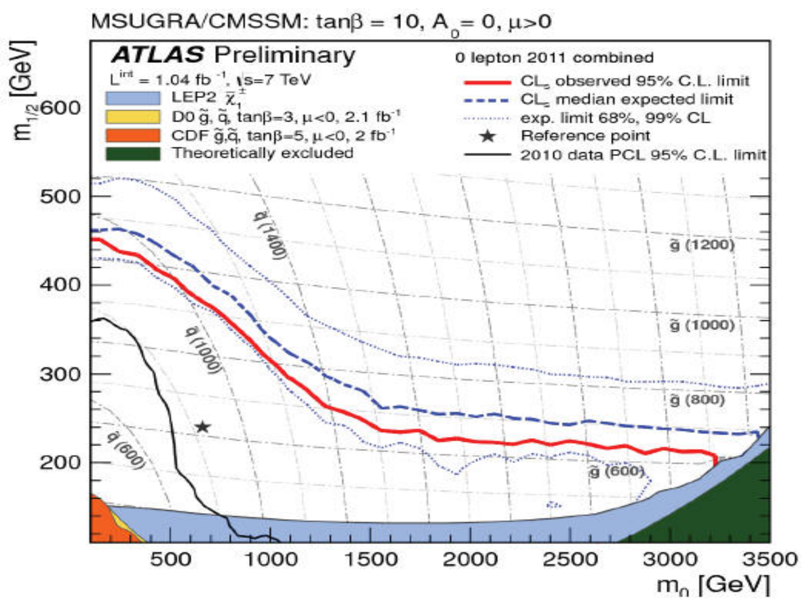
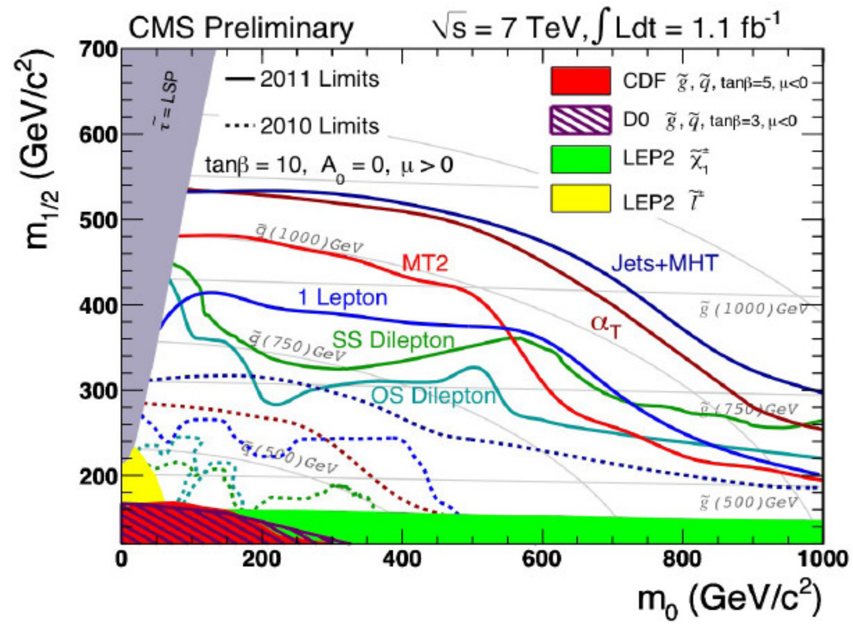
# ‘Difficult’ pMSSM Models @ the LHC : Tears ~~F~~or Fears ?





NATIONAL ACCELERATOR LABORATORY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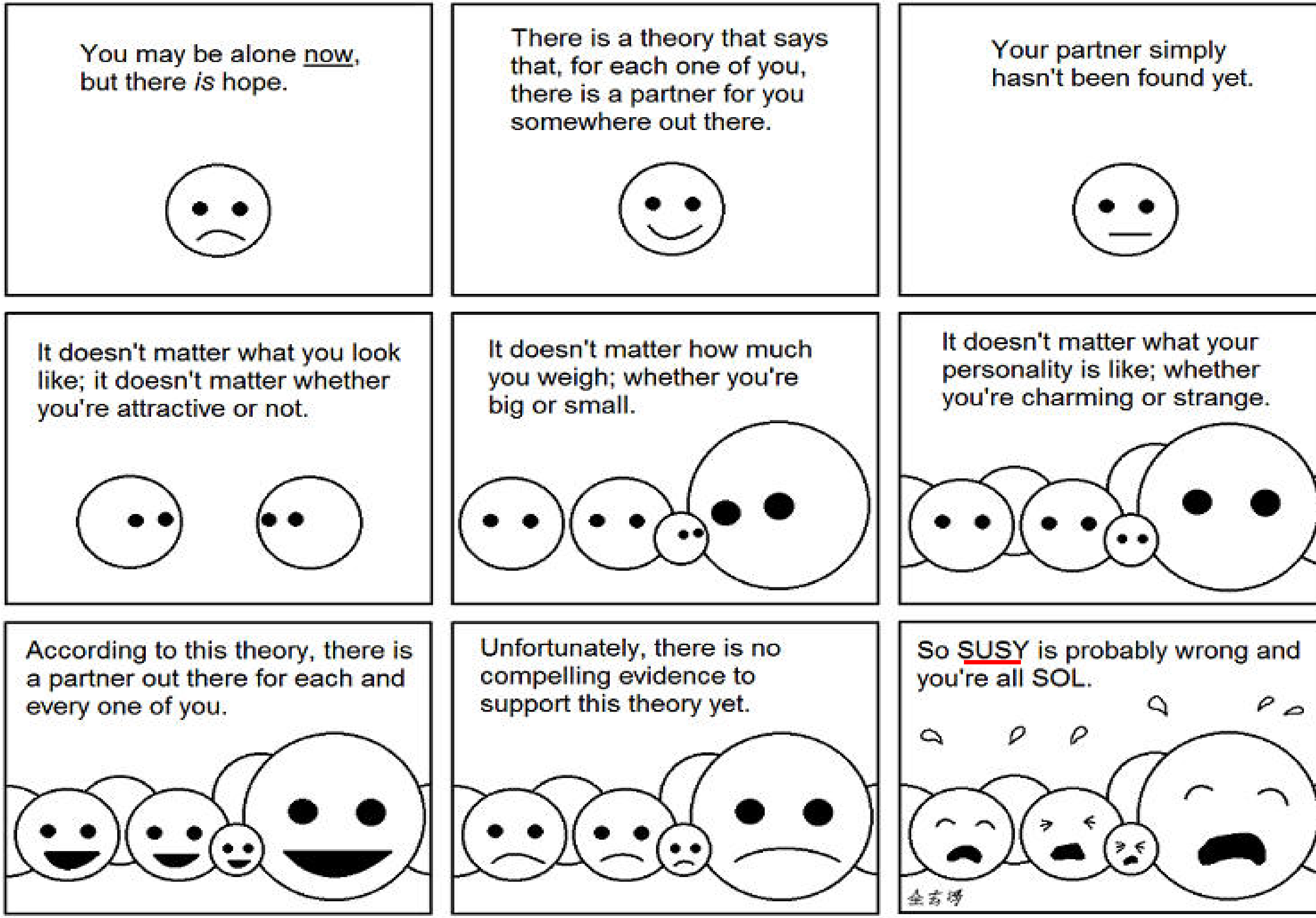
# Abstruse Goose gets it right ?



# A Reminder: Our First 2 Random Scans

(via SuSpect)

## Flat Priors

emphasizes moderate masses

100 GeV $\leq m_{sfermions} \leq$ 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

emphasizes lower masses but also extends to higher masses

100 GeV $\leq m_{sfermions} \leq$ 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
$1 \leq \tan\beta \leq 60$ (flat prior)
10 GeV $\leq |A_{t,b,\tau}| \leq$ 3 TeV

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

# ATLAS SUSY Analyses w/ pMSSM Sets

- Issue: Can the LHC find all the pMSSM model points?

- Question: We asked whether or not a standard set of LHC MET analyses, designed for the CMSSM, would find them.

- To be as realistic as possible we employed the ATLAS SUSY analysis suite at the fast simulation level. We obtained their pre-data SM background estimates & employed their anticipated range of systematic errors.

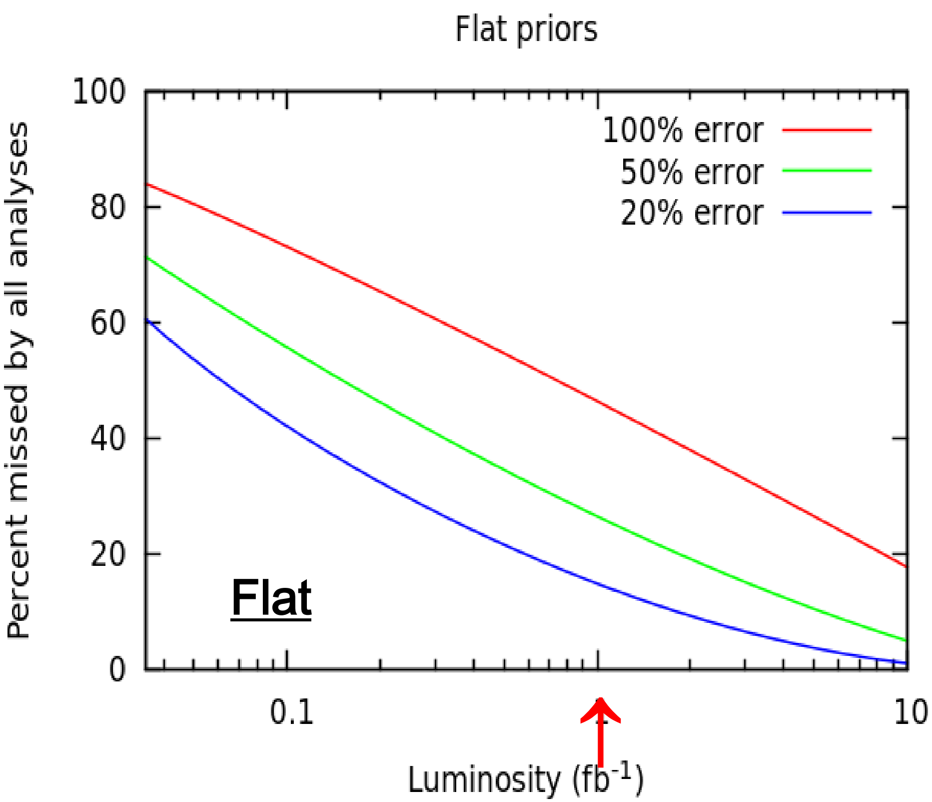
- We followed their multi-channel search analyses in detail (same cuts, etc.) as well as their statistical criterion for SUSY discovery for direct comparisons. We used their benchmarks for validation.

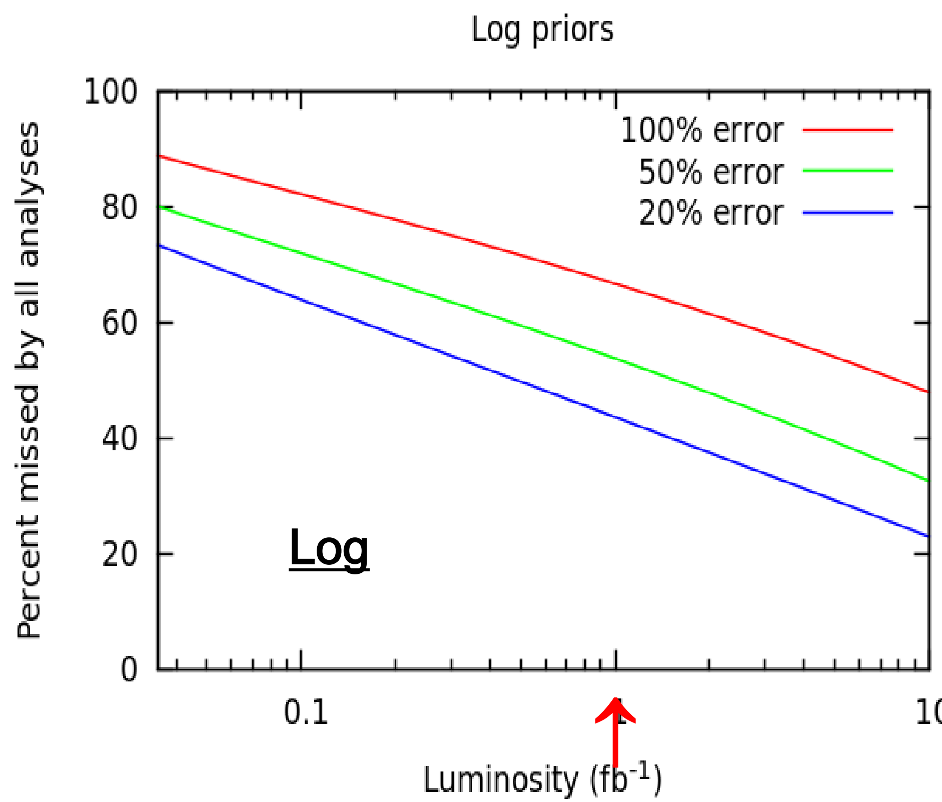
# The Question:

ATLAS = A Tool for Locating Any SUSY ?

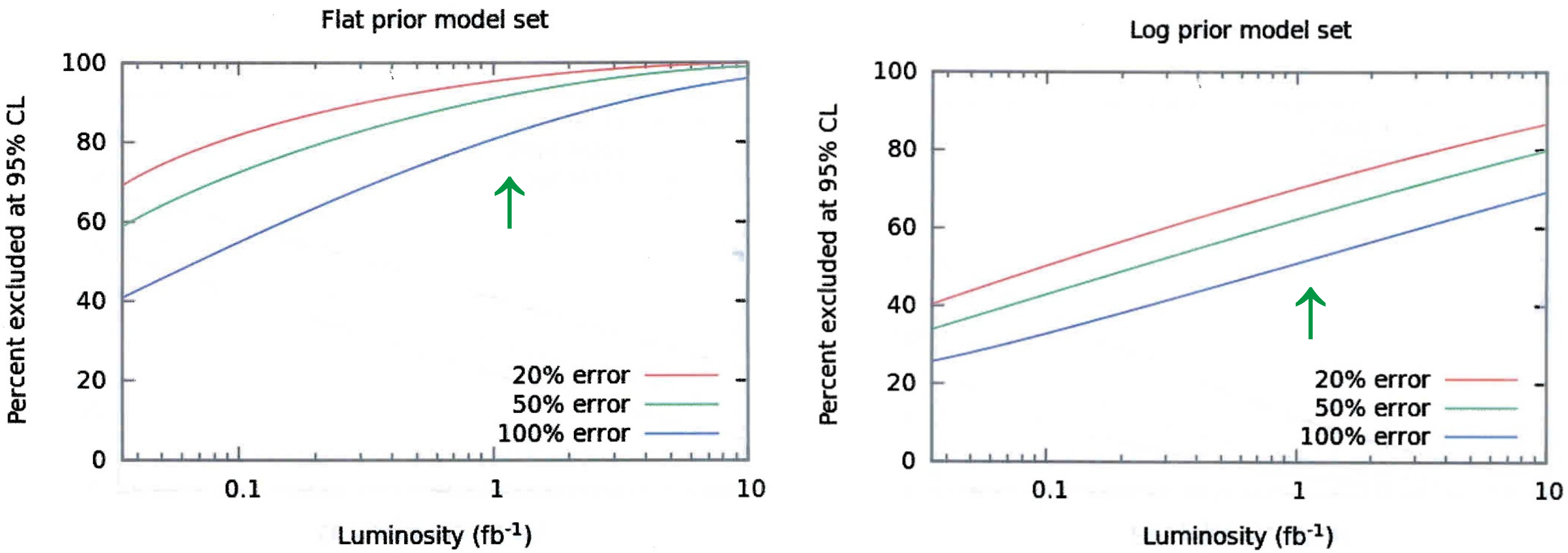
- What fraction of the model sets should not (yet) have been discovered ??

→ The coverage is quite good for both model sets !



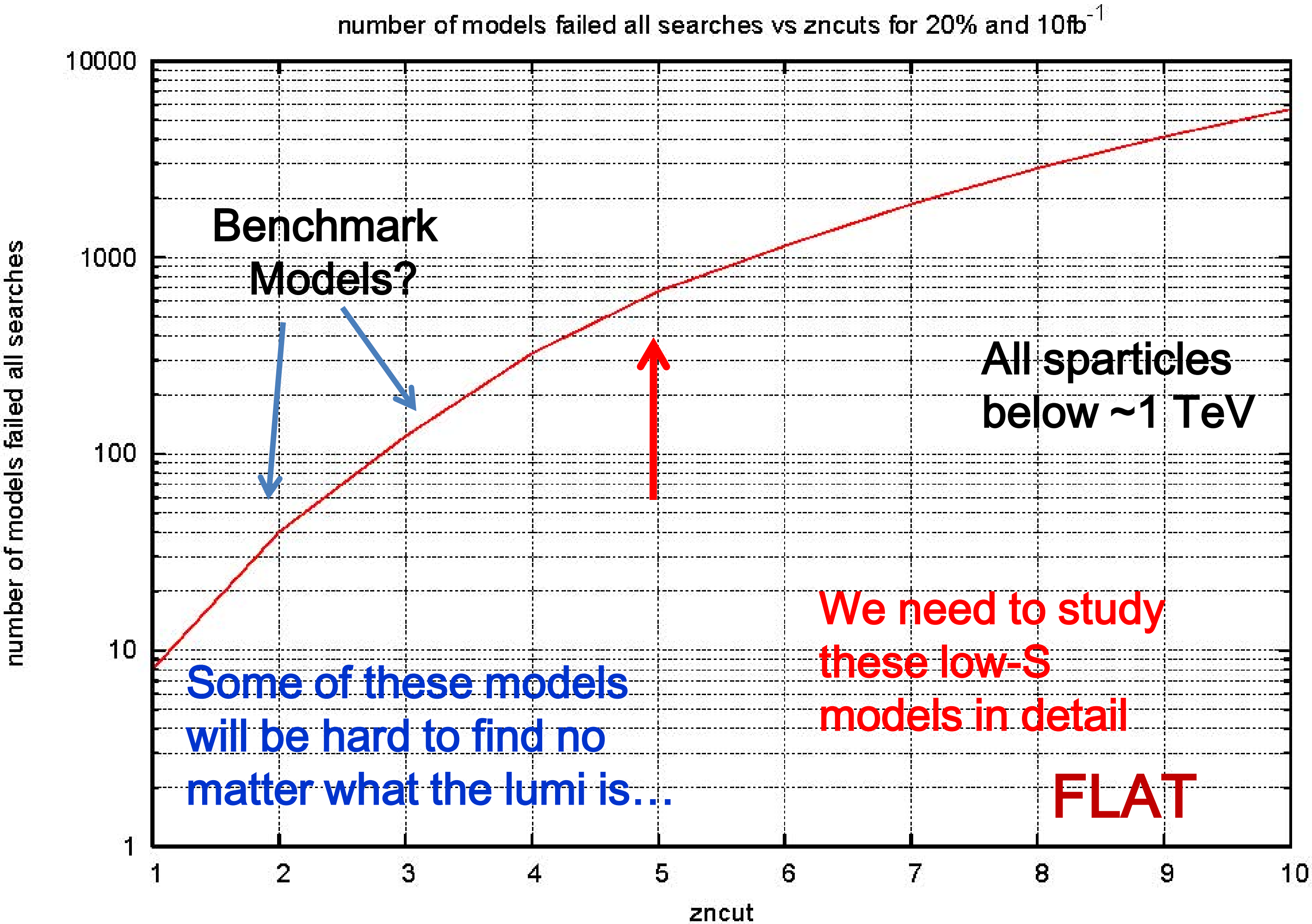



# What Fraction of Models are Excluded ?

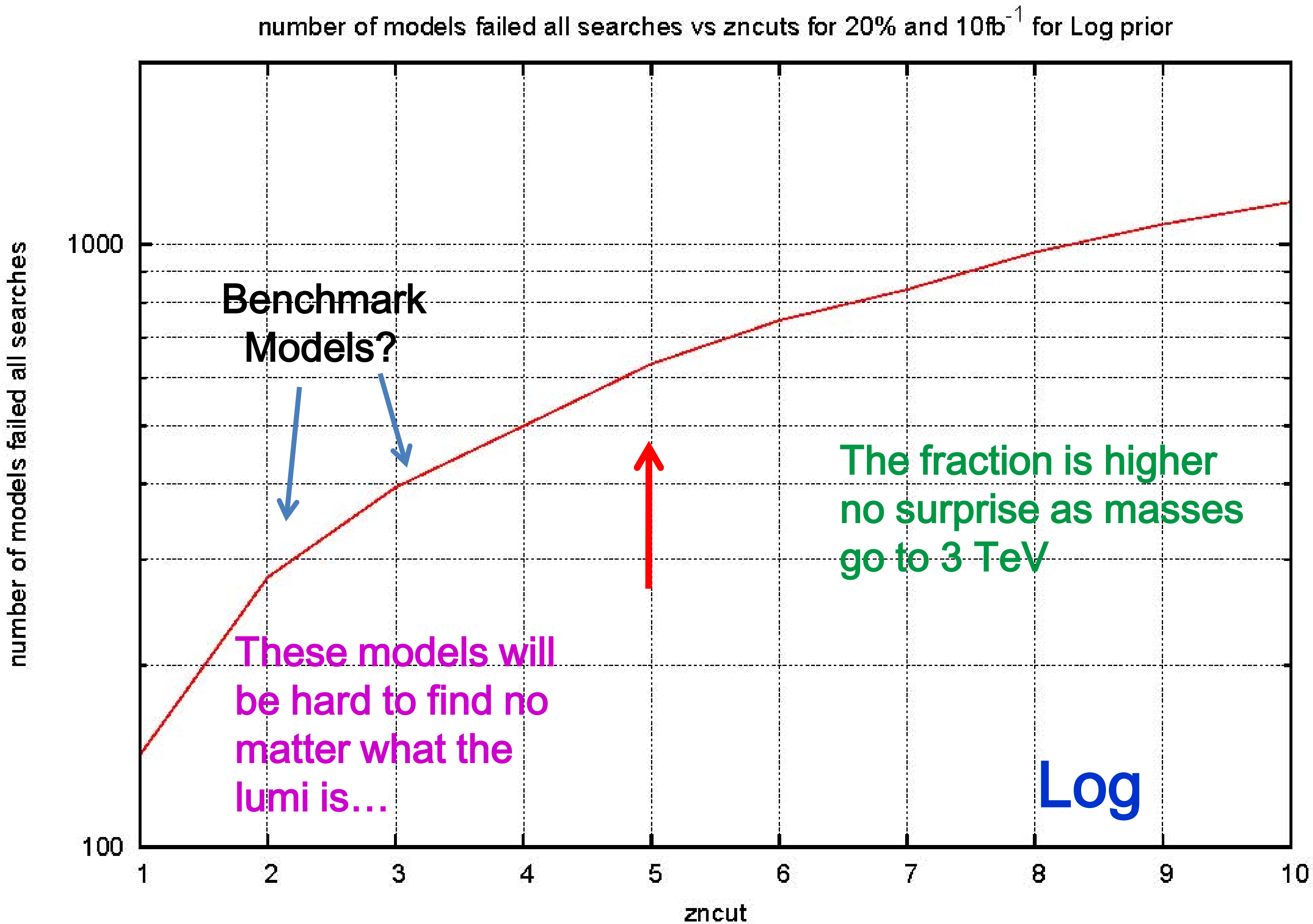



- Standard ATLAS MET searches do a very good job covering most of our pMSSM model sets…but there are some cases that are left over

# How many models fail to have even one channel with S > some fixed value with L=10 $fb^{-1}$ and $\delta B=20\%$?



# This same behavior is observed in the Log prior case



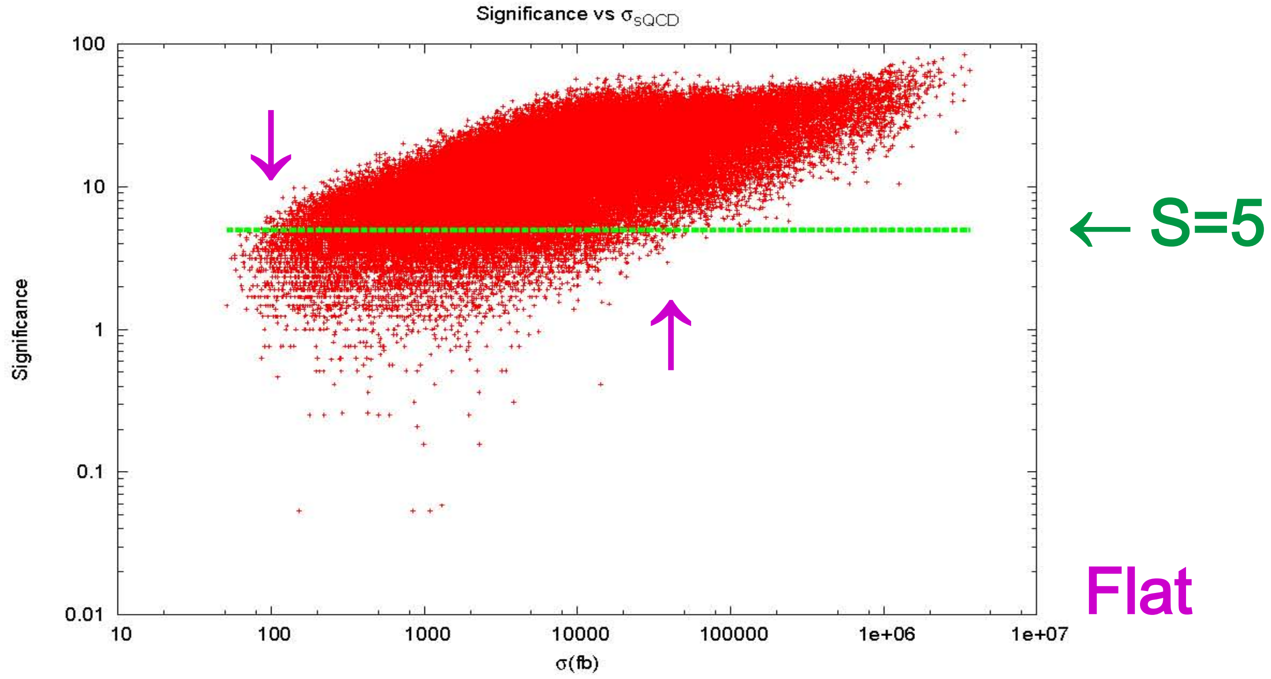
# The Undiscovered SUSY

## Why Do Models Get Missed by ATLAS?

Some of the most common contributing reasons are :

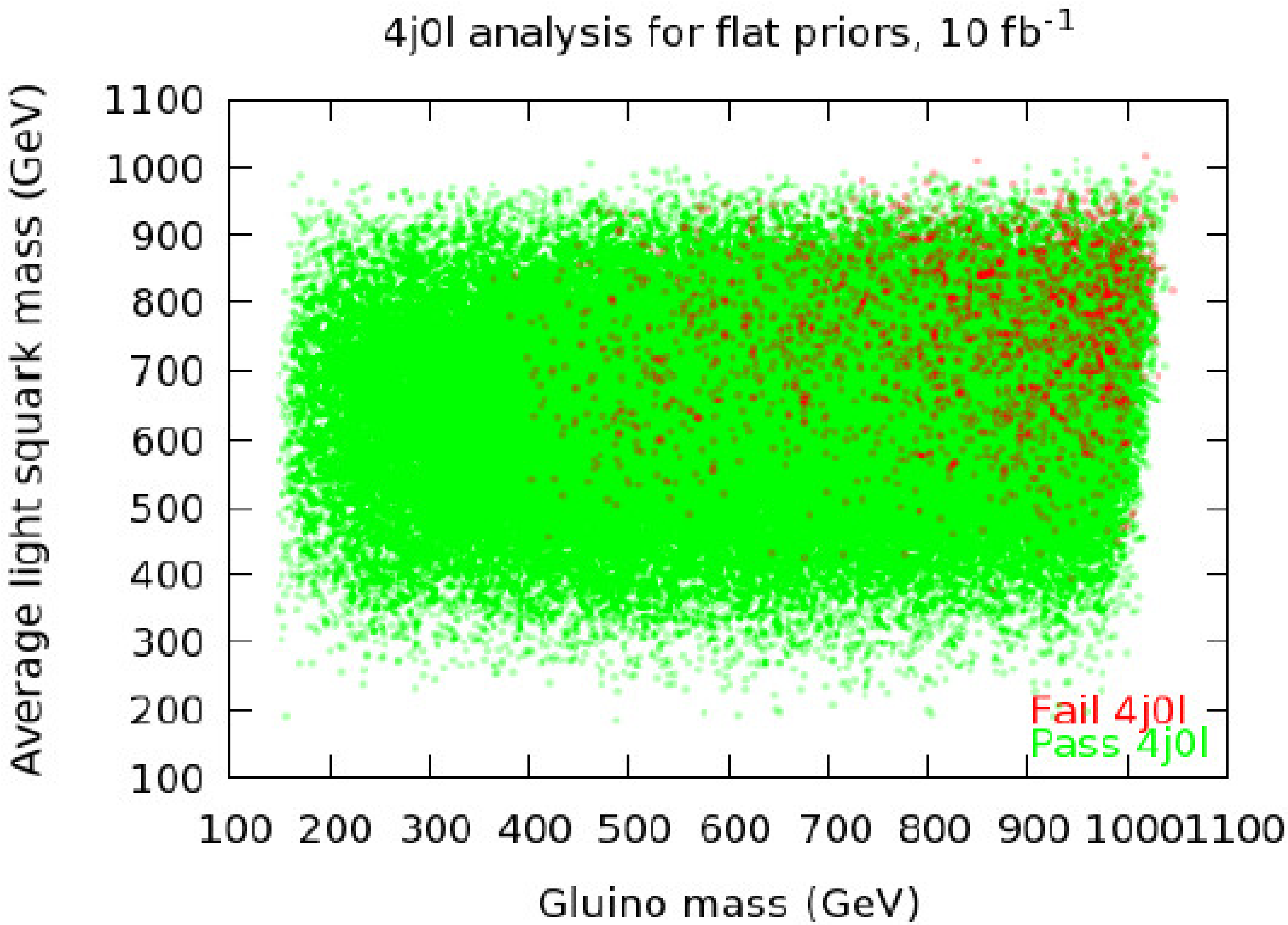
- small signal rates due to suppressed $\sigma$'s which are possibly correlated with 'larger' sparticle masses
- spectrum forbids hard leptons in cascades & nj0l buried in systematics
- small mass splittings w/ the LSP (compressed spectra)
- decay chains long or ending in stable sparticles $\rightarrow$low MET !
- inaccessibility of direct electroweak gaugino production
- will comment a bit about each of these

$\rightarrow$ BUT there are many more subtle situations that have to be examined on a case-by-case basis




Let's concentrate on the 4j0l channel as it is most powerful…

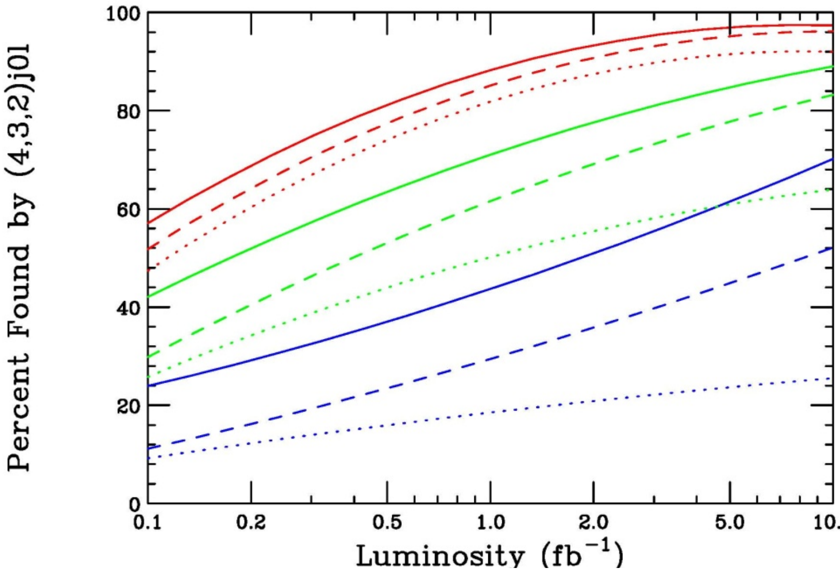
The result above is for the search significance @ 1fb $^{-1}$ as a function of the sum of the squark & gluino total $\sigma$'s. Note that low S values can occur with large $\sigma$'s and vice versa

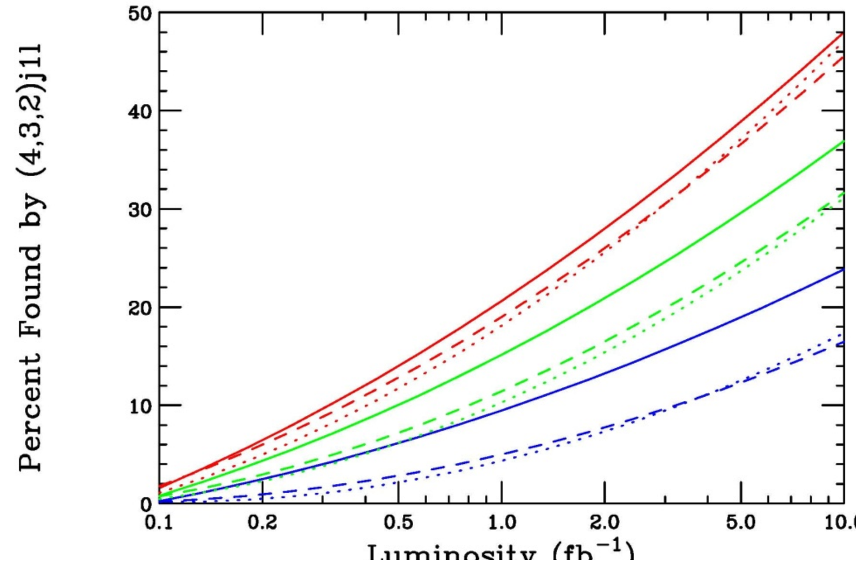



Models failing the 4j0l analysis @ 10 $fb^{-1}$ typically have heavy squarks & gluinos but not always. Sometimes, e.g., decay chains are lepton rich so nj0l searches must fail.

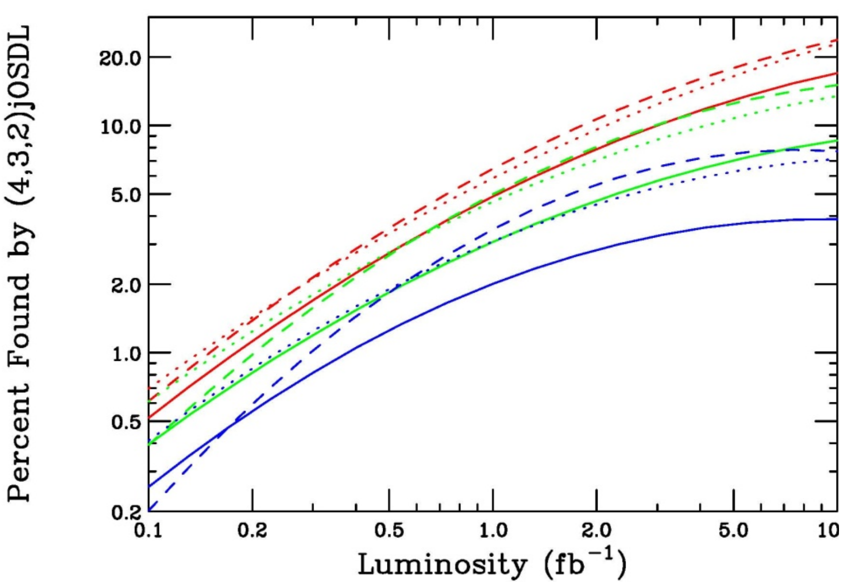
# FLAT

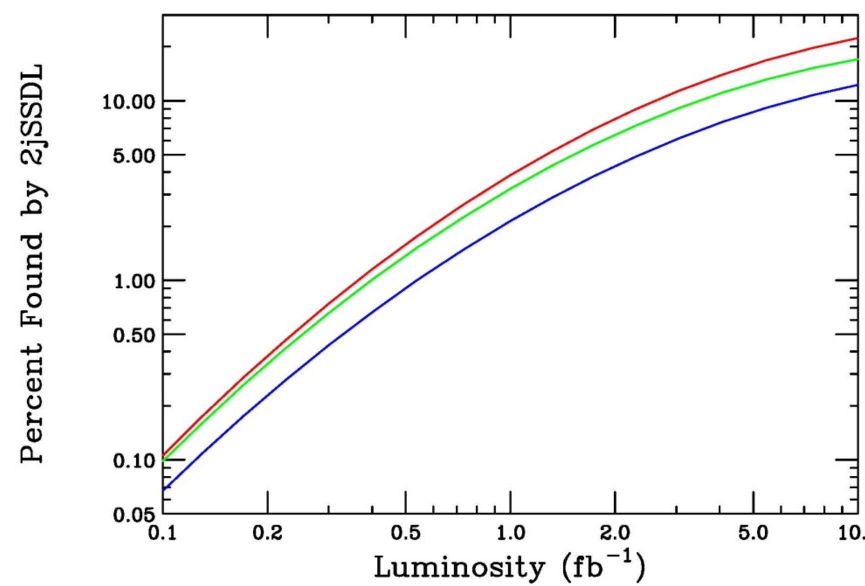
Solid=4j, dash=3j, dot=2j final states



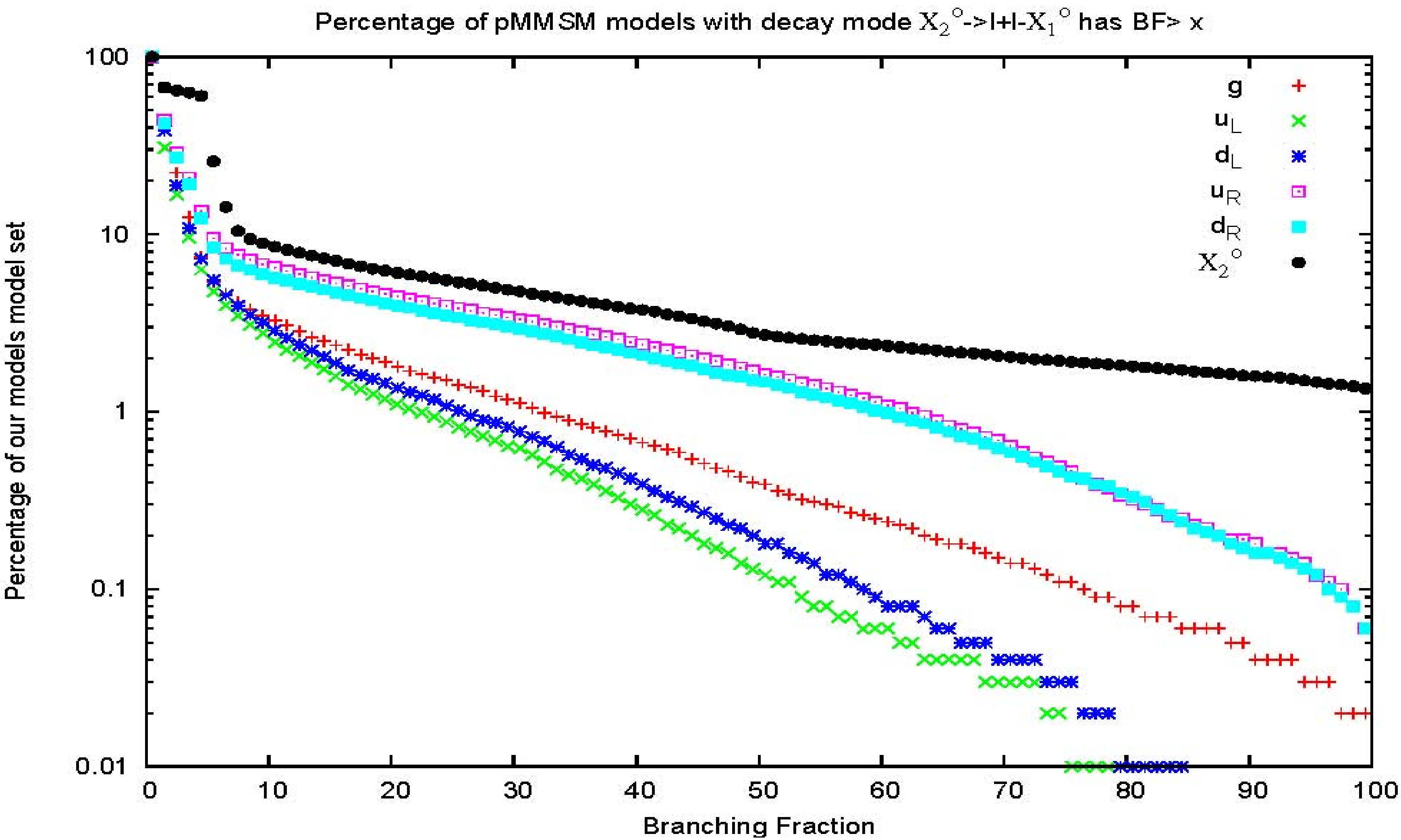




Red=20%,  green=50%, blue=100% background systematic errors



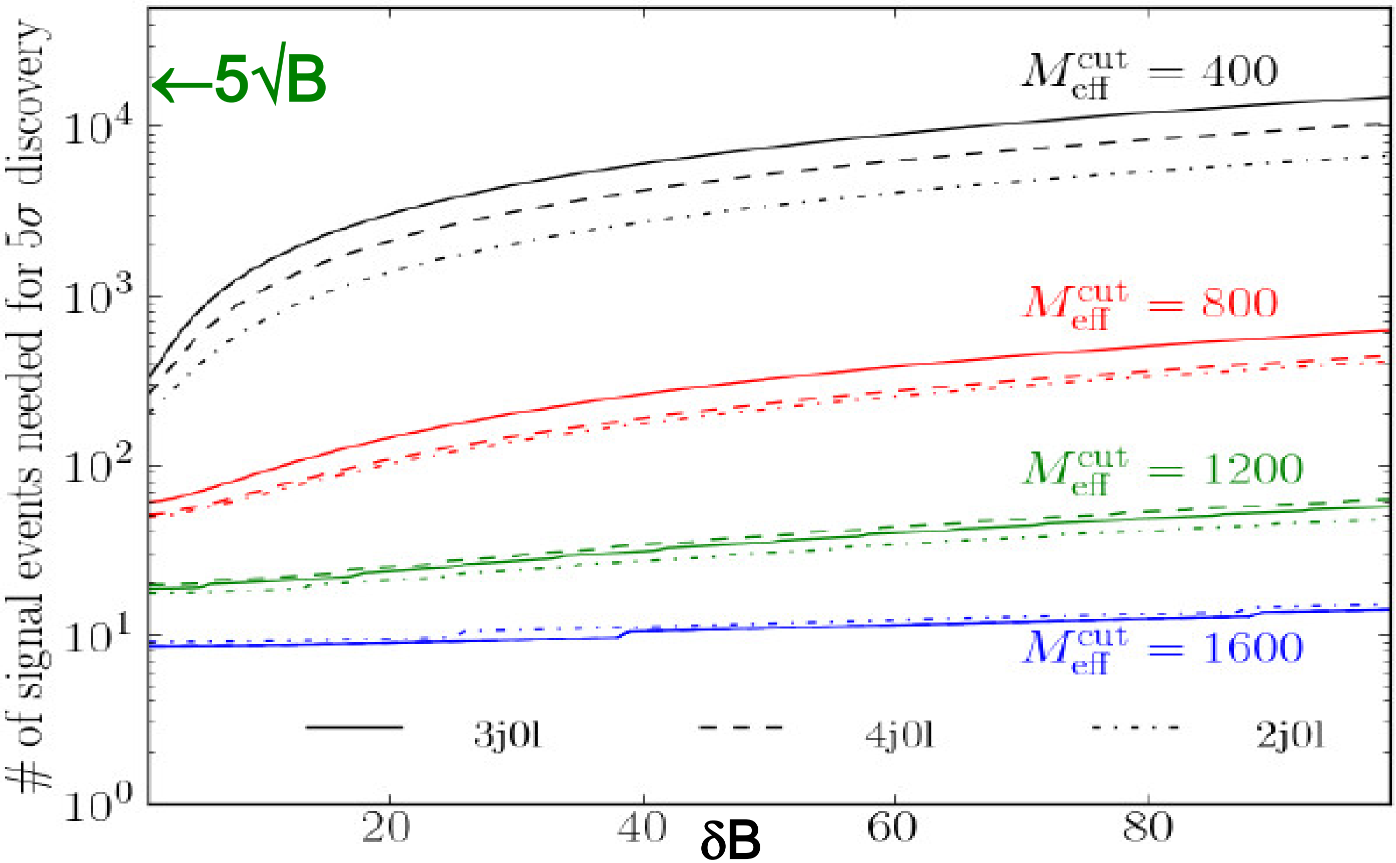



- For fixed lumi, as the number of required leptons increases, the corresponding model 'coverage' decreases. Why? The BF to lepton pairs is relatively small in our model sets...e.g. :



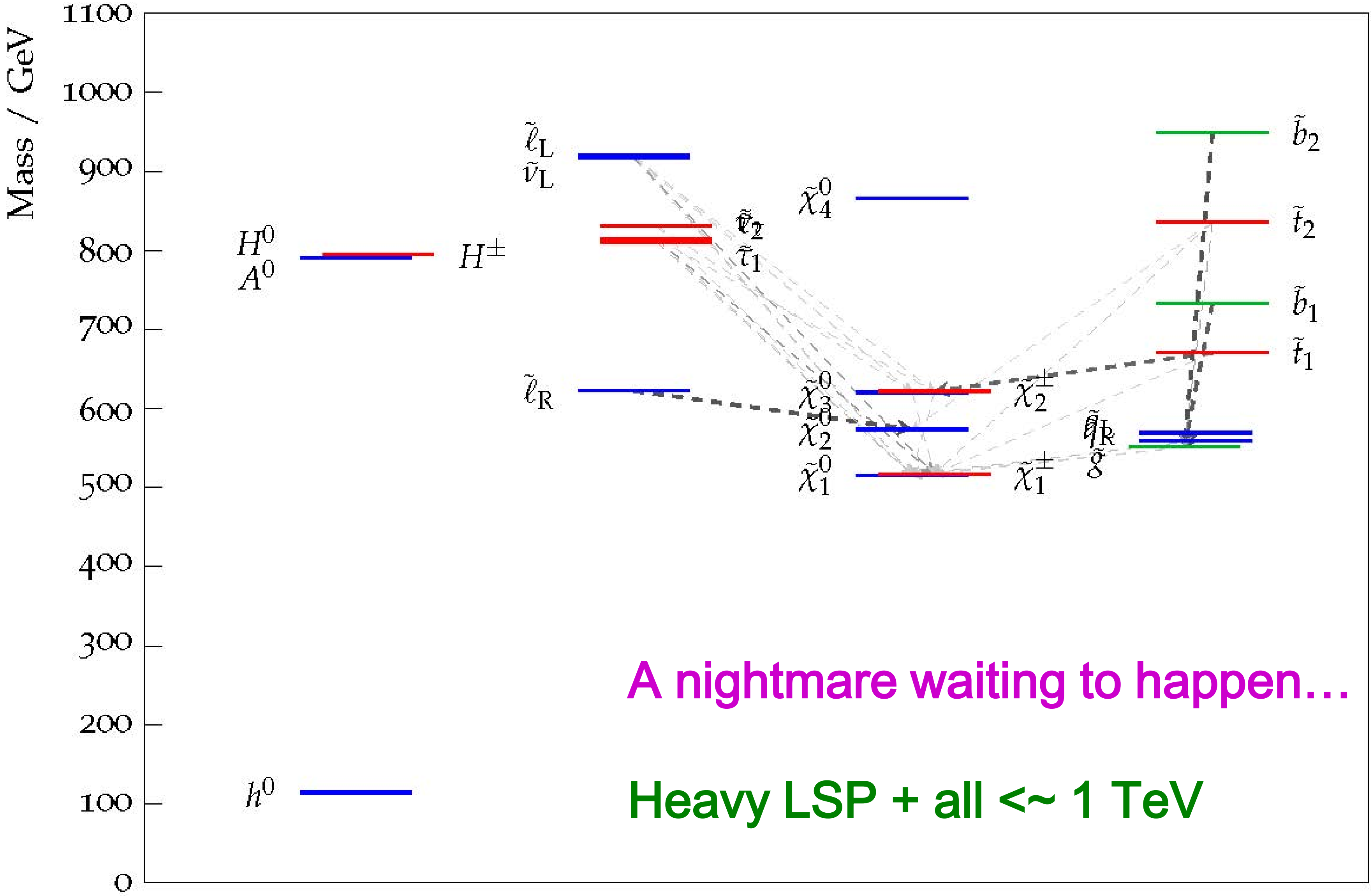
- How many signal events do we need to reach S=5?

Depends on the nj0l $M_{eff}$ cut




As lumi increases the leptonic searches w/ lower backgrounds & systematics become relatively more important

# Example: Very Degenerate Spectrum

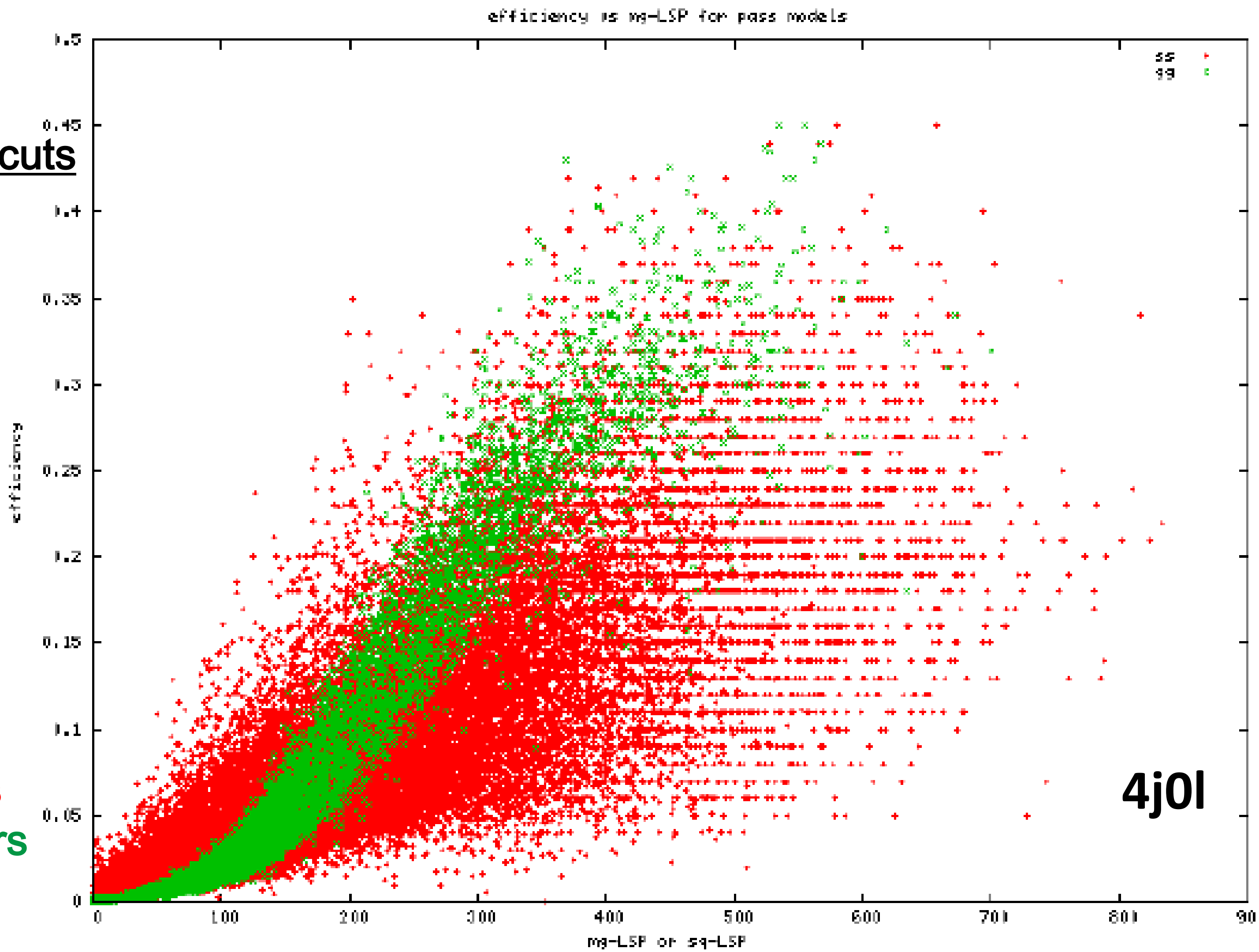



A nightmare waiting to happen…

Heavy LSP + all <~ 1 TeV

# For small mass splittings w/ the LSP a smaller fraction of events will pass analysis cuts. What wins? σ's or ε's ?

$$\frac{\text{\# of evts passing cuts}}{\text{total generated}}$$

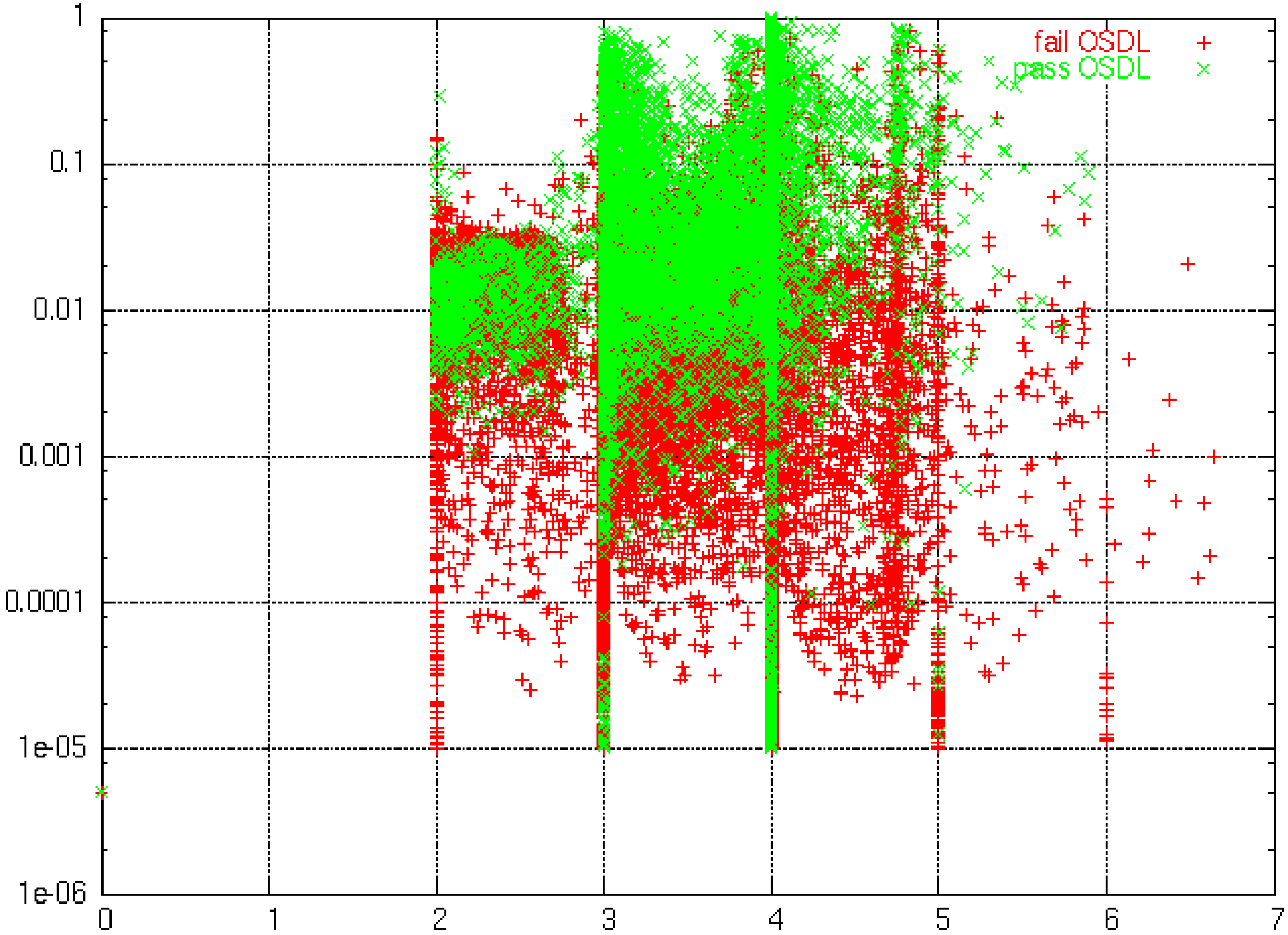



Mass Splitting with the LSP

Red=squark pairs
Green=gluino pairs

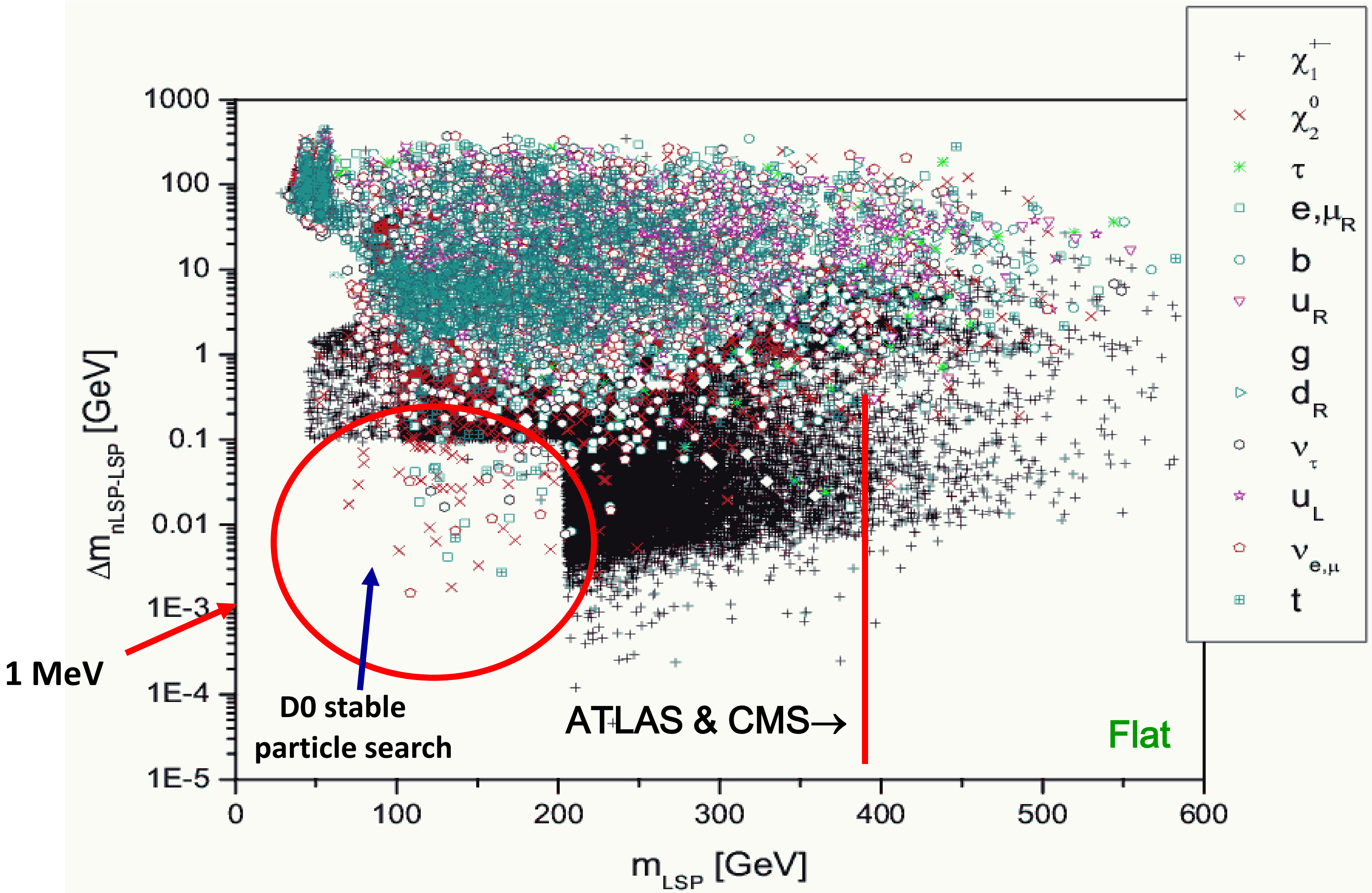
# Gluino initiated cascades leading to X $l^+ l^-$ MET

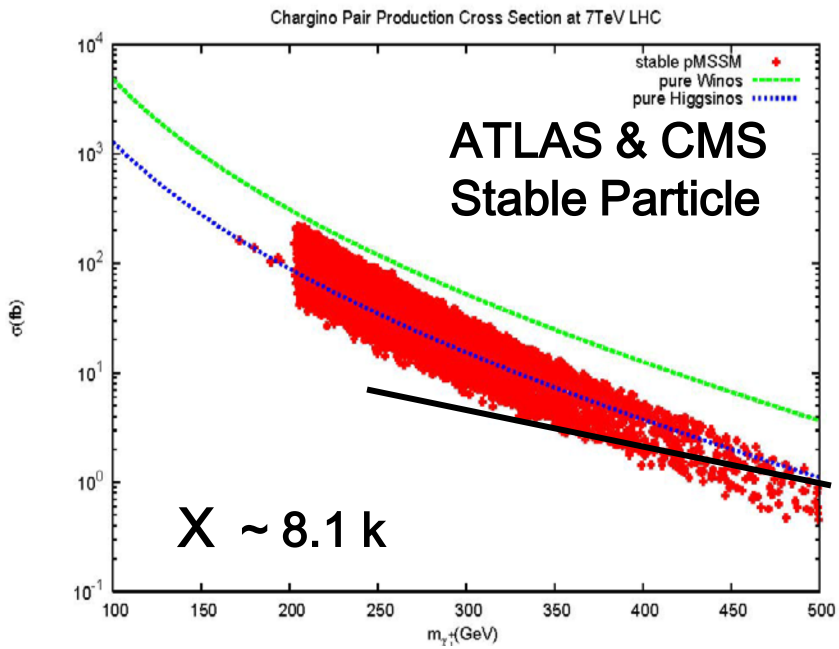
Inclusive Branching fraction



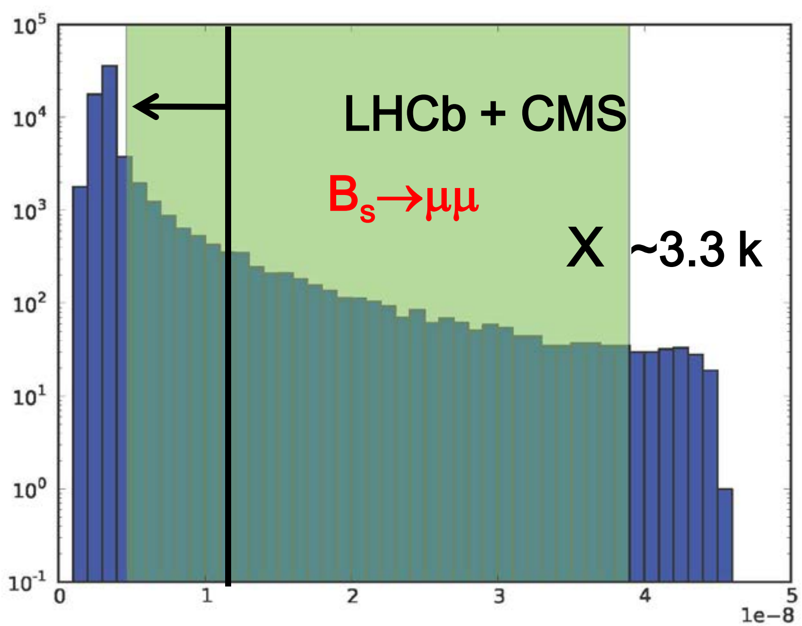

BF-weighted number of steps in decay chain .. Can be large !

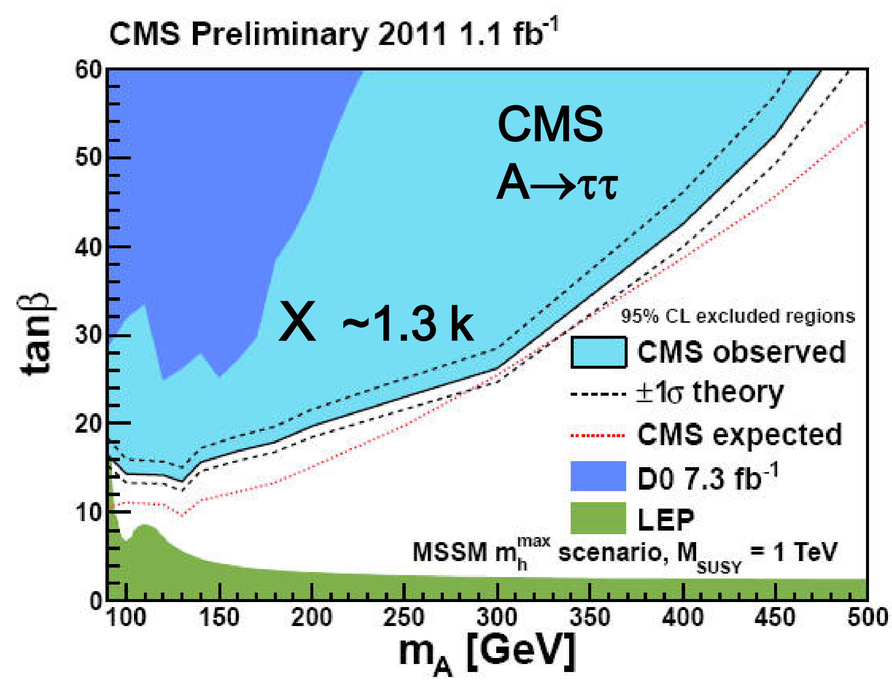
# nLSP-LSP Mass Difference



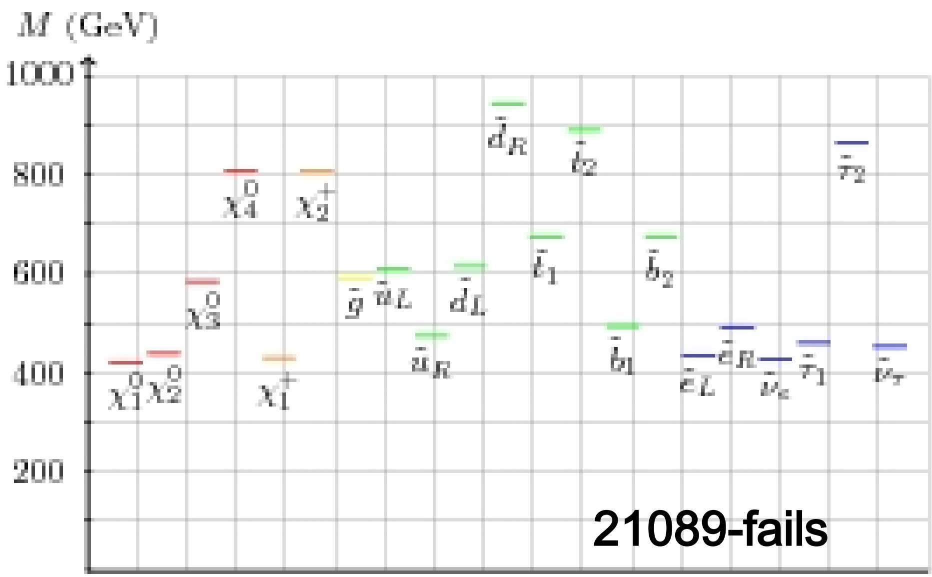


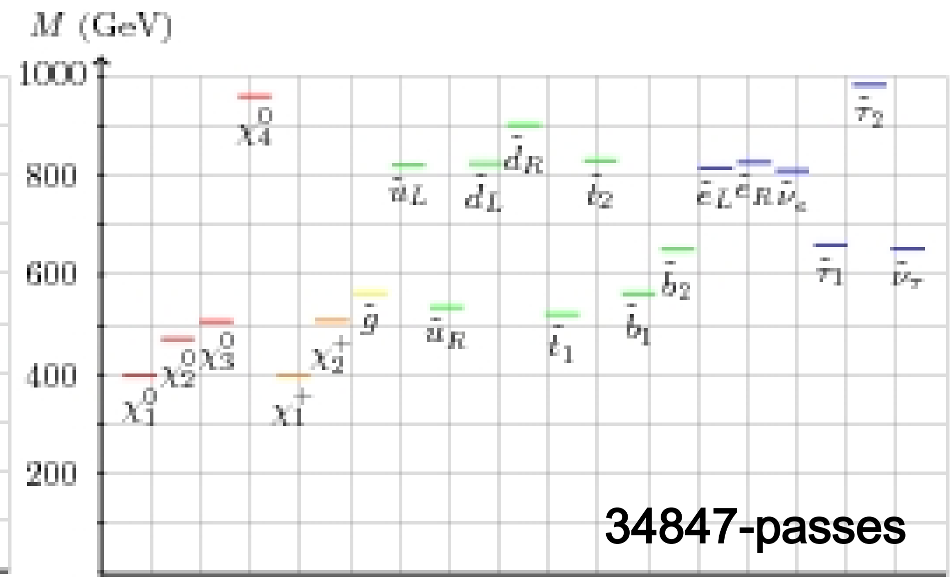

Other non-MET LHC searches are very important and have a significant impact on discovery or exclusion of pMSSM models as shown here



# 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 ??

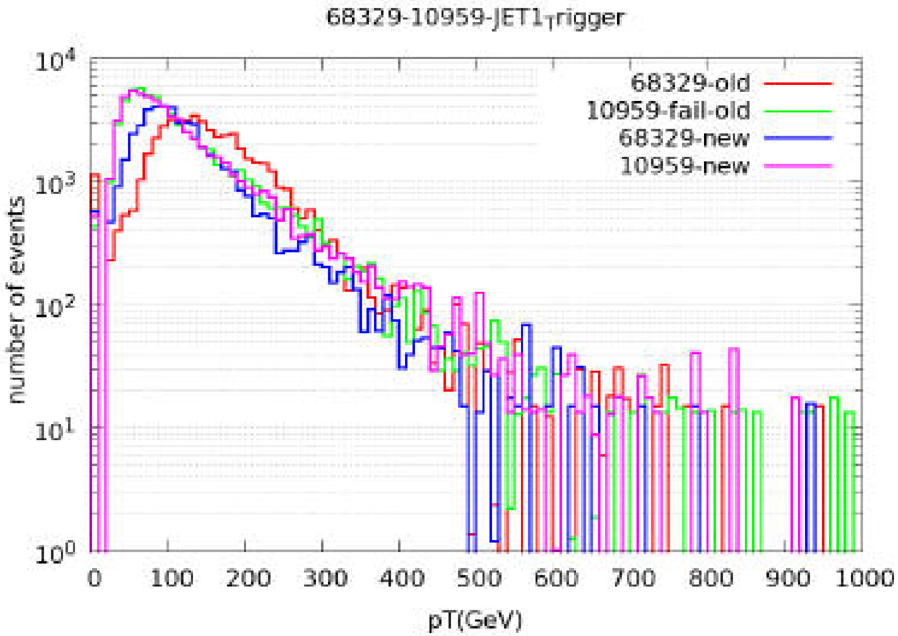
- 21089 ($\sigma \sim$ 4.6pb) & 34847 ($\sigma \sim$ 3.3pb) yet both models fail nj0l due to smallish $\Delta$m's. BUT 34847 is seen in the lower background channels (3,4)j1l

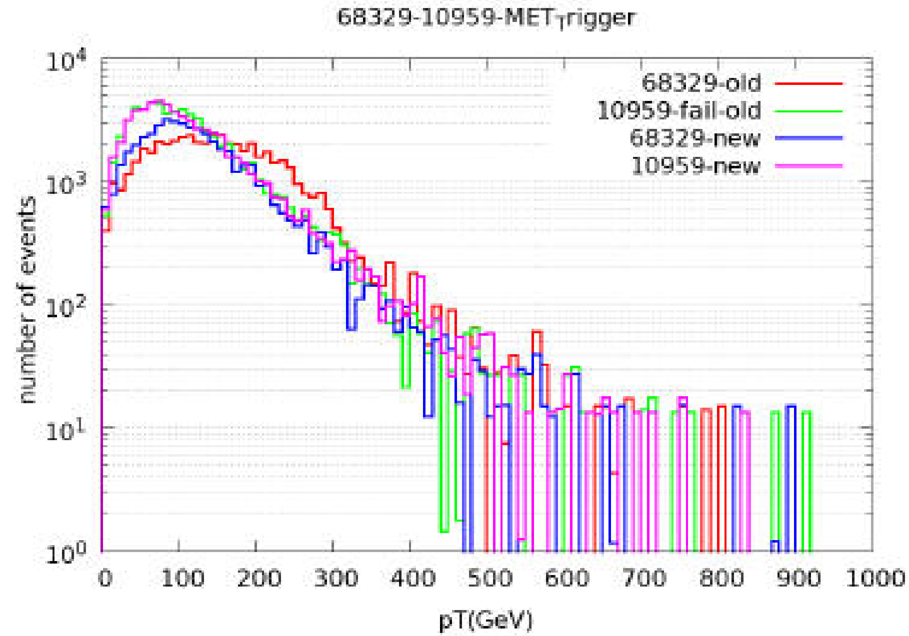
- In 34847, $u_R$ cascades to the LSP via $\chi_2^0$ & the chargino producing leptons via W emission. The LSP is mostly a wino in this case.

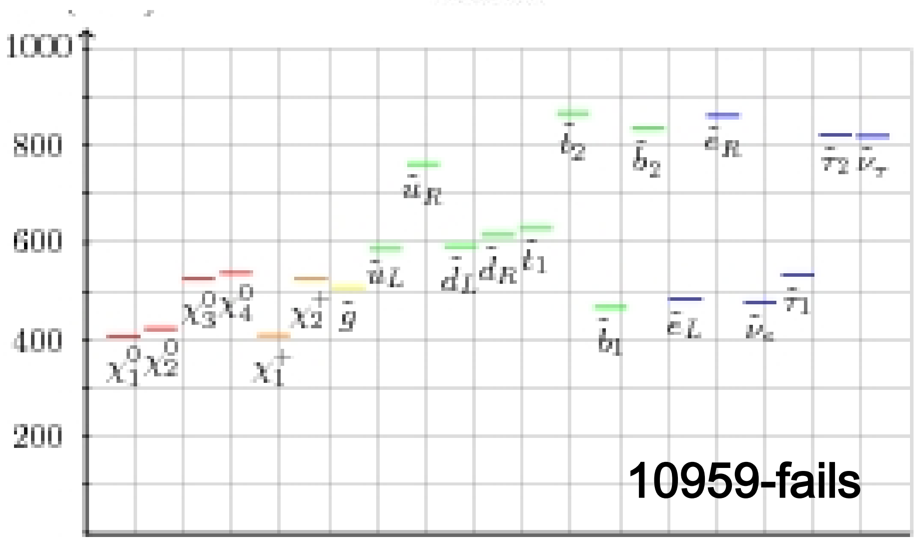
- In 21089, however, $u_R$ can only decay to the lighter ~Higgsino triplet which is sufficiently degenerate as to be incapable of producing high $p_T$ leptons

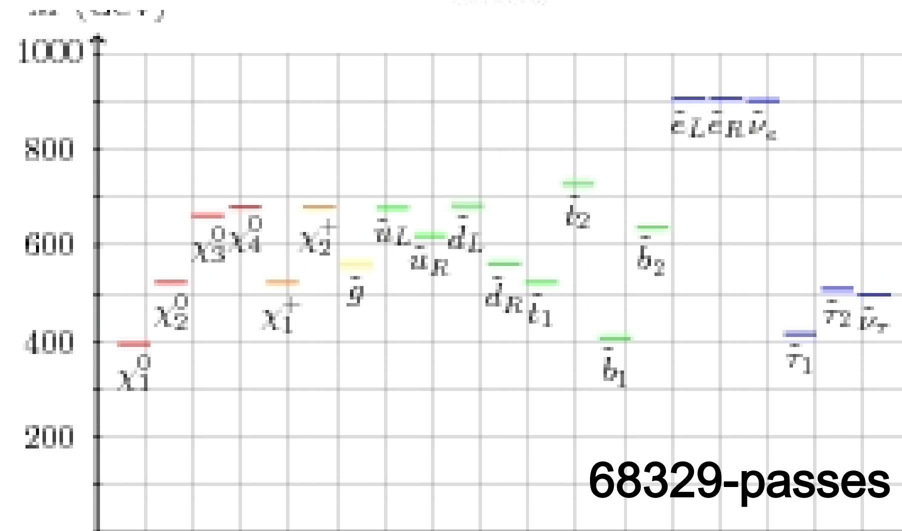
- A small change can make a big difference

# Missed vs Found Model Comparisons



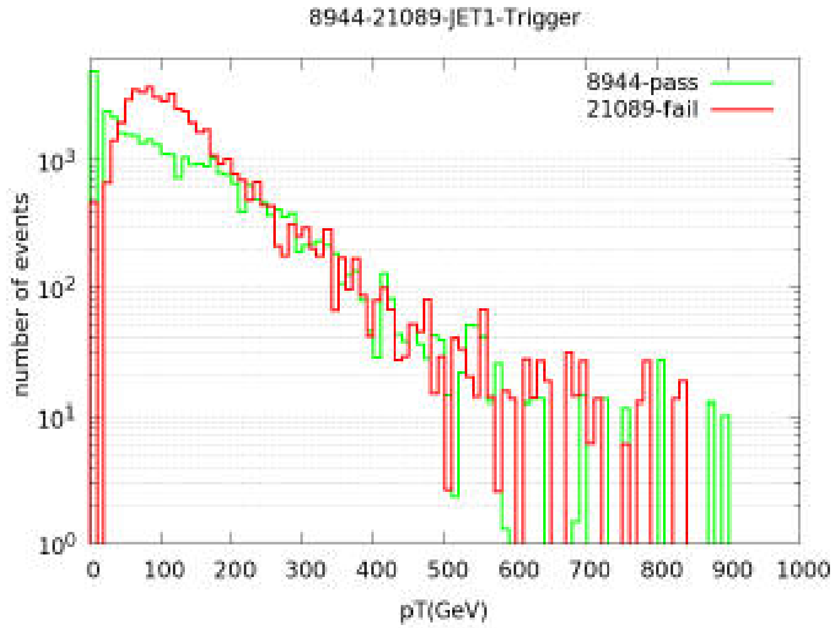



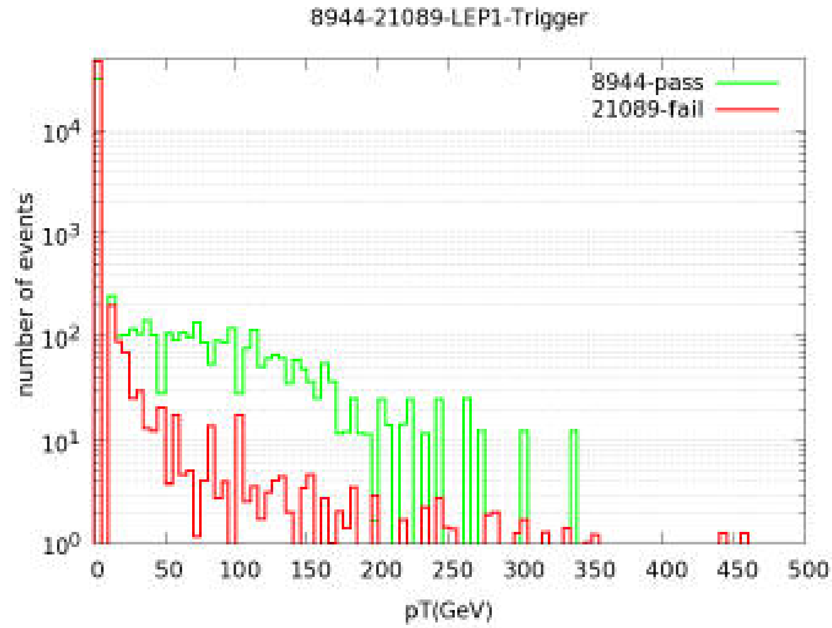



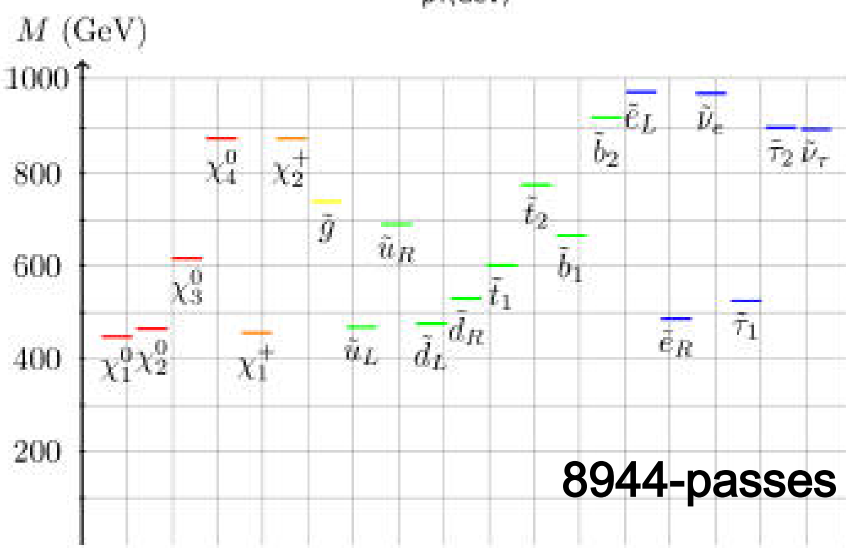
# What went wrong ??

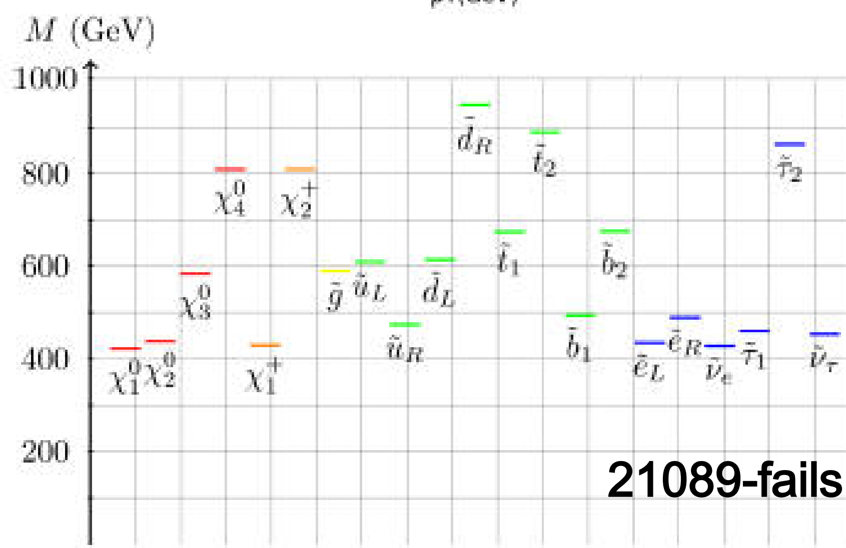
- 68329 passes 4j0l ($\sigma$~4.6 pb) while 10959 ($\sigma$~6.0 pb) fails all
- In 68329, $d_R$ decays to j+MET (B~95%) since the gluino is only ~3 GeV lighter. The gluino decays to the LSP via the sbottom (B~100%) with a $\Delta$m~150 GeV mass splitting . The LSP is bino-like in this model
- In 10959, $d_R$ decays via the ~107 GeV lighter gluino (B~99%) and the gluino decays (with $\Delta$m ~40 GeV) through sbottom & $2^{nd}$ neutralino to the (wino-like) LSP (with $\Delta$m~ 60 GeV).
- Raising the LSP & $b_1$ masses in 68239 by 50 GeV (the $2^{nd}$ set of curves) induces failure due to the new gluino decay path

# 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 $\sigma$ = (3.4, 4.6) pb

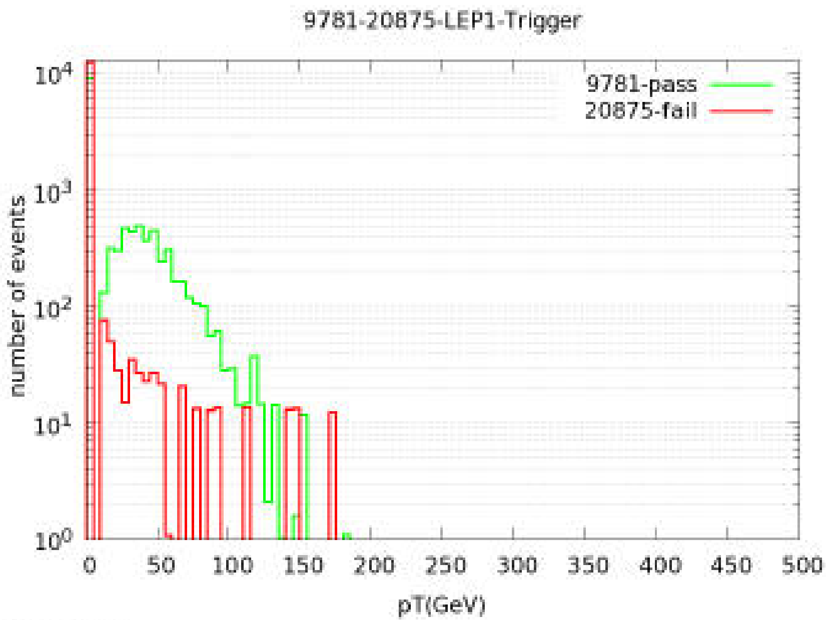
- models have similar gaugino sectors w/ $\chi_{1,2}^0$ Higgsino-like & $\chi_3^0$ bino-like

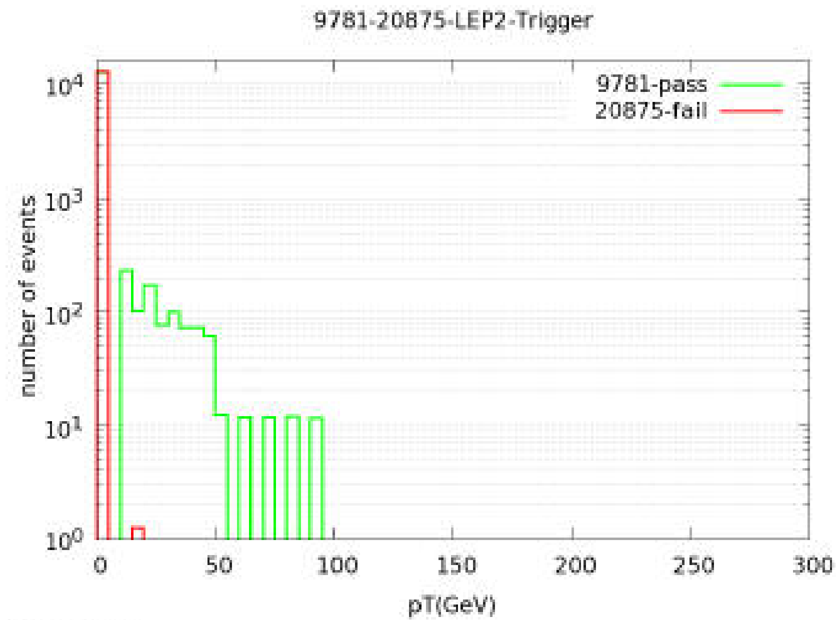
- $\chi_3^0$ can decay thru sleptons to produce OSDL + MET

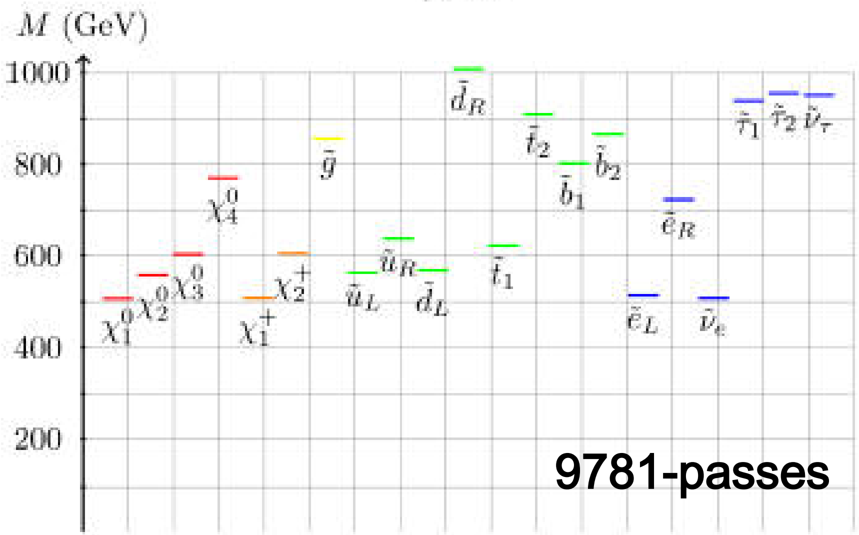
- However in 8944, the gluino is heavier than $d_R$ so that $d_R$ can decay to $\chi_3^0$

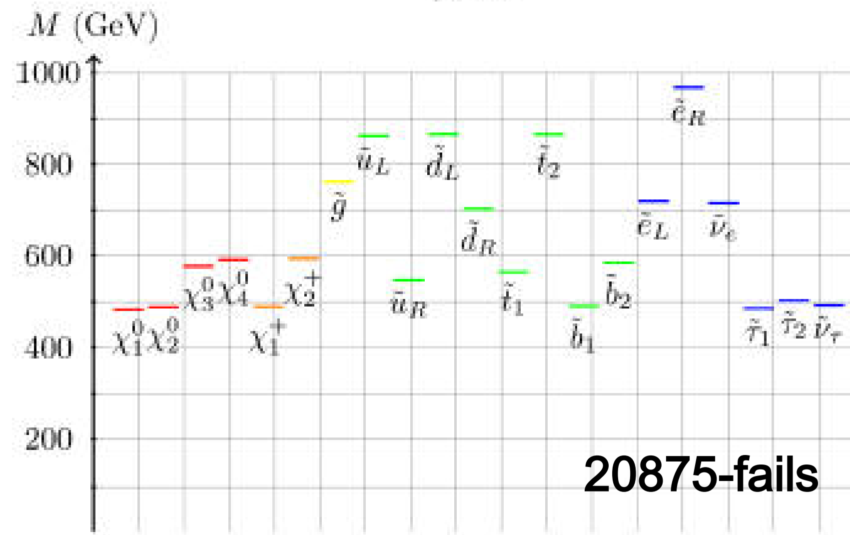
- But in 21089, the gluino is lighter than $d_R$ so that it decays into the gluino & not the bino so NO leptons

# 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 $\sigma$ = (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 $\chi_2^0$ through intermediate e,$\mu$ 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

# Conclusions

- In almost all cases the suite of MET analyses does a good job at covering our pMSSM model sets provided background systematics are well under control

- There can be many (obvious) reasons for some models to be missed: long decay chains, compressed mass spectra, stable sparticles , …

- Sometimes the reasons are quite subtle & possibly due to a fluke in the spectrum details, ie, small changes can render the model visible or not

- Non-MET searches can also be extremely important

# From F. Halzen's summary talk yesterday at Physics in Collision

## we are definitely missing something…

the dark energy problem at the end of the 19th century:

- geology and Darwin's evolution established the age of the sun to be larger than ~ 100 million years
- Lord Kelvin: neither chemistry, nor gravity can supply the required energy
- neither chemistry nor gravity solved this problem

→ Rutherford did

# Backup Slides