MSSM Model Generation and Parameter Scans: A Consumer Report

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Outline

- Scanning the pMSSM
- LHC SUSY searches
- Monte Carlo issues

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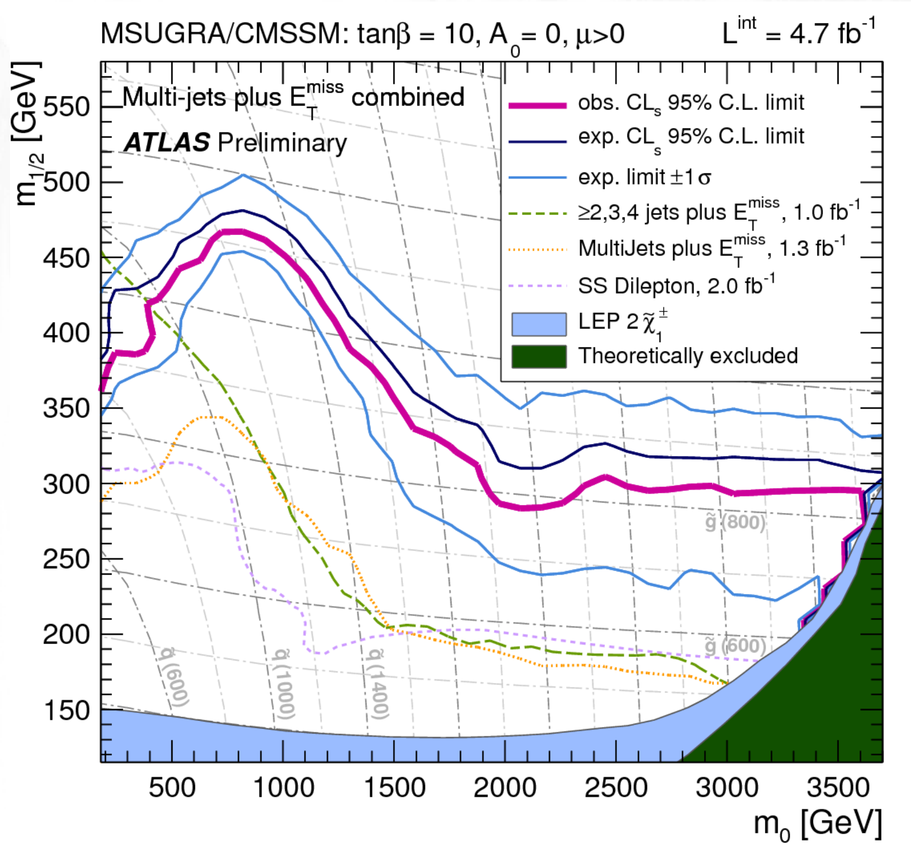


- The MSSM has many free parameters
- mSUGRA doesn't tell the whole story
- Tradeoff between generality and coverage

- Our approach: impose only experimentally motivated constraints on the full MSSM parameter space → phenomenological MSSM
- Minimal flavor violation, no new CP-violating phases, first two generations of sparticles degenerate
- 19 weak scale parameters relevant for colliders
- M_1, M_2, M_3, μ, tan β, M_A, $q_{1,3}$, $u_{1,3}$, $d_{1,3}$, $l_{1,3}$, $e_{1,3}$, $A_{t,b,\tau}$
- Generate random points in this parameter space, and test against experimental constraints (cf. Berger, Gainer, Hewett, Rizzo)

Scan ranges

- 50 GeV ≤ $|M_1|$ ≤ 4 TeV
- 100 GeV ≤ $|M_2, \mu|$ ≤ 4 TeV
- 400 GeV ≤ M_3 ≤ 4 TeV
- 1 ≤ $\tan\beta$ ≤ 60
- 100 GeV ≤ M_A ≤ 4 TeV
- 400 GeV ≤ q_1, u_1, d_1 ≤ 4 TeV, 200 GeV ≤ q_3, u_3, d_3 ≤ 4 TeV
- 100 GeV ≤ l, e ≤ 4 TeV
- $|A_{t,b,\tau}|$ ≤ 4 TeV

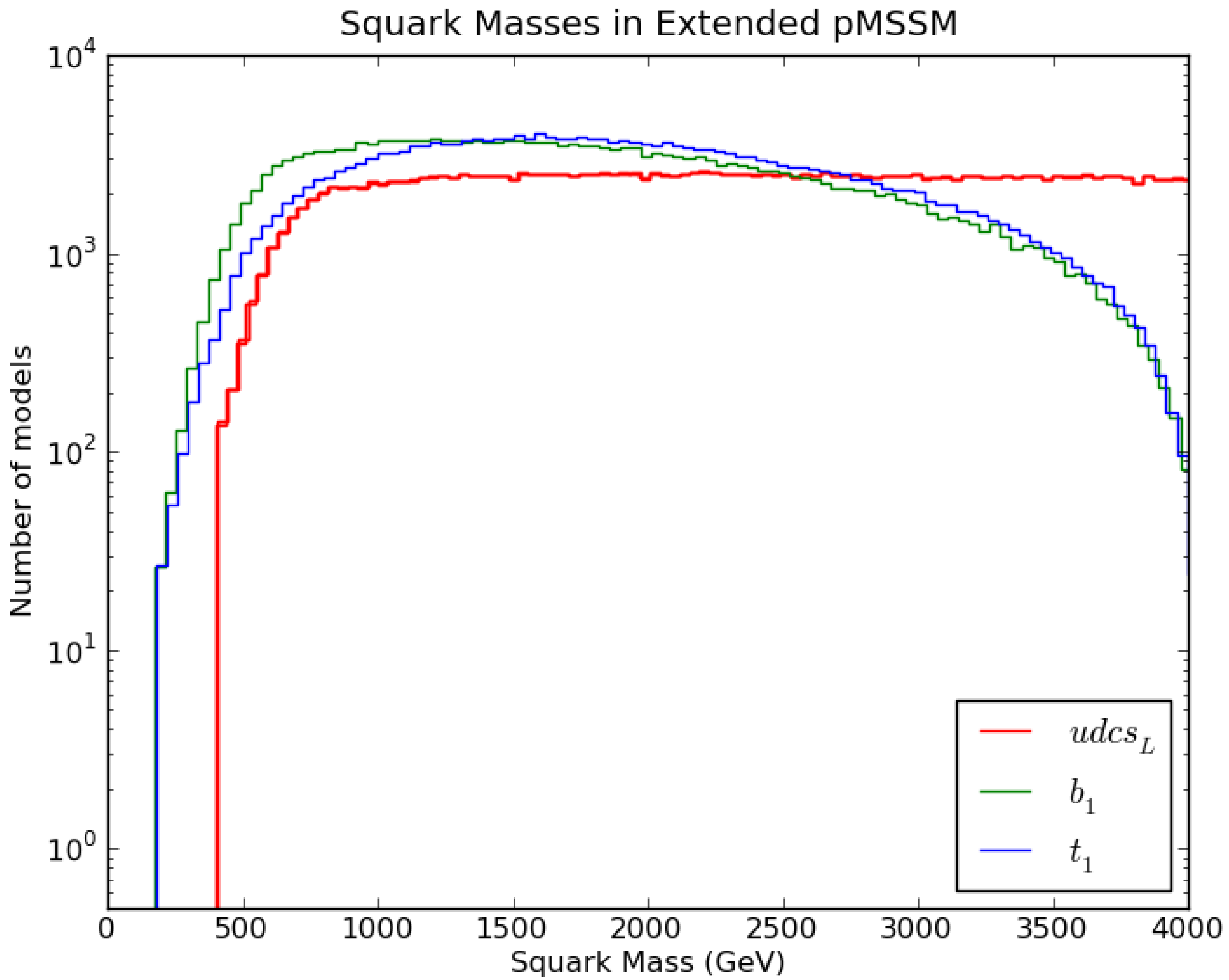
Neutralino LSP

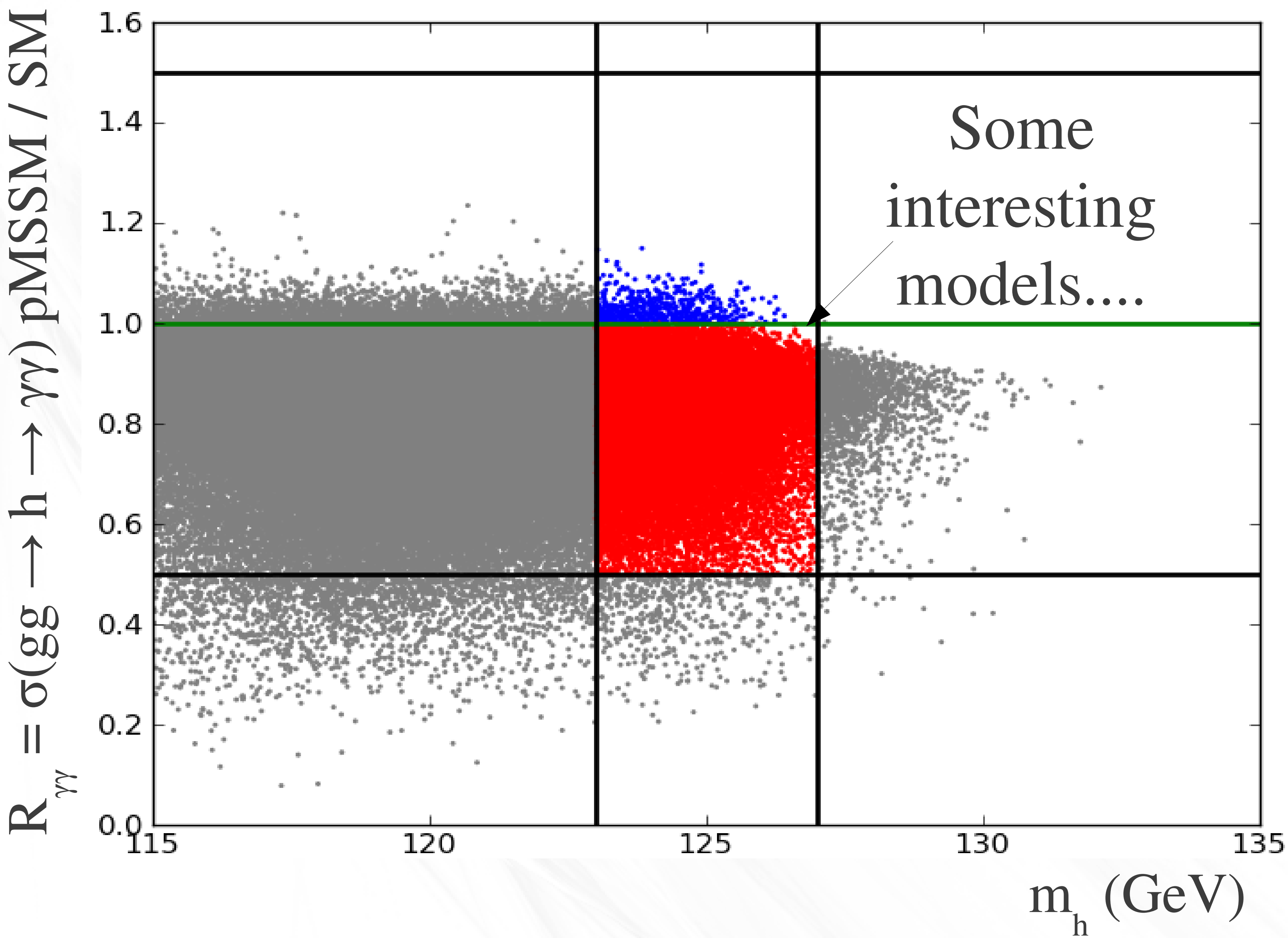
- Generate spectra for $3 \cdot 10^6$ points with SOFTSUSY, compare with SuSpect, decay with S(H)DECAY (do small mass splittings "by hand")
- Throw away models with tachyons, color/charge breaking minima, unbounded scalar potentials
- Require lightest neutralino to be LSP, and impose upper bound on its thermal relic density
- Check against DM direct detection, precision, flavor, LEP, Tevatron measurements

$2.2 \cdot 10^5$ remaining models

- All charged sparticles > 100 GeV
- Impose LHC stable particle, $\phi \to \tau\tau$ constraints

Can study resulting models....





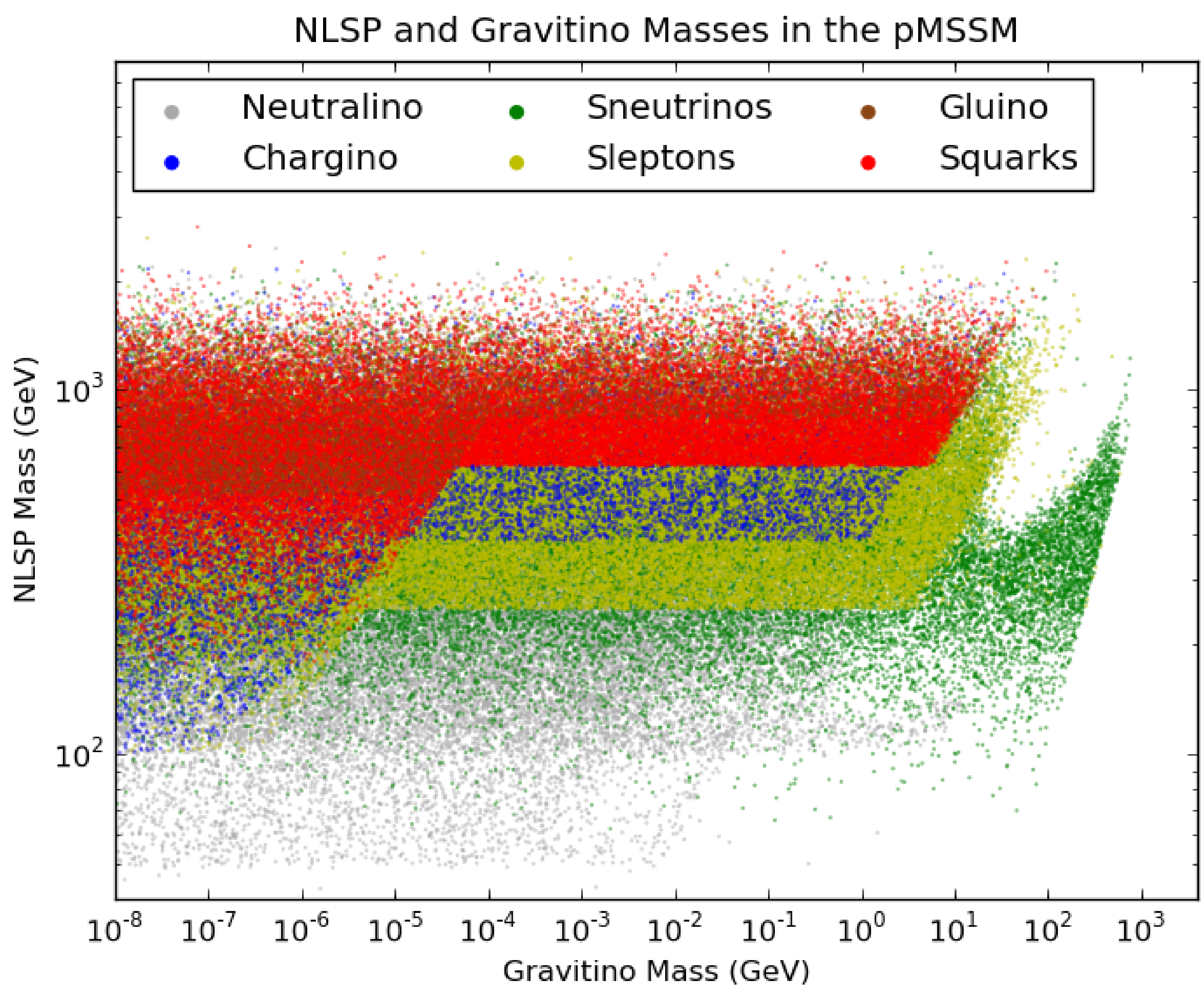
$R_{\gamma\gamma} = \sigma(gg \to h \to \gamma\gamma)$ pMSSM / SM
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
115
120
125
130
135
m_h (GeV)
Some interesting models....

Gravitino LSP

- One additional parameter: gravitino mass scanned with log prior from 1 eV to 1 TeV
- No assumption about reheating
- Require gravitino to be LSP
- Impose upper bound on gravitino relic density from non-thermal production through decay of thermal relic NLSP
- NLSP is generally long-lived, so stable particle searches become important as well
- BBN constraints

Gravitino LSP

- Often couldn't rely on existing MSSM codes, particularly for decay tables
- Many possibilities for long-lived NLSP
- Decays involving gravitinos in existing codes tend to be either missing or assume massless gravitinos
- CalcHEP and MadGraph used for many modes not included in standard codes like SDECAY


NLSP and Gravitino Masses in the pMSSM
Neutralino
Sneutrinos
Gluino
Chargino
Sleptons
Squarks
NLSP Mass (GeV)
10^3
10^2
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
Gravitino Mass (GeV)

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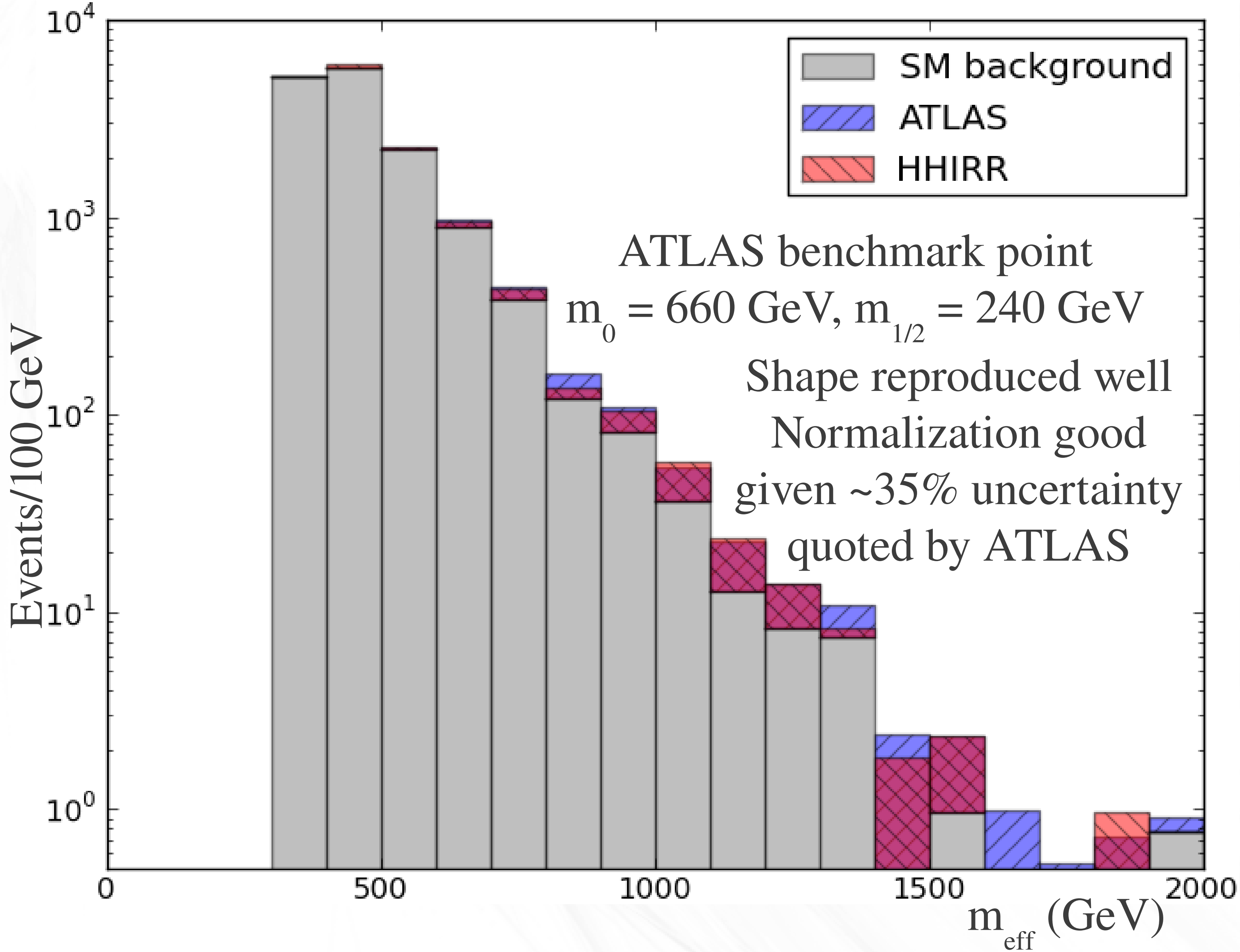
ATLAS searches

- Generate SUSY events for each neutralino LSP model with PYTHIA, scale with K-factors from Prospino, pass through PGS
- Analysis code based on 1009.2539, 1103.1697 (Conley, Gainer, Hewett, Le, Rizzo)
- 1/fb: jets + MET, many jets, one/two leptons
- 5/fb: jets + MET, many jets, one lepton; updated signal regions

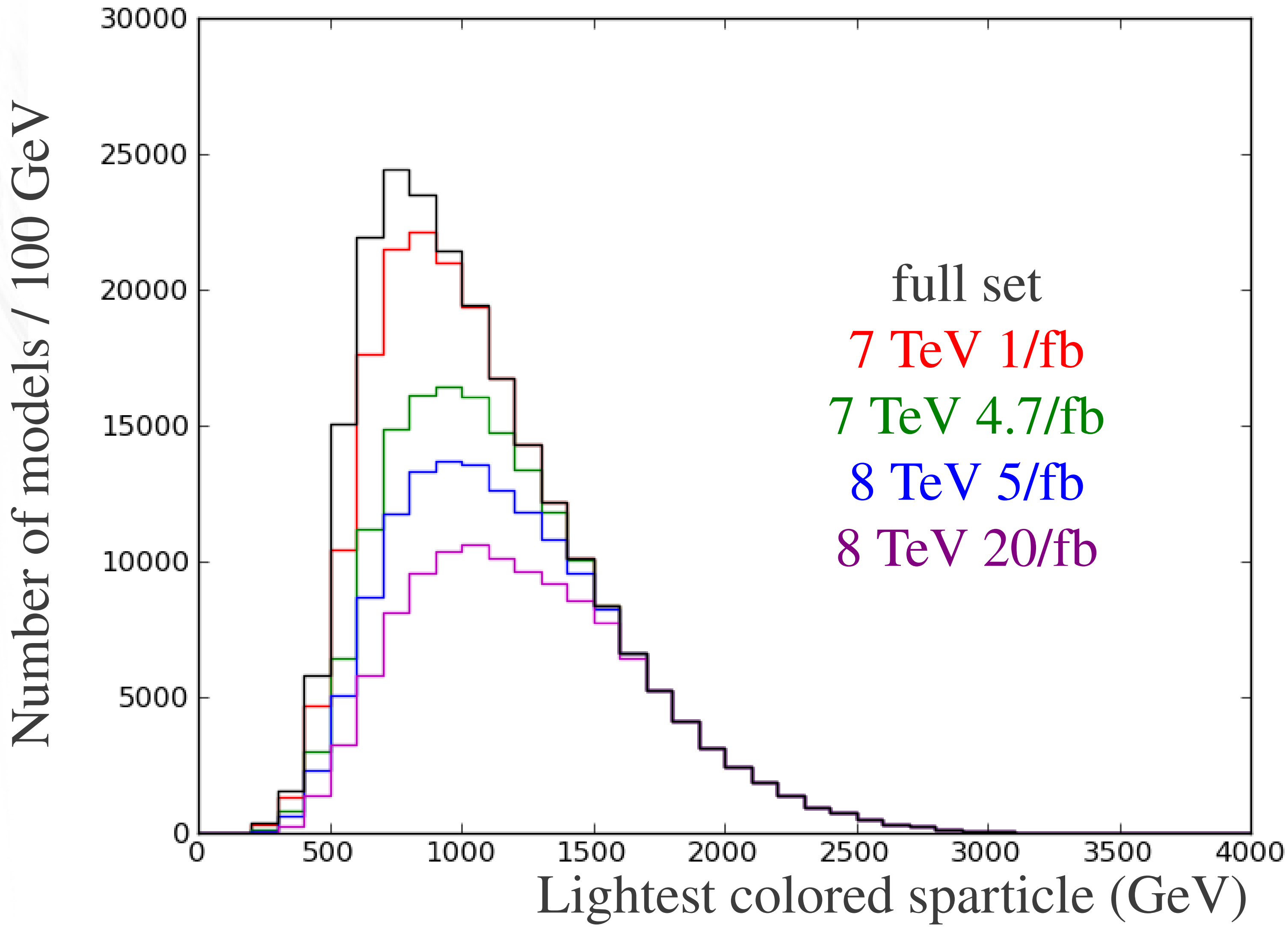


SM background
ATLAS
HHIRR
ATLAS benchmark point
m0 = 660 GeV, m1/2 = 240 GeV
Shape reproduced well
Normalization good
given ~35% uncertainty
quoted by ATLAS
Events/100 GeV
meff (GeV)
10^0
10^1
10^2
10^3
10^4
0
500
1000
1500
2000

ATLAS searches

- Also: generate 8 TeV events to estimate 2012 LHC performance
- Scale up 7 TeV backgrounds to 8 TeV in each search region, assuming cuts do not change, by “transfer factors” arrived at through simulating backgrounds at both energies with SHERPA 1.4.0, using ME+PS merging (0903.1219)
- Results provide a preliminary estimate of the eventual power of 8 TeV SUSY searches

Results



30000
25000
20000
15000
10000
5000
0
0
500
1000
1500
2000
2500
3000
3500
4000
Number of models / 100 GeV
Lightest colored sparticle (GeV)
full set
7 TeV 1/fb
7 TeV 4.7/fb
8 TeV 5/fb
8 TeV 20/fb

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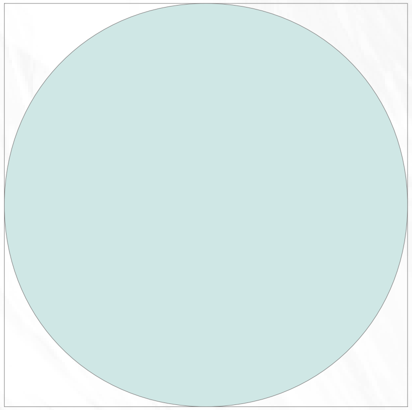
The curse of dimensionality

79% of circle in square



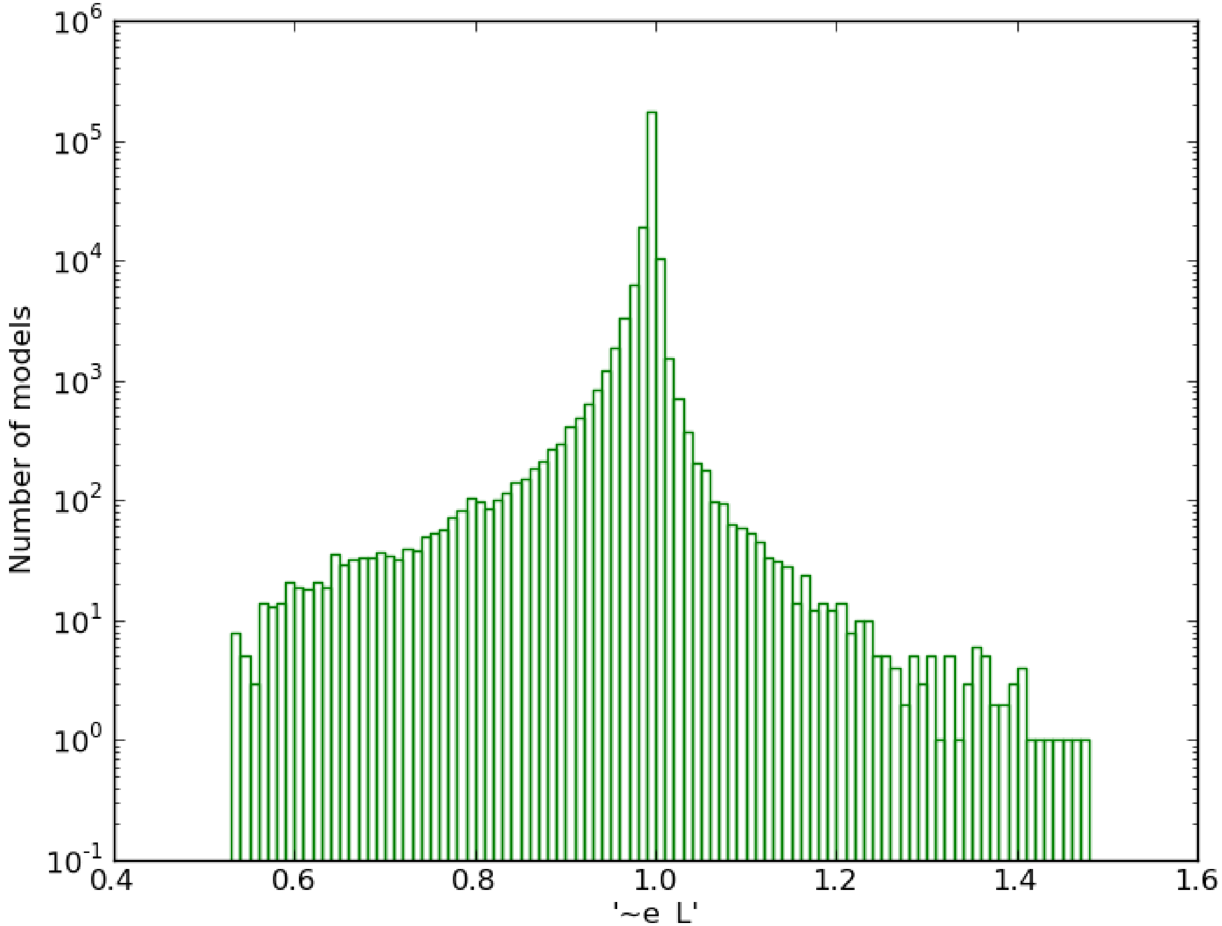
52% of sphere in cube

- As the dimension of a parameter space increases, randomly chosen points tend to be in corners
- Most of our points are “extreme” in some way

Monte Carlo issues

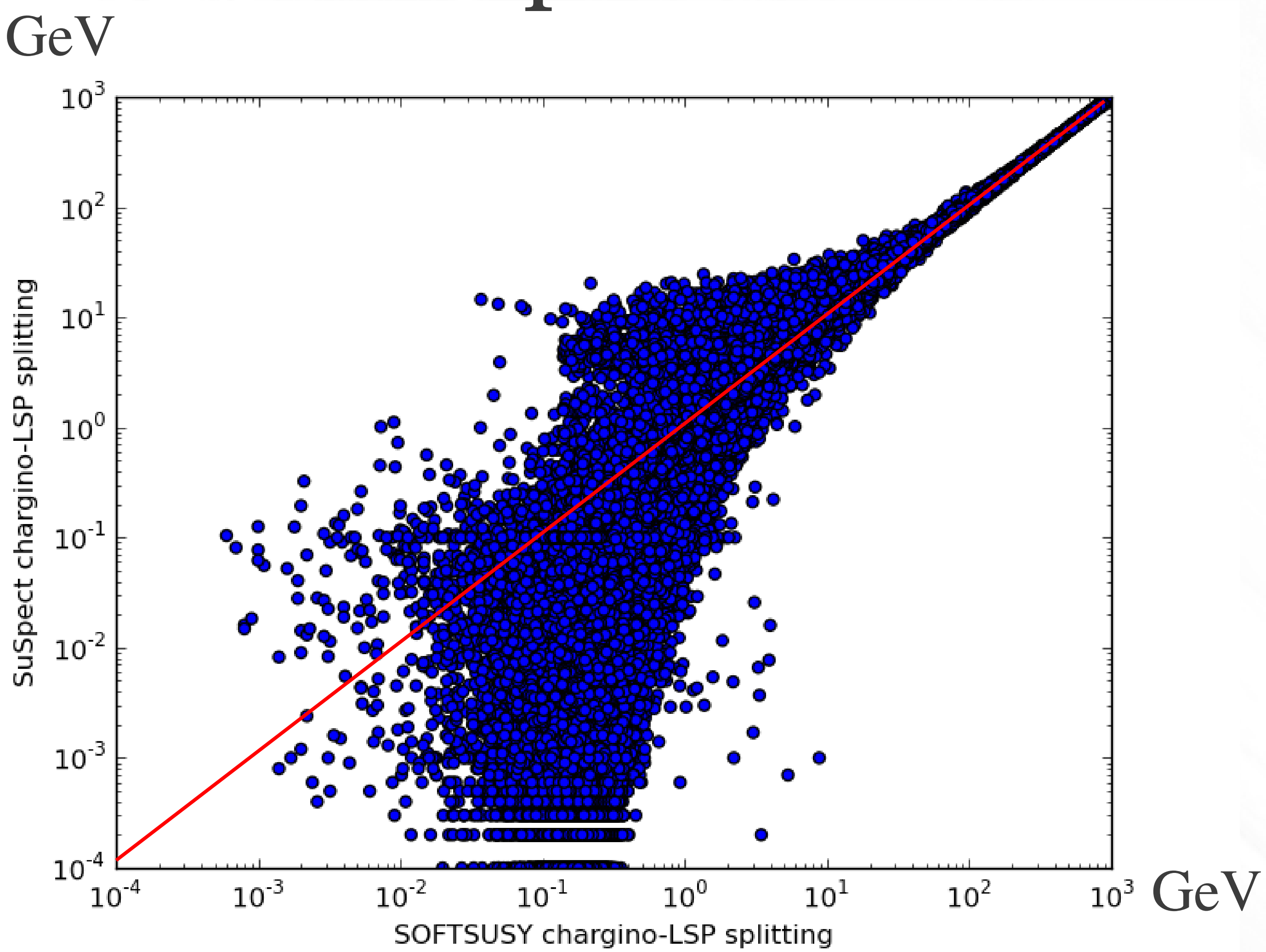
- We are able to thoroughly test various Monte Carlo tools by looking in corners of parameter space
- We find various incongruities in spectrum generators, cross section calculators, and detector simulations
- While we have considered the MSSM, many of our findings are more general, and should be useful for those doing MC with other theories

Issue 1: Spectrum generator discrepancies

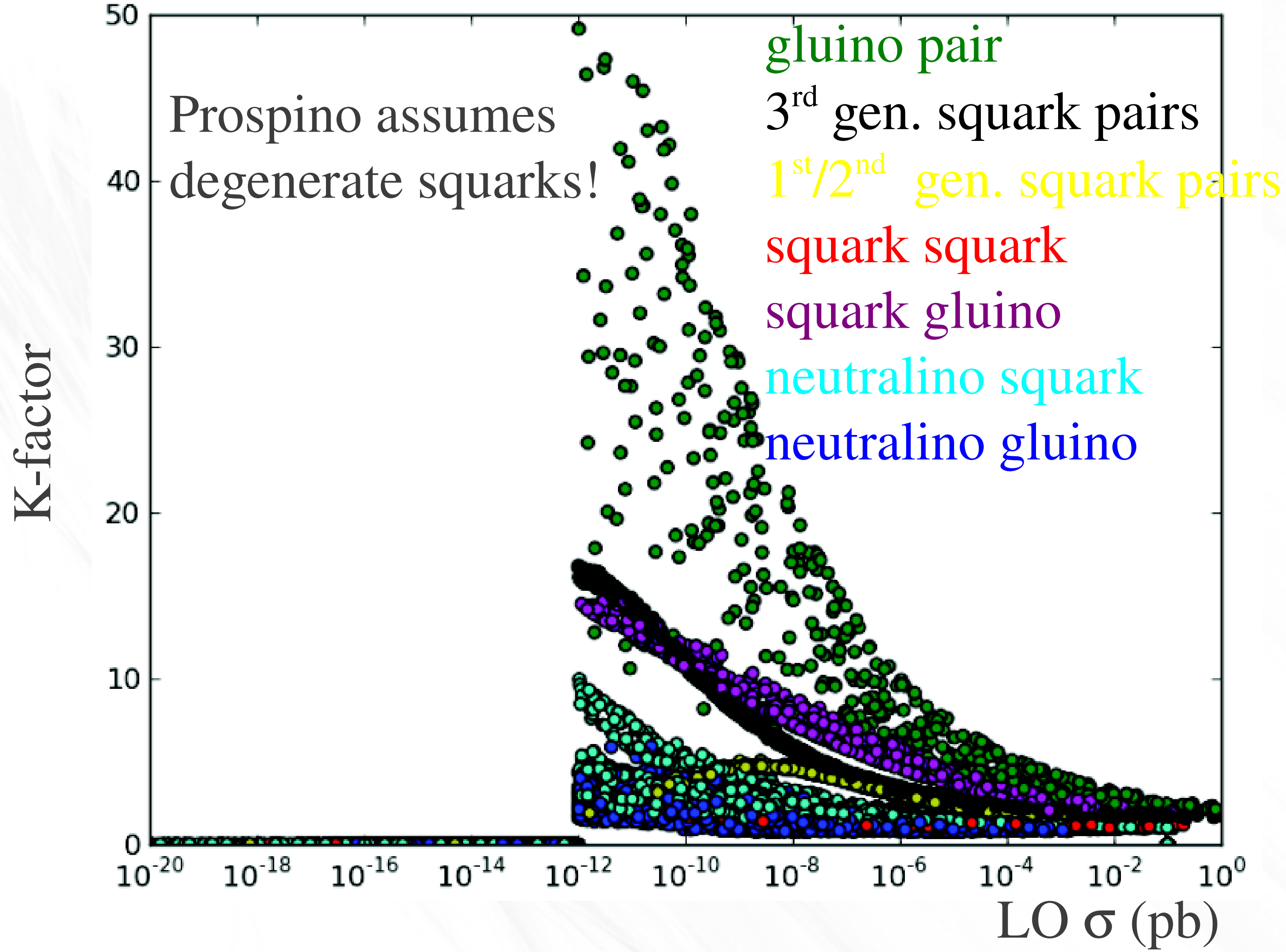


SuSpect/SOFTSUSY

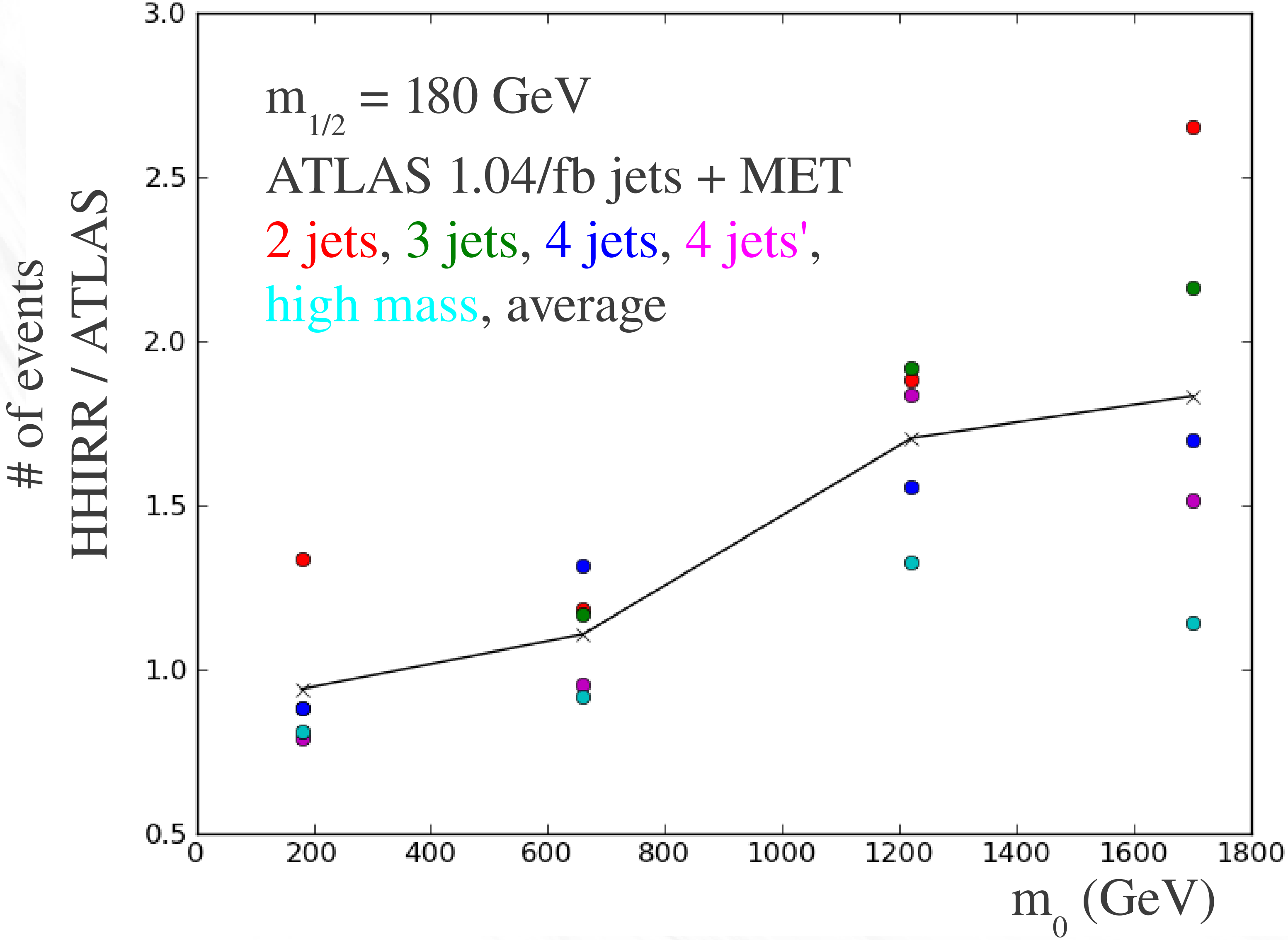
Issue 1: Spectrum generator discrepancies



Issue 2: NLO instability



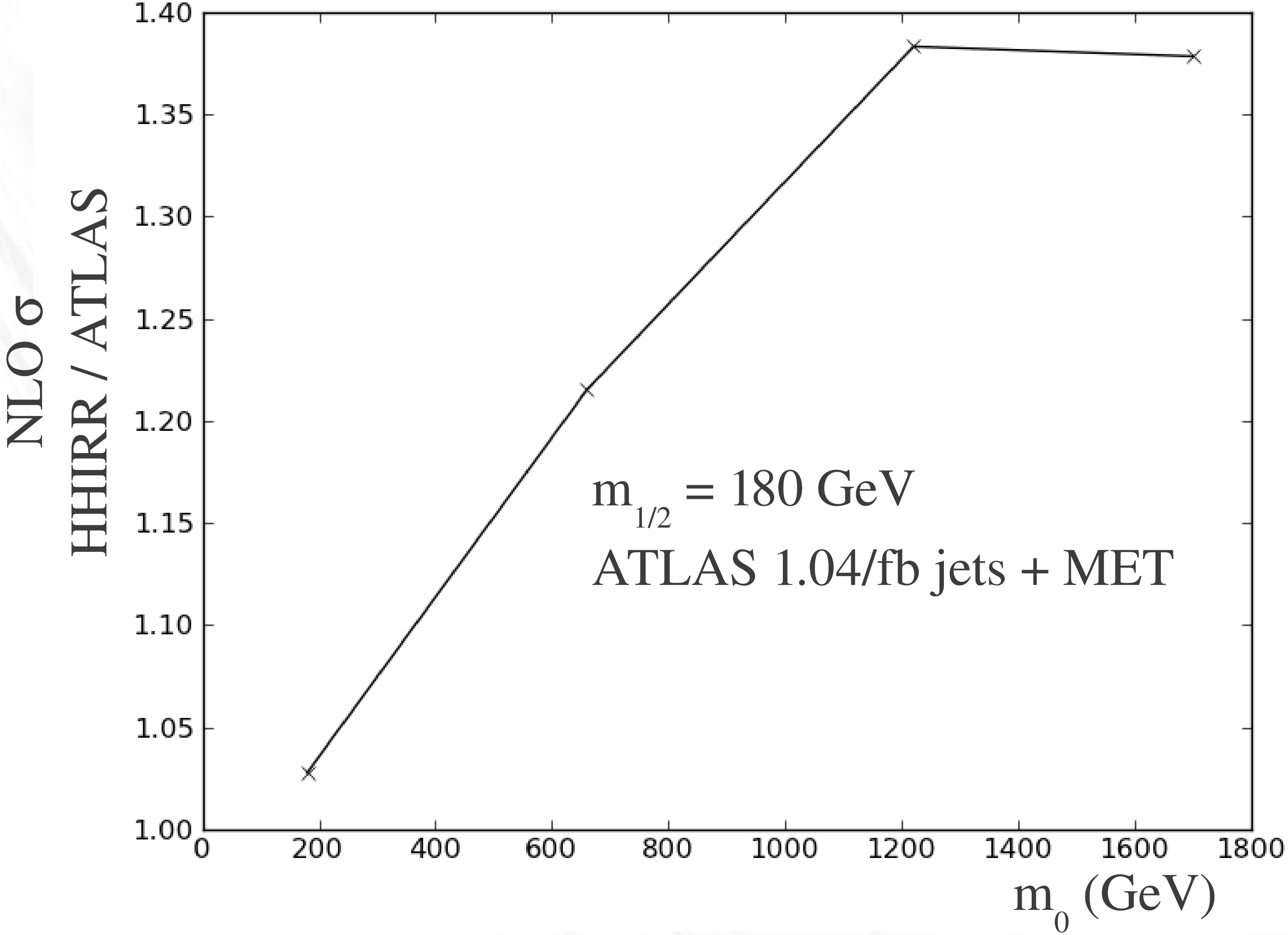
Issue 3: Validation



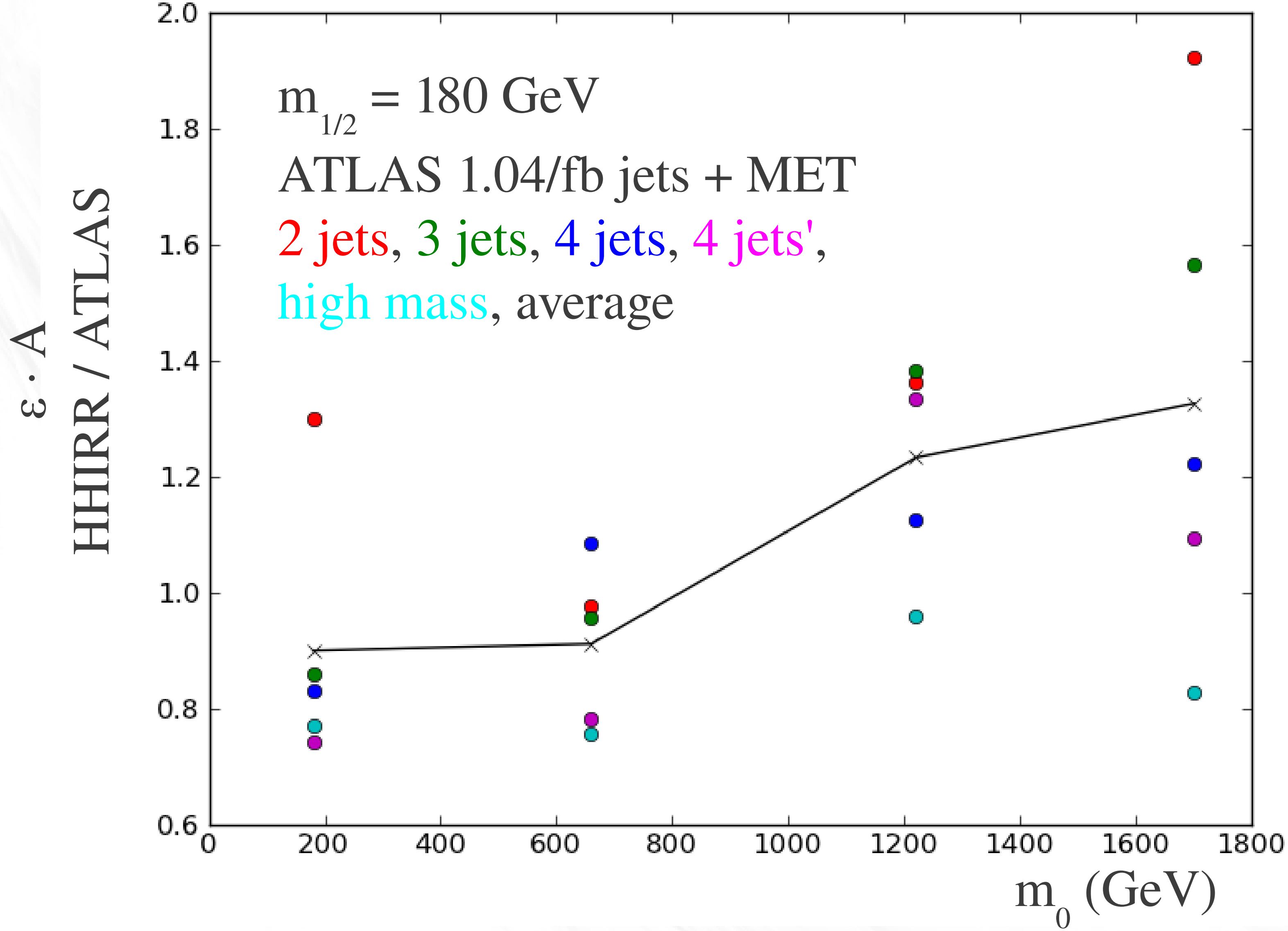
Validation: the dark side

- High numbers of signal events for benchmark models with heavy squarks
- Could be cross section (PYTHIA), NLO K-factor (Prospino), or detector acceptance (PGS)
- Some of these issues do not pose immediate problems for non-MSSM theories, but others do!
- We use PYTHIA + Prospino + PGS, while ATLAS uses HERWIG++ + Prospino + Geant4

Cross section is doing something...



...but acceptance is off as well!



Lessons learned

- Uncertainty in generating BSM events
- Public fast detector simulations are not necessarily able to produce accurate event counts in LHC signal regions
- Even production cross sections for a well-studied model like the MSSM can vary significantly between different codes
- Problems show up in the corners of parameter space—test your programs there!

Outlook

- The pMSSM is a much more general framework than mSUGRA for studying the MSSM at the LHC
- Future directions: keeping up with the LHC SUSY analyses, detailed stable particle searches with a whole new set of MC issues
- Generating events is relatively painless, but there are potential issues with cross sections and detector simulation, which are relevant to all using these tools

DELPHES issues

1202.6244, Strübig et al.

m_0	$m_{1/2}$		A	B	C	D	E
			Accepted fraction of signal events per signal region				
340	120	ATLAS	0.001	0.002	0.08	0.002	0.003
		DELPHES	0.002±0.0004	0.003±0.0005	0.06±0.003	0.003±0.0005	0.004±0.0006
	300	ATLAS	0.1	0.13	0.19	0.11	0.09
		DELPHES	0.15±0.004	0.14±0.004	0.16±0.004	0.1±0.003	0.06±0.003
	450	ATLAS	0.27	0.26	0.23	0.2	0.15
		DELPHES	0.33±0.006	0.27±0.005	0.18±0.004	0.17±0.004	0.11±0.003
1140	120	ATLAS	0.002	0.003	0.08	0.004	0.004
		DELPHES	0.003±0.0006	0.004±0.0006	0.06±0.002	0.004±0.0006	0.003±0.0005
	300	ATLAS	0.05	0.07	0.13	0.08	0.14
		DELPHES	0.05±0.002	0.07±0.003	0.1±0.003	0.07±0.003	0.09±0.003
	450	ATLAS	0.12	0.16	0.18	0.16	0.2
		DELPHES	0.09±0.003	0.09±0.003	0.08±0.003	0.08±0.003	0.1±0.003
2500	120	ATLAS	0.0001	0.002	0.07	0.002	0.003
		DELPHES	0.001±0.0003	0.002±0.0004	0.07±0.003	0.002 ±0.0004	0.003±0.0005
	300	ATLAS	0.02	0.05	0.12	0.07	0.11
		DELPHES	0.02±0.001	0.04±0.002	0.08±0.003	0.04±0.002	0.07±0.003
	360	ATLAS	0.03	0.07	0.13	0.08	0.15
		DELPHES	0.03±0.002	0.04±0.002	0.07±0.003	0.05±0.002	0.08±0.003