河南大學 Henan University

Testing a light Higgs at the LHC and future colliders

朱经亚 (Jingya Zhu)

zhujy@henu.edu.cn

河南大学 (Henan University)

Based on our works arXiv: 2410.13636; 2402.11232; 2506.21454; 2510.24662; 2312.17599; 2212.11739

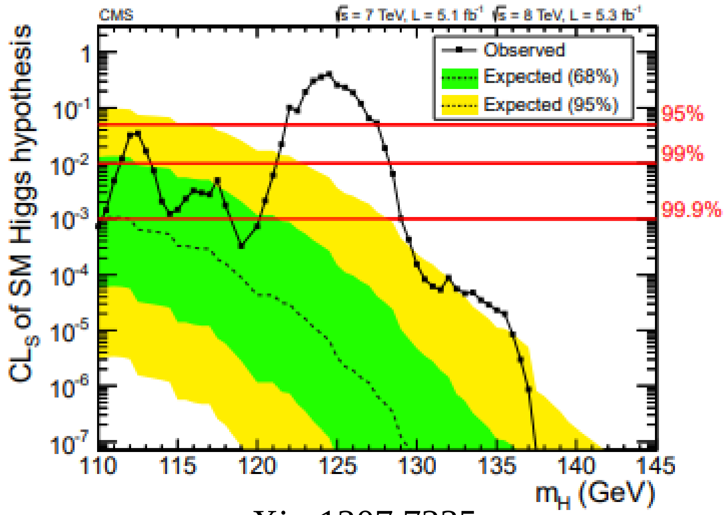
2025.10.31，Xinxiang

Outline

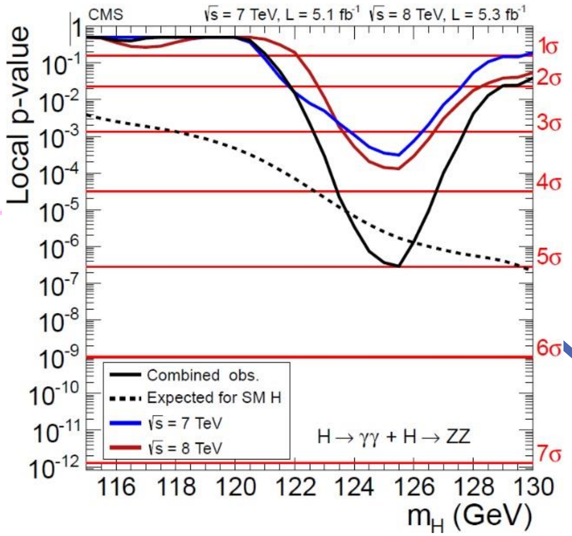
1. **Backgrounds and motivations**
2. **Models and technologies**
3. **95 GeV light Higgs at the LHC**
4. **95 GeV light Higgs at future hardon colliders**
5. **95 GeV light Higgs at the CEPC**
6. **Conclusions and outlooks**

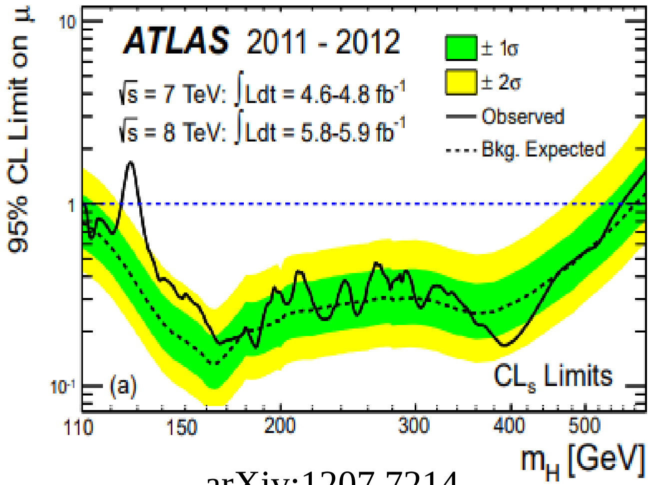
1. Backgrounds and motivations

A 125 GeV Higgs discovered!

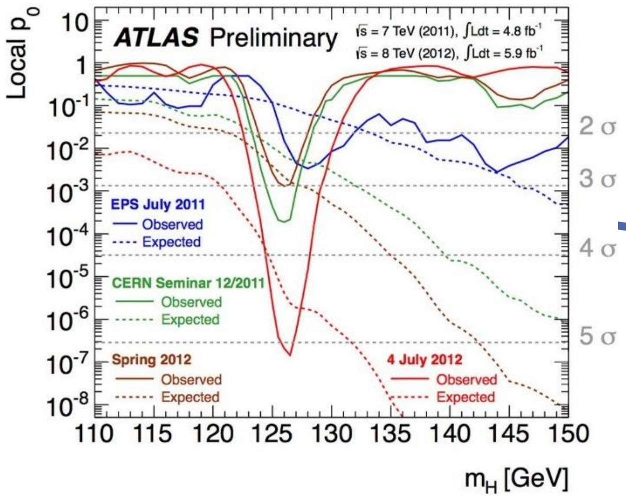


arXiv:1207.7235





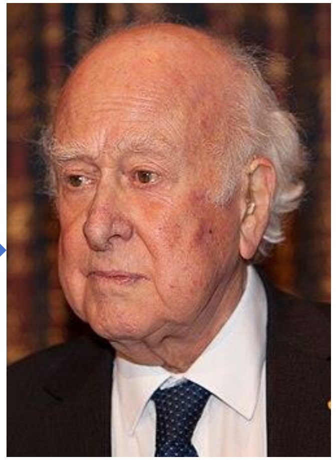
arXiv:1207.7214

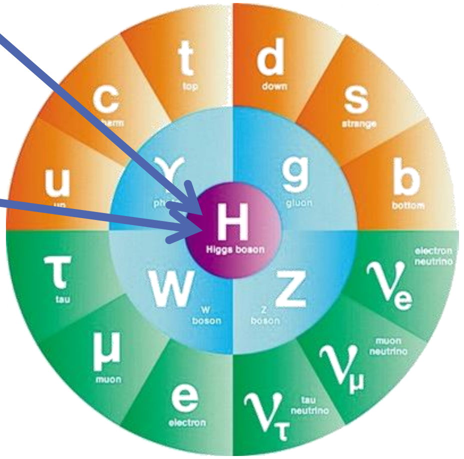


the final piece in SM

1964

2013





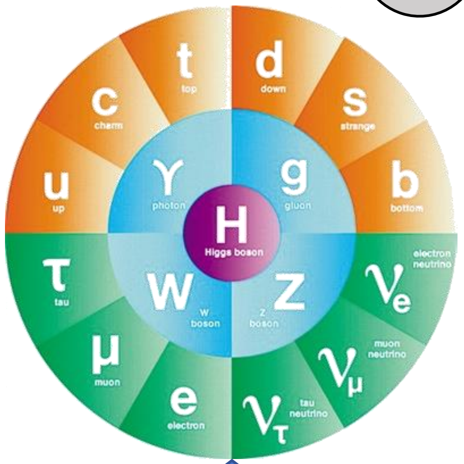
New physics needed!

- precisely measuring properties of the Higgs
- searching for new physics beyond the SM

Baryon asymmetry

Dark matter

Neutrino mass



……
Grand unification
Strong CP problem
Hierarchy problem

An important question: The properties of Higgs boson and the origin of mass

02 希格斯粒子性质和质量起源

- HL-LHC
- HE-LHC
- SppC
- FCC-hh
- FCC-ee
- ILC

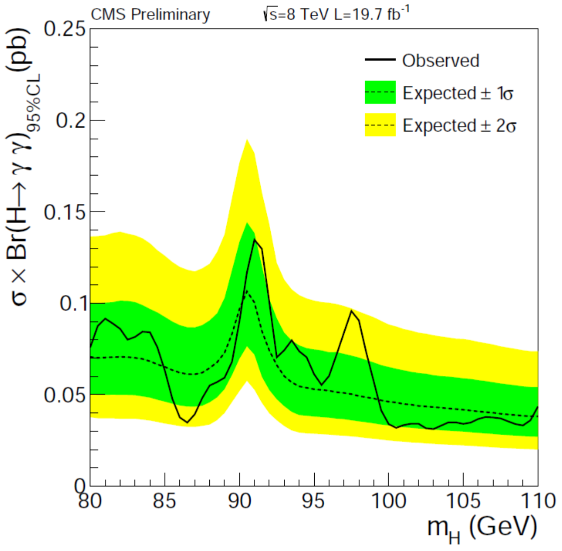
Colliders	Type	Energy	Luminosity Plan
LHC Run I & II	pp	13 TeV	~150 fb^{-1}
HL-LHC	pp	14 TeV	3000 fb^{-1}
HE-LHC	pp	27 TeV	10000 fb^{-1}
CEPC	e^+e^-	90-360 GeV	5600 fb^{-1}
SppC/FCC-hh	pp	100 TeV	30000 fb^{-1}
FCC-ee	e^+e^-	90-350 GeV	
ILC	e^+e^-	250-1000 GeV	

CEPC（环形正负电子对撞机）项目瞄准标准模型的核心，对质量起源以及超出标准模型的新物理信号进行高精度、多方位的探索。CEPC建成后，将无可争议地成为国际高能粒子物理实验的最前沿阵地，很有可能取得国际瞩目的重大突破。CEPC及其升级项目将在半个世纪的时间尺度上，使我国在高能物理实验领域处于世界领跑者地位。

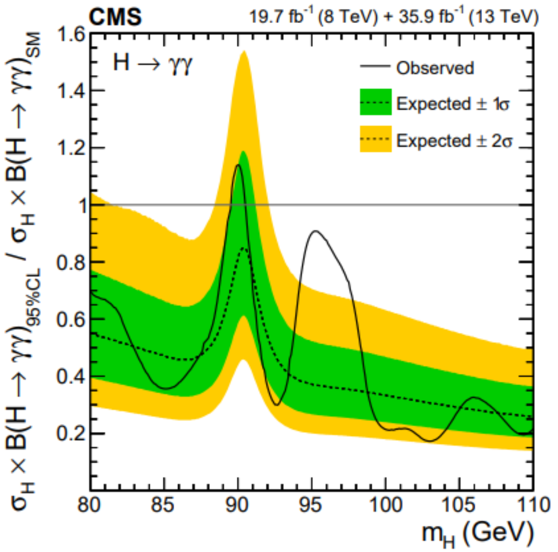
CEPC对技术发展将起到不可估量的引领和推动作用。CEPC将在低温、超导、高频、微波功率源、电子学与自动控制等一批关键技术领域大幅提升自主创新能力，对工艺新技术的发展、大规模工业制造将起到巨大的推动作用。

CEPC也将给我们带来一个国际化的科研中心，会对我国的科技体制改革、创新能力的提高以及人才培养等产生重大影响，会提高我们作为一个大国的硬实力、软实力和国际地位。

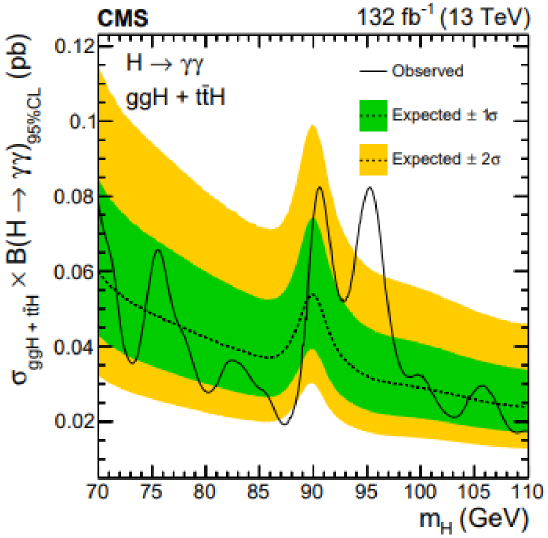
Another Higgs boson? A 95 GeV Higgs may be hinted



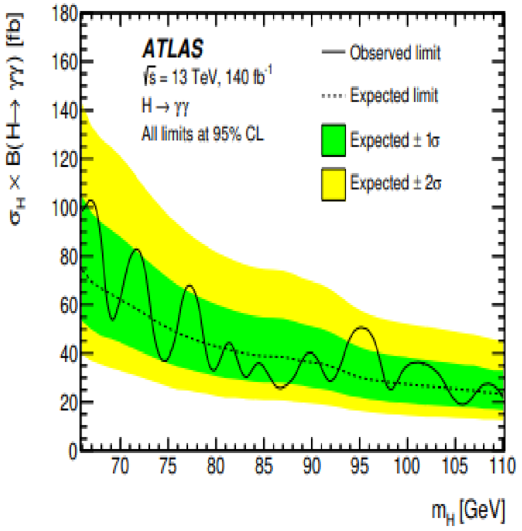
CMS-HIG-14-037, 2σ



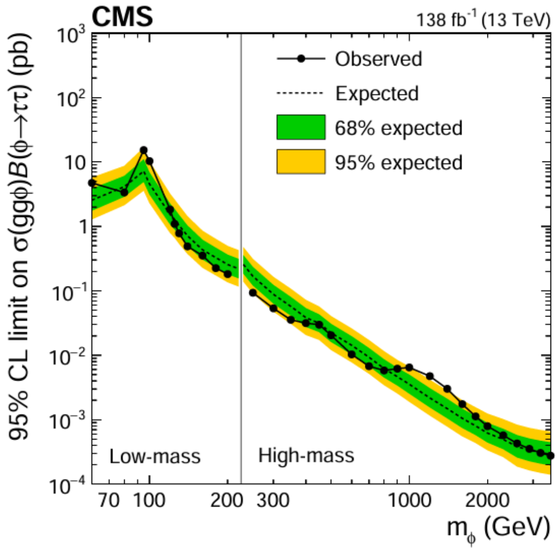
1811.08459, 2.8σ



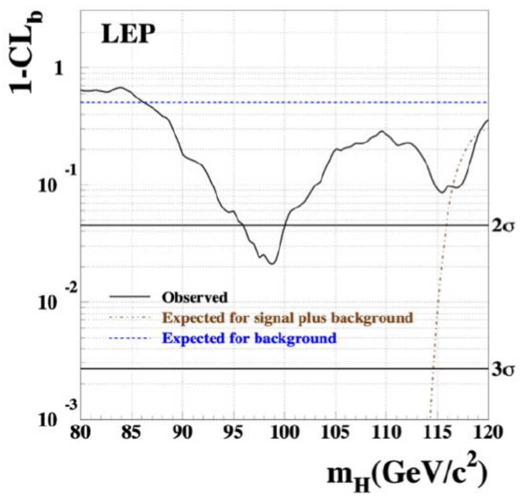
2407.07546, 2.9σ



2405.18149, 1.7σ



2208.02717, 3.1σ



hep-ex/0306033, 2.3σ

- Only one scalar in SM
- Additional scalar particle? Nature and important question. Far from been solved!

➢ ATLAS+CMS

$$\mu^{\text{ex}}_{\gamma\gamma} = 0.24^{+0.09}_{-0.08}$$

➢ CMS

$$\mu^{\text{ex}}_{\tau\tau} = 1.2 \pm 0.5$$

➢ LEP

$$\mu^{\text{ex}}_{bb} = 0.117 \pm 0.057$$

2. Models and technologies

Works	models	Different scenarios of mass generated
2402.11232 Wang, **JZ**	Minimal Dilaton Model	Top quark by both Higgs and dilaton
2410.13636 Dong, Wang, **JZ**	2HDM Type-I	All SM particles by the same doublet
2506.21454 Dong, Ruan, Wang, Yang, **JZ**	N2HDM Y	Charged leptons & up-type quarks by the same doublet
2510.24662 Dong, Ruan, Wang, Yang, **JZ**		
2312.17599 Li, Qiao, Wang, **JZ**	NMSSM II	Charged leptons & down-type quarks by the same doublet
2212.11739 Li, Qiao, **JZ**		

Models

Minimal Dilaton Model

$$\mathcal{L} = \mathcal{L}_{\rm SM}^{\text{without } V(H)} - \frac{1}{2}\partial_\mu S \partial^\mu S - \bar{T}\left(\not{D} + \frac{M}{f}S\right)T - \left[y'\bar{T}_R(q_{3L}\cdot H) + \text{ h.c. }\right] - \tilde{V}(S,H),$$

$$\tilde{V}(S,H) = m_H^2|H|^2 + \frac{\lambda_H}{4}|H|^4 + \frac{m_S^2}{2}S^2 + \frac{\lambda_S}{4!}S^4 + \frac{\kappa}{2}S^2|H|^2,$$

$$S = f + h\sin\theta_S + s\cos\theta_S,$$
$$H^0 = \frac{1}{\sqrt{2}}(v + h\cos\theta_S - s\sin\theta_S),$$
$$q_{3L}^u = \cos\theta_L t_L + \sin\theta_L t'_L,$$
$$T_L = -\sin\theta_L t_L + \cos\theta_L t'_L.$$

2HDM Type-I

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

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

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

mass parameter

pseudoscalar mass

neutral Higgs mass

charged Higgs mass

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

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

N2HDM Type-Y

$$V = m_{11}^2|\Phi_1|^2 + m_{22}^2|\Phi_2|^2 - m_{12}^2(\Phi_1^\dagger\Phi_2 + h.c.) + \frac{\lambda_1}{2}(\Phi_1^\dagger\Phi_1)^2 + \frac{\lambda_2}{2}(\Phi_2^\dagger\Phi_2)^2$$
$$+ \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + \frac{\lambda_5}{2}[(\Phi_1^\dagger\Phi_2)^2 + h.c.]$$
$$+ \frac{1}{2}m_S^2\Phi_S^2 + \frac{\lambda_6}{8}\Phi_S^4 + \frac{\lambda_7}{2}(\Phi_1^\dagger\Phi_1)\Phi_S^2 + \frac{\lambda_8}{2}(\Phi_2^\dagger\Phi_2)\Phi_S^2.$$

$$\boxed{\Phi_S = v_S + \rho_S}$$

$$C_{H_iff} = \begin{cases} s_{\alpha_1}c_{\alpha_2}/s_\beta, & i=1, \\ (c_{\alpha_1}c_{\alpha_3} - s_{\alpha_1}s_{\alpha_2}s_{\alpha_3})/s_\beta, & i=2, \\ -(c_{\alpha_1}s_{\alpha_3} + s_{\alpha_1}s_{\alpha_3}c_{\alpha_2})/s_\beta, & i=3, \end{cases} \qquad C_{H_iq_dq_d} = \begin{cases} c_{\alpha_1}c_{\alpha_2}/c_\beta, & i=1, \\ -(c_{\alpha_1}s_{\alpha_2}s_{\alpha_3} + c_{\alpha_3}s_{\alpha_1})/c_\beta, & i=2, \\ -(c_{\alpha_1}s_{\alpha_2}c_{\alpha_3} - s_{\alpha_1}s_{\alpha_3})/c_\beta, & i=3, \end{cases}$$

NMSSM

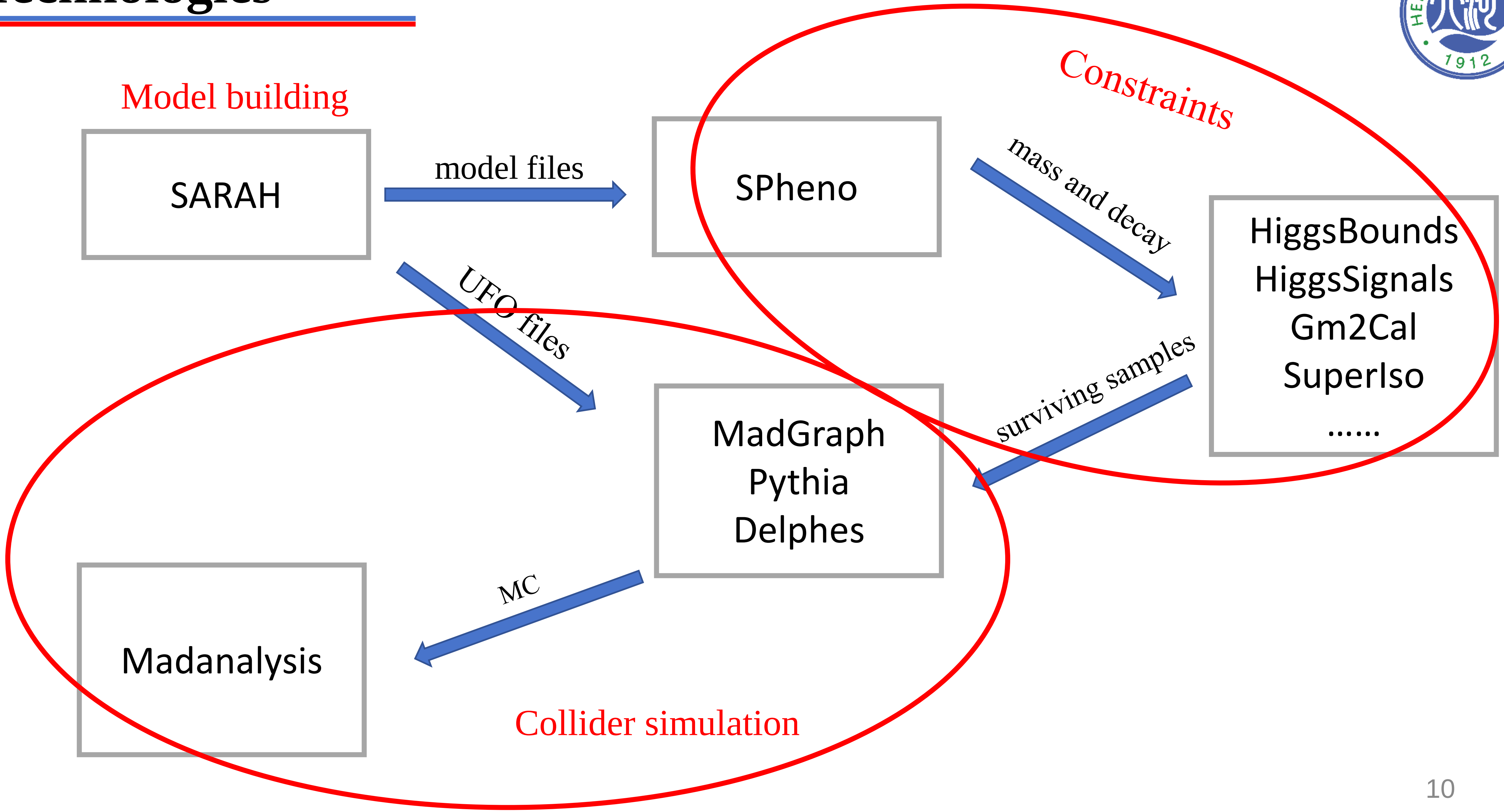
$$V^{\text{SUSY}} = V_{\text{F}} + V_{\text{D}} + V_{\text{soft}} \qquad V_{\text{F}} = F^{*i}F_i,\, F^{*i} = -W^i = -\frac{\delta W}{\delta\hat{\Phi}_i}$$

$$W^{\text{NMSSM}} = W_{\text{F}} + \lambda\hat{S}\hat{H}_u\cdot\hat{H}_d + \frac{\kappa}{3}\hat{S}^3 \qquad W_{\text{F}} = \bar{u}Y_u\hat{Q}\cdot\hat{H}_u - \bar{d}Y_d\hat{Q}\cdot\hat{H}_d - \bar{e}Y_e\hat{L}\cdot\hat{H}_d$$

$$V_{\text{soft}}^{\text{NMSSM}} = \tilde{m}_{\text{H}_\text{u}}^2|H_u|^2 + \tilde{m}_{\text{H}_\text{d}}^2|H_d|^2 + \tilde{m}_{\text{S}}^2|S|^2 + \left(\lambda A_\lambda S H_u\cdot H_d + \frac{\kappa}{3}A_\kappa S^3 + h.c.\right)$$

$$\boxed{S = \frac{v_S + \phi_S + i\varphi_S}{\sqrt{2}}}$$

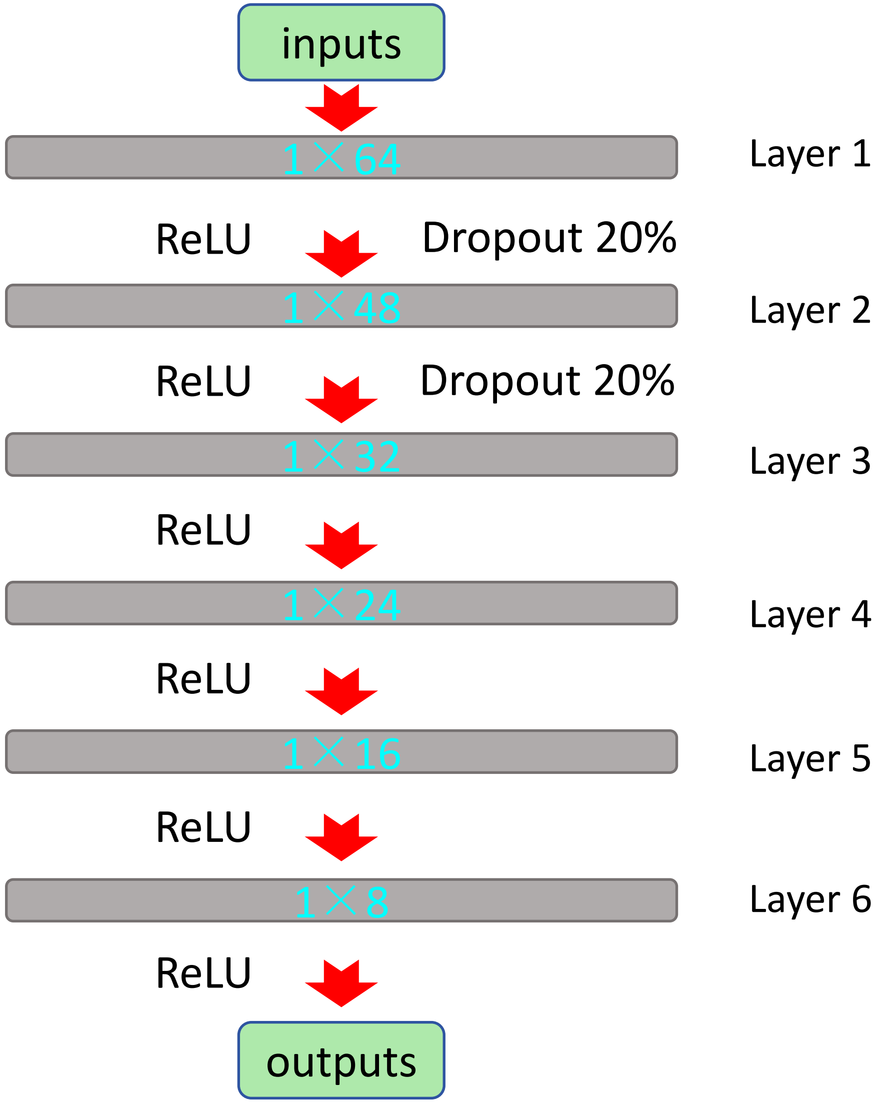
Technologies



Improving detection efficiency using machine learning

DNN

```python
# 定义 DNN 模型
class DNN(nn.Module):
    def __init__(self, input_size):
        super(DNN, self).__init__()
        self.Sequential = nn.Sequential(
            nn.Linear(input_size, 64),
            nn.BatchNorm1d(64),
            nn.Dropout(0.2),
            nn.ReLU(),

            nn.Linear(64, 48),
            nn.BatchNorm1d(48),
            nn.Dropout(0.2),
            nn.ReLU(),

            nn.Linear(48, 32),
            nn.BatchNorm1d(32),
            nn.ReLU(),

            nn.Linear(32, 24),
            nn.BatchNorm1d(24),
            nn.ReLU(),

            nn.Linear(24, 16),
            nn.BatchNorm1d(16),
            nn.ReLU(),

            nn.Linear(16, 8),
            nn.BatchNorm1d(8),
            nn.ReLU(),

            nn.Linear(8, 1),
            nn.Sigmoid()
        )

    def forward(self, x):
        return self.Sequential(x)
```



Data

train : 50000 * 0.7
test: 50000 * 0.3

Optimizer

Adam optimizer
Learn rate = 0.0001

Loss

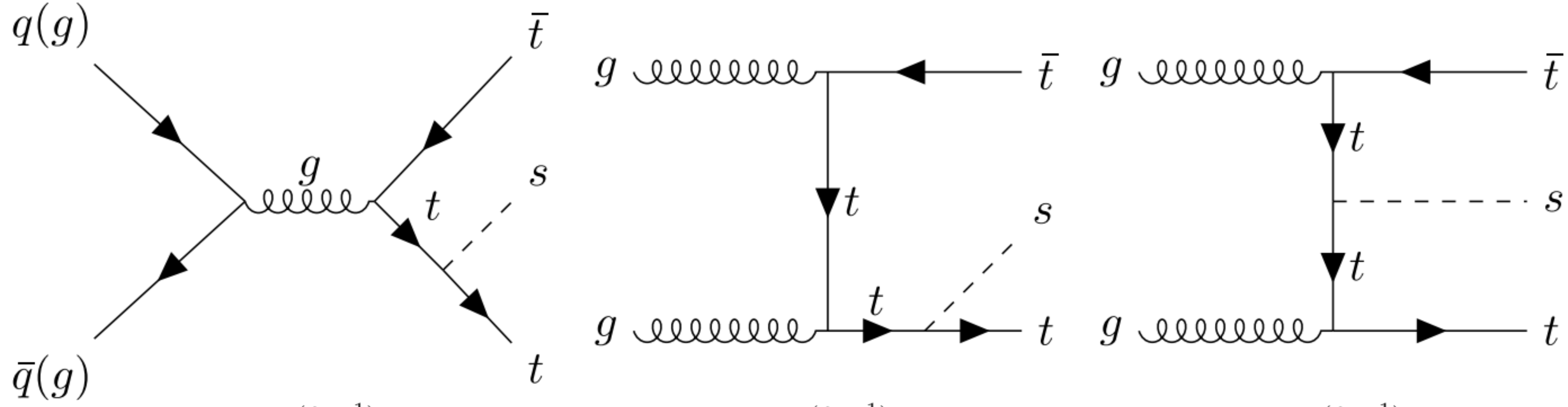
Binary Cross Entropy

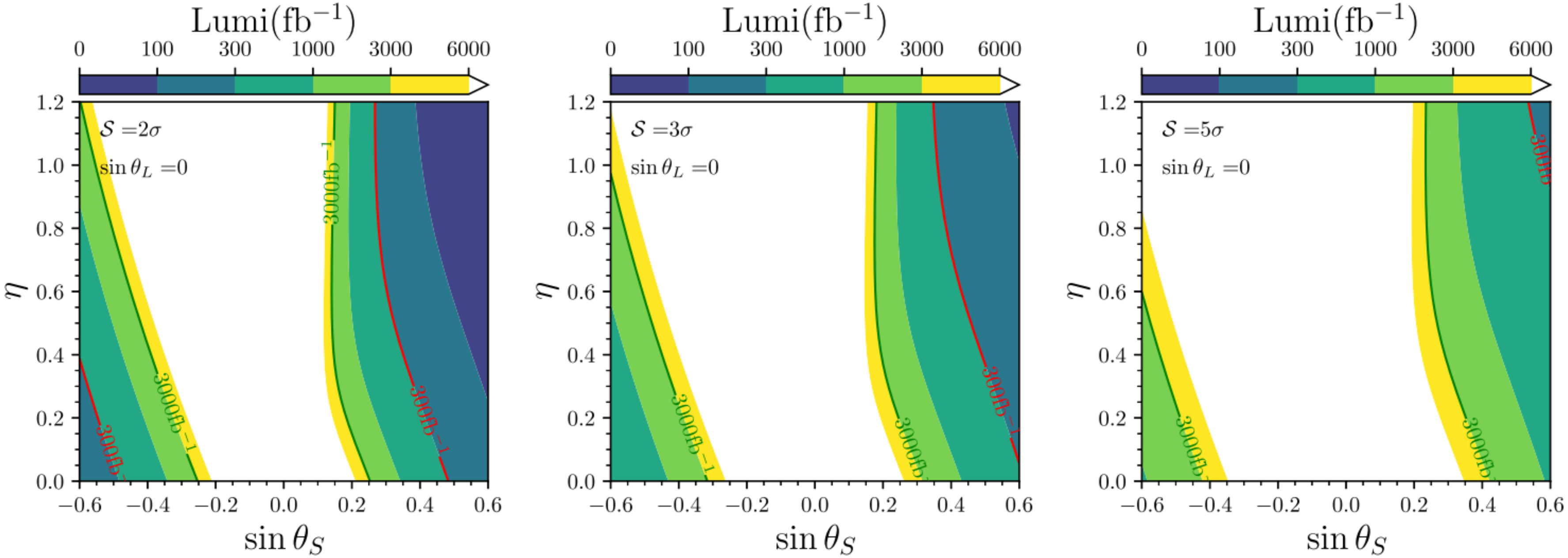
Training

epochs = 200
batch_size=128

3. 95 GeV light Higgs at the LHC

Signal: $pp \to t\bar{t}h(h \to \gamma\gamma)$





top-pair-associated diphoton channel

- light Higgs mass close to Z boson
- Z decays into e^-e^+ pairs & be misjudged as diphoton by detectors
- in associated with top pairs reduce this bkg

Minimal Dilaton Model:

With an integrated luminosity of 3000 fb^{-1}, regions of $|\sin\theta| > 0.2$ can be covered over the 3σ level.

4. 95 GeV light Higgs at future hadron colliders

2HDM-I: under current constraints

$$m_h = 95 \text{ GeV}, \ m_H = 125 \text{ GeV}$$

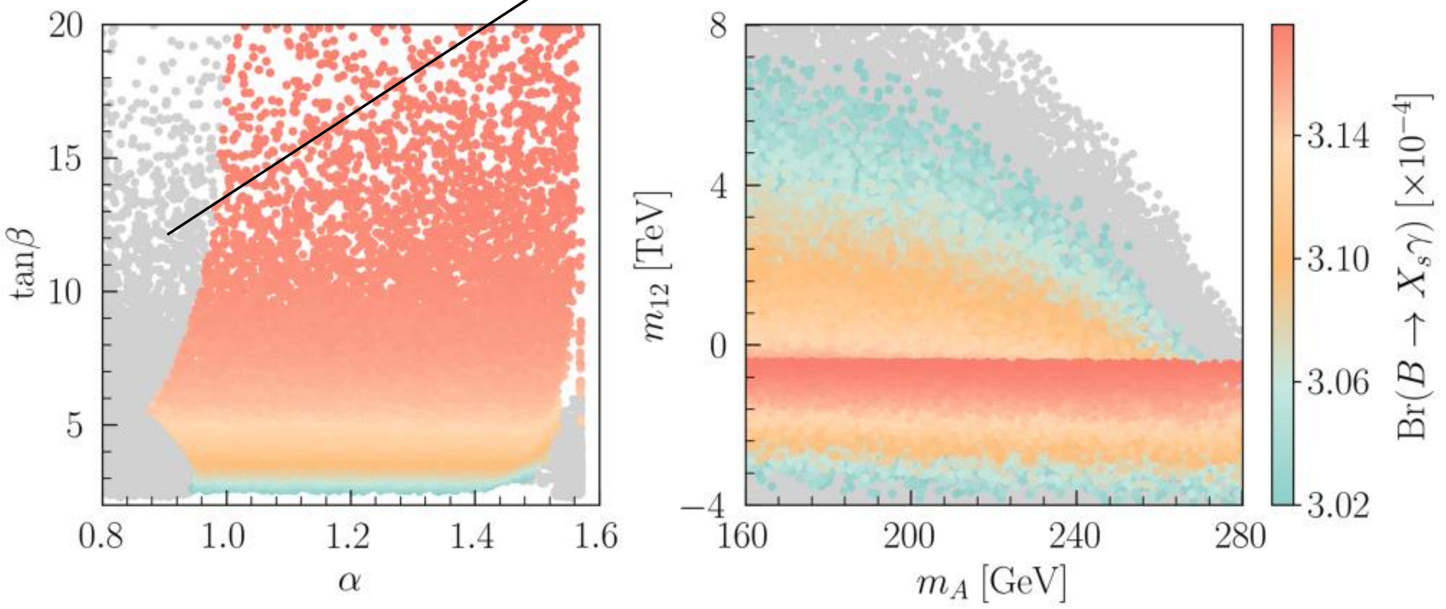
Parameter space

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

Constraints

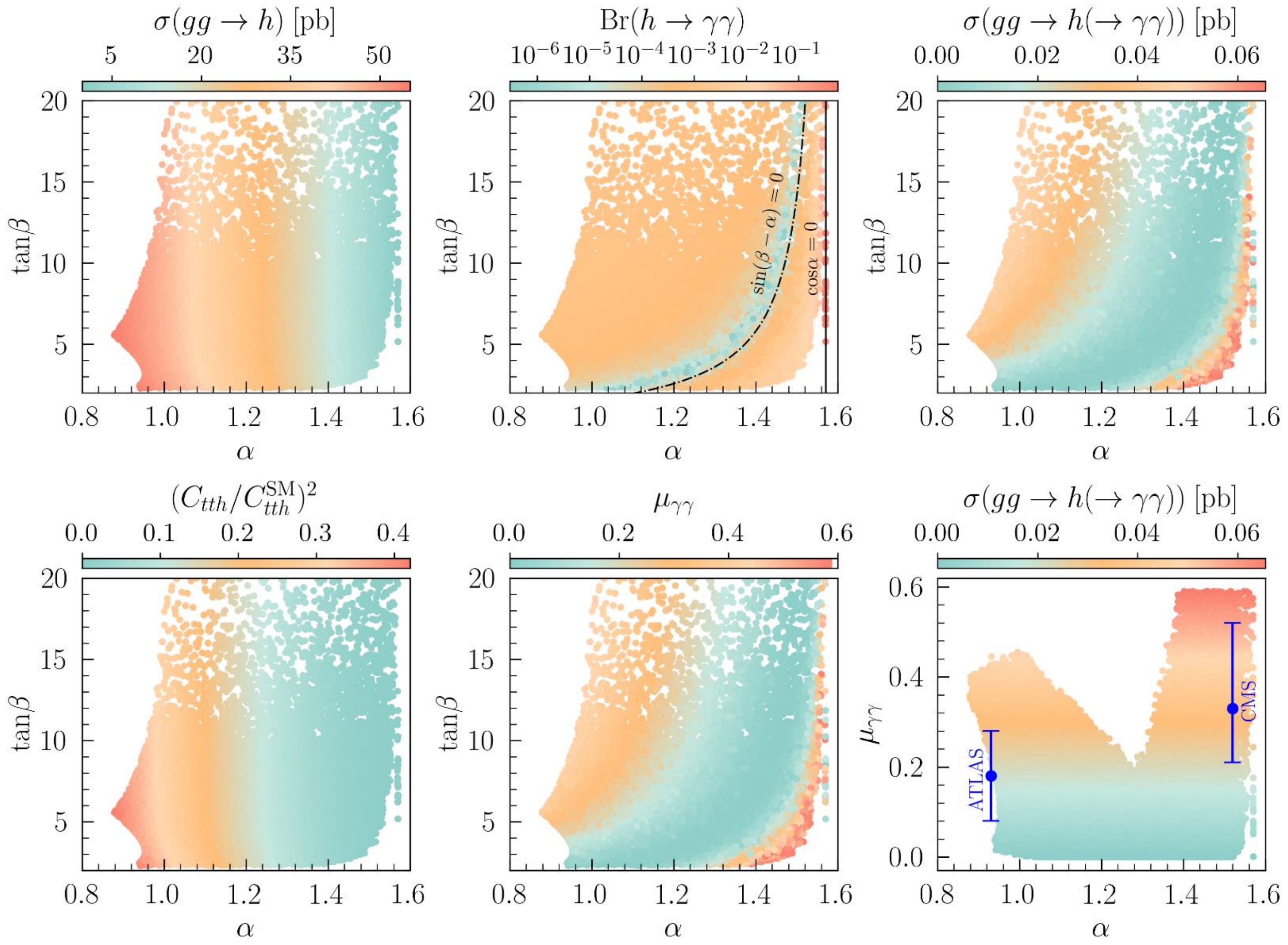
Theoretical	Experimental
unitarity vacuum stability perturbativity	Higgs searches EWPO B physics ……

Excluded by Higgs direct searches



Surviving samples in the $\tan\beta$ vs α and m_{12} vs m_A planes.

A 95 GeV light Higgs boson in 2HDM-I



Surviving samples in the $\tan\beta$ vs α and $\mu_{\gamma\gamma}$ vs α planes.

Signal strength

$$\mu_{\gamma\gamma} = \frac{\sigma(gg \to h) \times \mathrm{Br}(h \to \gamma\gamma)}{\sigma_{\mathrm{SM}}(gg \to h_{95}) \times \mathrm{Br}_{\mathrm{SM}}(h_{95} \to \gamma\gamma)}$$

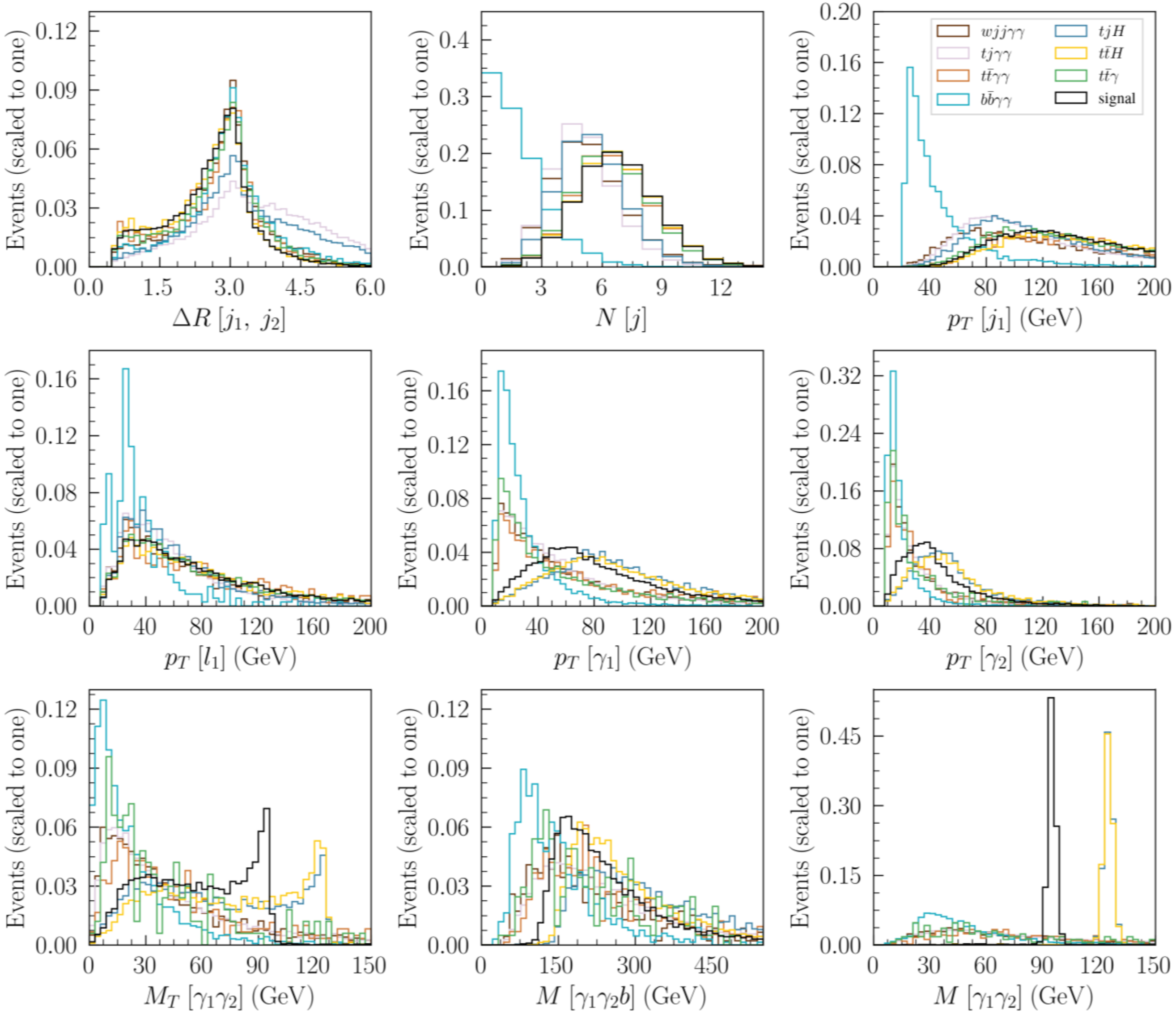
$\sigma_{\mathrm{SM}}(gg \to h_{95}) = 79.83$ pb

$Br_{\mathrm{SM}}(h_{95} \to \gamma\gamma) = 1.39 \times 10^{-3}$

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

ATLAS : $\mu_{\gamma\gamma}^{\mathrm{CMS}} = 0.18^{+0.1}_{-0.1}$

Signal vs backgrounds at HL-LHC



HL-LHC Events distribution

Events selecting

$$p_T^{j/b} > 20\ \text{GeV},\ \ p_T^{\ell/\gamma} > 10\ \text{GeV},\ \ |\eta_i| < 5\,,$$
$$\Delta R[i,\ j] > 0.4\,.\ (i, j = j, b, \ell, \gamma)$$

1. Basic Cuts:

$$N(l) \geq 1, N(\gamma) \geq 2, N(j) \geq 2, N(b) \geq 1,$$
$$p_T[\gamma_1] > 30\ \text{GeV}, p_T[j_1] > 40\ \text{GeV}, p_T[j_2] < 220\ \text{GeV},$$
$$\Delta R[j_1, j_2] < 4, \Delta R[\gamma_1, \gamma_2] < 3.6,$$
$$0.2 < \theta_{b_1} < 3, \eta_{j_1} > -2.6, \eta_{l_1} > -2.5, \gamma_{j_1} < 50.$$

2. Mass Cuts:

$$92\ \text{GeV} < M[\gamma_1, \gamma_2] < 98\ \text{GeV}, M[\gamma_1, \gamma_2] < 390\ \text{GeV},$$
$$M_T[\gamma_1] < 300\ \text{GeV}, M_T[\gamma_1, \gamma_2] < 98\ \text{GeV}.$$

3. Energy Cuts:

$$E_T > 200\ \text{GeV}, H_T < 900\ \text{GeV},$$
$$10\ \text{GeV} < E_T^{\text{miss}} < 190\ \text{GeV}, H_T^{\text{miss}} > 30\ \text{GeV}.$$

Cut flows at LHC and future hardon colliders

Cut flows

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	60	1536000	168	23	2293800	3354	5253	65400
Basic cut	5.27	4577.3	17.25	0.712	848.7	200.0	89.61	268.1
Mass cut	4.13	46.08	0.029	0.0	0.0	6.47	2.67	4.58
Energy cut	3.76	0.0	0.029	0.0	0.0	5.8	1.91	3.27

14 TeV HL-LHC 3 ab^{-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	192	3168000	927	115	3408000	14178	19920	206009
Basic cut	13.92	6874.6	80.06	3.23	1192.8	776.6	358.5	995.0
Mass cut	9.14	0.0	0.111	0.002	68.16	17.22	5.13	12.36
Energy cut	8.59	0.0	0.111	0.002	0.0	16.27	3.21	10.3

27 TeV HE-LHC 10 ab^{-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	2325	33120000	11724	1005	14856000	141570	138120	1255800
Basic cut	101.42	53985	621	17.1	6388.1	4764.2	1446.7	4897.6
Mass cut	64.94	662.4	1.06	0.0	148.6	91.0	24.82	37.67
Energy cut	59.75	0.0	0.821	0.0	0.0	78.86	21.28	25.12

100 TeV FCC-hh 30 ab^{-1}

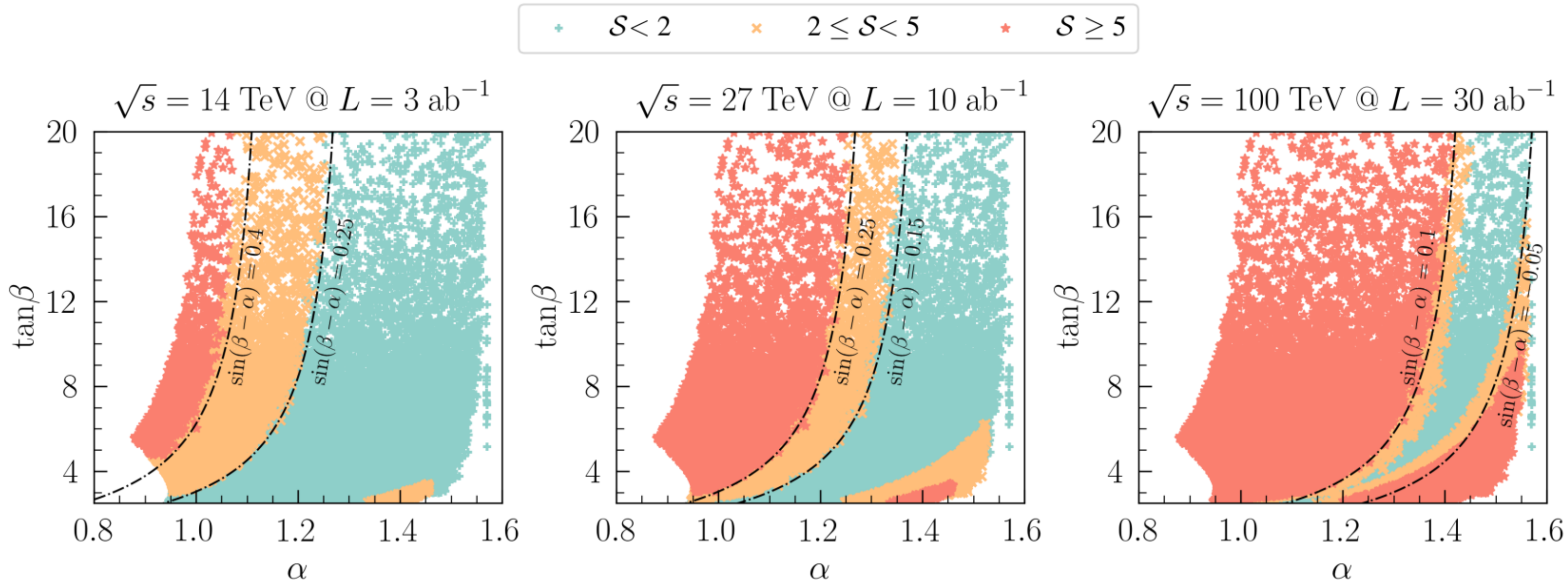
Checking a 95 GeV light Higgs boson at LHC and future hardon colliders

Signal significance

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

required minimum luminosity

	2σ	5σ
14 TeV HL-LHC	240 fb^{-1}	**1.4 ab^{-1}**
27 TeV HE-LHC	120 fb^{-1}	750 fb^{-1}
100 TeV FCC-hh	12 fb^{-1}	71 fb^{-1}



Covered parameter space in 2HDM-I

HL-LHC 3 ab^{-1}：
5 σ cover sin(α-β) > 0.4,
2 σ cover sin(α-β) > 0.25

HE-LHC 10 ab^{-1}：
5 σ cover sin(α-β) > 0.25,
2 σ cover sin(α-β) > 0.15

FCC-hh 30 ab^{-1}：
5 σ cover sin(α-β) >0.1 或 <-0.05

5. 95 GeV light Higgs at the CEPC

Higgsstrahlung $\tau\tau$ channel

Signal

$$e^+e^- \to Z(\to \mu^+\mu^-)S(\to \tau^+\tau^-)$$

Backgrounds

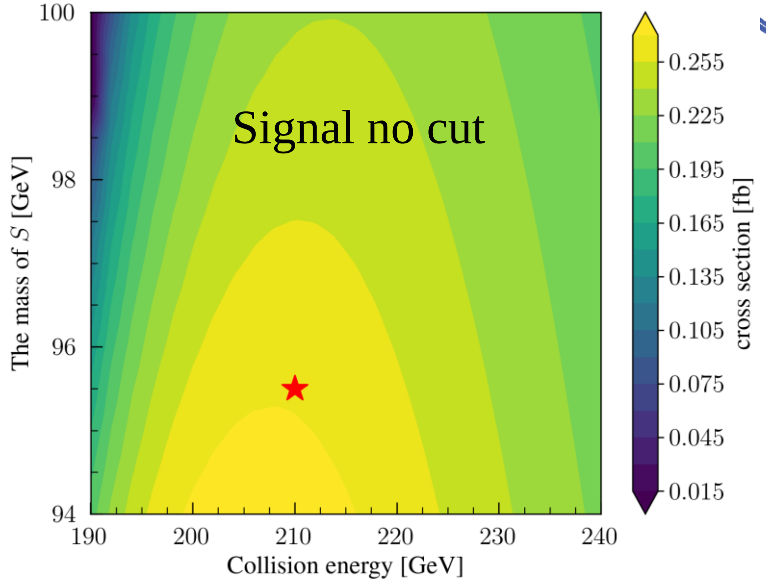
$Z\tau\tau$: $e^+e^- \to Z(\to \mu^+\mu^-)\tau^+\tau^-$

Zjj: $e^+e^- \to Z(\to \mu^+\mu^-)xx$, x is e, μ, jet

With cross section at 0.2 of SM

$$M_S \in [94, 100]\ \text{GeV}$$

$$\sqrt{s} \in [190, 240]\ \text{GeV}$$

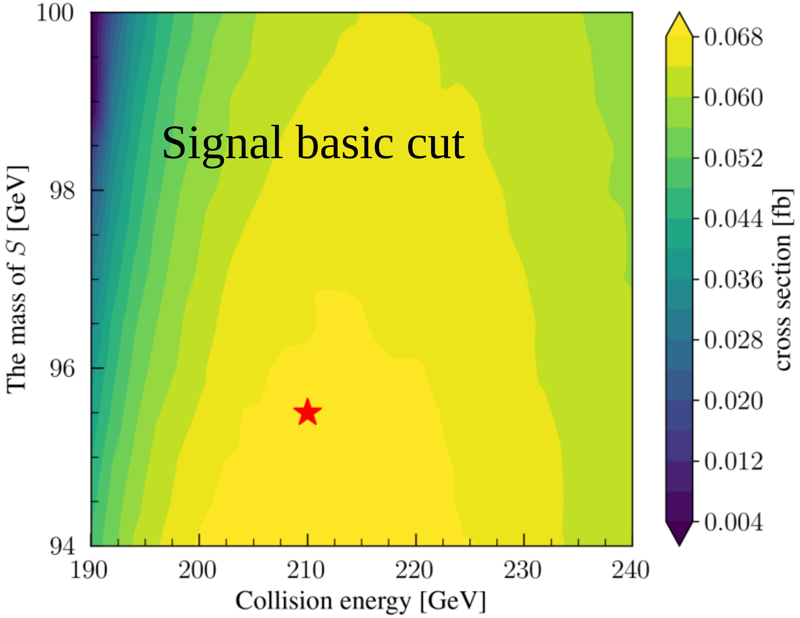


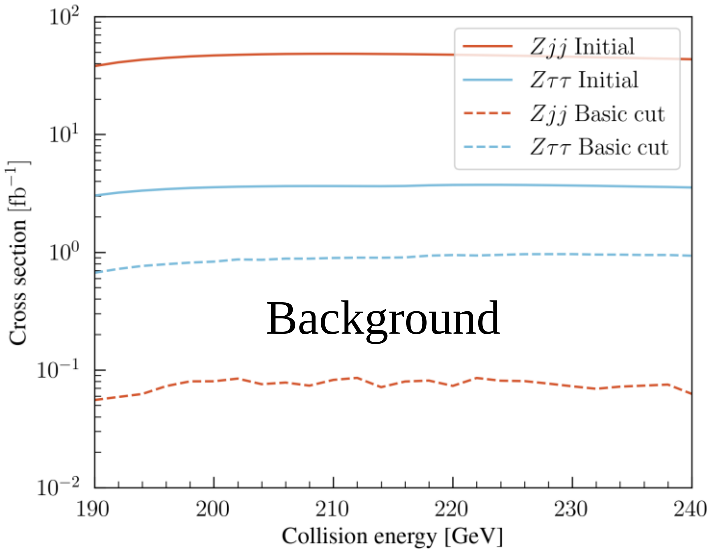
Basic Cuts

Two muon, one tau jet,

$p_{T_\mu} > 10$ GeV, $|\eta_\mu| < 2.5$,

$\Delta R(\mu_1, \mu_2) > 0.4$

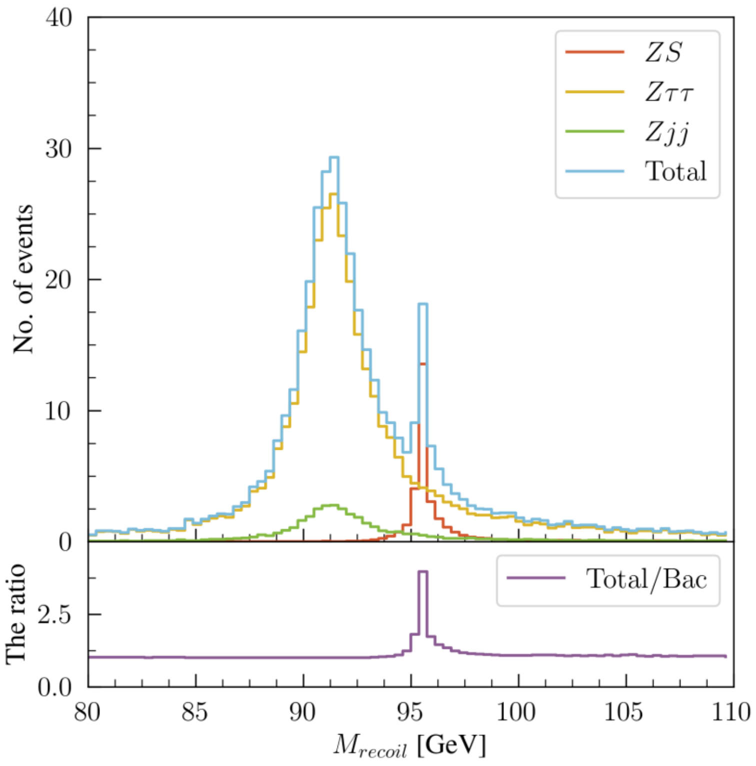




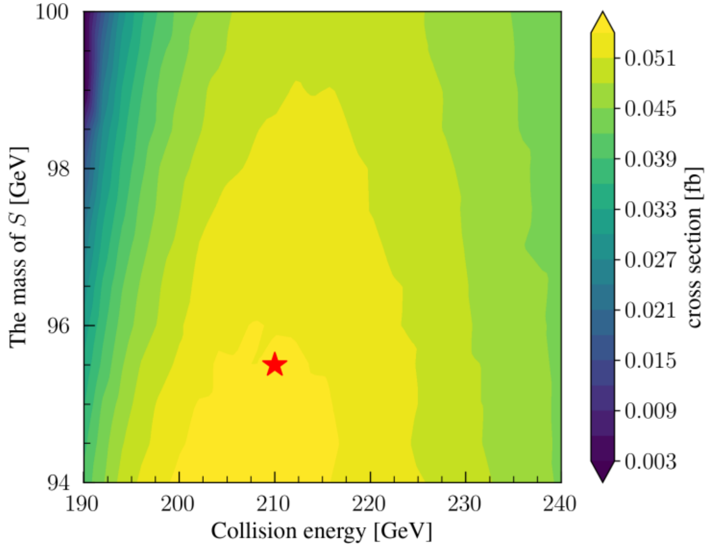
Finding the most effective collision energy

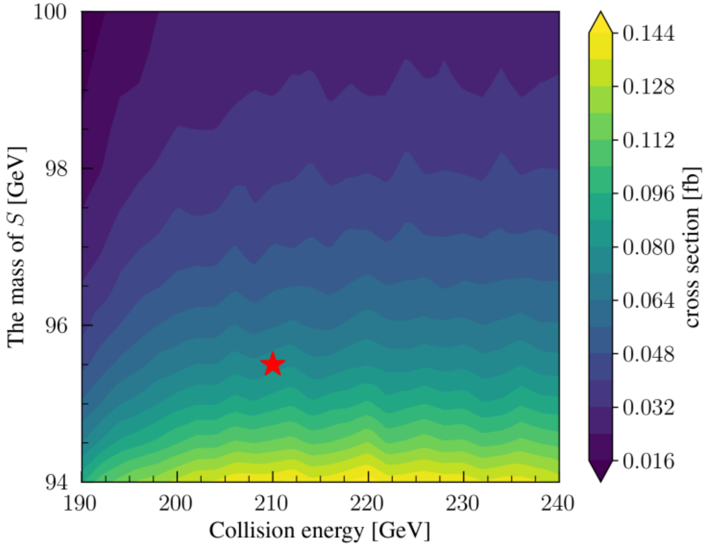
Low $\tau\tau$ reconstruction efficiency,
so use recoil mass instead of $M_{\tau\tau}$

$$M_{\text{recoil}} = \sqrt{s + M^2_{\mu^+\mu^-} - 2\sqrt{s}\left(E_{\mu^+} + E_{\mu^-}\right)}$$



Cut: $m_S - 1.5 < M_{\text{recoil}} < m_S + 1.5$

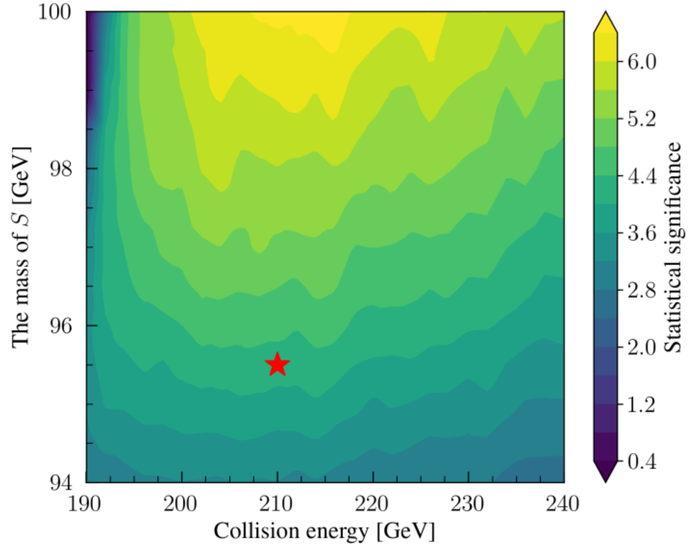




$$\mathcal{Z} = \sqrt{2L\left[(S+B)\ln\left(1+\frac{S}{B}\right) - S\right]}$$

Cuts	ZS	$Z\tau\tau$	Zjj	$\mathcal{Z}[\sigma]$
Initial	134 (109)	1819 (1769)	24187 (21745)	0.83 (0.7)
Basic	57.6 (51.2)	752.8 (797.5)	45.5 (55.9)	2.0 (1.7)
M_{recoil}	45.4 (37.6)	63.5 (65.2)	4.1 (5.7)	5.0 (4.1)

L=500 fb^{-1}, $\sqrt{s}$ = 210 (240) GeV



Improving detection efficiency using machine learning

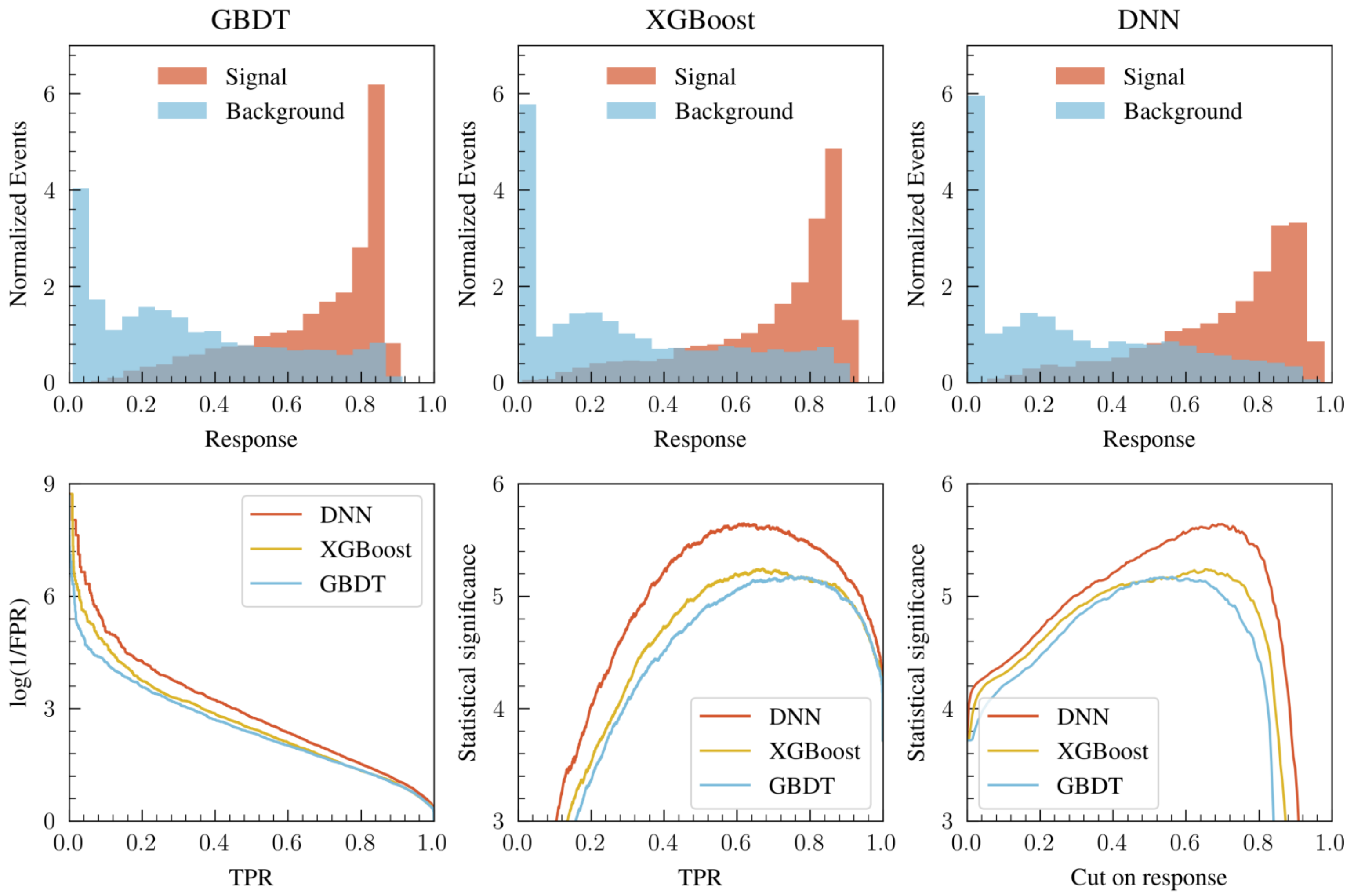
Machine Learning (ML)

22 features

Feature extraction

- Four-momenta P of two muon and one tau jet;
- Transverse momenta P_T and pseudorapidities η of two muon and one tau jet;
- Spatial separation ΔR of two muon and one tau jet;
- The recoil mass.

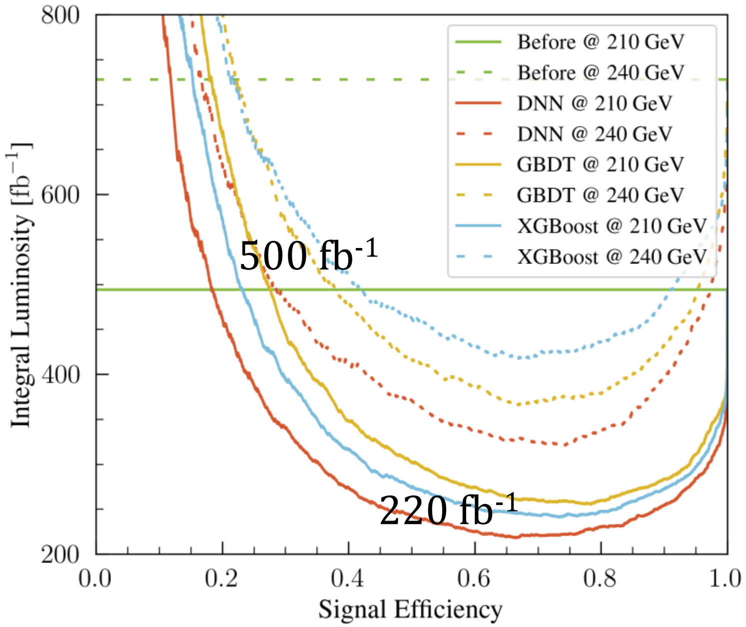
ML response

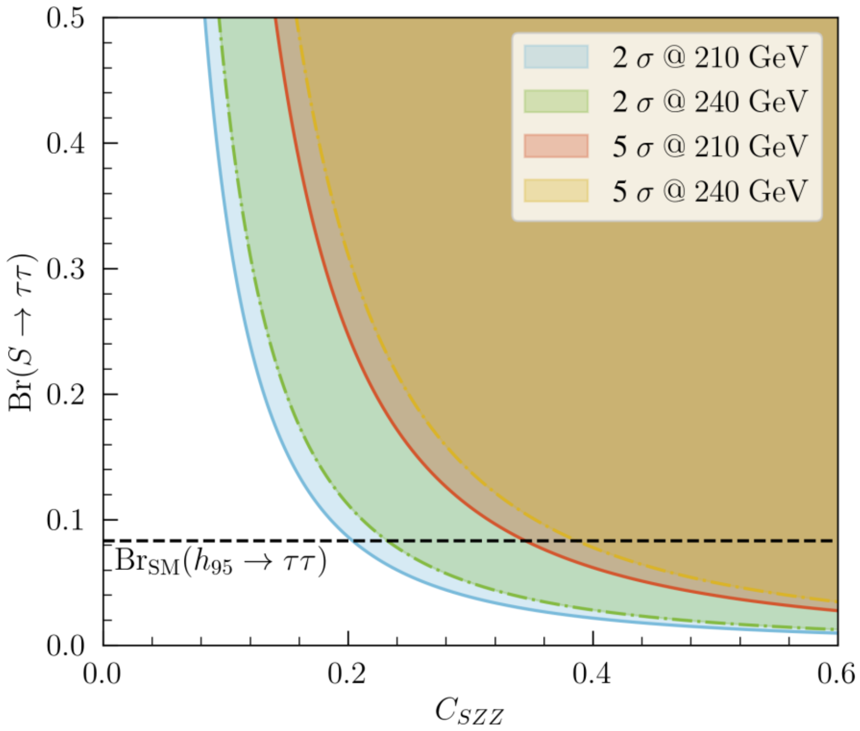


CEPC detection ability： model-independent

ML Result

CEPC overage (L=500 fb^{-1})





210 GeV, 500 fb^{-1}

$\mu^{ZH}_{\tau\tau} > 0.041$ (2σ)

$\mu^{ZH}_{\tau\tau} > 0.116$ (5σ)

240 GeV, 500 fb^{-1}

$\mu^{ZH}_{\tau\tau} > 0.052$ (2σ)

$\mu^{ZH}_{\tau\tau} > 0.150$ (5σ)

L=500 fb^{-1}, $\sqrt{s} = 210\ (240)$ GeV

Cuts	ZS	$Z\tau\tau$	Zjj	$\mathcal{Z}[\sigma]$
Initial	134 (109)	1819 (1769)	24187 (21745)	0.83 (0.7)
Basic	57.6 (51.2)	752.8 (797.5)	45.5 (55.9)	2.0 (1.7)
M_{recoil}	45.4 (37.6)	63.5 (65.2)	4.1 (5.7)	5.0 (4.1)
ML	30.0 (26.3)	7.6 (9.8)	0.5 (0.9)	7.6 (6.3)

$$\mu^{ZH}_{\tau\tau} \equiv \mathrm{k}_Z^2 \cdot \frac{\mathrm{Br}(S \to \tau\tau)}{\mathrm{Br}_\mathrm{S}\mathrm{M}(h_{95} \to \tau\tau)}.$$

Applying to special models： N2HDM-Flipped

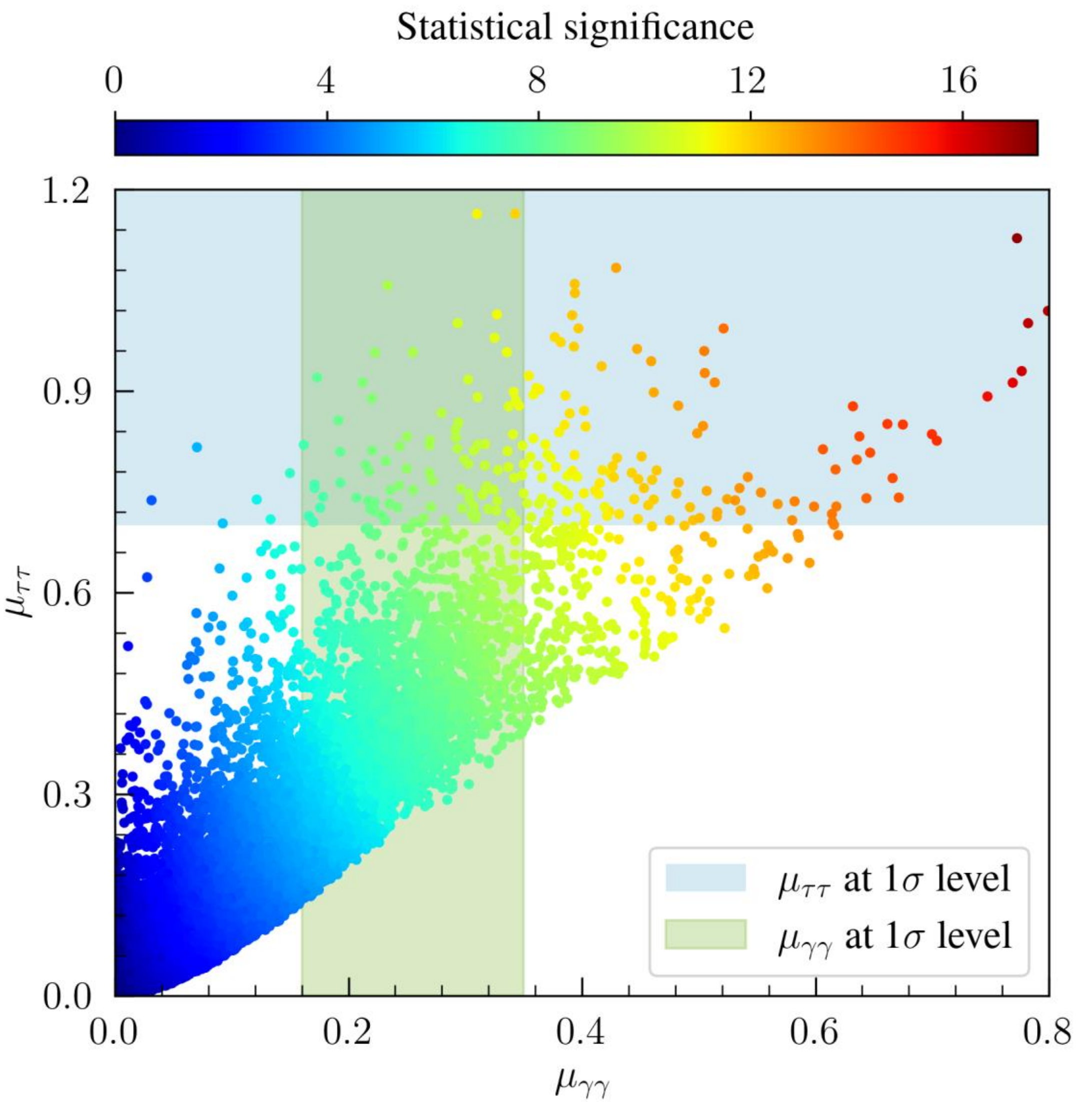
N2HDM-Flipped

Parameter space

$$m_{H_a} = 125.09 \text{ GeV}, \; m_{H_b} \in [95, 96] \text{ GeV}$$
$$m_{H_c,A} \in [300, 1500] \text{ GeV}, \; m_{h^\pm} \in [580, 1500] \text{ GeV},$$
$$\tan\beta \in [0.8, 10], \; \sin\mathrm{R}_{ac,bc} \in [-1, 1],$$
$$C^2_{H_a VV} \in [0.7, 1], \; C^2_{H_a tt} \in [0.7, 1.2],$$
$$m^2_{12} \in [10^{-3}, 5 \cdot 10^5], \; vs \in [1, 3000].$$

The constraints taken into consideration

- Direct searches for Higgs
- SM-like Higgs signal compatibility
- B physics
- Electroweak precision observables
- Vacuum stability
- Unitarity



210 GeV, 500 fb^{-1}

CEPC detection ability: N2HDM-Flipped

χ^2 analysis

$$\mu_{bb}^{\text{ex}} = 0.117 \pm 0.057$$

$$\mu_{\tau\tau}^{\text{ex}} = 1.2 \pm 0.5$$

$$\mu_{\gamma\gamma}^{\text{ex}} = 0.24^{+0.09}_{-0.08}$$

$$\chi^2 = \Sigma \frac{(\mu_{xx} - \mu_{xx}^{\text{exp}})^2}{(\Delta\mu_{xx}^{\text{exp}})^2},$$

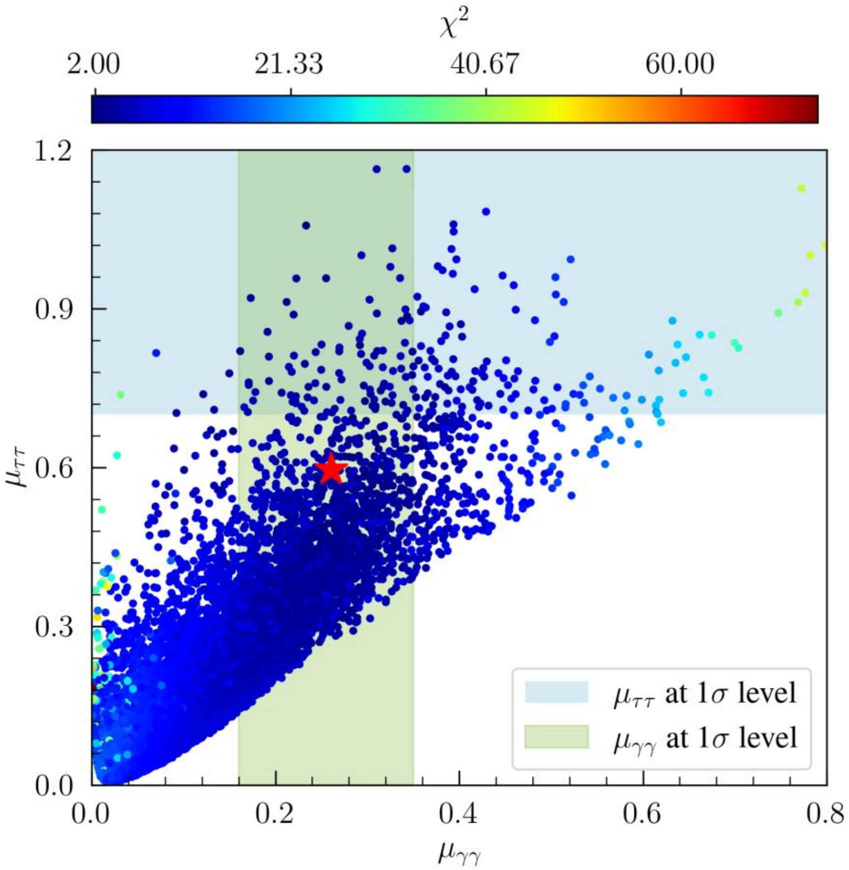
$\chi^2 < 8.23$ at 95% CL.

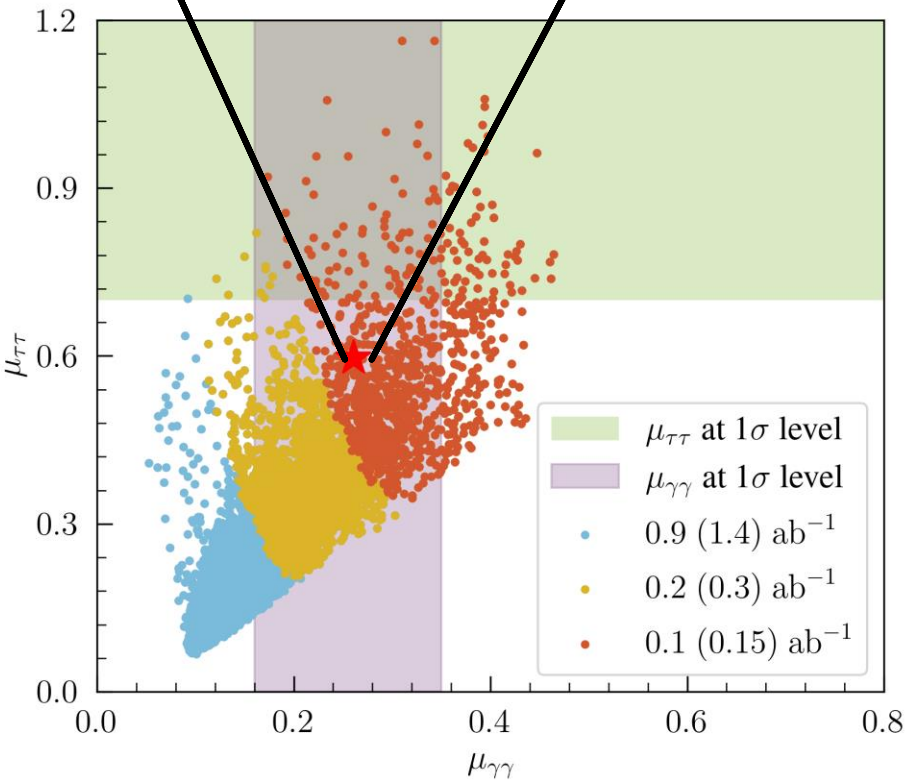
210 GeV

14 fb^{-1} 2σ
87 fb^{-1} 5σ

240 GeV

21 fb^{-1} 2σ
126 fb^{-1} 5σ





6. Conclusions and outlooks

top-pair-associated diphoton channel at the LHC and future hadron colliders

1. Higgs direct search data can exclude the most region with $\alpha \leq 0.95$.
2. Surviving samples can get maximum cross sections of the process $pp \to tth(\to \gamma\gamma)$ at the 0.44 fb, 1.42 fb, and 17.21 fb at HL-LHC, HE-LHC, and FCC-hh, respectively.
3. To achieve a 5σ significance at HL-LHC, HE-LHC, and FCC-hh, the required luminosity are at least 1.4 ab^{-1}, 750 fb^{-1}, and 71 fb^{-1}.
4. At 3 ab^{-1} HL-LHC, 10 ab^{-1} HE-LHC and 30 ab^{-1} FCC-hh, 2HDM-I with $\sin(\beta\text{-}\alpha) \geq 0.4$, 0.25, and 0.1 can be covered at 5 σ level.

Higgsstrahlung ττ channel at the CEPC

1. The signal excesses around 95 GeV or a little heavier, setting the collision energy to 210 GeV is the most appropriate at lepton collider.
2. After applying DNN, the required integral luminosity is reduced over 1/2 to cover the benchmark point.
3. When L=500 fb^{-1}, $\mu_{\tau\tau}^{ZH}$>0.041 (0.052) can be covered at 2σ level and $\mu_{\tau\tau}^{ZH}$>0.116 (0.15) can be covered at 5σ level for 210 (240) GeV collision energy.
4. The best fit point can be covered at 2σ level for L=14 (21) fb^{-1} and 5σ level for L=87 (126) fb^{-1} for 210 (240) GeV collision energy.

For detail at the CEPC, see Yabo Dong's talk

Thanks!