Models for WIMPs

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DMAstroLHC

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7 July 2014

Introduction

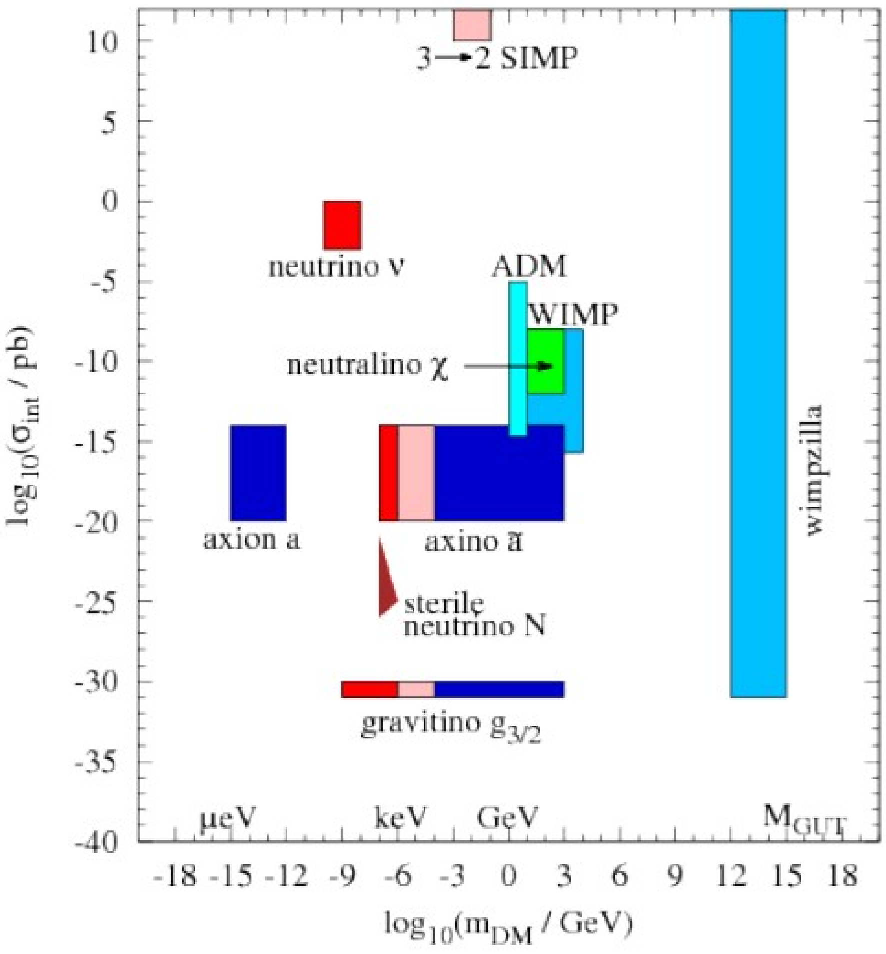
- Strong evidence for dark matter from astrophysical and cosmological observations.
- Motivation for new particles from particle physics : stabilization of Higgs, unification …
- Can one of these new particles explain the dark matter ?
- In last couple of years the LHC has made a major discovery : the Higgs boson and also made indirect/direct searches for new particles beyond the standard model (BSM) – no clear direction on 'beyond' but constraints on various models
- Possibility to probe new physics at TeV scale has rekindled interest in building models with observable predictions at the TeV scale including those addressing the DM problem

In addition various hints in direct/indirect detection motivate new DM models

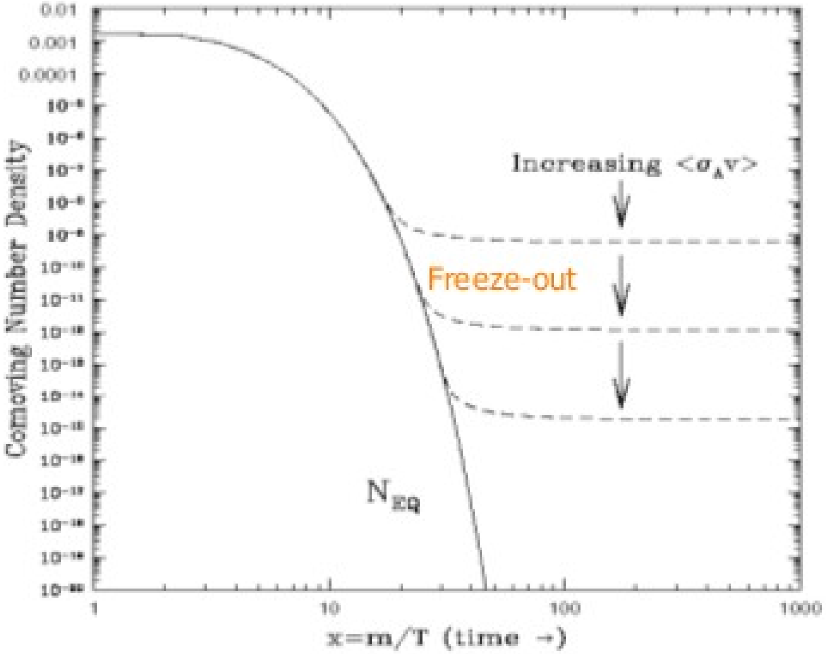
- DAMA/CoGenT, Fermi-LAT Galactic Center, Xray

Complementarity between collider searches for new particles and DM with astroparticle searches

Dark matter candidates



Wimp 'miracle'



$$\frac{dn}{dt} = -3Hn - <\sigma v> \left[n^2 - n_{eq}^2\right]$$

$$\Omega_\chi h^2 \approx \frac{3 \times 10^{-27}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma v \rangle} .$$

- ‘Typical’ weak interaction cross section --> $\Omega h^2 \sim 0.1$
- Precise determination of $\Omega h^2 = 0.1199 +/- 0.0027$ (PLANCK)

WIMP models

- A wide variety of models with weak scale stable neutral particle (stability ensured usually by symmetry) and different motivations
- Particle physics
  - Hierarchy problem – Higgs
  - Unification
  - Extra dimensions
  - Scalar sector
- Dark matter
  - Hidden sector
  - Minimal extensions of SM

Supersymmetric dark matter

Status

Neutralino

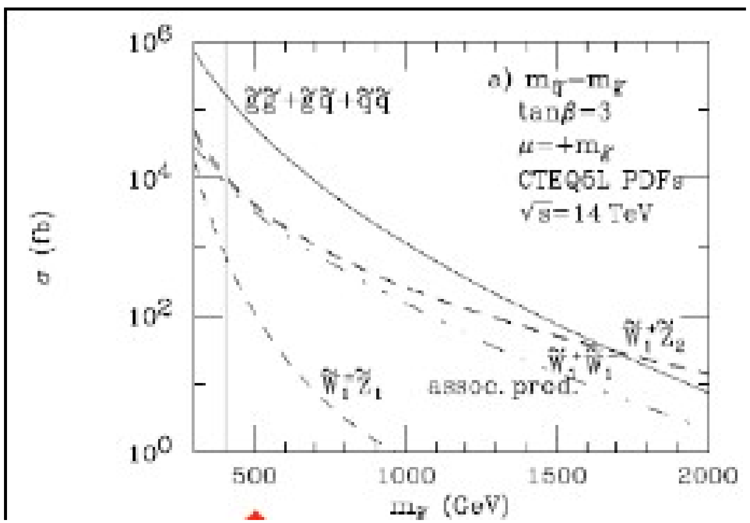
- Supersymmetry : symmetry fermion/boson – prevent large corrections to Hgigs mass
- Unification of couplings at GUT scale better than in SM
- With R-parity conservation – needed to suppress proton decay – get DM 'for free'
  - Usually the lightest neutralino : partner of neutral gauge bosons (bino/wino) and Higgs (Higgsino)
  - Lightest neutralino is stable and weakly interacting
- Exact nature not known (mixed state) -> properties not well defined : orders of magnitude variations in DM observables such as relic density, direct detection, indirect detection
- Since only SUSY particles known are SM ones : large parameter space to explore

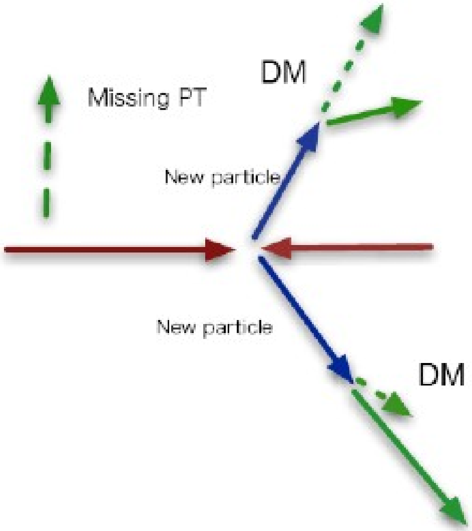
Neutralino in CMSSM

- Traditionally predictions in context of CMSSM (scenario with parameters defined at unification scale) full spectrum predictable from handful of parameters
- Neutralino is generally bino U(1) (too much dark matter unless m ~100GeV) or bino/higgsino
- Relations between masses of particles – e.g. m_{gluino}~6 m_{LSP}
- LHC has put strong constraints on this model – because m_h=125GeV with SM-like couplings, no squarks and/or gluino discovered , no evidence of SUSY in B physics

LHC

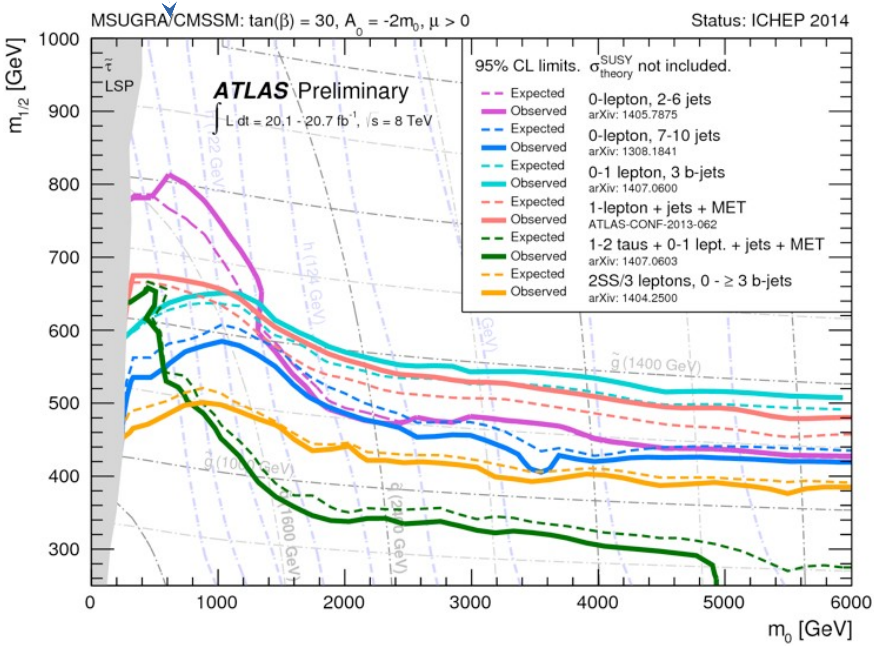
- pp collisions 7-8TeV (13TeV in 2015)
- Direct DM production missing energy no trigger – can use initial state radiation of gluon or photon
- Largest cross sections: coloured sparticles, DM in decays
- DM signature (missing E_T)

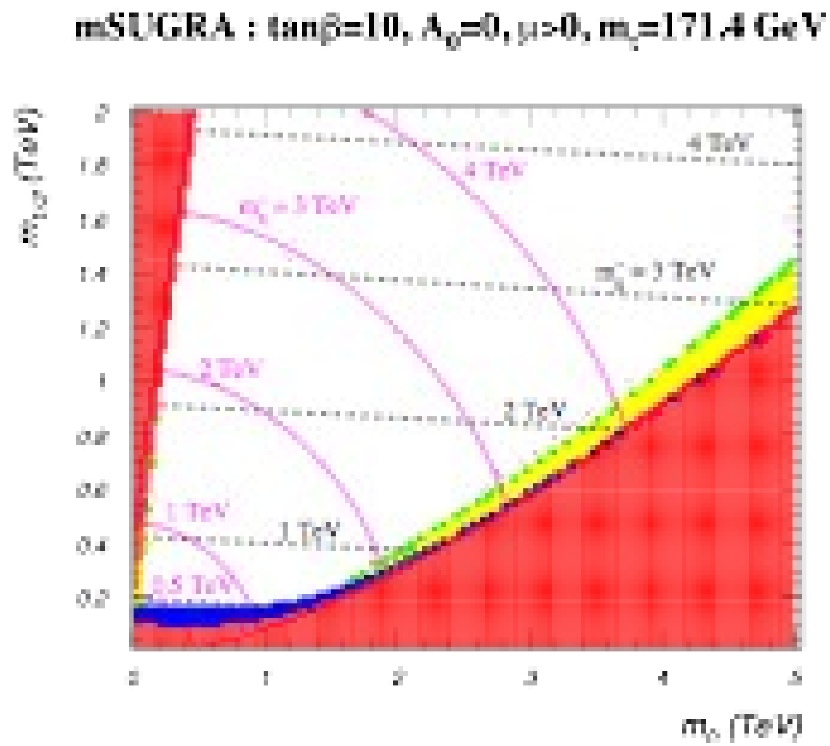




LHC limits on CMSSM

mh>122 GeV

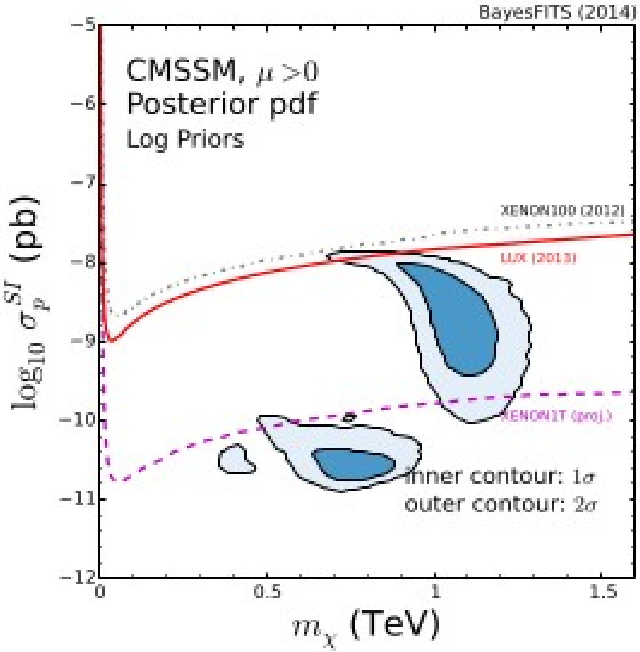


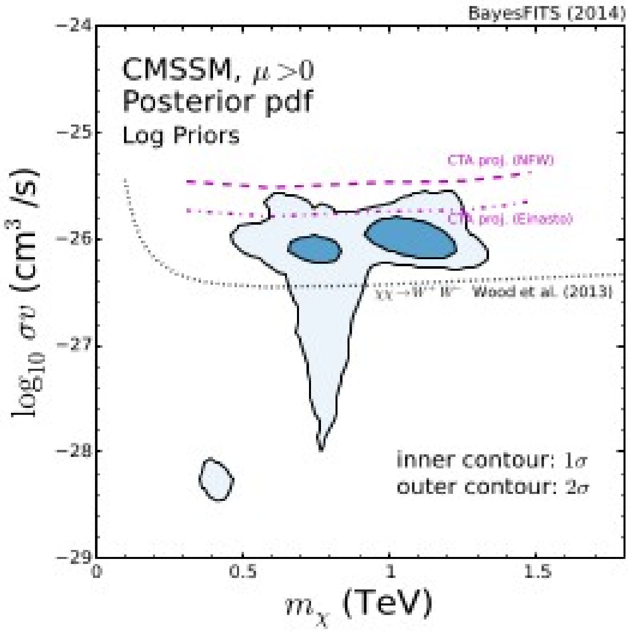


- gluino,squark > 1.4 TeV

What's left?
After fit to all observables

L. Roszkowski 1405.4289

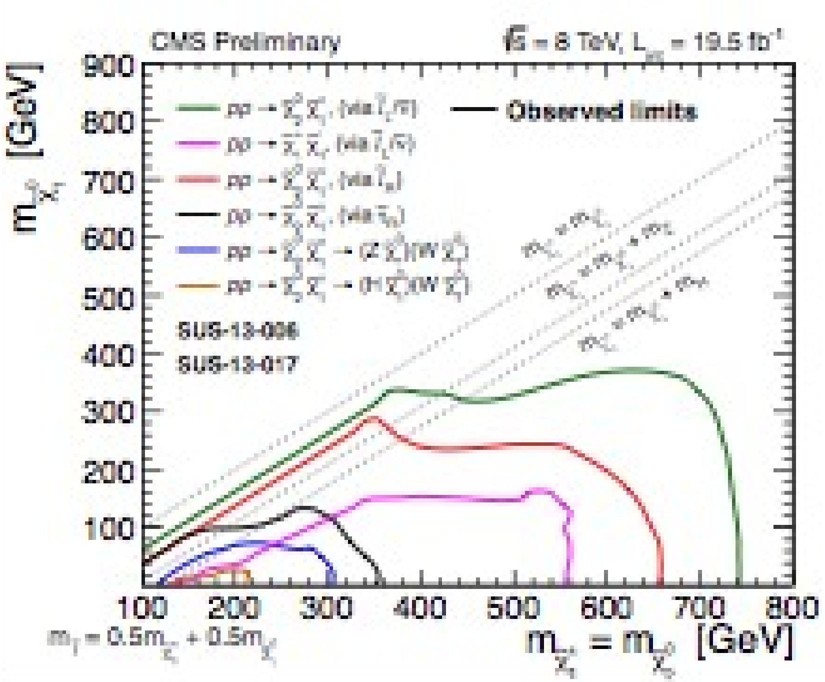




- Indirect detection : annihilation into bb and WW are usually dominant, annihilation into light fermions are suppressed at small v

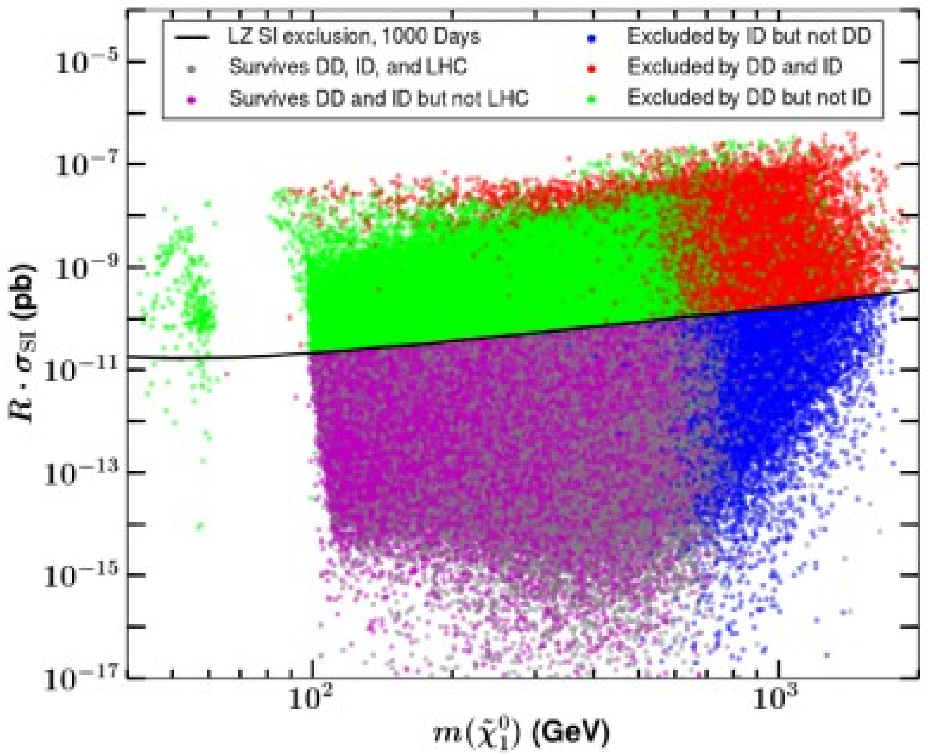
Neutralino in pMSSM

- Near the end of neutralino era ?
- Partly because use constrained model – neutralino with some higgsino/wino content leads to more efficient annihilation in W pairs
- pMSSM : phenomenological MSSM – electroweak scale input parameters ~19 with few assumptions
- Decouple strong and electroweak sector
- Important constraint from Higgs properties : mass (Higgs mass receives large contribution from stop sector) and couplings
- Satisfy LHC bounds from electroweak-ino searches (much weaker)



- Weak constraints on higgsino LSP (small mass splitting) and when dominant decay is into gauge bosons

Probing pMSSM DM – constraints and projections



Hewett et al, 1405.6716

- Include all particle physics constraints
- Only upper bound on relic density
- LHC + Projections for
  - Xenon1T
  - FermiLAT
  - CTA
  - IceCube/DeepCore

Susy DM

- Neutralino DM is alive and well even with several new particles below TeV scale
- Direct detection and indirect detection constrain parameter space and are complementary to LHC
- More possibilies for DM in MSSM extensions
  - NMSSM (singlino)
  - Sneutrino : partner of SM LH neutrino is not good DM candidate and RH sneutrino is too weakly interacting with SM particles for thermal DM - add new couplings e.g. to Higgs (mixed sneutrino), to Z' (UMSSM) to singlet Higgs (NMSSM)

Extra dimensions and DM

Extra Dimensions - UED

SM in a Universe with Xtra dimensions simplest case

One extra dimension compactified on S_1/Z_2 orbifold (mUED)

After compactification : only chiral SM – low-energy effective theory – each SM particle has tower Kaluza-Klein states

Conserved momentum in 5th dimension -> conserved KK number

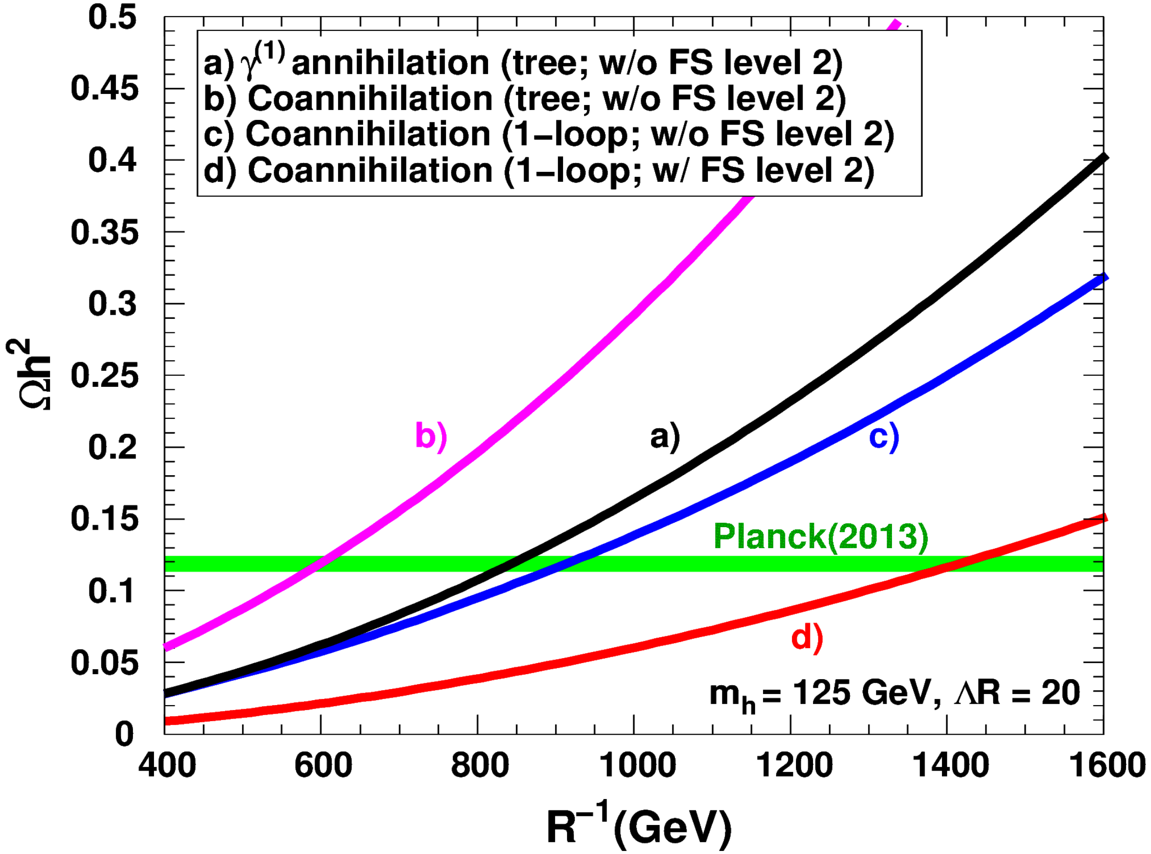
KK parity -> dark matter – lightest particle of level 1 (photon, neutrino, graviton)

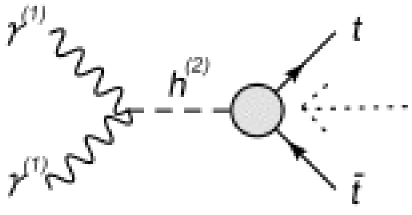
At each level KK particles nearly degenerate split only by symmetry breaking and loop effects

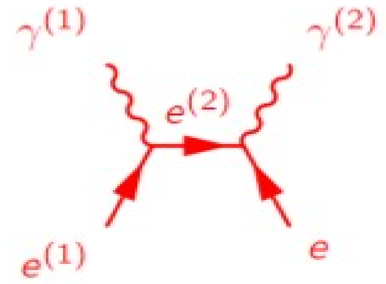
Many degenerate particles -> coannihilation

Parameters : cut-off scale, Λ, R^{-1}, m_h

Scale for UED DM





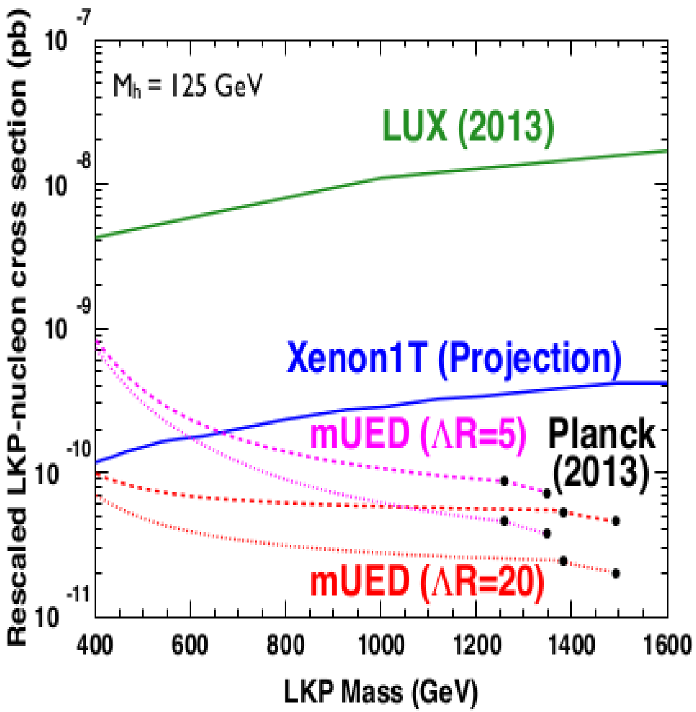


M. Kakizaki

GB, Kakizaki, Pukhov JCAP(2011)

Detection

Direct – rather weak



Indirect – large contribution from annihilation into fermions (leptons) - Suppression only when coannihilation dominant

LHC :

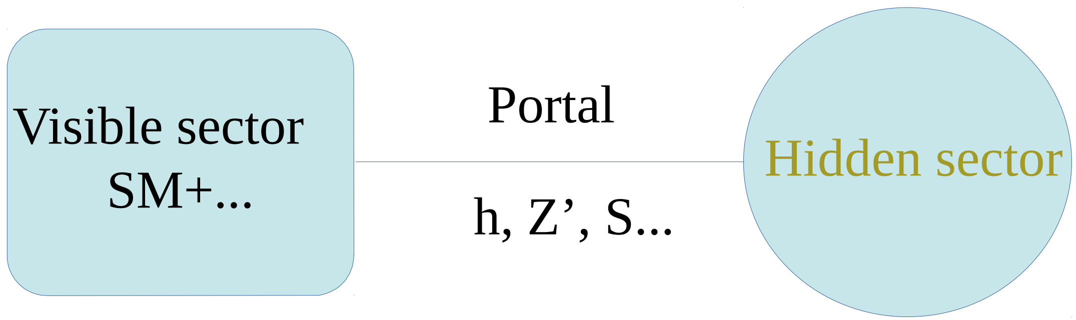
– trilepton searches-

R^{-1} > 1.2TeV (Belyaev et al 2012)

- contribution to H partial width--> R^{-1} > 600GeV

(GB et al, 1207.0798)

Portals



Higgs-field portal into hidden sectors
Patt, Wilczek 0605188

We present examples that are neither grotesque nor unnatural.

- DM and the Higgs portal
  - Bertolami,Rosenfeld, 0708.1794; March-Russell et al, 0801.3440; J. Mcdonald, Sahu, 0802.3847, 0905.1312; Tytgat, 0906.1100; Aoki et al, 0912.5536; Andreas et al, 1003.3295; Arina et al, 1004.3953; Cheug,Nomura (singlet)1008.5153; Djouadi et al, 1112.3299 ..
- DM and the Z' or A' portal
  - Krokilowski, 0712.0505; Chu et al, 1112.0493; Dudas et al, 0904.1745....

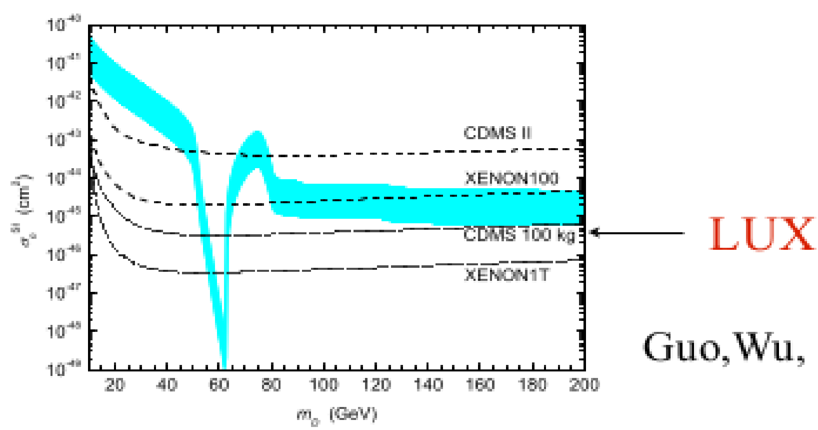
Minimal model

- Singlet scalar - stability guaranteed by some discrete symmetry
  - Silveira, Zee(1985); J. McDonald, PRD(1994) and hep-ph/0702143

$$L_S = \partial^\mu S_i^\dagger \partial_\mu S_i - m^2 S_i^\dagger S_i - \lambda_S S_i^\dagger S_i H^\dagger H$$

- Relic density $\Omega h^2 = 0.1199$ determines λ_{SH}/m_S (for heavy DM)
- The same coupling enters amplitude for elastic scattering on nuclei

Direct detection



Guo,Wu, 1103.5606

- LHC has discovered a Higgs boson – couplings close to SM, limited room for new decay modes such as decay in DM – invisible width of the Higgs <20 % of total width

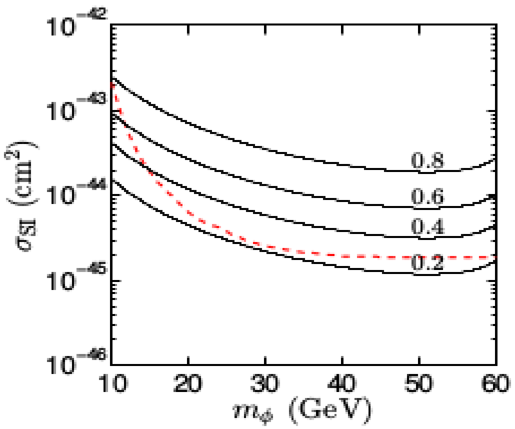
- Both the invisible width and SI cross section depend on h coupling to DM

$$\sigma_{SI} = \eta \mu_r^2 m_p^2 \frac{g^2}{M_W^2} \Gamma_{\rm inv} \left(\sum f_q^p \right)^2$$

- Such models could lead to large DD rate for 10GeV DM (CoGENT/CDMS/DAMA...) - ruled out by upper limit on invisible width - as in Higgs portal model, Djouadi et al, arXiv1112.3299

- In singlet scalar DM model, relic density requires coupling that leads to large Br_{inv} ---> $m_{S>}$ 55GeV

Scalar DM



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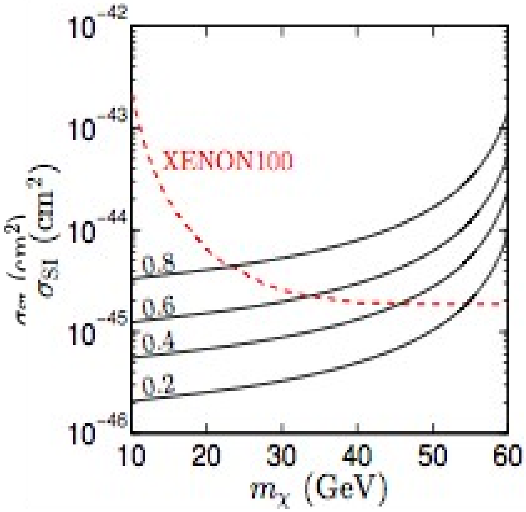
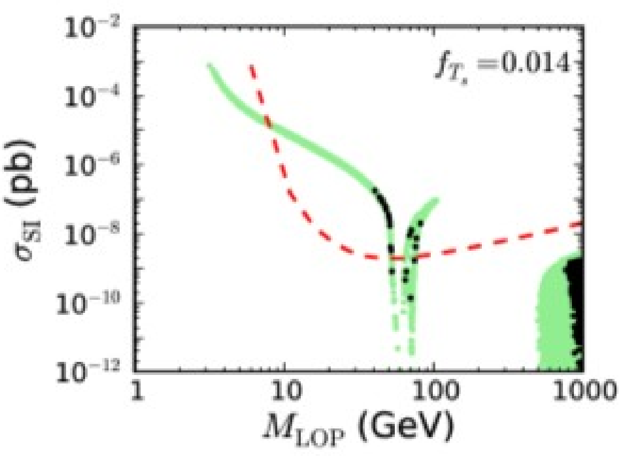


Less minimal scalar models

- Extended scalar sector generic in extensions of the SM
  - not LHC-friendly - can only probe Higgs sector
- Beyond minimality : increasing number of scalar fields (doublet, doublet+ singlet, triplets ...)
- Inert doublet : initially proposed as alternative to light Higgs – later reliased that good alternative to neutralino DM
- Despande, Ma (1978), Barbieri Hall Rychkov (2006)
- Z_2 symmetry : H or A stable
- No couplings to fermions
- Lopez Honorez et al (2007); Arina et al (2009); Hambye et al (2009), Lopez Honorez, Yaguna (2011);



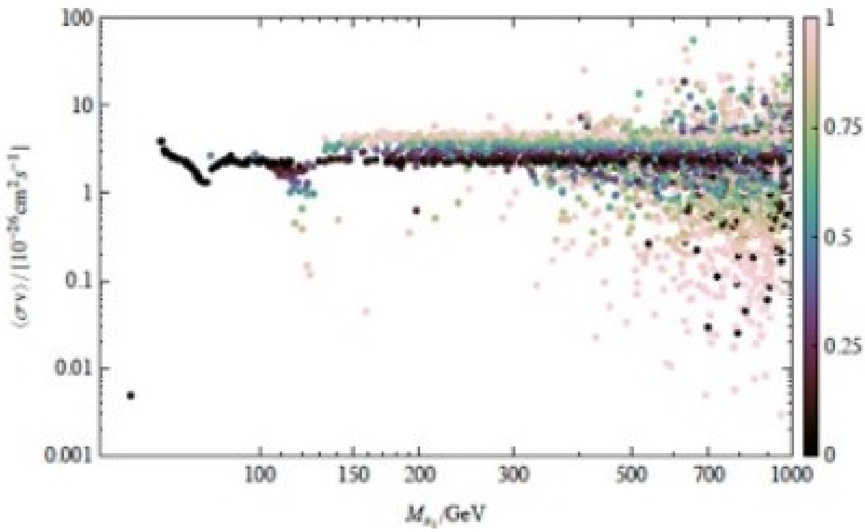
Goudelis, Herrmann, Stal 1303.3010

Inert doublet + singlet + Z_3

Extending discrete symmetry -> New phenomena : semi-annihilation, interactions between two DM candidates (GB et al 1202.2963, 1211.1014)

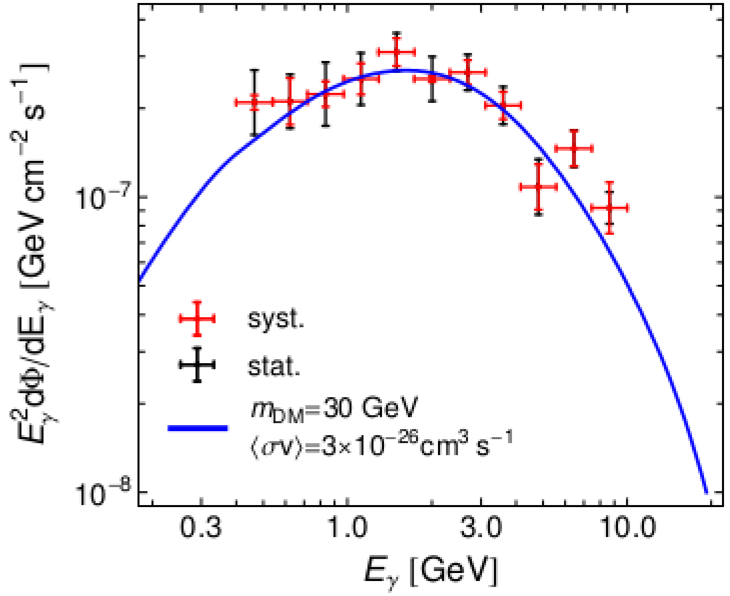
Possiblity of having large enhancement in σ v -> resonance effect when $m_{x1} \sim m_{x2}/2$

Main channels bb, WW, ZZ, hh, x_1h



Gamma-ray excess

- Fermi-LAT : gamma-ray excess from 7°X7° region around the GC
  - Hooper, Goodenough, PLB697(2011)
- Compatible with DM of 30 GeV annihilating in bb
- Simple model compatible with this and no other signal :
  - Dirac fermion coupled to pseudoscalar (coupling proportional to mass)
  - Few constraints on pseudoscalar



C. Boehm et al 1401.6458

XDM

Excited DM : dark sector U(1) kinetic mixing with SM + fermion and excited fermion + dipole operator (Finkbeiner, Weiner 2014)

$$\chi\chi \to \chi^*\chi^*, \text{ followed by } \chi^* \to \chi\gamma.$$

For keV mass splitting – decay cosmological scale

Compatible with Xray line at 3.56 keV from Galaxy clusters in XMM Newton

- Bulbul et al, Astrophys J 789 (2014)

Conclusions

- A variety of DM models (even only WIMPs)
- The next run of LHC (higher energy and luminosity) in 2015 will provide crucial information on TeV scale physics and beyond the standard model
- Expect much more info on DM from astroparticle and collider searches in next few year
- The results might be incompatible with better theoretically motivated models -> will have to focus on models that explain confirmed DM signals