FeynRules→MadGraph Tutorial

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The Model

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

+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

Field	Spin	$SU(3)_{QCD}$	$SU(2)_W$	$U(1)_Y$	Z_2
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$$\mathcal{L}_{fq} = i\bar{U}\not{D}U - M_U \bar{U}U + \bar{E}\not{D}E - M_E \bar{E}E$$

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

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

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

The Model

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

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

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

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The Model

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

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

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

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

The Model

Field	Spin	$SU(3)_{QCD}$	$SU(2)_W$	$U(1)_Y$	Z_2
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$$\mathcal{L}_{sq} = \frac{1}{2}\partial_\mu\phi_i\partial^\mu\phi_i - \frac{1}{2}M_{\phi ij}\phi_i\phi_j$$
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$$\mathcal{L}_{fq} = i\bar{U}\not{D}U - M_U\bar{U}U + i\bar{E}\not{D}E - M_E\bar{E}E$$

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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	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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]

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

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

$$\begin{aligned}\mathcal{L}_{yuk} &= \lambda_i \phi_i \bar{U} P_R u + \lambda'_i \phi_i \bar{E} P_R e + \text{h.c.} \\ &= \lambda_i U_{Sij} \Phi_j \bar{U} P_R u + \lambda'_i U_{Sij} \Phi_j \bar{E} P_R e + \text{h.c.}\end{aligned}$$

The Model

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin\alpha$	sina	$\cos\alpha$	cosa
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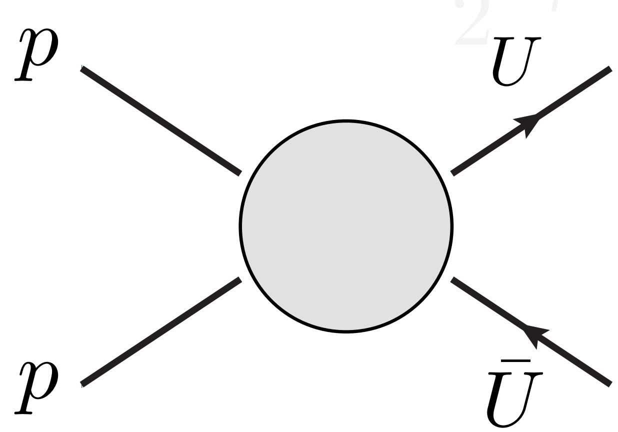
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi ij}$	MassM[i,j]

$$M_U > M_{\Phi 2} > M_E > M_{\Phi 1}$$



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ϕ_i	phiT[i]	$\sin\alpha$	sina	$\cos\alpha$	cosa
Φ_i	phiMi	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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]

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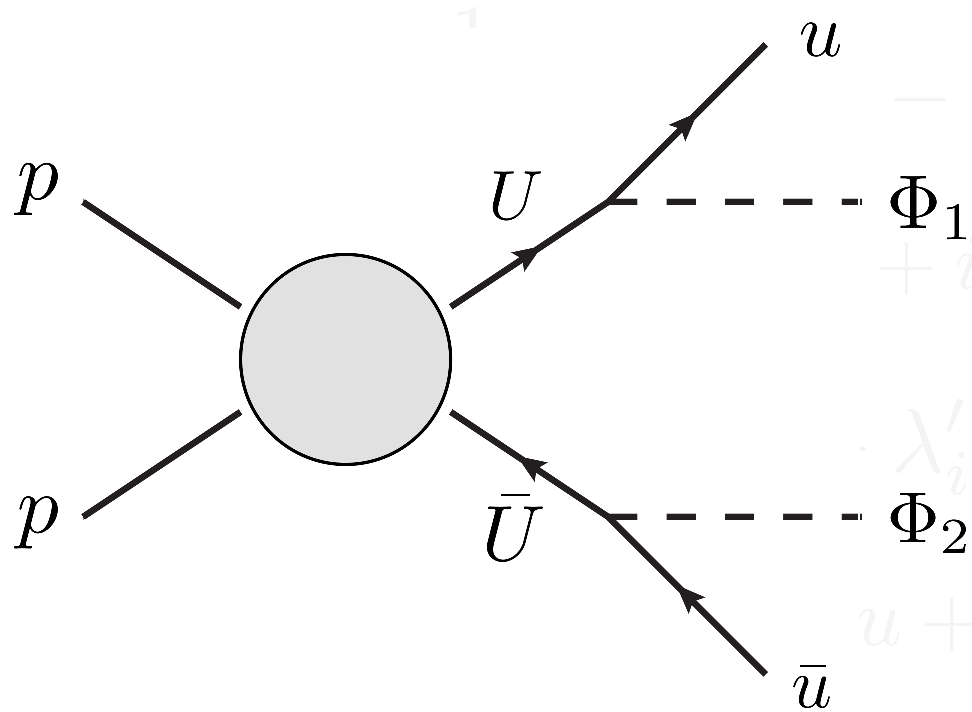
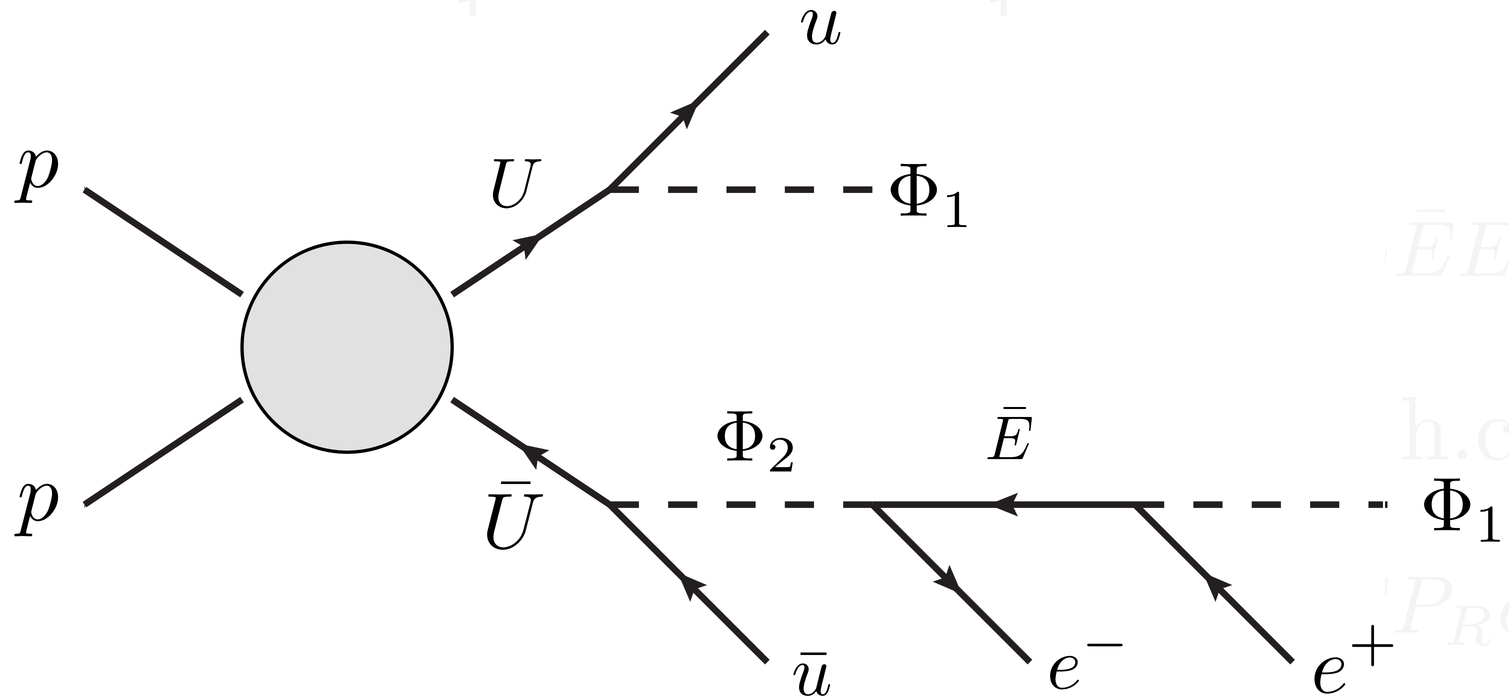


The Model

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin\alpha$	sina	$\cos\alpha$	cosa
Φ_i	phiMi	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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]

$$M_U > M_{\Phi 2} > M_E > M_{\Phi 1}$$



The Model

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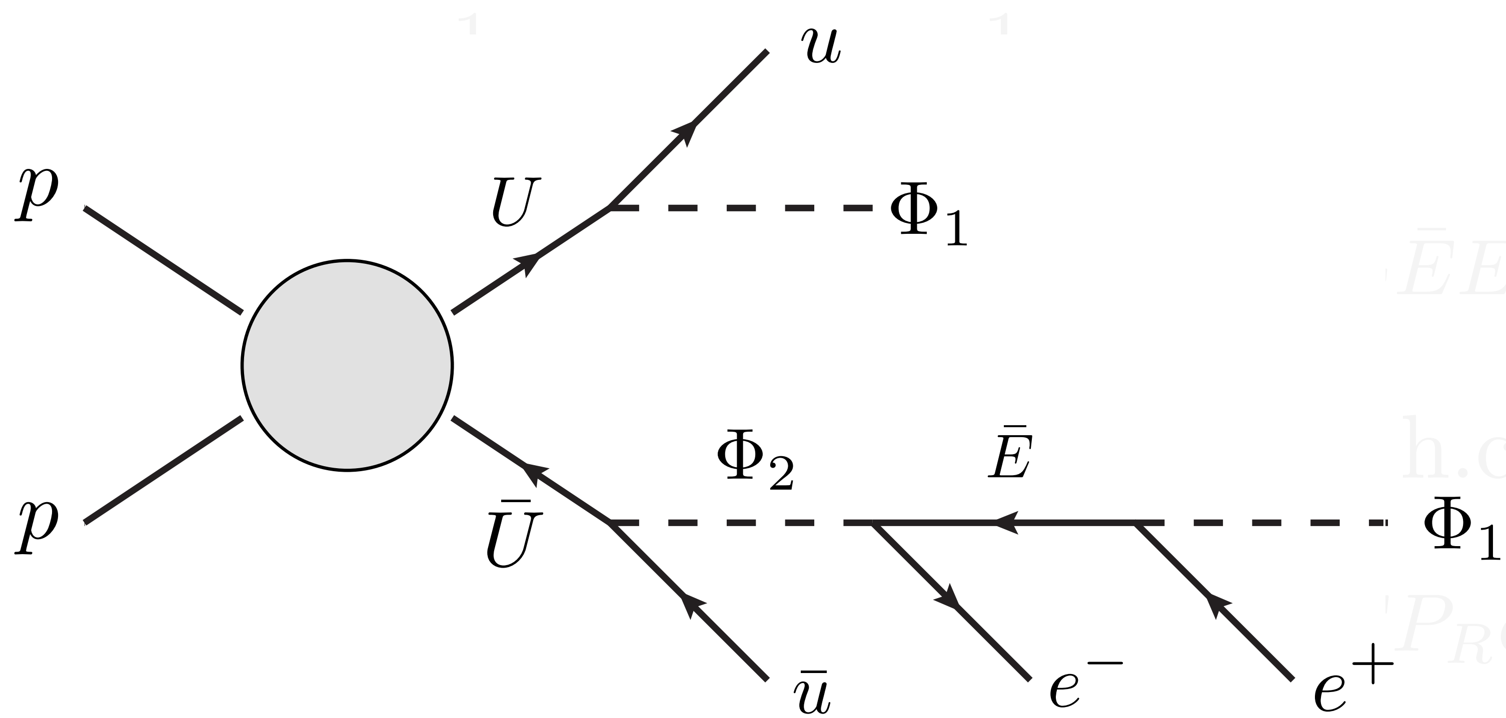
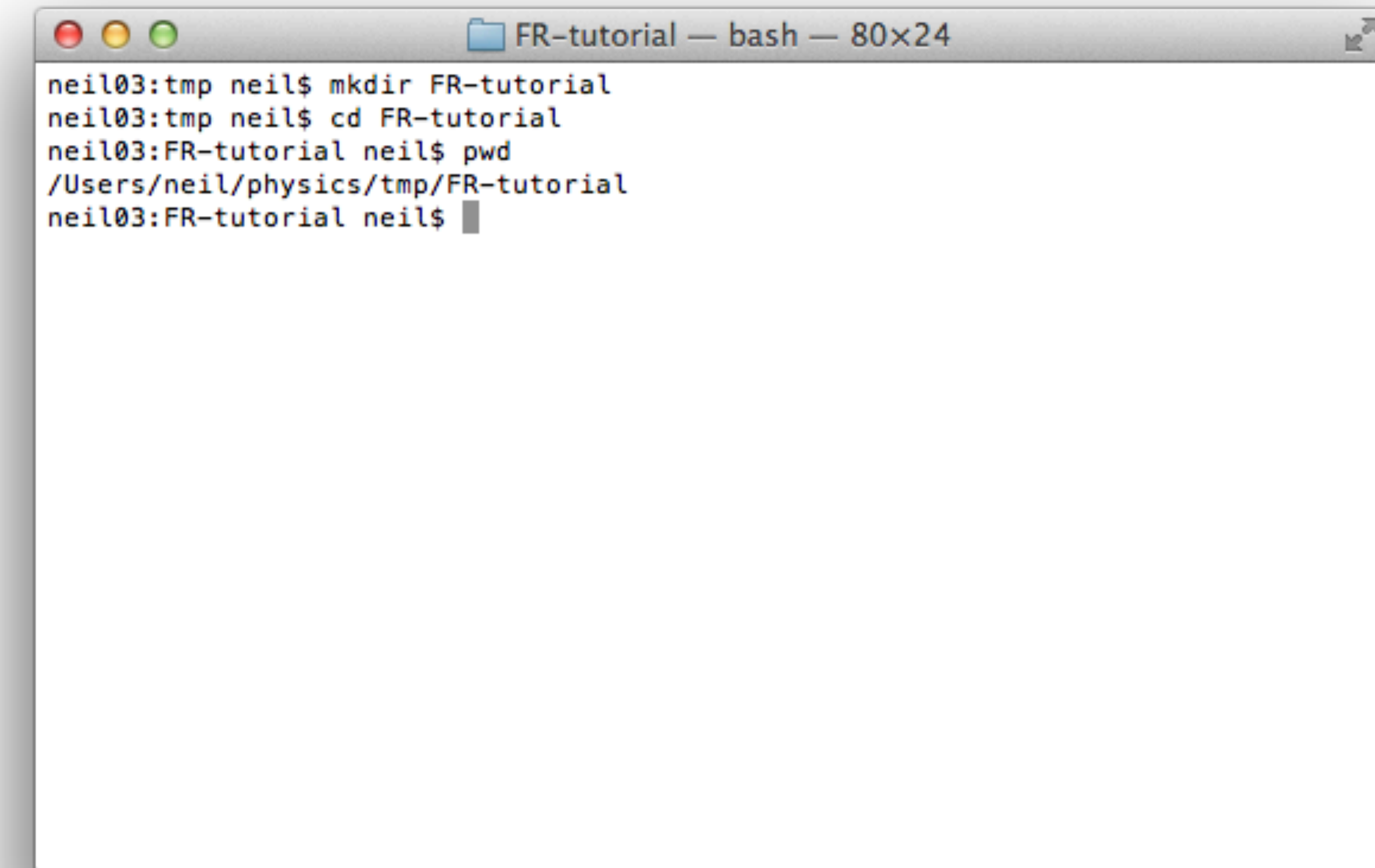
ϕ_i	phiT[i]	$\sin\alpha$	sina	$\cos\alpha$	cosa
Φ_i	phiMi	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	WphiMi
U	uv/uv~	M_U	Muv	Γ_U	Wuv
E	ev/ev~	M_E	Mev	Γ_E	Wev
λ_i	lambdai	λ'_i	lambdapi	$M_{\phi ij}$	MassM[i,j]

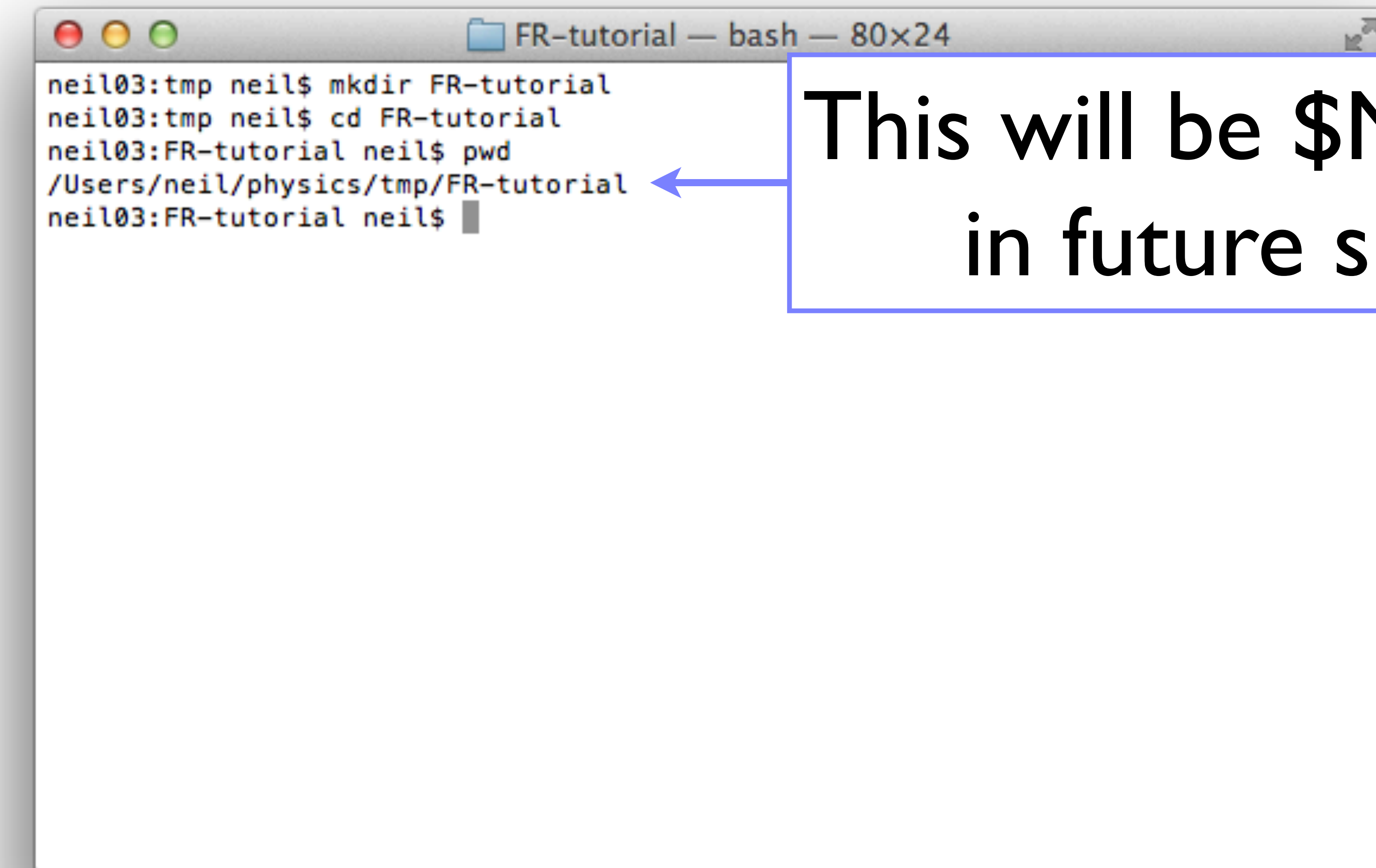
$$pp \to jje^+e^- + \text{missing}$$



The Implementation

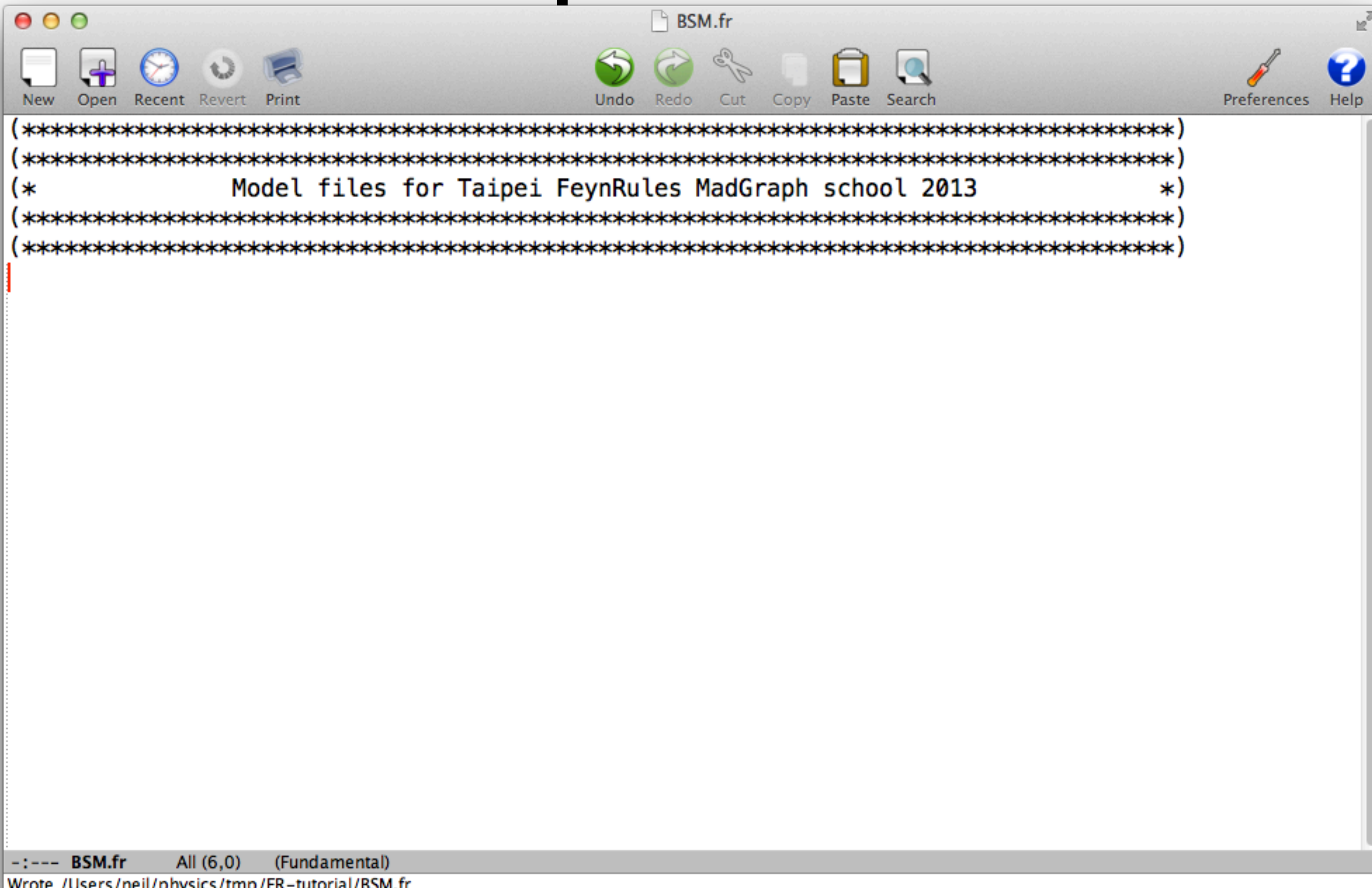


The Implementation

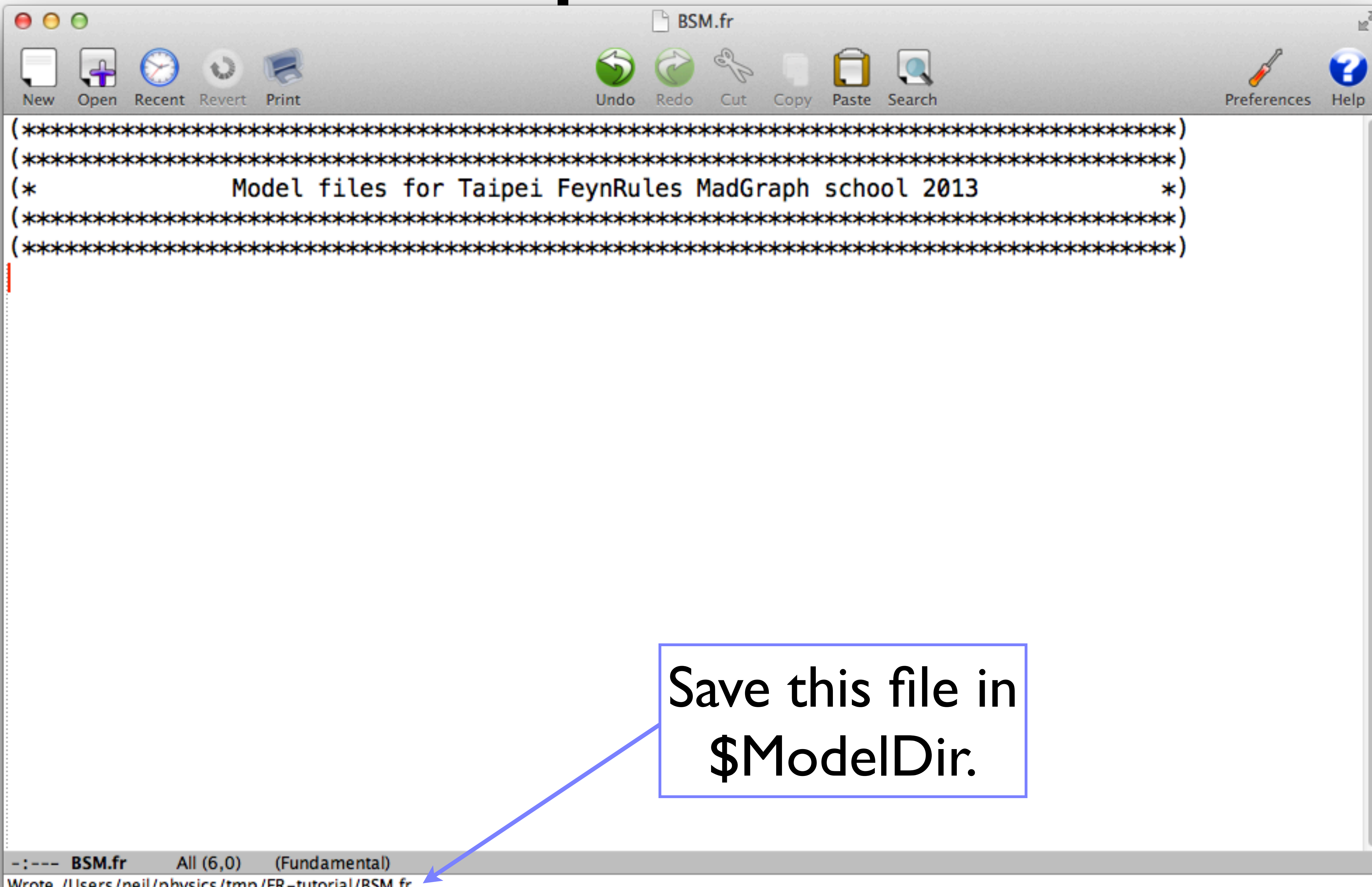


This will be $ModelDir in future slides.

The Implementation



The Implementation



The Implementation

BSM.fr

```
(****************************************************************************)
(****************************************************************************)
(*              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. *)
```

Model Name

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

The Implementation

BSM.fr

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(*****************************************************************************)
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Author List

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

The Implementation

BSM.fr

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```
(******************************************************************************)
(******************************************************************************)
(*             Model files for Taipei FeynRules MadGraph school 2013            *)
(******************************************************************************)
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Version Number

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

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Date

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

The Implementation

BSM.fr

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Institutions

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

The Implementation

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

The Implementation

BSM.fr

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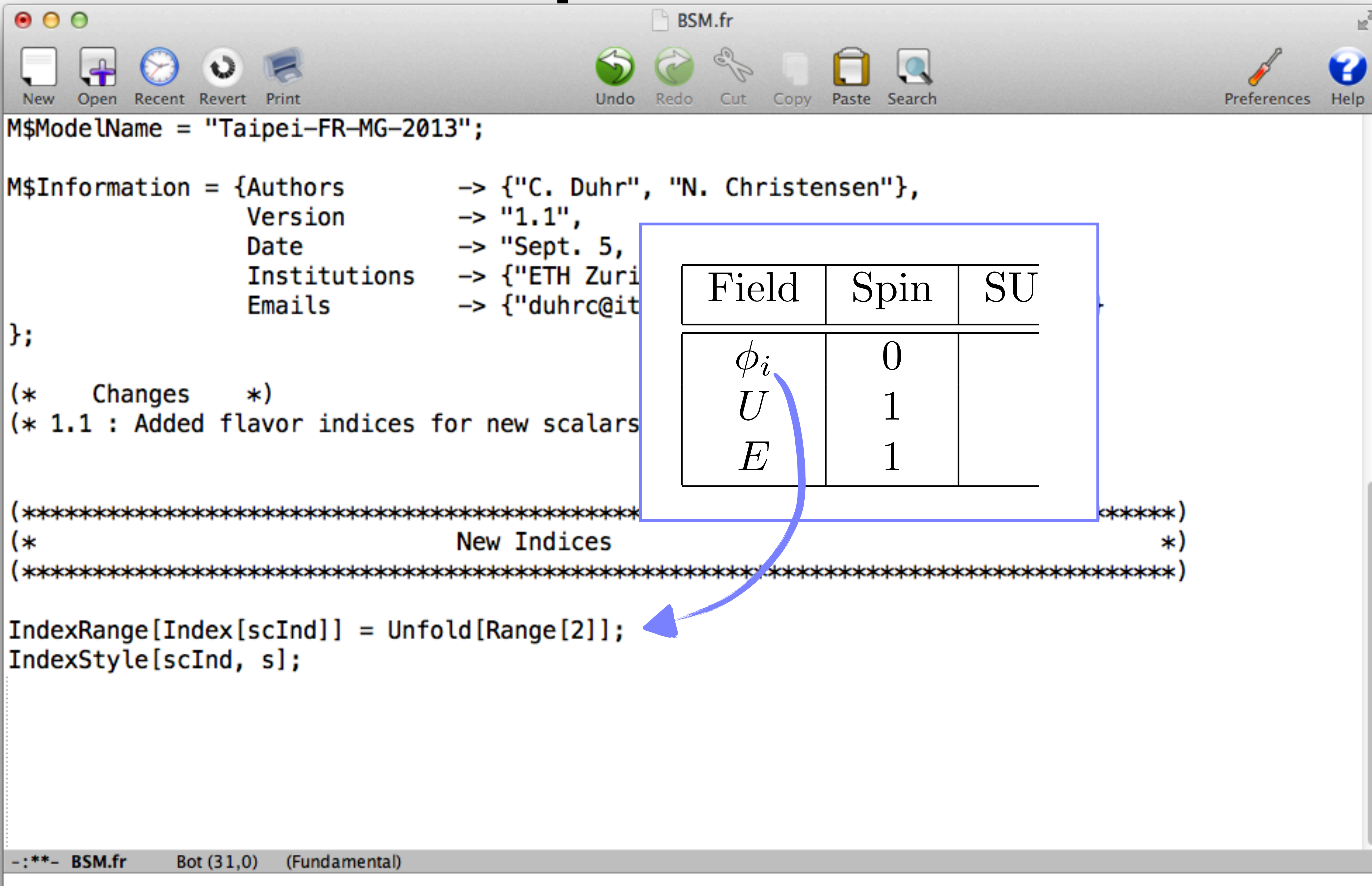
```

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

Changes

The Implementation



The Implementation

BSM.fr

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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


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

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.

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

The Implementation

BSM.fr

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

M$Information = {Authors        -> {"C. Duhr", "N. Christensen"},
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(*    Changes    *)
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(*****************************************                                  ******)
(*                         New Indices                                         *)
(*******************************************************************************)

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IndexStyle[scInd, s];
```

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

Field	Spin	SU
ϕ_i	0	
U	1	
E	1	

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

The Implementation

BSM.fr

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```
(*********************************************************************************)
(*
(*****************************
M$Parameters = {
          lambda == {
                Paramete
                ComplexP
                Indices
                Value
                Interact
          },
          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]}
          }
};
```

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin\alpha$	sina	$\cos\alpha$	cosa
Φ_i	phiMi	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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]

-:--- BSM.fr Bot (56,0) (Fundamental)

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The Implementation

BSM.fr

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```
(******************************************************************************)
(*                           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)

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Independent Parameters

The Implementation

BSM.fr

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```
(******************************************************************************)
(*                              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]}
            }
};
```

Real

-:--- BSM.fr Bot (56,0) (Fundamental)

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The Implementation

BSM.fr

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

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

```
(******************************************************************************)
(*                              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]}
             }
};
```

Numerical Value

The Implementation

BSM.fr

```
(*******************************************************************************)
(*                               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)

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Coupling Order

The Implementation

BSM.fr

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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)

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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

BSM.fr

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

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}
                 },
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                 ClassName       -> phiT,
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```

-:--- BSM.fr 66% (82,0) (Fundamental)

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The Implementation

Field	Spin	$SU(3)_{QCD}$	$SU(2)_W$	$U(1)_Y$	Z_2
ϕ_i	0	1	1	0	-1
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```
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               Width          -> {Wuv, 1}
               },
          F[21] == {
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               SelfConjugate  -> False,
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               Unphysical     -> True,
```

-:--- BSM.fr 66% (82,0) (Fundamental)

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The Implementation

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin\alpha$	sina	$\cos\alpha$	cosa
Φ_i	phiMi	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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]

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

M$ClassesDescription = {
          F[20] == {
               ClassName       -> uv,
               SelfConjugate   -> False,
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```

-:--- BSM.fr 66% (82,0) (Fundamental)

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The Implementation

BSM.fr

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Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin\alpha$	sina	$\cos\alpha$	cosa
Φ_i	phiMi	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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]

```
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                 Unphysical      -> True,
```

-:--- BSM.fr 66% (82,0) (Fundamental)

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The Implementation

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin\alpha$	sina	$\cos\alpha$	cosa
Φ_i	phiMi	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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]

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

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                  },
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                  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)

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The Implementation

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

```
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                  Mass             -> {Mev, 300},
                  Width            -> {Wev, 1}
                  },
            S[20] == {
                  ClassName        -> phiT,
                  Unphysical       -> True,
-:---  BSM.fr      66% (82,0)   (Fundamental)
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```

The Implementation

BSM.fr

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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

```
          ClassName
          SelfConjugat
          Indices
          QuantumNumbe
          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	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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]

BSM.fr

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```
          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,
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          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	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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]

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```
          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	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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]

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```
                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

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BSM.fr

Symbol	FR	Symbol	FR	Symbol	FR
ϕ_i	phiT[i]	$\sin\alpha$	sina	$\cos\alpha$	cosa
Φ_i	phiMi	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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] == {
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          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	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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] == {
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          FlavorIndex     -> scInd
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          ClassMembers    -> {phiM1,phiM2},
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          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	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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
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           Indices         -> {Index[scInd]},
           FlavorIndex     -> scInd,
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           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	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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,
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           FlavorIndex      -> scInd
           },
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```

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

The Implementation

Symbol	FR	Symbol	FR	Symbol	FR
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Φ_i	phiMi	$M_{\Phi i}$	MphiMi	$\Gamma_{\Phi i}$	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]

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

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

The Implementation

BSM.fr

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

```
};


(*****************************************************************************)
(*                              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];
```

-:**- BSM.fr   Bot (111,0)   (Fundamental)

The Implementation

BSM.fr

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

```
};

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

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

-:**- BSM.fr Bot (111,0) (Fundamental)

The Implementation

BSM.fr

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

```
};

(*****************************************************************************)
(*                          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];
```

-:**- BSM.fr Bot (111,0) (Fundamental)

The Implementation

BSM.fr

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

```
};

(*****************************************************************************)
(*                              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;

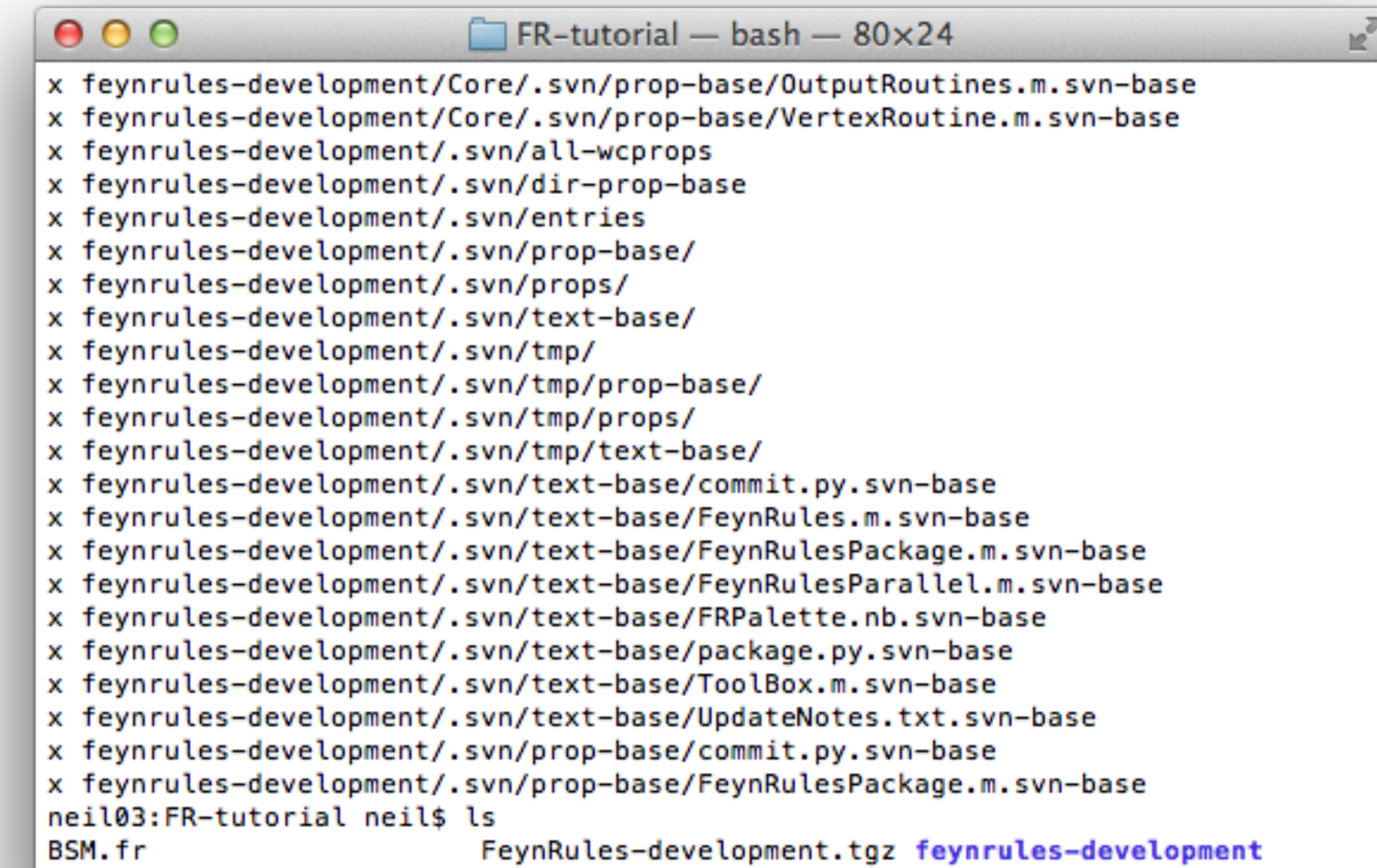
Lyuk = lambda[ii] phiT[ii] uvbar.ProjP.u + lambdap[ii] phiT[ii] evbar.ProjP.e;

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

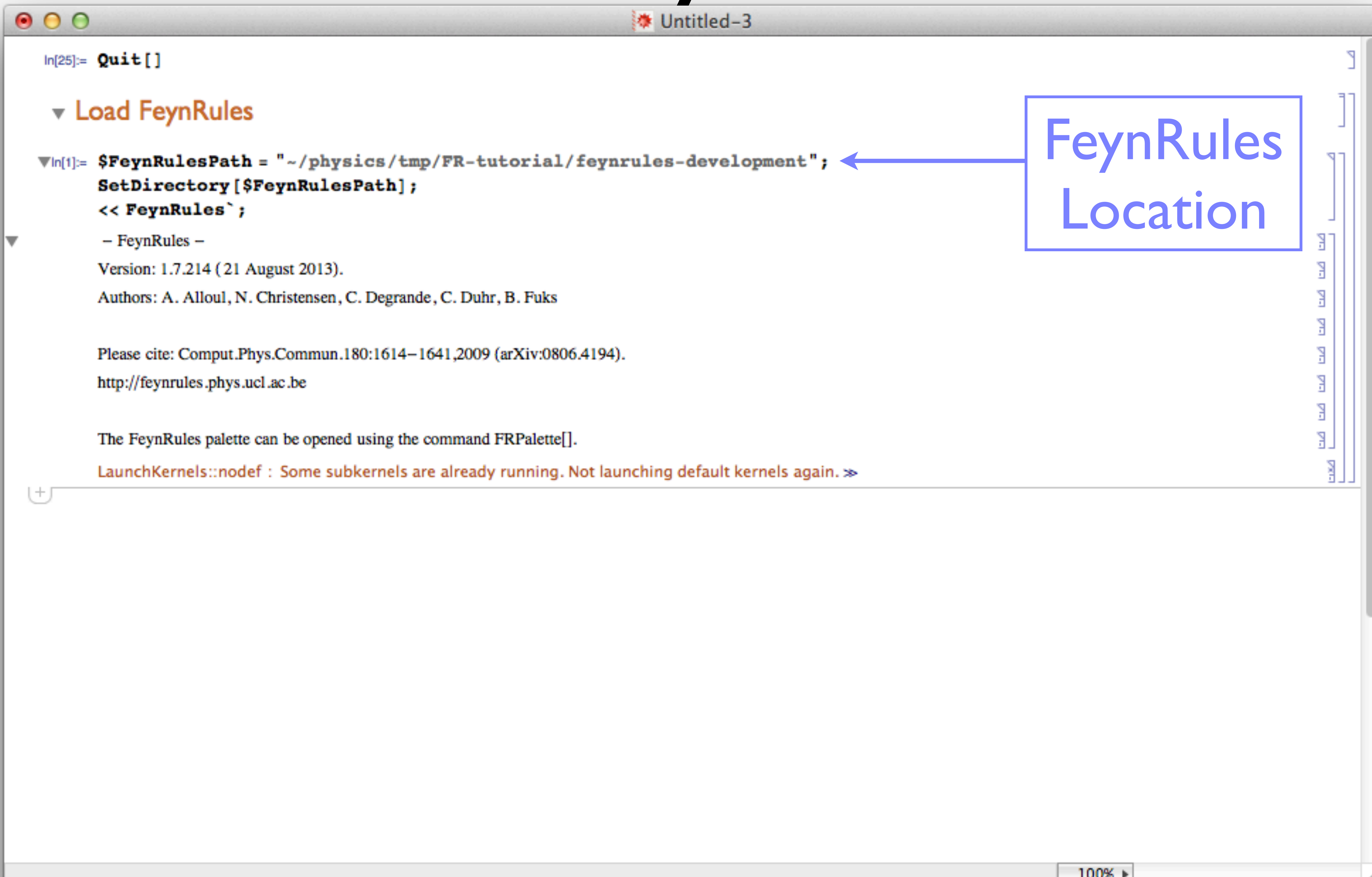
-:**- BSM.fr   Bot (111,0)   (Fundamental)

Run FeynRules

Run FeynRules



Run FeynRules



Run FeynRules

Untitled-3

```
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

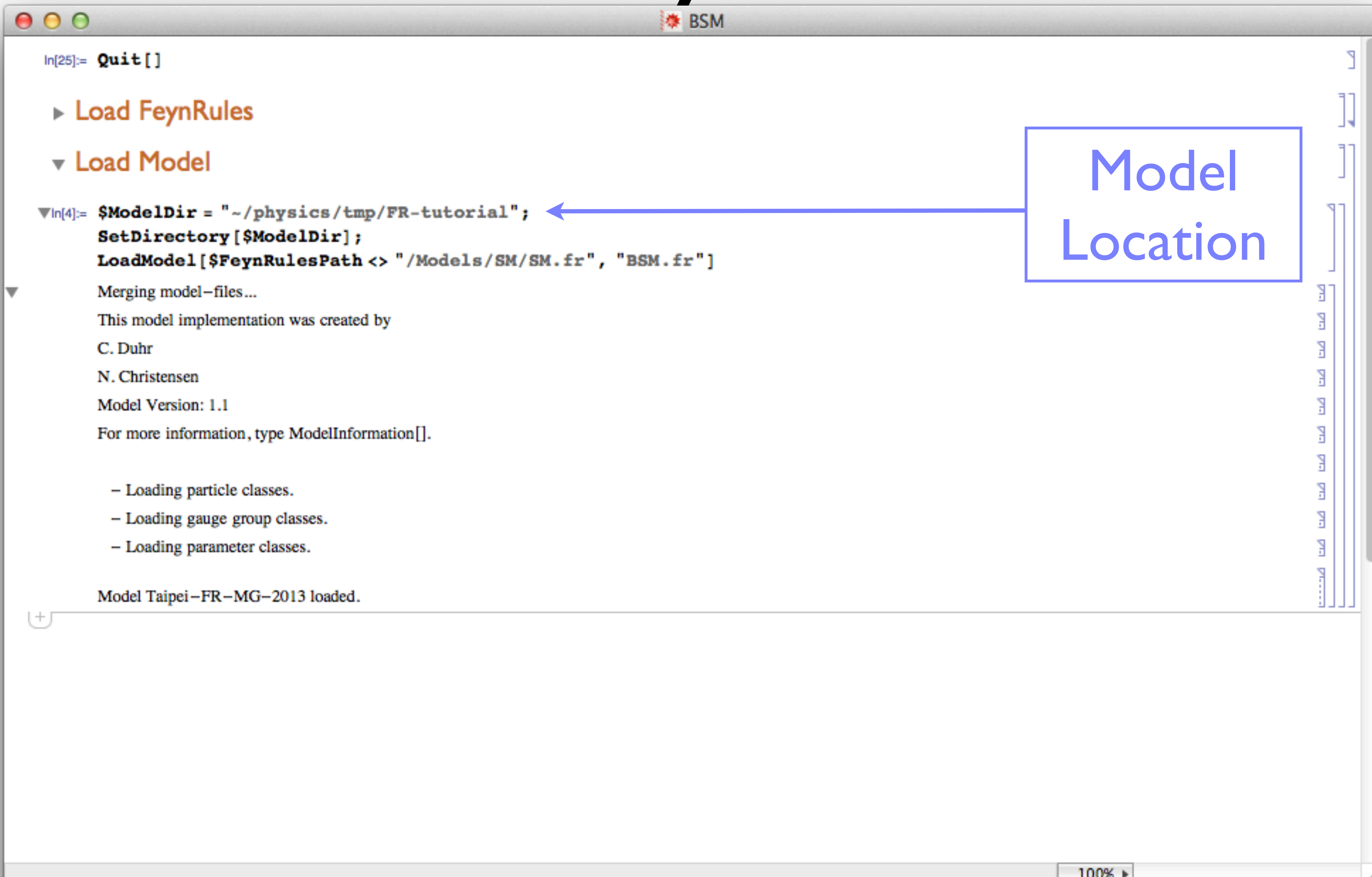
The FeynRules palette can be opened using the command FRPalette[].

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

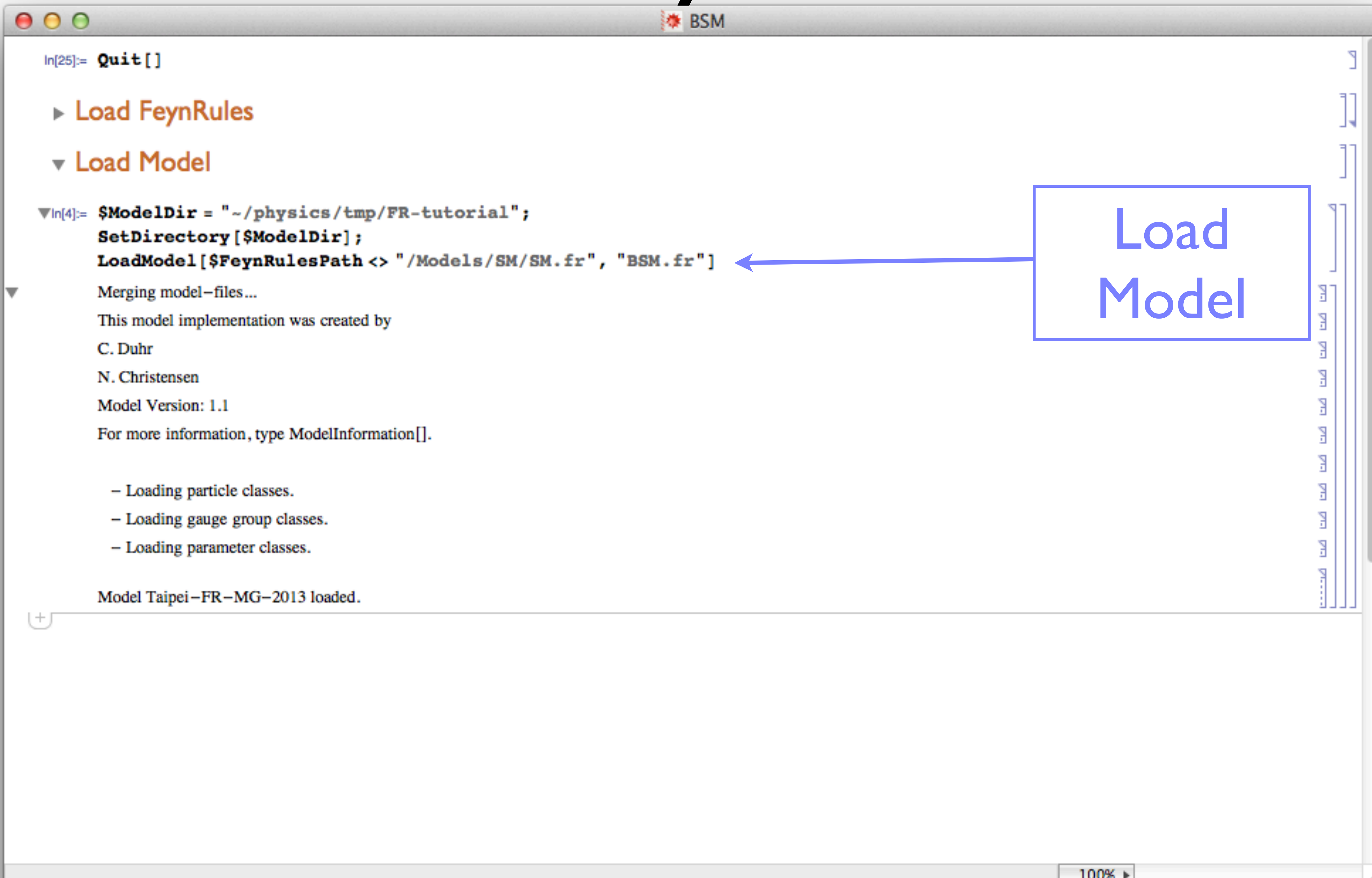
Load FeynRules

100%

Run FeynRules



Run FeynRules



Run FeynRules

BSM

```
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.

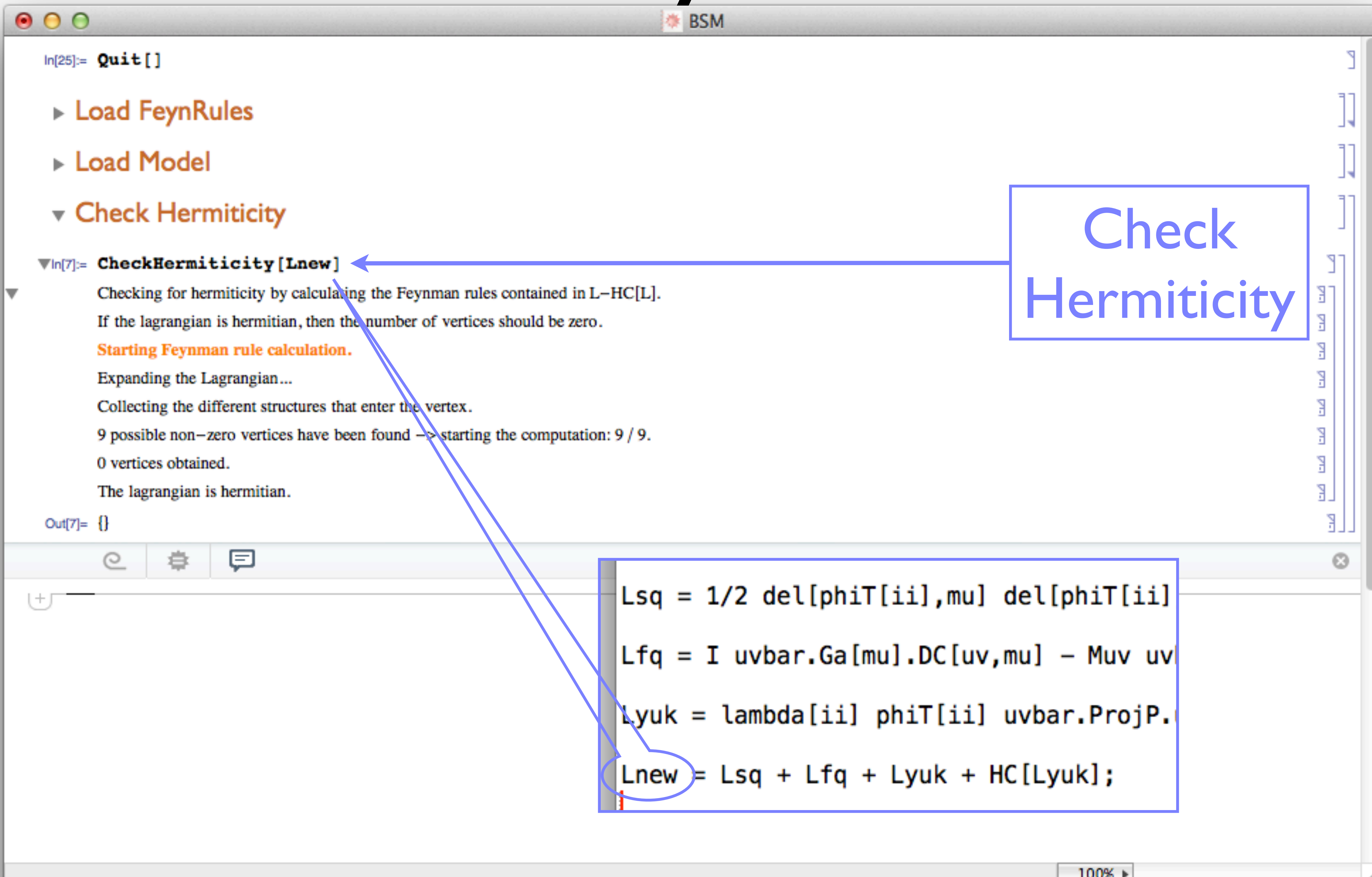
– Loading parameter classes.

Model Taipei–FR–MG–2013 loaded.

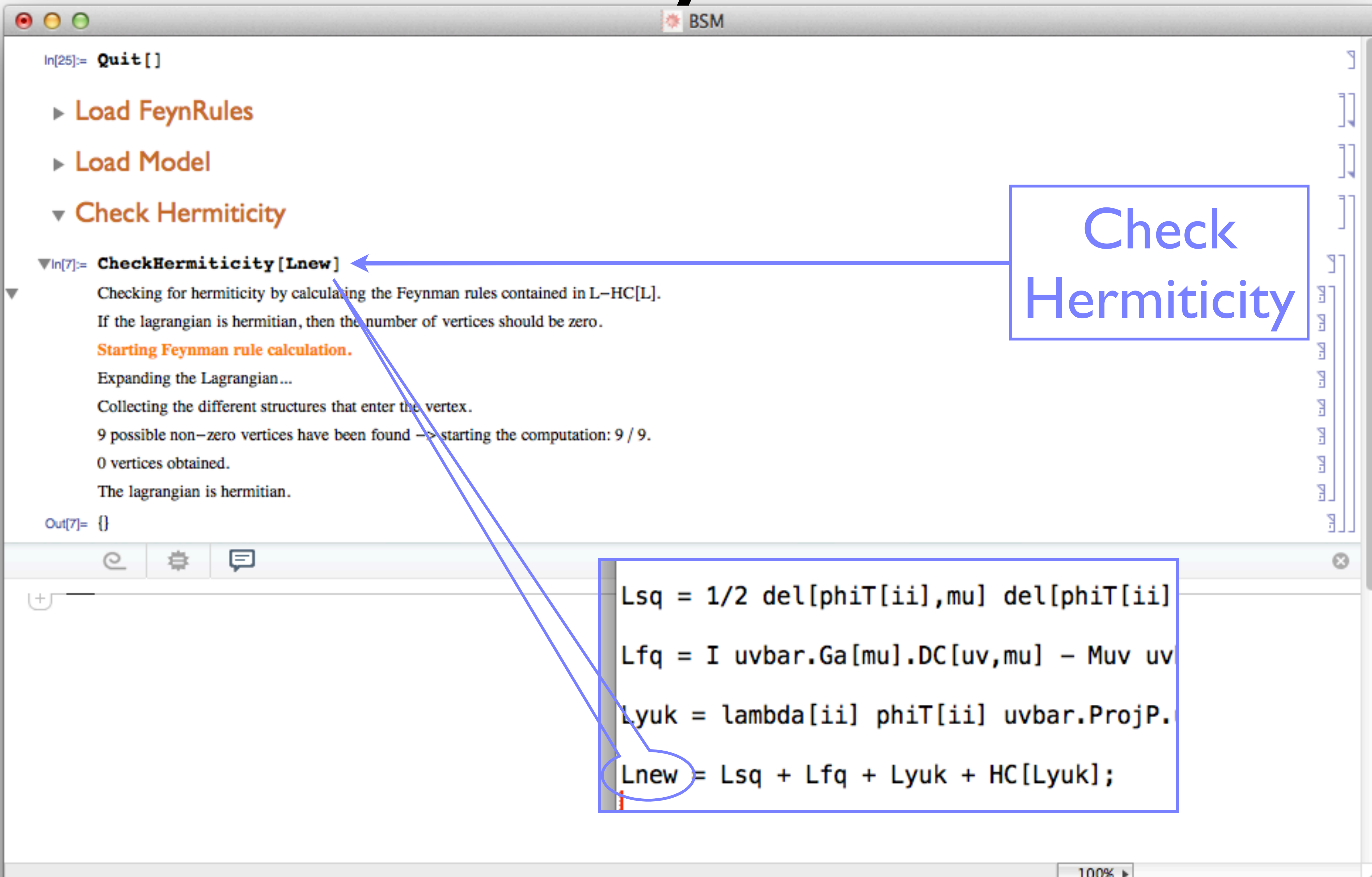
If you have problems at this stage, comment out lines of BSM.fr until you find the problem and fix it.

100%

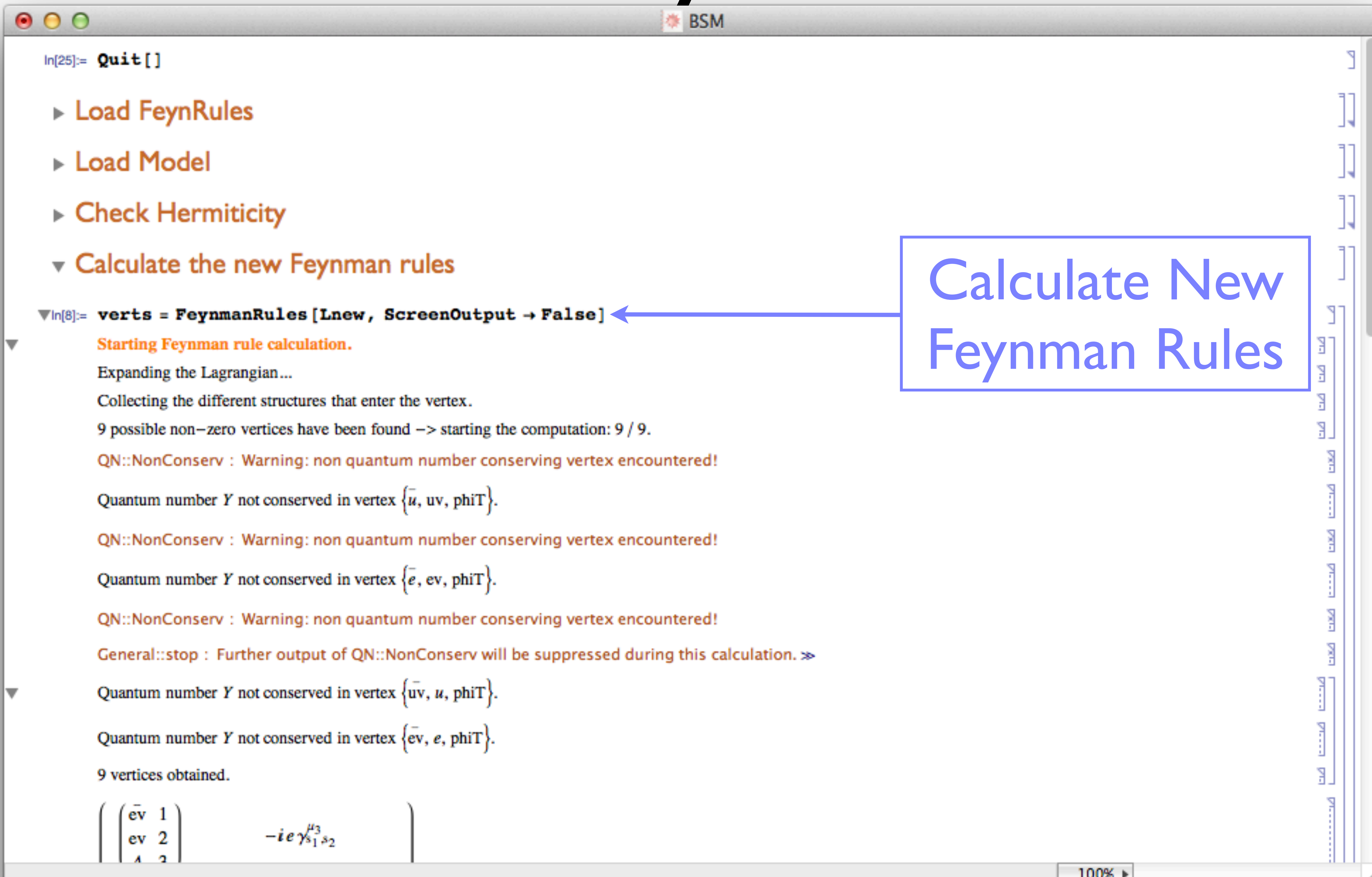
Run FeynRules



Run FeynRules



Run FeynRules



BSM

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 $\{\bar{u}, \text{uv}, \text{phiT}\}$.

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

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

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 $\{\overline{\text{uv}}, u, \text{phiT}\}$.

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

9 vertices obtained.

$\bar{\text{ev}}$ 1   ev 2 $-i e \gamma^{\mu_3}_{s_1 s_2}$

100%

Calculate New Feynman Rules

Run FeynRules

BSM

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 $\{\bar{u}, \text{uv}, \text{phiT}\}$.

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

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

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 $\{\bar{\text{uv}}, u, \text{phiT}\}$.

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

9 vertices obtained.

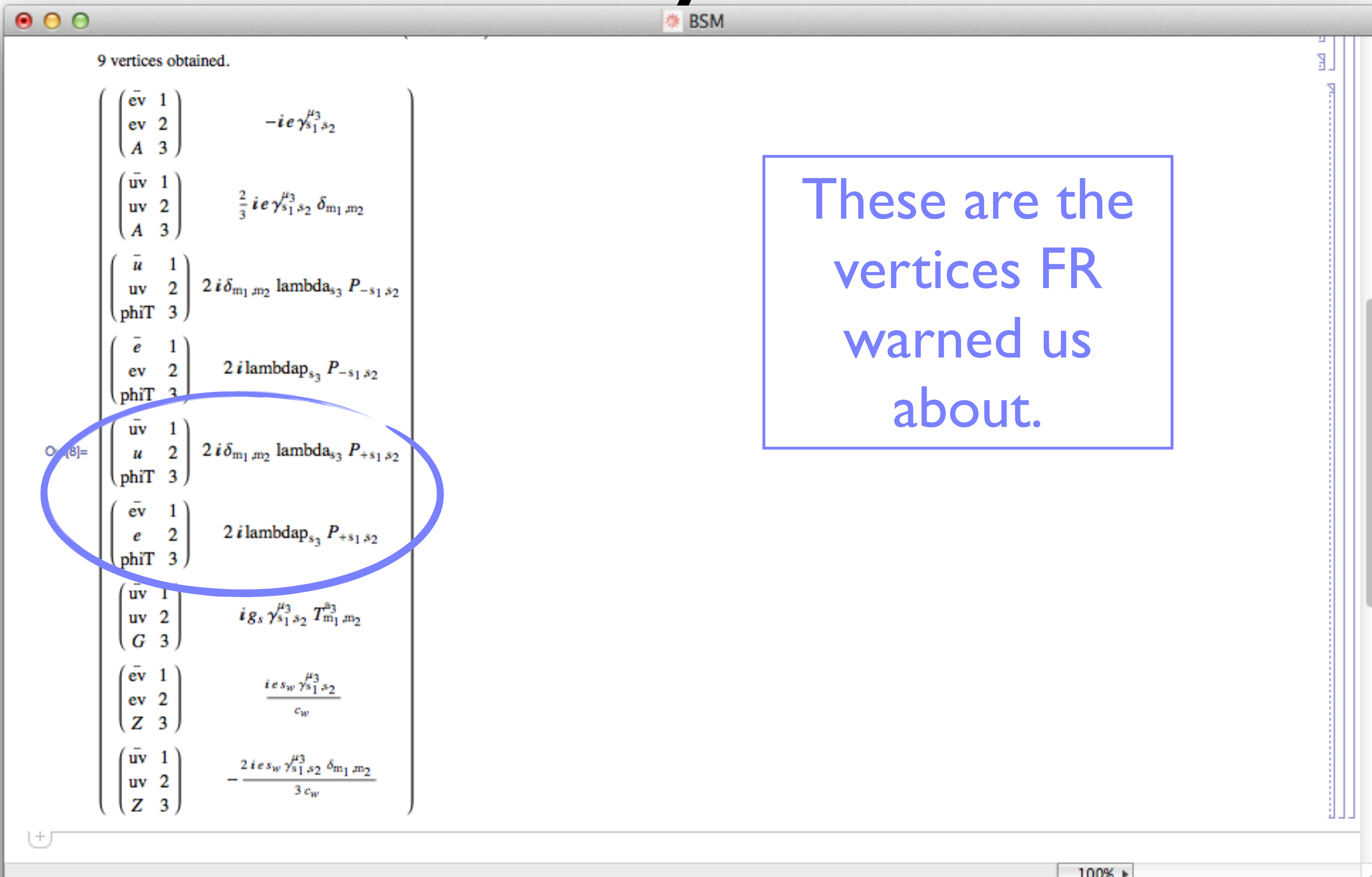
$\bar{\text{ev}}$ 1

ev 2 $\quad -i e \gamma^{\mu_3}_{s_1 s_2}$

100%

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

Run FeynRules



These are the vertices FR warned us about.

Run FeynRules

9 vertices obtained.

$$
\begin{pmatrix}
\begin{pmatrix} \bar{ev} & 1 \\ ev & 2 \\ A & 3 \end{pmatrix} & -i\,e\,\gamma^{\mu_3}_{s_1,s_2} \\
\begin{pmatrix} \bar{uv} & 1 \\ uv & 2 \\ A & 3 \end{pmatrix} & \frac{2}{3}\,i\,e\,\gamma^{\mu_3}_{s_1,s_2}\,\delta_{m_1,m_2} \\
\begin{pmatrix} \bar{u} & 1 \\ uv & 2 \\ phiT & 3 \end{pmatrix} & 2\,i\,\delta_{m_1,m_2}\,\text{lambda}_{s_3}\,P_{-s_1,s_2} \\
\begin{pmatrix} \bar{e} & 1 \\ ev & 2 \\ phiT & 3 \end{pmatrix} & 2\,i\,\text{lambdap}_{s_3}\,P_{-s_1,s_2} \\
\begin{pmatrix} \bar{uv} & 1 \\ u & 2 \\ phiT & 3 \end{pmatrix} & 2\,i\,\delta_{m_1,m_2}\,\text{lambda}_{s_3}\,P_{+s_1,s_2} \\
\begin{pmatrix} \bar{ev} & 1 \\ e & 2 \\ phiT & 3 \end{pmatrix} & 2\,i\,\text{lambdap}_{s_3}\,P_{+s_1,s_2} \\
\begin{pmatrix} \bar{uv} & 1 \\ uv & 2 \\ G & 3 \end{pmatrix} & i\,g_s\,\gamma^{\mu_3}_{s_1,s_2}\,T^{a_3}_{m_1,m_2} \\
\begin{pmatrix} \bar{ev} & 1 \\ ev & 2 \\ Z & 3 \end{pmatrix} & \frac{i\,e\,s_w\,\gamma^{\mu_3}_{s_1,s_2}}{c_w} \\
\begin{pmatrix} \bar{uv} & 1 \\ uv & 2 \\ Z & 3 \end{pmatrix} & -\frac{2\,i\,e\,s_w\,\gamma^{\mu_3}_{s_1,s_2}\,\delta_{m_1,m_2}}{3\,c_w}
\end{pmatrix}
$$

Note that there is a projection operator: P_R.

Run FeynRules

BSM

9 vertices obtained.

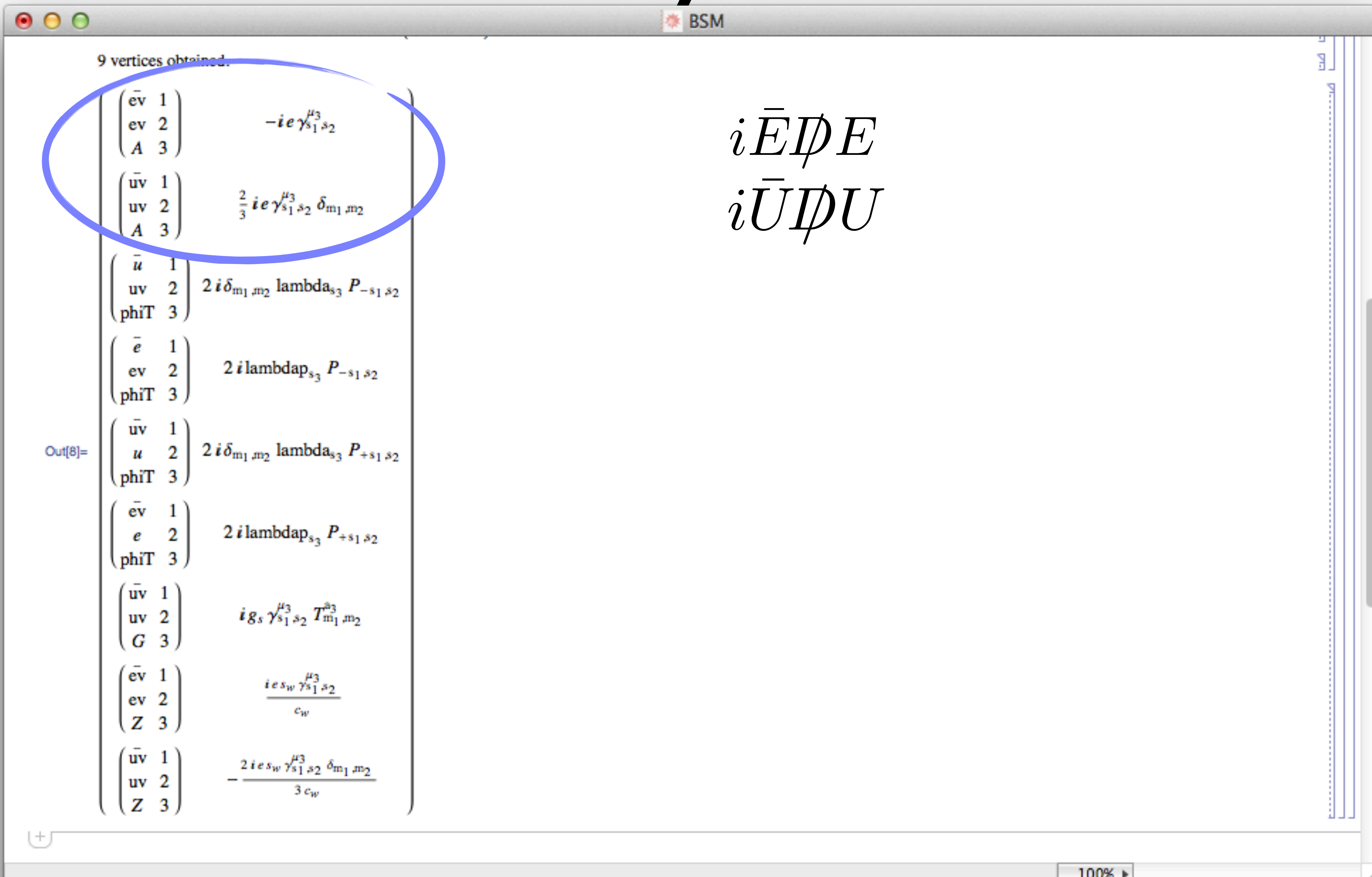
Out[8]=

$\bar{\text{ev}}$ 1, ev 2, A 3	$-i e \gamma^{\mu_3}_{s_1 s_2}$
$\bar{\text{uv}}$ 1, uv 2, A 3	$\frac{2}{3} i e \gamma^{\mu_3}_{s_1 s_2} \delta_{m_1, m_2}$
$\bar{u}$ 1, uv 2, phiT 3	$2 i \delta_{m_1, m_2} \text{lambda}_{s_3} P_{-s_1 s_2}$
$\bar{e}$ 1, ev 2, phiT 3	$2 i \text{lambdap}_{s_3} P_{-s_1 s_2}$
$\bar{\text{uv}}$ 1, u 2, phiT 3	$2 i \delta_{m_1, m_2} \text{lambda}_{s_3} P_{+s_1 s_2}$
$\bar{\text{ev}}$ 1, e 2, phiT 3	$2 i \text{lambdap}_{s_3} P_{+s_1 s_2}$
$\bar{\text{uv}}$ 1, uv 2, G 3	$i g_s \gamma^{\mu_3}_{s_1 s_2} T^{a_3}_{m_1, m_2}$
$\bar{\text{ev}}$ 1, ev 2, Z 3	$\frac{i e s_w \gamma^{\mu_3}_{s_1 s_2}}{c_w}$
$\bar{\text{uv}}$ 1, uv 2, Z 3	$-\frac{2 i e s_w \gamma^{\mu_3}_{s_1 s_2} \delta_{m_1, m_2}}{3 c_w}$

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

100%

Run FeynRules



Run FeynRules

BSM

9 vertices obtained.

Out[8]=

$\bar{\text{ev}}$ 1, ev 2, A 3	$-i e \gamma^{\mu_3}_{s_1 s_2}$
$\bar{\text{uv}}$ 1, uv 2, A 3	$\frac{2}{3} i e \gamma^{\mu_3}_{s_1 s_2} \delta_{m_1, m_2}$
$\bar{u}$ 1, uv 2, phiT 3	$2 i \delta_{m_1, m_2} \text{lambda}_{s_3} P_{-s_1 s_2}$
$\bar{e}$ 1, ev 2, phiT 3	$2 i \text{lambdap}_{s_3} P_{-s_1 s_2}$
$\bar{\text{uv}}$ 1, u 2, phiT 3	$2 i \delta_{m_1, m_2} \text{lambda}_{s_3} P_{+s_1 s_2}$
$\bar{\text{ev}}$ 1, e 2, phiT 3	$2 i \text{lambdap}_{s_3} P_{+s_1 s_2}$
$\bar{\text{uv}}$ 1, uv 2, G 3	$i g_s \gamma^{\mu_3}_{s_1 s_2} T^{a_3}_{m_1, m_2}$
$\bar{\text{ev}}$ 1, ev 2, Z 3	$\frac{i e s_w \gamma^{\mu_3}_{s_1 s_2}}{c_w}$
$\bar{\text{uv}}$ 1, uv 2, Z 3	$-\frac{2 i e s_w \gamma^{\mu_3}_{s_1 s_2} \delta_{m_1, m_2}}{3 c_w}$

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

100%

Run FeynRules

BSM

9 vertices obtained.

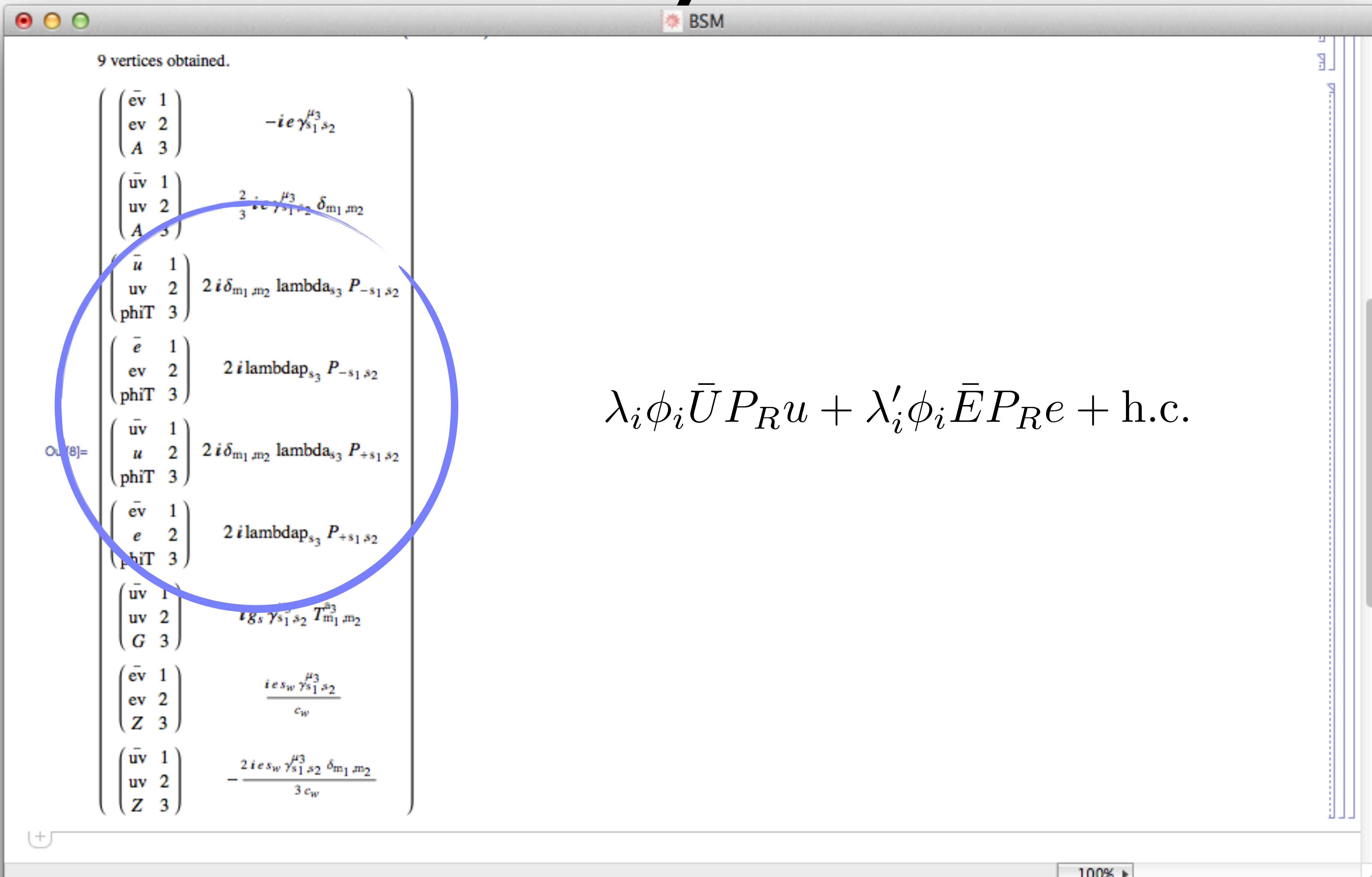
Out[8]=

$\bar{\text{ev}}$ 1, ev 2, A 3	$-i\,e\,\gamma^{\mu_3}_{s_1 s_2}$
$\bar{\text{uv}}$ 1, uv 2, A 3	$\frac{2}{3}\,i\,e\,\gamma^{\mu_3}_{s_1 s_2}\,\delta_{m_1, m_2}$
$\bar{u}$ 1, uv 2, phiT 3	$2\,i\,\delta_{m_1, m_2}\,\text{lambda}_{s_3}\,P_{-s_1 s_2}$
$\bar{e}$ 1, ev 2, phiT 3	$2\,i\,\text{lambdap}_{s_3}\,P_{-s_1 s_2}$
$\bar{\text{uv}}$ 1, u 2, phiT 3	$2\,i\,\delta_{m_1, m_2}\,\text{lambda}_{s_3}\,P_{+s_1 s_2}$
$\bar{\text{ev}}$ 1, e 2, phiT 3	$2\,i\,\text{lambdap}_{s_3}\,P_{+s_1 s_2}$
$\bar{\text{uv}}$ 1, uv 2, G 3	$i\,g_s\,\gamma^{\mu_3}_{s_1 s_2}\,T^{a_3}_{m_1, m_2}$
$\bar{\text{ev}}$ 1, ev 2, Z 3	$\frac{i\,e\,s_w\,\gamma^{\mu_3}_{s_1 s_2}}{c_w}$
$\bar{\text{uv}}$ 1, uv 2, Z 3	$-\frac{2\,i\,e\,s_w\,\gamma^{\mu_3}_{s_1 s_2}\,\delta_{m_1, m_2}}{3\,c_w}$

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

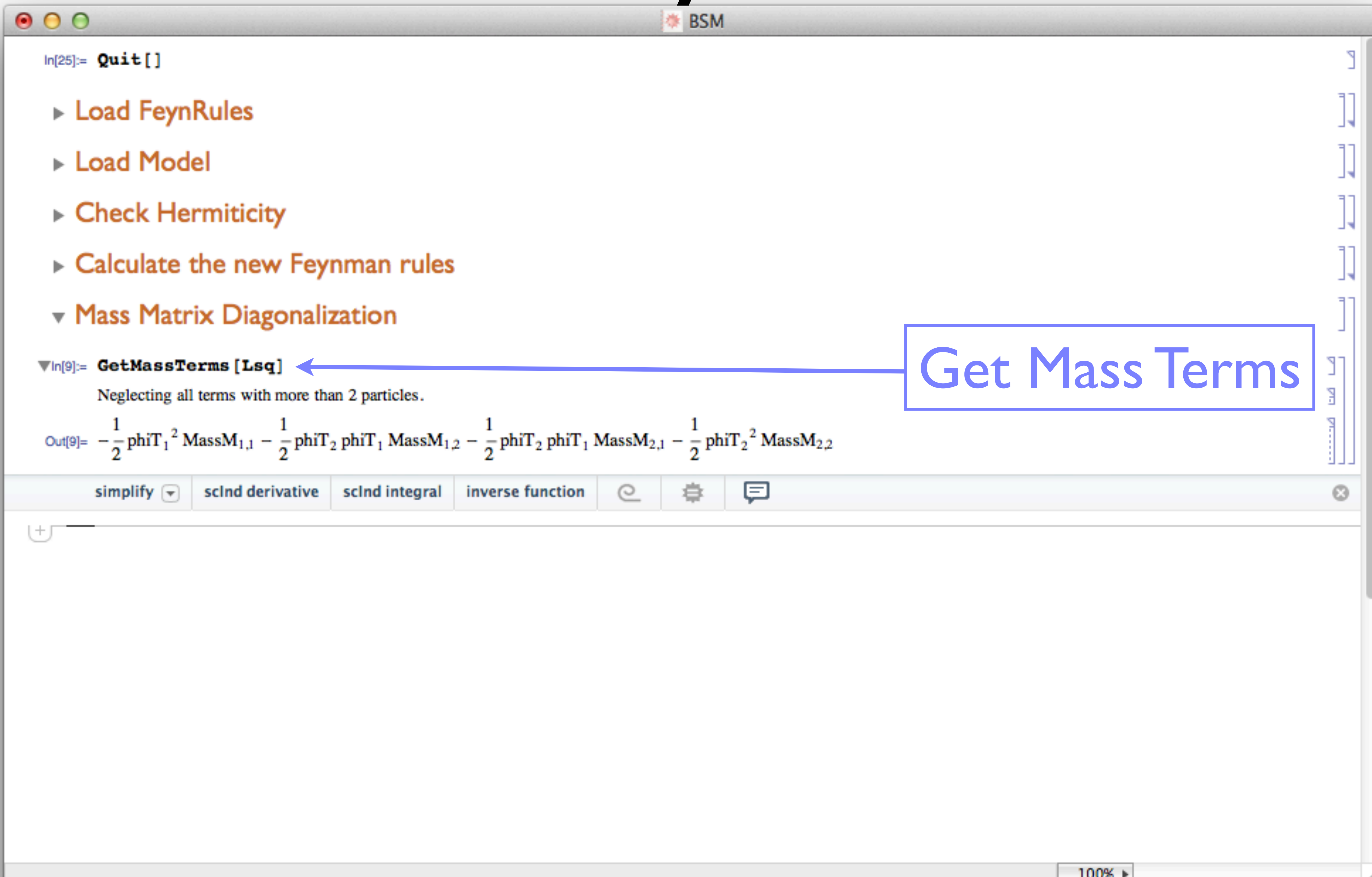
100%

Run FeynRules

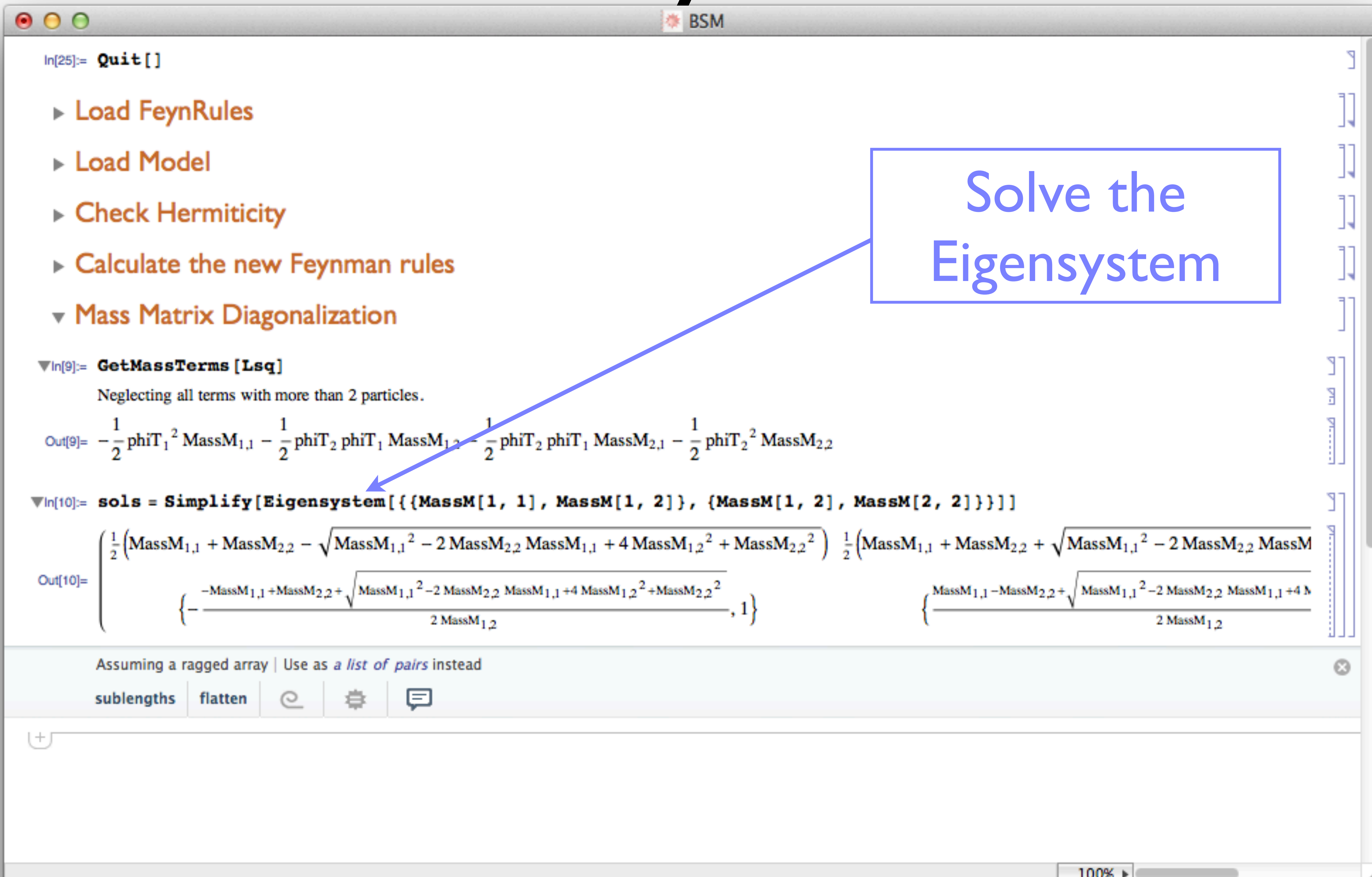


$$\lambda_i \phi_i \bar{U} P_R u + \lambda'_i \phi_i \bar{E} P_R e + \mathrm{h.c.}$$

Run FeynRules



Run FeynRules



Run FeynRules

BSM

▸ Calculate the new Feynman rules

▾ Mass Matrix Diagonalization

MphiM1

In[9]:=
```
GetMassTerms[Lsq]
```

Neglecting all terms with more than 2 particles.

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

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

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

In[11]:=
```
Simplify[Solve[{sols[[1, 1]] == MphiM1², sols[[1, 2]] == MphiM2², 1/Sqrt[sols[[2, 1, 1]]² + 1] == sina},
  {MassM[1, 1], MassM[1, 2], MassM[2, 2]}]]
```

Out[11]= $\{\{\mathrm{MassM}_{1,1}\to \mathrm{MphiM2}^2\,\mathrm{sina}^2-\mathrm{MphiM1}^2(\mathrm{sina}^2-1),\ \mathrm{MassM}_{1,2}\to -i\,\mathrm{sina}\sqrt{\mathrm{sina}^2-1}\,(\mathrm{MphiM1}^2-\mathrm{MphiM2}^2),$
$\mathrm{MassM}_{2,2}\to \mathrm{MphiM1}^2\,\mathrm{sina}^2-\mathrm{MphiM2}^2(\mathrm{sina}^2-1)\},\ \{\mathrm{MassM}_{1,1}\to \mathrm{MphiM2}^2\,\mathrm{sina}^2-\mathrm{MphiM1}^2(\mathrm{sina}^2-1),$
$\mathrm{MassM}_{1,2}\to i\,\mathrm{sina}\sqrt{\mathrm{sina}^2-1}\,(\mathrm{MphiM1}^2-\mathrm{MphiM2}^2),\ \mathrm{MassM}_{2,2}\to \mathrm{MphiM1}^2\,\mathrm{sina}^2-\mathrm{MphiM2}^2(\mathrm{sina}^2-1)\}\}$

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

BSM

▸ Calculate the new Feynman rules

▾ Mass Matrix Diagonalization

MphiM2

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]= $\Big(\frac{1}{2}\big(\text{MassM}_{1,1}+\text{MassM}_{2,2}-\sqrt{\text{MassM}_{1,1}{}^2-2\,\text{MassM}_{2,2}\,\text{MassM}_{1,1}+4\,\text{MassM}_{1,2}{}^2+\text{MassM}_{2,2}{}^2}\big)\quad \frac{1}{2}\big(\text{MassM}_{1,1}+\text{MassM}_{2,2}+\sqrt{\text{MassM}_{1,1}{}^2-2\,\text{MassM}_{2,2}\,\text{MassM}$

$\Big\{-\frac{-\text{MassM}_{1,1}+\text{MassM}_{2,2}+\sqrt{\text{MassM}_{1,1}{}^2-2\,\text{MassM}_{2,2}\,\text{MassM}_{1,1}+4\,\text{MassM}_{1,2}{}^2+\text{MassM}_{2,2}{}^2}}{2\,\text{MassM}_{1,2}},1\Big\}\quad \Big\{\frac{\text{MassM}_{1,1}-\text{MassM}_{2,2}+\sqrt{\text{MassM}_{1,1}{}^2-2\,\text{MassM}_{2,2}\,\text{MassM}_{1,1}+4\,\text{M}}}{2\,\text{MassM}_{1,2}}$

In[11]:= $\text{Simplify}\Big[\text{Solve}\Big[\Big\{\text{sols[[1, 1]]} == \text{MphiM1}^2,\ \text{sols[[1, 2]]} == \text{MphiM2}^2,\ \frac{1}{\sqrt{\text{sols[[2, 1, 1]]}^2+1}} == \text{sina}\Big\},$
$\{\text{MassM[1, 1]}, \text{MassM[1, 2]}, \text{MassM[2, 2]}\}\Big]\Big]$

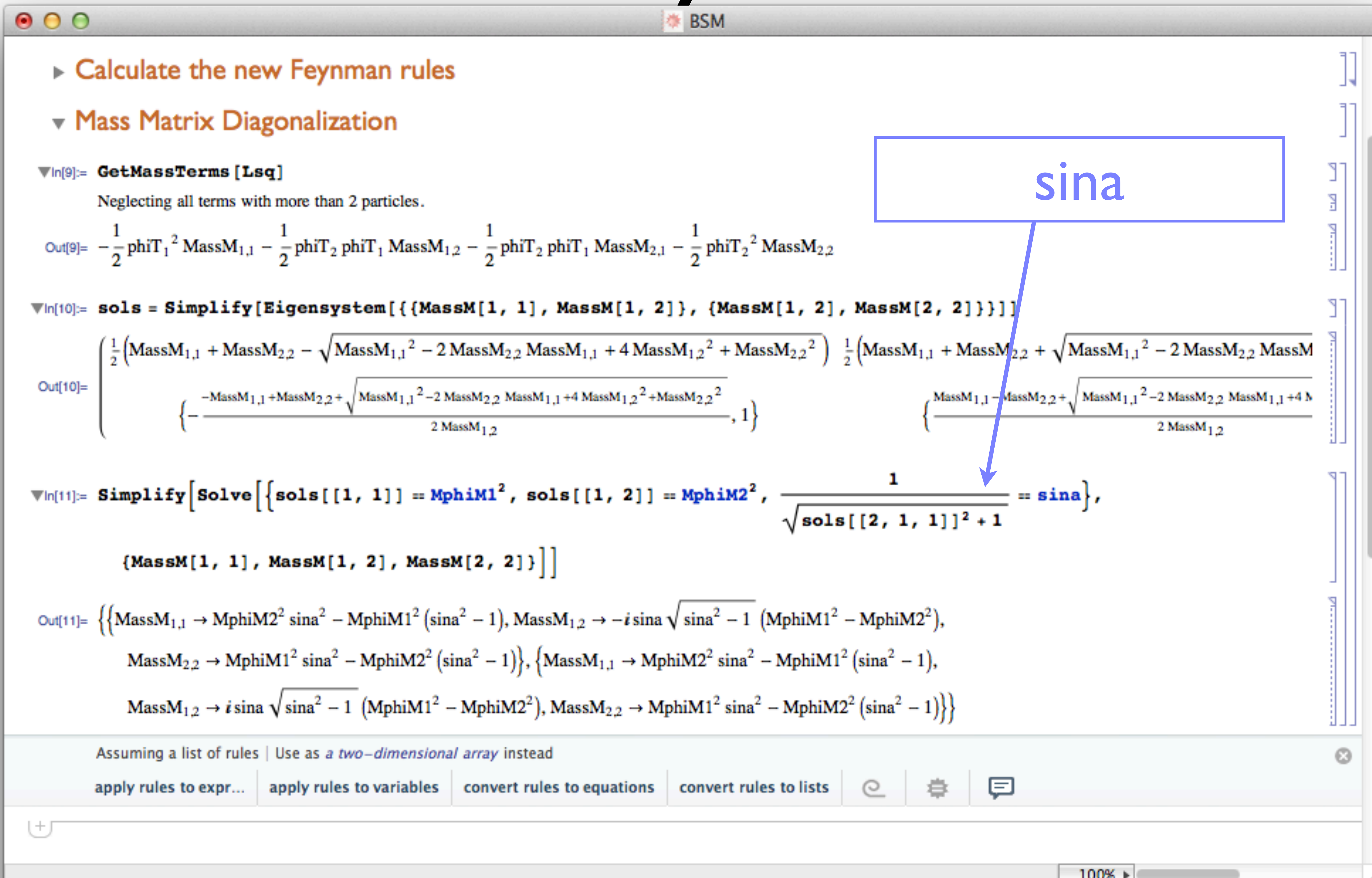
Out[11]= $\{\{\text{MassM}_{1,1}\to \text{MphiM2}^2\,\text{sina}^2-\text{MphiM1}^2\,(\text{sina}^2-1),\ \text{MassM}_{1,2}\to -i\,\text{sina}\sqrt{\text{sina}^2-1}\,(\text{MphiM1}^2-\text{MphiM2}^2),$
$\text{MassM}_{2,2}\to \text{MphiM1}^2\,\text{sina}^2-\text{MphiM2}^2\,(\text{sina}^2-1)\},\ \{\text{MassM}_{1,1}\to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

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



Run FeynRules

BSM

▸ Calculate the new Feynman rules

▾ Mass Matrix Diagonalization

Solve for MassM

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]= $\Big(\frac{1}{2}\Big(\text{MassM}_{1,1}+\text{MassM}_{2,2}-\sqrt{\text{MassM}_{1,1}{}^2-2\,\text{MassM}_{2,2}\,\text{MassM}_{1,1}+4\,\text{MassM}_{1,2}{}^2+\text{MassM}_{2,2}{}^2}\Big)\quad \frac{1}{2}\Big(\text{MassM}_{1,1}+\text{MassM}_{2,2}+\sqrt{\text{MassM}_{1,1}{}^2-2\,\text{MassM}_{2,2}\,\text{MassM}$

$\Big\{-\frac{-\text{MassM}_{1,1}+\text{MassM}_{2,2}+\sqrt{\text{MassM}_{1,1}{}^2-2\,\text{MassM}_{2,2}\,\text{MassM}_{1,1}+4\,\text{MassM}_{1,2}{}^2+\text{MassM}_{2,2}{}^2}}{2\,\text{MassM}_{1,2}},1\Big\}\quad \Big\{\frac{\text{MassM}_{1,1}-\text{MassM}_{2,2}+\sqrt{\text{MassM}_{1,1}{}^2-2\,\text{MassM}_{2,2}\,\text{MassM}_{1,1}+4\,\text{M}}}{2\,\text{MassM}_{1,2}}$

In[11]:=
$$\text{Simplify}\Big[\text{Solve}\Big[\Big\{\text{sols[[1, 1]]} == \text{MphiM1}^2,\ \text{sols[[1, 2]]} == \text{MphiM2}^2,\ \frac{1}{\sqrt{\text{sols[[2, 1, 1]]}^2+1}} == \text{sina}\Big\},$$
$$\{\text{MassM[1, 1]}, \text{MassM[1, 2]}, \text{MassM[2, 2]}\}\Big]\Big]$$

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

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

BSM

▸ Calculate the new Feynman rules

▾ Mass Matrix Diagonalization

Trig Identities

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]= $\left(\begin{array}{cc} \frac{1}{2}\left(\text{MassM}_{1,1}+\text{MassM}_{2,2}-\sqrt{\text{MassM}_{1,1}{}^2-2\,\text{MassM}_{2,2}\,\text{MassM}_{1,1}+4\,\text{MassM}_{1,2}{}^2+\text{MassM}_{2,2}{}^2}\right) & \frac{1}{2}\left(\text{MassM}_{1,1}+\text{MassM}_{2,2}+\sqrt{\text{MassM}_{1,1}{}^2-2\,\text{MassM}_{2,2}\,\text{MassM}\ldots}\right. \\ \left\{-\frac{-\text{MassM}_{1,1}+\text{MassM}_{2,2}+\sqrt{\text{MassM}_{1,1}{}^2-2\,\text{MassM}_{2,2}\,\text{MassM}_{1,1}+4\,\text{MassM}_{1,2}{}^2+\text{MassM}_{2,2}{}^2}}{2\,\text{MassM}_{1,2}},1\right\} & \left\{\frac{\text{MassM}_{1,1}-\text{MassM}_{2,2}+\sqrt{\text{MassM}_{1,1}{}^2-2\,\text{MassM}_{2,2}\,\text{MassM}_{1,1}+4\,\text{M}\ldots}}{2\,\text{MassM}_{1,2}}\right. \end{array}\right.$

In[12]:=
```
sols2 =
  Simplify[
   Simplify[Solve[{sols[[1, 1]] == MphiM1^2, sols[[1, 2]] == MphiM2^2, 1/Sqrt[sols[[2, 1, 1]]^2 + 1] == sina},
     {MassM[1, 1], MassM[1, 2], MassM[2, 2]}]] /. {Sqrt[sina^2 - 1] → I cosa, sina^2 - 1 → -cosa^2}];
sols2 // TableForm
```

Out[13]//TableForm=

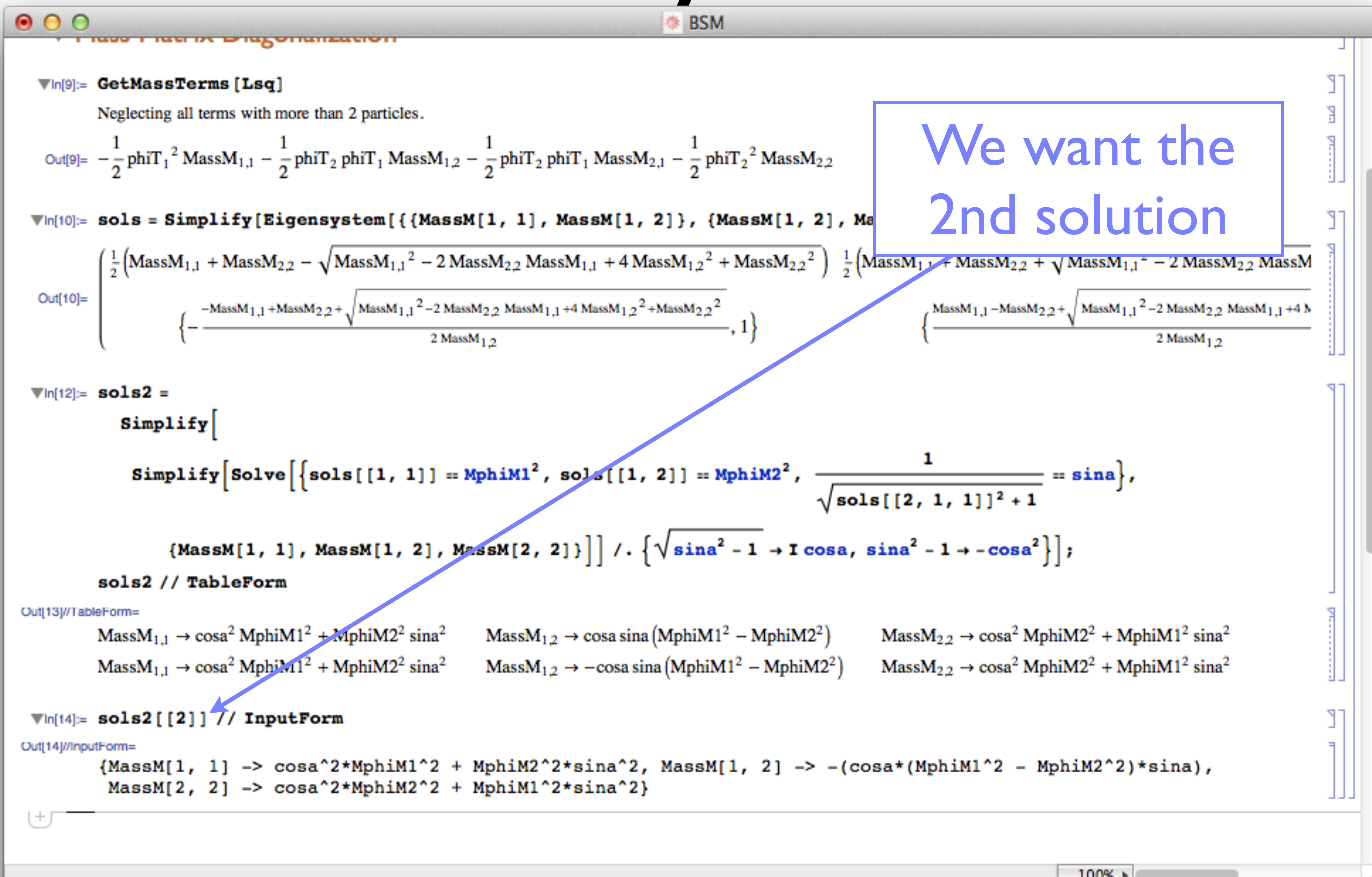
$\text{MassM}_{1,1}\to\text{cosa}^2\,\text{MphiM1}^2+\text{MphiM2}^2\,\text{sina}^2$	$\text{MassM}_{1,2}\to\text{cosa}\,\text{sina}\left(\text{MphiM1}^2-\text{MphiM2}^2\right)$	$\text{MassM}_{2,2}\to\text{cosa}^2\,\text{MphiM2}^2+\text{MphiM1}^2\,\text{sina}^2$
$\text{MassM}_{1,1}\to\text{cosa}^2\,\text{MphiM1}^2+\text{MphiM2}^2\,\text{sina}^2$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

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



Run FeynRules

BSM

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], Ma...`

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

In[12]:= `sols2 =`

`Simplify[`

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

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

`sols2 // TableForm`

Out[13]//TableForm=

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

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}
```

Copy this line.

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
                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}
        }
};
```

-:--- BSM.fr 38% (53,43) (Fundamental)

Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

Paste Definitions

The Implementation

BSM.fr

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```
          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}
          }
};
```

-:--- BSM.fr 38% (53,43) (Fundamental)

Wrote /Users/neil/physics/tmp/FR-tutorial/BSM.fr

Make Internal

The Implementation

BSM.fr

```
            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 == {
            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,
```

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

Add sina & cosa

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)

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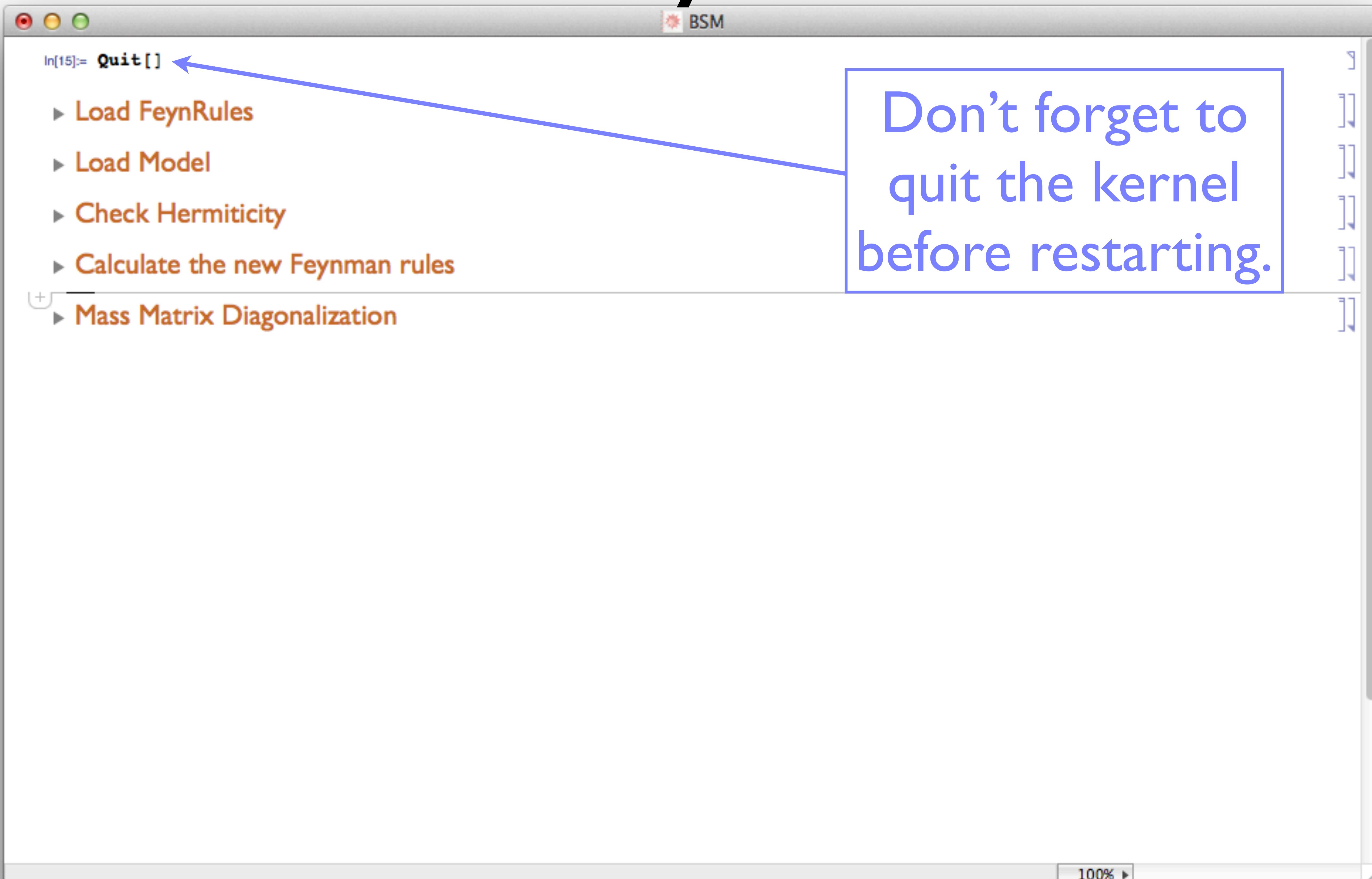
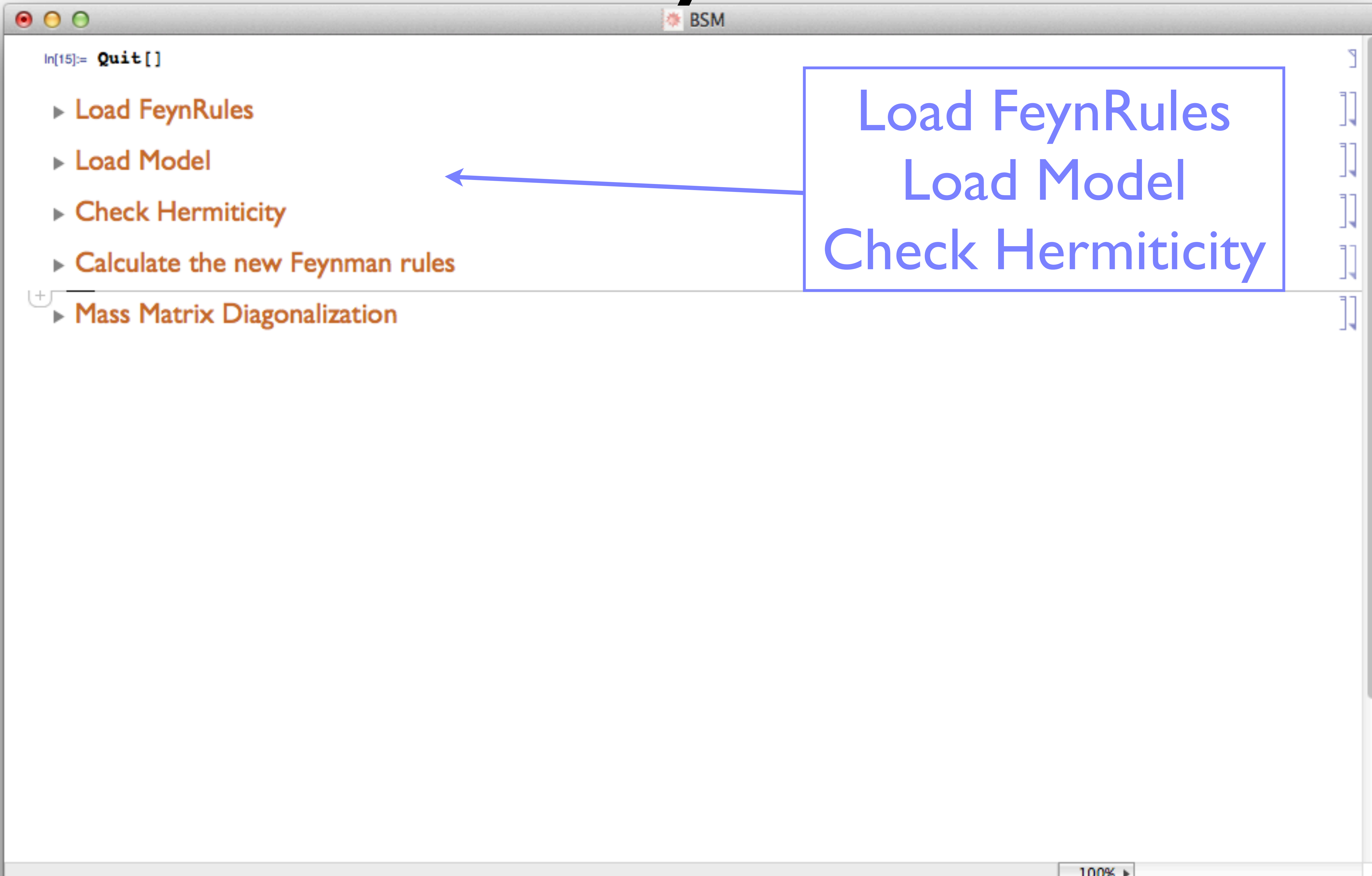
Run FeynRules



Run FeynRules



Run FeynRules

BSM

▸ 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 $\{\bar{u}, \text{uv}, \text{phiM1}\}$.

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

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

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 $\{\bar{e}, \text{ev}, \text{phiM1}\}$.

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

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

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

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

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

13 vertices obtained.

100%

Run FeynRules

BSM

Out[8]=

(uv 2, A 3)	$\frac{2}{3} i e \gamma^{\mu_3}_{s_1,s_2} \delta_{m_1,m_2}$
($\bar{u}$ 1, uv 2, phiM1 3)	$i \,\text{cosa}\, \delta_{m_1,m_2}\, \text{lambda}_1 P_{-s_1,s_2} - i \,\text{sina}\, \delta_{m_1,m_2}\, \text{lambda}_2 P_{-s_1,s_2}$
($\bar{u}$ 1, uv 2, phiM2 3)	$i \,\text{sina}\, \delta_{m_1,m_2}\, \text{lambda}_1 P_{-s_1,s_2} + i \,\text{cosa}\, \delta_{m_1,m_2}\, \text{lambda}_2 P_{-s_1,s_2}$
($\bar{e}$ 1, ev 2, phiM1 3)	$i \,\text{cosa}\, \text{lambdap}_1 P_{-s_1,s_2} - i \,\text{sina}\, \text{lambdap}_2 P_{-s_1,s_2}$
($\bar{e}$ 1, ev 2, phiM2 3)	$i \,\text{sina}\, \text{lambdap}_1 P_{-s_1,s_2} + i \,\text{cosa}\, \text{lambdap}_2 P_{-s_1,s_2}$
($\overline{\text{uv}}$ 1, u 2, phiM1 3)	$i \,\text{cosa}\, \delta_{m_1,m_2}\, \text{lambda}_1 P_{+s_1,s_2} - i \,\text{sina}\, \delta_{m_1,m_2}\, \text{lambda}_2 P_{+s_1,s_2}$
($\overline{\text{uv}}$ 1, u 2, phiM2 3)	$i \,\text{sina}\, \delta_{m_1,m_2}\, \text{lambda}_1 P_{+s_1,s_2} + i \,\text{cosa}\, \delta_{m_1,m_2}\, \text{lambda}_2 P_{+s_1,s_2}$
($\overline{\text{ev}}$ 1, e 2, phiM1 3)	$i \,\text{cosa}\, \text{lambdap}_1 P_{+s_1,s_2} - i \,\text{sina}\, \text{lambdap}_2 P_{+s_1,s_2}$
($\overline{\text{ev}}$ 1, e 2, phiM2 3)	$i \,\text{sina}\, \text{lambdap}_1 P_{+s_1,s_2} + i \,\text{cosa}\, \text{lambdap}_2 P_{+s_1,s_2}$
($\overline{\text{uv}}$ 1, uv 2, G 3)	$i g_s \gamma^{\mu_3}_{s_1,s_2} T^{a_3}_{m_1,m_2}$
($\overline{\text{ev}}$ 1, …)	$i e s_w \gamma^{\mu_3}_{s_1,s_2}$

100%

phiT expanded in terms of phiM!

Run FeynRules

BSM

- 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 then 0.1% agreement with model file values.

Out[14]//TableForm=

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

100%

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 then 0.1% agreement with model file values.

Out[14]//TableForm=

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

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

Try with a different value of sina.

Neglecting all terms with more than 2 particles.

All mass terms are diagonal.

Getting mass spectrum.

Checking for less then 0.1% agreement with model file values.

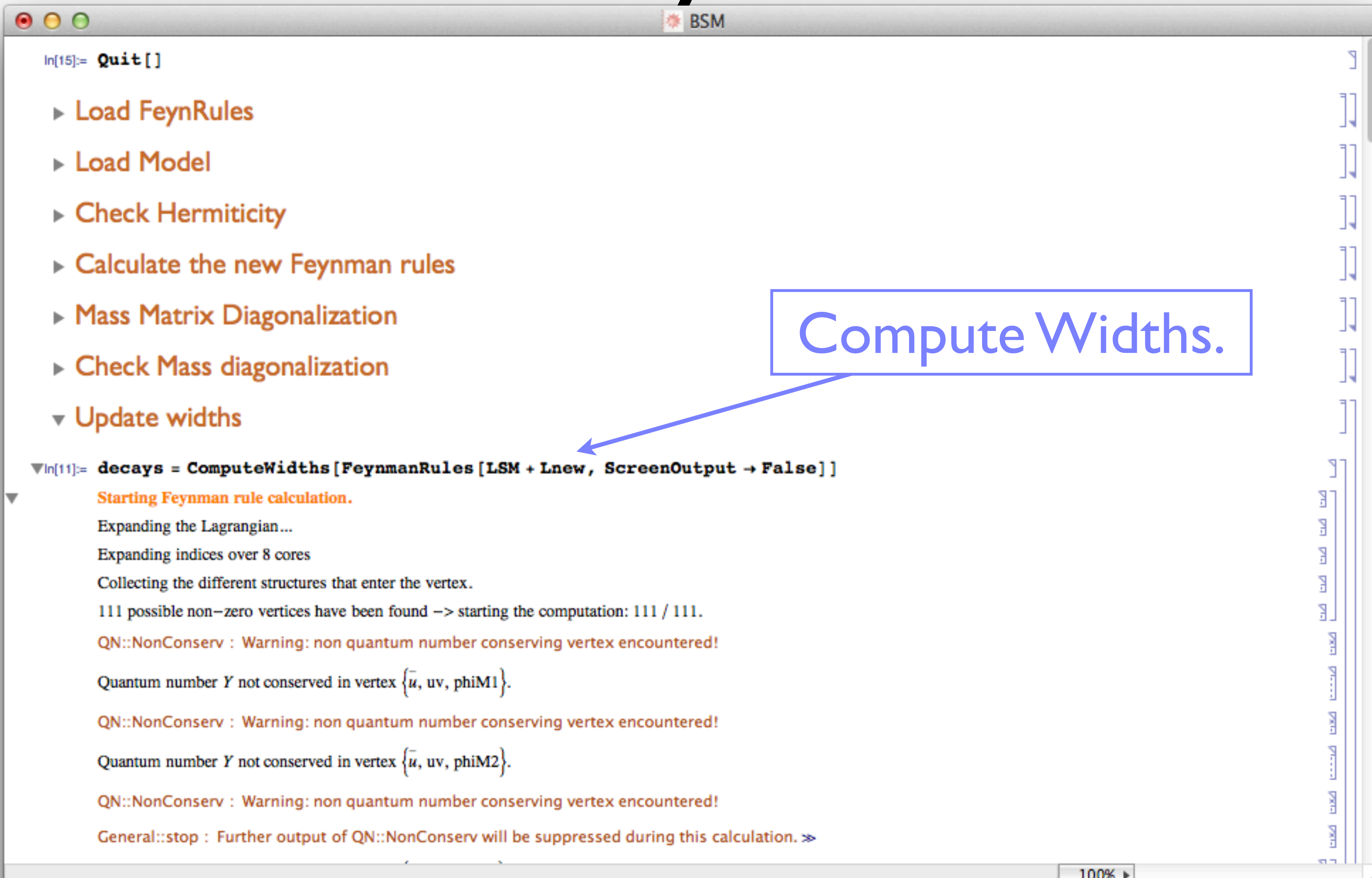
Out[10]//TableForm=

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

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

100%

Run FeynRules



Run FeynRules

Run FeynRules

BSM

$\{Z, vm, \bar{vm}\}$ — $\frac{\ldots}{96\, c_w^2\, \pi\, s_w^2\, |MZ|^3}$

$\{Z, vt, \bar{vt}\}$ — $\frac{e^2\, MZ^4\, (c_w^2 + s_w^2)^2}{96\, c_w^2\, \pi\, s_w^2\, |MZ|^3}$

$\{Z, W^\dagger, W\}$ — $\frac{c_w^2\, e^2\, \sqrt{MZ^4 - 4\, Mw^2\, MZ^2}\, (-48\, Mw^6 - 68\, MZ^2\, Mw^4 + 16\, MZ^4\, Mw^2 + MZ^6)}{192\, Mw^4\, \pi\, s_w^2\, |MZ|^3}$

In[12]:= **UpdateWidths[decays]** ← Update Widths

Wev = 0.0111601.

WH = 0.0058038.

WphiM1 = 0..

WphiM2 = 6.05574.

WT = 1.46688.

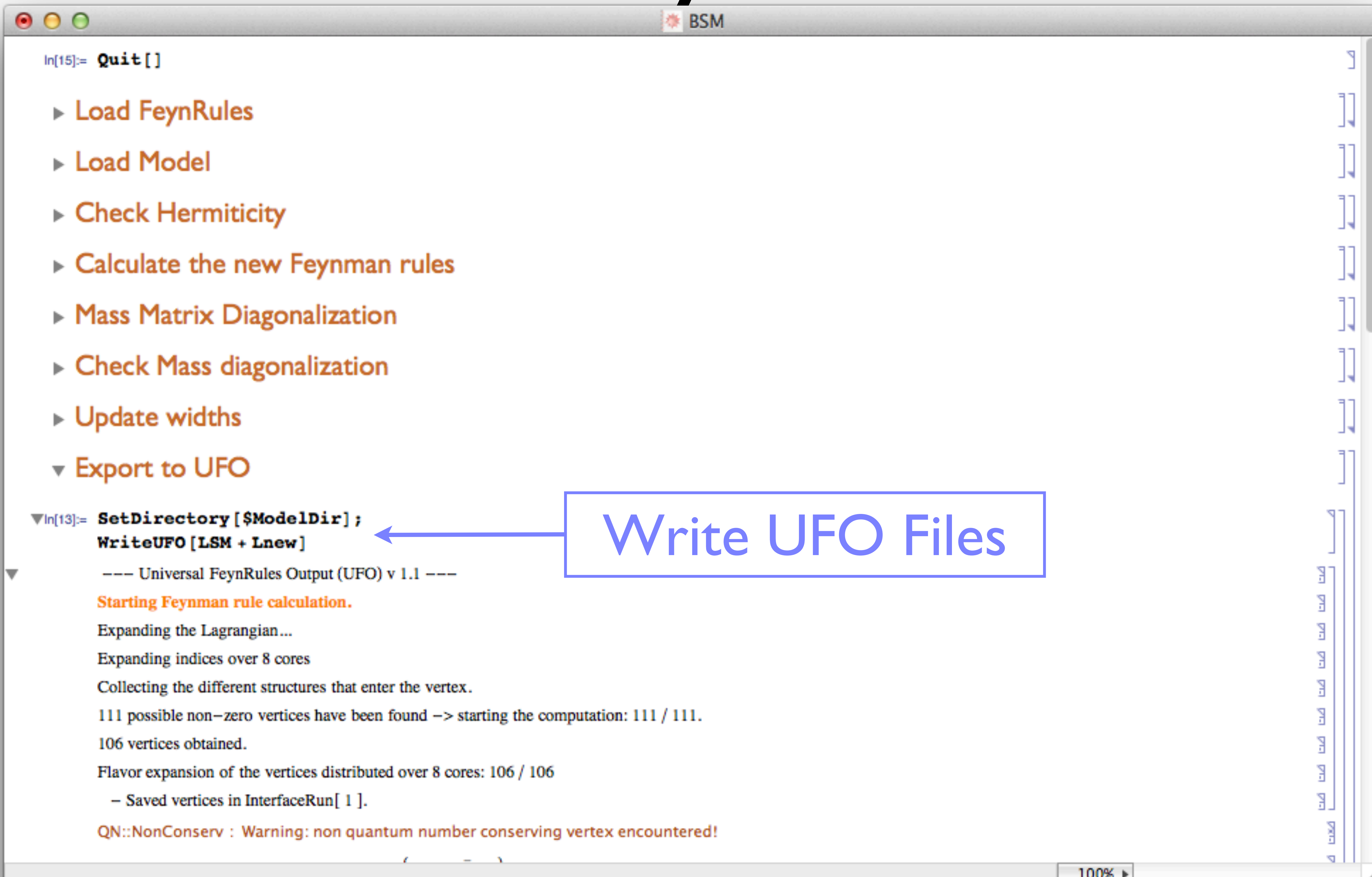
Wuv = 1.32387.

WW = 2.00252.

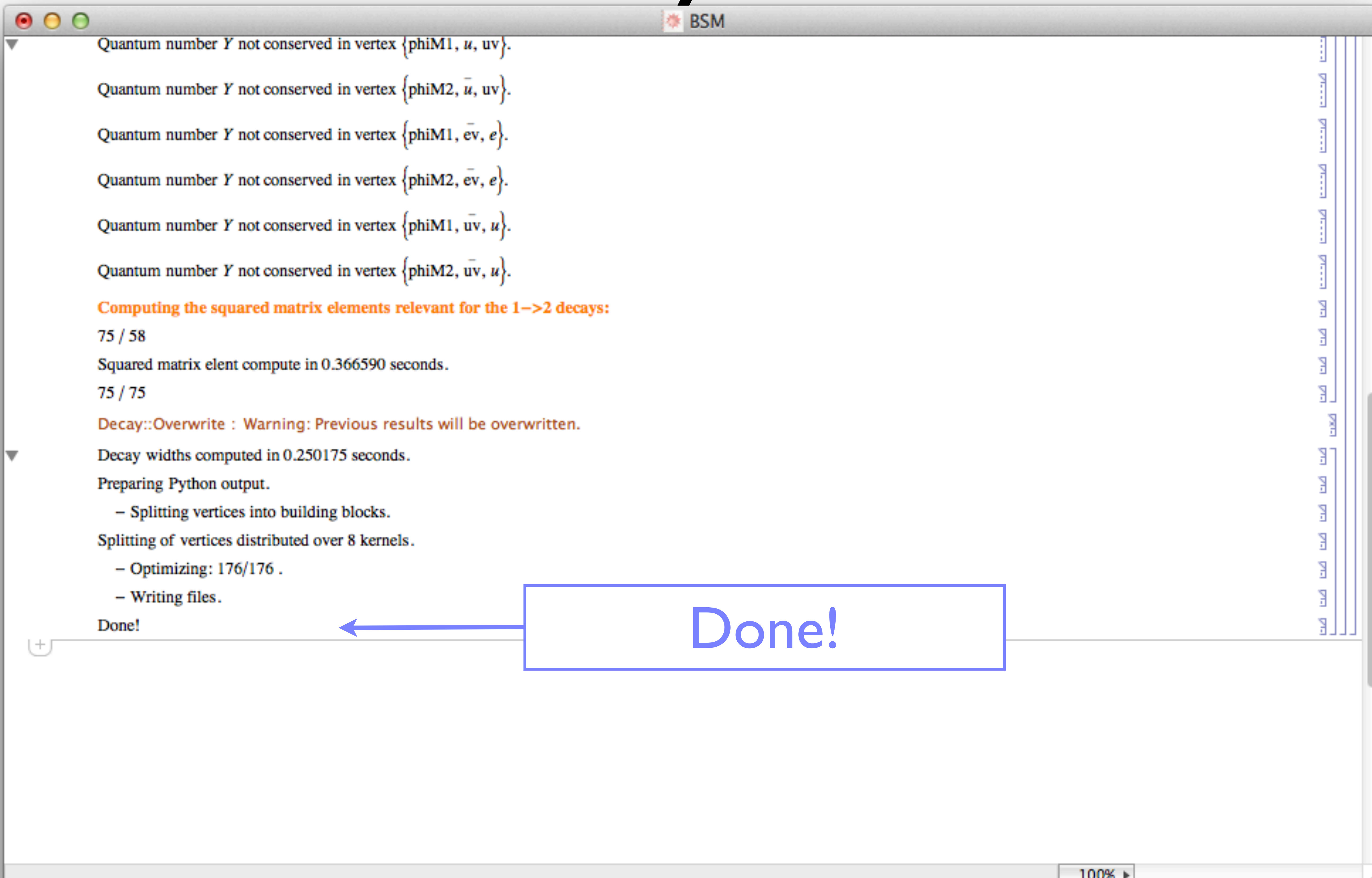
WZ = 2.4116.

100%

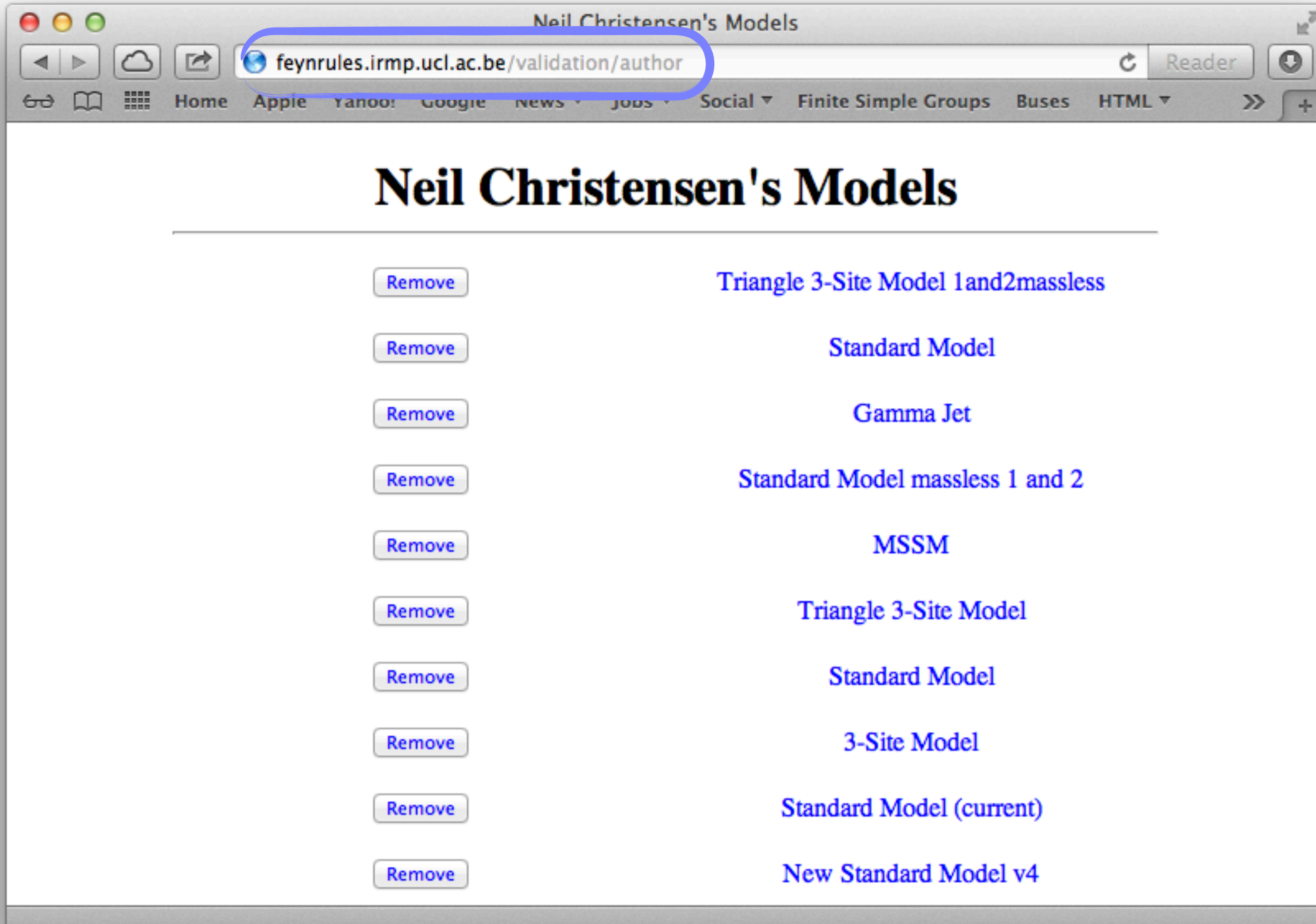
Run FeynRules



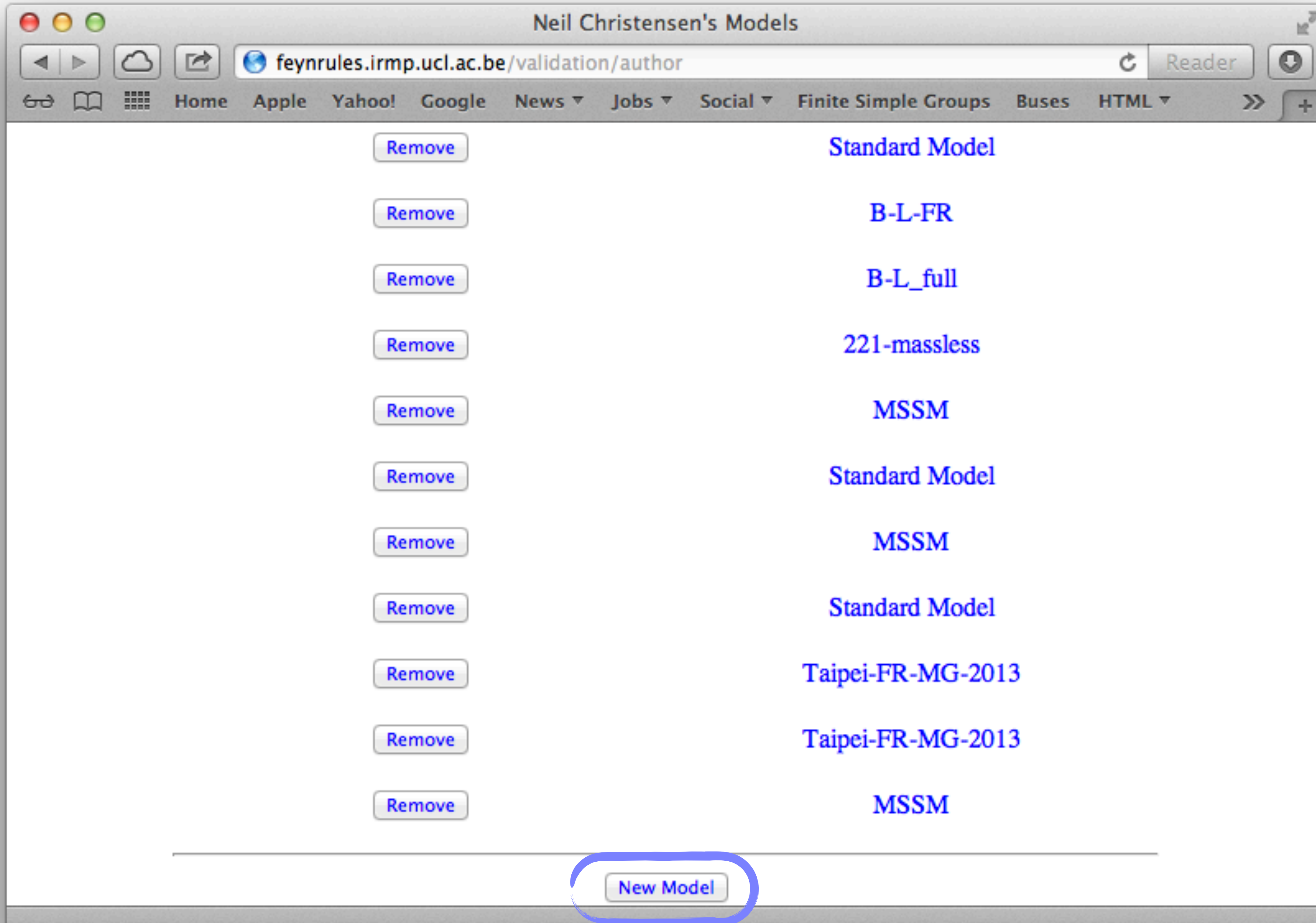
Run FeynRules



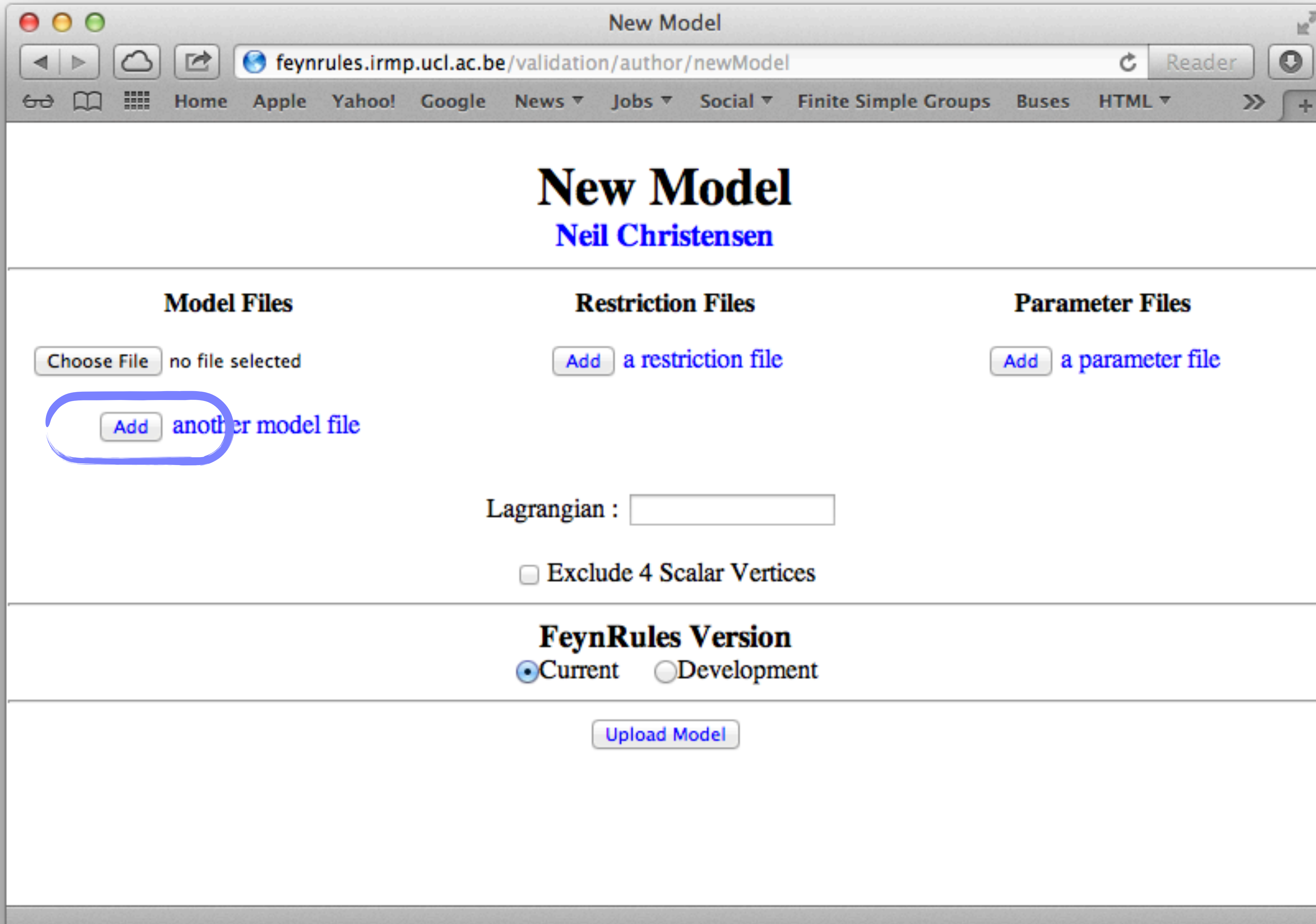
Start Web Validation



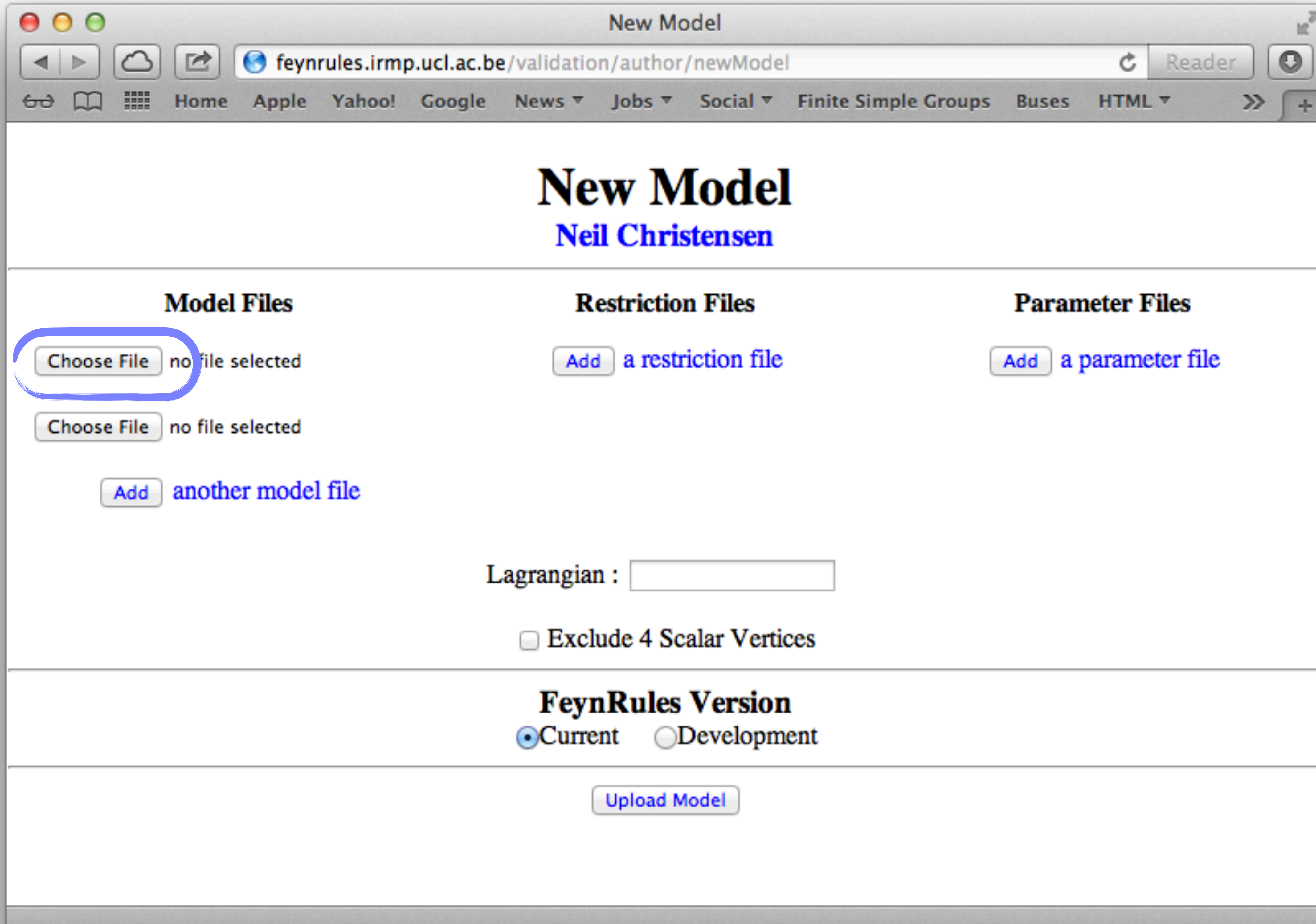
Start Web Validation



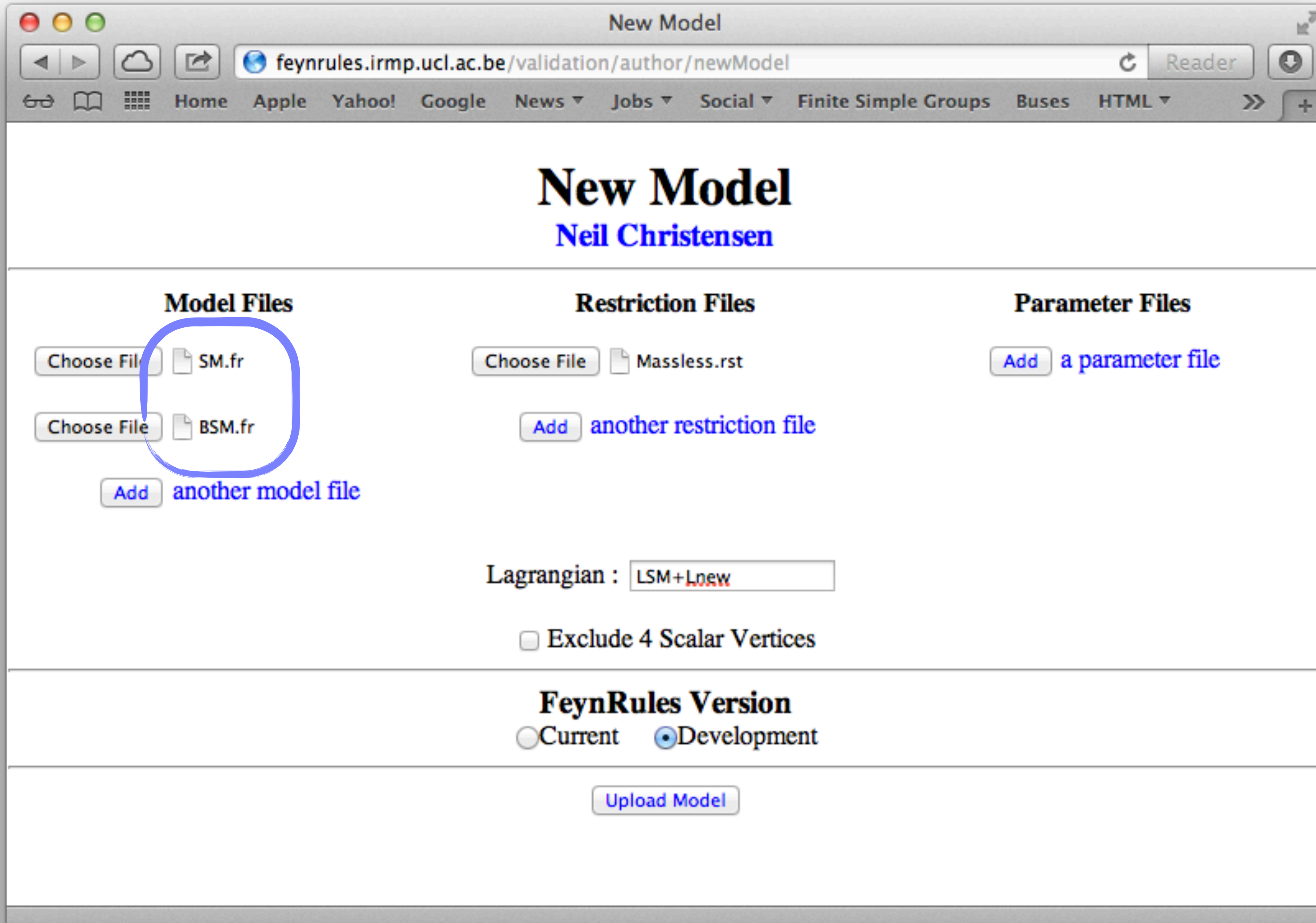
Start Web Validation



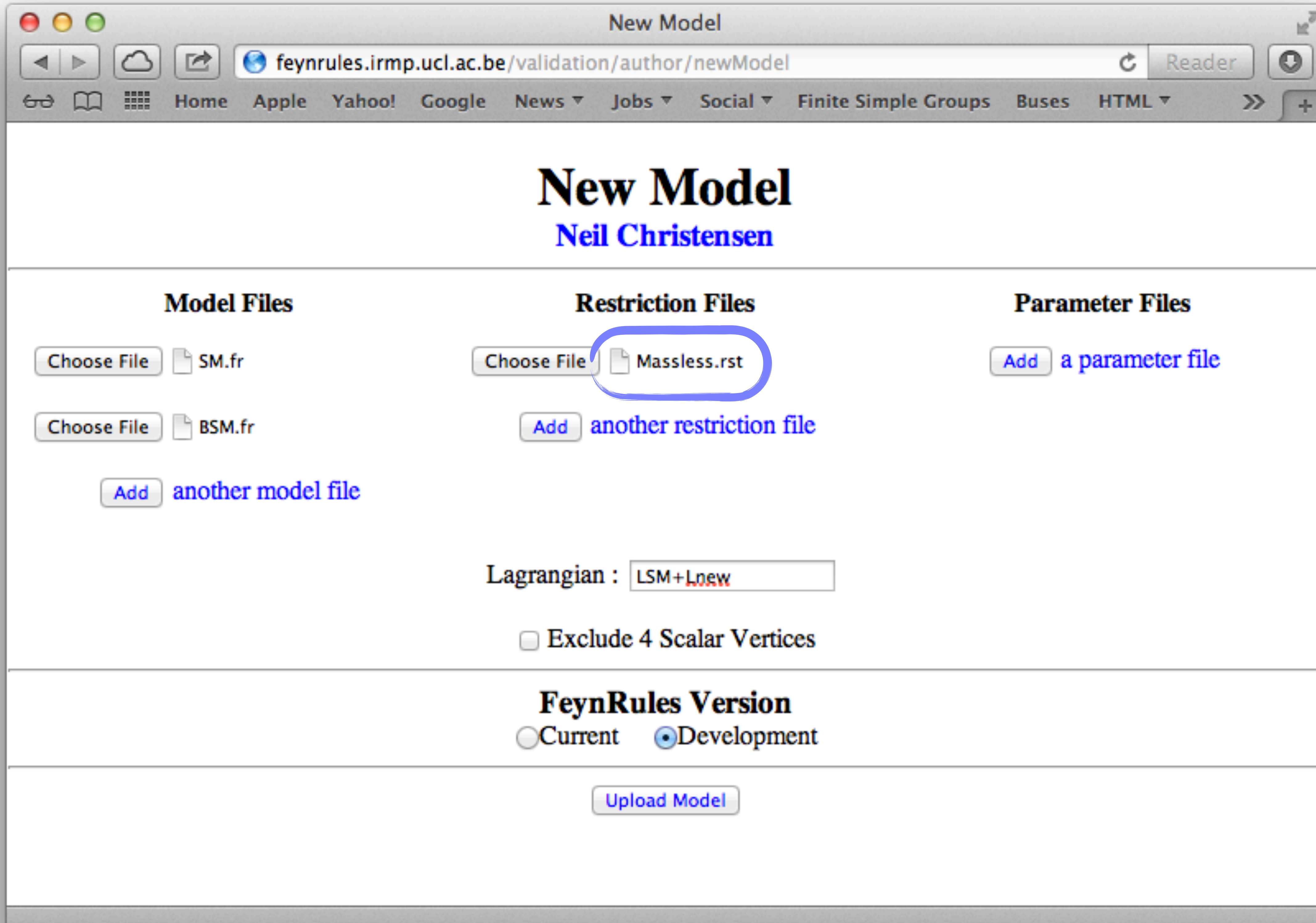
Start Web Validation



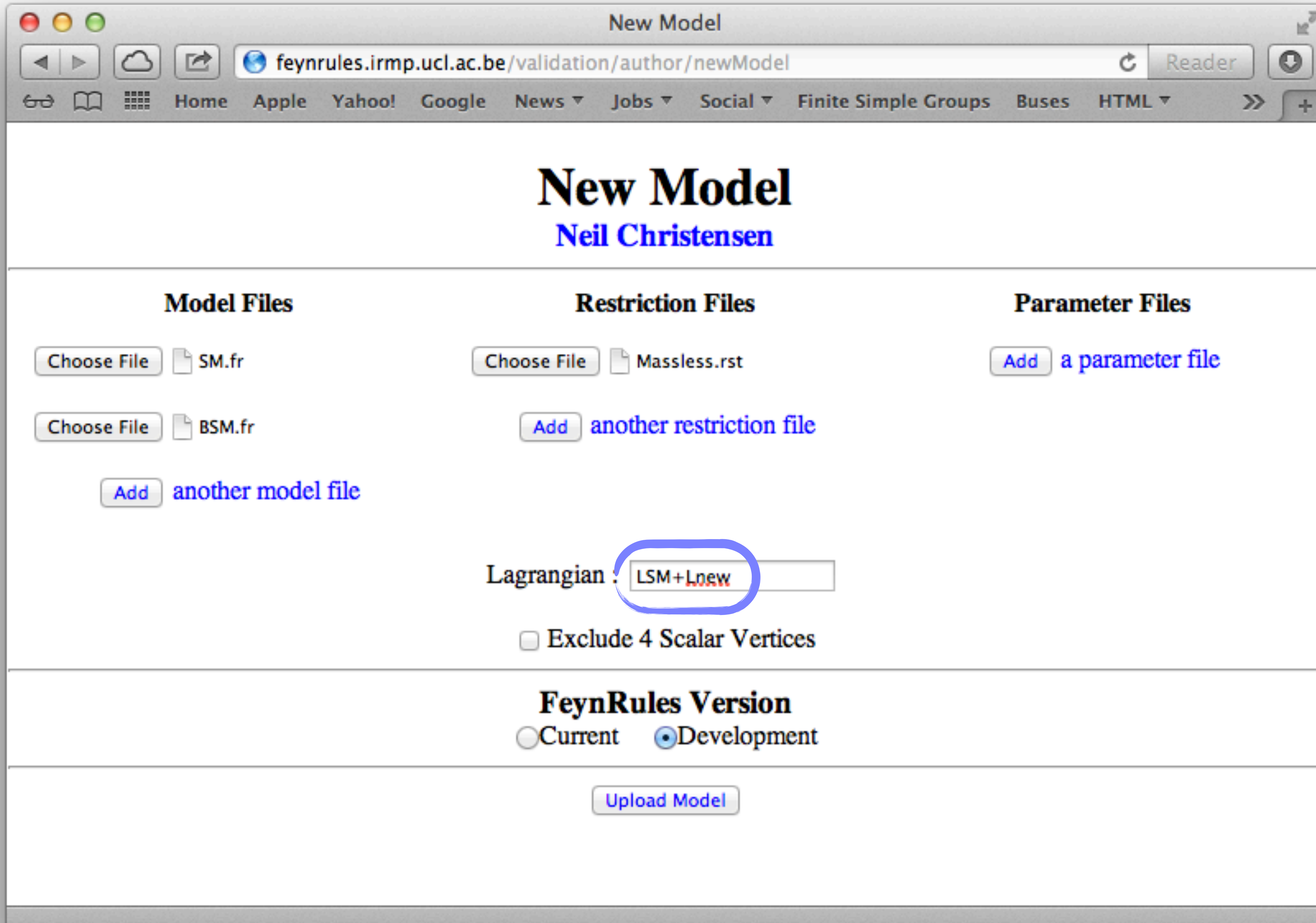
Start Web Validation



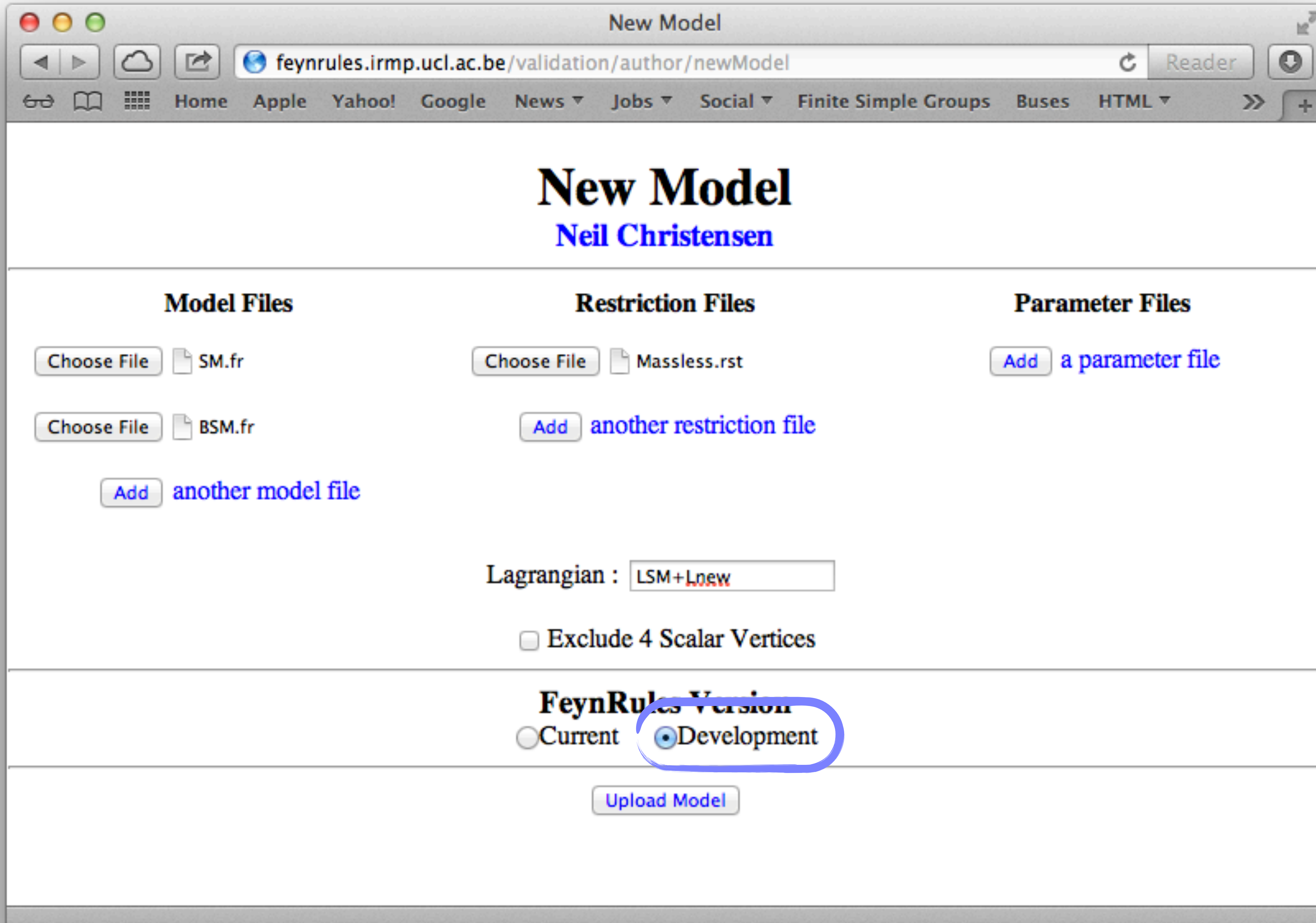
Start Web Validation



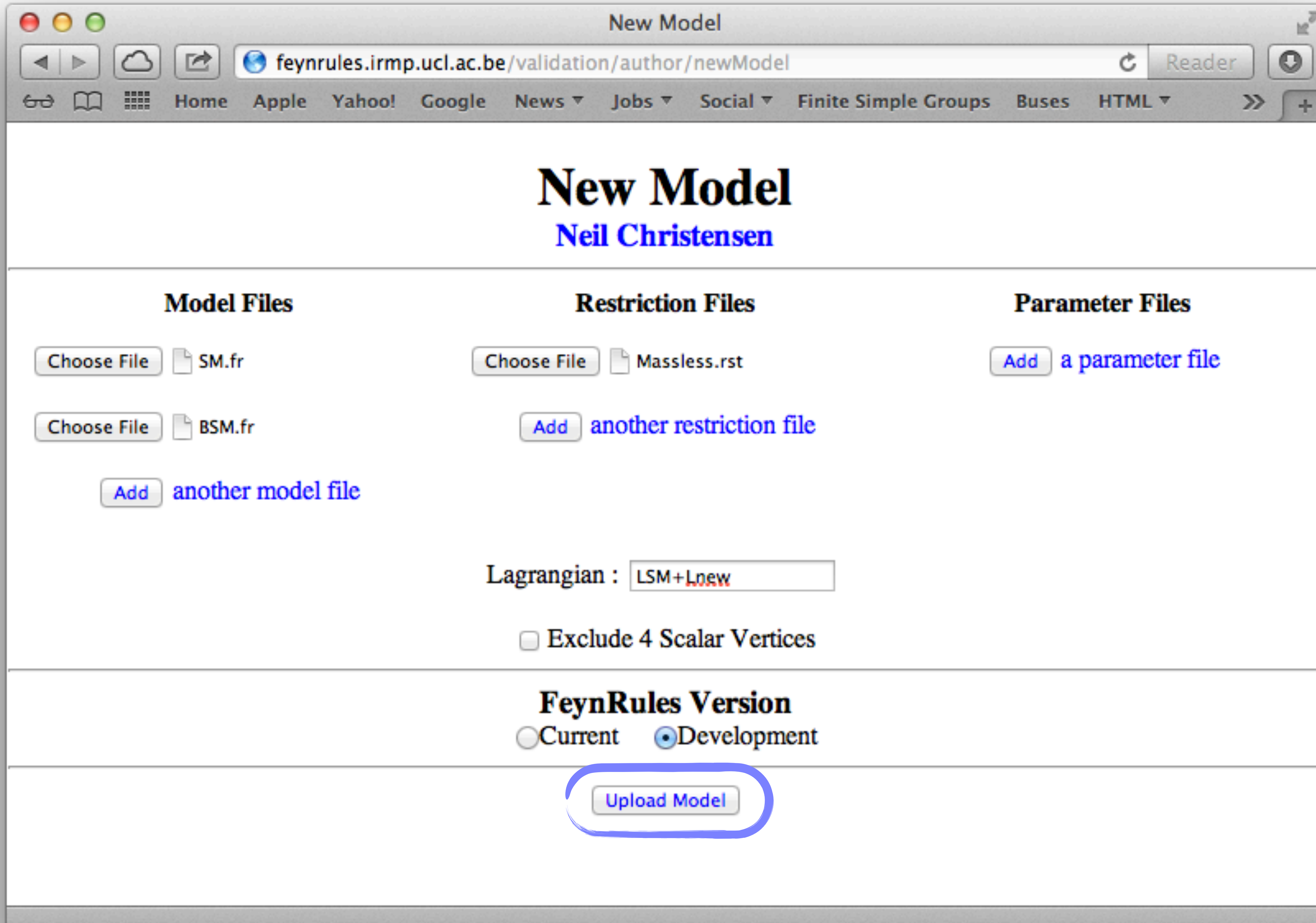
Start Web Validation



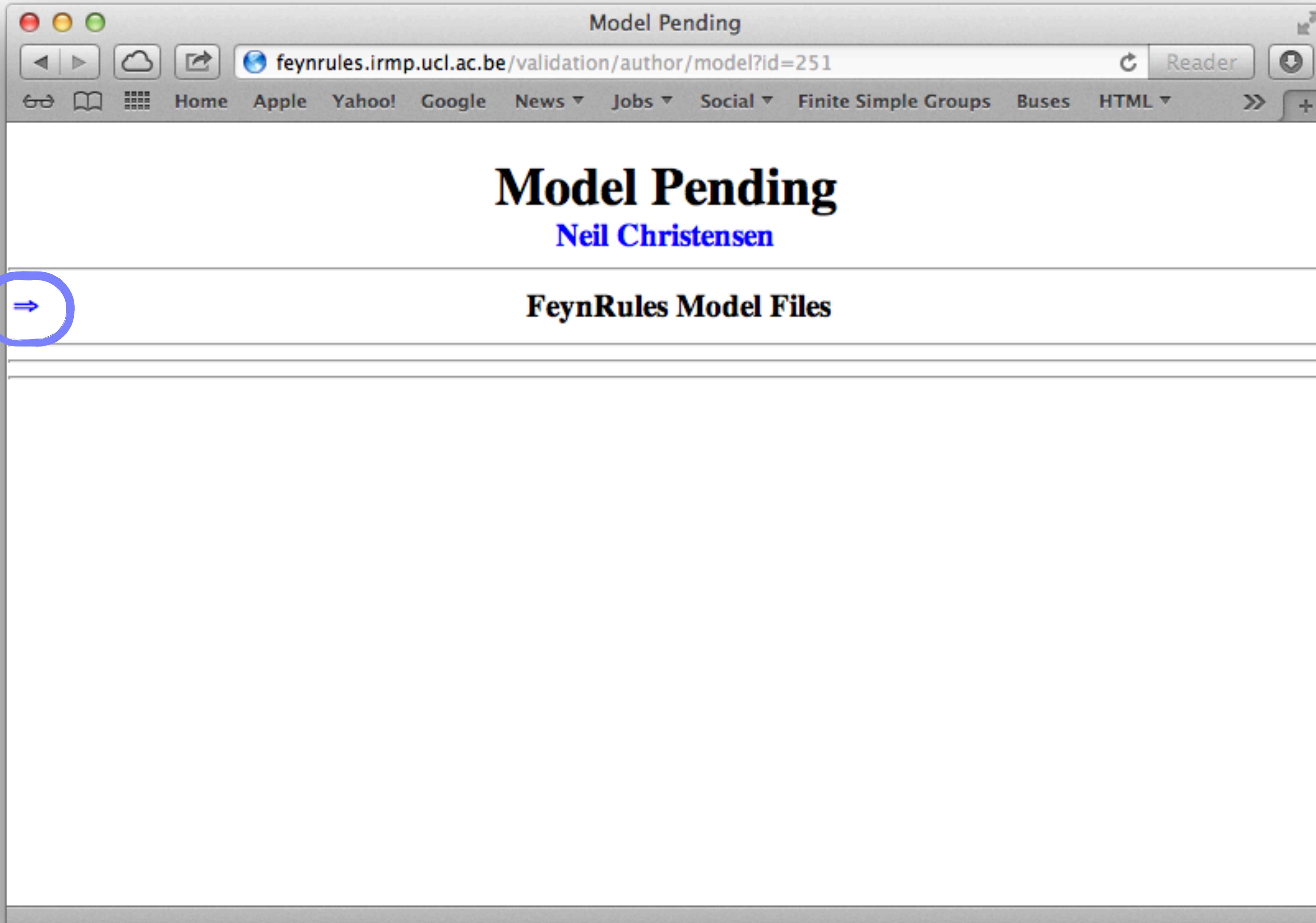
Start Web Validation



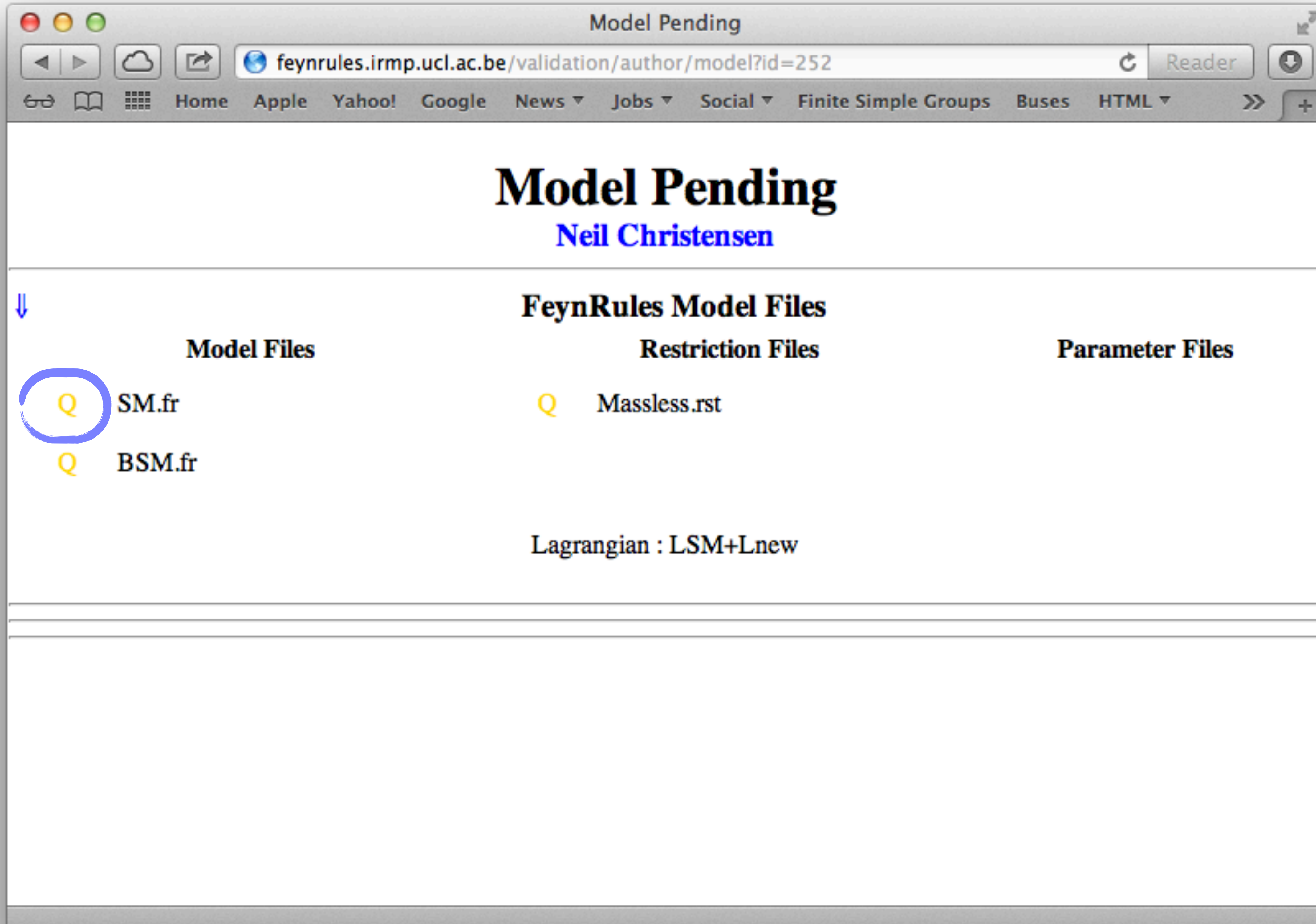
Start Web Validation



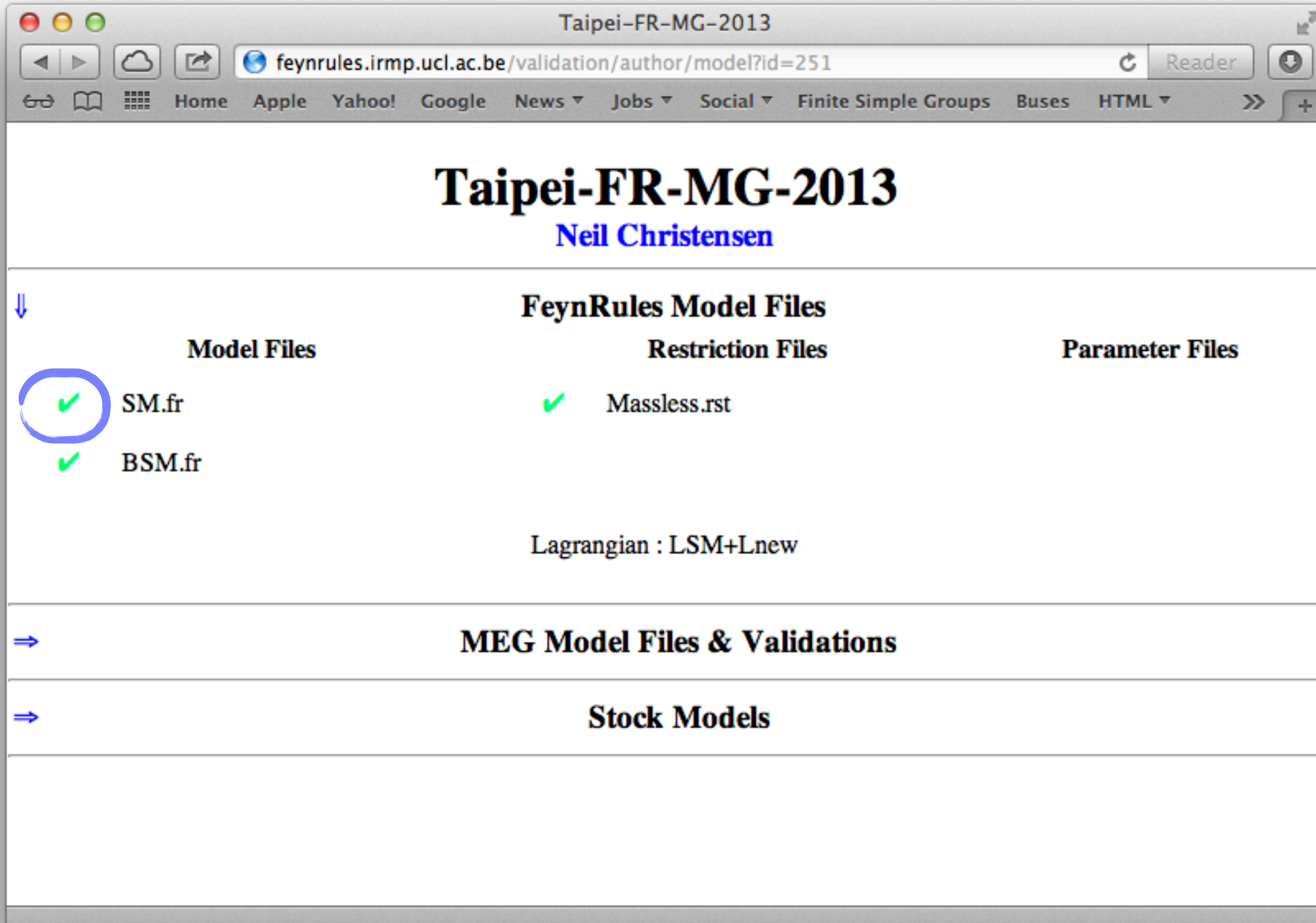
Start Web Validation



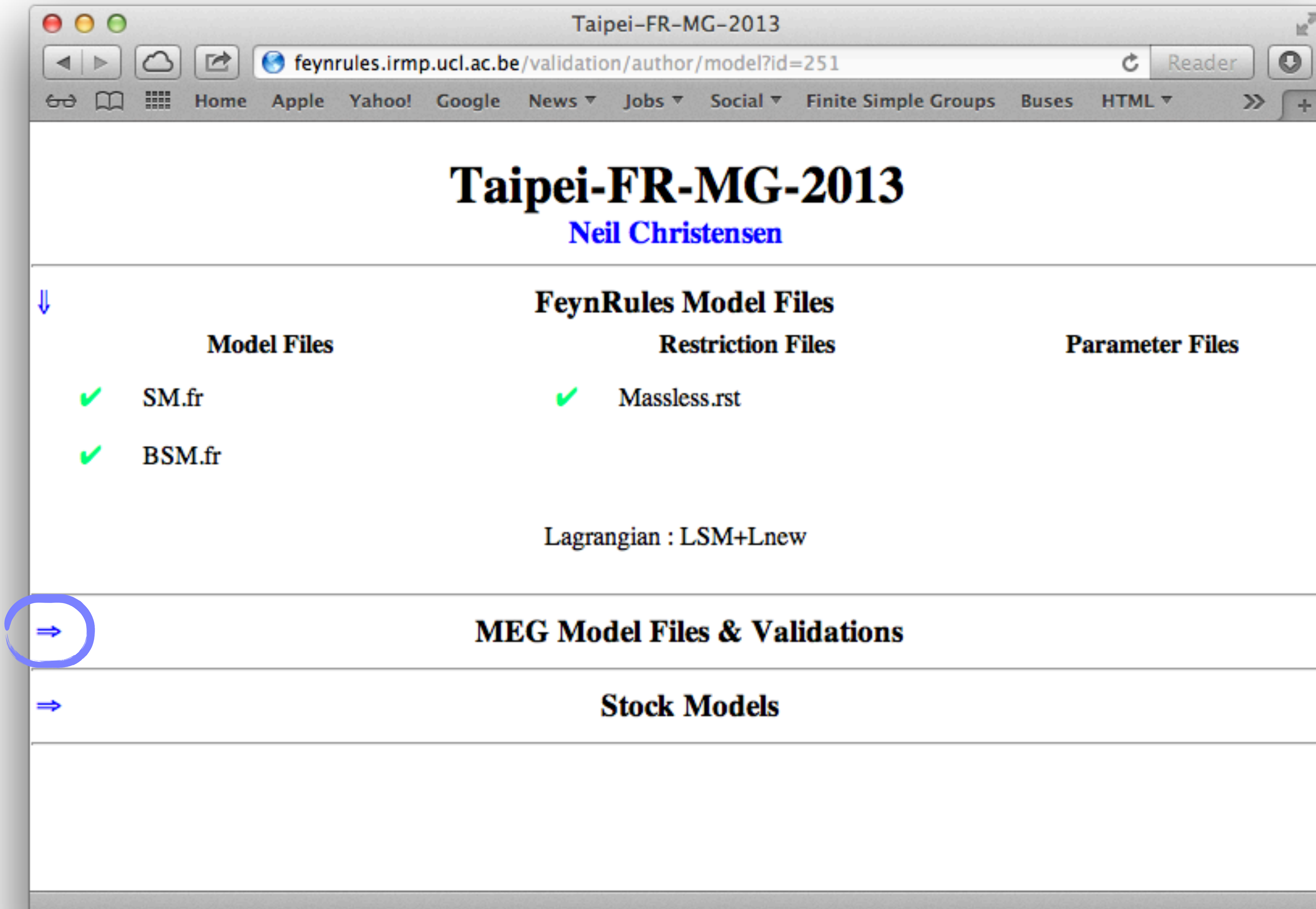
Start Web Validation



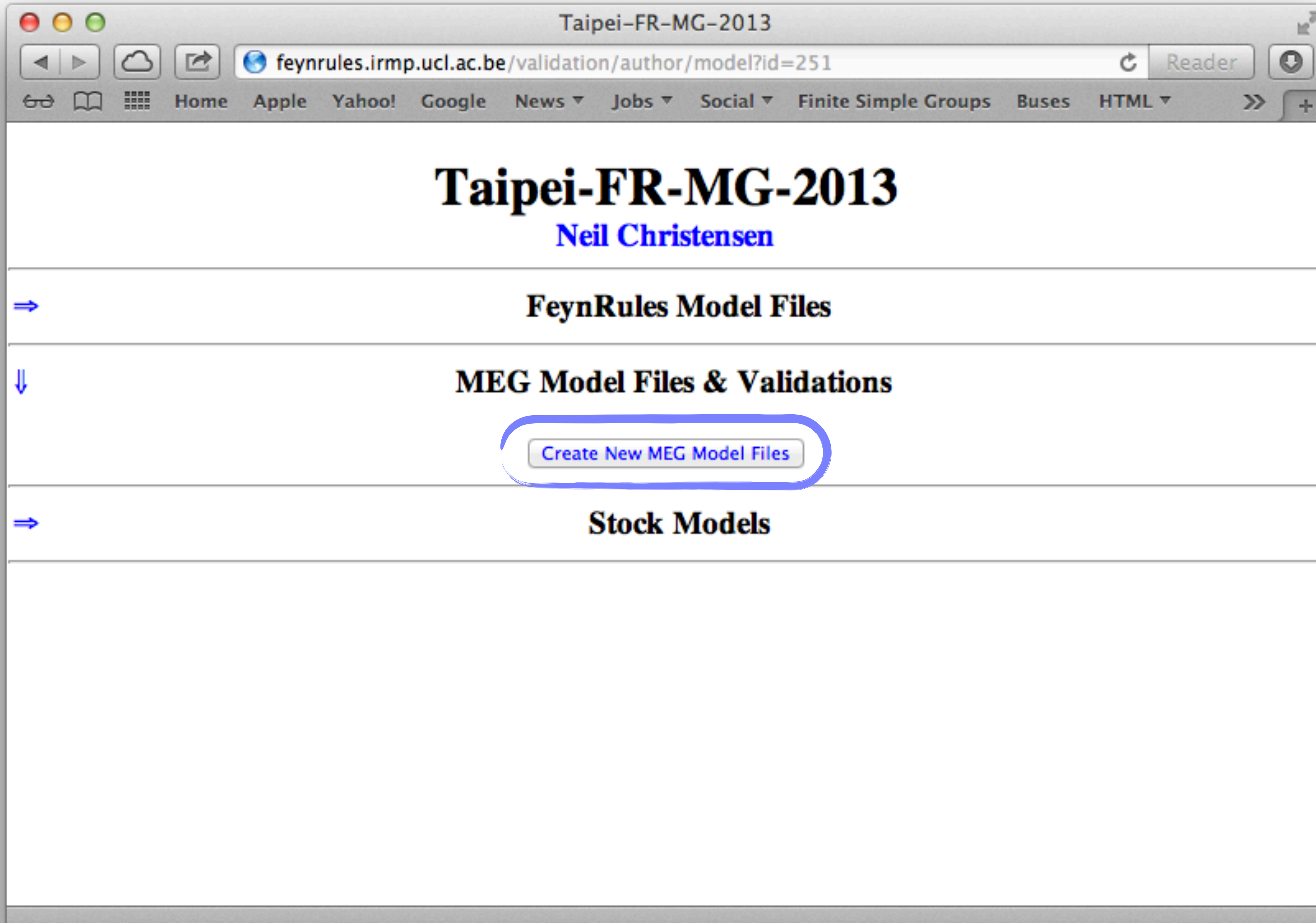
Start Web Validation



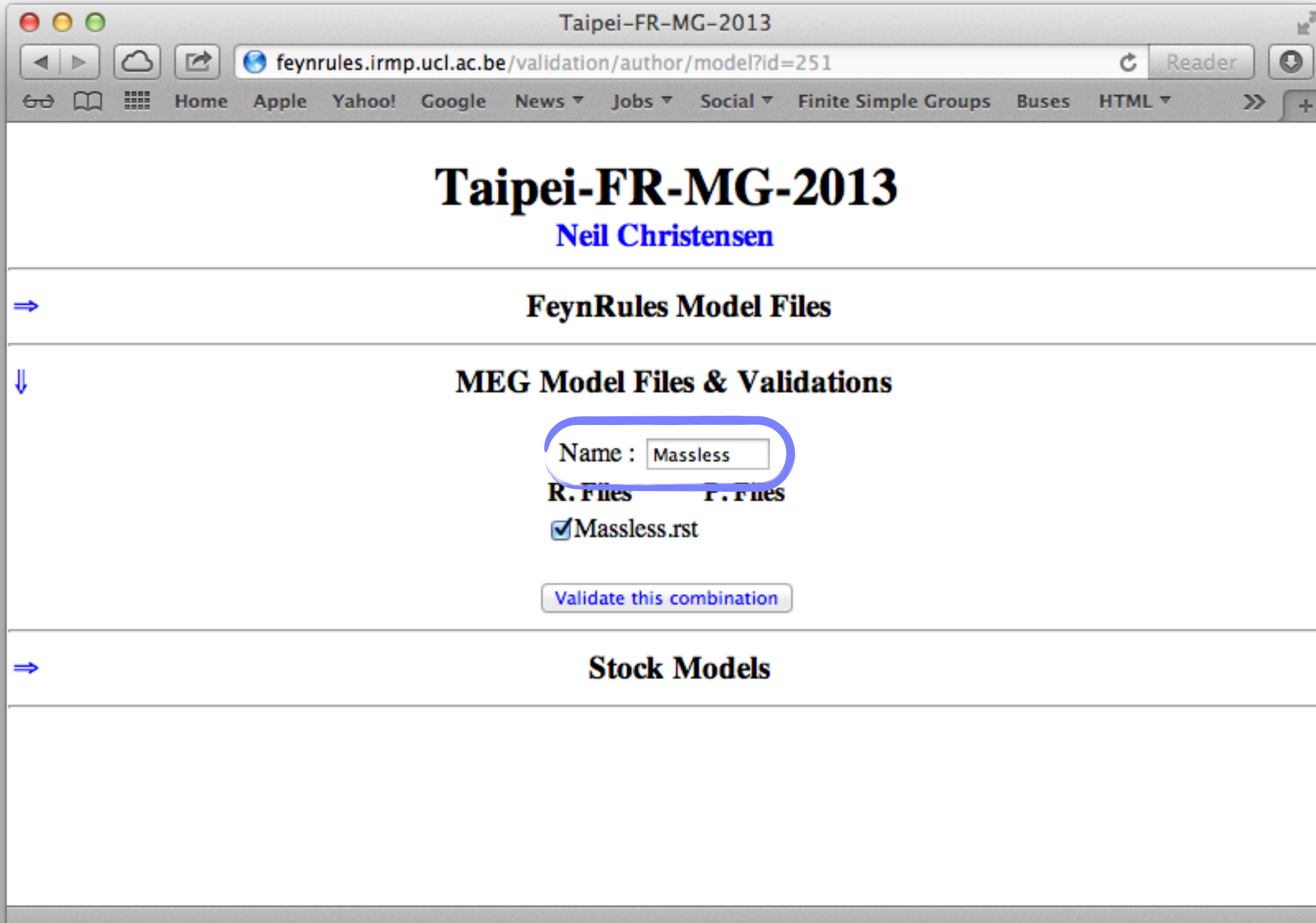
Start Web Validation



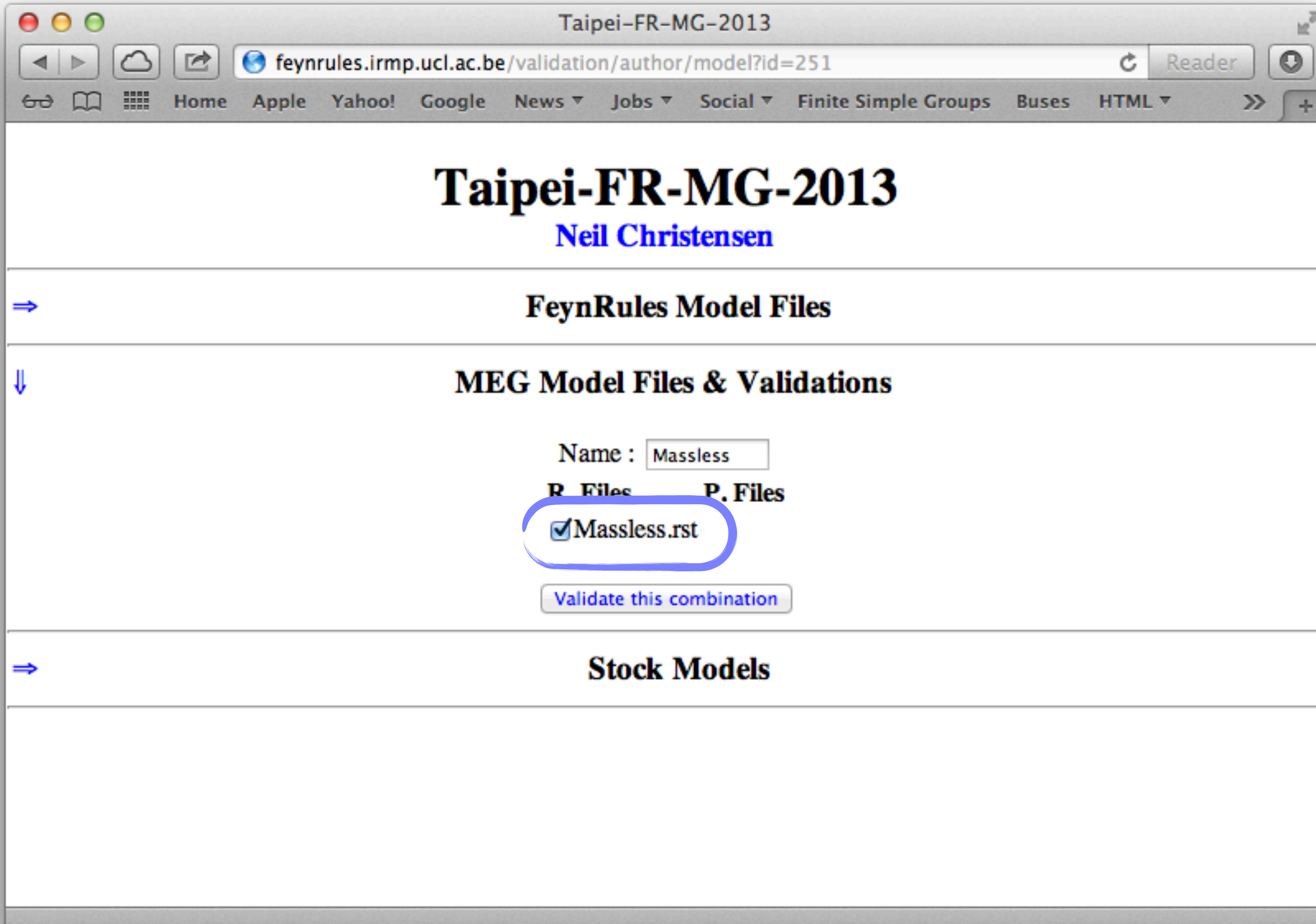
Start Web Validation



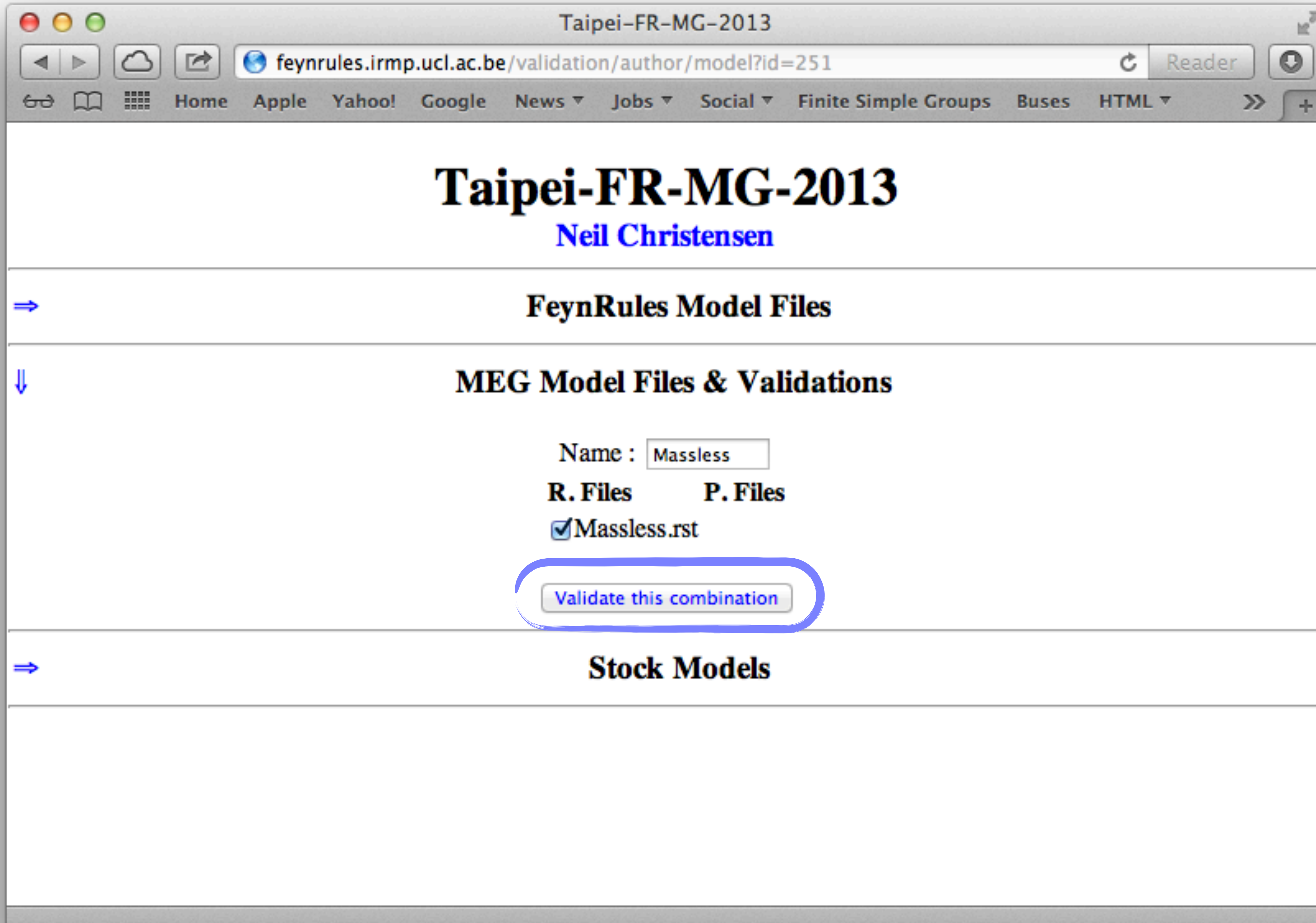
Start Web Validation



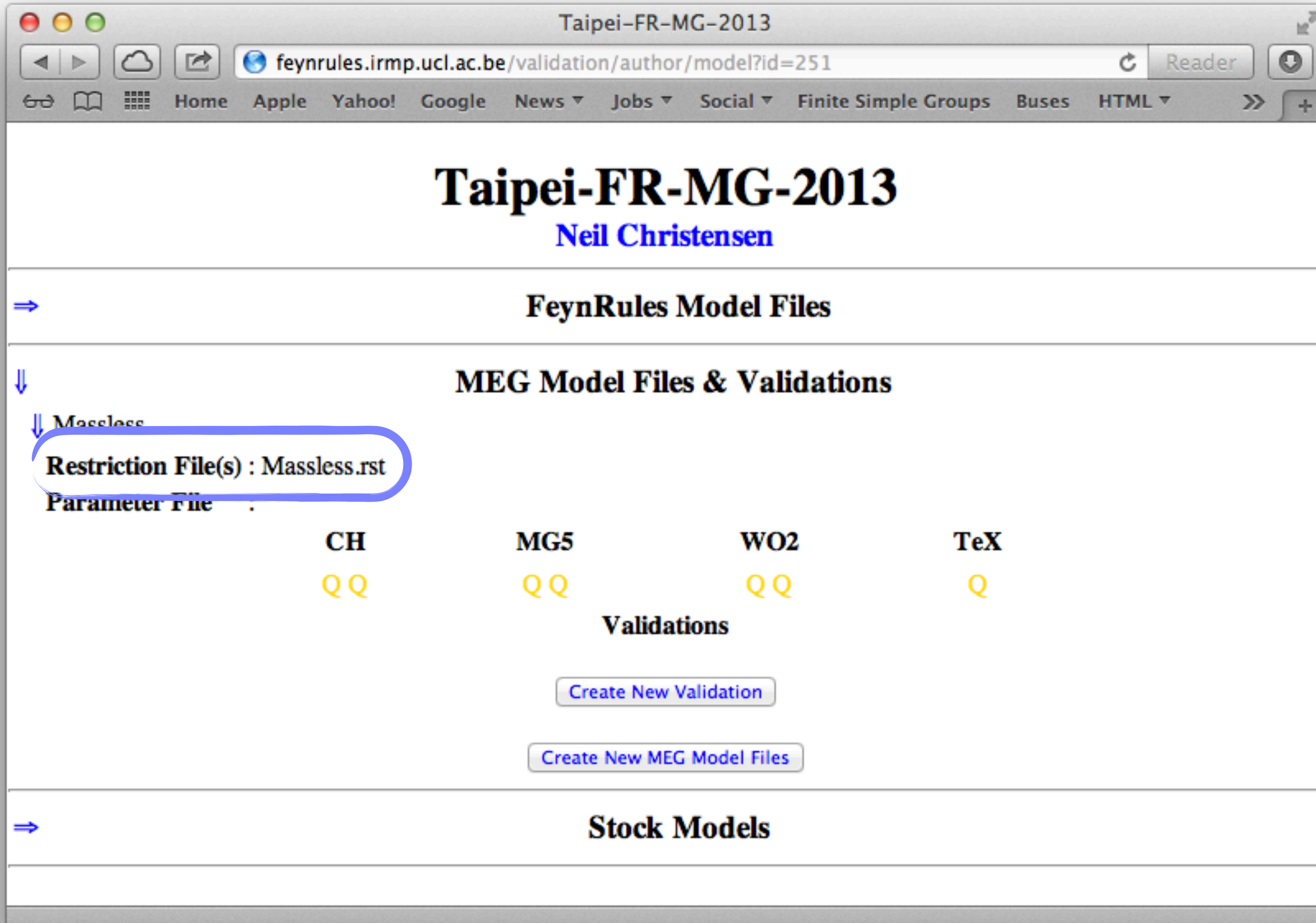
Start Web Validation



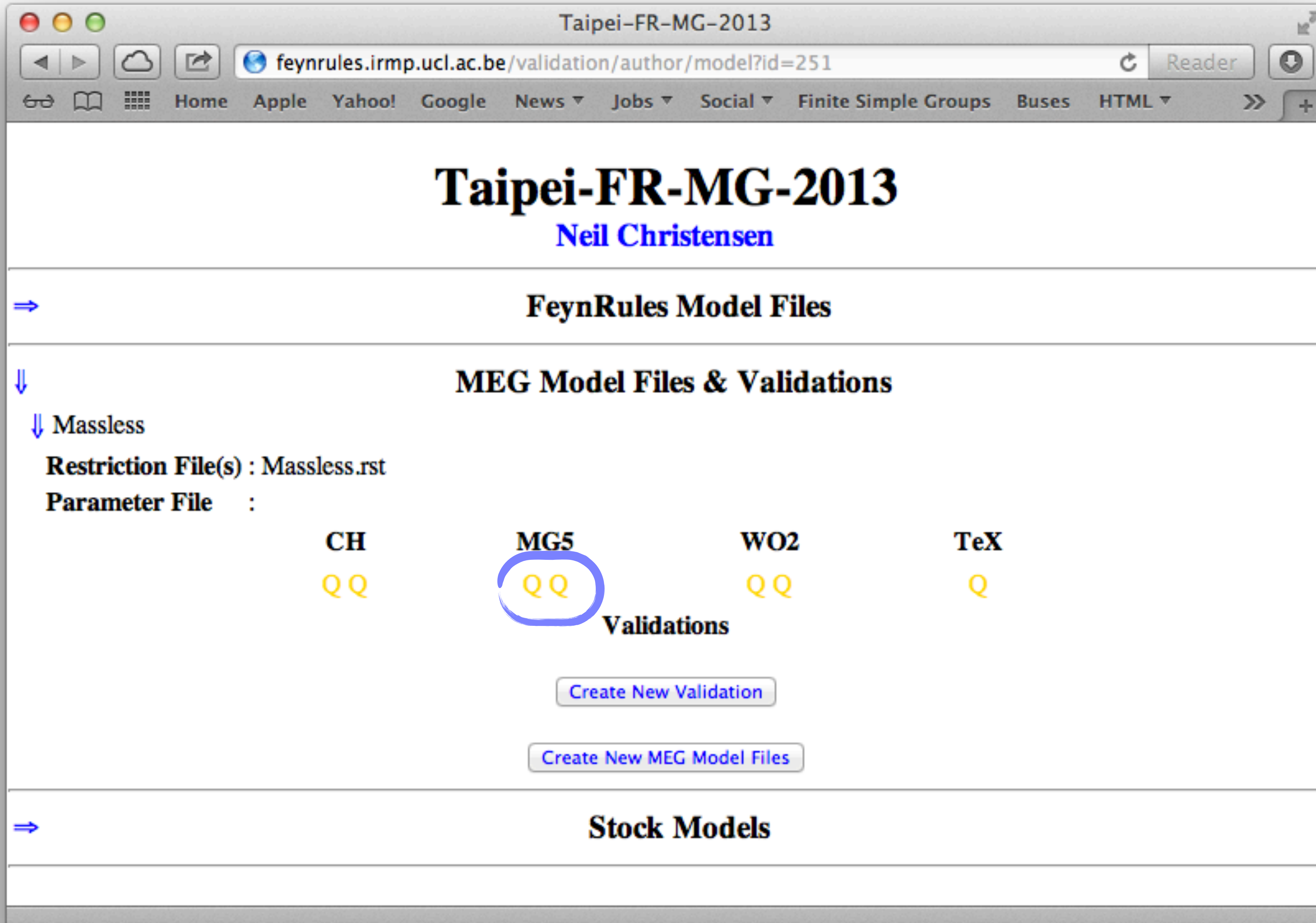
Start Web Validation



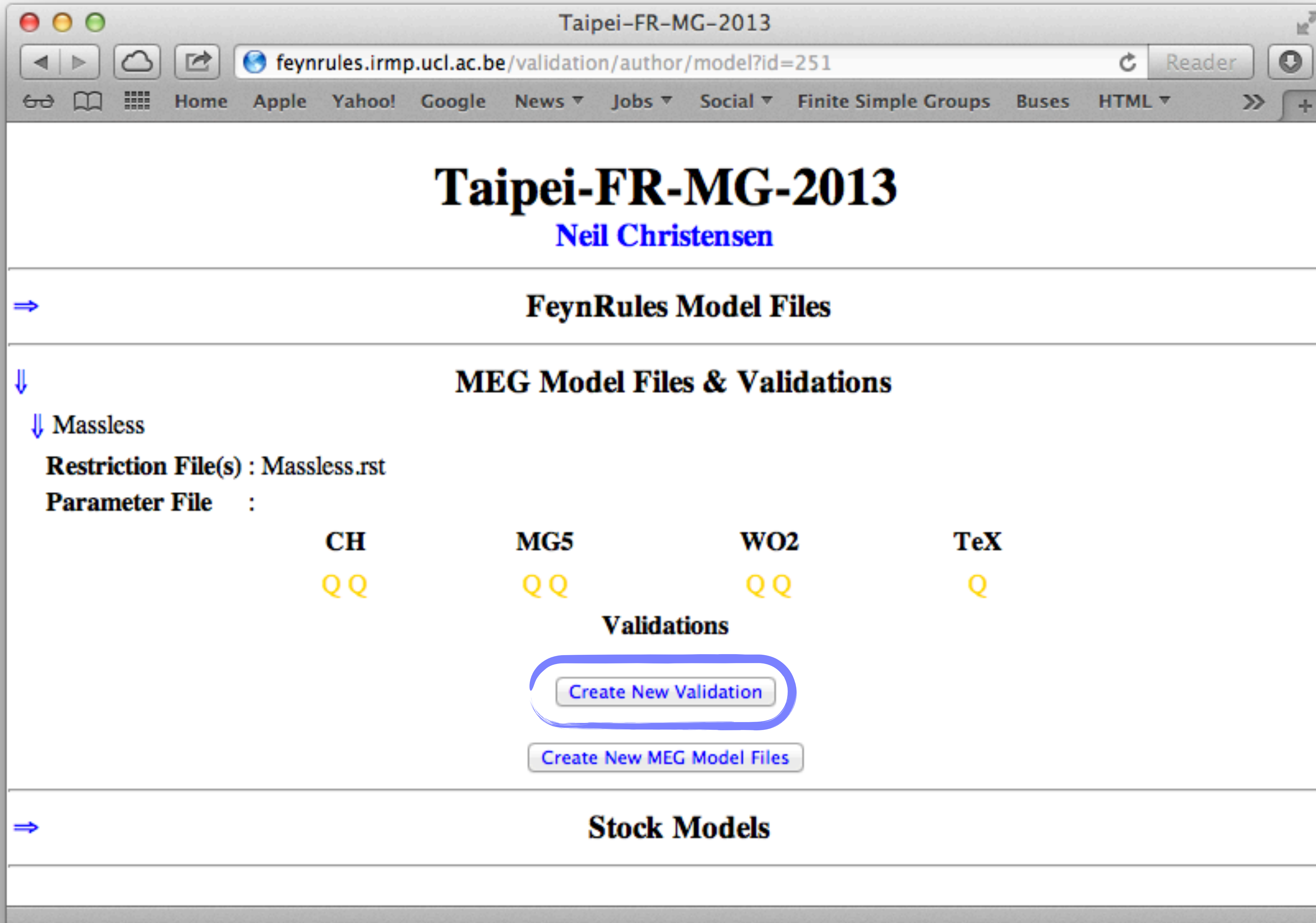
Start Web Validation



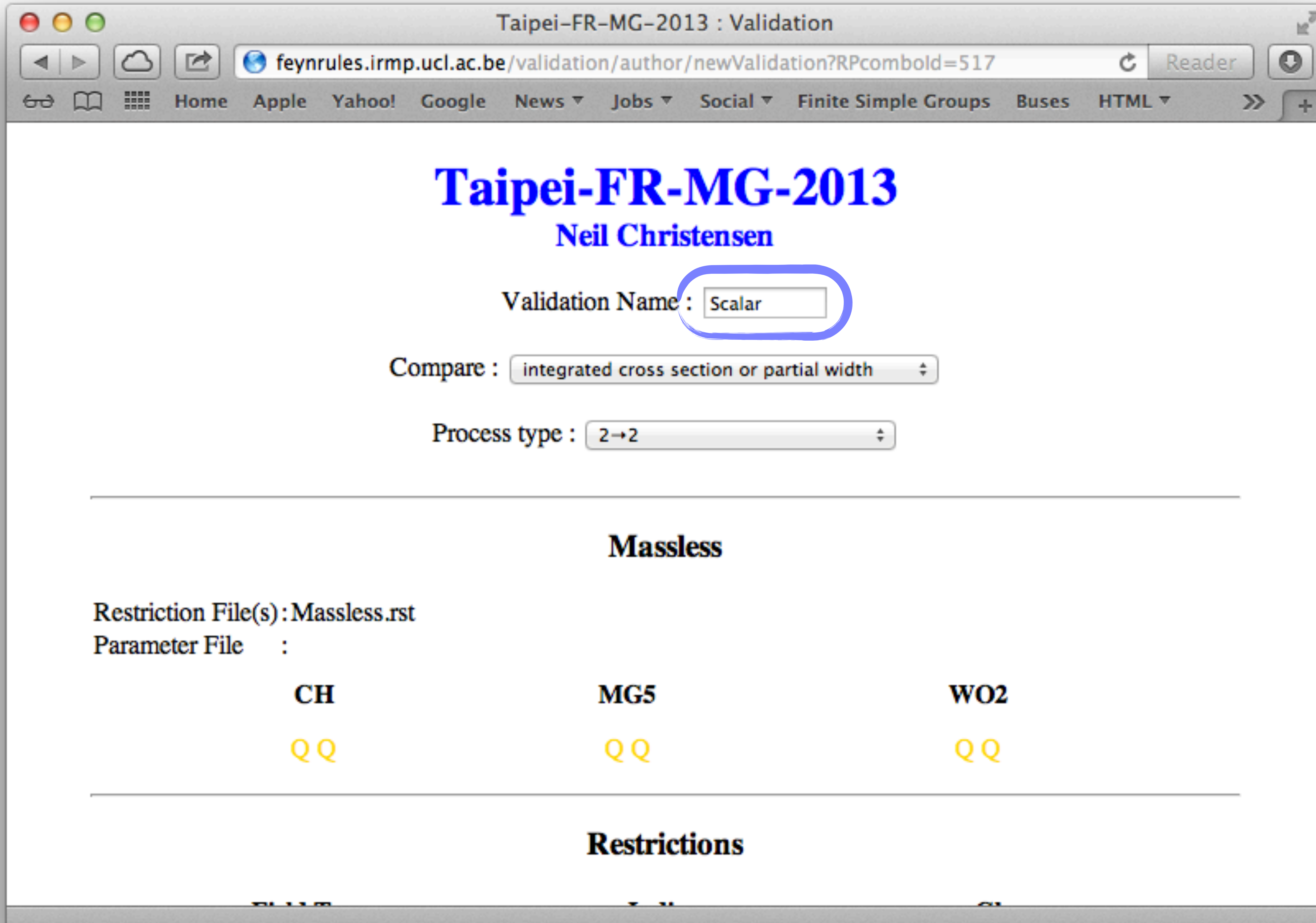
Start Web Validation



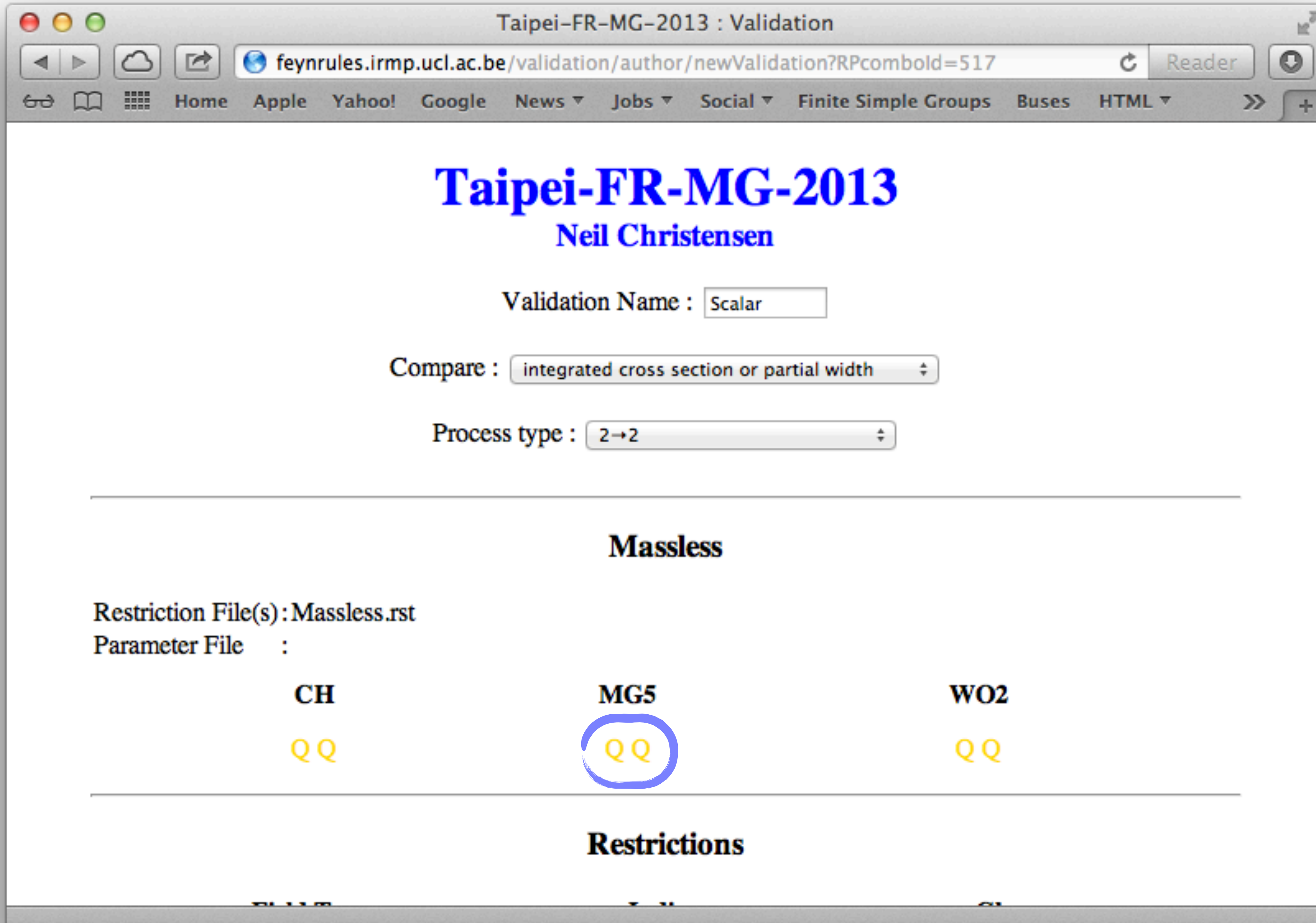
Start Web Validation



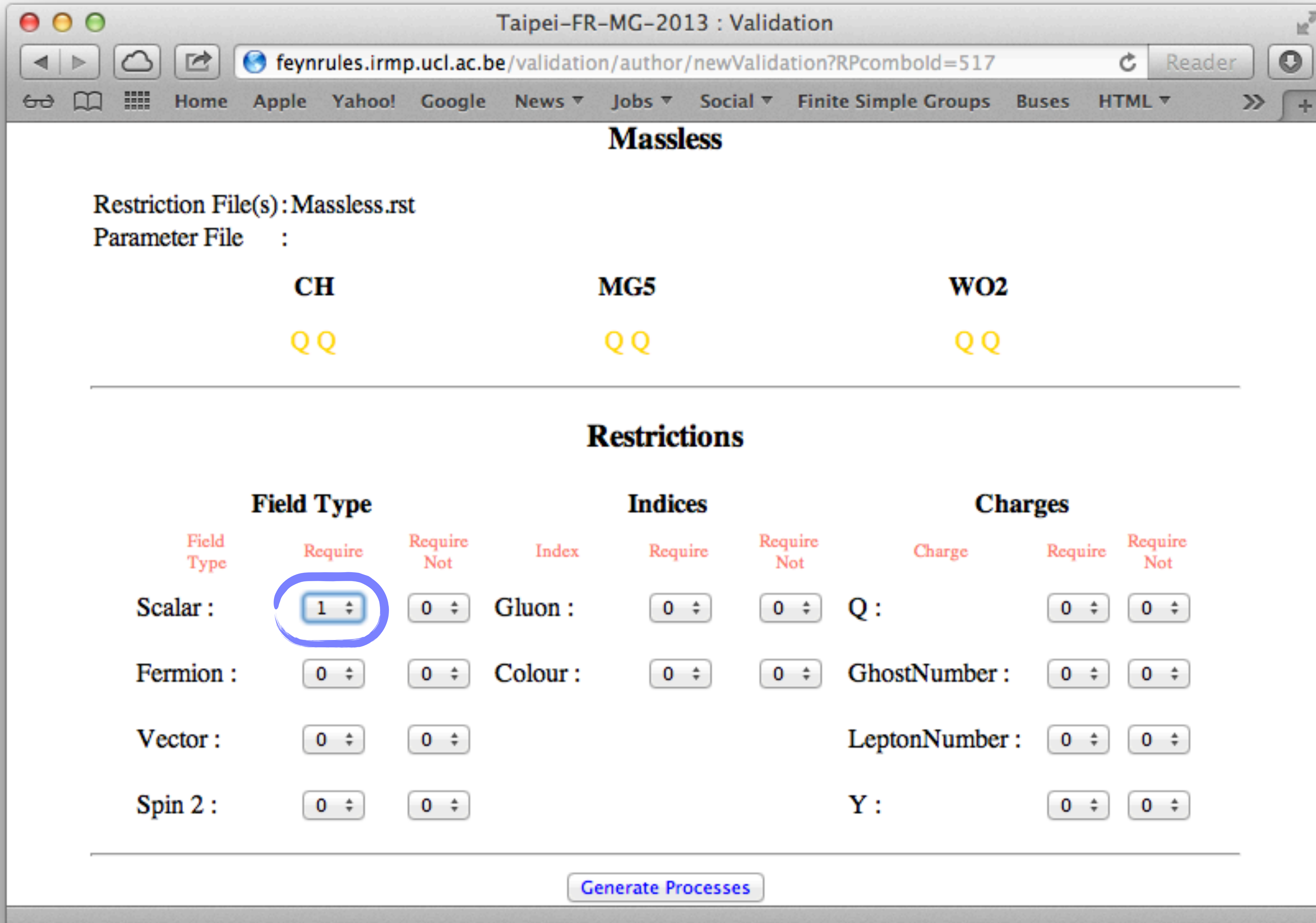
Start Web Validation



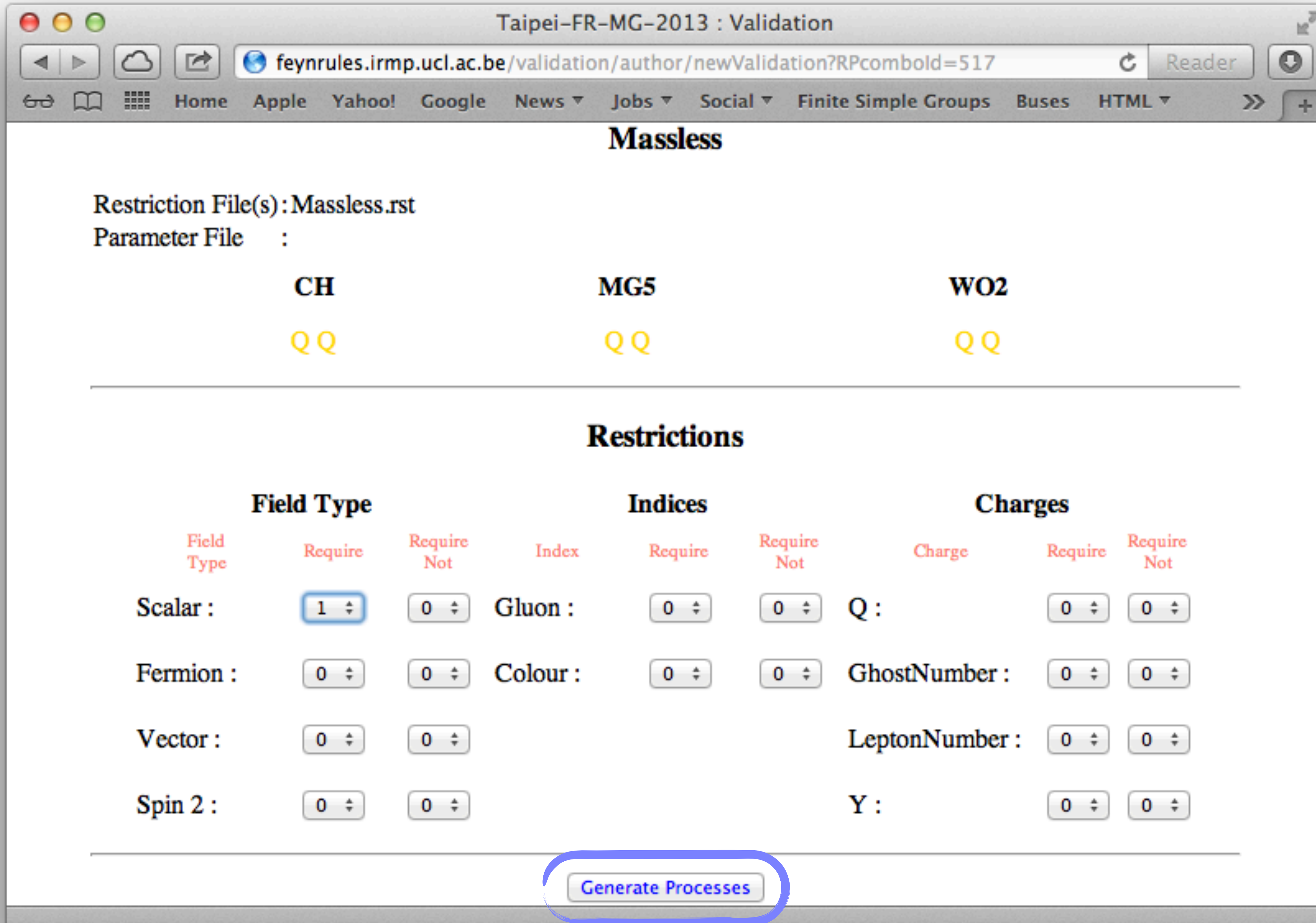
Start Web Validation



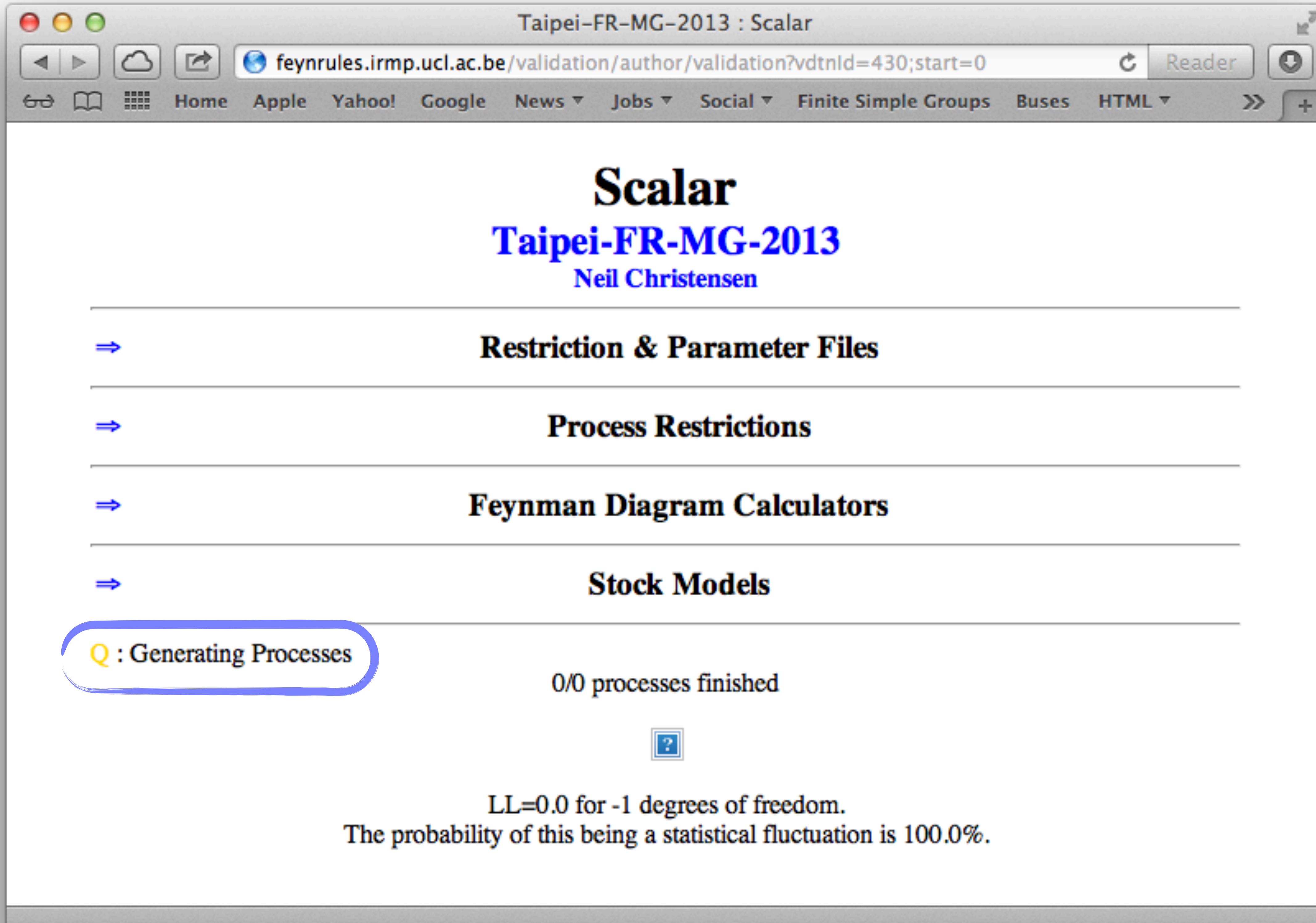
Start Web Validation



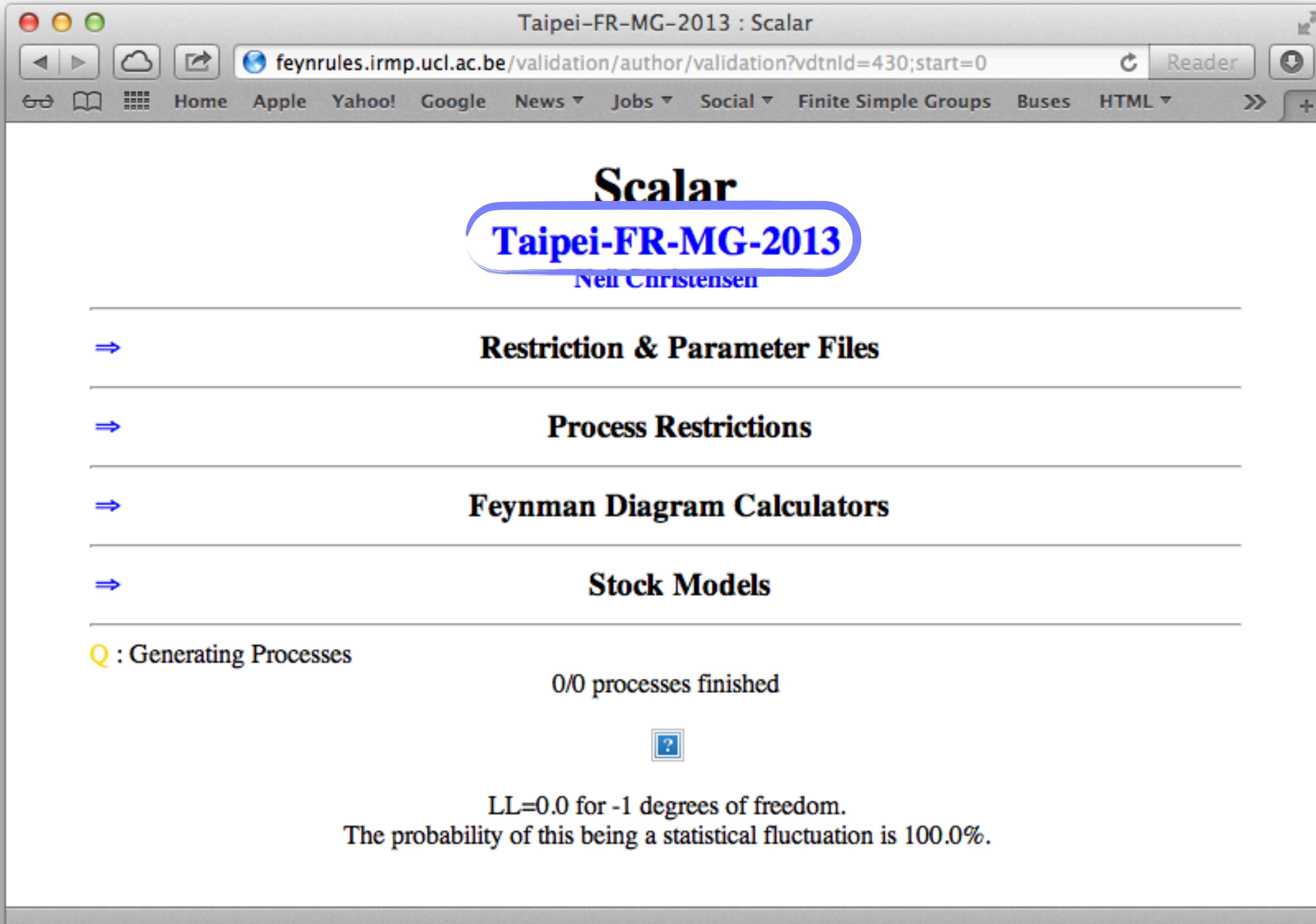
Start Web Validation



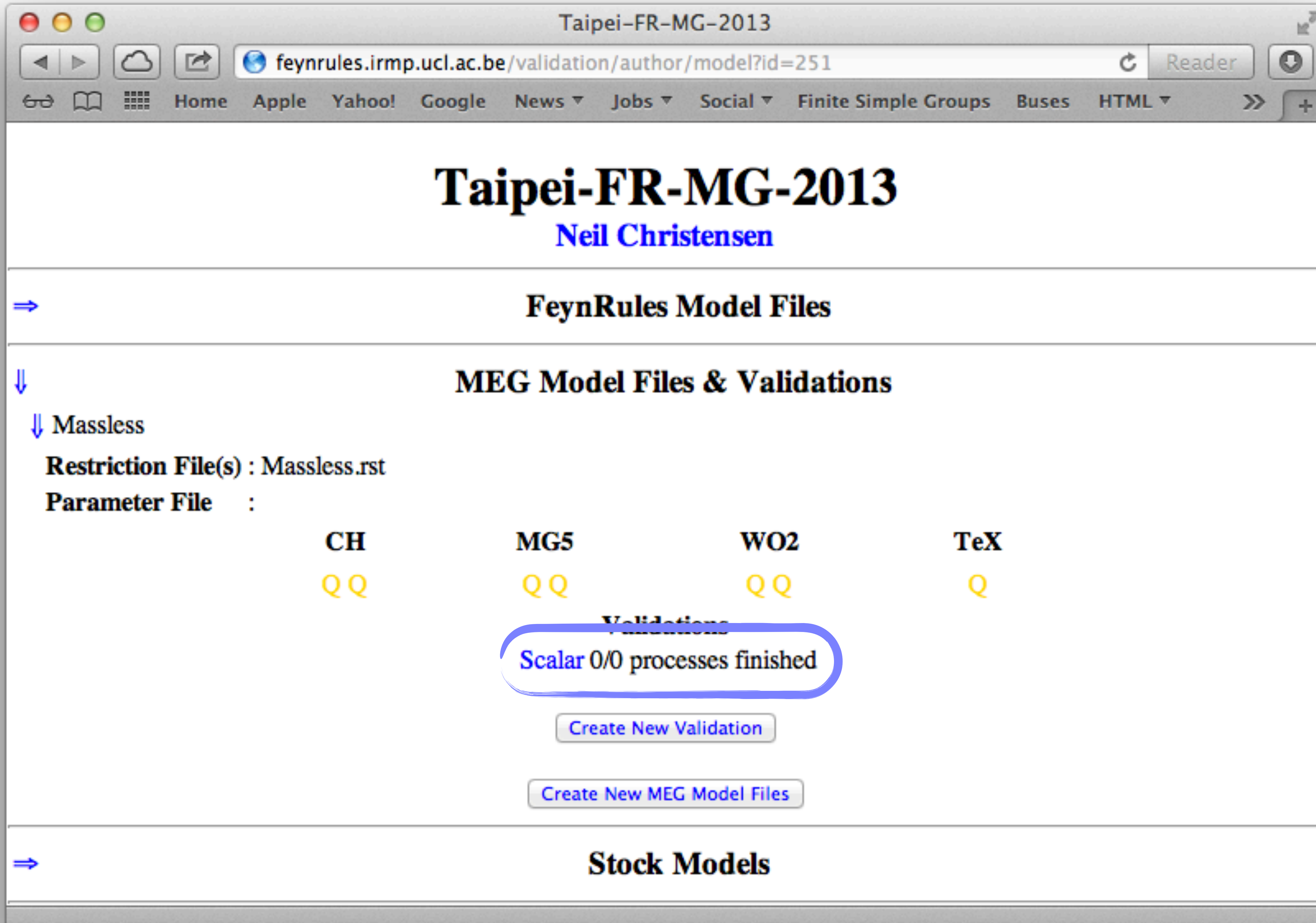
Start Web Validation



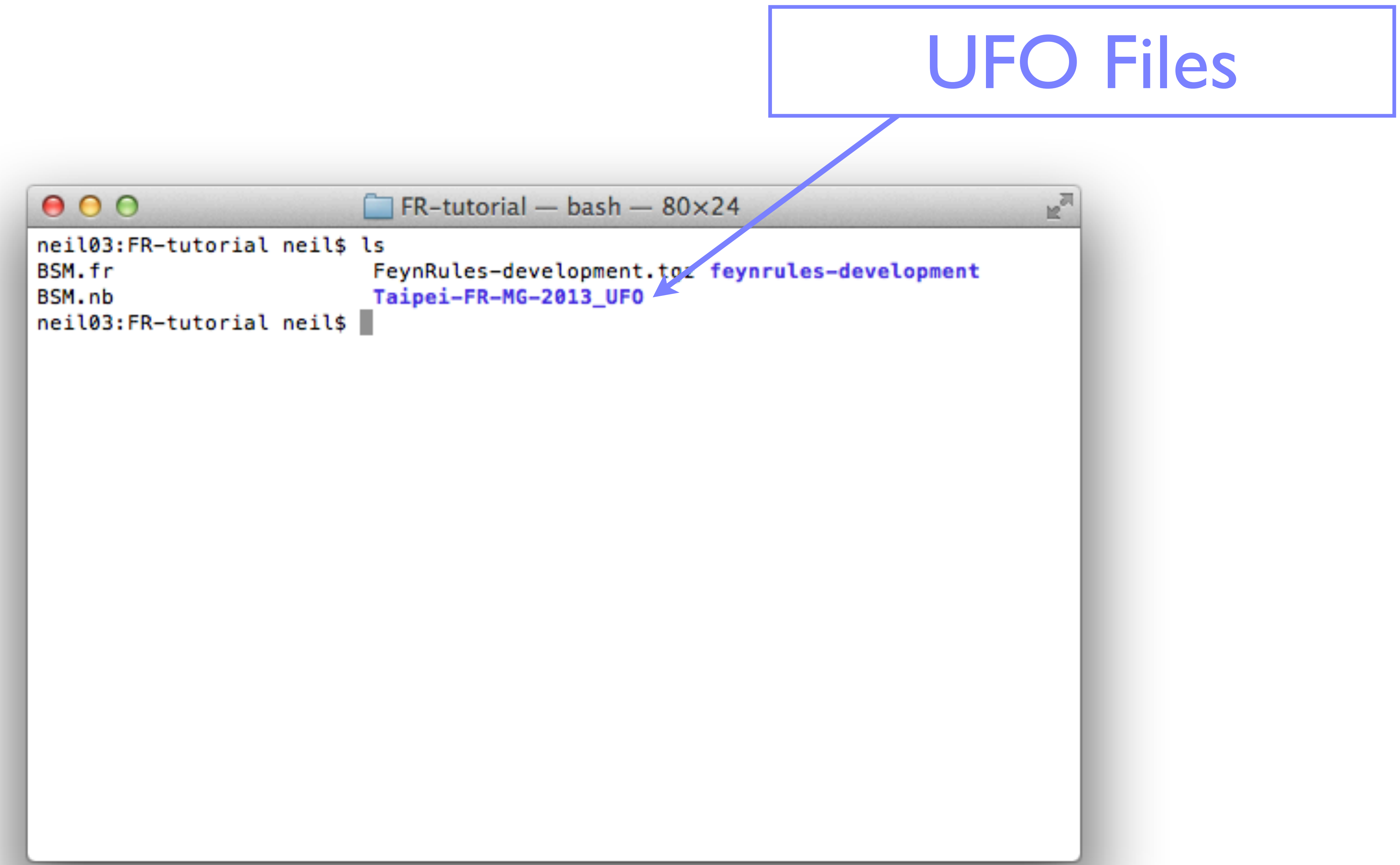
Start Web Validation



Start Web Validation



UFO Files


UFO Files
FR-tutorial — bash — 80×24
neil03:FR-tutorial neil$ ls
BSM.fr
FeynRules-development.tgz
feynrules-development
BSM.nb
Taipei-FR-MG-2013_UFO
neil03:FR-tutorial neil$

UFO Files

FR-tutorial — bash — 80×

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 — 80×24

```
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 — 80×24

```
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 — 80×24

```
                 order = {'QED':2})

GC_50 = Coupling(

GC_51 = Coupling(
```

$$\left| \begin{pmatrix} \bar{u}v & 1 \\ u & 2 \\ \text{phiM2} & 3 \end{pmatrix} i\,\text{sina}\,\delta_{m_1,m_2}\,\text{lambda}_1\,P_{+s_1,s_2} + i\,\text{cosa}\,\delta_{m_1,m_2}\,\text{lambda}_2\,P_{+s_1,s_2} \right|$$

```
GC_52 = Coupling(name = 'GC_52',
                 value = 'cosa*complex(0,1)*lambda2 + complex(0,1)*lambda1*sina'
,
                 order = {'NP':1})

GC_53 = Coupling(name = 'GC_53',
                 value = 'cosa*complex(0,1)*lambda1 - complex(0,1)*lambda2*sina'
,
                 order = {'NP':1})

GC_54 = Coupling(name = 'GC_54',
                 value = 'cosa*complex(0,1)*lambdap2 + complex(0,1)*lambdap1*sin
a',
:
```

UFO Files

FR-tutorial — bash — 80×24

```
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 — 80×24

Γ_{Φ_1}

```
*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 — 80×24

```
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 — 80×24

```
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

$\sin\alpha$

FR-tutorial — less — 80×24

```
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 — 80×24

```
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 — 80×24

```
               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',
:
```

Φ_1

UFO Files

FR-tutorial — bash — 80×24

```
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 — 80×24

```
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 — 80×24

```
               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',
               part
               colo
               lore
               coup

V_45 = Vertex(name
               part
               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',
:
```

$$\left| \begin{pmatrix} \bar{\mathrm{uv}} & 1 \\ u & 2 \\ \mathrm{phiM2} & 3 \end{pmatrix} i\,\mathrm{sina}\,\delta_{m_1,m_2}\,\mathrm{lambda}_1\,P_{+s_1\,s_2} + i\,\mathrm{cosa}\,\delta_{m_1,m_2}\,\mathrm{lambda}_2\,P_{+s_1\,s_2} \right|$$

UFO Files

FR-tutorial — bash — 80×24

```
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$
```

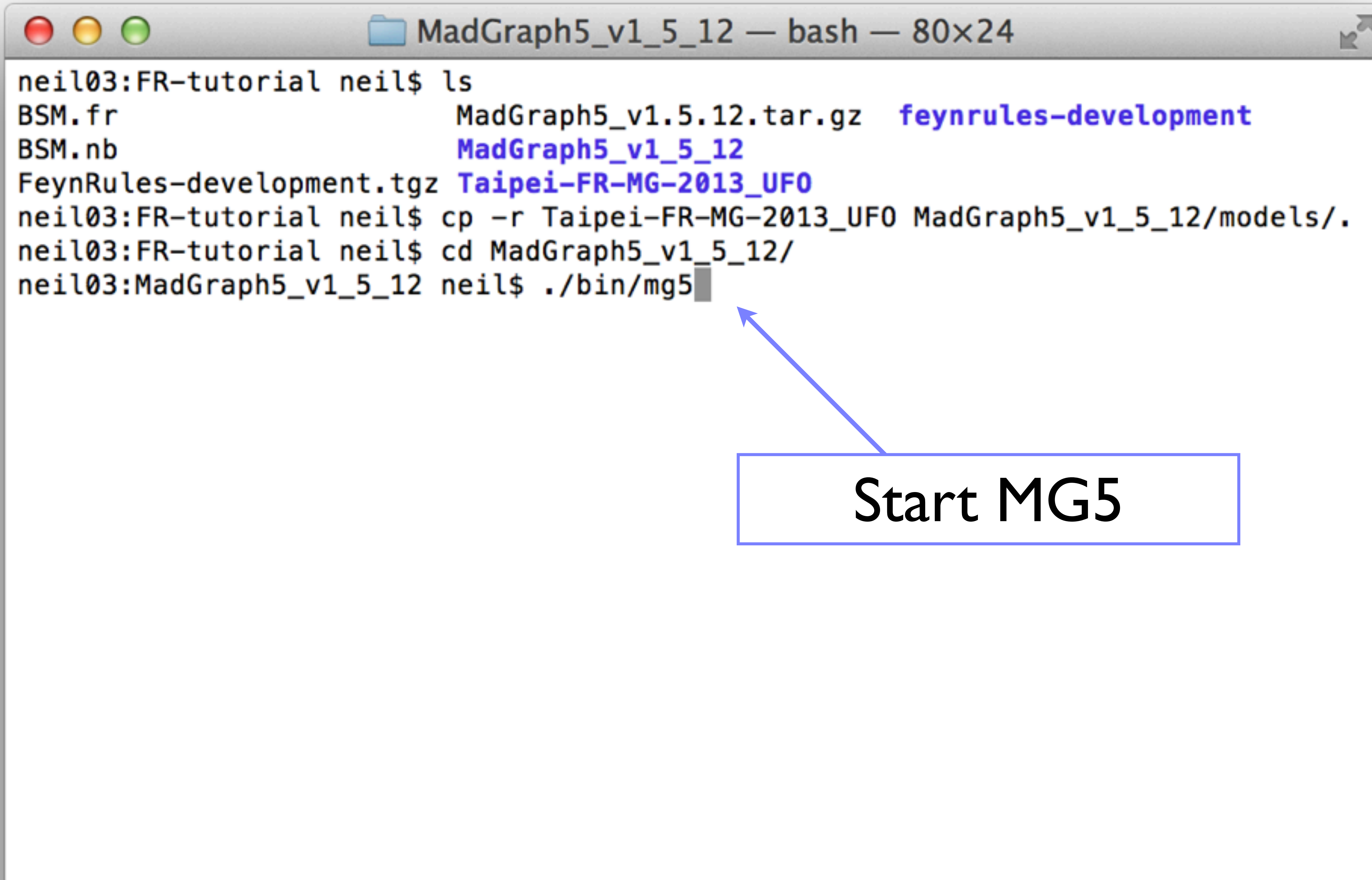
Import UFO → MG5

FR-tutorial — bash — 80×24

```
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



Import UFO → MG5

MadGraph5_v1_5_12 — Python — 80×24

```
*    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 i
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 — 80×24

```
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/s
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 — 80×24

```
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 — 80×24

```
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 — 80×24

```
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 — 80×24

```
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 — 80×24

```
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 — 80×24

```
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 — 80×24

```
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 — 80×24

```
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 0.096 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 — 80×24

```
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 — 80×24

```
      Decay: ev~ > e+ phim1 WEIGHTED=1
INFO: Finding symmetric diagrams for subprocess group ssx_uvuvx_uv_uphim2_phim2_
epev_ev_emphim1
History written to /Users/neil/physics/tmp/FR-tutorial/MadGraph5_v1_5_12/PROC_Ta
ipei-FR-MG-2013_UFO_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_UFO_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_UFO_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_UFO
_0/README
Run "open index.html" to see more information about this process.
mg5>launch
```

Generate Signal

MadGraph5_v1_5_12 — Python — 80×24

```
*                                                           *
*               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_UFO_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_UFO_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 — 80×24

```
    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 5.803798e-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 — 80×24

```
>1
open /Users/neil/physics/tmp/FR-tutorial/MadGraph5_v1_5_12/PROC_Taipei-FR-MG-201
3_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 those 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_Ta
ipei-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, 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]
>
```

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~ , uv > u phiM1 ,\ , p p > uv uv~ , uv > u phiM1 , ...

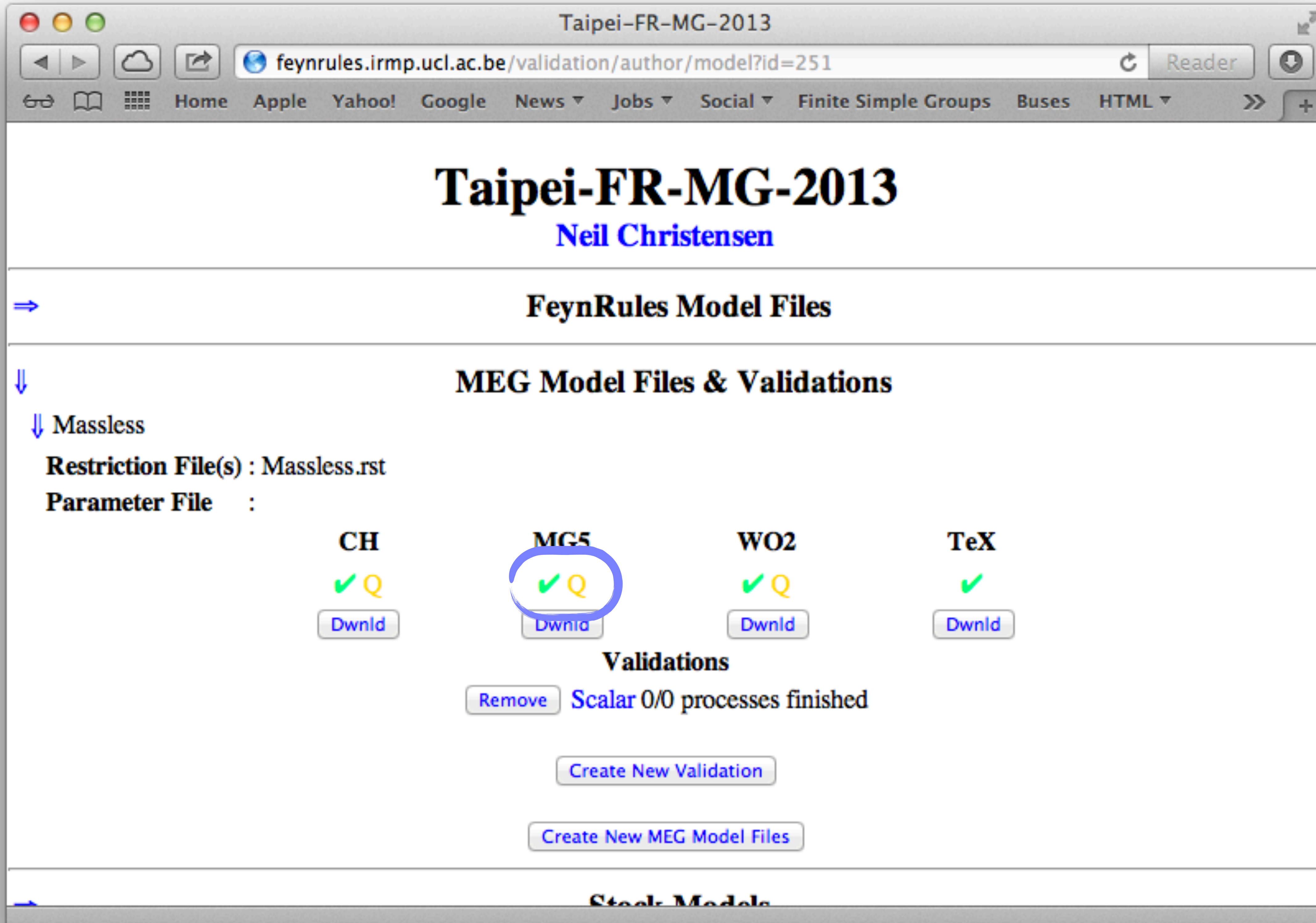
Available Results

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	remove run launch pythia

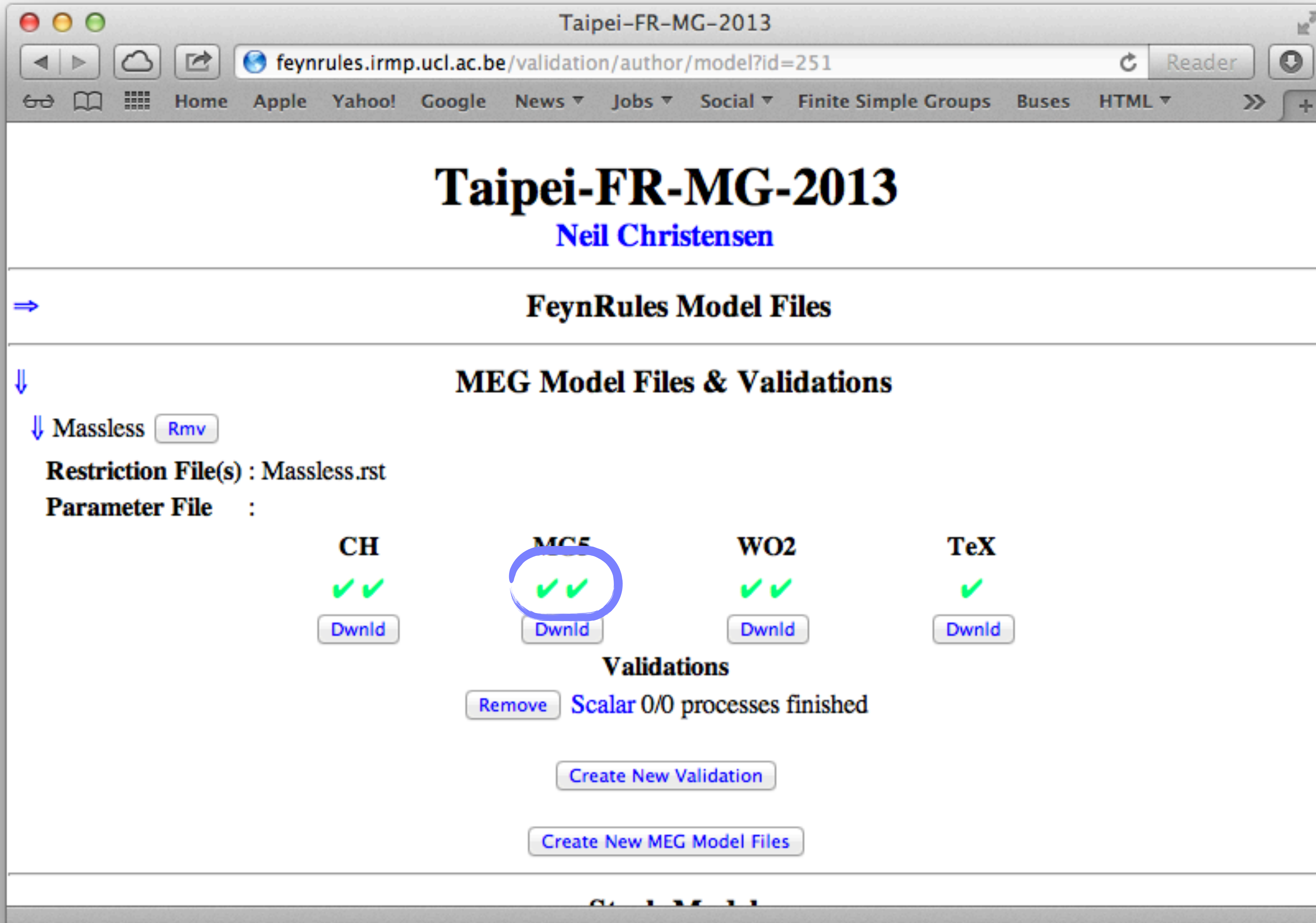
Main Page

Signal Events

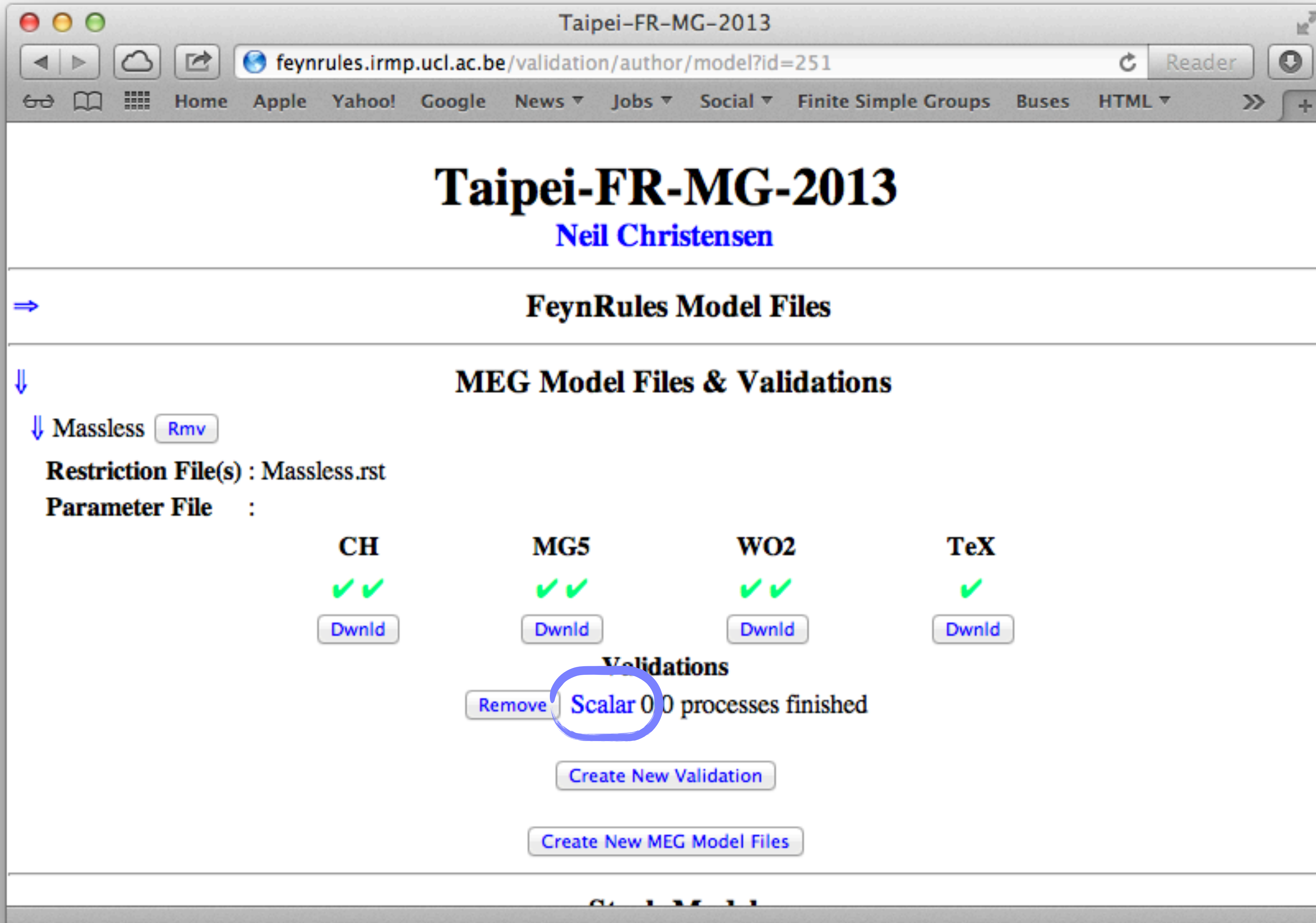
Web Validation



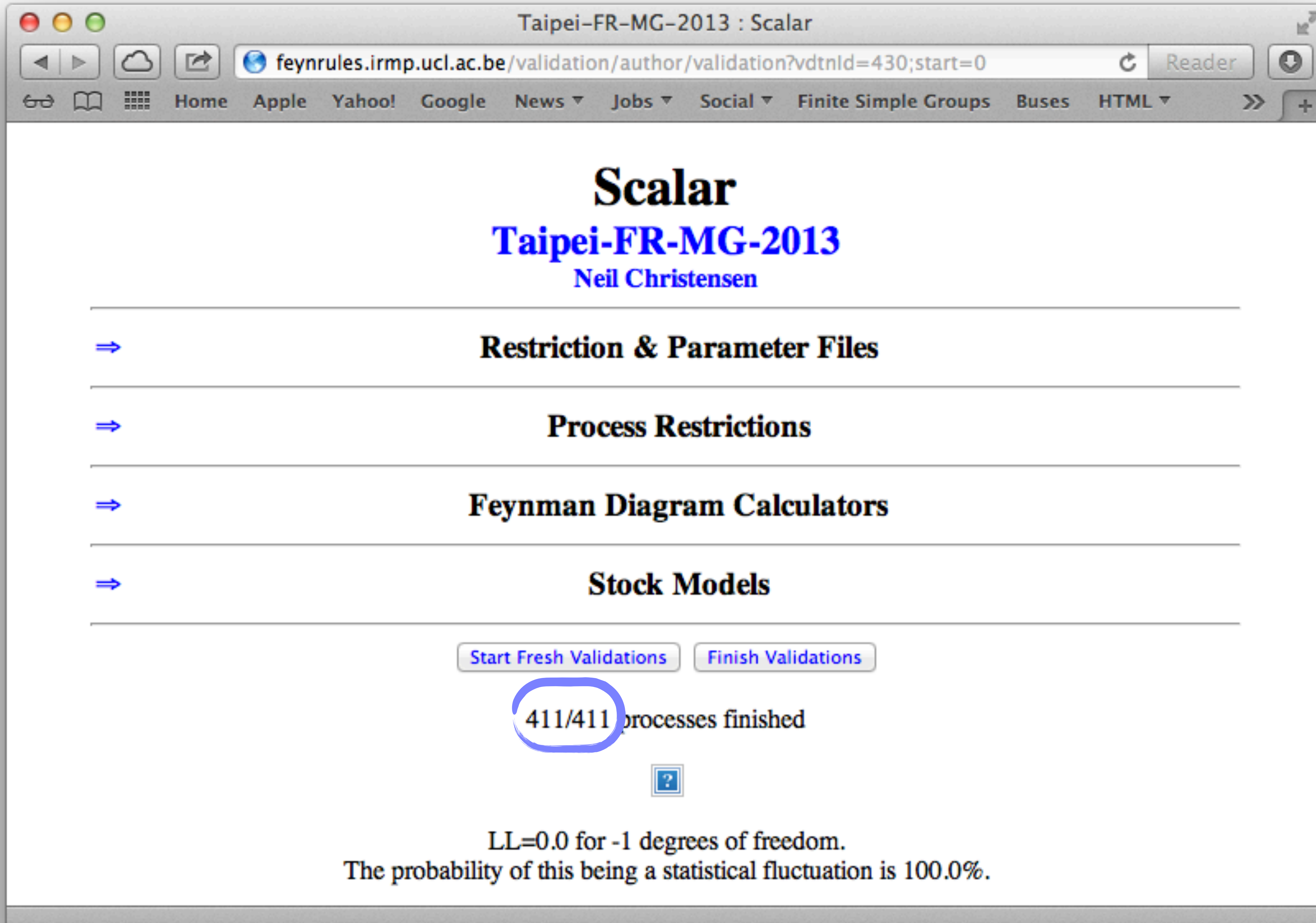
Web Validation



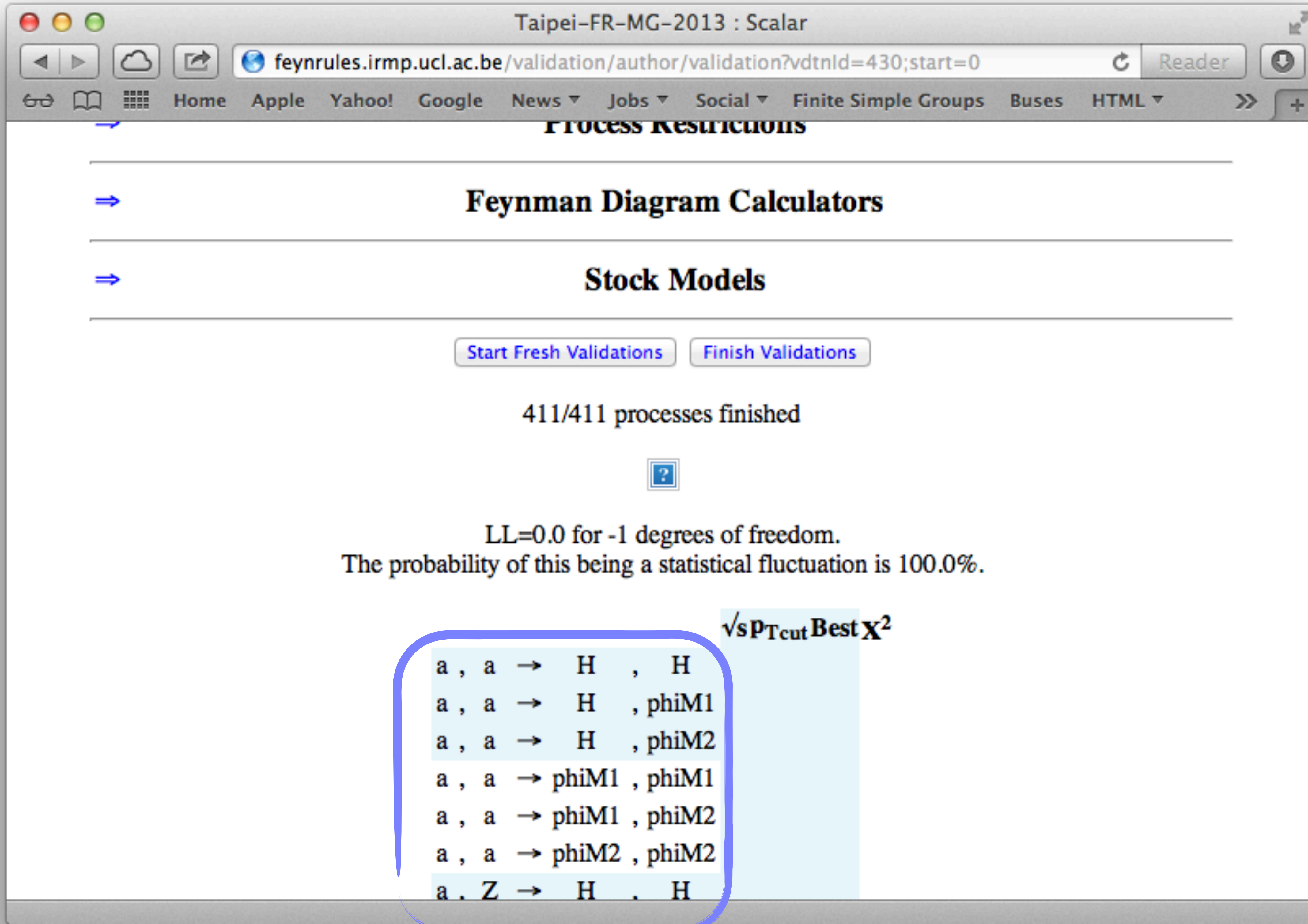
Web Validation



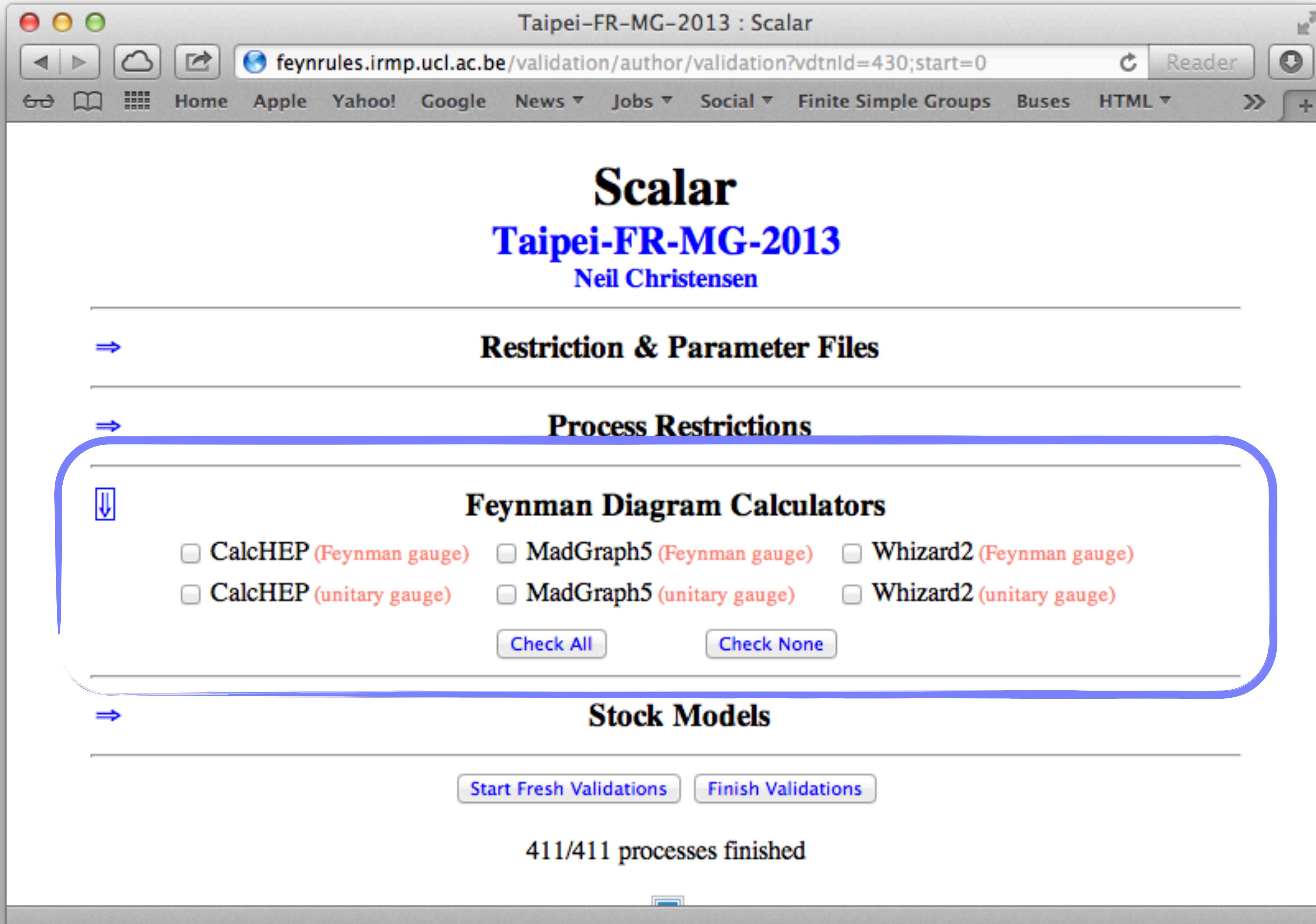
Web Validation



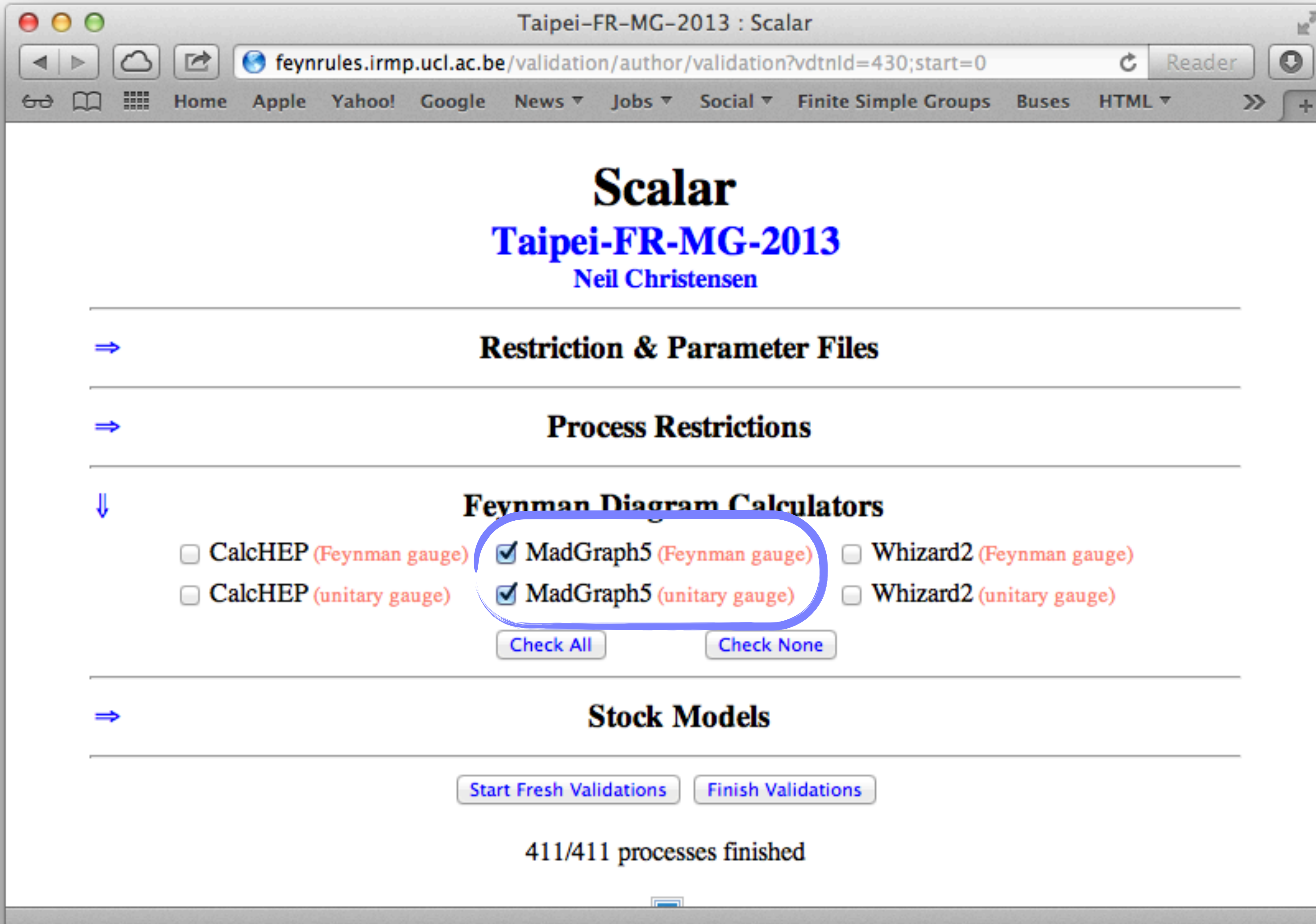
Web Validation



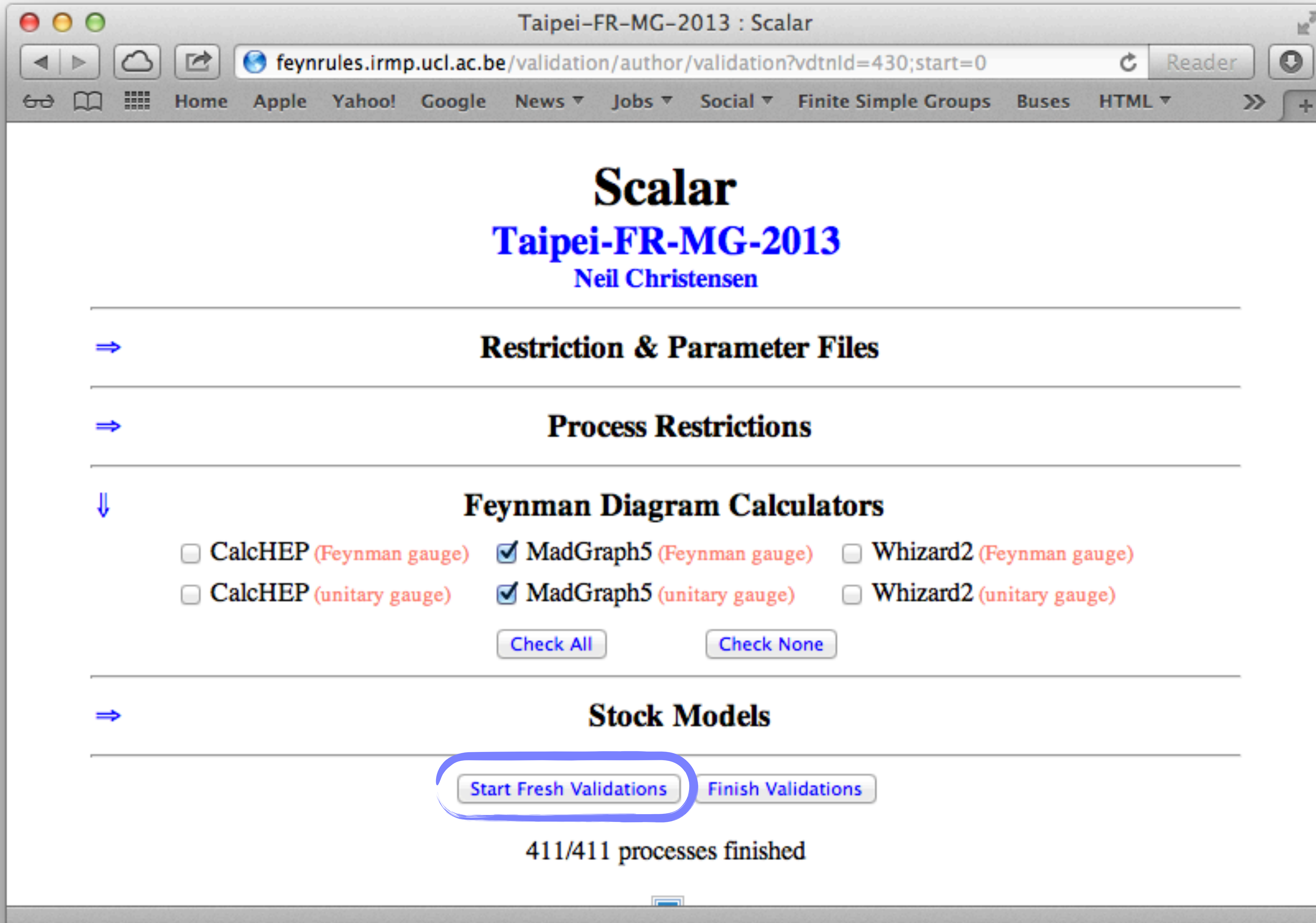
Web Validation



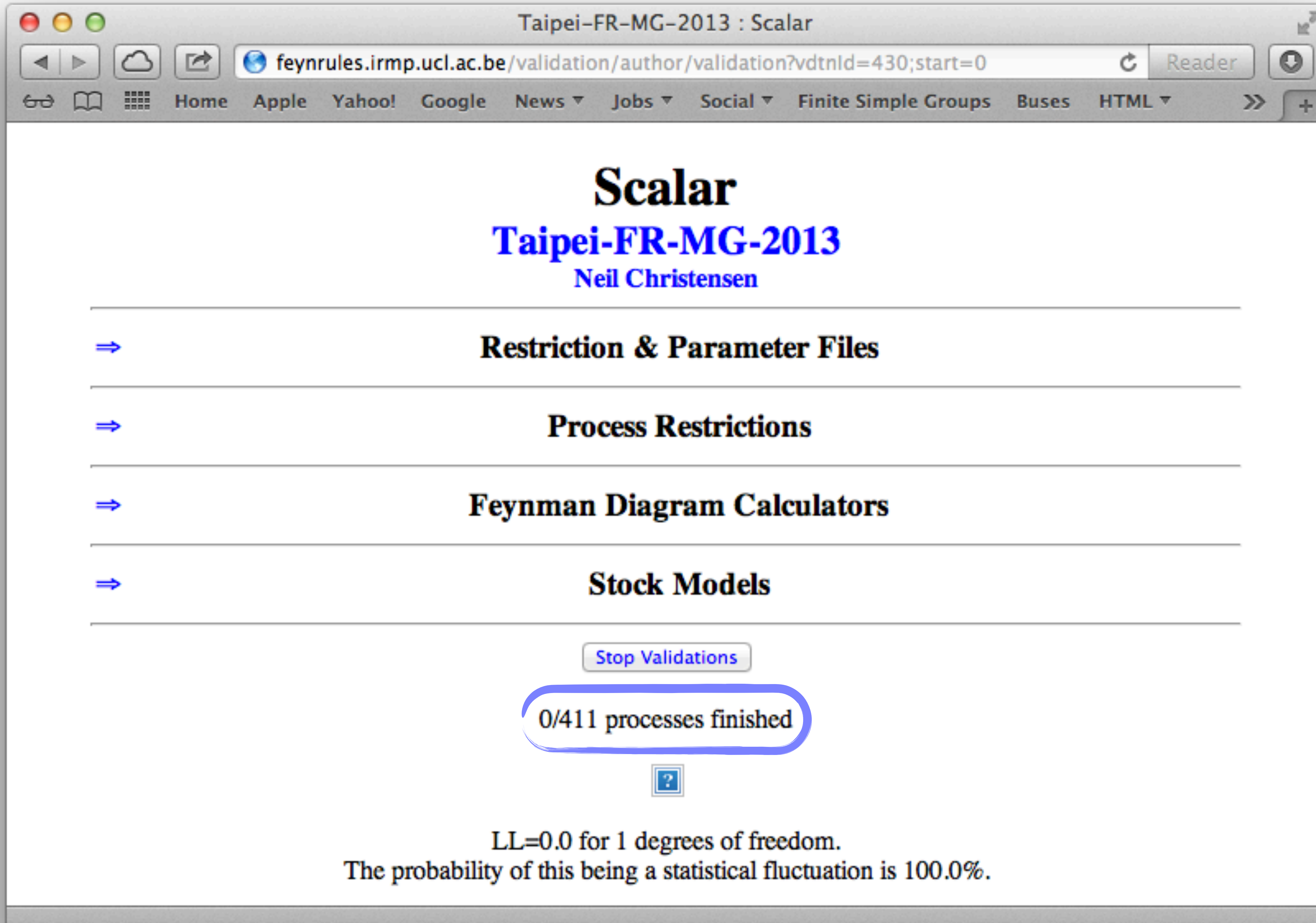
Web Validation



Web Validation



Web Validation

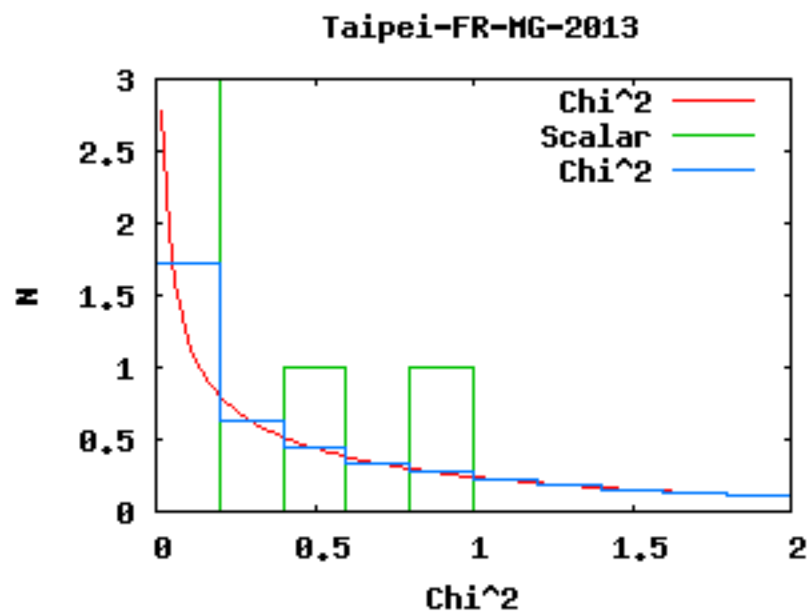


Web Validation

Taipei-FR-MG-2013 : Scalar

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

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



LL=2.4 for 3 degrees of freedom.

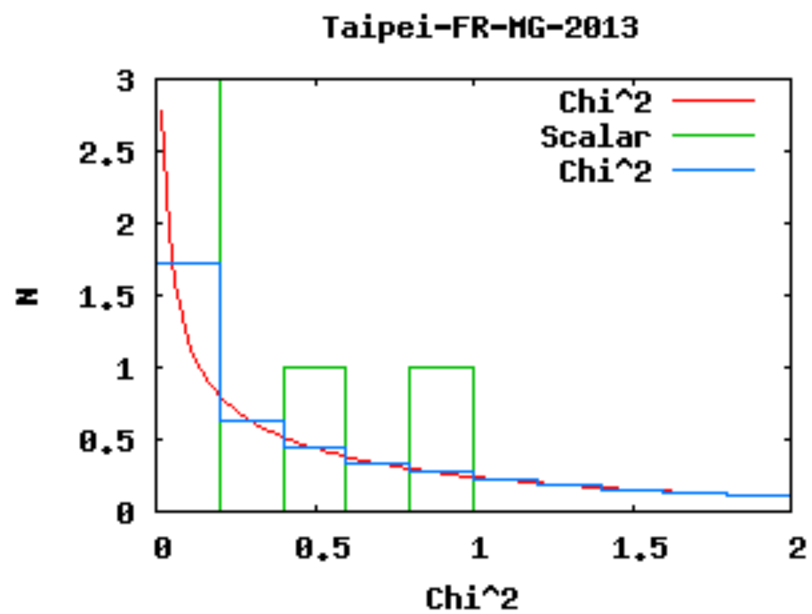
The probability of this being a statistical fluctuation is 49.36 %.

							$\sqrt{s}$	$p_{T,cut}$	Best	MG5(F)	MG5(u)	χ^2
a	,	b	→	b	,	H	1036.0	259.0	3.679E-05	3.669E-05	3.690E-05	9.7E-01
a	,	ta-	→	ta-	,	H	988.0	247.0	3.132E-05	3.141E-05	3.162E-05	3.1E-01
Z	,	ve	→	ve	,	H	845.0	211.25	1.231E+00	1.232E+00	1.229E+00	1.1E-01
a	,	t	→	t	,	H	1856.0	464.0	6.350E-02	6.356E-02	6.345E-02	8.9E-02
Z	,	Z	→	H	,	H	1690.0	422.5	2.495E-01	2.500E-01	2.490E-01	7.7E-02
a	,	a	→	H	,	H	960.0	240.0	0.000E+00	0.000E+00	0.000E+00	0.0E+00

Web Validation

Taipei-FR-MG-2013 : Scalar

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



LL=2.4 for 3 degrees of freedom.
The probability of this being a statistical fluctuation is 49.36 %.

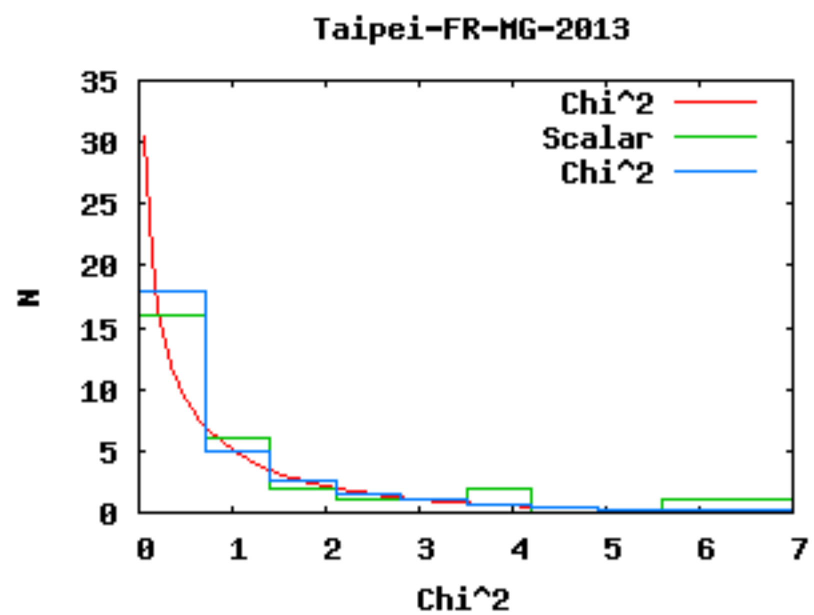
	$\sqrt{s}$	p_{Tcut}	Best	MG5(F)	MG5(u)	X^2
a , b → b , H	1036.0	259.0	3.679E-05	3.669E-05	3.690E-05	9.7E-01
a , ta- → ta- , H	988.0	247.0	5.152E-05	5.141E-05	5.162E-05	5.1E-01
Z , ve → ve , H	845.0	211.25	1.231E+00	1.232E+00	1.229E+00	1.1E-01
a , t → t , H	1856.0	464.0	6.350E-02	6.356E-02	6.345E-02	8.9E-02
Z , Z → H , H	1690.0	422.5	2.495E-01	2.500E-01	2.490E-01	7.7E-02
a , a → H , H	960.0	240.0	0.000E+00	0.000E+00	0.000E+00	0.0E+00

Web Validation

Taipei-FR-MG-2013 : Scalar

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

290/411 processes finished



LL=7.1 for 8 degrees of freedom.
The probability of this being a statistical fluctuation is 52.59 %.

					$\sqrt{s}$	p_{Tcut}	Best	MG5(F)	MG5(u)	χ^2
Z	, c	→	c	, H	845.0	211.25	7.080E-01	7.015E-01	7.147E-01	6.5E+00
W+	, W-	→	H	, H	1599.0	399.75	1.510E-01	1.484E-01	1.537E-01	5.7E+00
Z	, t	→	t	, H	2221.0	555.25	4.237E-01	4.261E-01	4.214E-01	3.9E+00
Z	, mu-	→	mu-	, H	845.0	211.25	6.235E-01	6.189E-01	6.278E-01	3.7E+00

Open "http://feynrules.irmp.ucl.ac.be/validation/author/disHistEPS?vdtnId=430" in a new tab

Web Validation

Taipei-FR-MG-2013 : Scalar

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

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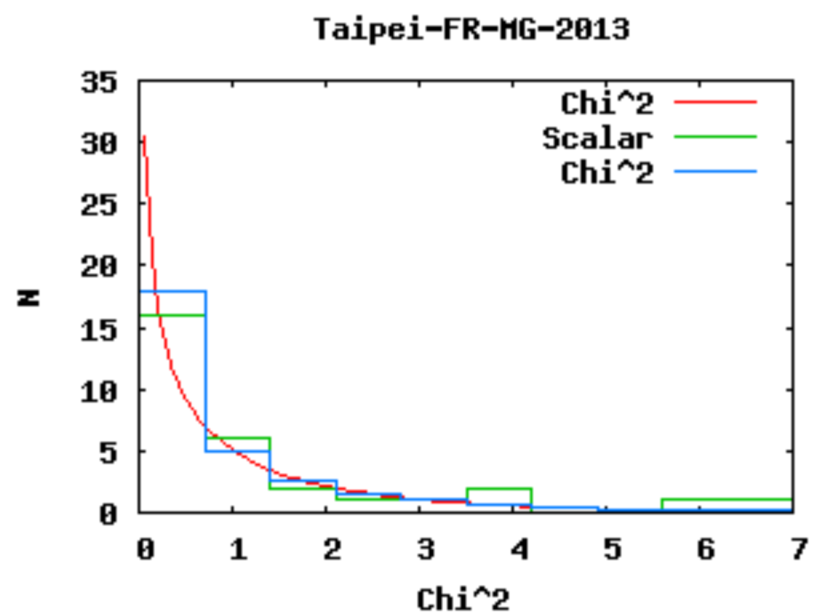
290/411 processes finished



LL=7.1 for 8 degrees of freedom.
The probability of this being a statistical fluctuation is 52.59 %.

Process	$\sqrt{s}$	$p_{T\,cut}$	Best	MG5(F)	MG5(u)	χ^2
Z , c → c , H	845.0	211.25	7.080E-01	7.015E-01	7.147E-01	6.5E+00
W+ , W- → H , H	1599.0	399.75	1.510E-01	1.484E-01	1.537E-01	5.7E+00
Z , t → t , H	2221.0	555.25	4.237E-01	4.261E-01	4.214E-01	3.9E+00
Z , mu- → mu- , H	845.0	211.25	6.235E-01	6.189E-01	6.278E-01	3.7E+00

Open "http://feynrules.irmp.ucl.ac.be/validation/author/disHistEPS?vdtnId=430" in a new tab

Web Validation

Taipei-FR-MG-2013 : Scalar

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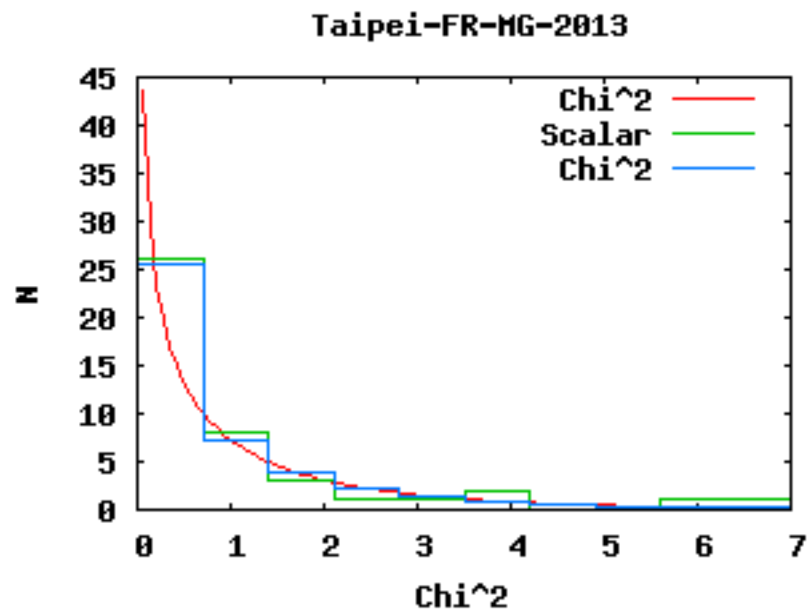
411/411 processes finished



LL=5.5 for 8 degrees of freedom.
The probability of this being a statistical fluctuation is 70.3526451428%.

	√s	$p_{T\,cut}$	Best	MG5(F)	MG5(u)	X^2
Z , c → c , H	845.0	211.25	7.080E-01	7.015E-01	7.147E-01	6.5E+00
W+ , W- → H , H	1599.0	399.75	1.510E-01	1.484E-01	1.537E-01	5.7E+00
Z , t → t , H	2221.0	555.25	4.237E-01	4.261E-01	4.214E-01	3.9E+00
Z , mu- → mu- , H	845.0	211.25	6.235E-01	6.189E-01	6.278E-01	3.7E+00

Web Validation

Taipei-FR-MG-2013 : Scalar

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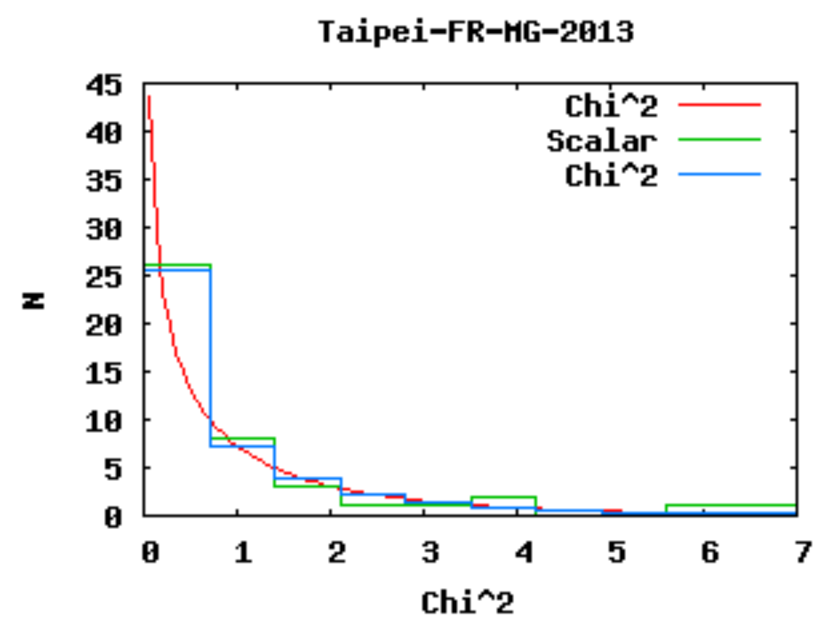
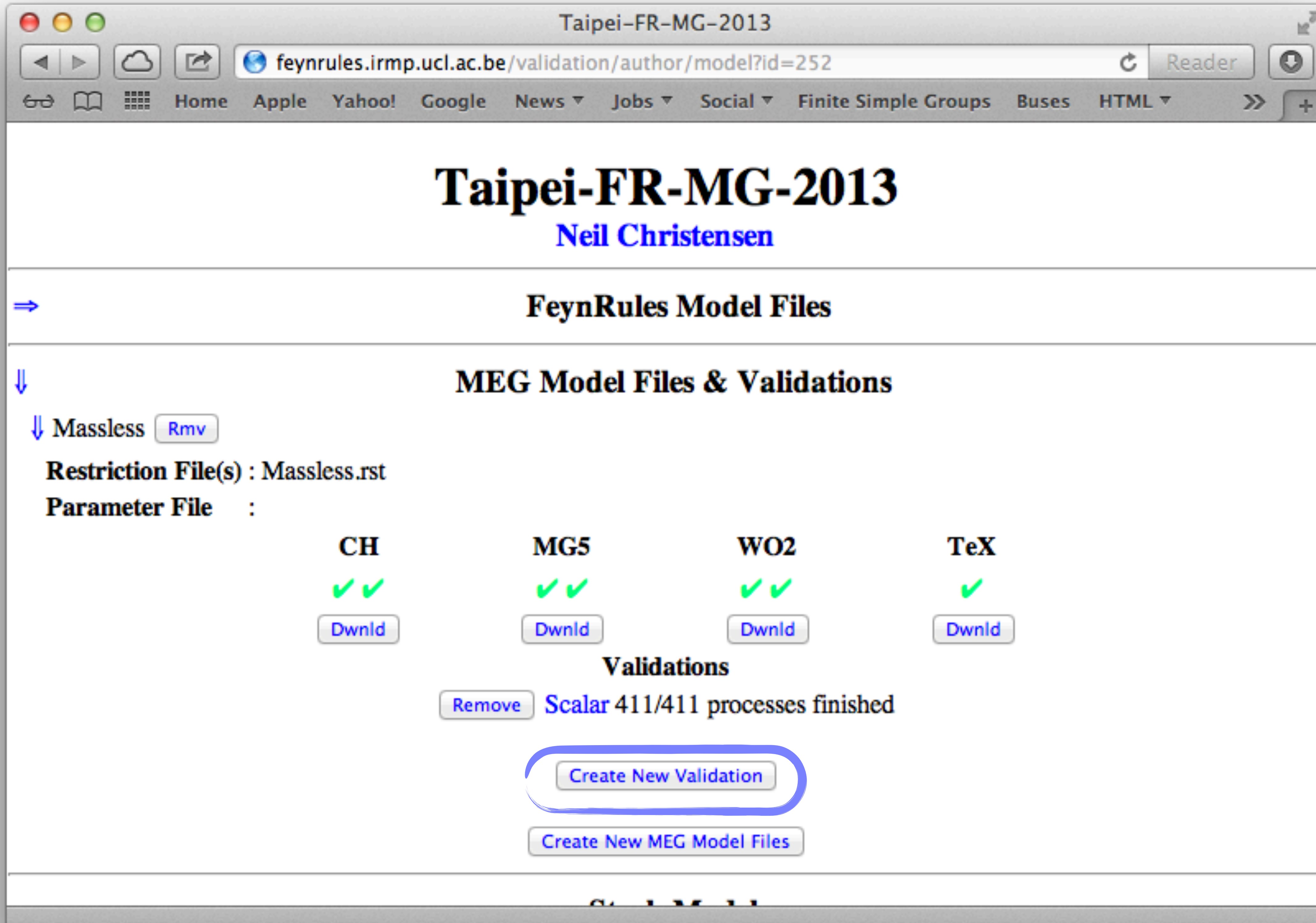
411/411 processes finished



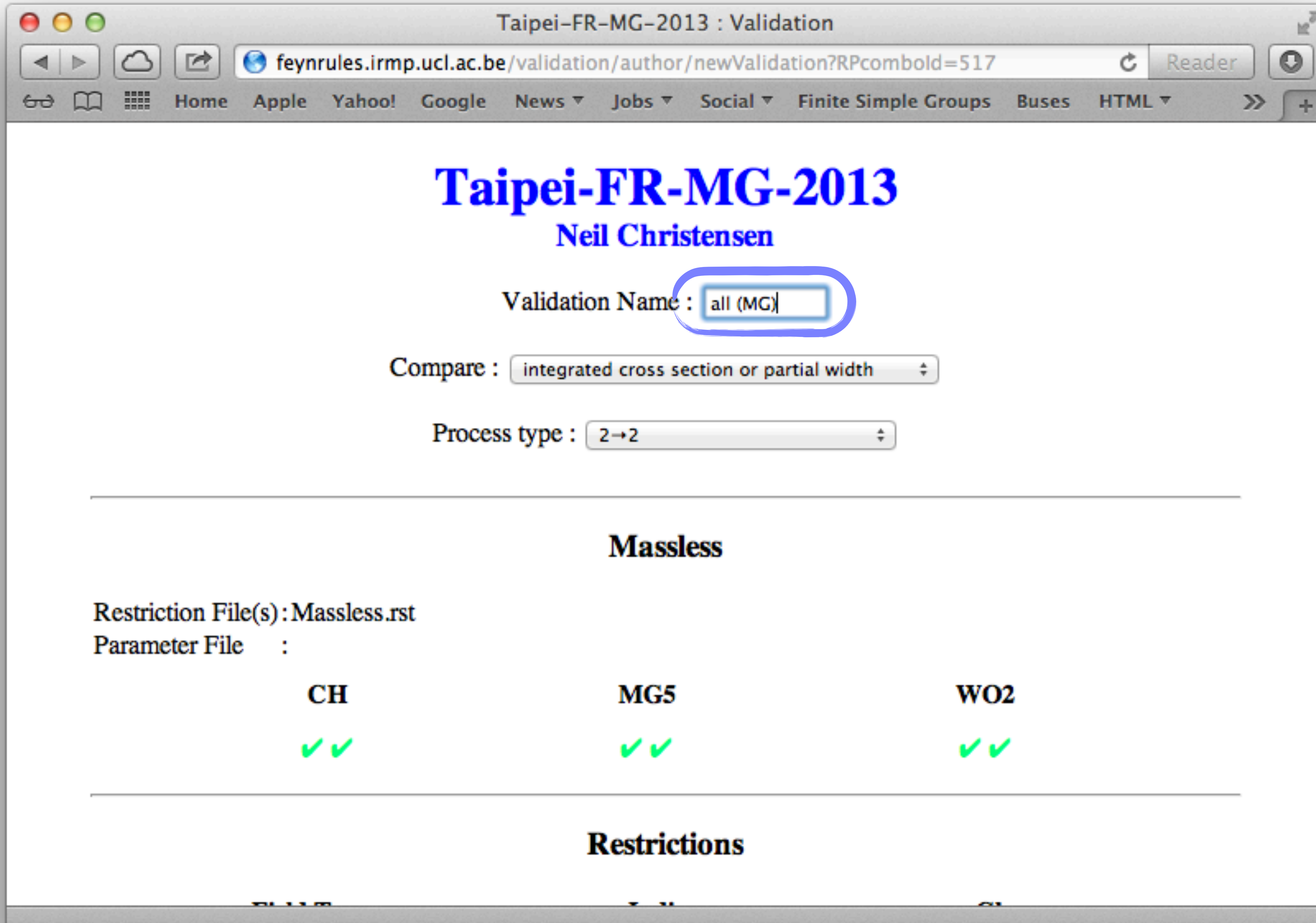
LL=5.5 for 8 degrees of freedom.
The probability of this being a statistical fluctuation is 70.3526451428%.

					$\sqrt{s}$	$p_{T\,cut}$	Best	MG5(F)	MG5(u)	X^2
Z	, c	→	c	, H	845.0	211.25	7.080E-01	7.015E-01	7.147E-01	6.5E+00
W+	, W-	→	H	, H	1599.0	399.75	1.510E-01	1.484E-01	1.537E-01	5.7E+00
Z	, t	→	t	, H	2221.0	555.25	4.237E-01	4.261E-01	4.214E-01	3.9E+00
Z	, mu-	→	mu-	, H	845.0	211.25	6.235E-01	6.189E-01	6.278E-01	3.7E+00

Web Validation



Web Validation



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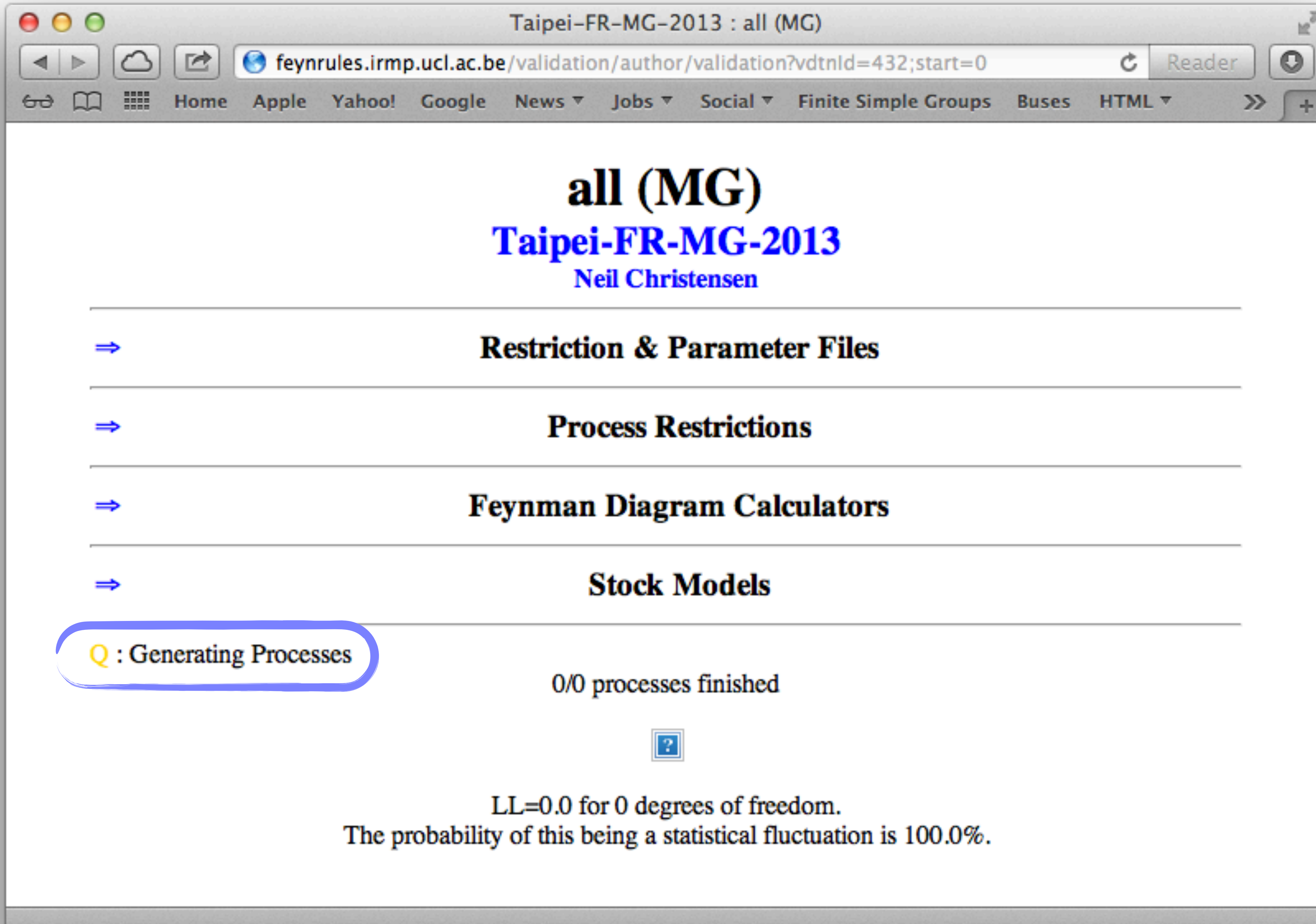
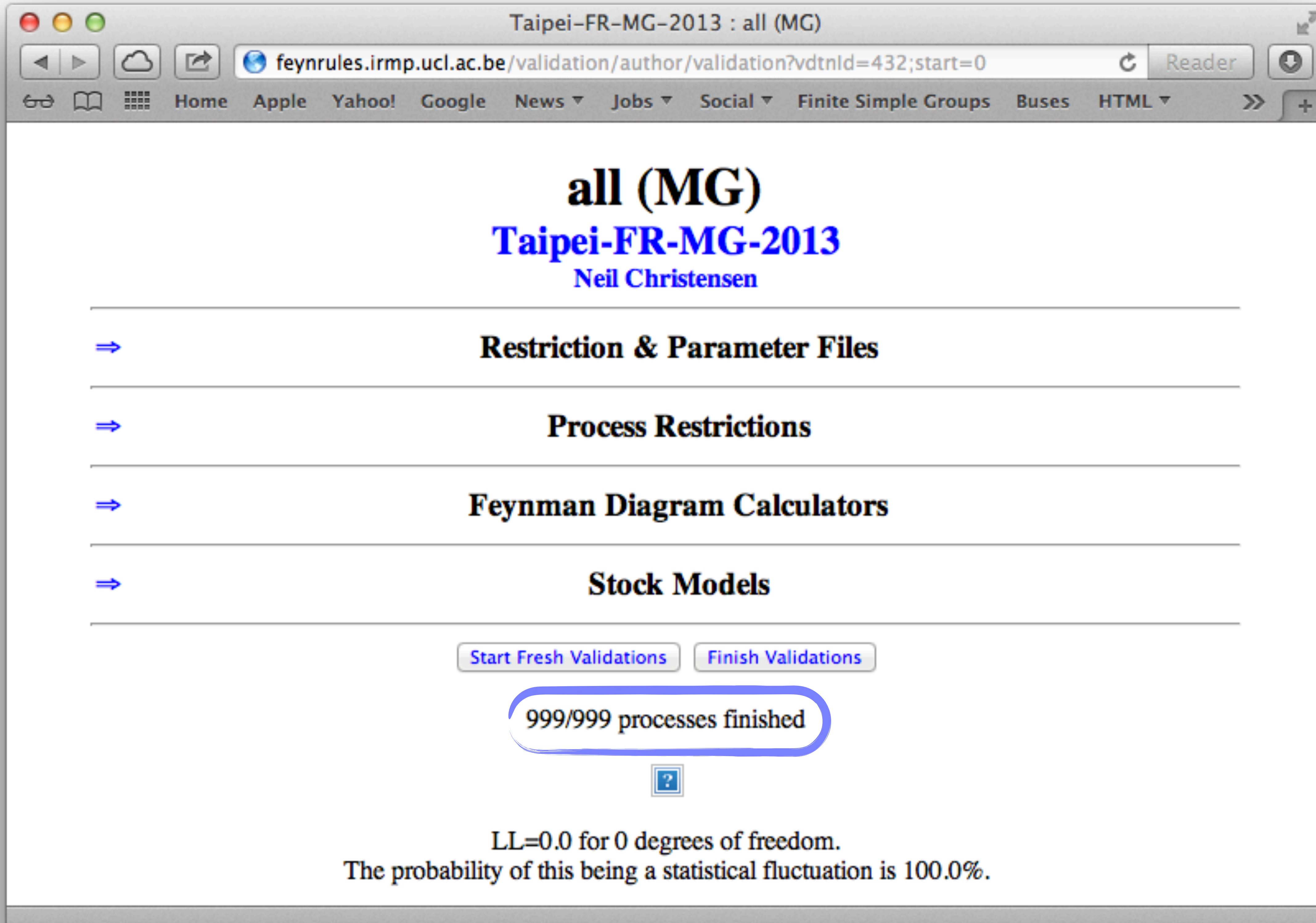
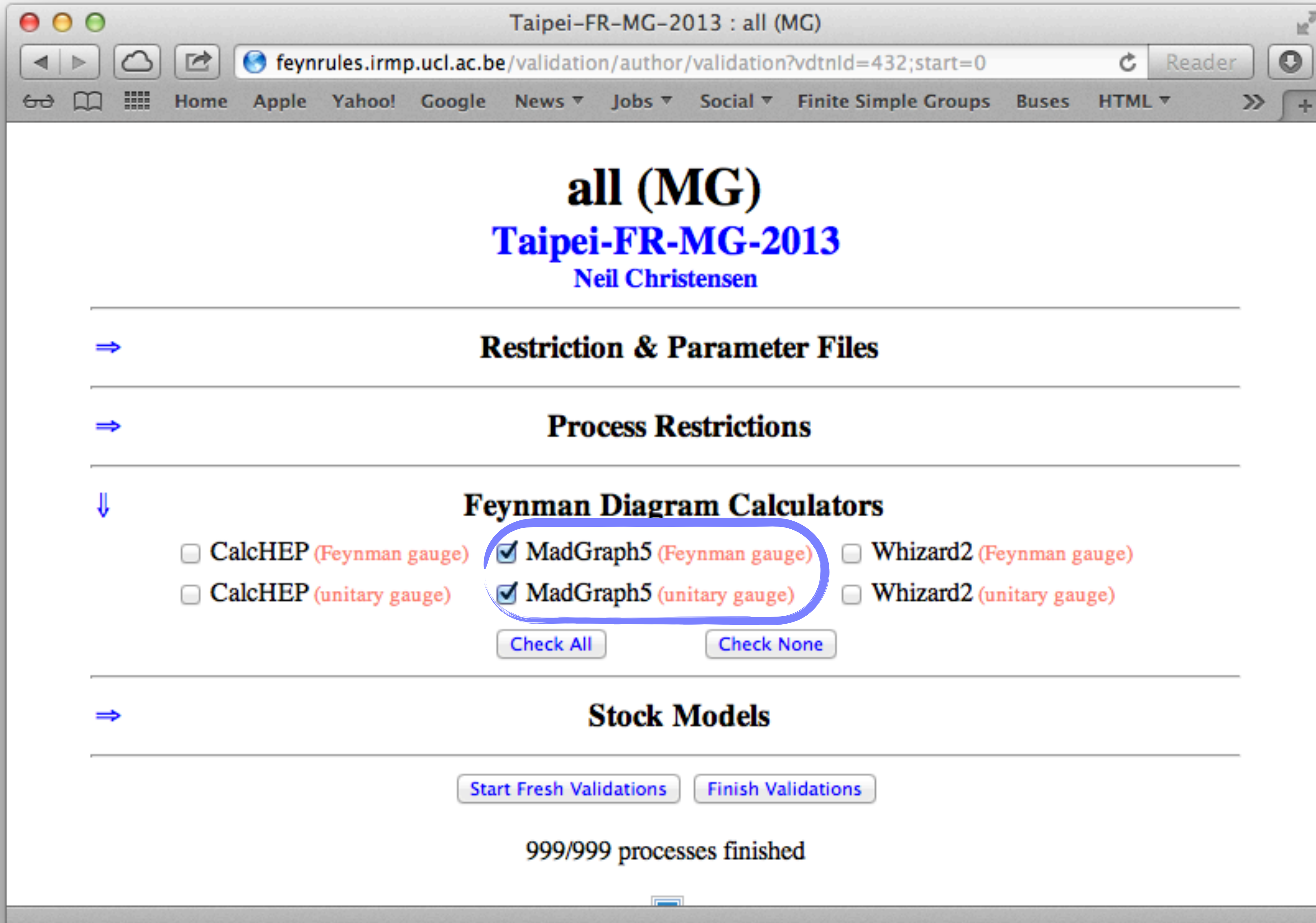


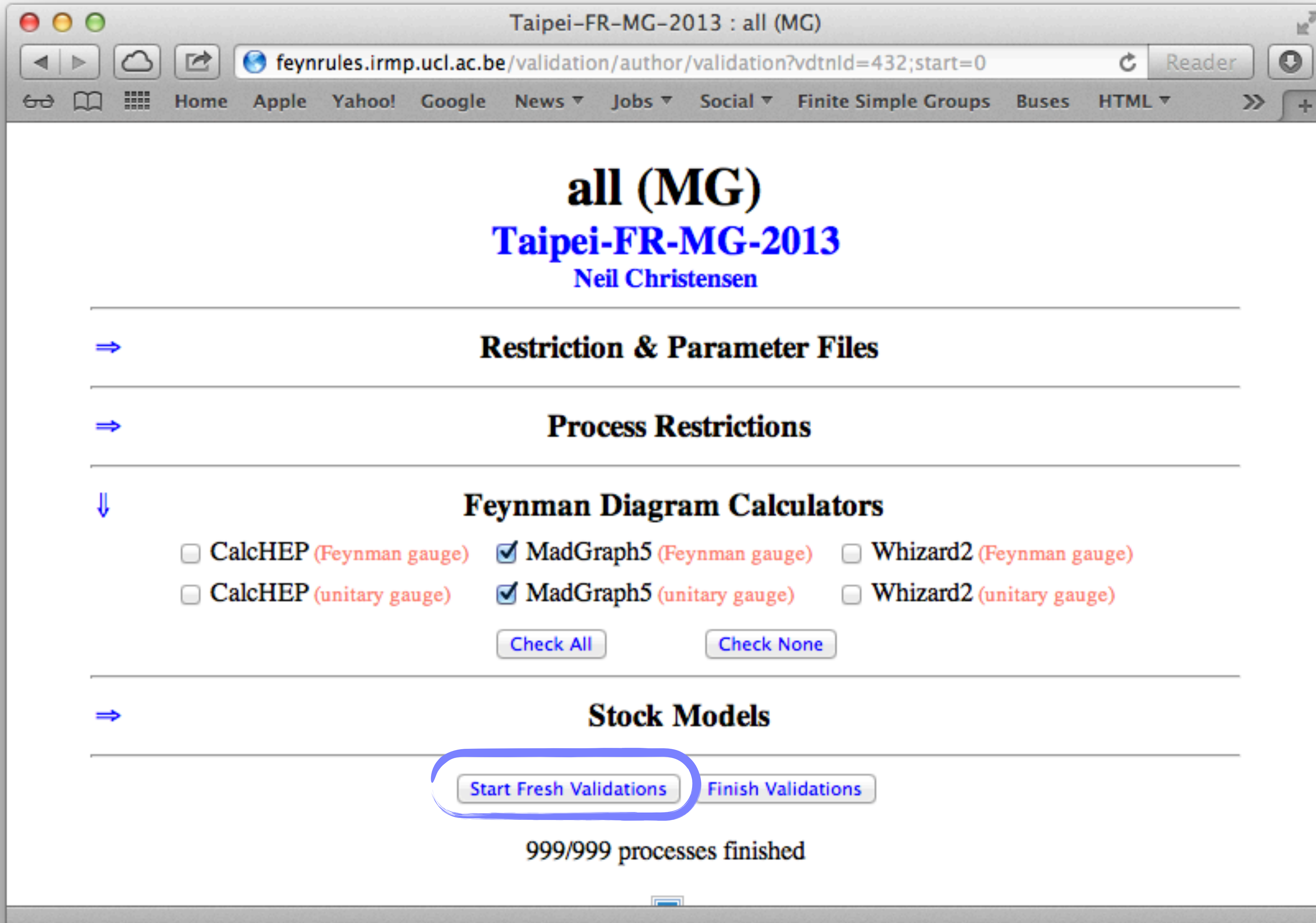
Web Validation



Web Validation



Web Validation



Web Validation

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

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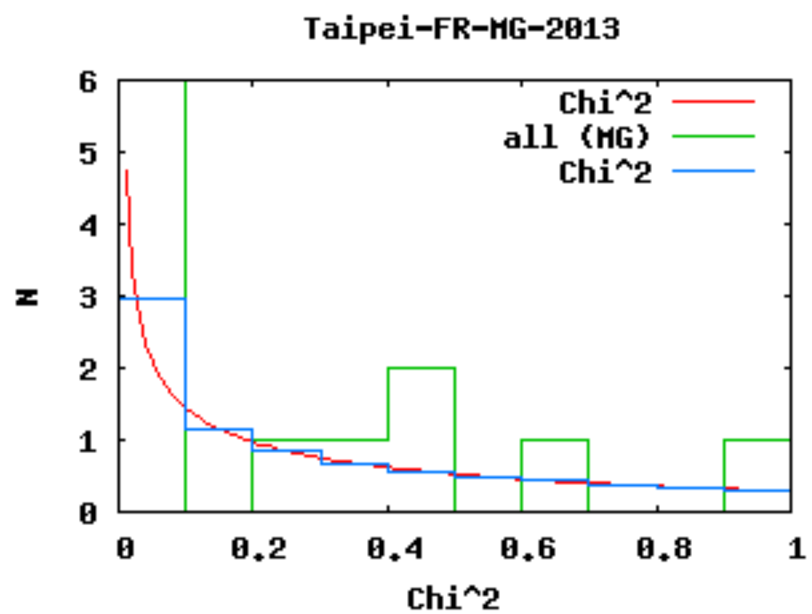

LL=6.2 for 6 degrees of freedom.
The probability of this being a statistical fluctuation is 40.0761347349%.

	$\sqrt{s}$	p_{Tcut}	Best	MG5(F)	MG5(u)	X^2
a , a → W+ , W-	639.0	159.75	1.642E+01	1.634E+01	1.654E+01	9.1E-01
a , a → d , d~	800.0	200.0	3.055E-02	3.061E-02	3.048E-02	6.1E-01
a , a → ta- , ta+	800.0	200.0	8.273E-01	8.260E-01	8.289E-01	4.3E-01
a , a → t , t~	1376.0	344.0	1.567E-01	1.565E-01	1.570E-01	4.1E-01
a , a → b , b~	800.0	200.0	3.070E-02	3.075E-02	3.065E-02	3.7E-01

Web Validation

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

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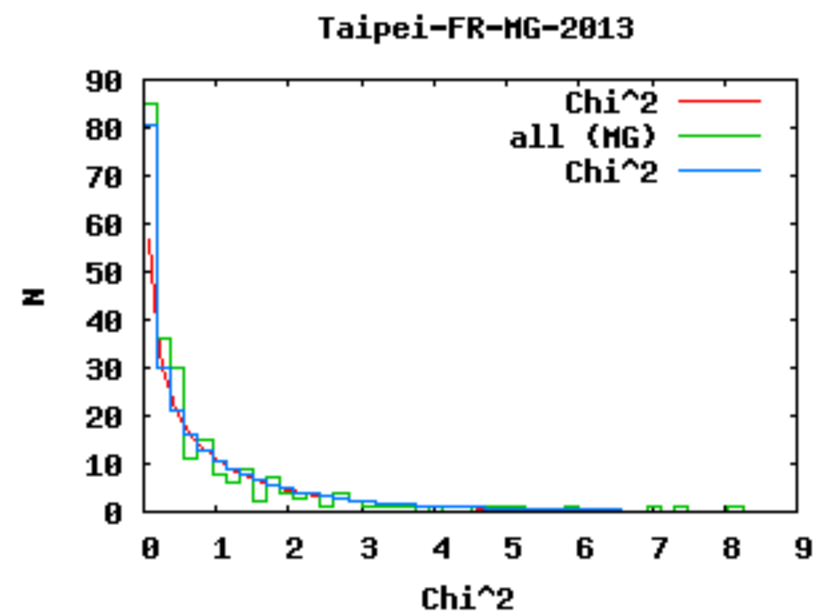

LL=26.0 for 29 degrees of freedom.
The probability of this being a statistical fluctuation is 62.5641141134%.

	$\sqrt{s}$	$p_{T\,cut}$	Best	MG5(F)	MG5(u)	X^2
u , u~ → ev , ev~	2400.0	600.0	1.858E-03	1.880E-03	1.845E-03	8.1E+00
e- , e- → e- , e-	800.0	200.0	8.882E+00	8.797E+00	8.953E+00	7.4E+00
Z , H → ev , ev~	3245.0	811.25	1.308E-03	1.321E-03	1.295E-03	7.0E+00
vm , mu+ → t , b~	707.0	176.75	5.073E-01	5.043E-01	5.103E-01	5.9E+00

Web Validation

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

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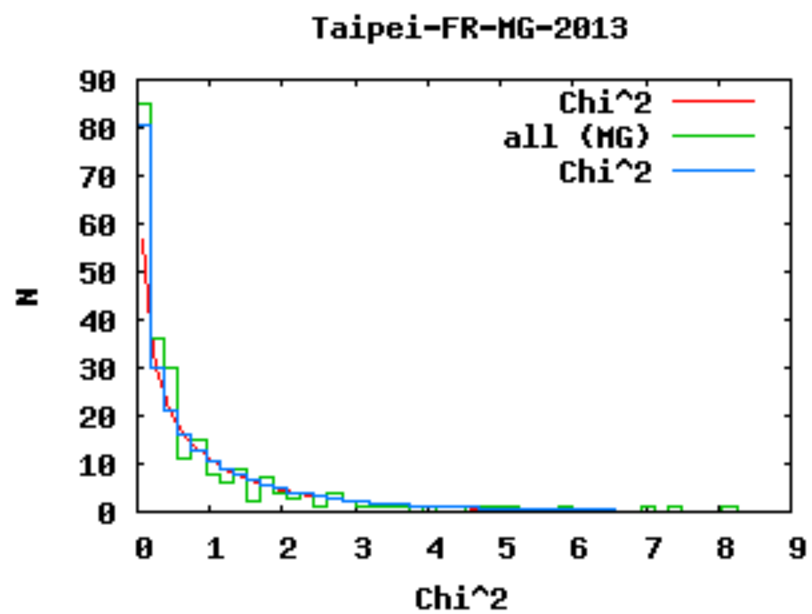

LL=26.0 for 29 degrees of freedom
The probability of this being a statistical fluctuation is 62.5641141134%.

Process	$\sqrt{s}$	p_{Tcut}	Best	MG5(F)	MG5(u)	X^2
u , u~ → ev , ev~	2400.0	600.0	1.858E-03	1.880E-03	1.845E-03	8.1E+00
e- , e- → e- , e-	800.0	200.0	8.882E+00	8.797E+00	8.953E+00	7.4E+00
Z , H → ev , ev~	3245.0	811.25	1.308E-03	1.321E-03	1.295E-03	7.0E+00
vm , mu+ → t , b~	707.0	176.75	5.073E-01	5.043E-01	5.103E-01	5.9E+00