Dark matter in the MSSM

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In collaboration with M. Battaglia & N. Mahmoudi

DM@LHC – Merton College, Oxford – September 26th, 2014

Phenomenological MSSM (pMSSM)

The most general MSSM scenario with R-parity, CP conservation and minimal flavour violation

$\rightarrow$ 19 independent parameters (20 with gravitino mass)

In the following, we consider the lightest neutralino or the gravitino as dark matter

The neutralino can be

- bino-like ($|M_1| \ll |M_2|, |\mu|$)
- wino-like ($|M_2| \ll |M_1|, |\mu|$)
- higgsino-like ($|\mu| \ll |M_1|, |M_2|$)
- or a mixed state

$\rightarrow$ Flat scans on the pMSSM parameters

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- or a mixed state

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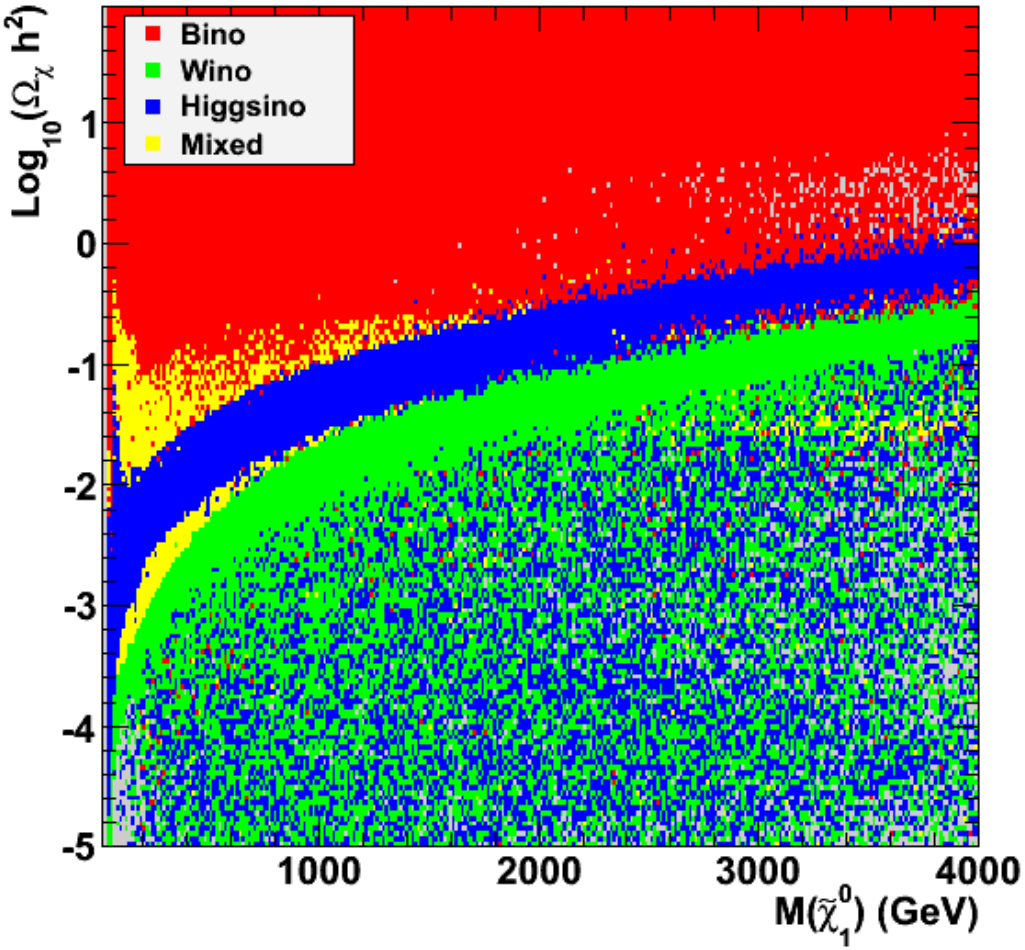
19 (20)-parameter pMSSM with neutralino (gravitino) dark matter

Parameter	Range (in GeV)
$\tan\beta$	[1, 60]
M_A	[0, 5000]
M_1	[-5000, 5000]
M_2	[-5000, 5000]
M_3	[0, 5000]
$A_d = A_s = A_b$	[-15000, 15000]
$A_u = A_c = A_t$	[-15000, 15000]
$A_e = A_\mu = A_\tau$	[-15000, 15000]
μ	[-5000, 5000]
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[0, 5000]
$M_{\tilde{e}_R} = M_{\tilde{\mu}_R}$	[0, 5000]
$M_{\tilde{\tau}_L}$	[0, 5000]
$M_{\tilde{\tau}_R}$	[0, 5000]
$M_{\tilde{q}_{1L}} = M_{\tilde{q}_{2L}}$	[0, 5000]
$M_{\tilde{q}_{3L}}$	[0, 5000]
$M_{\tilde{u}_R} = M_{\tilde{c}_R}$	[0, 5000]
$M_{\tilde{t}_R}$	[0, 5000]
$M_{\tilde{d}_R} = M_{\tilde{s}_R}$	[0, 5000]
$M_{\tilde{b}_R}$	[0, 5000]
$(M_{\text{gravitino}}$	$< M_{\tilde{\chi}_1^0})$

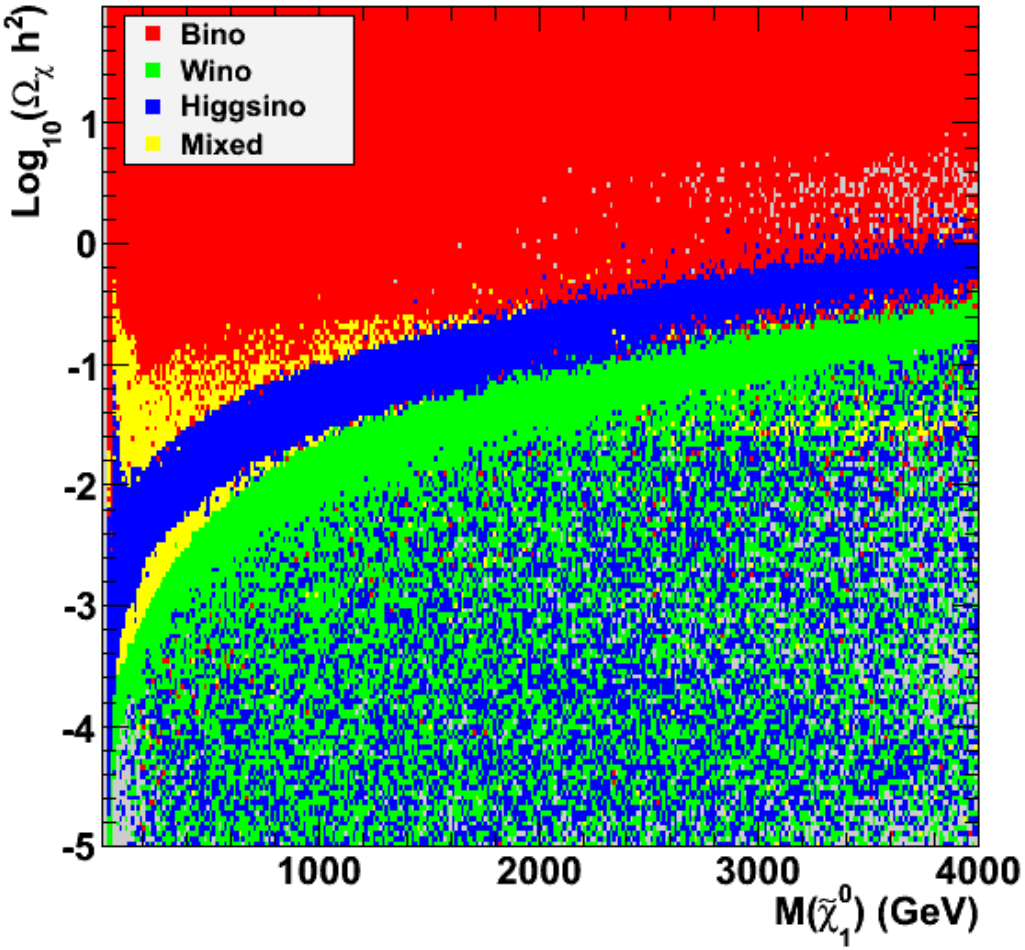
- Calculation of masses, mixings and couplings (SoftSusy, Suspect)
- Computation of low energy observables and Z widths (SuperIso)
- Computation of dark matter observables (SuperIso Relic, Micromegas, DarkSUSY)
- Determination of SUSY and Higgs mass limits (SuperIso, HiggsBounds)
- Calculation of Higgs cross-sections and decay rates (HDECAY, Higlu, FeynHiggs, SusHi)
- Calculation of SUSY decay rates (SDECAY)
- Event generation and evaluation of cross-sections (PYTHIA, Prospino, MadGraph)
- Implementation of ATLAS and/or CMS SUSY and monoX search results
- Determination of detectability with fast detector simulation (Delphes)



The colours give the nature of the neutralino with the largest fraction in each bin

Relic density "naturally" obtained for a Higgsino of 1.3 TeV or Wino of 2.7 TeV

In the following we impose $10^{-5} < \Omega_\chi h^2 < 0.163$



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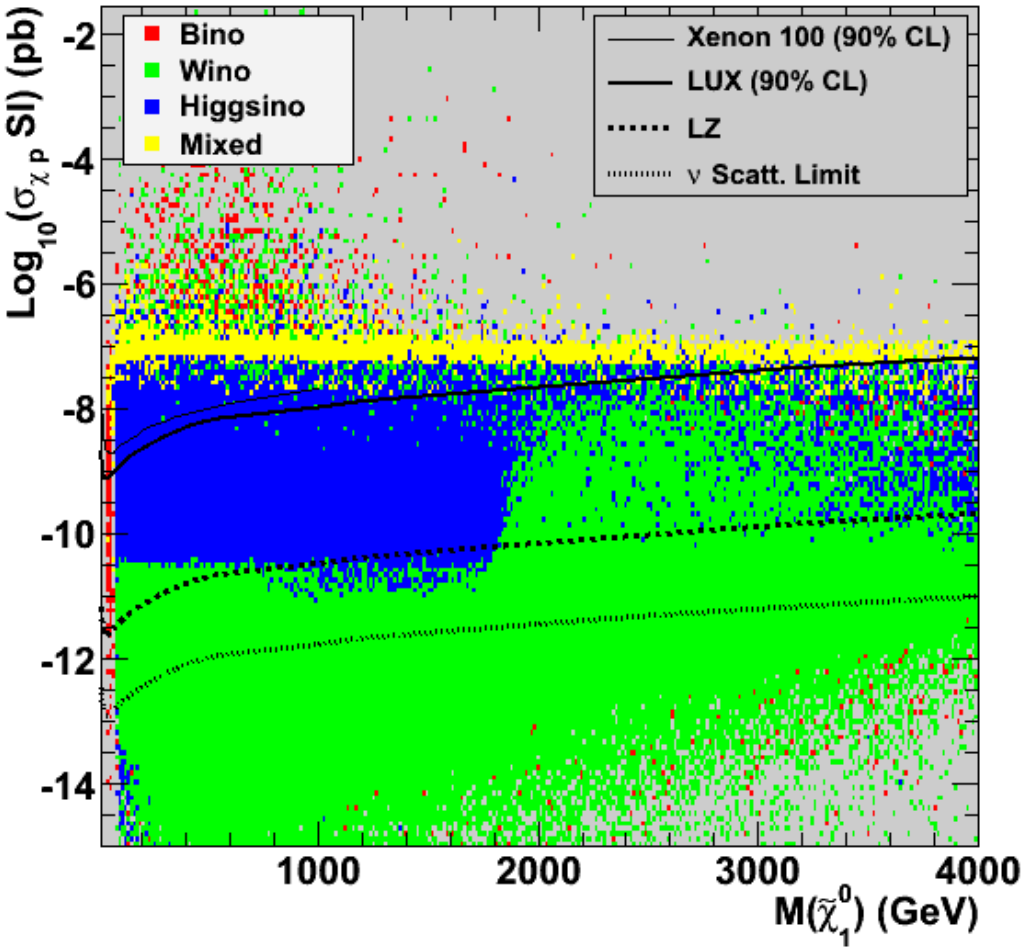

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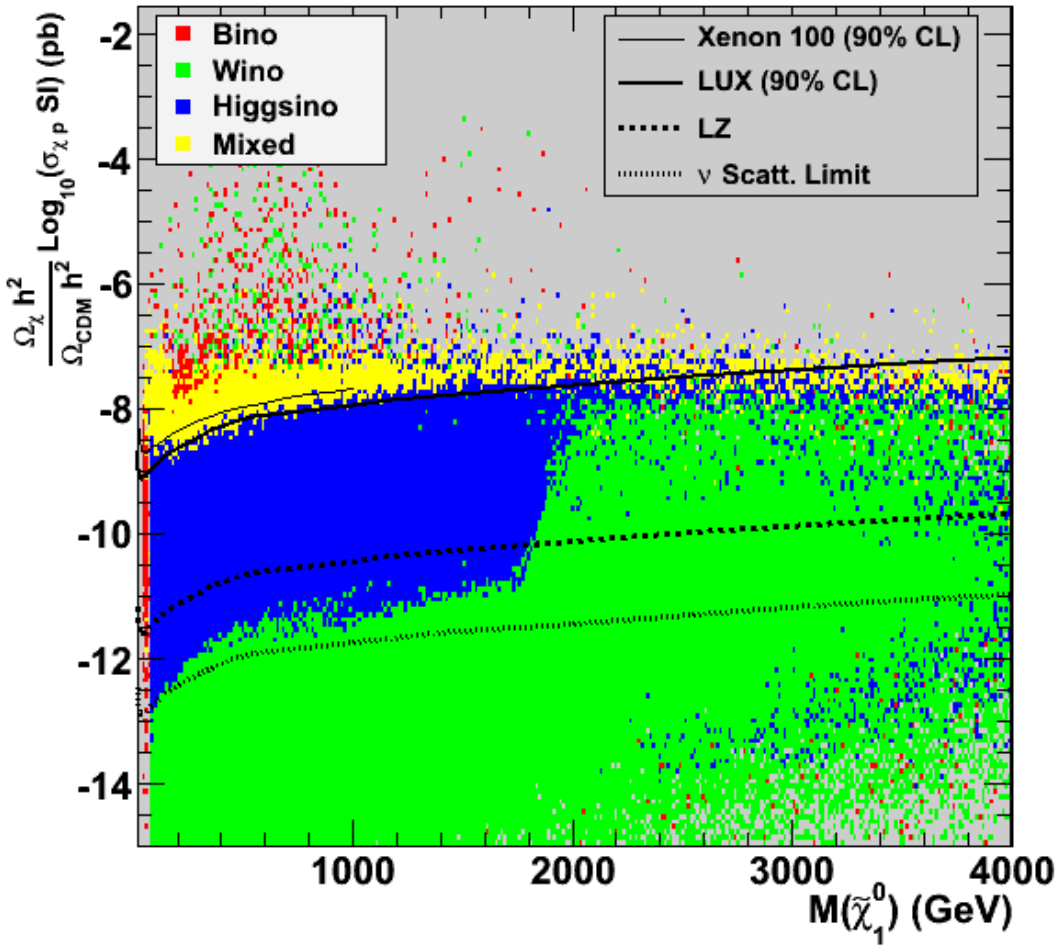
Case of a single component (local) dark matter



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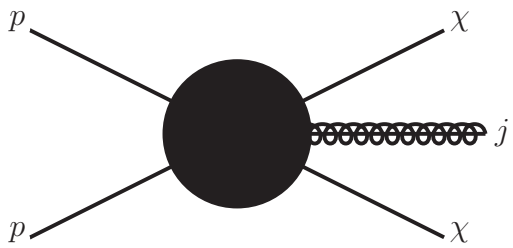
Case of a multiple component (local) dark matter
$\rightarrow$ normalisation by the neutralino relic density

Monojets in the pMSSM

Generic monojets in "simple" DM scenarios:



Monojets in the MSSM:

LHC very sensitive to the strongly interacting particles

$\rightarrow$ many SUSY events with monojet signature!

$\rightarrow$ particularly relevant when small mass splitting between squark/gluino and neutralino

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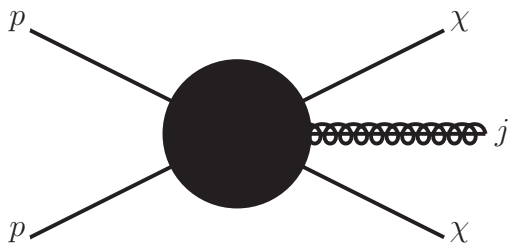

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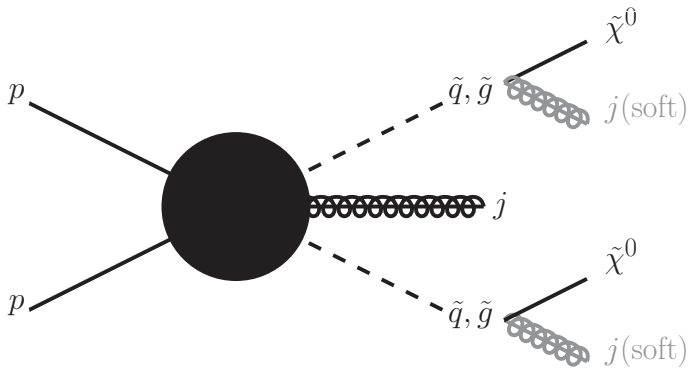

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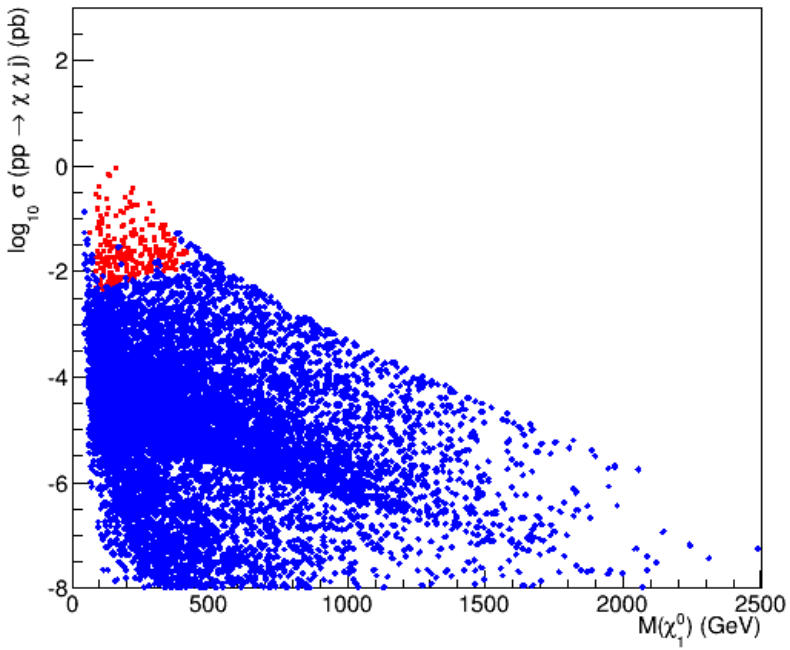
Analysis for the 14 TeV run with 300 fb^{-1}

Preliminary

Production cross-section vs. neutralino mass for

Monojets with neutralinos only



Red: excluded points
Blue: surviving points

Monojets particularly constraining on SUSY if all monojet signatures considered!

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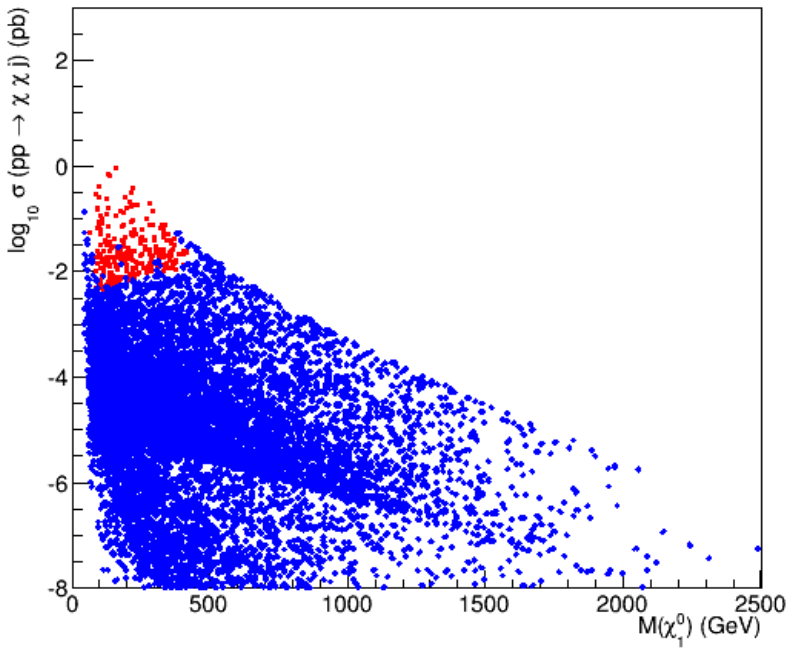
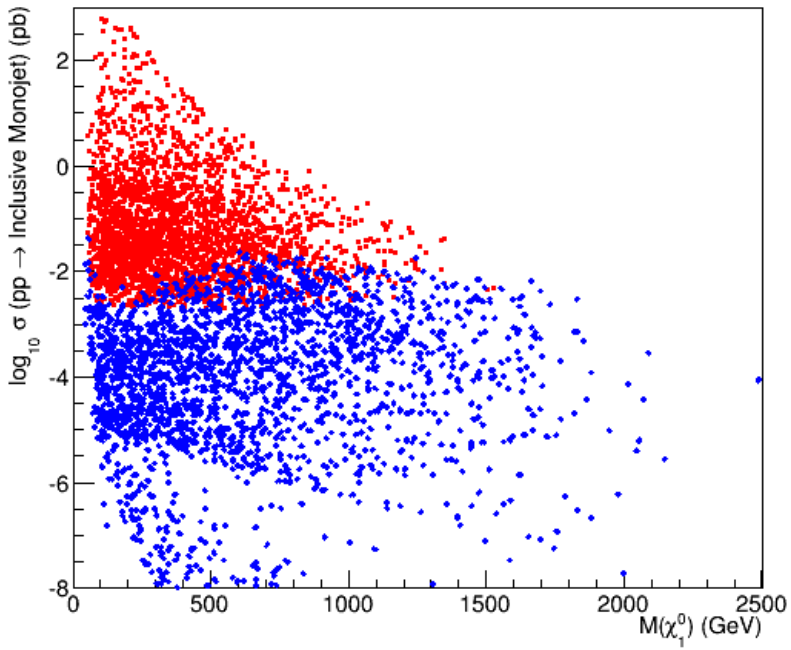


Other monojet signatures



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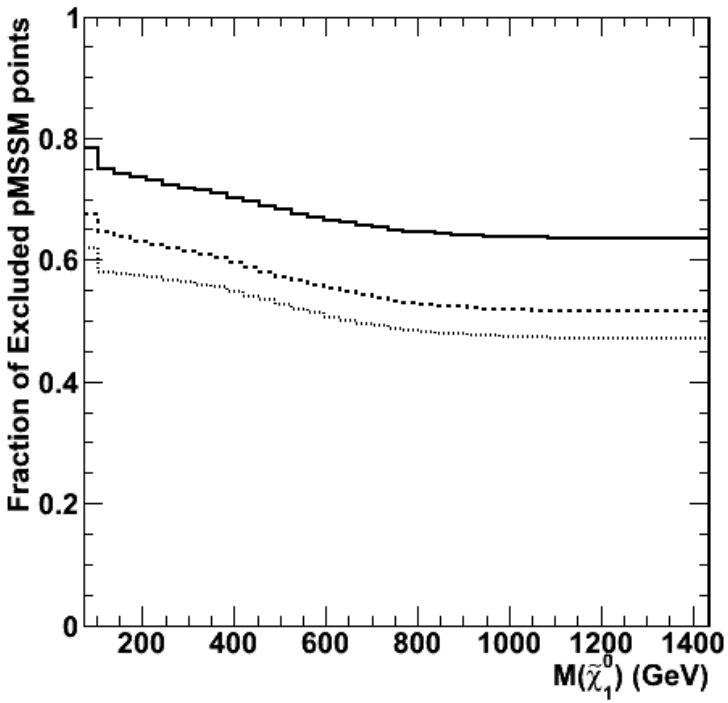
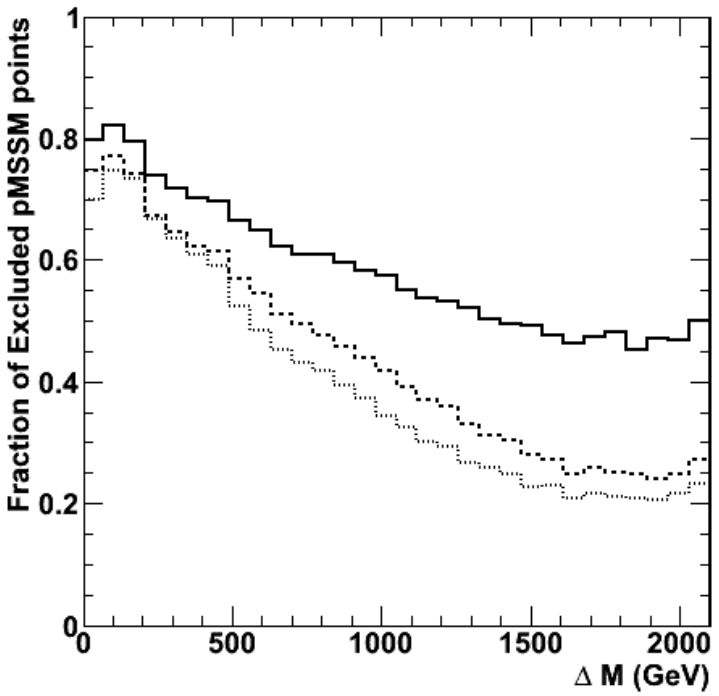
Fraction of excluded points vs.

Neutralino mass



Mass splitting with lightest squark/gluino



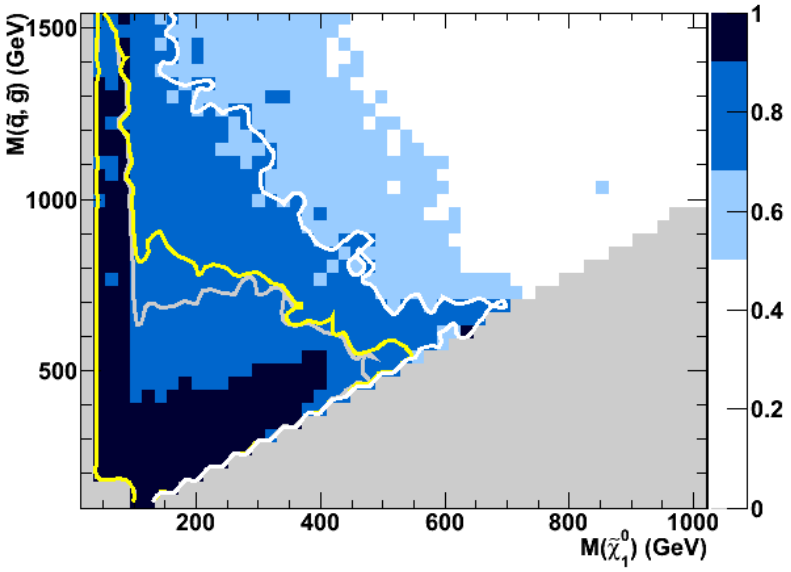
AA, M. Battaglia, F. Mahmoudi, Phys. Rev. D89 (2014) 077701

Dotted: jets/leptons+MET searches
Dashed: + monojet analyses
Plain: + LUX direct DM search

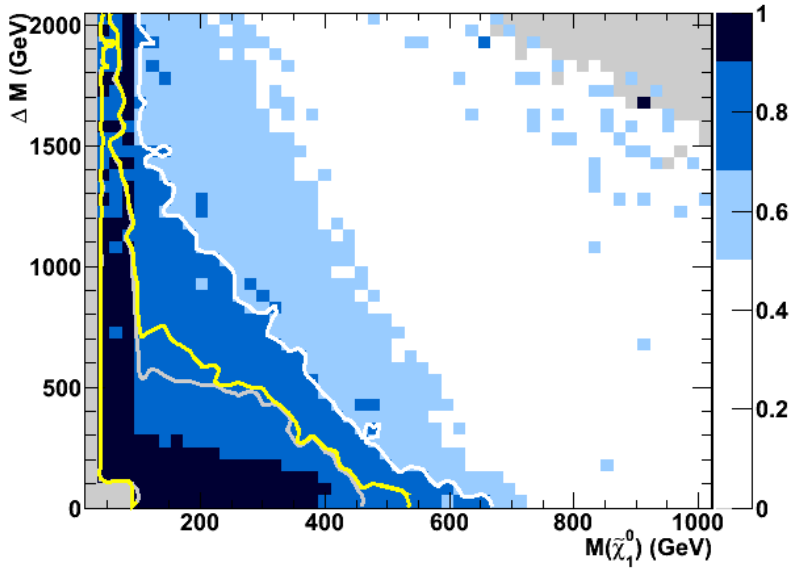
Monojet searches complementary to LHC SUSY searches and direct detection

Neutralino mass

vs. lightest squark/gluino mass



vs. mass splitting with lightest squark/gluino



AA, M. Battaglia, F. Mahmoudi, Phys. Rev. D89 (2014) 077701

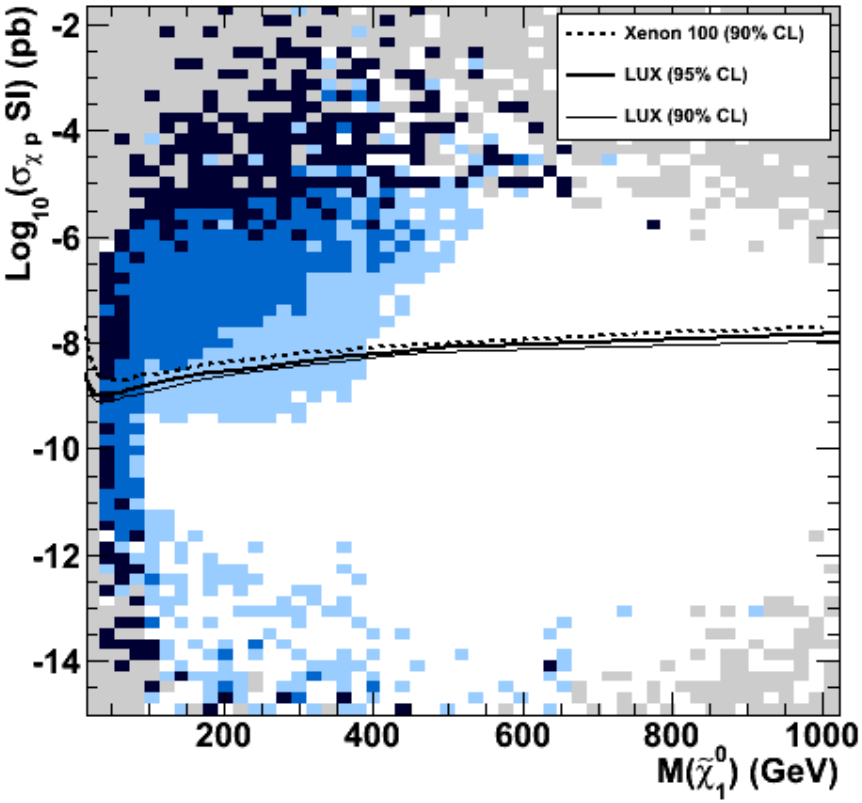
Colour scale: fraction of points excluded by jets/leptons+MET searches, monojet analyses and LUX direct DM search

Grey line: 68% C.L. exclusion by jets/leptons+MET searches
Yellow line: + monojet analyses
White line: + LUX direct DM search

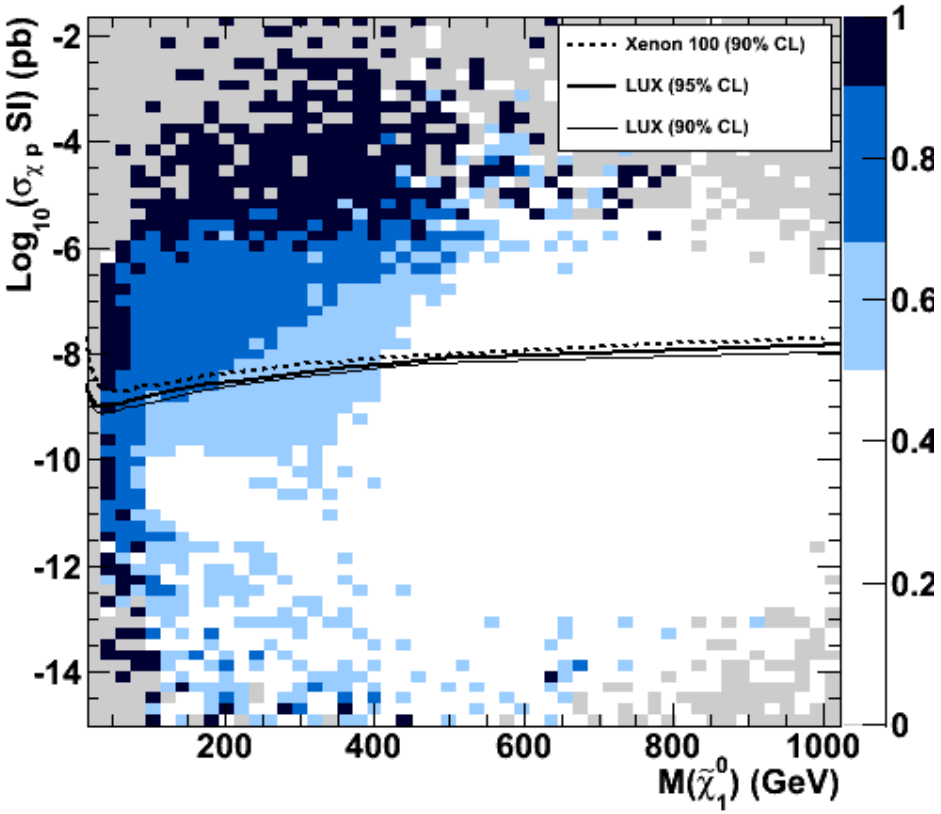
Monojet searches particularly interesting in small mass splitting regions

In the DM direct detection scattering cross section vs. neutralino mass plane:

jets/leptons+MET only



jets/leptons+MET searches and monojet



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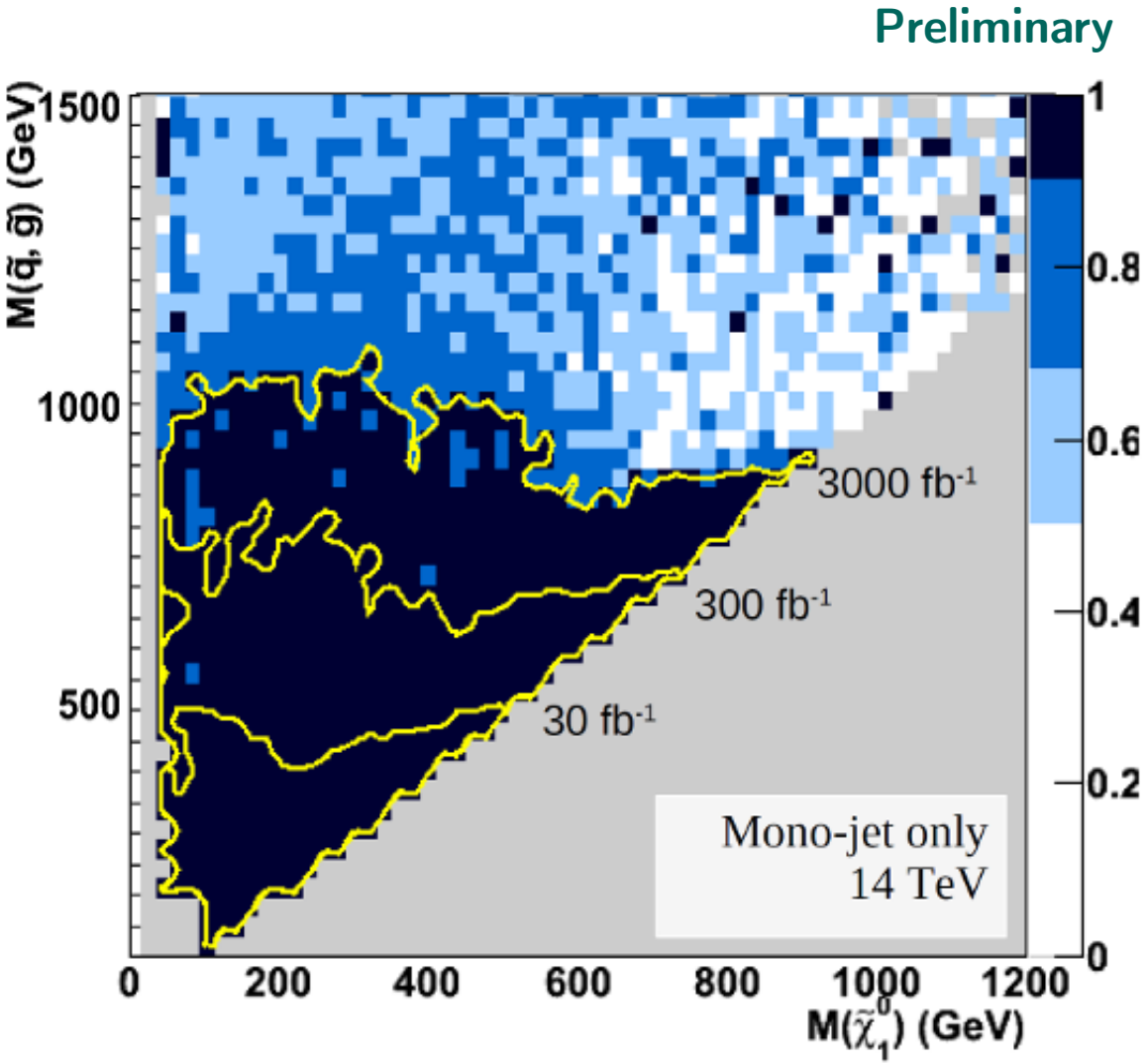
Colour scale: fraction of excluded points

Monojet searches complementary to LHC SUSY searches and direct detection

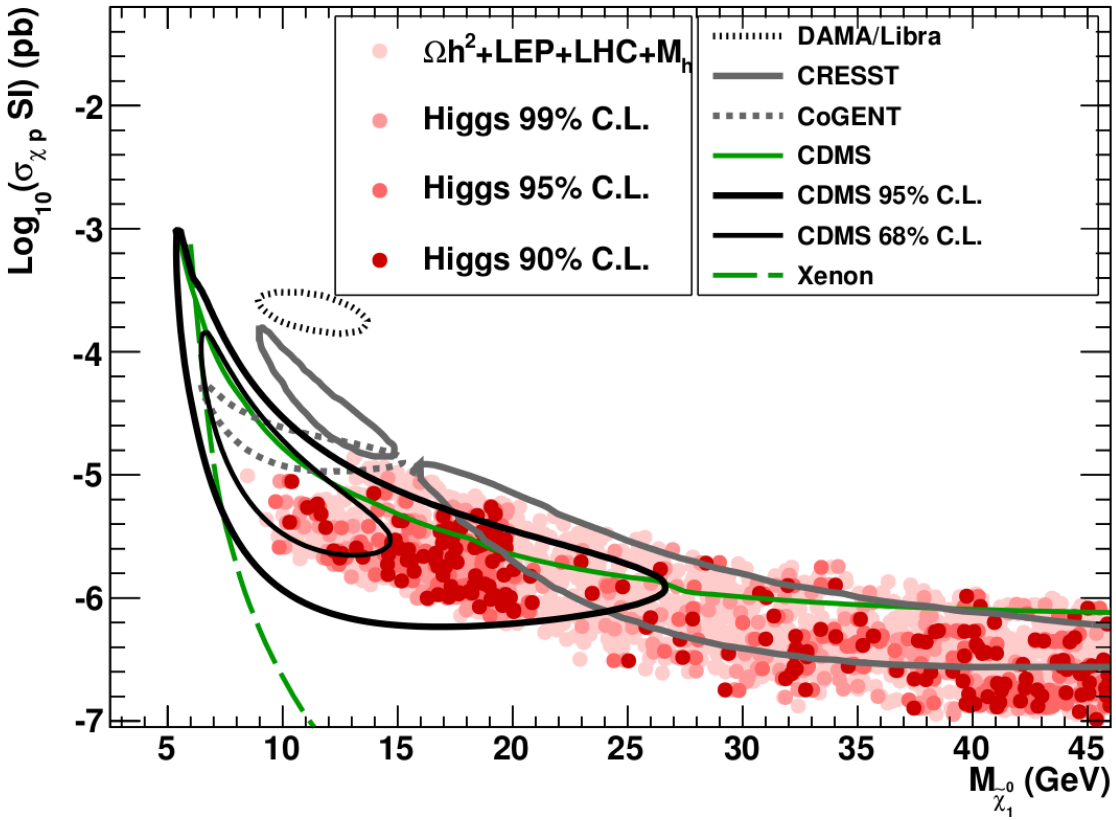
Fraction of points surviving the LHC monojet searches



Colour scale: fraction of excluded points

Monojet searches very powerful probes for SUSY!

Possible to find MSSM scenarios with very light neutralinos satisfying all the constraints!



AA, M. Battaglia, F. Mahmoudi, Eur.Phys.J. C72 (2012) 2169

Loose relic density constraint

$$10^{-4} < \Omega_\chi h^2 < 0.163$$

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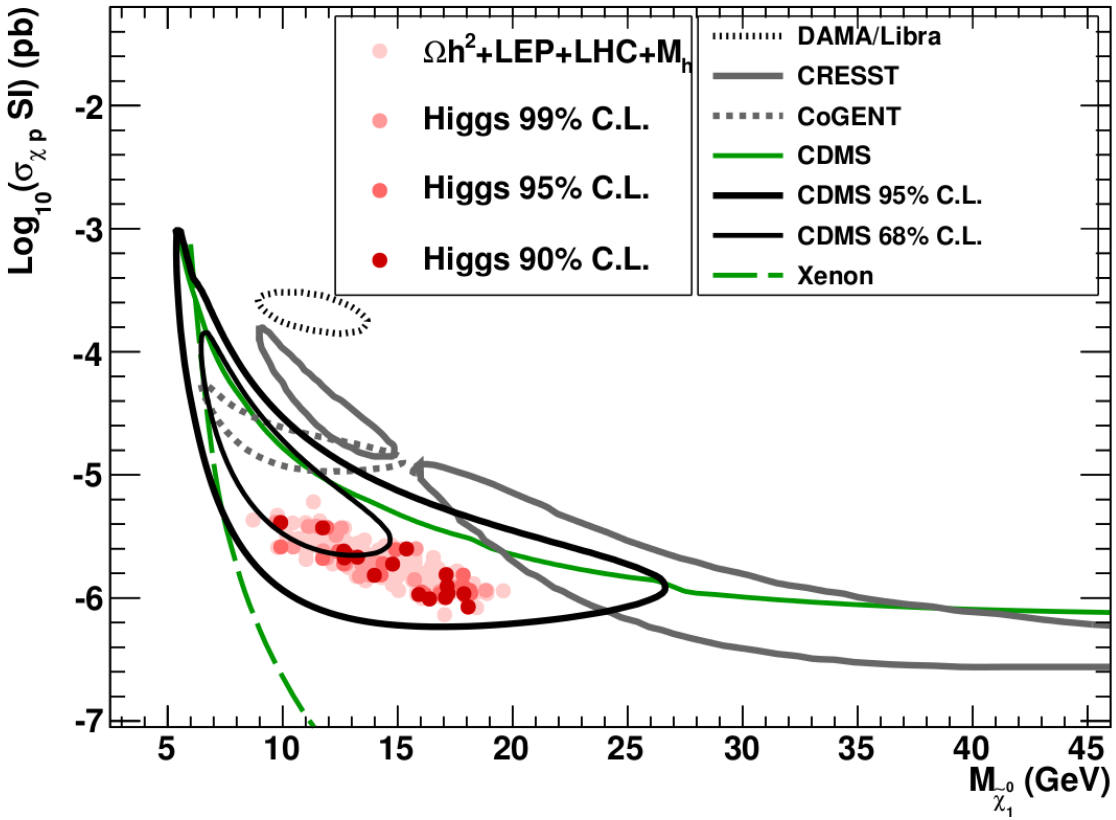


AA, M. Battaglia, F. Mahmoudi, Eur.Phys.J. C72 (2012) 2169

Tight relic density constraint

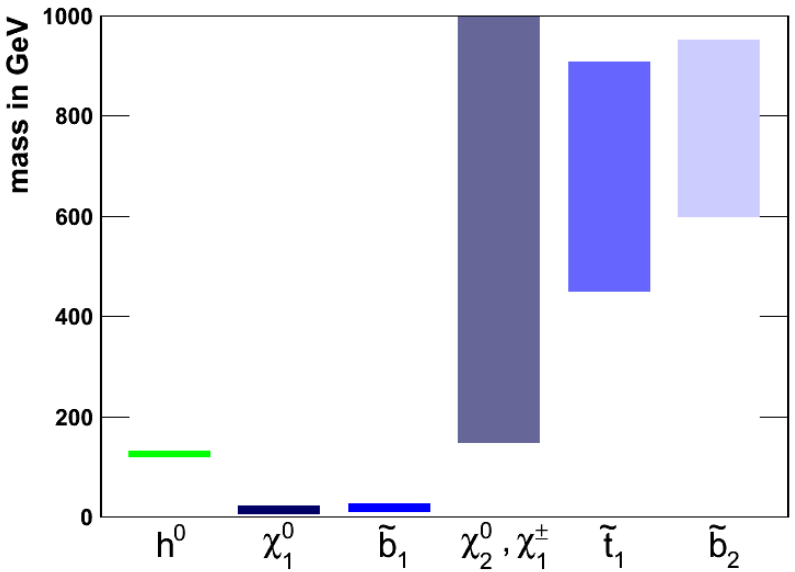
$0.076 < \Omega_\chi h^2 < 0.163$

Very light neutralino dark matter: Typical spectra

- Light bino-like neutralino of mass ~ 10 GeV
- Light right-handed sbottom of mass ~ 15 GeV

Needed features:

- bino-like $\tilde{\chi}_1^0$ to respect $\Gamma(Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0)$ and other LEP constraints
- right-handed $\tilde{b}_1$ to respect $\Gamma(Z \to \tilde{b}_1 \bar{\tilde{b}}_1)$ constraints
- small mass splitting $(M_{\tilde{b}_1} - M_{\tilde{\chi}_1^0})$ to get an adequate relic density



AA, M. Battaglia, F. Mahmoudi, Eur.Phys.J. C72 (2012) 2169

Other SUSY particle masses irrelevant for this scenario

Gravitino dark matter

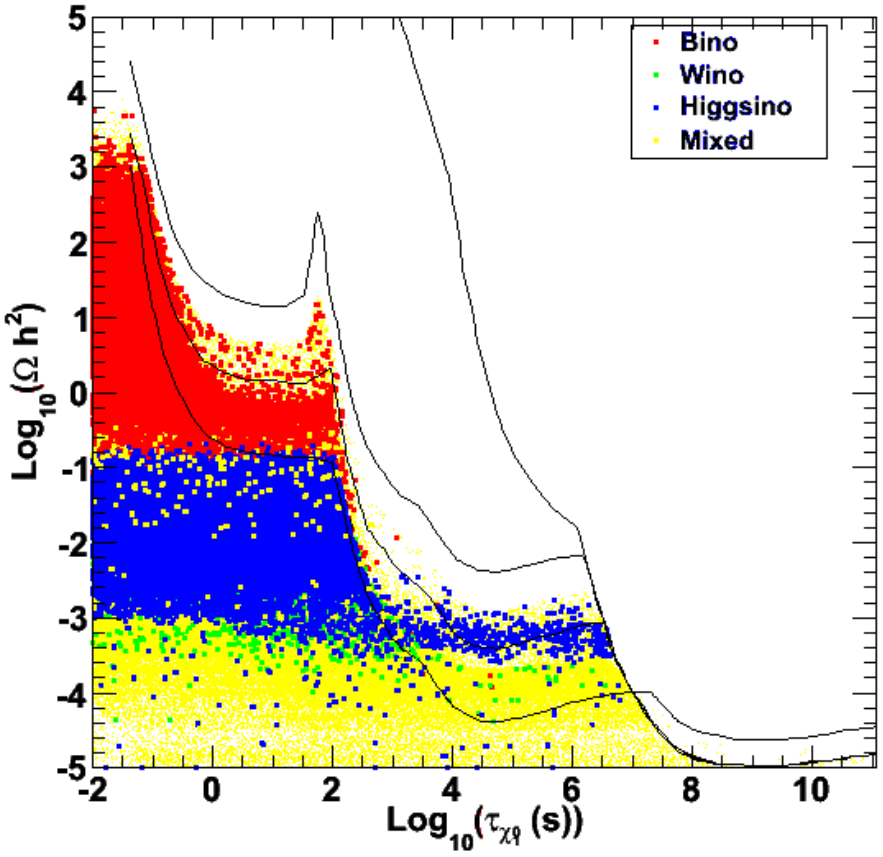
Study restricted to neutralino NLSP case for comparison with neutralino LSP scenario

- Gravitino LSP, single component of dark matter
- Neutralino NLSP short-lived with respect to cosmology
  $\rightarrow$ Gravitino produced either through NLSP decay or reheating
  $\rightarrow$ Neutralino lifetime constrained by Big-Bang Nucleosynthesis
- Neutralino NLSP long-lived with respect to collider physics
  $\rightarrow$ Same collider constraints as for neutralino LSP scenario
- DM composed exclusively of gravitinos
  $\rightarrow$ Constraints from direct and indirect detection completely escaped (gravitino very elusive!)
  $\rightarrow$ Constraints from relic density strongly relaxed (in particular because of gravitino production during reheating)

Gravitino LSP scenario much less constrained than the neutralino LSP scenario!

Constraints from Big-Bang Nucleosynthesis

(limits extracted from Jedamzik, hep-ph/060425)



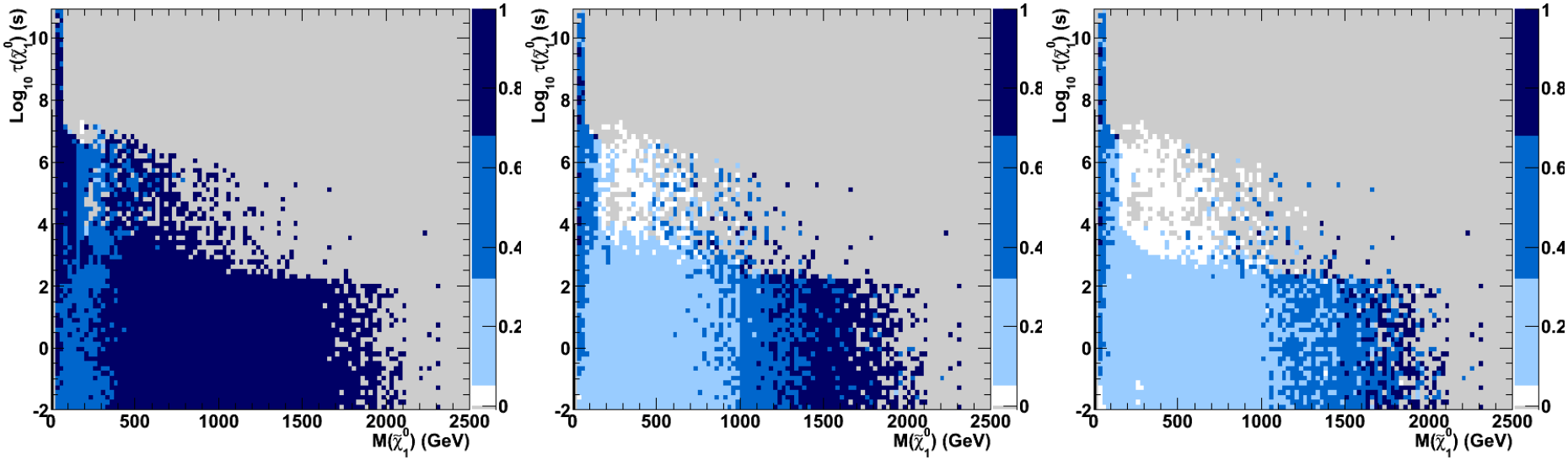
$\tau_{\tilde{\chi}_1^0}$: neutralino lifetime

Ωh^2: neutralino relic density (in absence of gravitino)

Preliminary

Fraction of points surviving the LHC SUSY and monojet searches

Preliminary

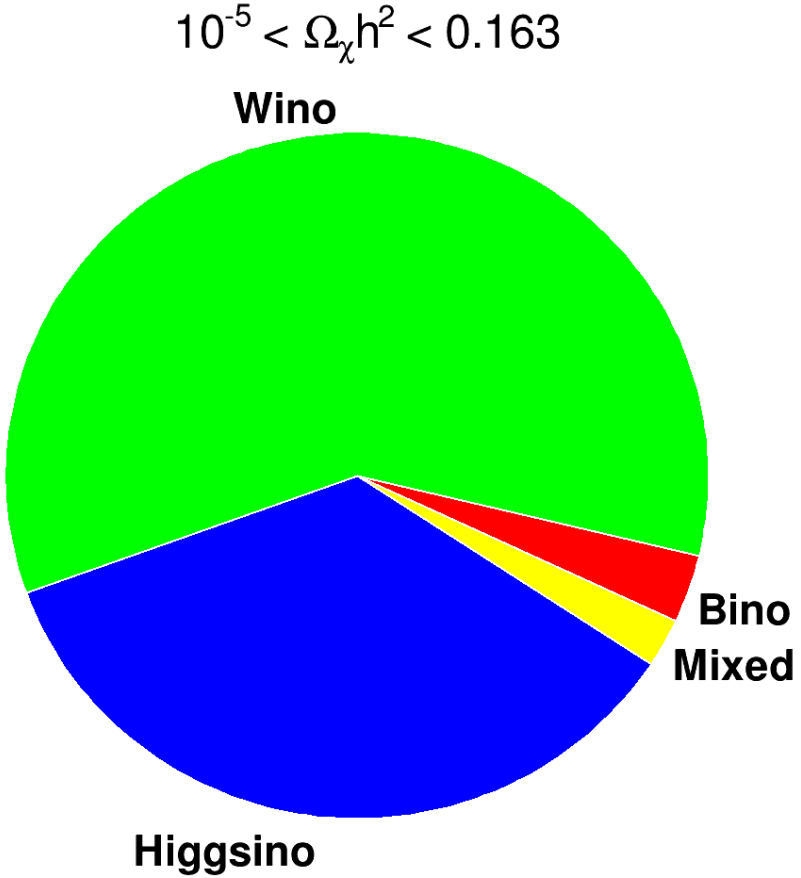


8 TeV, 25 fb^{-1} | 14 TeV, 300 fb^{-1} | 14 TeV, 3000 fb^{-1}

In the gravitino LSP scenario, LHC will probe neutralino masses up to $\sim$1.5 TeV

Fraction of neutralino states after dark matter constraints

Preliminary



Dark matter constraints strongly shape the neutralino sector

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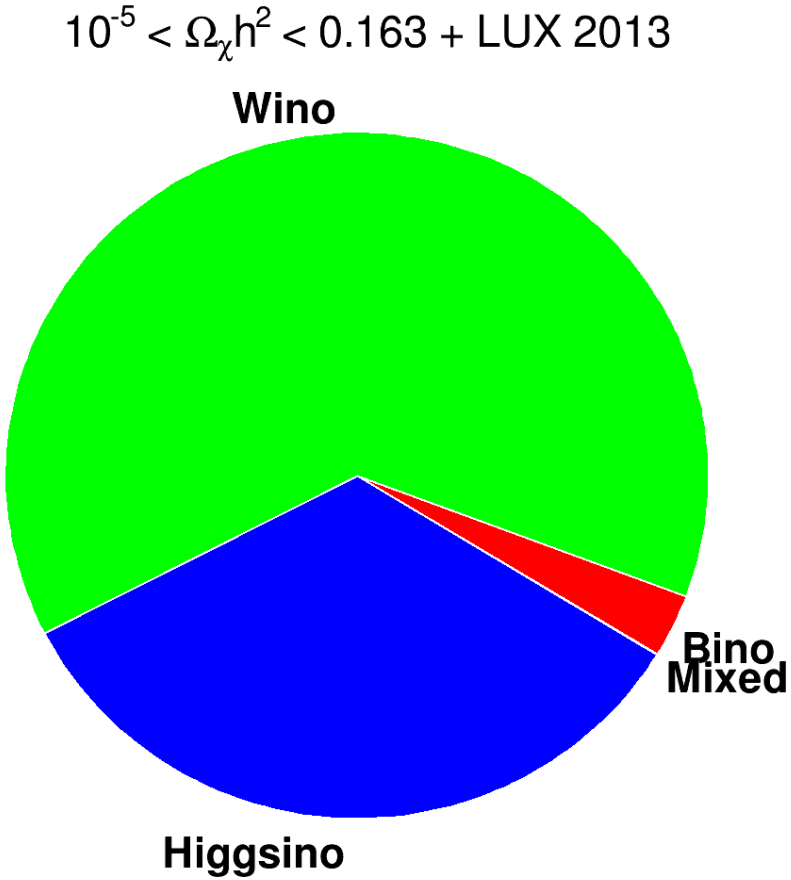

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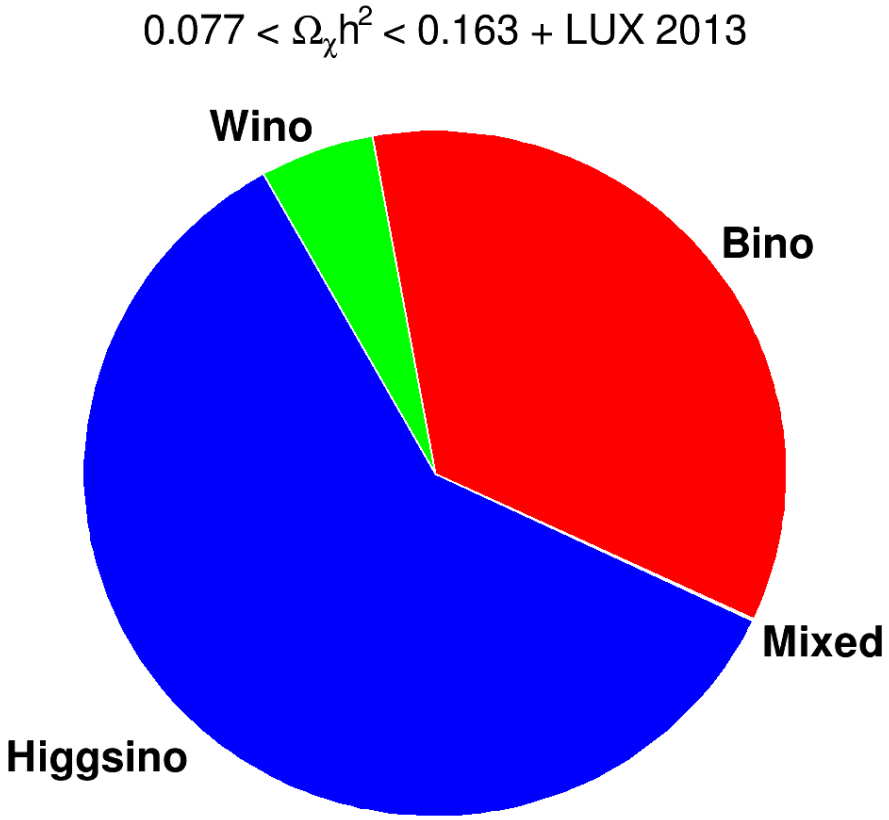

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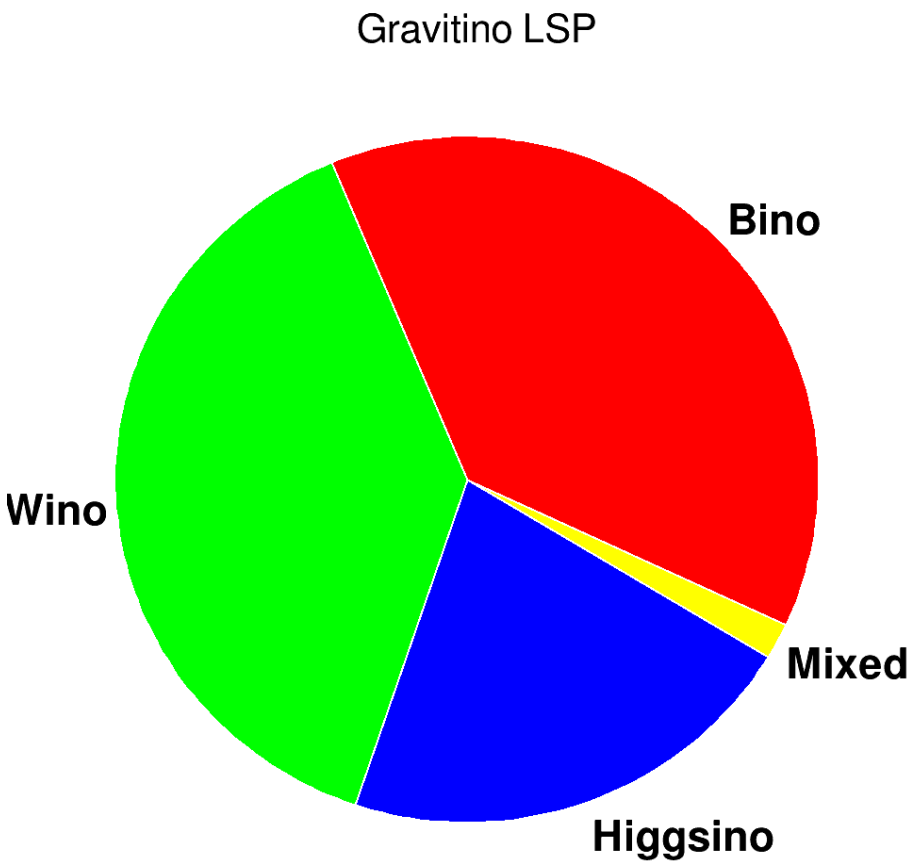

Dark matter constraints strongly shape the neutralino sector

Conclusions

- The pMSSM provides viable candidates for dark matter
- Dark matter searches are powerful probes for Supersymmetry
- Monojet searches are complementary to the usual SUSY searches at the LHC
- Monojet searches are to be considered beyond the effective theories for SUSY
- Gravitino DM scenario less constrained than the neutralino LSP scenario
- Still plenty of room for SUSY and New Physics!

Backup

Very light neutralino dark matter: Constraints

Type	Constraint
Higgs mass constraint Higgs signal strengths	$M_h \in [121, 129]$ GeV ATLAS+CMS
Z decay widths	$\Gamma(Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) < 3$ MeV $\Gamma(Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) + \Gamma(Z \to \tilde{b}_1 \tilde{b}_1) < 5$ MeV $0.21497 < R_b < 0.21761$
LEP and Tevatron SUSY searches	PDG limits + specific analysis of the $\tilde{\chi}^+ \tilde{\chi}^- / \tilde{\chi}_2^0 \tilde{\chi}_1^0$ channels
Oblique parameters S, T, U	LEP limits
Vacuum stability	stable or long-lived scalar potential minimum
Flavour physics	$2.63 \times 10^{-4} < \mathrm{BR}(B \to X_s \gamma) < 4.23 \times 10^{-4}$ $1.28 \times 10^{-9} < \mathrm{BR}(B_s \to \mu^+ \mu^-)_{\mathrm{untag}} < 4.52 \times 10^{-9}$ $0.40 \times 10^{-4} < \mathrm{BR}(B_u \to \tau \nu) < 1.88 \times 10^{-4}$ $4.7 \times 10^{-2} < \mathrm{BR}(D_s \to \tau \nu) < 6.1 \times 10^{-2}$ $2.9 \times 10^{-3} < \mathrm{BR}(B \to D^0 \tau \nu) < 14.2 \times 10^{-3}$ $0.985 < R_{\mu 23} < 1.013$
Muon anomalous magnetic moment	$-2.4 \times 10^{-9} < \delta a_\mu < 4.5 \times 10^{-9}$
Loose relic density Tight relic density	$10^{-4} < \Omega_\chi h^2 < 0.163$ $0.076 < \Omega_\chi h^2 < 0.163$
Dark matter annihilation cross-section	$\sigma v_{\mathrm{tot}} < 10^{-26}$ cm^3/s with $M_{\tilde{\chi}_1^0} < 50$ GeV $\sigma v_{bbg} < 2 \times 10^{-27}$ cm^3/s with $M_{\tilde{\chi}_1^0} < 50$ GeV
Dark matter direct detection	$10^{-7} < \sigma_{p-\chi}^{\mathrm{SI}} < 10^{-2}$ pb with $M_{\tilde{\chi}_1^0} < 50$ GeV (close to the CDMS contour and XENON limit)
LHC searches	Higgs searches SUSY searches monojet, monophoton and mono-Z/W searches