The Matters of Dark Matters

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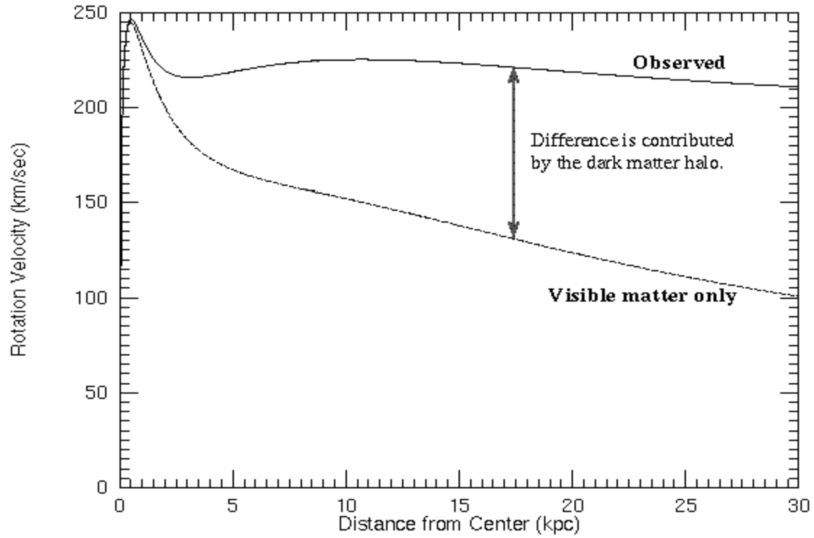
based on arXiv:1303.5386, JHEP **1306**, 113 (2013):
C. Boehm, B. Dev, A. Mazumdar, E.P.

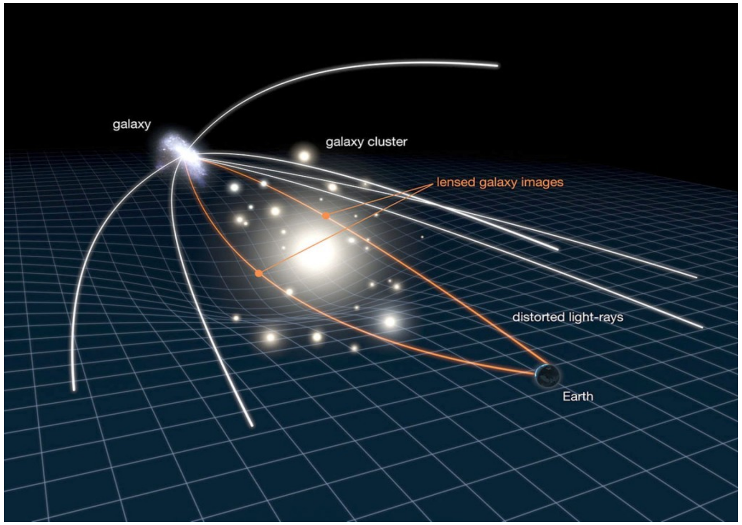
Outline

- ✓ How do we know DM exists?
- ✓ Experimental signals of light DM.
- ✓ How to get light DM in SUSY models?
- ✓ Scan setup and results.
- ✓ Naturalness issues.
- ✓ Conclusion.

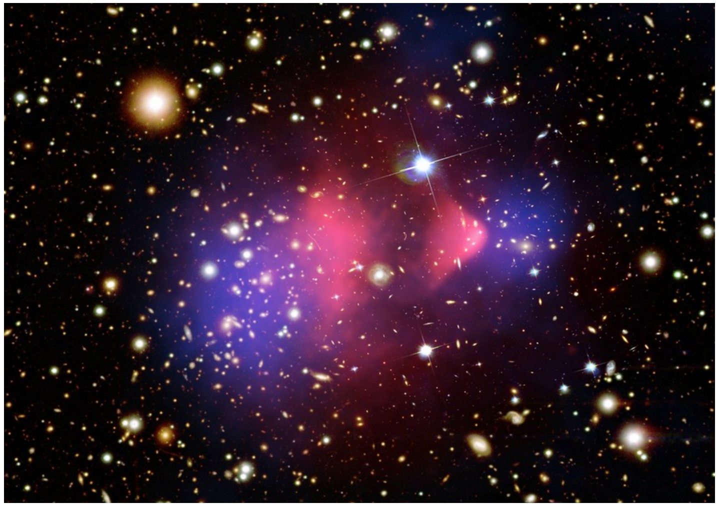
Evidence and origin of DM



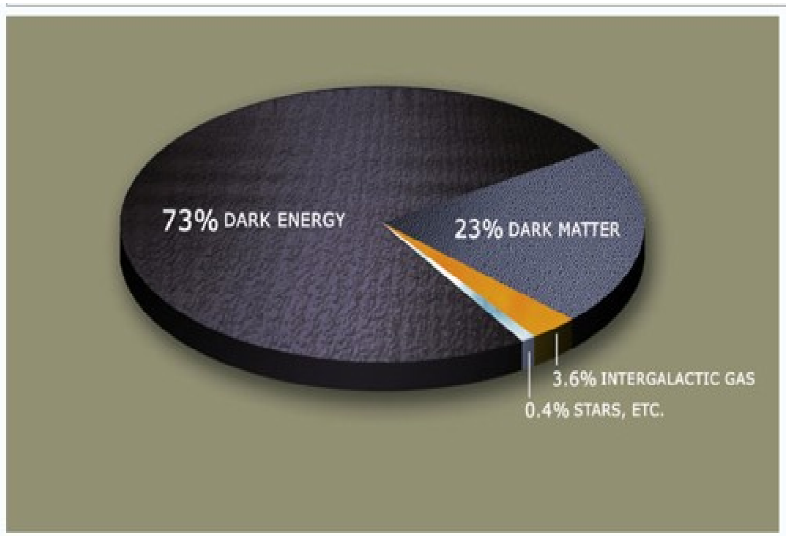
Galaxy's/cluster's rotation curves



Gravitational lensing



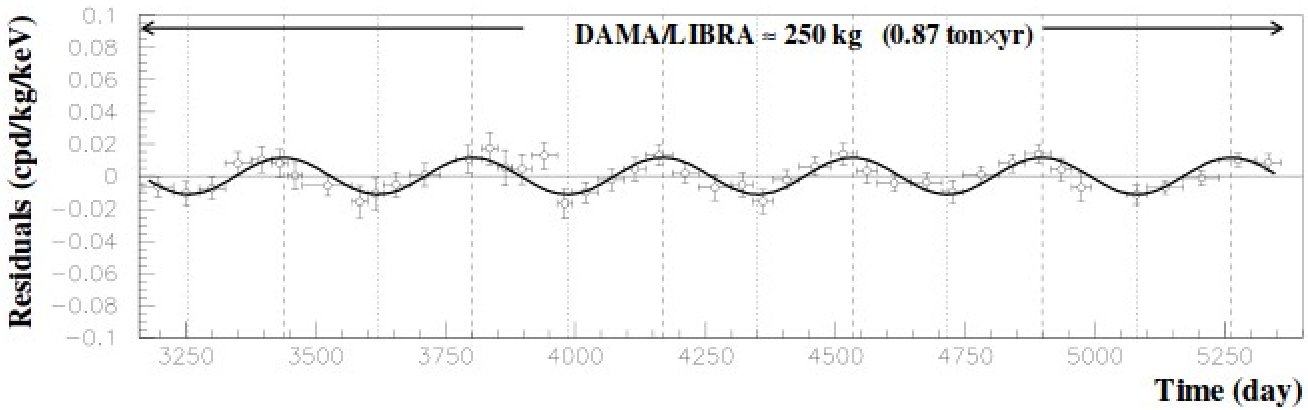
Bullet cluster-evidence for a particle-like origin of DM.



Energy budget of the Universe.

Signals of light DM

DAMA/LIBRA observed annual modulation at 8.9 σ.



CoGeNT supports annual modulation detected by DAMA/LIBRA.

-Favours 7-11 GeV DM.

CRESST-II likelihood analysis best fit gives:

$$m_{\tilde{\chi}_1^0} = 11.6 \text{ GeV at } 4.2\ \sigma$$
$$m_{\tilde{\chi}_1^0} = 25.3 \text{ GeV at } 4.7\ \sigma$$

CDMS highest likelihood at 8.6 GeV.

How people look at it

Pessimists: things can not get any worse...

-DAMA/LIBRA, CoGeNT, CRESST-II, CDMSII

Optimists: of course they can!!!

-XENON100, EDELWEISS II

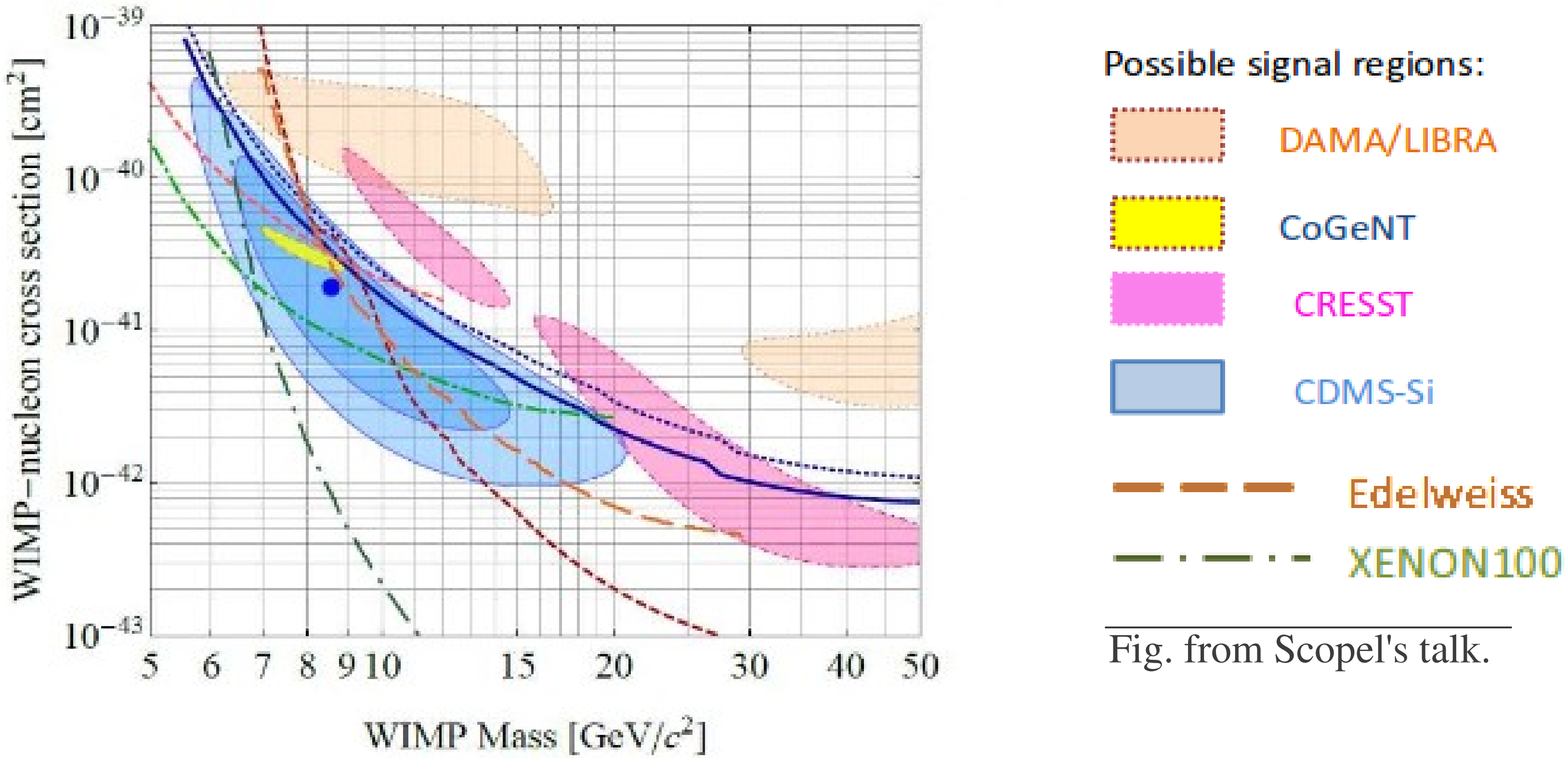


Fig. from Scopel's talk.

Opportunists:

-try to reconcile the data and theory.

-try to rule in/out particle physics models.

Dark Matter in MSSM

Neutralino mass matrix is given by:

$$M_{\widetilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -\frac{1}{\sqrt{2}}g'v_d & \frac{1}{\sqrt{2}}g'v_u \\ 0 & M_2 & \frac{1}{\sqrt{2}}gv_d & -\frac{1}{\sqrt{2}}gv_u \\ -\frac{1}{\sqrt{2}}g'v_d & \frac{1}{\sqrt{2}}gv_d & 0 & -\mu \\ \frac{1}{\sqrt{2}}g'v_u & -\frac{1}{\sqrt{2}}gv_u & -\mu & 0 \end{pmatrix}$$

$$\widetilde{\chi}_1^0 = N_{11}\widetilde{B} + N_{12}\widetilde{W}^0 + N_{13}\widetilde{H}_d^0 + N_{14}\widetilde{H}_u^0$$

In the limits where $m_Z \ll |M_1 \pm \mu|$ and $|M_2 \pm \mu|$

$$m_{\widetilde{\chi}_1^0} = M_1 - ...$$

$$m_{\widetilde{\chi}_2^0} = M_2 - ...$$

$$m_{\widetilde{\chi}_3^0}, m_{\widetilde{\chi}_4^0} = |\mu| + ...$$

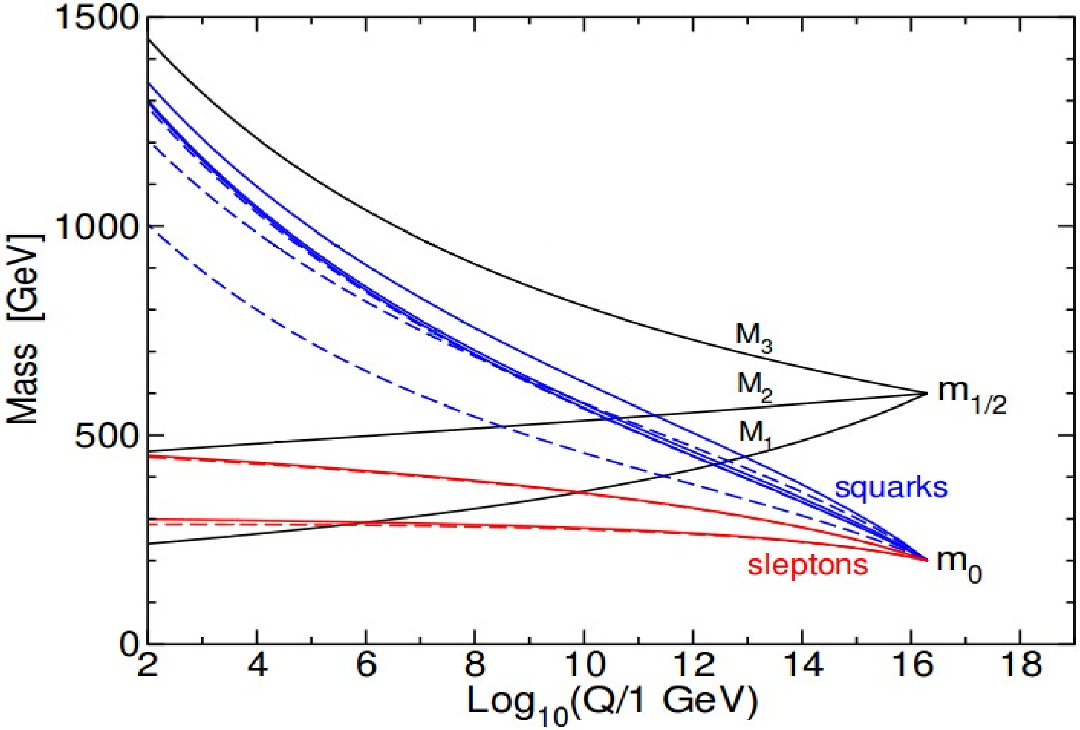
for chargino:

$$m_{\widetilde{\chi}_1^\pm} = M_2 - ...$$

$$m_{\widetilde{\chi}_2^\pm} = |\mu| + ...$$

How to get light DM?

for eg. in CMSSM: $M_1 = \frac{5}{3} \tan^2 \theta_W M_2 \approx 0.5 M_2$



LEP bound on chargino > 103.5 GeV

$\Longrightarrow$ $m_{\tilde{\chi}_1^0} > 46\text{GeV}$

relax universality conditions imposed in CMSSM!

Parametrising the fine tuning

Minimization condition for the Higgs potential in MSSM:

$$\frac{m_Z^2}{2} = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1} - \mu^2$$

calculate derivatives

$$\Delta p_i = \left| \frac{\partial \ln m_Z^2(p_i)}{\partial \ln p_i} \right| = \left| \frac{p_i}{m_Z^2} \frac{\partial m_Z^2}{\partial p_i} \right|$$

with $p_i = \{\mu^2, b, m_{H_u}, m_{H_d}\}$ and add

$$\Delta_{\rm tot} = \sqrt{(\Delta\mu^2)^2 + (\Delta b)^2 + (\Delta m_{H_u}^2)^2 + (\Delta m_{H_d}^2)^2}$$

the larger $\Delta_{\rm tot}$ the more fine tuned scenario.

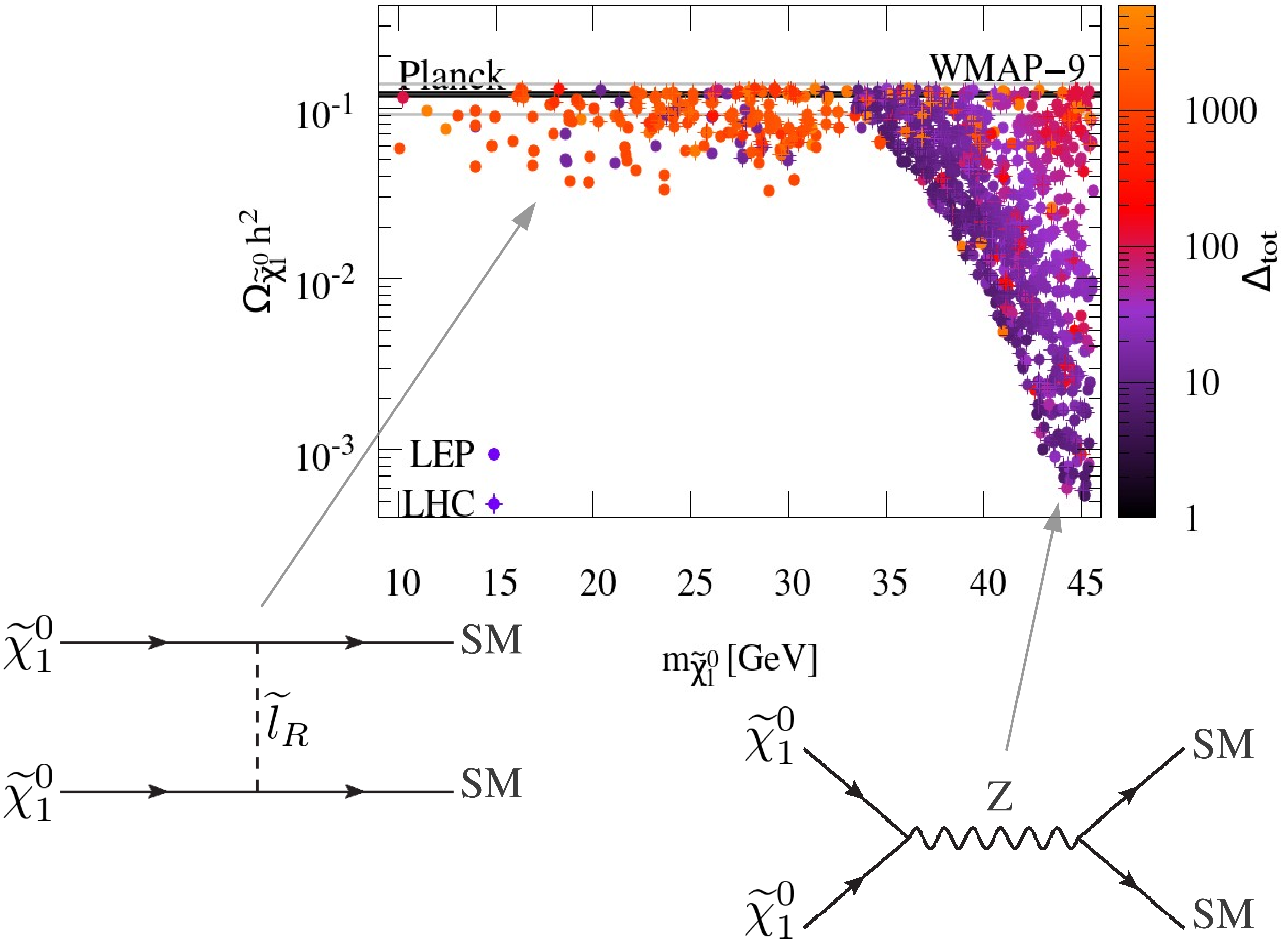
there is a tension between $m_h = 125$ GeV and naturalness

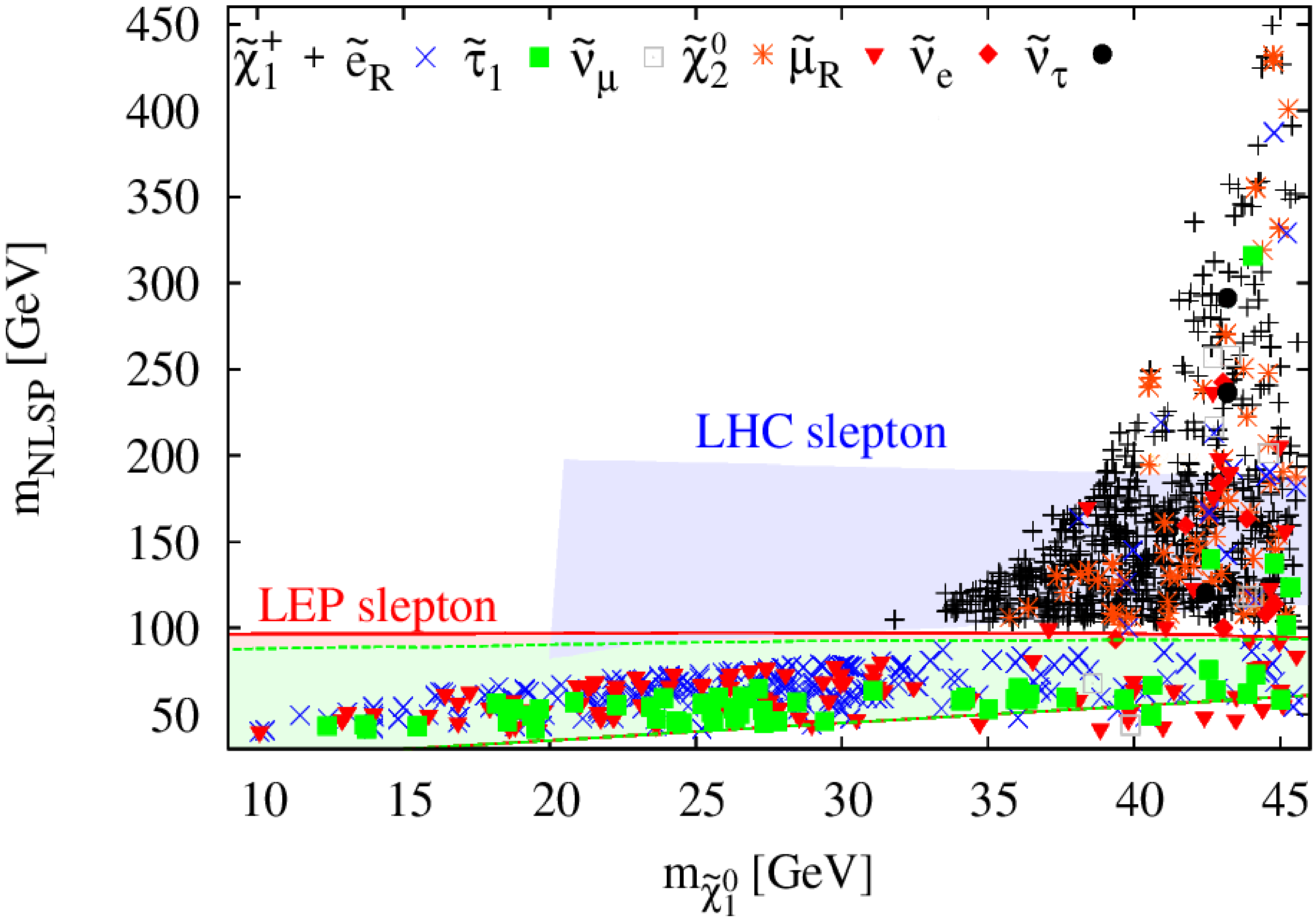
Ellis, Enqvist, Nanopoulos, Zwirner: Mod. Phys. Lett. A1 (1986) 57
Barbieri and Guidice: Nucl.Phys. B306 (1988) 63

Constraints imposed

- Dark matter abundance from WMAP & Planck.
- Cold DM particle $\widetilde{\chi}_1^0$.
- LEP bound on a mass of chargino.
- Higgsteria: Higgs mass constraint from ATLAS & CMS and the Duck test: *If it looks like a duck, swims like a duck, and quacks like a duck, then it probably is a duck.*
- Branching ratios: $B_s \to \mu^+\mu^-, b \to s\gamma$.
- $g_\mu - 2$.
- Invisible Z boson decay for neutralinos with masses $< \frac{m_z}{2}$.

Ωh^2 vs $m_{\tilde{\chi}_1^0}$





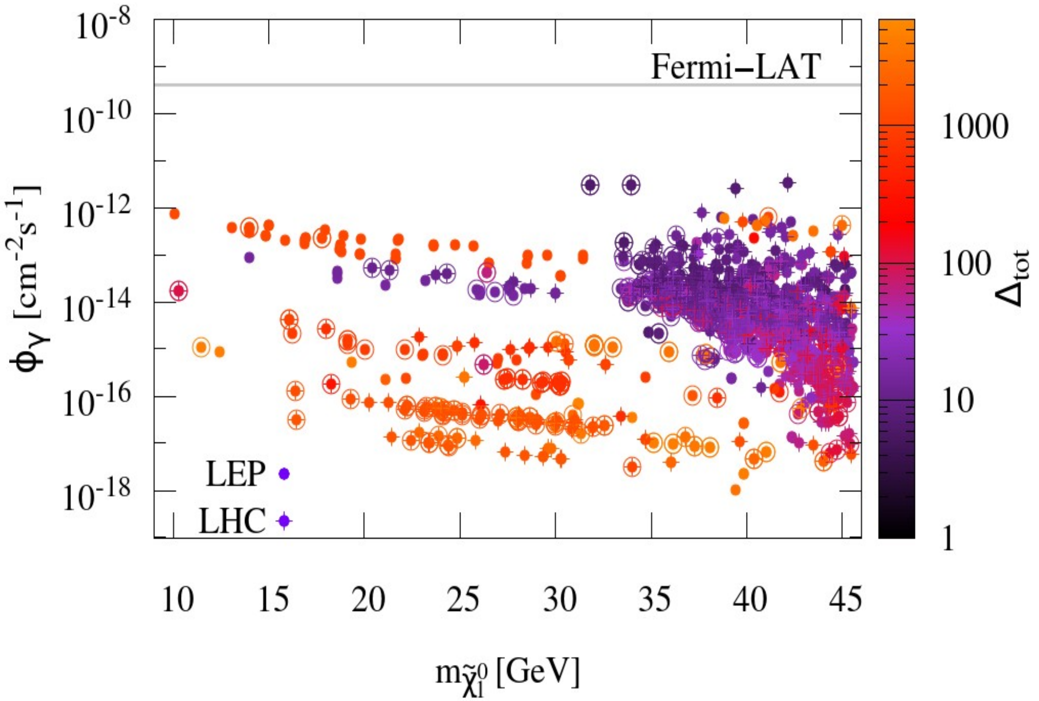
$$|\mathcal{M}|^2 \propto |Y|^4$$

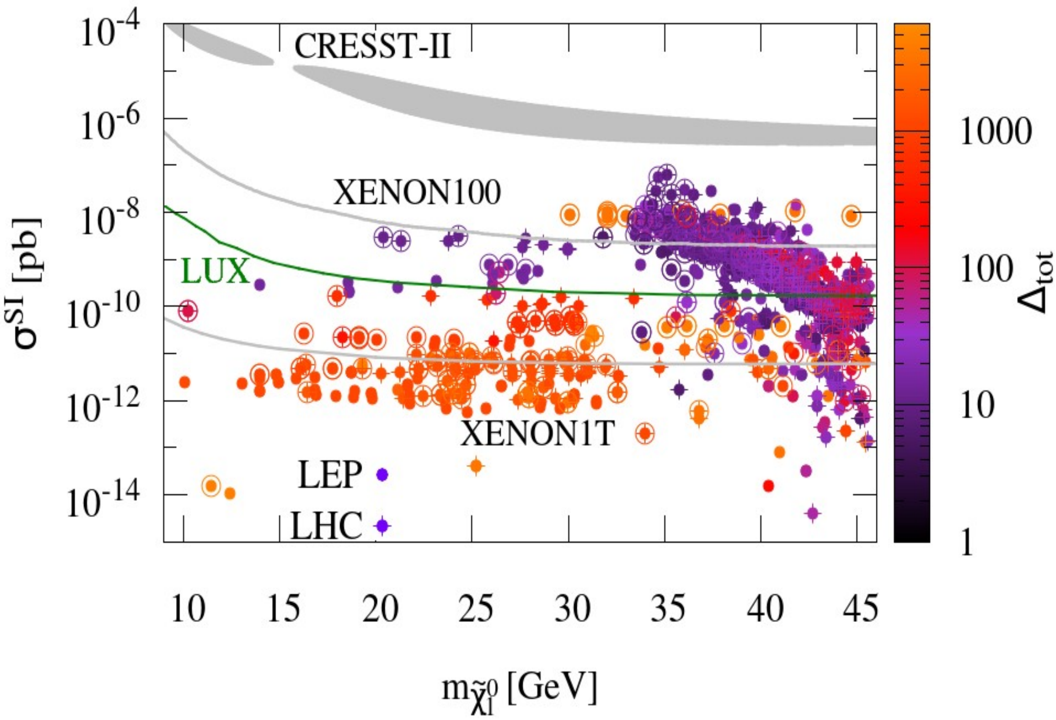
$$\Omega_{\tilde{B}} h^2 = 1.3 \times 10^{-2} \left(\frac{m_{\tilde{l}_R}}{100\text{GeV}}\right)^2 \frac{(1+r)^4}{r(1+r^2)} \left(1 + 0.07 \log \frac{\sqrt{r}100\text{GeV}}{m_{\tilde{l}_R}}\right)$$

$$r = \frac{M_1^2}{m_{\tilde{l}_R}^2}$$

Arkani-Hamed, Delgado, Guidice: hep-ph/0601041

DD and ID probes



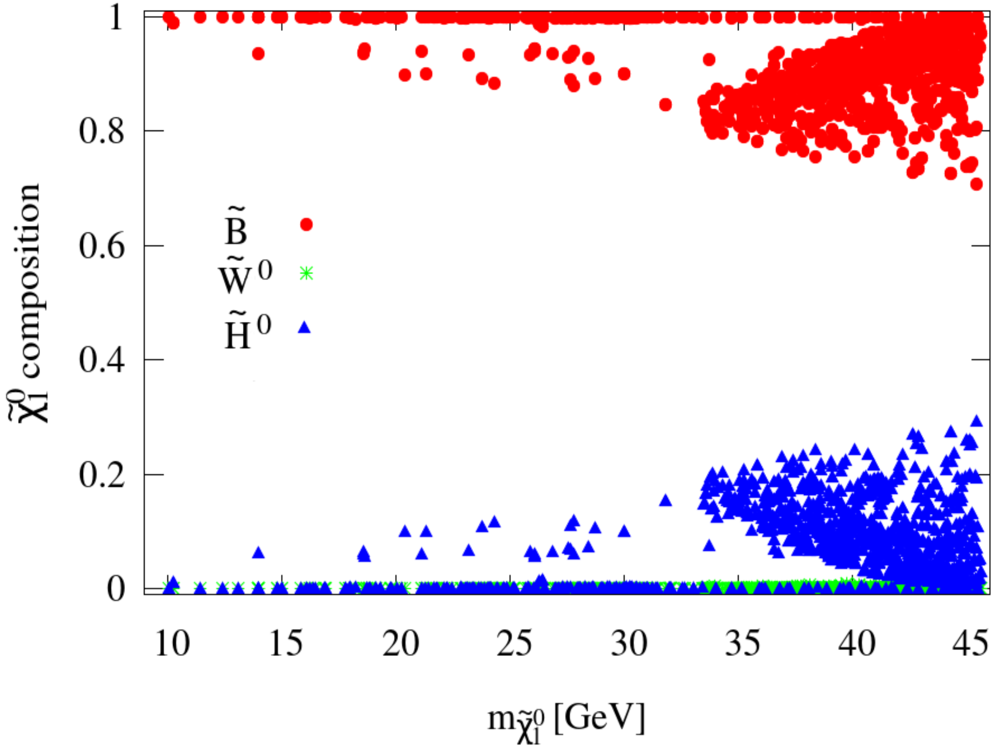


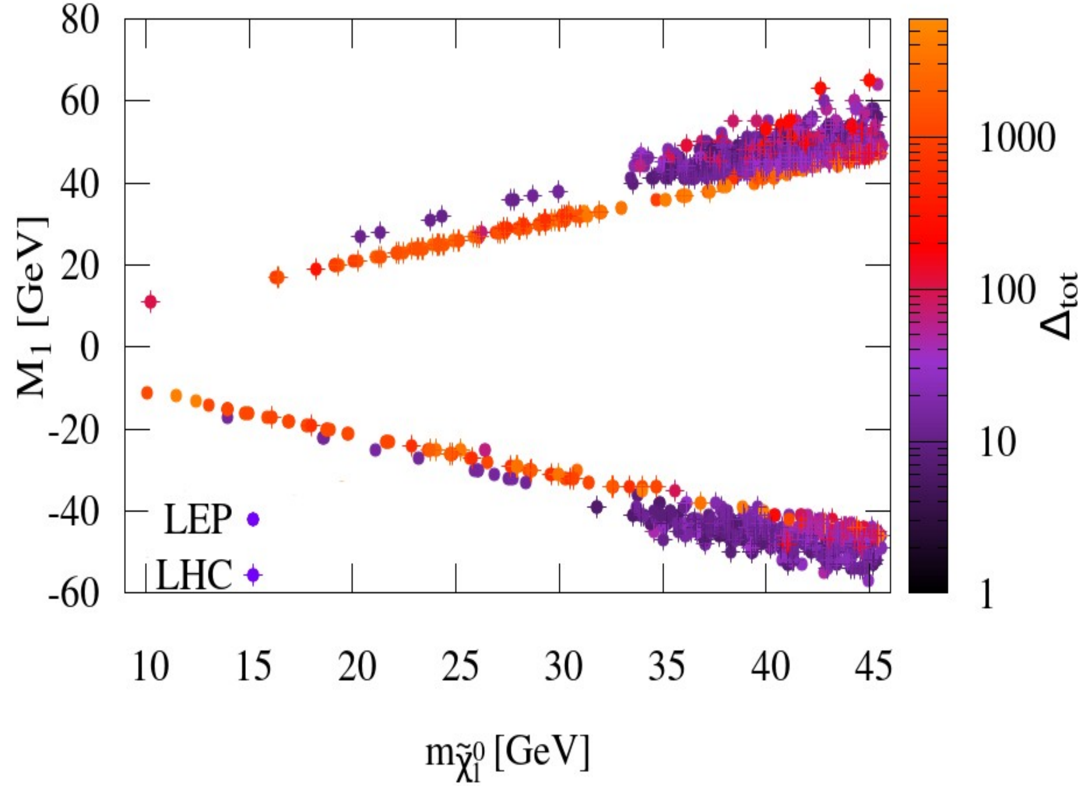
- No worries for ID but DD is biting a lot!
- pMSSM has potential to explain CRESST–II but not DAMA, CoGeNT or CDMS-II.

Conclusions

“What?” vs “ So What?”

Lightest neutralino must be dominantly bino





- Bound on chargino mass.
- Invisible Z decay:

$$\Gamma_{Z\to\tilde{\chi}_1^0\tilde{\chi}_1^0} = \frac{M_Z^3 G_F}{12\sqrt{2}\pi}(N_{13}^2 + N_{14}^2)^2\left(1 - \frac{4m_{\tilde{\chi}_1^0}^2}{M_Z^2}\right)^{3/2}$$