How to add fermionic dimension-8 operators to SmeftFR v3

Dimension-8 bosonic operators do not exhaust all possibilities that one may want to take into account. It is therefore important to know how to include in SmeftFR operators containing fermionic fields. As the procedure is currently still rather complicated, we did not make it a standard feature of published code, but we provide instructions on how to do that for a chosen example of fermionic operator.

The prescription below refers to specific line numbers of version 3.02 of the code. Corresponding places can be easily identified, even if changed, in the newer versions. We're working in the basis of [1] but operators in any basis can be added in this or similar way. Below we list the steps which one may follow in order to add 2-fermion dimension-8 operators.

1 Adding 1st fermionic operator

Operator that we are going to add is from Table 7 in [1]:

$$Q^{(4)}_{e^2BH^2D} = (\bar{e}_p\gamma^\nu e_r)\left(H^\dagger \overleftrightarrow{D}^\mu H\right)\widetilde{B}_{\mu\nu}$$

As mentioned above, we assume that the starting version of the code is identical with the one available on the SmeftFR webpage as v3.01. Modifications which needs to be done are:

1. Go to /lagrangian directory and create new file 29_TwoFermionDim8.fr containing the definition of the operator:

   ```
   LQe2Bphi2Dn4 := Module[ {sp1,sp2,ii,jj,ff1,ff2,mu,nu,al,be,aux},

   aux = (Phi8bar[jj] DC[Phi8[jj],mu] - DC[Phi8bar[jj],mu] Phi8[jj])
   lRbar[sp1,ff1].lR[sp2,ff2] Ga[nu,sp1,sp2] Eps[mu,nu,al,be]/2 HC[FS[B,al,be]];

   aux = ExpandIndices[ ToExpression[SMEFT$WB <> "e2Bphi2Dn4"][ff1,ff2]aux,
   FlavorExpand->{SU2W,SU2D} ];

   aux /.SMEFTGaugeRules];
   ```

2. Open file /code/smeft_variables.m and make the following changes:

   (a) Line 85: change SMEFT$Dim8Operators by adding "e2Bphi2Dn4".

   (b) Line 126: add TwoFermionOperators8 = {"e2Bphi2Dn4"};.

(c) Line 163: change `Tensor2WC` by adding `{"e2Bphi2Dn4", VLR,VLR,True,False}`.

(d) Line 234: change `Tensor2Class` by adding `"e2Bphi2Dn4" -> 2`.

(e) Line 299: change `Tensor2Ind` by adding
`"e2Bphi2Dn4" -> {{1, 1, True}, {1, 2, False}, {1, 3, False},`
`{2, 2, True}, {2, 3, False}, {3, 3, True}}`.

3. Open file `/code/smeft_io.m` and:

(a) Line 204: change `SMEFTLoadLagrangian` function by adding
`Get[FileNameJoin[{SMEFT$Path,"lagrangian","29_TwoFermionDim8.fr"}]];`.

4. Open file `/code/smeft_functions.m` and:

(a) Line 125: change `GenerateOperatorLists` function by adding
`SMEFT$Dim8FermionOperators = ToExpression[l <> #] & /@ Intersection[Join[`
`TwoFermionOperators8 ], SMEFT$OperatorList ];`.

(b) Line 131: change `SMEFT$Dim8NullList` in `GenerateOperatorLists` function in the following way
`SMEFT$Dim8NullList = Join[ (# -> 0 & /@ SMEFT$Dim8BosonOperators),`
`(#[__] -> 0 & /@ SMEFT$Dim8FermionOperators) ];`.

5. Open file `/code/smeft_initialization.m` and:

(a) Line 268: change `SMEFTLoadModel` function by adding
`SMEFT$LGferm6 = 0;`.

(b) Line 285: change `SMEFTLoadModel` function by adding
`If[ SMEFT$ExpansionOrder > 1,`
`If[ MemberQ[ SMEFT$OperatorList, # ], SMEFT$LGferm6 = SMEFT$LGferm6`
`+ Lam`^{2}` ToExpression["LQ"<>#] ] & /@ TwoFermionOperators8;];`.

6. Open file `/code/smeft_gaugeint.m` and:

(a) Line 19: modify `tmp` variable by adding `SMEFT$LGferm6`
`tmp = SMEFT$LGferm + SMEFT$LGferm6/.G[___]->0 /.uq[___]->0/.dq[___]->0;`.

7. Go to `smeft_fr_init.m` and `SmeftFR-init.nb` and add `"e2Bphi2Dn4"` to the `OpList8` which lists all available dimension-8 operators.

2 Adding subsequent operators

Once the first operator has been added, including the next one is much simpler and requires changes in only two files in `/code` directory. We'll present this on the another example from Table 7 in [1]:

$$Q_{e^2WH^2D}^{(4)} = (\bar{e}_p\gamma^\nu e_r)\left(H^\dagger \overleftrightarrow{D}^{I\mu} H\right)\widetilde{W}_{\mu\nu}^I$$

1. Open file `/lagrangian/29_TwoFermionDim8.fr` and add next operator.

   ```
   LQe2Wphi2Dn4 := Module[{sp1,sp2,m,ii,jj,ff1,ff2,mu,nu,al,be,aux},

   aux = 2 Ta[m,ii,jj] (Phi8bar[ii] DC[Phi8[jj],mu] - DC[Phi8bar[ii],mu]
   Phi8[jj]) lRbar[sp1,ff1].lR[sp2,ff2] Ga[nu,sp1,sp2] Eps[mu,nu,al,be]/2
   HC[FS[Wi,al,be,m]];

   aux = ExpandIndices[ ToExpression[SMEFT$WB <> "e2Wphi2Dn4"][ff1,ff2]
   aux, FlavorExpand->{SU2W,SU2D} ];

   aux /.  SMEFTGaugeRules ];
   ```

2. Open file `/code/smeft_variables.m` and follow the instructions below:

   (a) Line 85: change `SMEFT$Dim8Operators` by adding `"e2Wphi2Dn4"`.
   (b) Line 126: change `TwoFermionOperators8` by adding `"e2Wphi2Dn4"`.
   (c) Line 164: change `Tensor2WC` by adding `{"e2Wphi2Dn4", VLR,VLR,True,False}`.
   (d) Line 235: change `Tensor2Class` by adding `"e2Wphi2Dn4" -> 2`.
   (e) Line 302: change `Tensor2Ind` by adding
       `"e2Wphi2Dn4" -> {{1, 1, True}, {1, 2, False}, {1, 3, False},`
       `{2, 2, True}, {2, 3, False}, {3, 3, True}}`.

3. Go to `smeft_fr_init.m` and `SmeftFR-init.nb` and add `"e2Wphi2Dn4"` to the `OpList8` which lists all available dimension-8 operators.

References

[1] C. W. Murphy, Dimension-8 operators in the Standard Model Eective Field Theory, JHEP 10 (2020) 174. arXiv:2005.00059, doi:10.1007/JHEP10(2020)174.