SuperRelic: the relics of SuperIso

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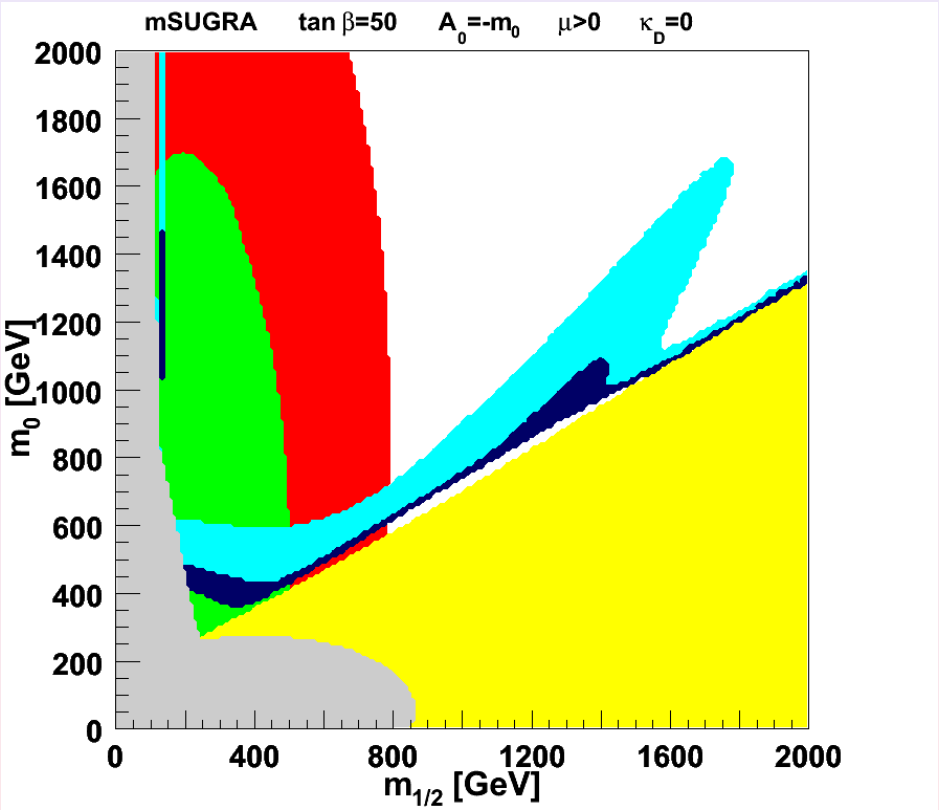
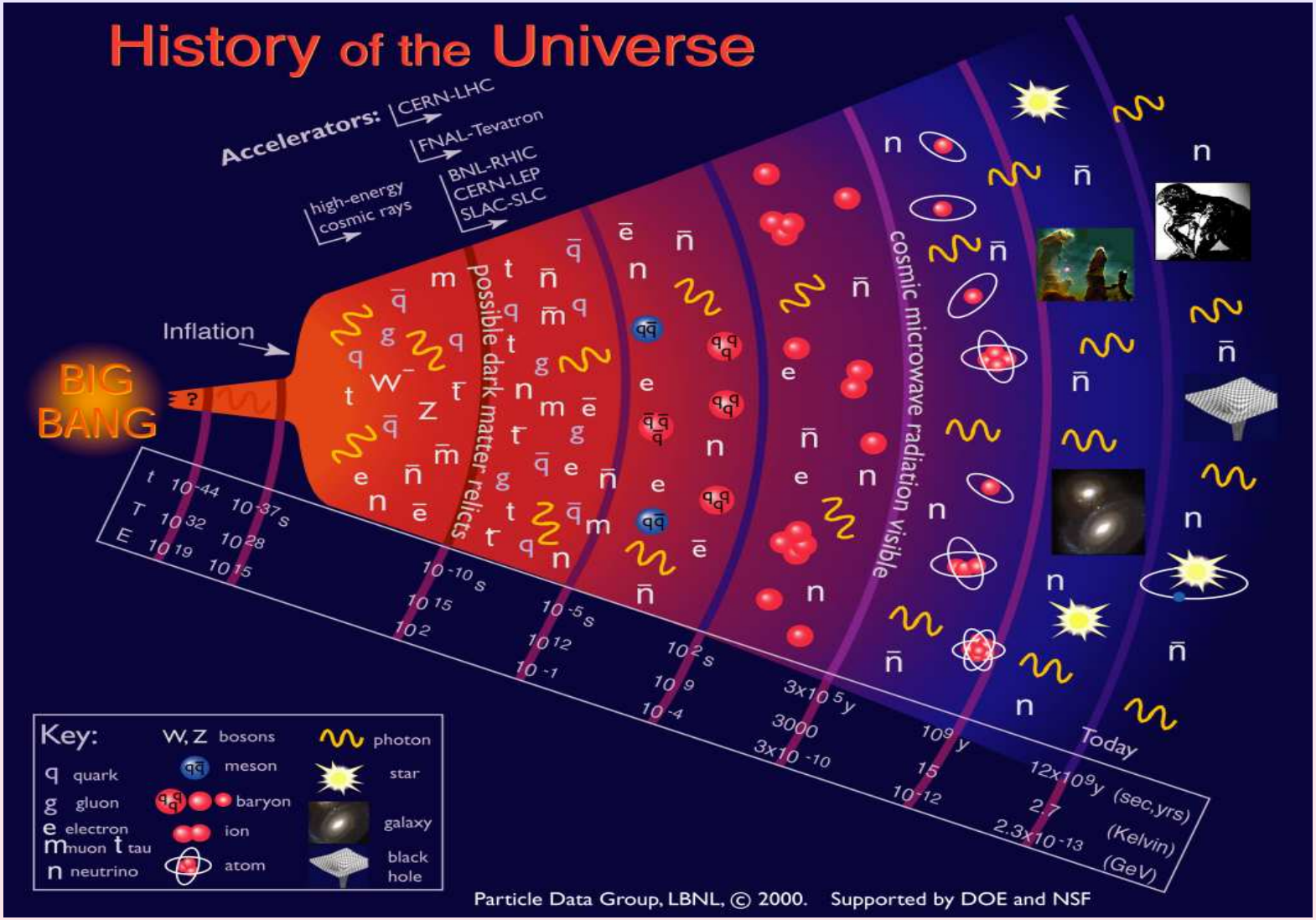
Outline

Relic density

The recent observations of the WMAP satellite, combined with other cosmological data impose the dark matter density range at 95% C.L.:

$$0.088 < \Omega_{DM} h^2 < 0.12$$




History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
Today
Key:
W, Z bosons
photon
q quark
meson
star
g gluon
baryon
e electron
ion
galaxy
m muon t tau
atom
black hole
n neutrino
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

Relic density

In the Standard Model of Cosmology:

- at and before nucleosynthesis time, the expansion is dominated by radiation

$$H^2 = 8\pi G/3 \times \rho_{\text{rad}}$$

- the evolution of the number density of supersymmetric particles follows the equation

$$\frac{dn}{dt} = -3Hn - \langle \sigma_{\text{eff}} v \rangle (n^2 - n_{\text{eq}}^2)$$

Relic density

Effective invariant annihilation rate W_{eff}:

(ij: SUSY coannihilating particles / kl: SM outgoing particles)

$$\frac{dW_{\text{eff}}}{d\cos\theta} = \sum_{ijkl} \frac{p_{ij} p_{kl}}{32\pi p_{\text{eff}} S_{kl} \sqrt{s}} \sum_{\text{helicities}} \left| \sum_{\text{diagrams}} \mathcal{M}(ij \to kl) \right|^2$$

Thermal average of effective cross section:

$$\langle \sigma_{\text{eff}} v \rangle = \frac{\int_0^\infty dp_{\text{eff}} p_{\text{eff}}^2 W_{\text{eff}} K_1\left(\frac{\sqrt{s}}{T}\right)}{m_1^4 T \left[\sum_i \frac{g_i}{g_1} \frac{m_i^2}{m_1^2} K_2\left(\frac{m_i}{T}\right)\right]^2}$$

($K_{1,2}$: modified Bessel functions)

Relic density

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- solving this equation leads to the relic density of SUSY particles in the present Universe

Problem: we have no good constraints on the pre-BBN era!

$\Rightarrow$ the expansion rate can be different from what expected in standard cosmology...

Relic density

For example, the expansion rate modification can be parametrized by adding a new density ρ_D: ($T_0 \sim$ BBN temperature)

$$H^2 = 8\pi G/3 \times (\rho_{\text{rad}} + \rho_D) \text{ with } \rho_D(T) = \rho_D(T_0)(T/T_0)^{n_D}$$

- $n_D = 4$: radiation-like behavior
- $n_D = 6$: behavior of a scalar field dominated by its kinetic term
- $n_D > 6$: extra-dimension effects

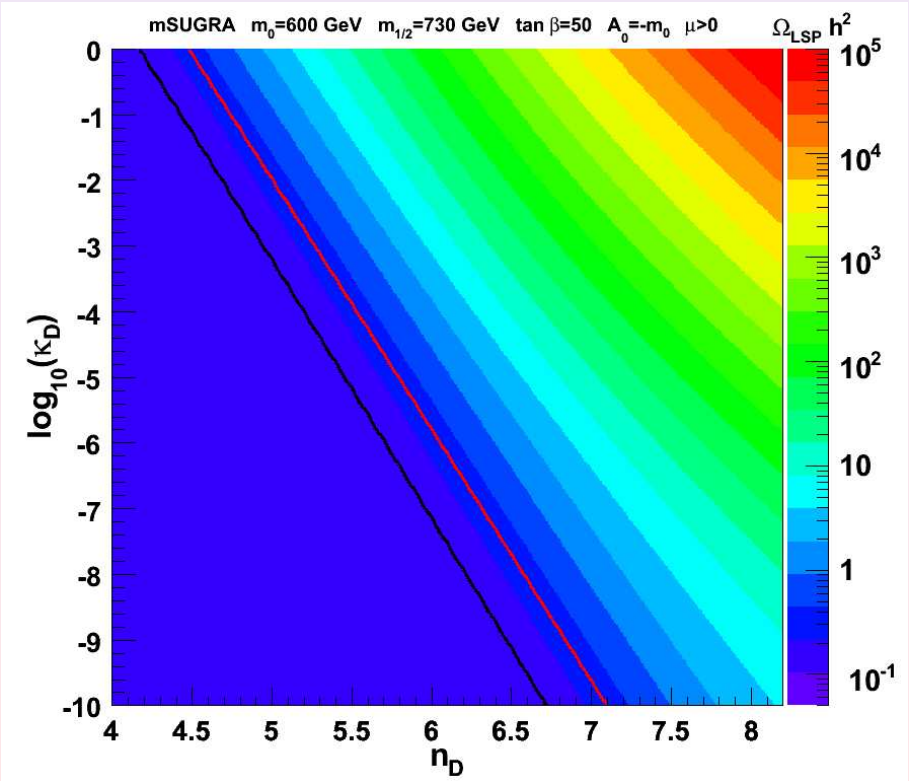
We introduce $\kappa_D = \rho_D(T_0)/\rho_{\text{rad}}(T_0)$

The modified expansion is in agreement with the observations provided $n_D > 4$ and $\kappa_D < 1$

Such a modification can drastically change the calculated relic density!

Relic density

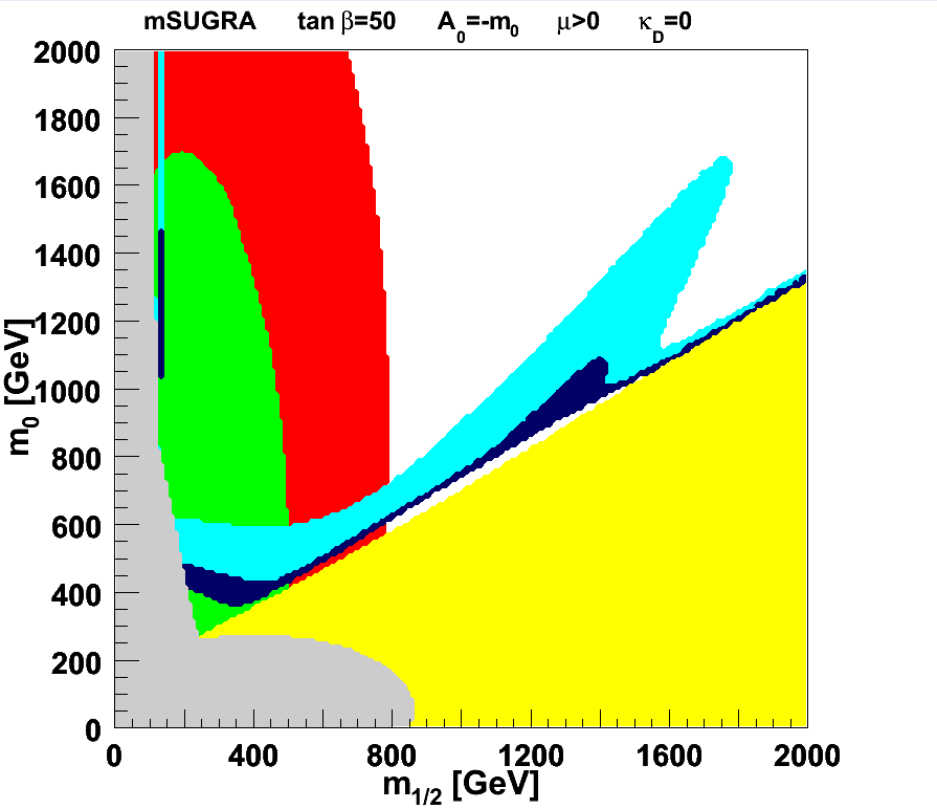
For a mSUGRA test-point with a relic density of $\Omega_{LSP}h^2 = 0.105$ (favored by WMAP) in the usual cosmological model, in the expansion rate modified scenario the computed relic density is changed:



Arbey & Mahmoudi, Phys. Lett. B669 (2008)

Relic density

Displacement of the WMAP limits in mSUGRA



Large even for a small expansion rate modification!

Arbey & Mahmoudi, Phys. Lett. B669 (2008)

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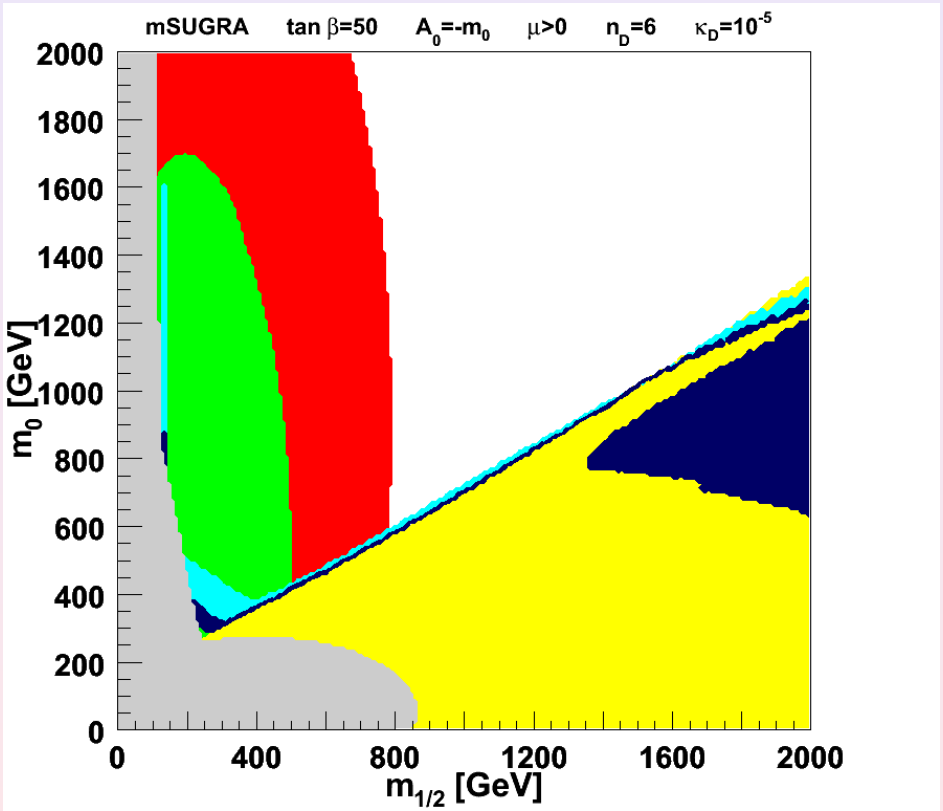

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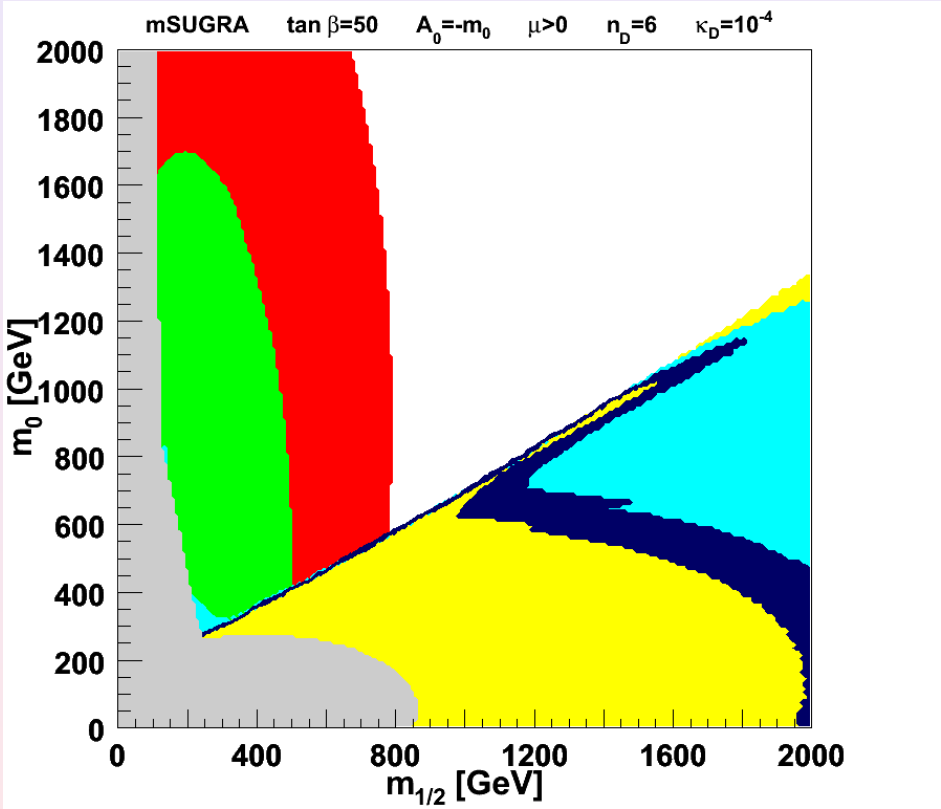

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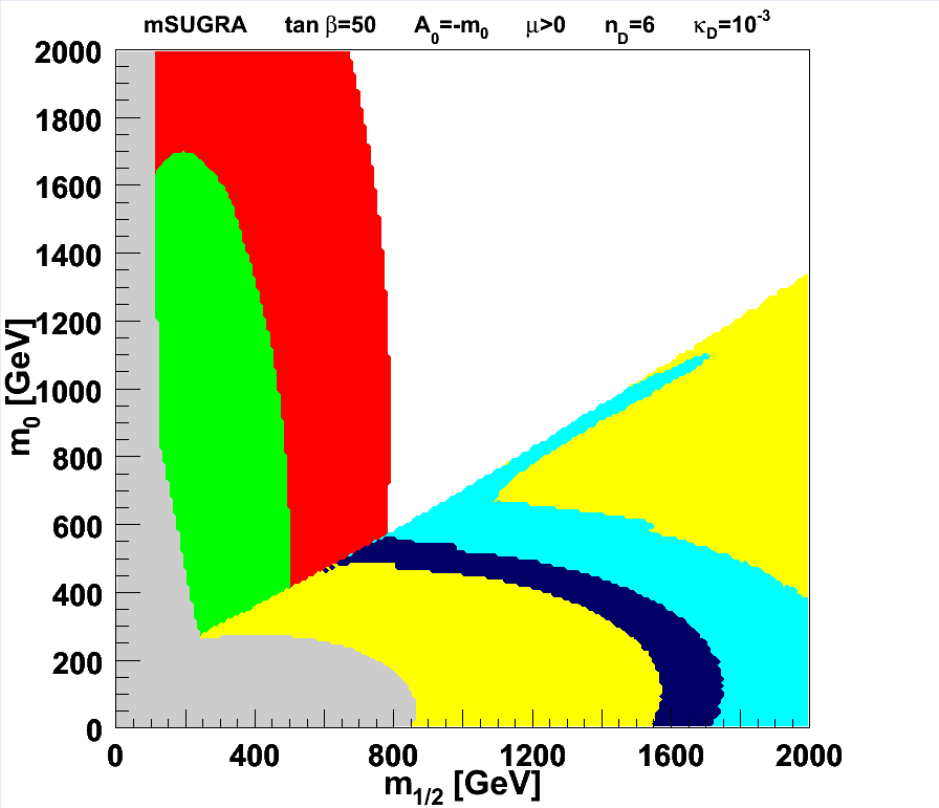

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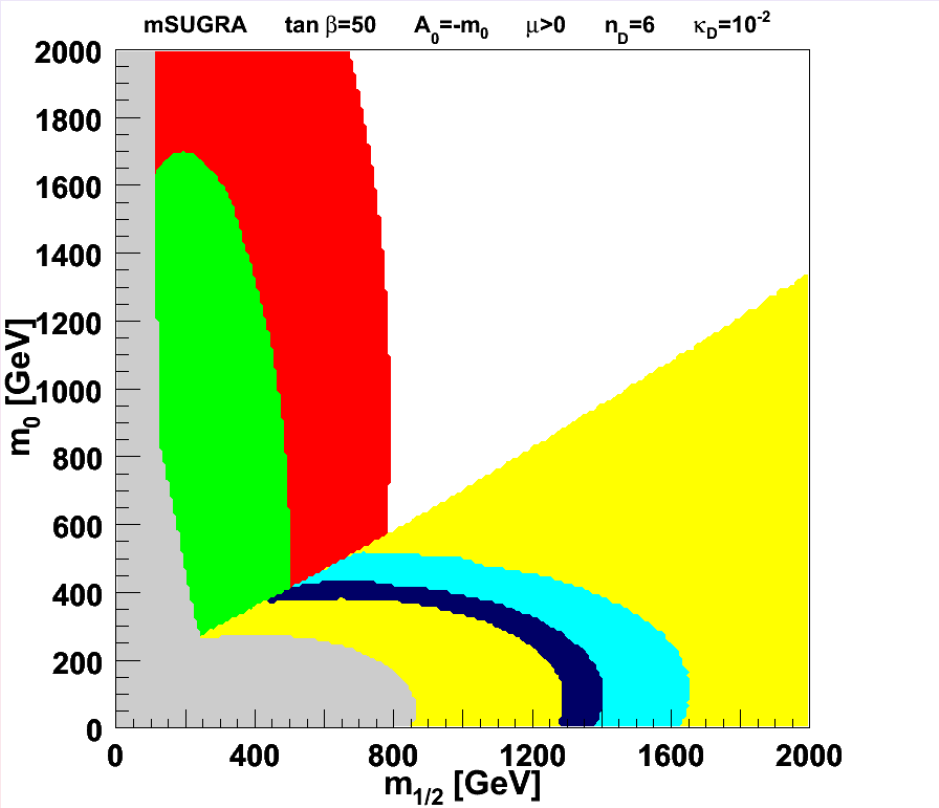

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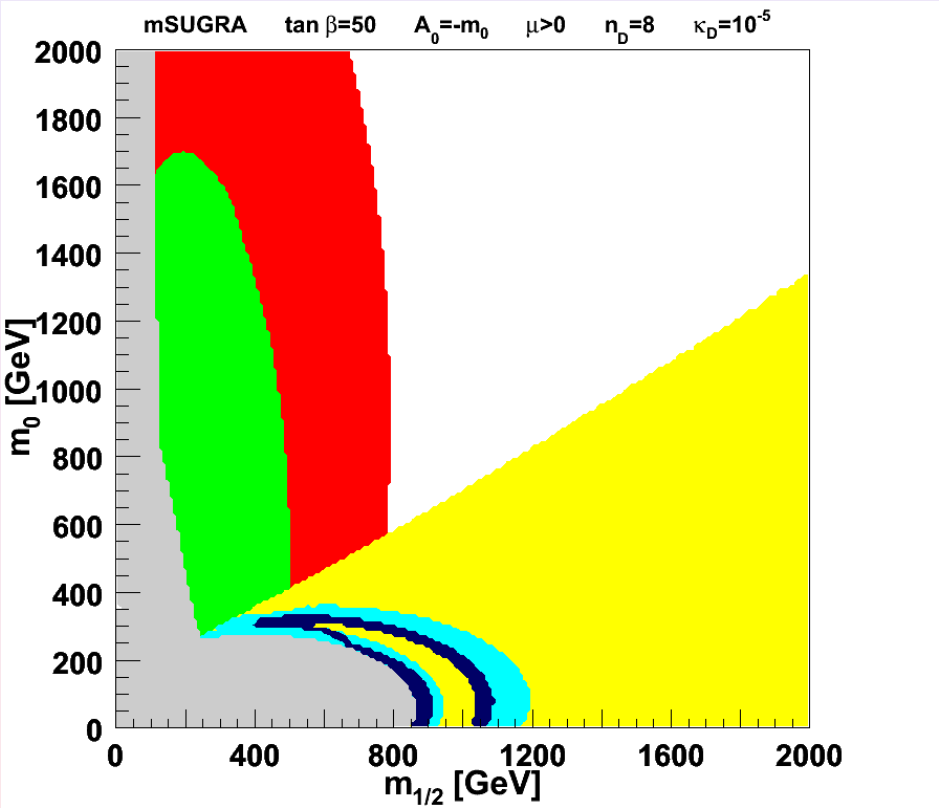

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Relic density

No public relic density calculator currently provides alternative cosmological models!

$\Longrightarrow$ SuperRelic...

SuperRelic

SuperRelic = SuperIso + relic density calculation

(for a presentation of SuperIso, see Nazila's tomorrow talk!)

Motivations

- Alternative relic density calculator
- Easily usable to constrain SUSY
- Flexible cosmological model implementation
- Flexible particle physics model implementation
- Automatized
- Fast and/or precise
- Modular

SuperRelic

Structure of the code

- Generation of a SLHA file with Isajet of Softsusy
- Initialization of the variables using the SLHA file
- Generation of additional Higgs sector variables with FeynHiggs
- Calculation of W_{eff} with Fortran functions
- Calculation of $\langle \sigma_{\text{eff}} v \rangle$ with C functions
- Solving of the Boltzmann equation with C functions
- Computation of the other SuperIso observables

SuperRelic

Structure of the code

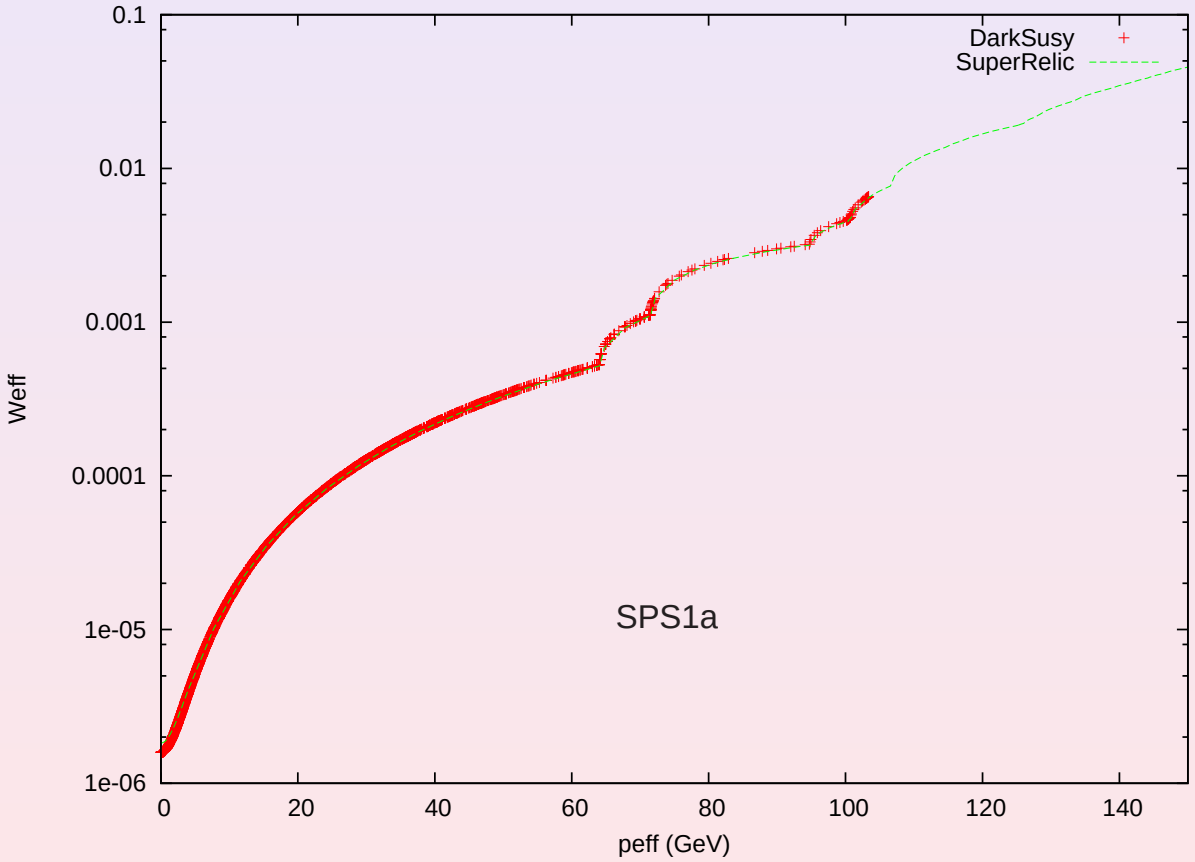
- Initial calculation of the amplitudes with Mathematica / FeynArts / FormCalc / FORM
- Interfacing of the FormCalc-generated Fortran code with the SuperIso C-functions
- Use of LoopTools (if needed) to compute loop amplitudes
- Possibility to use of FeynArts model file generators (FeynRules, LanHEP, ...)
- Use of (precompiled) static libraries for the amplitude calculation

SuperRelic

Status

- Calculation of amplitudes within MSSM with MFV at tree level fully implemented
- Relic density within the cosmological standard model fully implemented
- Good agreement with Micromegas and DarkSusy
- Speed optimization in progress
- Improvement of the compatibility with various architectures and compilers
- Will soon be made available as a public beta release

SuperRelic



Good agreement with DarkSusy!

SuperRelic

Future developments

- Extension to the NMSSM
- Implementation of alternative cosmological models:
  - Presence of a primordial dark density
  - Presence of reheating / entropy modification
  - Non-thermal production of relic particles
  - ...
- Loop computation of amplitudes (structure ready, amplitudes still pending...)
- Extension to NMFV
- ...

Conclusion

SuperRelic

Extension of SuperIso towards cosmological relics

Will include

- Alternative cosmological models...
- As well as alternative particle physics models...
- If possible at loop level...

Stay tuned for the first release of SuperRelic!!!