Interplay of dark matter searches and LHC data

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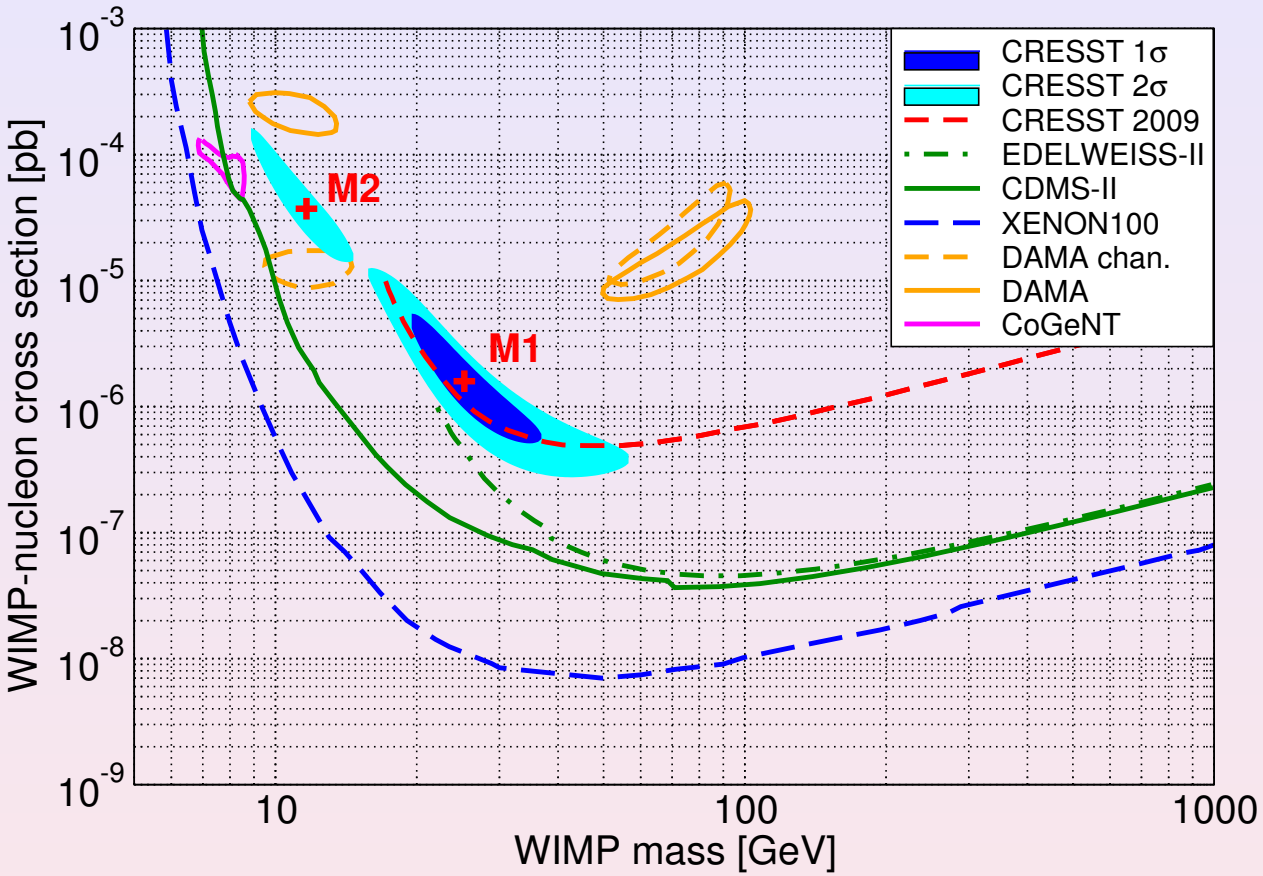
Status of Dark Matter Direct Detection



CRESST, Eur.Phys.J. C72 (2012) 1971

The constrained MSSM scenarios provide no candidate "compatible" with DAMA, CoGeNT, CRESST and XENON data

Flat scans over the pMSSM 19 parameters.

Using many codes: `SuperIso Relic`, `SoftSusy`, `FeynHiggs`, `Hdecay`, `Sdecay`, `Higgsbounds`, `Micromegas`, `Prospino`, `Pythia and Delphes`, with `SuperIso` as the central core.

$2.16 \times 10^{-4} < \mathrm{BR}(B \to X_s\gamma) < 4.93 \times 10^{-4}$
$\mathrm{BR}(B_s \to \mu^+\mu^-) < 5.0 \times 10^{-9}$
$0.56 < \mathrm{R}(B \to \tau\nu) < 2.70$
$4.7 \times 10^{-2} < \mathrm{BR}(D_s \to \tau\nu) < 6.1 \times 10^{-2}$
$2.9 \times 10^{-3} < \mathrm{BR}(B \to D^0\tau\nu) < 14.2 \times 10^{-3}$
$0.985 < \mathrm{R}_{\mu 23}(K \to \mu\nu) < 1.013$
$-2.4 \times 10^{-9} < \delta a_\mu < 4.5 \times 10^{-9}$
+ sparticle mass upper bounds
+ Higgs search limits **122.5 GeV** $< M_h <$ **127.5 GeV**

Particle	Limits	Conditions
$\tilde{\chi}_2^0$	62.4	$\tan\beta < 40$
$\tilde{\chi}_3^0$	99.9	$\tan\beta < 40$
$\tilde{\chi}_4^0$	116	$\tan\beta < 40$
$\tilde{\chi}_1^\pm$	92.4	$m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} < 4$ GeV
	103.5	$m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} > 4$ GeV
$\tilde{e}_R$	73	
$\tilde{e}_L$	107	
$\tilde{\tau}_1$	81.9	$m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0} > 15$ GeV
$\tilde{u}_R$	100	$m_{\tilde{u}_R} - m_{\tilde{\chi}_1^0} > 10$ GeV
$\tilde{u}_L$	100	$m_{\tilde{u}_L} - m_{\tilde{\chi}_1^0} > 10$ GeV
$\tilde{t}_1$	95.7	$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} > 10$ GeV
$\tilde{d}_R$	100	$m_{\tilde{d}_R} - m_{\tilde{\chi}_1^0} > 10$ GeV
$\tilde{d}_L$	100	$m_{\tilde{d}_L} - m_{\tilde{\chi}_1^0} > 10$ GeV
$\tilde{b}_1$	248	$m_{\tilde{\chi}_1^0} < 70$ GeV, $m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0} > 30$ GeV
	220	$m_{\tilde{\chi}_1^0} < 80$ GeV, $m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0} > 30$ GeV
	210	$m_{\tilde{\chi}_1^0} < 100$ GeV, $m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0} > 30$ GeV
	200	$m_{\tilde{\chi}_1^0} < 105$ GeV, $m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0} > 30$ GeV
	100	$m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0} > 5$ GeV
$\tilde{g}$	195	

Details of the scans and results can be found in:

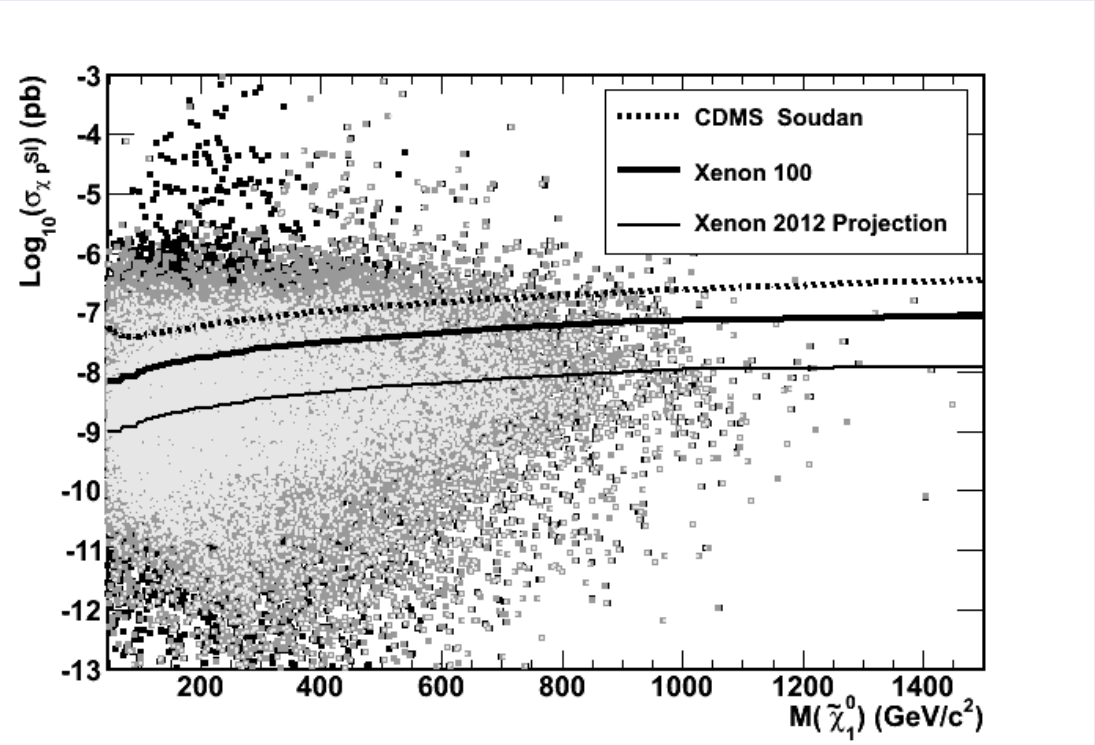
A. Arbey, M. Battaglia, F. Mahmoudi, Eur.Phys.J. C72 (2012) 1847

A. Arbey, M. Battaglia, F. Mahmoudi, Eur.Phys.J. C72 (2012) 1906

General scans in pMSSM: more than 60M generated points

Parameter	Range
$\tan\beta$	[1, 60]
M_A	[50, 2000]
M_1	[-2500, 2500]
M_2	[-2500, 2500]
M_3	[50, 2500]
$A_d = A_s = A_b$	[-10000, 10000]
$A_u = A_c = A_t$	[-10000, 10000]
$A_e = A_\mu = A_\tau$	[-10000, 10000]
μ	[-3000, 3000]
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[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]

pMSSM points and XENON dark matter exclusion limit



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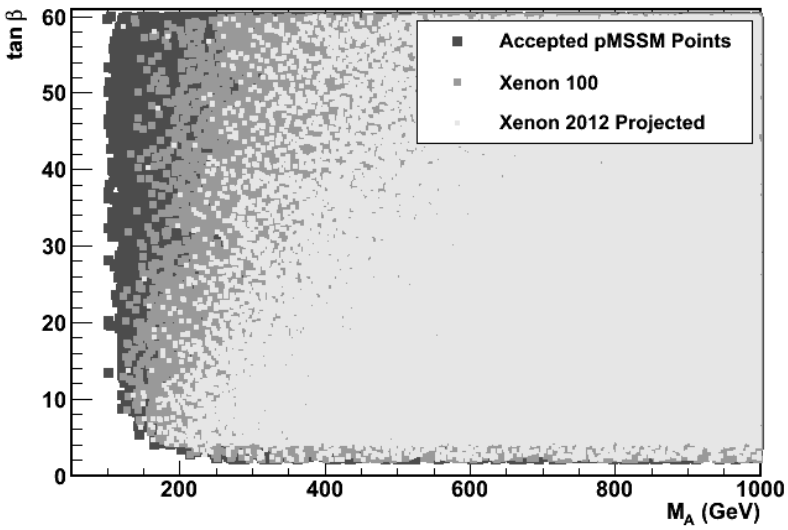

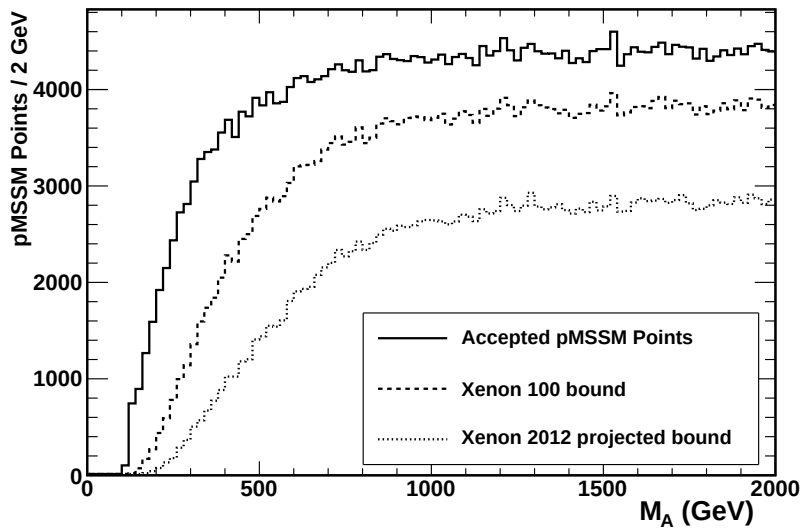

A. Arbey, M. Battaglia, F. Mahmoudi, Eur.Phys.J. C72 (2012) 1906

General scans in pMSSM $\longrightarrow$ Low-mass neutralino scans

Parameter	Range
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M_A	[50, 2000]
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$M_{\tilde{t}_R}$	[50, 2500]
$M_{\tilde{d}_R} = M_{\tilde{s}_R}$	[50, 2500]
$M_{\tilde{b}_R}$	[50, 2500]

$\longrightarrow$

Parameter	Range
$\tan\beta$	[1, 60]
M_A	[50, 2000]
M_1	[-300, 300]
M_2	[-650, 650]
M_3	[0, 2500]
$A_d = A_s = A_b$	[-10000, 10000]
$A_u = A_c = A_t$	[-10000, 10000]
$A_e = A_\mu = A_\tau$	[-10000, 10000]
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$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[0, 2500]
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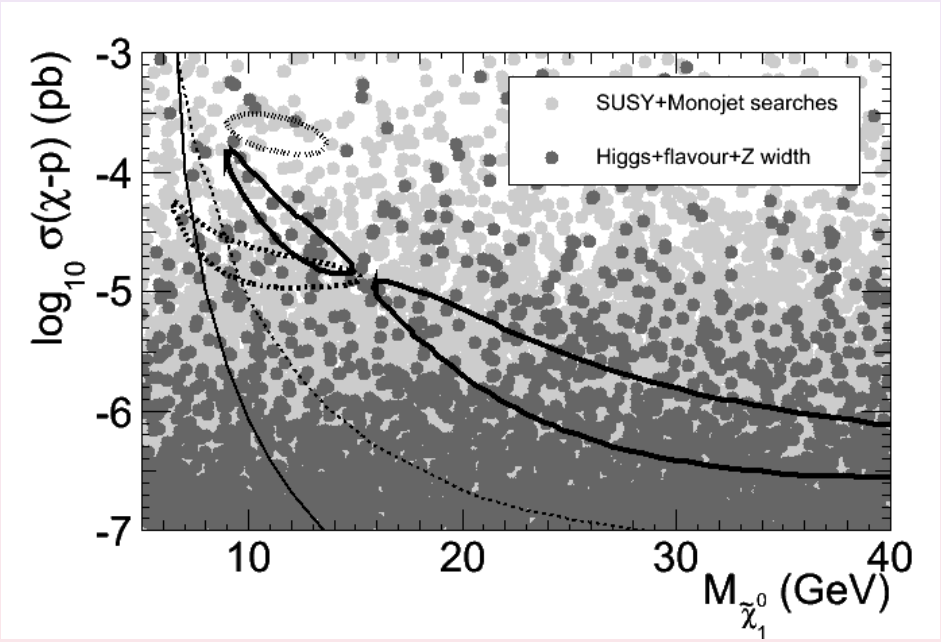
$M_{\tilde{b}_R}$	[0, 2500]

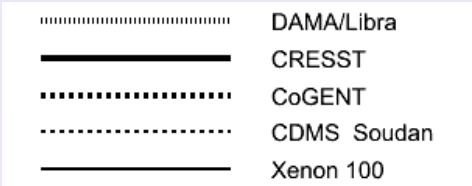
Low mass neutralino scans: more than **one billion** generated points

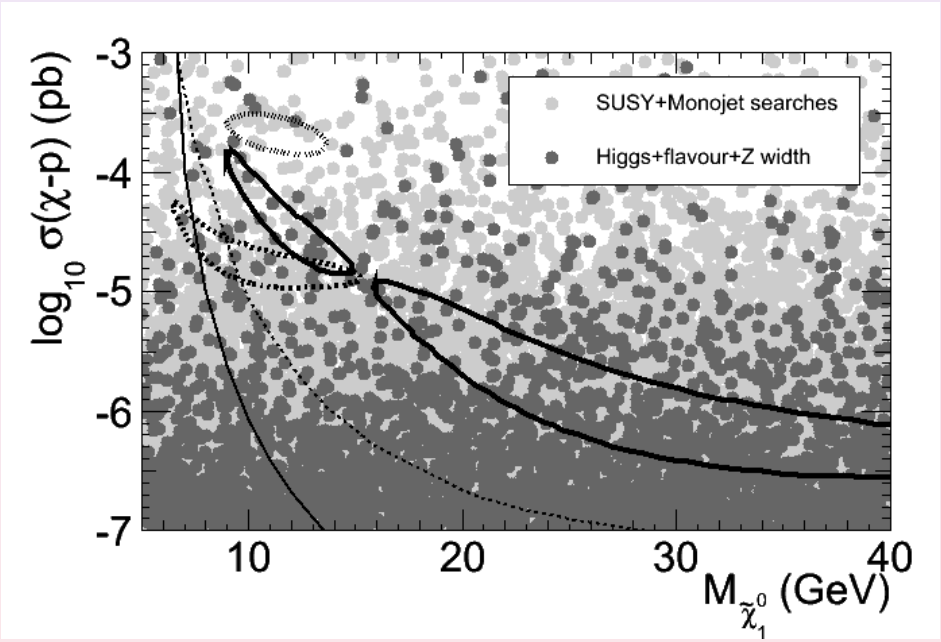


Selection	pMSSM points
Valid points with light χ_1^0, large $\sigma(\chi - p)$	1 M

A. Arbey, M. Battaglia, F. Mahmoudi, arXiv:1205.2557 [hep-ph]

Low mass neutralino scans: more than **one billion** generated points





Selection	pMSSM points
Valid points with light χ_1^0, large $\sigma(\chi - p)$	1 M
Monojet searches	280 k

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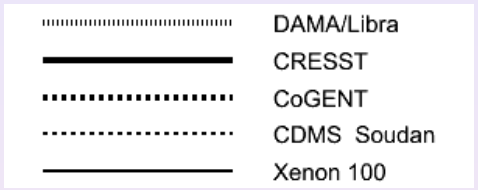

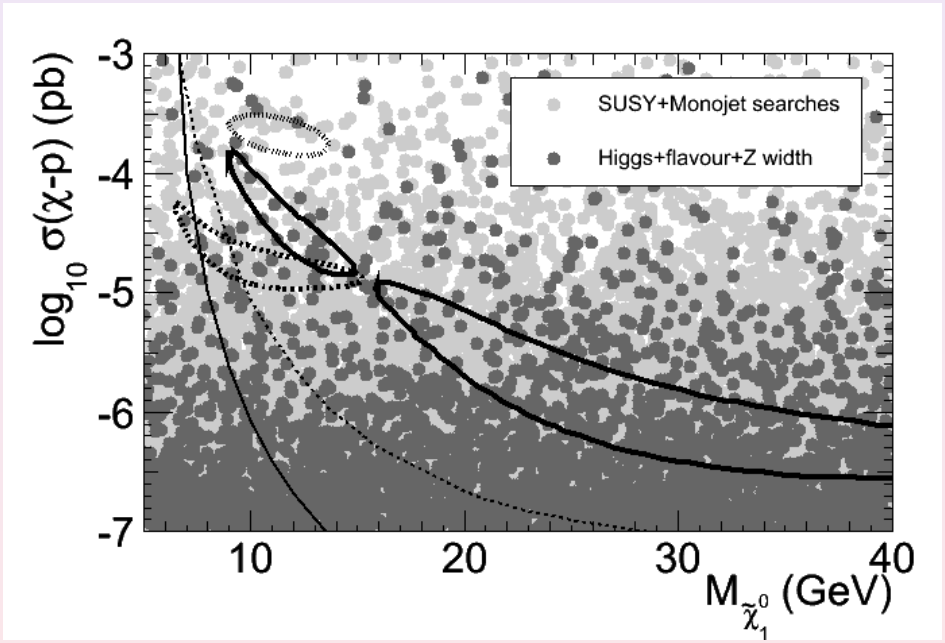

Selection	pMSSM points
Valid points with light χ_1^0, large $\sigma(\chi - p)$	1 M
Monojet searches	280 k
SUSY searches	90 k

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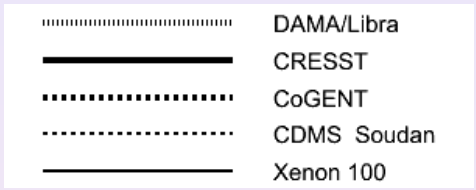

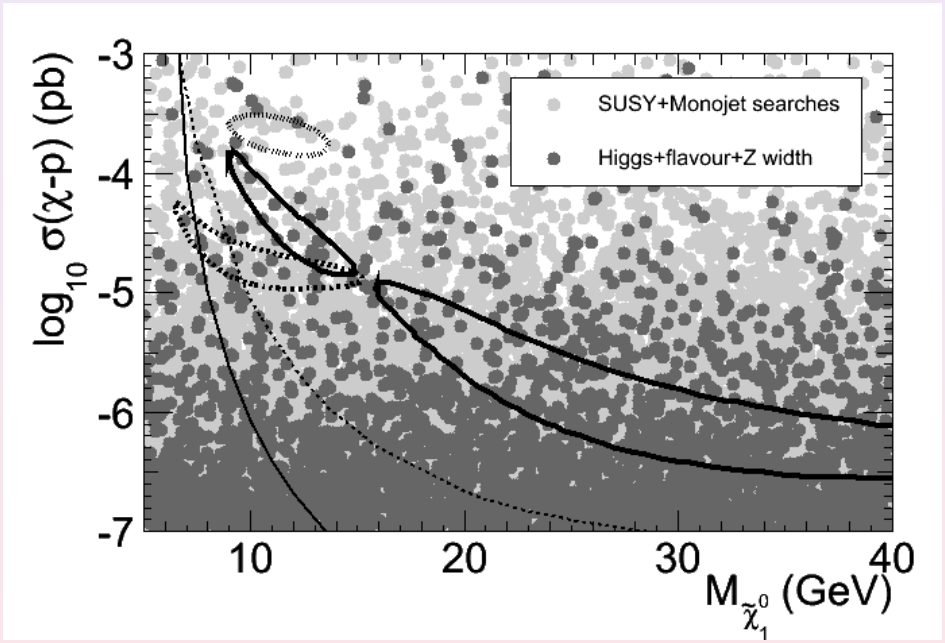

Selection	pMSSM points
Valid points with light χ_1^0, large $\sigma(\chi - p)$	1 M
Monojet searches	280 k
SUSY searches	90 k
LEP searches	50 k

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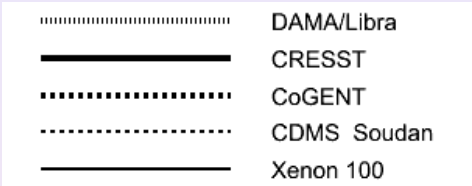

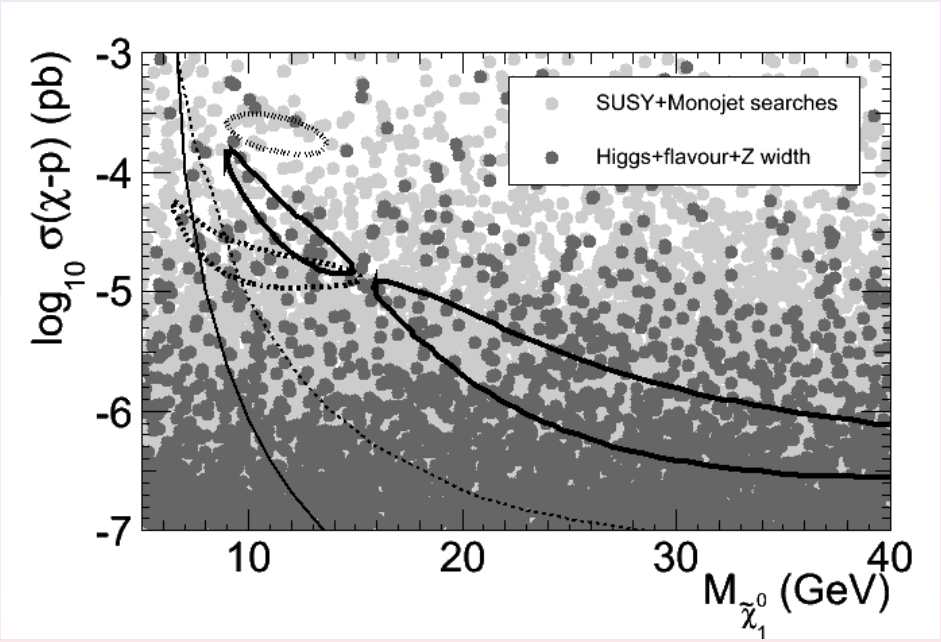

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LEP searches	50 k
Flavour physics	20 k

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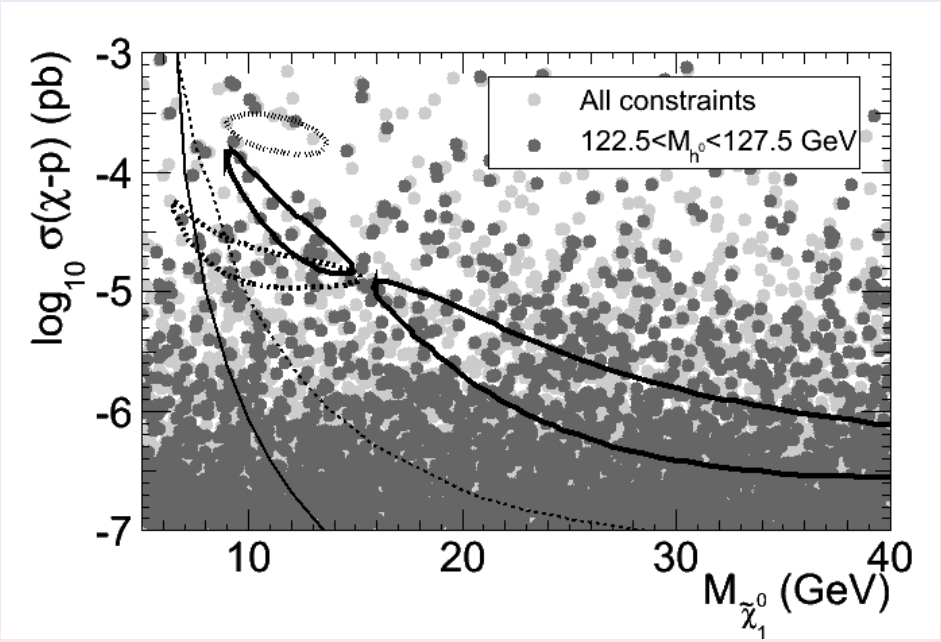

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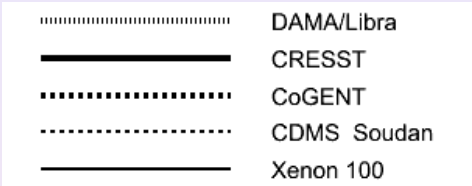

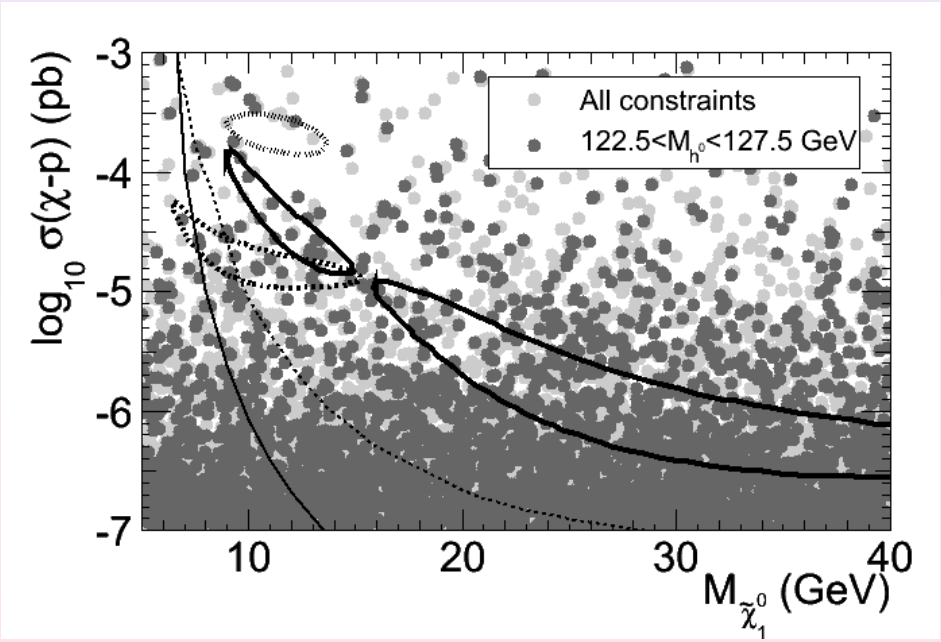

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Higgs searches	10 k
Loose WMAP limit	20

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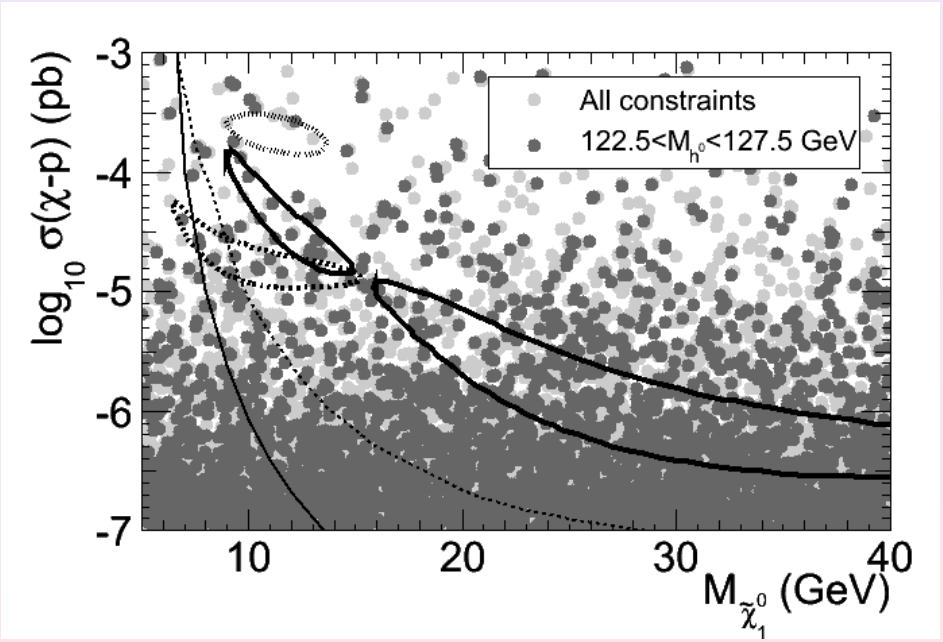
Low mass neutralino scans: more than **one billion** generated points



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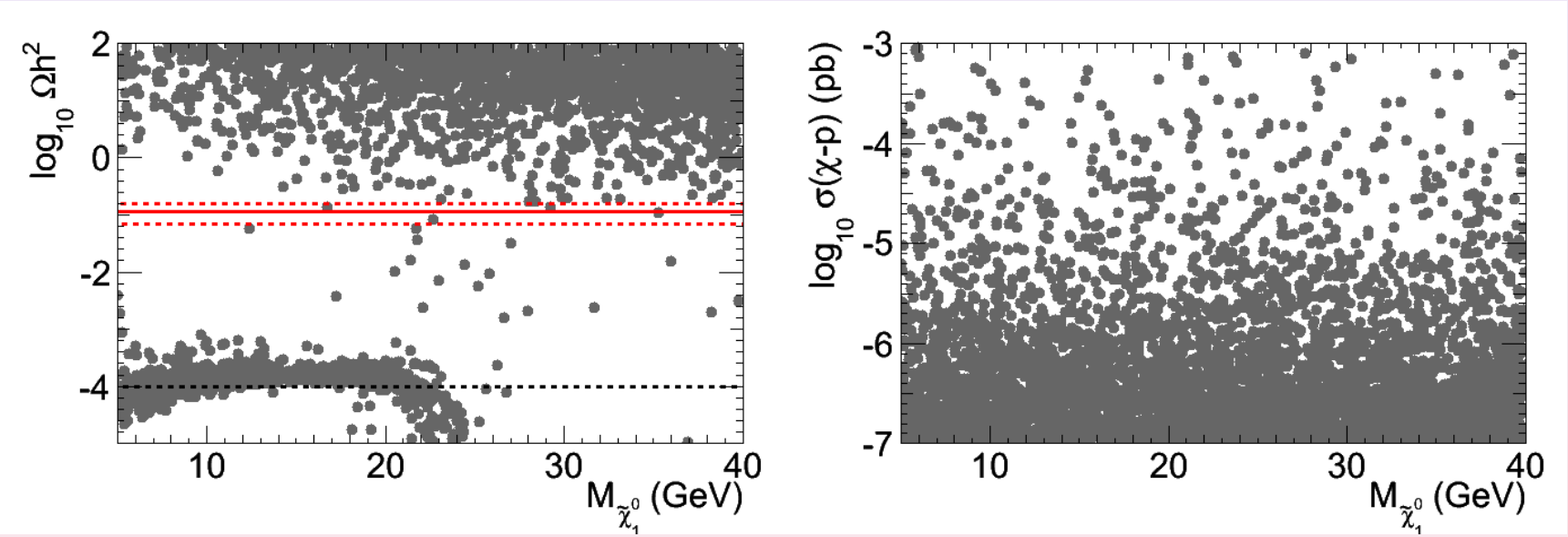
SUSY searches	90 k
LEP searches	50 k
Flavour physics	20 k
Higgs searches	10 k
Loose WMAP limit	20
Tight WMAP limit	5

A. Arbey, M. Battaglia, F. Mahmoudi, arXiv:1205.2557 [hep-ph]

How to reconcile relic density and direct dark matter detection when $M_{\tilde{\chi}^0} < 40$ GeV?



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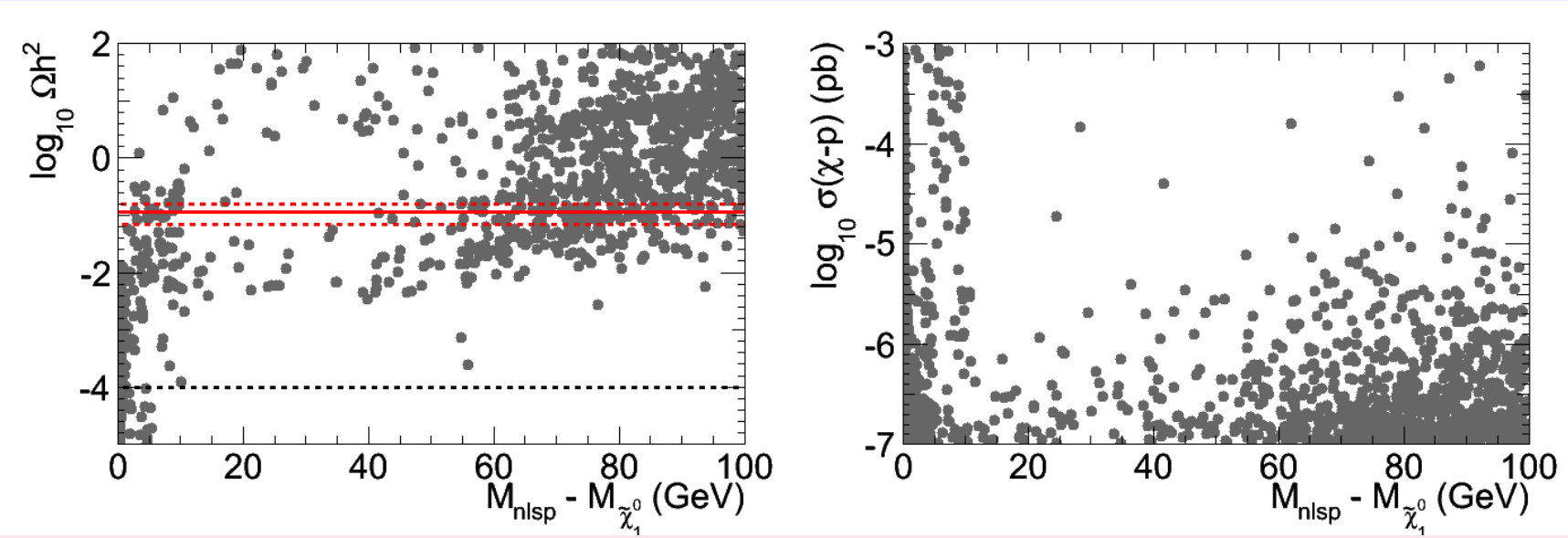


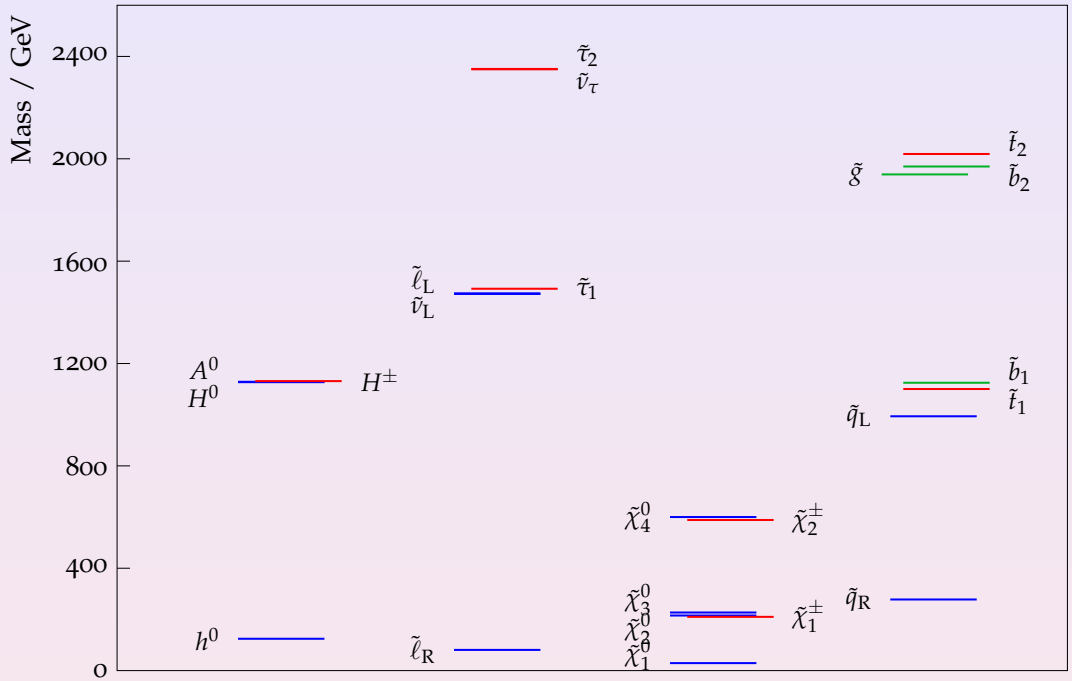
A. Arbey, M. Battaglia, F. Mahmoudi, arXiv:1205.2557 [hep-ph]

Light neutralinos and dark matter direct detection

Three main different classes of points can survive the constraints:

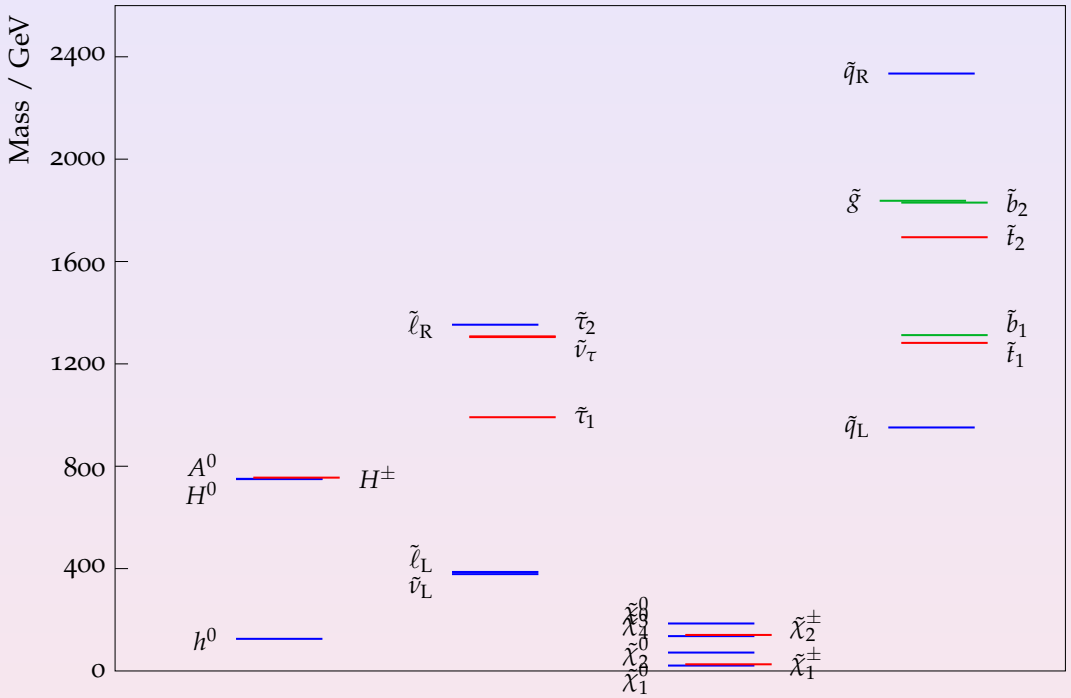
- a slepton with a mass close to LEP limit
  ($M_{\tilde{\chi}^0} \sim 20 - 40$ GeV)
- compressed spectrum in the neutralino/chargino sector
  ($M_{\tilde{\chi}^0} \sim 10 - 40$ GeV, $\sigma \sim 10^{-6}$ pb)
- one squark quasi-degenerate with the neutralino
  ($M_{\tilde{\chi}^0} \lesssim 10 - 20$ GeV, $\sigma \sim 10^{-4}$ pb)

Slepton with a mass at the LEP limit



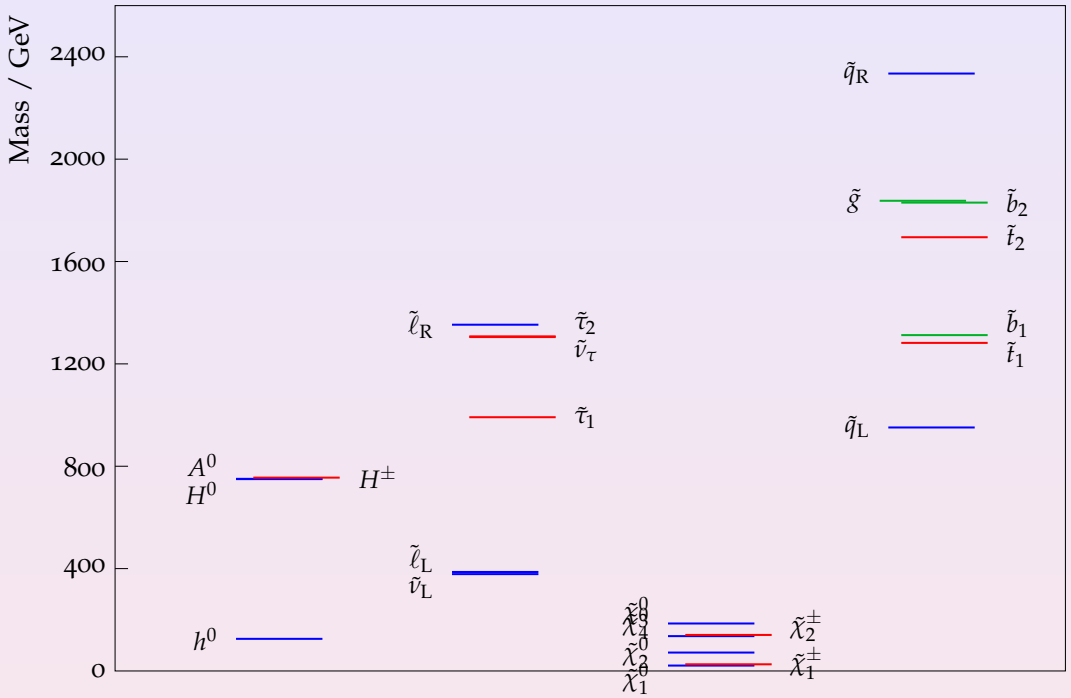
A relatively standard scenario, but the neutralino mass has to be larger (around 30 GeV) to give a large scattering cross-section.

Compressed spectrum in the neutralino/chargino sector



This scenario may be very interesting...

Compressed spectrum in the neutralino/chargino sector

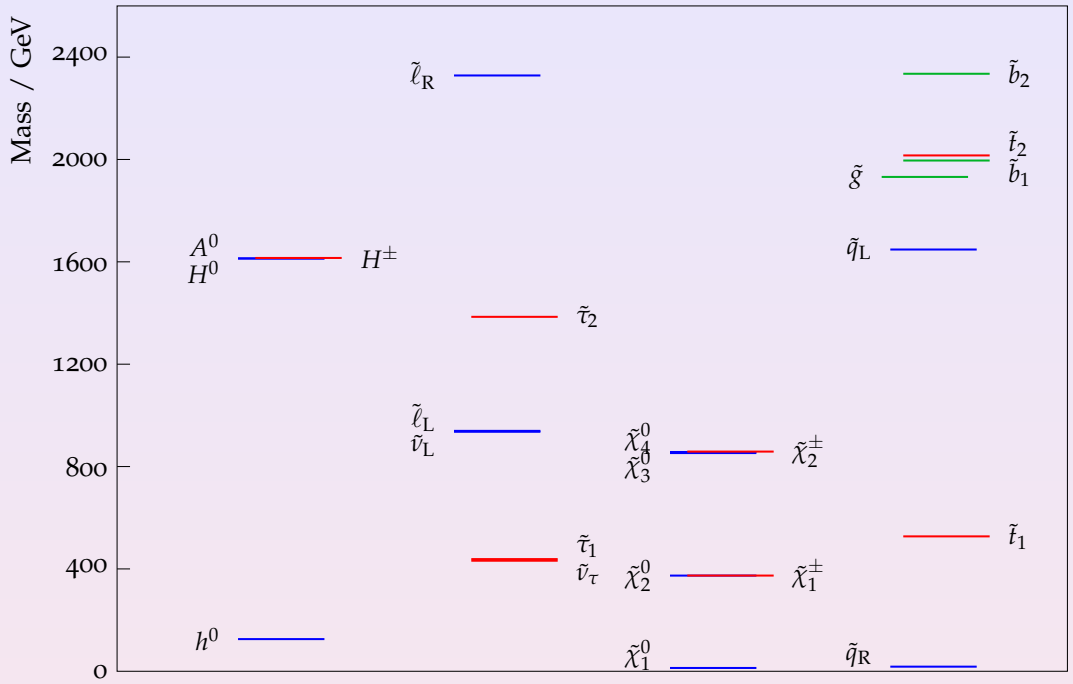


This scenario may be very interesting...

Unfortunately $\sigma(e^+e^- \to \chi_1^0\chi_2^0)$ is in general too large and ruled out by the LEP limits!

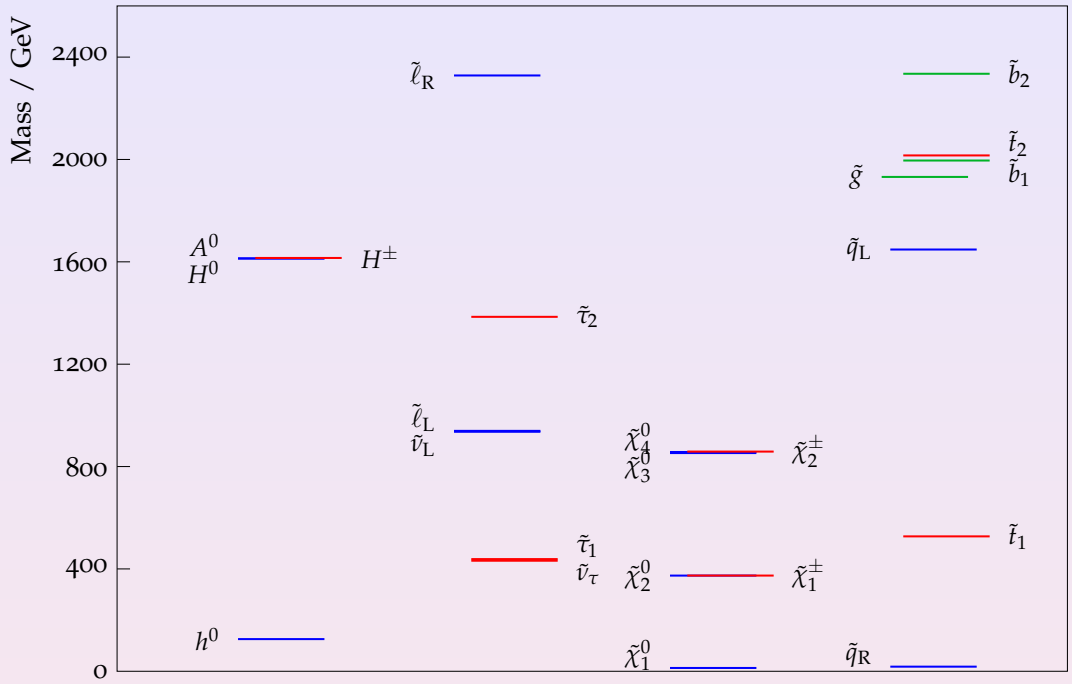
Light neutralinos and dark matter direct detection

One squark quasi-degenerate with the neutralino



These spectra can fulfill all the constraints and have simultaneously a neutralino mass under 15 GeV and a large scattering cross-section!

One squark quasi-degenerate with the neutralino



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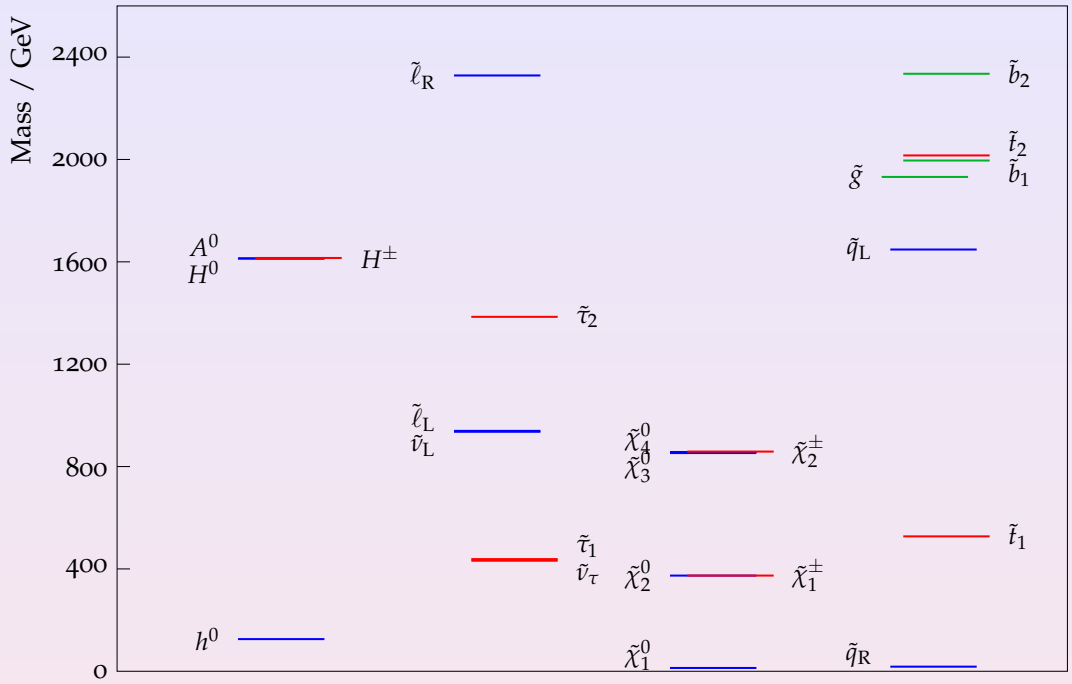
Two problems however: $\Gamma(Z \to \tilde{q}\bar{\tilde{q}})$ is very large and $BR(h^0 \to \tilde{q}\bar{\tilde{q}})$ is the dominant Higgs BR... for the first and second generations!

One squark quasi-degenerate with the neutralino



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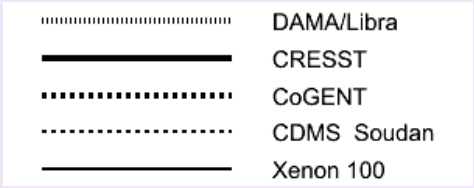
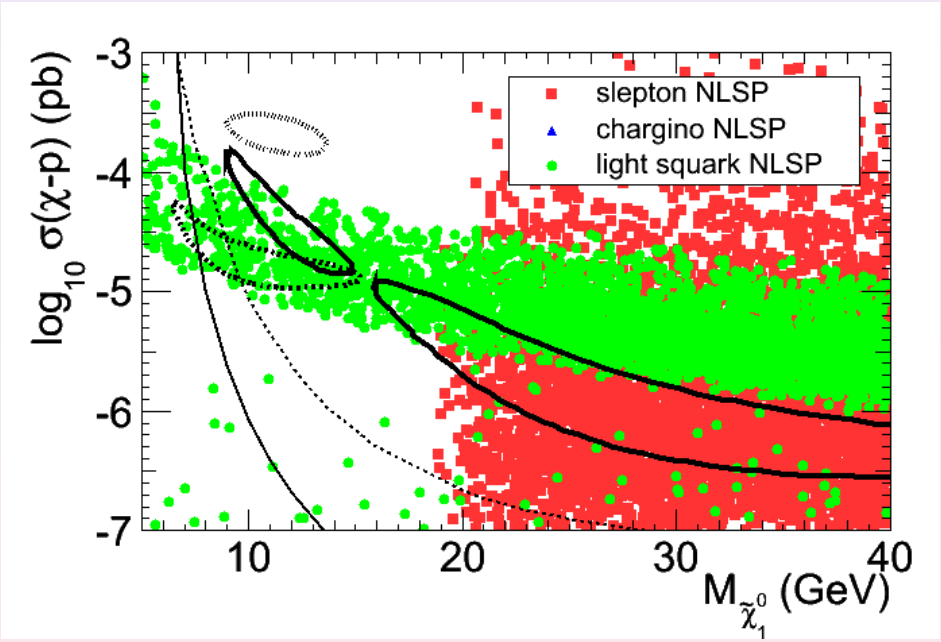
$\to$ A light sbottom can pass all these constraints!

Using dedicated scans:





Loose relic density constraint
$10^{-4} < \Omega_\chi h^2 < 0.155$

A. Arbey, M. Battaglia, F. Mahmoudi, arXiv:1205.2557 [hep-ph]

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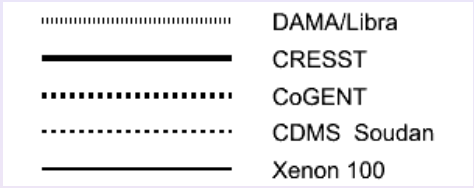
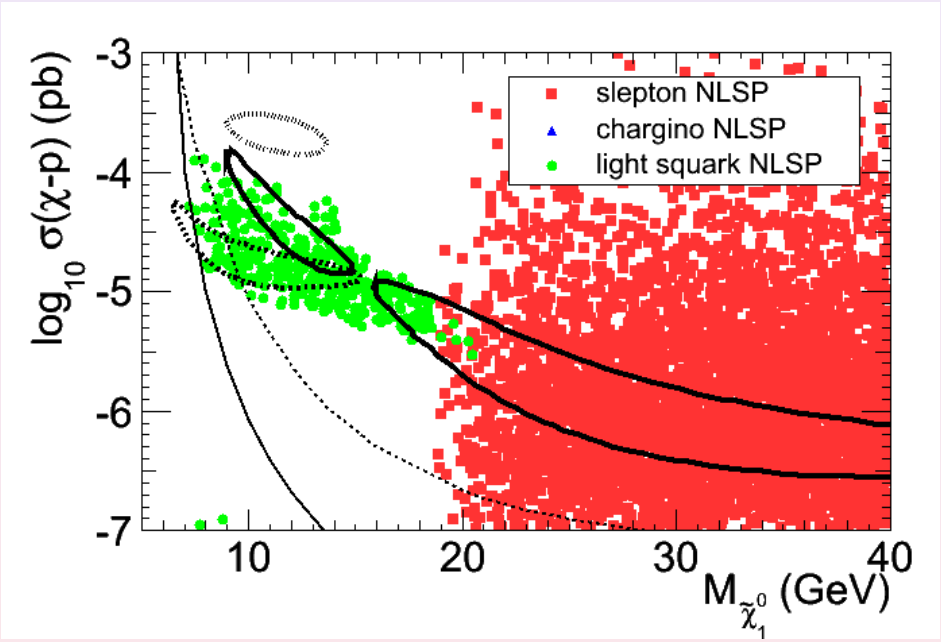




Tight relic density constraint
$0.068 < \Omega_\chi h^2 < 0.155$

A. Arbey, M. Battaglia, F. Mahmoudi, arXiv:1205.2557 [hep-ph]

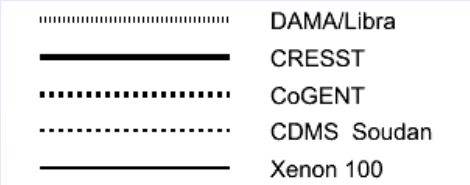
Relic density and direct detection constraints

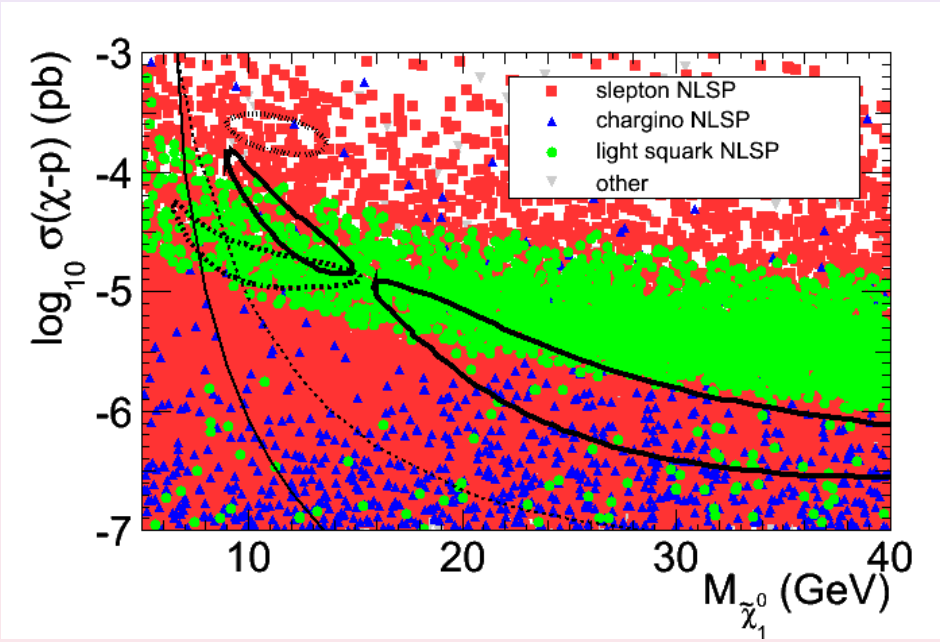
The relic density constraint rules out many models, but alternative cosmology can make them survive, e.g. if:

- the neutralino is not the only component of dark matter
- neutralinos are produced non-thermally (e.g. by the decay of an inflaton)
- dark energy accelerated the expansion of the Universe before the freeze-out
- additional entropy were generated in the early Universe
- ...

Also, the direct detection scattering cross-section can be enhanced or decreased if the local density and velocity of dark matter are very different from the usually assumed values.

Using dedicated scans:





Relaxing the relic density constraint

A. Arbey, M. Battaglia, F. Mahmoudi, arXiv:1205.2557 [hep-ph]

Conclusions and perspectives

pMSSM light neutralino can be compatible with all constraints!

Three different scenarios

- A sbottom quasi-degenerate with the neutralino
- Slepton with a mass close to the LEP limit
- Compressed spectrum in the gaugino sector

Next steps

- Characterise more these scenarios in terms of the ATLAS and CMS MET analyses
- Go to alternative scenarios (gravitino dark matter, beyond MSSM, ...)