

Multi-particle final states at 1-loop EW

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Electroweak corrections to charged-current $e^+e^- \rightarrow 4$ fermion processes: Technical details and further results

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Abstract

The complete electroweak $\mathcal{O}(\alpha)$ corrections have been calculated for the charged-current four-fermion production processes $e^+e^- \rightarrow \nu_\tau \tau^+ \mu^- \bar{\nu}_\mu$, $u\bar{d}\mu^-\bar{\nu}_\mu$, and $uds\bar{c}$. Here, technical details of this calculation are presented. These include the algebraic reduction of spinor chains to a few standard structures and the consistent implementation of the finite width of the W boson. To this end, a generalization of the complex-mass scheme to the one-loop level is proposed, and the practical application of this method is described. Finally, the effects of the complete $\mathcal{O}(\alpha)$ corrections to various differential cross sections of physical interest are discussed and compared to predictions based on the double-pole approximation, revealing that the latter approximation is not sufficient to fully exploit the potential of a future linear collider in an analysis of W-boson pairs at high energies.

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- Is it possible to redo this computation with general purpose Monte Carlo programs?
- Is it possible to do more complicated NLO EW computations at e^+e^- ?

Outlook:

- Status of matrix-element generators for EW corrections
 - Implementation/Automation in Monte Carlo for e^+e^-
 - ⚠ Potential overlap with talk of Stefano Frixione

Building blocks needed for NLO EW computations

- Tree and one-loop matrix elements
 - **Matrix-element providers**
- Integration, subtraction of IR divergences, PDF, non-perturbative physics etc.
 - **Monte Carlo programs**

Disclaimer

- Not an expert on e^+e^- computation
- Not an author of the tools reviewed

Status at hadron collider for high-multiplicity processes

- $2 \rightarrow 6$ processes
off-shell top quarks, tri-boson, vector-boson scattering ...
.. but only two computations publicly available with non-trivial resonance structure:
 - NLO QCD to off-shell $t\bar{t}$ [Ježo et al.; 1607.04538]
 - NLO EW to VBS same-sign W [Chiesa, Denner, Lang, MP; 1906.01863]

- $2 \rightarrow 7$ processes
 - NLO QCD to $t\bar{t}H$ [Denner, Feger; 1506.07448]
 - NLO QCD to $t\bar{t}j$ [Bevilacqua et al.; 1509.09242, 1609.01659]
 - NLO EW to $t\bar{t}H$ [Denner, Lang, MP, Uccirati; 1612.07138]
 - NLO QCD to $Wb\bar{b}jjj$ [Anger et al.; 1712.05721]
 - NLO QCD to $t\bar{t}\gamma$ [Bevilacqua et al.; 1803.09916]

- $2 \rightarrow 8$ processes
 - NLO QCD to $t\bar{t}(Z \rightarrow \nu\bar{\nu})$ [Bevilacqua et al.; 1907.09359]
 - NLO QCD to $t\bar{t}b\bar{b}$ [Denner, Lang, MP; 2008.00918]

GOSAM [CHIESA ET AL.]

- Allows to generate *in principle* **arbitrary** processes at NLO EW
- More at <https://gosam.hepforge.org/>

MADLOOP [HIRSCHI ET AL.; 1103.0621]

- Allows to generate **arbitrary** processes at NLO EW
- Provided in MADGRAPH5_AMC@NLO [Alwall et al.; 1405.0301]

NLOX [HONEYWELL, QUACKENBUSH, REINA, REUSCHLE; 1812.11925]

- Allows to compute **arbitrary** processes with up to 6 external particles at NLO EW **on-the fly**
- More at <http://www.hep.fsu.edu/~nlox/>

OPENLOOPS 2 [BUCCIONI ET AL.; 1907.13071]

→ Several **process libraries** available at NLO EW:

- $e^+e^- \rightarrow t\bar{t}$
- $e^+e^- \rightarrow 4\ell$
- $e^+e^- \rightarrow VV$ ($V = Z, W$)
- $e^+e^- \rightarrow 2\ell$
- $e^+e^- \rightarrow 2\ell H$

→ More on request: <https://openloops.hepforge.org/>

RECOLA [DENNER, LANG, UCCIRATI; 1705.06053]

→ Allows to compute **arbitrary** processes at NLO EW **on-the fly**

→ More at <https://recola.hepforge.org/>

Use in public Monte Carlo

→ MADGRAPH5_AMC@NLO [Alwall et al.; 1405.0301]

- Automation of NLO EW corrections ✓

[Frederix, Frixione, Hirschi, Pagani, Shao, Zaro; 1804.10017]

→ Using MADLOOP

- Available at NLO EW in public version for hadron collider ✓
- In the making at NLO EW in public version for e^+e^- ✓
- ISR + beamstrahlung effects NLO QCD in e^+e^- ✓
 $\mathcal{O}(1\text{month})$
- ISR + beamstrahlung effects NLO EW in e^+e^- ✓
 $\mathcal{O}(\text{few months})$

→ More information at <https://launchpad.net/mg5amcnlo>

Use in public Monte Carlo

→ SHERPA [Bothmann et al.; 1905.09127]

- Automation of NLO EW corrections ✓ [Schönherr; 1804.10017]
- Using
 - OPENLOOPS [Kallweit et al.; 1412.5157]
 - RECOLA [Biedermann et al.; 1704.05783]
- Available in private version for hadron collider/ e^+e^- ✓
- No ISR + beamstrahlung effects implemented ✗ (longer term)

→ More information at <https://sherpa-team.gitlab.io>

Use in public Monte Carlo

→ WHIZARD [Kilian, Ohl, Reuter; 0708.4233]

- Automation of NLO QCD corrections only ✓
- Using
 - OPENLOOPS
 - RECOLA
- NLO EW being validated for hadron collider/ e^+e^- ✓
- No ISR + beamstrahlung effects implemented ✗ (longer term)

→ More information at <https://whizard.hepforge.org>

Automatised NLO EW for e^+e^- already achieved!

- Not working and public for all generators yet
 - Electron PDF, non-perturbative effects etc. to be implemented
- All this will be there before any e^+e^- machine is built!

Thank you

BACK-UP