Supersymmetry Without Prejudice at the LHC

Conley, Gainer, JLH, Le, Rizzo   arXiv:1005.ASAP

Supersymmetry With or Without Prejudice?

- The Minimal Supersymmetric Standard Model has ~120 parameters
- Studies/Searches incorporate simplified versions
  - Theoretical assumptions @ GUT scale
  - Assume specific SUSY breaking scenarios (mSUGRA, GMSB, AMSB…)
  - Small number of well-studied benchmark points
- Studies incorporate various data sets

- Does this adequately describe the true breadth of the MSSM and all its possible signatures?

- The LHC is turning on, era of speculation will end, and we need to be ready for all possible signals

More Comprehensive MSSM Analysis

Berger, Gainer, JLH, Rizzo, arXiv:0812.0980

- Study Most general CP-conserving MSSM
  - Minimal Flavor Violation
  - Lightest neutralino is the LSP
  - First 2 sfermion generations are degenerate w/ negligible Yukawas
  - No GUT, SUSY-breaking assumptions

- ⇒ pMSSM: 19 real, weak-scale parameters

  scalars:

  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}

  gauginos: M_1, M_2, M_3

  tri-linear couplings: A_b, A_t, A_τ

  Higgs/Higgsino: μ, M_A, $\tan\beta$

Perform 2 Random Scans

Linear Priors

10^7 points – emphasize 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

$\sim 0.5\, M_Z \leq M_A \leq 1$ TeV

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

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

Log Priors

2×10^6 points – emphasize lower masses and extend 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

$\sim 0.5\, M_Z \leq M_A \leq 3$ TeV

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

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

Absolute values account for possible phases
only Arg ($M_i\, \mu$) and Arg ($A_f\, \mu$) are physical

Set of Experimental Constraints I

- Theoretical spectrum Requirements (no tachyons, etc)
- Precision measurements:
  - $\Delta\rho$, $\Gamma(Z\rightarrow$ invisible)
  - $\Delta(g-2)_\mu$??? $(30.2 \pm 8.8) \times 10^{-10}$ (0809.4062)
    $(29.5 \pm 7.9) \times 10^{-10}$ (0809.3085)
    $(\sim 14.0 \pm 8.4) \times 10\text{-}10$ (Davier/BaBar-Tau08)
    $\rightarrow (-10 \text{ to } 40) \times 10^{-10}$ to be conservative..

- Flavor Physics
  - $b \rightarrow s\,\gamma$, $B \rightarrow \tau\nu$, $B_s \rightarrow \mu\mu$
  - Meson-Antimeson Mixing : Constrains 1st/3rd sfermion mass ratios to be < 5 in MFV context

Set of Experimental Constraints II

- Dark Matter
  - Direct Searches: CDMS, XENON10, DAMA, CRESST I
  - Relic density: $\Omega h^2 < 0.1210$ → 5yr WMAP data

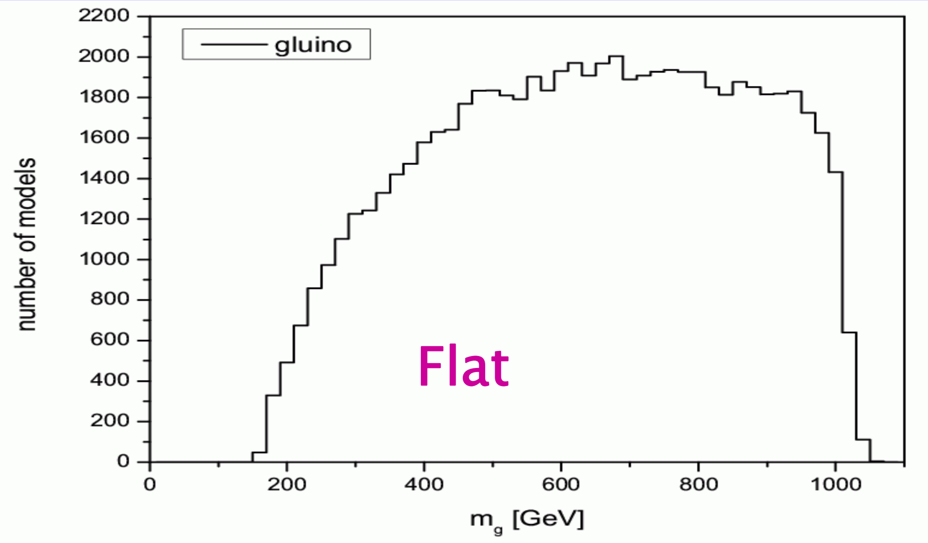
- Collider Searches: complicated with many caveats!
  - LEPII: Neutral & Charged Higgs searches
    Sparticle production
    Stable charged particles
  - Tevatron: Squark & gluino searches
    Trilepton search
    Stable charged particles
    BSM Higgs searches

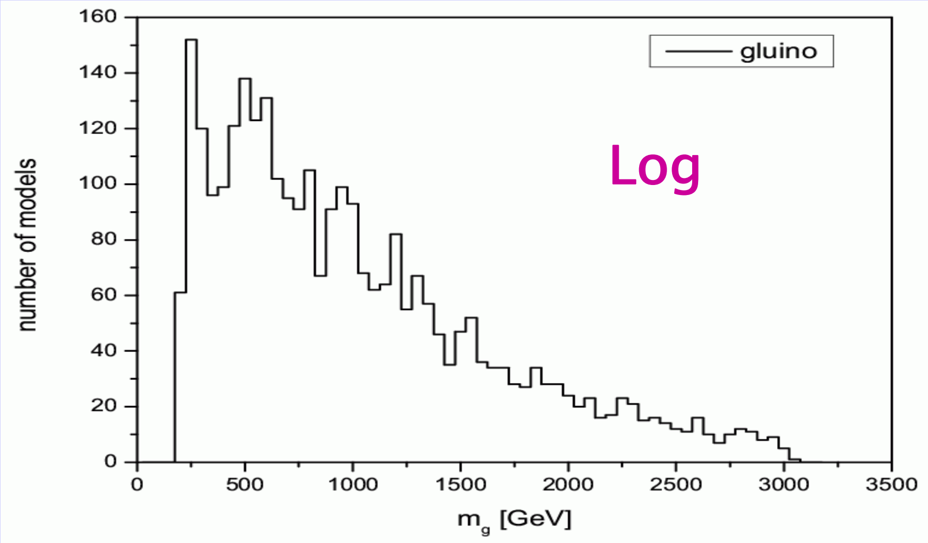
Survival Rates: 1 CPU Century Later

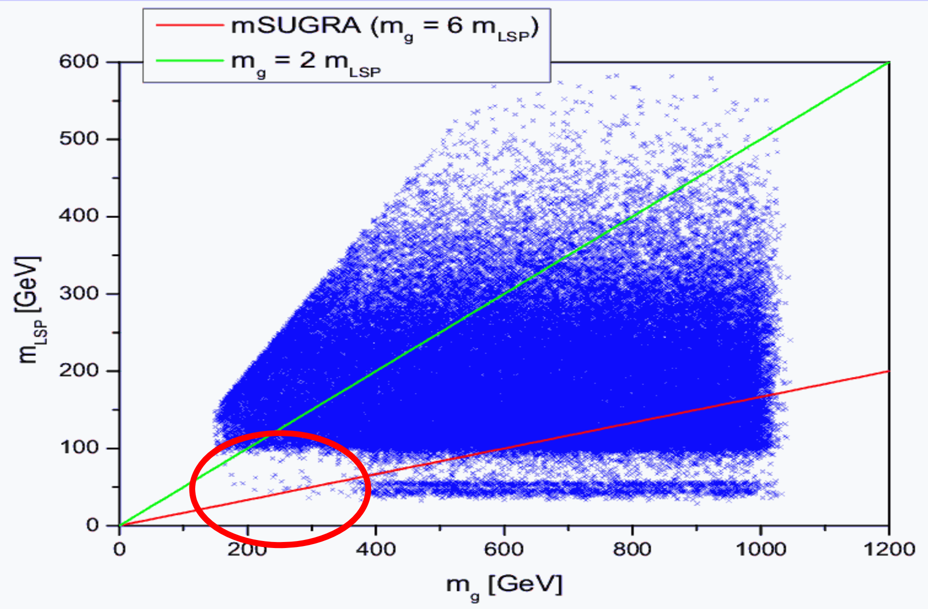
file	Description	Percent of Models Remaining
slha-okay.txt	SuSpect generates SLHA file	99.99 %
error-okay.txt	Spectrum tachyon, other error free	77.29%
lsp-okay.txt	LSP the lightest neutralino	32.70 %
deltaRho-okay.txt	$\Delta\rho$	32.61 %
gMinus2-okay.txt	$g - 2$	21.69 %
b2sGamma-okay.txt	$b \longrightarrow s\gamma$	6.17 %
Bs2MuMu-okay.txt	$B \longrightarrow \mu\mu$	5.95 %
vacuum-okay.txt	No CCB, potential not UFB	5.92 %
Bu2TauNu-okay.txt	$B \longrightarrow \tau\nu$	5.83 %
LEP-sparticle-okay.txt	LEP sfermion checks	4.72 %
invisibleWidth-okay.txt	Invisible Width of Z	4.71 %
susyhitProb-okay.txt	Heavy Higgs not problematic for SUSY-HIT	4.69 %
stableParticle-okay.txt	Tevatron stable chargino search	4.19 %
chargedHiggs-okay.txt	LEP/ Tevatron charged Higgs search	4.19 %
neutralHiggs-okay.txt	LEP neutral Higgs search	1.73 %
directDetection-okay.txt	WIMP direct detection	1.55 %
omega-okay.txt	Ωh^2	0.74 %
Bs2MuMu-2-okay.txt	$B \longrightarrow \mu\mu$	0.74 %
stableChargino-2-okay.txt	Tevatron stable chargino search	0.72 %
triLepton-okay.txt	Tevatron trilepton	0.72 %
jetMissing-okay.txt	Tevatron jet plus missing	0.70 %
final-okay.txt	Final after cutting models with e.g. light stop, sbottoms	0.68 %

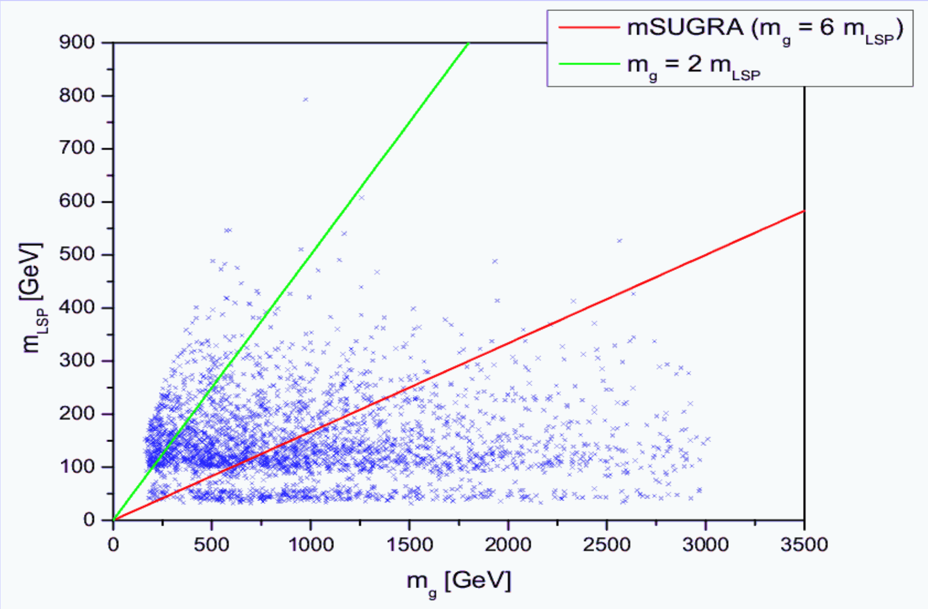
- Flat Priors : 10^7 models scanned , ~ 68.4 K (0.68%) survive
- Log Priors : $2\text{x}10^6$ models scanned , ~ 2.8 K (0.14%) survive

Gluino (and Squarks) Can Be Light !!

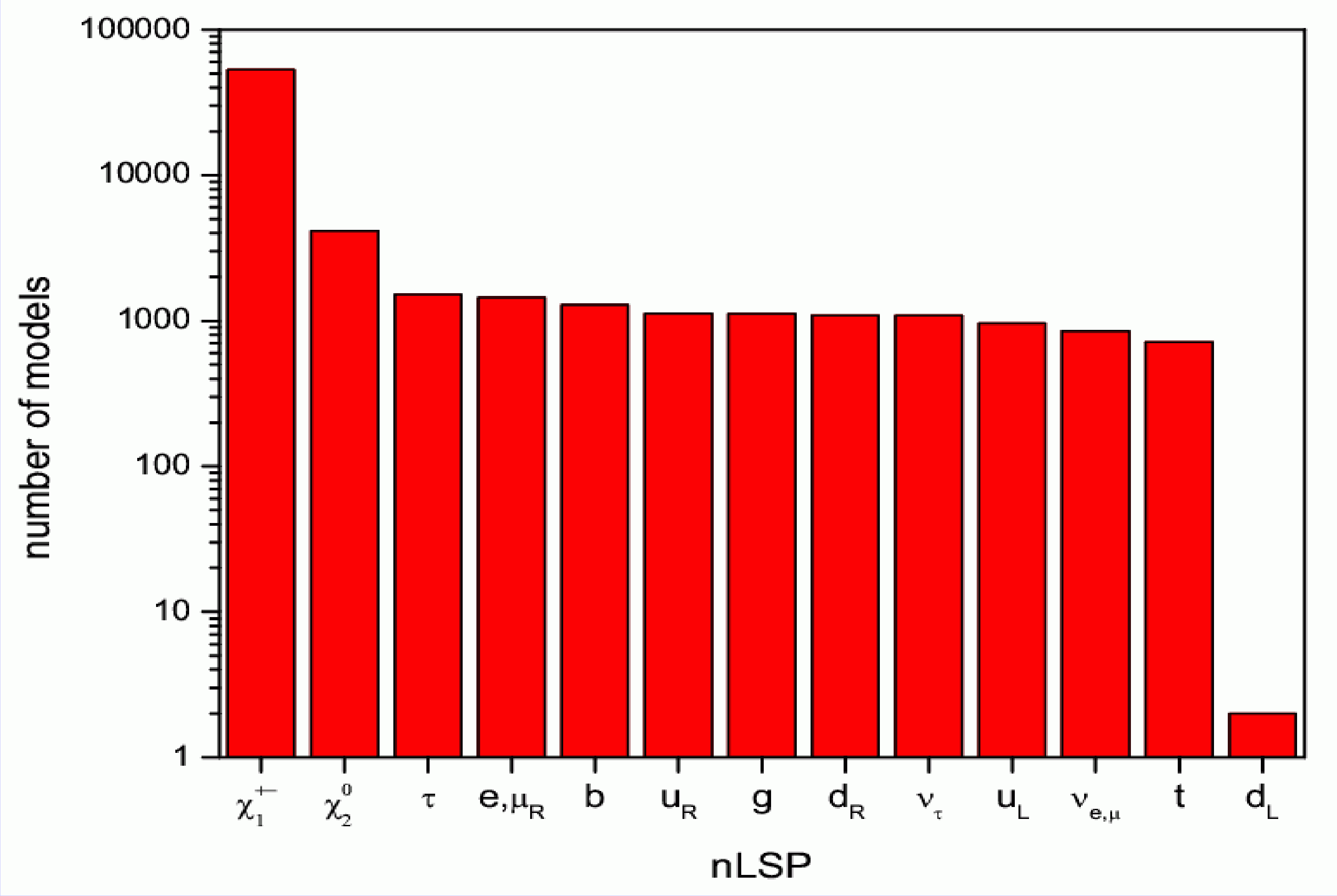




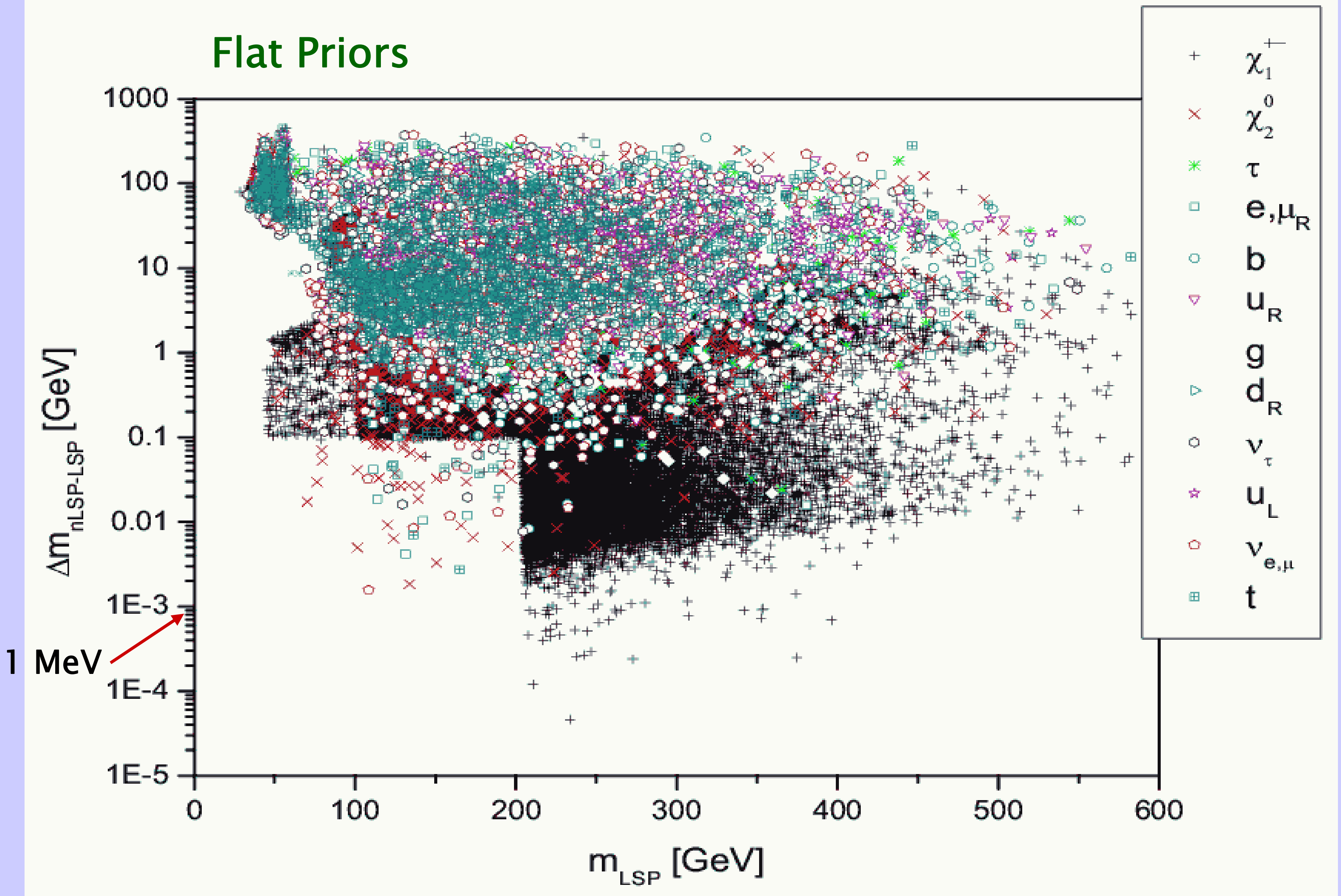




Character of the NLSP: it can be anything!



NLSP-LSP Mass Splitting



ATLAS SUSY Analyses with a Large Model Set

- We have passed these ~70k MSSM models through the ATLAS SUSY analysis suite, designed for mSUGRA , to explore its sensitivity to this far broader class of SUSY models

- We employed ATLAS SM backgrounds (Thanks!!!), their associated systematic errors & statistical criterion for SUSY 'discovery', etc. (No data on background distributions are used in the analyses due to potentially large 'NLO' shape uncertainties)

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

- By necessity there are some differences between the two analyses….

- This is extremely CPU intensive!

ATLAS has already made use of some of these models!

ATLAS NOTE

ATL-PUB-2009-XXX

July 20, 2009

Prospects for Supersymmetry and Univeral Extra Dimensions discovery based on inclusive searches at a 10 TeV centre-of-mass energy with the ATLAS detector

The ATLAS collaboration

ATL-PHYS-PUB-2009-081
22 July 2009

Abstract

This note presents an evaluation of the discovery potential of Supersymmetry and Universal Extra Dimensions for channels with jets, leptons and missing transverse energy. The LHC running scenario at a centre-of-mass energy of 10 TeV, delivering an integrated luminosity of 200 pb^{-1} for the 2009-2010 run is investigated.

The ATLAS SUSY analyses:

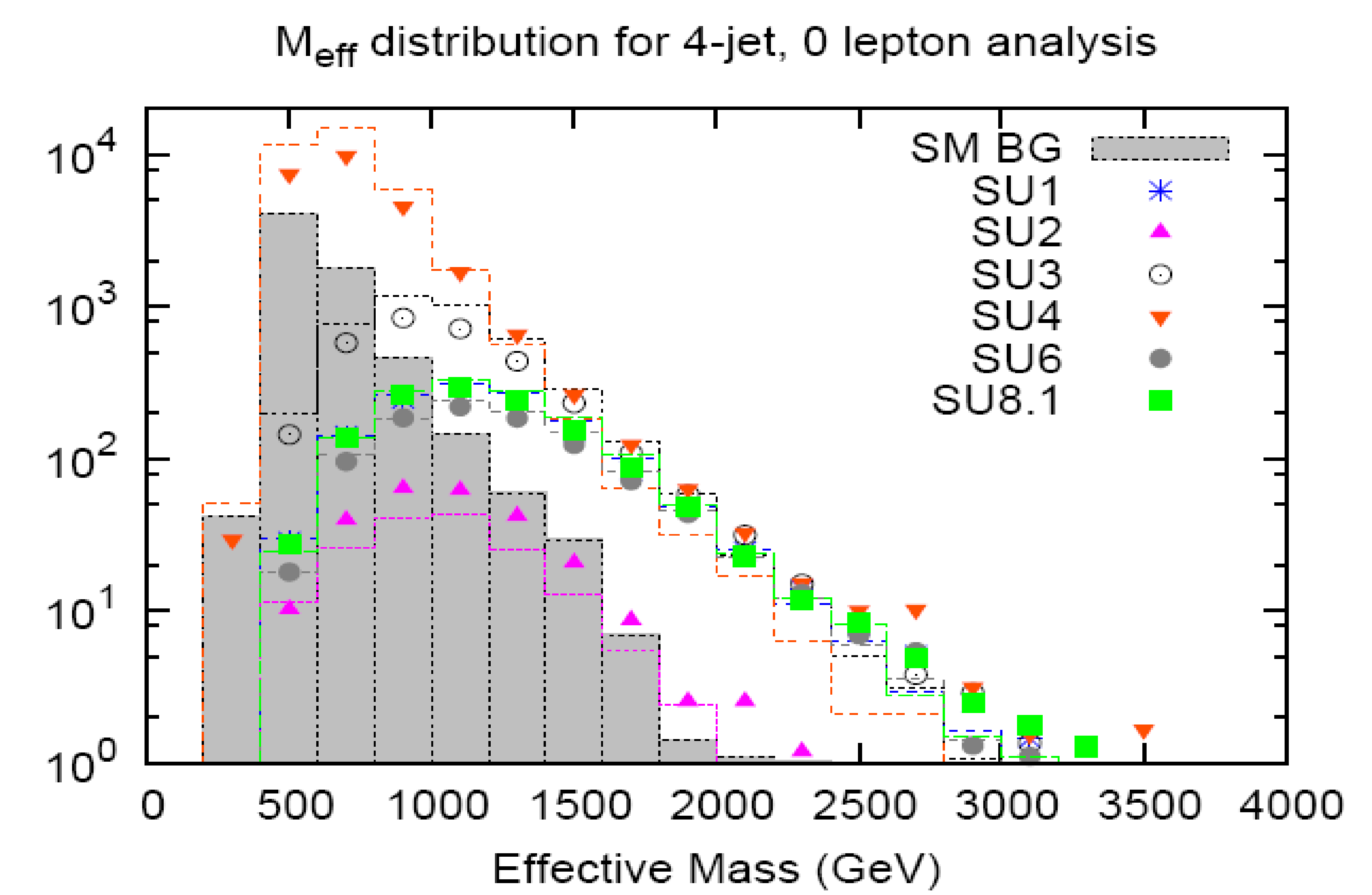
- 2,3,4-jet +MET
- 1l, ≥4-jet +MET
- SSDL
- OSDL
- Trileptons + (0,1)-j +MET
- τ +≥ 4j +MET
- ≥4j w/ ≥ 2btags + MET
- Stable particle search

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 processes using PROSPINO** & CTEQ6.6M
Herwig for fragmentation & hadronization	PYTHIA for fragmentation & hadronization
GEANT4 for full detector sim	PGS4-ATLAS for fast detector sim

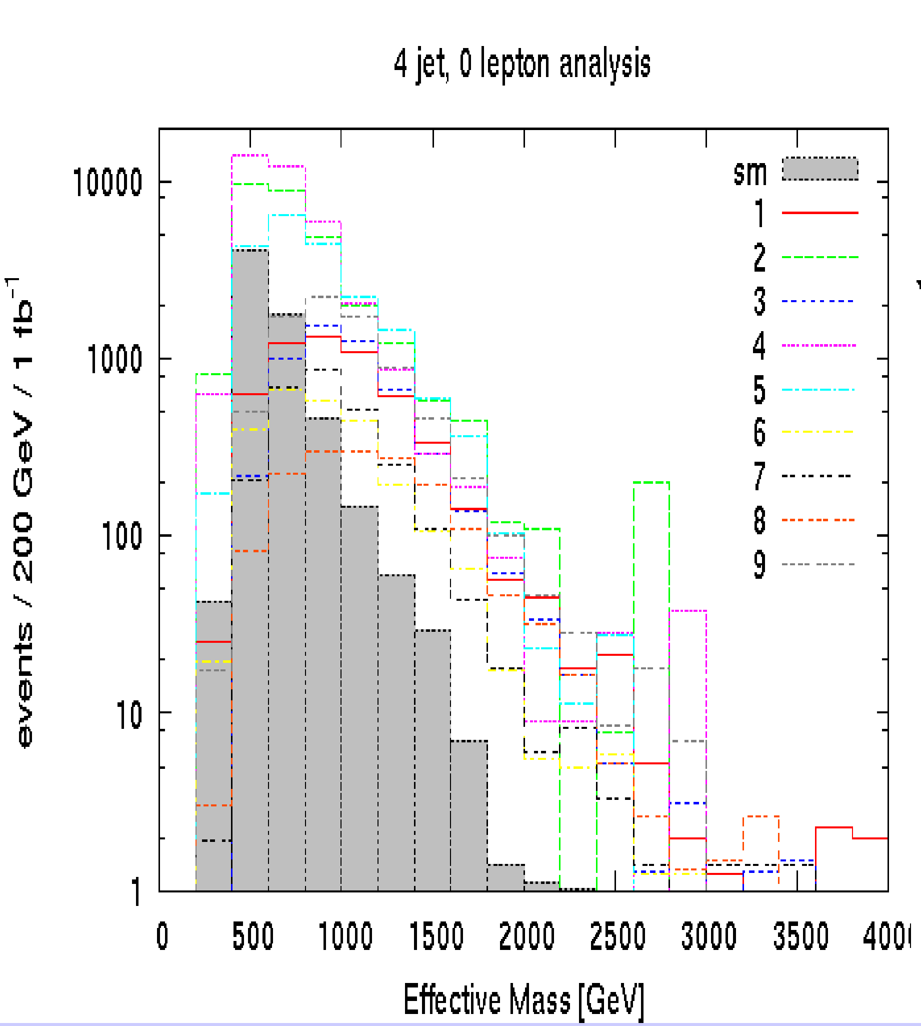
** version w/ negative K-factor errors corrected

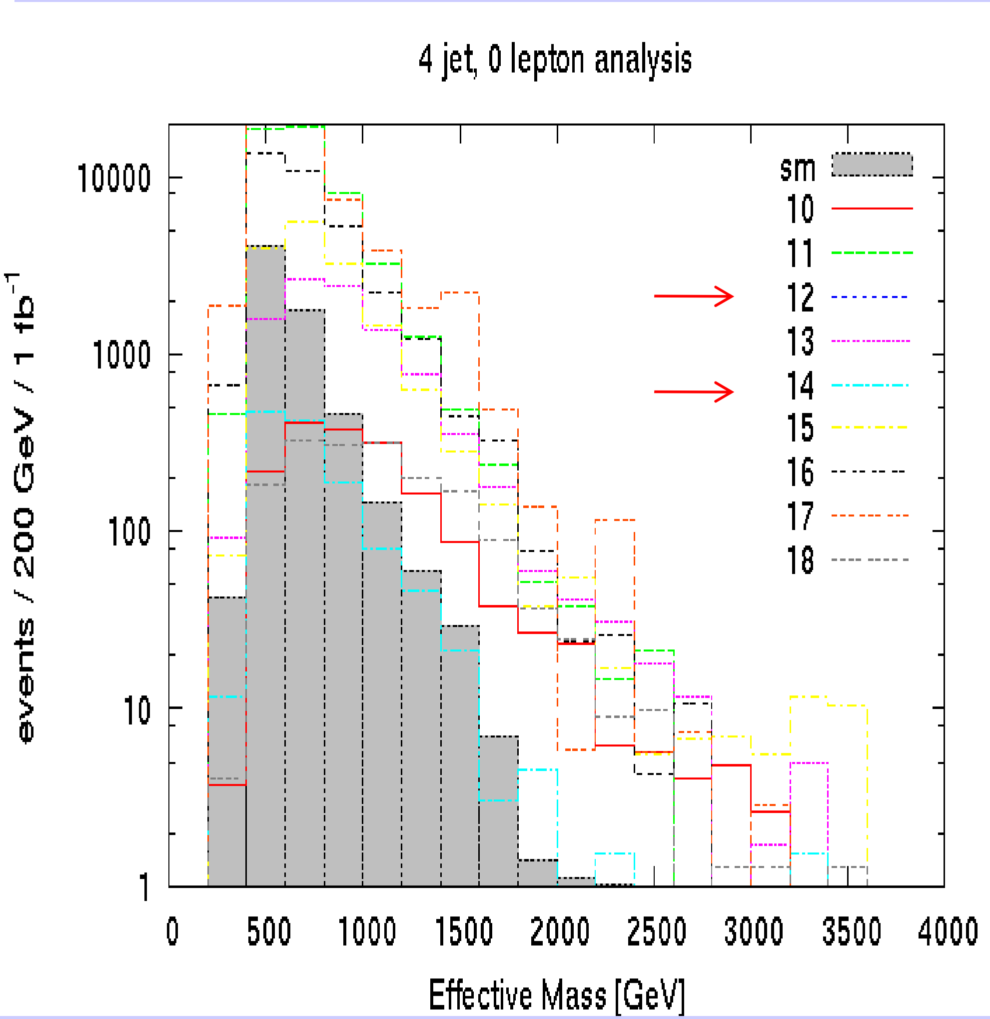
version w/o negative QCD corrections & with 1st & 2nd generation fermion masses included as well as explicit small Δm chargino decays

ATLAS Benchmark Tests: 4jets + MET



Sample Model Results





Number of Models Observed in each Analysis with 1 fb^{-1} @ 5σ

Analysis	# with Zn>5, no pystop	# with Zn>5, incl. pystops
4j0l	59537 (88.962 %)	59978 (87.708 %)
2j0l	58719 (87.74 %)	59208 (86.582 %)
1l4j	28560 (42.675 %)	28624 (41.858 %)
1l3j	45228 (67.581 %)	45405 (66.397 %)
1l2j	47011 (70.245 %)	47226 (69.06 %)
OSDL	7360 (10.998 %)	7364 (10.769 %)
SSDL	14280 (21.338 %)	14289 (20.895 %)
3lj	9139 (13.656 %)	9149 (13.379 %)
3lm	1843 (2.7539 %)	1847 (2.7009 %)
tau	57088 (85.303 %)	57483 (84.059 %) *
b	49760 (74.353 %)	50113 (73.282 %)

* τ ID & reconstruction in PGS has large fake rate

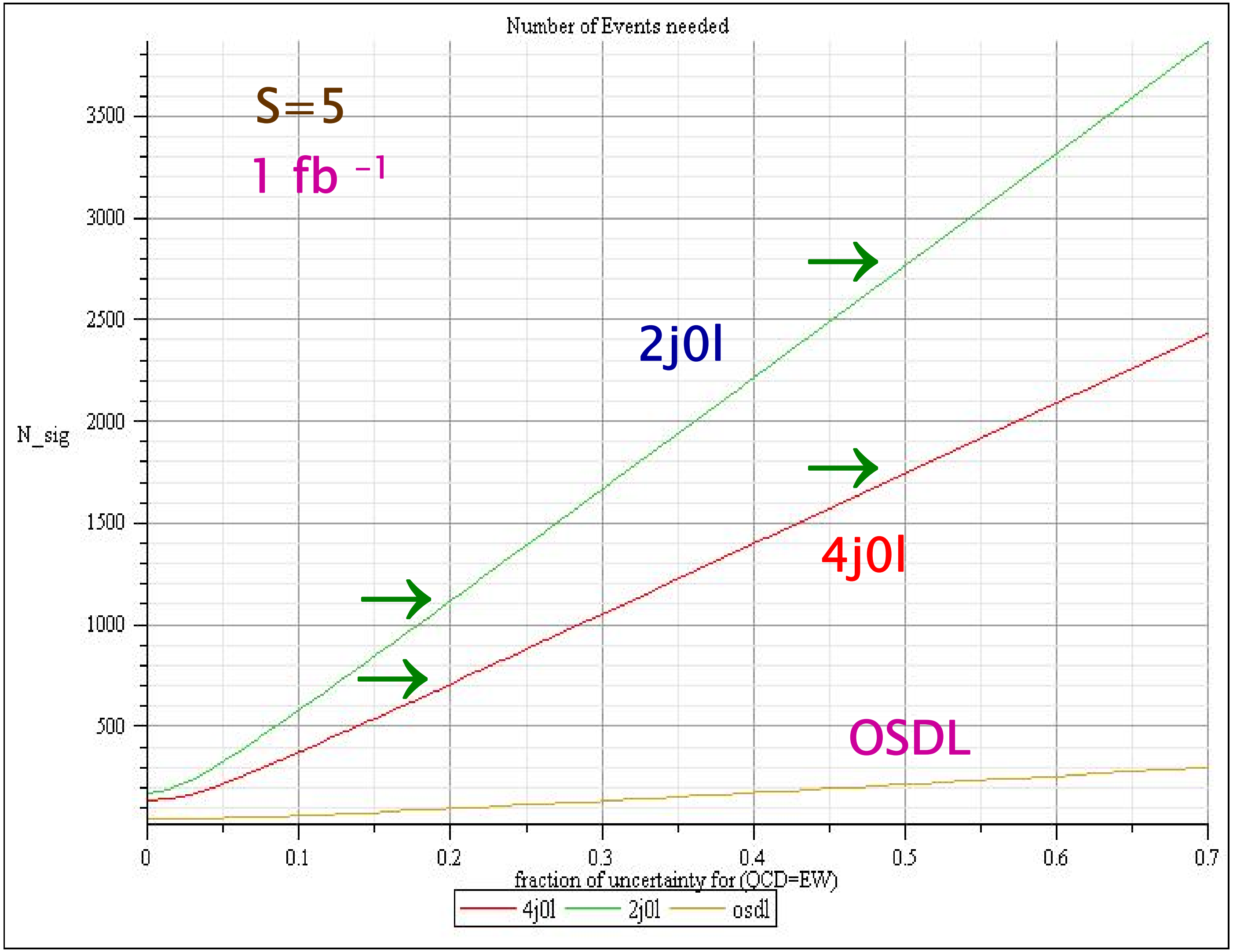
Number of Models Observed in each Analysis with 10 fb^{-1} @ 5σ

Analysis	# with Zn>5, no pystop	# with Zn>5, incl. pystops
4j0l	59682 (89.179 %)	60125 (87.923 %)
2j0l	58806 (87.87 %)	59296 (86.71 %)
1l4j	30565 (45.671 %)	30638 (44.803 %)
1l3j	49636 (74.168 %)	49878 (72.938 %)
1l2j	49854 (74.493 %)	50108 (73.274 %)
OSDL	7957 (11.89 %)	7961 (11.642 %)
SSDL	21487 (32.107 %)	21531 (31.485 %)
3lj	11702 (17.486 %)	11714 (17.13 %)
3lm	1953 (2.9182 %)	1958 (2.8632 %)
tau	58931 (88.057 %)	59348 (86.786 %)
b	51782 (77.374 %)	52147 (76.256 %)

Improvement in some analyses but not others

Background systematics are particularly important for both the 4j0l & 2j0l channels .. but not so much for the others:

Required number of signal events for observation



Reducing Systematics: 50% → 20%

L(fb^{-1})	1	10	1	10
Analysis	50	50h	20	20h
4j0l	88.962	89.179	99.009	99.093
2j0l	87.74	87.87	98.676	98.754
1l4j	42.675	45.671	57.968	64.074
1l3j	67.58	74.168	72.967	84.116
1l2j	70.244	74.493	79.399	86.972
OSDL	10.997	11.89	23.272	27.446
SSDL	21.337	32.107	25.161	39.138
3lj	13.656	17.486	19.386	28.857
3lm	2.7538	2.9182	4.916	5.8947
tau	85.303	88.057	97.139	98.657
b	74.352	77.374	91.915	94.97

This would be a very significant improvement in reach!

The number of models observed in n different analyses with 1 fb^{-1}

# passed	# models no pystop	# models incl. pystops	# models nopy no tau
0	240 (0.35862%)	1135 (1.6597 %)	389 (0.58126%)
1	751 (1.1222 %)	812 (1.1874 %)	957 (1.43 %)
2	2110 (3.1528 %)	2168 (3.1703 %)	8561 (12.792 %)
3	8232 (12.301 %)	8334 (12.187 %)	12055 (18.013 %)
4	12416 (18.552 %)	12608 (18.437 %)	6953 (10.389 %)
5	6962 (10.403 %)	7019 (10.264 %)	12697 (18.972 %)
6	11970 (17.886 %)	12022 (17.58 %)	12290 (18.364 %)
7	11890 (17.766 %)	11925 (17.438 %)	6358 (9.5003 %)
8	6033 (9.0147 %)	6038 (8.8296 %)	3138 (4.6889 %)
9	2898 (4.3303 %)	2900 (4.2408 %)	2714 (4.0553 %)
10	2654 (3.9657 %)	2655 (3.8825 %)	812 (1.2133 %)
11	768 (1.1476 %)	768 (1.1231 %)	0 (0 %)

The number of models observed in n different analyses with 10 fb^{-1}

# passed	# models no pystop	# models incl. pystops	# models nopy no tau
0	177 (0.26448%)	1050 (1.5354 %)	286 (0.42735%)
1	565 (0.84424%)	625 (0.91396%)	756 (1.1296 %)
2	1521 (2.2727 %)	1581 (2.3119 %)	6795 (10.153 %)
3	6697 (10.007 %)	6803 (9.9482 %)	10199 (15.24 %)
4	10348 (15.462 %)	10515 (15.376 %)	6688 (9.9934 %)
5	6929 (10.354 %)	6996 (10.23 %)	13714 (20.492 %)
6	13165 (19.672 %)	13235 (19.354 %)	10347 (15.461 %)
7	10140 (15.152 %)	10176 (14.881 %)	9477 (14.161 %)
8	9088 (13.58 %)	9104 (13.313 %)	4146 (6.1951 %)
9	3885 (5.8051 %)	3888 (5.6855 %)	3590 (5.3643 %)
10	3518 (5.2567 %)	3519 (5.1459 %)	926 (1.3837 %)
11	891 (1.3314 %)	892 (1.3044 %)	0 (0 %)

Why are models not observed?

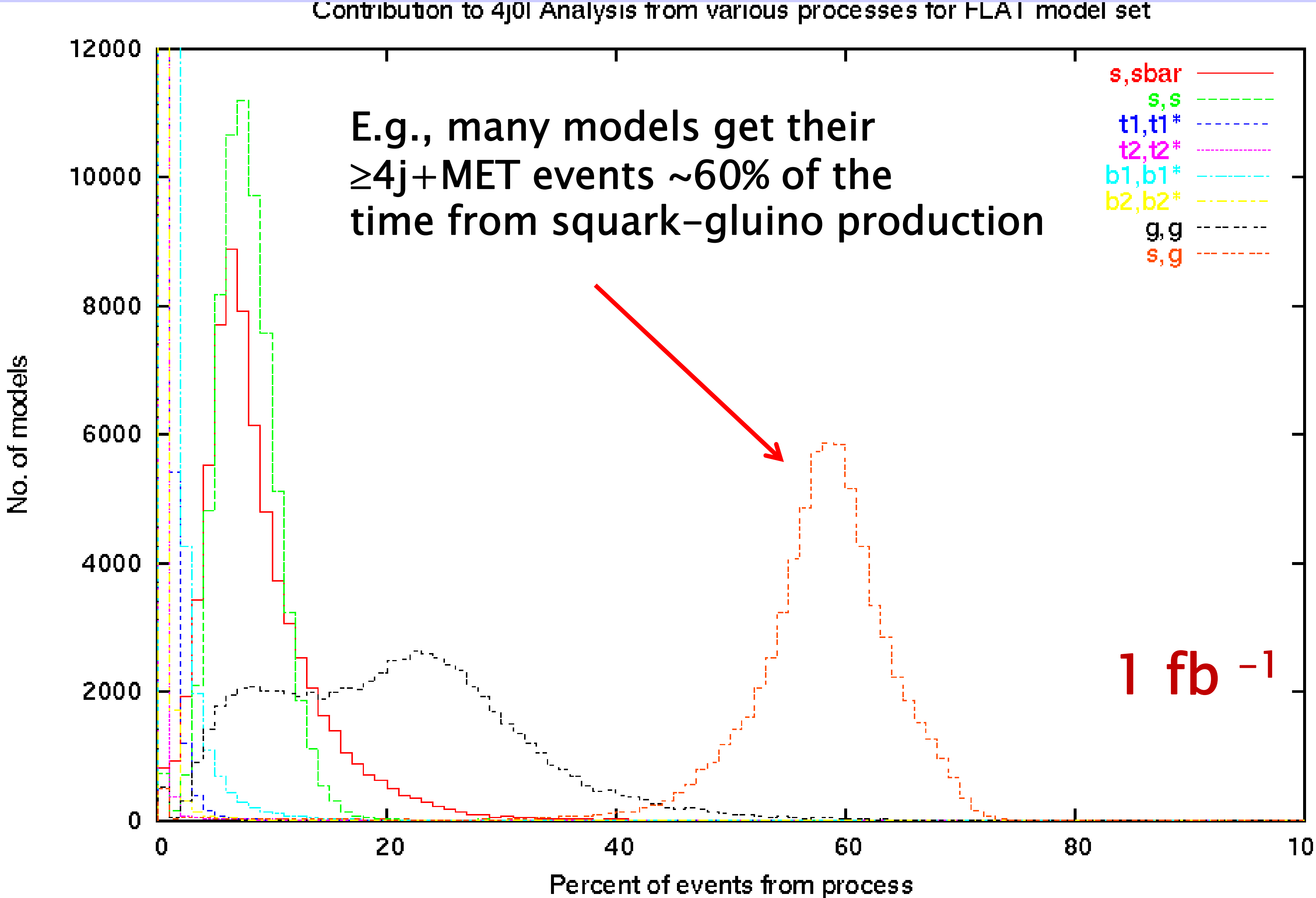
1. Sometimes cross section is too small

2. Sometimes background uncertainties are too large

3. Something else....

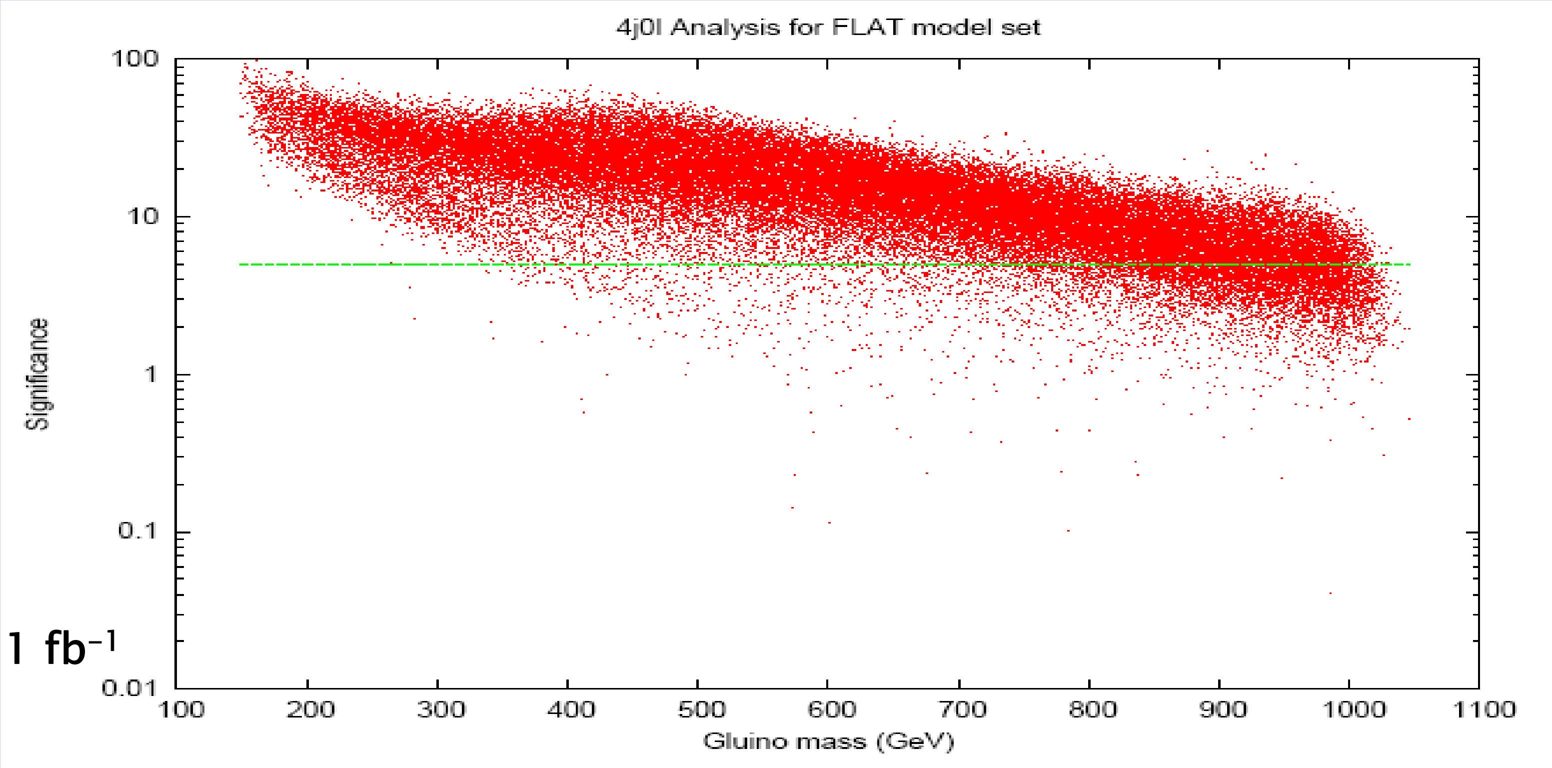
Examine 4j0l analyses

What processes produce the ≥4j+MET events ???

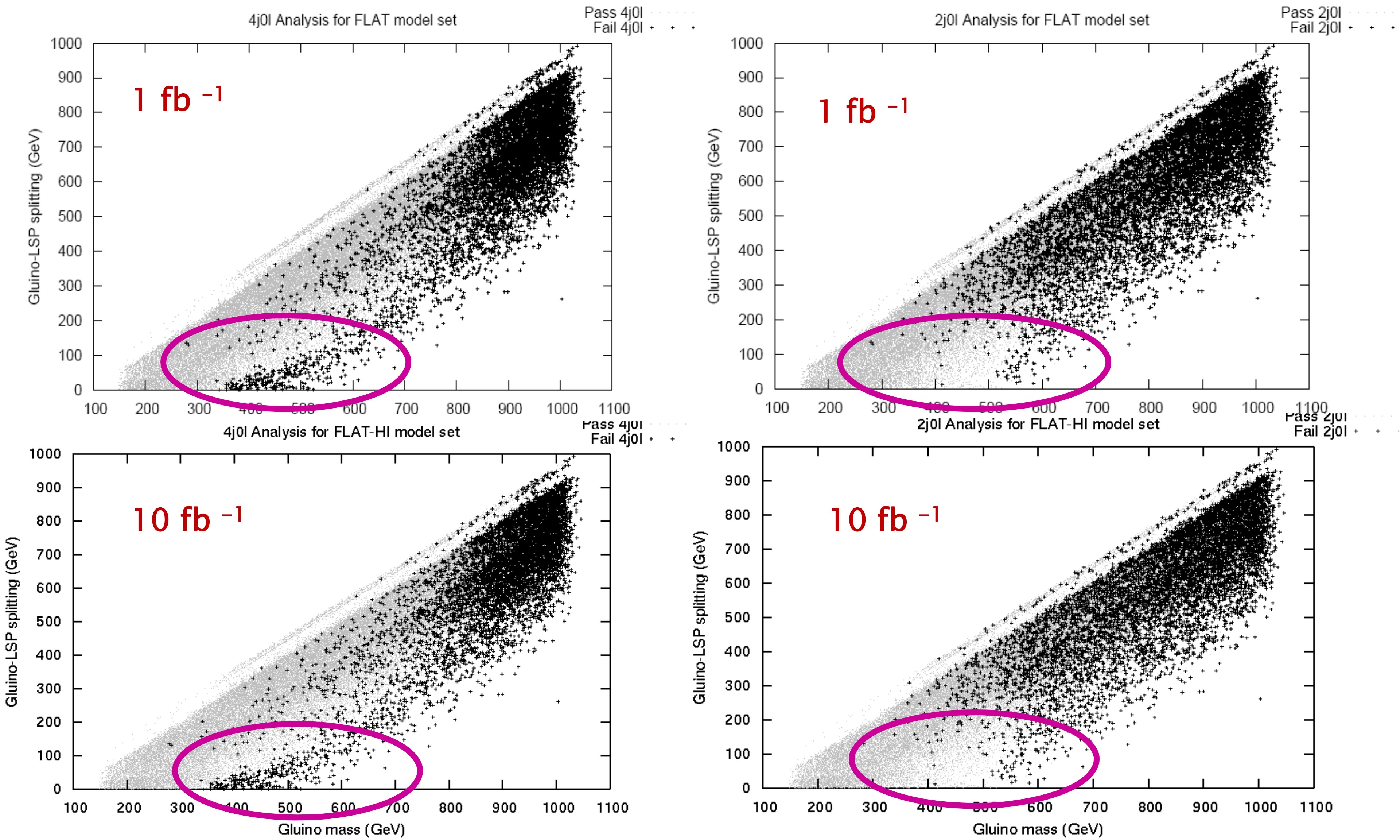


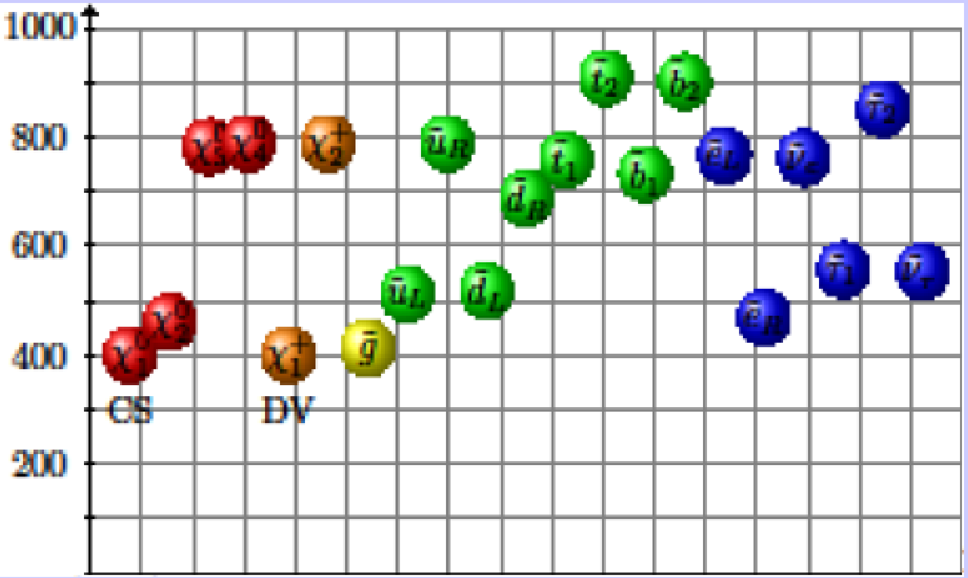
Undetected Models: Is it 'just the mass' ??

Significances for the 4j0l search…there IS a GENERAL reduction in S as the gluino mass increases. BUT we also see that there is quite a spread in significance at any fixed value of the mass.



Mass splittings leading to soft jets can be quite important.. but that's not all of it either :





Example: Model 15596

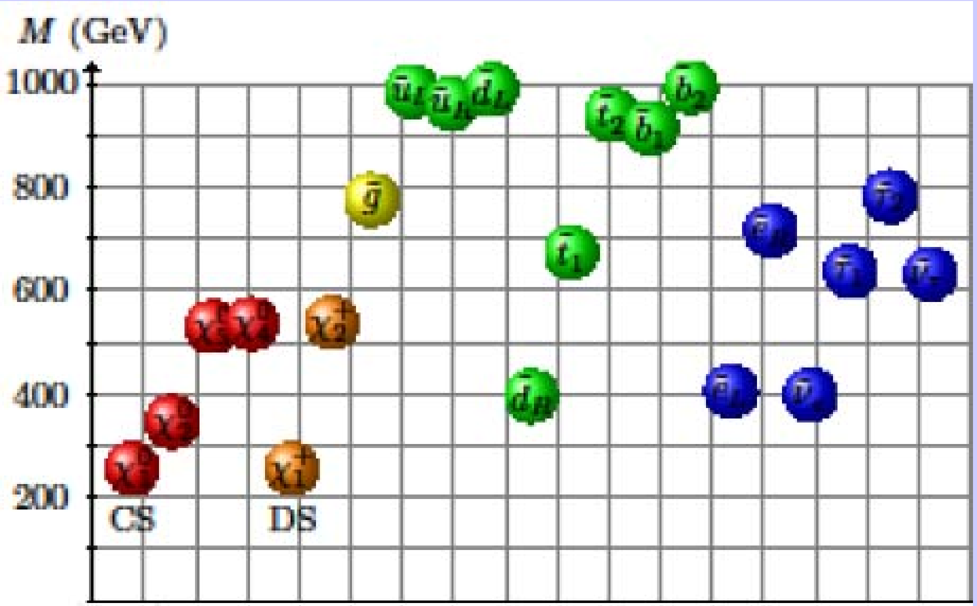
ss: 1823
gg: 13846
sg: 13006

HUGE number of events b/f cuts

→ ss→gg+2j, sg→gg+j

Signals: all squarks decay almost exclusively (~90%) to gluinos, with (~3%) to j + LSP & (~6%) to j + chargino. The squark-gluino mass splittings are in excess of 100 GeV. These generate a smallish 2j0l signal after cuts. Z_n ~4.4 in 2j0l

• The gluinos are nearly degenerate with the LSP , e.g., $\Delta m=12.6$ GeV, so their decays to jj+LSP or ‘detector stable’ charginos are too soft to populate 4j0l . Note that there are no significant sources of leptons, b’s or τ’s here. Stable particle searches are important in this case .



Example: Model 32864

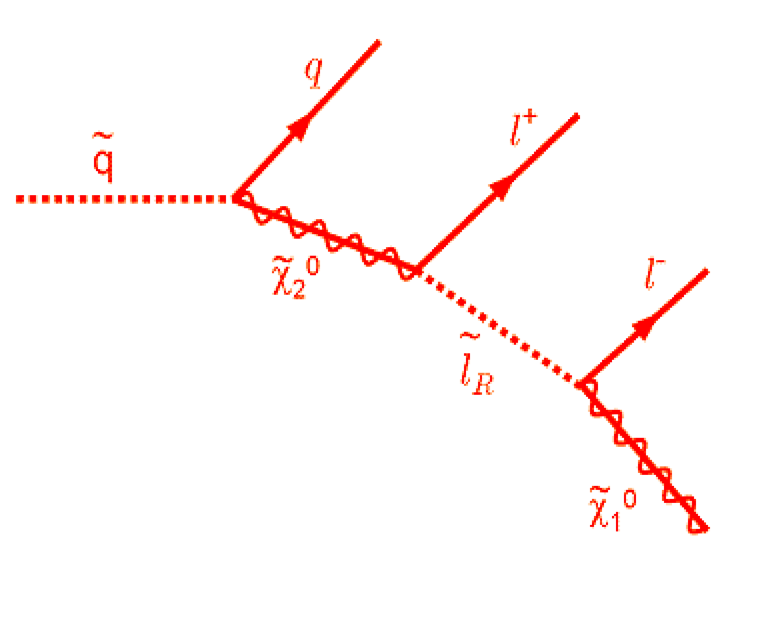
ss: 8029
gg: 2085
sg: 9811

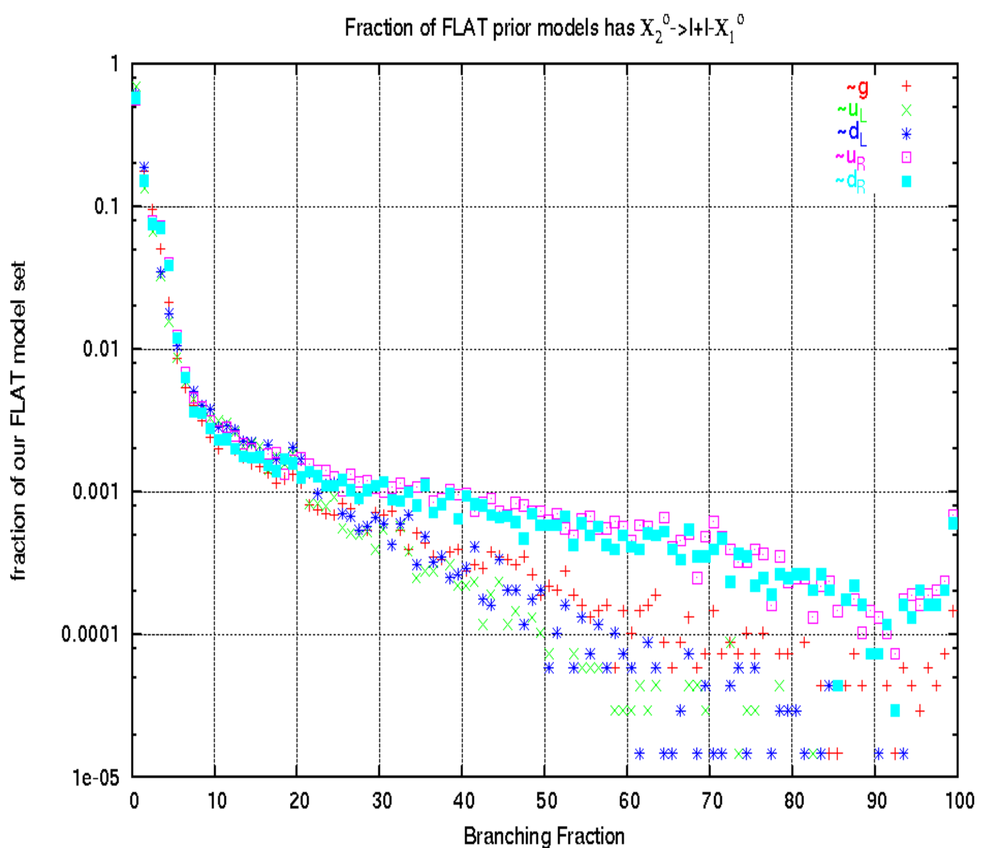
number of events b/f cuts

→ u_R ,$(u,d)_L$ >> g >>> d_R

- $q_L \to j + \chi_1^0$ (17%), $\chi_1^\pm$ (35%), gluino (46%)
- $u_R \to j + \chi_2^0$ (18%) , gluino (81%); gluino $\to j + d_R$
- $d_R \to j + \chi_2^0$; $\chi_2^0 \to \chi_1^\pm + W$ the chargino is stable
- Most of the decays end up as stable charginos so there is very little MET although there are many jets. No leptons or τ's & few b's

How often do these 'famous' decay chains actually occur in our model set??





It appears that this is not GENERALLY a common Mode in our sample

Summary

- The pMSSM has a far richer phenomenology than conventional SUSY breaking scenarios as the sparticle properties can be vastly different

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

- Substantial SM background systematics, compressed mass spectra & processes with low signal rates due to unusual decays lead to models being missed by the inclusive analyses.

- Long-lived particle searches are important.

-

BACKUP SLIDES

Cut Effectiveness: I (after M_{eff} cut)

fla
t

1 fb $^{-1}$

Analysis	# with Zn>5, no pystop	# with Zn>5, incl. pystops
4j0l_1: 4 hard jets	66745 (99.733 %)	67289 (98.399 %)
4j0l_2: $E^T_{\mathrm{miss}} > 0.2M_{\mathrm{eff}}$	66036 (98.673 %)	66556 (97.327 %)
4j0l_3: trans. sph.	63615 (95.056 %)	64071 (93.693 %)
4j0l_4: jets not near E^T_{\mathrm{miss}}	62857 (93.923 %)	63306 (92.574 %)
4j0l_5: no lepton	59537 (88.962 %)	59978 (87.708 %)
2j0l_1: 2 hard jets	66610 (99.531 %)	67173 (98.229 %)
2j0l_2: $E^T_{\mathrm{miss}} > 0.3M_{\mathrm{eff}}$	63573 (94.993 %)	64089 (93.719 %)
2j0l_3: jets not near E^T_{\mathrm{miss}}	63062 (94.229 %)	63568 (92.957 %)
2j0l_4: no lepton	58719 (87.74 %)	59208 (86.582 %)
1l4j_1: one isolated lepton	57665 (86.165 %)	58037 (84.869 %)
1l4j_2: no additional leptons	57374 (85.73 %)	57739 (84.433 %)
1l4j_3: four hard jets	47585 (71.103 %)	47777 (69.866 %)
1l4j_4: $E^T_{\mathrm{miss}} > 0.2M_{\mathrm{eff}}$ and $E^T_{\mathrm{miss}} > 100$	41798 (62.456 %)	41930 (61.316 %)
1l4j_5: trans. sph.	36400 (54.39 %)	36489 (53.359 %)
1l4j_6: $M_T > 100$	28560 (42.675 %)	28624 (41.858 %)
1l3j_1: one isolated lepton	66813 (99.834 %)	67917 (99.317 %)
1l3j_2: no additional leptons	66804 (99.821 %)	67902 (99.295 %)
1l3j_3: three hard jets	60755 (90.782 %)	61204 (89.5 %)
1l3j_4: $E^T_{\mathrm{miss}} > 0.25M_{\mathrm{eff}}$ and $E^T_{\mathrm{miss}} > 100$	54449 (81.359 %)	54763 (80.082 %)
1l3j_5: trans. sph.	51457 (76.889 %)	51714 (75.623 %)
1l3j_6: $M_T > 100$	45228 (67.581 %)	45405 (66.397 %)

Cut Effectiveness: II

1l2j_1: one isolated lepton	66271 (99.024 %)	67208 (98.28 %)
1l2j_2: no additional leptons	66233 (98.967 %)	67155 (98.203 %)
1l2j_3: two hard jets	62773 (93.797 %)	63329 (92.608 %)
1l2j_4: $E^T_{\rm miss} > 0.3 M_{\rm eff}$ and $E^T_{\rm miss} > 100$	57237 (85.525 %)	57616 (84.254 %)
1l2j_5: trans. sph.	53403 (79.796 %)	53696 (78.521 %)
1l2j_6: $M_T > 100$	47011 (70.245 %)	47226 (69.06 %)
OSDL_1: OSDL	33406 (49.916 %)	33513 (49.007 %)
OSDL_2: four hard jets	11993 (17.92 %)	12003 (17.552 %)
OSDL_3: $E^T_{\rm miss} > 0.2 M_{\rm eff}$ and $E^T_{\rm miss} > 100$	9916 (14.817 %)	9922 (14.509 %)
OSDL_4: trans. sph.	7360 (10.998 %)	7364 (10.769 %)
SSDL_1: SSDL	26800 (40.045 %)	26876 (39.302 %)
SSDL_2: four hard jets	14281 (21.339 %)	14290 (20.897 %)
SSDL_3: $E^T_{\rm miss} > 100$	14280 (21.338 %)	14289 (20.895 %)
SSDL_4: $E^T_{\rm miss} > 0.2 M_{\rm eff}$	14280 (21.338 %)	14289 (20.895 %)
3lj_1: at least three leptons	16310 (24.371 %)	16345 (23.902 %)
3lj_2: at least one hard (200 GeV) jet	9139 (13.656 %)	9149 (13.379 %)
3lm_1: at least three leptons	5128 (7.6624 %)	5140 (7.5164 %)
3lm_2: at least one OSSF pair with $M > 20$ GeV	4460 (6.6643 %)	4471 (6.5381 %)
3lm_3: lepton track isolation	4460 (6.6643 %)	4471 (6.5381 %)
3lm_4: $E^T_{\rm miss} > 30$	4306 (6.4342 %)	4315 (6.31 %)
3lm_5: $M < M_Z$ for any OSSF pair	1843 (2.7539 %)	1847 (2.7009 %)

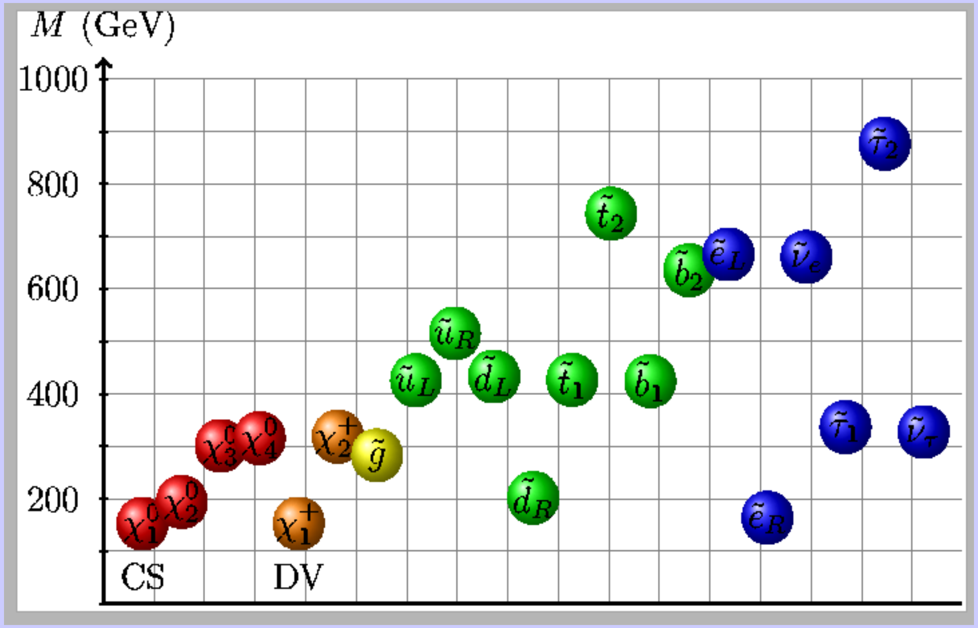
Cut Effectiveness: III

tau_1: four hard jets	66900 (99.964 %)	67568 (98.807 %)
tau_2: $E^T_{\mathrm{miss}} > 100$	66895 (99.957 %)	67524 (98.742 %)
tau_3: jets not near E^T_{\mathrm{miss}}	66883 (99.939 %)	67498 (98.704 %)
tau_4: no lepton	66780 (99.785 %)	67379 (98.53 %)
tau_5: at least one tau	64358 (96.166 %)	64839 (94.816 %)
tau_6: $E^T_{\mathrm{miss}} > 0.2 M_{\mathrm{eff}}$	61618 (92.072 %)	62061 (90.754 %)
tau_7: $M_T > 100$ (of hardest tau and E^T_{miss})	57088 (85.303 %)	57483 (84.059 %)
b_1: 4 hard jets with $p_T > 50$ GeV	66923 (99.999 %)	67893 (99.282 %)
b_2: leading jet with $p_T > 100$ GeV	66923 (99.999 %)	67892 (99.281 %)
b_3: $E^T_{\mathrm{miss}} > 100$ GeV	66923 (99.999 %)	67841 (99.206 %)
b_4: $E^T_{\mathrm{miss}} > 0.2 M_{\mathrm{eff}}$	66923 (99.999 %)	67775 (99.109 %)
b_5: trans sph.	66923 (99.999 %)	67669 (98.954 %)
b_6: at least 2 b-tags	49760 (74.353 %)	50113 (73.282 %)

Reducing Systematics: 50% → 20% (cont.)

Number of analyses	Flat	Flat high-$\mathcal{L}$	Log	Log high-$\mathcal{L}$
0	0.032873	0.025402	17.726	12.025
1	0.071722	0.046321	5.4596	4.9067
2	0.51999	0.20322	7.8093	7.0145
3	4.3302	2.2742	9.3642	7.9475
4	16.018	9.6976	16.966	14.824
5	7.7833	5.9306	7.8438	8.1894
6	14.044	17.512	8.7768	13.407
7	26.452	21.287	10.815	9.8825
8	10.361	14.058	5.5287	7.9475
9	6.9391	8.6217	3.4554	4.8376
10	9.9768	15.67	3.9046	5.8051
11	3.471	4.674	2.3497	3.2135

Sample Failure Analyses



Example: Model 53105

Heavier squarks essentially decay into gluinos + jets & then…

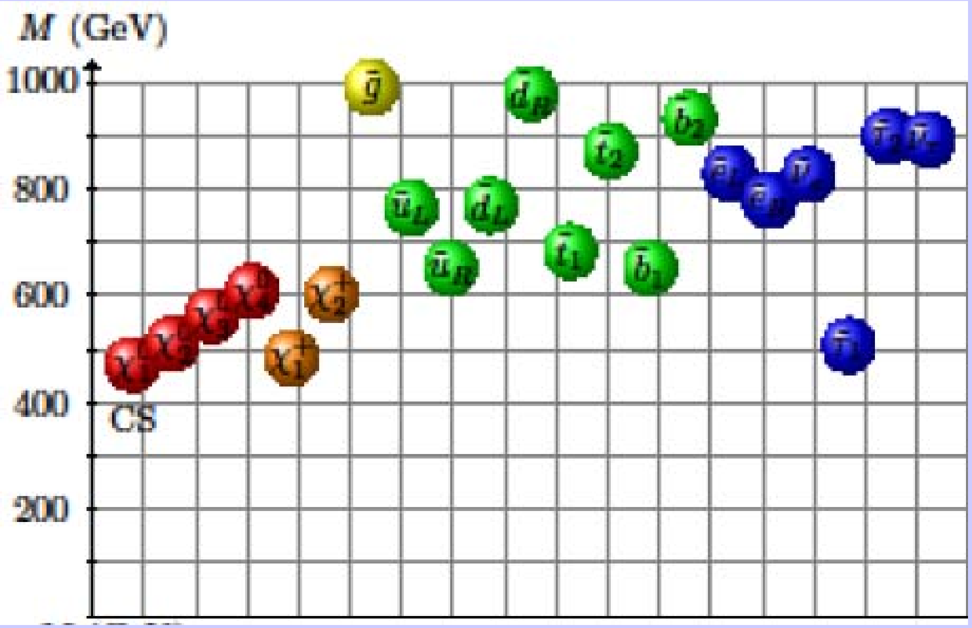
gluino(282.8) → $\tilde{d}_R$(201.7) j 100% Δm =81.1 GeV

$\tilde{d}_R$ (201.7) → $\tilde{\chi}_2^0$(193.8) j 97% Δm =7.9 GeV

$\tilde{\chi}_2^0$ (193.8) → $\tilde{l}_R^\pm$(163.9) l 100% Δm =30.0 GeV

$\tilde{l}_R^\pm$ (163.9) → $l^\pm$ +MET(152.5) 100% Δm =11.4 GeV

Model *fails* ATLAS (4,2)j0l cuts due to the presence of leptons!



Example: Model 949

ss: 2667
gg: 450.5
sg: 2611

number of events b/f cuts

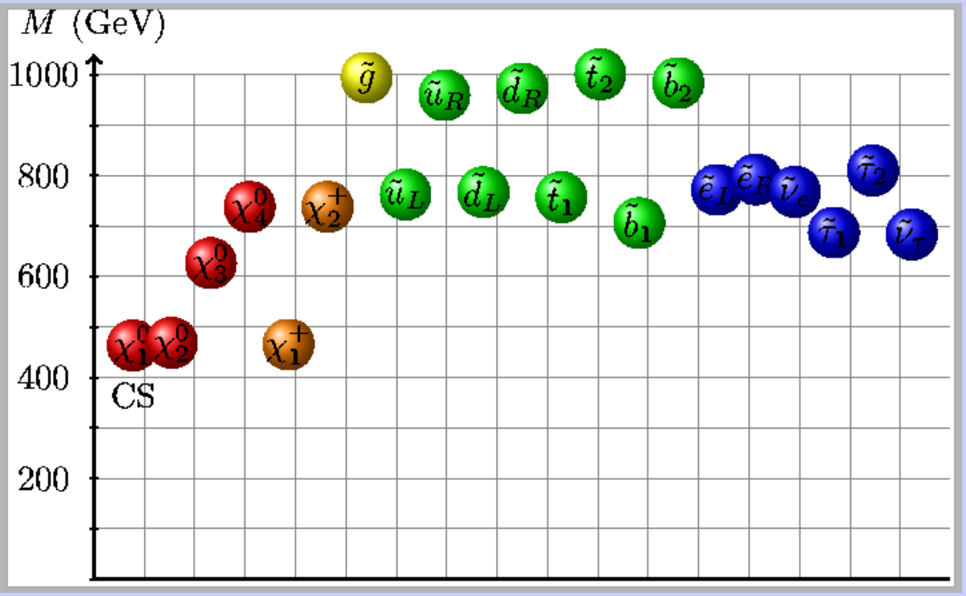
→ gg →ss+2j , gs→ss+j

Signals depend on what squarks do with the highly compressed gaugino spectrum. (Note $\chi^{\pm} \rightarrow$ LSP+W* w/ Δm=11.7 GeV)

•B(s→j + MET) ~0.11-0.37 → (4,2)j0l rates which are too small

•B(s→j + $\chi_{2,3}^{0}$) ~ 0.07-0.68 → ~soft τ's + MET as only staus are accessible → few (B~0.35) soft leptons from tau decays

•B(s→j + $\chi_1^{\pm}$) ~ 0-0.57 → soft jets/leptons + MET



However: Model 56838

is quite similar…BUT.. this model is FOUND

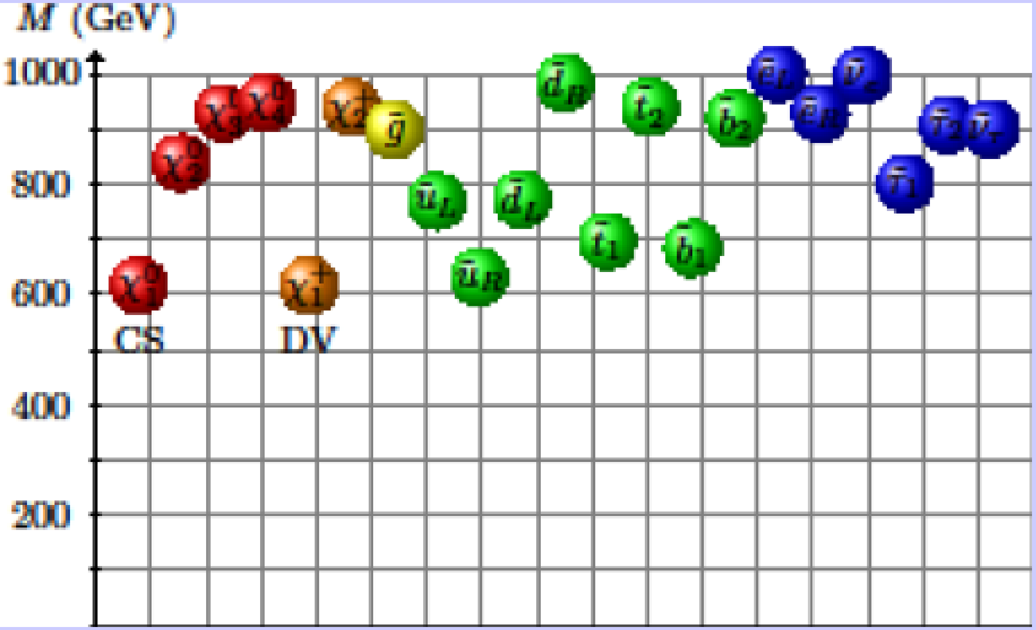
comparable production σ's

→ ! gg →ss+2j , gs→ss+j

There are more decays of gluinos to sbottoms here.
Signals again depend on what squarks do with the compressed gaugino spectrum. They have BFs to charginos & neutralinos comparable to Model 949.

- However, $\chi_{2,3}^{0}$ now will decay quite differently with reasonable BFs into final states with significant light leptons !

- 56838 is seen in both the (2,3)j1l analyses



Example: Model 7105

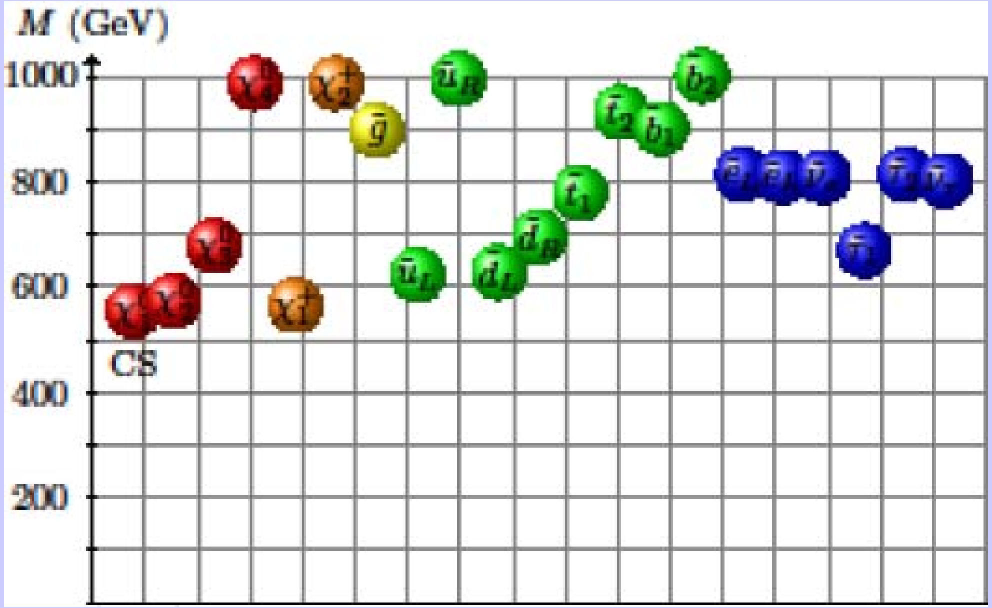
ss: 3391
gg: 777.8
sg: 5720

number of events b/f cuts

→ u_R ,(u,d)$_L$ < g < d_R

- d_R →j + χ_2^0 (2%), gluino (98%) ;
- gluino → j+ u_R (50%), (u,d)$_L$ (28%)
- u_L →j+ χ_1^0 (33%), $\chi_1^\pm$ (67%); d_L →j+ χ_1^0 (34%), $\chi_1^\pm$ (66%);
- u_R →j+ χ_1^0 ; $\chi_1^\pm$ is detector stable ($c\tau$ ~35m)

Long-lived searches in cascades are important !



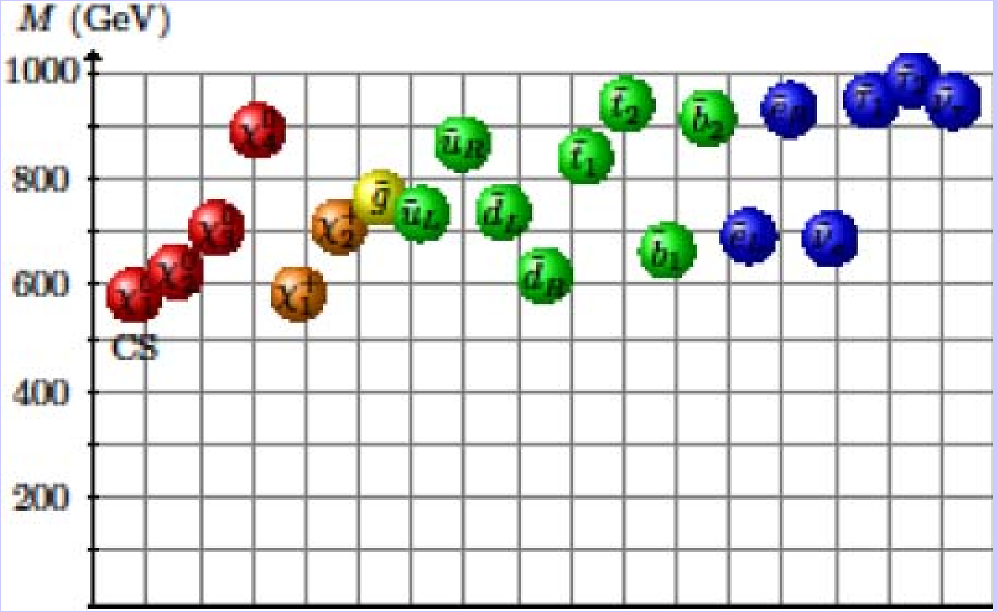
Example: Model 5700

ss: 3972
gg: 848.2
sg: 3840

number of events b/f cuts

→ d_R ,$(u,d)_L$ << g < u_R

- $u_R \rightarrow j + \chi_1^0$ (3%), χ_3^0 (22%), gluino (75%)
- gluino → j+ d_R (23%) , $(u,d)_L$ (76%)
- $u_L \rightarrow j + \chi_1^0$ (12%), $\chi_1^\pm$ (87%); $d_L \rightarrow j + \chi_1^0$ (66%), $\chi_1^\pm$ (32%);
- $d_R \rightarrow j + \chi_1^0$ (81%), χ_3^0 (18%); $\chi_3^0 \rightarrow h\, \chi_1^0$ (21%) , $W\, \chi_1^\pm$ (60%)
- $\chi_1^\pm \rightarrow W^* \chi_1^0$ ($\Delta m \sim 10.4$ GeV)



Example: Model 25692

ss: 4117
gg: 2168
sg: 9574

number of events b/f cuts

→ u_R > g > (u,d)$_L$, d_R

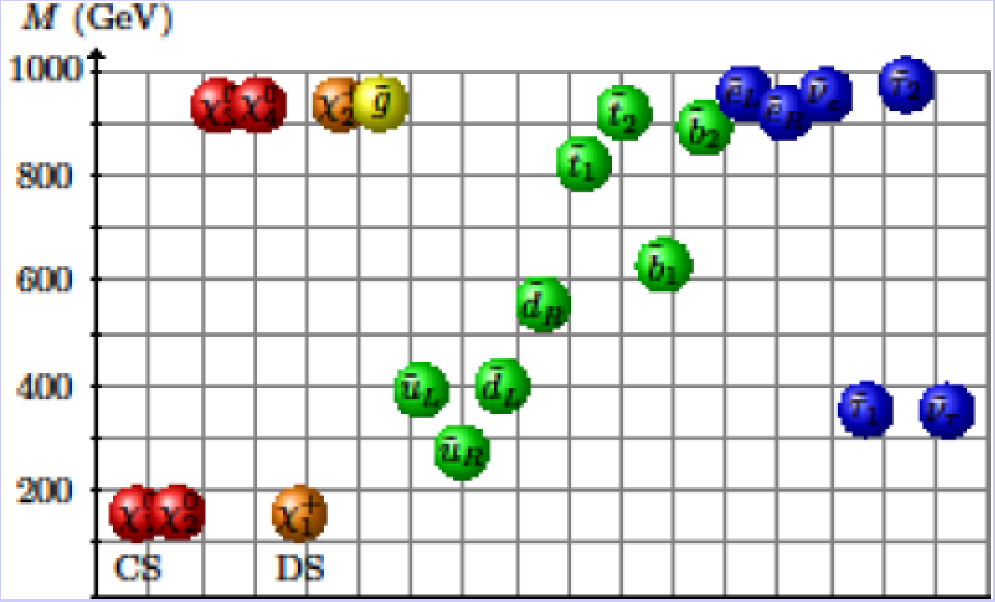
Note the compressed spectrum here leading to softer jets

- u_R (867) →j + gluino(763); gluino → j+ d_R (74%) , (u,d)$_L$ (7%)

- u_L (734) →j+ χ_1^0 (27%), $\chi_1^\pm$ (67%) [581,584] ;
- d_L (738) →j+ χ_1^0 (33%), $\chi_1^\pm$ (57%);

- d_R →j+ χ_1^0 ; $\chi_1^\pm$ → W* χ_1^0 (Δm ~ 3.8 GeV)

Note: Z_n ~4.2 for (2,4) j0l analyses



Example: Model 8829

ss: 5581
gg: 65.2
sg: 1727

number of events b/f cuts

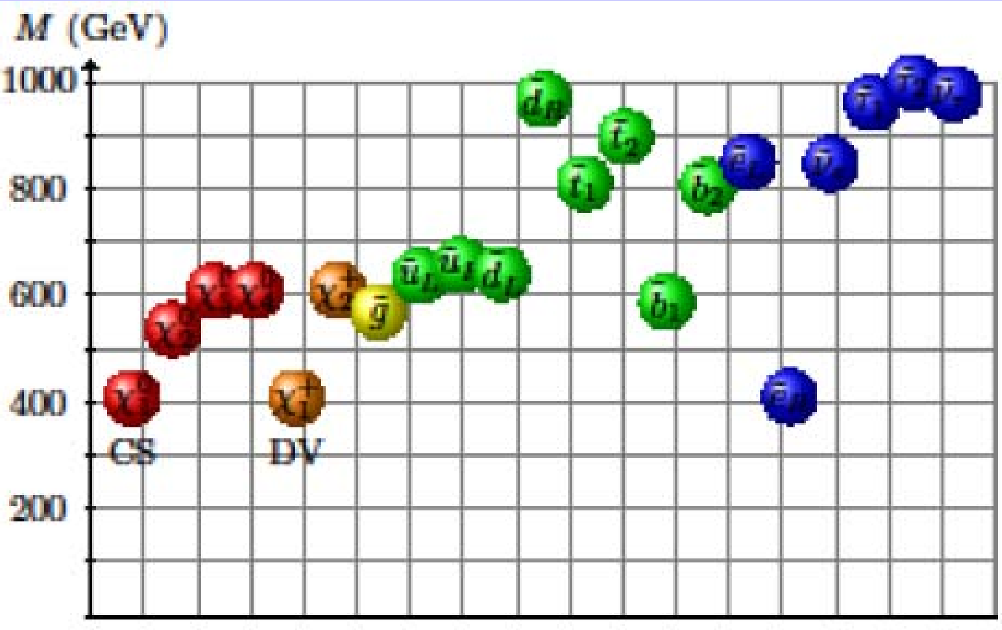
→ gg →ss+2j , gs→ss+j

Signals depend on the very light winos & bino in the spectrum. (Note $\chi^{\pm}_1$ are again detector stable)

•B(s→j + MET) ~0.07-0.34 → (4,2)j0l rates which are too small

•B(s_R→j + χ_2^0) ~ 0.92 → χ_2^0 decays inside the detector to $\chi_1^{\pm}$ w/ $c\tau$~1 cm !

•B(s_L→j + $\chi_1^{\pm}$) ~ 0.66 → j+stable Long-lived searches!!



Example: Model 62828

ss: 914.2
gg: 2120
sg: 4280

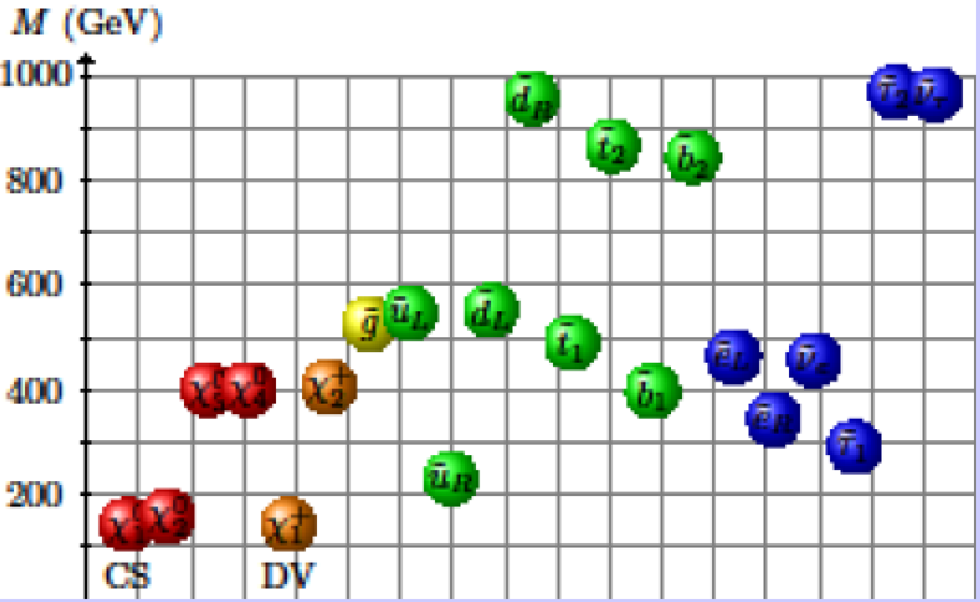
number of events b/f cuts

→ ss →gg+2j , gs→gg+j

Signals depend on the interplay of the gluino and weak gaugino mass spectra. (Note $\chi_1^\pm$ are 'just' detector stable, i.e, $c\tau$ ~25m with Δm=141.2 MeV)

•Squark decays to gluinos (B> 0.95 for s_R , ~0.4 for s_L) & somewhat hard jets, i.e., Δm >70 GeV . s_L have B~0.2 for j+MET, too small for (2,4)j0l searches, as well as B~0.4 for j+$\chi_1^\pm$ decays. Few hard b's and very few leptons or τ's.

•B(g→2j + MET) ~0.35, B(g→2j + $\chi_1^\pm$) ~0.65



Example: Model 42798

ss: 4767
gg: 764
sg: 4840

number of events b/f cuts

→ $d_R >> (u,d)_L >\sim g >> u_R$

A bit more complex than most but still killed by BFs

$\Delta m(d_R - g) \sim 420$ GeV, $\Delta m(u_L, d_L - g) \sim 20\text{–}25$ GeV,
$\Delta m(g - u_R) \sim 195$ GeV, $\Delta m(u_R - \text{LSP}) \sim 90$ GeV

- $c\tau(\chi_1^{\pm}) \sim 25$m; $\Delta m(\chi_2^0 - \text{LSP}) \sim 17$ GeV
- $\chi_2^0 \rightarrow (\gamma, Z^*) + \text{LSP}(\sim 5, 25\%)$, $\rightarrow W^* + \chi_1^{\pm} (\sim 70\%)$

```
       PDG             Width
AY    1000002      6.10464679E+00   # sup_L decays
         BR           NDA        ID1        ID2
   3.04263153E-01     2       1000022          2    # BR(~u_L -> ~chi_10 u)
   1.77955300E-02     2       1000023          2    # BR(~u_L -> ~chi_20 u)
   8.96664783E-04     2       1000025          2    # BR(~u_L -> ~chi_30 u)
   1.99959783E-03     2       1000035          2    # BR(~u_L -> ~chi_40 u)
   6.43930277E-01     2       1000024          1    # BR(~u_L -> ~chi_1+ d)
   5.45923139E-04     2       1000037          1    # BR(~u_L -> ~chi_2+ d)
   3.05688535E-02     2       1000021          2    # BR(~u_L -> ~g      u)

       PDG             Width
AY    2000002      1.46507482E-01   # sup_R decays
         BR           NDA        ID1        ID2
   1.05051938E-03     2       1000022          2    # BR(~u_R -> ~chi_10 u)
   9.98949481E-01     2       1000023          2    # BR(~u_R -> ~chi_20 u)

       PDG             Width
AY    1000001      6.01058767E+00   # sdown_L decays
         BR           NDA        ID1        ID2
   3.19502731E-01     2       1000022          1    # BR(~d_L -> ~chi_10 d)
   5.54071069E-03     2       1000023          1    # BR(~d_L -> ~chi_20 d)
   1.44382012E-03     2       1000025          1    # BR(~d_L -> ~chi_30 d)
   3.35582851E-03     2       1000035          1    # BR(~d_L -> ~chi_40 d)
   6.07976276E-01     2      -1000024          2    # BR(~d_L -> ~chi_1- u)
   1.36988317E-02     2      -1000037          2    # BR(~d_L -> ~chi_2- u)
   4.84818017E-02     2       1000021          1    # BR(~d_L -> ~g      d)

       PDG             Width
AY    2000001      3.05842014E+01   # sdown_R decays
         BR           NDA        ID1        ID2
   1.29360144E-05     2       1000022          1    # BR(~d_R -> ~chi_10 d)
   1.68826930E-02     2       1000023          1    # BR(~d_R -> ~chi_20 d)
   5.06488508E-05     2       1000025          1    # BR(~d_R -> ~chi_30 d)
   1.41365858E-04     2       1000035          1    # BR(~d_R -> ~chi_40 d)
   9.82912356E-01     2       1000021          1    # BR(~d_R -> ~g      d)
```

u_L decays to :

- g +j (~3%)
- LSP +j (~30%)
- $\chi_1^{\pm}$ +j (~64%)

u_R decays to χ_2^0 +j

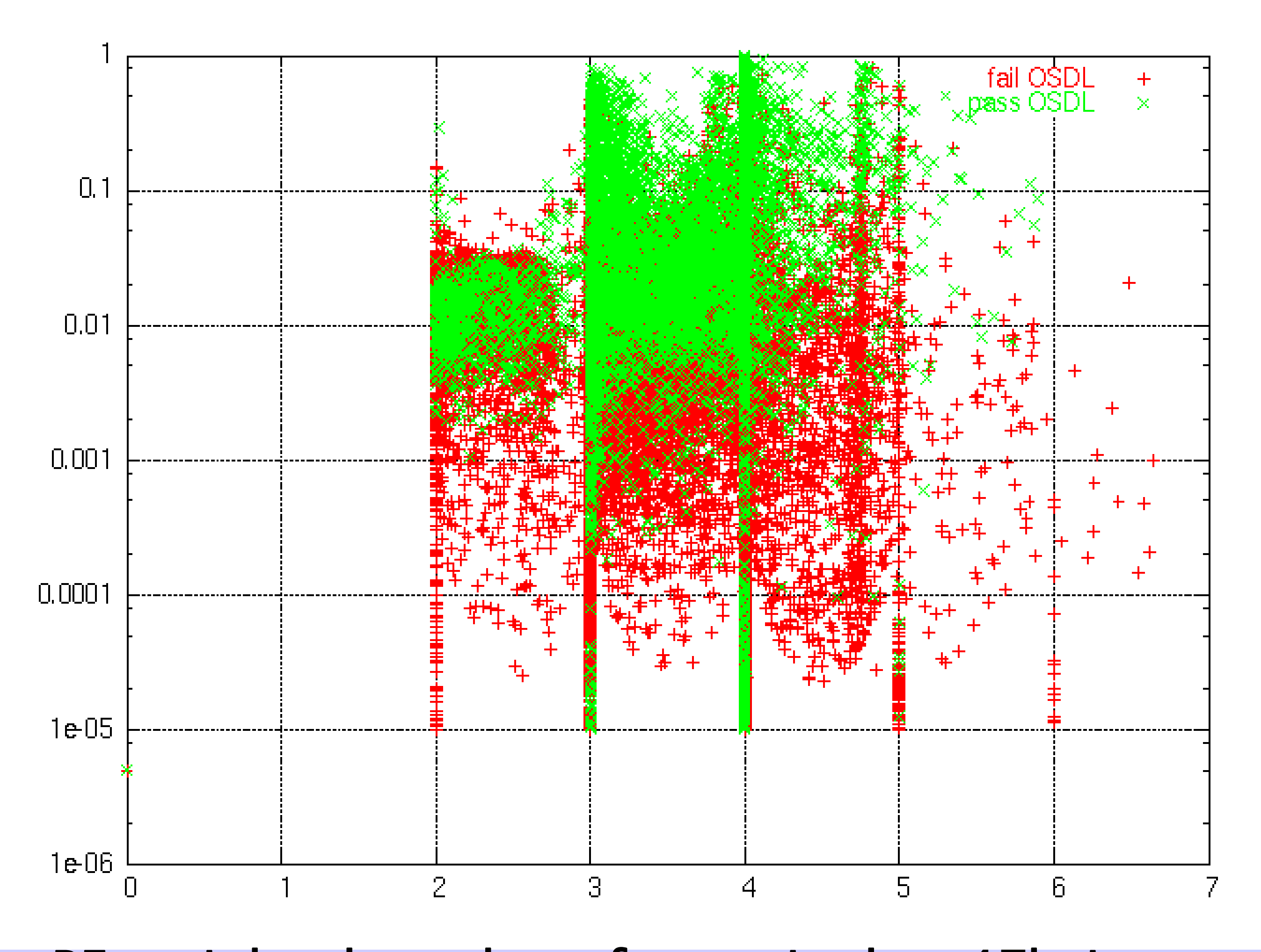
d_L decays to :

- g +j (~5%)
- LSP +j (~32%)
- $\chi_1^{\pm}$ +j (~61%)

d_R decays to g +j

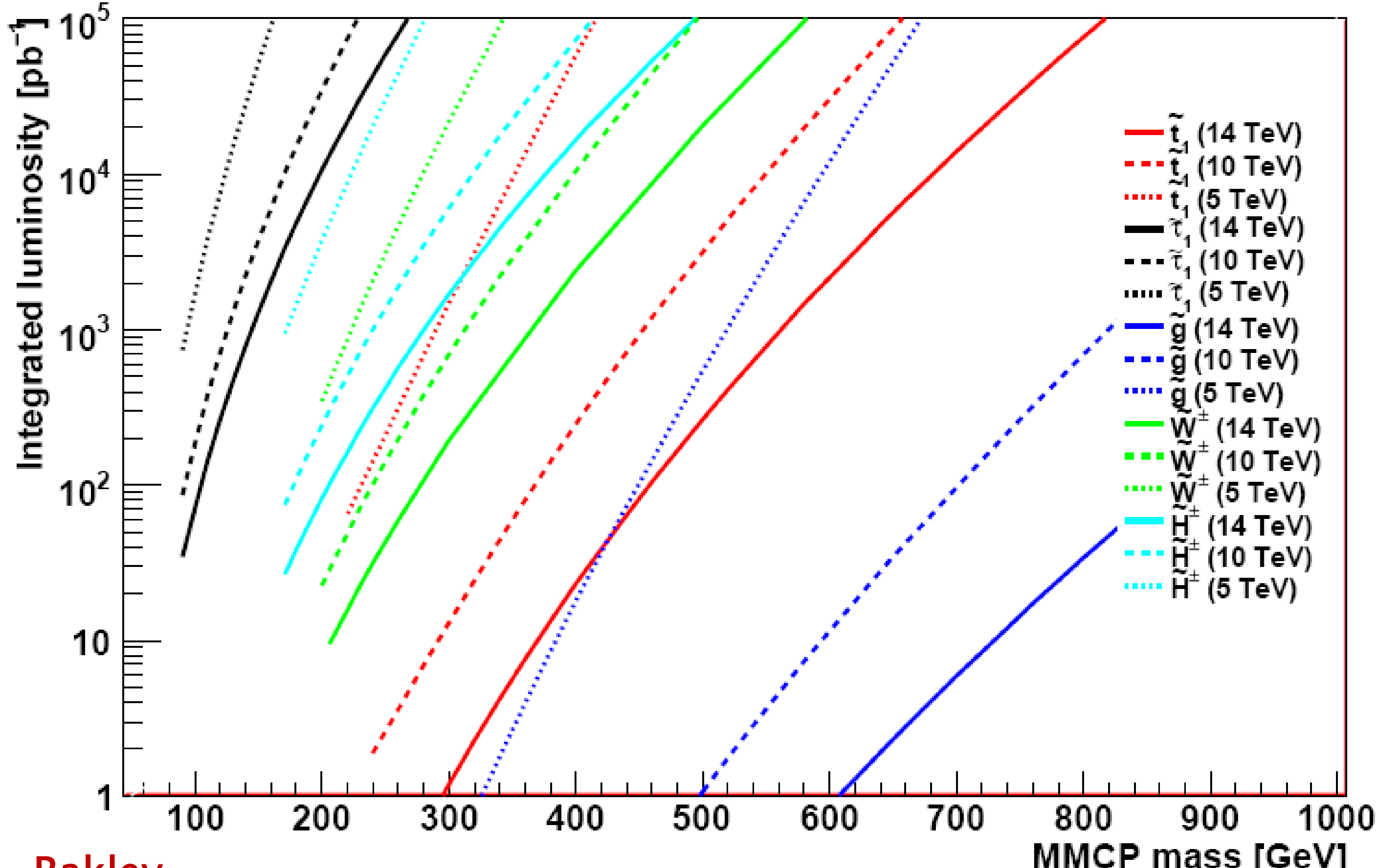
Gluino initiated cascades leading to X l^+ l^- MET

Inclusive Branching fraction



BF-weighted number of steps in decay chain

Stable SUSY Searches at LHC



A. Raklev

Long Lived/Stable Sparticles in the 71k Samp
with $c\tau > 20m$

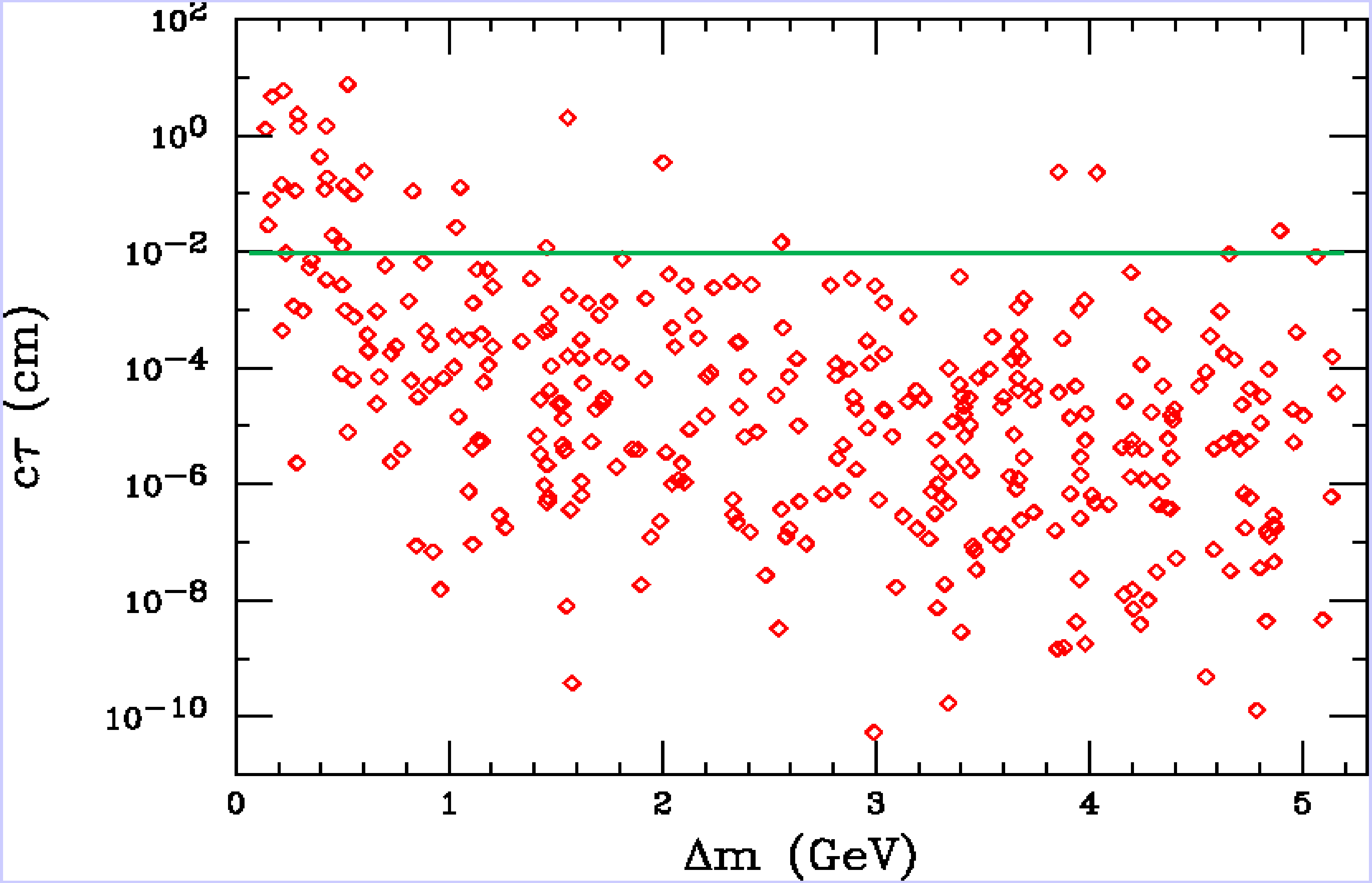
$\rightarrow$ 9462 (97,1) models w/ one (2,3) long-lived particle(s) !

- 8982 are lightest charginos
- 20 are second neutralinos
- 338 are sbottom_1's
- 179 are stau_1's
- 61 are stops
- 5 are gluinos
- 49 are c_R
- 17 are μ_R
- 8 are c_L
  etc.

Particles with $c\tau > 20m$ will be declared 'detector stable' in our analysis

NB: 4-body & CKM suppressed loop decays, e.g., $\tilde{b}_1 \rightarrow b^* (s,d) +$ LSP are missing , i.e., $\Delta m < m_{bottom}$ from SUSY-HIT

$\tilde{b}_1 \rightarrow s,d + LSP$ induced decay lengths for $\Delta m <$ r



Semi-Stable Sparticles in the 71k Sample with 200 μm < $c\tau$ < 20m

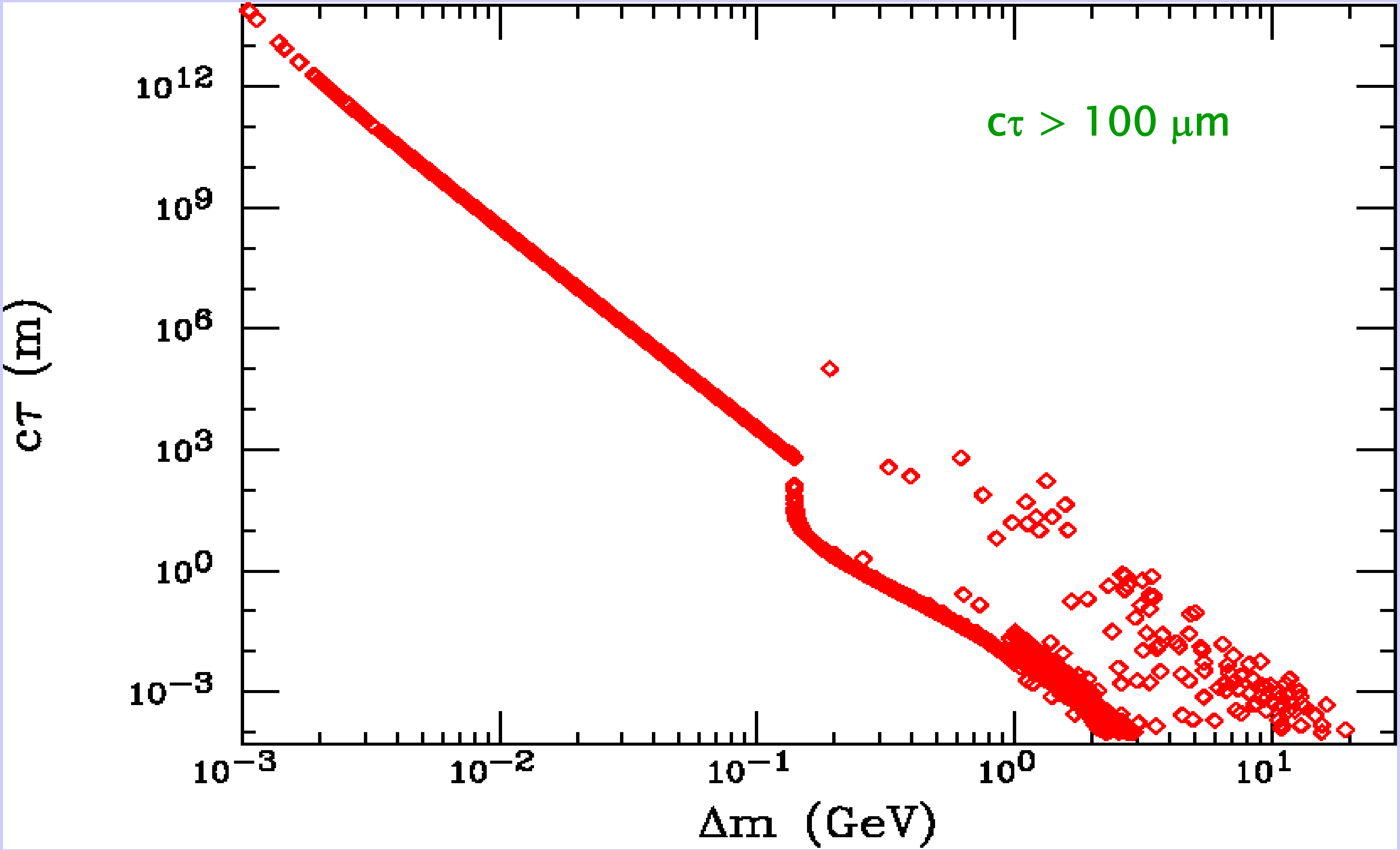
- 8326 models with at least 1 semi-stable state
- 344 (14) have 2 (3) of them

- 8187 are charginos
- 724 are second neutralinos
- 44 are stops
- 90 are gluinos
- 8 are c_L
- 6 are c_R
- 6 are d_R (s_R)

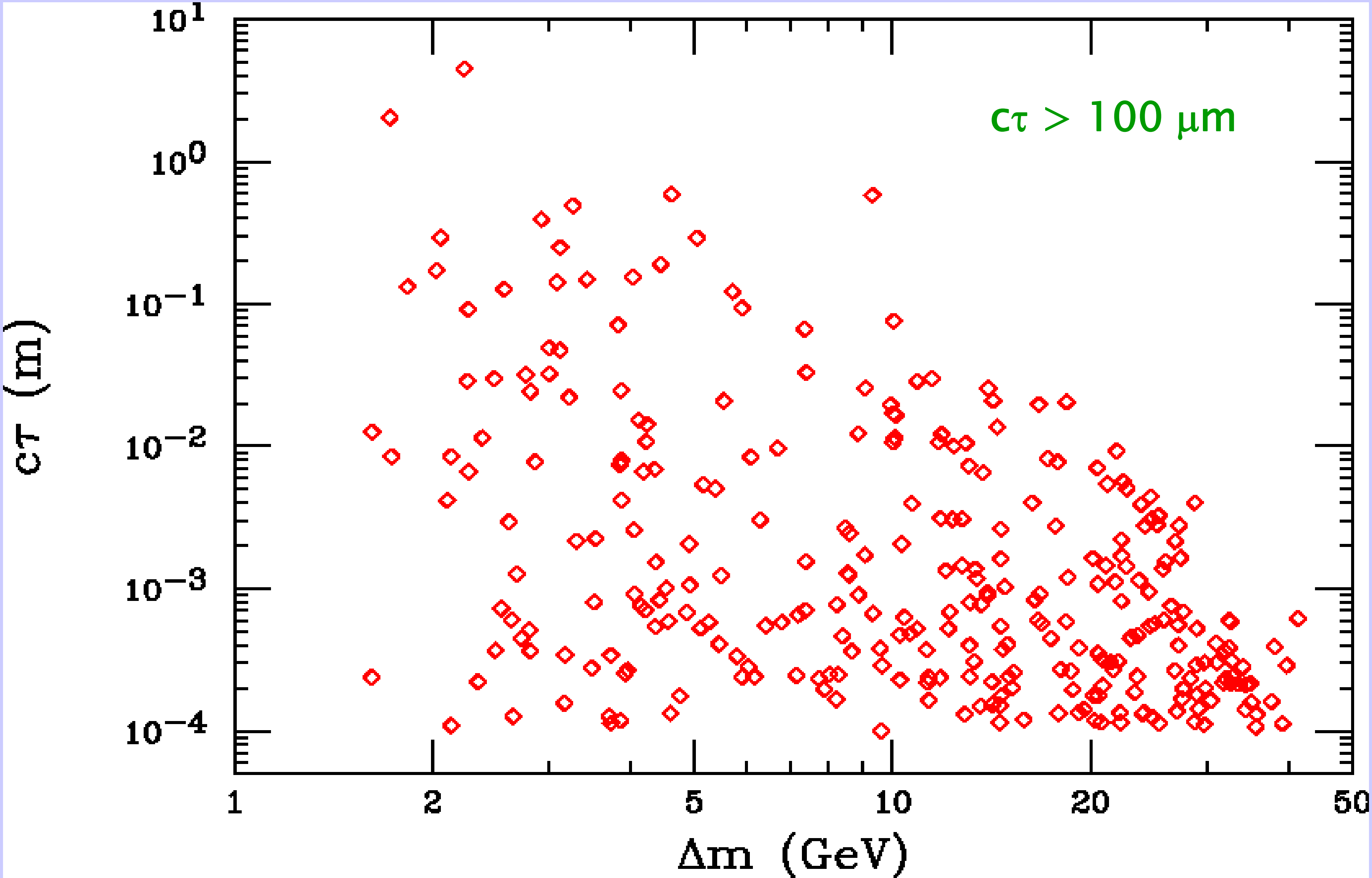
  etc.

Particles decaying inside the detector will require some special analyses to study but will likely not be seen by inclusive SUSY searches since their decay products are very soft.

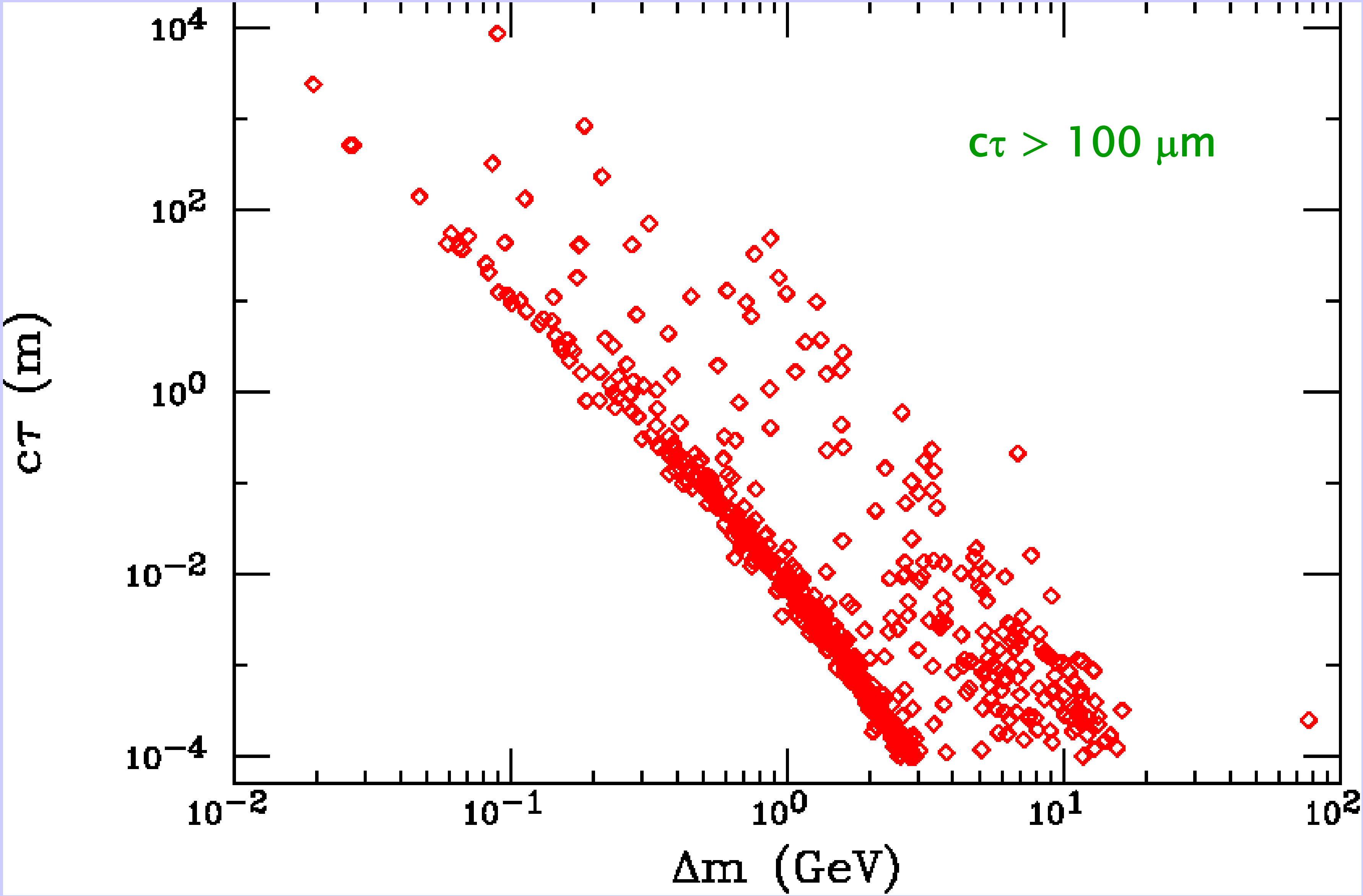
Example: Long-Lived Charginos



Example: Detector Decaying Stops



Example: Long-Lived χ_2^0 s

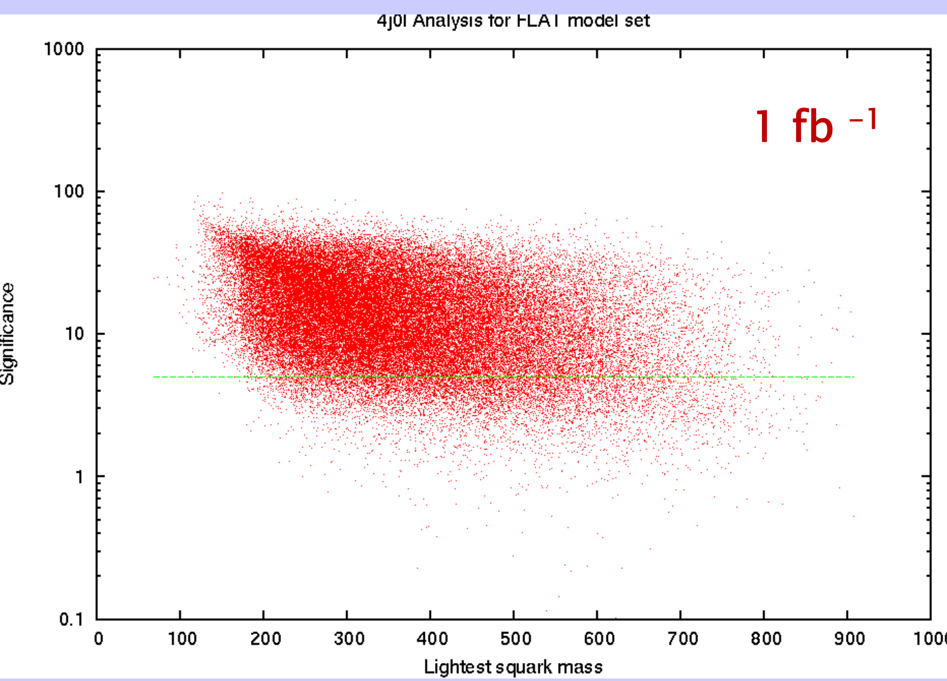


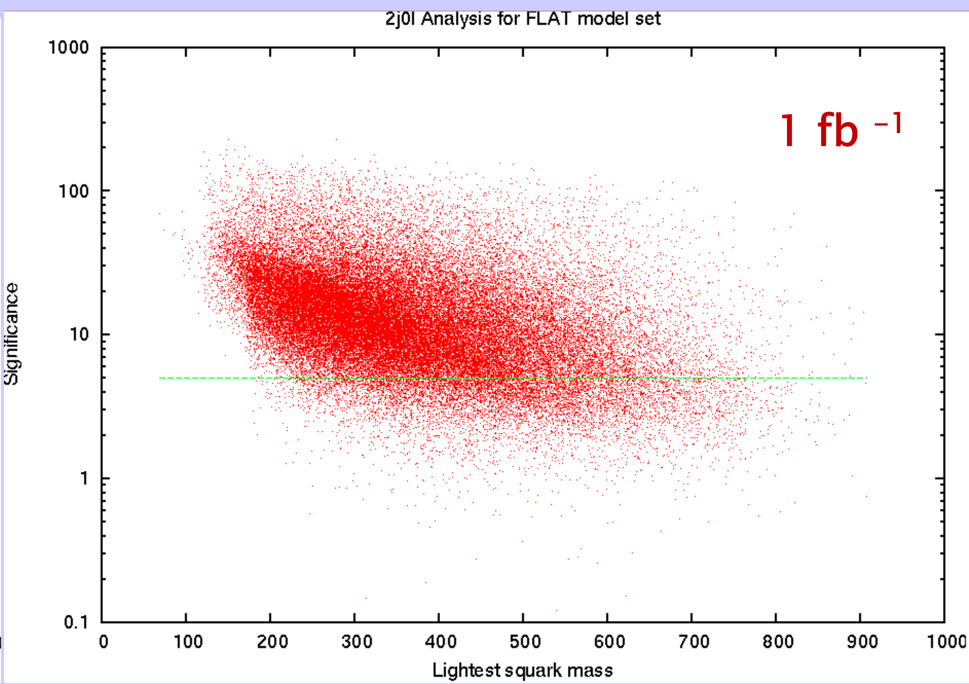
What Next ?

- Obtain & understand more of the details of the 14 TeV case. We have an *enormous* volume of data to look at…
- Examine the 7 TeV case… BUT not yet! While we have the ATLAS background data for 10 TeV, the 7 TeV results are not yet available as they are currently being generated. It would be nice to do this study soon !
- It may be interesting to do a similar analysis to this for other SUSY setups, e.g., the case of the gravitino LSP or…
- Dark matter analyses are ongoing(e.g., Ice Cube)

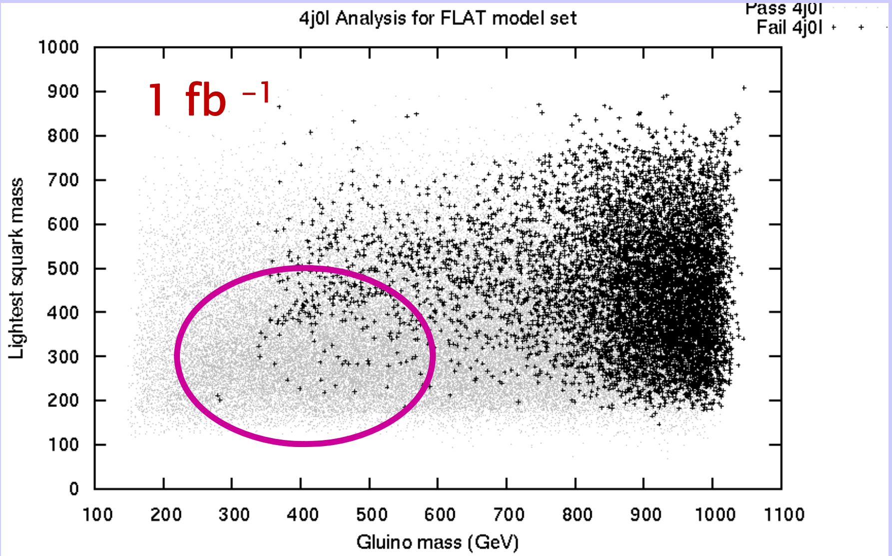
Search Significance Correlations : Dependence on the Lightest Squark Mass

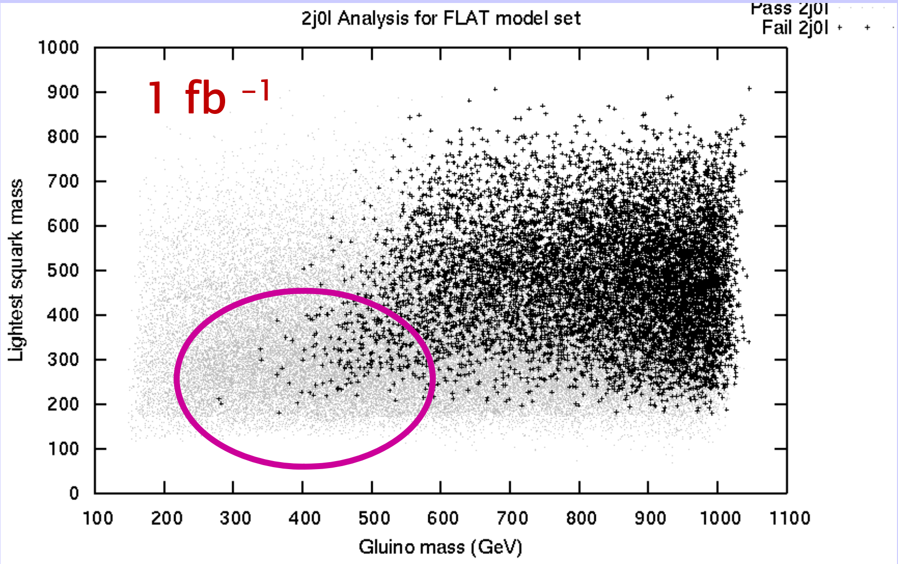
As the lightest of the u,d-squarks get heavier one might expect a qualitative fall off in the signal significance in the 2j0l &4j0l searches… here we see that this correlation is rather weak.

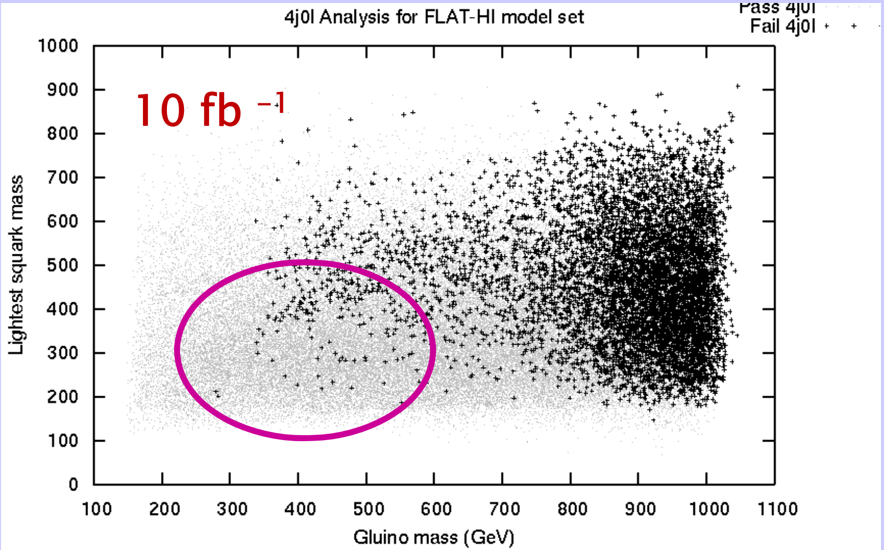


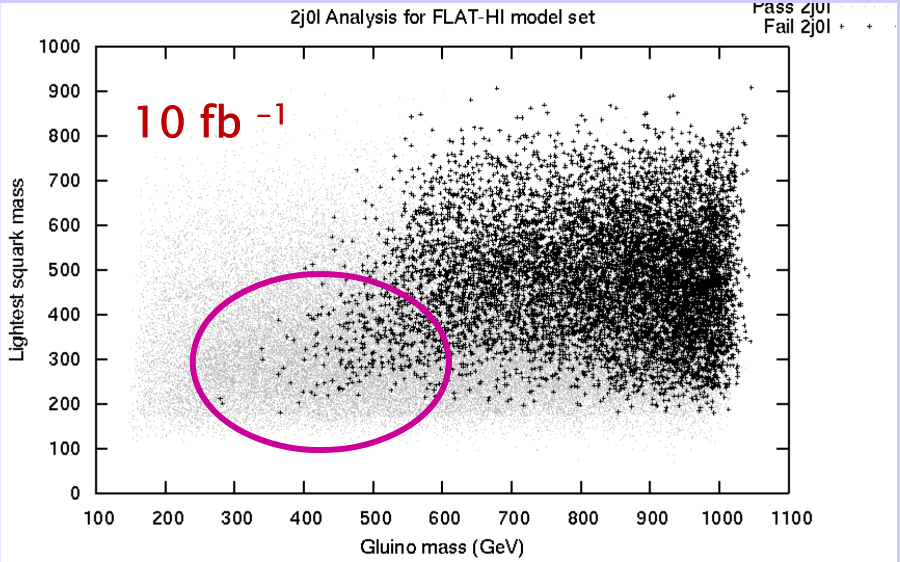


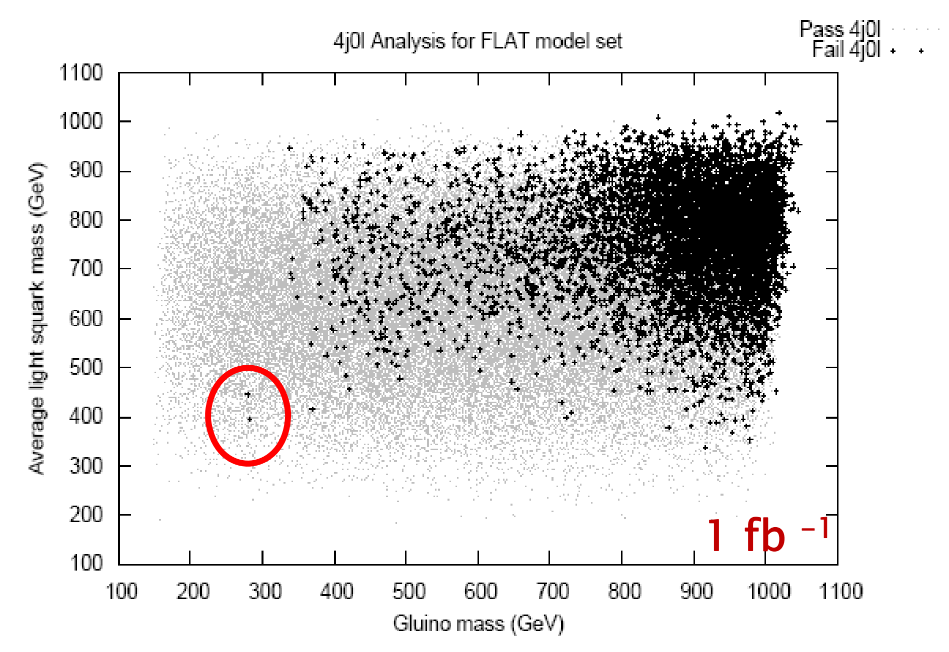
Lightest Squark Mass vs. Gluino Mass

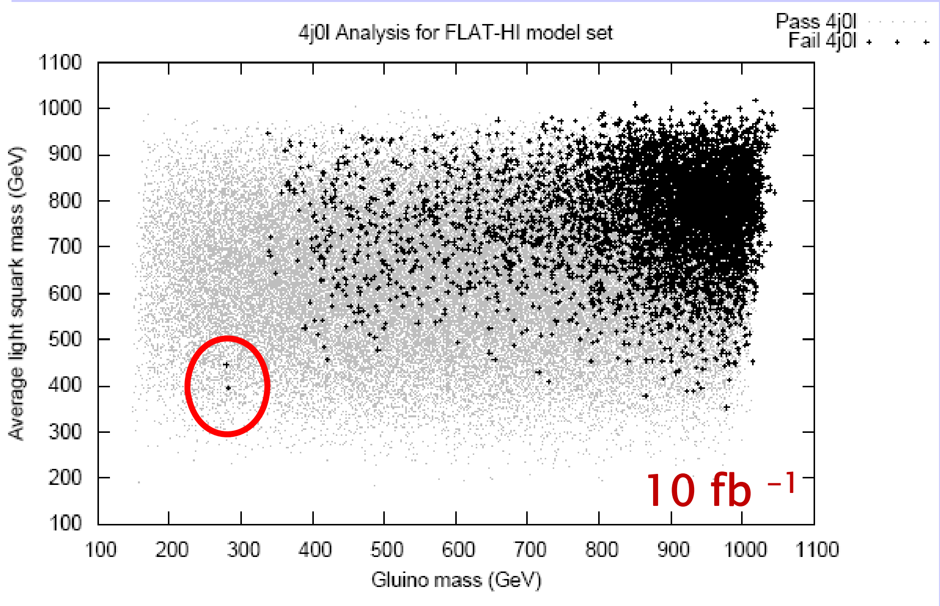




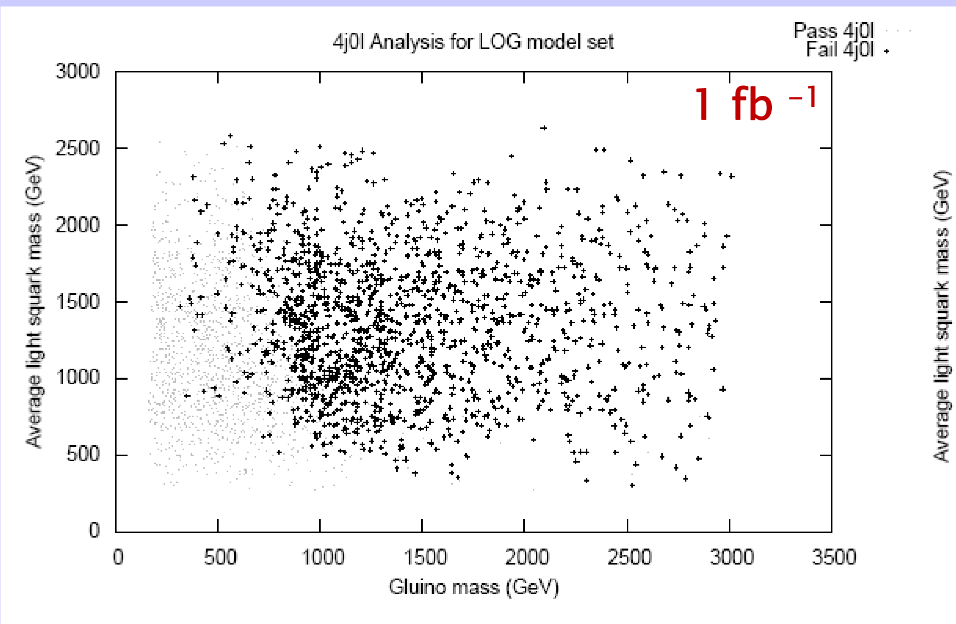


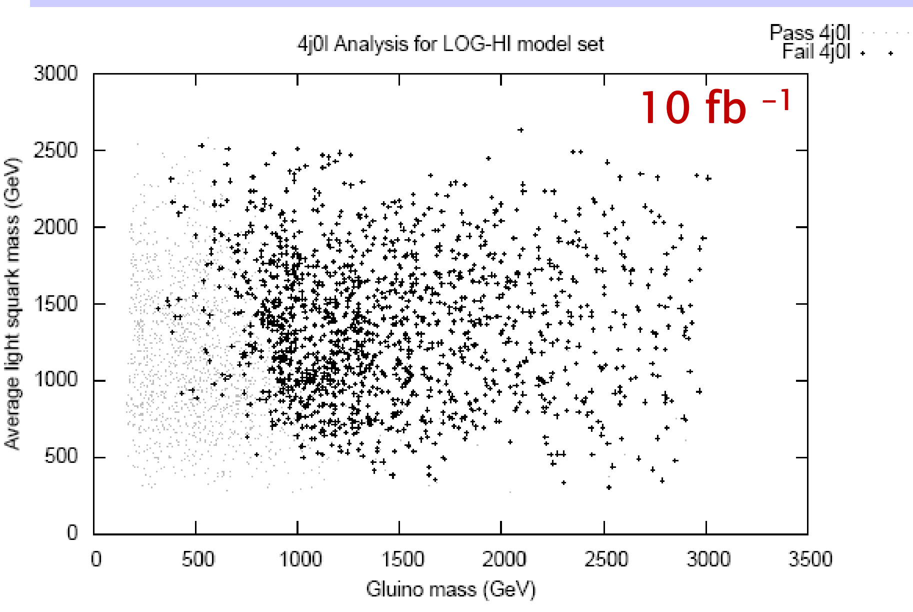




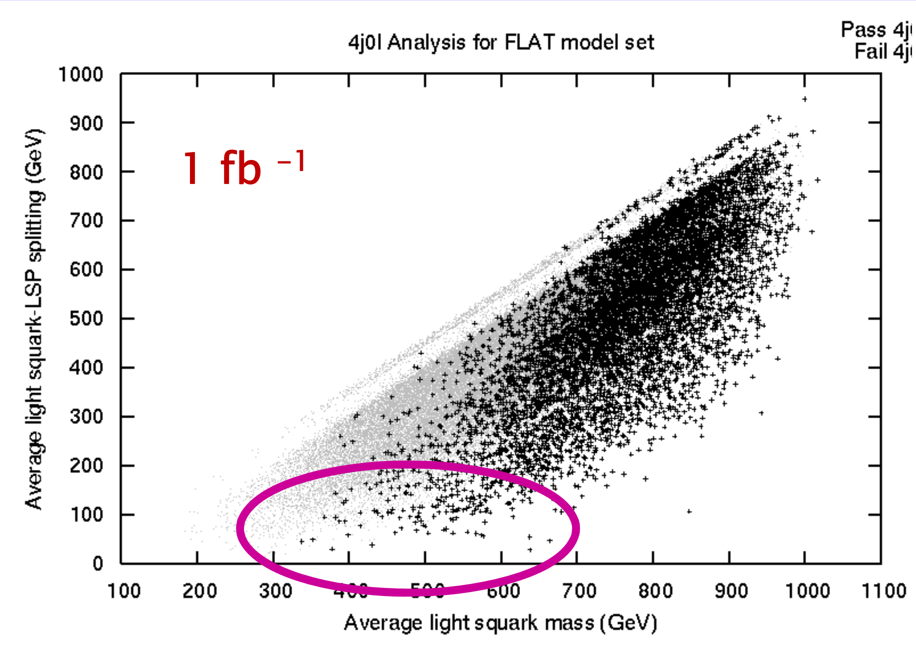


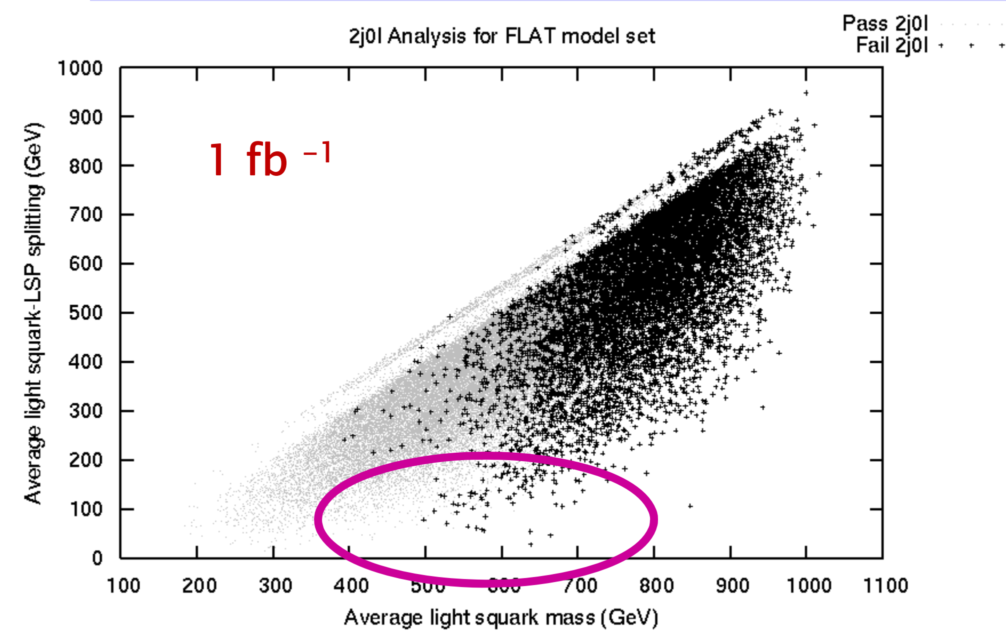
Some models w/ light squarks & gluinos ARE missed here
& adding lumi does not necessarily help much in all cases





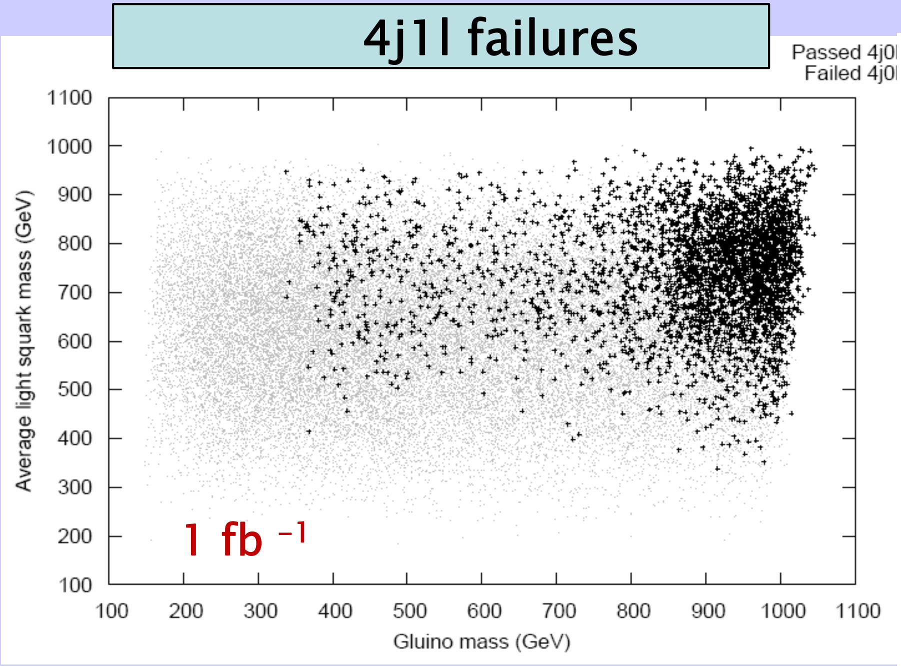
There is an even weaker correlation between small mass splittings for the squarks

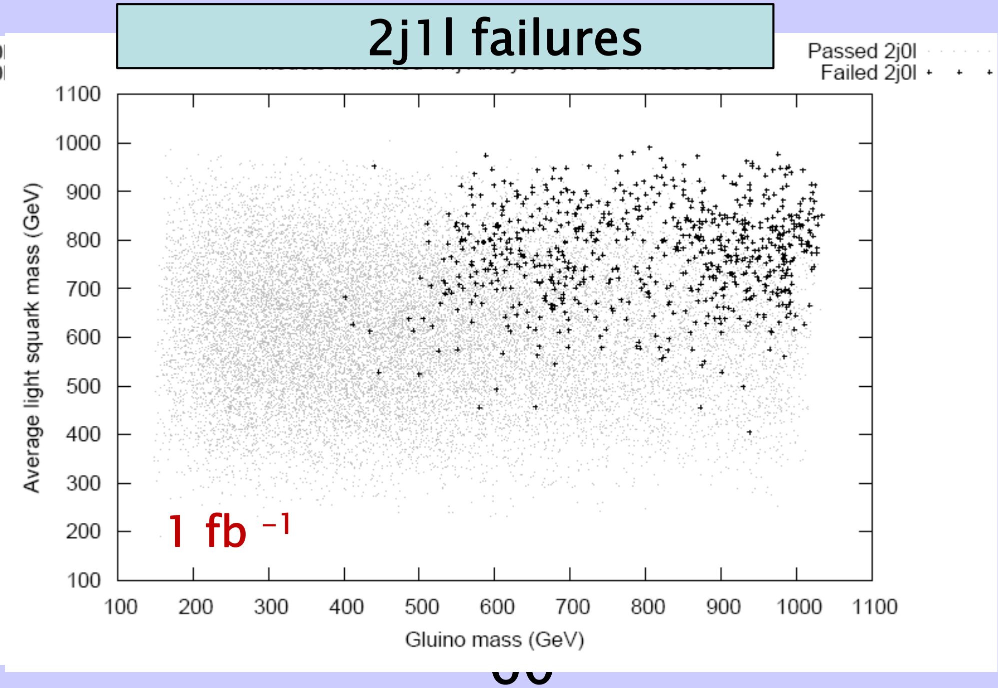


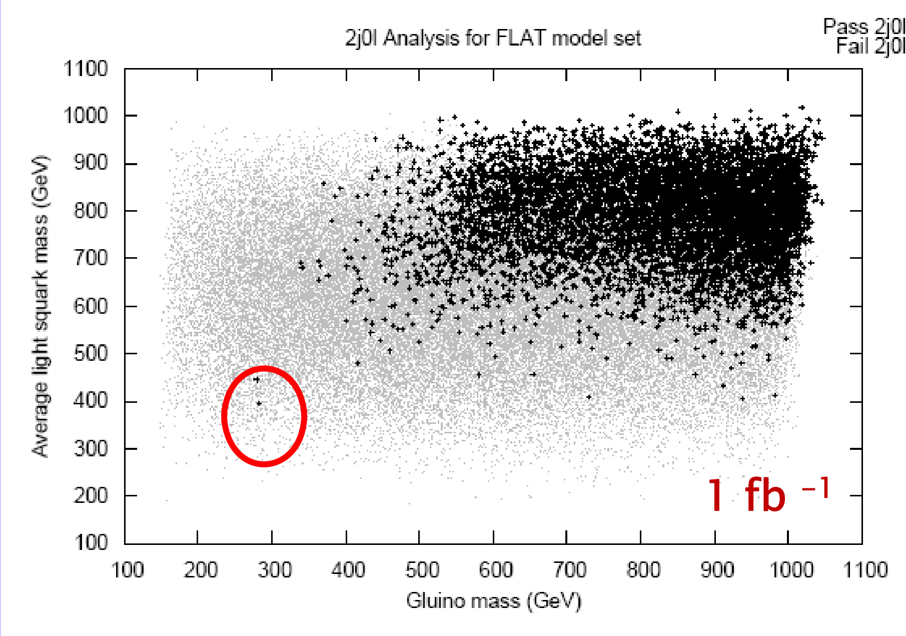


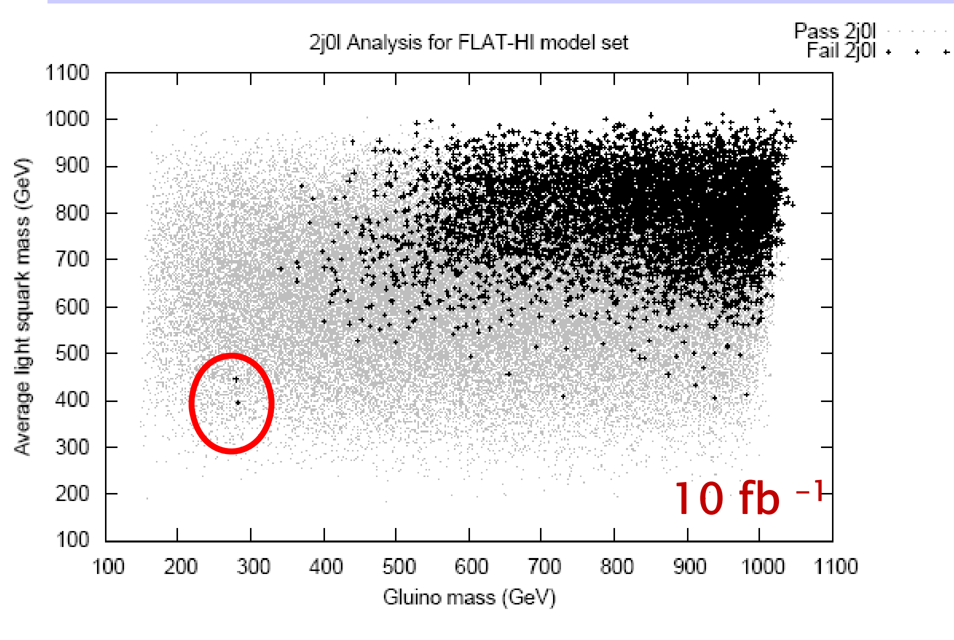
What about the other channels ??

- In the case of (2,4)j1l searches we can ask whether the model fails the ATLAS searches due to the 'hadronic' or the 'leptonic' parts of the cuts…

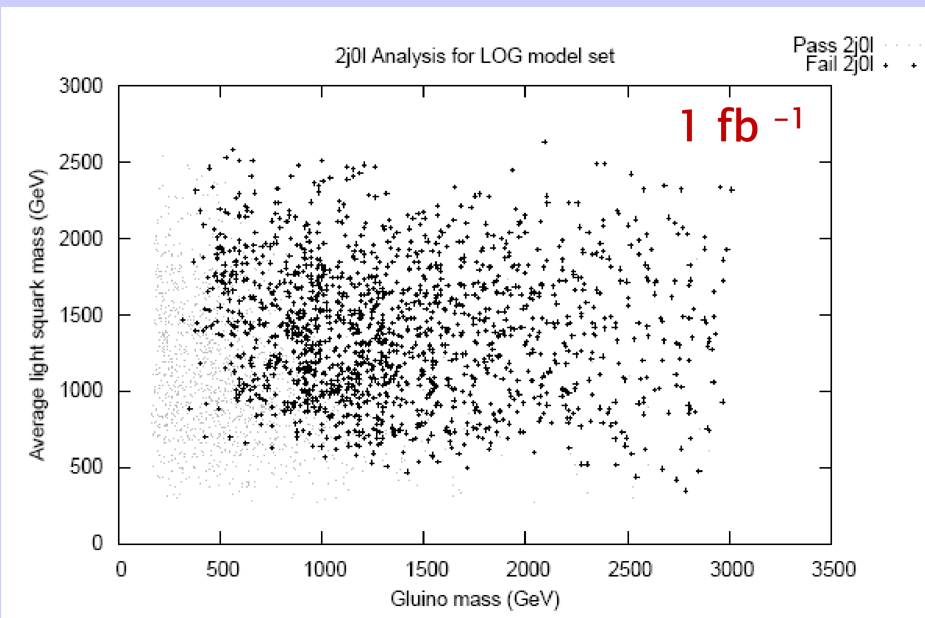


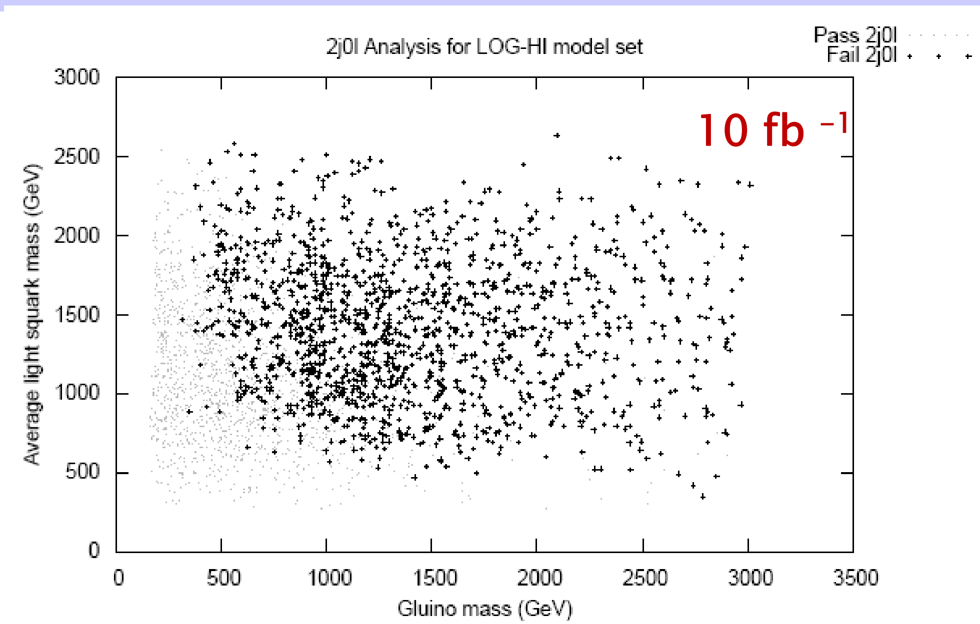


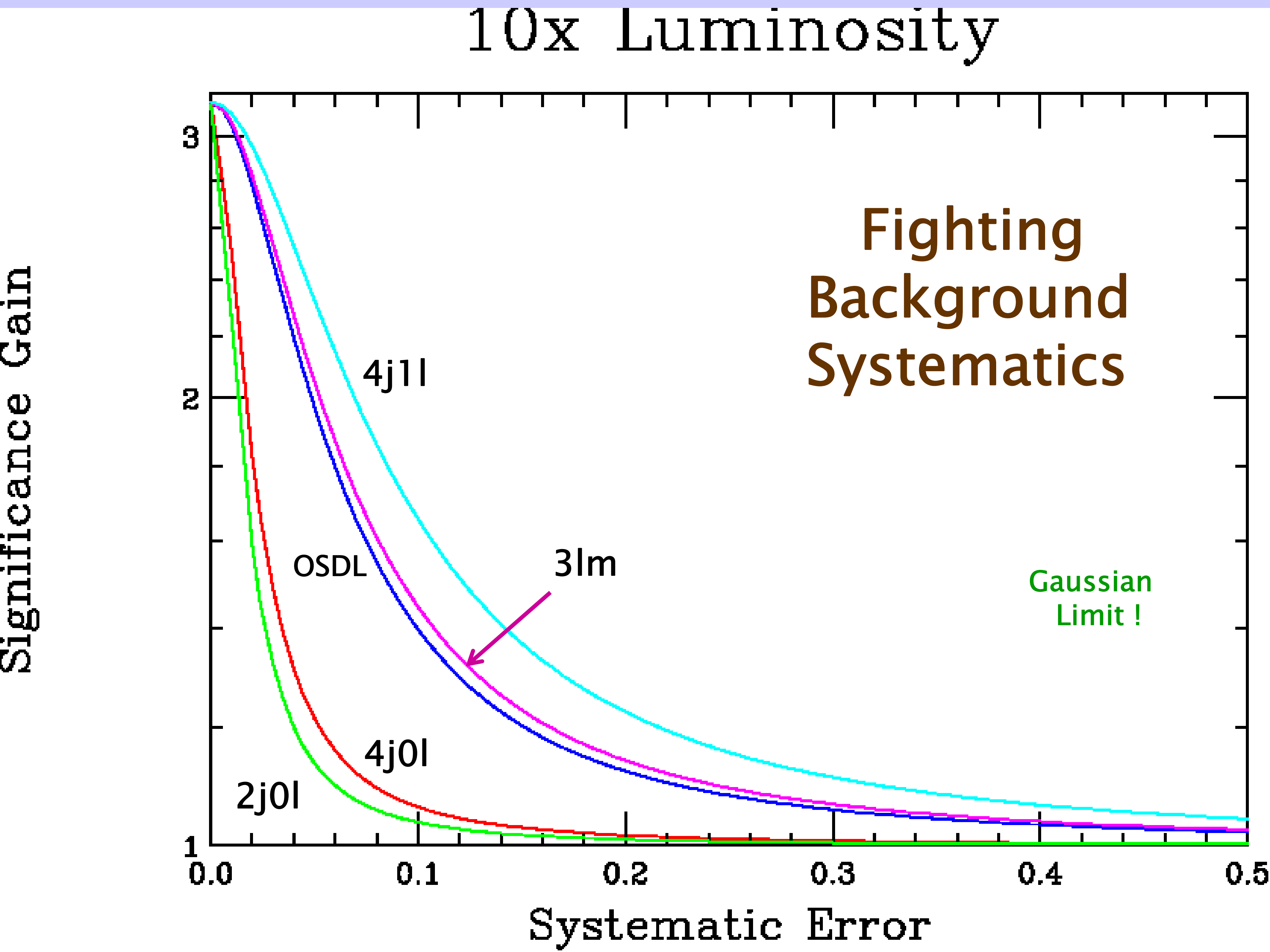




The same holds true for the 2j0l analysis

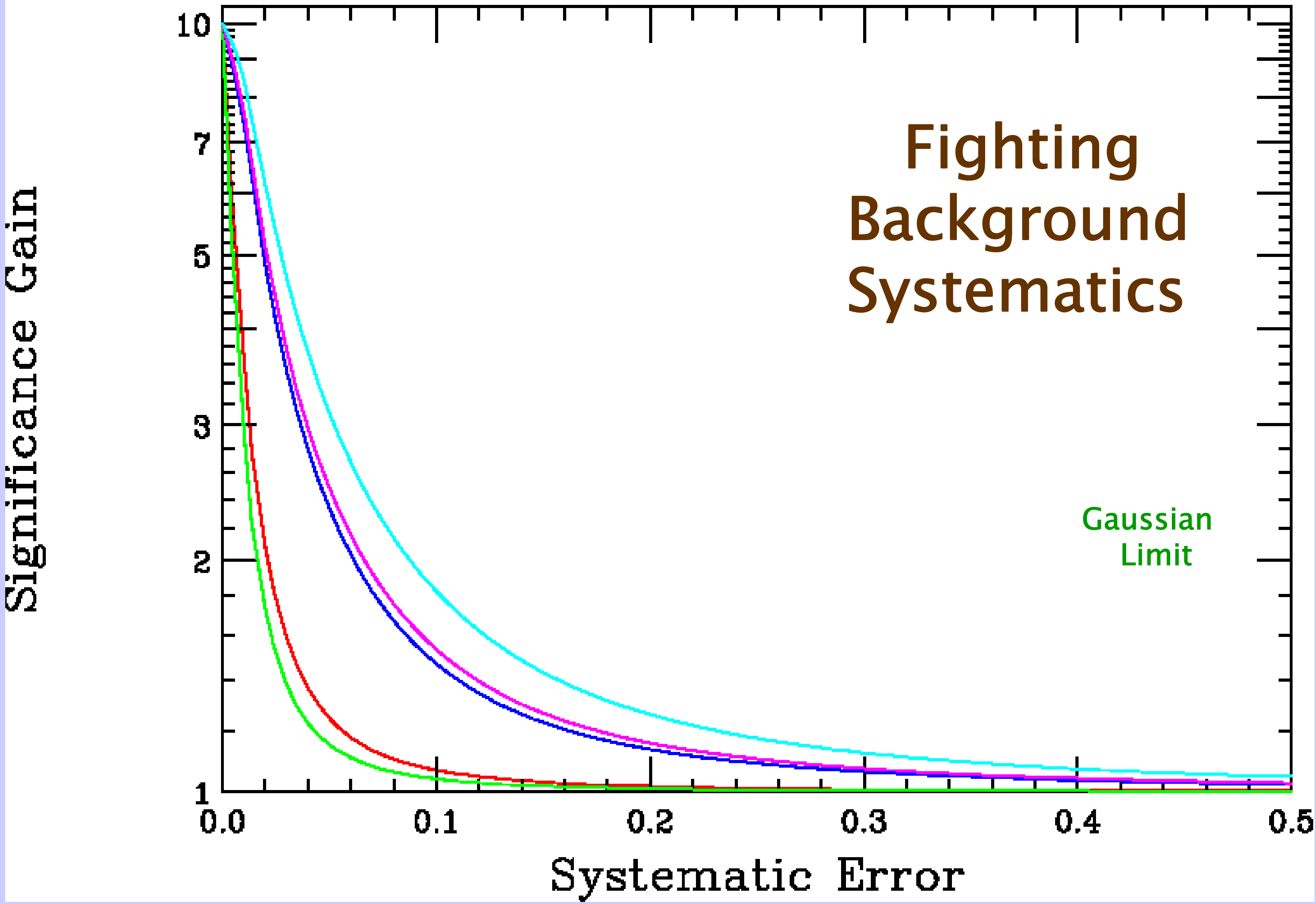


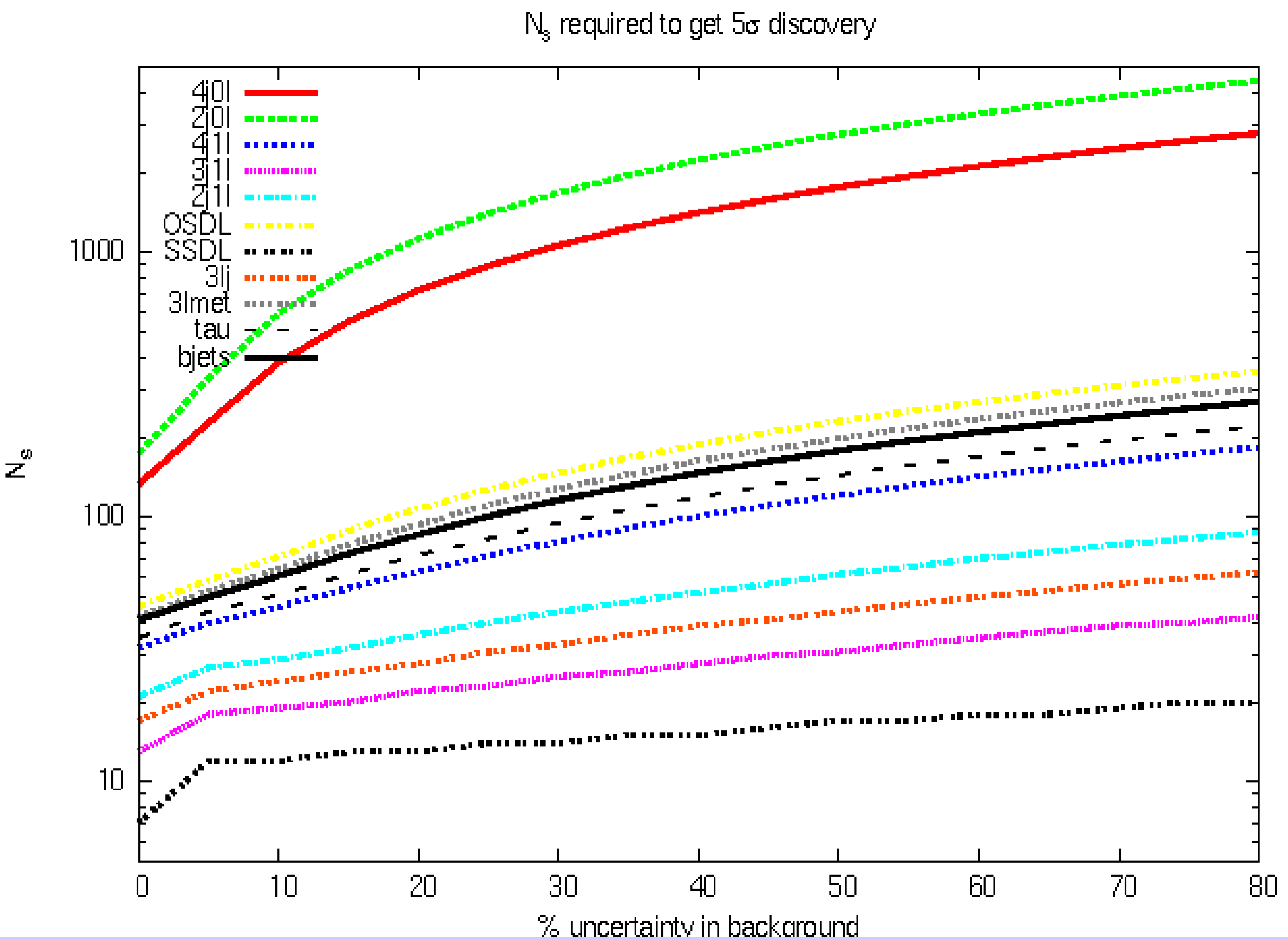




10x Luminosity
Fighting Background Systematics
4j1l
3lm
OSDL
4j0l
2j0l
Gaussian Limit !
Significance Gain
Systematic Error
1
2
3
0.0
0.1
0.2
0.3
0.4
0.5

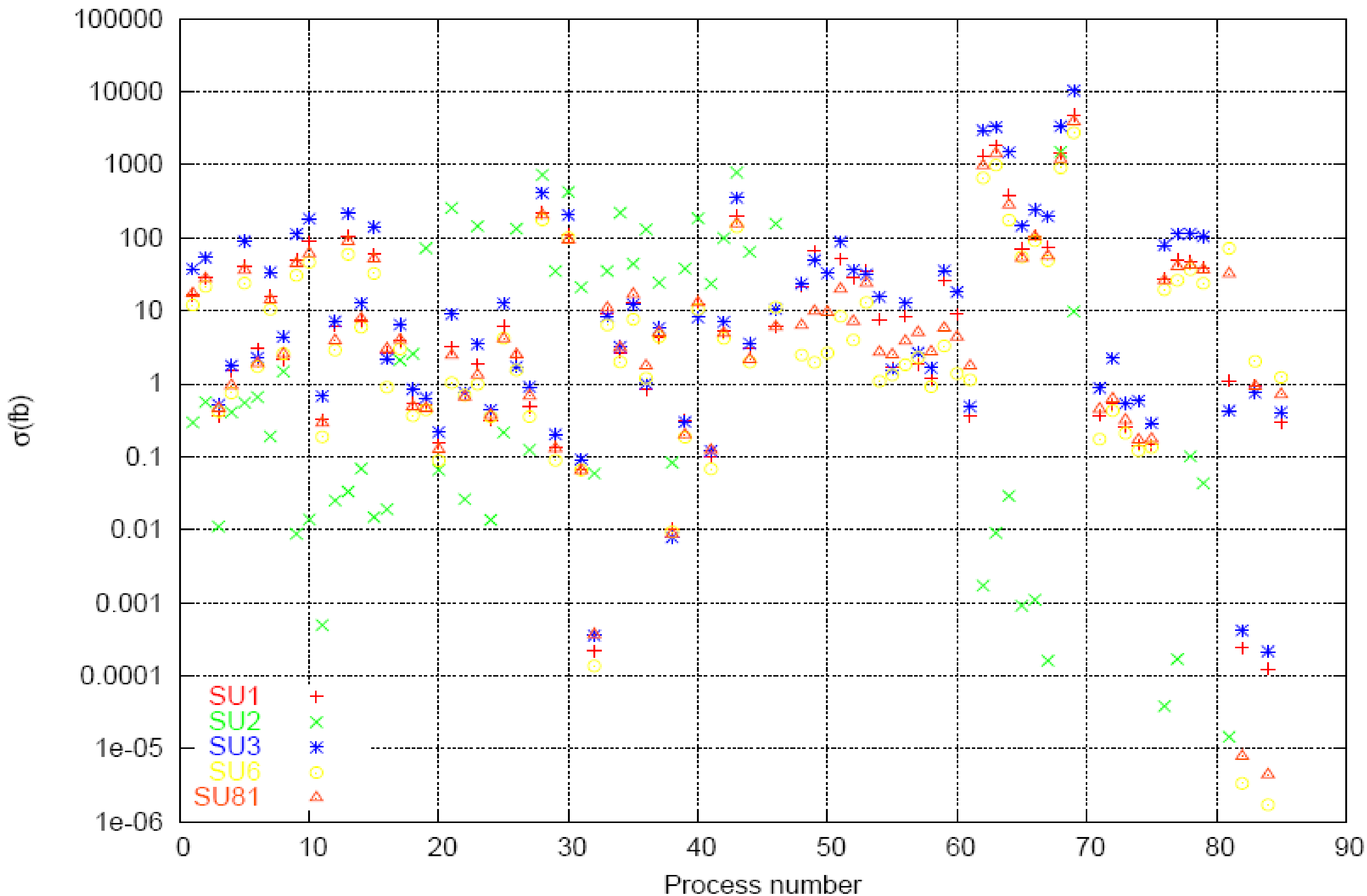
100x Luminosity





N_s required to get 5σ discovery
4l0l
2l0l
4l1l
3l1l
2l1l
OSDL
SSDL
3lj
3lmet
tau
bjets
1000
100
10
N_s
0
10
20
30
40
50
60
70
80
% uncertainty in background

Benchmark Model Process Cross Sections



4 jet, 0 lepton analysis

1. At least four jets with $p_T > 50$ GeV, at least one of which must have $p_T > 100$ GeV; and $E_T^{\mathrm{miss}} >$ 100 GeV
2. $E_T^{\mathrm{miss}} > 0.2 M_{\mathrm{eff}}$
3. Transverse sphericity $S_T > 0.2$
4. $\Delta\phi$ between each of three hardest jets and E_T^{miss} must be greater than 0.2
5. Reject events with an electron or muon.

3 jet, 0 lepton analysis

1. At least three jets with $p_T > 100$ GeV, at least one of which must have $p_T > 150$ GeV; and $E_T^{\mathrm{miss}} >$ 100 GeV
2. $E_T^{\mathrm{miss}} > 0.25 M_{\mathrm{eff}}$
3. $\Delta\phi$ between each of three hardest jets and E_T^{miss} must be greater than 0.2
4. Reject events with an electron or muon.

2 jet, 0 lepton analysis

1. At least two jets with $p_T > 100$ GeV, at least one of which must have $p_T > 150$ GeV; and $E_T^{\mathrm{miss}} >$ 100 GeV
2. $E_T^{\mathrm{miss}} > 0.3 M_{\mathrm{eff}}$
3. $\Delta\phi$ between each of two hardest jets and E_T^{miss} must be greater than 0.2
4. Reject events with an electron or muon.

One lepton, 4 jet analysis

1. Exactly one isolated electron or muon.
2. No additional leptons with $p_T > 10$ GeV.
3. At least four jets with $p_T > 50$ GeV, at least one of which must have $p_T > 100$ GeV
4. $E_T^{\rm miss} >$ 100 GeV and $E_T^{\rm miss} > 0.2 M_{\rm eff}$
5. Transverse sphericity $S_T > 0.2$
6. Tranverse mass $M_T > 100$ GeV
7. Reject events with an electron or muon.

One lepton, 3 jet analysis

1. Exactly one isolated electron or muon.
2. No additional leptons with $p_T > 10$ GeV.
3. At least three jets with $p_T > 100$ GeV, at least one of which must have $p_T > 150$ GeV
4. $E_T^{\rm miss} >$ 100 GeV and $E_T^{\rm miss} > 0.25 M_{\rm eff}$
5. Transverse sphericity $S_T > 0.2$
6. Tranverse mass $M_T > 100$ GeV
7. Reject events with an electron or muon.

One lepton, 2 jet analysis

1. Exactly one isolated electron or muon.
2. No additional leptons with $p_T > 10$ GeV.
3. At least two jets with $p_T > 100$ GeV, at least one of which must have $p_T > 150$ GeV
4. $E_T^{\rm miss} >$ 100 GeV and $E_T^{\rm miss} > 0.3 M_{\rm eff}$
5. Transverse sphericity $S_T > 0.2$
6. Tranverse mass $M_T > 100$ GeV
7. Reject events with an electron or muon.

OSDL analysis

1. Two opposite-sign leptons with $p_T > 10$ GeV and $|\eta| < 2.5$; no additional leptons
2. At least four jets with $p_T > 50$ GeV, at least one of which must have $p_T > 100$ GeV
3. $E_T^{\rm miss} >$ 100 GeV and $E_T^{\rm miss} > 0.2 M_{\rm eff}$
4. Transverse sphericity $S_T > 0.2$

SSDL analysis

1. Exactly two same-sign leptons with $p_T > 20$ GeV
2. At least four jets with $p_T > 50$ GeV, at least one of which must have $p_T > 100$ GeV
3. $E_T^{\rm miss} >$ 100 GeV
4. $E_T^{\rm miss} > 0.2 M_{\rm eff}$

Trilepton + jet analysis

1. At least three leptons with $p_T > 10$ GeV
2. At least one jet with $p_T > 200$ GeV

Trilepton + $E_T^{\rm miss}$ analysis

1. At least three leptons with $p_T > 10$ GeV
2. At least one OSSF dilepton pair with $M > 20$ GeV
3. Lepton track isolation: less than 1 (2) GeV maximum p_T of any track within $\Delta R < 0.2$ of a muon (electron).
4. $E_T^{\rm miss} >$ 30 GeV
5. $M < M_Z - 10$ GeV for any OSSF dilepton pair

τ analysis

1. At least four jets with $p_T > 50$ GeV, at least one of which must have $p_T > 100$ GeV
2. $E_T^{\rm miss} >$ 100 GeV
3. $\Delta\phi$ between each of three hardest jets and $E_T^{\rm miss}$ must be greater than 0.2
4. Reject events with an electron or muon.
5. At least one τ with $p_T > 40$ GeV and $|\eta| < 2.5$
6. $E_T^{\rm miss} > 0.2 M_{\rm eff}$
7. Tranverse mass $M_T > 100$ GeV, using the hardest τ and $E_T^{\rm miss}$

b -jet analysis

1. At least four jets with $p_T > 50$ GeV
2. at least one of which must have $p_T > 100$ GeV
3. $E_T^{\rm miss} >$ 100 GeV
4. $E_T^{\rm miss} > 0.2 M_{\rm eff}$
5. Transverse sphericity $S_T > 0.2$
6. At least two jets tagged as b -jets