carlomat

a program for automatic computation of multiparticle cross sections

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Katowice

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Motivation

Increasing energy of initial beams at particle colliders such as LHC, or ILC $\Rightarrow$ reactions with a few heavy particles at a time become possible.

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SM radiative corrections should be included, at least the leading ones.

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If the Higgs boson has mass below the $t\bar{t}$ threshold, $m_H < 2m_t$, then the $t\bar{t}H$ Yukawa coupling can be best determined from

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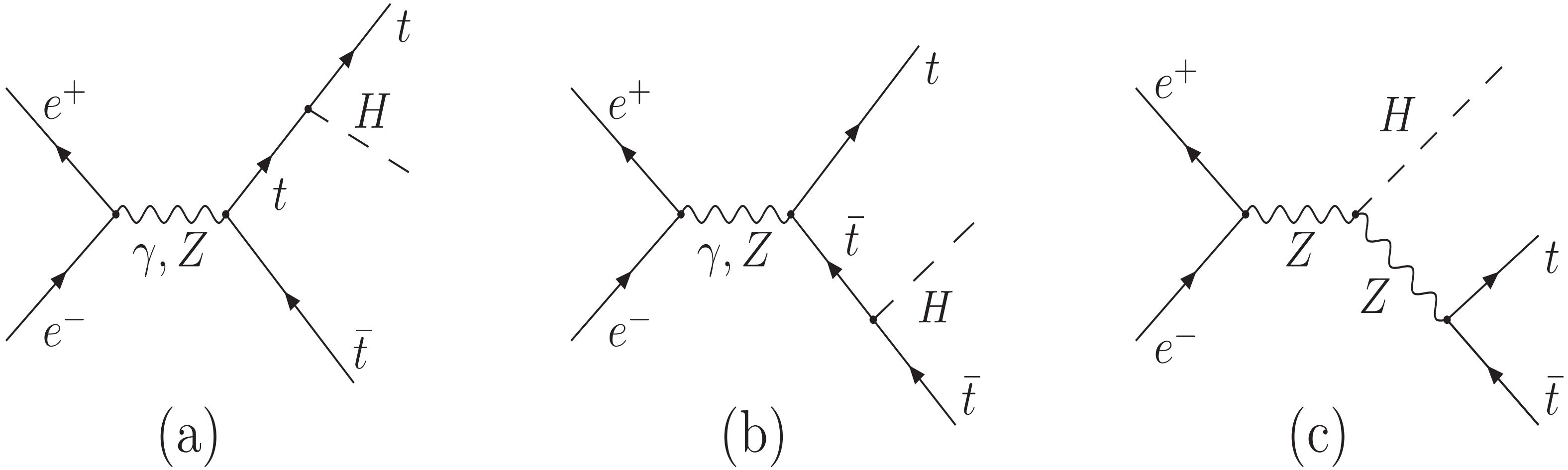

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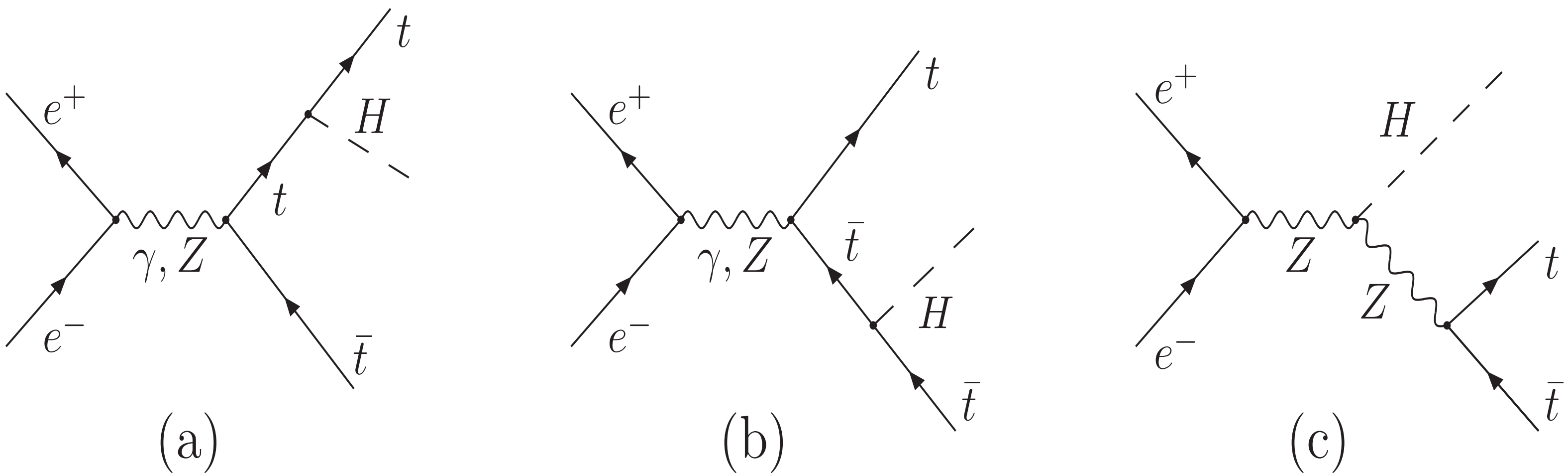

Diagrams (a) i (b) dominate $\Rightarrow$ the cross section $\sim g_{ttH}^2$.

$e^+e^- \to$ *8 fermions*

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- the top and antitop decay before they hadronize, predominantly into bW^+ and $\bar{b}W^-$
- the W's decay into $f\bar{f}'$-pairs,
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$\Rightarrow$ reactions of the form

$$e^+e^- \to bf_1\bar{f}_1'\bar{b}f_2\bar{f}_2'b\bar{b},$$

where $f_1, f_2' = \nu_e, \nu_\mu, \nu_\tau, u, c$ and $f_1', f_2 = e^-, \mu^-, \tau^-, d, s$, should be studied with a complete set of the Feynman diagrams, possibly including radiative corrections, at least the leading ones.

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Examples:

- $e^+e^- \to b\bar{b}b\bar{b}\tau^+\nu_\tau\mu^-\bar{\nu}_\mu$, leptonic [21 214 diagrams]

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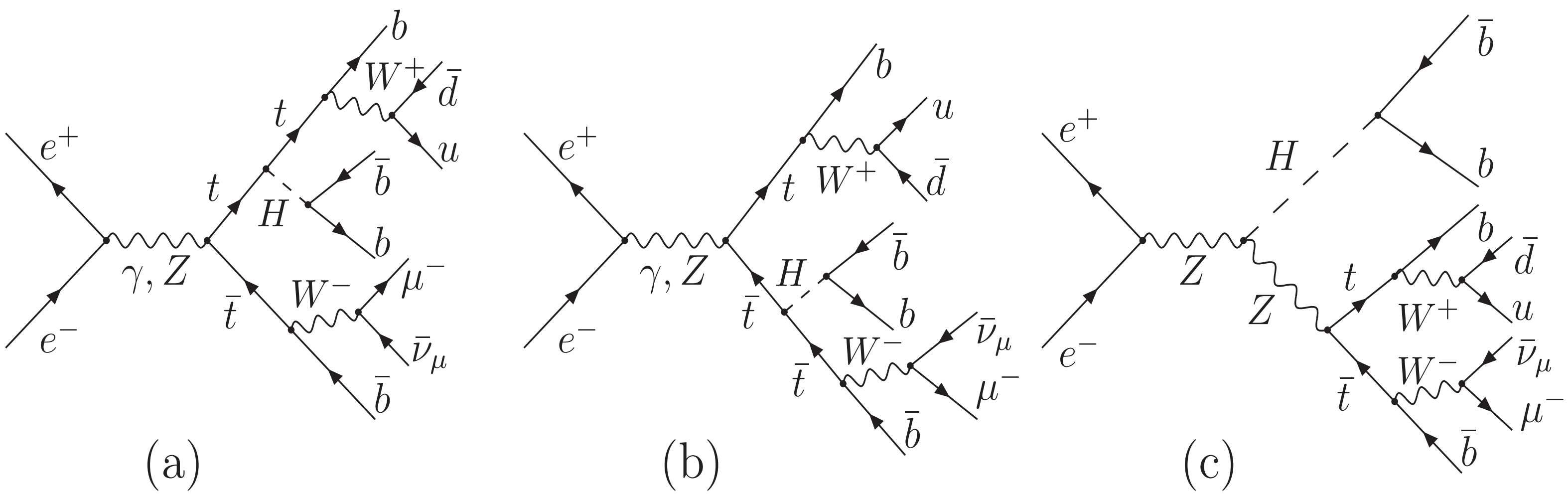
"Signal" diagrams in the semileptonic channel: [20 diagrams]



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Publicly available versions of multipurpose Monte Carlo generators as `HELAC/PHEGAS`, `AMAGIC++/Sherpa`, `O'Mega/Whizard`, `MadGraph/MadEvent`, `ALPGEN`, or `CompHEP/CalcHEP` may have problems while trying to handle reactions with that large numbers of the Feynman diagrams.

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Do it with `carlomat`!

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- fermion masses are not neglected
- the maximum number of external particles is 12
- only the Standard Model is implemented at the moment

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They are copied to another directory where the numerical program is executed.

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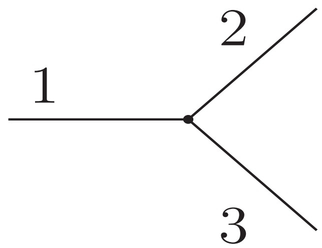

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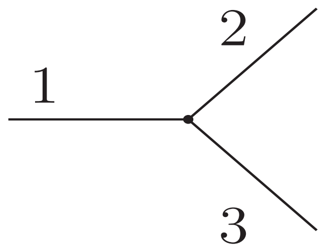
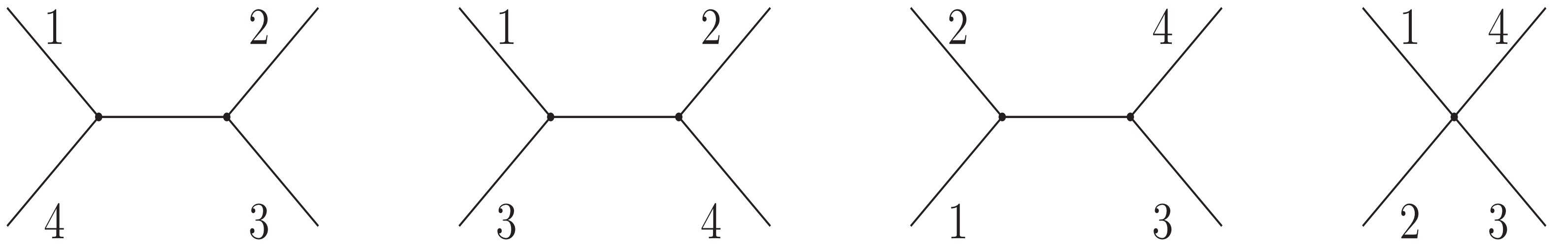


Attach line 4 to each line and to the vertex $\Rightarrow$ 4 topologies of a 4 particle process.



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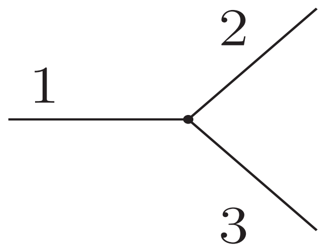

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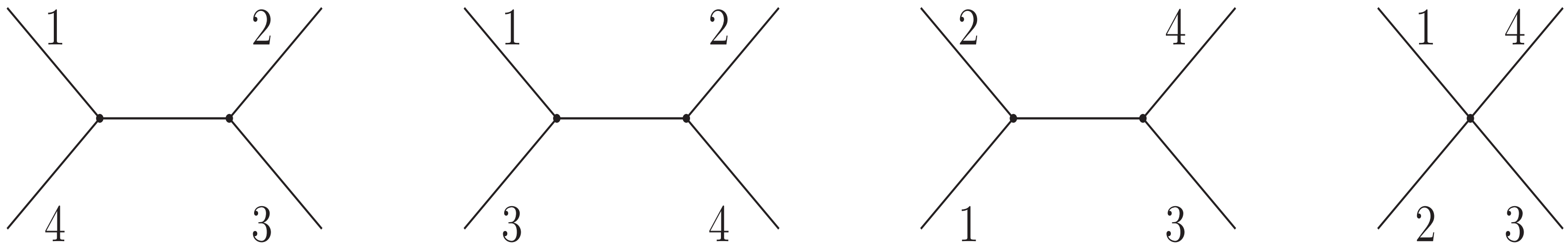

Attach line 5 to each line, including the internal ones, and to each triple vertex $\Rightarrow$ 25 topologies of a 5 particle process.

Generation of topologies

No. of topologies grows dramatically with No. of external particles.

No. of particles	No. of topologies
6	220
7	2 485
8	34 300
9	559 405
10	10 525 900
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Topologies can be pregenerated and stored on a disk.

Feynman diagrams

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- If the two parts match into a propagator $\Rightarrow$ the topology is accepted.
- The 'longer' part is further divided $\Rightarrow$ the Feynman diagram is made of 3 or 4 parts, merged into a triple or quartic vertex of the model.

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All the topologies checked $\Rightarrow$ subroutines for the matrix element, colour matrix and phase space integration are written.

Helicity amplitudes

Use is made of the routines developed for a Monte Carlo program `eett6f v. 1.0` [K. K., Comput. Phys. Commun. **151** (2003) 339], for calculating lowest order cross sections of $e^+e^- \to 6$ fermions relevant for a $t\bar{t}$-pair production and decay which have been tailored to meet needs of the automatic generation of amplitudes.

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Explicit summing over helicities is also possible. $\Rightarrow$ Spinors or polarization vectors representing particles, both on- and off-shell ones, are computed only once, for all the helicities of the external particles they are made of, and stored in arrays $\Rightarrow$ a novel feature with respect to *e.g.* `MadGraph`.

Helicity amplitudes

The constant widths of unstable particles are introduced through the complex mass parameters:

$$M_V^2 = m_V^2 - i m_V \Gamma_V, \qquad V = W, Z,$$

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which replace masses in the corresponding propagators, both in the s- and t-channel Feynman diagrams,

$$\Delta_F^{\mu\nu}(q) = \frac{-g^{\mu\nu} + q^\mu q^\nu / M_V^2}{q^2 - M_V^2},$$
$$\Delta_F(q) = \frac{1}{q^2 - M_H^2}, \qquad S_F(q) = \frac{\not{q} + M_t}{q^2 - M_t^2}.$$

Propagators of a photon and gluon are taken in the Feynman gauge.

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The EW mixing parameter may be defined either real (FWS) or complex (CMS),

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Colour matrix is calculated only once at the beginning of execution of the numerical program after having reduced its size with the use of the SU(3) algebra properties.

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Weights with which different kinematical channels contribute are adapted iteratively.

Tests

Matrix elements, for randomly selected sets of momenta, of

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Total cross sections checked against

- `ee4fgamma` [K.K., F. Jegerlehner] for $e^+e^- \longrightarrow 4$ fermions and a photon
- `eett6f` [K.K.] for several reactions of $e^+e^- \longrightarrow 6$ fermions

Agreement, within one standard deviation.

Top quark pair production in e^+e^- annihilation

Final state	$\sqrt{s}$	`carlomat`	`AMAGIC++`	`HELAC`
$b\bar{b}u\bar{u}d\bar{d}$	360	32.98(11)	32.90(15)	33.05(14)
	500	50.31(19)	49.74(21)	50.20(13)
$b\bar{b}u\bar{d}e^-\bar{\nu}_e$	360	11.448(26)	11.460(36)	11.488(15)
	500	17.424(56)	17.486(66)	17.492(41)
$b\bar{b}e^+\nu_e\mu^-\bar{\nu}_\mu$	360	3.843(5)	3.847(15)	3.848(7)
	500	5.856(11)	5.865(24)	5.868(10)
$b\bar{b}\mu^+\nu_\mu\mu^-\bar{\nu}_\mu$	360	3.837(5)	3.808(16)	3.861(19)
	500	5.834(10)	5.840(30)	5.839(12)

$\sqrt{s}$ in GeV, cross sections in fb. [T. Gleisberg, et al.]

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Cross sections of $e^+e^- \to b\bar{b}b\bar{b}u\bar{d}\mu^-\bar{\nu}_\mu$ without QCD contributions have been checked against `Whizard`.

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Further thorough comparisons with other multipurpose MC generators as `HELAC/PHEGAS`, `AMAGIC++/Sherpa`, `O'Mega/Whizard`, `MadGraph/MadEvent`, `ALPGEN`, or `CompHEP/CalcHEP` should be done.

Cross sections of $e^+e^- \to b\bar{b}b\bar{b}u\bar{d}\mu^-\bar{\nu}_\mu$

$\sqrt{s}$ [GeV]	σ_{all} [ab]	$\sigma_{\text{no QCD}}$ [ab]	σ_{signal} [ab]	$\sigma_{\text{signal}}^{\text{no cuts}}$ [ab]	$\sigma_{\text{NWA}}^{\text{no cuts}}$ [ab]
500	26.8(4)	7.80(3)	3.095(3)	3.796(3)	3.920(1)
800	100.2(8)	66.8(1)	46.27(2)	58.36(2)	60.03(2)
1000	93.1(3)	61.4(1)	40.18(2)	51.74(2)	52.42(3)
2000	47.4(2)	28.5(1)	15.14(3)	22.14(4)	20.68(3)

$$5^\circ < \theta(q,\text{beam}),\ \theta(l,\text{beam}) < 175^\circ,\ \ \theta(q,q'),\ \theta(l,q) > 10^\circ,$$

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Large off resonance background! [K.K., S. Szczypiński]

Cross sections [ab] at $\sqrt{s} = 500$ GeV of $e^+e^- \to$

$m_{bb}^{\rm cut}$	$b\bar{b}b\bar{b}u\bar{d}s\bar{c}$		$b\bar{b}b\bar{b}u\bar{d}\mu^-\bar{\nu}_\mu$		$b\bar{b}b\bar{b}\tau^+\nu_\tau\mu^-\bar{\nu}_\mu$	
[GeV]	$\sigma_{\rm all}$	$\sigma_{\rm sig.}$	$\sigma_{\rm all}$	$\sigma_{\rm sig.}$	$\sigma_{\rm all}$	$\sigma_{\rm sig.}$
20	13.88(6)	8.70(2)	3.50(2)	2.38	4.03(9)	0.86
5	10.17(4)	8.66(2)	2.62(1)	2.33	1.89(7)	0.86
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$$\left|m\left(b, \sim b_1, \sim b_2\right) - m_t\right| < 30\ {\rm GeV},$$

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$$\left|m\left(b_3, b_4\right) - m_H\right| < m_{bb}^{\rm cut}$$

Cross sections [ab] at $\sqrt{s} = 500$ GeV of $e^+e^- \to$

$m_{bb}^{\rm cut}$	$b\bar{b}b\bar{b}u\bar{d}s\bar{c}$		$b\bar{b}b\bar{b}u\bar{d}\mu^-\bar{\nu}_\mu$		$b\bar{b}b\bar{b}\tau^+\nu_\tau\mu^-\bar{\nu}_\mu$	
[GeV]	$\sigma_{\rm all}$	$\sigma_{\rm sig.}$	$\sigma_{\rm all}$	$\sigma_{\rm sig.}$	$\sigma_{\rm all}$	$\sigma_{\rm sig.}$
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Background substantially reduced! [K.K., S. Szczypiński]

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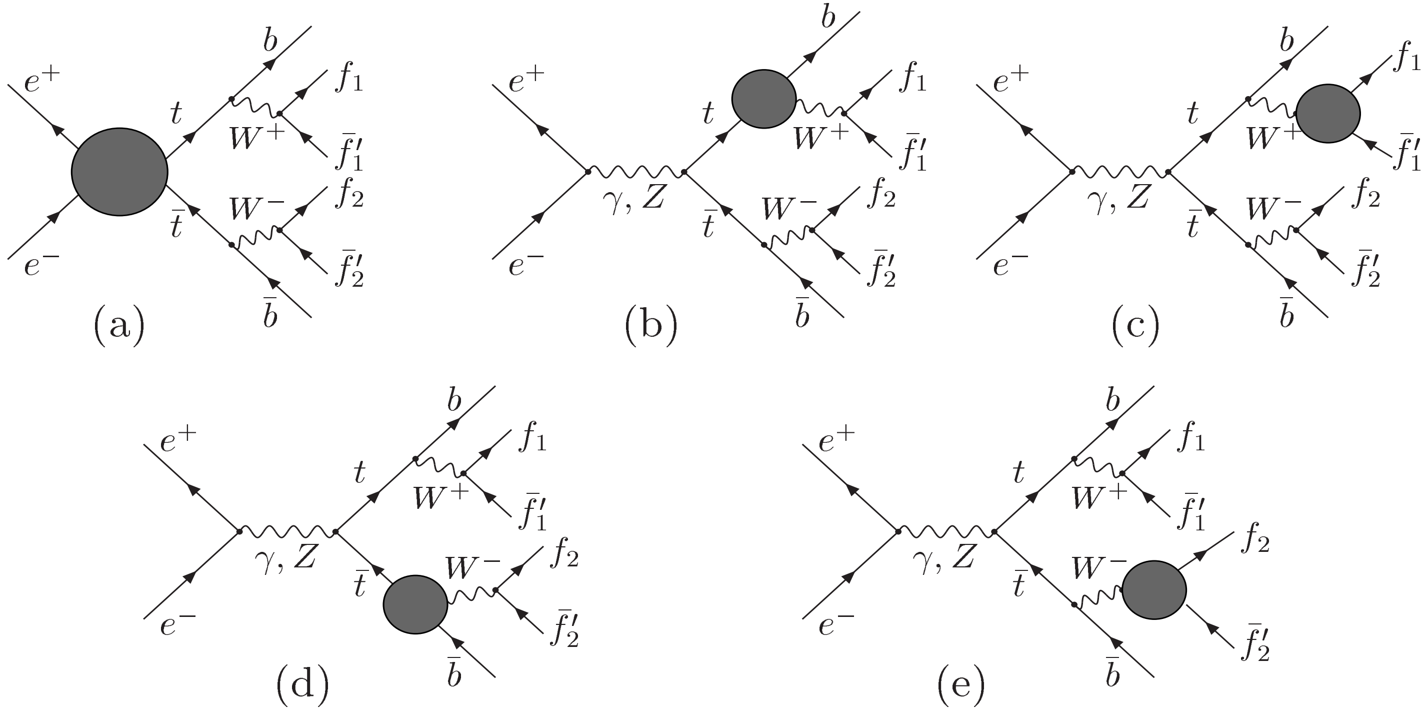

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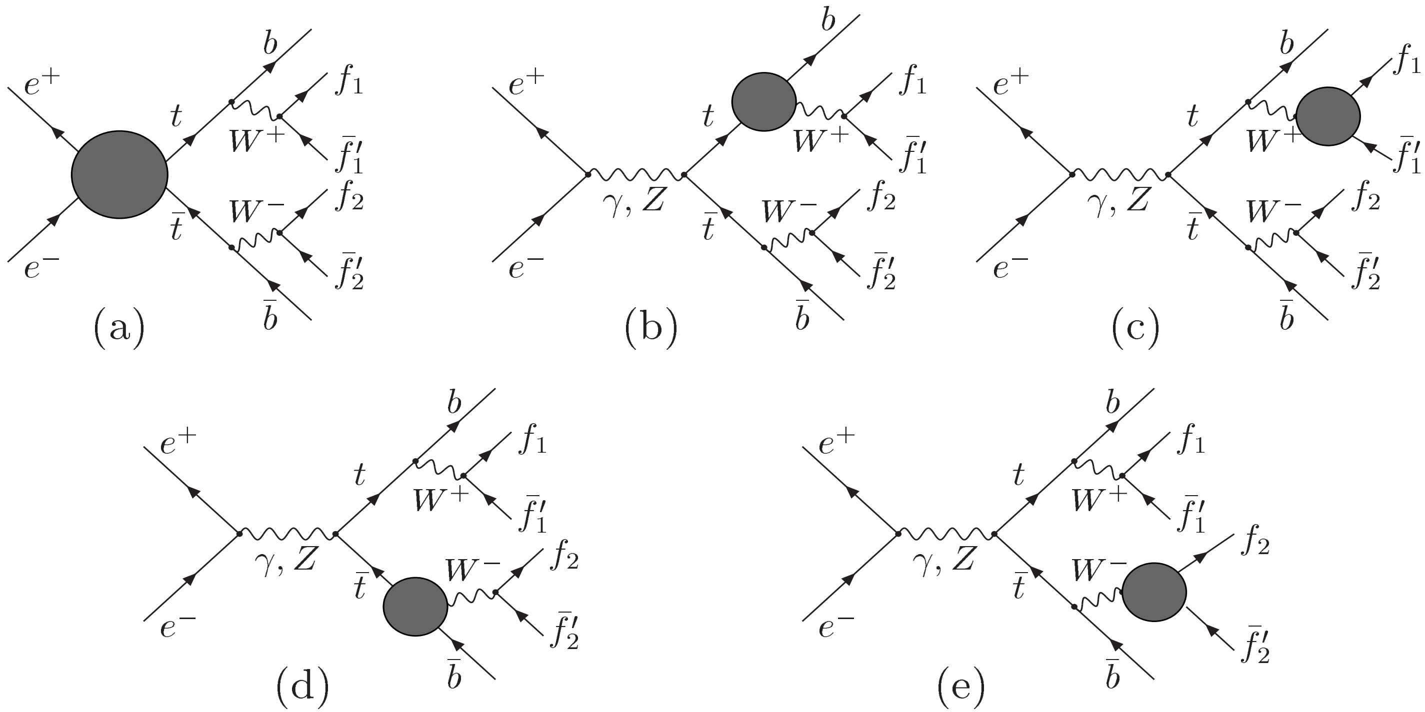

- (a) calculated with a subroutine based on `topfit`, by T. Riemann, *et al.*,
- (b)–(e) with subroutines written by A. Staroń.