Two component dark matter motivated by E6SSM

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Motivation

- There is strong evidence for the existence of dark matter from cosmology but we haven't found it in particle physics experiments
- Several ideas to explain the null results of collider/direct detection searches: light dark matter escapes direct detection, feebly coupled nearly invisible in all experiments...
- One assumption in the direct detection bounds is that dark matter saturates the relic density bound, if there are more than one dark matter particle, these would be ameliorated
- We tried to look at a model that could give two dark matter candidates in a rather natural way, the E6SSM has one candidate due to R-parity and in addition it has inert Higgs superfields
- The E6SSM can be motivated by heterotic string theory based on E8$\times$E8 but today we shall look at a low scale model that would emerge from E6

Outline

Today I'll try to discuss

- the particle content and good dark matter candidates in E6SSM
- in some detail one case, where you can get two dark matter components with comparable relic densities
- discovery prospects of the two dark matter components at different fronts

This talk is based on 2007.10966 (and work in progress) together with Shaaban Khalil, Stefano Moretti and Diana Rojas-Ciofalo

Short introduction to E6SSM

- E6 is one of the exceptional groups of the Cartan catalog
- E6 can break to SO(10)×U(1)→SU(5)×U(1)×U(1) and further down to SM with two extra U(1) groups
- We expect one of the U(1) breaking scales to be high but the second one can survive to a low scale effective theory
- The fundamental representation of E6 is 27-dimensional and under SU(5)×U(1) it decomposes like

$$27 \to \underbrace{(10, \frac{1}{\sqrt{40}}) + (\bar{5}, \frac{2}{\sqrt{40}})}_{=\text{quarks and leptons}} + \underbrace{(\bar{5}, \frac{-3}{\sqrt{40}}) + (5, \frac{-2}{\sqrt{40}})}_{=\text{Higgs doublets and exotic quarks}}$$

$$+ \underbrace{(1, \frac{5}{\sqrt{40}})}_{=\text{singlet Higgs}} + \underbrace{(1, 0)}_{=\text{RH neutrino}}$$

E6SSM needs three copies of **27**

- As we have three generations of quarks and leptons, we will need three copies of **27** for an extension of the SM
- We will have three copies of the NMSSM Higgs sector; in order to avoid FCNC one of the Higgs generations gets a VEV and the two others are inert with no couplings to SM fermions
- We may impose a Z_2 symmetry (3^{rd} gen. Higgses even, rest odd) in the inert sector so that we will get another DM candidate in addition to the standard one from R-parity
- We consider an effective model relevant for dark matter — in addition to NMSSM we have two generations of inert Higgs superfields (both doublet and singlet, good candidates for DM) and Z' (relevant for DM annihilation and direct detection)

We use the following effective superpotential

$$W = Y_u Q U^c H_u + Y_d Q D^c H_d + Y_e L E^c H_d + Y_\nu L \nu^c H_u + \lambda_{ijk} S_i H_{dj} H_{uk}$$

We look for scenarios, where both components give a large fraction of the relic density

We are mostly interested in cases, where

- both components give a significant fraction of the total relic density (so that there is a difference to the single component case)
- both DM components have masses at $\sim$LHC scale

The best candidates from the MSSM particle content are those, which lead to underabundance, *i.e.*

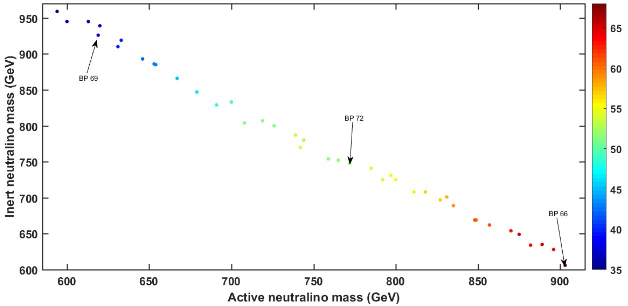
- higgsinos below 1 TeV
- winos below 2 TeV

In addition we have inert higgsinos and inert scalars as second DM candidates.

Inert scalar dark matter does not work

- Inert singlets are too heavy to be the LSP — they have a D-term component in their mass proportional to Z' mass so they are always in the multi-TeV region and, assuming soft SUSY breaking mass of the same order, heavier than inert doublet scalars
- Inert doublet Higgses can be the lightest inert sector particle, but due to being complex scalars they have a coupling to the Z boson and are excluded by direct detection searches
- Of other possible DM candidates RH sneutrinos are too heavy — they are likely at the scale of 10^{10} GeV or so
- The only viable inert sector DM candidate is the inert higgsino

Two higgsinos give a viable DM scenario with sub-TeV masses



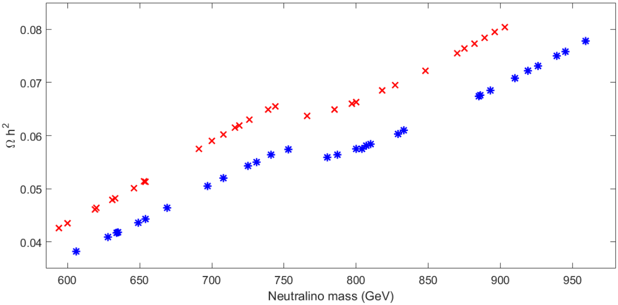
- As is well known, higgsino relic density increases with mass so in the case of two higgsinos the masses are anticorrelated and the heavier one contributes more
- The wino + inert higgsino case is similar, only the contribution from the wino is smaller so overall masses heavier

The heavier DM component can be more than a passive spectator

- In a two component DM freeze-out scenario the heavier component falls first out of thermal equilibrium
- This means that after freeze-out there is a component, whose density is far above that of thermal equilibrium
- If one component coannihilates with some other particle, scatterings with the heavier DM particle can produce additional coannihilating particles compared to the case where no second component is present
- Usually this means that the relic density will be less than the sum of two relic densities
- The effect can sometimes be quite large, see [1309.2986], so two component dark matter is not just summing two components!

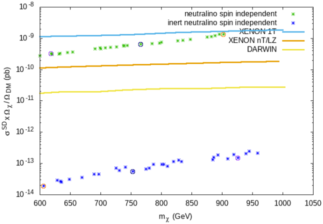
The second component has some effect on the relic density

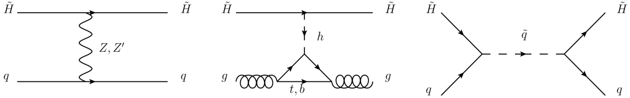
Here we plot the individual relic densities (red active, blue inert)



- The inert component has a slightly larger effective annihilation cross section due to smaller mass splittings
- The kink shows the effect of the two-component scenario, the higgsino-higgsino scatterings generate new charginos that coannihilate with the heavier component

The active higgsino can be seen in direct detection experiments, the inert cannot

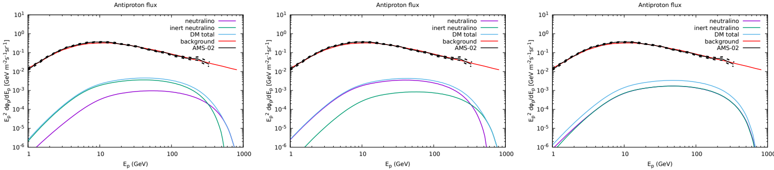




- The active higgsino can be seen in future direct detection experiments, the inert one is below the neutrino floor
- For the active the Z and h portals are the most important, for the inert one the Z' is the only unsuppressed one

Indirect detection signals are too much smaller than the background

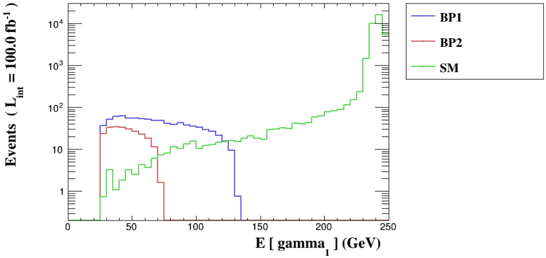
As an example the antiproton fluxes predicted from some benchmarks:



- The flux shapes are different and the fluxes are comparable between the two components, but unfortunately the intensities are too much below the background

A chargino-initiated monophoton signature is possible at ILC

- If the inert higgsino is light enough, there are some chances of seeing it at colliders
- The Z-boson coupling to neutralinos is suppressed, but γ and Z couple to charginos
- The resulting leptons/pions from $e^+e^- \to \tilde{\chi}^{I+}\tilde{\chi}^{I-} \to \ell^+\ell'^- +$MET are so soft that they will not be seen, instead a monophoton signature is possible with a kinematical maximum value for E_γ



Conclusions

- The E6SSM offers a framework for some viable two-component dark matter scenarios
- In the case of two higgsinos, the active component can be seen in future direct detection experiments, it escapes from current ones
- The inert higgsino may be seen at e^+e^- colliders through monophoton signatures, if it is sufficiently light, the prospects in other channels are not too good
- We aim to pursue further collider signatures of the model in the presence of two dark matter candidates