Gravity portal DM (1611.00725)

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Exit[]
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Branching ratios & Total width

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αW = 1 / 28 // N;
g2 = Sqrt[4 π αW];
sw = Sqrt[0.23];
cw = Sqrt[1 - sw^2];
GeVinSecond = 1.52 * 10^24;
Gf1 = 1.1663787 * 10^-5;
Mpl01 = 2.435 * 10^18;
mh = 125;
mZ = 91;
mW = 80;
mu = 0;
md = 0;
ms = 0;
mc = 1.29;
mb = 4.18;
mt = 172.44;
me = 0;
mμ = 0;
mτ = 1.776;
mν = 0;
vEW = 246;
αSinv[μS_] := 1/0.118 - (2 * 4 π)/(16 π^2) (-11 + 4/3 * 6) Log[μS/91]
gVZ1[TL3_, Q_] := g2/(2 cw) (TL3 - 2 Q sw^2)
gAZ1[TL3_, Q_] := g2/(2 cw) TL3
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scalar singlet

2-body decay channels

$$\Gamma_{\phi\to hh} = \frac{\xi^2 M^2 \kappa^4}{32\pi} m_\phi^3 (1+2x_h)^2 (1-4x_h)^{1/2} ,$$

$$\Gamma_{\phi\to ZZ} = \frac{\xi^2 M^2 \kappa^4}{32\pi} m_\phi^3 (1-4x_Z+12x_Z^2)(1-4x_Z)^{1/2} ,$$

$$\Gamma_{\phi\to WW} = \frac{\xi^2 M^2 \kappa^4}{16\pi} m_\phi^3 (1-4x_W+12x_W^2)(1-4x_W)^{1/2} ,$$

$$\Gamma_{\phi\to \bar{f}_i f_i} = N_c^{(f_i)} \frac{\xi^2 M^2 \kappa^4}{8\pi} m_\phi^3 \, x_{f_i} (1-4x_{f_i})^{3/2} ,$$

```
Γϕhh[M1_, ξ1_, κPl1_, mϕ_, xh_] :=
 If[xh < 0.25, ξ1^2 M1^2 κPl1^4/(32 π) mϕ^3 (1 + 2 xh)^2 (1 - 4 xh)^(1/2), 0.0]
Γϕ𝖹𝖹[M1_, ξ1_, κPl1_, mϕ_, xZ_] :=
 If[xZ < 0.25, ξ1^2 M1^2 κPl1^4/(32 π) mϕ^3 (1 - 4 xZ + 12 xZ^2)^2 (1 - 4 xZ)^(1/2), 0.0]
ΓϕWW[M1_, ξ1_, κPl1_, mϕ_, xW_] :=
 If[xW < 0.25, ξ1^2 M1^2 κPl1^4/(16 π) mϕ^3 (1 - 4 xW + 12 xW^2)^2 (1 - 4 xW)^(1/2), 0.0]
Γϕff[M1_, ξ1_, κPl1_, mϕ_, xf_, Nc_] :=
 If[xf < 0.25, Nc ξ1^2 M1^2 κPl1^4/(8 π) mϕ^3 xf (1 - 4 xf)^(3/2), 0.0]

Γϕhh001[ξ1_, mϕ_] := Γϕhh[Mpl01, ξ1, 1/Mpl01, mϕ, (mh/mϕ)^2]
Γϕ𝖹𝖹001[ξ1_, mϕ_] := Γϕ𝖹𝖹[Mpl01, ξ1, 1/Mpl01, mϕ, (mZ/mϕ)^2]
ΓϕWW001[ξ1_, mϕ_] := 2 * ΓϕWW[Mpl01, ξ1, 1/Mpl01, mϕ, (mW/mϕ)^2]
Γϕff001[ξ1_, mϕ_] :=
 Γϕff[Mpl01, ξ1, 1/Mpl01, mϕ, (mu/mϕ)^2, 3] + Γϕff[Mpl01, ξ1, 1/Mpl01, mϕ, (md/mϕ)^2, 3] +
  Γϕff[Mpl01, ξ1, 1/Mpl01, mϕ, (ms/mϕ)^2, 3] + Γϕff[Mpl01, ξ1, 1/Mpl01, mϕ, (mc/mϕ)^2, 3] +
  Γϕff[Mpl01, ξ1, 1/Mpl01, mϕ, (mb/mϕ)^2, 3] + Γϕff[Mpl01, ξ1, 1/Mpl01, mϕ, (mt/mϕ)^2, 3] +
  Γϕff[Mpl01, ξ1, 1/Mpl01, mϕ, (me/mϕ)^2, 1] + Γϕff[Mpl01, ξ1, 1/Mpl01, mϕ, (mμ/mϕ)^2, 1] +
  Γϕff[Mpl01, ξ1, 1/Mpl01, mϕ, (mτ/mϕ)^2, 1] + 3 * Γϕff[Mpl01, ξ1, 1/Mpl01, mϕ, (mν/mϕ)^2, 1]
```

3-body decay channels (m_ϕ >> v_{EW})

$$\Gamma_{\phi\to\bar{q}_i q_i g} \simeq \alpha_s \frac{\xi^2 M^2 \kappa^4}{4\pi^2} m_\phi^3 \,,$$

$$\Gamma_{\phi\to\bar{f}_i f'_j W} \simeq \frac{3}{4\sqrt{2}} G_F N_c^{(f_i)} |U_{ij}|^2 \frac{\xi^2 M^2 \kappa^4}{(4\pi)^3} m_\phi^5 \,,$$

$$\Gamma_{\phi\to\bar{f}_i f_i Z} \simeq \frac{3}{2\sqrt{2}} G_F N_c^{(f_i)} (g_V^2 + g_A^2) \frac{\xi^2 M^2 \kappa^4}{(4\pi)^3} m_\phi^5 \,,$$

```
Γϕqqg[M1_, ξ1_, κPl1_, mϕ_, αS_] := αS ξ1^2 M1^2 κPl1^4 / (4 π^2) mϕ^3

ΓϕffW[M1_, ξ1_, κPl1_, mϕ_, Gf_, Nc_, Uij_] := 3 / (4 Sqrt[2]) Gf Nc Uij^2 ξ1^2 M1^2 κPl1^4 / (4 π)^3 mϕ^5

ΓϕffZ[M1_, ξ1_, κPl1_, mϕ_, Gf_, Nc_, gVZ_, gVA_] :=
 3 / (2 Sqrt[2]) Gf Nc (gVZ^2 + gVA^2) ξ1^2 M1^2 κPl1^4 / (4 π)^3 mϕ^5

Γϕqqg001[ξ1_, mϕ_] := 6 * Γϕqqg[Mpl01, ξ1, 1/Mpl01, mϕ, 1/αSinv[mϕ]]

Γϕ ffW001[ξ1_, mϕ_] :=
 3 * ΓϕffW[Mpl01, ξ1, 1/Mpl01, mϕ, Gf1, 3, 1.0] + 3 * ΓϕffW[Mpl01, ξ1, 1/Mpl01, mϕ, Gf1, 1, 1.0]

Γϕ ffZ001[ξ1_, mϕ_] := 3 * Γϕffz[Mpl01, ξ1, 1/Mpl01, mϕ, Gf1, 3, gVZ1[1/2, 2/3], gAZ1[1/2, 2/3]] +
  3 * Γϕffz[Mpl01, ξ1, 1/Mpl01, mϕ, Gf1, 3, gVZ1[-1/2, -1/3], gAZ1[-1/2, -1/3]] +
  3 * Γϕffz[Mpl01, ξ1, 1/Mpl01, mϕ, Gf1, 1, gVZ1[1/2, 0], gAZ1[1/2, 0]] +
  3 * Γϕffz[Mpl01, ξ1, 1/Mpl01, mϕ, Gf1, 1, gVZ1[-1/2, -1], gAZ1[-1/2, -1]]
```

4-body decay channels (m_ϕ >> v_{EW})

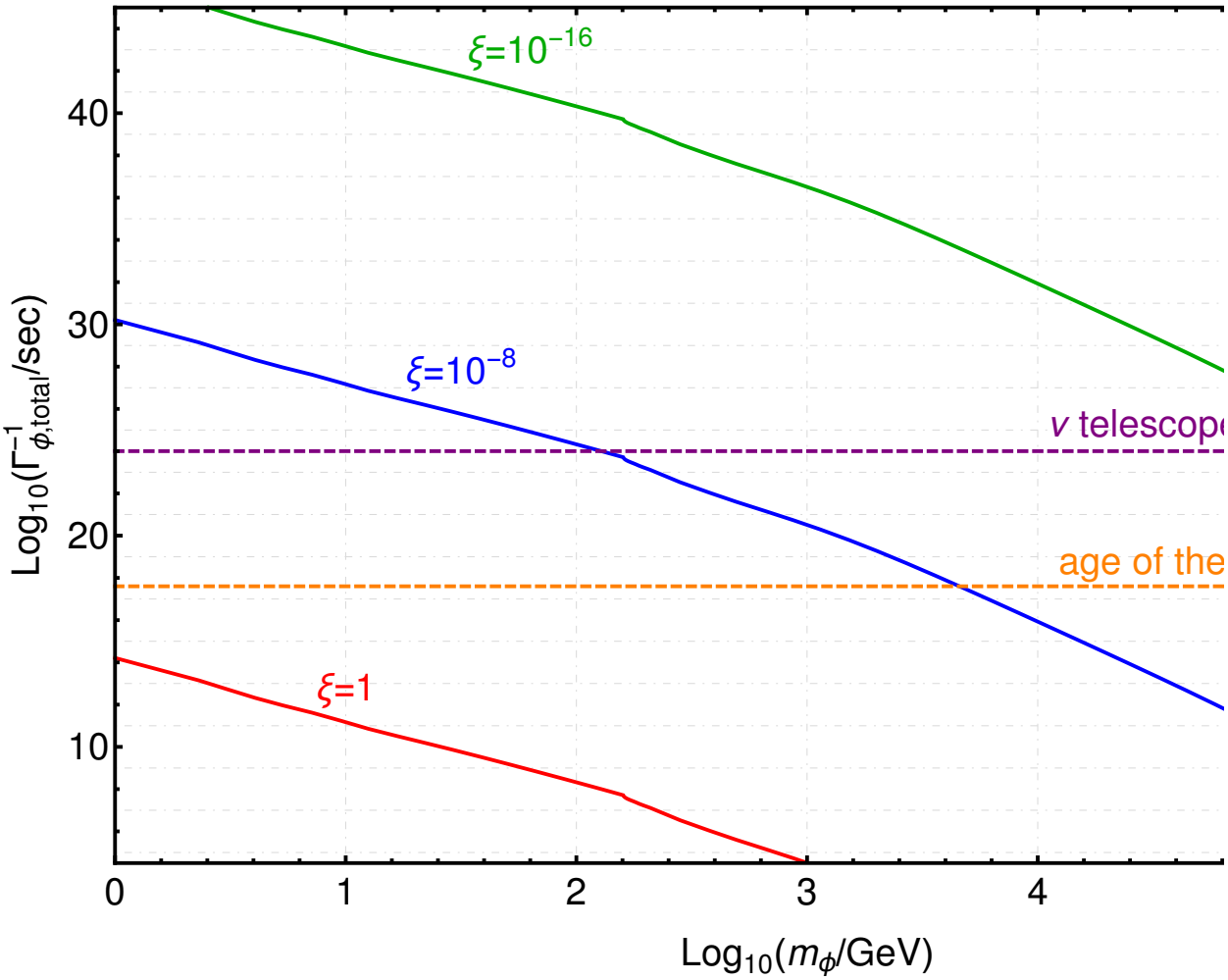
$$\Gamma_{\phi\to WWhh} \simeq \frac{\xi^2 M^2 \kappa^4}{15(8\pi)^5 v^4} m_\phi^7 \,,$$

$$\Gamma_{\phi\to ZZhh} \simeq \frac{\xi^2 M^2 \kappa^4}{30(8\pi)^5 v^4} m_\phi^7 \,,$$

```
Γϕ WWhh[M1_, ξ1_, κPl1_, mϕ_, vEW_] := ξ1^2 M1^2 κPl1^4 / (15 (8 π)^5 vEW^4) mϕ^7

Γϕ ZZhh[M1_, ξ1_, κPl1_, mϕ_, vEW_] := ξ1^2 M1^2 κPl1^4 / (30 (8 π)^5 vEW^4) mϕ^7

Γϕ WWhh001[ξ1_, mϕ_] := Γϕ WWhh[Mpl01, ξ1, 1/Mpl01, mϕ, vEW]

Γϕ ZZhh001[ξ1_, mϕ_] := Γϕ ZZhh[Mpl01, ξ1, 1/Mpl01, mϕ, vEW]
```

Total width

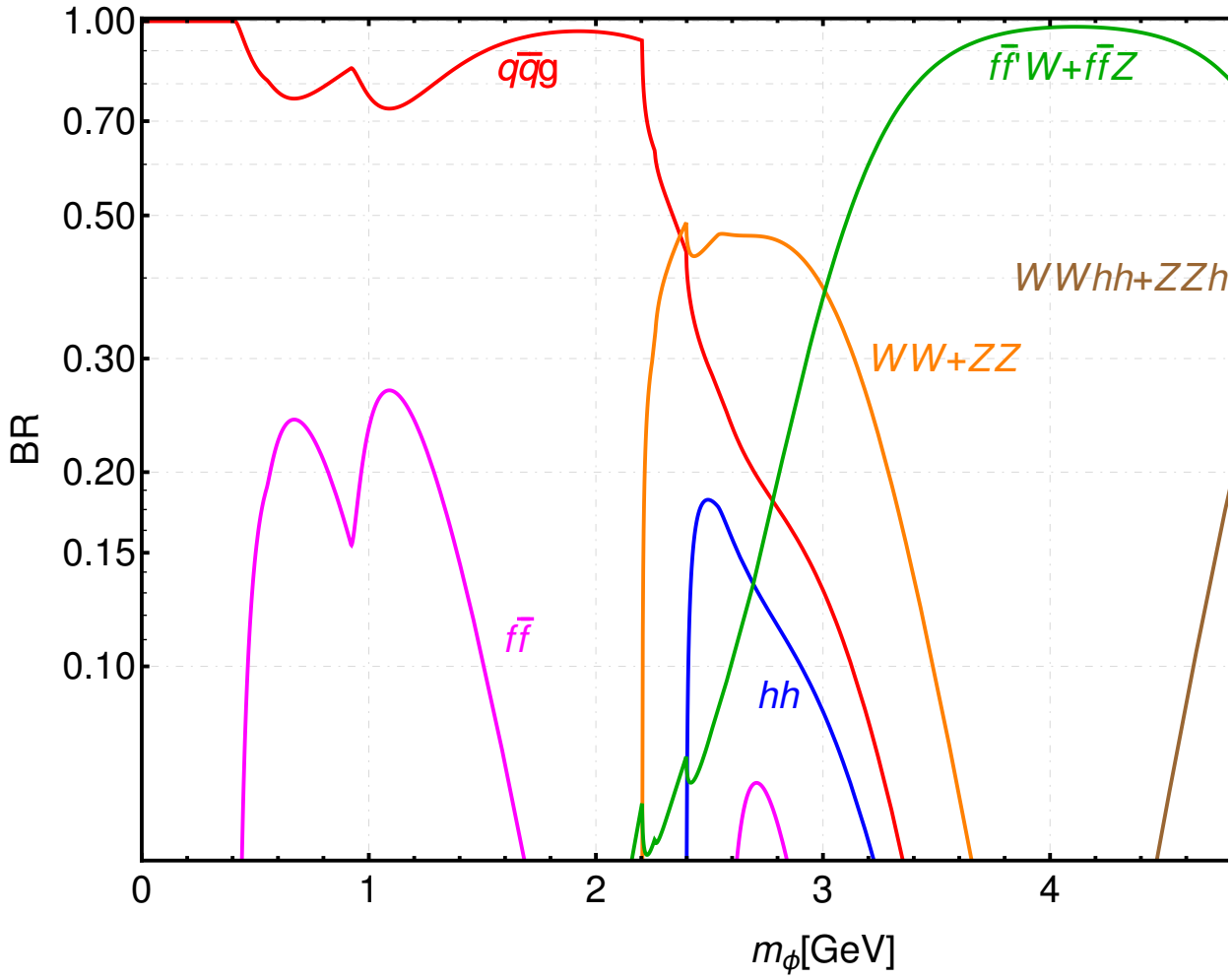
```
ΓϕTotal[ξ1_, mϕ_] :=
 Γϕhh001[ξ1, mϕ] + Γϕ ZZ001[ξ1, mϕ] + Γϕ WW001[ξ1, mϕ] + Γϕ ff001[ξ1, mϕ] + Γϕ qqg001[ξ1, mϕ] +
  Γϕ ffW001[ξ1, mϕ] + Γϕ ffZ001[ξ1, mϕ] + Γϕ WWhh001[ξ1, mϕ] + Γϕ ZZhh001[ξ1, mϕ]

Plot[
  {Log10[1 / (ΓϕTotal[1, 10^mϕLog] * GeVinSecond)], Log10[1 / (ΓϕTotal[10^-8, 10^mϕLog] * GeVinSecond)],
   Log10[1 / (ΓϕTotal[10^-16, 10^mϕLog] * GeVinSecond)], 24.0, Log10[4 * 10^17]},
  {mϕLog, 0.0, 6.0}, PlotRange → {{0.0, 6.0}, {4.5, 45.0}}, PlotStyle →
   {Directive[Red, Thick], Directive[Blue, Thick], Directive[Darker[Green], Thick],
    Directive[Purple, Thick, Dashed], Directive[Orange, Thick, Dashed]},
  Epilog → {Thread[Text[Style["ξ=1", Red, Thick], {{1.0, 12.8}}]],
    Thread[Text[Style["ξ=10^-8", Blue, Thick], {{1.5, 27.8}}]],
    Thread[Text[Style["ξ=10^-16", Darker[Green], Thick], {{1.8, 43.0}}]],
    Thread[Text[Style["age of the Universe", Orange, Thick], {{4.8, 18.8}}]],
    Thread[Text[Style["ν telescopes", Purple, Thick], {{4.5, 25.3}}]]},
  GridLines → {Flatten[Table[n, {n, 1 #, 9 #, 9 #}] & /@ (Range[0, 6])],
    Flatten[Table[n, {n, 1 #, 9 #, 9 #}] & /@ (Range[5, 45, 2])]},
  GridLinesStyle → Directive[LightGray, DotDashed], Ticks → Automatic,
  ImageSize → 800, Frame → True, FrameStyle → Thick,
  BaseStyle → {FontSize → 20, "Helvetica"},
  FrameLabel → {"Log10 (mϕ/GeV)", "Log10 (Γϕ,total^-1/sec)"},
  LabelStyle → Directive[Black, 20, FontFamily → "Helvetica"]] // Quiet
```



Branching ratios

```
Brϕqqg[ξ1_, mϕ_] := Γϕqqg001[ξ1, mϕ] / Γϕ Total[ξ1, mϕ]
Brϕff[ξ1_, mϕ_] := Γϕff001[ξ1, mϕ] / Γϕ Total[ξ1, mϕ]
BrϕWWorZZ[ξ1_, mϕ_] := (Γϕ ZZ001[ξ1, mϕ] + Γϕ WW001[ξ1, mϕ]) / Γϕ Total[ξ1, mϕ]
Brϕhh[ξ1_, mϕ_] := Γϕhh001[ξ1, mϕ] / Γϕ Total[ξ1, mϕ]
BrϕffWorffZ[ξ1_, mϕ_] := (Γϕ ffW001[ξ1, mϕ] + Γϕ ffZ001[ξ1, mϕ]) / Γϕ Total[ξ1, mϕ]
BrϕWWhhorZZhh[ξ1_, mϕ_] := (Γϕ WWhh001[ξ1, mϕ] + Γϕ ZZhh001[ξ1, mϕ]) / Γϕ Total[ξ1, mϕ]
```

```
LogPlot[{Brϕqqg[1, 10^mϕLog], Brϕff[1, 10^mϕLog], BrϕWWorZZ[1, 10^mϕLog],
   Brϕhh[1, 10^mϕLog], BrϕffWorffZ[1, 10^mϕLog], BrϕWWhhorZZhh[1, 10^mϕLog]},
  {mϕLog, 0.0, 6.0}, PlotRange → {{0.0, 6.0}, {0.05, 1.01}}, PlotStyle →
   {Directive[Red, Thick], Directive[Magenta, Thick], Directive[Orange, Thick],
    Directive[Blue, Thick], Directive[Darker[Green], Thick], Directive[Brown, Thick]},
  Axes → False, GridLines → {Flatten[Table[n, {n, 1 #, 9 #, 9 #}] & /@ (Range[0, 6])],
    Flatten[Table[n, {n, 1 #, 2 #, 9 #}] & /@ (Range[0.1, 1.0, 0.1])]},
  GridLinesStyle → Directive[LightGray, DotDashed],
  Epilog → {Thread[Text[Style["qq̄g", Red, Thick], {{1.7, Log@0.85}}]],
    Thread[Text[Style["ff̄", Magenta, Thick], {{1.65, Log@0.11}}]],
    Thread[Text[Style["WW+ZZ", Orange, Thick], {{3.53, Log@0.3}}]],
    Thread[Text[Style["hh", Blue, Thick], {{2.8, Log@0.09}}]],
    Thread[Text[Style["ff̄'W+ff̄Z", Darker[Green], Thick], {{4.05, Log@0.85}}]],
    Thread[Text[Style["WWhh+ZZhh", Brown, Thick], {{4.35, Log@0.4}}]],
    Thread[Text[Style["qq̄g", Red, Thick], {{1.7, Log@0.85}}]]}, ImageSize → 800,
  Frame → True, FrameStyle → Thick, BaseStyle → {FontSize → 20, "Helvetica"},
  FrameLabel → {"m_ϕ [GeV]", "BR"},
  LabelStyle → Directive[Black, 20, FontFamily → "Helvetica"]] // Quiet
```



Inert doublet scalar

2-body decay channels

$$\Gamma_{\eta\to hh} = \frac{\xi^2 v^2 \kappa^4}{32\pi} m_\eta^3 (1+2x_h)^2 (1-4x_h)^{1/2} ,$$
$$\Gamma_{\eta\to ZZ} = \frac{\xi^2 v^2 \kappa^4}{32\pi} m_\eta^3 (1-4x_Z+12x_Z^2)(1-4x_Z)^{1/2} ,$$
$$\Gamma_{\eta\to WW} = \frac{\xi^2 v^2 \kappa^4}{16\pi} m_\eta^3 (1-4x_W+12x_W^2)(1-4x_W)^{1/2} ,$$
$$\Gamma_{\eta\to \bar{f}_i f_i} = N_c^{(f_i)} \frac{\xi^2 v^2 \kappa^4}{8\pi} m_\eta^3 \, x_{f_i} (1-4x_{f_i})^{3/2} .$$

```
Γηhh[vEW_, ξ1_, κPl1_, mη_, xh_] :=
 If[xh < 0.25, ξ1^2 vEW^2 κPl1^4/(32 π) mη^3 (1 + 2 xh)^2 (1 - 4 xh)^1/2, 0.0]
Γηhh[vEW_, ξ1_, κPl1_, mη_, xZ_] :=
 If[xZ < 0.25, ξ1^2 vEW^2 κPl1^4/(32 π) mη^3 (1 - 4 xZ + 12 xZ)^2 (1 - 4 xZ)^1/2, 0.0]
Γηhh[vEW_, ξ1_, κPl1_, mη_, xW_] :=
 If[xW < 0.25, ξ1^2 vEW^2 κPl1^4/(16 π) mη^3 (1 - 4 xW + 12 xW)^2 (1 - 4 xW)^1/2, 0.0]
Γηff[vEW_, ξ1_, κPl1_, mη_, xf_, Nc_] :=
 If[xf < 0.25, Nc ξ1^2 vEW^2 κPl1^4/(8 π) mη^3 xf (1 - 4 xf)^3/2, 0.0]
```

3-body decay channels (m_ϕ >> v_{EW})

$$\Gamma_{\eta\to\bar{q}_i q_i g} \simeq \alpha_s \frac{\xi^2 v^2 \kappa^4}{4\pi^2} m_\eta^3 ,$$

$$\Gamma_{\eta\to\bar{f}_i f'_j W} \simeq \frac{3}{4\sqrt{2}} G_F N_c^{(f_i)} |U_{ij}|^2 \frac{\xi^2 v^2 \kappa^4}{(4\pi)^3} m_\eta^5 ,$$

$$\Gamma_{\eta\to\bar{f}_i f_i Z} \simeq \frac{3}{2\sqrt{2}} G_F N_c^{(f_i)} (g_V^2 + g_A^2) \frac{\xi^2 v^2 \kappa^4}{(4\pi)^3} m_\eta^5 ,$$

```
Γηqqg[vEW_, ξ1_, κPl1_, mη_, αS_] := αS ξ1^2 vEW^2 κPl1^4/(4 π^2) mη^3
ΓηffW[vEW_, ξ1_, κPl1_, mη_, Gf_, Nc_, Uij_] := 3/(4 Sqrt[2]) Gf Nc Uij^2 ξ1^2 vEW^2 κPl1^4/(4 π)^3 mη^5
ΓηffZ[vEW_, ξ1_, κPl1_, mη_, Gf_, Nc_, gVZ_, gVA_] :=
 3/(2 Sqrt[2]) Gf Nc (gVZ^2 + gVA^2) ξ1^2 vEW^2 κPl1^4/(4 π)^3 mη^5
```

4-body decay channels (m_ϕ >> v_{EW})

$$\Gamma_{\eta\to\bar{f}_i f'_j W h} \simeq \frac{3\sqrt{2}}{160} G_F N_c^{(f_i)} |U_{ij}|^2 \frac{\xi^2 \kappa^4}{(4\pi)^5} m_\eta^7 ,$$

$$\Gamma_{\eta\to\bar{f}_i f_i Z h} \simeq \frac{3\sqrt{2}}{80} G_F N_c^{(f_i)} (g_V^2 + g_A^2) \frac{\xi^2 \kappa^4}{(4\pi)^5} m_\eta^7 ,$$

```
ΓηffWh[ξ1_, κPl1_, mη_, Gf_, Nc_, Uij_] := 3 Sqrt[2]/160 Gf Nc Uij^2 ξ1^2 κPl1^4/(4 π)^5 mη^7
ΓηffZh[ξ1_, κPl1_, mη_, Gf_, Nc_, gVZ_, gVA_] := 3 Sqrt[2]/80 Gf Nc (gVZ^2 + gVA^2) ξ1^2 κPl1^4/(4 π)^5 mη^7
```

5-body decay channels (m_ϕ >> v_{EW})

$$\Gamma_{\eta\to WWhhh} \simeq \frac{2\xi^2\kappa^4}{75(8\pi)^7 v^4} m_\eta^9 \,,$$

$$\Gamma_{\eta\to ZZhhh} \simeq \frac{\xi^2\kappa^4}{75(8\pi)^7 v^4} m_\eta^9 \,.$$

```
ΓηWWhhh[M1_, ξ1_, κPl1_, mη_, vEW_] := 2 ξ1^2 κPl1^4 / (75 (8 π)^7 vEW^4) mη^9
ΓηZZhhh[M1_, ξ1_, κPl1_, mη_, vEW_] := ξ1^2 κPl1^4 / (75 (8 π)^7 vEW^4) mη^9
```

Branching ratios

Total width

Tmp01

Tmp01

Tmp01