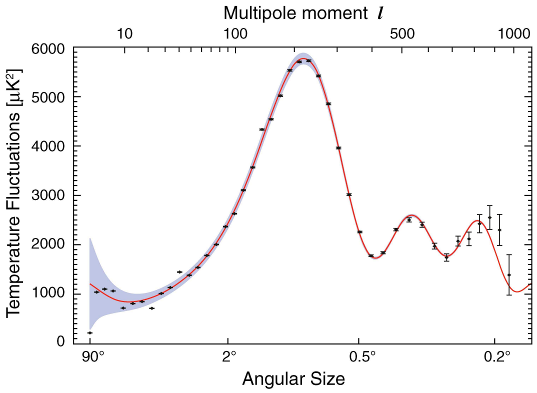
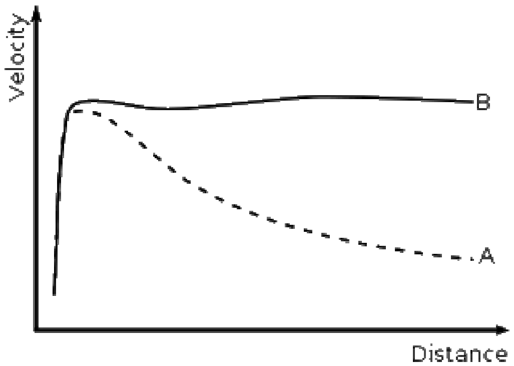
Reconstructing Dark Matter relic density from colliders and direct detection experiments

Based on the paper (in preparation) by G. Bertone, D. G. Cerdeno, M.F. and R. Ruiz de Austri

Mattia Fornasa
University of Padova – INFN Padova

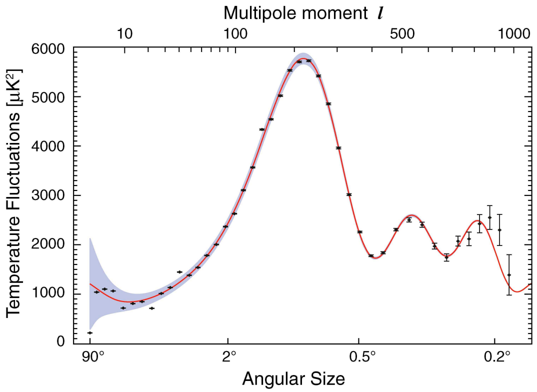
Dark Matter and experimental techniques





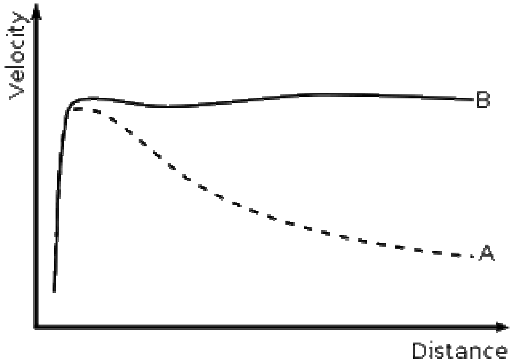
DM evidences:
• angular spectrum of anisotropies in the CMB
• rotation curves of galaxies
• weak lensing reconstruction in interacting clusters of galaxies

Dark Matter and experimental techniques



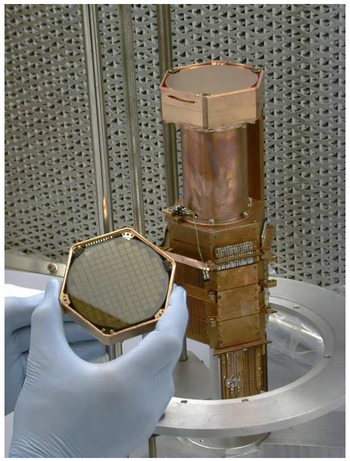
DM evidences:

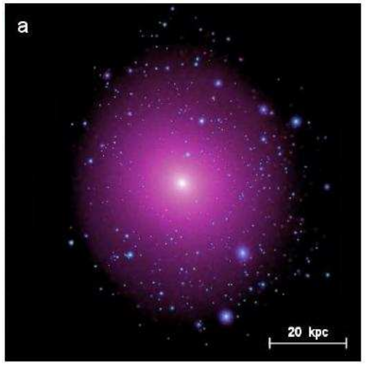
- angular spectrum of anisotropies in the CMB
- rotation curves of galaxies
- weak lensing reconstruction in interacting clusters of galaxies



Additional evidences and future detections are expected from:

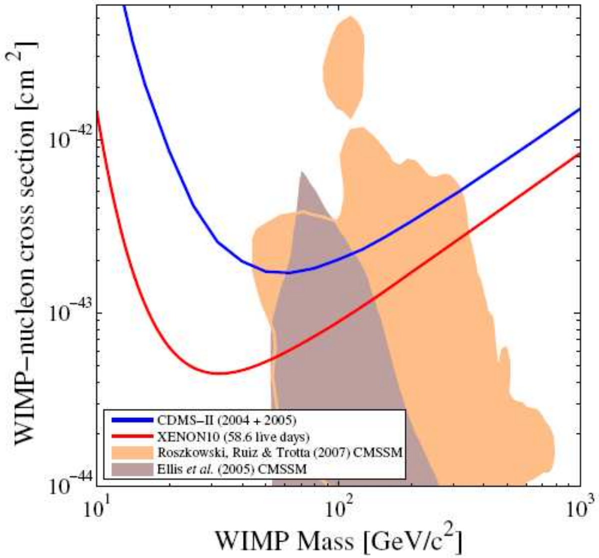
- colliders
- direct detection
- indirect detection





DM direct detection

Based on the possibility of detecting the recoil energy deposited by a DM particles to the nuclei of the detector when the particle passes through the detector itself.



From XENON10 Collaboration, Phys. Rev. Letters, 100, 021303 (2008)

Predicted event rate:

$$\lambda = \epsilon \int_{E_{th}}^{\infty} \frac{dR}{dE}(E) F^2(E) dE = \int_{E_{th}}^{\infty} c_1 R_0 e^{-E/(E_0 c_2)} F^2(E) dE \qquad (1)$$

$$R_0 = \frac{\sigma^{\rm SI}_{\chi,p} \rho_\chi A^2 c^2 (m_\chi + m_p)^2}{\sqrt{\pi} m_\chi^3 m_p^2 \ v_0} \qquad E_0 = \frac{2 m_\chi^2 v_0^2 A m_p}{(m_\chi + A m_p)^2 c^2} \qquad (2)$$

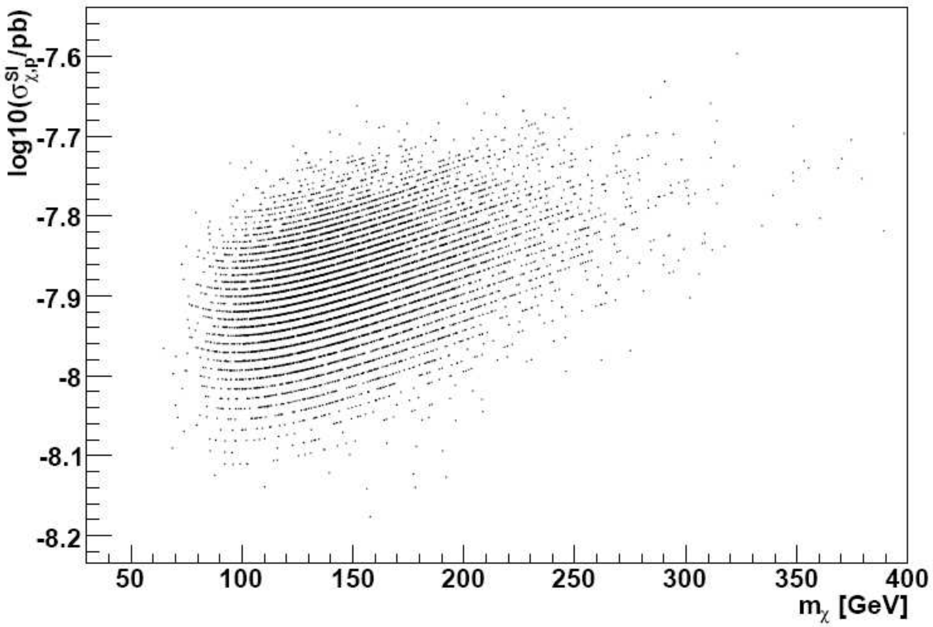
Reconstructing DM properties: direct detection

We choose a benchmark SUSY model and we want to determine the experimental capability of reconstructing observables relevant for DM searches: m_χ, $\sigma^{SI}_{\chi,p}$, $\Omega_\chi h^2$.

A direct detection experiment (CDMS-like) is associated to a likelihood, depending on the output of the experiments (N,{E_i}):

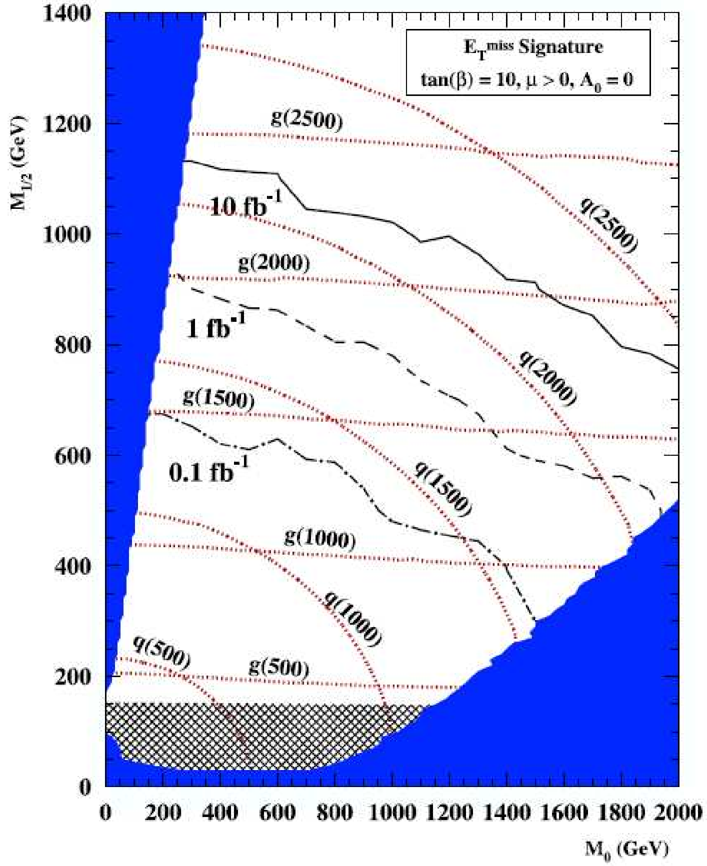
$$\mathcal{L} = \frac{e^{-N}\lambda^N}{N!}\prod_{i=1}^{N} f(E_i) \qquad (3)$$

Maximum-likelihood estimators for m_χ and $\sigma^{SI}_{\chi,p}$ can be obtained imposing the constraints $\partial L/\partial m=0$ and $\partial L/\partial \sigma=0$.



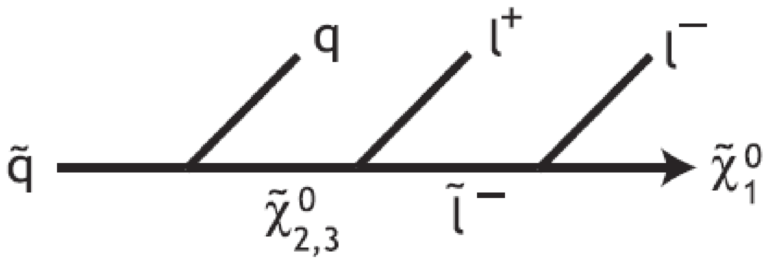
Colliders (LHC)

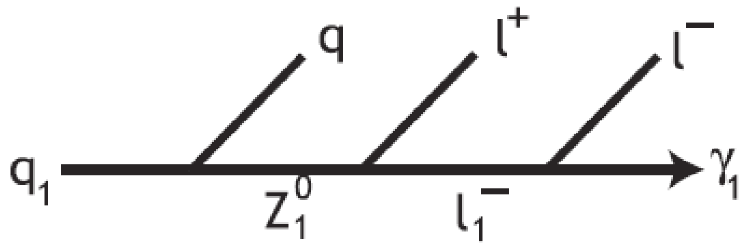
LHC (starting November 2009) will access an unexplored range of energies, with the possibility of detecting new, heavy particles beyond the Standard Model.



From Tovey, Eur. Phys. J., direct C4, N4

DM particle may be present as a decay product of primarily produced particles. Leaving the detector and being detectable only as missing energy.



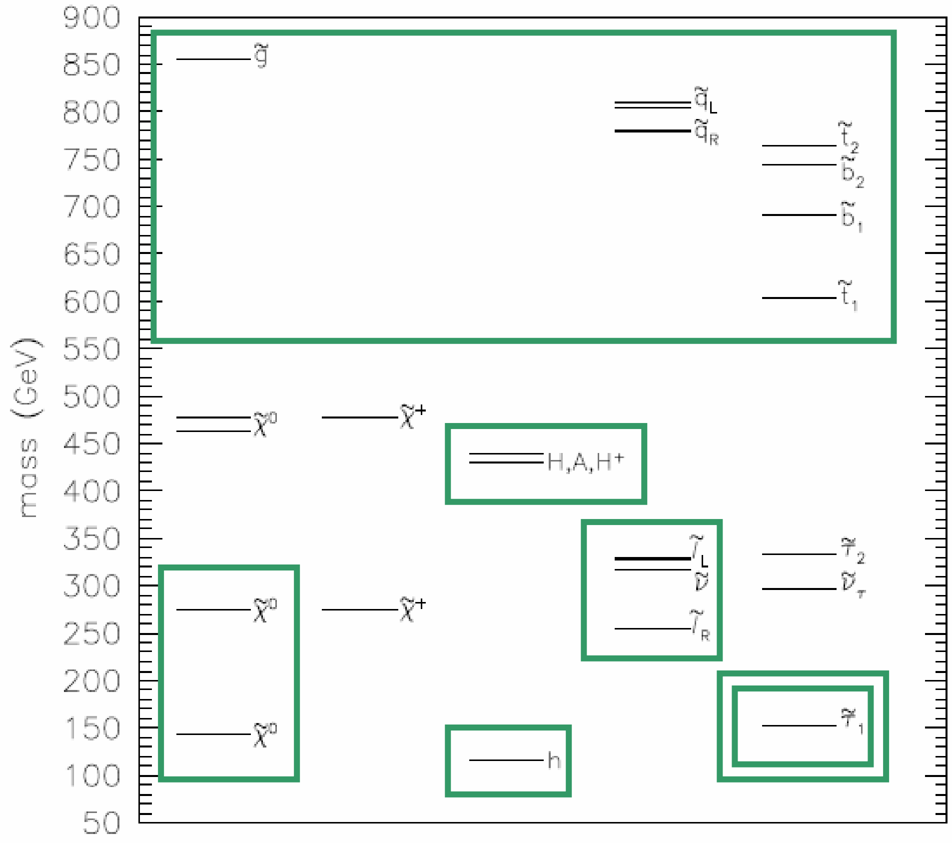


From Baltz et al., Phys. Rev. D74, 103521 (2006)

Reconstructing DM properties: colliders

- SUSY parameters' space is 24 dimensional
- our benchmark model is in the coannihilation region

LHC response to that benchmark model is simulated and a collection of *M* experimental measurements $\{d_i,\sigma_i\}$ is assumed.

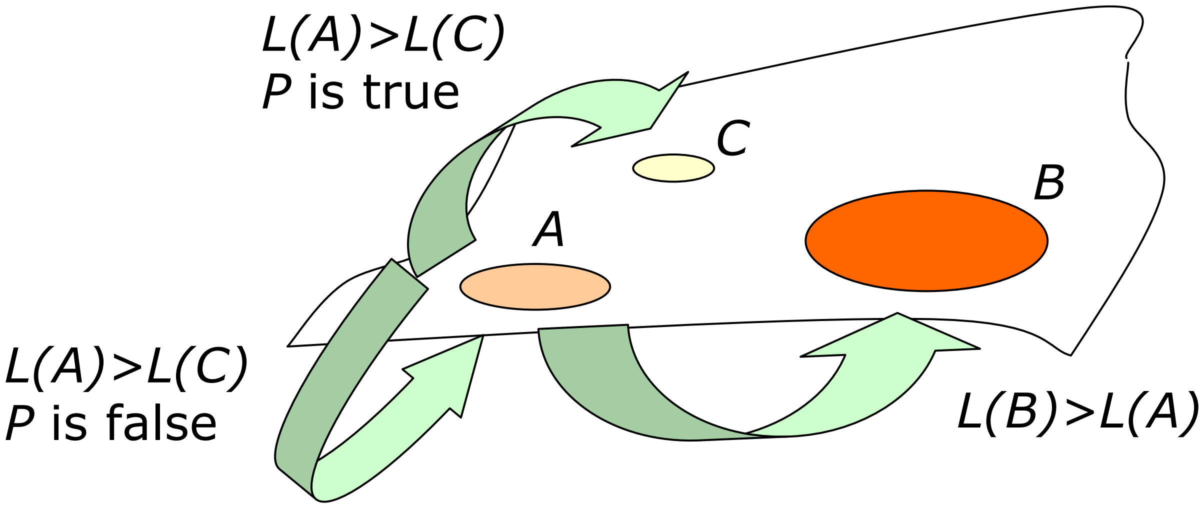


From Baltz et al.,
Phys. Rev. D 74 (2006) 103521

Reconstructing DM properties: MC Markov chains

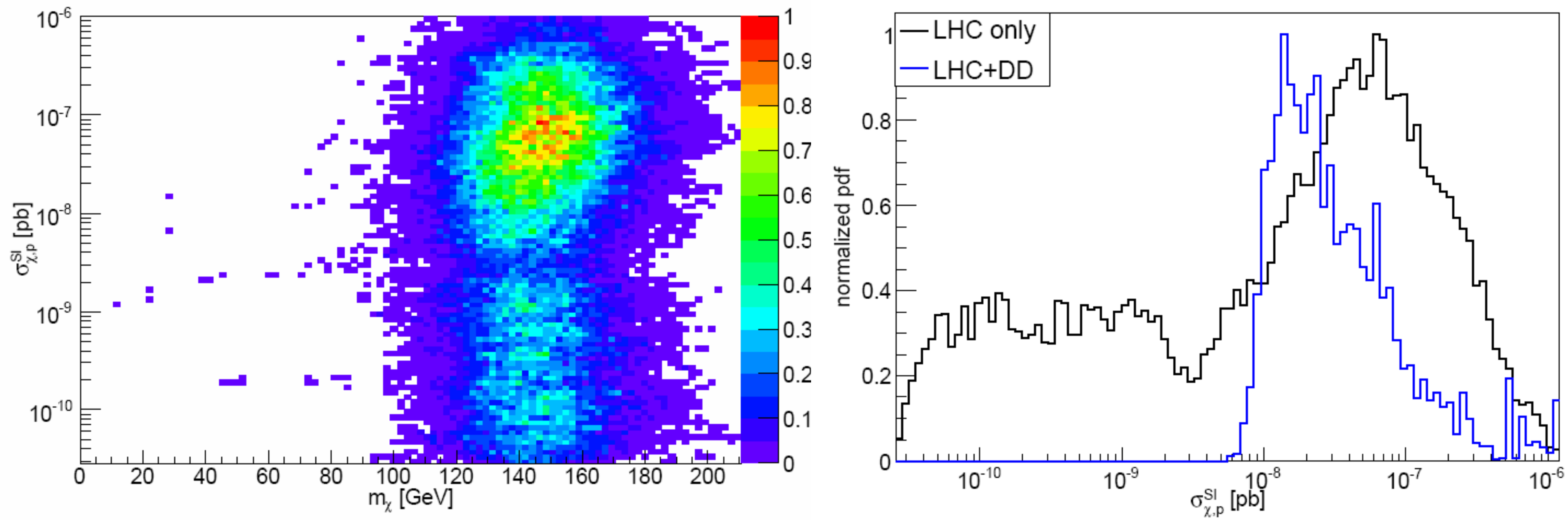
SUSY parameters' space is scanned with the use of MCMCs (based on the Bayesian theorem) and a likelihood is associated to each point:

$$\mathcal{L} = \prod_{i=1}^{M} \exp\left(-\frac{(d_i - d_i^{(j)})^2}{2\sigma_i^2}\right) \quad (4)$$



Posterior probability distribution function (pdf) of physical observables (m_χ, $\sigma^{SI}_{\chi,p}$, $\Omega_\chi h^2$) is obtained by the counting the multeplicity within the chains.

Reconstructing DM properties: $\sigma^{SI}_{\chi,p}$



Combining colliders with direct detection

Relic density $\Omega_\chi h^2$:

- assuming a signal at LHC
- assuming that the same particle leaves a signal in a direct detection experiment

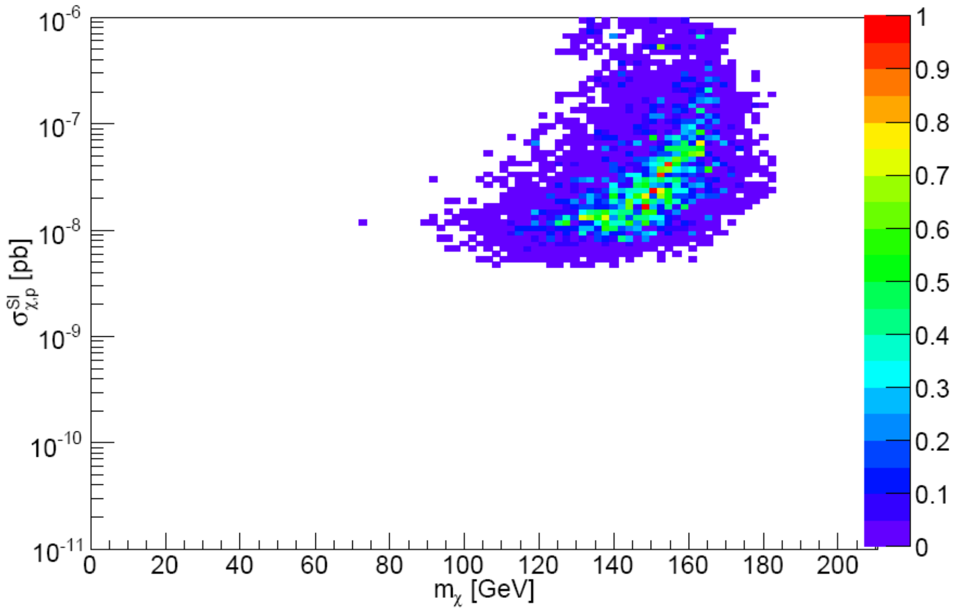
From the reconstruction of $\Omega_\chi h^2$ (breaking of degeneracies) it is possible to identify that particle as the cosmological DM (comparison with WMAP value).

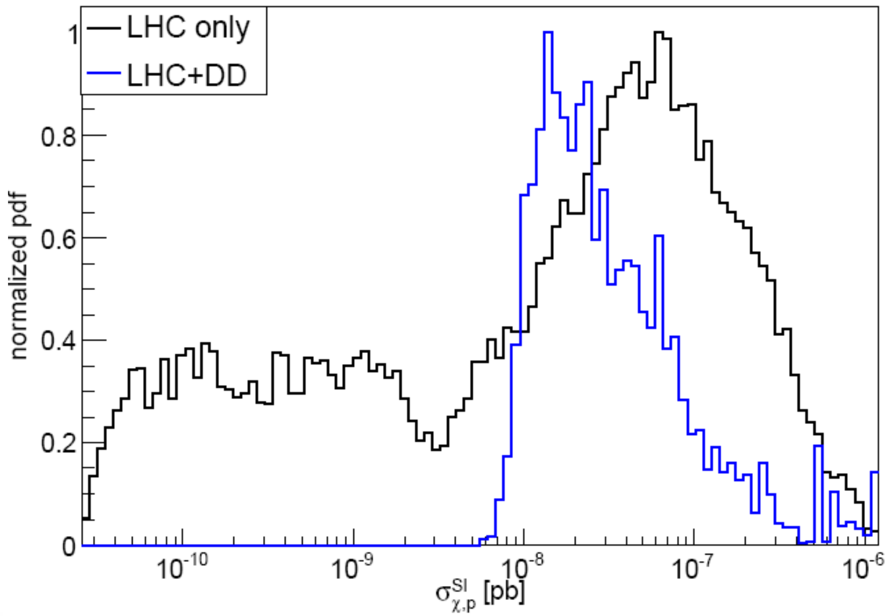
MCMCs can be sampled in order to account for informations from direct detection, i.e. the multeplicity of each point is changed by a factor:

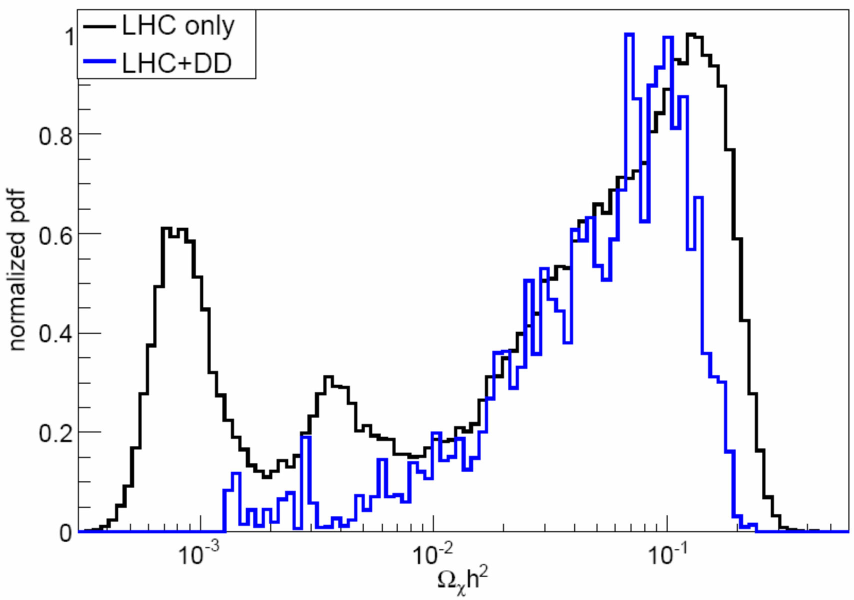
$$m_i \longrightarrow m_i \exp\left(-\frac{(\lambda - n^{(i)})^2}{2n^{(i)}}\right) \prod_{\text{bins, } j=1}^{4} \exp\left(-\frac{(n_j - n_j^{(i)})^2}{2n_j^{(i)}}\right) \quad (5)$$

Local density should be rescaled in the case of multi-component DM by a factor $\Omega_\chi^{(i)}/\Omega_\chi^{\mathrm{WMAP}}$.

Results







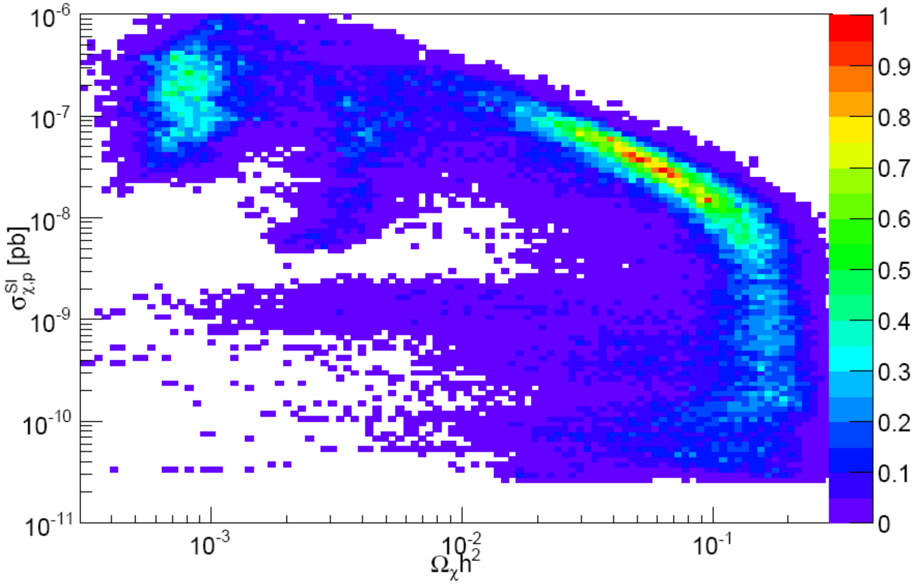
LHC only: $\Omega_\chi h^2 = 0.126_{0.042}^{0.207}$ (67%)

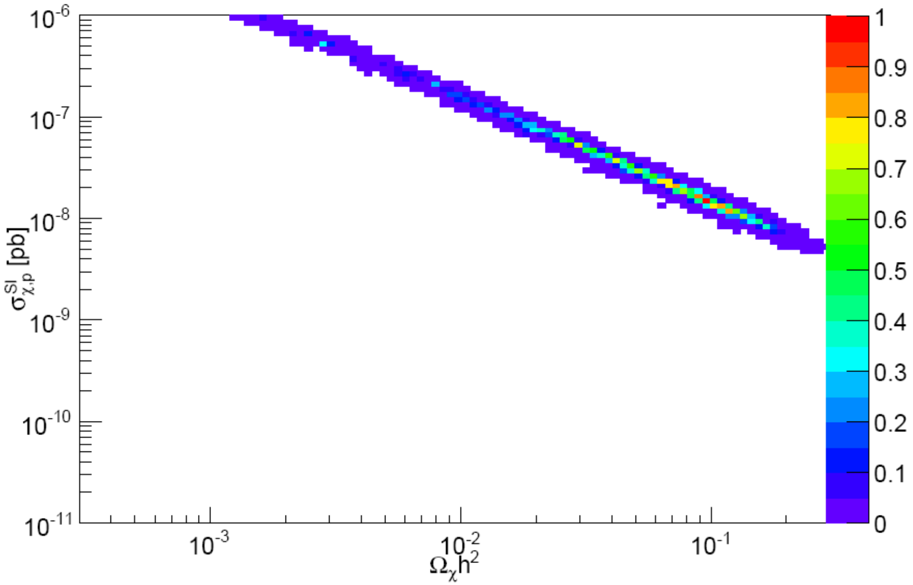
LHC+DD: $\Omega_\chi h^2 = 0.084_{0.061}^{0.122}$ (45%)

Conclusions

- Direct detection provides a good reconstruction of $\sigma^{SI}_{\chi,p}$
- LHC can constrain DM observables with the use, e.g., of MCMCs
- $\sigma^{SI}_{\chi,p}$ is very undetermined
- Combination of the two experimental techniques may largely improve the situation
- Breaking the degeneracies for the reconstruction of $\Omega_\chi h^2$
- The particle detected at LHC that, at the same time, leaves a signal in a direct detection experiment, can be identify as the DM and
- LHC may be used as a DM experiment

Underestimation of $\Omega_\chi h^2$

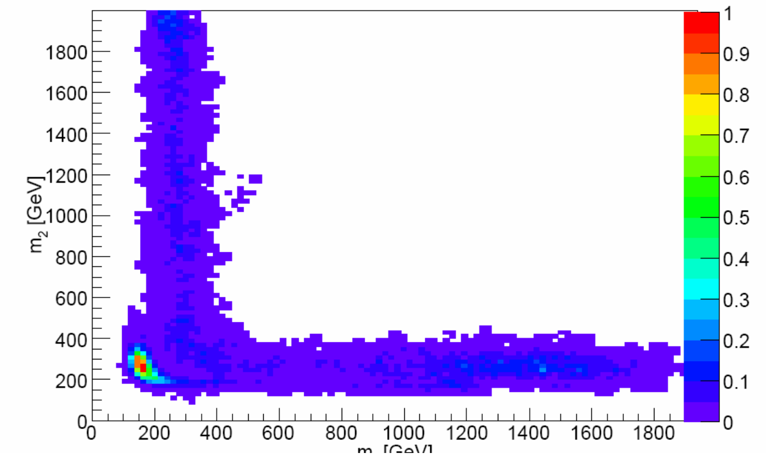


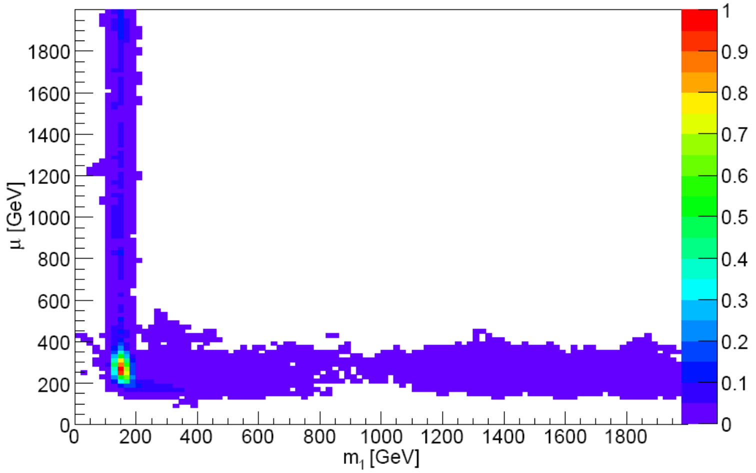


The underestimate of $\Omega_\chi h^2$ is due to the preference for large values of $\sigma^{SI}{}_{\chi,p}$ in the original chains (without direct detection data).

Neutralino nature

m_1, m_2 and μ are the parameters that determines the nature of neutralino.
Our benchmark model has $m_1<m_2<\mu$, but the fact that only the two lightest neutralinos are measured create some degeneracies:





- $m_1<\mu<m_2$: Bino/Higgsino neutralino
- $\mu<m_1<m_2$: Higgsino neutralino

Models with non-negligeble Higgsino fraction (large $\sigma^{SI}_{\chi,p}$) are possible.