FeynRules Tutorial

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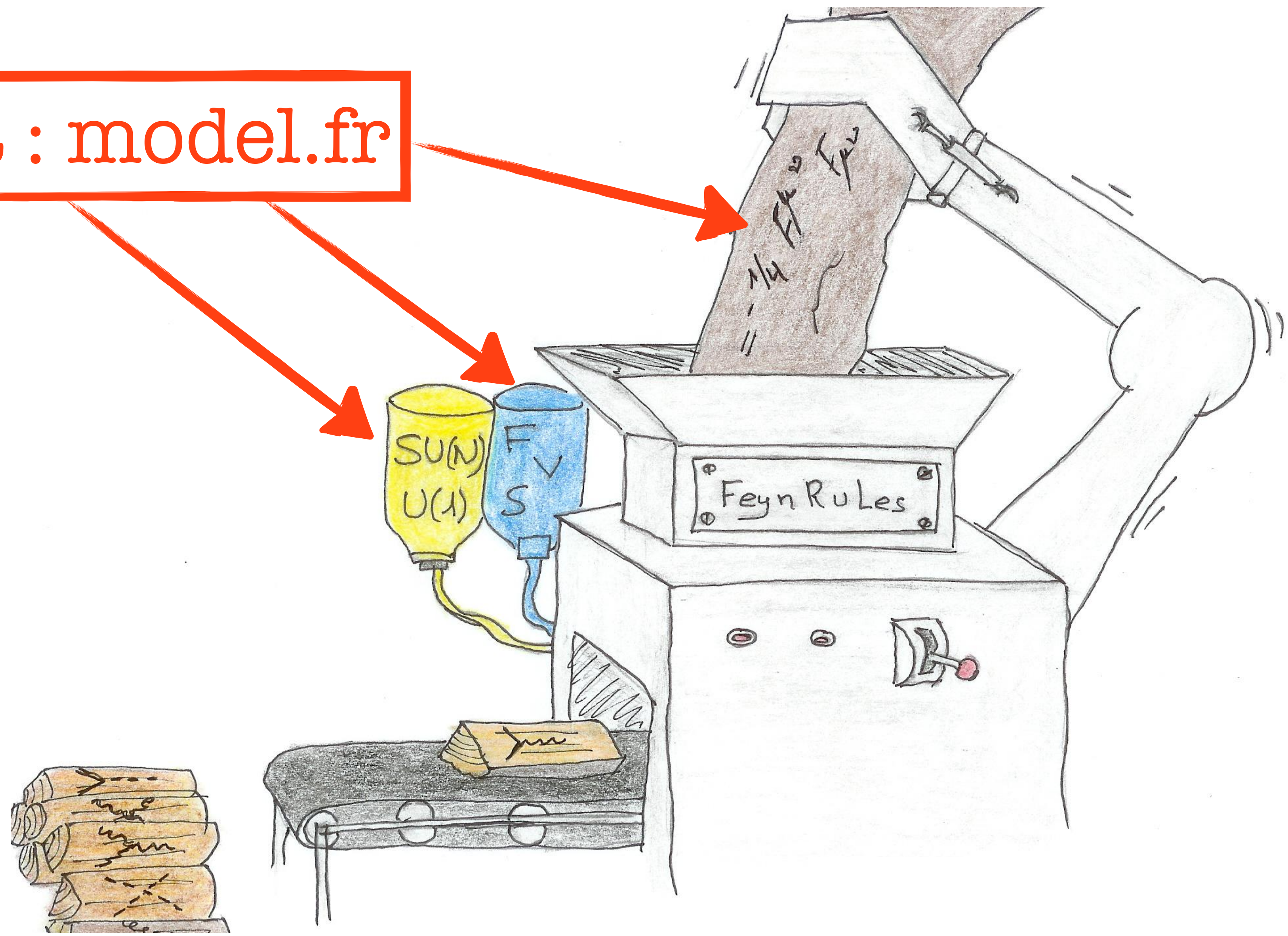
FeynRules

Input : model.fr



Output : vertices

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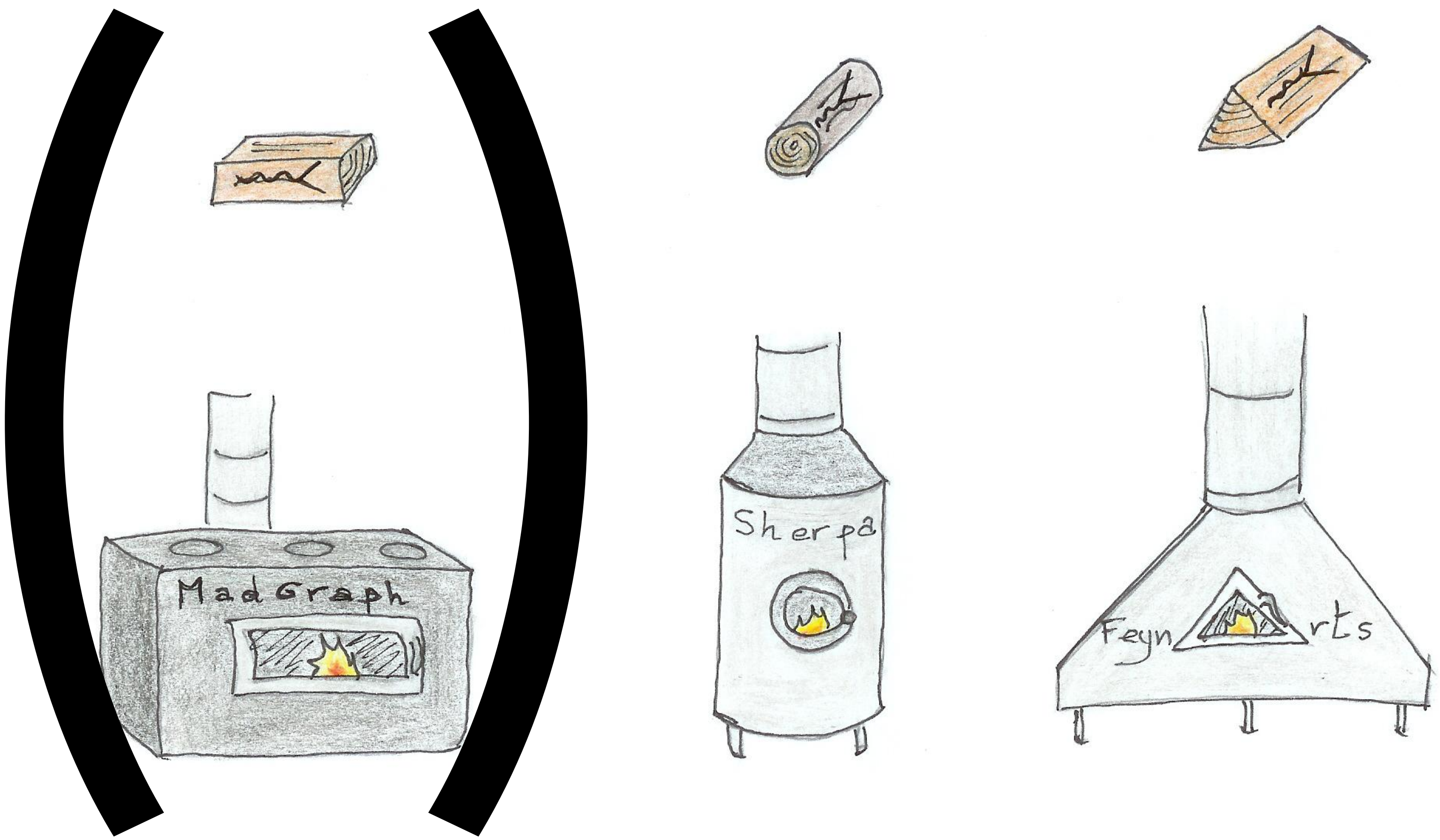
FeynRules outputs



FeynRules outputs can be used directly by event generators

UFO : output with the full information used by several generators

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The model : SM extension

$SU(3) \times SU(2) \times U(1)_Y \quad + \quad \mathbb{Z}_2$ (SM Fields: +1)

$$\left.\begin{array}{r} \phi_1 \sim (1,1,0) \\ \phi_2 \sim (1,1,0) \\ U \sim (3,1,2/3) \\ E \sim (1,1,-1) \end{array}\right\} \quad -1$$

Vector-like

$$\mathcal{L}_{kin,scalar} = 1/2\partial_\mu\phi_1\partial^\mu\phi_1 + 1/2\partial_\mu\phi_2\partial^\mu\phi_2 - \frac{m_1^2}{2}\phi_1^2 - \frac{m_2^2}{2}\phi_2^2 - m_{12}^2\phi_1\phi_2$$

$$\mathcal{L}_{dirac,mass} = M_U\overline{U}U + M_E\overline{E}E$$

+ Kinetic/ gauge term

$$\mathcal{L}_{FFS} = \lambda_1\,\phi_1\,\overline{U}P_R u + \lambda_2\,\phi_2\,\overline{U}P_R u + \lambda_1'\,\phi_1\,\overline{E}P_R l + \lambda_2'\,\phi_2\,\overline{E}P_R l + \text{h.c.}$$

! Sum over generation !

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Step 0

- Download FeynRules 2.0 from https://feynrules.irmp.ucl.ac.be
- Copy the SM directory in feynrules/models and rename it Tutorial
- Create a model file Tutorial.fr (text file) in the Tutorial directory

Step 1 : model information

```
M$ModelName = "Tutorial";

M$Information = {Authors -> {"C.
Degrande"},
 Version -> "1.0",
 Date -> "21. 07. 2014",
 Institutions -> {“IPPP Durham"},
 Emails ->
 {“celine.degrande@durham.ac.uk“}
};
```

Step 2 : parameters

- 9 new external parameters : m_1, m_2, m_{12}, M_U, M_E, λ_1, λ_2, λ'_1, λ'_2

See Step 3

```
M$Parameters = {
 ...
  MM1 == {
   ParameterType -> External,
   Value -> 200},
 ...
 };
```

Step 2 : parameters

- 9 new external parameters : m_1, m_2, m_{12}, M_U, M_E, λ_1, λ_2, λ'_1, λ'_2

```
M$Parameters = {
 ...
  lam1 == {
     ParameterType -> External,
     Indices -> {Index[Generation]},
     Value -> {lam1[1]->0.1,lam1[2]->0.1,
               lam1[3]->0.1},
     InteractionOrder -> {NP, 1},
     ComplexParameter -> False},
 ...
 };
```

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Step 2 : parameters

- 3 internal parameters : M_1, M_2, ϑ

$$\begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix} = \begin{pmatrix} -\sin\theta & \cos\theta \\ \cos\theta & \sin\theta \end{pmatrix} \begin{pmatrix} \Phi_1 \\ \Phi_2 \end{pmatrix}$$

Interaction eigenstates

Mass eigenstates

- `ParameterType` is `Internal`
- `Value` is a Mathematica expression

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Step 2 : parameters

Example : The mixing angle

```
M$Parameters = {
 ...
  th == {
      ParameterType -> Internal,
      Value -> ArcTan[2 MM12^2/(MM1^2 - MM2^2)]/
  2 + Pi/2},
 ...
 };
```

Diagonalisation

Mass matrix eigenvalues :

Sqrt[(MM1^2 + MM2^2 - Sqrt[MM1^4 + 4*MM12^4 - 2*MM1^2*MM2^2 + MM2^4])/2]

Sqrt[(MM1^2 + MM2^2 + Sqrt[MM1^4 + 4*MM12^4 - 2*MM1^2*MM2^2 + MM2^4])/2]

Step 3 : fields

U	E	ϕ_1	ϕ_2	Φ_1	Φ_2
uv	ev	pi1	pi2	p1	p2

```
M$ClassesDescription = {
...
 F[100] == {
  ClassName -> uv,
  SelfConjugate -> False,
  Indices -> {Index[Colour]},
  QuantumNumbers -> {Y -> 2/3, Q -> 2/3},
  Mass -> {Muv, 500},
  Width -> {Wuv,1}
 },
...
}
```

Id # : Unique (Check in SM.fr)

Defined in SM.fr

Step 3 : fields

U	E	ϕ_1	ϕ_2	Φ_1	Φ_2
uv	ev	pi1	pi2	p1	p2

```
M$ClassesDescription = {
...
S[102] == {
        ClassName      -> p1,
        SelfConjugate -> True,
        Indices        -> {},
        Mass           -> {MPe1, Internal},
        Width          -> {Wpe1, 1}},
...
}
```

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Step 3 : fields

U	E	ϕ_1	ϕ_2	Φ_1	Φ_2
uv	ev	pi1	pi2	p1	p2

```
S[100] == {
 ClassName -> pi1,
 SelfConjugate -> True,
 Indices -> {},
 Unphysical -> True,
 Definitions -> {pi1 -> - Sin[th] p1 +
 Cos[th] p2}
},
```

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Warning

with

{} , ; [] Case

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Step 4 : Lagrangian

```
$FeynRulesPath =
 SetDirectory["~/feynrules"];
<< FeynRules`

SetDirectory[ $FeynRulesPath <> "/Models/
Tutorial"]
LoadModel["SM.fr", "Tutorial.fr"]

LoadRestriction["DiagonalCKM.rst",
"Massless.rst"]
```

Step 4 : Lagrangian

$$\frac{1}{2}\partial_\mu\phi_1\partial^\mu\phi_1 - \frac{1}{2}m_1^2\phi_1^2$$

```
1/2 del[pi1, mu]del[pi1, mu] - 1/2 MM1^2 pi1^2
```

$$i\,\bar{U}\gamma^\mu D_\mu U - M_U\bar{U}U$$

```
I uvbar.Ga[mu].DC[uv, mu] - Muv uvbar.uv
```

Fermions anti-commute

Defined in SM.fr

$$\lambda_1\,\phi_1\,\bar{U}P_+t$$

```
Lint:=lam1[ff] pi1 ProjP[ss1,ss2]
  uvbar[ss1,ii].uq[ss2, ff, ii]
```

```
HC[Lint]
```

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Step 5 : run FeynRules

```
vertices = FeynmanRules[ LNew ];

CheckMassSpectrum[ LNew ]

ComputeWidths[vertices];
PartialWidth[ {uv, t, p1} ]
TotWidth[ uv ]
BranchingRatio[  {uv, t, p1}]

SetDirectory["~/mg5amcnlo/models"];
WriteUFO[ LSM + LNew ];
```