# Feynman Diagram calculations with FeynArts and FormCalc

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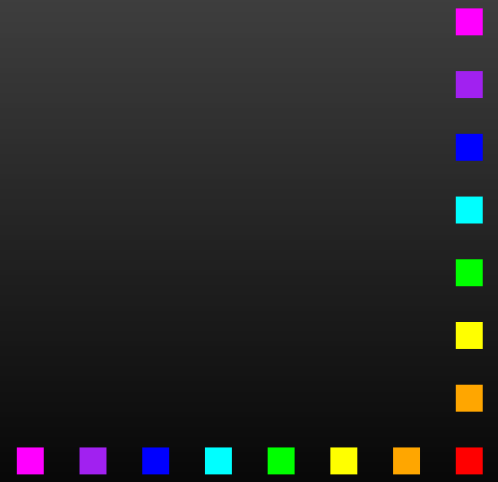


# Automated Diagram Evaluation

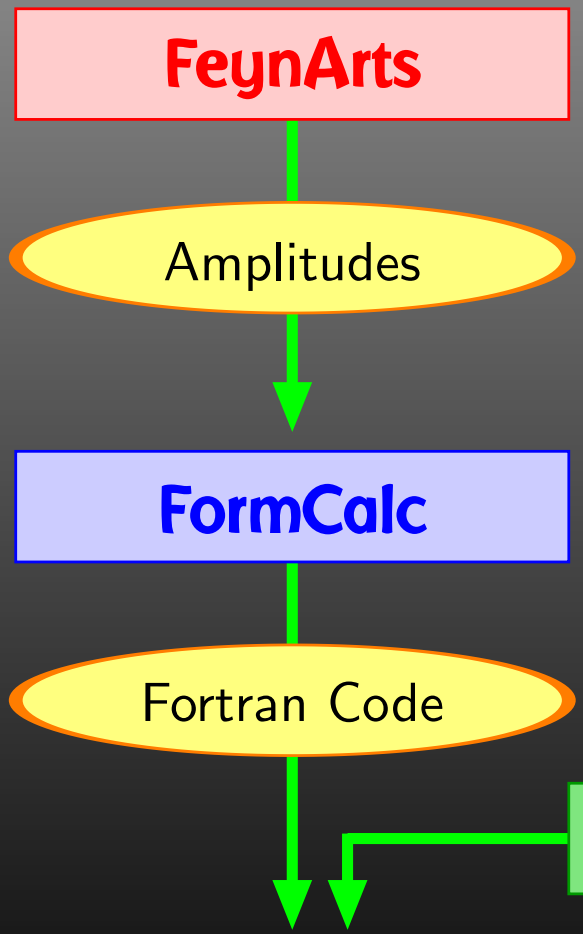



**Diagram Generation:**

- Create the topologies
- Insert fields
- Apply the Feynman rules
- Paint the diagrams

**Algebraic Simplification:**

- Contract indices
- Calculate traces
- Reduce tensor integrals
- Introduce abbreviations

**Numerical Evaluation:**

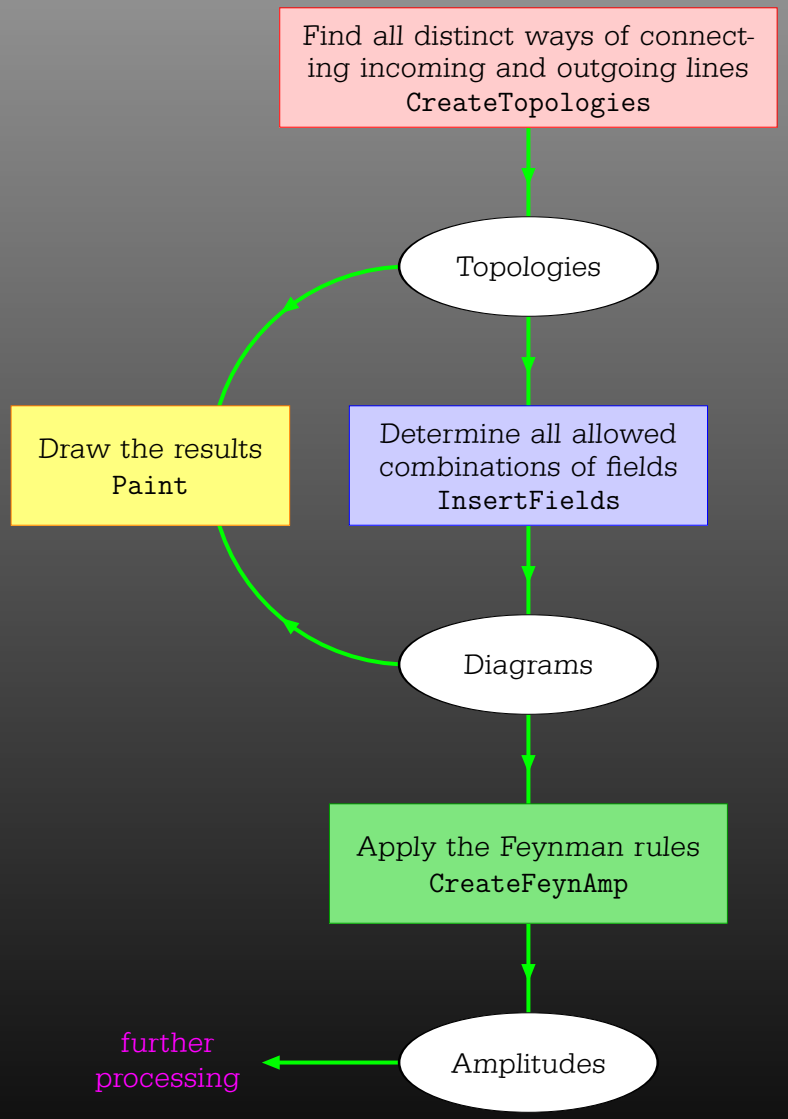
- Convert Mathematica output to Fortran code
- Supply a driver program
- Implementation of the integrals

Symbolic manipulation (Computer Algebra) for the structural and algebraic operations.

Compiled high-level language (Fortran) for the numerical evaluation.

$|\mathcal{M}|^2 \longrightarrow$ Cross-sections, Decay rates, ...

# FeynArts




EXAMPLE: generating the photon self-energy

```
top = CreateTopologies[ 1, 1 -> 1 ]
```

one loop

one incoming particle

one outgoing particle

```
Paint[top]
```

```
ins = InsertFields[ top, V[1] -> V[1],
        Model -> SM ]
```

use the Standard Model

the name of the photon in the "SM" model file

```
Paint[ins]
```

```
amp = CreateFeynAmp[ins]
```

```
amp >> PhotonSelfEnergy.amp
```

# Three Levels of Fields

**Generic level, e.g.** `F, F, S`

$$C(F_1, F_2, S) = G_- \omega_- + G_+ \omega_+$$

**Kinematical structure completely fixed, most algebraic simplifications (e.g. tensor reduction) can be carried out.**

**Classes level, e.g.** `-F[2], F[1], S[3]`

$$\bar{\ell}_i \nu_j G: \quad G_- = -\frac{\mathrm{i}\, e\, m_{\ell,i}}{\sqrt{2} \sin\theta_w M_W} \delta_{ij}\,, \quad G_+ = 0$$

**Coupling fixed except for $i$, $j$ (can be summed in do-loop).**

**Particles level, e.g.** `-F[2,{1}], F[1,{1}], S[3]`

**insert fermion generation (1, 2, 3) for $i$ and $j$**

# The Model Files

One has to set up, once and for all, a

- **Generic Model File** (seldomly changed) containing the generic part of the couplings,

Example: the `FFS` coupling

$$C(F,F,S) = G_- \omega_- + G_+ \omega_+ = \vec{G} \cdot \begin{pmatrix} \omega_- \\ \omega_+ \end{pmatrix}$$

```
AnalyticalCoupling[s1 F[j1, p1], s2 F[j2, p2], s3 S[j3, p3]]
== G[1][s1 F[j1], s2 F[j2], s3 S[j3]] .
     { NonCommutative[ ChiralityProjector[-1] ],
       NonCommutative[ ChiralityProjector[+1] ] }
```

# The Model Files

One has to set up, once and for all, a

- **Classes Model File** (for each model)
  declaring the particles and the allowed couplings

Example: the $\bar{\ell}_i \nu_j G$ coupling in the Standard Model

$$\vec{G}(\bar{\ell}_i, \nu_j, G) = \begin{pmatrix} G_- \\ G_+ \end{pmatrix} = \begin{pmatrix} -\frac{\mathrm{i}\, e\, m_{\ell,i}}{\sqrt{2} \sin\theta_w M_W} \delta_{ij} \\ 0 \end{pmatrix}$$

```
C[ -F[2,{i}], F[1,{j}], S[3] ]
== { {-I EL Mass[F[2,{i}]]/(Sqrt[2] SW MW) IndexDelta[i, j]},
     {0} }
```

# Current Status of Model Files

Model Files presently available for FeynArts:

- SM [w/QCD], normal and background-field version.
  All one-loop counter terms included.
- MSSM [w/QCD].
  Counter terms by T. Fritzsche.
- Two-Higgs-Doublet Model.
  Counter terms not included yet.
- ModelMaker utility generates Model Files from the Lagrangian.
- FeynRules package generates Model Files for FeynArts and other packages.
- SARAH package derives SUSY Models.

# Partial (Add-On) Model Files

FeynArts distinguishes

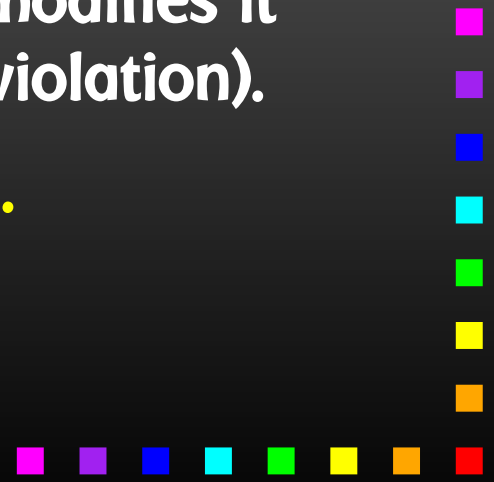
- **Basic Model Files** and
- **Partial (Add-On) Model Files.**

Basic Model Files, e.g. `SM.mod`, `MSSM.mod`, can be modified by Add-On Model Files. For example,

```
InsertFields[..., Model -> {"MSSMQCD", "FV"}]
```

This loads the Basic Model File `MSSMQCD.mod` and modifies it through the Add-On `FV.mod` (non-minimal flavour violation).

**Model files can thus be built up from several parts.**



# Tweaking Model Files

Or, How to efficiently make changes in an existing model file.

Bad: Copy the model file, modify the copy. – Why?

- It is typically not very transparent what has changed.
- If the original model file changes (e.g. bug fixes), these do not automatically propagate into the derivative model file.

Better: Create an add-on model file which modifies the particles and coupling tables.

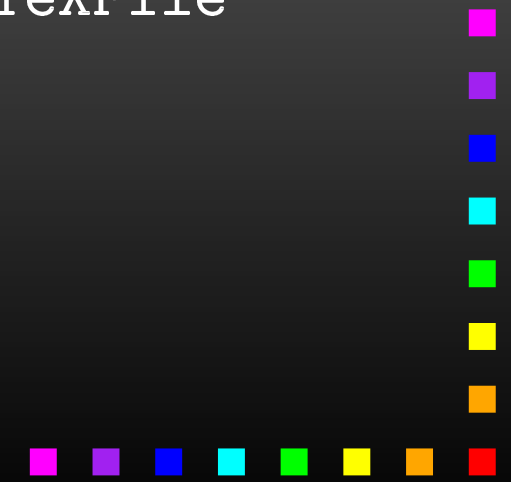
- `M$ClassesDescription` = list of particle definitions,
- `M$CouplingMatrices` = list of couplings.

# Tweaking Model Files

**Example: Introduce enhancement factors for the $b$-$\bar{b}$-$h_0$ and $b$-$\bar{b}$-$H_0$ Yukawa couplings in the MSSM.**

```
EnhCoup[(lhs:C[F[4,{g_,_}], -F[4,_], S[h:1|2]]) == rhs_] :=
  lhs == Hff[h,g] rhs

EnhCoup[other_] = other

M$CouplingMatrices = EnhCoup/@ M$CouplingMatrices
```

**To see the effect, make a printout with the `WriteTeXFile` utility of FeynArts.**



# Linear Combinations of Fields

New in FeynArts 3.5

FeynArts can automatically linear-combine fields, i.e. one can specify the couplings in terms of gauge rather than mass eigenstates. For example:

```
M$ClassesDescription = { ...,
  F[11] = {...,
    Indices -> {Index[Neutralino]},
    Mixture -> ZNeu[Index[Neutralino],1] F[111] +
               ZNeu[Index[Neutralino],2] F[112] +
               ZNeu[Index[Neutralino],3] F[113] +
               ZNeu[Index[Neutralino],4] F[114]} }
```

Since `F[111]...F[114]` are not listed in `M$CouplingMatrices`, they drop out of the model completely.

# Linear Combinations of Fields

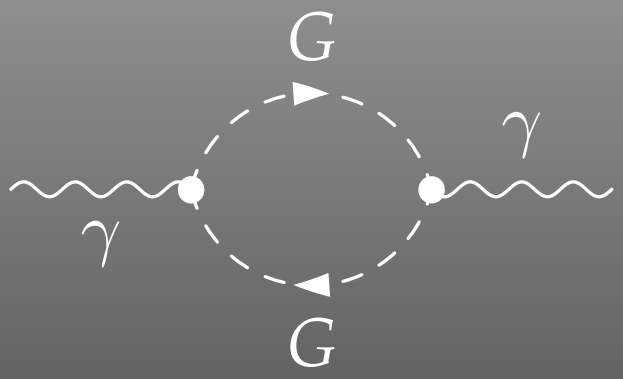
**Higher-order mixings can be added, too:**

```
M$ClassesDescription = { ...,
  S[1] = {...},
  S[2] = {...},
  S[10] == {...,
    Indices -> {Index[Higgs]},
    Mixture -> UHiggs[Index[Higgs],1] S[1] +
               UHiggs[Index[Higgs],2] S[2],
    InsertOnly -> {External, Internal}} }
```

**This time,** `S[10]` ***and*** `S[1],S[2]` **appear in the coupling list (including all mixing couplings) because all three are listed in** `M$CouplingMatrices`**.**

**Due to the** `InsertOnly`**,** `S[10]` **is inserted only on tree-level parts of the diagram, not in loops.**

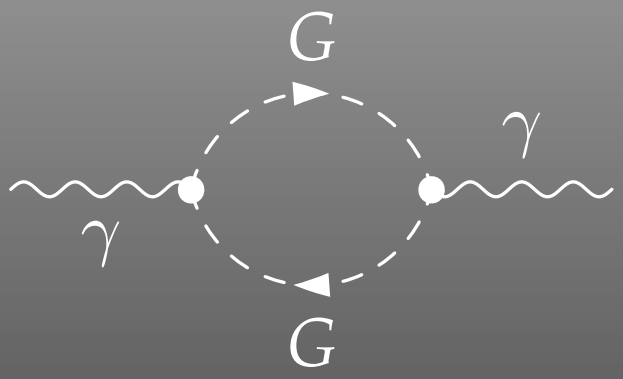
# Sample CreateFeynAmp output




= FeynAmp[ *identifier* ,
*loop momenta* ,
*generic amplitude* ,
*insertions* ]

```
GraphID[Topology == 1, Generic == 1]
```

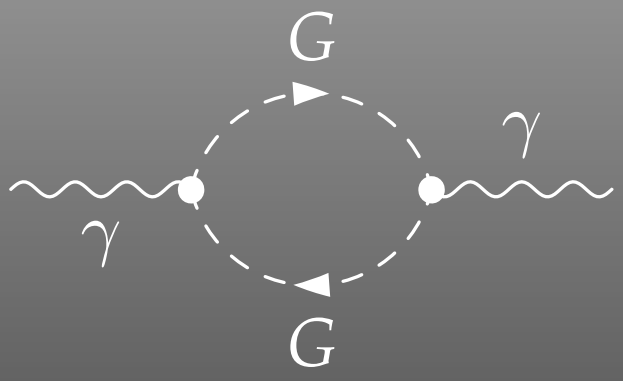
# Sample CreateFeynAmp output




= FeynAmp[ *identifier*,
*loop momenta*,
*generic amplitude*,
*insertions* ]

Integral[q1]

# Sample CreateFeynAmp output




= FeynAmp[ *identifier*,
*loop momenta*,
*generic amplitude*,
*insertions* ]

$\frac{\text{I}}{32\ \text{Pi}^4}$ RelativeCF ..... *prefactor*

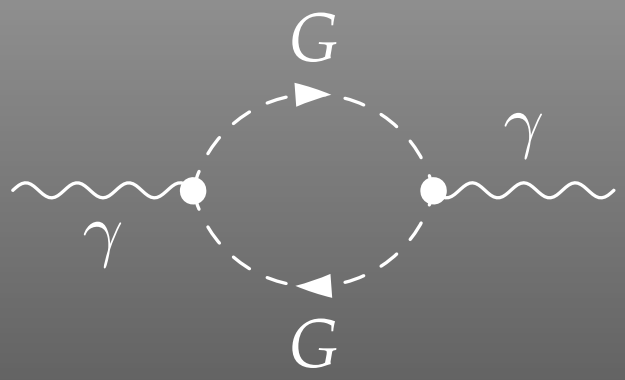
FeynAmpDenominator[$\frac{1}{\text{q1}^2 - \text{Mass[S[Gen3]]}^2}$, $\frac{1}{(-\text{p1} + \text{q1})^2 - \text{Mass[S[Gen4]]}^2}$] ..... *loop denominators*

(p1 - 2 q1)[Lor1] (-p1 + 2 q1)[Lor2] ..... *kin. coupling structure*

ep[V[1], p1, Lor1] ep*[V[1], k1, Lor2] ..... *polarization vectors*

$\text{G}^{(0)}_{\text{SSV}}$[(Mom[1] - Mom[2])[KI1[3]]]
$\text{G}^{(0)}_{\text{SSV}}$[(Mom[1] - Mom[2])[KI1[3]]], ..... *coupling constants*

# Sample CreateFeynAmp output

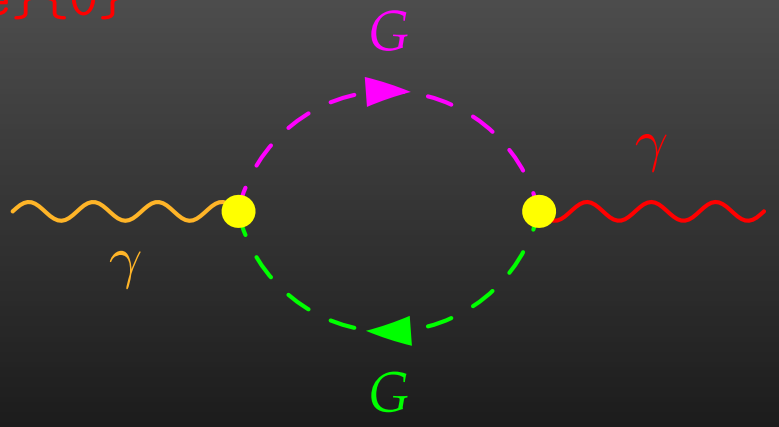



= FeynAmp[ *identifier*,
*loop momenta*,
*generic amplitude*,
*insertions* ]

```
{ Mass[S[Gen3]],
  Mass[S[Gen4]],
  G_SSV^(0)[(Mom[1] - Mom[2])[KI1[3]]],
  G_SSV^(0)[(Mom[1] - Mom[2])[KI1[3]]],
  RelativeCF } ->
Insertions[Classes][{MW, MW, I EL, -I EL, 2}]
```

# Sample Paint output

```
\begin{feynartspicture}(150,150)(1,1)
\FADiagram{}
\FAProp(6.,10.)(14.,10.)(0.8,){ScalarDash}{-1}
\FALabel(10.,5.73)[t]{$G$}
\FAProp(6.,10.)(14.,10.)(-0.8,){ScalarDash}{1}
\FALabel(10.,14.27)[b]{$G$}
\FAProp(0.,10.)(6.,10.)(0.,){Sine}{0}
\FALabel(3.,8.93)[t]{$\gamma$}
\FAProp(20.,10.)(14.,10.)(0.,){Sine}{0}
\FALabel(17.,11.07)[b]{$\gamma$}
\FAVert(6.,10.){0}
\FAVert(14.,10.){0}
\end{feynartspicture}
```

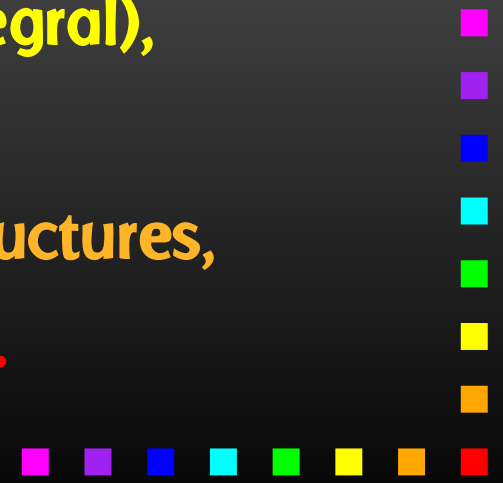



**Technically: uses its own PostScript prologue.**

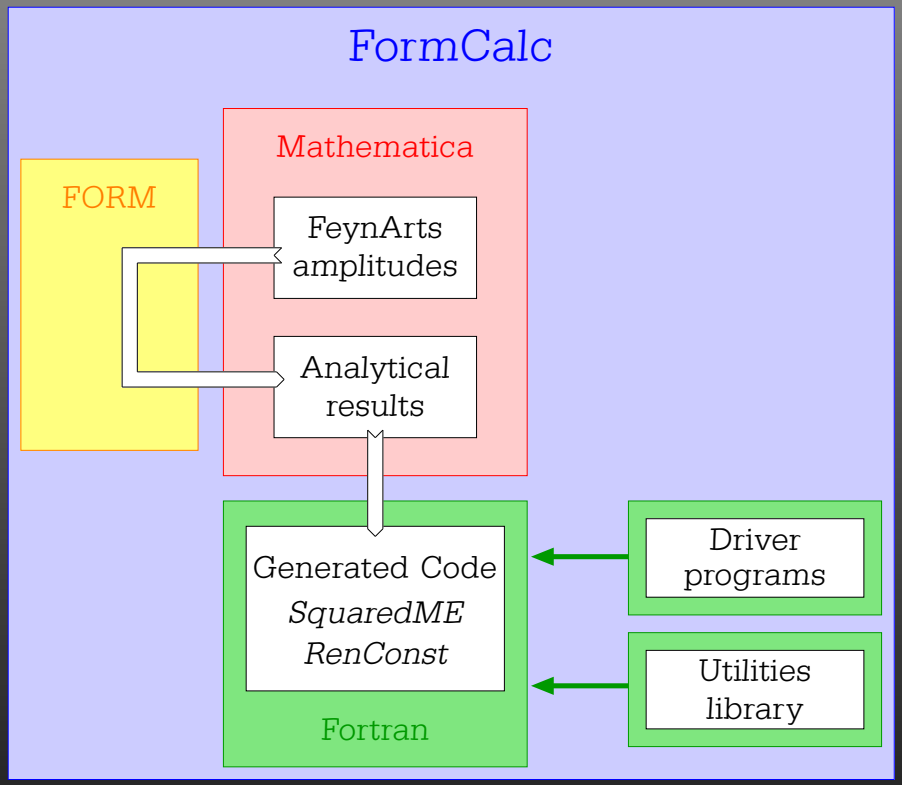
# Algebraic Simplification

The amplitudes output by FeynArts so far are in no good shape for direct numerical evaluation. Some objects must/should be handled symbolically, e.g. tensorial objects, Dirac traces, dimension (D vs. 4).

- contract indices as far as possible,
- evaluate fermion traces,
- perform the tensor reduction,
- add local terms arising from D·(divergent integral),
- simplify open fermion chains,
- simplify and compute the square of SU(N) structures,
- "compactify" the results as much as possible.



# FormCalc




EXAMPLE: Calculating the photon self-energy

```
In[1]:= << FormCalc`

FormCalc 6.1
by Thomas Hahn
last revised 6 Jul 09

In[2]:= CalcFeynAmp[<< PhotonSelfEnergy.amp]

preparing FORM code in /tmp/m1.frm
> 2 amplitudes with insertions
> 5 amplitudes without insertions
running FORM...  ok

Out[2]= Amp[{0} -> {0}][(-3 Alfa Pair1 A0[MW2])/(2 Pi) +
   (3 Alfa Pair1 B00[0, MW2, MW2])/Pi,
   ((Alfa Pair1 A0[MLE2[Gen1]])/Pi +
    (Alfa Pair1 A0[MQD2[Gen1]])/(3 Pi) +
    (4 Alfa Pair1 A0[MQU2[Gen1]])/(3 Pi) -
    (2 Alfa Pair1 B00[0, MLE2[Gen1], MLE2[Gen1]])/Pi -
    (2 Alfa Pair1 B00[0, MQD2[Gen1], MQD2[Gen1]])/(3 Pi) -
    (8 Alfa Pair1 B00[0, MQU2[Gen1], MQU2[Gen1]])/(3 Pi)) *
    SumOver[Gen1, 3]]
```

# FormCalc Output

A typical term in the output looks like

```
C0i[cc12, MW2, MW2, S, MW2, MZ2, MW2] *
  ( -4 Alfa2 MW2 CW2/SW2 S AbbSum16 +
    32 Alfa2 CW2/SW2 S^2 AbbSum28 +
    4 Alfa2 CW2/SW2 S^2 AbbSum30 -
    8 Alfa2 CW2/SW2 S^2 AbbSum7 +
    Alfa2 CW2/SW2 S(T-U) Abb1 +
    8 Alfa2 CW2/SW2 S(T-U) AbbSum29 )
```

= loop integral

= kinematical variables

= constants

= automatically introduced abbreviations

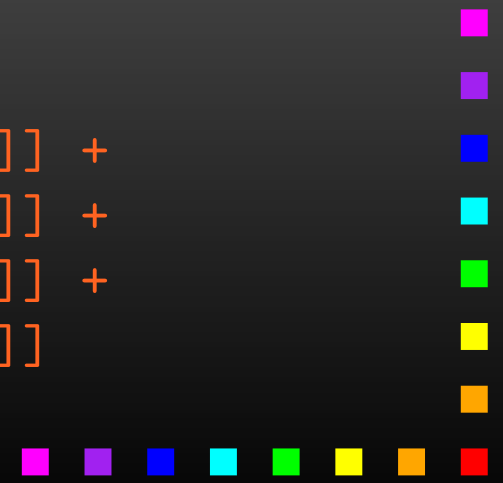
# Abbreviations

**Outright factorization is usually out of question.**
**Abbreviations are necessary to reduce size of expressions.**

```
AbbSum29 = Abb2 + Abb22 + Abb23 + Abb3

Abb22 = Pair1 Pair3 Pair6

Pair3 = Pair[e[3], k[1]]
```

**The full expression corresponding to `AbbSum29` is**

```
Pair[e[1], e[2]] Pair[e[3], k[1]] Pair[e[4], k[1]] +
Pair[e[1], e[2]] Pair[e[3], k[2]] Pair[e[4], k[1]] +
Pair[e[1], e[2]] Pair[e[3], k[1]] Pair[e[4], k[2]] +
Pair[e[1], e[2]] Pair[e[3], k[2]] Pair[e[4], k[2]]
```



# Categories of Abbreviations

- Abbreviations are recursively defined in several levels.
- When generating Fortran code, FormCalc introduces another set of abbreviations for the loop integrals.

In general, the abbreviations are thus costly in CPU time.
It is key to a decent performance that the abbreviations are separated into different Categories:

- Abbreviations that depend on the helicities,
- Abbreviations that depend on angular variables,
- Abbreviations that depend only on $\sqrt{s}$.

Correct execution of the categories guarantees that almost no redundant evaluations are made and makes the generated code essentially as fast as hand-tuned code.

# External Fermion Lines

An amplitude containing external fermions has the form

$$\mathcal{M} = \sum_{i=1}^{n_F} c_i \, F_i \quad \text{where} \quad F_i = \text{(Product of)} \, \langle u | \, \Gamma_i \, | v \rangle \, .$$

$n_F =$ number of fermionic structures.

Textbook procedure: Trace Technique

$$|\mathcal{M}|^2 = \sum_{i,j=1}^{n_F} c_i^* \, c_j \, F_i^* F_j$$

where $F_i^* F_j = \langle v | \, \bar{\Gamma}_i \, | u \rangle \, \langle u | \, \Gamma_j \, | v \rangle = \mathrm{Tr}\big( \bar{\Gamma}_i \, | u \rangle \langle u | \, \Gamma_j \, | v \rangle \langle v | \big) \, .$

# Problems with the Trace Technique

PRO: Trace technique is independent of any representation.

CON: For $n_F$ $F_i$'s there are $n_F^2$ $F_i^* F_j$'s.

Things get worse the more vectors are in the game: multi-particle final states, polarization effects . . .

Essentially $n_F \sim$ (# of vectors)! because all combinations of vectors can appear in the $\Gamma_i$.

Solution: Use Weyl–van der Waerden spinor formalism to compute the $F_i$'s directly.

# Sigma Chains

Define **Sigma matrices** and **2-dim. Spinors** as

$$\sigma_\mu = (\mathbb{1}, -\vec{\sigma})\,, \qquad \langle u|_{4\mathrm{d}} \equiv \left(\langle u_+|_{2\mathrm{d}}\,, \langle u_-|_{2\mathrm{d}}\right),$$

$$\overline{\sigma}_\mu = (\mathbb{1}, +\vec{\sigma})\,, \qquad |v\rangle_{4\mathrm{d}} \equiv \begin{pmatrix} |v_-\rangle_{2\mathrm{d}} \\ |v_+\rangle_{2\mathrm{d}} \end{pmatrix}.$$

**Using the chiral representation it is easy to show that every chiral 4-dim. Dirac chain can be converted to a *single* 2-dim. sigma chain:**

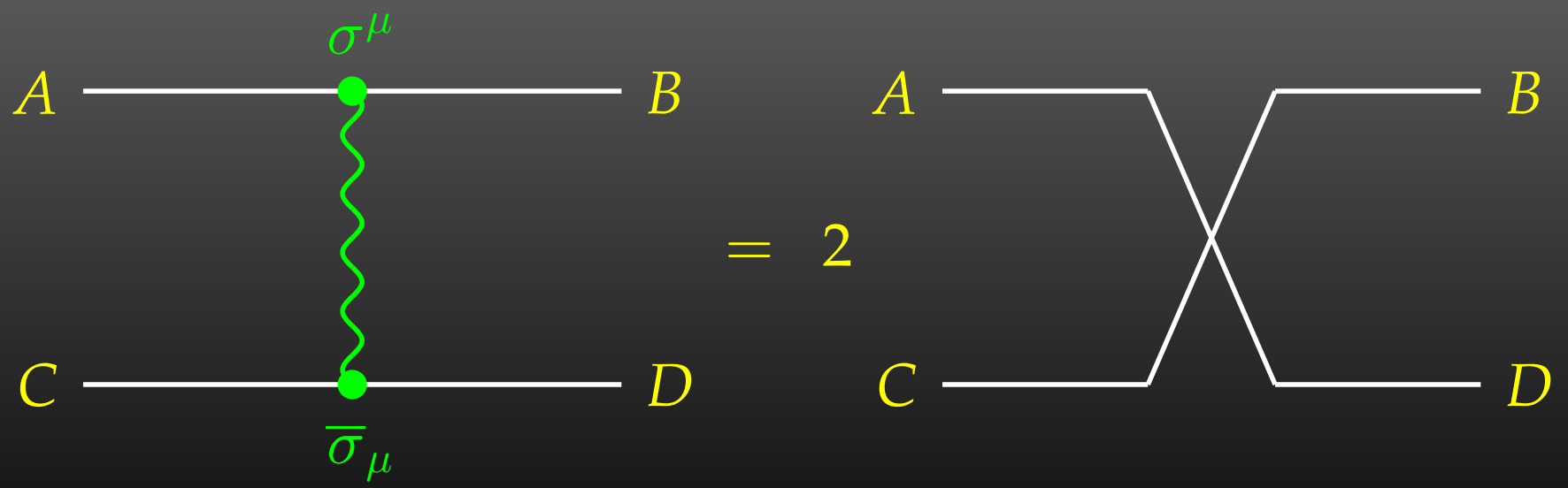
$$\langle u|\,\omega_-\gamma_\mu\gamma_\nu\cdots|v\rangle = \langle u_-|\,\overline{\sigma}_\mu\sigma_\nu\cdots|v_\pm\rangle\,,$$

$$\langle u|\,\omega_+\gamma_\mu\gamma_\nu\cdots|v\rangle = \langle u_+|\,\sigma_\mu\overline{\sigma}_\nu\cdots|v_\mp\rangle\,.$$

# Fierz Identities

**With the Fierz identities for sigma matrices it is possible to remove all Lorentz contractions between sigma chains, e.g.**

$$\langle A|\,\sigma_\mu\,|B\rangle\,\langle C|\,\overline{\sigma}^\mu\,|D\rangle \;=\; 2\,\langle A|D\rangle\,\langle C|B\rangle$$



# Implementation

- **Objects (arrays):** $|u_\pm\rangle \sim \begin{pmatrix} u_1 \\ u_2 \end{pmatrix}, \quad (\sigma \cdot k) \sim \begin{pmatrix} a & b \\ c & d \end{pmatrix}$
- **Operations (functions):**

$$\langle u|v\rangle \sim (u_1 \;\; u_2) \cdot \begin{pmatrix} v_1 \\ v_2 \end{pmatrix} \qquad \texttt{SxS}$$

$$(\overline{\sigma} \cdot k)\,|v\rangle \sim \begin{pmatrix} a & b \\ c & d \end{pmatrix} \cdot \begin{pmatrix} v_1 \\ v_2 \end{pmatrix} \qquad \texttt{VxS, BxS}$$

**Sufficient to compute any sigma chain:**

$$\langle u|\,\sigma_\mu \overline{\sigma}_\nu \sigma_\rho\,|v\rangle\, k_1^\mu k_2^\nu k_3^\rho = \texttt{SxS}(u, \texttt{VxS}(k_1, \texttt{BxS}(k_2, \texttt{VxS}(k_3, v))))$$

# More Freebies

- Polarization does not 'cost' extra:
  = Get spin physics for free.
- Better numerical stability because components of $k^\mu$ are arranged as 'small' and 'large' matrix entries, viz.

$$\sigma_\mu k^\mu = \begin{pmatrix} k_0 + k_3 & k_1 - \mathrm{i}k_2 \\ k_1 + \mathrm{i}k_2 & k_0 - k_3 \end{pmatrix}$$

$$\downarrow$$

Large cancellations of the form $\sqrt{k^2 + m^2} - \sqrt{k^2}$ when $m \ll k$ are avoided: better precision for mass effects.

# Dirac Chains in 4D

As numerical calculations are done mostly using Weyl-spinor chains, there has been a paradigm shift for Dirac chains to make them better suited for analytical purposes, e.g. the extraction of Wilson coefficients.

- Already in Version 5, Fierz methods have been implemented for Dirac chains, thus allowing the user to force the fermion chains into almost any desired order.
- Version 6 further adds the `Colour` method to the `FermionOrder` option of `CalcFeynAmp`, which brings the spinors into the same order as the external colour indices.
- Also new in Version 6: completely antisymmetrized Dirac chains, i.e. $\texttt{DiracChain}[-1, \mu, \nu] = \sigma_{\mu\nu}$.

# Alternate Link between FORM and Mathematica

FORM is renowned for being able to handle very large expressions. To produce (pre-)simplified expressions, however, terms have to be wrapped in functions, to avoid immediate expansion. The number of terms in a function is severely limited in FORM: on 32-bit systems to 32767.

Dilemma: FormCalc gets more sophisticated in pre-simplifying amplitudes while users want to compute larger amplitudes. Thus, users have recently seen many 'overflow' messages from FORM.

Solution: Pre-simplified generic amplitude is sent to Mathematica intermediately for introducing abbreviations. Result: significant reduction in size of intermediate expressions.

Tentukov, Vermaseren 2006

# Effect on Intermediate Amplitudes

## FORM $\longrightarrow$ Mathematica:

part of $uu \longrightarrow gg$ @ tree level

```
+Den[U,MU2]*(
  -8*SUNSum[Col5,3]*SUNT[Glu3,Col5,Col2]*SUNT[Glu4,Col1,Col5]*mul[Alfas*Pi]*
  abb[fme[WeylChain[DottedSpinor[k1,MU,-1],6,Spinor[k2,MU,1]]]*ec3.ec4
    -1/2*fme[WeylChain[DottedSpinor[k1,MU,-1],6,ec3,ec4,Spinor[k2,MU,1]]]
    +fme[WeylChain[DottedSpinor[k1,MU,-1],7,Spinor[k2,MU,1]]]*ec3.ec4
    -1/2*fme[WeylChain[DottedSpinor[k1,MU,-1],7,ec3,ec4,Spinor[k2,MU,1]]]]*MU
  -4*SUNSum[Col5,3]*SUNT[Glu3,Col5,Col2]*SUNT[Glu4,Col1,Col5]*mul[Alfas*Pi]*
  abb[fme[WeylChain[DottedSpinor[k1,MU,-1],6,ec3,ec4,k3,Spinor[k2,MU,1]]]
    -2*fme[WeylChain[DottedSpinor[k1,MU,-1],6,ec4,Spinor[k2,MU,1]]]*ec3.k2
    -2*fme[WeylChain[DottedSpinor[k1,MU,-1],6,k3,Spinor[k2,MU,1]]]*ec3.ec4
    +fme[WeylChain[DottedSpinor[k1,MU,-1],7,ec3,ec4,k3,Spinor[k2,MU,1]]]
    -2*fme[WeylChain[DottedSpinor[k1,MU,-1],7,ec4,Spinor[k2,MU,1]]]*ec3.k2
    -2*fme[WeylChain[DottedSpinor[k1,MU,-1],7,k3,Spinor[k2,MU,1]]]*ec3.ec4]
  +8*SUNSum[Col5,3]*SUNT[Glu3,Col5,Col2]*SUNT[Glu4,Col1,Col5]*mul[Alfas*MU*Pi]*
  abb[fme[WeylChain[DottedSpinor[k1,MU,-1],6,Spinor[k2,MU,1]]]*ec3.ec4
    -1/2*fme[WeylChain[DottedSpinor[k1,MU,-1],6,ec3,ec4,Spinor[k2,MU,1]]]
    +fme[WeylChain[DottedSpinor[k1,MU,-1],7,Spinor[k2,MU,1]]]*ec3.ec4
    -1/2*fme[WeylChain[DottedSpinor[k1,MU,-1],7,ec3,ec4,Spinor[k2,MU,1]]]] )
```

## Mathematica $\longrightarrow$ FORM:

```
-4*Den(U,MU2)*SUNSum(Col5,3)*SUNT(Glu3,Col5,Col2)*SUNT(Glu4,Col1,Col5)*
  AbbSum5*Alfas*Pi
```

# CutTools

Tensor loop integrals have in FormCalc so far been treated by Passarino-Veltman reduction only, e.g.

$$\frac{q_\mu q_\nu}{D_0 D_1} = g_{\mu\nu}\,\mathtt{B00}(p^2, m_1^2, m_2^2) + p_\mu p_\nu\,\mathtt{B11}(p^2, m_1^2, m_2^2)$$

where `B00` and `B11` are provided by LoopTools.

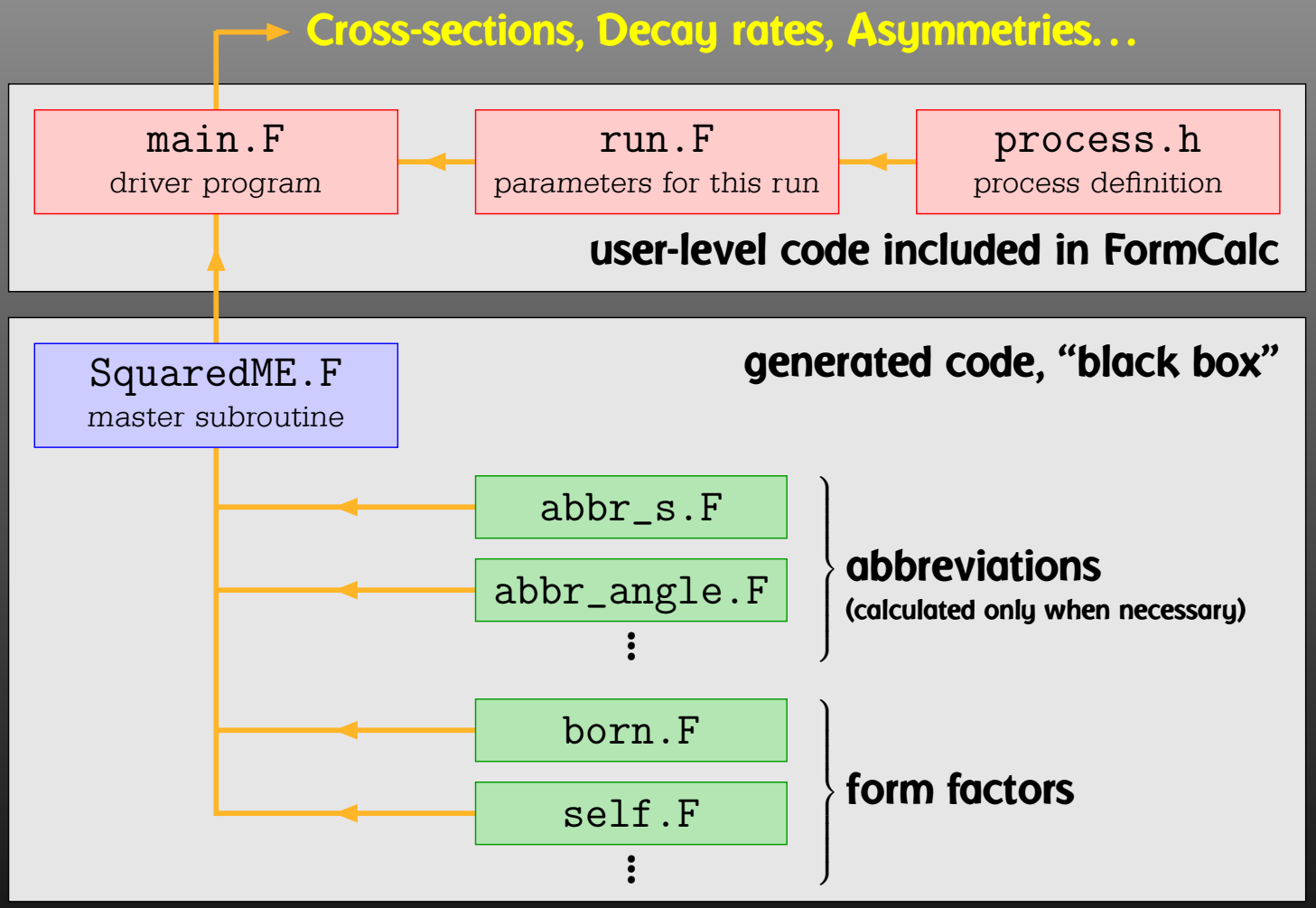
CutTools implements the cutting-technique-inspired OPP (Ossola, Papadopoulos, Pittau) method. It needs the numerator as a function of $q$ which it can sample:

$$\mathtt{Bcut}(2, \mathtt{num1}, \mathtt{num2}, p, m_1^2, m_2^2)$$

where $\mathtt{num1} = \mathtt{q}_\mu \mathtt{q}_\nu$ and $\mathtt{num2} = \mathtt{0}$ (coeff. of $D - 4$).

Independent way of checking LoopTools results.
Performance?

# Numerical Evaluation in Fortran 77



# Code-generation Functions

FormCalc's code-generation functions are now public and disentangled from the rest of the code. They can be used to **write out an arbitrary Mathematica expression as optimized Fortran code:**

- *handle* = `OpenFortran["`*file.F*`"]`
  opens *file.F* as a Fortran file for writing,
- `WriteExpr[`*handle*`, {`*var* `->` *expr*`, ...}]`
  writes out Fortran code which calculates *expr* and stores the result in *var*,
- `Close[`*handle*`]`
  closes the file again.

# Code generation

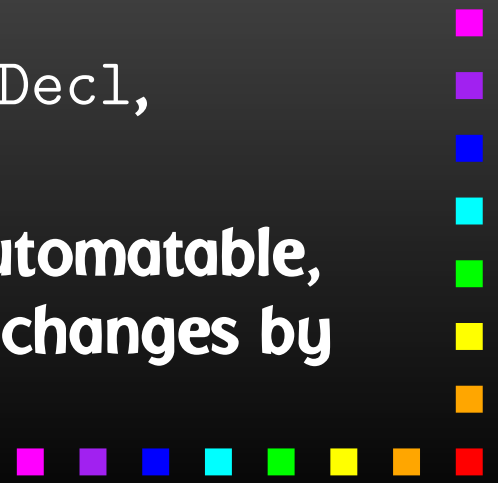
- **Expressions too large** for Fortran are split into parts, as in

```
var = part1
var = var + part2
...
```

- **High level of optimization,** e.g. common subexpressions are pulled out and computed in temporary variables.
- **Many ancillary functions,** e.g.

  `PrepareExpr`, `OnePassOrder`, `SplitSums`, `$SymbolPrefix`, `CommonDecl`, `SubroutineDecl`, etc.

  make code generation versatile and highly automatable, such that the resulting code needs few or no changes by hand.

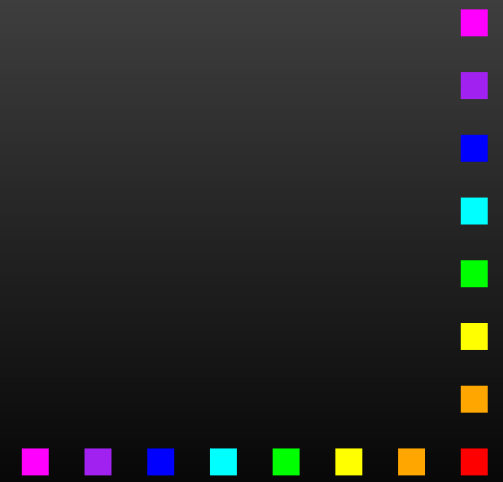


# Not the Cross-Section

## Or, How to get things the Standard Setup won't give you.

### Example: extract the Wilson coefficients for $b \to s\gamma$.

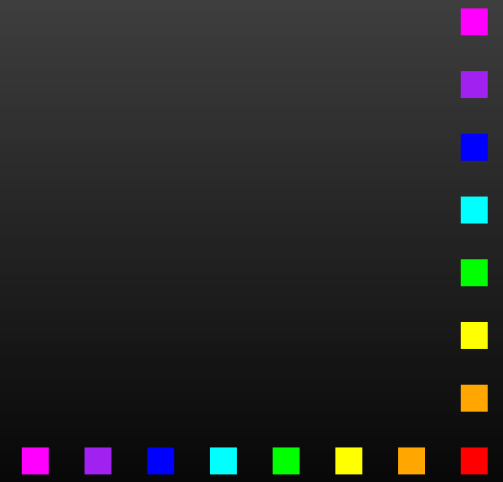
```
tops = CreateTopologies[1, 1 -> 2]
ins = InsertFields[tops, F[4,{3}] -> {F[4,{2}], V[1]}]
vert = CalcFeynAmp[CreateFeynAmp[ins], FermionChains -> Chiral]

mat[p_Plus] := mat/@ p

mat[r_. DiracChain[s2_Spinor, om_, mu_, s1:Spinor[p1_, m1_, _]]] :=
  I/(2 m1) mat[r DiracChain[sigmunu[om]]] +
  2/m1 r Pair[mu, p1] DiracChain[s2, om, s1]

mat[r_. DiracChain[sigmunu[om_]], SUNT[Col1, Col2]] :=
  r O7[om]/(EL MB/(16 Pi^2))

mat[r_. DiracChain[sigmunu[om_]], SUNT[Glu1, Col2, Col1]] :=
  r O8[om]/(GS MB/(16 Pi^2))

coeff = Plus@@ vert //. abbr /. Mat -> mat

c7 = Coefficient[coeff, O7[6]]
c8 = Coefficient[coeff, O8[6]]
```



# Not the Cross-Section

**Using FormCalc's output functions it is also pretty straightforward to generate your own Fortran code:**

```
file = OpenFortran["bsgamma.F"]

WriteString[file,
  SubroutineDecl["bsgamma(C7,C8)"] <>
  "\tdouble complex C7, C8\n" <>
  "#include \"looptools.h\"\n"]

WriteExpr[file, {C7 -> c7, C8 -> c8}]

WriteString[file, "\tend\n"]

Close[file]
```



# A Final Look

Using FeynArts and FormCalc is a lot like driving a car:

- You have to decide where to go (this is often the hardest decision).
- You have to turn the ignition key, work gas and brakes, and steer.
- But you don't have to know, say, which valve has to open at which time to keep the motor running.
- On the other hand, you can only go where there are roads. You can't climb a mountain with your car.

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