

Computer tools in particle physics

- Lecture 4 : Final exercise -

Avelino Vicente
IFIC – CSIC / U. Valencia

Curso de doctorado de la U. València

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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

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

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

Scalars

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

$U(1)_X$ breaking

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

Dark matter candidate

A model with a dark sector

[Aristizabal Sierra, Staub, AV, 2015]



Vector-like = “joker”
for model builders

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

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

Vector-like (Dirac)
masses

$$\mathcal{L}_Y = \lambda_Q \bar{Q}_R \phi q_L + \lambda_L \bar{L}_R \phi \ell_L + \text{h.c.}$$

VL – SM mixing

Symmetry breaking and dark matter

[Aristizabal Sierra, Staub, AV, 2015]

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

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

DM candidate: χ

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

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

Automatic DM stability

U(1) mixing

Nothing prevents **U(1) factors** from mixing

$$\mathcal{L} \supset \varepsilon F_{\mu\nu}^Y F_X^{\mu\nu}$$

This can be described by a **matrix** of gauge couplings:

$$\begin{pmatrix} g_1 & g_{1X} \\ g_{X1} & g_X \end{pmatrix}$$

DarkBS: benchmark point

BDarkBS1 benchmark point

$$\lambda = 0.26$$

$$\lambda_{\phi\chi} = 10^{-5}$$

$$m_{\chi}^2 = 3 \cdot 10^6 \text{ GeV}^2$$

$$m_Q = 1 \text{ TeV}$$

$$\lambda_{\phi} = 0.1$$

$$\lambda_{H\phi} = 0$$

$$\mu = 10 \text{ GeV}$$

$$m_L = 1 \text{ TeV}$$

$$\lambda_{\chi} = 10^{-5}$$

$$\lambda_{H\chi} = 0$$

$$g_X = 1$$

$$m_{Z'} = 4 \text{ TeV}$$

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

$$\lambda_L = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$

DarkBS at the LHC

$$p p \rightarrow \mu^+ \mu^-$$

Chuck Norris fact of the day
*Chuck Norris can kill two stones
with one bird*



DarkBS: benchmark point

BDarkBS2 benchmark point

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