

FeynRules → MadGraph Tutorial

Neil Christensen

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The Model

Field	Spin	$SU(3)_{\text{QCD}}$	$SU(2)_{\text{W}}$	$U(1)_{\text{Y}}$	Z_2
ϕ_i	0	1	1	0	-1
U	1	3	1	2/3	-1
E	1	1	1	-1	-1

+SM

Based on MC4BSM tutorial:
arXiv:1209.0297

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$$\mathcal{L}_{sq} = \frac{1}{2} \partial_\mu \phi_i \partial^\mu \phi_i - \frac{1}{2} M_{\phi ij} \phi_i \phi_j$$

SM Singlet

The Model

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Not necessarily diagonal

The Model

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$$\mathcal{L}_{sq} = \frac{1}{2} \partial_\mu \phi_i \partial^\mu \phi_i - \frac{1}{2} M_{\phi ij} \phi_i \phi_j$$

$$\mathcal{L}_{fq} = i\bar{U}\not{D}U - M_U \bar{U}U + i\bar{E}\not{D}E - M_E \bar{E}E$$

Gauge covariant derivative

The Model

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$$\mathcal{L}_{yuk} = \lambda_i \phi_i \bar{U} P_R u + \lambda'_i \phi_i \bar{E} P_R e + \text{h.c.}$$

Singlet Term

The Model

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$$\phi_i = U_{Sij} \Phi_j$$

$$\mathcal{L}_{yuk} = \lambda_i \phi_i \bar{U} P_R u + \lambda'_i \phi_i \bar{E} P_R e + \text{h.c.}$$

$$U_S = \begin{pmatrix} \cos \alpha & \sin \alpha \\ -\sin \alpha & \cos \alpha \end{pmatrix}$$

The Model

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$$\begin{aligned}\mathcal{L}_{sq} &= \frac{1}{2} \partial_\mu \phi_i \partial^\mu \phi_i - \frac{1}{2} M_{\phi_{ij}} \phi_i \phi_j \\ &= \frac{1}{2} \partial_\mu \Phi_i \partial^\mu \Phi_i - \frac{1}{2} M_{\Phi_i} \Phi_i \Phi_j\end{aligned}$$

$$\mathcal{L}_{fq} = i\bar{U}\not{\partial}U - M_U\bar{U}U + i\bar{E}\not{\partial}E - M_E\bar{E}E$$

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$$\mathcal{L}_{fq} = i\bar{U}\not{\partial}U - M_U\bar{U}U + i\bar{E}\not{\partial}E - M_E\bar{E}E$$

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The Model

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$$\mathcal{L}_{fq} = i\bar{U}\not{\partial}U - M_U\bar{U}U + i\bar{E}\not{\partial}E - M_E\bar{E}E$$

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$$= \lambda_i U_{Sij} \Phi_j \bar{U} P_R u + \lambda'_i U_{Sij} \Phi_j \bar{E} P_R e + \text{h.c.}$$

The Model

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$$= \lambda_i U_{Sij} \Phi_j \bar{U} P_R u + \lambda'_i U_{Sij} \Phi_j \bar{E} P_R e + \text{h.c.}$$

The Model

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

$$\begin{aligned} \mathcal{L}_{sq} &= \frac{1}{2} \partial_\mu \phi_i \partial^\mu \phi_i - \frac{1}{2} M_{\phi_{ij}} \phi_i \phi_j \\ &= \frac{1}{2} \partial_\mu \Phi_i \partial^\mu \Phi_i - \frac{1}{2} M_{\Phi_i} \Phi_i \Phi_j \end{aligned}$$

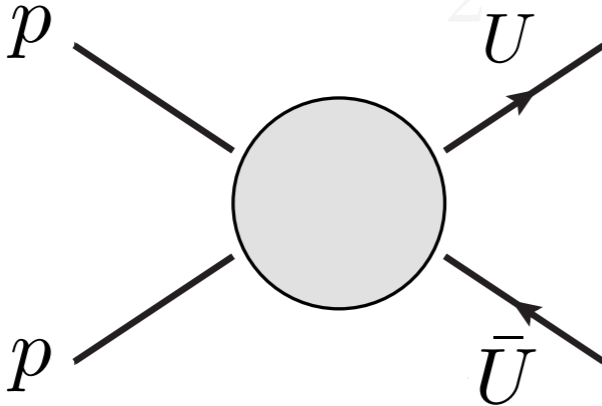
$$\mathcal{L}_{fq} = i\bar{U}\not{D}U - M_U\bar{U}U + i\bar{E}\not{D}E - M_E\bar{E}E$$

$$\mathcal{L}_{yuk} = \lambda_i \phi_i \bar{U} P_R u + \lambda'_i \phi_i \bar{E} P_R e + \text{h.c.}$$

$$= \lambda_i U_{Sij} \Phi_j \bar{U} P_R u + \lambda'_i U_{Sij} \Phi_j \bar{E} P_R e + \text{h.c.}$$

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Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

$$M_U > M_{\Phi_2} > M_E > M_{\Phi_1}$$


$$= \frac{1}{2} \partial_\mu \Phi_i \partial^\mu \Phi_i - \frac{1}{2} M_{\Phi_i} \Phi_i \Phi_j$$

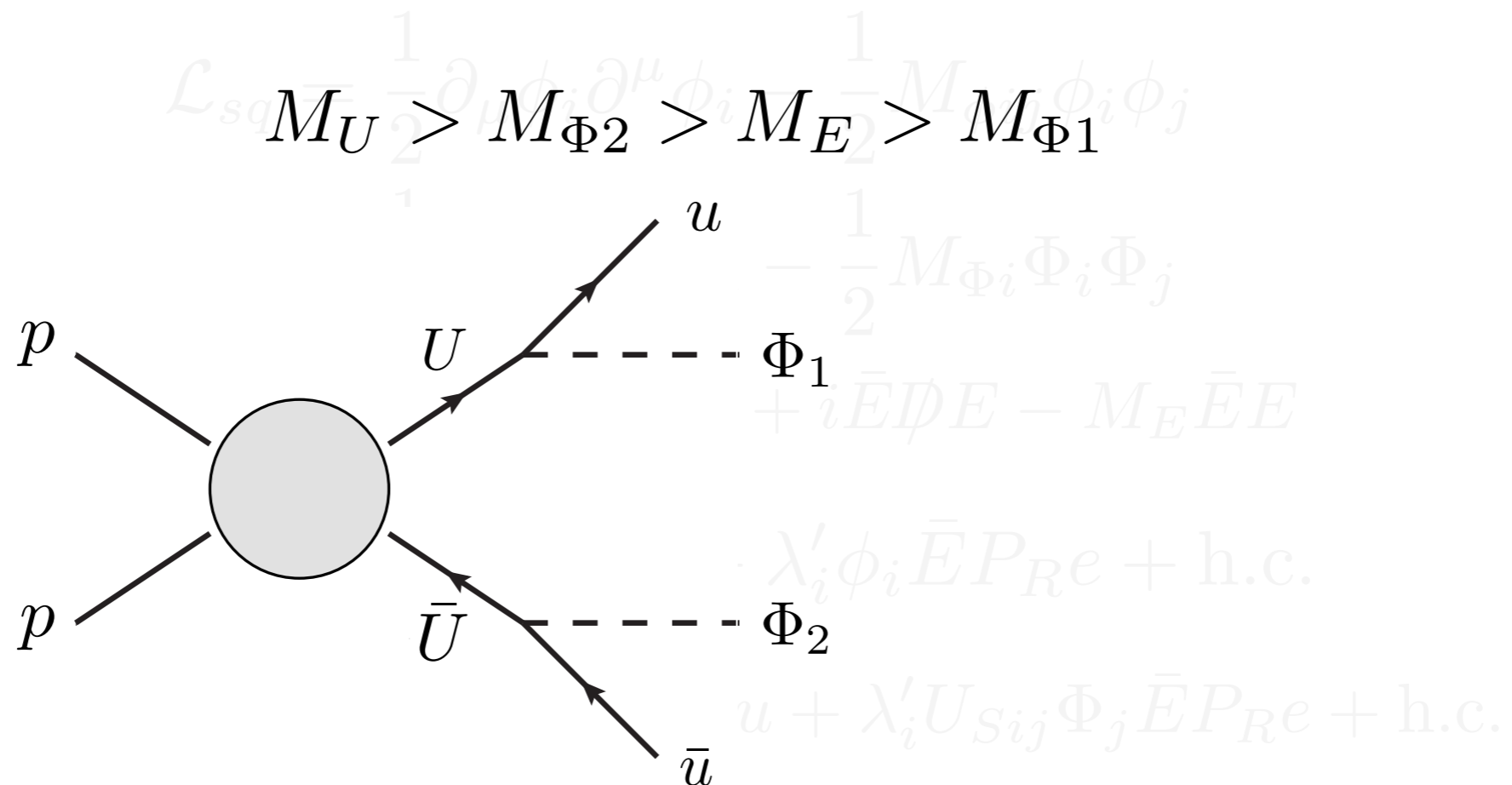
$$M_U \bar{U} U + i \bar{E} \not{D} E - M_E \bar{E} E$$

$$P_R u + \lambda'_i \phi_i \bar{E} P_R e + \text{h.c.}$$

$$= \lambda_i U_{Sij} \Phi_j \bar{U} P_R u + \lambda'_i U_{Sij} \Phi_j \bar{E} P_R e + \text{h.c.}$$

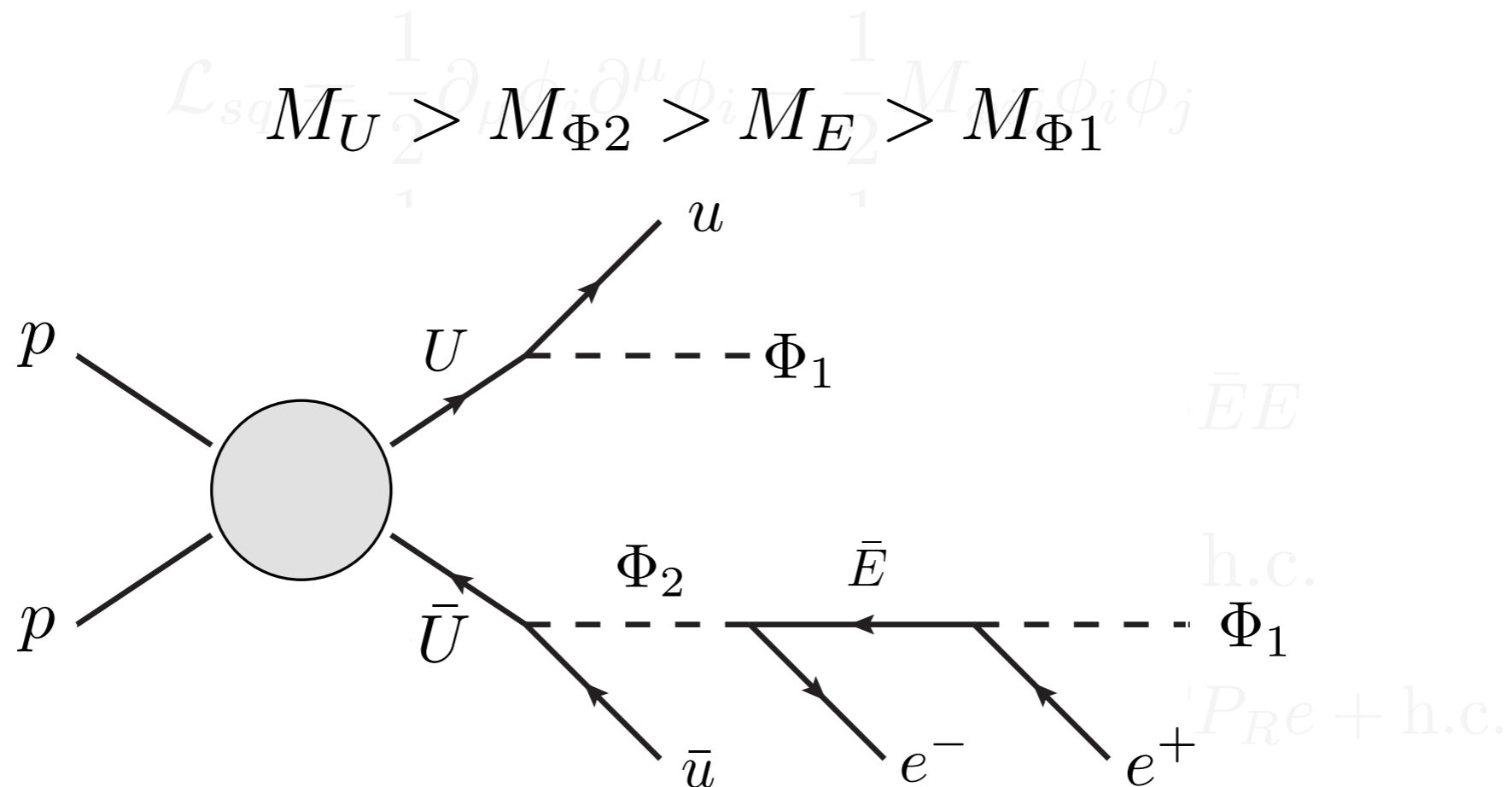
The Model

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]



The Model

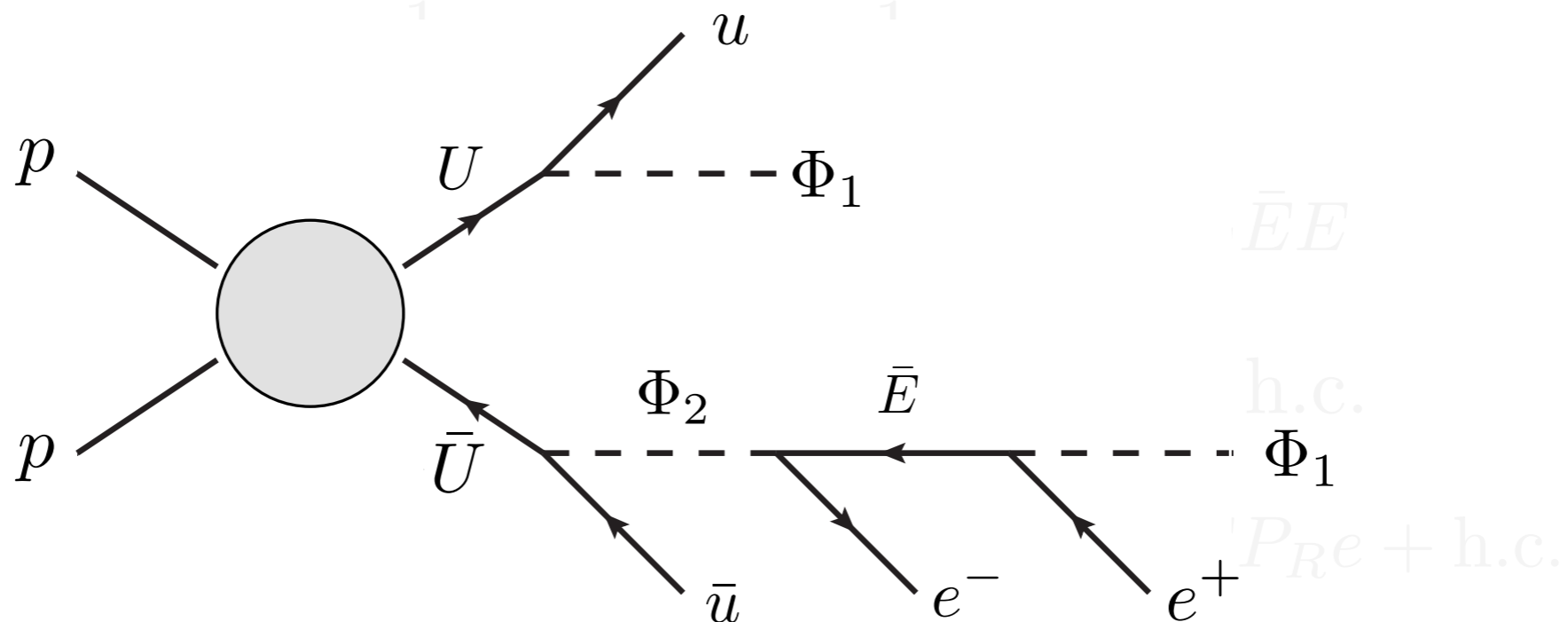
Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
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λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]



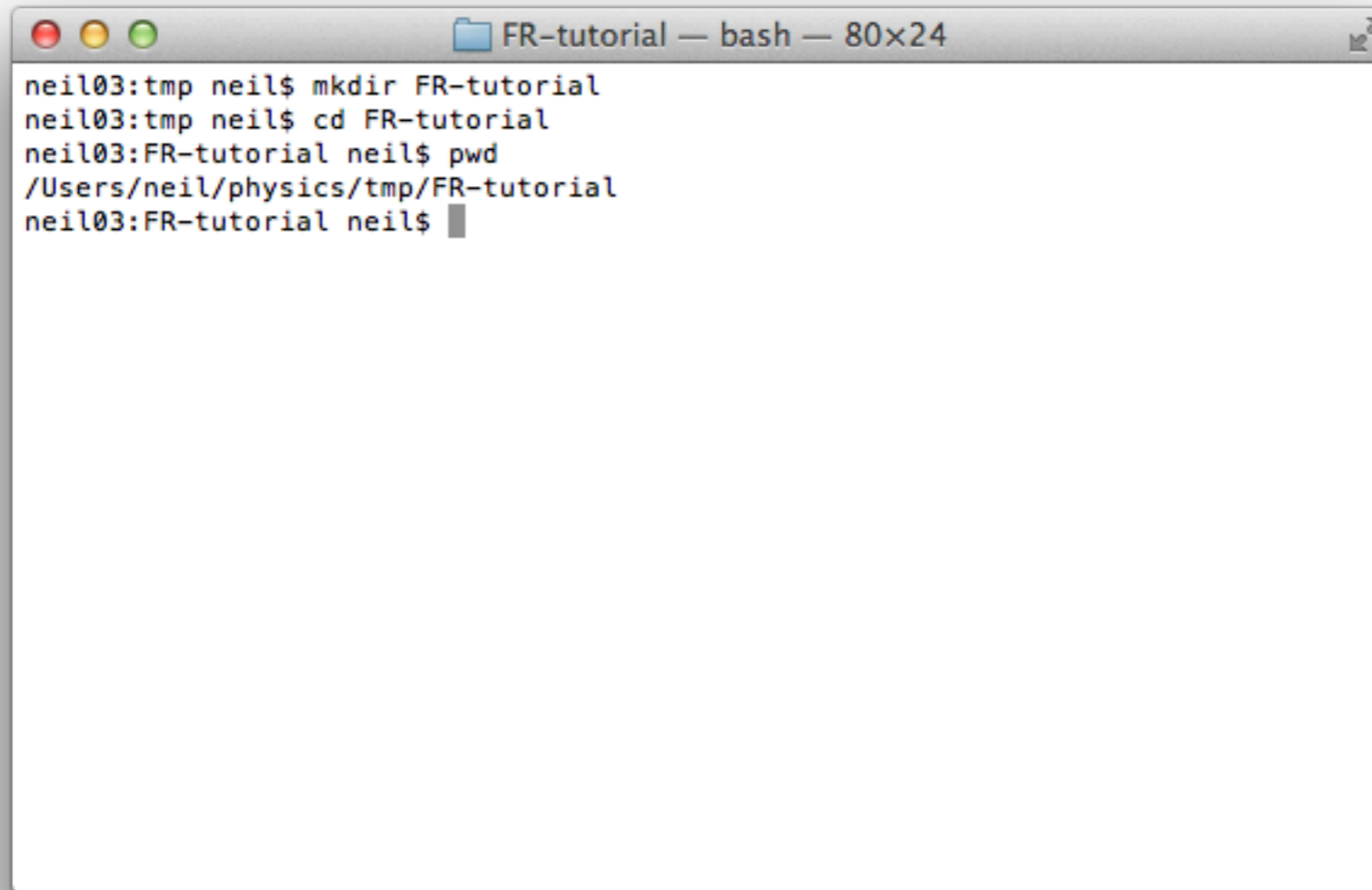
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λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

$$pp \rightarrow jj e^+ e^- + \text{missing}$$



The Implementation



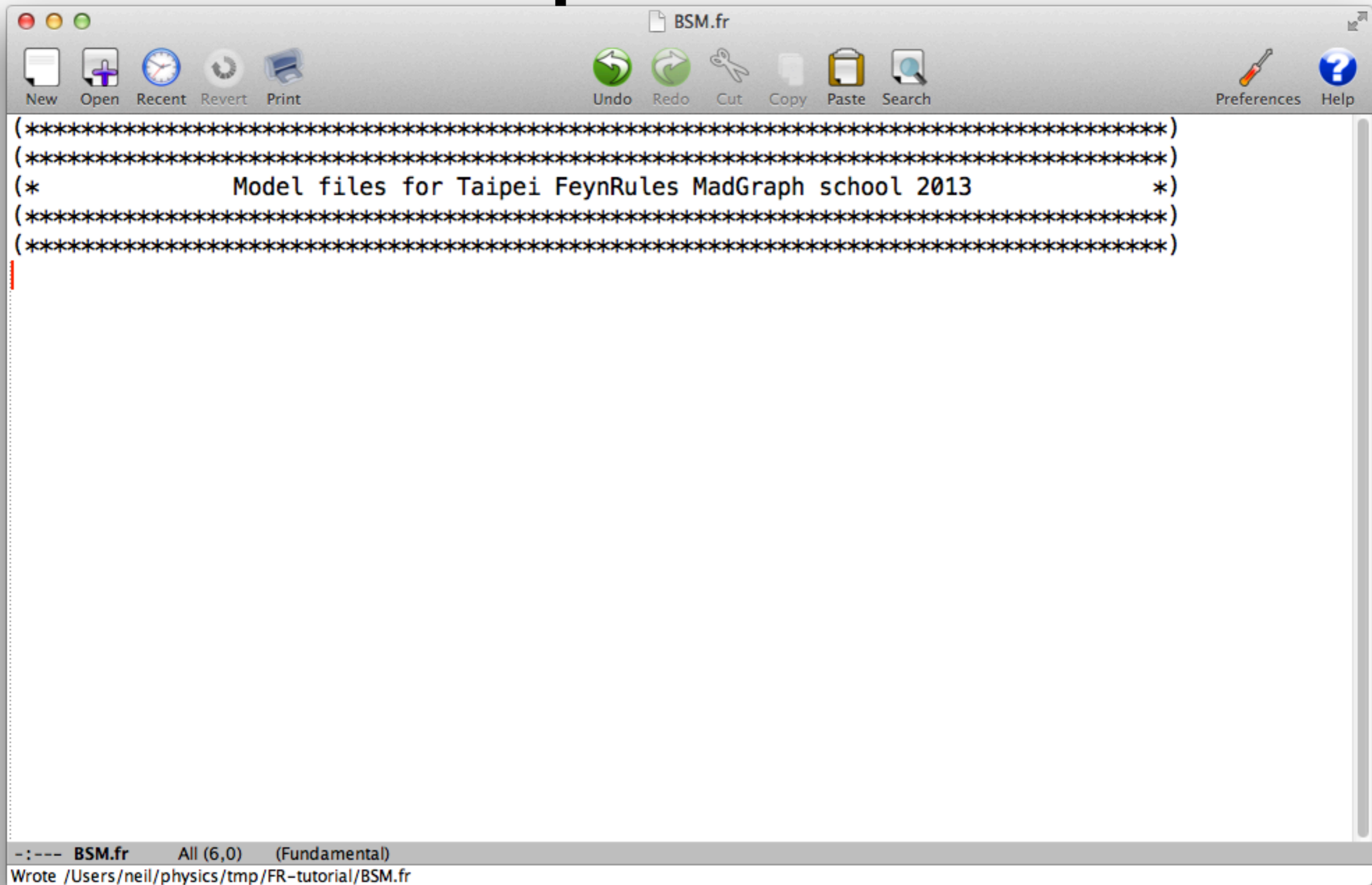
```
neil03:tmp neil$ mkdir FR-tutorial
neil03:tmp neil$ cd FR-tutorial
neil03:FR-tutorial neil$ pwd
/Users/neil/physics/tmp/FR-tutorial
neil03:FR-tutorial neil$
```

The Implementation

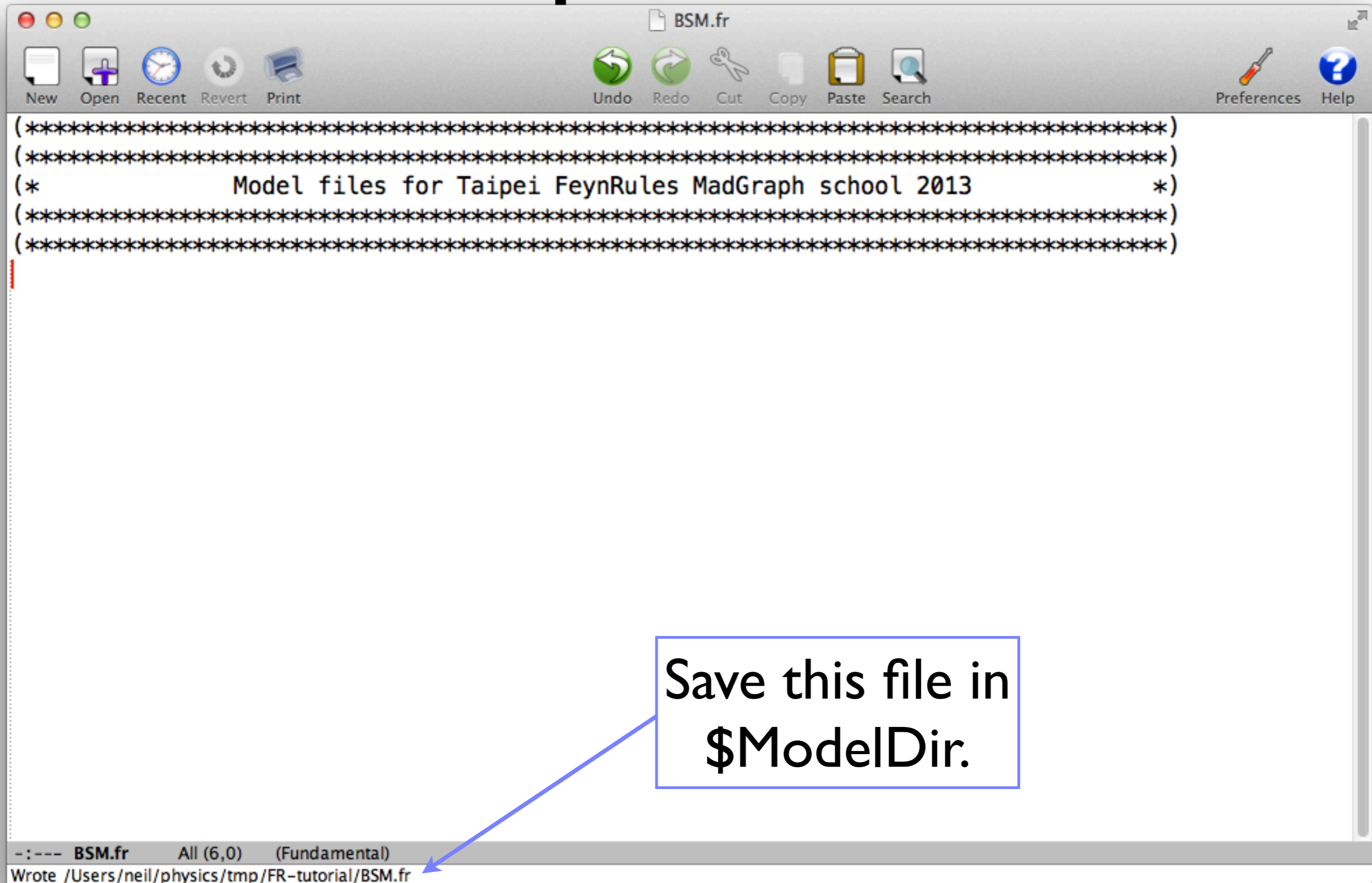
```
FR-tutorial — bash — 80x24
neil03:tmp neil$ mkdir FR-tutorial
neil03:tmp neil$ cd FR-tutorial
neil03:FR-tutorial neil$ pwd
/Users/neil/physics/tmp/FR-tutorial
neil03:FR-tutorial neil$
```

This will be `$ModelDir`
in future slides.

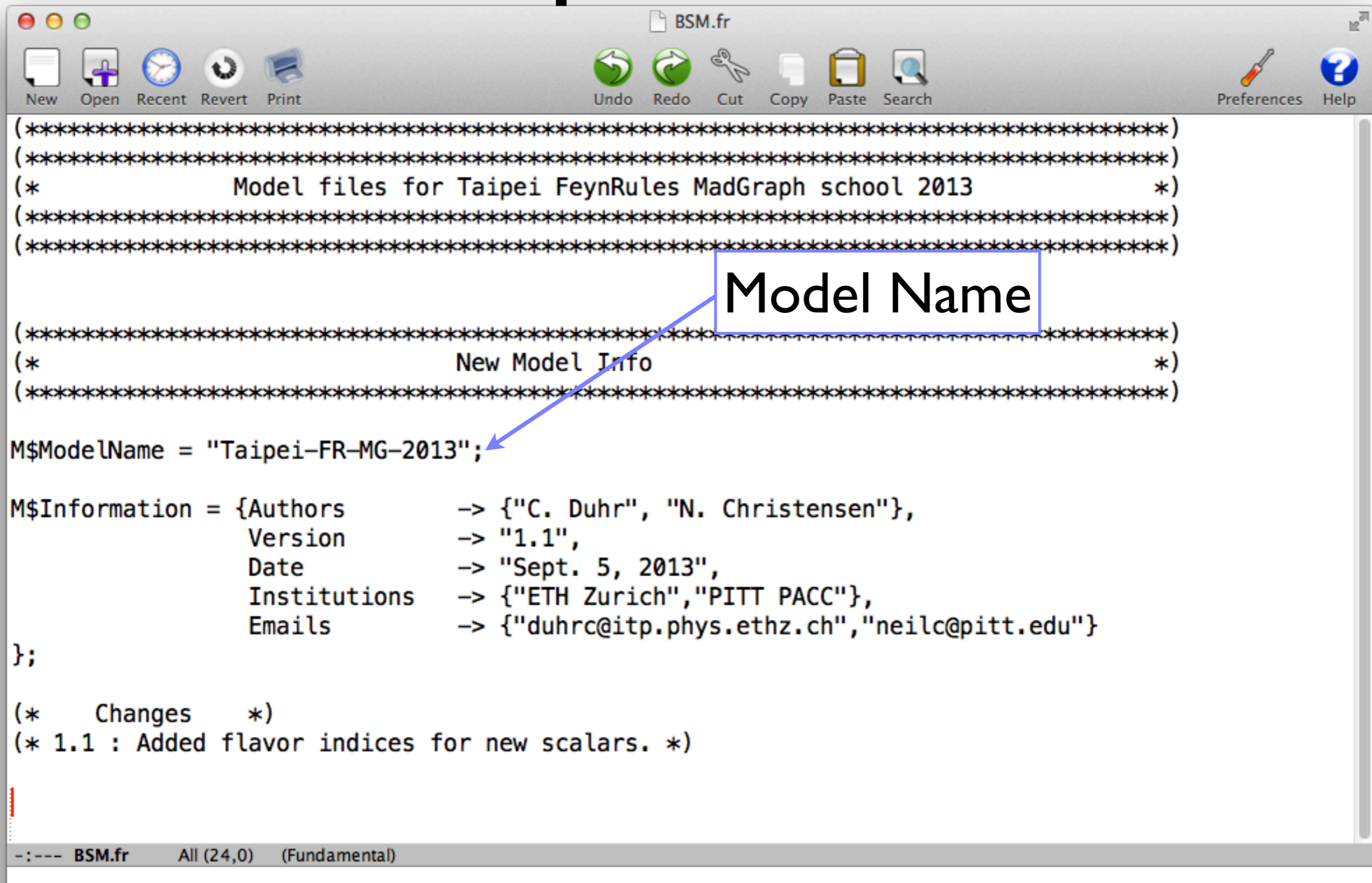
The Implementation



The Implementation

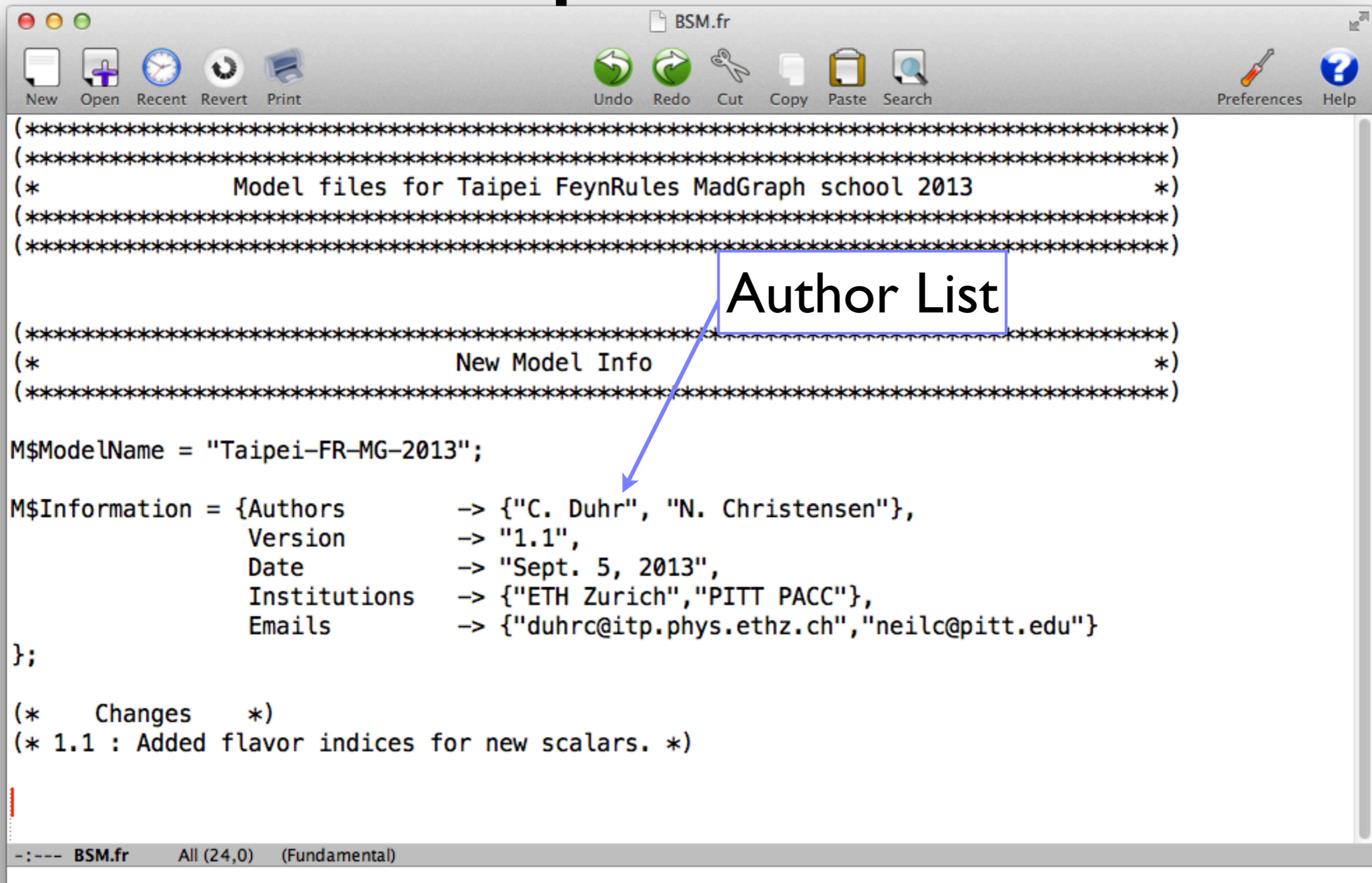


The Implementation



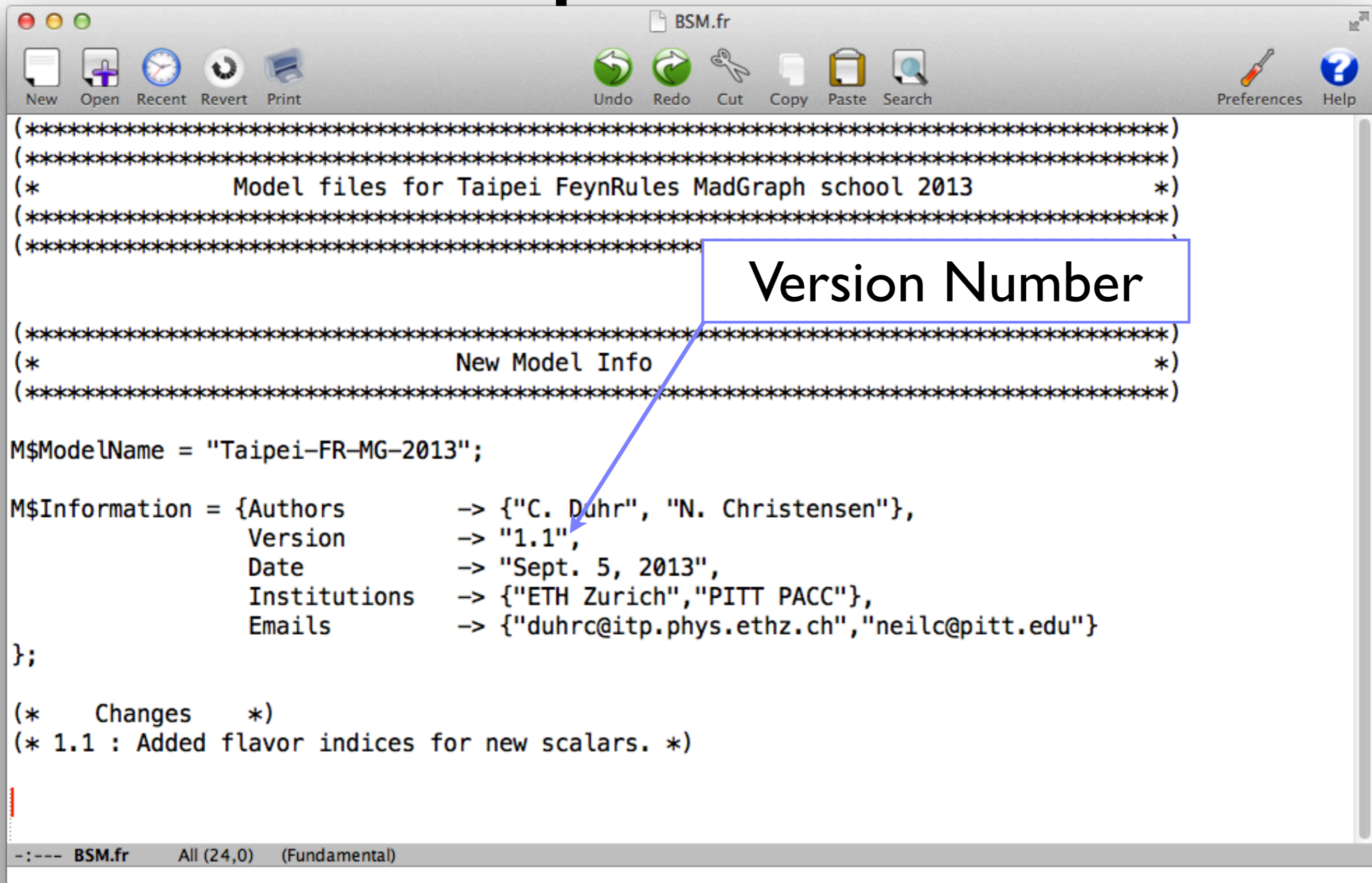
```
(*****  
(*****  
(*          Model files for Taipei FeynRules MadGraph school 2013          *)  
(*****  
(*****  
(*****  
(*****  
(*          New Model Info          *)  
(*****  
M$ModelName = "Taipei-FR-MG-2013";  
  
M$Information = {Authors      -> {"C. Duhr", "N. Christensen"},  
                  Version     -> "1.1",  
                  Date         -> "Sept. 5, 2013",  
                  Institutions  -> {"ETH Zurich", "PITT PACC"},  
                  Emails       -> {"duhrc@itp.phys.ethz.ch", "neilc@pitt.edu"}  
};  
  
(*    Changes    *)  
(* 1.1 : Added flavor indices for new scalars. *)  
  
-:--- BSM.fr    All (24,0)    (Fundamental)
```

The Implementation



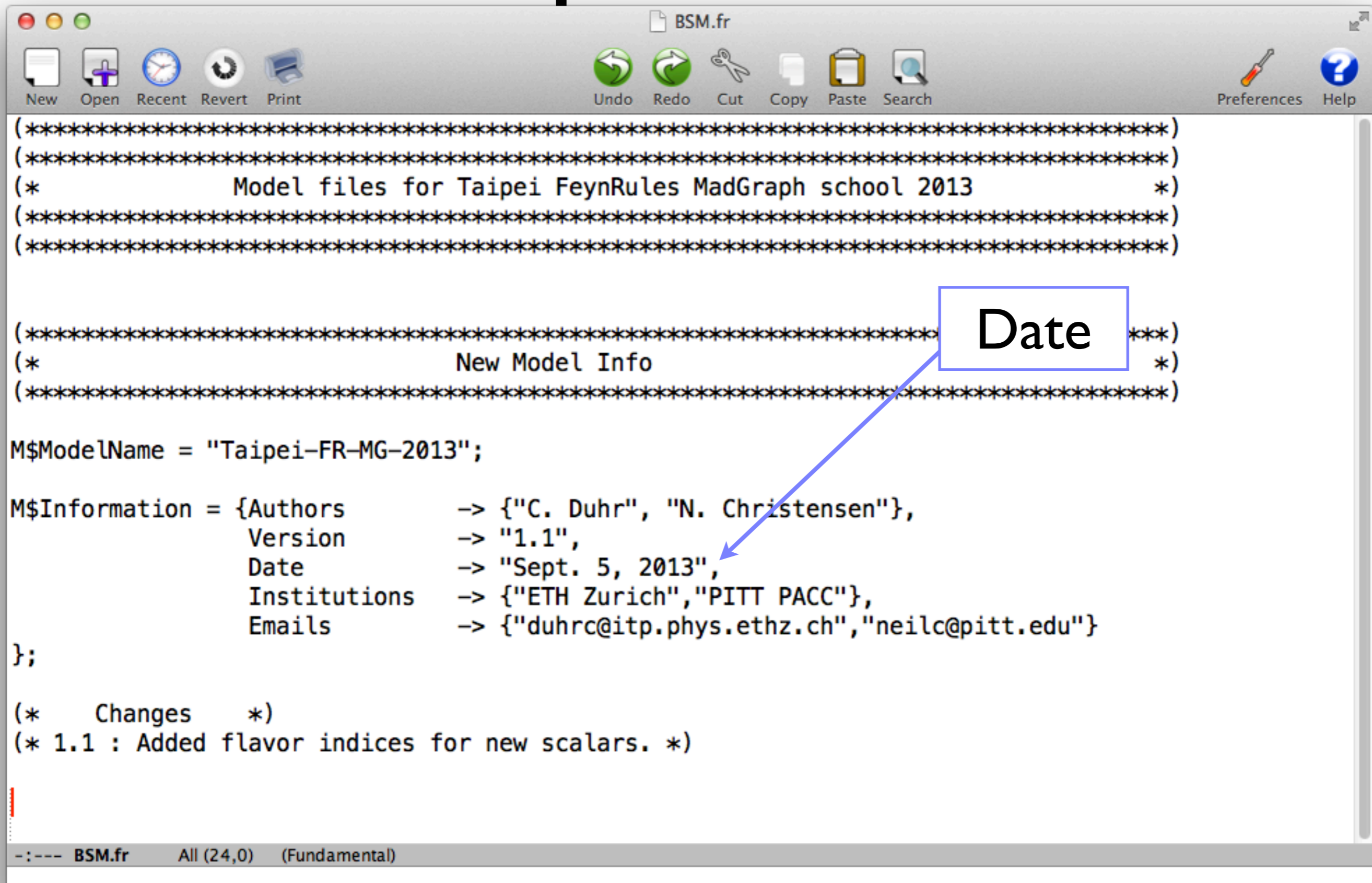
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The Implementation



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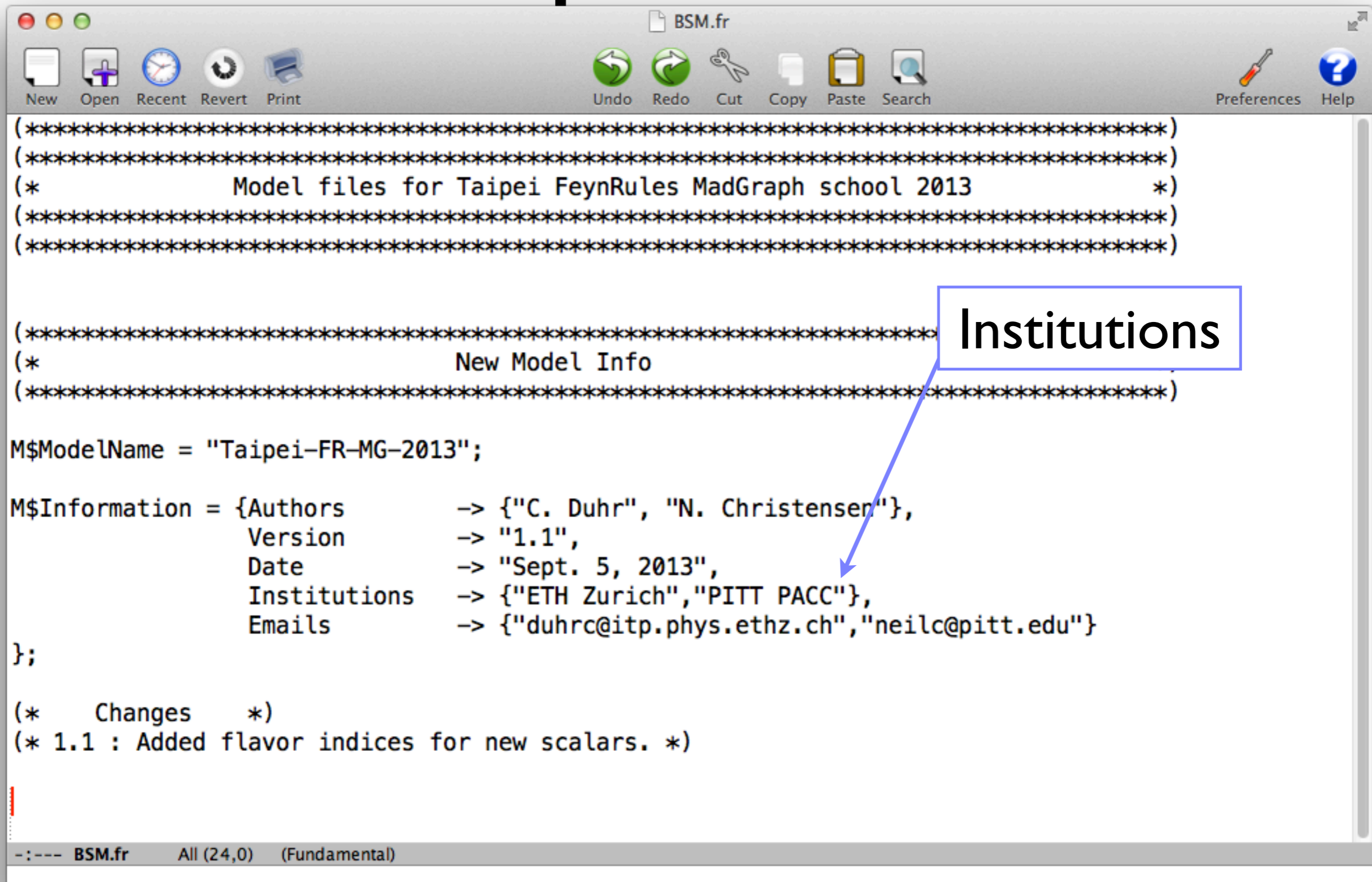
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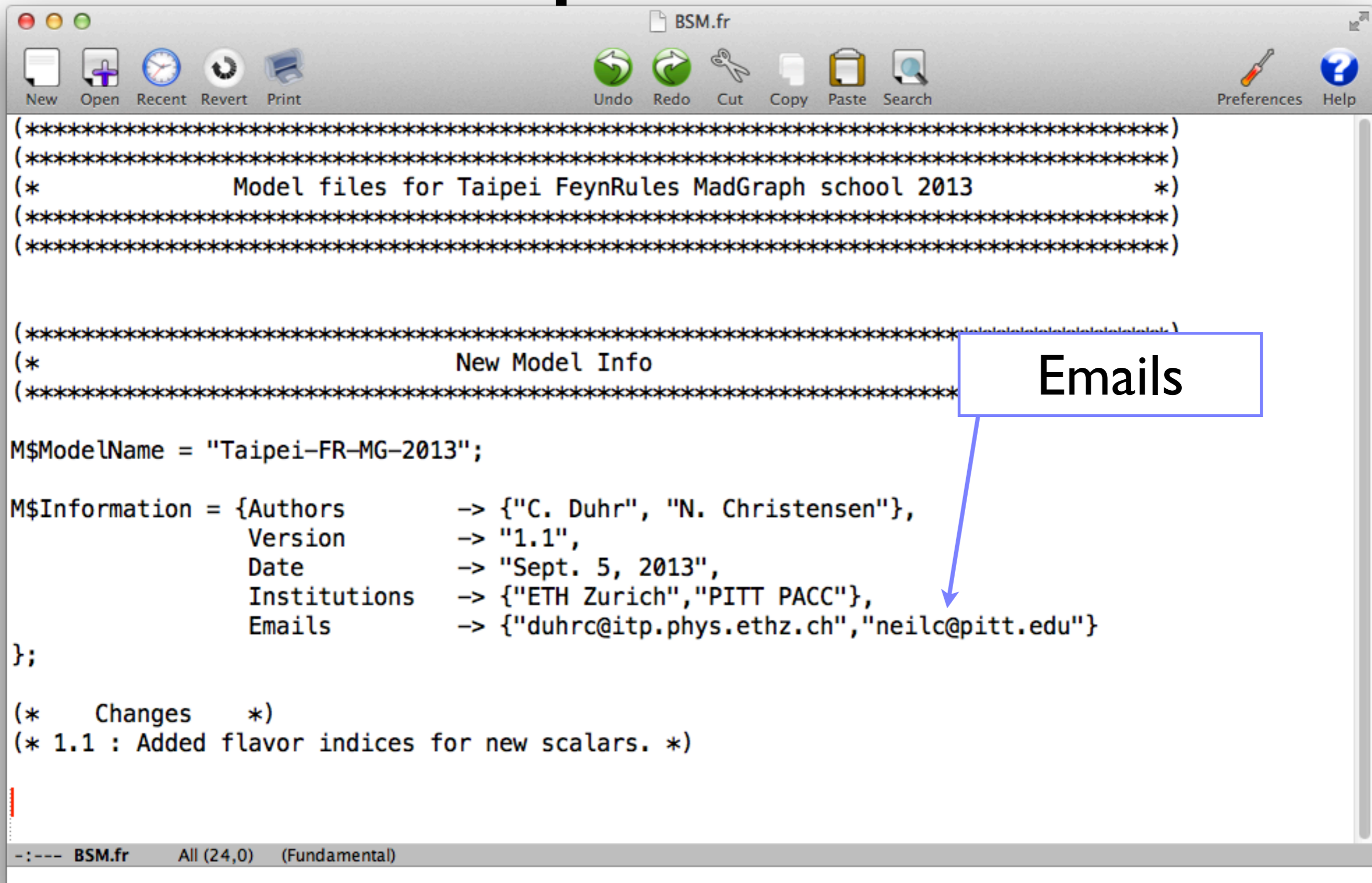
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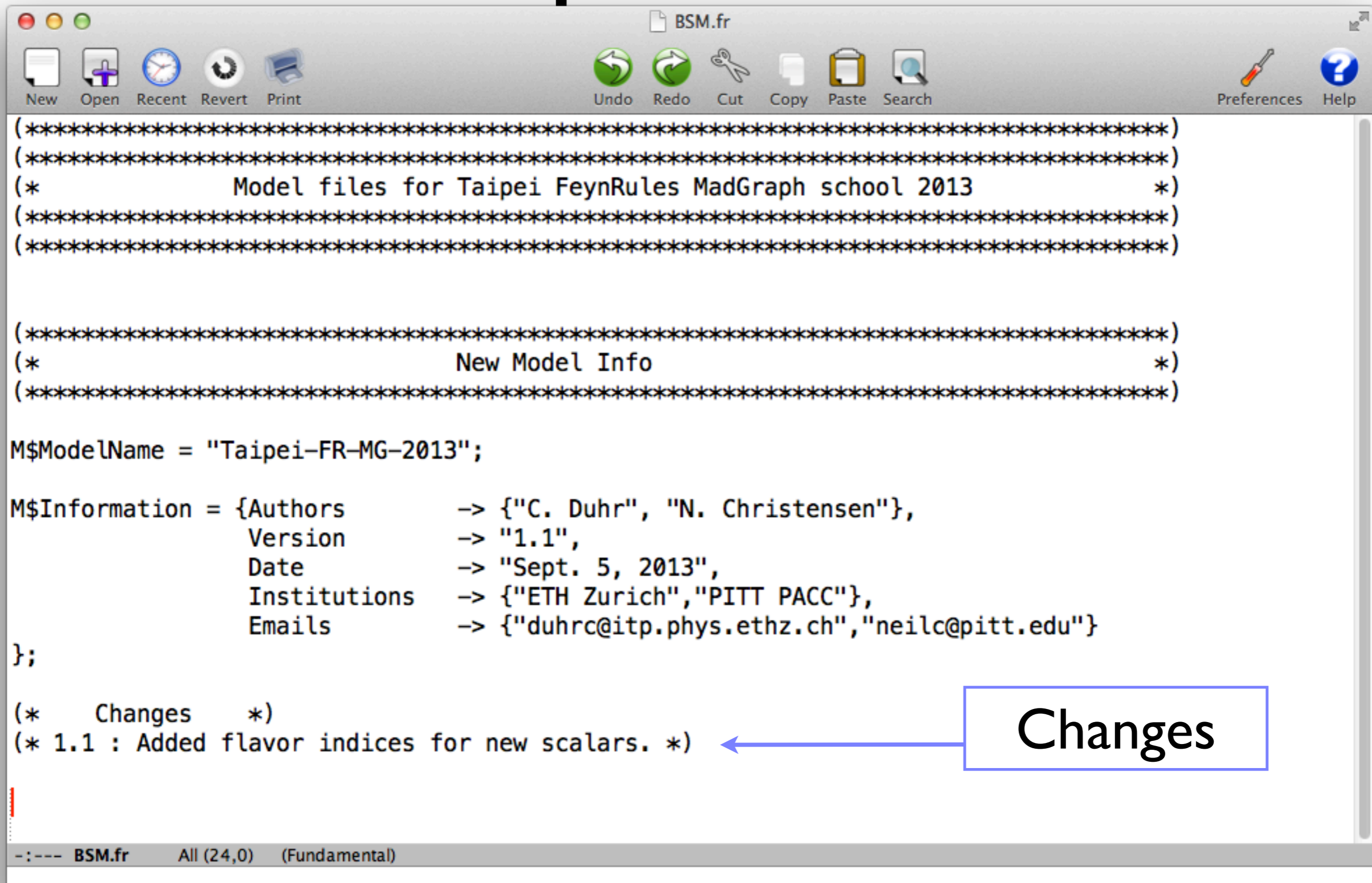
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Changes

-- BSM.fr All (24,0) (Fundamental)

The Implementation

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                Date         -> "Sept. 5,
                Institutions -> {"ETH Zuri
                Emails       -> {"duhrc@it
};

(* Changes *)
(* 1.1 : Added flavor indices for new scalars

(*****
(*               New Indices               *)
(*****

IndexRange[Index[scInd]] = Unfold[Range[2]];
IndexStyle[scInd, s];
```

Field	Spin	SU
ϕ_i	0	
U	1	
E	1	

***- BSM.fr Bot (31,0) (Fundamental)

The Implementation

```
M$ModelName = "Taipei-FR-MG-2013";

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                Version      -> "1.1",
                Date          -> "Sept. 5,
                Institutions   -> {"ETH Zuri
                Emails         -> {"duhrc@it
};

(*      Changes      *)
(* 1.1 : Added flavor indices for new scalars

(*****
*)
*)
(*****

IndexRange[Index[scInd]] = Unfold[Range[2]];
IndexStyle[scInd, s];
```

Field	Spin	SU
ϕ_i	0	
U	1	
E	1	

Range[2] tells FR that this index goes from 1 to 2.

Bot (31,0) (Fundamental)

The Implementation

```
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(* Changes *)
(* 1.1 : Added flavor indices for new scalars

(*****
*)
*)
(*****

IndexRange[Index[scInd]] = Unfold[Range[2]];
IndexStyle[scInd, s];
```

Field	Spin	SU
ϕ_i	0	
U	1	
E	1	

IndexStyle[...] tells FR what symbol to use when printing this index.

Bottom status bar: - : ** - BSM.fr Bot (31,0) (Fundamental)

The Implementation

The screenshot shows a text editor window titled "BSM.fr" with a menu bar (New, Open, Recent, Revert, Print, Undo, Redo, Cut, Copy, Paste, Search, Preferences, Help) and a toolbar. The code defines parameters for a model:

```

M$Parameters = {
  lambda == {
    ParameterType      -> External,
    ComplexParameter   -> False,
    Indices             -> {Index[scInd]},
    Value               -> {lambda[i]},
    InteractionOrder    -> {NP, 1}
  },
  lambdap == {
    ParameterType      -> External,
    ComplexParameter   -> False,
    Indices             -> {Index[scInd]},
    Value               -> {lambdap[1]->1, lambdap[2]->1},
    InteractionOrder    -> {NP, 1}
  },
  MassM == {
    ParameterType      -> External,
    ComplexParameter   -> False,
    Indices             -> {Index[scInd], Index[scInd]}
  }
};

```

A table is overlaid on the code, mapping mathematical symbols to Fortran names. Blue arrows point from the table to the corresponding code lines:

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

The status bar at the bottom shows: "B.S.M.fr Bot (56,0) (Fundamental) Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr"

The Implementation

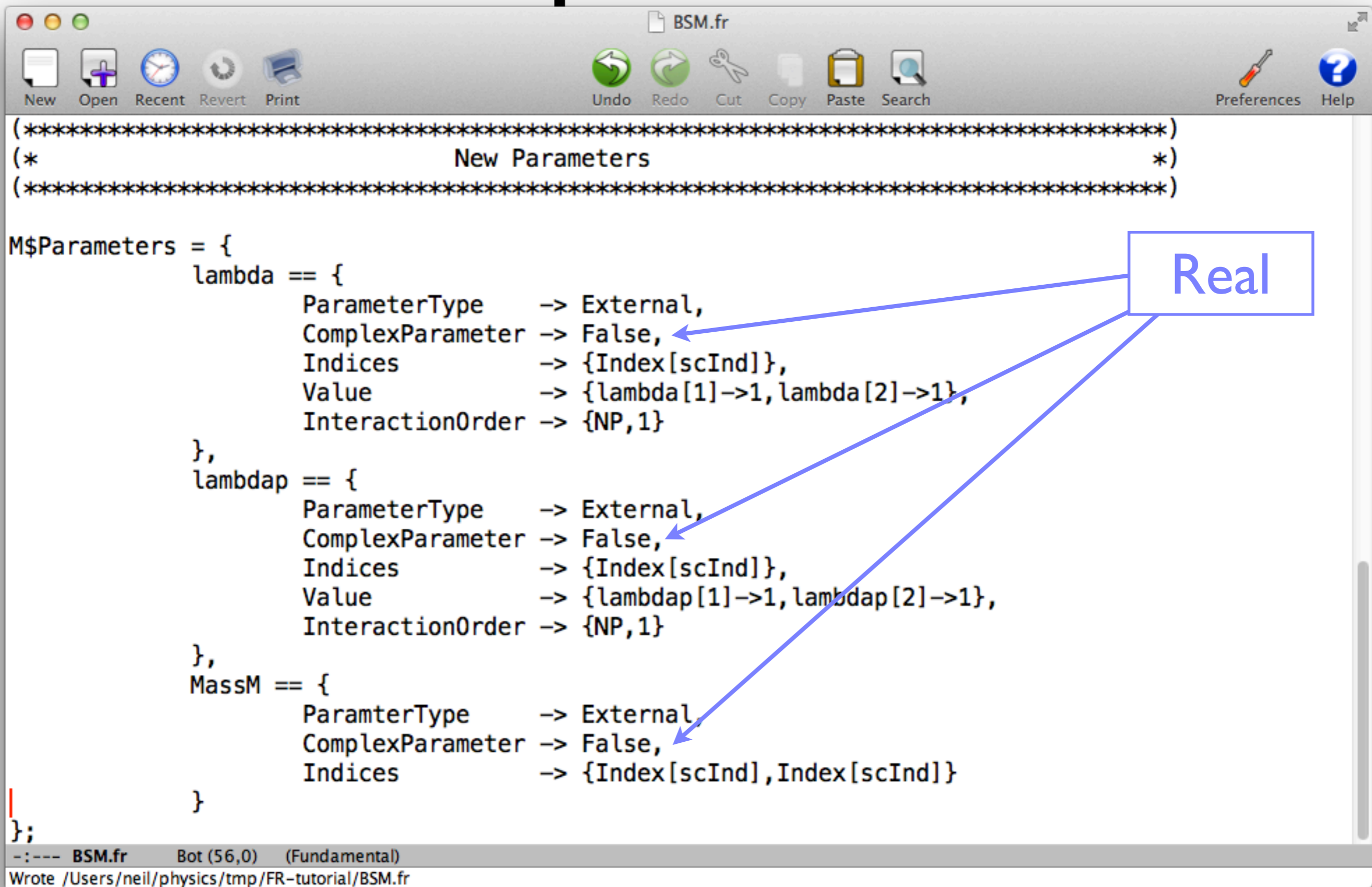
```
BSM.fr
New Open Recent Revert Print Undo Redo Cut Copy Paste Search Preferences Help
(*****)
(*          New Parameters          *)
(*****)

M$Parameters = {
  lambda == {
    ParameterType    -> External,
    ComplexParameter -> False,
    Indices          -> {Index[scInd]},
    Value            -> {lambda[1]->1, lambda[2]->1},
    InteractionOrder -> {NP,1}
  },
  lambdap == {
    ParameterType    -> External,
    ComplexParameter -> False,
    Indices          -> {Index[scInd]},
    Value            -> {lambdap[1]->1, lambdap[2]->1},
    InteractionOrder -> {NP,1}
  },
  MassM == {
    ParamterType    -> External,
    ComplexParameter -> False,
    Indices          -> {Index[scInd], Index[scInd]}
  }
};
```

Independent Parameters

BSM.fr Bot (56,0) (Fundamental)
Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation



The image shows a text editor window titled 'BSM.fr' with a menu bar containing 'New', 'Open', 'Recent', 'Revert', 'Print', 'Undo', 'Redo', 'Cut', 'Copy', 'Paste', 'Search', 'Preferences', and 'Help'. The main content is a code block for 'New Parameters' enclosed in asterisks. The code defines three parameter sets: 'lambda', 'lambdap', and 'MassM'. A blue box labeled 'Real' has three arrows pointing to the 'ComplexParameter' field in each of these parameter sets, which is set to 'False'.

```
(*****  
(*                               *)  
(*****  
  
M$Parameters = {  
  lambda == {  
    ParameterType    -> External,  
    ComplexParameter -> False,  
    Indices          -> {Index[scInd]},  
    Value            -> {lambda[1]->1, lambda[2]->1},  
    InteractionOrder -> {NP,1}  
  },  
  lambdap == {  
    ParameterType    -> External,  
    ComplexParameter -> False,  
    Indices          -> {Index[scInd]},  
    Value            -> {lambdap[1]->1, lambdap[2]->1},  
    InteractionOrder -> {NP,1}  
  },  
  MassM == {  
    ParamterType    -> External,  
    ComplexParameter -> False,  
    Indices          -> {Index[scInd], Index[scInd]}  
  }  
};
```

Real

--- BSM.fr Bot (56,0) (Fundamental)
Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation

```

BSM.fr
New Open Recent Revert Print Undo Redo Cut Copy Paste Search Preferences Help

(*****)
(*          New Parameters          *)
(*****)

M$Parameters = {
  lambda == {
    ParameterType    -> External,
    ComplexParameter -> False,
    Indices          -> {Index[scInd]},
    Value            -> {lambda[1]->1, lambda[2]->1},
    InteractionOrder -> {NP,1}
  },
  lambdap == {
    ParameterType    -> External,
    ComplexParameter -> False,
    Indices          -> {Index[scInd]},
    Value            -> {lambdap[1]->1, lambdap[2]->1},
    InteractionOrder -> {NP,1}
  },
  MassM == {
    ParamterType    -> External,
    ComplexParameter -> False,
    Indices          -> {Index[scInd], Index[scInd]}
  }
};

```

$\lambda_i \phi_i \bar{U} P_R u$

$\lambda'_i \phi_i \bar{E} P_R e$

$\frac{1}{2} M_{\phi ij} \phi_i \phi_j$

-:--- BSM.fr Bot (56,0) (Fundamental)
 Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation

```
BSM.fr
New Open Recent Revert Print Undo Redo Cut Copy Paste Search Preferences Help
(*****)
(*          New Parameters          *)
(*****)

M$Parameters = {
  lambda == {
    ParameterType    -> External,
    ComplexParameter -> False,
    Indices          -> {Index[scInd]},
    Value            -> {lambda[1]->1, lambda[2]->1},
    InteractionOrder -> {NP,1}
  },
  lambdap == {
    ParameterType    -> External,
    ComplexParameter -> False,
    Indices          -> {Index[scInd]},
    Value            -> {lambdap[1]->1, lambdap[2]->1},
    InteractionOrder -> {NP,1}
  },
  MassM == {
    ParamterType    -> External,
    ComplexParameter -> False,
    Indices          -> {Index[scInd], Index[scInd]}
  }
};

-:--- BSM.fr Bot (56,0) (Fundamental)
Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr
```

The Implementation

```
BSM.fr
New Open Recent Revert Print Undo Redo Cut Copy Paste Search Preferences Help
(*****)
(*          New Parameters          *)
(*****)

M$Parameters = {
  lambda == {
    ParameterType    -> External,
    ComplexParameter -> False,
    Indices          -> {Index[scInd]},
    Value            -> {lambda[1]->1, lambda[2]->1},
    InteractionOrder -> {NP,1}
  },
  lambdap == {
    ParameterType    -> External,
    ComplexParameter -> False,
    Indices          -> {Index[scInd]},
    Value            -> {lambdap[1]->1, lambdap[2]->1},
    InteractionOrder -> {NP,1}
  },
  MassM == {
    ParamterType    -> External,
    ComplexParameter -> False,
    Indices          -> {Index[scInd], Index[scInd]}
  }
};
```

Coupling Order

Bot (56,0) (Fundamental)
Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation

Field	Spin	SU(3) _{QCD}	SU(2) _W	U(1) _Y	Z ₂
ϕ_i	0	1	1	0	-1
U	1	3	1	2/3	-1
E	1	1	1	-1	-1

```
M$ClassesDescription = {
  F[20] == {
    ClassName      -> uv,
    SelfConjugate  -> False,
    Indices        -> {Index[Colour]},
    QuantumNumbers -> {Q->2/3, Y->2/3},
    Mass           -> {Muv, 500},
    Width          -> {Wuv, 1}
  },
  F[21] == {
    ClassName      -> ev,
    SelfConjugate  -> False,
    Indices        -> {},
    QuantumNumbers -> {Q->-1, Y->-1, LeptonNumber->1},
    Mass           -> {Mev, 300},
    Width          -> {Wev, 1}
  },
  S[20] == {
    ClassName      -> phiT,
    Unphysical     -> True,
  }
}
```

--- BSM.fr 66% (82,0) (Fundamental)
Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation

The image shows a text editor window titled "BSM.fr" with a menu bar (New, Open, Recent, Revert, Print) and a toolbar. The main content is a code block defining field classes and their quantum numbers. A table is overlaid on the code, summarizing the quantum numbers for fields ϕ_i , U , and E . A blue circle highlights the value '3' in the SU(3)_{QCD} column for the U field, with a blue arrow pointing to the corresponding '3' in the code's QuantumNumbers list for F[21].

Field	Spin	SU(3) _{QCD}	SU(2) _W	U(1) _Y	Z ₂
ϕ_i	0	1	1	0	-1
U	1	3	1	2/3	-1
E	1	1	1	-1	-1

```
M$ClassesDescription = {
  F[20] == {
    ClassName      -> uv,
    SelfConjugate  -> False,
    Indices        -> {Index[Colour]},
    QuantumNumbers -> {Q->2/3, Y->2/3},
    Mass           -> {Muv, 500},
    Width          -> {Wuv, 1}
  },
  F[21] == {
    ClassName      -> ev,
    SelfConjugate  -> False,
    Indices        -> {},
    QuantumNumbers -> {Q->-1, Y->-1, LeptonNumber->1},
    Mass           -> {Mev, 300},
    Width          -> {Wev, 1}
  },
  S[20] == {
    ClassName      -> phiT,
    Unphysical     -> True,
  }
}
```

--- BSM.fr 66% (82,0) (Fundamental)
Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation

Field	Spin	SU(3) _{QCD}	SU(2) _W	U(1) _Y	Z ₂
ϕ_i	0	1	1	0	-1
U	1	3	1	2/3	-1
E	1	1	1	-1	-1

```
M$ClassesDescription = {
  F[20] == {
    ClassName      -> uv,
    SelfConjugate  -> False,
    Indices        -> {Index[Colour]},
    QuantumNumbers -> {Q->2/3, Y->2/3},
    Mass           -> {Muv, 500},
    Width          -> {Wuv, 1}
  },
  F[21] == {
    ClassName      -> ev,
    SelfConjugate  -> False,
    Indices        -> {},
    QuantumNumbers -> {Q->-1, Y->-1, LeptonNumber->1},
    Mass           -> {Mev, 300},
    Width          -> {Wev, 1}
  },
  S[20] == {
    ClassName      -> phiT,
    Unphysical     -> True,
  }
}
```

--- BSM.fr 66% (82,0) (Fundamental)
Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation

`(*****
 (*
 (*****`

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

```

M$ClassesDescription = {
  F[20] == {
    ClassName      -> uv,
    SelfConjugate  -> False,
    Indices        -> {Index[Colour]},
    QuantumNumbers -> {Q->2/3, Y->2/3},
    Mass           -> {Muv, 500},
    Width         -> {Wuv, 1}
  },
  F[21] == {
    ClassName      -> ev,
    SelfConjugate  -> False,
    Indices        -> {},
    QuantumNumbers -> {Q->-1, Y->-1, LeptonNumber->1},
    Mass           -> {Mev, 300},
    Width         -> {Wev, 1}
  },
  S[20] == {
    ClassName      -> phiT,
    Unphysical     -> True,
  }
}

```

-:--- BSM.fr 66% (82,0) (Fundamental)
 Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation

The image shows a code editor window with Fortran code defining particle classes and a table mapping symbols to Fortran names. A blue box highlights the table, and a blue arrow points from the 'ev/ev~' entry in the table to the corresponding 'ev' entry in the Fortran code.

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

```

M$ClassesDescription = {
  F[20] == {
    ClassName      -> uv,
    SelfConjugate  -> False,
    Indices        -> {Index[Colour]},
    QuantumNumbers -> {Q->2/3, Y->2/3},
    Mass           -> {Muv, 500},
    Width          -> {Wuv, 1}
  },
  F[21] == {
    ClassName      -> ev,
    SelfConjugate  -> False,
    Indices        -> {},
    QuantumNumbers -> {Q->-1, Y->-1, LeptonNumber->1},
    Mass           -> {Mev, 300},
    Width          -> {Wev, 1}
  },
  S[20] == {
    ClassName      -> phiT,
    Unphysical     -> True,
  }
}

```

Bottom status bar: -:--- BSM.fr 66% (82,0) (Fundamental)
Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

```

(*****
(*)
(*****

M$ClassesDescription = {
  F[20] == {
    ClassName      -> uv,
    SelfConjugate  -> False,
    Indices        -> {Index[Colour]},
    QuantumNumbers -> {Q->2/3, Y->2/3},
    Mass           -> {Muv, 500},
    Width         -> {Wuv, 1}
  },
  F[21] == {
    ClassName      -> ev,
    SelfConjugate  -> False,
    Indices        -> {},
    QuantumNumbers -> {Q->-1, Y->-1, LeptonNumber->1},
    Mass           -> {Mev, 300},
    Width         -> {Wev, 1}
  },
  S[20] == {
    ClassName      -> phiT,
    Unphysical     -> True,

```

-:--- BSM.fr 66% (82,0) (Fundamental)
 Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation

The image shows a Mathematica notebook window with a table of symbols and their Fortran (FR) names. The table is highlighted with a blue border. Below the table, the code defines three classes: F[20], F[21], and S[20]. Blue lines connect the table entries to the code: M_U and $M_{\phi ij}$ from the table point to the Mass property of F[20]; M_E and $M_{\phi ij}$ point to the Mass property of F[21]; and λ_i points to the Indices property of S[20].

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi ij}$	MassM[i,j]

```

M$ClassesDescription = {
  F[20] == {
    ClassName      -> uv,
    SelfConjugate  -> False,
    Indices        -> {Index[Colour]},
    QuantumNumbers -> {Q->2/3, Y->2/3},
    Mass           -> {Muv, 500},
    Width         -> {Wuv, 1}
  },
  F[21] == {
    ClassName      -> ev,
    SelfConjugate  -> False,
    Indices        -> {},
    QuantumNumbers -> {Q->-1, Y->-1, LeptonNumber->1},
    Mass           -> {Mev, 300},
    Width         -> {Wev, 1}
  },
  S[20] == {
    ClassName      -> phiT,
    Unphysical     -> True,
  }
}

```

BSM.fr 66% (82,0) (Fundamental)
Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation

Field	Spin	SU(3) _{QCD}	SU(2) _W	U(1) _Y	Z ₂
ϕ_i	0	1	1	0	-1
U	1	3	1	2/3	-1
E	1	1	1	-1	-1

```
S[20] == {
  ClassName      -> phiT,
  Unphysical     -> True,
  SelfConjugate  -> True,
  Indices        -> {Index[scInd]},
  FlavorIndex    -> scInd
},

S[21] == {
  ClassName      -> phiM,
  SelfConjugate  -> True,
  Indices        -> {Index[scInd]},
  FlavorIndex    -> scInd,
  ClassMembers   -> {phiM1, phiM2},
  Mass           -> {MphiM, {MphiM1, 200}, {MphiM2, 400}},
  Width          -> {WphiM, {WphiM1, 1}, {WphiM2, 1}}
}

};
```

BSM.fr Bot (82,0) (Fundamental)

The Implementation

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

```

ClassName
SelfConjugate
Indices
QuantumNumber
Mass
Width
},
S[20] == {
  ClassName      -> phiT,
  Unphysical     -> True,
  SelfConjugate  -> True,
  Indices        -> {Index[scInd]},
  FlavorIndex    -> scInd
},
S[21] == {
  ClassName      -> phiM,
  SelfConjugate  -> True,
  Indices        -> {Index[scInd]},
  FlavorIndex    -> scInd,
  ClassMembers   -> {phiM1,phiM2},
  Mass           -> {MphiM, {MphiM1,200},{MphiM2,400}},
  Width          -> {WphiM, {WphiM1,1},{WphiM2,1}}
}
};

```

--- BSM.fr Bot (82,0) (Fundamental)

The Implementation

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

```

ClassName
SelfConjugate
Indices
QuantumNumber
Mass
Width
},
S[20] == {
  ClassName      -> phiT,
  Unphysical     -> True,
  SelfConjugate  -> True,
  Indices        -> {Index[scInd]},
  FlavorIndex    -> scInd
},
S[21] == {
  ClassName      -> phiM,
  SelfConjugate  -> True,
  Indices        -> {Index[scInd]},
  FlavorIndex    -> scInd,
  ClassMembers   -> {phiM1,phiM2},
  Mass           -> {MphiM, {MphiM1,200},{MphiM2,400}},
  Width         -> {WphiM, {WphiM1,1},{WphiM2,1}}
}
};

```

BSM.fr Bot (82,0) (Fundamental)

The Implementation

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

```

ClassName
SelfConjugate
Indices
QuantumNumber
Mass
Width
},
S[20] == {
  ClassName      -> phiT,
  Unphysical     -> True,
  SelfConjugate -> True,
  Indices       -> {Index[scInd]},
  FlavorIndex   -> scInd
},
S[21] == {
  ClassName      -> phiM,
  SelfConjugate -> True,
  Indices       -> {Index[scInd]},
  FlavorIndex   -> scInd,
  ClassMembers  -> {phiM1,phiM2},
  Mass          -> {MphiM, {MphiM1,200},{MphiM2,400}},
  Width        -> {WphiM, {WphiM1,1},{WphiM2,1}}
}
};

```

--:--- BSM.fr Bot (82,0) (Fundamental)

The Implementation

The image shows a Mathematica notebook window with a table of symbols and their Fortran (FR) representations. The table is highlighted with a blue box. Below the table, the code for defining two classes, S[20] and S[21], is shown. A blue circle highlights the 'phiMi' entry in the table, and a blue line points from it to the 'phiM' entry in the S[21] class definition.

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

```

ClassName
SelfConjugate
Indices
QuantumNumber
Mass
Width
},
S[20] == {
  ClassName      -> phiT,
  Unphysical     -> True,
  SelfConjugate -> True,
  Indices       -> {Index[scInd]},
  FlavorIndex   -> scInd
},
S[21] == {
  ClassName      -> phiM,
  SelfConjugate -> True,
  Indices       -> {Index[scInd]},
  FlavorIndex   -> scInd,
  ClassMembers  -> {phiM1, phiM2},
  Mass          -> {MphiM, {MphiM1, 200}, {MphiM2, 400}},
  Width        -> {WphiM, {WphiM1, 1}, {WphiM2, 1}}
}
};

```

BSM.fr Bot (82,0) (Fundamental)

The Implementation

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

```

ClassName
SelfConjugate
Indices
QuantumNumber
Mass
Width
},
S[20] == {
  ClassName      -> phiT,
  Unphysical     -> True,
  SelfConjugate -> True,
  Indices       -> {Index[scInd]},
  FlavorIndex   -> scInd
},
S[21] == {
  ClassName      -> phiM,
  SelfConjugate -> True,
  Indices       -> {Index[scInd]},
  FlavorIndex   -> scInd,
  ClassMembers  -> {phiM1,phiM2},
  Mass          -> {MphiM, {MphiM1,200},{MphiM2,400}},
  Width        -> {WphiM, {WphiM1,1},{WphiM2,1}}
}
};

```

--- BSM.fr Bot (82,0) (Fundamental)

The Implementation

The image shows a Mathematica notebook window with a table of symbols and their Fortran (FR) representations, and code defining two classes, S[20] and S[21].

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

```

ClassName
SelfConjugate
Indices
QuantumNumber
Mass
Width
},
S[20] == {
  ClassName      -> phiT,
  Unphysical     -> True,
  SelfConjugate -> True,
  Indices        -> {Index[scInd]},
  FlavorIndex   -> scInd
},
S[21] == {
  ClassName      -> phiM,
  SelfConjugate -> True,
  Indices        -> {Index[scInd]},
  FlavorIndex   -> scInd,
  ClassMembers  -> {phiM1, phiM2},
  Mass          -> {MphiM, {MphiM1, 200}, {MphiM2, 400}},
  Width        -> {WphiM, {WphiM1, 1}, {WphiM2, 1}}
}
};

```

At the bottom of the notebook, the following text is visible: `--:--- BSM.fr Bot (82,0) (Fundamental)`

The Implementation

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

```

ClassName
SelfConjugate
Indices
QuantumNumber
Mass
Width
},
S[20] == {
  ClassName      -> phiT,
  Unphysical     -> True,
  SelfConjugate -> True,
  Indices        -> {Index[scInd]},
  FlavorIndex    -> scInd
},
S[21] == {
  ClassName      -> phiM,
  SelfConjugate -> True,
  Indices        -> {Index[scInd]},
  FlavorIndex    -> scInd,
  ClassMembers   -> {phiM1, phiM2},
  Mass           -> {MphiM, {MphiM1, 200}, {MphiM2, 400}},
  Width          -> {WphiM, {WphiM1, 1}, {WphiM2, 1}}
}
};

```

BSM.fr Bot (82,0) (Fundamental)

The Implementation

The image shows a Mathematica notebook window with a table of symbol-to-Fortran name mappings and corresponding code definitions. A blue box highlights the table, and a blue arrow points from the 'WphiMi' entry in the table to its definition in the code block.

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin \alpha$	sina	$\cos \alpha$	cosa
Φ_i	phiMi	M_{Φ_i}	MphiMi	Γ_{Φ_i}	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi_{ij}}$	MassM[i,j]

```

ClassName
SelfConjugate
Indices
QuantumNumber
Mass
Width
},
S[20] == {
  ClassName      -> phiT,
  Unphysical     -> True,
  SelfConjugate  -> True,
  Indices        -> {Index[scInd]},
  FlavorIndex    -> scInd
},
S[21] == {
  ClassName      -> phiM,
  SelfConjugate  -> True,
  Indices        -> {Index[scInd]},
  FlavorIndex    -> scInd,
  ClassMembers   -> {phiM1, phiM2},
  Mass           -> {MphiM, {MphiM1, 200}, {MphiM2, 400}},
  Width          -> {WphiM, {WphiM1, 1}, {WphiM2, 1}}
}
};

```

BSM.fr Bot (82,0) (Fundamental)

The Implementation

The image shows a text editor window titled "BSM.fr" with a menu bar (New, Open, Recent, Revert, Preferences, Help) and a toolbar. The main content area contains the following text:

$$\mathcal{L}_{sq} = \frac{1}{2} \partial_{\mu} \phi_i \partial^{\mu} \phi_i - \frac{1}{2} M_{\phi ij} \phi_i \phi_j$$

};

```
(*****  
(*                               New Lagrangian                               *)  
(***)  
Lsq = 1/2 del[phiT[ii],mu] del[phiT[ii],mu] - 1/2 phiT[ii] MassM[ii,jj] phiT[jj];  
Lfq = I uvbar.Ga[mu].DC[uv,mu] - Muv uvbar.uv + I evbar.Ga[mu].DC[ev,mu] - Mev evbar.ev;  
Lyuk = lambda[ii] phiT[ii] uvbar.ProjP.u + lambdap[ii] phiT[ii] evbar.ProjP.e;  
Lnew = Lsq + Lfq + Lyuk + HC[Lyuk];  
|
```

At the bottom of the window, the status bar shows: -: ** - BSM.fr Bot (111,0) (Fundamental)

The Implementation

$$\mathcal{L}_{fq} = i\bar{U}\not{D}U - M_U\bar{U}U + i\bar{E}\not{D}E - M_E\bar{E}E$$

};

```
(*****  
(*                               *  
(*           New Lagrangian     *  
*****)
```

```
Lsq = 1/2 del[phiT[ii],mu] del[phiT[jj],mu] - 1/2 phiT[ii] MassM[ii,jj] phiT[jj];
```

```
Lfq = I uvbar.Ga[mu].DC[uv,mu] - Muv uvbar.uv + I evbar.Ga[mu].DC[ev,mu] - Mev evbar.ev;
```

```
Lyuk = lambda[ii] phiT[ii] uvbar.ProjP.u + lambdaap[ii] phiT[ii] evbar.ProjP.e;
```

```
Lnew = Lsq + Lfq + Lyuk + HC[Lyuk];
```

The Implementation

$$\mathcal{L}_{yuk} = \lambda_i \phi_i \bar{U} P_R u + \lambda'_i \phi_i \bar{E} P_R e + \text{h.c.}$$

};

```
(*****  
(*                               *)  
(*****  
Lsq = 1/2 del[phiT[ii],mu] del[phiT[ii],mu] - 1/2 phiT[ii] MassM[ii,jj] phiT[jj];  
Lfq = I uvbar.Ga[mu].DC[uv,mu] - Muv uvbar.uv + I evbar.Ga[mu].DC[ev,mu] - Mev evbar.ev;  
Lyuk = lambda[ii] phiT[ii] uvbar.ProjP.u + lambdap[ii] phiT[ii] evbar.ProjP.e;  
Lnew = Lsq + Lfq + Lyuk + HC[Lyuk];
```

The Implementation

$$\mathcal{L}_{yuk} = \lambda_i \phi_i \bar{U} P_R u + \lambda'_i \phi_i \bar{E} P_R e + \text{h.c.}$$

};

```
(*****  
(*                               *)  
*****)  
Lsq = 1/2 del[phiT[ii],mu] del[phiT[ii],mu] - 1/2 phiT[ii] MassM[ii,jj] phiT[jj];  
Lfq = I uvbar.Ga[mu].DC[uv,mu] - Muv uvbar.uv + I evbar.Ga[mu].DC[ev,mu] - Mev evbar.ev;  
Lyuk = lambda[ii] phiT[ii] uvbar.ProjP.u + lambdap[ii] phiT[ii] evbar.ProjP.e;  
Lnew = Lsq + Lfq + Lyuk + HC[Lyuk];
```


Run FeynRules

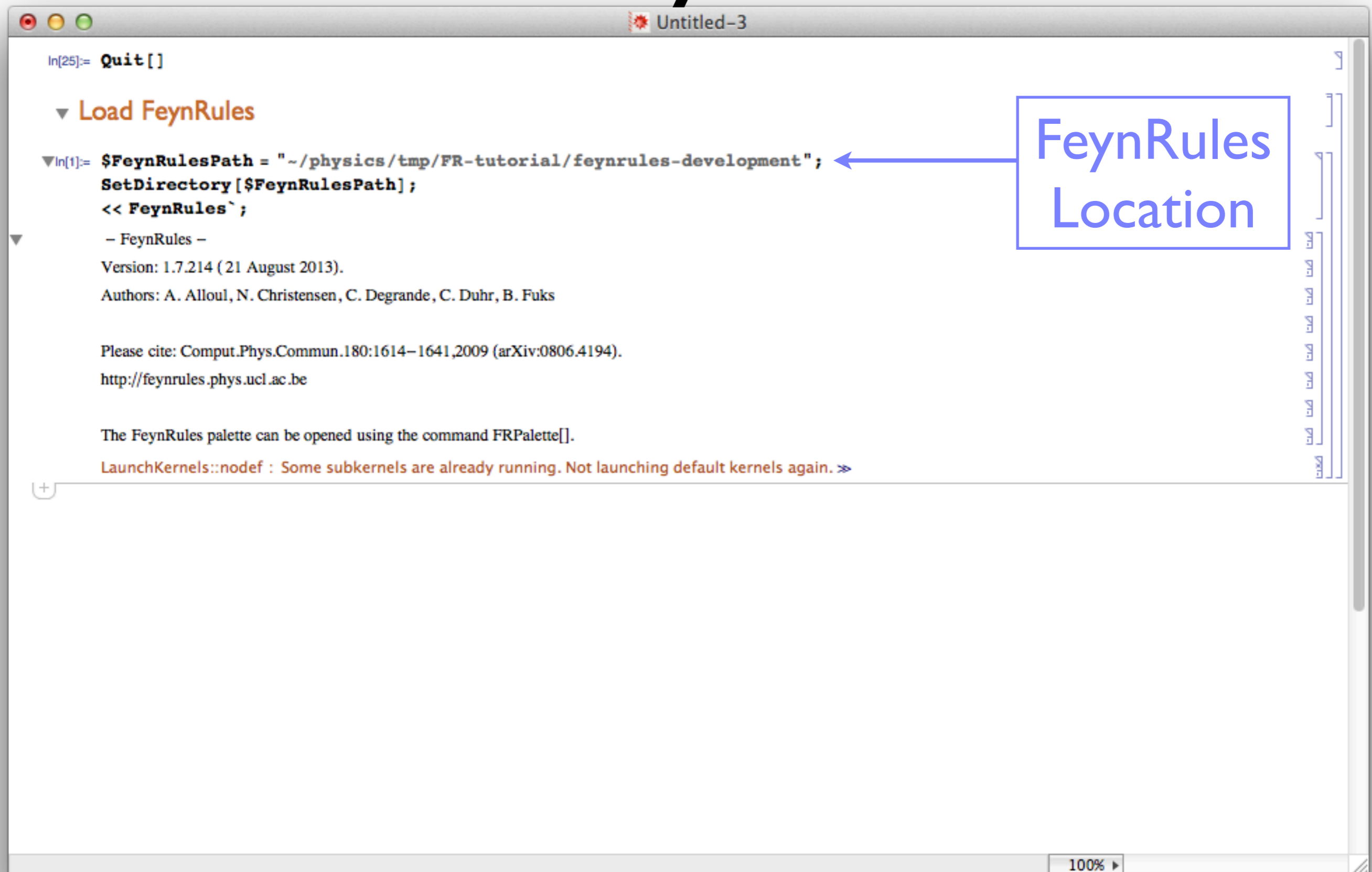


```
FR-tutorial — bash — 80x24
neil03:FR-tutorial neil$ ls
BSM.fr          FeynRules-development.tgz
neil03:FR-tutorial neil$ tar xvzf FeynRules-development.tgz
```

Run FeynRules

```
FR-tutorial — bash — 80x24
x feynrules-development/Core/.svn/prop-base/OutputRoutines.m.svn-base
x feynrules-development/Core/.svn/prop-base/VertexRoutine.m.svn-base
x feynrules-development/.svn/all-wcprops
x feynrules-development/.svn/dir-prop-base
x feynrules-development/.svn/entries
x feynrules-development/.svn/prop-base/
x feynrules-development/.svn/props/
x feynrules-development/.svn/text-base/
x feynrules-development/.svn/tmp/
x feynrules-development/.svn/tmp/prop-base/
x feynrules-development/.svn/tmp/props/
x feynrules-development/.svn/tmp/text-base/
x feynrules-development/.svn/text-base/commit.py.svn-base
x feynrules-development/.svn/text-base/FeynRules.m.svn-base
x feynrules-development/.svn/text-base/FeynRulesPackage.m.svn-base
x feynrules-development/.svn/text-base/FeynRulesParallel.m.svn-base
x feynrules-development/.svn/text-base/FRPalette.nb.svn-base
x feynrules-development/.svn/text-base/package.py.svn-base
x feynrules-development/.svn/text-base/ToolBox.m.svn-base
x feynrules-development/.svn/text-base/UpdateNotes.txt.svn-base
x feynrules-development/.svn/prop-base/commit.py.svn-base
x feynrules-development/.svn/prop-base/FeynRulesPackage.m.svn-base
neil@3:FR-tutorial neil$ ls
BSM.fr                               FeynRules-development.tgz feynrules-development
```

Run FeynRules



```
In[25]:= Quit[]

▼ Load FeynRules

▼ In[1]:= $FeynRulesPath = "~/physics/tmp/FR-tutorial/feynrules-development";
SetDirectory[$FeynRulesPath];
<< FeynRules` ;

- FeynRules -
Version: 1.7.214 (21 August 2013).
Authors: A. Alloul, N. Christensen, C. Degrande, C. Duhr, B. Fuks

Please cite: Comput.Phys.Commun.180:1614–1641,2009 (arXiv:0806.4194).
http://feynrules.phys.ucl.ac.be

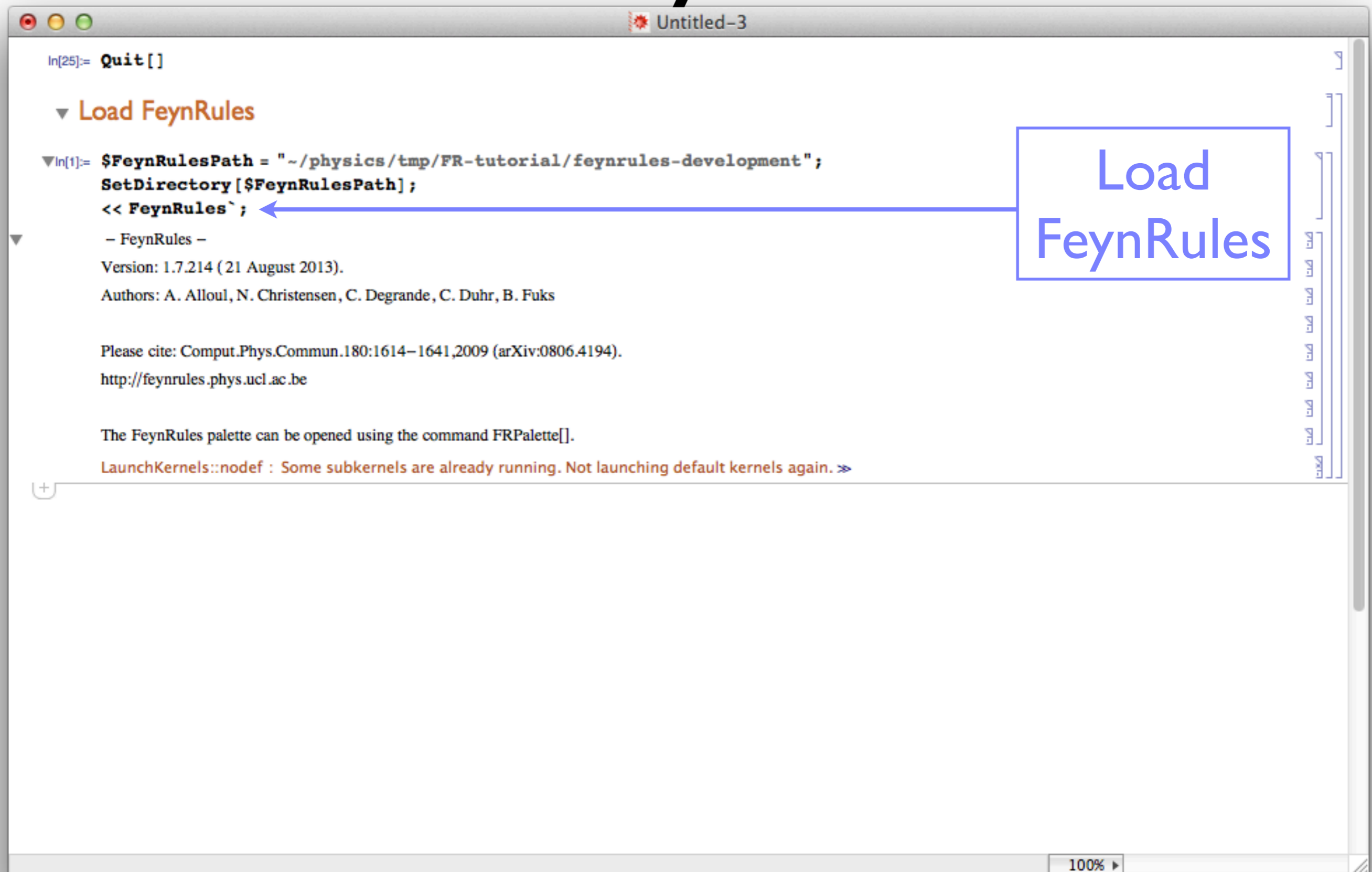
The FeynRules palette can be opened using the command FRPalette[].

LaunchKernels::nodef : Some subkernels are already running. Not launching default kernels again. ⌘
```

FeynRules Location

100%

Run FeynRules



```
In[25]:= Quit[]
```

▼ Load FeynRules

```
▼ In[1]:= $FeynRulesPath = "~/physics/tmp/FR-tutorial/feynrules-development";  
SetDirectory[$FeynRulesPath];  
<< FeynRules`;
```

– FeynRules –
Version: 1.7.214 (21 August 2013).
Authors: A. Alloul, N. Christensen, C. Degrande, C. Duhr, B. Fuks

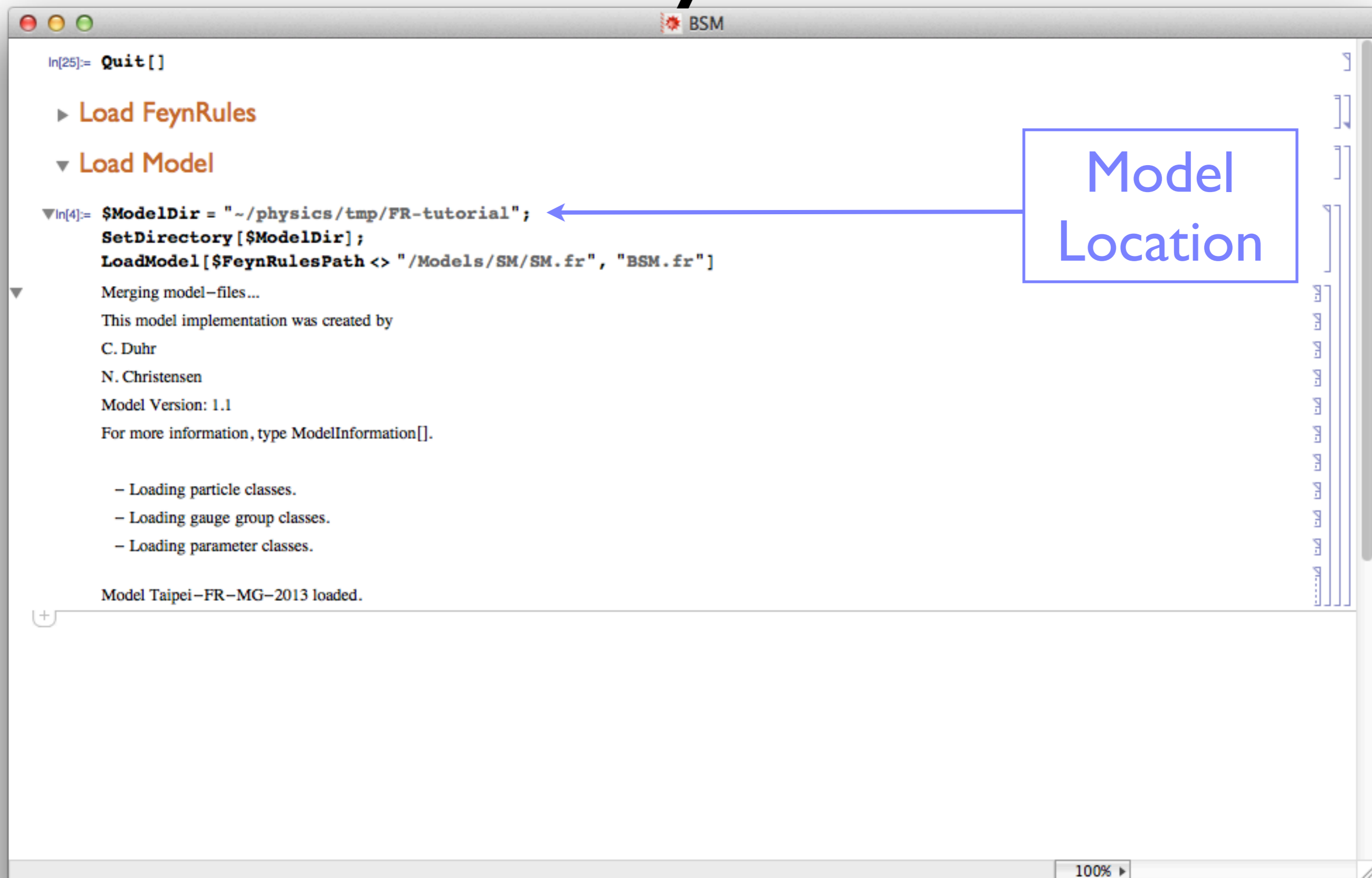
Please cite: Comput.Phys.Commun.180:1614–1641,2009 (arXiv:0806.4194).
<http://feynrules.phys.ucl.ac.be>

The FeynRules palette can be opened using the command FRPalette[].

LaunchKernels::nodef : Some subkernels are already running. Not launching default kernels again. ⌘

100%

Run FeynRules



The image shows a Mathematica notebook window titled "BSM". The notebook contains the following content:

```
In[25]:= Quit[]
```

▶ Load FeynRules

▼ Load Model

```
▼ In[4]:= $ModelDir = "~/physics/tmp/FR-tutorial";  
SetDirectory[$ModelDir];  
LoadModel[$FeynRulesPath <> "/Models/SM/SM.fr", "BSM.fr"]
```

Merging model-files...

This model implementation was created by

C. Duhr

N. Christensen

Model Version: 1.1

For more information, type ModelInformation[].

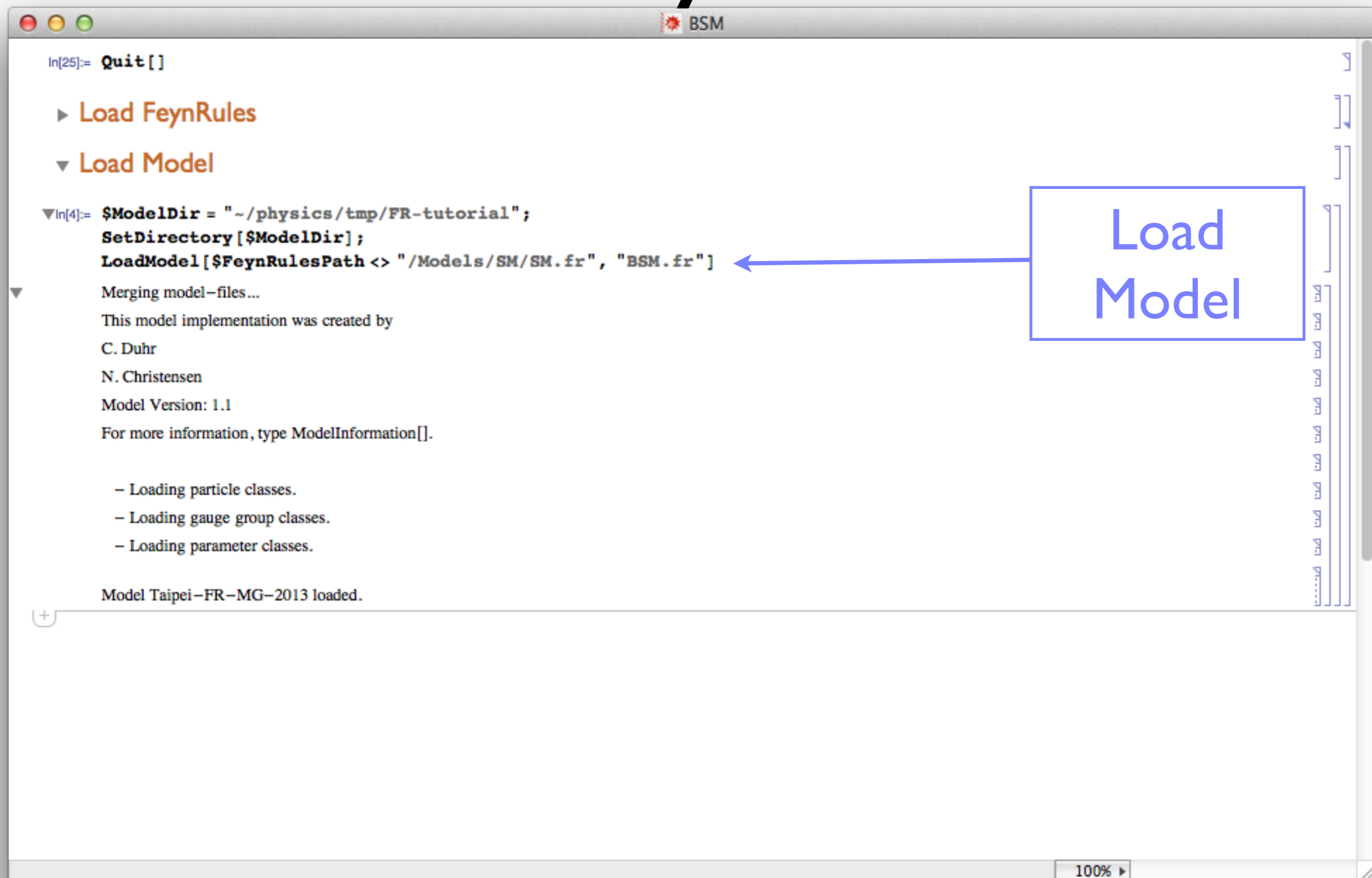
- Loading particle classes.
- Loading gauge group classes.
- Loading parameter classes.

Model Taipei-FR-MG-2013 loaded.

A blue box labeled "Model Location" is positioned to the right of the code, with a blue arrow pointing from the box to the path `"~/physics/tmp/FR-tutorial"` in the `$ModelDir` assignment.

100%

Run FeynRules



The screenshot shows a Mathematica notebook window titled "BSM". The notebook content is as follows:

```
In[25]:= Quit[]
```

► **Load FeynRules**

▼ **Load Model**

```
▼ In[4]:= $ModelDir = "~/physics/tmp/FR-tutorial";  
SetDirectory[$ModelDir];  
LoadModel[$FeynRulesPath <> "/Models/SM/SM.fr", "BSM.fr"]
```

Merging model-files...

This model implementation was created by

C. Duhr

N. Christensen

Model Version: 1.1

For more information, type ModelInformation[].

- Loading particle classes.
- Loading gauge group classes.
- Loading parameter classes.

Model Taipei-FR-MG-2013 loaded.

A blue box with the text "Load Model" and a blue arrow pointing to the `LoadModel` command in the code block is overlaid on the right side of the notebook.

100%

Run FeynRules

```
In[25]:= Quit[]
```

► Load FeynRules

▼ Load Model

```
▼In[4]:= $ModelDir = "~/physics/tmp/FR-tutorial";  
SetDirectory[$ModelDir];  
LoadModel[$FeynRulesPath <> "/Models/SM/SM.fr", "BSM.fr"]
```

Merging model-files...

This model implementation was created by
C. Duhr
N. Christensen
Model Version: 1.1
For more information, type ModelInformation[].

- Loading particle classes.
- Loading gauge group classes.
- Loading parameter classes.

Model Taipei-FR-MG-2013 loaded.

100%

If you have problems at this stage, comment out lines of BSM.fr until you find the problem and fix it.

Run FeynRules

In[25]:= `Quit[]`

- ▶ `Load FeynRules`
- ▶ `Load Model`
- ▼ `Check Hermiticity`

▼ In[7]:= `CheckHermiticity[Lnew]`

Checking for hermiticity by calculating the Feynman rules contained in L-HC[L].
If the lagrangian is hermitian, then the number of vertices should be zero.

Starting Feynman rule calculation.

Expanding the Lagrangian...

Collecting the different structures that enter the vertex.

9 possible non-zero vertices have been found -> starting the computation: 9 / 9.

0 vertices obtained.

The lagrangian is hermitian.

Out[7]= `{}`

```
Lsq = 1/2 del[phiT[ii],mu] del[phiT[ii]
Lfq = I uvbar.Ga[mu].DC[uv,mu] - Muv uv
Lyuk = lambda[ii] phiT[ii] uvbar.ProjP.
Lnew = Lsq + Lfq + Lyuk + HC[Lyuk];
```

100% ▶

Run FeynRules

In[25]:= `Quit[]`

- ▶ Load FeynRules
- ▶ Load Model
- ▼ Check Hermiticity

▼ In[7]:= `CheckHermiticity[Lnew]`

Checking for hermiticity by calculating the Feynman rules contained in L-HC[L].
If the lagrangian is hermitian, then the number of vertices should be zero.

Starting Feynman rule calculation.

Expanding the Lagrangian...

Collecting the different structures that enter the vertex.

9 possible non-zero vertices have been found -> starting the computation: 9 / 9.

0 vertices obtained.

The lagrangian is hermitian.

Out[7]= {}

```
Lsq = 1/2 del[phiT[ii],mu] del[phiT[ii]
Lfq = I uvbar.Ga[mu].DC[uv,mu] - Muv uv
Lyuk = lambda[ii] phiT[ii] uvbar.ProjP.
Lnew = Lsq + Lfq + Lyuk + HC[Lyuk];
```

100%

Run FeynRules

In[25]:= **Quit[]**

- ▶ Load FeynRules
- ▶ Load Model
- ▶ Check Hermiticity
- ▼ Calculate the new Feynman rules

▼ In[8]:= **verts = FeynmanRules[Lnew, ScreenOutput -> False]**

Starting Feynman rule calculation.
Expanding the Lagrangian...
Collecting the different structures that enter the vertex.
9 possible non-zero vertices have been found -> starting the computation: 9 / 9.

QN::NonConserv : Warning: non quantum number conserving vertex encountered!
Quantum number Y not conserved in vertex $\{\bar{u}, uv, \text{phiT}\}$.

QN::NonConserv : Warning: non quantum number conserving vertex encountered!
Quantum number Y not conserved in vertex $\{\bar{e}, ev, \text{phiT}\}$.

QN::NonConserv : Warning: non quantum number conserving vertex encountered!
General::stop : Further output of QN::NonConserv will be suppressed during this calculation. »

Quantum number Y not conserved in vertex $\{\bar{u}v, u, \text{phiT}\}$.

Quantum number Y not conserved in vertex $\{\bar{e}v, e, \text{phiT}\}$.

9 vertices obtained.

$$\left(\begin{array}{c} \bar{e}v \ 1 \\ ev \ 2 \\ \vdots \end{array} \right) \quad -ie\gamma_{s_1 s_2}^{\mu_3}$$

100%

Run FeynRules

```
In[25]:= Quit[]
```

- ▶ Load FeynRules
- ▶ Load Model
- ▶ Check Hermiticity
- ▼ Calculate the new Feynman rules

```
▼ In[8]:= verts = FeynmanRules[Lnew, ScreenOutput -> False]
```

Starting Feynman rule calculation.

Expanding the Lagrangian...

Collecting the different structures that enter the vertex.

9 possible non-zero vertices have been found -> starting the computation: 9 / 9.

QN::NonConserv : Warning: non quantum number conserving vertex encountered!

Quantum number Y not conserved in vertex $\{\bar{u}, uv, \text{phiT}\}$.

QN::NonConserv : Warning: non quantum number conserving vertex encountered!

Quantum number Y not conserved in vertex $\{\bar{e}, ev, \text{phiT}\}$.

QN::NonConserv : Warning: non quantum number conserving vertex encountered!

General::stop : Further output of QN::NonConserv will be suppressed during this calculation. »

Quantum number Y not conserved in vertex $\{\bar{u}v, u, \text{phiT}\}$.

Quantum number Y not conserved in vertex $\{\bar{e}v, e, \text{phiT}\}$.

9 vertices obtained.

$$\left(\begin{array}{c} \bar{e}v \ 1 \\ ev \ 2 \\ A \ 2 \end{array} \right) \quad -ie \gamma_{s_1 s_2}^{\mu_3}$$

Warning about possible non-conservation. But, these vertices are ok.

Run FeynRules

9 vertices obtained.

$\begin{pmatrix} \bar{e} \nu & 1 \\ e \nu & 2 \\ A & 3 \end{pmatrix}$	$-ie\gamma_{s_1 s_2}^{\mu_3}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u \nu & 2 \\ A & 3 \end{pmatrix}$	$\frac{2}{3} ie\gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}$
$\begin{pmatrix} \bar{u} & 1 \\ u \nu & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\delta_{m_1 m_2} \text{lambda}_{s_3} P_{-s_1 s_2}$
$\begin{pmatrix} \bar{e} & 1 \\ e \nu & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\text{lambda}_{s_3} P_{-s_1 s_2}$
$\begin{pmatrix} \bar{u} & 1 \\ u & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\delta_{m_1 m_2} \text{lambda}_{s_3} P_{+s_1 s_2}$
$\begin{pmatrix} \bar{e} \nu & 1 \\ e & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\text{lambda}_{s_3} P_{+s_1 s_2}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u \nu & 2 \\ G & 3 \end{pmatrix}$	$ig_s \gamma_{s_1 s_2}^{\mu_3} T_{m_1 m_2}^{\mu_3}$
$\begin{pmatrix} \bar{e} \nu & 1 \\ e \nu & 2 \\ Z & 3 \end{pmatrix}$	$\frac{ie s_w \gamma_{s_1 s_2}^{\mu_3}}{c_w}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u \nu & 2 \\ Z & 3 \end{pmatrix}$	$-\frac{2ie s_w \gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}}{3c_w}$

0 [8]=

These are the vertices FR warned us about.

100%

Run FeynRules

9 vertices obtained.

$\begin{pmatrix} \bar{e} \nu & 1 \\ e \nu & 2 \\ A & 3 \end{pmatrix}$	$-ie\gamma_{s_1 s_2}^{\mu_3}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u \nu & 2 \\ A & 3 \end{pmatrix}$	$\frac{2}{3} ie\gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}$
$\begin{pmatrix} \bar{u} & 1 \\ u \nu & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\delta_{m_1 m_2} \text{lambda}_{s_3} P_{-s_1 s_2}$
$\begin{pmatrix} \bar{e} & 1 \\ e \nu & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\text{lambda}_{p_{s_3}} P_{-s_1 s_2}$
$\begin{pmatrix} \bar{u} & 1 \\ u & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\delta_{m_1 m_2} \text{lambda}_{s_3} P_{+s_1 s_2}$
$\begin{pmatrix} \bar{e} \nu & 1 \\ e & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\text{lambda}_{p_{s_3}} P_{+s_1 s_2}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u \nu & 2 \\ G & 3 \end{pmatrix}$	$ig_s \gamma_{s_1 s_2}^{\mu_3} T_{m_1 m_2}^{\mu_3}$
$\begin{pmatrix} \bar{e} \nu & 1 \\ e \nu & 2 \\ Z & 3 \end{pmatrix}$	$\frac{ie s_w \gamma_{s_1 s_2}^{\mu_3}}{c_w}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u \nu & 2 \\ Z & 3 \end{pmatrix}$	$-\frac{2ie s_w \gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}}{3c_w}$

Note that there is a projection operator: P_R .

O₁[8]=

100% ▶

Run FeynRules

9 vertices obtained.

$\begin{pmatrix} \bar{e} \nu & 1 \\ e \nu & 2 \\ A & 3 \end{pmatrix}$	$-ie\gamma_{s_1 s_2}^{\mu_3}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u \nu & 2 \\ A & 3 \end{pmatrix}$	$\frac{2}{3} ie\gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}$
$\begin{pmatrix} \bar{u} & 1 \\ u \nu & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\delta_{m_1 m_2} \text{lambda}_{s_3} P_{-s_1 s_2}$
$\begin{pmatrix} \bar{e} & 1 \\ e \nu & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\text{lambda}_{s_3} P_{-s_1 s_2}$
$\begin{pmatrix} \bar{u} & 1 \\ u & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\delta_{m_1 m_2} \text{lambda}_{s_3} P_{+s_1 s_2}$
$\begin{pmatrix} \bar{e} \nu & 1 \\ e & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\text{lambda}_{s_3} P_{+s_1 s_2}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u \nu & 2 \\ G & 3 \end{pmatrix}$	$ig_s \gamma_{s_1 s_2}^{\mu_3} T_{m_1 m_2}^{\mu_3}$
$\begin{pmatrix} \bar{e} \nu & 1 \\ e \nu & 2 \\ Z & 3 \end{pmatrix}$	$\frac{ies_w \gamma_{s_1 s_2}^{\mu_3}}{c_w}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u \nu & 2 \\ Z & 3 \end{pmatrix}$	$-\frac{2ies_w \gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}}{3c_w}$

Only e_R and u_R are involved. These vertices do conserve Y .

100%

Run FeynRules

9 vertices obtained.

$\begin{pmatrix} \bar{e}v & 1 \\ ev & 2 \\ A & 3 \end{pmatrix}$	$-ie\gamma_{s_1 s_2}^{\mu_3}$
$\begin{pmatrix} \bar{u}v & 1 \\ uv & 2 \\ A & 3 \end{pmatrix}$	$\frac{2}{3}ie\gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}$
$\begin{pmatrix} \bar{u} & 1 \\ uv & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\delta_{m_1 m_2} \text{lambda}_{s_3} P_{-s_1 s_2}$
$\begin{pmatrix} \bar{e} & 1 \\ ev & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\text{lambda}_{s_3} P_{-s_1 s_2}$
$\begin{pmatrix} \bar{u}v & 1 \\ u & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\delta_{m_1 m_2} \text{lambda}_{s_3} P_{+s_1 s_2}$
$\begin{pmatrix} \bar{e}v & 1 \\ e & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\text{lambda}_{s_3} P_{+s_1 s_2}$
$\begin{pmatrix} \bar{u}v & 1 \\ uv & 2 \\ G & 3 \end{pmatrix}$	$ig_s \gamma_{s_1 s_2}^{\mu_3} T_{m_1 m_2}^{\mu_3}$
$\begin{pmatrix} \bar{e}v & 1 \\ ev & 2 \\ Z & 3 \end{pmatrix}$	$\frac{ies_w \gamma_{s_1 s_2}^{\mu_3}}{c_w}$
$\begin{pmatrix} \bar{u}v & 1 \\ uv & 2 \\ Z & 3 \end{pmatrix}$	$-\frac{2ies_w \gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}}{3c_w}$

Out[8]=

$i\bar{E}\not{D}E$
 $i\bar{U}\not{D}U$

100%

Run FeynRules

9 vertices obtained.

Out[8]=

$$\left(\begin{array}{l} (\bar{e} \nu 1) \\ (e \nu 2) \\ (A 3) \end{array} \right) -ie \gamma_{s_1 s_2}^{\mu_3}$$

$$\left(\begin{array}{l} (\bar{u} \nu 1) \\ (u \nu 2) \\ (A 3) \end{array} \right) \frac{2}{3} ie \gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}$$

$$\left(\begin{array}{l} (\bar{u} 1) \\ (u \nu 2) \\ (\text{phiT} 3) \end{array} \right) 2i \delta_{m_1 m_2} \text{lambda}_{s_3} P_{-s_1 s_2}$$

$$\left(\begin{array}{l} (\bar{e} 1) \\ (e \nu 2) \\ (\text{phiT} 3) \end{array} \right) 2i \text{lambda}_{s_3} P_{-s_1 s_2}$$

$$\left(\begin{array}{l} (\bar{u} \nu 1) \\ (u 2) \\ (\text{phiT} 3) \end{array} \right) 2i \delta_{m_1 m_2} \text{lambda}_{s_3} P_{+s_1 s_2}$$

$$\left(\begin{array}{l} (\bar{e} \nu 1) \\ (e 2) \\ (\text{phiT} 3) \end{array} \right) 2i \text{lambda}_{s_3} P_{+s_1 s_2}$$

$$\left(\begin{array}{l} (\bar{u} \nu 1) \\ (u \nu 2) \\ (G 3) \end{array} \right) ig_s \gamma_{s_1 s_2}^{\mu_3} T_{m_1 m_2}^{\mu_3}$$

$$\left(\begin{array}{l} (\bar{e} \nu 1) \\ (e \nu 2) \\ (Z 3) \end{array} \right) \frac{ie s_w \gamma_{s_1 s_2}^{\mu_3}}{c_w}$$

$$\left(\begin{array}{l} (\bar{u} \nu 1) \\ (u \nu 2) \\ (Z 3) \end{array} \right) -\frac{2ie s_w \gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}}{3c_w}$$

$$i \bar{E} \not{D} E$$

$$i \bar{U} \not{D} U$$

Run FeynRules

9 vertices obtained.

Out[8]=

$\begin{pmatrix} \bar{e} \nu & 1 \\ e \nu & 2 \\ A & 3 \end{pmatrix}$	$-ie\gamma_{s_1 s_2}^{\mu_3}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u \nu & 2 \\ A & 3 \end{pmatrix}$	$\frac{2}{3} ie\gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}$
$\begin{pmatrix} \bar{u} & 1 \\ u \nu & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\delta_{m_1 m_2} \text{lambda}_{s_3} P_{-s_1 s_2}$
$\begin{pmatrix} \bar{e} & 1 \\ e \nu & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\text{lambda}_{s_3} P_{-s_1 s_2}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\delta_{m_1 m_2} \text{lambda}_{s_3} P_{+s_1 s_2}$
$\begin{pmatrix} \bar{e} \nu & 1 \\ e & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\text{lambda}_{s_3} P_{+s_1 s_2}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u \nu & 2 \\ G & 3 \end{pmatrix}$	$ig_s \gamma_{s_1 s_2}^{\mu_3} T_{m_1 m_2}^{\mu_3}$
$\begin{pmatrix} e \nu & 1 \\ e \nu & 2 \\ Z & 3 \end{pmatrix}$	$\frac{ie s_w \gamma_{s_1 s_2}^{\mu_3}}{c_w}$
$\begin{pmatrix} \bar{u} \nu & 1 \\ u \nu & 2 \\ Z & 3 \end{pmatrix}$	$-\frac{2ie s_w \gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}}{3c_w}$

$i\bar{U}\not{D}U$

100%

Run FeynRules

9 vertices obtained.

$\begin{pmatrix} \bar{e}v & 1 \\ ev & 2 \\ A & 3 \end{pmatrix}$	$-ie\gamma_{s_1 s_2}^{\mu_3}$
$\begin{pmatrix} \bar{u}v & 1 \\ uv & 2 \\ A & 3 \end{pmatrix}$	$\frac{2}{3}ie\gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}$
$\begin{pmatrix} \bar{u} & 1 \\ uv & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\delta_{m_1 m_2} \text{lambda}_{s_3} P_{-s_1 s_2}$
$\begin{pmatrix} \bar{e} & 1 \\ ev & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\text{lambda}_{s_3} P_{-s_1 s_2}$
$\begin{pmatrix} \bar{u} & 1 \\ u & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\delta_{m_1 m_2} \text{lambda}_{s_3} P_{+s_1 s_2}$
$\begin{pmatrix} \bar{e} & 1 \\ e & 2 \\ \text{phiT} & 3 \end{pmatrix}$	$2i\text{lambda}_{s_3} P_{+s_1 s_2}$
$\begin{pmatrix} \bar{u}v & 1 \\ uv & 2 \\ G & 3 \end{pmatrix}$	$i g_s \gamma_{s_1 s_2}^{\mu_3} T_{m_1 m_2}^{\mu_3}$
$\begin{pmatrix} \bar{e}v & 1 \\ ev & 2 \\ Z & 3 \end{pmatrix}$	$\frac{ie s_w \gamma_{s_1 s_2}^{\mu_3}}{c_w}$
$\begin{pmatrix} \bar{u}v & 1 \\ uv & 2 \\ Z & 3 \end{pmatrix}$	$-\frac{2ie s_w \gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}}{3c_w}$

Out[8]=

$$\lambda_i \phi_i \bar{U} P_R u + \lambda'_i \phi_i \bar{E} P_R e + \text{h.c.}$$

100%

Run FeynRules

In[25]:= **Quit[]**

- ▶ Load FeynRules
- ▶ Load Model
- ▶ Check Hermiticity
- ▶ Calculate the new Feynman rules
- ▼ Mass Matrix Diagonalization

▼ In[9]:= **GetMassTerms [Lsq]** ← **Get Mass Terms**

Neglecting all terms with more than 2 particles.

Out[9]= $-\frac{1}{2} \text{phiT}_1^2 \text{MassM}_{1,1} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{1,2} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{2,1} - \frac{1}{2} \text{phiT}_2^2 \text{MassM}_{2,2}$

simplify ▾ scInd derivative scInd integral inverse function

100% ▶

Run FeynRules

In[25]:= `Quit[]`

- ▶ Load FeynRules
- ▶ Load Model
- ▶ Check Hermiticity
- ▶ Calculate the new Feynman rules
- ▼ Mass Matrix Diagonalization

▼ In[9]:= `GetMassTerms [Lsq]`
Neglecting all terms with more than 2 particles.

Out[9]=
$$-\frac{1}{2} \text{phiT}_1^2 \text{MassM}_{1,1} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{1,2} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{2,1} - \frac{1}{2} \text{phiT}_2^2 \text{MassM}_{2,2}$$

▼ In[10]:= `sols = Simplify[Eigensystem[{{MassM[1, 1], MassM[1, 2]}, {MassM[1, 2], MassM[2, 2]}}]`

Out[10]=
$$\left\{ \frac{1}{2} \left(\text{MassM}_{1,1} + \text{MassM}_{2,2} - \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2} \right), \frac{1}{2} \left(\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2} \right), \left\{ -\frac{-\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\}, \left\{ \frac{\text{MassM}_{1,1} - \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\} \right\}$$

Assuming a ragged array | Use as a *list of pairs* instead

sublengths flatten

100%

Run FeynRules

► Calculate the new Feynman rules

▼ Mass Matrix Diagonalization

▼ In[9]:= **GetMassTerms [Lsq]**

Neglecting all terms with more than 2 particles.

$$\text{Out[9]} = -\frac{1}{2} \text{phiT}_1^2 \text{MassM}_{1,1} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{1,2} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{2,1} - \frac{1}{2} \text{phiT}_2^2 \text{MassM}_{2,2}$$

MphiM1

▼ In[10]:= **sols = Simplify[Eigensystem[{{MassM[1, 1], MassM[1, 2]}, {MassM[1, 2], MassM[2, 2]}]]]**

$$\text{Out[10]} = \left(\begin{array}{l} \frac{1}{2} \left(\text{MassM}_{1,1} + \text{MassM}_{2,2} - \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2} \right) \frac{1}{2} \left(\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2} \right) \\ \left\{ -\frac{-\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\} \quad \left\{ \frac{\text{MassM}_{1,1} - \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\} \end{array} \right)$$

▼ In[11]:= **Simplify[Solve[{sols[[1, 1]] == MphiM1², sols[[1, 2]] == MphiM2², $\frac{1}{\sqrt{\text{sols}[[2, 1, 1]]^2 + 1}} = \text{sina}$ }, {MassM[1, 1], MassM[1, 2], MassM[2, 2]}]]]**

$$\text{Out[11]} = \left\{ \left\{ \text{MassM}_{1,1} \rightarrow \text{MphiM2}^2 \text{sina}^2 - \text{MphiM1}^2 (\text{sina}^2 - 1), \text{MassM}_{1,2} \rightarrow -i \text{sina} \sqrt{\text{sina}^2 - 1} (\text{MphiM1}^2 - \text{MphiM2}^2), \right. \right. \\ \left. \left. \text{MassM}_{2,2} \rightarrow \text{MphiM1}^2 \text{sina}^2 - \text{MphiM2}^2 (\text{sina}^2 - 1) \right\}, \left\{ \text{MassM}_{1,1} \rightarrow \text{MphiM2}^2 \text{sina}^2 - \text{MphiM1}^2 (\text{sina}^2 - 1), \right. \right. \\ \left. \left. \text{MassM}_{1,2} \rightarrow i \text{sina} \sqrt{\text{sina}^2 - 1} (\text{MphiM1}^2 - \text{MphiM2}^2), \text{MassM}_{2,2} \rightarrow \text{MphiM1}^2 \text{sina}^2 - \text{MphiM2}^2 (\text{sina}^2 - 1) \right\} \right\}$$

Assuming a list of rules | Use as a two-dimensional array instead

apply rules to expr...

apply rules to variables

convert rules to equations

convert rules to lists



Run FeynRules

► Calculate the new Feynman rules

▼ Mass Matrix Diagonalization

▼ In[9]:= **GetMassTerms [Lsq]**

Neglecting all terms with more than 2 particles.

$$\text{Out[9]} = -\frac{1}{2} \text{phiT}_1^2 \text{MassM}_{1,1} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{1,2} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{2,1} - \frac{1}{2} \text{phiT}_2^2 \text{MassM}_{2,2}$$

▼ In[10]:= **sols = Simplify[Eigensystem[{{MassM[1, 1], MassM[1, 2]}, {MassM[1, 2], MassM[2, 2]}]]]**

$$\text{Out[10]} = \left(\begin{array}{l} \frac{1}{2} \left(\text{MassM}_{1,1} + \text{MassM}_{2,2} - \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2} \right) \frac{1}{2} \left(\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2} \right) \\ \left\{ -\frac{-\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\} \quad \left\{ \frac{\text{MassM}_{1,1} - \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\} \end{array} \right)$$

▼ In[11]:= **Simplify[Solve[{sols[[1, 1]] == MphiM1², sols[[1, 2]] == MphiM2², $\frac{1}{\sqrt{\text{sols}[[2, 1, 1]]^2 + 1}} = \text{sina}$ }, {MassM[1, 1], MassM[1, 2], MassM[2, 2]}]]]**

$$\text{Out[11]} = \left\{ \left\{ \text{MassM}_{1,1} \rightarrow \text{MphiM2}^2 \text{sina}^2 - \text{MphiM1}^2 (\text{sina}^2 - 1), \text{MassM}_{1,2} \rightarrow -i \text{sina} \sqrt{\text{sina}^2 - 1} (\text{MphiM1}^2 - \text{MphiM2}^2), \right. \right. \\ \left. \left. \text{MassM}_{2,2} \rightarrow \text{MphiM1}^2 \text{sina}^2 - \text{MphiM2}^2 (\text{sina}^2 - 1) \right\}, \left\{ \text{MassM}_{1,1} \rightarrow \text{MphiM2}^2 \text{sina}^2 - \text{MphiM1}^2 (\text{sina}^2 - 1), \right. \right. \\ \left. \left. \text{MassM}_{1,2} \rightarrow i \text{sina} \sqrt{\text{sina}^2 - 1} (\text{MphiM1}^2 - \text{MphiM2}^2), \text{MassM}_{2,2} \rightarrow \text{MphiM1}^2 \text{sina}^2 - \text{MphiM2}^2 (\text{sina}^2 - 1) \right\} \right\}$$

MphiM2

Assuming a list of rules | Use as a *two-dimensional array* instead

apply rules to expr...

apply rules to variables

convert rules to equations

convert rules to lists



Run FeynRules

BSM

- ▶ Calculate the new Feynman rules
- ▼ Mass Matrix Diagonalization

▼ In[9]:= **GetMassTerms [Lsq]**
 Neglecting all terms with more than 2 particles.

Out[9]= $-\frac{1}{2} \text{phiT}_1^2 \text{MassM}_{1,1} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{1,2} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{2,1} - \frac{1}{2} \text{phiT}_2^2 \text{MassM}_{2,2}$

▼ In[10]:= **sols = Simplify[Eigensystem[{{MassM[1, 1], MassM[1, 2]}, {MassM[1, 2], MassM[2, 2]}}]**

Out[10]=
$$\left(\begin{array}{l} \frac{1}{2} \left(\text{MassM}_{1,1} + \text{MassM}_{2,2} - \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2} \right) \frac{1}{2} \left(\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2} \right) \\ \left\{ -\frac{-\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\} \quad \left\{ \frac{\text{MassM}_{1,1} - \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\} \end{array} \right)$$

▼ In[11]:= **Simplify[Solve[{sols[[1, 1]] == MphiM1², sols[[1, 2]] == MphiM2², $\frac{1}{\sqrt{\text{sols}[[2, 1, 1]]^2 + 1}} = \text{sina}$ }, {MassM[1, 1], MassM[1, 2], MassM[2, 2]}]]**

Out[11]=
$$\left\{ \left\{ \text{MassM}_{1,1} \rightarrow \text{MphiM2}^2 \text{sina}^2 - \text{MphiM1}^2 (\text{sina}^2 - 1), \text{MassM}_{1,2} \rightarrow -i \text{sina} \sqrt{\text{sina}^2 - 1} (\text{MphiM1}^2 - \text{MphiM2}^2), \right. \right.$$

$$\left. \text{MassM}_{2,2} \rightarrow \text{MphiM1}^2 \text{sina}^2 - \text{MphiM2}^2 (\text{sina}^2 - 1) \right\}, \left\{ \text{MassM}_{1,1} \rightarrow \text{MphiM2}^2 \text{sina}^2 - \text{MphiM1}^2 (\text{sina}^2 - 1), \right.$$

$$\left. \text{MassM}_{1,2} \rightarrow i \text{sina} \sqrt{\text{sina}^2 - 1} (\text{MphiM1}^2 - \text{MphiM2}^2), \text{MassM}_{2,2} \rightarrow \text{MphiM1}^2 \text{sina}^2 - \text{MphiM2}^2 (\text{sina}^2 - 1) \right\}$$

Assuming a list of rules | Use as a two-dimensional array instead

apply rules to expr... apply rules to variables convert rules to equations convert rules to lists

100%

Run FeynRules

► Calculate the new Feynman rules

▼ Mass Matrix Diagonalization

▼ In[9]:= **GetMassTerms [Lsq]**

Neglecting all terms with more than 2 particles.

$$\text{Out[9]} = -\frac{1}{2} \text{phiT}_1^2 \text{MassM}_{1,1} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{1,2} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{2,1} - \frac{1}{2} \text{phiT}_2^2 \text{MassM}_{2,2}$$

Solve for
MassM

▼ In[10]:= **sols = Simplify[Eigensystem[{{MassM[1, 1], MassM[1, 2]}, {MassM[1, 2], MassM[2, 2]}}]**

$$\text{Out[10]} = \left\{ \begin{array}{l} \frac{1}{2} \left(\text{MassM}_{1,1} + \text{MassM}_{2,2} - \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2} \right) \frac{1}{2} \left(\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2} \right) \\ \left\{ -\frac{-\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\} \quad \left\{ \frac{\text{MassM}_{1,1} - \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\} \end{array} \right.$$

▼ In[11]:= **Simplify[Solve[{sols[[1, 1]] == MphiM1², sols[[1, 2]] == MphiM2², $\frac{1}{\sqrt{\text{sols}[[2, 1, 1]]^2 + 1}} = \text{sina}$ }, {MassM[1, 1], MassM[1, 2], MassM[2, 2]}]]**

$$\text{Out[11]} = \left\{ \left\{ \text{MassM}_{1,1} \rightarrow \text{MphiM2}^2 \text{sina}^2 - \text{MphiM1}^2 (\text{sina}^2 - 1), \text{MassM}_{1,2} \rightarrow -i \text{sina} \sqrt{\text{sina}^2 - 1} (\text{MphiM1}^2 - \text{MphiM2}^2), \right. \right.$$

$$\left. \text{MassM}_{2,2} \rightarrow \text{MphiM1}^2 \text{sina}^2 - \text{MphiM2}^2 (\text{sina}^2 - 1) \right\}, \left\{ \text{MassM}_{1,1} \rightarrow \text{MphiM2}^2 \text{sina}^2 - \text{MphiM1}^2 (\text{sina}^2 - 1), \right.$$

$$\left. \text{MassM}_{1,2} \rightarrow i \text{sina} \sqrt{\text{sina}^2 - 1} (\text{MphiM1}^2 - \text{MphiM2}^2), \text{MassM}_{2,2} \rightarrow \text{MphiM1}^2 \text{sina}^2 - \text{MphiM2}^2 (\text{sina}^2 - 1) \right\}$$

Assuming a list of rules | Use as a *two-dimensional array* instead

apply rules to expr...

apply rules to variables

convert rules to equations

convert rules to lists



Run FeynRules

► Calculate the new Feynman rules

▼ Mass Matrix Diagonalization

▼ In[9]:= **GetMassTerms [Lsq]**

Neglecting all terms with more than 2 particles.

$$\text{Out[9]} = -\frac{1}{2} \text{phiT}_1^2 \text{MassM}_{1,1} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{1,2} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{2,1} - \frac{1}{2} \text{phiT}_2^2 \text{MassM}_{2,2}$$

▼ In[10]:= **sols = Simplify[Eigensystem[{{MassM[1, 1], MassM[1, 2]}, {MassM[1, 2], MassM[2, 2]}]}]**

$$\text{Out[10]} = \left(\begin{array}{c} \frac{1}{2} (\text{MassM}_{1,1} + \text{MassM}_{2,2} - \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}) \\ \frac{1}{2} (\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}) \end{array} \right) \left(\begin{array}{c} -\frac{\text{MassM}_{1,1} - \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \\ \frac{\text{MassM}_{1,1} - \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \end{array} \right)$$

▼ In[12]:= **sols2 =**

Simplify[

$$\text{Simplify[Solve[{\text{sols}[[1, 1]] = \text{MphiM1}^2, \text{sols}[[1, 2]] = \text{MphiM2}^2, \frac{1}{\sqrt{\text{sols}[[2, 1, 1]]^2 + 1}} = \text{sina}},$$

$$\{\text{MassM}[1, 1], \text{MassM}[1, 2], \text{MassM}[2, 2]\}]] /. \{\sqrt{\text{sina}^2 - 1} \rightarrow \text{I cosa}, \text{sina}^2 - 1 \rightarrow -\text{cosa}^2\}];$$

sols2 // TableForm

Out[13]/TableForm=

$\text{MassM}_{1,1} \rightarrow \text{cosa}^2 \text{MphiM1}^2 + \text{MphiM2}^2 \text{sina}^2$	$\text{MassM}_{1,2} \rightarrow \text{cosa sina} (\text{MphiM1}^2 - \text{MphiM2}^2)$	$\text{MassM}_{2,2} \rightarrow \text{cosa}^2 \text{MphiM2}^2 + \text{MphiM1}^2 \text{sina}^2$
$\text{MassM}_{1,1} \rightarrow \text{cosa}^2 \text{MphiM1}^2 + \text{MphiM2}^2 \text{sina}^2$	$\text{MassM}_{1,2} \rightarrow -\text{cosa sina} (\text{MphiM1}^2 - \text{MphiM2}^2)$	$\text{MassM}_{2,2} \rightarrow \text{cosa}^2 \text{MphiM2}^2 + \text{MphiM1}^2 \text{sina}^2$

Trig Identities

Assuming a list of rules | Use as a two-dimensional array instead

apply rules to expr...

apply rules to variables

convert rules to equations

convert rules to lists



Run FeynRules

BSM

▼In[9]:= **GetMassTerms [Lsq]**
 Neglecting all terms with more than 2 particles.

Out[9]= $-\frac{1}{2} \text{phiT}_1^2 \text{MassM}_{1,1} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{1,2} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{2,1} - \frac{1}{2} \text{phiT}_2^2 \text{MassM}_{2,2}$

▼In[10]:= **sols = Simplify[Eigensystem[{{MassM[1, 1], MassM[1, 2]}, {MassM[1, 2], Ma**

Out[10]=
$$\left(\frac{1}{2} \left(\text{MassM}_{1,1} + \text{MassM}_{2,2} - \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2} \right), \frac{1}{2} \left(\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2} \right) \right)$$

$$\left\{ \left\{ -\frac{-\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\}, \left\{ \frac{\text{MassM}_{1,1} - \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\} \right\}$$

▼In[12]:= **sols2 =**
Simplify[
Simplify[Solve[{sols[[1, 1]] == MphiM1², sols[[1, 2]] == MphiM2², $\frac{1}{\sqrt{\text{sols}[[2, 1, 1]]^2 + 1}} = \text{sina}$ },
{MassM[1, 1], MassM[1, 2], MassM[2, 2]}]] /. { $\sqrt{\text{sina}^2 - 1} \rightarrow \text{I cosa}$, $\text{sina}^2 - 1 \rightarrow -\text{cosa}^2$ }}];
sols2 // TableForm

Out[13]//TableForm=
 $\text{MassM}_{1,1} \rightarrow \text{cosa}^2 \text{MphiM1}^2 + \text{MphiM2}^2 \text{sina}^2$ $\text{MassM}_{1,2} \rightarrow \text{cosa sina} (\text{MphiM1}^2 - \text{MphiM2}^2)$ $\text{MassM}_{2,2} \rightarrow \text{cosa}^2 \text{MphiM2}^2 + \text{MphiM1}^2 \text{sina}^2$
 $\text{MassM}_{1,1} \rightarrow \text{cosa}^2 \text{MphiM1}^2 + \text{MphiM2}^2 \text{sina}^2$ $\text{MassM}_{1,2} \rightarrow -\text{cosa sina} (\text{MphiM1}^2 - \text{MphiM2}^2)$ $\text{MassM}_{2,2} \rightarrow \text{cosa}^2 \text{MphiM2}^2 + \text{MphiM1}^2 \text{sina}^2$

▼In[14]:= **sols2[[2]] // InputForm**

Out[14]//InputForm=
 $\{\text{MassM}[1, 1] \rightarrow \text{cosa}^2 \text{MphiM1}^2 + \text{MphiM2}^2 \text{sina}^2, \text{MassM}[1, 2] \rightarrow -(\text{cosa} (\text{MphiM1}^2 - \text{MphiM2}^2) \text{sina}),$
 $\text{MassM}[2, 2] \rightarrow \text{cosa}^2 \text{MphiM2}^2 + \text{MphiM1}^2 \text{sina}^2\}$

We want the 2nd solution

←

100%

Run FeynRules

BSM

▼In[9]:= **GetMassTerms [Lsq]**
 Neglecting all terms with more than 2 particles.

Out[9]= $-\frac{1}{2} \text{phiT}_1^2 \text{MassM}_{1,1} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{1,2} - \frac{1}{2} \text{phiT}_2 \text{phiT}_1 \text{MassM}_{2,1} - \frac{1}{2} \text{phiT}_2^2 \text{MassM}_{2,2}$

▼In[10]:= **sols = Simplify[Eigensystem[{{MassM[1, 1], MassM[1, 2]}, {MassM[1, 2], MassM[2, 2]}}, {MassM[1, 1], MassM[1, 2], MassM[2, 2]}]]**

Out[10]=
$$\left(\begin{array}{l} \frac{1}{2} (\text{MassM}_{1,1} + \text{MassM}_{2,2} - \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}) \quad \frac{1}{2} (\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}) \\ \left\{ -\frac{-\text{MassM}_{1,1} + \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\} \quad \left\{ \frac{\text{MassM}_{1,1} - \text{MassM}_{2,2} + \sqrt{\text{MassM}_{1,1}^2 - 2 \text{MassM}_{2,2} \text{MassM}_{1,1} + 4 \text{MassM}_{1,2}^2 + \text{MassM}_{2,2}^2}}{2 \text{MassM}_{1,2}}, 1 \right\} \end{array} \right)$$

▼In[12]:= **sols2 = Simplify[Simplify[Solve[{sols[[1, 1]] == MphiM1^2, sols[[1, 2]] == MphiM2^2, $\frac{1}{\sqrt{\text{sols}[[2, 1, 1]]^2 + 1}} = \text{sina}$ }, {MassM[1, 1], MassM[1, 2], MassM[2, 2]}]] /. { $\sqrt{\text{sina}^2 - 1} \rightarrow \text{I cosa}$, $\text{sina}^2 - 1 \rightarrow -\text{cosa}^2$ }]];**
sols2 // TableForm

Out[13]//TableForm=

$\text{MassM}_{1,1} \rightarrow \text{cosa}^2 \text{MphiM1}^2 + \text{MphiM2}^2 \text{sina}^2$	$\text{MassM}_{1,2} \rightarrow \text{cosa sina} (\text{MphiM1}^2 - \text{MphiM2}^2)$	$\text{MassM}_{2,2} \rightarrow \text{cosa}^2 \text{MphiM2}^2 + \text{MphiM1}^2 \text{sina}^2$
$\text{MassM}_{1,1} \rightarrow \text{cosa}^2 \text{MphiM1}^2 + \text{MphiM2}^2 \text{sina}^2$	$\text{MassM}_{1,2} \rightarrow -\text{cosa sina} (\text{MphiM1}^2 - \text{MphiM2}^2)$	$\text{MassM}_{2,2} \rightarrow \text{cosa}^2 \text{MphiM2}^2 + \text{MphiM1}^2 \text{sina}^2$

▼In[14]:= **sols2[[2]] // InputForm**

Out[14]//InputForm=

```
{MassM[1, 1] -> cosa^2*MphiM1^2 + MphiM2^2*sina^2, MassM[1, 2] -> -(cosa*(MphiM1^2 - MphiM2^2)*sina),
MassM[2, 2] -> cosa^2*MphiM2^2 + MphiM1^2*sina^2}
```

100%

The Implementation

```
BSM.fr
New Open Recent Revert Print Undo Redo Cut Copy Paste Search Preferences Help

lambda == {
  ParameterType      -> External,
  ComplexParameter  -> False,
  Indices            -> {Index[scInd]},
  Value              -> {lambda[1]->1, lambda[2]->1},
  InteractionOrder  -> {NP,1}
},
lambdap == {
  ParameterType      -> External,
  ComplexParameter  -> False,
  Indices            -> {Index[scInd]},
  Value              -> {lambdap[1]->1, lambdap[2]->1},
  InteractionOrder  -> {NP,1}
},
MassM == {
  ParameterType      -> Internal,
  ComplexParameter  -> False,
  Indices            -> {Index[scInd], Index[scInd]},
  Definitions        -> {MassM[1, 1] -> cosa^2*MphiM1^2 + MphiM2^2*sina^2,
                        MassM[1, 2] -> -cosa*(MphiM1^2 - MphiM2^2)*sina,
                        MassM[2, 1] -> -cosa*(MphiM1^2 - MphiM2^2)*sina,
                        MassM[2, 2] -> cosa^2*MphiM2^2 + MphiM1^2*sina^2}
}
};
```

Paste Definitions

--:--- BSM.fr 38% (53,43) (Fundamental)
Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation

```
BSM.fr
New Open Recent Revert Print Undo Redo Cut Copy Paste Search Preferences Help

lambda == {
  ParameterType    -> External,
  ComplexParameter -> False,
  Indices          -> {Index[scInd]},
  Value           -> {lambda[1]->1, lambda[2]->1},
  InteractionOrder -> {NP,1}
},
lambdap == {
  ParameterType    -> External,
  ComplexParameter -> False,
  Indices          -> {Index[scInd]},
  Value           -> {lambdap[1]->1, lambdap[2]->1},
  InteractionOrder -> {NP,1}
},
MassM == {
  ParamterType -> Internal,
  ComplexParameter -> False,
  Indices      -> {Index[scInd], Index[scInd]},
  Definitions  -> {MassM[1, 1] -> cosa^2*MphiM1^2 + MphiM2^2*sina^2,
                  MassM[1, 2] -> -cosa*(MphiM1^2 - MphiM2^2)*sina,
                  MassM[2, 1] -> -cosa*(MphiM1^2 - MphiM2^2)*sina,
                  MassM[2, 2] -> cosa^2*MphiM2^2 + MphiM1^2*sina^2}
}
};
```

Make Internal

-- BSM.fr 38% (53,43) (Fundamental)
Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

The Implementation

```
BSM.fr
New Open Recent Revert Print Undo Redo Cut Copy Paste Search Preferences Help

InteractionOrder -> {NP,1}
},
lambdap == {
  ParameterType -> External,
  ComplexParameter -> False,
  Indices -> {Index[scInd]},
  Value -> {lambdap[1]->1, lambdap[2]->1},
  InteractionOrder -> {NP,1}
},
sina == {
  ParameterType -> External,
  ComplexParameter -> False,
  Value -> 0.35
},
cosa == {
  ParameterType -> Internal,
  ComplexParameter -> False,
  Value -> Sqrt[1-sina^2]
},
MassM == {
  ParameterType -> Internal,
  ComplexParameter -> False,
  Indices -> {Index[scInd], Index[scInd]},
  Definitions -> {MassM[1, 1] -> cosa^2*MphiM1^2 + MphiM2^2*sina^2,
    MassM[1, 2] -> -cosa*(MphiM1^2 - MphiM2^2)*sina,
```

Add sina & cosa

```
};
```

-:**~ BSM.fr 40% (61,15) (Fundamental)

The Implementation

```
BSM.fr
New Open Recent Revert Print Undo Redo Cut Copy Paste Search Preferences Help

    Mass      -> {Muv, 500},
    Width     -> {Wuv, 1}
  },
F[21] == {
  ClassName   -> ev,
  SelfConjugate -> False,
  Indices     -> {},
  QuantumNumbers -> {Q->-1, Y->-1, LeptonNumber->1},
  Mass       -> {Mev, 300},
  Width     -> {Wev, 1}
},
S[20] == {
  ClassName   -> phiT,
  Unphysical  -> True,
  SelfConjugate -> True,
  Indices     -> {Index[scInd]},
  FlavorIndex -> scInd,
  Definitions -> {phiT[1]-> cosa phiM[1] + sina phiM[2],
                  phiT[2]->-sina phiM[1] + cosa phiM[2]}
},
S[21] == {
  ClassName   -> phiM,
  SelfConjugate -> True,
  Indices     -> {Index[scInd]},
  FlavorIndex -> scInd,

```

Add Definitions

```

-:--- BSM.fr 68% (92,76) (Fundamental)
Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr
```

Run FeynRules

The screenshot shows a Mathematica notebook window titled "BSM". The notebook content is as follows:

```
In[15]:= Quit[]
```

- ▶ Load FeynRules
- ▶ Load Model
- ▶ Check Hermiticity
- ▶ Calculate the new Feynman rules
- + ▶ Mass Matrix Diagonalization

A blue arrow points from a text box to the `Quit[]` command. The text box contains the following text:

Don't forget to quit the kernel before restarting.

The notebook interface includes standard window controls (red, yellow, green buttons) at the top left, a title bar with the name "BSM", and a zoom level indicator "100%" at the bottom right.

Run FeynRules

In[15]:= `Quit[]`

- ▶ Load FeynRules
- ▶ Load Model
- ▶ Check Hermiticity
- ▶ Calculate the new Feynman rules
- + ▶ Mass Matrix Diagonalization

Load FeynRules
Load Model
Check Hermiticity

100% ▶

Run FeynRules

▶ Load Model

▶ Check Hermiticity

▼ Calculate the new Feynman rules

▼ In[8]:= `verts = FeynmanRules[Lnew, ScreenOutput -> False]` ← FeynmanRules

Starting Feynman rule calculation.

Expanding the Lagrangian...

Collecting the different structures that enter the vertex.

13 possible non-zero vertices have been found -> starting the computation: 13 / 13.

QN::NonConserv : Warning: non quantum number conserving vertex encountered!

Quantum number Y not conserved in vertex $\{\bar{u}, uv, \text{phiM1}\}$.

QN::NonConserv : Warning: non quantum number conserving vertex encountered!

Quantum number Y not conserved in vertex $\{\bar{u}, uv, \text{phiM2}\}$.

QN::NonConserv : Warning: non quantum number conserving vertex encountered!

General::stop : Further output of QN::NonConserv will be suppressed during this calculation. »

Quantum number Y not conserved in vertex $\{\bar{e}, ev, \text{phiM1}\}$.

Quantum number Y not conserved in vertex $\{\bar{e}, ev, \text{phiM2}\}$.

Quantum number Y not conserved in vertex $\{\bar{uv}, u, \text{phiM1}\}$.

Quantum number Y not conserved in vertex $\{\bar{uv}, u, \text{phiM2}\}$.

Quantum number Y not conserved in vertex $\{\bar{ev}, e, \text{phiM1}\}$.

Quantum number Y not conserved in vertex $\{\bar{ev}, e, \text{phiM2}\}$.

13 vertices obtained.

100%

Run FeynRules

BSM

Out[8]=

$\left(\begin{array}{l} \bar{u} \ 2 \\ A \ 3 \end{array} \right)$	$\frac{2}{3} i e \gamma_{s_1 s_2}^{\mu_3} \delta_{m_1 m_2}$
$\left(\begin{array}{l} \bar{u} \ 1 \\ uv \ 2 \\ \text{phiM1} \ 3 \end{array} \right)$	$i \cos \alpha \delta_{m_1 m_2} \text{lambda}_1 P_{-s_1 s_2} - i \sin \alpha \delta_{m_1 m_2} \text{lambda}_2 P_{-s_1 s_2}$
$\left(\begin{array}{l} \bar{u} \ 1 \\ uv \ 2 \\ \text{phiM2} \ 3 \end{array} \right)$	$i \sin \alpha \delta_{m_1 m_2} \text{lambda}_1 P_{-s_1 s_2} + i \cos \alpha \delta_{m_1 m_2} \text{lambda}_2 P_{-s_1 s_2}$
$\left(\begin{array}{l} \bar{e} \ 1 \\ ev \ 2 \\ \text{phiM1} \ 3 \end{array} \right)$	$i \cos \alpha \text{lambda}_{d1} P_{-s_1 s_2} - i \sin \alpha \text{lambda}_{d2} P_{-s_1 s_2}$
$\left(\begin{array}{l} \bar{e} \ 1 \\ ev \ 2 \\ \text{phiM2} \ 3 \end{array} \right)$	$i \sin \alpha \text{lambda}_{d1} P_{-s_1 s_2} + i \cos \alpha \text{lambda}_{d2} P_{-s_1 s_2}$
$\left(\begin{array}{l} \bar{u} \nu \ 1 \\ u \ 2 \\ \text{phiM1} \ 3 \end{array} \right)$	$i \cos \alpha \delta_{m_1 m_2} \text{lambda}_1 P_{+s_1 s_2} - i \sin \alpha \delta_{m_1 m_2} \text{lambda}_2 P_{+s_1 s_2}$
$\left(\begin{array}{l} \bar{u} \nu \ 1 \\ u \ 2 \\ \text{phiM2} \ 3 \end{array} \right)$	$i \sin \alpha \delta_{m_1 m_2} \text{lambda}_1 P_{+s_1 s_2} + i \cos \alpha \delta_{m_1 m_2} \text{lambda}_2 P_{+s_1 s_2}$
$\left(\begin{array}{l} \bar{e} \nu \ 1 \\ e \ 2 \\ \text{phiM1} \ 3 \end{array} \right)$	$i \cos \alpha \text{lambda}_{d1} P_{+s_1 s_2} - i \sin \alpha \text{lambda}_{d2} P_{+s_1 s_2}$
$\left(\begin{array}{l} \bar{e} \nu \ 1 \\ e \ 2 \\ \text{phiM2} \ 3 \end{array} \right)$	$i \sin \alpha \text{lambda}_{d1} P_{+s_1 s_2} + i \cos \alpha \text{lambda}_{d2} P_{+s_1 s_2}$
$\left(\begin{array}{l} \bar{u} \nu \ 1 \\ uv \ 2 \\ G \ 3 \end{array} \right)$	$i g_s \gamma_{s_1 s_2}^{\mu_3} T_{m_1 m_2}^{\mu_3}$
$\left(\begin{array}{l} \bar{e} \nu \ 1 \end{array} \right)$	$i e s_w \gamma_{s_1 s_2}^{\mu_3}$

phiT expanded in terms of phiM!

100% ▶

Run FeynRules

- ▶ Load FeynRules
- ▶ Load Model
- ▶ Check Hermiticity
- ▶ Calculate the new Feynman rules
- ▶ Mass Matrix Diagonalization
- ▼ Check Mass diagonalization

▼ In[14]:= **CheckMassSpectrum [Lnew]**

Neglecting all terms with more than 2 particles.
All mass terms are diagonal.
Getting mass spectrum.
Checking for less than 0.1% agreement with model file values.

Out[14]//TableForm=

Particle	Analytic value	Numerical value	Model-file value
phiM1	$\sqrt{2} \sqrt{\frac{\cos^4 M_{\text{phiM1}}^2}{2} + \cos^2 M_{\text{phiM1}}^2 \sin^2 + \frac{M_{\text{phiM1}}^2 \sin^4}{2}}$	200.	200.
phiM2	$\sqrt{2} \sqrt{\frac{\cos^4 M_{\text{phiM2}}^2}{2} + \cos^2 M_{\text{phiM2}}^2 \sin^2 + \frac{M_{\text{phiM2}}^2 \sin^4}{2}}$	400.	400.
ev	Mev	300.	300.
uv	Muv	500.	500.

Check that the mass terms are diagonalized

Run FeynRules

BSM

▼In[14]:= **CheckMassSpectrum [Lnew]**

Neglecting all terms with more than 2 particles.
 All mass terms are diagonal.
 Getting mass spectrum.
 Checking for less than 0.1% agreement with model file values.

Out[14]/TableForm=

Particle	Analytic value	Numerical value	Model-file value
phiM1	$\sqrt{2} \sqrt{\frac{\cos^4 \text{MphiM1}^2}{2} + \cos^2 \text{MphiM1}^2 \text{sina}^2 + \frac{\text{MphiM1}^2 \text{sina}^4}{2}}$	200.	200.
phiM2	$\sqrt{2} \sqrt{\frac{\cos^4 \text{MphiM2}^2}{2} + \cos^2 \text{MphiM2}^2 \text{sina}^2 + \frac{\text{MphiM2}^2 \text{sina}^4}{2}}$	400.	400.
ev	Mev	300.	300.
uv	Muv	500.	500.

▼In[9]:= **UpdateParameters [sina → 0.76]**
CheckMassSpectrum [Lnew]

Neglecting all terms with more than 2 particles.
 All mass terms are diagonal.
 Getting mass spectrum.
 Checking for less than 0.1% agreement with model file values.

Out[10]/TableForm=

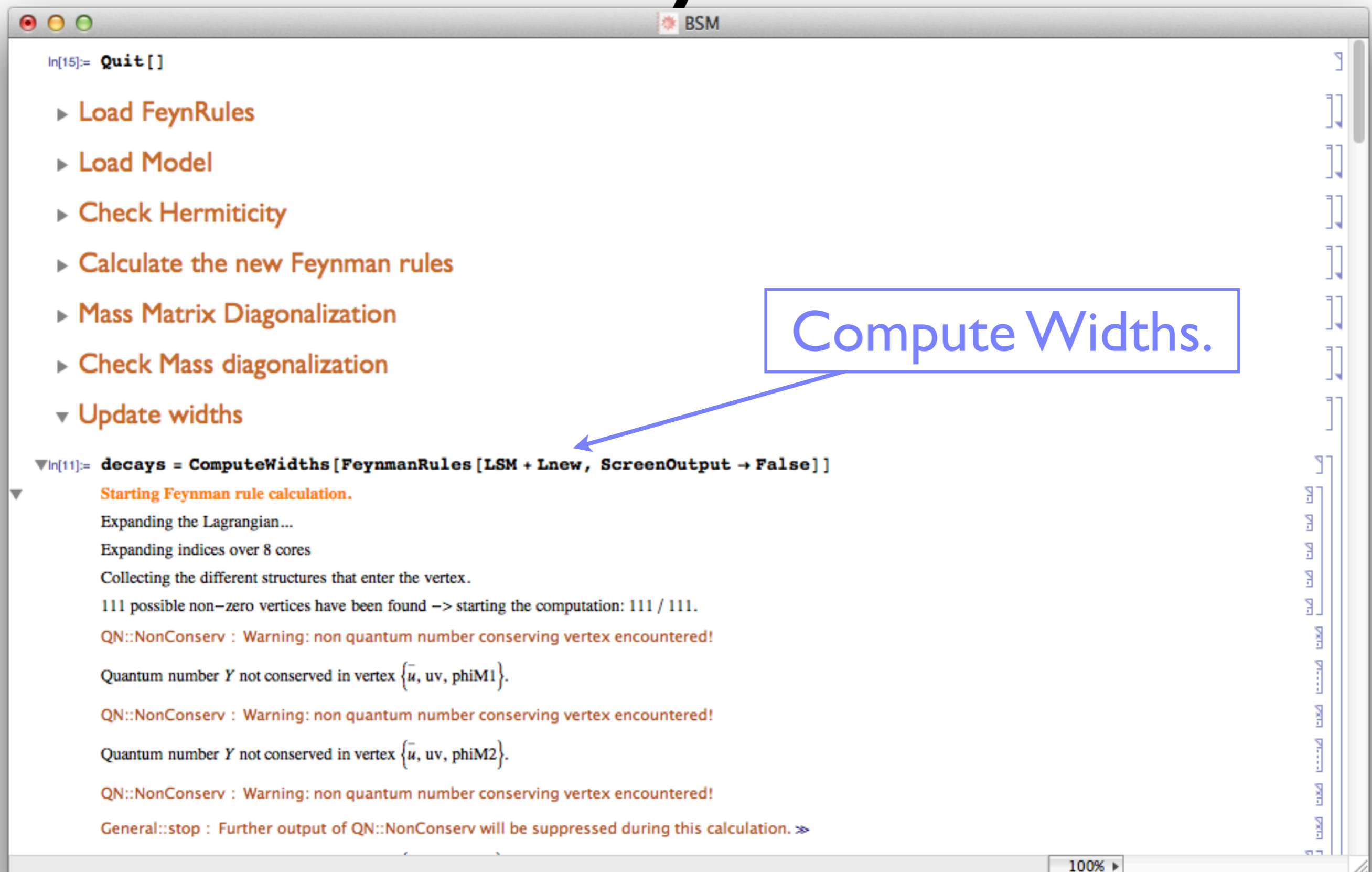
Particle	Analytic value	Numerical value	Model-file value
phiM1	$\sqrt{2} \sqrt{\frac{\cos^4 \text{MphiM1}^2}{2} + \cos^2 \text{MphiM1}^2 \text{sina}^2 + \frac{\text{MphiM1}^2 \text{sina}^4}{2}}$	200.	200.
phiM2	$\sqrt{2} \sqrt{\frac{\cos^4 \text{MphiM2}^2}{2} + \cos^2 \text{MphiM2}^2 \text{sina}^2 + \frac{\text{MphiM2}^2 \text{sina}^4}{2}}$	400.	400.
ev	Mev	300.	300.
uv	Muv	500.	500.

Try with a different value of sina.

Assuming a two-dimensional array | Use as a list of lists instead

100%

Run FeynRules



The screenshot shows a Mathematica notebook window titled "BSM". The notebook content is as follows:

```
In[15]:= Quit[]
```

- ▶ Load FeynRules
- ▶ Load Model
- ▶ Check Hermiticity
- ▶ Calculate the new Feynman rules
- ▶ Mass Matrix Diagonalization
- ▶ Check Mass diagonalization
- ▼ Update widths

```
▼ In[11]:= decays = ComputeWidths[FeynmanRules[LSM + Lnew, ScreenOutput -> False]]
```

Starting Feynman rule calculation.

Expanding the Lagrangian...

Expanding indices over 8 cores

Collecting the different structures that enter the vertex.

111 possible non-zero vertices have been found -> starting the computation: 111 / 111.

QN::NonConserv : Warning: non quantum number conserving vertex encountered!

Quantum number Y not conserved in vertex $\{\bar{u}, uv, \text{phiM1}\}$.

QN::NonConserv : Warning: non quantum number conserving vertex encountered!

Quantum number Y not conserved in vertex $\{\bar{u}, uv, \text{phiM2}\}$.

QN::NonConserv : Warning: non quantum number conserving vertex encountered!

General::stop : Further output of QN::NonConserv will be suppressed during this calculation. »

A blue box with the text "Compute Widths." and a blue arrow pointing to the `ComputeWidths` function in the code above.

100%

Run FeynRules

BSM

$\{u, \text{phiM1}, uv\}$	$-\frac{(M_{\text{phiM1}}^2 - MU^2 - M_{uv}^2) \sqrt{M_{\text{phiM1}}^4 - 2(MU^2 + M_{uv}^2) M_{\text{phiM1}}^2 + (MU^2 - M_{uv}^2)^2} (\cos \lambda_1 - \lambda_2 \sin \lambda_1)^2}{32 \pi MU ^3}$
$\{u, \text{phiM2}, uv\}$	$-\frac{(M_{\text{phiM2}}^2 - MU^2 - M_{uv}^2) \sqrt{M_{\text{phiM2}}^4 - 2(MU^2 + M_{uv}^2) M_{\text{phiM2}}^2 + (MU^2 - M_{uv}^2)^2} (\cos \lambda_2 + \lambda_1 \sin \lambda_2)^2}{32 \pi MU ^3}$
$\{u, W, b\}$	$\frac{\text{CKM1x3} e^2 (M_B^4 + (M_W^2 - 2 MU^2) M_B^2 + MU^4 - 2 M_W^4 + MU^2 M_W^2) \sqrt{M_B^4 - 2(MU^2 + M_W^2) M_B^2 + (MU^2 - M_W^2)^2} \text{CKM1x3}^*}{64 M_W^2 \pi s_w^2 MU ^3}$
$\{u, W, d\}$	$\frac{\text{CKM1x1} e^2 (M_D^4 + (M_W^2 - 2 MU^2) M_D^2 + MU^4 - 2 M_W^4 + MU^2 M_W^2) \sqrt{M_D^4 - 2(MU^2 + M_W^2) M_D^2 + (MU^2 - M_W^2)^2} \text{CKM1x1}^*}{64 M_W^2 \pi s_w^2 MU ^3}$
$\{u, W, s\}$	$\frac{\text{CKM1x2} e^2 (M_S^4 + (M_W^2 - 2 MU^2) M_S^2 + MU^4 - 2 M_W^4 + MU^2 M_W^2) \sqrt{M_S^4 - 2(MU^2 + M_W^2) M_S^2 + (MU^2 - M_W^2)^2} \text{CKM1x2}^*}{64 M_W^2 \pi s_w^2 MU ^3}$
$\{uv, \text{phiM1}, u\}$	$-\frac{(M_{\text{phiM1}}^2 - MU^2 - M_{uv}^2) \sqrt{M_{\text{phiM1}}^4 - 2(MU^2 + M_{uv}^2) M_{\text{phiM1}}^2 + (MU^2 - M_{uv}^2)^2} (\cos \lambda_1 - \lambda_2 \sin \lambda_1)^2}{32 \pi M_{uv} ^3}$
$\{uv, \text{phiM2}, u\}$	$-\frac{(M_{\text{phiM2}}^2 - MU^2 - M_{uv}^2) \sqrt{M_{\text{phiM2}}^4 - 2(MU^2 + M_{uv}^2) M_{\text{phiM2}}^2 + (MU^2 - M_{uv}^2)^2} (\cos \lambda_2 + \lambda_1 \sin \lambda_2)^2}{32 \pi M_{uv} ^3}$
$\{W, c, \bar{b}\}$	$-\frac{\text{CKM2x3} e^2 (M_B^4 + (M_W^2 - 2 M_C^2) M_B^2 + M_C^4 - 2 M_W^4 + M_C^2 M_W^2) \sqrt{M_B^4 - 2(M_C^2 + M_W^2) M_B^2 + (M_C^2 - M_W^2)^2} \text{CKM2x3}^*}{32 M_W^2 \pi s_w^2 M_W ^3}$
$\{W, c, \bar{d}\}$	$-\frac{\text{CKM2x1} e^2 (M_C^4 + (M_W^2 - 2 M_D^2) M_C^2 + M_D^4 - 2 M_W^4 + M_D^2 M_W^2) \sqrt{M_C^4 - 2(M_D^2 + M_W^2) M_C^2 + (M_D^2 - M_W^2)^2} \text{CKM2x1}^*}{32 M_W^2 \pi s_w^2 M_W ^3}$
$\{W, c, \bar{s}\}$	$-\frac{\text{CKM2x2} e^2 (M_C^4 + (M_W^2 - 2 M_S^2) M_C^2 + M_S^4 - 2 M_W^4 + M_S^2 M_W^2) \sqrt{M_C^4 - 2(M_S^2 + M_W^2) M_C^2 + (M_S^2 - M_W^2)^2} \text{CKM2x2}^*}{32 M_W^2 \pi s_w^2 M_W ^3}$
$\{W, t, \bar{b}\}$	$-\frac{\text{CKM3x3} e^2 (M_B^4 + (M_W^2 - 2 M_T^2) M_B^2 + M_T^4 - 2 M_W^4 + M_T^2 M_W^2) \sqrt{M_B^4 - 2(M_T^2 + M_W^2) M_B^2 + (M_T^2 - M_W^2)^2} \text{CKM3x3}^*}{32 M_W^2 \pi s_w^2 M_W ^3}$
$\{W, t, \bar{d}\}$	$-\frac{\text{CKM3x1} e^2 (M_D^4 + (M_W^2 - 2 M_T^2) M_D^2 + M_T^4 - 2 M_W^4 + M_T^2 M_W^2) \sqrt{M_D^4 - 2(M_T^2 + M_W^2) M_D^2 + (M_T^2 - M_W^2)^2} \text{CKM3x1}^*}{32 M_W^2 \pi s_w^2 M_W ^3}$

uv partial width

←

100%

Run FeynRules

The screenshot shows a software window titled "BSM" with a list of decay channels on the left and their corresponding mathematical formulas on the right. A blue box with the text "Update Widths" and an arrow points to the "UpdateWidths [decays]" command in the input field.

Decay Channel	Formula
$\{Z, \nu m, \bar{\nu} m\}$	$\frac{e^{-2} M_Z^2 (c_w^2 + s_w^2)}{96 c_w^2 \pi s_w^2 M_Z ^3}$
$\{Z, \nu t, \bar{\nu} t\}$	$\frac{e^2 M_Z^4 (c_w^2 + s_w^2)^2}{96 c_w^2 \pi s_w^2 M_Z ^3}$
$\{Z, W^+, W\}$	$\frac{c_w^2 e^2 \sqrt{M_Z^4 - 4 M_W^2 M_Z^2} (-48 M_W^6 - 68 M_Z^2 M_W^4 + 16 M_Z^4 M_W^2 + M_Z^6)}{192 M_W^4 \pi s_w^2 M_Z ^3}$

▼In[12]:= **UpdateWidths [decays]**

- Wev = 0.0111601.
- WH = 0.0058038.
- WphiM1 = 0..
- WphiM2 = 6.05574.
- WT = 1.46688.
- Wuv = 1.32387.
- WW = 2.00252.
- WZ = 2.4116.

100%

Run FeynRules

The screenshot shows a Mathematica notebook window titled "BSM". The notebook content is as follows:

```
In[15]:= Quit[]
```

- ▶ Load FeynRules
- ▶ Load Model
- ▶ Check Hermiticity
- ▶ Calculate the new Feynman rules
- ▶ Mass Matrix Diagonalization
- ▶ Check Mass diagonalization
- ▶ Update widths
- ▼ Export to UFO

```
▼ In[13]:= SetDirectory[$ModelDir];  
WriteUFO[LSM + Lnew]
```

--- Universal FeynRules Output (UFO) v 1.1 ---

Starting Feynman rule calculation.

Expanding the Lagrangian...

Expanding indices over 8 cores

Collecting the different structures that enter the vertex.

111 possible non-zero vertices have been found -> starting the computation: 111 / 111.

106 vertices obtained.

Flavor expansion of the vertices distributed over 8 cores: 106 / 106

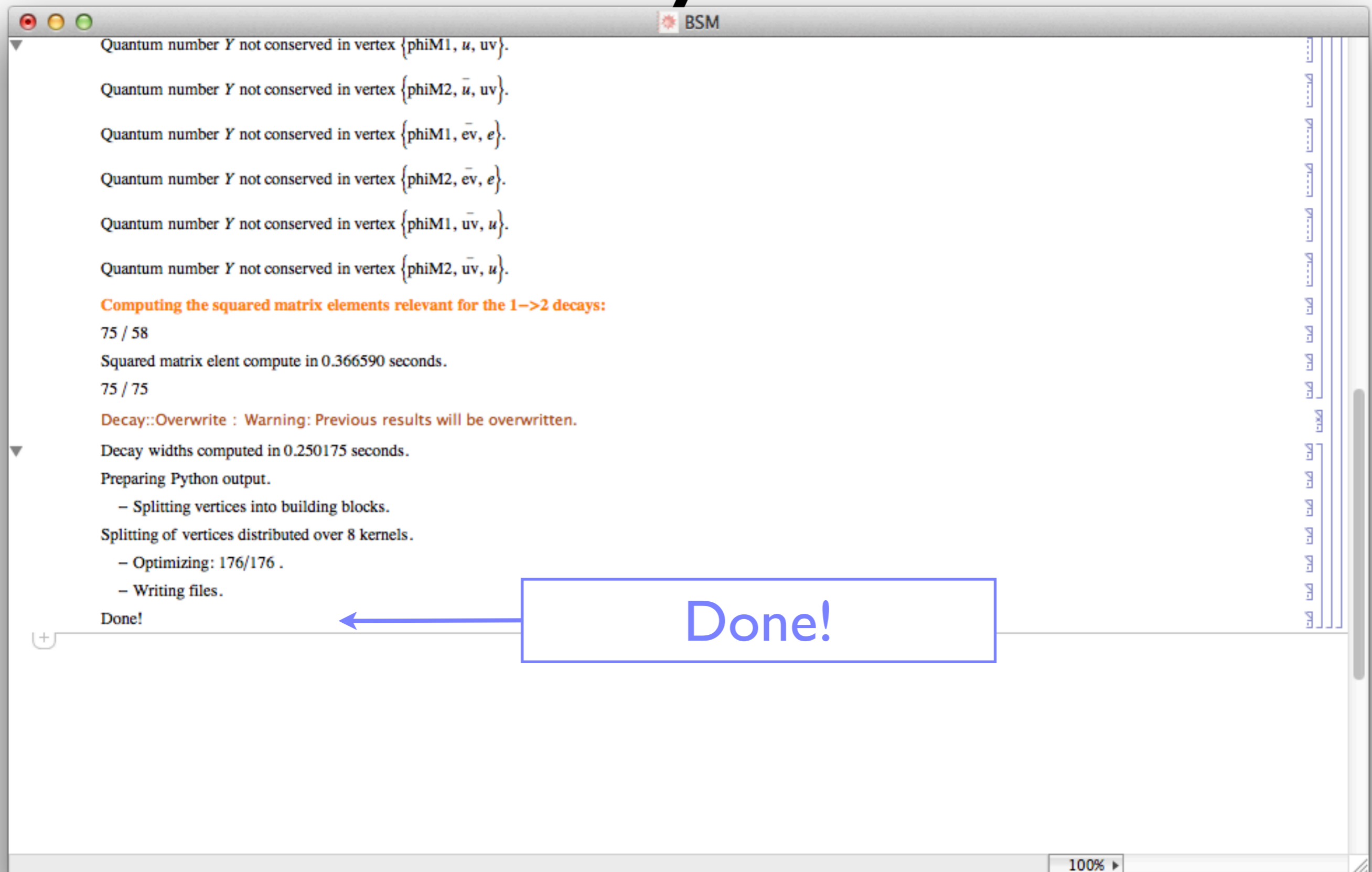
- Saved vertices in InterfaceRun[1].

QN::NonConserv : Warning: non quantum number conserving vertex encountered!

A blue box with the text "Write UFO Files" and an arrow pointing to the `WriteUFO` command in the code cell is overlaid on the notebook.

100%

Run FeynRules

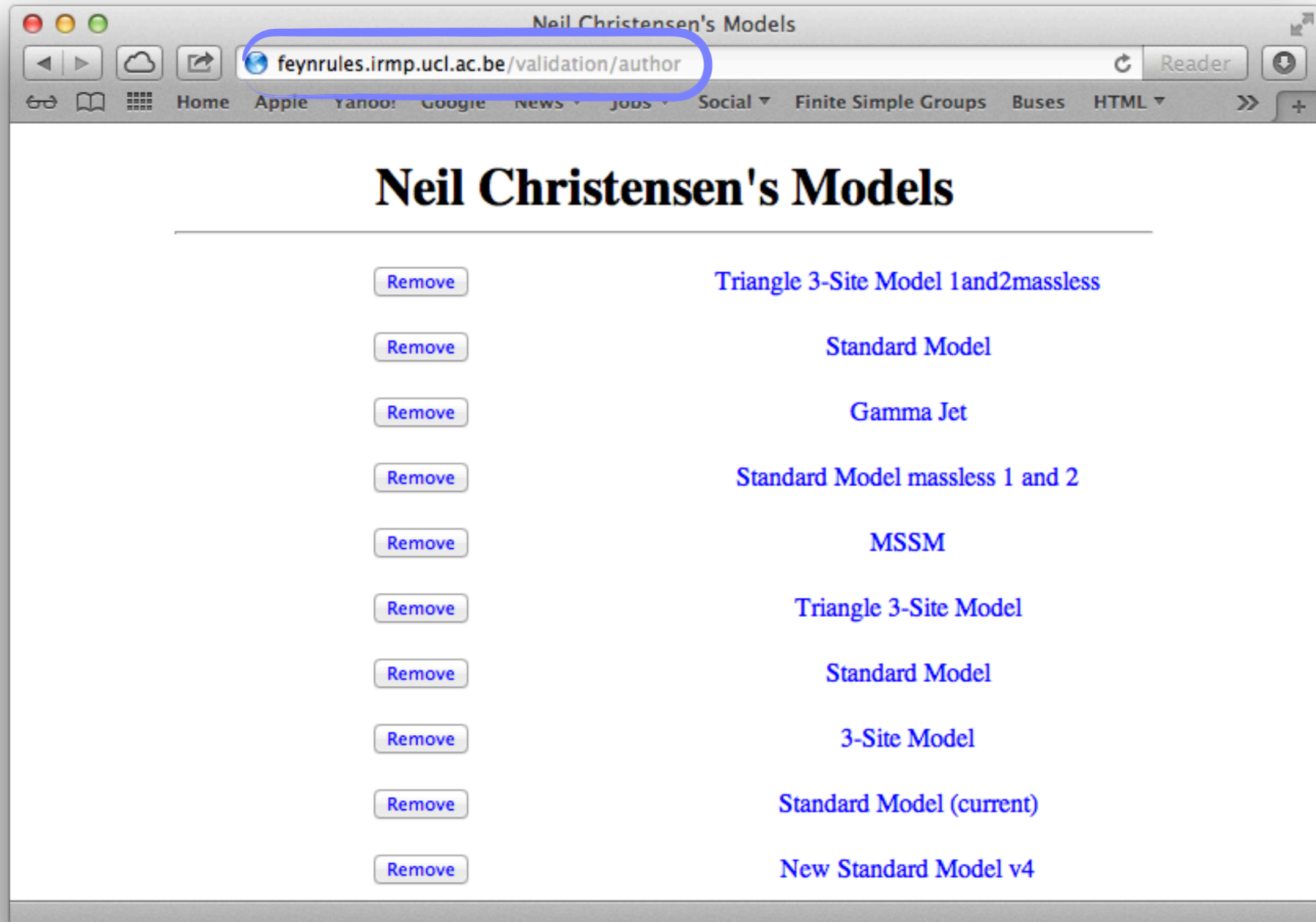


```
BSM
Quantum number Y not conserved in vertex {phiM1, u, uv}.
Quantum number Y not conserved in vertex {phiM2, u-bar, uv}.
Quantum number Y not conserved in vertex {phiM1, e-bar, e}.
Quantum number Y not conserved in vertex {phiM2, e-bar, e}.
Quantum number Y not conserved in vertex {phiM1, u-bar, u}.
Quantum number Y not conserved in vertex {phiM2, u-bar, u}.
Computing the squared matrix elements relevant for the 1->2 decays:
75 / 58
Squared matrix element compute in 0.366590 seconds.
75 / 75
Decay::Overwrite : Warning: Previous results will be overwritten.
Decay widths computed in 0.250175 seconds.
Preparing Python output.
- Splitting vertices into building blocks.
Splitting of vertices distributed over 8 kernels.
- Optimizing: 176/176 .
- Writing files.
Done!
```

Done!

100%

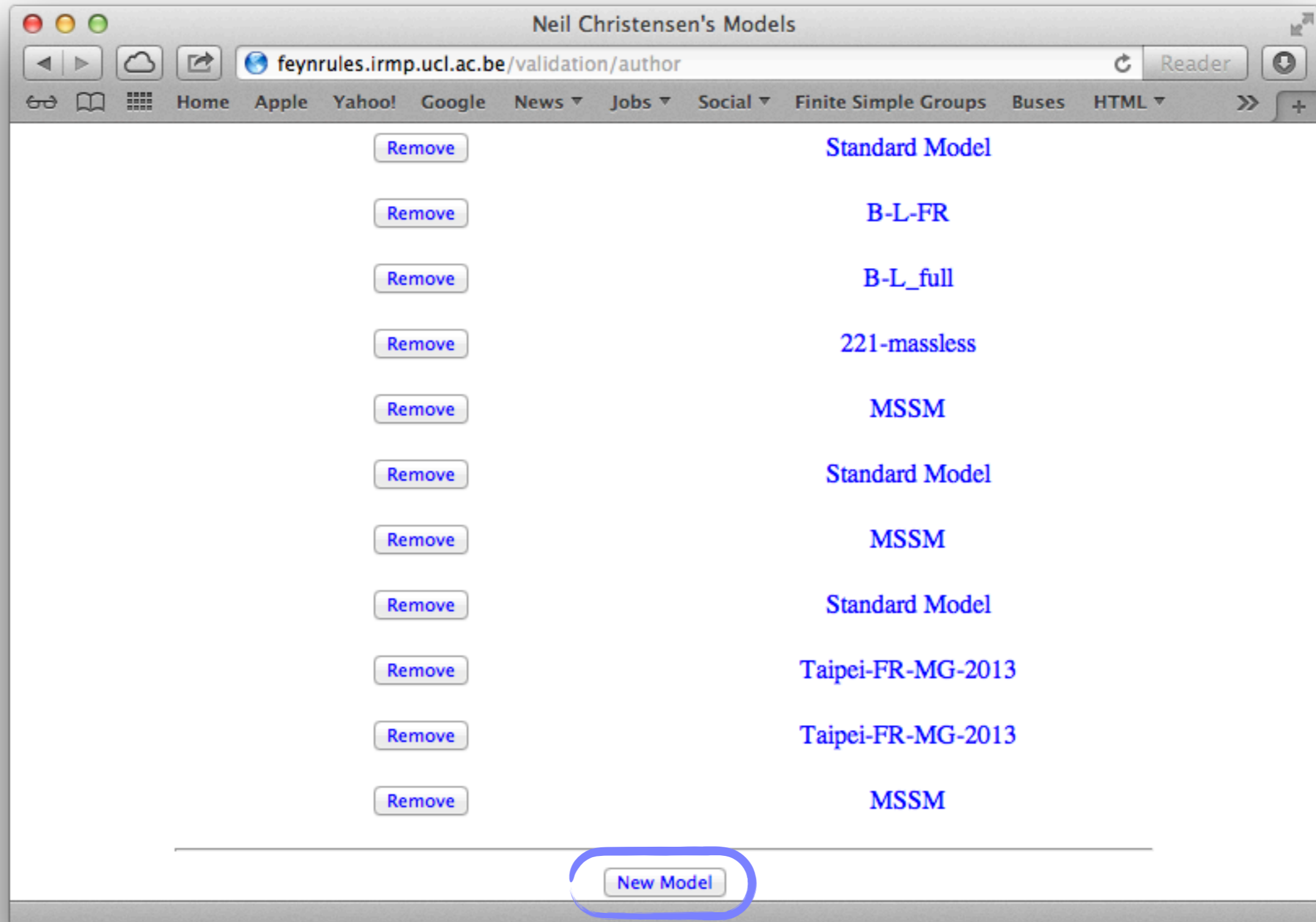
Start Web Validation



The screenshot shows a web browser window with the title "Neil Christensen's Models". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author", which is circled in blue. The browser's toolbar includes navigation buttons (back, forward, home, refresh), a search bar, and a "Reader" mode button. Below the browser window, the page content is displayed. The main heading is "Neil Christensen's Models". Below this heading, there is a list of models, each with a "Remove" button on the left and the model name on the right. The models listed are:

- Remove Triangle 3-Site Model 1and2massless
- Remove Standard Model
- Remove Gamma Jet
- Remove Standard Model massless 1 and 2
- Remove MSSM
- Remove Triangle 3-Site Model
- Remove Standard Model
- Remove 3-Site Model
- Remove Standard Model (current)
- Remove New Standard Model v4

Start Web Validation



Start Web Validation

New Model

feynrules.irmp.ucl.ac.be/validation/author/newModel

Reader

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

New Model

Neil Christensen

Model Files

Choose File no file selected

Add another model file

Restriction Files

Add a restriction file

Parameter Files

Add a parameter file

Lagrangian :

Exclude 4 Scalar Vertices

FeynRules Version

Current Development

Upload Model

Start Web Validation

New Model

feynrules.irmp.ucl.ac.be/validation/author/newModel

Reader

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

New Model

Neil Christensen

Model Files

no file selected

no file selected

another model file

Restriction Files

a restriction file

Parameter Files

a parameter file

Lagrangian :

Exclude 4 Scalar Vertices

FeynRules Version

Current Development

Start Web Validation

New Model

feynrules.irmp.ucl.ac.be/validation/author/newModel

New Model

Neil Christensen

Model Files	Restriction Files	Parameter Files
<input type="button" value="Choose File"/> SM.fr	<input type="button" value="Choose File"/> Massless.rst	<input type="button" value="Add"/> a parameter file
<input type="button" value="Choose File"/> BSM.fr	<input type="button" value="Add"/> another restriction file	
<input type="button" value="Add"/> another model file		

Lagrangian :

Exclude 4 Scalar Vertices

FeynRules Version

Current Development

Start Web Validation

New Model

feynrules.irmp.ucl.ac.be/validation/author/newModel

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

New Model

Neil Christensen

Model Files	Restriction Files	Parameter Files
Choose File SM.fr	Choose File Massless.rst	Add a parameter file
Choose File BSM.fr	Add another restriction file	
Add another model file		

Lagrangian : LSM+Lnew

Exclude 4 Scalar Vertices

FeynRules Version

Current Development

[Upload Model](#)

Start Web Validation

New Model

feynrules.irmp.ucl.ac.be/validation/author/newModel

New Model

Neil Christensen

Model Files	Restriction Files	Parameter Files
<input type="button" value="Choose File"/> SM.fr	<input type="button" value="Choose File"/> Massless.rst	<input type="button" value="Add"/> a parameter file
<input type="button" value="Choose File"/> BSM.fr	<input type="button" value="Add"/> another restriction file	
<input type="button" value="Add"/> another model file		

Lagrangian :

Exclude 4 Scalar Vertices

FeynRules Version

Current Development

Start Web Validation

New Model

feynrules.irmp.ucl.ac.be/validation/author/newModel

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

New Model

Neil Christensen

Model Files	Restriction Files	Parameter Files
<input type="button" value="Choose File"/> SM.fr	<input type="button" value="Choose File"/> Massless.rst	<input type="button" value="Add"/> a parameter file
<input type="button" value="Choose File"/> BSM.fr	<input type="button" value="Add"/> another restriction file	
<input type="button" value="Add"/> another model file		

Lagrangian :

Exclude 4 Scalar Vertices

FeynRules Version

Current Development

Start Web Validation

New Model

feynrules.irmp.ucl.ac.be/validation/author/newModel

Reader

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

New Model

Neil Christensen

Model Files	Restriction Files	Parameter Files
Choose File SM.fr	Choose File Massless.rst	Add a parameter file
Choose File BSM.fr	Add another restriction file	
Add another model file		

Lagrangian :

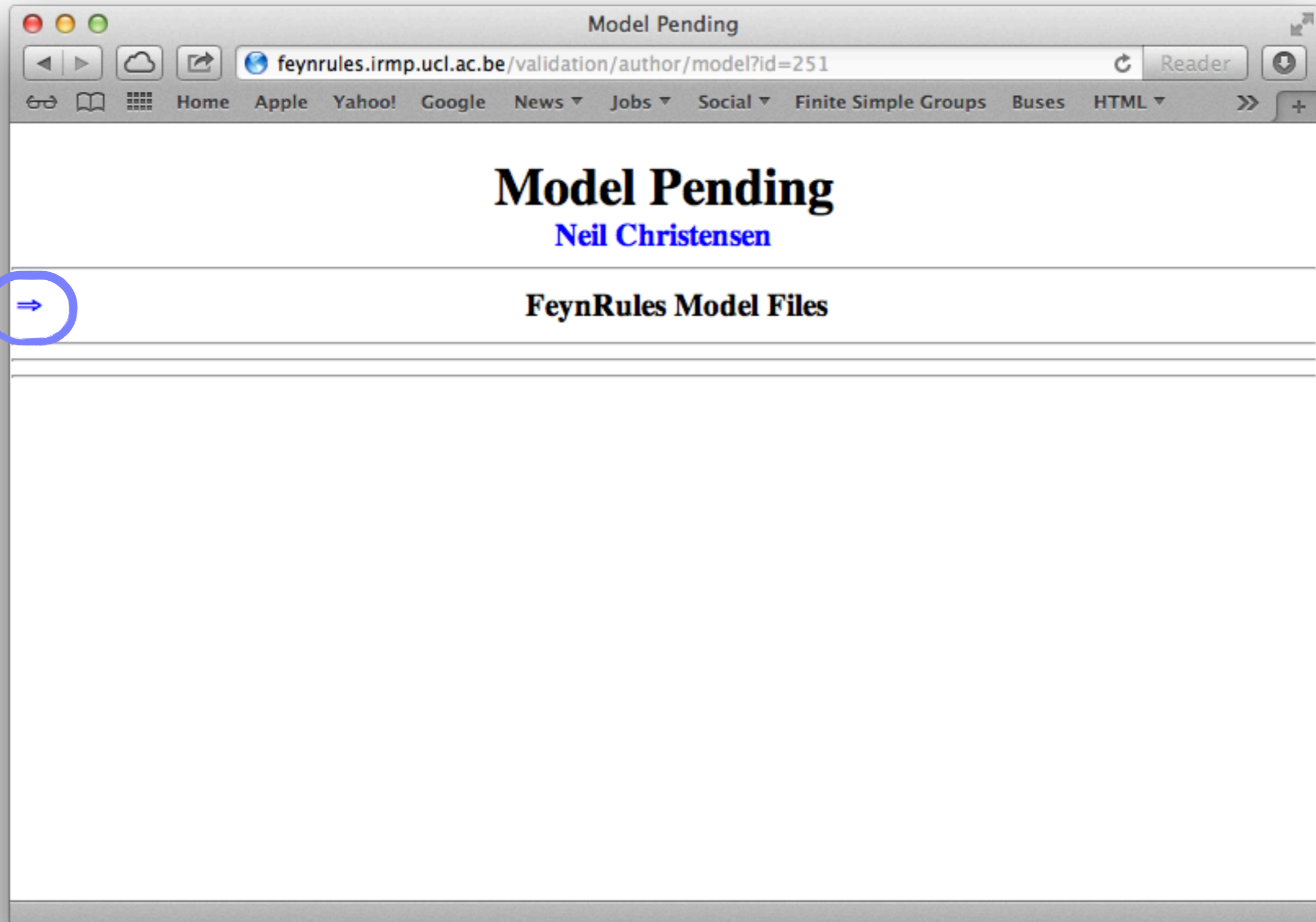
Exclude 4 Scalar Vertices

FeynRules Version

Current Development

[Upload Model](#)

Start Web Validation



Start Web Validation

The screenshot shows a web browser window titled "Model Pending" with the URL `feynrules.irmp.ucl.ac.be/validation/author/model?id=252`. The browser's address bar includes navigation icons, a search bar, and a "Reader" button. The browser's menu bar shows "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content of the page is titled "Model Pending" and "Neil Christensen". Below this, there is a section titled "FeynRules Model Files" with a downward arrow icon on the left. This section is divided into three columns: "Model Files", "Restriction Files", and "Parameter Files".

- Model Files:** Contains two entries: "SM.fr" and "BSM.fr". Each entry has a yellow question mark icon to its left. The "SM.fr" entry is circled in blue.
- Restriction Files:** Contains one entry: "Massless.rst" with a yellow question mark icon to its left.
- Parameter Files:** Is currently empty.

Below the "Restriction Files" section, the text "Lagrangian : LSM+Lnew" is displayed.

Start Web Validation

Taipei-FR-MG-2013

feynrules.irmp.ucl.ac.be/validation/author/model?id=251

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

Taipei-FR-MG-2013

Neil Christensen

↓

Model Files	Restriction Files	Parameter Files
✓ SM.fr	✓ Massless.rst	
✓ BSM.fr		

Lagrangian : LSM+Lnew

→ MEG Model Files & Validations

→ Stock Models

Start Web Validation

Taipei-FR-MG-2013

feynrules.irmp.ucl.ac.be/validation/author/model?id=251

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

Taipei-FR-MG-2013

Neil Christensen

↓

FeynRules Model Files

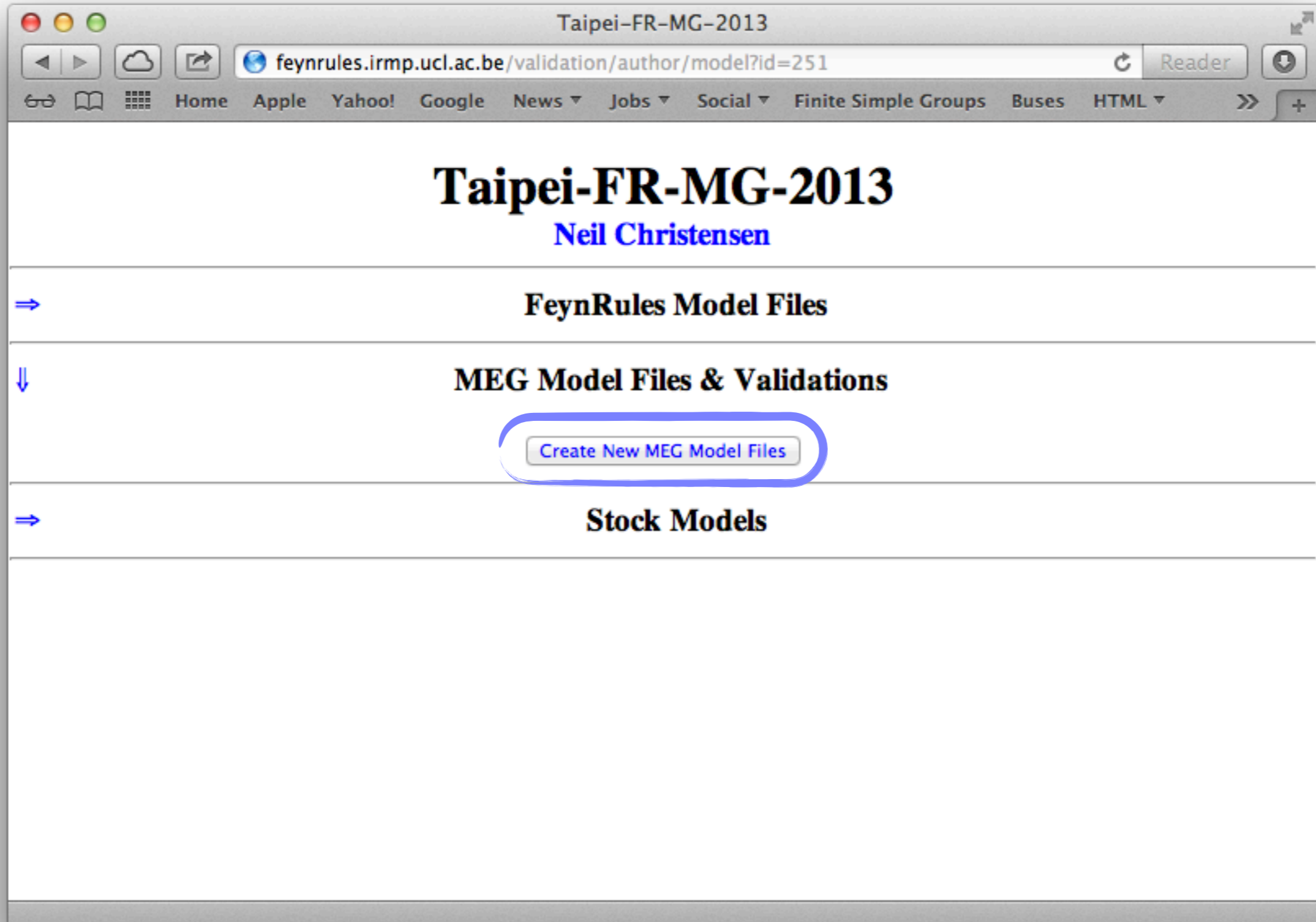
Model Files	Restriction Files	Parameter Files
✓ SM.fr	✓ Massless.rst	
✓ BSM.fr		

Lagrangian : LSM+Lnew

→ **MEG Model Files & Validations**

→ **Stock Models**

Start Web Validation



The screenshot shows a web browser window with the title "Taipei-FR-MG-2013". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/model?id=251". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML". The main content area features the following elements:

- Taipei-FR-MG-2013** (Large bold heading)
- [Neil Christensen](#) (Blue link)
- FeynRules Model Files** (Section header with a right-pointing arrow icon)
- MEG Model Files & Validations** (Section header with a double-down arrow icon)
- [Create New MEG Model Files](#) (A button with a blue border and blue text, highlighted with a blue oval)
- Stock Models** (Section header with a right-pointing arrow icon)

Start Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/model?id=251". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area is titled "Taipei-FR-MG-2013" and "Neil Christensen". Below this, there are three sections:

- FeynRules Model Files**: Indicated by a right-pointing arrow (⇒).
- MEG Model Files & Validations**: Indicated by a down-pointing arrow (⇩). This section contains a form with a "Name" field set to "Massless", "R. Files" and "F. Files" labels, a checked checkbox for "Massless.rst", and a "Validate this combination" button.
- Stock Models**: Indicated by a right-pointing arrow (⇒).

Start Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/model?id=251". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area features a large heading "Taipei-FR-MG-2013" in bold black text, with the author's name "Neil Christensen" in blue text below it. A horizontal line separates this from the next section, "FeynRules Model Files", which is preceded by a blue right-pointing arrow. Another horizontal line follows, leading to the "MEG Model Files & Validations" section, preceded by a blue double-headed vertical arrow.

In the "MEG Model Files & Validations" section, there is a form with a "Name:" label and a text input field containing "Massless". Below this, there are two columns of radio buttons labeled "R. Files" and "P. Files". Under the "R. Files" column, the option "Massless.rst" is selected, indicated by a checked checkbox and a blue oval highlight. Below the radio buttons is a button labeled "Validate this combination".

A final horizontal line separates the "MEG Model Files & Validations" section from the "Stock Models" section, which is preceded by a blue right-pointing arrow. The "Stock Models" section is currently empty.

Start Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/model?id=251". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area displays the following sections:

- Taipei-FR-MG-2013**
Neil Christensen
- FeynRules Model Files** (indicated by a right-pointing arrow)
- MEG Model Files & Validations** (indicated by a down-pointing arrow)
 - Name :
 - R. Files** **P. Files**
 - Massless.rst
 -
- Stock Models** (indicated by a right-pointing arrow)

Start Web Validation

Taipei-FR-MG-2013

feynrules.irmp.ucl.ac.be/validation/author/model?id=251

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

Taipei-FR-MG-2013

Neil Christensen

FeynRules Model Files

MEG Model Files & Validations

↓ Massless

Restriction File(s) : Massless.rst

Parameter File .

CH	MG5	WO2	TeX
QQ	QQ	QQ	Q

Validations

Create New Validation

Create New MEG Model Files

Stock Models

Start Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/model?id=251". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area displays the following information:

- Taipei-FR-MG-2013**
[Neil Christensen](#)
- FeynRules Model Files**
- MEG Model Files & Validations**
- ↓ Massless
- Restriction File(s) : Massless.rst
- Parameter File :
- CH MG5 WO2 TeX
- QQ QQ QQ Q
- Validations
- Create New Validation
- Create New MEG Model Files
- Stock Models**

The "MG5" label and its corresponding "QQ" validation count are circled in blue.

Start Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/model?id=251". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area displays the following information:

- Taipei-FR-MG-2013**
[Neil Christensen](#)
- FeynRules Model Files**
- MEG Model Files & Validations**
 - ↓ Massless
 - Restriction File(s) : Massless.rst
 - Parameter File :

CH	MG5	WO2	TeX
QQ	QQ	QQ	Q
- Validations**
 - [Create New Validation](#) (highlighted with a blue oval)
 - [Create New MEG Model Files](#)

- Stock Models**

Start Web Validation

Taipei-FR-MG-2013 : Validation

feynrules.irmp.ucl.ac.be/validation/author/newValidation?RPcombold=517

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

Taipei-FR-MG-2013

Neil Christensen

Validation Name :

Compare :

Process type :

Massless

Restriction File(s) : Massless.rst
Parameter File :

CH	MG5	WO2
QQ	QQ	QQ

Restrictions

Start Web Validation

Taipei-FR-MG-2013 : Validation

feynrules.irmp.ucl.ac.be/validation/author/newValidation?RPcombold=517

Reader

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

Taipei-FR-MG-2013

Neil Christensen

Validation Name :

Compare :

Process type :

Massless

Restriction File(s) : Massless.rst
Parameter File :

CH	MG5	WO2
QQ	QQ	QQ

Restrictions

Start Web Validation

Taipei-FR-MG-2013 : Validation

feynrules.irmp.ucl.ac.be/validation/author/newValidation?RPcombold=517

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

Massless

Restriction File(s): Massless.rst
Parameter File :

CH	MG5	WO2
QQ	QQ	QQ

Restrictions

Field Type	Field Type		Index	Indices		Charge	Charges	
	Require	Require Not		Require	Require Not		Require	Require Not
Scalar :	<input type="text" value="1"/>	<input type="text" value="0"/>	Gluon :	<input type="text" value="0"/>	<input type="text" value="0"/>	Q :	<input type="text" value="0"/>	<input type="text" value="0"/>
Fermion :	<input type="text" value="0"/>	<input type="text" value="0"/>	Colour :	<input type="text" value="0"/>	<input type="text" value="0"/>	GhostNumber :	<input type="text" value="0"/>	<input type="text" value="0"/>
Vector :	<input type="text" value="0"/>	<input type="text" value="0"/>				LeptonNumber :	<input type="text" value="0"/>	<input type="text" value="0"/>
Spin 2 :	<input type="text" value="0"/>	<input type="text" value="0"/>				Y :	<input type="text" value="0"/>	<input type="text" value="0"/>

[Generate Processes](#)

Start Web Validation

Taipei-FR-MG-2013 : Validation

feynrules.irmp.ucl.ac.be/validation/author/newValidation?RPcombold=517

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

Massless

Restriction File(s): Massless.rst
Parameter File :

CH	MG5	WO2
QQ	QQ	QQ

Restrictions

	Field Type			Indices			Charges	
	Require	Require Not	Index	Require	Require Not	Charge	Require	Require Not
Scalar :	<input type="text" value="1"/>	<input type="text" value="0"/>	Gluon :	<input type="text" value="0"/>	<input type="text" value="0"/>	Q :	<input type="text" value="0"/>	<input type="text" value="0"/>
Fermion :	<input type="text" value="0"/>	<input type="text" value="0"/>	Colour :	<input type="text" value="0"/>	<input type="text" value="0"/>	GhostNumber :	<input type="text" value="0"/>	<input type="text" value="0"/>
Vector :	<input type="text" value="0"/>	<input type="text" value="0"/>				LeptonNumber :	<input type="text" value="0"/>	<input type="text" value="0"/>
Spin 2 :	<input type="text" value="0"/>	<input type="text" value="0"/>				Y :	<input type="text" value="0"/>	<input type="text" value="0"/>

[Generate Processes](#)

Start Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013 : Scalar". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/validation?vdtId=430;start=0". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content of the page is as follows:

Scalar

Taipei-FR-MG-2013

Neil Christensen

⇒ **Restriction & Parameter Files**


⇒ **Process Restrictions**

⇒ **Feynman Diagram Calculators**

⇒ **Stock Models**

Q : Generating Processes

0/0 processes finished



LL=0.0 for -1 degrees of freedom.
The probability of this being a statistical fluctuation is 100.0%.

Start Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013 : Scalar". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/validation?vdtid=430;start=0". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content of the page is centered and features the following elements:

- Scalar** (in large black font)
- Taipei-FR-MG-2013** (in blue font, enclosed in a blue rounded rectangle)
- Neil Christensen** (in blue font, below the title)
- A horizontal line
- ⇒ Restriction & Parameter Files**
- A horizontal line
- ⇒ Process Restrictions**
- A horizontal line
- ⇒ Feynman Diagram Calculators**
- A horizontal line
- ⇒ Stock Models**
- A horizontal line
- Q : Generating Processes**
- 0/0 processes finished**
- A small blue square icon with a white question mark
- LL=0.0 for -1 degrees of freedom.**
- The probability of this being a statistical fluctuation is 100.0%.**

Start Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013" and the URL "feynrules.irmp.ucl.ac.be/validation/author/model?id=251". The browser's address bar and navigation buttons are visible. The main content area displays the following information:

Taipei-FR-MG-2013
Neil Christensen

⇒ **FeynRules Model Files**

⇓ **MEG Model Files & Validations**

⇓ Massless
Restriction File(s) : Massless.rst
Parameter File :

CH	MG5	WO2	TeX
QQ	QQ	QQ	Q

Validations
Scalar 0/0 processes finished

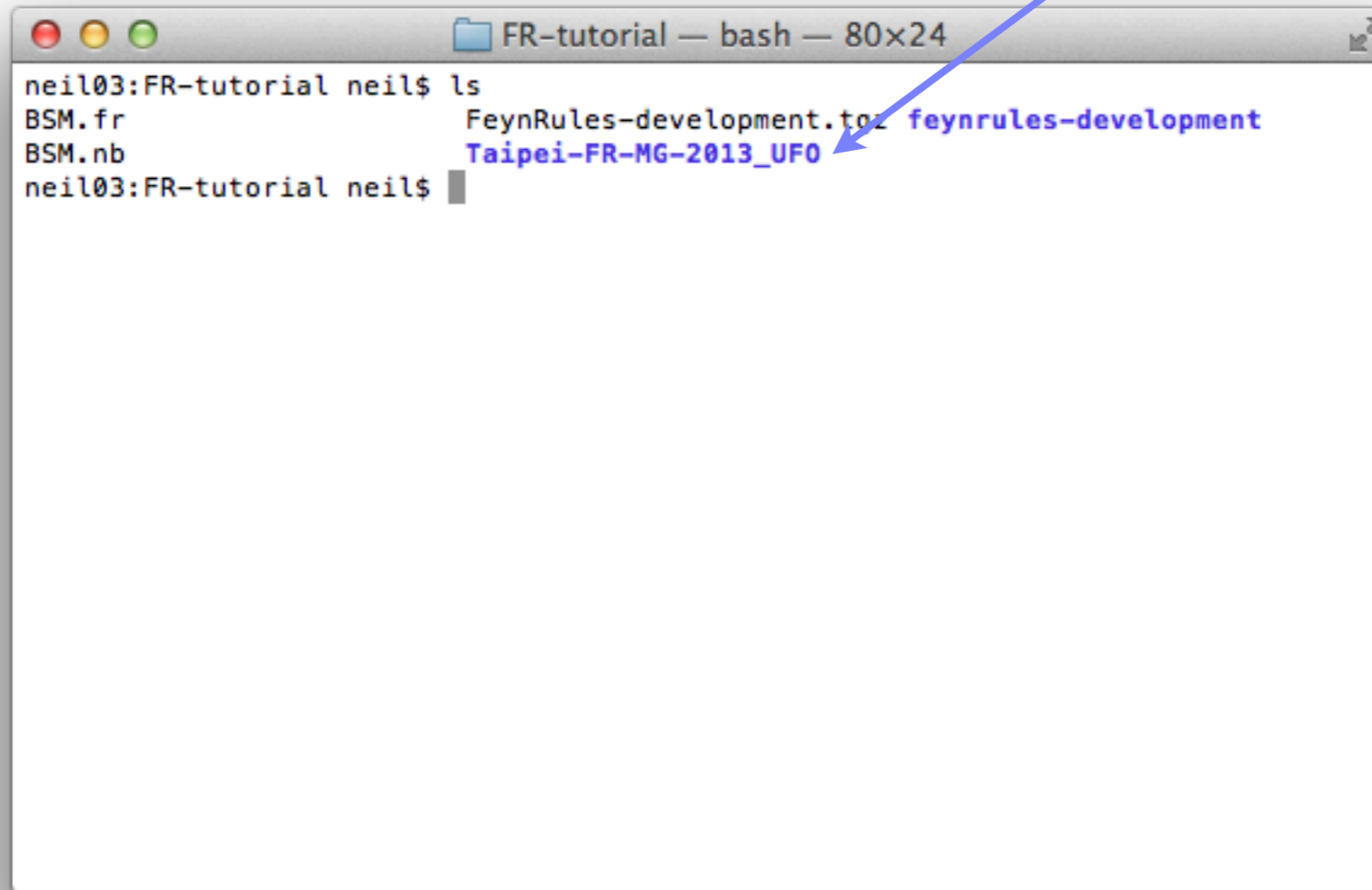
[Create New Validation](#)

[Create New MEG Model Files](#)

⇒ **Stock Models**

UFO Files

UFO Files



```
neil03:FR-tutorial neil$ ls
BSM.fr          FeynRules-development.tar feynrules-development
BSM.nb          Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$
```

The image shows a terminal window titled "FR-tutorial — bash — 80x24". The terminal output shows the command "ls" being executed, resulting in a listing of files: "BSM.fr", "BSM.nb", "FeynRules-development.tar", and "Taipei-FR-MG-2013_UFO". A blue arrow points from a box labeled "UFO Files" to the file "Taipei-FR-MG-2013_UFO".

UFO Files

UFO Files

```
neil03:FR-tutorial neil$ ls
BSM.fr          FeynRules-development.tgz feynrules-development
BSM.nb          Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$ ls Taipei-FR-MG-2013_UFO/
CT_couplings.py      decays.py                particles.py
Taipei-FR-MG-2013_UFO.log function_library.py      propagators.py
__init__.py          lorentz.py               vertices.py
coupling_orders.py  object_library.py        write_param_card.py
couplings.py         parameters.py
neil03:FR-tutorial neil$
```

UFO Files

```
FR-tutorial — bash — 80x24
neil03:FR-tutorial neil$ ls
BSM.fr          FeynRules-development.tgz feynrules-development
BSM.nb          Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$ ls Taipei-FR-MG-2013_UFO/
CT_couplings.py decays.py                particles.py
Taipei-FR-MG-2013_UFO.log function_library.py      propagators.py
__init__.py      lorentz.py              vertices.py
coupling_orders.py object_library.py        write_param_card.py
couplings.py     parameters.py
neil03:FR-tutorial neil$
```


UFO Files

```
FR-tutorial — bash — 80x24
neil03:FR-tutorial neil$ ls
BSM.fr          FeynRules-development.tgz feynrules-development
BSM.nb          Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$ ls Taipei-FR-MG-2013_UFO/
CT_couplings.py      decays.py                particles.py
Taipei-FR-MG-2013_UFO.log function_library.py      propagators.py
__init__.py          lorentz.py               vertices.py
coupling_orders.py  object_library.py       write_param_card.py
couplings.py         parameters.py
neil03:FR-tutorial neil$
```

UFO Files

```
FR-tutorial — less — 80x24

order = {'QED':2})

GC_50 = Coupling(name = 'GC_50',
                  value = '1',
                  order = {'QED':2})

GC_51 = Coupling(name = 'GC_51',
                  value = 'i sin(a) delta_m1_m2 lambda_1 P_{+s1,s2} + i cos(a) delta_m1_m2 lambda_2 P_{+s1,s2}',
                  order = {'QED':2})

GC_52 = Coupling(name = 'GC_52',
                  value = 'cos(a)*complex(0,1)*lambda_2 + complex(0,1)*lambda_1*sin(a)',
                  order = {'NP':1})

GC_53 = Coupling(name = 'GC_53',
                  value = 'cos(a)*complex(0,1)*lambda_1 - complex(0,1)*lambda_2*sin(a)',
                  order = {'NP':1})

GC_54 = Coupling(name = 'GC_54',
                  value = 'cos(a)*complex(0,1)*lambda_2 + complex(0,1)*lambda_1*sin(a)',
                  order = {'NP':1})
```

$$\begin{pmatrix} \bar{u}v & 1 \\ u & 2 \\ \text{phiM2} & 3 \end{pmatrix} i \sin a \delta_{m_1, m_2} \lambda_{a_1} P_{+s_1, s_2} + i \cos a \delta_{m_1, m_2} \lambda_{a_2} P_{+s_1, s_2}$$

UFO Files

```
FR-tutorial — bash — 80x24
neil03:FR-tutorial neil$ ls
BSM.fr          FeynRules-development.tgz feynrules-development
BSM.nb          Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$ ls Taipei-FR-MG-2013_UFO/
CT_couplings.py      decays.py                particles.py
Taipei-FR-MG-2013_UFO.log function_library.py      propagators.py
__init__.py          lorentz.py              vertices.py
coupling_orders.py  object_library.py       write_param_card.py
couplings.py         parameters.py
neil03:FR-tutorial neil$
```

UFO Files

```
FR-tutorial — less — 80x24
*2))/(32.*i*abs(MM)**3)'}))
Decay_phiM1 = Decay(name = 'Decay_phiM1',
                    particle = P.phiM1,
                    partial_widths = {(P.e__minus__,P.ev__tilde__):'((- (cosa**2*
lambdap1**2*Me**2) - cosa**2*lambdap1**2*Mev**2 + cosa**2*lambdap1**2*MphiM1**2
+ 2*cosa*lambdap1*lambdap2*Me**2*sina + 2*cosa*lambdap1*lambdap2*Mev**2*sina - 2
*cosa*lambdap1*lambdap2*MphiM1**2*sina - lambdap2**2*Me**2*sina**2 - lambdap2**2
*Mev**2*sina**2 + lambdap2**2*MphiM1**2*sina**2)*cmath.sqrt(Me**4 - 2*Me**2*Mev*
**2 + Mev**4 - 2*Me**2*MphiM1**2 - 2*Mev**2*MphiM1**2 + MphiM1**4))/(16.*cmath.pi
*abs(MphiM1)**3)',
(P.ev,P.e__plus__):'((- (cosa**2*lambdap1**
2*Me**2) - cosa**2*lambdap1**2*Mev**2 + cosa**2*lambdap1**2*MphiM1**2 + 2*cosa*l
ambdap1*lambdap2*Me**2*sina + 2*cosa*lambdap1*lambdap2*Mev**2*sina - 2*cosa*lamb
dap1*lambdap2*MphiM1**2*sina - lambdap2**2*Me**2*sina**2 - lambdap2**2*Mev**2*si
na**2 + lambdap2**2*MphiM1**2*sina**2)*cmath.sqrt(Me**4 - 2*Me**2*Mev**2 + Mev**
4 - 2*Me**2*MphiM1**2 - 2*Mev**2*MphiM1**2 + MphiM1**4))/(16.*cmath.pi*abs(MphiM
1)**3)',
(P.u,P.uv__tilde__):'((3*cosa**2*lambda1**
2*MphiM1**2 - 3*cosa**2*lambda1**2*MU**2 - 3*cosa**2*lambda1**2*Muv**2 - 6*cosa*
lambda1*lambda2*MphiM1**2*sina + 6*cosa*lambda1*lambda2*MU**2*sina + 6*cosa*lamb
da1*lambda2*Muv**2*sina + 3*lambda2**2*MphiM1**2*sina**2 - 3*lambda2**2*MU**2*si
na**2 - 3*lambda2**2*Muv**2*sina**2)*cmath.sqrt(MphiM1**4 - 2*MphiM1**2*MU**2 +
:█
```

UFO Files

```
FR-tutorial — bash — 80x24
neil03:FR-tutorial neil$ ls
BSM.fr          FeynRules-development.tgz feynrules-development
BSM.nb          Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$ ls Taipei-FR-MG-2013_UFO/
CT_couplings.py      decays.py                particles.py
Taipei-FR-MG-2013_UFO.log function_library.py      propagators.py
__init__.py          lorentz.py               vertices.py
coupling_orders.py  object_library.py        write_param_card.py
couplings.py         parameters.py
neil03:FR-tutorial neil$
```

UFO Files

```
FR-tutorial — bash — 80x24
neil03:FR-tutorial neil$ ls
BSM.fr          FeynRules-development.tgz feynrules-development
BSM.nb          Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$ ls Taipei-FR-MG-2013_UFO/
CT_couplings.py      decays.py                particles.py
Taipei-FR-MG-2013_UFO.log function_library.py      propagators.py
__init__.py          lorentz.py              vertices.py
coupling_orders.py  object_library.py       write_param_card.py
couplings.py         parameters.py
neil03:FR-tutorial neil$
```

UFO Files

$\sin \alpha$

```
sina = Parameter(name = 'sina',
                 nature = 'external',
                 type = 'real',
                 value = 0.76,
                 texname = '\\text{sina}',
                 lhablock = 'FRblock',
                 lhacode = [ 1 ])

lambda1 = Parameter(name = 'lambda1',
                   nature = 'external',
                   type = 'real',
                   value = 1,
                   texname = '\\text{lambda1}',
                   lhablock = 'FRblock6',
                   lhacode = [ 1 ])

lambda2 = Parameter(name = 'lambda2',
                   nature = 'external',
                   type = 'real',
                   value = 1,
                   texname = '\\text{lambda2}',
                   lhablock = 'FRblock6',
```

UFO Files

```
FR-tutorial — bash — 80x24
neil03:FR-tutorial neil$ ls
BSM.fr          FeynRules-development.tgz feynrules-development
BSM.nb          Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$ ls Taipei-FR-MG-2013_UFO/
CT_couplings.py      decays.py                particles.py
Taipei-FR-MG-2013_UFO.log function_library.py      propagators.py
__init__.py          lorentz.py               vertices.py
coupling_orders.py  object_library.py        write_param_card.py
couplings.py         parameters.py
neil03:FR-tutorial neil$
```


UFO Files

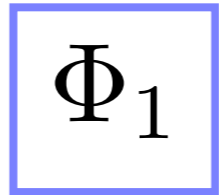
```
FR-tutorial — less — 80x24

    GhostNumber = 0,
    LeptonNumber = 1,
    Y = -1)

ev__tilde__ = ev.anti()

phiM1 = Particle(pdg_code = 9000008,
                 name = 'phiM1',
                 antiname = 'phiM1',
                 spin = 1,
                 color = 1,
                 mass = Param.MphiM1,
                 width = Param.WphiM1,
                 texname = 'phiM1',
                 antitexname = 'phiM1',
                 charge = 0,
                 GhostNumber = 0,
                 LeptonNumber = 0,
                 Y = 0)

phiM2 = Particle(pdg_code = 9000009,
                 name = 'phiM2',
                 antiname = 'phiM2',
```



UFO Files

```
FR-tutorial — bash — 80x24
neil03:FR-tutorial neil$ ls
BSM.fr          FeynRules-development.tgz feynrules-development
BSM.nb          Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$ ls Taipei-FR-MG-2013_UFO/
CT_couplings.py      decays.py                particles.py
Taipei-FR-MG-2013_UFO.log function_library.py      propagators.py
__init__.py          lorentz.py               vertices.py
coupling_orders.py  object_library.py        write_param_card.py
couplings.py         parameters.py
neil03:FR-tutorial neil$
```

UFO Files

```
FR-tutorial — bash — 80x24
neil03:FR-tutorial neil$ ls
BSM.fr          FeynRules-development.tgz feynrules-development
BSM.nb          Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$ ls Taipei-FR-MG-2013_UFO/
CT_couplings.py      decays.py                particles.py
Taipei-FR-MG-2013_UFO.log function_library.py      propagators.py
__init__.py          lorentz.py               vertices.py
coupling_orders.py  object_library.py       write_param_card.py
couplings.py         parameters.py
neil03:FR-tutorial neil$
```

UFO Files

```
FR-tutorial — less — 80x24

    color = [ 'Identity(1,2)' ],
    lorentz = [ L.FFS1 ],
    couplings = {(0,0):C.GC_53})

V_43 = Vertex(name = 'V_43',
    particles = [ P.uv__tilde__, P.u, P.phiM2 ],
    color = [ 'Identity(1,2)' ],
    lorentz = [ L.FFS1 ],
    couplings = {(0,0):C.GC_52})

V_44 = Vertex(name = 'V_44',
    particles = [ P.uv__tilde__, P.d, P.G__plus_1 ],
    color = [ 'Identity(1,2)' ],
    lorentz = [ L.FFS1 ],
    couplings = {(0,0):C.GC_51})

V_45 = Vertex(name = 'V_45',
    particles = [ P.uv__tilde__, P.u, P.phiM2 ],
    color = [ 'Identity(1,2)' ],
    lorentz = [ L.FFS1, L.FFS3 ],
    couplings = {(0,0):C.GC_14, (0,1):C.GC_23})

V_46 = Vertex(name = 'V_46',
    :
```

$$\left(\begin{array}{cc} \bar{u}v & 1 \\ u & 2 \\ \text{phiM2} & 3 \end{array} \right) i \sin \alpha \delta_{m_1, m_2} \lambda_{1} P_{+s_1, s_2} + i \cos \alpha \delta_{m_1, m_2} \lambda_{2} P_{+s_1, s_2}$$

UFO Files

```
FR-tutorial — bash — 80x24
neil03:FR-tutorial neil$ ls
BSM.fr          FeynRules-development.tgz feynrules-development
BSM.nb          Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$ ls Taipei-FR-MG-2013_UFO/
CT_couplings.py      decays.py                particles.py
Taipei-FR-MG-2013_UFO.log function_library.py      propagators.py
__init__.py          lorentz.py              vertices.py
coupling_orders.py  object_library.py       write_param_card.py
couplings.py         parameters.py
neil03:FR-tutorial neil$
```

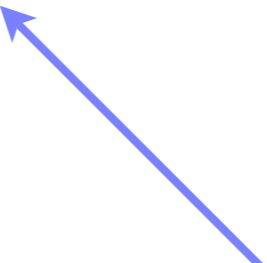
Import UFO → MG5

```
neil03:FR-tutorial neil$ ls
BSM.fr          MadGraph5_v1.5.12.tar.gz  feynrules-development
BSM.nb          MadGraph5_v1_5_12
FeynRules-development.tgz Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$ cp -r Taipei-FR-MG-2013_UFO MadGraph5_v1_5_12/models/.
neil03:FR-tutorial neil$
```

Recursively copy
the UFO model
file directory to
the MG5 models
directory.

Import UFO → MG5

```
neil03:FR-tutorial neil$ ls
BSM.fr          MadGraph5_v1.5.12.tar.gz  feynrules-development
BSM.nb          MadGraph5_v1_5_12
FeynRules-development.tgz Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$ cp -r Taipei-FR-MG-2013_UFO MadGraph5_v1_5_12/models/.
neil03:FR-tutorial neil$ cd MadGraph5_v1_5_12/
neil03:MadGraph5_v1_5_12 neil$ ./bin/mg5
```

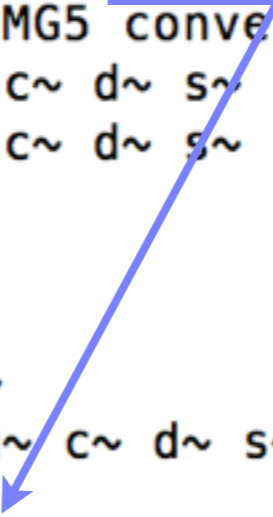


Start MG5

Import UFO → MG5

```
MadGraph5_v1_5_12 — Python — 80x24
* The MadGraph Development Team - Please visit us at *
* https://server06.fynu.ucl.ac.be/projects/madgraph *
* *
* Type 'help' for in-line help. *
* Type 'tutorial' to learn how MG5 works *
* *
*****
load MG5 configuration from input/mg5_configuration.txt
Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
Loading default model: sm
INFO: load particles
INFO: load vertices
INFO: Restrict model sm with file models/sm
INFO: Run "set stdout_level DEBUG" before j
INFO: Change particles name to pass to MG5 convention
Defined multiparticle p = g u c d s u~ c~ d~ s~
Defined multiparticle j = g u c d s u~ c~ d~ s~
Defined multiparticle l+ = e+ mu+
Defined multiparticle l- = e- mu-
Defined multiparticle vl = ve vm vt
Defined multiparticle vl~ = ve~ vm~ vt~
Defined multiparticle all = g u c d s u~ c~ d~ s~ a ve vm vt e- mu- ve~ vm~ vt~
e+ mu+ t b t~ b~ z w+ h w- ta- ta+
mg5>import model Taipei-FR-MG-2013_UFO █
```

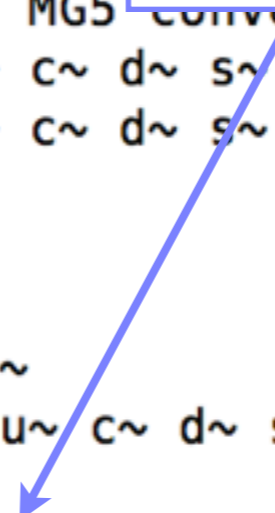
Import new model



Import UFO → MG5

```
MadGraph5_v1_5_12 — Python — 80x24
Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
Loading default model: sm
INFO: load particles
INFO: load vertices
INFO: Restrict model sm with file models/sm
INFO: Run "set stdout_level DEBUG" before
INFO: Change particles name to pass to MG5 convention
Defined multiparticle p = g u c d s u~ c~ d~ s~
Defined multiparticle j = g u c d s u~ c~ d~ s~
Defined multiparticle l+ = e+ mu+
Defined multiparticle l- = e- mu-
Defined multiparticle vl = ve vm vt
Defined multiparticle vl~ = ve~ vm~ vt~
Defined multiparticle all = g u c d s u~ c~ d~ s~ a ve vm vt e- mu- ve~ vm~ vt~
e+ mu+ t b t~ b~ z w+ h w- ta- ta+
mg5>import model Taipei-FR-MG-2013_UFO
INFO: load particles
INFO: load vertices
INFO: The model has interaction violating the charge: Y
INFO: Change particles name to pass to MG5 convention
Kept definitions of multiparticles l- / j / vl / l+ / p / vl~ unchanged
Defined multiparticle all = g a ve vm vt ve~ vm~ vt~ u c t d s b uv u~ c~ t~ d~
s~ b~ uv~ z w+ h phim1 phim2 w- e- mu- ta- ev e+ mu+ ta+ ev~
mg5>
```

Import new model



Import UFO → MG5

```
MadGraph5_v1_5_12 — Python — 80x24
Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
Loading default model: sm
INFO: load particles
INFO: load vertices
INFO: Restrict model sm with file models/sm/restrict_default.dat .
INFO: Run "set stdout_level DEBUG" before import for more information.
INFO: Change particles name to pass to MG5 convention
Defined multiparticle p = g u c d s u~ c~ d~ s~
Defined multiparticle j = g u c d s u~ c~ d~ s~
Defined multiparticle l+ = e+ mu+
Defined multiparticle l- = e- mu-
Defined multiparticle vl = ve vm vt
Defined multiparticle vl~
Defined multiparticle all = vt e- mu- ve~ vm~ vt~
e+ mu+ t b t~ b~ z w+ h w-
mg5>import model Taipei-FR-MG-2013_UFO
INFO: load particles
INFO: load vertices
INFO: The model has interaction violating the charge: Y
INFO: Change particles name to pass to MG5 convention
Kept definitions of multiparticles l- / j / vl / l+ / p / vl~ unchanged
Defined multiparticle all = g a ve vm vt ve~ vm~ vt~ u c t d s b uv u~ c~ t~ d~
s~ b~ uv~ z w+ h phim1 phim2 w- e- mu- ta- ev e+ mu+ ta+ ev~
mg5>check p p > uv uv~
```

Check p p > uv uv~

Import UFO → MG5

```
MadGraph5_v1_5_12 — Python — 80x24
Gauge results (switching between Unitary/Feynman):
Process          Unitary          Feynman          Relative diff.   Result
g g > uv uv~    4.6280449975e-01 4.6280449975e-01 0.0000000000e+00 Passed
u u~ > uv uv~    9.0300369162e-01 9.0300369162e-01 0.0000000000e+00 Passed
c c~ > uv uv~    8.4256239684e-01 8.4256239684e-01 0.0000000000e+00 Passed
d d~ > uv uv~    8.4709902490e-01 8.4709902490e-01 0.0000000000e+00 Passed
s s~ > uv uv~    9.7144064677e-01 9.7144064677e-01 0.0000000000e+00 Passed
Summary: 5/5 passed, 0/5 failed
Lorentz invariance results:
Process          Min element      Max element      Relative diff.   Result
g g > uv uv~    4.8020434562e-01 4.8020434562e-01 2.3119803782e-16 Passed
u u~ > uv uv~    9.2315267407e-01 9.2315267407e-01 2.0444929586e-15 Passed
c c~ > uv uv~    8.7955925403e-01 8.7955925403e-01 6.3112463403e-16 Passed
d d~ > uv uv~    8.4304382787e-01 8.4304382787e-01 1.8436909009e-15 Passed
s s~ > uv uv~    9.2621007569e-01 9.2621007569e-01 1.3185403173e-15 Passed
Summary: 5/5 passed, 0/5 failed
Process permutation results:
Process          Min element      Max element      Relative diff.   Result
g g > uv uv~    7.5704630629e-01 7.5704630629e-01 1.0265635150e-15 Passed
u u~ > uv uv~    6.9559674954e-01 6.9559674954e-01 4.7882182832e-16 Passed
c c~ > uv uv~    8.6853185413e-01 8.6853185413e-01 7.6696532385e-16 Passed
d d~ > uv uv~    9.7414225260e-01 9.7414225260e-01 0.0000000000e+00 Passed
s s~ > uv uv~    8.5872932568e-01 8.5872932568e-01 1.2928672533e-16 Passed
Summary: 5/5 passed, 0/5 failed
```

Import UFO → MG5

```
MadGraph5_v1_5_12 — Python — 80x24

Gauge results (switching between Unitary/Feynman):
Process          Unitary          Feynman          Relative diff.   Result
g g > uv uv~    4.6280449975e-01 4.6280449975e-01 0.0000000000e+00 Passed
u u~ > uv uv~    9.0300369162e-01 9.0300369162e-01 0.0000000000e+00 Passed
c c~ > uv uv~    8.4256239684e-01 8.4256239684e-01 0.0000000000e+00 Passed
d d~ > uv uv~    8.4709902490e-01 8.4709902490e-01 0.0000000000e+00 Passed
s s~ > uv uv~    9.7144064677e-01 9.7144064677e-01 0.0000000000e+00 Passed
Summary: 5/5 passed, 0/5 failed

Lorentz invariance results:
Process          Min element      Max element      Relative diff.   Result
g g > uv uv~    4.8020434562e-01 4.8020434562e-01 2.3119803782e-16 Passed
u u~ > uv uv~    9.2315267407e-01 9.2315267407e-01 2.0444929586e-15 Passed
c c~ > uv uv~    8.7955925403e-01 8.7955925403e-01 6.3112463403e-16 Passed
d d~ > uv uv~    8.4304382787e-01 8.4304382787e-01 1.8436909009e-15 Passed
s s~ > uv uv~    9.2621007569e-01 9.2621007569e-01 1.3185403173e-15 Passed
Summary: 5/5 passed, 0/5 failed

Process permutation results:
Process          Min element      Max element      Relative diff.   Result
g g > uv uv~    7.5704630629e-01 7.5704630629e-01 1.0265635150e-15 Passed
u u~ > uv uv~    6.9559674954e-01 6.9559674954e-01 4.7882182832e-16 Passed
c c~ > uv uv~    8.6853185413e-01 8.6853185413e-01 7.6696532385e-16 Passed
d d~ > uv uv~    9.7414225260e-01 9.7414225260e-01 0.0000000000e+00 Passed
s s~ > uv uv~    8.5872932568e-01 8.5872932568e-01 1.2928672533e-16 Passed
Summary: 5/5 passed, 0/5 failed
```

Import UFO → MG5

```
MadGraph5_v1_5_12 — Python — 80x24

Gauge results (switching between Unitary/Feynman):
Process          Unitary          Feynman          Relative diff.   Result
g g > uv uv~    4.6280449975e-01 4.6280449975e-01 0.0000000000e+00 Passed
u u~ > uv uv~    9.0300369162e-01 9.0300369162e-01 0.0000000000e+00 Passed
c c~ > uv uv~    8.4256239684e-01 8.4256239684e-01 0.0000000000e+00 Passed
d d~ > uv uv~    8.4709902490e-01 8.4709902490e-01 0.0000000000e+00 Passed
s s~ > uv uv~    9.7144064677e-01 9.7144064677e-01 0.0000000000e+00 Passed
Summary: 5/5 passed, 0/5 failed

Lorentz invariance results:
Process          Min element      Max element      Relative diff.   Result
g g > uv uv~    4.8020434562e-01 4.8020434562e-01 2.3119803782e-16 Passed
u u~ > uv uv~    9.2315267407e-01 9.2315267407e-01 2.0444929586e-15 Passed
c c~ > uv uv~    8.7955925403e-01 8.7955925403e-01 6.3112463403e-16 Passed
d d~ > uv uv~    8.4304382787e-01 8.4304382787e-01 1.8436909009e-15 Passed
s s~ > uv uv~    9.2621007569e-01 9.2621007569e-01 1.3185403173e-15 Passed
Summary: 5/5 passed, 0/5 failed

Process permutation results:
Process          Min element      Max element      Relative diff.   Result
g g > uv uv~    7.5704630629e-01 7.5704630629e-01 1.0265635150e-15 Passed
u u~ > uv uv~    6.9559674954e-01 6.9559674954e-01 4.7882182832e-16 Passed
c c~ > uv uv~    8.6853185413e-01 8.6853185413e-01 7.6696532385e-16 Passed
d d~ > uv uv~    9.7414225260e-01 9.7414225260e-01 0.0000000000e+00 Passed
s s~ > uv uv~    8.5872932568e-01 8.5872932568e-01 1.2928672533e-16 Passed
Summary: 5/5 passed, 0/5 failed
```

Generate Signal

```
MadGraph5_v1_5_12 — Python — 80x24
u u~ > uv uv~ 9.0300369162e-01 9.0300369162e-01 0.0000000000e+00 Passed
c c~ > uv uv~ 8.4256239684e-01 8.4256239684e-01 0.0000000000e+00 Passed
d d~ > uv uv~ 8.4709902490e-01 8.4709902490e-01 0.0000000000e+00 Passed
s s~ > uv uv~ 9.7144064677e-01 9.7144064677e-01 0.0000000000e+00 Passed
Summary: 5/5 passed, 0/5 failed
Lorentz invariance results:
Process      Min element      Max element      Relative diff.   Result
g g > uv uv~  4.8020434562e-01 4.8020434562e-01 2.3119803782e-16 Passed
u u~ > uv uv~  9.2315267407e-01 9.2315267407e-01 2.0444929586e-15 Passed
c c~ > uv uv~  8.7955925403e-01 8.7955925403e-01 6.3112463403e-16 Passed
d d~ > uv uv~  8.4304382787e-01 8.4304382787e-01 1.8436909009e-15 Passed
s s~ > uv uv~  9.2621007569e-01 9.2621007569e-01 1.3185403173e-15 Passed
Summary: 5/5 passed, 0/5 failed
Process permutation results:
Process      Min element      Max element      Relative diff.   Result
g g > uv uv~  7.5704630629e-01 7.5704630629e-01 1.0265635150e-15 Passed
u u~ > uv uv~  6.9559674954e-01 6.9559674954e-01 4.7882182832e-16 Passed
c c~ > uv uv~  8.6853185413e-01 8.6853185413e-01 7.6696532385e-16 Passed
d d~ > uv uv~  9.7414225260e-01 9.7414225260e-01 0.0000000000e+00 Passed
s s~ > uv uv~  8.5872932568e-01 8.5872932568e-01 1.2928672533e-16 Passed
Summary: 5/5 passed, 0/5 failed
```

```
mg5>generate p p > uv uv~ , uv > u phiM1 , \
mg5> (uv~ > u~ phiM2 , (phiM2 > e+ ev , ev > e- phiM1))
```

Generate Signal

```
MadGraph5_v1_5_12 — Python — 80x24
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process: uv > u phim1 WEIGHTED=1
INFO: Process has 1 diagrams
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process: uv~ > u~ phim2 WEIGHTED=1
INFO: Process has 1 diagrams
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process: phim2 > e+ ev WEIGHTED=1
INFO: Process has 1 diagrams
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process: ev > e- phim1 WEIGHTED=1
INFO: Process has 1 diagrams
1 processes with 13 diagrams generated in 0.107 s
Total: 1 processes with 13 diagrams
mg5>add process p p > uv uv~ , uv > u phiM1 , \
mg5> (uv~ > u~ phiM2 , (phiM2 > e- ev~ , ev~ > e+ phiM1))
```

Generate Signal

```
MadGraph5_v1_5_12 — Python — 80x24
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process: uv > u phim1 WEIGHTED=1
INFO: Process has 1 diagrams
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process: uv~ > u~ phim2 WEIGHTED=1
INFO: Process has 1 diagrams
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process: phim2 > e- ev~ WEIGHTED=1
INFO: Process has 1 diagrams
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process: ev~ > e+ phim1 WEIGHTED=1
INFO: Process has 1 diagrams
1 processes with 13 diagrams generated in 0.103 s
Total: 2 processes with 26 diagrams
mg5>add process p p > uv uv~ , \
mg5>          (uv > u phim2 , (phim2 > e+ ev , ev > e- phim1)) \
mg5>          uv~ > u~ phim1
```


Generate Signal

```
MadGraph5_v1_5_12 — Python — 80x24
INFO: Process  $u \sim u > uv \ uv \sim$  added to mirror process  $u \ u \sim > uv \ uv \sim$ 
INFO: Process  $c \sim c > uv \ uv \sim$  added to mirror process  $c \ c \sim > uv \ uv \sim$ 
INFO: Process  $d \sim d > uv \ uv \sim$  added to mirror process  $d \ d \sim > uv \ uv \sim$ 
INFO: Process  $s \sim s > uv \ uv \sim$  added to mirror process  $s \ s \sim > uv \ uv \sim$ 
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process:  $uv > u \ \text{phiM2}$  WEIGHTED=1
INFO: Process has 1 diagrams
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process:  $\text{phiM2} > e^+ \ e^-$  WEIGHTED=1
INFO: Process has 1 diagrams
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process:  $ev > e^- \ \text{phiM1}$  WEIGHTED=1
INFO: Process has 1 diagrams
1 processes with 12 diagrams generated in 0.096 s
Total: 3 processes with 38 diagrams
mg5>add process p p > uv uv~ , \
mg5>          (uv > u phiM2 , (phiM2 > e- ev~ , ev~ > e+ phiM1)) \
mg5>          uv~ > u~ phiM1
```

Generate Signal

```
MadGraph5_v1_5_12 — Python — 80x24
INFO: Trying process: s s~ > uv uv~ WEIGHTED=2
INFO: Process has 1 diagrams
INFO: Process u~ u > uv uv~ added to mirror process u u~ > uv uv~
INFO: Process c~ c > uv uv~ added to mirror process c c~ > uv uv~
INFO: Process d~ d > uv uv~ added to mirror process d d~ > uv uv~
INFO: Process s~ s > uv uv~ added to mirror process s s~ > uv uv~
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process: uv > u phim2 WEIGHTED=1
INFO: Process has 1 diagrams
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process: phim2 > e- ev~ WEIGHTED=1
INFO: Process has 1 diagrams
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=1
INFO: Trying process: ev~ > e+ phim1 WEIGHTED=1
INFO: Process has 1 diagrams
1 processes with 12 diagrams generated in 0.093 s
Total: 4 processes with 50 diagrams
mg5>output
```

Generate Signal

```
MadGraph5_v1_5_12 — Python — 80x24

Decay: ev~ > e+ phim1 WEIGHTED=1
INFO: Finding symmetric diagrams for subprocess group ssx_uvuvx_uv_uvim2_phim2_
epev_ev_emvim1
History written to /Users/neil/physics/tmp/FR-tutorial/MadGraph5_v1_5_12/PROC_Ta
ipei-FR-MG-2013_UF0_0/Cards/proc_card_mg5.dat
Generated helas calls for 20 subprocesses (36 diagrams) in 0.416 s
Wrote files for 292 helas calls in 0.693 s
Export UFO model to MG4 format
ALOHA: aloha creates FFS1 routines
ALOHA: aloha creates FFS3 routines
ALOHA: aloha creates FFV1 routines
ALOHA: aloha creates VVV1 routines
save configuration file to /Users/neil/physics/tmp/FR-tutorial/MadGraph5_v1_5_12
/PROC_Taipei-FR-MG-2013_UF0_0/Cards/me5_configuration.txt
INFO: Use Fortran compiler gfortran
INFO: Generate jpeg diagrams
INFO: Generate web pages
Output to directory /Users/neil/physics/tmp/FR-tutorial/MadGraph5_v1_5_12/PROC_T
aipei-FR-MG-2013_UF0_0 done.
Type "launch" to generate events from this process, or see
/Users/neil/physics/tmp/FR-tutorial/MadGraph5_v1_5_12/PROC_Taipei-FR-MG-2013_UF0
_0/README
Run "open index.html" to see more information about this process.

mg5>launch
```

Generate Signal

```
MadGraph5_v1_5_12 — Python — 80x24
*
*      Type 'help' for in-line help.
*
*****
load configuration from /Users/neil/physics/tmp/FR-tutorial/MadGraph5_v1_5_12/PR
OC_Taipei-FR-MG-2013_UF0_0/Cards/me5_configuration.txt
load configuration from /Users/neil/physics/tmp/FR-tutorial/MadGraph5_v1_5_12/in
put/mg5_configuration.txt
load configuration from /Users/neil/physics/tmp/FR-tutorial/MadGraph5_v1_5_12/PR
OC_Taipei-FR-MG-2013_UF0_0/Cards/me5_configuration.txt
Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
generate_events run_01
Will run in mode parton
Do you want to edit one cards (press enter to bypass editing)?
1 / param      : param_card.dat (be carefull about parameter consistency, especia
lly widths)
2 / run        : run_card.dat
you can also
- enter the path to a valid card or banner.
- use the 'set' command to modify a parameter directly.
The set option works only for param_card and run_card.
Type 'help set' for more information on this command.
[0, done, 1, param, 2, run, enter path][60s to answer]
>1
```

Generate Signal

```
MadGraph5_v1_5_12 — vim — 80x24

 3 1.010000e-01 # yms
 4 1.270000e+00 # ymc
 5 4.700000e+00 # ymb
 6 1.720000e+02 # ymt
11 5.110000e-04 # yme
13 1.056600e-01 # ymm
15 1.777000e+00 # ymtau

#####
## INFORMATION FOR DECAY
#####
DECAY 6 1.466877e+00 # WT
DECAY 23 2.411596e+00 # WZ
DECAY 24 2.002524e+00 # WW
DECAY 25 5.803709e-03 # WH
DECAY 9000006 auto # Wuv
DECAY 9000007 auto # Wev
DECAY 9000008 0.000000e+00 # WphiM1
DECAY 9000009 auto # WphiM2
## Dependent parameters, given by model restrictions.
## Those values should be edited following the
## analytical expression. MG5 ignores those values
## but they are important for interfacing the output of MG5
-- INSERT --
```

Generate Signal

```
MadGraph5_v1_5_12 — Python — 80x24
>1
open /Users/neil/physics/tmp/FR-tutorial/MadGraph5_v1_5_12/PROC_Taipei-FR-MG-2013_UFO_0/Cards/param_card.dat
Computing the width set on auto in the param_card.dat
Be carefull automatic computation of the width is
ONLY valid if all three (or more) body decay are negligeable. In doubt use a
calculator.
In a future version of MG5 these mode will also be taken into account
INFO: load particles
INFO: load vertices
INFO: The model has interaction violating the charge: Y
Results written to /Users/neil/physics/tmp/FR-tutorial/MadGraph5_v1_5_12/PROC_Taipei-FR-MG-2013_UFO_0/Cards/param_card.dat
Do you want to edit one cards (press enter to bypass editing)?
  1 / param      : param_card.dat (be carefull about parameter consistency, especially widths)
  2 / run        : run_card.dat
you can also
- enter the path to a valid card or banner.
- use the 'set' command to modify a parameter directly.
  The set option works only for param_card and run_card.
  Type 'help set' for more information on this command.
[0, done, 1, param, 2, run, enter path][60s to answer]
>
```

Generate Signal

Online Event Generation

file:///Users/neil/physics/tmp/FR-tutorial/MadGraph5_v1_5_12/PROC_Taipei-FR-MG Reader

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

**Results in the Taipei-FR-MG-2013_UFO for $p p > uv uv^{\sim}, uv > u \text{ phiM1}, \lambda,$
 $p p > uv uv^{\sim}, uv > u \text{ phiM1}, \dots$**

Available Results

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	$p p$ 7000 x 7000 GeV	tag_1	1.857 ± 0.006	10000	parton	LHE	<input type="button" value="remove run"/> <input type="button" value="launch pythia"/>

[Main Page](#)

Signal Events

Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/model?id=251". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area displays the following information:

- Taipei-FR-MG-2013**
Neil Christensen
- FeynRules Model Files**
- MEG Model Files & Validations**
- ↓ Massless
- Restriction File(s) : Massless.rst
- Parameter File :

Model	Status	Action
CH	✓ Q	Dwnld
MG5	✓ Q	Dwnld
WO2	✓ Q	Dwnld
TeX	✓	Dwnld

Validations

Remove Scalar 0/0 processes finished

Create New Validation

Create New MEG Model Files

Stack Models

Web Validation

Taipei-FR-MG-2013

feynrules.irmp.ucl.ac.be/validation/author/model?id=251

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

Taipei-FR-MG-2013

Neil Christensen

FeynRules Model Files

MEG Model Files & Validations

↓ Massless [Rmv](#)

Restriction File(s) : Massless.rst
Parameter File :

CH ✓✓ Dwnld	MG5 ✓✓ Dwnld	WO2 ✓✓ Dwnld	TeX ✓ Dwnld
--	---	---	--

Validations

[Remove](#) Scalar 0/0 processes finished

[Create New Validation](#)

[Create New MEG Model Files](#)

Web Validation

Taipei-FR-MG-2013

feynrules.irmp.ucl.ac.be/validation/author/model?id=251

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

Taipei-FR-MG-2013

Neil Christensen

FeynRules Model Files

MEG Model Files & Validations

↓ Massless [Rmv](#)

Restriction File(s) : Massless.rst
Parameter File :

CH	MG5	WO2	TeX
✓✓	✓✓	✓✓	✓
Dwnld	Dwnld	Dwnld	Dwnld

Validations

[Remove](#) **Scalar** 0 0 processes finished

[Create New Validation](#)

[Create New MEG Model Files](#)

Web Validation

Taipei-FR-MG-2013 : Scalar

feynrules.irmp.ucl.ac.be/validation/author/validation?vdtid=430;start=0

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

Scalar

Taipei-FR-MG-2013

Neil Christensen

⇒ **Restriction & Parameter Files**

⇒ **Process Restrictions**

⇒ **Feynman Diagram Calculators**

⇒ **Stock Models**

[Start Fresh Validations](#) [Finish Validations](#)

411/411 processes finished

?

LL=0.0 for -1 degrees of freedom.
The probability of this being a statistical fluctuation is 100.0%.

Web Validation

Taipei-FR-MG-2013 : Scalar

feynrules.irmp.ucl.ac.be/validation/author/validation?vdtid=430;start=0

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

PROCESS RESTRICTIONS

⇒ Feynman Diagram Calculators

⇒ Stock Models

Start Fresh Validations Finish Validations

411/411 processes finished

LL=0.0 for -1 degrees of freedom.
The probability of this being a statistical fluctuation is 100.0%.

	$\sqrt{s} P_{Tcut} \text{ Best } X^2$
a , a → H , H	
a , a → H , phiM1	
a , a → H , phiM2	
a , a → phiM1 , phiM1	
a , a → phiM1 , phiM2	
a , a → phiM2 , phiM2	
a . Z → H . H	

Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013 : Scalar". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/validation?vdtid=430;start=0". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area displays the following sections:

- Scalar**
Taipei-FR-MG-2013
Neil Christensen
- Restriction & Parameter Files**
- Process Restrictions**
- Feynman Diagram Calculators**
 - CalcHEP (Feynman gauge)
 - MadGraph5 (Feynman gauge)
 - Whizard2 (Feynman gauge)
 - CalcHEP (unitary gauge)
 - MadGraph5 (unitary gauge)
 - Whizard2 (unitary gauge)

Buttons: [Check All](#) [Check None](#)
- Stock Models**

Buttons: [Start Fresh Validations](#) [Finish Validations](#)

411/411 processes finished

Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013 : Scalar". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/validation?vdtId=430;start=0". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area displays the following sections:

- Scalar**
Taipei-FR-MG-2013
Neil Christensen
- Restriction & Parameter Files** (indicated by a right-pointing arrow)
- Process Restrictions** (indicated by a right-pointing arrow)
- Feynman Diagram Calculators** (indicated by a downward-pointing arrow)
 - CalcHEP (Feynman gauge)
 - MadGraph5 (Feynman gauge)
 - Whizard2 (Feynman gauge)
 - CalcHEP (unitary gauge)
 - MadGraph5 (unitary gauge)
 - Whizard2 (unitary gauge)

Buttons: [Check All](#) [Check None](#)
- Stock Models** (indicated by a right-pointing arrow)

At the bottom, there are two buttons: [Start Fresh Validations](#) and [Finish Validations](#). Below these buttons, the text "411/411 processes finished" is displayed.

Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013 : Scalar". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/validation?vdtId=430;start=0". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area displays the following sections:

- Scalar**
Taipei-FR-MG-2013
Neil Christensen
- Restriction & Parameter Files** (indicated by a right-pointing arrow)
- Process Restrictions** (indicated by a right-pointing arrow)
- Feynman Diagram Calculators** (indicated by a downward-pointing arrow)
 - CalcHEP (Feynman gauge) MadGraph5 (Feynman gauge) Whizard2 (Feynman gauge)
 - CalcHEP (unitary gauge) MadGraph5 (unitary gauge) Whizard2 (unitary gauge)

Buttons: [Check All](#) [Check None](#)
- Stock Models** (indicated by a right-pointing arrow)
 - [Start Fresh Validations](#) [Finish Validations](#)

411/411 processes finished

Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013 : Scalar". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/validation?vdtid=430;start=0". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area displays the following information:

- Scalar**
- Taipei-FR-MG-2013**
- Neil Christensen

⇒ **Restriction & Parameter Files**

⇒ **Process Restrictions**

⇒ **Feynman Diagram Calculators**

⇒ **Stock Models**

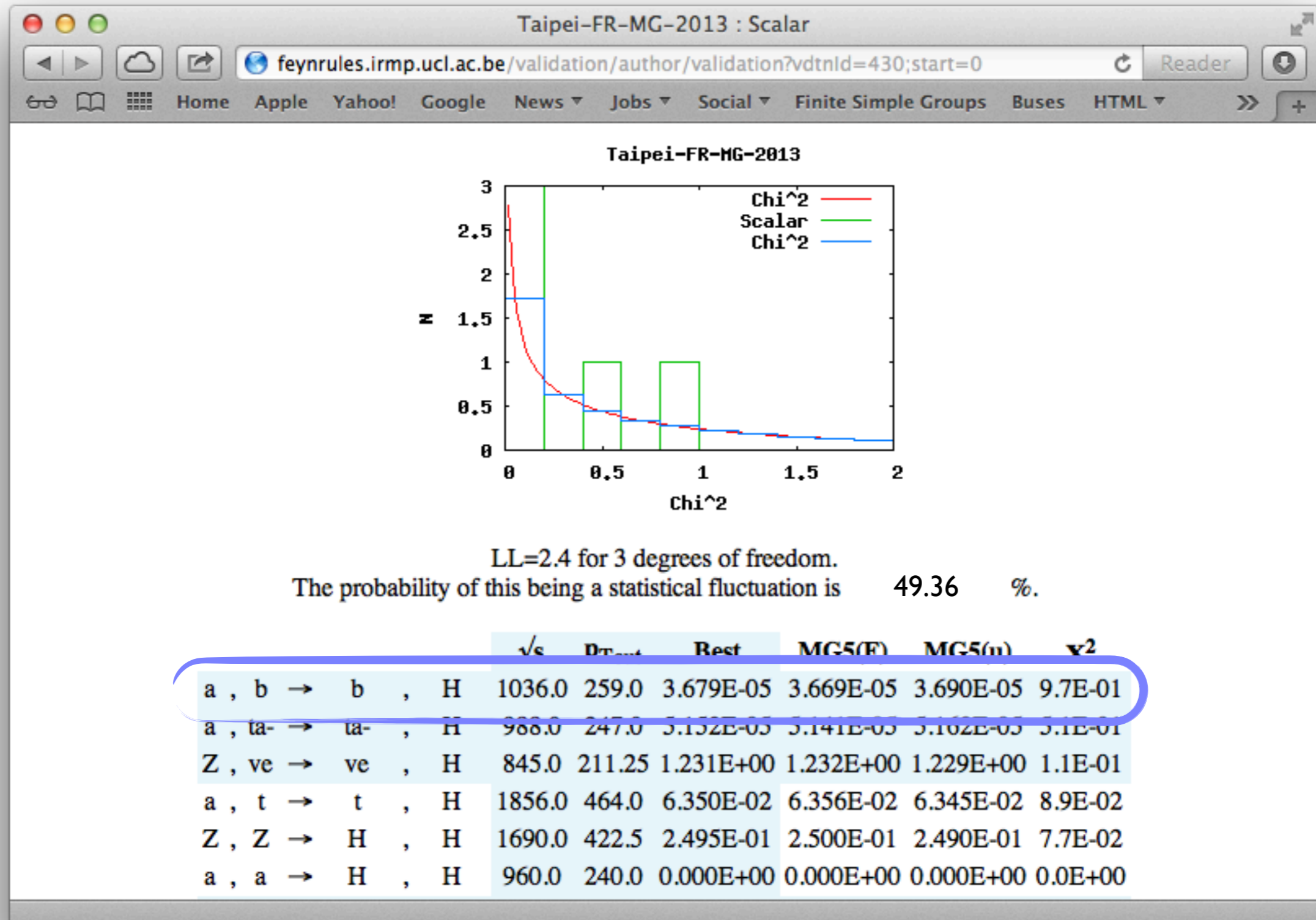
[Stop Validations](#)

0/411 processes finished

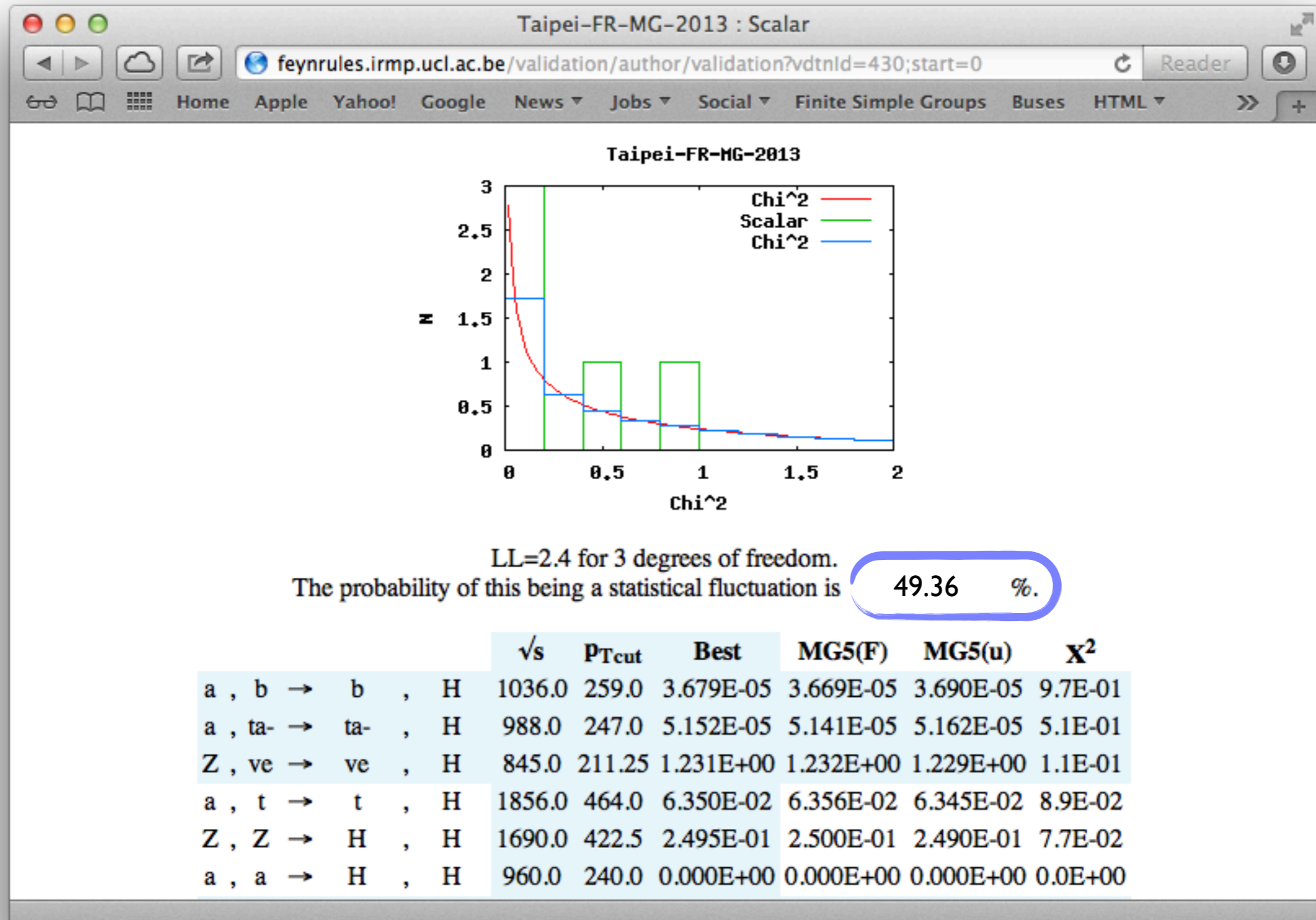
?

LL=0.0 for 1 degrees of freedom.
The probability of this being a statistical fluctuation is 100.0%.

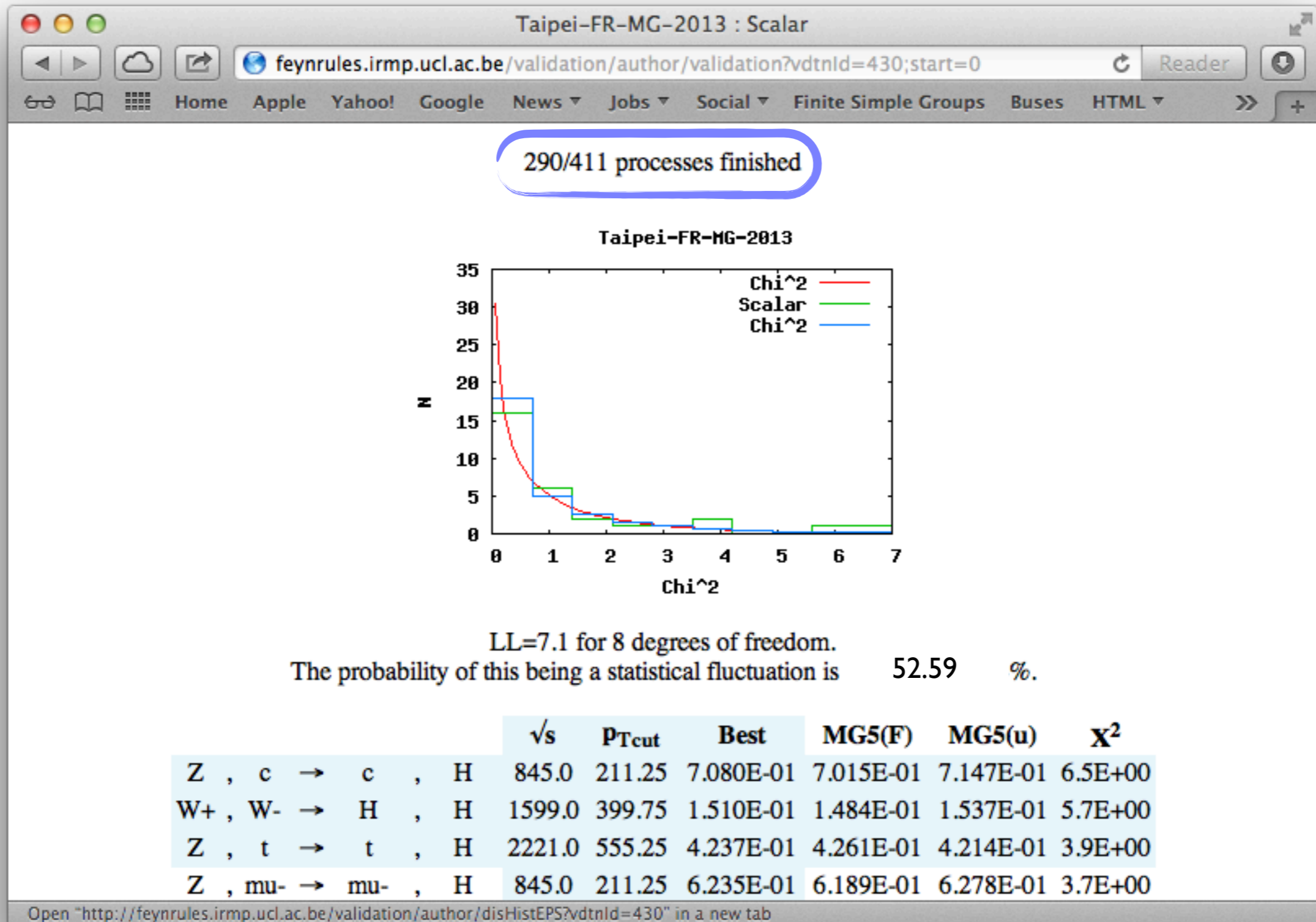
Web Validation



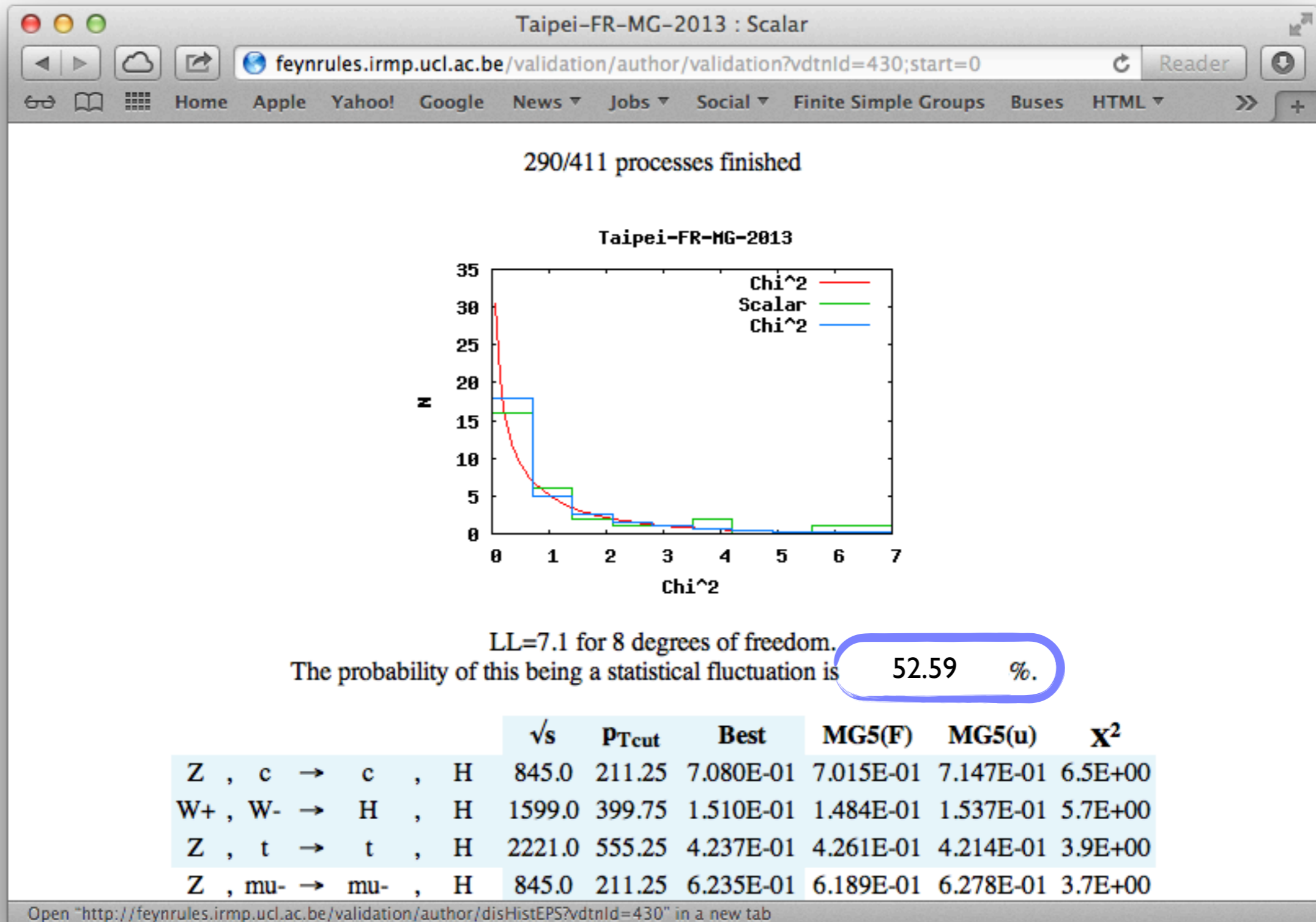
Web Validation



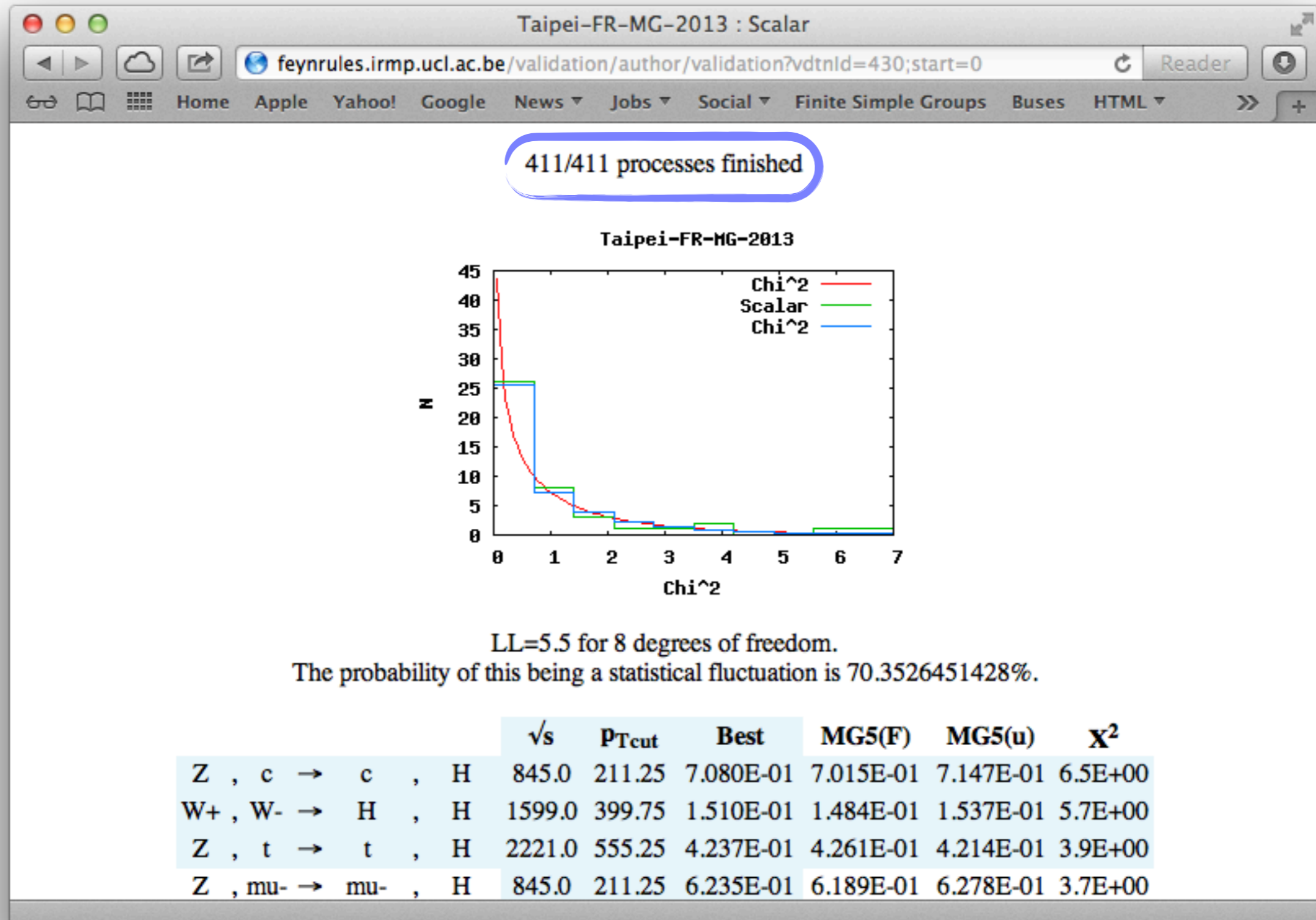
Web Validation



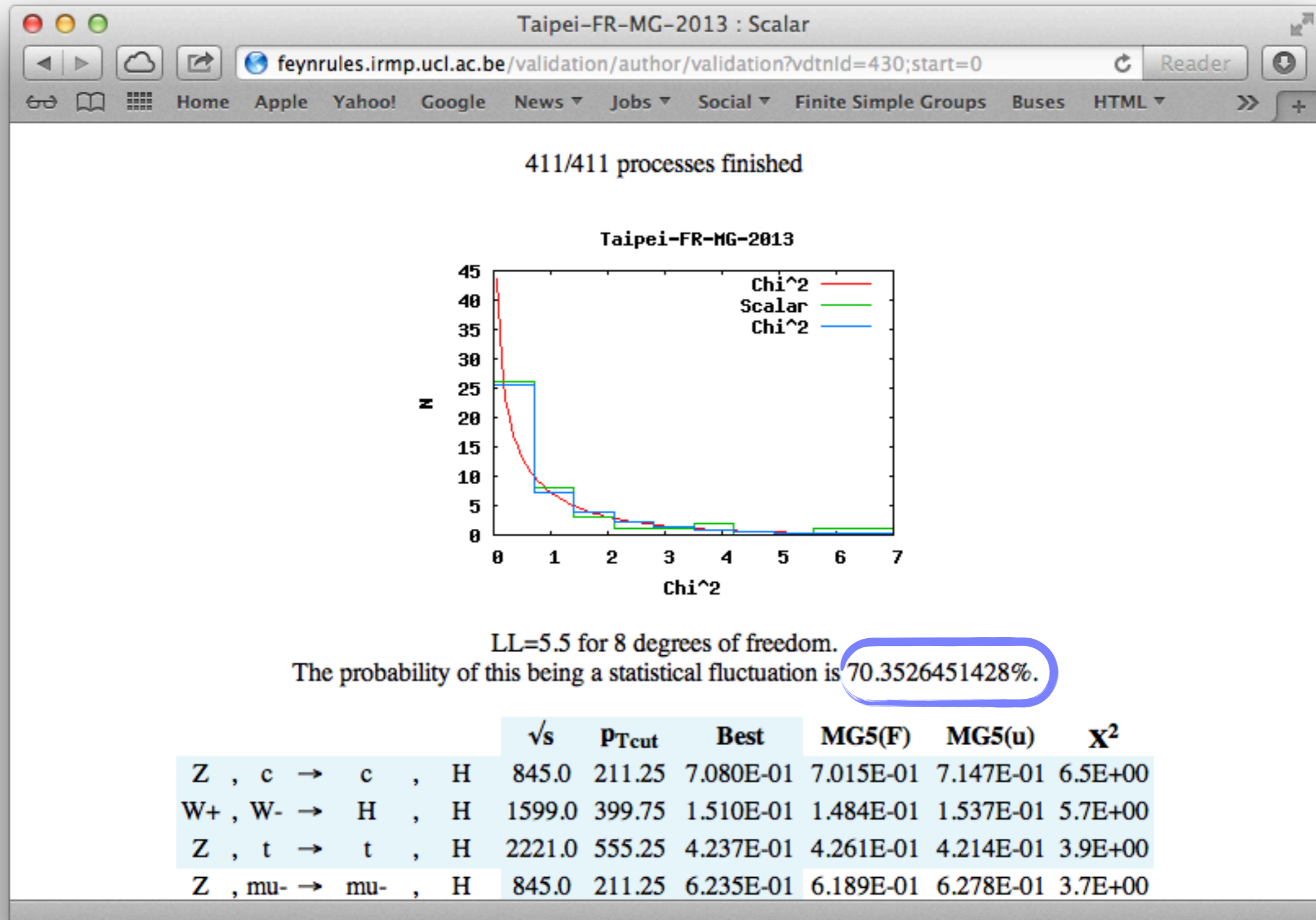
Web Validation



Web Validation



Web Validation



Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/model?id=252". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area displays the title "Taipei-FR-MG-2013" and the author "Neil Christensen". Below this, there is a section for "FeynRules Model Files" and a section for "MEG Model Files & Validations".

In the "MEG Model Files & Validations" section, there is a sub-section for "Massless" with a "Rmv" button. Below this, it lists "Restriction File(s) : Massless.rst" and "Parameter File :".

There are four columns representing different models: CH, MG5, WO2, and TeX. Each column shows two green checkmarks and a "Dwnld" button.

Below the model columns, there is a "Validations" section with a "Remove" button and the text "Scalar 411/411 processes finished".

At the bottom of the page, there are two buttons: "Create New Validation" (highlighted with a blue circle) and "Create New MEG Model Files".

Web Validation

Taipei-FR-MG-2013 : Validation

feynrules.irmp.ucl.ac.be/validation/author/newValidation?RPcombold=517

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

Taipei-FR-MG-2013

Neil Christensen

Validation Name :

Compare :

Process type :

Massless

Restriction File(s) : Massless.rst
Parameter File :

CH	MG5	WO2
✓✓	✓✓	✓✓

Restrictions

Web Validation

Taipei-FR-MG-2013 : all (MG)

feynrules.irmp.ucl.ac.be/validation/author/validation?vdtId=432;start=0

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

all (MG)

Taipei-FR-MG-2013

Neil Christensen

⇒ **Restriction & Parameter Files**

⇒ **Process Restrictions**

⇒ **Feynman Diagram Calculators**

⇒ **Stock Models**

Q : Generating Processes

0/0 processes finished

?

LL=0.0 for 0 degrees of freedom.
The probability of this being a statistical fluctuation is 100.0%.

Web Validation

Taipei-FR-MG-2013 : all (MG)

feynrules.irmp.ucl.ac.be/validation/author/validation?vdtId=432;start=0

Home Apple Yahoo! Google News Jobs Social Finite Simple Groups Buses HTML

all (MG)

Taipei-FR-MG-2013

Neil Christensen

⇒ **Restriction & Parameter Files**

⇒ **Process Restrictions**

⇒ **Feynman Diagram Calculators**

⇒ **Stock Models**

[Start Fresh Validations](#) [Finish Validations](#)

999/999 processes finished

?

LL=0.0 for 0 degrees of freedom.
The probability of this being a statistical fluctuation is 100.0%.

Web Validation

The screenshot shows a web browser window with the title "Taipei-FR-MG-2013 : all (MG)". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/validation?vdtid=432;start=0". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area displays the following sections:

- all (MG)**
Taipei-FR-MG-2013
Neil Christensen
- Restriction & Parameter Files** (indicated by a right-pointing arrow)
- Process Restrictions** (indicated by a right-pointing arrow)
- Feynman Diagram Calculators** (indicated by a downward-pointing arrow)
 - CalcHEP (Feynman gauge)
 - MadGraph5 (Feynman gauge)
 - Whizard2 (Feynman gauge)
 - CalcHEP (unitary gauge)
 - MadGraph5 (unitary gauge)
 - Whizard2 (unitary gauge)

Buttons:
- Stock Models** (indicated by a right-pointing arrow)

At the bottom, there are two buttons: and . Below these buttons, the text "999/999 processes finished" is displayed.

Web Validation

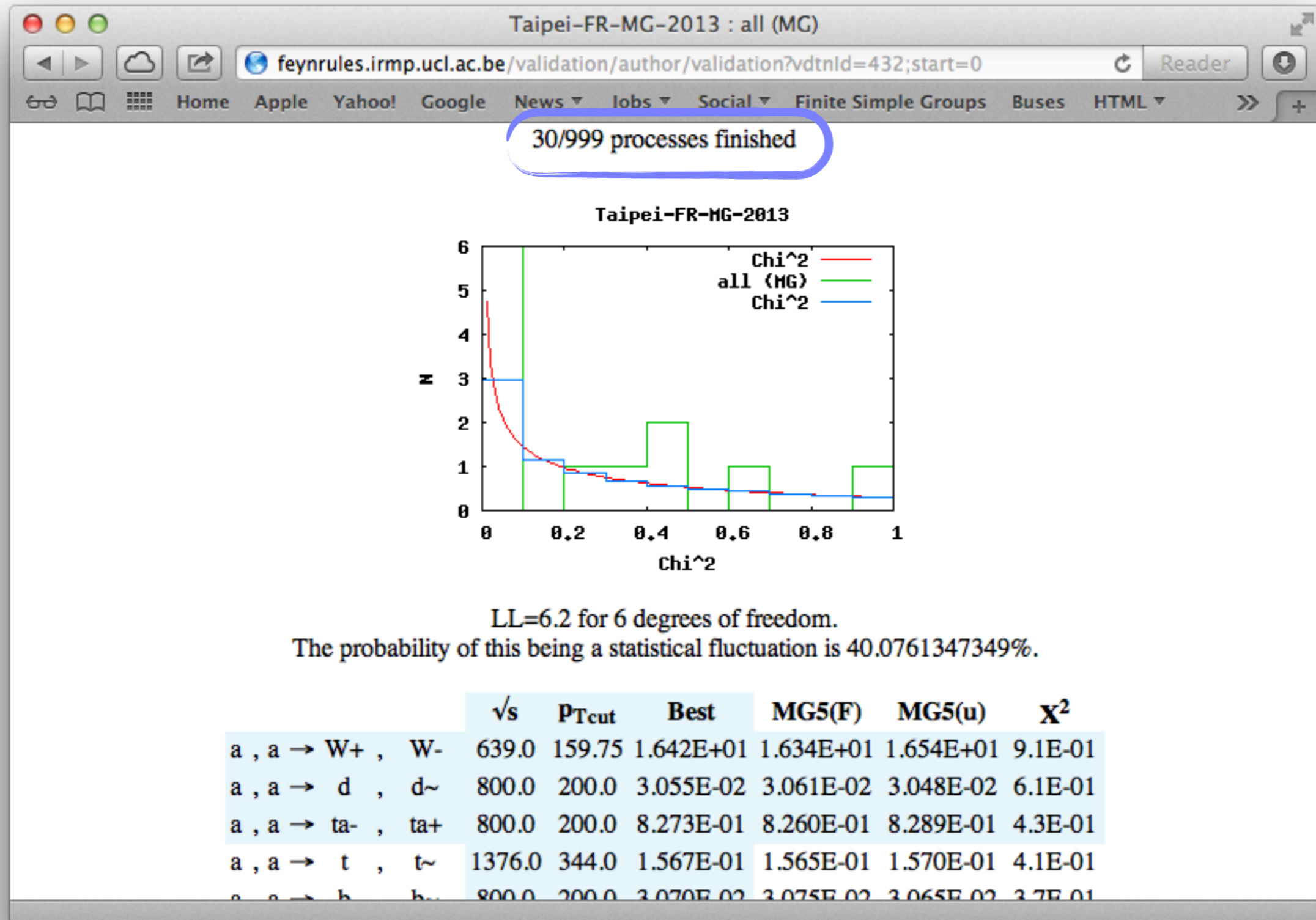
The screenshot shows a web browser window with the title "Taipei-FR-MG-2013 : all (MG)". The address bar contains the URL "feynrules.irmp.ucl.ac.be/validation/author/validation?vdtid=432;start=0". The browser's menu bar includes "Home", "Apple", "Yahoo!", "Google", "News", "Jobs", "Social", "Finite Simple Groups", "Buses", and "HTML".

The main content area displays the following information:

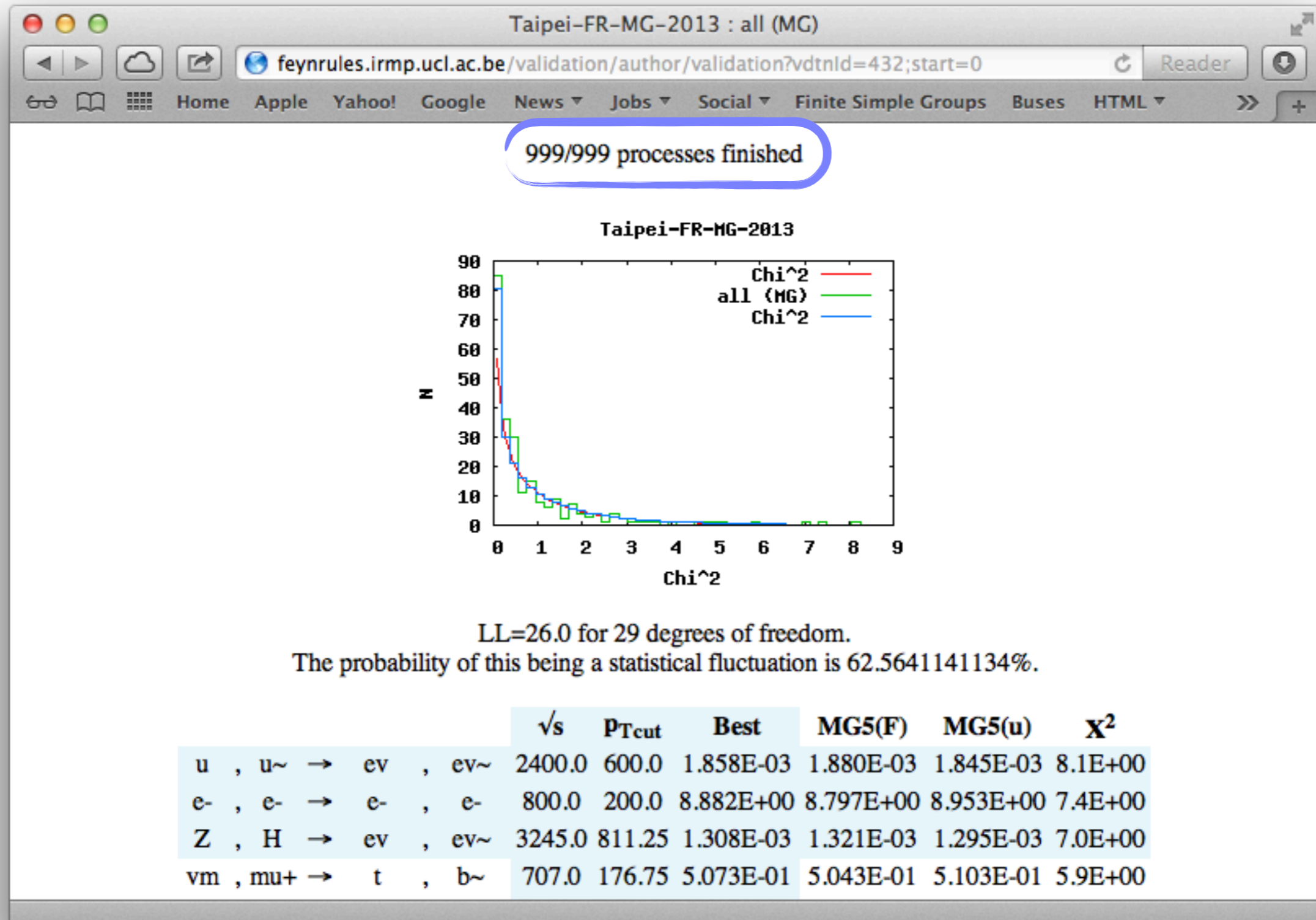
- all (MG)**
Taipei-FR-MG-2013
Neil Christensen
- Restriction & Parameter Files** (indicated by a right-pointing arrow)
- Process Restrictions** (indicated by a right-pointing arrow)
- Feynman Diagram Calculators** (indicated by a downward-pointing arrow)
 - CalcHEP (Feynman gauge) MadGraph5 (Feynman gauge) Whizard2 (Feynman gauge)
 - CalcHEP (unitary gauge) MadGraph5 (unitary gauge) Whizard2 (unitary gauge)
- Stock Models** (indicated by a right-pointing arrow)
 -

At the bottom of the page, it displays "999/999 processes finished".

Web Validation



Web Validation



Web Validation

