Perspectives of direct Detection of supersymmetric Dark Matter in the MSSM and NMSSM

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The MSSM and NMSSM

Parameters

MSSM

$$m_0$$
$$m_{1/2}$$
$$A_0$$
$$\mu$$
$$\tan\beta = \frac{v_u}{v_d}$$

+

NMSSM

$$\lambda H_u H_d S + \frac{\kappa}{3} S^3 + soft\ terms$$

$$\lambda$$
$$\kappa$$
$$A_\lambda$$
$$A_\kappa$$
$$\mu_{eff} = \lambda < s >$$

Higgs mass

$$M_H^2 \approx M_Z^2 \cos^2 2\beta + \Delta_{\tilde{t}} + \lambda^2 v^2 \sin^2 2\beta - \frac{\lambda^2}{\kappa^2}(\lambda - \kappa \sin 2\beta)^2$$

Tree level (MSSM) Rad Corr NMSSM new terms

Choice of parameters

Full set of parameters (9) $m_0, m_{1/2}, A_0, \tan\beta, \lambda, \kappa, A_\lambda, A_\kappa, \mu_{eff}$

Reduced set of parameters (3) m_{H_1} or $m_{H_2}, m_{A_1}, m_{A_2} \approx m_{H_3} \approx m_{H^\pm}$

To fulfill all constraints including:

- The light Higgs mass of 125 GeV with correct couplings,
- Dark Matter abundance,
- LHC limits, etc

One gets Two scenarios:
I Large lambda and kappa and small tan beta
II Small lambda and kappa and larger tan beta

NMSSMTools 4.6.0
U. Ellwanger et al,

micrOMEGAs3.1
A. Pukhov et al.

- For both scenarios one can have either H_1=H_SM or H_2=H_SM
- In both scenarios the turning point for either a singlino or higgsino-dominated LSP is around 2κ/λ = 1

Dark Matter Content

Neutralino mass matrix

MSSM

$$\mathcal{M} = \begin{pmatrix} M_1 & 0 & -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_1 v_u}{\sqrt{2}} \\ 0 & M_2 & \frac{g_2 v_d}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} \\ -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_2 v_d}{\sqrt{2}} & 0 & -\mu \\ \frac{g_1 v_u}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} & -\mu & 0 \end{pmatrix}$$

NMSSM

$$\mathcal{M}_0 = \begin{pmatrix} M_1 & 0 & -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_1 v_u}{\sqrt{2}} & 0 \\ 0 & M_2 & \frac{g_2 v_d}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} & 0 \\ -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_2 v_d}{\sqrt{2}} & 0 & -\mu_{\text{eff}} & -\lambda v_u \\ \frac{g_1 v_u}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} & -\mu_{\text{eff}} & 0 & -\lambda v_d \\ 0 & 0 & -\lambda v_u & -\lambda v_d & 2\kappa s \end{pmatrix}$$

LSP=Dark Matter

$$\tilde{\chi}_1^0 = N_{1,1}|\tilde{B}> +N_{1,2}|\tilde{W}^0> +N_{1,3}|\tilde{H}_1^0> +N_{1,4}|\tilde{H}_2^0> +N_{1,5}|\tilde{S}>$$

gaugino — higgsino — singlino

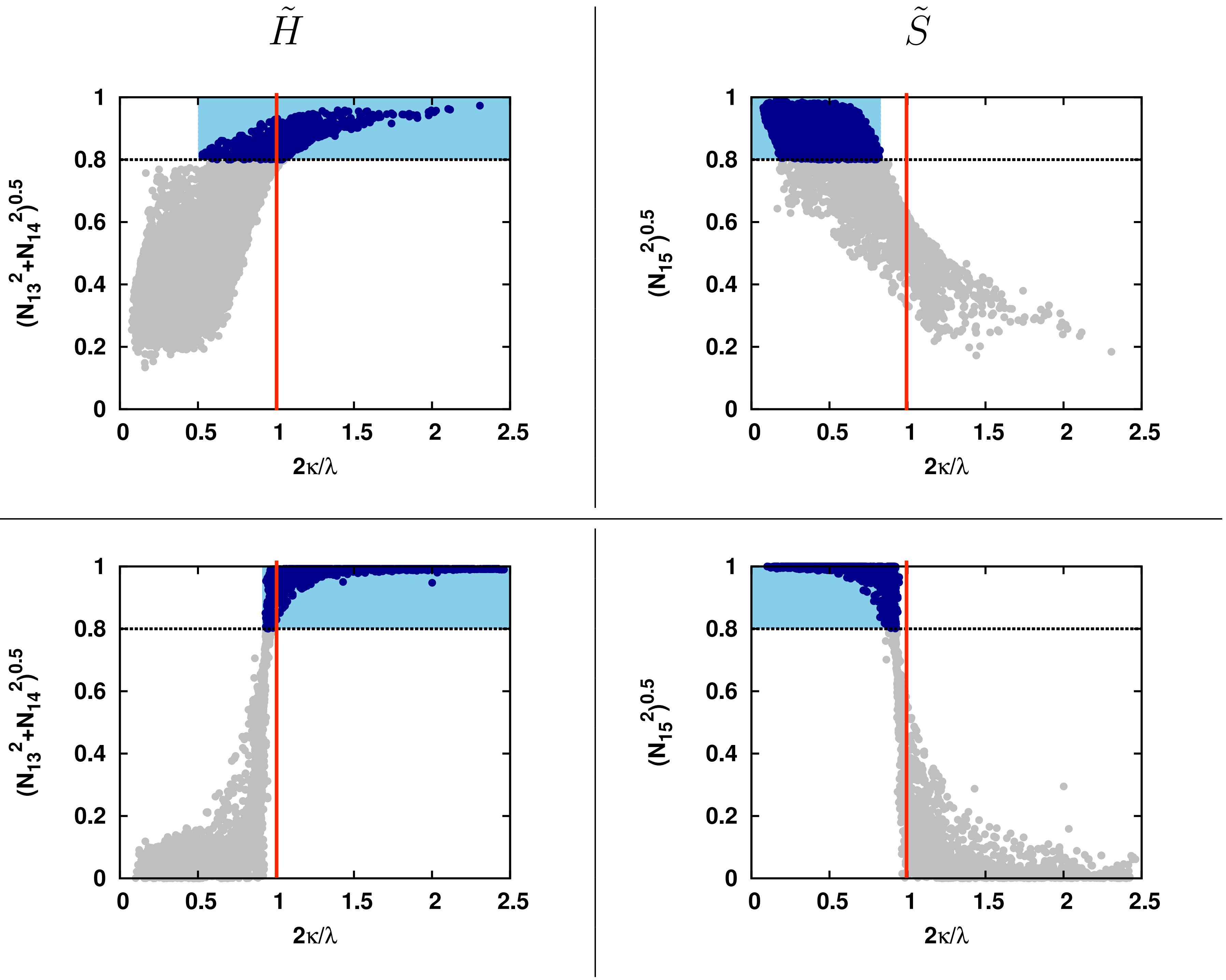
LSP Content in NMSSM

Scenario I

(large λ, κ, small $\tan\beta$)

Scenario II

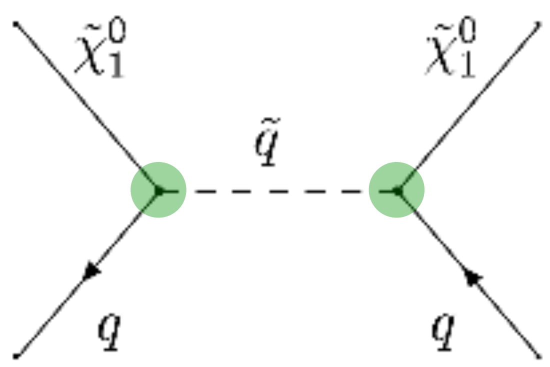
(small λ, κ, large $\tan\beta$)



Elastic WIMP-Nucleon Scattering

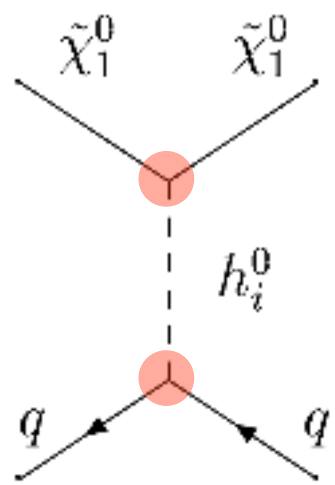
Spin-independent cross section

- Contributions from **squark-** and **Higgs-**exchanging diagrams:



Squark-exchange

$$\sigma_{\tilde{\chi}_1^0 - p} \propto \frac{m_r^2}{4\pi}\left(\frac{g'^2 \sin\theta}{m_{\tilde{q}}^2 - m_{\tilde{\chi}_1^0}^2}\right)^2 |N_{11}|^4$$



Higgs-exchange

It is the leading contribution, and increases when

$$\sigma_{\tilde{\chi}_1^0 - p} \propto \frac{m_r^2}{4\pi}\frac{\lambda_q^2}{m_h^4}|N_{13,\,14}\,(g' N_{11} - g N_{12})|^2$$

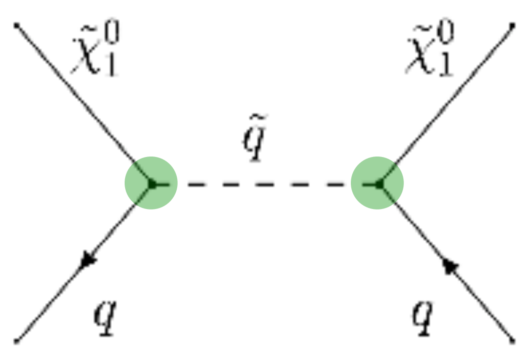
- The Higgsino components of the neutralino increase $\mu \downarrow$
- The Higgs masses decrease $m_h,\ m_{H^0}\ m_{A^0} \downarrow$

Elastic WIMP-Nucleon Scattering

Detectability

Spin-dependent cross section

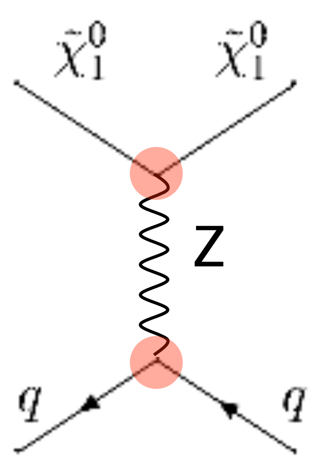
- Contributions from **squark-** and **Z-**exchanging diagrams:



Squark-exchange

$$\alpha_{2i}^{\tilde{q}} = \frac{1}{4(m_{1i}^2 - m_\chi^2)}\left[|Y_i|^2 + |X_i|^2\right] + \frac{1}{4(m_{2i}^2 - m_\chi^2)}\left[|V_i|^2 + |W_i|^2\right]$$

- Typically very small unless $m_{\tilde{q}} \sim m_\chi$



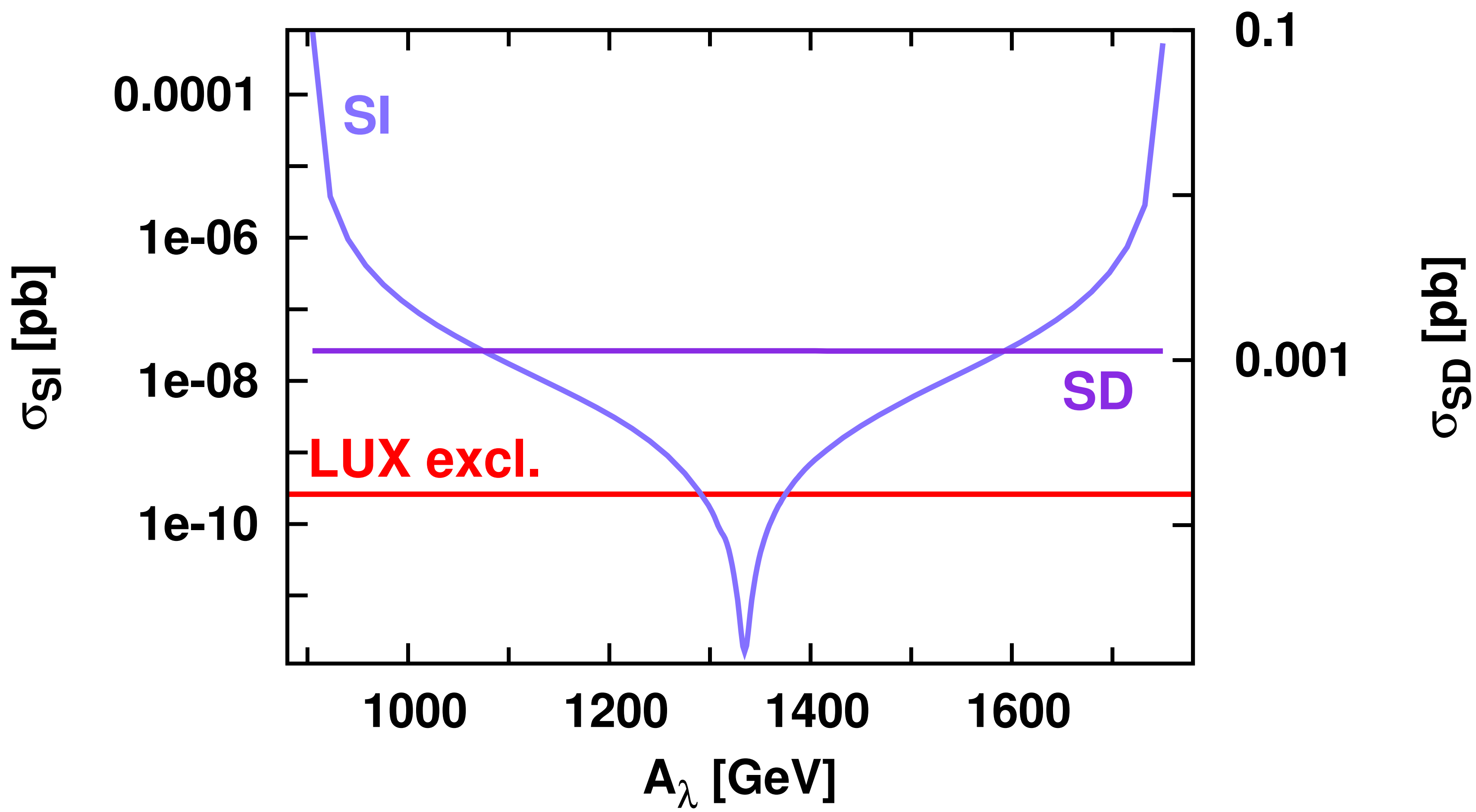
Z-exchange

$$\alpha_{2i}^{Z} = -\frac{g^2}{4m_Z^2 \cos^2\theta_W}\left[|N_{13}|^2 - |N_{14}|^2\right]\frac{T_{3i}}{2}$$

Leading contribution but has an upper bound: $\sigma \leq 6.2 \times 10^{-2}$ pb

- It also increases with the neutralino Higgsino components: $\mu \downarrow$

SI versus SD X-sections



Negative interference of two Higgses for SI x-section $\sigma_{SI} \propto N_{13}^2 - N_{14}^2$

versus additive SD x-section $\sigma_{SD} \propto N_{13}^2 + N_{14}^2$

Relic Density Abundance

Exp. relic abundance

Scenario I

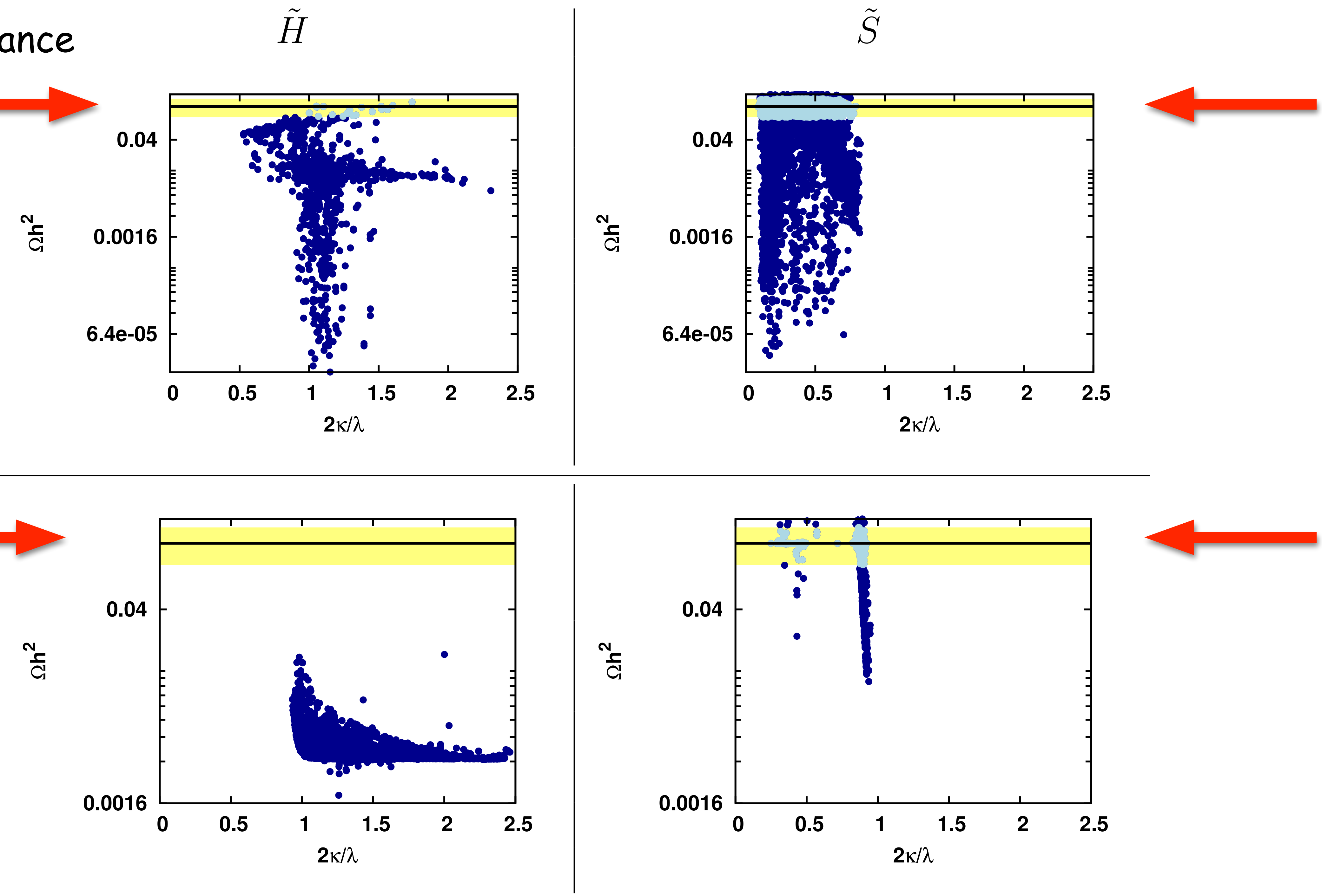
(large λ, κ,

small $\tan\beta$)

Scenario II

(small λ, κ,

large $\tan\beta$)



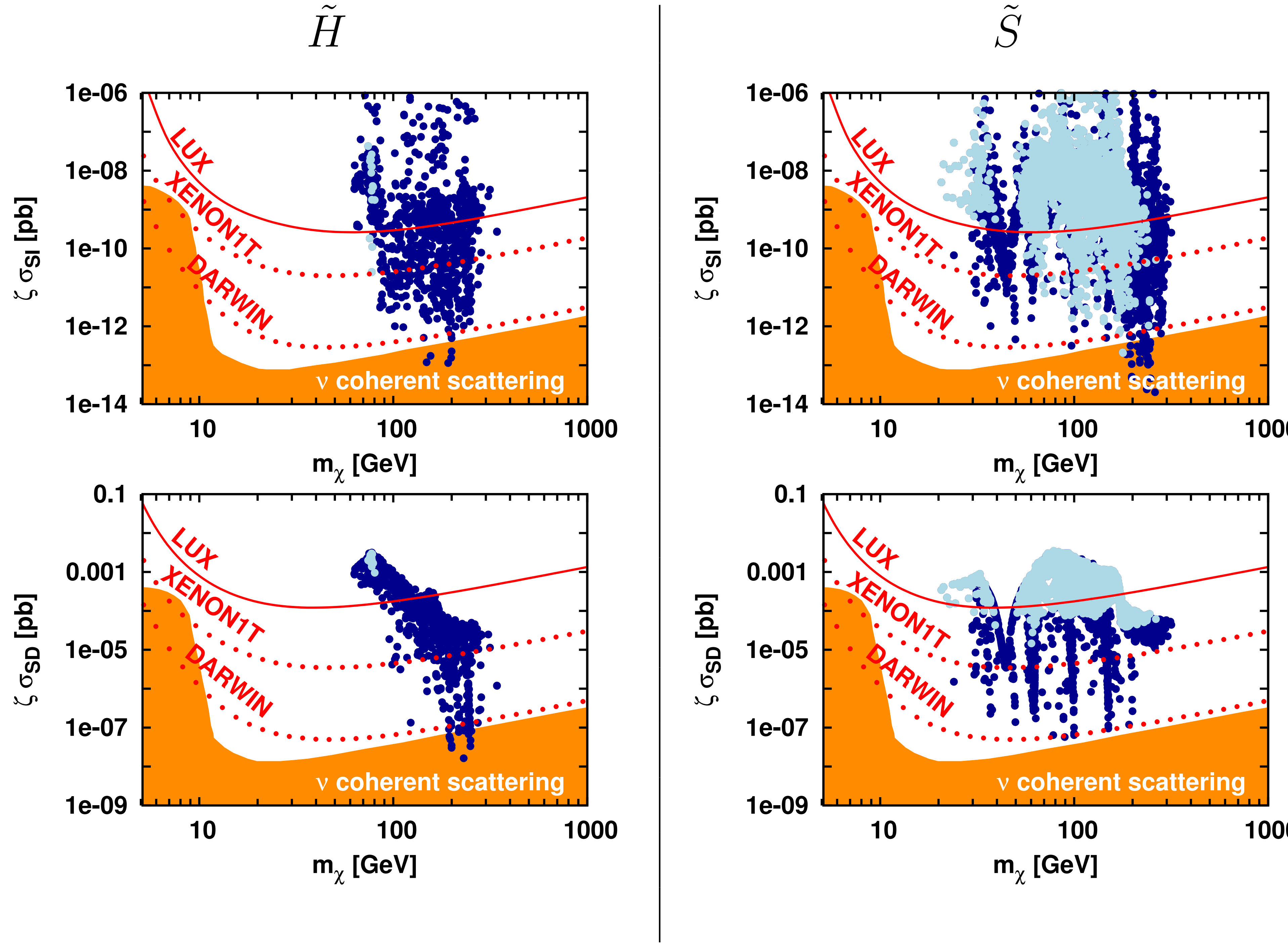
Direct Detection of Dark Matter

Scenario I (large λ, κ, small $\tan\beta$) $[m_{H_i} + \zeta\Omega h^2,\ \zeta < 1$ ● $\zeta = 1$ ●]

$m_{H2} =$ 125 GeV

SI

SD



Direct Detection of Dark Matter

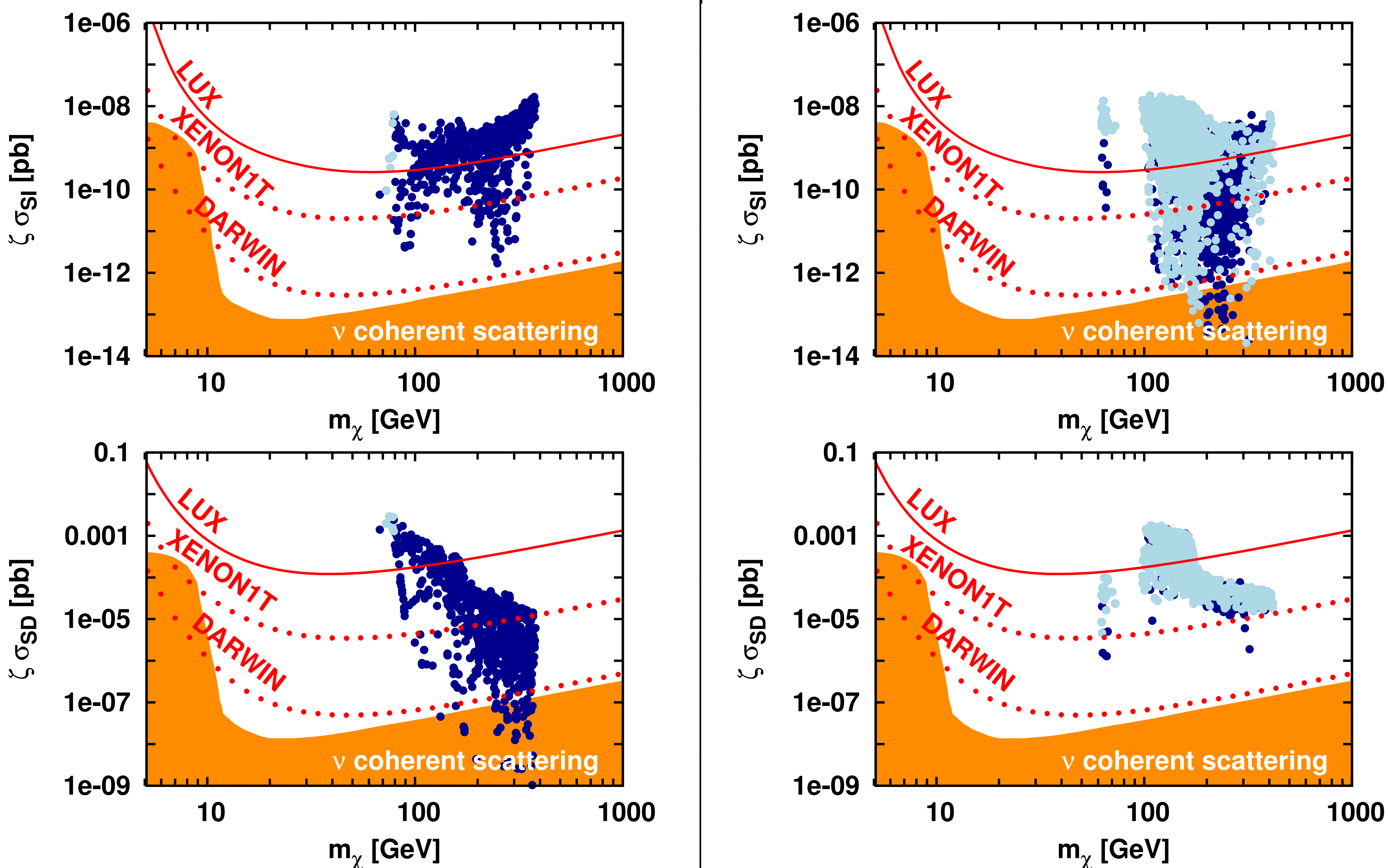
Scenario I (large λ, κ, small $\tan\beta$) $[m_{H_i} + \zeta\Omega h^2,\ \zeta < 1$ ● $\quad \zeta = 1$ ●$]$

$\tilde{H}$ | $\tilde{S}$

SI

$m_{H1} =$ 125 GeV

SD



Direct Detection of Dark Matter

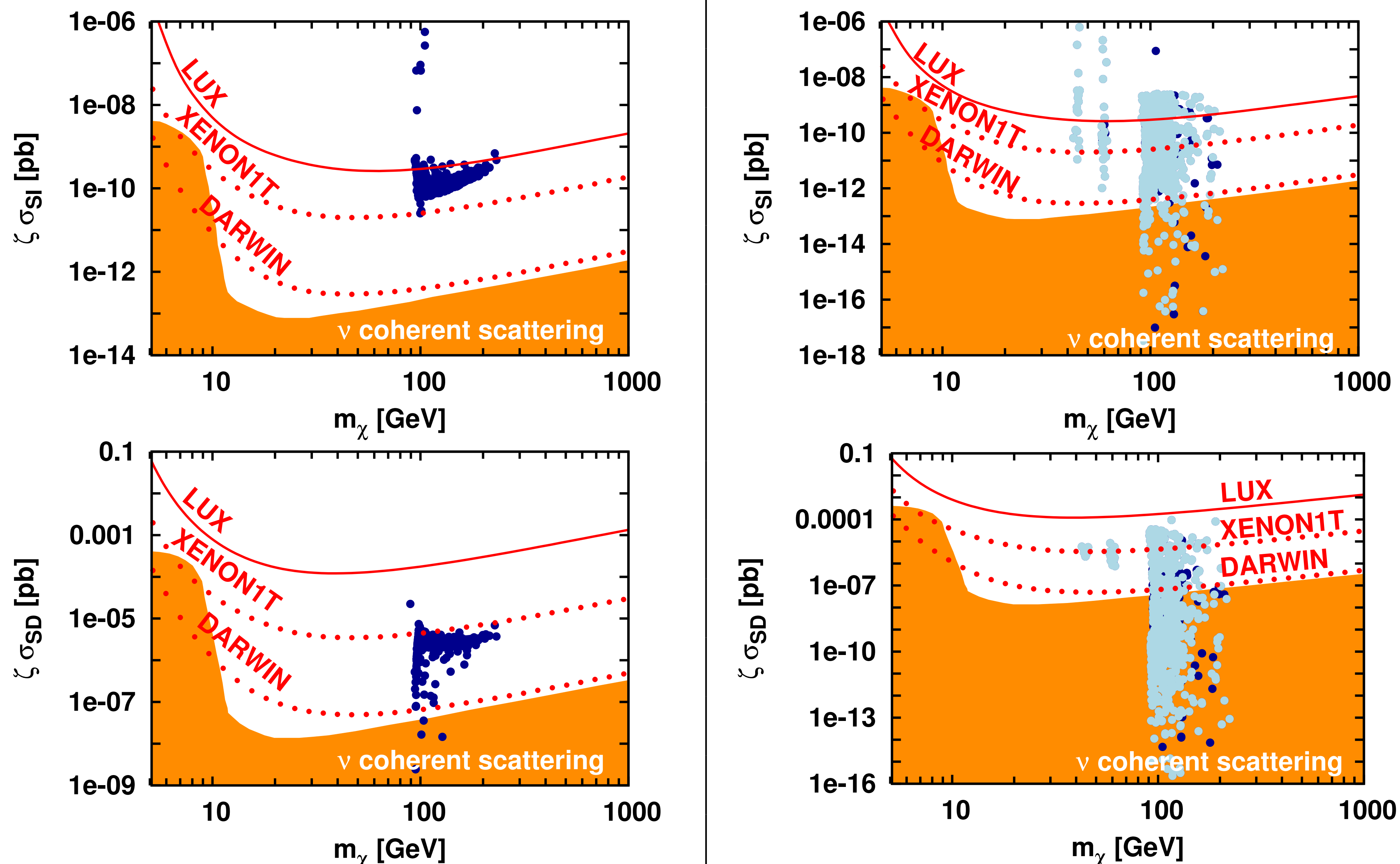
Scenario II (small λ, κ, large $\tan\beta$) $[m_{H_i} + \zeta\Omega h^2,\ \zeta < 1$ ● $\quad \zeta = 1$ ●$]$

$\tilde{H}$ | $\tilde{S}$

SI

SD

$m_{H2} =$ 125 GeV



Direct Detection of Dark Matter

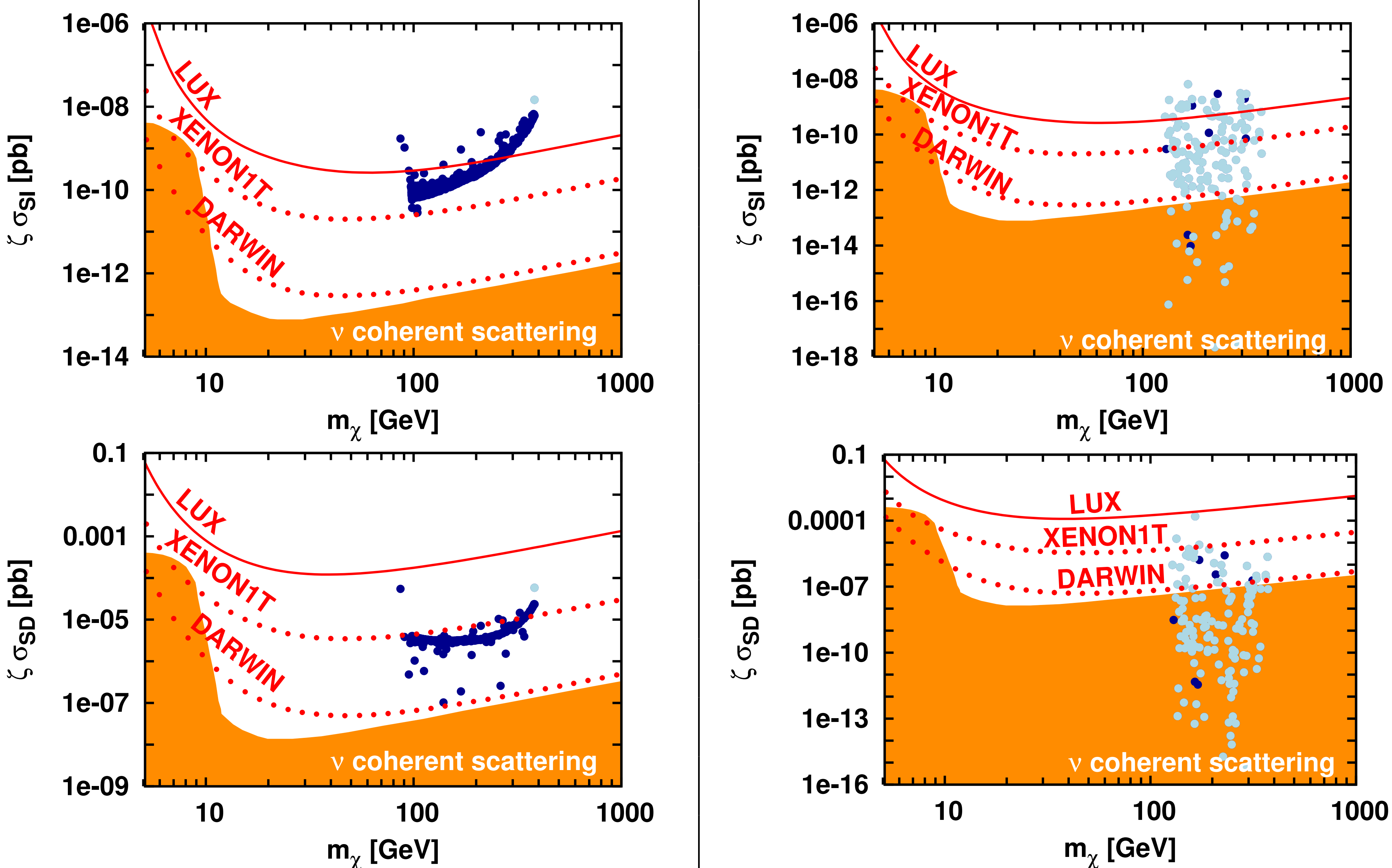
Scenario II (small λ, κ, large $\tan\beta$) $[m_{H_i} + \zeta\Omega h^2,\ \zeta < 1$ ● $\zeta = 1$ ●$]$

$\tilde{H}$ $\tilde{S}$

SI

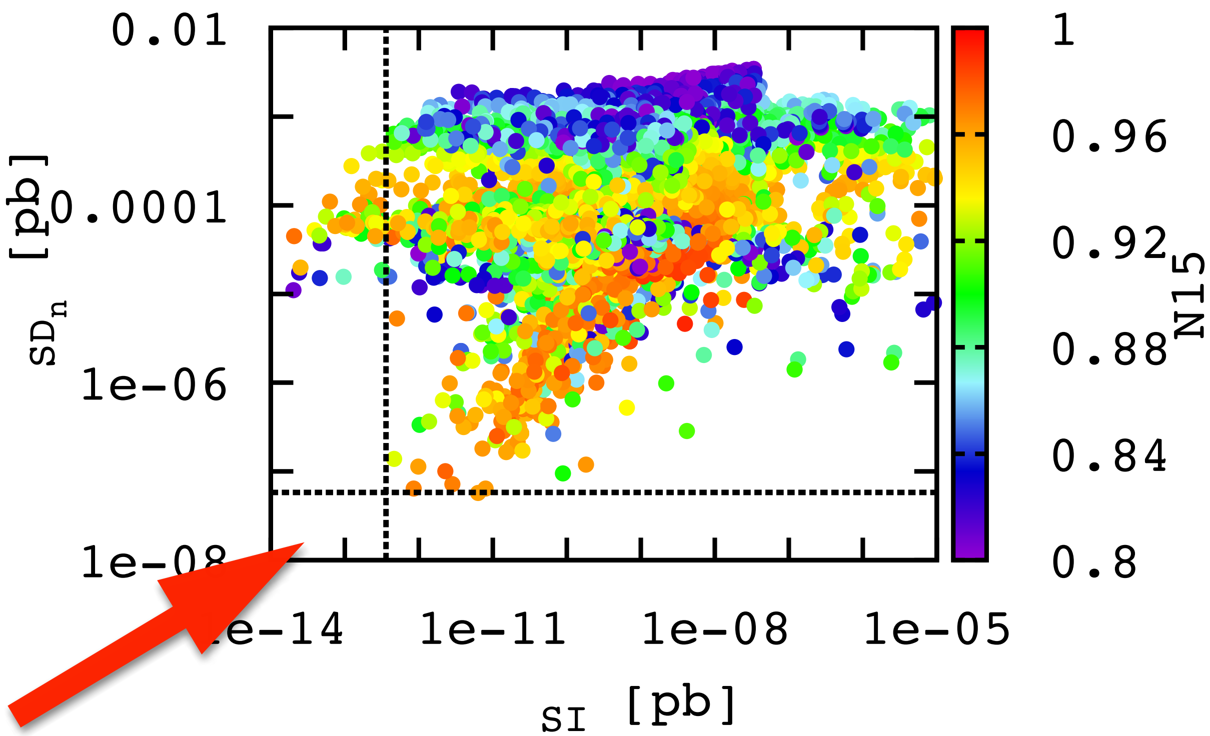
SD

$m_{H1} =$ 125 GeV



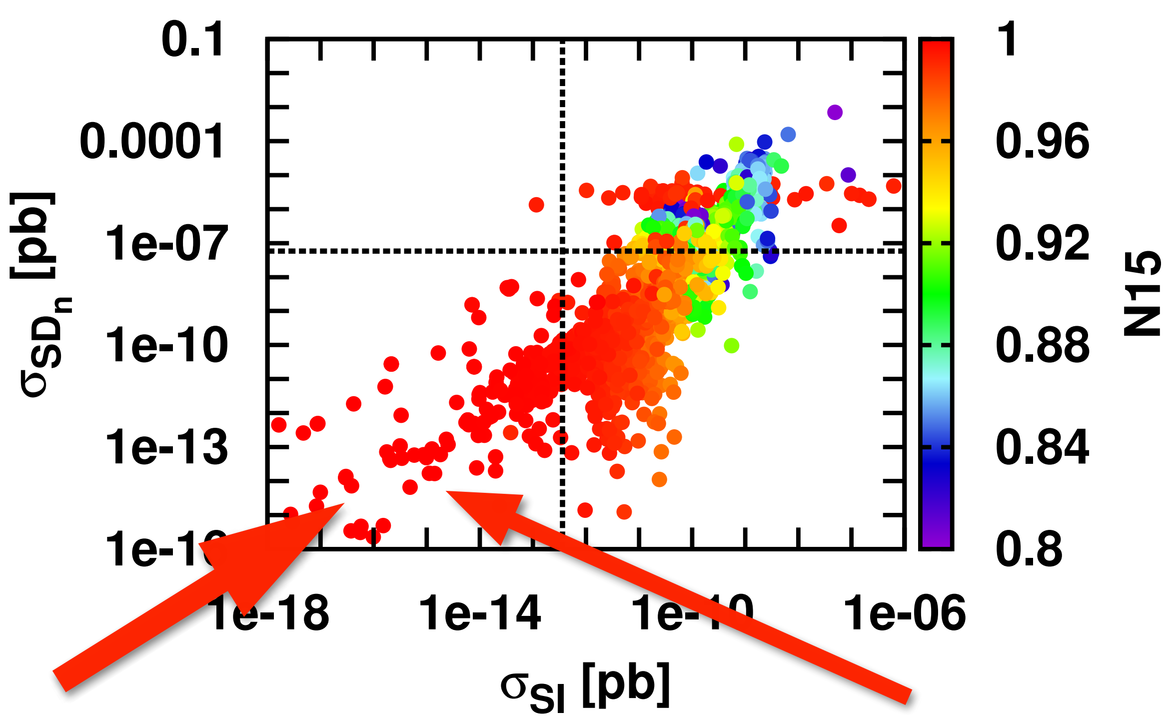
Experiment Reach in the Nearest Future

Scenario I



Will not be covered by experiment

Scenario II



Will not be covered by experiment

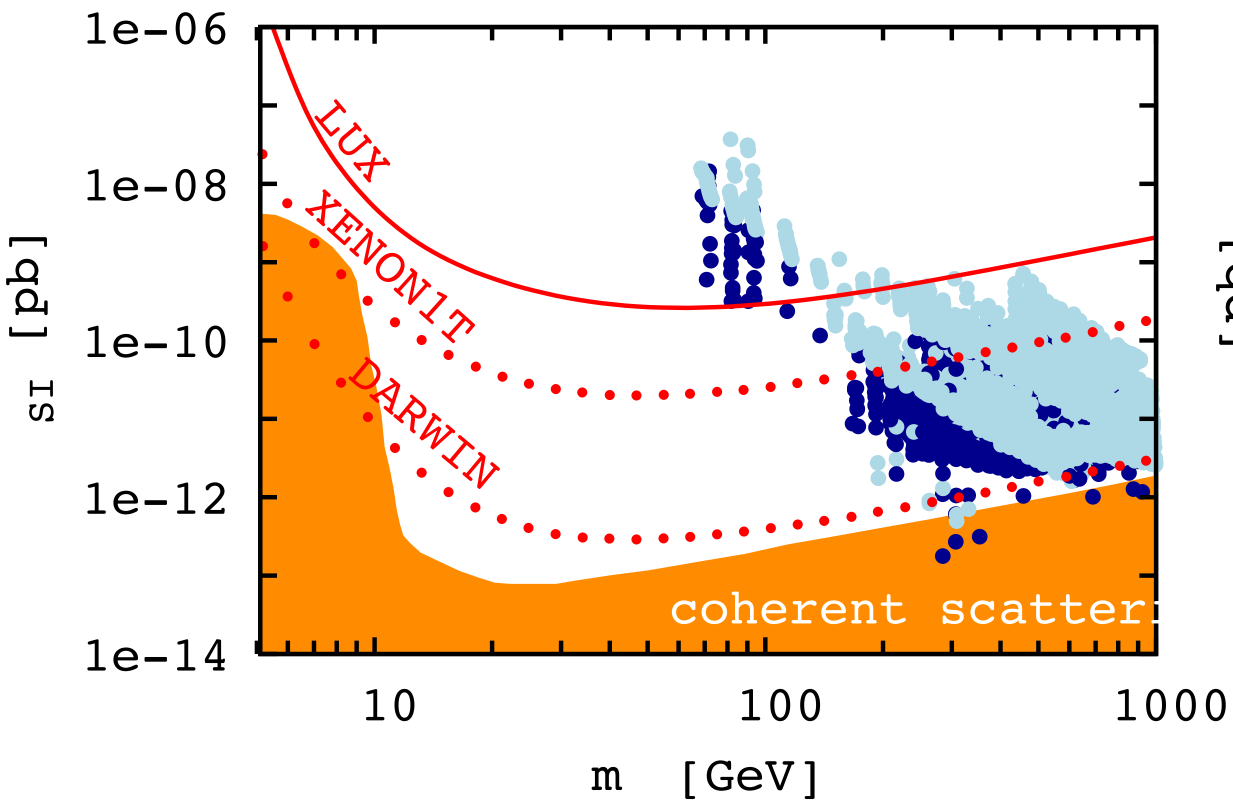
Almost pure singlino

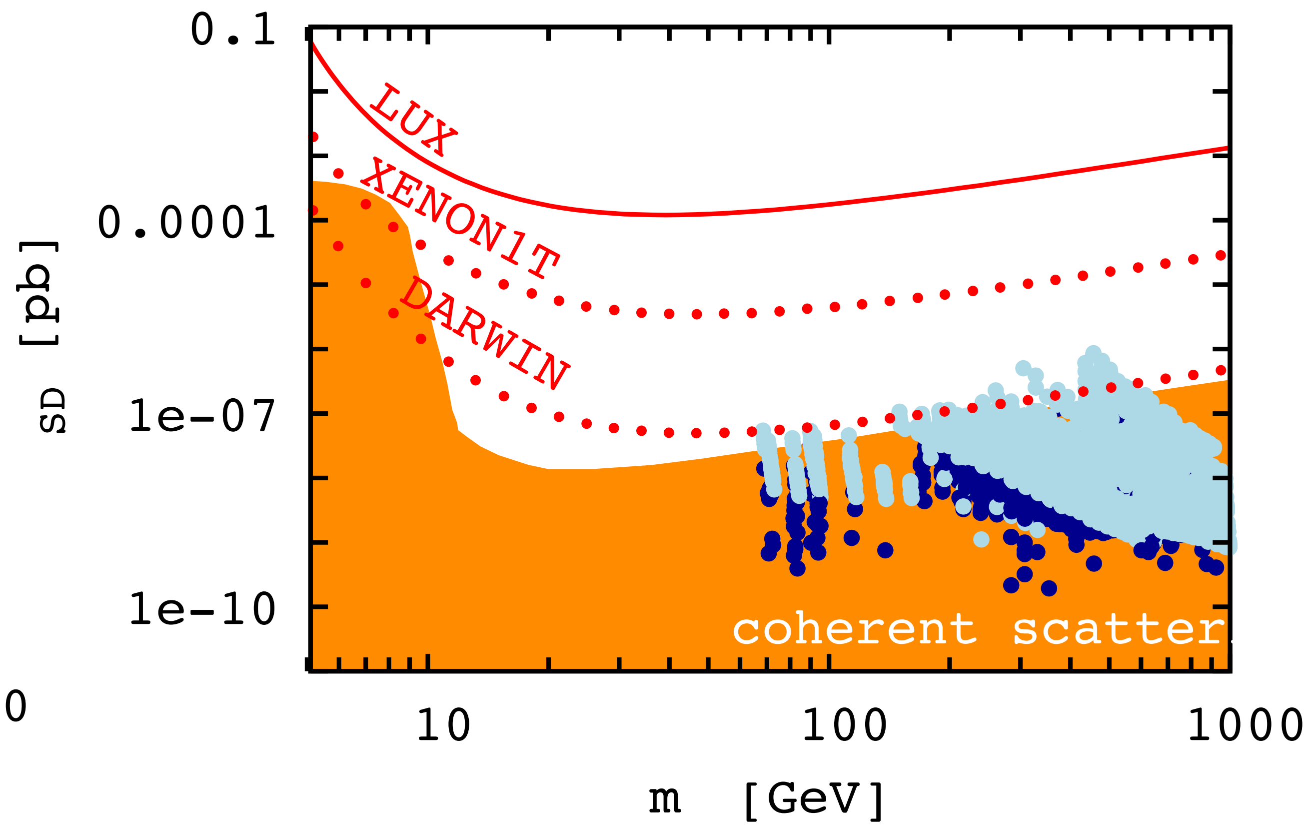
Conclusion: in the framework of the NMSSM

- for Scenario I future experiments will cover all allowed range
- for Scenarion II future experiments will cover almost all allowed range except for small part of pure singlino LSP

Experiment Reach in the Nearest Future

CMSSM LSP ≈ Bino





Conclusion: in the framework of the MSSM
the SI searches will cover all allowed region,
the SD searches will not be essential

Conclusions

- In case of MSSM the future direct searches for DM will cover all allowed region of x-sections up to neutrino floor.
- In case of NMSSM and higgsino dominated LSP the future searches will also cover the whole range.
- In case of NMSSM and singlino dominated LSP the future searches for scenario I will cover the whole range and for scenarios II the small domain might remain which corresponds to almost >90% singlino DM.
- The SD dependent searches do not add significant information to SI searches in all cases.