A model independent probe for Elusive Dark Sectors at Future Experiments

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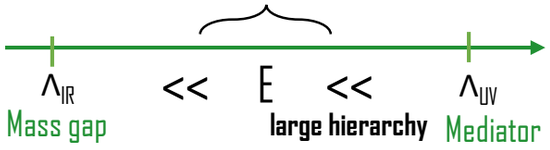
Work in Progress with R. K. Mishra, M. Costa

Goal

Derive **model independent bounds** on SM-neutral and light dark sectors coupled to the visible sector via irrelevant portal interactions [1] from **future experiments dedicated to long lived particle (LLP) searches**.

Elusive Dark Sector (DS)

theory is **approx. conformal**



At $\Lambda_{UV} << E << \Lambda_{IR}$ → use **CFT** (conformal field theory) composite operators for DS !

$$\mathcal{L}_{\text{portal}} = \underbrace{\mathcal{O}_{\text{CFT}}}_{\mathcal{O},\, J_\mu^{DS},\, T_{\mu\nu}^{DS}} \times \underbrace{\mathcal{O}_{\text{SM}}}_{H^\dagger H,\, \bar{\psi}\gamma^\mu\psi,\, \ldots} \quad \Rightarrow \quad \text{Dim}[\mathcal{O}_{DS}\, \mathcal{O}_{SM}] > 4$$

$\text{dim}[\mathcal{O}_{SM}] \leq 4$

Minimal lagrangian

$$\mathcal{L}_{\text{portal}} = \frac{\kappa_{\mathcal{O}}}{\Lambda_{\text{UV}}^{\Delta_{\mathcal{O}}-2}} \mathcal{O}\, H^\dagger H + \frac{\kappa_J}{\Lambda_{\text{UV}}^2} J_\mu^{DS} J_{SM}^\mu + \frac{\kappa_T}{\Lambda_{\text{UV}}^4} T_{DS}^{\mu\nu} O_{\mu\nu}^{SM}$$

Dimless coefficients : $\kappa_{\mathcal{O}}, \kappa_J, \kappa_T$

Benchmark Models:

- Pure Yang Mills Dark Sector ,
- theory with free fermions and
- 5 D Randall Sundrum Dark Sectors

Dark Sector Production

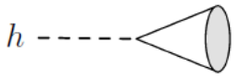
At $\Lambda_{\text{IR}} \ll \sqrt{\hat{s}} \ll \Lambda_{\text{UV}}$ **DS inclusive production** approximated by considering contributions only from conformal regime and using optical theorem:

$$\sum_n \int d\Phi_{DS} |\langle 0|O_{DS}|n\rangle|^2 = 2\,\text{Im}\,[i\langle 0|T\{O_{DS}O_{DS}\}|0\rangle]$$

operator interpolating DS state n from vacuum.

For higgs production ($\Lambda_{IR} < m_{higgs}$):

$$\Gamma_{h\to DS} = -\frac{1}{m_h}\frac{\kappa_{\mathcal{O}}^2 v^2}{\Lambda_{\text{UV}}^{2\Delta_{\mathcal{O}}-4}} \underbrace{\text{Im}\; i\,\langle \mathcal{O}(-p)\mathcal{O}(p)\rangle\,|_{p^2=m_h^2}}_{\text{CFT 2 point correlation function}} .$$



$$\frac{c_{\mathcal{O}}}{\pi^{3/2}} \frac{\Gamma(\Delta_{\mathcal{O}}+1/2)}{\Gamma(\Delta_{\mathcal{O}}-1)\Gamma(2\Delta_{\mathcal{O}})} (p^2)^{\Delta_{\mathcal{O}}-2}$$

Lifetime of Lightest DS Particle

When probed at energies >> Λ_{IR} $\mathcal{O}_{DS}$ excites CFT states with DS d.o.f.s
Strongly coupled # d.o.f.s > Weakly coupled # d.o.f.s

All DS decays to LDSP (ψ) which decays back to SM via portal of dim D.

- $m_\psi > m_{\text{EW}}$ $\quad \tau_\psi \sim \left[\Lambda_{\text{IR}} \frac{\kappa^2}{8\pi} \left(\frac{f^2}{\Lambda_{\text{IR}}^2}\right) \left(\frac{\Lambda_{\text{IR}}^2}{\Lambda_{\text{UV}}^2}\right)^{D-4}\right]^{-1}$ decay constant

$$\langle 0|\mathcal{O}|\psi\rangle = \hat{A}\, f\, \Lambda_{\text{IR}}^{\Delta-2}$$

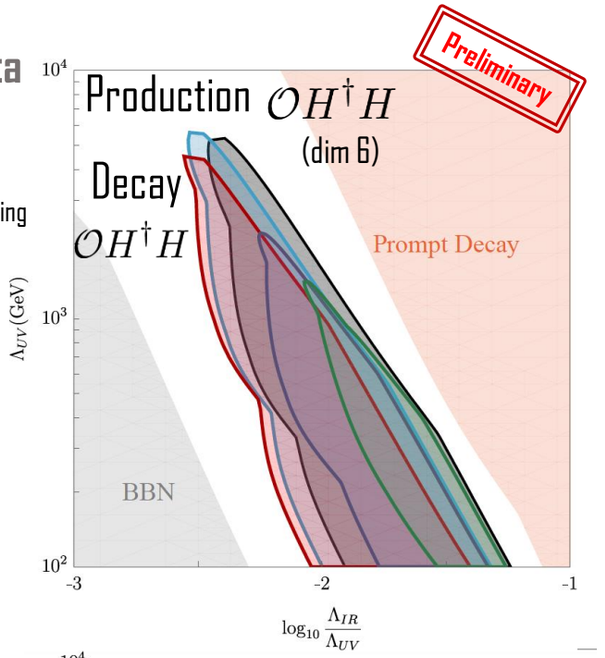
- $m_\psi < m_{\text{EW}}$ $\quad \tau_\psi = (\Gamma_h(m_\psi)\sin^2\theta_h)^{-1}$,

mixing angle

$$\tan 2\theta_h = \frac{2\delta_h}{m_\psi^2 - m_h^2},$$

mass mixing term

$$\delta_h = \kappa_{\mathcal{O}} v f \left(\frac{\Lambda_{\text{IR}}}{\Lambda_{UV}}\right)^{\Delta-2}$$



Results

- Constraints on resonant DS production via D=6 higgs portal from **displaced vertices (DV)** searches.
- Plots assume **weakly coupled** dark dynamics with n. of LDSPs = 2.
- *(top left)* decay via same **D=6 higgs portal**
- *(bottom left)* **generic D=6 portal**
- Model independent bounds from **current 2 DV searches in ATLAS** [2][3] + 1 DV searches in future proposed LLP experiments: **ANUBIS**, **MATHUSLA**, **AL3X**, **CODEX-b**.
- Big Bang Nucleosynthesis (BBN) exclusion since $\tau_{LDSP} < 1\ s$.
- Prompt decays ⟶ model dependent.

Conclusions

- Dark sectors coupled to SM via irrelevant portals are very elusive.
- Current collider searches barely probe the parameter space for such sectors.
- Future experiments will be powerful probes for such sectors.

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References: [1] Contino, Max, Mishra 2012.08537, [2] ATLAS Collaboration 1811.07370, [3] ATLAS Collaboration 1911.12575