Dark Matter and the ILC

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LPT Orsay

Dark matter and SUSY

Zwicky (1933) $\Rightarrow$ WMAP (2003-2007) $\Rightarrow$ PLANCK (2008):

The Univers is made by $\sim$ 25% of cold dark matter (CDM)

- **Past: galaxy rotation, formation of big structures, ...**
- **Present: WMAP measur. of temperature anisotropies in CMB, ...**
  $\Omega_{\rm DM}\, h^2 \simeq 0.11 \pm 0.006 \Rightarrow 0.09 \leq \Omega_{\rm DM}\, h^2 \leq 0.13$ **at 99% CL**
- **Future: PLANCK satellite will measure $\Delta\Omega_{\rm DM}\, h^2$ at $\sim 2\%$**

$\Rightarrow$ **Needs a particle that is neutral, weakly interacting, massive, stable.**

No such a type of particle in the Standard Model.

In SUSY: this is possible and the neutralino χ_1^0 is the best candidate:

– electrically neutral and (often maybe too) weakly interacting

– massive: $m_{\chi_1^0} \gtrsim 50$ GeV in constrained models

– stable if R–parity, $\mathbf{R_p = (-1)^{2s+3B+L}}$, is conserved.

Question: does $\boldsymbol{\chi_1^0}$ has the right cosmological relic density?

Calculation of the cosmological relic density

- **Early Universe: χ_1^0 in thermal equilibrium (production=annihilation).**

Evolution of the number density given by Boltzmann equation:

$$dn_{\chi_1^0}/dt + 3Hn_{\chi_1^0} = -\langle v\,\sigma_{\rm ann}\rangle (n^2_{\chi_1^0} - n^{\rm eq\,2}_{\chi_1^0})$$

- **χ_1^0 decouples from bath of SM particles at a temperature**

$$x_F \equiv m_{\chi_1^0}/T_F = 0.38 M_P \langle v\sigma_{\rm ann}\rangle c(c+2) m_{\chi_1^0}\,(g_* x_F)^{-1/2} \sim 20-25$$

- **The present relic density (normalised to the critical density):**

$$\Omega_\chi h^2 = \frac{2.13\cdot 10^8/{\rm GeV}}{\sqrt{g_*} M_P J(x_F)}\,,\ \ {\rm with}\ \ J(x_F) = \int_{x_F}^\infty \frac{\langle v\sigma_{\rm ann}\rangle(x)}{x^2}dx$$

- **The annihilation cross section is given by**

$$v\,\sigma_{\rm ann} \equiv v\,\sigma(\chi_1^0\chi_1^0 \to {\rm SM\,particles}) = a + bv^2 + \mathcal{O}(v^4)$$

$\cdots$ **HEP job: calculate exactly $\sigma_{\rm ann}$ (a et b) and measure as precisley**

as possible $m_{\chi_1^0}$ $\cdots$ and all the parameters entering the game.....

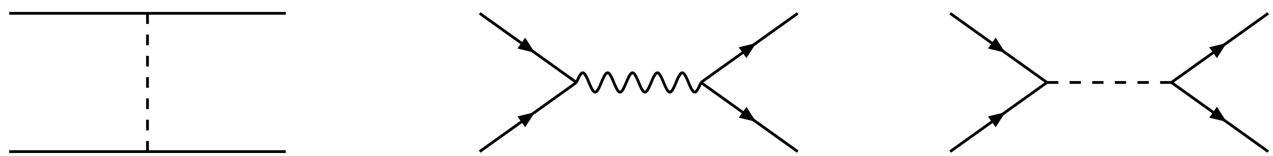
(co)Annihilation of χ_1^0 in cMSSM

Calculation of $\sigma(\chi_1^0\chi_1^0 \to \mathrm{SM\,particles})$ rather complicated:

- **Many possible final states ($\Phi_i = h, H, A, H^\pm$; $f = \tau, b, t, ..$):**

$$\chi_1^0\chi_1^0 \to f\bar{f}, WW, ZZ, \Phi_i\Phi_j, \Phi_i Z, H^\pm W^\mp \text{ etc....}$$

- **Several channels might be present; for example in $\chi_1^0\chi_1^0 \to f\bar{f}$:**



- **Co-annihilation processes to be taken into account:**

$$\chi_1^0 + \tilde{P} \leftrightarrow X + Y \text{ and } \tilde{P} + \tilde{P}^{(*)} \leftrightarrow X + Y \text{ if } m_{\tilde{P}} \sim m_{\chi_1^0}$$

- **SUSY parameter space to handle. In fact:**

– General MSSM too complicated ($105 \to 22$ free paramaters).

– Work simpler and more predictivity in constrained MSSMs.

– Example, in mSUGRA: $m_0, m_{1/2}, A_0, \tan\beta$, sign($\mu$).

Determination of spectrum in mSUGRA

Very complicated:

- **RGEs (two loops)**
- **EWSB (iterations)**
- **Masses, couplings, etc...**
- **Radiative corrections**

Sophisticated RGE programs:

- **example of SuSpect**

(Kneur, Moultaka, AD)

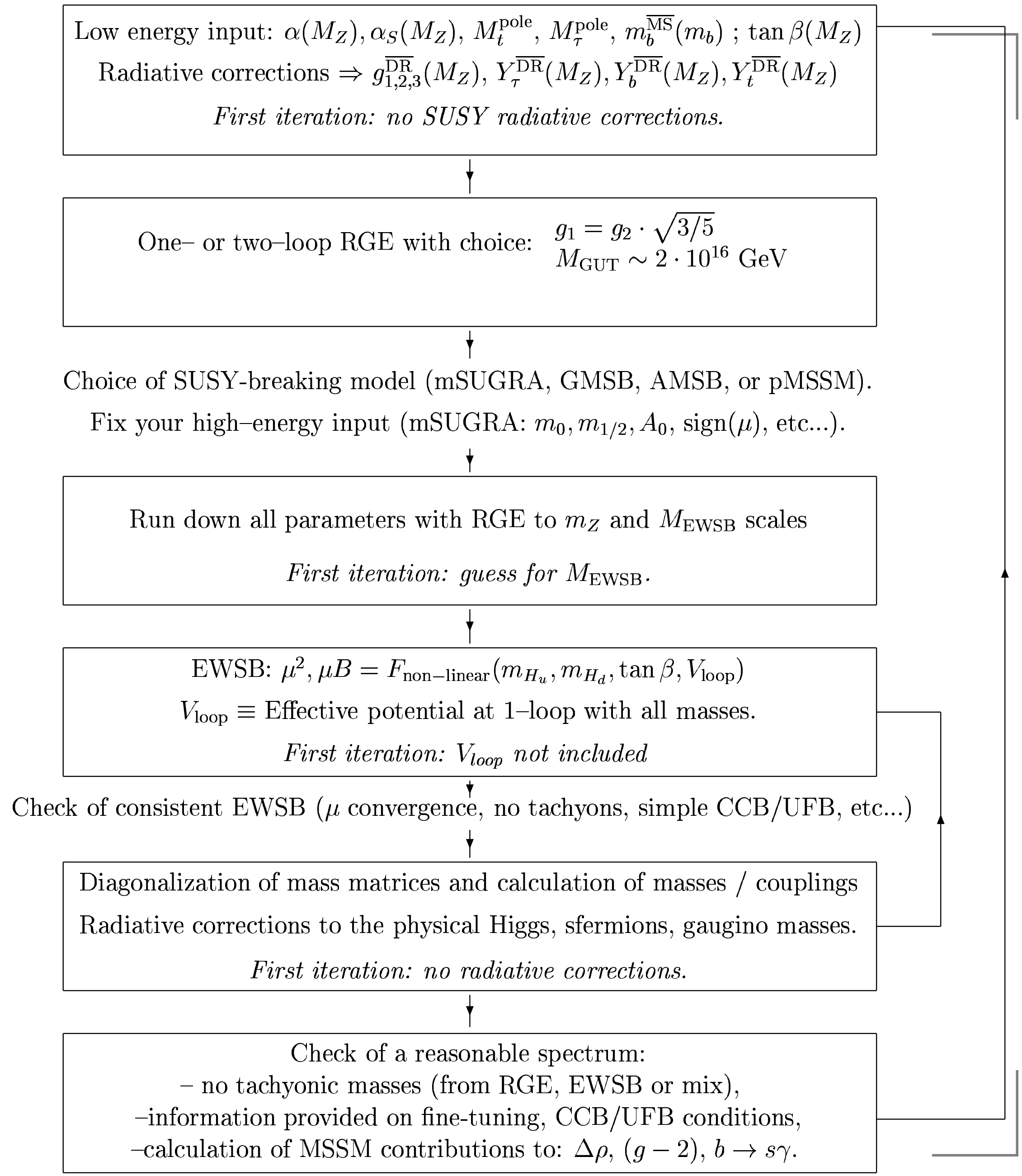
- **other programs exist....**

(Isajet, SoftSUSY, Spheno, ...)

Viable parameter space:

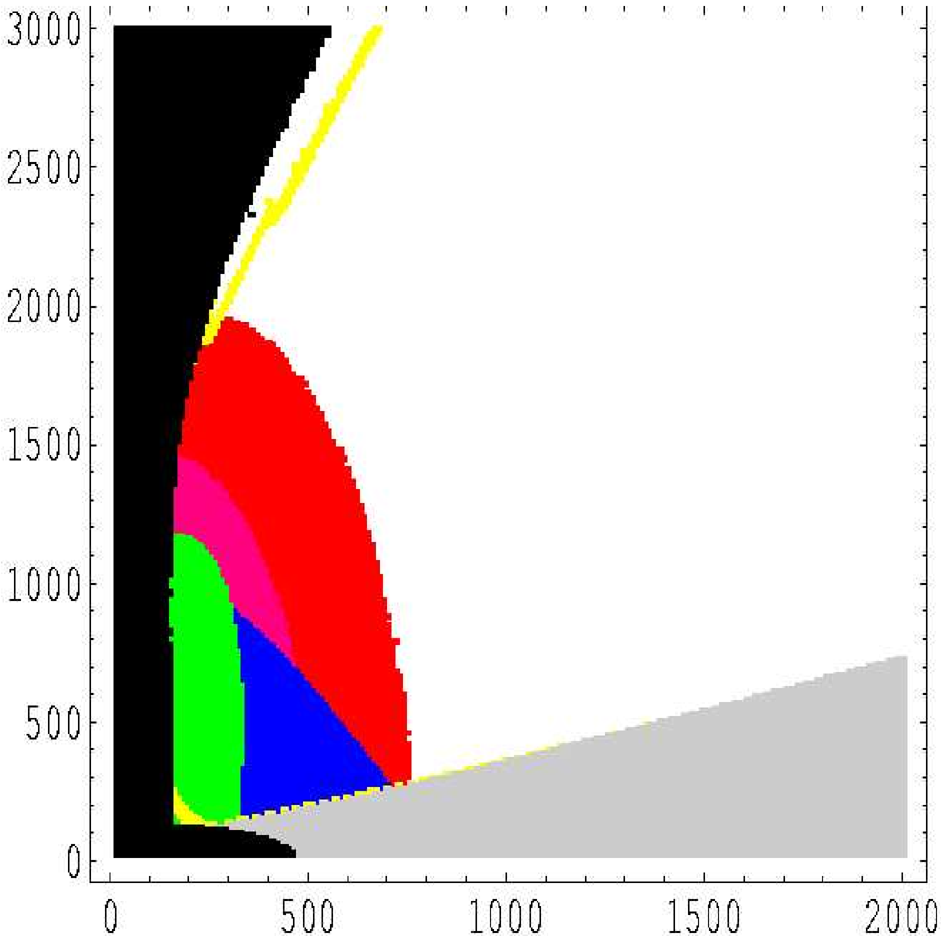
- **choose inputs, param. scan**
- **impose known constraints**

(TH, M_h, HPM, DM, ...)

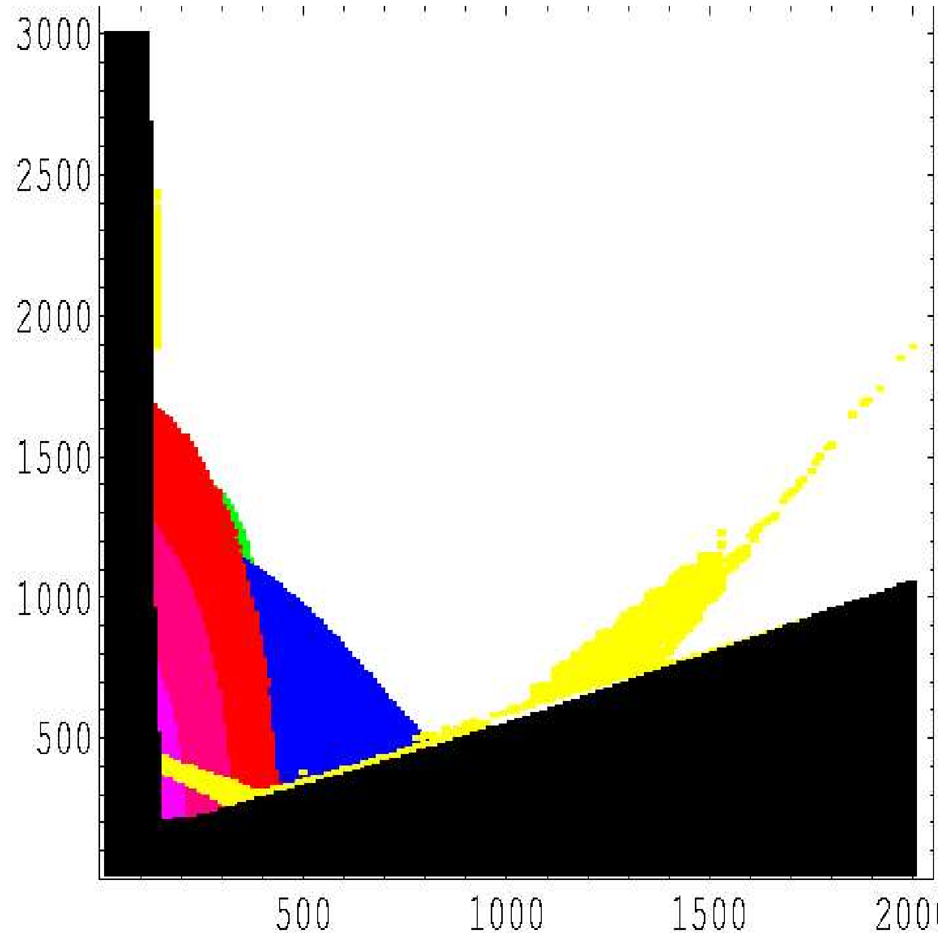


An $(m_{1/2}, m_0)$ scan in mSUGRA with $A = 0, \mu > 0$

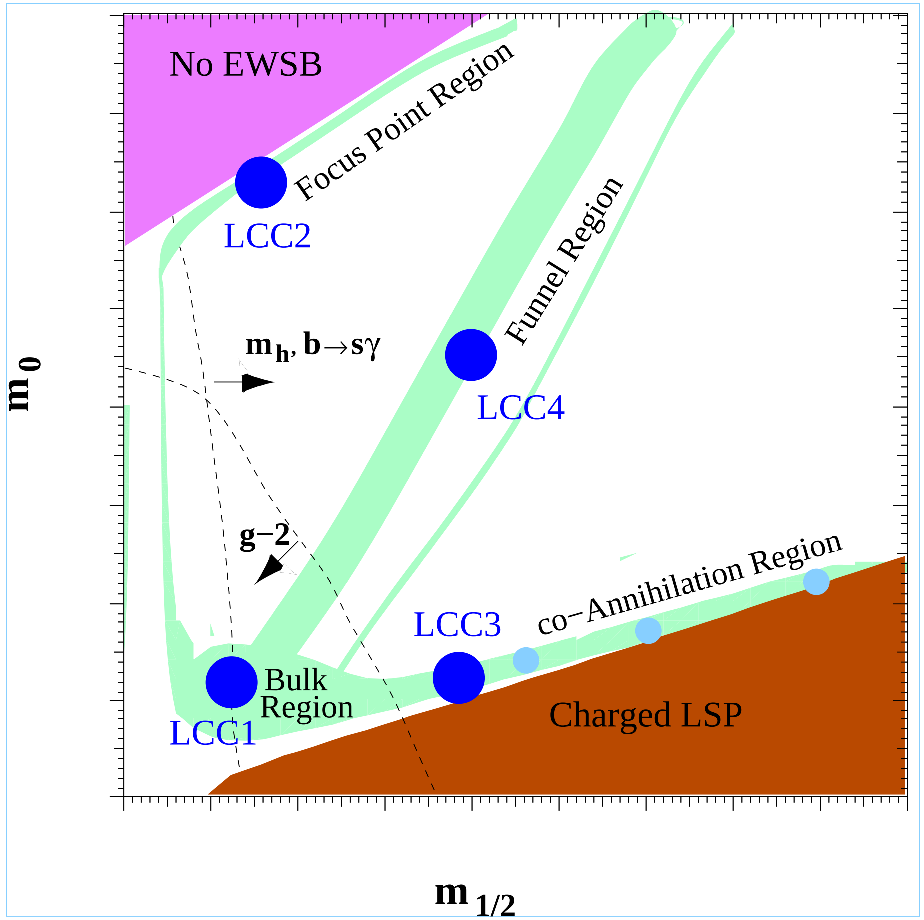
$m_t = 173$ GeV, $\tan\beta = 30$



$m_t = 178$ GeV, $\tan\beta = 50$



Good DM regions in mSUGRA



Generically, four/five regions with the required ammount of DM:

bulk region, focus point, co-annihilation, A pole and h pole.....

High precision measurements to perform

- **Suppose that except for $\sigma_{\rm ann}$ and $m_{\chi_1^0}$ all parameters are known (leave to cosmologists the precisle determination of $H, x_F, g_*, ...$).**
- **Measure everything: masses, production cross sections and asymmetries, decay widths and BRs in sparticle and Higgs production**
- **Determine the couplings of these particles (in practice softs terms) when including RC and all experimental and theoretical errors....**
- **Inject all in Ω_χ or $\sigma_{\rm ann}$ and check if OK with WMAP or PLANCK**

If yes, Bingo! A great success of HEP and/plus COSMO

If not, we have a problem:

– determination of other cosmological parameters?

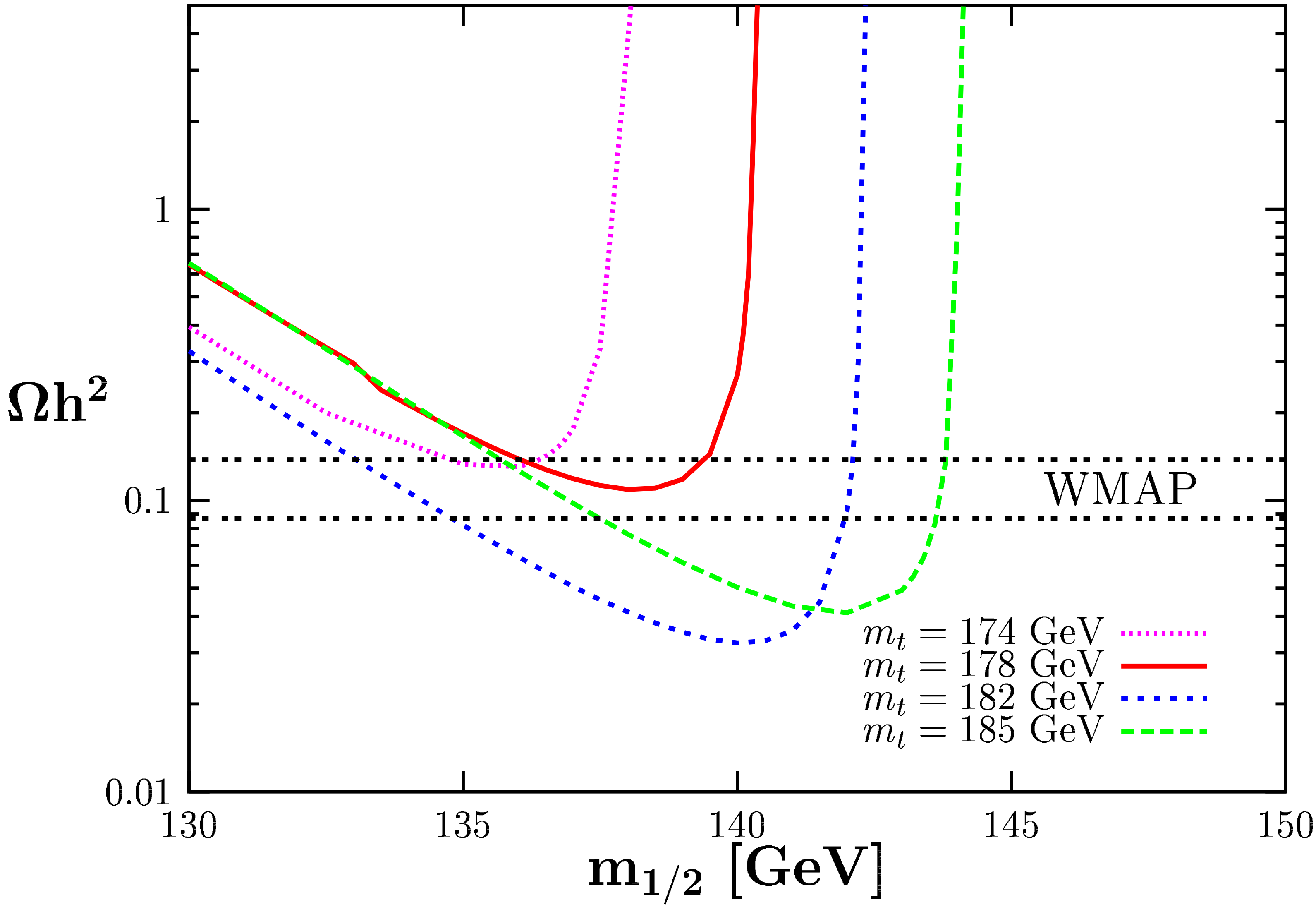
– maybe there is something else than SUSY CDM?

– other thoughts/nightmares....

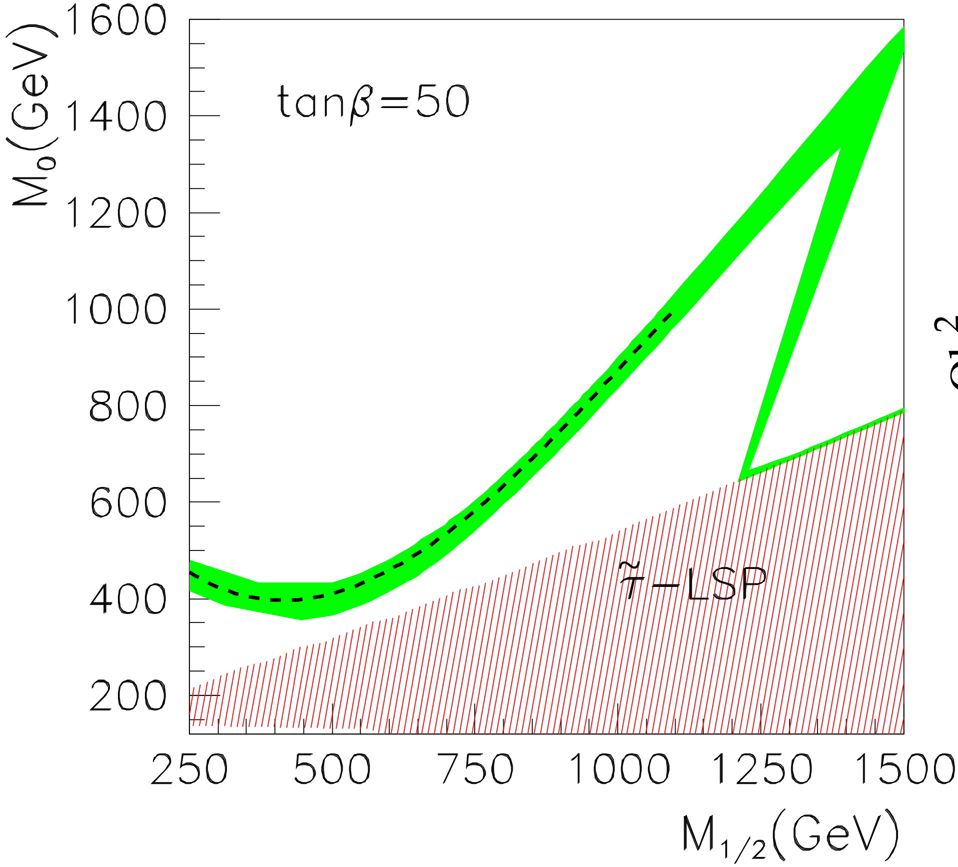
A very hard theoretical and experimental work to get to this point:

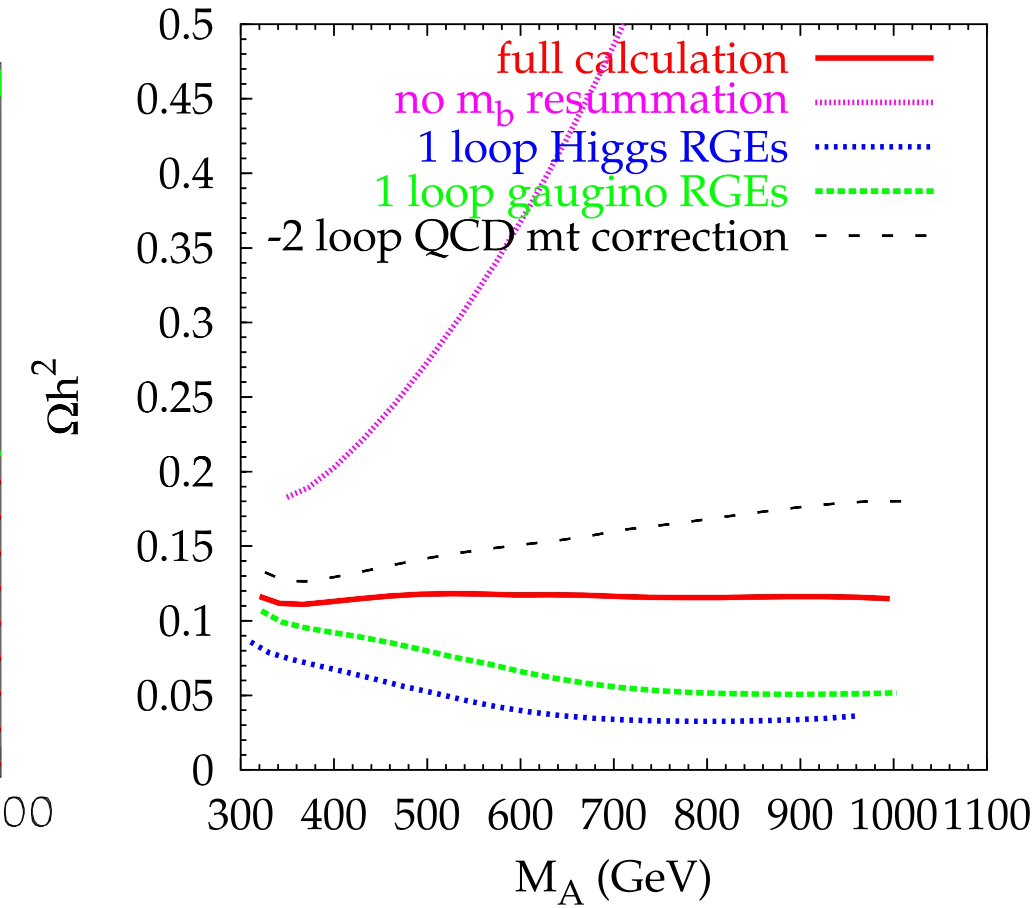
– High precision is needed: only ILC can achieve this..........

Region 1: annihilation via h exchange

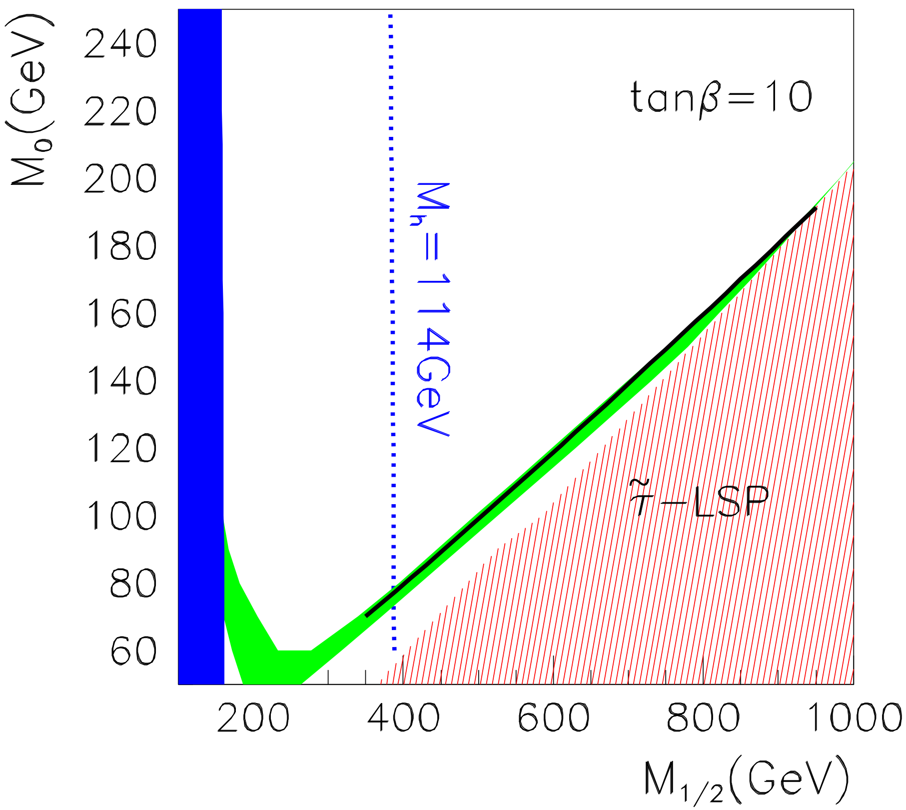


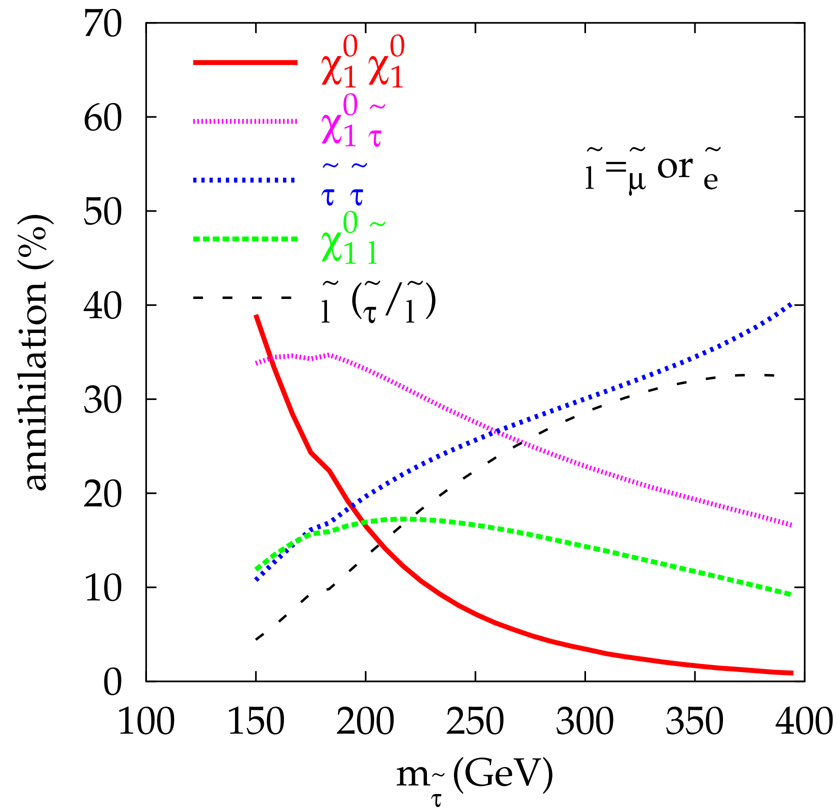
Region 2: annihilation via A exchange





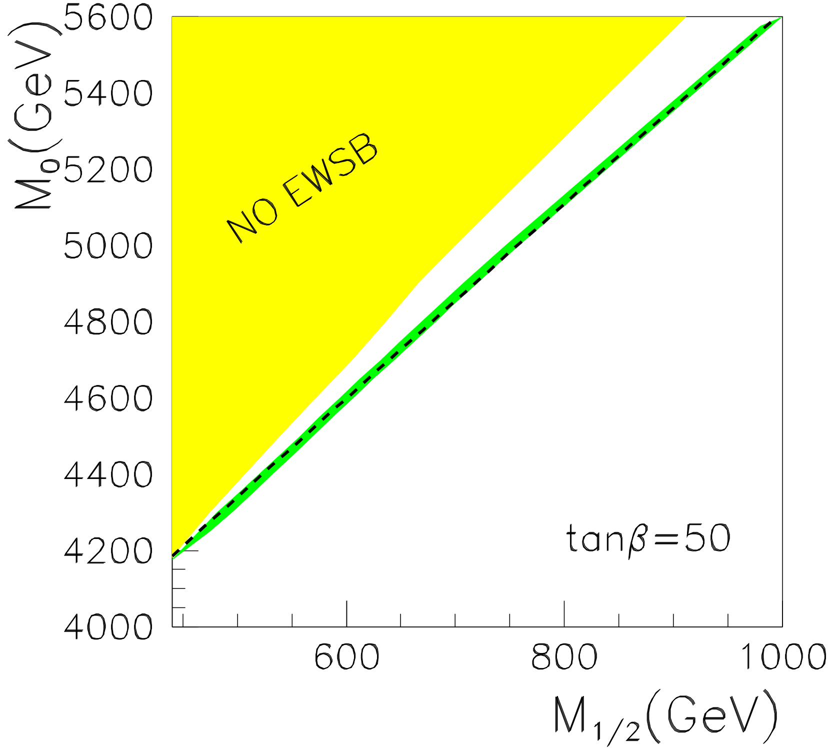
Region 3: co–annihilation with stau leptons

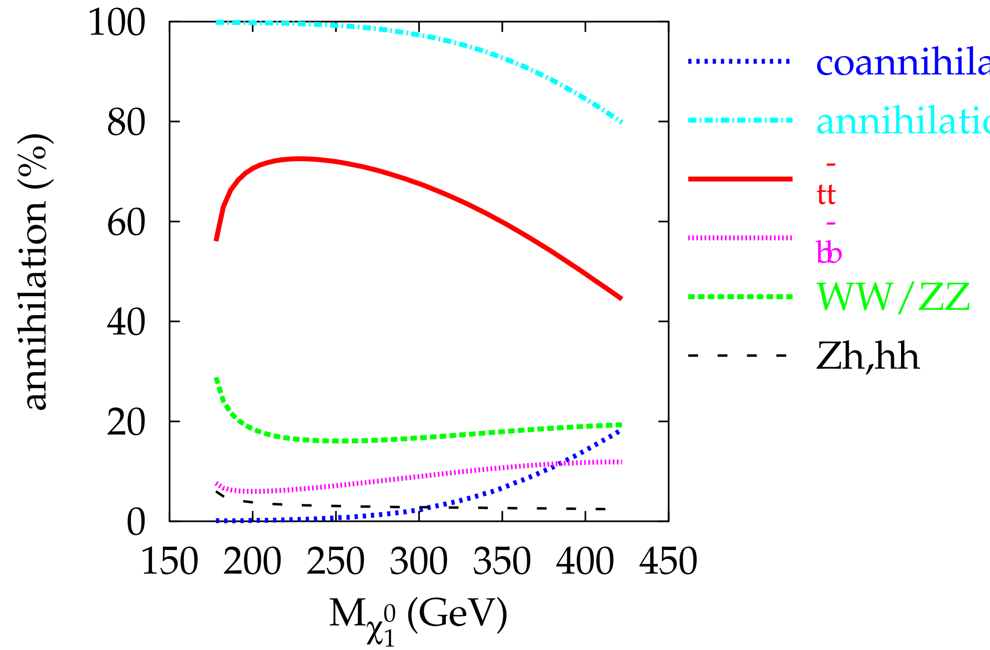




The staus are almost degenerate with the LSP neutralinos! Z. Zhang.

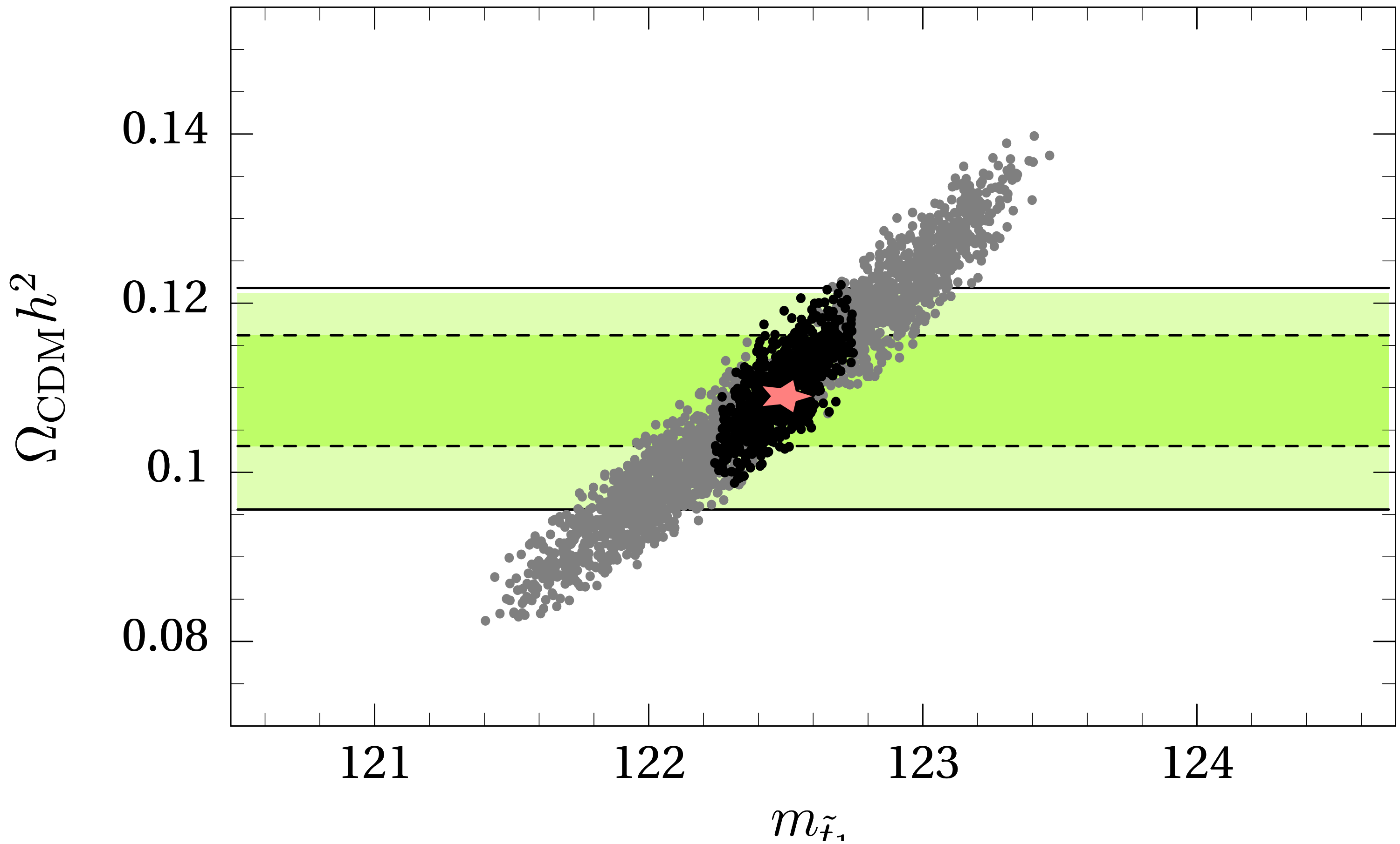
Region 4: focus point region





The lightest $\chi_1^{\pm}$ and next-to-lightest χ_2^0 are almost degenerate with χ_1^0!

Region 5: light stop scenario



The lightest $\chi_1^\pm$ should be almost degenerate with the lightest stop!

A scenario that is favored is SUSY has to explain EW baryogenesis!

Conclusions

SUSY has natural DM candidate: χ_1^0.

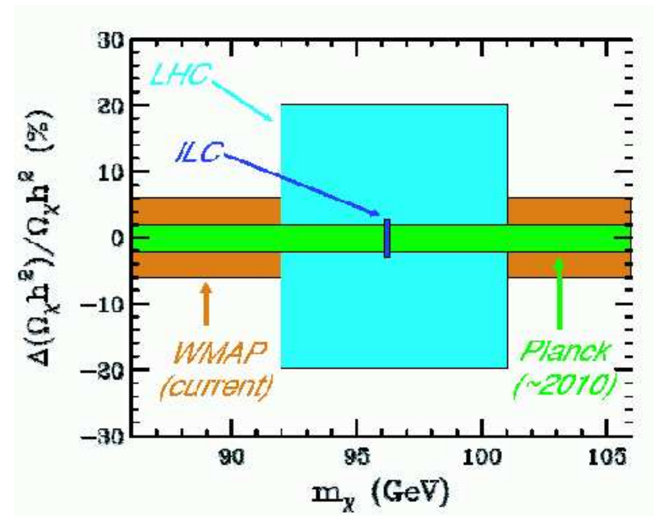
WMAP and PLANCK: $\Omega_{\rm DM}h^2$ very precise.

An important goal is to determine/check the value of $\Omega_{\rm DM}h^2$ in collider physics,

i.e: measure all parameters which enter in.

LHC can provide a 10–100% determination.

Only ILC provides a $\mathcal{O}(1\%)$ determination!



However, in many cases needs LSP degeneracy with some sparticle...

Production of NLSP at ILC leads to soft $f + \not{E}$($\tilde{\tau} \to \tau\chi_1^0, \chi_2^0 \to q\bar{q}\chi_1^0$, $\tilde{t} \to c\chi_1^0$...) which are subject to the huge two–photon background.

Moralité: we need a very good calorimeter in the very forward region.

So please do a good job!