FeynRules-Madgrah pipeline tutorial

immediate

May 23, 2016

Task I

We will extend the SM with the following Z' Lagrangian:

$$\mathcal{L}_{Z'} \;=\; -\frac{1}{4}\,Z'_{\mu\nu}Z'^{\mu\nu} \;+\; \frac{M_{Z'}^2}{2}Z'_{\mu}Z'^{\mu} \;+\; \frac{c_u}{2}\;Z'_{\mu}\;(\bar{u}_R\gamma^{\mu}u_R) \;+\; \frac{c_t}{2}\;Z'_{\mu}\;(\bar{t}_R\gamma^{\mu}t_R) \tag{1}$$

We will not assume that Z' is a gauge boson, just a massive vector field. We will now create a model file `Zprime_Vipava.fr` for this Lagrangian using the template file.

Complete the following steps. Don't hesitate to ask for help if necessary :)

- In a new model file define the Z' boson as `V[6]` in the `M$ClassesDescription`. Assign a 1 TeV mass and 1 GeV width. For the syntax, take a good look at the Z-boson class in the SM model file, try to immitate it for the Z'. Do not include the Quarks, these are already in the SM model file `sm.fr`.
- Include the two new couplings in `M$Parameters` as real external parameters. For the syntax, imitate the any of the scalar parameters in the SM model file. Asign a `BlockName` of your choice, e.g. ZPRIME. Set the coupling values for both parameters to 1. And also include `"InteractionOrder->` {`NP,1`}", this is for MadGraph to understand that any vertex with one of these couplings is NP, i.e. New Physics!
- To write down the Lagrangian, use the following expressions for the right handed (RH) upper quark currents: `uRbar[r,f,i].uR[s,f,i]` (the dot is curacial here! fermions do not commute). The RH fields `uR` are defined in F[14] in the SM model file. Try to understand the indices.

Once you have written down the Lagrangian, add the following lines to the file:

```
M$InteractionOrderHierarchy = { {QCD, 1}, {QED, 2}, {NP, 1} }
M$InteractionOrderLimit = { { { NP,2 } } }
```

This is for MadGRaph to understand that the NP coupling is as important as QCD at the moment of simulating the collisions.

Save `Zprime_Vipava.fr` in its own directory in /models. Open a Mathematica notebook `.nb`, load FeynRules and set the path to the Zprime model file. Load the model along with the SM model file:

```
LoadModel["SM.fr", "Zprime_Vipava.fr"]
```

Now check that the Lagrangian has the correct form and that the following is ok:

```
CheckHermiticity[LSM + LZprime]
CheckMassSpectrum[LSM + LZprime]
```

Generate the Feynman rules:

```
FeynmanRules[LZprime, FlavorExpand -> True]
FeynmanRules[LSM, FlavorExpand -> True]
```

Finally, if everything is fine write the UFO for MadGraph:

```
WriteUFO[LSM + LZprime ]
```

Move the UFO directory to the MG5/models.

Task II

1. Load the Zprime model in MG (syntax: import model Zprime_Vipava) and type

```
generate p p > t t
output
open index.html
```

Go to "Feynman diagrams" column in "Process information". Check out all the diagrams contributing. Find the signal process with the Z'. Notice that the rest of the diagrams are mediated by SM particles and constitue the main background to our NP contribution!

In order to have a consistent toy model we need to calculate the correct decay width of Z' (the 1 GeV value put in FeynRules is not the true width).

Decay 1000 Z' events into its possible decay channels using the "add process" command. Go to the Zprime_Vipava UFO directory and change the value of the width from 1 to the one you just calculated. Relaunch Magraph for it to take effect. We now have a consistent Z prime toy model :)...

2. Calculate the branching ratios of each decay channel. They should be approximately equal. Why are they not exactly equal? Hint: Remember the the $M_{Z'} = 1\text{TeV}$ while $m_u = 0$ and $m_t = 173$ GeV.

3. Calculate the $t\bar{t}$ resonance via Z' in the narrow width approximation (NWA) i.e. calculate the cross-section of Z' production and then multiply by the Branching ratio into $t\bar{t}$. Now calculate the full cross-section of the process $pp \to t\bar{t}$ through the s-channel Z' only. In order to isolate the signal diagram from the background diagrams play with the interaction orders `QED, QCD, NP`. Look at the $t\bar{t}$ resonance in the plot!

4. Redo the previous process $pp \to t\bar{t}$ but now decay the top pair in the full hadronic channel $t \to bW^+ \to bjj$, $\bar{t} \to \bar{b}W^- \to \bar{b}jj$. In order to isolate the signal from the background veto the unwanted background diagrams with the command "/" [1]. Generate 10k events and now run `Pythia` and also turn on the detector simulator `Delphes`. Look at the plot of the invariant mass of the leading and subleading jets in the partonic plots. Any resonance? What happened? Now look at the Plots at the detector level. What changed? what happened?

5. Since our resonance is lost due to the inhability to recontruct the top quarks due to the high jet multiplicity, parton showers, and also because of the detector smearing effects, we will now try to implement a simple search strategy. If we are lucky we may extract the resonance!

Generate $pp \to t\bar{t}$ and decay the tops in the hadronic channel. This time allow for SM diagrams also (the peak is now even more hidden under background!). Generate 20k events. Now go into the delphes_card. We will now change the cone definition of the jet! Change in the `MC truth jet finder` and `jet finder` Modules and change `ParameterR` from 0.5 to 1.5. This parameter when larger allows for jets with larger cones. Run pythia and Delphes. Check now at the invariant mass of the b and jets. Any little bump? Why do you think allowing for fat jets works could work?

Hint: Think about the top quarks being boosted and their decays being collimated.

6. Besides the $t\bar{t}$ resonance, which other resonance should you expect? Does it have the same issues as the $t\bar{t}$ resonance discussed above? Check it out!

[1] `pp > X / g`, vetoes any diagram with an internal gluon