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New Physics Implication of Higgs Precision Measurements

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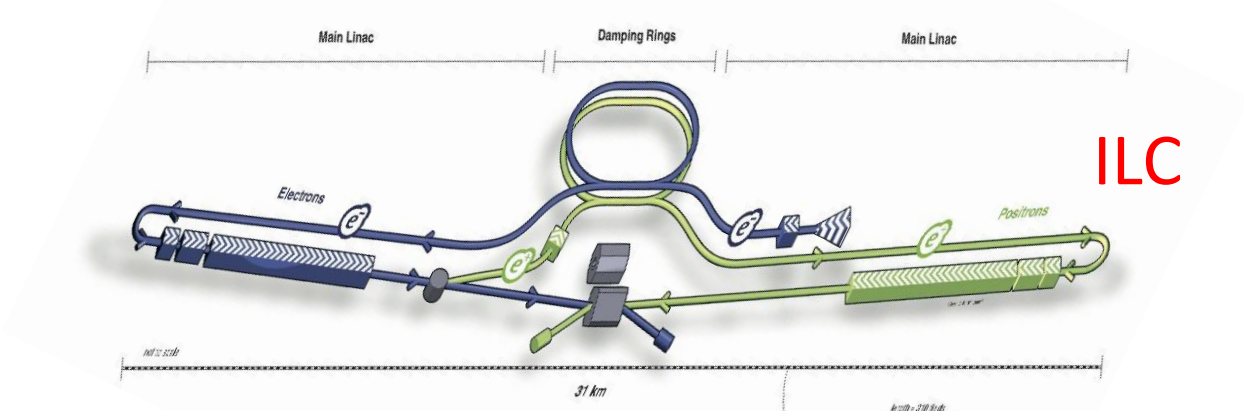
Outline

- **Higgs Precision Measurements**
- **Common strategies**
- **Perturbative BSM: 2HDM**
- **Strong Coupling BSM: Composite Higgs Models**
- **Conclusion**

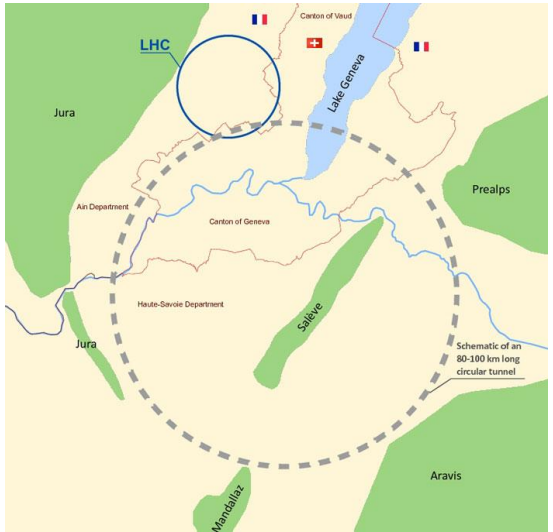
Higgs Precision Measurements

Collider	$\Delta\mu$ (hbb)	$\Delta\mu$(hZZ)
LHC Run-I	50% (wh)	≈32%(ggh)
LHC 14 TeV $300fb^{-1}$	26%	7%
LHC 14 TeV $3000fb^{-1}$	12%	4%
CEPC 240 GeV $5ab^{-1}$ (zh)	0.28%	4.3%
FCC-ee 240 GeV $10ab^{-1}$ (zh)	0.2%	3.1%
ILC 240 GeV $2ab^{-1}$ (zh)	0.42%	6.7%
ILC 350 GeV $0.2ab^{-1}$ (zh)	1.6%	28%
ILC 500 GeV $4ab^{-1}$ (vvh)	0.24%	2.9%



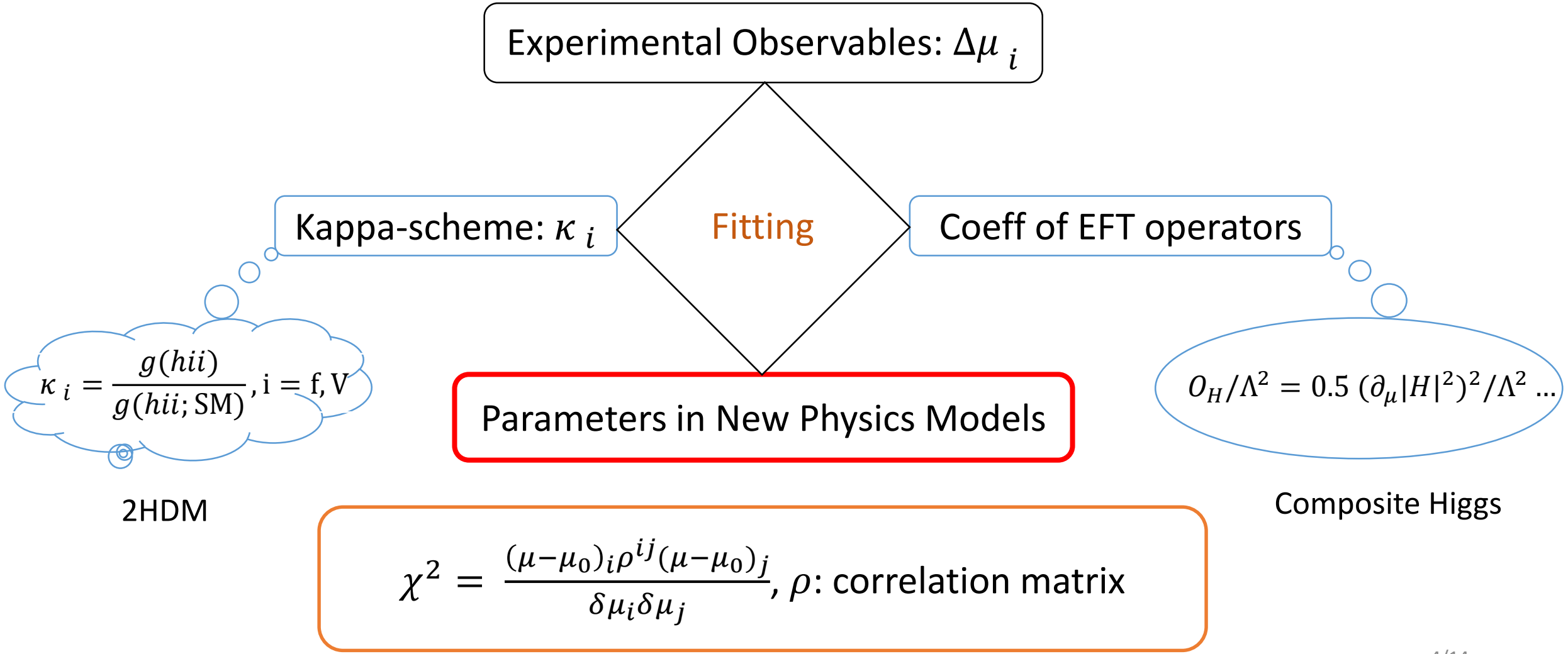
ILC

CEPC



LHC
HL-LHC
FCC

Common strategies



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)

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

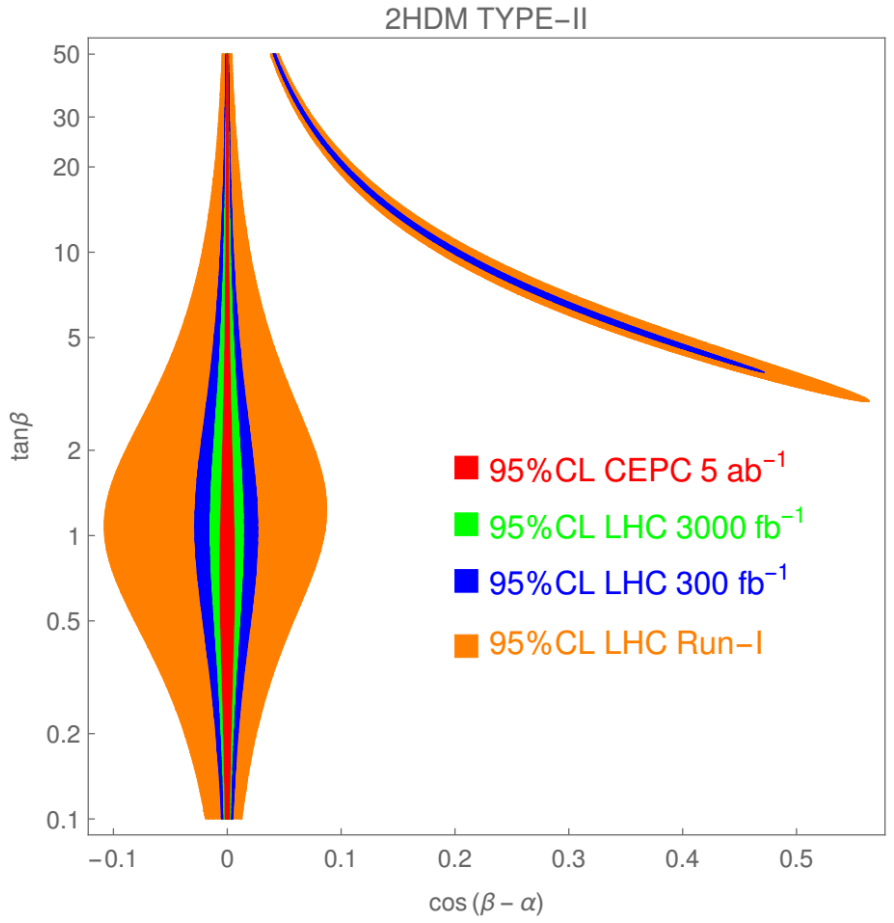
Soft Z_2 symmetry breaking: m_{12}^2

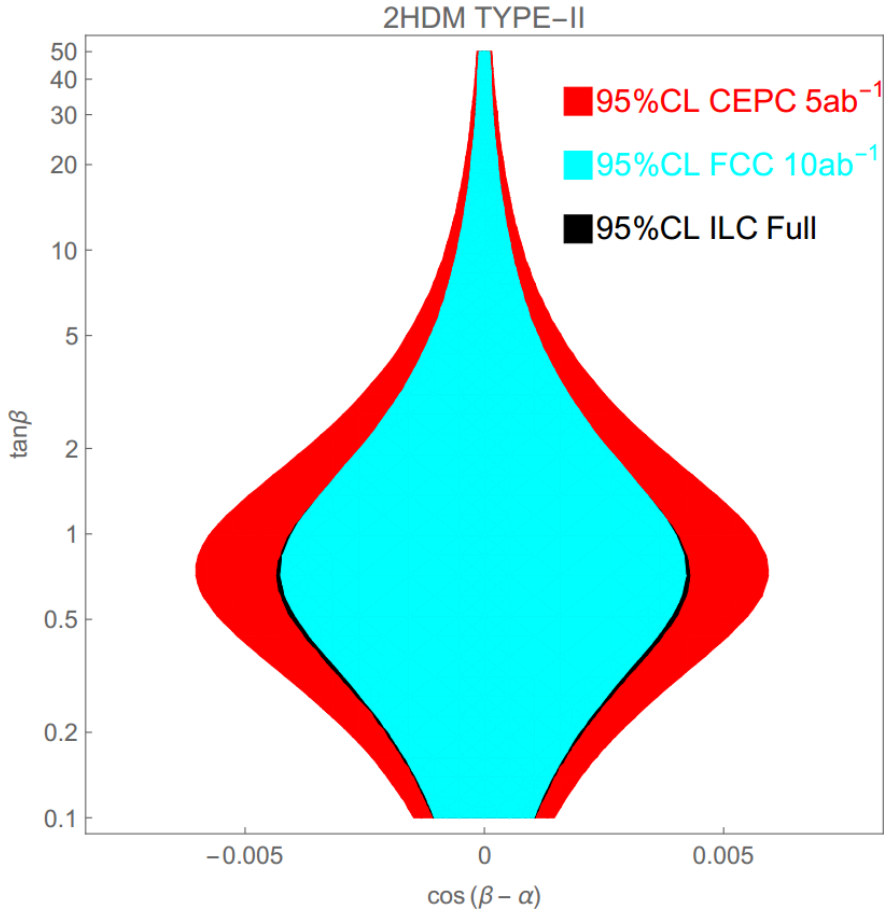
246 GeV 125. GeV

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





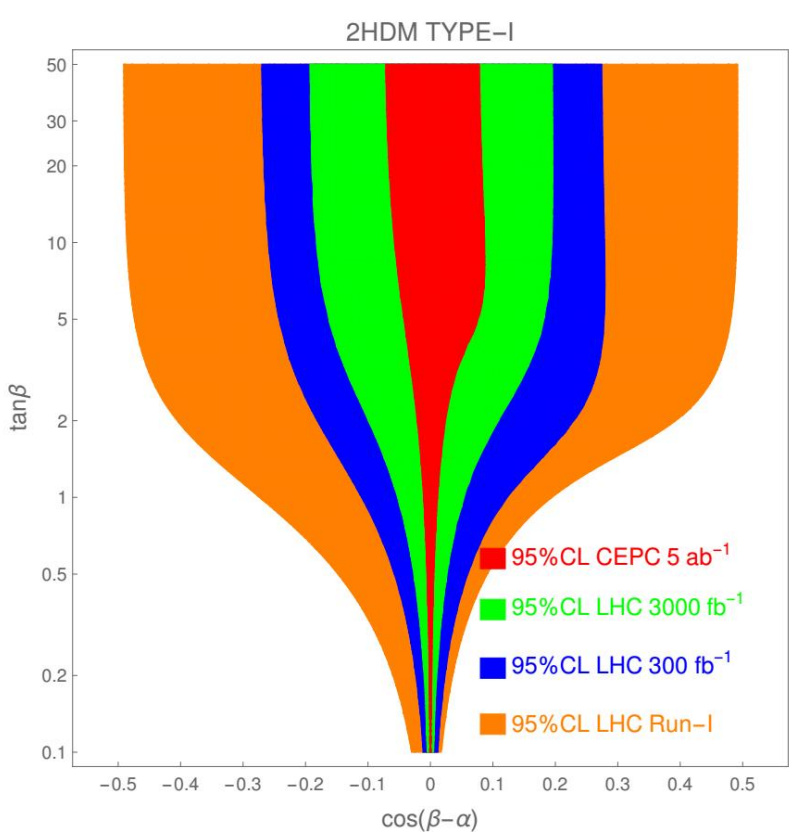
Alignment limit :

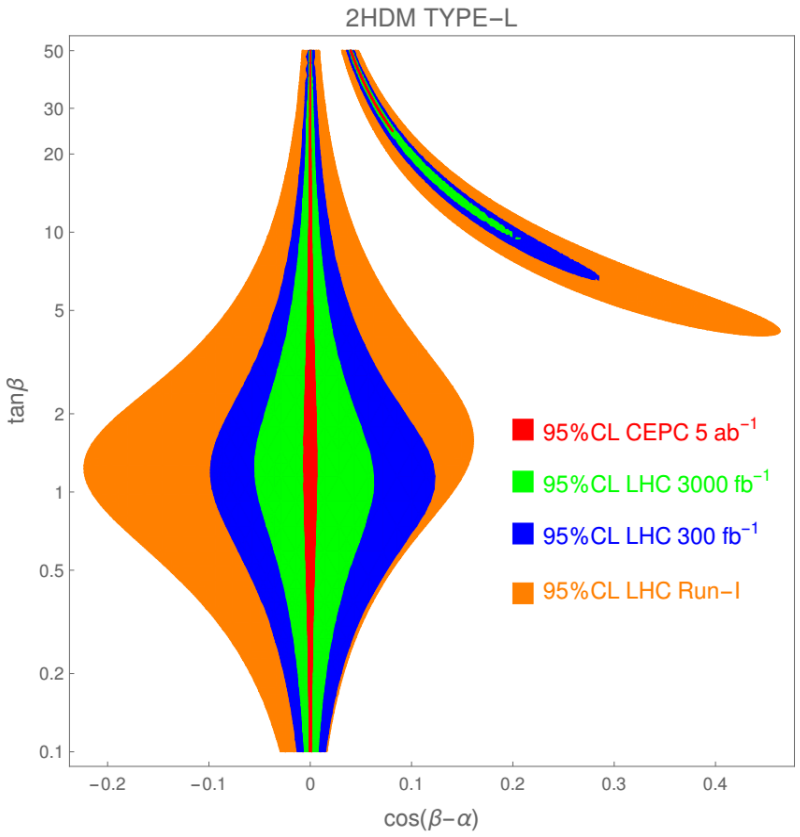
$\cos(\beta-\alpha)=0$

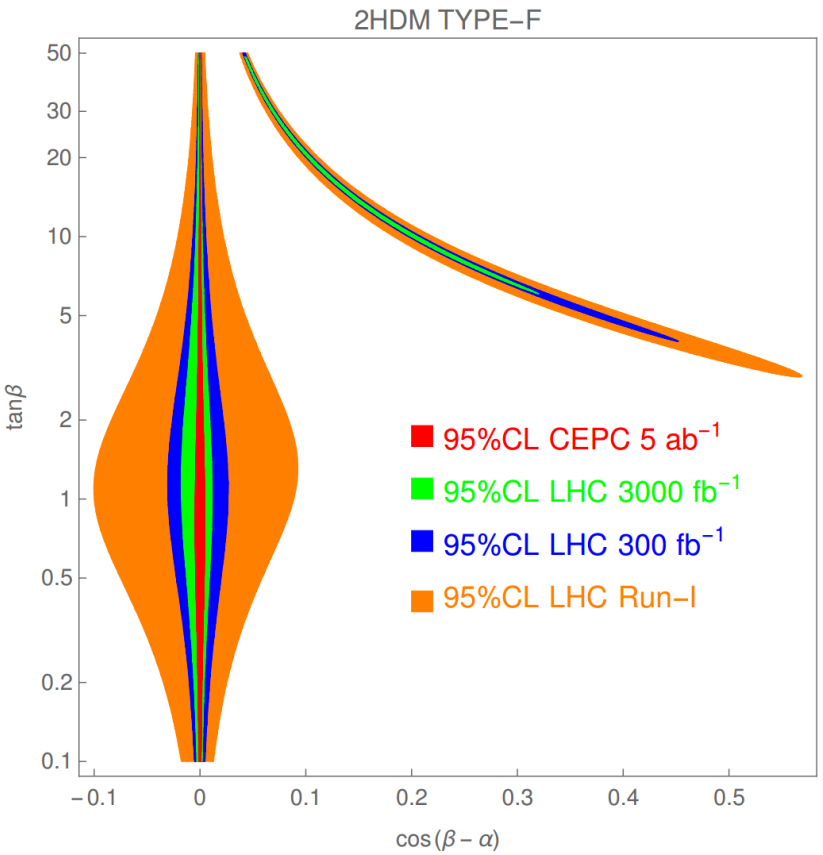
$g(2HDM)=g(SM)$

2HDM: Tree Level

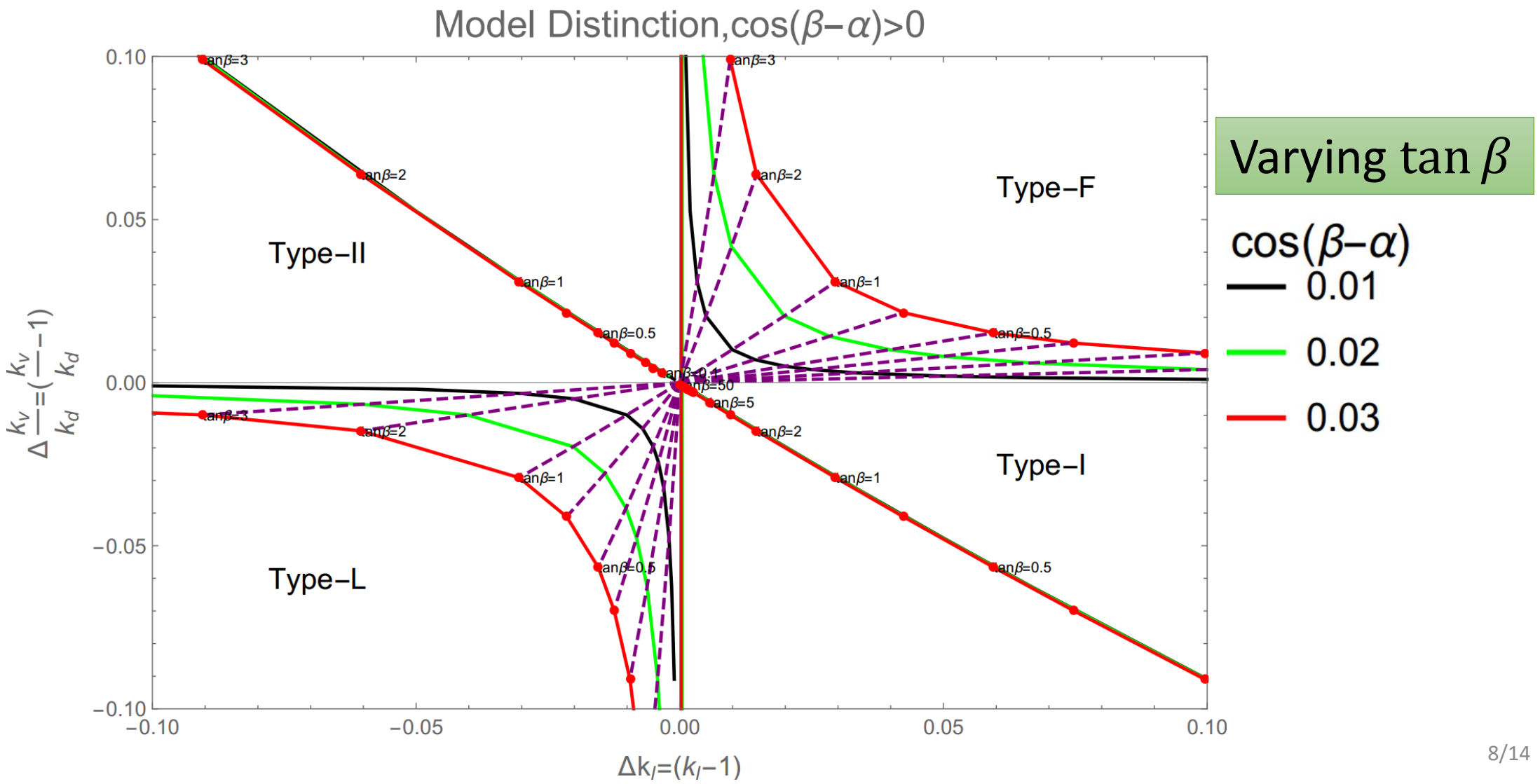
Other three types





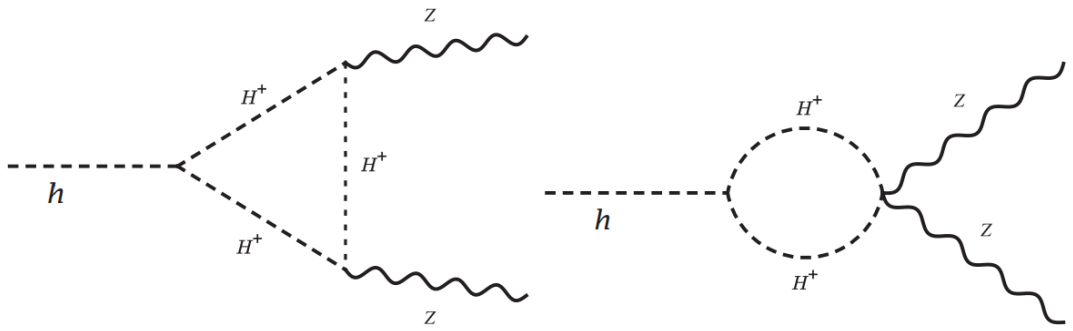


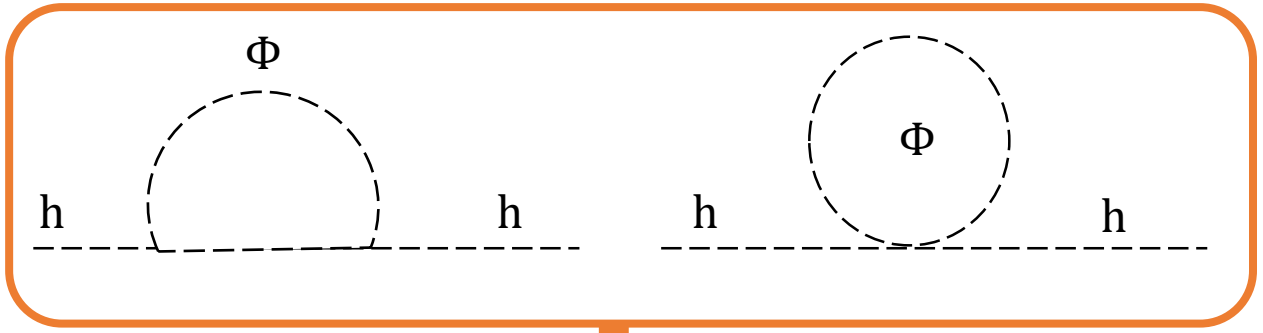
2HDM: Tree Level Model Distinction



2HDM: One-Loop Level

Alignment limit : $\cos(\beta - \alpha) = 0$





Main contribution

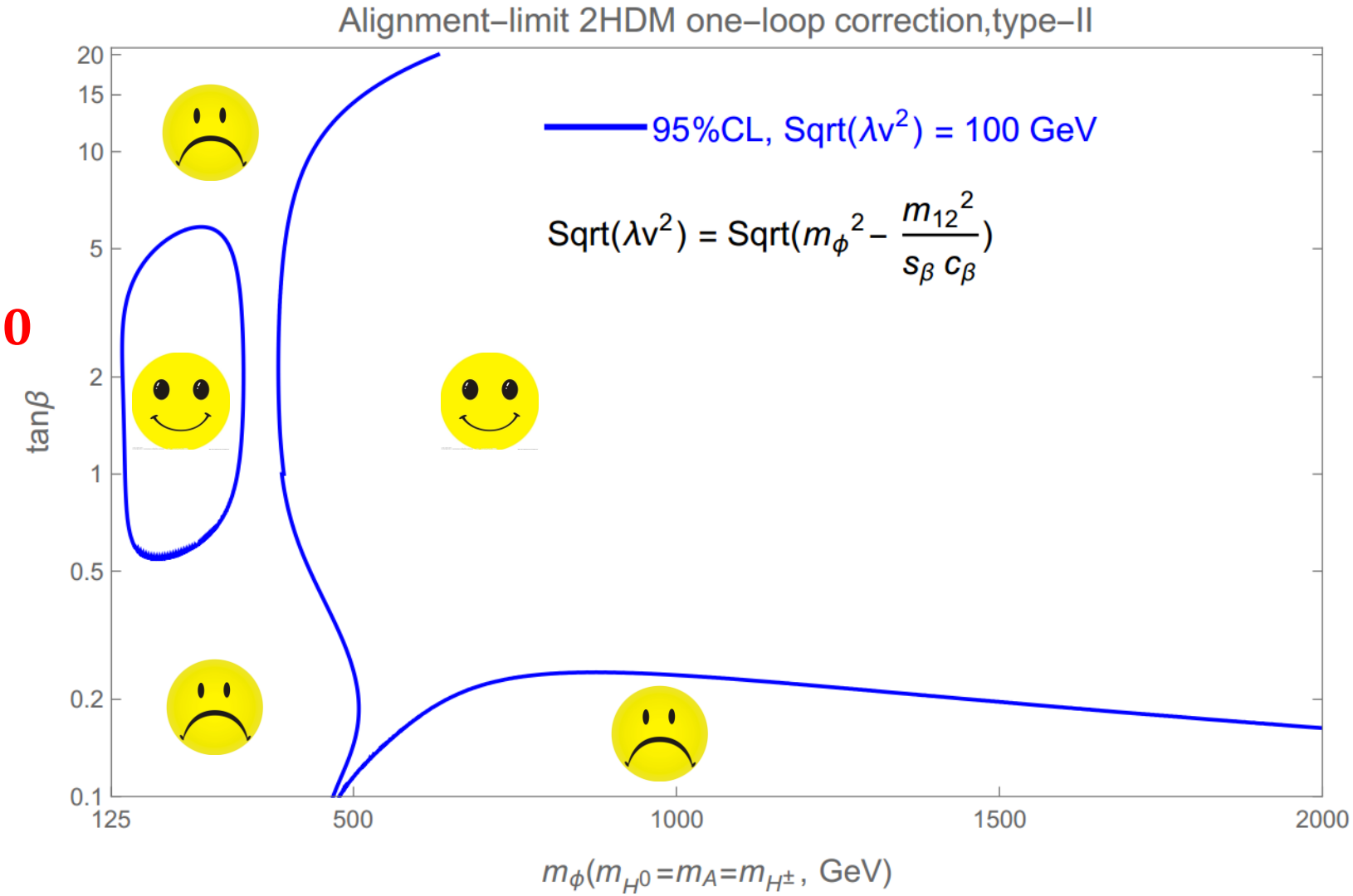
- Setting : $m_\Phi \equiv m_H = m_A = m_{H^\pm}$
- Theoretical constraints: $-125^2\mathrm{GeV}^2 < \lambda \mathrm{v}^2 < 600^2\mathrm{GeV}^2$

Soft Z_2 symmetry breaking m_{12}^2

2HDM: One-Loop Level

CEPC fit, Type-II

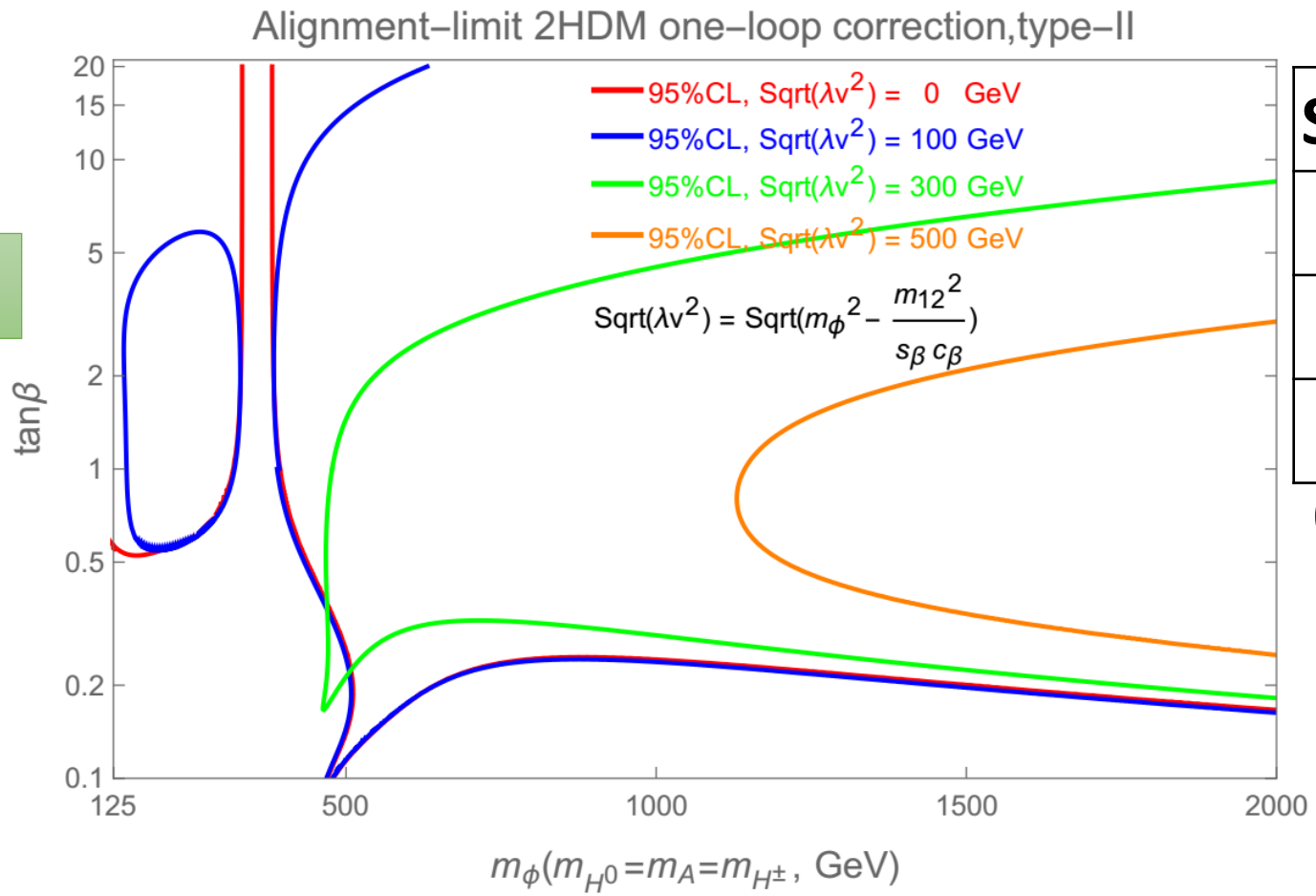
$\cos(\beta - \alpha) = 0$



2HDM: One-Loop Level

CEPC fit, Type-II

Varying λv^2



Sqrt(λv^2)	$m_\Phi >$
100	400
300	500
500	1100

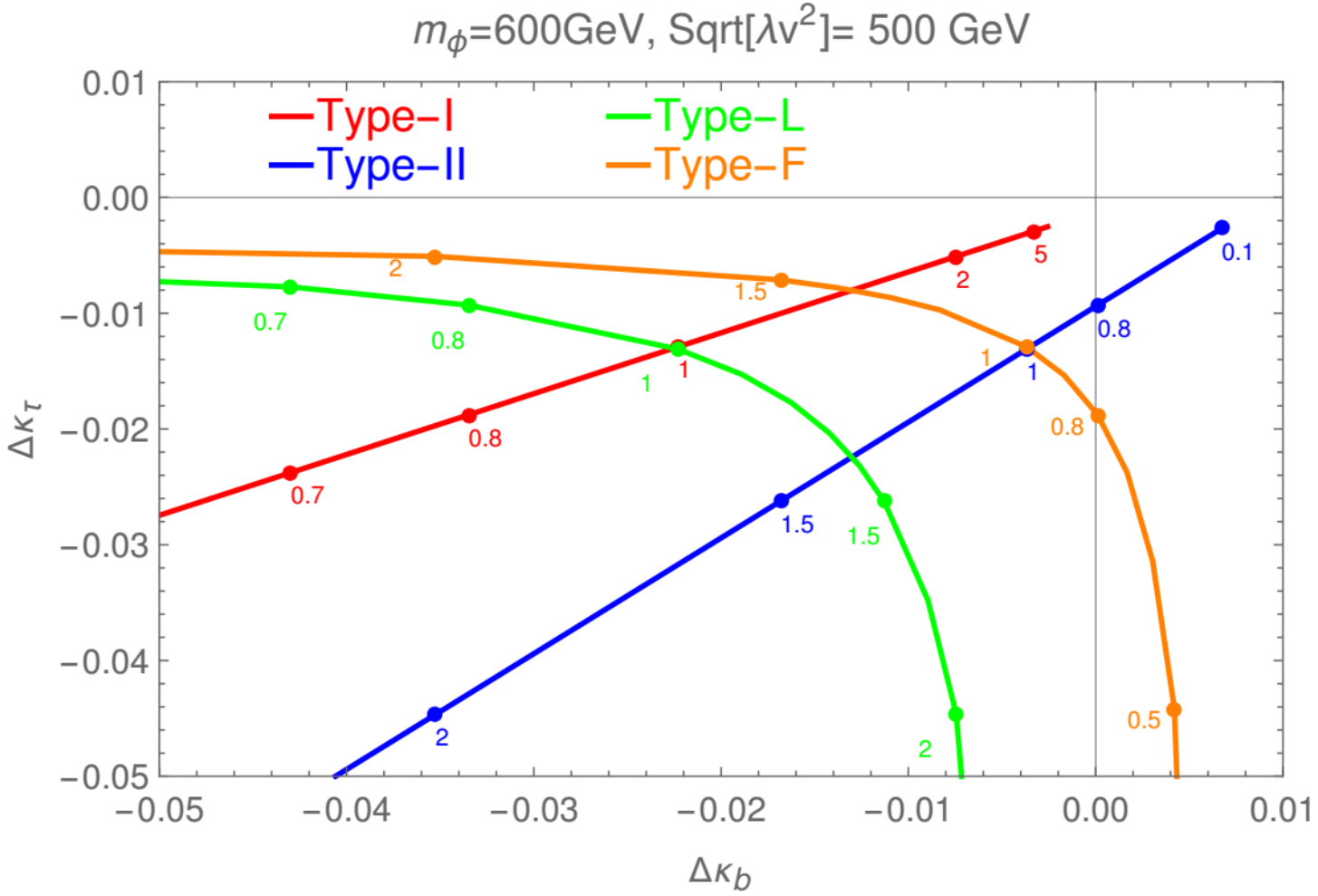
(GeV)

$$\cos(\beta-\alpha)=0\,,\ -125^2\mathrm{GeV}^2<\lambda v^2<600^2\mathrm{GeV}^2$$

2HDM: One-Loop Level Model Distinction

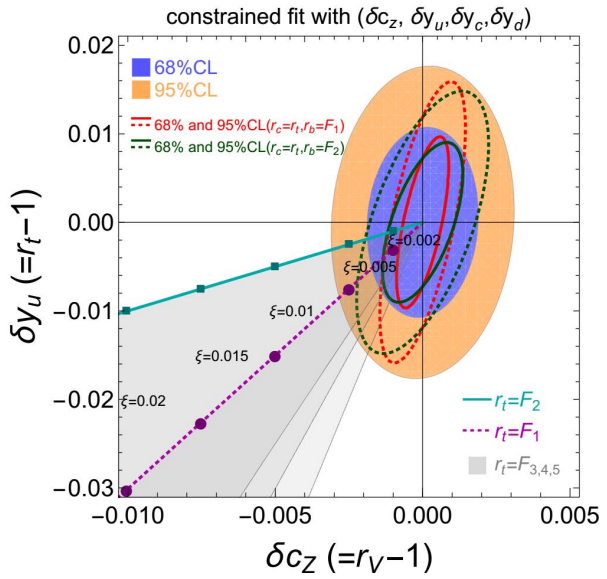
Varying $\tan\beta$

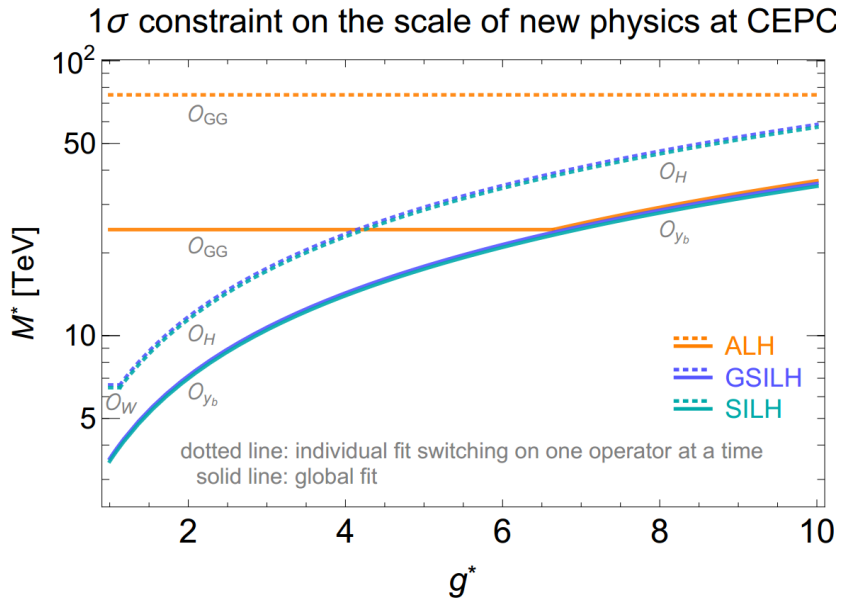
Alignment limit :
$\cos(\beta-\alpha)=0$



Composite Higgs

- Higgs coupling precision: **ee collider 1 order better than HL-LHC**
- EFT operator scale : Λ lager than 3TeV (CEPC)





Conclusion

- Higgs precision measurement ⟹ constraints of model space
- Generally, three ee colliders sensitivities are comparable
- BSM physics sensitivity
  - 2HDM
    Tree: **ee collider 3 times better than HL-LHC**
    One-loop : generally, $m_\Phi > 400$ GeV (CEPC)
    for $\sqrt{\lambda v^2} = 500$ GeV, $m_\Phi > 1.1$ TeV ⟸ alignment limit
  - Composite Higgs
    Coupling precision: **ee collider 1 order better than HL-LHC**
    EFT operator scale : $\Lambda \geq 3$ TeV (CEPC)
  - After all, **future colliders >> LHC Run-I**

Thanks for your attention

BACKUP

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

- $\Delta = -\sin\alpha/\cos\beta - 1 \approx -\tan\beta\cos(\beta-\alpha) \leq 1\%$, $\tan\beta$ enhancement

2HDM: One-Loop Level Model Distinction

$$\text{loop: } \lambda v^2 \equiv m_\Phi^2 - m_{12}^2/s_\beta c_\beta = -\lambda_5 v^2$$

CHM: Coeff of Operators

$$\mathcal{O}_H = \frac{1}{2}\left(\partial_\mu |H|^2\right)^2 , \qquad \mathcal{O}_{y_f} = |H|^2 \bar{q}_L H f_R ,$$

$$\mathcal{O}_{GG} = |H|^2 G_{\mu\nu} G^{\mu\nu} , \qquad \mathcal{O}_{BB} = |H|^2 B_{\mu\nu} B^{\mu\nu} ,$$

$$\mathcal{O}_W = \frac{i}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D}_\mu H\right) D^\nu W^a_{\mu\nu} , \qquad \mathcal{O}_B = \frac{i}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right) \partial^\nu B_{\mu\nu} ,$$

$$\mathcal{O}_{HW} = i\left(D^\mu H\right)^\dagger \sigma^a \left(D^\nu H\right) W^a_{\mu\nu} , \qquad \mathcal{O}_{HB} = i\left(D^\mu H\right)^\dagger \left(D^\nu H\right) B_{\mu\nu} .$$

Composite Higgs

SM Higgs: PNGB

hVV: $r_V \equiv \frac{g_{hVV}^{\rm CH}}{g_{hVV}^{\rm SM}} = \sqrt{1-\xi}$

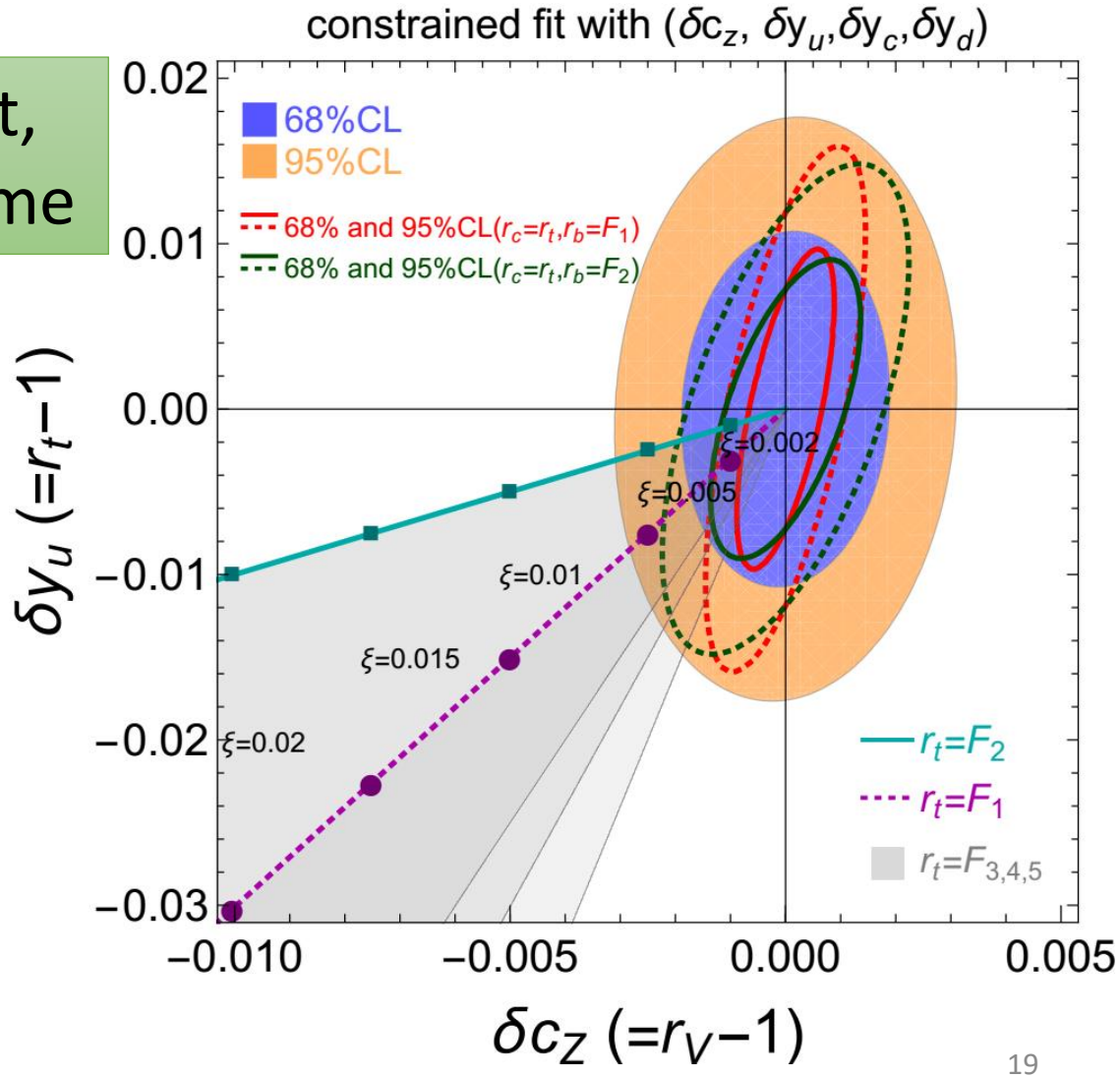
hff: depend on fermion representation

$F_1 \equiv \frac{1-2\xi}{\sqrt{1-\xi}}, \qquad F_2 \equiv \sqrt{1-\xi}$

$\boldsymbol{r_c = r_t, r_b = F_1}$

ee collider fit is about one order better than HL-LHC

CEPC fit, κ scheme



Composite Higgs

CEPC fit,
EFT scheme

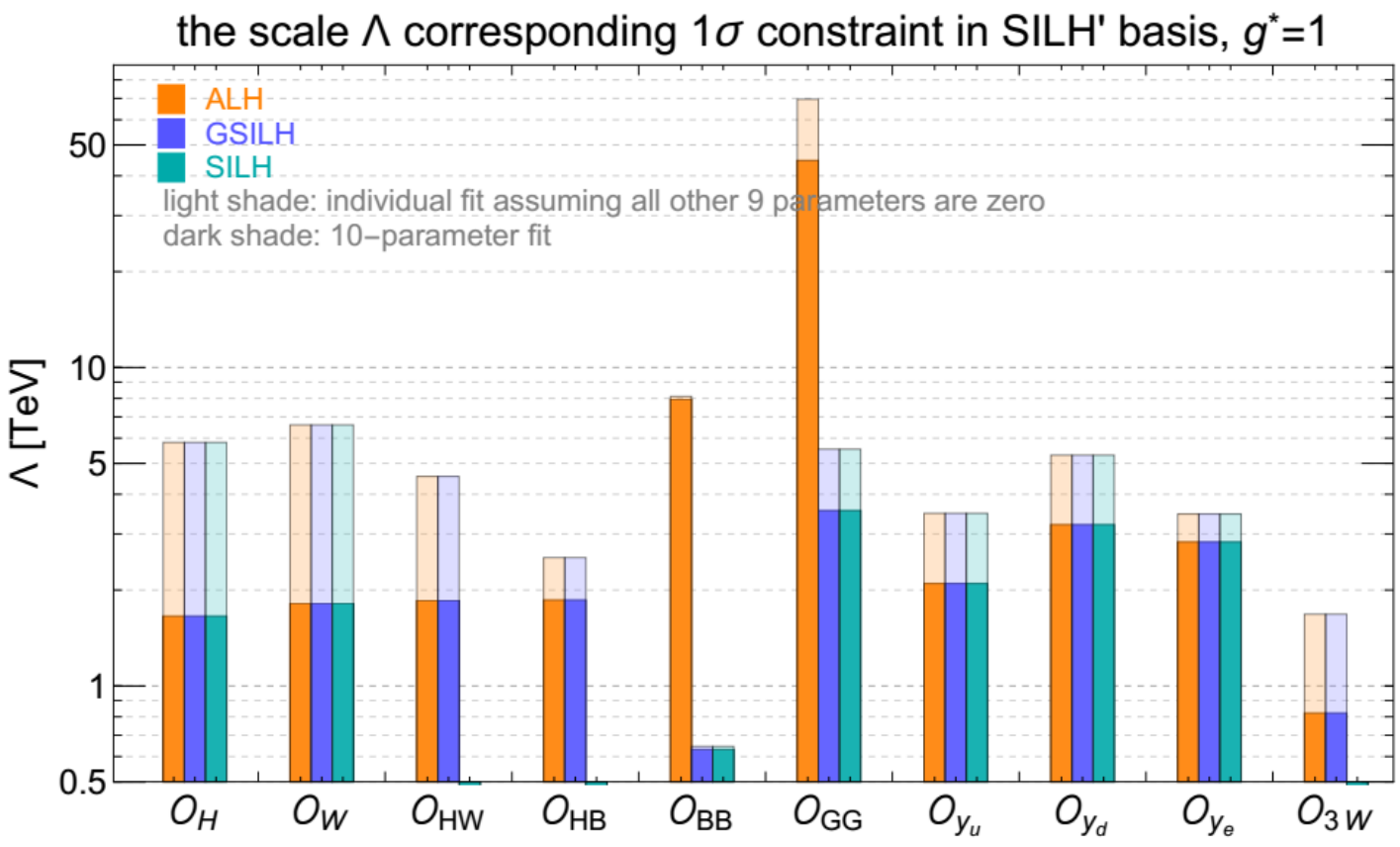
$$\mathcal{O}_H = \frac{1}{2}\left(\partial_\mu |H|^2\right)^2 ,$$

$$\mathcal{O}_{GG} = |H|^2 G_{\mu\nu} G^{\mu\nu} ,$$

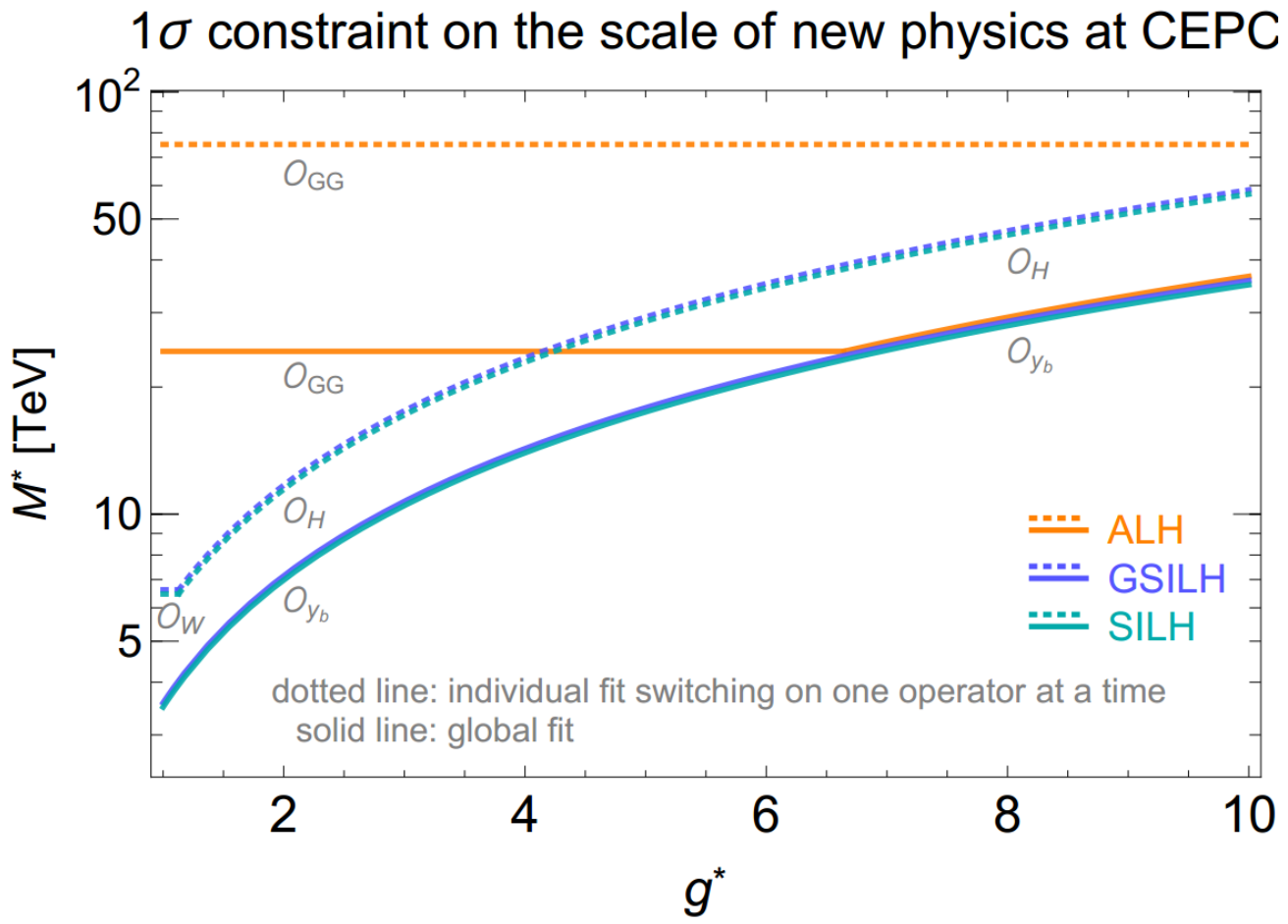
$$\mathcal{O}_{BB} = |H|^2 B_{\mu\nu} B^{\mu\nu}$$

…

$\Lambda \geq 1$ TeV



Composite Higgs



CHM: Coeff of Operators