Extended Dark Matter EFT

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[arXiv:1712.07626] (TA, F. Goertz)

Outline

DMEFT vs. simplified models

DMEFT	Simplified models

• General, gauge invariant
• Need separation of scales
  ▸ Mediator much heavier than probing energy scale
  ▸ Works well for direct detection, but limited applicability for LHC physics [Busoni et al., PLB728 (2014), Bruggisser et al., JHEP11 (2016)...]
	• Renormalisable
	• Requiring gauge invariance may require non-minimal particle content
	• Valid both at DD and LHC
	• Specific model realisations $\Rightarrow$ Generalisations not easily incorporated

eDMEFT

- Goal: restore the validity of DMEFT at LHC & increase the generality of simplified models in a unified framework

eDMEFT

- Goal: restore the validity of DMEFT at LHC & increase the generality of simplified models in a unified framework
- Add mediator as a dynamical DoF
  - Assume a light mediator ($\sim$ EW–TeV scale) and other heavier states integrated out $\Rightarrow$ effective operators
  - Motivation e.g. composite-Higgs models with pGBs
- Construct gauge-invariant Lagrangian with leading effective operators
  - For (pseudo-)scalar mediator, lowest effective operators $D = 5$
    $\Rightarrow$ Leading higher-order effects with limited number of EFT operators
- Possibility of correlating DD and LHC data in a unified framework with minimal number of DoF's

Example: Fermionic DM, scalar mediator

- Four classes: Fermion/scalar DM, scalar/pseudo-scalar mediator
  - Concrete example: fermion DM, scalar mediator:

$$
\begin{aligned}
\mathscr{L}_{\text{eff}}^{S\chi} &= \mathscr{L}_{\text{SM}} + \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{1}{2}\mu_S^2 S^2 + \overline{\chi} i \partial\!\!\!/ \chi - m_\chi \overline{\chi}\chi \\
&- \lambda'_{S1} v^3 S - \frac{\lambda'_S}{2\sqrt{2}} v S^3 - \frac{\lambda_S}{4} S^4 - \lambda'_{HS} v |H|^2 S - \lambda_{HS} |H|^2 S^2 \\
&- y_S S \overline{\chi}_{\text{L}} \chi_{\text{R}} - \frac{y_S^{(2)} S^2 + y_H^{(2)} |H|^2}{\Lambda} \overline{\chi}_{\text{L}} \chi_{\text{R}} + \text{h.c.} \\
&- \frac{S}{\Lambda}\left[c_{\lambda S} S^4 + c_{HS} |H|^2 S^2 + c_{\lambda H} |H|^4\right] \\
&- \frac{S}{\Lambda}\left[(y_d^S)^{ij} \overline{Q}_{\text{L}}^i H d_{\text{R}}^j + (y_u^S)^{ij} \overline{Q}_{\text{L}}^i \tilde{H} u_{\text{R}}^j + (y_\ell^S)^{ij} \overline{L}_{\text{L}}^i H \ell_{\text{R}}^j + \text{h.c.}\right] \\
&- \frac{S}{\Lambda}\frac{1}{16\pi^2}\left[g'^2 c_B^S B_{\mu\nu} B^{\mu\nu} + g^2 c_W^S W^{I\mu\nu} W_{\mu\nu}^I + g_s^2 c_G^S G^{a\mu\nu} G_{\mu\nu}^a\right]
\end{aligned}
$$

Case study: Quark- vs. gluon-induced production

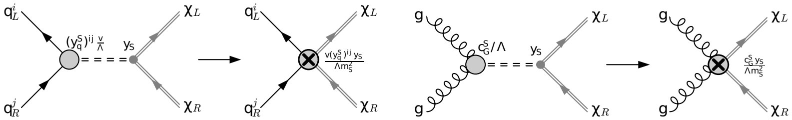
- Turn on only two new operators connecting DM to SM

$$
\begin{aligned}
\mathscr{L}_{\text{eff}}^{S\chi} \;=\;& \mathscr{L}_{\text{SM}} + \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{1}{2}\mu_S^2 S^2 + \overline{\chi} i \partial\!\!\!/ \chi - m_\chi \overline{\chi}\chi \\
& - \lambda'_{S1} v^3 S - \frac{\lambda'_S}{2\sqrt{2}} v S^3 - \frac{\lambda_S}{4} S^4 - \lambda'_{HS} v |H|^2 S - \lambda_{HS} |H|^2 S^2 \\
& - y_S S \overline{\chi}_{\text{L}} \chi_{\text{R}} - \frac{y_S^{(2)} S^2 + y_H^{(2)} |H|^2}{\Lambda} \overline{\chi}_{\text{L}} \chi_{\text{R}} + \text{h.c.} \\
& - \frac{S}{\Lambda}\left[c_{\lambda S} S^4 + c_{HS} |H|^2 S^2 + c_{\lambda H} |H|^4 \right] \\
& - \frac{S}{\Lambda}\left[(y_d^S)^{ij} \overline{Q}_{\text{L}}^i H d_{\text{R}}^j + (y_u^S)^{ij} \overline{Q}_{\text{L}}^i \widetilde{H} u_{\text{R}}^j + (y_\ell^S)^{ij} \overline{L}_{\text{L}}^i H \ell_{\text{R}}^j + \text{h.c.} \right] \\
& - \frac{S}{\Lambda}\frac{1}{16\pi^2}\left[g'^2 c_B^S B_{\mu\nu} B^{\mu\nu} + g^2 c_W^S W^{I\mu\nu} W^I_{\mu\nu} + g_s^2 c_G^S G^{a\mu\nu} G^a_{\mu\nu} \right]
\end{aligned}
$$

Quark- vs. gluon-induced production

- DM–mediator coupling via Yukawa $y_S S \overline{\chi}_L \chi_R$
- Mediator–SM coupling via $D = 5$ operators

$$\frac{S}{\Lambda}\left[(y_d^S)^{ij}\overline{Q}_L^i H d_R^j + (y_u^S)^{ij}\overline{Q}_L^i \widetilde{H} u_R^j\right] \quad \text{or} \quad \frac{S}{\Lambda}\frac{1}{16\pi^2}\left[g_s^2 c_G^S G^{a\mu\nu} G^a_{\mu\nu}\right]$$



- Minimal scenario: $D = 5$ Yukawa only with up-quark
- If $m_\chi < m_S$, both $\sigma_{\rm SI}$ and $\langle v\sigma\rangle$ proportional to $y_S^2 (y_u^S)^2$ or $y_S^2 (c_G^S)^2$
  $\Rightarrow$ DD limits lead to overabundance in the minimal setting
  $\Rightarrow$ consider $m_\chi > m_S$
- Dominant annihilation channel $\chi\chi \to SS$: $\langle v\sigma\rangle \sim y_S^4$, while $\sigma_{\rm SI} \sim y_S^2 (y_u^S)^2$ or $y_S^2 (c_G^S)^2$

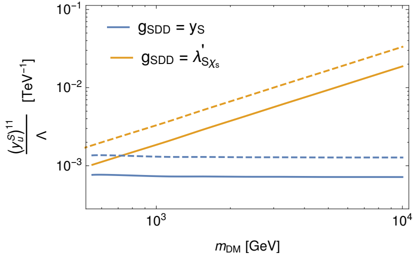
Quark- vs. gluon-induced production

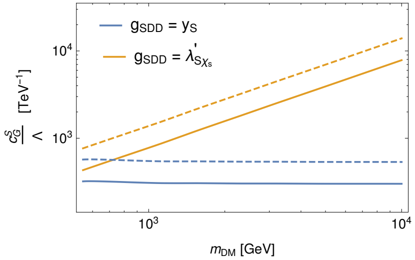
- The maximum value for the $D = 5$ coupling from XENON1T limits:

$$\frac{|(y_u^S)^{11}|}{\Lambda} \lesssim 2.9 \times 10^{-3} f_{\rm rel}^{-1/4} \left(\frac{m_S}{1\ \rm TeV}\right)^2 \rm TeV^{-1}$$

$$\frac{c_G^S}{\Lambda} \lesssim 1.3 \times 10^{3} f_{\rm rel}^{-1/4} \left(\frac{m_S}{1\ \rm TeV}\right)^2 \rm TeV^{-1}$$

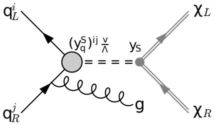
- Fermion vs. scalar DM

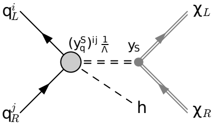




Prospects at LHC

- Benchmark point: $m_\chi = 500\,\text{GeV}$, $m_S = 400\,\text{GeV}$, $f_{\text{rel}} = 1$



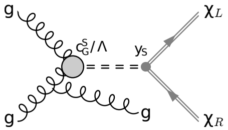


- Quark: (for LHC@13TeV)

$$\sigma_j| \lesssim 1.2\cdot10^{-7}\,\text{fb},$$
$$\sigma_{h+\not{E}_T}| \lesssim 1.6\cdot10^{-8}\,\text{fb}$$

- Gluon:

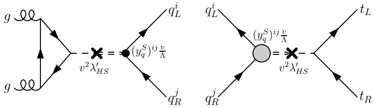
$$\sigma_j| \lesssim 1.9\cdot10^{3}\,\text{fb}$$



- Energy dependence of different pdf's!
- Most interesting scenarios beyond these extreme cases: e.g. couplings to heavy quarks
  - But: already this toy example shows that there is possibility for interesting collider pheno!

Beyond the simplest scenario

- In realistic scenarios several (non-)renormalisable operators non-zero, e.g. Higgs–mediator mixing
  - Can new parts of the parameter space open up?
  - Are the constraints on the simplified models too strict in some parts?
- A more comprehensive analysis in progress...
- Pseudoscalar mediator ↔ 2HDM + a
- Further processes at LHC
  - Resonant searches of the mediator
  - Invisible Higgs decays
  - Higgs pair $+\not{E}_T$
  - ...



Conclusions and outlook

- Framework to consistently correlate between DD and LHC with minimal number of DoF's
- With (pseudo-)scalar mediators the number fo leading ($D = 5$) effective operators rather limited
- A way to generalise the simplified models to larger class of UV models
  - Particularly motivated for composite-Higgs-type UV completions with large amount of strongly coupled states and few lighter pGB's

Outlook:

- Framework for the next generation of simplified models at colliders
- To-do list:
  - More comprehensive study of the parameter space and further processes
  - Mapping UV completions to the framework
  - Vector mediators?

Thank you!