Degenerate scalar and pseudoscalar Higgs bosons near 125 GeV in NUHM-CNMSSM

(based on 1305.0591, to appear in PRD)

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Outline

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A $\sim$125 GeV a_1

- A light singletlike pseudoscalar, a_1, achievable in the NMSSM

$$m_{a_1}^2 \simeq -3\kappa s A_\kappa^{\rm SUSY} - \frac{M_{P,12}^4}{M_{P,11}^2}$$

$M_{P,11}^2 \simeq \mu_{\rm eff}(A_\lambda^{\rm SUSY} + \kappa s)tan\beta$, $M_{P,12}^2 \simeq \lambda(A_\lambda^{\rm SUSY} - 2\kappa s)v$

$\rightarrow$ Relative signs of $\mu_{\rm eff}$ and A_κ crucial

$\rightarrow$ Dependence on the sign and magnitude of A-terms through RGEs

- Mass degeneracy with the SM-like h_1 would imply

$$R_{\gamma\gamma}^Y({\rm obs}) = R_{\gamma\gamma}^Y(h_1) + R_{\gamma\gamma}^Y(a_1) \simeq 1 + R_{\gamma\gamma}^Y(a_1)\,;$$
$$R_{WW/ZZ}^Y({\rm obs}) = R_{WW/ZZ}^Y(h_1) \simeq 1$$

where $R_X^Y(h_i) \equiv \frac{\sigma(Y\to h_i)}{\sigma(Y\to h_{\rm SM})} \times \frac{BR(h_i\to X)}{BR(h_{\rm SM}\to X)} \approx C_{a_1}^2(Y)\, C_{a_1}^2(X)\, \frac{\Gamma_{h_{\rm SM}}^{\rm total}}{\Gamma_{a_1}^{\rm total}}$

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$\gamma\gamma$ decay of a light a_1

- The effective coupling of a_i to two photons

$$C_{a_i}^{\rm eff}(\gamma\gamma) \simeq \frac{g_{a_1\chi_1^\pm\chi_1^\pm}}{\sqrt{\sqrt{2}G_F}\, m_{\chi_1^\pm}} A_{1/2}^{a_i}(\tau_i); \quad \tau_i = \frac{m_{a_i}^2}{4m_{\chi_1^\pm}^2} \to A_{1/2}^{a_i}(\tau_i) \simeq 1$$

- $\sim C_{h_{\rm SM}}^{\rm eff}(\gamma\gamma)$ in the presence of a higgsino-like chargino

$$g_{a_i\chi_1^\pm\chi_1^\pm} = i\Big[\frac{\lambda}{\sqrt{2}} P_{i3} \sin\theta_U \sin\theta_V - \frac{g_2}{\sqrt{2}}(P_{i2}\cos\theta_U \sin\theta_V + P_{i1}\sin\theta_U \cos\theta_V)\Big]$$

- Singlet $a_1 \Rightarrow P_{13} \simeq 1$ and higgsino $\chi_1^\pm \Rightarrow \sin\theta_{U,V} \simeq 1$ yield

$$C_{a_1}(\gamma\gamma) \simeq \lambda \times \frac{130\ {\rm GeV}}{m_{\chi_1^\pm}}$$

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Associated production with $b\bar{b}$

- Signal rate suppressed in the gluon fusion production mode!

$$R^{gg}_{\gamma\gamma}(a_1) = C^2_{a_1}(gg)\, C^2_{a_1}(\gamma\gamma)\, \frac{\Gamma^{\rm total}_{h_{\rm SM}}}{\Gamma^{\rm total}_{a_1}}$$

- Potentially enhanced in the $b\bar{b}h$ production mode instead

$$R^{bb}_{\gamma\gamma}(a_1) \simeq \left|\frac{(A^{\rm SUSY}_\lambda - 2\kappa s)v}{\mu(A^{\rm SUSY}_\lambda + \kappa s)}\right|^2 \lambda^4 \left(\frac{130{\rm GeV}}{m_{\chi^\pm_1}}\right)^2 \left(\frac{1}{\Gamma^{\rm total}_{a_1}/\Gamma^{\rm total}_{h_{\rm SM}}}\right)$$

- Signal rates in the $b\bar{b}$ and $\tau^+\tau^-$ channels also enhanced

$$R^{bb}_{b\bar{b}/\tau^+\tau^-}(a_1) \simeq \left|\frac{\lambda(A^{\rm SUSY}_\lambda - 2\kappa s)v}{\mu(A^{\rm SUSY}_\lambda + \kappa s)}\right|^4 \left(\frac{1}{\Gamma^{\rm total}_{a_1}/\Gamma^{\rm total}_{h_{\rm SM}}}\right)$$

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Model and analysis

- Assuming 'full' unification at the GUT-scale leads to

$$p_i = \{m_0,\, m_{1/2},\, A_0,\, \lambda\}$$

- CNMSSM-NUHM: $m_S,\, m_{H_u},\, m_{H_d} \neq m_0;\, A_\lambda = A_\kappa \neq A_0 \rightarrow p_i + \{\tan\beta,\, \kappa,\, \mu_{\rm eff},\, A_\lambda\}$
- Model scanned using NMSSMTools imposing constraints from b-physics, LHC SUSY searches, RD measurements and D^{3}M
- Required $122\,\mathrm{GeV} \leq m_{h_1/a_1} \leq 130\,\mathrm{GeV}$ and $R_X^{bb}(h_1) \simeq 1$
- Three regions distinguishable by χ_1^0 composition found

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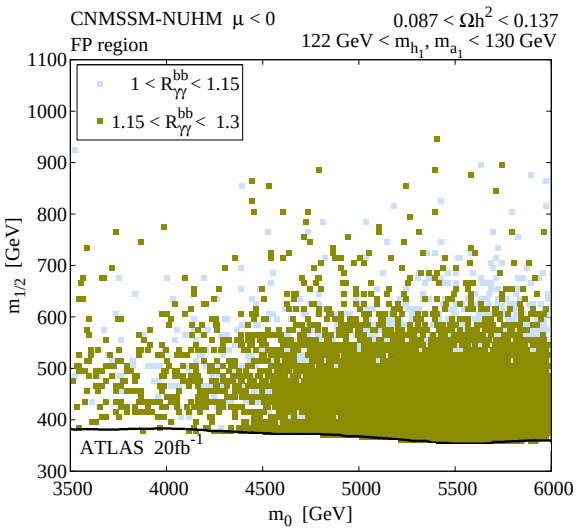
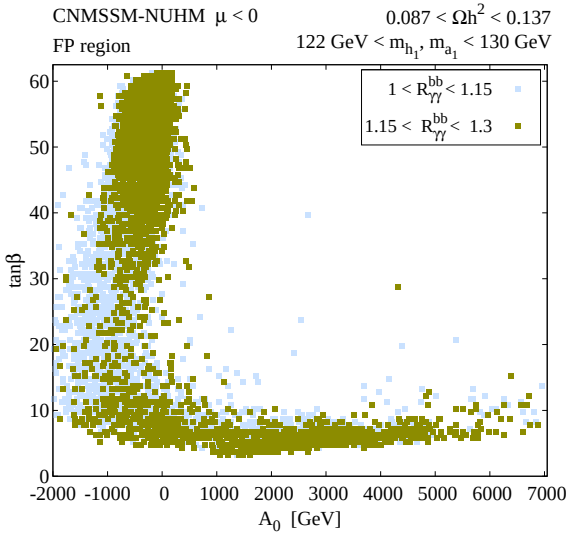
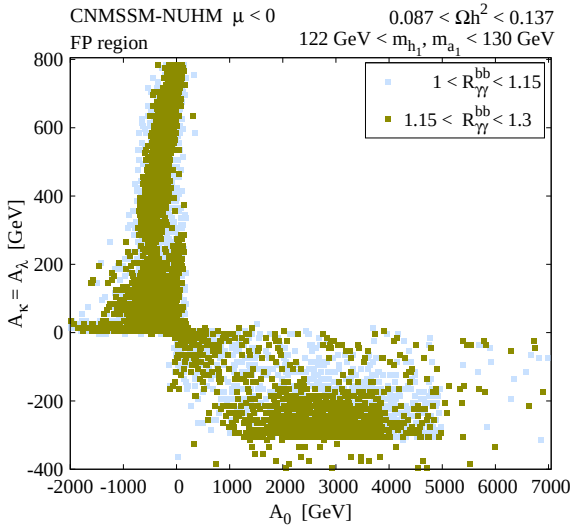
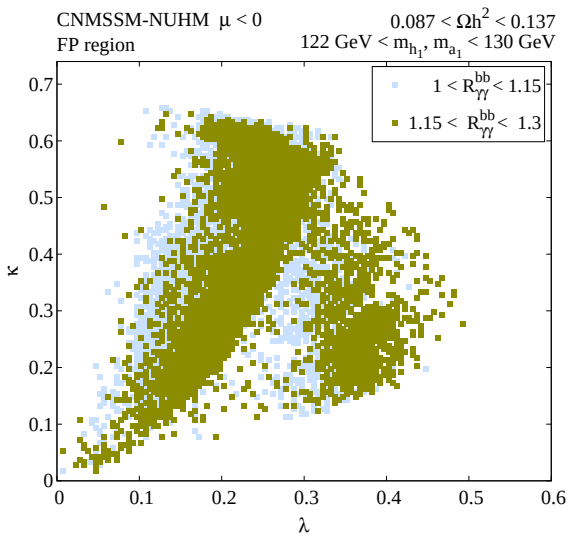
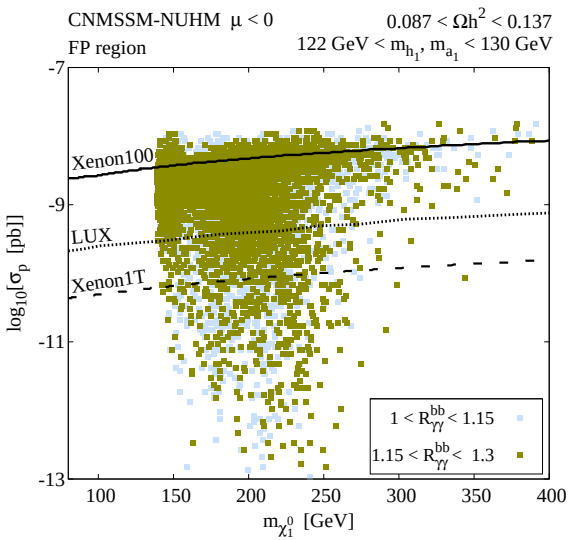
The FP region

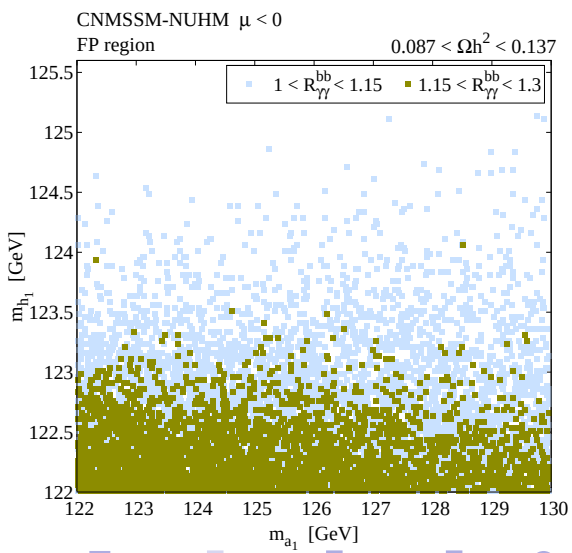




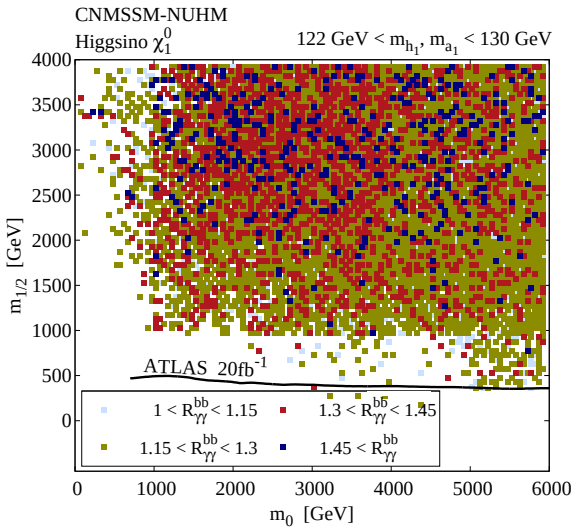


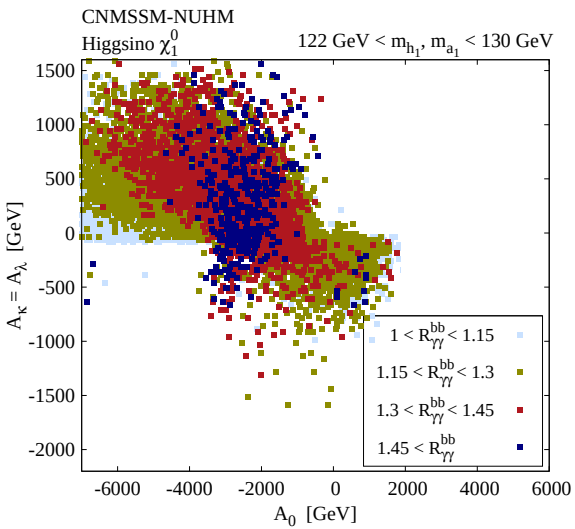


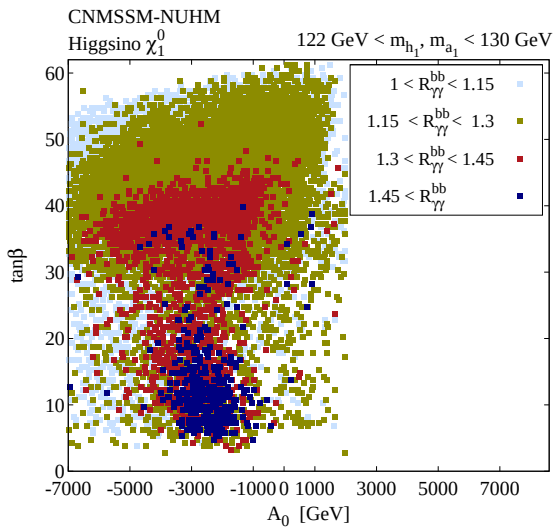


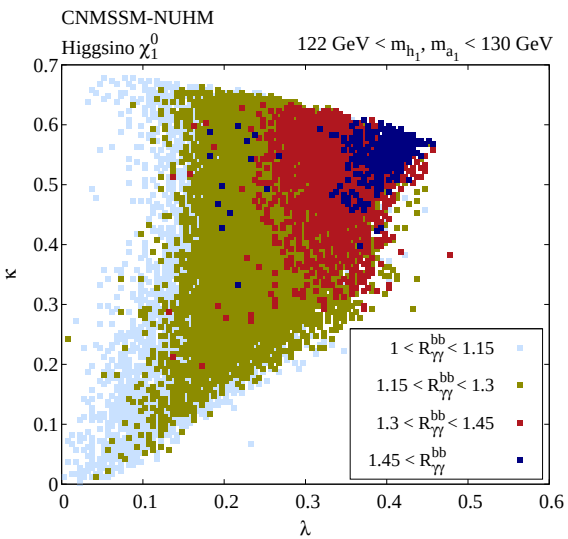


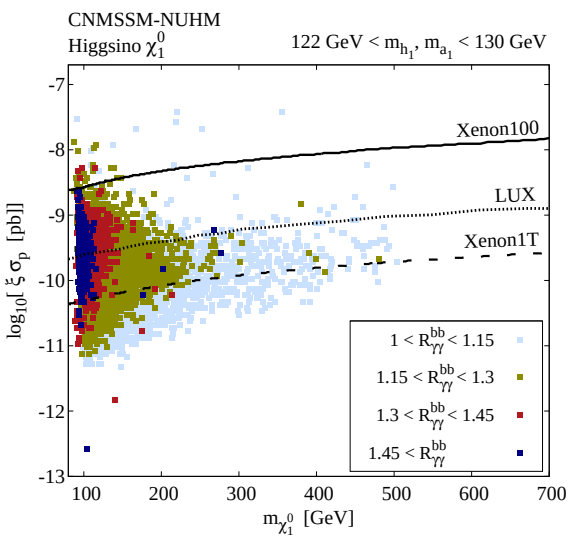
The higgsino region











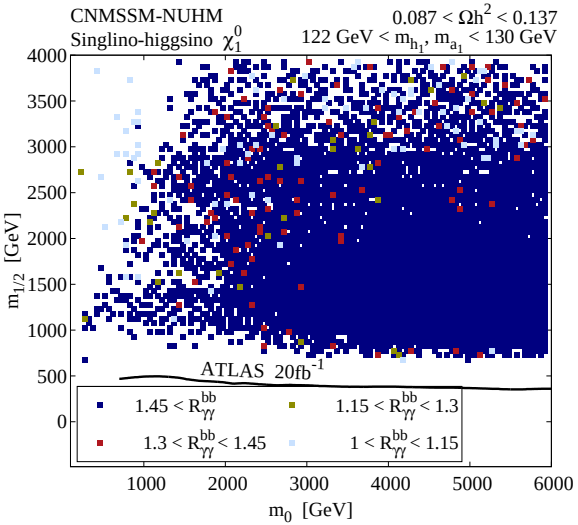
→ *Assumption: Relic density only partially due to* χ_1^0

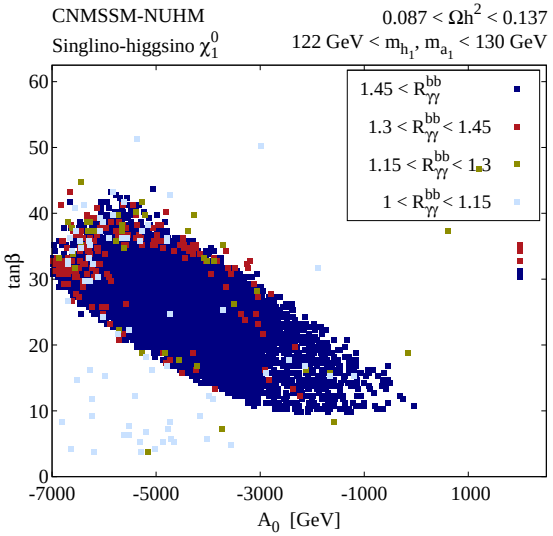
The singlino-higgsino region

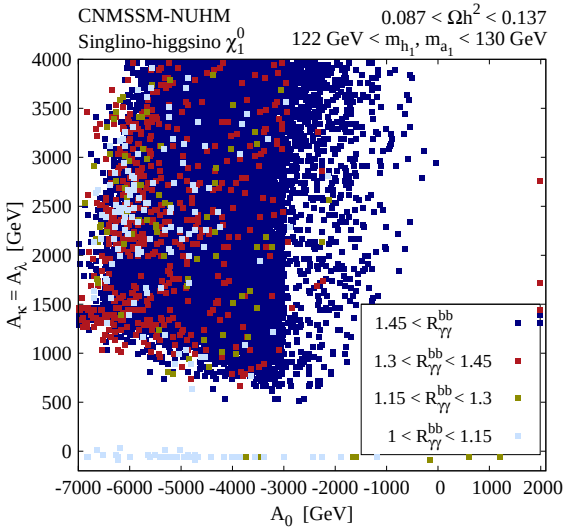
→ Region allowing

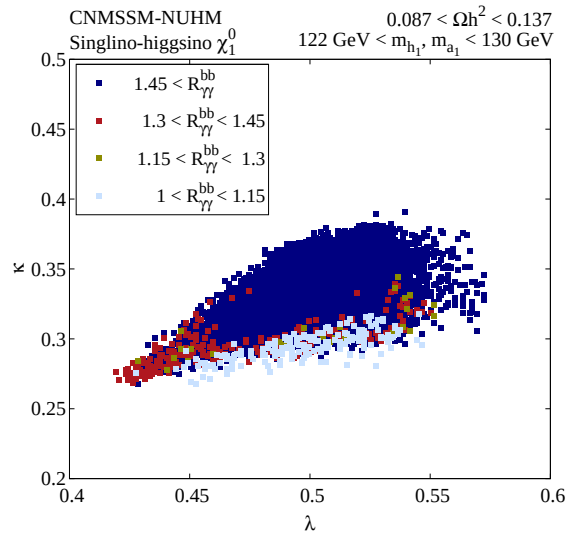
maximum enhancement

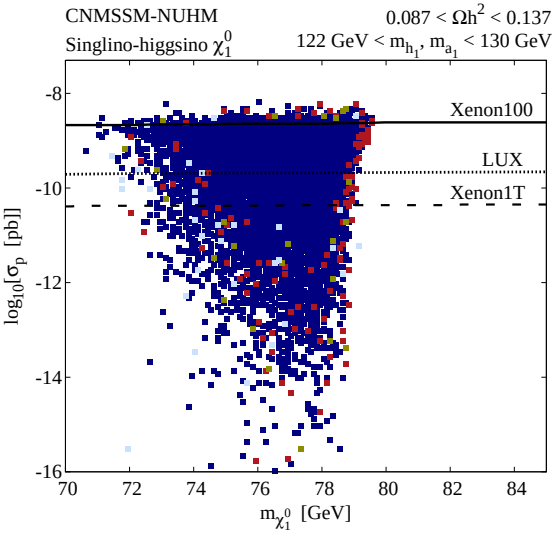
in $R_{\gamma\gamma}(h_{a_1})$ (∼60%)!



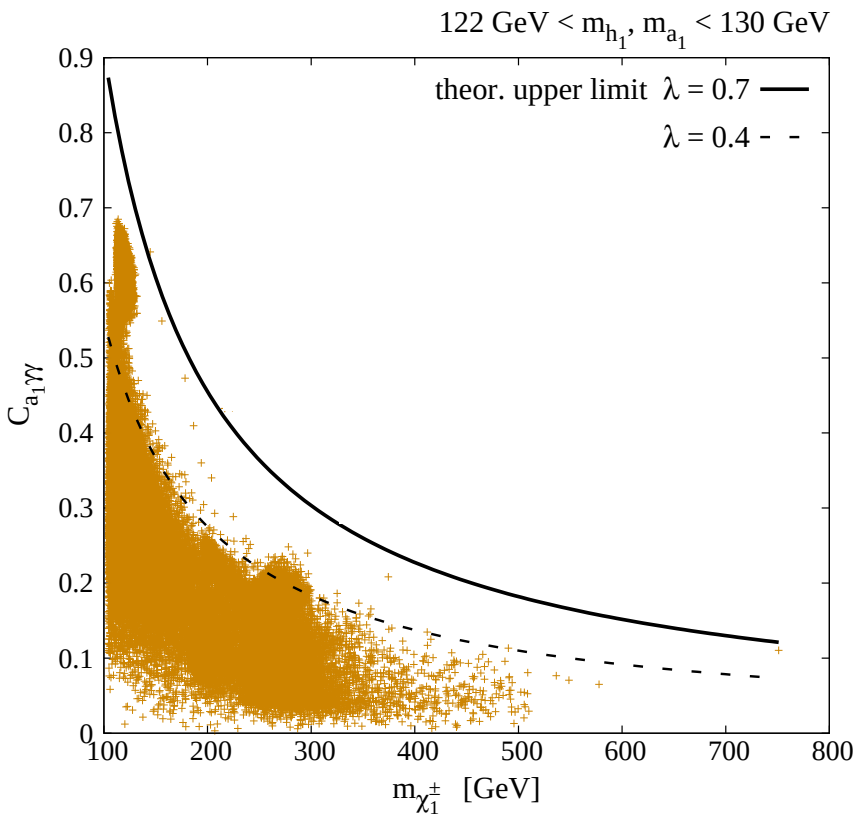


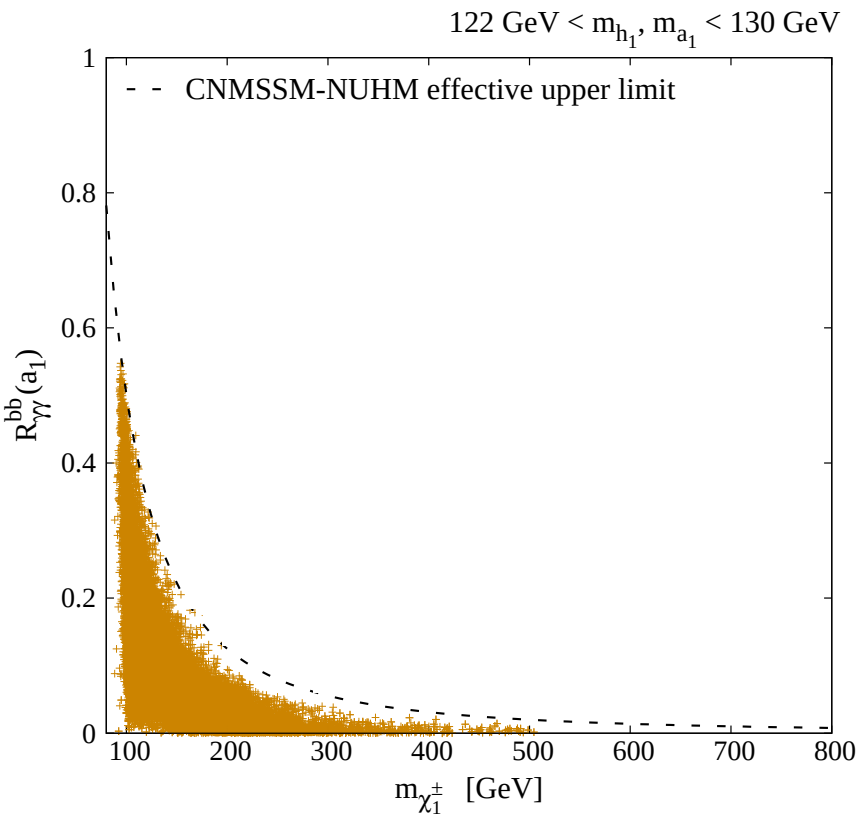






Upper limit on $\chi_1^\pm$ (and χ_1^0) mass in CNMSSM-NUHM

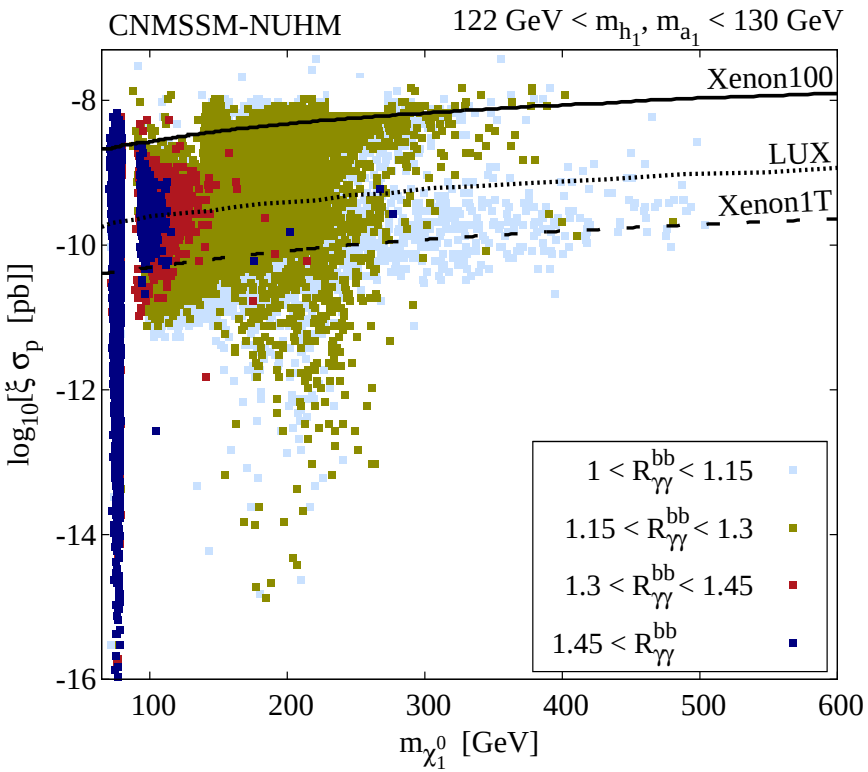


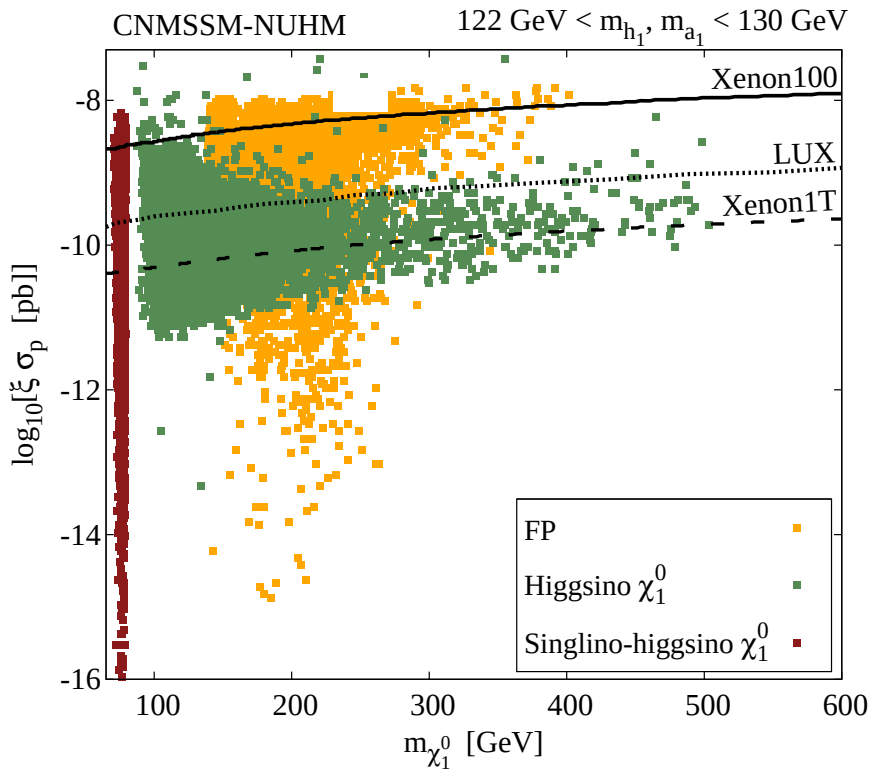


Summary

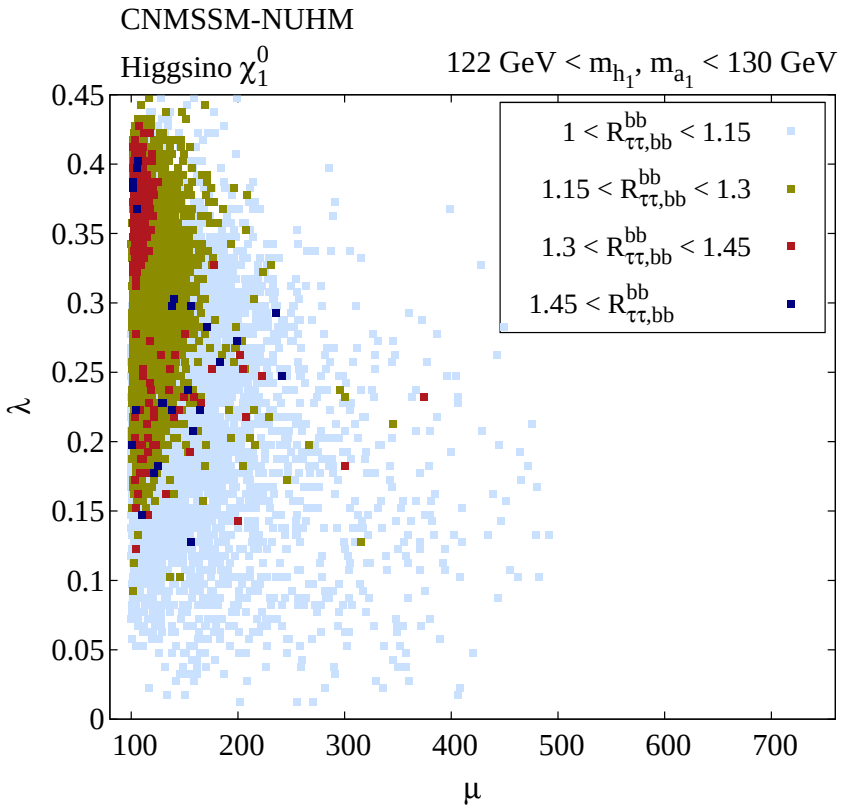
- A $125\,\mathrm{GeV}$ a_1 achievable when the universality condition is lifted from the Higgs sector
- With a light and higgsino-like $\chi_1^{\pm}$, a_1 could result in an enhancement in the $\gamma\gamma$ rate around $125\,\mathrm{GeV}$
- A dedicated analysis of the $b\bar{b}$ associated Higgs production mode important for identifying this (and some other possible) BSM scenario(s)

Backup 1


CNMSSM-NUHM
122 GeV < m_{h_1}, m_{a_1} < 130 GeV
Xenon100
LUX
Xenon1T
1 < R_{γγ}^{bb} < 1.15
1.15 < R_{γγ}^{bb} < 1.3
1.3 < R_{γγ}^{bb} < 1.45
1.45 < R_{γγ}^{bb}
log10[ξ σp [pb]]
m_{χ1^0} [GeV]


CNMSSM-NUHM
122 GeV < m_{h_1}, m_{a_1} < 130 GeV
Xenon100
LUX
Xenon1T
FP
Higgsino χ1^0
Singlino-higgsino χ1^0
log10[ξ σp [pb]]
m_{χ1^0} [GeV]

Backup 2


CNMSSM-NUHM
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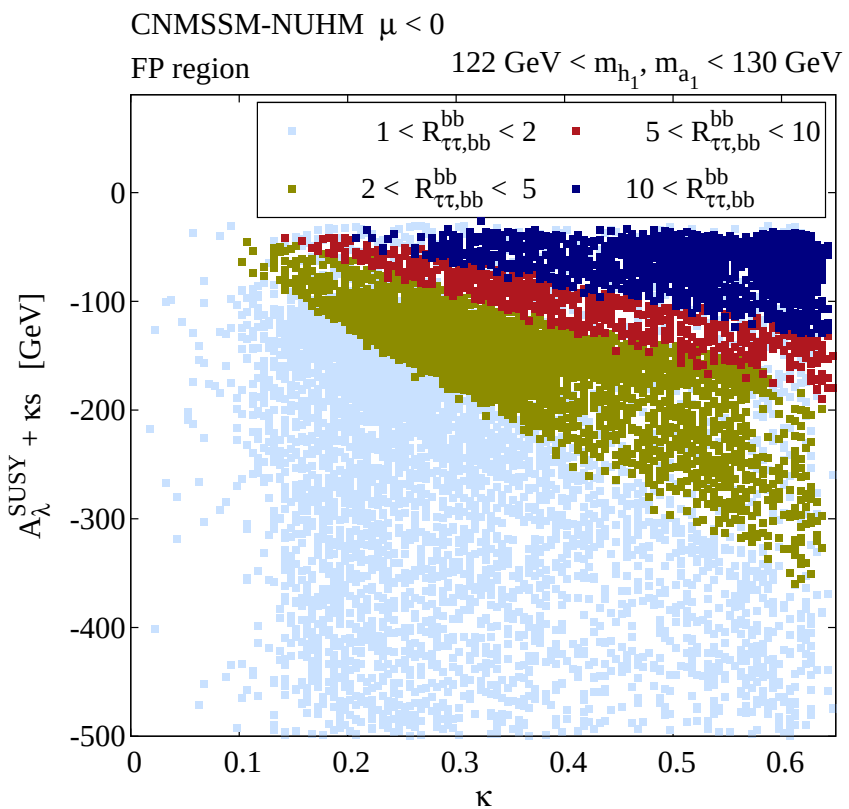
$1.15 < R^{bb}_{\tau\tau,bb} < 1.3$
$1.3 < R^{bb}_{\tau\tau,bb} < 1.45$
$1.45 < R^{bb}_{\tau\tau,bb}$
λ
μ
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
100
200
300
400
500
600
700


CNMSSM-NUHM μ < 0
FP region
122 GeV < m_{h_1}, m_{a_1} < 130 GeV
$1 < R^{bb}_{\tau\tau,bb} < 2$
$2 < R^{bb}_{\tau\tau,bb} < 5$
$5 < R^{bb}_{\tau\tau,bb} < 10$
$10 < R^{bb}_{\tau\tau,bb}$
$A_\lambda^{SUSY} + \kappa s$ [GeV]
κ
0
-100
-200
-300
-400
-500
0
0.1
0.2
0.3
0.4
0.5
0.6