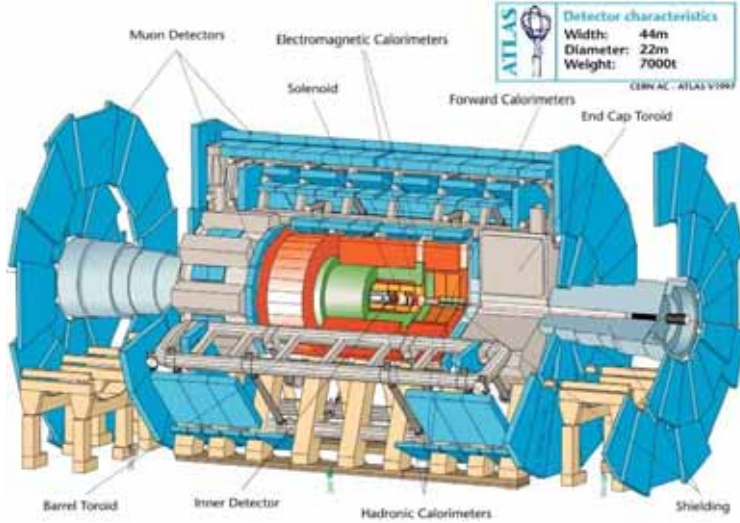


# No Prejudice in SUSY Searches @ 7 TeV with ATLAS

J.A. Conley, J. S. Gainer, J. L. Hewett, M.-P. Le & TGR ; arXiv:1009.2539,1102.xxxx



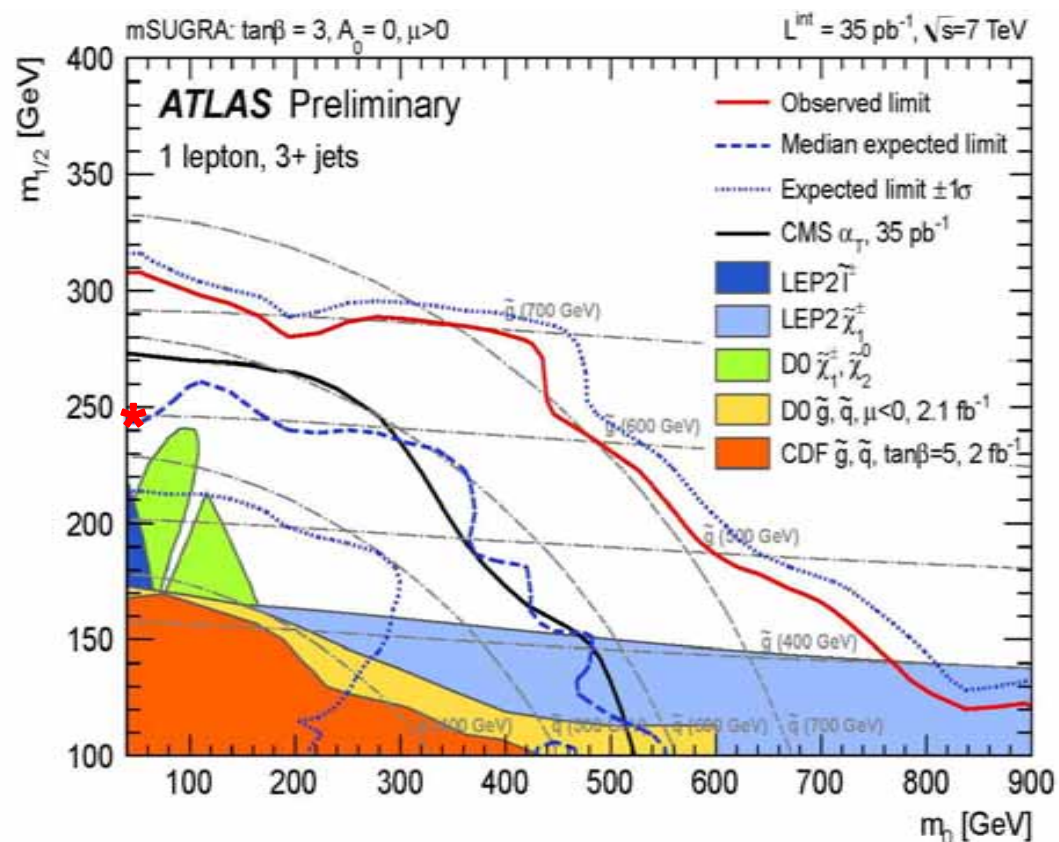
# SUSY searches at the LHC have gotten real !

## The Amazing Power of $\sqrt{s}$ !

Even w/ low lumi the LHC probes masses far beyond the reach of the Tevatron...

We'd like to perform LHC SUSY searches in a model independent way

However, most searches rely on some specific model assumptions, usually mSUGRA/CMSSM....we want to do better & explore SUSY more generally so nothing is accidentally missed. This is a non-trivial task...



## Issues:

- The general MSSM is too difficult to study due to the very large number of soft SUSY breaking parameters ( $\sim 100$ ).
- Analyses are generally limited to specific SUSY breaking scenarios having only a few parameters...

## Our Model Generation Assumptions :

- The most general, CP-conserving MSSM with R-parity
- Minimal Flavor Violation at the TeV scale
- The lightest neutralino is the LSP & a thermal relic.
- The first two sfermion generations are degenerate
- The first two generations have negligible Yukawa's.
- No assumptions about SUSY-breaking or unification

This leaves us with the pMSSM:

→ the MSSM with **19** real, TeV/weak-scale parameters...

# 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:  $A_b, A_t, A_\tau$

3 Higgs/Higgsino:  $\mu, M_A, \tan\beta$

# What are (aren't) the Goals of this Study???

- Prepare a large model sample, ~50k, satisfying 'all' experimental constraints which are ('easily') kinematically accessible at the LHC.
  - Examine the properties of the surviving 'models'.
  - →→ Do physics analyses with these models.
- Our goal is **NOT** to find the 'best-fit' model(s) but to search for possible new physics that is not seen in the more familiar SUSY breaking frameworks
- We will be specifically interested in the capability of the LHC running at 7(&14) TeV to discover **some signal** for all of these models. Here we focus on the ATLAS SUSY analyses...

# How? Perform 2 Random Scans

## Flat Priors

emphasizes moderate masses

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

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

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

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

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

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

## Log Priors

emphasizes lower masses but also extends to higher masses

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

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

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

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

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

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

- **Flat Priors** :  $10^7$  models scanned , 68422 ( $\sim 0.684\%$ ) survive
  - **Log Priors** :  $2 \times 10^6$  models scanned , 2908 ( $\sim 0.145\%$ ) survive
- **Comparison of these two scans will show the prior sensitivity.**

## Some Constraints

- **W/Z ratio**                      **b → s γ**
- **$\Delta(g-2)_\mu$**                        **$\Gamma(Z \rightarrow \text{invisible})$**
- **Meson-Antimeson Mixing**
- **$B_s \rightarrow \mu\mu$**                        **$B \rightarrow \tau\nu$**

- **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* of these searches & they 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 SUSY Analyses w/ a Large Model Set

- We passed these models through the ATLAS MET analyses, both 7 & 14 TeV, designed for mSUGRA, to explore this broader class of SUSY models (~1.5 core-centuries)
- We used the ATLAS SM backgrounds (Thanks!!!), with their associated systematic errors #, their search analyses/cuts & also their statistical criterion for SUSY discovery, etc.
- We verified that we can approximately reproduce the 7 & 14 TeV ATLAS results for their benchmark mSUGRA models with our analysis techniques for each channel. ..BUT beware of some analysis differences:

# We use the exact expressions for  $Z_n$  as given by ATLAS without any approximations ..causing some numerical differences with the ATLAS CSC public results @ 14 TeV



# ATLAS

ISASUGRA generates spectrum  
& sparticle decays

Partial NLO cross sections using  
PROSPINO & CTEQ6M

Herwig for fragmentation &  
hadronization

GEANT4 for full detector sim

# US

SuSpect generates spectra  
with SUSY-HIT# for decays

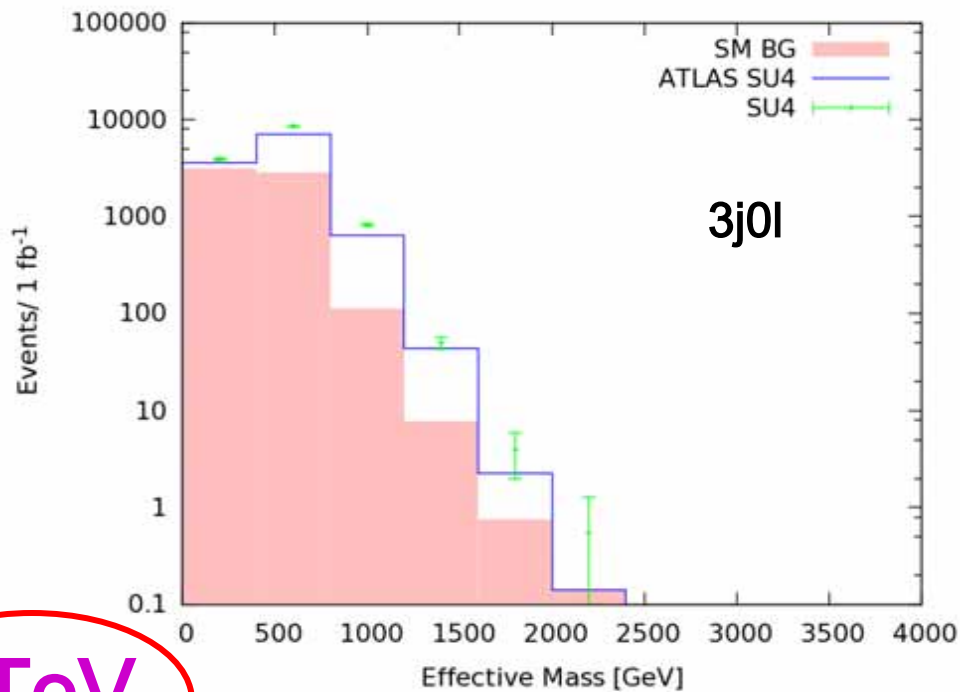
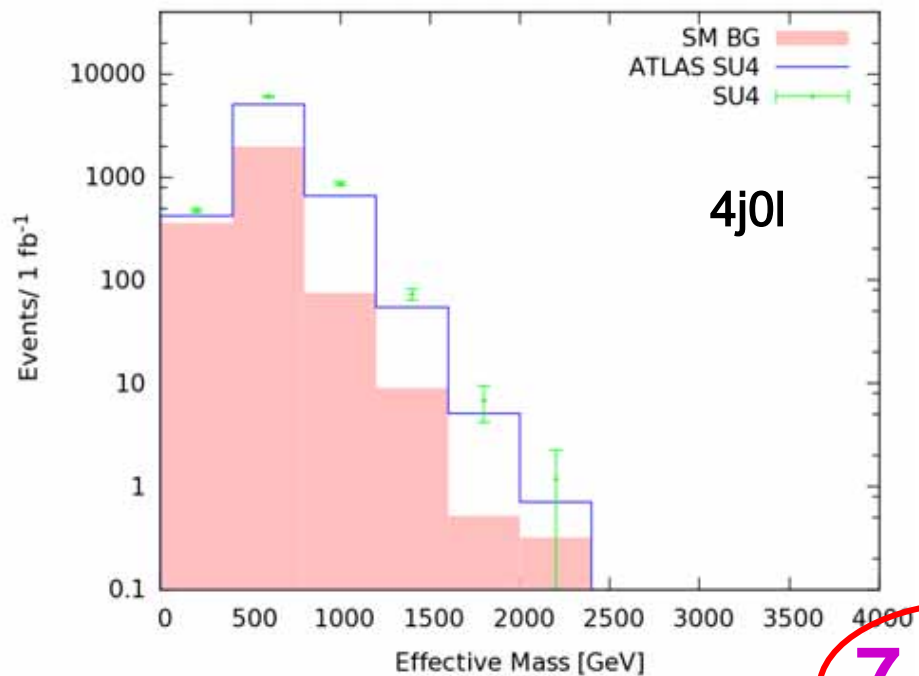
NLO cross section for all 85  
processes using PROSPINO\*\*  
& CTEQ6.6M

PYTHIA for fragmentation &  
hadronization

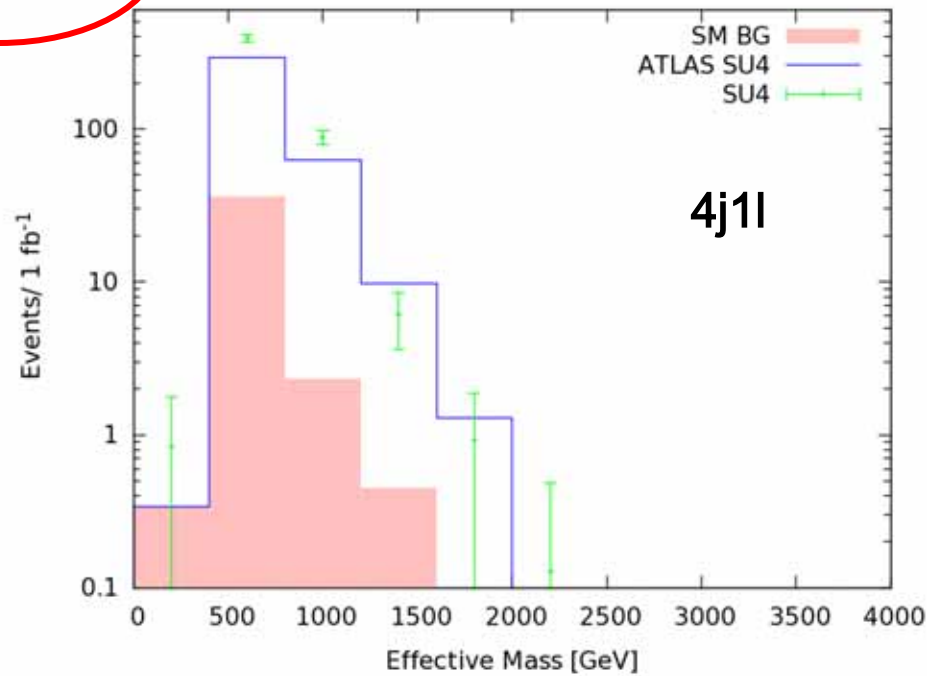
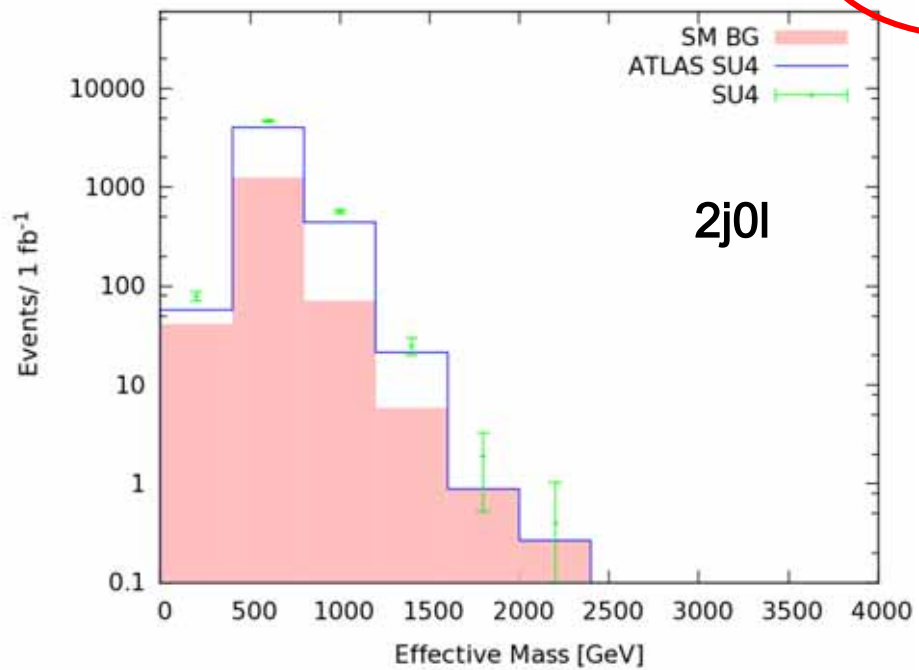
PGS4-ATLAS for fast detector  
simulation

\*\* version w/ negative K-factor errors corrected

# version w/o negative QCD corrections, with 1<sup>st</sup> & 2<sup>nd</sup> generation fermion masses & other very numerous PS fixes included. e.g., explicit small  $\Delta m$  chargino decays, etc.



7 TeV

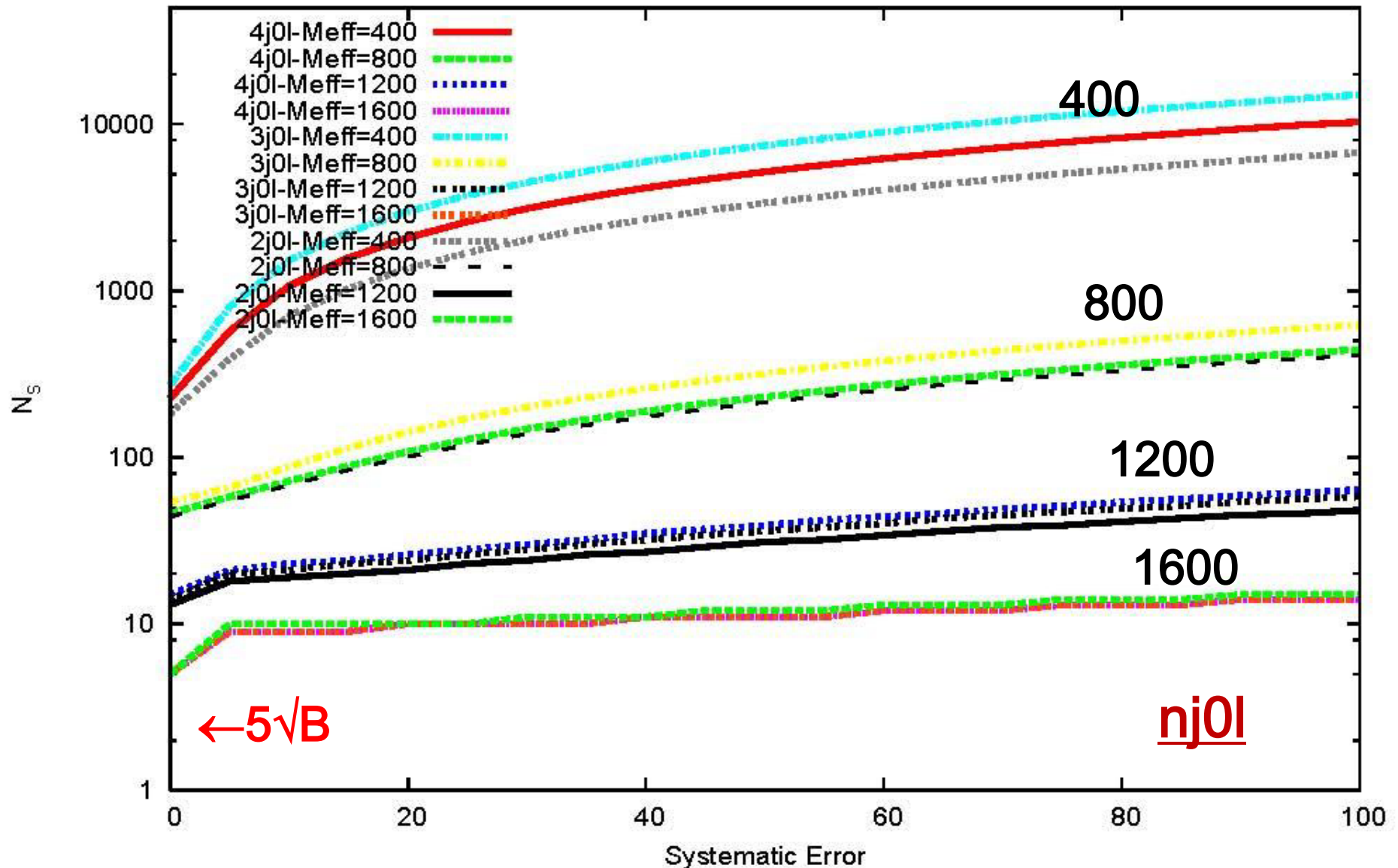


→ We do quite well reproducing ATLAS 7 & 14 TeV benchmarks with some small differences due to, e.g., (modified) public code usages

- The first question: ‘How well do the ATLAS analyses cover these pMSSM model sets?’ More precisely, ‘what fraction of these models can be discovered (or not!) by any of the various ATLAS analyses & which ones do best?’
  - **CLEARLY** this will depend on the integrated luminosity & the assumed systematic uncertainty on the SM backgrounds ..understanding these is critical !
- Next, we’ll need to understand **WHY** some models are missed by these analyses even when high luminosities are available

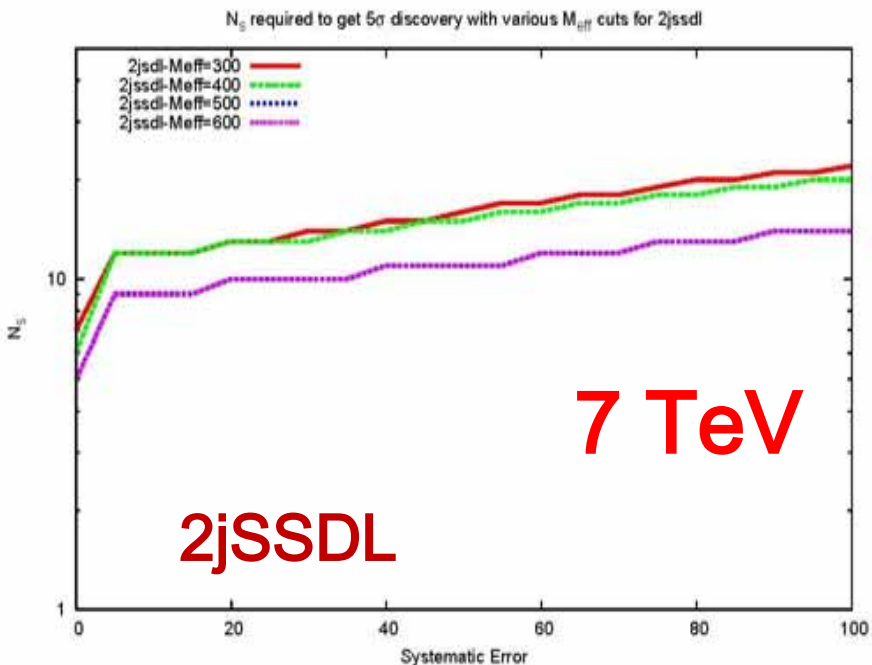
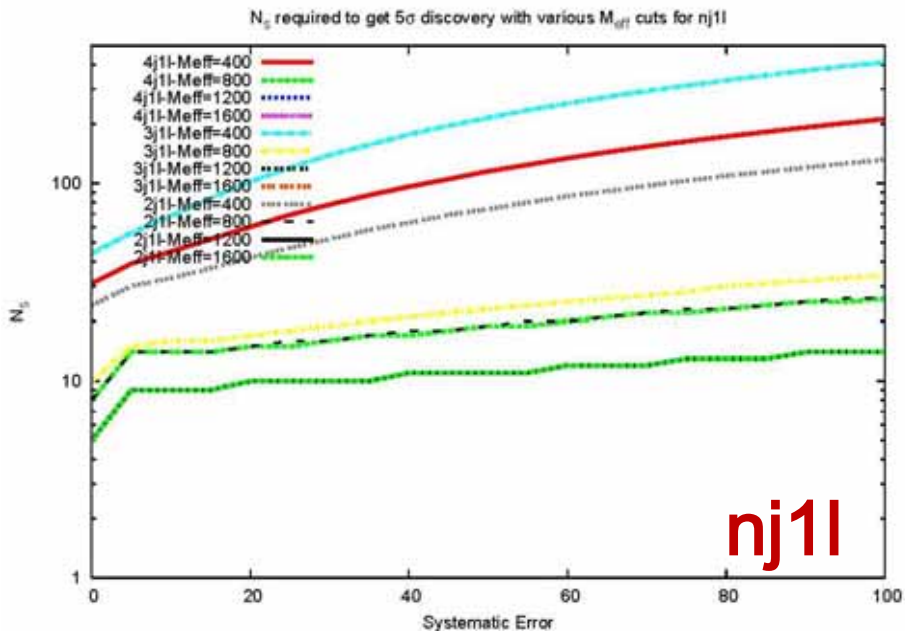
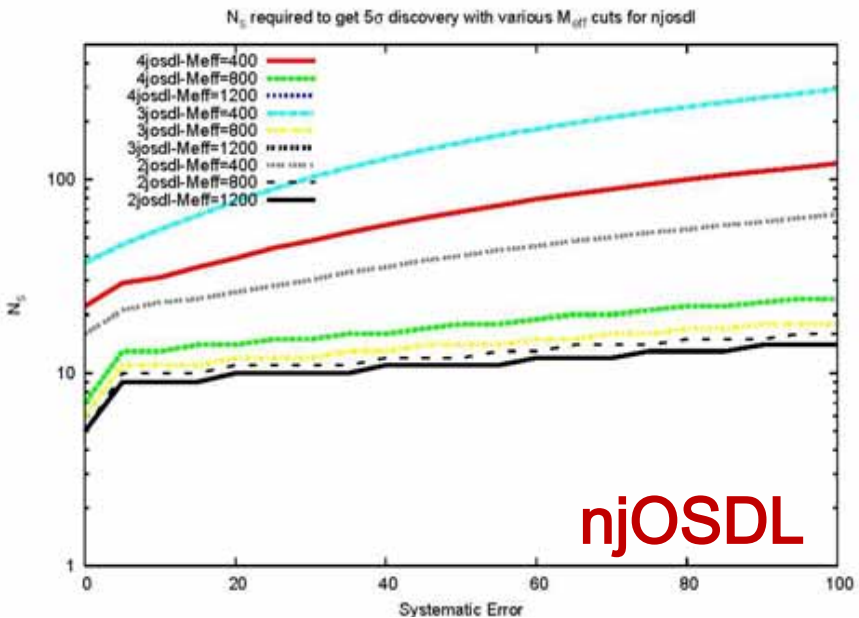
- **How many signal events do we need to reach  $S=5$ ?**  
 Depends on the  $M_{\text{eff}}$  'cut' which is now 'optimized' @ 7 TeV

$N_S$  required to get  $5\sigma$  discovery with various  $M_{\text{eff}}$  cuts for  $nj0l$



- The size of the background systematic error can play a very significant role in the pMSSM model coverage especially for  $n_j(0,1)$  ...

- ATLAS now essentially using  $\sim 100\%$  for these analyses



# Overall 7 TeV Results for the Flat Prior Set

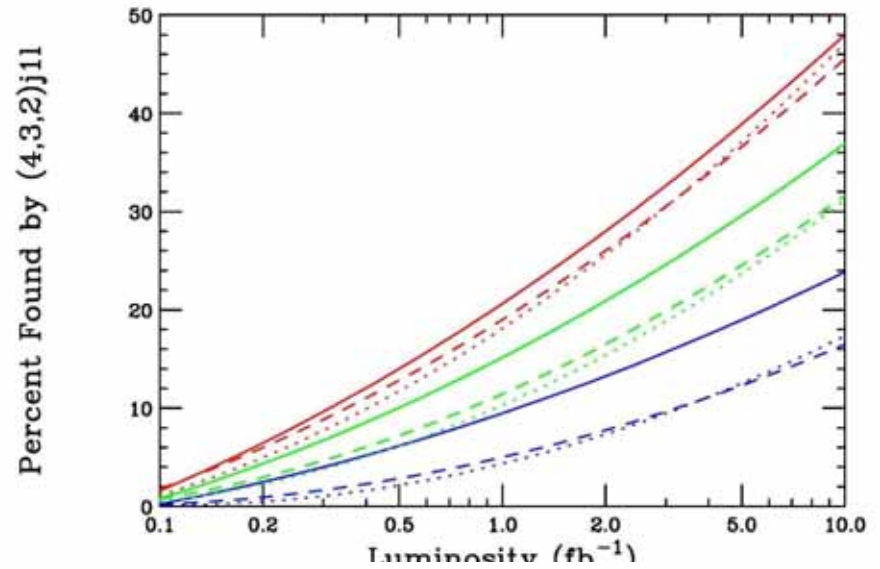
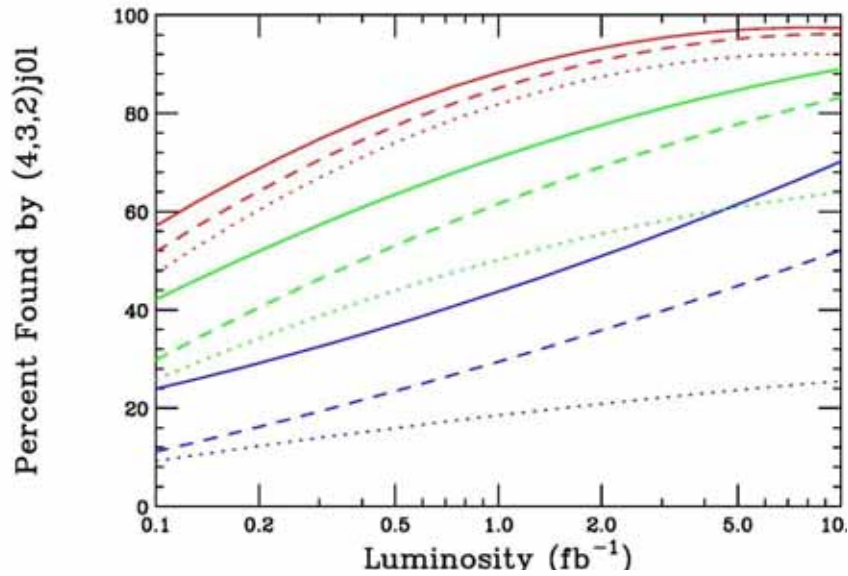
These are the fractions of the model set that are **discovered** at the S=5 level by each of the 7 TeV ATLAS analyses

Analysis	20 $\mathcal{L}_{0.1}$	20 $\mathcal{L}_1$	20 $\mathcal{L}_{10}$	50 $\mathcal{L}_{0.1}$	50 $\mathcal{L}_1$	50 $\mathcal{L}_{10}$	100 $\mathcal{L}_{0.1}$	100 $\mathcal{L}_1$	100 $\mathcal{L}_{10}$
4j0l	57.073	88.241	97.356	42.061	71.018	88.967	23.906	43.661	70.148
3j0l	51.792	85.087	96.172	29.822	61.56	83.203	11.135	29.427	52.12
2j0l	47.423	81.842	92.004	25.771	50.162	63.931	9.2019	18.507	25.502
4j1l	1.5773	20.611	47.976	0.79985	15.132	36.902	0.23832	9.4566	23.839
3j1l	1.771	18.988	45.544	0.71941	11.406	31.611	0.17874	4.878	16.473
2j1l	1.0888	18.096	47.116	0.46769	10.265	31.096	0.16086	4.3254	17.358
4jOSDL	0.51536	4.8646	17.018	0.39471	3.0728	8.5827	0.25619	2.0108	3.8683
3jOSDL	0.61068	6.4449	23.797	0.39173	4.9718	15.061	0.20108	3.4928	7.7218
2jOSDL	0.69409	5.8685	22.915	0.60919	4.6129	13.474	0.4096	3.0892	7.1319
2jSSDL	0.10575	3.8443	22.327	0.098305	3.2307	17.003	0.067026	2.1374	12.25

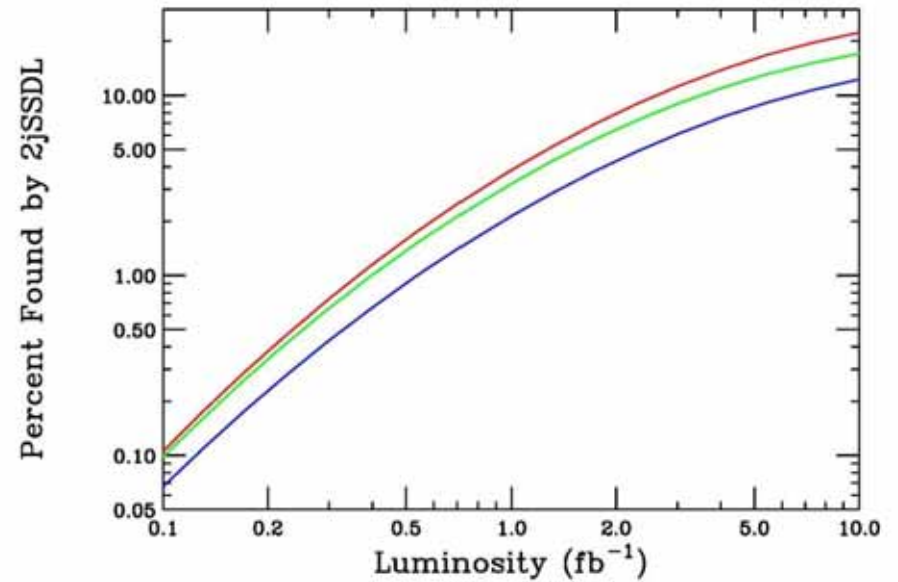
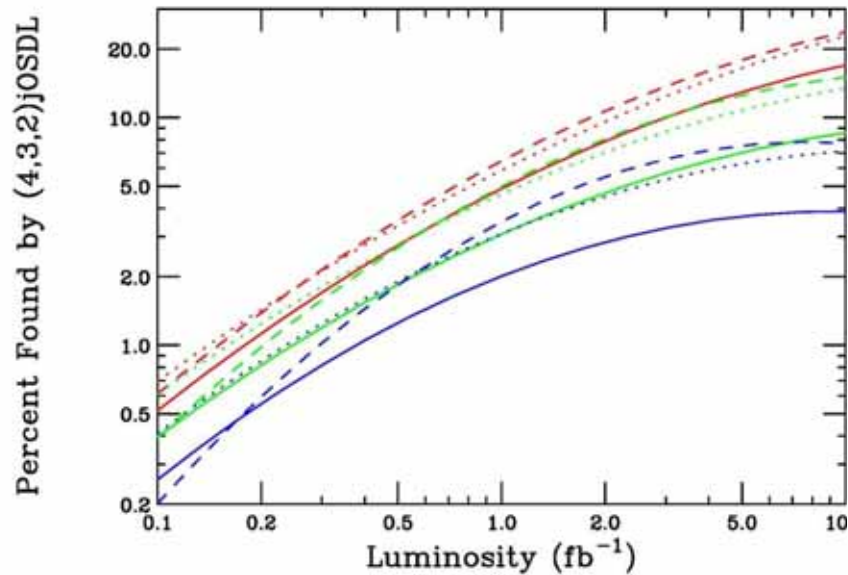
...however, plots are much easier to look at...

# FLAT

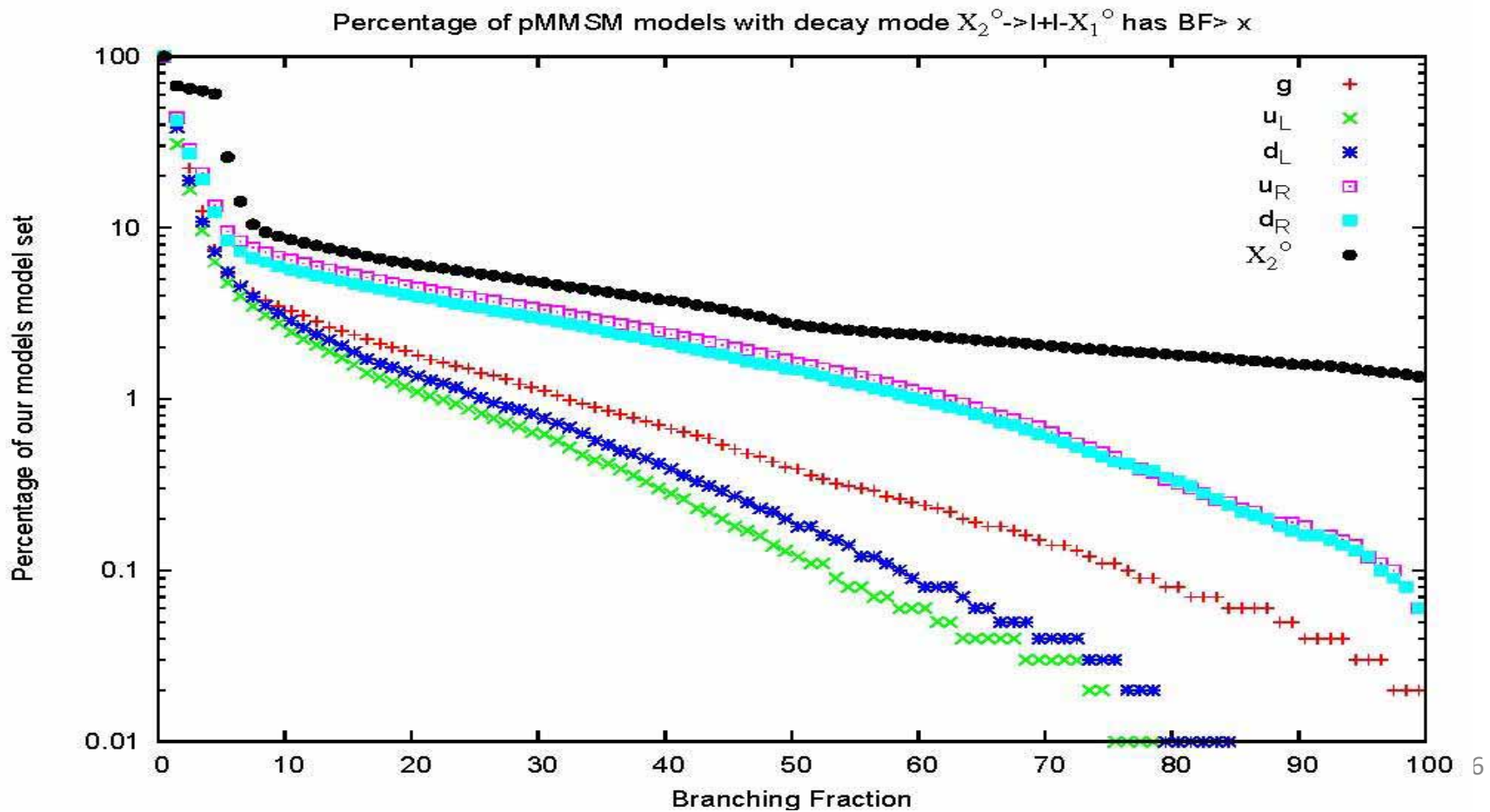
Solid=4j, dash=3j, dot=2j final states



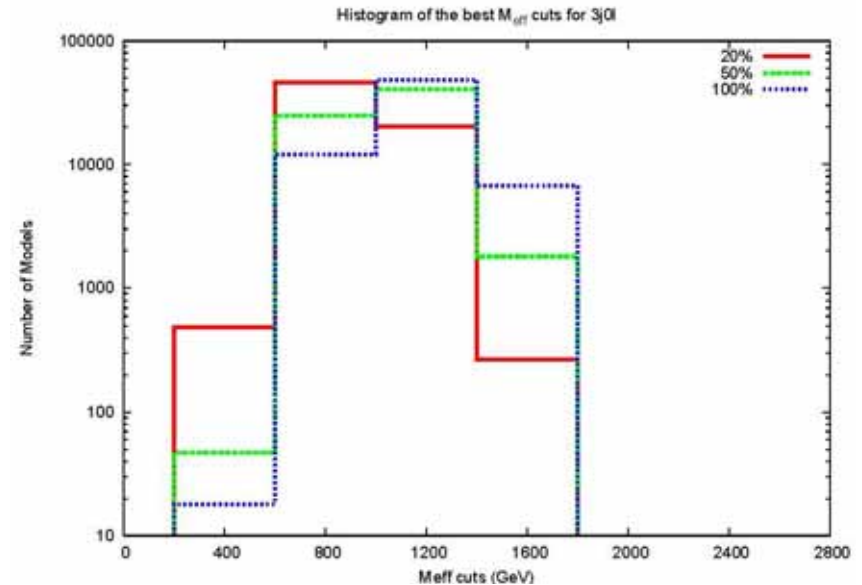
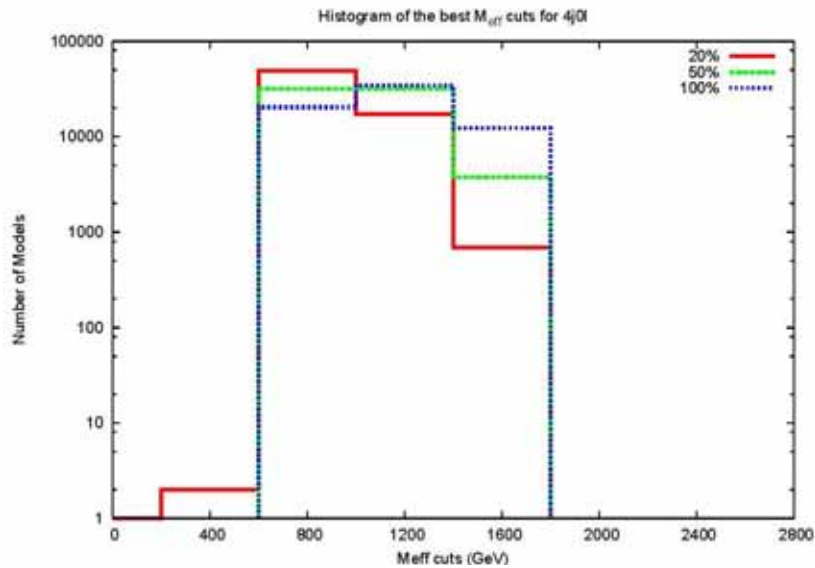
Red=20%, green=50%, blue=100% background systematic errors



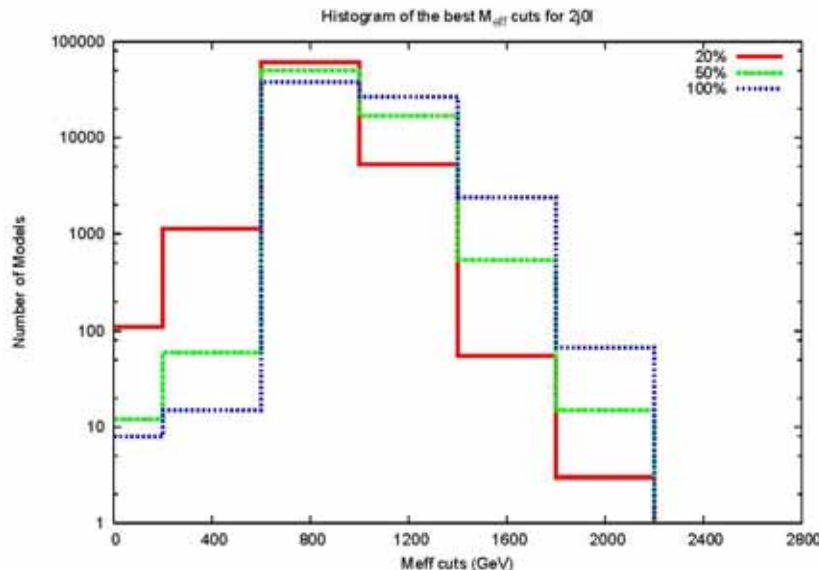
- Note that as the number of required leptons increases the corresponding model 'coverage' decreases significantly unless the integrated lumi is large. Why? The BF to lepton pairs is relatively small in our model set...e.g. :







## 'Best' $M_{\text{eff}}$ cut

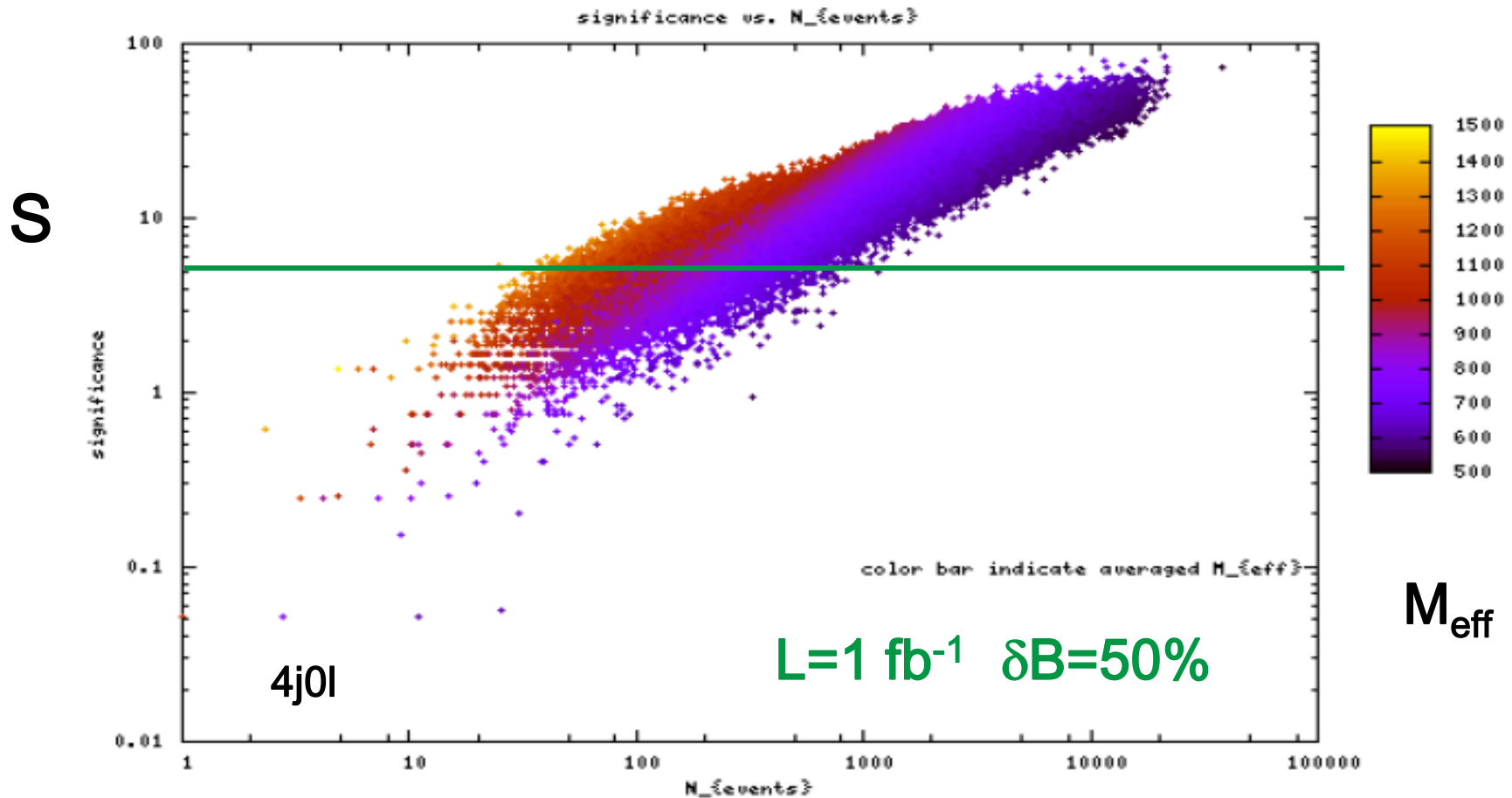


- As the **background uncertainty** grows, **harder  $M_{\text{eff}}$  cuts** are needed to achieve **maximum model significance** in all of the various channels.

- Note that the  $M_{\text{eff}}$  cut is **less important** for final states with **fewer jets**. This persists even in analyses with leptons.

# Aside :

Note that for models with smaller numbers of signal events **harder**  $M_{\text{eff}}$  cuts are necessary to obtain  $S=5$



# Overall 7 TeV Results for the Log Prior Set

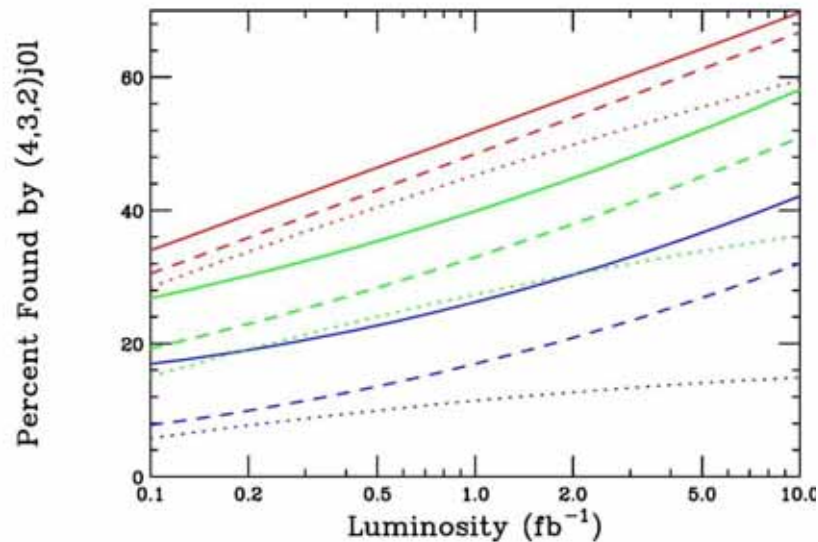
Remember that these models have masses extending out to 3 TeV so the numbers are lower than in the FLAT case..

Analysis	20 $\mathcal{L}_{0.1}$	20 $\mathcal{L}_1$	20 $\mathcal{L}_{10}$	50 $\mathcal{L}_{0.1}$	50 $\mathcal{L}_1$	50 $\mathcal{L}_{10}$	100 $\mathcal{L}_{0.1}$	100 $\mathcal{L}_1$	100 $\mathcal{L}_{10}$
4j0l	33.999	51.762	69.669	26.807	39.847	58.118	16.927	26.19	42.136
3j0l	30.476	48.456	66.727	19.252	32.946	50.926	7.7733	16.927	32.038
2j0l	28.442	45.26	59.535	15.946	27.352	36.179	5.7755	11.406	14.893
4j1l	1.0897	10.243	25.863	0.47221	7.0832	18.017	0.18162	4.1773	11.115
3j1l	1.3803	8.5361	22.412	0.54486	4.5405	13.331	0.18162	1.4893	5.8482
2j1l	0.69016	7.1195	22.993	0.21794	3.3418	12.459	0.10897	1.344	5.8118
4jOSDL	0.47221	3.3418	9.1173	0.36324	2.1794	4.9764	0.21794	1.3803	2.3974
3jOSDL	0.58118	3.8503	12.423	0.36324	2.5427	7.4101	0.29059	1.7436	3.6687
2jOSDL	0.54486	3.3781	11.551	0.50854	2.2521	6.2841	0.25427	1.5619	3.4508
2jSSDL	0.21794	2.47	12.822	0.1453	1.9615	9.5169	0.10897	1.453	6.2841

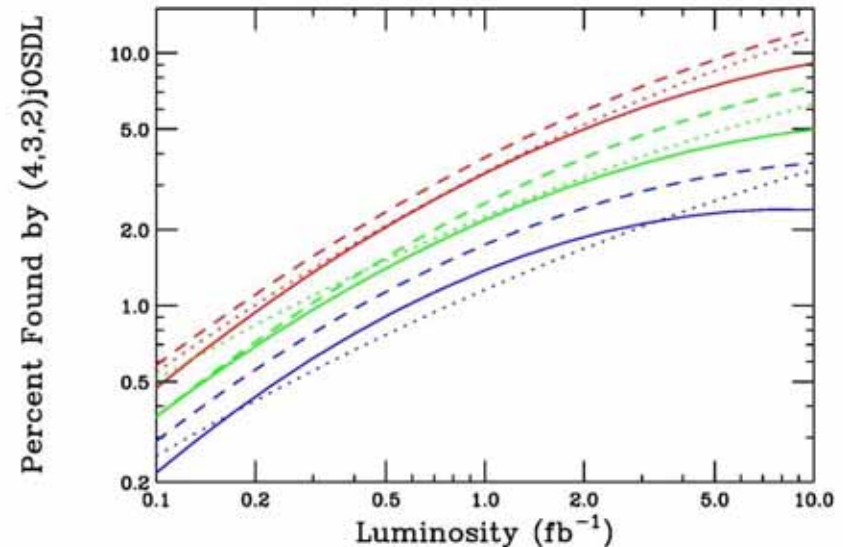
...again, plots are much easier to look at...

# LOG

In the **LOG prior** case, a very similar pattern is observed **except** that the reaches are **reduced in all channels by roughly ~30-50%** since the spectrum extends out to larger sparticle masses, i.e., up to ~3 TeV.



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

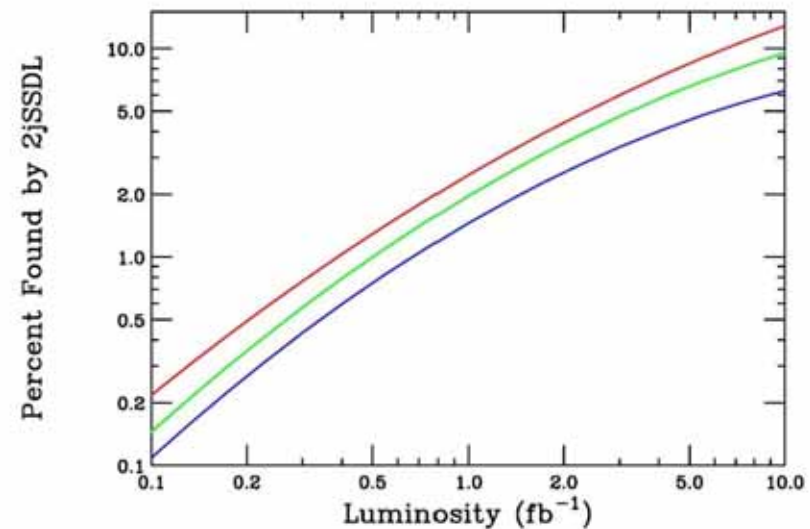
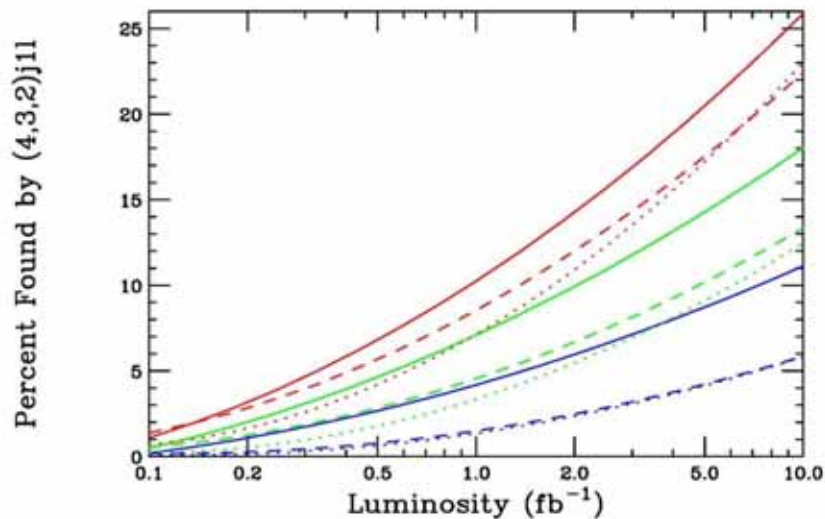


Red=20%, green=50%, blue=100% background systematic errors

# LOG (cont.)

Also, at larger lumi's, the discovery curves **do not flatten** as much as in the FLAT case since the **systematic errors** are **less important** for the LOG priors. This is because the search limitations can be **statistics dominated** due to the heavier mass spectrum.

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



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

## Next Question(s):

If models are found, are they found in only one of these analyses or many? What fraction of our models are missed completely by ATLAS ?

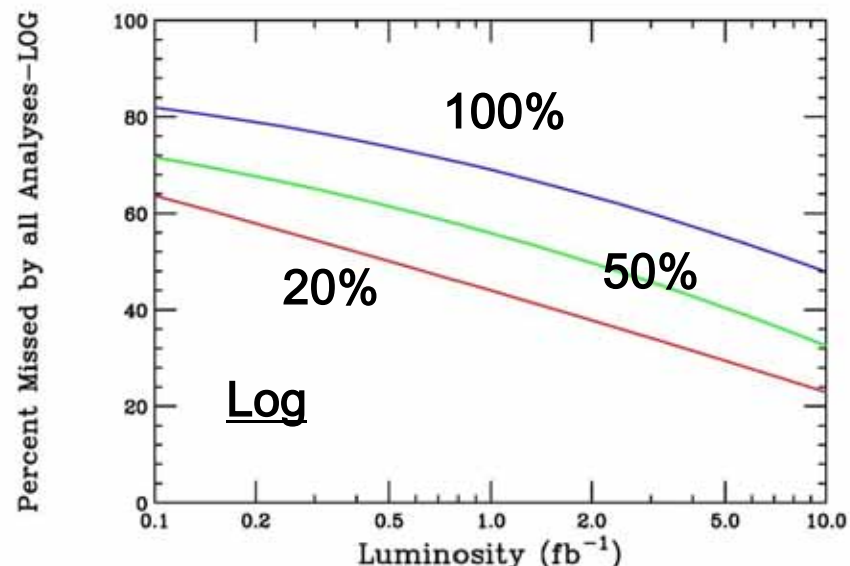
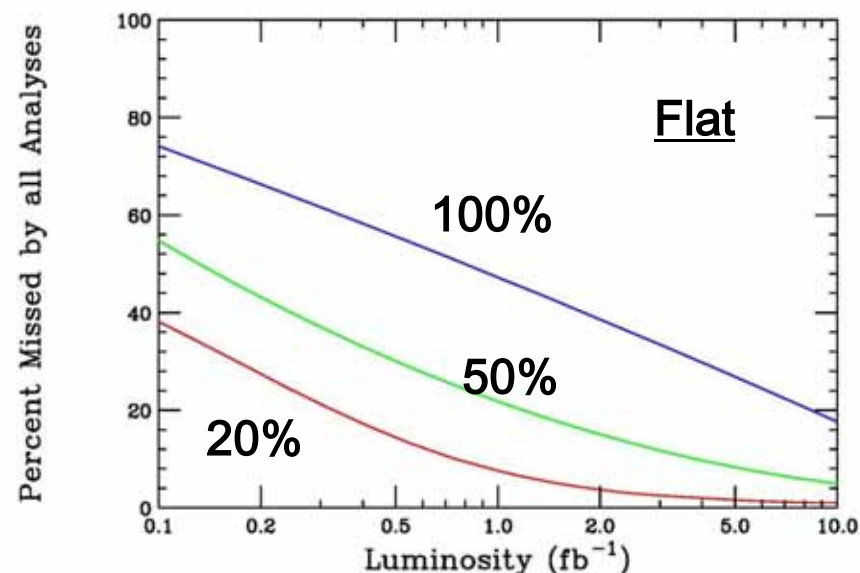
- If models are found only in one analysis we may worry about that the validity of that particular analysis...

What fraction of models are found by (only)  $n$  analyses @ 7 TeV assuming  $\delta B=50\%$

# 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	54.756	21.772	4.8782	71.558	55.903	32.546
1	14.143	10.547	4.847	8.1729	7.3011	9.8801
2	7.8435	11.453	9.959	5.0854	7.1195	12.532
→ 3	22.552	42.949	40.705	14.857	24.228	28.478
4	0.29938	4.1407	8.3533	0.18162	1.7436	4.5768
5	0.15788	3.1562	7.619	0	1.3803	3.4871
6	0.1415	3.3036	9.1487	0.072648	1.0534	3.4871
7	0.061068	1.4075	6.049	0.036324	0.79913	1.9615
8	0.031279	0.58536	3.6166	0.036324	0.32692	1.4166
9	0.013405	0.43493	2.9716	0	0.036324	1.235
10	0.0014895	0.25172	1.853	0	0.10897	0.39956

Clearly the case  $n=0$ , where NO models are found, is the most interesting !

# How does the pMSSM coverage evolve w/ lumi ??



The coverage is quite good..BUT REMEMBER these models were designed (hopefully) for relatively early LHC discovery !

The models that FAIL to be found are even more interesting...



Estimated ATLAS pMSSM Model Coverage  
**RIGHT NOW** for  $\sim 35 \text{ pb}^{-1}$  @ 7 TeV

<u><math>\delta B</math></u> :	<u>100%</u>	<u>50%</u>	<u>20%</u>
<b>FLAT:</b>	<b>14%</b>	<b>23%</b>	<b>43%</b>
<b>LOG :</b>	<b>15%</b>	<b>24%</b>	<b>30%</b>

**Wow!** This is actually quite impressive as these LHC SUSY searches are **just beginning !!!**

These figures emphasize the importance of decreasing the background systematic error to obtain good pMSSM model coverage. For FLAT priors we see that, e.g.,

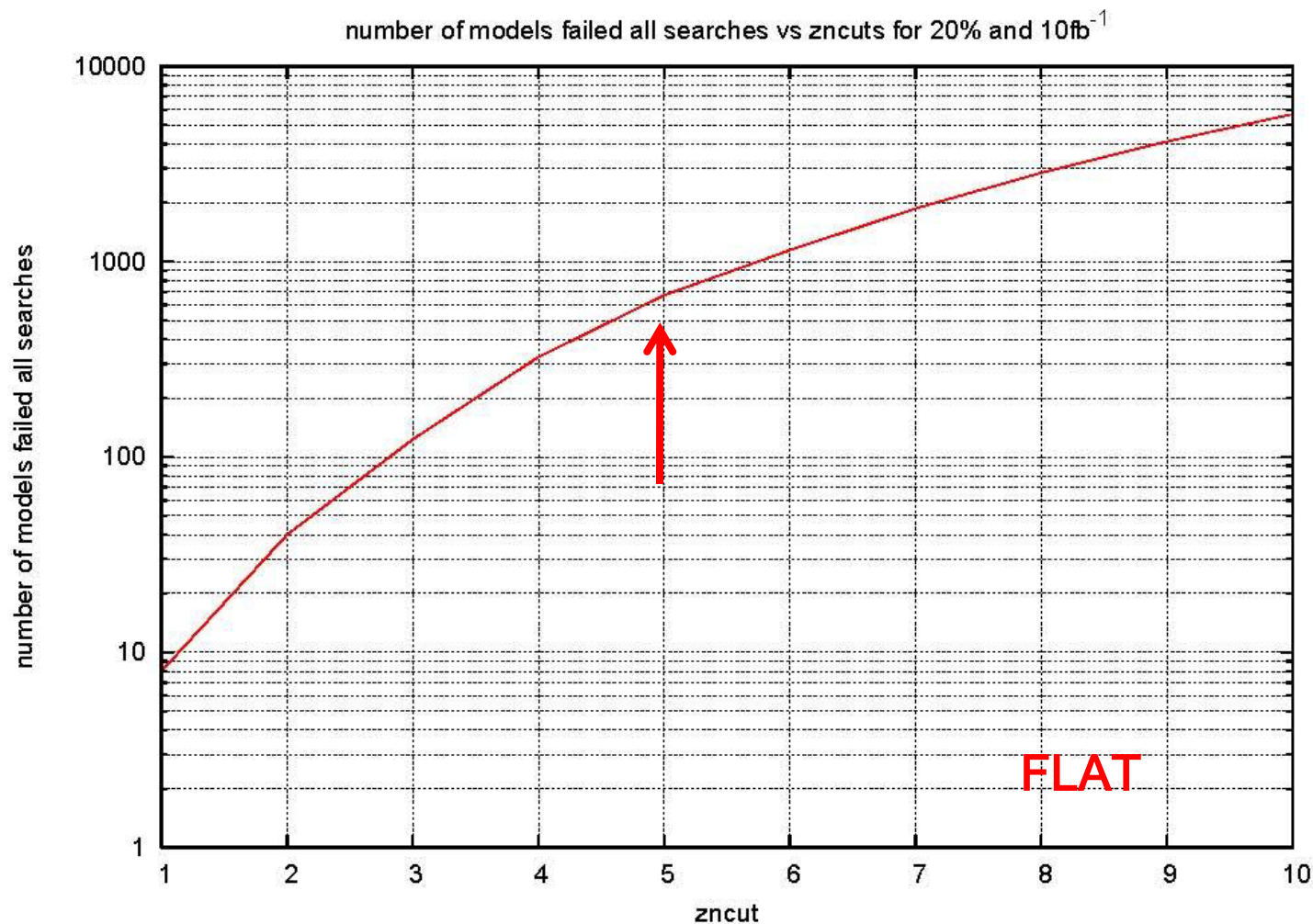
$L=5(10) \text{ fb}^{-1}$  and  $\delta B=100\%$  is 'equivalent' to

$L=0.65(1.4) \text{ fb}^{-1}$  and  $\delta B=50\%$  ( $x \sim 7$ ) OR to

$L=0.20(0.39) \text{ fb}^{-1}$  and  $\delta B=20\%$  ( $x \sim 25$ ) !!

This effect is **less dramatic** for the LOG case due to the potentially heavier mass spectrum

**Aside:** How many models remain missing in the 'best' case as the minimum requirements of 'S=5' for all searches is weakened?



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

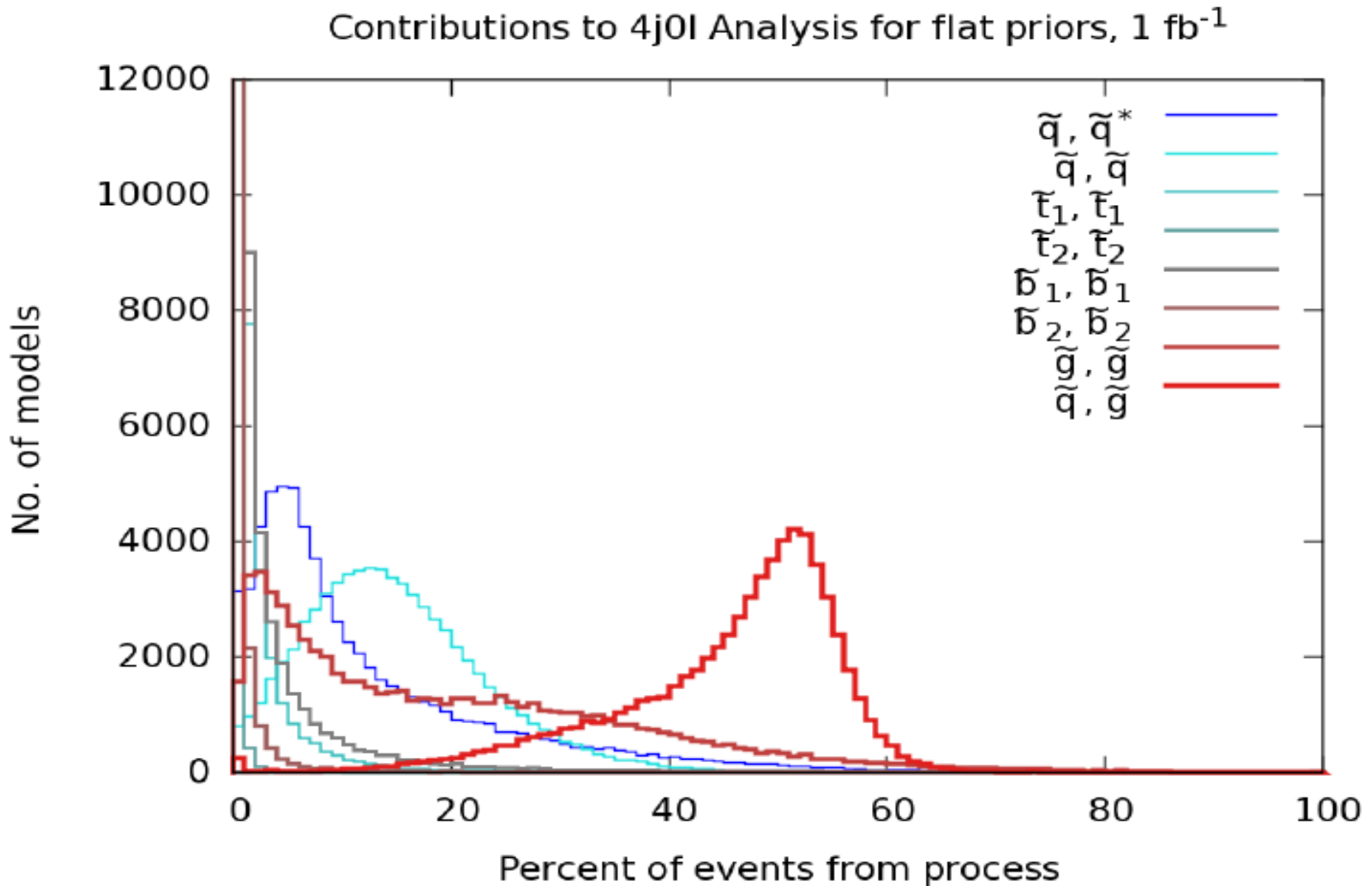
Analysis	Flat $\mathcal{L}_{0.1}$	Flat $\mathcal{L}_1$	Flat $\mathcal{L}_{10}$	Log $\mathcal{L}_{0.1}$	Log $\mathcal{L}_1$	Log $\mathcal{L}_{10}$
4j0l	84.381	72.165	61.678	87.556	70.149	61.397
3j0l	0.084255	11.496	18.777	0.44444	6.4677	12.868
2j0l	14.018	3.7424	1.6595	8.8889	5.4726	4.7794
4j1l	0.2633	7.1883	8.3589	0.88889	14.428	8.8235
3j1l	0.052659	0.43779	1.0449	0	0	0.73529
2j1l	0.094787	1.9065	3.4112	0	0	1.1029
4jOSDL	0.073723	0.014122	0	0	0	0
3jOSDL	0.010532	0.93207	0.4917	0	0.49751	1.1029
2jOSDL	0.97946	1.6099	0.95267	1.7778	0.99502	0.36765
2jSSDL	0.042127	0.5084	3.6263	0.44444	1.99	8.8235

$\delta B=50\%$

→ → 4j0l is the most powerful analysis...

# Aside :

4j0l is mostly sourced by gluino-squark production



# What about searches @ 14 TeV ?

FLAT

Analysis	50% error 1 fb <sup>-1</sup>	50% error 10 fb <sup>-1</sup>	20% error 1 fb <sup>-1</sup>	20% error 10 fb <sup>-1</sup>
4j0l	88.331	88.578	98.912	99.014
2j0l	87.616	87.774	98.75	98.802
1l4j	41.731	44.885	56.849	63.045
1l3j	64.058	70.907	69.725	81.111
1l2j	62.942	68.419	70.646	80.641
OSDL	6.0958	6.6796	15.262	18.659
SSDL	14.774	25.518	18.501	32.887
3lj	13.549	17.361	19.293	28.97
3lm	2.7406	2.9135	4.8844	5.8284
tau	83.51	86.505	96.928	98.695
b	73.983	76.939	91.672	94.867

!!

The fraction of models 'found' by  $n$  different analyses  
 @14 TeV for  $\delta B=50\%$  :

Number of analyses	Flat, 1 fb <sup>-1</sup>	Flat, 10 fb <sup>-1</sup>	Log, 1 fb <sup>-1</sup>	Log, 10 fb <sup>-1</sup>
0	0.56754	0.36796	31.823	27.024
1	1.3458	0.98841	6.2704	6.5374
2	3.396	2.5141	8.9525	10.072
3	13.175	10.635	11.816	11.098
4	22.014	18.455	16.491	16.344
5	9.5512	10.3	5.6905	6.6135
6	15.227	16.929	6.0529	7.1456
7	20.081	17.697	6.7416	6.1954
8	7.6394	11.75	3.0083	4.371
9	3.9205	6.3569	1.5223	2.6226
10	2.0825	2.7943	1.0511	1.1783
11	1.0013	1.2116	0.57992	0.79818

# The Undiscovered SUSY

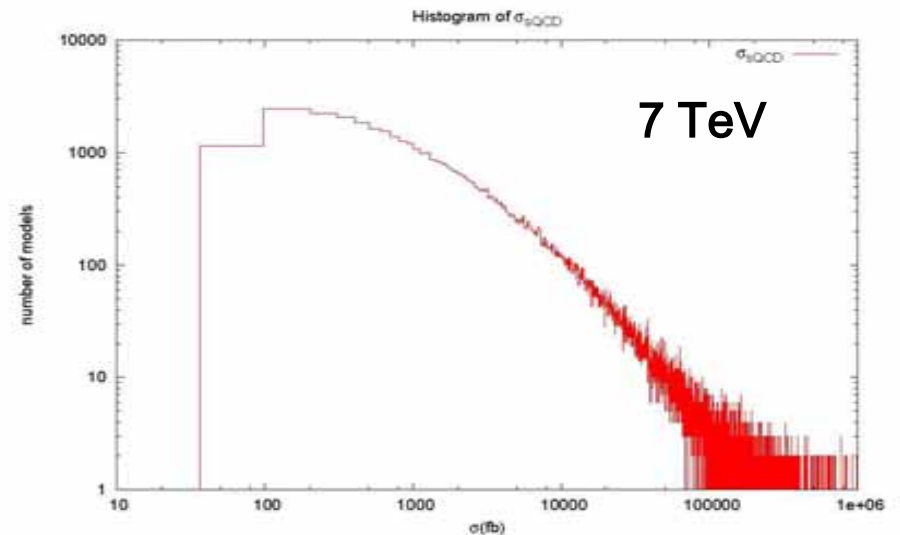
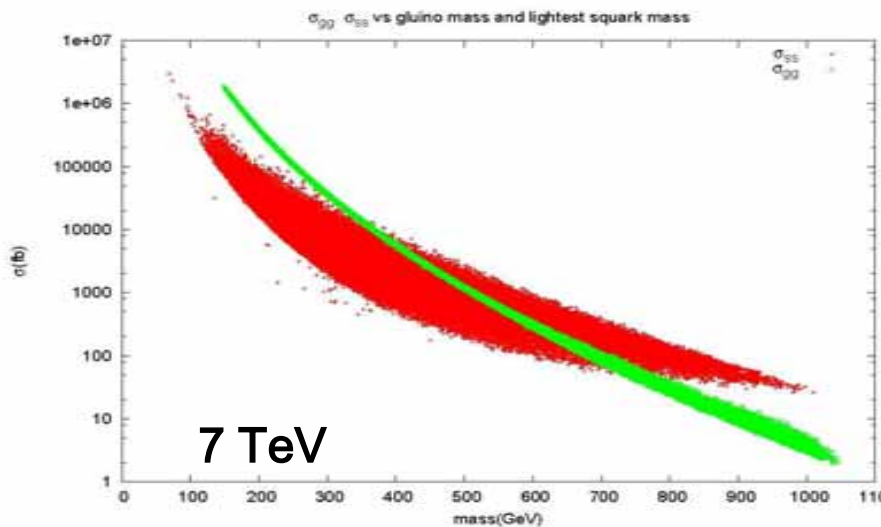
## Why Do Models Get Missed by ATLAS?

The most obvious things to look at **first** are :

- small signal rates due to suppressed  $\sigma$ 's
- which can be correlated with large sparticle masses
- & can be associated w/ large SM background systematics



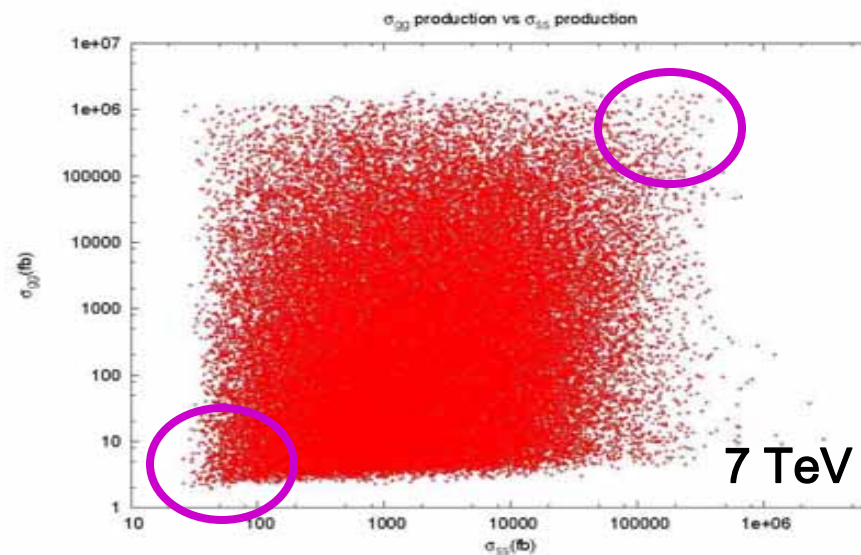
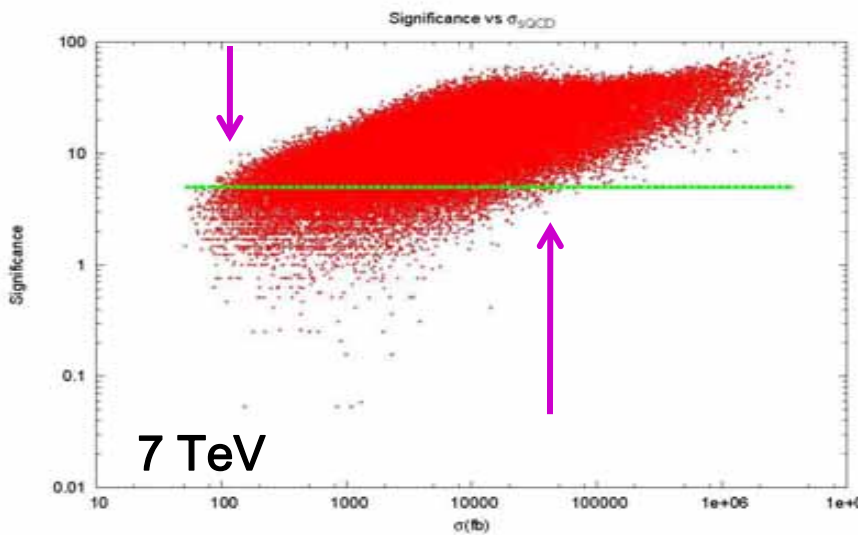
$\sigma$ 's : Squark & gluino production cross sections @ 7 TeV cover a very **wide range** & are well correlated with the **search significance**. But, some models with large production rates lead **to a low** significance assuming  **$L=1 \text{ fb}^{-1}$**  &  **$\delta B=50\%$** . There are models with  **$\sigma > 30 \text{ pb}$**  that are **missed by all ATLAS analyses !**



Note that for a given value of the cross section, the search significance can vary over a very wide range.

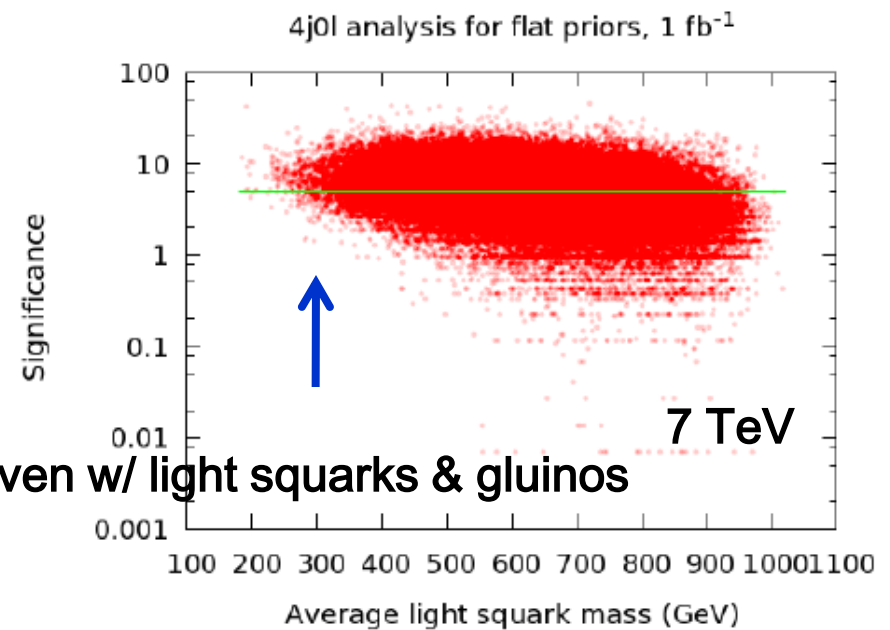
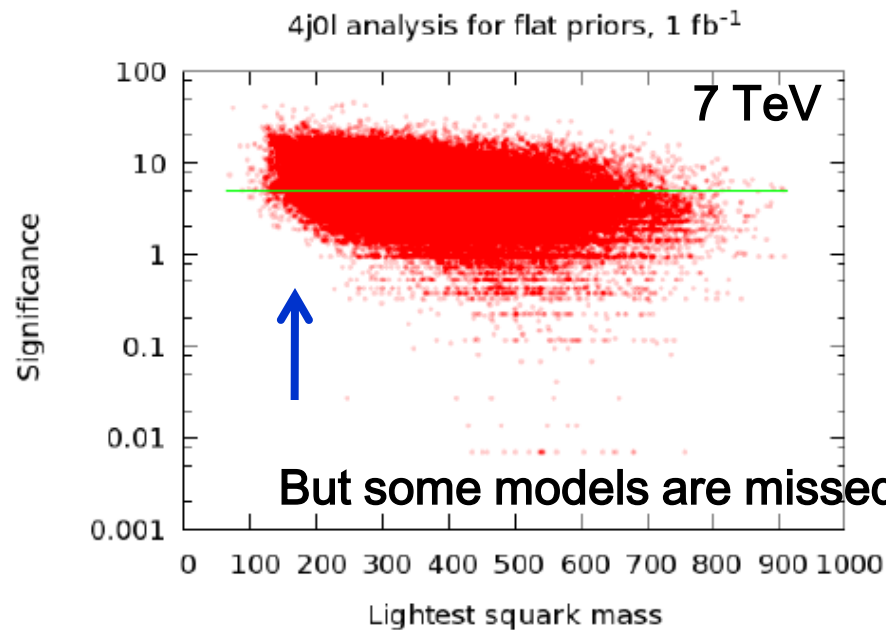
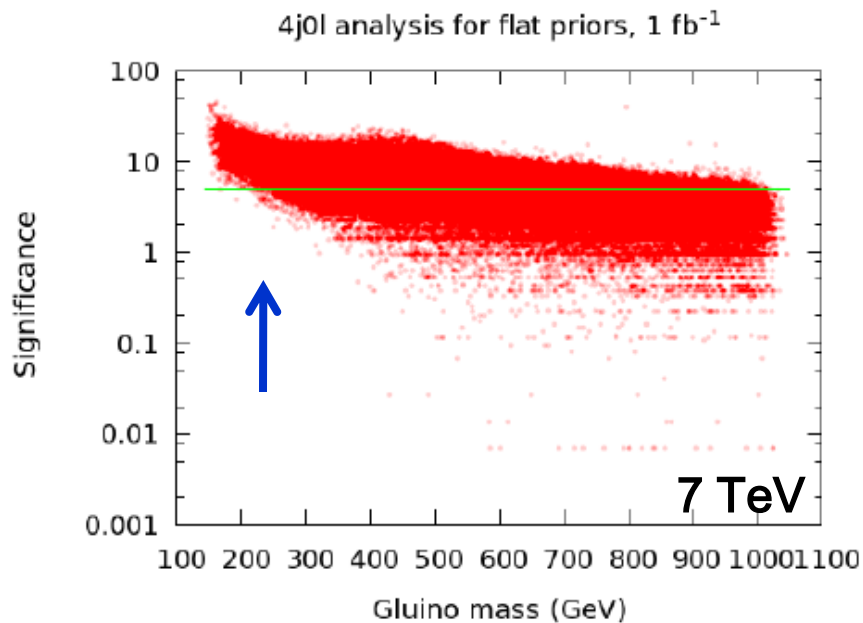
Certainly some models will be missed at 7(or 14) TeV due to their associated small production cross sections but this is the least interesting situation...

What about the sparticle masses themselves?



**Masses:** We clearly observe that some models will be missed when either squarks & or gluinos are very heavy...no surprise!

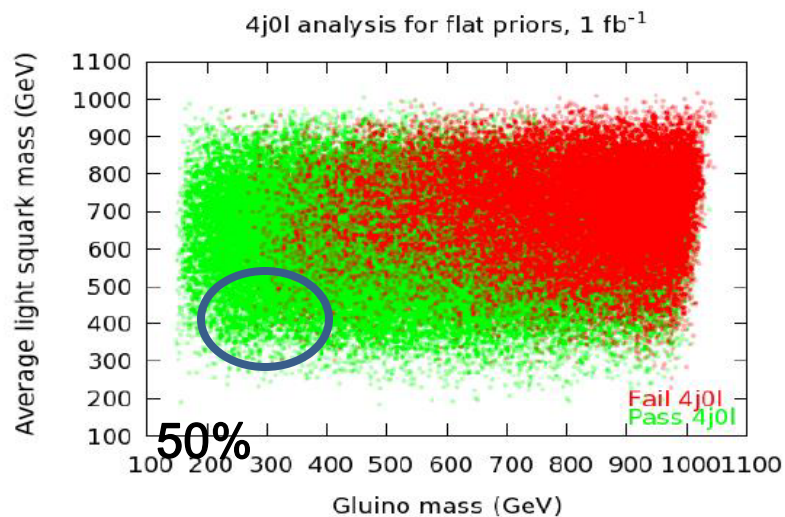
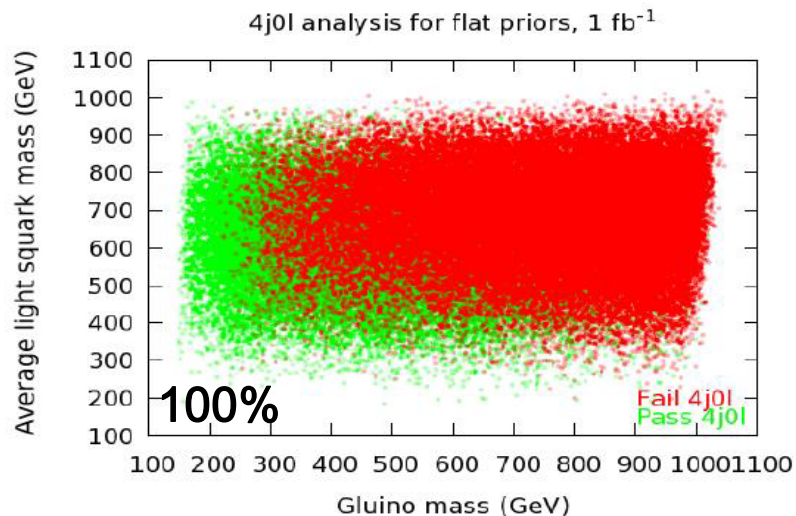
**However** we see here that for a given squark or gluino mass the search significance spans a wide range due to other aspects of the model parameter space.



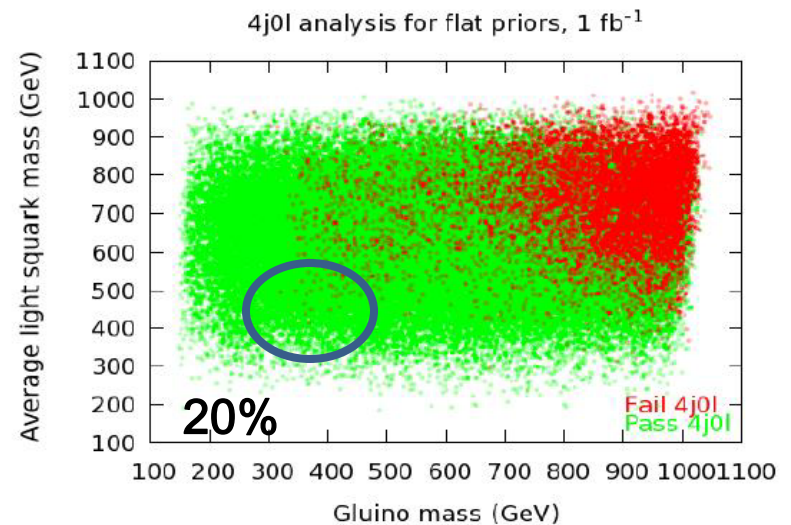
**SYSTEMATICS:** The 4j0l analysis has the best coverage but is quite sensitive to the systematic error. 3j0l is even more so.

The number of missed models is also quite sensitive to the size of background uncertainty.

But there are models w/ light squarks &/or gluinos that are always missed...

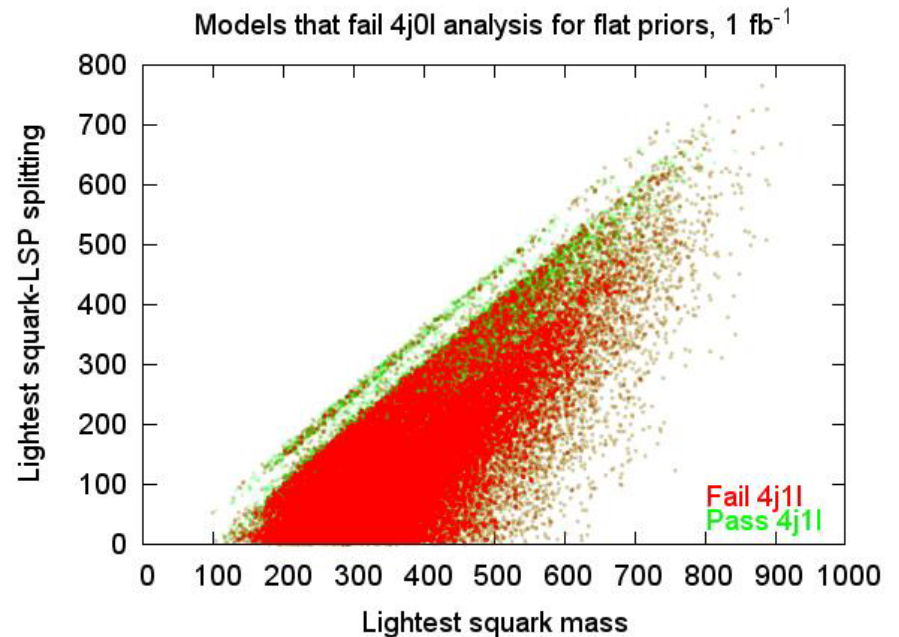
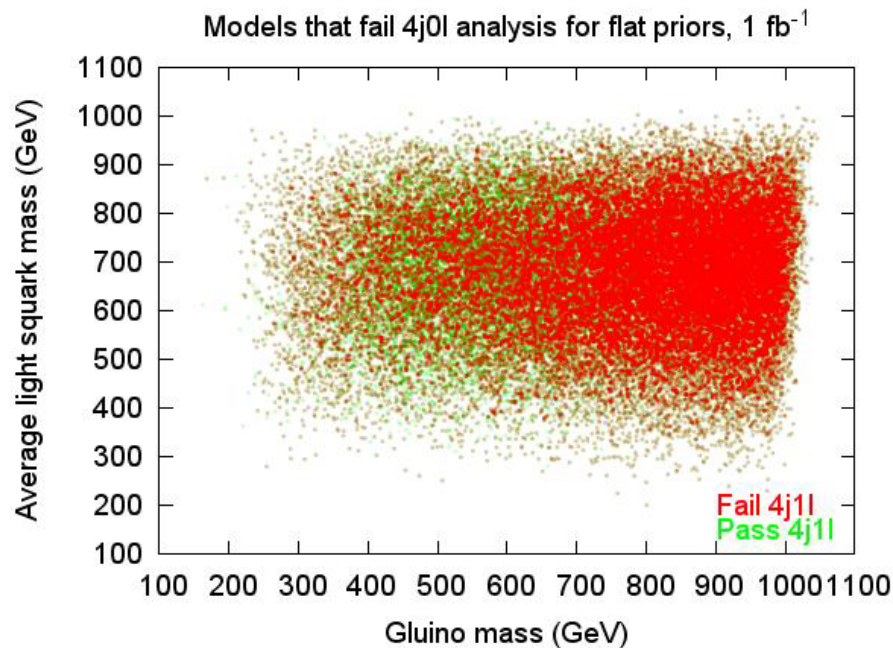


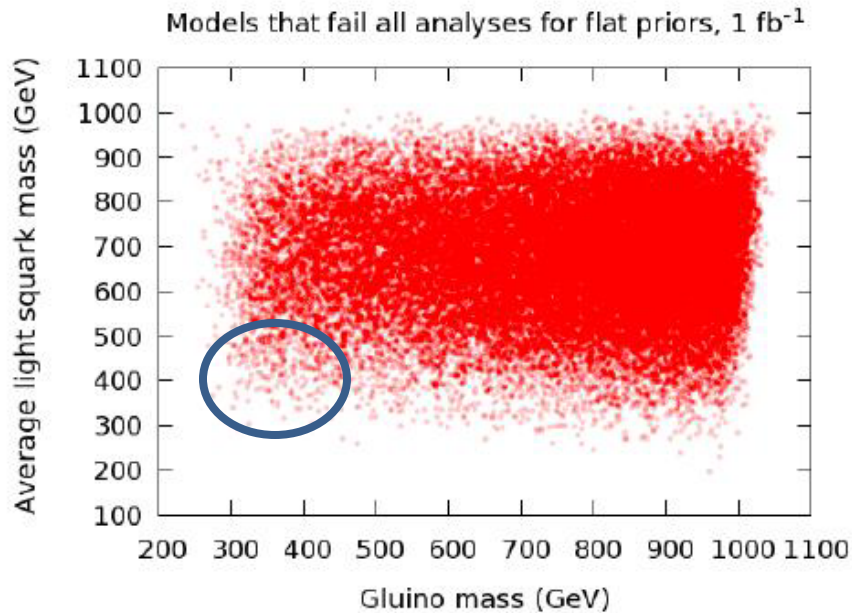
7 TeV



# Aside:

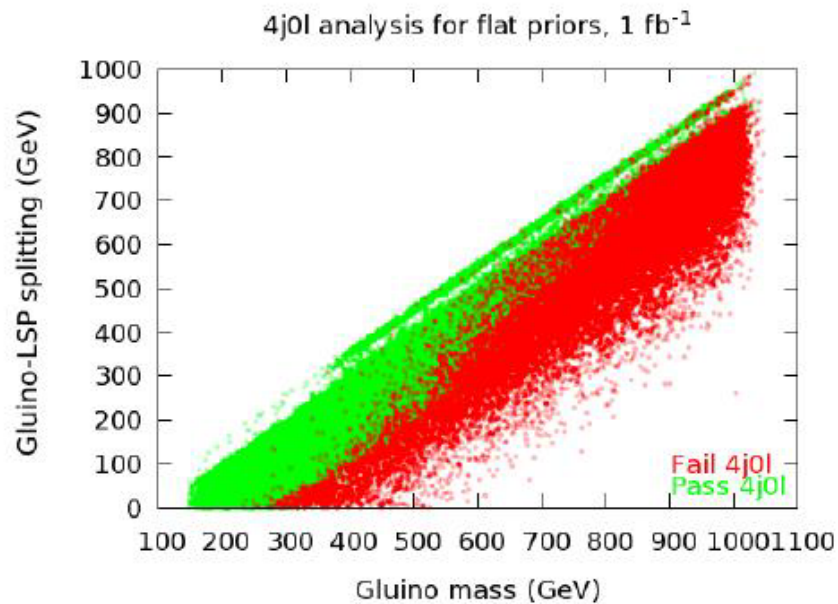
- Powerful analyses , e.g.,  $(2,3,4)j0l$  , can fail completely in ‘**exceptional**’ cases. This could happen if the model spectrum almost always leads to **high  $p_T$  leptons**. But then these models **could** be captured in many cases by the analogous  $(2,3,4)j1l$  analyses. E.g. :



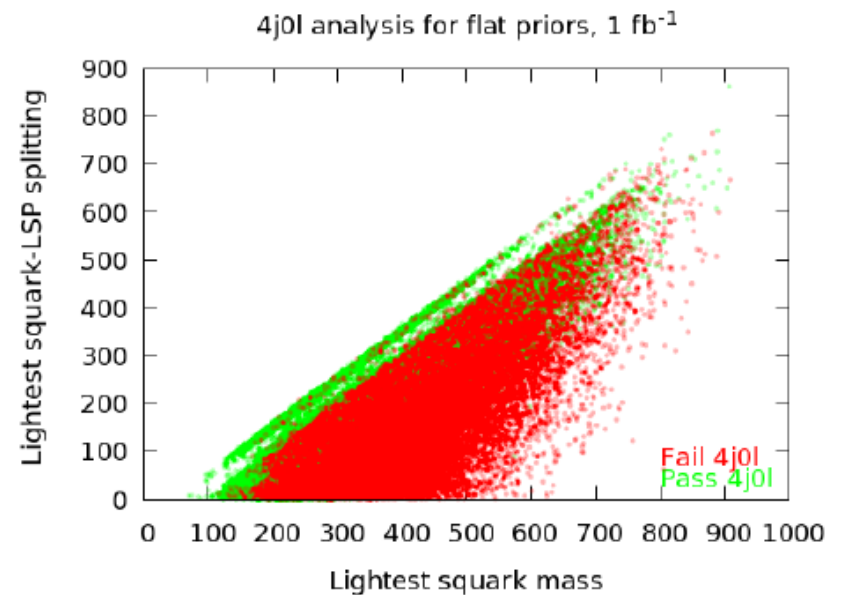


## Cause I: Soft jets & leptons

Both 7 & 14 TeV models can be missed due to **small mass splittings** between squarks and/or gluinos and the LSP  $\rightarrow$  softer jets or leptons not passing cuts. **ISR helps in some cases...**

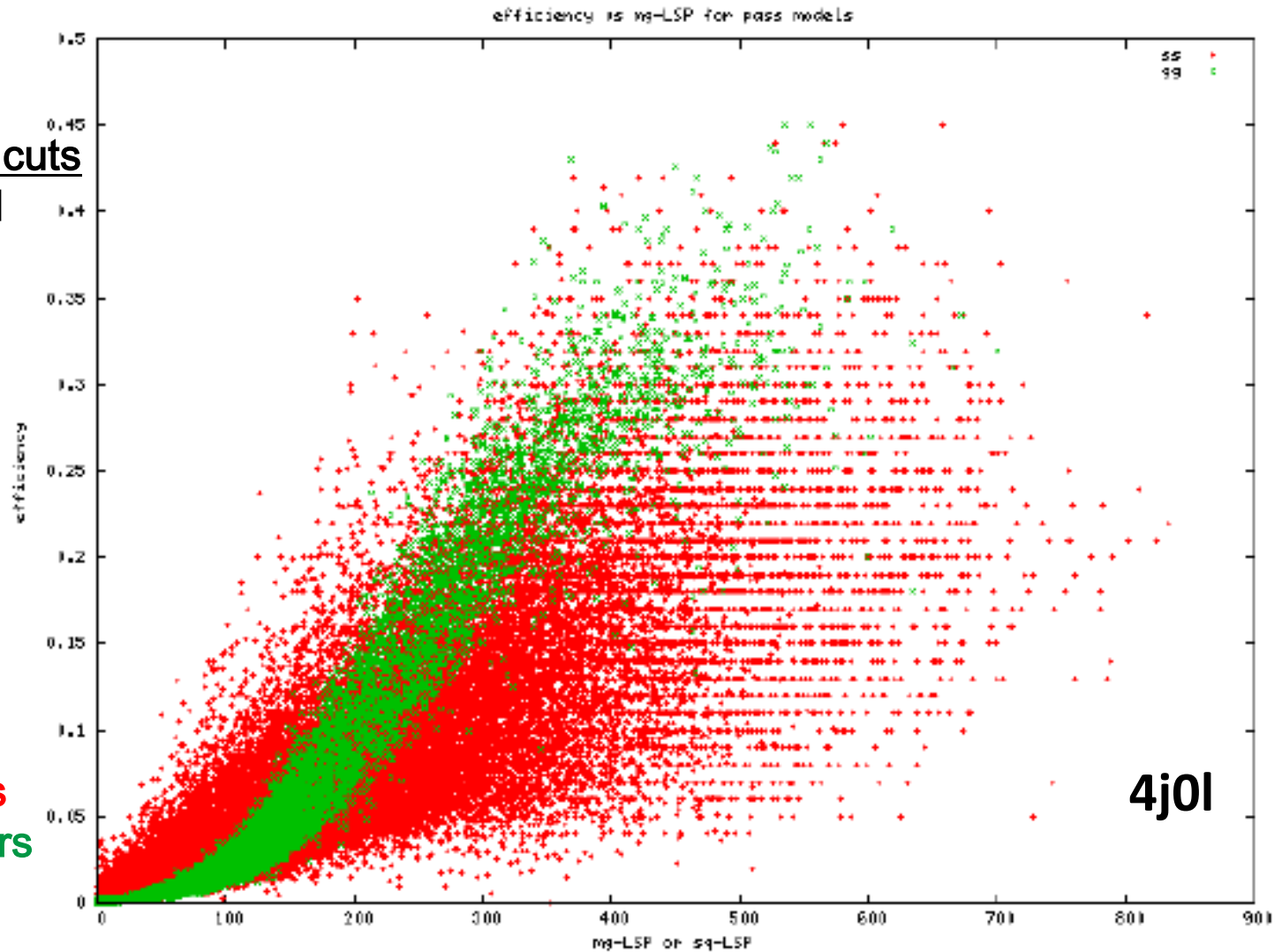


7 TeV



For small mass splittings w/ the LSP a smaller fraction of events will pass analysis cuts

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



Red=squark pairs  
Green=gluino pairs

4j0l

Mass Splitting with the LSP

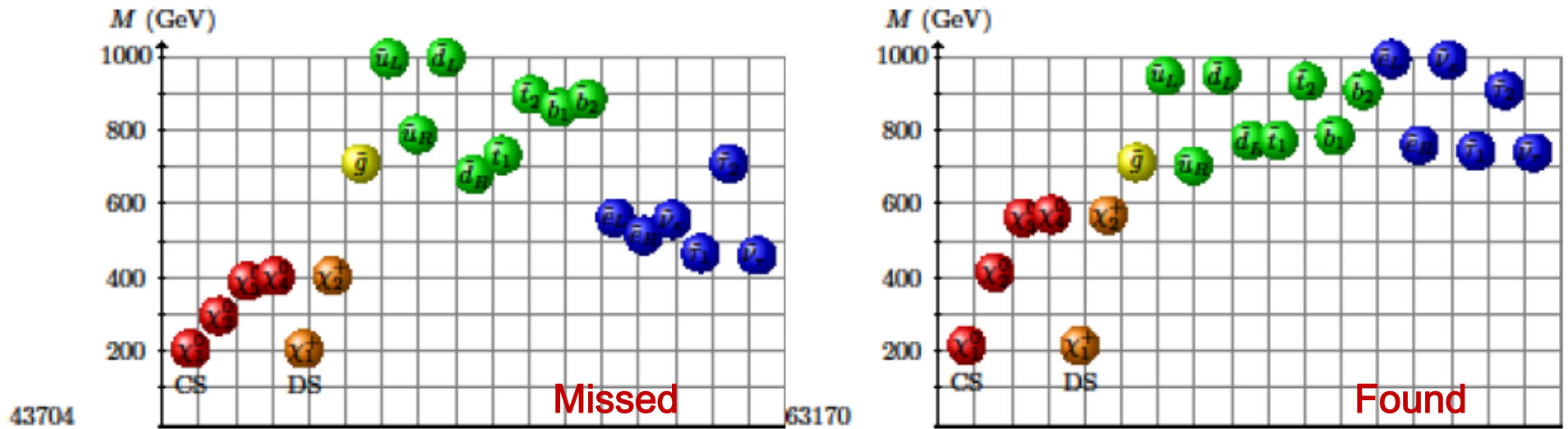
- This generalizes to the case where the **overall** sparticle spectrum is '**compressed**' (especially in the LOG case)

## Cause II: Low MET final states

- There are pMSSM model cascades that dominantly end in **long-lived charginos** that are **detector-stable** so the amount of MET is **too small** for **any** of these analyses.
- **Small changes** in the sparticle spectrum can lead to **significant changes** in the model visibility
- **Here is one out of MANY examples...**



# A 14 TeV Example:



Failed model 43704(process-partonicXS-fullXS-frac.diff)				Sister model 63170			
62	591.6537	552.6714	0.0705342	62	554.1683	598.2279	-0.0736501
63	919.5316	1007.283	-0.0871171	63	1136.412	1115.883	0.0183972
68	1689.407	2207.448	-0.234679	68	1574.955	2111.774	-0.254203
69	4117.824	4558.5	-0.0966714	69	4469.741	4868.156	-0.0818411

#Cut	lepton-pt	num-leps	MET	hardest-jet	Meff-4	Meff-3	Meff-2	Sum-4jet-pt	Sum-3jet-pt	Sum-2jet-pt
43704	46.50313	0.3305726	114.8049	424.9652	1070.408	996.6819	859.0967	893.2752	819.5494	681.9642
63170	74.5432	0.3209754	200.8012	368.0755	1090.669	1005.495	867.3606	819.9918	734.8182	596.6838

# What went wrong ??

In 43704: gluinos  $\rightarrow d_R \rightarrow \chi_2^0 \rightarrow W +$  'stable' chargino ( $\sim 100\%$ )  
(Zanesville, OH) as the  $\chi_2^0$ -LSP mass splitting is  $\sim 91$  GeV

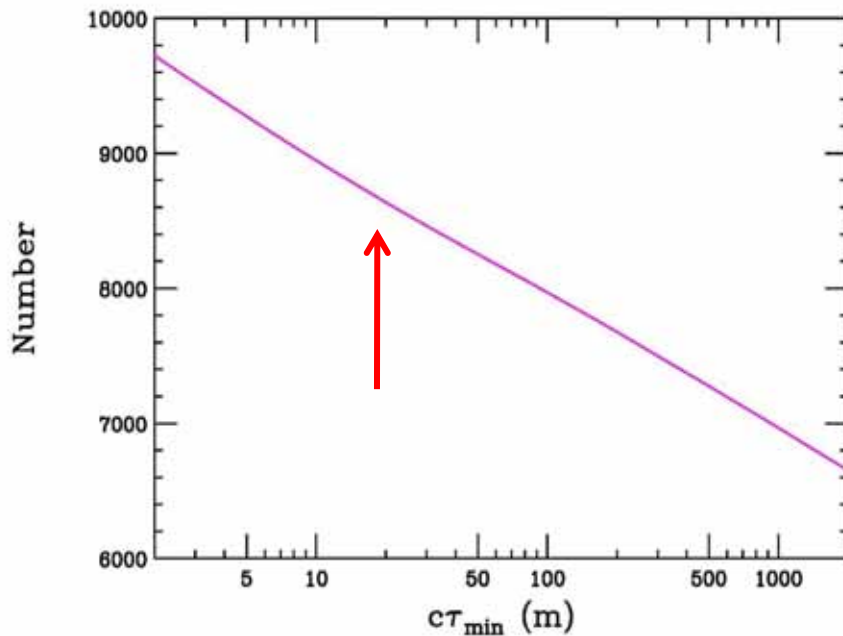
In 63170: gluinos  $\rightarrow u_R \rightarrow \chi_2^0 \rightarrow Z/h +$  LSP ( $\sim 30\%$ ) as the  
(St. Louis, MO)  $\chi_2^0$ -LSP mass splitting is larger  $\sim 198$  GeV

- Again: a small spectrum change can have a large effect on the signal observability!
- $\rightarrow$  Searches for stable charged particles may fill in some gaps

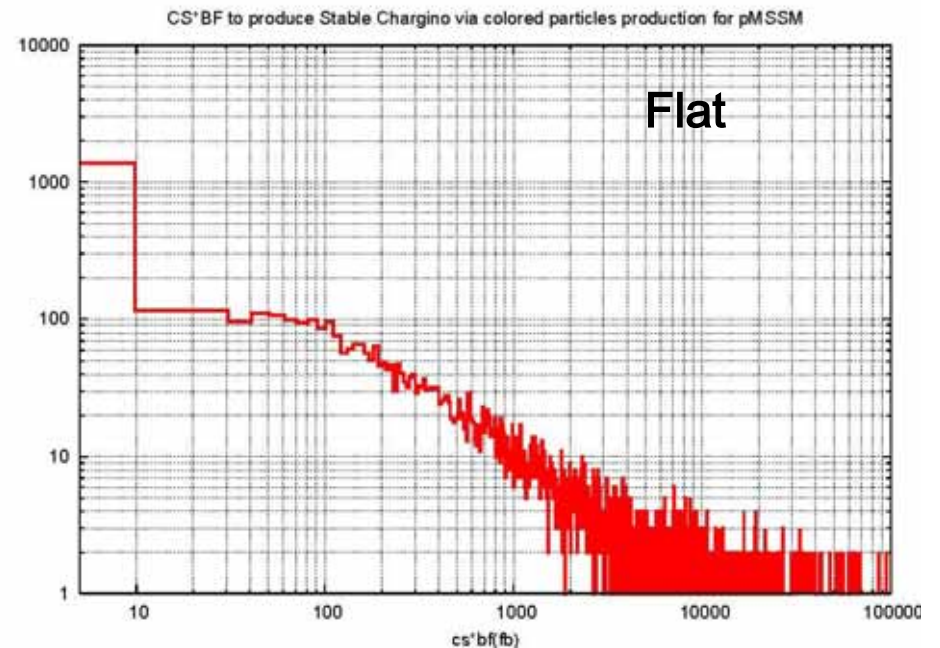
# 'Stable' Charged Particles in Cascades

→ Mostly long-lived charginos produced in long decay chains

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



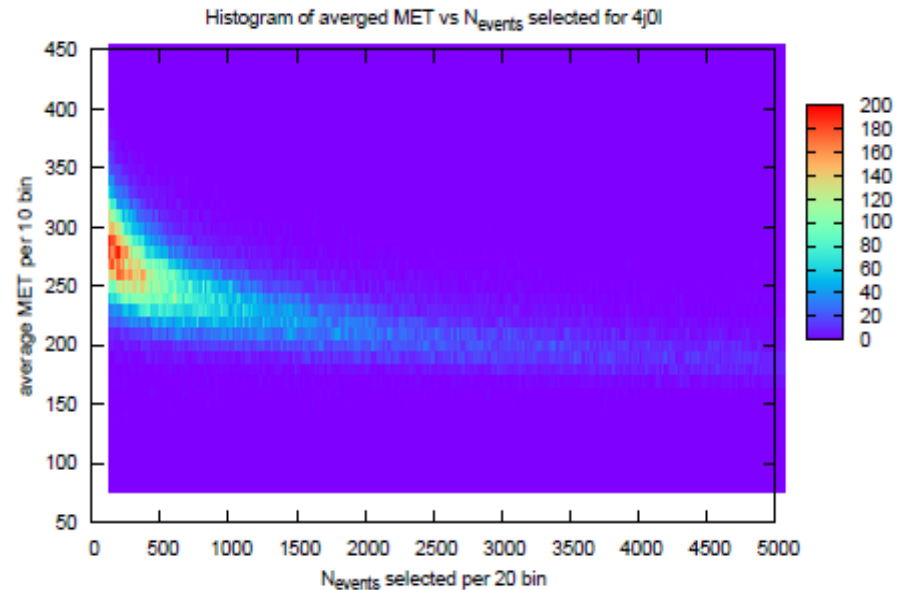
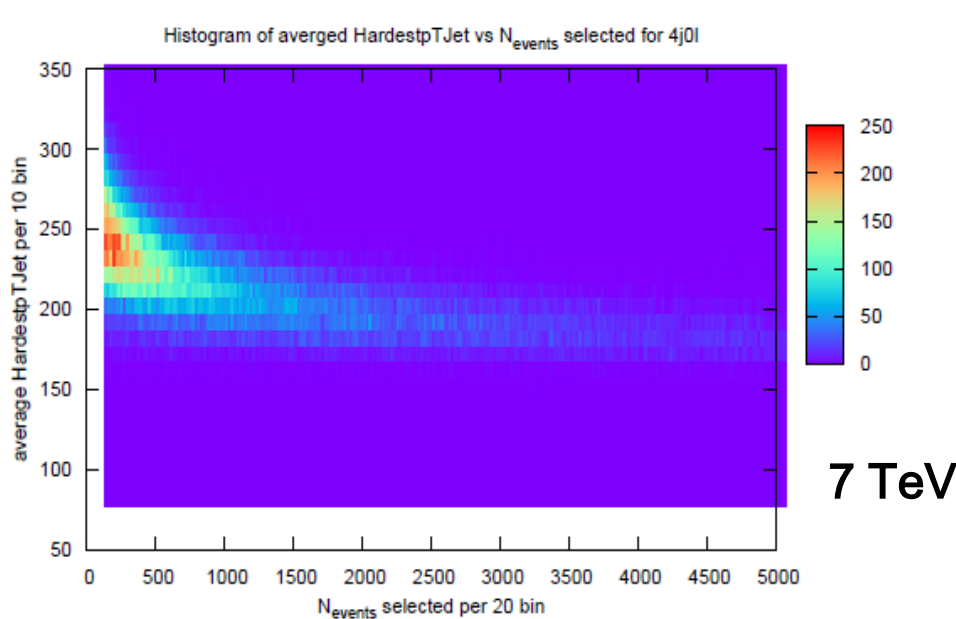
Unboosted Decay Length



Estimated  $\sigma_B$

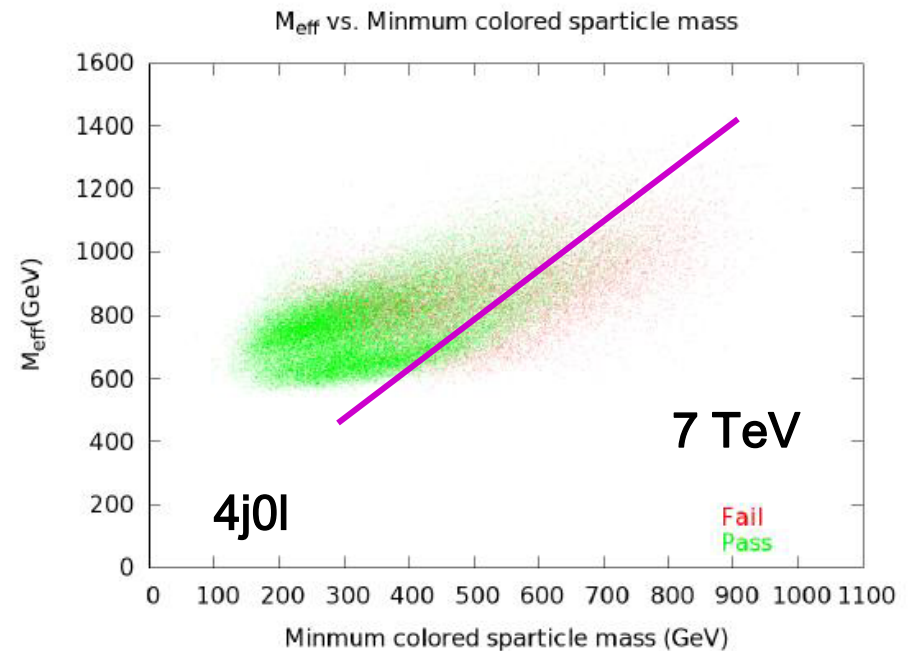
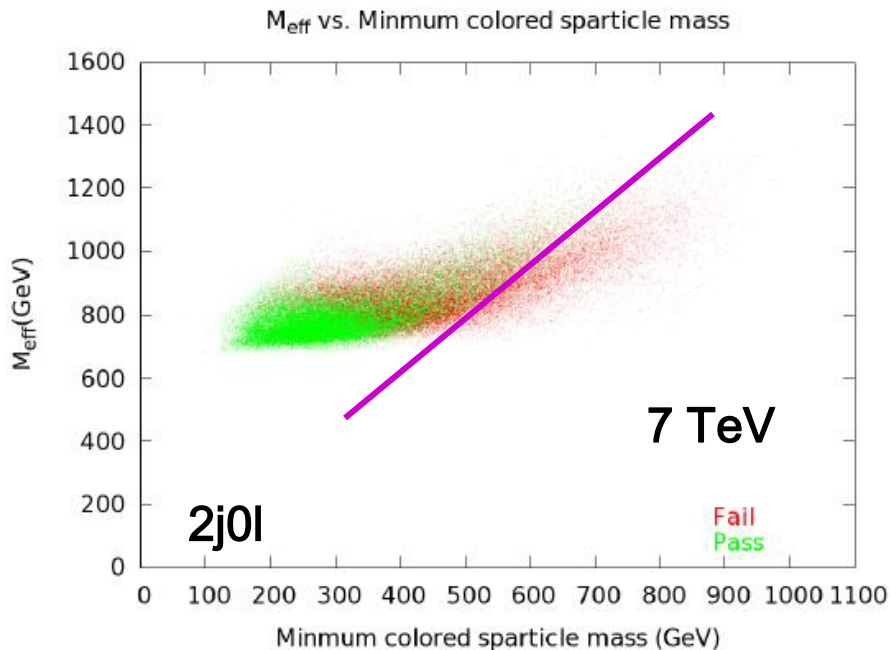
# Tightening Analysis Cuts

- In many cases analysis cuts may be **increased significantly** w/o any substantial **loss of signal rates** for **most** models. E.g., we could increase the  $p_T$  requirement on
  - i) the leading jet to  $\sim 150$  GeV (from 100 GeV) in (4,3)j0l
  - ii) the lepton to  $\sim 25$  GeV (from 20 GeV) in 4j1l
  - iii) the MET to  $\sim 175$  GeV (from 80 GeV) in (4,3)j0l



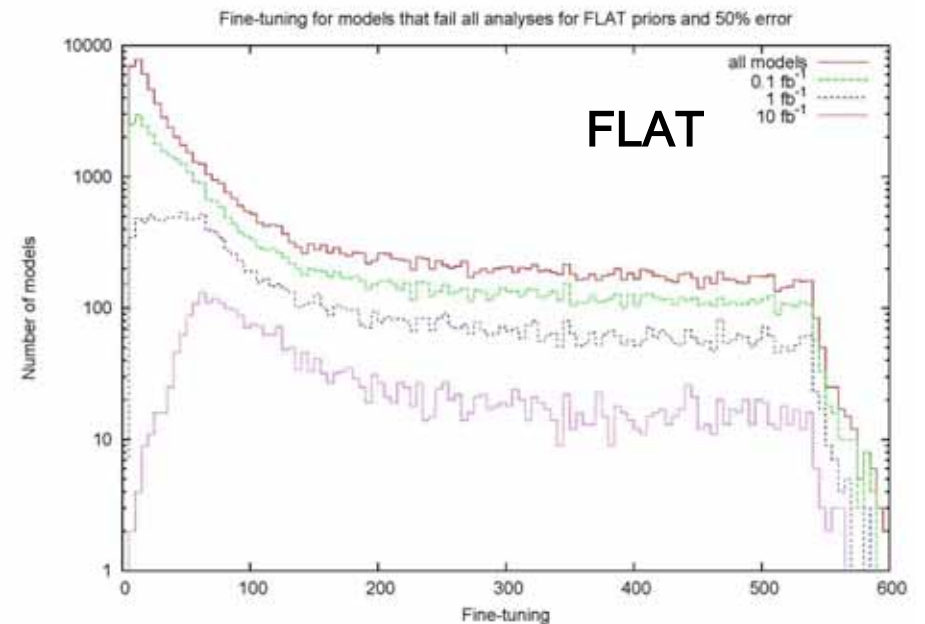
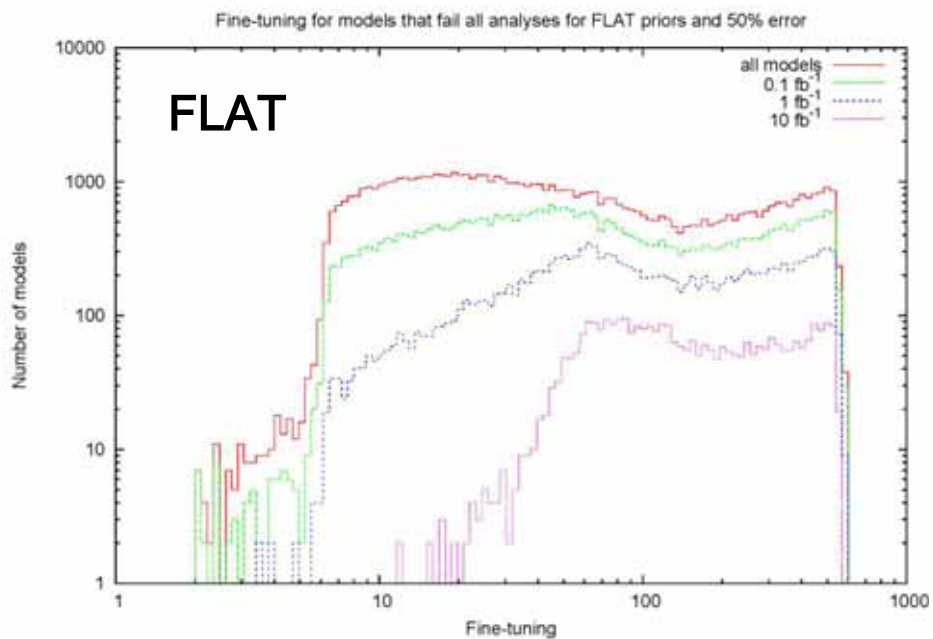
# The SUSY 'mass scale'

- In mSUGRA, one finds  $M_{\text{eff}} \sim 1.5 M$  (lightest colored particle)
- @ 7 TeV for pMSSM models this is **not** generally true except when the lightest colored sparticle mass is  $> \sim 600$  GeV
- This is also true @ 14 TeV...



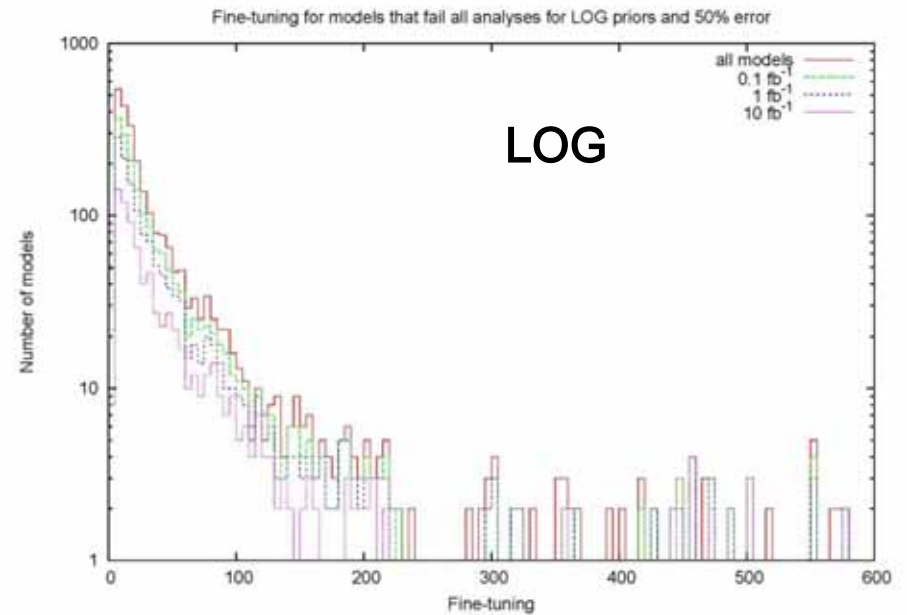
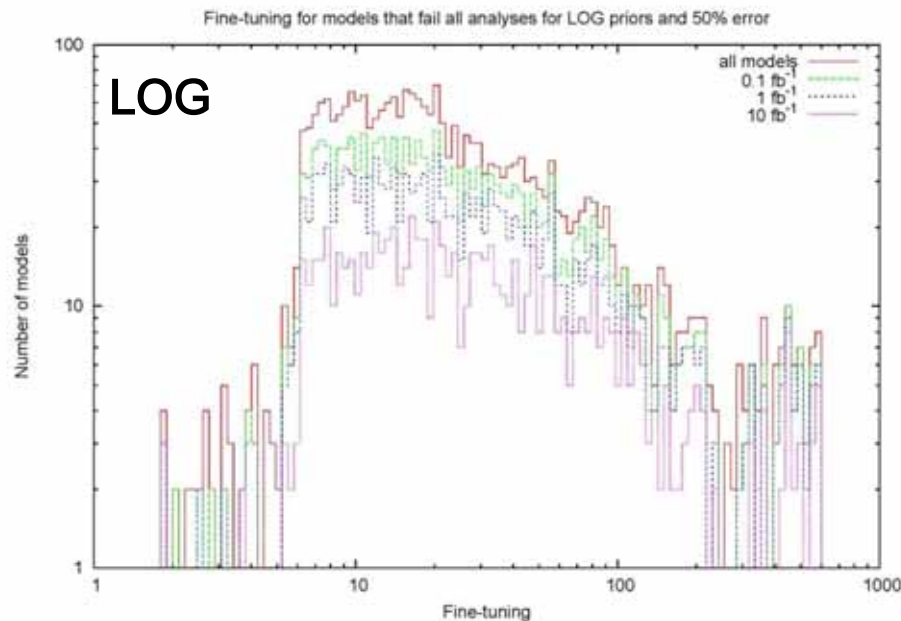
# Fine-Tuning SUSY ?

- 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 the pMSSM??



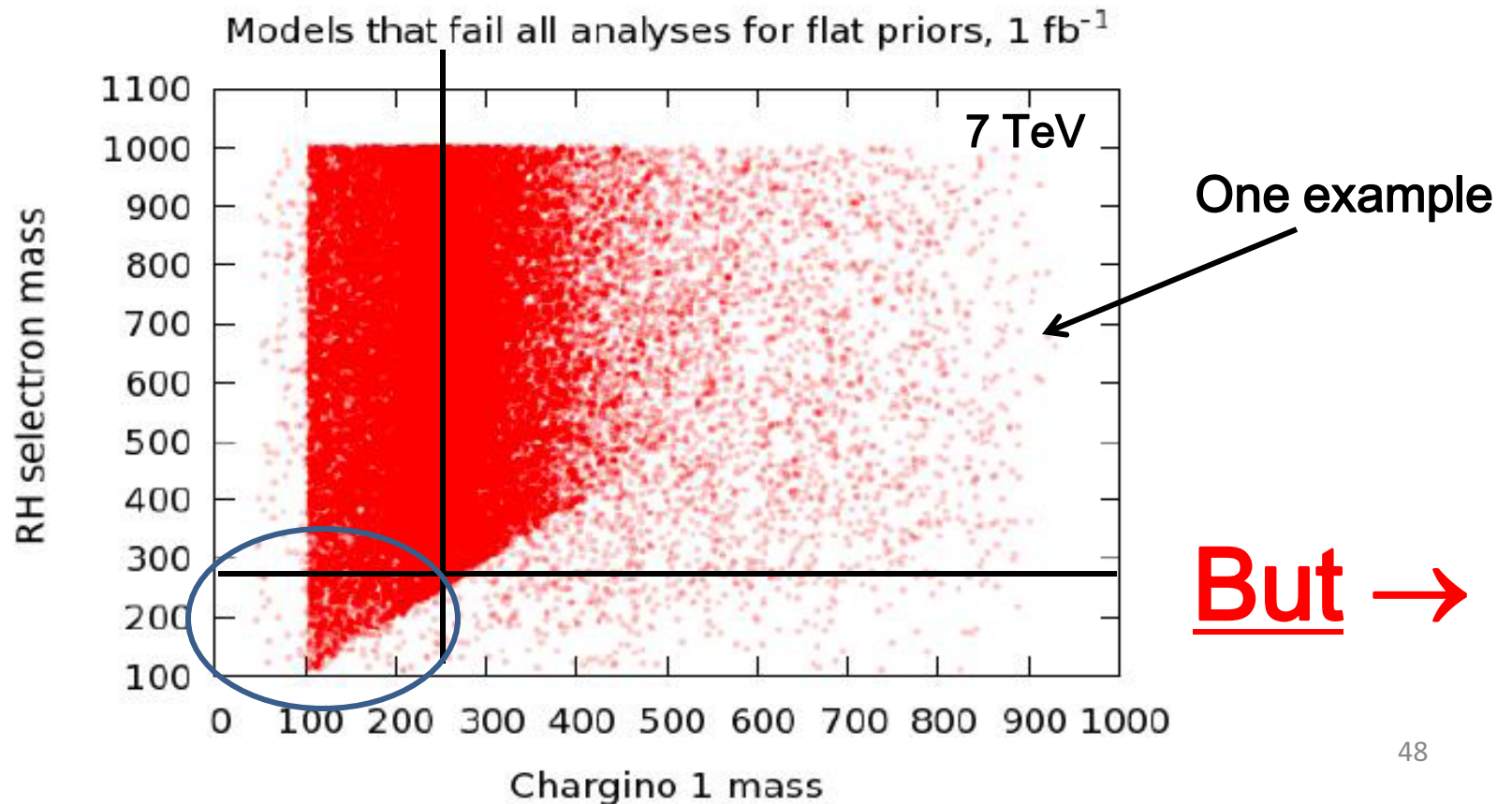
→ It is certainly true that models w/ low tuning do appear to 'suffer' more than those w/ larger values from any null SUSY searches

- 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 stretch-out



# LC Implications

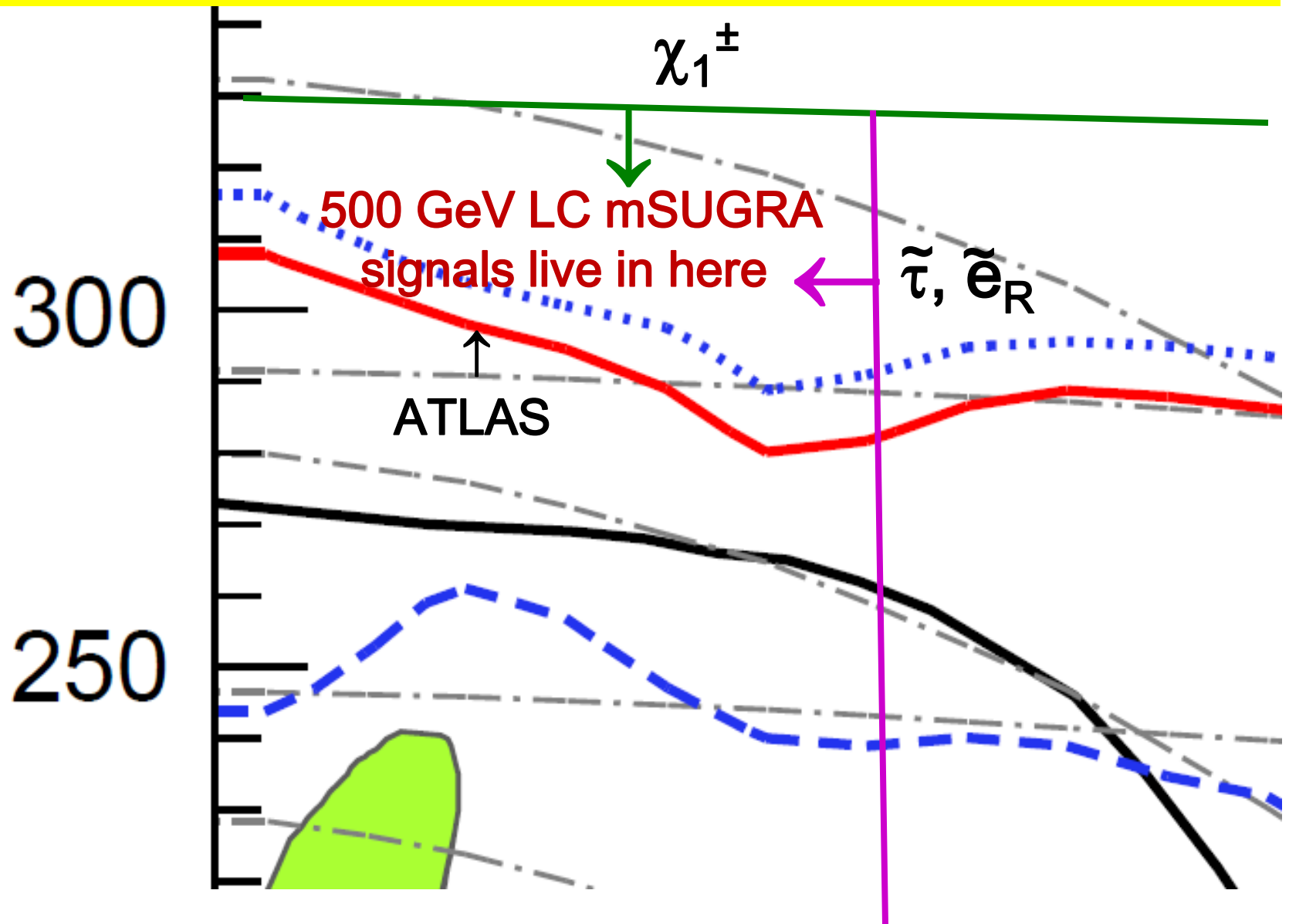
- It is often said that if the LHC 'doesn't find anything in 2011-2' then a 500 GeV LC is 'useless'. BUT what if we look at our failing set of models? Are there SUSY particles kinematically accessible @ 500 GeV in them? YES!





$m_{1/2}$

**Right now ATLAS leaves little room for mSUGRA at the 500 GeV LC!**



→ In the set of **14623(1546) FLAT(LOG)** models **NOT** found at 7 TeV w/ 1 fb<sup>-1</sup> and δB=50% there are...

eL	107(101)	dL	35(11)
eR	260(209)	dR	220(96)
τ1	730(381)	uL	52(16)
τ2	30(36)	uR	124(64)
νe	151(117)	b1	289(75)
ντ	386(236)	b2	1(0)
N1	5487(1312)	t1	93(9)
N2	2738(1035)	t2	0(0)
N3	429(352)	C1	4856(1208) \$\$
N4	10(18)	C2	94(54)
g	0(0)		

**But →**

\$\$ many of these are detector-stable charginos

→ In the set of 672(663) **FLAT(LOG)** models **NOT** found at 7 TeV w/ 10 fb<sup>-1</sup> and δB=20% there are **only**...

eL	0(37)	dL	0(3)
eR	0(72)	dR	1(18)
τ1	2(142)	uL	0(5)
τ2	0(11)	uR	0(14)
νe	0(42)	b1	0(20)
ντ	0(85)	b2	0(0)
N1	26(507)	t1	1(2)
N2	4(397)	t2	0(0)
N3	0(136)	C1	25(467)
N4	0(5)	C2	0(17)
g	0(0)		

i.e, not a whole lot in the **FLAT** case...so the 'SUSY @ the LC window' depends where we end up & spectrum shape details

# Summary & Conclusions

- ATLAS searches at **both 7 & 14 TeV** (& **any value** in between) with modest lumi will do **quite well** at 'discovering' the **FLAT** pMSSM models & **not at all badly** with the **LOG** prior set
- **With  $\sim 35 \text{ pb}^{-1}$** , a **reasonable fraction** of this model space has already been 'covered' ! **Let's see at Moriond...**
- **Reducing SM background uncertainties** is **crucial** to enhancing model coverage..much more so than **lumi increases alone**
- Models 'missed' primarily due to either **compressed spectra** *or* because of **low MET** cascades ending in 'stable' **charginos** *or...*
- **The search for TeV scale SUSY has finally begun !**

# BACKUP SLIDES

→ Reducing systematics, in the set of 5072(1216) **FLAT(LOG)** models **NOT** found at 7 TeV w/ 1 fb<sup>-1</sup> and  $\delta B=20\%$  there are...

eL	26(76)	dL	2(3)
eR	58(155)	dR	28(59)
$\tau_1$	164(381)	uL	2(6)
$\tau_2$	6(36)	uR	7(43)
$\nu_e$	45(117)	b1	43(51)
$\nu_\tau$	81(236)	b2	0(0)
N1	1276(1312)	t1	20(6)
N2	519(1035)	t2	0(0)
N3	66(352)	C1	1157(940)
N4	1(18)	C2	21(41)
g	0(0)		

Not too bad...

**But** →

→ Increasing lumi, in the set of 3278(899) **FLAT(LOG)** models **NOT** found at 7 TeV w/ 10 fb<sup>-1</sup> and  $\delta B=50\%$  there are...

eL	2(101)	dL	1(11)
eR	3(209)	dR	4(96)
$\tau_1$	23(381)	uL	1(16)
$\tau_2$	1(36)	uR	2(64)
$\nu_e$	6(117)	b1	4(75)
$\nu_\tau$	7(236)	b2	0(0)
N1	318(1312)	t1	9(9)
N2	71(1035)	t2	0(0)
N3	3(352)	C1	292(1208)
N4	0(18)	C2	2(54)
g	0(0)		

A bit worse...

**But** →

**What Happens at  $\sqrt{s}=1$  TeV ?**



→ In fact, in the set of 14623(1546) **FLAT(LOG)** models **NOT** found at 7 TeV w/ 1 fb<sup>-1</sup> and  $\delta B=50\%$  there are...

eL	3052(347)	dL	2459(117)
eR	3938(565)	dR	3630(526)
$\tau_1$	7431(869)	uL	2545(123)
$\tau_2$	1288(207)	uR	3581(273)
$\nu_e$	3168(356)	b1	5553(590)
$\nu_\tau$	4366(553)	b2	409(21)
N1	15410(1539)	t1	3727(217)
N2	10714(1395)	t2	2(0)
N3	5667(903)	C1	13561(1495)
N4	1267(202)	C2	3412(456)
g	1088(65)		

No surprise, of course this is WAY better ! **But** →

→ In the set of 672(633) **FLAT(LOG)** models **NOT** found at 7 TeV w/ 10 fb<sup>-1</sup> and  $\delta B=20\%$  there are...

eL	63(142)	dL	73(24)
eR	53(223)	dR	63(157)
$\tau_1$	165(338)	uL	81(24)
$\tau_2$	9(69)	uR	86(79)
$\nu_e$	64(146)	b1	103(189)
$\nu_\tau$	81(236)	b2	3(4)
N1	587(626)	t1	94(58)
N2	352(557)	t2	0(0)
N3	57(357)	C1	505(608)
N4	5(66)	C2	16(170)
g	27(5)		

Still not great... but much better than 500 GeV!

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

$\delta B=20\%$

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	90.094	75.633	73.564	92.989	78.859	61.856
3j0l	0.053602	6.6891	8.1851	0	4.0268	15.722
2j0l	8.2226	1.9023	0.81944	6.2731	2.0134	1.2887
4j1l	0.35377	11.626	8.7438	0.369	12.416	9.7938
3j1l	0.032161	0.08848	0.88463	0	0	0.7732
2j1l	0.096484	1.3184	3.343	0	0	1.5464
4jOSDL	0.11792	0.017696	0.0093119	0	0.67114	0
3jOSDL	0	1.221	0.29798	0.369	0.33557	0
2jOSDL	1.0077	1.0441	0.88463	0	1.0067	1.2887
2jSSDL	0.021441	0.4601	3.2685	0	0.67114	7.732

$\delta B=100\%$

# What fraction of models are found by $n$ analyses @ 7 TeV assuming $\delta B=100\%$ ?

→

# 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	74.112	47.23	17.635	81.911	69.016	47.875
1	13.894	16.834	15.996	9.8438	10.825	14.094
2	4.4759	13.331	21.917	3.1602	7.7007	15.91
3	7.3282	18.166	26.186	4.9401	10.607	15.365
4	0.10575	1.8827	6.478	0.036324	0.79913	2.6153
5	0.037237	1.0322	4.7174	0.036324	0.32692	1.7436
6	0.023832	0.7075	3.3008	0	0.32692	1.0171
7	0.019363	0.57345	2.1703	0.072648	0.36324	0.87178
8	0.0029789	0.16831	1.0025	0	0.036324	0.36324
9	0.0014895	0.064047	0.46474	0	0	0.10897
10	0	0.011916	0.13257	0	0	0.036324

Plots of these results are more informative, e.g., for  $n=0$

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

# 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

The  $n=0$  case is the most interesting one..

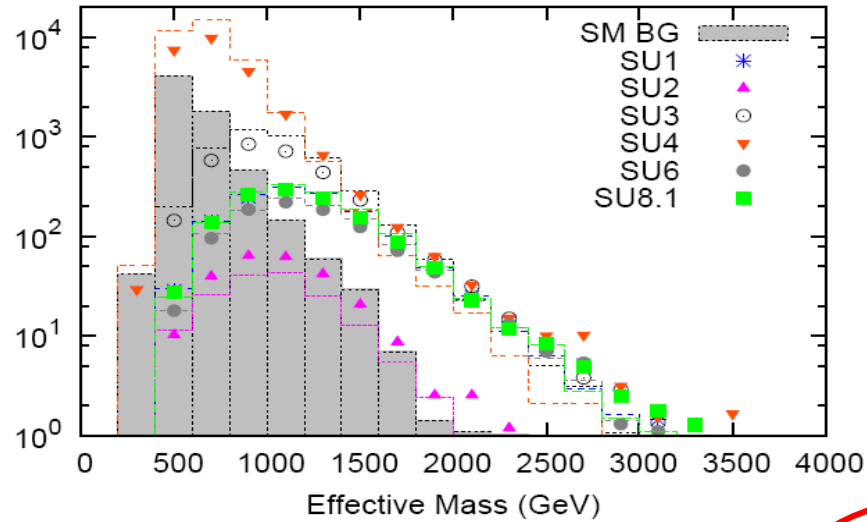
The results are highly sensitive to the SM background uncertainty

# ATLAS 14TeV/ 1fb<sup>-1</sup> Backgrounds & 'Target' Signal Counts

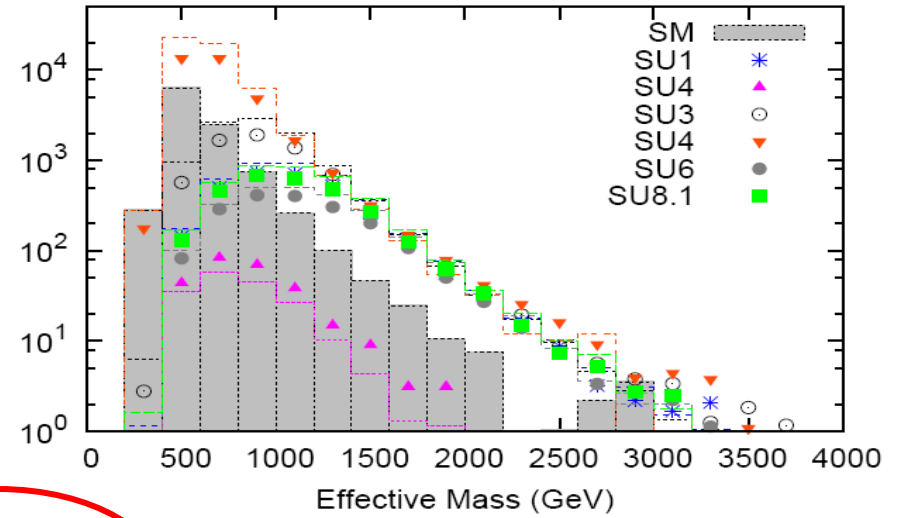
<u>ANALYSIS</u>	<u>BACKGROUND</u>	<u>S=5, <math>\delta B=50\%</math></u>	<u><math>\delta B=20\%</math></u>
4j0l	709	1759	721
2j0l	1206	2778	1129
4j1l	41.6	121	62
3j1l	7.2	44	28
2j1l	18.2	61	36
OSDL	84.7	230	108
SSDL	2.3	17	13
3l1j	12	44	28
3lm	72.5	198	94
$\tau$	51	144	72
b	69	178	86

Pure 'QCD' processes, which have the largest reach, ALSO have the bar set high for S=5 due to the large SM backgrounds & their uncertainties

$M_{\text{eff}}$  distribution for 4-jet, 0 lepton analysis



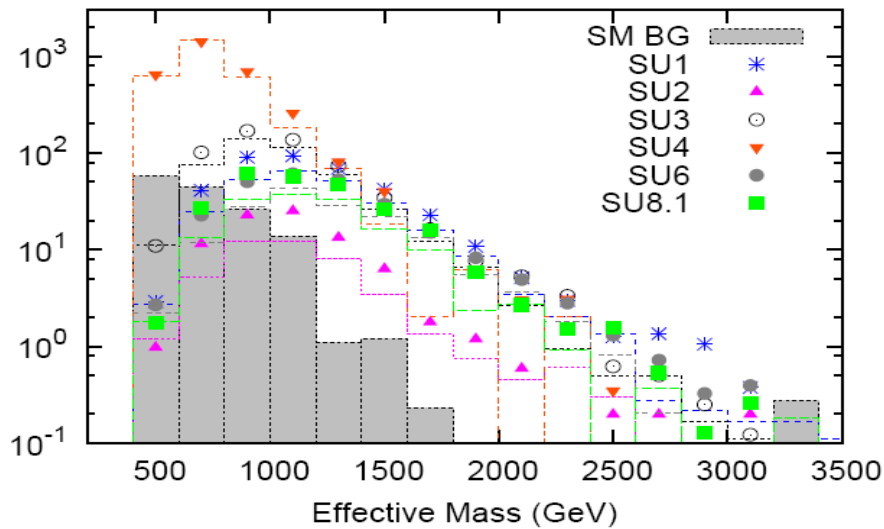
$M_{\text{eff}}$  distribution for 2-jet, 0 lepton analysis



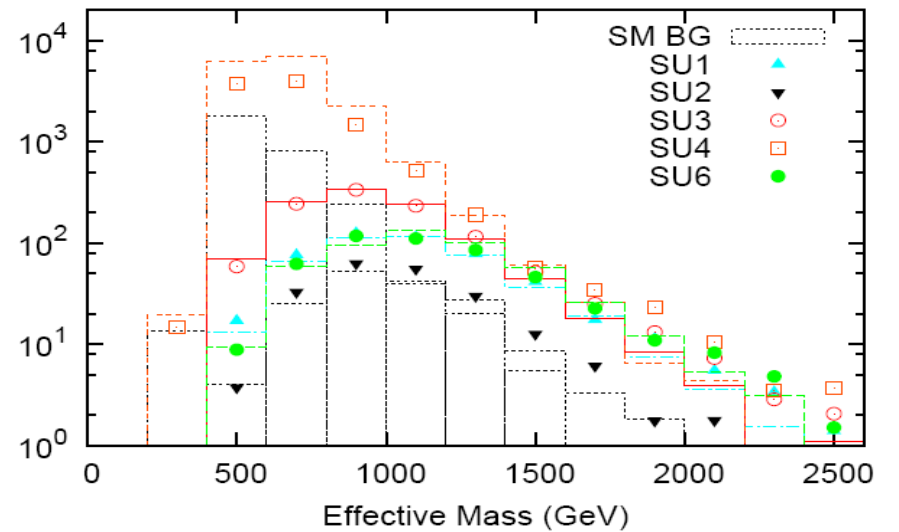
14 TeV

4j

$M_{\text{eff}}$  distribution for  $\tilde{M}_1$  lepton analysis



$M_{\text{eff}}$  distribution for b-jet analysis





- **However**, we see that models w/ low tuning DO survive..how many will depend on the exact lumi & systematic errors achieved by ATLAS searches. Note the variation w/ the background systematic errors..the fewer surviving models, the more fine-tuned they are

