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Light neutralinos in the NMSSM

In collaboration with C. Boehm, G. Bélanger, A. Pukhov & J. Silk

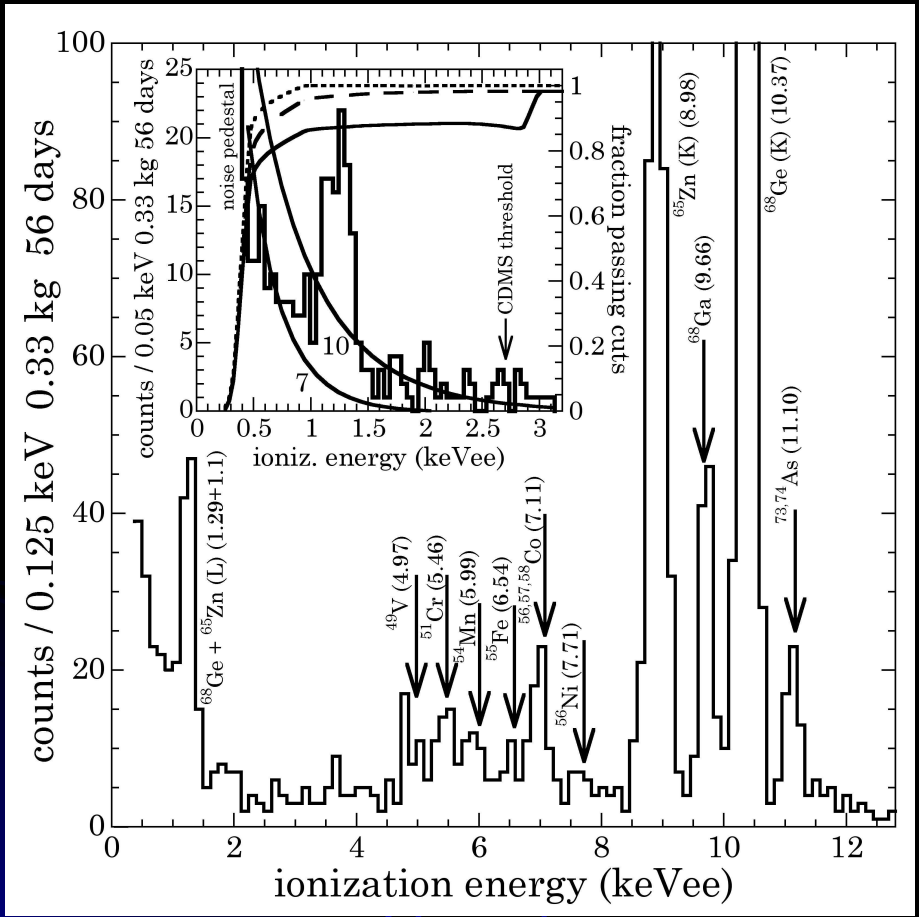
arXiv:1009.4380

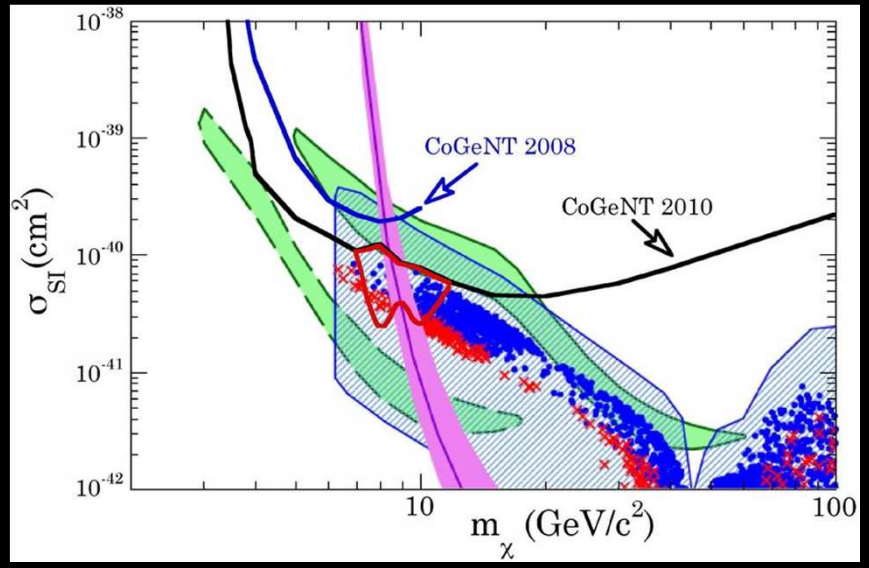
Outline

- Introduction
- Model and Method
- Light NMSSM Neutralinos
- Conclusions

Introduction

Introduction – February 2010

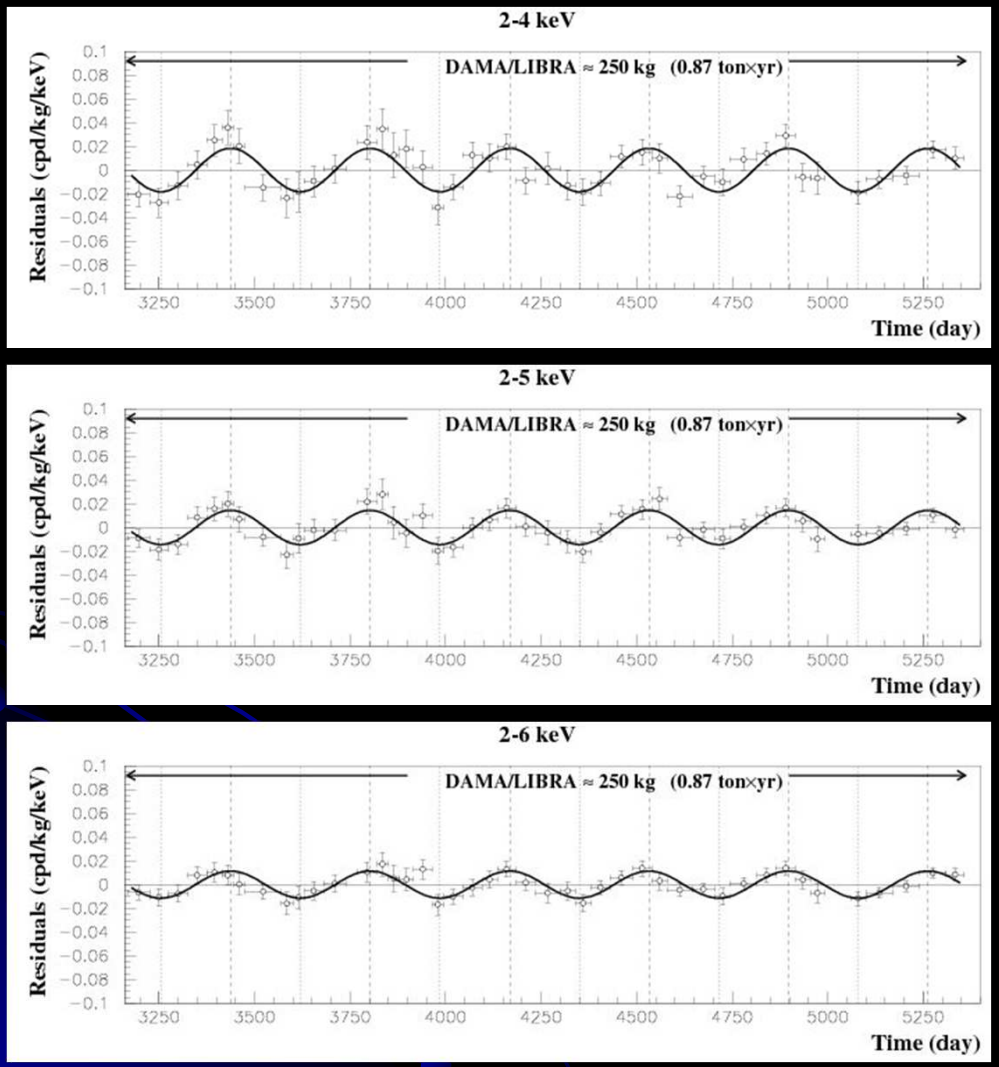




- Unexplained bulk-like signal
- Very low energy
- Preferred mass range: 7-11 GeV

Aalseth et al. (CoGent collaboration) – arXiv:1002.4703

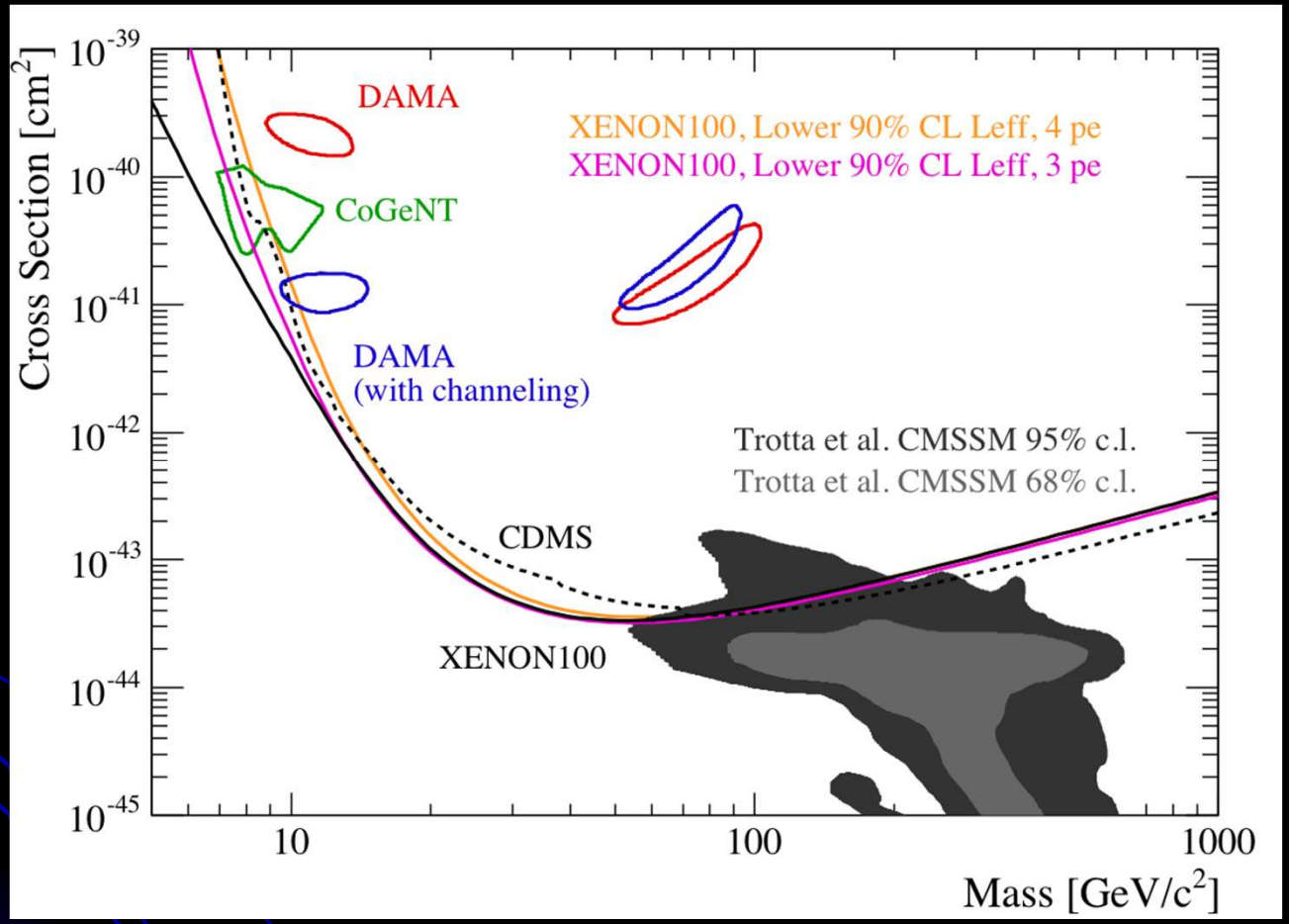
Introduction – February 2010



- Modulated WIMP-like signal
- 8.9 σ C.L. (cumulated)
- Low energy
- Preferred mass range: 5-15 GeV

Bernabei et al. (DAMA collaboration) – arXiv:1002.1028

Introduction – May 2010



Aprile et al. – arXiv:1005.0380, arXiv:1005.2615

Introduction

- Possible Dark Matter signals
  DAMA, CoGent, CRESST, Edelweiss, CDMS, Xenon100…?
- Rather Light WIMPS
- MSSM fails to provide a neutralino lighter than ~ 30 GeV
- Can the NMSSM provide such a candidate?

Model & Method

NMSSM

- MSSM + addition of a Higgs singlet (of the SM)
- 3 new neutral Higgses: one scalar and two pseudo-scalars
- Contraints on the lightest neutral Higgs are lifted
- New neutralino component: singlino

MSSM $\longrightarrow$ NMSSM

$$\mu H_1 . H_2 \longrightarrow \lambda S H_1 . H_2 + \frac{1}{3} \kappa S^3$$

$\mu \longrightarrow \mu, \lambda, \kappa, A_\lambda, A_\kappa$

NMSSM – Neutralino LSP

$$M_{\chi^0}^{NMSSM} = \begin{pmatrix} M_1 & 0 & -M_Z s_W c_\beta & M_Z s_W s_\beta & 0 \\ 0 & M_2 & M_Z c_W c_\beta & -M_Z c_W s_\beta & 0 \\ -M_Z s_W c_\beta & M_Z c_W c_\beta & 0 & -\mu & -\frac{\lambda v_1}{\sqrt{2}} \\ M_Z s_W s_\beta & -M_Z c_W s_\beta & -\mu & 0 & -\frac{\lambda v_2}{\sqrt{2}} \\ 0 & 0 & -\frac{\lambda v_1}{\sqrt{2}} & -\frac{\lambda v_2}{\sqrt{2}} & 2\frac{\mu\kappa}{\lambda} \end{pmatrix}$$

$$\chi_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}_3^0 + N_{13}\tilde{H}_d + N_{14}\tilde{H}_u + N_{15}\tilde{S}$$

Parameters

Gaugino masses: M_1, M_2

Higgs sector: μ, tan β, M_A

Trilinear coupling: At

Sfermion masses $M_{\tilde{l}}$, $M_{\tilde{q}}$

Parameter Space (GeV units)

$$1 < M_1 < 100$$
$$100 < M_2 < 2000$$
$$0 < \mu < 1000$$
$$1 < \tan\beta < 75$$
$$0 < \lambda < 0.75$$
$$0 < \kappa < 0.65$$
$$-2000 < A_\lambda < 5000$$
$$-5000 < A_\kappa < 2000$$
$$-3000 < A_t < 3000$$
$$100 < M_{\tilde{l}} < 2000$$
$$300 < M_{\tilde{q}} < 2000$$

Tools

- micrOMEGAs 2.4
- EWSB spectrum calculator: NMSSMTools
- Amplitude calculations through CalcHep: constraints and Direct Detection cross sections
- Existing functions for several processes: easy comparison with data

Priors: What and Where

1. Spectrum has to be computable:

   Dirac discrimination of spectrum calculators

2. Parameter Space:

   Plateau-weight with round boundaries on predefined intervals

3. Light Neutralino LSP:

   Plateau-weight with round boundaries in two cases:

$$1\ GeV < M_{\chi} < 15\ GeV$$

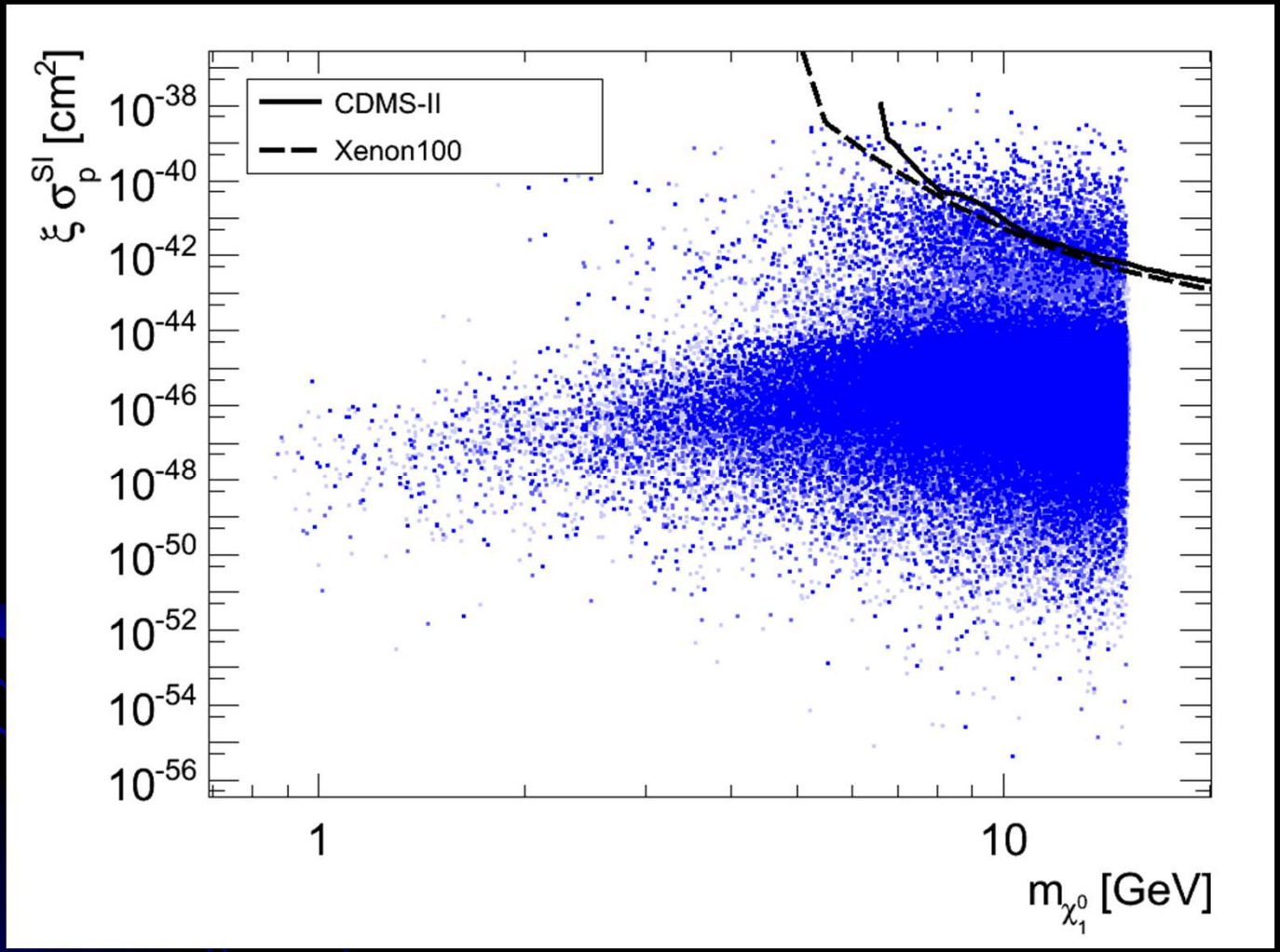
$$1\ GeV < M_{\chi} < 50\ GeV$$

Likelihoods: fitting data

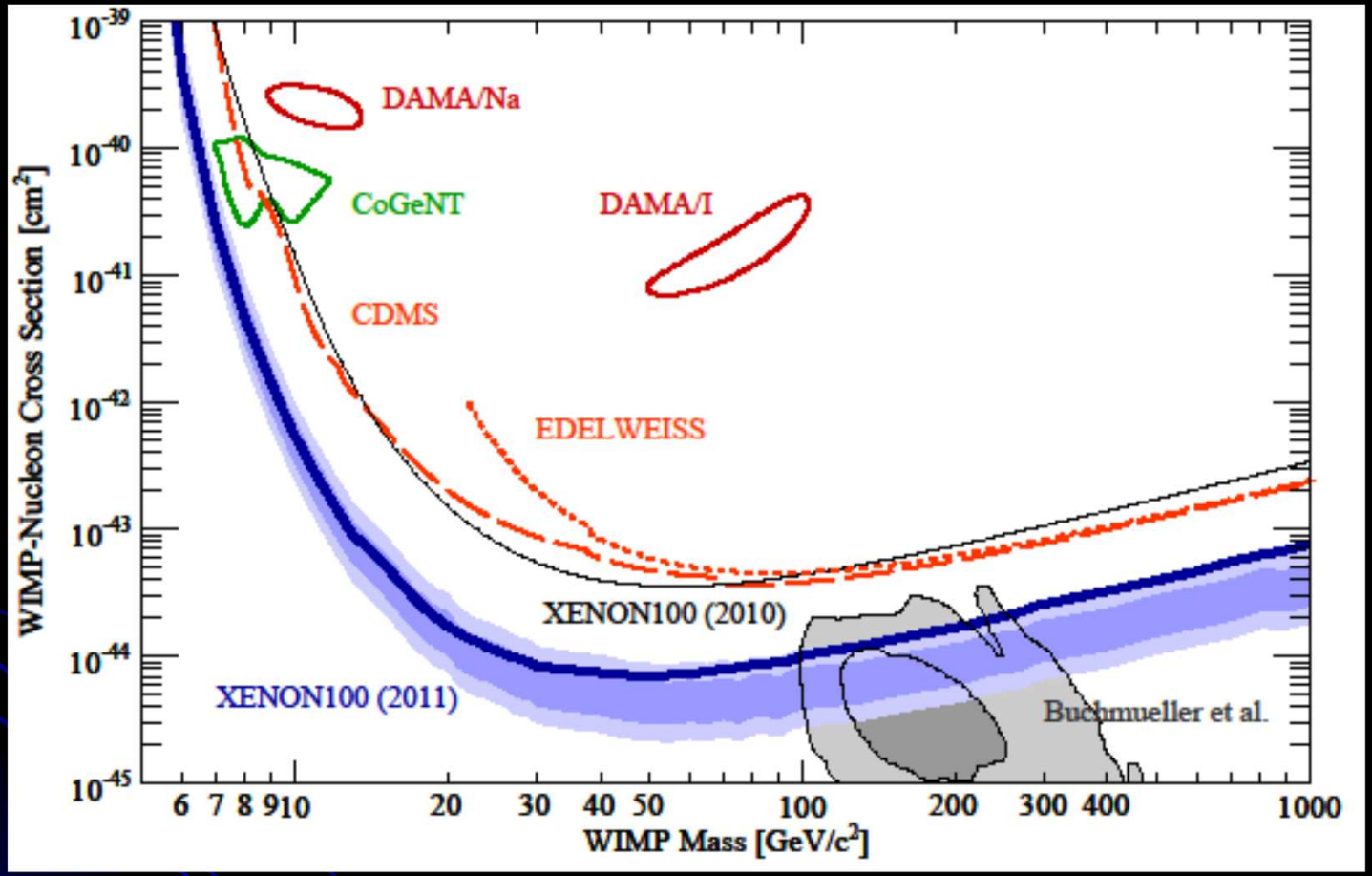
- Dark Matter: thermal relic $\left\{ \begin{array}{l} 10\%\ \Omega_{WMAP} < \Omega_{\chi} < \Omega_{WMAP} \\ \Omega_{WMAP} h^2 = 0.1131 \end{array} \right\}$
- Supersymmetry: unfruitful searches of new particles $\left\{ M_H,\ M_{\chi^+},\ \ldots \right\}$
- Electroweak precision measurements $\left\{ \begin{array}{l} (g-2)_{\mu},\ \Delta\rho \\ Z \to \chi\chi \\ e^+e^- \to \chi_1\chi_{2,3} \to \chi_1\chi_1 Z \end{array} \right\}$
- B-physics $\left\{ \begin{array}{l} B(b \to s\gamma) \\ B(B_s \to \mu^+\mu^-) \\ B(B \to \tau\nu_{\tau}) \\ \Delta M_s,\ \Delta M_d \end{array} \right\}$

Light NMSSM Neutralinos

NMSSM does the job!

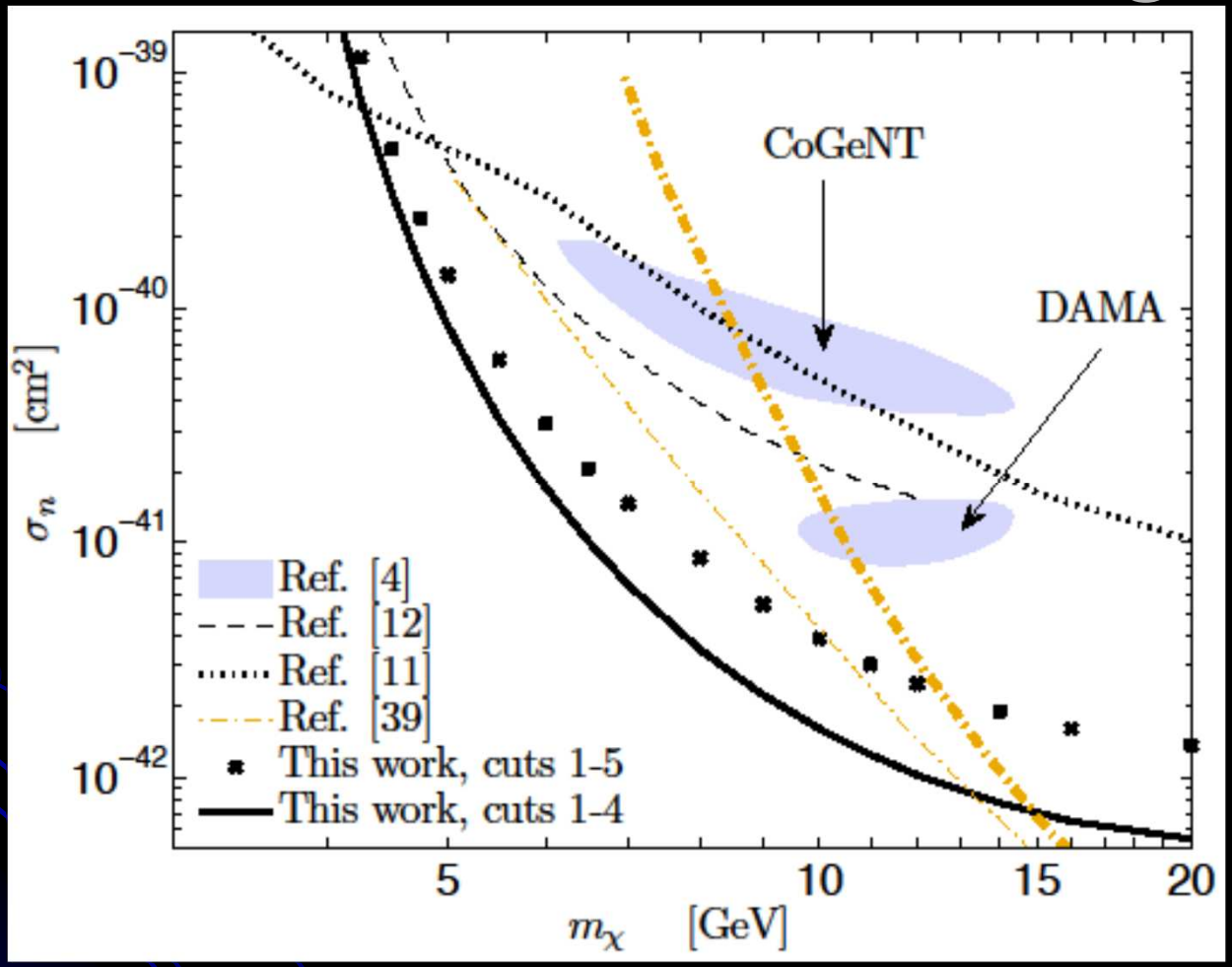


NMSSM: for how long?



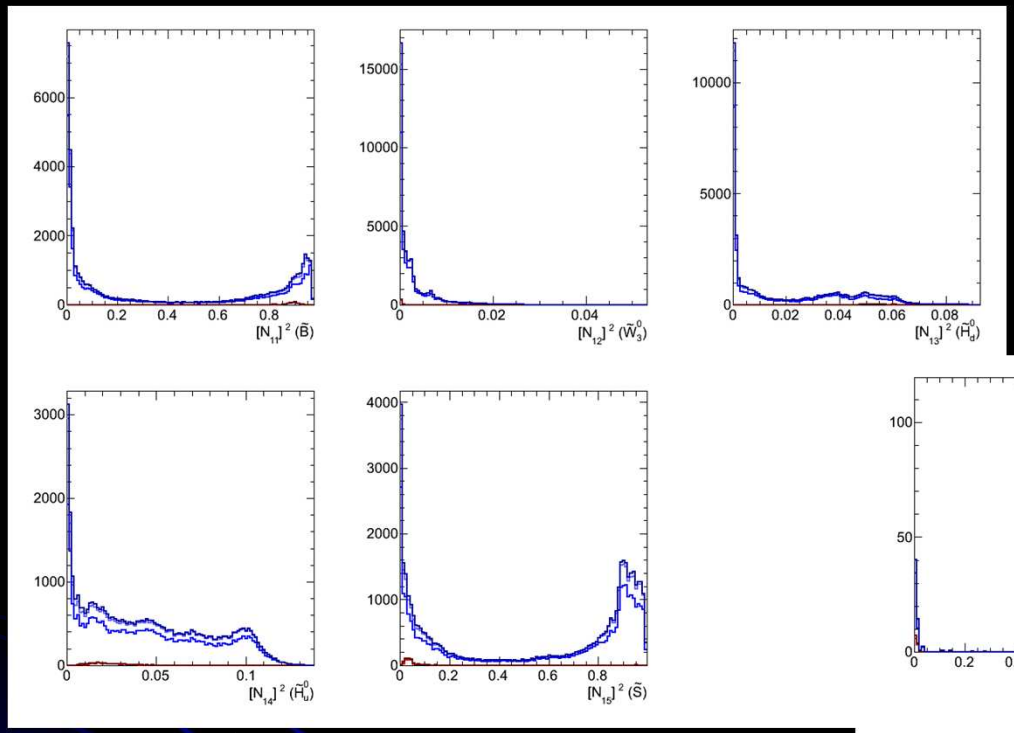
Aprile et al. (Xenon100 collaboration) – arXiv:1104.2549

NMSSM: for how long?

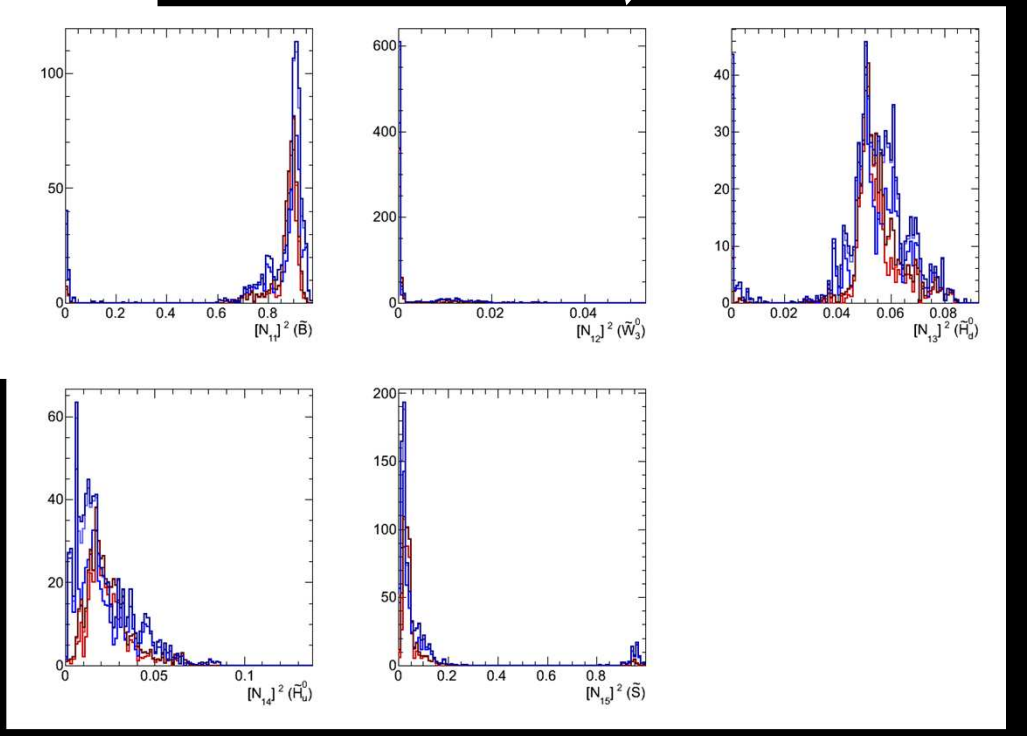


Angle et al. (Xenon10 collaboration) – arXiv:1104.3088

Neutralino

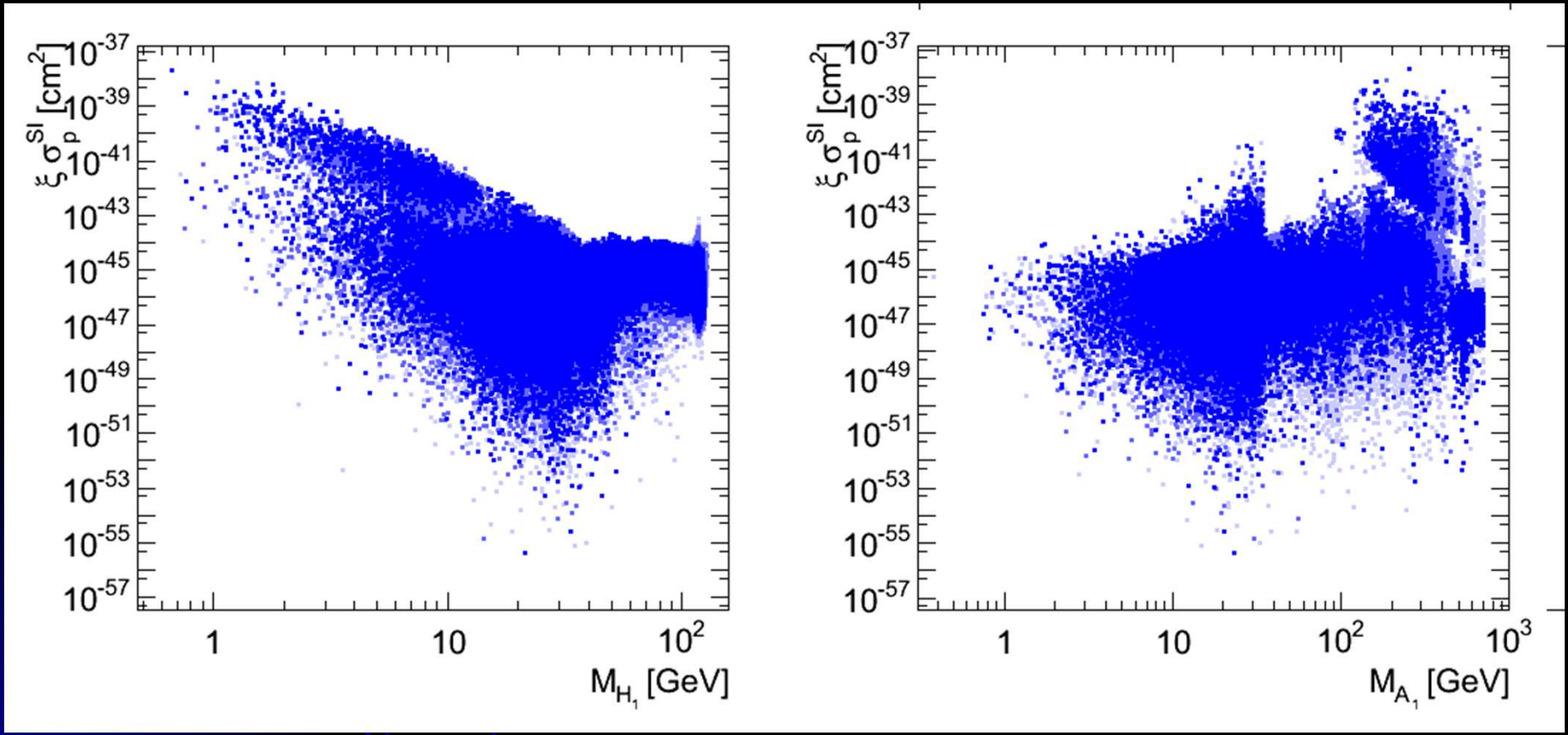


Large cross sections

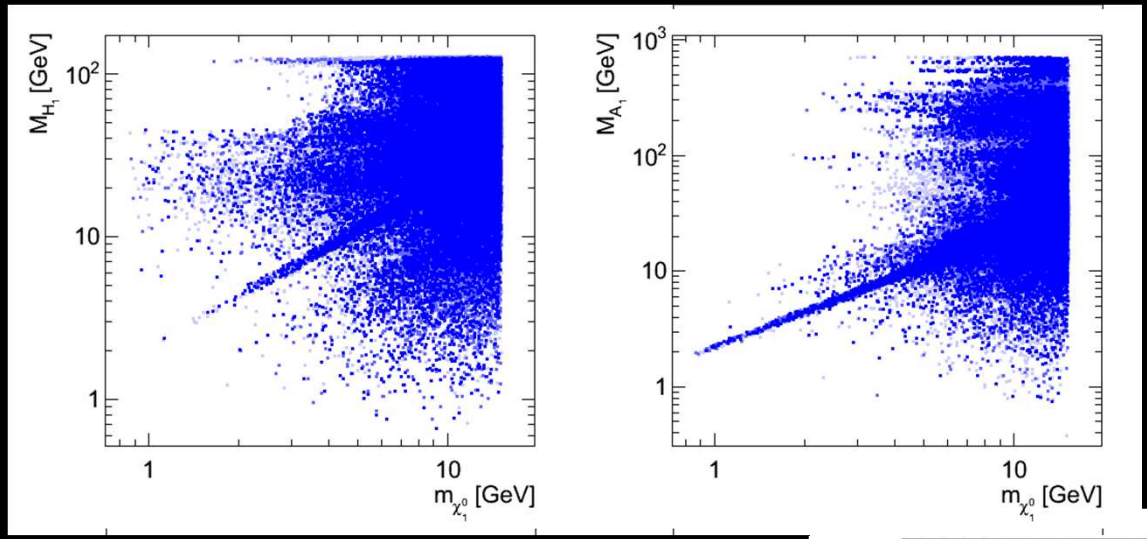


All

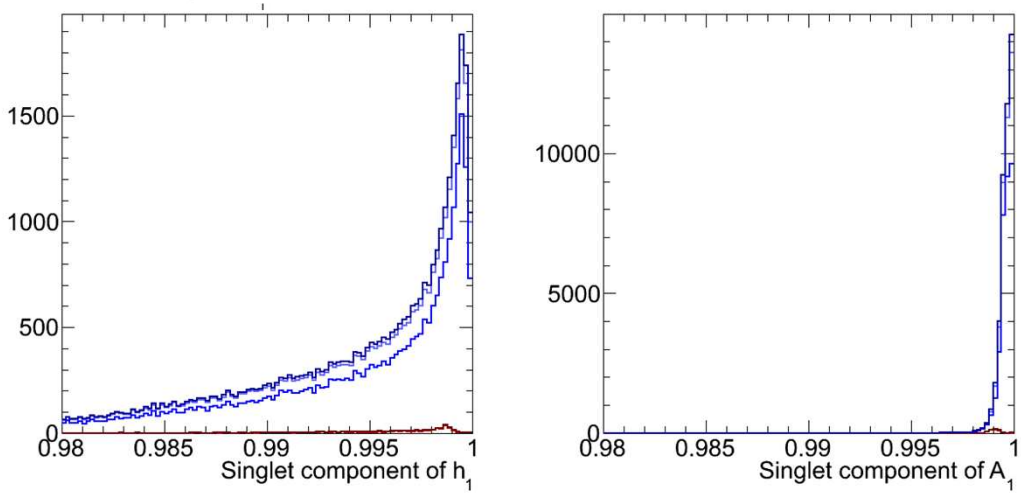
Interactions & Higgses



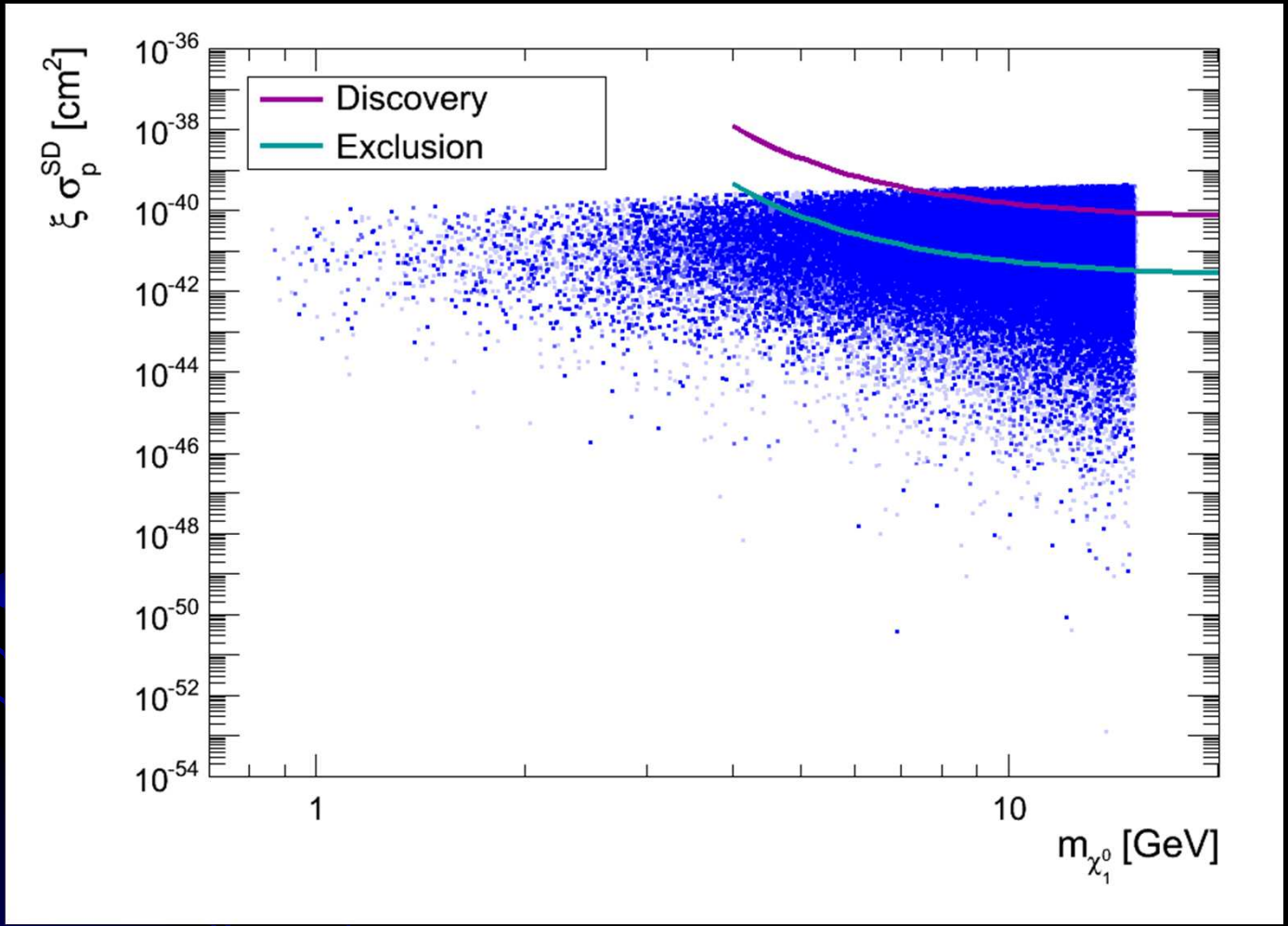
Light Higgses



- Light singlet-like Higgses
- Twice the neutralino mass



Light NMSSM and MIMAC



NMSSM – A Viable Candidate

- Neutralinos are either Bino or Singlino dominated, but always have a non-vanishing Higgsino component.

- Neutralinos annihilate through a Higgs resonance (and/or into very light Higgs).

- Large cross sections achieved through very light even Higgses, mostly singlet.

Conclusions

Conclusions

- Spin independent elastic scattering signals may be explained by light NMSSM neutralinos
- Direct Detection is very constraining, but may also provide a way to determine light NMSSM neutralinos
- Further constraints are coming from indirect searches and the LHC

Thank you!

Questions?

Back up slides

Model

- SuperSymmetry
- NMSSM at Electro Weak scales: 11 parameter spaces
- EW Symmetry Breaking: input parameters defined at the weak scale
- Non universal gaugino masses, universal sfermion masses
- Neutralino LSP & DM

Algorithm – MCMC

- Monte Carlo Markov Chain
- Each point has a Prior (P) and a total Likelihood (L) yielding a total weight Q (= P x L)
- Metropolis-Hastings algorithm
  - Random walk: multidimensional Gaussian deviation
  - Discrimination using point's total weight
- Starting point
  - Random point, compute Q without mass prior
  - If Q = 0, reject
  - Else, start a pre-chain till we are in the right mass region, using an exponential prior

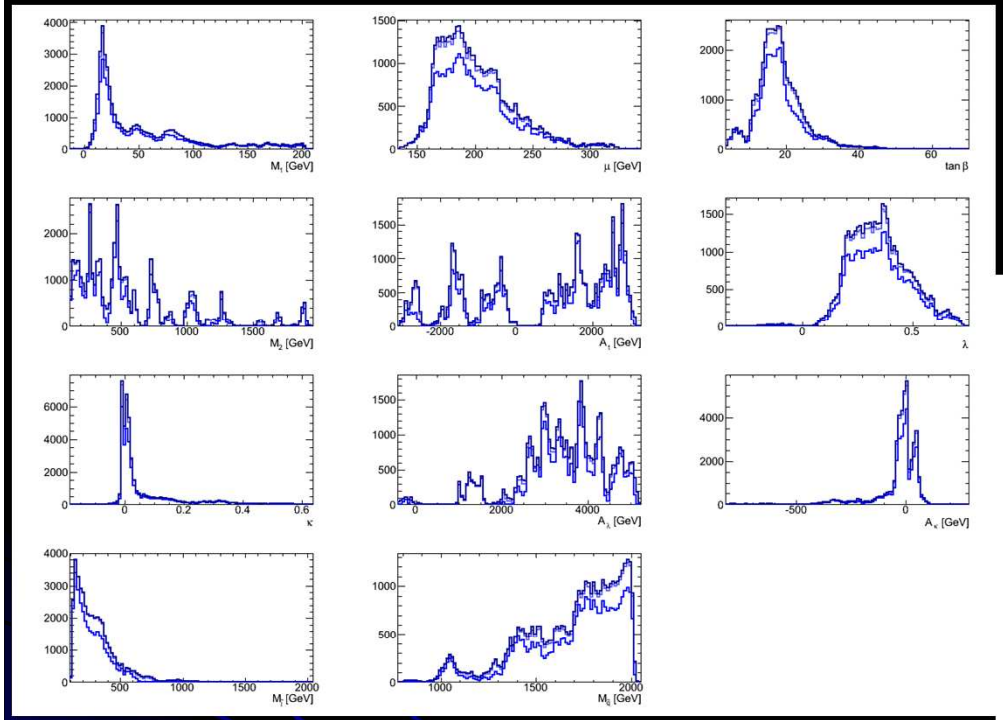
Direct Detection: Uncertainties

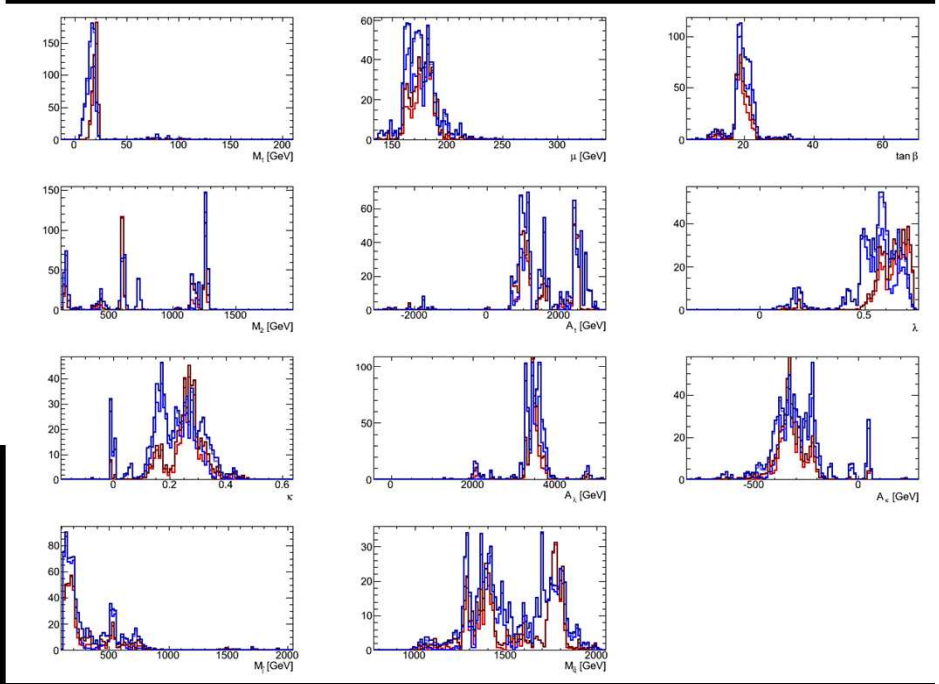
- Nuclear form factors: smallest of the

"standard" sets (not the most conservative)

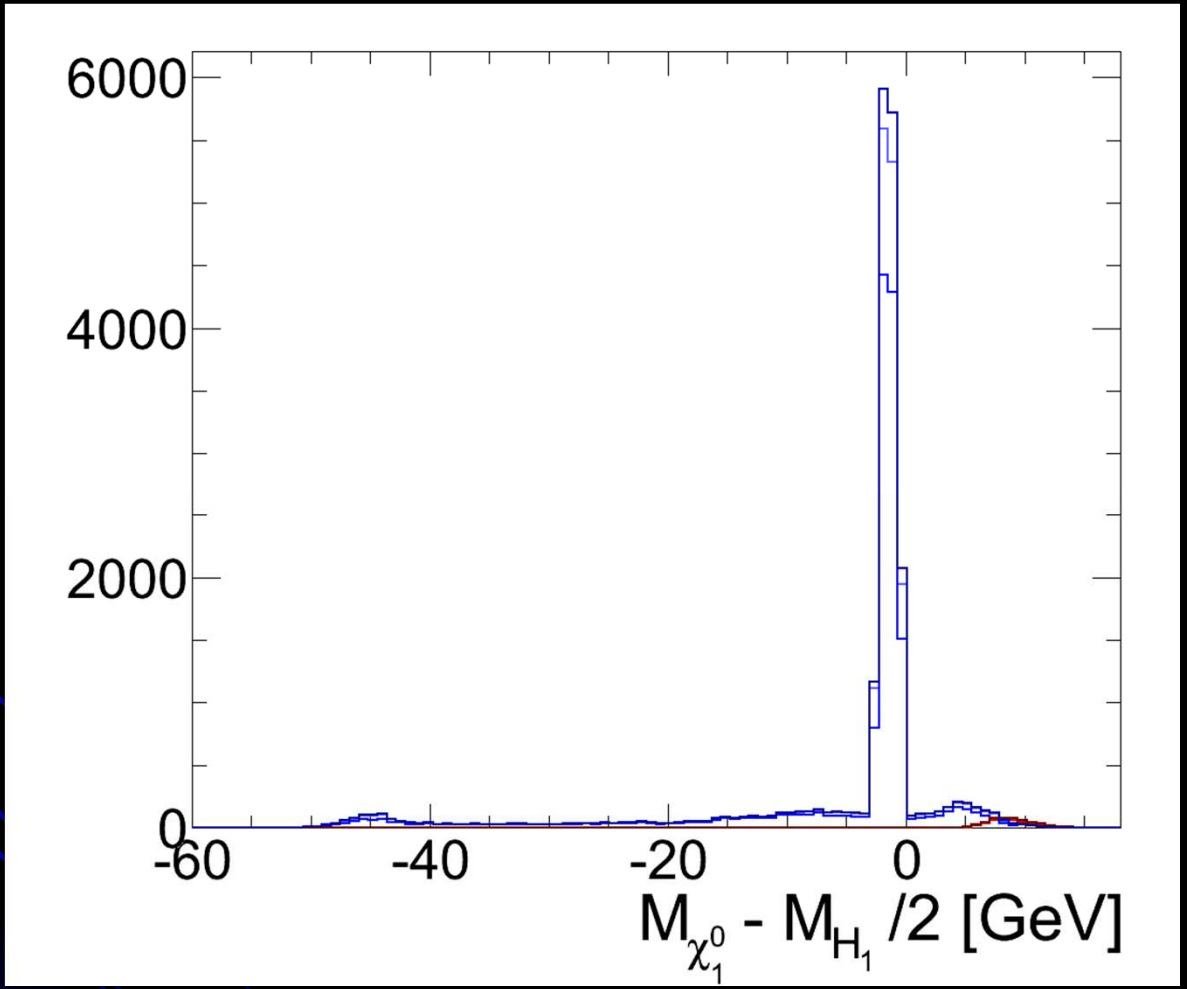
- Xenon100 Limit: decreasing Leff
- Dark Matter Halo
  - Local density: $\rho_0 = 0.3$ GeV cm^{-3}
  - Maxwellian distribution for velocities
  - $v_{rot} = 220$ km s^{-1}
  - $v_{esc} = 650$ km s^{-1}

NMSSM – Parameters

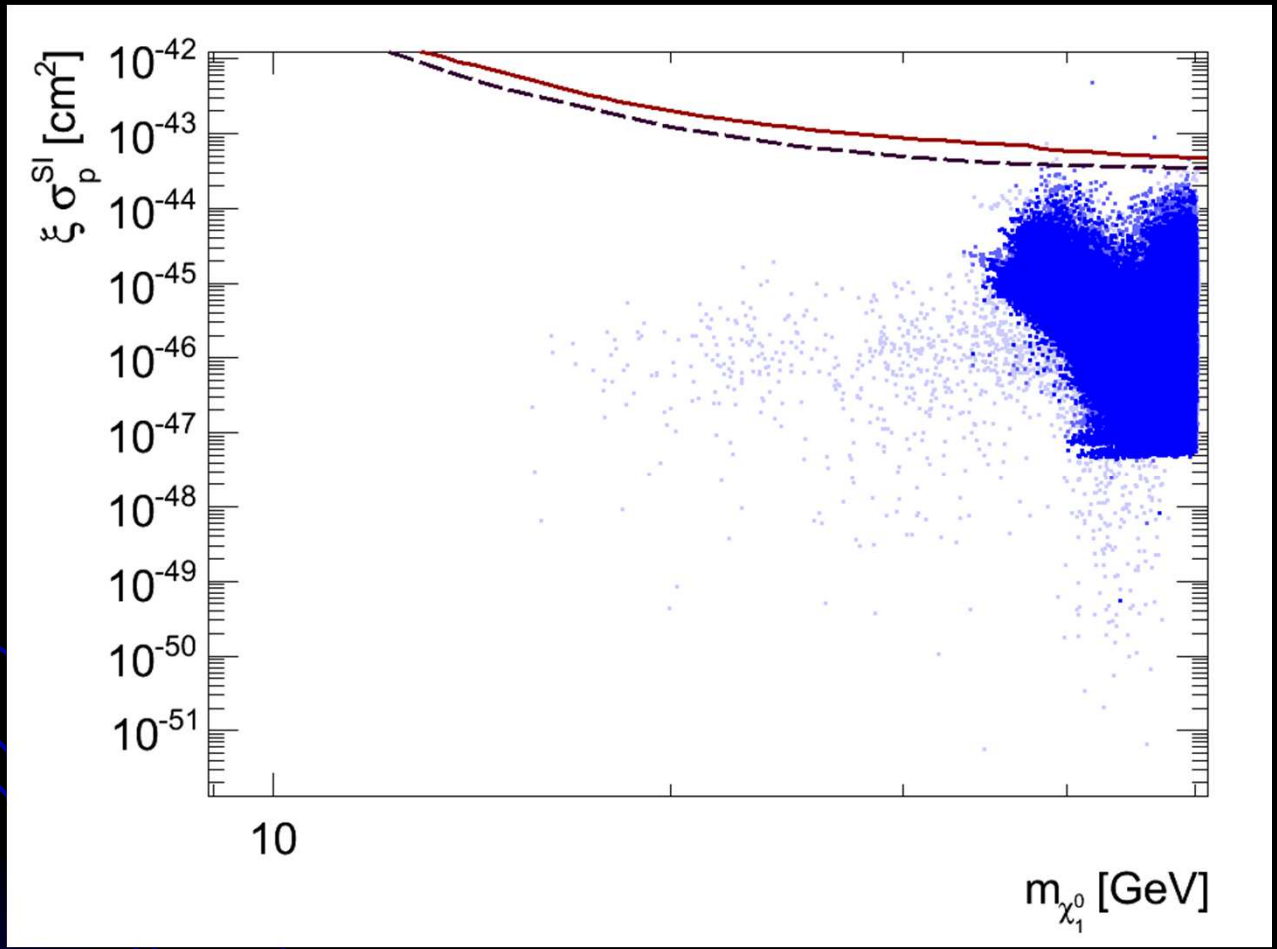




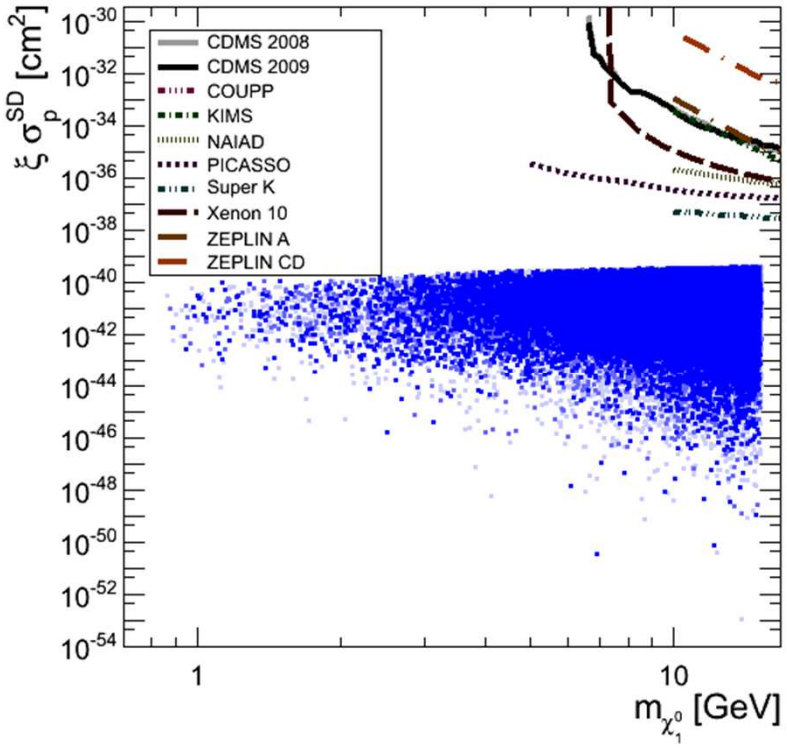
NMSSM – Higgs Masses

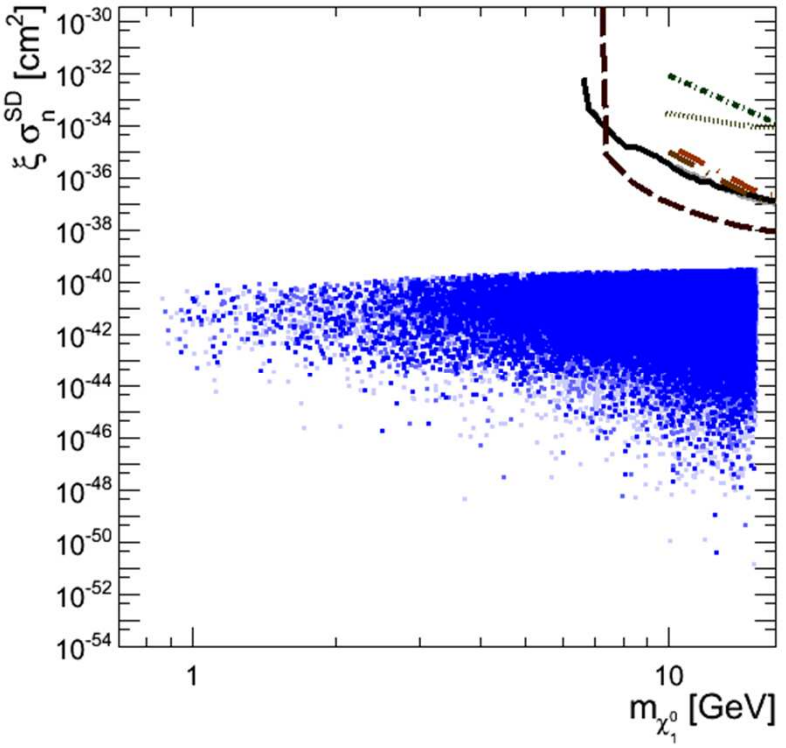


NMSSM – Larger Masses



NMSSM – SD interactions





NMSSM – A word for other studies

- D. Das & U. Ellwanger [arXiv:1007.1151]
  - tanβ = 35-44 and μ = 128 GeV
  - Bino-like neutralino, large Higgsino component
  - Larger Higgs masses (> $2m_{\chi}$), not singlet-like (large κ)
  - SI cross sections below 10^{-5} pb
- J. F. Gunion, A. F. Belikov & D. Hooper [arXiv:1009.2555]
  - Fixed tanβ = 40 and |μ| = 200 GeV
  - Bino-like neutralino, very small Higgsino component
  - Light Higgses, singlet-like
  - Cross sections below those required for CoGent and DAMA/LIBRA

NMSSM – A word for other studies

- J. Cao et al. [arXiv:1104.1754]
  - Light Higgs & NMSSM
  - Naturalness problem claimed in our work
  - No 2-photon signal at LHC
- P. Draper et al. [arXiv:1009.3963]
  - Light Higgs in the NMSSM
  - Further constraints in Higgs decays at Tevatron and LEP

Light WIMPS: possible?

- G. Hütsi et al. [arXiv:1103.2766]
  - CMB limits on light WIMPS
  - Assume annihilation channels
  - No considerations of Light Higgses
- R. Kappl & M. W. Winkler [arXiv:1104.0679]
  - Limits from Super-K
  - WIMP trapped at the Sun and emit neutrinos
  - Constrain elastic scattering interactions
  - Assume annihilation channels
  - No consideration of Light Higgses