Dark Matter Implications for SUSY

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1. Introduction and motivation

2. The main idea

3. Some results

4. Future plans

1. Introduction and motivation

Supersymmetry (SUSY) : Symmetry between

$$\text{Bosons} \leftrightarrow \text{Fermions}$$

$$Q\ |\text{Fermion}\rangle \rightarrow |\text{Boson}\rangle$$
$$Q\ |\text{Boson}\rangle \rightarrow |\text{Fermion}\rangle$$

Simplified examples:

$$Q\ |\text{top},\ t\rangle \rightarrow |\text{scalar top},\ \tilde{t}\rangle$$
$$Q\ |\text{gluon},\ g\rangle \rightarrow |\text{gluino},\ \tilde{g}\rangle$$

$\Rightarrow$ each SM multiplet is enlarged to its double size

Unbroken SUSY: All particles in a multiplet have the same mass

Reality: $m_e \neq m_{\tilde{e}}$ $\Rightarrow$ SUSY is broken . . .

. . . via soft SUSY-breaking terms in the Lagrangian (added by hand)

SUSY particles are made heavy: $M_{\text{SUSY}} = \mathcal{O}(1\ \text{TeV})$

Supersymmetry: Motivation

The SM is in a pretty good shape.

Why MSSM? (Is it worth to double the particle spectrum?)

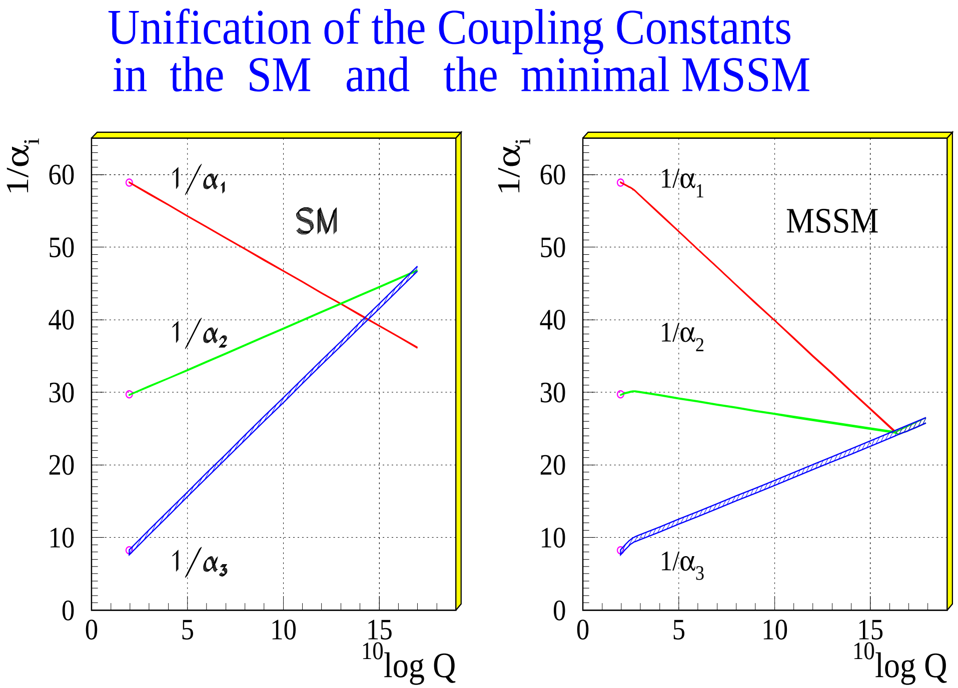
1.) Stability of the Higgs mass against higher-order corr.

2.) Unification of gauge couplings: Not possible in the SM, but in the MSSM (although it was not designed for it.)

3.) Spontaneous symmetry breaking via Higgs mechanism is automatic in SUSY GUTs

4.) SUSY provides CDM candidate

5.) . . .



[*Amaldi, de Boer, Fürstenau '92*]

The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles

$$\left[u, d, c, s, t, b\right]_{L,R} \quad \left[e, \mu, \tau\right]_{L,R} \quad \left[\nu_{e,\mu,\tau}\right]_{L} \qquad \text{Spin } \tfrac{1}{2}$$

$$\left[\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{t}, \tilde{b}\right]_{L,R} \quad \left[\tilde{e}, \tilde{\mu}, \tilde{\tau}\right]_{L,R} \quad \left[\tilde{\nu}_{e,\mu,\tau}\right]_{L} \qquad \text{Spin } 0$$

$$g \quad \underbrace{W^{\pm}, H^{\pm}} \quad \underbrace{\gamma, Z, H_1^0, H_2^0} \qquad \text{Spin 1 / Spin 0}$$

$$\tilde{g} \quad \tilde{\chi}^{\pm}_{1,2} \quad \tilde{\chi}^{0}_{1,2,3,4} \qquad \text{Spin } \frac{1}{2}$$

Candidates for Cold Dark Matter: $\tilde{\nu}$, $\tilde{\chi}_1^0$, $\tilde{G}$

$\tilde{\nu}$: scalar neutrino, mostly excluded as CDM candidate

$\tilde{\chi}_1^0$: lightest neutralino $\Rightarrow$ good candidate

$\tilde{G}$: gravitino, superpartner of graviton $\Rightarrow$ possible candidate ($\rightarrow$ backup)

2. The main idea

- Assume standard cosmology
- Calculate CDM density in the early universe
- Compare with experimental result

$$(\Omega_{\rm CDM} h^2)^{\rm exp} = 0.1099 \pm 0.0062$$

$\Rightarrow$ Find viable regions in the MSSM parameter space

Note:
Naturally the lightest neutralino gives you

$$\Omega_{\rm CDM} h^2 = \mathcal{O}(1)$$

Problem:
The unconstrained MSSM has more than 100 free parameters

Simple models: 1.) CMSSM (or mSUGRA):

⇒ Scenario characterized by

$$m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ \text{sign}\,\mu$$

m_0 : universal scalar mass parameter

$m_{1/2}$: universal gaugino mass parameter

A_0 : universal trilinear coupling

} at the GUT scale

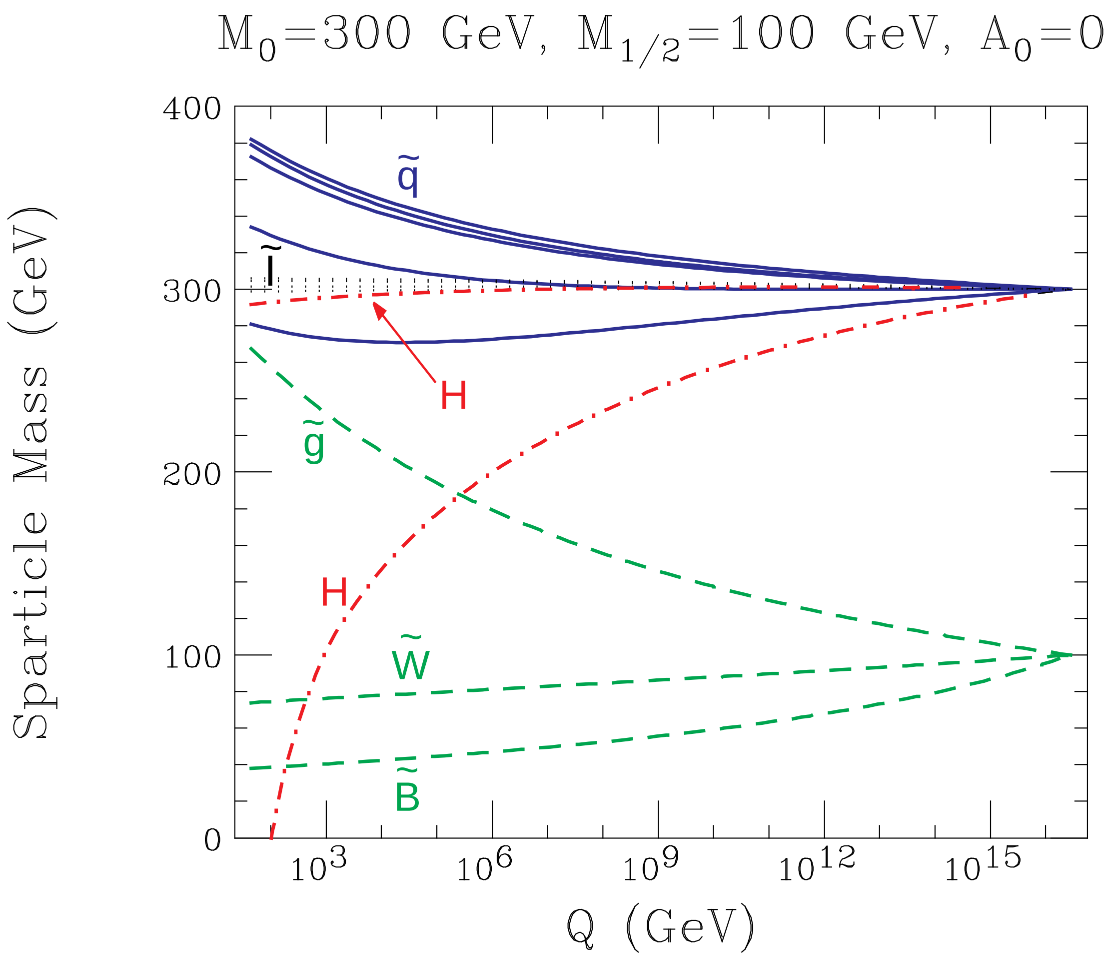
$\tan\beta$: ratio of Higgs vacuum expectation values

sign(μ) : sign of supersymmetric Higgs parameter

⇒ particle spectra from renormalization group running to weak scale

⇒ Lightest SUSY particle (LSP) is the lightest neutralino

⇒ particle spectra from renormalization group running to weak scale



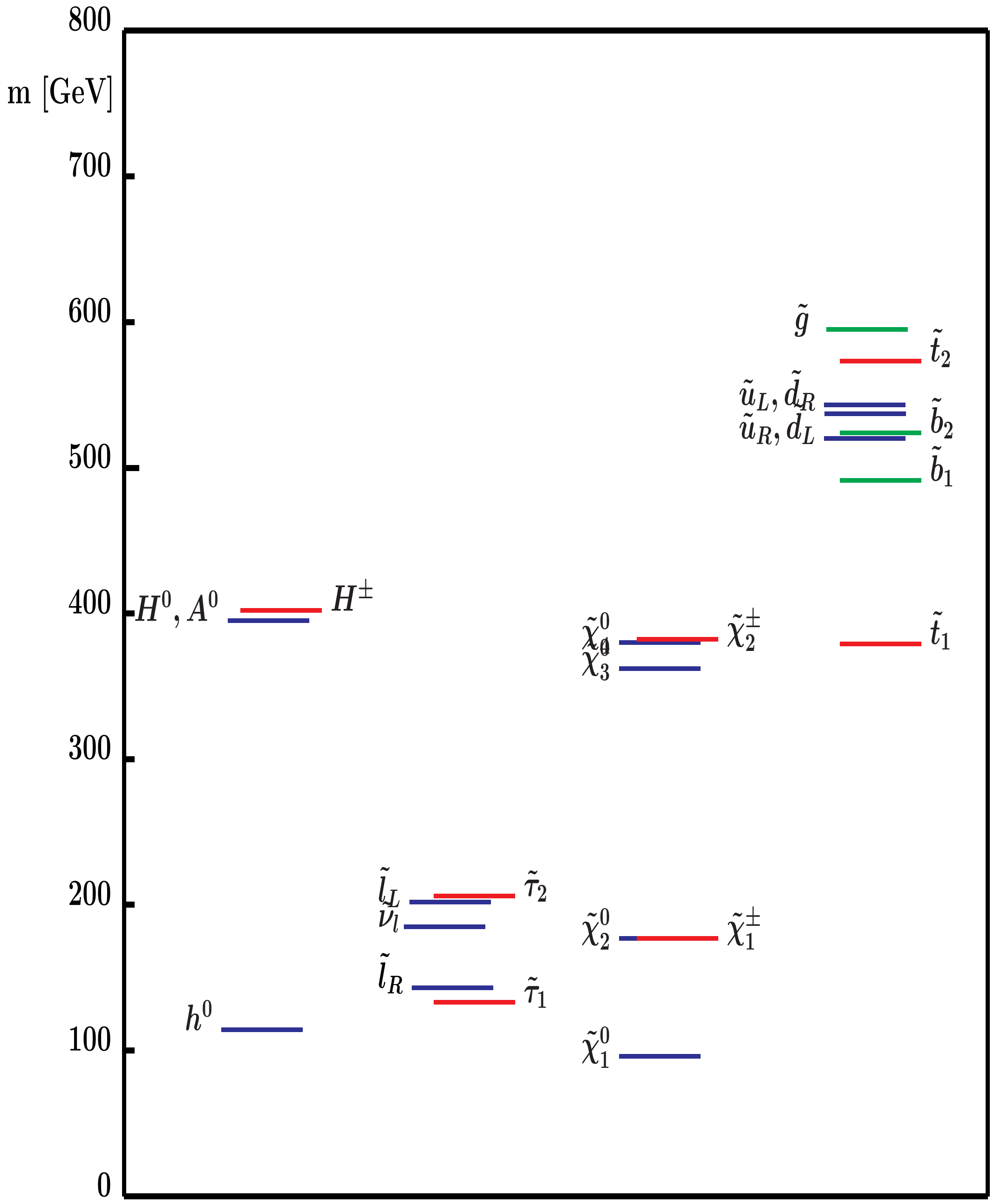
⇒ one parameter turns negative ⇒ Higgs mechanism for free

“Typical” CMSSM scenario

(SPS 1a benchmark scenario):

SPS home page:

`www.ippp.dur.ac.uk/~georg/sps`



Simple models: 2.) NUHM1: (Non-universal Higgs mass model)

Assumption: no unification of scalar fermion and scalar Higgs parameter at the GUT scale

⇒ effectively M_A or μ as free parameters at the EW scale

> ⇒ besides the CMSSM parameters
>
> M_A or μ

Further extension: NUHM2:

Assumption: no unification of the Higgs parameters at the GUT scale

⇒ effectively M_A and μ as free parameters at the EW scale

> ⇒ besides the CMSSM parameters
>
> M_A and μ

Dark Matter in the CMSSM parameter space:

schematic picture

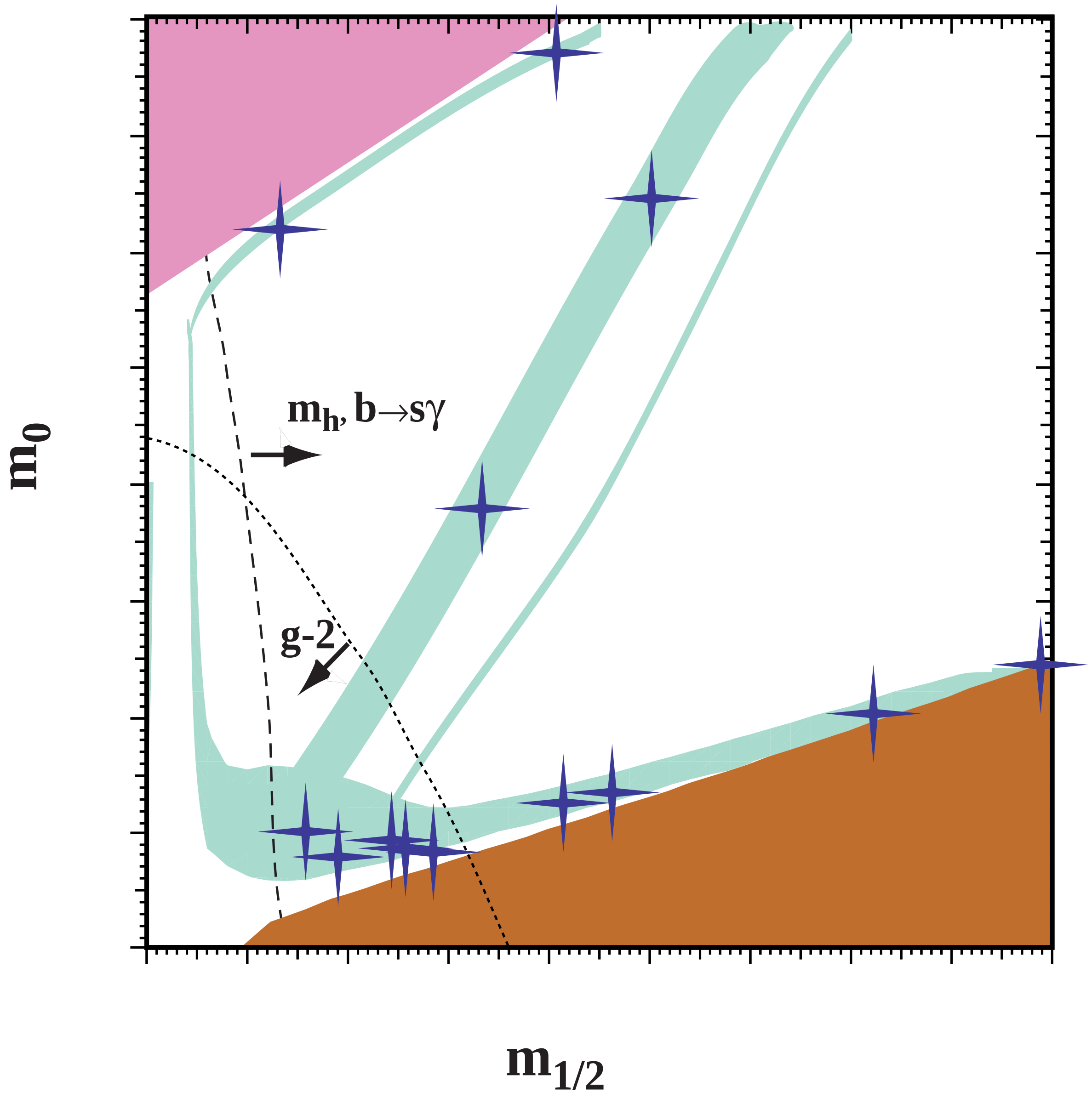
$(0.1 \leq \Omega_\chi h^2 \leq 0.3)$

[*K. Olive et al. '02*]

Despite its simplicity
CMSSM fulfils all
experimental bounds

Four mechanisms for
"good" $\langle \sigma\, v \rangle$:

– Bulk
– Stau coannihilation
– Higgs-pole annihilation
– Focus-Point



crosses: benchmark points

The main idea (II)

[Buchmüller, Cavanaugh, De Roeck, Ellis, Flächer, S.H., Isidori, Olive, Ronga, Weiglein '09]

Take the most simple MSSM version: CMSSM/NUHM1
$\rightarrow$ just three/four GUT scale parameters + $\tan\beta$

– combine all electroweak precision data as in the SM
– combine with B physics observables
– combine with CDM and $(g-2)_\mu$
– include SM parameters with their errors: m_t, . . .

MasterCode (`cern.ch/mastercode`)

– scan over the full CMSSM/NUHM1 parameter space

$\Rightarrow$ make predictions for the LHC, DM searches, . . .

Other groups: *[R. Ruiz de Austri et al.]* *[A. Casas et al.]* [. . .]

3. Some results/predictions

1. SUSY masses

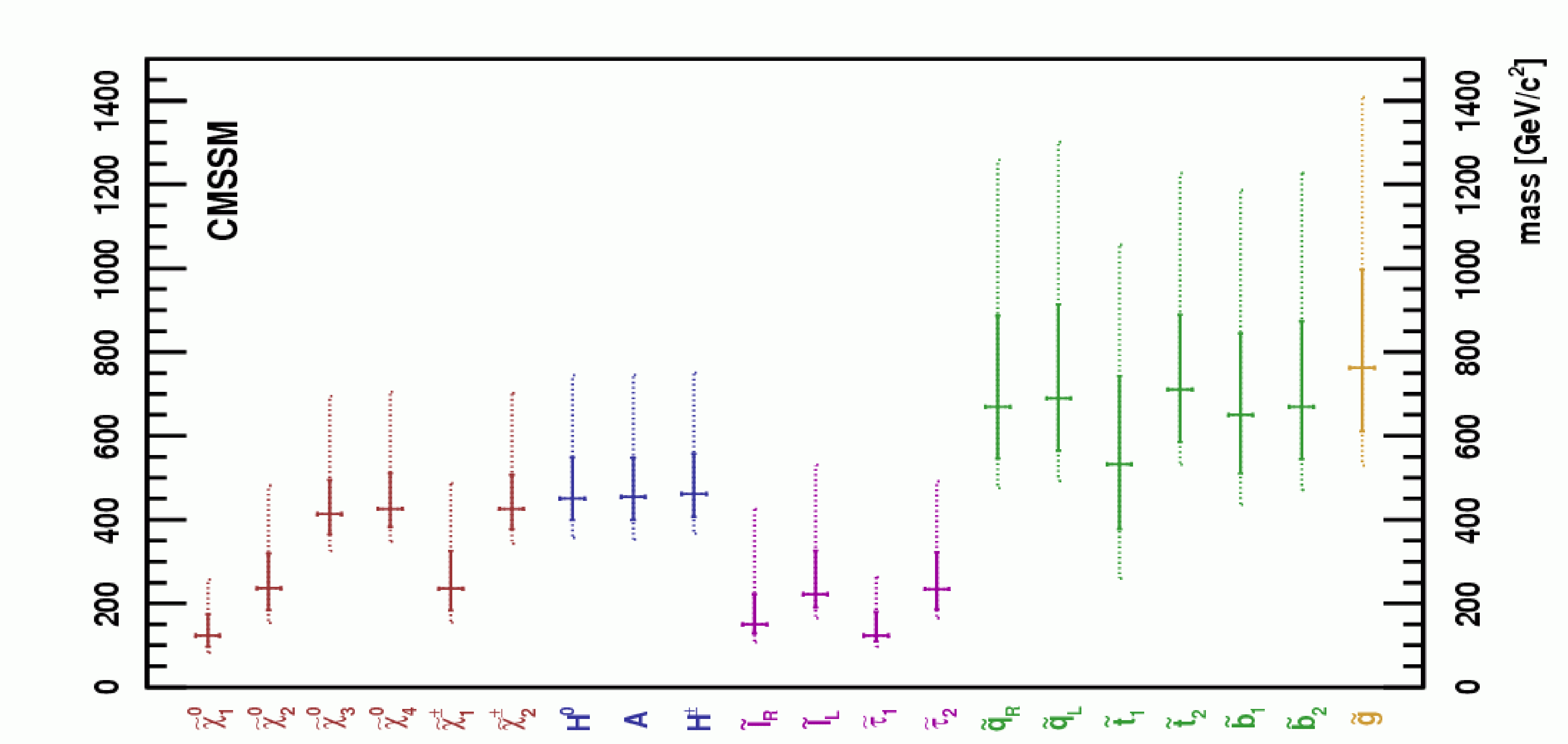
2. Direct detection cross sections

3. Dark Matter density (without measurement)

$\Rightarrow$ many more exist, but no time . . .

1.) Masses for best-fit points: CMSSM

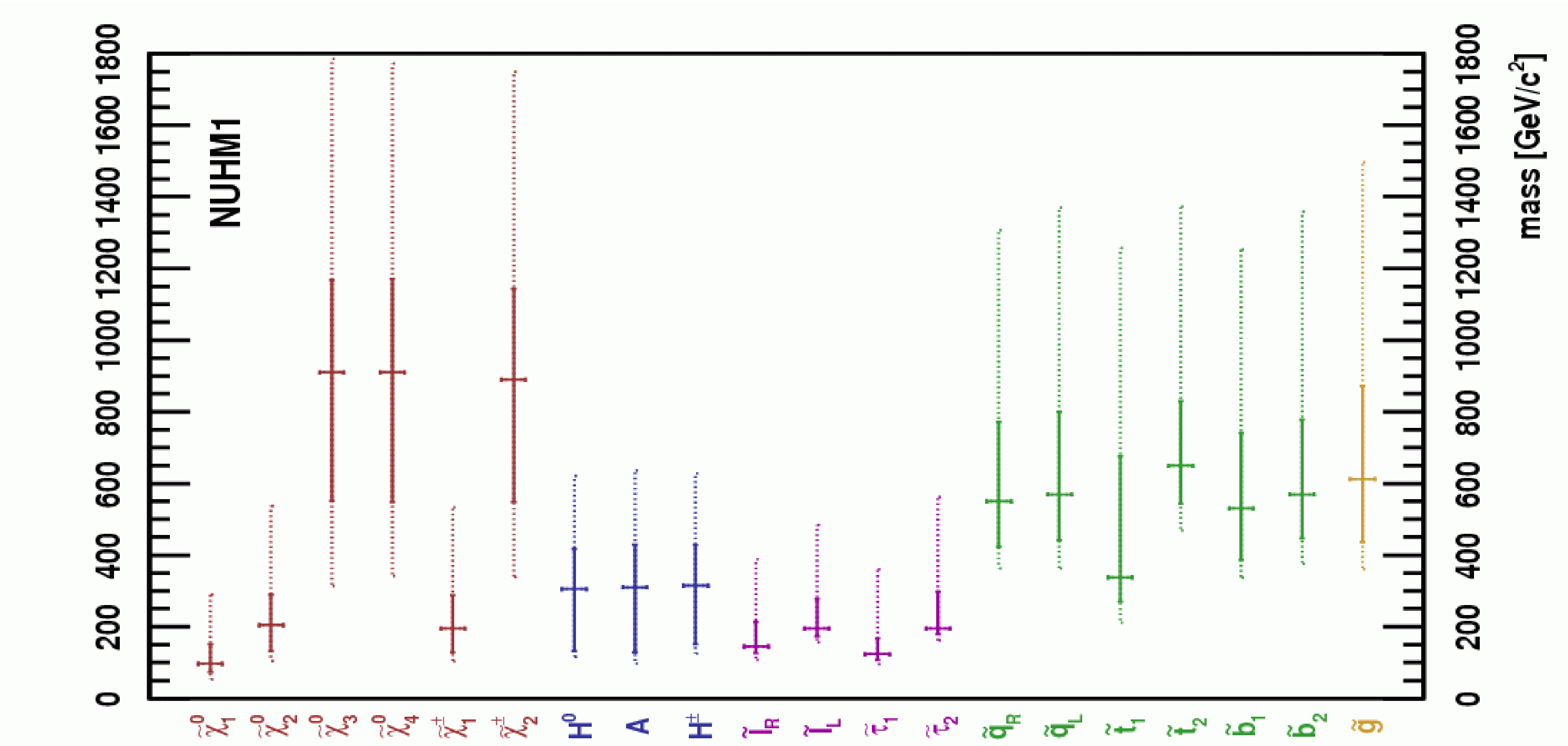
[2009]



⇒ largely accessible spectrum for LHC and ILC

1.) Masses for best-fit points: CMSSM

[2009]

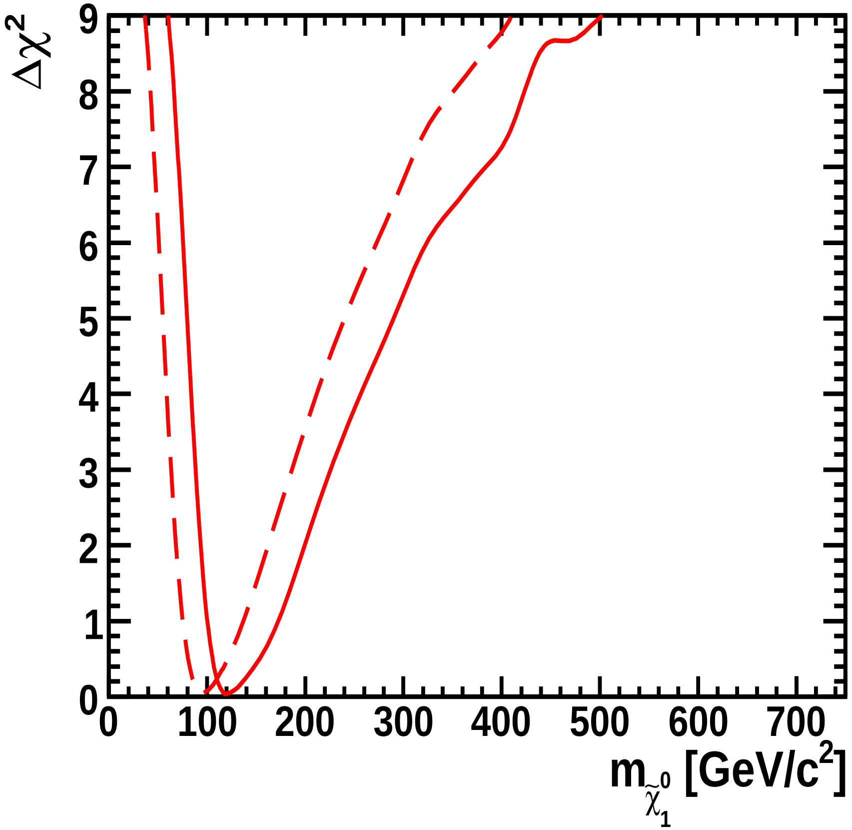


⇒ largely accessible spectrum for LHC and ILC

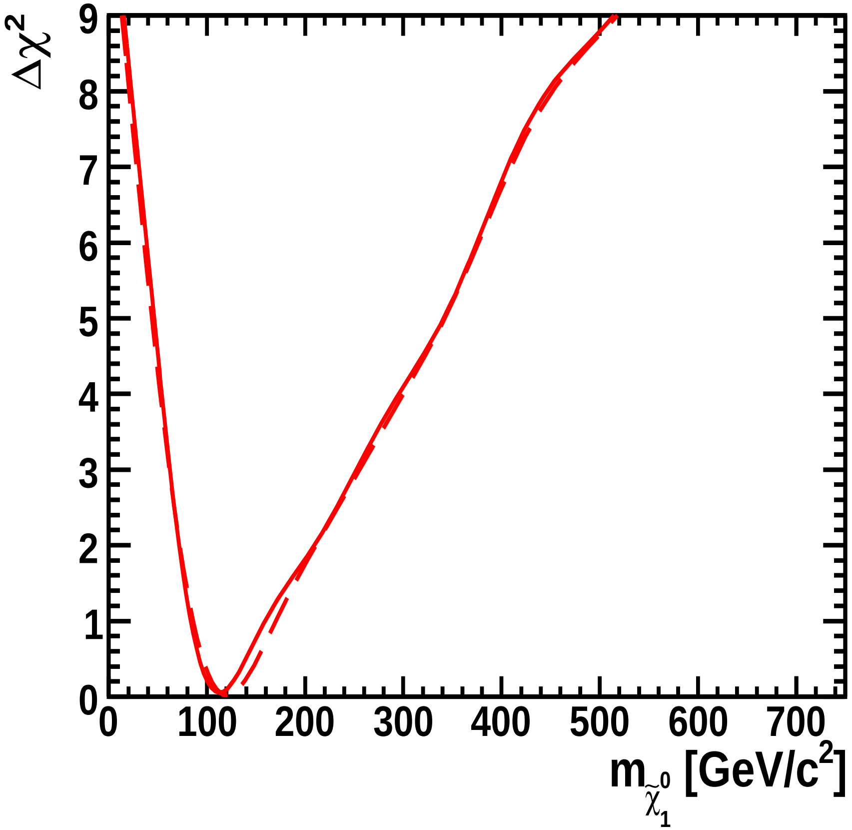
1.) Mass of the LSP

[2009]

CMSSM



NUHM1

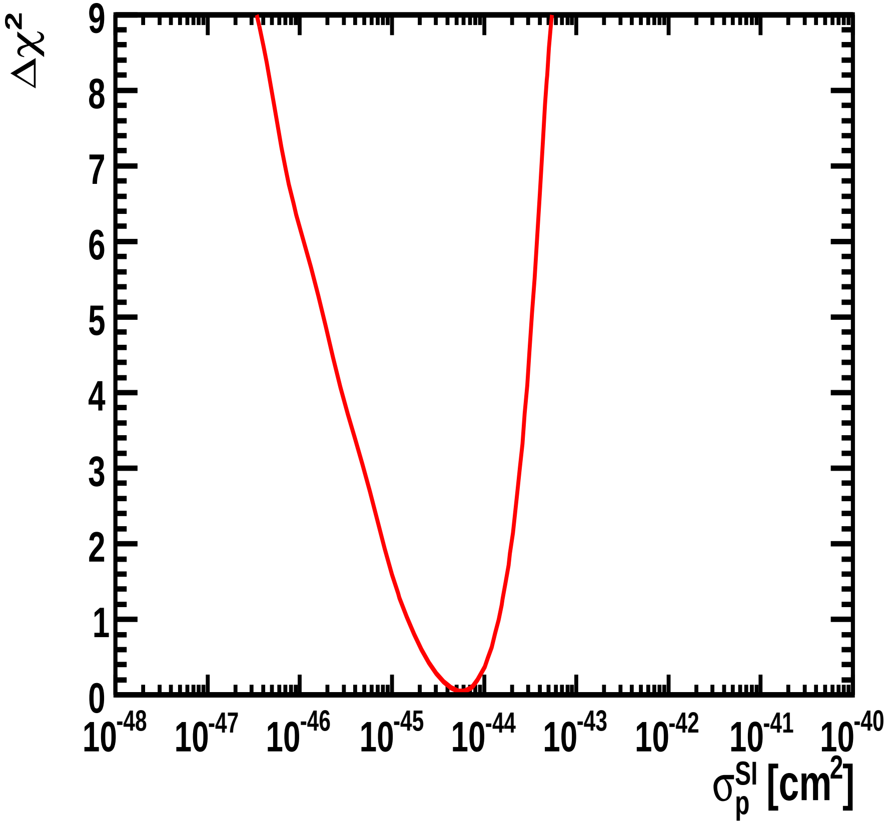


(dashed: no LEP bound on M_h)

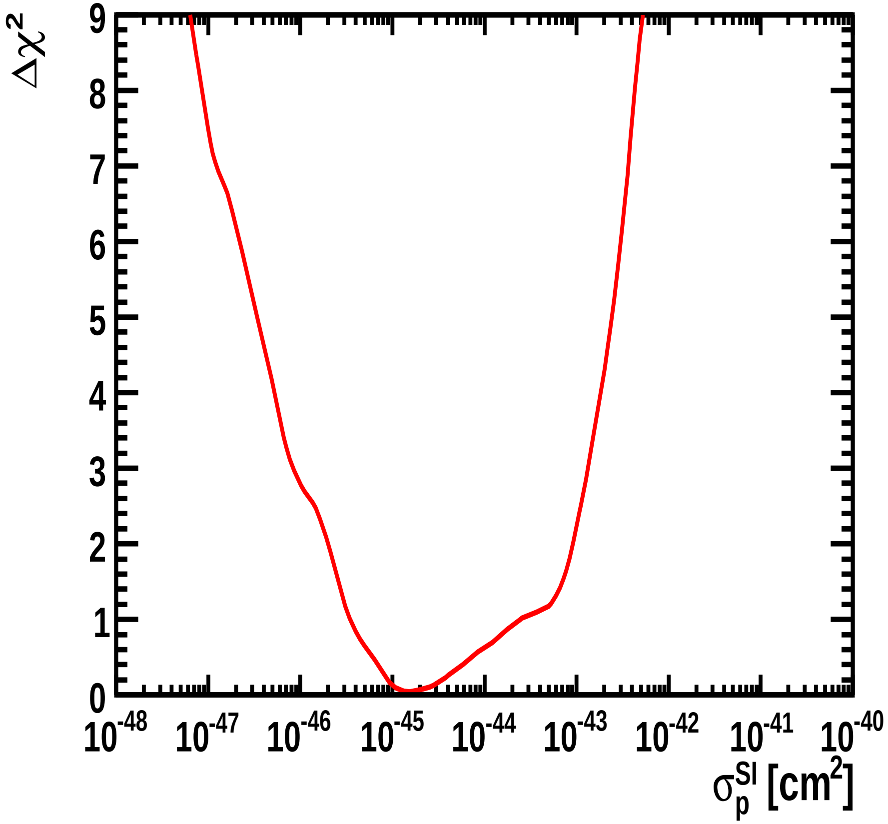
2.) Direct detection cross section

[2009]

CMSSM



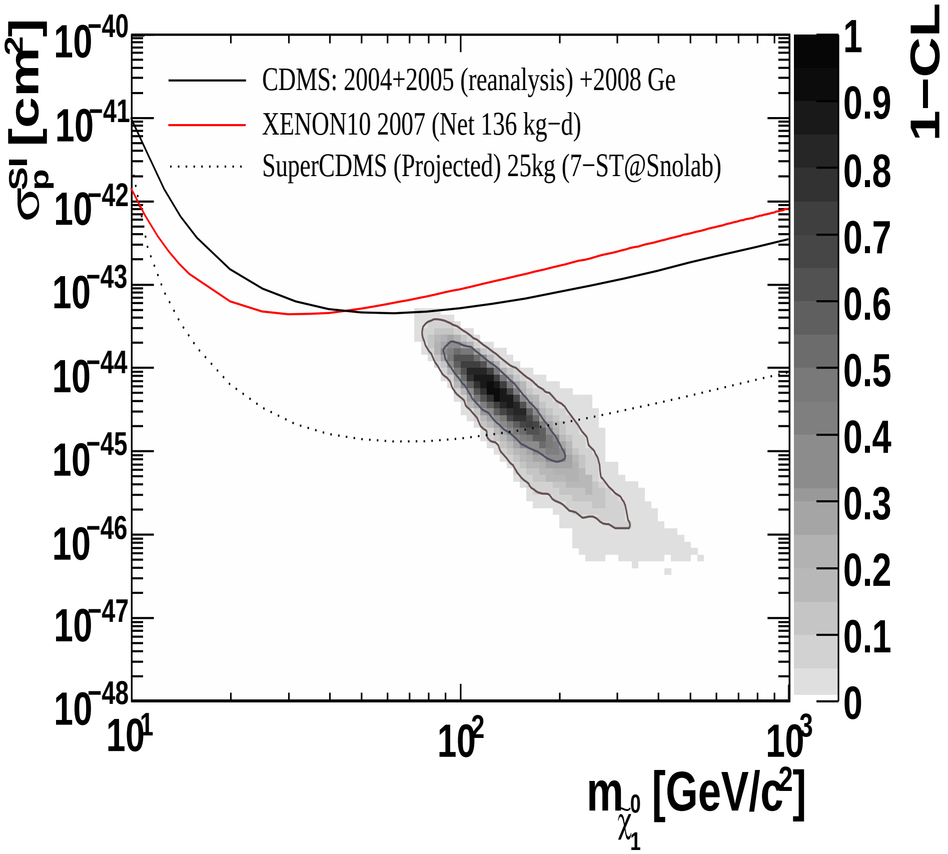
NUHM1



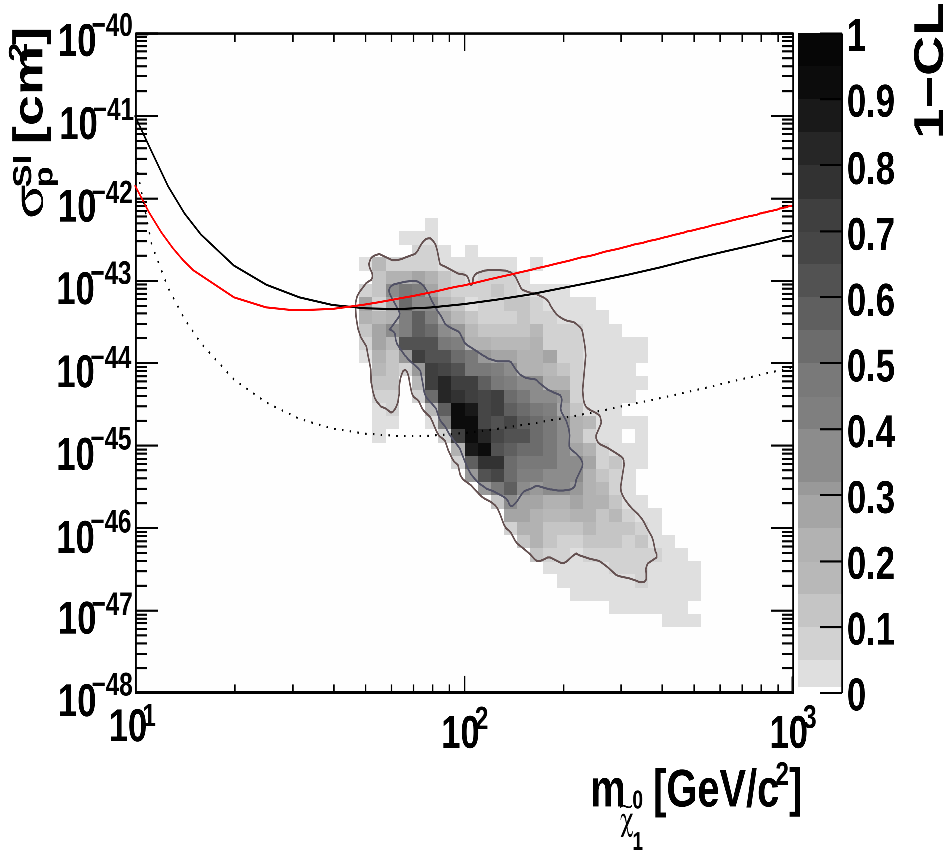
2.) LSP mass and cross section combined

[2009]

CMSSM



NUHM1

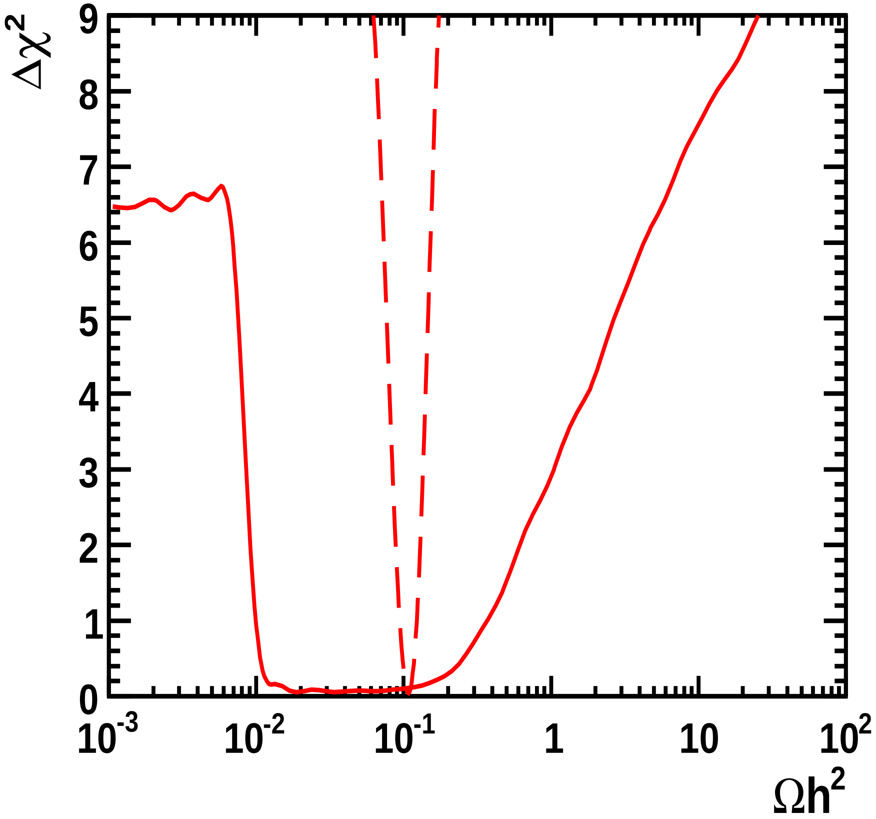


⇒ large parts covered by future experiments

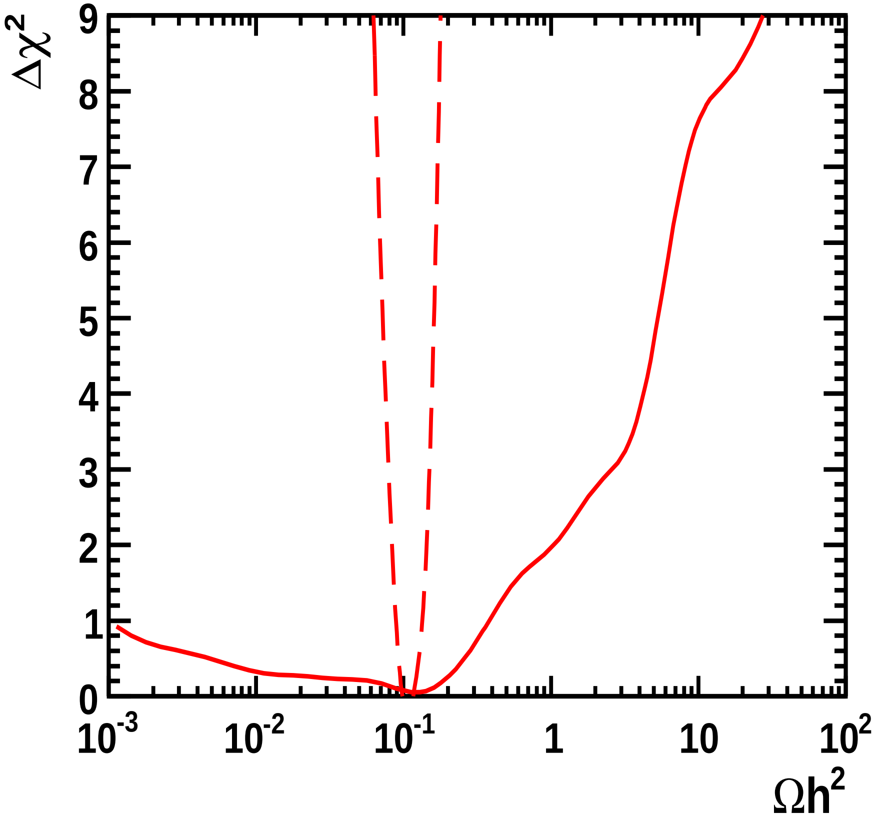
3.) Prediction of CDM density with/without measurement

[2009]

CMSSM



NUHM1



$\Rightarrow$ CDM density "natural", but strong constraint

4. Future plans

- More LSP-related LHC predictions
- Inclusion of early LHC data into the fits/predictions
- Inclusion of other DM related experiments into the fits/predictions
  $\longrightarrow$ MultiDark?!
- Extension of analyses to other MSSM-based models
- Higher-order corrections (to match anticipated experimental precisions) within the MSSM-based models
  $\longrightarrow$ Postdoc project?!
- Inclusion of new higher-order corrections into computer codes
  $\longrightarrow$ Postdoc project?!
- Calculations for models beyond the MSSM
  $\longrightarrow$ Postdoc project?!

Back-up

The models (III):

VCMSSM: (Very Constrained MSSM)

> $\Rightarrow$ In addition to CMSSM: assume relation between A_0 and m_0:
> $$A_0/m_0 = 0,\ 3/4,\ 3-\sqrt{3},\ 2$$

Additional constraint also fixes $\tan\beta$

Free parameters: $m_{1/2}$, A_0/m_0

m_0 and $\tan\beta$ fixed via CDM constraint

Lightest SUSY particle (LSP) is the lightest neutralino

GDM (mSUGRA): (Gravitino DM in mSUGRA)

> $\Rightarrow$ In addition to CMSSM: assume relation between A_0 and m_0:
> $$A_0/m_0 = 0,\ 3/4,\ 3-\sqrt{3},\ 2$$

mSUGRA: $m_{\text{gravitino}} = m_0 \Rightarrow$ gravitino can be the LSP

Free parameters: $m_{1/2}$, A_0/m_0

Lightest SUSY particle (LSP) is the gravitino

The models (III):

VCMSSM: (Very Constrained MSSM)

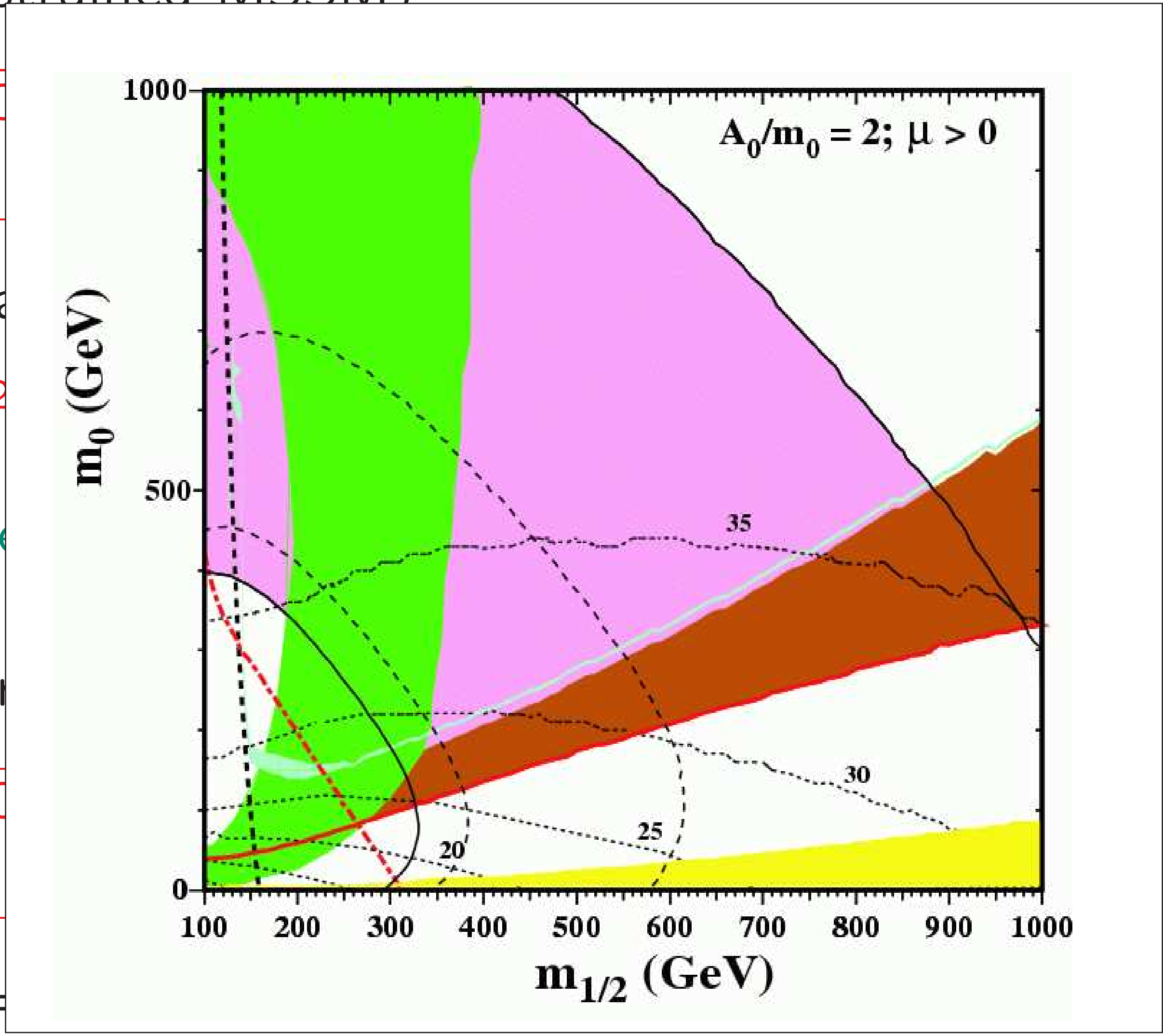
⇒ In addition to C

Additional constraint a

Free parameters: $m_{1/2}$

m_0 and $\tan\beta$ fixed via

Lightest SUSY particle



GDM (mSUGRA): (Gr

⇒ In addition to C

mSUGRA: $m_{\text{gravitino}}$ =

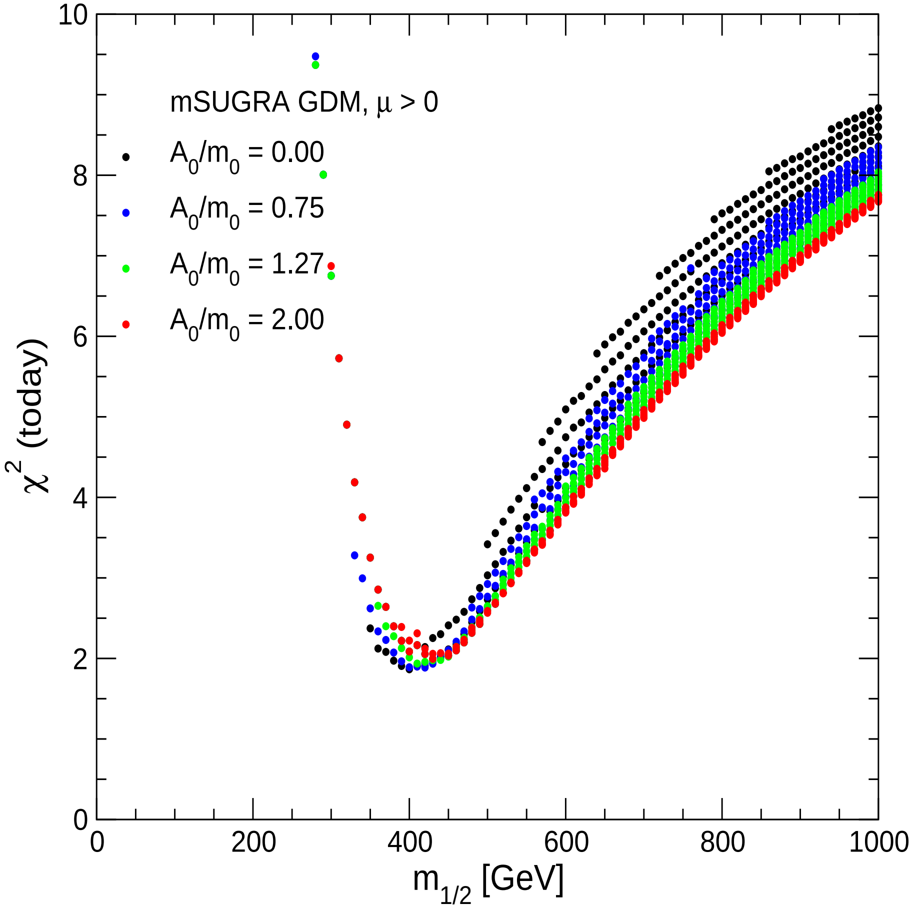
Free parameters: $m_{1/2}$, A_0/m_0

Lightest SUSY particle (LSP) is the gravitino

Results (IV): GDM (mSUGRA)

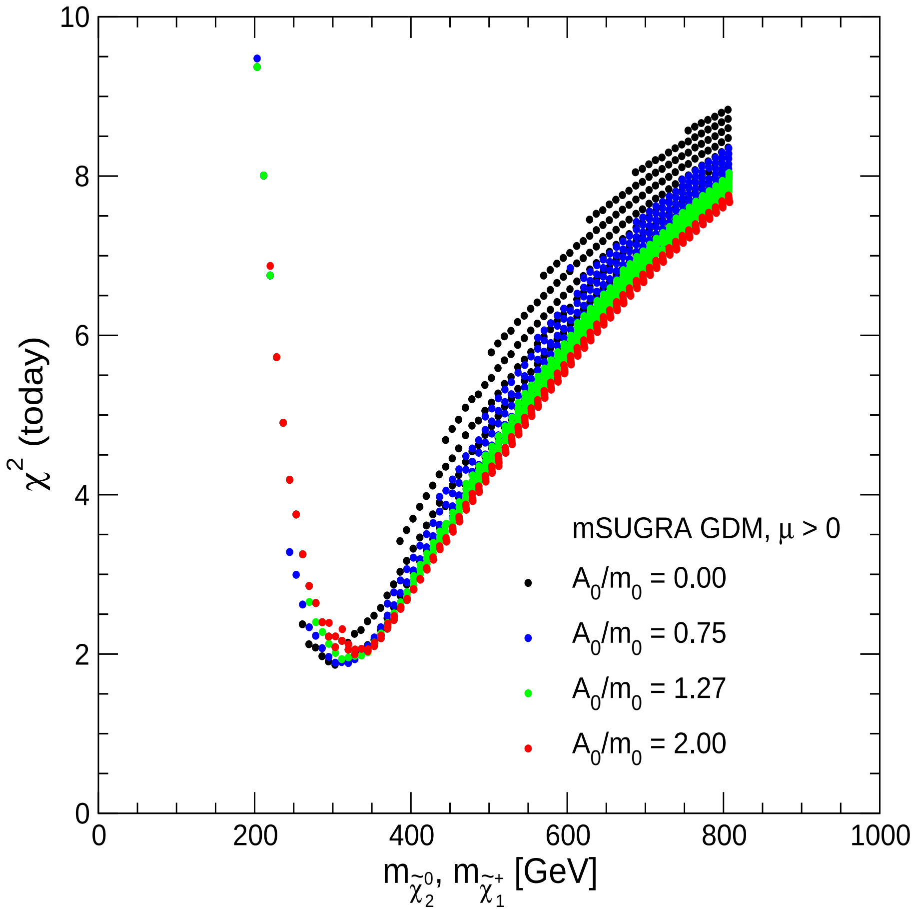
[*J. Ellis, S.H., K. Olive, G. Weiglein '06*]

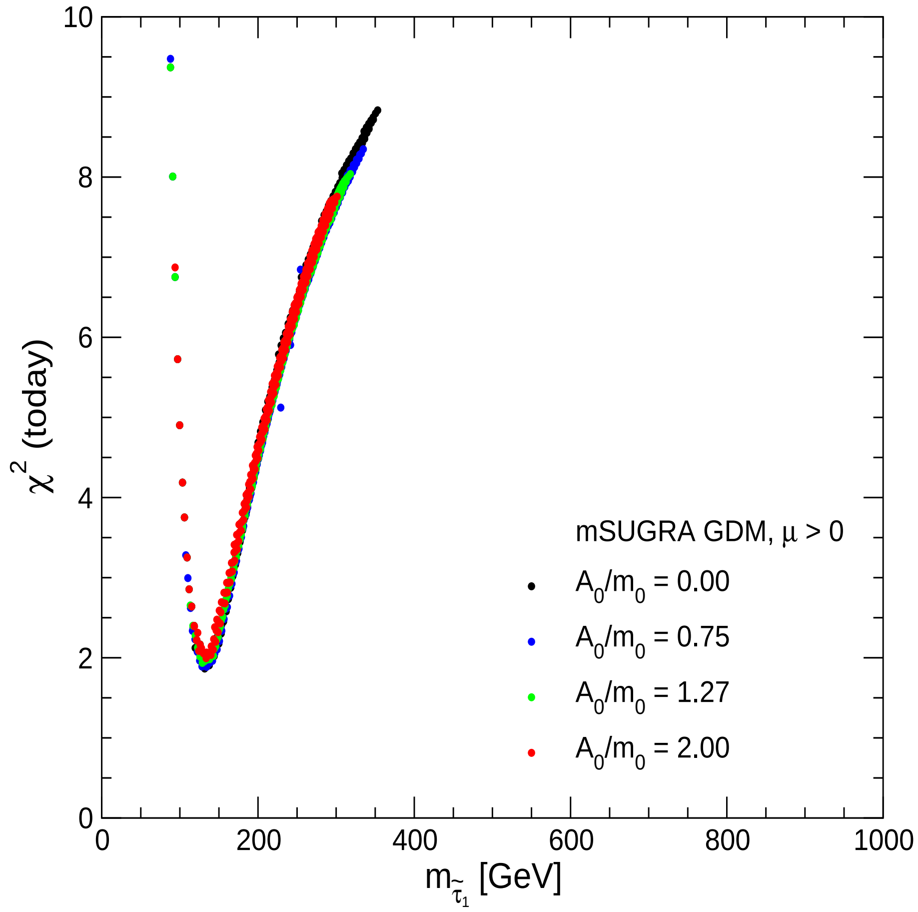
GDM (mSUGRA): scan over full parameter space



⇒ all A_0/m_0 values similarly good

GDM (mSUGRA): scan over full parameter space



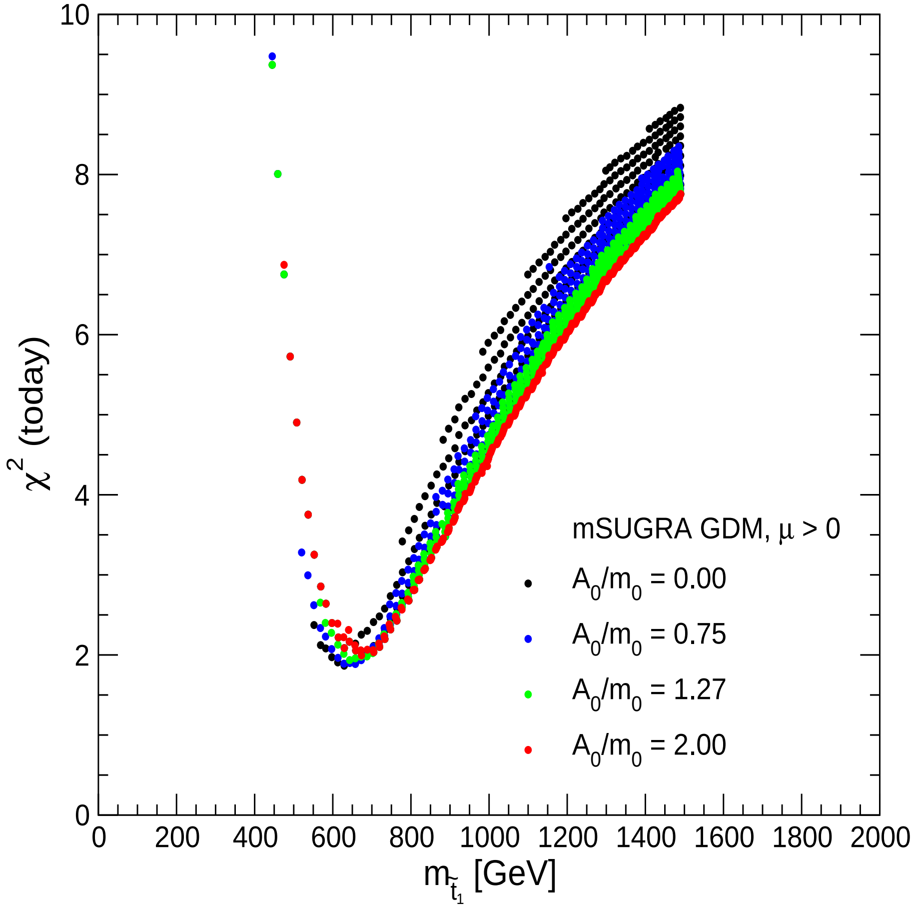


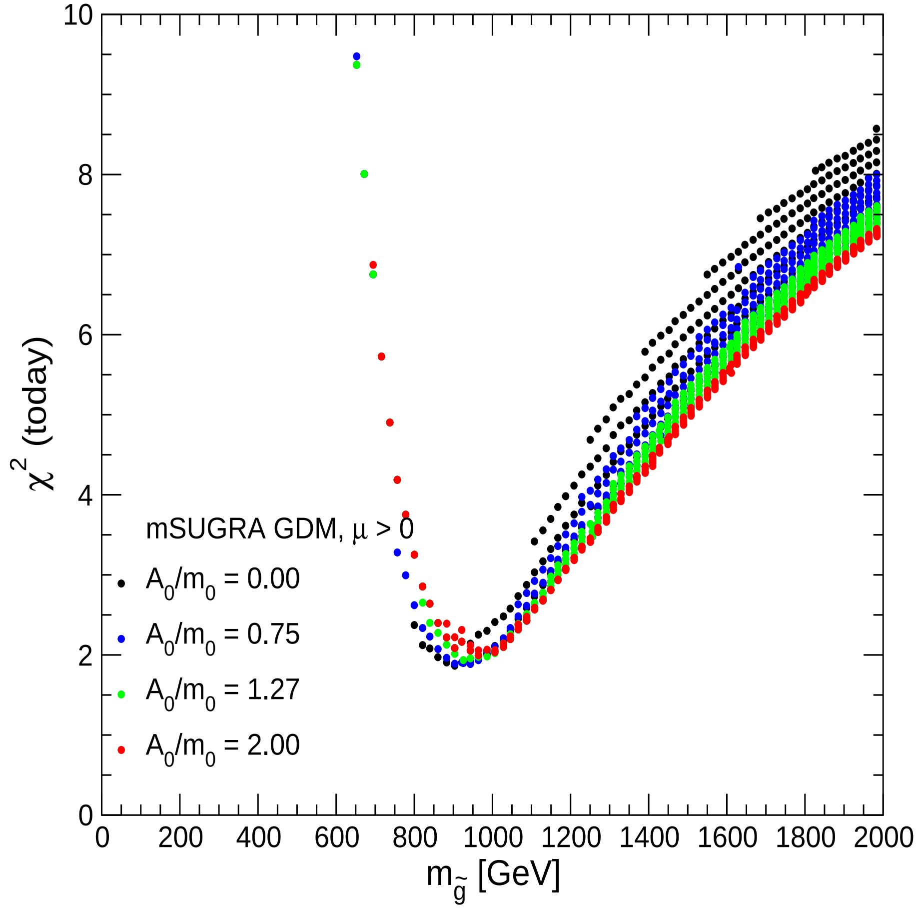
⇒ all A_0/m_0 values similarly good

⇒ sleptons, charginos, neutralinos in reach for ILC(1000) and LHC

⇒ even chances for the Tevatron

GDM (mSUGRA): scan over full parameter space





⇒ all A_0/m_0 values similarly good

⇒ stops and gluinos only in reach for the LHC