LAPTH – Annecy-le-Vieux – 18th of October 2010

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Oxford Astrophysics

Lightest neutralinos in the MSSM & NMSSM

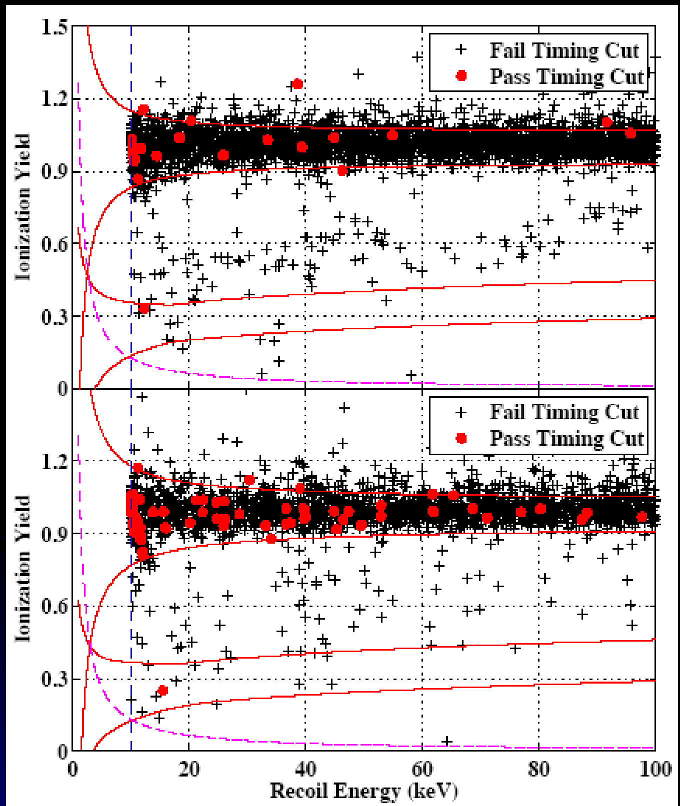
In collaboration with C. Boehm, G. Bélanger, A. Pukhov & J. Silk

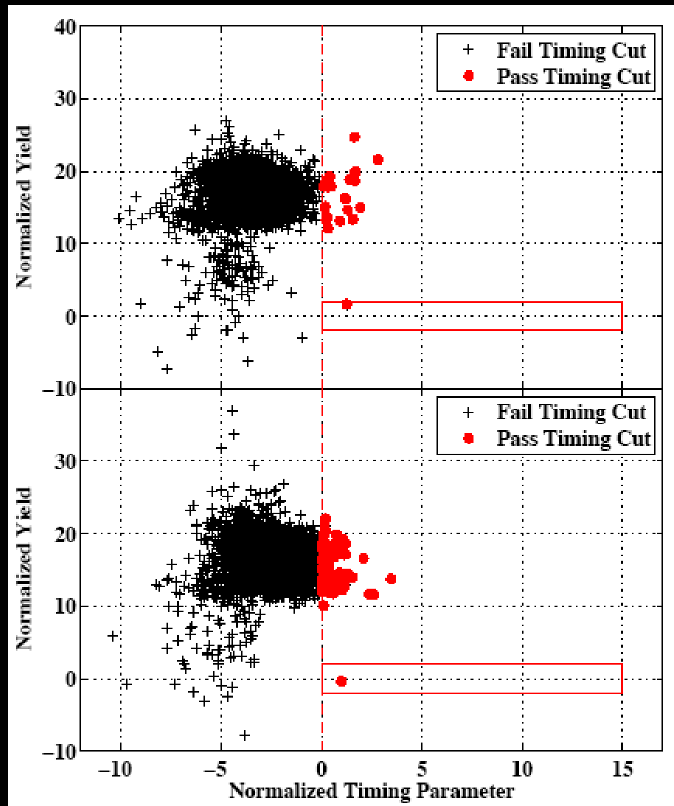
Outline

- Introduction
- Models and Method
- MSSM
- NMSSM
- Conclusions

Introduction

Introduction – December 2009

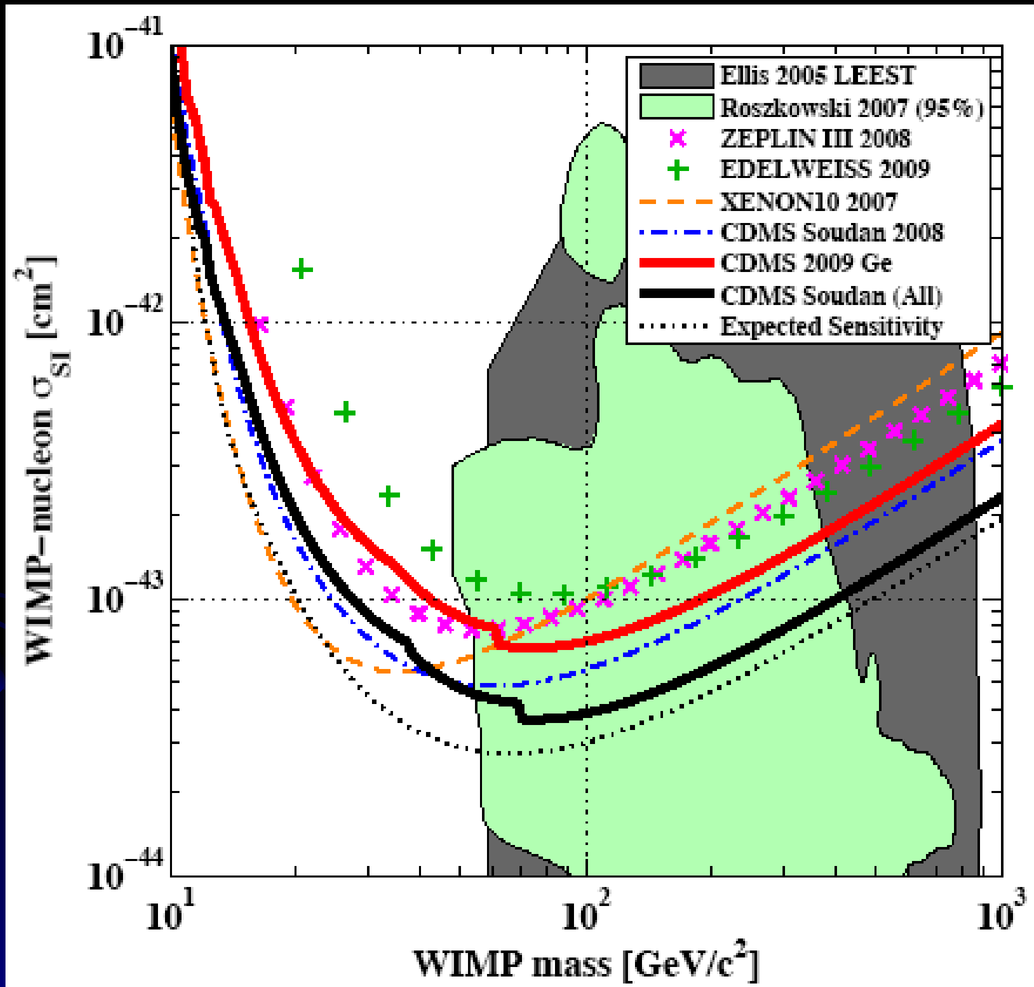


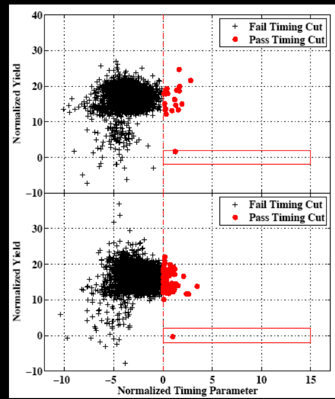


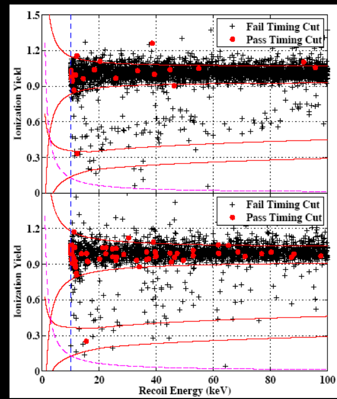
- 2 Events WIMP-like (23% probability)
- Preferred mass range: 7-40 GeV

Ahmed et al. (CDMS collaboration) – arXiv:0912.3592

Introduction – December 2009



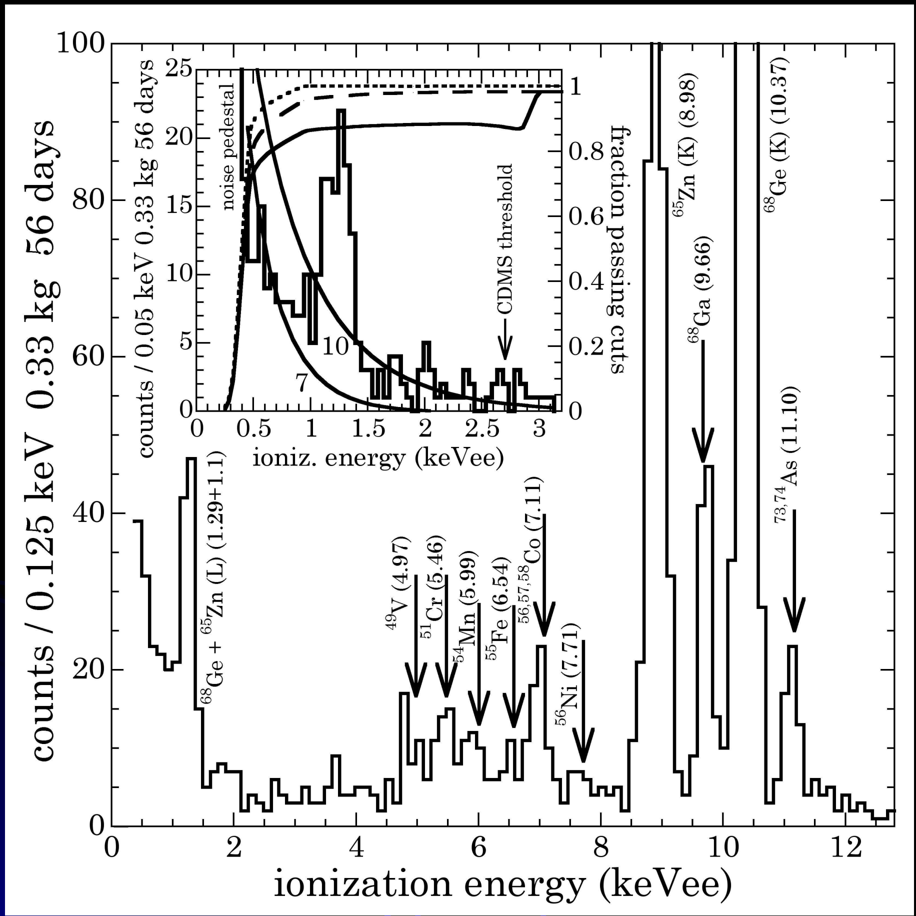


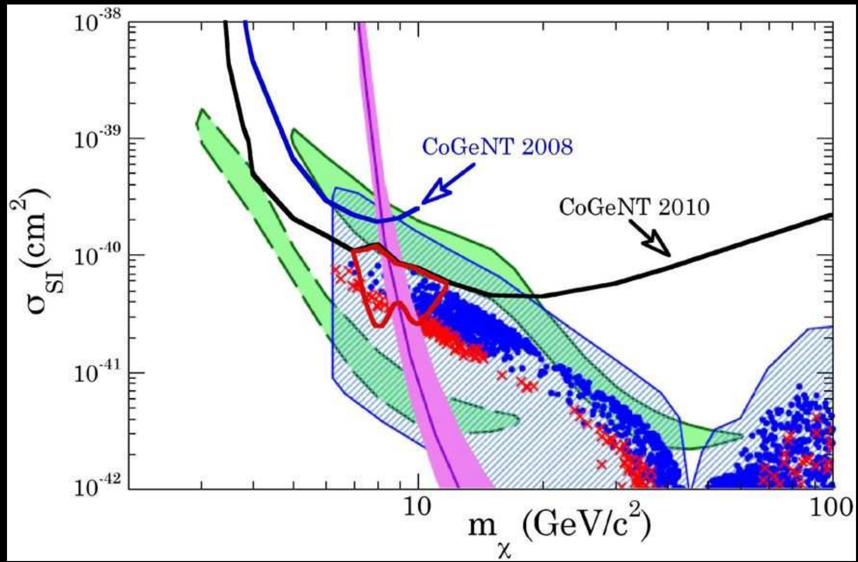


- 2 WIMP-like Events: not many!
- New limits in WIMP-nucleon interactions

[Ahmed et al. (CDMS collaboration) – arXiv:0912.3592]

Introduction – February 2010

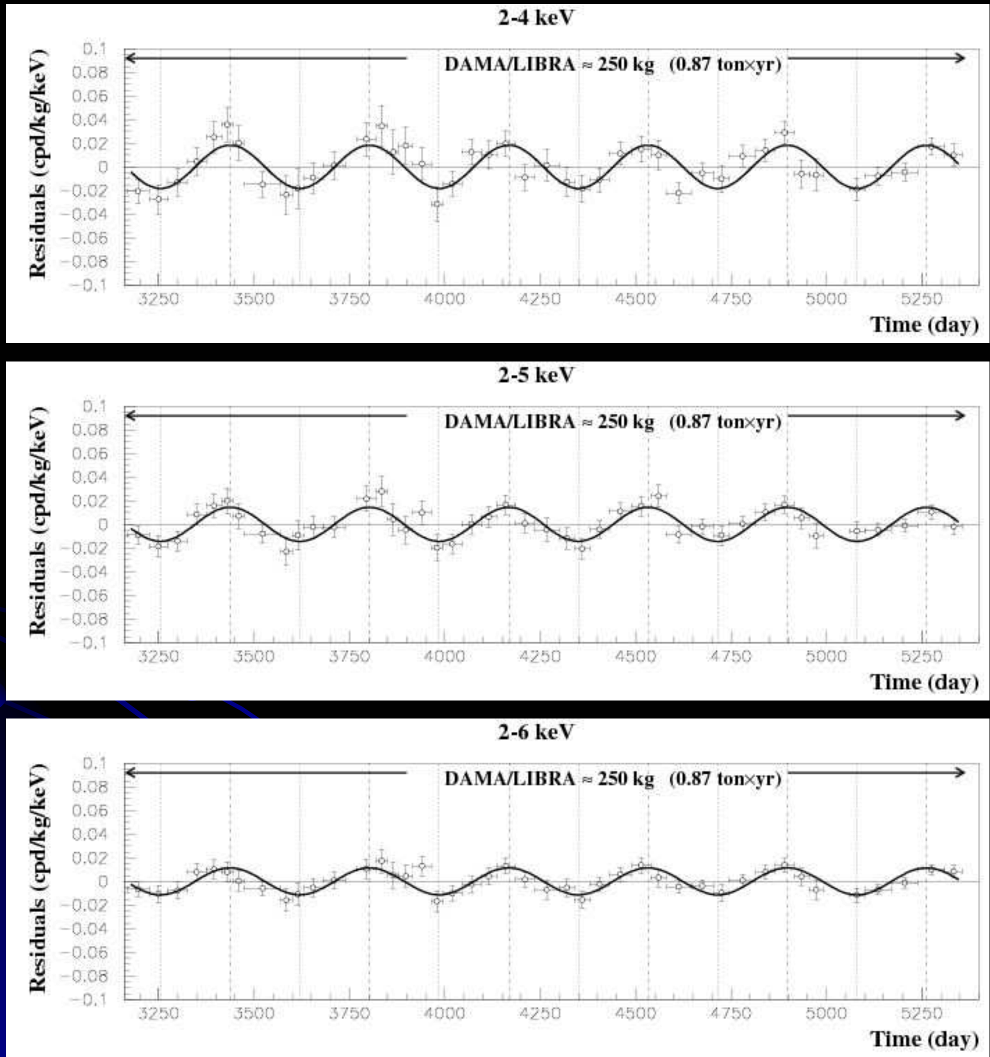




- Unexplained bulk-like signal
- Very low energy
- Preferred mass range: 7-11 GeV

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

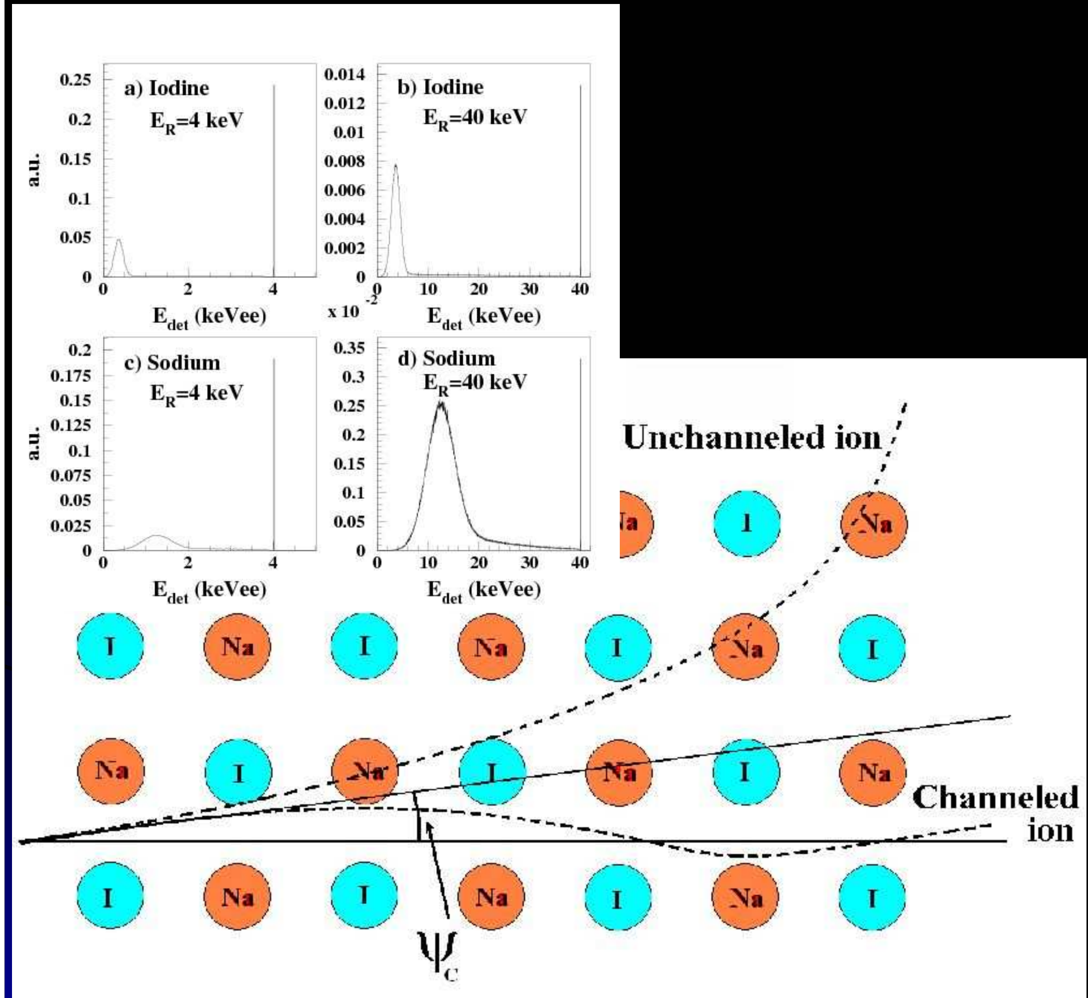
Introduction – February 2010



- 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 – Quenching

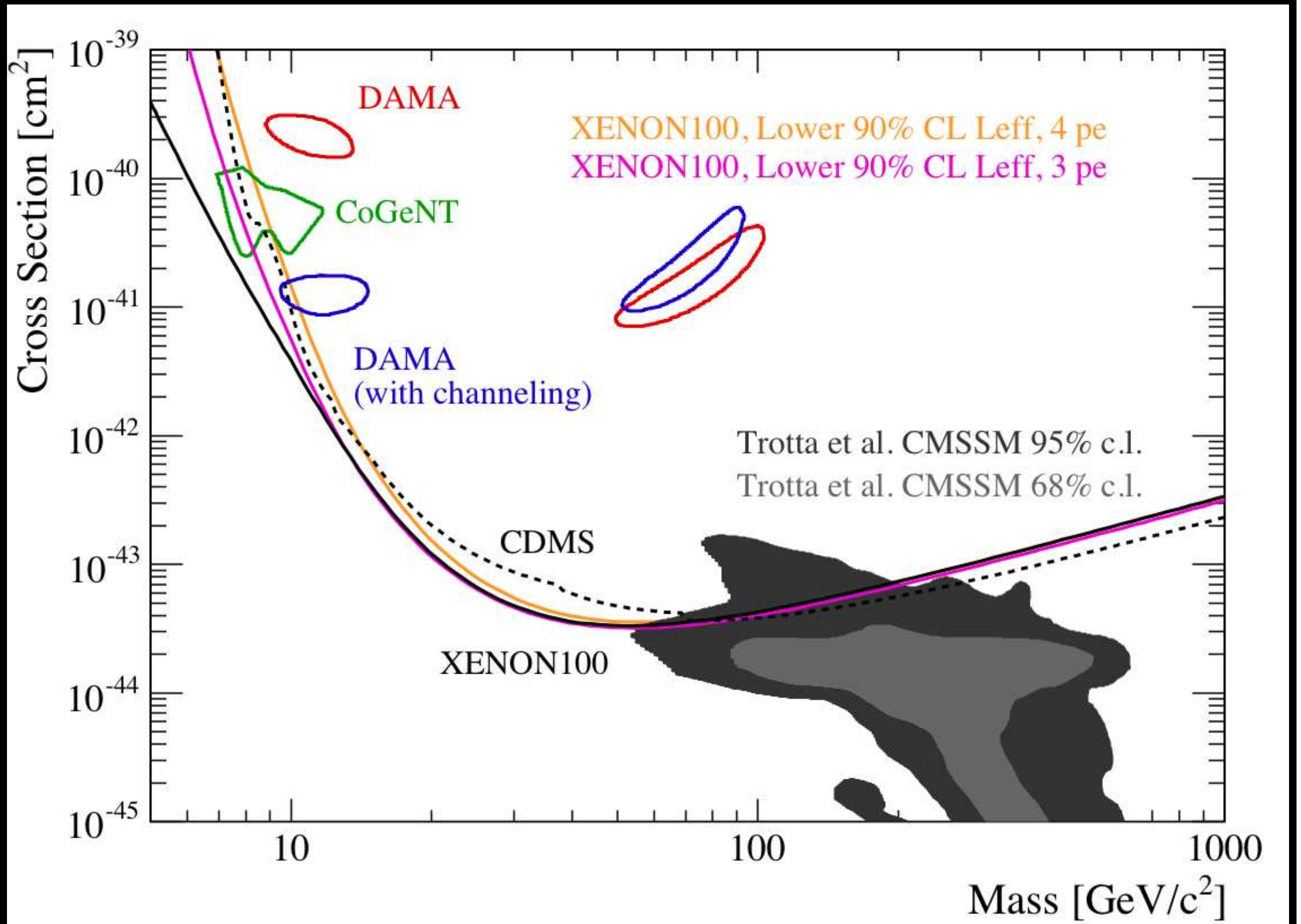


Bernabei et al. – arXiv:0710.0288

- Classic approach: quenching factor
- Sometimes, have channeling
- Two approcahes: quenching factor, or total channeling
- Need something in between

Introduction – May 2010

- L_{eff}: Scintillator efficiency
- At low energies, not well understood
- Extrapolations: constant, decreasing



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

Introduction

- Possible Dark Matter signals
- Rather Light WIMPS
- Collider, Cosmological, Xenon100 constraints
- Can Supersymmetry provide such a candidate?

Models & Method

Models

- SuperSymmetry
- MSSM & NMSSM at Electro Weak scales: 8 & 11 parameter spaces
- EW Symmetry Breaking: input parameters defined at the weak scale
- Non universal gaugino masses
- Neutralino LSP & DM

Tools

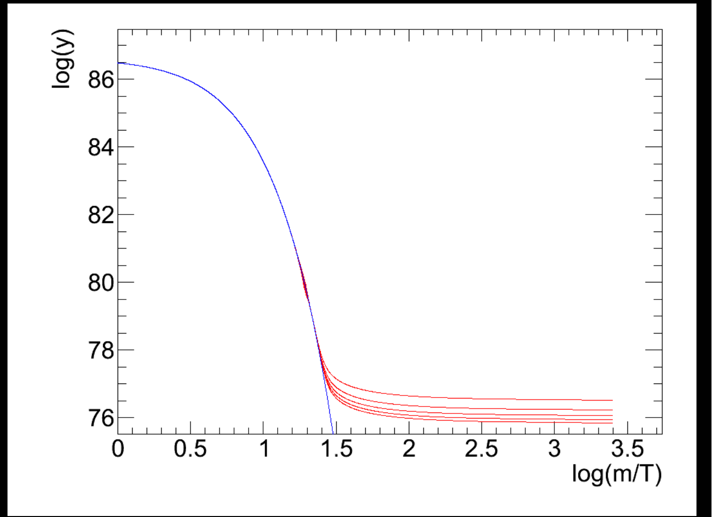
- micrOMEGAs 2.4
- EWSB spectra calculators:
  - MSSM: SuSpect
  - NMSSM: NMSSMTools
- Amplitude calculations through CalcHep: constraints and Direct Detection cross sections
- Existing functions for several processes: easy comparison with data

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
- Get a 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

Algorithm – MCMC

- Require:
  - Search for GeV dark matter particles
  - Consistent SuSy models and spectra
  - LSP: neutralino



- Data:
  - Unseen particles in colliders: couplings, masses constrained
  - Check corrections and room allowed
  - Cosmological dark matter: Relic Density

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

Direct Detection: Uncertainties

- Xenon100 Limit: decreasing Leff
- Nuclear form factors: smallest available
- Dark Matter Halo
  - Local density: ρ_0 0.2 – 0.3 GeV cm^{-3}
  - Maxwellian distribution for velocities
  - v_{rot} = 180 – 220 m s^{-1}
  - v_{esc} = 500 – 600 m s^{-1}

MSSM

MSSM – Neutralino LSP

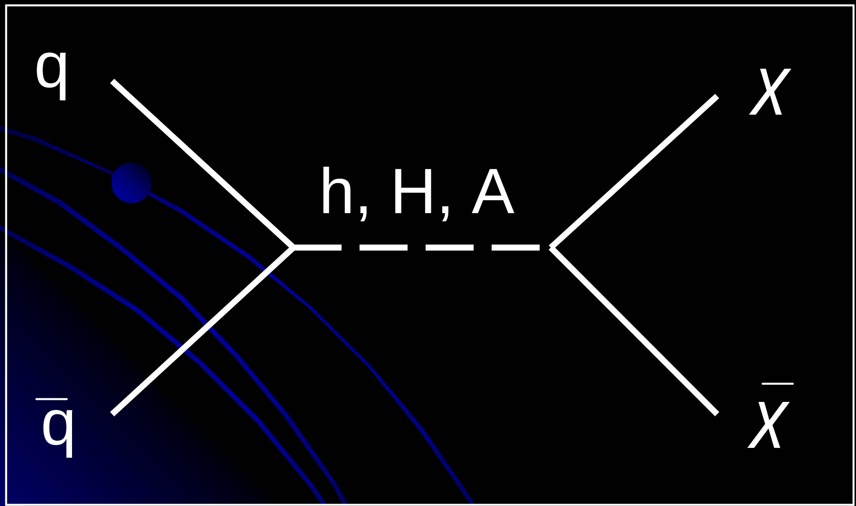
$$M_{\chi^0}^{MSSM} = \begin{pmatrix} M_1 & 0 & -M_Z s_W c_\beta & M_Z s_W s_\beta \\ 0 & M_2 & M_Z c_W c_\beta & -M_Z c_W s_\beta \\ -M_Z s_W c_\beta & M_Z c_W c_\beta & 0 & -\mu \\ M_Z s_W s_\beta & -M_Z c_W s_\beta & -\mu & 0 \end{pmatrix}$$

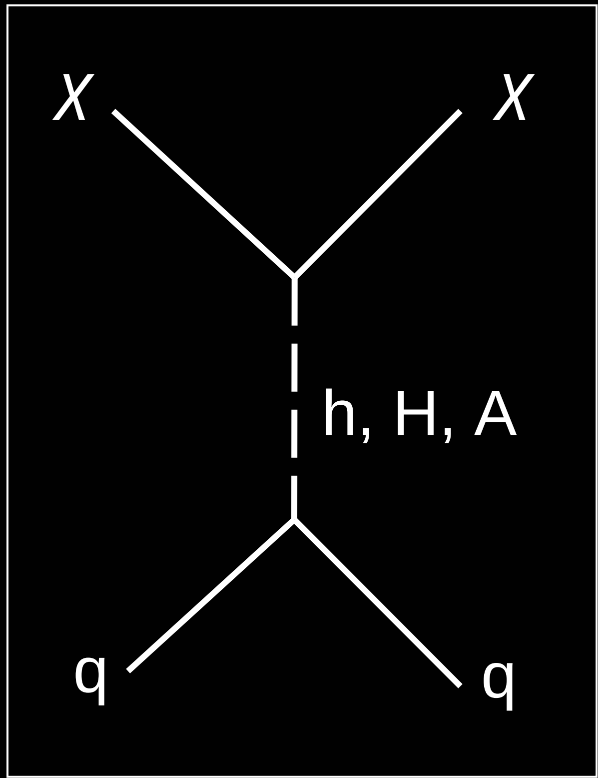
$$\chi_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}_3^0 + N_{13}\tilde{H}_d + N_{14}\tilde{H}_u$$

Couplings – Higgs

$$q_d \bar{q}_d h \propto q_d \bar{q}_d H \propto \frac{1}{\cos\beta}$$

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





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)

$$1 < M_1 < 100$$

$$100 < M_2 < 2000$$

$$0 < \mu < 1000$$

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

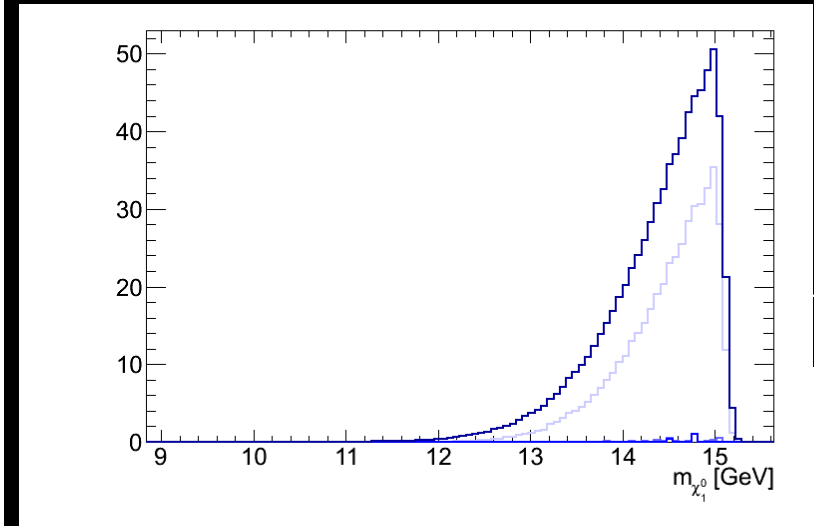
$$100 < M_A < 1000$$

$$-3000 < A_t < 3000$$

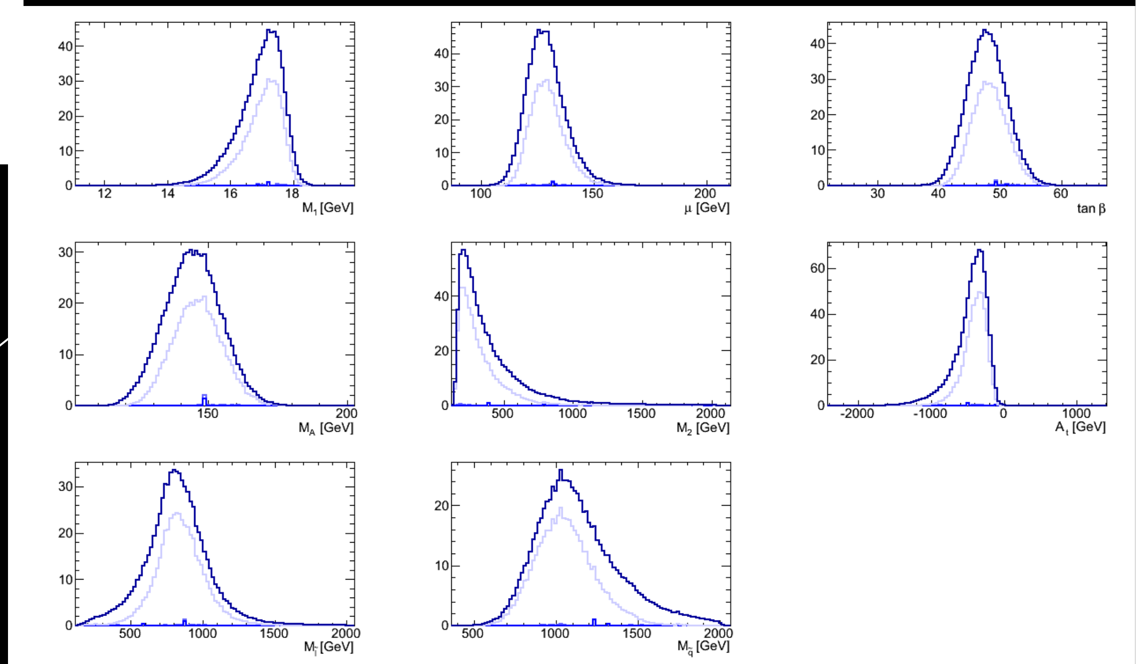
$$100 < M_{\tilde{l}} < 2000$$

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

MSSM

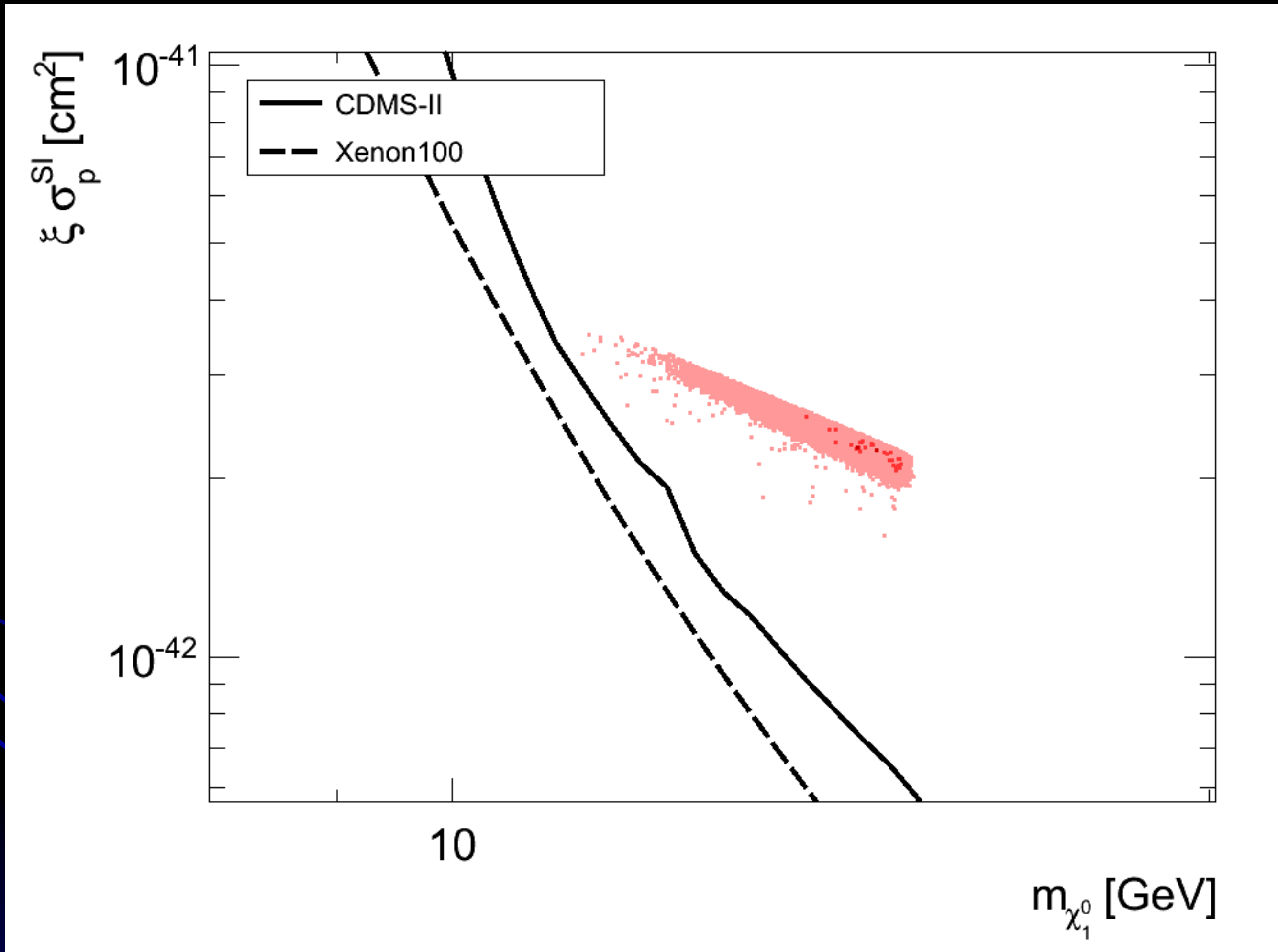


Difficult to come to low masses!

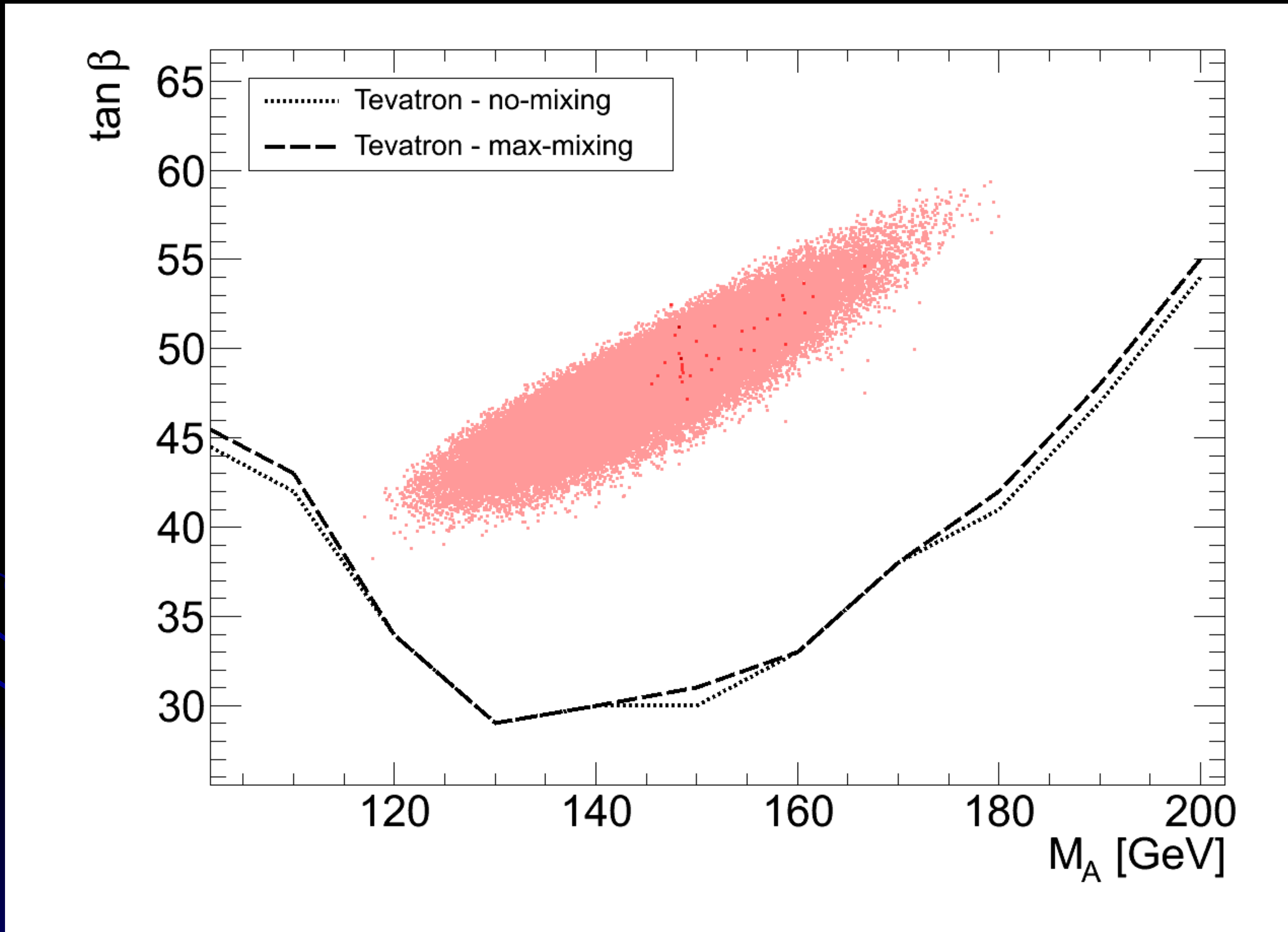


Bino-like neutralino.
Large tan β, small μ.

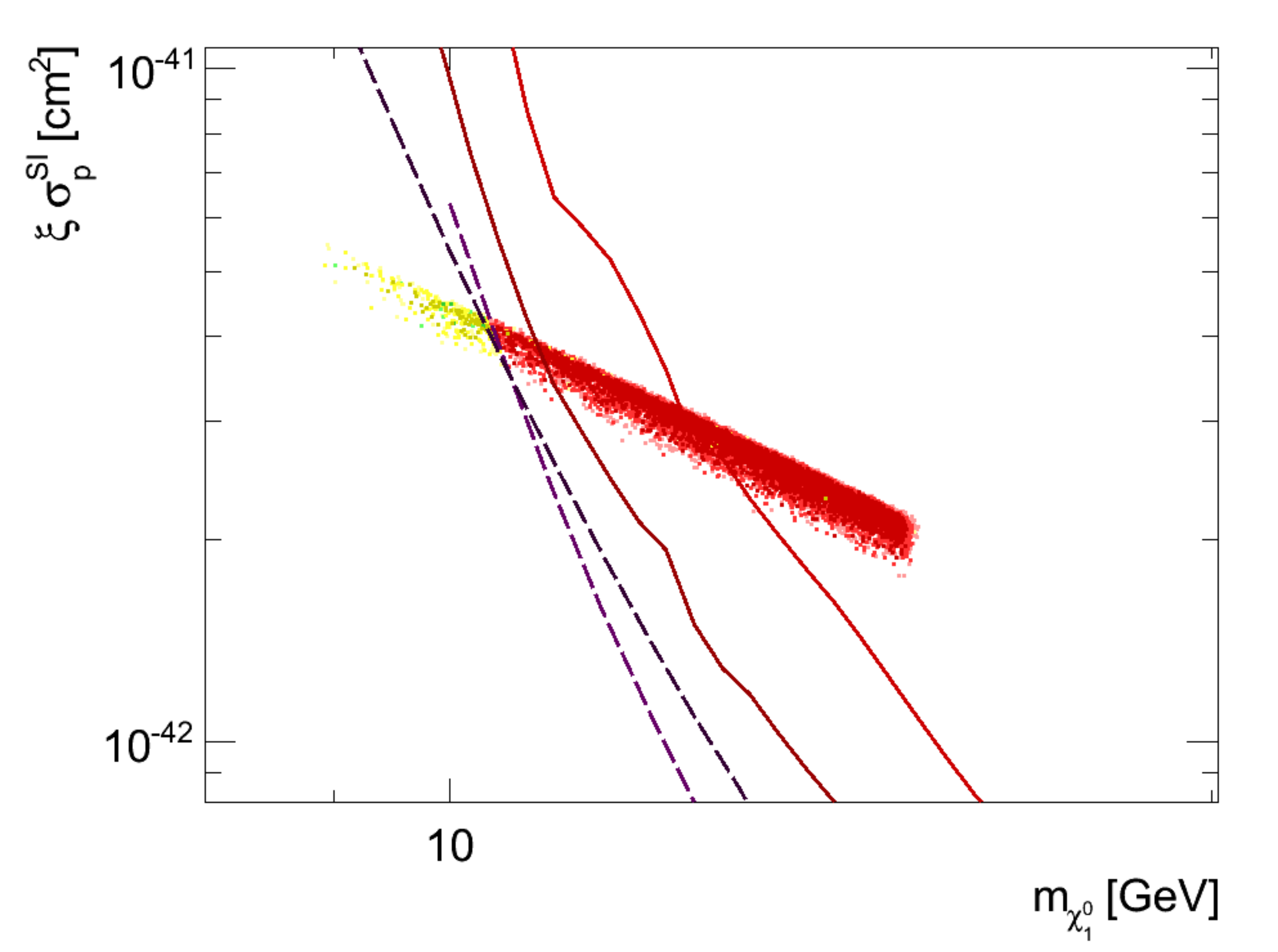
MSSM – Direct Detection



MSSM – Tevatron Higgs limit



MSSM – No ($B_s \rightarrow \mu_+\mu_-$)



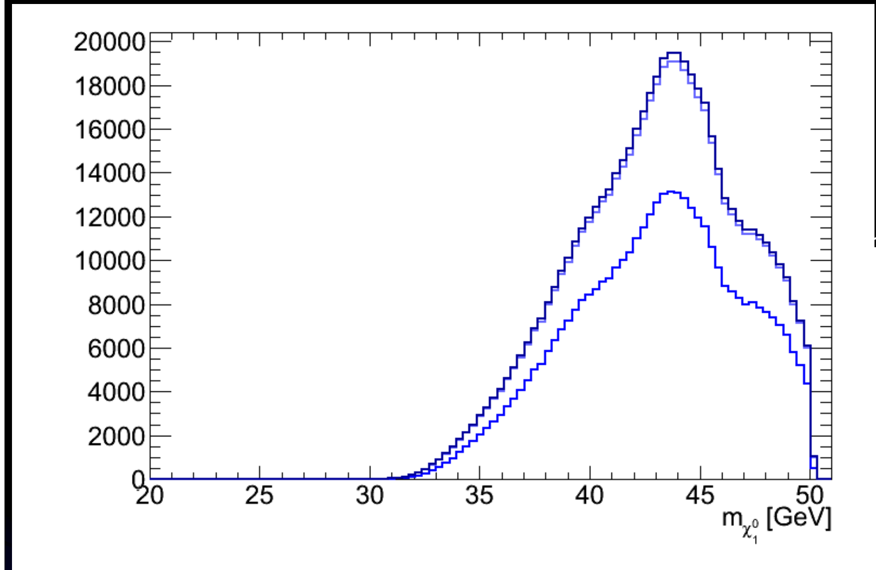
MSSM – No candidate

- The MCMC did not found neutralinos lighter than 10 GeV

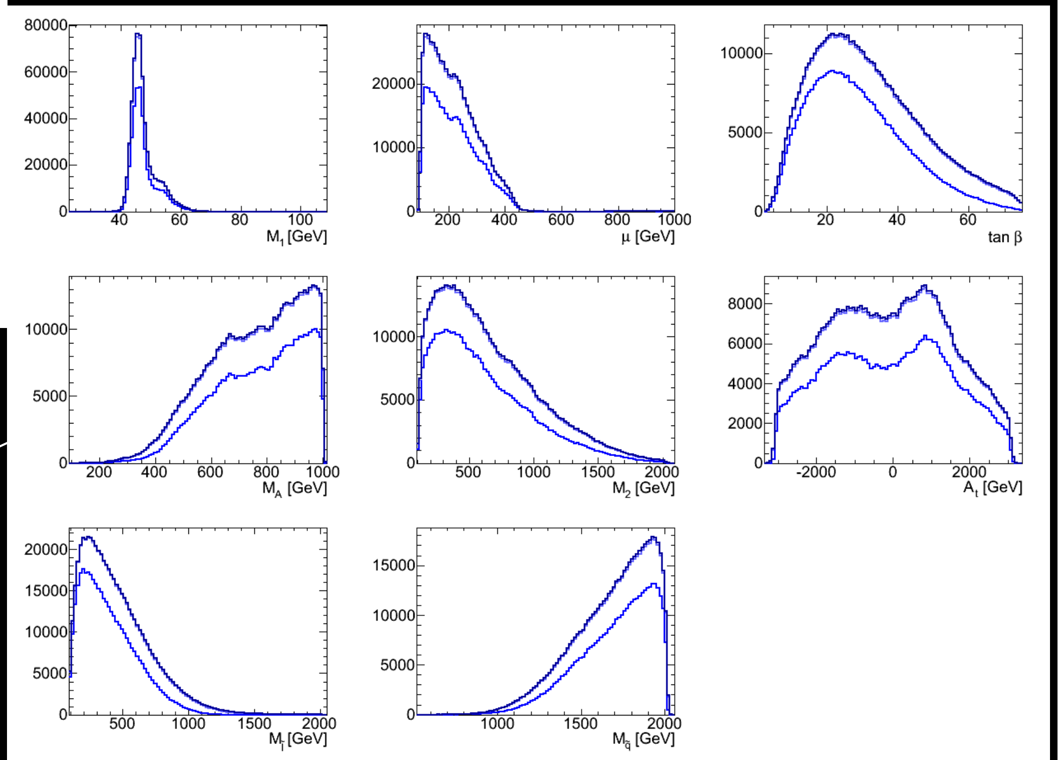
- Both Direct Detection experiments (CDMS-II & Xenon100) and TeVatron exclude the remaining light MSSM neutralinos

- What is the lightest neutralino in the MSSM?

MSSM – New lower limit

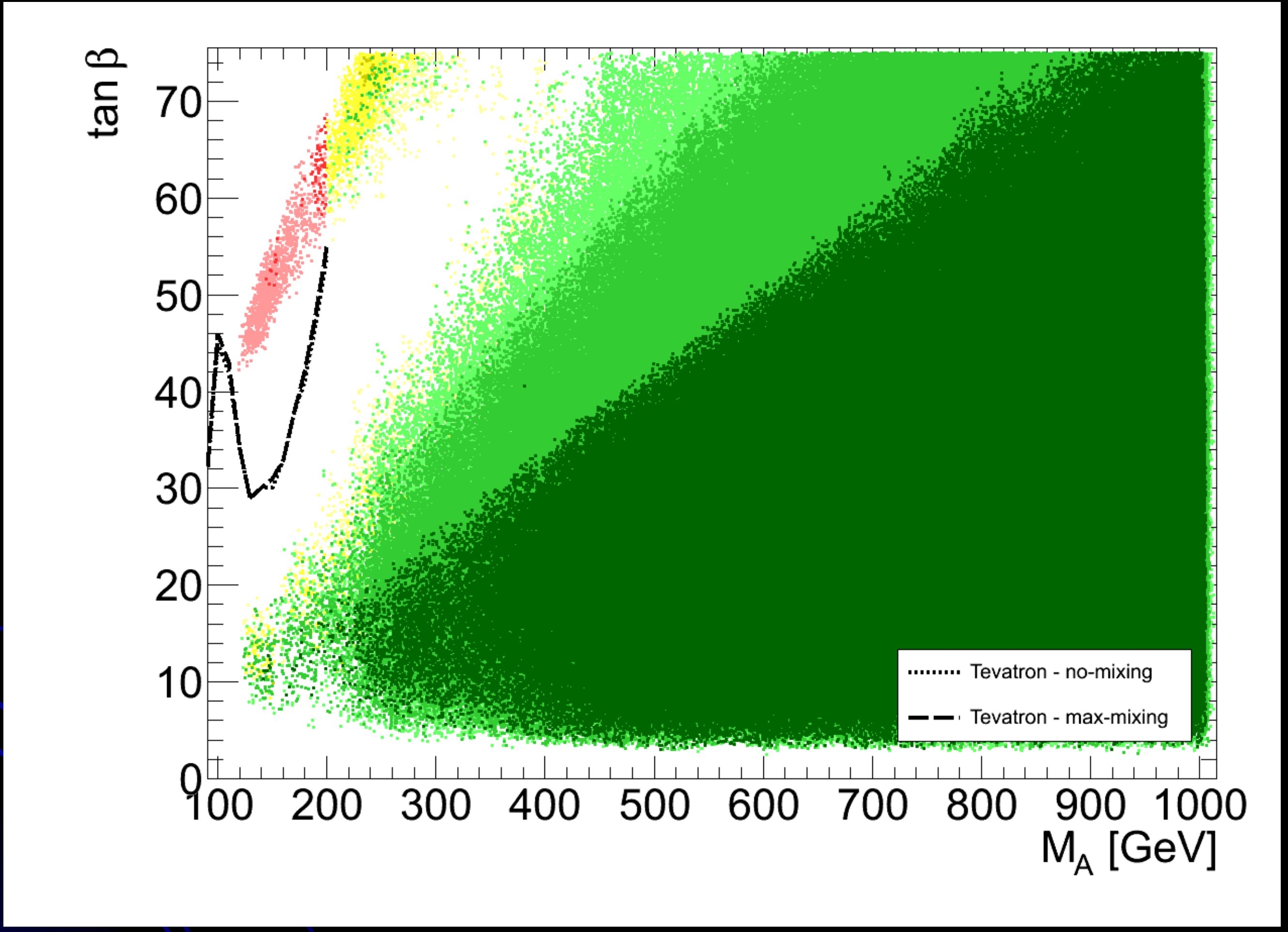


Peaked at $M_Z/2$

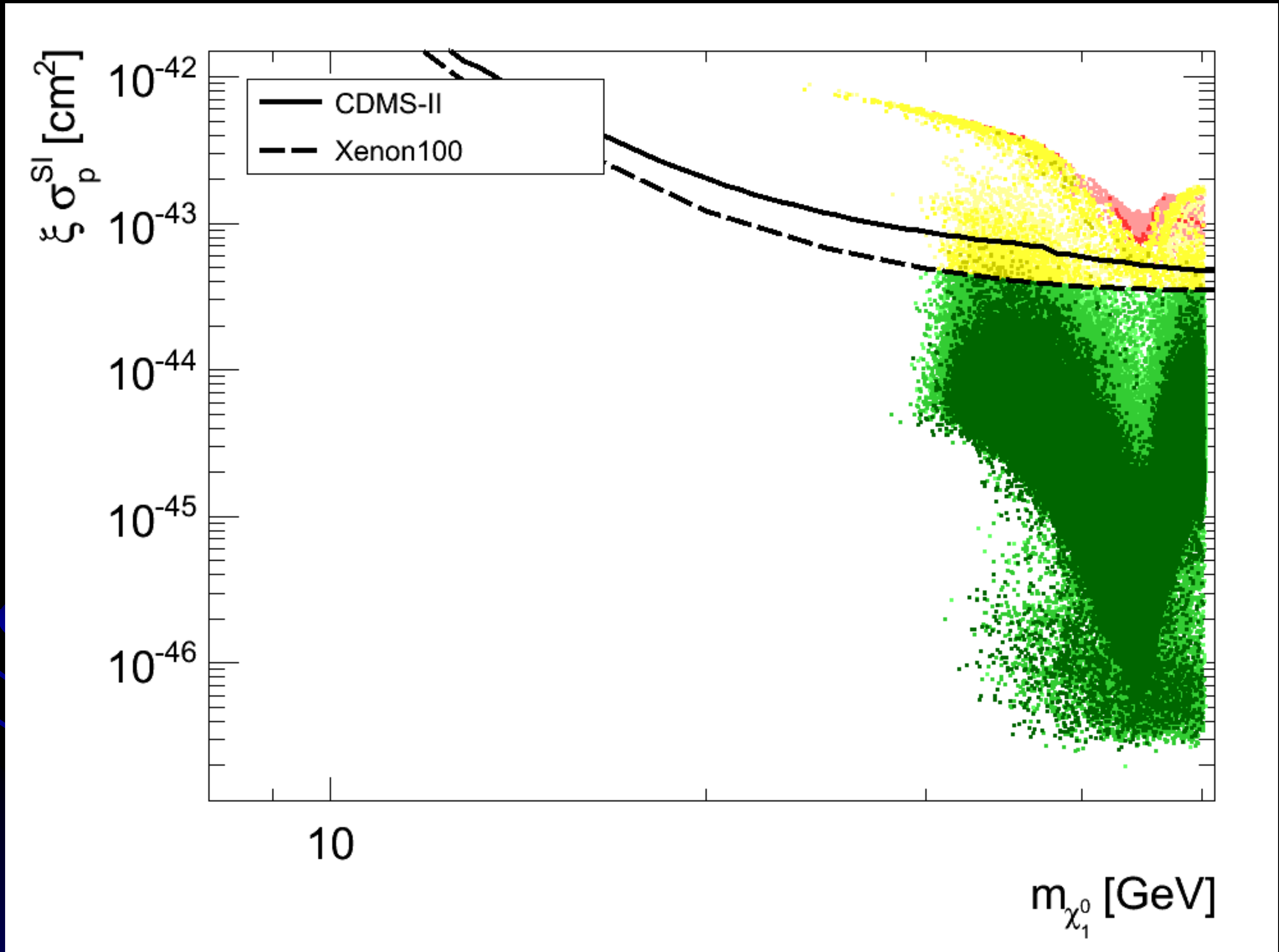


Bino-like neutralino.
Wider tan β range.

MSSM – New lower limit



MSSM – New lower limit



MSSM – Lower limit

- Larger values of neutralino mass give plausible candidates for DM

- Going towards the Z-resonance, do not need specially large tanβ nor low m_A

- New lower limit for the mass is 29 GeV

NMSSM

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

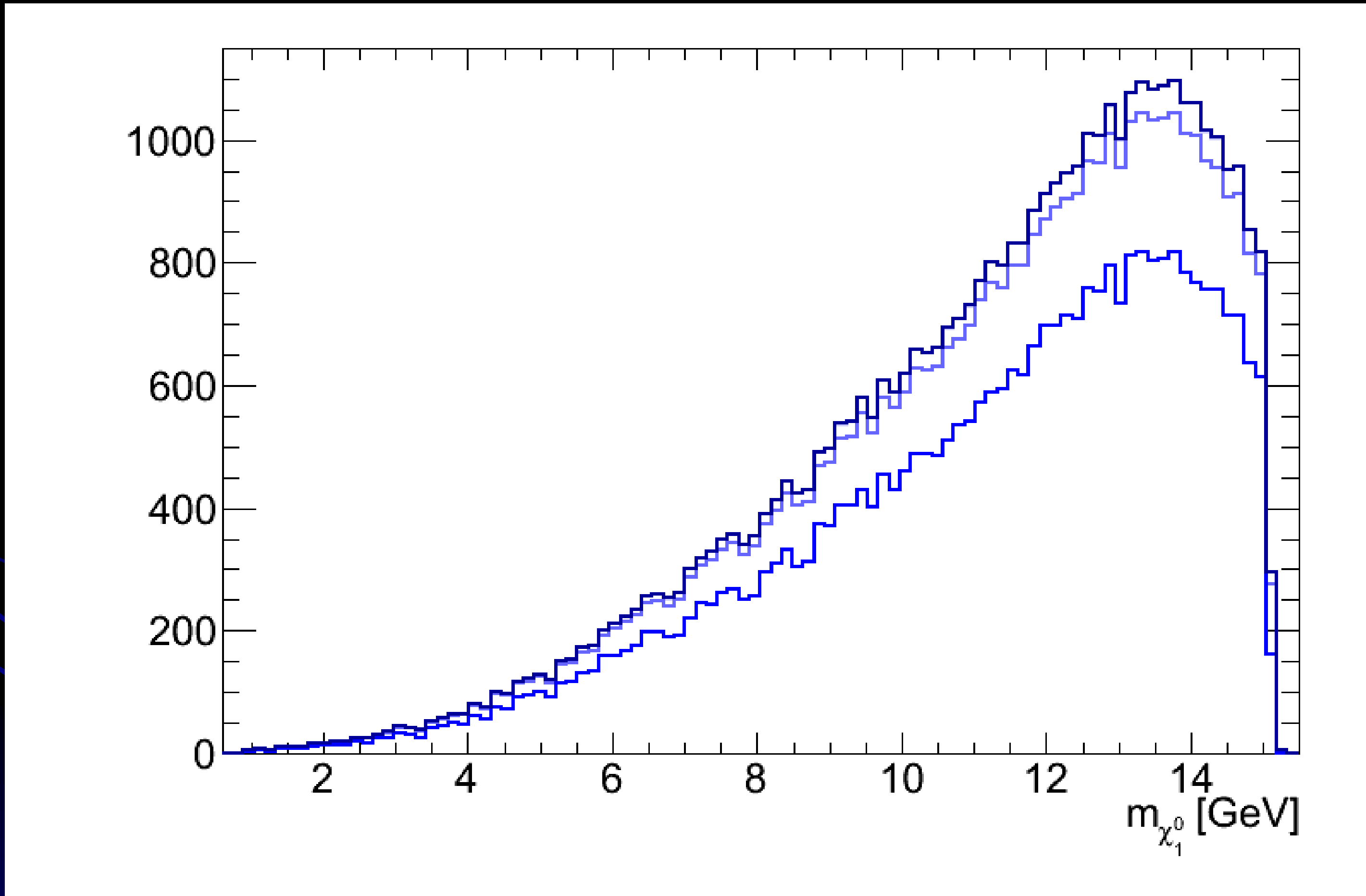
Trilinear coupling: At

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

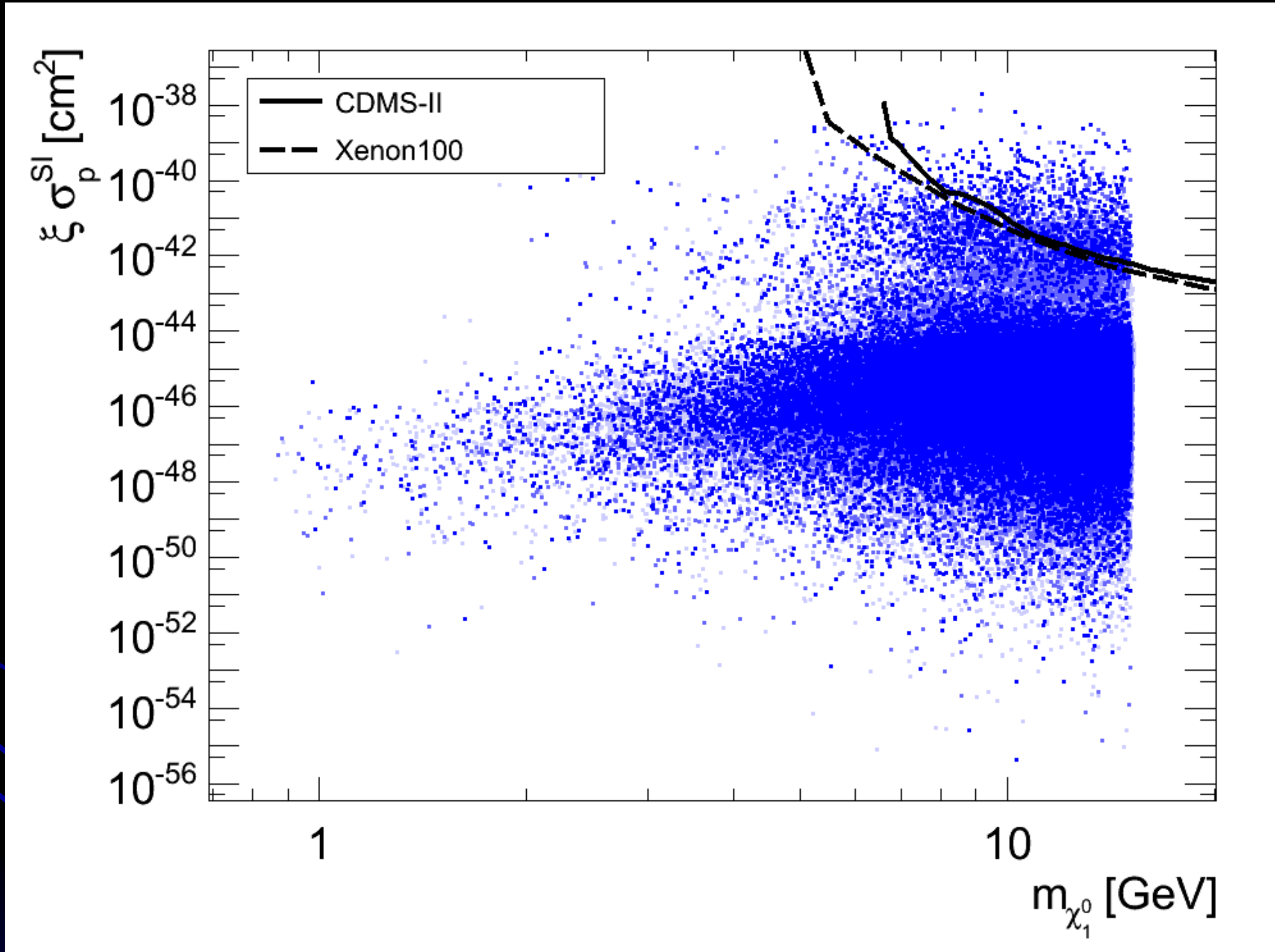
Parameter Space (GeV units)

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

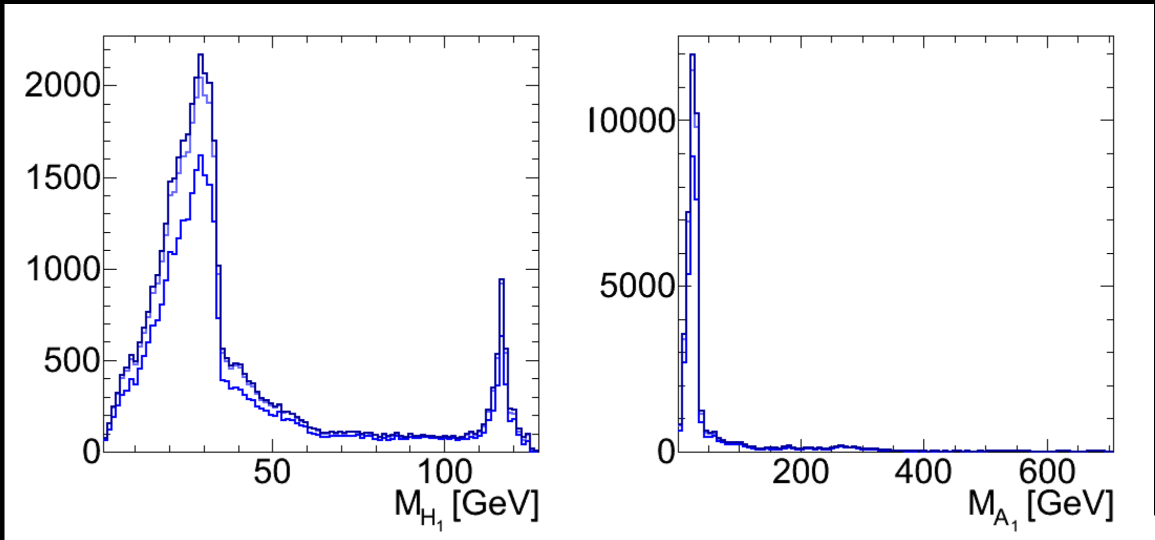
NMSSM – Low Masses!



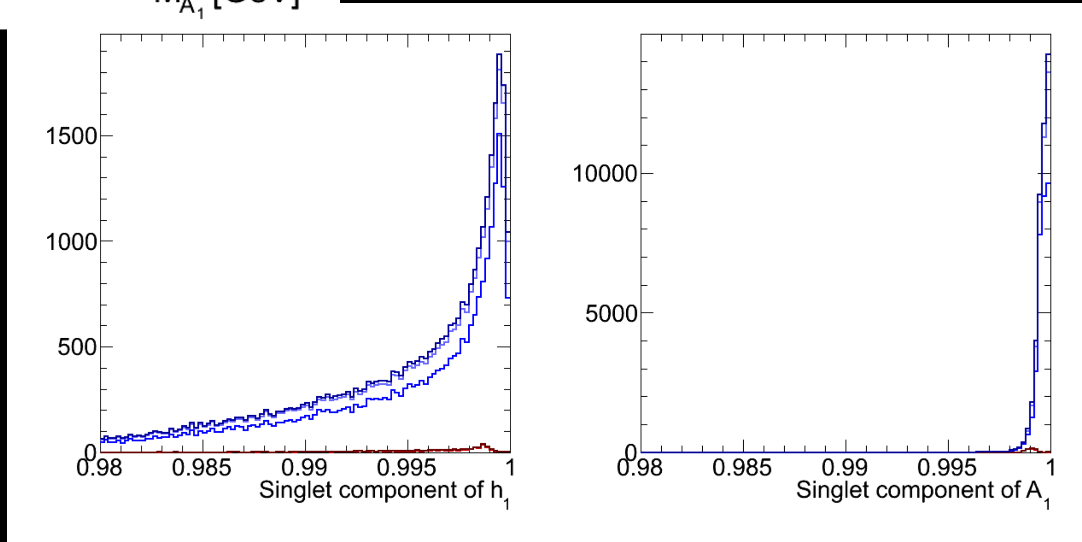
NMSSM does the job!



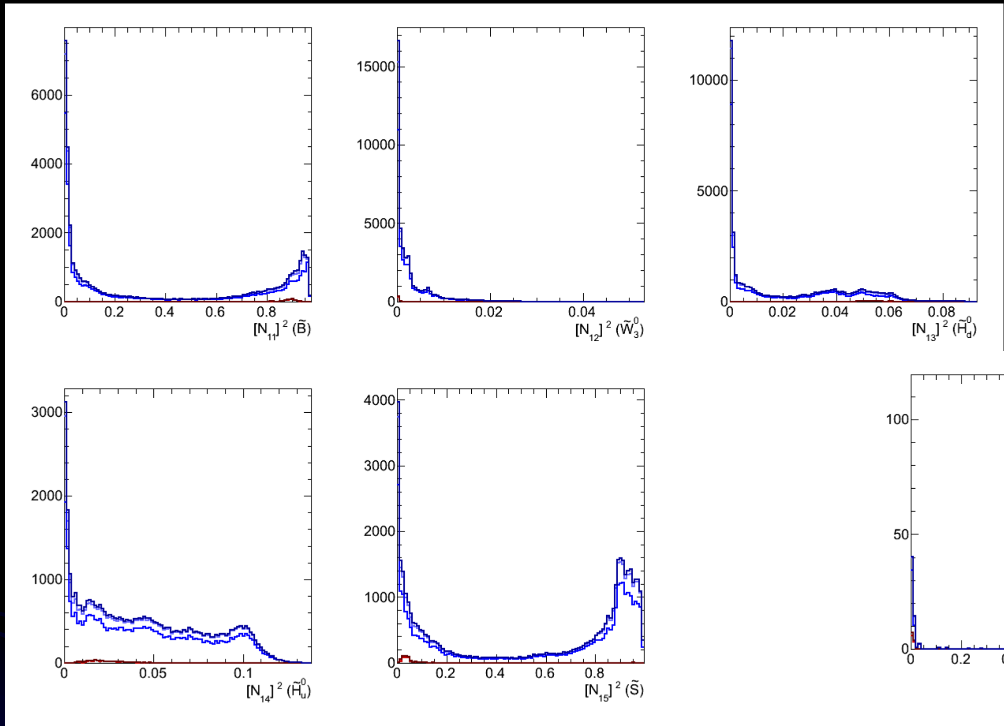
NMSSM – Higgses



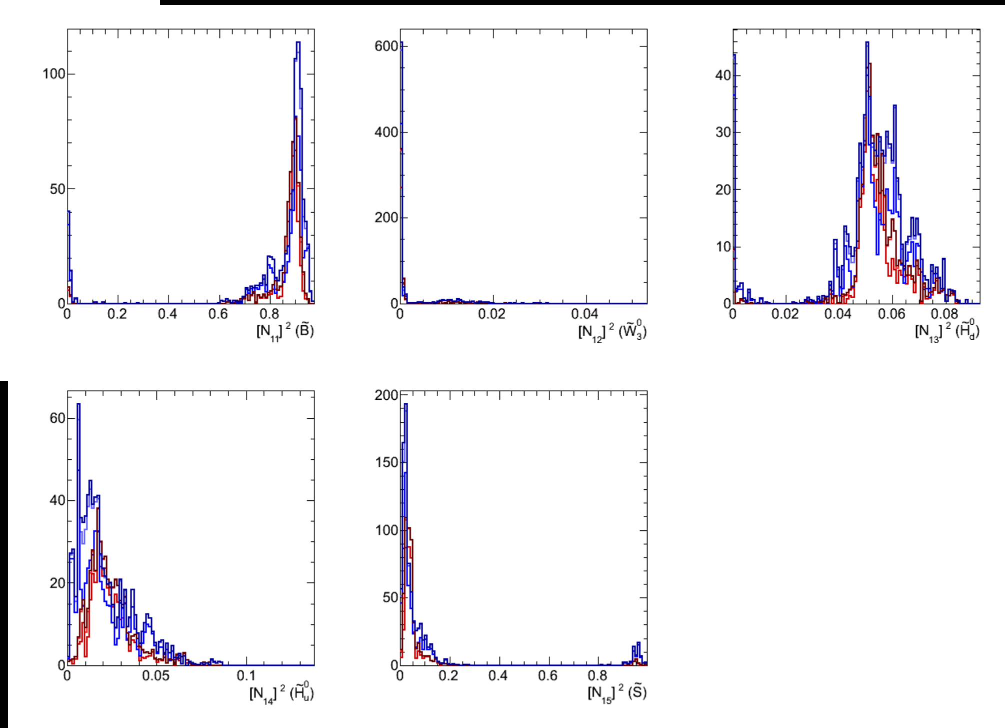
- Light singlet-like Higgses
- Twice the neutralino mass



NMSSM – Neutralino



- Bino-like Neutralinos



NMSSM – A Viable Explanation

• 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 Higgs, mostly singlet.

Conclusions

Conclusions

- Spin independent elastic scattering signals may be explained by Supersymmetric Dark Matter

- The MSSM fails to provide a Neutralino featuring the suited mass and interaction rates

- In the NMSSM, however, we found configurations in which the LSP is a sufficiently light and interacting Dark Matter candidate

Work in progress…

- New signatures for the LHC: the light Higgs scenario in the NMSSM

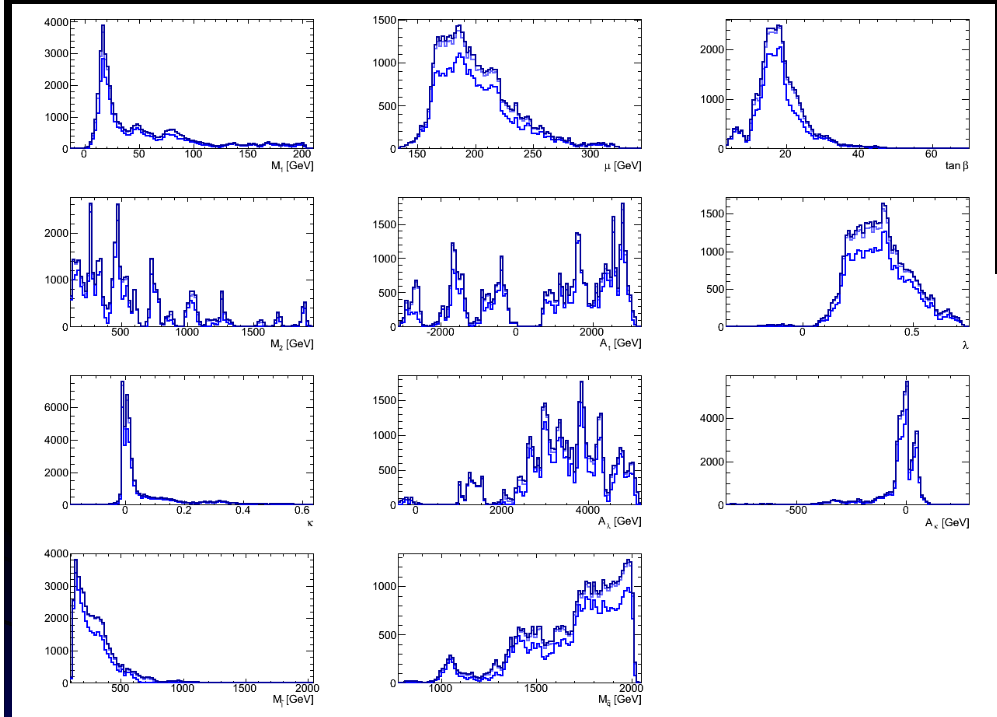
- Astrophysical constraints: what about gamma fluxes, cosmic rays, …?

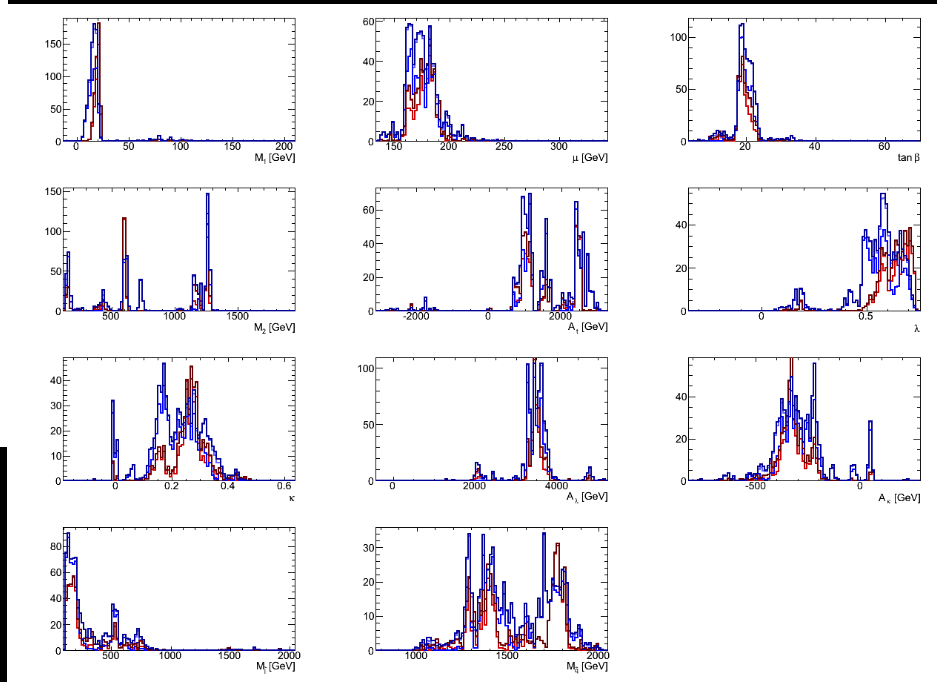
Stay tunned to the arXiv

Thank you!

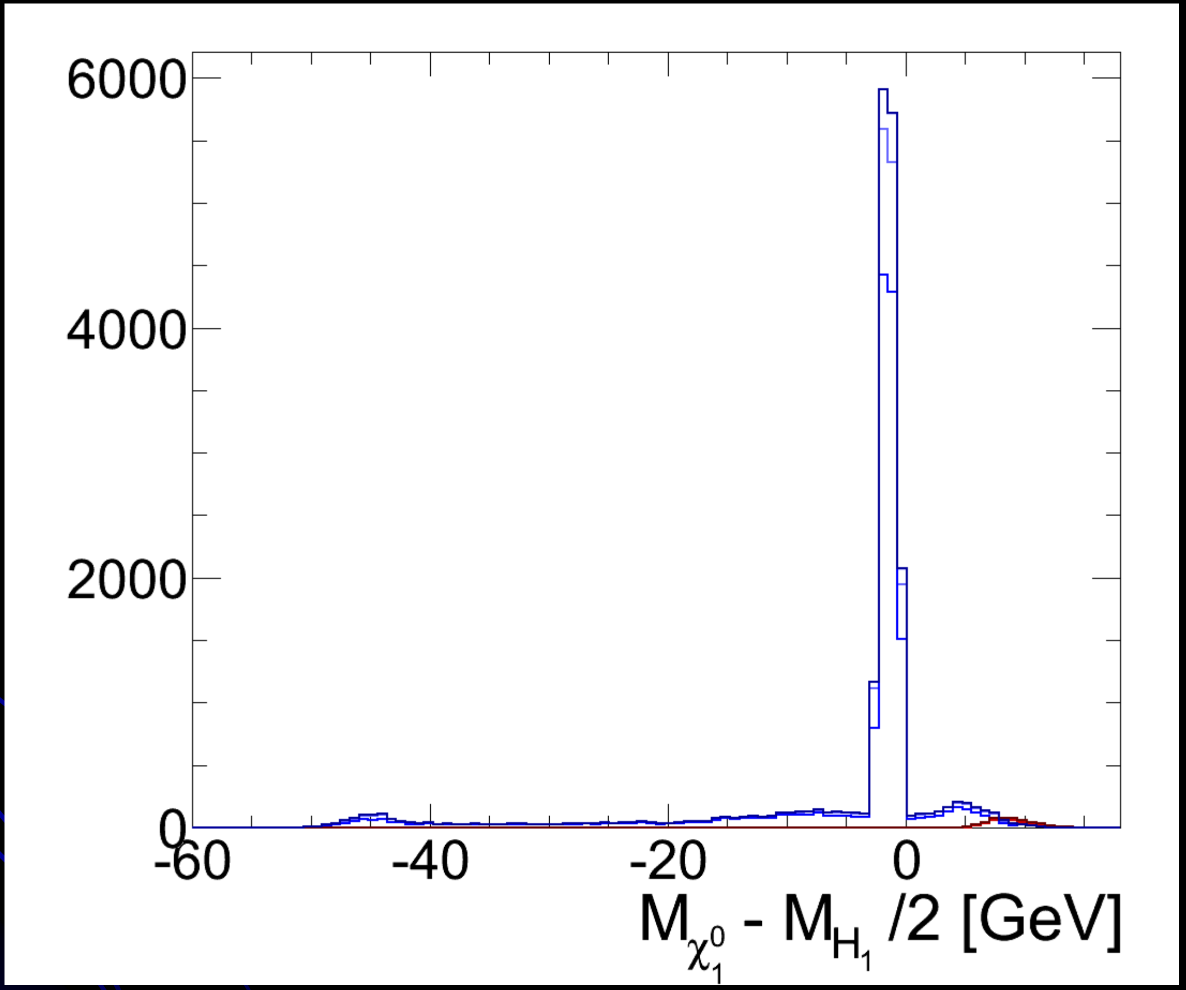
Questions?

NMSSM – Parameters





NMSSM – Higgs masses



NMSSM – Larger masses