CLHCP2024, Qingdao, Nov 13-17, 2024

河南大學

Henan University

Probing 2HDM-I light Higgs in the top-pair-associated diphoton channel

Yabo Dong (董亚博)

Based on arXiv:2410.13636

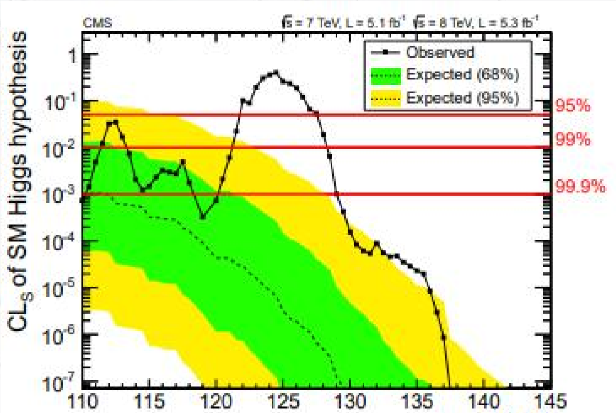
on behalf of Dr. Kun Wang and Prof. Jingya Zhu

CONTENTS

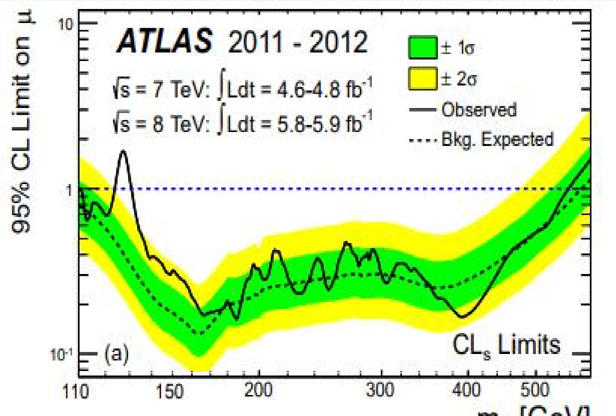
Background and motivation

Higgs discovered

the discover of 125 GeV Higgs at 5σ

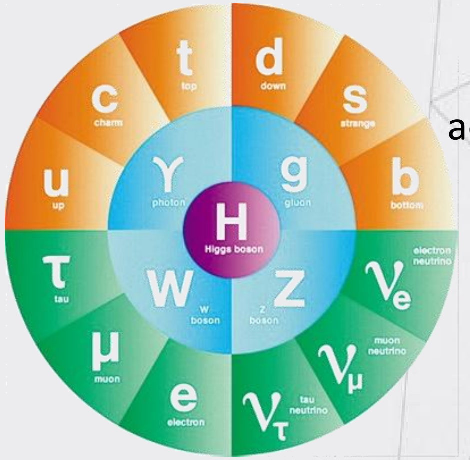


arXiv:1207.7235



arXiv:1207.7214

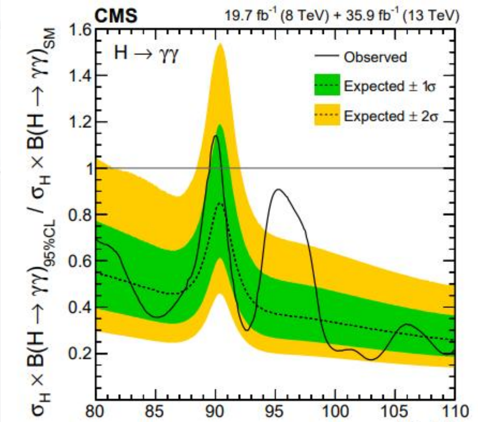
add the final piece



additional scalars ?

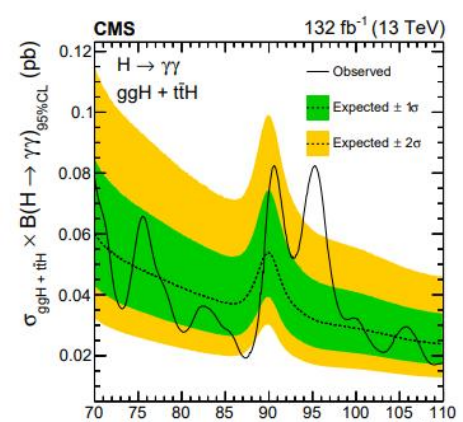
Recent signal excess

2.8σ diphoton excess near 95.3 GeV



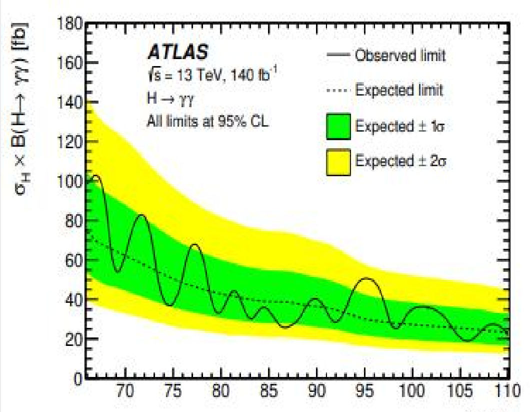
arXiv:1811.08459

2.9σ (95.4 GeV)



arXiv:2405.18149

1.7σ (95.4 GeV)

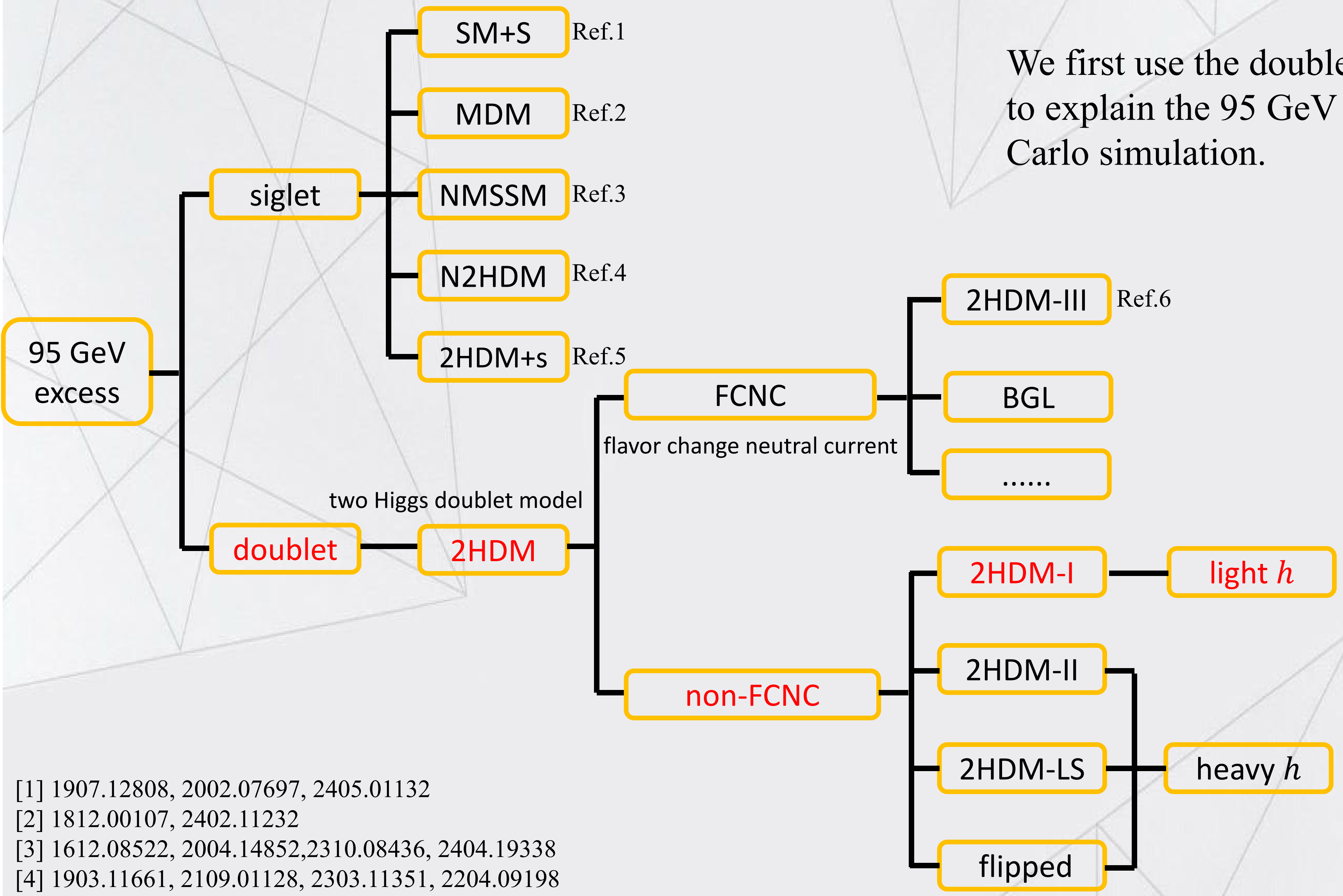


arXiv:2407.07546

imply the existence

new physic?

Background and motivation



We first use the doublet scalar of non-FCNC 2HDM-I to explain the 95 GeV excess and do relevant Monte Carlo simulation.

top-pair-associated ?

Reason 1

$pp \to t\bar{t}h$ — depress → Backgrounds

Z (91GeV)

	$X = Z$ [fb]	$X = h$ [fb]
$pp \to X$	4.6×10^{7}	8.2×10^{4}
$pp \to X(\to \gamma\gamma)$	6.7×10^{2}	1.2×10^{2}
$pp \to t\bar{t}X$	7.1×10^{2}	1.3×10^{3}
$pp \to t\bar{t}X(\to \gamma\gamma)$	1.0×10^{-2}	2.0×10^{0}

Reason 2

SM-like Higgs — confirmed → $pp \to t\bar{t}H$

[1] 1907.12808, 2002.07697, 2405.01132
[2] 1812.00107, 2402.11232
[3] 1612.08522, 2004.14852,2310.08436, 2404.19338
[4] 1903.11661, 2109.01128, 2303.11351, 2204.09198
[5] 2112.11958, 2108.10864, 2306.03889, 2303.12018
[6] 2405.02899, 2306.09029
[7] 1001.1759, 1106.0034, 1706.07414, 2111.06712

THDM-I and Parameter scan

Scalar potential

$$V(\Phi_1,\Phi_2) = m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 - m_{12}^2(\Phi_1^\dagger\Phi_2 + h.c.) + \frac{\lambda_1}{2}(\Phi_1^\dagger\Phi_1)^2 + \frac{\lambda_2}{2}(\Phi_2^\dagger\Phi_2)^2 + \lambda_3\Phi_1^\dagger\Phi_1\Phi_2^\dagger\Phi_2 + \lambda_4\Phi_1^\dagger\Phi_2\Phi_2^\dagger\Phi_1 + \frac{\lambda_5}{2}[(\Phi_1^\dagger\Phi_2)^2 + h.c.]$$

$$m_{11}, m_{22}, m_{12}, \lambda_i (i = 1, 2, 3, 4, 5)$$

Electroweak symmetry breaking

$$\alpha, tan\beta, m_{12}, m_A, m_h, m_H, m_{H^\pm}$$

two neutral Higgs mixing angle and the ratio of VEV

charged Higgs mass

mass parameter

pseudoscalar mass

neutral Higgs mass

Lagrange of 2HDM-I

$$\mathcal{L} = -\sum_{f=u,d,e}\frac{m_f}{v}(\xi_h^f\bar{f}fh + \xi_H^f\bar{f}fH - i\xi_A^f\bar{f}fA)$$

$$-\left\{\frac{\sqrt{2}V_{ud}}{v}\bar{u}(m_u\xi_A^u P_L + m_d\xi_A^d P_R)dH^+ + \frac{\sqrt{2}m_\ell\xi_A^\ell}{v}\bar{v}_L\ell_R H^+ + h.c.\right\}$$

Interesting part

Coupling of Higgs to bosons

$$C_{hVV} = C_{hVV}^{SM} \times sin(\alpha - \beta),$$
$$C_{HVV} = C_{HVV}^{SM} \times cos(\alpha - \beta)$$

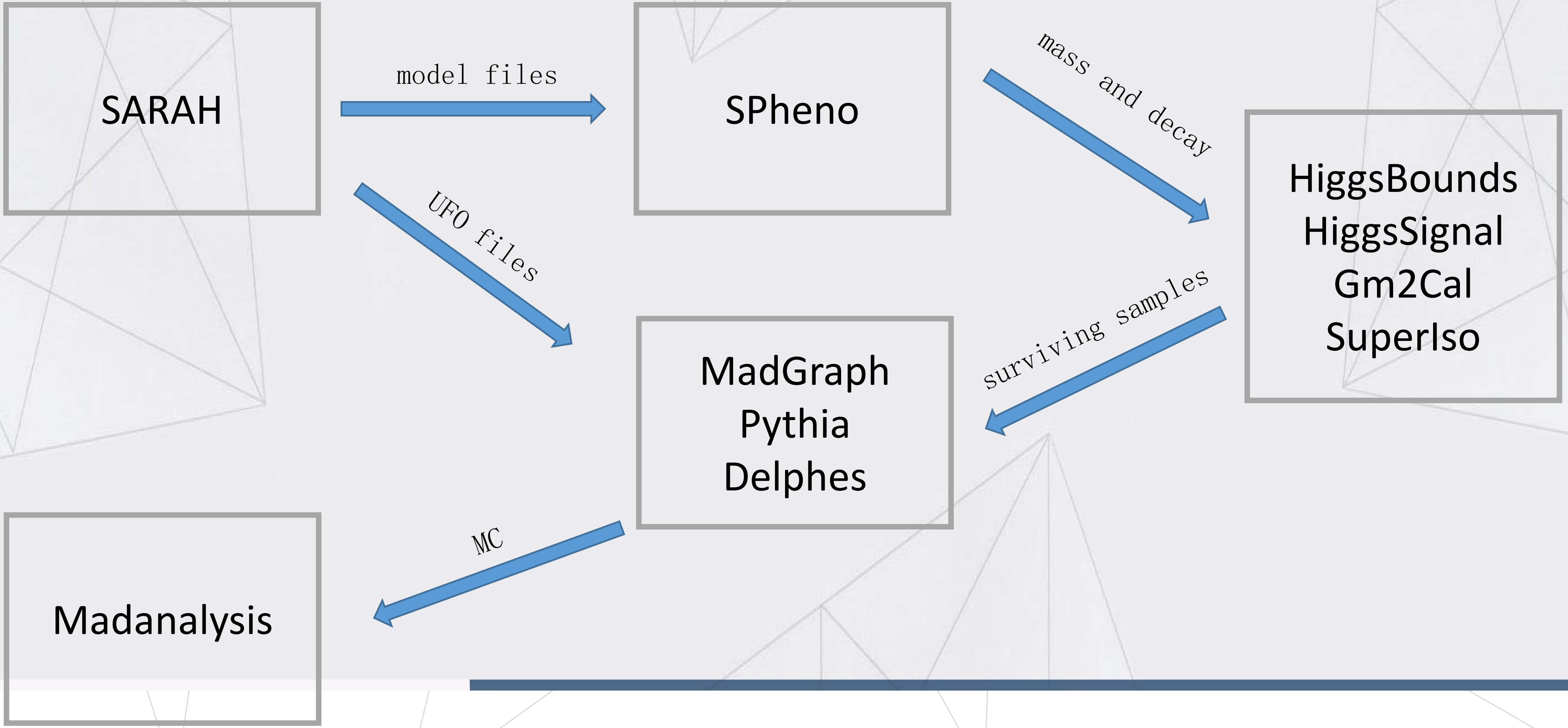
Coupling of Higgs to fermions

$$C_{hff} = C_{hff}^{SM} \times cos\alpha/sin\beta,$$
$$C_{Hff} = C_{Hff}^{SM} \times sin\alpha/sin\beta$$

$$\Gamma(h \to \gamma\gamma) = \frac{G_F\alpha^2 M_h^3}{128\sqrt{2}\pi^3}\left|\sum_{f\in\{t,b\}} C_{hff}Q_f^2 N_c A_{1/2}(\tau_f) + C_{hWW}A_1(\tau_W) + C_h A_0(\tau_{H^\pm})\right|^2$$

can get loop contributions from top and bottom quarks , W boson and charged Higgs

THDM-I and Parameter scan



THDM-I and Parameter scan

Parameter selecting

$m_h = 95$ GeV, $m_H = 125$ GeV

$\alpha \in [-\pi/2, \pi/2]$,
$\tan\beta \in [0, 20]$,
$m_{12} \in [-10\ TeV, 10\ TeV]$,
$m_{H^\pm} = m_A \in [150\ GeV, 1000\ GeV]$

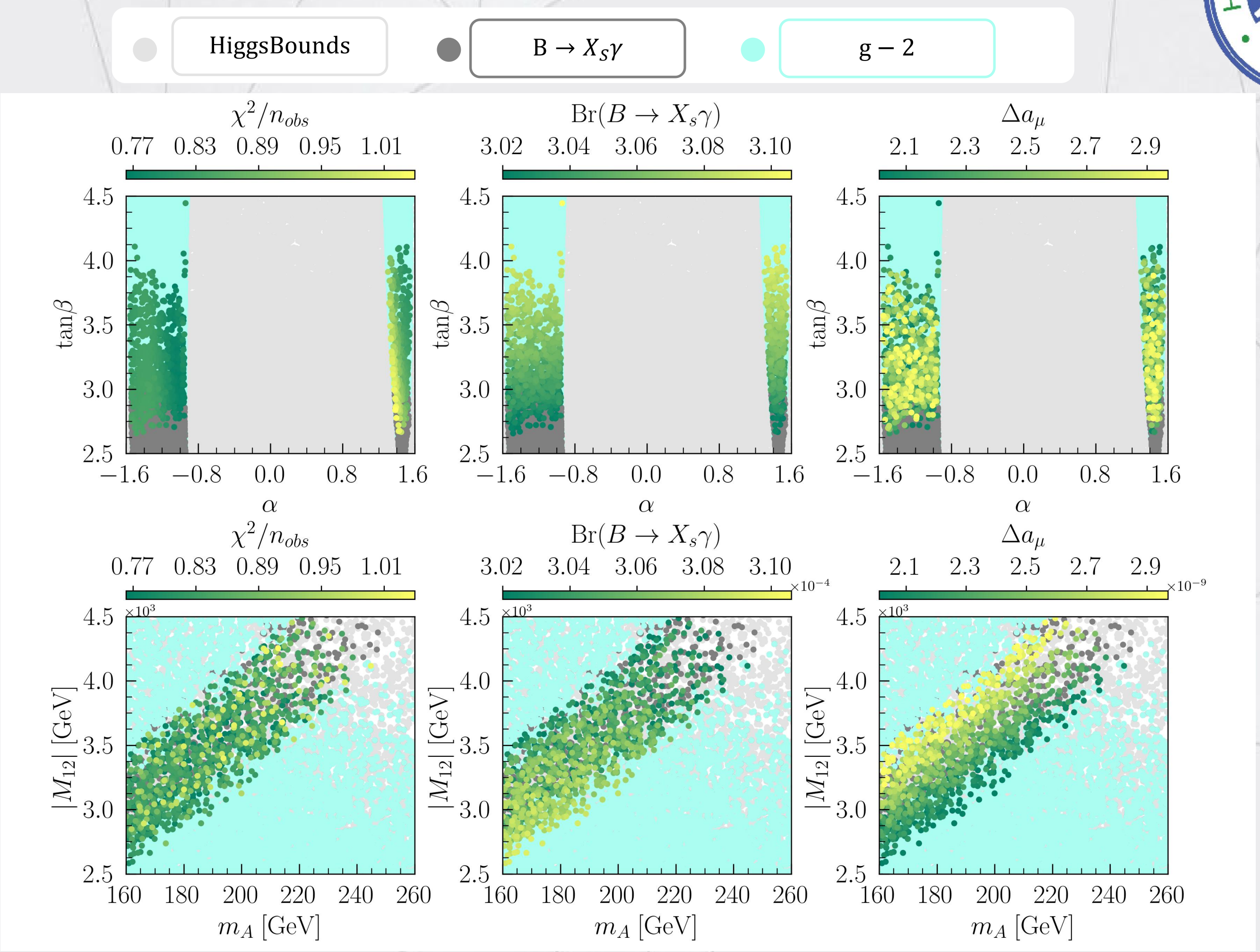
Constraints

Theoretical

unitarity
vacuum stability
perturbativity

Experimental

B physics
muon g-2
Higgs direct search
electroweak precision observables



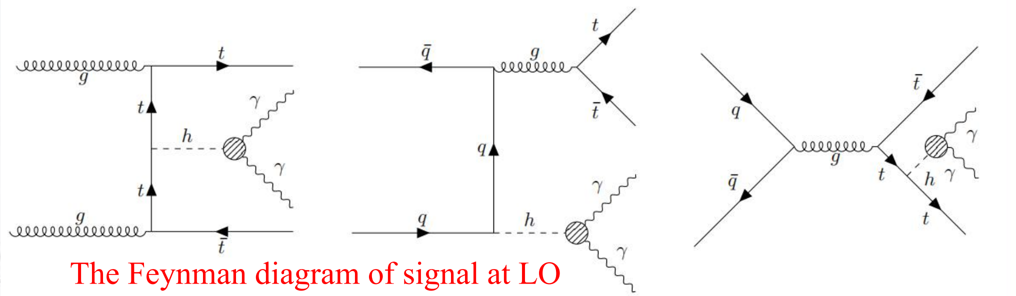
- HiggsBounds exclude $-0.9 \lesssim \alpha \lesssim 1.3$,
- $B \to X_s\gamma$ require $\tan\beta \gtrsim 2.6$,
- Muon g-2 need $20\ m_A - 0.5 < |m_{12}| < 20\ m_A + 0.5$ TeV .

excluded regions with corresponding constraints.

Collider simulations

Signal

$pp \to t(\to W^+ b)\bar{t}(\to W^- \bar{b})h(\to \gamma\gamma)$



The Feynman diagram of signal at LO

Backgrounds

resonant

$pp \to t(\to W^+ b)\bar{t}(\to W^- \bar{b})H(\to \gamma\gamma)$

$pp \to t(\to W^+ b)jH(\to \gamma\gamma)$

non-resonant

$pp \to t(\to W^+ b)\bar{t}(\to W^- \bar{b})\gamma\gamma$

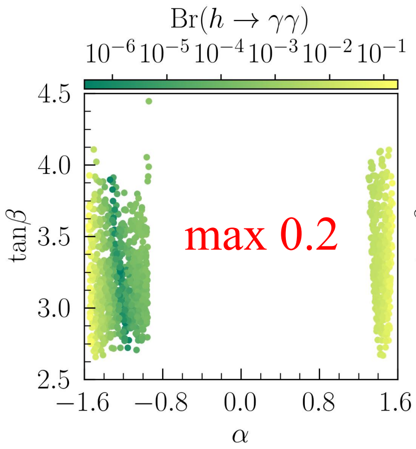
$pp \to t(\to W^+ b)j\gamma\gamma$

$pp \to b\bar{b}\gamma\gamma$

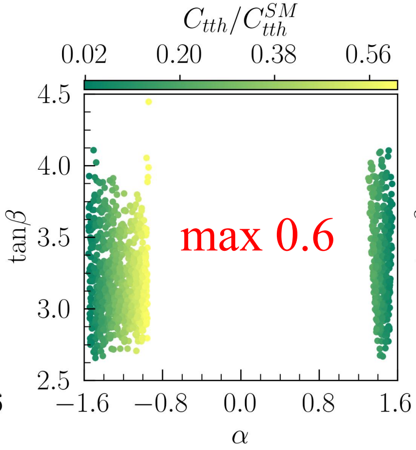
$pp \to Wjj\gamma\gamma$

$pp \to t(\to W^+ b)\bar{t}(\to W^- \bar{b})\gamma$

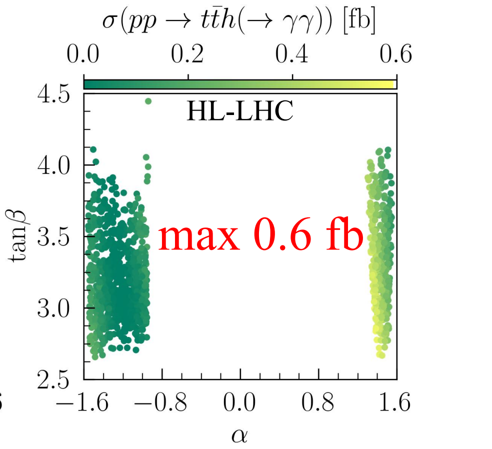
branching ratio of $h \to \gamma\gamma$



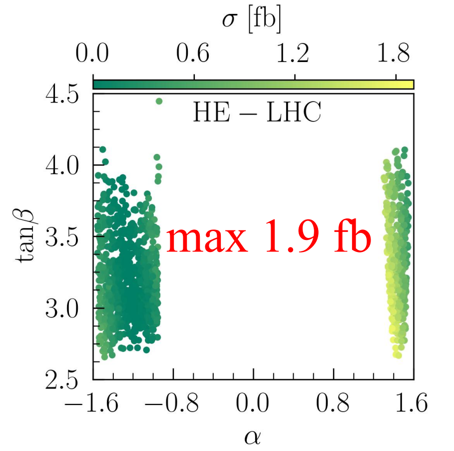
reduced coupling of top-Higgs



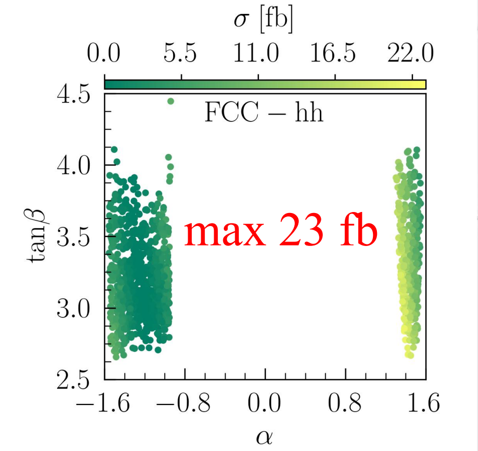
cross section at HL-LHC



cross section at HE-LHC



cross section at FCC-hh



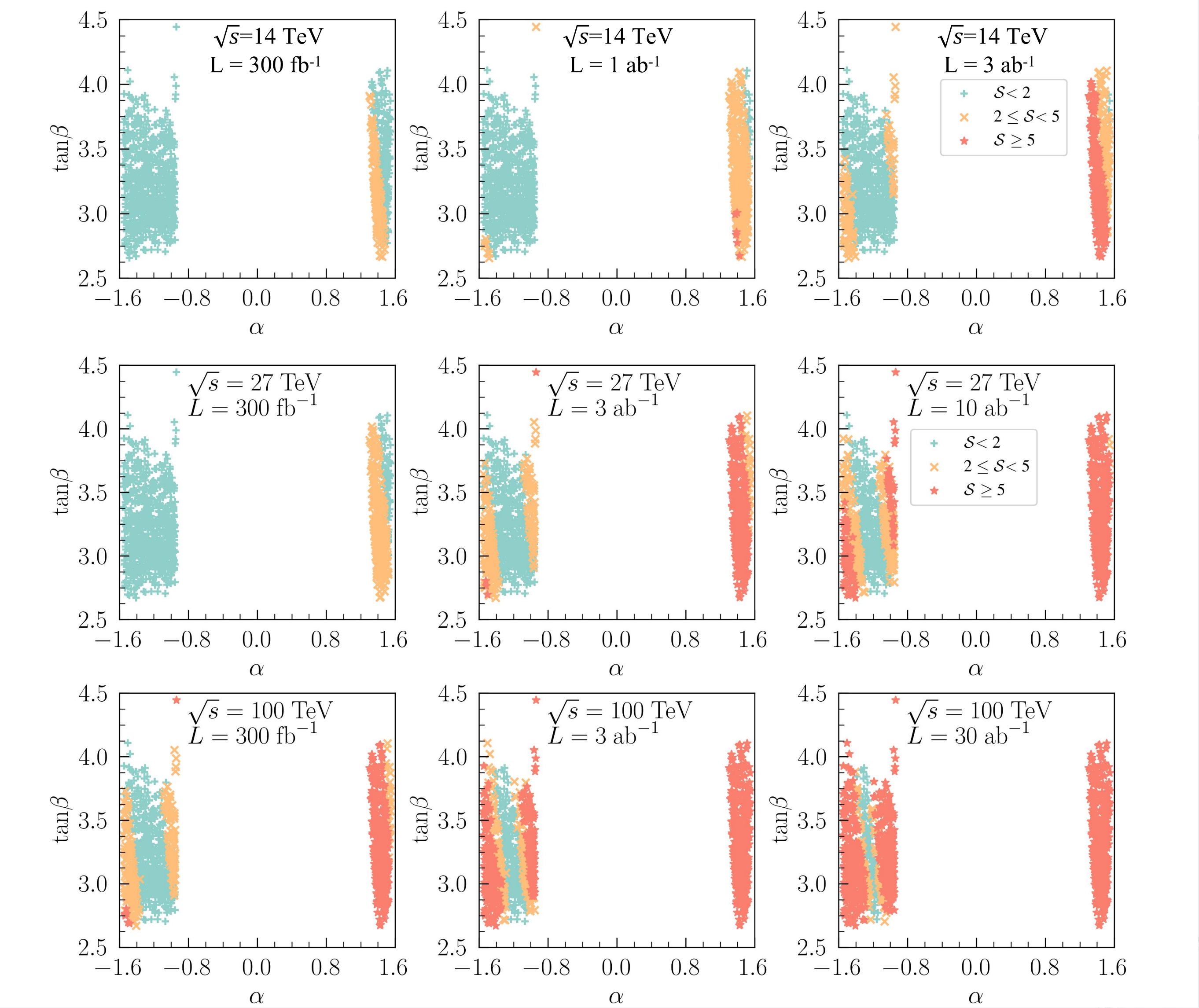
cross section at HL-LHC given by:

$$\sigma(pp \to t\bar{t}h(\to \gamma\gamma)) = |\sigma(pp \to t\bar{t}H)|^{SM}_{m_h = 95\,GeV} \times (C_{t\bar{t}h}/C^{SM}_{t\bar{t}h})^2 \times Br(h \to \gamma\gamma)$$

cross section at HE-LHC and FCC-hh given by:

$$\sigma_{HE-LHC(FCC-hh)} = \sigma^{BP}_{HE-LHC(FCC-hh)} \times \frac{C^2_{t\bar{t}h} \times Br(h \to \gamma\gamma)}{(C^{BP}_{t\bar{t}h})^2 \times Br^{BP}(h \to \gamma\gamma)}$$

Collider simulations



the cut flow at HL-LHC with L=300 fb^{-1}

Cuts	Signal($\sigma\times L$)	Background($\sigma\times L$)						
	$t\bar{t}h$	$t\bar{t}\gamma$	$t\bar{t}H$	tjH	$b\bar{b}\gamma\gamma$	$t\bar{t}\gamma\gamma$	$tj\gamma\gamma$	$Wjj\gamma\gamma$
Initial	165	1536000	168	23	2293800	3354	5253	65400
Basic cut	14.5	4577.3	17.25	0.712	848.7	200.0	89.61	268.1
Mass cut	11.03	46.08	0.023	0.0	0.0	6.47	2.67	4.58
Energy cut	10.33	0.0	0.023	0.0	0.0	5.8	1.91	3.27

$$\mathcal{S} = \sqrt{2L\left[(S+B)ln\left(1+\frac{S}{B}\right)-S\right]}$$

required luminosity to get 2σ or 5σ significance

	2σ	5σ
HL-LHC	137 fb^{-1}	**859 fb^{-1}**
HE-LHC	69 fb^{-1}	430 fb^{-1}
FCC-hh	6.8 fb^{-1}	43 fb^{-1}

Conclusions

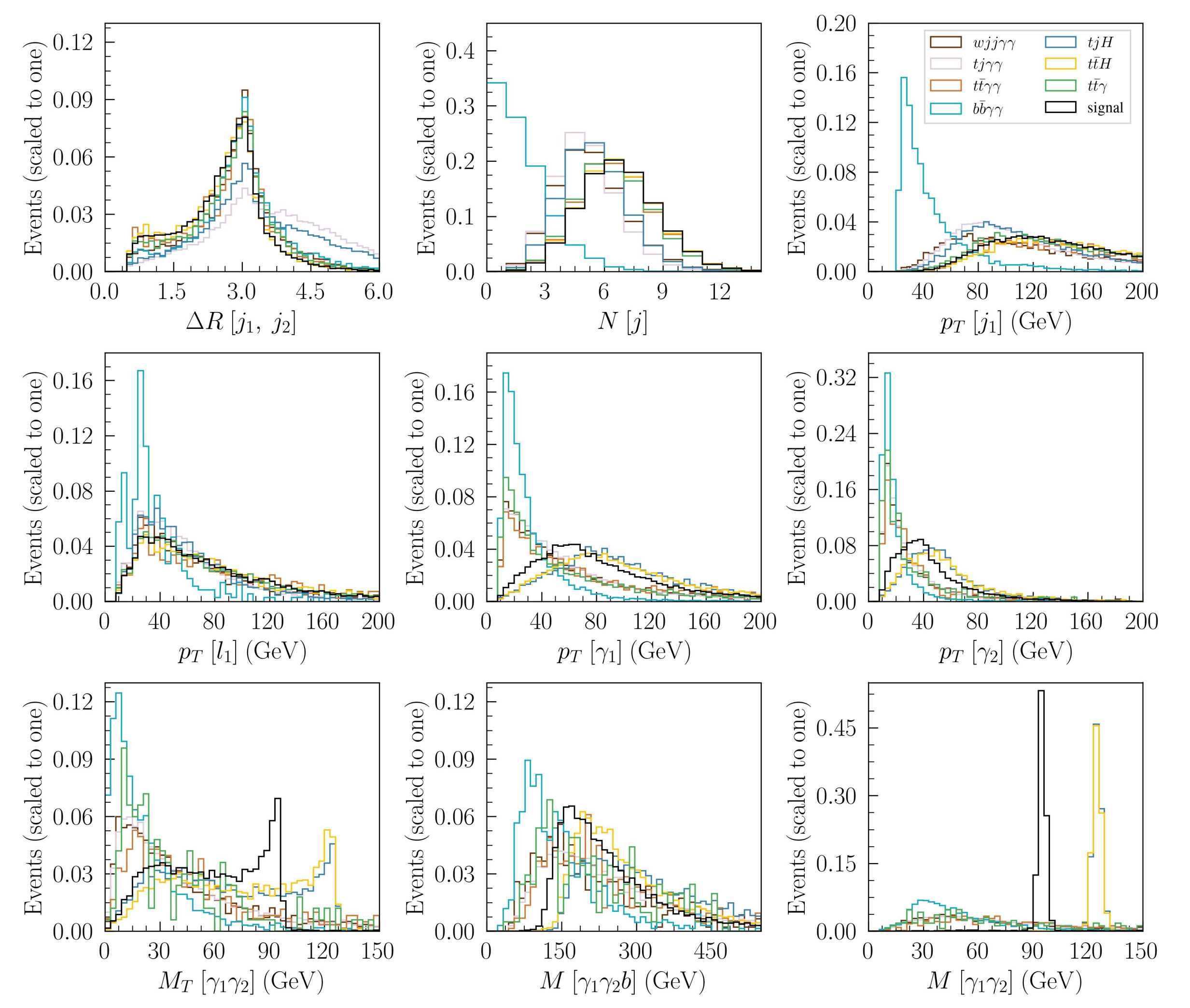
1.The data of Higgs direct search strongly constrain the model parameter α, the samples with $-0.9 \lesssim \alpha \lesssim 1.3$ are excluded. Constraints from $B \to X_s\gamma$, require $\tan\beta \gtrsim 2.6$. Muon g-2 need $20\, m_A - 0.5 < |m_{12}| < 20\, m_A + 0.5$ TeV.

2. The $Br(h \to \gamma\gamma)$ and reduced top-Higgs coupling are mainly affected by α and tan β, having max values 0.2 and 0.6 . The cross section $\sigma(pp \to t\bar{t}h(\to \gamma\gamma))$ at HL-LHC peaks at 0.6 fb when sin α is close to 1 and tanβ is near 2.7.

3. The backgrounds of $t\bar{t}\gamma\gamma$, $tj\gamma\gamma$, and $Wjj\gamma\gamma$ are difficult to eliminate. The samples with $\alpha \approx -1.2$ can hardly be covered all at 2σ level by the diphoton channel , even with increasing collider energy or integrated luminosity.

4. For the surviving samples, to get a significance of 2σ and 5σ at the HL-LHC require at least about 137 fb^{-1} and 859 fb^{-1} . The same significance can be achieved at the HE-LHC with 69 fb^{-1} and 430 fb^{-1} and at the FCC-hh with 6.8 fb^{-1} and 43 fb^{-1}.

Thanks!



Beasic

$\Delta R[j_1,\ j_2] < 4$ and $\Delta R[\gamma_1,\ \gamma_2] < 3.6$.

$0.2 < \theta_{b_1} < 3,\ \eta_{j_1} > -2.6,\ \eta_{\ell_1} > -2.5,$ and $\gamma_{j_1} < 50$.

$p_T[\gamma_1] > 30\text{GeV},\ p_T[j_1] > 40\ \text{GeV},$ and $p_T[j_2] < 220$ GeV.

Mass

$92\ \text{GeV} < M[\gamma_1\gamma_2] < 98\ \text{GeV},$ and $M[\gamma_2 j_1] < 390$ GeV.

$M_T[\gamma_1] < 300\ \text{GeV},\ M_T[\gamma_1\gamma_2] < 96\ \text{GeV},$ and $M_T[\gamma_1\gamma_2 b_1] < 440$ GeV.

Eneragy

$E_T > 200\ \text{GeV},\ H_T < 900\ \text{GeV},\ 10\text{GeV} < \not E_T < 190\ \text{GeV},$ and $\not H_T > 30$ GeV.

Cuts	Signal($\sigma \times L$)	Background($\sigma \times L$)						
	$t\bar{t}h$	$t\bar{t}\gamma$	$t\bar{t}H$	tjH	$b\bar{b}\gamma\gamma$	$t\bar{t}\gamma\gamma$	$tj\gamma\gamma$	$Wjj\gamma\gamma$
Initial	165	1536000	168	23	2293800	3354	5253	65400
Basic cut	14.5	4577.3	17.25	0.712	848.7	200.0	89.61	268.1
Mass cut	11.03	46.08	0.023	0.0	0.0	6.47	2.67	4.58
Energy cut	10.33	0.0	0.023	0.0	0.0	5.8	1.91	3.27

	Type I	Type II	Lepton-specific	Flipped
ξ_h^u	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
ξ_h^d	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
ξ_h^ℓ	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$
ξ_H^u	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$
ξ_H^d	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$
ξ_H^ℓ	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$
ξ_A^u	$\cot\beta$	$\cot\beta$	$\cot\beta$	$\cot\beta$
ξ_A^d	$-\cot\beta$	$\tan\beta$	$-\cot\beta$	$\tan\beta$
ξ_A^ℓ	$-\cot\beta$	$\tan\beta$	$\tan\beta$	$-\cot\beta$

arXiv: 1106.0034

$$v^2\lambda_1 = \frac{m_H^2 c_\alpha^2 + m_h^2 s_\alpha^2 - m_{12}^2 \tan\beta}{c_\beta^2}, \qquad v^2\lambda_2 = \frac{m_H^2 s_\alpha^2 + m_h^2 c_\alpha^2 - m_{12}^2/\tan\beta}{s_\beta^2},$$
$$v^2\lambda_3 = \frac{(m_H^2 - m_h^2) s_\alpha c_\alpha + 2m_{H^\pm}^2 s_\beta c_\beta - m_{12}^2}{s_\beta c_\beta}, \qquad v^2\lambda_4 = \frac{(m_A^2 - 2m_{H^\pm}^2) s_\beta c_\beta + m_{12}^2}{s_\beta c_\beta},$$
$$v^2\lambda_5 = \frac{-m_A^2 s_\beta c_\beta + m_{12}^2}{s_\beta c_\beta}. \tag{A.1}$$

$$m_{11}^2 = m_{12}^2 \tan\beta - \frac{1}{2}v^2\left(\lambda_1 c_\beta^2 + (\lambda_3+\lambda_4+\lambda_5)s_\beta^2\right),$$
$$m_{22}^2 = m_{12}^2 \cot\beta - \frac{1}{2}v^2\left(\lambda_2 s_\beta^2 + (\lambda_3+\lambda_4+\lambda_5)c_\beta^2\right).$$

arXiv: 2408.07366

from vacuum stability, tree-level unitarity, Z decays into hadrons, and the Δr parameter. The ratio was analyzed for the neutral CP-even Higgs h with 110 GeV $\lesssim M_h \lesssim$ 150 GeV (which is the region where an SM-like light Higgs boson h can be discovered at the LHC in $h \to \gamma\gamma$), and with $M_{H^\pm}$ = 100 GeV for the charged Higgs boson. The maximal possible enhancement differs for the potentials considered due to different interference scenarios. For the IDM the maximal enhancement was found to be around +70%, for V_A around −20%. The results for V and V_B were

1001.1759, 1706.07414