Electroweak and Higgs fits in the SM and beyond with HEPfit

EW and Flavor Physics @ CEPC Beijing, November 9th 2017

Otto Eberhardt

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SM and the search beyond

SM is complete and no direct hint for New Physics at LHC energy. Two possibilities to search for new physics:



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SM and the search beyond

SM is complete and no direct hint for New Physics at LHC energy. Two possibilities to search for new physics:

More energy





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SM is complete and no direct hint for New Physics at LHC energy. Two possibilities to search for new physics:

More energy

More precision





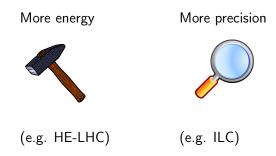


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More energy

&

More precision

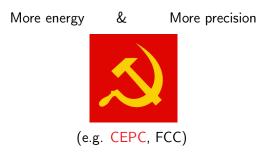


(e.g. CEPC, FCC)



SM and the search beyond

SM is complete and no direct hint for New Physics at LHC energy. Two possibilities to search for new physics:





Future colliders

Different concepts: HE-LHC, ILC, CLIC, CEPC/SppC, FCC(ee)

They all have in common that we will have to wait for decades:





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For the time being...

Let's try to scrutinize as well as possible the SM.

New Physics might hide in the details.

However, we need to combine all information as consistently as possible.





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Introduction

HEPfit

EW physics

Higgs physics

Summary



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 $\ensuremath{\mathsf{EW}}\xspace$ and $\ensuremath{\mathsf{Higgs}}\xspace$ fits in the SM and beyond

HEPfit

What? Why? Where? Who?

When?



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 $\ensuremath{\mathsf{EW}}\xspace$ and $\ensuremath{\mathsf{Higgs}}\xspace$ fits in the SM and beyond

HEPfit

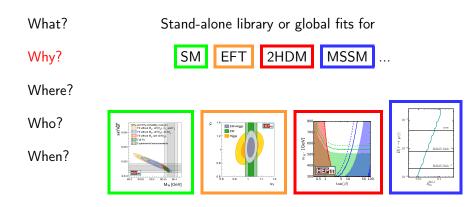
What?			
	High energy physics observables		
Why?	in the SM and beyond		
Where?	featuring	Flavour observables,	
Who?		Electroweak precision observables and Higgs observables	
When?	at best av	vailable precision	



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 EW and Higgs fits in the SM and beyond

HEPfit

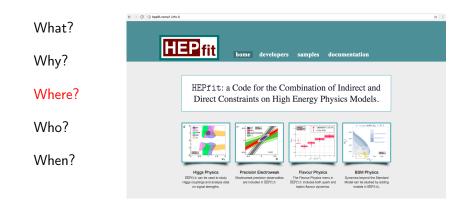




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HEPfit



http://hepfit.roma1.infn.it



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EW and Higgs fits in the SM and beyond

HEPfit

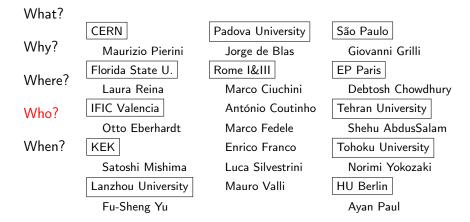
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Why?	PoS EPS-HEP2015 187			
Where?	JHEP 1611 (2016) 026			
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HEPfit





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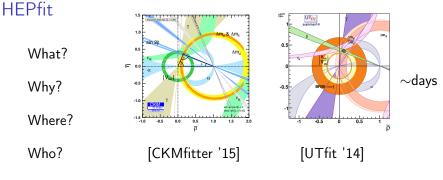
HEPfit

What?	
Why?	Already now: development version
Where?	https://github.com/silvest/HEPfit
Who?	Winter 2017/18: first fully documented release
When?	http://hepfit.roma1.infn.it



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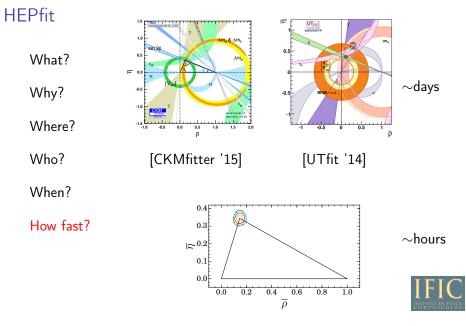
When?

How fast?



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HEPfit

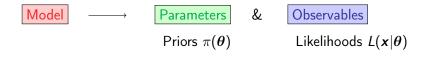
What?	
Why?	
Where?	It's free and it's open-source!
Who?	
When?	
How fast?	
How much?	



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 $\ensuremath{\mathsf{EW}}\xspace$ and $\ensuremath{\mathsf{Higgs}}\xspace$ fits in the SM and beyond

General overview



Output:

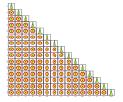
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General overview



Output: Parameter and observable posterior distributions



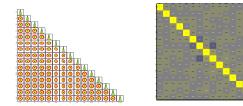
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General overview

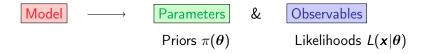


Output: Parameter and observable posterior distributions Parameter correlations

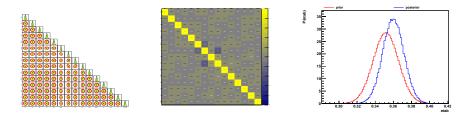


EW and Higgs fits in the SM and beyond

General overview



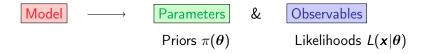
Output: Parameter and observable posterior distributions Parameter correlations Comparison of prior and posterior



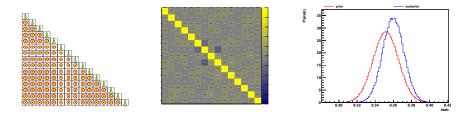
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General overview



Output: Parameter and observable posterior distributions Parameter correlations Comparison of prior and posterior Global mode and normalisation



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EW and Higgs fits in the SM and beyond

HEPfit – models

- Standard Model
- "Model independent models": EW oblique parameters (S, T, U; ε_i) Modified Zbb̄ vertex (δg^b_{L,R}, δg^b_{V,A}) Higgs signal strengths μ_i Mod. Higgs couplings κ_i (with and w/o universal V and f couplings) Various dim-6 bases (GIMR, BS with and w/o QFU,LFU) Flavour Wilson coefficients
 - Flavour vulson coefficient
- \mathbb{Z}_2 symmetric 2HDM's
- MSSM with complex couplings

In development: General 2HDM, LRSM, Georgi-Machacek, Manohar-Wise



HEPfit – observables

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$\label{eq:constraints} Tropological Tropol$	THOM THOM THOM THOM THOM THOM THOM THOM	$\vec{q} = 11, 22, 12$ i = 12, 14, 45 i = 12 i = (1,, 12) r = 0, 1 r = 0,
$\label{eq:constraints} Tropolog (Constraints) (Constrain$	THOM THOM THOM THOM THOM THOM THOM THOM	$\vec{q} = 11, 22, 12$ i = 12, 14, 45 i = 12 i = (1,, 12) r = 0, 1 r = 0,
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$\label{eq:constraints} Trappic Q \\ Trappic Q \\ Trappic Q \\ Q \\ 1 \\ minimum Q \\ minimum Q$	THOM THOM THOM THOM THOM THOM THOM THOM	$\vec{q} = 11, 22, 12$ i = 12, 14, 45 i = 12 i = (1,, 12) r = 0, 1 r = 0,
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 $\ensuremath{\mathsf{EW}}\xspace$ and $\ensuremath{\mathsf{Higgs}}\xspace$ fits in the SM and beyond

HEPfit - observables









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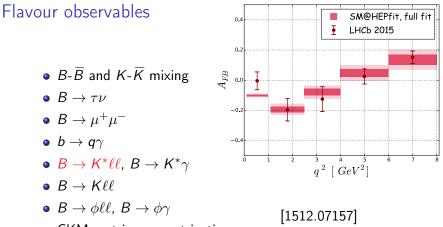
EW and Higgs fits in the SM and beyond

Flavour observables

- $B \overline{B}$ and $K \overline{K}$ mixing
- $B \to \tau \nu$
- $B \to \mu^+ \mu^-$
- $b \rightarrow q\gamma$
- $B \to K^* \ell \ell$, $B \to K^* \gamma$
- $B \to K\ell\ell$
- $B \to \phi \ell \ell$, $B \to \phi \gamma$
- CKM matrix parametrizations



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CKM matrix parametrizations



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EW and Higgs fits in the SM and beyond

Introduction

HEPfit

EW physics

Higgs physics

Summary



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 $\ensuremath{\mathsf{EW}}\xspace$ and $\ensuremath{\mathsf{Higgs}}\xspace$ fits in the SM and beyond

EW physics – precision observables

Experiment	Observables	Theory
Z resonance Cross sections (total and differential) → Asymmetries (LR, FB)	$ \begin{array}{l} m_Z, \ \Gamma_Z, \ \sigma^0_{had} \\ \leftarrow R^0_{b/c/\ell}, \ A^{0,b/c/\ell}_{FB} \\ \mathcal{A}_{b/c/\ell}, \ \sin^2 \theta^{eff}_{\ell} \end{array} $	SM calculations up to 3-loop precision
W resonance \rightarrow	$ m_W, \Gamma_W$	
$(g-2)_{\mu}$ $ ightarrow$	$ \begin{array}{l} & m_t \\ & \Delta \alpha_{had}^{(5)} \\ & \alpha_s \\ & m_h \end{array} $	



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EWPO – SM fit with HEPfit

	Measurement	Posterior	Prediction	Pull
$\alpha_s(M_Z)$	0.1180 ± 0.0010	0.1180 ± 0.0009	0.1184 ± 0.0028	-0.1
$\Delta \alpha_{had}^{(5)}(M_Z)$	0.02750 ± 0.00033	0.02743 ± 0.00025	0.02734 ± 0.00037	0.3
M_Z [GeV]	91.1875 ± 0.0021	91.1880 ± 0.0021	91.198 ± 0.010	-1.0
m_t [GeV]	$173.1 \pm 0.6 \pm 0.5$	173.43 ± 0.74	176.1 ± 2.2	-1.3
m_H [GeV]	125.09 ± 0.24	125.09 ± 0.24	100.6 ± 23.6	1.0
M_W [GeV]	80.379 ± 0.012	80.3643 ± 0.0058	80.3597 ± 0.0067	1.4
Γ_W [GeV]	2.085 ± 0.042	2.08873 ± 0.00059	2.08873 ± 0.00059	-0.1
$\sin^2 \theta_{\text{eff}}^{\text{lept}}(Q_{\text{FB}}^{\text{had}})$	0.2324 ± 0.0012	0.231454 ± 0.000084	0.231449 ± 0.000085	0.8
$P_{\tau}^{\text{pol}} = A_{\ell}$	0.1465 ± 0.0033	0.14756 ± 0.00066	0.14761 ± 0.00067	-0.3
Γ_Z [GeV]	2.4952 ± 0.0023	2.49424 ± 0.00056	2.49412 ± 0.00059	0.5
σ_h^0 [nb]	41.540 ± 0.037	41.4898 ± 0.0050	41.4904 ± 0.0053	1.3
R^0_ℓ	20.767 ± 0.025	20.7492 ± 0.0060	20.7482 ± 0.0064	0.7
$\sigma_h^0 [\mathrm{nb}] \ R_\ell^0 \ A_{\mathrm{FB}}^{0,\ell}$	0.0171 ± 0.0010	0.01633 ± 0.00015	0.01630 ± 0.00015	0.8
A_{ℓ} (SLD)	0.1513 ± 0.0021	0.14756 ± 0.00066	0.14774 ± 0.00074	1.6
$egin{array}{c} R_b^0 \ R_c^0 \end{array}$	0.21629 ± 0.00066	0.215795 ± 0.000027	0.215793 ± 0.000027	0.7
R_c^0	0.1721 ± 0.0030	0.172228 ± 0.000020	0.172229 ± 0.000021	-0.05
$A_{\rm FB}^{0,b}$	0.0992 ± 0.0016	0.10345 ± 0.00047	0.10358 ± 0.00052	-2.6
$A_{\mathrm{FB}}^{0,b}$ $A_{\mathrm{FB}}^{0,c}$	0.0707 ± 0.0035	0.07394 ± 0.00036	0.07404 ± 0.00040	-0.9
A_b	0.923 ± 0.020	0.934787 ± 0.000054	0.934802 ± 0.000061	-0.6
A_c	0.670 ± 0.027	0.66813 ± 0.00029	0.66821 ± 0.00032	0.1
$\sin^2 \theta_{\text{eff}}^{\text{lept}}(\text{Tev/LHC})$	0.23166 ± 0.00032	0.231454 ± 0.000084	0.231438 ± 0.000087	0.7

[1710.05402]



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 $\ensuremath{\mathsf{EW}}\xspace$ and $\ensuremath{\mathsf{Higgs}}\xspace$ fits in the SM and beyond

EW physics - precision observables for New Physics

Experiment		Observables		Theory
Z resonance Cross sections (total and differentia Asymmetries	I) \rightarrow			NP calculations
(LR, FB)		$\mathcal{A}_{b/c/\ell}$, $\sin^2 heta_\ell^{ ext{eff}}$		\downarrow
W resonance	\rightarrow	m_W, Γ_W		EW pseudo-
t resonance	\rightarrow	m _t	-7	observables
$(g-2)_{\mu}$	\rightarrow	$\Delta lpha_{\sf had}^{(5)}$		
au decays	\rightarrow	α_s		
h resonance	\rightarrow	m _h		



EWPO – pseudo-observables

 ρ parameter [Kennedy, Lynn]

Peskin-Takeuchi parameters (oblique paramters) S, T, U

Altarelli-Barbieri parameters ϵ_1 , ϵ_2 , ϵ_3 , ϵ_b

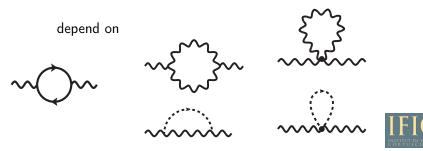
[Kennedy-Langacker parameters h_V , h_{AZ} , h_{AW}]



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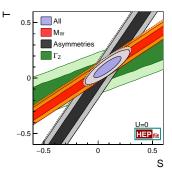
EWPO – pseudo-observables

- ρ parameter [Kennedy, Lynn]
- Peskin-Takeuchi parameters (oblique parameters) S, T, U Altarelli-Barbieri parameters ϵ_1 , ϵ_2 , ϵ_3 , ϵ_b
- [Kennedy-Langacker parameters h_V , h_{AZ} , h_{AW}]



EWPO – STU

	Result	Correlation Matrix						
S	0.09 ± 0.10	1.00						
	(0.08 ± 0.10)							
T	0.11 ± 0.12	0.86	1.00					
	(0.11 ± 0.12)	(0.85)						
U	-0.01 ± 0.09	-0.56	-0.84	1.00				
	(0.00 ± 0.09)	(-0.49)	(-0.79)					
S	0.09 ± 0.08	1.00						
	(0.08 ± 0.09)							
T	0.10 ± 0.06	0.87	1.00					
	(0.11 ± 0.07)	(0.86)						
(U = 0)	. /	. /						



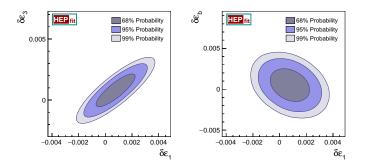
[1710.05402]



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EW and Higgs fits in the SM and beyond

$\mathsf{EWPO} - \delta \varepsilon_1, \ \delta \varepsilon_2, \ \delta \varepsilon_3, \ \delta \varepsilon_b$



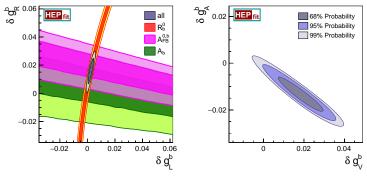
[1608.01509]



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EW and Higgs fits in the SM and beyond

EWPO – δg_L , δg_R , δg_V , δg_A



$$g_{i}^{b} = g_{i,SM}^{b} + \delta g_{i}^{b}$$
 for $i = L, R$ or V, A
[1608.01509]

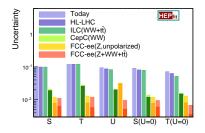


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EW and Higgs fits in the SM and beyond

EWPO at future colliders

	Current	CepC
	Data	Серс
$\alpha_s(M_Z)$	0.1179 ± 0.0012	
$\Delta \alpha_{had}^{(5)}(M_Z)$	0.02750 ± 0.00033	
M_Z [GeV]	91.1875 ± 0.0021	± 0.0005
m_t [GeV]	173.34 ± 0.76	
m_H [GeV]	$125.09{\pm}0.24$	± 0.0059
M_W [GeV]	$80.385 {\pm} 0.015$	± 0.003
Γ_W [GeV]	2.085 ± 0.042	
Γ_Z [GeV]	2.4952 ± 0.0023	± 0.0005
σ_h^0 [nb]	41.540 ± 0.037	± 0.037
$\sin^2 \theta_{eff}^{lept}$	0.2324 ± 0.0012	± 0.000023
P_{τ}^{pol}	0.1465 ± 0.0033	
A_{ℓ}	0.1513 ± 0.0021	
A_c	0.670 ± 0.027	
A_b	0.923 ± 0.020	
$A_{FB}^{0,\ell}$	0.0171 ± 0.0010	± 0.0010
$A^{0,c}_{FB}$	0.0707 ± 0.0035	
$A_{FB}^{0,b}$	0.0992 ± 0.0016	± 0.00014
R_{ℓ}^0	20.767 ± 0.025	± 0.007
R_c^0	0.1721 ± 0.0030	
R_b^0	$0.21629 {\pm} 0.00066$	± 0.00018



	Current	HL-LHC	П	.C				FC	Cee				Ce	pC
					Z (n	o pol)	Z (pol)	W	W	t	ī		
$\Delta S \ [\times 10^{-3}]$	100	99	99	99	12	7.8	11	6.4	11	6.4	11	6.3	21	19
$\Delta T [\times 10^{-3}]$	120	120	120	120	13	8.1	13	7.9	13	7.9	12	5.8	28	26
$\Delta U \ [\times 10^{-3}]$	95	87	83	82	32	31	32	31	9.8	5.4	9.6	5.2	21	20
$\Delta S \ [\times 10^{-3}]$	91	81	79	79	12	7.8	11	6.4	9.5	6.1	9.5	6	14	12
$\Delta T [\times 10^{-3}]$	72	63	52	52	13	8.1	13	7.9	10	7.4	6.8	3.6	16	15
(U = 0)														
$\Delta \varepsilon_1^{NP}[\times 10^{-5}]$	96	96	96	95	11	7.3	11	7.2	11	7.2	9.5	4.7	25	23
$\Delta \varepsilon_2^{NP}[\times 10^{-5}]$	86	81	77	76	29	28	28	28	8.6	4.8	8.5	4.7	21	19
$\Delta \varepsilon_3^{NP}[\times 10^{-5}]$	91	87	88	87	9.9	6.6	9.3	5.5	9.2	5.5	9.3	5.5	20	18
$\Delta \varepsilon_b^{\rm NP}[\times 10^{-5}]$	130	130	130	130	15	12	15	12	15	12	14	11	41	37
$\Delta \delta g_L^b [\times 10^{-4}]$	14	14	14	14	1.5	1.3	1.2	1.1	1.2	1.1	1.2	1.1	2.4	2.2
$\Delta \delta g_R^b [imes 10^{-4}]$	72	70	70	70	7.1	6.6	5.3	5.3	5.3	5.3	5.3	5.3	8.9	8.6

[1608.01509]



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EW and Higgs fits in the SM and beyond

Introduction

HEPfit

EW physics

Higgs physics

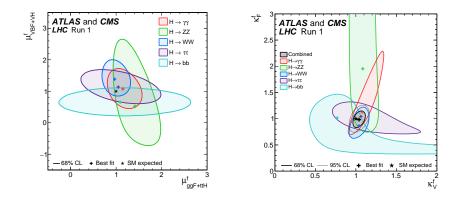
Summary



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 $\ensuremath{\mathsf{EW}}\xspace$ and $\ensuremath{\mathsf{Higgs}}\xspace$ fits in the SM and beyond

The completion of the SM?

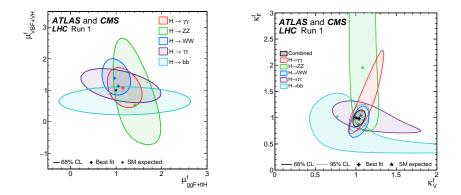




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EW and Higgs fits in the SM and beyond

The completion of the SM?



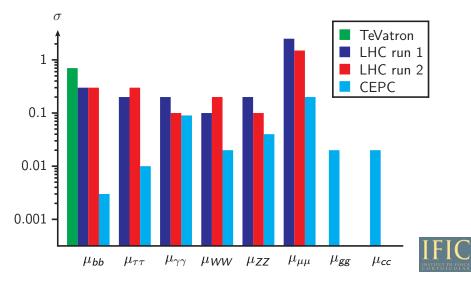
... or is it the first sign of New Physics?



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EW and Higgs fits in the SM and beyond

Current and future signal strength sensitivity

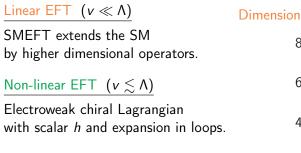


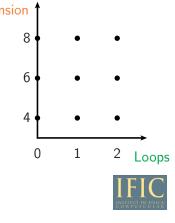
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EW and Higgs fits in the SM and beyond

Effective field theories

Description of New Physics at Λ in a generic way:





SM effective field theory I

$$\mathcal{L}_{\mathsf{SMEFT}} = \mathcal{L}_{\mathsf{SM}} \left(+ \mathcal{L}_5 \right) + \frac{1}{\Lambda^2} \sum_i c_i Q_i^{(6)} + \dots$$

	X^3	φ^6 and $\varphi^4 D^2$			$\psi^2 \varphi^3$	$(\bar{L}L)(\bar{L}L)$			
Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(\varphi^{\dagger}\varphi)^{3}$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$	Q	u	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	
$Q_{\tilde{G}}$	$f^{ABC} {\widetilde G}^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	$Q_{\varphi \square}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	$Q_{u\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\tilde{\varphi})$	$Q_q^{(}$		$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	
Q_W	$\varepsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^{\dagger}D^{\mu}\varphi\right)^{\star}\left(\varphi^{\dagger}D_{\mu}\varphi\right)$	$Q_{d\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$	$Q_q^{(}$		$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}_{\mu}^{I\nu}W_{\nu}^{J\rho}W_{\rho}^{K\mu}$					$Q_l^{(i)}$	1) q	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$	
	$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$	$Q_l^{(i)}$	3) q	$(\bar{l}_p \gamma_\mu \tau^I l_r) (\bar{q}_s \gamma^\mu \tau^I q_t)$	
$Q_{\varphi G}$	$\varphi^{\dagger}\varphi G^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^{\dagger}i \overleftrightarrow{D}_{\mu} \varphi)(\overline{l}_{p} \gamma^{\mu} l_{r})$				
$Q_{\varphi \widetilde{G}}$	$\varphi^{\dagger}\varphi \widetilde{G}^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^{\dagger}i \overleftrightarrow{D}_{\mu}^{I} \varphi)(\overline{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$				
$Q_{\varphi W}$	$\varphi^{\dagger}\varphi W^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{\varphi} G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^{\dagger}i \overleftrightarrow{D}_{\mu} \varphi)(\bar{e}_{p}\gamma^{\mu}e_{r})$				
$Q_{\varphi \widetilde{W}}$	$\varphi^{\dagger}\varphi \widetilde{W}^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{\varphi} W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^{\dagger} i \overleftrightarrow{D}_{\mu} \varphi)(\overline{q}_{p} \gamma^{\mu} q_{r})$				
$Q_{\varphi B}$	$\varphi^{\dagger}\varphiB_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^{\dagger}i \overleftrightarrow{D}_{\mu}^{I} \varphi)(\overline{q}_{p}\tau^{I}\gamma^{\mu}q_{r})$	[GI	MR 1008.48	841
$Q_{\varphi \tilde{B}}$	$\varphi^{\dagger}\varphi \widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^{\dagger}i \overleftrightarrow{D}_{\mu} \varphi)(\overline{u}_{p}\gamma^{\mu}u_{r})$	L			- ·]
$Q_{\varphi WB}$	$\varphi^{\dagger} \tau^{I} \varphi W^{I}_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\overline{d}_{p}\gamma^{\mu}d_{r})$				
$Q_{\varphi \widetilde{W}B}$	$\varphi^{\dagger} \tau^{I} \varphi \widetilde{W}^{I}_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\tilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r})$				ΕI

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EW and Higgs fits in the SM and beyond

SM effective field theory I

$$\mathcal{L}_{\mathsf{SMEFT}} = \mathcal{L}_{\mathsf{SM}} \left(+ \mathcal{L}_5 \right) + \frac{1}{\Lambda^2} \sum_i c_i Q_i^{(6)} + \dots$$

X^3			φ^6 and $\varphi^4 D^2$	$\psi^2 \varphi^3$			
Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(\varphi^{\dagger}\varphi)^3$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$		
$Q_{\tilde{G}}$	$f^{ABC} {\widetilde G}^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	$Q_{\varphi \Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	$Q_{u\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\tilde{\varphi})$		
Q_W	$\varepsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$(\varphi^{\dagger}D^{\mu}\varphi)^{\star}(\varphi^{\dagger}D_{\mu}\varphi)$	$Q_{d\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$		
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}_{\mu}^{I\nu}W_{\nu}^{J\rho}W_{\rho}^{K\mu}$						
	$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$		
$Q_{\varphi G}$	$\varphi^{\dagger}\varphi G^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\overline{l}_{p}\gamma^{\mu}l_{r})$		
$Q_{\varphi \widetilde{G}}$	$\varphi^{\dagger}\varphi G^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^{\dagger}i \overleftrightarrow{D}_{\mu}^{I} \varphi)(\overline{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$		
$Q_{\varphi W}$	$\varphi^{\dagger}\varphi W^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \tilde{\varphi} G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^{\dagger}i \overleftrightarrow{D}_{\mu} \varphi)(\overline{e}_{p}\gamma^{\mu}e_{r})$		
$Q_{\varphi \widetilde{W}}$	$\varphi^{\dagger}\varphi W^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{\varphi} W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{q}_{p}\gamma^{\mu}q_{r})$		
$Q_{\varphi B}$	$\varphi^{\dagger}\varphi B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^{\dagger}i \overleftrightarrow{D}_{\mu}^{I} \varphi)(\bar{q}_{p} \tau^{I} \gamma^{\mu} q_{r})$		
$Q_{\varphi \tilde{B}}$	$\varphi^{\dagger}\varphi \tilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}u_{r})$		
$Q_{\varphi WB}$	$\varphi^{\dagger} \tau^{I} \varphi W^{I}_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\overline{d}_{p}\gamma^{\mu}d_{r})$		
$Q_{\varphi \widetilde{W}B}$	$\varphi^{\dagger} \tau^{I} \varphi \widetilde{W}^{I}_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\tilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r})$		

$(\bar{L}L)(\bar{L}L)$						
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$					
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$					
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r) (\bar{q}_s \gamma^\mu \tau^I q_t)$					
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$					
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$					

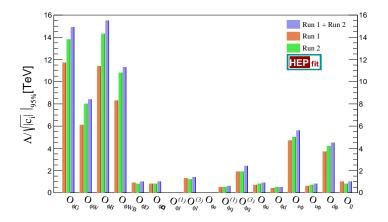
[GIMR 1008.4884]



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SM effective field theory II



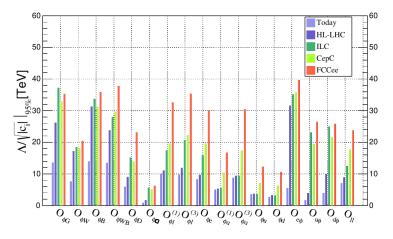
^[1608.01509,1710.05402]



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SM effective field theory II



[1608.01509,1710.05402]



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EW and Higgs fits in the SM and beyond

Non-linear effective field theory I

Leading order Lagrangian:

$$\mathcal{L}_{\mathsf{NLEFT}} = 2c_V \left(m_W^2 W_{\mu}^+ W^{-\mu} + \frac{1}{2} m_Z^2 Z_{\mu} Z^{\mu} \right) \frac{h}{v} - \sum_f c_f Y_f \bar{f} f h$$
$$+ \frac{e^2}{16\pi^2} c_{\gamma\gamma} F_{\mu\nu} F^{\mu\nu} \frac{h}{v} + \frac{e^2}{16\pi^2} c_{Z\gamma} Z_{\mu\nu} F^{\mu\nu} \frac{h}{v} + \frac{g_s^2}{16\pi^2} c_{gg} \operatorname{Tr}[G_{\mu\nu} G^{\mu\nu}] \frac{h}{v}$$

with

$$c_{i} = \begin{cases} 1 + \mathcal{O}(\frac{v^{2}}{\Lambda^{2}}) & \text{for } i = V, t, b, c, \tau, \mu \\ \mathcal{O}(\frac{v^{2}}{\Lambda^{2}}) & \text{for } i = gg, \gamma\gamma, Z\gamma \end{cases}$$

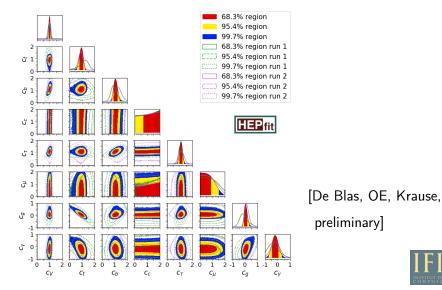
[Buchalla, Cata, Celis, Krause, '15]



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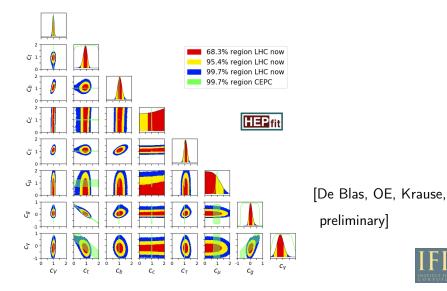
Non-linear effective field theory II



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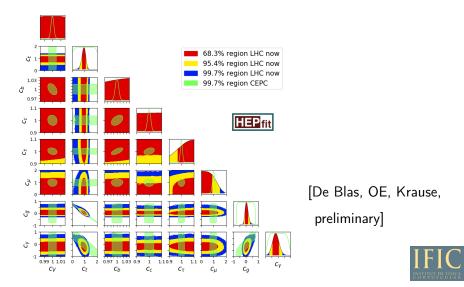
Non-linear effective field theory II



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The \mathbb{Z}_2 symmetric 2HDM of type II

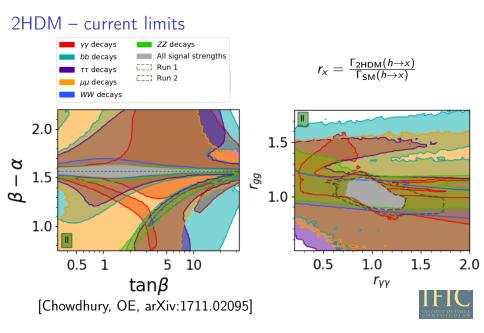
$$\begin{split} V_{H}^{\text{2HDM}} &= \textit{m}_{11}^{2} \Phi_{1}^{\dagger} \Phi_{1} + \textit{m}_{22}^{2} \Phi_{2}^{\dagger} \Phi_{2} - \textit{m}_{12}^{2} \left(\Phi_{1}^{\dagger} \Phi_{2} + \Phi_{2}^{\dagger} \Phi_{1} \right) \\ &+ \frac{\lambda_{1}}{2} \left(\Phi_{1}^{\dagger} \Phi_{1} \right)^{2} + \frac{\lambda_{2}}{2} \left(\Phi_{2}^{\dagger} \Phi_{2} \right)^{2} + \lambda_{3} \left(\Phi_{1}^{\dagger} \Phi_{1} \right) \left(\Phi_{2}^{\dagger} \Phi_{2} \right) \\ &+ \lambda_{4} \left(\Phi_{1}^{\dagger} \Phi_{2} \right) \left(\Phi_{2}^{\dagger} \Phi_{1} \right) + \frac{\lambda_{5}}{2} \left[\left(\Phi_{1}^{\dagger} \Phi_{2} \right)^{2} + \left(\Phi_{2}^{\dagger} \Phi_{1} \right)^{2} \right] \end{split}$$

Type II: b, τ couple to Φ_1 , t couples to Φ_2 Physical parameters: $v, m_h, m_H, m_A, m_{H^+}, m_{12}^2, \alpha, \beta$



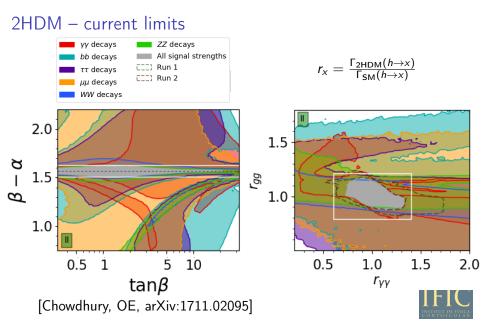
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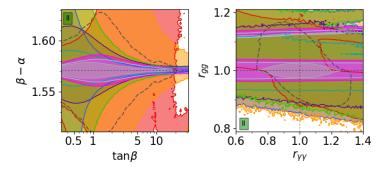


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2HDM – CEPC projections





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Further extended Higgs sectors

We are implementing further extensions in the scalar sector:

- $\bullet\,$ Three other types of \mathbb{Z}_2 symmetric 2HDM
- Flavour-aligned 2HDM
- General 2HDM
- Manohar-Wise model: SM $(1,2)_1 + (8,2)_1$
- Manohar-Wise 2HDM: $2HDM + (8,2)_1$
- Left-Right symmetric models



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Summary

EW and Higgs physics will be measured precisely by future colliders.

It is important to combine all information that we have as consistently as possible.

Only then, we can make reliable statements on the validity of the SM and constrain (or find hints for) New Physics.



is a comprehensive tool which covers many aspects of EW, Higgs and flavour physics.



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Summary

Projected CEPC fits:

EW pseudo-observables will change by a factor of 2 to 8 EFT probed NP scales will increase by a factor of 2 to 6 NLEFT coefficients will be up to 100 times as precise 2HDM alignment will be 30 times as precise



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