Mounting evidence for a 95 GeV Higgs boson

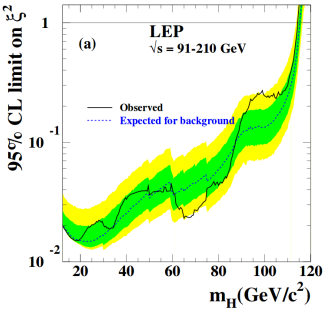
Based on [2303.12018] and [2306.03889] in collaboration with
Sven Heinemeyer and Georg Weiglein,
and on [2305.19716] in collaboration with Duarte Azevedo and Pedro Ferreira

EPS-HEP 2023 in Hamburg

23-08-2023

Thomas Biekötter

The 95GeV excesses until 2022



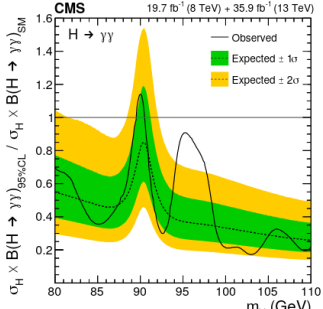
[LEP: hep-ex/0306033]

Local significance: 2.3σ

Extracted signal strength:

$$\mu_{bb}\left(e^+e^- \to Zh \to Zb\bar{b}\right) = 0.117 \pm 0.057$$

[Cao, Guo, He, Wu, Zhang: 1612.08522]



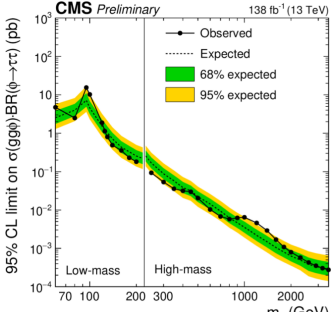
[CMS: 1811.08459]

Local significance: 2.8σ

Extracted signal strength:

$$\mu_{\gamma\gamma}\left(gg \to h \to \gamma\gamma\right) = 0.6 \pm 0.2$$

[CMS: 1811.08459]



[CMS: 2208.02717]

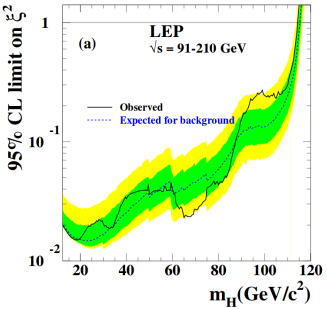
Local significance: 3.1σ

Extracted signal strength:

$$\mu_{\tau\tau}\left(gg \to h \to \tau^+\tau^-\right) = 1.2 \pm 0.5$$

[CMS: 2208.02717]

New CMS results in March 2023



[LEP: hep-ex/0306033]

Local significance: 2.3σ

Signal strength:

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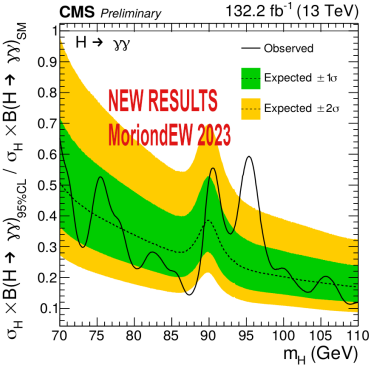
[Cao, Guo, He, Wu, Zhang: 1612.08522]

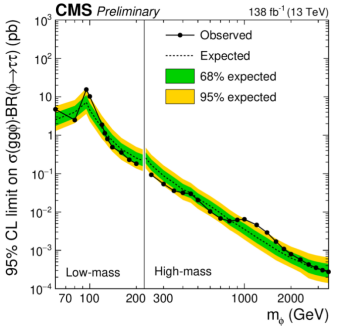


[CMS HIG-20-002]

Local significance: 2.9σ

Signal strength:

$$\mu_{\gamma\gamma}\left(gg \to h \to \gamma\gamma\right) \approx 0.33^{+0.19}_{-0.12}$$



[CMS: 2208.02717]

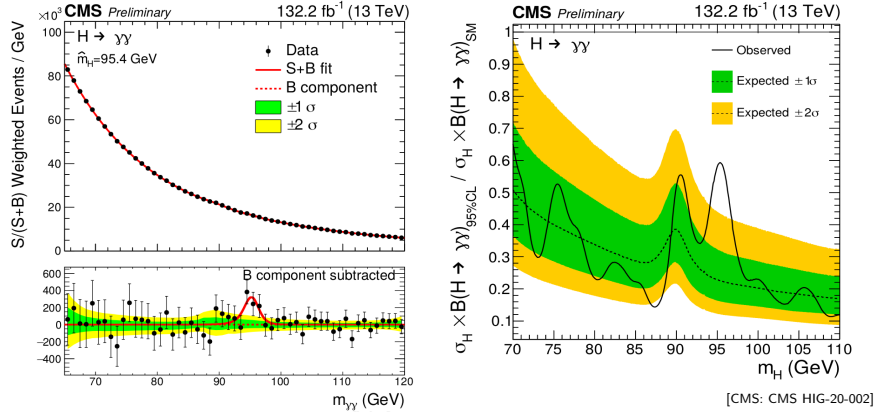
Local significance: 3.1σ

Signal strength:

$$\mu_{\tau\tau}\left(gg \to h \to \tau^+\tau^-\right) = 1.2 \pm 0.5$$

[CMS: 2208.02717]

New CMS results in March 2023

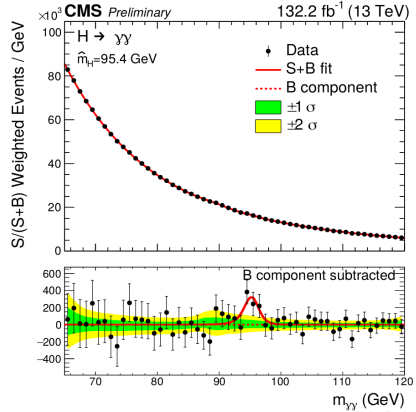


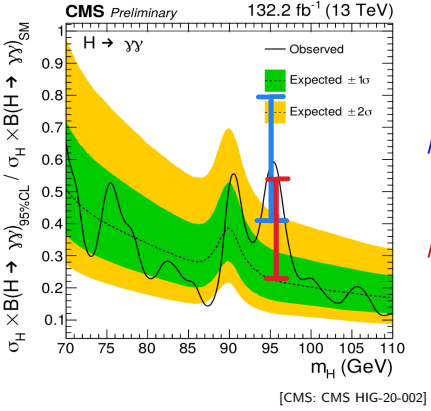
[CMS: CMS HIG-20-002]

Refined analysis regarding $Z \to e^+e^-$ background: the excess persists!

2.9σ local significance (practically unchanged), but signal strength reduced

New CMS results in March 2023





[CMS: CMS HIG-20-002]

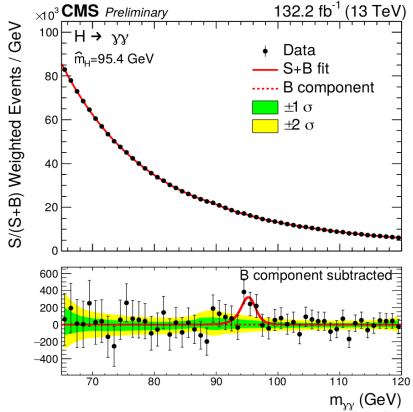
$$\mu_{\gamma\gamma}^{\text{CMS 1st-year Run 2}} = 0.6 \pm 0.2$$

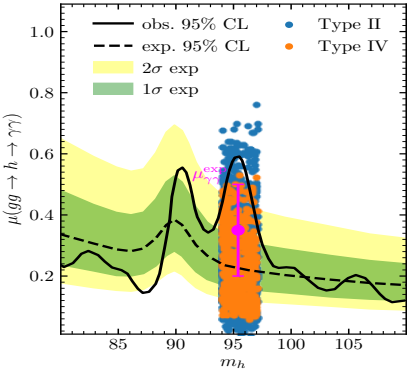
$$\mu_{\gamma\gamma}^{\text{CMS Full Run 2}} = 0.33^{+0.19}_{-0.12}$$

Refined analysis regarding $Z \to e^+e^-$ background: the excess persists!

2.9σ local significance (practically unchanged), but signal strength reduced

New CMS results in March 2023





Implications for model interpretations

[TB, S. Heinemeyer, G. Weiglein, 2303.12018]

Refined analysis regarding $Z \to e^+e^-$ background: the excess persists!

2.9σ local significance (practically unchanged), but signal strength reduced

S2HDM: Singlet-extended 2HDM

S2HDM = **2HDM**(ϕ_1, ϕ_2) + Complex scalar singlet(ϕ_s) [TB, M.O. Olea, 2108.10864]

Higgs potential

$$V = V_{\rm 2HDM}(\Phi_1, \Phi_2)|_{Z_2} + m_{12}^2 \left(\Phi_1 \Phi_2^\dagger + \text{h.c.}\right) + V_{\rm portal}(\Phi_1, \Phi_2, \Phi_S)|_{U(1)} - \frac{\mu_\chi}{4}\left(\Phi_S^2 + \text{h.c.}\right)$$

Type-II/IV(flipped): u_R **coupled to** Φ_2**,** d_R **coupled to** Φ_1**,** ℓ_R **coupled to** Φ_1/Φ_2

EW vacuum:

$$\langle \Phi_1 \rangle = \begin{pmatrix} 0 \\ v_1/\sqrt{2} \end{pmatrix} \quad , \quad \langle \Phi_2 \rangle = \begin{pmatrix} 0 \\ v_2/\sqrt{2} \end{pmatrix} \quad , \quad \langle \Phi_S \rangle = v_S/\sqrt{2} \quad \in \mathbb{R} \quad \tan\beta := v_2/v_1$$

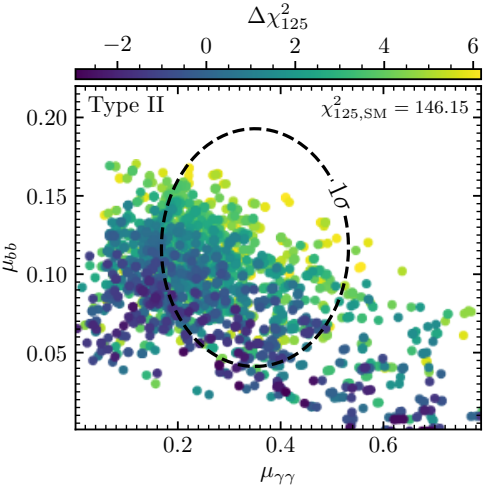
Visible sector:

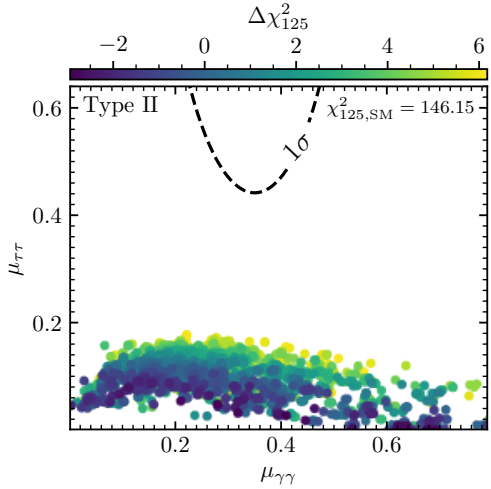
CP-even scalars $h_1 = h_{95}, h_2 = h_{125}, h_3$ CP-odd scalar A charged scalars $H^\pm$

Dark sector:

Scalar pseudo-Nambu-Goldstone (pNG) dark matter state χ

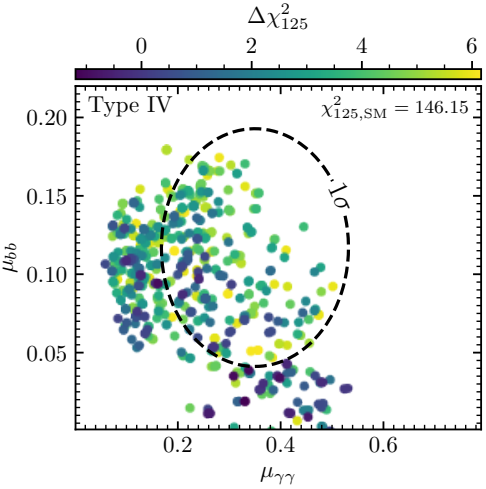
S2HDM Type II Interpretation

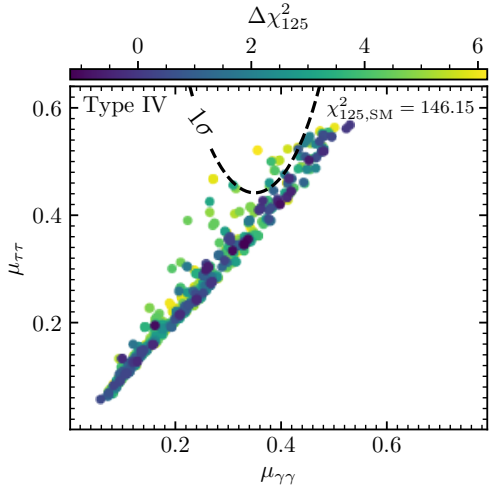




[TB, S. Heinemeyer, G. Weiglein, 2303.12018]

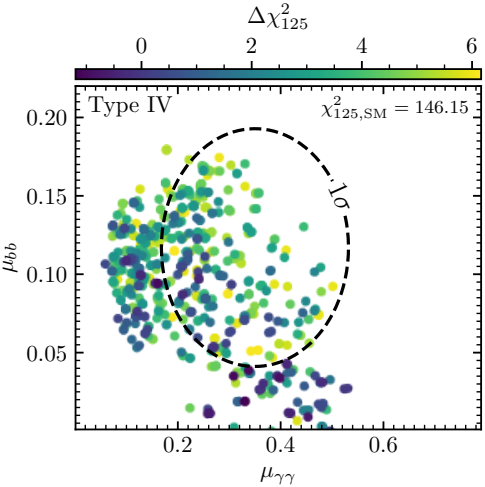
S2HDM Type IV Interpretation

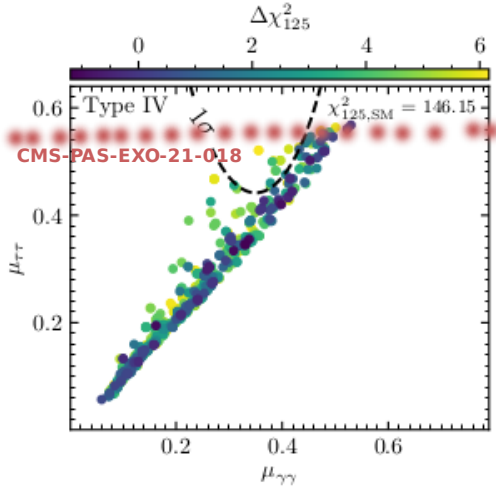




[TB, S. Heinemeyer, G. Weiglein, 2303.12018]

S2HDM Type IV Interpretation

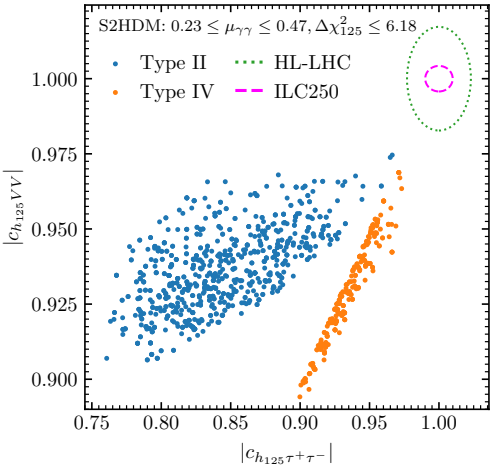




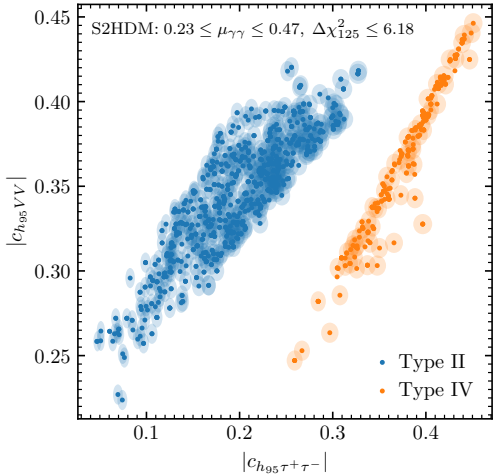
CMS-PAS-EXO-21-018: $pp \to t\bar{t}\Phi \to t\bar{t}\tau^+\tau^-$

CP-odd state A_{95}? [D. Azevedo, TB, P. Ferreira, 2305.19716]

S2HDM: Future Prospects



Indirectly via coupling measurements of h_{125}

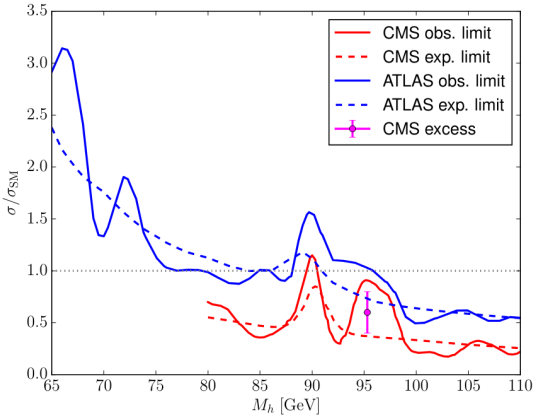


Directly producung h_{95} at "Higgs factory"

What about ATLAS?

The situation until June 2023: Di-photon search using $80\ \mathrm{fb}^{-1}$

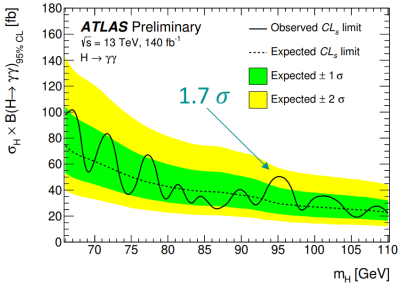
[ATLAS-CONF-2018-025]

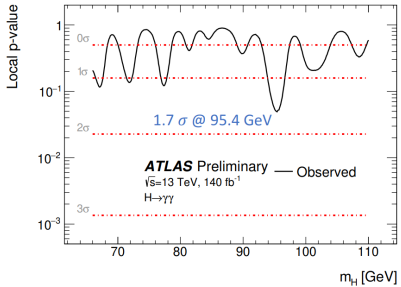


[S. Heinemeyer, T. Stefaniak, 1812.05864]

New ATLAS results in June 2023

[ATLAS-CONF-2023-035]

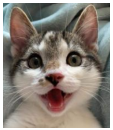




Most significant excess at 95 GeV

$$\mu_{\gamma\gamma}^{\text{ATLAS Run 2}} \approx 0.18 \pm 0.10$$

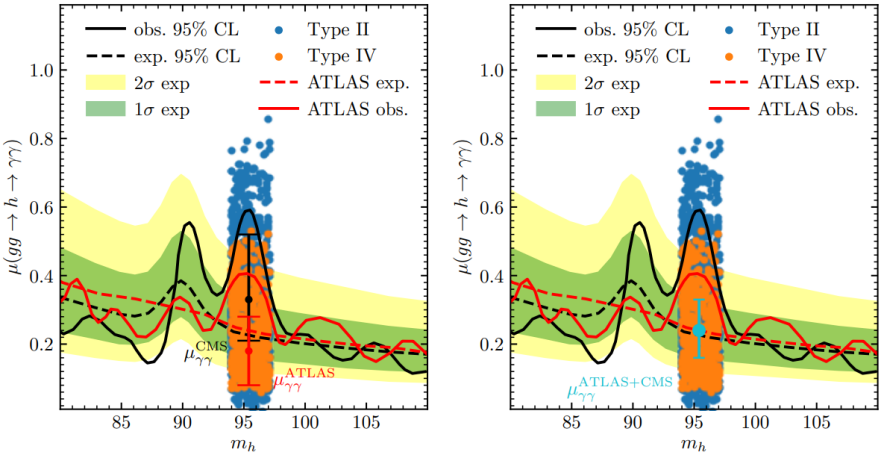
[TB, S. Heinemeyer, G. Weiglein, 2306.03889]



Local 1.7σ excess at **95 GeV**

Local 1.7σ excess at 95 GeV

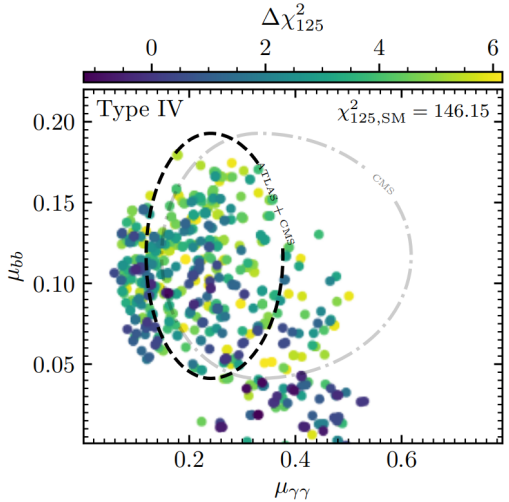
S2HDM: Impact of ATLAS result

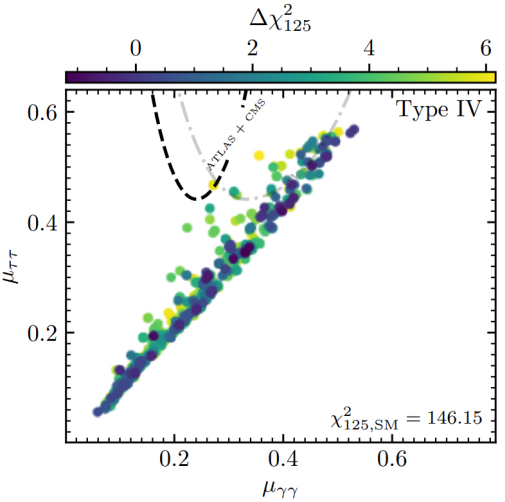


Combination: $\mu_{\gamma\gamma}^{\text{ATLAS+CMS}} = 0.24^{+0.09}_{-0.08}$

[TB, S. Heinemeyer, G. Weiglein, 2306.03889]

S2HDM: Impact of ATLAS result





[TB, S. Heinemeyer, G. Weiglein, 2306.03889]

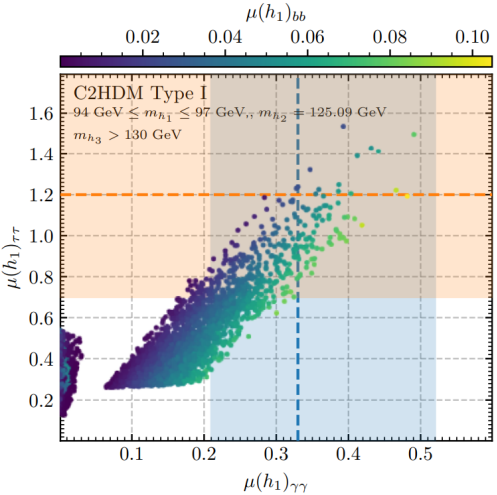
2HDM interpretations

2HDM interpretations had been discarded due to limited di-photon signal rates

With the updated experimental results the picture has changed

$h_{95} \approx A$ dominantly CP-odd state
$\rightarrow$ Enhanced ggA production XS
$\rightarrow$ Smaller $t\bar{t}A$ production XS
$\rightarrow$ LEP excess requires CP violation

Can also describe the di-tau excess, but tensions with indirect constraints from flavour physics and electron EDMs



[D. Azevedo, TB, P. Ferreira, 2305.19716]

Summary: Status of h_{95}

New exp. results in 2023: Full Run 2 di-photon searches below 125 GeV

→ CMS: Significance of excess unchanged, signal strength reduced

→ ATLAS: Same sensitivity, excess at the right spot, but less significance

S2HDM interpretations: $h_{95} \approx h_S$ as singlet-like scalar mixed with h_{125}

→ LEP $b\bar{b}$ excess ✓ CMS + ATLAS $\gamma\gamma$ excess ✓ CMS $\tau^+\tau^-$ excess (✓)

→ Predicts $|c(h_{125}VV)| < 1$, will be probed at HL-LHC and Higgs factory

→ No tension with indirect constraints

→ Interesting connections to other anomalies

→ Dark matter and galactic-center excess [TB, M.O. Olea, 2108.10864]

→ W-boson mass discrepancies [TB, S. Heinemeyer, G. Weiglein, 2204.05975]

2HDM interpretations: $h_{95} \approx A$ as dominantly CP-odd scalar

→ LEP $b\bar{b}$ excess ✓ CMS + ATLAS $\gamma\gamma$ excess ✓ CMS $\tau^+\tau^-$ excess ✓

→ Only LEP excess required modifications of h_{125} couplings

→ Light spectrum, H and $H^\pm$ with masses around m_t

→ Tensions with indirect constraints from flavour physics and EDMs

Thanks!