INTERECTIONS OF DIRAC DARK MATTER FERMIONS WITH NUCLEONS and Xe NUCLEI IN COMPOSITE HIGGS MODELS

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CONTENT

- E_6 inspired Composite Higgs model (E_6CHM)
- Ligtest dirac composite particle (LDCP)
- Interection of LDCP with nucleons and Xe nuclei
- Conclusions

COMPOSITE HIGGS MODELS

General features of composite Higgs models (CHM):

- Two sectros: elementary and strongly coupled
- At the scale f strongly coupled sector results in the set of resonances.
- Strongly coupled sector possesses an approximate symmetry G. Composite states form complete representations of G.
- Higgs origin: Higgs doublet arise as a set of composite pseudo Nambu-Goldstone bosons (pNGb) at the scale f as a result of spontaneous breakdown of G.

E_6CHM

- Approximate $SU(6) \subset E_6$ symmetry in strong sector. Spontaneous breakdown of $SU(6)$ to $SU(5)$ at the scale $f \sim 5-10$ TeV results in 11 composite pNGb : $\Omega = (\mathbf{3},\mathbf{1}) \oplus (\mathbf{1},\mathbf{2}) \oplus (\mathbf{1},\mathbf{1}) = (T, H, \phi_0)$ of $SU(3)_C \times SU(2)_W$.
- Explicit symmetry breaking is caused by the SM gauge couplings and mixing between sectors.
- $U(1)_B$ is introduced to suppress proton decay rate.
- Colored triplet T with mass $\sim 1-2$ TeV is a distinctive signature of E_6CHM.

LIGHTEST COMPOSITE DIRAC PARTICLE

Strongly coupled sector results in (with $SU(3)_c \times SU(2)_W \times U(1)_Y \times U(1)_B$ in brakets)

$$\begin{aligned} \bar{\mathbf{6}}_1 \quad \rightarrow \quad & D_1^c = \left(\bar{3},\, 1,\, \frac{1}{3},\, \frac{1}{3}\right), \\ & L_1 = \left(1,\, 2,\, -\frac{1}{2},\, \frac{1}{3}\right), \\ & N_1 = \left(1,\, 1,\, 0,\, \frac{1}{3}\right); \end{aligned} \qquad \begin{aligned} \bar{\mathbf{6}}_2 \quad \rightarrow \quad & D_2^c = \left(\bar{3},\, 1,\, \frac{1}{3},\, -\frac{1}{3}\right), \\ & L_2 = \left(1,\, 2,\, -\frac{1}{2},\, -\frac{1}{3}\right), \\ & \overline{N}_2 = \left(1,\, 1,\, 0,\, -\frac{1}{3}\right), \end{aligned} \tag{1}$$

$$\mathcal{L}^N_{mass} = g_N f\, \left(\bar{6}_1\Omega\right)\left(\bar{6}_2\Omega\right) \rightarrow \mathcal{L}^N_{mass} = \mu_N \bar{N}_2 N_1 + h.c. = \mu_N \bar{\chi}_R \chi_L + h.c. \tag{2}$$

To suppress μ_N extra $U(1)_E$ approximate symmetry is imposed:

$$\bar{\mathbf{6}}_\mathbf{2} \longrightarrow e^{i\beta} \bar{\mathbf{6}}_\mathbf{2}, \qquad \bar{\mathbf{6}}_\mathbf{1} \longrightarrow \bar{\mathbf{6}}_\mathbf{1} \tag{3}$$

Dirac fermion $\chi \simeq N_1 + N_2$ is the lightest composite state in the spectrum

$\rightarrow$ $U(1)_B$ symmetry conservaton implies that χ is stable

After the $SU(2)_W \times U(1)_Y$ breakdown singlets N_1 and $\bar{N}_2$ get mixed with neutral components of $SU(2)_W$ doublets $L_1,\, L_2$ correspondingly:

$$\chi_L = N_1 \cos\theta_1 - \nu_1 \sin\theta_1\,, \quad \chi_R = N_2 \cos\theta_2 - \bar{\nu}_2 \sin\theta_2 \tag{4}$$

mixing angle $\sin\theta_1 \sim \sin\theta_2 \sim \frac{\eta}{f}$, where $\eta = 246\, GeV$

LDCP INTERECTION WITH SM

Interaction of χ with Z boson:

$$\mathcal{L}_Z^{(1)} = \frac{\lambda_1}{f^2} H^+ iD_\mu H \bar{N}_1 \gamma_\mu N_1 + \frac{\lambda_2}{f^2} H^+ iD_\mu H \bar{N}_2 \gamma_\mu N_2 \qquad \mathcal{L}_Z^{(2)} = \frac{\bar{g}}{2} Z_\mu \bar{\nu}_1 \gamma_\mu \nu_1 + \frac{\bar{g}}{2} Z_\mu \bar{\nu}_2 \gamma_\mu \nu_2 \tag{5}$$

$$\mathcal{L}_Z = \overline{\chi}(a_V^\chi \gamma^\mu + a_{PV}^\chi \gamma^\mu \gamma^5)\chi Z_\mu, \tag{6}$$

$$a_V^\chi = \frac{\bar{g}\eta^2}{8f^2} c_V\,, \qquad c_V \sim 1 \tag{7}$$

$$a_{PV}^\chi = \frac{\bar{g}\eta^2}{8f^2} c_{PV}\,, \qquad c_{PV} \sim 1 \tag{8}$$

Interaction of χ with Higgs doublet and photon are suppressed by $U(1)_E$:

$$\frac{\varepsilon_H}{f} H^\dagger H(\overline{N}_2 N_1) + h.c \to \mathcal{L}_{\chi\chi h} = \varepsilon_H \tfrac{\eta}{f} \bar{\chi}\chi h, \qquad \varepsilon_H \ll 1$$

$$\mathcal{L}_\gamma = \tfrac{\mu_\chi}{2} \bar{\chi}_R \sigma^{\mu\nu} \chi_L F_{\mu\nu} + h.c. \qquad \mu_\chi \sim \varepsilon_\mu \tfrac{e}{f} \ll \tfrac{e}{f}$$

Latest experimental constraints

$$\mu_{DM}^{exp} \leqslant 10^{-8}\text{GeV}^{-1}, \qquad \mu_\chi < \mu_{DM}^{exp} \left(\frac{\rho_{DM}}{\rho_\chi}\right)^{1/2} \tag{9}$$

B. Ali et al. [PICO], Phys. Rev. D 106 (2022) no.4, 042004 [arXiv:2204.10340 [astroph.CO]].

INTERECTION WITH NUCLEONS

Cross-section of spin-independent intection of χ (LDCP) with nucleons for $\mu_\chi = 0$

$$\sigma_{SI}^{N\chi} \overset{NR}{=} \frac{\mu^2}{\pi} \left\{ \frac{c_H^N \varepsilon_H^\chi \eta}{m_H^2 f} - \frac{c_V^N a_V^\chi}{m_Z^2} \right\}^2, \quad \mu = \frac{m_\chi m_N}{m_\chi + m_N} \tag{10}$$

Experimental constraints:

- $m_\chi = 200\ GeV: \quad \sigma_{SI}^{N\chi} < 6yb \times \frac{\rho_{DM}}{\rho_\chi}$
- $m_\chi = 500\ GeV: \quad \sigma_{SI}^{N\chi} < 12yb \times \frac{\rho_{DM}}{\rho_\chi} \qquad yb = 10^{-48}\,sm^2$
- $m_\chi = 1000\ GeV: \quad \sigma_{SI}^{N\chi} < 30yb \times \frac{\rho_{DM}}{\rho_\chi}$

Aalbers J. et al. Dark Matter Search Results from 4.2 Tonne-Years of Exposure of the LUX-ZEPLIN Experiment //arXiv preprint arXiv:2410.17036. – 2024.

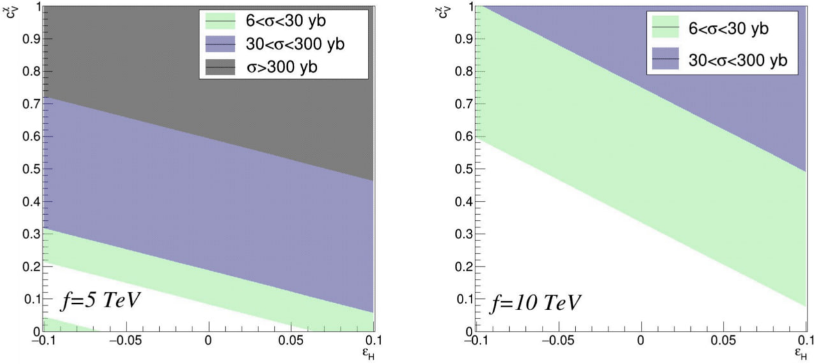

Рис. 1: Allowed range of the E_6CHM parameter space (white and green regions) in the $c_V^\chi - \varepsilon_H$ plane.

- For $f = 5$ TeV LDCP can comprise only a small fraction of DM: $\frac{\rho_\chi}{\rho_{DM}} \sim 0.1$
- For $f = 10$ TeV LDCP can comprise a significant fraction of DM: $\frac{\rho_\chi}{\rho_{DM}} \sim 1$

INTERACTION WITH Xe NUCLEI

In nonrelativistic limit amplitude is proportional to the interaction potential $U_N(q)$

$$M_{\chi N} \overset{NR}{=} -2m_N \cdot 2m_\chi \left(\xi^+_{j'}\xi^+_{s'}\right) \hat{U}_N(\vec{q}) \left(\xi_j \xi_s\right). \tag{11}$$

The potential of LDCP-nuclear interactions can be presented in the following form

$$\hat{U}(\vec{q}) = \sum_N \hat{U}_N(\vec{q}) = \hat{U}_{SI}(\vec{q}) + \hat{U}_{SD}(\vec{q}) \to \frac{d\sigma}{d\varepsilon_{rec}} = \frac{m_T}{2\pi \vec{v}_\chi^2}\langle \hat{U}^+ \hat{U}\rangle \tag{12}$$

$$\frac{d\sigma^{SI}_{DM-T}}{dy} = \frac{\tilde{\mu}^2 F^2_{SI}(\vec{q}^2)}{\pi}\left[c_1^2 + \frac{(e\mu_\chi Z)^2}{4\mu^2}\left(\frac{1}{y} - 1\right)\right] \tag{13}$$

$$c_1 = \frac{Ze\mu_\chi}{2m_\chi} - \frac{A\langle c_V^N\rangle a_V^\chi}{m_Z^2} + \frac{Ac_H^N c_H^\chi}{m_H^2}, \qquad y = \frac{\varepsilon_{rec}}{\varepsilon_{max}}, \qquad \tilde{\mu} = \frac{m_T m_\chi}{m_T + m_\chi} \qquad \varepsilon_{max} = \frac{(2\tilde{\mu}\vec{v}_\chi)^2}{2m_T} \tag{14}$$

where $\varepsilon_{rec} = \frac{\vec{q}^2}{2m_T}$, m_T - nuclear mass and nuclear formfactor:

$$F_{SI}(\vec{q}^2) = 3\left[\frac{\sin(|\vec{q}|r) - rq\cos(|\vec{q}|r)}{(|\vec{q}|r)^3}\right] e^{-|\vec{q}|^2 s^2} \tag{15}$$

$r = 1.12A^{1/3}$ fm, s =1 fm.

Hambye T., Xu X. J. Dark matter electromagnetic dipoles: the WIMP expectation //Journal of High Energy Physics.

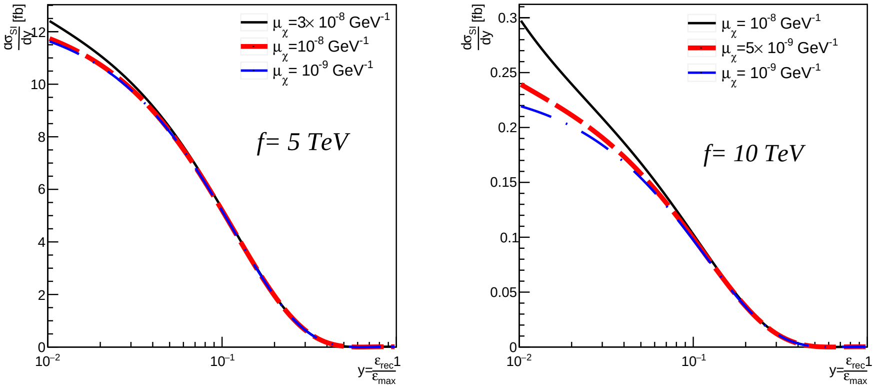

Рис. 2: Differential cross-section of spin-independent interection as a function of $^{129}_{54}\mathrm{Xe}$ nuclear recoil energy, i.e. $y = \varepsilon_{rec}/\varepsilon_{max}$, for different μ_χ values.

Current detector sensitivity ($\varepsilon_{rec} \gtrsim 3$ KeV) doesn't permit to observe the enhancement of $\chi - T$ differential cross-section at low recoil energies which is caused by electromagnetic interaction of LDCP.

CONCLUSIONS

It was argued that in CHMs the lightest dirac composite particle (LDCP) can comprise some fraction of the DM density.

In the E_6CHM with approximate $U(1)_E$

- interactions of LDCP with Z-boson, H-boson and photon are suppressed by scale f.
- the mass of LDCP, its magnetic moment and the interaction of LDCP with Higgs boson are futher suppressed by the approximate $U(1)_E$ symmetry.
- latest experimental constraints on DM-N spin-independent cross-section σ_{SI} imlies that LCDP can comprise only a small fraction of DM density for $f \sim 5$ TeV.
- current detectors sensitivity does not enable to detect the enhancement of $\chi - T$ differential cross-section at low recoil energies which is caused by electromagnetic interaction of LDCP.