Multi Higgs Production and Models

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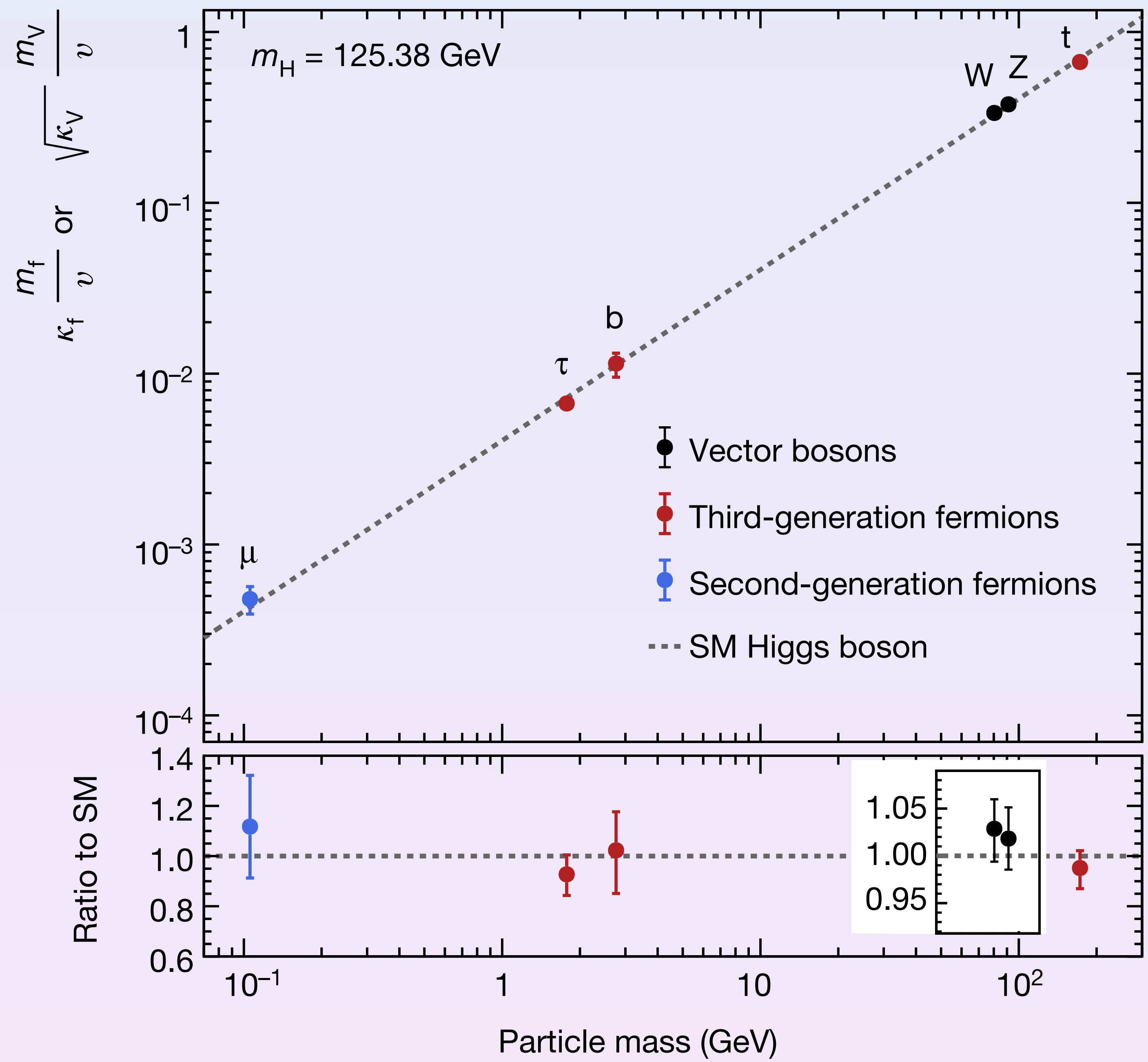
Higgs Couplings

- Higgs couplings to massive vector bosons and third generation fermions measured with amazing precision

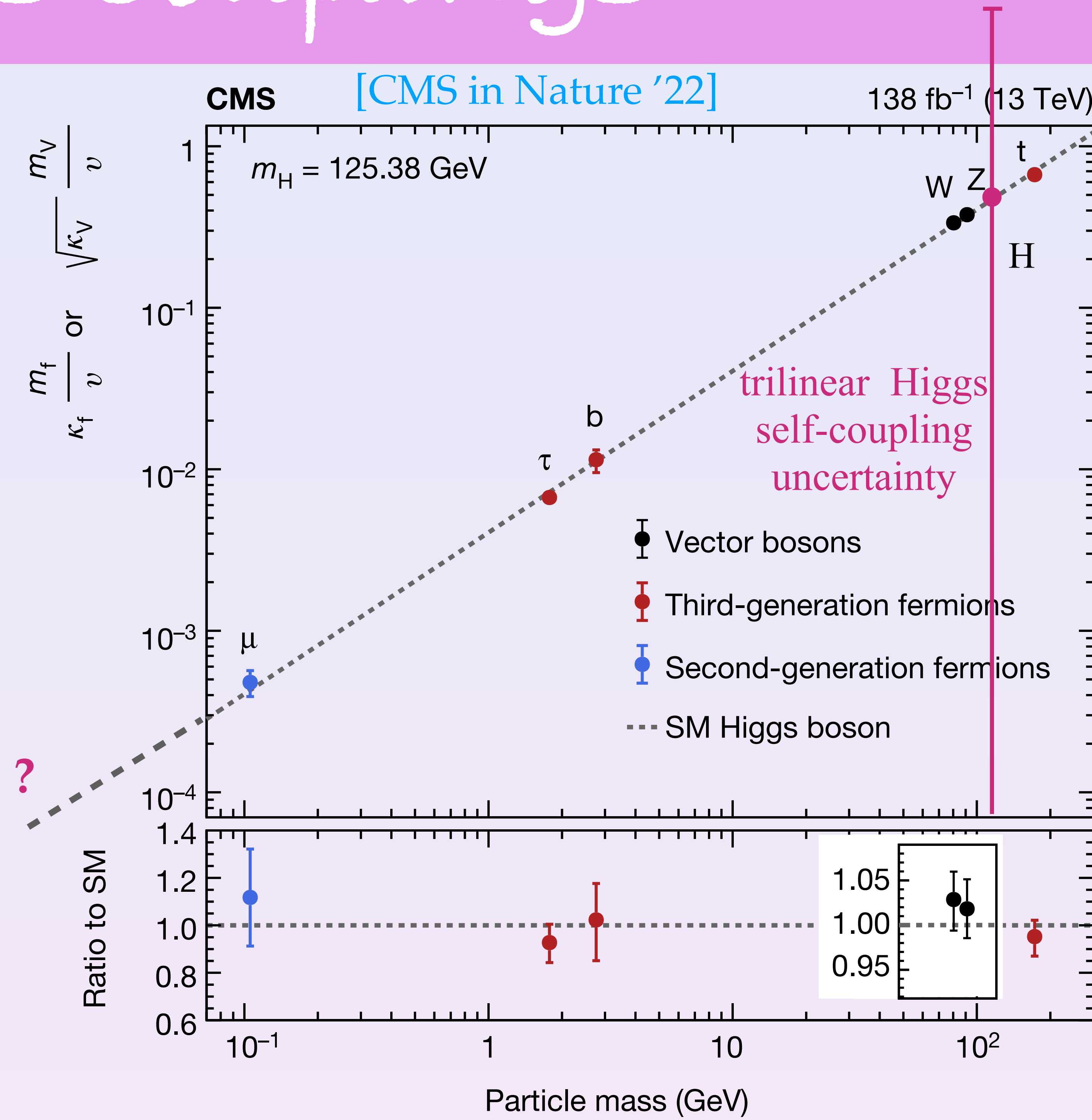
[CMS in Nature '22]



Higgs Couplings

- Higgs couplings to massive vector bosons and third generation fermions measured with amazing precision

- first/(second) generation? Higgs self-couplings?



Higgs self-couplings basically unconstrained

$$-1.7 < \lambda_{hhh}/\lambda_{hhh}^{SM} < 6.6$$ [ATLAS ’25]

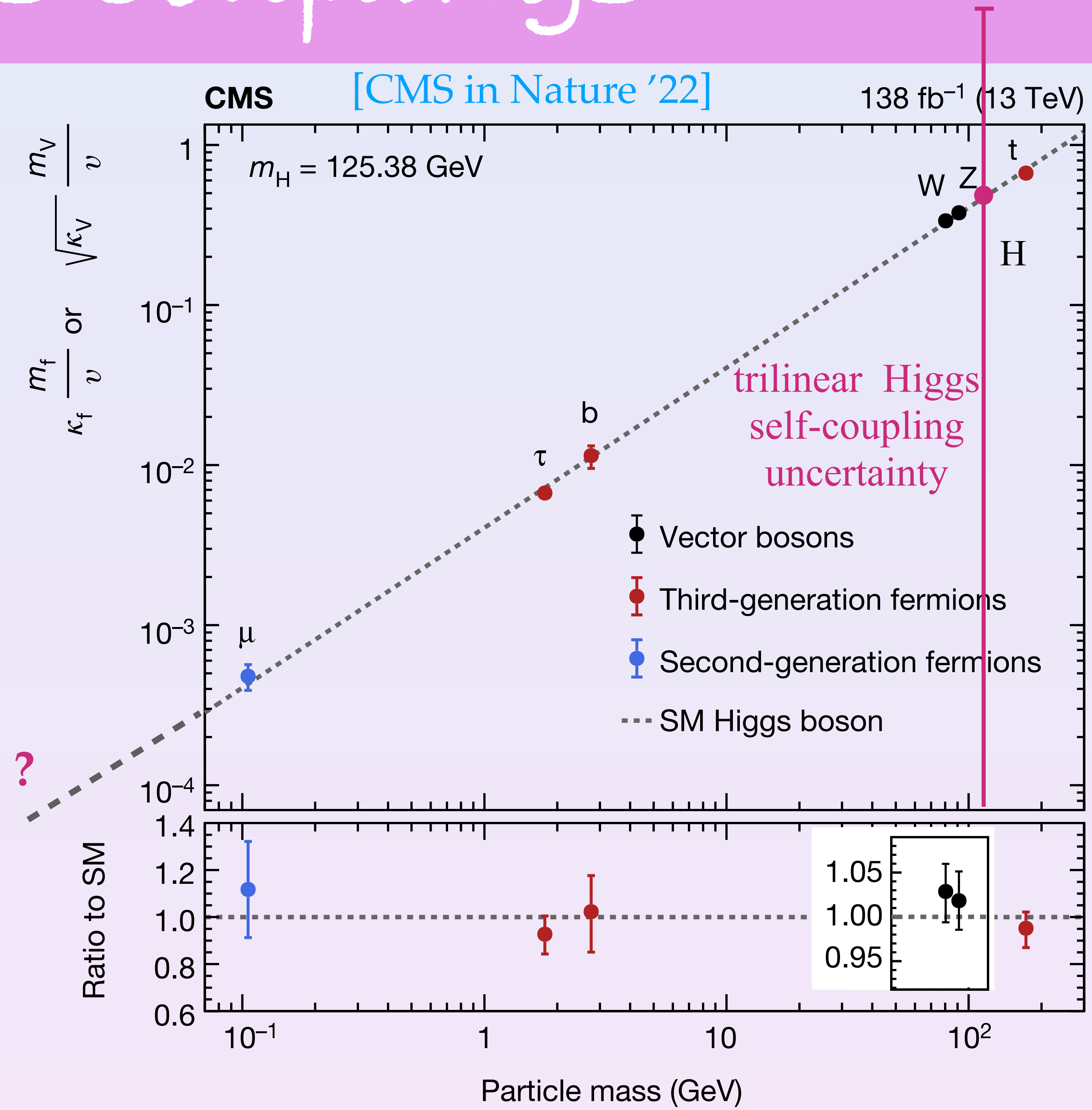
type of coupling never measured
implications for baryogengesis

Higgs Couplings

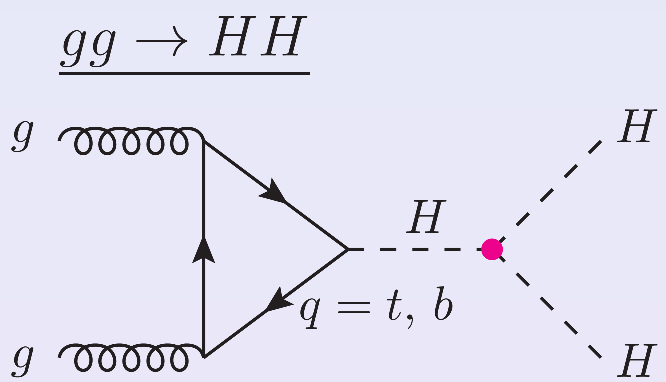
- Higgs couplings to massive vector bosons and third generation fermions measured with amazing precision

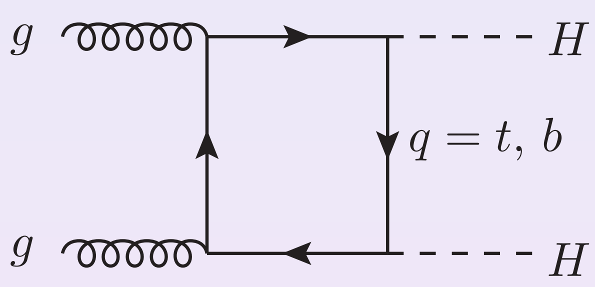
- first/(second) generation? Higgs self-couplings?

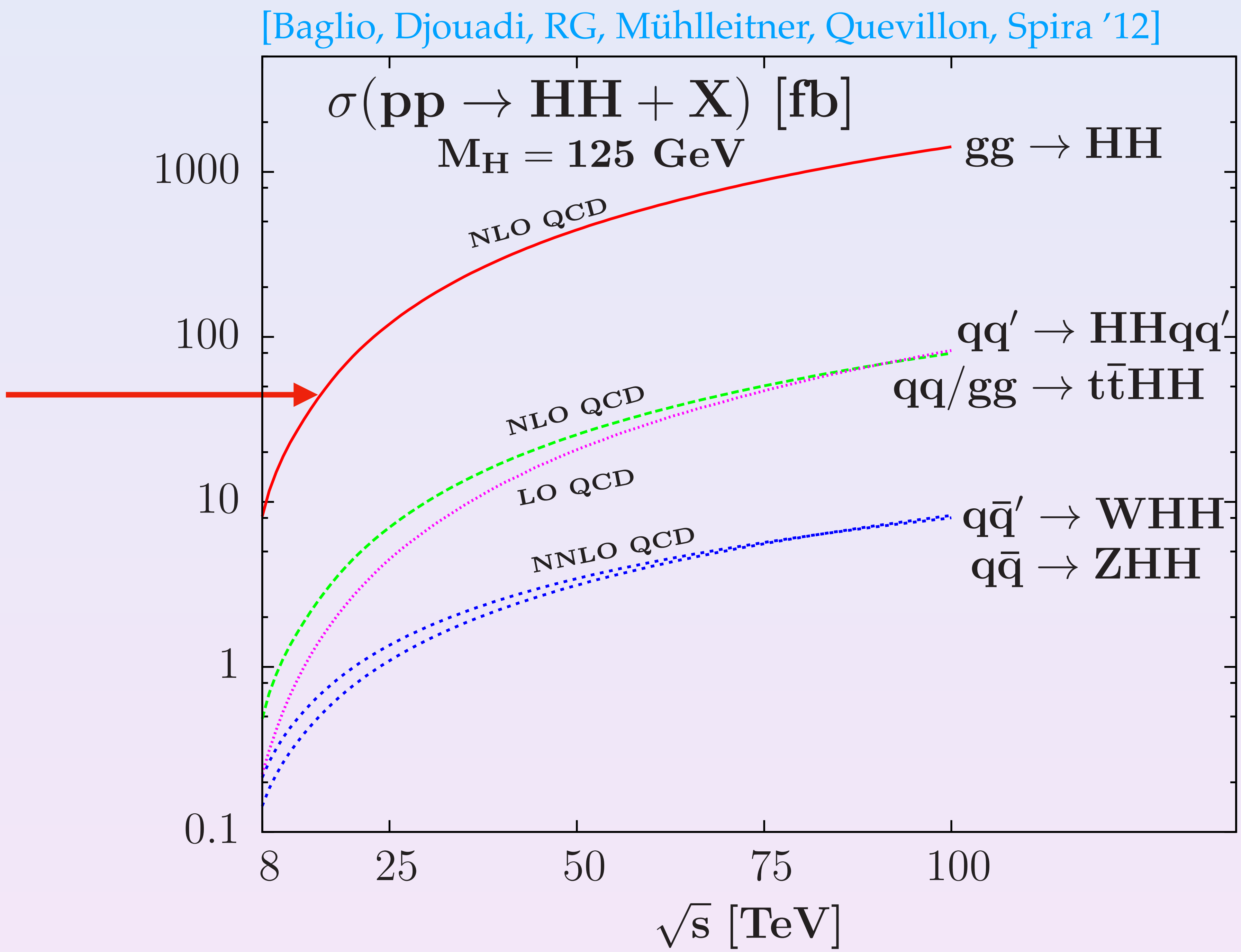
- More generically: Constrain Effective Lagrangian where several operators modify the Higgs interactions



Double Higgs Production





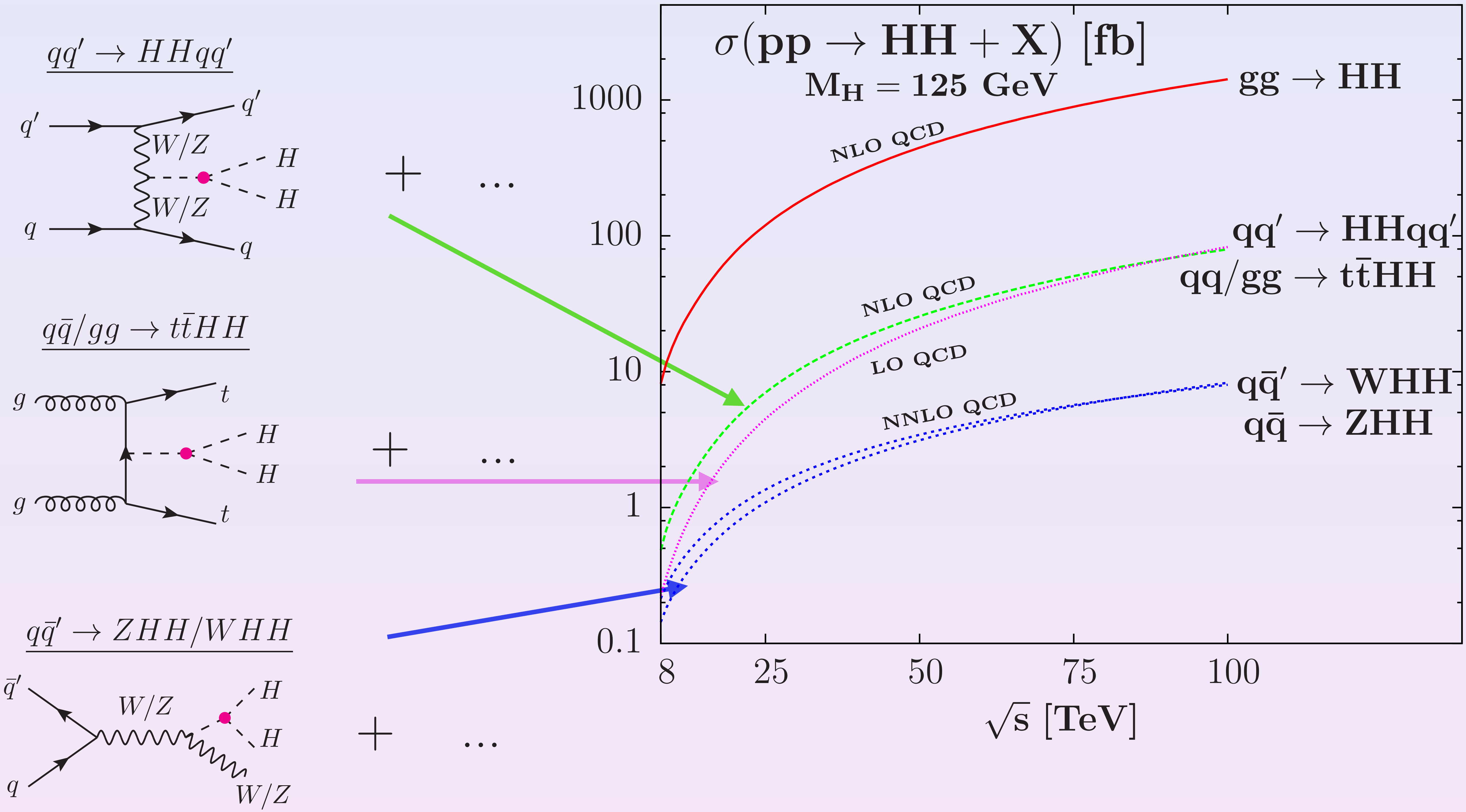


Small cross section

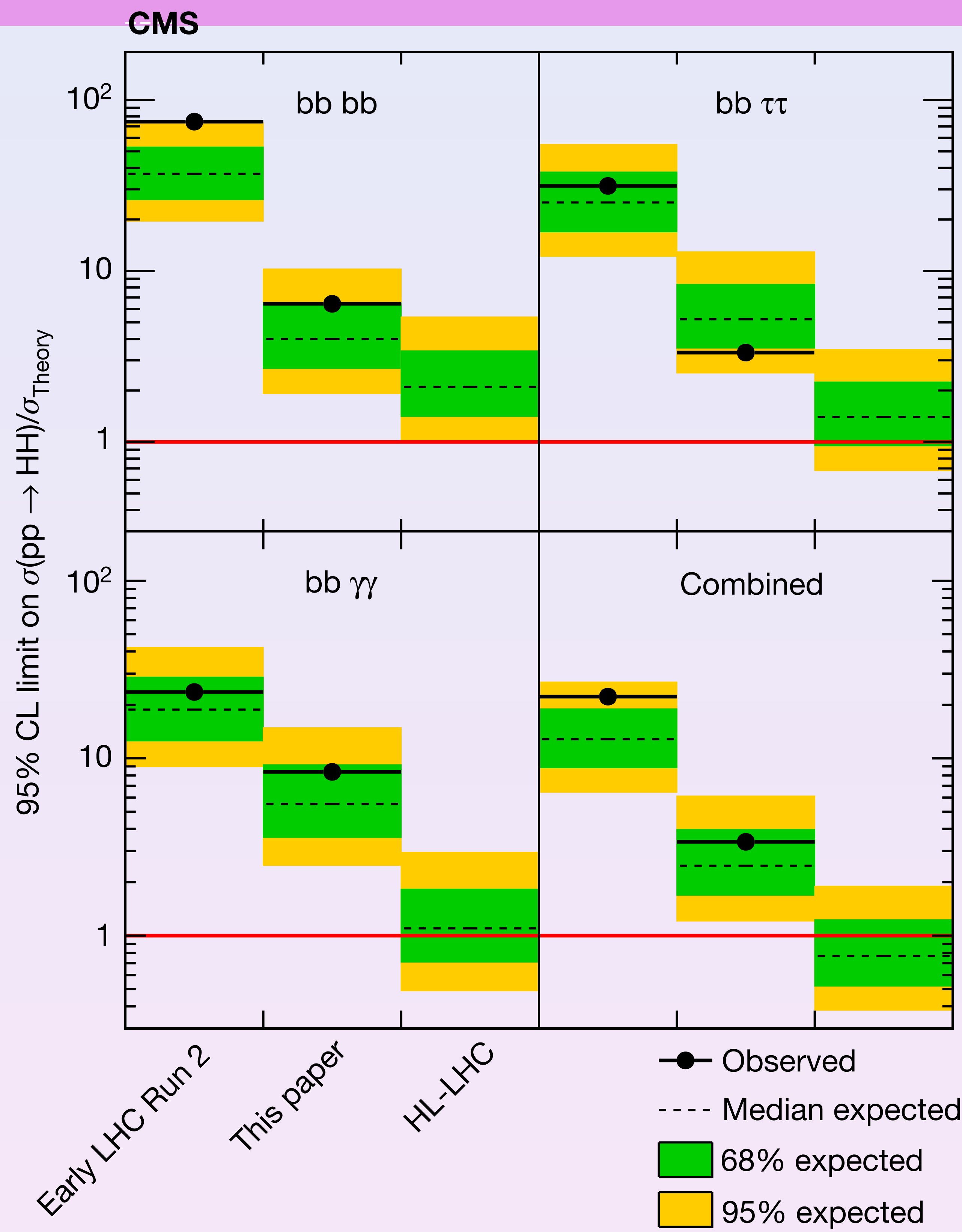
Difficult to measure

Double Higgs Production

[Baglio, Djouadi, RG, Mühlleitner, Quevillon, Spira ’12]

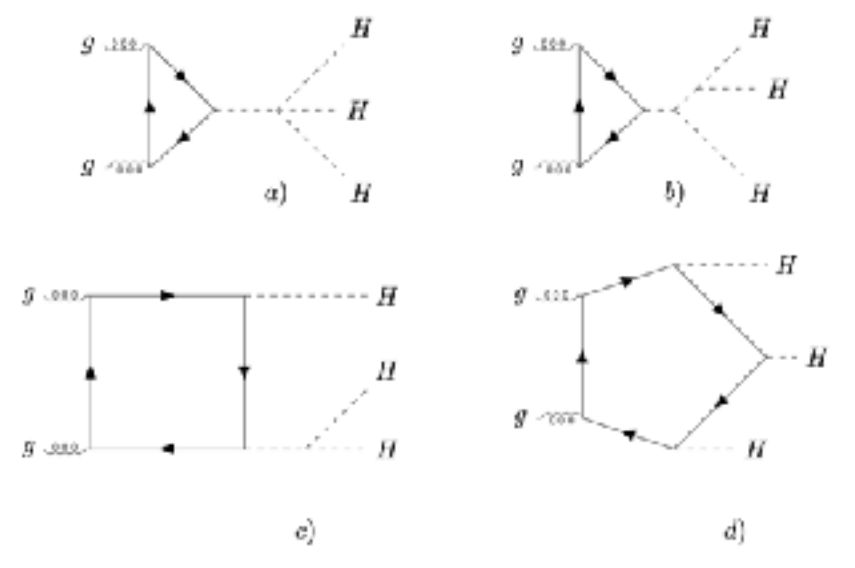


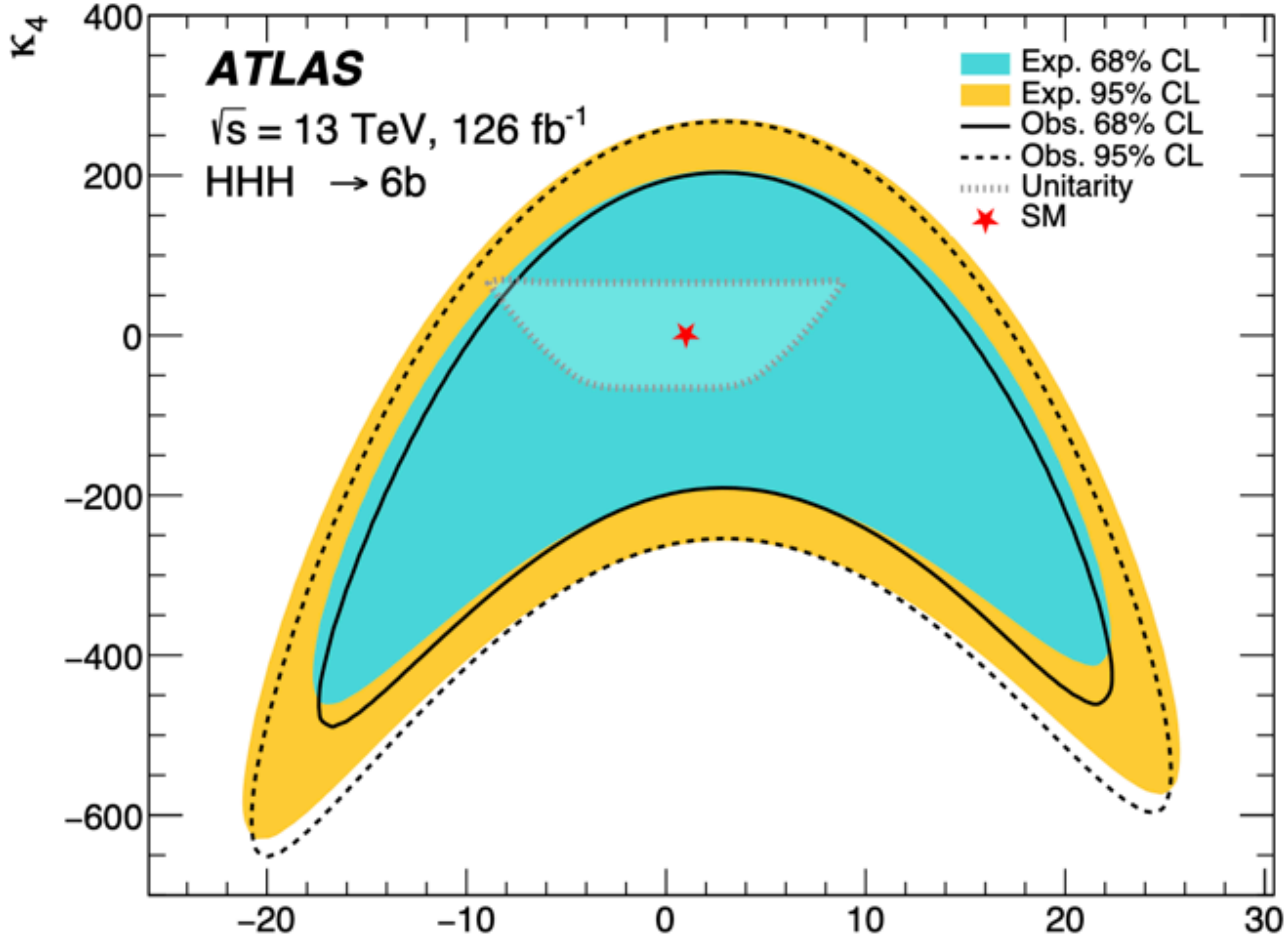
Triple Higgs Production



[CMS Nature ’22]

Triple Higgs Production

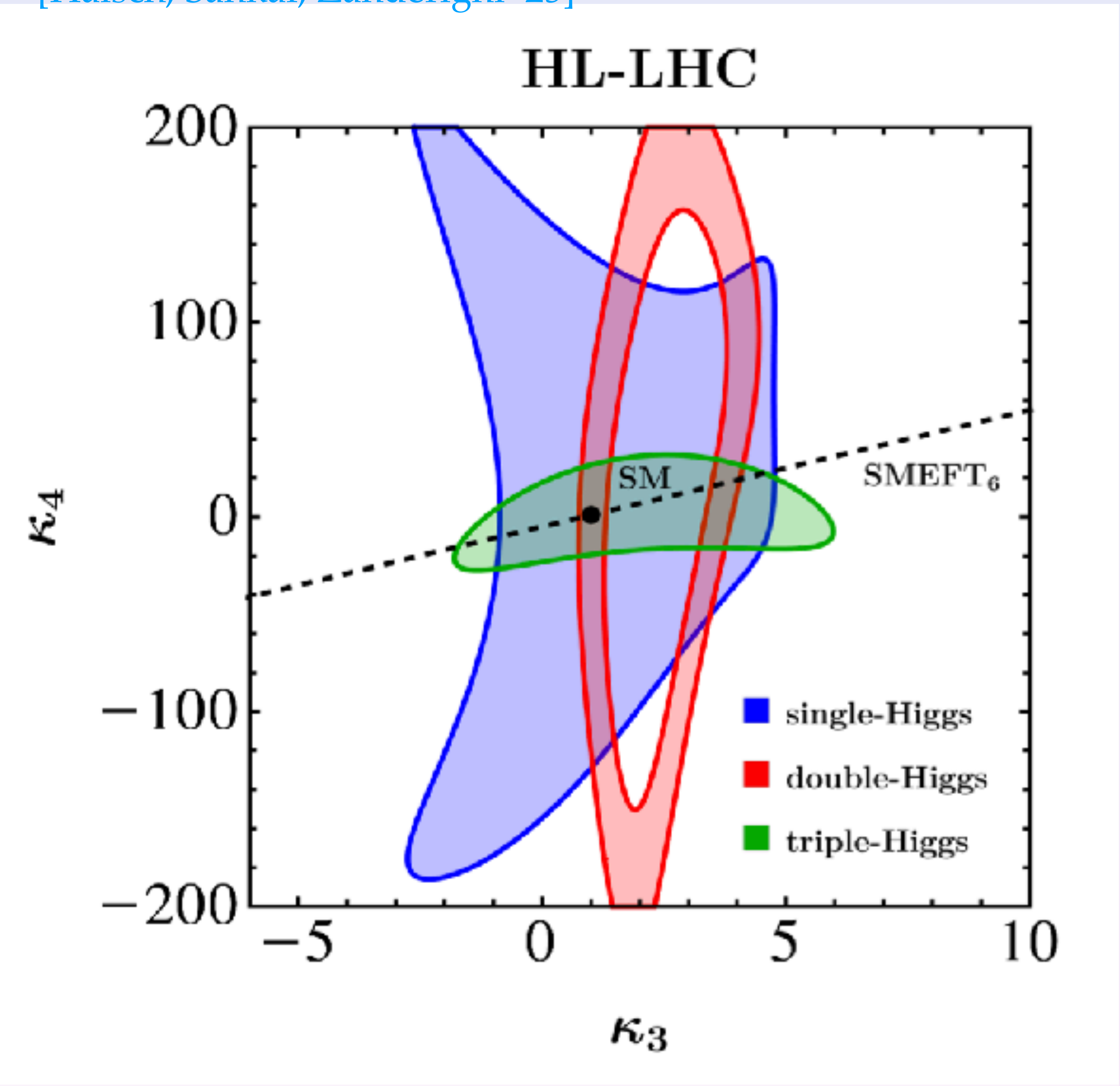




[ATLAS '24]

Complementarity Multi-H Production

[Haisch, Sankar, Zanderighi '25]

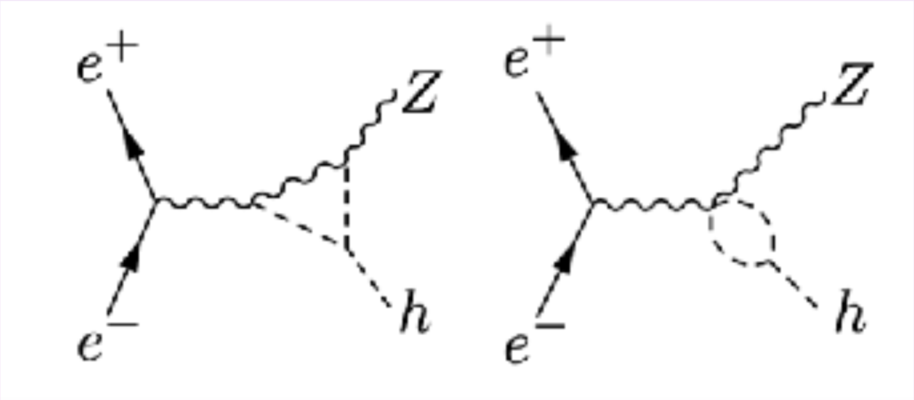


Indirect probes via electroweak corrections

Complementarity between different probes

What do we really learn from triple Higgs production in terms of self-couplings?

at the FCC-ee only indirect probe of κ_3
Sufficient?



Precision in di-Higgs Production

$$\boxed{\sigma_{SM}(13.6\,TeV) = 34.13^{+6\%}_{-23\%}\, fb \pm 2.3\,\%}$$

NNLO QCD $\mathrm{FT}_{\mathrm{approx}}$

[Grazzini et al. ’18]

known up to N^{3}LO in infinite top mass [Chen, Li, Shan, Wang ’19; Ajjath, Shao ‘22]

at NLO QCD in full top mass [numeric: Borowka et al ’16; Baglio et al. ’18; expansions: Bagnaschi, Degrassi, RG ’23; Davies, Schönwald, Steinhauser, Strammer ’25]

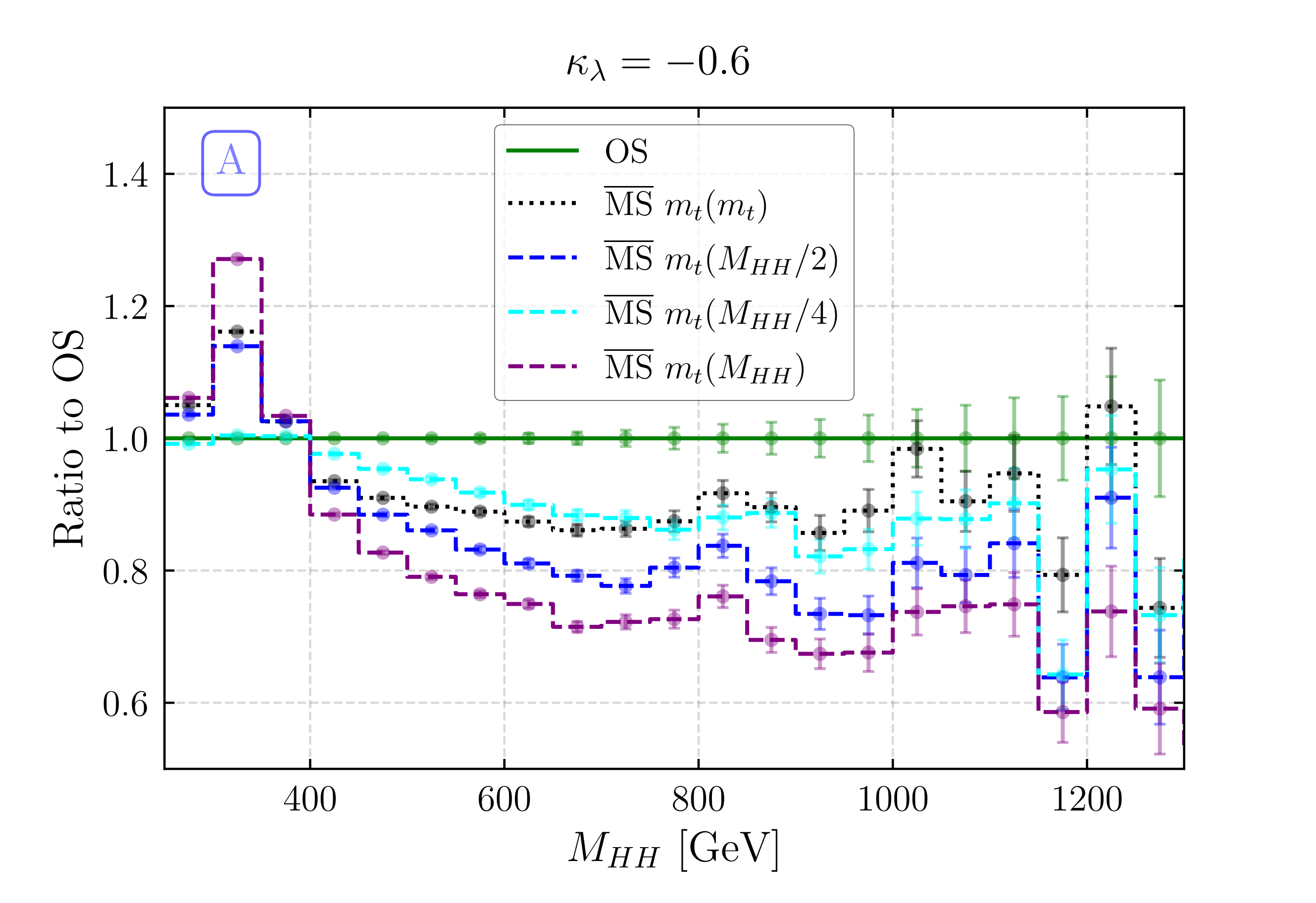
various efforts for the EW corrections [Mühlleitner et al. ’22; Bi et al. ’23 Heinrich et al ’24; Davies et al. ’25, Bonetti et. al. ’25, Baglio et al. ’18]

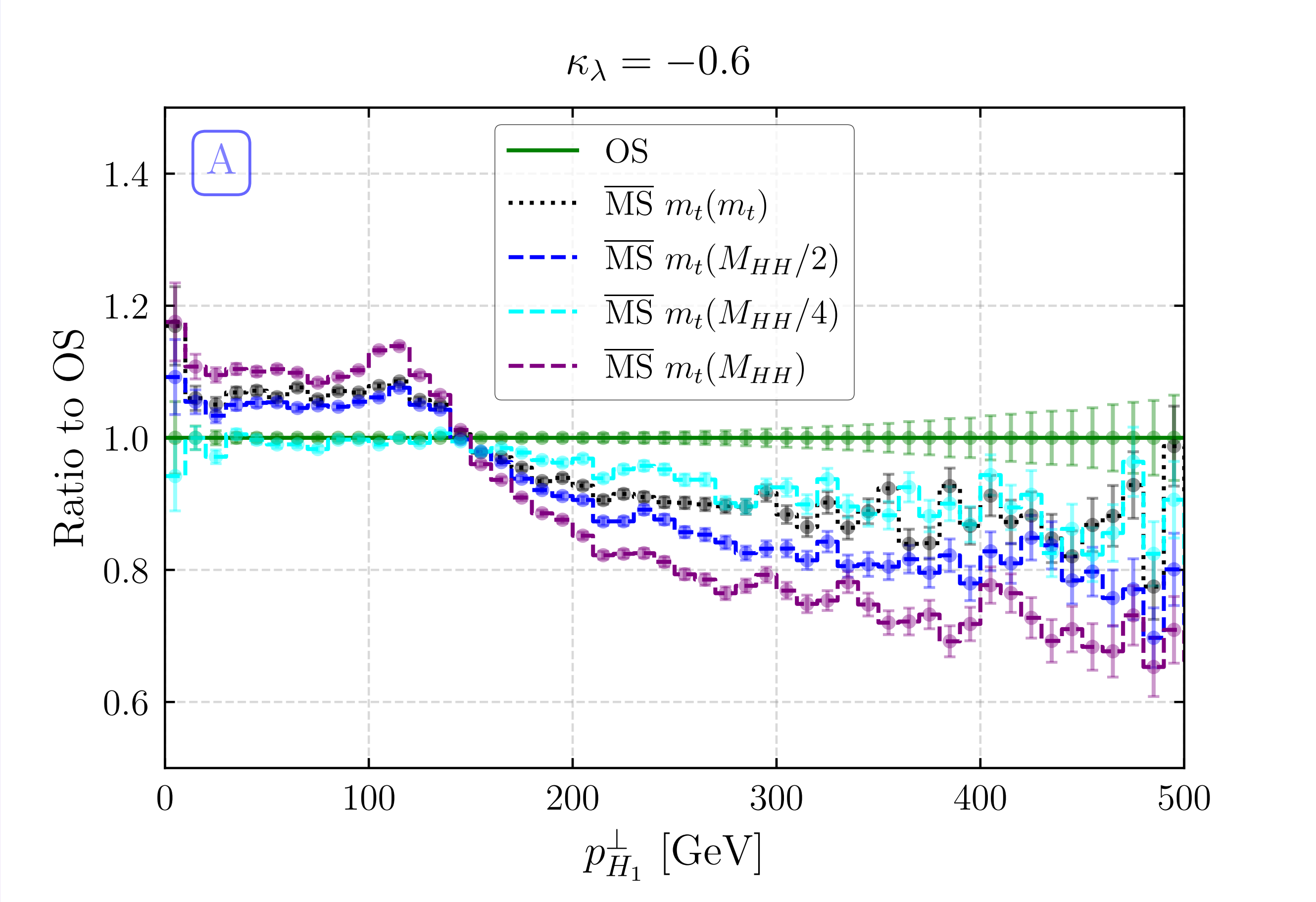
largest uncertainty from choice of top mass scheme [Baglio et al. ’18]

how to diminish theory uncertainties? by HL-LHC halving required

Top mass uncertainty

[Bagnaschi, Degrassi, RG '23]

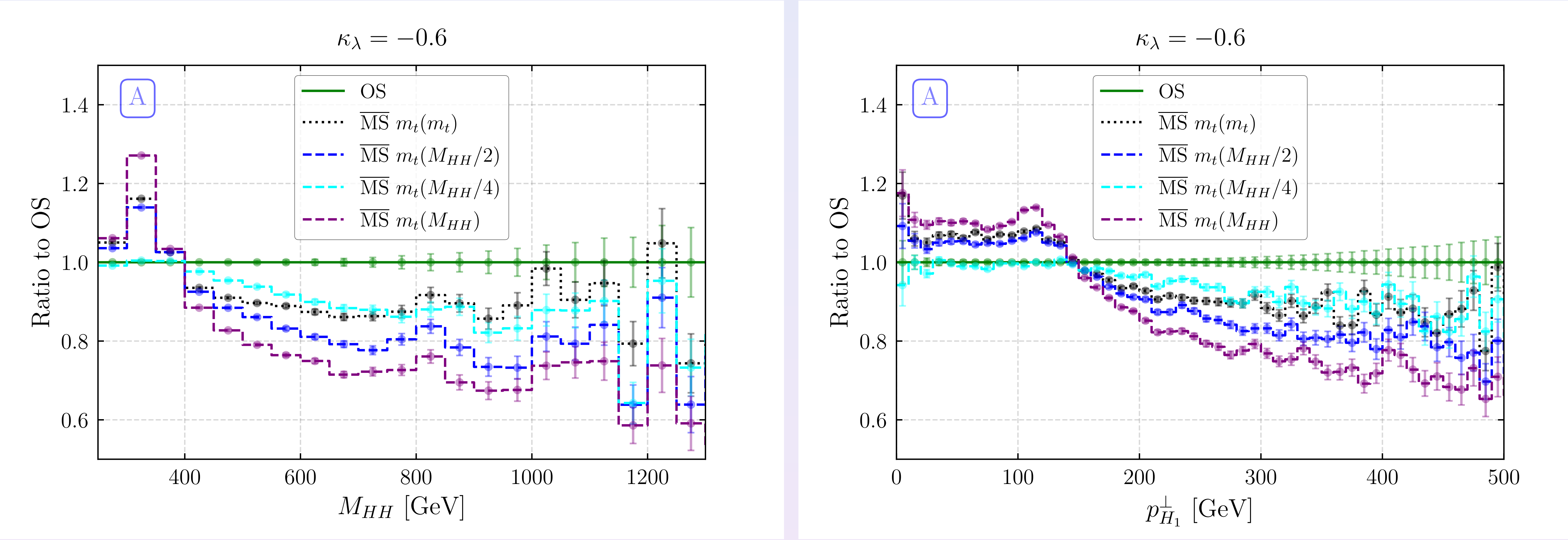




Large Uncertainty due to choice of renormalisation scheme of top quark mass

Top mass uncertainty

[Bagnaschi, Degrassi, RG '23]



Large Uncertainty due to choice of renormalisation scheme of top quark mass

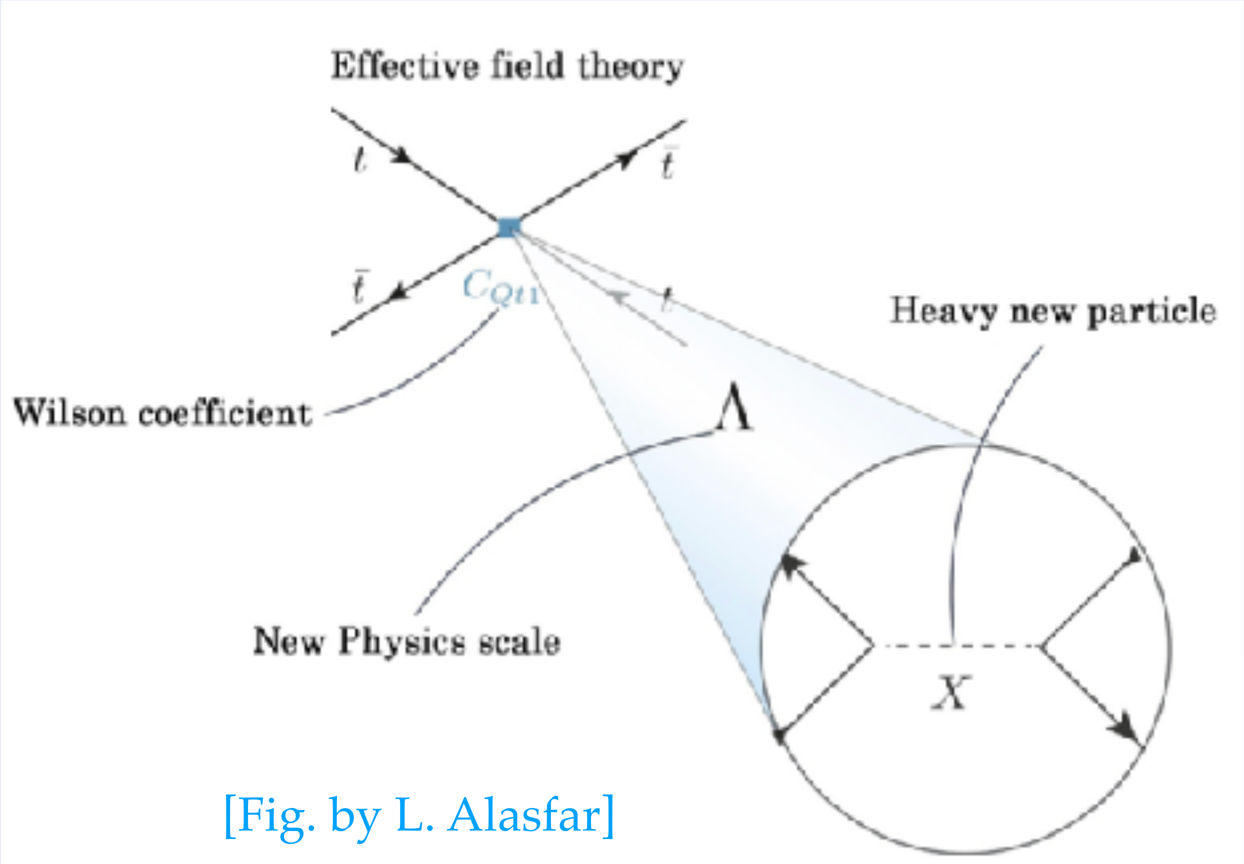
Uncertainty addressed in [Jaskiewicz, Jones, Szafron, Ulrich '25]

in high-energy limit can be understood in SCET $\longrightarrow$

include tower of higher log's in OS definition in HE range to reduce uncertainty

Effective Field Theory

Effective Field Theory



[Fig. by L. Alasfar]

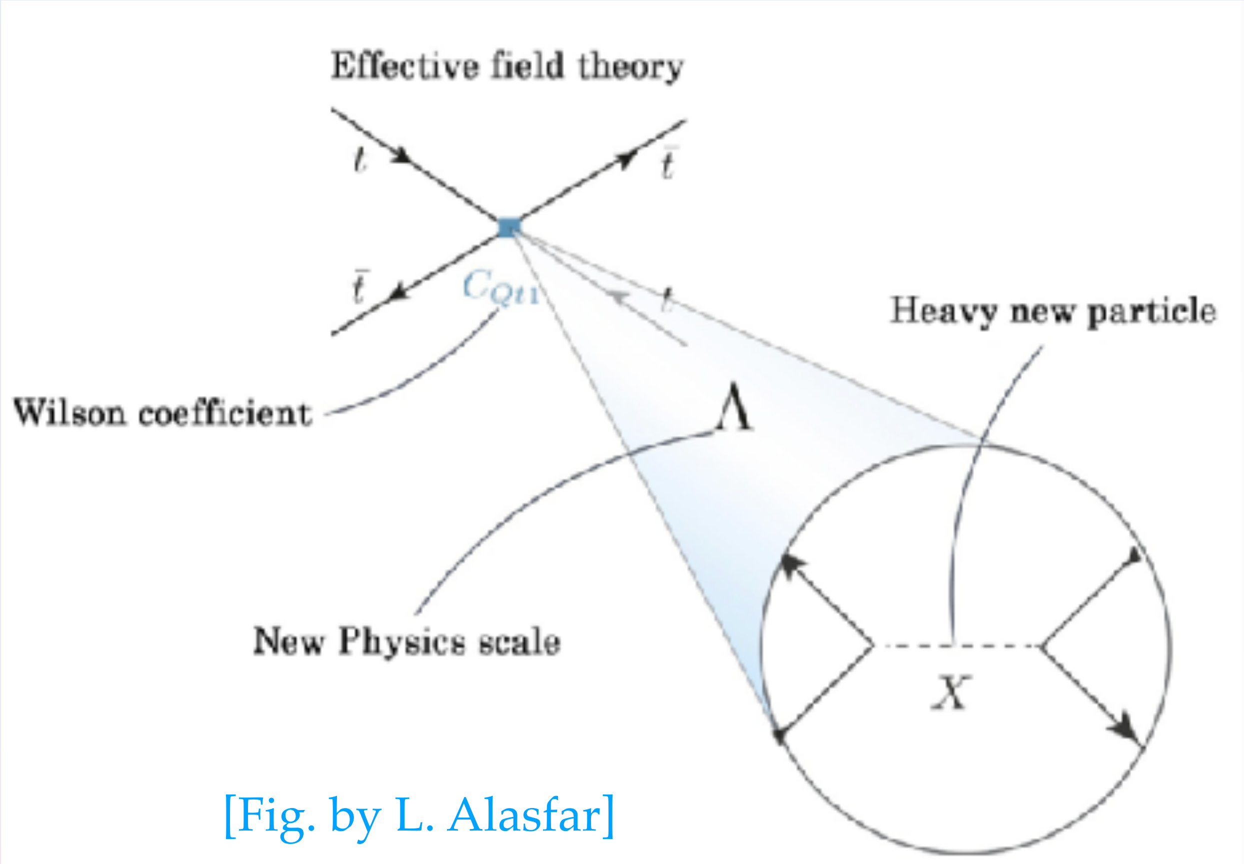
Standard Model Effective Field Theory

$$\mathscr{L} = \mathscr{L}_{SM} + \sum_i \frac{c_{\mathcal{O}}}{\Lambda^i} \mathcal{O}_i$$

for Higgs physics
$i \geq 2$

respects the SM gauge symmetries, all fields transform as in SM

Effective Field Theory



[Fig. by L. Alasfar]

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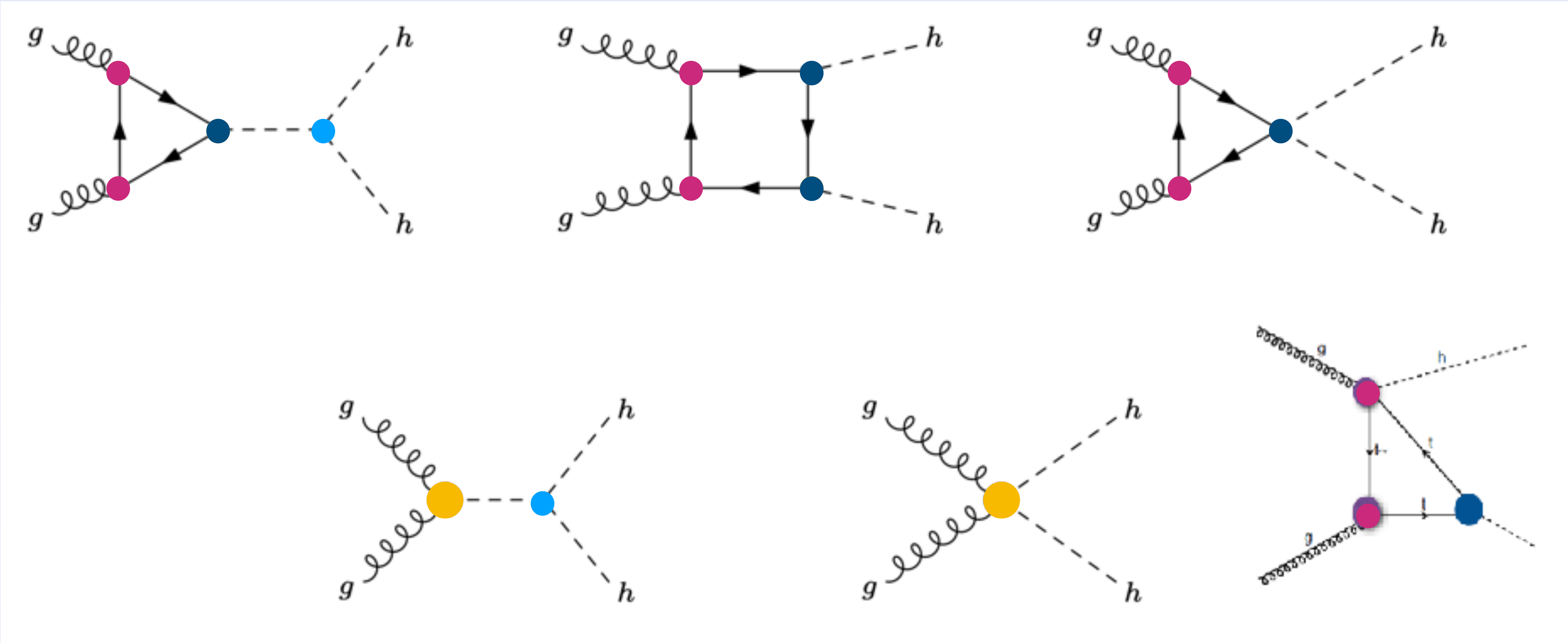
Higgs Effective Field Theory

Goldstone matrix

$$\mathscr{L} = \mathscr{L}_{kin,SM} + V(h) - \frac{v^2}{2}Tr(V_\mu V^\mu)F(h) - \frac{v}{\sqrt{2}}(\bar{F}_L U Y_F(h) F_R + h.c.)$$

polynomial in the physical Higgs field, i.e. $F(h) = a\frac{h}{v} + b\frac{h^2}{v^2} + ..$

SMEFT in HH



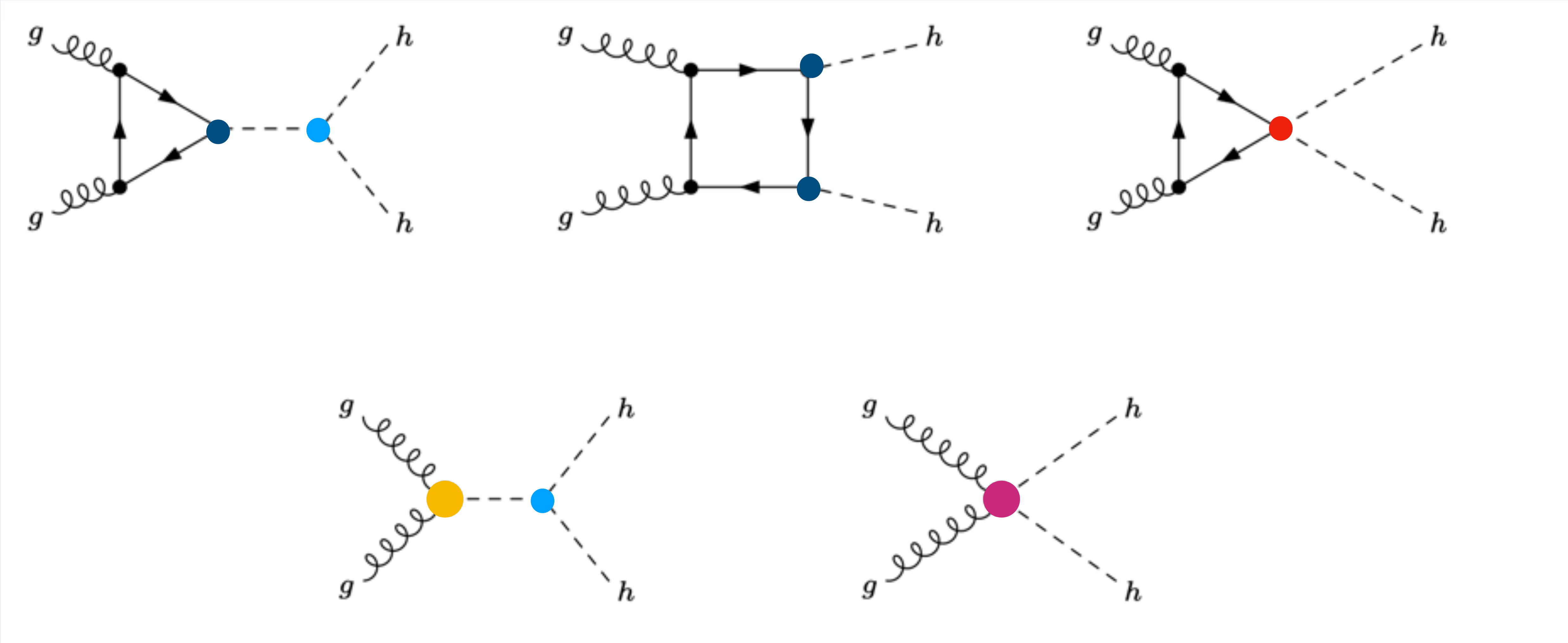
SMEFT:

$$\mathscr{L} = C_{H,\Box}(H^\dagger H)\Box(H^\dagger H) + C_{HD}D_\mu(H^\dagger H)D^\mu(H^\dagger H)^* + C_H|H|^6 + C_{HG}|H|^2 G_{\mu\nu}G^{\mu\nu} + C_{uH}\bar{Q}_L\tilde{H}t_R|H|^2 + h.c. + C_{uG}\bar{Q}_L\sigma_{\mu\nu}T^a\tilde{H}t_R G^a_{\mu\nu} + h.c.$$

Warsaw basis

coefficients of $\mathcal{O}(1/\Lambda^2)$

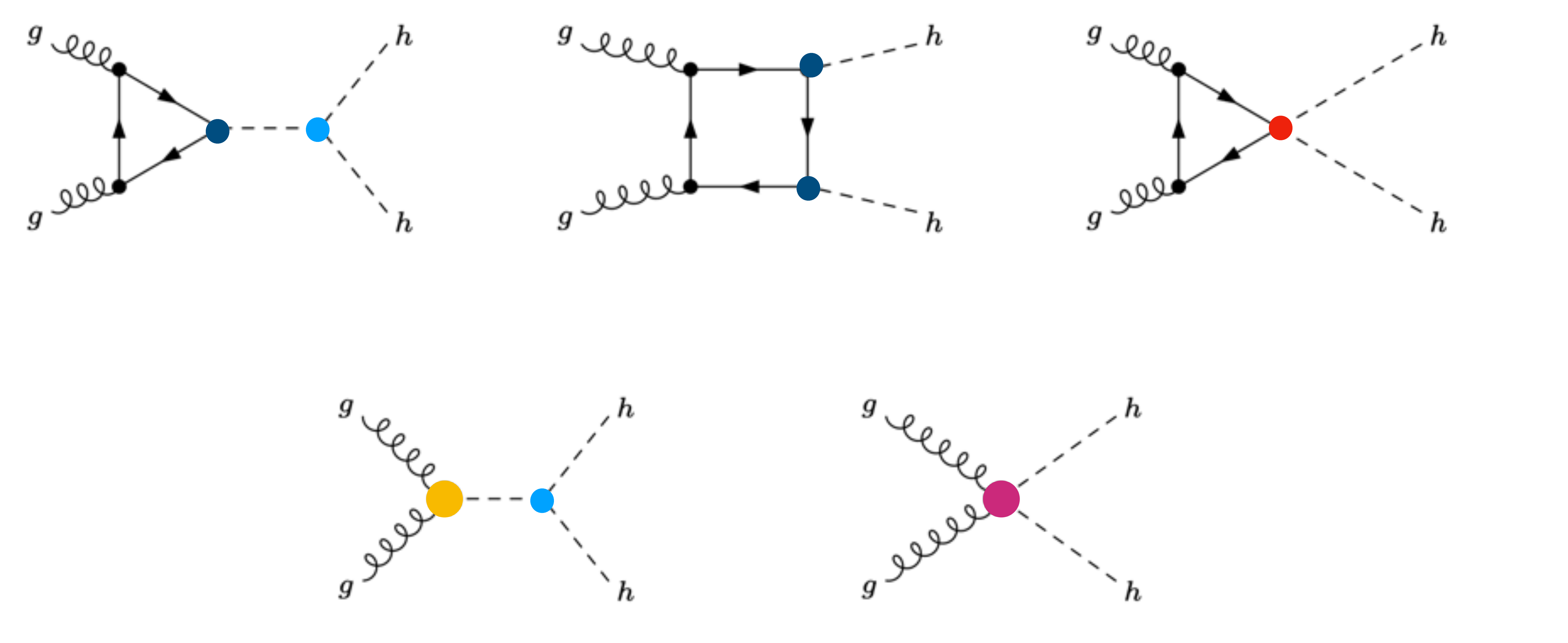
Effective Theory for HH



HEFT:

$$\mathscr{L} = -m_t \bar{t} t \left(c_t \frac{h}{v} + c_{tt} \frac{h^2}{v^2} \right) + \frac{\alpha_s}{8\pi} \left(c_g \frac{h}{v} + c_{gg} \frac{h^2}{v^2} \right) G^{\mu\nu} G_{\mu\nu} + c_{hhh} \frac{m_h^2}{2v} h^3$$

Effective Theory for HH

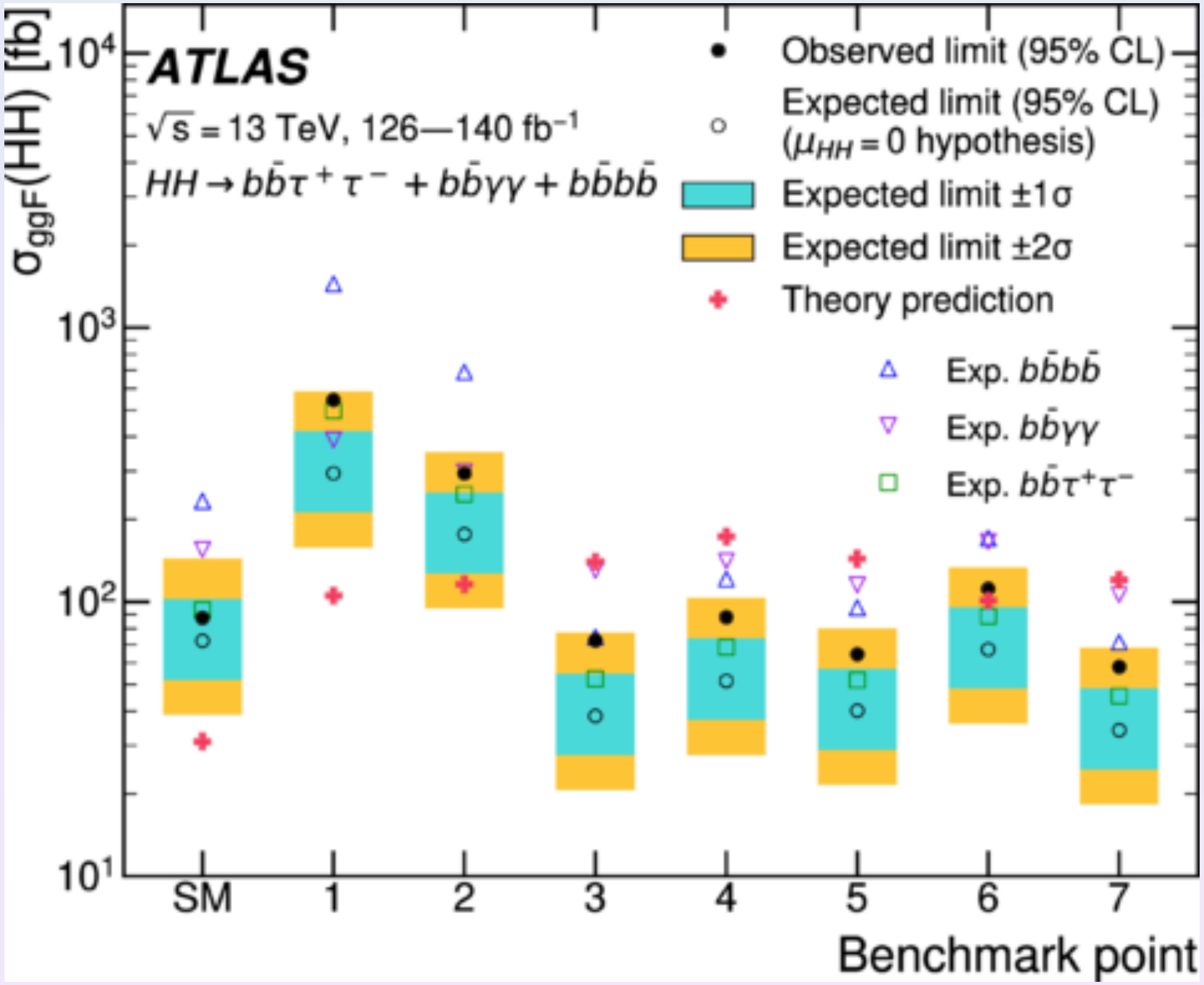


HEFT:

two Higgs couplings only to be probed in HH

$$\mathcal{L} = -m_t \bar{t} t \left(c_t \frac{h}{v} + c_{tt} \frac{h^2}{v^2} \right) + \frac{\alpha_s}{8\pi} \left(c_g \frac{h}{v} + c_{gg} \frac{h^2}{v^2} \right) G^{\mu\nu} G_{\mu\nu} + c_{hhh} \frac{m_h^2}{2v} h^3$$

EFT searches in HH

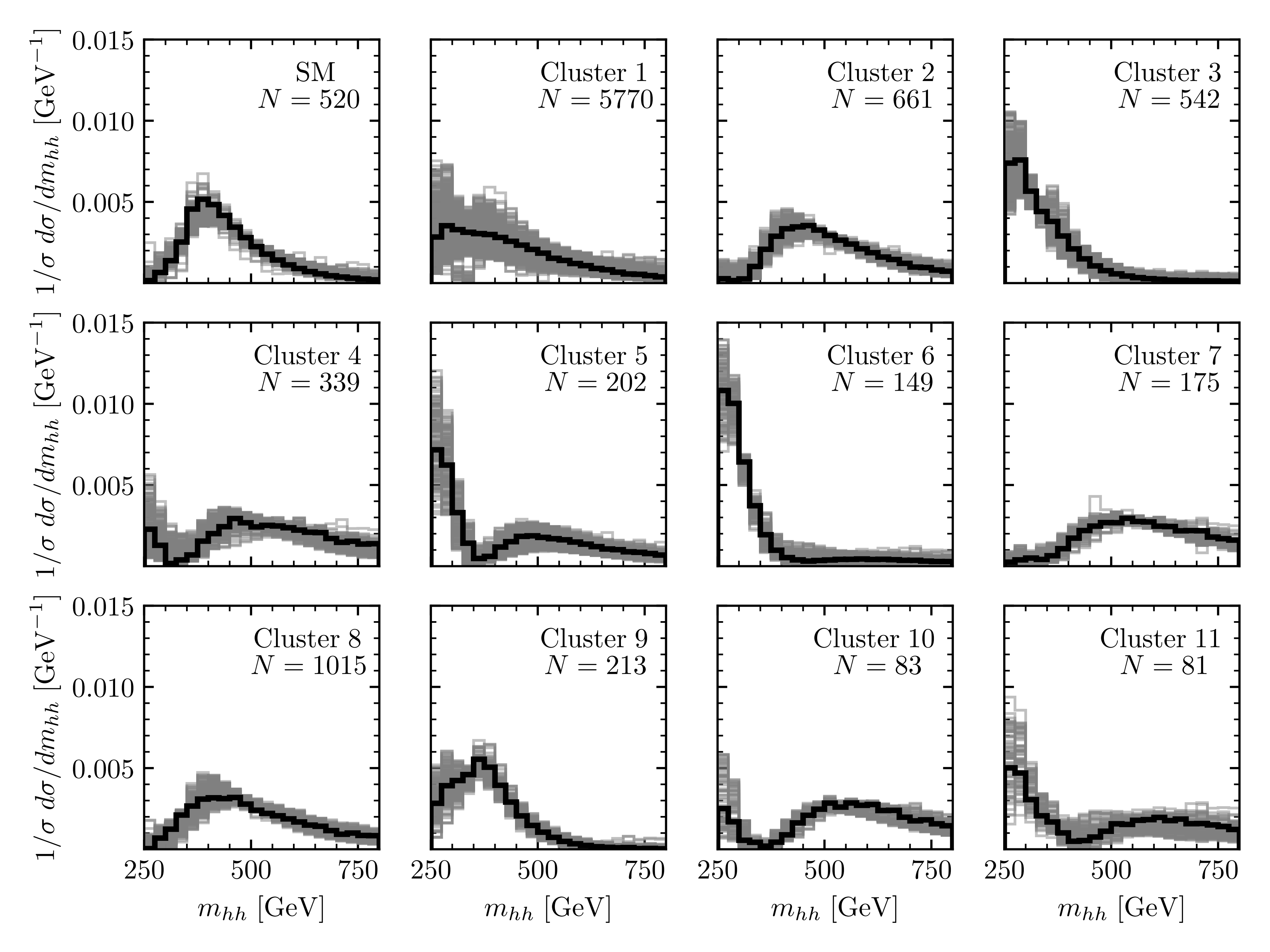


[ATLAS Collaboration '24]

Non-resonant di-Higgs EFT searches are built on kinematic benchmark scenarios to account for EFT modifications of m_{hh} shapes

[Carvalho et al. '15; Capozzi, Heinrich '19; Alasfar et al. '23]

Kinematic Benchmarks



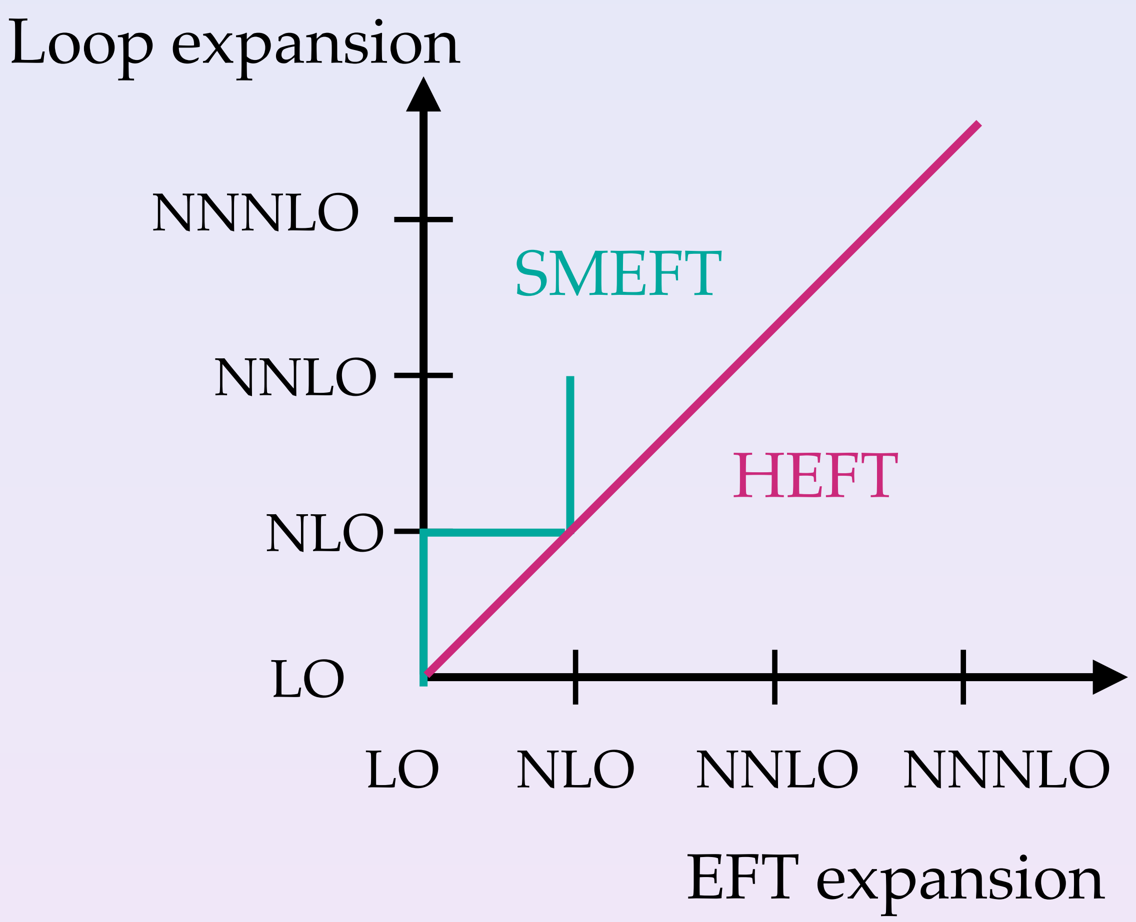
[Brivio, RG, Schmid
'in preparation]

Heft LO Lagrangian

HEFT in HH

Powercounting

[Brivio, RG, Schmid 'in preparation]



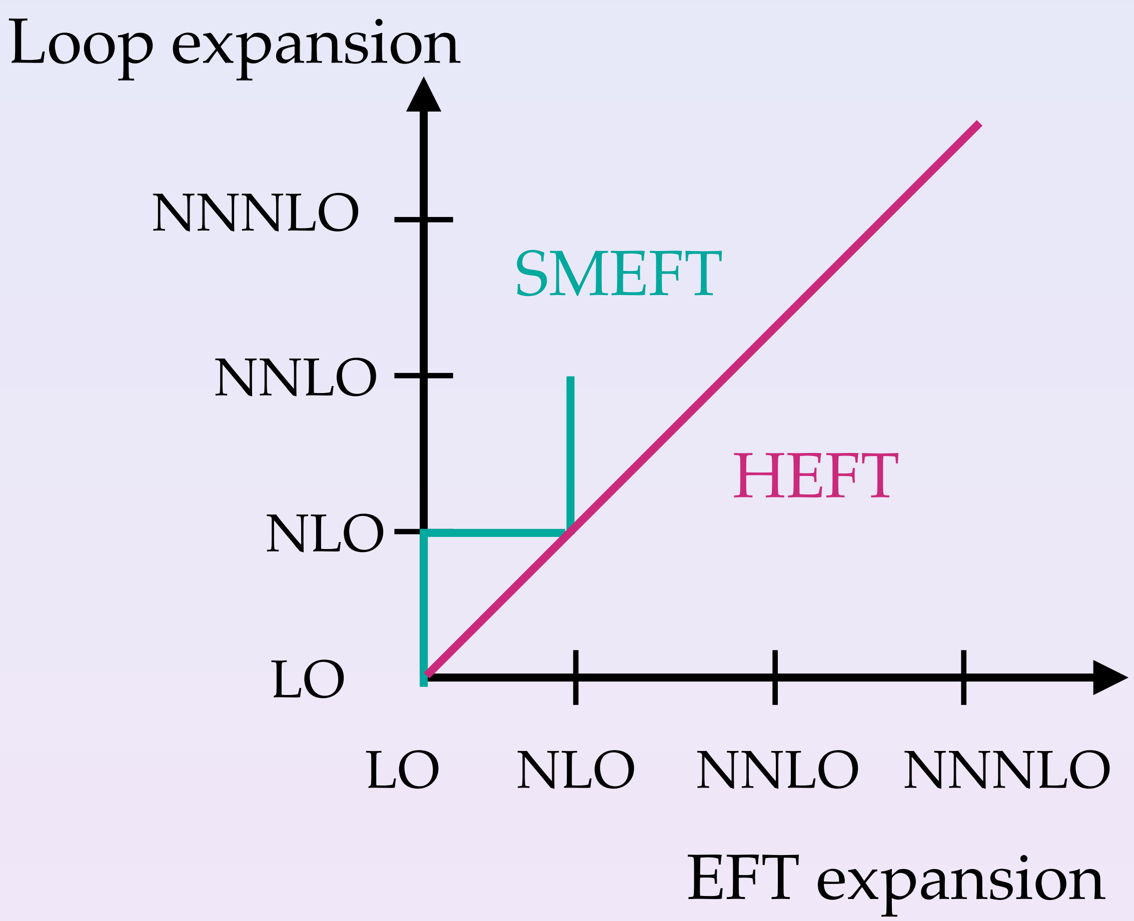
SMEFT power counting keeps EFT expansion independent of loop expansion

HEFT power counting counts loops, so one is constrained on the diagonal

HEFT in HH

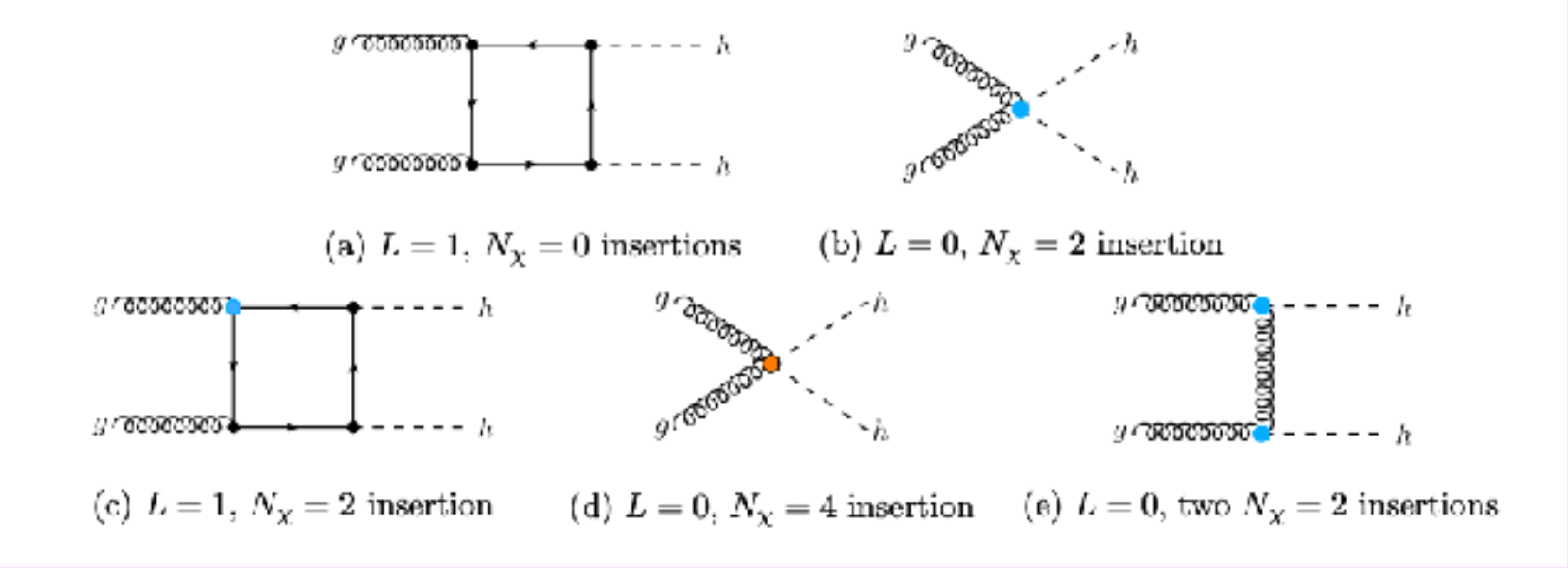
Powercounting

[Brivio, RG, Schmid 'in preparation]



SMEFT power counting keeps EFT expansion independent of loop expansion

HEFT power counting counts loops, so one is constrained on the diagonal (QCD expansion can also be kept separately)



(a) $L = 1$, $N_\chi = 0$ insertions (b) $L = 0$, $N_\chi = 2$ insertion

(c) $L = 1$, $N_\chi = 2$ insertion (d) $L = 0$, $N_\chi = 4$ insertion (e) $L = 0$, two $N_\chi = 2$ insertions

HEFT in HH

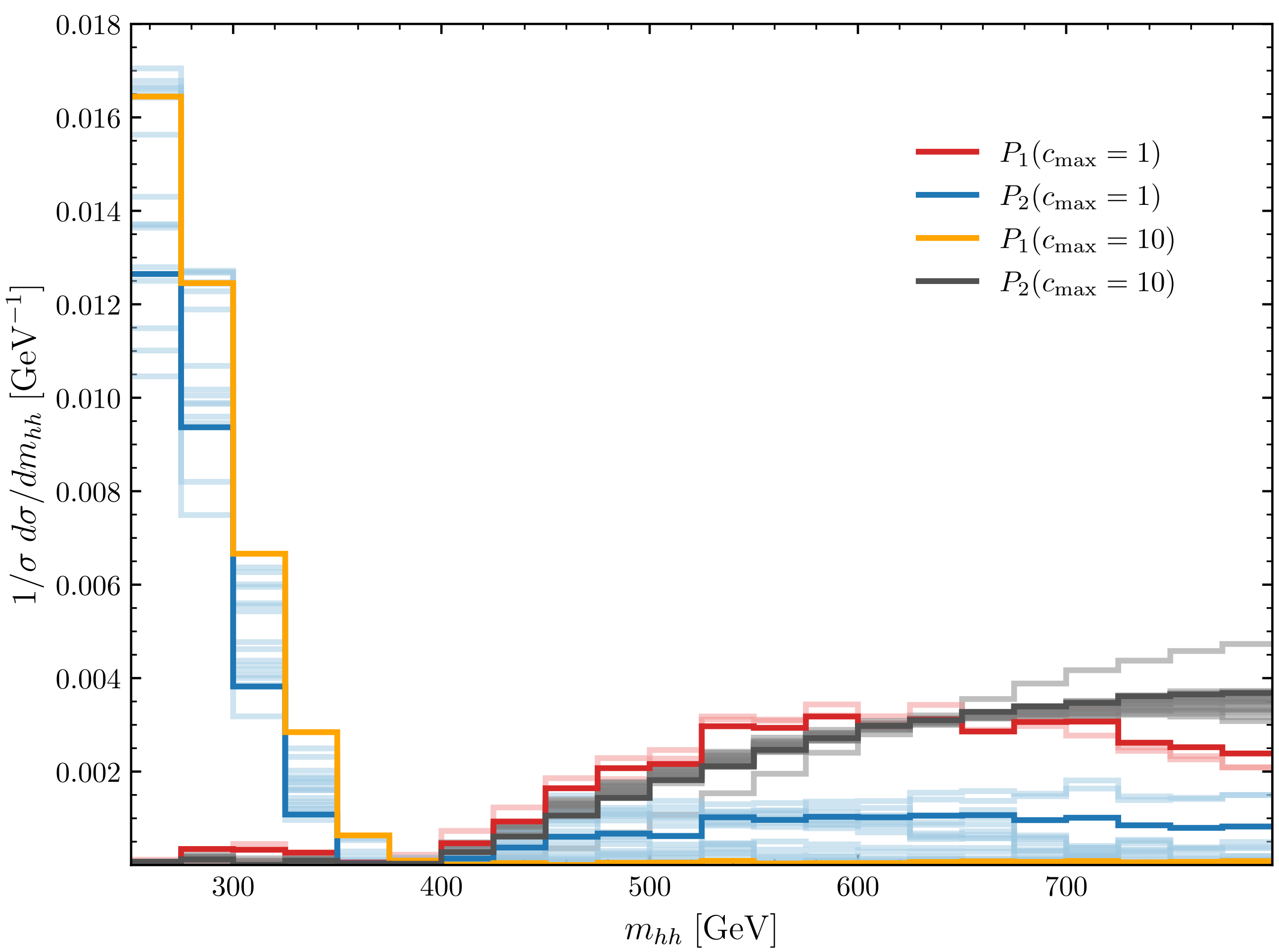
[Brivio, RG, Schmid 'in prep]

$$\mathcal{L}_{\text{HEFT}} \supset \mathcal{L}_\kappa + \delta\mathcal{L}$$

$$\mathcal{L}_\kappa = \frac{1}{2}(\partial_\mu h)^2 - \frac{1}{2}m_h^2 h^2 - a_{\lambda^3}\lambda v h^3 - \frac{1}{4}G^a_{\mu\nu}G^{a\mu\nu} + i\bar{t}\not{D}t - \frac{y_t v}{\sqrt{2}}\left(a_t\frac{h}{v} + b_t\frac{h^2}{v^2}\right)\bar{t}t + \frac{g_s^2}{16\pi^2}G^a_{\mu\nu}G^{a\mu\nu}\left(a_g\frac{h}{v} + b_g\frac{h^2}{v^2}\right)$$

$$\delta\mathcal{L} = \frac{y_t b_D}{4\pi\Lambda}\frac{1}{v^2}(\partial_\mu h)^2\bar{t}t + \frac{g_s y_t}{4\pi\Lambda}\left(\bar{t}_L\sigma^{\mu\nu}G^a_{\mu\nu}T^a t_R + \text{h.c.}\right)\left(d_c + a_c\frac{h}{v} + b_c\frac{h^2}{v^2}\right) + \frac{g_s^2 b_g^{(1)}}{16\pi^2\Lambda^2}\frac{h^2}{v^2}(D^\mu G^{a\nu\lambda})(D_\mu G^a_{\nu\lambda}) + \frac{g_s^2 b_g^{(2)}}{16\pi^2\Lambda^2}\frac{h}{v}G^{a\lambda\nu}G^{a\mu}_{\lambda}\frac{1}{v}(\partial_\mu\partial_\nu h).$$

Loop and higher orders in N_χ in operators can arise at same order



Consider up to $N_{HEFT}^{s,\mathscr{M}} = 6$

Kinematic distributions beyond the ones in [Carvalho et al. '15; Capozzi, Heinrich '19] possible

HEFT in HH: Cluster analysis

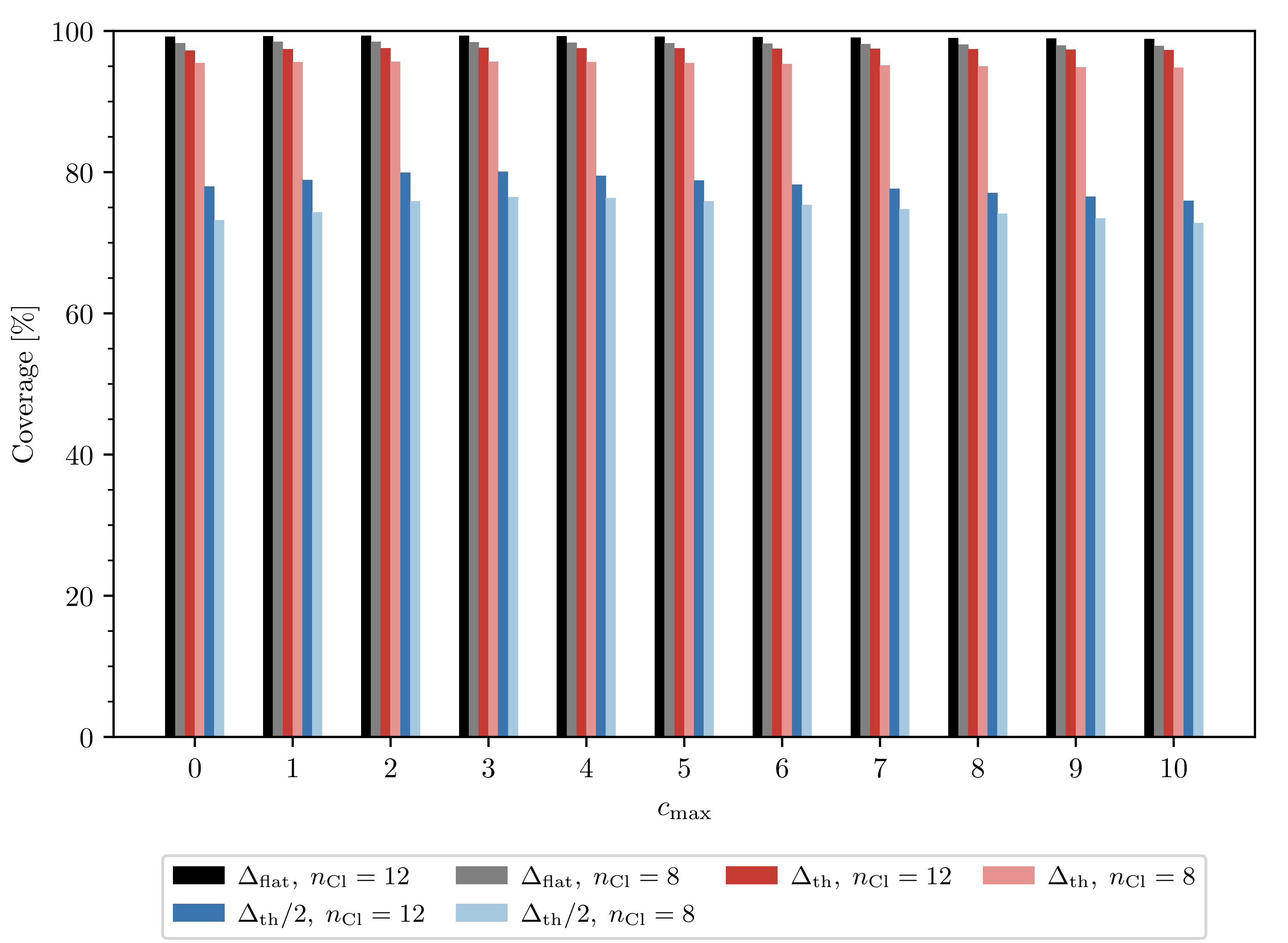
Re-do a cluster analysis, use chi2-test

$$\chi^2(P_1, P_2) = \sum_{i \in bins} \frac{(D_{1,i} - D_{2,i})^2}{\Delta_i^2 (D_{i,1}^2 + D_{i,2}^2)}$$

Two points in parameter space follow the same kinematic benchmark if

$$\chi^2(P_1, P_2) < \chi^2_{thres}$$

[Brivio, RG, Schmid 'in prep]



Better ideas? Disentangle EFT effects?

Can other production modes help?

Amplitudes

[RG, Rossia, Ryczkowski '25]

We can even be more general using amplitude techniques

Idea: Check with amplitudes where HEFT and SMEFT depart, in a processes that can test differences

Multi-Higgs production

Amplitudes

[RG, Rossia, Ryczkowski '25]

We can even be more general using amplitude techniques

Idea: Check with amplitudes where HEFT and SMEFT depart, in a processes that can test differences

Multi-Higgs production

? Is SMEFT falsifiable (in multi-Higgs production)? ?

[Gomez-Ambrosio, Llanes-Estrada, Salas-Bernárdez, Sanz-Cillero '22]

Concentrate for the time being on gluon - Higgs interactions

OnShell Amplitudes

Lorentz invariance

Global symmetries

Locality

Helicity and little group scaling

Physical degrees of freedom

bootstrap

Simple scattering amplitudes

Emergence of gauge symmetries

bottom-up approach to EFTs without field redefinition ambiguities

[Shadmi, Weiss '18; Durieux et al. '19, Huber, De Angelis '21, …]

OnShell Amplitudes

Lorentz invariance

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Physical degrees of freedom

bootstrap $\longrightarrow$

Simple scattering amplitudes

Emergence of gauge symmetries

bottom-up approach to EFTs without field redefinition ambiguities

[Shadmi, Weiss '18; Durieux et al. '19, Huber, De Angelis '21, …]

Building blocks (based on spinor-helicity formalism) are

[Elvang, Huang '13, Arkani-Hamed et al '17]

Momenta: $p_{\alpha\dot\alpha} \equiv p_\mu \sigma^\mu_{\alpha\dot\alpha} \equiv |p\rangle_\alpha [p|_{\dot\alpha}\,, \quad \bar p^{\dot\alpha\alpha} \equiv p_\mu \bar\sigma^{\mu\,\dot\alpha\alpha} \equiv |p]^{\dot\alpha} \langle p|^\alpha\,,$

Spinors: $u_+(p) = |p], \quad u_-(p) = |p\rangle\,,$ $\bar u_+(p) = [p|, \quad \bar u_-(p) = \langle p|\,,$

Polarisation vectors: $\epsilon^\mu_+(p) == \frac{1}{\sqrt{2}}\frac{\langle \xi|\sigma^\mu|p]}{\langle p|\xi\rangle}\,,$ $\epsilon^\mu_-(p) = \frac{1}{\sqrt{2}}\frac{\langle p|\sigma^\mu|\xi]}{[p|\xi]}\,,$

OnShell MultiHiggs

Strategy:

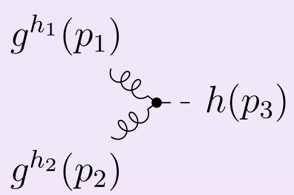
Build non-factorisable and factorisable on shell amplitudes multiplied by kinematic invariants, check if and how they arise in SMEFT and HEFT

Double Higgs

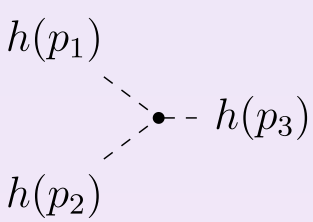
Non-Factorisable

$$\begin{aligned}\mathcal{M}\left(g^{a,+}(p_1);g^{b,+}(p_2);h(p_3);h(p_4)\right)_{\rm NF} &= i\,\delta^{ab}c^{++}_{gghh}\;[1|2]^2\,,\\ \mathcal{M}\left(g^{a,+}(p_1);g^{b,-}(p_2);h(p_3);h(p_4)\right)_{\rm NF} &= i\delta^{ab}c^{+-}_{gghh}\;[1|\mathbf{3}-\mathbf{4}|2\rangle^2\,,\end{aligned}\quad \times\sum_n\sum_{i,j=1}^{3}c^n_{ij}(s_{ij})^n$$

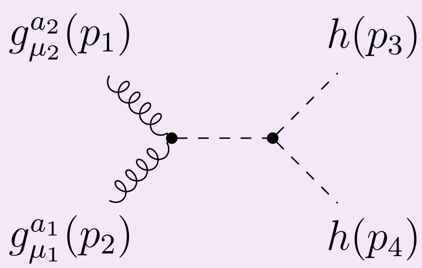
Factorisable



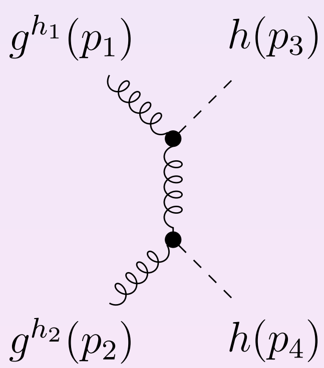
$$= \mathcal{M}\left(g_1^{a,h_1};g_2^{b,h_2};h\right) = i\,\delta^{ab}\,[1|2]^n\,g_{-\ell}(s_{12},\Lambda)\,,$$



$$= \mathcal{M}(h;h;h) = i\,c_{3h}\,.$$



$$= \mathcal{M}\left(g_1^{a,+};g_2^{b,+};h_3;h_4\right)_{s\text{–ch.}} = -\delta^{ab}\frac{c_{3h}\,c_{ggh}}{s_{12}-m_h^2}[1|2]^2\,.$$

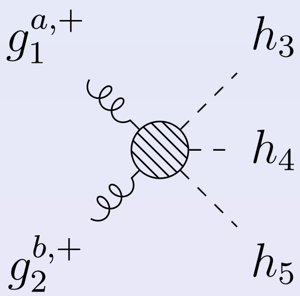


$$\begin{aligned}&\mathcal{M}\left(g_1^{a,+};g_2^{b,-};h_3;h_4\right)_{t+u\text{–ch.}}\\ &= -\,\delta^{ab}\frac{|c_{ggh}|^2}{4}[1|\mathbf{3}-\mathbf{4}|2\rangle^2\left(\frac{1}{s_{13}}+\frac{1}{s_{23}}\right),\\ &= -\,\delta^{ab}\frac{|c_{ggh}|^2}{4}[1|\mathbf{3}-\mathbf{4}|2\rangle^2\frac{2m_h^2-s_{12}}{s_{13}s_{23}}\,.\end{aligned}$$

OnShell Double Higgs

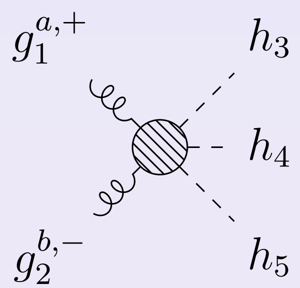
Amplitude	Helicity	Spinor structure	Coeff.	Dimension	Minimal order SMEFT	Minimal order HEFT
			Three-point			
$gg \to h$	$++$	$[1\|2]^2$	c_{ggh}	$-1\,(1/\overline{\Lambda})$	$6\,(v/\Lambda^2)$	NLO*
$hh \to h$	-	-	c_{hhh}	$1\,(\overline{\Lambda})$	4	LO
			Four-point			
$hh \to hh$	-	-	c_{4h}	0	4	LO
$gg \to hh$	$++$	$[1\|2]^2$	c_{gghh}^{++}	$-2\,(1/\overline{\Lambda}^2)$	$6\,(1/\Lambda^2)$	NLO*
	$+-$	$[1\|\mathbf{3}-\mathbf{4}\|2\rangle^2$	c_{gghh}^{+-}	$-4\,(1/\overline{\Lambda}^4)$	$8\,(1/\Lambda^4)$	NNLO*

All structures arise at same order, in SMEFT more coefficients but same physics



$$= \mathcal{M}\left(g_1^{a,+}; g_2^{b,+}; h_3; h_4; h_5\right)_{\rm NF} = i\,\delta^{ab}\, c_{gghhh}^{++,(1)} [1|2]^2$$

$$+\, i\,\delta^{ab}\, c_{gghhh}^{++,(2)} \left([1|\mathbf{34}|2][1|\mathbf{43}|2] + [1|\mathbf{35}|2][1|\mathbf{53}|2] + [1|\mathbf{45}|2][1|\mathbf{54}|2]\right)$$



$$= \mathcal{M}\left(g_1^{a,+}; g_2^{b,-}; h_3; h_4; h_5\right)_{\rm NF}$$

$$= i\,\delta^{ab}\, c_{gghhh}^{+-} \left(([1|\mathbf{3}|2\rangle)^2 + ([1|\mathbf{4}|2\rangle)^2 + ([1|\mathbf{5}|2\rangle)^2\right),$$

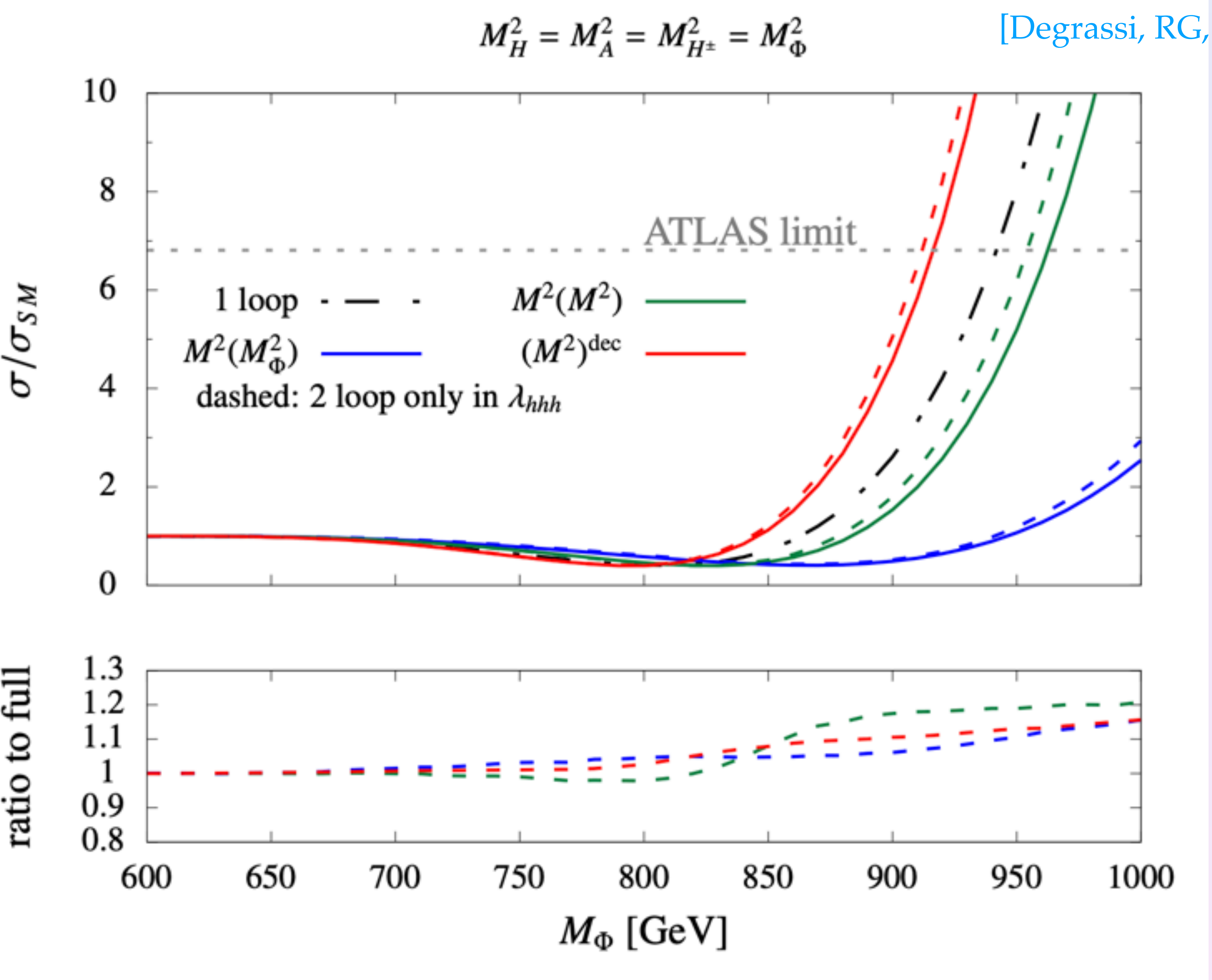
Amplitude	Helicity	Spinor structure	Coeff.	Dimension	Minimal SMEFT order	Minimal HEFT order
			Five-point			
$hh \to hhh$	-	-	c_{5h}	0	$6\,(v/\Lambda^2)$	LO
$gg \to hhh$	$++$	$[1\vert 2]^2$	$c_{gghhh}^{++,(1)}$	$-3\,(1/\overline{\Lambda}^3)$	$8\,(v/\Lambda^4)$	NLO*
	$++$	$[1\vert\mathbf{34}\vert 2]^2$	$c_{gghhh}^{++,(2)}$	$-7\,(1/\overline{\Lambda}^7)$	$12\,(v/\Lambda^8)$	N^{3}LO*
	$+-$	$[1\vert\mathbf{3}\vert 2\rangle^2$	c_{gghhh}^{+-}	$-5\,(1/\overline{\Lambda}^5)$	$10\,(v/\Lambda^6)$	NNLO*

contributions arise at different orders

we cannot *falsify* just probe convergence

Multi-Higgs Models and resonant production

Multi-Higgs Models: 2HDM



[Degrassi, RG, Slavich '25]

2HDM: even in the alignment limit in presence of large scalar couplings huge corrections to trilinear Higgs self-coupling possible

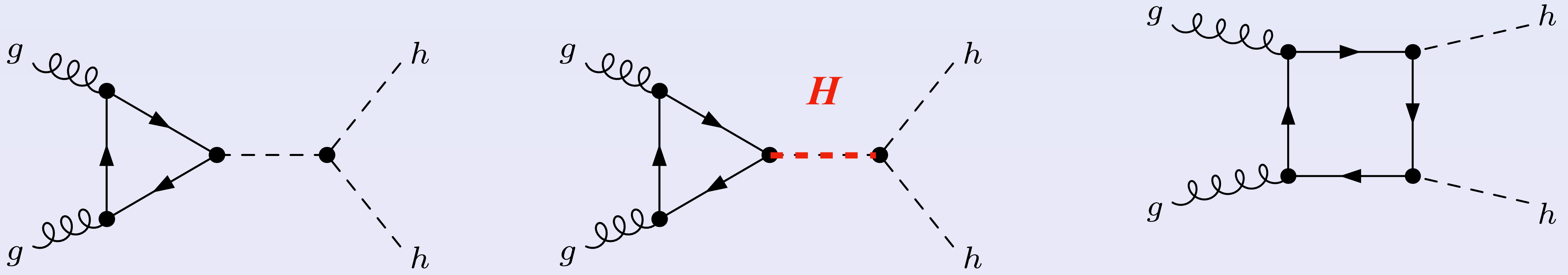
[Braathen, Kanemura '19]

Also in other models with extended Higgs sector

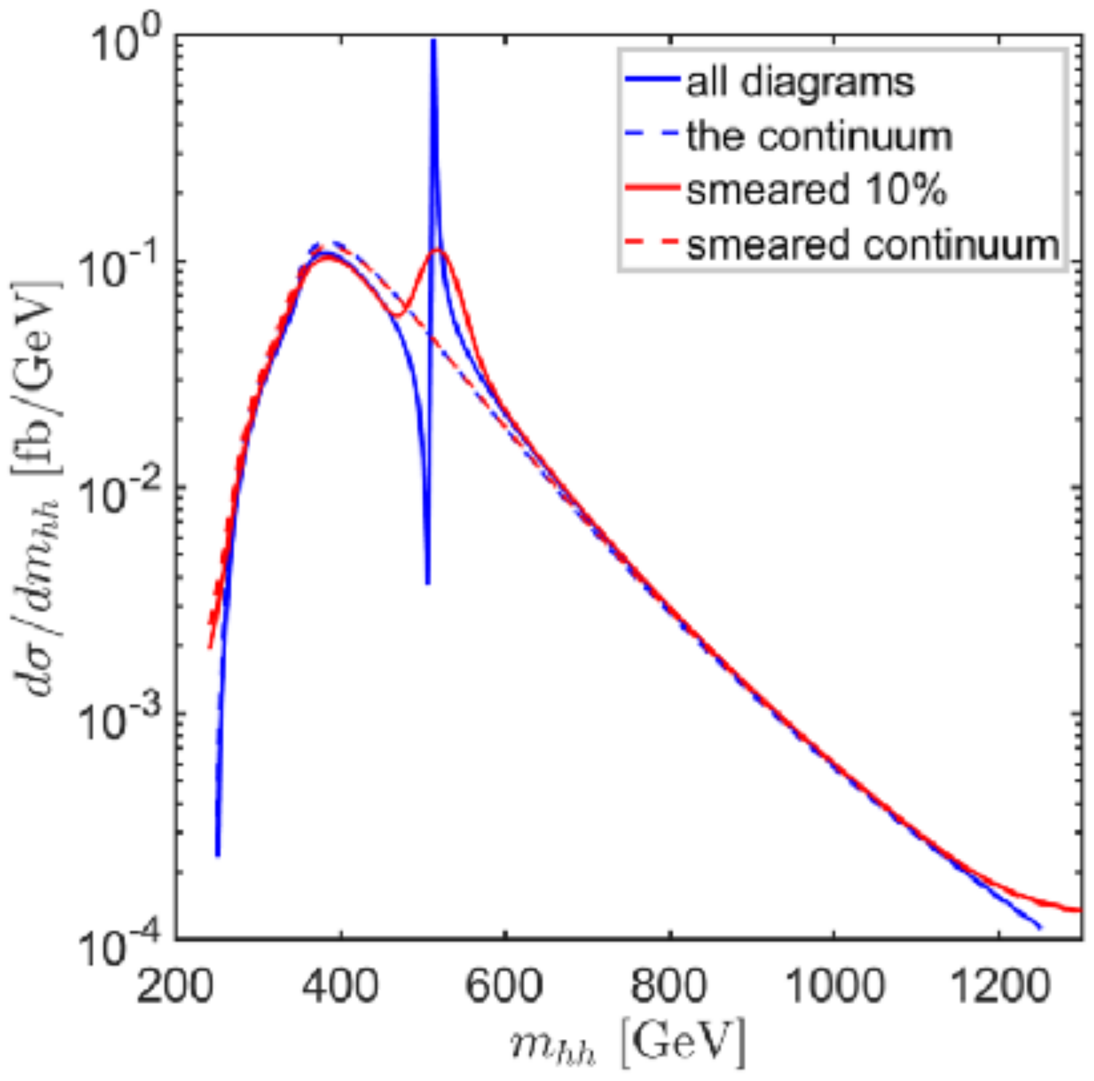
[Bahl et al. '23; Bahl, Braathen, Gabelmann, Paßehr '25]

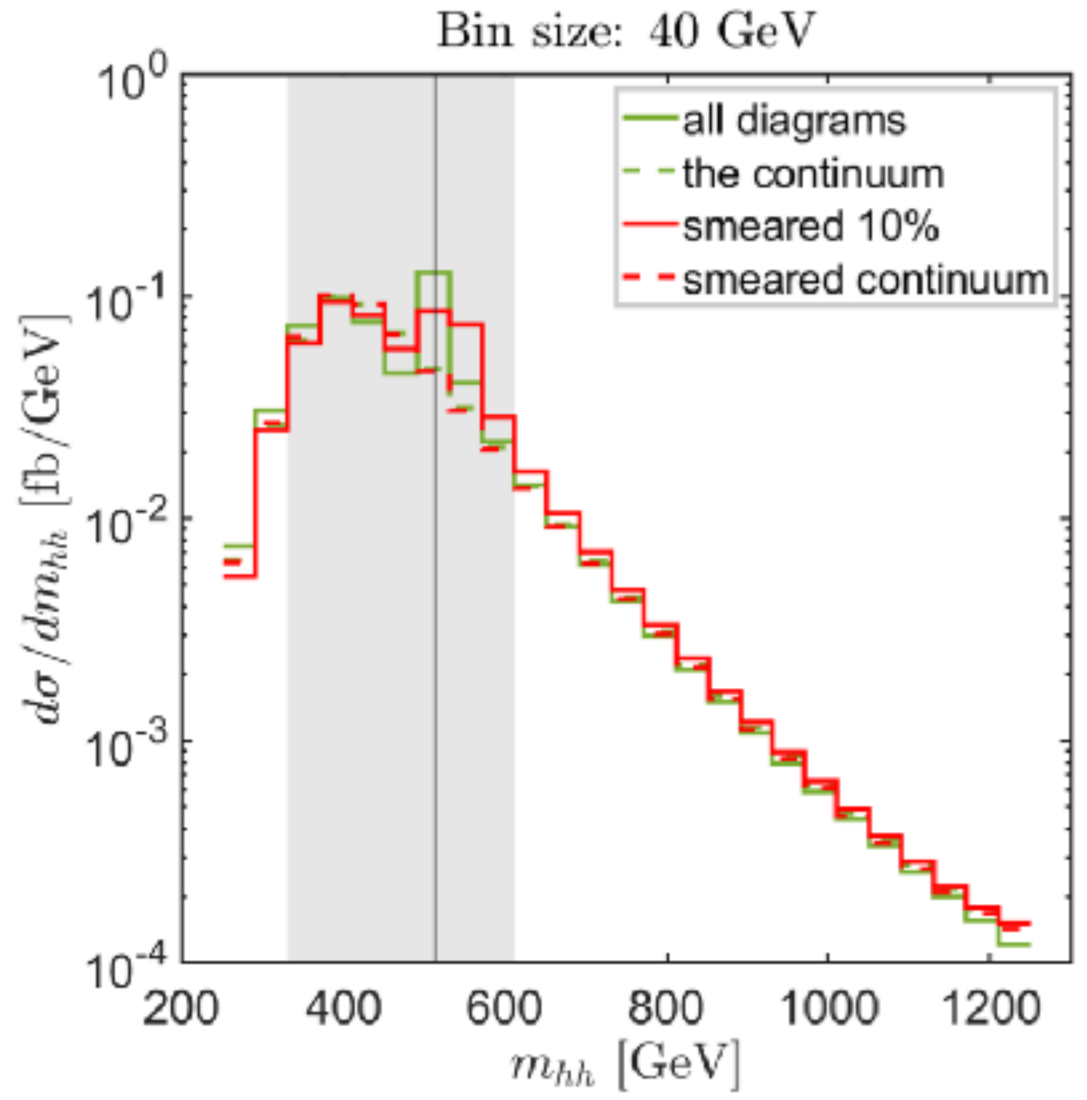
And what if we find deviations in κ_λ?

Resonant di-Higgs searches



[Arco, Heinemeyer, Mühlleitner, Radechenko '22]





Resonant di-Higgs searches

Interference effects can be important

reweighing techniques important to increase computationally efficiencies for exp analysis

[Feuerstake, Fuchs, Robens, Winterbottom '25]

how to treat interference effects as model-independent as possible? benchmarks or anything better?

how to treat best final states with different Higgs bosons?

Conclusion

- Multi-Higgs Production promises to measure existing physics

- is challenging experimentally, in particular triple Higgs production
  what can we learn new?

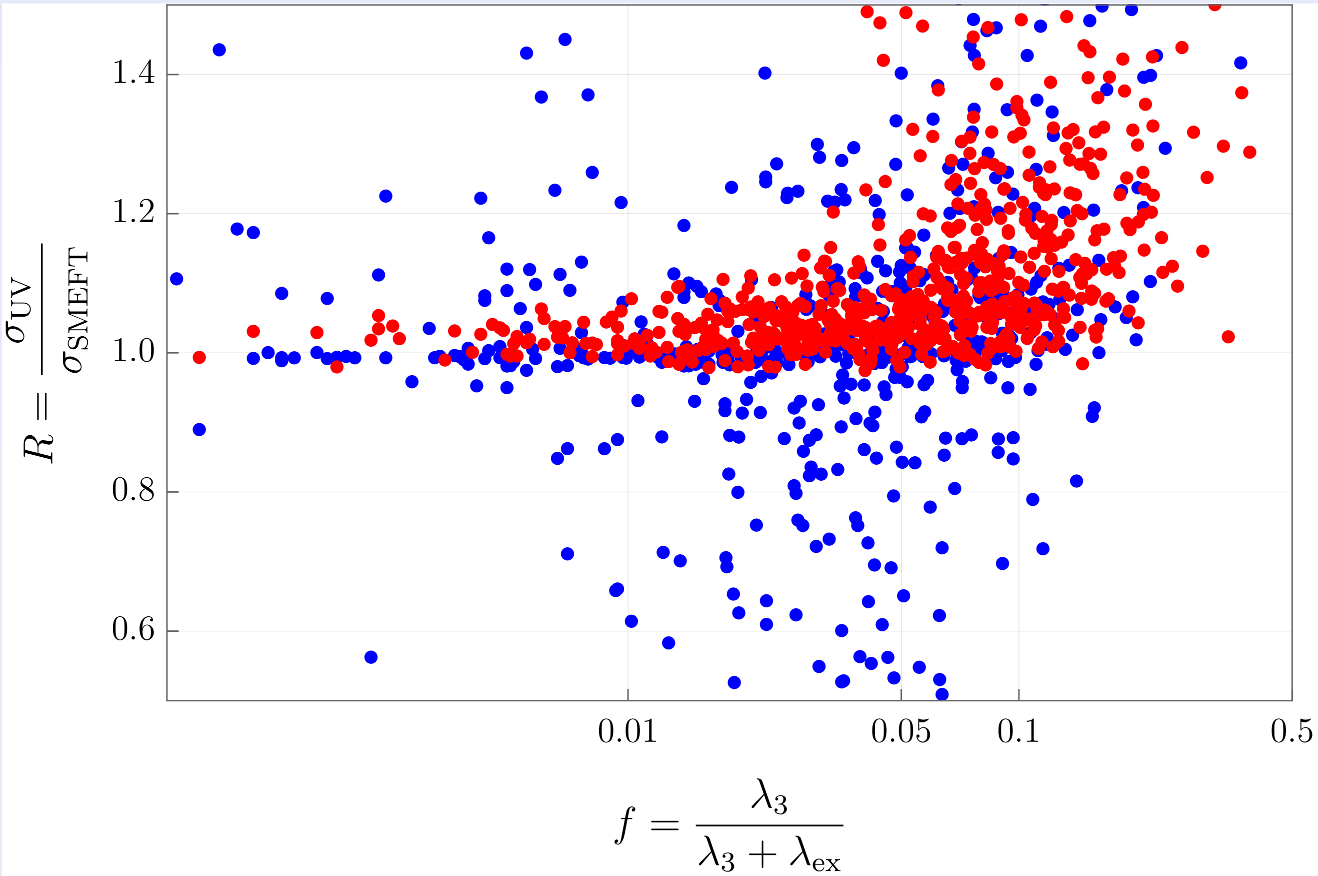
- Theory uncertainties in SM need shrinking

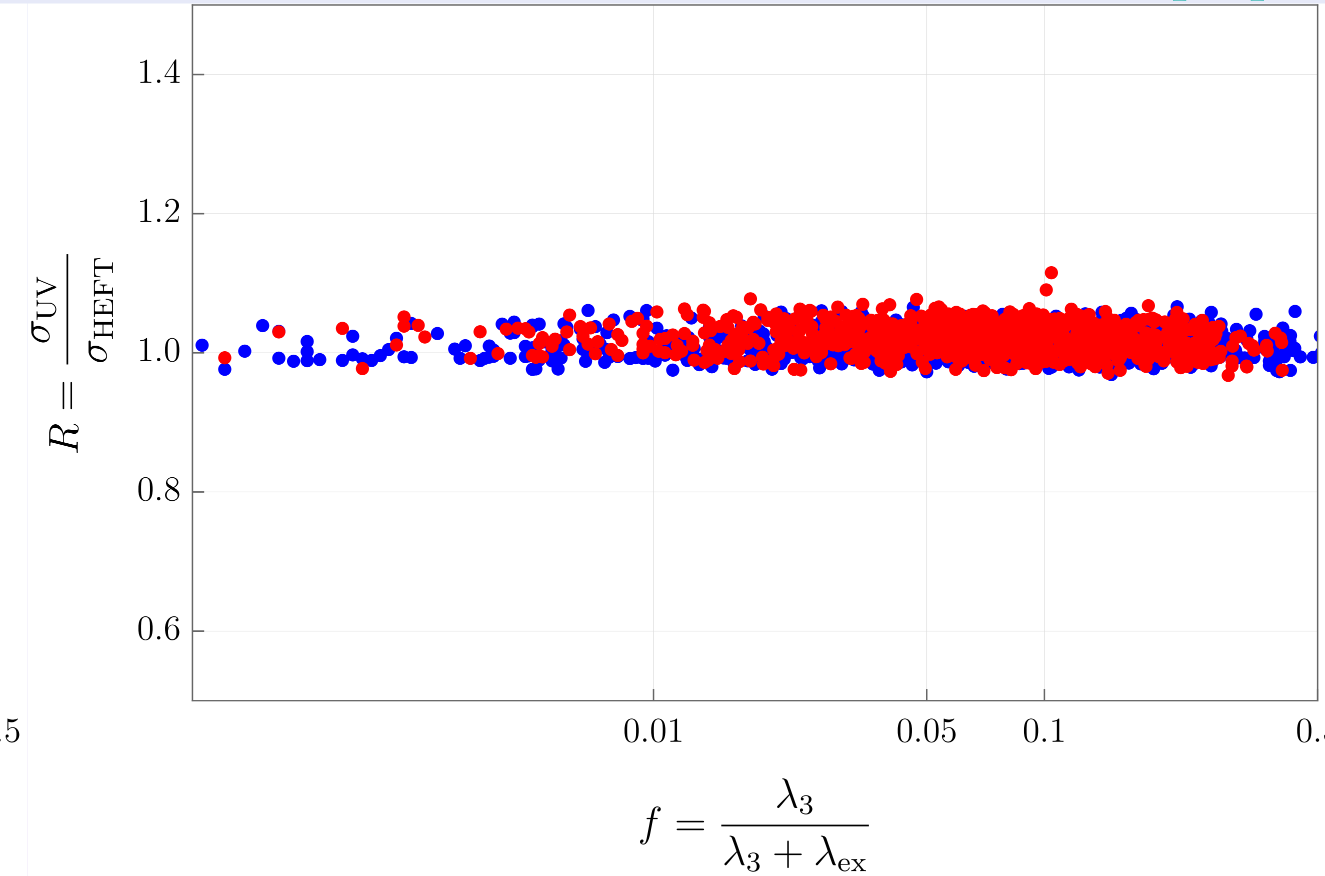
- EFT, in particular HEFT can bring changes in kinematic distributions
  so far not considered

- Multi-Higgs Models have rich di-Higgs phenomenology

UV models for HEFT HH

[Asiáin, RG, Tiberi 'in prep]





red points: $v_s \in [0,0.1 v_H]$

blue points: $v_s \in [0,5 v_H]$

$f = \frac{\lambda_3}{\lambda_3 + \frac{2\mu_2^2}{v_H^2}} = \frac{\lambda_3}{\lambda_3 + \lambda_{\rm ex}}$ is a measure how much of the singlet mass comes from EWSB

HEFT is the better EFT to be used in Higgs pair production for singlet model

Power counting

With Naive Dimensional Analysis, reinstating powers of $c = \hbar$ and with $\hbar^{-1/2} \sim 4\pi$

$$\mathscr{L} \supset \frac{\Lambda^4}{(4\pi)^2} \left(\frac{\partial_\mu}{\Lambda}\right)^q \left(\frac{4\pi\phi}{\Lambda}\right)^s \left(\frac{4\pi\psi}{\Lambda^{3/2}}\right)^f \left(\frac{g}{4\pi}\right)^{n_g} \left(\frac{\lambda}{(4\pi)^2}\right)^{n_\lambda} \left(\frac{4\pi v}{\Lambda}\right)^{n_v}$$

[Manohar, Georgi '84;
Gavela, Jenkins,
Manohar, Merlo '16]

SMEFT:
Assuming that $\Lambda \gg v$ allows us to power count N_Λ

$$\mathscr{L} = \mathscr{L}_{SM} + \sum_i \frac{c_{\mathscr{O}}}{\Lambda^i} \mathscr{O}_i$$

for Higgs physics
$i \geq 2$

respects the SM gauge symmetries, all fields transform as in SM

Power counting

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[Manohar, Georgi '84;
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SMEFT:
Assuming that $\Lambda \gg v$ allows us to power count N_Λ

HEFT:
The prize of splitting the SU(2) doublet of GBs and Higgs is that the theory becomes non-unitary at $\Lambda > 4\pi v$

We cannot expand in N_Λ $\longrightarrow$ Power count in chiral dimension $N_\chi = N_\Lambda + N_{4\pi}$

[Buchalla, Cata, Krause '13]

Chiral dimension

$$\mathscr{L} \supset \frac{\Lambda^4}{(4\pi)^2} \left(\frac{\partial_\mu}{\Lambda}\right)^q \left(\frac{4\pi\phi}{\Lambda}\right)^s \left(\frac{4\pi\psi}{\Lambda^{3/2}}\right)^f \left(\frac{g}{4\pi}\right)^{n_g} \left(\frac{\lambda}{(4\pi)^2}\right)^{n_\lambda} \left(\frac{4\pi v}{\Lambda}\right)^{n_v}$$

From the NDA scaling we see easily that the chiral dimension counts up by

0 units for each boson field $\phi = \varphi, A_\mu$
for each VEV v

chiral dimension
$N_\chi = N_\Lambda + N_{4\pi}$

1/2 unit for each fermionic field ψ

1 unit for each gauge/Yukawa coupling
for each derivative

2 units for coupling of scalar interaction φ^4

HEFT Lagrangian

LO Lagrangian

$$\mathcal{L}_{LO} = -\frac{1}{4}G^a_{\mu\nu}G^{a\mu\nu} - \frac{1}{4}W^I_{\mu\nu}W^{I\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}\partial_\mu h \partial^\mu h - \frac{v^2}{4}\mathrm{Tr}\left(\mathbf{V}_\mu \mathbf{V}^\mu\right)\mathcal{F}_C(h) - \lambda v^4 \mathcal{V}(h)$$
$$+ i\overline{Q}_L \not{D} Q_L + i\overline{Q}_R \not{D} Q_R + i\overline{L}_L \not{D} L_L + i\overline{L}_R \not{D} L_R$$
$$- \frac{v}{\sqrt{2}}\left(\overline{Q}_L \mathbf{U} \mathcal{Y}_Q(h) Q_R + \mathrm{h.c.}\right) - \frac{v}{\sqrt{2}}\left(\overline{L}_L \mathbf{U} \mathcal{Y}_L(h) L_R + \mathrm{h.c.}\right),$$

Goldstone matrix

$$\mathbf{U} = e^{\frac{i\pi^a\sigma^a}{v}} \qquad \mathbf{V}_\mu = (D_\mu \mathbf{U})\mathbf{U}^\dagger$$

Flare functions

$$\mathcal{F}_C(h) = 1 + \sum_{n=1}^{\infty} a_C^{(n)}\left(\frac{h}{v}\right)^n,$$
$$\mathcal{V}(h) = \frac{h^2}{v^2} + a_V^{(3)}\frac{h^3}{v^3} + a_V^{(4)}\frac{h^4}{4v^4} + \sum_{n=5}^{\infty} a_V^{(n)}\left(\frac{h}{v}\right)^n,$$
$$\mathcal{Y}_Q(h) = \mathrm{diag}\left(\mathcal{Y}_U(h), \mathcal{Y}_D(h)\right), \qquad \mathcal{Y}_L(h) = \mathrm{diag}\left(0, \mathcal{Y}_E(h)\right),$$
$$\mathcal{Y}_{U,D,E}(h) = Y_{u,d,e}\left(1 + \sum_{n=1}^{\infty} a_{u,d,e}^{(n)}\left(\frac{h}{v}\right)^n\right),$$

HEFT Lagrangian

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The choice of the LO Lagrangian ($N_\chi = 2$) is convention (i.e. could also contain 4 fermion operators, custodial violating operators, …)

HEFT cross sections

[Brivio, RG, Schmid 'in prep]

Count all occurrences of $p \sim m$

$$\mathcal{M} \sim p^{4-n}(4\pi)^{n-2} \left(\frac{p}{\Lambda}\right)^{N^p_{\Lambda,\mathcal{M}}} \left(\frac{4\pi v}{\Lambda}\right)^{N_{v,\mathcal{M}}} \left(\frac{g}{4\pi}\right)^{N_{g,\mathcal{M}}} \left(\frac{y}{4\pi}\right)^{N_{y,\mathcal{M}}} \left(\frac{\lambda}{(4\pi)^2}\right)^{N_{\lambda,\mathcal{M}}}$$

where n is the number of legs

At the level of the cross section

$$\int d\mathrm{PS}_k = \int \prod_{j=1}^{k} \frac{dq_j}{(2\pi)^3 2E_j} q_j^2 d\Omega_j (2\pi)^4 \delta^4 \left(q_{\text{init}} - \textstyle\sum_n q_n\right) \quad \sim \quad p^{2k-4}(4\pi)^{3-2k}$$

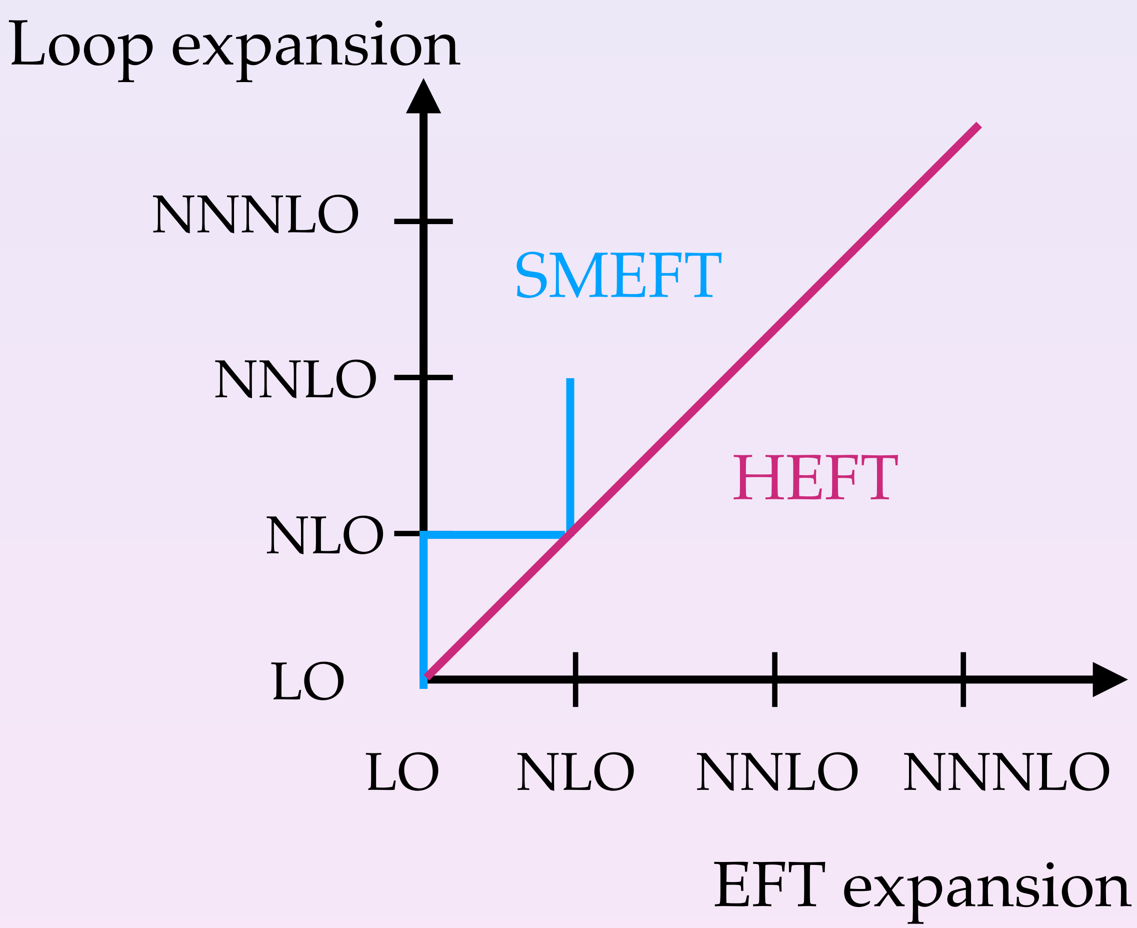
dependence on number of legs necessary for cancellation of IR divergencies at same order in counting

HEFT power counting

[Brivio, RG, Schmid 'in prep]

In the end we should count loops, external legs and chiral dimension of couplings

$$N^{s,\mathscr{M}}_{HEFT} = n - 2 + 2L + \sum_{i \in vert} N_{\chi,i}$$



SMEFT power counting keeps EFT expansion independent of loop expansion

HEFT power counting counts loops, so one is constrained on the diagonal

HEFT power counting

[Brivio, RG, Schmid 'in prep]

In the end we should count loops, external legs and chiral dimension of couplings

$$N^{s,\mathcal{M}}_{HEFT} = n - 2 + 2L + \sum_{i \in vert} N_{\chi,i}$$

counting $g_s \sim p \sim m$ not necessary instead we can count alternatively

$$N^{\mathcal{M}}_{HEFT} = N^{s,\mathcal{M}}_{HEFT} - N^{\mathcal{M}}_{g_s}$$