

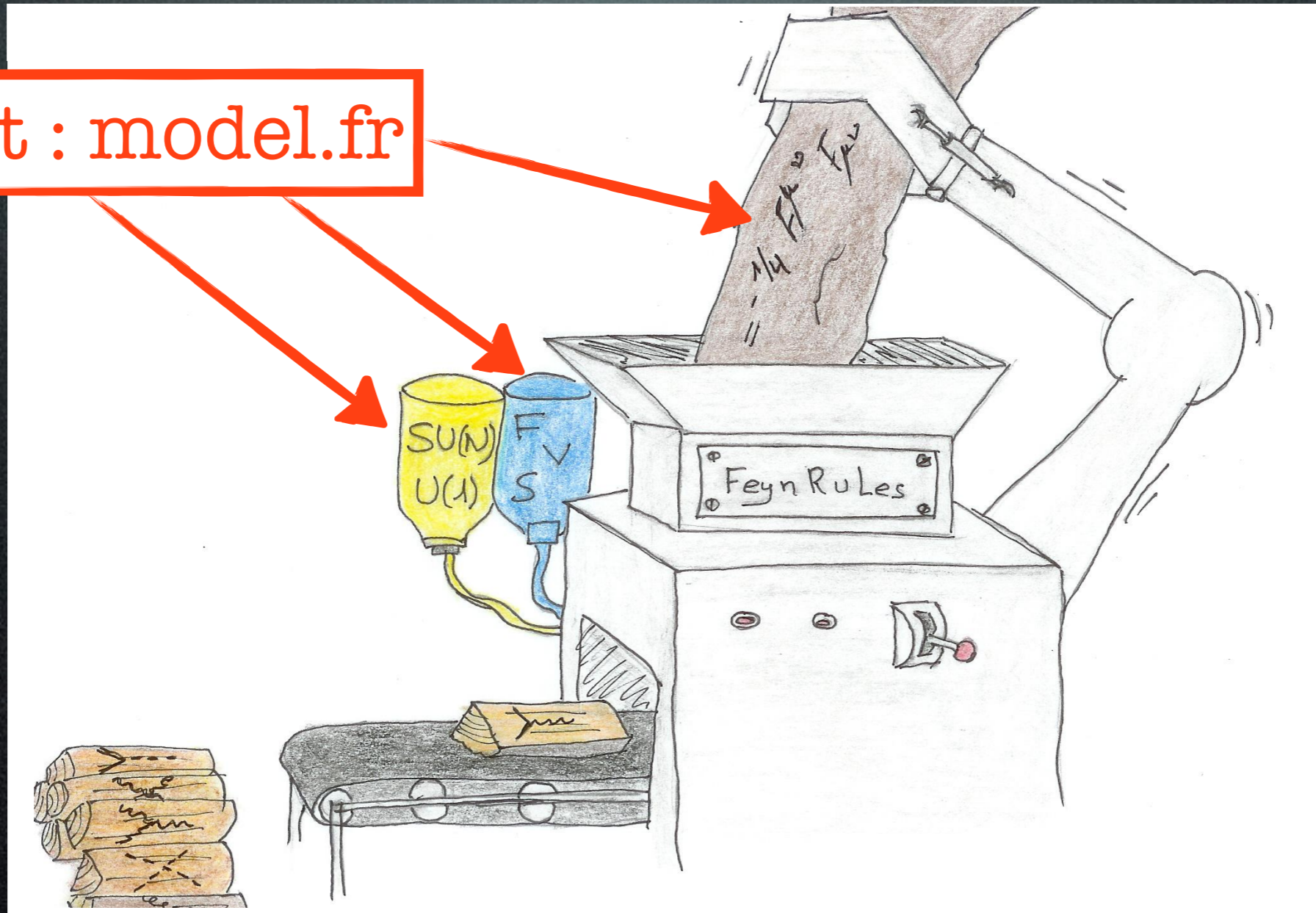
FeynRules Tutorial

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FeynRules

Input : model.fr



Output : vertices

FeynRules outputs



FeynRules
outputs can be
used directly by
event generators

UFO : output with
the full information
used by several
generators



The model : SM extension

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

$$\phi_1 \sim (1, 1, 0)$$

$$\phi_2 \sim (1, 1, 0)$$

$$U \sim (3, 1, 2/3)$$

$$E \sim (1, 1, -1)$$

} -1

Vector-like

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

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

+ Kinetic/
gauge term

$$\mathcal{L}_{FFS} = \lambda_1 \phi_1 \bar{U} P_R t + \lambda_2 \phi_2 \bar{U} P_R t + \lambda'_1 \phi_1 \bar{E} P_R e + \lambda'_2 \phi_2 \bar{E} P_R e + H.c.$$

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)

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 : $m_1, m_2, m_{12}, M_U, M_E, \lambda_1, \lambda_2, \lambda'_1, \lambda'_2$

See Step 3

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

Step 2 : parameters

- 9 new external parameters : $m_1, m_2, m_{12}, M_U, M_E, \lambda_1, \lambda_2, \lambda'_1, \lambda'_2$

See Step 3

```
M$Parameters = {
```

```
...
```

```
MM1 == {  
  ParameterType -> External,  
  Value -> 200},
```

```
...
```

```
};
```

```
InteractionOrder -> {NP, 1},
```


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

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}  
},
```

```
...
```

```
}
```

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, Defined in SM.fr  
  Indices -> {Index[Colour]},  
  QuantumNumbers -> {Y -> 2/3, Q -> 2/3},  
  Mass -> {Muv, 500},  
  Width -> {Wuv, 1}  
},  
...  
}
```

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, 0 -> 2/3},
```

```
Mass -> {Muv, 500, {Mpe1, Internal}}
```

```
Width -> {Wuv, 1}
```

```
},
```

```
...
```

```
}
```

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}  
},
```

Step 4 : Lagrangian

```
$FeynRulesPath =  
  SetDirectory[ "~/feynrules" ];  
<< FeynRules`  
  
SetDirectory[ $FeynRulesPath <> "/Models/  
Tutorial" ]  
LoadModel[ "SM.fr", "Tutorial.fr" ]  
  
LoadRestriction[ "DiagonalCKM.rst",  
"Massless.rst" ]
```

Step 4 : Lagrangian

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

$$1/2 \text{del}[\text{pi}1, \text{mu}] \text{del}[\text{pi}1, \text{mu}] - 1/2 \text{MM}1^2 \text{pi}1^2$$

Step 4 : Lagrangian

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

$$1/2 \text{del}[\text{pi1}, \text{mu}] \text{del}[\text{pi1}, \text{mu}] - 1/2 M^2 \text{pi1}^2$$

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

$$i \text{uvbar} \cdot \text{Ga}[\text{mu}] \cdot \text{DC}[\text{uv}, \text{mu}] - M_{uv} \text{uvbar} \cdot \text{uv}$$

Fermions anti-commute

Step 4 : Lagrangian

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

$$1/2 \text{del}[pi1, mu] \text{del}[pi1, mu] - 1/2 MM1^2 pi1^2$$

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

$$I \text{ uvbar} \cdot \text{Ga}[\text{mu}] \cdot \text{DC}[\text{uv}, \text{mu}] - M_{uv} \text{ uvbar} \cdot \text{uv}$$

Fermions anti-commute

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

Defined in SM.fr

$$\text{Lint} := \text{lam1 pi1 uvbar} \cdot \text{ProjP} \cdot t$$

$$\text{HC}[\text{Lint}]$$

Step 5 : run FeynRules

```
vertices = FeynmanRules[ LNew ];
```

```
CheckMassSpectrum[ LNew ]
```

```
ComputeWidths[vertices];
```

```
PartialWidth[ {uv, t, p1} ]
```

```
TotWidth[ {uv, t, p1} ]
```

```
BranchingRatio[ {uv, t, p1}]
```

```
SetDirectory["~/mg5amcnlo/models"];
```

```
WriteUFO[ LSM + LNew ];
```