

Light neutralino dark matter in the MSSM

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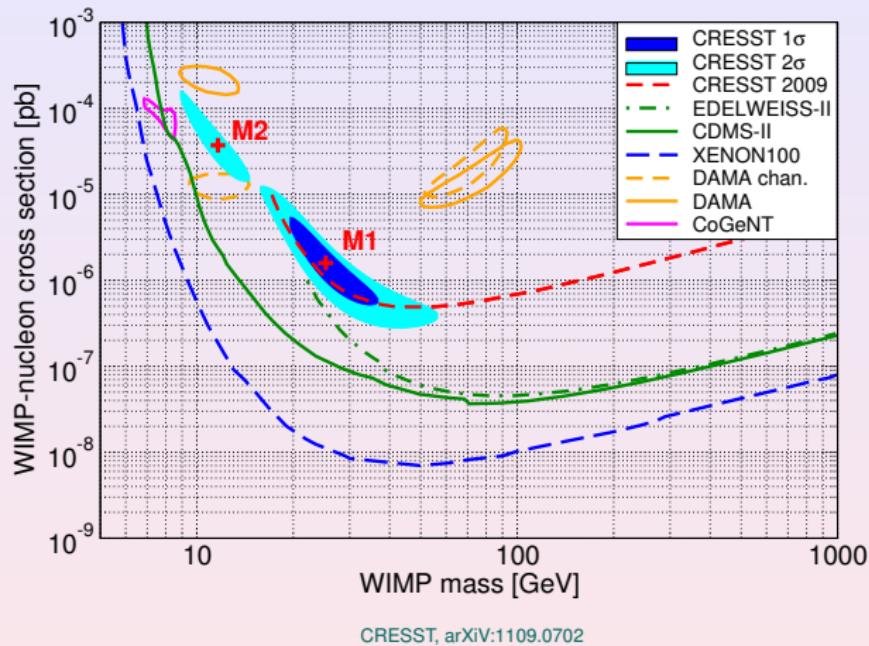
Université Lyon 1

in collaboration with M. Battaglia and N. Mahmoudi

GDR Terascale

Clermont-Ferrand, April 24, 2012

Status of Dark Matter Direct Detection



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.

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

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	$\tan \beta < 40$
$\tilde{\chi}_1^\pm$	94	$\tan \beta < 40, m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} > 5 \text{ GeV}$
\tilde{e}_R	73	
\tilde{e}_L	107	
$\tilde{\tau}_1$	81.9	$m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0} > 15 \text{ GeV}$
\tilde{u}_R	100	$m_{\tilde{u}_R} - m_{\tilde{\chi}_1^0} > 10 \text{ GeV}$
\tilde{u}_L	100	$m_{\tilde{u}_L} - m_{\tilde{\chi}_1^0} > 10 \text{ GeV}$
\tilde{t}_1	95.7	$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} > 10 \text{ GeV}$
\tilde{d}_R	100	$m_{\tilde{d}_R} - m_{\tilde{\chi}_1^0} > 10 \text{ GeV}$
\tilde{d}_L	100	$m_{\tilde{d}_L} - m_{\tilde{\chi}_1^0} > 10 \text{ GeV}$
\tilde{b}_1	248 220 210 200 100	$m_{\tilde{\chi}_1^0} < 70 \text{ GeV}, m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0} > 30 \text{ GeV}$ $m_{\tilde{\chi}_1^0} < 80 \text{ GeV}, m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0} > 30 \text{ GeV}$ $m_{\tilde{\chi}_1^0} < 100 \text{ GeV}, m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0} > 30 \text{ GeV}$ $m_{\tilde{\chi}_1^0} < 105 \text{ GeV}, m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0} > 30 \text{ GeV}$ $m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0} > 5 \text{ GeV}$
\tilde{g}	195	

Details of the scans and results can be found in:

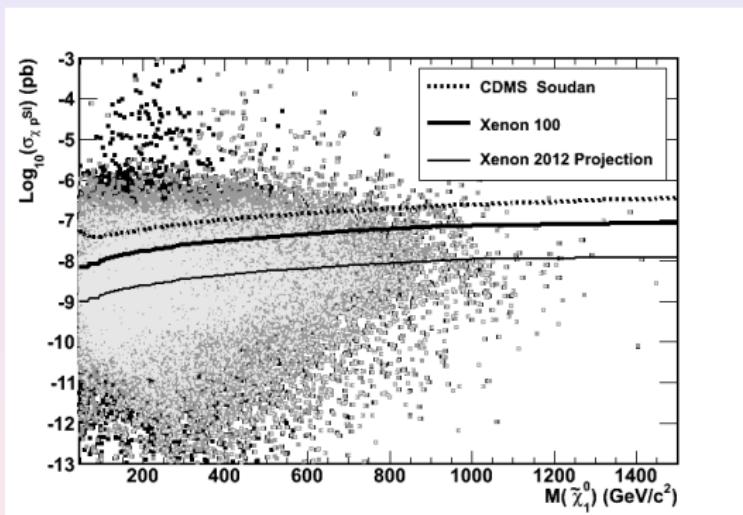
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General scans in pMSSM: more than 60M generated points

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]

Neutralinos and dark matter direct detection

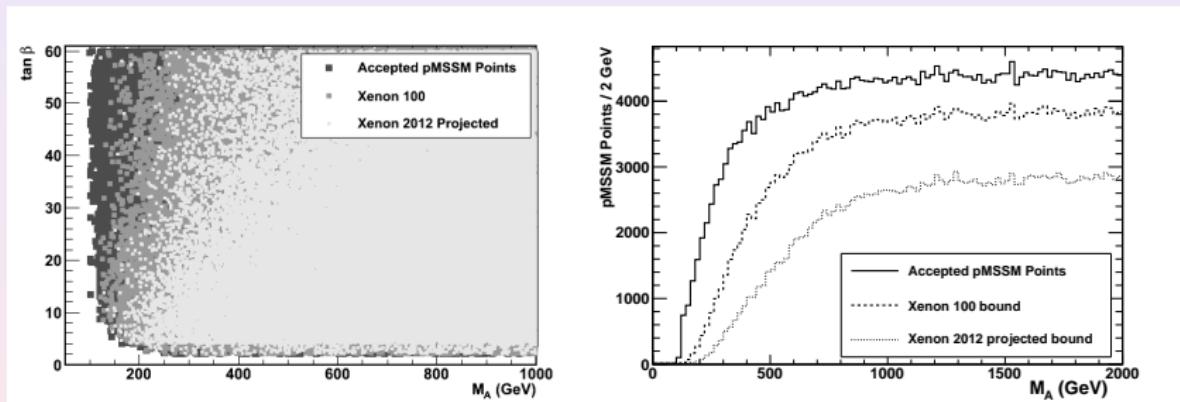
pMSSM points and XENON dark matter exclusion limit



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Neutralinos and dark matter direct detection

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General scans in pMSSM → Low-mass neutralino scans

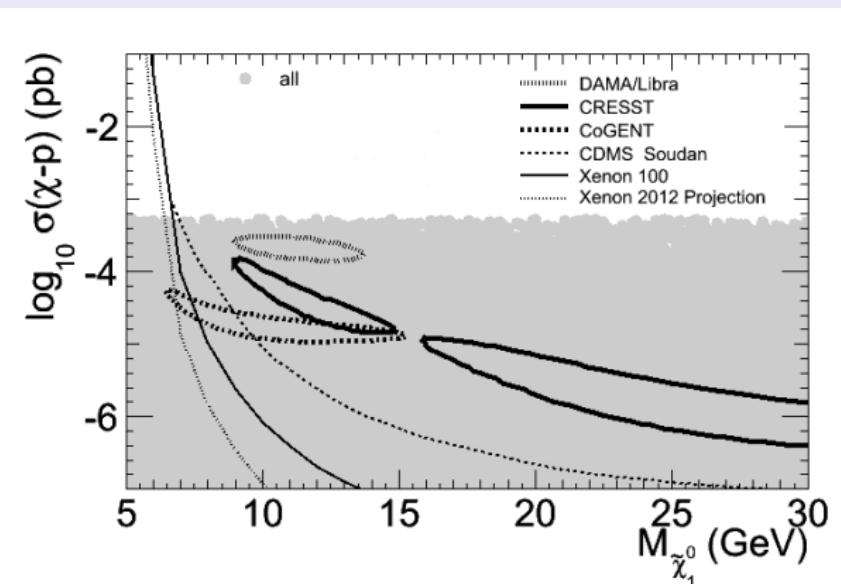
Parameter	Range
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M_A	[50, 2000]
M_1	[-2500, 2500]
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μ	[-3000, 3000]
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[50, 2500]
$M_{\tilde{e}_R} = M_{\tilde{\mu}_R}$	[50, 2500]
$M_{\tilde{\tau}_L}$	[50, 2500]
$M_{\tilde{\tau}_R}$	[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]



Parameter	Range
$\tan \beta$	[1, 60]
M_A	[50, 2000]
M_1	[-300, 300]
M_2	[-650, 650]
M_3	[0, 2000]
$A_d = A_s = A_b$	[-10000, 10000]
$A_u = A_c = A_t$	[-10000, 10000]
$A_e = A_\mu = A_\tau$	[-10000, 10000]
μ	[-3000, 3000]
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[0, 2500]
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$M_{\tilde{q}_{1L}} = M_{\tilde{q}_{2L}}$	[0, 2500]
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$M_{\tilde{b}_R}$	[0, 2500]

Light neutralinos and dark matter direct detection

Low mass neutralino scans: more than 500M generated points

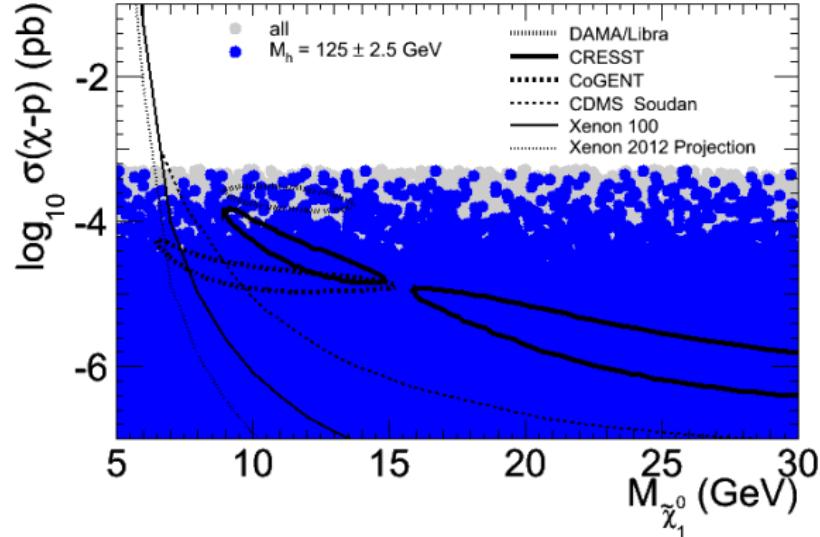


~ 1M points

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Light neutralinos and dark matter direct detection

Low mass neutralino scans: more than 500M generated points

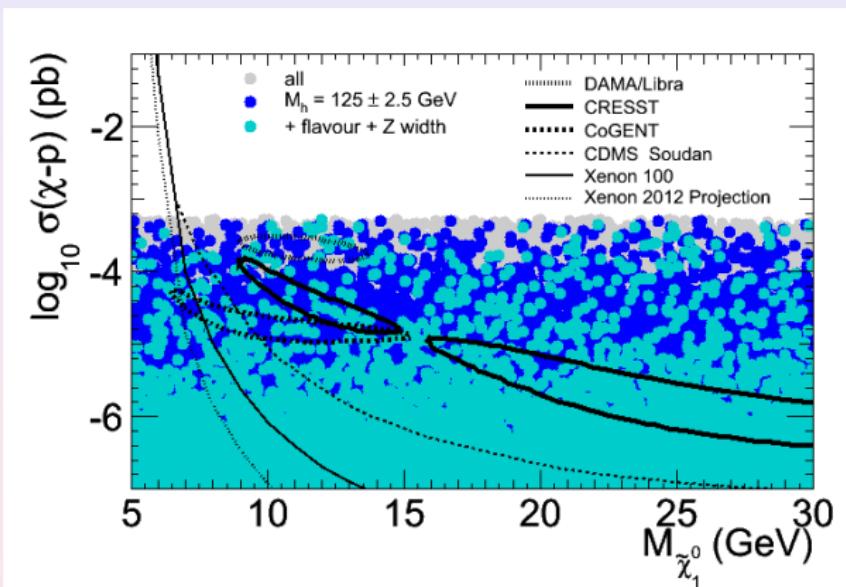


$\sim 100k$ points (10%)

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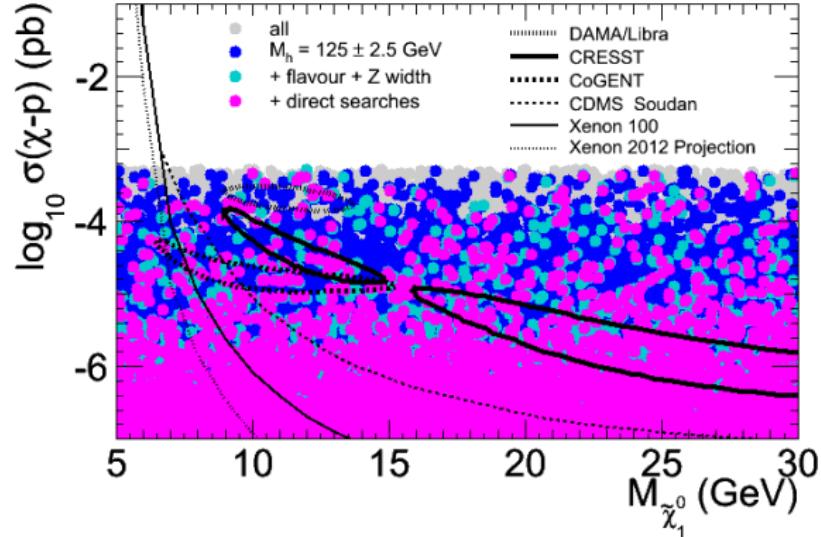


$\sim 10k$ points (1%)

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Light neutralinos and dark matter direct detection

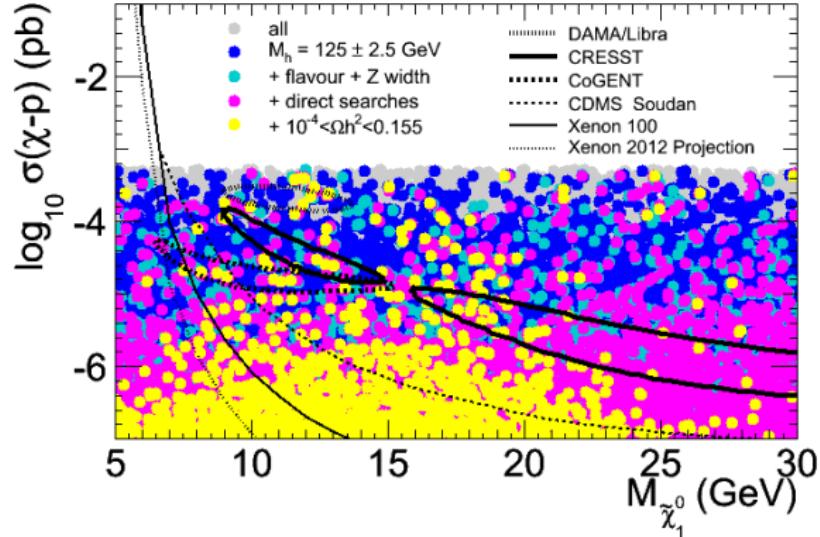
Low mass neutralino scans: more than 500M generated points



A. Arbey, M. Battaglia, F. Mahmoudi, in preparation

Light neutralinos and dark matter direct detection

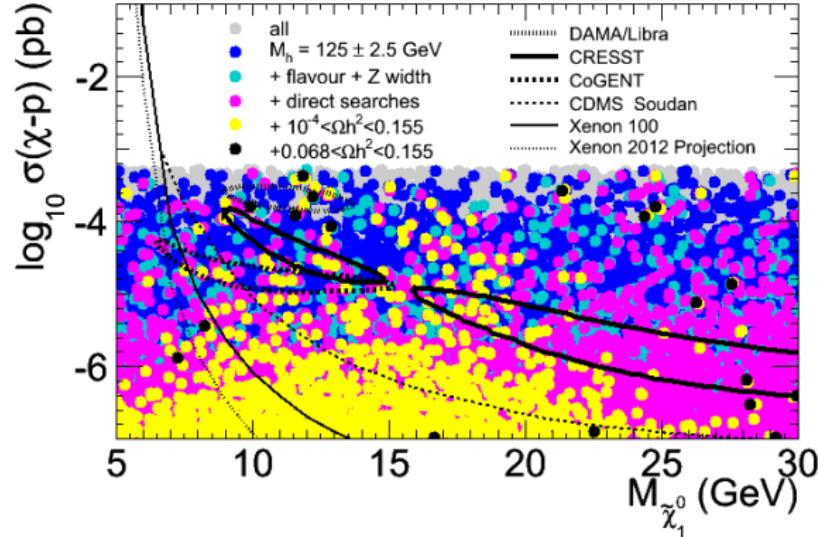
Low mass neutralino scans: more than 500M generated points



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Light neutralinos and dark matter direct detection

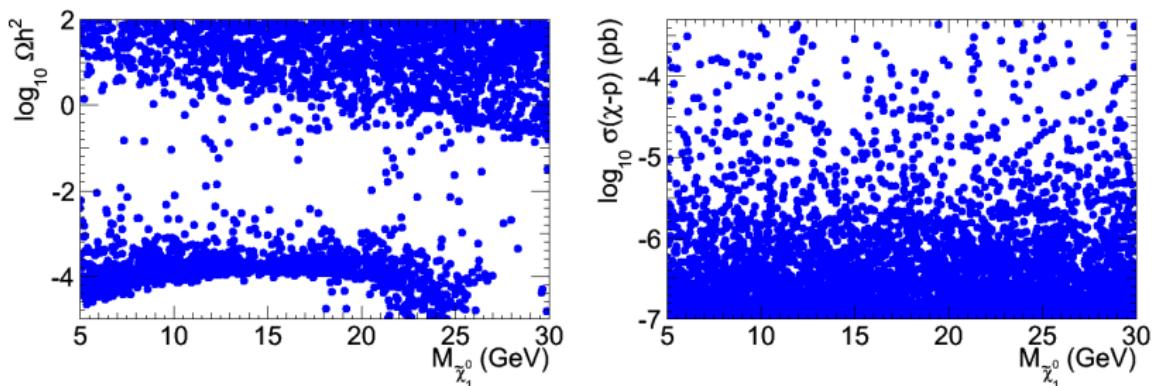
Low mass neutralino scans: more than 500M generated points



~ 18 points (0.002%)

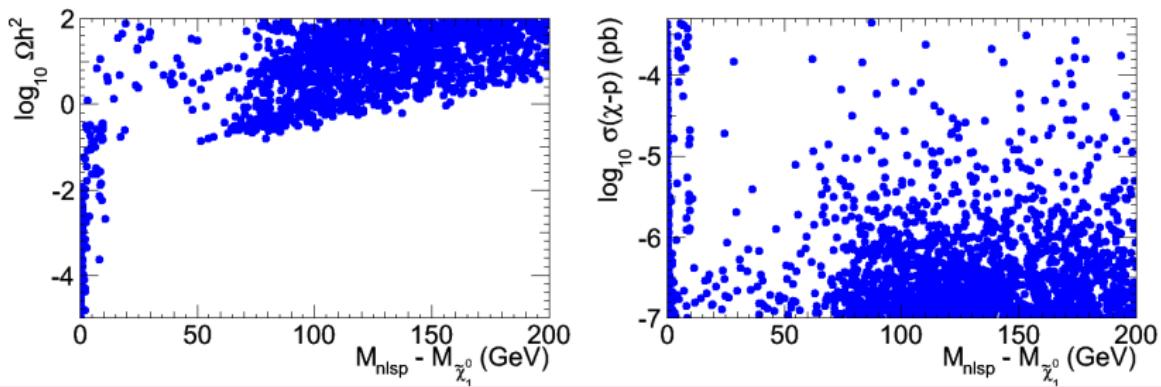
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How to reconcile relic density and direct dark matter detection when
 $M_{\tilde{\chi}_1^0} < 30 \text{ GeV}$?



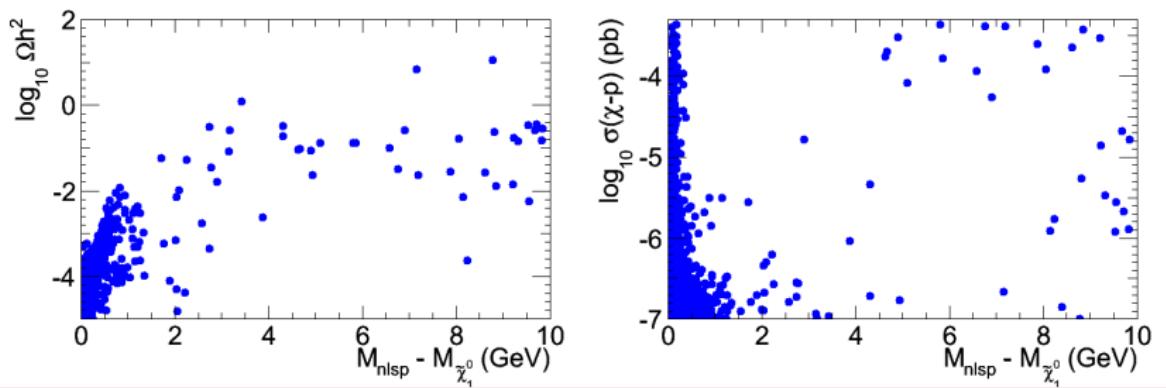
A. Arbey, M. Battaglia, F. Mahmoudi, in preparation

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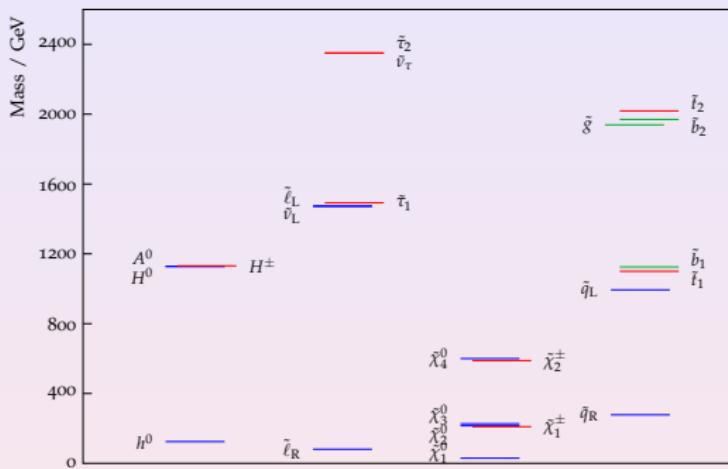
A. Arbey, M. Battaglia, F. Mahmoudi, in preparation

Three different classes of points passing all the constraints:

- a slepton with a mass close to LEP limit
 $(M_{\tilde{\chi}^0} \sim 30 \text{ GeV}, \sigma \sim 10^{-6} \text{ pb})$
- compressed spectrum in the neutralino/chargino sector
 $(M_{\tilde{\chi}^0} \sim 30 \text{ GeV}, \sigma \sim 10^{-6} \text{ pb})$
- one squark quasi-degenerate with the neutralino
 $(M_{\tilde{\chi}^0} \lesssim 15 \text{ GeV}, \sigma \sim 10^{-4} \text{ pb})$

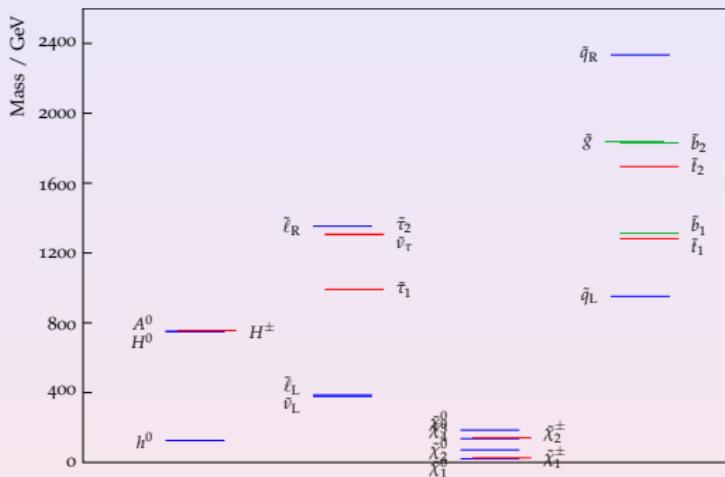
Most of the (yellow) points, i.e. for which the relic density is too small, and which have $M_{\tilde{\chi}^0} \lesssim 15 \text{ GeV}$ and $\sigma \sim 10^{-4}$, are of the third category.

Slepton with a mass at the LEP limit



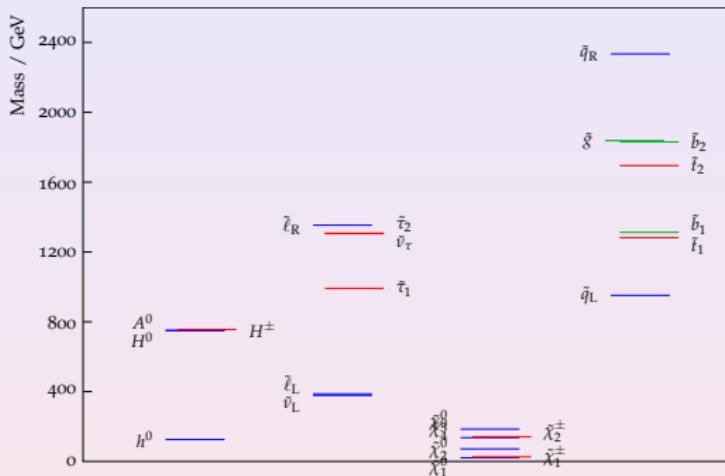
A relatively standard scenario, but the neutralino mass has to be larger (around 30 GeV) to give a large scattering cross-section.

Compressed spectrum in the neutralino/chargino sector



This scenario may be very interesting...

Compressed spectrum in the neutralino/chargino sector

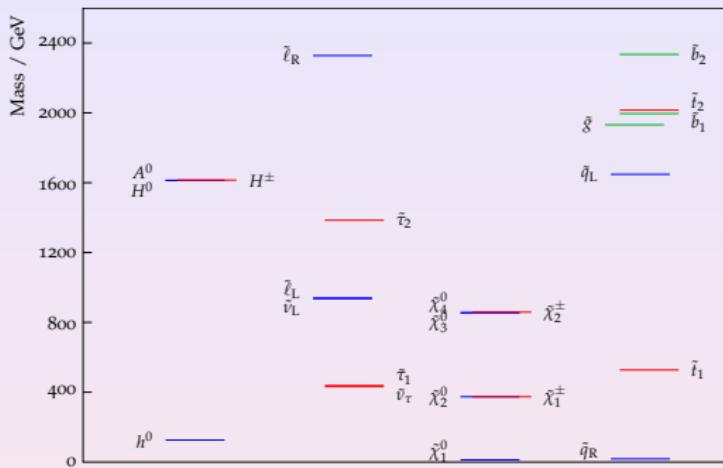


This scenario may be very interesting...

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

Light neutralinos and dark matter direct detection

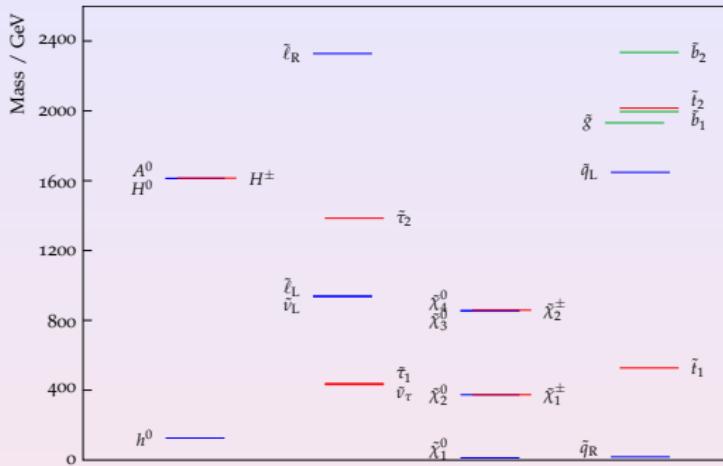
One squark quasi-degenerate with the neutralino



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

Light neutralinos and dark matter direct detection

One squark quasi-degenerate with the neutralino

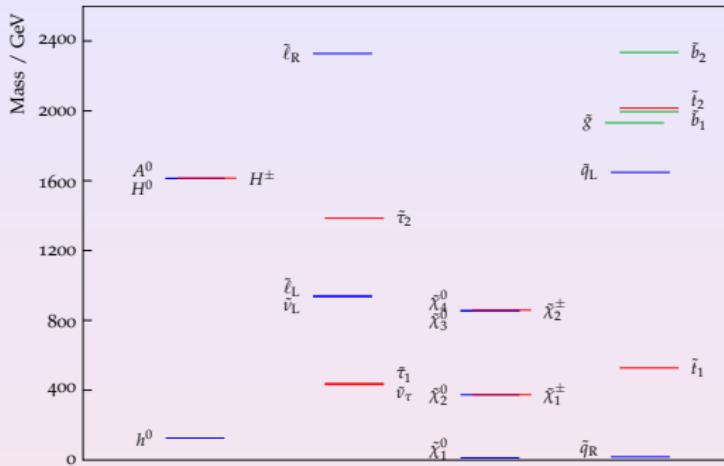


These spectra can fulfill all the constraints and have simultaneously a neutralino mass under 15 GeV and a large scattering cross-section!

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

Light neutralinos and dark matter direct detection

One squark quasi-degenerate with the neutralino



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→ A light sbottom can pass all these constraints!

Relic density and direct detection constraints

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

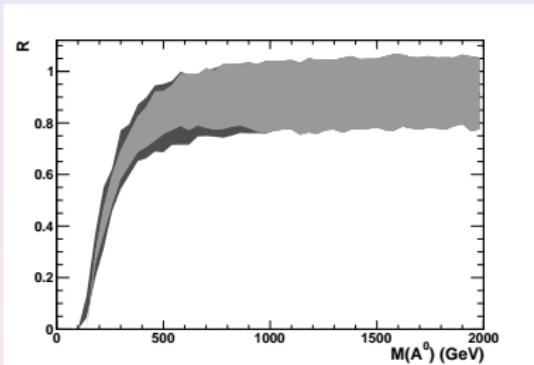
- the neutralino is not the only component of dark matter
- neutralinos are produced non-thermally (e.g. by the decay of an inflaton)
- dark energy accelerated the expansion of the Universe before the freeze-out
- additional entropy were generated in the early Universe
- ...

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.

What about the Higgs rates?

A light neutralino/light spectrum opens up different possibilities for the Higgs decays:

- Higgs decays into light SUSY particles
- Higgs invisible decays



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pMSSM light neutralino can be compatible with all constraints!

Three different scenarios

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