3rd CYGNUS Workshop - Aussois
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MIMAC potential discovery and exclusion of neutralinos in the MSSM and NMSSM

In collaboration with G. Bélanger, F. Mayet & J. Billard

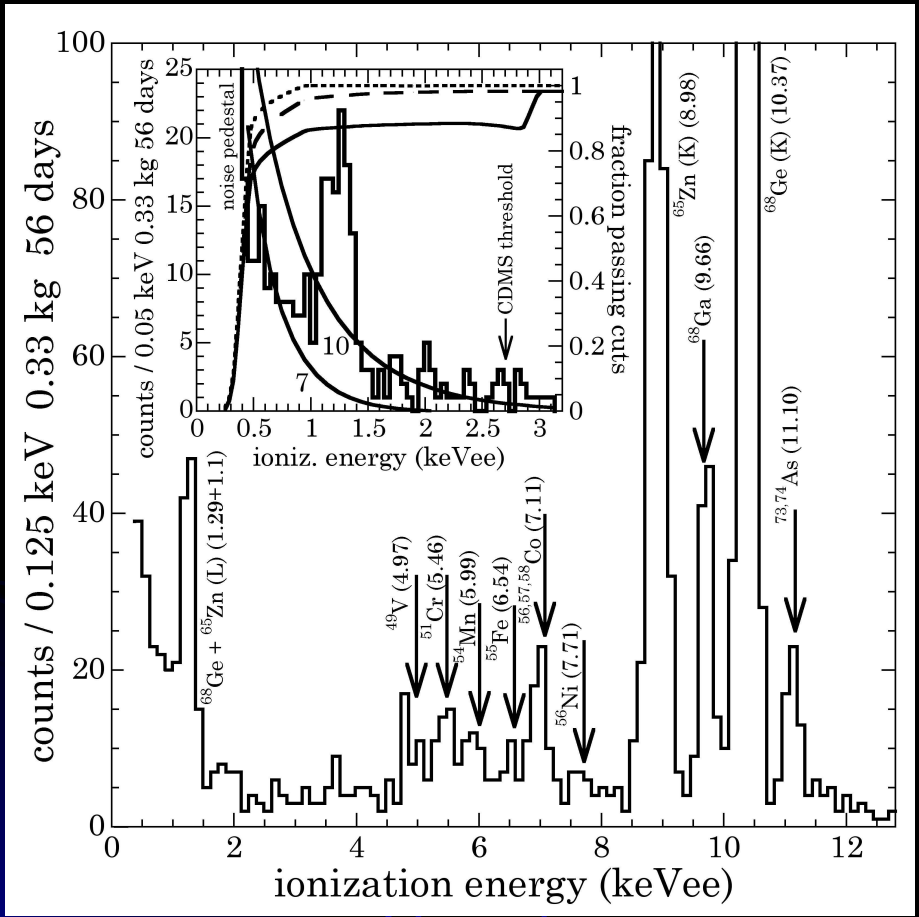
arXiv:1009.4380, 1106.????

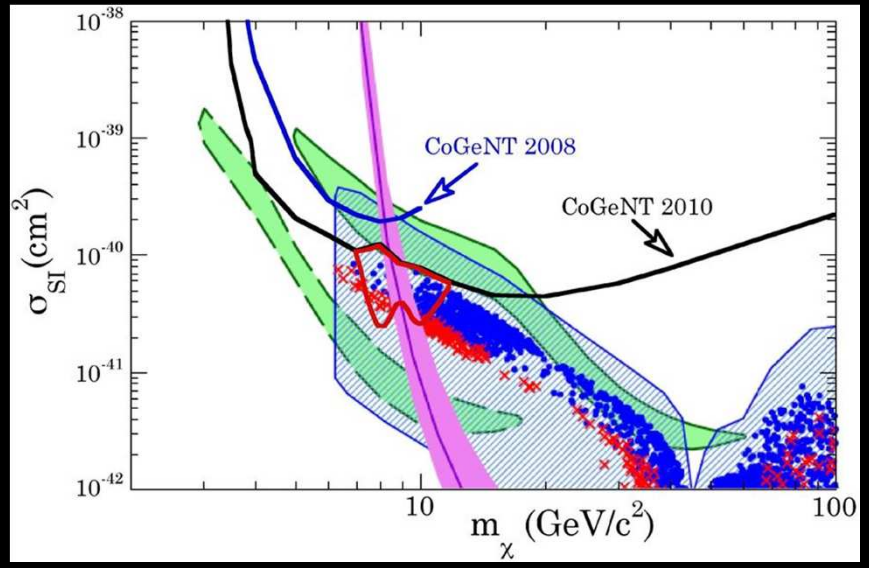
Outline

- Introduction
- Neutralinos: let’s get them
- Neutralinos: let’s get rid of them
- MIMAC & Neutralinos
- Conclusions

Introduction

Introduction – February 2010

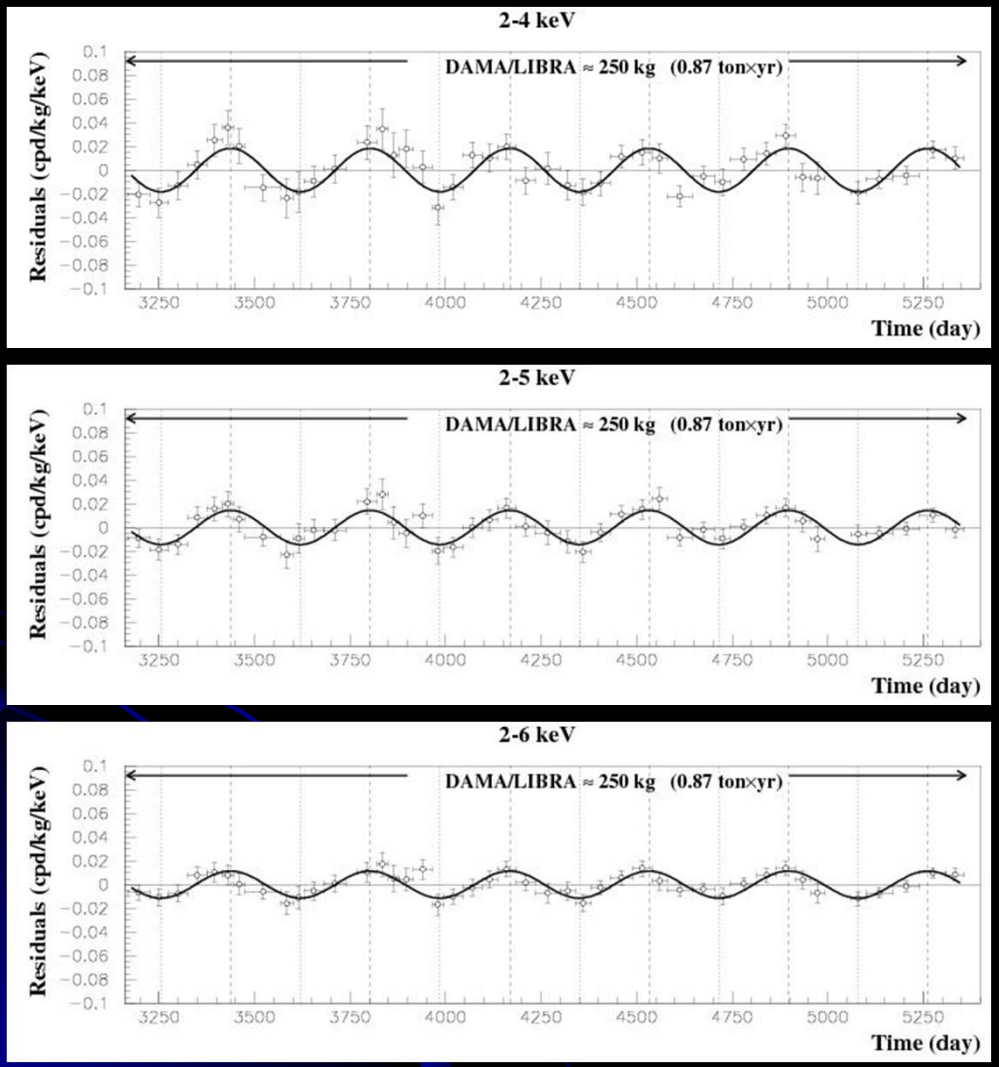




- Unexplained bulk-like signal
- Very low energy
- Preferred mass range: 7-11 GeV

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

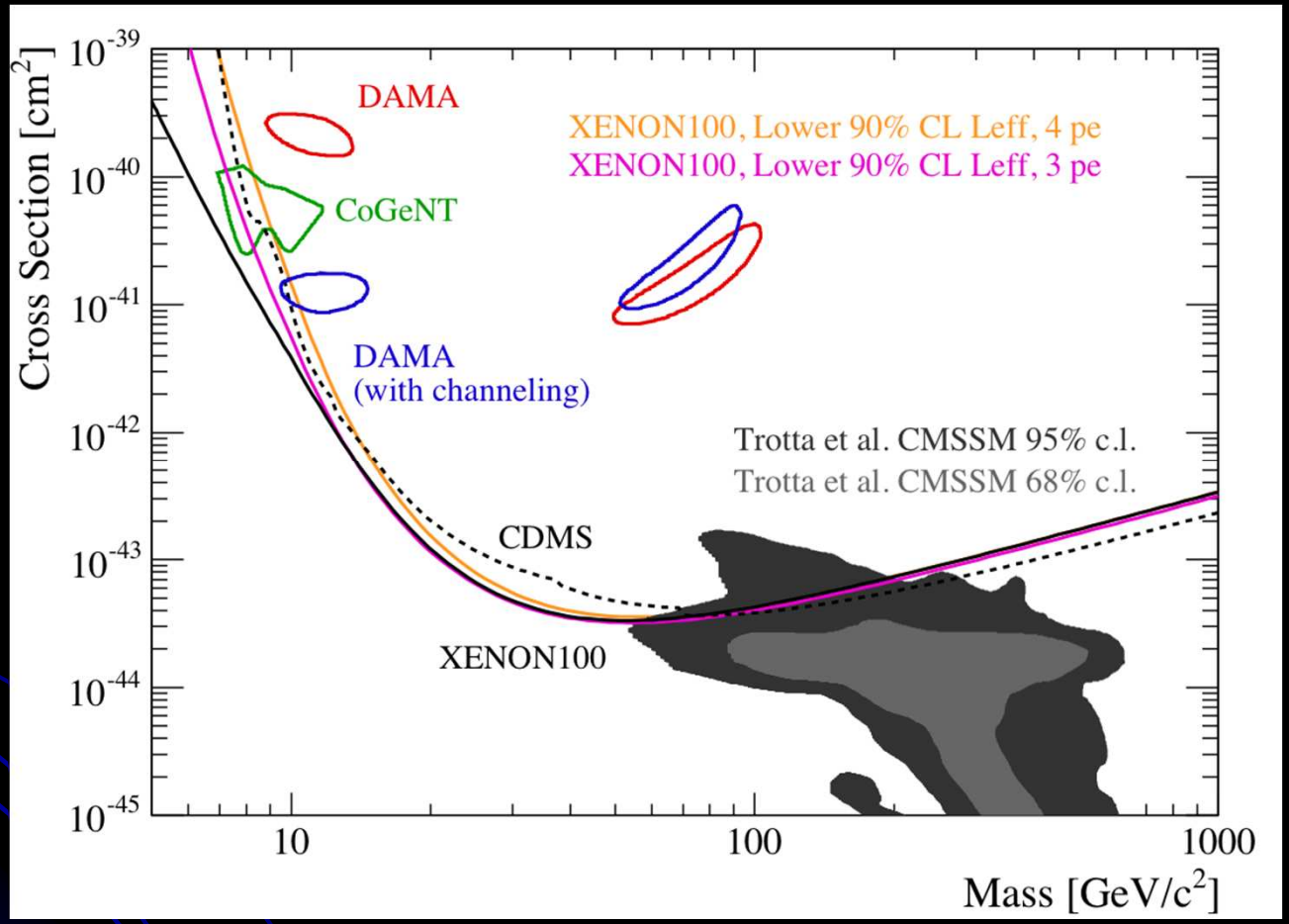
Introduction – February 2010



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

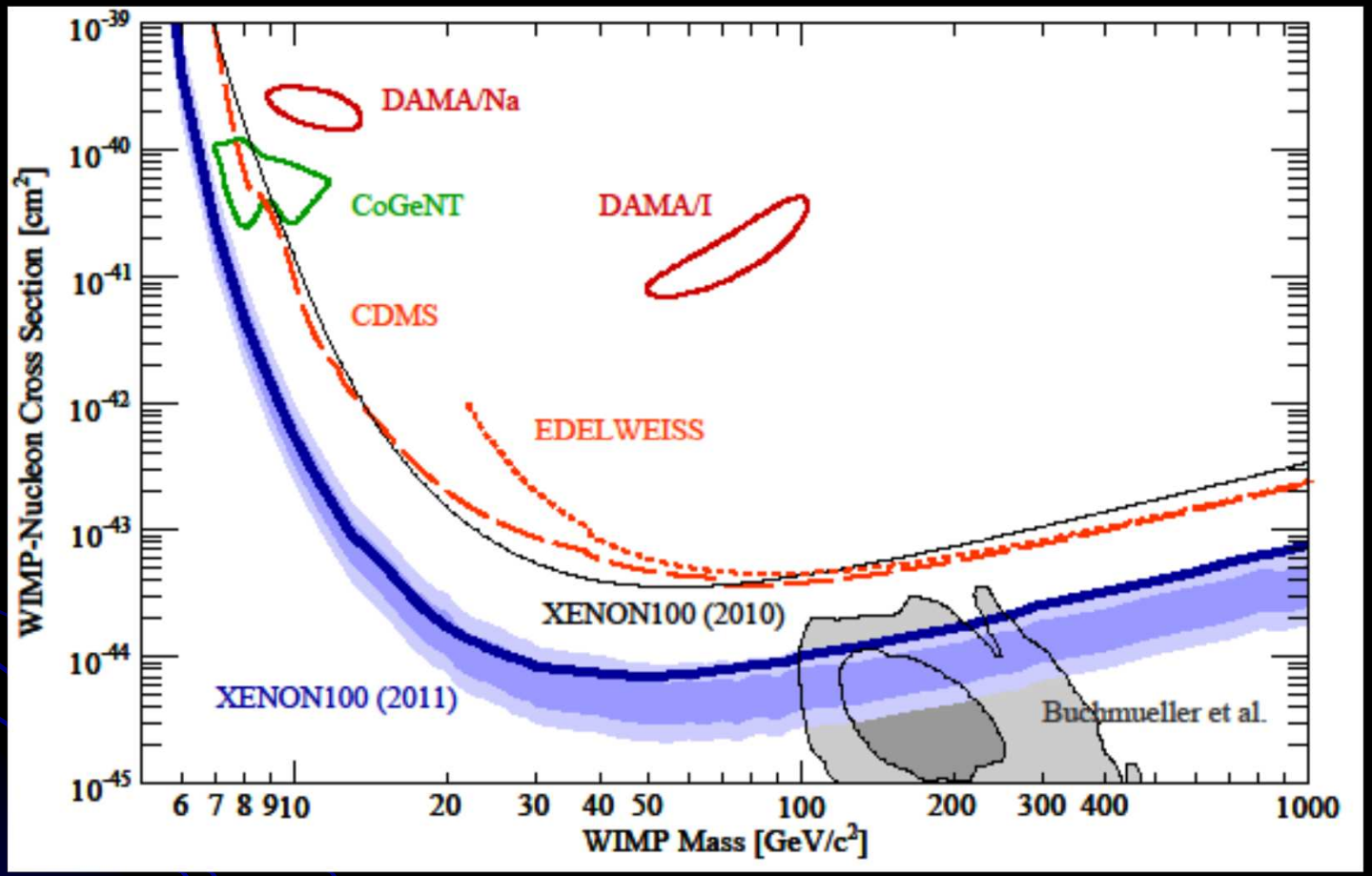
Bernabei et al. (DAMA collaboration) – arXiv:1002.1028

Introduction – May 2010



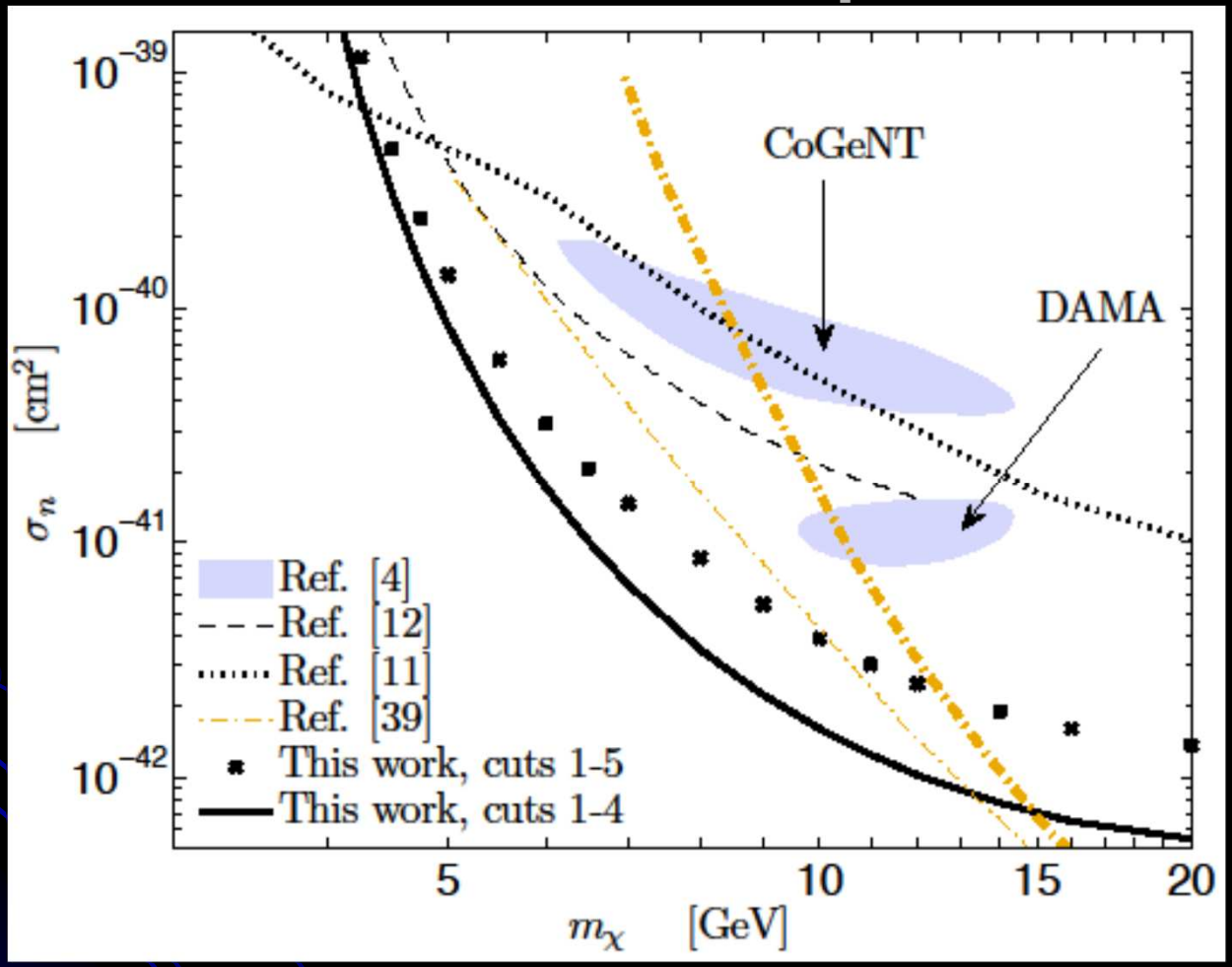
Aprile et al. – arXiv:1005.0380, arXiv:1005.2615

Introduction – April 2011



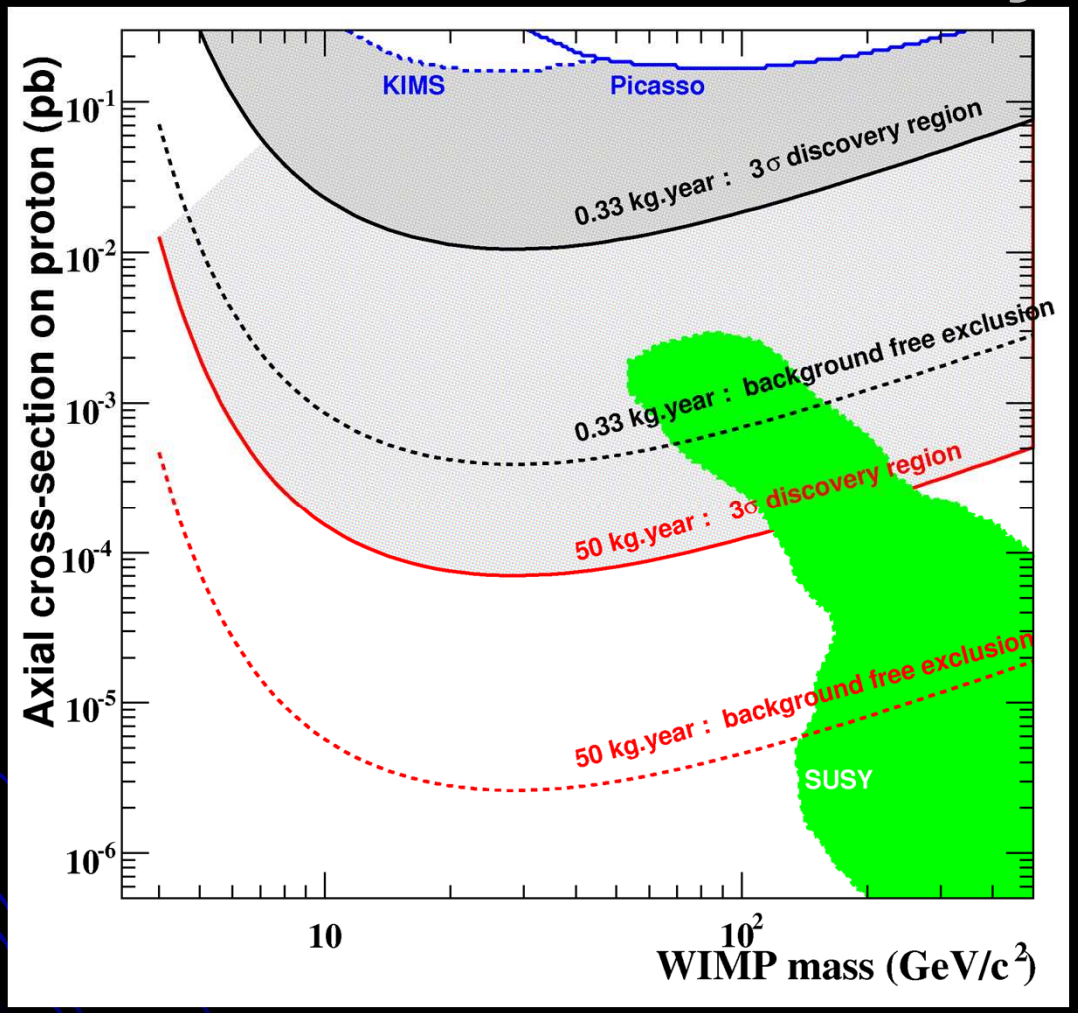
Aprile et al. (Xenon100 collaboration) – arXiv:1104.2549

Introduction – April 2011



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

MIMAC – Sensitivity



J. Billard et al. – arXiv:1101.1275

MIMAC & Neutralinos

- Neutralinos: a WIMP-like DM candidate
- Do they fall in detection and/or exclusion regions
- Exploring MSSM and NMSSM neutralinos: what kind of configurations can be attained?
- Is MIMAC sensitive to what is not possible to scan with spin-independent interactions and/or indirect detection?

Neutralinos: let’s get them

Models

- SuperSymmetry
- MSSM & NMSSM: ~10 parameters
- Non universal gaugino masses, input parameters defined at Electro Weak scales
- Neutralino LSP & DM candidate

Tools

- micrOMEGAs 2.4
- EWSB spectra calculators:
  - MSSM: SuSpect
  - NMSSM: NMSSMTools
- Existing functions for several processes: easy comparison with data
- Amplitude calculations through CalcHep: constraints and Direct Detection cross sections

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

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 for:

$$1\ GeV < M_{\chi} < 30\ GeV$$

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 $\left\{ \begin{array}{l} B(b \to s\gamma) \\ B(B_s \to \mu^+\mu^-) \\ B(B \to \tau\nu_{\tau}) \\ \Delta M_s,\ \Delta M_d \end{array} \right\}$

MSSM – Neutralino LSP

$$M_{\chi^0}^{MSSM} = \begin{pmatrix} M_1 & 0 & -M_Z s_W c_\beta & M_Z s_W s_\beta \\ 0 & M_2 & M_Z c_W c_\beta & -M_Z c_W s_\beta \\ -M_Z s_W c_\beta & M_Z c_W c_\beta & 0 & -\mu \\ M_Z s_W s_\beta & -M_Z c_W s_\beta & -\mu & 0 \end{pmatrix}$$

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

Parameters

Gaugino masses: M_1 ,

M_2, M_3

Higgs sector: μ, tan β, M_A

Trilinear coupling: At

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

Parameter Space (GeV units)

$$1 < M_1 < 100$$

$$100 < M_2 < 2000$$

$$500 < M_3 < 6000$$

$$0 < \mu < 1000$$

$$1 < \tan\beta < 75$$

$$100 < M_A < 1000$$

$$-3000 < A_t < 3000$$

$$100 < M_{\tilde{l}} < 2000$$

$$300 < M_{\tilde{q}} < 2000$$

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 ⟶ NMSSM

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

μ ⟶ μ, λ, κ, A_λ, A_κ

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)

$$1 < M_1 < 100$$
$$100 < M_2 < 2000$$
$$500 < M_3 < 6000$$
$$0 < \mu < 1000$$
$$1 < \tan\beta < 75$$
$$0 < \lambda < 0.75$$
$$0 < \kappa < 0.65$$
$$-2000 < A_\lambda < 5000$$
$$-5000 < A_\kappa < 2000$$
$$-3000 < A_t < 3000$$
$$100 < M_{\tilde{l}} < 2000$$
$$300 < M_{\tilde{q}} < 2000$$

Neutralinos: let’s get rid of them

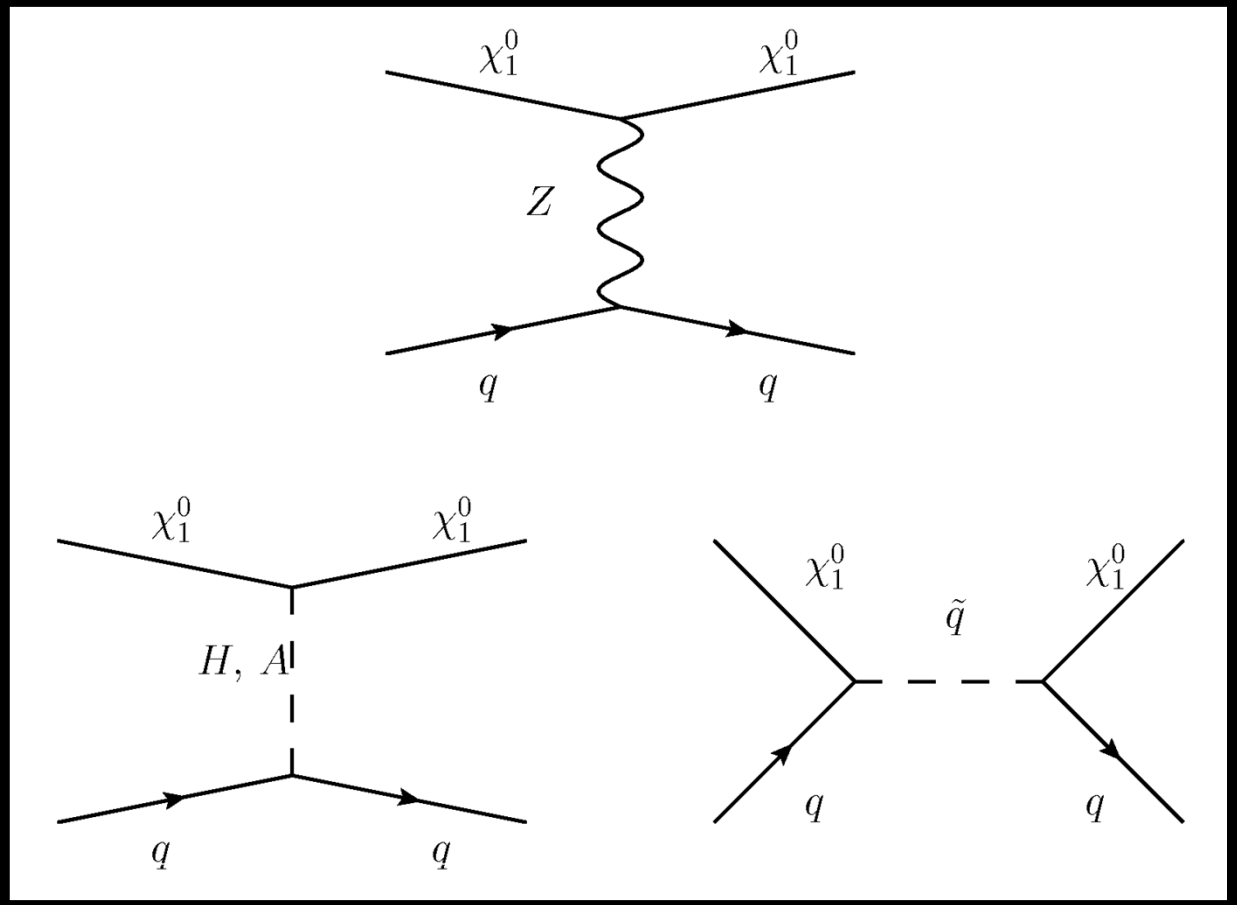
Elastic Scattering Couplings

$$q_d \bar{q}_d h \propto -\frac{\sin\alpha}{\cos\beta}$$

$$q_d \bar{q}_d H \propto \frac{\cos\alpha}{\cos\beta}$$

$$q_d \bar{q}_d A \propto \tan\beta$$

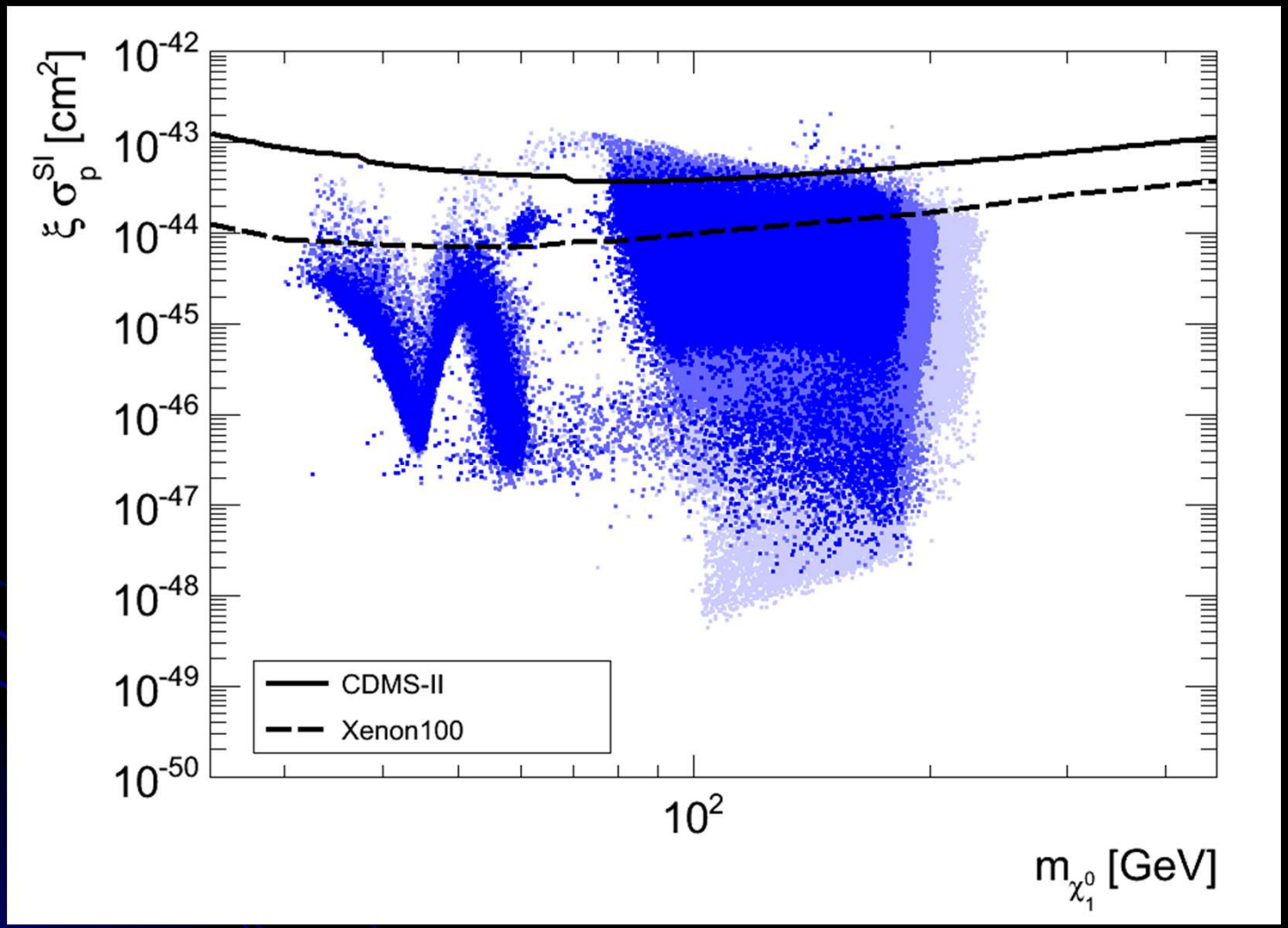
$$\chi_1^0 \chi_1^0 Z \propto N_{13}^2 - N_{14}^2$$



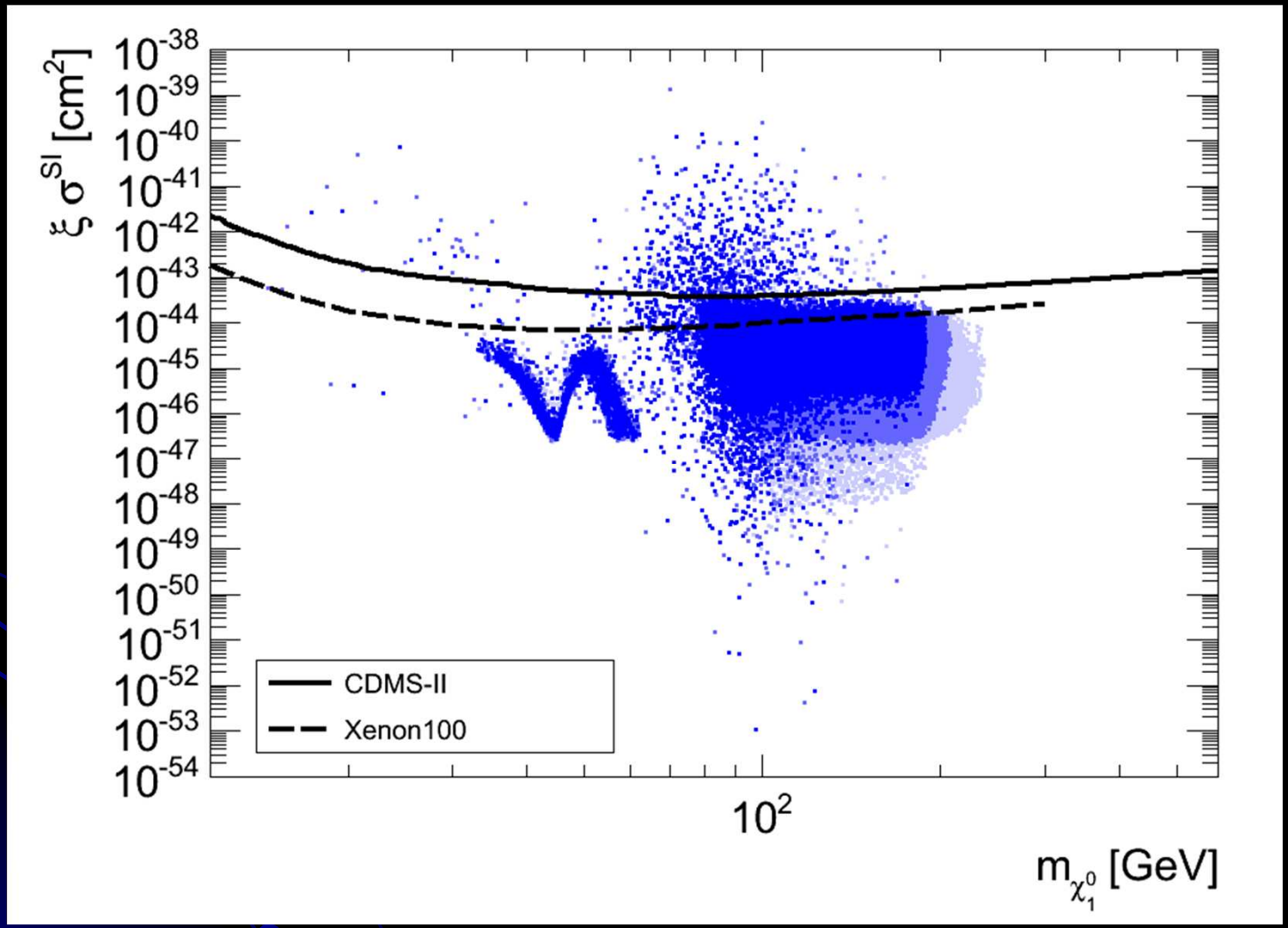
Direct Detection: Uncertainties

- Nuclear form factors: smallest of the “standard” sets (new lattice results?)
- Xenon100 Limit: decreasing Leff
- Dark Matter Halo (latest results differ though)
  - Local density: $\rho_0 = 0.3$ GeV cm^{-3}
  - Maxwellian distribution for velocities
  - $v_{rot} = 220$ km s^{-1}
  - $v_{esc} = 600$ km s^{-1}

SI – MSSM


$\xi\,\sigma_p^{SI}$ [cm^2]
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-50}
CDMS-II
Xenon100
10^2
$m_{\chi_1^0}$ [GeV]

SI – NMSSM


$\xi\sigma^{SI}$ [cm^2]
10^{-38}
10^{-39}
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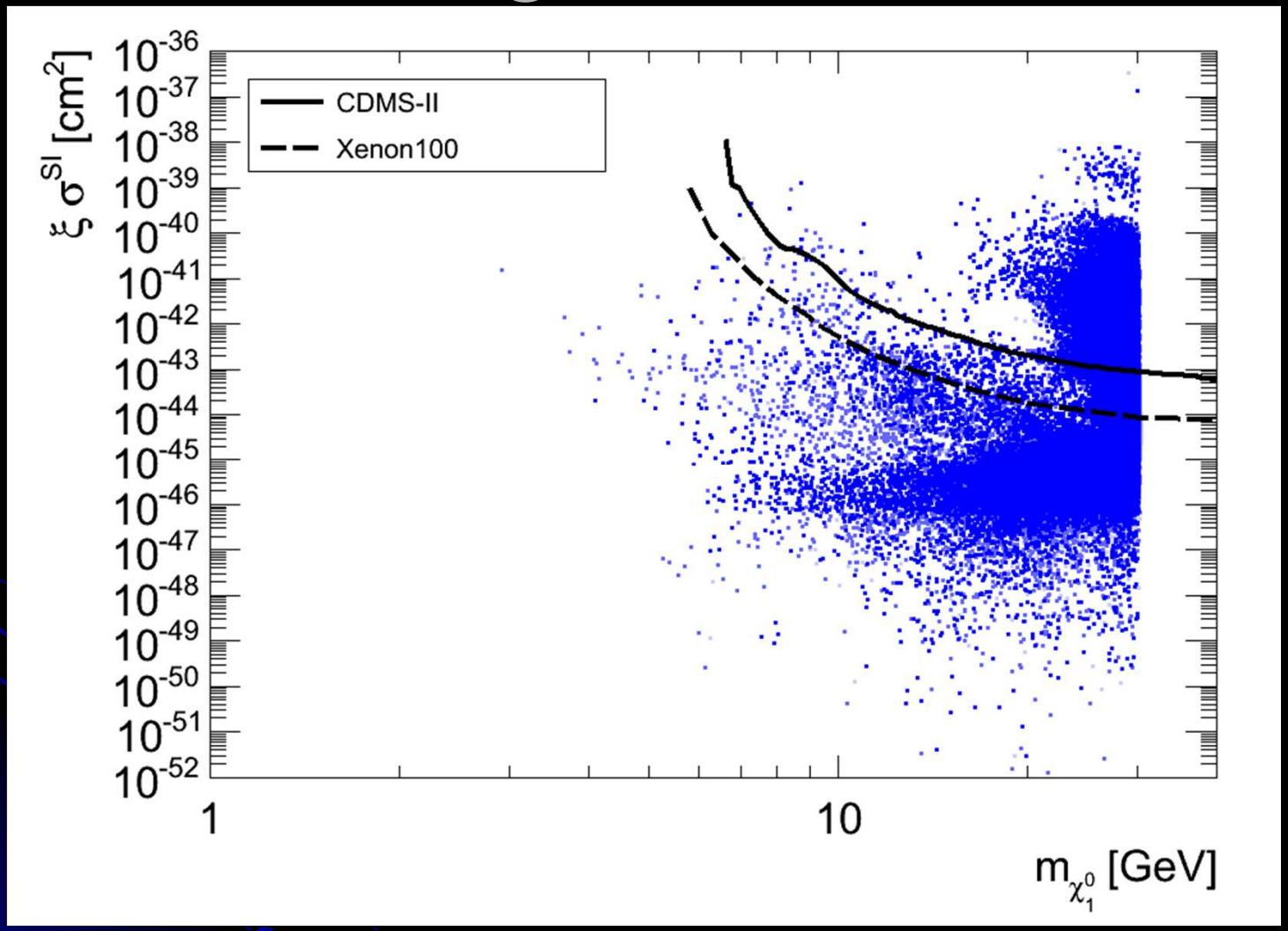
10^{-50}
10^{-51}
10^{-52}
10^{-53}
10^{-54}
CDMS-II
Xenon100
10^2
$m_{\chi_1^0}$ [GeV]

SI – light NMSSM



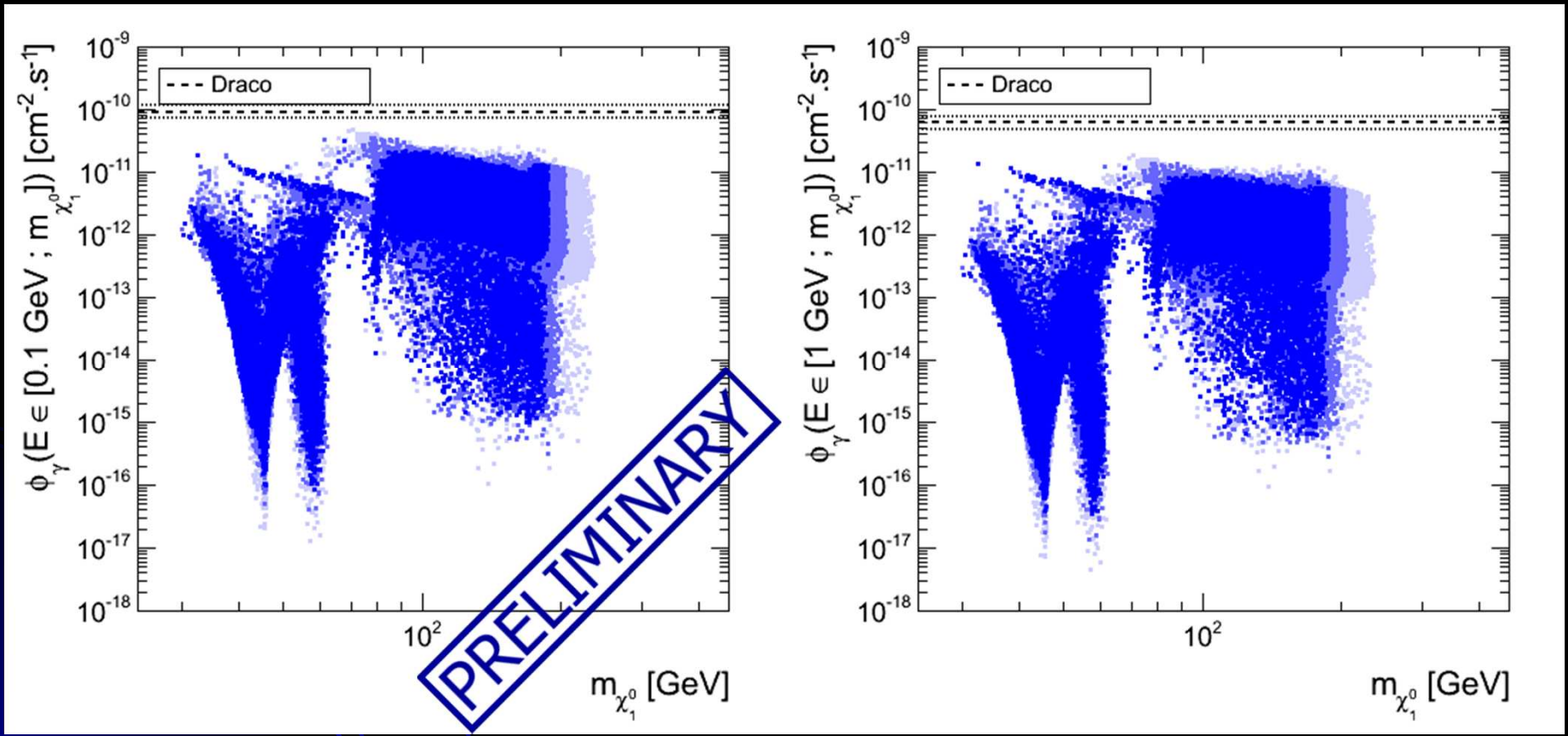
Indirect Detection: gamma rays from dSphs

- FERMI-LAT results on Dwarf Spheroidal galaxies: no flux [1001.4531]
- 8 preferred dSphs: Draco, the best (worst)

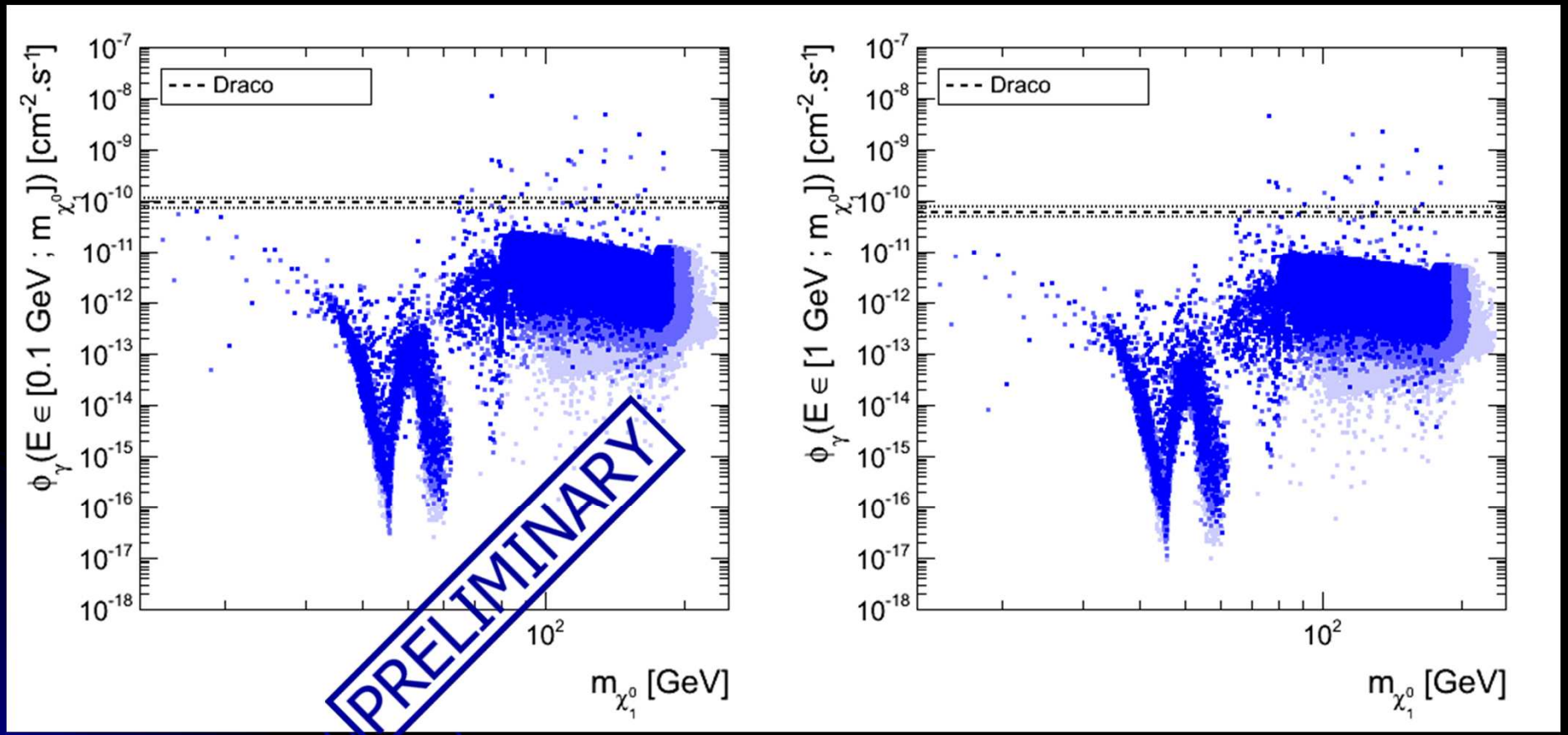
$$\phi(E,\psi) = J(\psi) \times \phi^{PP}(E)$$

$$= \int_{LOS} dl(\psi)\, \xi^2\, \rho^2\left(l(\psi)\right) \times \frac{1}{2} \frac{\sigma v}{4\pi m^2_{\chi_1^0}} \sum_f \frac{dN_f}{dE} BR_f$$

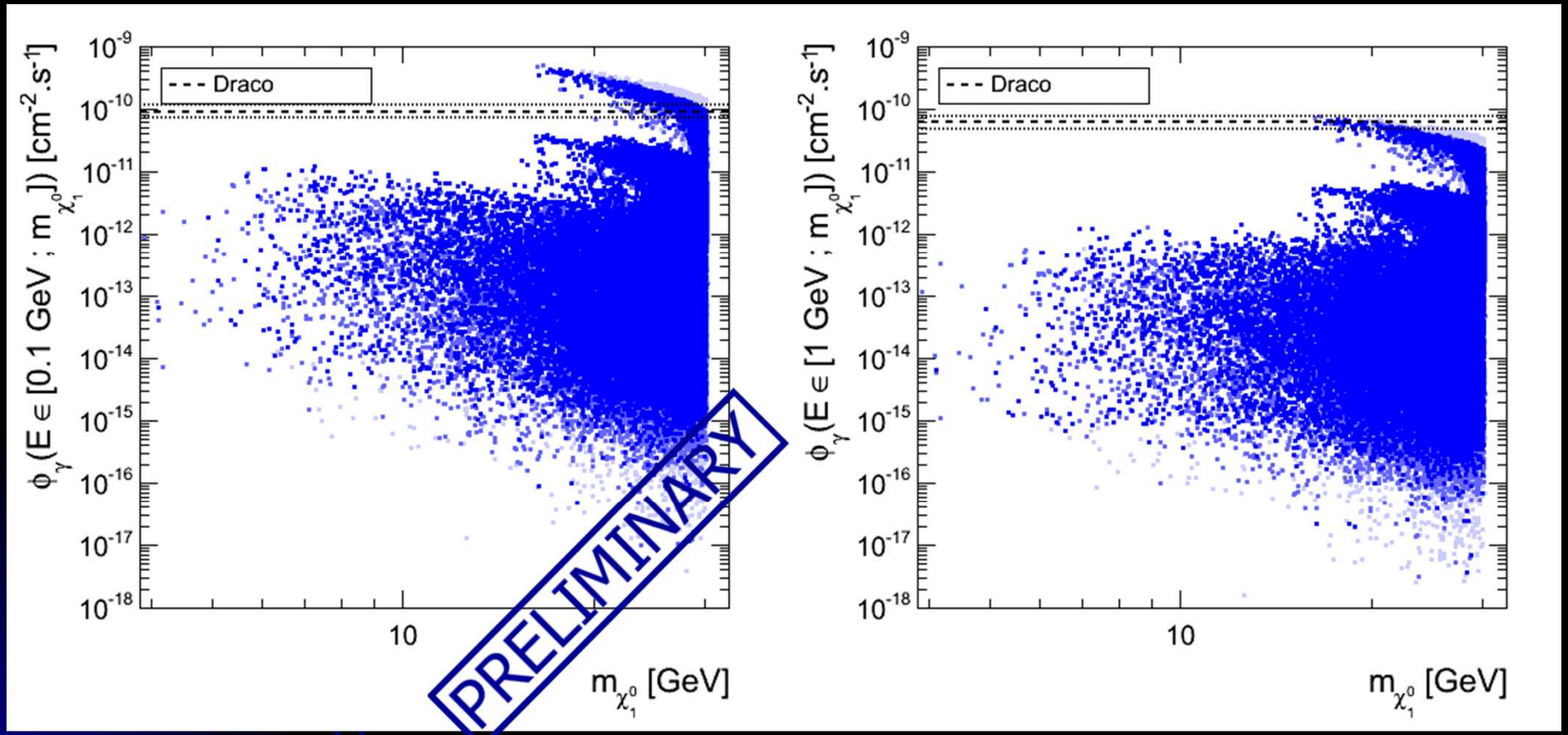
Draco – MSSM


Draco
$\phi_\gamma (E \in [0.1\ \text{GeV} ; m_{\chi_1^0}])\ [\text{cm}^{-2}.\text{s}^{-1}]$
$m_{\chi_1^0}$ [GeV]
PRELIMINARY
Draco
$\phi_\gamma (E \in [1\ \text{GeV} ; m_{\chi_1^0}])\ [\text{cm}^{-2}.\text{s}^{-1}]$
$m_{\chi_1^0}$ [GeV]

Draco – NMSSM

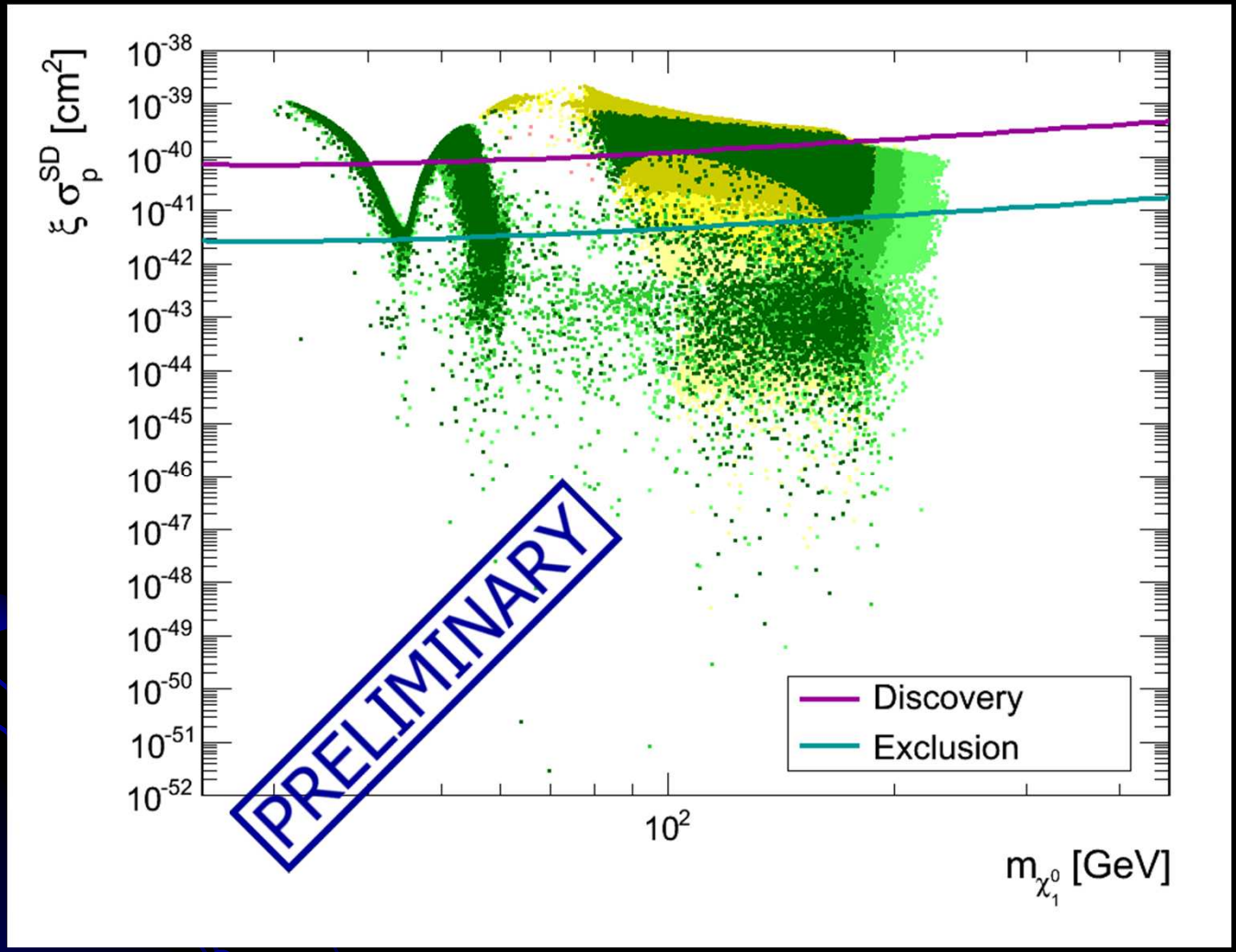

Draco
$\phi_\gamma(E \in [0.1\ \text{GeV} ; m_{\chi_1^0}])\ [\text{cm}^{-2}.\text{s}^{-1}]$
$m_{\chi_1^0}$ [GeV]
PRELIMINARY
Draco
$\phi_\gamma(E \in [1\ \text{GeV} ; m_{\chi_1^0}])\ [\text{cm}^{-2}.\text{s}^{-1}]$
$m_{\chi_1^0}$ [GeV]

Draco – light NMSSM

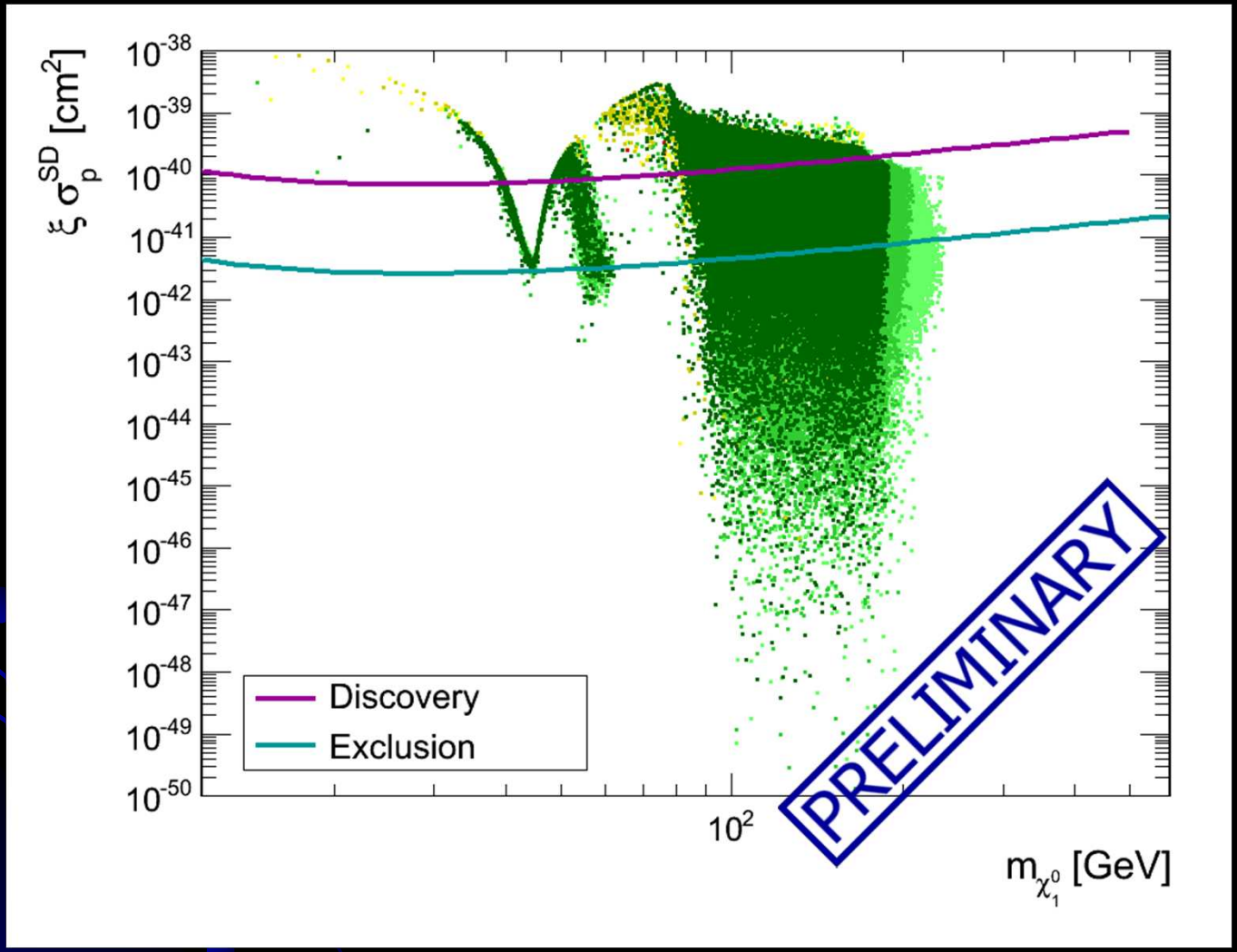


MIMAC & Neutralinos

SDp – MSSM


$\xi\,\sigma_p^{SD}$ [cm^2]
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-50}
10^{-51}
10^{-52}
10^2
$m_{\chi_1^0}$ [GeV]
PRELIMINARY
Discovery
Exclusion

SDp – NMSSM


$\xi\,\sigma_p^{SD}$ [cm^2]
10^{-38}
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10^{-47}
10^{-48}
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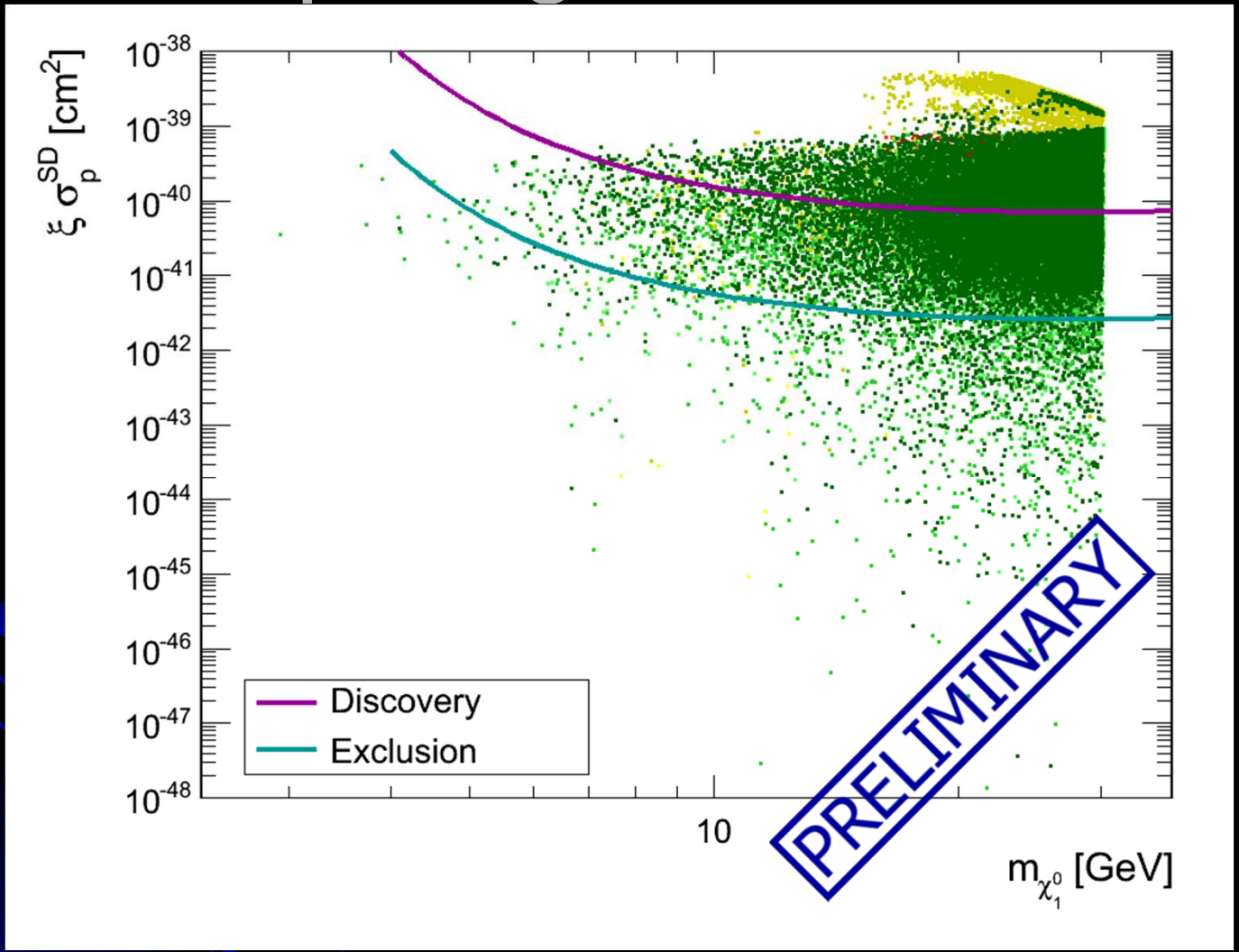
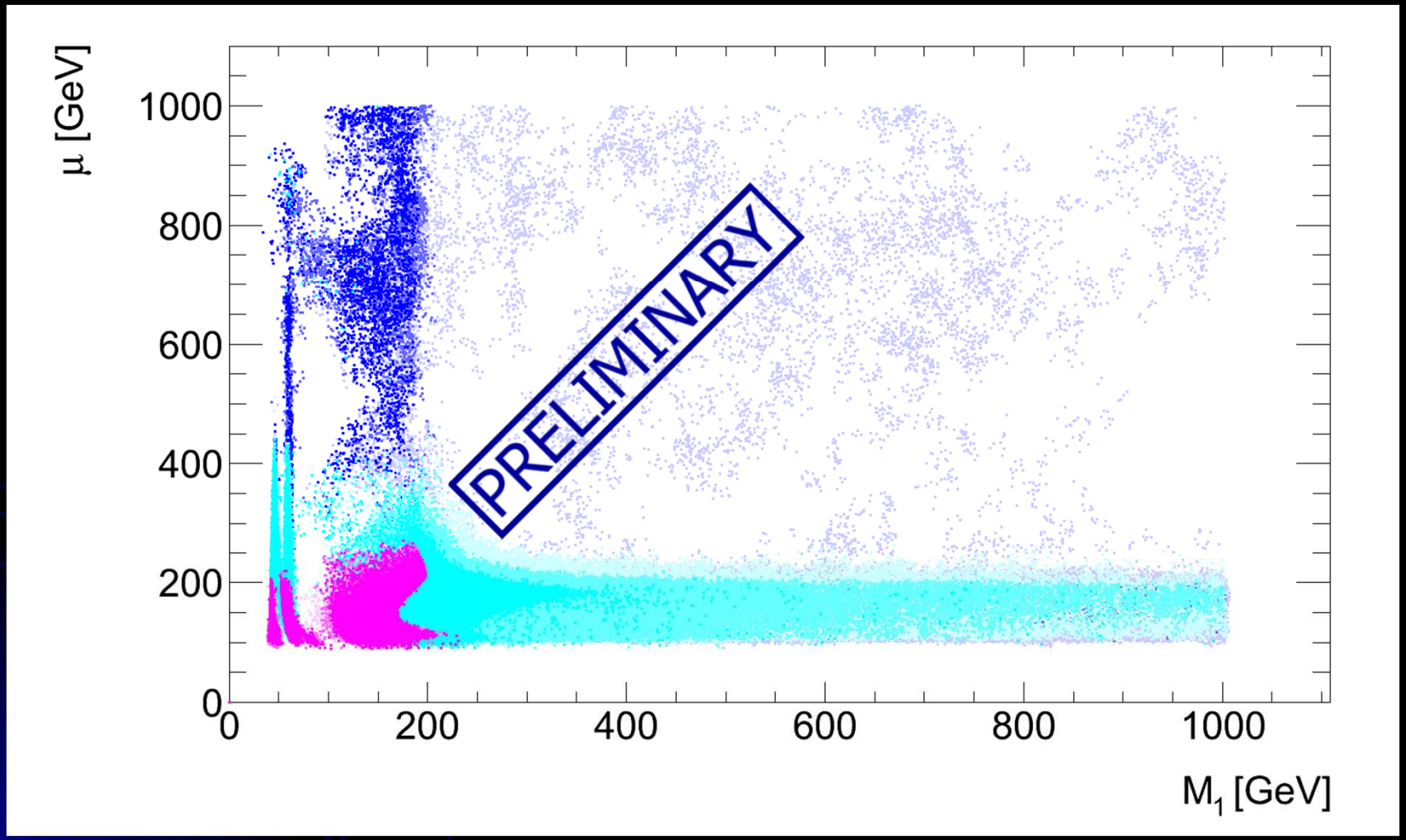
10^{-50}
Discovery
Exclusion
10^2
PRELIMINARY
$m_{\chi_1^0}$ [GeV]

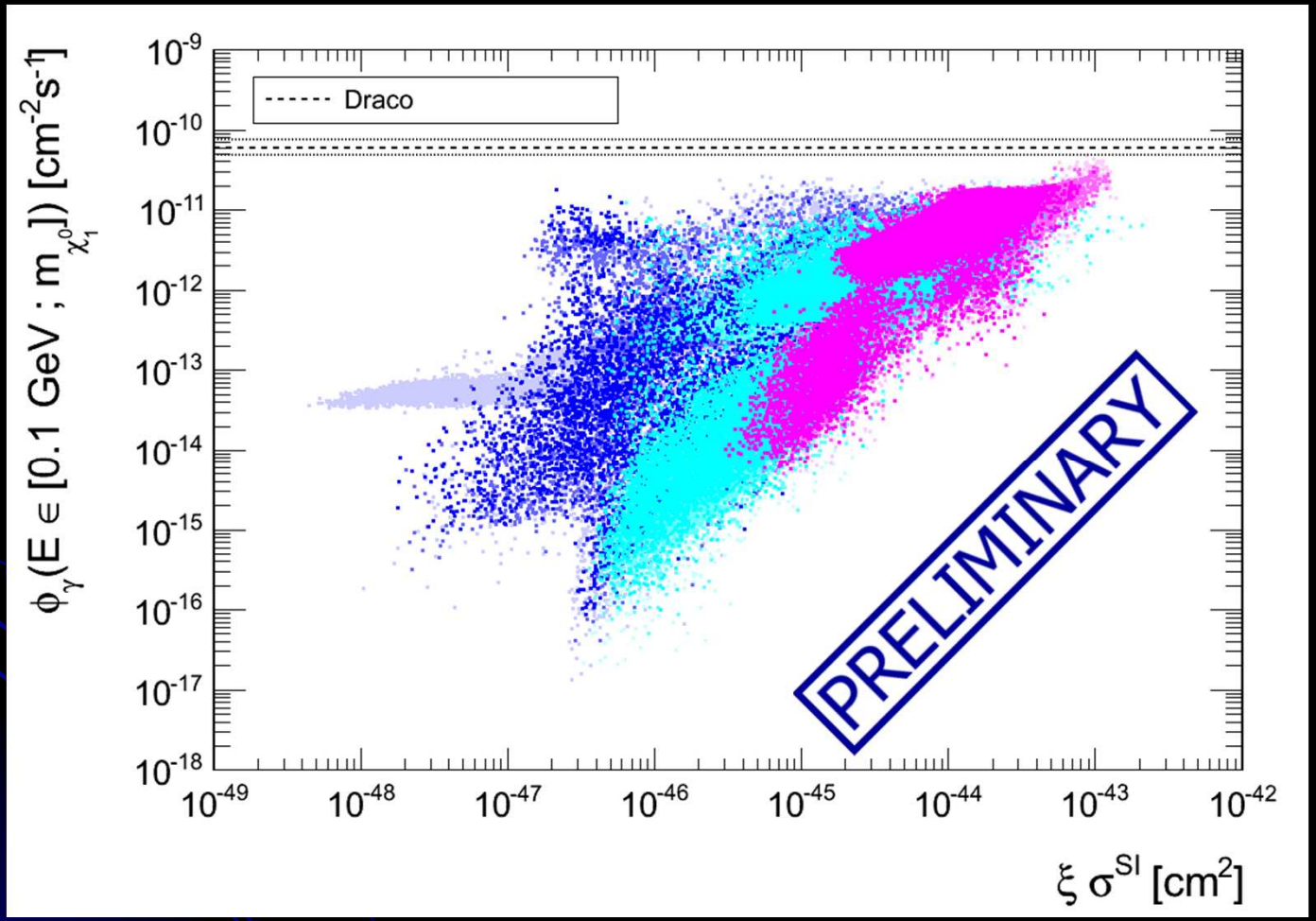
SDp – light NMSSM



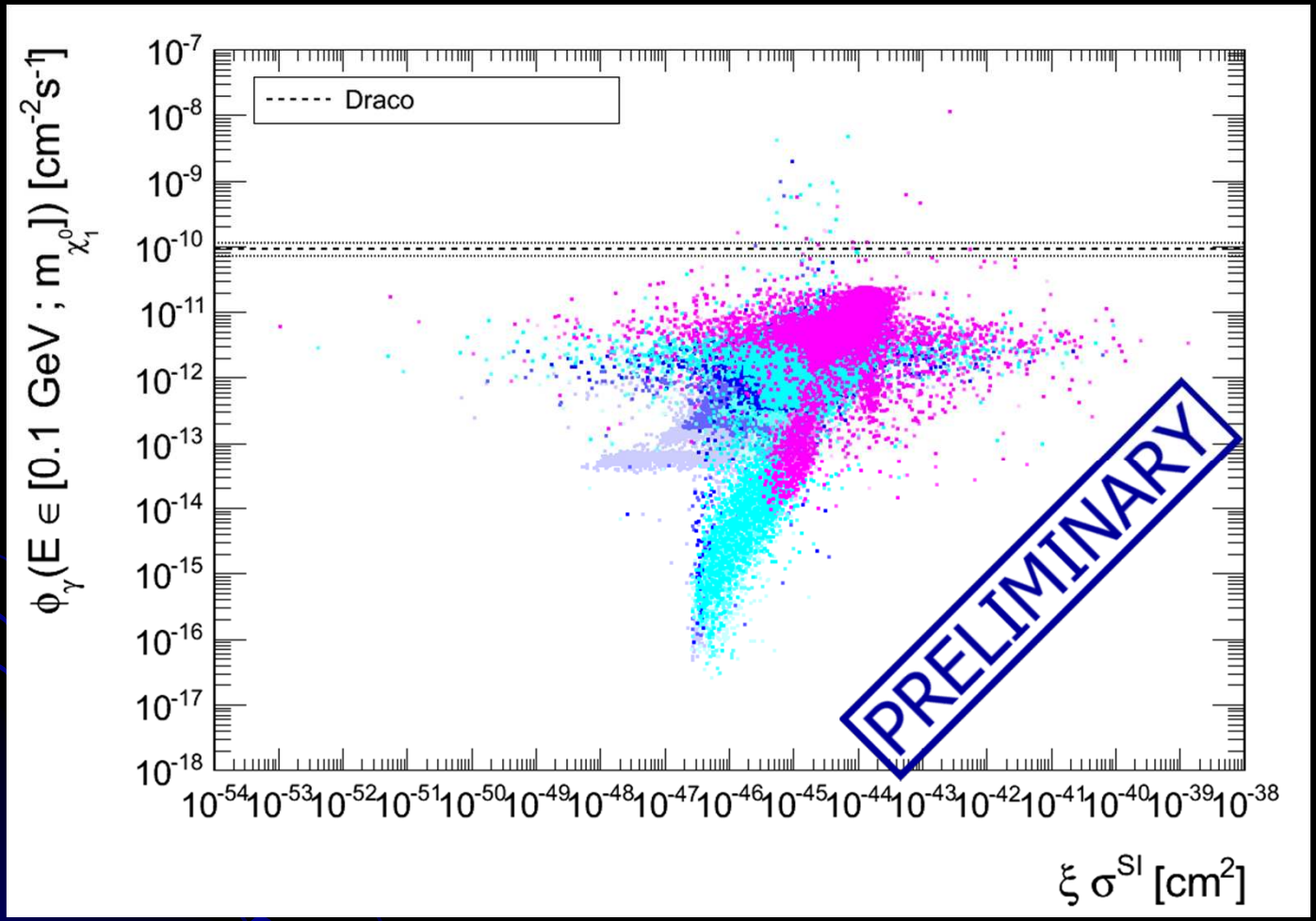
What MIMAC would see



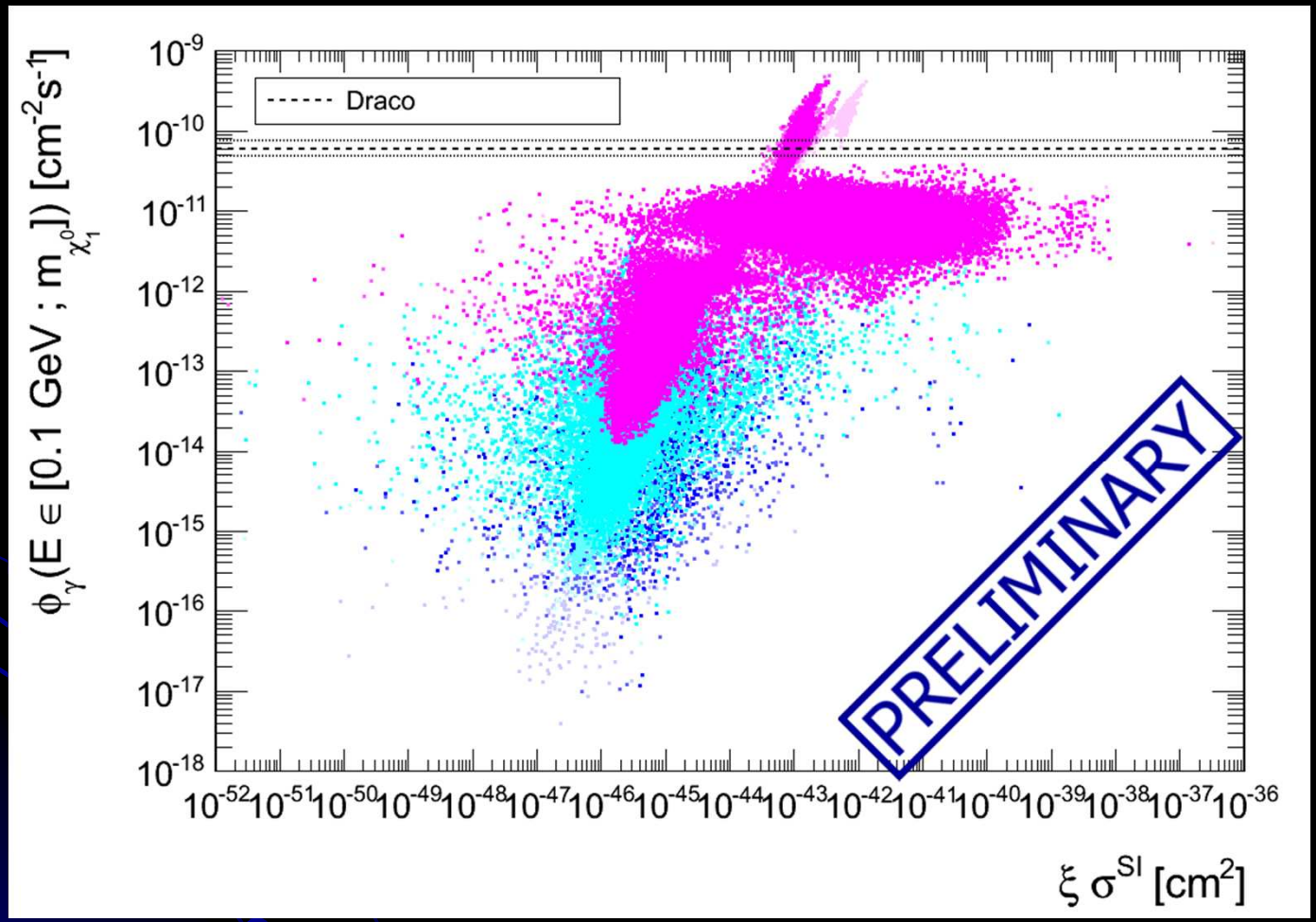
MIMAC vs. Xenon100 vs. FERMI: MSSM



MIMAC vs. Xenon100 vs. FERMI: NMSSM



MIMAC vs. Xenon100 vs. FERMI: light NMSSM



Conclusions

Conclusions

- Neutralinos are all over the place
- MIMAC could see bino-like neutralinos
- MIMAC / SD detectors will be sensitive where SI detectors and indirect detectors are not
- Determine the neutralino → information on μ: collider predictions?

Thank you!

And stay tuned to the arxiv