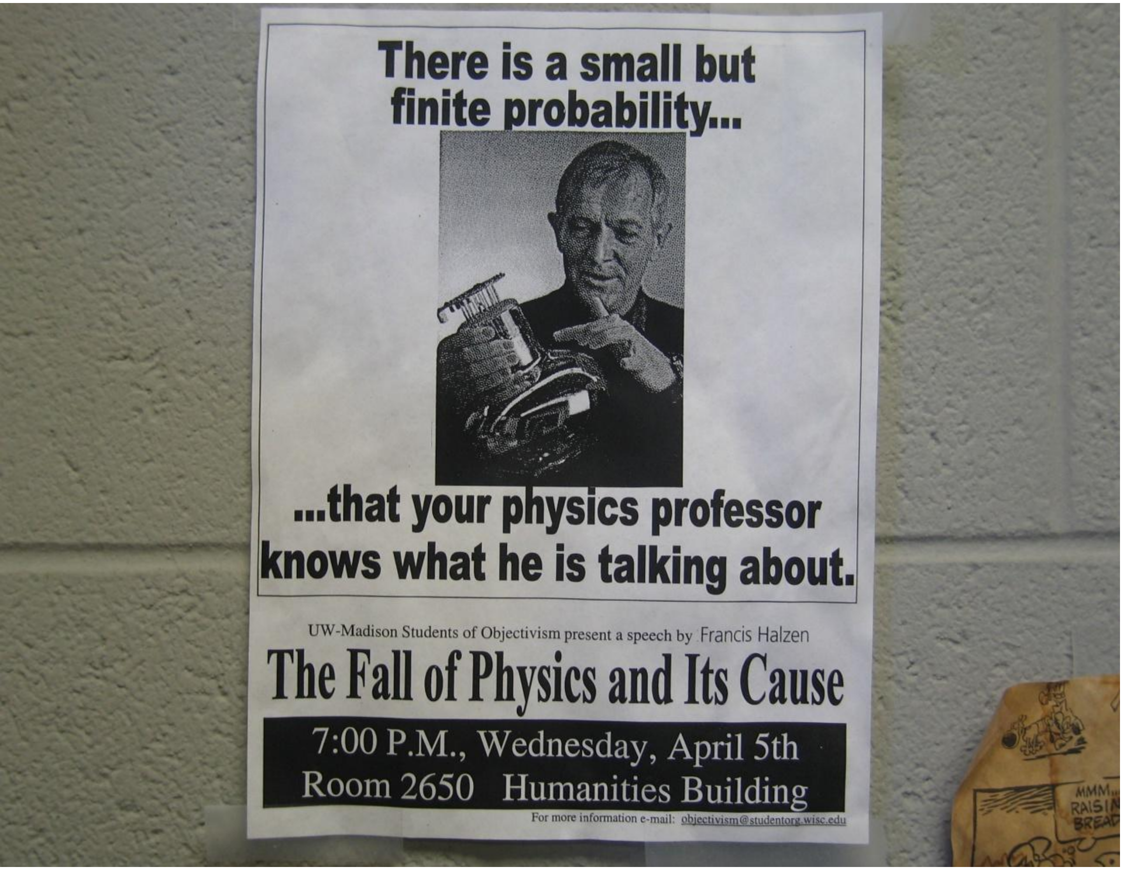
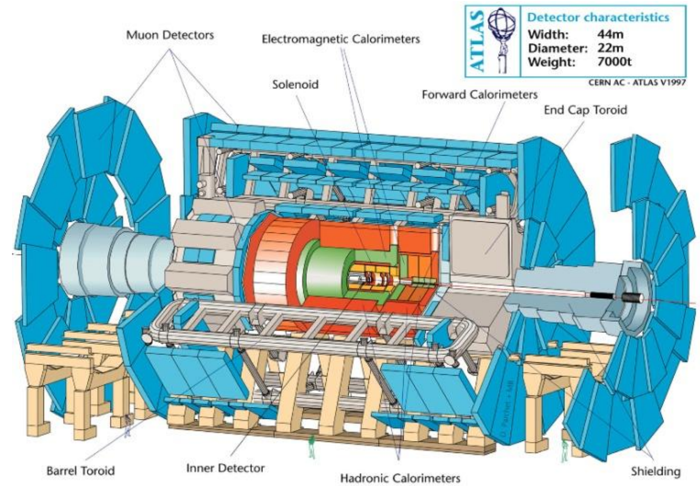
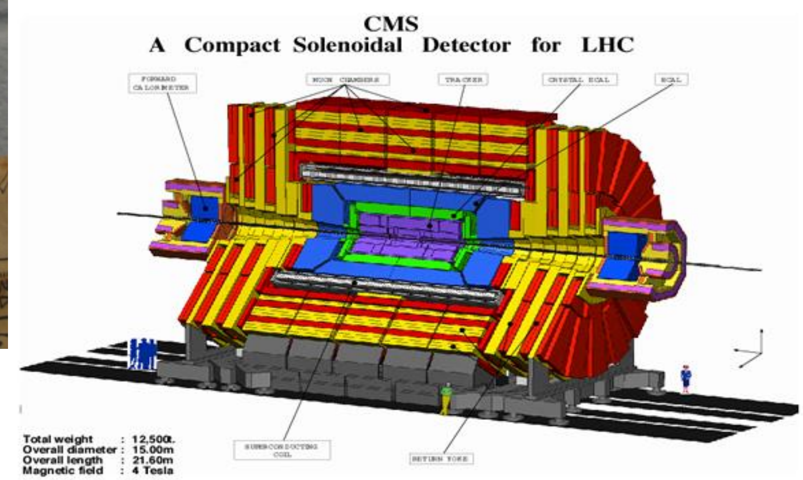
pMSSM SUSY Searches @ 7 TeV







SLAC NATIONAL ACCELERATOR LABORATORY

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T.G. Rizzo 5/9/11

Problem: SUSY may be missed at the LHC if only signatures within specific breaking scenarios (mSUGRA, GMSB,..) are searched for..

But the (100+parameter) MSSM is too difficult to study !

Solutions: Simplified Models or the 19-parameter pMSSM

- 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 & have negligible Yukawa's.

Choose the ranges of these parameters & how they're selected

Scan: look for points in this space satisfying all existing data & then study their signatures @ the LHC & elsewhere

We Perform 2 Random Scans

Flat Priors

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

emphasizes lower masses but also extends to higher masses

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

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

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

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

$1 \leq \tan\beta \leq 60$ (flat prior)

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

- Flat Priors : 10^7 points scanned , 68422 survive
- Log Priors : 2×10^6 points scanned , 2908 survive

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

ATLAS SUSY Analyses w/ a Large Model Set

• We passed these points through the ATLAS inclusive MET analyses (@ both 7 &14TeV !), designed for the CMSSM , to explore this broader class of models (~150 core-yrs)

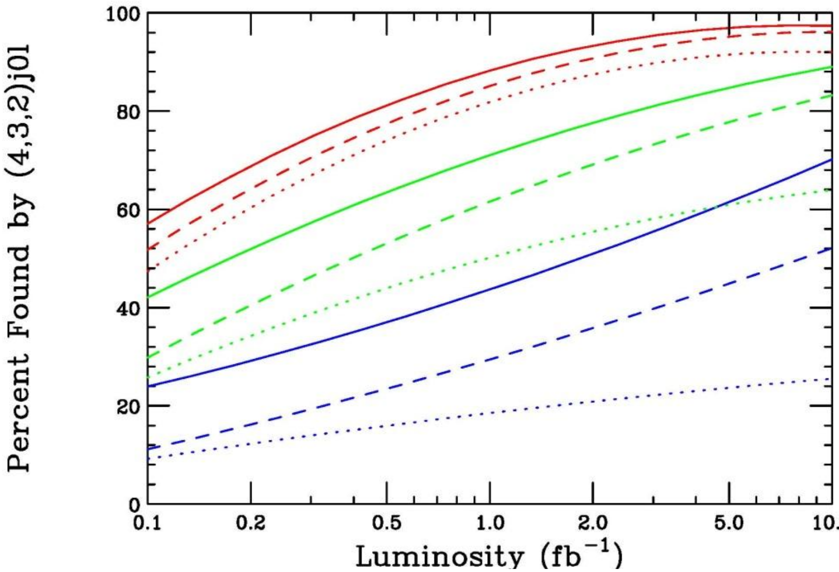
• We used the pre-data ATLAS MC SM backgrounds with their estimated systematic errors, search analyses/cuts & criterion for SUSY discovery for comparisons. ($\rightarrow$ ATL-PHYS-PUB-2010-010 for 7 TeV, CSC for 14 TeV)

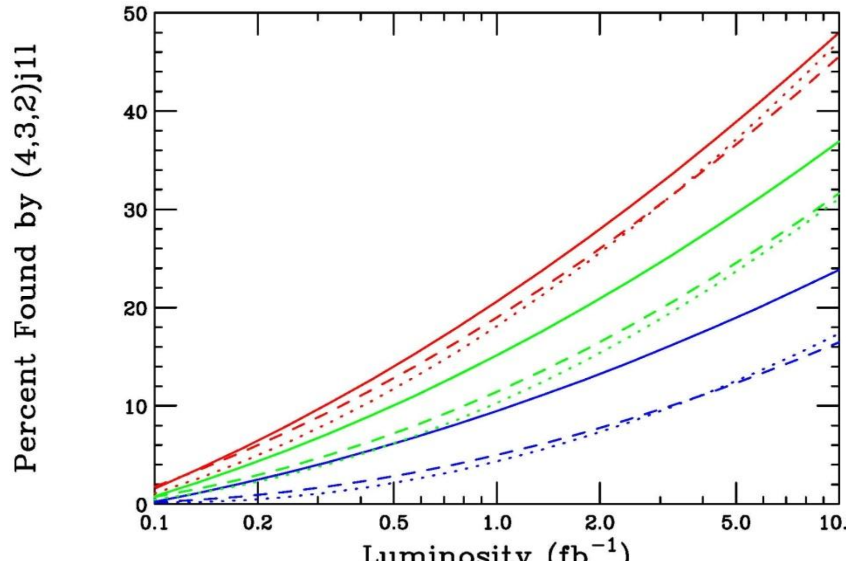
• We verified that we can approximately reproduce both the 7 & 14 TeV ATLAS results for their benchmark CMSSM models with our analysis techniques for each channel. ..BUT there are some analysis differences

$\rightarrow$ How well do the 7 TeV analyses do at model coverage?

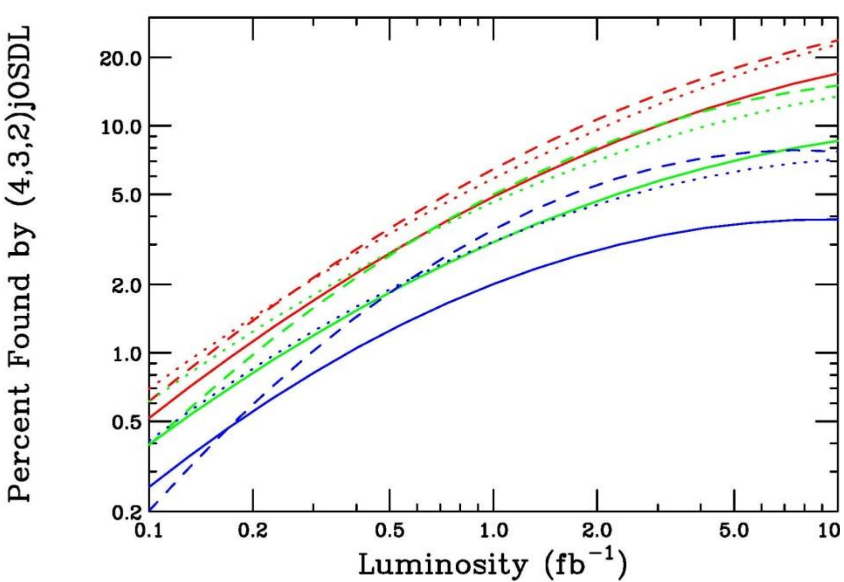
FLAT

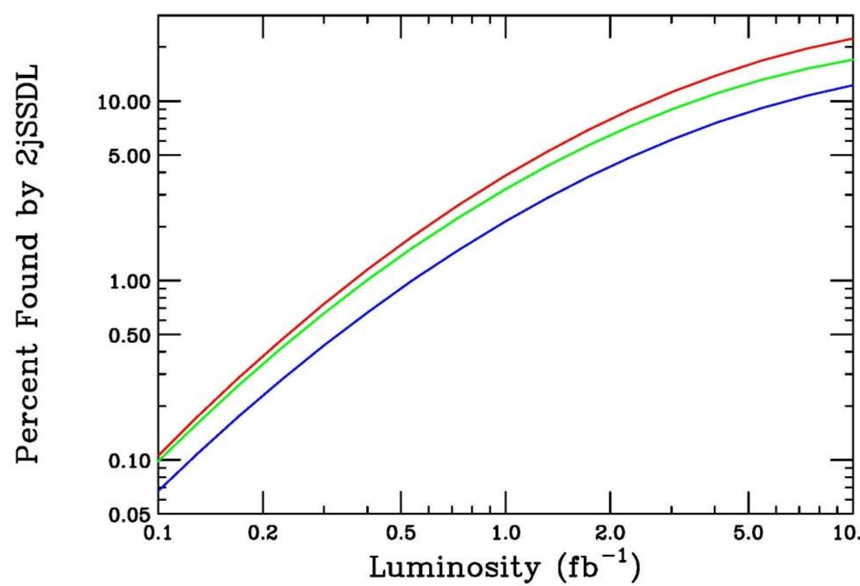
Solid=4j, dash=3j, dot=2j final states





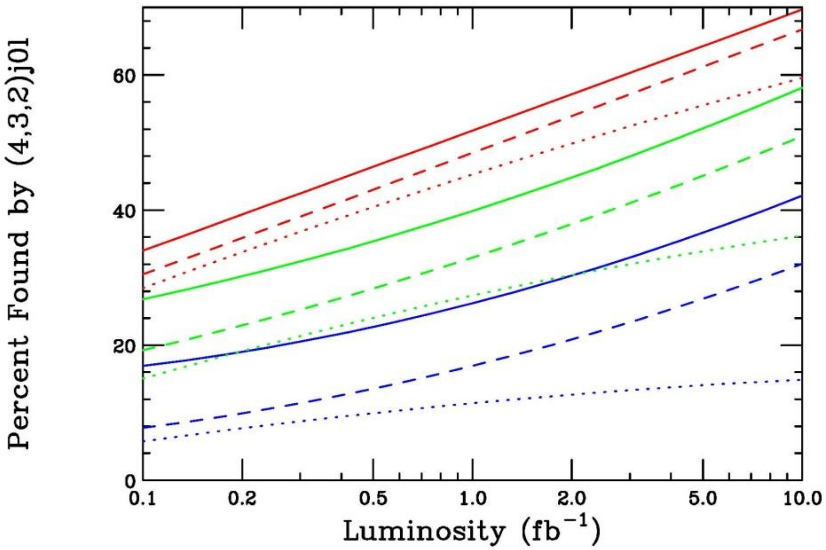
Red=20%, green=50%, blue=100% background systematic errors

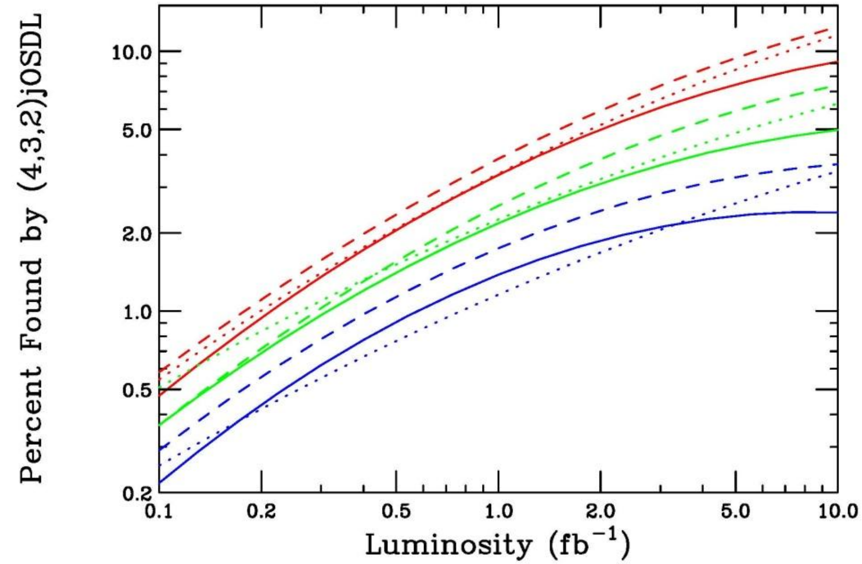




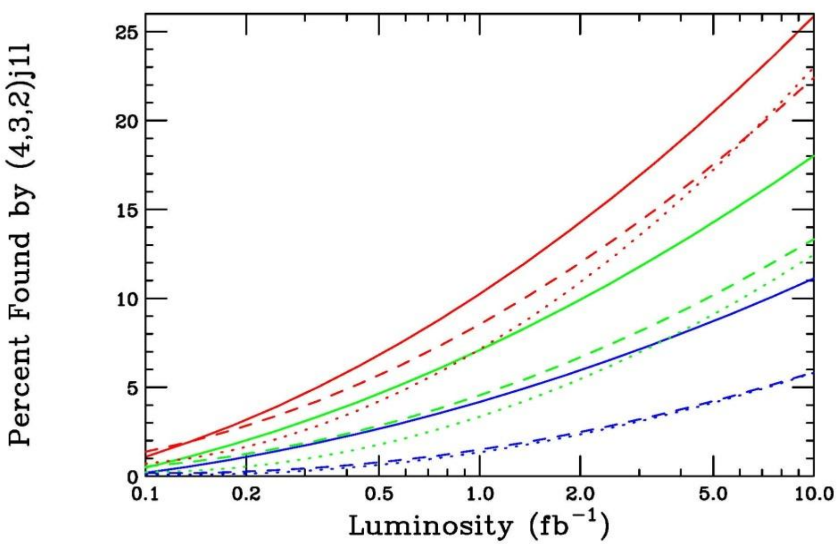
LOG

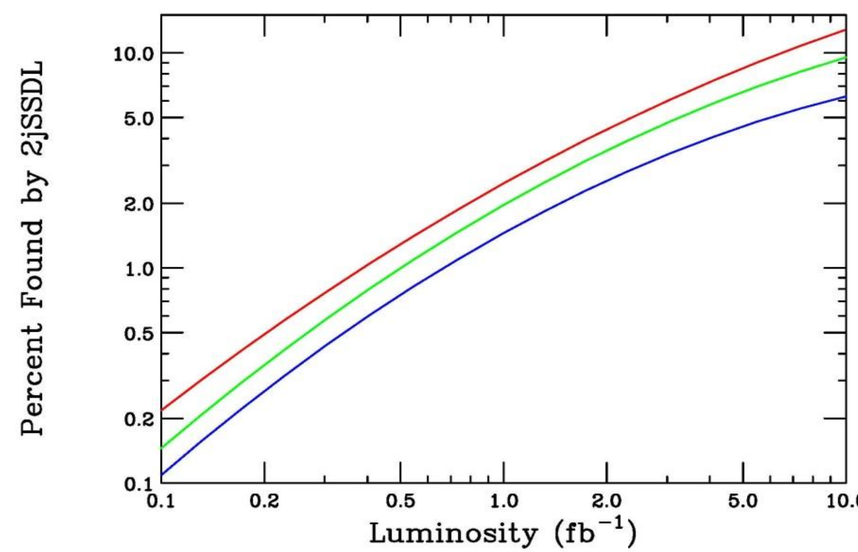
Solid=4j, dash=3j, dot=2j final states





Red=20%, green=50%, blue=100% background systematic errors





Search 'effectiveness': If a model is found by only 1 analysis which one is it??

Analysis	Flat $\mathcal{L}_{0.1}$	Flat $\mathcal{L}_1$	Flat $\mathcal{L}_{10}$	Log $\mathcal{L}_{0.1}$	Log $\mathcal{L}_1$	Log $\mathcal{L}_{10}$
4j0l	71.037	63.533	59.18	75.676	63.433	41.615
3j0l	1.154	11.493	18.689	1.3514	11.94	21.118
2j0l	26.206	13.799	4.4262	20.27	15.672	12.422
4j1l	0.30454	4.6116	6.5574	0	5.9701	7.4534
3j1l	0.096169	0.81589	0.98361	0	0	0.62112
2j1l	0.080141	1.8801	4.0984	0	0	6.2112
4jOSDL	0.048085	0	0	0	0.74627	0
3jOSDL	0.032056	1.6318	0.32787	0	0	0.62112
2jOSDL	0.99375	1.6673	0.4918	1.3514	1.4925	1.8634
2jSSDL	0.048085	0.56758	5.2459	1.3514	0.74627	8.0745

δB=20%

→ → 4j0l is the most powerful analysis…leptonic ones weaker

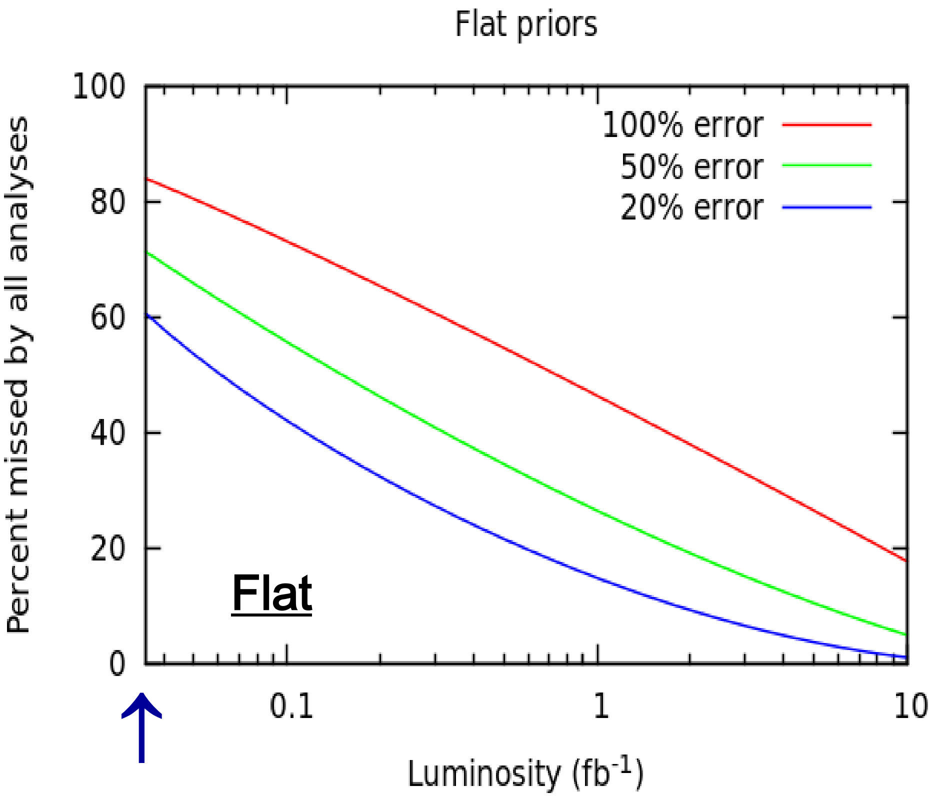
What fraction of models are found by n analyses @7 TeV assuming, e.g., δB=20% ?

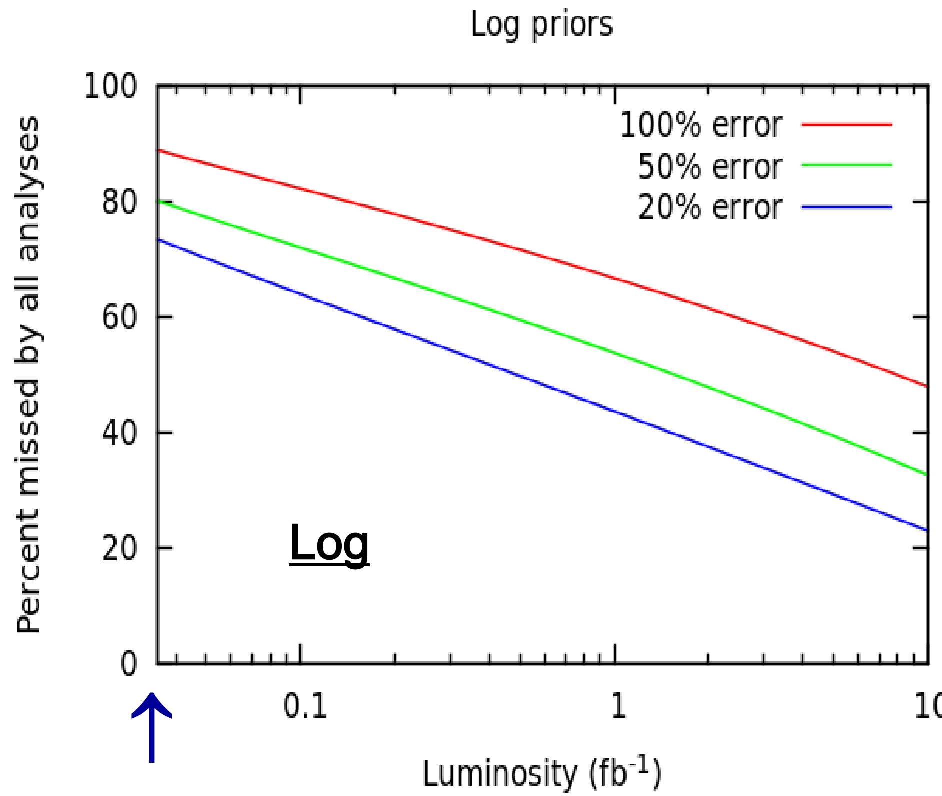
# anl.	Flat $\mathcal{L}_{0.1}$	Flat $\mathcal{L}_1$	Flat $\mathcal{L}_{10}$	Log $\mathcal{L}_{0.1}$	Log $\mathcal{L}_1$	Log $\mathcal{L}_{10}$
0	38.172	7.5501	0.9965	63.64	43.988	22.92
1	9.2928	4.1988	0.90862	5.376	4.8674	5.8482
2	8.7432	4.6665	1.6102	3.6687	5.6665	6.0298
3	41.836	59.878	39.573	26.008	34.907	35.38
4	0.65686	4.9257	7.9422	0.25427	2.2158	6.4657
5	0.53472	4.2629	6.7163	0.47221	2.0341	4.8311
6	0.54366	8.5391	13.494	0.32692	3.0875	6.5383
7	0.067026	2.5217	8.9044	0.21794	1.453	4.1773
8	0.062558	1.2288	5.6364	0.036324	0.72648	2.2884
9	0.077452	1.2958	6.548	0	0.58118	2.9422
10	0.013405	0.93241	7.6711	0	0.47221	2.579

→ → SUSY signals usually seen in multiple analyses

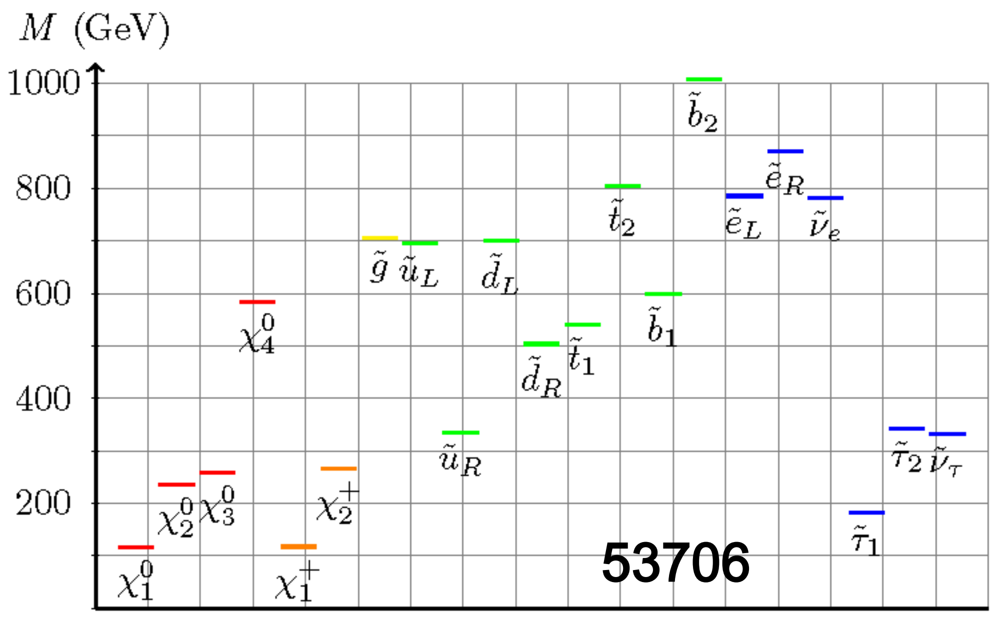
How good is the pMSSM coverage @ 7 TeV as the lumi evolves (assuming a universal background uncertainty)?

The coverage is <u>quite good</u> for both model sets !





Many models are found in multiple channels..



e.g.

The *notorious*
PHENO MODEL
(Zip Code 53706)

Due to many large mass splittings there are lots of energetic jets & leptons as well as MET ! This model is seen in all nj0l & nl1l channels as well as in 2jSSDL.

- But it's more important to understand why models are missed

The Undiscovered SUSY

Why Do Models Get Missed by ATLAS?

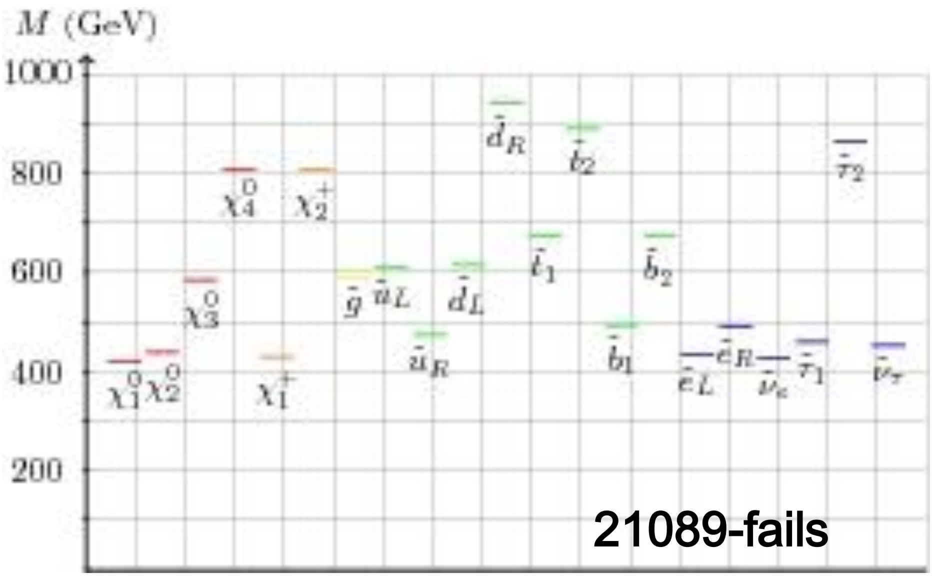
The most common reasons are :

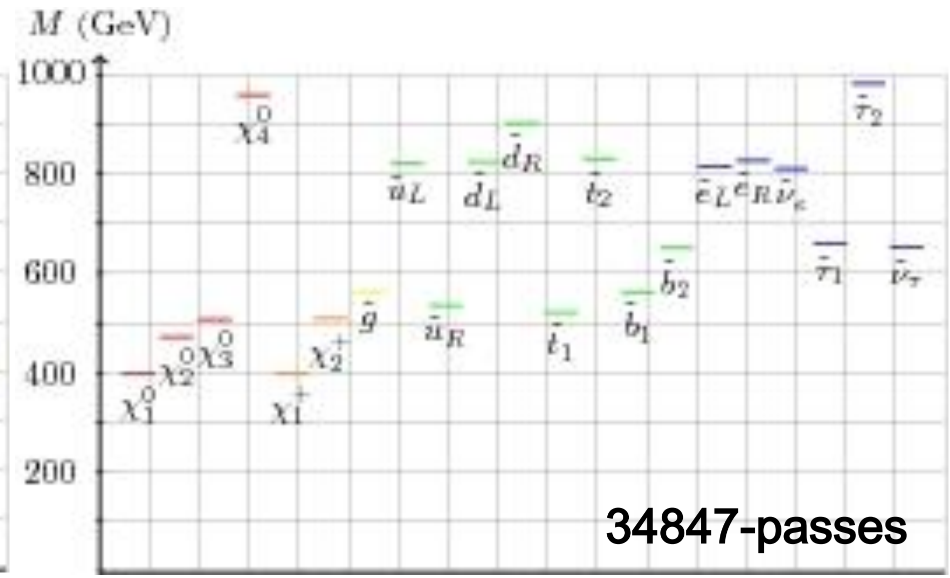
- small signal rates due to suppressed σ's
- which can be correlated with large sparticle masses
- small mass splittings w/ the LSP (compressed spectra)
- decay chains ending in stable sparticles $\rightarrow$ NO MET !

$\rightarrow$ BUT there are many more subtle cases to consider.

There are MANY examples…

Missed vs Found Model Comparisons





- It is useful to compare models with somewhat similar mass spectra where one is ‘seen’ and the other isn’t by the full set of ATLAS analyses to examine what ‘goes wrong’..

What went wrong ??

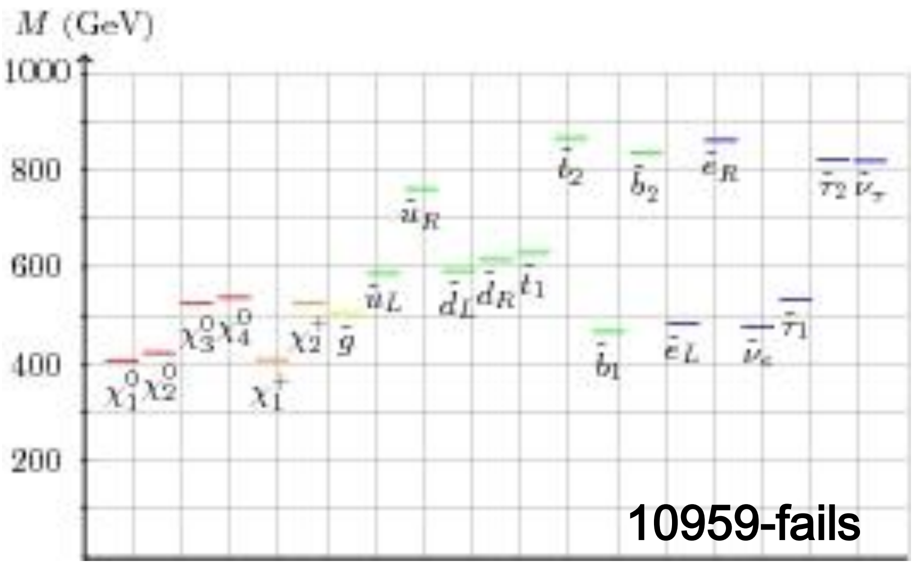
- 21089 (σ ~ 4.6pb) & 34847 (σ ~ 3.3pb) yet both models fail nj0l due to smallish Δm's. BUT 34847 is seen in the lower background channels (3,4)j1l

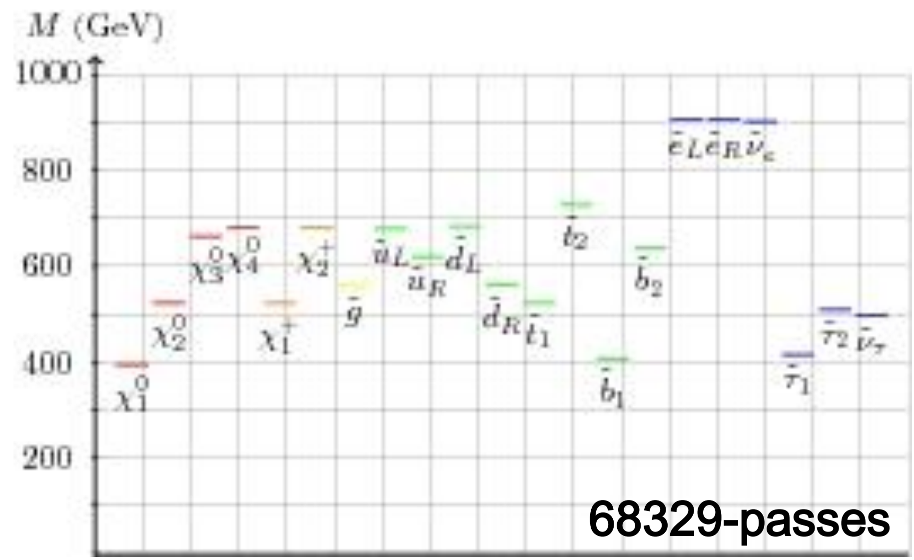
- In 34847, u_R cascades to the LSP via χ_2^0 & the chargino producing leptons via W emission. The LSP is mostly a wino in this case.

- In 21089, however, u_R can only decay to the lighter ~Higgsino triplet which is sufficiently degenerate as to be incapable of producing high p_T leptons

- The jets in both u_R decays have similar p_T's

Missed vs Found Model Comparisons





→ Here's an typical example where only a slight adjustment in the SUSY mass spectrum can make all the difference..

What went wrong ??

- 68329 passes 4j0l (σ~4.6 pb) while 10959 (σ~6.0 pb) fails all
- In 68329, d_R decays to j+MET (B~95%) & NOT the gluino as it's only ~3 GeV lighter. The gluino decays to the LSP via sbottom (B~100%) with a Δm~150 GeV mass splitting . The LSP is bino-like in this model
- In 10959, d_R decays via the ~107 GeV lighter gluino (B~99%) and the gluino decays (with Δm ~40 GeV) through sbottom & 2nd neutralino to the (wino-like) LSP (with Δm~ 60 GeV).
- Raising the LSP & b_1 masses in 68239 by 50 GeV induces search failure due to decay patch changes

Summary & Conclusions

- ATLAS searches at 7 TeV with ~10 fb^{-1} will do quite well at finding or excluding most of our FLAT pMSSM models & not badly with our LOG set

- With ~35 pb^{-1} , a good fraction of our models have been 'covered' !

- Reducing SM background uncertainties is quite important in enhancing model coverage..

- There are actually MANY reasons that models are missed..small changes in sparticle spectra can be important

- Searches in other channels, e.g., stable charged particles & MSSM Higgs, will play an important role in covering our models

BACKUP SLIDES

19 pMSSM Parameters

10 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}

3 gaugino masses: M_1, M_2, M_3

3 tri-linear couplings: A_b, A_t, A_τ

3 Higgs/Higgsino: μ, M_A, $\tan\beta$

Some Constraints

- W/Z ratio — $b \to s\,\gamma$
- $\Delta(g\text{-}2)_\mu$ — $\Gamma(Z \to \text{invisible})$
- Meson-Antimeson Mixing
- $B_s \to \mu\mu$ — $B \to \tau\nu$

- DM density: $\Omega h^2 < 0.121$. We treat this only as an *upper bound* on the neutralino thermal relic contribution

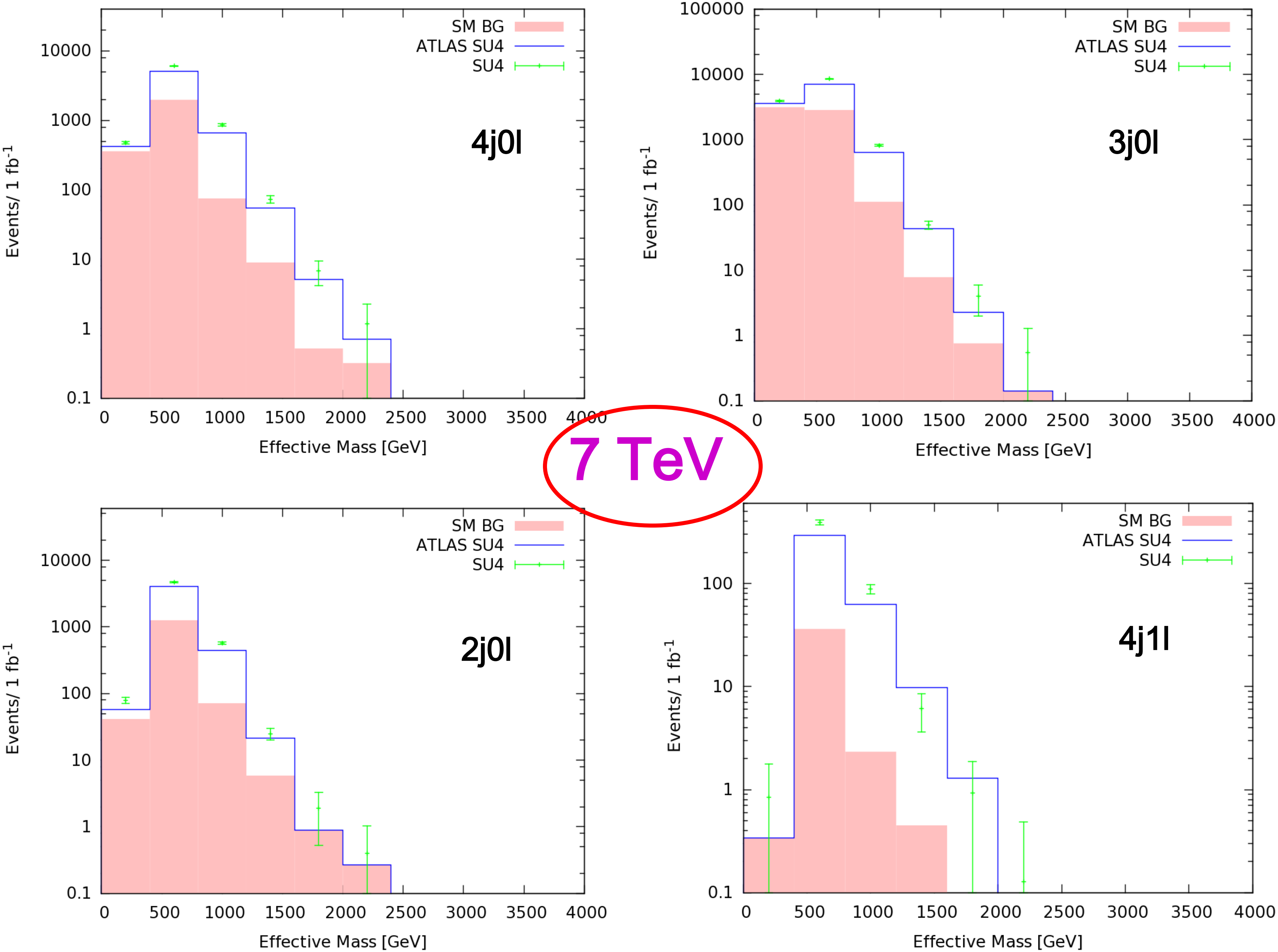
- Direct Detection Searches for DM (CDMS, XENON…)

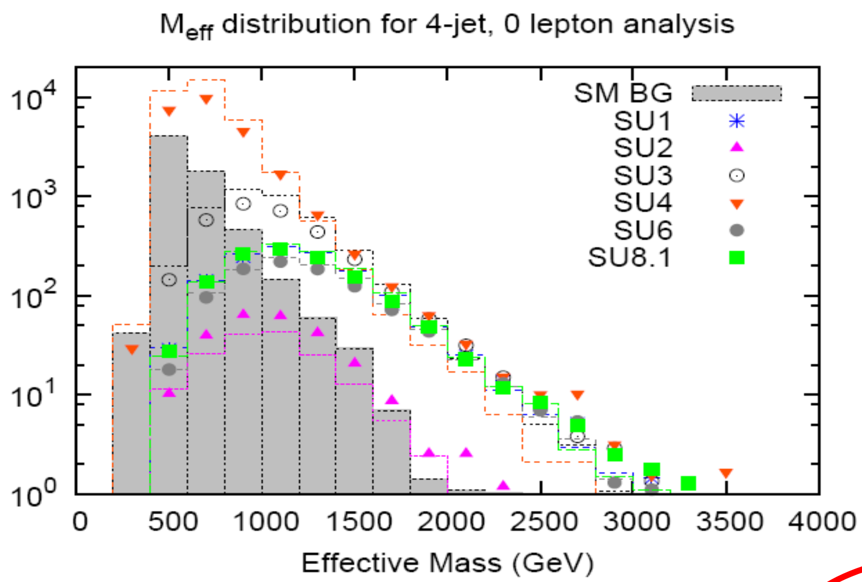
- LEP and Tevatron Direct Higgs & SUSY searches : there are *many* searches & some are quite complicated with many caveats…. These needed to be 'revisited' for the more general case considered here → simulations limit model set size (~1 core-century for set generation)

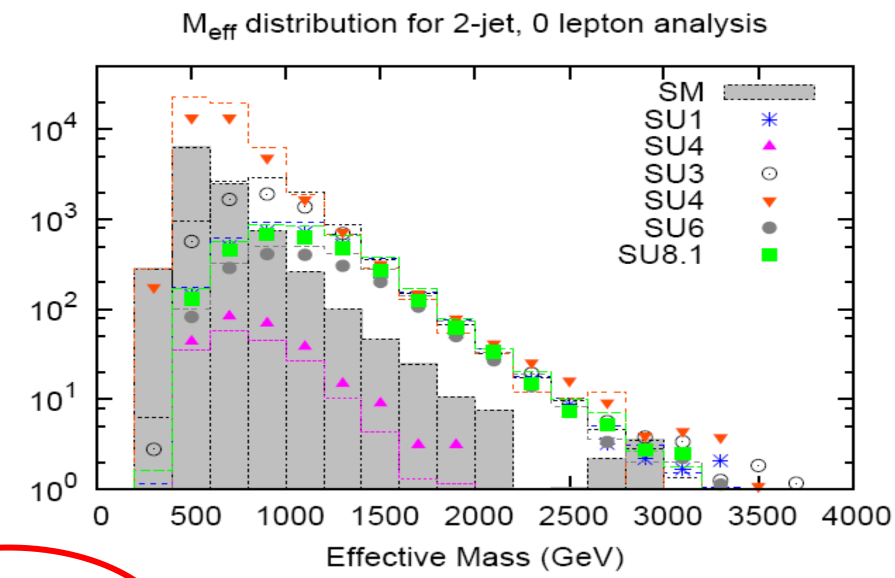
ATLAS	US
ISASUGRA generates spectrum & sparticle decays	SuSpect generates spectra with SUSY-HIT# for decays
Partial NLO cross sections using PROSPINO & CTEQ6M	NLO cross section for all 85 processes using PROSPINO** & CTEQ6.6M (~6M K-factors)
Herwig for fragmentation & hadronization	PYTHIA for fragmentation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

** version w/ negative K-factor errors corrected

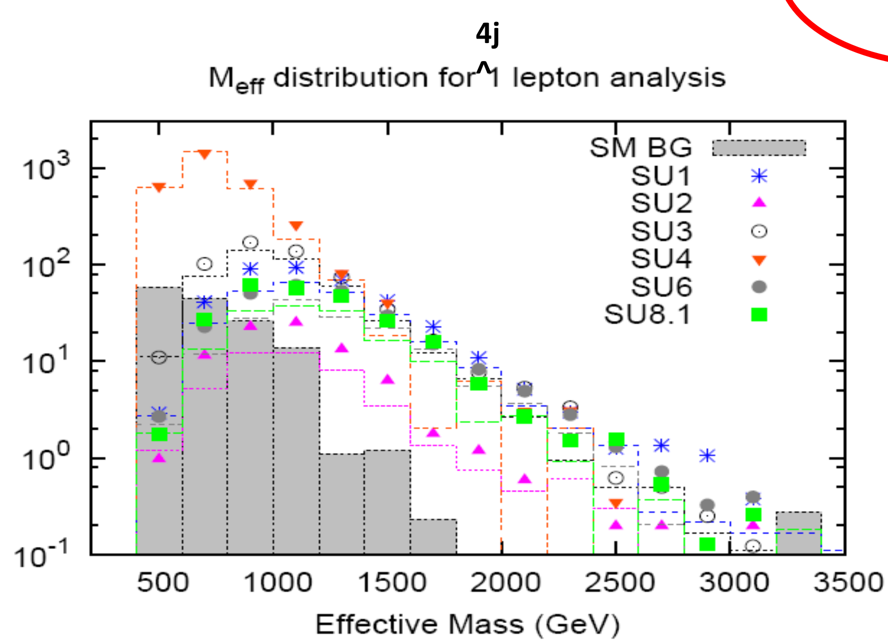
version w/o negative QCD corrections, with 1st & 2nd generation fermion masses & other very numerous PS fixes included. e.g., explicit small Δm chargino decays, etc.

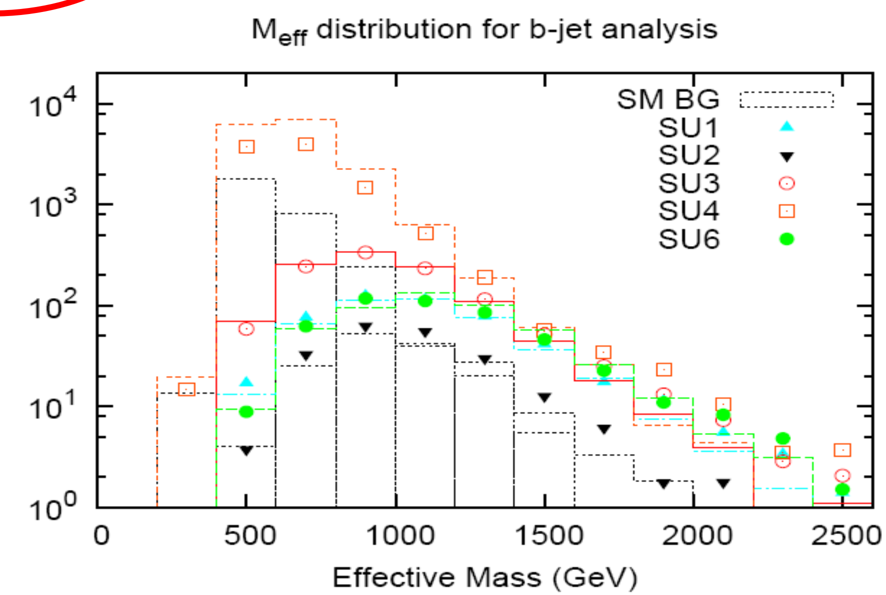

7 TeV
4j0l
3j0l
2j0l
4j1l
SM BG
ATLAS SU4
SU4
Events/ 1 fb^{-1}
Effective Mass [GeV]
0.1
1
10
100
1000
10000
100000
0
500
1000
1500
2000
2500
3000
3500
4000


M_eff distribution for 4-jet, 0 lepton analysis
SM BG
SU1
SU2
SU3
SU4
SU6
SU8.1
Effective Mass (GeV)

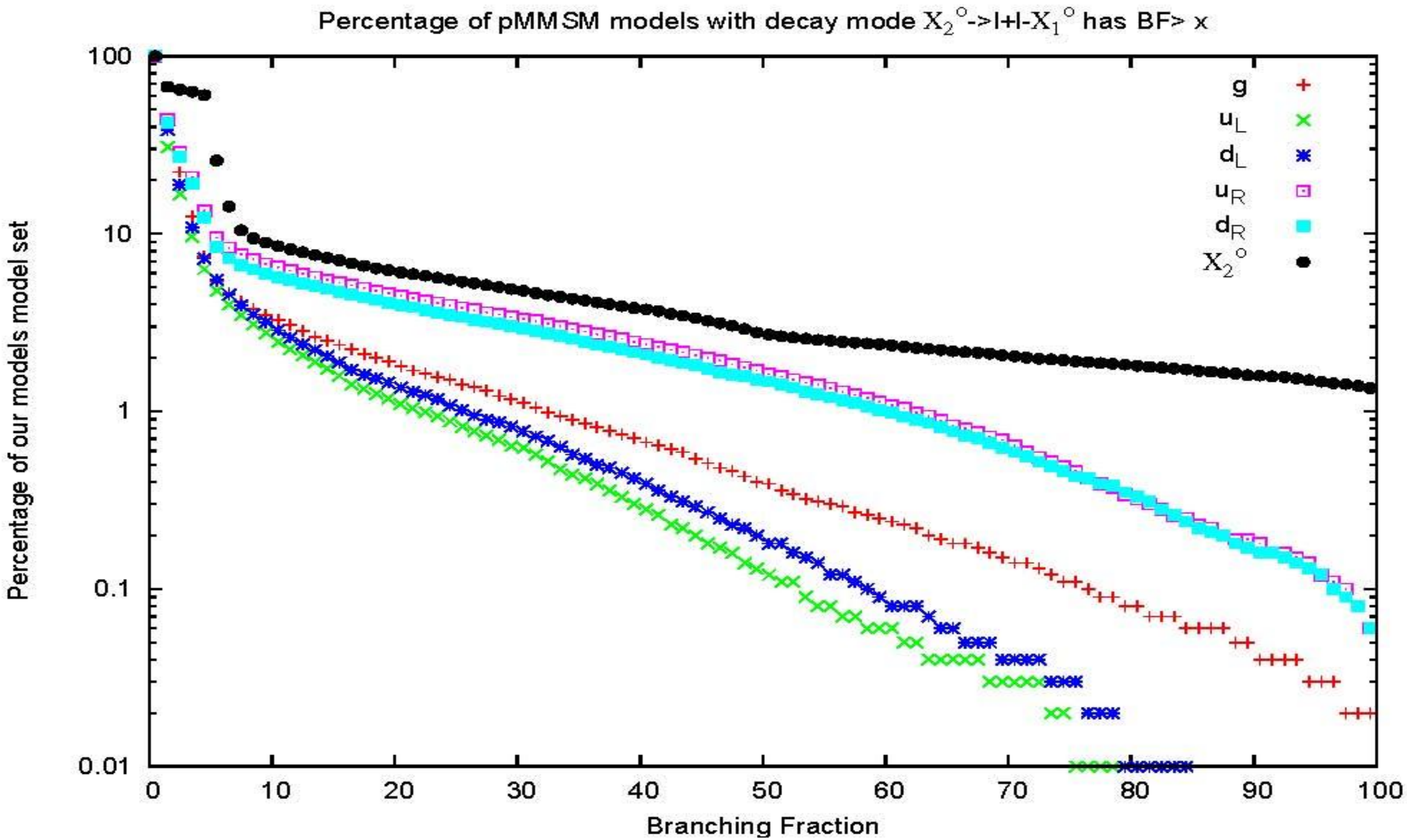

M_eff distribution for 2-jet, 0 lepton analysis
SM
SU1
SU4
SU3
SU4
SU6
SU8.1
Effective Mass (GeV)

14 TeV

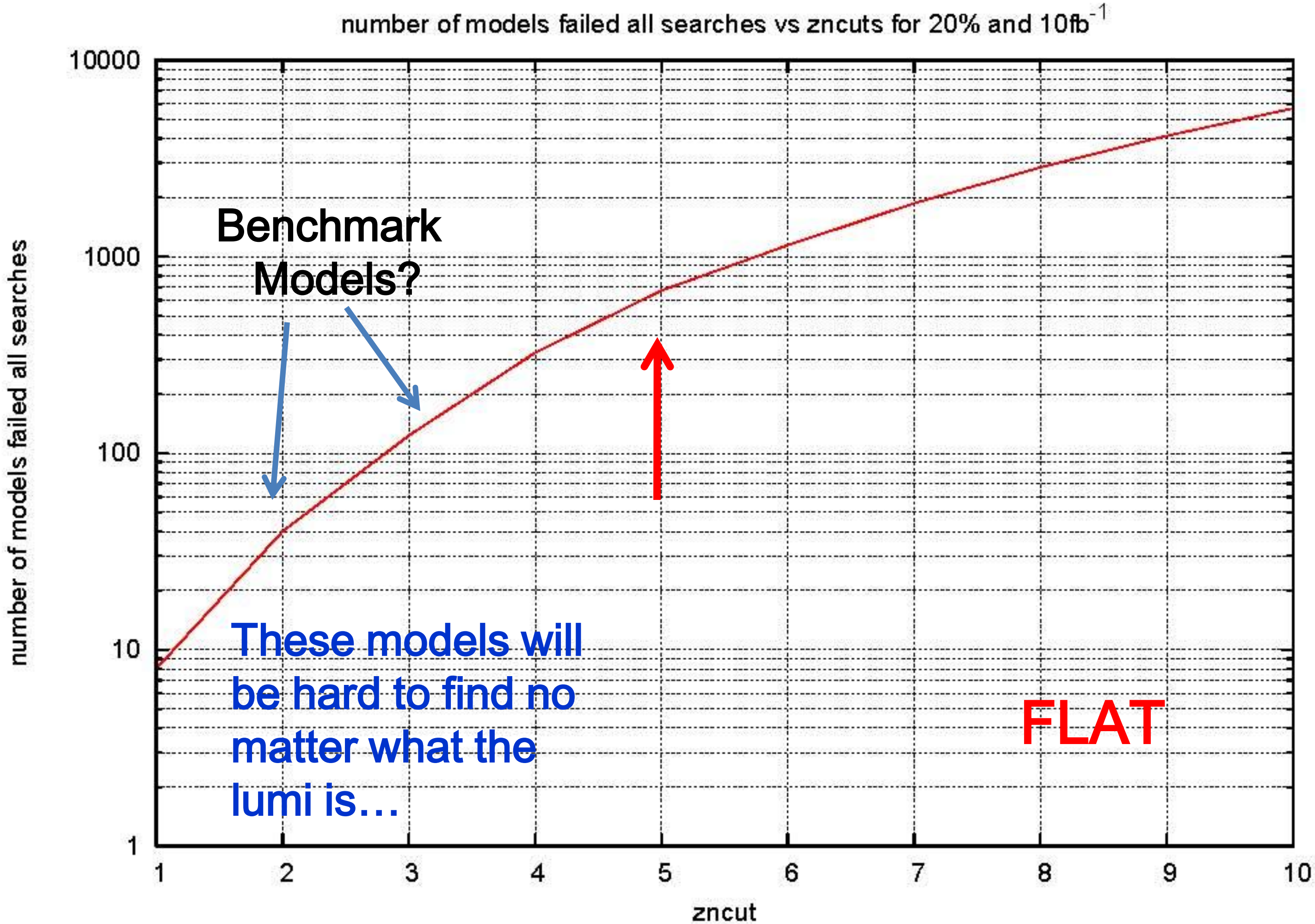

4j
M_eff distribution for^1 lepton analysis
SM BG
SU1
SU2
SU3
SU4
SU6
SU8.1
Effective Mass (GeV)


M_eff distribution for b-jet analysis
SM BG
SU1
SU2
SU3
SU4
SU6
Effective Mass (GeV)

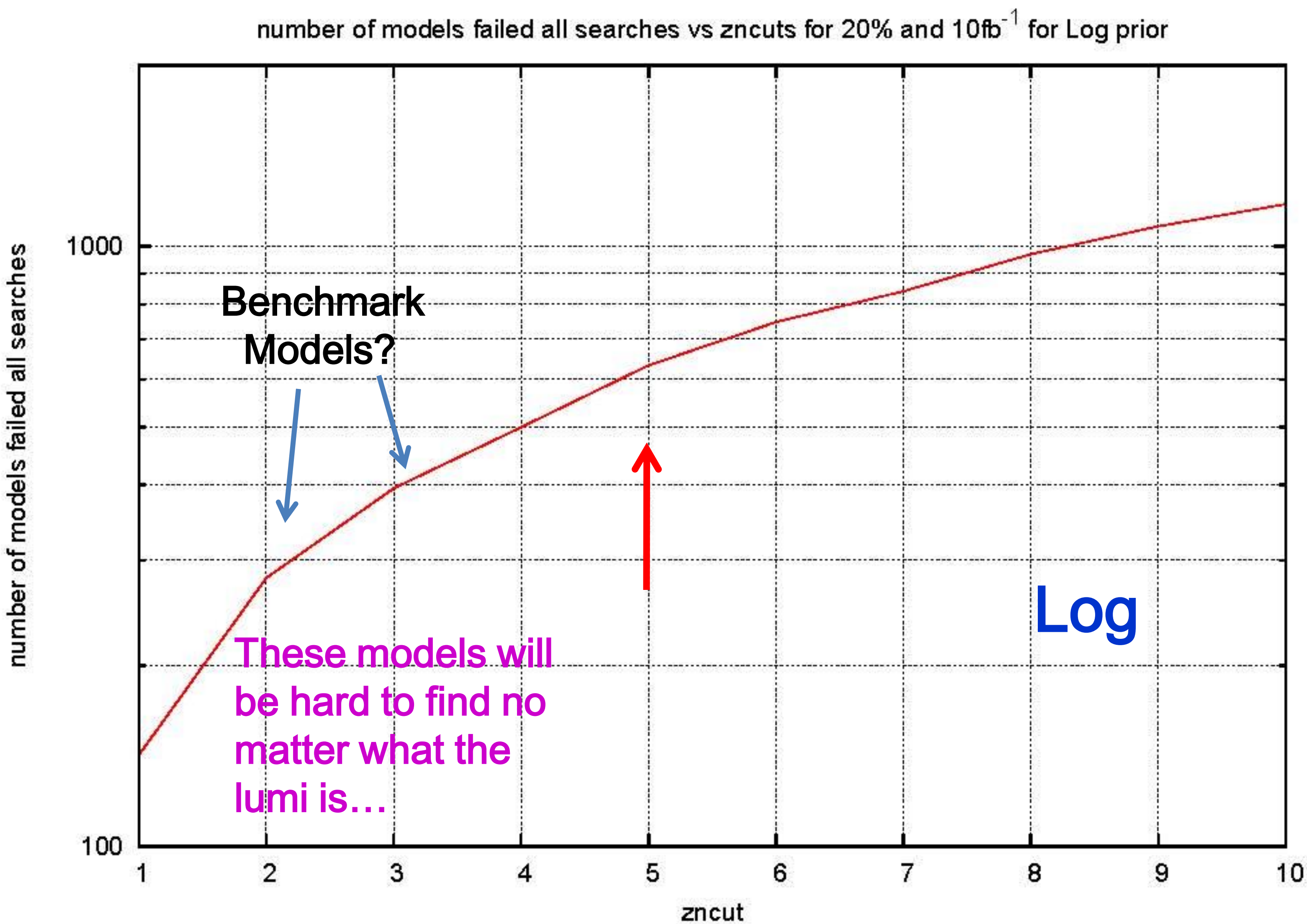
- Note that as the number of required leptons increases the corresponding model 'coverage' decreases. Why? The BF to lepton pairs is relatively small in our model sets...e.g. :

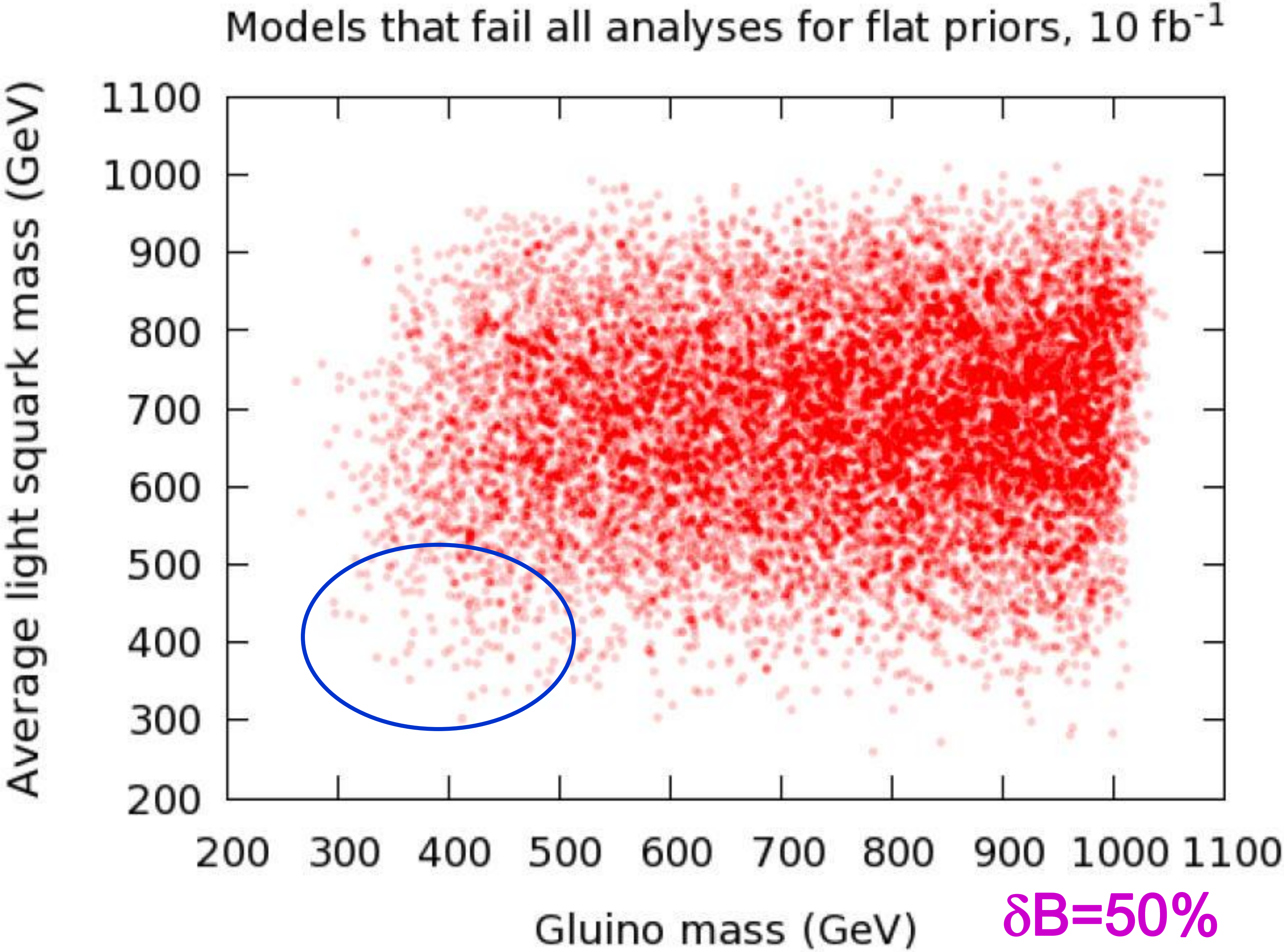


Aside: How many models will fail to have even one analysis with S > some fixed value by the end of 2012 assuming L=10 fb^{-1} and δB=20%?



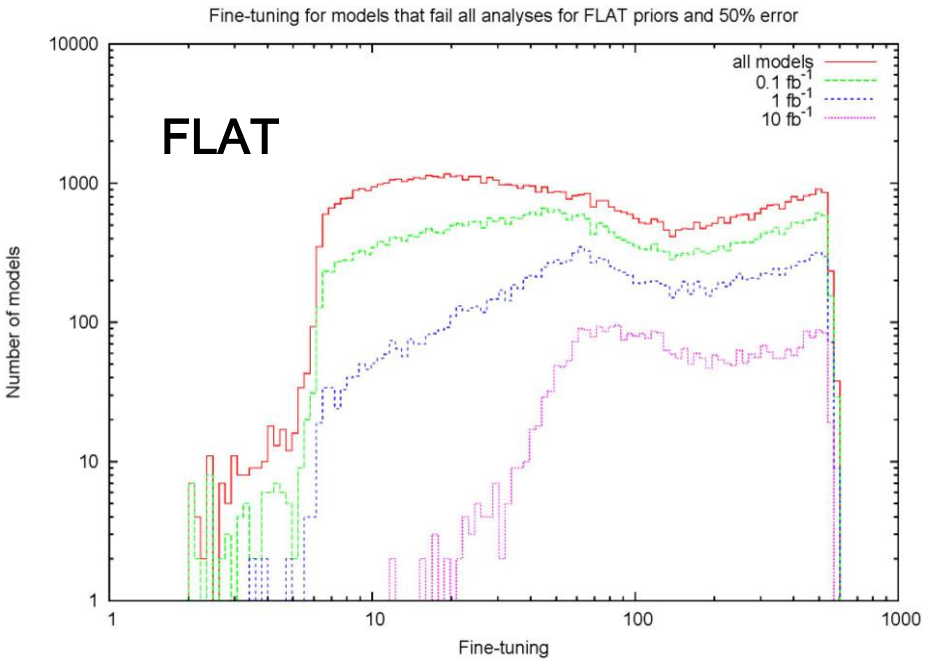
This same behavior is observed in the Log prior case

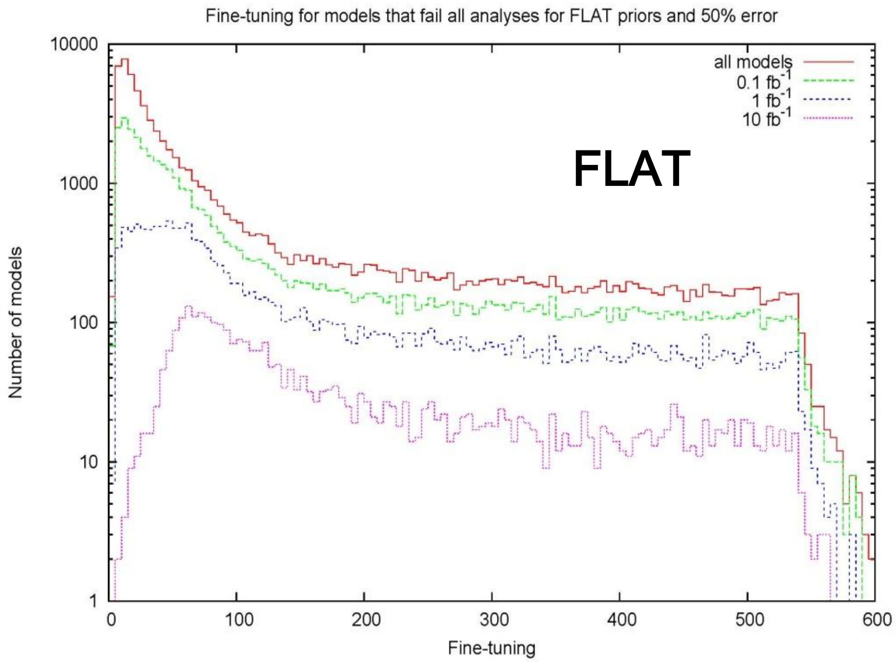



Models that fail all analyses for flat priors, 10 fb-1
Average light squark mass (GeV)
1100
1000
900
800
700
600
500
400
300
200
200
300
400
500
600
700
800
900
1000
1100
Gluino mass (GeV)
δB=50%

Fine-Tuning SUSY ?

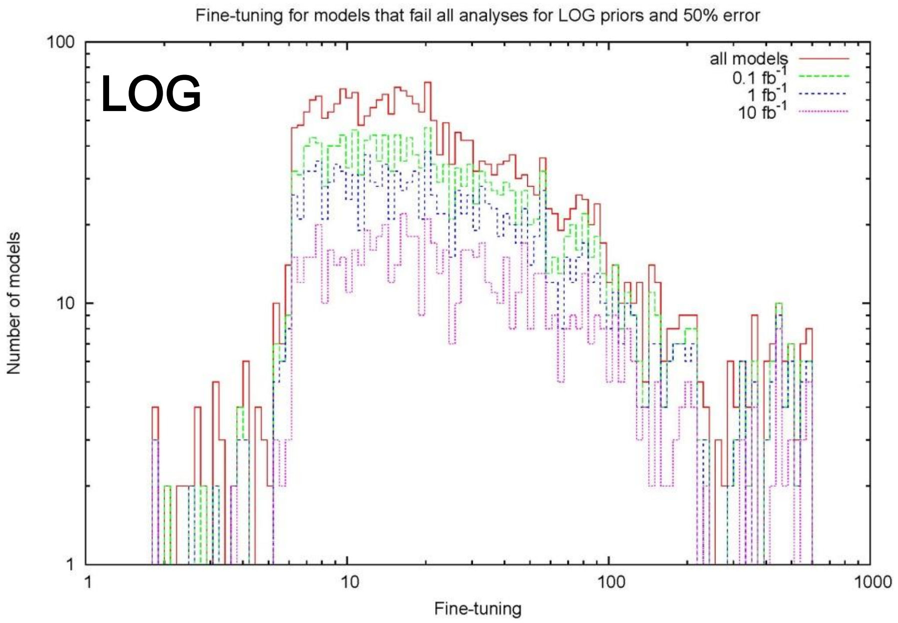
- It is often claimed that if the LHC (@7 TeV) does not find anything then SUSY must be VERY fine-tuned & so 'less likely'. Is this true for our pMSSM model sets??





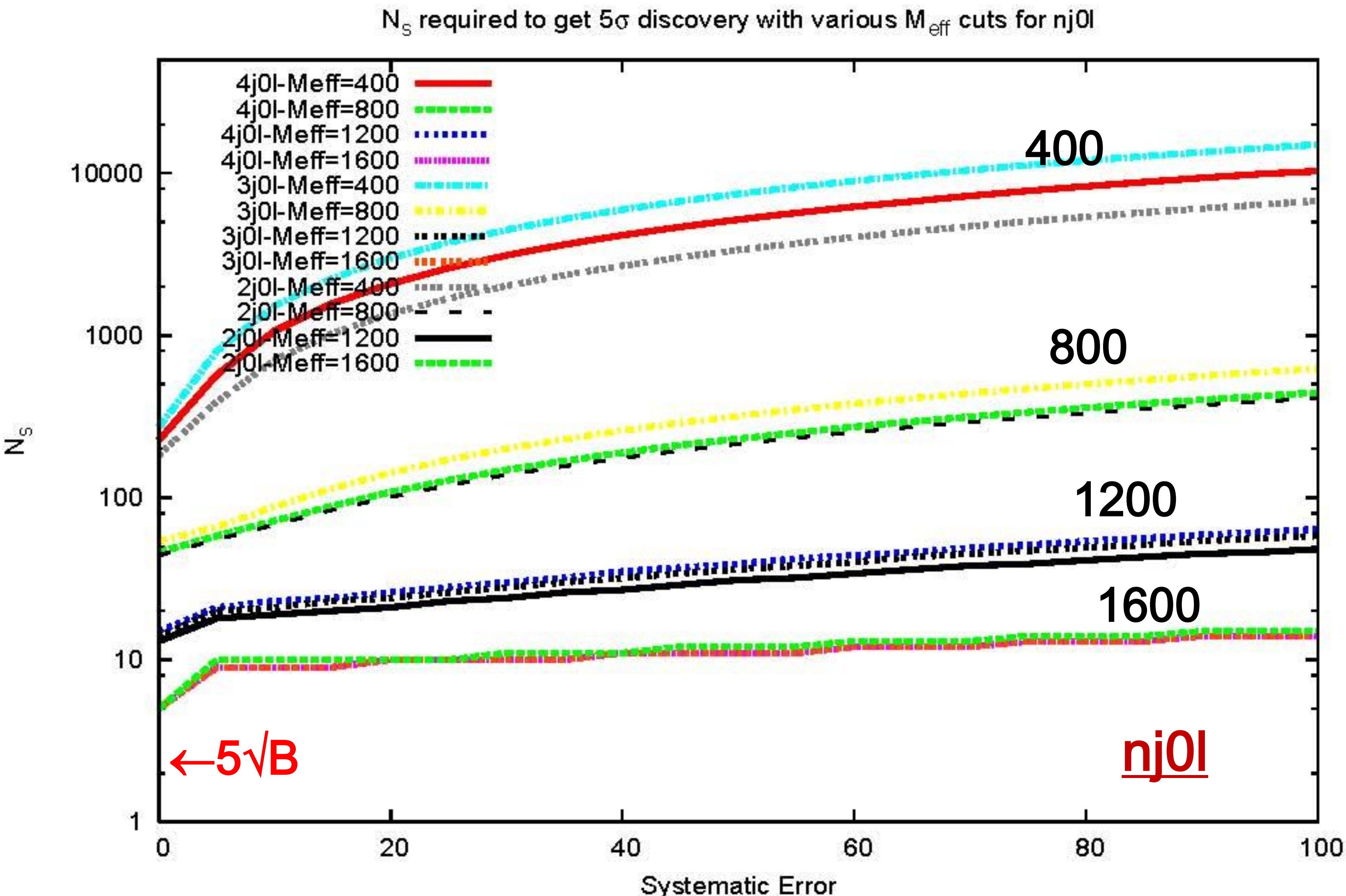
→ Models w/ low tuning do appear to 'suffer' more than those w/ larger values from null SUSY searches

- The amount of fine tuning in the LOG prior set is somewhat less influenced by null ATLAS searches due to spectrum differences , i.e., compression plus mass stretch-out

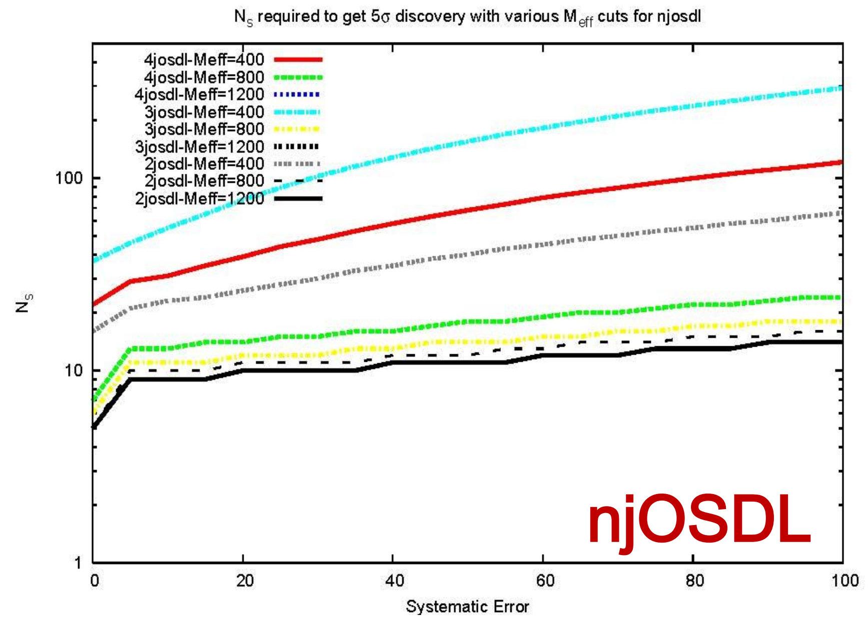


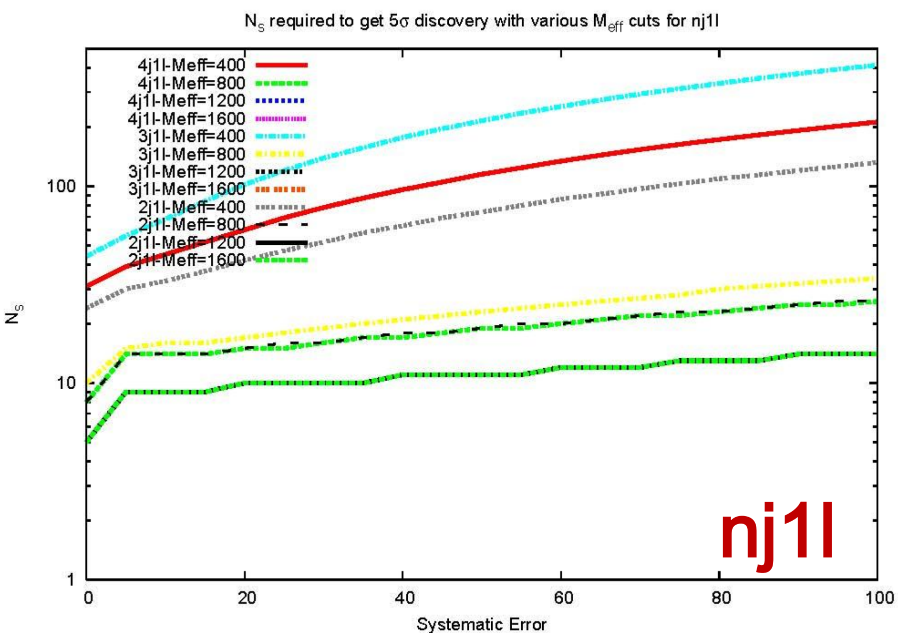
- How many signal events do we need to reach S=5?

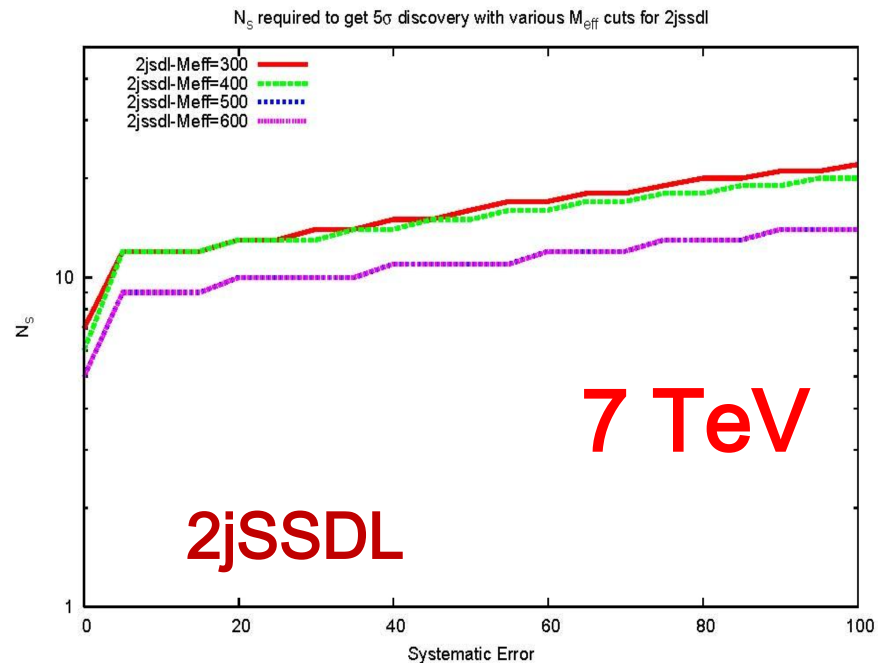
Depends on the M_{eff} ‘cut’ which is now ‘optimized’ @ 7 TeV

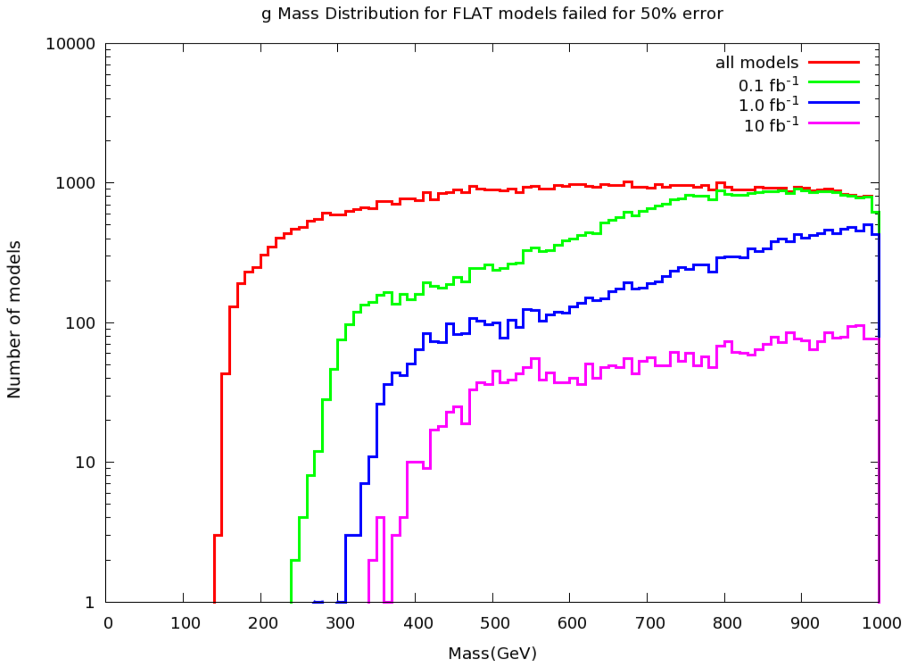


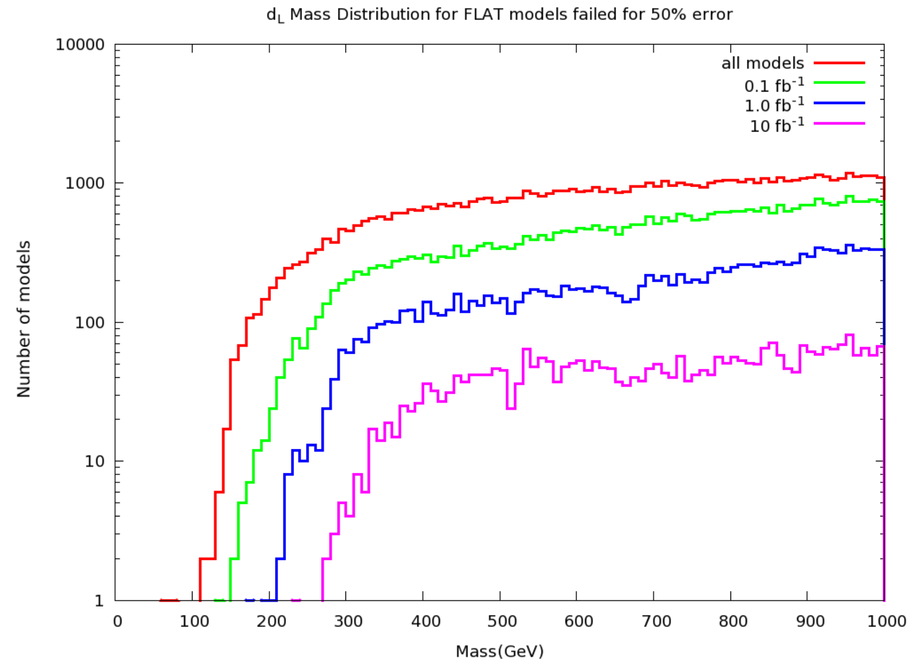
• The size of the background systematic error can play a very significant role in the pMSSM model coverage especially for nj(0,1)l …

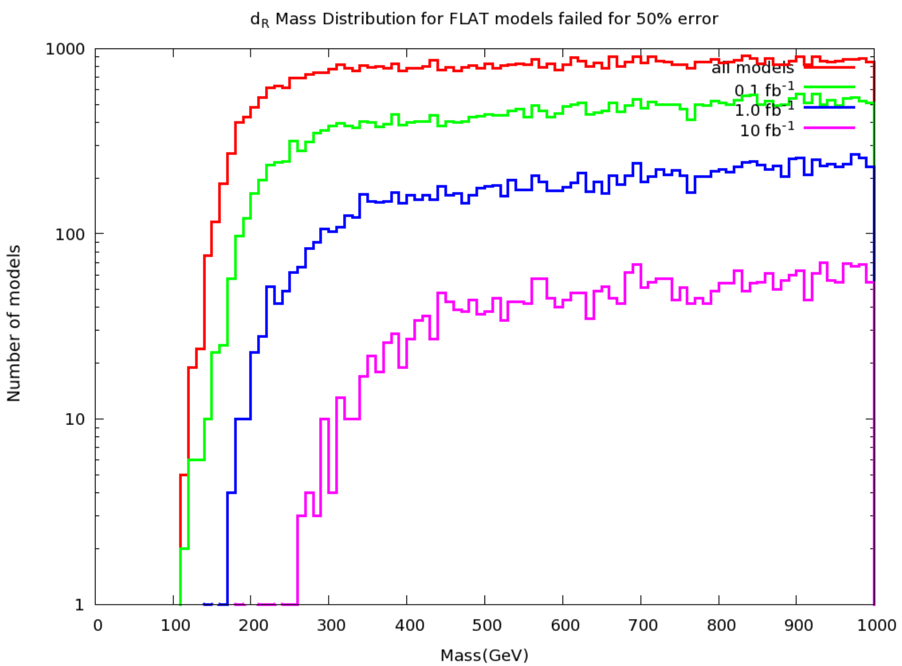


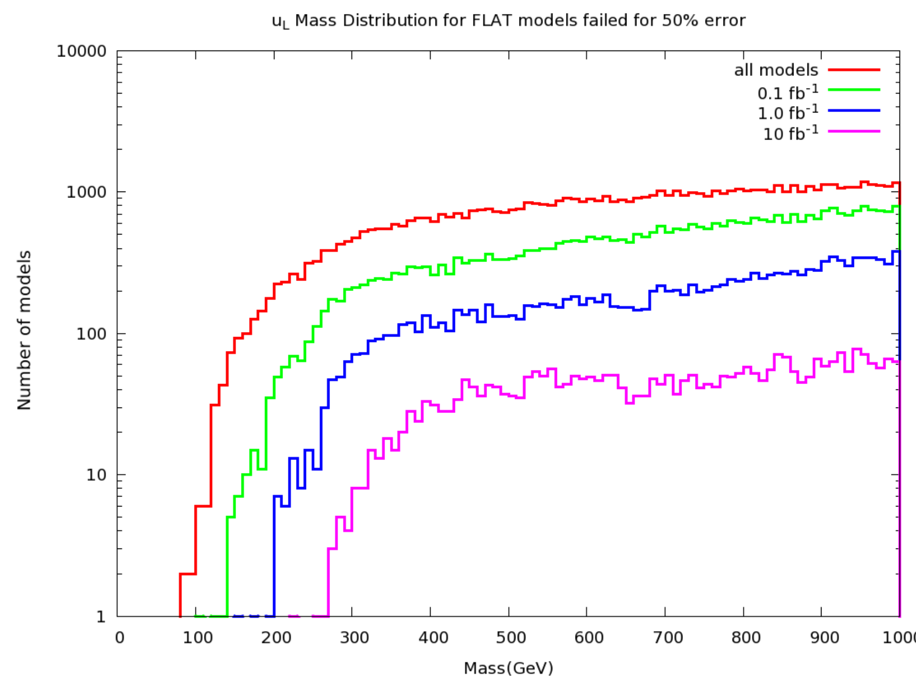


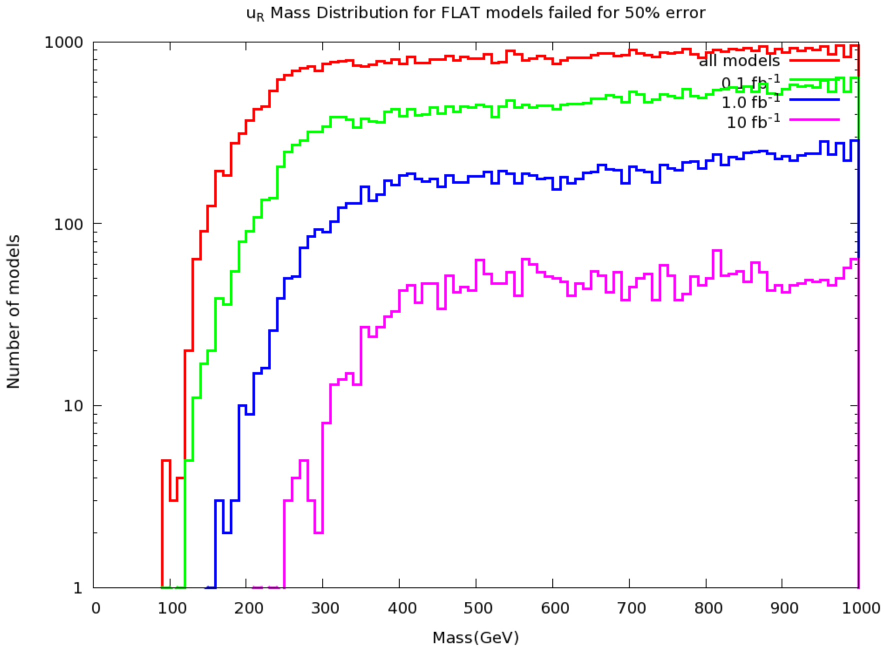


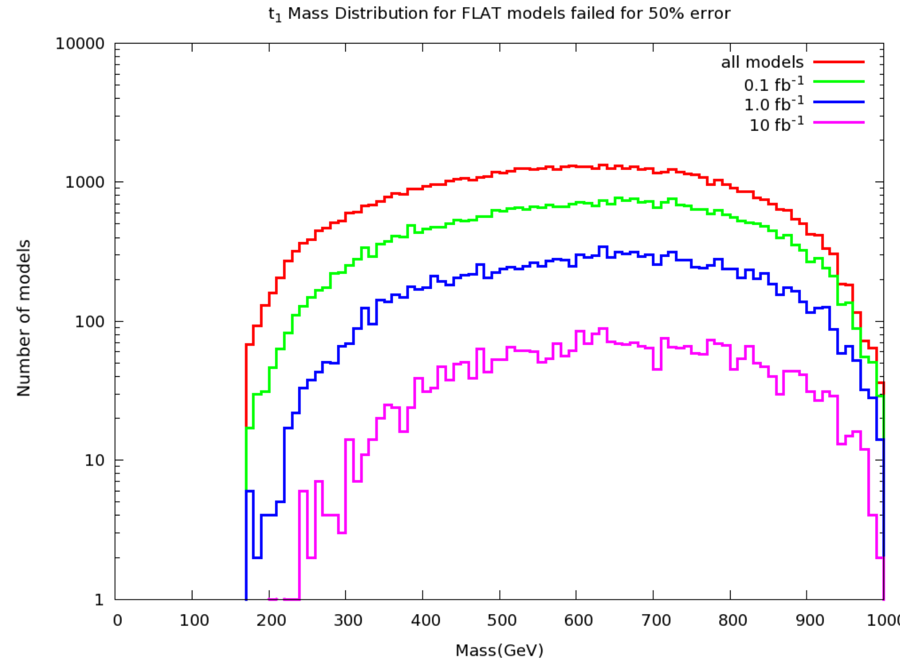

g Mass Distribution for FLAT models failed for 50% error
all models
0.1 fb-1
1.0 fb-1
10 fb-1
Number of models
Mass(GeV)

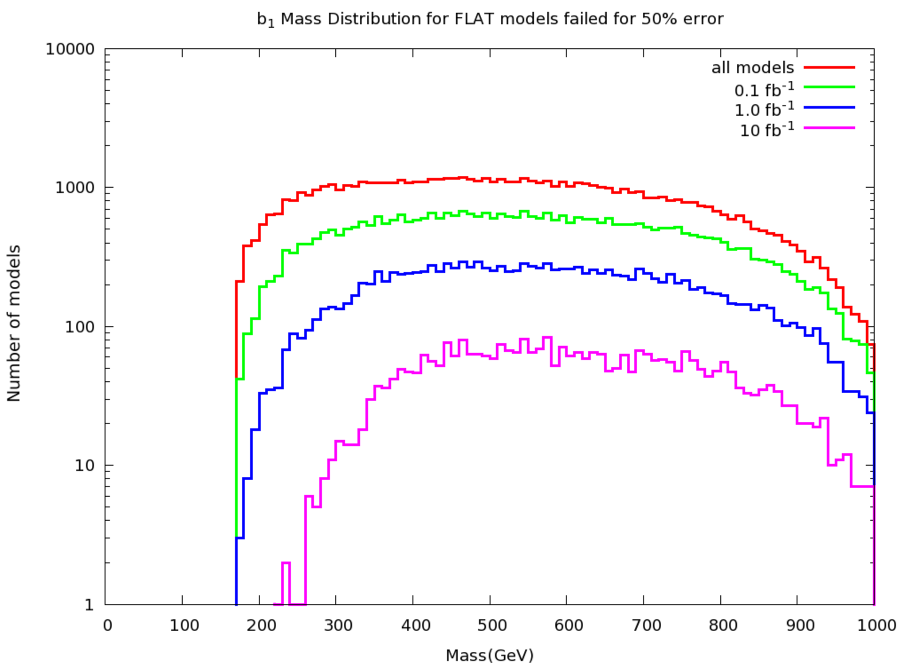

dL Mass Distribution for FLAT models failed for 50% error
all models
0.1 fb-1
1.0 fb-1
10 fb-1
Number of models
Mass(GeV)

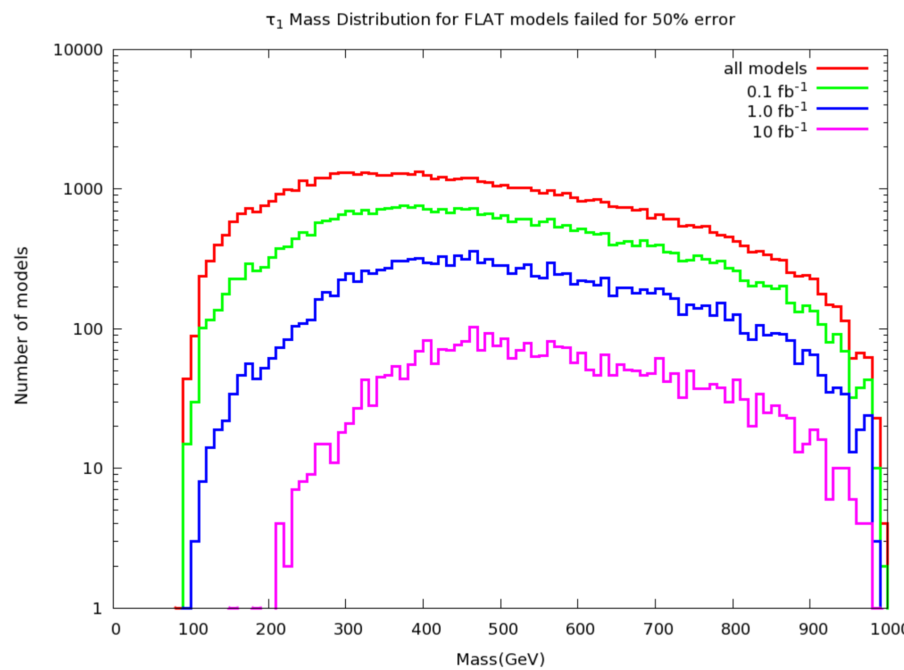

dR Mass Distribution for FLAT models failed for 50% error
all models
0.1 fb-1
1.0 fb-1
10 fb-1
Number of models
Mass(GeV)

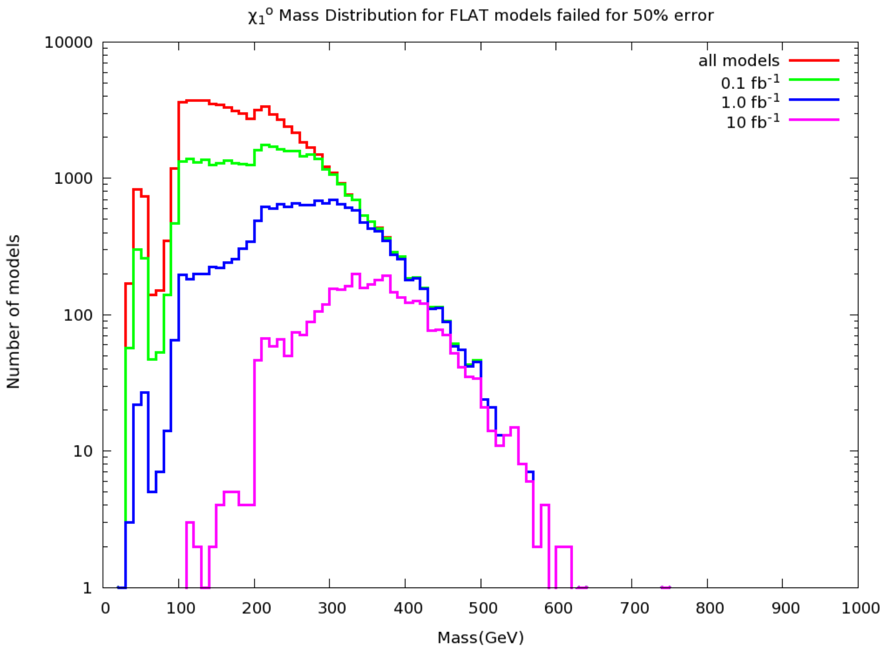
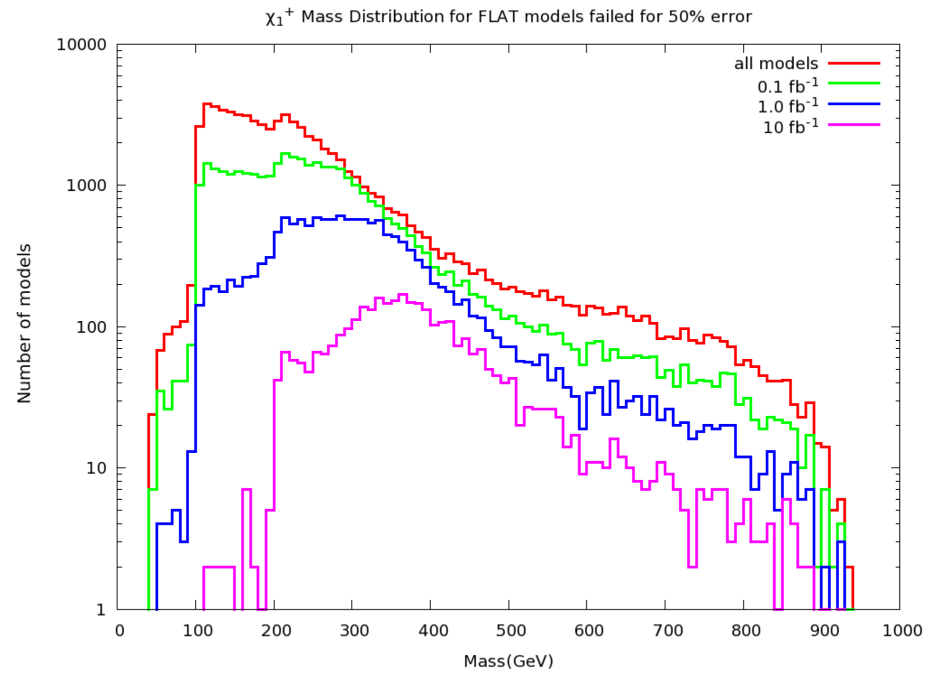
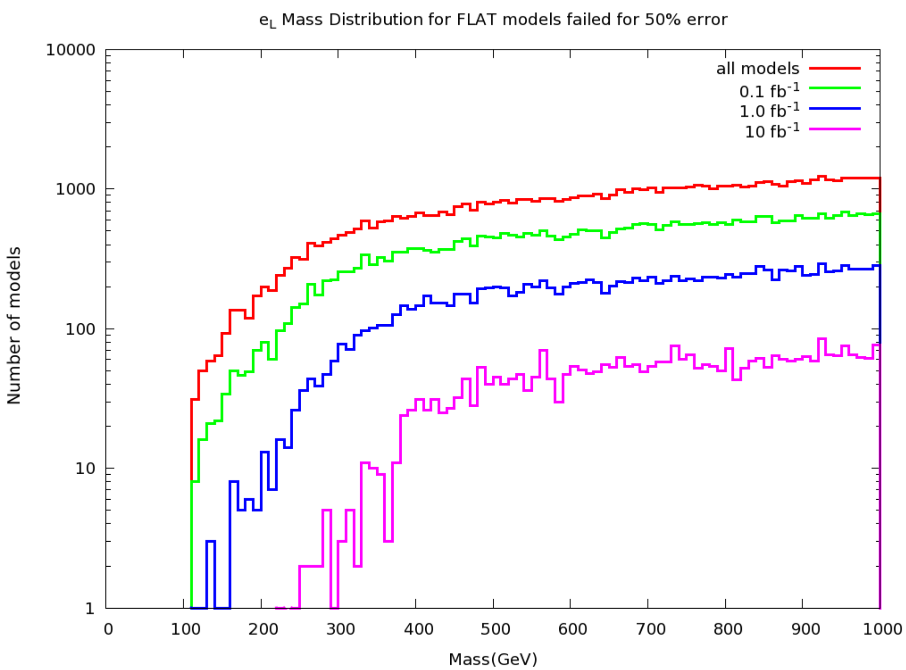
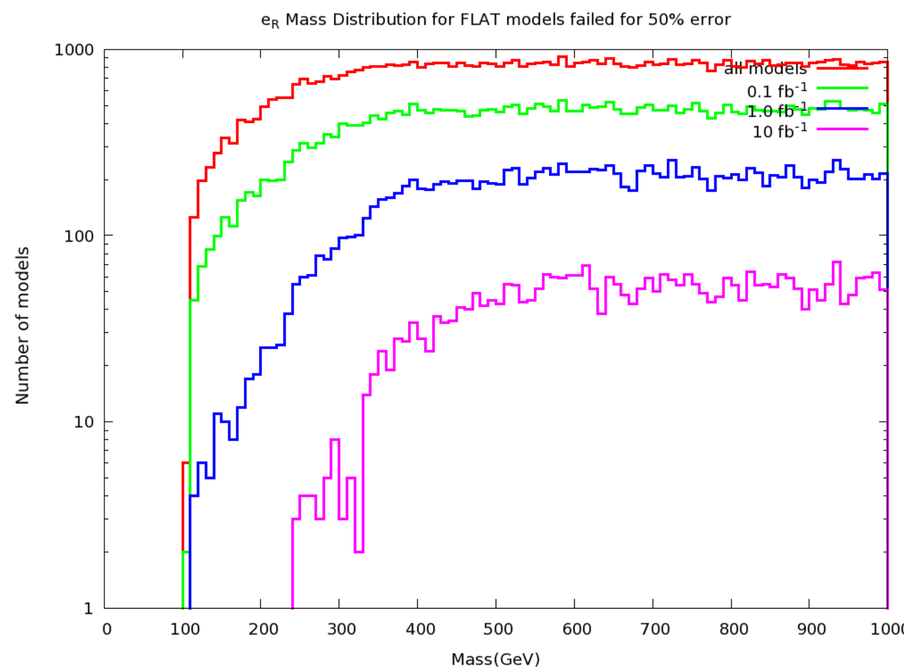

uL Mass Distribution for FLAT models failed for 50% error
all models
0.1 fb-1
1.0 fb-1
10 fb-1
Number of models
Mass(GeV)


u_R Mass Distribution for FLAT models failed for 50% error
Number of models
Mass(GeV)
all models
0.1 fb-1
1.0 fb-1
10 fb-1
1
10
100
1000
0
100
200
300
400
500
600
700
800
900
1000


t_1 Mass Distribution for FLAT models failed for 50% error
Number of models
Mass(GeV)
all models
0.1 fb-1
1.0 fb-1
10 fb-1
1
10
100
1000
10000
0
100
200
300
400
500
600
700
800
900
1000


b_1 Mass Distribution for FLAT models failed for 50% error
Number of models
Mass(GeV)
all models
0.1 fb-1
1.0 fb-1
10 fb-1
1
10
100
1000
10000
0
100
200
300
400
500
600
700
800
900
1000

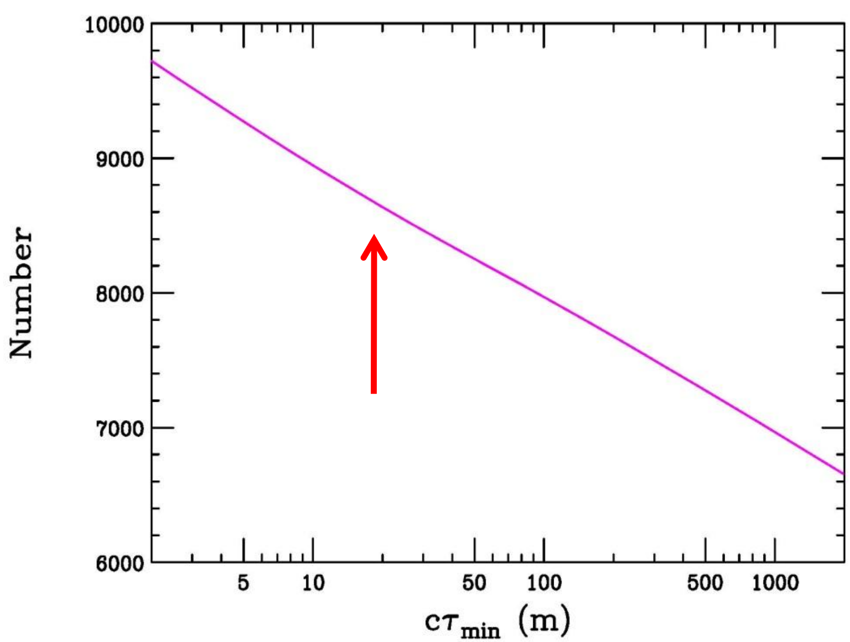

τ_1 Mass Distribution for FLAT models failed for 50% error
Number of models
Mass(GeV)
all models
0.1 fb-1
1.0 fb-1
10 fb-1
1
10
100
1000
10000
0
100
200
300
400
500
600
700
800
900
1000


χ1° Mass Distribution for FLAT models failed for 50% error
all models
0.1 fb-1
1.0 fb-1
10 fb-1
Number of models
Mass(GeV)

χ1+ Mass Distribution for FLAT models failed for 50% error
all models
0.1 fb-1
1.0 fb-1
10 fb-1
Number of models
Mass(GeV)

eL Mass Distribution for FLAT models failed for 50% error
all models
0.1 fb-1
1.0 fb-1
10 fb-1
Number of models
Mass(GeV)

eR Mass Distribution for FLAT models failed for 50% error
all models
0.1 fb-1
1.0 fb-1
10 fb-1
Number of models
Mass(GeV)

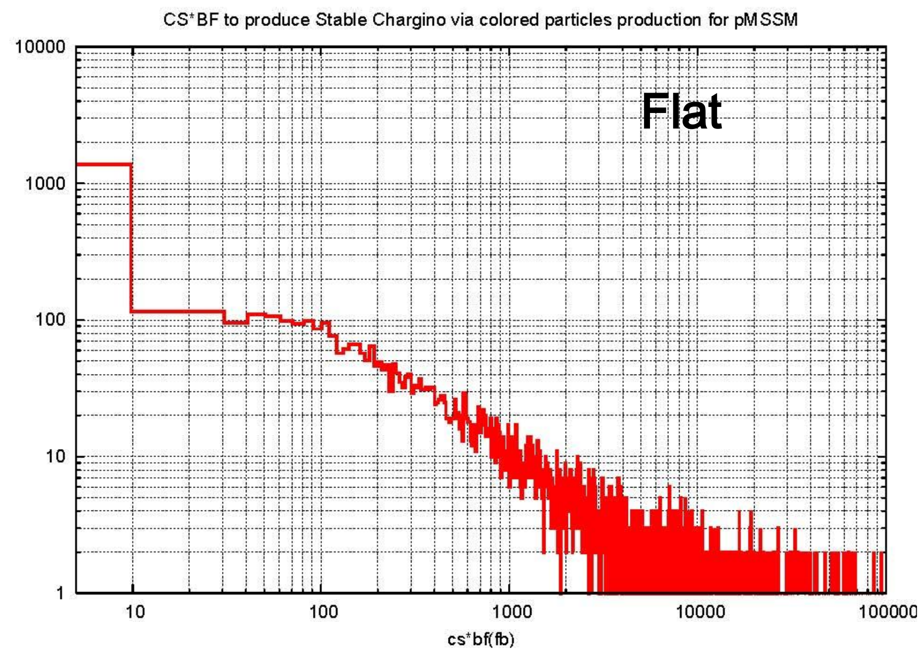
'Stable' Charged Particles in Cascades

→ Mostly long-lived charginos produced in gluino/squark initiated decay chains

~84% of these $\chi_1^{\pm}$ with $c\tau$>20m have σB>10 fb @ 7 TeV



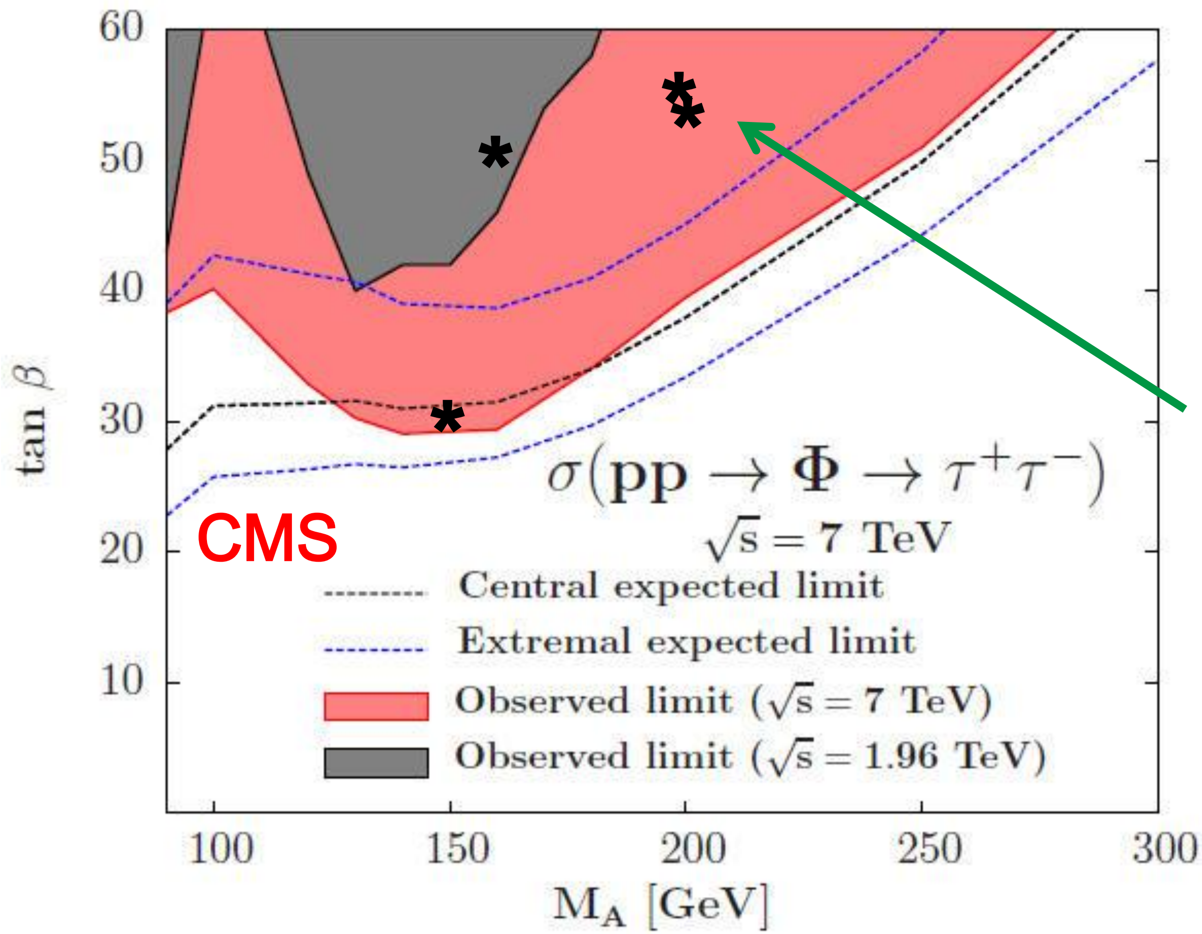
Unboosted Minimum Decay Length



Estimated σB

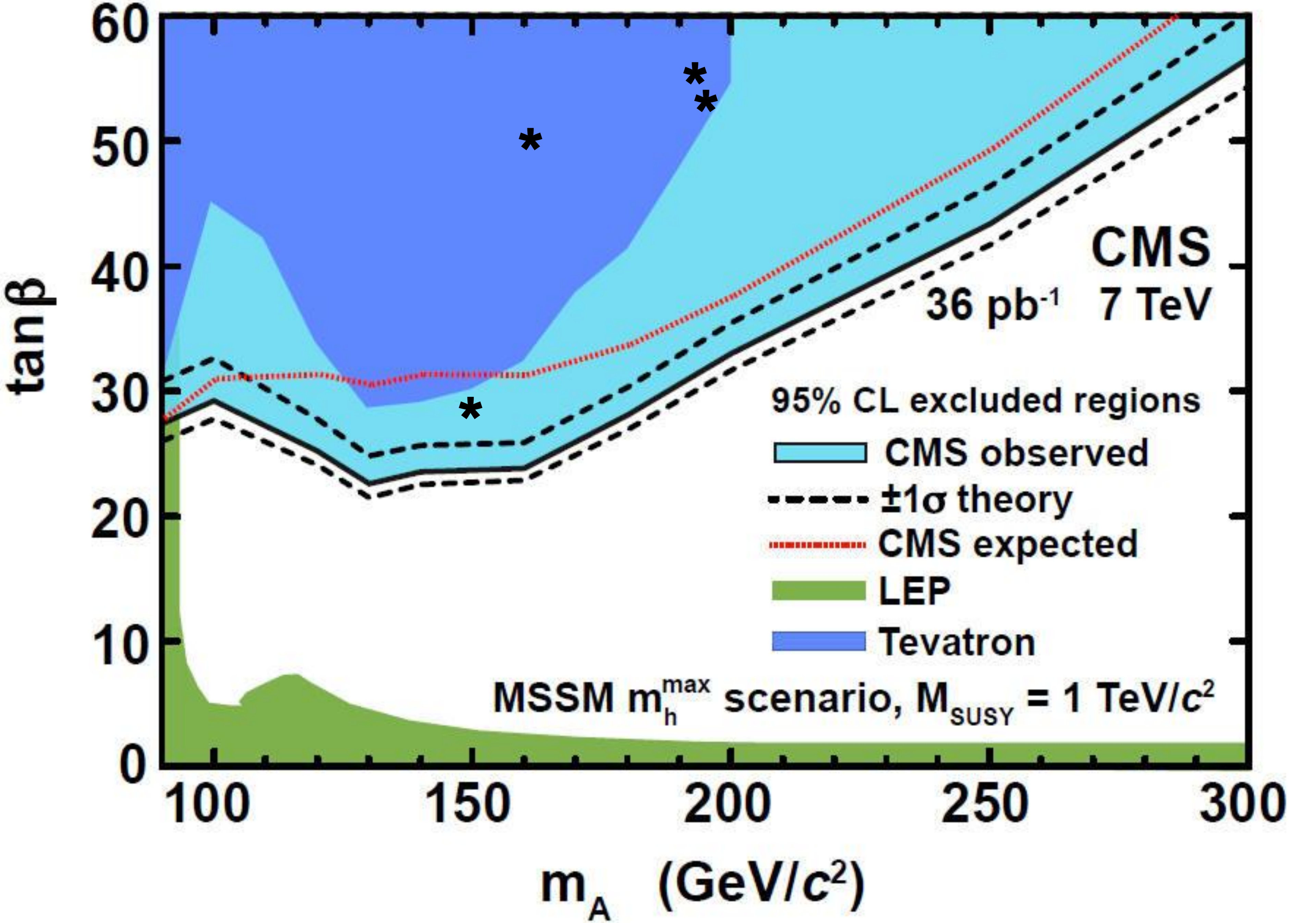
Impact of Higgs Searches

Searches for the various components of the SUSY Higgs sector also can lead to very important constraints on SUSY parameter space.



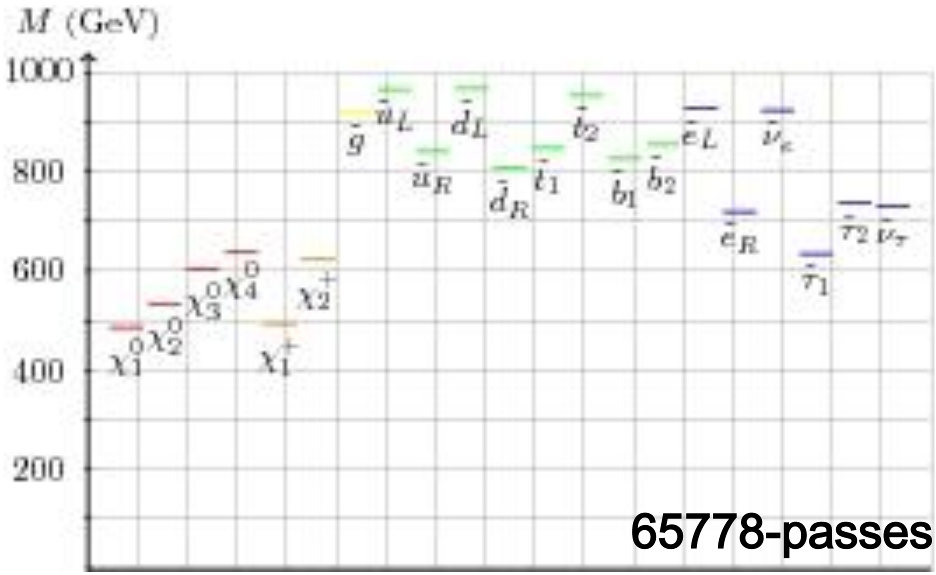
So far with ~35 pb^{-1} these searches have excluded only <u>**4**</u> of our models (due to the existing strong flavor constraints) but these searches are just beginning ..

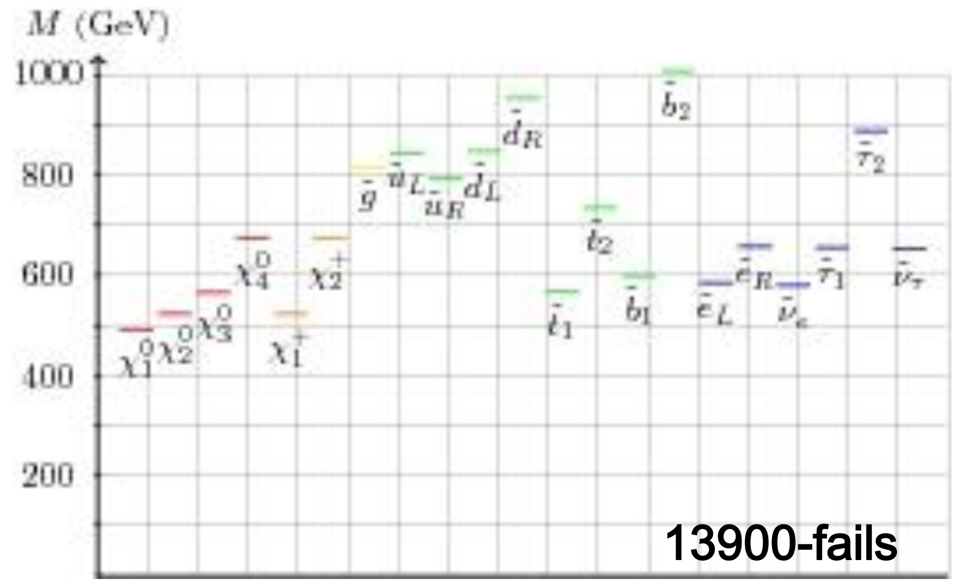
Baglio & Djouadi 1103.6247



tanβ
60
50
40
30
20
10
0
100
150
200
250
300
m_A (GeV/c^2)
CMS
36 pb^{-1} 7 TeV
95% CL excluded regions
CMS observed
±1σ theory
CMS expected
LEP
Tevatron
MSSM m_h^{max} scenario, M_{SUSY} = 1 TeV/c^2

Missed vs Found Model Comparisons



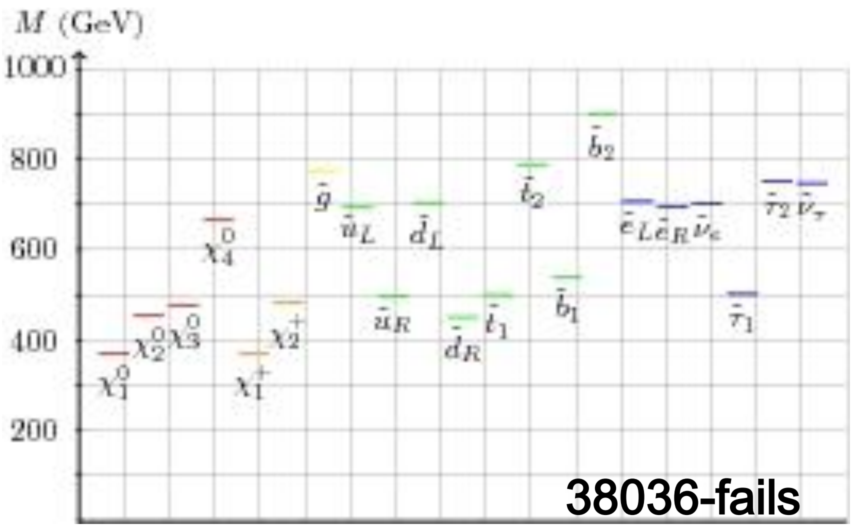


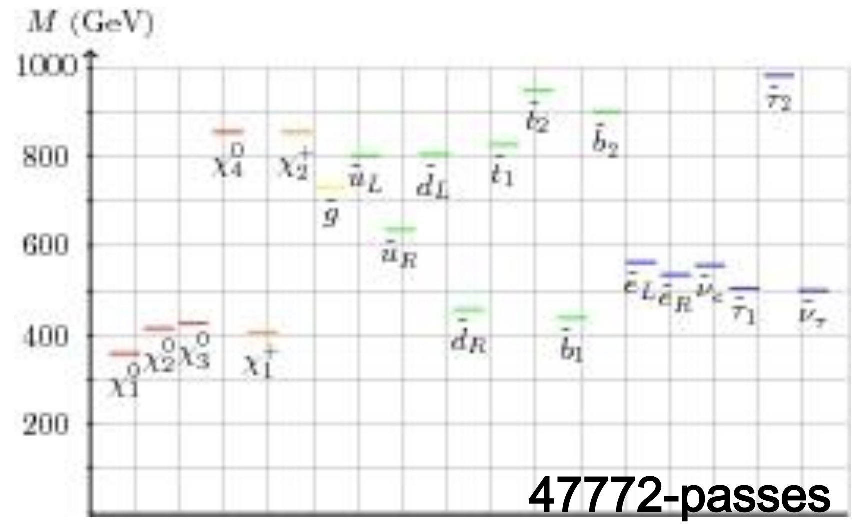
- 13900 & 65778 have heavy spectra & well-mixed gauginos w/ $\sigma \sim 0.36(0.22)$ pb, too small for nj0l but 65778 seen in 4j1l

- In 13900 the gluino decays to sbottoms & stops while u_R goes mostly to the LSP, so no leptons

- In 65778, $(d,u)_R$ decay to $j+\chi_{2,4}^0$, then to $W\chi_1^\pm$ w/ B~75% & Δm~160-270 GeV, producing a subsequent hard lepton

Missed vs Found Model Comparisons

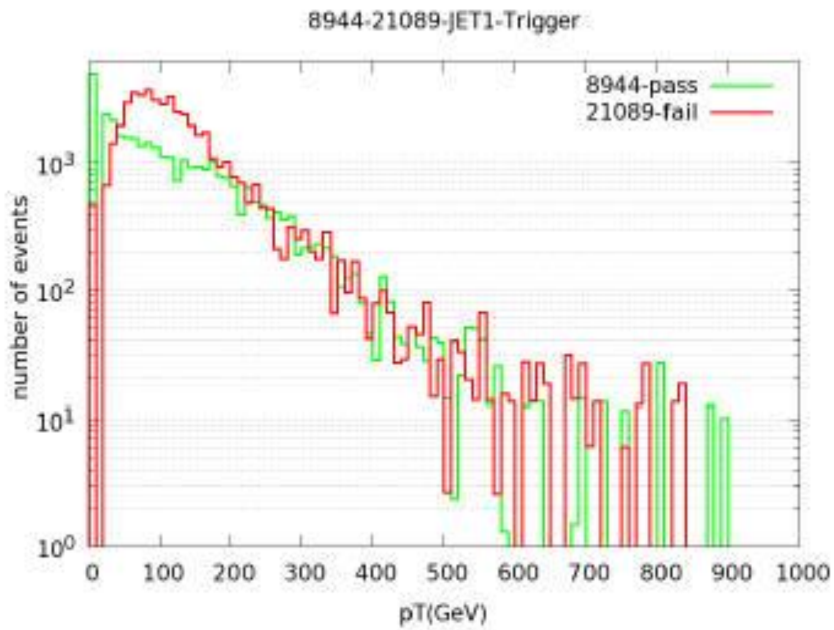


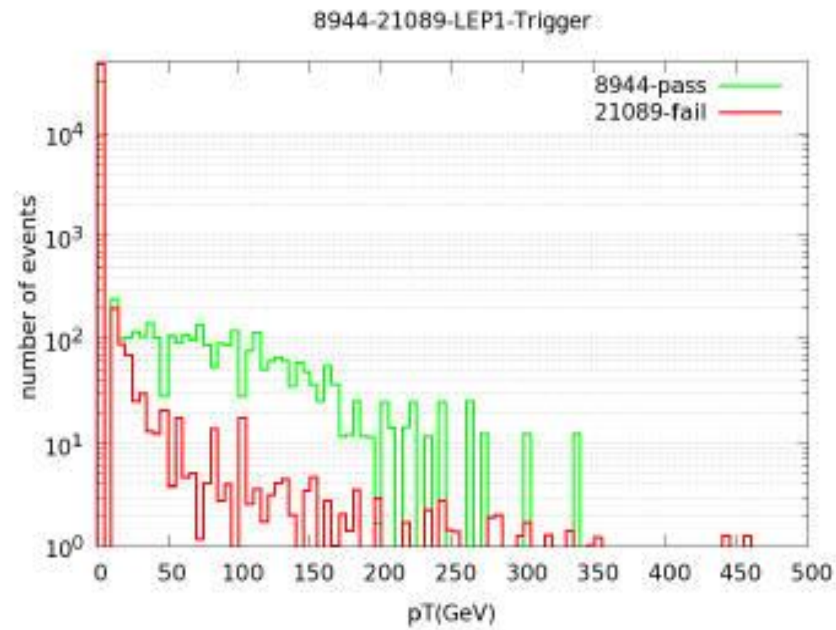


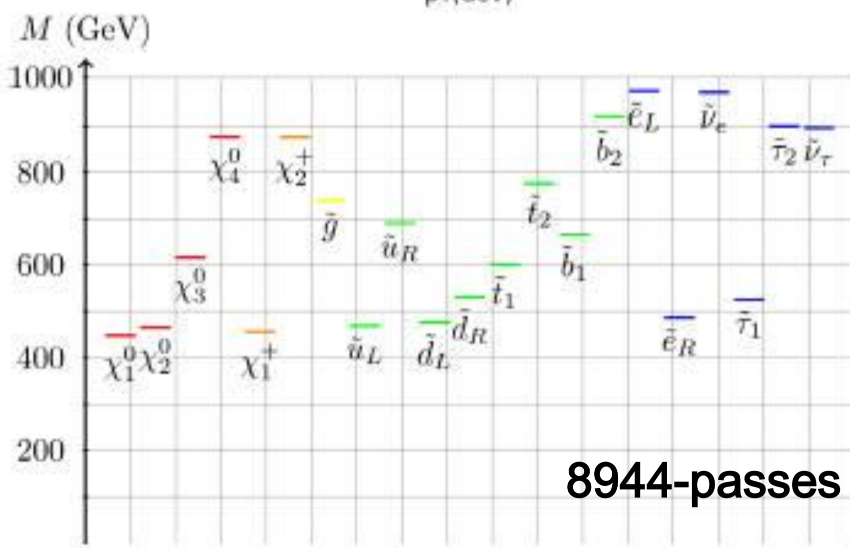
- 38036 (~2.5 pb) fails while 47772 (~1.7 pb) passes all nj0l
- u_R lighter (~500 vs ~635 GeV) & produces larger σ in 38036 but decays ~75% to j+MET in both models
- BUT due to the Δm w/ LSP difference ($\rightarrow$ eff ~13% vs ~3.5%) 38036 fails to have a large enough rate after cuts

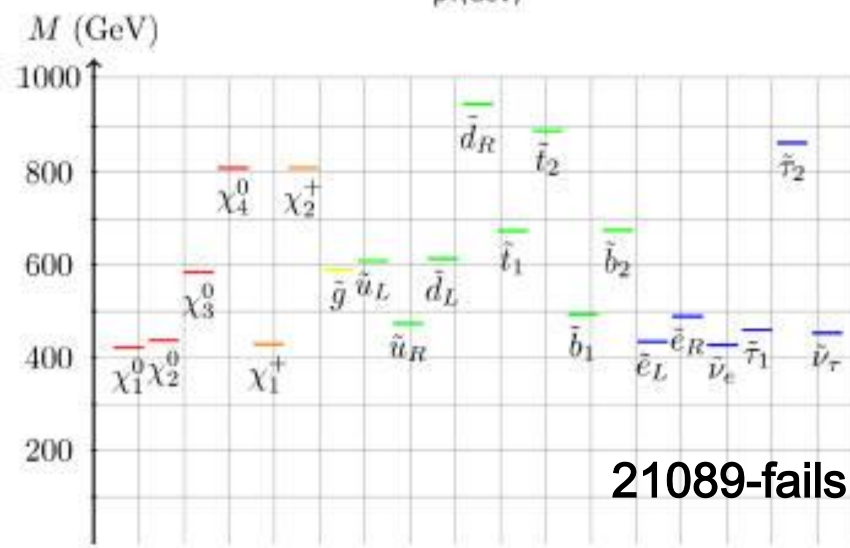
Efficiencies win over cross sections !

Missed vs Found Model Comparisons









What went wrong ??

- 8944 seen in (3,4)OSDL while 21089 is completely missed nj0l fail due to spectrum compression but with very similar colored sparticle total σ = (3.4, 4.6) pb

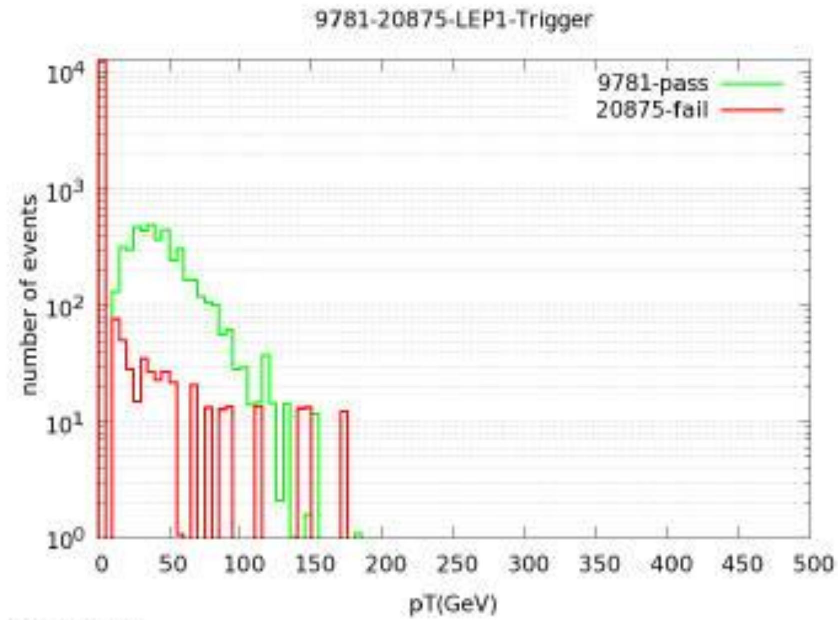
- models have similar gaugino sectors w/ $\chi_{1,2}^0$ Higgsino-like & χ_3^0 bino-like

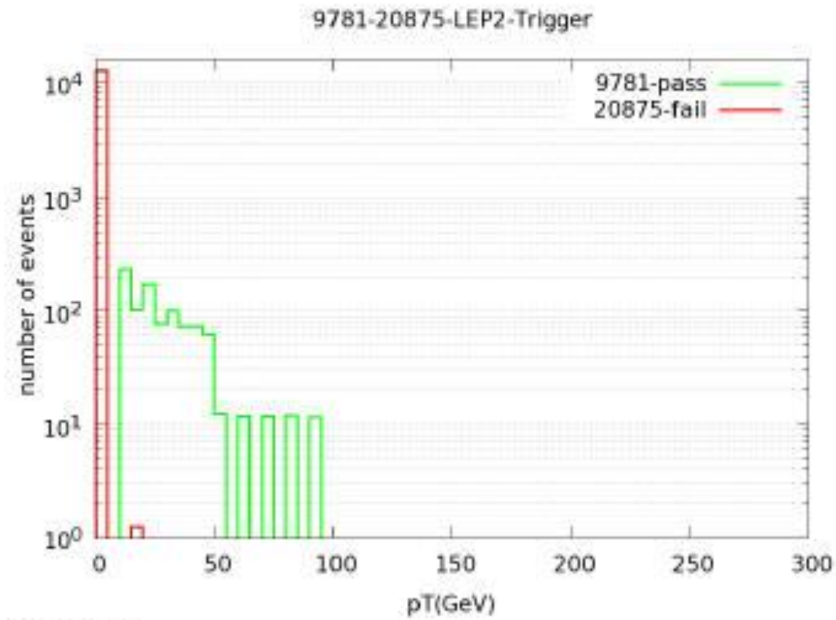
- χ_3^0 can decay thru sleptons to produce OSDL + MET

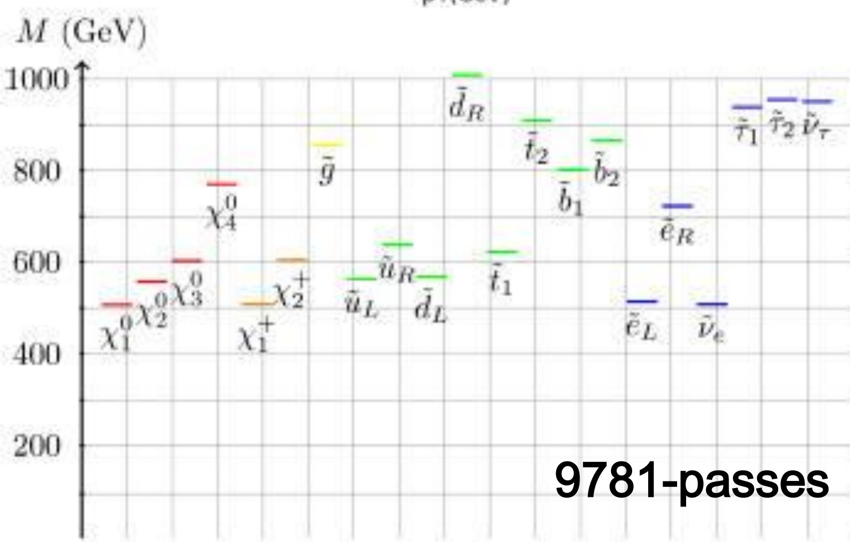
- However in 8944, the gluino is heavier than d_R so that d_R can decay to χ_3^0

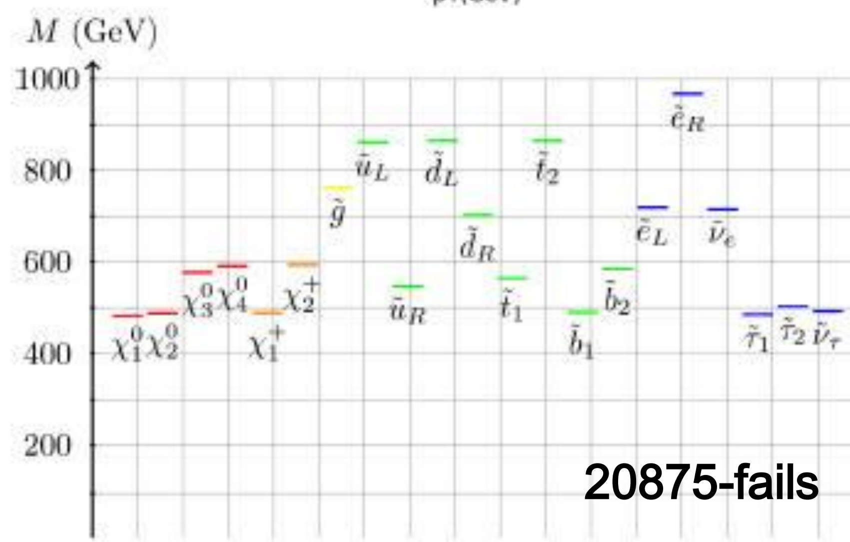
- But in 21089, the gluino is lighter than u_R so that it decays into the gluino & not the bino so NO leptons

Missed vs Found Model Comparisons









What went wrong ??

- 9781 seen in 2jSSDL while 20875 is completely missed nj0l fail due to spectrum compression but with very similar colored sparticle total σ = (1.1, 1.3) pb

- Both models have highly mixed neutralinos & charginos w/ a relatively compressed spectrum

- In model 9781, u_R can decay to j+leptons+MET via the bino part of χ_2^0 through intermediate e,μ sleptons

- But in 20875, these sleptons are too heavy to allow for decay on-shell & only staus are accessible. The resulting leptons from the taus are too soft to pass analysis cuts