Implications of LHC Searches
on SUSY Particle Spectra with pMSSM Scans

Neutralino Dark Matter and Light Neutralino Dark Matter

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with contributions by
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LPCC Workshop
Implications of LHC Results for TeV-scale Physics
CERN, August 30th, 2011

pMSSM Scans

| Parameter	Range
$\tan\beta$	[1, 60]
M_A	[50, 2000]
M_1	[-2500, 2500]
M_2	[-2500, 2500]
M_3	[50, 2500]
$A_d = A_s = A_b$	[-2000, 2000]
$A_u = A_c = A_t$	[-2000, 2000]
$A_e = A_\mu = A_\tau$	[-2000, 2000]
μ	[-1000, 2000]
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[50, 2500]
$M_{\tilde{e}_R} = M_{\tilde{\mu}_R}$	[50, 2500]
$M_{\tilde{\tau}_L}$	[50, 2500]
$M_{\tilde{\tau}_R}$	[50, 2500]
$M_{\tilde{q}_{1L}} = M_{\tilde{q}_{2L}}$	[50, 2500]
$M_{\tilde{q}_{3L}}$	[50, 2500]
$M_{\tilde{u}_R} = M_{\tilde{c}_R}$	[50, 2500]
$M_{\tilde{t}_R}$	[50, 2500]
$M_{\tilde{d}_R} = M_{\tilde{s}_R}$	[50, 2500]
$M_{\tilde{b}_R}$	[50, 2500]

Flat scan of 19 pMSSM parameters:

presently have 10M pMSSM points generated

→ 903k valid MSSM spectra
      after mass limit cuts
→ 688k accepted after flavour cuts
→ 677k accepted after g-2 cut
→ 275k accepted after Ωh^2 cut
→ 273k simulated & analysed

In the process to increase statistics x 5

Parameter	Value
$\alpha_s(M_Z)$	0.1184
$\bar{m}_b(\bar{m}_b)$	4.19 GeV
m_t^{pole}	172.9 GeV

Software and Tools

| pMSSM Parameters | →.slha→ | SoftSUSY 3.1.7 | →.slha→ | PYTHIA 6.4.24 | →.hepmc→ | Delphes 1.9 |

pMSSM Parameters → .slha → SoftSUSY 3.1.7 → .slha → PYTHIA 6.4.24 → .hepmc → Delphes 1.9

FeynHiggs 2.8.4

Prospino 2.0

Delphes 1.9 → .root → ROOT Analyser

Sdecay 1.3

HiggsBounds 3.4.0

SuperIsoRelic 3.1

micrOMEGAs 2.4
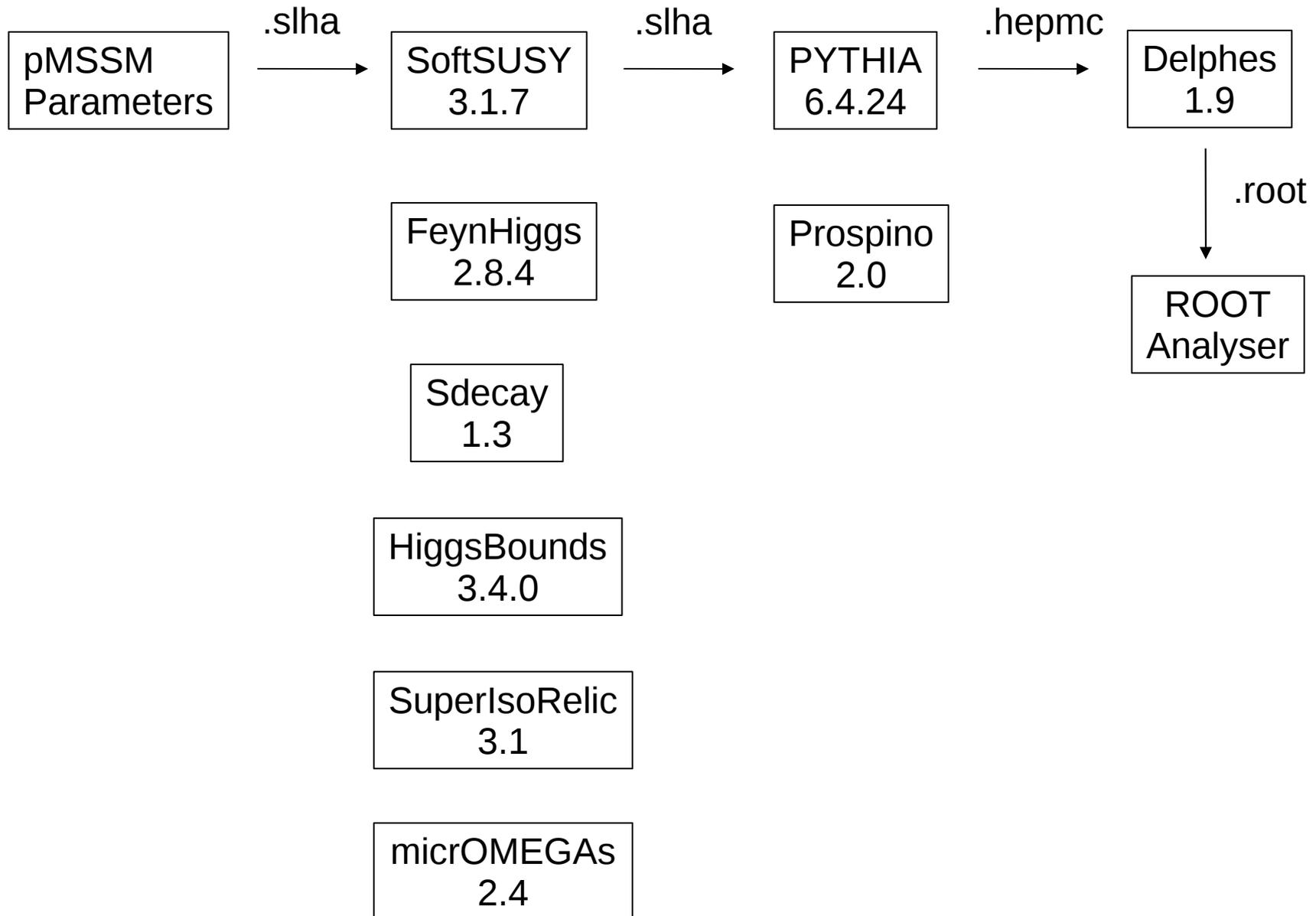
Constraints

Flavour Physics and Other Constraints

$$2.16 \times 10^{-4} < \mathrm{BR}(B \to X_s \gamma) < 4.93 \times 10^{-4}$$

$$\longrightarrow \quad \mathrm{BR}(B_s \to \mu^+ \mu^-) < 1.08 \times 10^{-8}$$

$$0.56 < \frac{\mathrm{BR}(B \to \tau \nu)}{\mathrm{BR}_{SM}(B \to \tau \nu)} < 2.70 \,,$$

$$4.7 \times 10^{-2} < \mathrm{BR}(D_s \to \tau \nu) < 6.1 \times 10^{-2} \,,$$
$$2.9 \times 10^{-3} < \mathrm{BR}(B \to D^0 \tau \nu) < 14.2 \times 10^{-3} \,,$$
$$0.985 < \mathrm{R}_{\ell 23}(K \to \mu \nu) < 1.013 \,.$$

$$-2.4 \times 10^{-9} < \delta a_\mu < 4.5 \times 10^{-9}$$

$$10^{-4} < \Omega_{DM} h^2 < 0.135$$

Mass Limits from LEP and Tevatron

Particle	Limits	Conditions
χ_1^0	46	
χ_2^0	62.4	$\tan \beta < 40$
χ_3^0	99.9	$\tan \beta < 40$
χ_4^0	116	$\tan \beta < 40$
$\chi_1^\pm$	94	$\tan \beta < 40,\ m_{\chi_1^\pm} - m_{\chi_1^0} > 5$ GeV
$\tilde{e}_R$	73	
$\tilde{e}_L$	107	
$\tilde{\tau}_1$	81.9	$m_{\tilde{\tau}_1} - m_{\chi_1^0} > 15$ GeV
$\tilde{u}_R$	100	$m_{\tilde{u}_R} - m_{\chi_1^0} > 10$ GeV
$\tilde{u}_L$	100	$m_{\tilde{u}_L} - m_{\chi_1^0} > 10$ GeV
$\tilde{t}_1$	95.7	$m_{\tilde{t}_1} - m_{\chi_1^0} > 10$ GeV
$\tilde{d}_R$	100	$m_{\tilde{d}_R} - m_{\chi_1^0} > 10$ GeV
$\tilde{d}_L$	100	$m_{\tilde{d}_L} - m_{\chi_1^0} > 10$ GeV
$\tilde{b}_1$	248	$m_{\chi_1^0} < 70$ GeV, $m_{\tilde{b}_1} - m_{\chi_1^0} > 30$ GeV
	220	$m_{\chi_1^0} < 80$ GeV, $m_{\tilde{b}_1} - m_{\chi_1^0} > 30$ GeV
	210	$m_{\chi_1^0} < 100$ GeV, $m_{\tilde{b}_1} - m_{\chi_1^0} > 30$ GeV
	200	$m_{\chi_1^0} < 105$ GeV, $m_{\tilde{b}_1} - m_{\chi_1^0} > 30$ GeV
	100	$m_{\tilde{b}_1} - m_{\chi_1^0} > 5$ GeV
$\tilde{g}$	195	

Constraints

Fraction of accepted MSSM points (out of 270k valid points)
for the three sets of constraints applied vs. SUSY particle masses
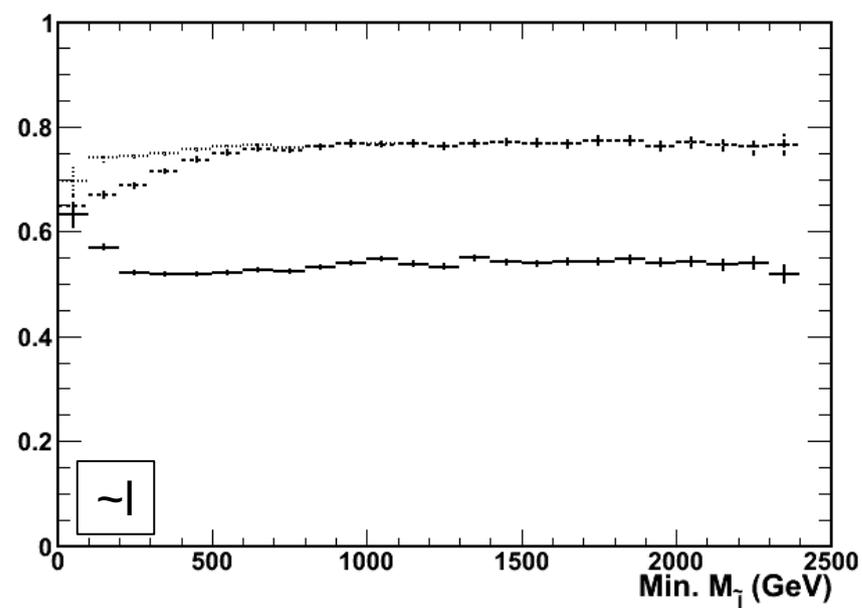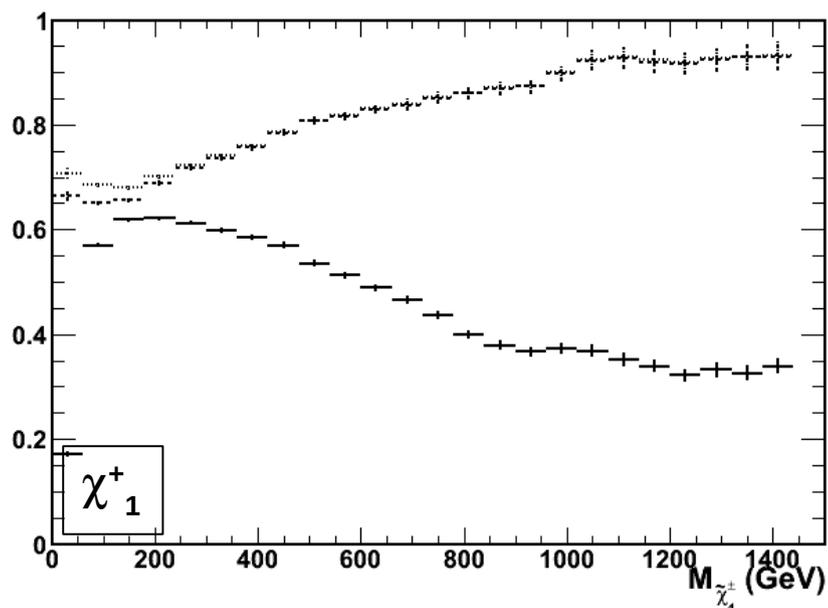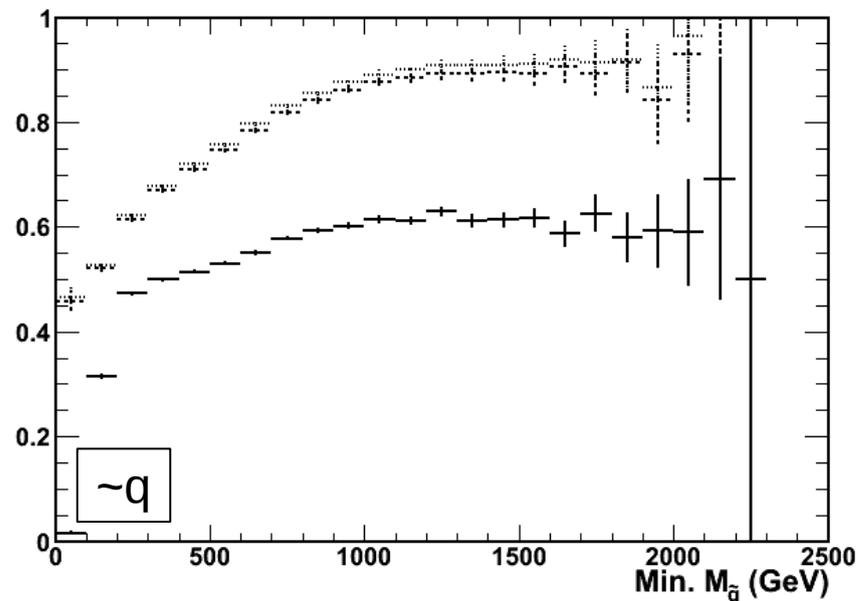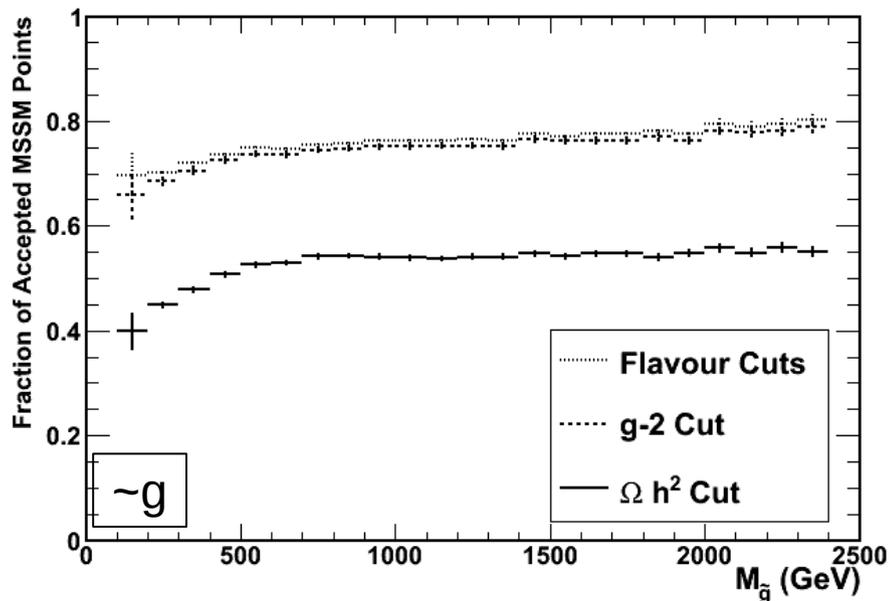
LHC Analysis Simulation and Validation

Implement three analyses presented by CMS at
<u>EPS 2011</u> on Delphes reconstructed objects:

- hadronic α_T
- same sign isolated di-leptons with jets
- opposite sign di-leptons

Count nb. of events in same signal regions as
CMS analyses, validate on CMSSM LM points
shape of discriminating observables and rates;

Use CMS estimated rates of SM backgrounds in
signal regions;

Obtain signal observability or 95% exclusion for
each point using CLs technique, assuming all signal
regions and three analyses as independent data sets.

Available on the CERN CDS information server   **CMS PAS SUS-11-003**

CMS Physics Analysis Summary

Contact: cms-pag-conveners-susy@cern.ch   2011/07/26

Search for supersymmetry in all-hadronic events with α_T

The CMS Collaboration

Available on the CERN CDS information server   **CMS PAS SUS-11-010**

CMS Physics Analysis Summary

Contact: cms-pag-conveners-susy@cern.ch   2011/07/23

Search for new physics with same-sign isolated dilepton
events with jets and missing energy

The CMS Collaboration

Available on the CERN CDS information server   **CMS PAS SUS-11-011**

CMS Physics Analysis Summary

Contact: cms-pag-conveners-susy@cern.ch   2011/07/23

Search for new physics in events with opposite-sign
dileptons and missing transverse energy

The CMS Collaboration

LHC Analysis Simulation and Validation
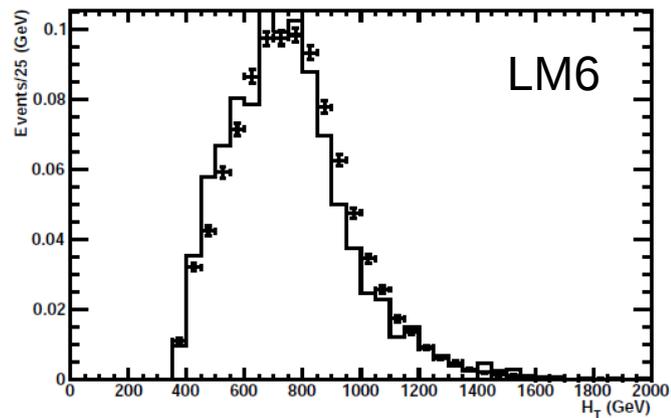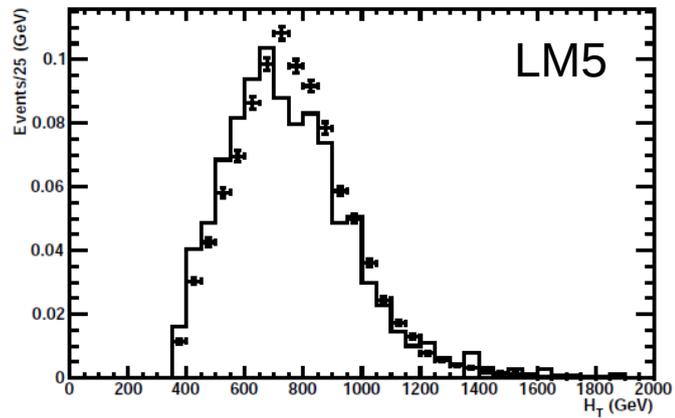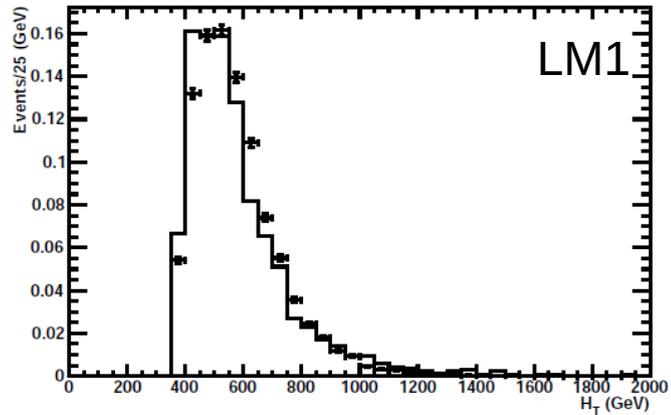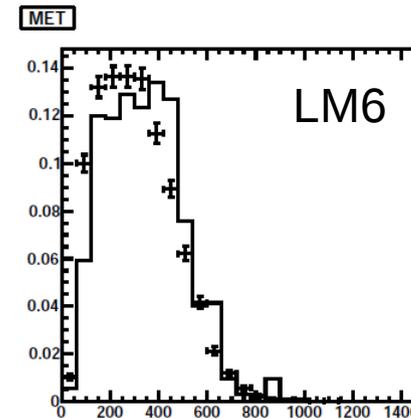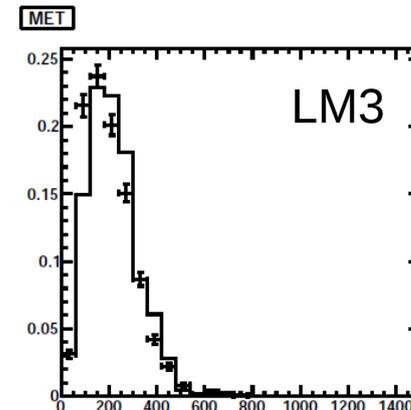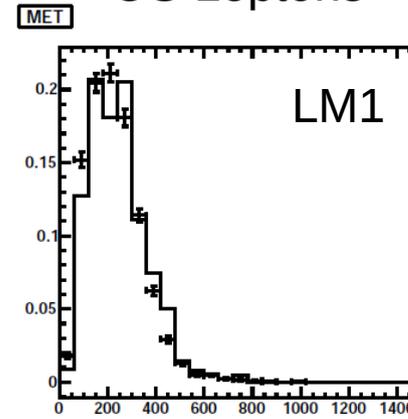
# LHC Analysis Simulation and Validation

Calculate 95% C.L. exclusion contours for 1 fb^{-1} and compare to expected contours from CMS simulation in the CMSSM m_0-$m_{1/2}$ plane for tan β = 10, sgn(μ)>0 and A=0. Comparison shows that sensitivity from our Delphes analysis agrees to better than 20% with that from full CMS simulation and reconstruction.
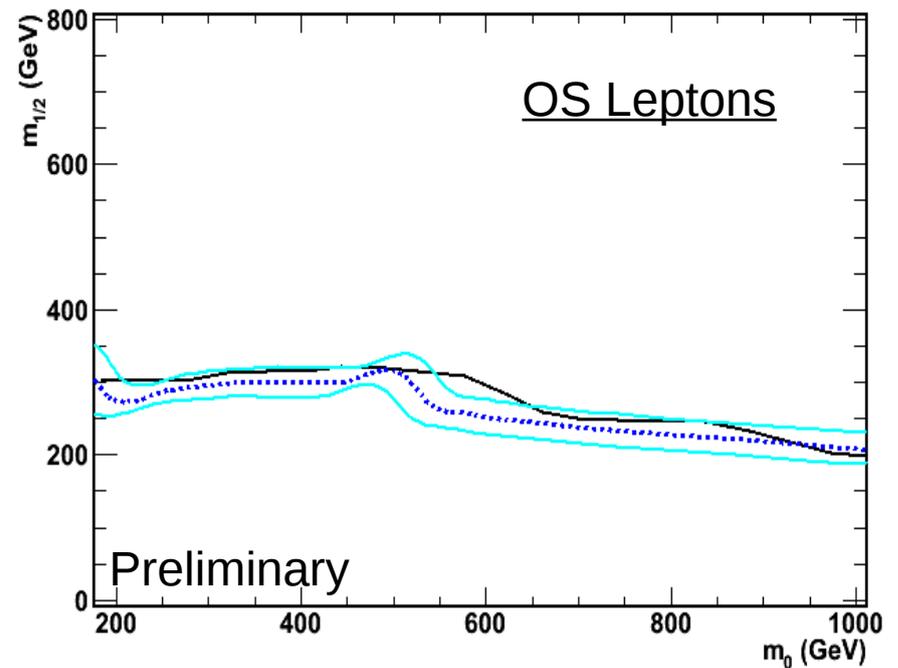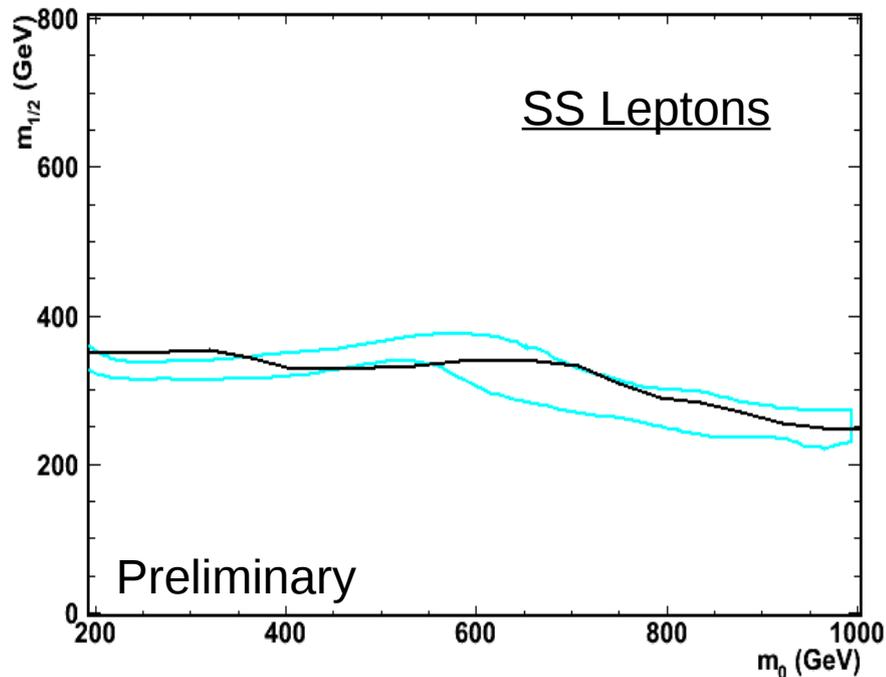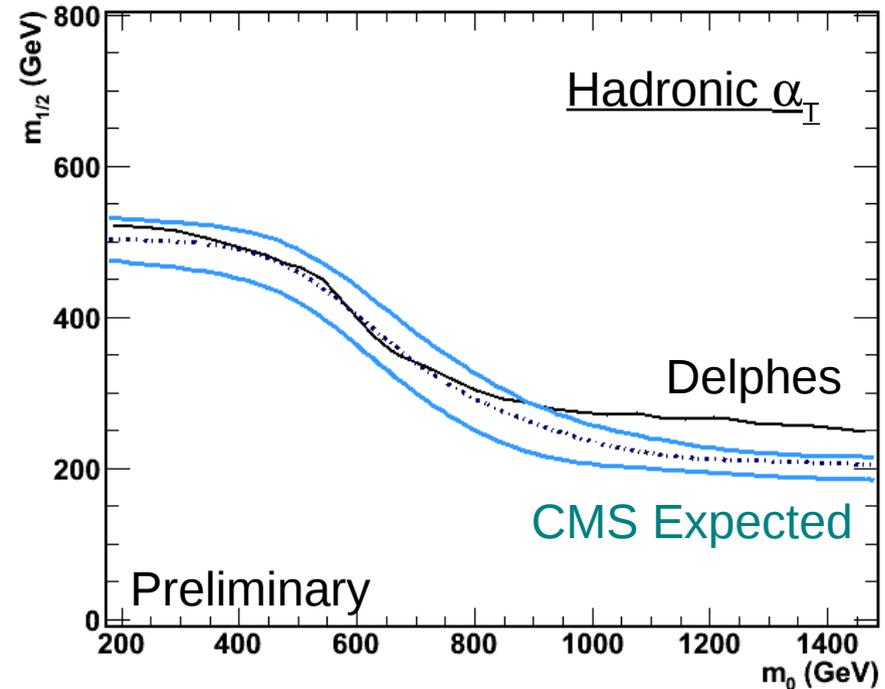
# The pMSSM Parameter Space
with Neutralino Dark Matter

LHC Limits and the Spectra of Strongly-interacting SUSY Particles
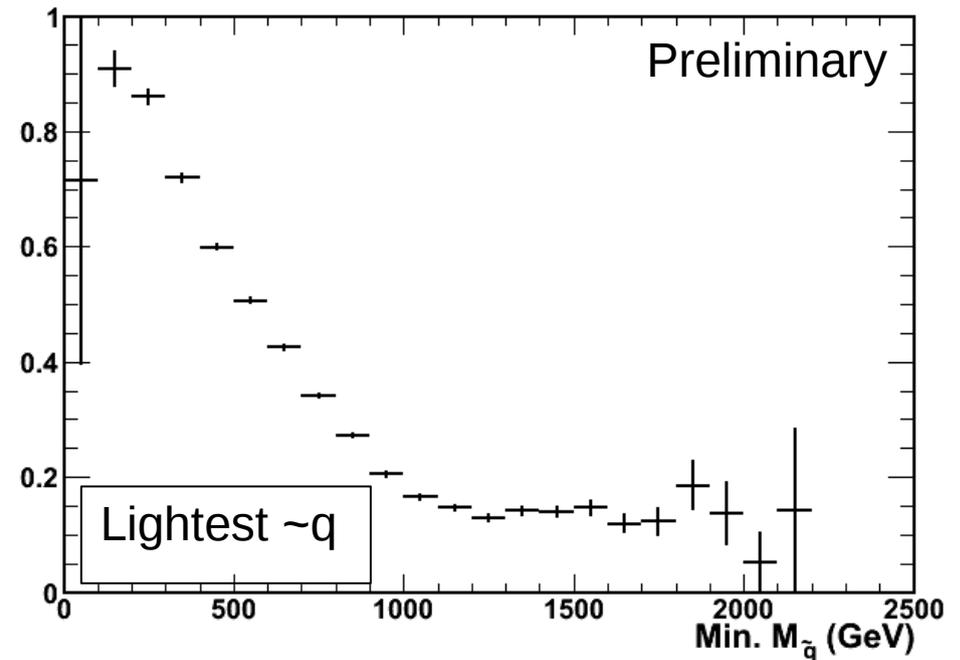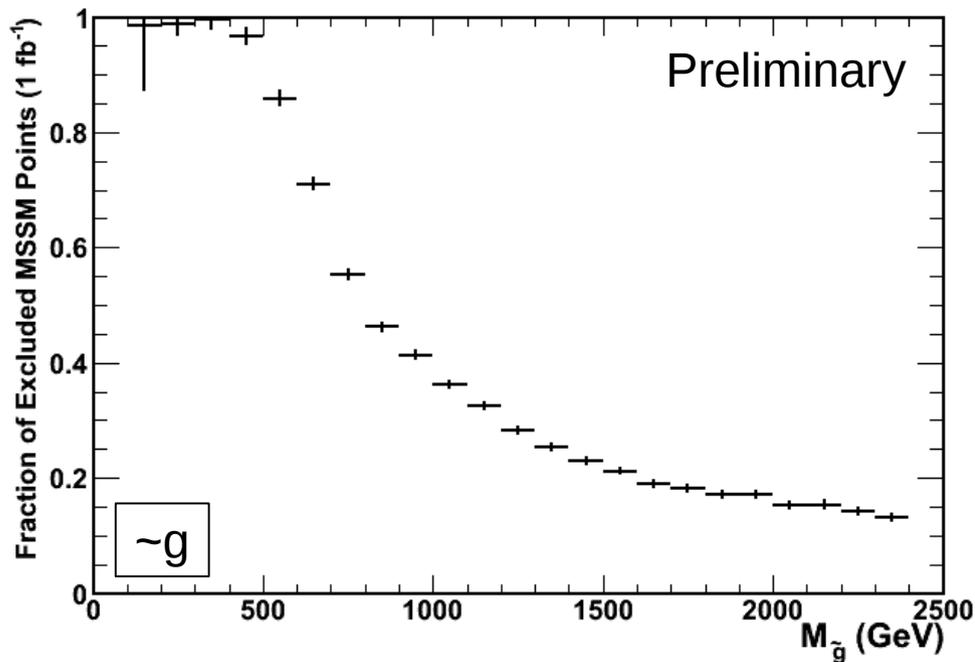
Characterise LHC limits as the fraction of MSSM points compatible with constraints which are excluded at 95% C.L. by simulated analyses plotted as a function of mass of various sparticles. For strongly-interacting sparticles this provides an indication of a "generic" mass limit.

The pMSSM Parameter Space with Neutralino Dark Matter

LHC Limits and inclusive NLO SUSY Cross Section
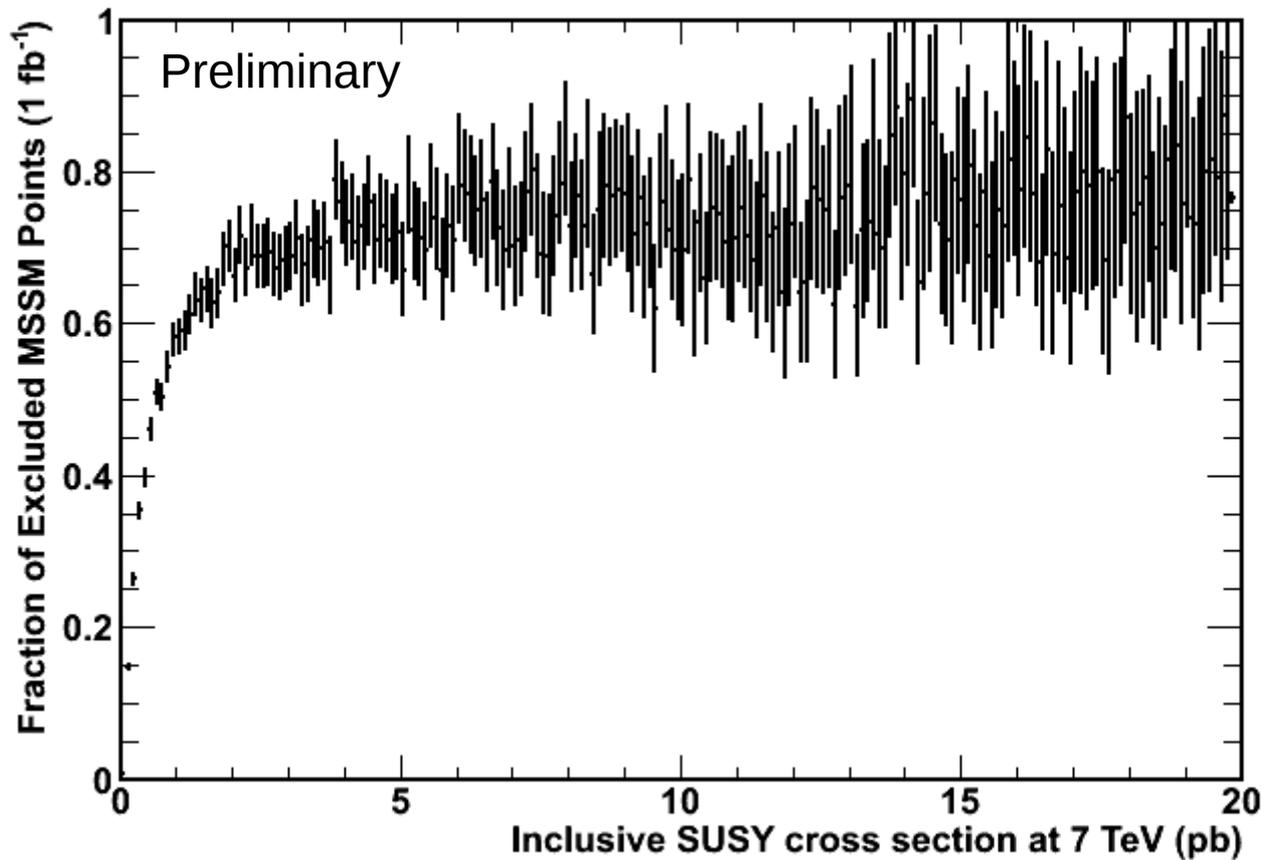
The pMSSM Parameter Space
with Neutralino Dark Matter

LHC Limits and the Spectra of Weakly-interacting SUSY Particles
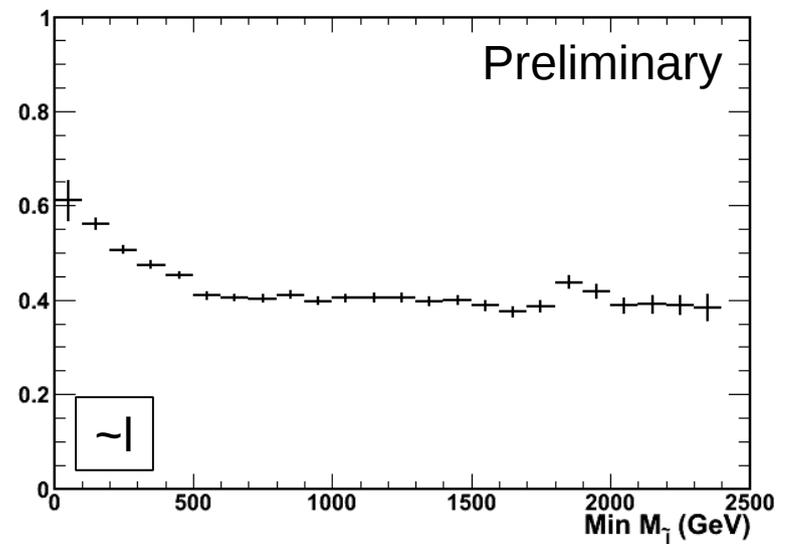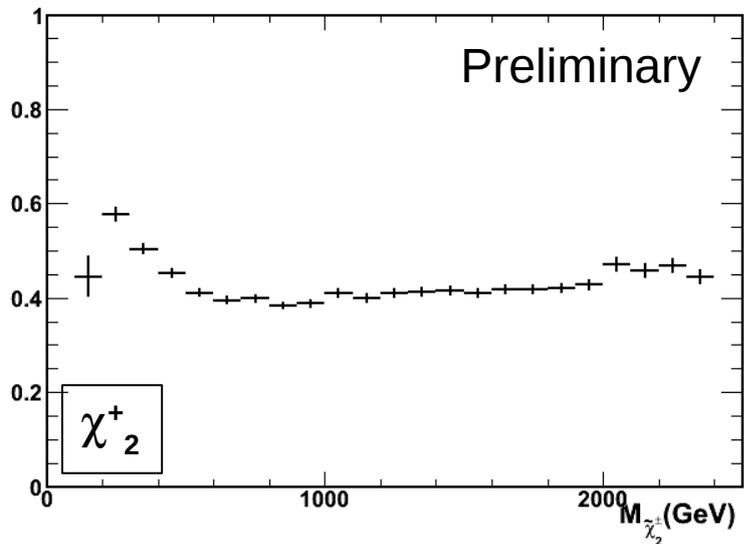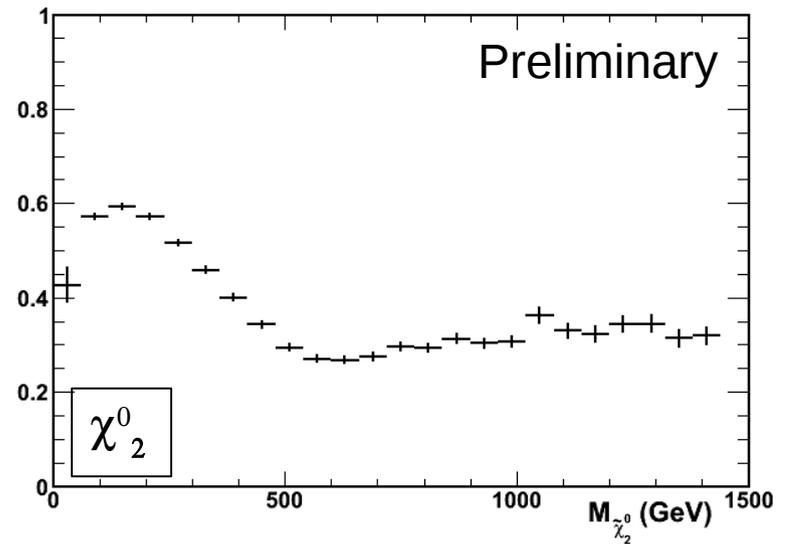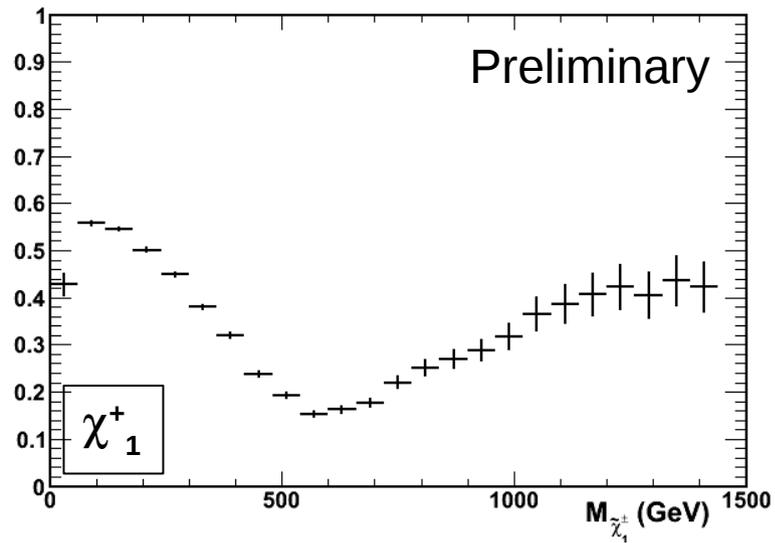
The pMSSM Parameter Space
with Neutralino Dark Matter
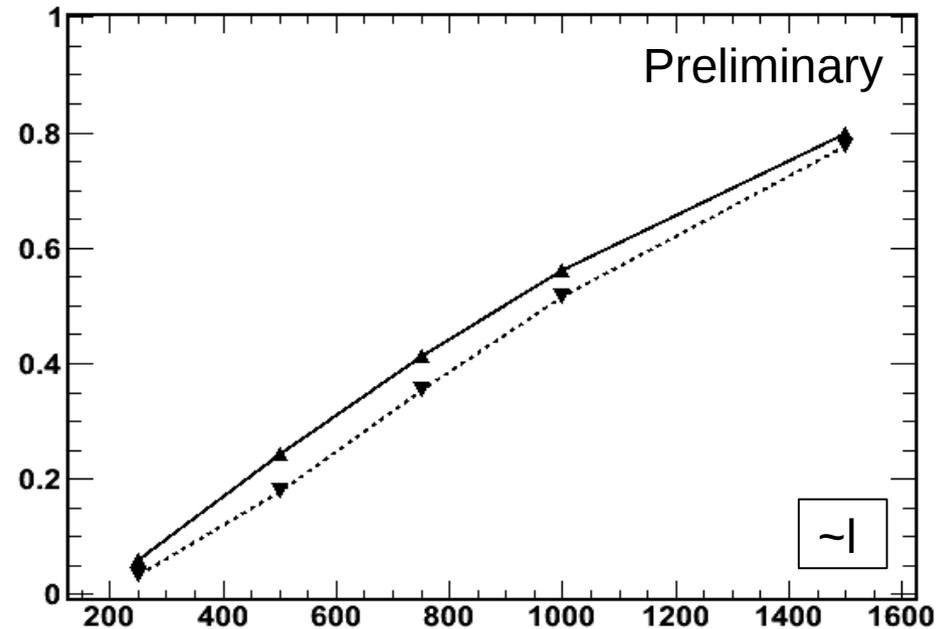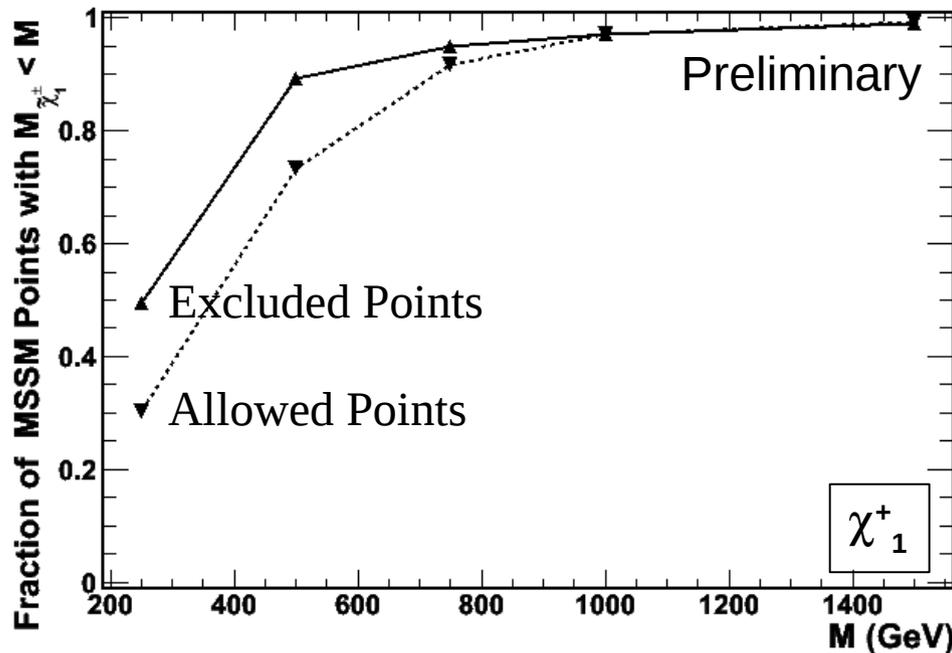
For weakly-interacting sparticles we derive information on the effect of the LHC limits to the allowed spectrum of each SUSY particle. We observe that the domain of SUSY particle masses > 400 GeV is virtually unaffected by the present LHC data.

The pMSSM Parameter Space
with Light Neutralino Dark Matter

Study scenarios with light χ^0_1 and large χp cross section in pMSSM corresponding to region highlighted by DAMA and CoGeNT results;

Dedicated 20M point scan to explore light χ^0_1 and large scattering cross sections (computed with micrOMEGAs):

Additional constraints: $m_{\tilde{\chi}^0_1} < 20$ GeV and $\sigma_p^{SI} > 10^{-6}$pb

→ 58k accepted points
→ 20k accepted after mass limit cuts
→ 1k accepted after flavour cuts
→ 140 accepted after Ωh^2 cut

Parameter	Range
$\tan \beta$	[1, 60]
M_A	[50, 2000]
M_1	[-120, 120]
M_2	[-650, 650]
M_3	[0, 2000]
$A_d = A_s = A_b$	[-2000, 2000]
$A_u = A_c = A_t$	[-2000, 2000]
$A_e = A_\mu = A_\tau$	[-2000, 2000]
μ	[-1000, 2000]
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[50, 2500]
$M_{\tilde{e}_R} = M_{\tilde{\mu}_R}$	[50, 2500]
$M_{\tilde{\tau}_L}$	[50, 2500]
$M_{\tilde{\tau}_R}$	[50, 2500]
$M_{\tilde{q}_{1L}} = M_{\tilde{q}_{2L}}$	[50, 2500]
$M_{\tilde{q}_{3L}}$	[50, 2500]
$M_{\tilde{u}_R} = M_{\tilde{c}_R}$	[50, 2500]
$M_{\tilde{t}_R}$	[50, 2500]
$M_{\tilde{d}_R} = M_{\tilde{s}_R}$	[50, 2500]
$M_{\tilde{b}_R}$	

The pMSSM Parameter Space
with Light Neutralino Dark Matter

χ-p Cross Section vs. χ Mass from
Low Mass pMSSM Scans
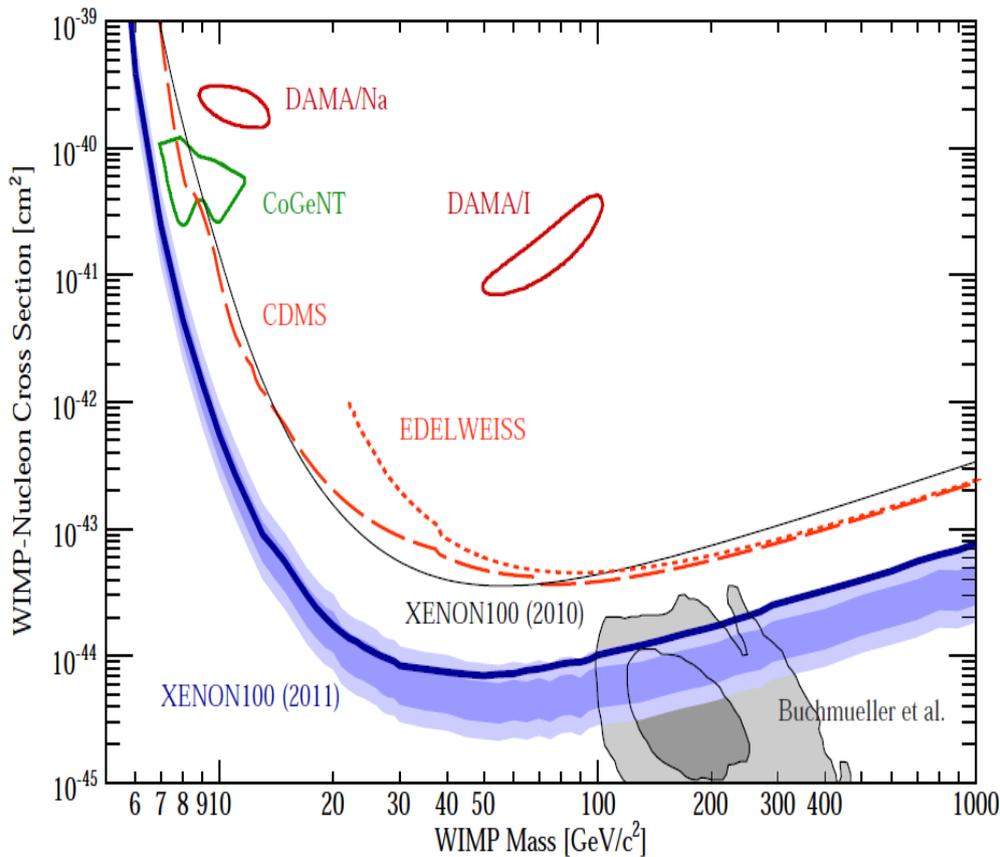
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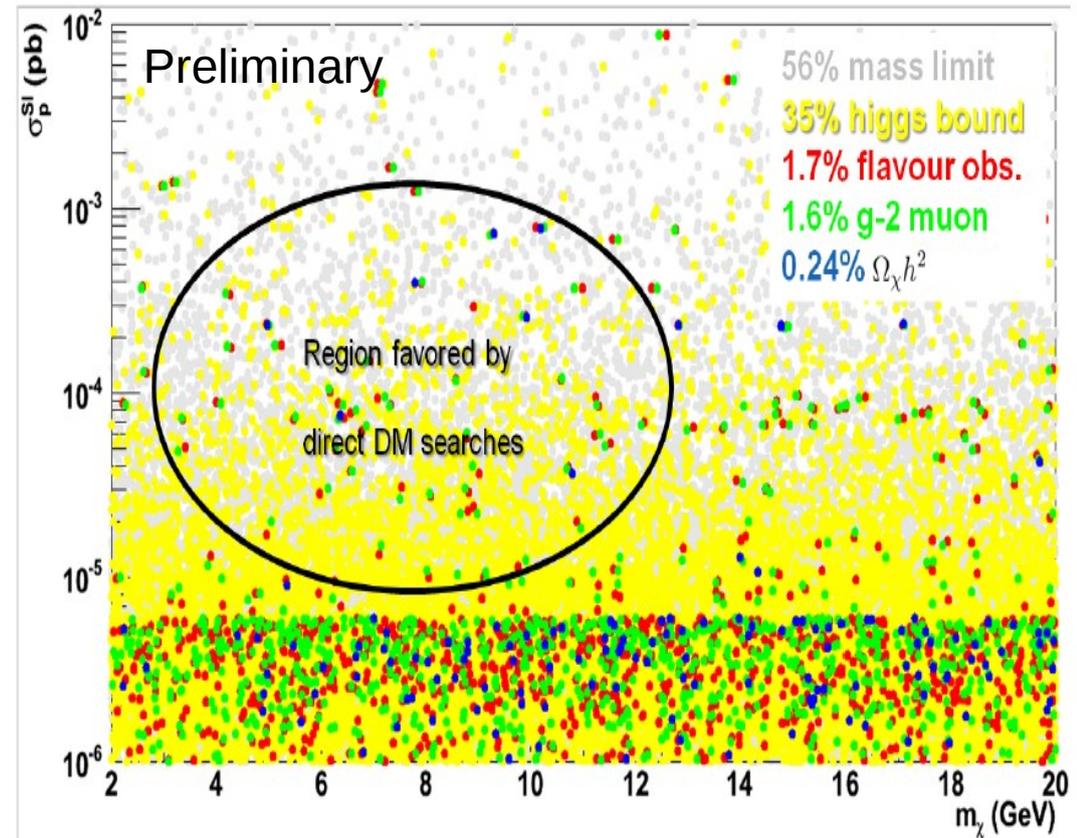
Two classes of spectra:

i) One ~q degenerate with the LSP, relatively heavy ~q and χs:
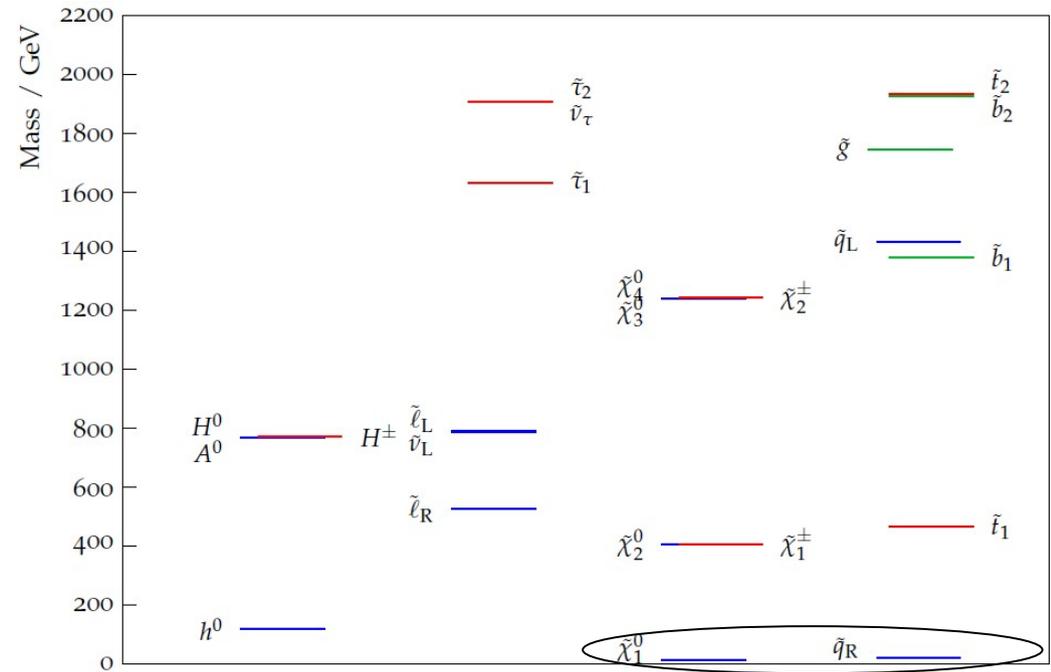
ii) χ^+_1 degenerate with the LSP, compressed gaugino spectrum and light Higgs bosons:
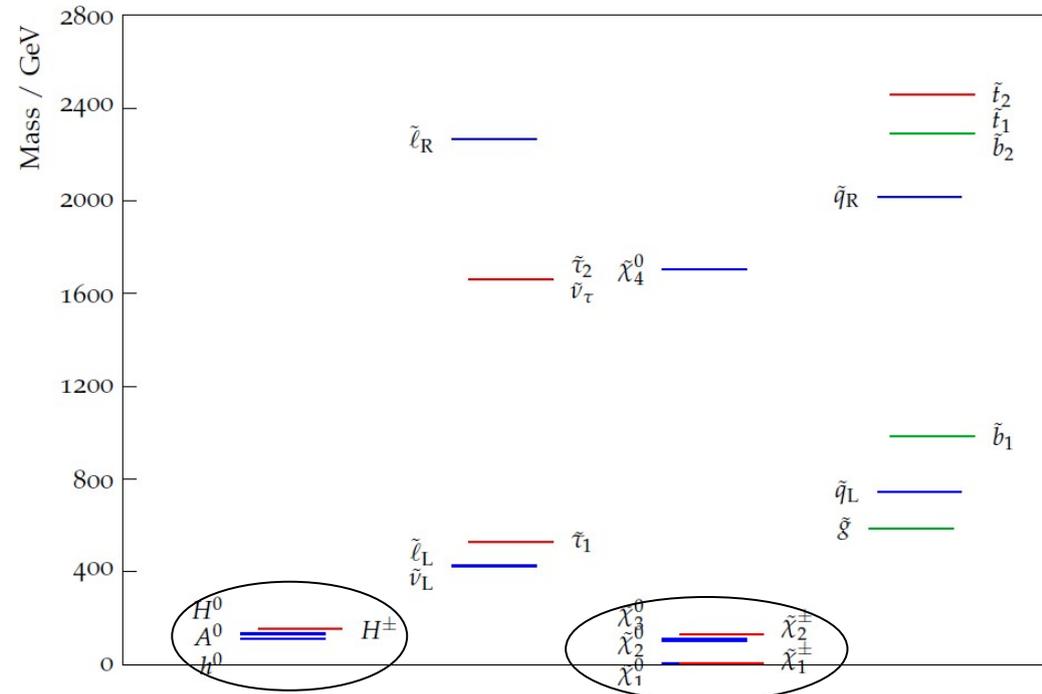
Ωh^2 constrain requires NLSP almost degenerate with light χ^0_1 : this implies characteristic spectra with light gauginos or squarks, if this constrained is relaxed, a third class of spectra is allowed:

iii) one ~q with $50 < M(\sim q) - M(\chi^0_1) < 200$ GeV, broad ~q spectrum and intermediate mass χs.

Spectra of type i) have typically large inclusive SUSY cross sections but soft jet p_T spectrum in hadronic channel, soft MET and no/small signal in leptonic channels.
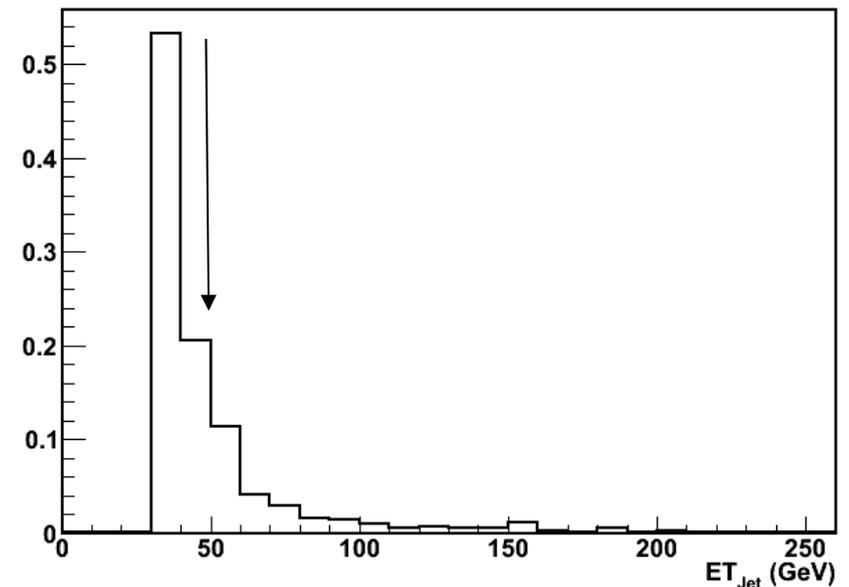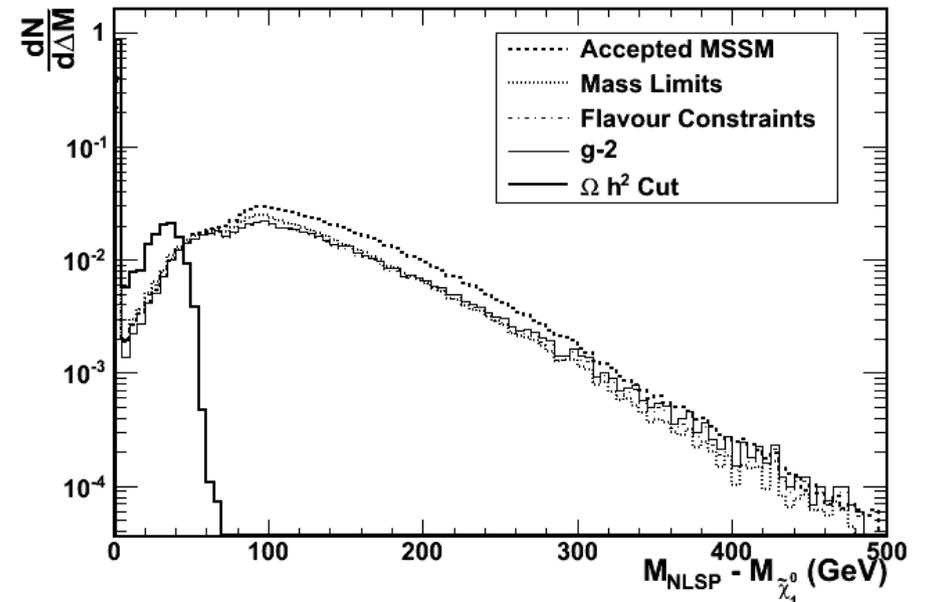
Spectra of type ii) may have ~q and ~g beyond current sensitivity:
Study allowed and explorable region with increasing gluino and squark masses
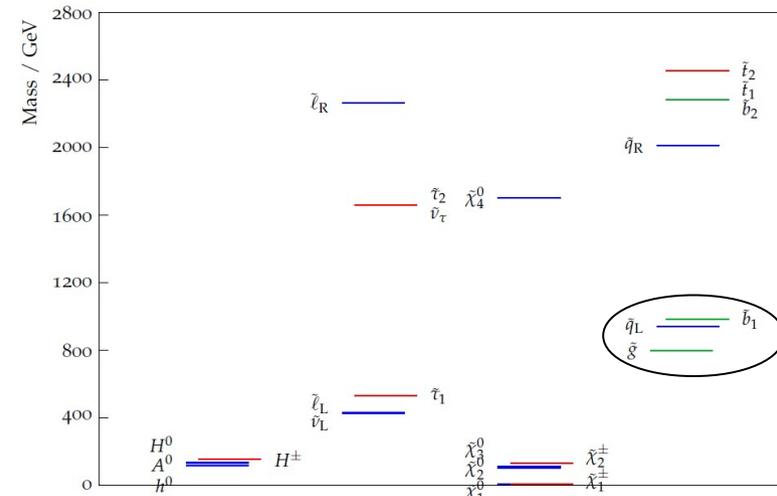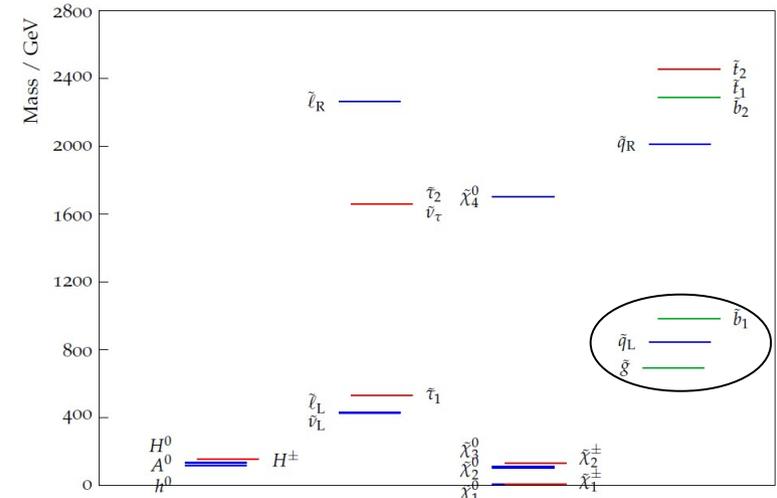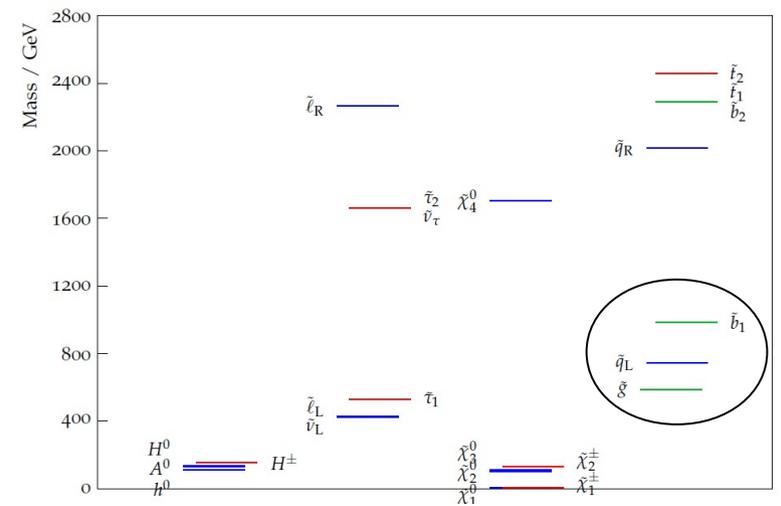
M($\tilde{g}$) (GeV)	BR($b \to s\gamma$)	$\Omega_\chi h^2$	σ_{SUSY} (pb)	1-CLs
502	4.766 10^{-4}	0.1253	0.81	1.000
602	4.888 10^{-4}	0.1257	0.27	0.998
702	4.977 10^{-4}	0.1258	0.10	0.888

Status and Plans

First flat scan performed on pMSSM parameter space providing 200k accepted points, simulated and analysed according to the hadronic, same-sign lepton and opposite-sign lepton analyses presented by CMS at EPS 2011;

Characterise LHC limits as the fraction of MSSM points compatible with constraints excluded at 95% C.L. by CMS analyses as a function of mass of various SUSY particles. For strongly-interacting sparticles this provides a preliminary "generic" mass limit $M(\tilde{g}) > 500$ GeV;

For weakly-interacting sparticles the effect of the LHC limits on the allowed spectra is limited to the range < 400 GeV. Higher masses are virtually unaffected by the present LHC data and ~40% of the accepted points with masses < 400 GeV are still not excluded;

Dedicated scan searching for light χ^0_1 points compatible with DAMA/CoGeNT data identifies three classes of spectra, all characterised by the chargino or a squark degenerate with the LSP, yielding large SUSY inclusive cross sections but small pT jets and small MET;

Plan to increase statistics ×5, study additional models (Gravitino DM, NMSSM).