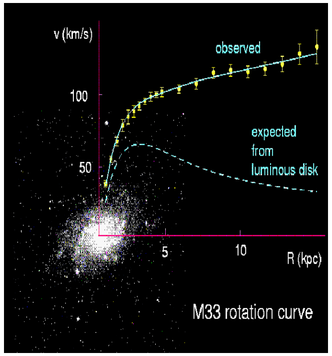
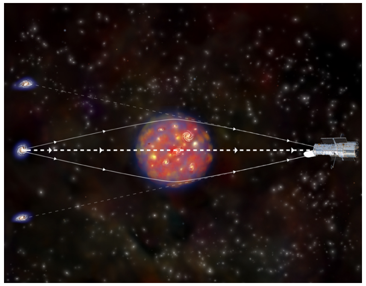
The origin of DM and constraints from astroparticles and the LHC

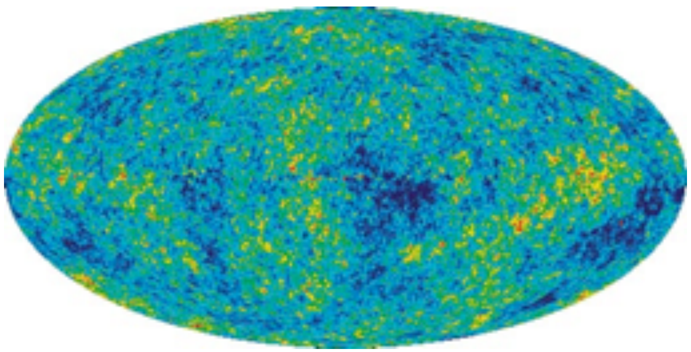
G. Bélanger
LAPTH, Annecy-le-Vieux

12/10/2012

DM evidence







- Ordinary matter only 4% of matter content of the Universe

Dark matter : a WIMP?

- Data from galaxies, clusters, CMB all point to large DM component
- Structure formation: DM is mostly cold and weakly interacting
- DM stable at cosmological scale
- Can DM be explained by some new weakly interacting particle (WIMP)?

In standard cosmological scenario where DM particles are thermal equilibrium in early universe and during expansion universe DM "freeze-out" , relic abundance

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

A WIMP has 'typical' annihilation cross section for $\Omega h^2 \sim 0.1$ (WMAP)

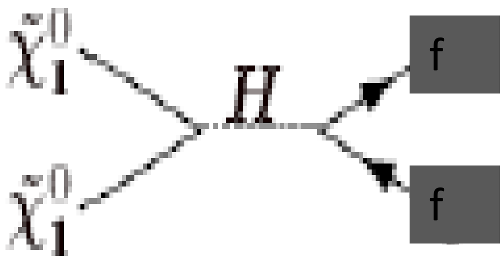
- Can extensions of SM which address hierarchy problem and/or motivated by theory naturally provide WIMP DM candidate
  - Many possibilities
  - Are predictions for DM models compatible with limits/ hints from DM searches or collider results

- LHC and astroparticle experiments should provide data to answer this question
- New this year: the limits from LHC -> constraints on DM models and new physics in general
- The discovery of the Higgs further constrains new physics models -> impact on DM
- Also improved limits from Xenon (direct detection)
- New limits from Fermi-LAT (photon flux)
- AMS is taking data

DM : Astro/Cosmo/Colliders

Direct
Elastic scattering

Annihilation
Relic , indirect

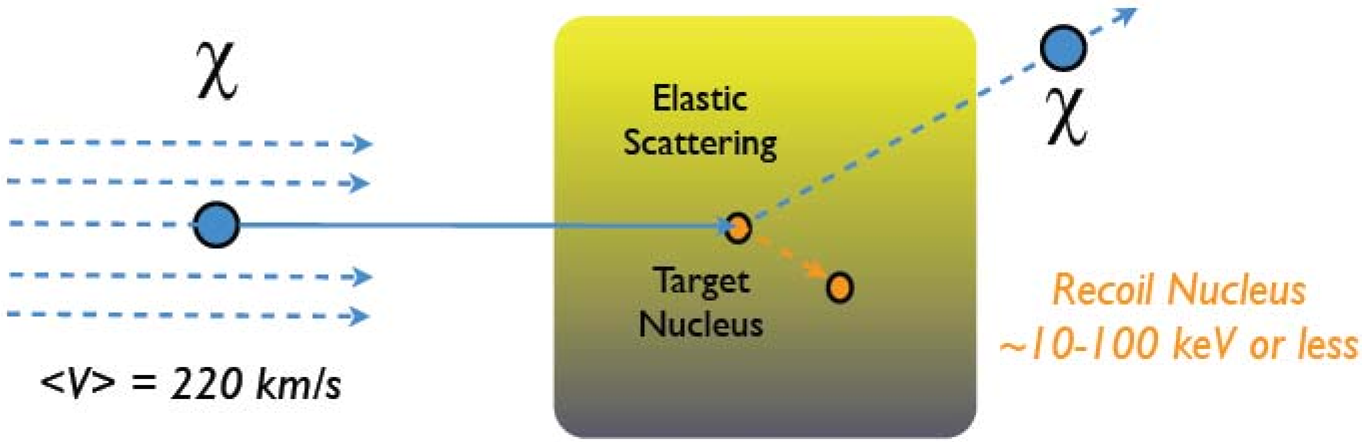


Colliders

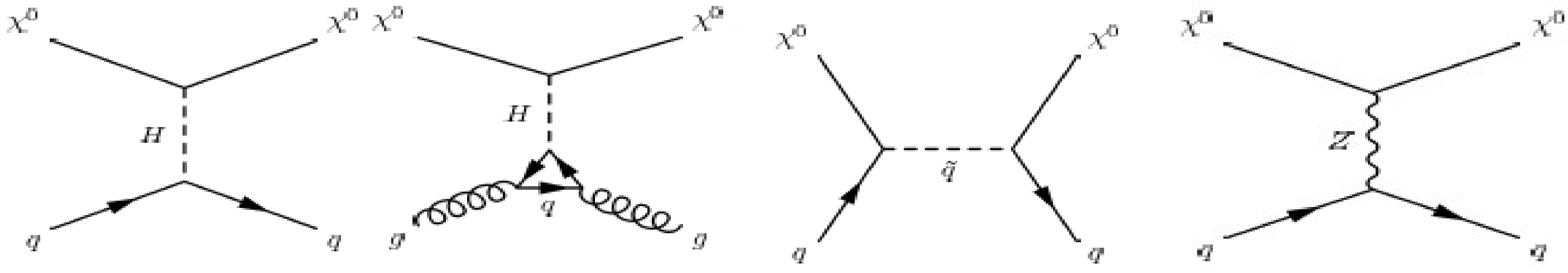
(DM is not detected,
Look at other new particles)

Particle physics model

Direct detection



- Elastic scattering of WIMPs off nuclei in large detector
- Would give best evidence that WIMPs form DM
- Two types of scattering:
  - Spin independent (coherent scattering on A nucleons)
  - Spin dependent (only one unpaired nucleon)



- SI cross-section determined mainly from DM interactions with Higgs (Majorana DM)

$$\frac{dN^{SI}}{dE} = \frac{2M_{det}t}{\pi}\frac{\rho_0}{M_\chi}F_A^2(q)\left(\lambda_p Z + \lambda_n(A-Z)\right)^2 I(E)$$

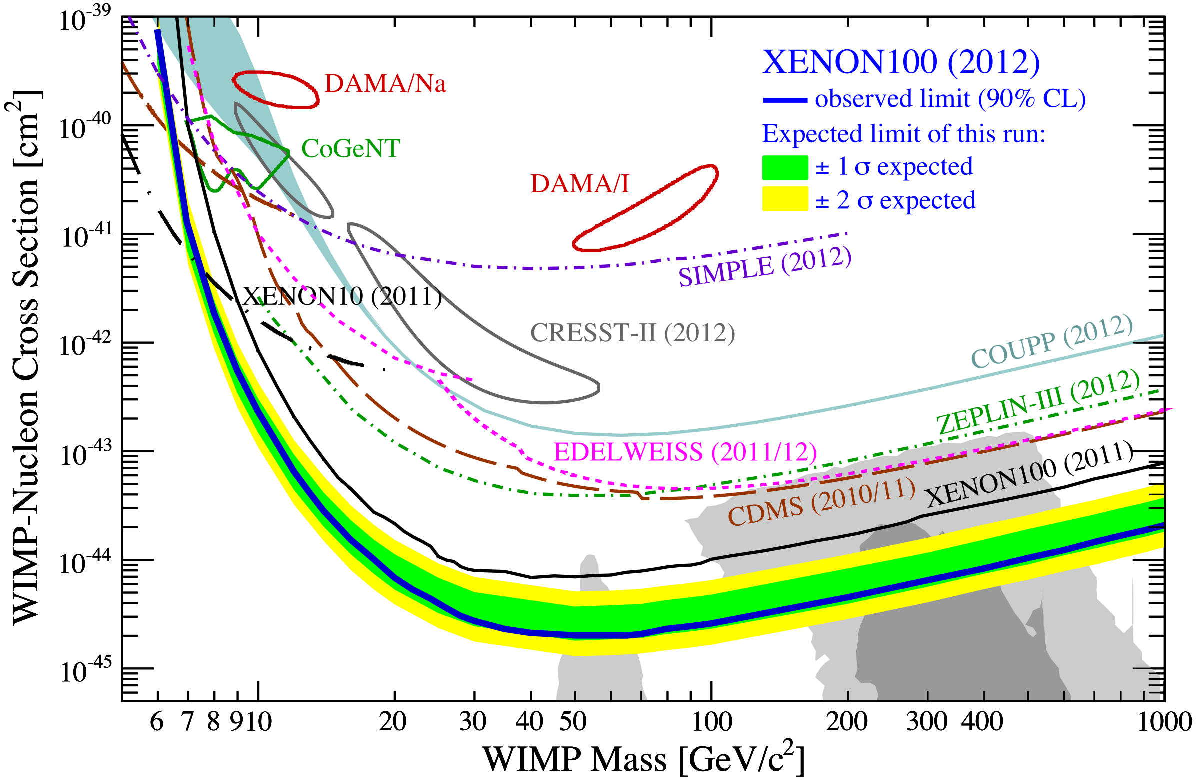
Nuclear form factors

Particle physics
+ quark content in nucleon

DM velocity
distribution

Direct detection - results

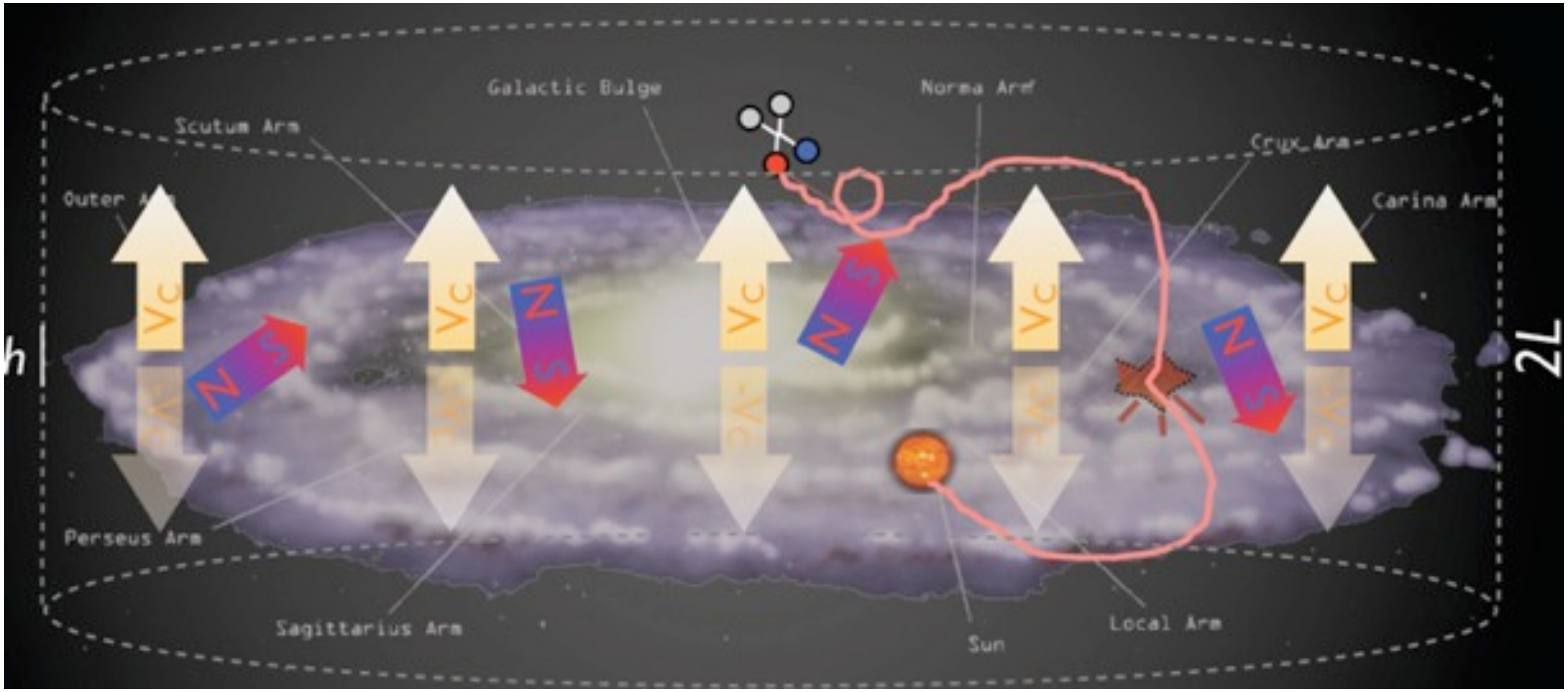
- Numerous experiments with different materials - sensitive enough to constrain popular DM models.
- Hints of signals (no consistent explanation)



1207.5988

Indirect detection

- Annihilation of pair of DM into SM particles

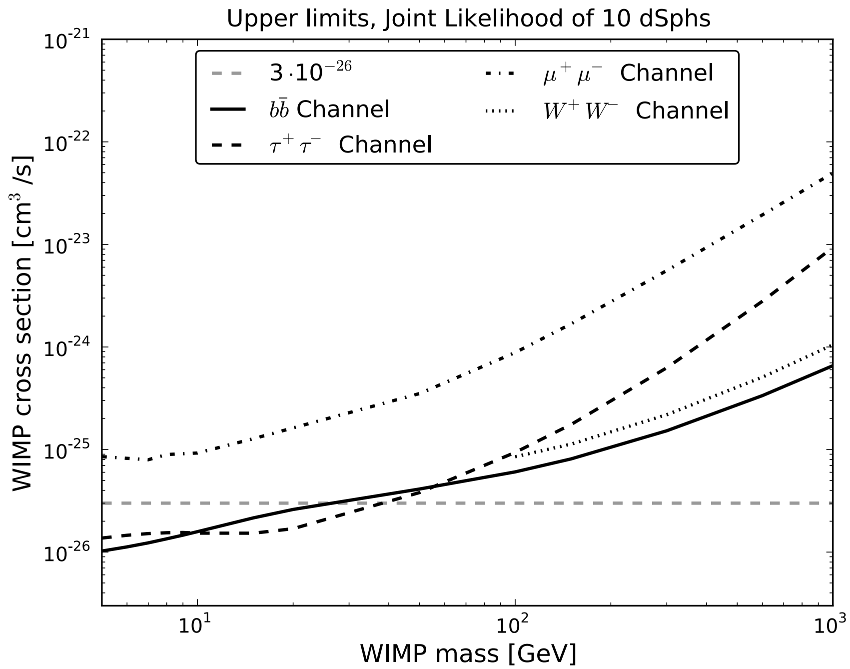


$$\frac{\partial N}{\partial t} - \nabla \cdot [K(\mathbf{x}, E) \nabla N] - \frac{\partial}{\partial E}[b(E)\, N] = q(\mathbf{x}, E)$$

Source

DM Indirect detection

- Searches for DM in 4 channels
  - antiprotons (PAMELA, AMS)
  - Positrons/electrons(Pamela, Fermi, AMS)
  - Photons from GC, Dwarf galaxies (Fermi,Hess...)
  - Neutrinos from Sun(IceCube..)



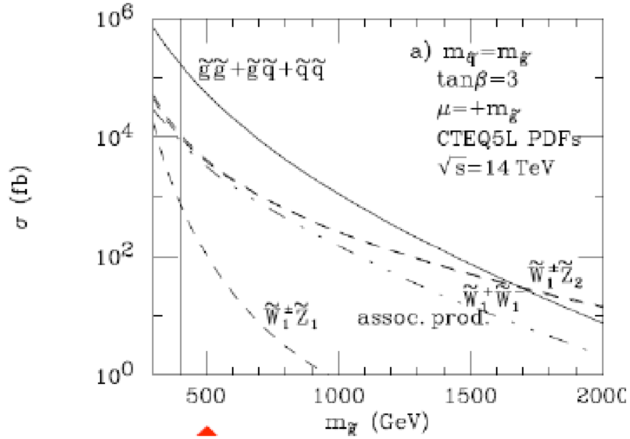
Fermi, 1108.3546

- With photons FermiLAT probes the canonical Xsection for light Wimps

LHC

- LHC a pp collider
  - 7TeV(2011) 5fb^{-1}
  - 8TeV(2012) 15fb^{-1} ++
  - ~14 TeV(2014) 100fb^{-1}

- Large cross sections for coloured particles

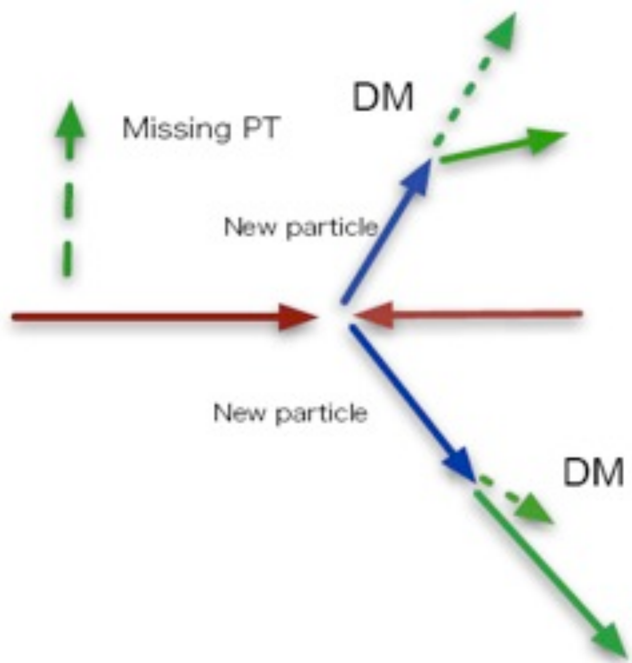


DM at LHC

- Direct production : missing energy no trigger
- Direct production +X : trigger but lower cross section
- Production of coloured particles : DM in decay chain

- Signatures of DM:
  - missing pT
  - missing E_T

- Channel jets+ missing E_T : first use to put limit on new particles that decay into invisible particle



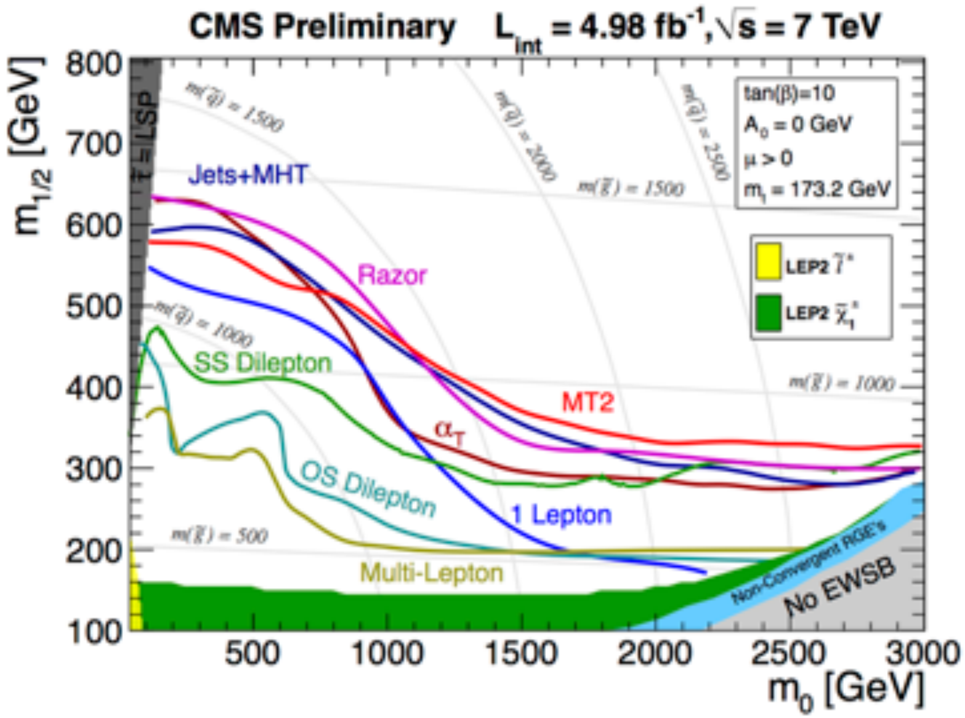
Supersymmetry

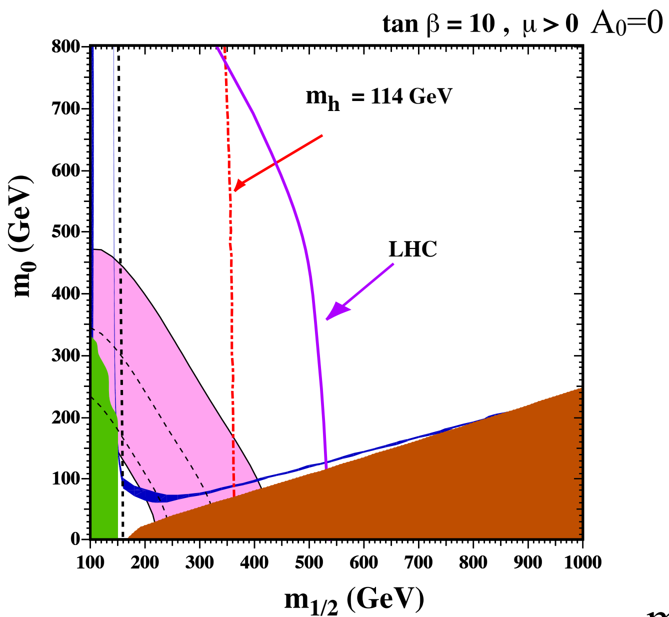
- Symmetry that relates boson/fermion
- Provide a solution to hierarchy problem
- LSP is stable because of R-parity (needed for stability of proton)
- if LSP neutral : good DM candidate, usually neutralino spin 1/2 partner of gauge bosons and Higgs scalars

- Many free parameters
- Consider constrained model (e.g. CMSSM) : only 4 1/2 parameters at GUT scale-> relation between masses of sfermions/gauginos

Constrained MSSM

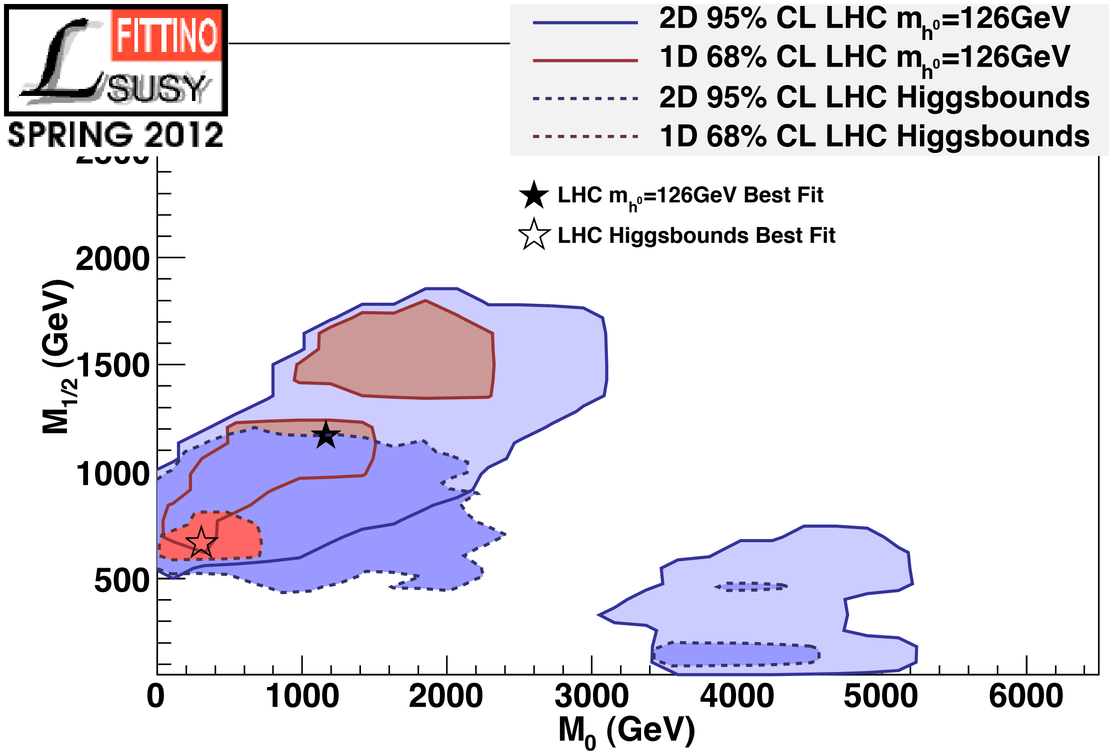
- Both Higgs and searches for squarks and gluinos constrain the low mass sector





↑
m_h=125

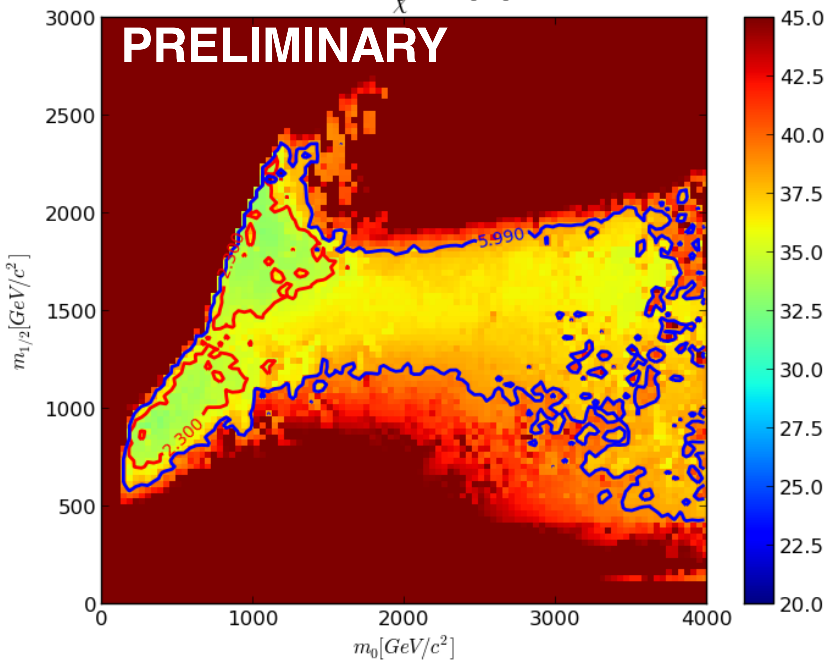
Global fit to all observables



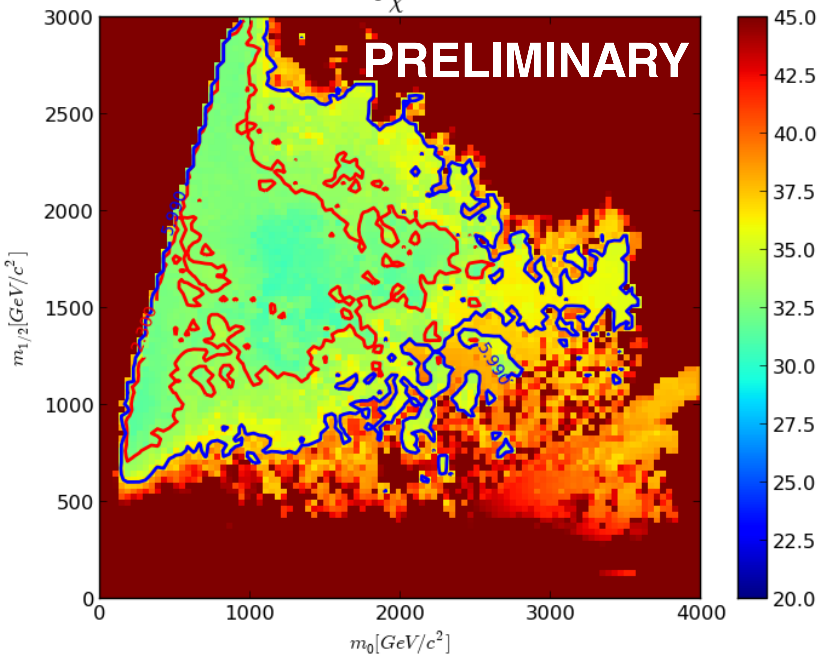
- LHC Susy searches, Higgs, Flavour (B physics), muon g-2, relic density, Xenon

Fine-tuning

CMSSM



NUHM1



- After LHC results - large fine-tuning
- Improves in models with more free parameters or extended particle content

Neutralino DM

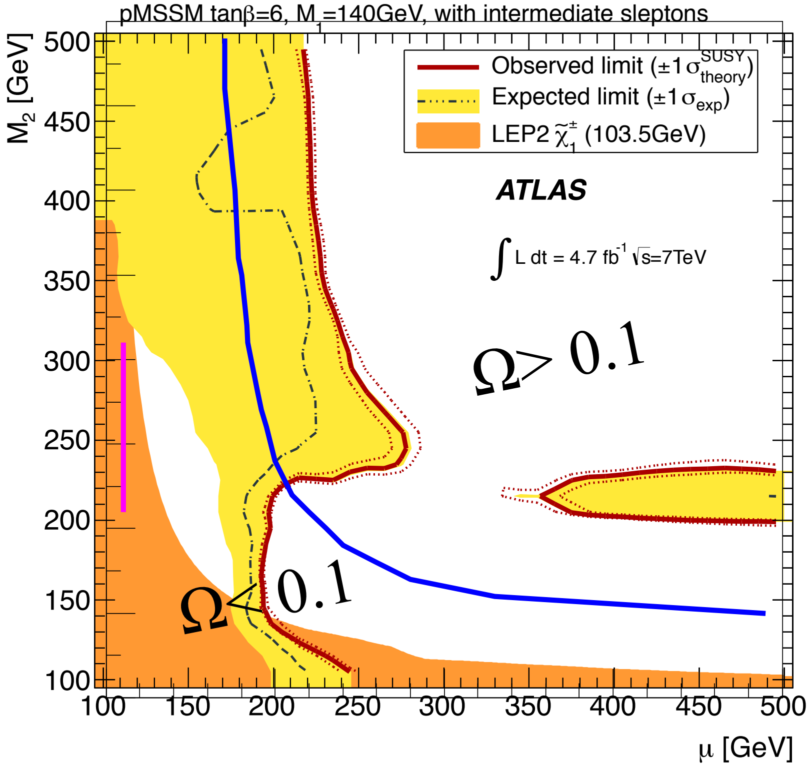
- Strong sector not necessarily correlated with EW sector, e.g. in "natural" SUSY only gauginos, higgsinos and stops are "light"

- In pMSSM (19-24 parameters) many scenarios compatible with m_h=125GeV and other LHC searches
- CMSSM and simplified models (only a few new particles) are not general enough - need to interpret the LHC results for different type of SUSY and other new physics

- More direct information on DM : look directly at the EW sector (despite lower cross sections)

EW production

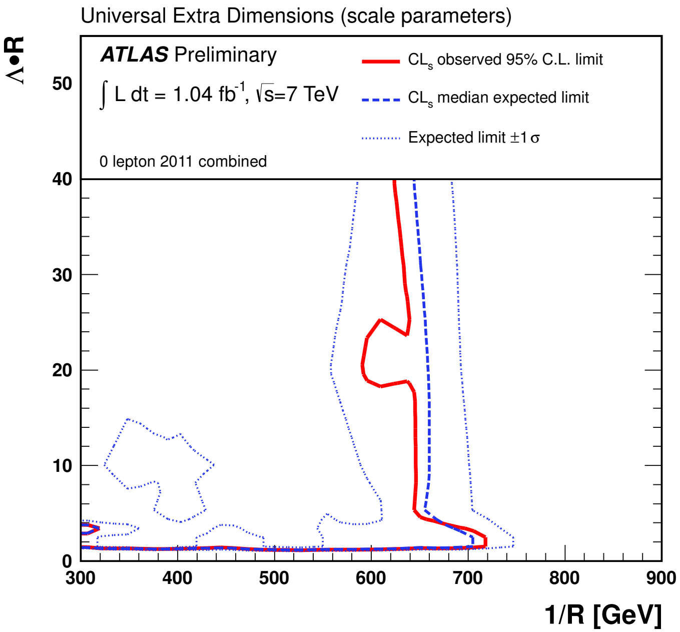
- Direct gaugino production, multi-lepton final states
- Only 4 parameters in neutralino/chargino sector
- Start to constrain SUSY DM

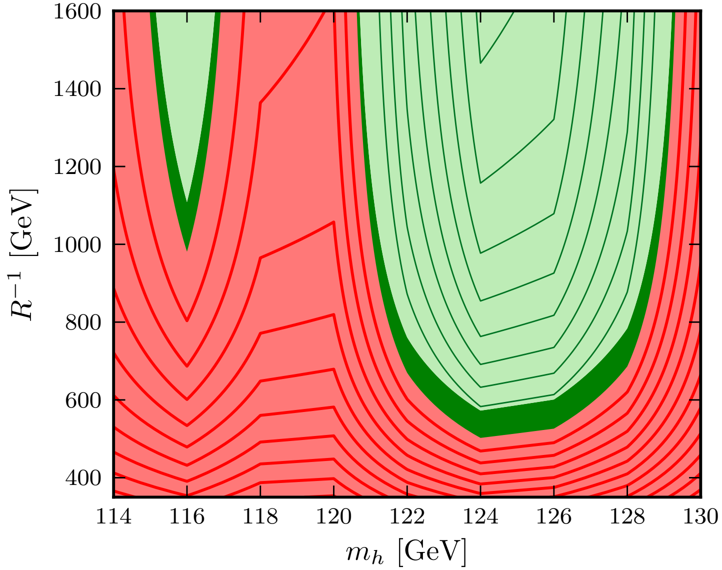


Other new physics

- Similar searches apply to other SM extensions with stable neutral particle
- UED: extra dimensional model with KK parity for proton stability
- DM candidate is the KK partner of photon (spin 1)
- KK particles influence Higgs couplings (different from SUSY) : new KK top enhance ggh, suppress $h\gamma\gamma$
- Searches for KK particles similar signatures as SUSY
  - typically spectrum is nearly degenerate

UED - results

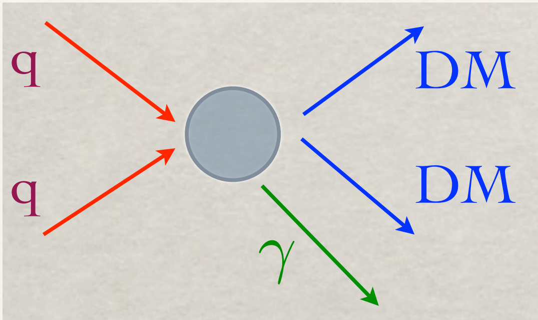


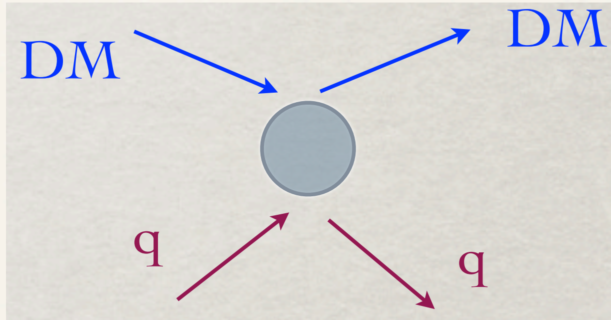


- Higgs and direct searches both set lower bound on scale of KK particles : compatible with DM relic density (upper bound over 1 TeV)

- Many possible new physics models with DM candidate (neutral stable particle)
  - MSSM+υ,NMSSM,UMSSM,BMSSM ....
  - UED, little Higgs, Inert doublet (scalar) ...

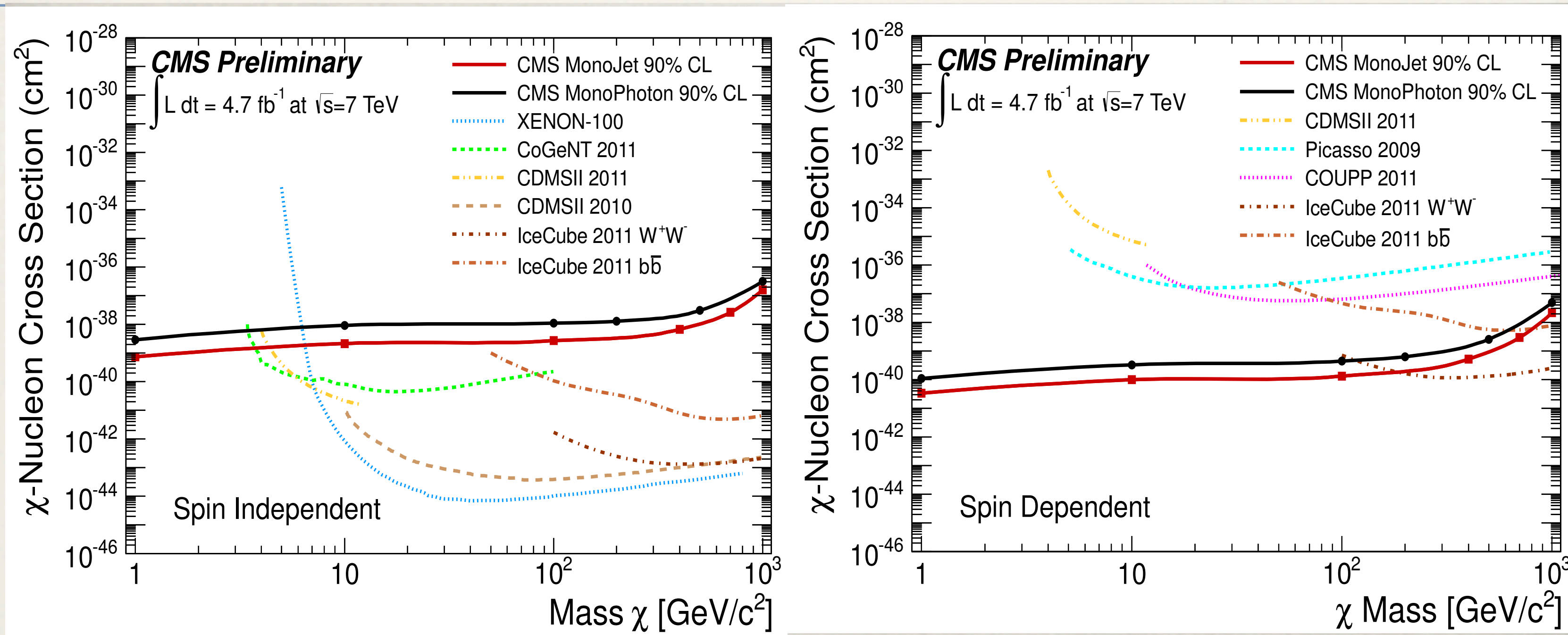
Model independent approach





- DM production: no trigger
- Radiate photon or jet -> limit on DM production apply to any model
- Use effective operator approach -> relate LHC cross section with direct detection
- Caveat: effective operator not always valid
- Direct detection : contribution from heavy quarks quite large

Monojet-monophoton



- Very powerful to probe light DM (where direct detection insensitive)
- Most powerful for spin-dependent interactions

Objectives for DM at LHC

- Find signal in at least one missing E_T channel
- Extract DM properties (gives possibility to control particle physics dependence in DM observables) and confront with astro/cosmo results
- What do we need to measure?

What do we need to measure?

- Mass scale for DM
- Presence of particles in s-channel for DM annihilation (more Higgses)
- Coupling of DM to Higgs (determination of invisible Higgs) and/or Higgs in NP decays
- Presence of nearly degenerate particles -> coannihilation or not
- Coupling of DM to new particles (model dependent)

Conclusion

- Exciting times: with experiments providing lots of new data (collider/astro/cosmo) expect that in the next few years will make great progress in understanding better the nature of DM

- Eventually might even conclude that DM is not connected to hierarchy/NP or that DM is not a WIMP