EFFECTIVE FIELD THEORY OF HIGGS-BOSON PROPERTIES

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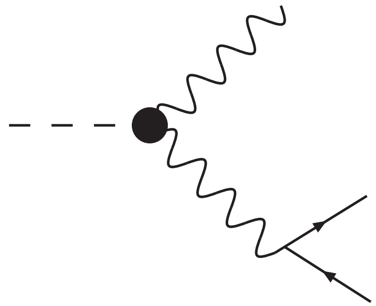
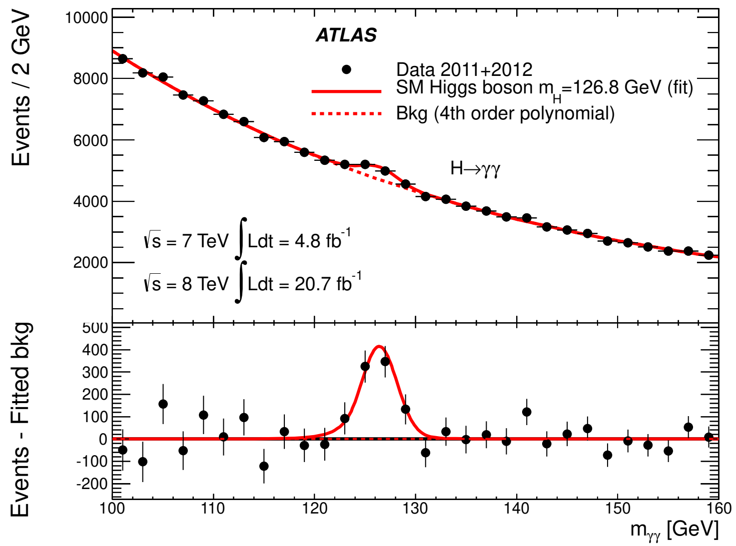
Matthias Fest MITP – May 2023



- Anomalous Higgs couplings
- Electroweak chiral Lagrangian (HiggsEFT)
- Applications

G.B., Oscar Catà, Alejandro Celis, Marc Knecht, Claudius Krause Gudrun Heinrich, Marius Höfer, Christoph Müller-Salditt, Florian Pandler

Higgs resonance



no other new particles so far; $m_h \ll \Lambda$

$\rightarrow$ Effective Field Theory

- quarks, leptons, $SU(3)_C$, $SU(2)_L$, $U(1)_Y$

- Goldstones φ^a, $U = \exp(2i\varphi^a T^a/v)$
- light Higgs h

$$U \to g_L U g_R^\dagger, \qquad h \to h, \qquad g_{L,R} \in SU(2)_{L,R}$$

relation to Higgs doublet:

$$(\tilde{\Phi}, \Phi) \equiv (v + h)U$$

SM Lagrangian

$$\mathcal{L}_{SM} = -\frac{1}{2}\langle G_{\mu\nu}G^{\mu\nu}\rangle - \frac{1}{2}\langle W_{\mu\nu}W^{\mu\nu}\rangle - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \bar{\psi}i\not{D}\psi$$

$$+\frac{v^2}{4}\,\langle D_\mu U^\dagger D^\mu U\rangle \left(1 + 2\frac{h}{v} + \left(\frac{h}{v}\right)^2\right)$$

$$+\frac{1}{2}\partial_\mu h \partial^\mu h - v^4 \left(\frac{\lambda}{2}\left(\frac{h}{v}\right)^2 + \frac{\lambda}{2}\left(\frac{h}{v}\right)^3 + \frac{\lambda}{8}\left(\frac{h}{v}\right)^4\right)$$

$$-v\left[\bar{q}\hat{Y}_u U P_+ r \left(1 + \frac{h}{v}\right) + \text{h.c.} + \ldots\right]$$

- $U = \exp(2i\varphi^a T^a/v)$
- $\mathcal{L}_{SM}$, renormalizable

$$\mathcal{L}_{LO} = -\frac{1}{2}\langle G_{\mu\nu}G^{\mu\nu}\rangle - \frac{1}{2}\langle W_{\mu\nu}W^{\mu\nu}\rangle - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \bar{\psi}i\not{D}\psi$$

$$+\frac{v^2}{4}\langle D_\mu U^\dagger D^\mu U\rangle \left(1 + F_1\frac{h}{v} + F_2\left(\frac{h}{v}\right)^2 + \ldots\right)$$

$$+\frac{1}{2}\partial_\mu h \partial^\mu h - v^4\left(V_2\left(\frac{h}{v}\right)^2 + V_3\left(\frac{h}{v}\right)^3 + V_4\left(\frac{h}{v}\right)^4 + \ldots\right)$$

$$-v\left[\sum_{n=0}^{\infty}\bar{q}\hat{Y}_u^{(n)}UP_+r\left(\frac{h}{v}\right)^n + \text{h.c.} + \ldots\right]$$

- $U = \exp(2i\varphi^a T^a/v)$, $\quad F_i - F_{i,SM} \sim \xi \equiv v^2/f^2$, etc.
- $\mathcal{L}_{LO}$ non-renormalizable, cut-off $\Lambda = 4\pi f$ $\quad\rightarrow\quad$ EWχL

Basic assumptions

- **particle content** of SM, mass gap

  gauge bosons and fermions weakly coupled to Higgs dynamics

- **symmetries**: SM gauge symmetries

  conservation of lepton and baryon number

  conservation *at lowest order* of custodial symmetry,

  CP invariance in the Higgs sector, (fermion flavour).

- **power counting** by chiral dimensions $\Leftrightarrow$ loop expansion

Loop counting $\equiv$ chiral counting

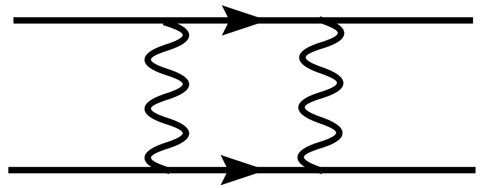
Urech; Knecht, Neufeld, Rupertsberger, Talavera; G.B., Catà, Krause

chiral dimensions: $[A_\mu, \varphi, h]_c = 0, \quad [\partial_\mu, g, y, \psi\bar{\psi}]_c = 1$

loop order: $2L + 2 = \Sigma \; (chiral\ dim.)$

examples:

$$m_h^2 = \lambda v^2$$



$\Rightarrow [\mathcal{L}_{LO}]_c = 2, \qquad [\mathrm{NLO}]_c = 4 \qquad$ (local terms; D^n, $n \geq 0$)

$$UhD^4, \quad g^2X^2Uh, \quad gXUhD^2, \quad y^2\psi^2UhD, \quad y\psi^2UhD^2, \quad y^2\psi^4Uh$$

One-loop renormalization and RGE

$$e^{iS_{eff}} \sim \int d\varphi_i \, d\chi \, d\bar{\chi} \; e^{i\int d^Dx \, \mathcal{L}_2(\varphi_i,\chi,\bar{\chi})}$$

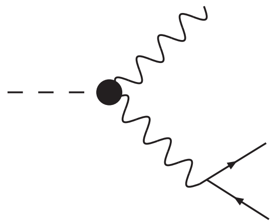
NLO counterterms: *G.B., Catà, Celis, Knecht, Krause; Alonso et al.*

super-heat-kernel expansion: *Neufeld, Gasser, Ecker*

hVV coupling F_1:

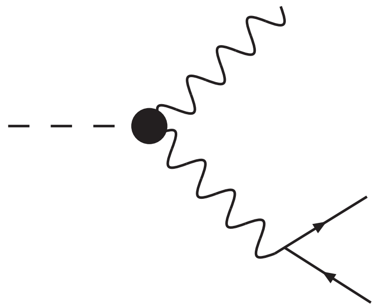
$$\frac{F_1(\mu)}{2} \approx \frac{F_1(v)}{2} + (4F_2 - F_1^2)\frac{N_c m_t^4}{8\pi^2 v^2 m_h^2} \ln\frac{\mu}{v}$$

$$\approx \frac{F_1(v)}{2} + (4F_2 - F_1^2)\, 0.125$$

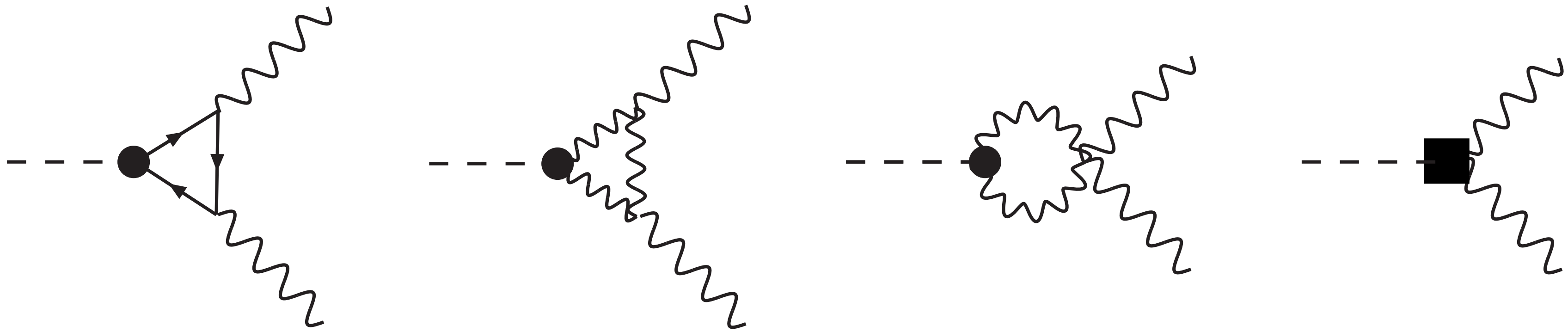


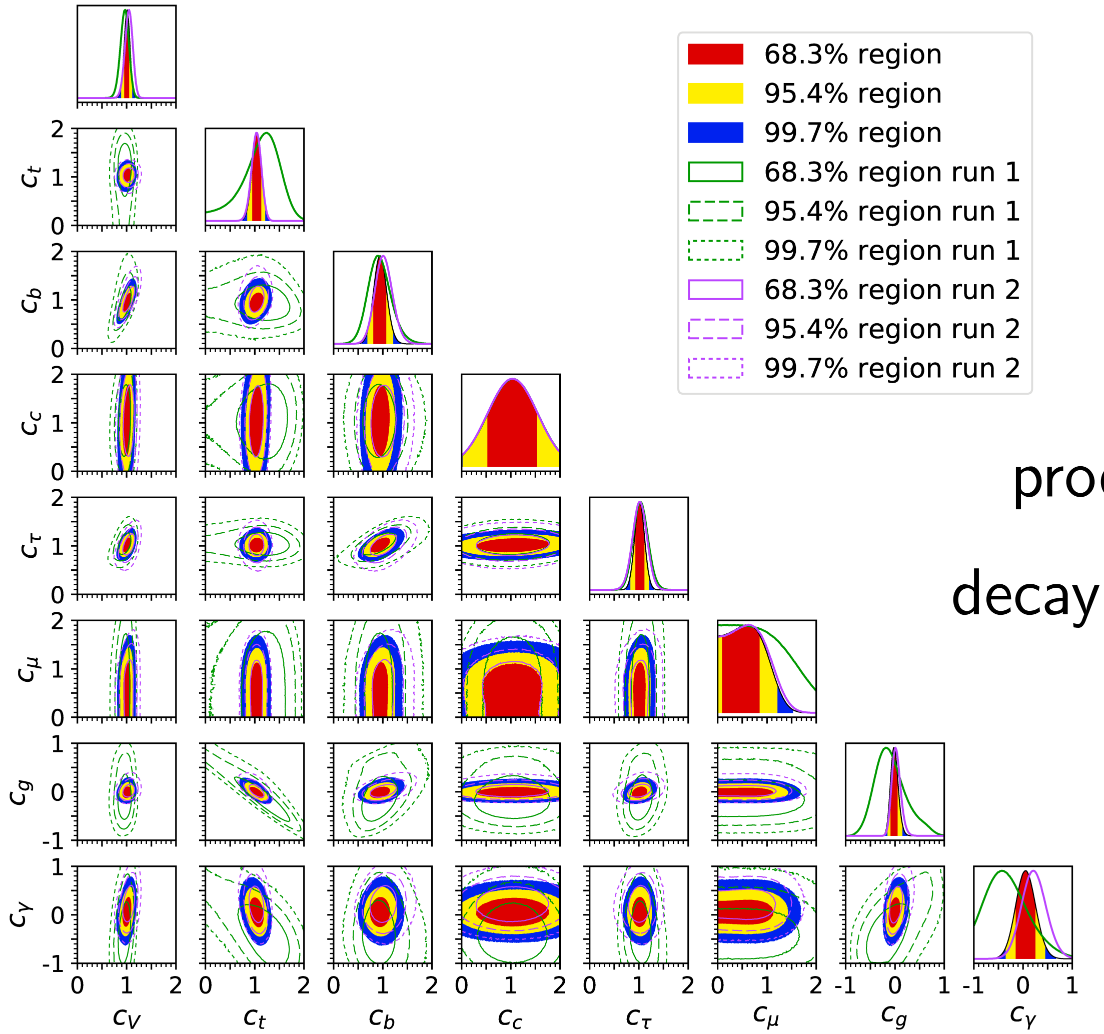
Applications

$h \to Z\ell^+\ell^-$



$h \to \gamma\gamma$



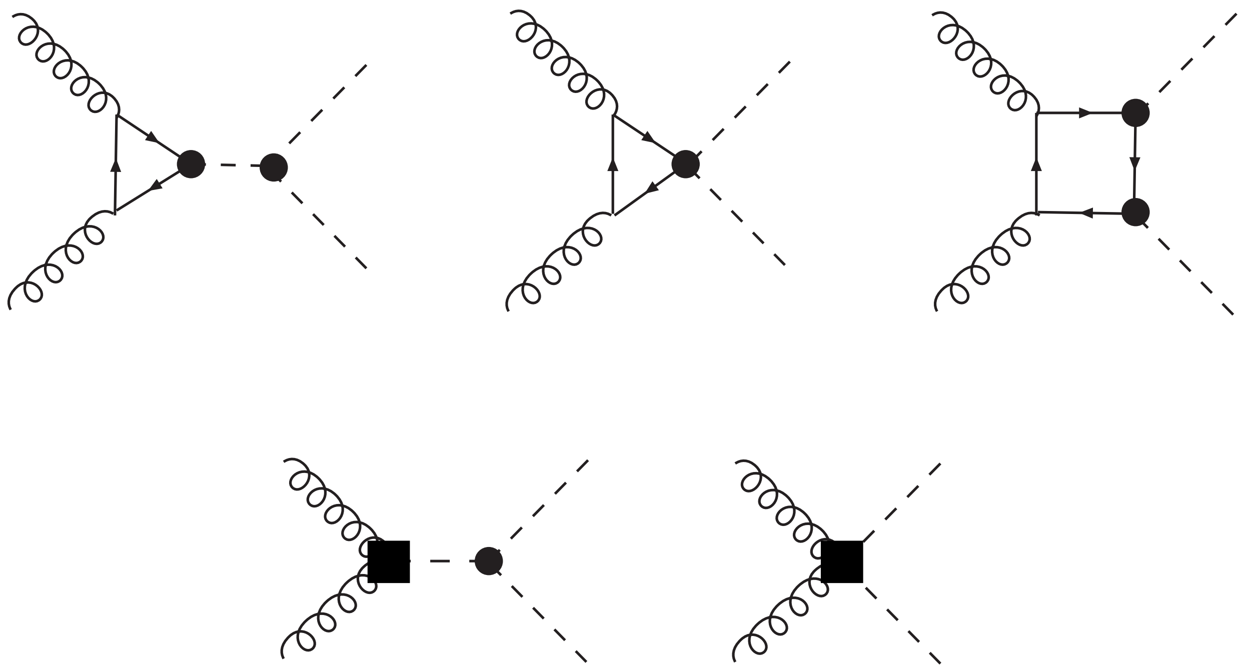


production: ggh, Wh/Zh, VBF, $t\bar{t}h$

decay: $h \to \gamma\gamma$, WW, ZZ, $b\bar{b}$, $\tau\bar{\tau}$, ...

de Blas, Eberhardt, Krause, '18

Higgs-pair production in gluon fusion



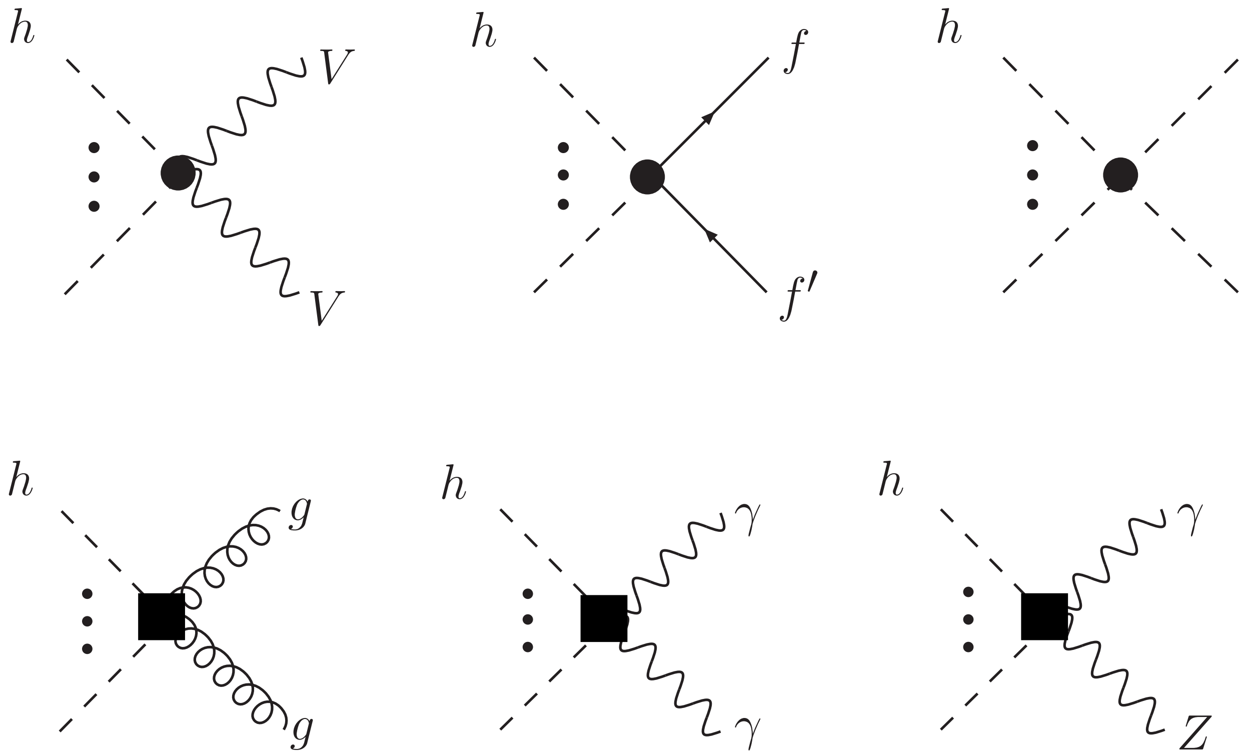
Gröber, Mühlleitner, Spira, Streicher

Borowka, Greiner, Heinrich, Jones, Kerner, Schlenk, Zirke

G.B., Capozi, Celis, Heinrich, Scyboz

Summary

- natural framework for anomalous Higgs couplings
- consistent EFT, systematic improvement possible
- well adapted to LHC precision with 300 fb^{-1} (Run 2 and 3)
- QFT justification of κ-framework



$$\mathcal{L} = 2c_V \left(m_W^2 W_\mu^+ W^{-\mu} + \tfrac{1}{2} m_Z^2 Z_\mu Z^\mu\right) \frac{h}{v} - c_t y_t \bar{t} t h - c_b y_b \bar{b} b h - c_\tau y_\tau \bar{\tau}\tau h$$
$$+ \frac{e^2}{16\pi^2} c_{\gamma\gamma} F_{\mu\nu} F^{\mu\nu} \frac{h}{v} + \frac{g_s^2}{16\pi^2} c_{gg} \langle G_{\mu\nu} G^{\mu\nu} \rangle \frac{h}{v}$$

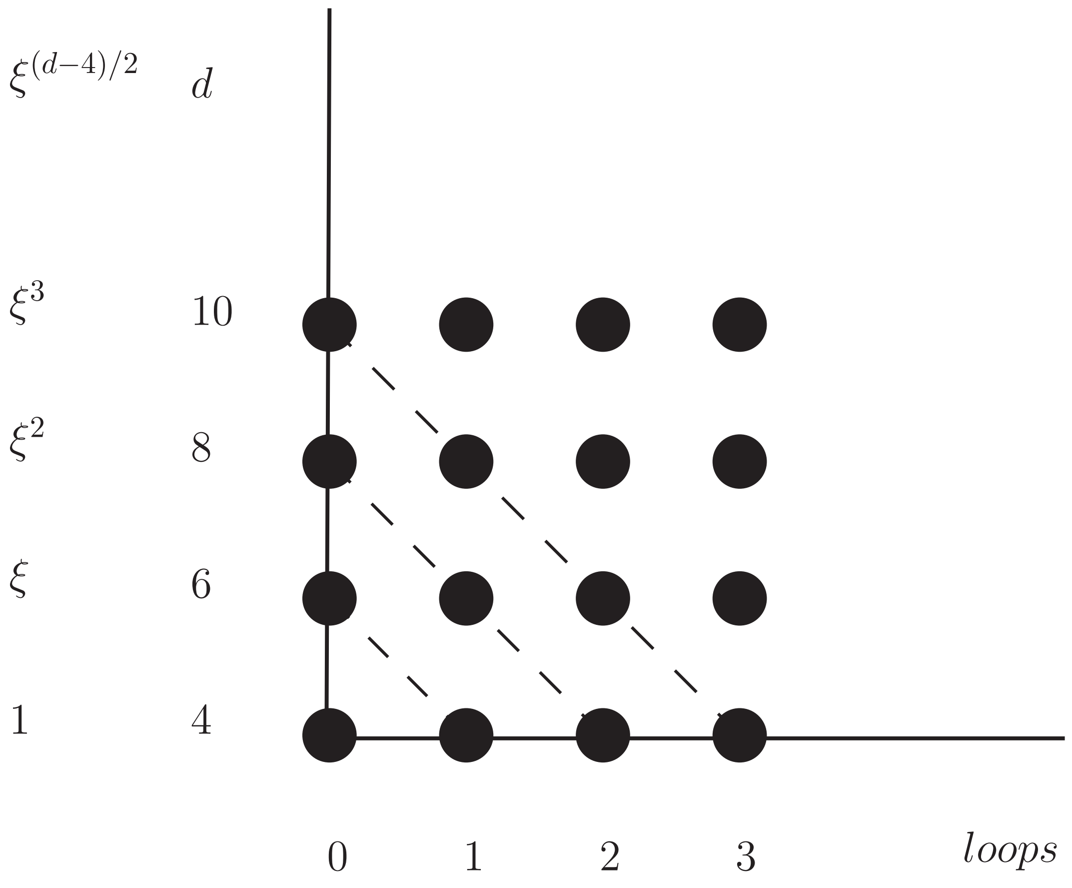
$$\Lambda = 4\pi f$$

$$f$$

$$v$$

$$\xi = \frac{v^2}{f^2} \to \text{dim. exp.}$$

$$\frac{1}{16\pi^2} \approx \frac{f^2}{\Lambda^2} \to \text{loop exp.}$$



BACKUP: $gg \to h$