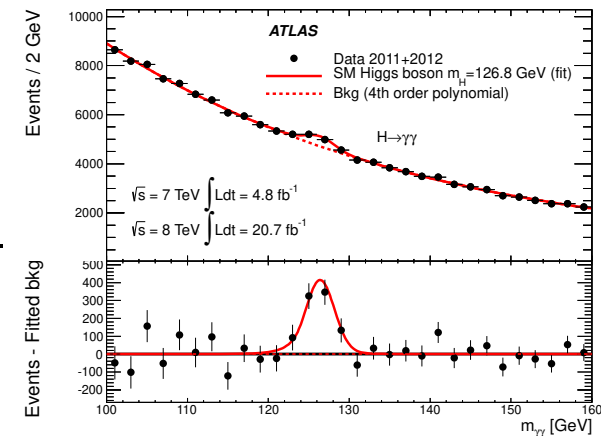


Gerhard Buchalla

LMU München

Ulifest KIT – July 2026

- Anomalous Higgs couplings
- Electroweak chiral Lagrangian (HiggsEFT)
- A simple model: SM extended by a heavy scalar S



G.B., O. Catà, A. Celis, M. Knecht, C. Krause

G. Heinrich, M. Höfer, Ch. Müller-Salditt, F. Pandler, F. König

- 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

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

relation to Higgs doublet:

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

$$\begin{aligned}\mathcal{L}_{SM} = & -\frac{1}{2}\langle G_{\mu\nu}G^{\mu\nu}\rangle - \frac{1}{2}\langle W_{\mu\nu}W^{\mu\nu}\rangle - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \bar{\psi}i\not{D}\psi \\ & + \frac{v^2}{4}\langle D_\mu U^\dagger D^\mu U\rangle \left(1 + 2\frac{h}{v} + \left(\frac{h}{v}\right)^2\right) \\ & + \frac{1}{2}\partial_\mu h\partial^\mu h - v^4\left(\frac{\lambda}{2}\left(\frac{h}{v}\right)^2 + \frac{\lambda}{2}\left(\frac{h}{v}\right)^3 + \frac{\lambda}{8}\left(\frac{h}{v}\right)^4\right) \\ & - v\left[\bar{q}\hat{Y}_u U P_{+r}\left(1 + \frac{h}{v}\right) + \text{h.c.} + \dots\right]\end{aligned}$$

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

$$\begin{aligned}
 \mathcal{L}_{LO} = & -\frac{1}{2}\langle G_{\mu\nu}G^{\mu\nu}\rangle - \frac{1}{2}\langle W_{\mu\nu}W^{\mu\nu}\rangle - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \bar{\psi}i\not{D}\psi \\
 & + \frac{v^2}{4}\langle D_\mu U^\dagger D^\mu U\rangle \left(1 + F_1\frac{h}{v} + F_2\left(\frac{h}{v}\right)^2 + \dots\right) \\
 & + \frac{1}{2}\partial_\mu h\partial^\mu h - v^4\left(V_2\left(\frac{h}{v}\right)^2 + V_3\left(\frac{h}{v}\right)^3 + V_4\left(\frac{h}{v}\right)^4 + \dots\right) \\
 & - v\left[\sum_{n=0}^{\infty}\bar{q}\hat{Y}_u^{(n)}UP_{+r}\left(\frac{h}{v}\right)^n + \text{h.c.} + \dots\right]
 \end{aligned}$$

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

- **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

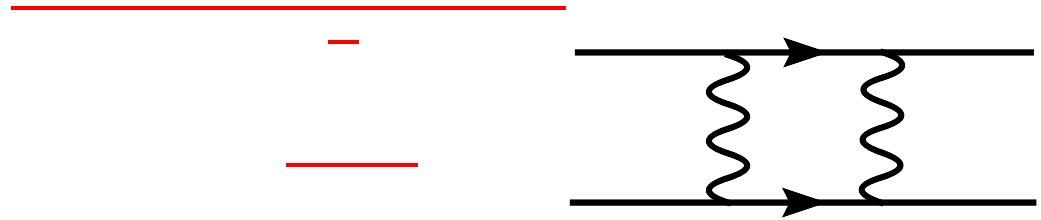
Urech; Knecht, Neufeld, Rupertsberger, Talavera; G.B., Catà, Krause

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

loop order: $2L + 2 = \Sigma (\text{chiral dim.})$

examples:

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

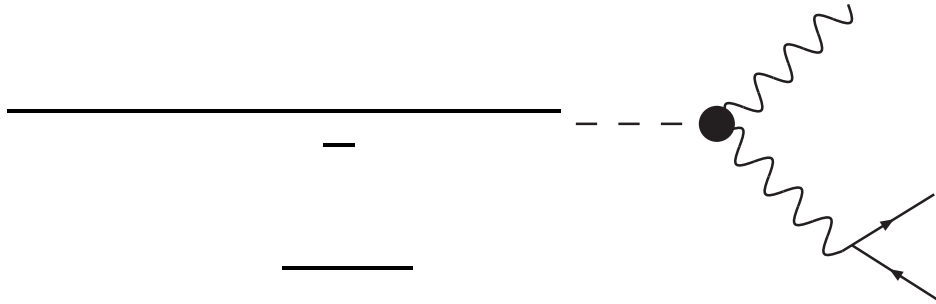


$\Rightarrow [\mathcal{L}_{LO}]_c = 2, \quad [\text{NLO}]_c = 4 \quad (\text{local terms; } D^n, n \geq 0)$

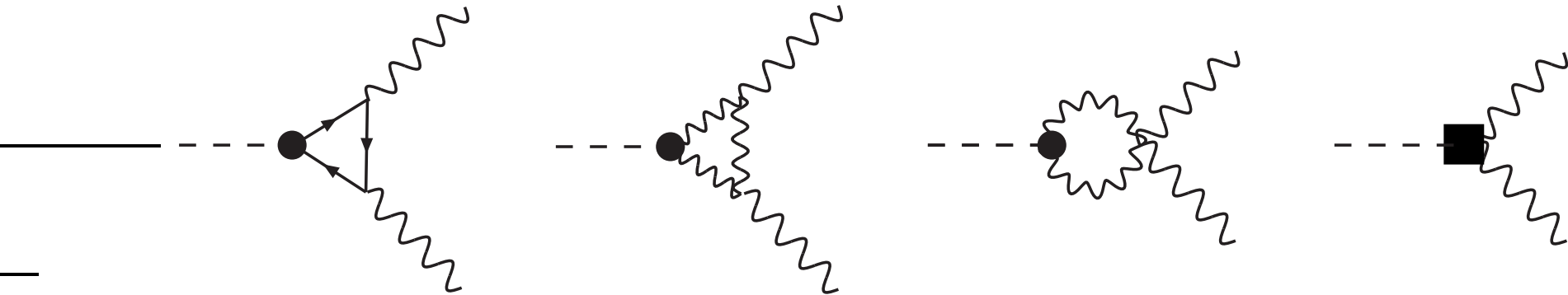
$$UhD^4, \quad g^2 X^2 Uh, \quad gXUhD^2, \quad y^2\psi^2UhD, \quad y\psi^2UhD^2, \quad y^2\psi^4Uh$$

Applications

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



$$h \rightarrow \gamma\gamma$$



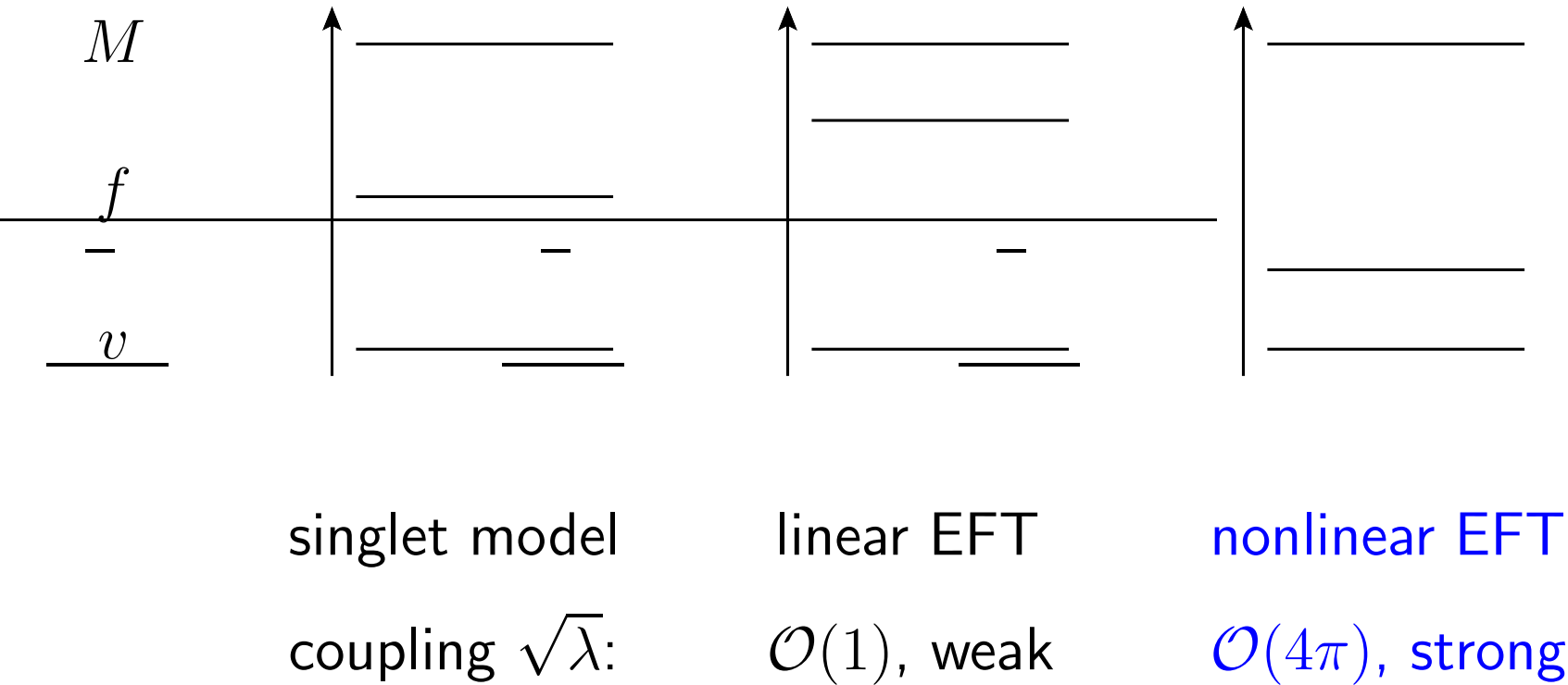
$$\mathcal{L} = (D^\mu \Phi)^\dagger (D_\mu \Phi) + \partial^\mu S \partial_\mu S - V(\Phi, S)$$

$$V(\Phi, S) = -\frac{\mu_1^2}{2} \Phi^\dagger \Phi - \frac{\mu_2^2}{2} S^2 + \frac{\lambda_1}{4} (\Phi^\dagger \Phi)^2 + \frac{\lambda_2}{4} S^4 + \frac{\lambda_3}{2} \Phi^\dagger \Phi S^2$$

$$\Phi = \frac{v + h_1}{\sqrt{2}} U \begin{pmatrix} 0 \\ 1 \end{pmatrix}, \quad S = \frac{v_s + h_2}{\sqrt{2}}, \quad \boxed{f^2 \equiv v^2 + v_s^2}$$

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{bmatrix} \cos \chi & -\sin \chi \\ \sin \chi & \cos \chi \end{bmatrix} \begin{pmatrix} h_1 \\ h_2 \end{pmatrix}$$

$$m, \quad v, \quad M, \quad \xi \equiv \frac{v^2}{f^2}, \quad \omega \equiv \sin^2 \chi \quad \boxed{\approx SO(5)}$$



$$\lambda_i \approx \frac{2M^2}{f^2} \quad \frac{v^2}{f^2} = \xi$$

$$\begin{aligned}
\mathcal{L}_{hH} = & \frac{1}{2} \partial_\mu h \partial^\mu h + \frac{1}{2} \partial_\mu H \partial^\mu H - V(h, H) \\
& + \frac{v^2}{4} \langle D_\mu U^\dagger D^\mu U \rangle \left(1 + \frac{2c}{v} h + \frac{2s}{v} H + \frac{c^2}{v^2} h^2 + \frac{s^2}{v^2} H^2 + \frac{2sc}{v^2} hH \right) \\
& - v \left(\bar{q} Y_u U P_+ r + \bar{q} Y_d U P_- r + \bar{\ell} Y_e U P_- \eta + \text{h.c.} \right) \left[1 + \frac{c}{v} h + \frac{s}{v} H \right]
\end{aligned}$$

e.o.m. : $(-\partial^2 - M^2 + 2J_2)H + J_1 + 3J_3H^2 + 4J_4H^3 = 0$

$$H = H_0 + H_1 + H_2 + \dots, \quad H_l = \mathcal{O}(1/M^{2l})$$

$$J_i \equiv M^2 J_i^0(h) + \bar{J}_i$$

$$\mathcal{O}(M^2) : \quad J_1^0 + (-1 + 2J_2^0)H_0 + 3J_3^0 H_0^2 + 4J_4^0 H_0^3 = 0$$

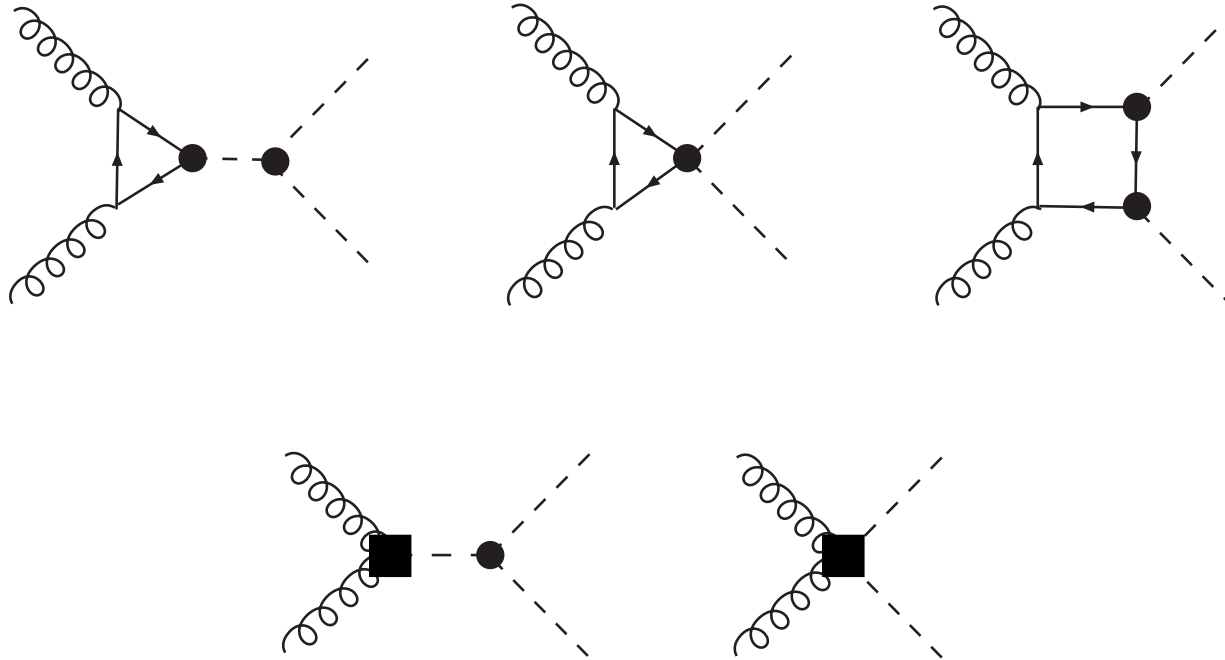
$$\text{solution :} \quad H_0(h) = \sum_{k=2}^{\infty} r_k h^k$$

- integrating out H at strong coupling $M \gg f \sim v$
- nonlinear EFT from a simple model
- governed by chiral dimensions
- similar for 2HDM
- $f \gg v \rightarrow$ transition to SMEFT

- natural framework for anomalous Higgs couplings
- toy model: SM + heavy singlet
- consistent EFT, systematic improvement possible
- well adapted to LHC precision
- supersedes κ -framework

BACKUP:

Higgs-pair production in gluon fusion



*Gröber, Mühlleitner, Spira, Streicher
Borowka, Greiner, Heinrich, Jones, Kerner, Schlenk, Zirke
G.B., Capozzi, Celis, Heinrich, Scyboz*

