`GoSam 2.0.4`: $gg \to HH$

scyboz

2017-05-18 (13:57:12)

Abstract

This process consists of 3 tree-level diagrams and 36 NLO diagrams. GoSam has identified 3 groups of NLO diagrams by analyzing their one-loop integrals.

Contents

1 Helicities

Index	1	2	3	4
0	$-$	$-$	0	0
$1 \to 0$	$+$	$-$	0	0
$2 \to 0$	$-$	$+$	0	0
$3 \to 0$	$+$	$+$	0	0

2 Wave Functions

In this section, we use $l_i = k_i$ for massless particles; in spinors $|i\rangle$ (resp. $|i]$) denote $|l_i\rangle$ (resp. $|l_i]$). For the massive particles we have:

$$l_3 = k_3 - \frac{mH^2}{2k_3 \cdot k_2} k_2 \tag{1}$$

$$l_4 = k_4 - \frac{mH^2}{2k_4 \cdot k_2} k_2 \tag{2}$$

All helicity amplitudes are defined in terms of the following wave functions:

- $g(k_1)$

$$\varepsilon_+^\mu(k_1) = \frac{\langle 2|\gamma^\mu|1]}{\sqrt{2}\langle 2|1\rangle} \tag{3}$$

$$\varepsilon_-^\mu(k_1) = \frac{[2|\gamma^\mu|1\rangle}{\sqrt{2}[1|2]} \tag{4}$$

- $g(k_2)$

$$\varepsilon_+^\mu(k_2) = \frac{\langle 1|\gamma^\mu|2]}{\sqrt{2}\langle 1|2\rangle} \tag{5}$$

$$\varepsilon_-^\mu(k_2) = \frac{[1|\gamma^\mu|2\rangle}{\sqrt{2}[2|1]} \tag{6}$$

- $H(k_3)$

$$\epsilon(k_3) = 1 \tag{7}$$

- $H(k_4)$

$$\epsilon(k_4) = 1 \tag{8}$$

3 Colour Basis

$$|c_1\rangle = g_{(1)}^{A_1} g_{(2)}^{A_2} \mathrm{tr}\left\{T^{A_2} T^{A_1}\right\} \tag{9}$$

4 Tree Diagrams

QGraf Setup

```
                              qgraf-3.1.4

output = 'diagrams-0.hh';
style = 'form.sty';
model = 'model';
in = g[k1], g[k2];
out = H[k3], H[k4];
loops=0;
loop_momentum=p;
options=onshell, nosnail;
true=iprop[U,D,S,C,B,0,0];
true=vsum[QED,2,2];

  23P  ---  7+  16-  ---  5N+  2C+  16C-

  140V  ---  3^111  4^28  5^1

   -   4^1   -   ---  0 diagrams
  3^2   -    -   ---  3 diagrams

  total =  3 diagrams
```

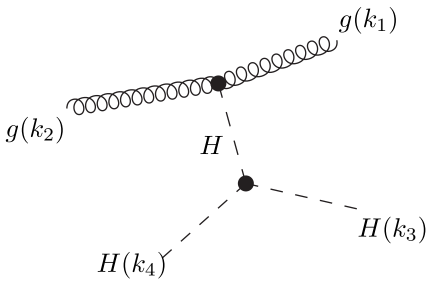


Diagram 1

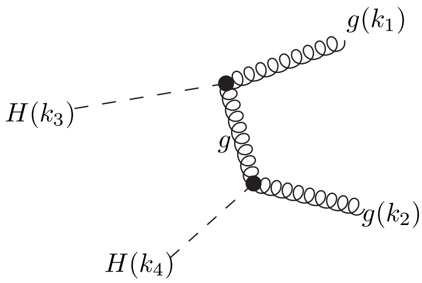


Diagram 2

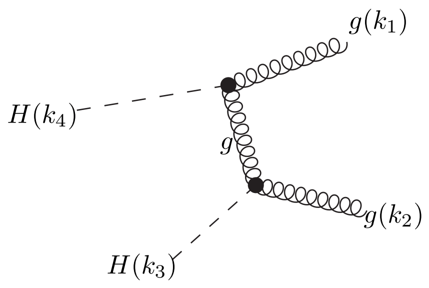


Diagram 3

5 One-Loop Diagrams

General Information

QGraf Setup

```
--------------------------------------------------------------------
                          qgraf-3.1.4
--------------------------------------------------------------------

output = 'diagrams-1.hh';
style = 'form.sty';
model = 'model';
in = g[k1], g[k2];
out = H[k3], H[k4];
loops=1;
loop_momentum=p;
options=onshell, nosnail;
true=iprop[U,D,S,C,B,0,0];
true=vsum[QED,2,2];

--------------------------------------------------------------------

  23P  ---  7+  16-  ---  5N+  2C+  16C-

  140V  ---  3^111  4^28  5^1

--------------------------------------------------------------------

  3^1   -    5^1  ---  2 diagrams
   -   4^2    -   ---  2 diagrams
  3^2  4^1    -   ---  22 diagrams
  3^4   -     -   ---  14 diagrams

  total =  40 diagrams
```

Loop diagrams are grouped into sets of diagrams which share loop-propagators. A loop integral can be written as

$$\int \frac{\mathrm{d}^n k}{i\pi^{\frac{n}{2}}} \frac{\mathcal{N}(q)}{\prod_{j=1} N\left[(k+r_j)^2 - (m_j^2 - i m_j \Gamma_j) + i\delta\right]}. \tag{10}$$

For each group we list r_j, m_j and Γ_j. For m_j and Γ_j only non-vanishing symbols are listed. Furthermore, we give the matrix S which is defined as

$$S_{\alpha\beta} = (r_\alpha - r_\beta)^2 - (m_\alpha^2 - i m_\alpha \Gamma_\alpha) - (m_\beta^2 - i m_\beta \Gamma_\beta). \tag{11}$$

For each diagram we denote how the matrix S' for the specific diagram is obtained from the original S. The notation

$$S' = S_{Q\to q'}^{\{l_1, l_2, \ldots\}} \tag{12}$$

means, that the rows and columns labeled by $l_1, l_2, \ldots$ should be removed from S (likewise $r_{l_1}, r_{l_2}, \ldots$ are removed from the list of propagators) and $\mathcal{N}(q)$ has to be replaced by $\mathcal{N}(q')$. The maximum effective rank of a group is the rank that has to be passed to Samurai if the whole group is reduced at once; this number is calculated as

$$\max_{\text{diagrams}} \left\{(\text{rank of diagram}) + (\text{number of pinches})\right\}. \tag{13}$$

Diagrams with massless closed quark lines are multiplied by a factor `Nfrat` $=$ `Nf/Nfgen`. This multiplication is indicated by the symbol N_f following the rank. By default `Nfrat` evaluates to one but can be changed by modifying `Nf` or `Nfgen` in the model file.

5.1 Group 0 (4-Point)

General Information

The maximum effective rank in this group is 6.

$$r_1 = -k_2 + k_4 \tag{14a}$$
$$r_2 = -k_2 \tag{14b}$$
$$r_3 = 0 \tag{14c}$$
$$r_4 = -k_3 \tag{14d}$$

$$S = \begin{pmatrix} 0 & S_{1,2} & S_{1,3} & 0 \\ S_{2,1} & 0 & 0 & S_{2,4} \\ S_{3,1} & 0 & 0 & S_{3,4} \\ 0 & S_{4,2} & S_{4,3} & 0 \end{pmatrix} \tag{15}$$

$$S_{1,2} = m_H^2 \tag{16a}$$
$$S_{1,3} = -s_{23} - s_{12} + 2m_H^2 \tag{16b}$$
$$S_{2,4} = s_{23} \tag{16c}$$
$$S_{3,4} = m_H^2 \tag{16d}$$

5.1.1 Diagrams (10)

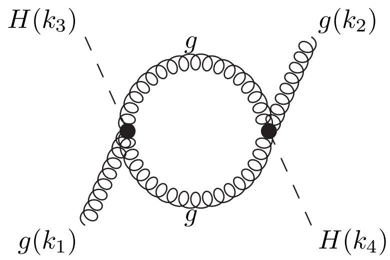


Diagram 3
$S' = S^{\{2,4\}}_{Q\to q-(k2-k4)}$, $\mathrm{rk} = 2$

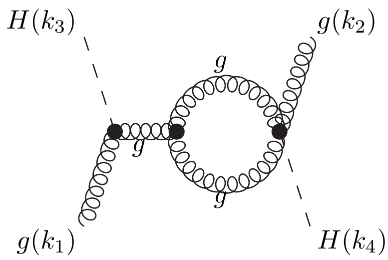


Diagram 5
$S' = S^{\{2,4\}}_{Q\to q-(k2-k4)}$, $\mathrm{rk} = 2$

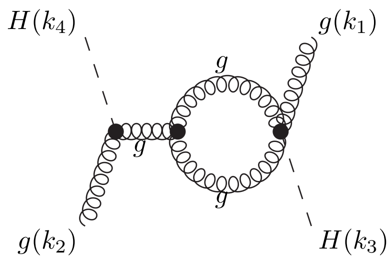


Diagram 8
$S' = S^{\{2,4\}}_{Q\to -q-(-k2+k4)}$, $\mathrm{rk} = 2$

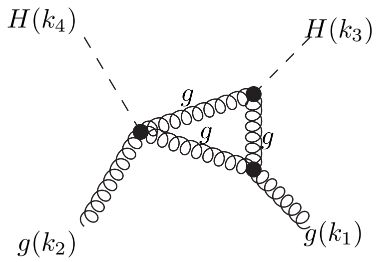


Diagram 10
$S' = S^{\{2\}}_{Q\to -q-(-k3)}$, $\mathrm{rk} = 4$

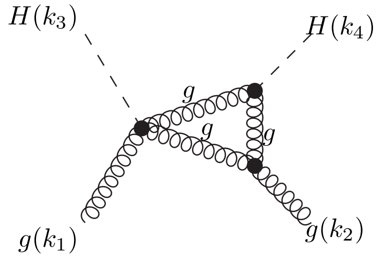
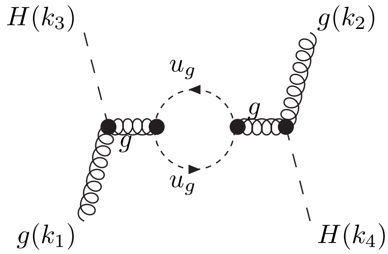


Diagram 13
$S' = S^{\{4\}}_{Q\to -q-(-k2)}$, $\mathrm{rk} = 4$



-Diagram 28
$S' = S^{\{2,4\}}_{Q\to q-(k2-k4)}$, $\mathrm{rk} = 2$

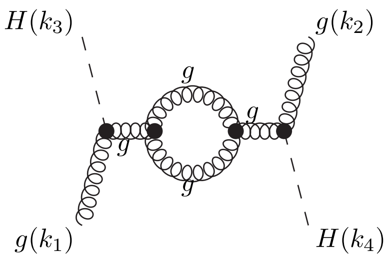


Diagram 29
$S' = S^{\{2,4\}}_{Q\to q-(k2-k4)}$, rk = 2

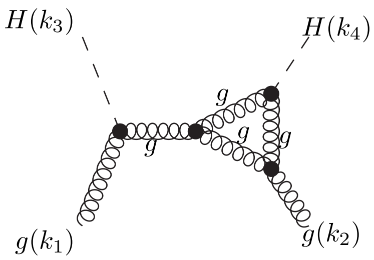


Diagram 33
$S' = S^{\{4\}}_{Q\to -q-(-k2)}$, rk = 4

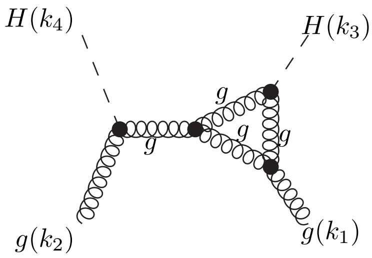


Diagram 36
$S' = S^{\{2\}}_{Q\to -q-(-k3)}$, rk = 4

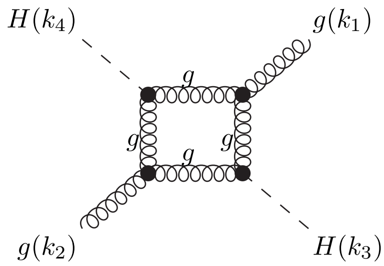


Diagram 40
$S' = S_{Q\to -q-(-k3)}$, rk = 6

5.2 Group 1 (4-Point)

General Information

The maximum effective rank in this group is 6.

$$r_1 = -k_3 - k_4 \tag{17a}$$
$$r_2 = -k_3 \tag{17b}$$
$$r_3 = 0 \tag{17c}$$
$$r_4 = -k_2 \tag{17d}$$

$$S = \begin{pmatrix} 0 & S_{1,2} & S_{1,3} & 0 \\ S_{2,1} & 0 & S_{2,3} & S_{2,4} \\ S_{3,1} & S_{3,2} & 0 & 0 \\ 0 & S_{4,2} & 0 & 0 \end{pmatrix} \tag{18}$$

$$S_{1,2} = m_H^2 \tag{19a}$$
$$S_{1,3} = s_{12} \tag{19b}$$
$$S_{2,3} = m_H^2 \tag{19c}$$
$$S_{2,4} = s_{23} \tag{19d}$$

5.2.1 Diagrams (25)

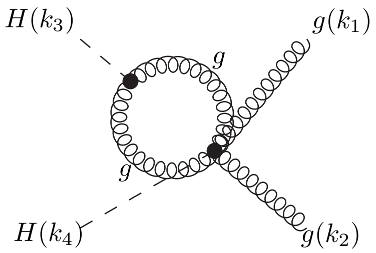


Diagram 1
$S' = S^{\{1,4\}}_{Q\to q-(k3)}$, rk $= 2$

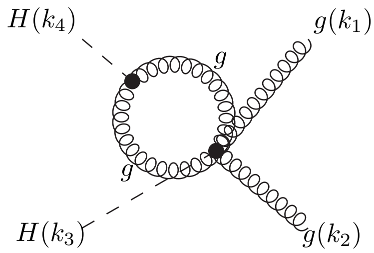


Diagram 2
$S' = S^{\{3,4\}}_{Q\to q-(k3+k4)}$, rk $= 2$

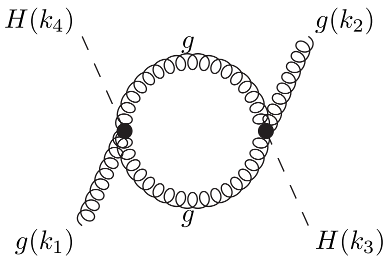


Diagram 4
$S' = S^{\{1,3\}}_{Q\to -q-(-k3)}$, rk $= 2$

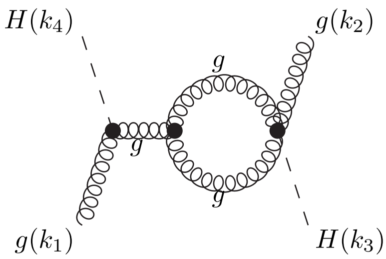


Diagram 6
$S' = S^{\{1,3\}}_{Q\to -q-(-k3)}$, rk $= 2$

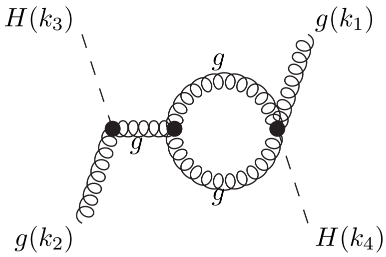


Diagram 7
$S' = S^{\{1,3\}}_{Q\to q-(k3)}$, rk $= 2$

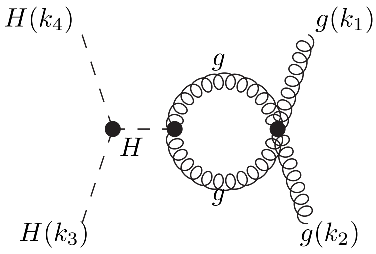


Diagram 9
$S' = S^{\{2,4\}}_{Q\to q-(k3+k4)}$, rk $= 2$

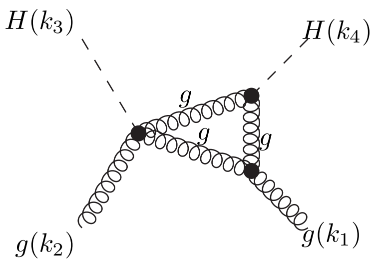


Diagram 11
$S' = S^{\{3\}}_{Q\to -q-(-k3-k4)}$, rk = 4

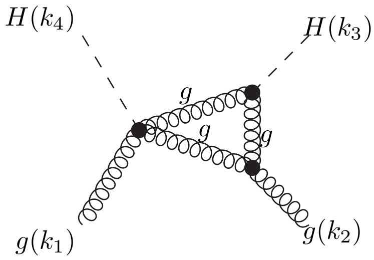


Diagram 12
$S' = S^{\{1\}}$, rk = 4

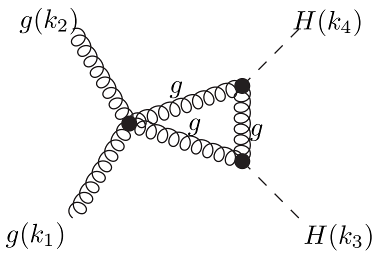


Diagram 14
$S' = S^{\{4\}}_{Q\to q-(k3)}$, rk = 4

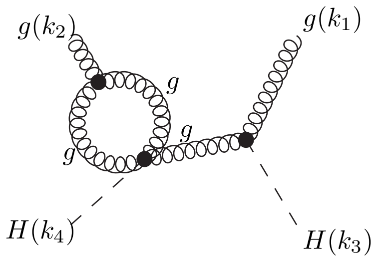


Diagram 17
$S' = S^{\{1,2\}}$, rk = 2

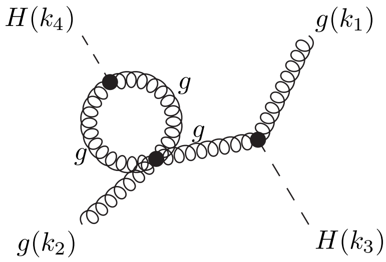


Diagram 18
$S' = S^{\{3,4\}}_{Q\to q-(k3+k4)}$, rk = 2

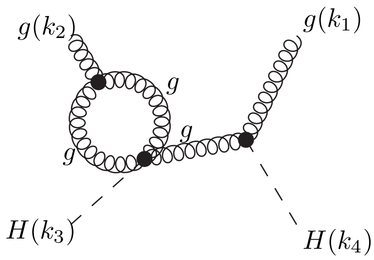


Diagram 19
$S' = S^{\{1,2\}}$, rk = 2

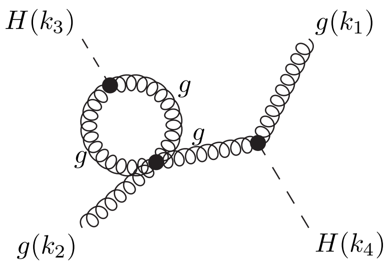


Diagram 20

$S' = S^{\{1,4\}}_{Q\to q-(k3)}$, $\mathrm{rk} = 2$

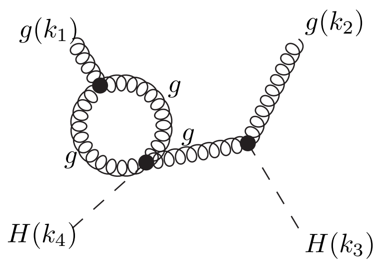


Diagram 21

$S' = S^{\{2,3\}}_{Q\to -q-(-k3-k4)}$, $\mathrm{rk} = 2$

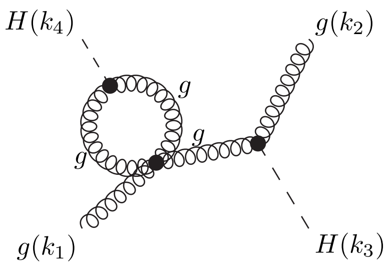


Diagram 22

$S' = S^{\{3,4\}}_{Q\to q-(k3+k4)}$, $\mathrm{rk} = 2$

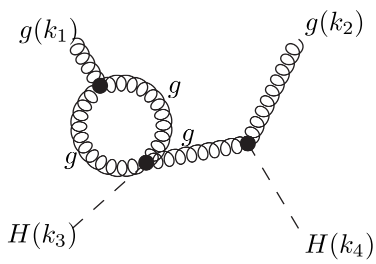


Diagram 23

$S' = S^{\{2,3\}}_{Q\to -q-(-k3-k4)}$, $\mathrm{rk} = 2$

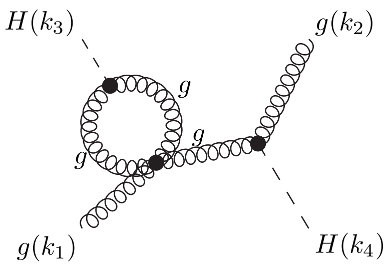


Diagram 24

$S' = S^{\{1,4\}}_{Q\to q-(k3)}$, $\mathrm{rk} = 2$

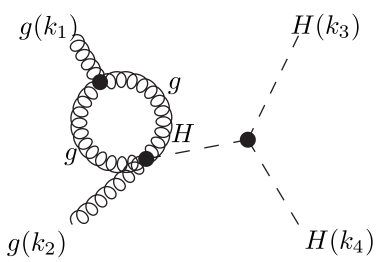


Diagram 25

$S' = S^{\{2,3\}}_{Q\to -q-(-k3-k4)}$, $\mathrm{rk} = 2$

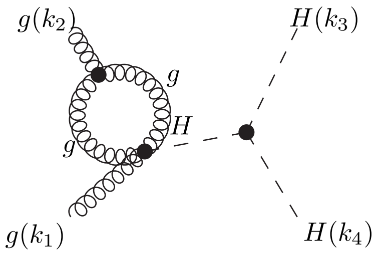
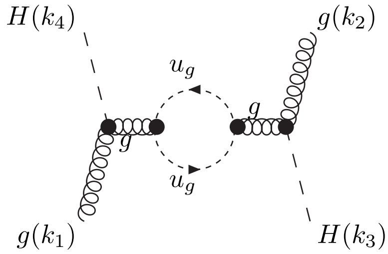


Diagram 26
$S' = S^{\{1,2\}}$, rk = 2



-Diagram 30
$S' = S^{\{1,3\}}_{Q\to -q-(-k3)}$, rk = 2

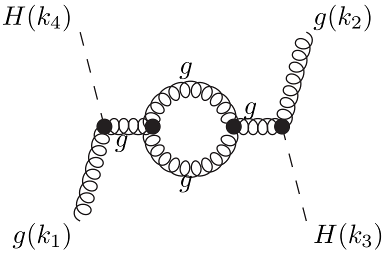


Diagram 31
$S' = S^{\{1,3\}}_{Q\to -q-(-k3)}$, rk = 2

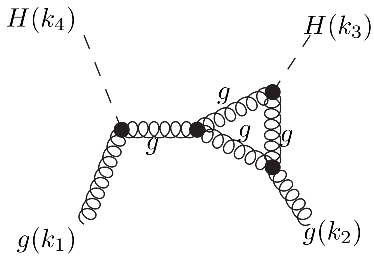


Diagram 34
$S' = S^{\{1\}}$, rk = 4

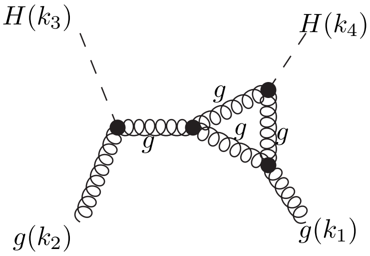


Diagram 35
$S' = S^{\{3\}}_{Q\to -q-(-k3-k4)}$, rk = 4

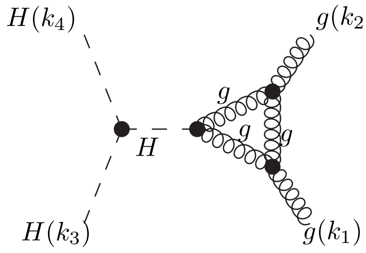


Diagram 37
$S' = S^{\{2\}}_{Q\to q-(k2)}$, rk = 4

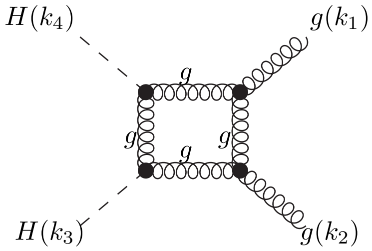


Diagram 39
$S' = S_{Q\to q-(k2)}$, rk = 6

5.3 Group 2 (4-Point)

General Information

The maximum effective rank in this group is 6.

$$r_1 = -k_3 - k_4 \tag{20a}$$
$$r_2 = -k_4 \tag{20b}$$
$$r_3 = 0 \tag{20c}$$
$$r_4 = -k_2 \tag{20d}$$

$$S = \begin{pmatrix} 0 & S_{1,2} & S_{1,3} & 0 \\ S_{2,1} & 0 & S_{2,3} & S_{2,4} \\ S_{3,1} & S_{3,2} & 0 & 0 \\ 0 & S_{4,2} & 0 & 0 \end{pmatrix} \tag{21}$$

$$S_{1,2} = m_H^2 \tag{22a}$$
$$S_{1,3} = s_{12} \tag{22b}$$
$$S_{2,3} = m_H^2 \tag{22c}$$
$$S_{2,4} = -s_{23} - s_{12} + 2m_H^2 \tag{22d}$$

5.3.1 Diagrams (1)

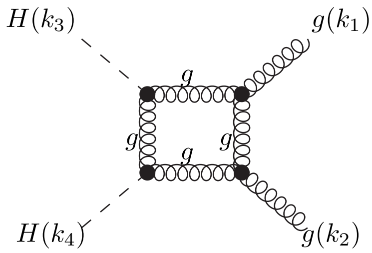


Diagram 38
$S' = S_{Q\to q-(k2)}$, $\mathrm{rk} = 6$

Index of all Loop Diagrams

6 Related Work

If you publish results obtained by using this matrix element code please cite the appropriate papers in the bibliography of this document.

Scientific publications prepared using the present version of GoSam or any modified version of it or any code linking to GoSam or parts of it should make a clear reference to the publications [1, 2].

For graph generation we use QGraf [3]. The Feynman diagrams are further processed with the symbolic manipulation program FORM [4, 5] using the FORM library SPINNEY [6]. The Fortran 90 code is generated using FORM [4, 5]. For the reduction of the tensor integrals the code uses an implementation of the Laurent series expansion method [8] from the library Ninja [7].

Please, make sure, you also give credit to the authors of the scalar loop libraries, if you configured the amplitude code such that it calls other libraries than the ones mentioned so far. Depending on your configuration you might use one or more of the following programs for the evaluation of the scalar integrals:

- OneLOop [12],
- QCDLoop [13], which uses FF [14],
- LoopTools [15], which uses FF [14].
- GOLEM95 [10, 9] which uses OneLOop [12] and may be configured such that it uses LoopTools [15, 14].

References

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