What have we learned after LHC first-run?
Implications of $m_H \approx 125$ GeV

It has shaken the TH community:
No clear indication where this points to

$m_H \approx 125$ GeV
(the most relevant piece of LHC)
Rough Higgs-mass range predictions

- **SM** (valid up to $M_P$) (multiverse?)
- MSSM
- Composite PGB Higgs
- Higgsless

Higgs mass range:
- 50 GeV
- 100 GeV
- 150 GeV
- 200 GeV
125 GeV SM Higgs
In the SM:

$$m_H^2 = \lambda v^2$$

Evolves with the energy

Demanding $\lambda$ not too large (keep perturbativity), not too negative that destabilizes the Higgs potential:

Only a small window in the Higgs mass makes the SM consistent all the way to the Planck scale

In the SM:

\[ m_H^2 = \lambda v^2 \]

Evolves with the energy

Demanding \( \lambda \) not too large (keep perturbativity), not too negative that destabilizes the Higgs potential:

A 125 GeV Higgs is in this window!

Only a small window in the Higgs mass makes the SM consistent all the way to the Planck scale

For $M_h \sim 125$ GeV, we are at the border of stability and meta-stability:

but do not worry, even in meta-stable, lifetime of decay larger than the age of the universe!
125 GeV MSSM Higgs
In the MSSM:

\[ M_h^2 \leq M_Z^2 + \Delta m^2 \]

both have similar size:
Non-small Susy breaking terms

(125 GeV)^2 (91 GeV)^2 (86 GeV)^2

susy breaking term (at one-loop)

Bosons Fermions
The tree-level MSSM parameters: at tree level, the weak gauge bosons. The SM-Higgs mass and proper-towere examined in detail and use this supersymmetry, especially in the context of the minimalthe LHC, considerable discovery potential still remains try remains the best-motivated solution to the hierarchy significance to become a Higgs discovery, but it is not too like Higgs boson have been reported by the LHC. The $\sim 200$ GeV, there exists a light channel near the same mass $\sim 126$ GeV. The CMS collaboration $\sim 123$ GeV and two events in $\sim 125$ GeV. In this paper, we explore the potential consequences of a 125 GeV Higgs for the MSSM and Low-Scale SUSY Breaking.

Very heavy stops (beyond LHC reach) or large susy-breaking trilinear terms

$\rightarrow$ The MSSM is becoming unnatural ($>99\%$ parameter space excluded)
125 GeV Composite Pseudo-Goldstone Higgs
Higgs as a composite PGB:

Similarly as in QCD, we could have from a new TeV strong-sector:

Spectrum of “mesons”:

\[ \text{TeV} \]
\[ 100 \text{ GeV} \]

Other resonances too heavy to be seen at the LHC 8TeV

Pseudo-Goldstone bosons (PGB)
(as pions in QCD)
Example: Just take QCD (with two flavors) replace $SU(3)_c$ by $SU(2)_c$

Global symmetry: $SU(2)_L \otimes SU(2)_R$ \quad $SU(4)$

\[ <\psi\psi> \neq 0 \quad <\psi\psi> \neq 0 \]

\[ SU(2)_V \quad SO(5) \]

3 Goldstones = $\pi^0, \pi^+, \pi^-$

5 Goldstones = Higgs doublet + singlet
Light Higgs since its mass arises from one loop (explicit breaking of the global symmetry \(h \rightarrow h + c\) due to the SM couplings):

\[
 m_h^2 \sim \frac{(\text{TeV})^2}{16\pi^2} \sim (100 \text{ GeV})^2
\]
Using techniques used in QCD, we can get for the minimal composite PGB Higgs:

\[
m_h^2 \simeq \frac{N_c}{\pi^2} \left[ \frac{m_t^2}{f^2} \frac{m_{Q_4}^2 m_{Q_1}^2}{m_{Q_1}^2 - m_{Q_4}^2} \log \left( \frac{m_{Q_1}^2}{m_{Q_4}^2} \right) \right]
\]

\(N_c=3\)

mass of color vector-like fermions with EM charges \(5/3, 2/3, -1/3\)

Fermion resonances below the TeV that should be seen at the LHC

\(f = \text{Decay-constant of the PGB Higgs}\)

(model dependent but expected \(f \sim v\))

\(125\) GeV Higgs

\(f = 1000\) GeV

\(f = 500\) GeV
Implications from Higgs-coupling measurements
Main pieces of information to be extracted from data:

\[ \mathcal{L} = g_{hf} f \bar{f} \bar{L} \bar{f} + h.c. + g_{hVV} hV^\mu V_\mu + g_{hGG} hG^{\mu\nu} G_{\mu\nu} + g_{h\gamma\gamma} hF^{\mu\nu} F_{\mu\nu} \]

(\text{other Lorentz structures are possible, but we neglect them for the moment})

1) \quad f=\text{fermions}

2) 

3) 

4) 

they determine the nature of the Higgs
Main pieces of information to be extracted from data:

\[ \mathcal{L} = g_{hf f} h \bar{f}_L f_R + h.c. + g_{hVV} h V^\mu V_\mu + g_{hGG} h G^{\mu\nu} G_{\mu\nu} + g_{h\gamma\gamma} h F^{\mu\nu} F_{\mu\nu} \]

(\text{other Lorentz structures are possible, but we neglect them for the moment})

1) \( f = \text{fermions} \)

2) Most genuine Higgs coupling (discloses its role in EWSB)

3) \( H \)

4) \( H \)
But present data is telling us that the 125 GeV state has to do with EWSB.

at the LHC:

![Diagram of Higgs boson decaying into fermions](image)

Falkowski, Riva, Urbano
arXiv:1303.1812

Affects the Z propagator, whose properties were well-measured at LEP.
Higgs coupling determination

\[ \kappa_i = \frac{g_{hii}}{g_{hii}^{SM}} \]
**ATLAS Preliminary**

$m_H = 125.5$ GeV

| Process | $|\mu|$ [stat. + theory] | Total uncertainty |
|---------|-------------------------|------------------|
| $H \rightarrow \gamma\gamma$ | $1.57^{+0.33}_{-0.28}$ | $\pm 1\sigma$ on $\mu$ |
| $H \rightarrow ZZ^* \rightarrow 4l$ | $1.44^{+0.40}_{-0.35}$ |
| $H \rightarrow WW^* \rightarrow lvlv$ | $1.00^{+0.32}_{-0.29}$ |
| Combined $H \rightarrow \gamma\gamma$, $ZZ^*$, $WW^*$ | $1.35^{+0.21}_{-0.20}$ |

| Process | $|\mu|$ [stat. + theory] |
|---------|-------------------------|
| $W, Z H \rightarrow b\bar{b}$ | $0.2^{+0.7}_{-0.6}$ |
| $H \rightarrow \tau\tau$ (8 TeV data only) | $1.4^{+0.5}_{-0.4}$ |
| Combined $H \rightarrow b\bar{b}$, $\tau\tau$ | $1.09^{+0.36}_{-0.32}$ |
| Combined | $1.30^{+0.18}_{-0.17}$ |

$\sqrt{s} = 7$ TeV $\int L dt = 4.6-4.8$ fb$^{-1}$

$\sqrt{s} = 8$ TeV $\int L dt = 20.3$ fb$^{-1}$

$\kappa_i = \frac{g_{iii}}{g_{SM}}$

$\kappa_i$ values for different models and $p_{SM}$ uncertainties:

- Model: $\kappa_i$, $\kappa_F$
  - $p_{SM} = 10\%$  
    - $\kappa_i = 1.15^{+0.08}_{-0.08}$
    - $\kappa_F = 0.99^{+0.17}_{-0.15}$

- Model: $\kappa_i$, $\kappa_g$
  - $p_{SM} = 9\%$
    - $\kappa_i = 1.08^{+0.15}_{-0.13}$
    - $\kappa_g = 1.19^{+0.15}_{-0.12}$

- Model: $\kappa_i$, $\kappa_{B_i}$
  - $p_{SM} = 18\%$
    - $\text{BR}_{i,u} = 0.16^{+0.29}_{-0.30}$

$\sqrt{s} = 7$ TeV $\int L dt = 4.6-4.8$ fb$^{-1}$

$\sqrt{s} = 8$ TeV $\int L dt = 20.3$ fb$^{-1}$

$\pm 1\sigma$  $\pm 2\sigma$
The different origins of the Higgs give different predictions for the Higgs couplings

Two examples:

a) **Supersymmetry (MSSM)**
with a Heavy spectrum \( M_{\text{susy}} \gg m_W \)

b) **Composite PGB Higgs**
MSSM with heavy spectrum (\( \gg 100 \text{ GeV} \))

Main effects from the 2nd Higgs doublet:

\[ \sim \frac{v^4}{M_H^4} v^2 \]

\[ \sim \frac{v^2}{M_H^2} \]

Dominant effect!

Superpartners can only modify Higgs couplings at the loop-level: Only stops/sbottoms give some contribution to \( hgg/h\gamma\gamma \) (not very large)
Corrections to h coupling to fermions:

\[ C_i = \frac{g_{hi}^{SM}}{g_{hi}} \]

1) MSSM (no mixing):

\[ c_b \approx 1 + \frac{m_h^2 - m_Z^2 \cos 2\beta}{m_H^2}, \]

\[ c_t \approx 1 - (\cot \beta)^2 \frac{m_h^2 - m_Z^2 \cos 2\beta}{m_H^2}. \]

2) MSSM (with extra D-terms):

\[ c_b \approx 1 + 2 \frac{m_h^2}{m_H^2} \frac{t_\beta^2}{t_\beta^2 - 1}, \]

\[ c_t \approx 1 - 2 \frac{m_h^2}{m_H^2} \frac{1}{t_\beta^2 - 1}. \]

3) NMSSM (with heavy singlet and light stops):

\[ c_b \approx 1 - \frac{t_\beta^2 - 1}{2} \frac{m_h^2 - m_Z^2}{m_H^2}, \]

\[ c_t \approx 1 + \frac{t_\beta^2 - 1}{2t_\beta^2} \frac{m_h^2 - m_Z^2}{m_H^2}. \]

from arXiv:1212.524
Relevant plane for susy Higgs couplings:

\[
\begin{align*}
g_{hbb}^{\text{SM}} & \quad g_{hbb} \\
g_{htt}^{\text{SM}} & \quad g_{htt} 
\end{align*}
\]

2HDM type II (MSSM)  
2HDM type I  
2HDM type I  
2HDM type II
Relevant plane for susy Higgs couplings:

MSSM ($X_t=0$)

$g_{hbb} / g_{hbb}^{SM}$

from arXiv:1212.524
(data before Moriond 13)
Relevant plane for susy Higgs couplings:

**MSSM** ($X_t \neq 0$)

![Graph](image-url)

*from arXiv:1212.524*
Higgs coupling measurements are already ruling out susy-parameter space.

**Figure 5**: Regions of the \((m_A, \tan \beta)\) plane excluded in a simplified MSSM model via fits to the measured rates of Higgs boson production and decays. The likelihood contours where \(2 \ln \mathcal{L} = 6\), corresponding approximately to 95% CL (2\sigma), are indicated for the data and expectation assuming the SM Higgs sector. The light shaded and hashed regions indicate the observed and expected exclusions, respectively. The SM decoupling limit is \(m_A \rightarrow 1\) for \(\tan \beta < 10\), with the limit increasing to larger masses for \(\tan \beta < 2\). The observed limit is stronger than expected since the measured rates in the \(h \rightarrow \tau \tau\) (expected to be dominated by a W boson loop) and \(h \rightarrow ZZ^*\) channels are higher than predicted by the SM, but the simplified MSSM has a physical boundary \(\kappa > 1\) so the vector boson coupling cannot be larger than the SM value. The physical boundary is accounted for by computing the profile likelihood ratio with respect to the maximum likelihood obtained within the physical region of the parameter space, \(m_A > 0\) and \(\tan \beta > 0\). The range \(0 \leq \tan \beta \leq 10\) is shown as only that part of the parameter space was scanned in the present version of this analysis. The compatible region extends to larger \(\tan \beta\) values.

The results reported here pertain to the simplified MSSM model studied and are not fully general. The MSSM includes other possibilities such as Higgs boson decays to supersymmetric particles, decays of heavy Higgs bosons to lighter ones, and effects from light supersymmetric particles which are not investigated here.

Many "Higgs portal" models introduce an additional weakly-interacting massive particle (WIMP) as a dark matter candidate. It is assumed to interact very weakly with the SM particles, except for the Higgs boson. In this study, the coupling of the Higgs boson to the WIMP is taken to be a free parameter.

The upper limit on the branching ratio of the Higgs boson to invisible final states, \(\text{BR}_i\), is derived using the combination of rate measurements from the \(h \rightarrow \gamma \gamma, ZZ^*, WW^*, \tau \tau, b\bar{b}\) channels, together with the measured upper limit on the rate of the \(Zh \rightarrow \ell^+\ell^- + E_T\) process. The couplings of the Higgs boson to massive particles other than the WIMP are assumed to be equal to the SM predictions, allowing the corresponding partial decay widths and invisible decay width
Composite Higgs scenarios
Composite PGB Higgs couplings

Couplings dictated by symmetries (as in the QCD chiral Lagrangian)

\[
\frac{g_{hWW}^{SM}}{g_{hWW}} = \sqrt{1 - \frac{v^2}{f^2}}
\]

\[
\frac{g_{hff}^{SM}}{g_{hff}} = \frac{1 - (1 + n) \frac{v^2}{f^2}}{\sqrt{1 - \frac{v^2}{f^2}}}
\]

\[n = 0, 1, 2, \ldots\]

\[f = \text{Decay-constant of the PGB Higgs}\]

\[[\text{model dependent but expected } f \sim v] \]

small deviations on the \(h\gamma\gamma(gg)\)-coupling due to the
Goldstone nature of the Higgs
In composite Higgs models the Higgs couplings to fermions generically deviate from their SM values. For different values of \( m \), the Higgs couplings reduce, for the case \( n = 0 \), the Higgs couplings to SM fermions are maximal, implying that extra contributions are larger. For \( m = 0 \), the Higgs mass Eq. (43) can be as small as 40 GeV. Larger values of implies

\[
\left( \mu \right)_{\text{SM}}^{f} = \mathcal{O}(100) \text{TeV},
\]

To see deviations for \( v/f \sim 0.5 \)!

\[
\mu_{\text{SM}}^{f} = \frac{g_{\text{hff}}}{g_{\text{hff}}^{\text{SM}}} \]

\[
\frac{g_{\text{hWW}}}{g_{\text{hWW}}^{\text{SM}}} = \frac{g_{\text{hWW}}}{g_{\text{hWW}}^{\text{31}}} = 0.5
\]

\[
c_{gg} = c_{\gamma \gamma} = c_{Zf} = 0, \quad c_{t} = c_{b} = c_{\tau} = c_{f}
\]
Invisible Higgs decay

Possible in certain models:

\[ \chi = \text{Dark Matter} = \text{extra scalar, neutralinos, ...} \]

(or \( \chi \chi \) = gravitino + neutrino, as in models in which the Higgs is the susypartner of the neutrino)

\[ \text{arXiv:1211.4526} \]
**Bounds on invisible Higgs decay**

Given the accuracy of present measurement of Higgs branching fractions, there is a lot of room for non-SM decays, e.g., decays into invisible particles. Many theoretical models predict such decays, e.g.:

- Higgs coupled to light dark matter
- Hidden valley models
- Right-handed neutrino models

Search is done in associated production with the Z boson decaying leptonically.

Discriminating variables: ME\(\not{E}_T\) (ATLAS), ME\(E_T\) (CMS).

**ATLAS (4.7+13.0 fb\(^{-1}\)):**
- \(\text{Br}(H \rightarrow \chi\chi) < 65\%\) (84\% exp.) \(\times 95\%\) CL, \(m_H = 125\) GeV

**CMS (5+20 fb\(^{-1}\)):**
- \(\text{Br}(H \rightarrow \chi\chi) < 75\%\) (91\% exp.) \(\times 95\%\) CL, \(m_H = 125\) GeV
Future...
towards a better image of the Higgs
• A better Higgs-mass measurement?

Finding $m_H \approx 125$ GeV shook us, but knowing $m_H = 125.457\ldots$ GeV will leave us indifferent.

Probably only "true-believers" of the SM up to the Planck scale would like to know $m_H$ in order to learn about the stability of the Higgs potential.

But also strong dependence on top-mass and $\alpha_s$!
• A better Higgs-mass measurement?

Finding $m_H \approx 125 \text{ GeV}$ shook us, but knowing $m_H = 125.457... \text{ GeV}$ will leave us indifferent.

• Spin, CP determination of H?

$\rightarrow$ If one trusted theorist in the search for the Higgs, trust them now!! It is $s=0$ and CP-even.

Of course, it is good to check, but the outcome as interesting as knowing who will win today’s game *Brazil-Cameroon*.

• Better determination of couplings? Absolutely ✓
Parametrization of BSM effects in Higgs physics

Assuming a large new-physics scale, $\Lambda >> m_W$:

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{C_i}{\Lambda^2} O_i$$

where $\mathcal{L}_{\text{SM}}$ is the Standard Model Lagrangian, $C_i$ are coefficients, $O_i$ are operators, and $\Lambda$ is the NP scale.

For CP-odd operators the identities are:

$$\mu = \mu'$$

These can be eliminated using the identities

$$\text{dim}=6$$

The operators give the deviations to SM Higgs physics from BSM

$$\Rightarrow \text{effective theory for Higgs physics}$$

$$\Rightarrow \text{approach valid for all BSM with heavy particles!}$$

“Non-renormalizable theories are as renormalizable as renormalizable theories”

S. Weinberg

(means: take $E<\Lambda$ and no problems)
How many Higgs coupling can deviate from SM?
(not effecting other experiments)

Eight! (assuming CP-conservation)

| | \[|H|^2 G^A_{\mu\nu} G^{A\mu\nu}\] \[\rightarrow\] GG\rightarrow h
| | \[|H|^2 B_{\mu\nu} B^{\mu\nu}\] \[\rightarrow\] h\rightarrow\gamma\gamma
| | \[|H|^2 W^a_{\mu\nu} W^{\mu\nu a}\] \[\rightarrow\] h\rightarrow Z\gamma
| | \[H^2 D_\mu H|^2\] \[\rightarrow\] h\rightarrow VV^* (custodial invariant)
| | \[|H|^6\] \[\rightarrow\] Affects \(h^3\): It can be measured in the far future by GG\rightarrow hh
| | \[|H|^2 \bar{f}_L H f_R + h.c.\] \[\rightarrow\] h\rightarrow bb, \tau\tau
| | (f=t, b, \tau)

h\rightarrow bb, \tau\tau

htt deviation

GG\rightarrow tth

arXiv: 1308.1879; 1308.2803
How many Higgs coupling can deviate from SM?
(not effecting other experiments)

Effects that on the vacuum, \( \phi = v \), give only a redefinition of the SM couplings:

\[
\frac{1}{g_s^2} G_{\mu \nu}^2 + \frac{|H|^2}{\Lambda^2} G_{\mu \nu}^2 \rightarrow \left( \frac{1}{g_s^2} + \frac{v^2}{\Lambda^2} \right) G_{\mu \nu}^2
\]

But can affect h physics:

\( h \)

affects \( GG \rightarrow h \)!
that when needed the Hermitian conjugate of a given operator is included in the analysis. In
and the CP-odd operators

where

In the third class of operators, $O_{RR}^{LR}$, $O_{LR}^{RR}$, and $O_{LR}^{LR}$, we include a Yukawa coupling that couples to the Higgs boson. The
operators $O_{RR}^{LR}$ and $O_{LR}^{RR}$ are CP-odd, and $O_{LR}^{LR}$ is CP-even. The operators $O_{RR}^{LR}$ and $O_{LR}^{RR}$ involve two Higgs fields and their corresponding coe-

Most genuine Higgs coupling is mediated only by quark loops; Fig. 2.14. Nevertheless, the

Eqs. (14)

Therefore, the possible probe for new charged

For fermions, only the heavy top quark and, to a lesser extent

tools heavy to be produced directly. These decays are thus extremely interest-

the entire Higgs boson mass and can be used as a po-

to scales far beyond the Higgs boson mass.
Experimental bound on $h \rightarrow Z\gamma$

$\text{BR} \sim 0.001$
small in the SM since it comes at one-loop:

... last hope for finding O(1) deviations?
(possibility in composite Higgs models)

CMS (H → Zγ): $\mu < 9$ (9 expected) at 95% CL

still allow to be $9 \times \text{BR}_{\text{SM}}$
Don’t expect high-precision measurements of Higgs couplings:

Projected Higgs couplings with 300 fb⁻¹

- **Two scenarios:**
  - **Scenario 1:** same systematics as in 2012
  - **Scenario 2:** theory systematics scaled by a factor ½, other systematics scaled by $1/\sqrt{\int L dt}$

Don’t expect high-precision measurements of Higgs couplings:

Linear colliders have a point here!
Don’t expect high-precision measurements of Higgs couplings:

Linear colliders have a point here!
Figure 2: Comparison of the capabilities of LHC and ILC for model-independent measurements of Higgs boson couplings. The plot shows (from left to right in each set of error bars) 1 $\sigma$ confidence intervals for LHC at 14 TeV with 300 fb$^{-1}$, for ILC at 250 GeV and 250 fb$^{-1}$ (‘HLC’), for the full ILC program up to 500 GeV with 500 fb$^{-1}$ (‘ILC’), and for a program with 1000 fb$^{-1}$ for an upgraded ILC at 1 TeV (‘ILCTeV’). The marked horizontal band represents a 5% deviation from the Standard Model prediction for the coupling.
Other Higgs couplings
e.g., form-factors (momentum-dependence)

Already tested in other experiments:

\[ \begin{align*}
\text{h} & \quad \text{Z} \quad f \quad f \quad = \quad \frac{1}{2v} \times \quad \text{Z} \\
\text{H}^\dagger D_\mu H f \gamma^\mu f
\end{align*} \]

Modifications in \( h \rightarrow Zff \) related to \( Z \rightarrow ff \)

\[ \text{Constrained by LEPI at the per-mille level!} \]

& also constraints from triple gauge-boson couplings:

\[ \begin{align*}
\text{Z, } \gamma & \quad \text{W} \\
\text{W} & \quad \text{from e.g. } (D^\mu H)^\dagger (D^\nu H) B_{\mu \nu}
\end{align*} \]
Nevertheless, worthy to explore as already started at the LHC

**Off-shell Higgs couplings:**

\[ pp \to H^* \to ZZ^* \to 4l \]
Momentum distribution in $H \rightarrow \gamma \gamma$

Figure 4: Observed differential cross sections of the Higgs bosons decaying into two isolated photons, $d\sigma/d|\cos(\theta*)| \ [fb]$ for $|y| < 1$ and $d\sigma/dp_T \ [fb/GeV]$ for $p_T > 0$.

ATLAS Preliminary

- $ggH$ NLO+PS (POWHEG+Pythia8) + $XH$
- $ggH$ NNLO+NNLL ($H$Res1.0) + $XH$
- $XH = VBF + VH + t\bar{t}H$

$H \rightarrow \gamma \gamma$, $\sqrt{s} = 8$ TeV

$\int L \, dt = 20.3$ fb$^{-1}$

(a) $p_T^{\gamma\gamma}$
Deviations in $h_{WW}$ vs $h_{ZZ}$

$\frac{g_{hZZ}}{g_{hZZ}^{SM}}$ from $h$ physics

$\frac{g_{hWW}}{g_{hWW}^{SM}}$ from EWPT & TGC

$\rightarrow$ No large custodial-breaking effects allowed
In the future:

**h→Wff, Zff form-factors:**

\[ M(h \rightarrow V J_f) = (\sqrt{2} G_F)^{1/2} \epsilon^{\mu}(q) J^V_{\mu}(p) \left[ A^V_f \eta_{\mu\nu} + B^V_f (p \cdot q \eta_{\mu\nu} - p_\mu q_\nu) \right] \]

\[
A^V_f = a^V_f + \tilde{a}^V_f \frac{p^2 + M_V^2}{p^2 - M_V^2} \\
B^V_f = b^V_f \frac{1}{p^2 - M_V^2} + \tilde{b}^V_f \frac{1}{p^2}
\]

 заболевания to be measured in momentum/angle distributions

~ order one bounds from SM values expected after the end of run2
Higgs Boson Properties: Field Strength Tensor Structure via $H \rightarrow ZZ^* \rightarrow 4f$

$$A(H \rightarrow ZZ) = v^{-1} \left( a_1 m_Z^2 e_2^* e_2^* + a_2 f_{\mu\nu}^{(1)} f^{(2),\mu\nu} + a_3 f_{\mu\nu}^{(1)} f^{(2),\mu\nu} \right)$$

- SM tree process
- Loop CP-even contributions
- CP-odd contributions (BSM)

Test for presence of extra anomalous CP-even (coupling $a_2 \leftrightarrow g_2$) and CP-odd (coupling $a_3 \leftrightarrow g_4$) components

- 8D fit involving kinematical variables sensitive to $a_2$ and $a_3$
- with free parameters $\text{Re}(a_i)/a_1$ and $\text{Im}(a_i)/a_1$, $i=\{2,3\}$

95% CL limits: (0,0) corresponds to pure CP-even ‘0+’ SM state

Factor ~2-3 improvement in precision between 300 and 3000 fb⁻¹
With the Higgs \( \rightarrow \) the SM is completed

\( \Rightarrow \) No need for anything else to (at least) around the Planck scale

… but very unnatural theory!

Expected “deformations” from SM properties
To see them, we must test the Higgs very well

If not found… ➡ Multiverse?
If we find them in \( h \rightarrow ff \) only ➡ probably MSSM
In a reduction of couplings ➡ probably Composite Higgs