SuperIso Relic new extensions for direct and indirect detection

Glenn ROBBINS
Université de Lyon, Centre de Recherche Astrophysique de Lyon

In collaboration with Alexandre Arbey and Nazila Mahmoudi

DSU18, Annecy-Le-Vieux
25th June 2018

SuperIso Relic

SuperIso (flavour physics calculation) + **Relic** density calculation

Mahmoudi, Comp. Phys. Comm. 178 (2008) 745 **Arbey & Mahmoudi, Comp. Phys. Comm. 181 (2010)**

Concept of the code

- Automatized computation of flavour observables and relic density in SUSY
- Flexible particle physics model implementation (MSSM, NMSSM, ...)
- Cosmological model implementation (dark energy, dark entropy, ...)
- Publicly available on **http://superiso.in2p3.fr/relic**

New extensions in SuperIso Relic

To complete the panel of constraints in SuperIso Relic, we implemented:

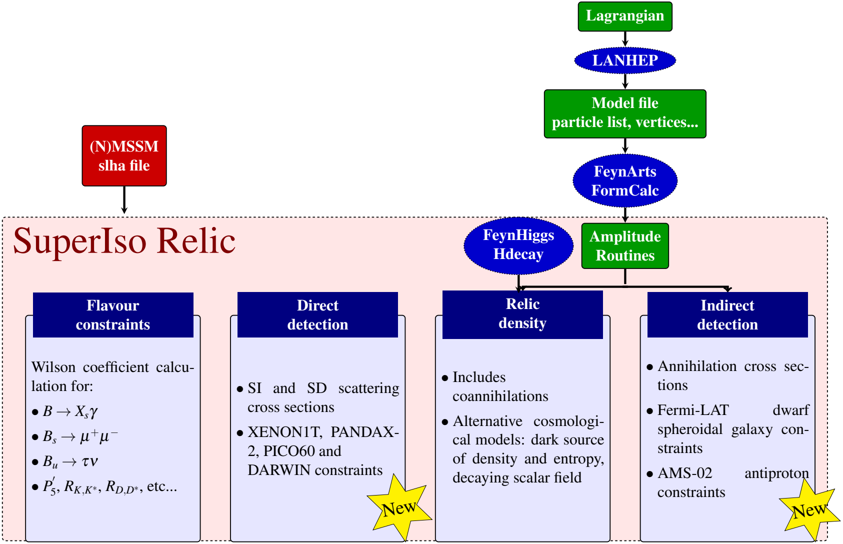
Indirect detection:

- Annihilation cross-section calculation in the (N)MSSM
- Fermi-LAT dwarf spheroidal galaxies constraints
- AMS-02 antiproton constraints, using the propagation code by Mathieu Boudaud & Pierre Salati

Direct detection:

- Spin-Dependent (SD) and spin-independent (SI) cross-section calculation in the (N)MSSM
- Constraints from XENON1T, PANDAX-2, PICO60 and prospects from DARWIN

New extensions in SuperIso Relic



New extensions in SuperIso Relic

Several public codes already display part of those features (micrOMEGAs, DarkSUSY, MadDM...) but are most often used without taking into account astrophysical and nuclear uncertainties.

As a follow-up to our work on the impact of astrophysical uncertainties in the pMSSM (Arbey et al., JHEP 1711 (2017)), we decided to **encourage the user to consider those uncertainties**.

For every calculation of experimental constraint, one will be able to choose between a **"conservative"**, **"standard"** and **"stringent"** mode, related to the underlying uncertainties.

Scattering cross sections and experimental likelihoods

- Our neutralino-nucleon scattering amplitude calculation in the MSSM is based on **Drees and Nojiri (1993)**
- QCD and SUSY-QCD corrections were also added, using **Djouadi and Drees (2000)**
- Comparison with micrOMEGAs showed small relative differences
- Likelihoods for XENON1T, PICO60, PANDAX-2 and DARWIN are computed using efficiency tables from DarkBit (2017)

Uncertainties from nucleon SI form factors

SI scattering amplitudes depend on nucleon form factors $f_i^{p,n}$ probing the quark content of protons and neutrons

$$A^{SI}_{\chi\, p,n \to \chi\, p,n} = \sum_{i=u,d,s} A^{SI}_{\chi\, i \to \chi\, i} \times f_i^{p,n}$$

Those form factors can be calculated from three quantities involving the light and strange quark content of nucleons :

$$\sigma_l \equiv \langle N|\bar{u}u + \bar{d}d|N\rangle \ , \quad \sigma_s \equiv \langle N|\bar{s}s|N\rangle \ , \quad z \equiv \frac{\langle N|\bar{u}u|N\rangle - \langle N|\bar{s}s|N\rangle}{\langle N|\bar{d}d|N\rangle - \langle N|\bar{s}s|N\rangle}.$$

From pion-nucleon scattering results, fits of the parameters of baryon chiral perturbation theory and lattice QCD

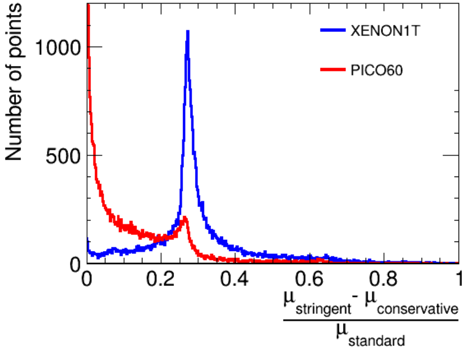
$\sigma_l = 46 \pm 11$ MeV, $\quad \sigma_s = 35 \pm 16$ MeV, $\quad z = 1.5 \pm 0.5$

(values from arXiv:1805.09795)

Uncertainties from nucleon SI form factors

We calculated the number of events per unit of time μ which could be measured by XENON1T and PICO60 for $\approx$ 40000 points in the pMSSM 19 for the “conservative”, “standard” and “stringent” options :

- In the fluorine experiment PICO60, the uncertainties can be neglected most of the time
- In xenon experiments such as XENON1T, **we have a typical error of 27%**



Uncertainties from nucleon SD form factors

SD scattering amplitudes depend on nucleon form factors $\Delta_i^{(p,n)}$ probing the quark spin content of protons and neutrons

$$A^{SD}_{\chi\, p,n \to \chi\, p,n} = \sum_{i=u,d,s} A^{SD}_{\chi\, i \to \chi\, i} \times \Delta_i^{(p,n)}$$

Those form factors are calculated from 3 quantities:

$a_3 = \Delta_u^{(p)} - \Delta_d^{(p)}$
$a_8 = \Delta_u^{(p)} + \Delta_d^{(p)} - 2\Delta_s^{(p)}$
and $\Delta_s^{(p)}$ itself

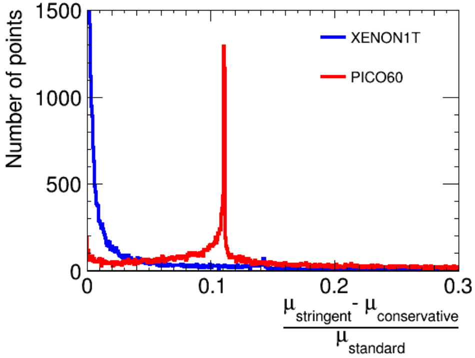
From neutron β-decay, hyperon β-decay measurements and from a measurement of the spin-dependent structure function of the deuteron from the COMPASS fixed target experiment

$a_3 = 1.2723 \pm 0.0023$
$a_8 = 0.585 \pm 0.023$
$\Delta_s^{(p)} = -0.09 \pm 0.03$ (values from DarkBit (2017))

Uncertainties from nucleon SD form factors

In xenon experiments such as XENON1T, the uncertainties can be neglected

In fluorine experiments such as PICO60, we have a **typical error of 11%**



Uncertainties from nuclear SD structure factors

SD scattering neutralino-nucleus cross-section depends on the structure factor S(q) which account for the finite size of the nucleus. q being the momentum transfer.

$$S(q) = a_0^2 S_{00}(q) + a_1^2 S_{11}(q) + a_0 a_1 S_{01}(q)$$

With $a_0 = A^{SD}_{\chi p \to \chi p} + A^{SD}_{\chi n \to \chi n}$ and $a_1 = A^{SD}_{\chi p \to \chi p} - A^{SD}_{\chi n \to \chi n}$

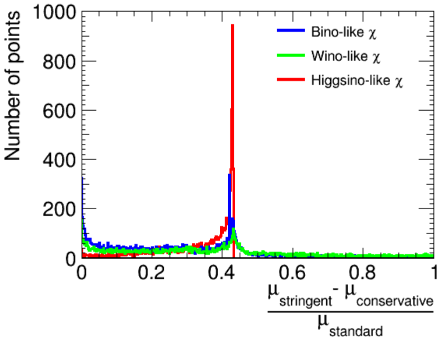
Structure factors from large-scale shell-model calculations (Klos et al. Phys.Rev. D89 (2014))

Large uncertainties on S_{01} and S_{11} structure factors from two-body currents.
$\Rightarrow$ relevant for isospin violating model
(i.e. when $A^{SD}_{\chi p \to \chi p} \neq A^{SD}_{\chi n \to \chi n}$)

Uncertainties from nuclear SD structure factors

Can be neglected for xenon experiments

For fluorine experiments, **more than 40 % of uncertainties**, especially for Higgsino-like neutralinos, as the neutralino coupling with Z boson is proportional to the isospin and the Higgsino fractions.

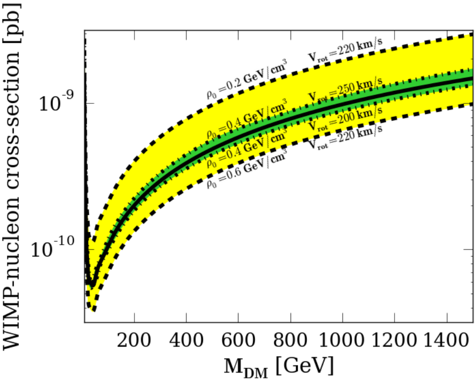


Relative difference of the event rate calculated for PICO60 experiment between the “conservative” and “stringent” options.

Uncertainties from the dark matter halo

Two sources of uncertainty relevant for all experiments:

- the **local DM density** $\rho_0 = 0.2 - 0.6$ GeV/cm^3
- the **DM velocity distribution**, whose main parameter in the standard halo model is the disc rotation velocity $v_{rot} = 200 - 250$ km/s



$\Rightarrow$ The local density uncertainties have the largest impact

Fermi-LAT spheroidal dwarf galaxies

The likelihoods are interpolated from the tabulated likelihoods provided by the collaboration.
Two sources of uncertainties are considered:

- **J-factors of some galaxies are not directly measured but "predicted"** from an empirical relation depending on the distance of the galaxy. The uncertainty on the J-factor is then arbitrary.
  We use $log_{10}(\Delta J) = 0.8$ dex, 0.6 dex and 0.4 dex for the "conservative", "standard" and "stringent" options respectively.
- Fermi-LAT collaboration defines a "conservative", "nominal", and "inclusive" dSphs samples, depending on the **ambiguity of the kinematics of the galaxies**.
  The differences between the constraints from these three samples can be substantial and are also taken into account.

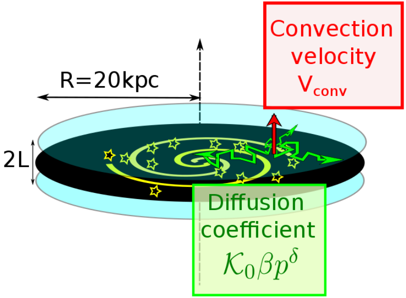
AMS-02 antiprotons

The antiproton spectra after propagation through the galactic medium are calculated with the code by Mathieu Boudaud and Pierre Salati.

Two-zone diffusion model

The galactic disc
$R \approx 20$ kpc, $h \approx 100$pc
The magnetic halo
$R \approx 20$ kpc,
$1 \leq L \leq 20$ kpc

Semi-analytical resolution of the propagation equation
$\Rightarrow$ faster than the numerical approaches used by codes such as GALPROP



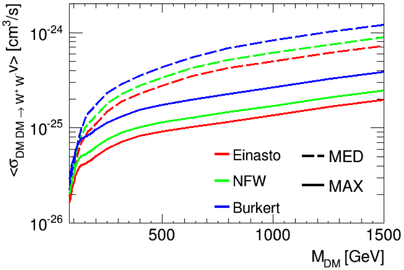
AMS-02 antiprotons

Two sources of uncertainties are considered:

- The dark matter density profile
- The propagation parameters

Antiproton spectra are already provided for:

- Einasto, Burkert and NFW density profiles
- MIN, MED, MAX benchmark sets of propagation parameters



"conservative": Burkert MED
"standard": Einasto MED
"stringent": Einasto MAX

The user can also create his own model by:

Setting other values of the propagation parameters

Defining any DM density profile with **cylindrical symmetry**

Conclusion

SuperIso Relic v4.0 is available on **http://superiso.in2p3.fr/relic**

This version also includes:

- the implementation of a decaying scalar field in the relic density calculation
- the parallelization wih OpenMP $\Rightarrow$ the compilation is much faster now!

The new manual will be released in the coming days!