# Dark Matter and Fine Tuning in the pMSSM

-Invisibles Premeeting in Madrid-

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# Outline

- The Fine Tuning Problem
  - The pMSSM
  - EWSB
  - Measures of Fine Tuning
- Experimental Constraints on SUSY
  - Collider Physics
  - Dark Matter
- Numerical Analysis

# The pMSSM

The complete "unconstrained" MSSM has 105 new parameters. Too many for an examiniation!

**assumptions**

- no new CP violation
- no FCNC at tree level (MFV)

$\Rightarrow$ end up with 22 input parameters:

6 trilinear couplings "A terms" $(A_u, A_d, A_e, A_t, A_b, A_\tau)$
15 masses $(m_{\tilde{q}}, m_{\tilde{u}_R}, m_{\tilde{d}_R}, m_{\tilde{l}}, m_{\tilde{e}_R}, m_{\tilde{Q}}, m_{\tilde{t}_R}, m_{\tilde{b}_R}, m_{\tilde{L}}, m_{\tilde{\tau}_R}, m_{M_i}, m^2_{H_u}, m^2_{H_d})$
ratio of the vev's $(tan\beta)$

# The Higgs Potential

$$V = (|\mu|^2 + m_{H_u}^2)|H_u^0|^2 + (|\mu|^2 + m_{H_d}^2)|H_d^0|^2 - (bH_u^0 H_d^0 + c.c.)$$
$$+ \frac{1}{8}(g^2 + g'^2)(|H_u^0|^2 - |H_d^0|^2)^2$$

We need consistency with EWSB from the SM:

## relations

- $v_u^2 + v_d^2 = v^2 = 2m_Z^2/(g^2 + g'^2)$
- minimize the potential $\Rightarrow m_Z^2 = \frac{|m_{H_d}^2 - m_{H_u}^2|}{\sqrt{1 - sin^2(2\beta)}} - m_{H_u}^2 - m_{H_d}^2 - 2|\mu|^2$

Requirements for the parameters already exist!

# EWSB

Further requirement: Change into mass eigenstates and compute the Higgs Mass! (at tree level:)

$$m_{h^0} < m_Z |cos(2\beta)| \leq m_Z$$

$\Rightarrow$ Need loop corrections to respect bounds on Higgs mass!

$$\Delta m^2_{h^0} \propto m_t^2 ln(m_{\tilde{t_1}} m_{\tilde{t_2}} / m_t^2)$$

## consequences

- need rather large $m_{\tilde{t}}$ for correct Higgs mass
- then also $m_{H_u}$, $m_{H_d}$ are increased
- amount of cancellations needed to get correct $m_Z$ rises:

$$m_Z^2 = \frac{|m^2_{H_d} - m^2_{H_u}|}{\sqrt{1 - sin^2(2\beta)}} - m^2_{H_u} - m^2_{H_d} - 2|\mu|^2$$

# Finetuning measure

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

Barbieri, Giudice (1988)

de Carlos, Casas (1993)

$$\Delta_{tot} = \sqrt{\sum_i \Delta_i^2}$$

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

Ellis, Olive (2001); Cassel, Ghilencea, Ross (2010)

# Collider Physics

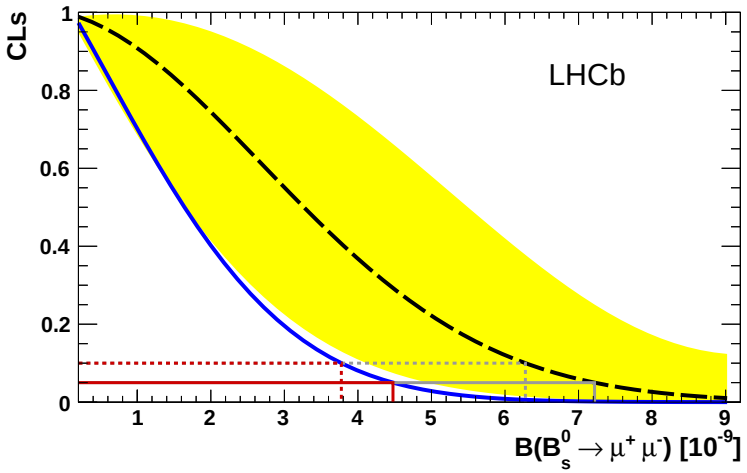
- Decays with SUSY enhancement:
  - $B \to \tau\nu : 0.52 < R_{B\tau\nu} < 2.61$

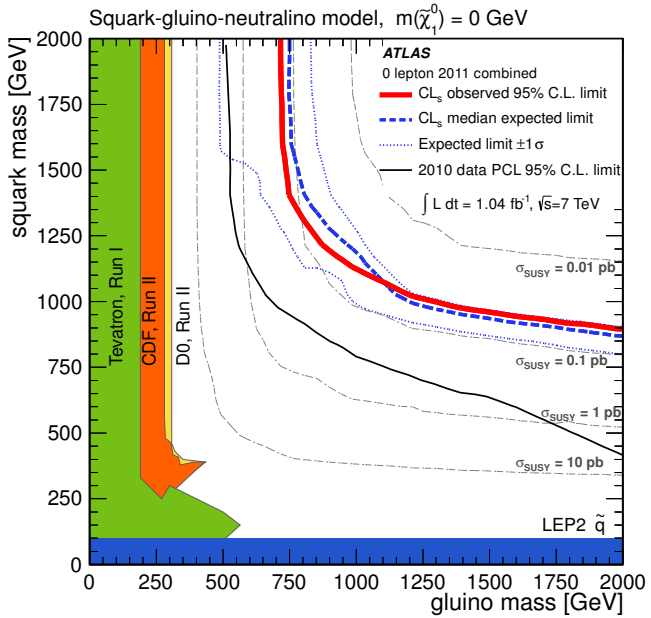
    $$R_{B\tau\nu} \equiv \frac{BR(B \to \tau\nu)}{BR(B \to \tau\nu)_{SM}} \simeq \left[1 - \frac{m_B^2}{m_{H^\pm}^2} \frac{\tan^2\beta}{1 + \epsilon tan\beta}\right]^2$$

  - $K \to \mu\nu : 0.985 < R_{l23} < 1.013$
  - $BR(b \to s\gamma) \in [2.89, 4.21] \times 10^{-4}$
  - $BR(B_s \to \mu^+\mu^-) < 4.5 \times 10^{-9}$

    $$BR(B_s \to \mu^+\mu^-) \propto \frac{m_b^2 m_\mu^2 \tan^6\beta}{m_A^4}$$

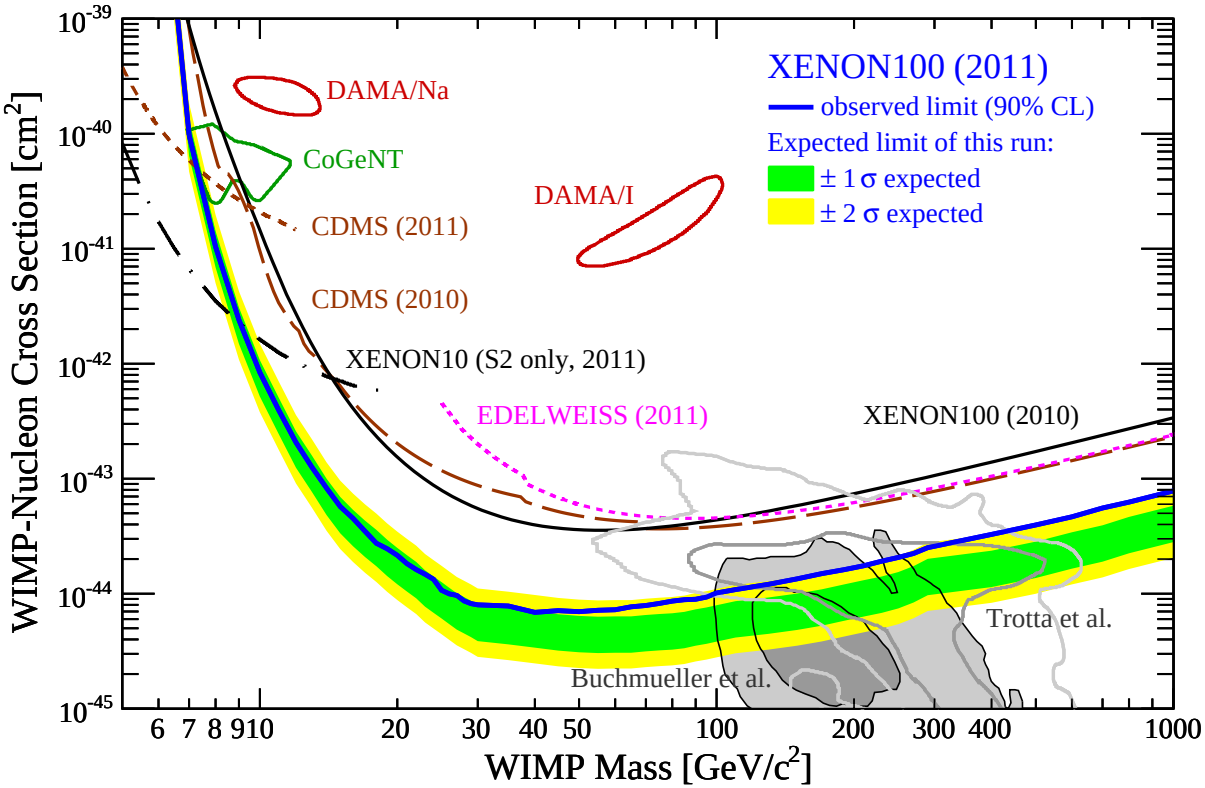
- SUSY particle masses
- Higgs mass

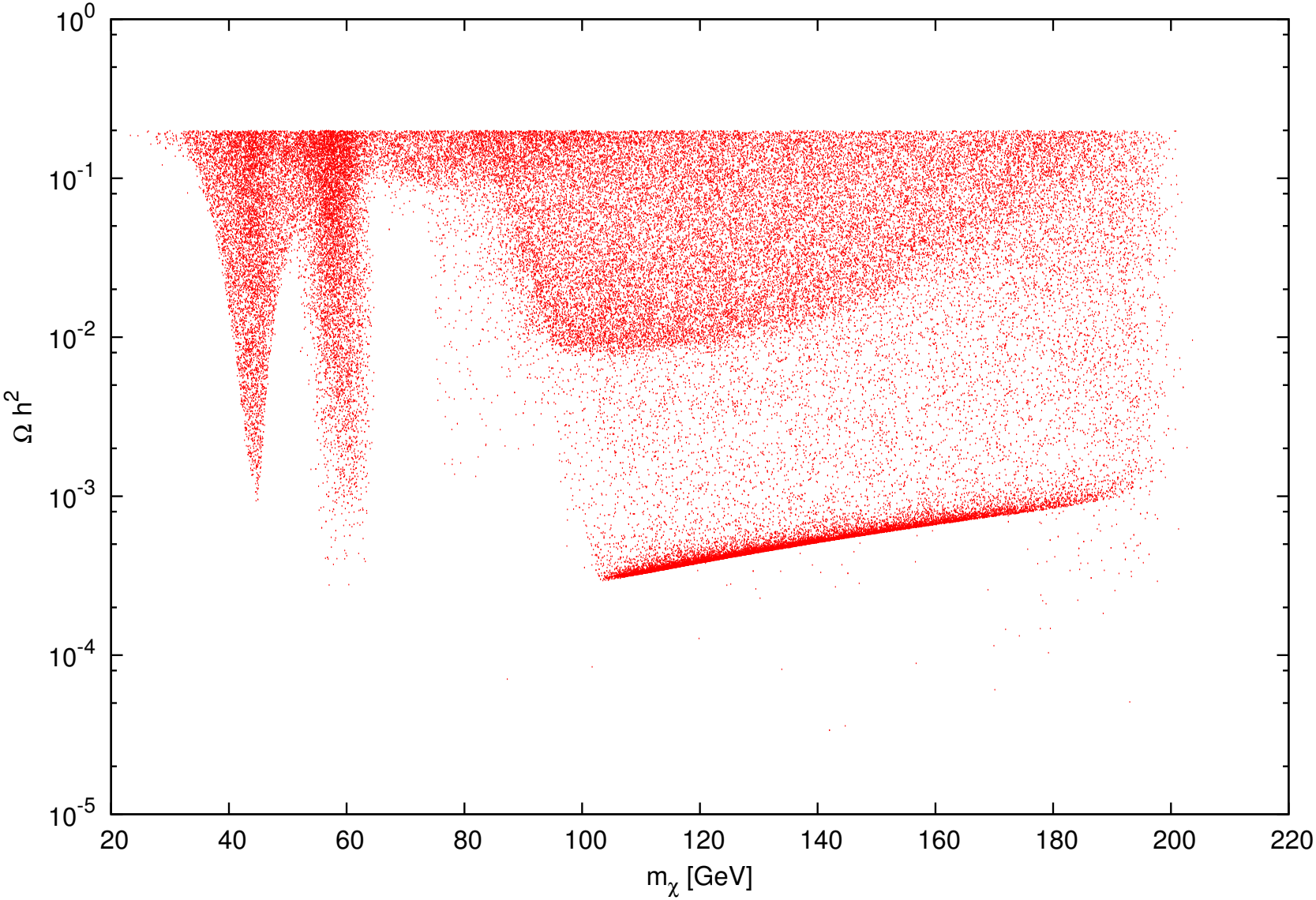


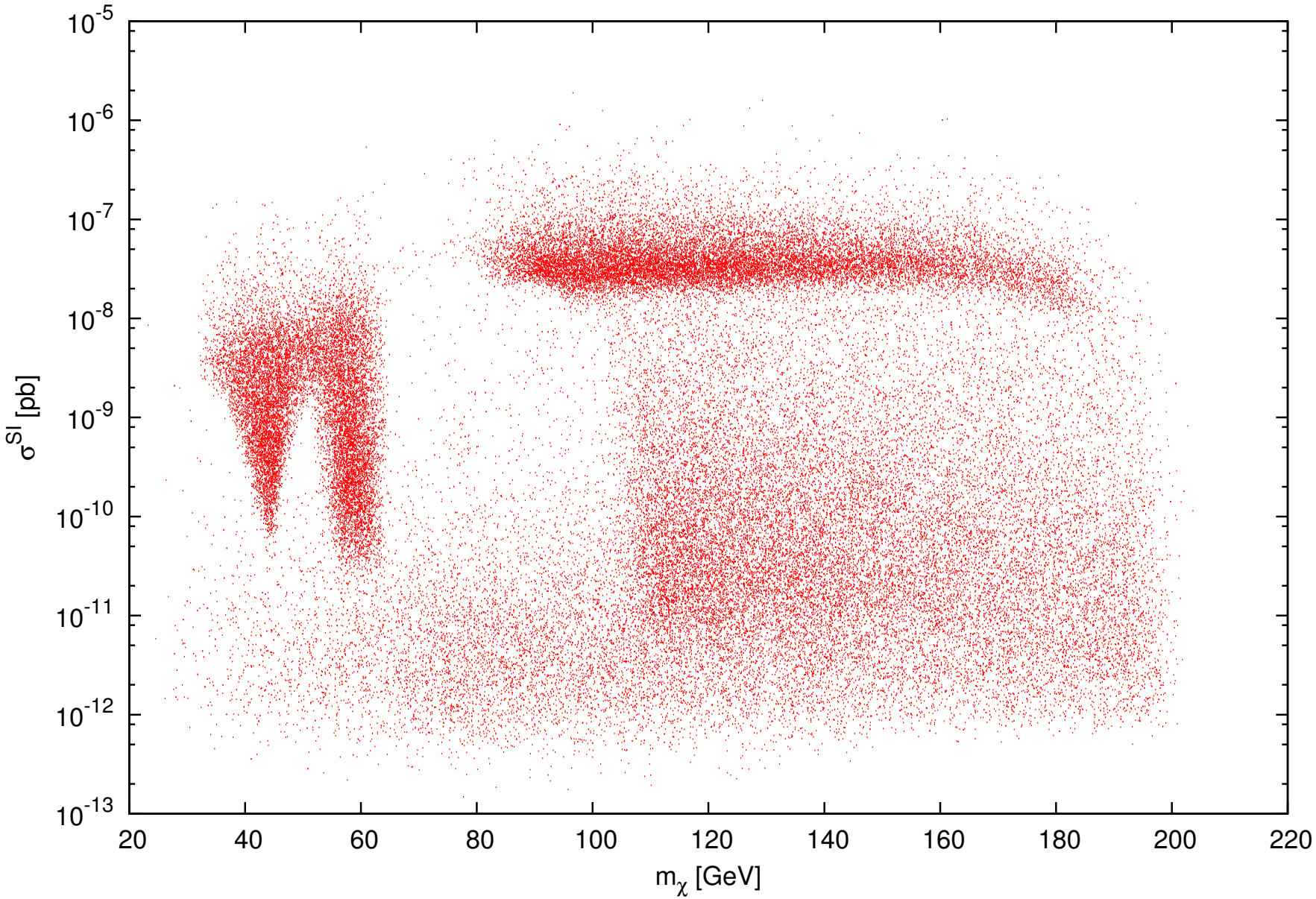



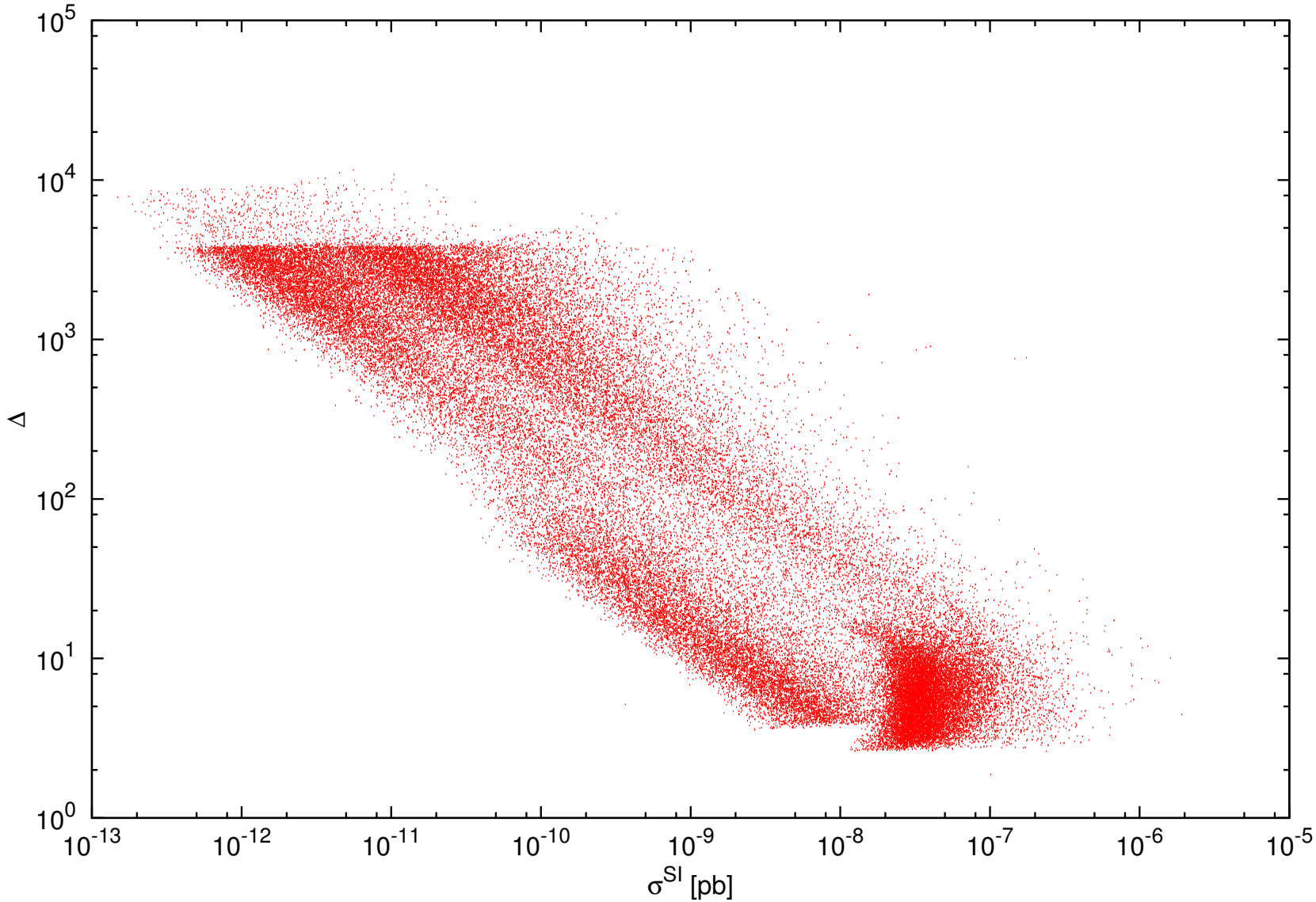
# Dark Matter Constraints

- $? < \Omega h^2 < 0.135$
- Direct Detection
- Indirect Detection

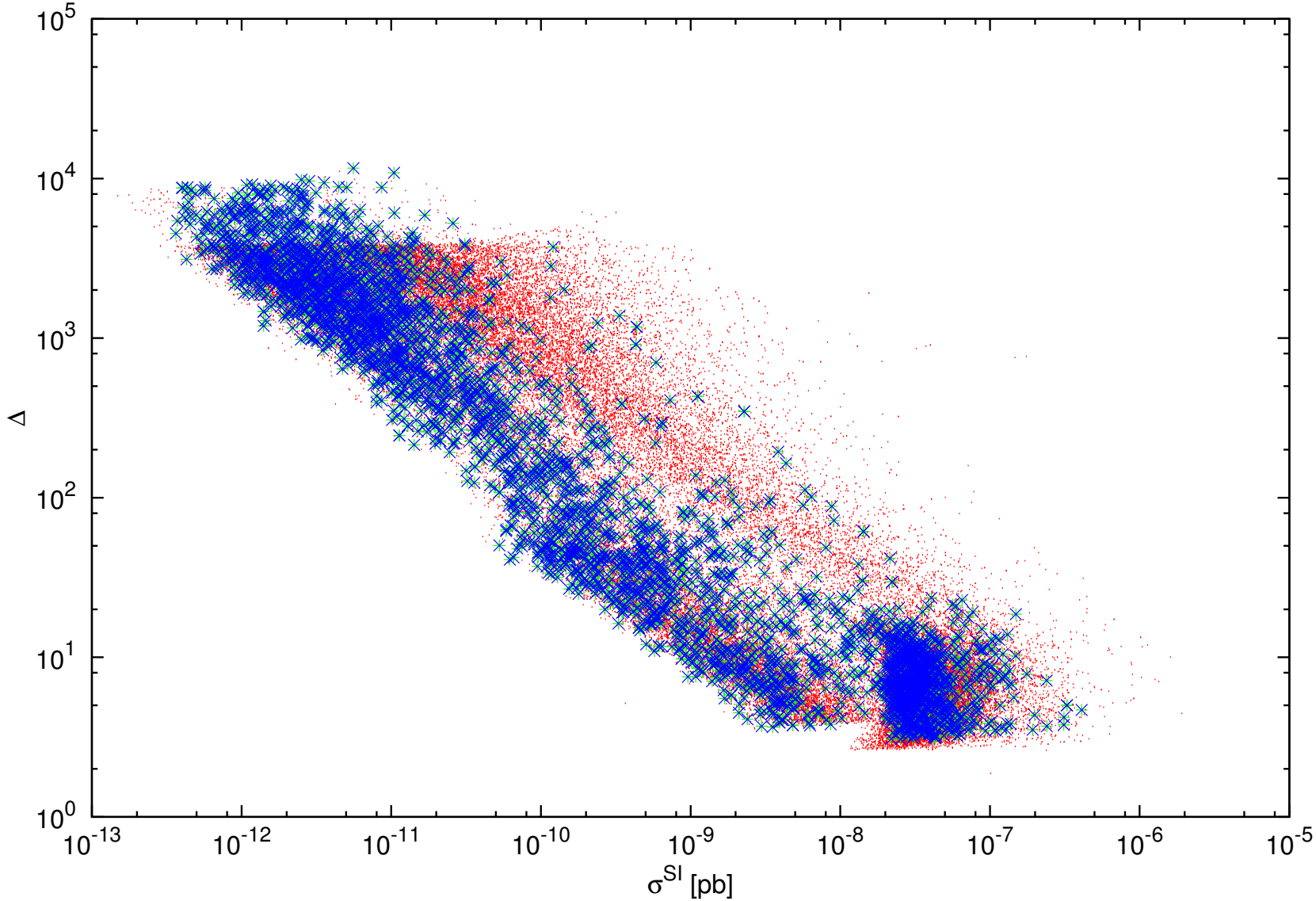



$10^0$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
$\Omega\, h^2$
20
40
60
80
100
120
140
160
180
200
220
$m_\chi$ [GeV]


$10^{-5}$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$\sigma^{SI}$ [pb]
20
40
60
80
100
120
140
160
180
200
220
$m_\chi$ [GeV]



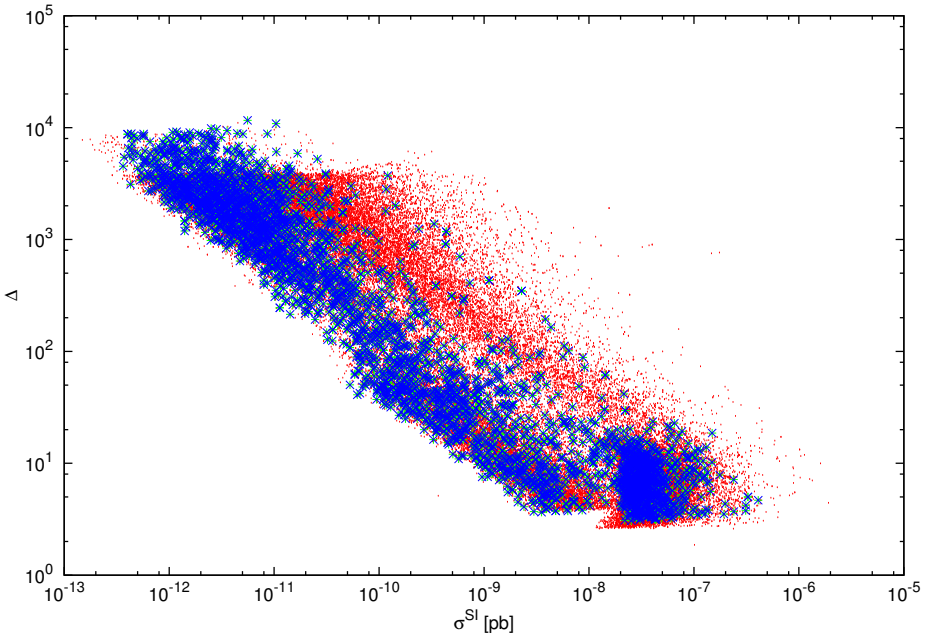

Perelstein, Shakya (2011)




Perelstein, Shakya (2011)

# Conclusions

- SUSY searches start to exclude large regions of the parameter space.
- At the moment small FT is still possible.
- A smaller $\sigma^{SI}$ corresponds to higher FT.
- Natural explanation of Dark Matter will become more difficult as Direct Search Limits increase.



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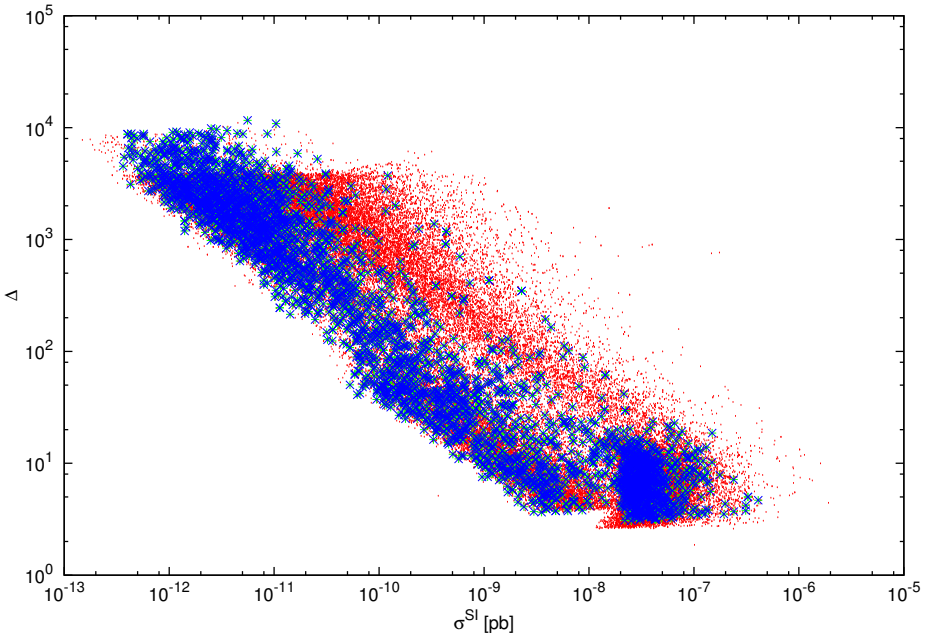


Thank you!