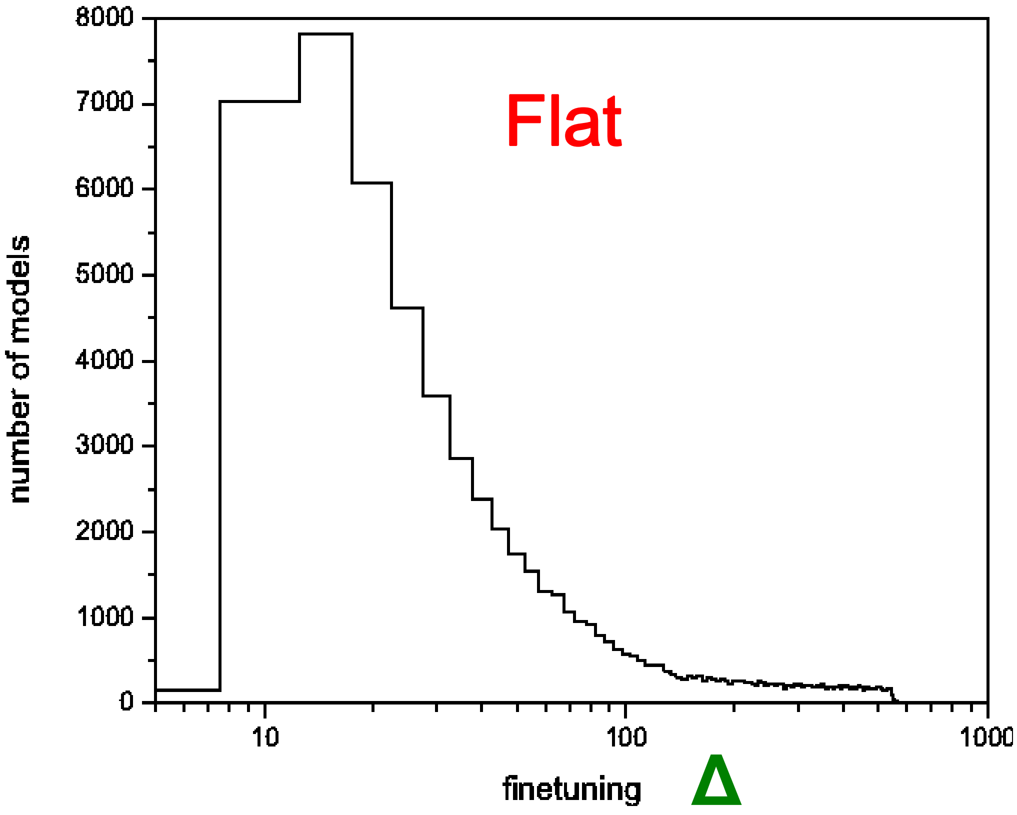
		% of Models	
mSP	Mass Pattern	Linear Priors	Log Priors
mSP1	$\tilde{\chi}_1^0 < \tilde{\chi}_1^\pm < \tilde{\chi}_2^0 < \tilde{\chi}_3^0$	9.82	18.59
mSP2	$\tilde{\chi}_1^0 < \tilde{\chi}_1^\pm < \tilde{\chi}_2^0 < A/H$	2.08	0.68
mSP3	$\tilde{\chi}_1^0 < \tilde{\chi}_1^\pm < \tilde{\chi}_2^0 < \tilde{\tau}_1$	5.31	6.64
mSP4	$\tilde{\chi}_1^0 < \tilde{\chi}_1^\pm < \tilde{\chi}_2^0 < \tilde{g}$	2.96	3.73
mSP5	$\tilde{\chi}_1^0 < \tilde{\tau}_1 < \tilde{\ell}_R < \tilde{\nu}_\tau$	0.02	0.14
mSP6	$\tilde{\chi}_1^0 < \tilde{\tau}_1 < \tilde{\chi}_1^\pm < \tilde{\chi}_2^0$	0.46	1.22
mSP7	$\tilde{\chi}_1^0 < \tilde{\tau}_1 < \tilde{\ell}_R < \tilde{\chi}_1^\pm$	0.02	0.03
mSP8	$\tilde{\chi}_1^0 < \tilde{\tau}_1 < A \sim H$	0.10	0
mSP9	$\tilde{\chi}_1^0 < \tilde{\tau}_1 < \tilde{\ell}_R < A/H$	0.01	0
mSP10	$\tilde{\chi}_1^0 < \tilde{\tau}_1 < \tilde{t}_1 < \tilde{\ell}_R$	0	0
mSP11	$\tilde{\chi}_1^0 < \tilde{t}_1 < \tilde{\chi}_1^\pm < \tilde{\chi}_2^0$	0.09	0
mSP12	$\tilde{\chi}_1^0 < \tilde{t}_1 < \tilde{\tau}_1 < \tilde{\chi}_1^\pm$	0.01	0
mSP13	$\tilde{\chi}_1^0 < \tilde{t}_1 < \tilde{\tau}_1 < \tilde{\ell}_R$	0.01	0
mSP14	$\tilde{\chi}_1^0 < A \sim H < H^\pm$	0.35	0.10
mSP15	$\tilde{\chi}_1^0 < A \sim H < \tilde{\chi}_1^\pm$	0.08	0
mSP16	$\tilde{\chi}_1^0 < A \sim H < \tilde{\tau}_1$	0.01	0.03
mSP17	$\tilde{\chi}_1^0 < \tilde{\tau}_1 < \tilde{\chi}_2^0 < \tilde{\chi}_1^\pm$	0.18	0.41
mSP18	$\tilde{\chi}_1^0 < \tilde{\tau}_1 < \tilde{\ell}_R < \tilde{t}_1$	0.01	0
mSP19	$\tilde{\chi}_1^0 < \tilde{\tau}_1 < \tilde{t}_1 < \tilde{\chi}_1^\pm$	0.01	0
mSP20	$\tilde{\chi}_1^0 < \tilde{t}_1 < \tilde{\chi}_2^0 < \tilde{\chi}_1^\pm$	0.06	0
mSP21	$\tilde{\chi}_1^0 < \tilde{t}_1 < \tilde{\tau}_1 < \tilde{\chi}_2^0$	0.01	0
mSP22	$\tilde{\chi}_1^0 < \tilde{\chi}_2^0 < \tilde{\chi}_1^\pm < \tilde{g}$	0.27	0.51

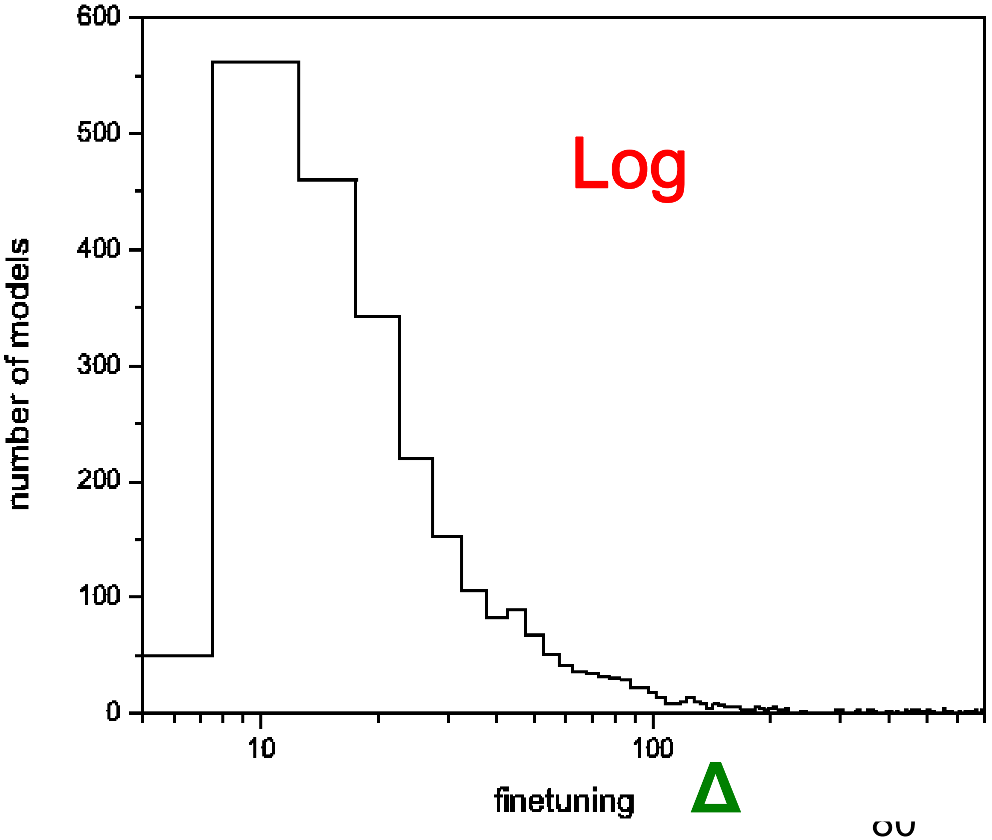
Frequency of the 'most common' mSUGRA mass patterns (which are rank ordered according to P. Nath et .al.) found in our flat and log prior model samples

Many are rare & some do not occur at all at this level of statistics !

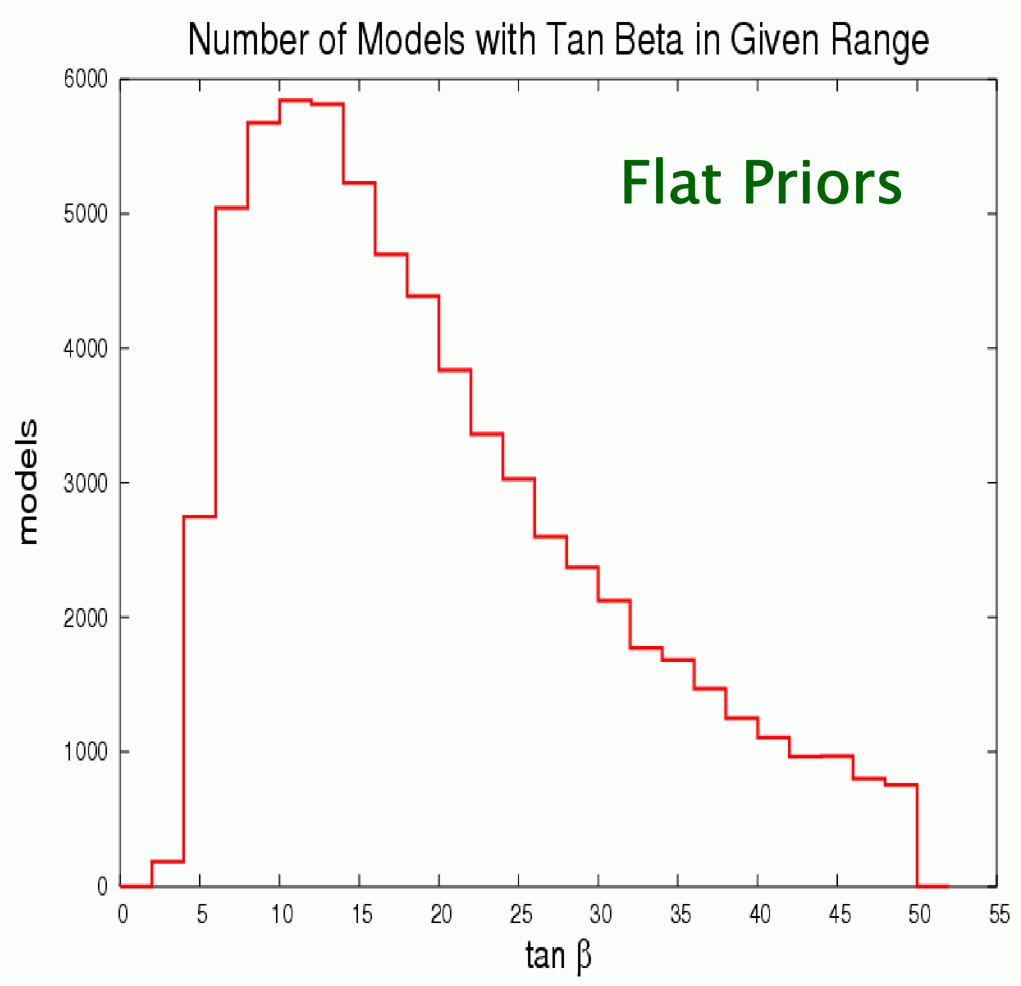
‘Fine-Tuning’ or Naturalness Criterion

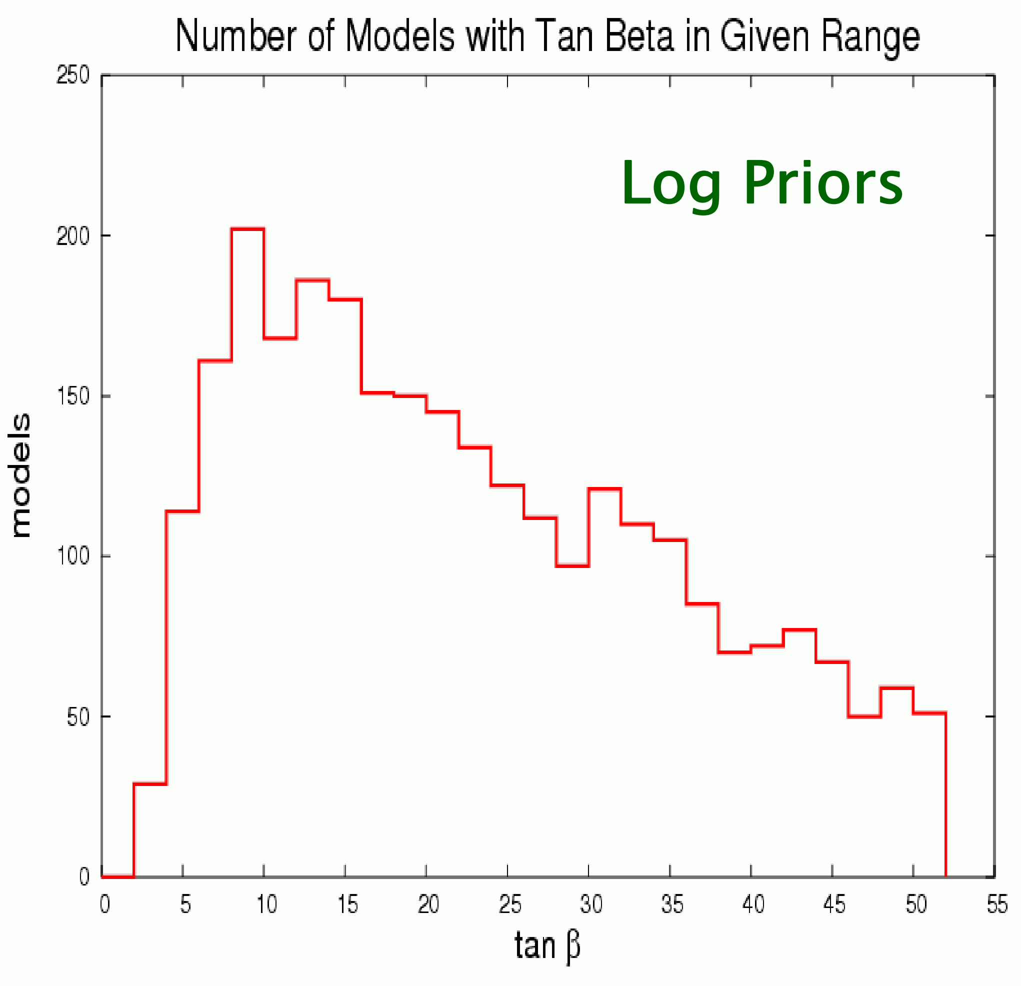
We find that small values of `fine-tuning’ are very common !





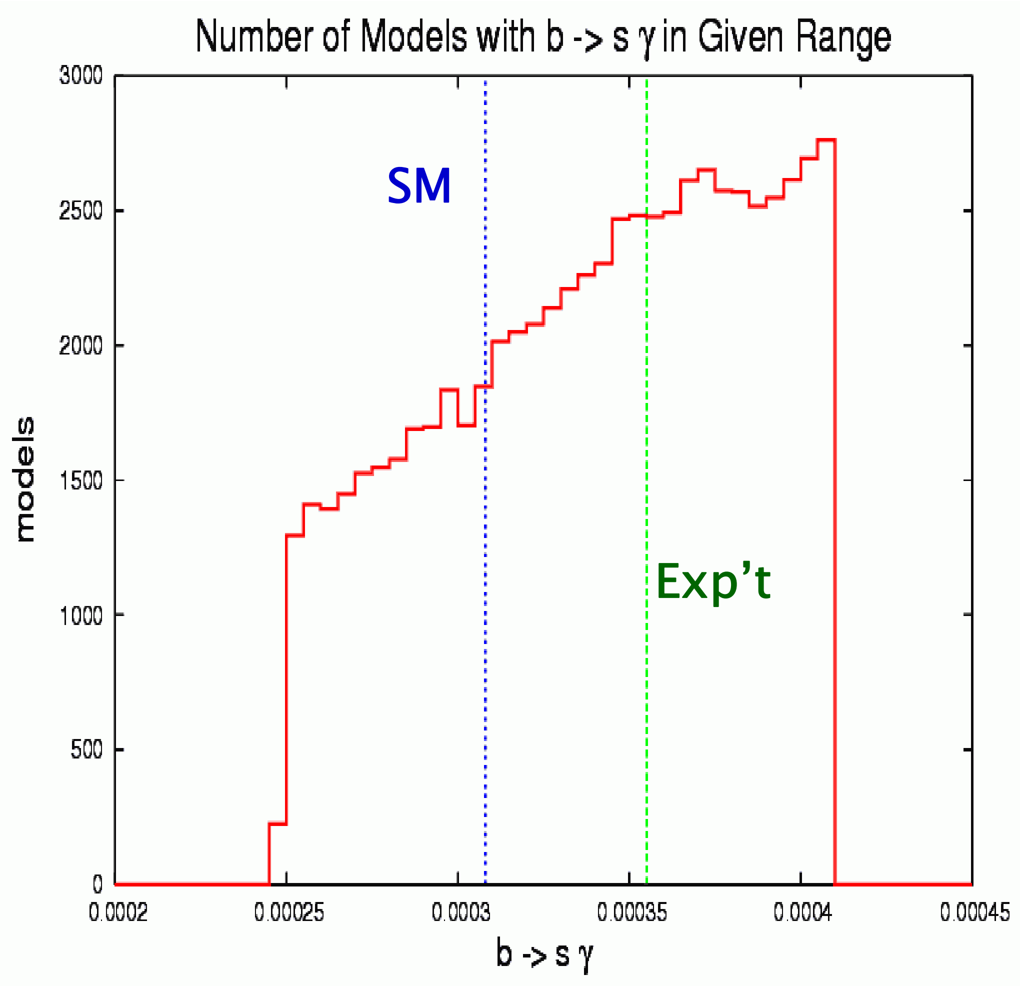
Distribution for tan beta



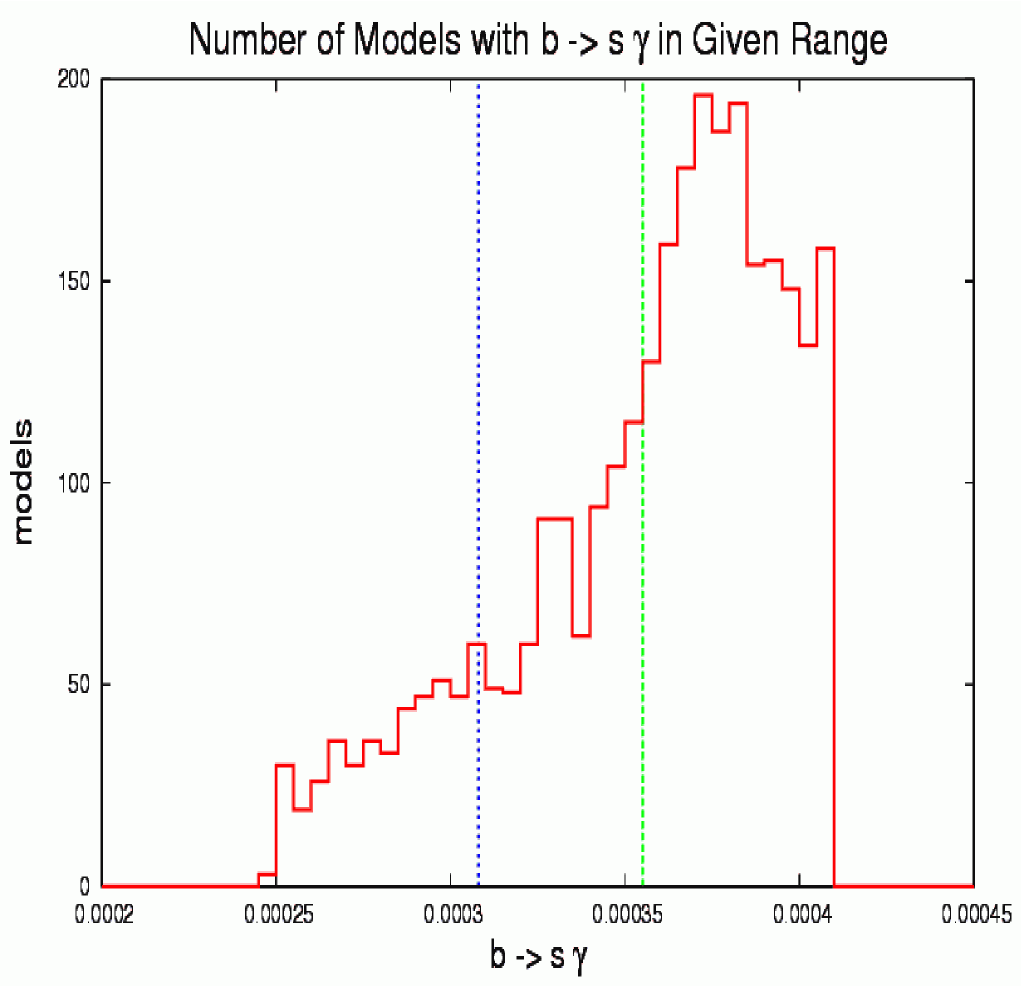


Predictions for b→sγ

Flat Priors

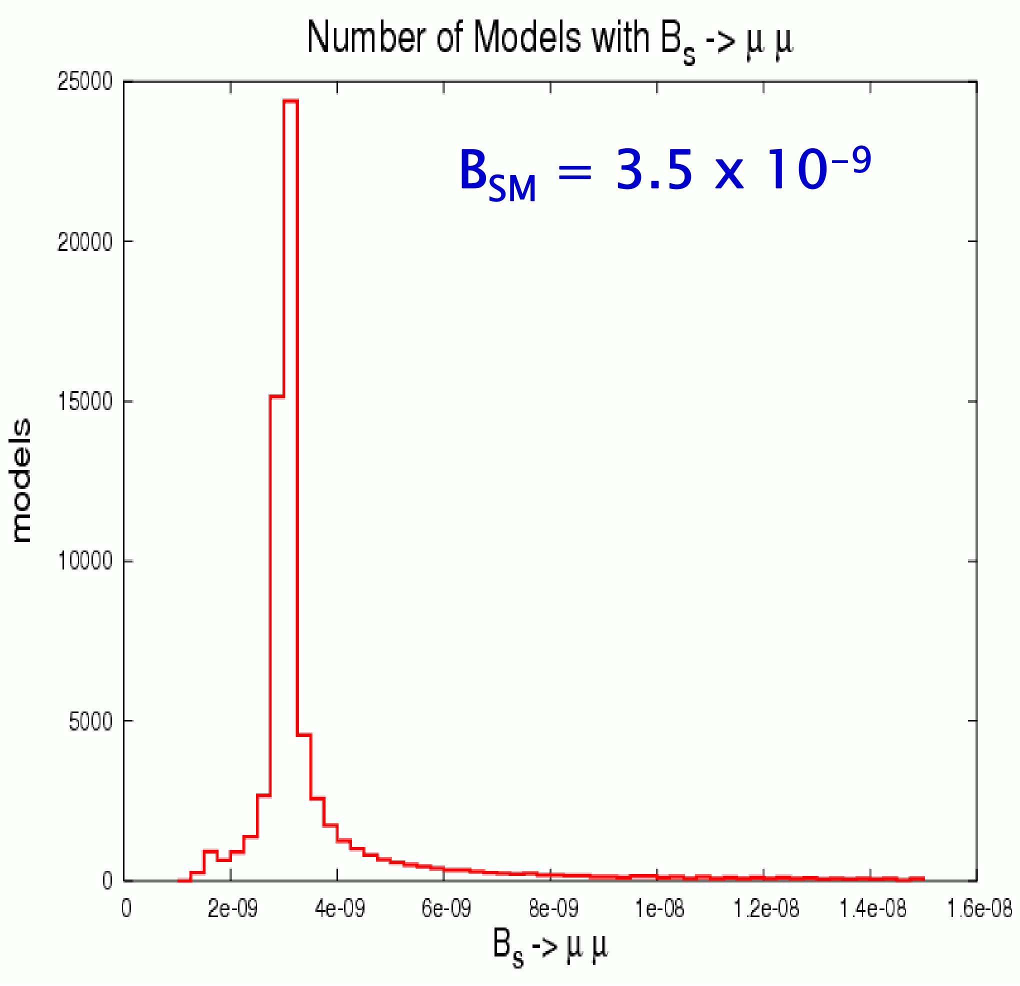


Log Priors



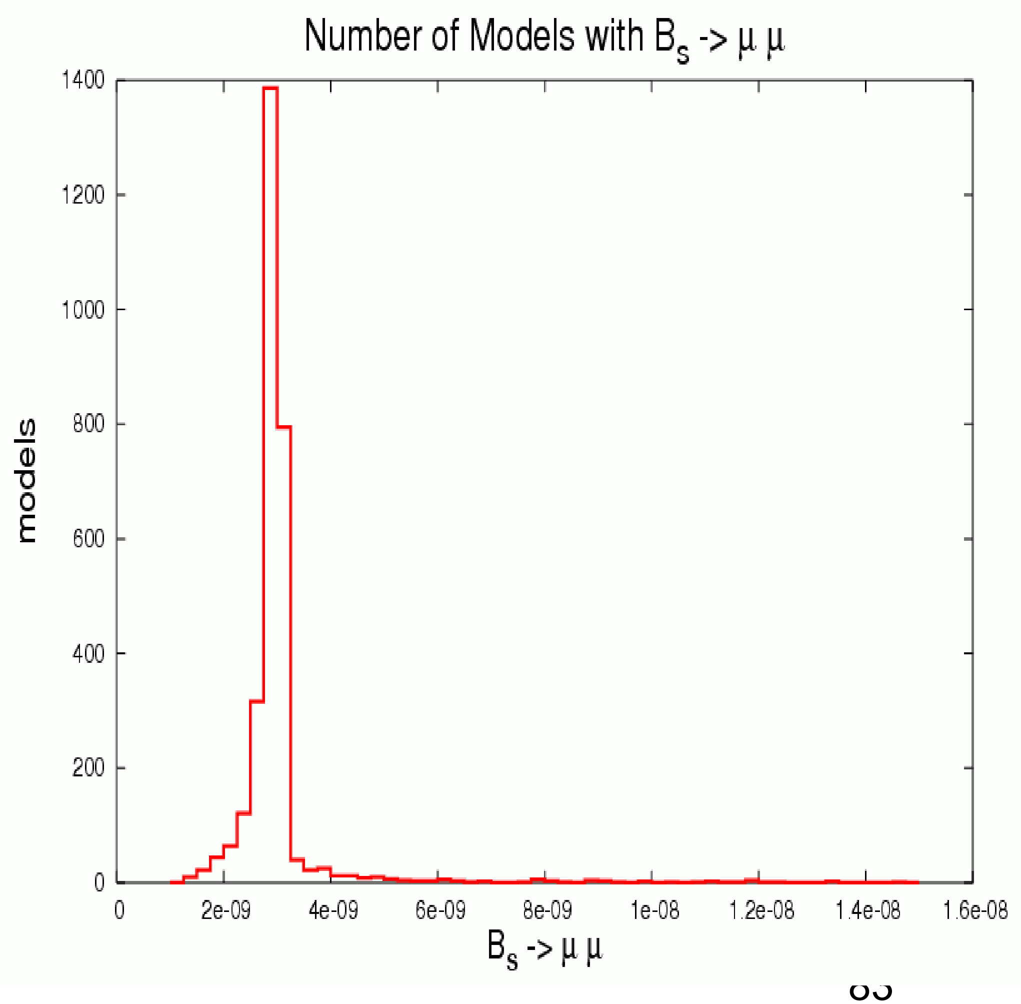
Predictions for $B_s \rightarrow \mu\mu$

Flat Priors

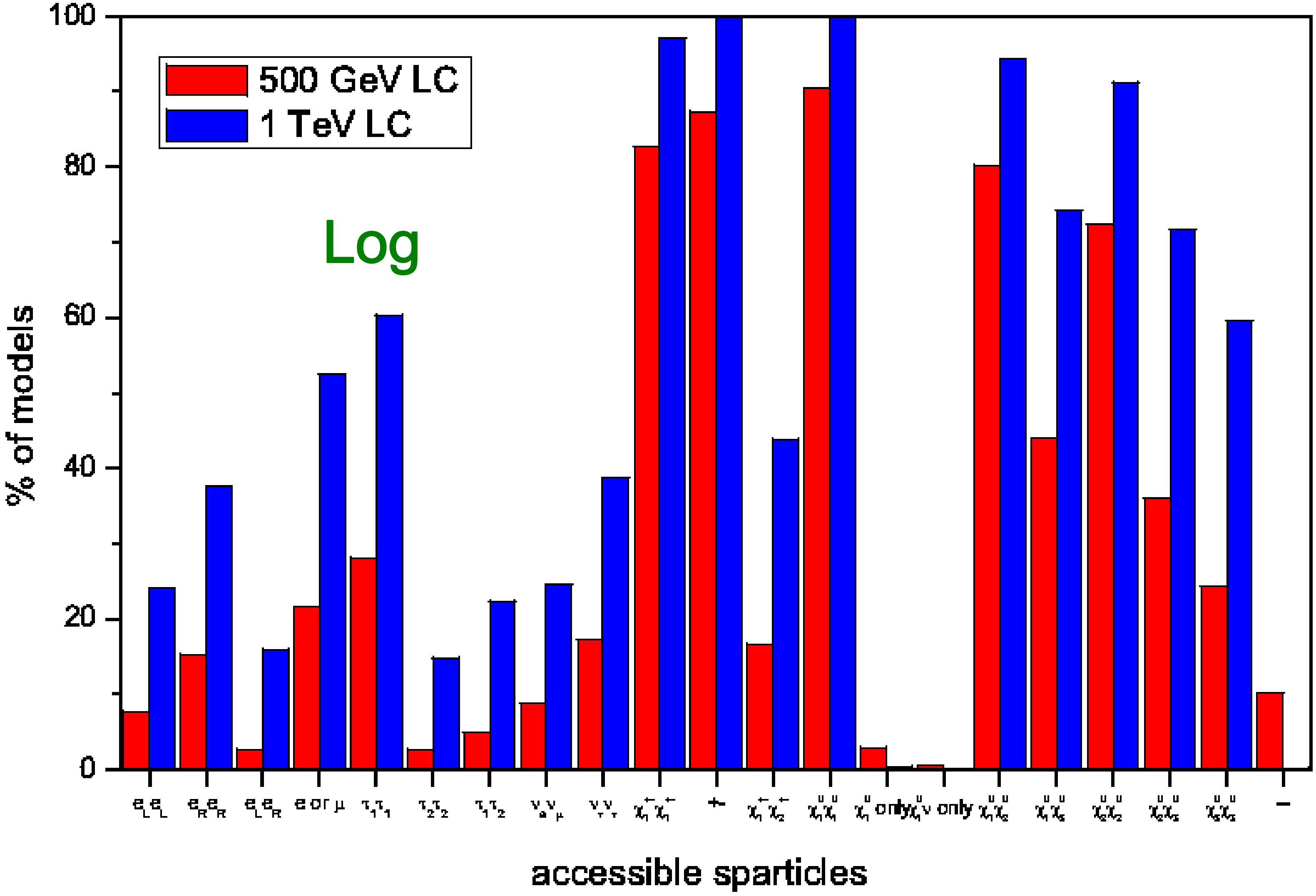


$B_{SM} = 3.5 \times 10^{-9}$

Log Priors

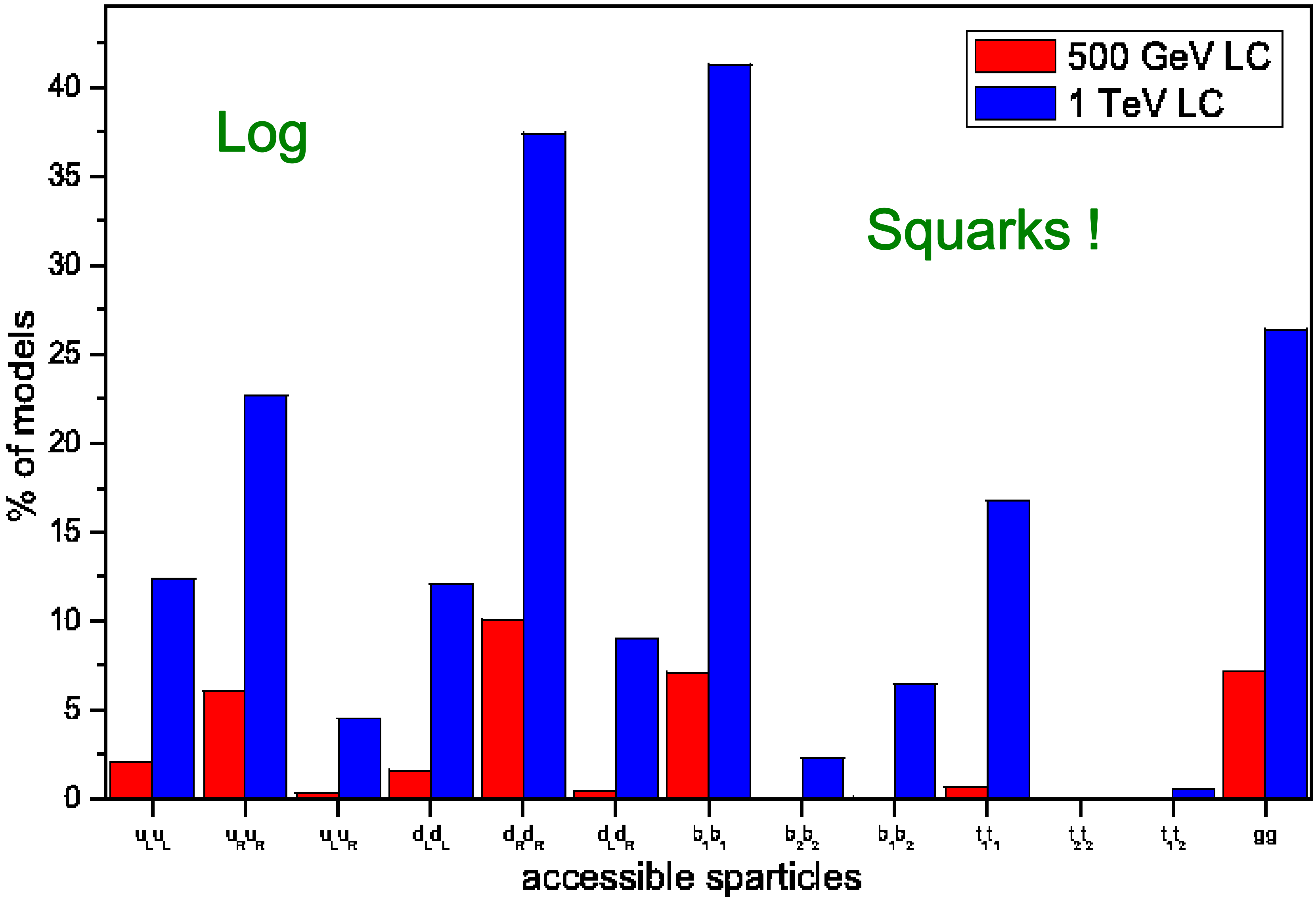


Kinematic Accessibility at the ILC : II



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 : IV



Log

Squarks !