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LHC Higgs XS WG – 11th Workshop

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- Chiral Lagrangian and power counting
- Linear vs. nonlinear
- Higgs couplings
- Section outline

LHCHXSWG – Yellow Report 4
Working Group 2 – Nonlinear EFT

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Leading-order Lagrangian

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

$$+\frac{v^2}{4}\langle D_\mu U^\dagger D^\mu U\rangle\,(1+F_U(h/v)) + \frac{1}{2}\partial_\mu h\partial^\mu h - V(h)$$

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

- $U = \exp(2i\varphi^a T^a/v)$, $F_U(h/v) = \sum_{n=1}^{\infty} f_n(h/v)^n$, etc.
- SM: $f_1 = 2$, $f_2 = 1$, $f_{n>2} = 0$, etc.
- deviations $\sim \xi \equiv \frac{v^2}{f^2}$; $\xi \sim 10\%$ still allowed
- $\mathcal{L}_{LO}$ non-renormalizable, cut-off $\Lambda = 4\pi f$ $\rightarrow$ EWχL

- **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

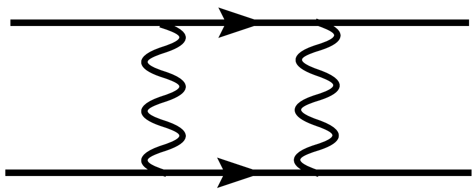
Loop counting $\equiv$ chiral counting

Urech; Nyffeler, Schenk; Hirn, Stern; G.B., Catà, Krause

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

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

example: $4_p - 6_p + 4_g + 2_\psi = 4$



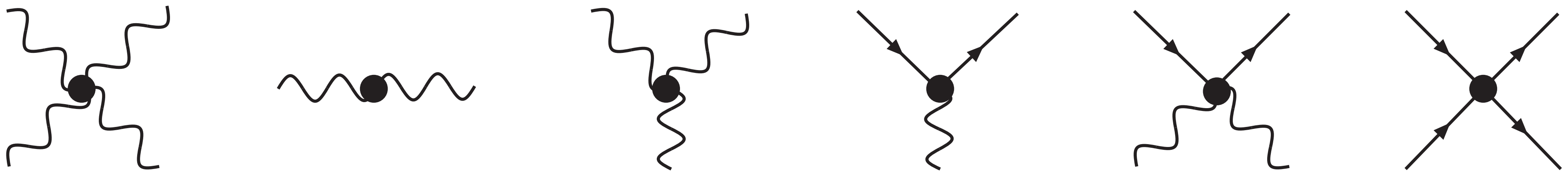
$\Rightarrow [\mathcal{L}_{LO}]_c = 2, \qquad [\mathrm{NLO}]_c = 4 \qquad$ (local terms; D^n, $n \geq 0$)

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

- $\bar{\psi}\psi\bar{\psi}\psi$, X^2Uh not LO

→ classification of NLO operators

$UhD^4, \quad X^2Uh, \quad XUhD^2, \quad \psi^2UhD, \quad \psi^2UhD^2, \quad \psi^4Uh$



related work: *Giudice et al., Contino et al., Alonso et al.*

Loop vs. dimensional counting

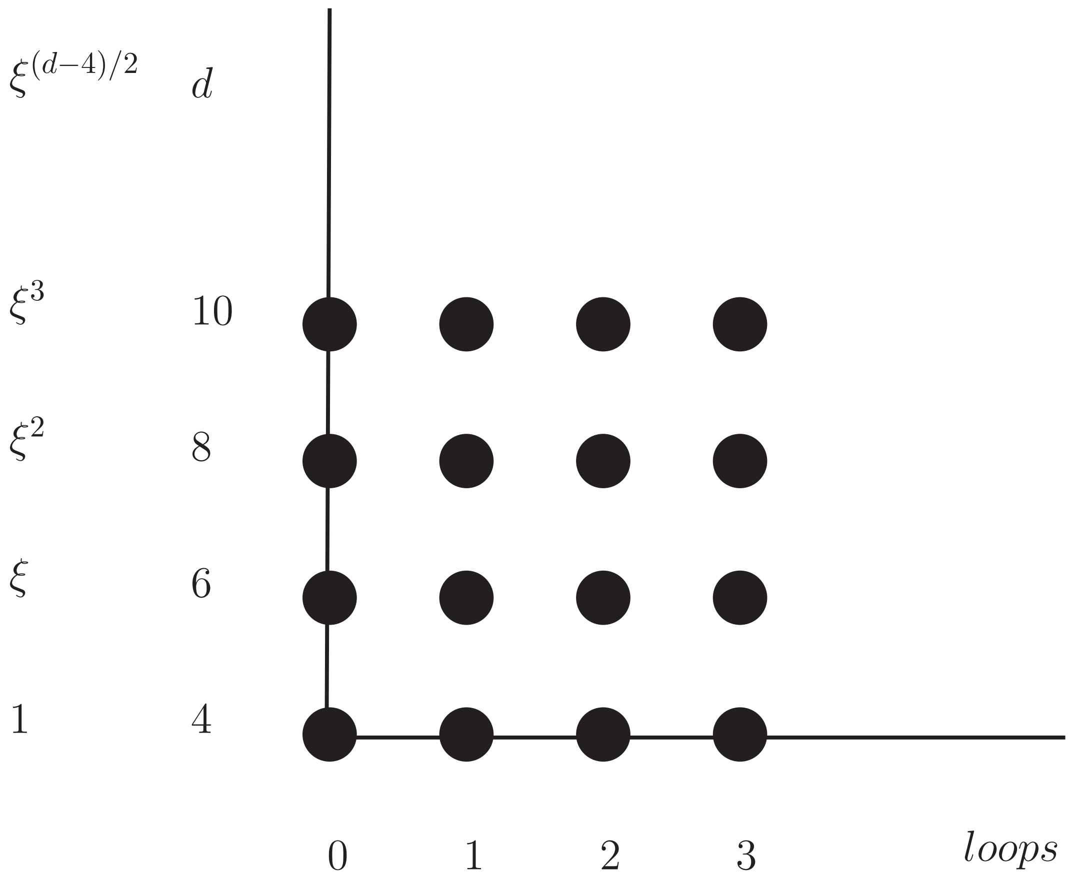
$$\Lambda = 4\pi f$$

$$f$$

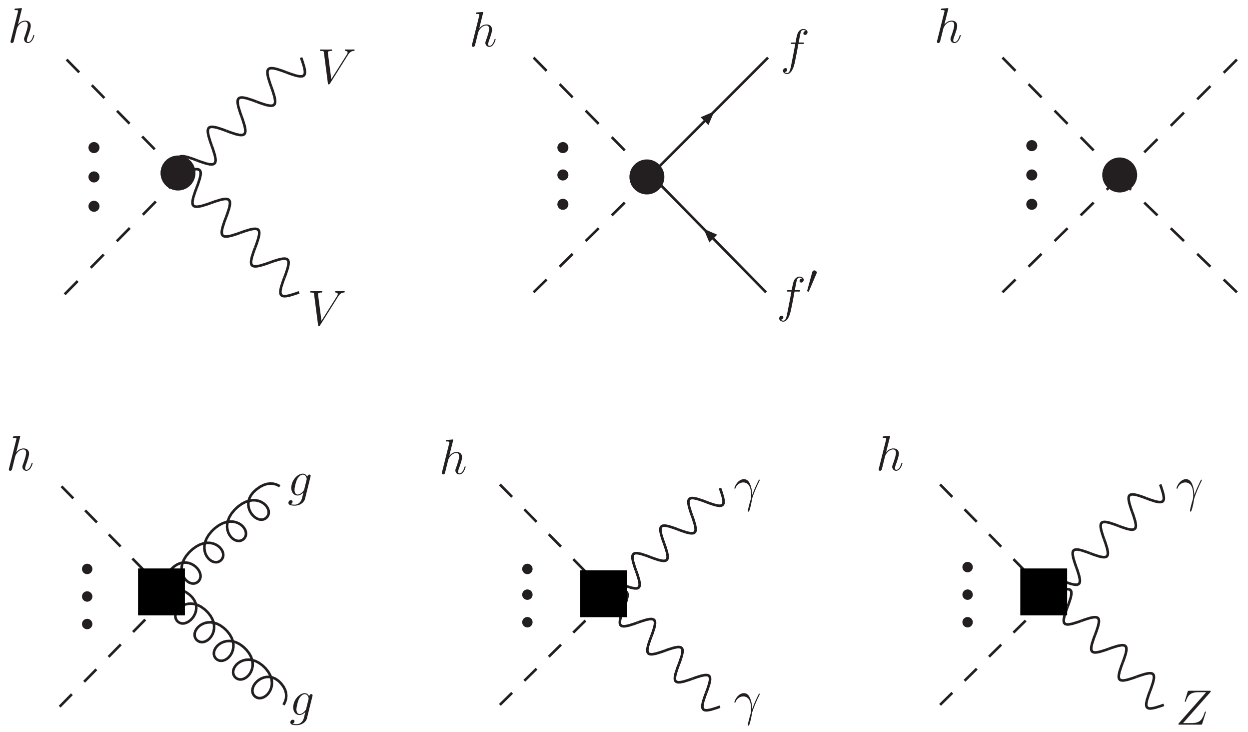
$$v$$

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

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



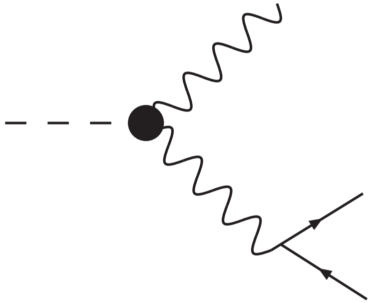
LO couplings



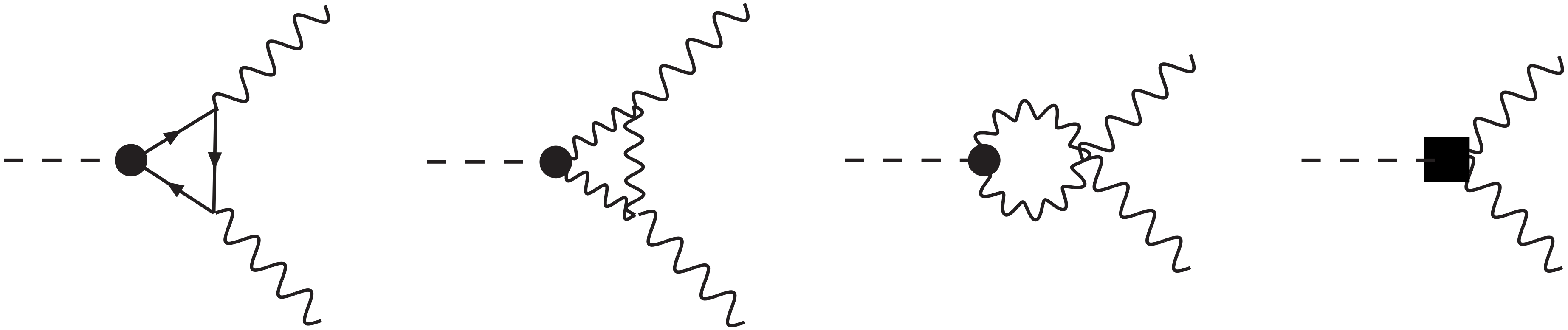
$$\mathcal{L} = 2c_V \left(m_W^2 W_\mu^+ W^{-\mu} + \frac{1}{2} m_Z^2 Z_\mu Z^\mu\right) \frac{h}{v} - c_t y_t \bar{t} t h - c_b y_b \bar{b} b h - c_\tau y_\tau \bar{\tau} \tau h$$
$$+ \frac{e^2}{16\pi^2} c_{\gamma\gamma} F_{\mu\nu} F^{\mu\nu} \frac{h}{v} + \frac{e g'}{16\pi^2} c_{Z\gamma} Z_{\mu\nu} F^{\mu\nu} \frac{h}{v} + \frac{g_s^2}{16\pi^2} c_{gg} \langle G_{\mu\nu} G^{\mu\nu} \rangle \frac{h}{v}$$

Sample applications

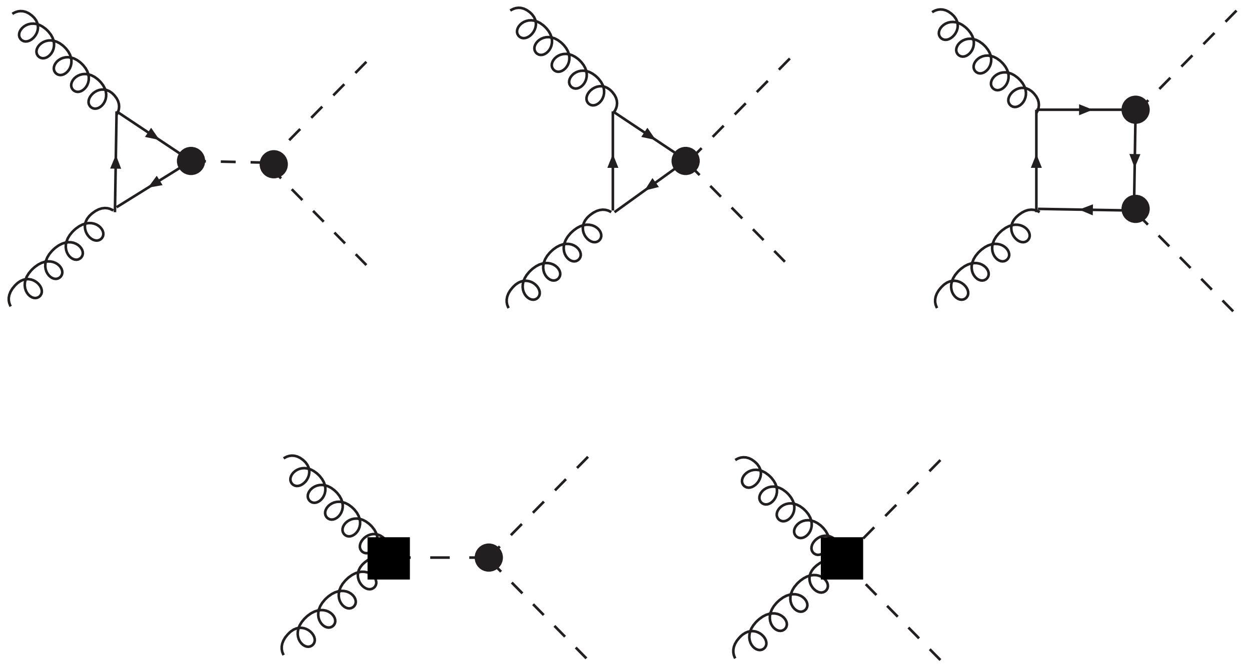
$h \to Z\ell^+\ell^-$



$h \to \gamma\gamma$

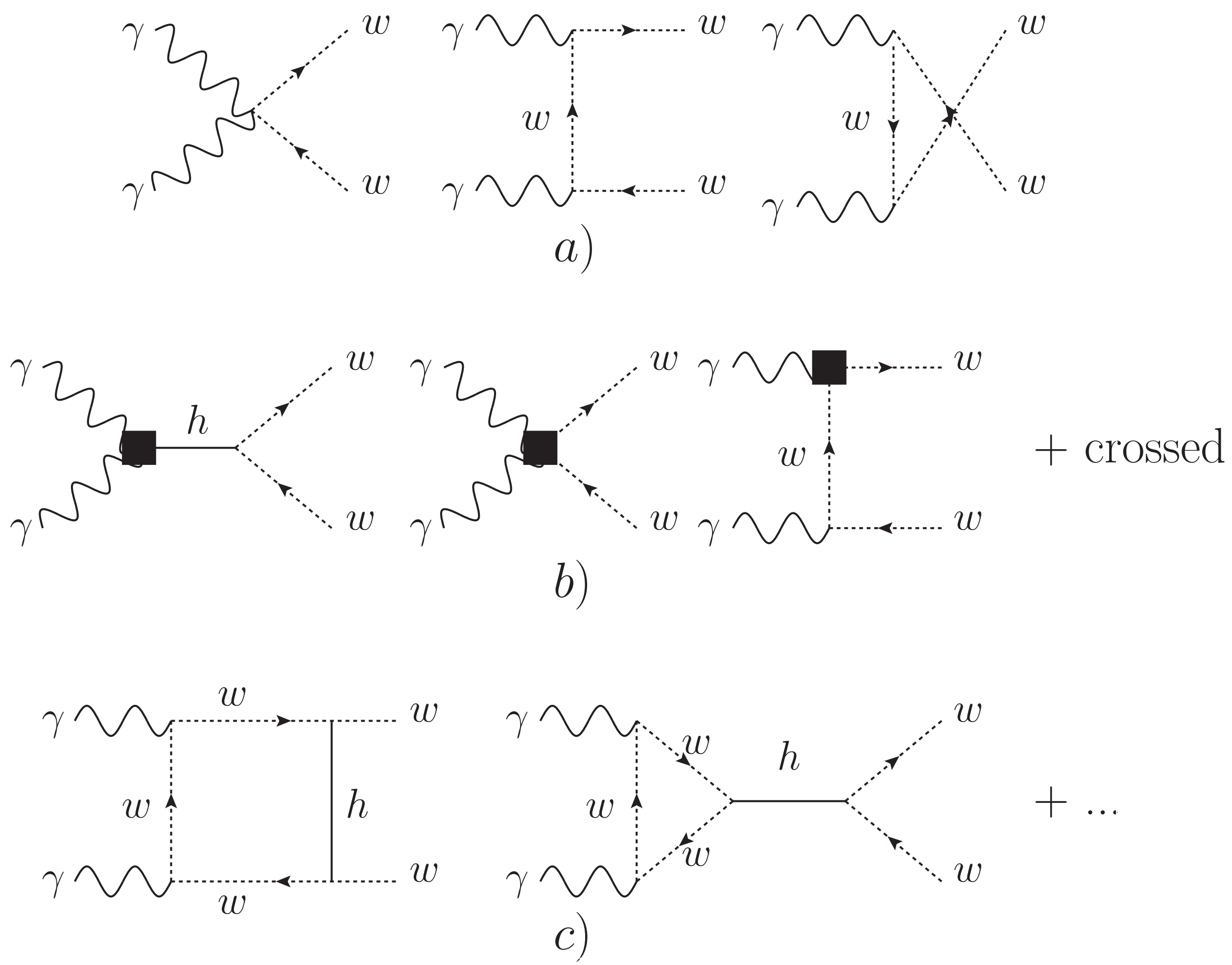


Higgs-pair production in gluon fusion



Gröber, Mühlleitner, Spira, Streicher

$\gamma\gamma \to ww$



Delgado, Dobado, Herrero, Sanz-Cillero

1. Motivation and leading-order Lagrangian
2. Renormalization of the chiral Lagrangian
3. Connection of chiral Lagrangian to κ-formalism
4. Linear vs. nonlinear EFT
5. Sample applications
   - $h \to Z l^+ l^-$, $h \to \gamma\gamma$, $h \to Z\gamma$
   - Higgs-pair production in gluon fusion
   - $\gamma\gamma$ scattering; $\gamma^* \to w^+ w^-$, $\gamma^*\gamma^* \to h$ form factors
   - TeV-scale particle pair production at NLO
6. Concluding remarks

Summary

- natural framework for sizable NP in Higgs couplings

- power counting by chiral dimensions

- consistent EFT, systematic improvement possible

- LO description $\leftrightarrow$ κ-formalism