Status of Dark Matter searches

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A very short summary of a long story:

Dammit! Another year without the identification of the dark matter component of the Universe!

Outline:

- A review focussed on the WIMPs as thermal relic particles

- Null detection so far of physics beyond the Standard Model at the LHC and its impact on the WIMP paradigm

- The inconclusive picture from direct detection: a light WIMP preferred?

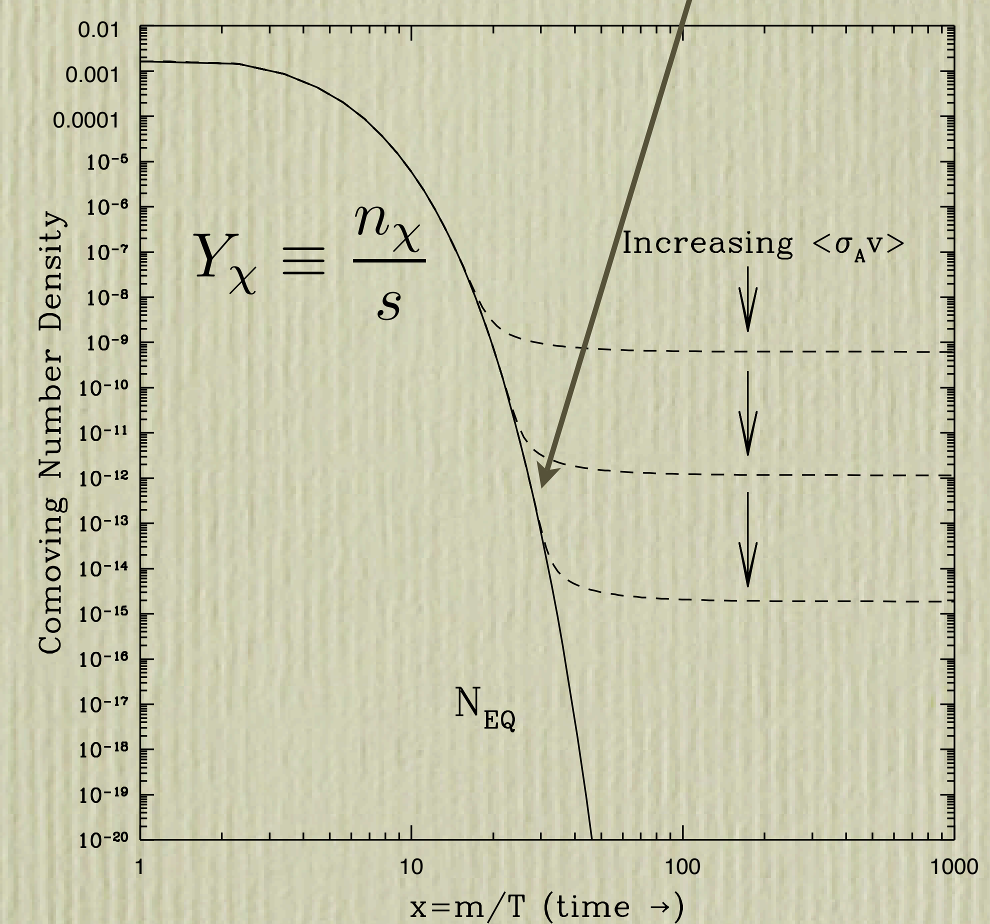
- The cross correlation with indirect detection signals: limits or "hints" of detection? Complementarities among different detection techniques as the key to solve the dark matter puzzle.

Disclaimer: a short review not exhaustive of all results in the last year and no attempt to produce an exhaustive list of references

CDM particles as thermal relics

Thermal equilibrium of χ enforced via: $\chi\,\bar{\chi} \leftrightarrow \mathrm{SM}\,\overline{\mathrm{SM}}$

$$\Gamma(T_f) = n_\chi^{eq}(T_f)\langle\sigma_A v\rangle_{T=T_f} \simeq H(T_f)$$



$$\Omega_\chi h^2 \simeq \frac{M_\chi\, s_0\, Y_\chi^{eq}(T_f)}{\rho_c/h^2}$$

(freeze-out + entropy conservation)

$$\simeq \frac{M_\chi\, s_0}{\rho_c/h^2}\,\frac{H(T_f)}{s(T_f)\langle\sigma_A v\rangle_{T_f}}$$

(standard rad. dominated cosmology)

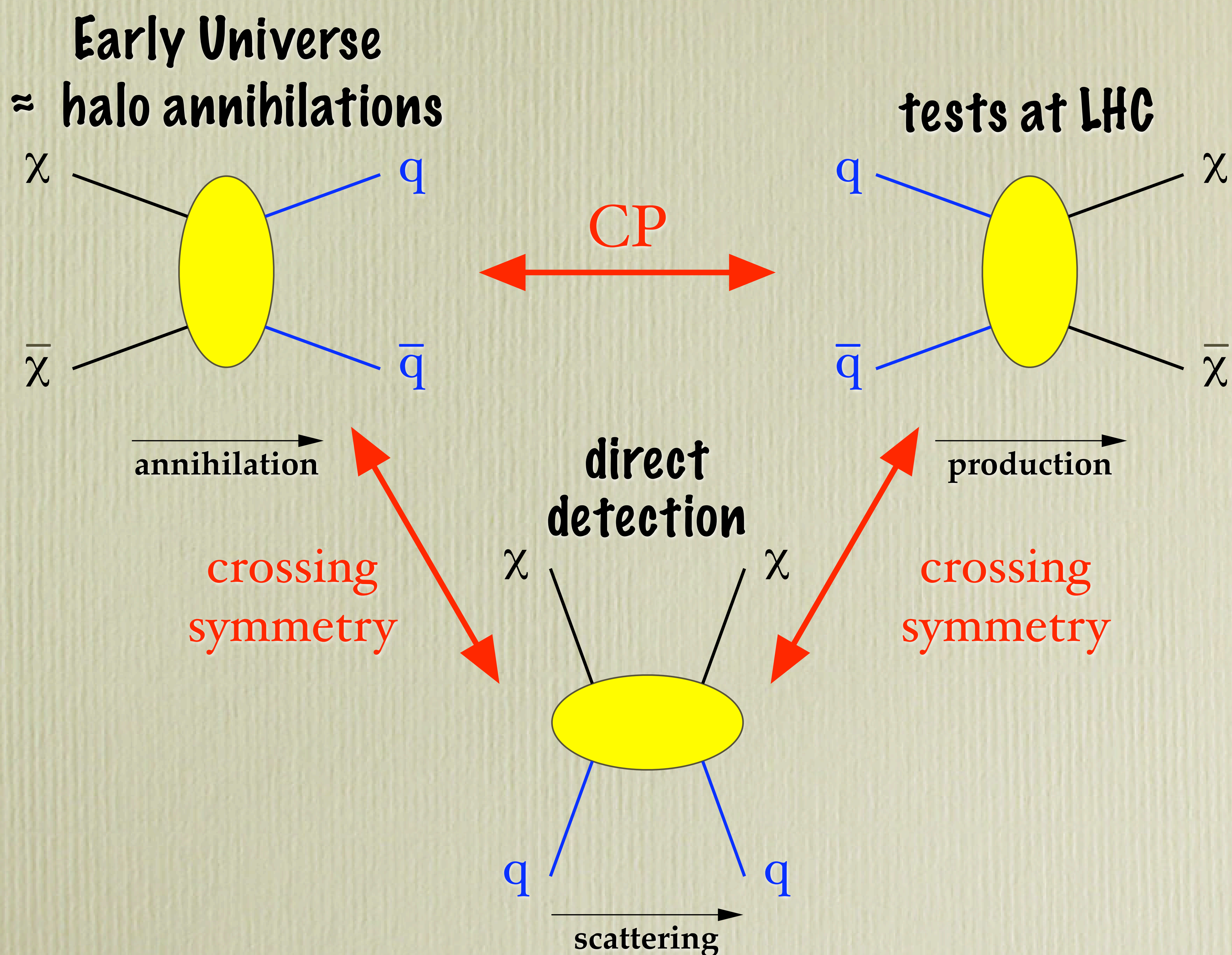
$$\simeq \frac{M_\chi}{T_f}\,\frac{g_\chi^\star}{g_{\rm eff}}\,\frac{1\cdot 10^{-27}\mathrm{cm}^{-3}\mathrm{s}^{-1}}{\langle\sigma_A v\rangle_{T=T_f}}$$

with: $M_\chi/T_f \sim 20$

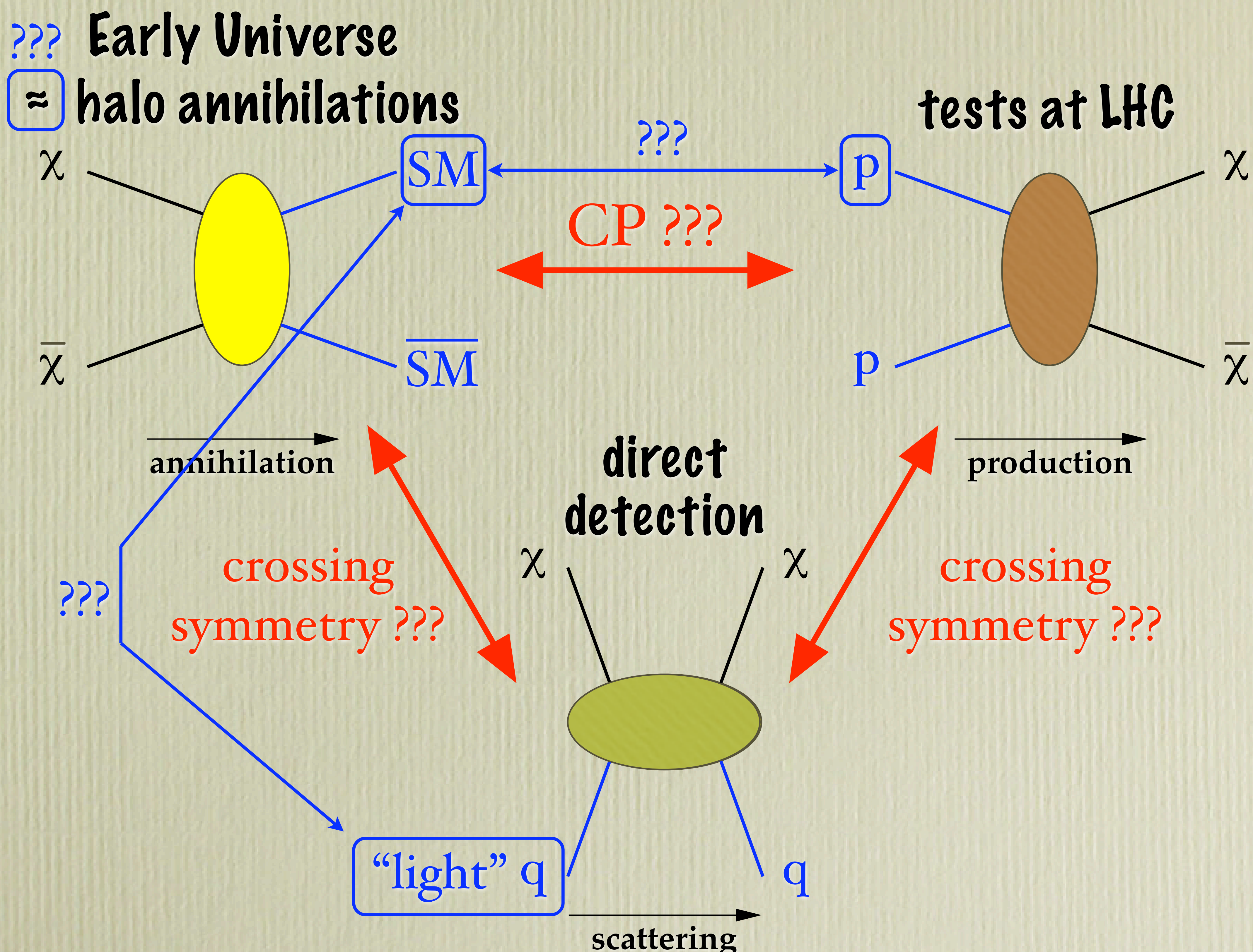
$$\Omega_\chi h^2 \simeq \frac{3\cdot 10^{-27}\mathrm{cm}^{-3}\mathrm{s}^{-1}}{\langle\sigma_A v\rangle_{T=T_f}}$$ → WIMP "miracle"

The WIMP recipe to embed a dark matter candidate in a SM extension: foresee an extra particle χ that is stable (or with lifetime exceeding the age of the Universe), massive (non-relativistic at freeze-out) and weakly interacting. Plenty of frameworks in which it is viable to apply this recipe.

WIMP coupling to ordinary matter:



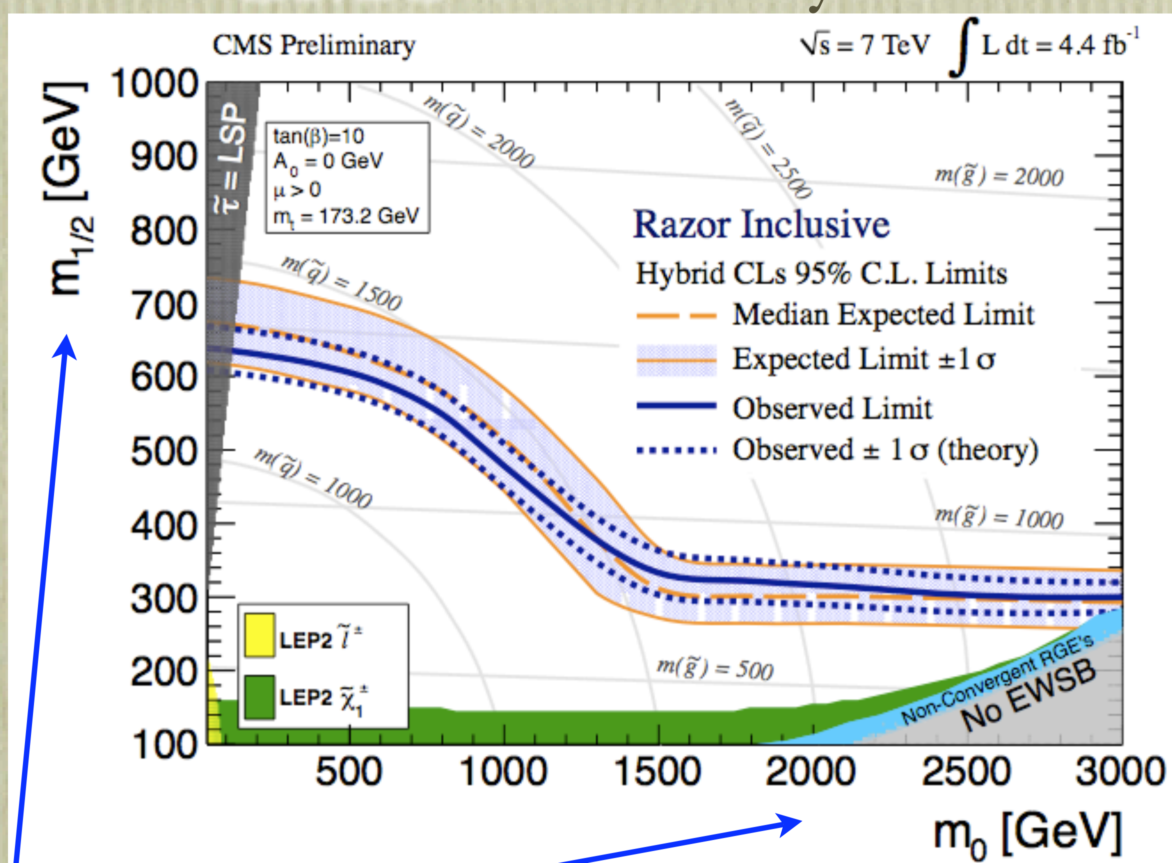
WIMP coupling to ordinary matter:



LHC searches for BSM states

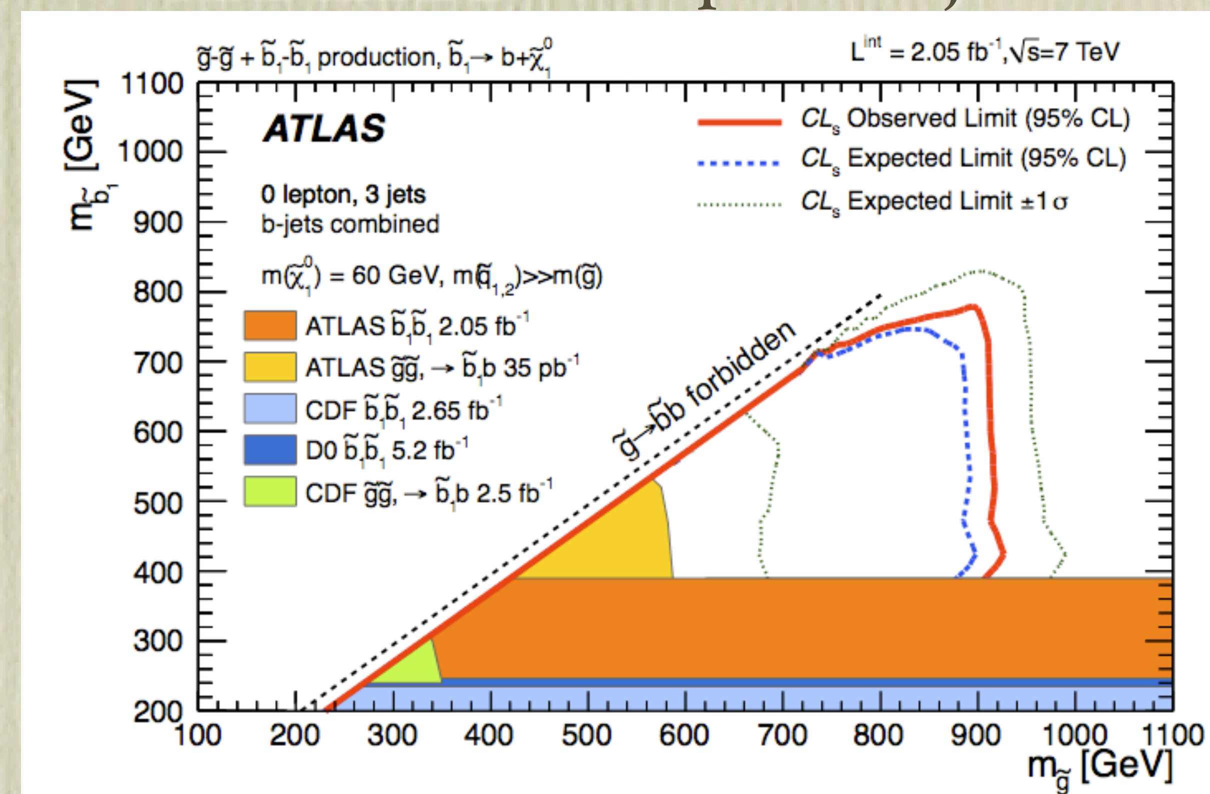
Null detection so far for physics BSM; early analyses focussed on limits on extra particles carrying SU(3) charge being directly produced in pp collisions. In a SUSY context , limits on 1st and 2nd generations squarks and gluinos, e.g.:

CMS (razor analysis)



CMS-SUS-12-005

ATLAS (0 leptons + jets)



arXiv:1203.6193

CMSSM framework: the gaugino mass parameter setting the gluino mass, the scalar mass parameter driving the squark mass scale.

LHC searches for BSM states & WIMP DM

Unless you restrict to frameworks which are designed to be over-constrained, like, e.g., in the SUSY context the CMSSM (in which, e.g., the lightest neutralino is in most regions of the parameter space a bino and has a mass = 1/6 · gluino mass), the impact on the WIMP DM scenario has not been dramatic so far.

Most scenarios with thermalization guaranteed by colored particles were actually already disfavored before the latest LHC results:

E.g., in the "bulk region" of the CMSSM the relic abundance of a bino scales with the inverse of the helicity-suppressed annihilation rate for:

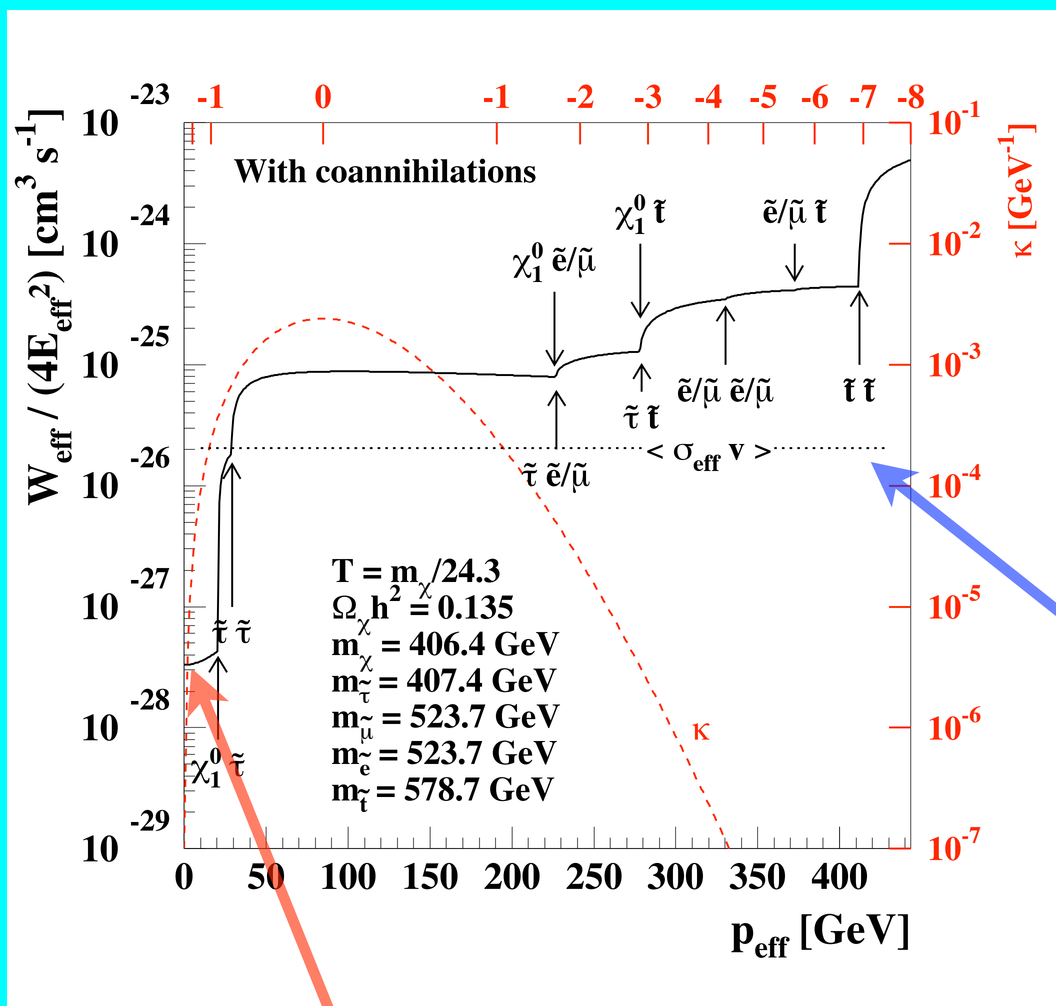
$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \leftrightarrow f \bar{f}$ mediated by a $\tilde{f}$ in the t - & u-channels

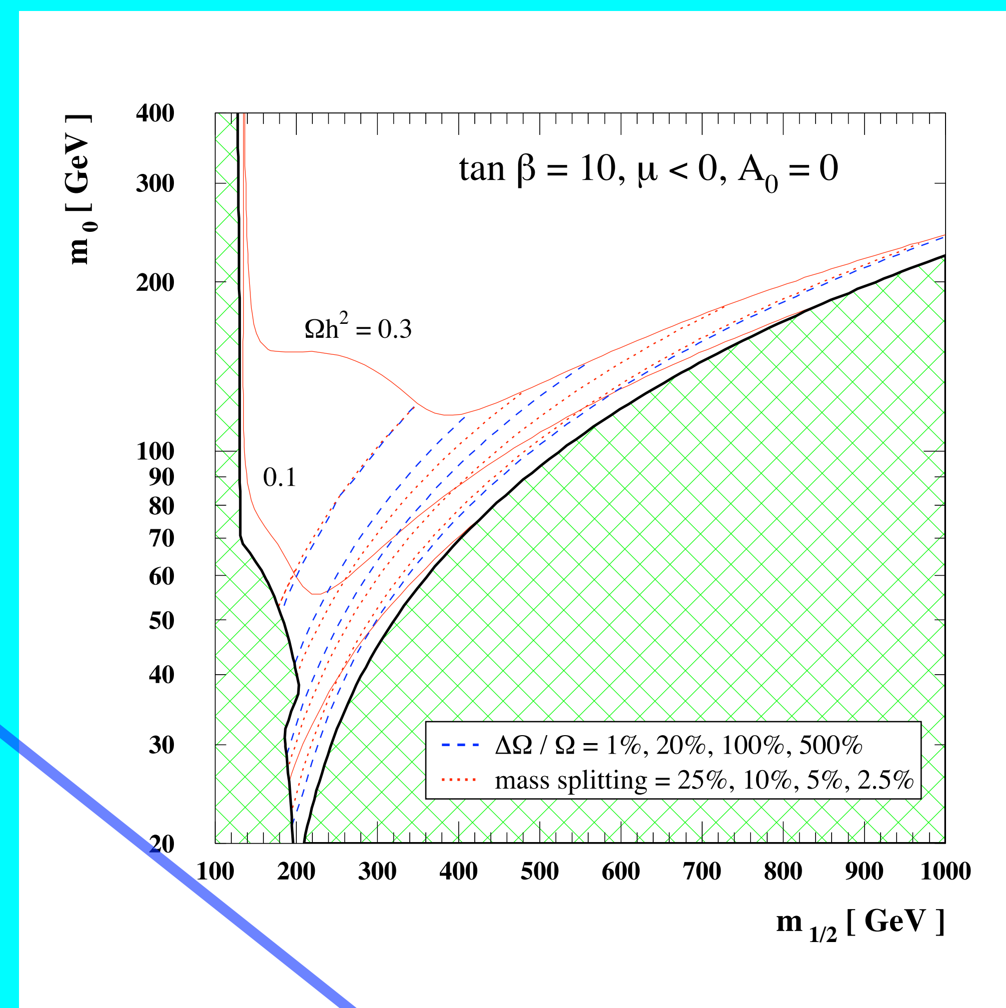
which is dominated by heavy fermions (quarks). The relic abundance matches the cosmological DM density only for neutralino masses of about 100-150 GeV and fairly light sfermions (squarks). This picture was already in trouble because of B physics and the Higgs boson limits, and it is now excluded more directly by the LHC.

How much room is left for (thermal) SUSY DM?

There are still several loopholes, including:

Neutralino-slepton coannihilations: the early Universe thermal relic density set by a slepton which is nearly degenerate in mass. The mass scale for the neutralino LSP as large as 300-400 GeV.





Edsjo, Schelke, PU & Gondolo, hep-ph/0301106

in DM halos: indirect signals suppressed

in early Universe

How much room is left for (thermal) SUSY DM?

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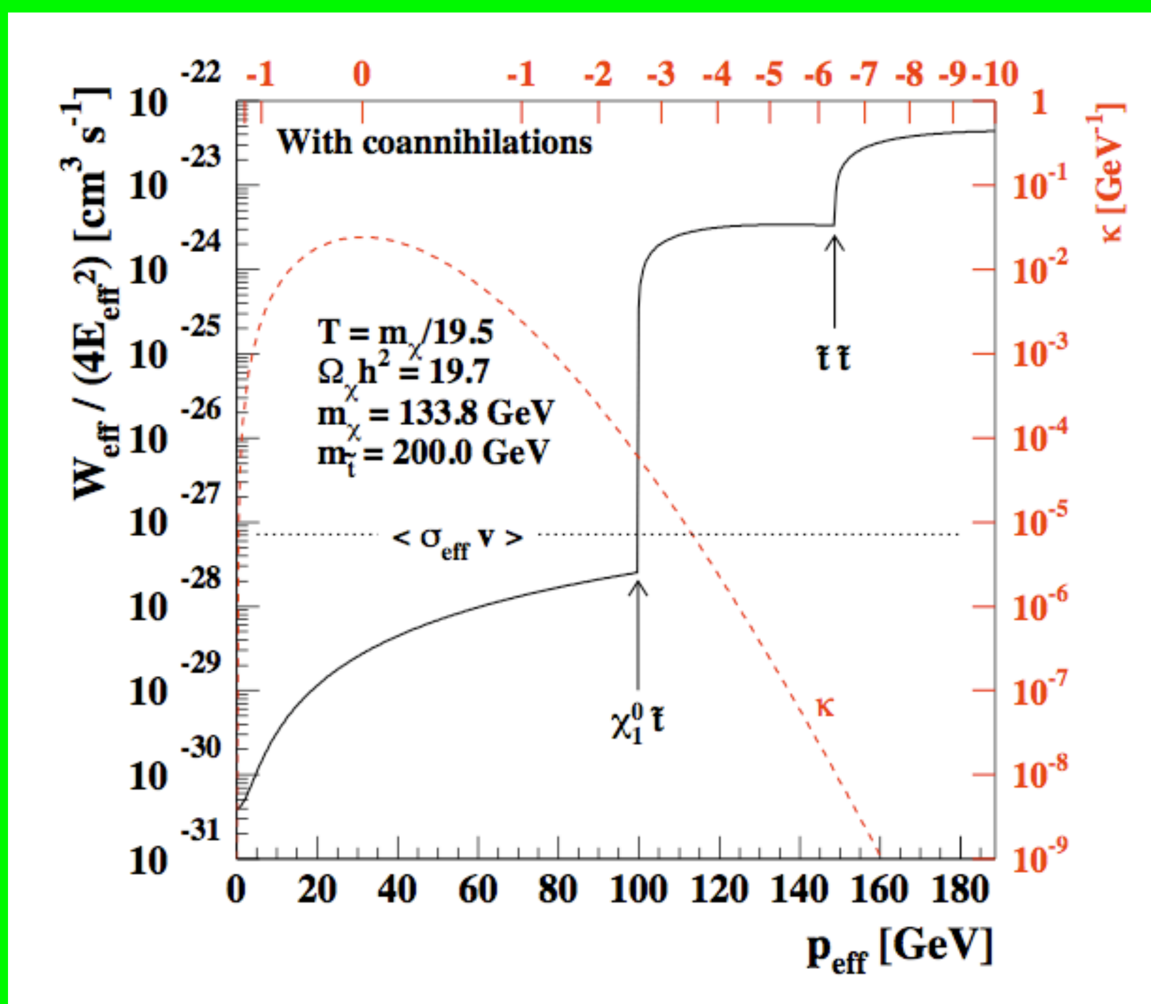
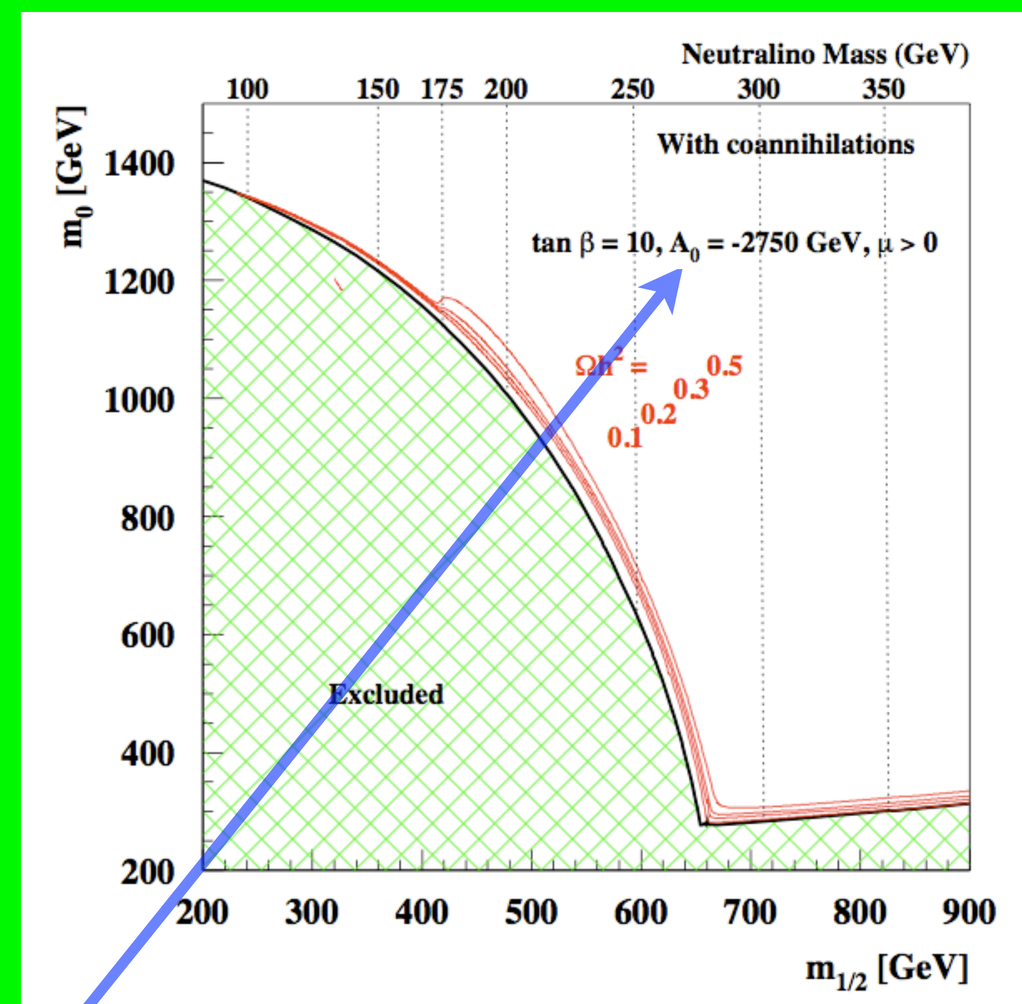
Neutralino-stop/sbottom coannihilations: a third generation squark and the LSP within a 50% in mass splitting, with the neutralino LSP mass scale in the range of few hundred GeV.





Edsjo, Schelke, PU & Gondolo, hep-ph/0301106

a large (-) A, allowing for a light stop while other squarks are heavy

How much room is left for (thermal) SUSY DM?

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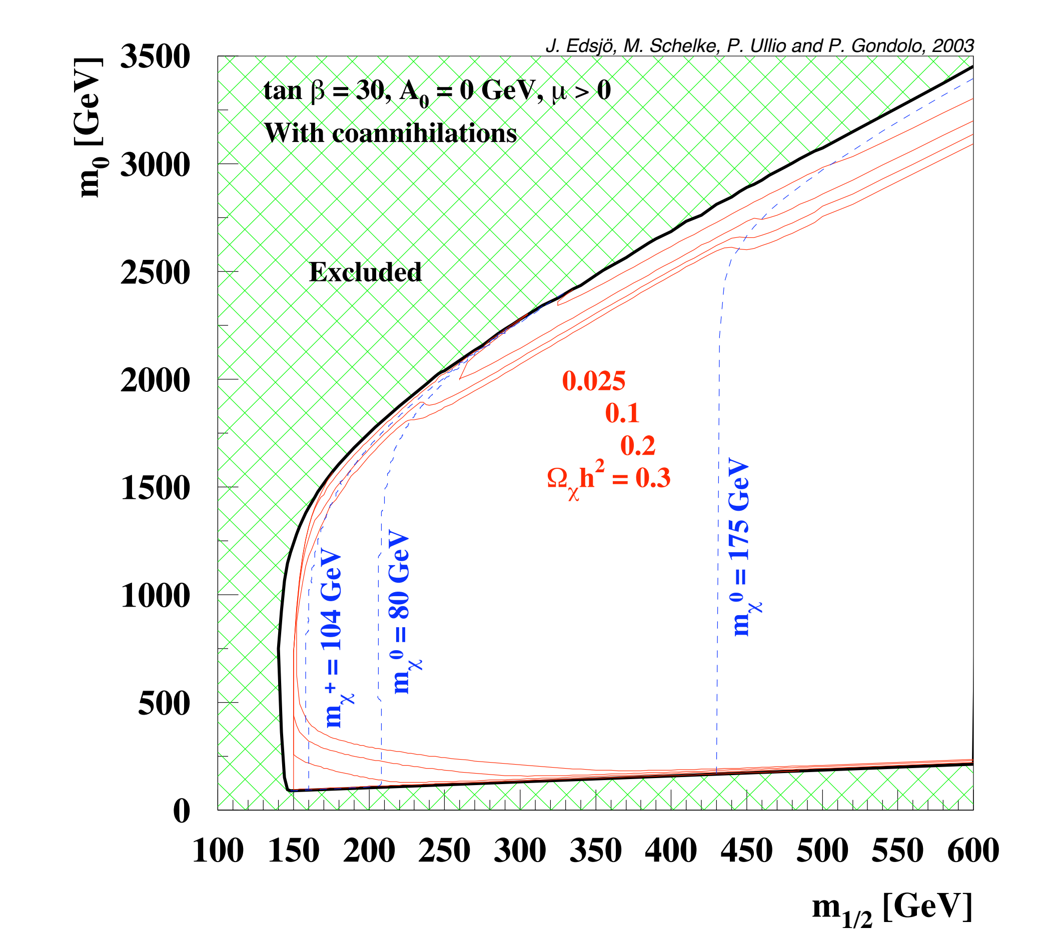
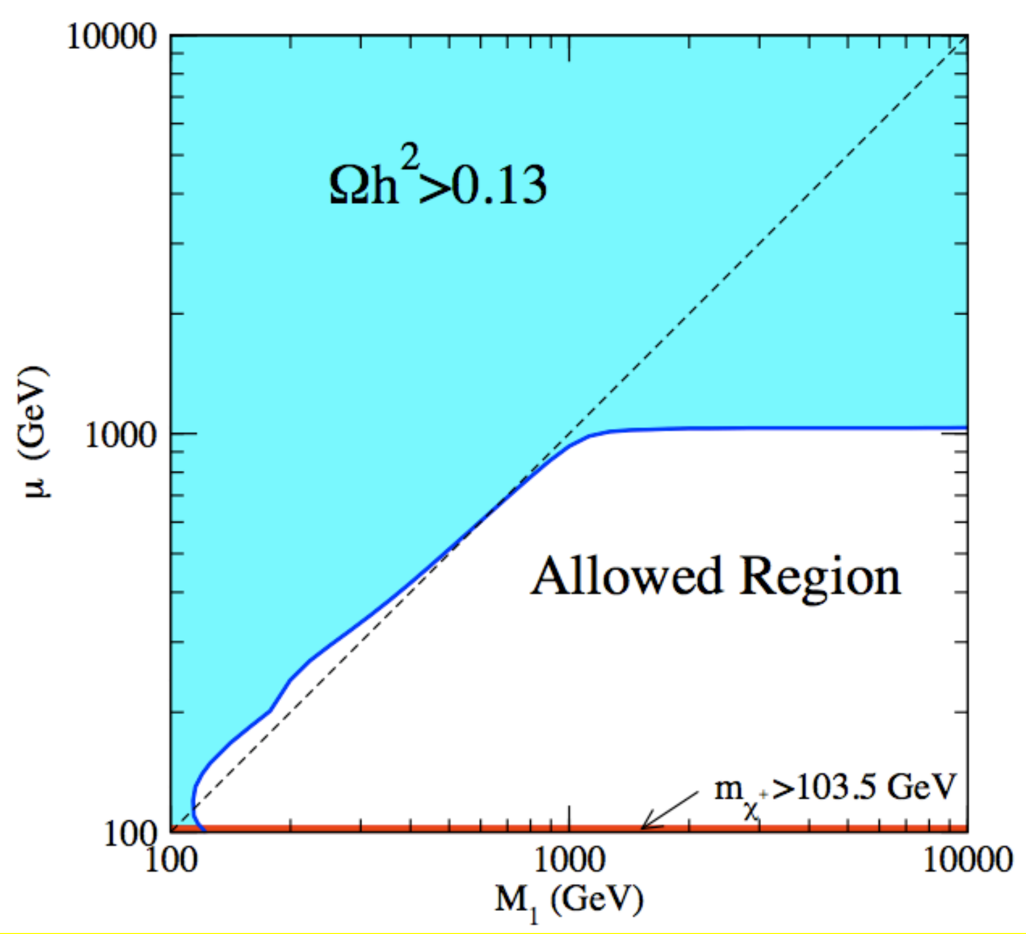
Bino-Higgsino mixing: annihilation into weak gauge bosons driven by the Higgsino term in the LSP. Adjusting the Higgsino fraction the thermal relic LSP spans all the range between 100 GeV and 1.1 TeV



Edsjo, Schelke, PU & Gondolo, hep-ph/0301106



Masiero, Profumo,& PU, hep-ph/0412058

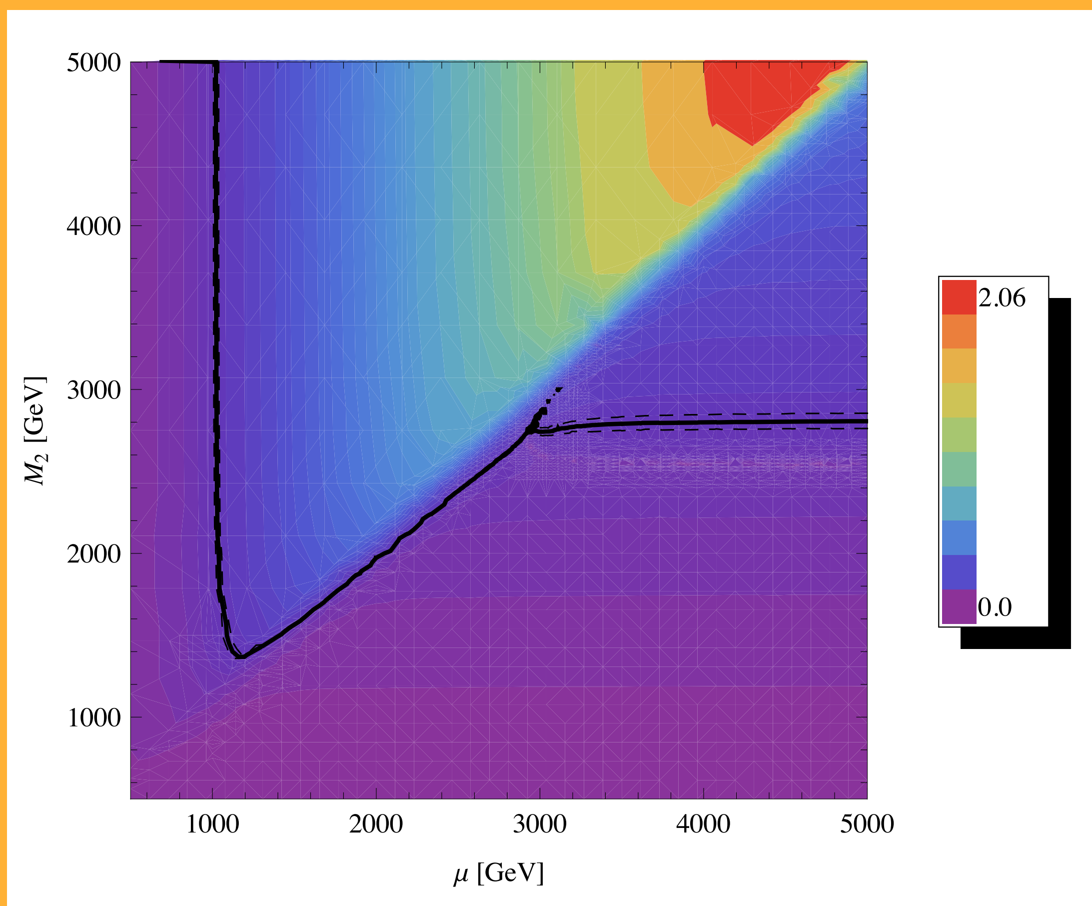
"focus point" in the CMSSM

Split SUSY

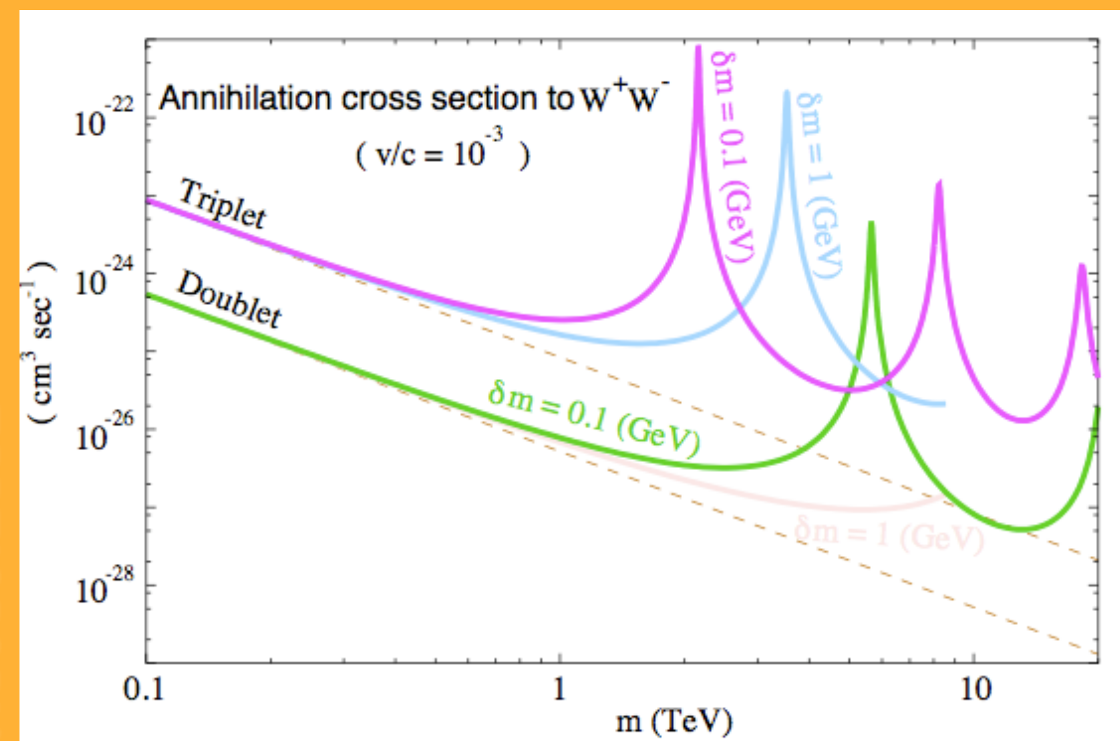
How much room is left for (thermal) SUSY DM?

There are still several loopholes, including:

Pure Higgsinos to pure winos (SU(2) doublet to triplet): thermal relic LSP in the mass range between 1.1 TeV and 2.5 TeV



Hryczuk, Iengo & PU, arXiv:1010.2172



Hisano, Matsumoto & Nojiri, hep-ph/0307216

including Sommerfeld enhancement effect

"Explosives" DM annihilations due to the weak interaction becoming long-range

How much room is left for (thermal) SUSY DM?

A picture which is challenging for collider searches:

Neutralino / stop coannihil.	Bino - Higgsino mixing	Neutralino / slepton coannihil.	Heavy Higgsinos / winos

Hard to test at LHC → not testable at LHC

A picture hardly addressing the naturalness problem:

Neutralino / stop coannihil.	Neutralino / slepton coannihil.	Bino - Higgsino mixing	Heavy Higgsinos / winos

Large fine-tuning → no attempt to address it

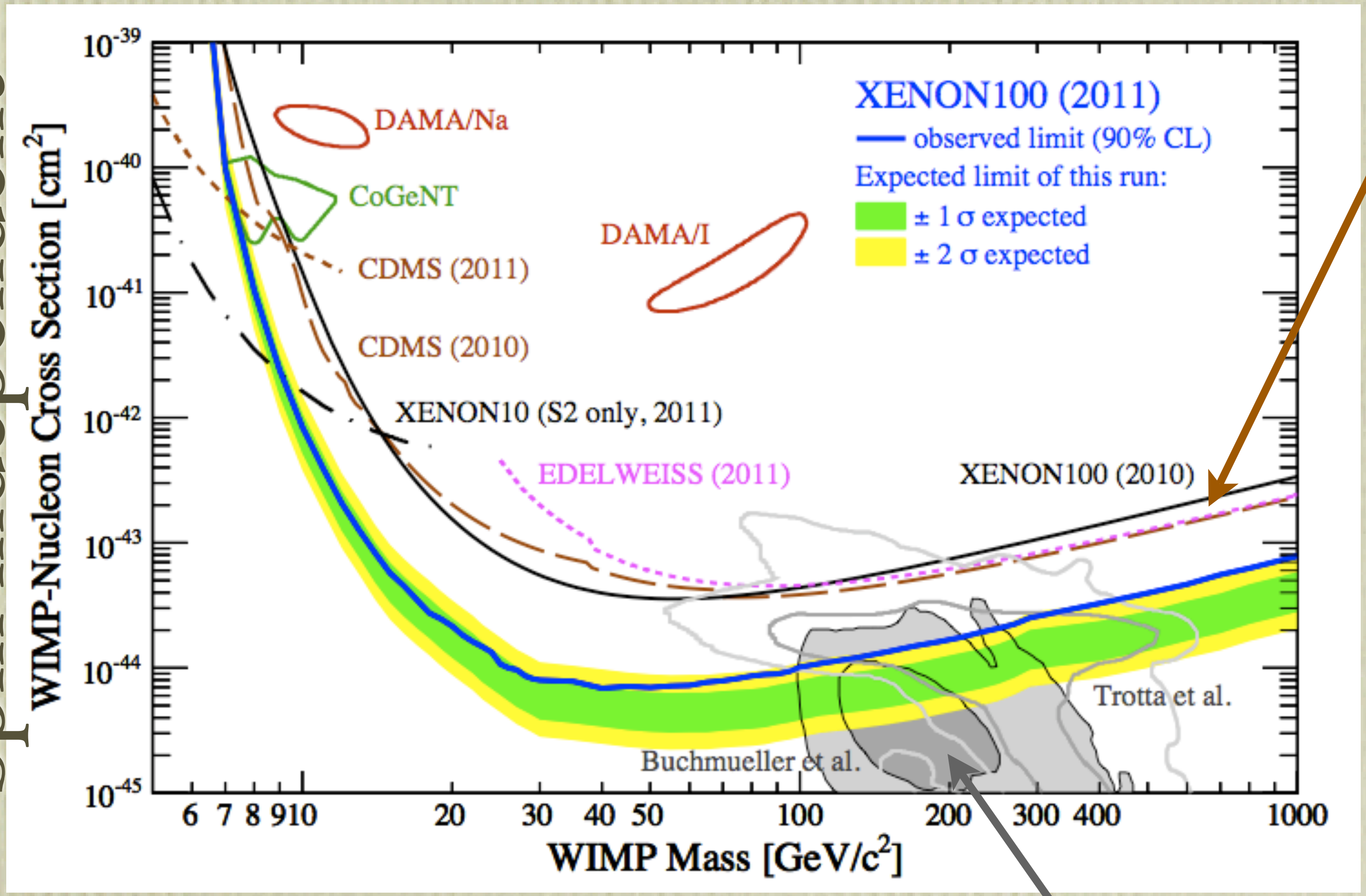
Maybe a sign that thermal production is not the correct picture and in favor of other mechanisms, such low reheating scenarios with neutralino production from moduli decays (e.g., Moroi & Randall, hep-ph/9906527) with a significant shift in the LSP mass scale (e.g. Arcadi & PU, arXiv:1104.3591).

Current direct detection picture

Focussing on Spin Independent (coherent) WIMP-nucleus elastic scatterings (the effect expected, e.g., for SUSY DM), and on the bulk of the mass scale expected for WIMPs (around the weak scale), in the latest years there has been a steady and fairly rapid progress in sensitivities:

Xenon 100, Aprile et al., arXiv:1104.2549

Spin independent



CDMS, Ahmed et al., arXiv:0912.3592

Ongoing run by Xenon with reduced background; data release expected in the spring!

Many projects upcoming

Limits on SUSY models, competitive with the LHC: they test the Bino-Higgsino mixing region since the scattering via CP even Higgs states scales via the gaugino-higgsino mixing

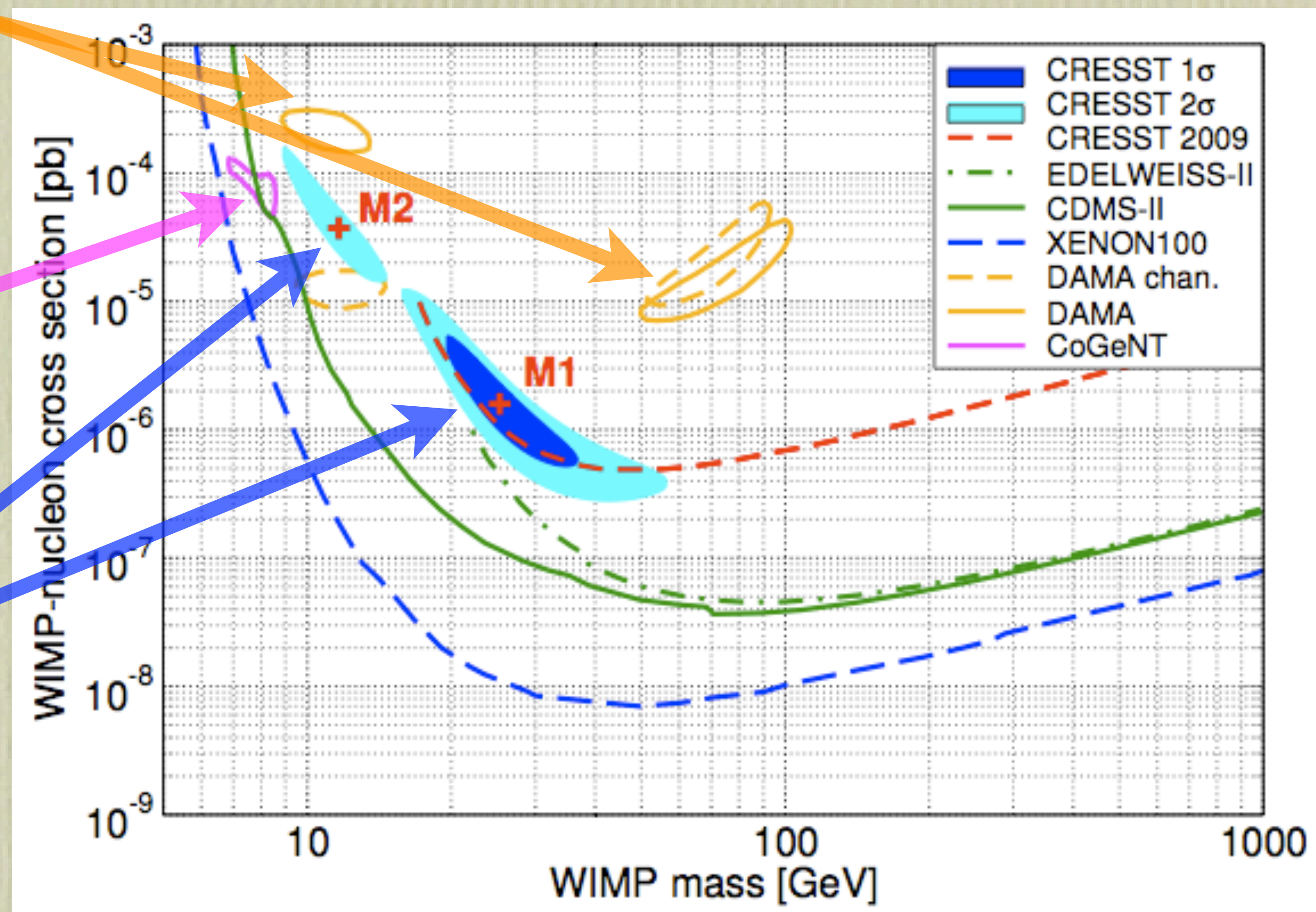
Direct detection picture - the "light" mass window

Recently the emphasis has been on the mass range around 10 GeV or so:

DAMA/LIBRA
(annual modulation)
Bernabei et al., arXiv:0804.2741

CoGeNT
(excess + ann. mod.)
Aalseth et al., arXiv:1106.0650

CRESST
(excess)
Angloher et al., arXiv:1109.0702



tension iff results taken at face value

see also PICASSO limit:
Archambault et al., arXiv:1202.1240

Latest updates:

DAMA/LIBRA: data taking phase with new high quantum efficiency PMTs, allowing to lower the threshold. DM-Ice-17 deployed at the South Pole (in the IceCube detector used as additional veto) as a feasibility study for another large NaI detector (in southern hemisphere).

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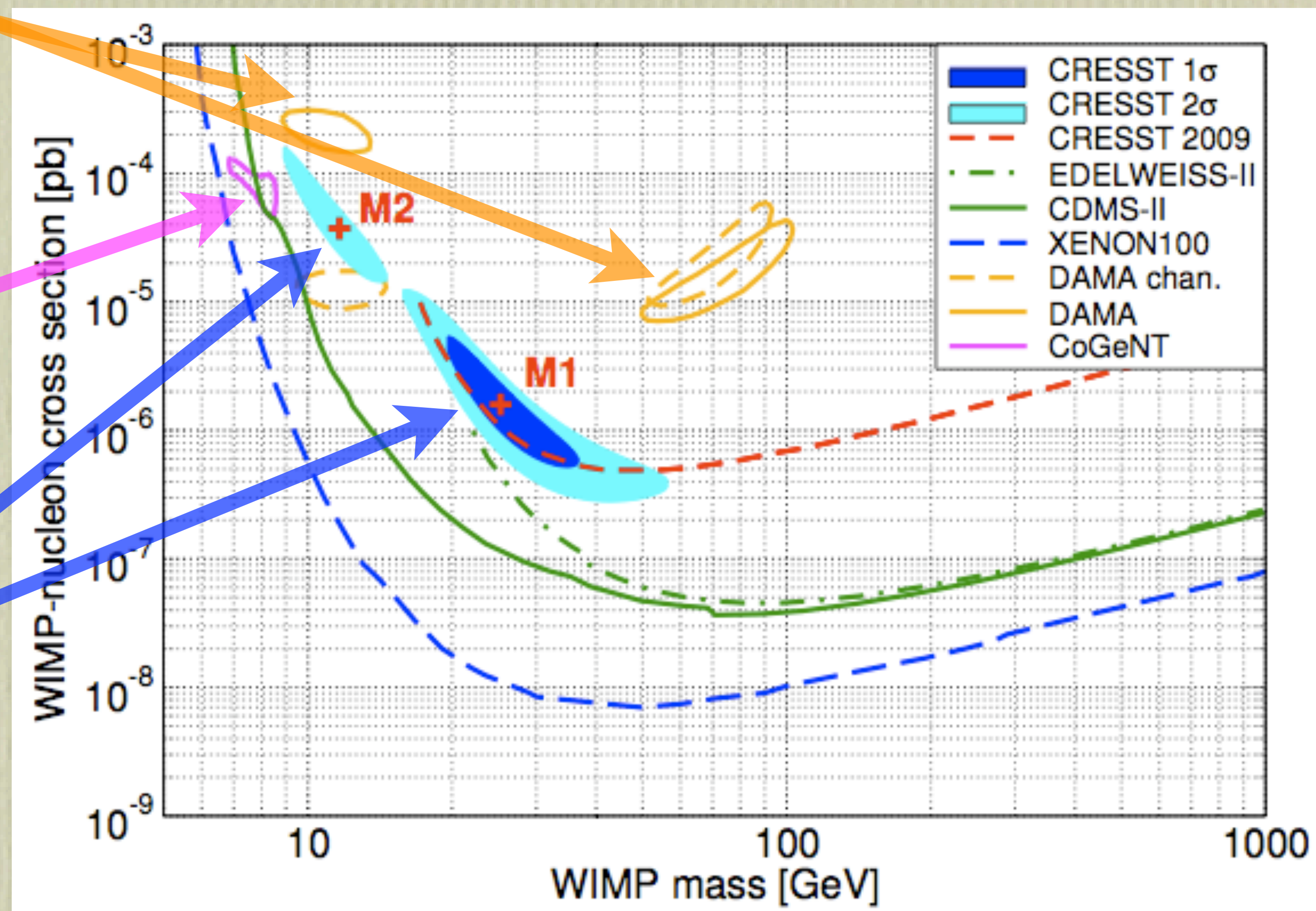

tension iff results taken at face value

see also PICASSO limit: Archambault et al., arXiv:1202.1240

Latest updates:

CoGeNT: an extra background component from surface events (work in progress, Collar, 2011-12) shifting the signal to lower cross sections and larger masses into the M2 CRESST region. Is the modulation amplitude still compatible? Probably needing non-standard halo models.

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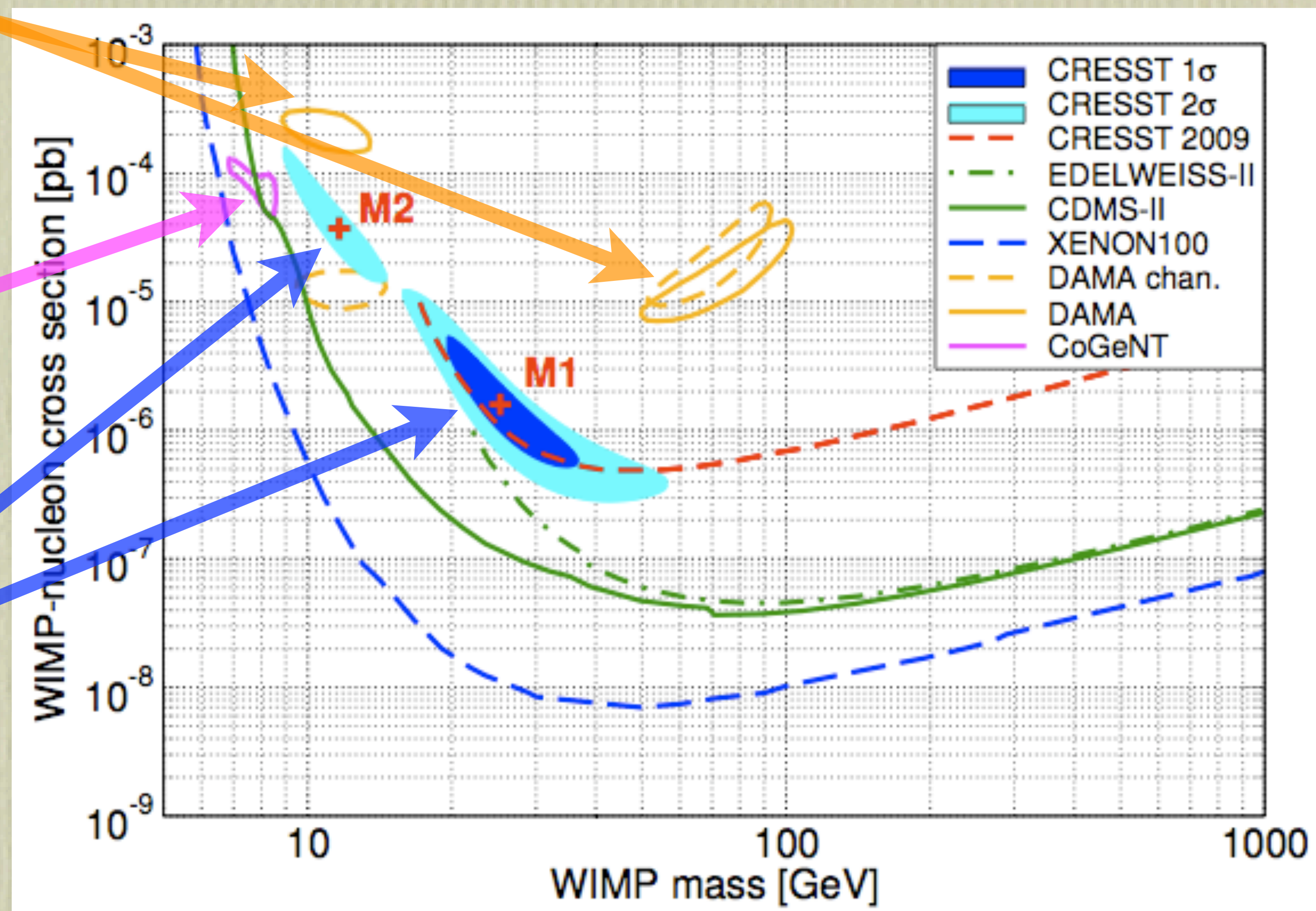

tension iff results taken at face value

see also PICASSO limit:
Archambault et al., arXiv: 1202.1240

Latest updates:

CRESST: Florian Reindel (MPI/TUM) diploma thesis contains a new analysis with improved cuts giving: 52 events in 572 kg d (compared to 67 events in 730 kg d), 1.9 σ significance (compared to 4.2 σ) in M2 region, 2.5 σ (4.7 σ) in M1. (see also Rick Gaitskell’s talk at UCLA DM 2012)

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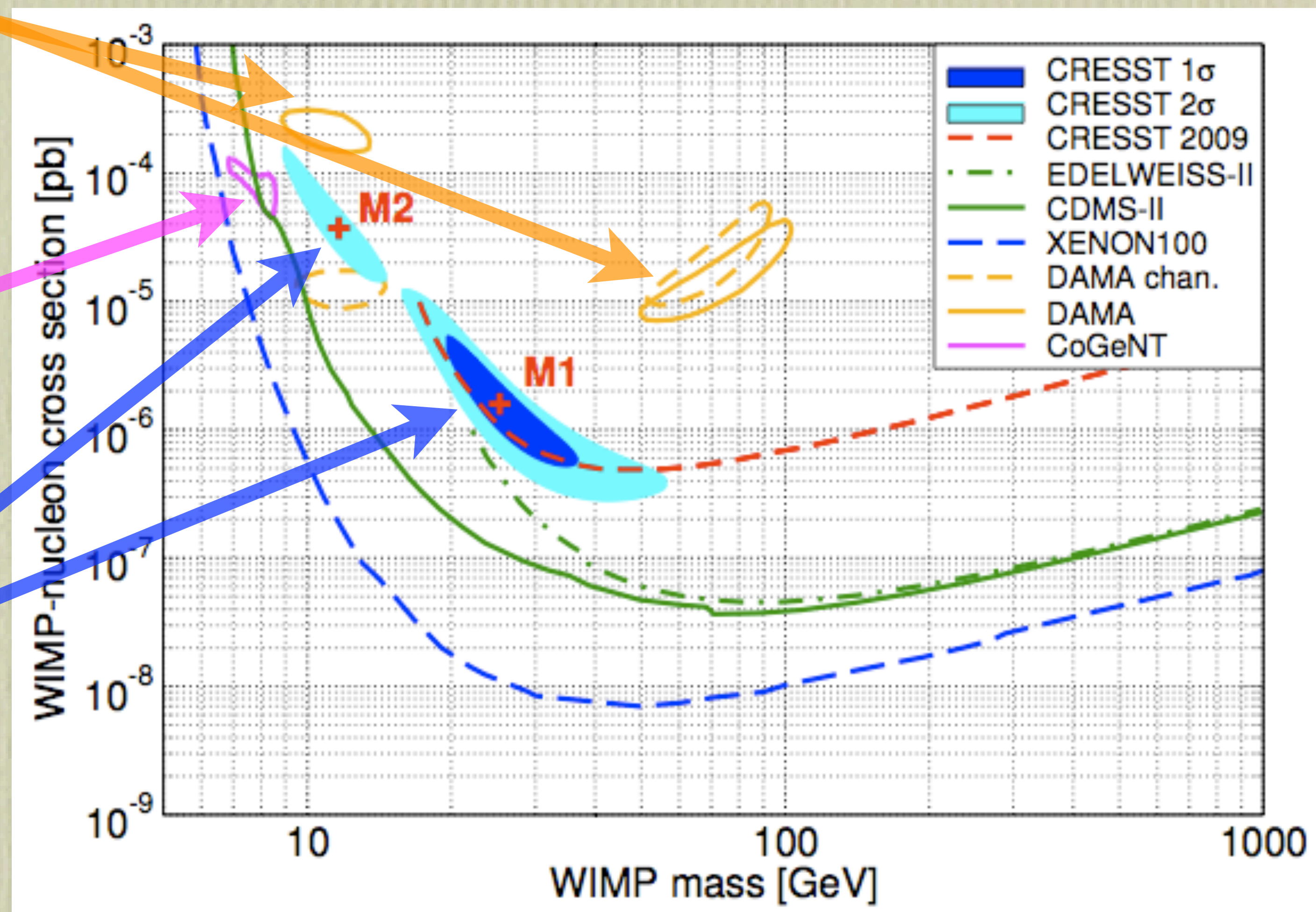

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Further caveat:

It is possible that the interpretation in terms of WIMP-nucleon SI coupling is not the proper one, what about some exotica like, e.g., a magnetic dipole moment coupling? Could that milden the tension among results with different target materials and detection techniques?

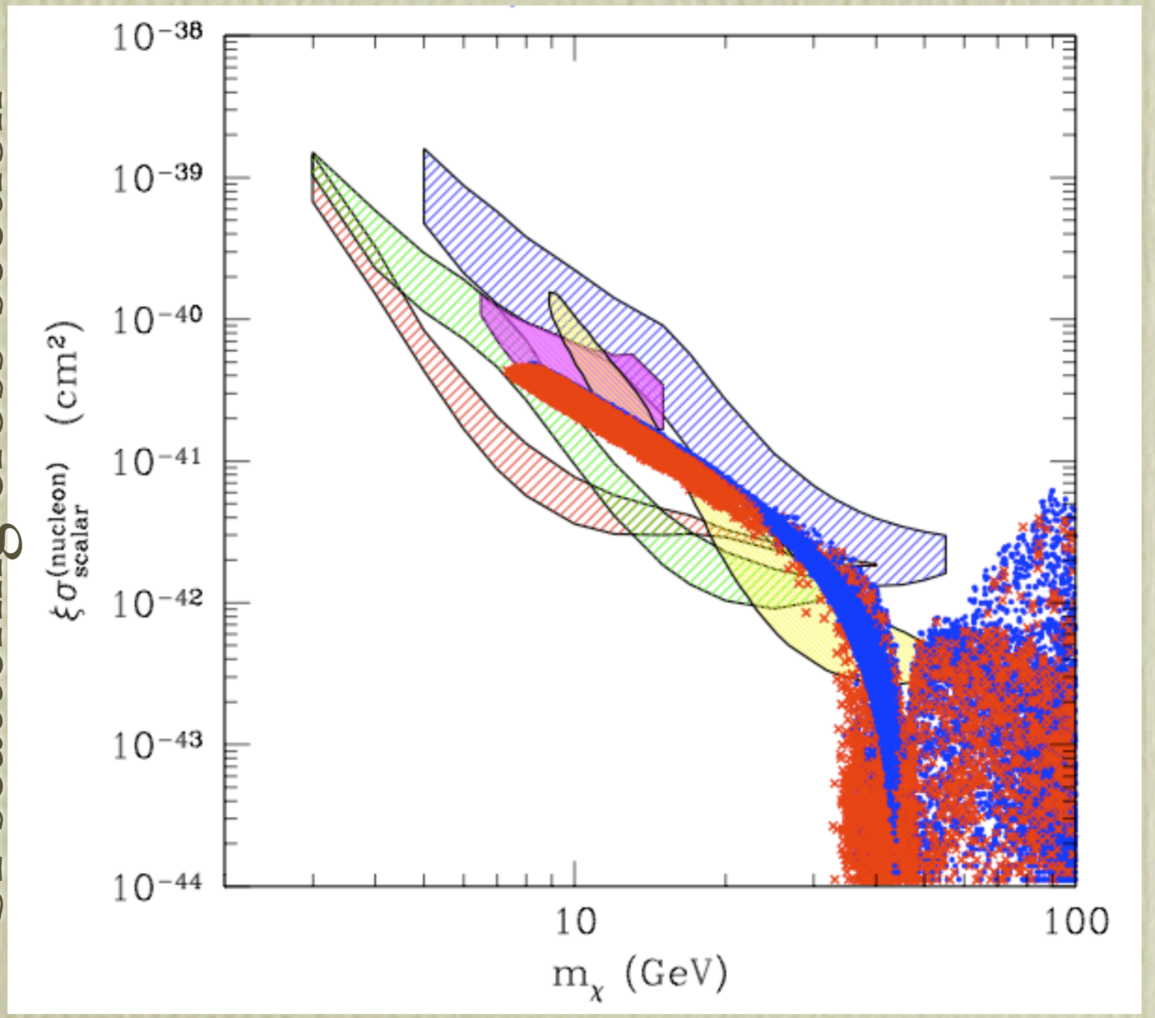
E.g., Del Nobile et al., arXiv:1203.6652

Neutralino DM in the "light" mass window

Original idea: MSSM with i) Bino much lighter than Wino (to avoid LEP bounds on charginos); ii) a light psedoscalar Higgs and a moderately large $\tan\beta$; iii) a sizable Bino-Higgsino mixing. A light thermal neutralino viable, regardless of the sfermion mass spectrum!

Prior LHC 2011 results, models with neutralinos as light as 7-8 GeV allowed:

SI scattering cross-section



Fornengo, Scopel & Bottino, arXiv:1011.4743

9 parameter MSSM focussed on:

$$m_A \sim (90 - 200)\ \mathrm{GeV}$$
$$\tan\beta \sim 20 - 45$$
$$|\mu| \simeq (100 - 200)\ \mathrm{GeV}$$

NOTE: other analyses claimed it was hard to satisfy Higgs and flavor constraints, see, e.g.:

Calibbi, Ota & Takanishi, arXiv: 1104.1134, or ...

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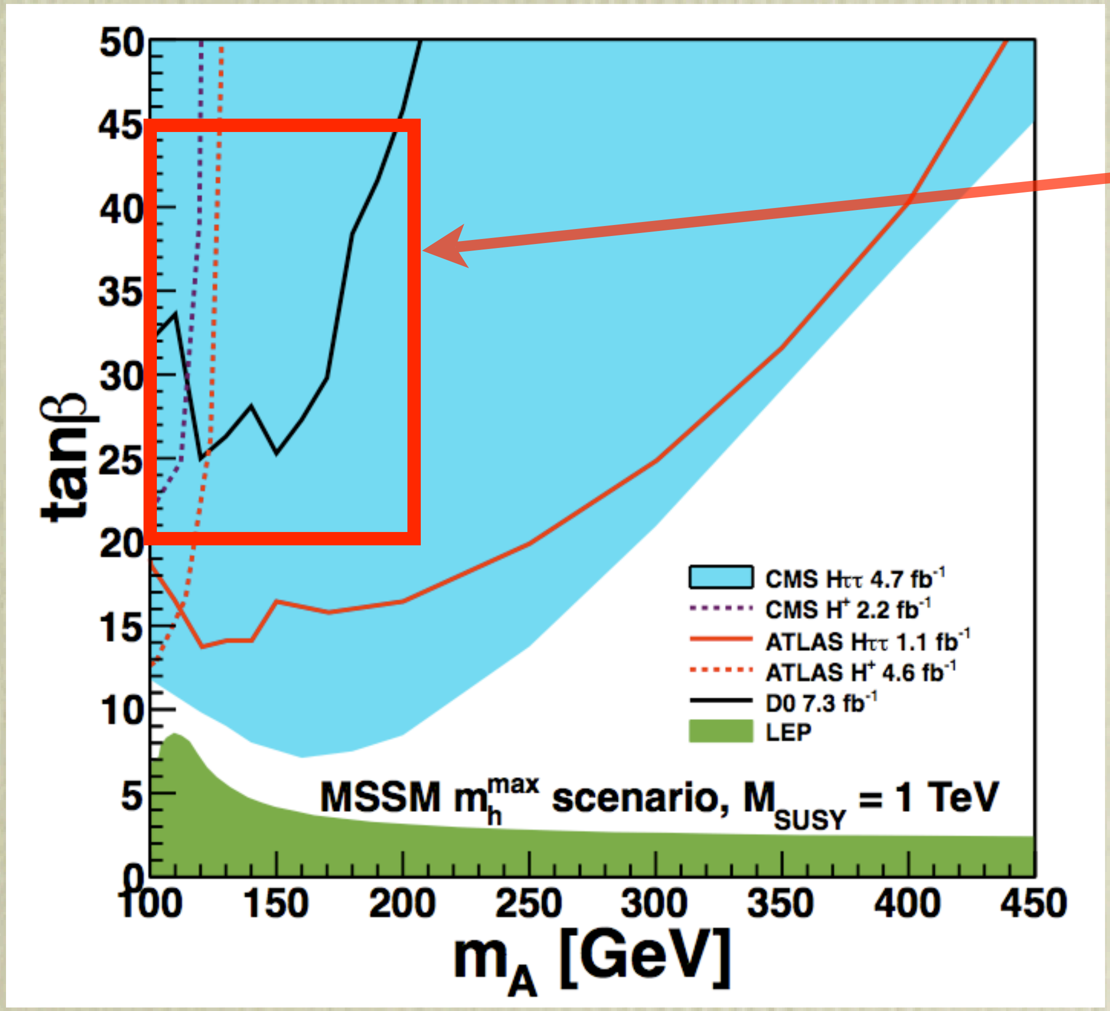
Range shrunk to above 18 GeV by CMS and LHCb 2011 searches (Bottino, Fornengo & Scopel, arXiv:1112.5666), and possibly further above with 2012 results:

CMS, arXiv:1202.4083 (+ATLAS)



≈ parameter space in scatter plot from arXiv:1011.4743

Go beyond the MSSM? Turn to sneutrino DM or other models?

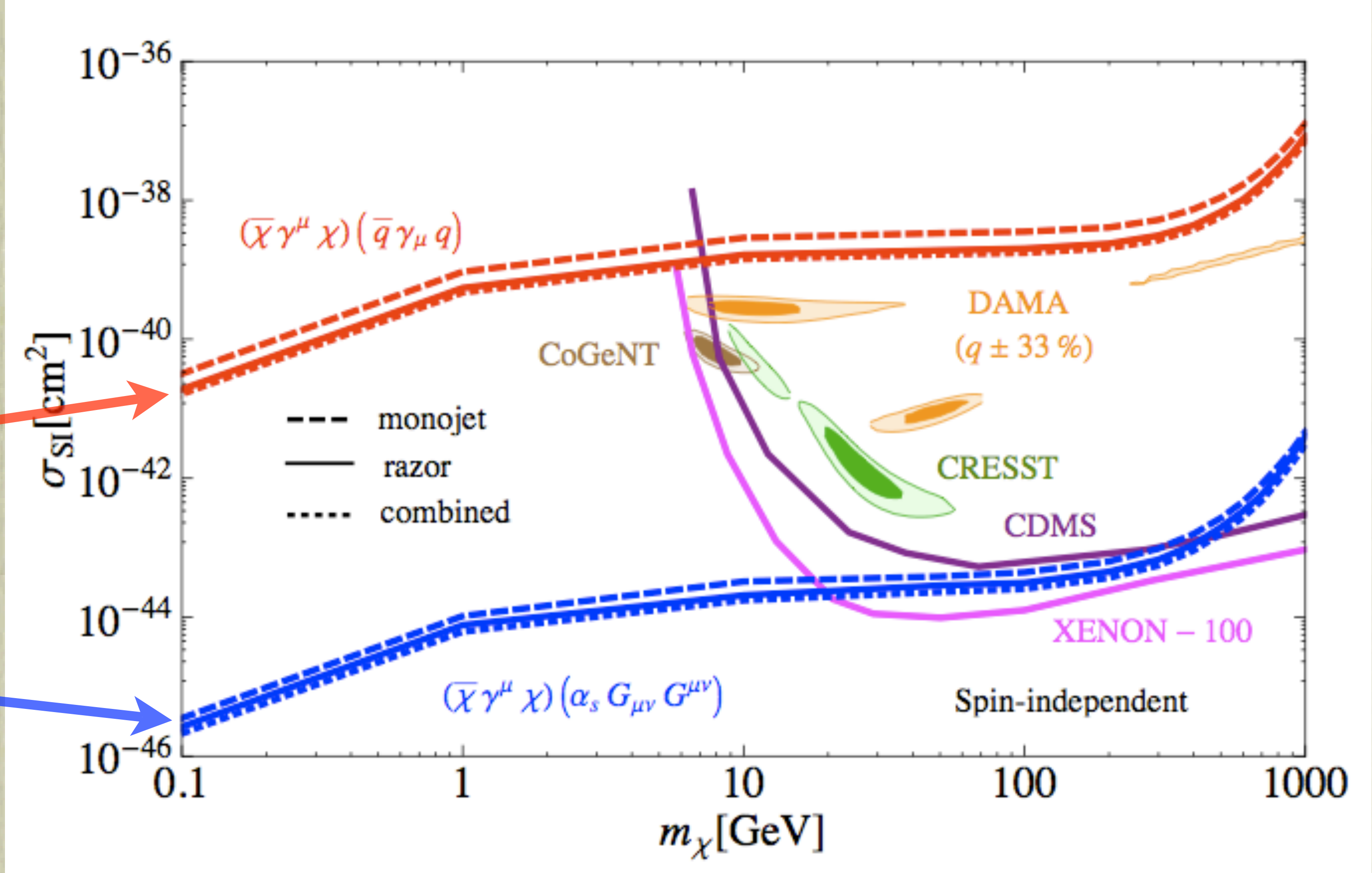
"Light" WIMPs & a model independent approach

Introduce effective operators assuming that the mediator particle coupling the DM and SM states in elastic scatterings can be integrated out. Use then crossing symmetry arguments to extrapolate signatures for the production of DM particle at the LHC. E.g.:

DM as Dirac fermion with sample operators:

$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

$$\mathcal{O}_G = \alpha_s \frac{(\bar{\chi}\chi)(G^a_{\mu\nu}G^{a\mu\nu})}{\Lambda^3}$$



Fox et al., arXiv: 1203.1662

Focus on generic LHC signatures like monojet emission or razor variables to extrapolate a lower limit on the scale Λ.

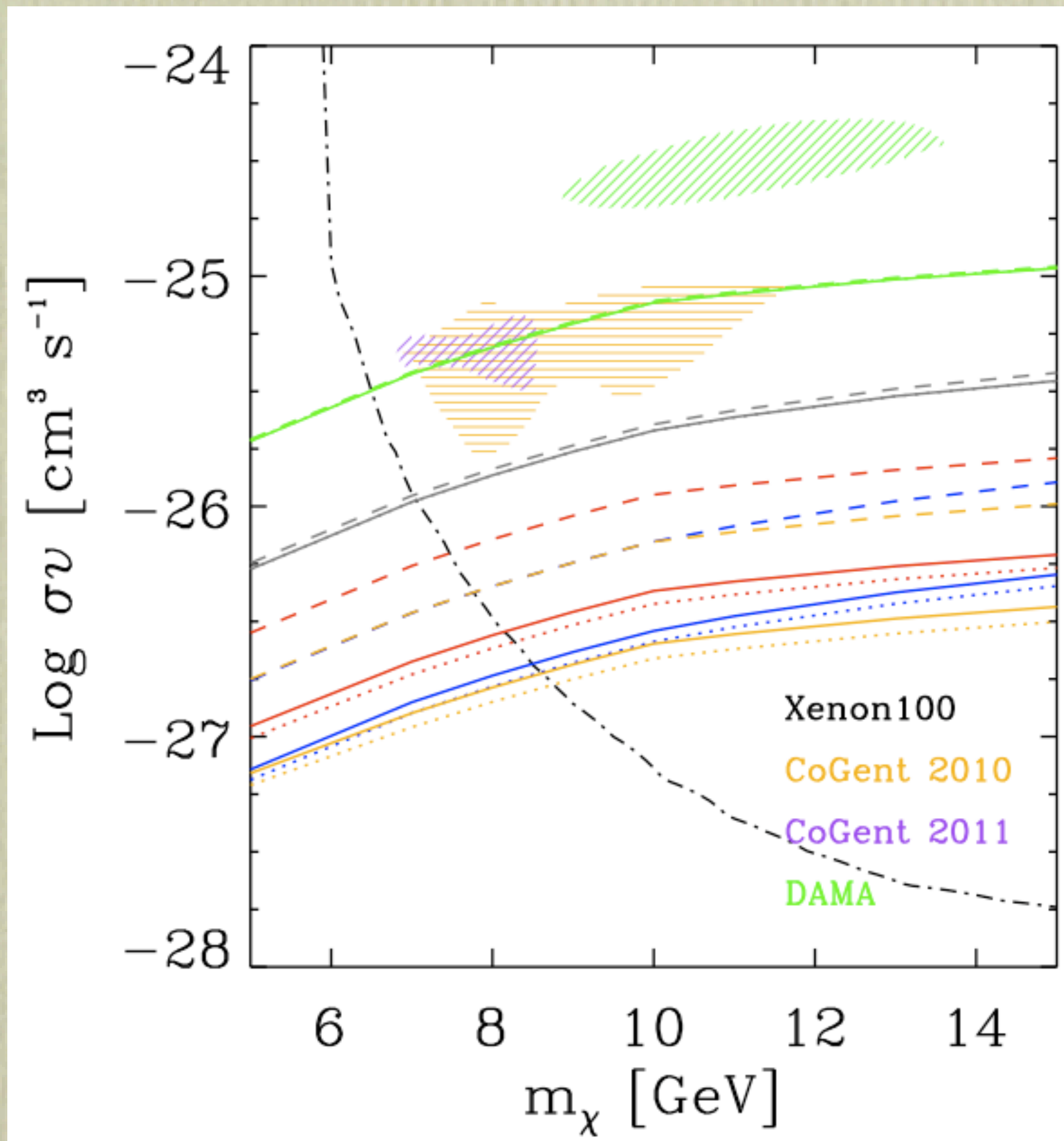
“Light” WIMPs & limits from annihilation signals

Using crossing symmetry arguments, still at the level of effective operators, one can cross-correlate with searches for DM halo yields. Tight bounds come from **antiprotons** measurements, most recently from PAMELA (Adriani et al., 2010) & BESS Polar II (Abe et al., arXiv:1107.6000). E.g.:

DM as a Majorana fermion with sample operator:

Keung et al., arXiv:1010.1774

$$\mathcal{O}_s = c_q \frac{2m_\phi}{\Lambda^2}\phi^2\,\bar{q}q$$



Limits depending on propagation model (tuned to B/C) & (mildly) on DM halo profile:

- thin (z_t= 0.5 kpc)
- convective (dv_c/dz = 50 km/s/kpc)
- Kraichnan
- Kolmogorov
- thick (z_t= 10 kpc)

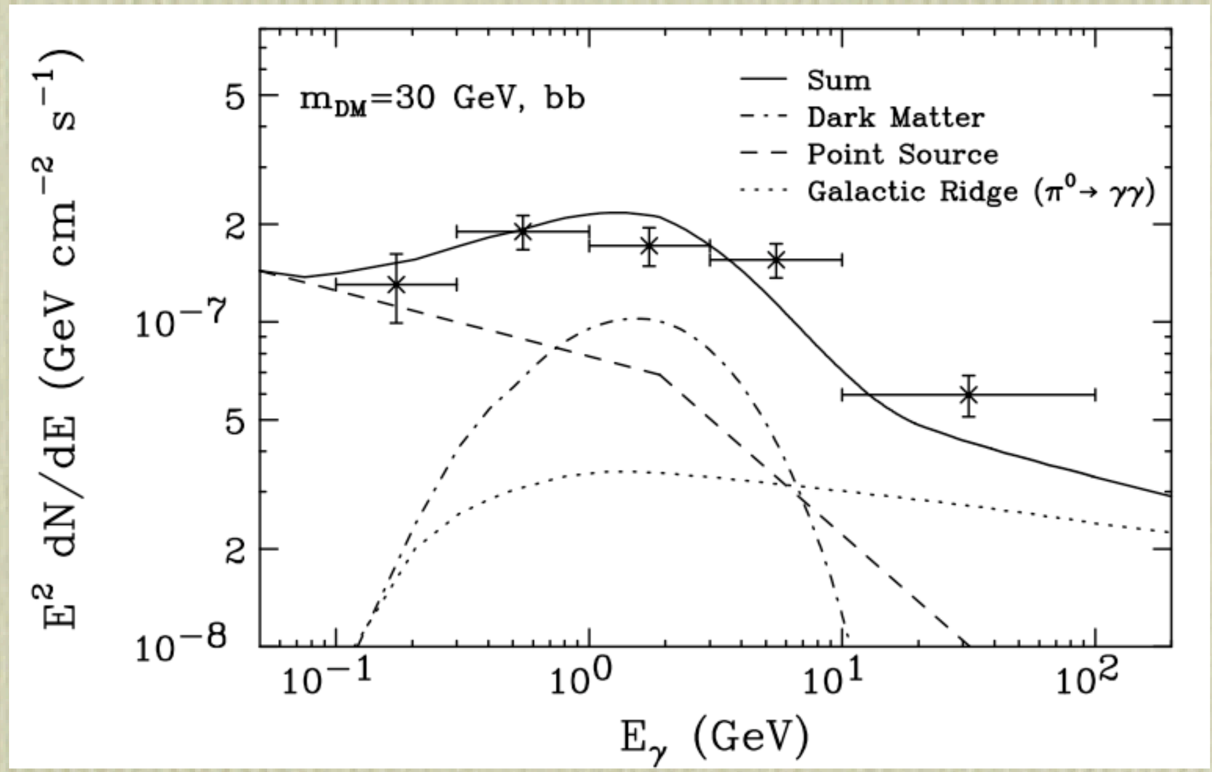
- Einasto
- NFW
- Burkert

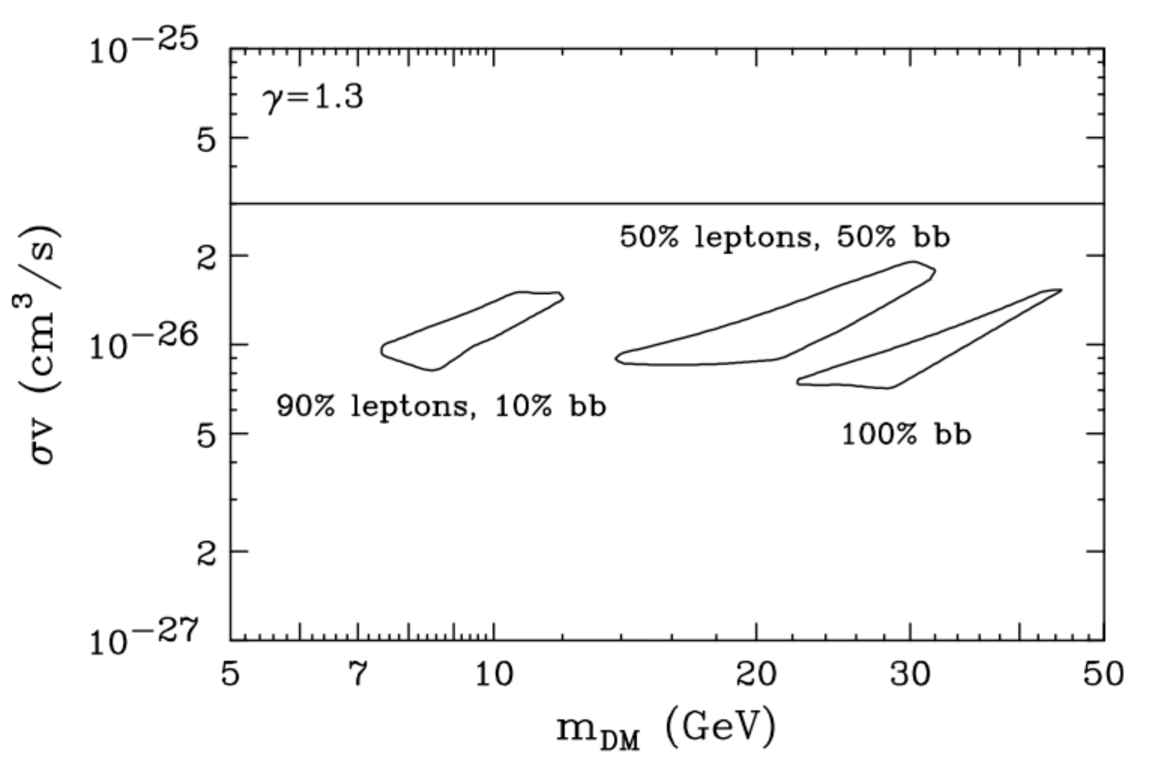
Evoli, Cholis, Grasso, Maccione & PU, arXiv: 1108.0664

"Light" WIMPs & Galactic center FERMI data

Possibly, an excess compared to the background model (following previous claims based on data from EGRET, Integral, ... , which however faded away)

γ-ray flux from the Galactic center region (<5 deg)





Hooper & Linden, arXiv:1110.0006

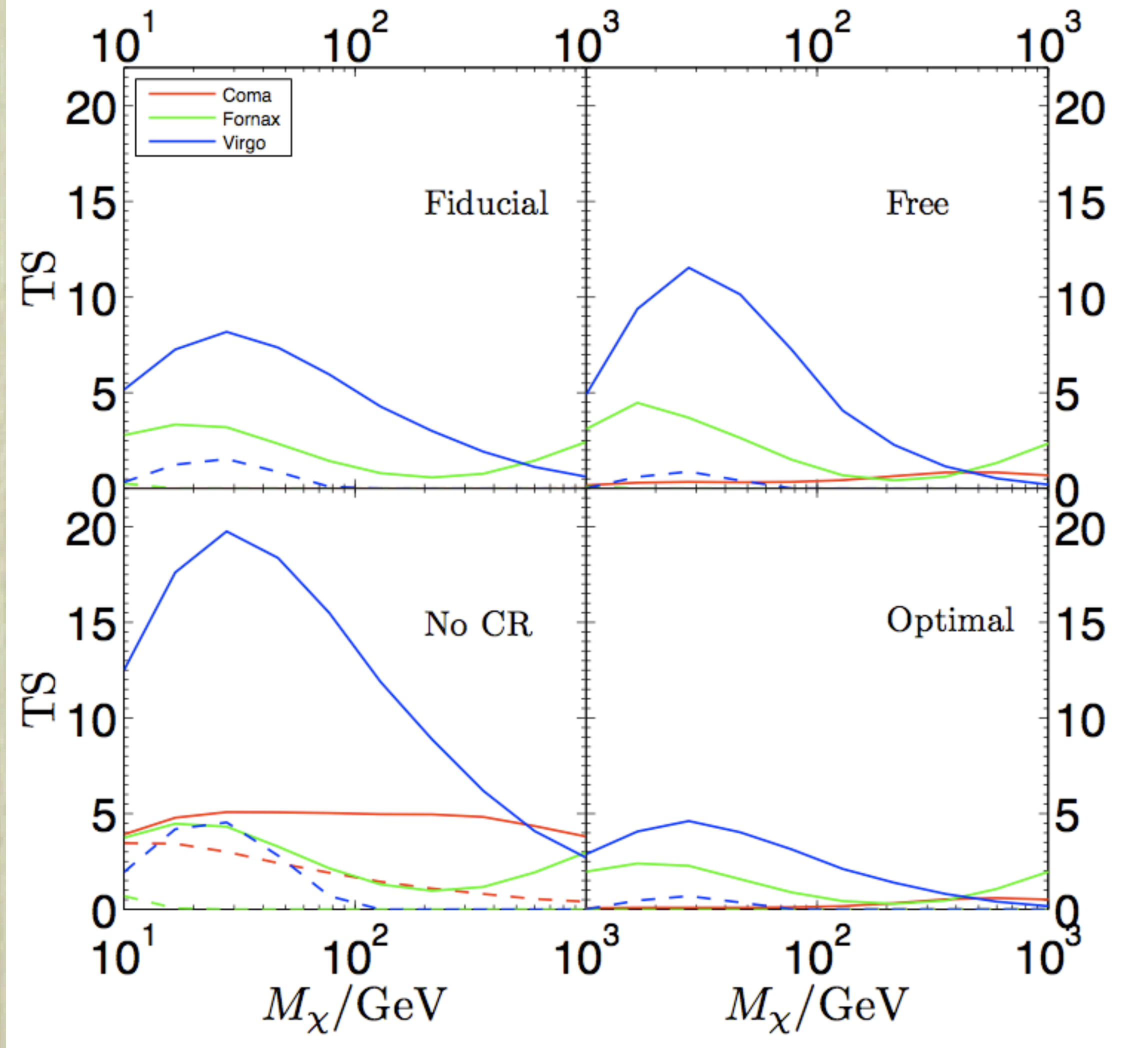
Room (or maybe even need) for a component from a light DM WIMP; thermal values for the annihilation cross section but rather cuspy DM profile.

Caveat: the interpretation relies heavily on what you are assuming (extrapolating) for the background component. The GC is a busy spot, difficult to model.

Other hints of detection from FERMI data:

Analysis on **galaxy clusters** with 4.4 σ detection significance for Virgo (annihilation into $b\bar{b}$):

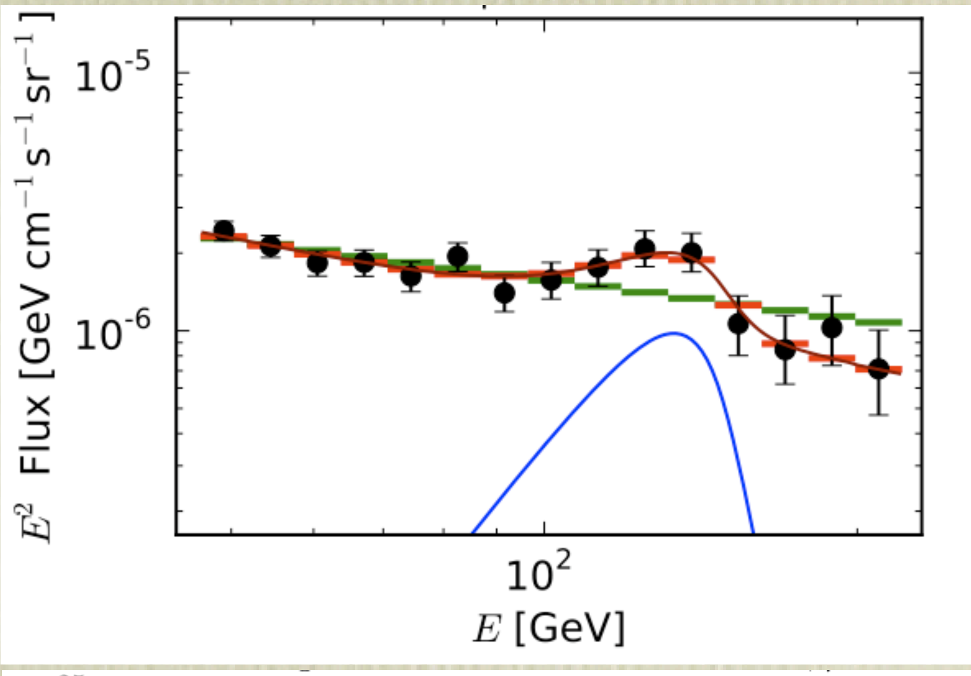
Han et al., arXiv:1201.1003

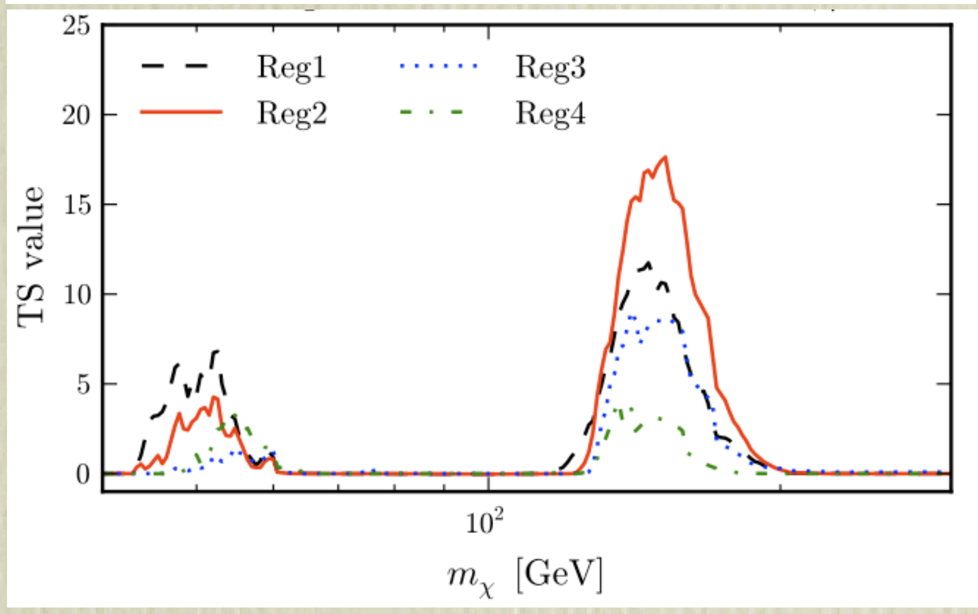


Caveat: Virgo is a hard-to-model target.

IB spectral feature (possibly also a γ line) in the **galactic center** region with 3.1 σ indication:

Bringmann et al., arXiv:1203.1312

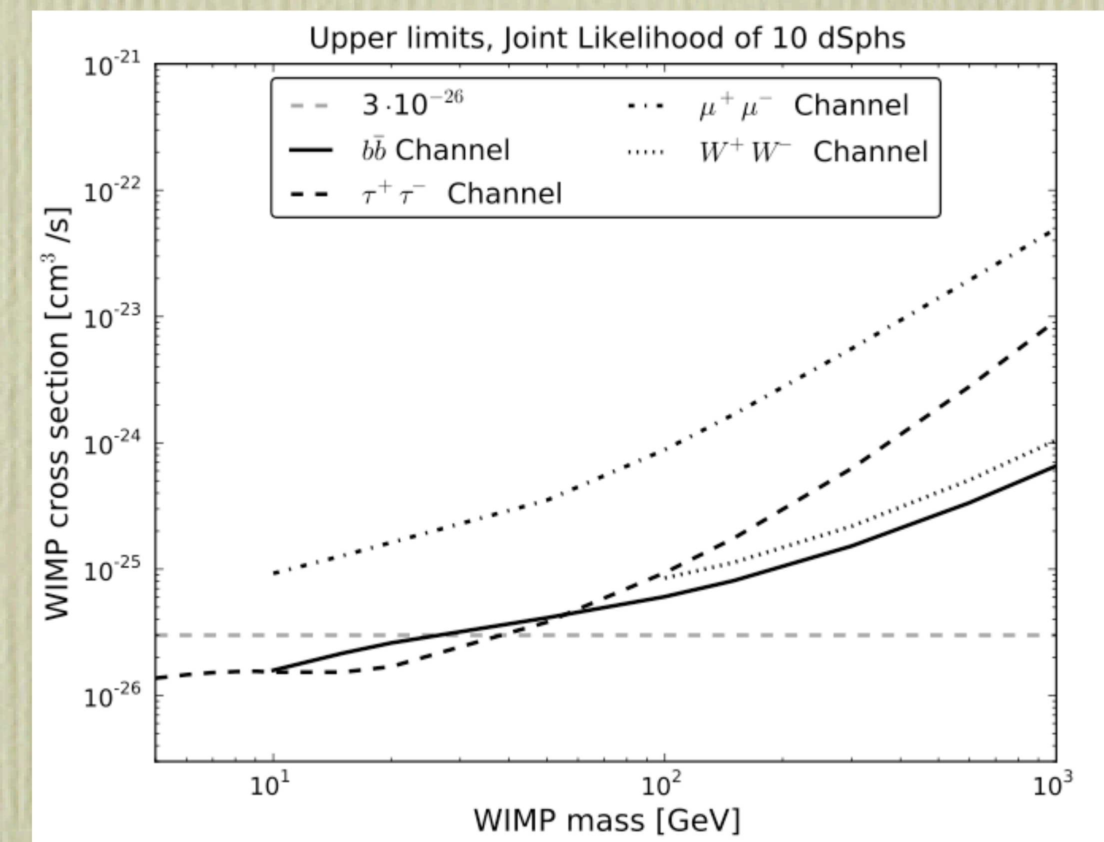




Other upper limits on DM from FERMI γ-ray data

Stacking analysis on **dwarf satellites**, among the tightest limits based on indirect detection:

Fermi-LAT coll., arXiv:1108.3546

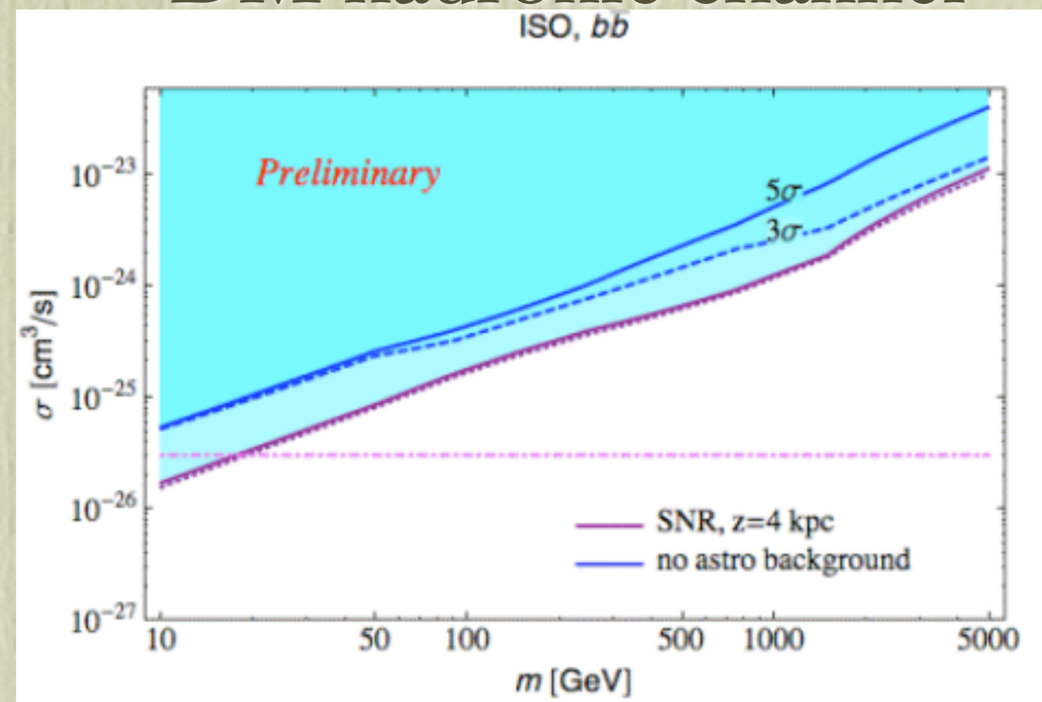


Caveat: subtleties in how background and signals are treated, see, e.g., Cholis & Salucci, arXiv:1203.2954

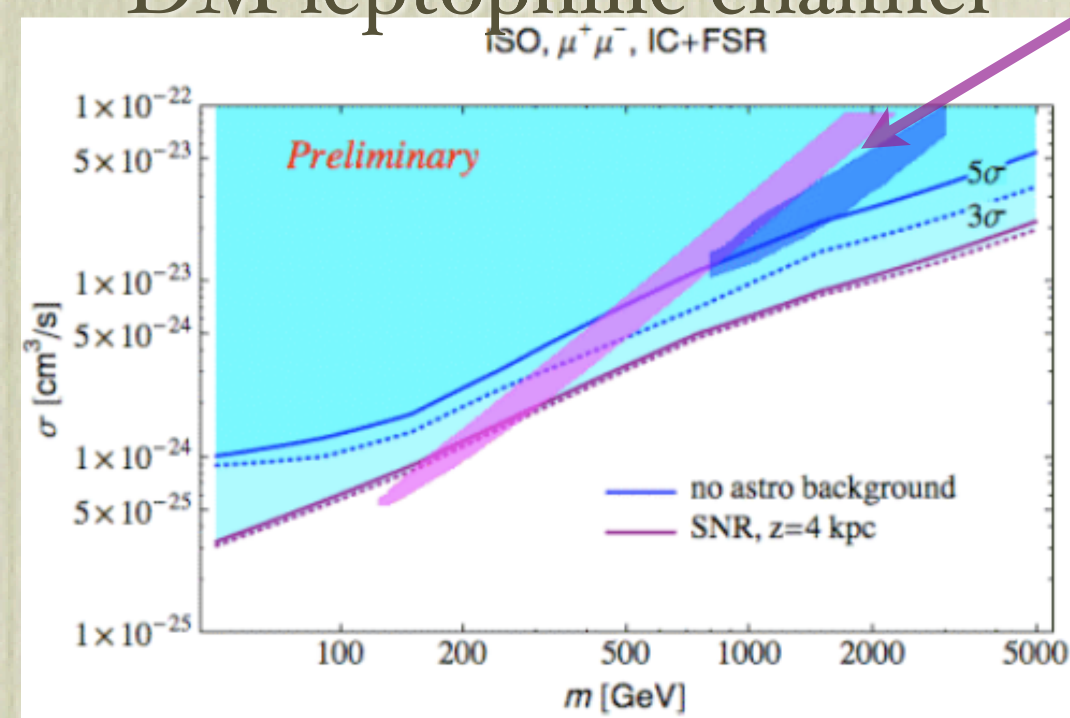
Limits from the **Galactic diffuse emission**:

Zaharijas et al., arXiv:1012.0588

DM hadronic channel



DM leptophilic channel



Models potentially interesting for the CR electron/positron puzzle from Pamela & Fermi

Outlook for DM detection via γ-rays

• The analysis on dwarfs is going to improve: error bars are statistics dominated + new targets may be identified soon (a few dwarfs have been recently discovered in SDSS data, which however has mapped only a small region of the sky)

• Searches for spectral features (internal Bremsstrahlung or γ-ray lines) are also at the moment limited by statistics: bounds will improve, hints of signals will be cleaned up.

• Improvements in the models for the diffuse γ-ray emission in the Galaxy are needed to shed light on the presence of a possible component from WIMP annihilations. Current models (derived, e.g., in a run with Galprop) are effective models tuned to reproduce the data; it would be preferable to switch to models defined from first principles.

Outlook with multi-wavelength and multi-messenger techniques

• We have a poor understanding of the CR lepton populations in the Galaxy. Does DM play any role in the puzzle on the locally measured CR electron and positron CR flux? or in the haze/bubbles identified in the central region of the Galaxy in the microwave and γ-ray bands? There are morphological & spectral features connected to the DM explanations to discriminate against alternative solutions; the picture can be clarified via multi-wavelength campaigns.

• We are eagerly waiting for AMS data to improve our understanding of CR propagation in the Galaxy (and eventually demonstrate the presence of a component due to WIMP annihilations). Planck will allow to improve WMAP limits on WIMP annihilations at the early stages of structure formation. The multi-messenger approach is emerging as very powerful tool to discriminate among DM models.

Summary and conclusions

• The WIMP paradigm is not excessively shaking because of the null detection so far for particles BSM at the LHC, the underlying frameworks are however getting less natural.

• The picture from direct detection searches is still contradictory, with apparent inconsistencies if all reported results are taken at face value (without invoking exotic scenarios). There has been steady progresses in the field, with new datasets being released soon.

• DM is not "bright" in any of the proposed indirect detection channels; no clean signal identified, a few "hints" of detection have been claimed. There is still the chance of singling out morphological and/or spectral signatures. The multi-wavelength / multi-messenger approaches as a promising (but challenging) option.