The Chacal 2024 Competition

MC generators and LHC recasting

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Competition open until February 15, 2024

Send your entry as a single slide to Deepak and Louie

The model - a composite dark matter setup

Inspiration from theories with DM and partial compositeness

- Top mass from mixing SM quarks with two VLQ partners ➞ an $SU(2)_L$ doublet and an $SU(2)_L$ singlet

$$Q_{L,R} = \begin{pmatrix} T_{L,R} \\ B_{L,R} \end{pmatrix} \qquad \widetilde{T}_{L,R}$$

Model similar to those currently studied by the LHC DM WG

- A scalar dark matter candidate X

Simplified model

- 3 mediators and 1 dark matter

$$T_{L,R}\,, \quad \tilde{T}_{L,R}\,, \quad B_{L,R} \quad \text{and} \quad X$$

- Lagrangian

$$\mathcal{L}_{\text{BSM}} = \mathcal{L}_{\text{kin}} - M_T \overline{T}\, T - M_B \overline{B}\, B - M_{\tilde{T}} \overline{\tilde{T}}\, \tilde{T} - \frac{1}{2} M_X X^2 + \left(\lambda_Q \left[\, \overline{T_R}\, t_L + \overline{B_R}\, b_L \,\right] X + \lambda_T\, \overline{\tilde{T}_L}\, t_R\, X + \text{H.c.} \right)$$

➞ free parameters: 4 masses and 2 couplings

Further-simplified model

- All VLQ masses equal: $M_Y \equiv M_T = M_B = M_{\widetilde{T}}$
- All BSM couplings equal: $\lambda \equiv \lambda_Q = \lambda_T$
- 3 parameters in total :
  - ➞ The VLQ mass M_Y
  - ➞ The DM mass M_X
  - ➞ The BSM coupling λ

Simulation tool chain

Hard process and VLQ decays with MG5aMC

- The 'Chacal' UFO model with the 'F3S-VLQ' restriction
  (https://cernbox.cern.ch/s/RkBO8vAFQpy2x0w)

  ➙ to be imported in the MG5aMC CLI (to be started with `./bin/mg5_aMC` from the MG5aMC installation folder)

```
import model DMSimp_t-F3S_VLQ --modelname
```

The QCD environment

- Parton showering and hadronisation with Pythia 8 (to be run within MG5aMC)

  ➙ generation of hepmc files describing the signal

- Confrontation to measurements with Contur

  ➙ determination of CLs exclusion level

Setting up MG5aMC

To make life easier: multiparticle labels

- Definition of a common VLQ label `yy`

```
define yy = yf3qu3 yf3qu3~ yf3qd3 yf3qd3~ yf3u3 yf3u3~
```

$\widetilde{T}$ PDG code: 5920006

T PDG code: 5910006

B PDG code: 5910005

- The DM particle label (PDG code 51): `xs`

Signal simulation at leading order in QCD

- The monojet component

```
generate p p > xs xs j $ yy
```

- Associated production

```
generate p p > xs yy
```

→ VLQ decay via MADSPIN

The $ sign make sure the two samples do not overlap

- VLQ pair production

```
generate p p > yy yy
```

→ VLQ decay with MADSPIN
(MADSPIN card to be modified on run time)

```
decay yy > all xs
```

Test of the setup

Benchmark point (changes in the parameter card)

- VLQ mass $M_Y = 1$ TeV
- BSM coupling $\lambda = 1$
- DM mass $M_X = 50$ GeV
- All VLQ widths to be recalculated (set to `auto`)

Tasks

- Get the widths of all VLQs
- Get the cross sections for all signal contributions
- Get the exclusion from CONTUR

Processes	Cross sections
$pp \to XXj$	0.063 fb
$pp \to YX, \quad Y \to qX$	1.90 fb
$pp \to YY, \quad Y \to qX$	75.8 fb

Collider setup (changes in the run card)

- Number of events
  - ➙ line 26: `50000 = nevents`
- NNPDF4.0 parton densities (LO set)
  - ➙ line 42: `lhapdf = pdlabel`
  - ➙ line 43: `331900 = lhaid`
- No systematics
  - ➙ line 132: `False = use_syst`

VLQ	Total width	Main decay modes
B	10.7 GeV	$\mathrm{BR}(B \to Xb) = 92.1\,\%$ $\mathrm{BR}(B \to XW^- t) = 4.71\,\%$
T	10.8 GeV	$\mathrm{BR}(T \to Xt) = 91.3\,\%$ $\mathrm{BR}(T \to XW^+ b) = 5.22\,\%$
$\widetilde{T}$	9.89 GeV	$\mathrm{BR}(\widetilde{T} \to Xt) = 100\,\%$

2-body decays considered only

Exercise

16 proposed benchmark points (choices of masses)

- VLQ mass $M_Y =$ 750 GeV, 1 TeV, 1.5 TeV, 2 TeV
- BSM coupling $\lambda = 1$
- DM mass $M_X =$ 50 GeV, 125 GeV, 250 GeV, 500 GeV
- Pick up a few points and get cross sections and exclusions
  ➙ preferably different points from those of your friends

Tasks

- Get the widths of all VLQs
- Get the cross sections for all signal contributions
- Get the exclusion from CONTUR