



Light and Heavy Scalar Resonances in the GNMSSM with Correct Dark Matter Relic Abundance

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with Prof. Junjie Cao, Prof. Yao-Bei Liu and Dr. Xinglong Jia

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Outline

- **Motivation**
- **Scalar Resonances near 95.4 GeV and 650 GeV**
- **GNMSSM interpretation**
- **Conclusion**

Motivation

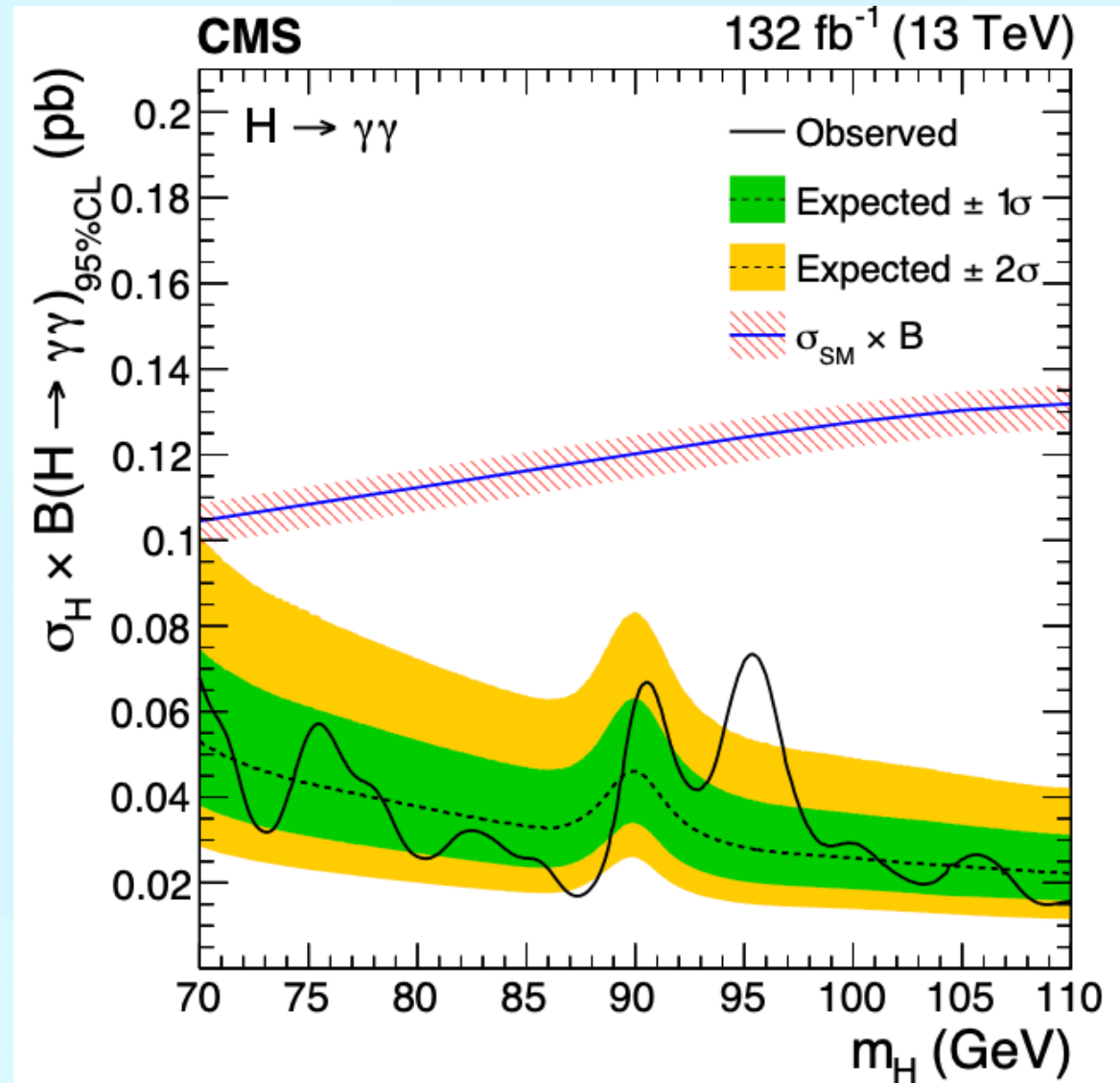
BSM New physics must exist:

- Dark matter and Dark energy
- Matter-Antimatter asymmetry
- Neutrino mass
- Hierarchy problem
- Unification of forces
-

Experimental hints:

- Extra Higgs searches
- Lepton $g-2$
- Flavor Anomalies
- Sparticles in Compressed Scenarios
- Galactic Center γ -ray excess
-

95.4 GeV Excesses at colliders



CMS-PAS-HIG-20-002

◆ 2015, 19.7fb⁻¹, 8TeV:

97GeV, 2.0 σ

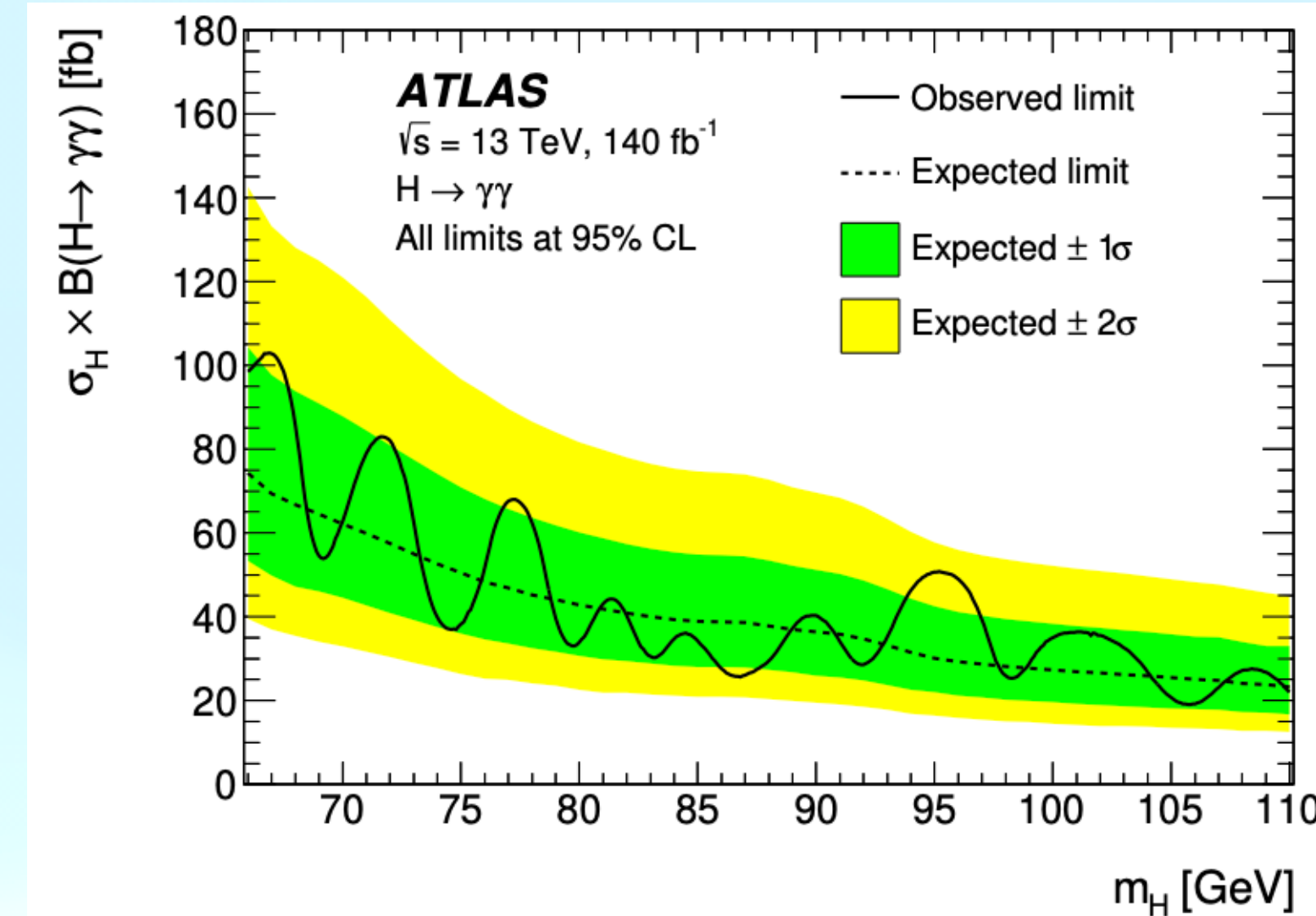
◆ 2018, 35.9fb⁻¹, 13TeV:

95GeV, 2.8 σ

◆ 2023, Run-2, 13TeV:

95GeV, 2.9 σ

$$\mu_{\gamma\gamma} = 0.33^{+0.19}_{-0.12}$$



CERN-EP-2024-166, JHEP 01 (2025) 053

◆ 2018, 80fb⁻¹:

Nothing

◆ 2023, Run-2:

95GeV, 1.7 σ

$$\mu_{\gamma\gamma} = 0.18 \pm 0.10$$

Combined result in the **di-photon** channel: $\mu_{\gamma\gamma}^{\text{exp}} \equiv \mu_{\gamma\gamma}^{\text{ATLAS+CMS}} = 0.24^{+0.09}_{-0.08} (3.1\sigma)$

T. Biekötter *et al.*, PRD (2024)109:035005.

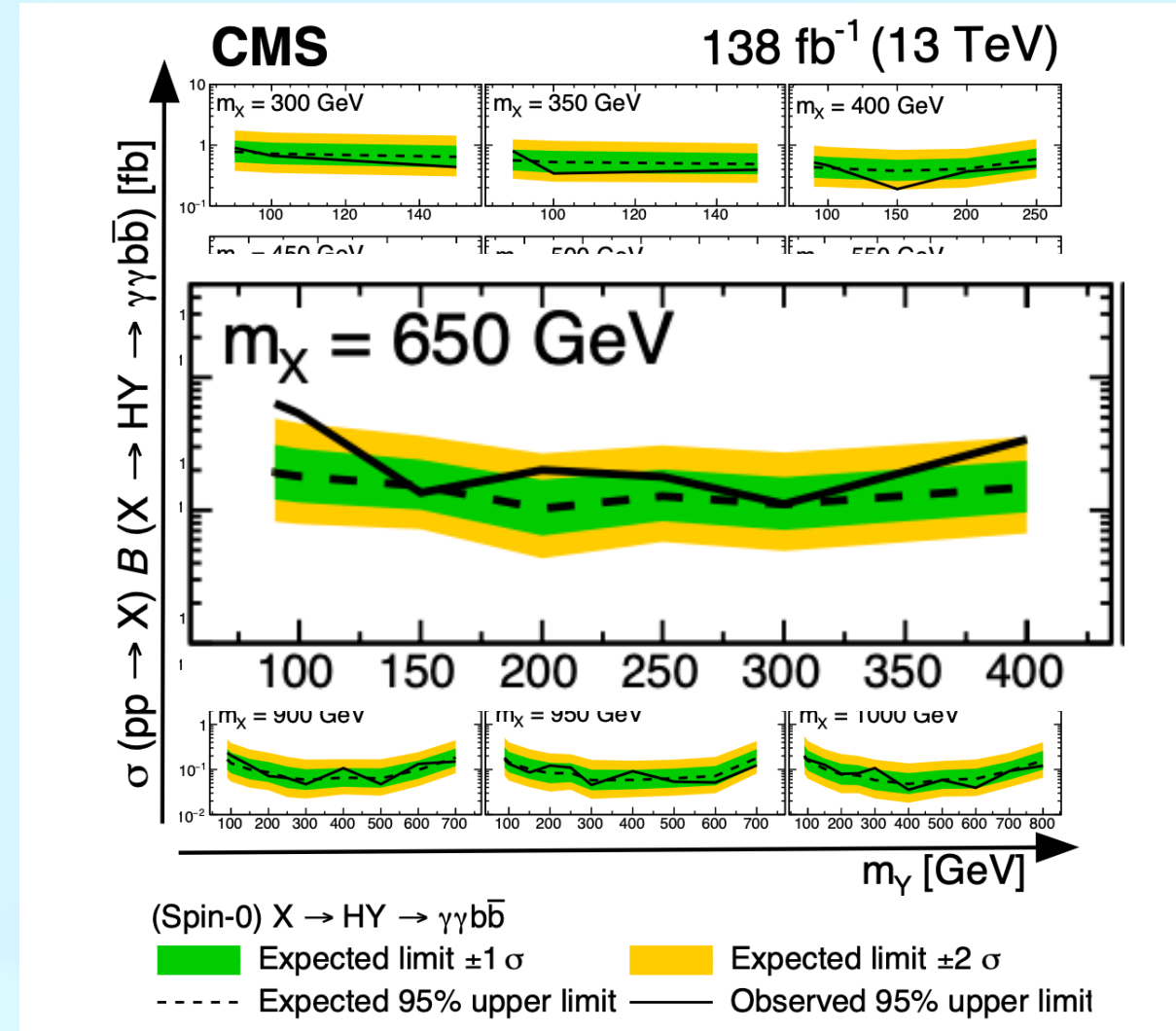
Besides, a local excess in the **di-tau** channel at 95 GeV observed by CMS: $\mu_{\tau\bar{\tau}}^{\text{exp}} = 1.38^{+0.69}_{-0.55} (2.6\sigma)$

A. Tumasyan *et al.*, JHEP 07 (2023) 073; U. Ellwanger *et al.*, Eur. Phys. J. C 83 (2023) 1138

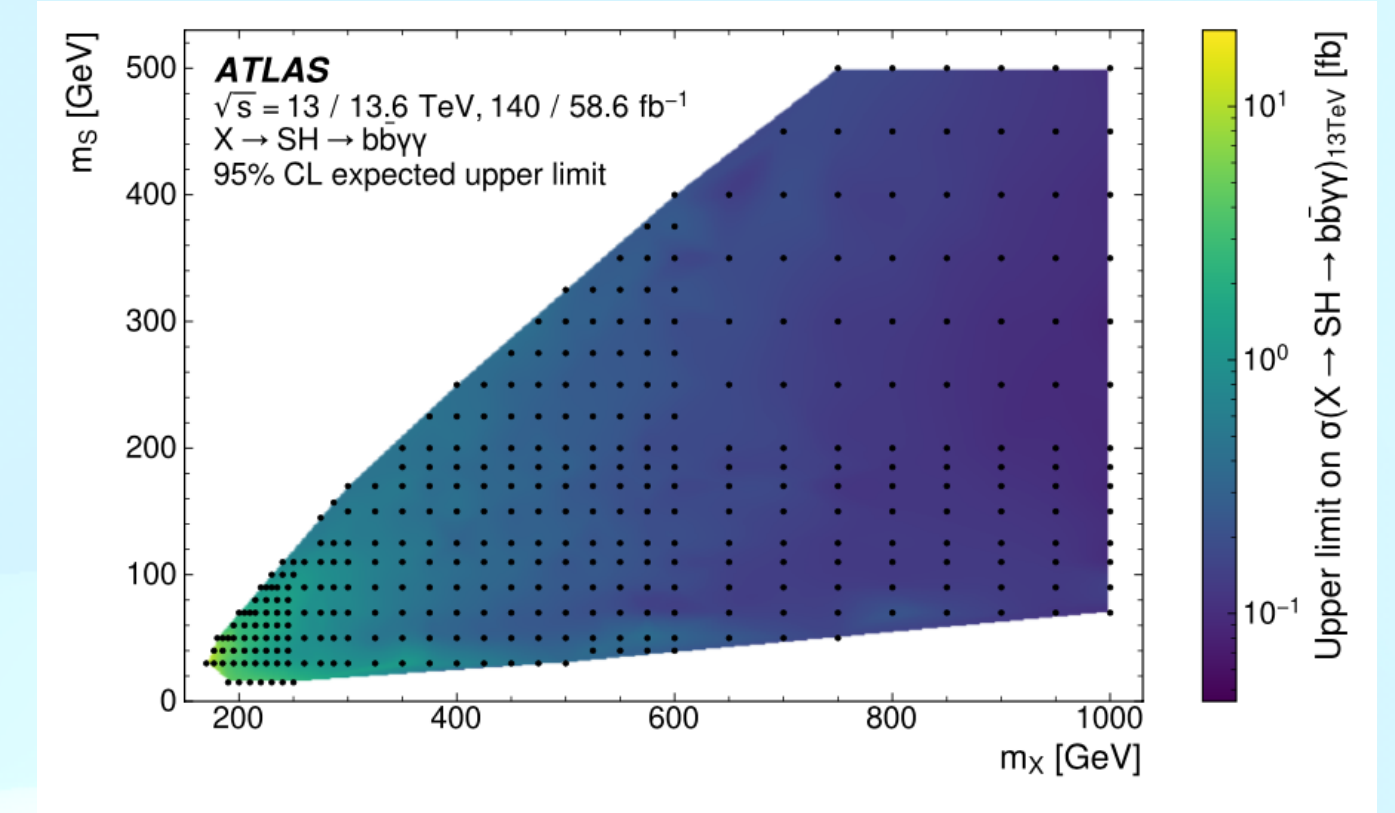
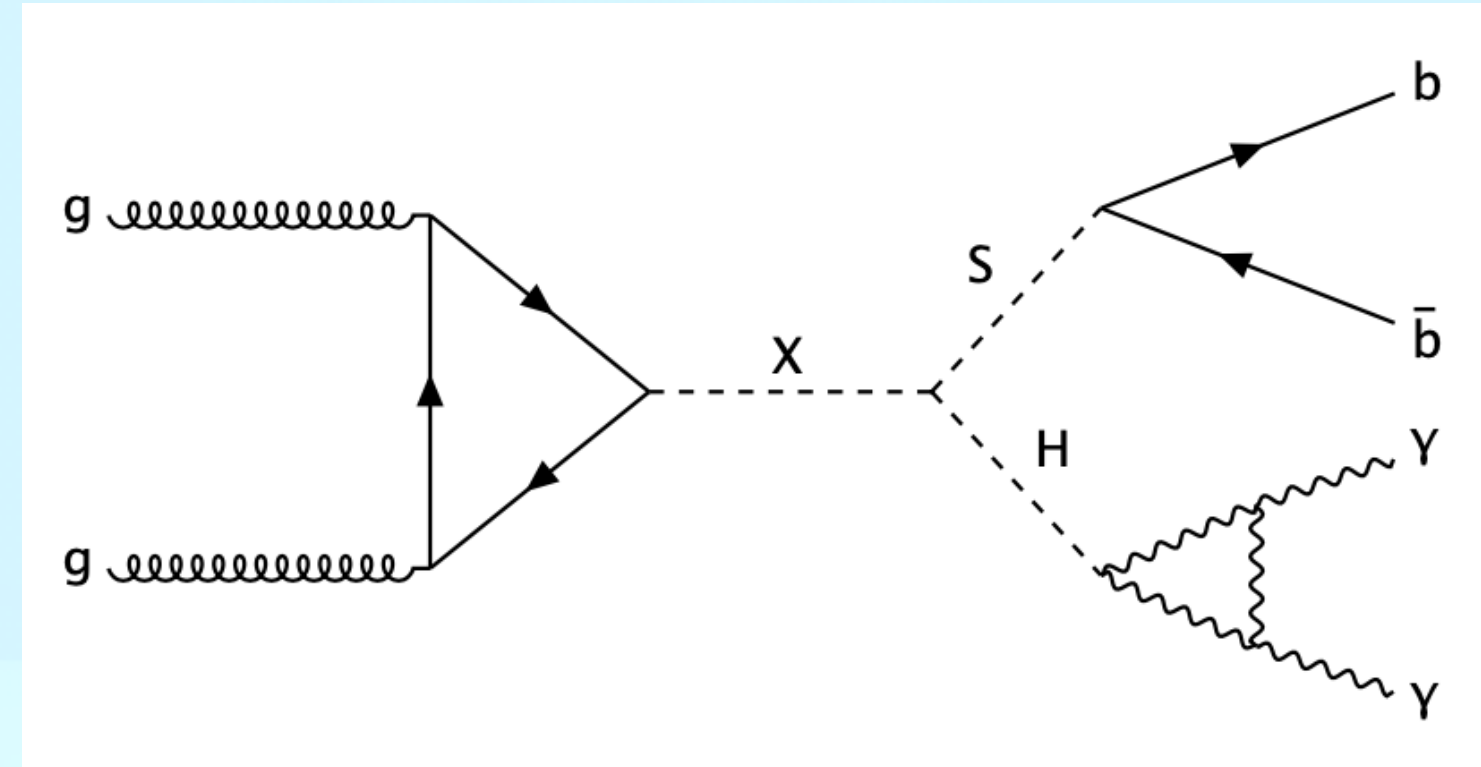
At LEP, a local excess near 98 GeV in $e^+e^- \rightarrow Z\phi \rightarrow Z(b\bar{b})$ channel: $\mu_{b\bar{b}}^{\text{exp}} = 0.117 \pm 0.057 (2.3\sigma)$

LEP collaborations, PLB(2003)565:61-75; Junjie Cao *et al.*, PRD(2017)95:116001.

Heavy Scalar Resonance Anomaly



JHEP 05 (2024) 316



CERN-EP-2025-204

$$\sigma(gg \rightarrow X \rightarrow H_{\text{SM}}(\gamma\gamma) + S(b\bar{b})) = 0.35^{+0.17}_{-0.13} \text{ fb}$$

A global (local) excess of 2.8σ (3.8σ) at $(m_X, m_S) = (650, 90)$ GeV was seen by CMS using Run-2 data [JHEP 05 (2024) 316], but **not** observed in the later CMS report [JHEP 12 (2025) 178], and **not** in the ATLAS analyses [JHEP 11 (2024) 047] and [CERN-EP-2025-204] either.

Considering an upper 95% CL limit of approximately 3 fb on $\sigma(X \rightarrow H_{\text{SM}}(\tau\bar{\tau}) + \phi(b\bar{b}))$ [JHEP 11 (2021) 057], $\sigma_{\gamma\gamma b\bar{b}}$ should be less than 0.1 fb.

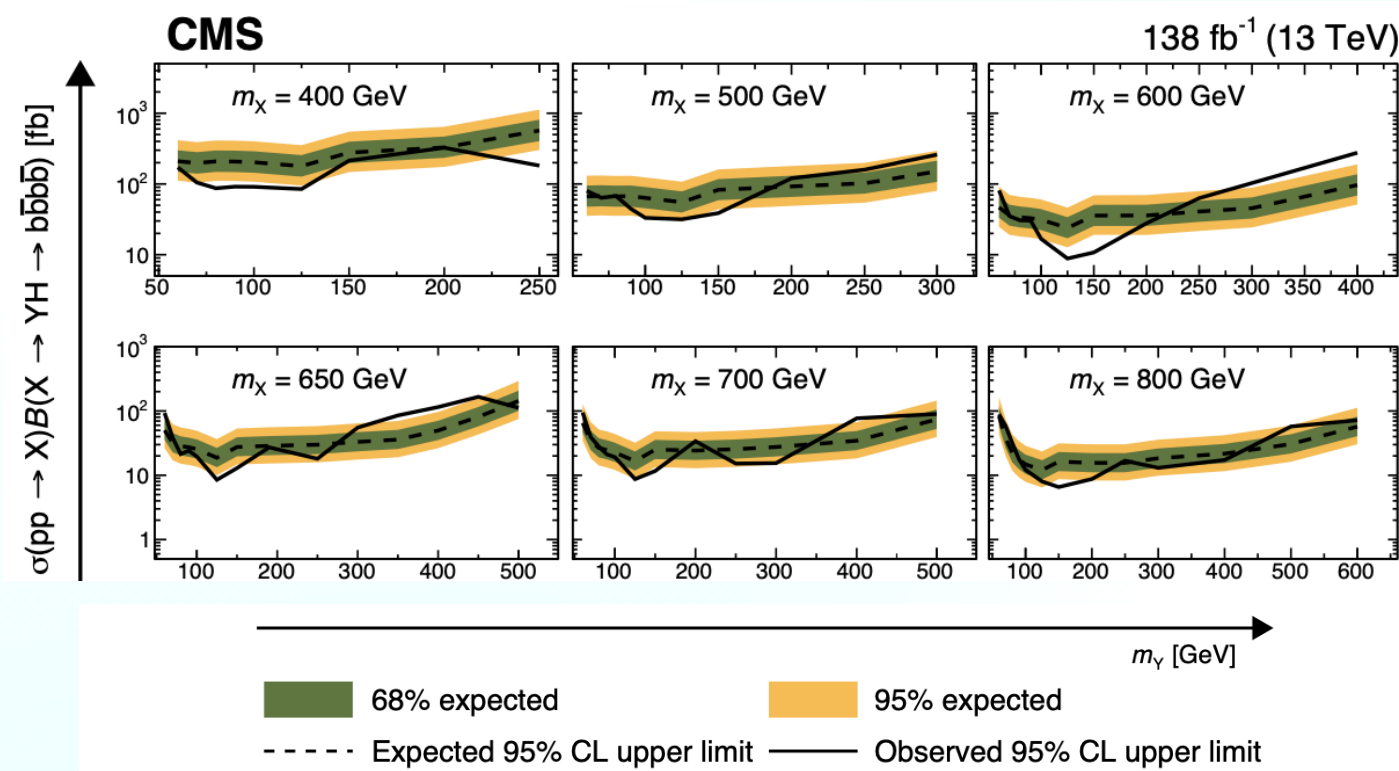


Figure 5: Expected and observed 95% CL upper limits on $\sigma(pp \rightarrow X)B(X \rightarrow YH \rightarrow b\bar{b}b\bar{b})$. The limits are shown as functions of $m_{Y\text{reco}}$ for selected values of $m_{X\text{reco}}$. The black dashed and solid lines represent expected and observed limits, respectively. The dark green and light yellow bands represent the ± 1 and ± 2 standard deviations for the expected limit, respectively. The largest excess (deficit) of the observed limit compared with the expected limit is for $m_{X\text{reco}} = 600$ GeV and $m_{Y\text{reco}} = 400$ GeV ($m_{X\text{reco}} = 600$ GeV and $m_{Y\text{reco}} = 150$ GeV).

CERN-EP-2026-010, arXiv:2605.02848

Supersymmetry

Standard Model of Elementary Particles					
three generations of matter (fermions)			interactions / force carriers (bosons)		
	I	II	III		
mass	$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	0	$\approx 125.09 \text{ GeV}/c^2$
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	1	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
	u up	c charm	t top	g gluon	H higgs
	d down	s strange	b bottom	γ photon	
	e electron	μ muon	τ tau	Z Z boson	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	

超对称变换:

$Q|\text{玻色子}\rangle = |\text{费米子}\rangle$,

$Q|\text{费米子}\rangle = |\text{玻色子}\rangle$

旋量生成元:

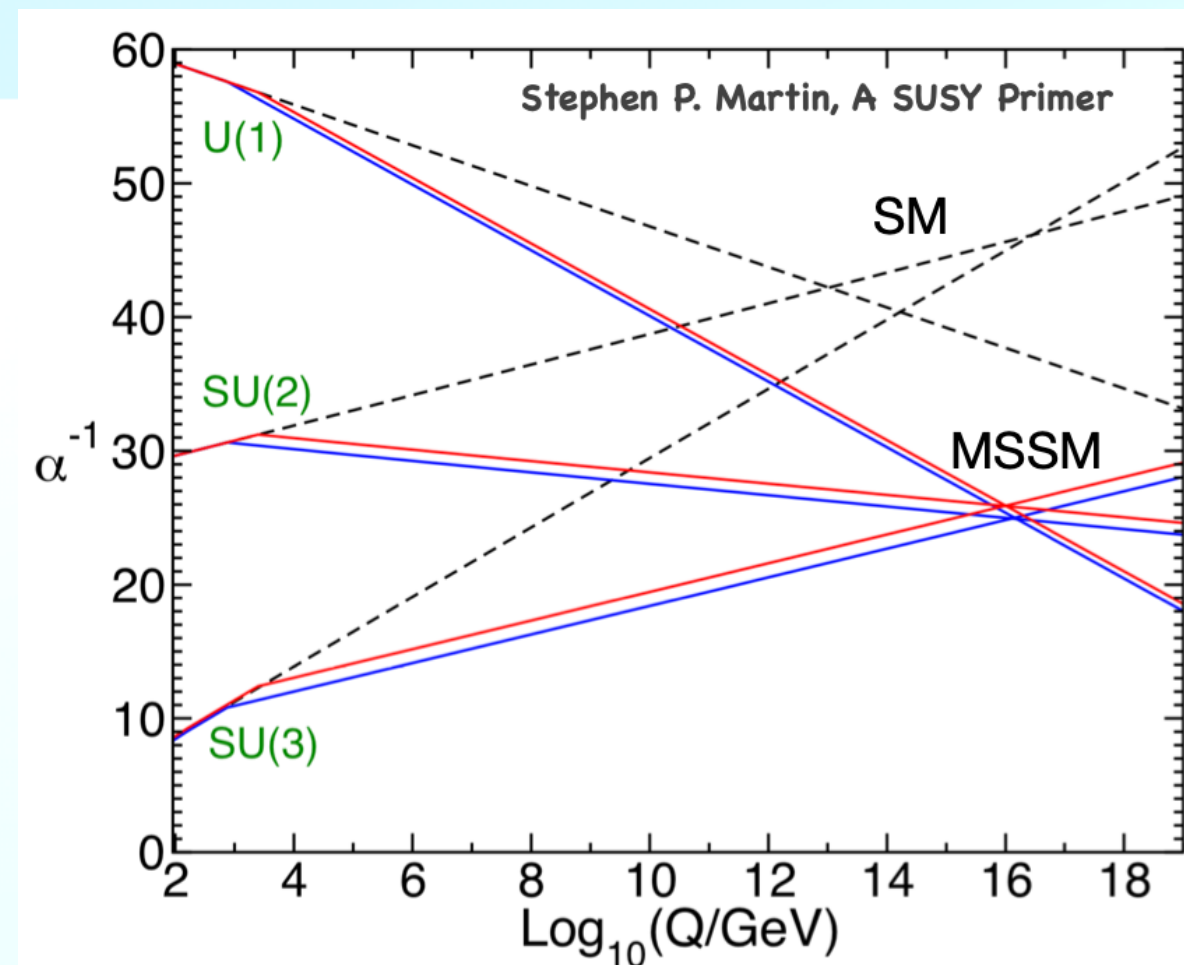
Q_a^i 及其厄米共轭 $Q_a^{\dagger i}$,

构成超庞加莱代数

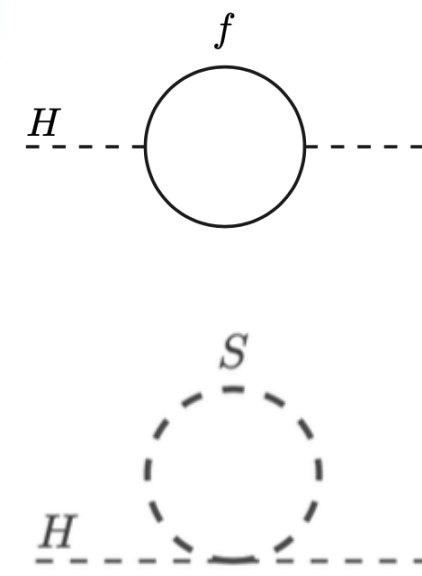
SUSY particles					
ū	c̃	t̃	γ̃	H̃	
đ	s̃	b̃	g̃	Higgsino	
ν̃_e	ν̃_μ	ν̃_τ	z̃		
ẽ	μ̃	τ̃	W̃		

● squarks ● sleptons ● SUSY force particles

Gauge Unification



Natural EW scale



$$m_h^2 = m_0^2 - \delta m_h^2,$$

$$\delta m_h^2 = -\frac{Y_f^2}{8\pi^2} [\Lambda^2 + \dots],$$

$$\mathcal{L}_s = -\lambda_s |H|^2 |S|^2$$

$$\delta m_h^2|_s = \frac{\lambda_s}{16\pi^2} [\Lambda^2 + \dots]$$

DM Candidates

- Collisionless WIMP
- Self-interacting DM
- Asymmetric DM
- Freeze-in DM
- Axion and axino

Can a simple SUSY model explain the scalar resonances and simultaneously provide the correct relic abundance?

General Next-to-Minimal Supersymmetric Standard Model (GNMSSM)

❖ Chiral Superfield

SF	Spin 0	Spin $\frac{1}{2}$	Generations	$(U(1) \otimes SU(2) \otimes SU(3))$
$\hat{q}$	$\tilde{q}$	q	3	$(\frac{1}{6}, \mathbf{2}, \mathbf{3})$
$\hat{l}$	$\tilde{l}$	l	3	$(-\frac{1}{2}, \mathbf{2}, \mathbf{1})$
$\hat{H}_d$	H_d	$\tilde{H}_d$	1	$(-\frac{1}{2}, \mathbf{2}, \mathbf{1})$
$\hat{H}_u$	H_u	$\tilde{H}_u$	1	$(\frac{1}{2}, \mathbf{2}, \mathbf{1})$
$\hat{d}$	$\tilde{d}_R^*$	d_R^*	3	$(\frac{1}{3}, \mathbf{1}, \overline{\mathbf{3}})$
$\hat{u}$	$\tilde{u}_R^*$	u_R^*	3	$(-\frac{2}{3}, \mathbf{1}, \overline{\mathbf{3}})$
$\hat{e}$	$\tilde{e}_R^*$	e_R^*	3	$(1, \mathbf{1}, \mathbf{1})$
$\hat{s}$	S	$\tilde{S}$	1	$(0, \mathbf{1}, \mathbf{1})$

❖ Superpotential — no ad hoc symmetry!

$$W = W_{Yukawa} + \lambda \hat{S} \hat{H}_u \cdot \hat{H}_d + \frac{1}{3} \kappa \hat{s}^3 + \mu \hat{H}_u \cdot \hat{H}_d + \frac{1}{2} \mu' \hat{s}^2 + \xi \hat{S}$$

- $\mathbb{Z}_3$ -violating terms originate from unified theories with $\mathbb{Z}_4^R$.
- The $\xi \hat{S}$ term can be eliminated by field redefinitions.
- Solve domain wall and tapole problem in $\mathbb{Z}_3$ – NMSSM.

DM sector

❖ Neutralino mass matrix in the base $\psi \equiv (\tilde{B}, \tilde{W}, \tilde{H}_d^0, \tilde{H}_u^0, \tilde{S})$

$$\mathcal{M} = \begin{pmatrix} M_1 & 0 & -m_Z \sin \theta_W \cos \beta & m_Z \sin \theta_W \sin \beta & 0 \\ & M_2 & m_Z \cos \theta_W \cos \beta & -m_Z \cos \theta_W \sin \beta & 0 \\ & & 0 & -\mu_{tot} & -\frac{1}{\sqrt{2}} \lambda v \sin \beta \\ & & & 0 & -\frac{1}{\sqrt{2}} \lambda v \cos \beta \\ & & & & m_N \end{pmatrix}$$

with $\mu_{tot} \equiv \lambda v_s / \sqrt{2} + \mu$, $m_N \equiv \sqrt{2} \kappa v_s + \mu'$. Diagonalizing $\mathcal{M}$ gives five mass eigenstates: $\tilde{\chi}_i^0 = N_{i1} \psi_1^0 + N_{i2} \psi_2^0 + N_{i3} \psi_3^0 + N_{i4} \psi_4^0 + N_{i5} \psi_5^0$.

Assuming $\tilde{\chi}_1^0$ LSP as sole DM candidates, $\tilde{\chi}_1^0$ should be $\tilde{S}$ - or $\tilde{B}$ - like to reproduce the correct relic abundance while complying with the stringent direct detection experiments .

DM sector

★ DM annihilation channels:

- $\tilde{S}$ -dominated $\tilde{\chi}_1^0$ ($m_{\tilde{\chi}_1^0} \simeq m_N$)

$$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow h_s A_s, h_s h_s, A_s A_s, \dots;$$

$\tilde{S} - \tilde{H}, \tilde{W}$ coannihilation

- $\tilde{B}$ -dominated $\tilde{\chi}_1^0$ ($m_{\tilde{\chi}_1^0} \simeq M_1$)

A_S -funnel into $h_s A_H$;

$\tilde{B} - \tilde{H}, \tilde{W}$ coannihilation

★ DM-nucleon Scattering cross section:

$$\sigma_{\tilde{\chi}_1^0-N}^{\text{SI}} \simeq 5 \times 10^{-45} \text{cm}^2 \times \left(\frac{V_h^{\text{SM}} C_{\tilde{\chi}_1^0 \tilde{\chi}_1^0 h} + V_{h_s}^{\text{SM}} C_{\tilde{\chi}_1^0 \tilde{\chi}_1^0 h_s}}{0.1} \right)^2,$$

$$C_{\tilde{\chi}_1^0 \tilde{\chi}_1^0 h_i} \simeq \frac{\sqrt{2} \mu_{\text{tot}}}{v} \left(\frac{\lambda v}{\mu_{\text{tot}}} \right)^2 \frac{V_{h_i}^{\text{SM}} (m_{\tilde{\chi}_1^0} / \mu_{\text{tot}} - \sin 2\beta)}{1 - (m_{\tilde{\chi}_1^0} / \mu_{\text{tot}})^2} + \dots,$$

$$\sigma_{\tilde{\chi}_1^0-N}^{\text{SD}} \simeq 10^{-39} \text{cm}^2 \times \left(\frac{C_{\tilde{\chi}_1^0 \tilde{\chi}_1^0 Z}}{0.1} \right)^2,$$

$$C_{\tilde{\chi}_1^0 \tilde{\chi}_1^0 Z} = \frac{m_Z}{\sqrt{2} v} (N_{13}^2 - N_{14}^2) \propto \frac{\cos 2\beta}{1 - (m_{\tilde{\chi}_1^0} / \mu_{\text{tot}})^2},$$

Blind Spot: $m_{\tilde{\chi}_1^0} / \mu_{\text{tot}} \approx \sin 2\beta$ for SI; $\cos 2\beta$ vanishes when $\tan \beta \approx 1$ for SD.

Higgs sector

★ Soft-breaking terms:

$$-\mathcal{L}_{soft} = \left[\lambda A_\lambda S H_u \cdot H_d + \frac{1}{3} \kappa A_\kappa S^3 + m_3^2 H_u \cdot H_d + \frac{1}{2} m_S'^2 S^2 + \xi' S + h.c. \right] + m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 + m_S^2 |S|^2,$$

★ CP-even Squared Mass Matrix in $(H_{NSM}, H_{SM}, \text{Re}[S])$ with $H_{NSM} = \sqrt{2} \text{Re}(\cos \beta H_u^0 - \sin \beta H_d^0)$, $H_{SM} = \sqrt{2} \text{Re}(\sin \beta H_u^0 + \cos \beta H_d^0)$,

$$\mathcal{M}_{S,11}^2 = m_A^2 + \frac{1}{2} (2m_Z^2 - \lambda^2 v^2) \sin^2 2\beta,$$

$$\mathcal{M}_{S,12}^2 = -\frac{1}{4} (2m_Z^2 - \lambda^2 v^2) \sin 4\beta,$$

$$\mathcal{M}_{S,13}^2 = \sqrt{2} \lambda \mu_{tot} v (\delta - 1) \cot 2\beta,$$

$$\mathcal{M}_{S,22}^2 = m_Z^2 \cos^2 2\beta + \frac{1}{2} \lambda^2 v^2 \sin^2 2\beta,$$

$$\mathcal{M}_{S,23}^2 = \sqrt{2} \lambda \mu_{tot} v \delta,$$

$$\mathcal{M}_{S,33}^2 = m_B^2,$$

$$h_i = V_{h_i}^{NSM} H_{NSM} + V_{h_i}^{SM} H_{SM} + V_{h_i}^S \text{Re}[S]$$

CP odd Mass Matrix in $(A_{NSM}, \text{Im}[S])$ with $A_{NSM} = \sqrt{2} \text{Im}(\cos \beta H_u^0 + \sin \beta H_d^0)$:

$$\mathcal{M}_{P,11}^2 = m_A^2, \quad \mathcal{M}_{P,22}^2 = M_C^2, \quad \mathcal{M}_{P,12}^2 = \frac{\lambda v}{\sqrt{2}} (A_\lambda - m_N),$$

S field mixing factor : $\delta = 1 - \frac{A_\lambda + m_N}{2\mu} \sin 2\beta,$

Parameters in terms of masses : $m_3^2 = F(m_A^2)$ $A_\kappa = F(m_B^2)$ $\mu' = F(m_C^2)$
 $(m_C = 800 \text{ GeV})$

3 CP-even Scalars: h_s, h, H ; 2 CP-odd Scalars: A_S, A_H ;
 and a pair of charged scalars: $H^\pm$.

h_s — 95.4 GeV CP-even Scalar

1. Normalized $\gamma\gamma$ signal strength

$$\mu_{\gamma\gamma} = \frac{\sigma_{\text{SUSY}}(pp \rightarrow h_s)}{\sigma_{\text{SM}}(pp \rightarrow h_s)} \times \frac{\text{Br}_{\text{SUSY}}(h_s \rightarrow \gamma\gamma)}{\text{Br}_{\text{SM}}(h_s \rightarrow \gamma\gamma)} \simeq |C_{h_s gg}|^2 \times |C_{h_s \gamma\gamma}|^2 \times R_{\text{Width}},$$

2. Normalized $b\bar{b}$ signal strength

$$\mu_{b\bar{b}} = \frac{\sigma_{\text{SUSY}}(e^+e^- \rightarrow Zh_s)}{\sigma_{\text{SM}}(e^+e^- \rightarrow Zh_s)} \times \frac{\text{Br}_{\text{SUSY}}(h_s \rightarrow b\bar{b})}{\text{Br}_{\text{SM}}(h_s \rightarrow b\bar{b})} \simeq |C_{h_s VV}|^2 \times |C_{h_s b\bar{b}}|^2 \times R_{\text{Width}},$$

$$1/R_{\text{Width}} \simeq 0.801 \times |C_{h_s b\bar{b}}|^2 + 0.083 \times |C_{h_s \tau\bar{\tau}}|^2 + 0.041 \times |C_{h_s c\bar{c}}|^2 + 0.067 \times |C_{h_s g\bar{g}}|^2 + \dots$$

h_s — 95.4 GeV CP-even Scalar

Tree level normalized couplings:

$$C_{h_s t\bar{t}} = V_{h_s}^{\text{SM}} + V_{h_s}^{\text{NSM}} \cot \beta \simeq V_{h_s}^{\text{SM}}, \quad C_{h_s b\bar{b}} = V_{h_s}^{\text{SM}} - V_{h_s}^{\text{NSM}} \tan \beta, \quad C_{h_s VV} = V_{h_s}^{\text{SM}},$$
$$C_{h_s c\bar{c}} = C_{h_s t\bar{t}}, \quad C_{h_s \tau\bar{\tau}} = C_{h_s b\bar{b}}, \quad C_{h_s gg} \simeq C_{h_s t\bar{t}}, \quad C_{h_s \gamma\gamma} \simeq V_{h_s}^{\text{SM}},$$

Considering loop mediated by quarks and squarks:

$C_{h_s gg}$ and $C_{h_s \gamma\gamma}$ deviates from $C_{h_s t\bar{t}}$ by 4% and 11%;

Contributions from charginos and charged Higgs to $C_{h_s \gamma\gamma}$ are not crucial

Central values of $\mu_{\gamma\gamma}$ and $\mu_{b\bar{b}}$ correspond to:

$$V_{h_s}^{\text{SM}} \simeq 0.35, \quad (V_{h_s}^{\text{SM}} - V_{h_s}^{\text{NSM}} \tan \beta) \simeq 0.81 \times V_{h_s}^{\text{SM}} \simeq 0.28,$$

$$\text{Br}_{\text{SUSY}}(h_s \rightarrow \gamma\gamma) \simeq 1.77 \times \text{Br}_{\text{SM}}(h_s \rightarrow \gamma\gamma) \simeq 2.5 \times 10^{-3},$$

$$\text{Br}_{\text{SUSY}}(h_s \rightarrow b\bar{b}) \simeq 0.95 \times \text{Br}_{\text{SM}}(h_s \rightarrow b\bar{b}) \simeq 76.1 \%,$$

h_s — 95.4 GeV CP-even Scalar

Using eigenstate equations in the limit $m_{h_s,h} \ll m_A$:

$$V_{h_s}^{\text{NSM}} \simeq \frac{V_{h_s}^S}{\sqrt{2}} \times \frac{\lambda v \bar{A}_\lambda \cos 2\beta}{m_A^2}, \quad \lambda (\mu_{\text{tot}} - \bar{A}_\lambda \sin \beta \cos \beta) \simeq \frac{V_{h_s}^{\text{SM}} V_{h_s}^S}{\sqrt{2}} \times \frac{m_{h_s}^2 - m_h^2}{v},$$

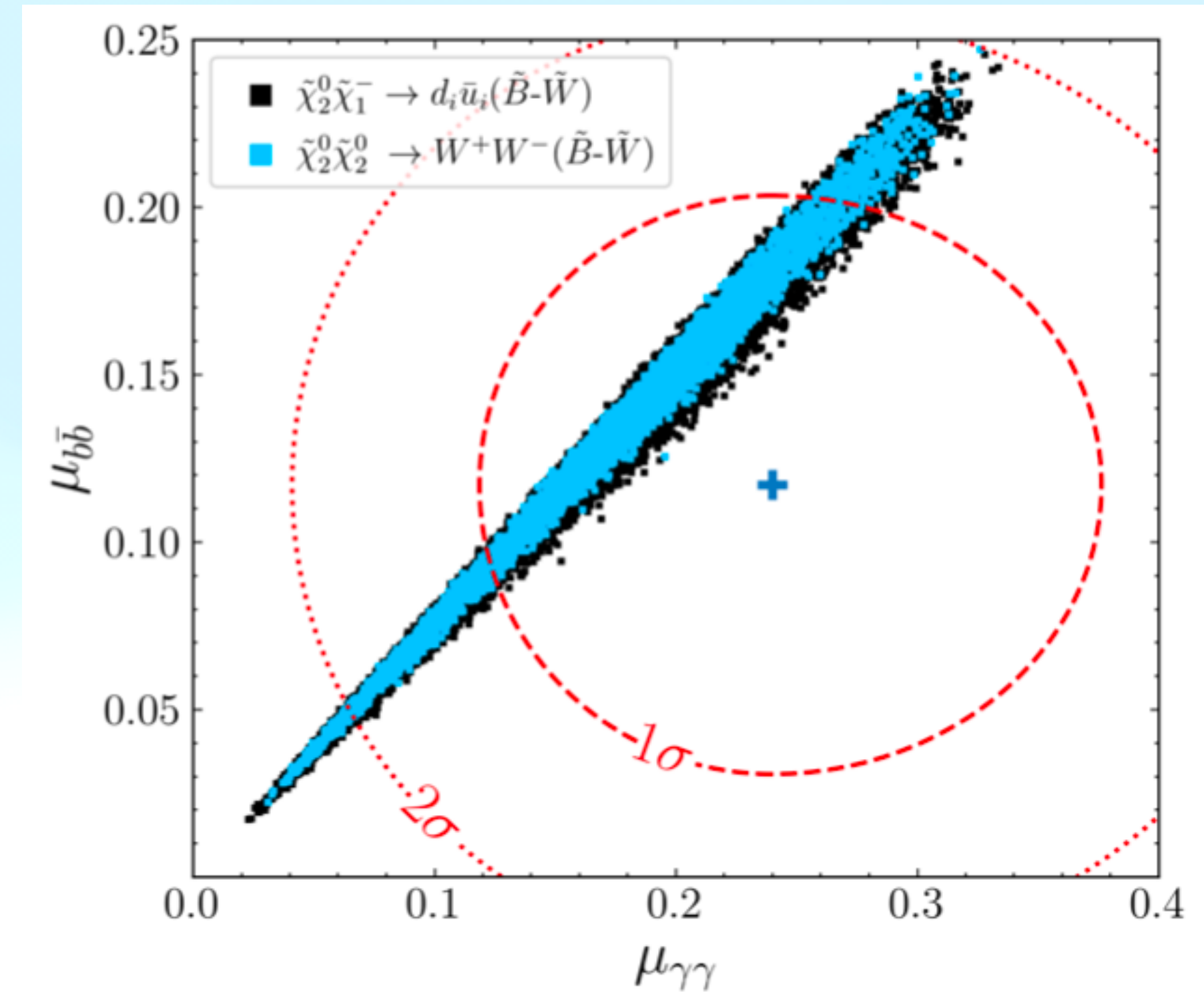
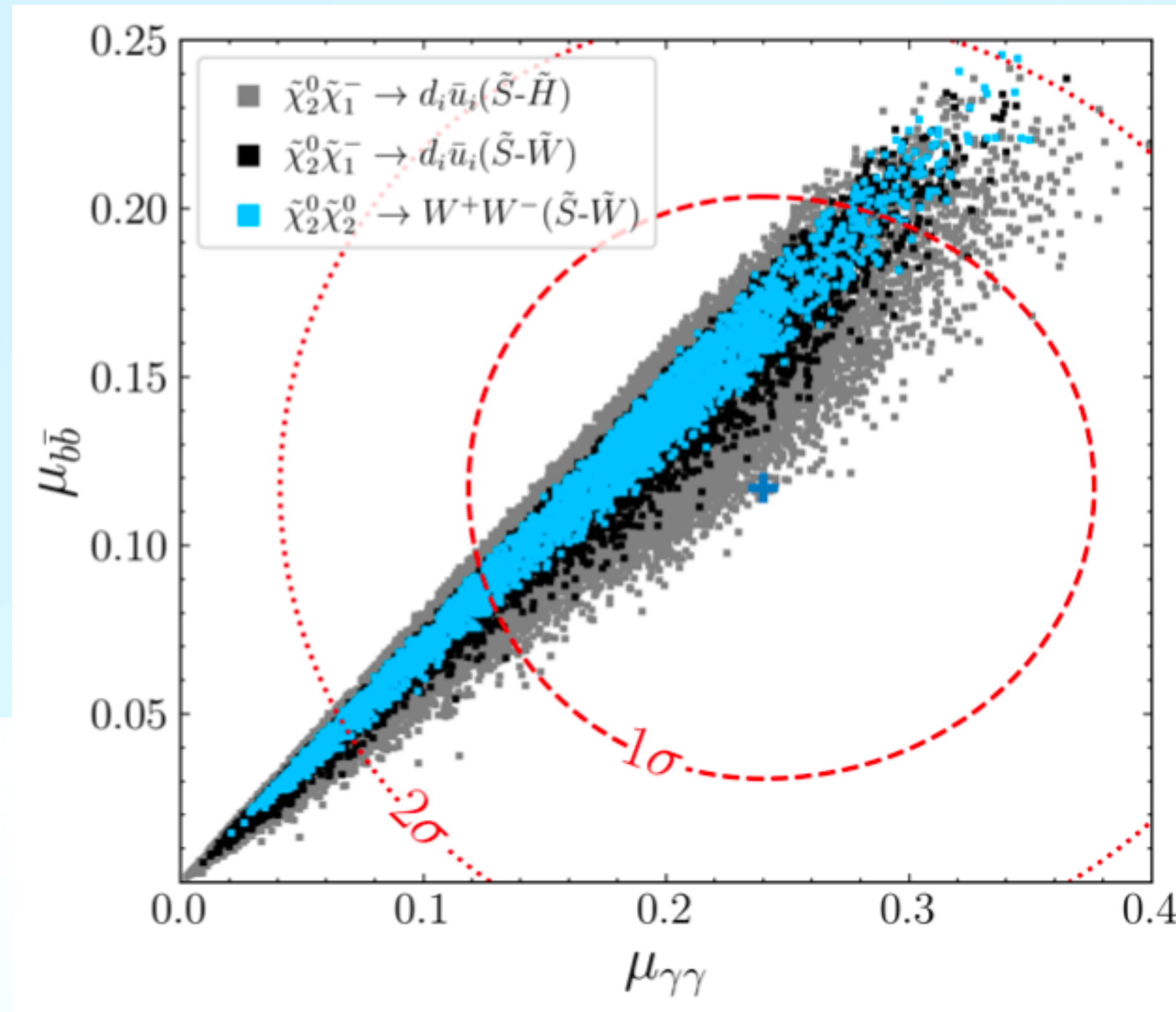
$$m_B^2 \simeq m_{h_s}^2 |V_{h_s}^S|^2 + m_h^2 |V_{h_s}^{\text{SM}}|^2, \quad \mathcal{M}_{S,22}^2 \simeq m_h^2 |V_{h_s}^S|^2 + m_{h_s}^2 |V_{h_s}^{\text{SM}}|^2,$$

with $\bar{A}_\lambda \equiv A_\lambda + m_N$. This implies that

$$\lambda \simeq 0.06 \times \left(\frac{V_{h_s}^{\text{SM}}}{0.35} \right) \times \left(\frac{\mu_{\text{tot}} - \bar{A}_\lambda \sin \beta \cos \beta}{100 \text{ GeV}} \right)^{-1},$$

$$\lambda \gtrsim 0.017 \times \frac{1}{|\cos 2\beta|} \times \left(\frac{\tan \beta}{50} \right)^{-1} \times \left(\frac{\bar{A}_\lambda}{2 \text{ TeV}} \right)^{-1} \times \left(\frac{m_A}{2 \text{ TeV}} \right)^2,$$

Explanation of $\gamma\gamma$ and $b\bar{b}$ excesses near 95.4 GeV



- Bayesian evidence: $\tilde{S}$ -like $\tilde{\chi}_1^0$, coannihilating with $\tilde{H}$, 53%, $\chi^2_{\gamma\gamma+b\bar{b}} \simeq 0.0$
 $\tilde{B}$ -like $\tilde{\chi}_1^0$, coannihilating with $\tilde{W}$, 47%, $\chi^2_{\gamma\gamma+b\bar{b}} \simeq 0.27$

Scalar Resonances near 95.4 and 650 GeV

- **The cross section of $gg \rightarrow H \rightarrow h(\gamma\gamma) + h_s(b\bar{b})$ in the GNMSSM:**

$$\sigma_{\gamma\gamma b\bar{b}} = \sigma(gg \rightarrow H) \times \text{Br}_{\text{SUSY}}(H \rightarrow hh_s) \times \text{Br}_{\text{SUSY}}(h \rightarrow \gamma\gamma) \times \text{Br}_{\text{SUSY}}(h_s \rightarrow b\bar{b}),$$

- Light scalar (h_s): singlet-like CP-even boson with mass of 95.4 ± 1 GeV ;
- SM-like Higgs (h): the Higgs boson discovered at LHC with mass of 125 ± 3 GeV
- Heavy scalar (H): doublet-like CP-even boson with mass of 650 ± 25 GeV.

- **The χ^2 function:**

$$\chi_{650+95}^2 = \left(\frac{\sigma_{\gamma\gamma b\bar{b}} - 0.35}{0.13} \right)^2 + \left(\frac{\mu_{\gamma\gamma} - 0.24}{0.08} \right)^2 + \left(\frac{\mu_{b\bar{b}} - 0.117}{0.057} \right)^2$$

Scalar Resonances near 95.4 and 650 GeV

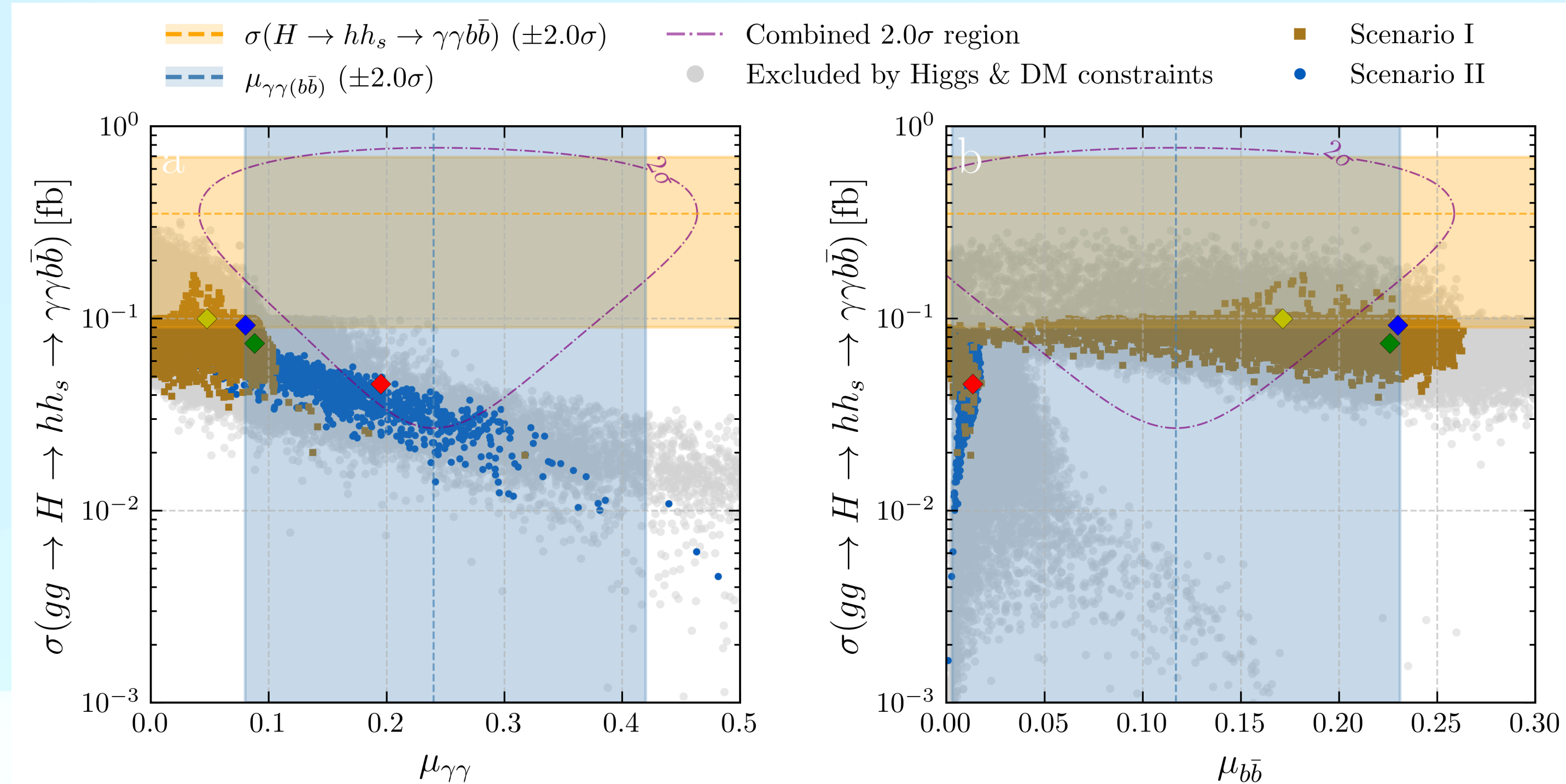
$$\mathcal{L} = \exp\left(\frac{1}{2}\chi_{650+95}^2\right) \times \mathcal{L}_{\text{Res}}$$

The required restrictions include:

- ▶ **Higgs data fit** using *HiggsSignals-2.6.2*
- ▶ **Extra Higgs searches** using *HiggsBounds-5.10.2*
- ▶ **DM relic density:** 20% uncertainties of $\Omega h^2 = 0.120$
- ▶ **DM-nucleon scattering cross sections:** LZ-2025
- ▶ **B physics observables:** $B_s \rightarrow \mu^+ \mu^-$ and $B \rightarrow X_s \gamma$
- ▶ **Vacuum stability** using *Vevacious++*
- ▶ **Electroweak precision observables:** S,T,U

Parameter	Prior	Range
$\mu_{\text{tot}}/\text{TeV}$	Flat	$0.5 \sim 1.0$
$\mu_{\text{eff}}/\text{TeV}$	Flat	$-1.0 \sim 1.0$
m_A/TeV	Flat	$0.50 \sim 0.65$
m_B/TeV	Flat	$0.09 \sim 0.12$
m_N/TeV	Flat	$-1.0 \sim 1.0$
A_t/TeV	Flat	$1.0 \sim 3.0$
M_1/TeV	Flat	$-1.0 \sim -0.2$
M_2/TeV	Flat	$0.2 \sim 1.0$
λ	Flat	$0.5 \sim 0.7$
κ	Flat	$-0.5 \sim 0.5$
δ	Flat	$-0.05 \sim 0.05$
$\tan \beta$	Flat	$1.0 \sim 2.0$

Scalar Resonances near 95.4 and 650 GeV



◆ **Scenario I** ($\approx 92\%$):

A_s funnel annihilation or coannihilation with $\tilde{S}$ -like $\tilde{\chi}_2^0$ s, typically into the $h_s A_H$ final state.

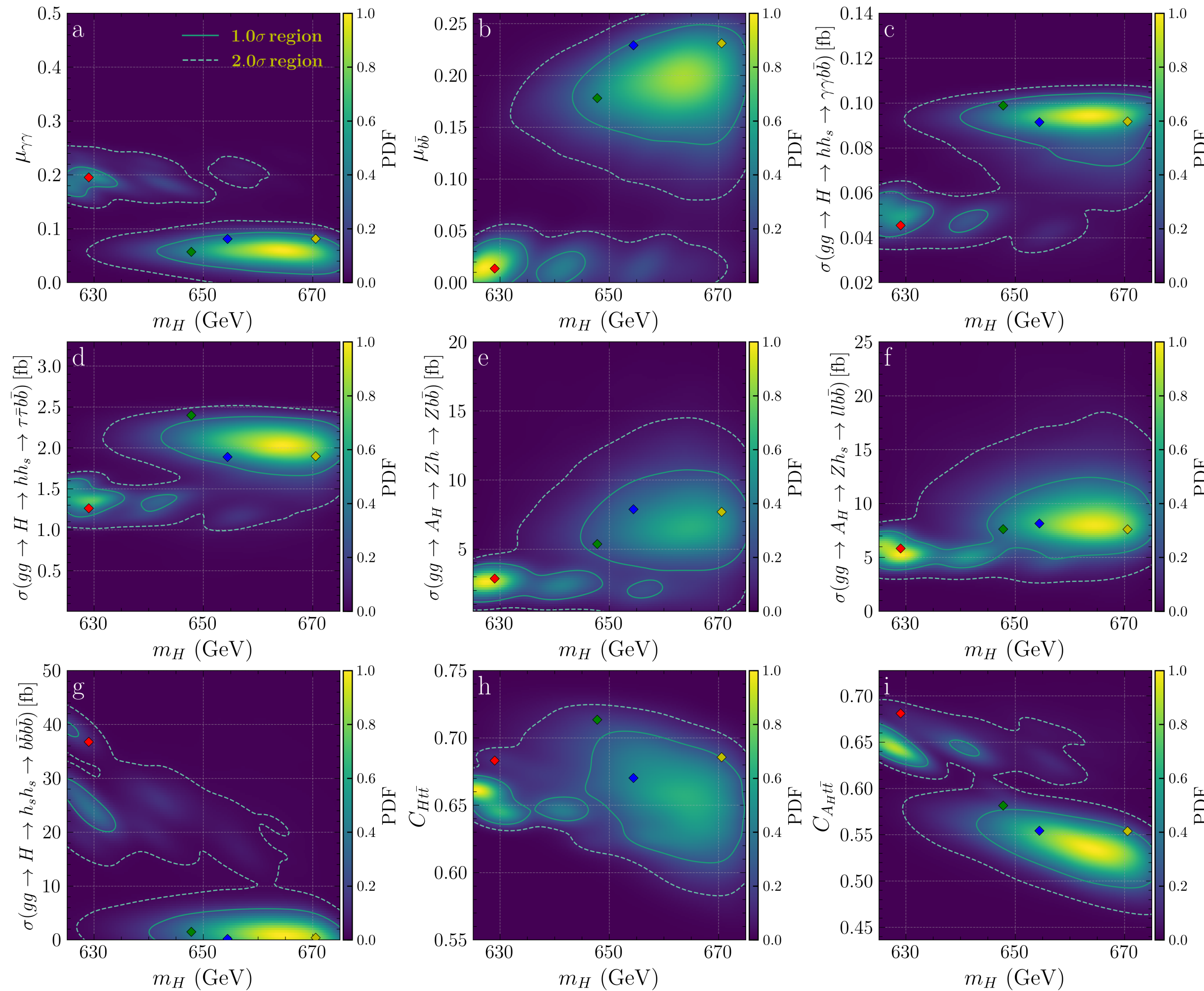
A few points can interpret the $\sigma_{\gamma\gamma b\bar{b}}$ and $\mu_{\gamma\gamma}$ and $\mu_{b\bar{b}}$ excesses at the 2σ level at the same time.

◆ **Scenario II** ($\approx 8\%$):

coannihilation with $\tilde{H}$ -like $\tilde{\chi}_2^0$ s or $\tilde{\chi}_1^\pm$ s, favoring the $h_s A_s$ final state.

$\sigma_{\gamma\gamma b\bar{b}}$ can reach at most 0.08 fb. It can achieve an overall 2σ fit when combining the $\sigma_{\gamma\gamma b\bar{b}}$ and μ_{rr} excess, i.e., $\chi_{\sigma_{\gamma\gamma b\bar{b}}}^2 + \chi_{\mu_{rr}}^2 \leq 6.18$

Scalar Resonances near 95.4 and 650 GeV



◆ **Scenario I** ($\approx 68\%$ Bayesian evidence):

$$640 \text{ GeV} \lesssim m_H \lesssim 675 \text{ GeV}$$

$$0.02 \lesssim \mu_{\gamma\gamma} \lesssim 0.09, \quad 0.14 \lesssim \mu_{b\bar{b}} \lesssim 0.25,$$

$$0.07 \text{ fb} \lesssim \sigma(gg \rightarrow H \rightarrow hh_s \rightarrow \gamma\gamma b\bar{b}) \lesssim 0.105 \text{ fb}$$

$$C_{A_H t\bar{t}} \lesssim 0.60$$

◆ **Scenario II** ($\approx 23\%$ Bayesian evidence):

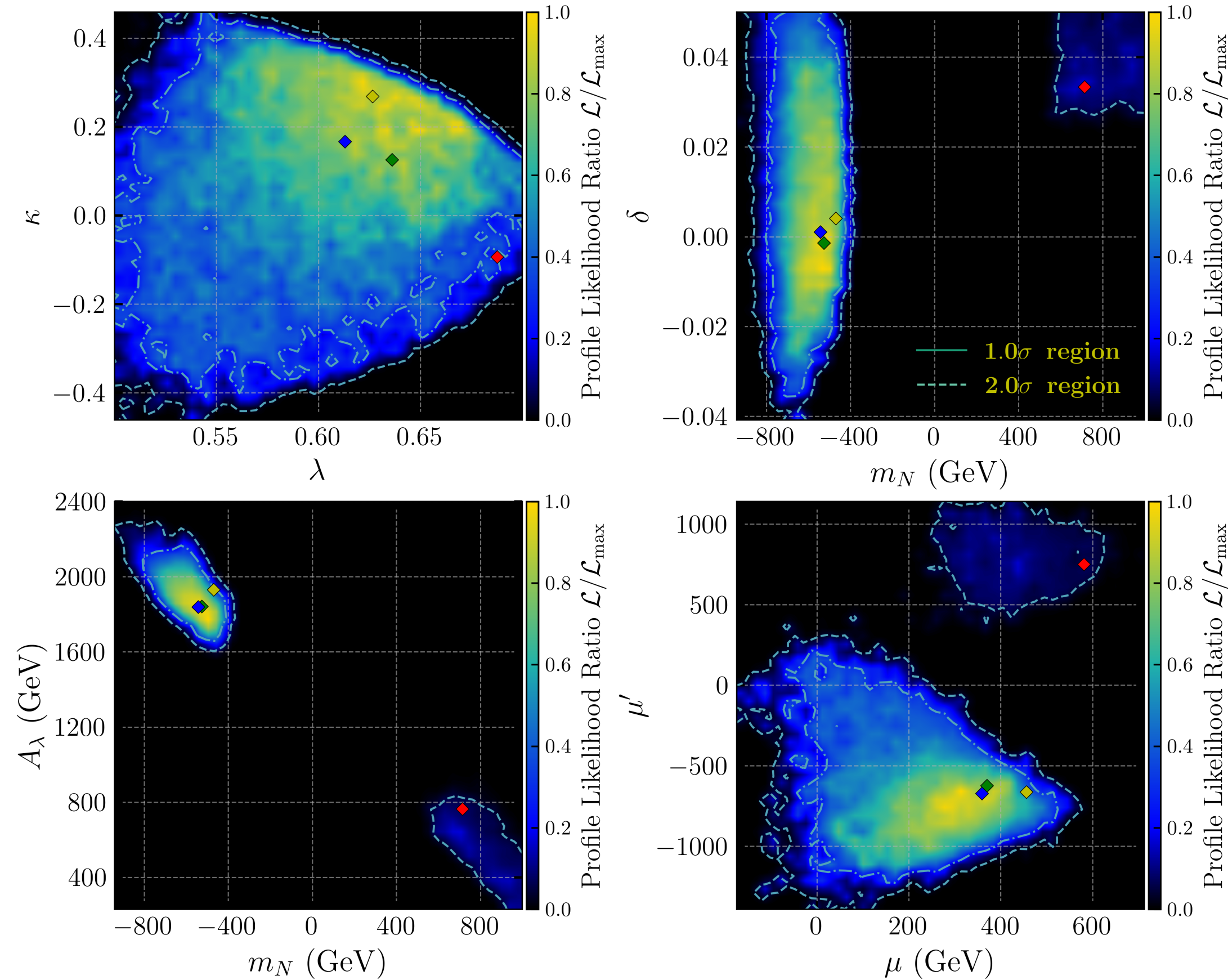
$$625 \text{ GeV} \lesssim m_H \lesssim 640 \text{ GeV}$$

$$0.16 \lesssim \mu_{\gamma\gamma} \lesssim 0.21, \quad 0.0 \lesssim \mu_{b\bar{b}} \lesssim 0.04,$$

$$0.04 \text{ fb} \lesssim \sigma(gg \rightarrow H \rightarrow hh_s \rightarrow \gamma\gamma b\bar{b}) \lesssim 0.06 \text{ fb}$$

$$C_{A_H t\bar{t}} \gtrsim 0.60$$

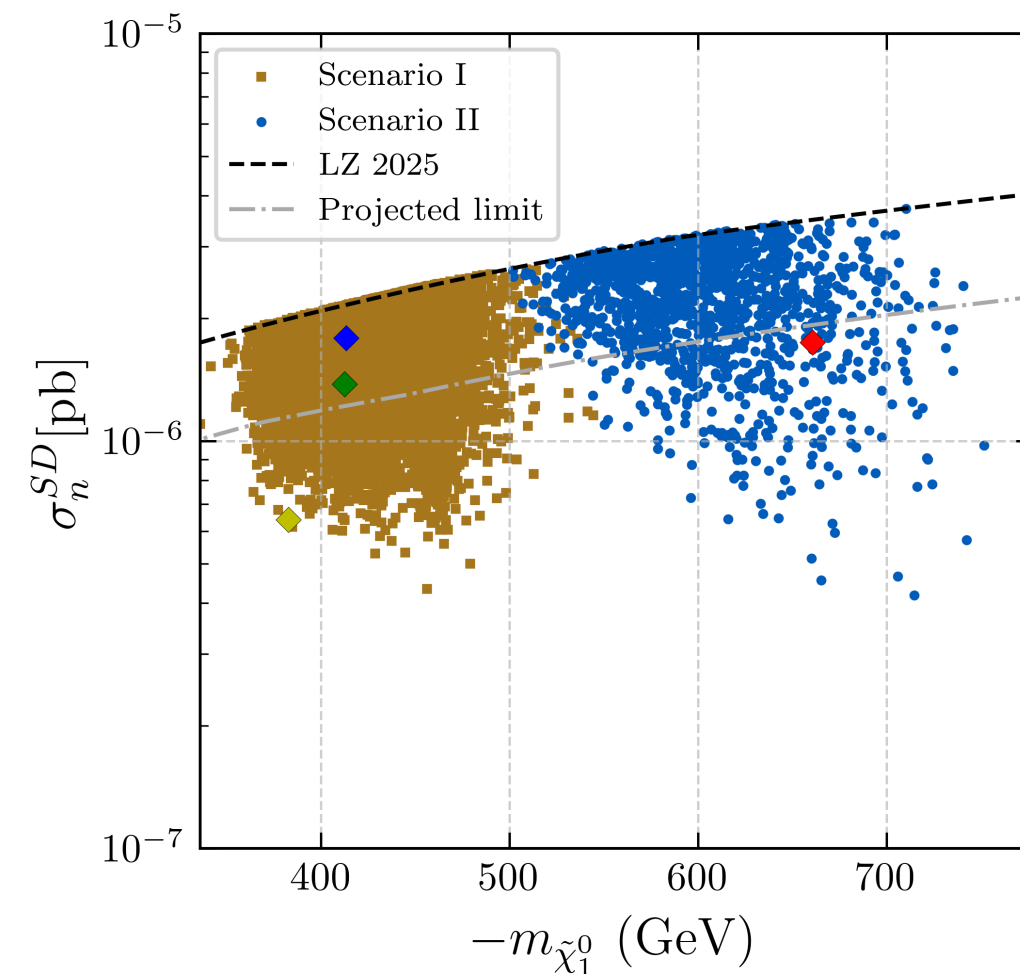
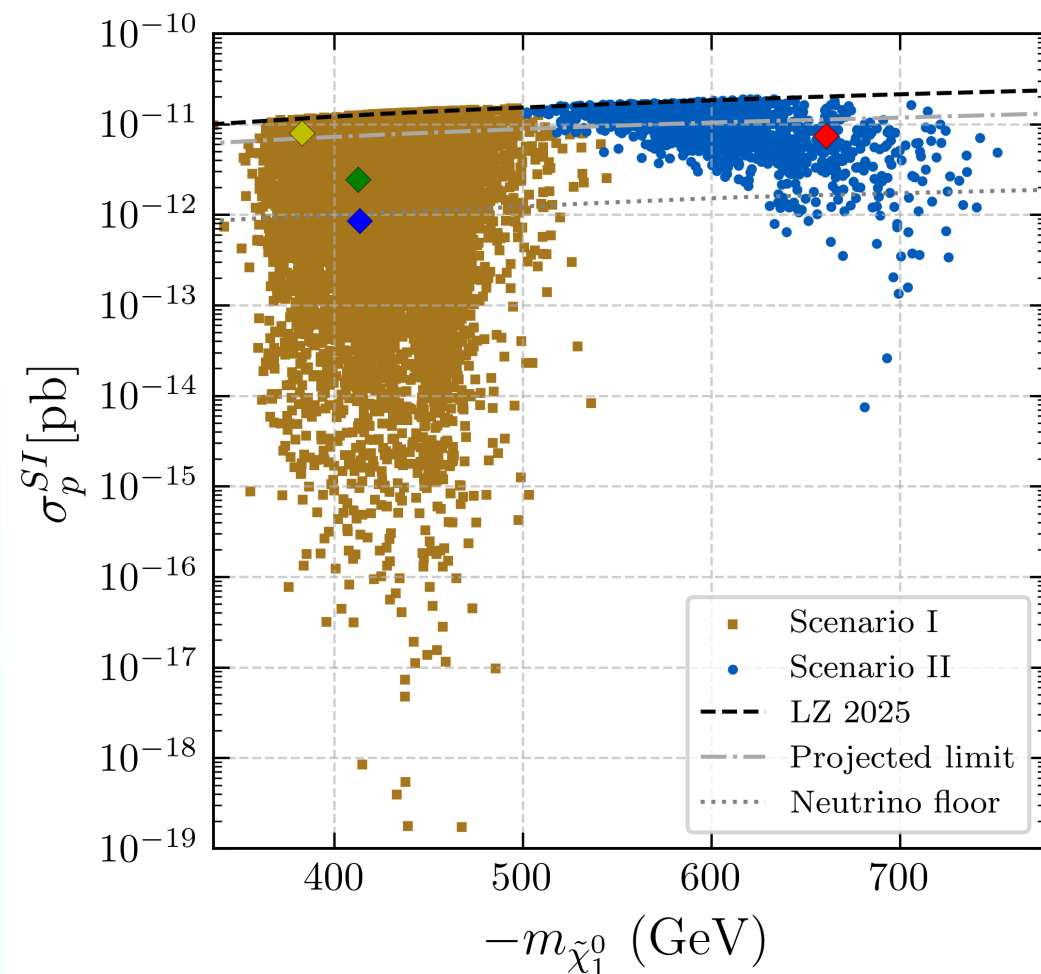
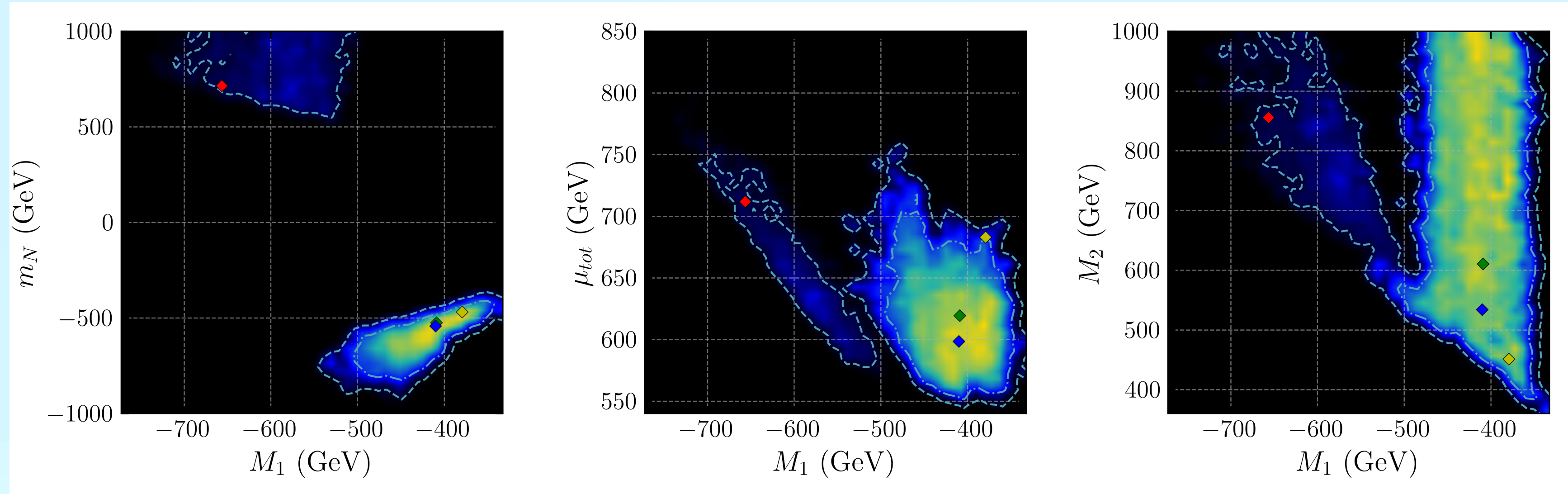
Scalar Resonances near 95.4 and 650 GeV



Two-dimensional PL functions projection

- ◆ Best point yields a combined value of $\chi^2_{650+95} + \chi^2_{125} \simeq 162$.
- ◆ prefers relatively large and positive λ, κ .
- ◆ The behavior in (A_λ, m_N) follows $A_\lambda + m_N \simeq 2\mu_{tot}$ given $\tan \beta \simeq 1.6$ to keep δ small enough.
- ◆ **Scenario I:**
 $m_N \lesssim -390 \text{ GeV}, \quad A_\lambda \gtrsim 1600 \text{ GeV}, \quad \mu' \lesssim 400 \text{ GeV}$
- ◆ **Scenario II:**
 $m_N \gtrsim 550 \text{ GeV}, \quad A_\lambda \lesssim 800 \text{ GeV}, \quad \mu' \gtrsim 500 \text{ GeV}$

Scalar Resonances near 95.4 and 650 GeV



◆ Scenario I:

$$-500 \text{ GeV} \lesssim M_1 \lesssim -300 \text{ GeV},$$

s -channel $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow h_s A_H$ enhanced when $2m_{\tilde{\chi}_1^0} \simeq m_{A_s} \simeq 800 \text{ GeV}$,
or coannihilation with $\tilde{S}$ via $\tilde{\chi}_2^0 \tilde{\chi}_2^0, \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow h_s A_H$,

◆ Scenario II:

$$M_1 \lesssim -500 \text{ GeV},$$

coannihilation with $\tilde{H}$ via $\tilde{\chi}_1^+ \tilde{\chi}_1^-, \tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow h_s A_s, \tilde{\chi}_1^+ \tilde{\chi}_2^0 \rightarrow u\bar{d}, h_s W^+$,

Conclusion

- The singlet-like scalar h_s in the GNMSSM can simultaneously account for the $\gamma\gamma$ and $b\bar{b}$ excesses at a 1σ level without conflicting with all other constraints. DM physics significantly influences the unified explanation and favors $\tilde{S}$ -like DM case.
- The heavy scalar H near 650 GeV decaying into h and h_s can also account for the observed $\gamma\gamma b\bar{b}$ signal at a 2σ level, characterized by small $\tan\beta$ and large λ , which is theoretically well-motivated for elevating the mass of the 125 GeV Higgs boson h .
- The unified interpretation prefers a $\tilde{B}$ -like $\tilde{\chi}_1^0$ DM. The measured relic density is achieved mainly through A_s funnel annihilation or coannihilation with $\tilde{S}$ -like $\tilde{\chi}_2^0$ s.
- Future colliders experiments, e.g. HL-LHC, ILC and CEPC, are worth looking forward to.

THANKS! 敬请各位专家批评指正