MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Extended Dark Matter EFT

Valentin Titus Tenorth

Work in progress with:
T. Alanne, G. Arcadi, F. Goertz,
K. Tame-Navaez & S. Vogl

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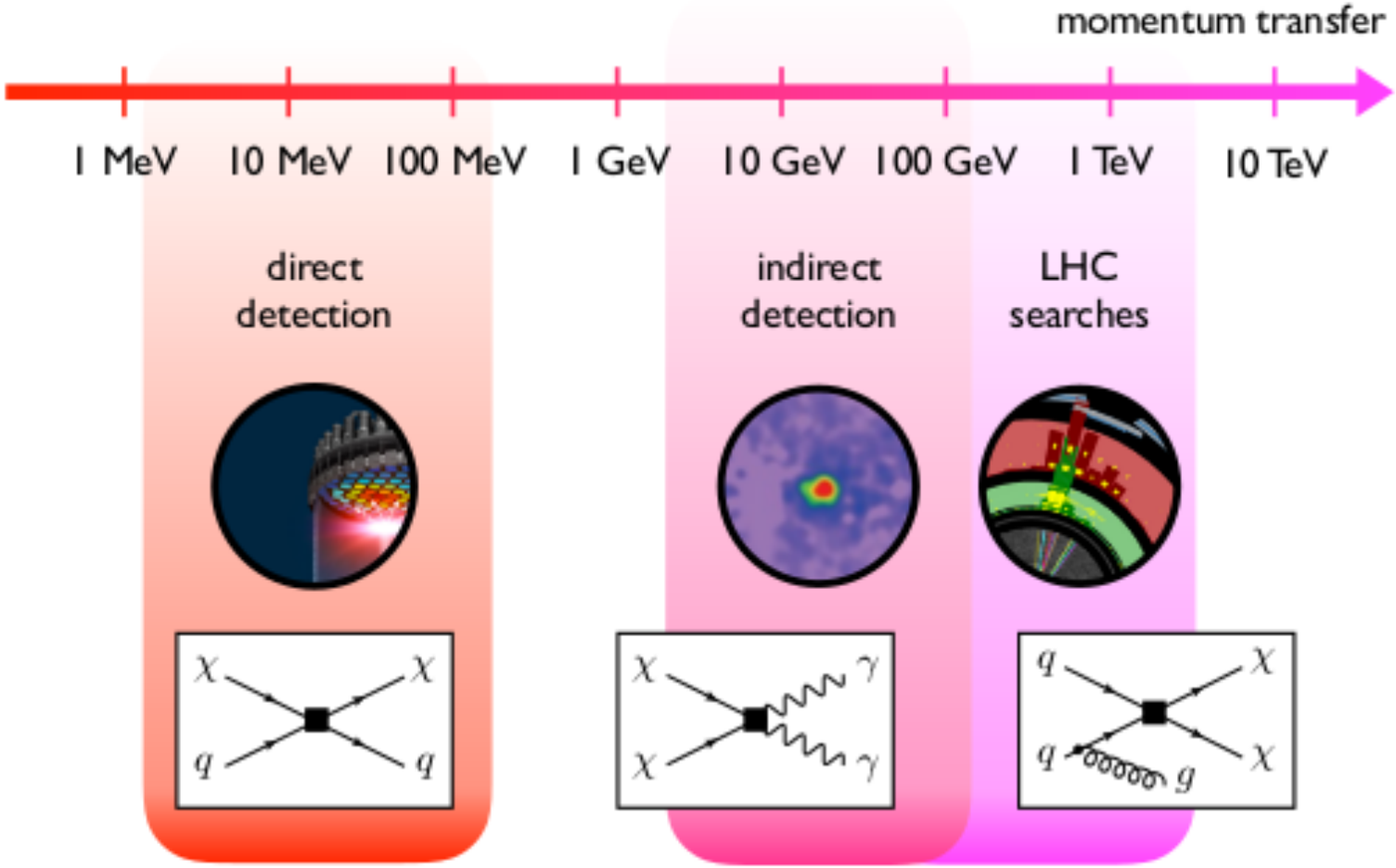
Tsukuba - December 4th

INTERNATIONAL MAX PLANCK RESEARCH SCHOOL

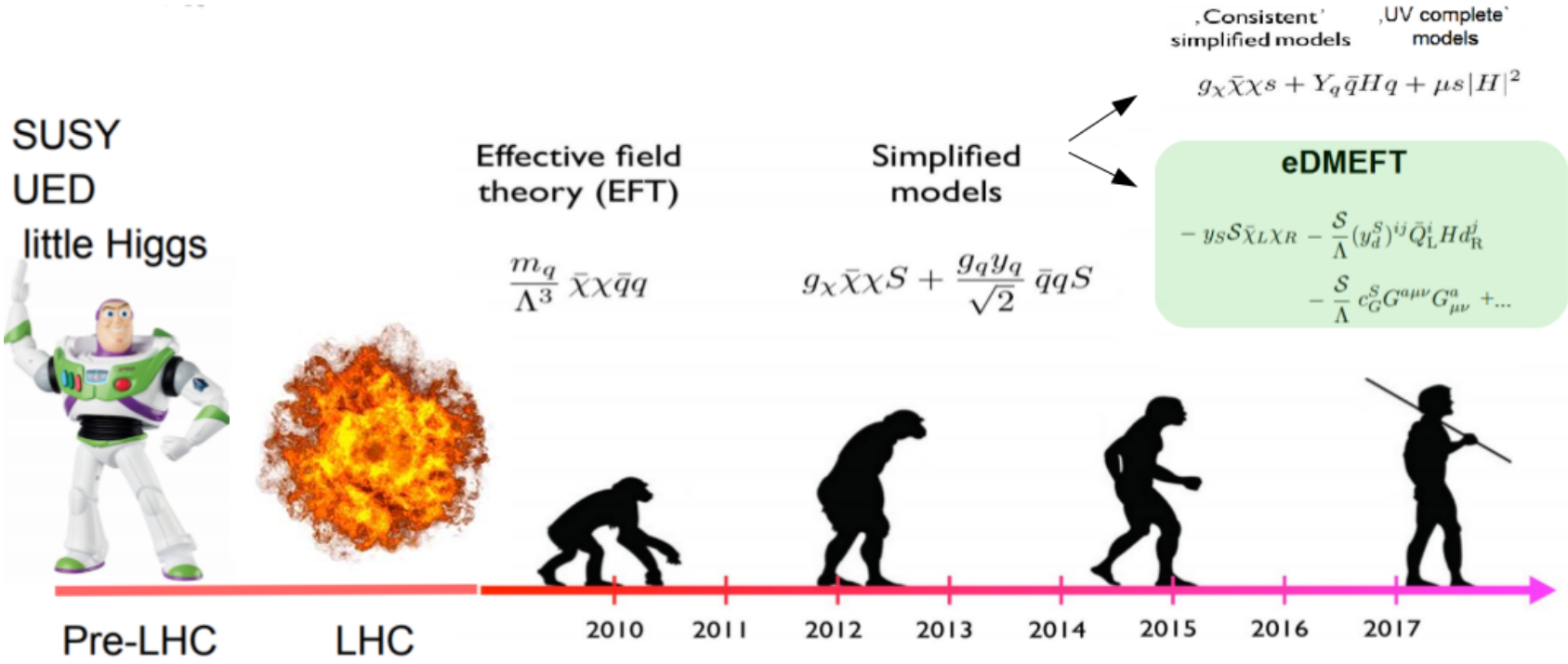
PT FS FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES

WIMP DM - Search Strategies



1810.09420

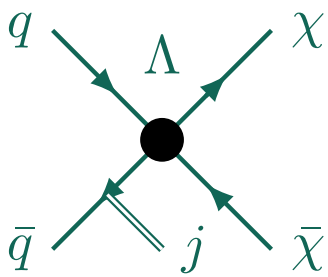
Evolution of Theories for DM at LHC



G. Polesello, U. Haisch, F.Goertz

DM EFT and Simplified Models

$$\mathcal{L}_{\text{EFT}} = \frac{c_\chi}{\Lambda^2} \left(\bar{q}\,\Gamma^a q\right) \left(\bar{\chi}\,\Gamma'_a\,\chi\right)$$



$$p^2 \ll \Lambda^2$$

+ Valid for Direct Detection
+ Wide class of models
– Break down @LHC
  → Restore Mediator

1008.1783, 1402.1275

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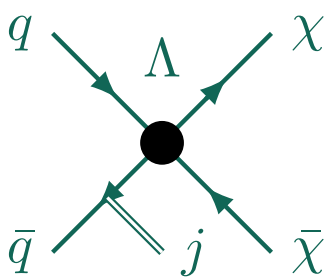

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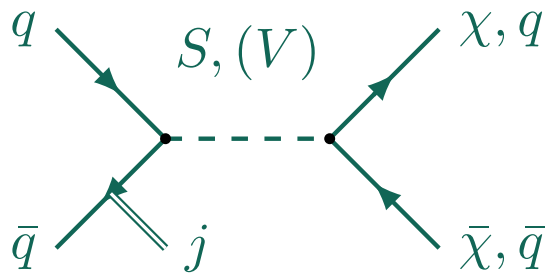
1008.1783, 1402.1275

$$\mathcal{L}_{\text{simp}} = g_q \, S \, \bar{q} q + g_\chi S \, \bar{\chi} \chi$$



$$\propto \frac{g_q \, g_\chi}{p^2 - M_S^2}$$

+ Improve LHC kinematics
– Not gauge invariant
– Rather specific
  → Combine approaches

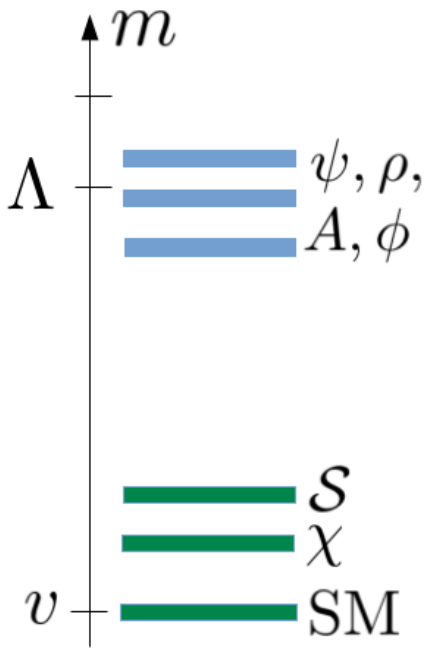
1409.2893, 1507.00966 (ref. therein)

Extended Dark Matter EFT

Combine advantages of both approaches

TA,FG, 1712.07626

Effective operators up to dimension 5 including:
SM + Scalar Mediator $\mathcal{S}$ + Fermionic DM χ



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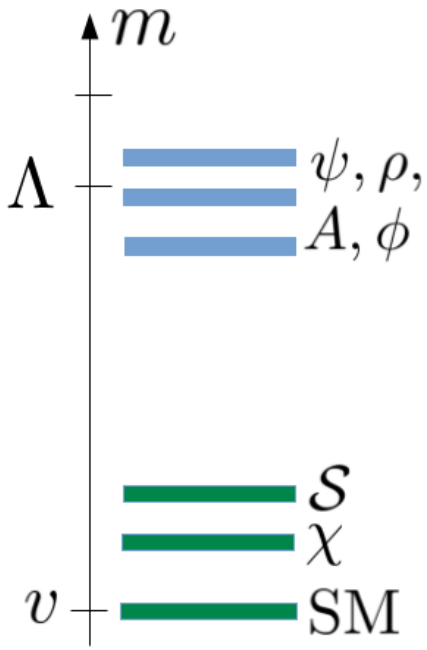
$$
\begin{aligned}
\mathcal{L}_{\text{eff}}^{\mathcal{S}\text{int}} \supset & -\lambda'_{H\mathcal{S}} v |H|^2 \mathcal{S} - \lambda_{H\mathcal{S}} |H|^2 \mathcal{S}^2 \\
& - \frac{\mathcal{S}}{\Lambda} \left[c_{\lambda\mathcal{S}} \mathcal{S}^4 + c_{H\mathcal{S}} |H|^2 \mathcal{S}^2 + c_{\lambda H} |H|^4 \right] \\
& - y_{\mathcal{S}} \mathcal{S} \bar{\chi}\chi - \frac{y_{\mathcal{S}}^{(2)} \mathcal{S}^2 + y_H |H|^2}{\Lambda} \bar{\chi}\chi \\
& - \frac{\mathcal{S}}{\Lambda} \sum_{f=u,d,l} y_f^{\mathcal{S}} \, \bar{F}_{\text{L}} \, H \, f_{\text{R}} \\
& - \frac{\mathcal{S}}{\Lambda} \left[C_{BB}^{\mathcal{S}} B_{\mu\nu} B^{\mu\nu} + C_{WW}^{\mathcal{S}} W^{i\mu\nu} W_{\mu\nu}^i \right. \\
& \left. \quad + C_{GG}^{\mathcal{S}} G^{a\mu\nu} G_{\mu\nu}^a \right]
\end{aligned}
$$



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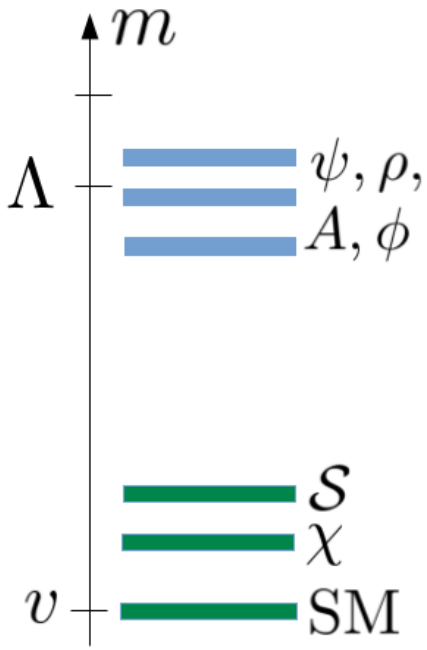
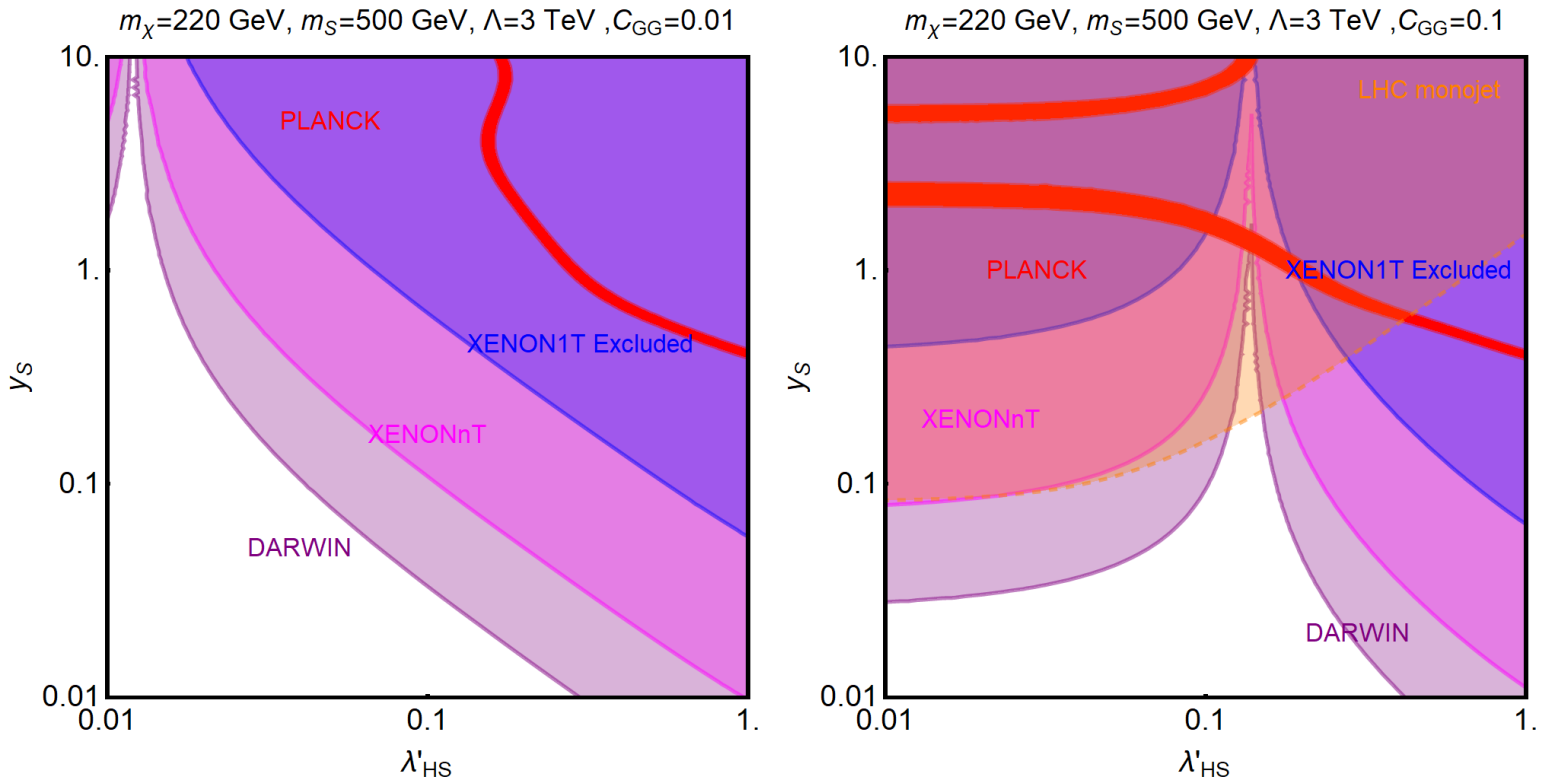
$$\begin{aligned}\mathcal{L}_{\text{eff}}^{\mathcal{S}\text{int}} \supset & -\lambda'_{H\mathcal{S}} v |H|^2 \mathcal{S} - \lambda_{H\mathcal{S}} |H|^2 \mathcal{S}^2 \\ & - \frac{\mathcal{S}}{\Lambda}\left[c_{\lambda\mathcal{S}}\mathcal{S}^4 + c_{H\mathcal{S}}|H|^2\mathcal{S}^2 + c_{\lambda H}|H|^4\right] \\ & - y_{\mathcal{S}}\mathcal{S}\bar{\chi}\chi - \frac{y_{\mathcal{S}}^{(2)}\mathcal{S}^2 + y_H|H|^2}{\Lambda}\bar{\chi}\chi \\ & - \frac{\mathcal{S}}{\Lambda}\sum_{f=u,d,l} y_f^{\mathcal{S}}\,\bar{F}_{\mathrm{L}}\,H\,f_{\mathrm{R}} \\ & - \frac{\mathcal{S}}{\Lambda}\left[C_{BB}^{\mathcal{S}} B_{\mu\nu}B^{\mu\nu} + C_{WW}^{\mathcal{S}} W^{i\mu\nu}W^i_{\mu\nu}\right. \\ & \left. + C_{GG}^{\mathcal{S}} G^{a\mu\nu}G^a_{\mu\nu}\right]\end{aligned}$$



Higgs Mixing + Gluon Coupling - Scalar

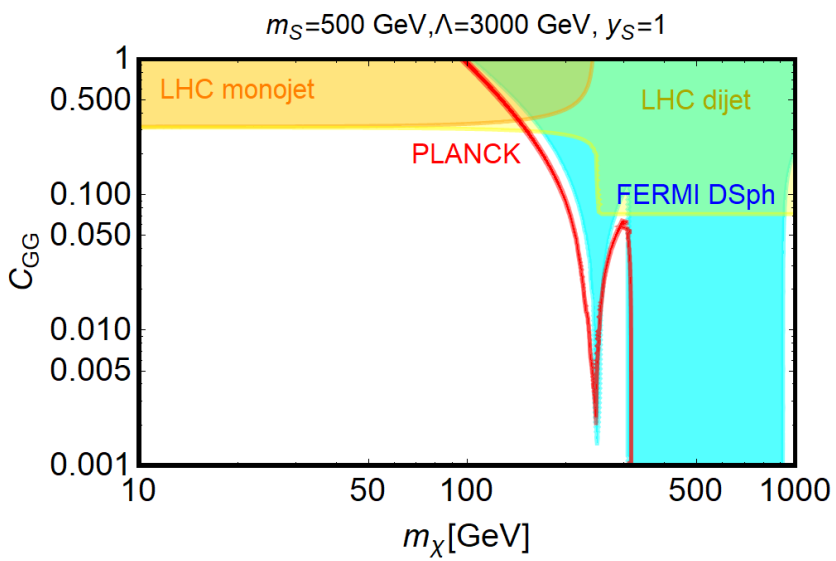
Interesting case: Turn on more than two operators

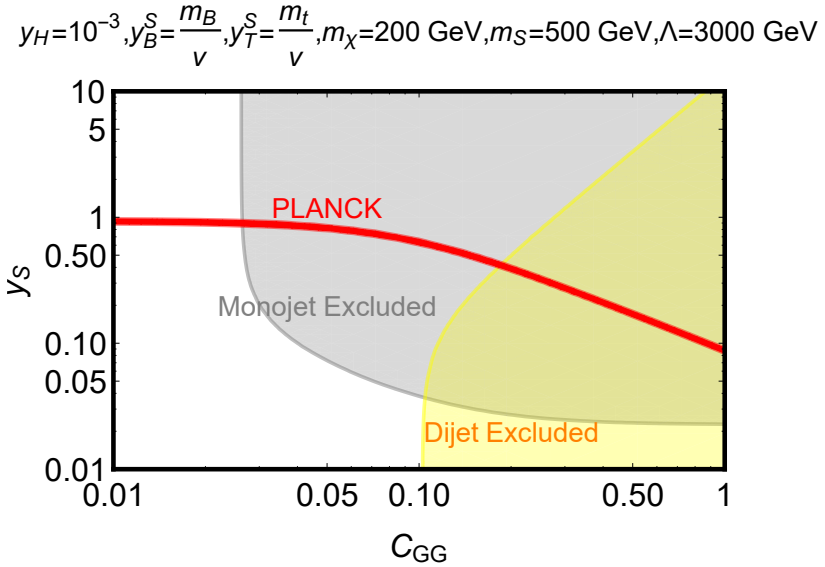


Preliminary Plots

Quark + Gluon Couplings - Pseudoscalar

$$\mathcal{L}_{\text{eff}}^{\tilde{\mathcal{S}}\text{int}} \supset -\frac{i\tilde{\mathcal{S}}}{\Lambda}\left[y_b^{\tilde{\mathcal{S}}}\bar{Q}_L H b_R + y_t^{\tilde{\mathcal{S}}}\bar{Q}_L \tilde{H} t_R\right] - y_{\tilde{\mathcal{S}}}\,\tilde{\mathcal{S}}\,\bar{\chi}\chi - \frac{g_s^2 c_G^{\tilde{\mathcal{S}}}}{16\pi^2\Lambda}\,\tilde{\mathcal{S}}\,G^{a\mu\nu}G^{\tilde{a}}_{\mu\nu}$$





Preliminary Plots

Matching-Example: 2HDM + $\mathcal{S}$

$$\mathcal{L}_{\text{2HDM}+\mathcal{S}} \supset \mathcal{L}_{\text{2HDM}} + \lambda_{12}^{\mathcal{S}} v\, H_1^\dagger H_2\, \mathcal{S} + \lambda_{12}^{2\mathcal{S}}\, H_1^\dagger H_2\, \mathcal{S}^2 + y_{\mathcal{S}} \mathcal{S} \bar{\chi}\chi$$

H_2 heavy - motivated by Higgs signal strength

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$\downarrow$ H_2 heavy - motivated by Higgs signal strength

$$\mathcal{L}_{\text{eff}}^{\mathcal{S}\text{int}} \propto \frac{-\lambda_{12}^{\mathcal{S}} v}{M^2}\, \mathcal{S} \left(Z_6 |H_1|^4 + \sum_{f=u,d,l} \frac{\eta_f\, y_f}{\tan\beta}\, \bar{F}_{\text{L}} H_1 f_{\text{R}} + 2\lambda_{12}^{2\mathcal{S}} \mathcal{S}^2 |H_1|^2 \right)$$

$$- \frac{\mathcal{S}\, v}{16\pi^2 M^2} \left[c_B B_{\mu\nu} B^{\mu\nu} + c_W W^{i\mu\nu} W^i_{\mu\nu} \right] \qquad \text{@ 1-loop}$$

$$c_{H\mathcal{S}} = \frac{-2\lambda_{12}^{\mathcal{S}} \lambda_{12}^{2\mathcal{S}}\, v}{M} \quad \bullet \quad c_{\lambda\mathcal{S}} = \frac{2 Z_6 \lambda_{12}^{\mathcal{S}}\, v}{M} \quad \bullet \quad y_q^{\mathcal{S}} = \frac{\lambda_{12}^{\mathcal{S}} \eta_q}{M \tan\beta}$$

Preliminary Result

Summary and Outlook

- Increase applicability of Dark Matter EFT
- Allows matching of various UV theories
- Account for correlations by gauge symmetry
- Proper treatment of Higgs mixing and interaction

- Prepare FeynRules model database entry
- Extend LHC analyses to richer phenomenology
- Present constrains on the Wilson coefficients
- Provide matching of simpler (vector quarks, $2\mathrm{HDM} + \mathcal{S}$) and more complex theories (Composite Models, NMSSM, . . .)

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Thanks for your attention!