

DIANA [1] and applications to fermion production in electron positron annihilation

(1) DIANA

- (a) **Graphics** [2, 3, 4]
- (b) **Distribution of integration momenta** [3, 4]
- (c) **Parallelization** [4]

(2) $t\bar{t}$ in one-loop including hard Bremsstrahlung

(3) Factorizing one-loop contributions in two-loop Bhabha scattering.

For applications see also [5]

References

- [1] M. Tentyukov, J. Fleischer, *Comput. Phys. Comm.* **132** (2000) 124.
- [2] J. Fleischer, M. Tentyukov, "A Feynman diagram analyser DIANA: Graphic facilities", in: P. Bhat and M. Kasemann (eds.), Proc. of the VIIth Int. Workshop ACAT 2000, Batavia, USA, 16-20 Oct. 2000, AIP Conference Proceedings (Melville, New York, 2001), vol. 583, p. 193, hep-ph/0012189.
- [3] M. Tentyukov, J. Fleischer, Contribution to ACAT 2002, Moscow, Russia, June 24-28, 2002, hep-ph/0210179.
- [4] J. Fleischer, M. Tentyukov and O.V. Tarasov, Contribution to Radcor and Loops and Legs 2002, September 8 - 13, Kloster Banz, to appear in *Nucl. Phys. B (Proc. Suppl.)*, hep-ph/0211209
- [5] J. Fleischer *et al.*, *Phys. Lett.* **B459** (1999) 625; J. Fleischer, O. V. Tarasov and M. Tentyukov, *Nucl. Phys. Proc. Suppl.* **89** (2000) 112; F. Jegerlehner, M. Y. Kalmykov and O. Veretin, *Nucl. Phys.* **B641** (2002) 285; J. Fleischer *et al.*, hep-ph/0202109; A. Onishchenko and O. Veretin, hep-ph/0209010; M. Awramik *et al.*, hep-ph/0209084.

DIANA (DIagram ANAlyzer)
written in C

M. Tentyukov and J. F. (CPC 132 (2000))

- QGRAF Nogueira
- TM text manipulating language:
creation of text files Tentyukov

By preparing a 'create' (style) file, the user specifies the model and the process and **DIANA** will generate all other necessary files. The user types :

diana - c create.proc
(proc = processname),

then calls: **diana -c config.proc**

config.proc contains the TM program for the evaluation of Feynman diagrams, produced by **DIANA**.

The output filename is proc.in: FORM input

Recent development:

various graphic representations (ps) of F.d.'s.
encapsulated postscript files for publications.
choice of integration momenta by clicking on the line.
parallelization of DIANA.

see also : web-site

<http://www.physik.uni-bielefeld.de/~tentukov/diana.html>

```
SET _processname = Bhabha
SET _TOPOLOGYEDITORNAME = tedi
only interpret
\openlanguage(create.tml)
\Begin(program)
  \Begin(model,SM.model)
    \End(model)
    \Begin(process)
      ingoing e(;p1),E(;p4);
      outgoing e(; -p2),E(; -p3);
      loops = 1;
    \End(process)
    \Begin(qgrafoptions)
      options=notadp,onshell;
      ...
    \End(qgrafoptions)
    \Begin(tmlprogram,folders.tml)
      ...
    \End(tmlprogram)
    \indices(mu,mu1,mu2,mu3,... )
    \vectors(p1,p2,...,q1,q2,...,k,...,zero)
    \zeromomentum(zero)
    \loopmomenta(k)
\End(program)
```

```
\Begin(boson)
*
* Minimal Standard Model
* ~~~~~
*****
*
* PARTICLE CONTENTS
* ~~~~~
*
* Fermions:
*   a) leptons    e,E  nu,NU
*   b) quarks     u,U  d,D  b,B  t,T
*
* Gauge bosons:
*   A, Z, (Wp,Wm)
*
* Higgses:
*   H, GO, (Gp,Gm)
*
*****
*
* NOTATIONS
* ~~~~~
*
*   e   --- electromagnetic coupling
*   s   --- sin(theta_W)
*   c   --- cos(theta_W)
*   mt,mW,mZ,mH  --- masses
*   mmmt,mmW,mmZ,mmH- masses squared
*
*   Qe,Qt,Qb electric charges
*           in units of proton i.e. -1,2/3,-1/3
*   GAe,GAu,GAf,GAf --- axial couplings
*   GVe,GVnu,GVt,GVb --- vector couplings
*
*****
```

In general: num -> line (or vertex) number
fnum-> fermion line number
ind -> index
vec -> momentum

*

* We have three (c)functions for **PROPAGATORS** :
* SS, FF and VV

*

*

*

* **vector** propagator

[A,A ;a; VV(num,ind:1 ,ind:2 ,vec, 0)*i_ ; 0]
[Z,Z ;Z; VV(num,ind:1 ,ind:2 ,vec, 1)*i_ ;mmZ]
[Wm,Wp ;W; VV(num,ind:2 ,ind:1 ,vec, 2)*i_ ;mmW]

* **scalar** propagator

[H,H ; h ; SS(num,0)*i_ ; mmH]
[G0,G0; Z ; SS(num,1)*i_ ; mmZ]
[Gm,Gp; W ; SS(num,2)*i_ ; mmW]

\End(boson)

\Begin(fermion)

* **fermion** propagator

[nu,NU ;n ; FF(num,fnum,vec, 0)*i_ ; 0]
[e,E ;e ; FF(num,fnum,vec, me)*i_ ; mme]
[b,B ;b ; FF(num,fnum,vec, mb)*i_ ; mmb]
[t,T ;t ; FF(num,fnum,vec, mt)*i_ ; mmmt]

\End(fermion)

```

\Begin(vertex)
-----
*   For VERTICES we use V and F, e.g.
* cubic vector (indicated by last index '3')

[Wm,Wp,A;; V(num,ind:1,ind:2,ind:3,
           vec:1,vec:2,vec:3,3)*(-i_)*e      ]
[Wm,Wp,Z;; V(num,ind:1,ind:2,ind:3,
           vec:1,vec:2,vec:3,3)*(+i_)*e*c/s]
-----
* charged weak currents:          ffV
|
[NU,e,Wp;; F(num,fnum,ind:3, 1,-1, 1)*
           (+i_)*e/2/sqrt2/s]
[E,nu,Wm;; F(num,fnum,ind:3, 1,-1, 1)*
           (+i_)*e/2/sqrt2/s]
[T,b,Wp;; F(num,fnum,ind:3, 1,-1, 1)*
           (+i_)*e/2/sqrt2/s]
[B,t,Wm;; F(num,fnum,ind:3, 1,-1, 1)*
           (+i_)*e/2/sqrt2/s]
* neutral weak currents

[NU,nu,Z;; F(num,fnum,ind:3, GVnu,-GAnu, 1)*
           (+i_)*e/2/s/c]
[E,e,Z;; F(num,fnum,ind:3, GVe ,-GAe , 1)*
           (+i_)*e/2/s/c]
[T,t,Z;; F(num,fnum,ind:3, GVt ,-GAt , 1)*
           (+i_)*e/2/s/c]
[B,b,Z;; F(num,fnum,ind:3, GVb ,-GAb , 1)*
           (+i_)*e/2/s/c]
* electromagnetic currents

[E,e,A;; F(num,fnum,ind:3, 1,0, 1)*(-i_)*e*Qe]
[T,t,A;; F(num,fnum,ind:3, 1,0, 1)*(-i_)*e*Qt]
[B,b,A;; F(num,fnum,ind:3, 1,0, 1)*(-i_)*e*Qb]
-----
\End(vertex)

```

```

#procedure feynmanrules()
nwrite statistics;

* propagators

#do i=1,'LINE'
id SS('i',0) = 1/c'i';
id FF('i',c?,p1?,mt?) = (gamma(c,p1)+mt)/c'i';
#enddo

*
* FEYNMAN GAUGE
*
#do i=1,'LINE'
id SS('i',c?!=0) = 1/c'i';

id VV('i',mu1?,mu2?,q?,0) = (-d_(mu1,mu2))/c'i';
id VV('i',mu1?,mu2?,q?,1) = (-d_(mu1,mu2))/c'i';
id VV('i',mu1?,mu2?,q?,2) = (-d_(mu1,mu2))/c'i';
id VV('i',mu1?,mu2?,q?,3) = (-d_(mu1,mu2))/c'i';
.sort
#enddo

* VVV vertex
id V(s?,mu1?,mu2?,mu3?,p1?,p2?,p3?,3) =
(
+(p1(mu3)-p2(mu3))*d_(mu1,mu2)
+(p2(mu1)-p3(mu1))*d_(mu2,mu3)
+(p3(mu2)-p1(mu2))*d_(mu3,mu1)
);

* fermion-(axial)vector-fermion
id F(s?,c?,mu1?,GVe?,GAe?,1) =
gamma(c,mu1)*(GVe + GAe*gamma5(c));

#endprocedure feynmanrules
;

```

File "runfrm" (*executable*):

```
#!/diana -smp 3 -c runpar.tml
\STARTSERVERS(phya25,phya26,phya27,phya28)
\system(echo > log.all)
\REPEAT(N)
\exec(form -d i=\get(N) do_tt.frm > /tmp/log.\get(N))
\stick(cat /tmp/log.\get(N)>>log.all;rm /tmp/log.\get(N))
\ENDREPEAT()
\waitall(2000)
```

Example: The user enters:

runfrm 186 200

The system executes:

diana -smp 3 -c runpar.tml runfrm 186 200

The option **-smp 3**: *Symmetric MultiProcessing*,
three-processor host (**default=1**).

\STARTSERVERS(..., phya26, ...):
ssh phya26 cd /home/user/jobs ; diana -d 1 -q

The option **-d 1**: DIANA starts a daemon (server
running in the background) accepting one connection.

\REPEAT(N) ... \ENDREPEAT():

The variable **N** runs from 186 to 200. E.g., for **N=190**:

form -d i=190 do_tt.frm > /tmp/log.190

cat /tmp/log.190>>log.all;rm /tmp/log.190

The **\stick()** operator: the **cat** will wait until all
previous jobs are completed and acts on the same node
as the **form** job.

\waitall(2000) - reports every 2000 milliseconds
how many jobs are not yet finished.

t \bar{t} in one-loop

**(1) COMPLETE ELECTROWEAK ONE LOOP RADIATIVE CORRECTIONS TO TOP PAIR PRODUCTION AT TESLA:
A COMPARISON.**

J. Fleischer, T. Hahn , W. Hollik, T. Riemann, C. Schappacher, A. Werthenbach,
Feb. 2002, hep-ph/0202109 .

(2) ONE LOOP CORRECTIONS TO THE PROCESS $e^+e^- \rightarrow t\bar{t}$ INCLUDING HARD BREMSSTRAHLUNG

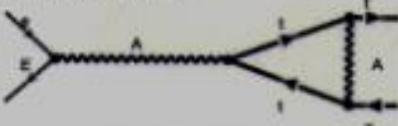
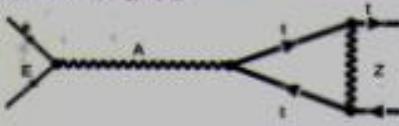
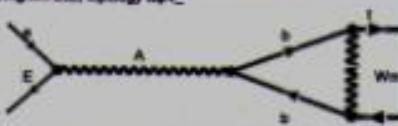
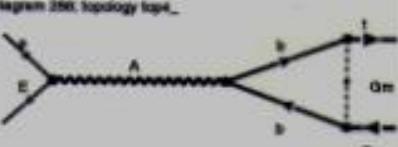
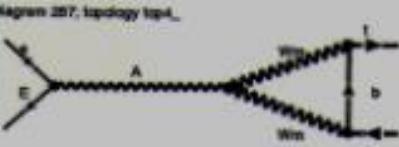
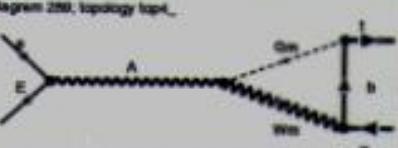
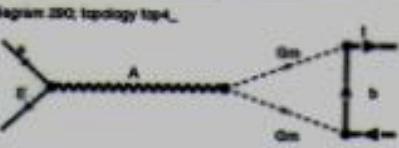
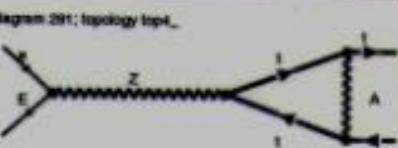
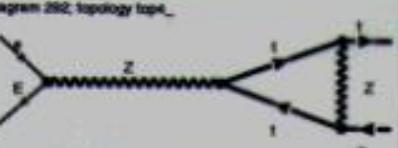
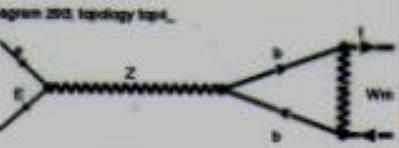
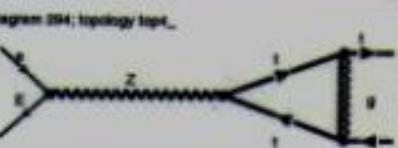
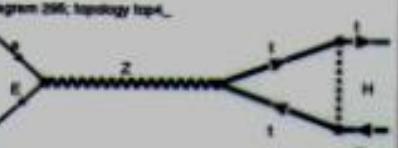
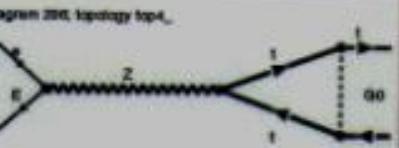
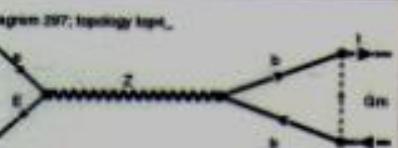
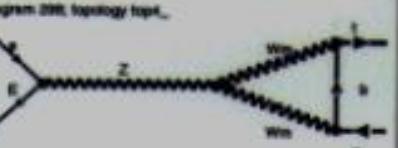
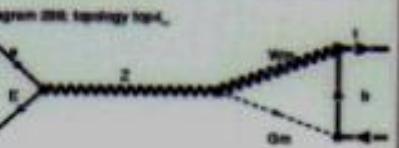
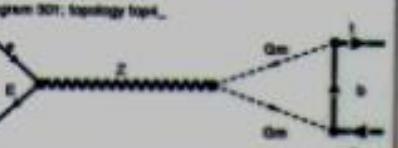
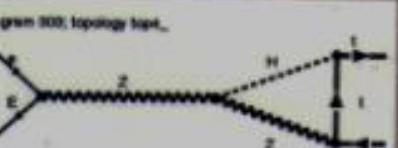
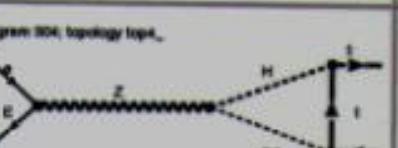
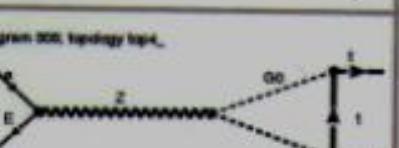
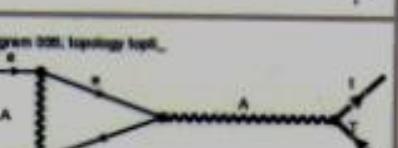
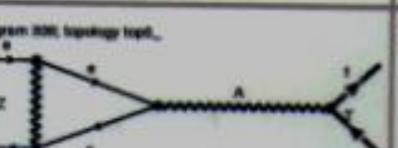
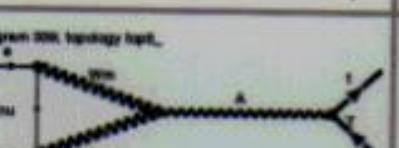
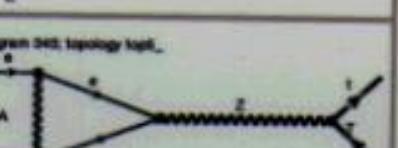
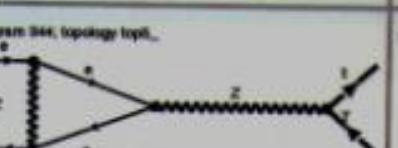
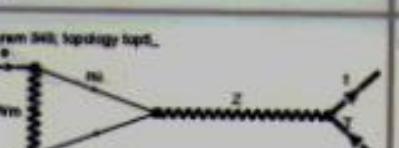
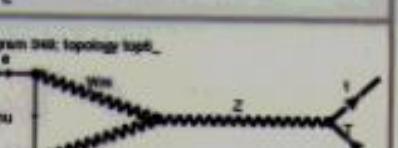
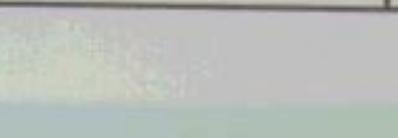
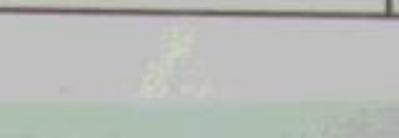
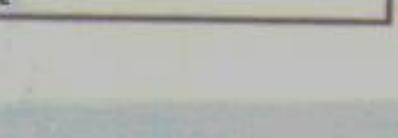
J. Fleischer, J. Fujimoto, T. Ishikawa, A. Leike, T. Riemann, Y. Shimizu,
A. Werthenbach,
hep-ph/0203220

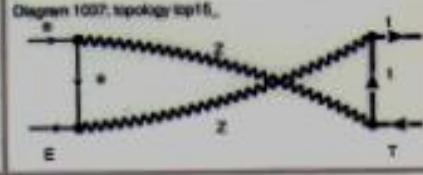
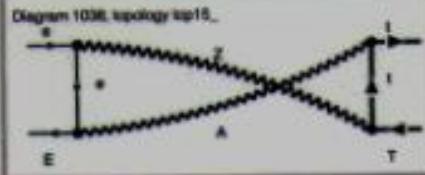
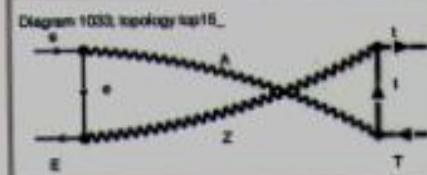
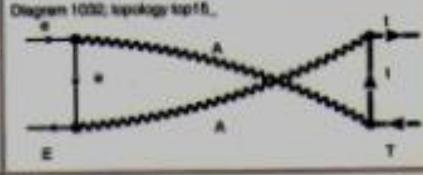
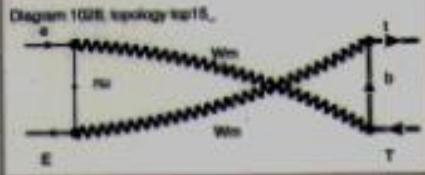
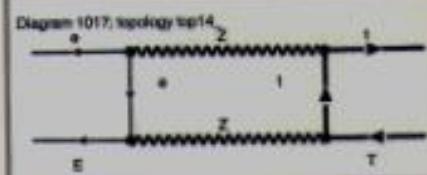
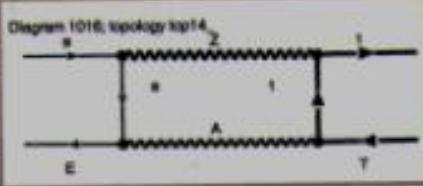
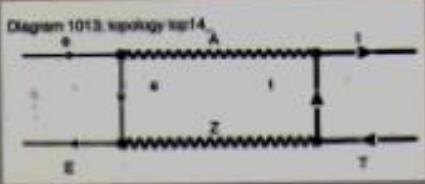
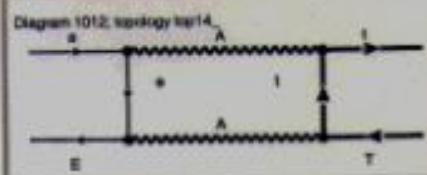
(3) Complete $O(\alpha)$ corrections to the process $e^+e^- \rightarrow t\bar{t}(\gamma)$

J. Fleischer, A. Leike, T. Riemann, A. Werthenbach
DESY 02-204, BI-TP 2002/29, LMU 12/02

**(4) Fortran Program topfit.F v.0.911 (15 Nov 2002),
J. Fleischer, A. Leike, T. Riemann, A. Werthenbach**

<http://www-zeuthen.desy.de/riemann/>.

Diagram 280; topology top4_	Diagram 281; topology top4_	Diagram 282; topology top4_
		
Diagram 283; topology top4_	Diagram 284; topology top4_	Diagram 285; topology top4_
		
Diagram 286; topology top4_	Diagram 287; topology top4_	Diagram 288; topology top4_
		
Diagram 289; topology top4_	Diagram 290; topology top4_	Diagram 291; topology top4_
		
Diagram 292; topology top4_	Diagram 293; topology top4_	Diagram 294; topology top4_
		
Diagram 295; topology top4_	Diagram 296; topology top4_	Diagram 297; topology top4_
		
Diagram 298; topology top4_	Diagram 299; topology top4_	Diagram 300; topology top4_
		
Diagram 301; topology top4_	Diagram 302; topology top4_	Diagram 303; topology top4_
Diagram 304; topology top4_	Diagram 305; topology top4_	Diagram 306; topology top4_
		
Diagram 307; topology top4_	Diagram 308; topology top4_	Diagram 309; topology top4_
		
Diagram 310; topology top4_	Diagram 311; topology top4_	Diagram 312; topology top4_
		
Diagram 313; topology top4_	Diagram 314; topology top4_	Diagram 315; topology top4_
		



Top pair production: topfit and Grace, angular distribution

$\cos \theta$	ω/\sqrt{s}	$\left[\frac{d\sigma}{d\cos \theta} \right]_{\text{Born}}$	$\left[\frac{d\sigma}{d\cos \theta} \right]_{\text{QED}}$	$\left[\frac{d\sigma}{d\cos \theta} \right]_{\text{SM}}$	$\left[\frac{d\sigma}{d\cos \theta} \right]_{\text{tot}}$
-0.9	T : 0.1	0.108839194075	+0.098664253	+0.11408410	0.13144
	T : 0.0001	0.108839194075	-0.017474702	-0.002054858	0.13229
	G : 0.0001	0.108839194076		-0.002054859	0.13206(12)
-0.5	T : 0.1	0.142275069392	+0.12850790	+0.14308121	0.15973
	T : 0.0001	0.142275069392	-0.029702340	-0.015129038	0.16029
	G : 0.0001	0.142275069393		-0.015129039	0.16013(13)
+0.0	T : 0.1	0.225470464033	+0.20239167	+0.21718801	0.23638
	T : 0.0001	0.225470464033	-0.058010508	-0.043214169	0.23476
	G : 0.0001	0.225470464033		-0.043214168	0.23513(14)
+0.5	T : 0.1	0.354666470332	+0.31511723	+0.32933727	0.35651
	T : 0.0001	0.354666470332	-0.109721291	-0.095501257	0.35062
	G : 0.0001	0.354666470332		-0.095501252	0.35104(17)
+0.9	T : 0.1	0.491143715767	+0.43071437	+0.44290816	0.48796
	T : 0.0001	0.491143715767	-0.179672655	-0.16747886	0.47768
	G : 0.0001	0.491143715767		-0.16747886	0.47709(21)

Various differential cross sections. The upper and lower numbers correspond to the topfit (T) and GRACE (G) approach, respectively, $\sqrt{s} = 500$ GeV.

Factorizing one-loop contributions to two-loop Bhabha scattering

J. F., T. Riemann, O.V. Tarasov, A. Werthenbach

'Massive two-loop Bhabha scattering: the factorizable subset',
BI-TP-2002-27, CERN-TH-2002-306, DESY-02-196, Nov. 2002,
hep-ph/0211167 (RADCOR and Loops & Legs 2002, Banz);
see also ACAT2002, Moscow, hep-ph/0210180

We are moving in the direction of **two-loop** Bhabha scattering: important, in particular at higher energies, for the luminosity determination.

Factorizing one-loop contributions enter e.g. via **renormalization**. Mass-renormalization: in any Feynman diagram we replace

$$\frac{1}{k^2 - (m^2 + \delta(m^2))} \rightarrow \frac{1}{k^2 - m^2} \left(1 + \frac{\delta(m^2)}{k^2 - m^2}\right),$$

thus obtaining '**dotted**' diagrams.

Decomposition of the diagrams into Amplitudes A_j (here diagram 8)

$O_1 =$	$U(-p_2)$	I	$V(-p_3) \cdot \bar{V}(p_4)$	I	$U(p_1)$
$O_2 =$	$U(-p_2)$	\hat{p}_4	$V(-p_3) \cdot \bar{V}(p_4)$	I	$U(p_1)$
$O_3 =$	$U(-p_2)$	I	$V(-p_3) \cdot \bar{V}(p_4)$	\hat{p}_2	$U(p_1)$
$O_4 =$	$U(-p_2)$	\hat{p}_4	$V(-p_3) \cdot \bar{V}(p_4)$	\hat{p}_2	$U(p_1)$
$O_5 =$	$U(-p_2)$	γ_μ	$V(-p_3) \cdot \bar{V}(p_4)$	γ^μ	$U(p_1)$
$O_6 =$	$U(-p_2)$	$\gamma_\mu \hat{p}_4$	$V(-p_3) \cdot \bar{V}(p_4)$	γ^μ	$U(p_1)$
$O_7 =$	$U(-p_2)$	γ_μ	$V(-p_3) \cdot \bar{V}(p_4)$	$\gamma^\mu \hat{p}_2$	$U(p_1)$
$O_8 =$	$U(-p_2)$	$\gamma_\mu \gamma_\nu$	$V(-p_3) \cdot \bar{V}(p_4)$	$\gamma^\nu \gamma^\mu$	$U(p_1)$
$O_9 =$	$U(-p_2)$	$\gamma_\mu \gamma_\nu \hat{p}_4$	$V(-p_3) \cdot \bar{V}(p_4)$	$\gamma^\nu \gamma^\mu$	$U(p_1)$
$O_{10} =$	$U(-p_2)$	$\gamma_\mu \gamma_\nu$	$V(-p_3) \cdot \bar{V}(p_4)$	$\gamma^\nu \gamma^\mu \hat{p}_2$	$U(p_1)$
$O_{11} =$	$U(-p_2)$	$\gamma_\mu \gamma_\nu \hat{p}_4$	$V(-p_3) \cdot \bar{V}(p_4)$	$\gamma^\nu \gamma^\mu \hat{p}_2$	$U(p_1)$
$O_{12} =$	$U(-p_2)$	$\gamma_\mu \gamma_\nu \gamma_\rho$	$V(-p_3) \cdot \bar{V}(p_4)$	$\gamma^\rho \gamma^\nu \gamma^\mu$	$U(p_1)$

$$\text{On-shell diagram} = \sum_{j=1}^{12} A_j O_j,$$

Further relations between amplitudes (solving a system of equations):

$$A_3 = A_2, \quad A_7 = A_6, \quad A_{10} = A_9$$

$$A_8 = \frac{1}{4} A_1 - \frac{m_e}{2} A_2 + A_{12}, \quad A_9 = \frac{1}{4m_e} A_1 - \frac{1}{2} A_2 - \frac{1}{2} A_6, \quad A_{11} = \frac{1}{4m_e^2} A_1 - \frac{1}{2m_e} A_2$$

Thus: there are **only 6 independent amplitudes**.

Other diagrams: Crossing!

