In[1]:=
```
(*  F[1, {0}] = electron neutrino,
F[1, {1}] = muon neutrino, F[1, {2}] = tau neutrino,
    F[2, {0}] = electron, F[2, {1}] = muon, F[2, {2}] = tau,
    F[3, {0}] = up, F[3, {1}] = charm, F[3, {2}] = top,
    F[4, {0}] = down, F[4, {1}] = strange, F[4, {2}] = bottom,
    V[1] = photon, V[2] = Z, V[3] = W-, S[1] = H *)
$LoadAddOns = {"FeynArts"};
<< FeynCalc`
$FAVerbose = 0;

MakeBoxes[p1, TraditionalForm] := "\!\(\*SubscriptBox[\(p\), \(1\)]\)";
MakeBoxes[p2, TraditionalForm] := "\!\(\*SubscriptBox[\(p\), \(2\)]\)";
MakeBoxes[p3, TraditionalForm] := "\!\(\*SubscriptBox[\(p\), \(3\)]\)";
MakeBoxes[p4, TraditionalForm] := "\!\(\*SubscriptBox[\(p\), \(4\)]\)";
```

FeynCalc 10.0.0 (dev version). For help, use the online documentation, visit the forum and have a look at the supplied examples. The PDF–version of the manual can be downloaded here.

If you use FeynCalc in your research, please evaluate FeynCalcHowToCite[] to learn how to cite this software.

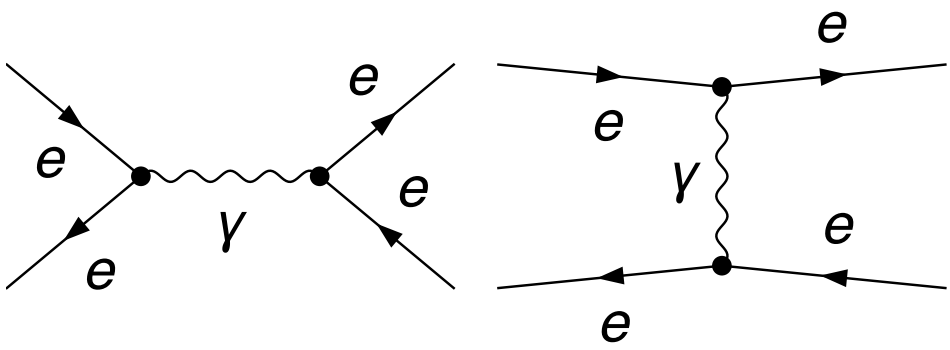
Please keep in mind that the proper academic attribution of our work is crucial to ensure the future development of this package!

FeynArts 3.12 (24 May 2024) patched for use with FeynCalc, for documentation see the manual or visit www.feynarts.de.

If you use FeynArts in your research, please cite

- T. Hahn, Comput. Phys. Commun., 140, 418–431, 2001, arXiv:hep–ph/0012260

In[8]:=
```
(* QED: e- e+ → e- e+ (Bhabha) *)
topology = CreateTopologies[0, 2 → 2];
feynman1 =
  InsertFields[topology, {F[2, {1}], -F[2, {1}]} → {F[2, {1}], -F[2, {1}]},
   InsertionLevel → {Classes}, Restrictions → QEDOnly];
Paint[feynman1, Numbering → None, SheetHeader → False,
  ColumnsXRows → {4, 1}, ImageSize → {1032, 256}];
amplitude1[0] = FCFAConvert[CreateFeynAmp[feynman1], IncomingMomenta → {p1, p2},
  OutgoingMomenta → {p3, p4}, UndoChiralSplittings → True ,
  ChangeDimension → 4, List → False, SMP → True, Contract → True]
FCClearScalarProducts[];
SetMandelstam[s, t, u, p1, p2, -p3, -p4,
  SMP["m_e"], SMP["m_e"], SMP["m_e"], SMP["m_e"]];
squareamplitude1[0] = (amplitude1[0] (ComplexConjugate[amplitude1[0]])) //
     FeynAmpDenominatorExplicit //
    FermionSpinSum[#, ExtraFactor → 1 / 2^2] & // DiracSimplify // Simplify
masslesssquareamplitude1[0] =
 squareamplitude1[0] // ReplaceAll[#, {SMP["m_e"] → 0}] & // Simplify
(* output = feynman diagrams, amplitude,
squared amplitude, massless squared amplitude *)
```



Out[11]=

$$\frac{e^2\,(\varphi(\overline{p_3}, m_e))\cdot\bar{\gamma}^{\text{Lor1}}\cdot(\varphi(\overline{p_1}, m_e))\,(\varphi(-\overline{p_2}, m_e))\cdot\bar{\gamma}^{\text{Lor1}}\cdot(\varphi(-\overline{p_4}, m_e))}{(\overline{p_4}-\overline{p_2})^2} - \frac{e^2\,(\varphi(-\overline{p_2}, m_e))\cdot\bar{\gamma}^{\text{Lor2}}\cdot(\varphi(\overline{p_1}, m_e))\,(\varphi(\overline{p_3}, m_e))\cdot\bar{\gamma}^{\text{Lor2}}\cdot(\varphi(-\overline{p_4}, m_e))}{(\overline{p_3}+\overline{p_4})^2}$$

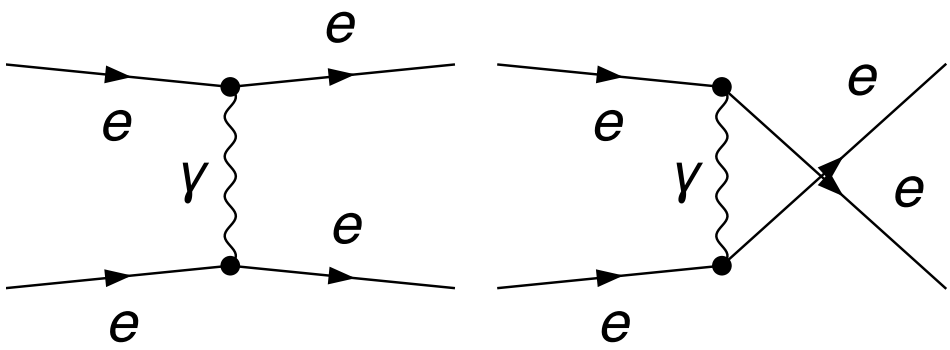
Out[14]=

$$\frac{2\,e^4\left(8\,m_e^4\left(s^2+s\,t+t^2\right)-4\,m_e^2\left(s^3+s^2\,(u-2\,t)+s\,t\,(3\,u-2\,t)+t^2\,(t+u)\right)+s^4+s^2\,u^2+2\,s\,t\,u^2+t^4+t^2\,u^2\right)}{s^2\,t^2}$$

Out[15]=

$$\frac{2\,e^4\left(s^4+s^2\,u^2+2\,s\,t\,u^2+t^4+t^2\,u^2\right)}{s^2\,t^2}$$

In[16]:=
```
(* QED: e- e- → e- e- *)
topology = CreateTopologies[0, 2 → 2];
feynman2 =
  InsertFields[topology, {F[2, {1}], F[2, {1}]} → {F[2, {1}], F[2, {1}]},
   InsertionLevel → {Classes}, Restrictions → QEDOnly];
Paint[feynman2, Numbering → None, SheetHeader → False,
  ColumnsXRows → {4, 1}, ImageSize → {1032, 256}];
amplitude2[0] = FCFAConvert[CreateFeynAmp[feynman1], IncomingMomenta → {p1, p2},
  OutgoingMomenta → {p3, p4}, UndoChiralSplittings → True ,
  ChangeDimension → 4, List → False, SMP → True, Contract → True]
FCClearScalarProducts[];
SetMandelstam[s, t, u, p1, p2, -p3, -p4,
  SMP["m_e"], SMP["m_e"], SMP["m_e"], SMP["m_e"]];
squareamplitude2[0] = (amplitude2[0] (ComplexConjugate[amplitude2[0]])) //
     FeynAmpDenominatorExplicit //
    FermionSpinSum[#, ExtraFactor → 1 / 2^2] & // DiracSimplify // Simplify
masslesssquareamplitude2[0] =
 squareamplitude2[0] // ReplaceAll[#, {SMP["m_e"] → 0}] & // Simplify
(* output = feynman diagrams, amplitude,
squared amplitude, massless squared amplitude *)
```



Out[19]=

$$\frac{e^2\,(\varphi(\overline{p_3}, m_e))\cdot\bar{\gamma}^{\text{Lor1}}\cdot(\varphi(\overline{p_1}, m_e))\,(\varphi(-\overline{p_2}, m_e))\cdot\bar{\gamma}^{\text{Lor1}}\cdot(\varphi(-\overline{p_4}, m_e))}{(\overline{p_4}-\overline{p_2})^2} - \frac{e^2\,(\varphi(-\overline{p_2}, m_e))\cdot\bar{\gamma}^{\text{Lor2}}\cdot(\varphi(\overline{p_1}, m_e))\,(\varphi(\overline{p_3}, m_e))\cdot\bar{\gamma}^{\text{Lor2}}\cdot(\varphi(-\overline{p_4}, m_e))}{(\overline{p_3}+\overline{p_4})^2}$$

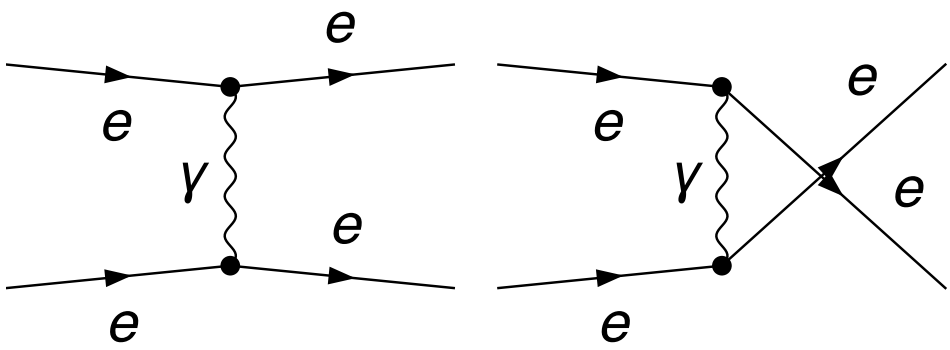
Out[22]=

$$\frac{2\,e^4\left(8\,m_e^4\left(s^2+s\,t+t^2\right)-4\,m_e^2\left(s^3+s^2\,(u-2\,t)+s\,t\,(3\,u-2\,t)+t^2\,(t+u)\right)+s^4+s^2\,u^2+2\,s\,t\,u^2+t^4+t^2\,u^2\right)}{s^2\,t^2}$$

Out[23]=

$$\frac{2\,e^4\left(s^4+s^2\,u^2+2\,s\,t\,u^2+t^4+t^2\,u^2\right)}{s^2\,t^2}$$

In[24]:=
```
(* QED: e+ e+ → e+ e+ *)
topology = CreateTopologies[0, 2 → 2];
feynman3 =
  InsertFields[topology, {F[2, {1}], F[2, {1}]} → {F[2, {1}], F[2, {1}]},
   InsertionLevel → {Classes}, Restrictions → QEDOnly];
Paint[feynman3, Numbering → None, SheetHeader → False,
  ColumnsXRows → {4, 1}, ImageSize → {1032, 256}];
amplitude3[0] = FCFAConvert[CreateFeynAmp[feynman3], IncomingMomenta → {p1, p2},
  OutgoingMomenta → {p3, p4}, UndoChiralSplittings → True ,
  ChangeDimension → 4, List → False, SMP → True, Contract → True]
FCClearScalarProducts[];
SetMandelstam[s, t, u, p1, p2, -p3, -p4,
  SMP["m_e"], SMP["m_e"], SMP["m_e"], SMP["m_e"]];
squareamplitude3[0] = (amplitude3[0] (ComplexConjugate[amplitude3[0]])) //
     FeynAmpDenominatorExplicit //
    FermionSpinSum[#, ExtraFactor → 1 / 2^2] & // DiracSimplify // Simplify
masslesssquareamplitude3[0] =
 squareamplitude3[0] // ReplaceAll[#, {SMP["m_e"] → 0}] & // Simplify
(* output = feynman diagrams, amplitude,
squared amplitude, massless squared amplitude *)
```



Out[27]=

$$\frac{e^2\,(\varphi(\overline{p_4}, m_e))\cdot\bar{\gamma}^{\text{Lor1}}\cdot(\varphi(\overline{p_1}, m_e))\,(\varphi(\overline{p_3}, m_e))\cdot\bar{\gamma}^{\text{Lor1}}\cdot(\varphi(\overline{p_2}, m_e))}{(\overline{p_3}-\overline{p_2})^2} - \frac{e^2\,(\varphi(\overline{p_3}, m_e))\cdot\bar{\gamma}^{\text{Lor2}}\cdot(\varphi(\overline{p_1}, m_e))\,(\varphi(\overline{p_4}, m_e))\cdot\bar{\gamma}^{\text{Lor2}}\cdot(\varphi(\overline{p_2}, m_e))}{(\overline{p_4}-\overline{p_2})^2}$$

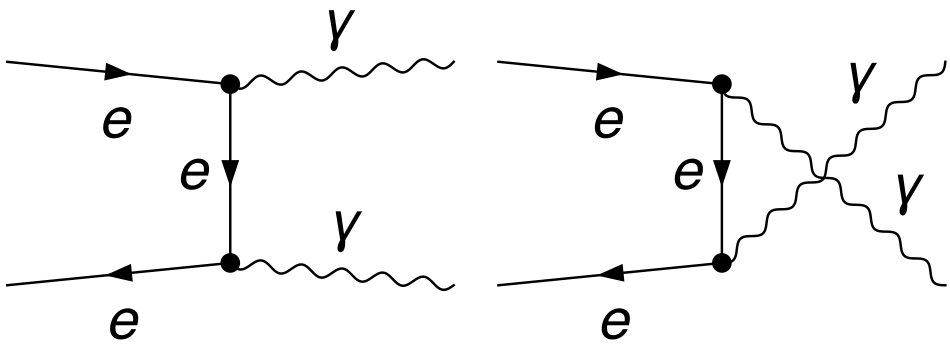
Out[30]=

$$\frac{2\,e^4\left(-4\,m_e^2\left(s\left(t^2+3\,t\,u+u^2\right)+t^3-2\,t^2\,u-2\,t\,u^2+u^3\right)+8\,m_e^4\left(t^2+t\,u+u^2\right)+s^2\,(t+u)^2+t^4+u^4\right)}{t^2\,u^2}$$

Out[31]=

$$\frac{2\,e^4\left(s^2\,(t+u)^2+t^4+u^4\right)}{t^2\,u^2}$$

In[32]:=
```
(* QED: e- e+ → photon photon (annihilation) *)
topology = CreateTopologies[0, 2 → 2];
feynman4 = InsertFields[topology, {F[2, {1}], -F[2, {1}]} → {V[1], V[1]},
   InsertionLevel → {Classes}, Restrictions → QEDOnly];
Paint[feynman4, Numbering → None, SheetHeader → False,
  ColumnsXRows → {4, 1}, ImageSize → {1032, 256}];
amplitude4[0] = FCFAConvert[CreateFeynAmp[feynman4], IncomingMomenta → {p1, p2},
  OutgoingMomenta → {p3, p4}, UndoChiralSplittings → True ,
  ChangeDimension → 4, TransversePolarizationVectors → {p3, p4},
  List → False, SMP → True, Contract → True]
FCClearScalarProducts[];
SetMandelstam[s, t, u, p1, p2, -p3, -p4, SMP["m_e"], SMP["m_e"], 0, 0];
squareamplitude4[0] = (amplitude4[0] (ComplexConjugate[amplitude4[0]])) //
        FeynAmpDenominatorExplicit //
       DoPolarizationSums[#, p3, 0] & // DoPolarizationSums[#, p4, 0] & //
     FermionSpinSum[#, ExtraFactor → 1 / 2^2] & // DiracSimplify //
   TrickMandelstam[#, {s, t, u, 2 SMP["m_e"]^2}] & // Simplify
masslesssquareamplitude4[0] =
 squareamplitude4[0] // ReplaceAll[#, {SMP["m_e"] → 0}] & // Simplify
(* output = feynman diagrams, amplitude,
squared amplitude, massless squared amplitude *)
```



Out[35]=

$$-\frac{e^2\,(\varphi(-\overline{p_2}, m_e)).(\overline{\gamma}\cdot\overline{\varepsilon}^*(p_3)).(\overline{\gamma}\cdot(\overline{p_3}-\overline{p_2})+m_e).(\overline{\gamma}\cdot\overline{\varepsilon}^*(p_4)).(\varphi(\overline{p_1}, m_e))}{(\overline{p_2}-\overline{p_3})^2-m_e^2} -$$
$$\frac{e^2\,(\varphi(-\overline{p_2}, m_e)).(\overline{\gamma}\cdot\overline{\varepsilon}^*(p_4)).(\overline{\gamma}\cdot(\overline{p_4}-\overline{p_2})+m_e).(\overline{\gamma}\cdot\overline{\varepsilon}^*(p_3)).(\varphi(\overline{p_1}, m_e))}{(\overline{p_2}-\overline{p_4})^2-m_e^2}$$

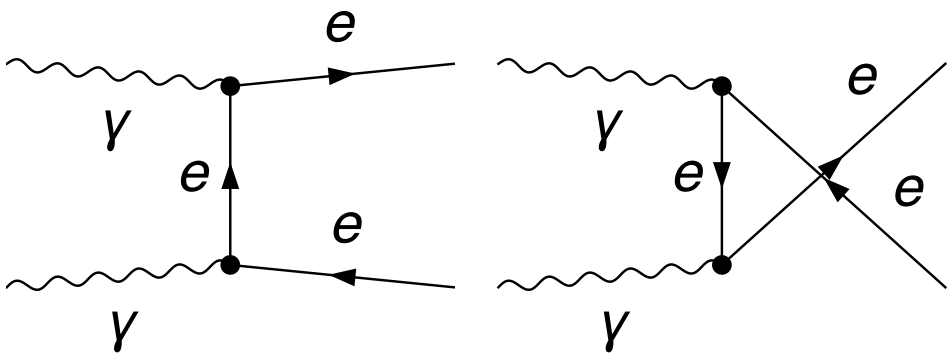
Out[38]=

$$\frac{2\,e^4\left(m_e^4\left(3\,t^2+14\,t\,u+3\,u^2\right)-m_e^2\left(t^3+7\,t^2\,u+7\,t\,u^2+u^3\right)-6\,m_e^8+t\,u\left(t^2+u^2\right)\right)}{\left(t-m_e^2\right)^2\left(u-m_e^2\right)^2}$$

Out[39]=

$$\frac{2\,e^4\left(t^2+u^2\right)}{t\,u}$$

In[40]:=
```
(* QED: photon photon → e- e+ (pair creation)*)
topology = CreateTopologies[0, 2 → 2];
feynman5 = InsertFields[topology, {V[1], V[1]} → {F[2, {1}], -F[2, {1}]},
   InsertionLevel → {Classes}, Restrictions → QEDOnly];
Paint[feynman5, Numbering → None, SheetHeader → False,
  ColumnsXRows → {4, 1}, ImageSize → {1032, 256}];
amplitude5[0] = FCFAConvert[CreateFeynAmp[feynman5], IncomingMomenta → {p1, p2},
  OutgoingMomenta → {p3, p4}, UndoChiralSplittings → True ,
  ChangeDimension → 4, TransversePolarizationVectors → {p1, p2},
  List → False, SMP → True, Contract → True]
FCClearScalarProducts[];
SetMandelstam[s, t, u, p1, p2, -p3, -p4, 0, 0, SMP["m_e"], SMP["m_e"]];
squareamplitude5[0] = (amplitude5[0] (ComplexConjugate[amplitude5[0]])) //
        FeynAmpDenominatorExplicit //
       DoPolarizationSums[#, p1, 0] & // DoPolarizationSums[#, p2, 0] & //
     FermionSpinSum[#, ExtraFactor → 1 / 2^2] & // DiracSimplify //
   TrickMandelstam[#, {s, t, u, 2 SMP["m_e"]^2}] & // Simplify
masslesssquareamplitude5[0] =
 squareamplitude5[0] // ReplaceAll[#, {SMP["m_e"] → 0}] & // Simplify
(* output = feynman diagrams, amplitude,
squared amplitude, massless squared amplitude *)
```



Out[43]=

$$\frac{e^2\,(\varphi(\overline{p_3}, m_e)).(\overline{\gamma}\cdot\overline{\varepsilon}(p_2)).(\overline{\gamma}\cdot(\overline{p_3}-\overline{p_2})+m_e).(\overline{\gamma}\cdot\overline{\varepsilon}(p_1)).(\varphi(-\overline{p_4}, m_e))}{(\overline{p_2}-\overline{p_3})^2-m_e^2} +$$
$$\frac{e^2\,(\varphi(\overline{p_3}, m_e)).(\overline{\gamma}\cdot\overline{\varepsilon}(p_1)).(\overline{\gamma}\cdot(\overline{p_2}-\overline{p_4})+m_e).(\overline{\gamma}\cdot\overline{\varepsilon}(p_2)).(\varphi(-\overline{p_4}, m_e))}{(\overline{p_4}-\overline{p_2})^2-m_e^2}$$

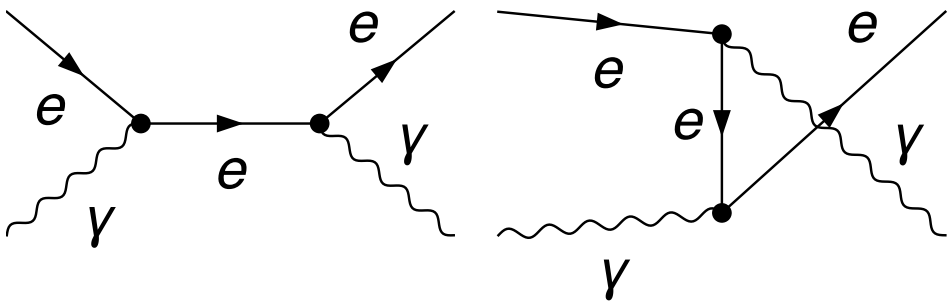
Out[46]=

$$\frac{2\,e^4\left(m_e^4\left(3t^2+14tu+3u^2\right)-m_e^2\left(t^3+7t^2u+7tu^2+u^3\right)-6m_e^8+tu\left(t^2+u^2\right)\right)}{\left(t-m_e^2\right)^2\left(u-m_e^2\right)^2}$$

Out[47]=

$$\frac{2\,e^4\left(t^2+u^2\right)}{tu}$$

In[48]:=
```
(* QED: e- photon → e- photon (Compton)*)
topology = CreateTopologies[0, 2 → 2];
feynman6 = InsertFields[topology, {F[2, {1}], V[1]} → {F[2, {1}], V[1]},
   InsertionLevel → {Classes}, Restrictions → QEDOnly];
Paint[feynman6, Numbering → None, SheetHeader → False,
  ColumnsXRows → {4, 1}, ImageSize → {1032, 256}];
amplitude6[0] = FCFAConvert[CreateFeynAmp[feynman6], IncomingMomenta → {p1, p2},
  OutgoingMomenta → {p3, p4}, UndoChiralSplittings → True ,
  ChangeDimension → 4, TransversePolarizationVectors → {p2, p4},
  List → False, SMP → True, Contract → True]
FCClearScalarProducts[];
SetMandelstam[s, t, u, p1, p2, -p3, -p4, SMP["m_e"], 0, SMP["m_e"], 0];
squareamplitude6[0] = (amplitude6[0] (ComplexConjugate[amplitude6[0]])) //
        FeynAmpDenominatorExplicit //
       DoPolarizationSums[#, p2, 0] & // DoPolarizationSums[#, p4, 0] & //
     FermionSpinSum[#, ExtraFactor → 1 / 2^2] & // DiracSimplify //
   TrickMandelstam[#, {s, t, u, 2 SMP["m_e"]^2}] & // Simplify
masslesssquareamplitude6[0] =
 squareamplitude6[0] // ReplaceAll[#, {SMP["m_e"] → 0}] & // Simplify
(* output = feynman diagrams, amplitude,
squared amplitude, massless squared amplitude *)
```



Out[51]=

$$-\frac{e^2\,(\varphi(\overline{p_3}, m_e)).(\overline{\gamma}\cdot\overline{\varepsilon}(p_2)).(\overline{\gamma}\cdot(\overline{p_3}-\overline{p_2})+m_e).(\overline{\gamma}\cdot\overline{\varepsilon}^*(p_4)).(\varphi(\overline{p_1}, m_e))}{(\overline{p_2}-\overline{p_3})^2-m_e^2} -$$
$$\frac{e^2\,(\varphi(\overline{p_3}, m_e)).(\overline{\gamma}\cdot\overline{\varepsilon}^*(p_4)).(\overline{\gamma}\cdot(\overline{p_3}+\overline{p_4})+m_e).(\overline{\gamma}\cdot\overline{\varepsilon}(p_2)).(\varphi(\overline{p_1}, m_e))}{(-\overline{p_3}-\overline{p_4})^2-m_e^2}$$

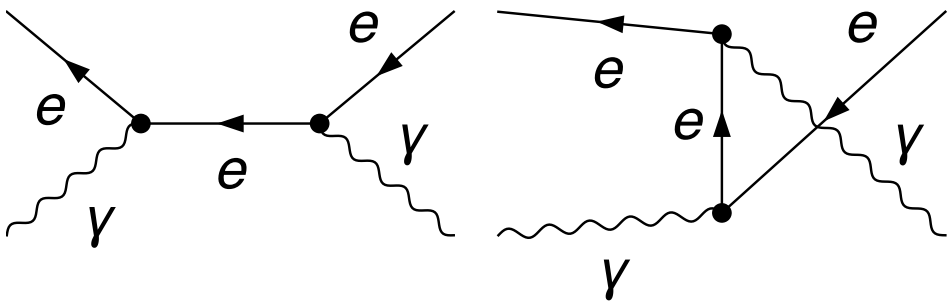
Out[54]=

$$\frac{2\,e^4\left(-m_e^4\left(3\,s^2+14\,s\,u+3\,u^2\right)+m_e^2\left(s^3+7\,s^2\,u+7\,s\,u^2+u^3\right)+6\,m_e^8-s\,u\left(s^2+u^2\right)\right)}{\left(s-m_e^2\right)^2\left(u-m_e^2\right)^2}$$

Out[55]=

$$-\frac{2\,e^4\left(s^2+u^2\right)}{s\,u}$$

In[56]:=
```
(* QED: e+ photon → e+ photon *)
topology = CreateTopologies[0, 2 → 2];
feynman7 = InsertFields[topology, {-F[2, {1}], V[1]} → {-F[2, {1}], V[1]},
   InsertionLevel → {Classes}, Restrictions → QEDOnly];
Paint[feynman7, Numbering → None, SheetHeader → False,
  ColumnsXRows → {4, 1}, ImageSize → {1032, 256}];
amplitude7[0] = FCFAConvert[CreateFeynAmp[feynman7], IncomingMomenta → {p1, p2},
  OutgoingMomenta → {p3, p4}, UndoChiralSplittings → True ,
  ChangeDimension → 4, TransversePolarizationVectors → {p2, p4},
  List → False, SMP → True, Contract → True]
FCClearScalarProducts[];
SetMandelstam[s, t, u, p1, p2, -p3, -p4, SMP["m_e"], 0, SMP["m_e"], 0];
squareamplitude7[0] = (amplitude7[0] (ComplexConjugate[amplitude7[0]])) //
        FeynAmpDenominatorExplicit //
       DoPolarizationSums[#, p2, 0] & // DoPolarizationSums[#, p4, 0] & //
     FermionSpinSum[#, ExtraFactor → 1 / 2^2] & // DiracSimplify //
   TrickMandelstam[#, {s, t, u, 2 SMP["m_e"]^2}] & // Simplify
masslesssquareamplitude7[0] =
 squareamplitude7[0] // ReplaceAll[#, {SMP["m_e"] → 0}] & // Simplify
(* output = feynman diagrams, amplitude,
squared amplitude, massless squared amplitude *)
```



Out[59]=

$$\frac{e^2\,(\varphi(-\overline{p_1}, m_e)).(\overline{\gamma}\cdot\overline{\varepsilon}^*(p_4)).(\overline{\gamma}\cdot(\overline{p_2}-\overline{p_3})+m_e).(\overline{\gamma}\cdot\overline{\varepsilon}(p_2)).(\varphi(-\overline{p_3}, m_e))}{(\overline{p_3}-\overline{p_2})^2-m_e^2} +$$
$$\frac{e^2\,(\varphi(-\overline{p_1}, m_e)).(\overline{\gamma}\cdot\overline{\varepsilon}(p_2)).(\overline{\gamma}\cdot(-\overline{p_3}-\overline{p_4})+m_e).(\overline{\gamma}\cdot\overline{\varepsilon}^*(p_4)).(\varphi(-\overline{p_3}, m_e))}{(\overline{p_3}+\overline{p_4})^2-m_e^2}$$

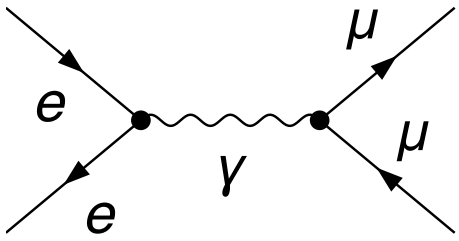
Out[62]=

$$\frac{2\,e^4\left(-m_e^4\left(3\,s^2+14\,s\,u+3\,u^2\right)+m_e^2\left(s^3+7\,s^2\,u+7\,s\,u^2+u^3\right)+6\,m_e^8-s\,u\left(s^2+u^2\right)\right)}{\left(s-m_e^2\right)^2\left(u-m_e^2\right)^2}$$

Out[63]=

$$-\frac{2\,e^4\left(s^2+u^2\right)}{s\,u}$$

In[64]:=
```
(* QED: e- e+ → mu- mu+ *)
topology = CreateTopologies[0, 2 → 2];
feynman8 =
  InsertFields[topology, {F[2, {1}], -F[2, {1}]} → {F[2, {2}], -F[2, {2}]},
   InsertionLevel → {Classes}, Restrictions → QEDOnly];
Paint[feynman8, Numbering → None, SheetHeader → False,
  ColumnsXRows → {4, 1}, ImageSize → {1032, 256}];
amplitude8[0] = FCFAConvert[CreateFeynAmp[feynman8], IncomingMomenta → {p1, p2},
  OutgoingMomenta → {p3, p4}, UndoChiralSplittings → True ,
  ChangeDimension → 4, List → False, SMP → True, Contract → True]
FCClearScalarProducts[];
SetMandelstam[s, t, u, p1, p2, -p3, -p4,
  SMP["m_e"], SMP["m_e"], SMP["m_mu"], SMP["m_mu"]];
squareamplitude8[0] = (amplitude8[0] (ComplexConjugate[amplitude8[0]])) //
     FeynAmpDenominatorExplicit //
    FermionSpinSum[#, ExtraFactor → 1 / 2^2] & // DiracSimplify // Simplify
masslesssquareamplitude8[0] = squareamplitude8[0] //
   ReplaceAll[#, {SMP["m_e"] → 0, SMP["m_mu"] → 0}] & // Simplify
(* output = feynman diagrams, amplitude,
squared amplitude, massless squared amplitude *)
```



Out[67]=

$$-\frac{e^2\,(\varphi(-\overline{p_2}, m_e))\cdot\bar{\gamma}^{\text{Lor2}}\cdot(\varphi(\overline{p_1}, m_e))\,(\varphi(\overline{p_3}, m_\mu))\cdot\bar{\gamma}^{\text{Lor2}}\cdot(\varphi(-\overline{p_4}, m_\mu))}{(\overline{p_3}+\overline{p_4})^2}$$

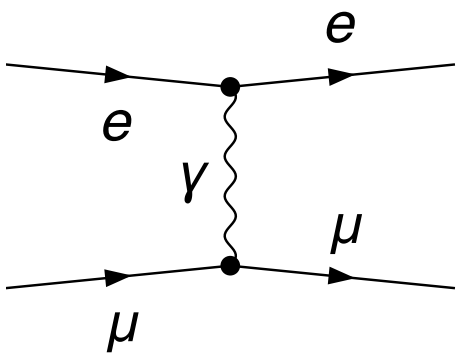
Out[70]=

$$\frac{2\,e^4\left(2\,m_e^2\left(2\,m_\mu^2+s-t-u\right)+2\,m_e^4+2\,m_\mu^4+2\,m_\mu^2\,(s-t-u)+t^2+u^2\right)}{s^2}$$

Out[71]=

$$\frac{2\,e^4\left(t^2+u^2\right)}{s^2}$$

In[72]:=
```
(* QED: e- mu- → e- mu- *)
topology = CreateTopologies[0, 2 → 2];
feynman9 =
  InsertFields[topology, {F[2, {1}], F[2, {2}]} → {F[2, {1}], F[2, {2}]},
   InsertionLevel → {Classes}, Restrictions → QEDOnly];
Paint[feynman9, Numbering → None, SheetHeader → False,
  ColumnsXRows → {4, 1}, ImageSize → {1032, 256}];
amplitude9[0] = FCFAConvert[CreateFeynAmp[feynman9], IncomingMomenta → {p1, p2},
  OutgoingMomenta → {p3, p4}, UndoChiralSplittings → True ,
  ChangeDimension → 4, List → False, SMP → True, Contract → True]
FCClearScalarProducts[];
SetMandelstam[s, t, u, p1, p2, -p3, -p4,
  SMP["m_e"], SMP["m_mu"], SMP["m_e"], SMP["m_mu"]];
squareamplitude9[0] = (amplitude9[0] (ComplexConjugate[amplitude9[0]])) //
     FeynAmpDenominatorExplicit //
    FermionSpinSum[#, ExtraFactor → 1 / 2^2] & // DiracSimplify // Simplify
masslesssquareamplitude9[0] = squareamplitude9[0] //
   ReplaceAll[#, {SMP["m_e"] → 0, SMP["m_mu"] → 0}] & // Simplify
(* output = feynman diagrams, amplitude,
squared amplitude, massless squared amplitude *)
```



Out[75]=

$$-\frac{e^2\,(\varphi(\overline{p_3}, m_e))\cdot\bar{\gamma}^{\text{Lor2}}\cdot(\varphi(\overline{p_1}, m_e))\,(\varphi(\overline{p_4}, m_\mu))\cdot\bar{\gamma}^{\text{Lor2}}\cdot(\varphi(\overline{p_2}, m_\mu))}{(\overline{p_4}-\overline{p_2})^2}$$

Out[78]=

$$\frac{2\,e^4\left(-2\,m_e^2\left(-2\,m_\mu^2+s-t+u\right)+2\,m_e^4+2\,m_\mu^4-2\,m_\mu^2\,(s-t+u)+s^2+u^2\right)}{t^2}$$

Out[79]=

$$\frac{2\,e^4\left(s^2+u^2\right)}{t^2}$$

In[80]:=
```
Print["\tCPU Time used: ", Round[N[TimeUsed[], 4], 0.001], " s."];
```

CPU Time used: 5.838 s.

In[81]:=
```
FeynCalcHowToCite[]
```

- V. Shtabovenko, R. Mertig and F. Orellana, arXiv:2312.14089.
- V. Shtabovenko, R. Mertig and F. Orellana, Comput.Phys.Commun. 256 (2020) 107478, arXiv:2001.04407.
- V. Shtabovenko, R. Mertig and F. Orellana, Comput.Phys.Commun. 207 (2016) 432–444, arXiv:1601.01167.
- R. Mertig, M. Böhm, and A. Denner, Comput. Phys. Commun. 64 (1991) 345–359.

Out[81]=

Null