New Physics Implication of Higgs Precision Measurements

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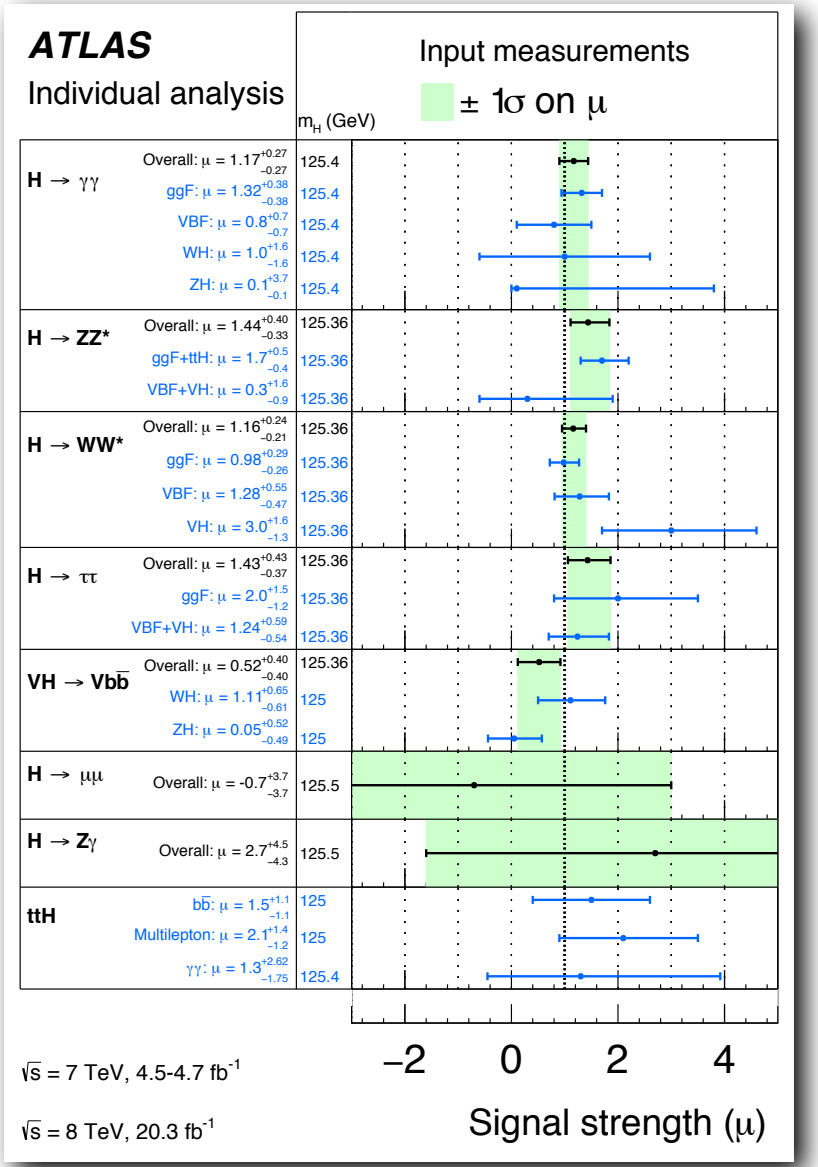
Collaboration with J. Gu, H. Li, Z. Liu, W. Su.

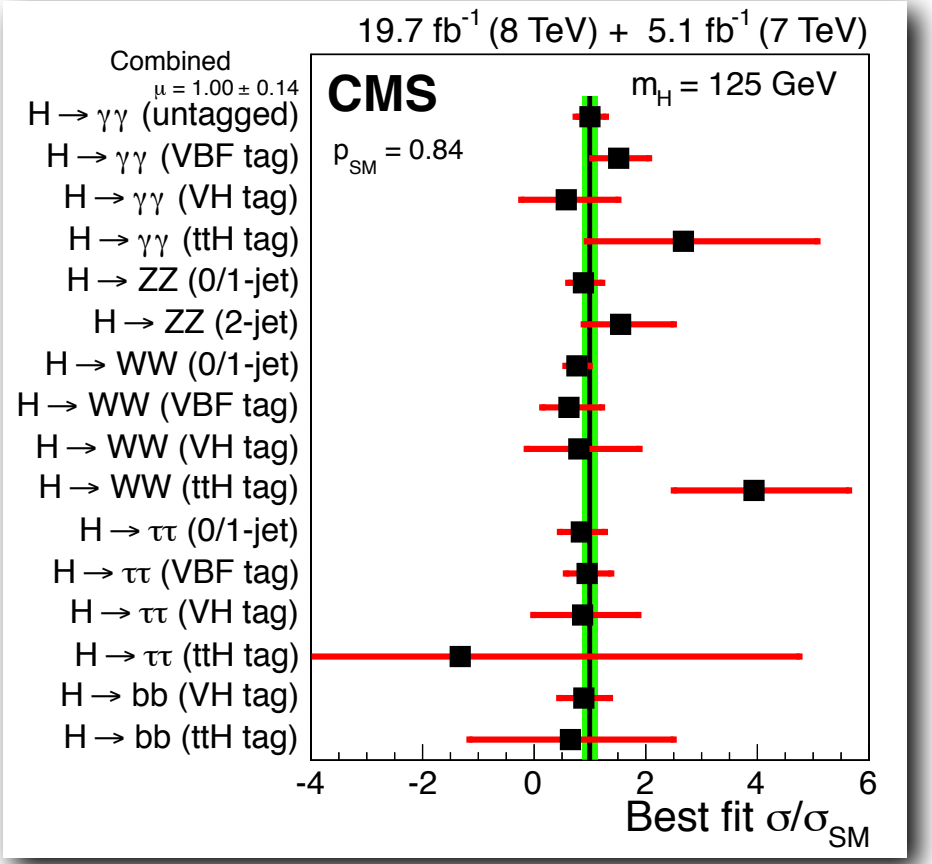
Outline

- Higgs precision measurements
- Common strategies
- 2HDM
- Composite Higgs Models
- Conclusion

Higgs Precision Measurements

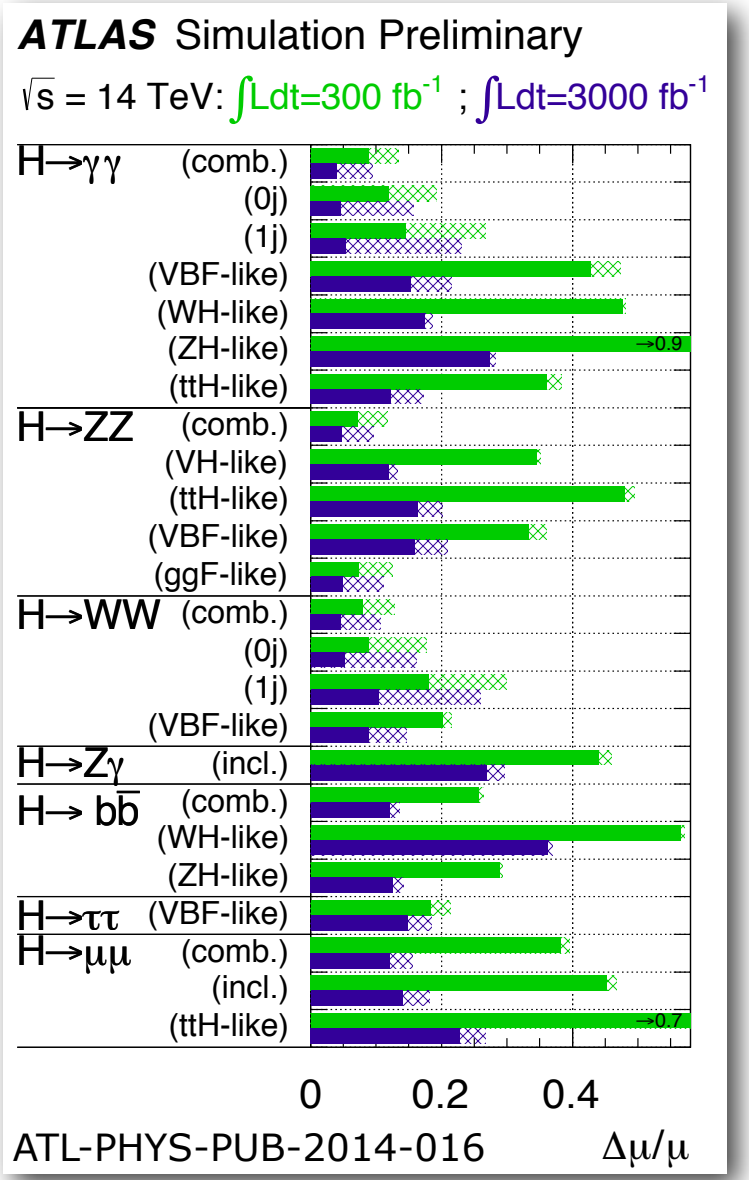


LHC: 7+8 TeV



CERN-PH-EP-2015-125
CERN-PH-EP-2013-037

Higgs Precision Measurements



LHC: 14 TeV, 300 fb^{-1}, 3000 fb^{-1}

$\Delta\mu/\mu$	300 fb^{-1}		3000 fb^{-1}	
	All unc.	No theory unc.	All unc.	No theory unc.
$H \to \gamma\gamma$ (comb.)	0.13	0.09	0.09	0.04
(0j)	0.19	0.12	0.16	0.05
(1j)	0.27	0.14	0.23	0.05
(VBF-like)	0.47	0.43	0.22	0.15
(WH-like)	0.48	0.48	0.19	0.17
(ZH-like)	0.85	0.85	0.28	0.27
($t\bar{t}H$-like)	0.38	0.36	0.17	0.12
$H \to ZZ$ (comb.)	0.11	0.07	0.09	0.04
(VH-like)	0.35	0.34	0.13	0.12
($t\bar{t}H$-like)	0.49	0.48	0.20	0.16
(VBF-like)	0.36	0.33	0.21	0.16
(ggF-like)	0.12	0.07	0.11	0.04
$H \to WW$ (comb.)	0.13	0.08	0.11	0.05
(0j)	0.18	0.09	0.16	0.05
(1j)	0.30	0.18	0.26	0.10
(VBF-like)	0.21	0.20	0.15	0.09
$H \to Z\gamma$ (incl.)	0.46	0.44	0.30	0.27
$H \to b\bar{b}$ (comb.)	0.26	0.26	0.14	0.12
(WH-like)	0.57	0.56	0.37	0.36
(ZH-like)	0.29	0.29	0.14	0.13
$H \to \tau\tau$ (VBF-like)	0.21	0.18	0.19	0.15
$H \to \mu\mu$ (comb.)	0.39	0.38	0.16	0.12
(incl.)	0.47	0.45	0.18	0.14
($t\bar{t}H$-like)	0.74	0.72	0.27	0.23

Higgs Precision Measurements

CEPC, 250 GeV, 5 ab^{-1}

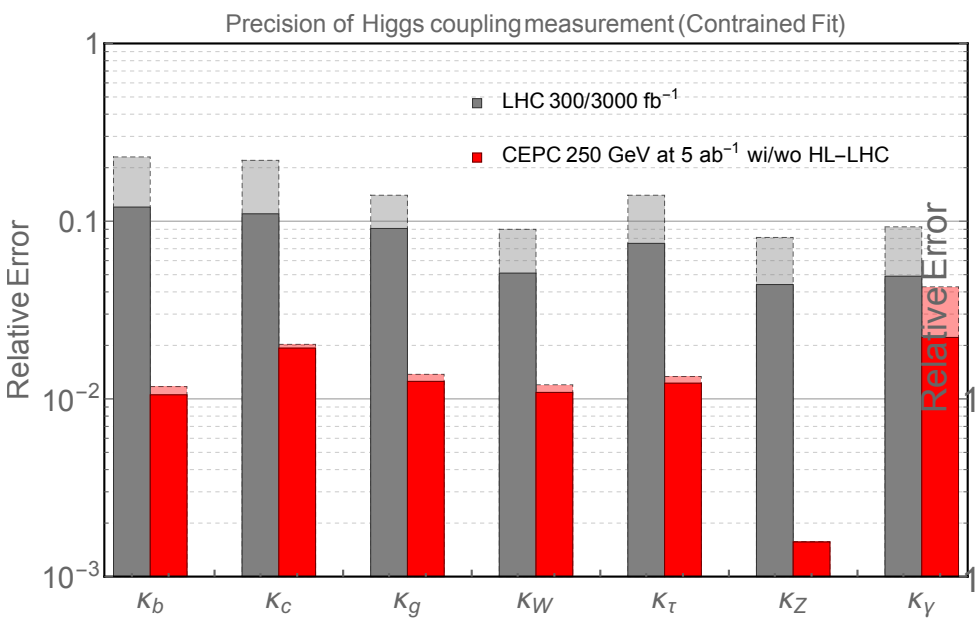
ΔM_H	Γ_H	$\sigma(ZH)$	$\sigma(\nu\nu H) \times \mathrm{BR}(H \to bb)$
5.5 MeV	2.8%	0.51%	2.8%

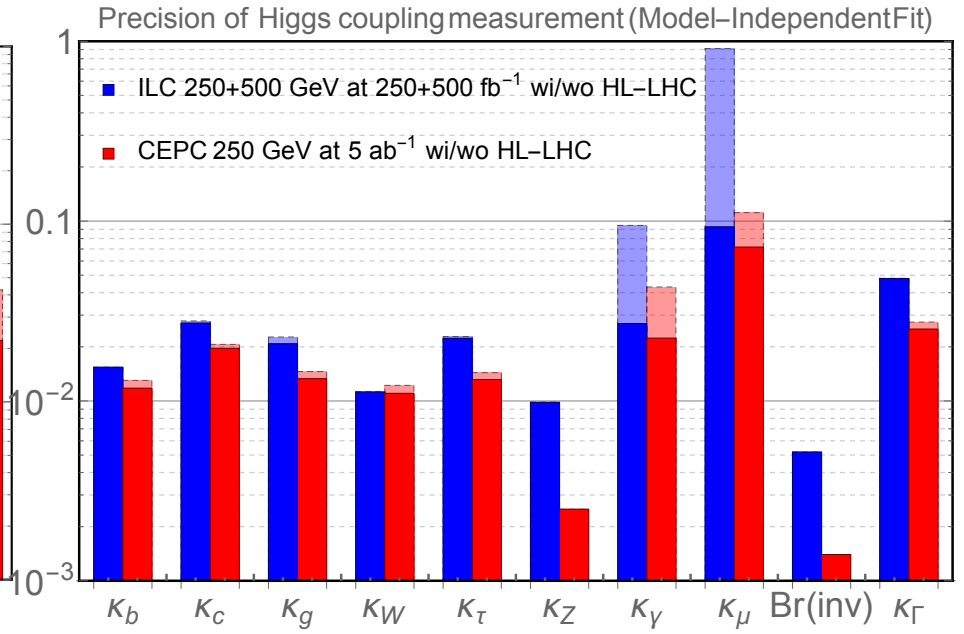
Decay mode	$\sigma(ZH) \times \mathrm{BR}$	BR
$H \to bb$	0.28%	0.58%
$H \to cc$	2.2%	2.3%
$H \to gg$	1.6%	1.7%
$H \to \tau\tau$	1.2%	1.3%
$H \to WW$	1.5%	1.6%
$H \to ZZ$	4.3%	4.3%
$H \to \gamma\gamma$	9.0%	9.0%
$H \to \mu\mu$	17%	17%
$H \to$ inv	0.28%	0.28%

Common Strategies

- **kappa-scheme**

$$\kappa_f = \frac{g(hff)}{g(hff;\mathrm{SM})},\ \kappa_V = \frac{g(hVV)}{g(hff;\mathrm{SM})}$$





Be aware of assumptions and constraints.

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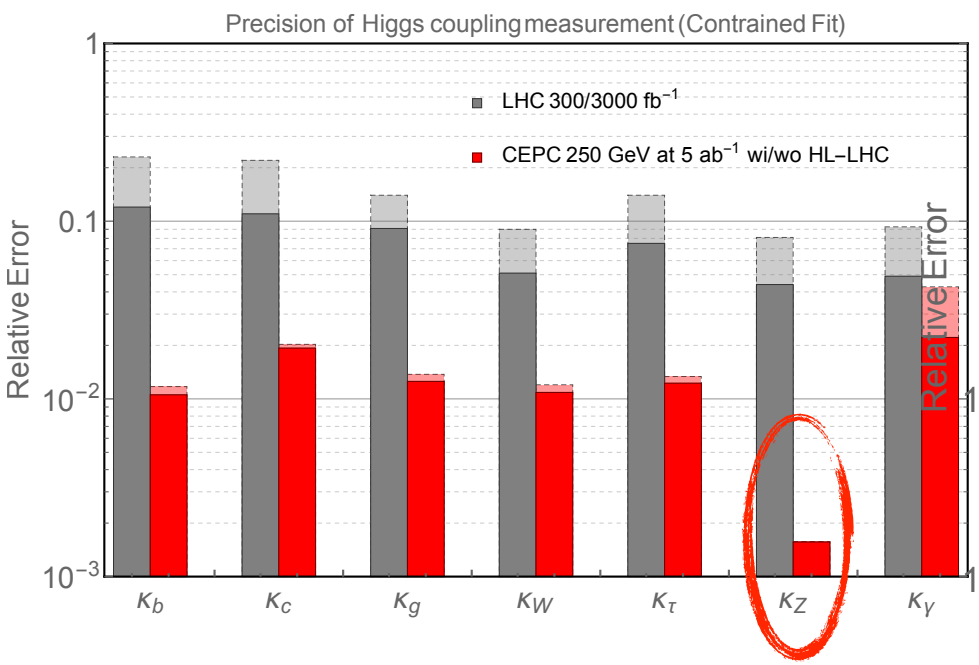

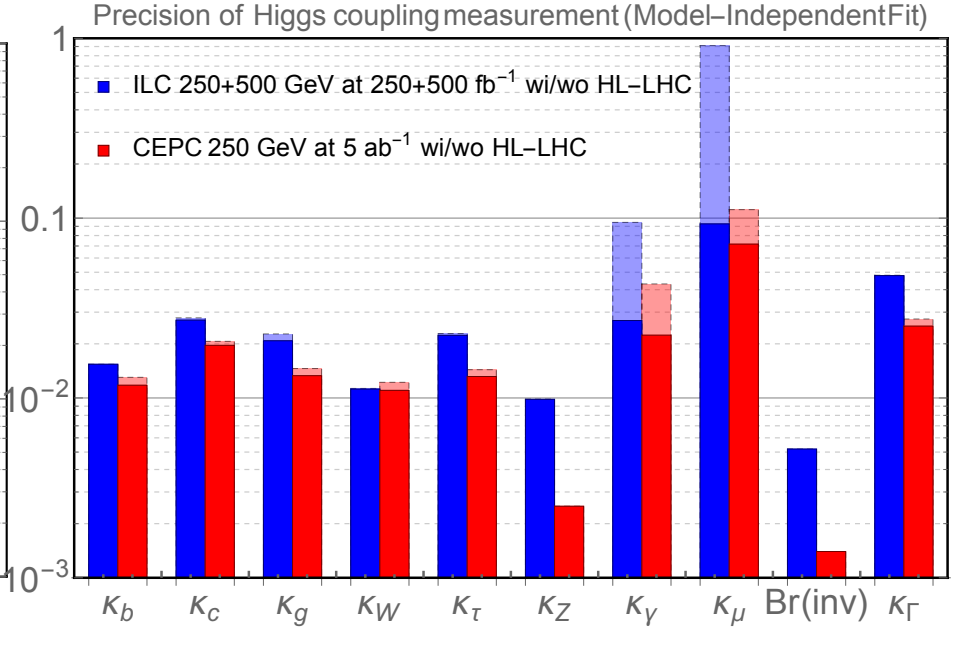

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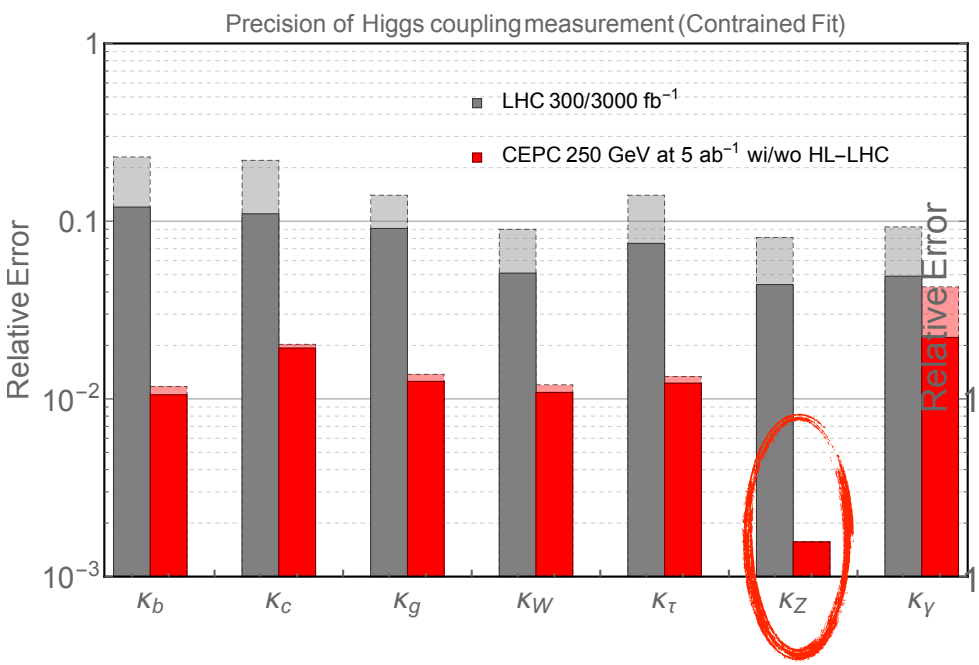
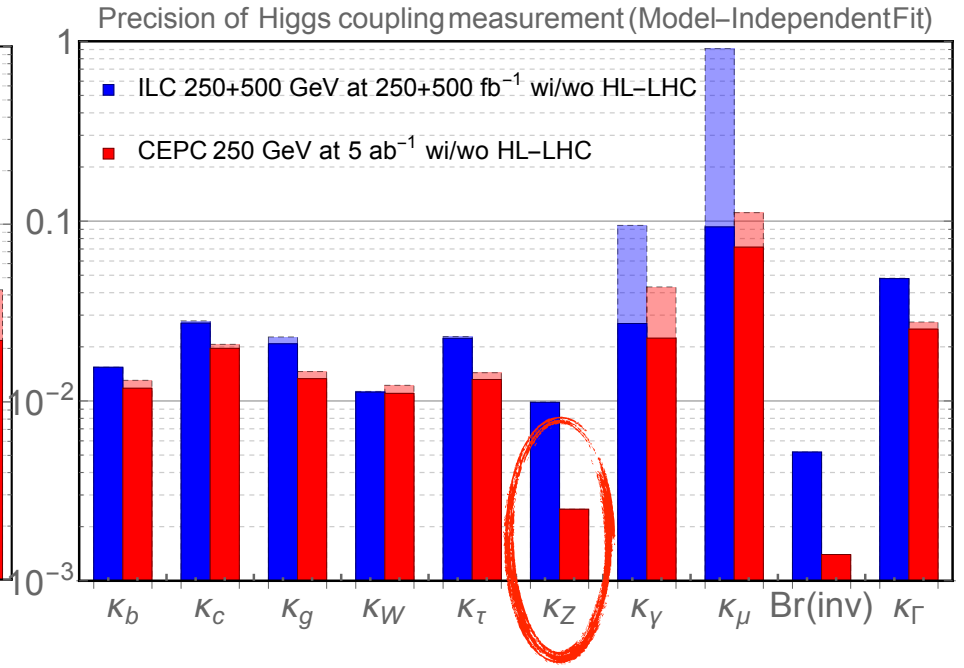


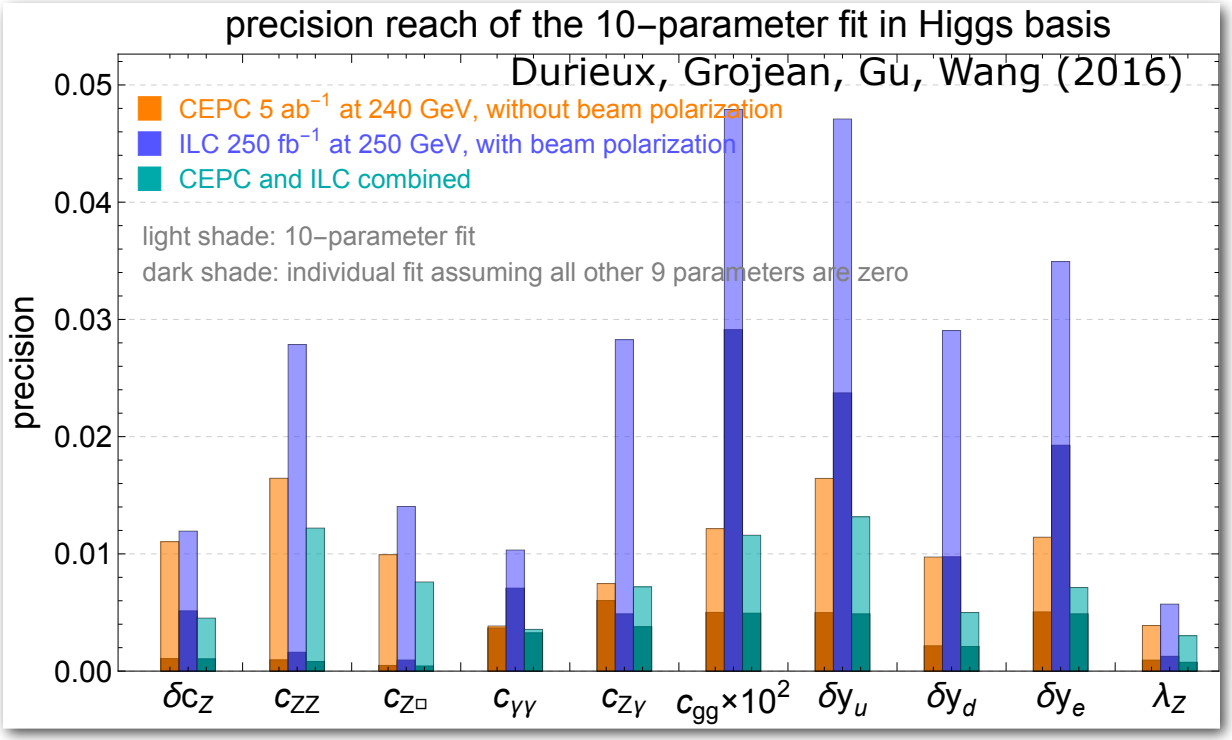


Be aware of assumptions and constraints.

Common Strategies

- **EFT: Warsaw basis, SILH basis, Higgs basis**

$$\delta c_Z\,,\quad c_{ZZ}\,,\quad c_{Z\Box}\,,\quad c_{\gamma\gamma}\,,\quad c_{Z\gamma}\,,\quad c_{gg}\,,\quad \delta y_u\,,\quad \delta y_d\,,\quad \delta y_e\,,\quad \lambda_Z$$



$$\chi^2 = \sum_{ij} (c - c_0)_i \, \sigma_{ij}^{-2} \, (c - c_0)_j$$

$$\sigma_{ij}^{-2} \equiv (\delta c_i \, \rho_{ij} \, \delta c_j)^{-1}$$

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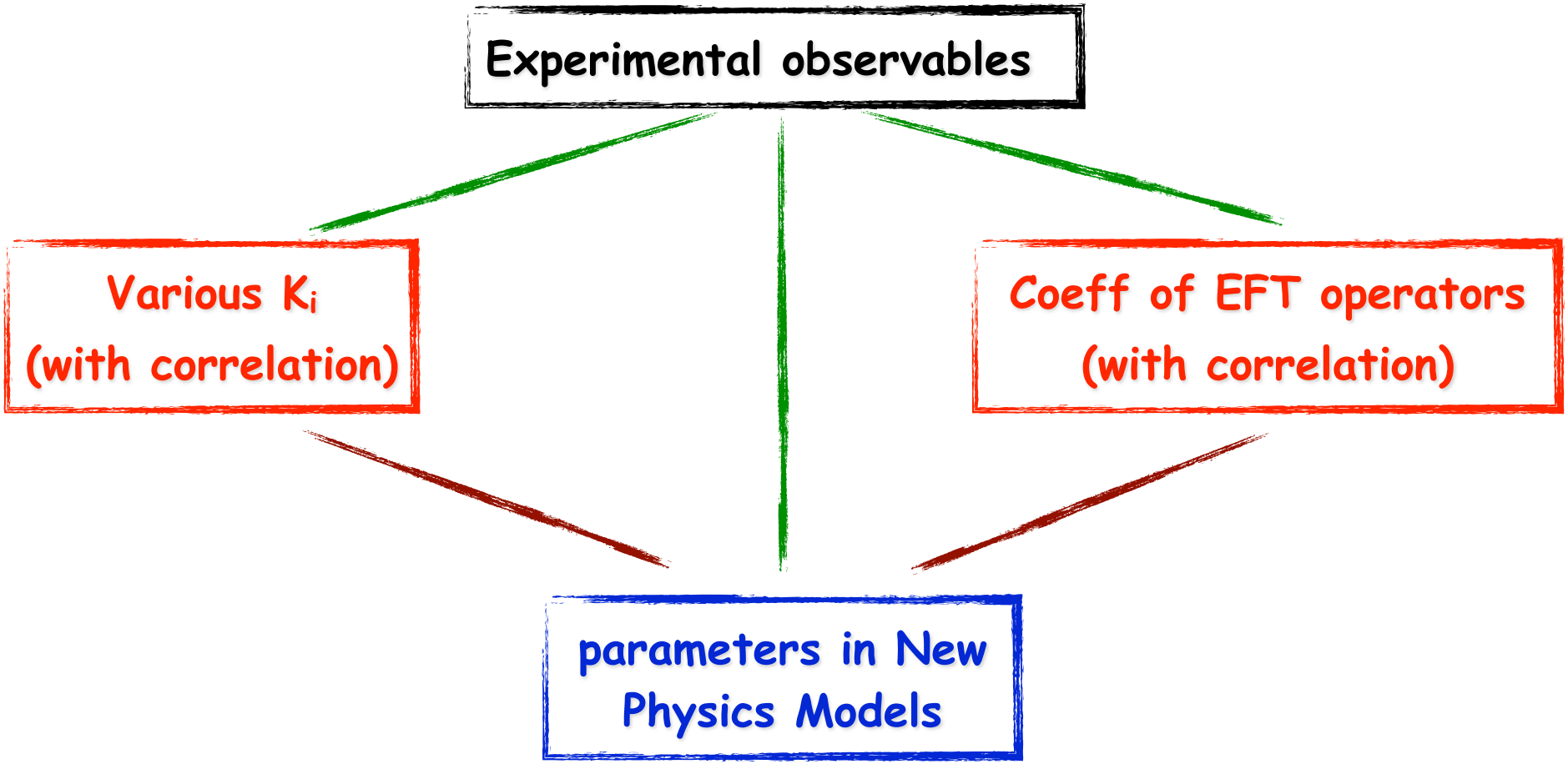
For certain new physics models, only need subset.

New Physics Implication



2HDM in one slide

- **Two Higgs Doublet Model (CP-conserving)**

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

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

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

after EWSB, 5 physical Higgses
CP-even Higgses: h^0, H^0 , CP-odd Higgs: A^0, Charged Higgses: $H^\pm$

- **h^0/H^0 VV coupling**

$$g_{H^0VV} = \frac{m_V^2}{v}\cos(\beta-\alpha), \quad g_{h^0VV} = \frac{m_V^2}{v}\sin(\beta-\alpha).$$

alignment limit: $\cos(\beta-\alpha)=0$, h^0 is the SM Higgs with SM couplings.

2HDM parameters

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

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

- parameters (CP-conserving, flavor limit, Z_2 symmetry)

246 GeV 125 GeV

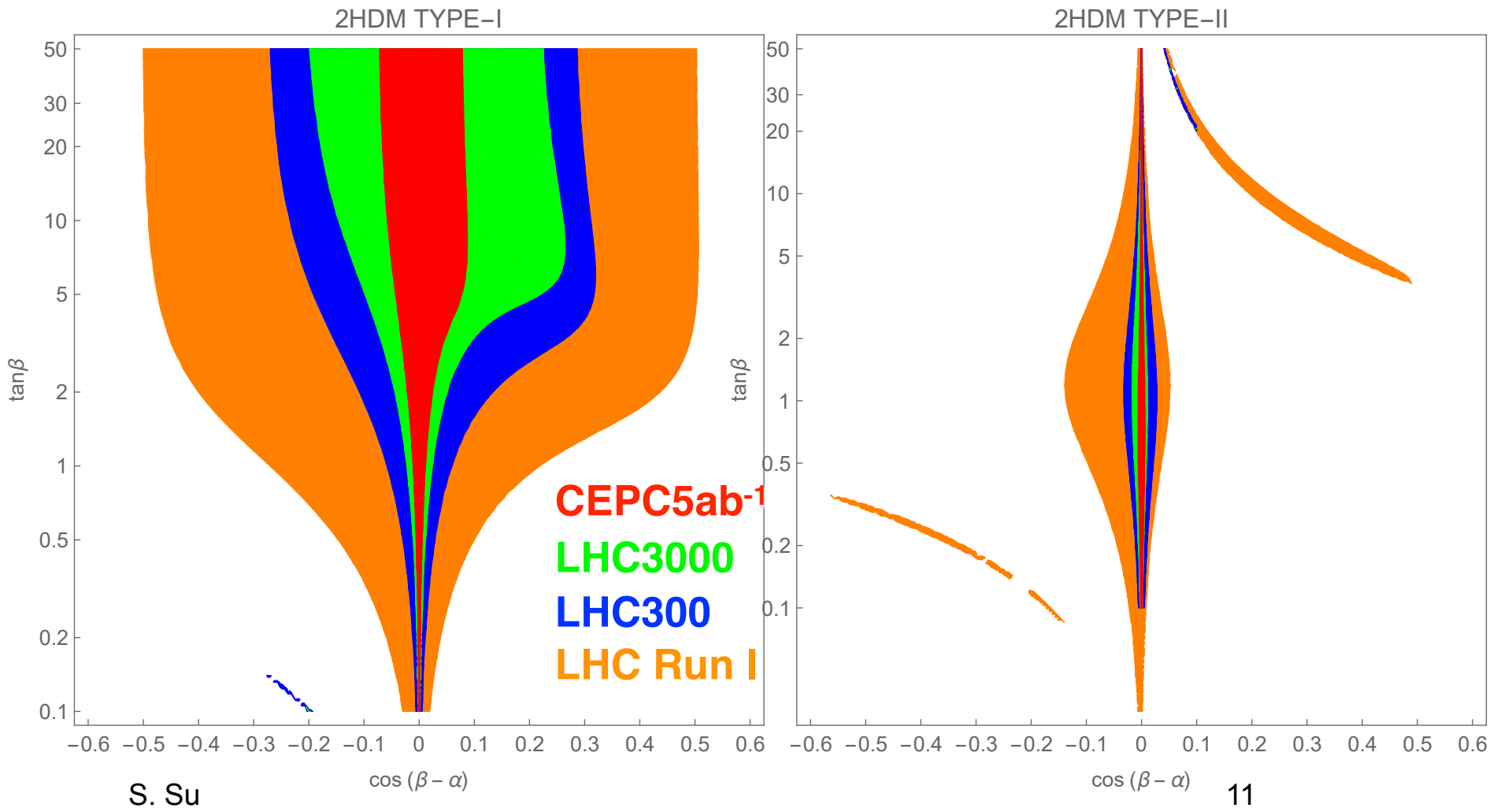
$$m_{11}^2,\ m_{22}^2,\ \lambda_1,\ \lambda_2,\ \lambda_3,\ \lambda_4,\ \lambda_5 \rightarrow v, \tan\beta, \alpha, m_h, m_H, m_A, m_{H^\pm}$$

soft Z2 breaking: m_{12}^2

tanβ, cos(β-α),
control tree level h^0 couplings

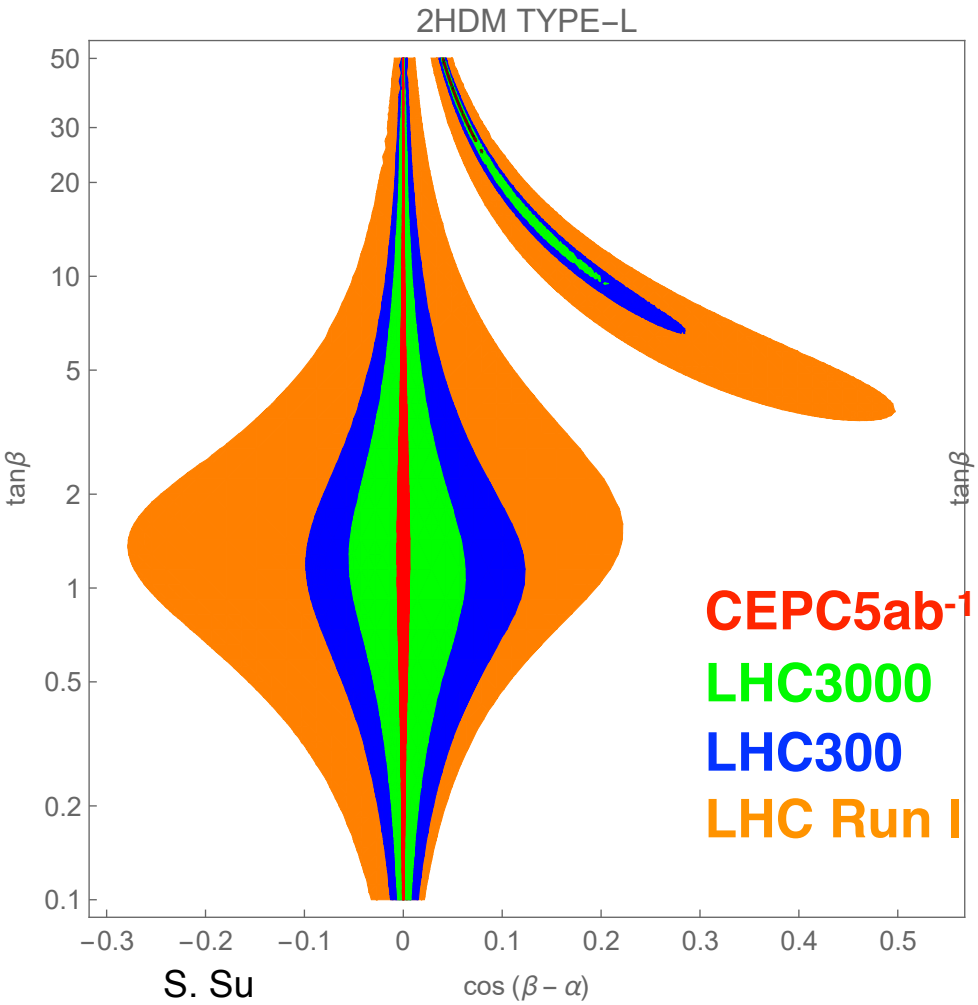
Tree-level 2HDM fit

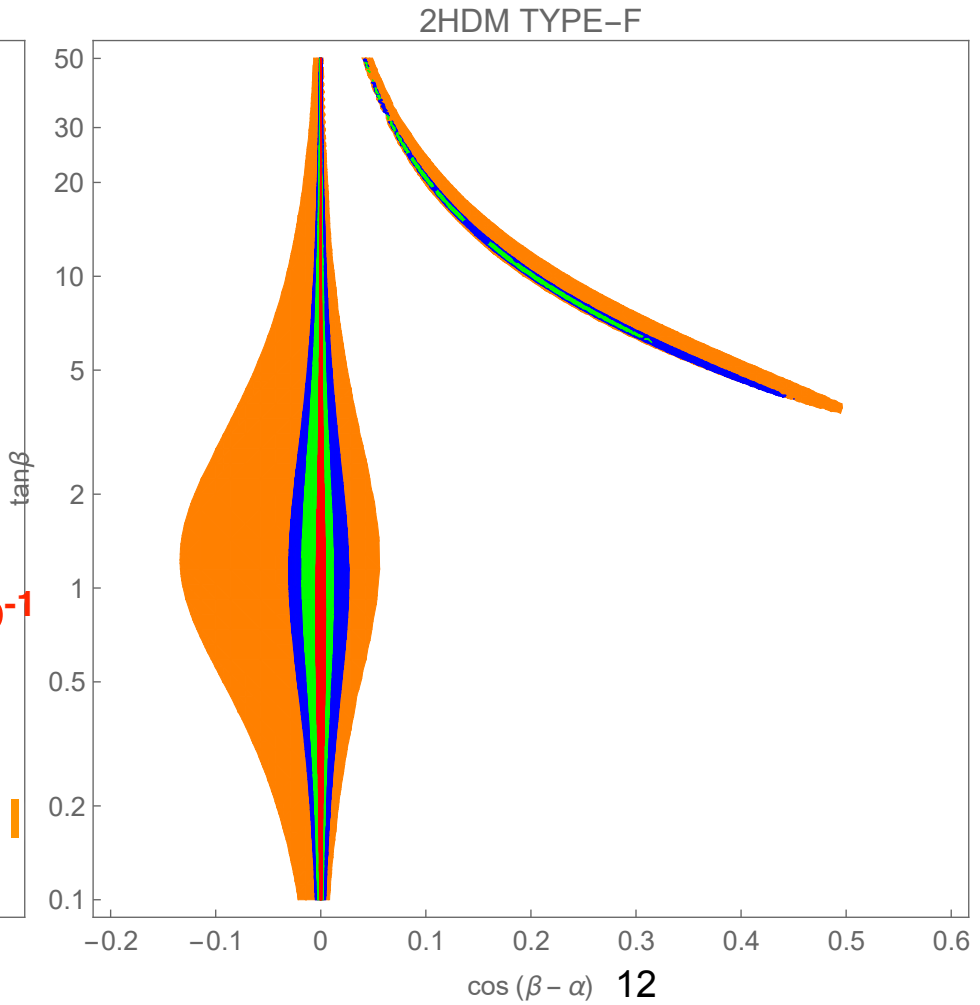
2HDM, LHC/CEPC fit



Tree-level 2HDM fit

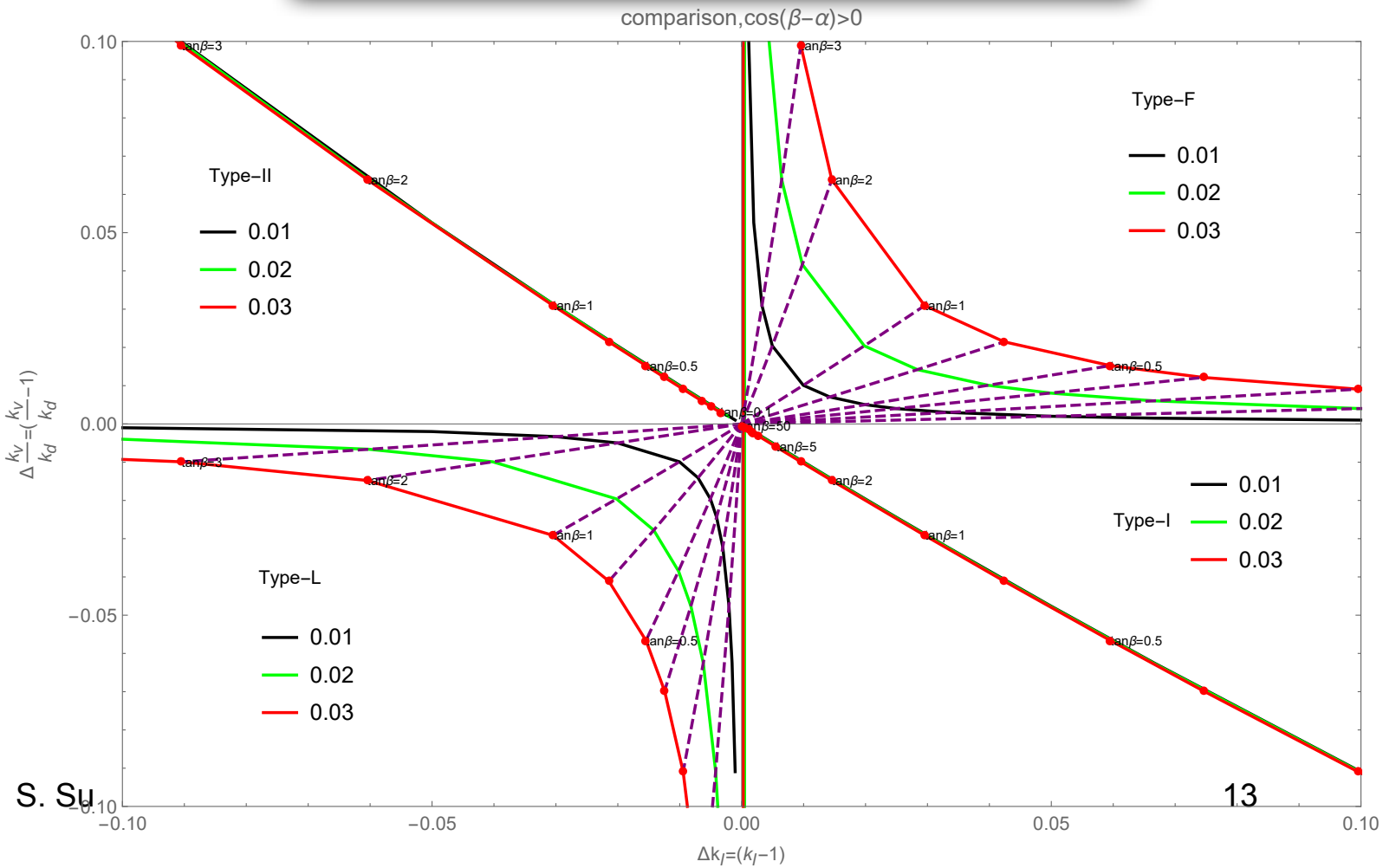
2HDM, LHC/CEPC fit



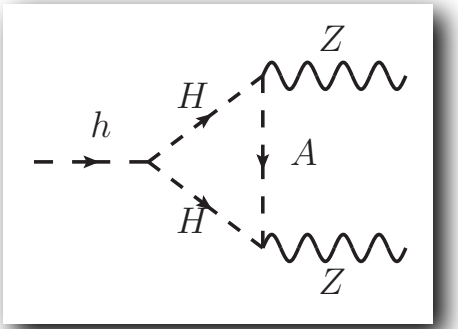


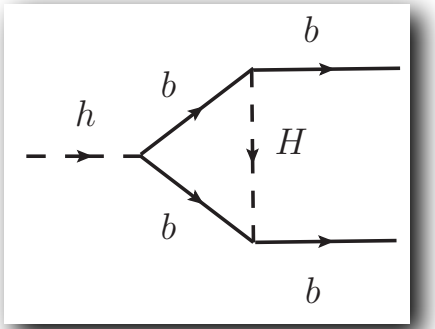
Model Distinction

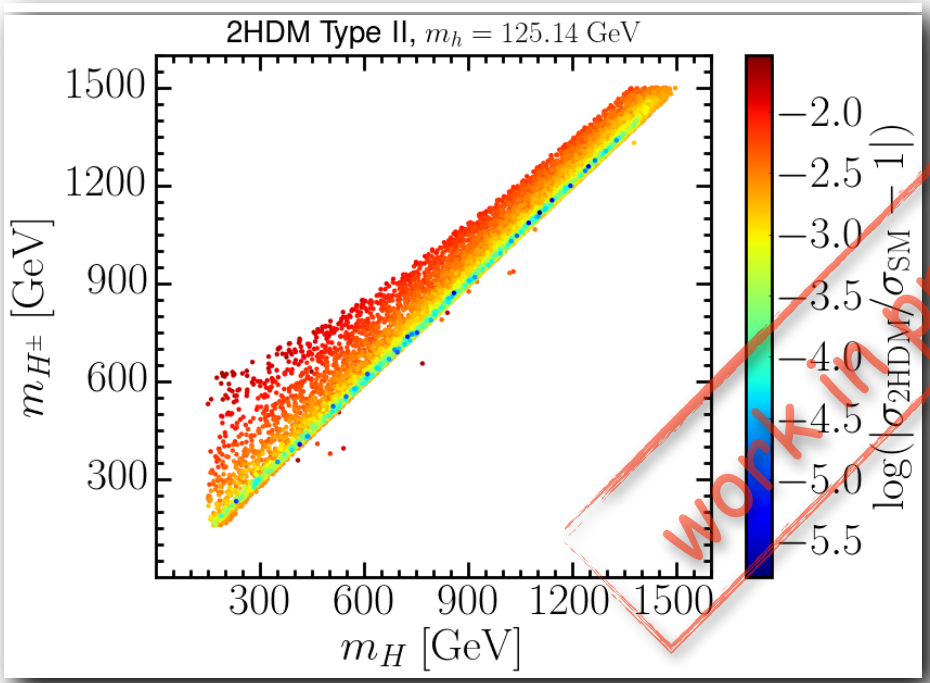
Model	κ_V	κ_u	κ_d	κ_ℓ
2HDM-I	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
2HDM-II	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$-\sin\alpha/\cos\beta$
2HDM-L	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$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

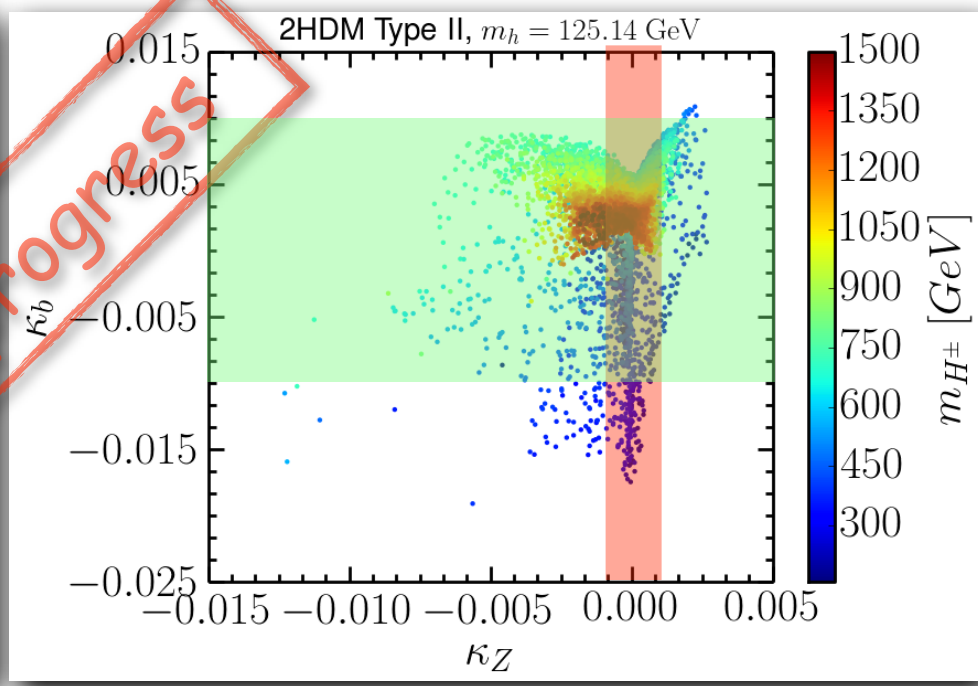


2HDM: Loop









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Han, Wu, SS, Zhang, work in progress

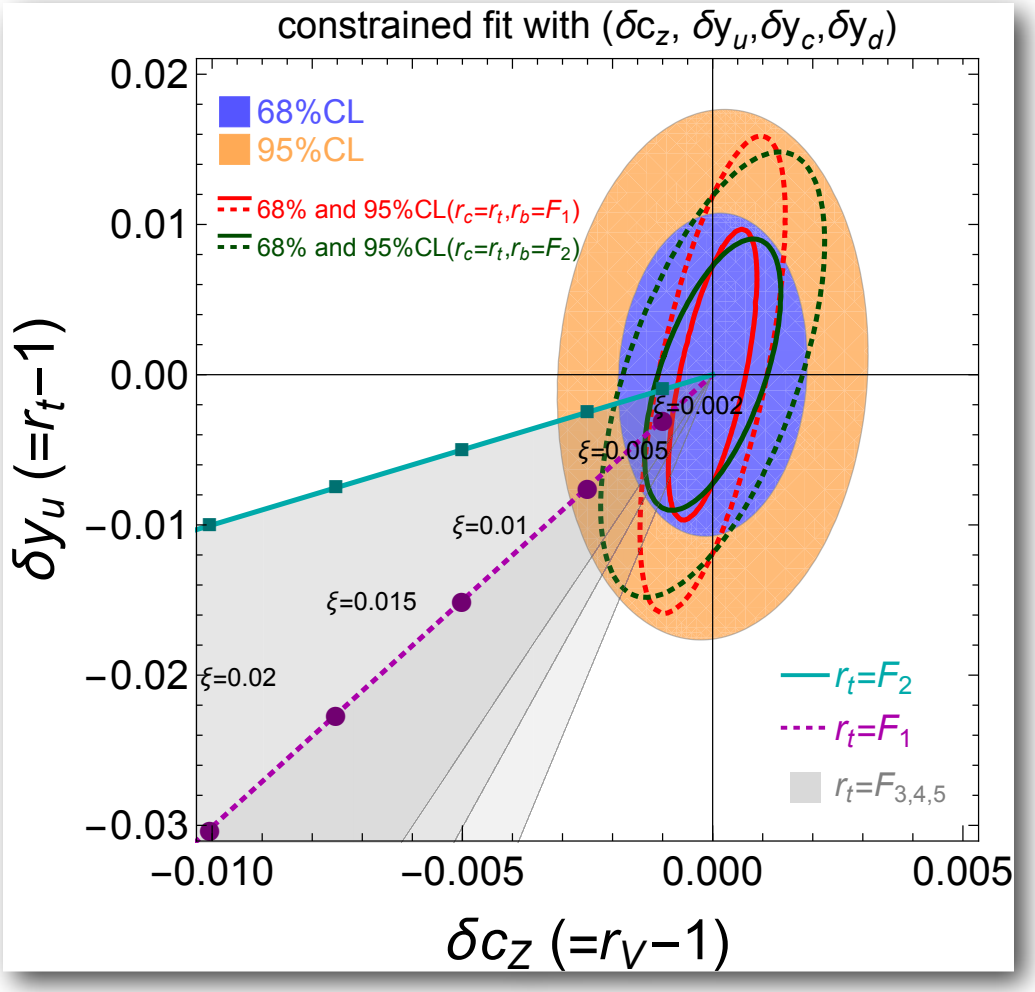
Composite Higgs in one slide

- Higgs is the PNGB of the spontaneous breaking of G⇒H
- EWSB is induced by vacuum misalignment, parametrized by $\xi=v^2/f^2$
- mass of SM fermion generated by mixing with composite states
- light top partners can be searched at the LHC
- minimal coset (with custodial symmetry breaking) SO(5)/SO(4)
  - hVV $\quad r_V \equiv \frac{g^{\rm CH}_{hVV}}{g^{\rm SM}_{hVV}} = \sqrt{1-\xi}$
  - hff: depends on the fermion representation

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

Composite Higgs

CEPC fit



Conclusion

- CEPC could measure Higgs properties to a high precision
- Kappa-scheme and EFT scheme
- New physics sensitivity
  - tree level: constrain model parameters

    2HDM, composite Higgs, ...
  - loop level: constrain new particle masses

    2HDM, SUSY, ...