Higgs system of the NMSSM

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Outline

- NMSSM – introduction
- Higgs sector in NMSSM
  - SM-like Higgs scalar and fine tuning
  - mixing in the scalar sector
  - light singlet-dominated scalar
- Experimental bounds and signatures
  - properties of SM-like Higgs
  - signatures specific for NMSSM
- Neutralino sector in NMSSM
  - blind spots of σ_{SI} (DM direct detection experiments)
  - blind spots vs properties of Higgs particles
- Blind spots and relic density
- Summary

NMSSM – introduction

NMSSM = MSSM + gauge singlet chiral superfield S

$$W_{\rm NMSSM} = W_{\rm MSSM} + \lambda S H_u H_d + f(S)$$

with $f(S) = \frac{1}{3}\kappa S^3 + \frac{1}{2}\mu' S^2 + \xi_S S$.

Soft terms in the Higgs sector:

$$\begin{aligned} -\mathcal{L}_{\rm soft} \supset\ & m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 + m_S^2 |S|^2 \\ & + (A_\lambda \lambda S H_u H_d + m_3^2 H_u H_d + \frac{1}{3}\kappa A_\kappa S^3 + \frac{1}{2} m_S'^2 S^2 + \xi_S' S + \text{h.c.}) \end{aligned}$$

There are versions of NMSSM with less parameters e.g.

- "$\mathbb{Z}_3$–invariant" NMSSM: $\mu' = \xi_S' = m_3^2 = m_S'^2 = \xi_S = 0$
- nMSSM: $\kappa = 0$, no $\mathbb{Z}_3$ symmetry
- "$\mathbb{Z}_8^R$–invariant" NMSSM: $\mu' = 0$

The Higgs squared mass matrix in the basis $(\hat{h}, \hat{H}, \hat{s})$

$(\hat{h} = \cos\beta H_d + \sin\beta H_u, \hat{H} = \sin\beta H_d - \cos\beta H_u, \hat{s} = S)$

($\hat{h}$ has the same couplings as the SM Higgs)

$$M^2 = \begin{pmatrix} M^2_{\hat{h}\hat{h}} & \cdots & \cdots \\ \frac{1}{2}(m_Z^2 - \lambda^2 v^2)\sin 4\beta & M^2_{\hat{H}\hat{H}} & \cdots \\ \lambda v(2\mu - \Lambda\sin 2\beta) & \lambda v \Lambda \cos 2\beta & M^2_{\hat{s}\hat{s}} \end{pmatrix}$$

$$\Lambda = A_\lambda + \left\langle \partial_S^2 f(S) \right\rangle$$

$$M^2_{\hat{h}\hat{h}} = M_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta + (\delta m_h^2)^{\rm rad}$$

The mass eigenstates h, H, s, are given by the mixing matrix $\tilde{S}$:

$$\begin{aligned} h &= \tilde{S}_{h\hat{h}}\hat{h} + \tilde{S}_{h\hat{H}}\hat{H} + \tilde{S}_{h\hat{s}}\hat{s} \\ H &= \tilde{S}_{H\hat{h}}\hat{h} + \tilde{S}_{H\hat{H}}\hat{H} + \tilde{S}_{H\hat{s}}\hat{s} \\ s &= \tilde{S}_{s\hat{h}}\hat{h} + \tilde{S}_{s\hat{H}}\hat{H} + \tilde{S}_{s\hat{s}}\hat{s} \end{aligned}$$

The mass of the SM-like Higgs h:

$$m_h^2 = M_Z^2 \cos^2 2\beta + (\delta m_h^2)^{\rm rad} + \lambda^2 v^2 \sin^2 2\beta + (\delta m_h^2)^{\rm mix}$$

NMSSM contributions:

- tree-level contribution due to $\lambda S H_u H_d$ interaction
- contribution due to mixing among $\hat{h}$, $\hat{s}$, $\hat{H}$ states – mainly $\hat{h}$-$\hat{s}$

small $\tan\beta$ regime:

- $\sin 2\beta$ is close to 1
- big λ necessary (tree-level MSSM term $M_Z^2 \cos^2 2\beta$ is small)
- possible problems with Landau poles (λSUSY Barbieri et al., 2006)

moderate and large $\tan\beta$ regime: Badziak, M.O., Pokorski, 2013

- $\sin 2\beta$ is small
- tree-level MSSM term $M_Z^2 \cos^2 2\beta$ close to maximal
- substantial $(\delta m_h^2)^{\rm mix}$ is needed
- usually small λ is preferred

Additional contributions to the Higgs mass allow to obtain $m_h = 125$ GeV with smaller radiative corrections

$\Rightarrow$ less fine tuning necessary in NMSSM as compared to MSSM

especially in versions less constrained than the (most popular) $\mathbb{Z}_3$-symmetric one Ross, Schmidt-Hoberg, Staub, 2012

h-s mixing implies more fine tuning in small $\tan\beta$ (big λ) region

$$M^2_{\hat{h}\hat{s}} = \lambda v \left[2\mu - \left(A_\lambda + \left\langle \partial_S^2 f(S) \right\rangle\right) \sin 2\beta\right]$$

Higgs sector in NMSSM – scalar mixing

In order to have big contribution the SM-Higgs mass from the mixing $(\delta m_h^2)^{\rm mix} \approx \tilde{S}_{h\hat{s}}^2 \left(m_h^2 - m_s^2\right)$ we prefer

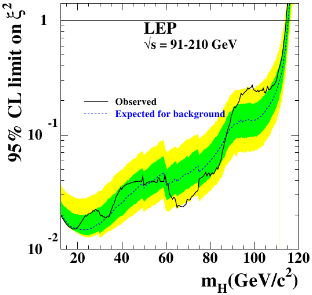
- big h-s mixing
- small mass of the singlet-dominated scalar s

Relatively light scalar which mixes with the SM-like Higgs has many interesting consequences

- properties of the 125 GeV Higgs different from SM and MSSM predictions
  - there are some more-then-2σ experimental effects (as usually)
- different/new experimental signatures
- modifications of DM cross-sections
  - especially $\sigma_{\rm SI}$ important for direct detection (DD) experiments

s-H mixing may substantially influence the BRs of s
smaller BR($s \to b\bar{b}$) $\Rightarrow$ bigger BR($s \to \gamma\gamma$)

Past (LEP) and present (LHC) experimental constraints must be fulfilled



Higgs sector in NMSSM – light singlet-dominated scalar

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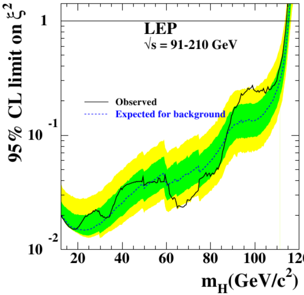

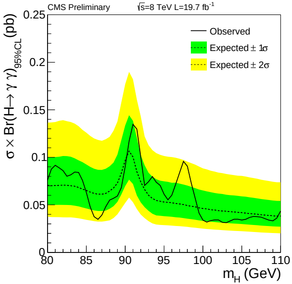

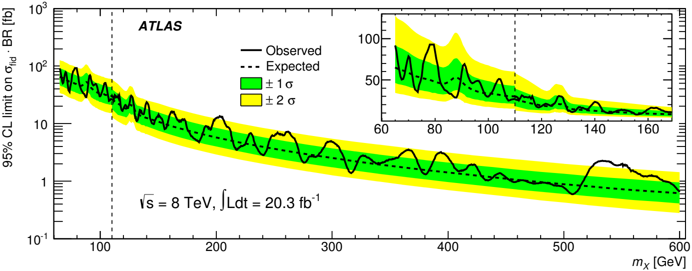

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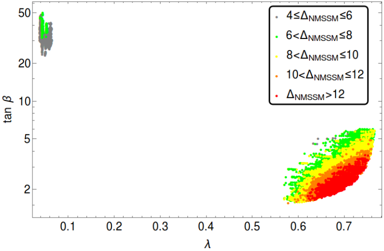
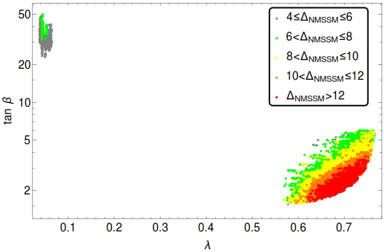


Ellwanger, Rodriguez-Vazquez, 2016

700 GeV$\leq m_{U_3}, m_{D_3}, m_{Q_3} \leq$ 1 TeV
-1 TeV $\leq A_t \leq$ 1 TeV

NMSSM-specific corrections to m_h may be as big as 17 (8) GeV for small (large) $\tan\beta$



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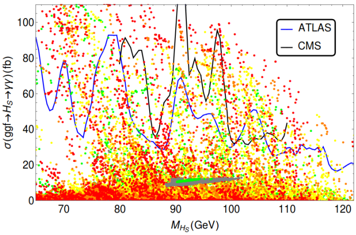
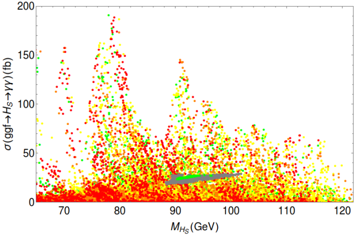
Some low $\tan\beta$ points already excluded by the LHC 8 TeV bounds on $\sigma(\mathrm{ggf} \to s \to \gamma\gamma)$



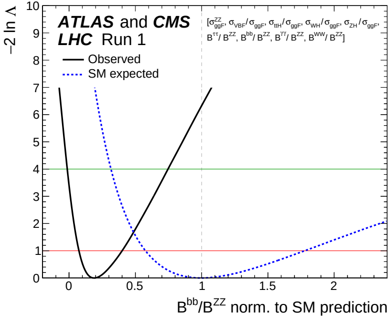
Predictions for $\sigma(\mathrm{ggf} \to s \to \gamma\gamma)$ at 13 TeV:



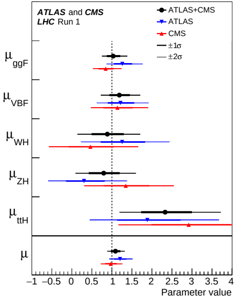
Properties of the Higgs particle measured at LHC are quite similar to the SM predictions.
Of course there are some deviations

Two more-then-2σ deviations form the SM predictions: arXiv:1606.02266

B^{bb}/B^{ZZ} too small



μ_{tth} too big



NMSSM is (much) more flexible and may accommodate some of such deviations

It is easy to increase the tth coupling and decrease the bbh coupling in 2HDM model with small $\tan\beta$
However, this leads to too high gluon fusion production rate of h

Experimental signatures – properties of SM-like Higgs

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Light stops in MSSM could solve the last problem by compensating the increase of the top induced contribution to the gluon fusion production
However, the Higgs mass is too low for small $\tan\beta$ and light stops

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The above problem may be solved in NMSSM: Badziak, Wagner, 2016

$\tan\beta \lesssim 2 \quad \lambda \sim 0.5$
$m_{s,a} \sim 85 \div 110$ GeV
$m_{A,H} \sim 300 \div 450$ GeV
$m_{H^\pm} \sim 250 \div 300$ GeV
$m_{\tilde{t}_1} \sim 275$ GeV
$m_{\tilde{t}_2} \sim 1$ TeV
$m_{\chi_1} \sim 235$ GeV

large s-H mixing is crucial for tth enhancement
large a-A mixing results in large $\sigma(gga) \gtrsim 20$ pb
most of the parameter space may be probed at HL LHC
other interesting signatures ...

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Flexibility of NMSSM is (fortunately) limited

- e.g. explanation of the famous 750 GeV diphoton signal was just at the border of NMSSM flexibility (and far beyond that of MSSM)

Experimental signatures – specific for NMSSM

Experimental signatures of NMSSM Higgs sector… may be diverse

"Handbook of LHC Higgs cross sections: 4. Deciphering the nature of the Higgs sector"

Report of the LHC Higgs Cross Section Working Group arXiv:1610.07922

Two diverse examples with light (pseudo)scalar sector

- "natural" $\mathbb{Z}_3$-symmetric NMSSM King et al., 2014
  - spectrum:
    $m_s \sim 170$ GeV, $m_a \sim 85$ GeV, $m_{A,H} \sim 300$ GeV
  - signatures:
    cascade Higgs-to-Higgs boson decays lead to multi-photon (up to 6γ) and multi-fermion final states
- "worst case" NMSSM Ellwanger, Teixeira, 2014
  - spectrum:
    $m_s \sim 82$ GeV, $m_{\chi 1} \sim 5$ GeV, $m_{\chi 2} \sim 88$ GeV, squarks and gluinos below 1 TeV
  - signatures:
    missing missing-energy
    hard jests, invariant mass of $b\bar{b}$, $\tau^+\tau^-$, $\gamma\gamma$ peaks at ~ 82 GeV

  light singlino-dominated LSP crucial

Neutralino sector of NMSSM

$$M_{\chi^0} = \begin{pmatrix} M_1 & 0 & -\frac{g_1 v}{\sqrt{2}} c_\beta & \frac{g_1 v}{\sqrt{2}} s_\beta & 0 \\ 0 & M_2 & \frac{g_2 v}{\sqrt{2}} c_\beta & -\frac{g_2 v}{\sqrt{2}} s_\beta & 0 \\ -\frac{g_1 v}{\sqrt{2}} c_\beta & \frac{g_2 v}{\sqrt{2}} c_\beta & 0 & -\mu & -\lambda v s_\beta \\ \frac{g_1 v}{\sqrt{2}} s_\beta & -\frac{g_2 v}{\sqrt{2}} s_\beta & -\mu & 0 & -\lambda v c_\beta \\ 0 & 0 & -\lambda v s_\beta & -\lambda v c_\beta & \langle \partial_S^2 f \rangle \end{pmatrix}$$

Only one additional neutralino but many new features

- important for experimental signatures
- more possibilities for a well-tempered LSP
- more funnel regions (resonant s or/and a exchange)
- new kinds of blind spots in spin-independent LSP-nucleon cross-sections (direct detection)
- additional annihilation channels (aa, sa, ha, ss $\ldots$) change Ωh^2 and constraints from indirect detection experiments

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We concentrate on models with decoupled gauginos
$\Rightarrow$ the LSP is a singlino-higgsino mixture

Neutralino sector of NMSSM

The 3×3 mass sub-matrix of (light) neutralinos depends only on 4 (combinations of) parameters: μ, λ, $\tan\beta$ and $\langle \partial_S^2 f \rangle$

Trading $\langle \partial_S^2 f \rangle$ for the LSP mass, m_χ, one can write its composition as

$$\frac{N_{13}}{N_{15}} = \frac{\lambda v}{\mu} \, \frac{(m_\chi/\mu)\sin\beta - \cos\beta}{1 - (m_\chi/\mu)^2}$$

$$\frac{N_{14}}{N_{15}} = \frac{\lambda v}{\mu} \, \frac{(m_\chi/\mu)\cos\beta - \sin\beta}{1 - (m_\chi/\mu)^2}$$

LSP's mass and composition give us (almost) all couplings relevant for its relic abundance and for comparison with the DM (in)direct detection experiments

For example Z exchange above the $t\bar{t}$ threshold gives

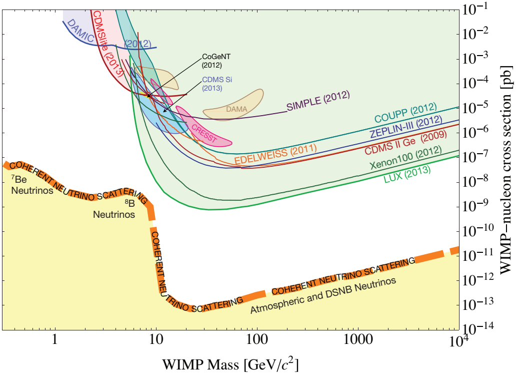
$$\Omega h^2 \approx 0.1 \left(\frac{0.05}{N_{13}^2 - N_{14}^2} \right)^2 \left[\left(1 - \frac{m_t^2}{m_\chi^2} \right)^{1/2} + \frac{3}{4} \frac{1}{x_f} \left(1 - \frac{m_t^2}{2 m_\chi^2} \right) \left(1 - \frac{m_t^2}{m_\chi^2} \right)^{-1/2} \right]^{-1}$$

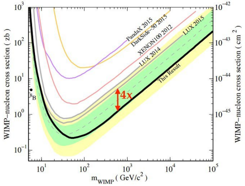
$$N_{13}^2 - N_{14}^2 = \frac{\left[1 - (m_\chi/\mu)^2 \right] \cos 2\beta}{1 + (m_\chi/\mu)^2 - 2\,(m_\chi/\mu)\sin 2\beta + \left[1 - (m_\chi/\mu)^2 \right]^2 (\mu/\lambda v)^2}$$

Neutralino sector of NMSSM – blind spots of $\sigma_{\rm SI}$

DM particles have not been observed in DD experiments

J. Billard, L. Strigari, E. Figueroa-Feliciano, Phys. Rev. D 89 (2014) 2, 023524





from Aaron Manalaysay presentation for the LUX collaboration, *"Dark-matter results from 332 new live days of LUX data"*

Future experiments, (XENON1T, LZ, XENONnT, DARWIN), will be filling the gap between the present bounds and the neutrino background

There are blind spots (BS) in the parameter space
for which $\sigma_{\rm SI}$ is very small - even below the neutrino background

Formulae for neutralino-nucleus spin-independent cross section in NMSSM are quite complicated

Assumption: sfermions are very heavy
$\Rightarrow$ $\sigma_{\rm SI}$ is dominated by the exchange of the Higgs scalars

$$\sigma_{\rm SI} = \frac{4\mu_{\rm red}^2}{\pi^2}\,\frac{\left[Zf^{(p)} + (A-Z)f^{(n)}\right]^2}{A^2}$$

$$f^{(N)} \approx \sum_{i=1}^{3} f_{h_i}^{(N)} \equiv \sum_{i=1}^{3} \frac{\alpha_{h_i\chi\chi}\alpha_{h_iNN}}{2m_{h_i}^2}$$

$$\alpha_{h_i\chi\chi} \approx \sqrt{2}\lambda\left[\tilde{S}_{h_i\hat{h}}N_{15}\left(N_{13}\sin\beta + N_{14}\cos\beta\right)\right.$$
$$\left. + \tilde{S}_{h_i\hat{H}}N_{15}\left(N_{14}\sin\beta - N_{13}\cos\beta\right) + \tilde{S}_{h_i\hat{s}}\left(N_{13}N_{14} - (\kappa/\lambda)N_{15}^2\right)\right]$$

$$\alpha_{h_iNN} \approx \frac{m_N F^{(N)}}{\sqrt{2}v}\left[2\tilde{S}_{h_i\hat{h}} + \tilde{S}_{h_i\hat{H}}\left(\tan\beta - \frac{1}{\tan\beta}\right)\right]$$

Blind spots in MSSM

- "old" blind spots ($m_H \to \infty$):

$$\frac{m_\chi}{\mu} + \sin 2\beta \simeq 0$$

  - $\tan\beta \sim 1$ for mixed or higgsino-dominated LSP
  - LSP strongly bino-dominated for bigger $\tan\beta$

- "new" blind spots ($m_H \gg m_h$):

$$\frac{m_\chi}{\mu} + \sin 2\beta \approx \frac{\tan\beta}{2}\left(\frac{m_h}{m_H}\right)^2$$

  - small m_h/m_H may be (partially) compensated by large $\tan\beta$

Huang, Wagner, 2014

Badziak, M.O., Szczerbiak, 2016
and work in progress

The blind spot condition with only h exchange contributing to $\sigma_{\rm SI}$:

$$\frac{m_\chi}{\mu} - \sin 2\beta = -\frac{\tilde{S}_{h\hat{s}}}{\tilde{S}_{h\hat{h}}}\frac{\mu}{\lambda v}\left[1-\left(\frac{m_\chi}{\mu}\right)^2\right]\left(\frac{N_{13}}{N_{15}}\frac{N_{14}}{N_{15}}-\frac{\kappa}{\lambda}\right) - \frac{\tilde{S}_{h\hat{H}}}{\tilde{S}_{h\hat{h}}}\cos 2\beta$$

- The parameters translate to physical quantities for which there are (experimental) bounds
  - for example: $\frac{\tilde{S}_{h\hat{s}}}{\tilde{S}_{h\hat{h}}} \approx \mathrm{sgn}(\Lambda \sin 2\beta - 2\mu)\frac{\sqrt{2|\Delta_{\rm mix}|m_h}}{m_s}$
  - $|\Delta_{\rm mix}|$ should be small because $\Delta_{\rm mix} < 0$ for $m_s > m_h$
- There are BS for both signs of m_χ/μ

The blind spot condition with h and s exchange:

$$\frac{m_\chi}{\mu} - \sin 2\beta \approx -\frac{\frac{\tilde{S}_{h\hat{s}}}{\tilde{S}_{h\hat{h}}} + \mathcal{A}_s}{1 + + \mathcal{A}_s \frac{\tilde{S}_{s\hat{h}}}{\tilde{S}_{h\hat{h}}}} \frac{\mu}{\lambda v} \left[1 - \left(\frac{m_\chi}{\mu}\right)^2\right] \left(\frac{N_{13}}{N_{15}} \frac{N_{14}}{N_{15}} - \frac{\kappa}{\lambda}\right)$$

$$\mathcal{A}_s \approx \frac{\tilde{S}_{s\hat{h}}}{\tilde{S}_{h\hat{h}}} \frac{1 + c_s}{1 + c_h} \left(\frac{m_h}{m_s}\right)^2 \qquad \frac{\tilde{S}_{s\hat{h}}}{\tilde{S}_{h\hat{h}}} \approx -\frac{\tilde{S}_{h\hat{s}}}{\tilde{S}_{h\hat{h}}}$$

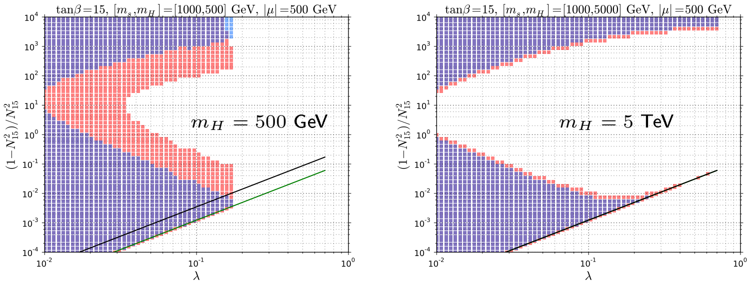
$$c_{h_i} \equiv 1 + \frac{\tilde{S}_{h_i\hat{H}}}{\tilde{S}_{h_i\hat{h}}} \left(\tan\beta - \frac{1}{\tan\beta}\right) = \frac{g_{h_i bb}/g_{h_{\rm SM} bb}}{g_{h_i ZZ}/g_{h_{\rm SM} ZZ}}$$

New contributions are related to the couplings of h and s

LHC results suggest c_h (substantially) below the SM value

Even for heavy singlet-dominated scalar the blind spot region is much bigger than the "standard" blind spot (green line) or blind spot modified by the H exchange (black line) due to the mixing

$m_\chi \mu > 0$ $m_\chi \mu < 0$ $m_s = 1$ TeV -1 GeV $< \Delta_{\rm mix} < 0$ $\tan\beta = 15$



Modifications from the mixing with 1 TeV s much bigger than from the exchange of 500 GeV H

Bigger higgsino component allowed $\rightarrow$ important for Ωh^2

We are interested in regions of the parameters space giving big positive contribution from the mixing to the SM-like Higgs: $\Delta_{\rm mix}$

There are blind spots when $\Delta_{\rm mix}$ is substantial

- not for (strongly) higgsino-dominated LSP
- bigger higgsino component allowed for $c_s > 1$
- possible value of $\Delta_{\rm mix}$ is correlated with the properties of the singlet-dominated scalar
  - $c_s \sim 1$ for $m_s \sim 95\,{\rm GeV}$

$$\Delta_{\rm mix} > 4\,{\rm GeV} \;\Rightarrow\; c_s \gtrsim 0.5$$

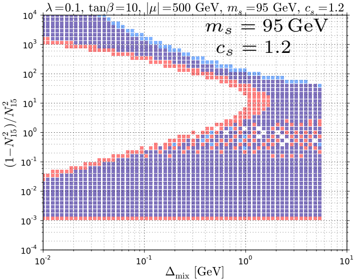
$$\Delta_{\rm mix} > 5\,{\rm GeV} \;\Rightarrow\; c_s \gtrsim 0.9$$

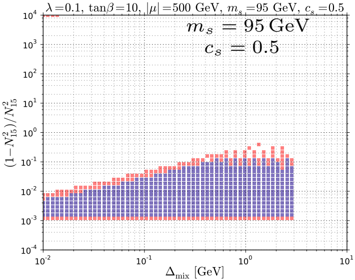
  - $|c_s|$ must be small for $m_s \sim 70\,{\rm GeV}$

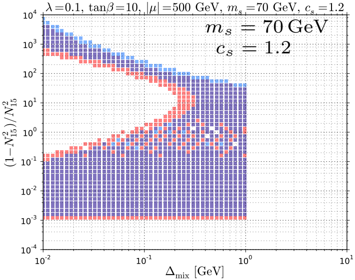
$$\Delta_{\rm mix} > 3\,{\rm GeV} \;\Rightarrow\; |c_s| \lesssim 0.2 \div 0.4$$

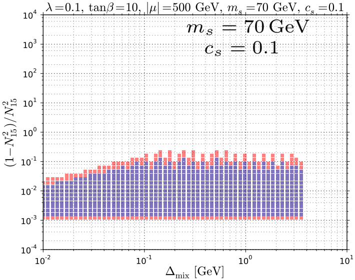
- It is much more difficult to find solutions in low $\tan\beta$ regime.

$\tan\beta = 10 \qquad \lambda = 0.1$





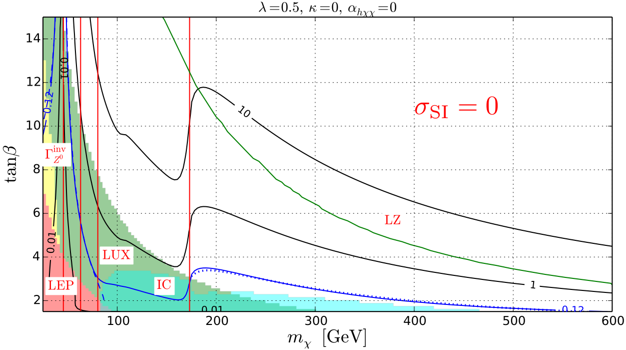




Blind spots and relic density

It is possible to have BS and $\Omega h^2 \approx 0.12$

Simplest case: heavy s and H, no mixing

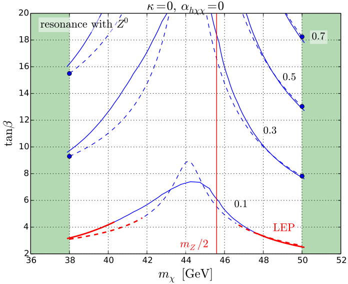


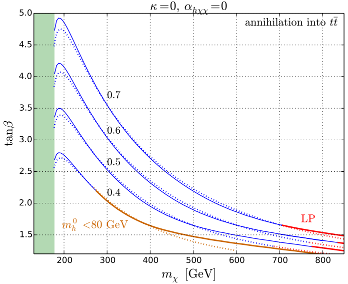
Only two regions survive LUX and IceCube bounds on $\sigma_{\rm SD}$:

- close to the Z resonance
- above the $t\bar{t}$ threshold

Blind spot and relic density

$m_{\rm LSP} \sim \frac{1}{2} M_Z$ moderate or big $\tan\beta$	$7 \gtrsim \tan\beta \gtrsim 4$ for $\lambda \sim 0.1$ $\tan\beta \gtrsim 8$ for $\lambda \gtrsim 0.3$ $\tan\beta \gtrsim 18$ for $\lambda \gtrsim 0.7$
$m_{\rm LSP} > m_t$ small $\tan\beta$	$\tan\beta \lesssim 3$ for $\lambda \lesssim 0.4$ $\tan\beta \lesssim 5$ for $\lambda \lesssim 0.7$



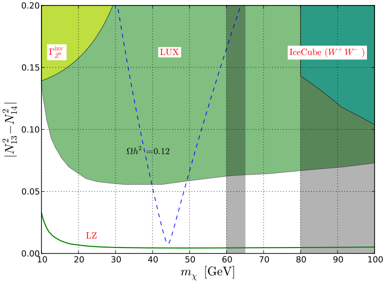


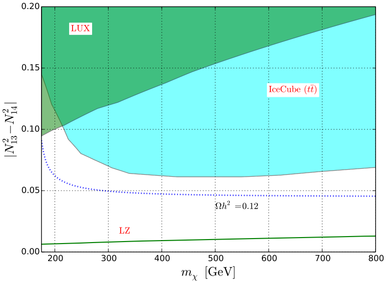
Allowed regions of $\tan\beta$ are bigger for non-vanishing mixing

Blind spot and relic density

$\sigma_{\rm SD}$ is dominated by Z exchange $\Rightarrow$ is proportional to $\left(N_{13}^2 - N_{14}^2\right)^2$

for simple BS: $\left|N_{13}^2 - N_{14}^2\right| = \left(\frac{\lambda v_h}{m_\chi}\right)^2 \frac{\sin^2 2\beta}{|\cos 2\beta|} \left[1 + \left(\frac{\lambda v_h}{m_\chi}\right)^2 \tan^2 2\beta\right]^{-1}$





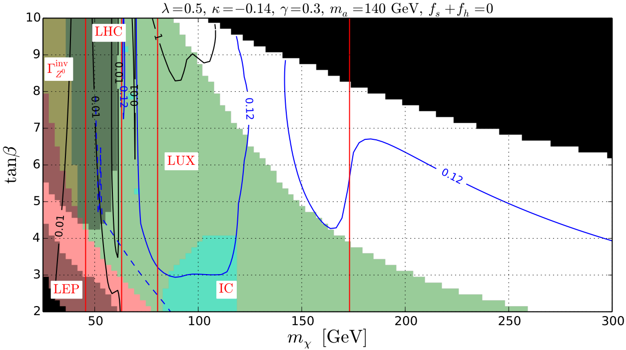
Next run of IceCube may explore the region with $m_{\rm LSP} > m_t$

Sensitivity of LZ enough to explore both allowed regions

Blind spot and relic density

Situation becomes (much) more complicated when the singlet-dominated scalar (and pseudoscalar) is (are) light

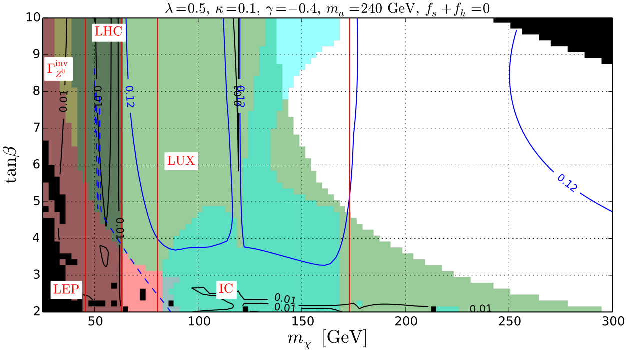
Some region with $m_{\mathrm{LSP}} < m_t$ may be allowed



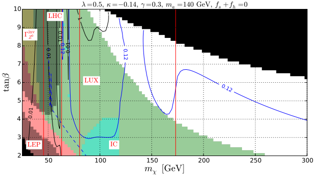
Blind spot and relic density

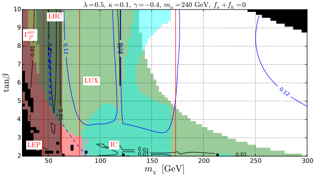
Situation becomes (much) more complicated when the singlet-dominated scalar (and pseudoscalar) is (are) light

Some region with $m_{\mathrm{LSP}} > m_t$ may be forbidden



Blind spot and relic density





annihilation dominated by final states including s and/or a $\Rightarrow$

- smaller Z-exchange contribution needed
- $\Omega h^2 = 0.12$ curve goes up (above the LUX bound)
- IceCube bounds are much relaxed for $2m_\chi > m_s + m_a$ (softer secondary neutrinos)

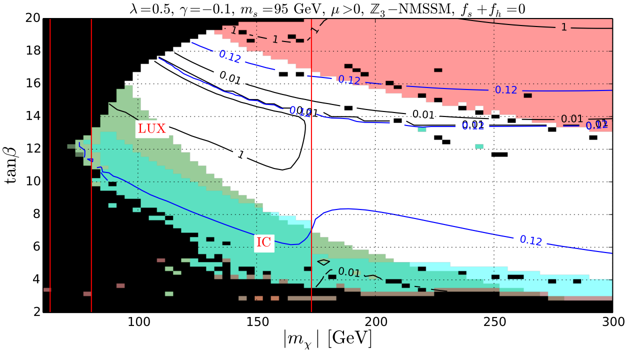
channels involving s and a are sub-dominant but

- more complicated BS condition involving s exchange may not be fulfilled simultaneously with $\Omega h^2 \approx 0.12$ (for some m_χ/μ)
- IceCube bounds are stronger (weaker) due to constructive (destructive) interference between Z- and a-mediated annihilation into $b\bar{b}$

In both (and many other) cases the singlet-dominated (pseudo)scalars play crucial role in determining the LSP properties

Blind spot and relic density

Correlations appear in NMSSM with additional symmetries



In $\mathbb{Z}_3$–invariant NMSSM

- for each $m_{\rm LSP}$ there are 3 values of $\tan\beta$ leading to $\Omega h^2 \approx 0.12$
- two upper curves are related to resonant a exchange
- loop corrections to m_a are crucial
- smaller $\Delta_{\rm mix}$ may be obtained

Summary – Higgs sector

- (General) NMSSM vs MSSM
  - only 3 extra particles – s, a and $\tilde{s}$
  - a lot of new features
- Extra contributions to SM-like Higgs mass – less fine tuning
- Two different interesting regions
  - small $\tan\beta$, large λ
  - moderate/large $\tan\beta$, small λ

  both have advantages and disadvantages
- Mixing among (pseudo)scalars is very important
  - properties of SM-like Higgs
  - interactions and relic abundance of DM
  - experimental signatures

    may be much different from MSSM
- Extra light scalars not excluded by LHC
- Existing experimental data should be re-examined
- New search strategies should be proposed/applied

Summary – Higgs sector and Dark Matter

- For decoupled gauginos the neutralino sector of NMSSM depends only on the LSP mass and (some of) the parameters of the Higgs sector
- Much more possibilities for blind spots of $\sigma_{\rm SI}$ (and much more complicated structure of BS)
- BS with big $\Delta_{\rm mix}$ favour
  - moderate $\tan\beta$ with small λ over small $\tan\beta$ with large λ
  - light scalar with mass corresponding to the LEP excess
  - BR($s\to\gamma\gamma$) smaller than for the SM-Higgs
- BS and $\Omega h^2 \approx 0.12$
  - heavy s and a: prefer small $\tan\beta$ and region of DM particles $\sim 175 \div 800$ GeV
  - light s and/or a: larger values of $\tan\beta$ and different DM masses possible;
  - light s and/or a: bounds from IceCube may be strongly influenced

Summary – Higgs sector and Dark Matter

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  - light s and/or a: bounds from IceCube may be strongly influenced
- optimistic scenario: (very precise) BS will not be necessary if DM particles are discovered soon...