Snowmass EF02: 2HDM Meeting

Implication of Higgs Precision Measurements on 2HDMs

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Outline

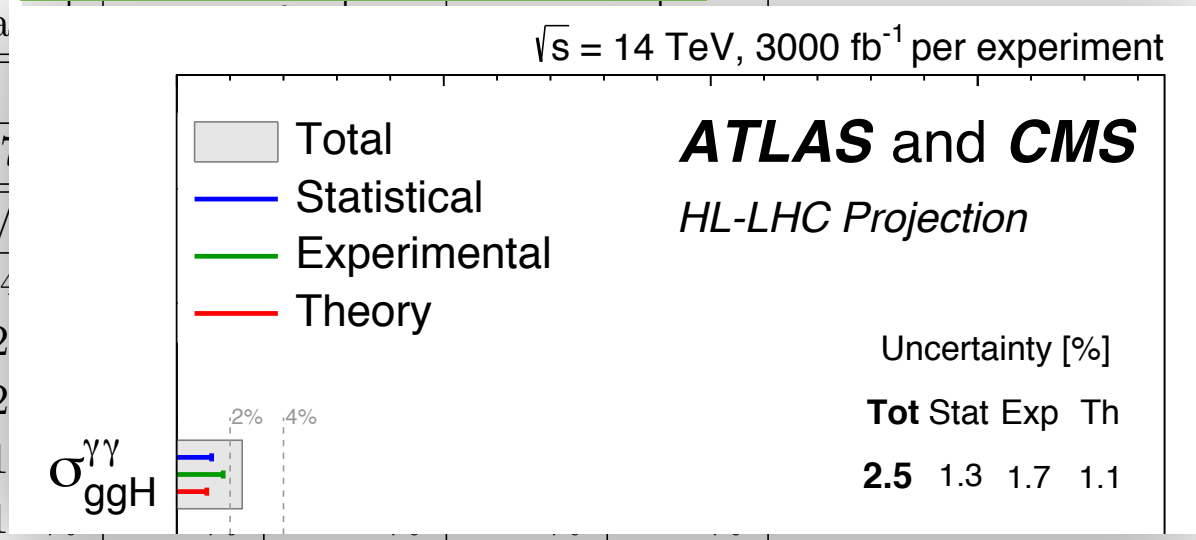
- Higgs Precision Measurements
- 2HDM: brief introduction
- Tree-level results
- Loop-level results
- Summary

Precision: Higgs couplings

CEPC-CDR , FCC-ee, ILC Operating Scenarios

collider	CEPC	FCC-ee			ILC				
$\sqrt{s}$	240 GeV	240 GeV	365 GeV		250 G				
$\int \mathcal{L}dt$	5.6 ab^{-1}	5 ab^{-1}	1.5 ab^{-1}		2 a				
production	Zh	Zh	Zh	$\nu\bar{\nu}h$					
$\Delta\sigma/\sigma$	0.5%	0.5%	0.9%	–	0.7				
decay					$\Delta(\sigma \cdot BR)/$				
$h \to b\bar{b}$	0.27%	0.3%	0.5%	0.9%	0.4				
$h \to c\bar{c}$	3.3%	2.2%	6.5%	10%	2				
$h \to gg$	1.3%	1.9%	3.5%	4.5%	2				
$h \to WW^*$	1.0%	1.2%	2.6%	3.0%	1				
$h \to \tau^+\tau^-$	0.8%	0.9%	1.8%	8.0%	1				
$h \to ZZ^*$	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%	–	–	–	–

HL-LHC: 1902.00134



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, Z_2 Symmetry)

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

Soft Z_2 symmetry breaking: m_{12}^2

246 GeV

125. GeV

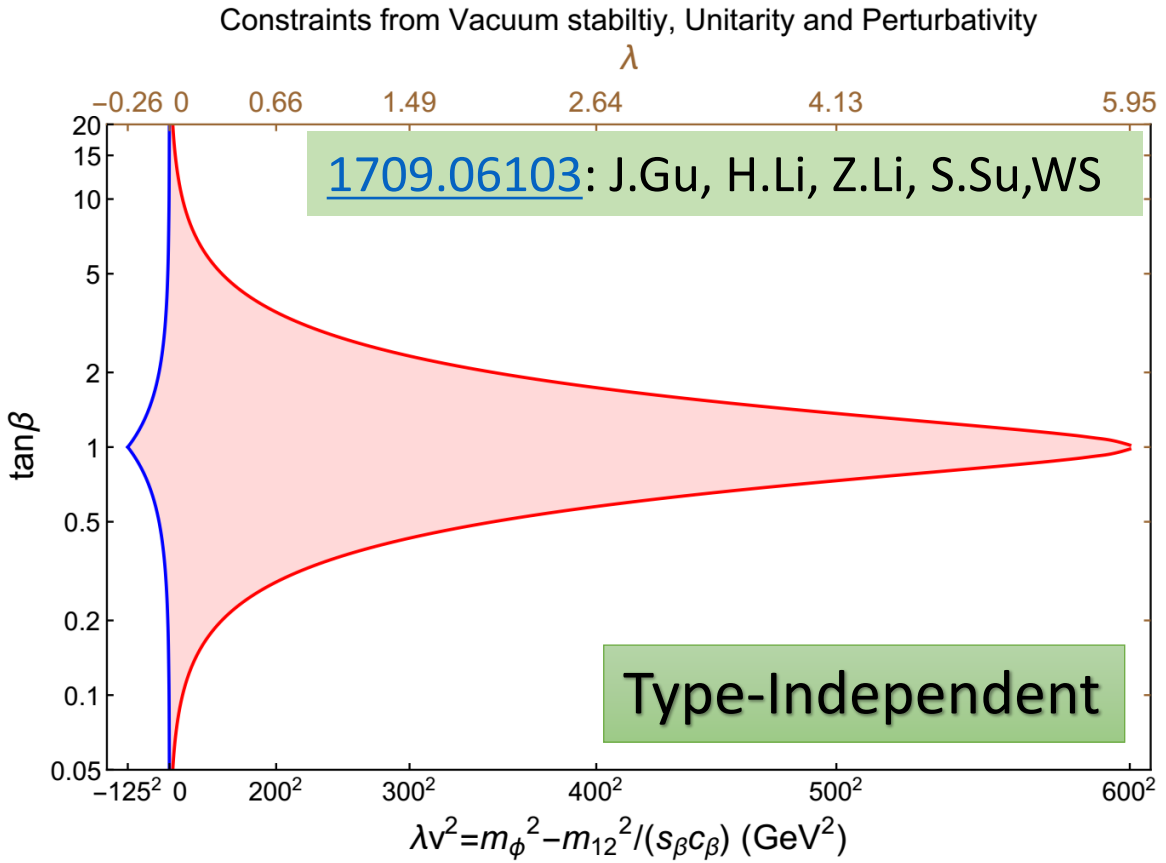
Constraints: theory

- Perturbativity
- Stability of the potential
- Unitarity of the scattering matrix

$$\cos(\beta-\alpha)=0,$$
$$m_\Phi \equiv m_H = m_A = m_{H^\pm}$$

$$\lambda v^2 \equiv m_\Phi^2 - m_{12}^2/s_\beta c_\beta$$

$$-125^2\,\mathrm{GeV}^2 < \lambda v^2 < 600^2\,\mathrm{GeV}^2$$

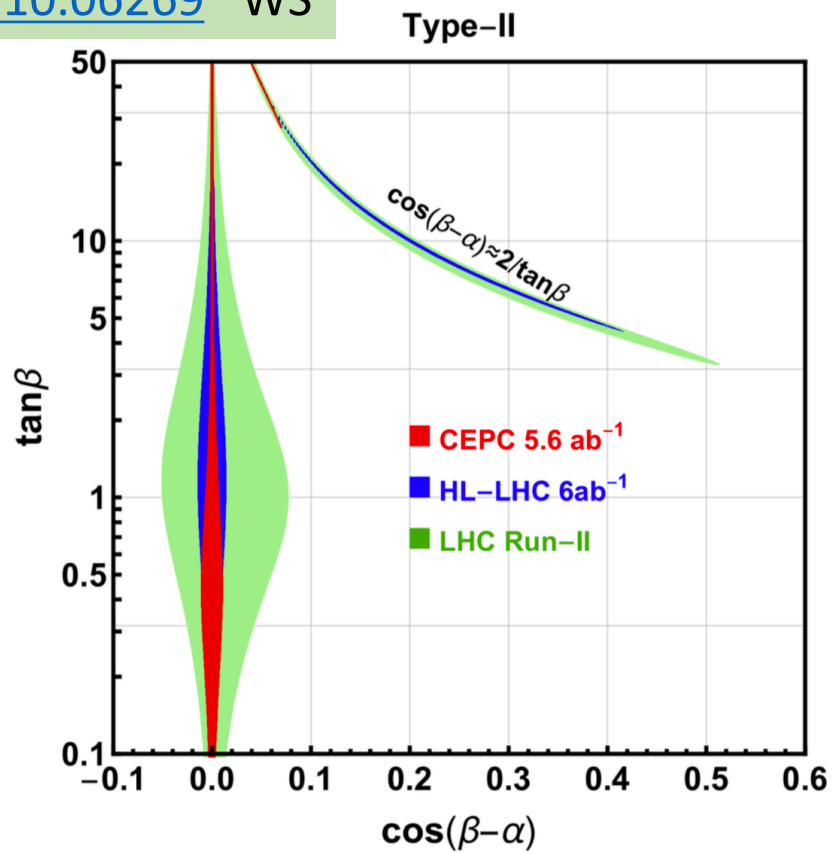


2HDM: Tree Level

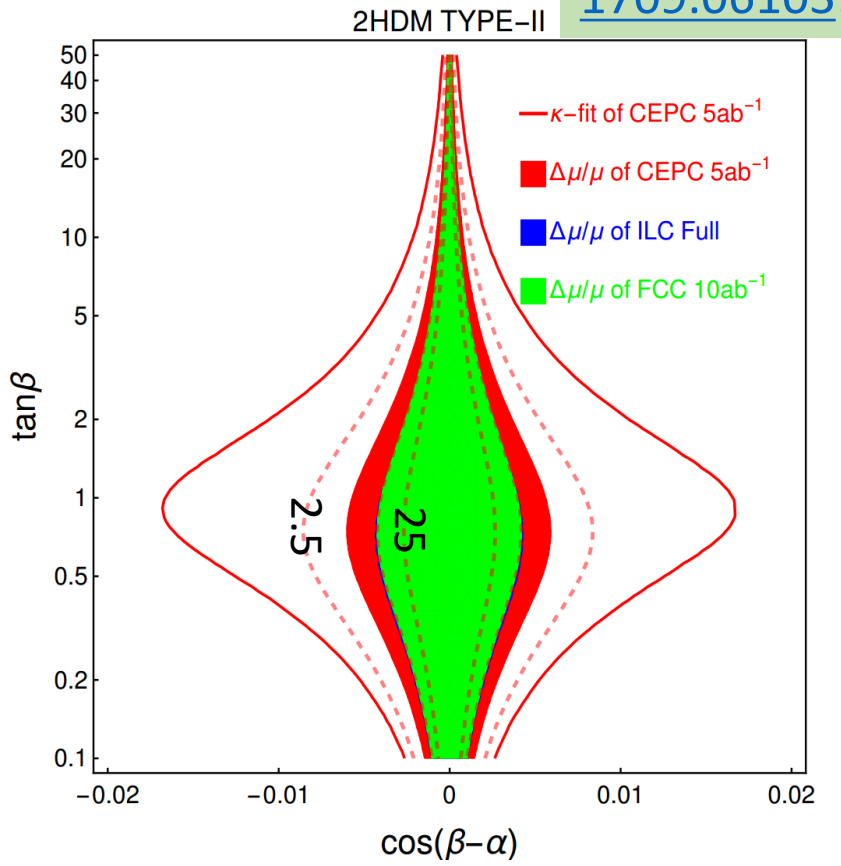
Model	κ_V	κ_u	κ_d	κ_ℓ
2HDM-I	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
2HDM-II	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$-\sin\alpha/\cos\beta$
2HDM-L	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$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

2HDM Type-II

1910.06269 WS



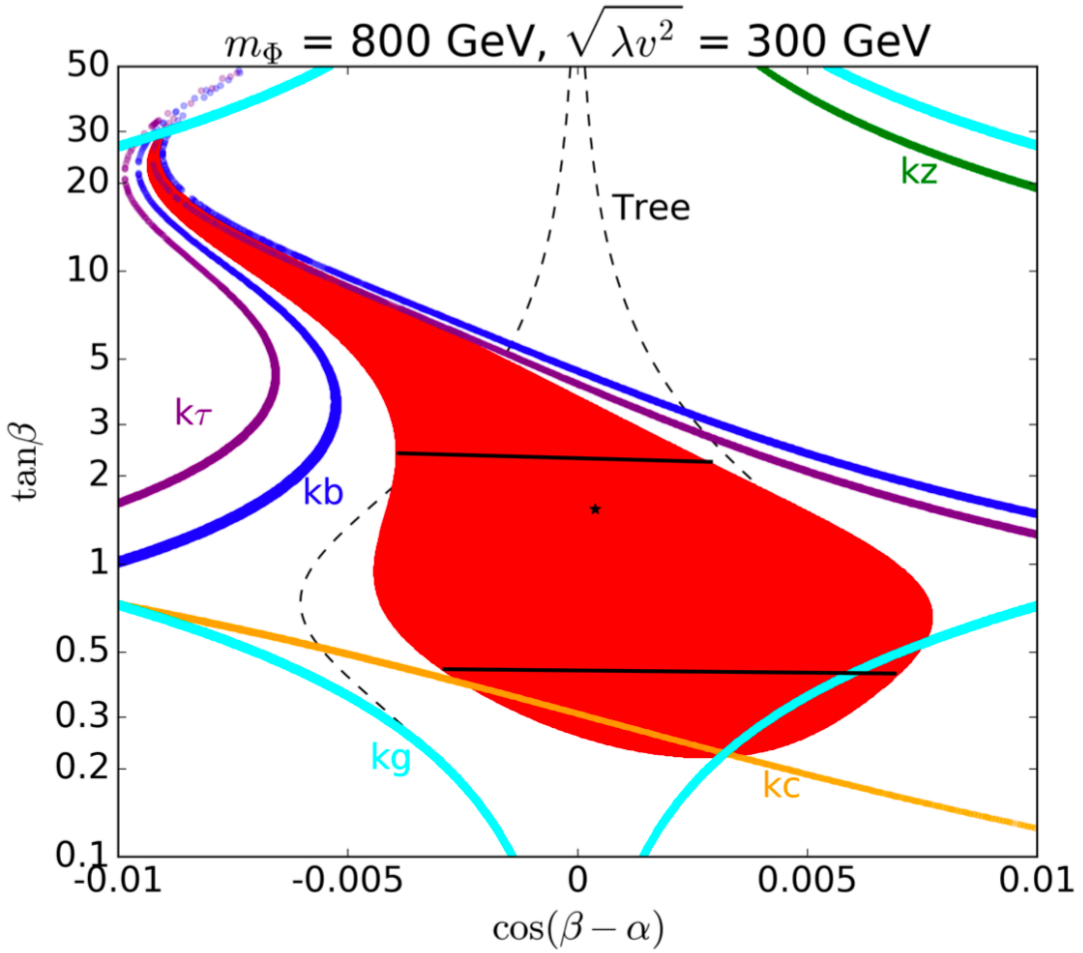
1709.06103: J.Gu, H.Li, Z.Li, S.Su,WS

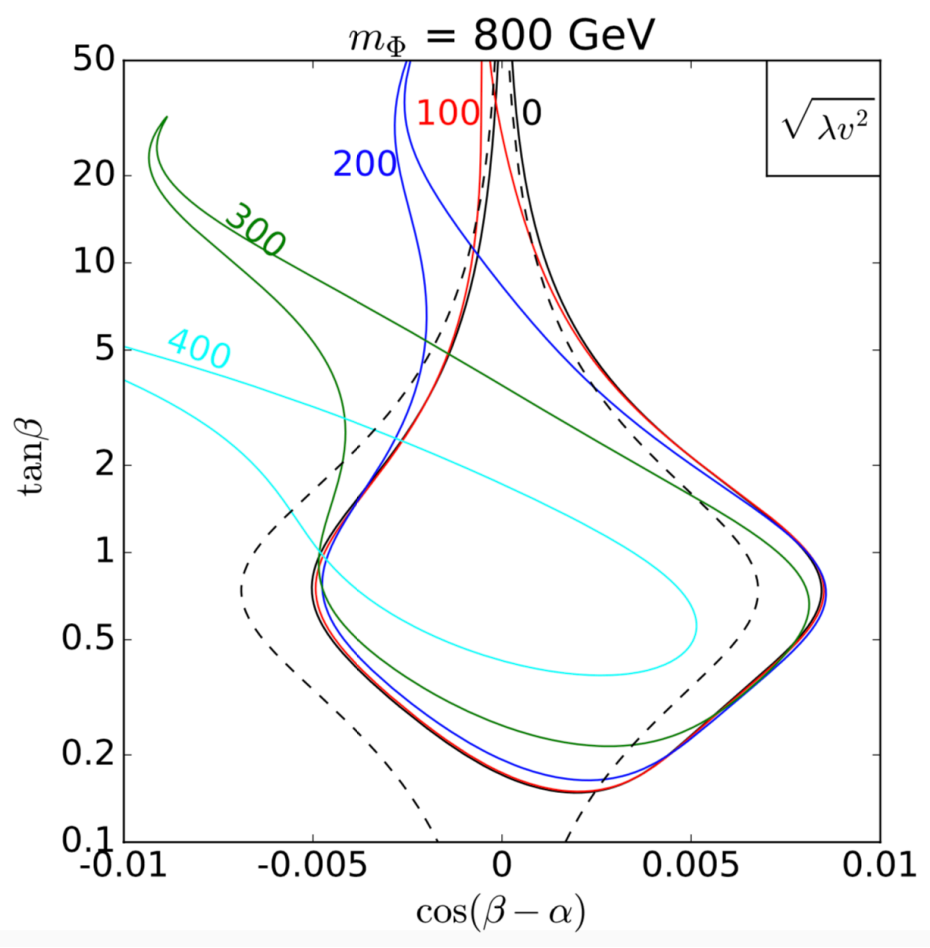


Alignment limit :
$\cos(\beta-\alpha)=0$
$g(2HDM)=g(SM)$

Not the latest report data, for more please check

Type-II: *Tree + Loop + degenerate*





Type-I

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	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$

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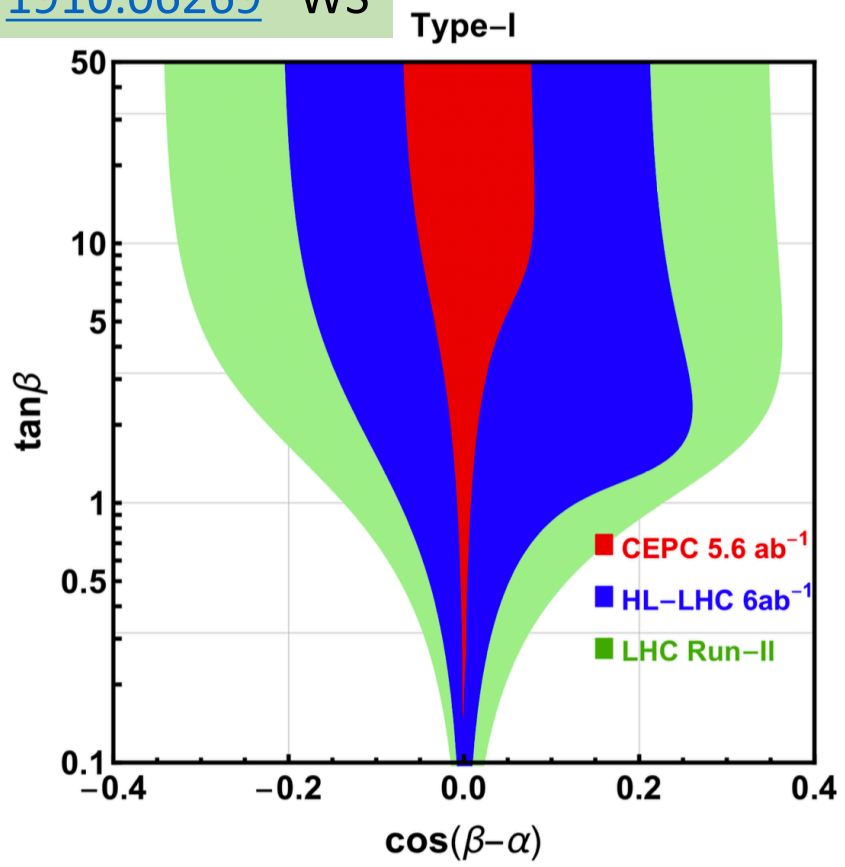
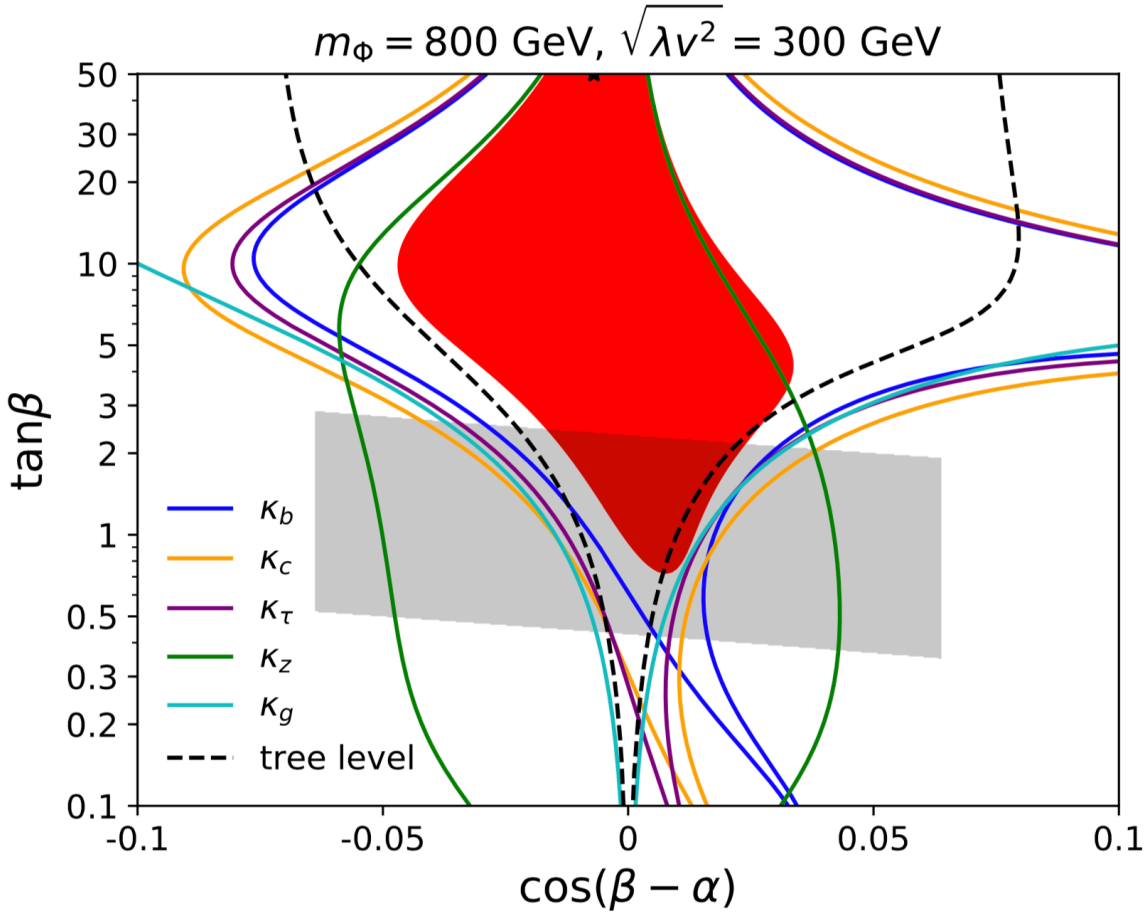
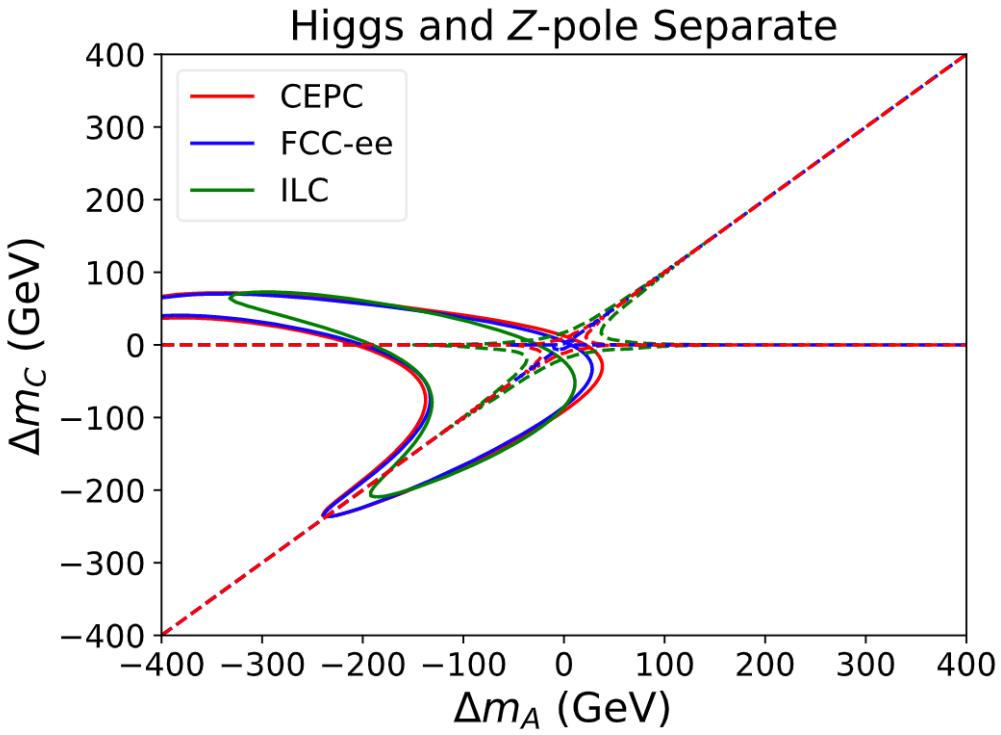
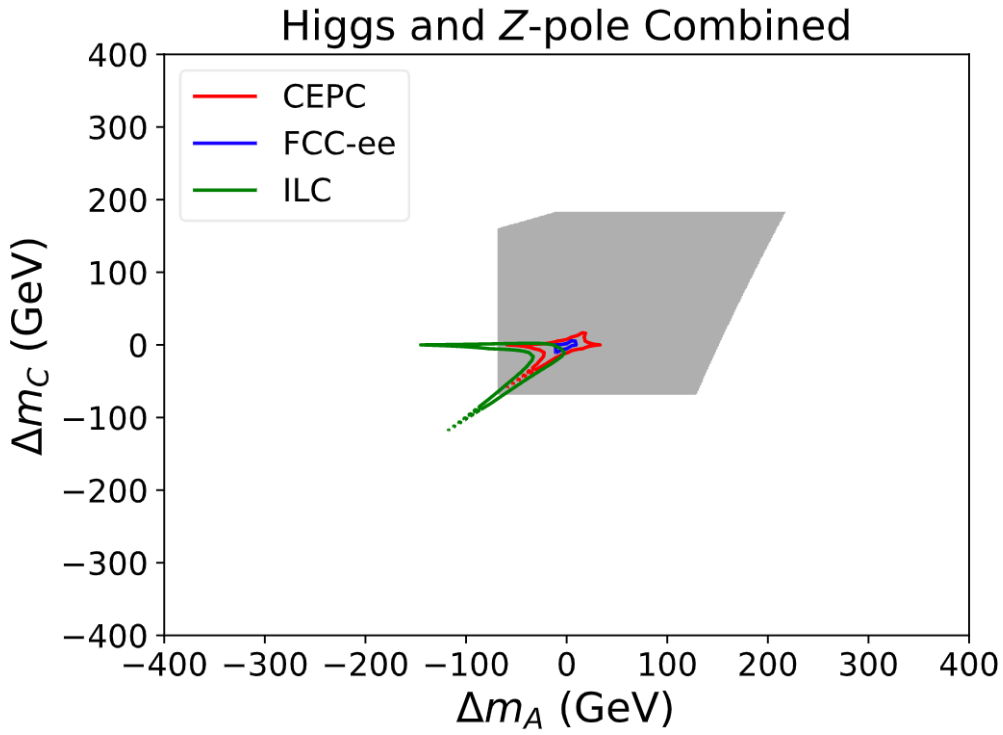




2HDM under Higgs+Z observables

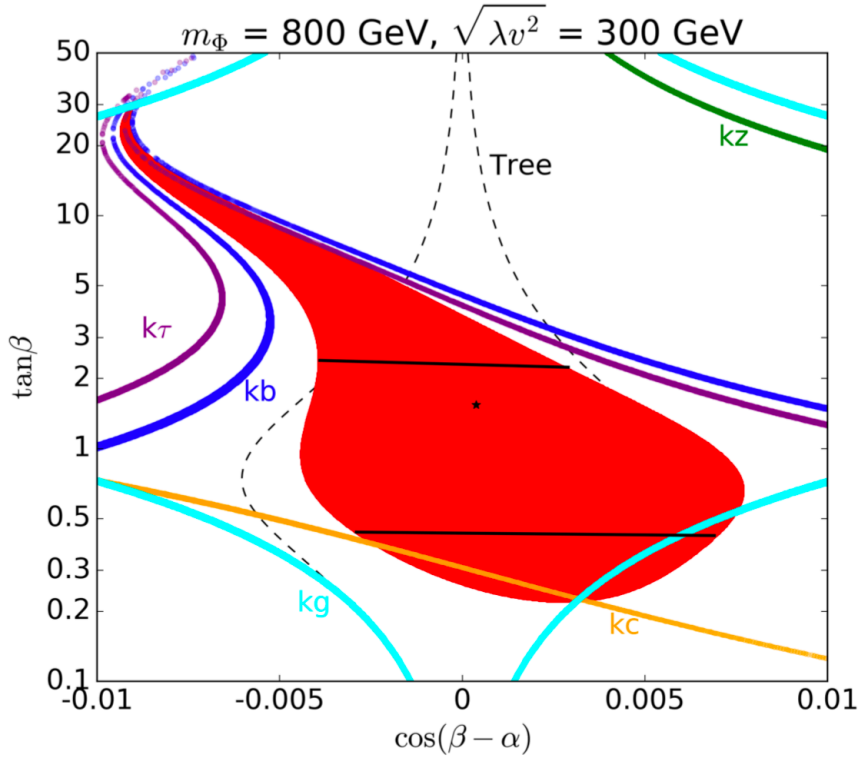
Type-I: mH=800 GeV, $\cos(\beta-\alpha)=0$, $\tan\beta$=1



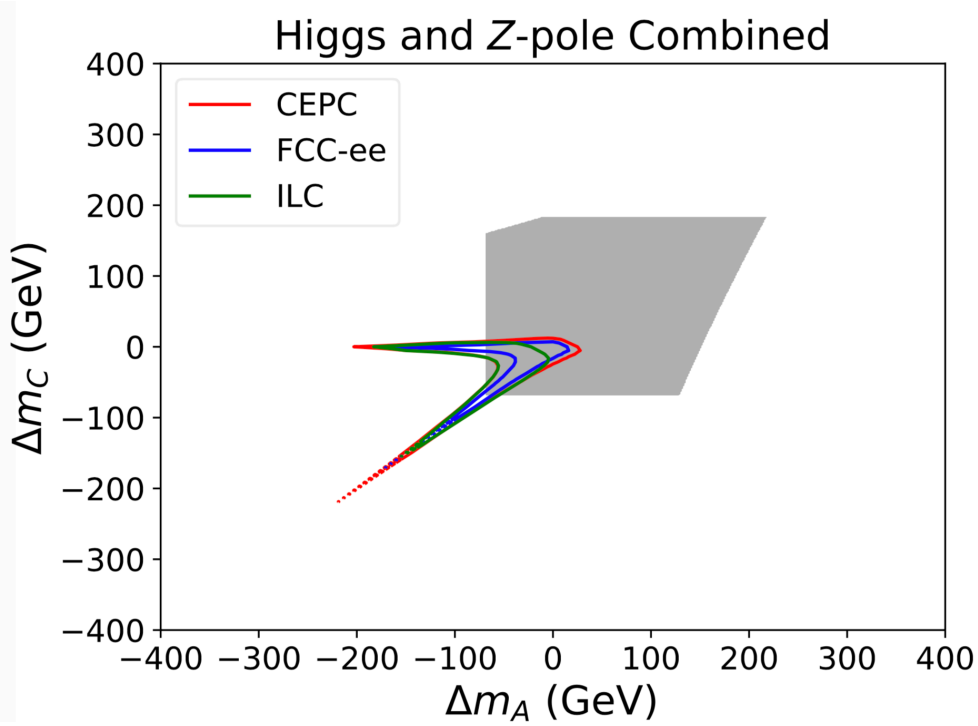


Summery

1. Loop effects are important under Higgs precisions



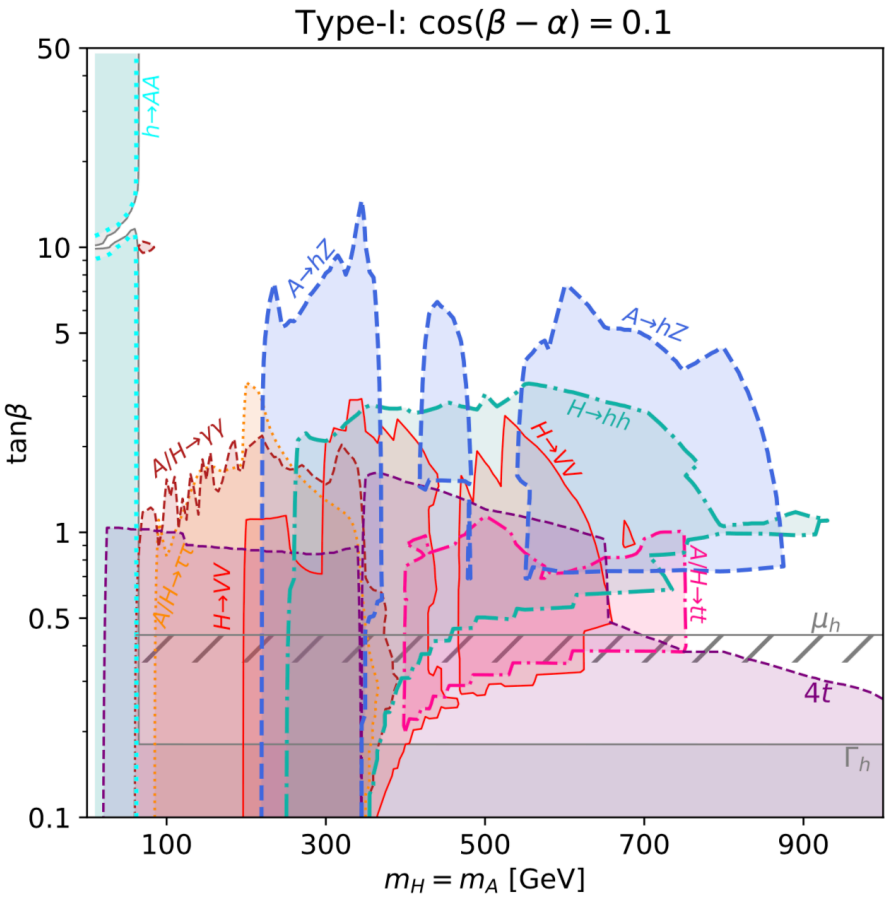
2. Higgs+Z precision together constrain mass splitting better

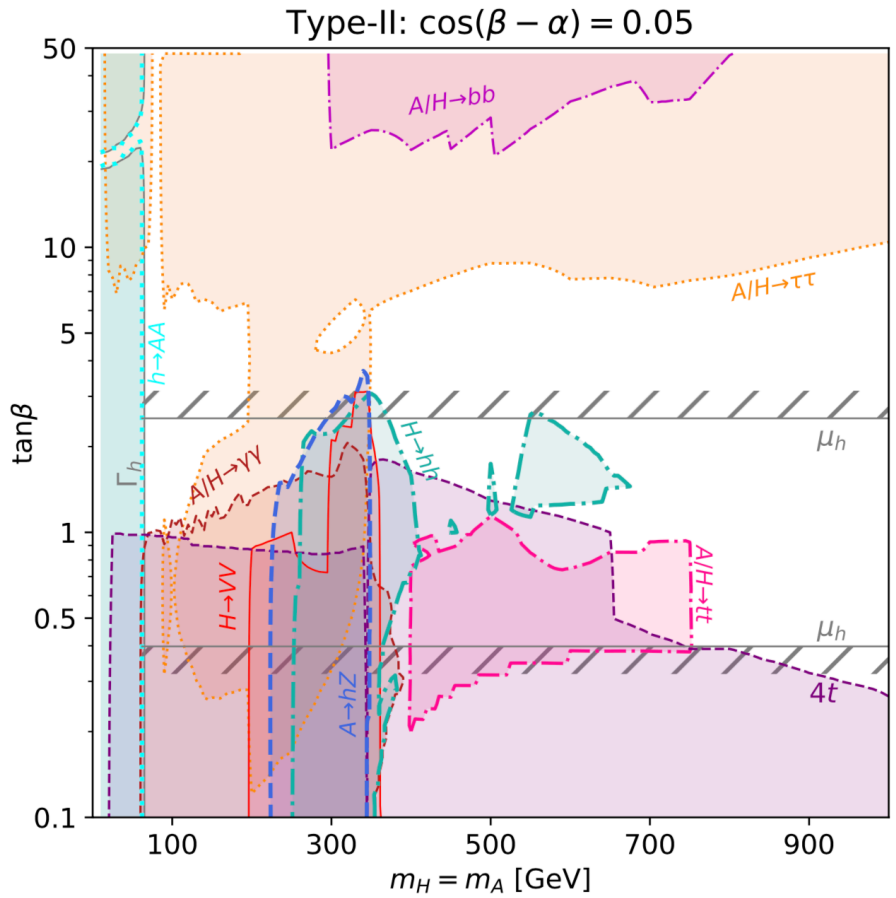


Thanks for your attention !

2HDM: Tree Level

2004.04172 F.Kling, S.Su, WS

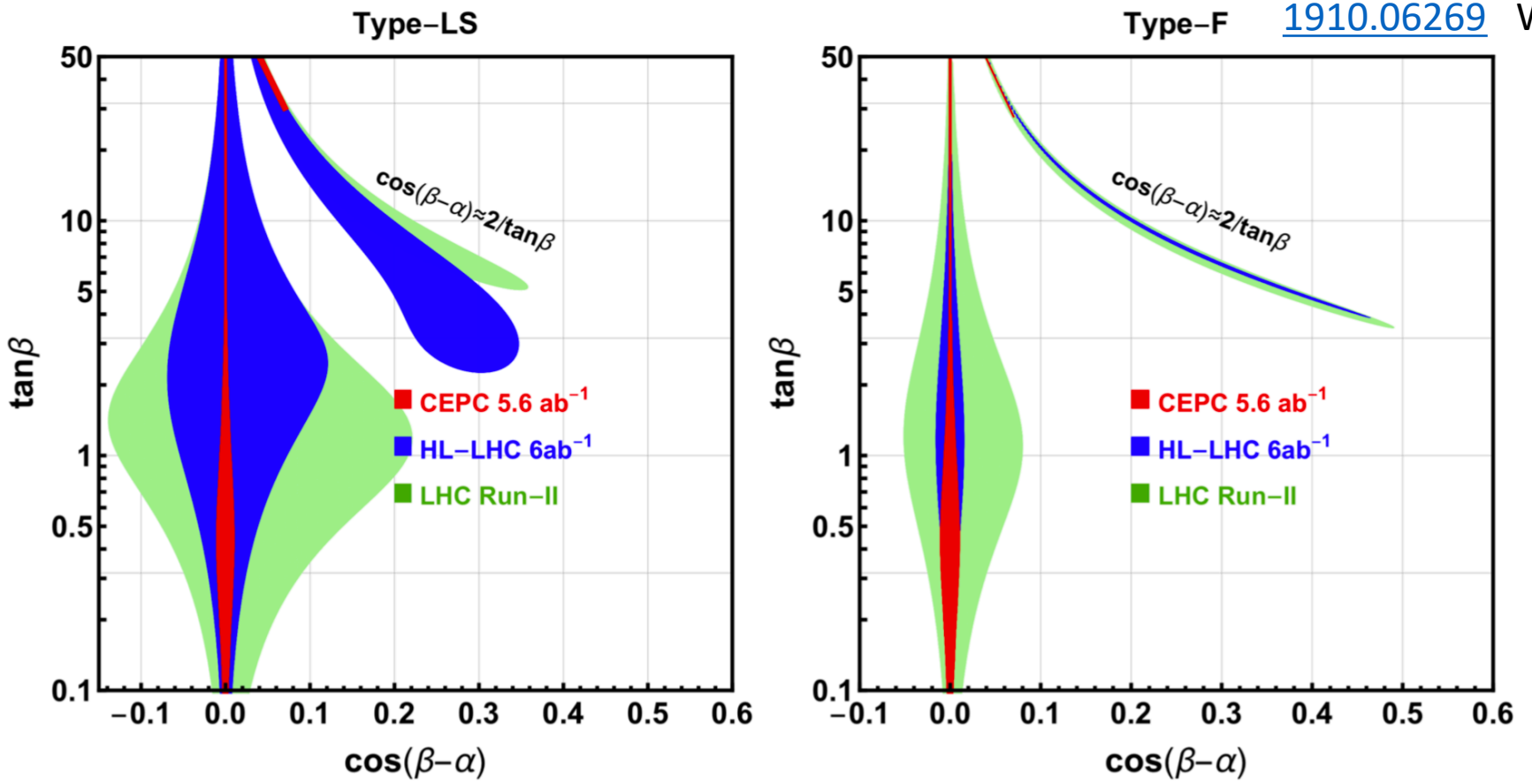




	Current				CEPC				FCC-ee				ILC			
	σ	correlation			σ (10^{-2})	correlation			σ (10^{-2})	correlation			σ (10^{-2})	correlation		
		S	T	U		S	T	U		S	T	U		S	T	U
S	0.04 ± 0.11	1	0.92	-0.68	1.78	1	0.999	-0.982	0.32	1	0.999	-0.842	3.41	1	0.998	-0.971
T	0.09 ± 0.14	–	1	-0.87	2.52	–	1	-0.986	0.46	–	1	-0.844	4.79	–	1	-0.977
U	-0.02 ± 0.11	–	–	1	1.80	–	–	1	0.38	–	–	1	3.45	–	–	1

Further study

- Discovery potential + distinguish models


Type−LS
Type−F
1910.06269
WS
tanβ
cos(β−α)
cos(β−α)≈2/tanβ
CEPC 5.6 ab−1
HL−LHC 6ab−1
LHC Run−II
50
10
5
1
0.5
0.1
−0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6