Supersymmetric neutralino as DM: putting togheter direct detection with collider data

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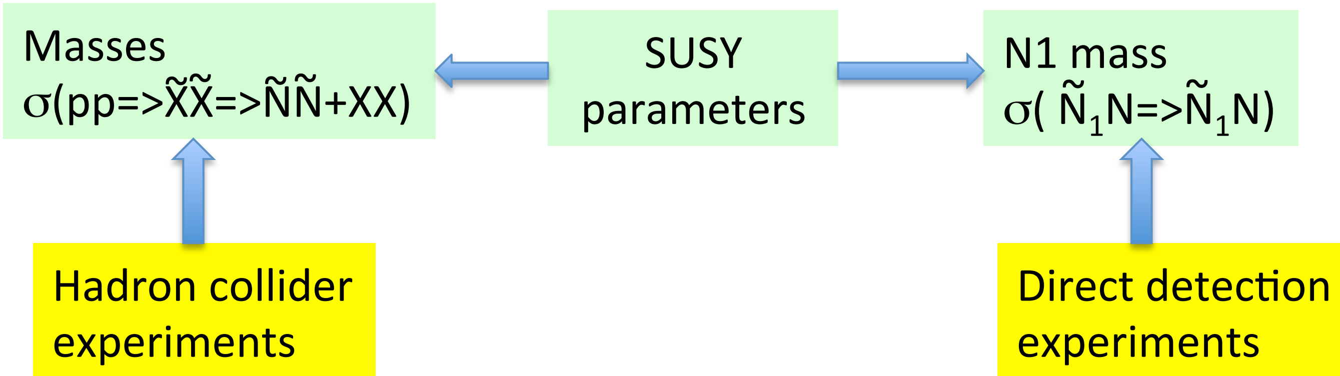
Some words as introduction

- My specific field of expertise is the search for supersymmetric particles with the ATLAS detector
- The question I'd like to discuss here is what we can say about a supersymmetric explanation to the Dark Matter
- In what follows, I will focus on the lightest neutralino as candidate Dark Matter particle

Connecting collider and direct detection



- Now each set of SUSY parameters predict the observables measured at colliders and direct detection experiments (ok, with some uncertainties)
- So in principle if all SUSY parameters value are considered one can say (assuming no observation, otherwise things get much more interesting)
  - x% of the parameter space yields a relic density consistent with measurements
  - y%,z%,w% of this parameter space is excluded by LHC, XENON, LHC+XENON data
  - y',z',w'% of the remaining space will be probed by future LHC, XENON, LHC+XENON data (or any facilities under consideration)
- If w' = 100% neutralino DM is ruled out
- Also interesting is a statement like: for remaining solutions, mN_1 > X TeV, because this has an impact on SUSY as solution for the hierarchy problem and on accessibility at lepton collider
- Now the above is not possible because there are hundreds of continuous SUSY parameters
- In fact **it is probably possible** because direct detection signals and some collider signals depend on very few parameters

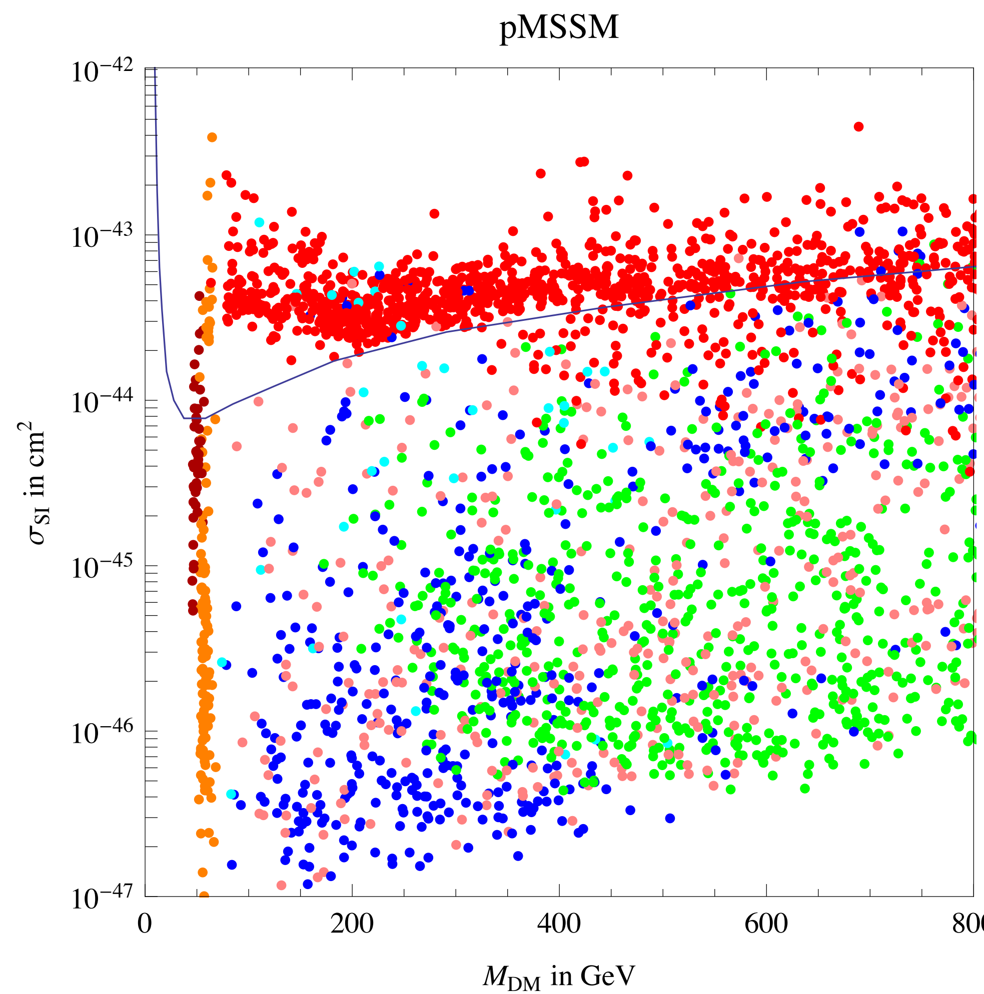
- The gaugino mass spectrum depends on M_1, M_2, μ, tan β
- For bino-like neutralinos ($M_1 << M_2,\mu$) the relic density is too high, need a mechanism to reduce it
  - s-channel annihilation via Z, h : need a (fine tuned) mass half that of the boson (the Higgs can be the known or one of the yet undiscovered states)
  - Coannihilation: need an other particle (lepton, squark, gluino) close in mass to the neutralino, the mass difference must have a precise value
- For wino-like or higgsino-like neutralino (the other cases) the relic density is too low
  - I've seen axion-neutralino mixing suggested to get the relic density right.
- A careful mixture of eigenstates (well tempered neutralino) is also ok. This predicts the gaugino spectrum as a function of the N_1 mass.

- For each of the solutions above, the relic density is a function of **one or two theory parameters**
- Scattering cross section and the signals from pair production at LHC of the SUSY particles whose mass depend only on those one/two parameters are also predicted – **the predictions can be tested at colliders and underground experiments (in principle)**

Implications of XENON100 and LHC results for Dark Matter models (updated including 2012 data)

Marco Farina[a], Mario Kadastik[b], Duccio Pappadopulo[c], Joosep Pata[d], Martti Raidal[b], Alessandro Strumia[b,e]

- The plot for a MSSM scan illustrates the concept
- What are the *minimum* LHC signals for each of the points in the plot ?
  - Minimum in the sense that does not depend on other theory parameters



Red points: well tempered neutralino.

Dark red: neutralino has half the Z mass

Orange: CP-even Higgs resonance

Green: Heavy Higgs resonance

Blue: slepton co-annihilation

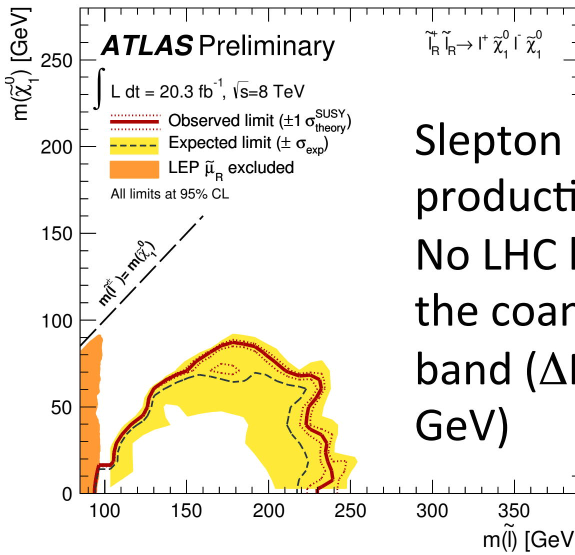
Magenta: stop co-annihilation

Light blue: neutral Higgses with tan b enhanced couplings

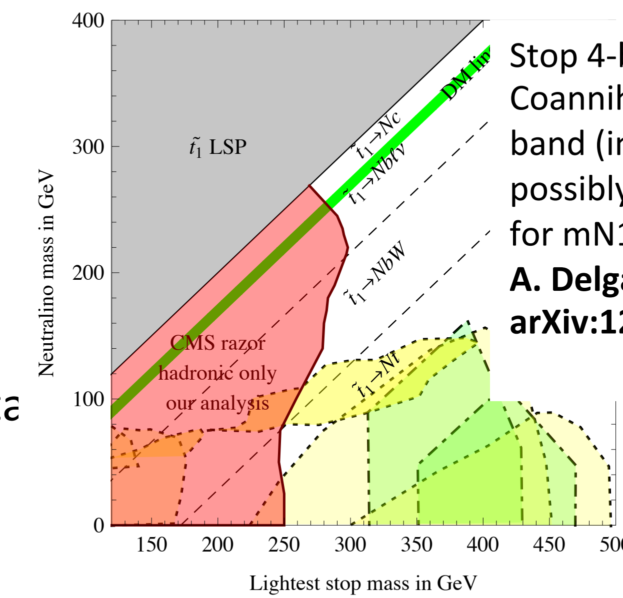
Looks like the well tempered neutralino scenario is out, I won't comment on it. Notice that it predicts a spectrum of gauginos at LHC which could have been detected

Coannihilation scenarios

- If there is a charged or coloured particle which is 20 or 40 GeV heavier than the LSP, then the slepton(squark) pair production followed by their decay to the LSP might be observed at LHC
- Sub-categories depending on the nature of this other particle: first generation squark, stop, first generation sleptons, staus are separate cases.
- Experimental limits on first generation squark case exist.
- The stop might decay to cN_1 (via a loop) or $bff'N_1$ (direct 4-body), experimental limits exist on the first, theory-calculated ones on the second.
- No limits on the difficult slepton and stau cases yet.
- I am not aware of any future LHC sensitivity studies for any of the above, this can be something I would be interested to study with LHC MC generators - up to which N_1 mass the future hadron collider (planned or proposed) data would be sensitive assuming the coannihilation scenario ?



Slepton pair production.
No LHC limit for the coannihilation band ($\Delta M \approx 20$ GeV)



Stop 4-body. Coannihilation band (in green) possibly excluded for mN1<250 GeV
A. Delgado et al. arXiv:12126847

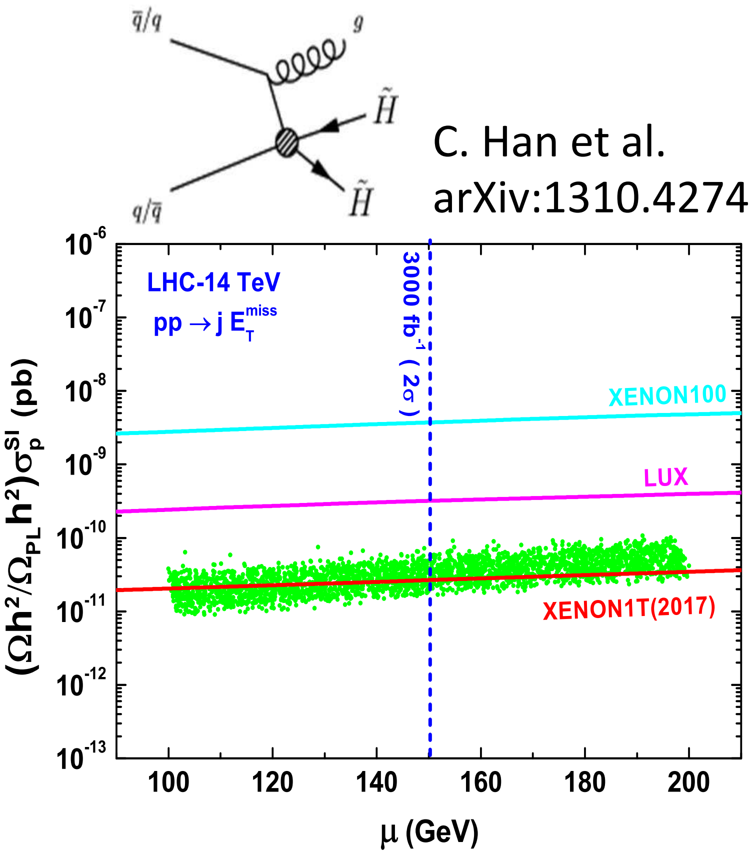
Resonance scenario

- I am not sure it's possible to observe at hadron collider a bino-like neutralino of 45 GeV if all other SUSY particles are heavy
- What is the jet+N_1N_1 cross section ?
  - I am afraid (but I do not know for sure) it might be very small
  - Good sensitibity is claimed by monojet +EtMiss LHC analysis but they use an effective operator approach which is valid only for a heavy BSM mediator – here interactions are mediated by Z bosons
- Can we probe this scenario with direct detection ? The plot of the previous slide gives points with $5\ 10^{-46} < \sigma < 4\ 10^{-44}$. What is this spread due to ?

- For an Higgs resonance:
  - Prediction of the invisible H(125) decay BRs ? Projected LHC sensitivities ?
  - For heavy Higgs resonances, coverage from the invisible and $\tau\tau$ decay modes ? [dependence on mass and tan b, anything else?]
  - From the previous plots, the scattering cross section changes over many orders of magnitude. Which parameters does it depend on ?

Pure higgsino scenario

- Well motivated by naturalness
- Difficult for LHC if everything else is heavy – only three mass-degenerate states accessible (N_1,N_2,C_1)
- Relic density is not right, but I have read that mixing with axions can fix the problem and lead to well defined scattering cross section
- Interesting, that sits at the edge of Xenon 1T sensitivity
- LHC: VBF production of Higgsinos might be accessible with 3000 fb^{-1} at 14 TeV if the higgsino is light (μ < 150 GeV)



C. Han et al. arXiv:1310.4274

But again: what would be the sensitivity of high energy hadron collider, if we somehow do not get a linear collider ? What would it take to improve a factor of 5 over Xenon1T(2017) ? Would then the scenario ruled out, or are there ways to evade these limits ?

If Xenon 1T has a small signal by 2017, VBF production at LHC(2025) would test the higgsino-axion Interpretation and measure the mass if this is light enough.

- LHC and direct detection can probe neutralino Dark Matter without assumptions on non-DM related SUSY parameters
- Quite some information is available in literature
- As far as I am aware, sensitivity from future data from hadron collider is studied only for a few cases, and always by theorists (experiments have focused on a few easier scenarios than those relevant here)
- I would also like to understand the spread in the scattering cross section, which parameters does depend on
- What would it take to exclude neutralino Dark Matter, if possible ?
- In case of an observation, what information can we get from direct and LHC measurements ?