第二届“无中微子双贝塔衰变及相关物理研讨会”

Probing EWPT in 2HDM with Future Lepton Colliders

Wei Su

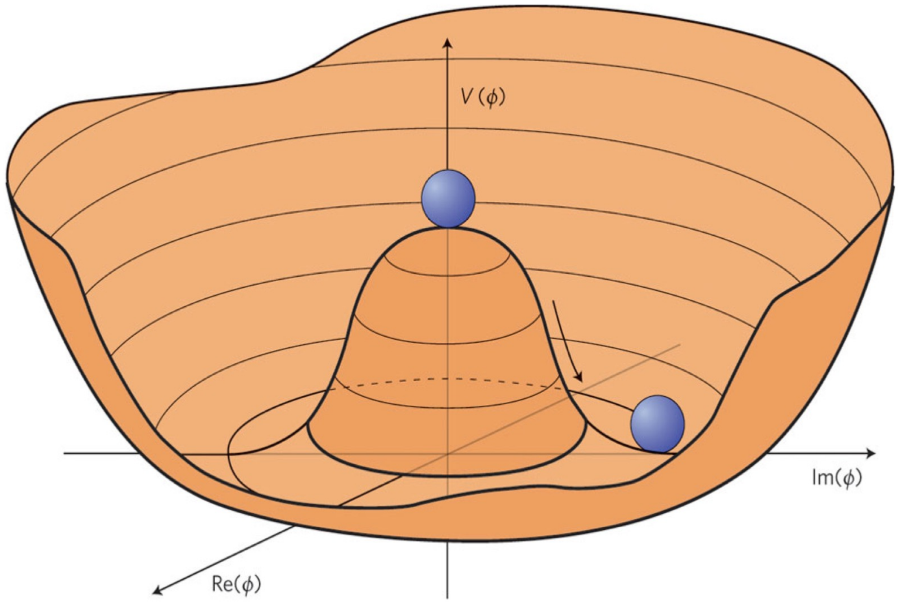
2011.04540 (WS, A G. Williams, M. Zhang)
2204.05085 (HY. Song, WS, M. Zhang)

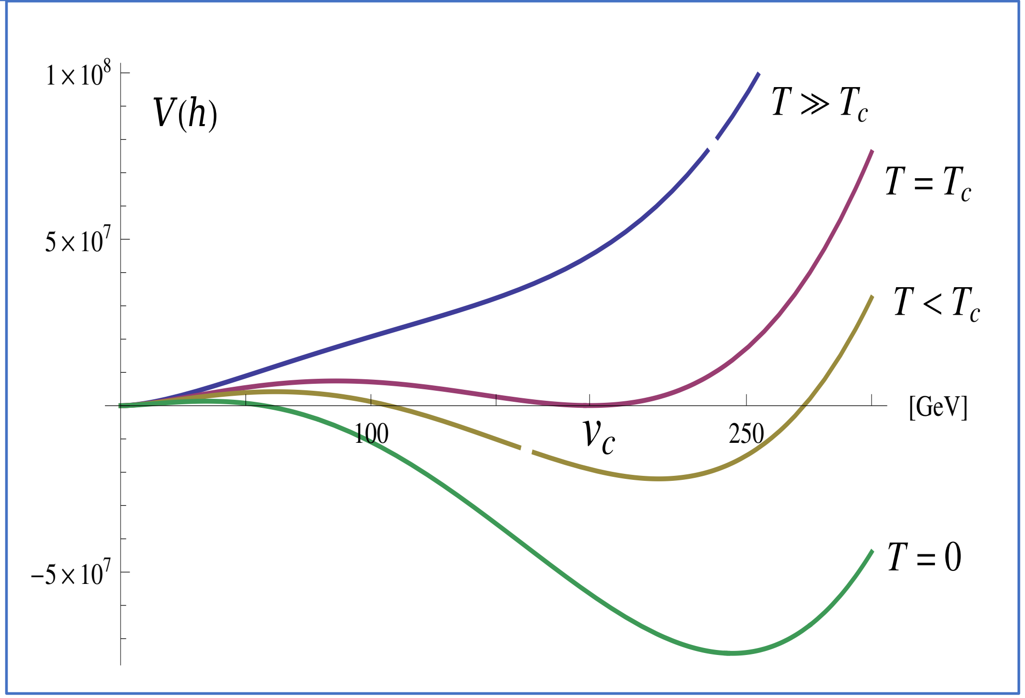
Outline

- 2HDM and Phase Transition
- Higgs/Z-pole Precision Measurements
- Results: 3 cases and general scan
- Conclusion

Electroweak Phase Transition

baryon asymmetry of the Universe (BAU)





SM: Cross-over around T=100 GeV

BSM: bubble formation → asymmetry

2HDM: Brief Introduction

- Two Higgs Doublet Model

$$\Phi_i = \begin{pmatrix} \phi_i^+ \\ (v_i + \phi_i^0 + iG_i)/\sqrt{2} \end{pmatrix}$$

$$v_u^2 + v_d^2 = v^2 = (246\text{GeV})^2$$
$$\tan\beta = v_u/v_d$$

$$\begin{pmatrix} H^0 \\ h^0 \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \phi_1^0 \\ \phi_2^0 \end{pmatrix}, \quad \begin{aligned} A &= -G_1 \sin\beta + G_2 \cos\beta \\ H^\pm &= -\phi_1^\pm \sin\beta + \phi_2^\pm \cos\beta \end{aligned}$$

	Φ_1	Φ_2
Type I	u,d,l	
Type II	u	d,l
lepton-specific	u,d	l
flipped	u,l	d

- Parameters (CP-conserving, Flavor Limit, Z_2 Symmetry)

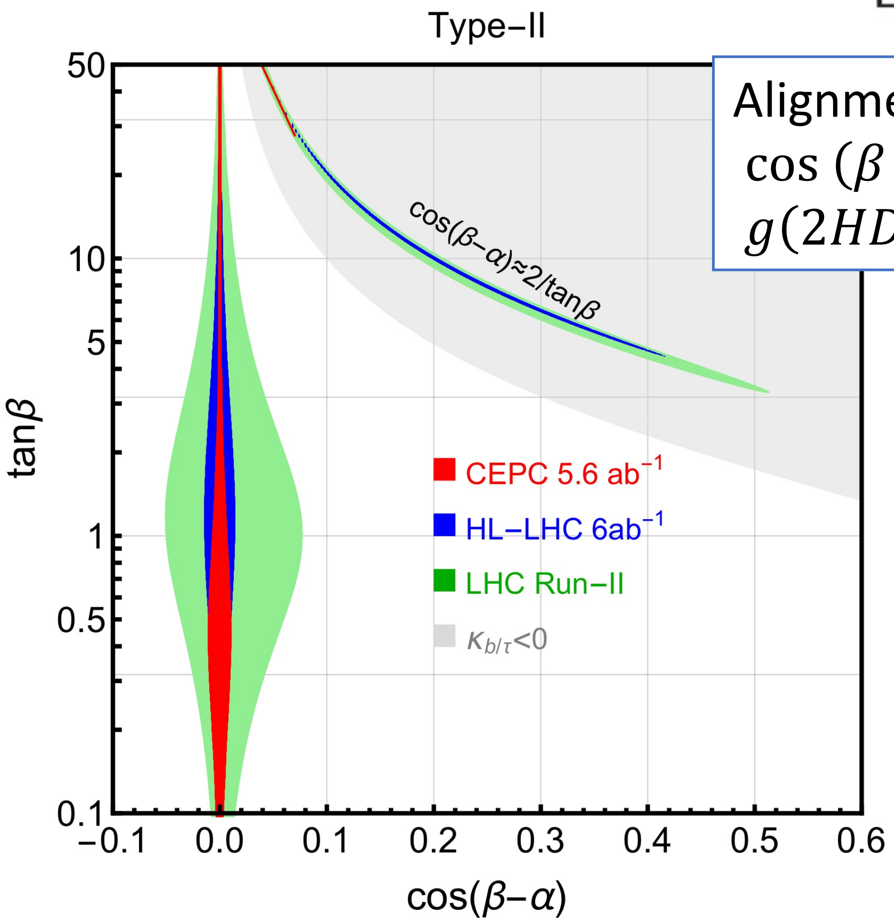
$m_{11}^2, m_{22}^2, \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5$ → $v, \tan\beta, \alpha, m_h, m_H, m_A, m_{H^\pm}$

v → 246 GeV, m_h → 125. GeV

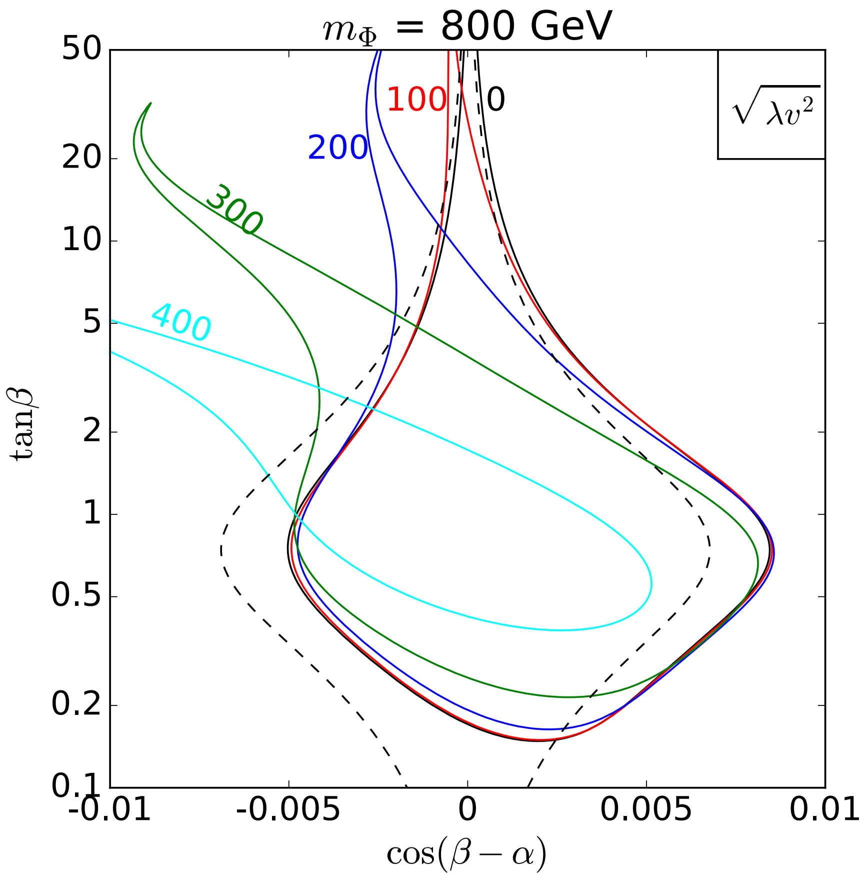
Soft Z_2 symmetry breaking: m_{12}^2

2HDM: precision

Model	κ_V	κ_u	κ_d	κ_ℓ
2HDM-I	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
2HDM-II	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$-\sin\alpha/\cos\beta$
2HDM-L	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
2HDM-F	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$



Alignment limit :
$\cos(\beta-\alpha)=0$
$g(2HDM)=g(SM)$



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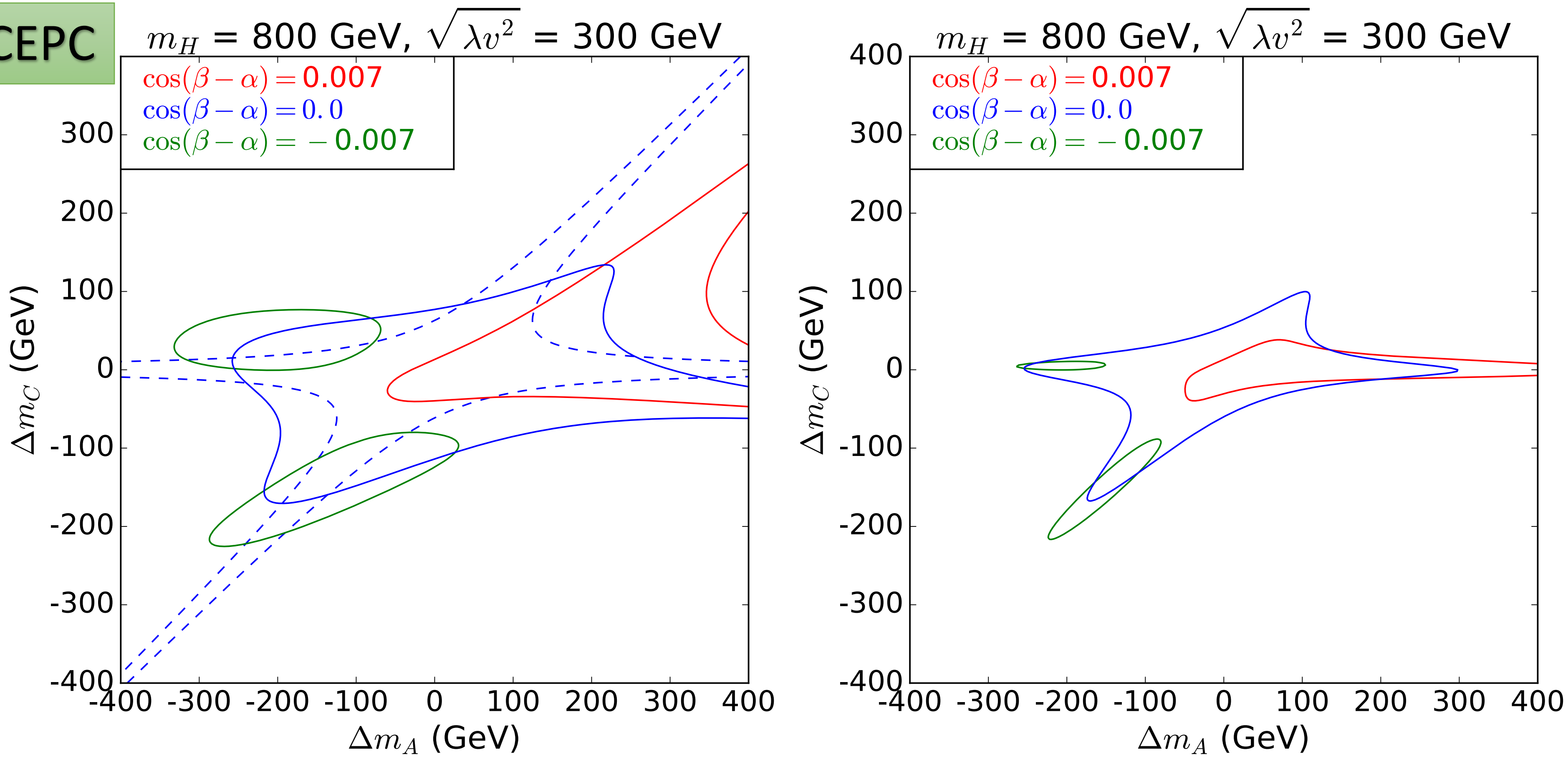
1808.02037 N. Chen, T. Han, S. Su, WS, Y. Wu

2HDM: precision

1808.02037 N. Chen, T. Han, S. Su, WS, Y. Wu

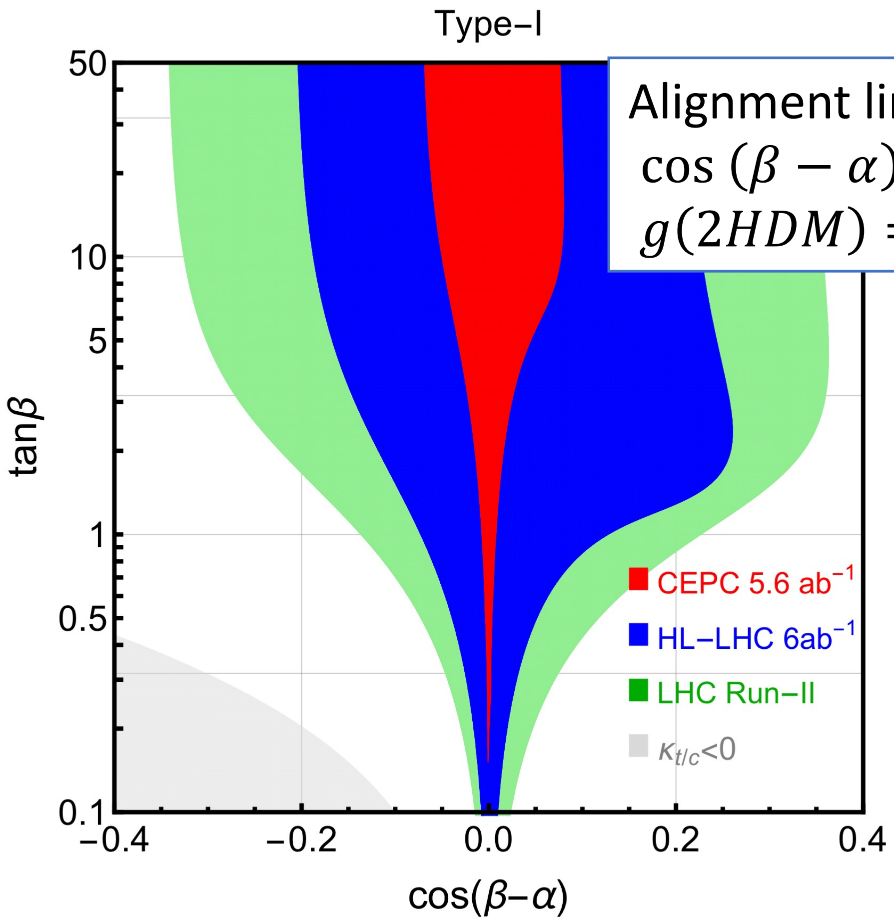
Type-II, CEPC



2HDM: precision

Model	κ_V	κ_u	κ_d	κ_ℓ
2HDM-I	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$

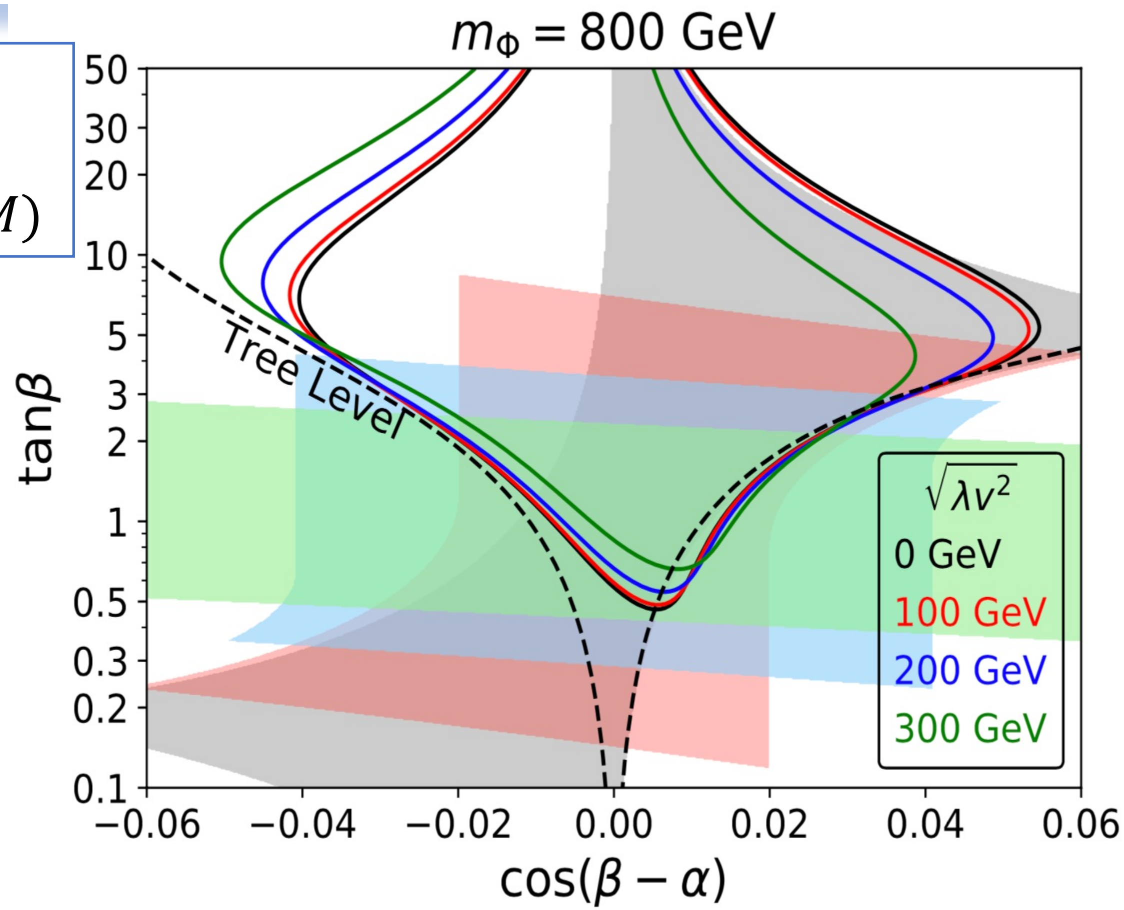
$$\Delta\kappa_{u,d,e} = \frac{\cos\alpha}{\sin\beta} - 1 = -\frac{1}{2}\cos^2(\beta-\alpha) + \frac{\cos(\beta-\alpha)}{\tan\beta}$$



Alignment limit :

$\cos(\beta-\alpha) = 0$

$g(2HDM) = g(SM)$



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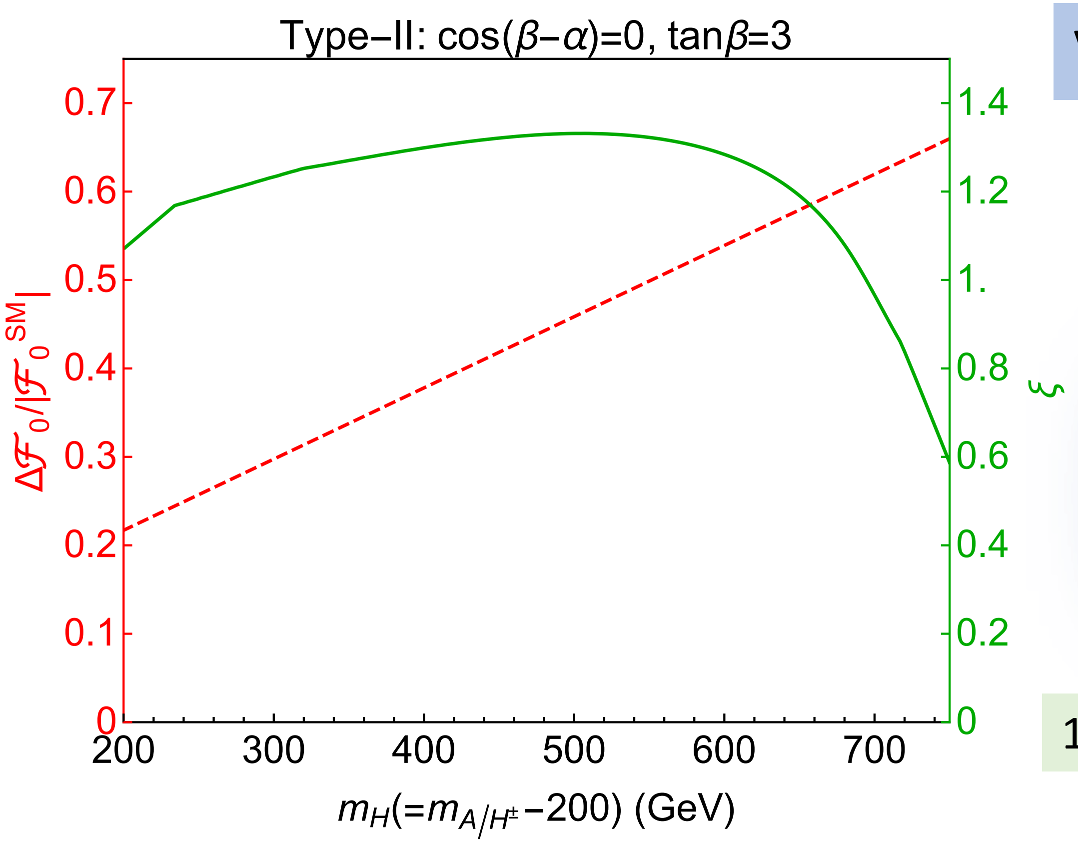
PT vs. vacuum uplifting



Vacuum energy F

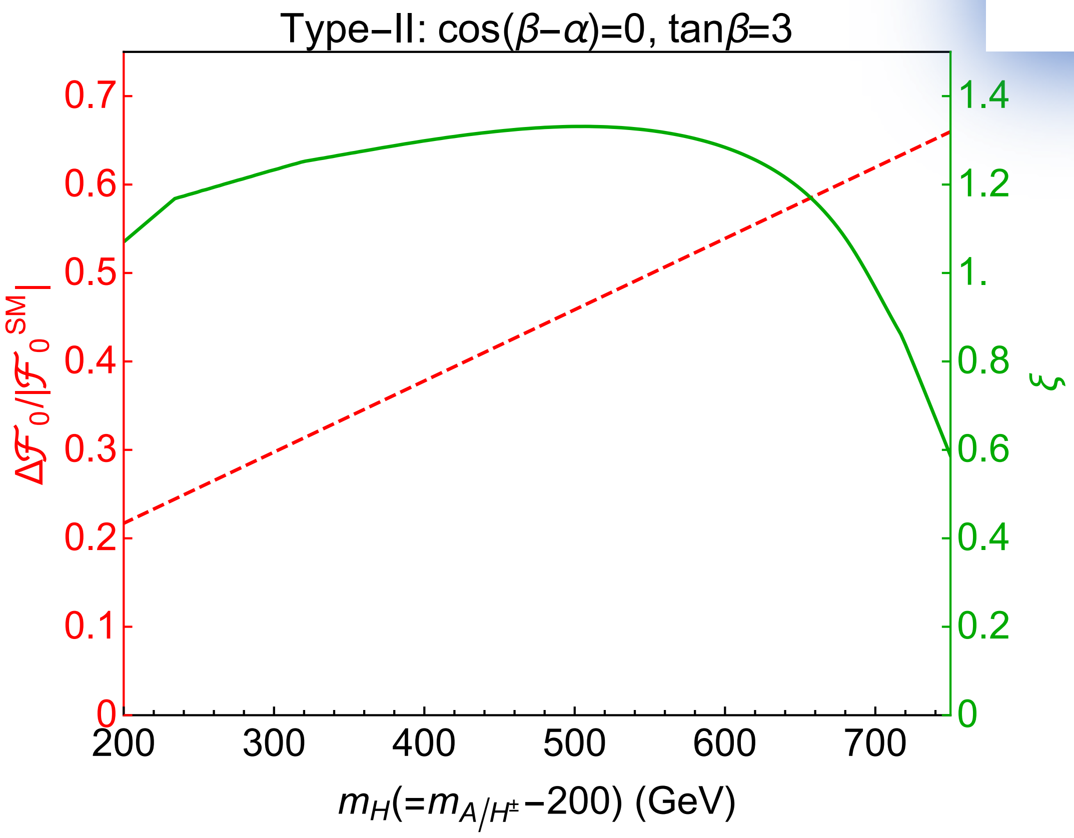
$$\mathcal{F}_0^{\rm SM} = -\frac{m_h^2 v^2}{8} + \frac{1}{64\pi^2}\left(3m_W^4 + \frac{3}{2}m_Z^4 - 6m_t^4\right) + \frac{m_h^4}{64\pi^2}(3+\log 2)$$

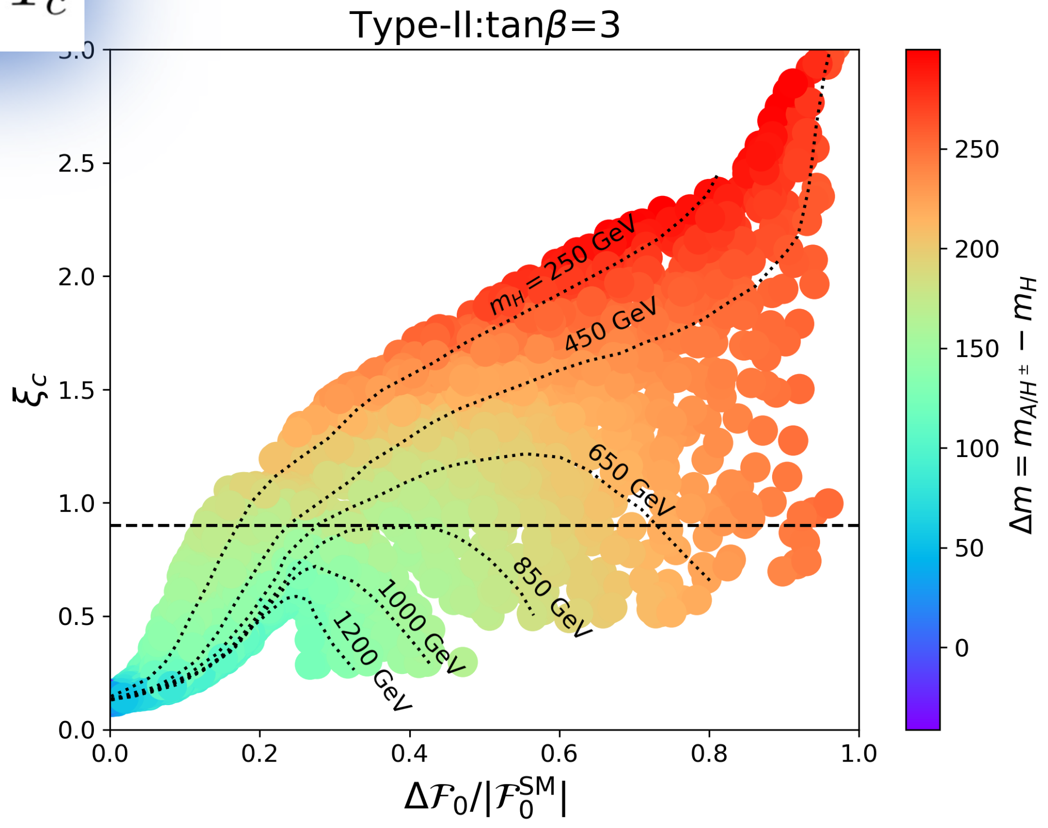
$$\xi_c \equiv \frac{v_c}{T_c}$$

1705.09186 G. C. Dorsch, S. J. Huber, K. Mimasu, J. M. No

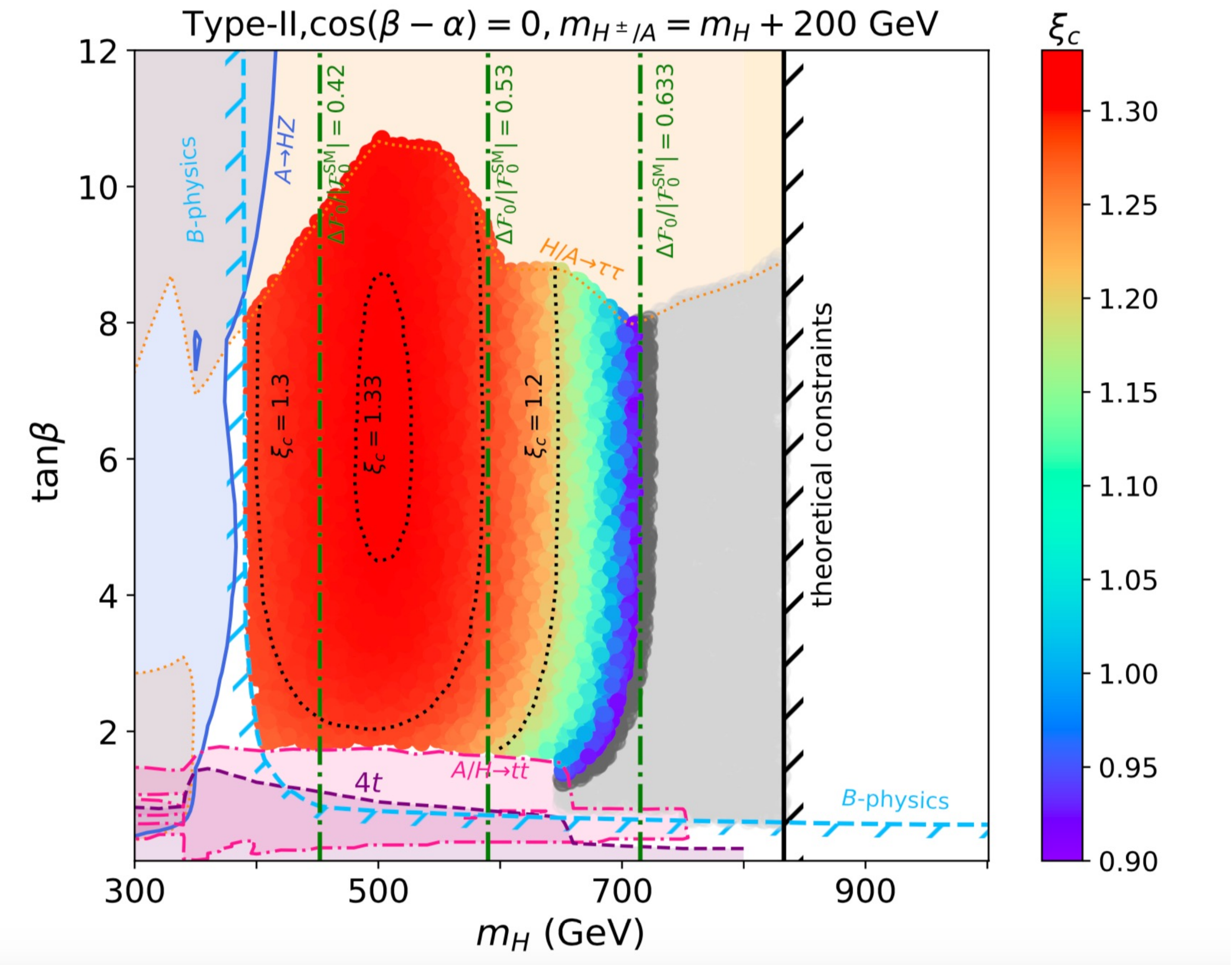
PT vs. vacuum uplifting

$$\xi_c \equiv \frac{v_c}{T_c}$$





Results: Case-1

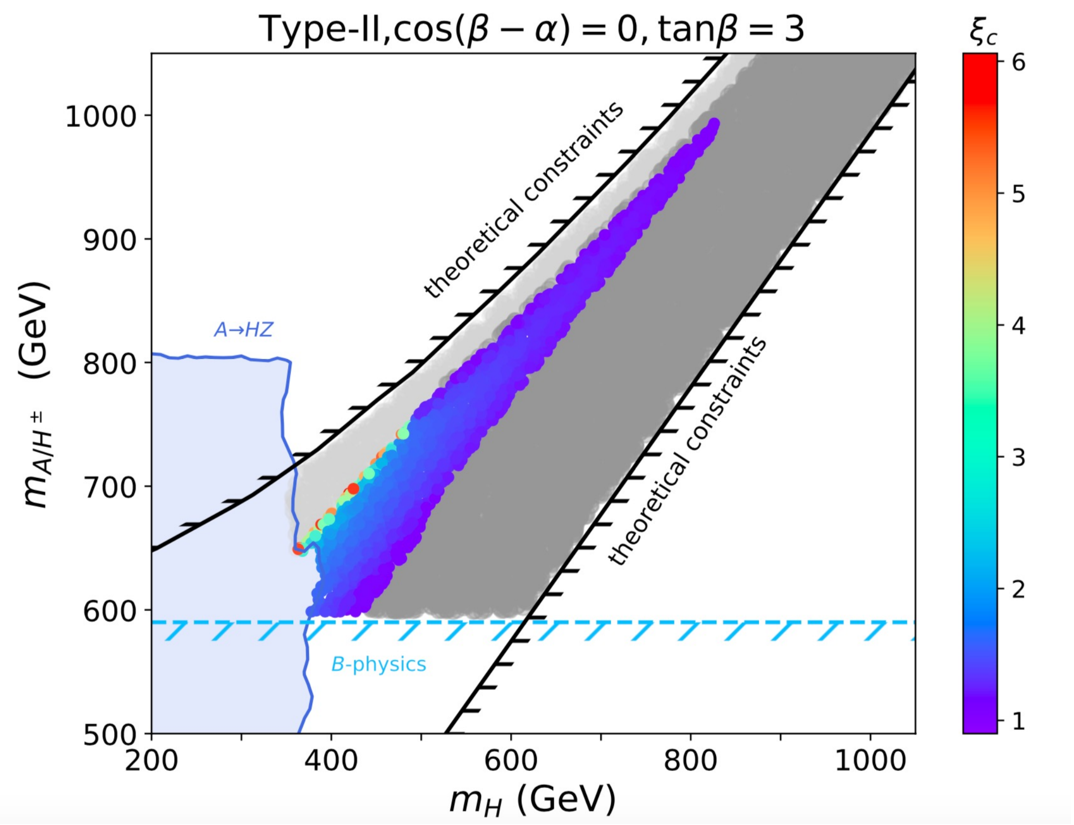


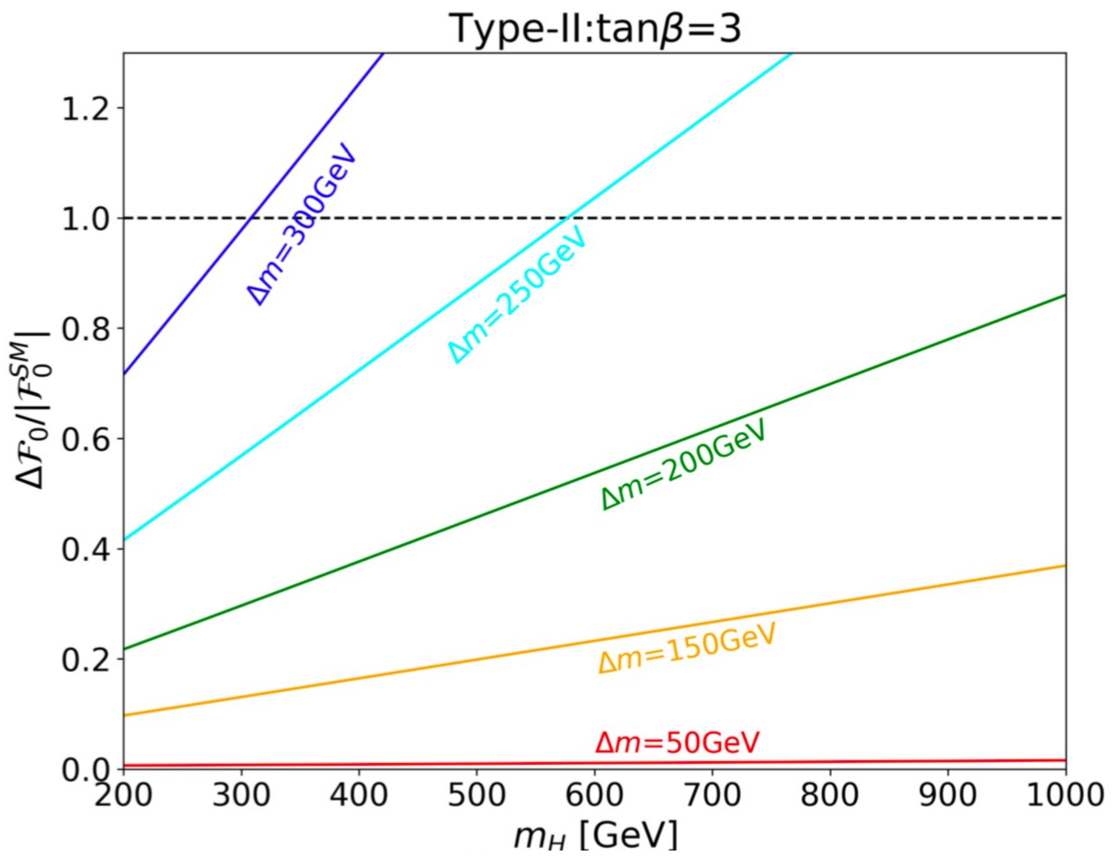
Type-II
fixed mass splitting 200 GeV

$m_H < 710$ GeV
$tan\beta \; \epsilon \; (1.8,10)$

Results: Case-2

$$m_A = m_{H^\pm} \;\; \tan\beta = 3$$





Results: Case-2

High T approximation:

$$V(\phi_h, T) \approx (DT^2 - \mu^2)\phi_h^2 - ET\phi_h^3 + \frac{\tilde{\lambda}}{4}\phi_h^4$$

$$D = \frac{1}{24}\left[6\frac{m_W^2}{v^2} + 3\frac{m_Z^2}{v^2} + \frac{m_h^2}{v^2} + 6\frac{m_t^2}{v^2} + \frac{m_H^2 - M^2}{v^2} + \frac{m_A^2 - M^2}{v^2} + 2\frac{m_{H^\pm}^2 - M^2}{v^2}\right]$$

$$E = \frac{1}{12\pi}\left[6\frac{m_W^3}{v^3} + 3\frac{m_Z^3}{v^3} + \frac{m_h^3}{v^3}\right] + E_{(H/A/H^\pm)}$$

$$E_{(\alpha)} \approx \begin{cases} \frac{1}{12\pi}\lambda_\alpha^{3/2} = \frac{1}{12\pi}\frac{m_\alpha^3}{v^3}, & M^2 \ll \lambda_\alpha\phi_h^2 \\ 0, & M^2 \gg \lambda_\alpha\phi_h^2 \end{cases}$$

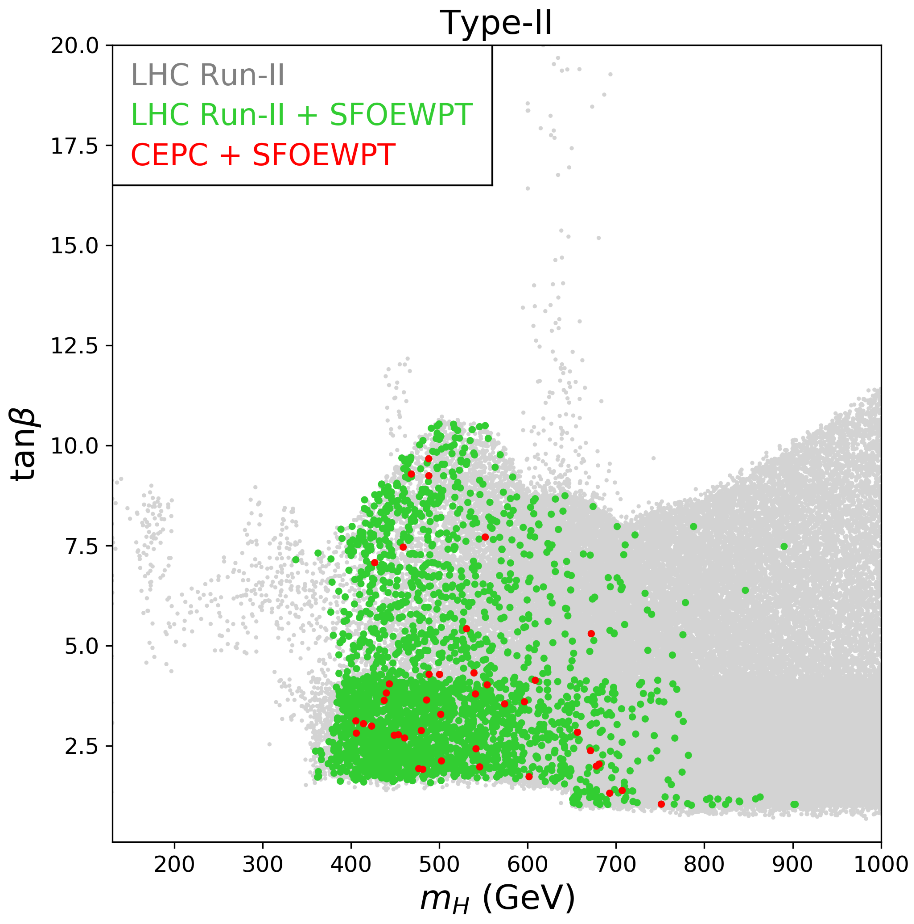
$$\lambda_{A/H^\pm}v^2 = (\Delta m)^2 + 2m_H\Delta m$$

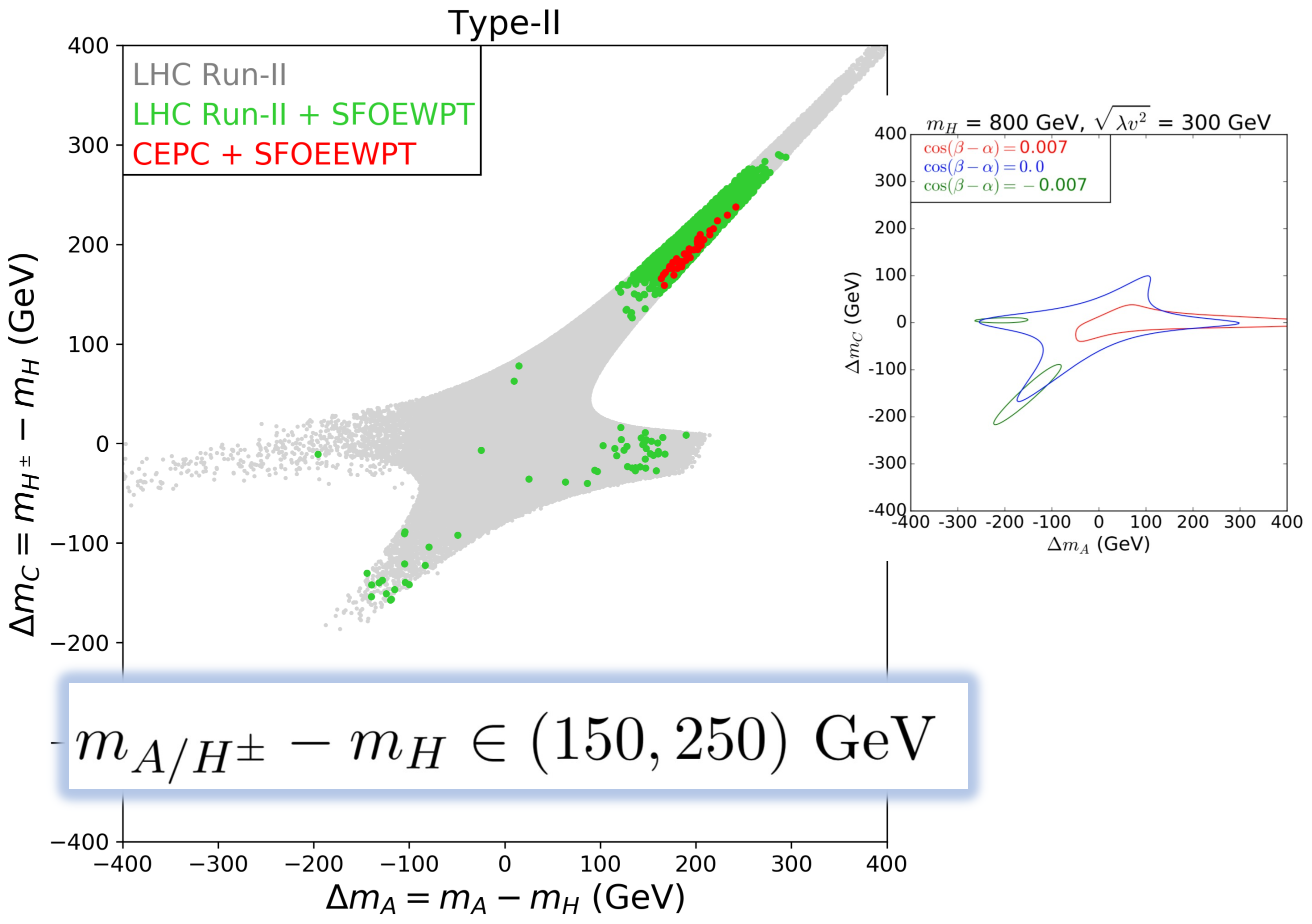
Vacuum uplifting:

$$\Delta\mathcal{F}_0 = \frac{1}{64\pi^2}\left[\left(m_h^2 - 2M^2\right)^2\left(\frac{3}{2} + \frac{1}{2}\log\left[\frac{4m_A m_H m_{H^\pm}^2}{\left(m_h^2 - 2M^2\right)^2}\right]\right)\right.$$
$$\left. + \frac{1}{2}\left(m_A^4 + m_H^4 + 2m_{H^\pm}^4\right) + \left(m_h^2 - 2M^2\right)\left(m_A^2 + m_H^2 + 2m_{H^\pm}^2\right)\right]$$

Too large masses or mass splitting can not generate SFOEWPT

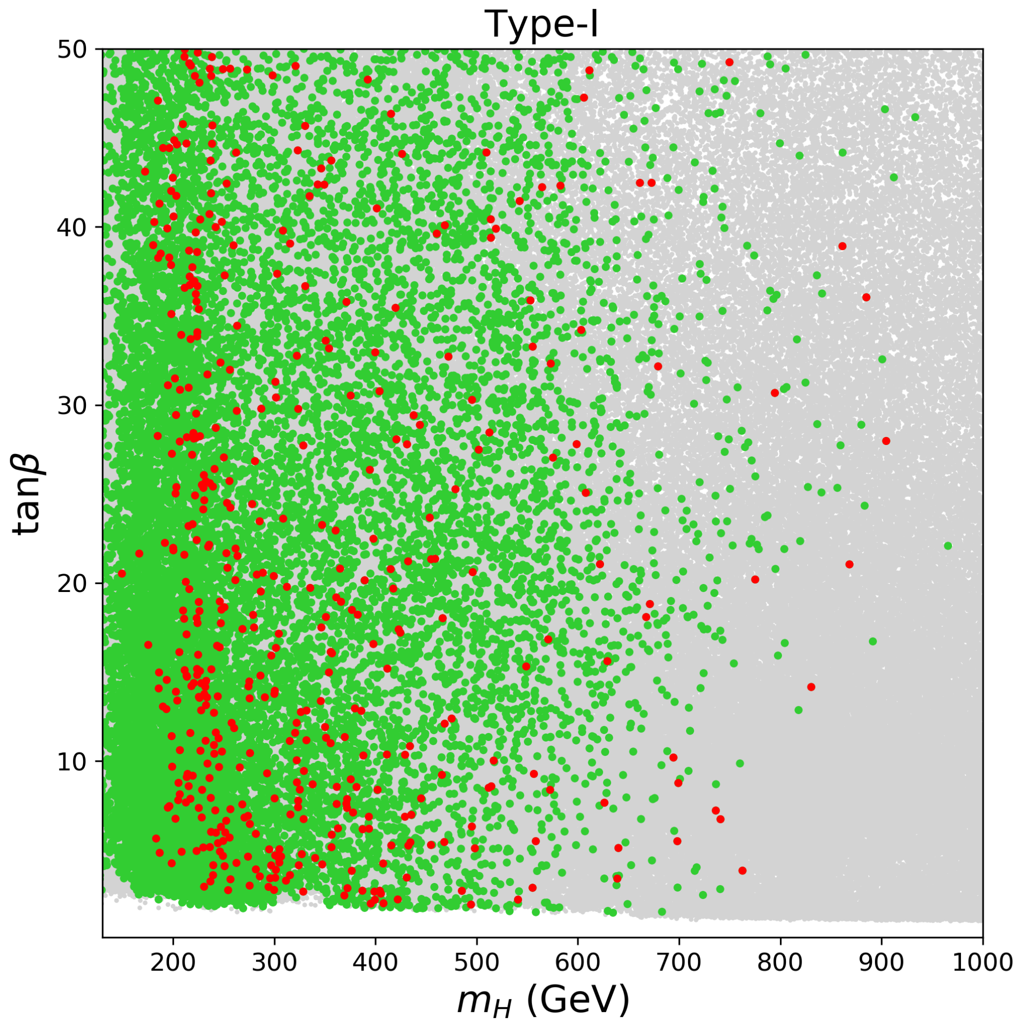
Results: Type-II

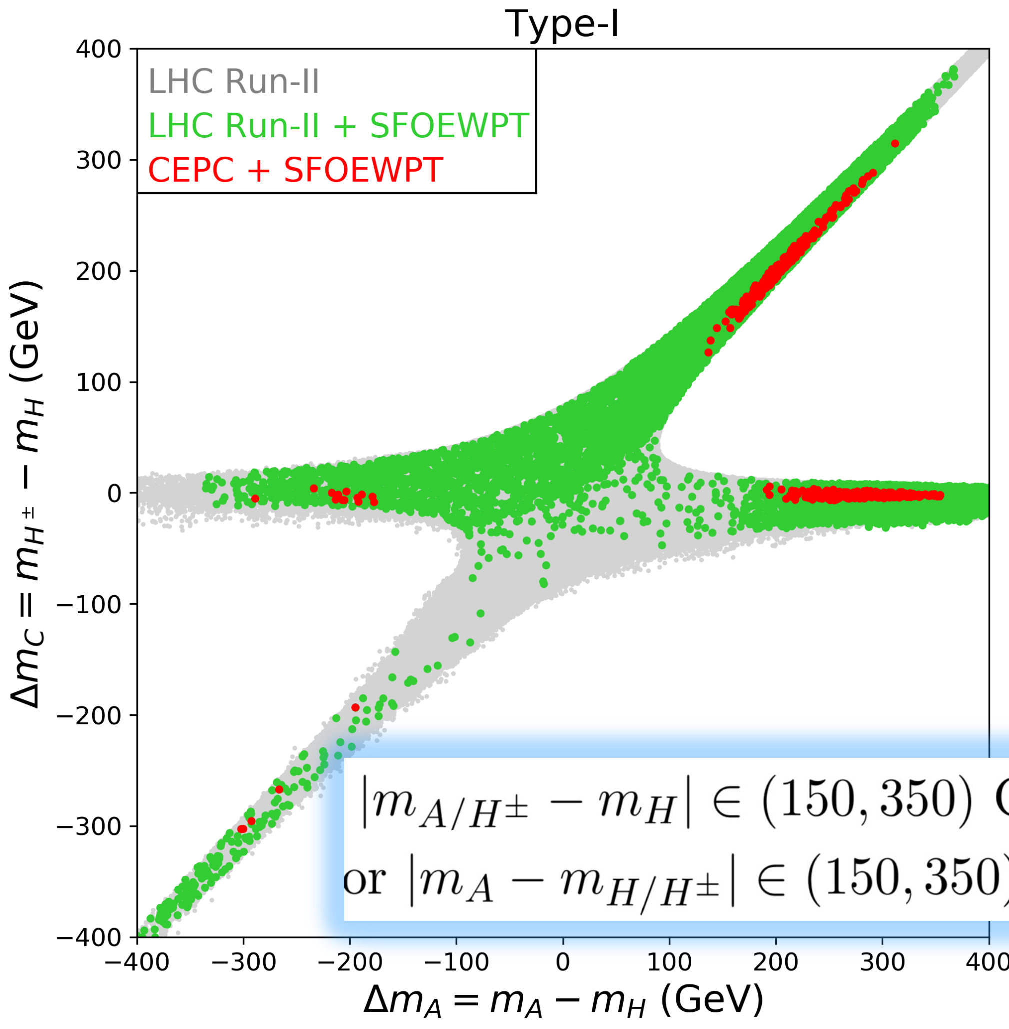




$$m_{A/H^\pm} - m_H \in (150, 250)\ \text{GeV}$$

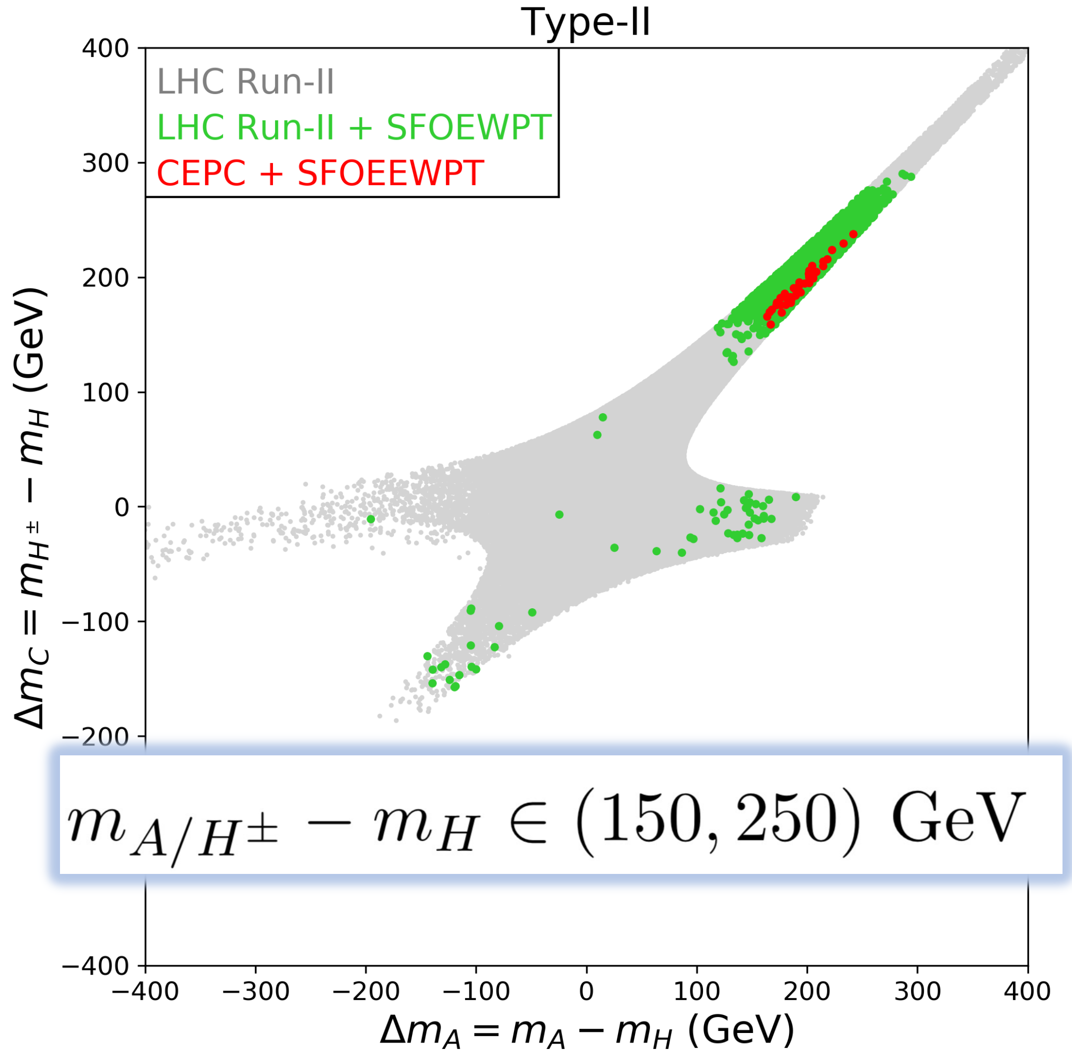
Results: Type-I



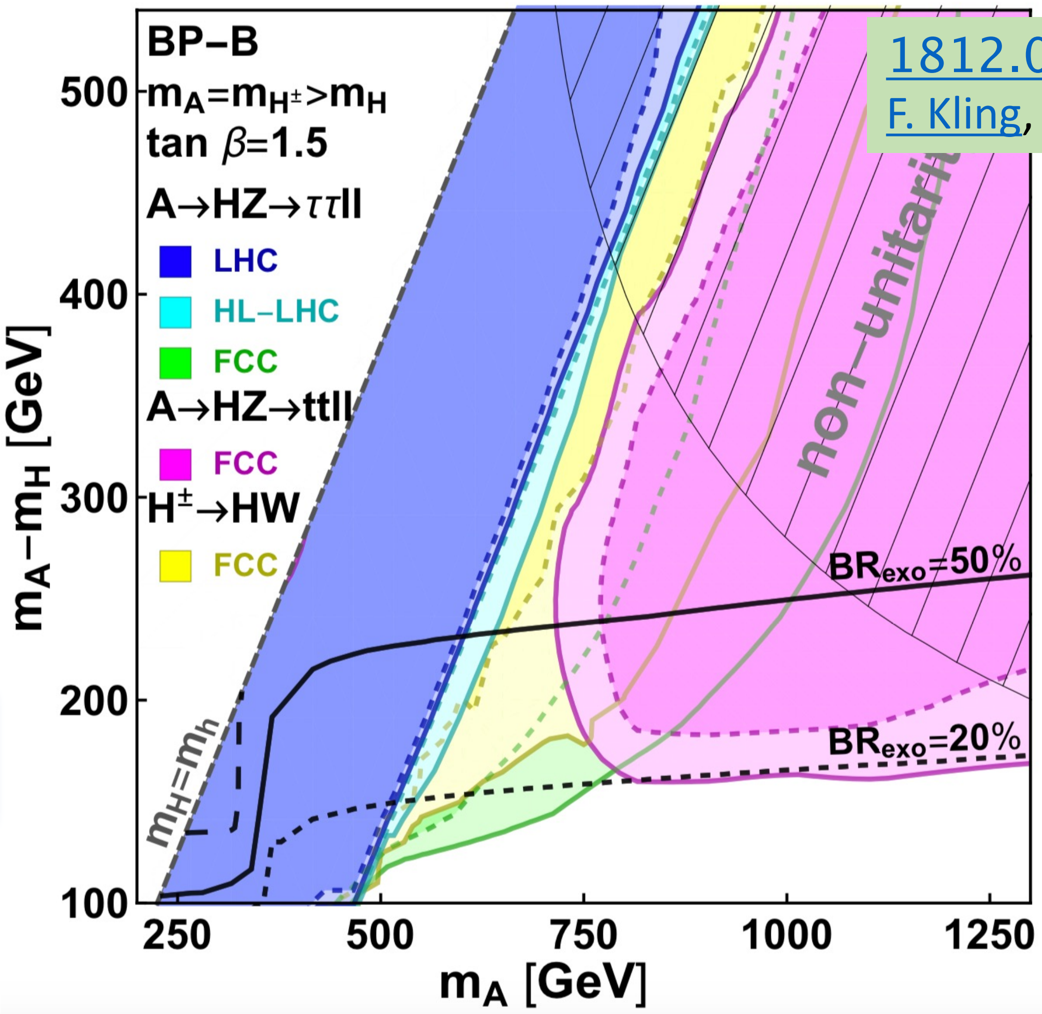


$$|m_{A/H^\pm} - m_H| \in (150, 350)\ \text{GeV}$$
$$\text{or } |m_A - m_{H/H^\pm}| \in (150, 350)\ \text{GeV}$$

Future



$$m_{A/H^\pm} - m_H \in (150, 250)\ \text{GeV}$$



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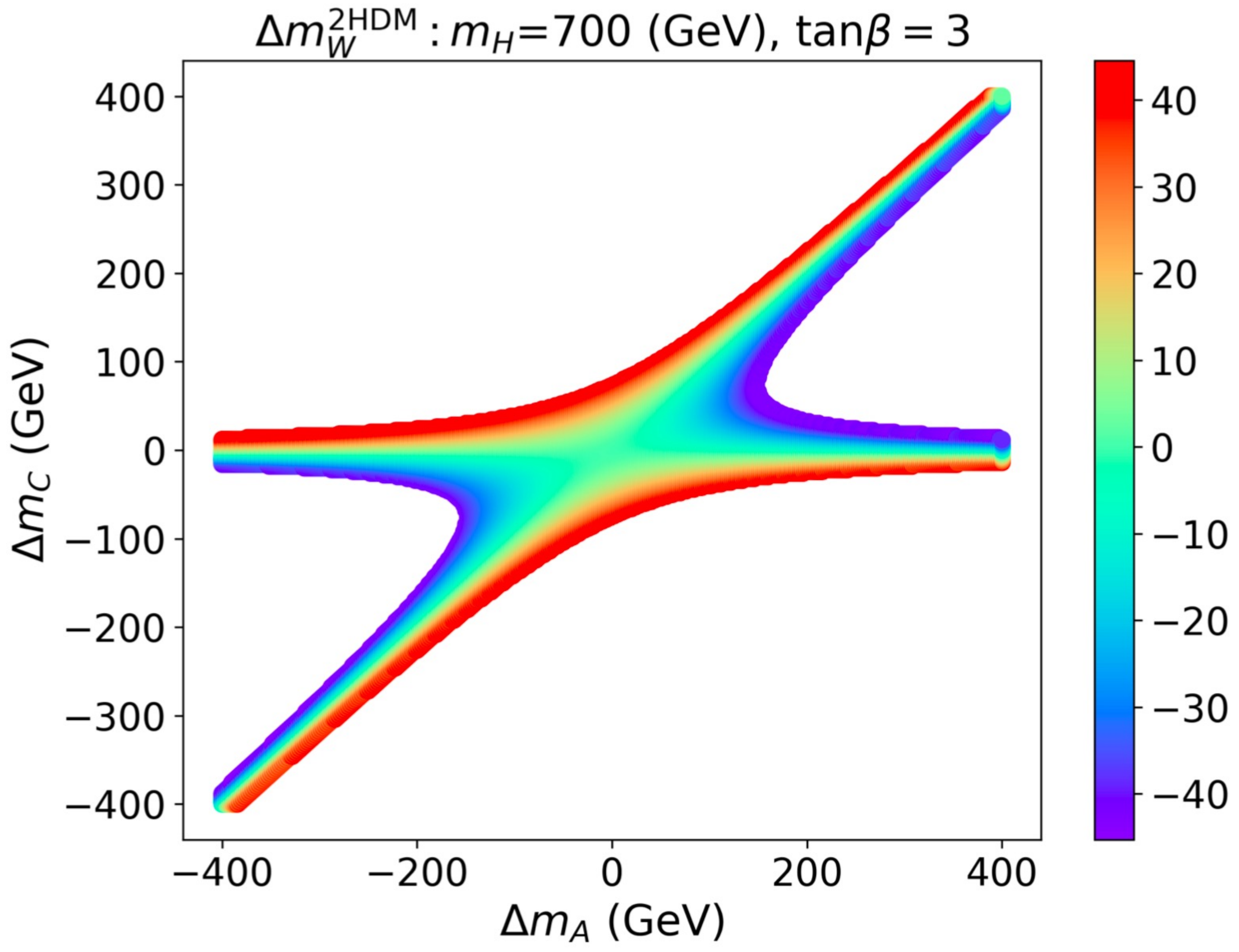
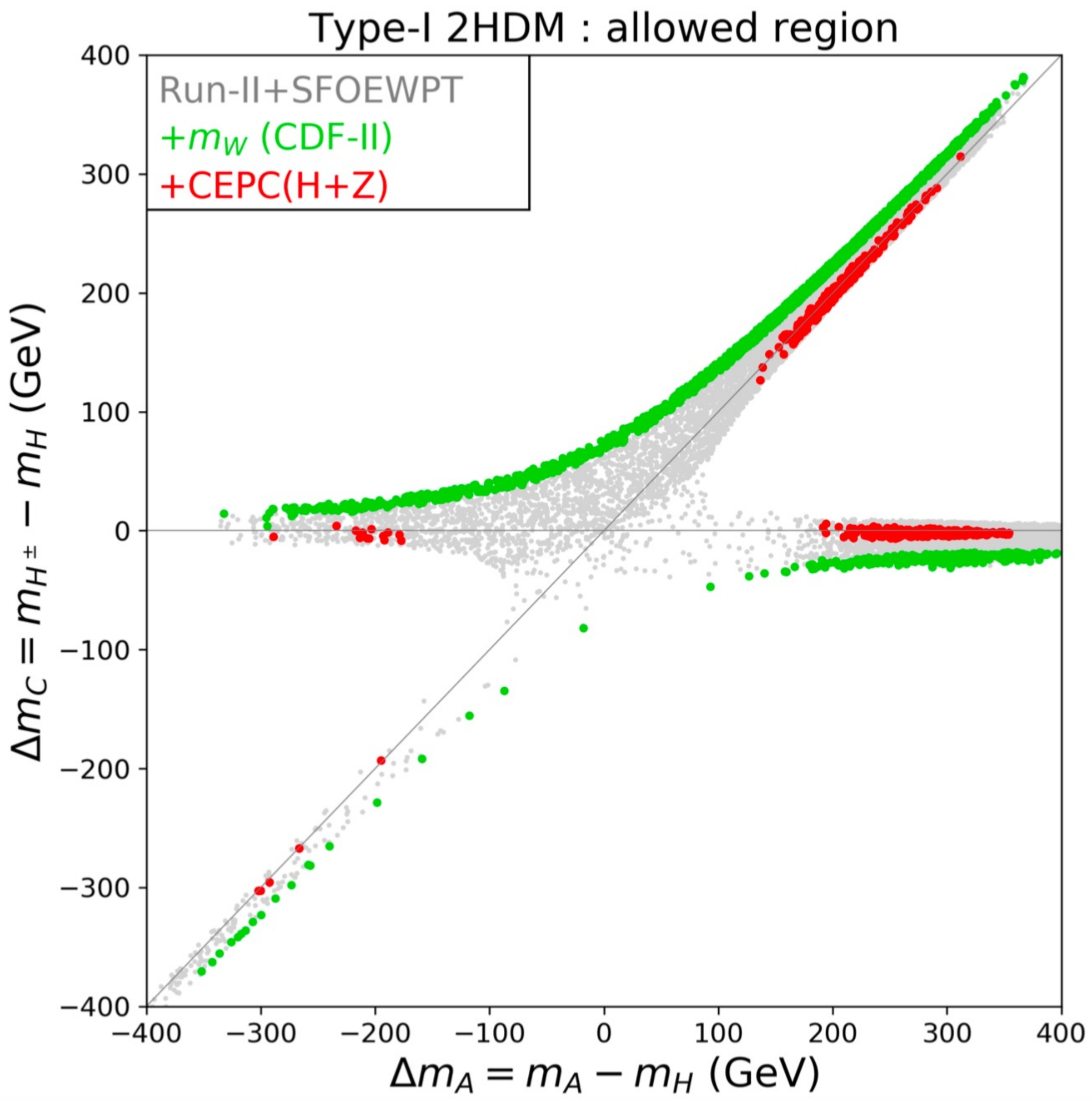
F. Kling, H. Li, etc

W mass

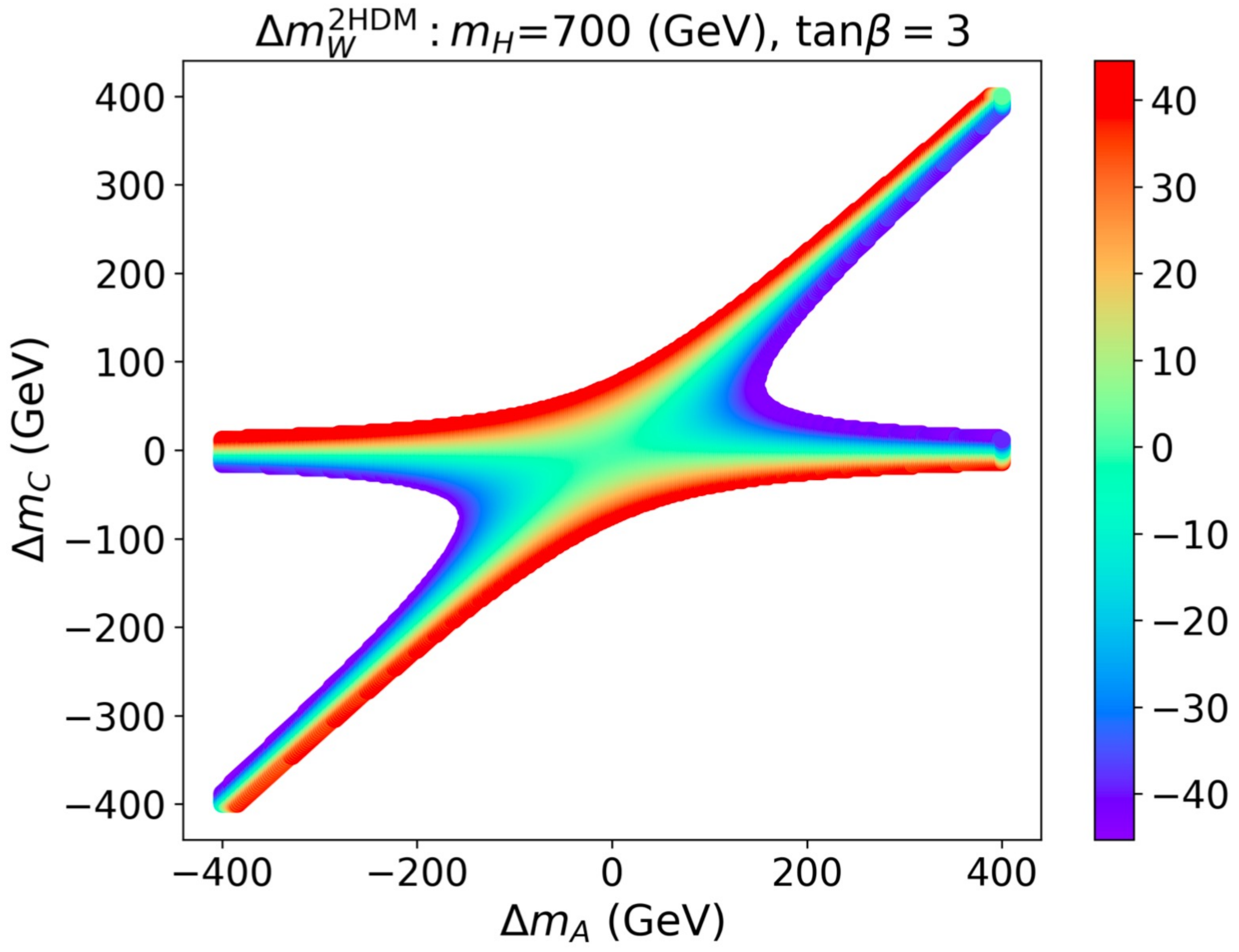


$\Delta m_W^{2HDM} : m_H$=700 (GeV), tan$\beta = 3$
Δm_C (GeV)
Δm_A (GeV)
400
300
200
100
0
−100
−200
−300
−400
−400
−200
0
200
400
40
30
20
10
0
−10
−20
−30
−40

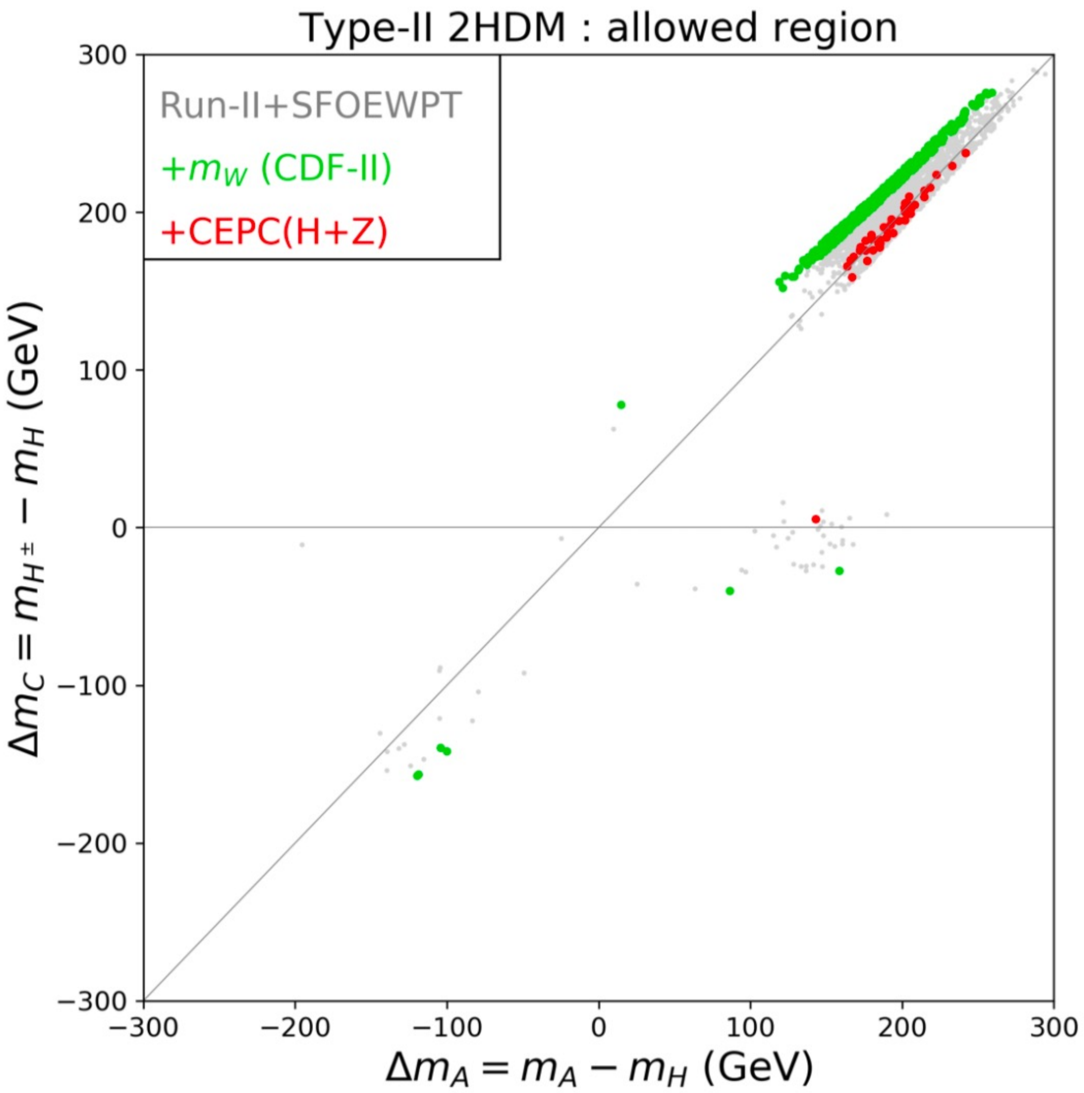


Type-I 2HDM : allowed region
Run-II+SFOEWPT
$+m_W$ (CDF-II)
+CEPC(H+Z)
$\Delta m_C = m_{H^\pm} - m_H$ (GeV)
$\Delta m_A = m_A - m_H$ (GeV)
400
300
200
100
0
−100
−200
−300
−400
−400
−300
−200
−100
0
100
200
300
400

W mass

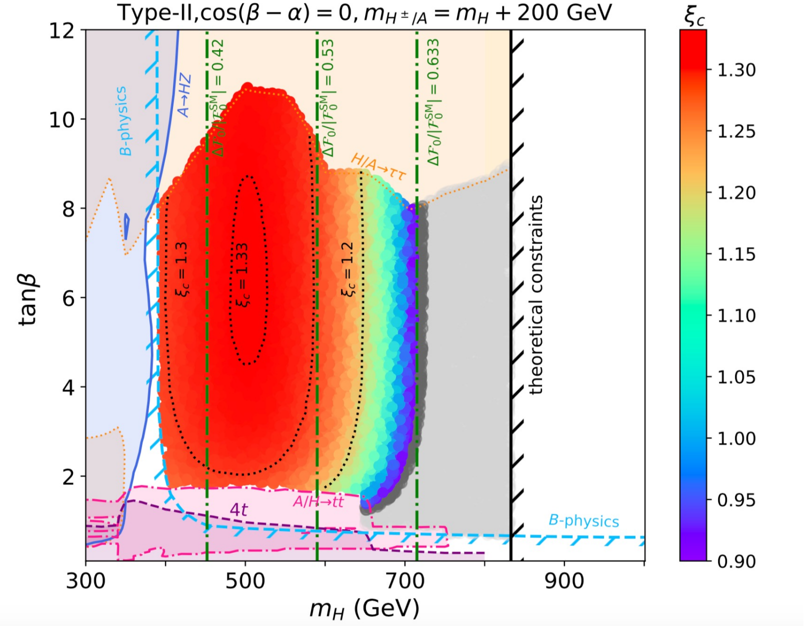


$\Delta m_W^{\mathrm{2HDM}}: m_H$=700 (GeV), tan$\beta = 3$
Δm_C (GeV)
Δm_A (GeV)
400
300
200
100
0
−100
−200
−300
−400
−400
−200
0
200
400
40
30
20
10
0
−10
−20
−30
−40

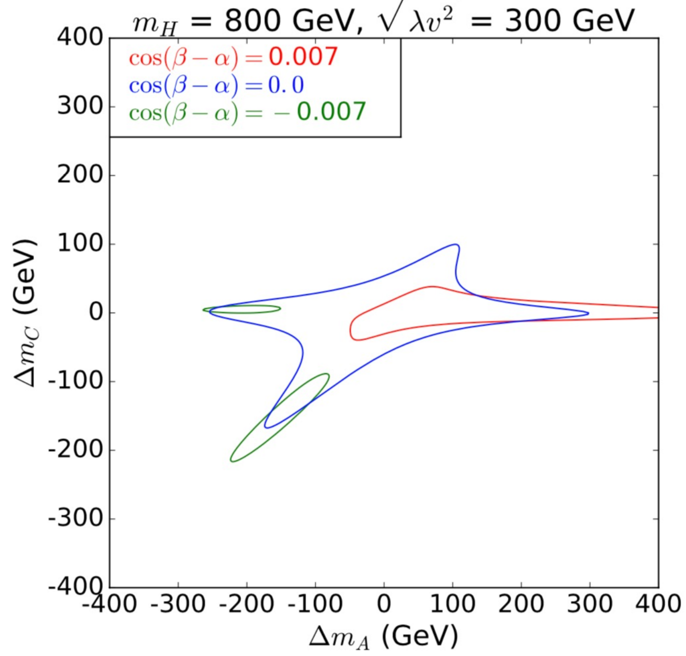


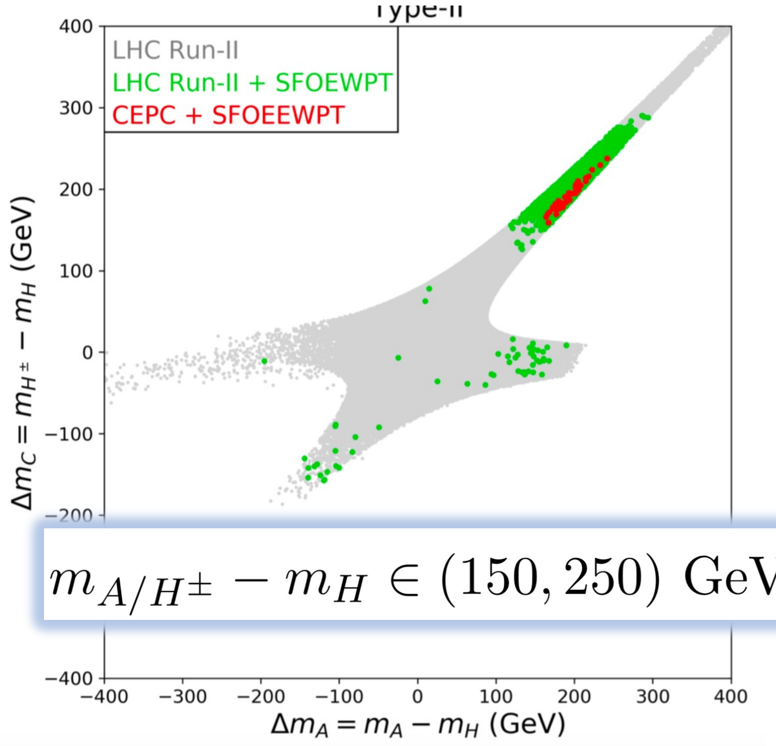
Type-II 2HDM : allowed region
Run-II+SFOEWPT
$+m_W$ (CDF-II)
+CEPC(H+Z)
$\Delta m_C = m_{H^\pm} - m_H$ (GeV)
$\Delta m_A = m_A - m_H$ (GeV)
300
200
100
0
−100
−200
−300
−300
−200
−100
0
100
200
300

Conclusion

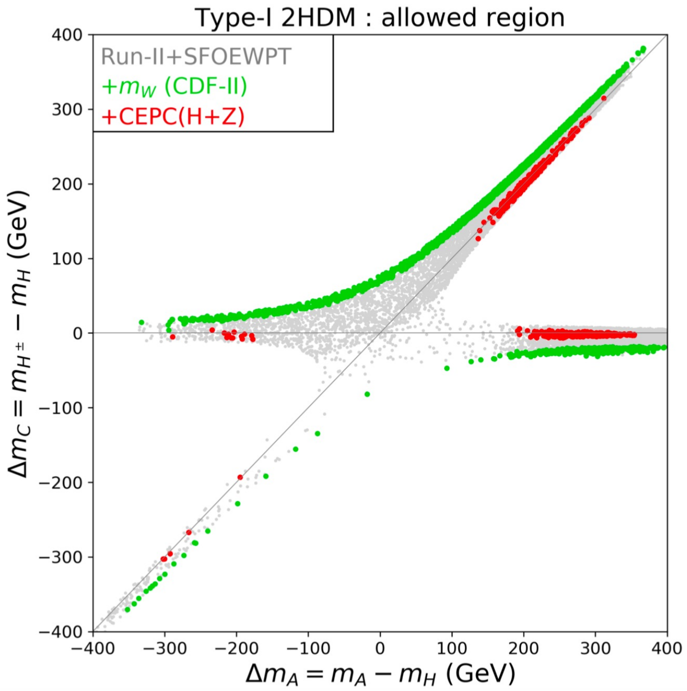


Mass less than 1 TeV





$$m_{A/H^\pm} - m_H \in (150, 250)\ \text{GeV}$$



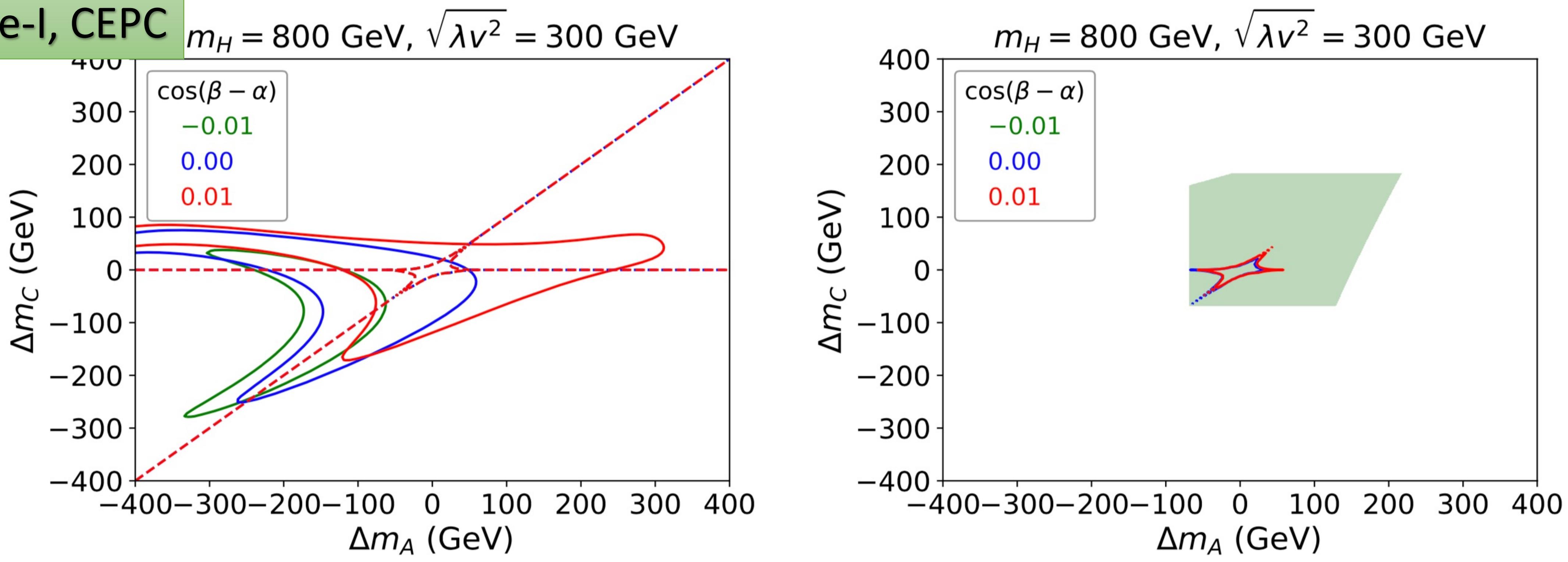
Thanks!

成立于2021年，粒子物理（理论+实验）是重要学科，欢迎大家加入！

2HDM: precision

[1912.01431](https://arxiv.org/abs/1912.01431) N. Chen, T. Han, S. Li, S. Su, WS, Y. Wu

Type-I, CEPC



The precisions changed for Type-I and Type-II

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