Computer tools in particle physics

- Lecture 4 : Final exercise -

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A model with a dark sector

[Aristizabal Sierra, Staub, AV, 2015]

$$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_X$$

Vector-like = “joker” for model builders

Vector-like fermions

Link to SM fermions

$$Q = \left(\mathbf{3}, \mathbf{2}, \frac{1}{6}, 2 \right) \qquad L = \left(\mathbf{1}, \mathbf{2}, -\frac{1}{2}, 2 \right)$$

Scalars

$$\phi = (\mathbf{1}, \mathbf{1}, 0, 2) \qquad \chi = (\mathbf{1}, \mathbf{1}, 0, -1)$$

$U(1)_X$ breaking

Dark matter candidate

A model with a dark sector

[Aristizabal Sierra, Staub, AV, 2015]

$$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_X$$

Vector-like = “joker” for model builders

$$\mathcal{L}_m = m_Q \overline{Q} Q + m_L \overline{L} L$$

Vector-like (Dirac) masses

$$\mathcal{L}_Y = \lambda_Q \overline{Q_R} \phi q_L + \lambda_L \overline{L_R} \phi \ell_L + \text{h.c.}$$

VL – SM mixing

Symmetry breaking and dark matter

[Aristizabal Sierra, Staub, AV, 2015]

$$\langle H^0 \rangle = \frac{v}{\sqrt{2}} \qquad \langle \phi \rangle = \frac{v_\phi}{\sqrt{2}}$$

Massive Z' boson: $m_{Z'} = 2 g_X v_\phi$

DM candidate: χ

$$\begin{aligned} \mathcal{V}(\chi) &= m_\chi^2 |\chi|^2 + \frac{\lambda_\chi}{2} |\chi|^4 + \lambda_{H\chi} |H|^2 |\chi|^2 \\ &+ \lambda_{\phi\chi} |\phi|^2 |\chi|^2 + \left(\mu \, \phi \chi^2 + \text{h.c.} \right) \end{aligned}$$

$$\boxed{U(1)_X \to \mathbb{Z}_2}$$

Automatic DM stability

U(1) mixing

Nothing prevents U(1) factors from mixing

$$\mathcal{L} \supset \varepsilon \, F^{Y}_{\mu\nu} F^{\mu\nu}_{X}$$

This can be described by a matrix of gauge couplings:

$$\left(\begin{array}{cc} g_1 & g_{1X} \\ g_{X1} & g_X \end{array} \right)$$

DarkBS: benchmark point

BDarkBS1 benchmark point

$$\lambda = 0.26 \qquad \lambda_\phi = 0.1 \qquad \lambda_\chi = 10^{-5}$$
$$\lambda_{\phi\chi} = 10^{-5} \qquad \lambda_{H\phi} = 0 \qquad \lambda_{H\chi} = 0$$
$$m_\chi^2 = 3 \cdot 10^6 \, \mathrm{GeV}^2 \qquad \mu = 10 \, \mathrm{GeV} \qquad g_X = 1$$
$$m_Q = 1 \, \mathrm{TeV} \qquad m_L = 1 \, \mathrm{TeV} \qquad m_{Z'} = 4 \, \mathrm{TeV}$$

$$\lambda_Q = \begin{pmatrix} 0 \\ 3 \cdot 10^{-3} \\ 3 \cdot 10^{-3} \end{pmatrix} \qquad \lambda_L = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$

DarkBS at the LHC

$$\boxed{p\,p \to \mu^+\,\mu^-}$$

Chuck Norris fact of the day

Chuck Norris can kill two stones with one bird

DarkBS: benchmark point

BDarkBS2 benchmark point

$$m_{Z'} = 300\,\mathrm{GeV} \qquad \lambda_Q = \begin{pmatrix} 1 \\ 3 \cdot 10^{-3} \\ 3 \cdot 10^{-3} \end{pmatrix}$$