

```
In[2]:= NotebookDirectory []
```

```
Out[2]= /home/gluza/calculations/Zdecay_Nmix_NLO/Szymon/
```

```
In[ * ]:= Quit[]
```

```
In[ * ]:= << FeynArts`
```

```
FeynArts 3.11 (25 Mar 2022)
```

```
by Hagen Eck, Sepp Kueblbeck, and Thomas Hahn
```

```
In[ * ]:= << FormCalc`
```

```
FormCalc 9.9 (11 Dec 2021)
```

```
by Thomas Hahn
```

```
(*
```

```
gluza@gluzaX1:~/calculations/FeynInstall_all_2022/FeynArts-3.11/Models$ ln-  
s~/calculations/Zdecay_Nmix_NLO/Szymon/SM_HeavyNU_FA/SM_HeavyNU_FA.mod
```

```
gluza@gluzaX1:~/calculations/FeynInstall_all_2022/FeynArts-3.11/Models$ ln-  
s~/calculations/Zdecay_Nmix_NLO/Szymon/SM_HeavyNU_FA/SM_HeavyNU_FA.gen
```

```
*)
```

```
In[ * ]:= SetOptions[InsertFields, Model → "SM_HeavyNU_FA",  
GenericModel → "SM_HeavyNU_FA", InsertionLevel → {Classes}];
```

```
In[ * ]:= SetOptions[Paint, PaintLevel → {Classes}, FieldNumbers → True, ColumnsXRows → {3, 3}];
```

```
In[ * ]:= topologies = CreateTopologies [1, 1 → 2, ExcludeTopologies → {Internal, Tadpoles}];
```

```
In[ * ]:= cttopologies = CreateCTTopologies [1, 1 → 2];
```

```
In[ * ]:= proces = V[2] → {F[4], -F[4]};
```

```
In[ * ]:= counter = InsertFields[cttopologies, proces];
```

```
inserting at level(s) {Classes}  
> Top. 1: 0 Classes insertions  
> Top. 2: 0 Classes insertions  
> Top. 3: 0 Classes insertions  
> Top. 4: 0 Classes insertions  
> Top. 5: 0 Classes insertions  
> Top. 6: 0 Classes insertions  
> Top. 7: 0 Classes insertions  
> Top. 8: 0 Classes insertions  
in total: 0 Classes insertions
```

```
Zdecay = InsertFields [cttopologies , proces];
```

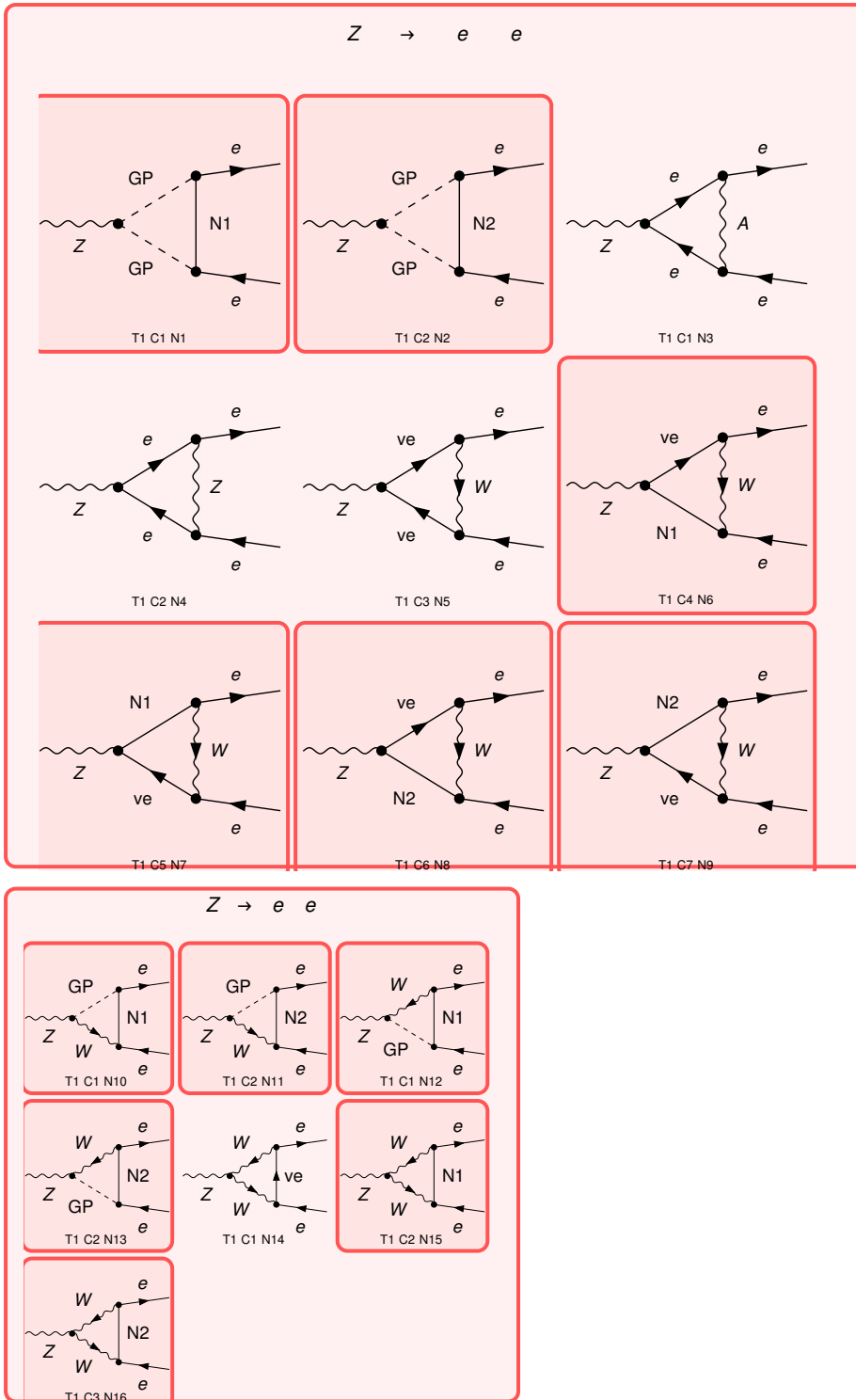
```
loading generic model file  
/home/gluza/calculations /FeynInstall_all _2022/FeynArts -3.11/Models /SM_HeavyNU _FA.gen  
> $GenericMixing is OFF  
generic model {SM_HeavyNU_FA} initialized
```

```
loading classes model file  
/home/gluza/calculations /FeynInstall_all _2022/FeynArts -3.11/Models /SM_HeavyNU _FA.mod  
> 45 particles (incl. antiparticles) in 26 classes  
> $CounterTerms are ON  
> 173 vertices  
classes model {SM_HeavyNU_FA} initialized
```

```
inserting at level(s) {Classes}  
> Top. 1: 16 Classes insertions  
> Top. 2: 0 Classes insertions  
> Top. 3: 0 Classes insertions  
> Top. 4: 0 Classes insertions  
in total: 16 Classes insertions
```

```
Inf * := Paint[Zdecay];
```

> Top. 1 ad/becf/dedfef.m, 0 diagrams



`In[]:= CreateFeynAmp [Zdecay][6]`

```
creating amplitudes at level(s) {Classes}
```

```
> Top. 1: 16 Classes amplitudes
```

```
in total: 16 Classes amplitudes
```

```
Out[ * ]:= FeynAmp[GraphID[Topology == 1, Generic == 2, Classes == 4, Number == 6], Integral[q1],
-  $\frac{1}{16 \pi^4} \bar{u}[k1, 0].(i \text{ gc159 ga[Lor2]}.(\text{omSubscript[-]})).\text{gs}[q1].(i \text{ gc129 ga[Lor1]}.(\text{omSubscript[-]})).$ 
(mN1 + gs[q1 - k1 - k2]).(i \text{ gc111 ga[Lor3]}.(\text{omSubscript[-]})).v[k2, 0] FeynAmpDenominator [
 $\frac{1}{(q1)^2}, \frac{1}{-MW2 + (q1 - k1)^2}, \frac{1}{-mN1^2 + (q1 - k1 - k2)^2}$ ] g[Lor2, Lor3] ep[V[2], p1, Lor1]
```

```
In[ * ]:= Paint[counter]
```

```
In[ * ]:= proces2 = V[2] → {F[5], -F[5]};
```

```
In[ * ]:= Zdecay2 = InsertFields [topologies , proces2];
```

```
inserting at level(s) {Classes}
```

```
> Top. 1: 16 Classes insertions
```

```
> Top. 2: 0 Classes insertions
```

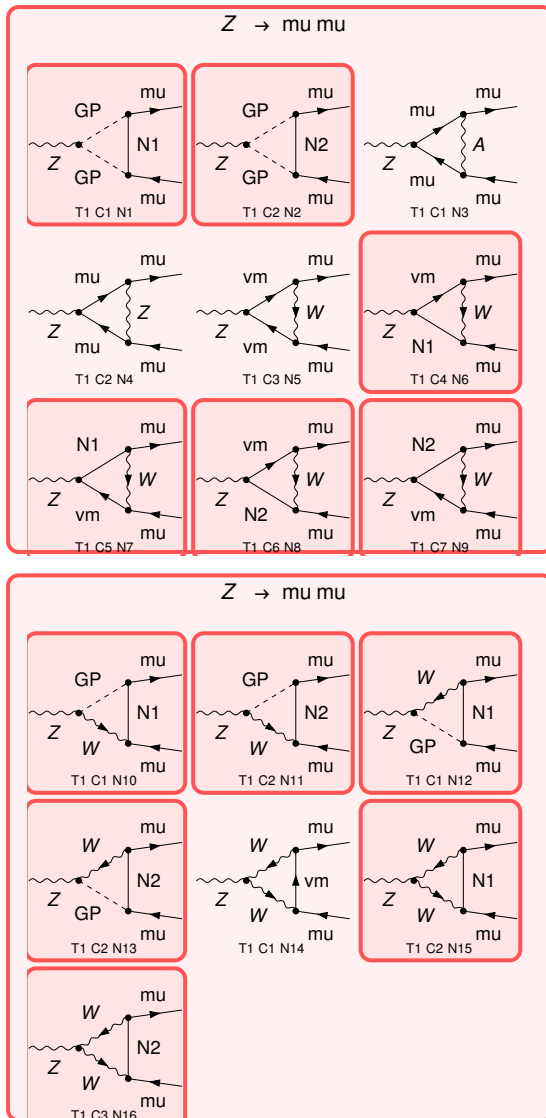
```
> Top. 3: 0 Classes insertions
```

```
> Top. 4: 0 Classes insertions
```

```
in total: 16 Classes insertions
```

```
In[ * ]:= Paint[Zdecay2];
```

> Top. 1 ad/becf/dedfef .m, 0 diagrams



```
In[ ]:= proces3 = V[2] → {F[6], -F[6]};
```

```
In[ ]:= Zdecay3 = InsertFields[topologies, proces3];
```

```
inserting at level(s) {Classes}
```

```
> Top. 1: 16 Classes insertions
```

```
> Top. 2: 0 Classes insertions
```

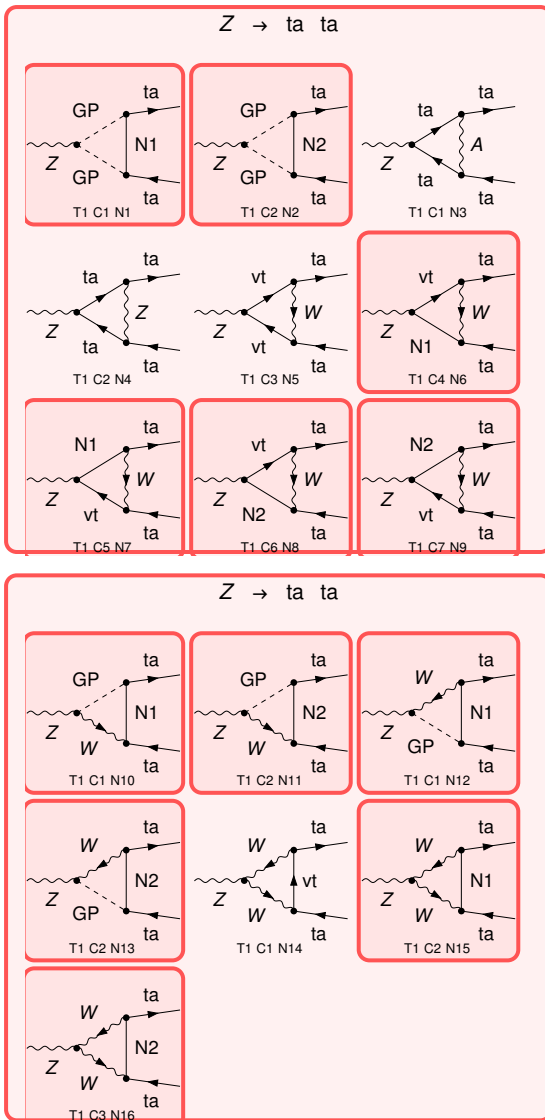
```
> Top. 3: 0 Classes insertions
```

```
> Top. 4: 0 Classes insertions
```

```
in total: 16 Classes insertions
```

```
In[ ]:= Paint[Zdecay3];
```

> Top. 1 ad/becf/dedfef .m, 0 diagrams



`In[]:= proces4 = V[2] → {F[1], F[13]};`

`In[]:= Zdecay4 = InsertFields [topologies , proces4];`

inserting at level(s) {Classes}

> Top. 1: 41 Classes insertions

> Top. 2: 0 Classes insertions

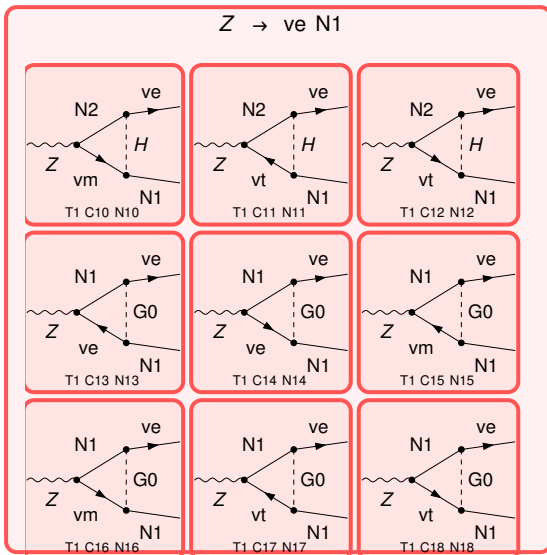
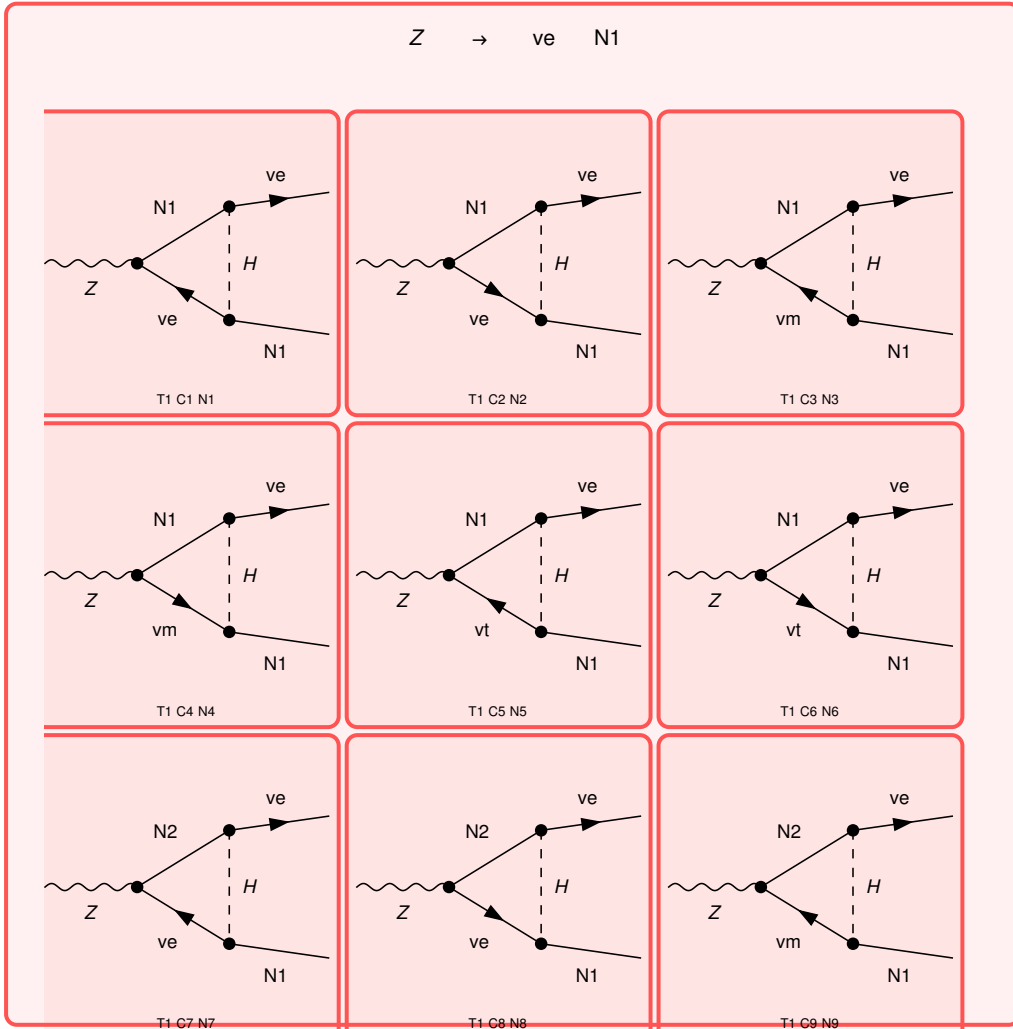
> Top. 3: 0 Classes insertions

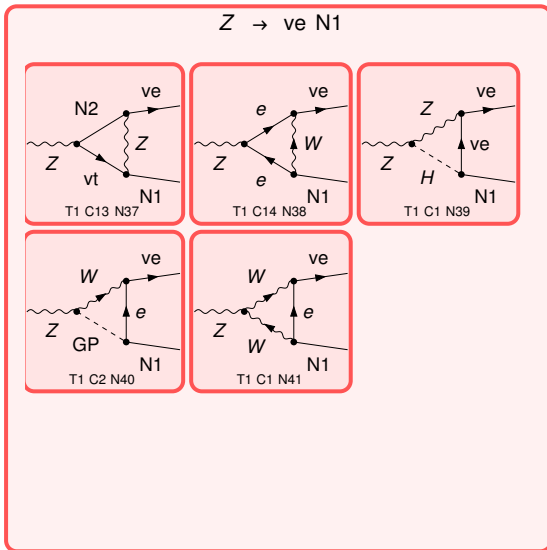
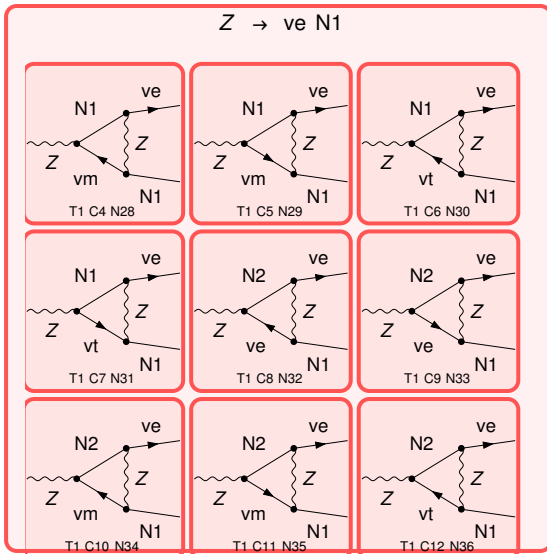
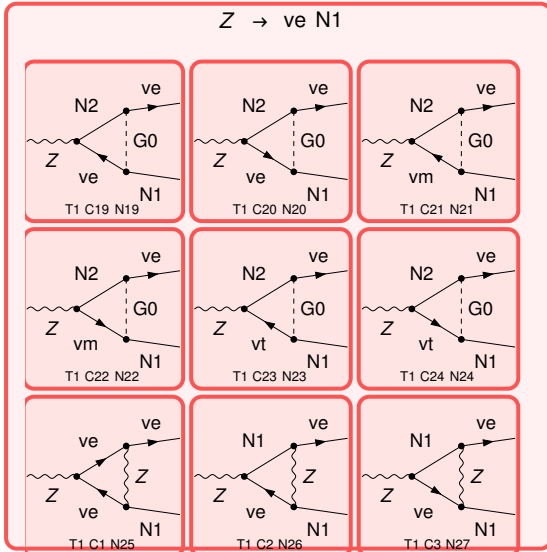
> Top. 4: 0 Classes insertions

in total: 41 Classes insertions

`In[]:= Paint[Zdecay4];`

> Top. 1 ad/becf/dedfef .m, 0 diagrams





In[*]:= CreateFeynAmp [Zdecay]

creating amplitudes at level(s) {Classes}

> Top. 1: 16 Classes amplitudes

in total: 16 Classes amplitudes

Out[*]:= FeynAmpList [Process →

{{V[2], p1, MZ, {}} → {{F[4], k1, 0, {-Q, LeptonNumber}}, {-F[4], k2, 0, {Q, -LeptonNumber}}},
Model → {SM_HeavyNU_FA}, GenericModel → {SM_HeavyNU_FA}, AmplitudeLevel → {Classes},
ExcludeParticles → {}, ExcludeFieldPoints → {}, LastSelections → {}]

FeynAmp [GraphID [Topology == 1, Generic == 1, Classes == 1, Number == 1], Integral [q1],

$$\frac{1}{16 \pi^4} \bar{u}[k1, 0].(gc59R (omSubscript[+])). (mN1 + gs[-(q1) + k1]).(gc38 (omSubscript[-])). v[k2, 0]$$

$$\text{FeynAmpDenominator} \left[\frac{1}{-MW2 + (q1)^2}, \frac{1}{-mN1^2 + (q1 - k1)^2}, \frac{1}{-MW2 + (q1 - k1 - k2)^2} \right]$$

$$(-i gc98 (-(q1))[Lor1] + i gc98 (q1 - k1 - k2)[Lor1]) \text{ep}[V[2], p1, Lor1],$$

FeynAmp [GraphID [Topology == 1, Generic == 1, Classes == 2, Number == 2], Integral [q1],

$$\frac{1}{16 \pi^4} \bar{u}[k1, 0].(gc60R (omSubscript[+])). (mN2 + gs[-(q1) + k1]).(gc47 (omSubscript[-])). v[k2, 0]$$

$$\text{FeynAmpDenominator} \left[\frac{1}{-MW2 + (q1)^2}, \frac{1}{-mN2^2 + (q1 - k1)^2}, \frac{1}{-MW2 + (q1 - k1 - k2)^2} \right]$$

$$(-i gc98 (-(q1))[Lor1] + i gc98 (q1 - k1 - k2)[Lor1]) \text{ep}[V[2], p1, Lor1],$$

FeynAmp [GraphID [Topology == 1, Generic == 2, Classes == 1, Number == 3], Integral [q1],

$$-\frac{1}{16 \pi^4} \bar{u}[k1, 0].(i gc135 ga[Lor2].(omSubscript[-]) + i gc135 ga[Lor2].(omSubscript[+])). gs[q1].$$

$$(i gc171L ga[Lor1].(omSubscript[-]) + i gc171R ga[Lor1].(omSubscript[+])). gs[q1 - k1 - k2].$$

$$(i gc135 ga[Lor3].(omSubscript[-]) + i gc135 ga[Lor3].(omSubscript[+])). v[k2, 0]$$

$$\text{FeynAmpDenominator} \left[\frac{1}{(q1)^2}, \frac{1}{(q1 - k1)^2}, \frac{1}{(q1 - k1 - k2)^2} \right] g[Lor2, Lor3] \text{ep}[V[2], p1, Lor1],$$

FeynAmp [GraphID [Topology == 1, Generic == 2, Classes == 2, Number == 4], Integral [q1],

$$-\frac{1}{16 \pi^4} \bar{u}[k1, 0].(i gc171L ga[Lor2].(omSubscript[-]) + i gc171R ga[Lor2].(omSubscript[+])).$$

$$gs[q1].(i gc171L ga[Lor1].(omSubscript[-]) + i gc171R ga[Lor1].(omSubscript[+])).$$

$$gs[q1 - k1 - k2].(i gc171L ga[Lor3].(omSubscript[-]) + i gc171R ga[Lor3].(omSubscript[+])).$$

$$v[k2, 0] \text{FeynAmpDenominator} \left[\frac{1}{(q1)^2}, \frac{1}{-MZ2 + (q1 - k1)^2}, \right.$$

$$\left. \frac{1}{(q1 - k1 - k2)^2} \right] g[Lor2, Lor3] \text{ep}[V[2], p1, Lor1],$$

FeynAmp [GraphID [Topology == 1, Generic == 2, Classes == 3, Number == 5],

$$\begin{aligned}
& \text{Integral}[q1], -\frac{1}{16 \pi^4} \\
& \bar{u}[k1, 0].(i \text{ gc159 ga[Lor2]}.(\text{omSubscript[-]})).\text{gs}[q1].(i \text{ gc168 ga[Lor1]}.(\text{omSubscript[-]})). \\
& \text{gs}[q1 - k1 - k2].(i \text{ gc156 ga[Lor3]}.(\text{omSubscript[-]})).\text{v}[k2, 0] \text{ FeynAmpDenominator} \left[\right. \\
& \left. \frac{1}{(q1)^2}, \frac{1}{-MW2 + (q1 - k1)^2}, \frac{1}{(q1 - k1 - k2)^2} \right] \text{g[Lor2, Lor3] ep[V[2], p1, Lor1]}, \\
& \text{FeynAmp}[\text{GraphID}[\text{Topology} == 1, \text{Generic} == 2, \text{Classes} == 4, \text{Number} == 6], \\
& \text{Integral}[q1], -\frac{1}{16 \pi^4} \\
& \bar{u}[k1, 0].(i \text{ gc159 ga[Lor2]}.(\text{omSubscript[-]})).\text{gs}[q1].(i \text{ gc129 ga[Lor1]}.(\text{omSubscript[-]})). \\
& (\text{mN1} + \text{gs}[q1 - k1 - k2]).(i \text{ gc111 ga[Lor3]}.(\text{omSubscript[-]})).\text{v}[k2, 0] \text{ FeynAmpDenominator} \left[\right. \\
& \left. \frac{1}{(q1)^2}, \frac{1}{-MW2 + (q1 - k1)^2}, \frac{1}{-mN1^2 + (q1 - k1 - k2)^2} \right] \text{g[Lor2, Lor3] ep[V[2], p1, Lor1]}, \\
& \text{FeynAmp}[\text{GraphID}[\text{Topology} == 1, \text{Generic} == 2, \text{Classes} == 5, \text{Number} == 7], \\
& \text{Integral}[q1], -\frac{1}{16 \pi^4} \bar{u}[k1, 0].(i \text{ gc117 ga[Lor2]}.(\text{omSubscript[-]})). \\
& (\text{mN1} + \text{gs}[q1]).(i \text{ gc123 ga[Lor1]}.(\text{omSubscript[-]})).\text{gs}[q1 - k1 - k2]. \\
& (i \text{ gc156 ga[Lor3]}.(\text{omSubscript[-]})).\text{v}[k2, 0] \text{ FeynAmpDenominator} \left[\frac{1}{-mN1^2 + (q1)^2}, \right. \\
& \left. \frac{1}{-MW2 + (q1 - k1)^2}, \frac{1}{(q1 - k1 - k2)^2} \right] \text{g[Lor2, Lor3] ep[V[2], p1, Lor1]}, \\
& \text{FeynAmp}[\text{GraphID}[\text{Topology} == 1, \text{Generic} == 2, \text{Classes} == 6, \text{Number} == 8], \\
& \text{Integral}[q1], -\frac{1}{16 \pi^4} \\
& \bar{u}[k1, 0].(i \text{ gc159 ga[Lor2]}.(\text{omSubscript[-]})).\text{gs}[q1].(i \text{ gc130 ga[Lor1]}.(\text{omSubscript[-]})). \\
& (\text{mN2} + \text{gs}[q1 - k1 - k2]).(i \text{ gc114 ga[Lor3]}.(\text{omSubscript[-]})).\text{v}[k2, 0] \text{ FeynAmpDenominator} \left[\right. \\
& \left. \frac{1}{(q1)^2}, \frac{1}{-MW2 + (q1 - k1)^2}, \frac{1}{-mN2^2 + (q1 - k1 - k2)^2} \right] \text{g[Lor2, Lor3] ep[V[2], p1, Lor1]}, \\
& \text{FeynAmp}[\text{GraphID}[\text{Topology} == 1, \text{Generic} == 2, \text{Classes} == 7, \text{Number} == 9], \\
& \text{Integral}[q1], -\frac{1}{16 \pi^4} \bar{u}[k1, 0].(i \text{ gc118 ga[Lor2]}.(\text{omSubscript[-]})). \\
& (\text{mN2} + \text{gs}[q1]).(i \text{ gc126 ga[Lor1]}.(\text{omSubscript[-]})).\text{gs}[q1 - k1 - k2]. \\
& (i \text{ gc156 ga[Lor3]}.(\text{omSubscript[-]})).\text{v}[k2, 0] \text{ FeynAmpDenominator} \left[\frac{1}{-mN2^2 + (q1)^2}, \right. \\
& \left. \frac{1}{-MW2 + (q1 - k1)^2}, \frac{1}{(q1 - k1 - k2)^2} \right] \text{g[Lor2, Lor3] ep[V[2], p1, Lor1]}, \\
& \text{FeynAmp}[\text{GraphID}[\text{Topology} == 1, \text{Generic} == 3, \text{Classes} == 1, \text{Number} == 10], \\
& \text{Integral}[q1], \frac{1}{8 \text{ cw } \pi^3} \text{Alfa vev } \bar{u}[k1, 0].(\text{gc59R}(\text{omSubscript[+]})). \\
& (\text{mN1} + \text{gs}[-(q1) + k1]).(i \text{ gc111 ga[Lor3]}.(\text{omSubscript[-]})).\text{v}[k2, 0]
\end{aligned}$$

$$\text{FeynAmpDenominator} \left[\frac{1}{-MW2 + (q1)^2}, \frac{1}{-mN1^2 + (q1 - k1)^2}, \frac{1}{-MW2 + (q1 - k1 - k2)^2} \right]$$

$$g[\text{Lor1}, \text{Lor2}] g[\text{Lor2}, \text{Lor3}] \text{ep}[\text{V}[2], \text{p1}, \text{Lor1}],$$

$$\text{FeynAmp}[\text{GraphID}[\text{Topology} == 1, \text{Generic} == 3, \text{Classes} == 2, \text{Number} == 11],$$

$$\text{Integral}[q1], \frac{1}{8 \text{cw} \pi^3} \text{Alfa} \text{vev} \bar{u}[k1, 0].(\text{gc60R}(\text{omSubscript}[+])).$$

$$(mN2 + \text{gs}[-(q1) + k1]).(\text{i gc114} \text{ga}[\text{Lor3}].(\text{omSubscript}[-])).\text{v}[k2, 0]$$

$$\text{FeynAmpDenominator} \left[\frac{1}{-MW2 + (q1)^2}, \frac{1}{-mN2^2 + (q1 - k1)^2}, \frac{1}{-MW2 + (q1 - k1 - k2)^2} \right]$$

$$g[\text{Lor1}, \text{Lor2}] g[\text{Lor2}, \text{Lor3}] \text{ep}[\text{V}[2], \text{p1}, \text{Lor1}],$$

$$\text{FeynAmp}[\text{GraphID}[\text{Topology} == 1, \text{Generic} == 4, \text{Classes} == 1, \text{Number} == 12],$$

$$\text{Integral}[q1],$$

$$-\frac{1}{8 \text{cw} \pi^3} \text{Alfa} \text{vev} \bar{u}[k1, 0].(\text{i gc117} \text{ga}[\text{Lor3}].(\text{omSubscript}[-])).(mN1 + \text{gs}[-(q1) + k1]).$$

$$(\text{gc38}(\text{omSubscript}[-])).\text{v}[k2, 0] \text{FeynAmpDenominator} \left[\frac{1}{-MW2 + (q1)^2}, \frac{1}{-mN1^2 + (q1 - k1)^2}, \right.$$

$$\left. \frac{1}{-MW2 + (q1 - k1 - k2)^2} \right] g[\text{Lor1}, \text{Lor2}] g[\text{Lor2}, \text{Lor3}] \text{ep}[\text{V}[2], \text{p1}, \text{Lor1}],$$

$$\text{FeynAmp}[\text{GraphID}[\text{Topology} == 1, \text{Generic} == 4, \text{Classes} == 2, \text{Number} == 13],$$

$$\text{Integral}[q1],$$

$$-\frac{1}{8 \text{cw} \pi^3} \text{Alfa} \text{vev} \bar{u}[k1, 0].(\text{i gc118} \text{ga}[\text{Lor3}].(\text{omSubscript}[-])).(mN2 + \text{gs}[-(q1) + k1]).$$

$$(\text{gc47}(\text{omSubscript}[-])).\text{v}[k2, 0] \text{FeynAmpDenominator} \left[\frac{1}{-MW2 + (q1)^2}, \frac{1}{-mN2^2 + (q1 - k1)^2}, \right.$$

$$\left. \frac{1}{-MW2 + (q1 - k1 - k2)^2} \right] g[\text{Lor1}, \text{Lor2}] g[\text{Lor2}, \text{Lor3}] \text{ep}[\text{V}[2], \text{p1}, \text{Lor1}],$$

$$\text{FeynAmp}[\text{GraphID}[\text{Topology} == 1, \text{Generic} == 5, \text{Classes} == 1, \text{Number} == 14],$$

$$\text{Integral}[q1], \frac{1}{16 \pi^4} \bar{u}[k1, 0].(\text{i gc159} \text{ga}[\text{Lor3}].(\text{omSubscript}[-])).$$

$$\text{gs}[-(q1) + k1].(\text{i gc156} \text{ga}[\text{Lor5}].(\text{omSubscript}[-])).\text{v}[k2, 0]$$

$$\text{FeynAmpDenominator} \left[\frac{1}{-MW2 + (q1)^2}, \frac{1}{(q1 - k1)^2}, \frac{1}{-MW2 + (q1 - k1 - k2)^2} \right] g[\text{Lor2}, \text{Lor3}]$$

$$(-\text{i gc93}(\text{p1})[\text{Lor4}] g[\text{Lor1}, \text{Lor2}] + \text{i gc93}(-(q1))[\text{Lor4}] g[\text{Lor1}, \text{Lor2}] + \text{i gc93}(\text{p1})[\text{Lor2}] g[\text{Lor1},$$

$$\text{Lor4}] - \text{i gc93}(q1 - k1 - k2)[\text{Lor2}] g[\text{Lor1}, \text{Lor4}] - \text{i gc93}(-(q1))[\text{Lor1}] g[\text{Lor2}, \text{Lor4}] +$$

$$\text{i gc93}(q1 - k1 - k2)[\text{Lor1}] g[\text{Lor2}, \text{Lor4}] g[\text{Lor4}, \text{Lor5}] \text{ep}[\text{V}[2], \text{p1}, \text{Lor1}],$$

$$\text{FeynAmp}[\text{GraphID}[\text{Topology} == 1, \text{Generic} == 5, \text{Classes} == 2, \text{Number} == 15],$$

$$\text{Integral}[q1], \frac{1}{16 \pi^4} \bar{u}[k1, 0].(\text{i gc117} \text{ga}[\text{Lor3}].(\text{omSubscript}[-])).$$

$$(mN1 + \text{gs}[-(q1) + k1]).(\text{i gc111} \text{ga}[\text{Lor5}].(\text{omSubscript}[-])).\text{v}[k2, 0]$$

