Combining direct detection with colliders

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

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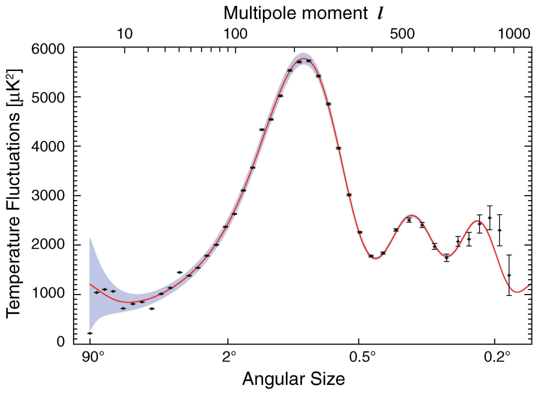
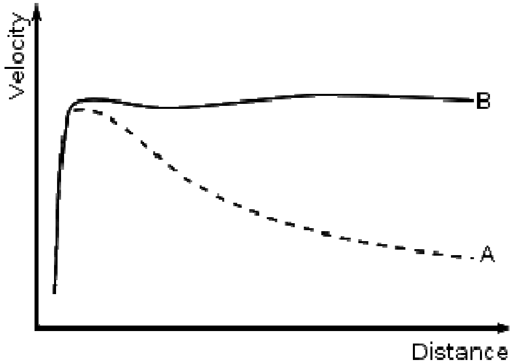
Dark Matter and experimental techniques





DM evidences:

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

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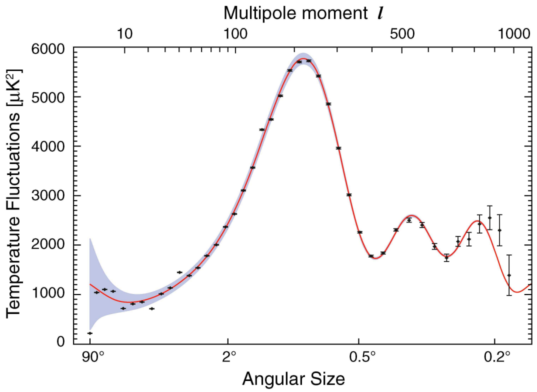

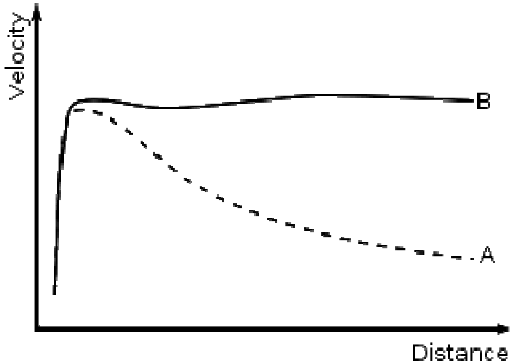

DM evidences:
- angular spectrum of anisotropies in the CMB
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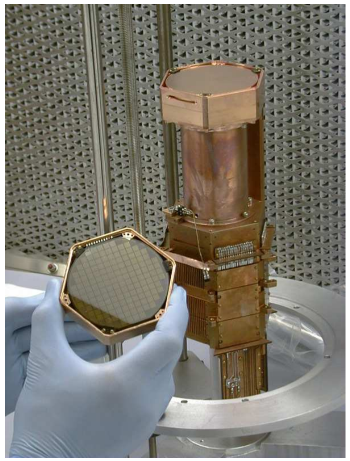
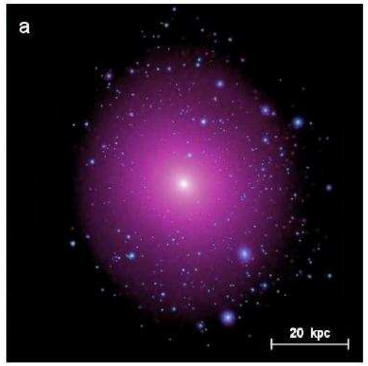
Additional evidences and future detections are expected from:
- colliders
- direct detection
- indirect detection

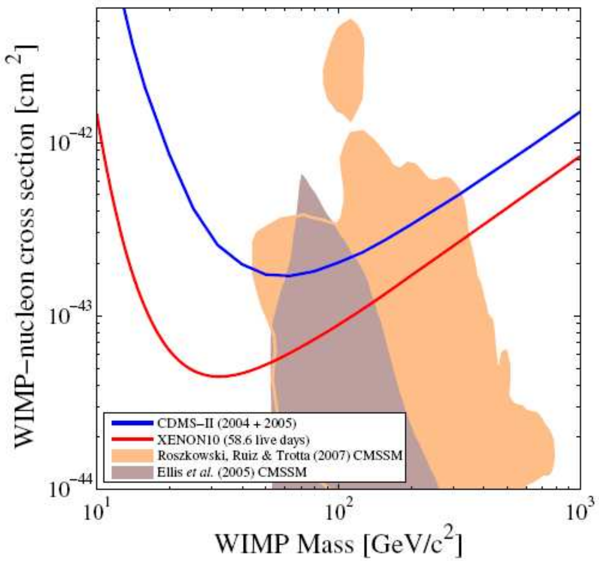




DM direct detection

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

CDMS-II detection of 2 events with an estimated background of 0.9



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

Predicted event number:

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

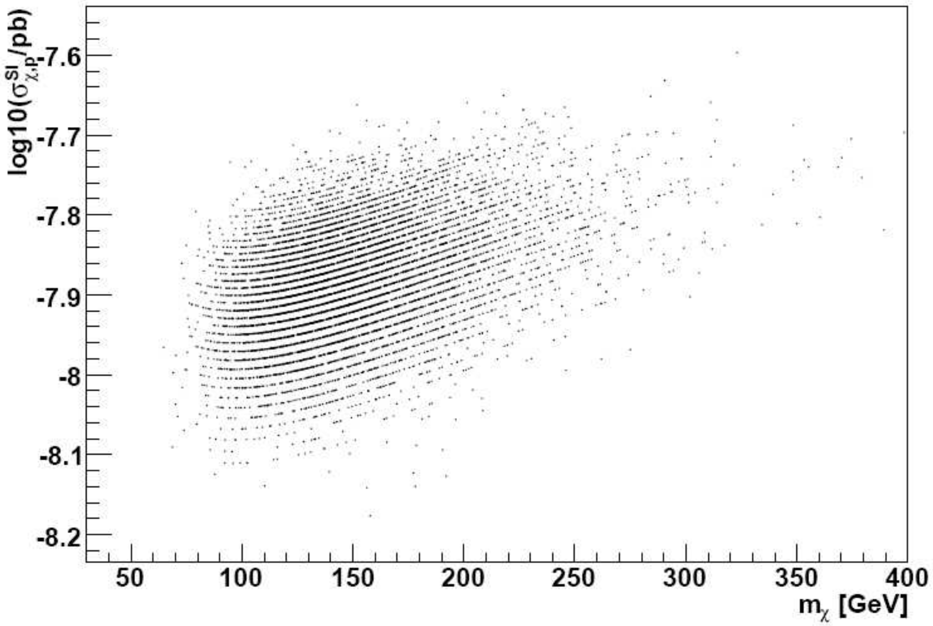
$$R_0 = \frac{\sigma^{\rm SI}_{\chi,p} \rho_\chi A^2 c^2 (m_\chi + m_p)^2}{\sqrt{\pi} m_\chi^3 m_p^2 \; v_0} \qquad E_0 = \frac{2 m_\chi^2 v_0^2 A m_p}{(m_\chi + A m_p)^2 c^2} \tag{2}$$

Reconstructing DM properties: direct detection

Reconstruction from direct detection has been studied by Anne Green (hep-ph/0703217 and 0805.1704):
• choose a benchmark model
• predict the response of a direct detection experiment (λ,$\{\varepsilon_i\}$)
• simulate a large number of experiments (N,$\{E_i\}$)
• associate a likelihood function to each of them

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

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



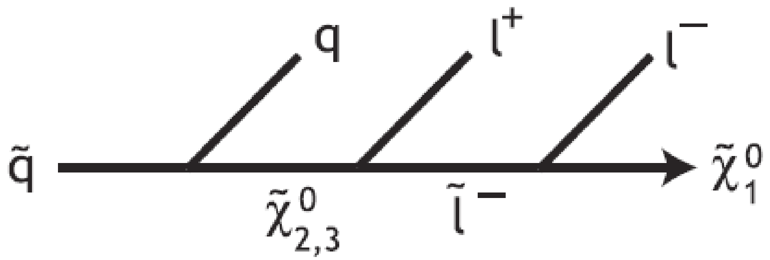
Colliders phenomenology - I

LHC (finally restarted!) will access an unexplored range of energies, with the possibility of detecting new, heavy particles beyond the Standard Model.

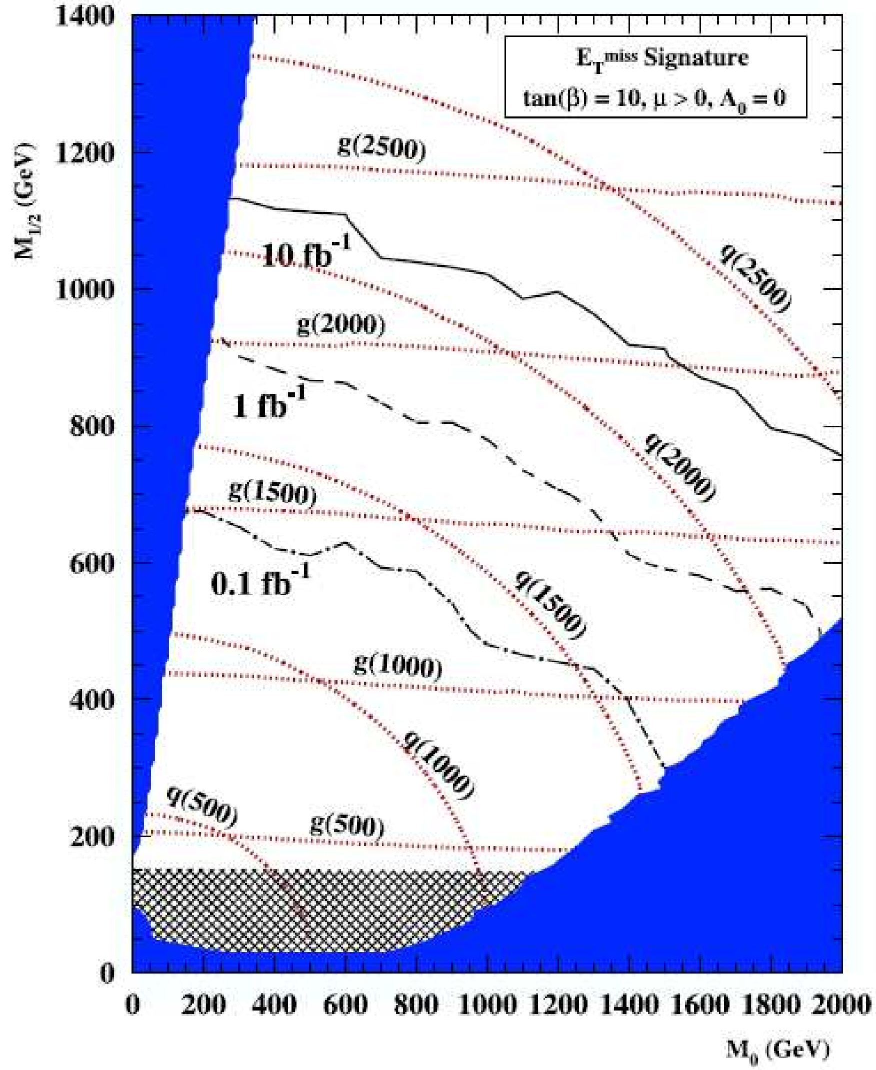
WIMP DM candidate leaves the detector appearing as unbalanced, missing energy.

Possibility of measuring other non-SM particles:

- they decay into the WIMP
- theoretical model can be constrained more efficiently



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

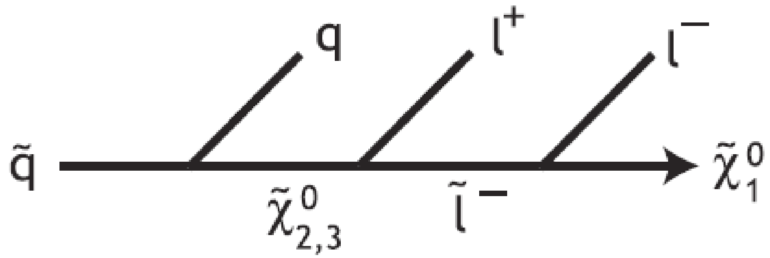


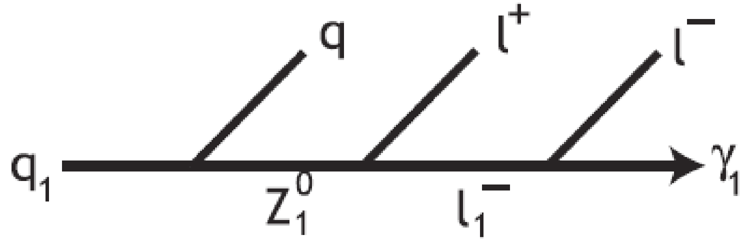
From Baltz et al., Phys. Rev. D74, 103521 (2006)

Colliders phenomenology - II

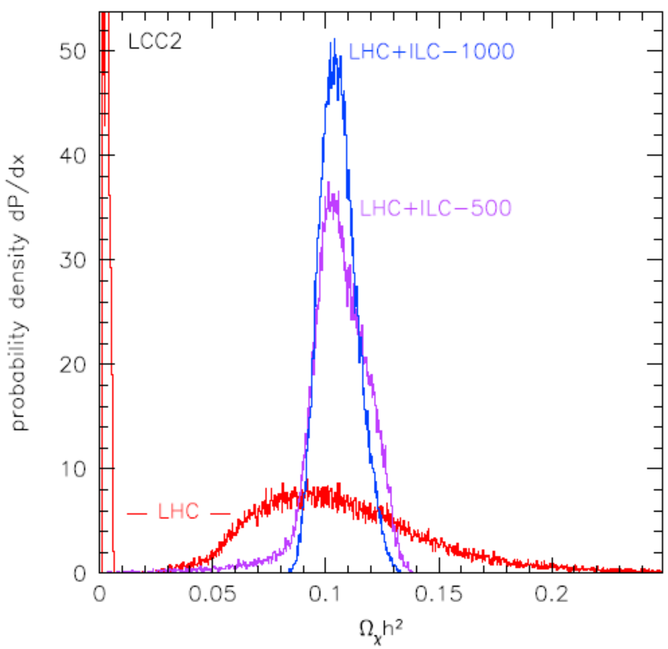
Difficult and challenging task:

- degeneracies among theoretical models





- degeneracies among parameters



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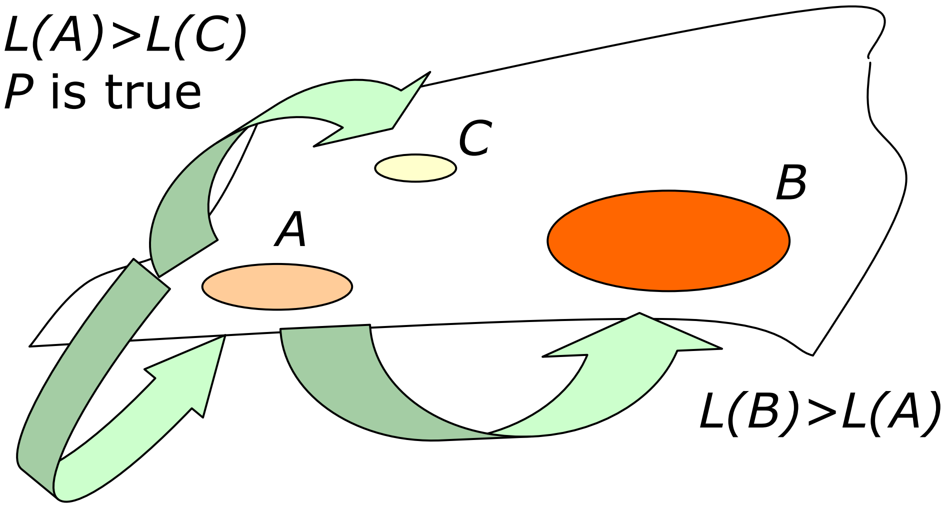
Monte Carlo Markov Chains

First input is a set of experimental measurements $\{d_i, \sigma_i\}$.
SUSY parameters space is scanned with the use of MCMCs (based on the Bayesian theorem) and a likelihood is associated to each point:

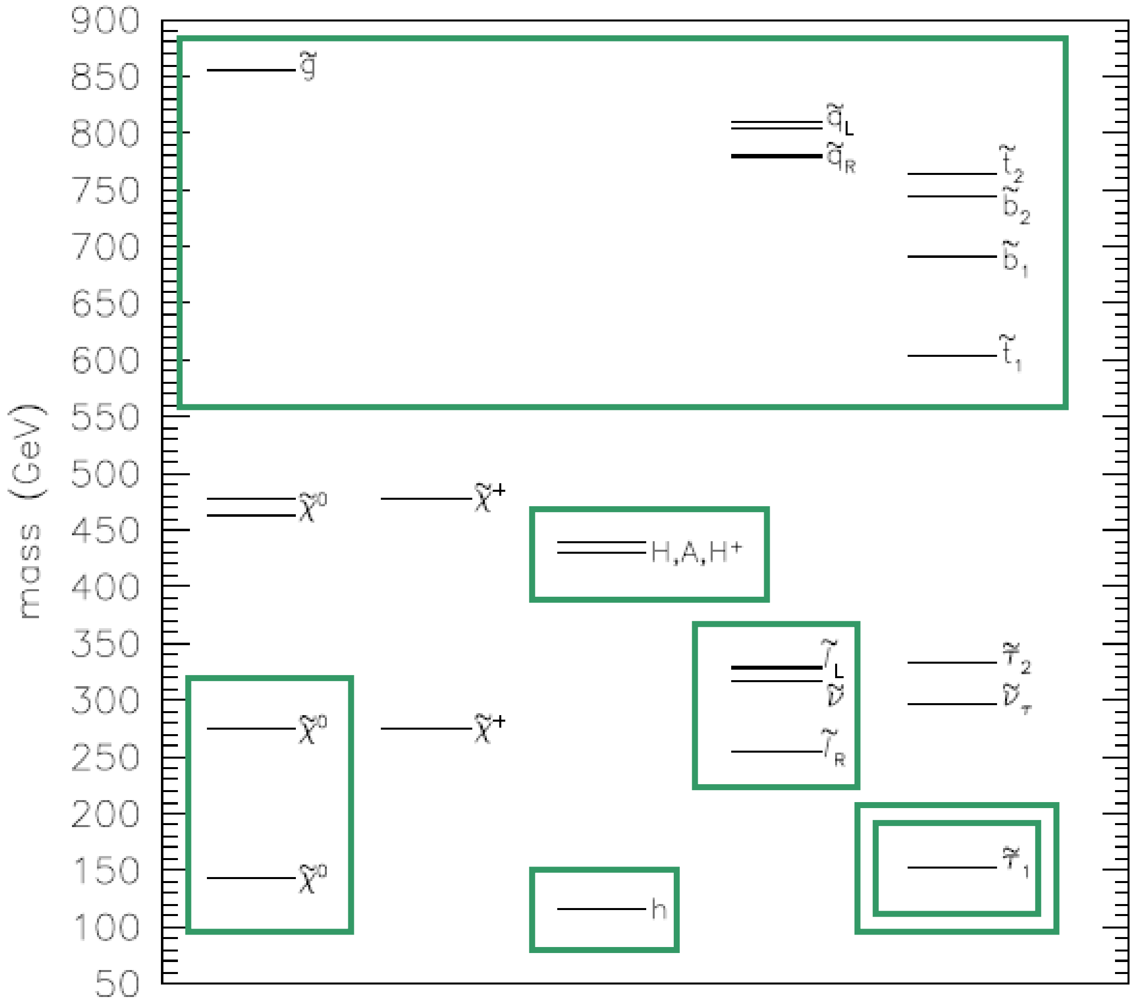
$$\mathcal{L} = \prod_{i=1}^{M} \exp\left(-\frac{(d_i - d_i^{(j)})^2}{2\sigma_i^2}\right) \quad (4)$$



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

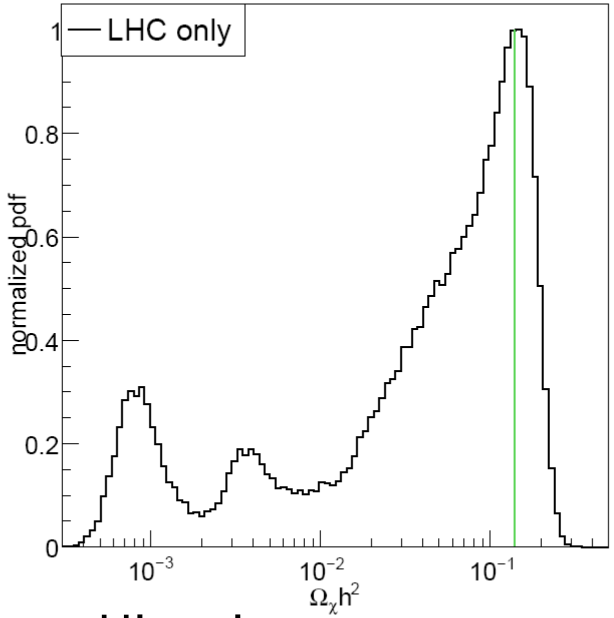
Reconstructing DM properties: colliders

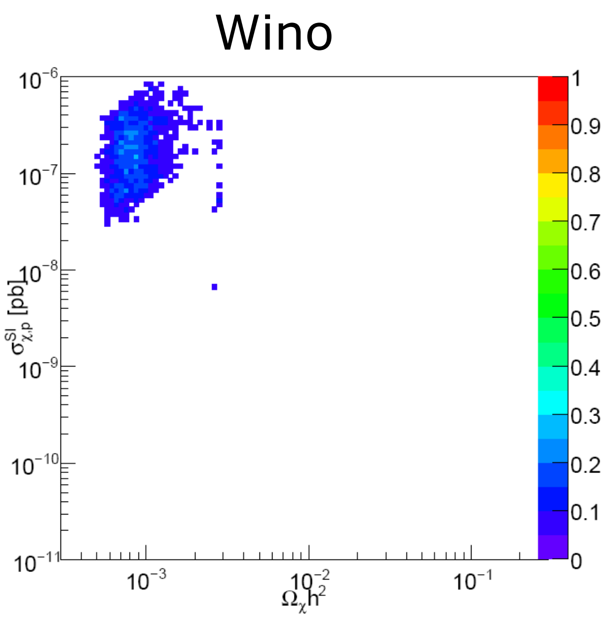
- SUSY parameters space is 24 dimensional
- our benchmark model is in the coannihilation region

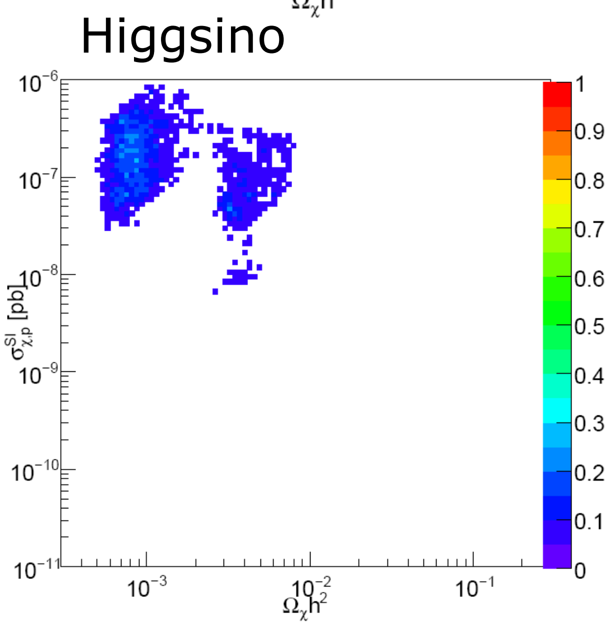


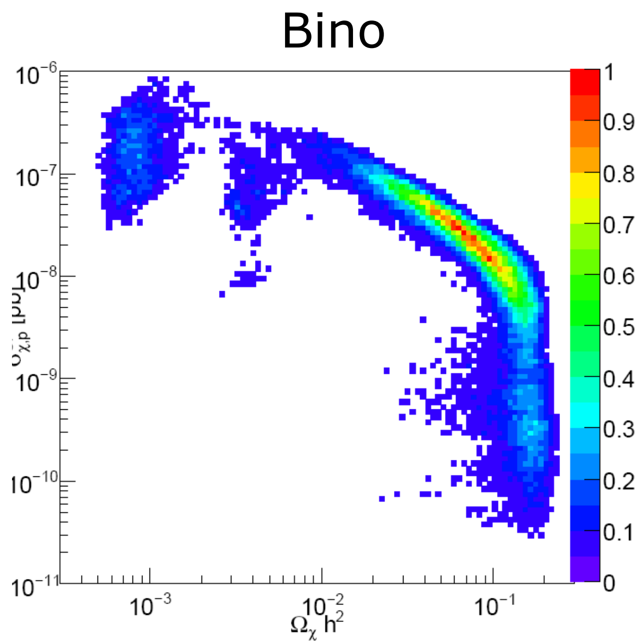
From Baltz et al.,
Phys. Rev. D 74 (2006)
103521

Reconstructing DM properties: $\Omega_\chi h^2$









Combining colliders with direct detection

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:

$$m_i \longrightarrow m_i \exp\left(-\frac{(\lambda - n^{(i)})^2}{2n^{(i)}}\right) \prod_{\mathrm{bins},j=1}^{10} \exp\left(-\frac{(n_j - n_j^{(i)})^2}{n_j^{(i)}}\right) \qquad (5)$$

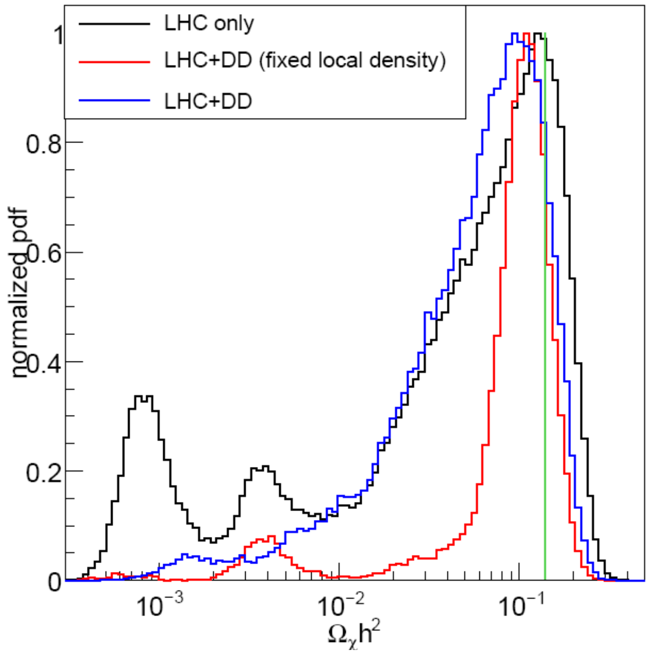
Relic density $\Omega_\chi h^2$:

- 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).

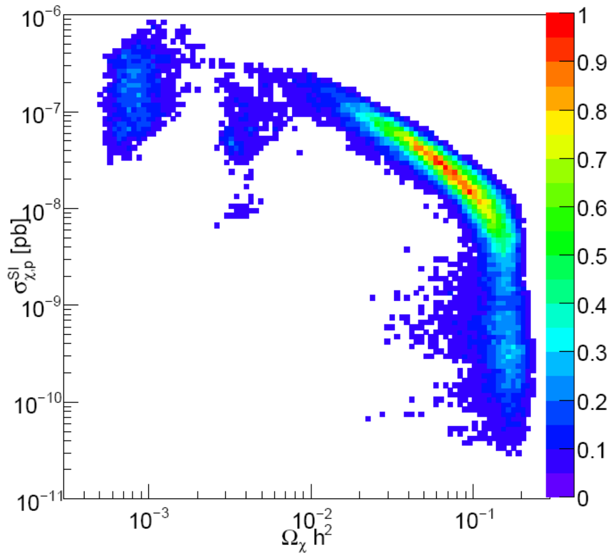
Local density should be rescaled in the case of multi-component DM by a factor $\Omega_\chi^{(i)}/\Omega_\chi^{\mathrm{WMAP}}$.

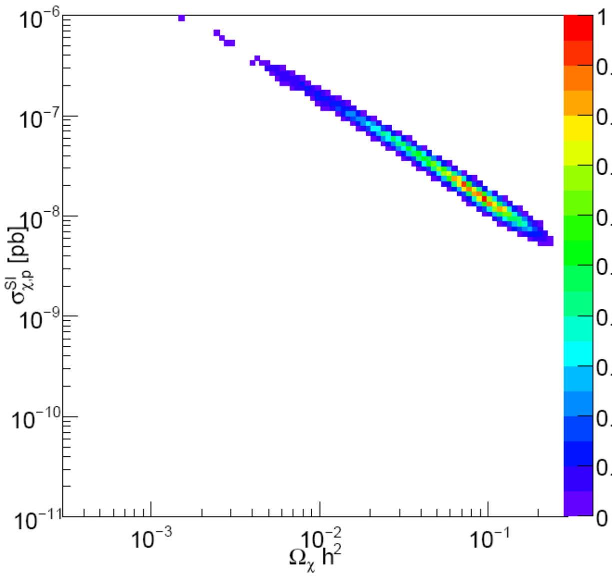
Results

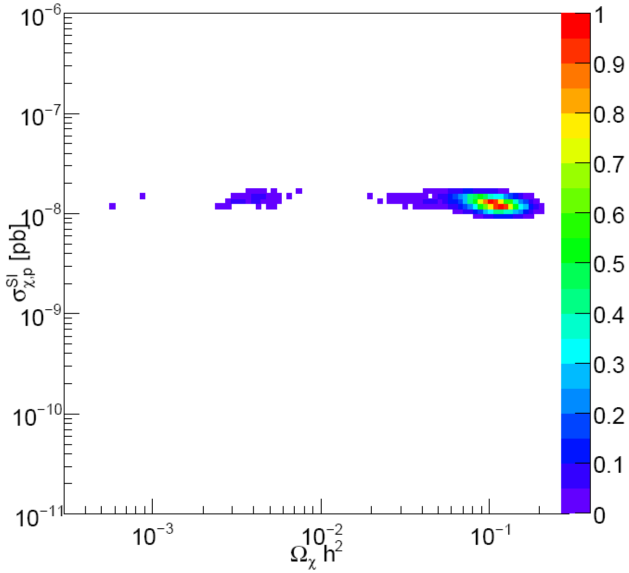


LHC only: $\Omega_\chi h^2=0.147_{0.035}^{0.206}$ (76%)

LHC+DD: $\Omega_\chi h^2=0.109_{0.035}^{0.165}$ (68%)







Conclusions

- Direct detection provides a good reconstruction of $\sigma^{SI}_{\chi,p}$

- LHC can constrain DM observables with the use, e.g., of MCMCs

- Internal degeneracies

- 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

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 leads to models with other hierarchies that equally fit well the data:

Neutralino nature