2HDM under the Higgs and Electroweak Precision Measurements

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EF02: LOI Review
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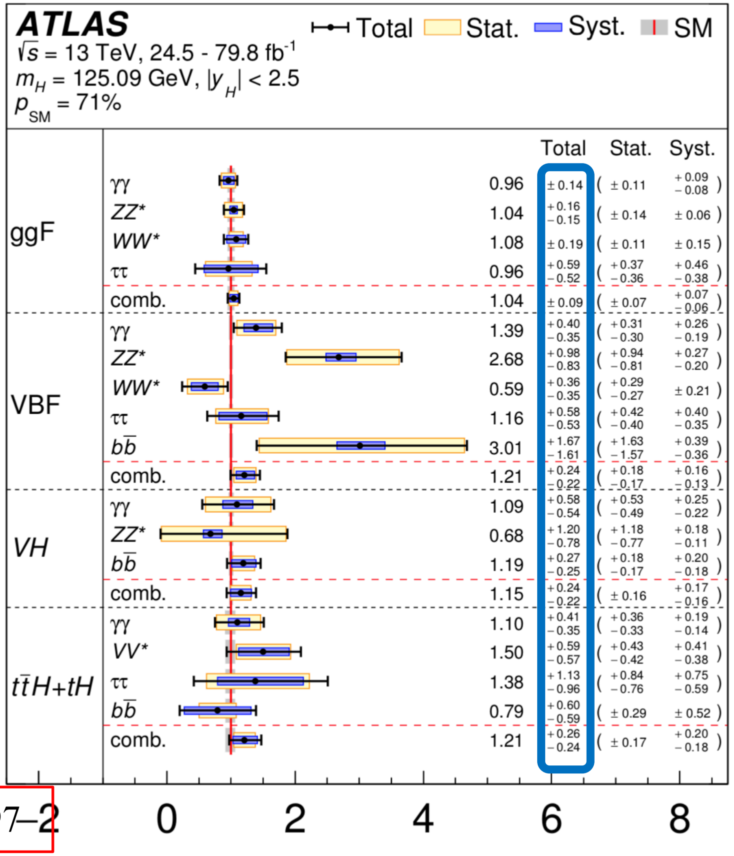
1709.06103: J. Gu, H. Li, *et al.*
1808.02037: N. Chen, T. Han, *et al.*
1912.01431: N. Chen, T. Han, *et al.*
2008.05492: T. Han, S. Li, *et al.*

Higgs and Electroweak Precision Measurement

1808.02037

$$\mu = \frac{\sigma \times \mathrm{Br}}{(\sigma \times \mathrm{Br})_{\mathrm{SM}}}$$



CERN-EP-2019-097

collider	CEPC	FCCee			ILC				
$\sqrt{s}$	240 GeV	240 GeV	365 GeV		250 GeV	350 GeV		500 GeV	
$\int \mathcal{L}dt$	5.6 ab^{-1}	5 ab^{-1}	1.5 ab^{-1}		2 ab^{-1}	200 fb^{-1}		4 ab^{-1}	
production	Zh	Zh	Zh	$\nu\bar{\nu}h$	Zh	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$
$\Delta\sigma/\sigma$	0.5%	0.5%	0.9%	–	0.71%	2.0%	–	1.05	–
decay	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$								
$h \to b\bar{b}$	0.27%	0.3%	0.5%	0.9%	0.46%	1.7%	2.0%	0.63%	0.23%
$h \to c\bar{c}$	3.3%	2.2%	6.5%	10%	2.9%	12.3%	21.2%	4.5%	2.2%
$h \to gg$	1.3%	1.9%	3.5%	4.5%	2.5%	9.4%	8.6%	3.8%	1.5%
$h \to WW^*$	1.0%	1.2%	2.6%	3.0%	1.6%	6.3%	6.4%	1.9%	0.85%
$h \to \tau^+\tau^-$	0.8%	0.9%	1.8%	8.0%	1.1%	4.5%	17.9%	1.5%	2.5%
$h \to ZZ^*$	5.1%	4.4%	12%	10%	6.4%	28.0%	22.4%	8.8%	3.0%
$h \to \gamma\gamma$	6.8%	9.0%	18%	22%	12.0%	43.6%	50.3%	12.0%	6.8%
$h \to \mu^+\mu^-$	17%	19%	40%	–	25.5%	97.3%	178.9%	30.0%	25.0%
$(\nu\bar{\nu})h \to b\bar{b}$	2.8%	3.1%	–	–	3.7%	–	–	–	–

- **Higgs and Electroweak precision measurement can improve from ~10 percent at current stage to sub-percent level at proposed *ee*-colliders in precision.**

	Current (1.7×10^7 Z's)				CEPC (10^{10} Z's)				FCC-ee (7×10^{11} Z's)				ILC (10^9 Z's)			
	σ	correlation			σ	correlation			σ	correlation			σ	correlation		
		S	T	U	(10^{-2})	S	T	U	(10^{-2})	S	T	U	(10^{-2})	S	T	U
S	0.04 ± 0.11	1	0.92	−0.68	2.46	1	0.862	−0.373	0.67	1	0.812	0.001	3.53	1	0.988	−0.879
T	0.09 ± 0.14	–	1	−0.87	2.55	–	1	−0.735	0.53	–	1	−0.097	4.89	–	1	−0.909
U	-0.02 ± 0.11	–	–	1	2.08	–	–	1	2.40	–	–	1	3.76	–	–	1

Benchmark Model: 2HDM

- **Two-Higgs-Doublet Model**

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

- **Five Higgs states: *h*, *H*, *A*, *H*±**

$$\begin{pmatrix} H^\pm \\ G^\pm \end{pmatrix} = \begin{pmatrix} c_\beta & -s_\beta \\ s_\beta & c_\beta \end{pmatrix} \begin{pmatrix} \phi_2^\pm \\ \phi_1^\pm \end{pmatrix}$$

$$\begin{pmatrix} A^0 \\ G^0 \end{pmatrix} = \begin{pmatrix} c_\beta & -s_\beta \\ s_\beta & c_\beta \end{pmatrix} \begin{pmatrix} G_2^0 \\ G_1^0 \end{pmatrix}$$

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} c_\alpha & -s_\alpha \\ s_\alpha & c_\alpha \end{pmatrix} \begin{pmatrix} \phi_2^0 \\ \phi_1^0 \end{pmatrix}$$

- **Six free parameters**
  Tree: $\cos(\beta-\alpha),\ \tan\beta$
  Loop: $m_H,\ m_A,\ m_{H^\pm}$

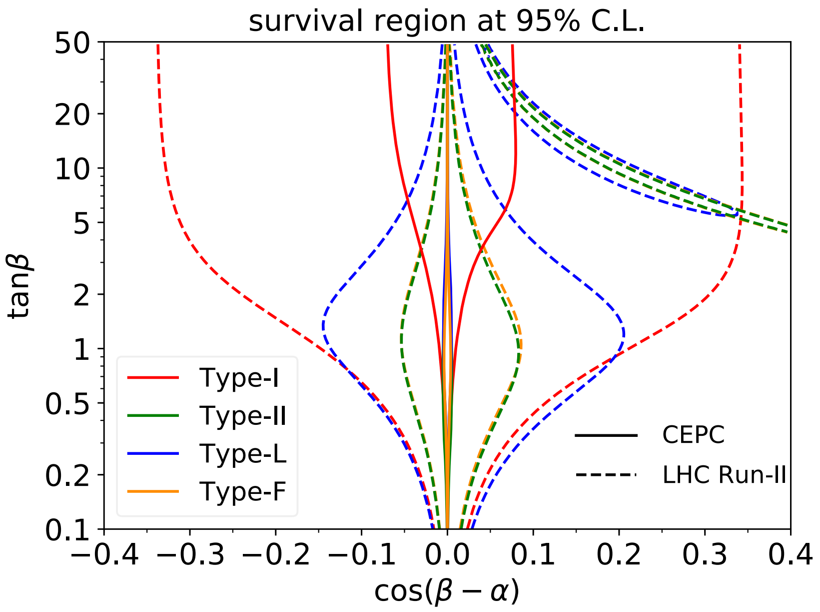
$$\lambda v^2 \equiv m_H^2 - \frac{m_{12}^2}{\cos\beta\sin\beta}$$

- **Four types of 2HDMs**

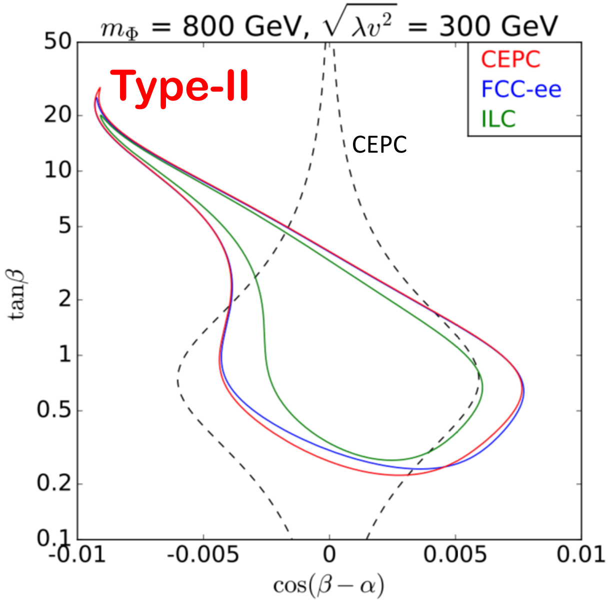
	Tree-level Normalized Higgs couplings			
	κ_h^u	κ_h^d	κ_h^e	κ_h^V
Type-I	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\sin(\beta-\alpha)$
Type-II	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\sin(\beta-\alpha)$
Type-L	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\sin(\beta-\alpha)$
Type-F	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\sin(\beta-\alpha)$

Constraints on tanβ vs. cos(β - α) plane

Tree level



One-loop

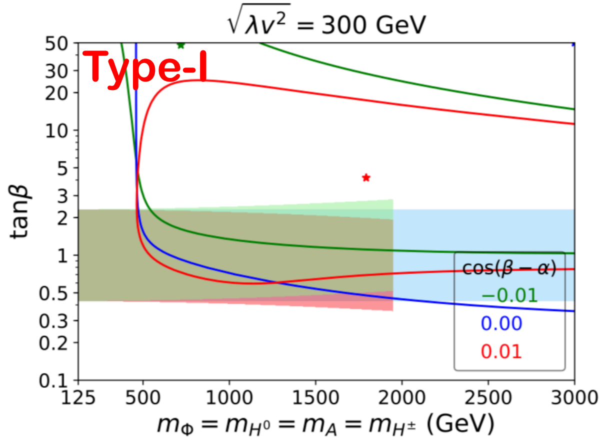


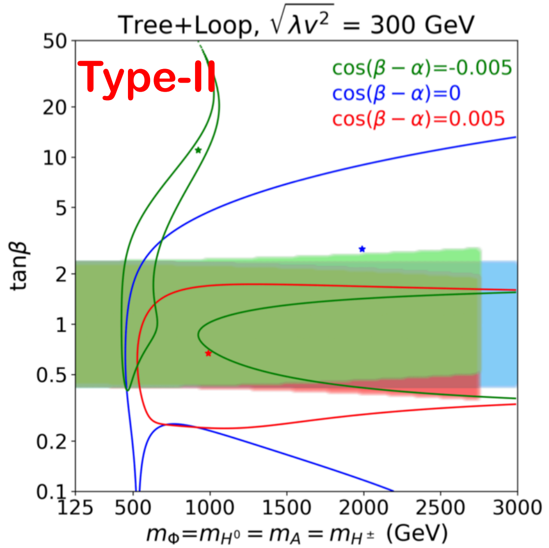
- **We perform global χ^2-fit to probe the survival region in parameter space.**
- **The allowed range of cos(β - α) will be reduced by a factor of 10.**
- **The constraints are sensitive to loop correction.**

Constraints on Heavy Higgs Mass

- **Higgs precision measurement sets a lower bound on heavy Higgs mass.**
- **The constraints on mass splitting from Higgs precision measurement is comparable but complementary to Electroweak precision measurement.**

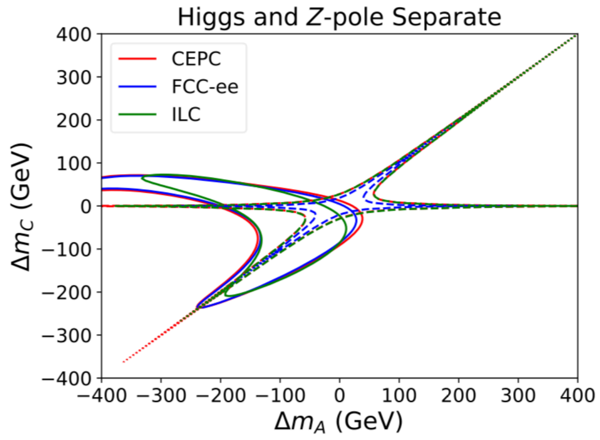
On degenerate mass

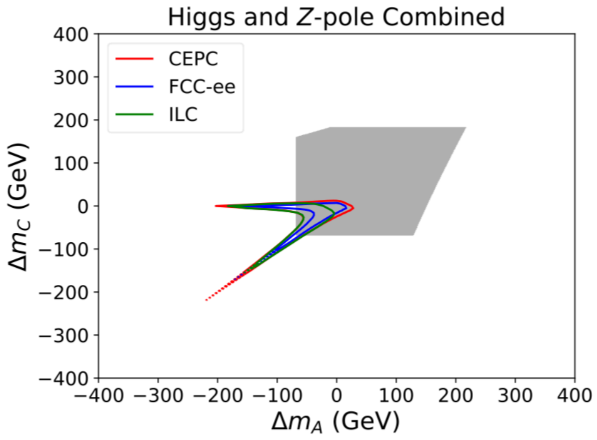




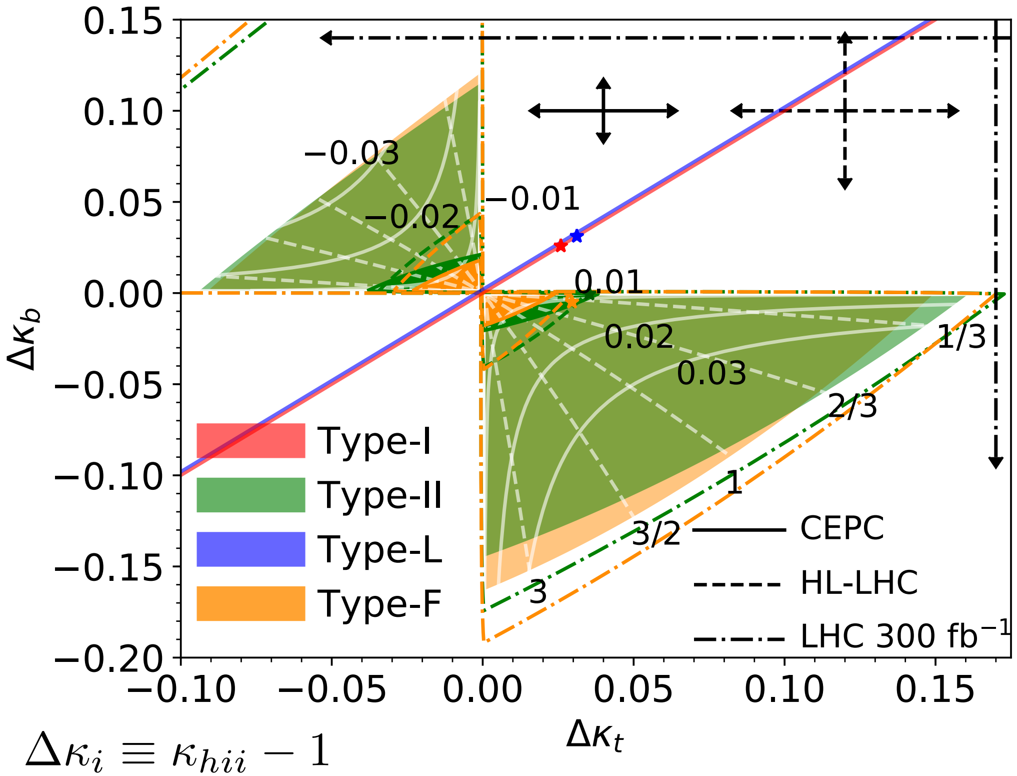
On mass splitting

Type-I

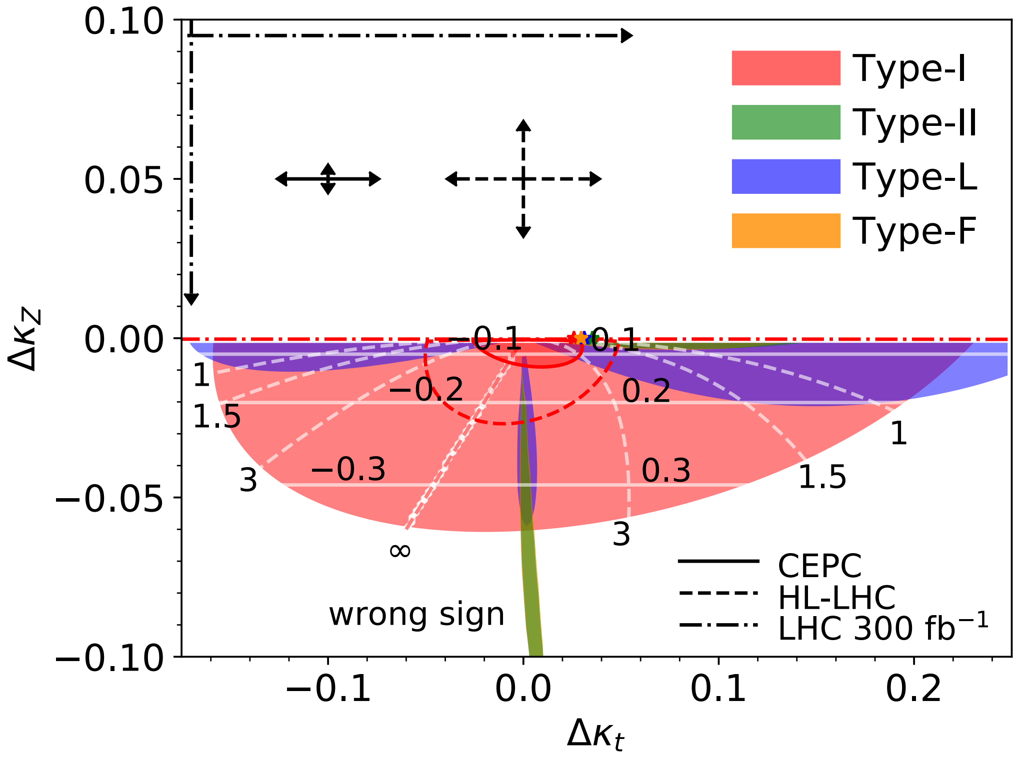




Discovery Potential of Higgs Precision Measurement



$\Delta\kappa_i \equiv \kappa_{hii} - 1$



- **Provides great potential for discovering 2HDM. arXiv: 2008.05492**

$$\text{Type-I:} \quad \cos(\beta-\alpha) \lesssim -0.1 \text{ or } \gtrsim 0.08 \text{ for } 2 \lesssim \tan\beta \lesssim 5;$$
$$\text{Type-L, II, F:} \quad |\cos(\beta-\alpha)| \gtrsim 0.02 \text{ for } \tan\beta \sim 1.$$

- **Four types of 2HDMs exhibit distinct features in the Higgs precision observables.**

Distinguish Four Types of 2HDMs

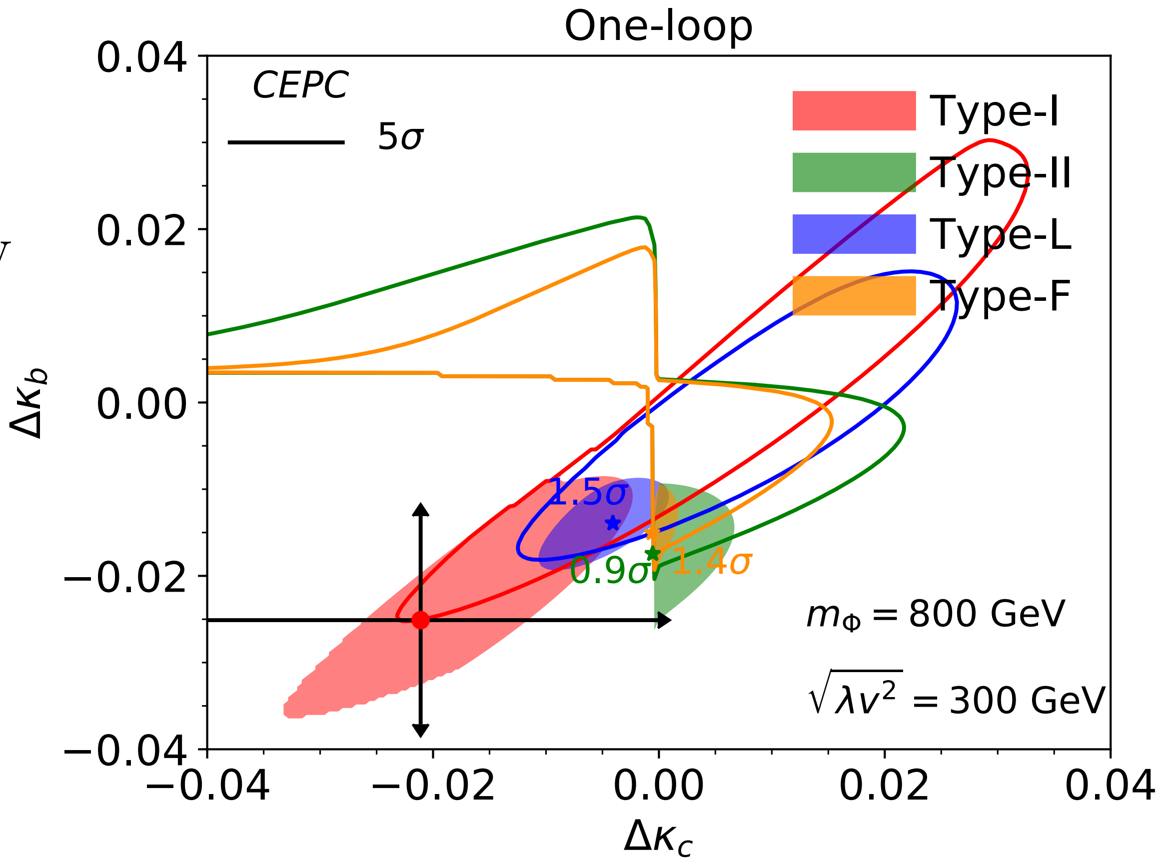
- **Benchmark point at**

$$\cos(\beta-\alpha) = -0.019,\ \tan\beta = 1$$

$$m_H = m_A = m_{H^\pm} = 800\ \text{GeV}, \sqrt{\lambda v^2} = 300\ \text{GeV}$$

in Type-I allowing for 5σ discovery from Higgs precision measurement

- **Possible to distinguish from most of the parameter space of other types.**
- **Provide powerful tool to assist distinguishing different types of 2HDMs**



arXiv: 2008.05492

Summary

- **Precision measurements have strong impact on 2HDMs.**
- **In the context of 2HDMs, Higgs and Electroweak precision measurements provide comparable but complementary constraints to the heavy Higgs masses.**
- **Except for constraints, precision measurements also show great potential for discovery. It could assist distinguishing four types of 2HDMs.**
- **Although we use 2HDMs as a benchmark model throughout the study, this endeavor should be continued in extending to other BSMs.**

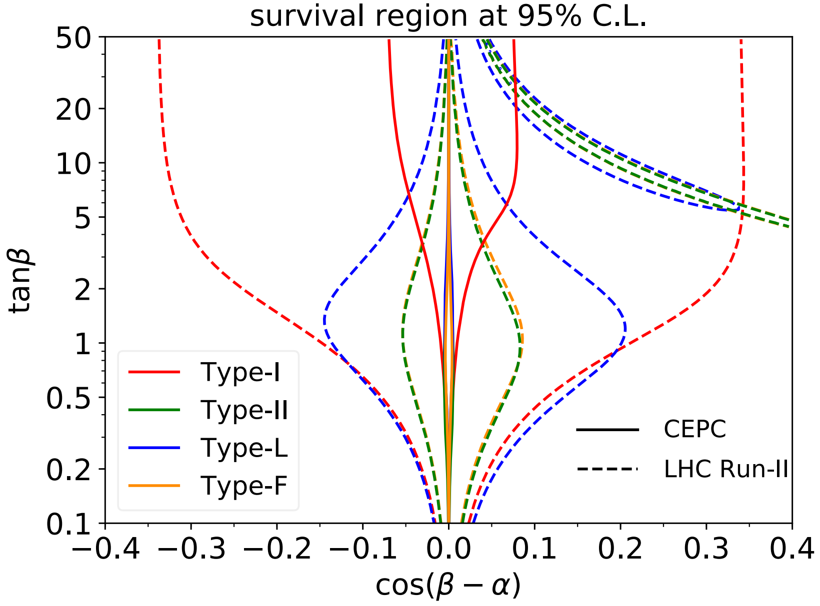
Backup Slides

Global χ^2 fitting

- **Higgs precision observables**
  - **fit on signal strength**
    $$\mu = \frac{\sigma \times \ \mathrm{Br}}{(\sigma \times \ \mathrm{Br})_{\ \mathrm{SM}}}$$
  - **method**
    $$\chi^2 = \sum_i \frac{(\mu_i^{\mathrm{BSM}} - \mu_i^{\mathrm{obs}})^2}{\sigma_{\mu_i}^2}$$
- **Electroweak precision observables**
  - **fit on oblique parameters**
    $$S,\ T,\ U$$
  - **method**
    $$\chi^2 \equiv \sum_{ij} (X_i - \hat{X}_i)(\sigma^2)^{-1}_{ij}(X_j - \hat{X}_j)$$

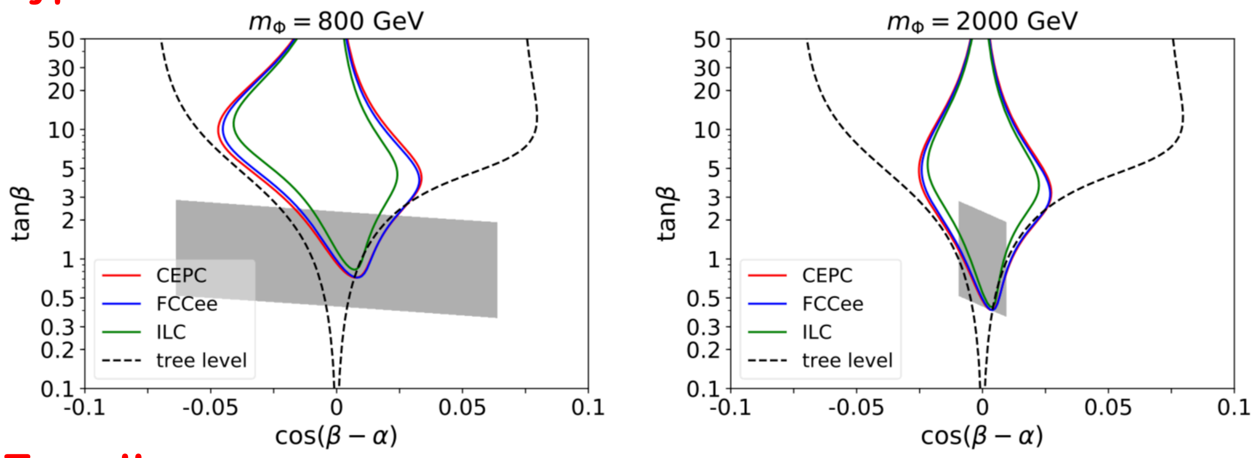
Constraints on tanβ vs. cos(β - α) plane

Tree level

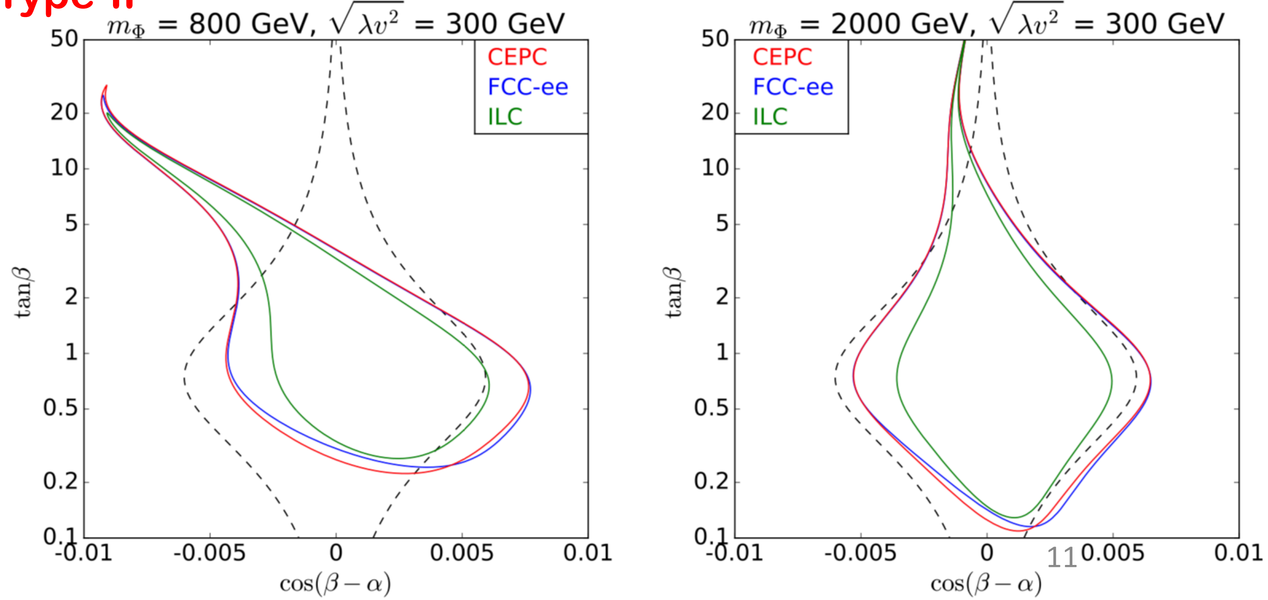


One-loop

Type-I



Type-II



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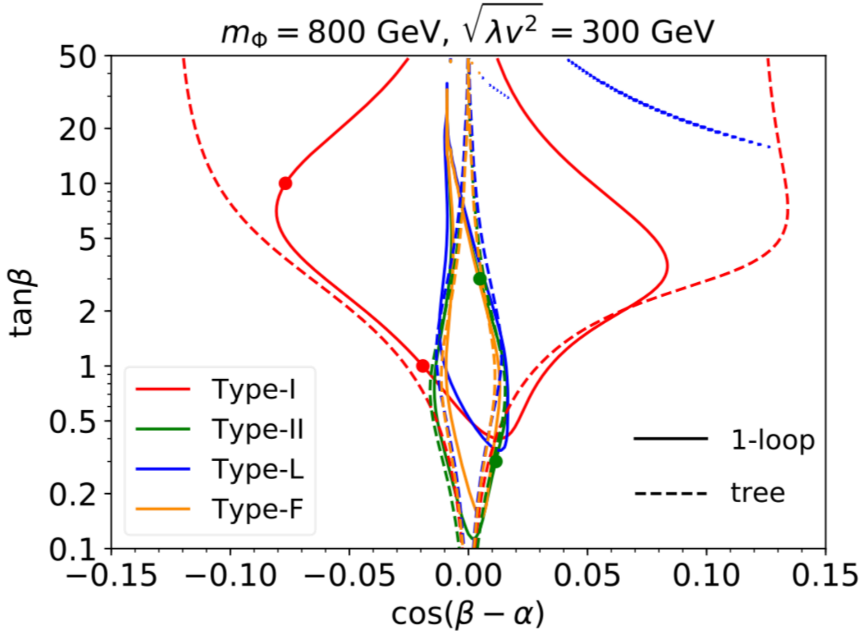
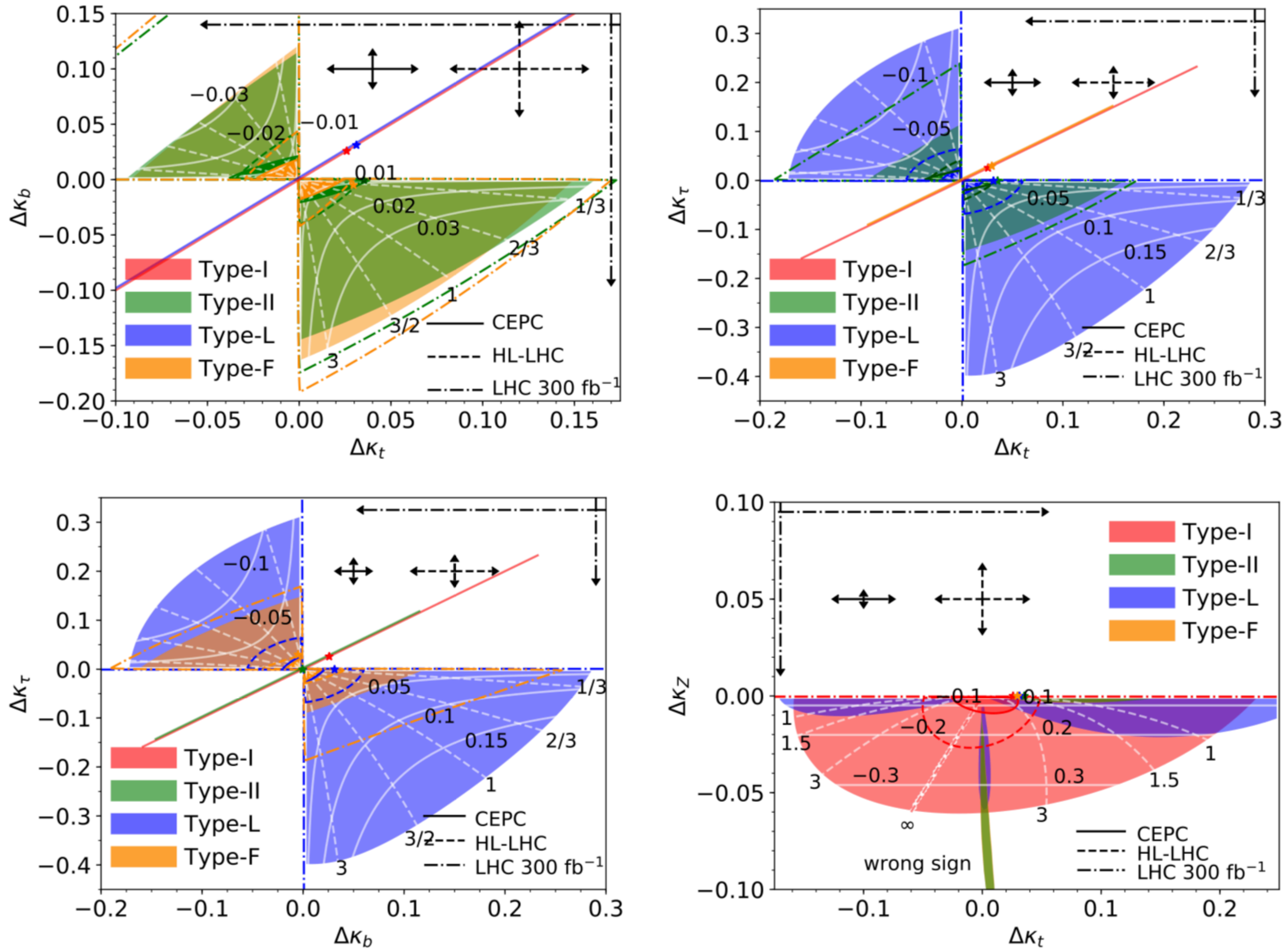
Discovery Potential of Higgs Precision Measurement





- **Provides great potential for discovering 2HDM.**

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