γ + q → g + q

```
Off[General::spell];
Off[General::spell1];
```

====================================
Load FeynArts:

====================================
Create Topologies: Photon+Quark->Quark+Gluon

```
tops= CreateTopologies[0,4
         ,Tadpoles->False
         ,SelfEnergies->False
      ];
Length[tops]
```

{ 0: Loops
4: External Particles }

4

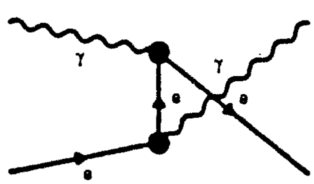
γ F γ F

```
ins=InsertFields[tops,{V[1],F[1]}->{V[1],F[1]}
                 ,Model->{SM}];
```

(Fake gluon with photon)

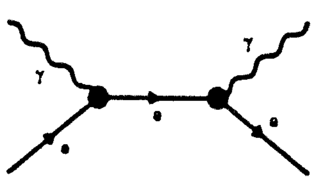
```
ins

Paint[ins
     ,GraphsPerRow -> 1
     ,RowsPerSheet -> 2];
```

\+ e --> γ + e



t- Channel

Top.1 Ins.1



S- Channel

Top.2 Ins.1

Internal FeynArts Form

```
amp=CreateFeynAmp[ins];

amp

FeynAmpList[Model -> {SM}, Generation1 -> True,
   Generation2 -> True, Generation3 -> True,
   ElectronHCoupling -> True, LightFHCoupling -> True,
   QuarkMixing -> False, UnitaryGauge -> False,
   RemoveEmptyTops -> True, ProcessName -> V1F1V1F1,
   Process ->
    {{V[1], p1, 0}, {F[1], p2, ME}} ->
     {{V[1], k1, 0}, {F[1], k2, ME}}][FeynAmp[V1F1V1F1, T1, I1,
        2
    N1][(EL  ep[p1, li2] ep(*)[k1, li4] Integral[]
      u[k2, ME] . ga[li2] . (ME + gs[-k1 + p2]) . ga[li4] .
                        2             2
       u[p2, ME]) / (-ME  + (k1 - p2) )],
                                  2
  FeynAmp[V1F1V1F1, T2, I1, N2][(EL  ep[p1, li2] ep(*)[k1, li4]
      Integral[] u[k2, ME] . ga[li4] . (ME + gs[p1 + p2]) .
                                   2             2
       ga[li2] . u[p2, ME]) / (-ME  + (p1 + p2) )]]

InputForm[amp]
```

```
Off[General::spell];Off[General::spell1];
```

A ≡ t - Channel

B ≡ S - Channel

■ ==================================

Load FeynCalc2.1

■ ==================================

Input Raw Amps From FeynArts:

```
amps={rawamps[[1,2]],rawamps[[2,2]]}
```

$\{A, B\}$

```
((EL^2 ep[p1, li2] ep(*)[k1, li4]
     u[k2, ME] ga[li2] (-gs[k1 - p2] + ME) ga[li4] u[p2, ME]) /
   ((k1 - p2)^2 - ME^2), (EL^2 ep[p1, li2] ep(*)[k1, li4]
     u[k2, ME] ga[li4] (gs[p1 + p2] + ME) ga[li2] u[p2, ME]) /
   ((p1 + p2)^2 - ME^2))
```

■ ==================================

Conugate Amps

```
camps=ComplexConjugate[amps]
```

$\{A^* \quad B^*\}$

```
((EL^2 ep[k1, li4*] ep(*)[p1, li2*]
     u[p2, ME] ga[li4*] (-gs[k1 - p2] + ME) ga[li2*] u[k2, ME]) \
   / ((k1 - p2)^2 - ME^2), (EL^2 ep[k1, li4*] ep(*)[p1, li2*]
     u[p2, ME] ga[li2*] (gs[p1 + p2] + ME) ga[li4*] u[k2, ME]) /
   ((p1 + p2)^2 - ME^2))
```

■ ==================================

Square Amps

```
msquared1=Outer[Times,amps,camps];
Dimensions[msquared1]
```

$$|M|^2 = \begin{pmatrix} AA^* & AB^* \\ BA^* & BB^* \end{pmatrix}$$

■ ==================================

Set ME=0 for simplicity:

```
ME=0;
```

■ ==================================

Contract Polarization Vectors:
e[mu] e*[nu] -> g[mu,nu]

$$\varepsilon^\mu \varepsilon^{*\nu} \to g^{\mu\nu}$$

```
Clear[ContractBosons];
ContractBosons={

  Pair[LorentzIndex[ComplexIndex[li1_]],
         Momentum[Polarization[p_, _]]]*
  Pair[LorentzIndex[                li2_] ,
         Momentum[Polarization[p_, _]]]
   :> MetricTensor[ComplexIndex[li1],li2]

 );
```

■ ==================================

Evaluate Square Amps

```
msquared2=
  ( msquared1  //.ContractBosons
               //Contract
               //Map[FermionSpinSum,#,{2}]&
               //Map[EvaluateDiracTrace,#,{2}]&
               //PropagatorDenominatorExplicit
    )
```

■ ==================================

Examine Mandelstam Variables

```
SetMandelstam[s,t,u,p1,p2,-k2,-k1,q,0,ME,ME];

( {ScalarProduct[p1+p2,p1+p2]
  ,ScalarProduct[p1-k2,p1-k2]
  ,ScalarProduct[p1-k1,p1-k1]}
     //ExpandScalarProduct
     //Simplify
  )

{s, t, u}
```

$s = (P_1 + P_2)^2$

$t = (P_1 - K_2)^2$

$u = (P_1 - K_1)^2$

■ ==================================

Evaluate Square Amps

```
q /: q^2 =-Q^2;

msquared2=msquared2 //ExpandScalarProduct;

msquared3=
 TrickMandelstam[ msquared2, {s,t,u,-Q^2+2 ME^2}]
```

$$\left\{\left\{\frac{-8\ EL^4\ s}{t}, \frac{8\ EL^4\ Q^2\ u}{s\ t}\right\}, \left\{\frac{8\ EL^4\ Q^2\ u}{s\ t}, \frac{-8\ EL^4\ t}{s}\right\}\right\}$$

```
msquared4= msquared3 /(8 EL^4)  /.{ME->0}
```

$$\left\{\left\{-\left(\frac{s}{t}\right), \frac{Q^2\ u}{s\ t}\right\}, \left\{\frac{Q^2\ u}{s\ t}, -\left(\frac{t}{s}\right)\right\}\right\} \longleftarrow |\mathcal{M}|^2 = \{\{AA^*, AB^*\}, \{BA^*, BB^*\}\}$$

```
msquared5= Plus @@ Plus @@ msquared4
```

$$-\left(\frac{s}{t}\right) - \frac{t}{s} + \frac{2\ Q^2\ u}{s\ t} \quad = |\mathcal{M}|^2$$

Cross term $AB^* + BA^*$ (→ $\frac{2 Q^2 u}{s t}$)

s - channel BB^* (→ $-\frac{t}{s}$)

t - channel AA^* (→ $-\frac{s}{t}$)