aMC@NLO and top pair production at LC

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for the MadGraph/aMC@NLO team

Full list of contributors:
http://amcatnlo.web.cern.ch/amcatnlo/people.htm
Plan of the Talk

- aMC@NLO
  - MadLoop
  - MadFKS
  - NLO+PS
- MadSpin
- DEMO
- top pair production at LC
- Conclusion
aMC@NLO: A Joint Venture

MadGraph

FKS

CutTools

MC@NLO
Why automation?

- Time: Less tools, means more time for physics
- Robust: Easier to test, to trust
- Easy: One framework/tool to learn
aMC@NLO

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  ➤ Robust: Easier to test, to trust
  ➤ Easy: One framework/tool to learn

• Why NLO?
  ➤ Reliable prediction of the total rate
  ➤ Reduction of the theoretical uncertainty
aMC@NLO

• Why **automation**?
  ➡ Time: Less tools, means more time for physics
  ➡ Robust: Easier to test, to trust
  ➡ Easy: One framework/tool to learn

• Why **NLO**?
  ➡ Reliable prediction of the total rate
  ➡ Reduction of the theoretical uncertainty

• Why **matched to the PS**?
  ➡ Parton are not an detector observables
  ➡ Matching cure some fix-order ill behaved observables
NLO Basics

\[ \sigma^{NLO} = \int_m d^{(d)} \sigma^V + \int_{m+1} d^{(d)} \sigma^R + \int_m d^{(4)} \sigma^B \]
NLO Basics

NLO Virtual Real Born

\[
\sigma^{NLO} = \int_m d^{(d)} \sigma^V + \int_{m+1} d^{(d)} \sigma^R + \int_m d^{(4)} \sigma^B
\]

Need to deal with singularities

\[
\sigma^{NLO} = \int_m d^{(d)} (\sigma^V + \int_1 d\phi_1 C) + \int_{m+1} d^{(d)} (\sigma^R - C) + \int_m d^{(4)} \sigma^B
\]
NLO Basics

NLO  Virtual  Real  Born

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MadLoop  MadFKS  MadGraph
MADLOOP
The virtual
OPP Reduction

- decomposition to scalar integrals
  works at the level of the integrals

\[ M^{1\text{-loop}} = \sum_{i_0 < i_1 < i_2 < i_3} d_{i_0 i_1 i_2 i_3} \text{Box}_{i_0 i_1 i_2} \]
\[ + \sum_{i_0 < i_1 < i_2} c_{i_0 i_1 i_2} \text{Triangle}_{i_0 i_1} \]
\[ + \sum_{i_0 < i_1} b_{i_0 i_1} \text{Bubble}_{i_0 i_1} \]
\[ + \sum_{i_0} a_{i_0} \text{Tadpole}_{i_0} \]
\[ + R + O(\epsilon) \]

[Ossola, Papadopoulos, Pittau 2006]
OPP Reduction

- decomposition to scalar integrals works at the level of the integrals
- If we would know a similar relation at the integrand level, we would be able to manipulate the integrands and extract the coefficients without doing the integrals

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[Ossola, Papadopoulos, Pittau 2006]
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If we would know a similar relation at the integrand level, we would be able to manipulate the integrands and extract the coefficients without doing the integrals

\[ M^{1\text{-loop}} = \sum_{i_0<i_1<i_2<i_3} d_{i_0i_1i_2i_3} \text{Box}_{i_0i_1i_2i_3} + \sum_{i_0<i_1<i_2} c_{i_0i_1i_2} \text{Triangle}_{i_0i_1i_2} + \sum_{i_0<i_1} b_{i_0i_1} \text{Bubble}_{i_0i_1} + \sum_{i_0} a_{i_0} \text{Tadpole}_{i_0} + R + \mathcal{O}(\epsilon) \]

\[ N(l) = \sum_{i_0<i_1<i_2<i_3}^{m-1} \left[ d_{i_0i_1i_2i_3} + \tilde{d}_{i_0i_1i_2i_3}(l) \right] \prod_{i\neq i_0,i_1,i_2,i_3}^{m-1} D_i + \sum_{i_0<i_1<i_2}^{m-1} \left[ c_{i_0i_1i_2} + \tilde{c}_{i_0i_1i_2}(l) \right] \prod_{i\neq i_0,i_1,i_2}^{m-1} D_i + \sum_{i_0<i_1}^{m-1} \left[ b_{i_0i_1} + \tilde{b}_{i_0i_1}(l) \right] \prod_{i\neq i_0,i_1}^{m-1} D_i + \sum_{i_0}^{m-1} \left[ a_{i_0} + \tilde{a}_{i_0}(l) \right] \prod_{i\neq i_0}^{m-1} D_i + \tilde{P}(l) \prod_{i}^{m-1} D_i \]

[Ossola, Papadopoulos, Pittau 2006]
OPP Reduction

- decomposition to scalar integrals works at the level of the integrals

$M^{1\text{-loop}} = \sum_{i_0 < i_1 < i_2 < i_3} d_{i_0 i_1 i_2 i_3} \text{Box}_{i_0 i_1 i_2 i_3}
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+ \sum_{i_0} a_{i_0} \text{Tadpole}_{i_0}
+ R + \mathcal{O}(\epsilon)$

If we would know a similar relation at the integrand level, we would be able to manipulate the integrands and extract the coefficients without doing the integrals

$N(l) = \sum_{i_0 < i_1 < i_2 < i_3} ^{m-1} d_{i_0 i_1 i_2 i_3} - \tilde{d}_{i_0 i_1 i_2 i_3}(l) \prod_{i \neq i_0, i_1, i_2, i_3} D_i
+ \sum_{i_0 < i_1 < i_2} ^{m-1} c_{i_0 i_1 i_2} - \tilde{c}_{i_0 i_1 i_2}(l) \prod_{i \neq i_0, i_1} D_i
+ \sum_{i_0 < i_1} ^{m-1} b_{i_0 i_1} - \tilde{b}_{i_0 i_1}(l) \prod_{i \neq i_0} D_i
+ \sum_{i_0} ^{m-1} a_{i_0} - \tilde{a}_{i_0}(l) \prod_{i \neq i_0} D_i
+ \tilde{P}(l) \prod_{i} D_i$

Spurious term

[Ossola, Papadopoulos, Pittau 2006]
**OPP Reduction**

- decomposition to scalar integrals works at the level of the integrals
- If we would know a similar relation at the **integrand** level, we would be able to manipulate the integrands and extract the coefficients **without doing the integrals**

\[
\mathcal{M}^{1\text{-loop}} = \sum_{i_0<i_1<i_2<i_3} d_{i_0 i_1 i_2 i_3} \text{Box}_{i_0 i_1 i_2 i_3} \\
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+ \sum_{i_0} a_{i_0} \text{Tadpole}_{i_0} \\
+ R + \mathcal{O}(\epsilon)
\]

- feed cut tools with numerator value and it returns the coefficients

\[
N(l) = \sum_{i_0<i_1<i_2<i_3} \left[ d_{i_0 i_1 i_2 i_3} - d_{i_0 i_1 i_2 i_3}(l) \right] \prod_{i \neq i_0,i_1,i_2} D_i \\
+ \sum_{i_0<i_1<i_2} \left[ c_{i_0 i_1 i_2} - c_{i_0 i_1 i_2}(l) \right] \prod_{i \neq i_0,i_1,i_2} D_i \\
+ \sum_{i_0<i_1} \left[ b_{i_0 i_1} - b_{i_0 i_1}(l) \right] \prod_{i \neq i_0,i_1} D_i \\
+ \sum_{i_0} \left[ a_{i_0} - a_{i_0}(l) \right] \prod_{i \neq i_0} D_i \\
+ \tilde{P}(l) \prod_{i} D_i
\]

**Spurious term**

[Ossola, Papadopoulos, Pittau 2006]
OPP in a nutshell

- In OPP reduction we reduce the system at the integrand level.
- We can solve the system numerically: we only need a numerical function of the (numerator of) integrand. We can set-up a system of linear equations by choosing specific values for the loop momentum $l$, depending on the kinematics of the event.
- OPP reduction is implemented in CutTools (publicly available). Given the integrand, CutTools provides all the coefficients in front of the scalar integrals and the $R1$ term.
- The OPP reduction leads to numerical unstabilities whose origins are not well under control. Require quadruple precision.
- Analytic information is needed for the $R2$ term, but can be compute once and for all for a given model.
• Diagram Generation
MADLOOP

• Diagram Generation

Diagram 19 QCD=4, QED=0

Diagram 20 QCD=4, QED=0

Diagram 21 QCD=4, QED=0

Diagram 22 QCD=4, QED=0

2>2
MADLOOP

- **Diagram Generation**
  - Generate diagrams with 2 extra particles
  - Need to filter result
• Diagram Generation
  ➡ Generate diagrams with 2 extra particles
  ➡ Need to filter result

• Evaluation of the Numerator:
  ➡ OpenLoops technique [S. Pozzorini & al.(2011)]

\[
\mathcal{N}(l^\mu) = \sum_{r=0}^{r_{\text{max}}} C_{\mu_0 \mu_1 \ldots \mu_r}^{(r)} l^{\mu_0} l^{\mu_1} \ldots l^{\mu_r}
\]
MADFKS
The real
FKS subtraction

- Find parton pairs $i, j$ that can give collinear singularities
- Split the phase space into regions with one collinear singularities
- Integrate them independently
  - with an adhoc PS parameterization
  - can be run in parallel
- $\#$ of contributions $\sim n^2$

[S. Frixione, Z Kunst, A Signer (1995)]
MC@NLO
Matching to the shower
Sources of double counting

- There is double counting between the real emission matrix elements and the parton shower: the extra radiation can come from the matrix elements or the parton shower.

- There is also an overlap between the virtual corrections and the Sudakov suppression in the zero-emission probability.
MC@NLO procedure

Parton shower

Born+Virtual:

Real emission:

\[ \frac{d\sigma_{\text{NLOwPS}}}{dO} = \left[ d\Phi_m(B + \int_{\text{loop}} V + \int d\Phi_1 MC') \right] I_{MC}^{(m)}(O) \]
\[ + \left[ d\Phi_{m+1}(R - MC') \right] I_{MC}^{(m+1)}(O) \]

• Double counting is explicitly removed by including the “shower subtraction terms”
Four-lepton production

- 4-lepton invariant mass is almost insensitive to parton shower effects.
- 4-lepton transverse momenta is extremely sensitive

[Frederix, Frixione, Hirschi, maltoni, Pittau & Torrielli (2011)]
results

- Errors are the MC integration uncertainty only
- Cuts on jets, $\gamma^*/Z$ decay products and photons, but no cuts on $b$ quarks (their mass regulates the IR singularities)
- Efficient handling of exceptional phase-space points: their uncertainty always at least two orders of magnitude smaller than the integration uncertainty
- Running time: two weeks on ~150 node cluster leading to rather small integration uncertainties

<table>
<thead>
<tr>
<th>Process</th>
<th>$\mu$</th>
<th>$n_f$</th>
<th>Cross section (pb)</th>
<th>LO</th>
<th>NLO</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.1 $pp \rightarrow t\bar{t}$</td>
<td>$m_{\text{top}}$</td>
<td>5</td>
<td>123.76 ± 0.05</td>
<td>162.08 ± 0.12</td>
<td></td>
</tr>
<tr>
<td>a.2 $pp \rightarrow tj$</td>
<td>$m_{\text{top}}$</td>
<td>5</td>
<td>34.78 ± 0.03</td>
<td>41.03 ± 0.07</td>
<td></td>
</tr>
<tr>
<td>a.3 $pp \rightarrow tjj$</td>
<td>$m_{\text{top}}$</td>
<td>5</td>
<td>11.851 ± 0.006</td>
<td>13.71 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>a.4 $pp \rightarrow tbj$</td>
<td>$m_{\text{top}}/4$</td>
<td>4</td>
<td>25.62 ± 0.01</td>
<td>30.96 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>a.5 $pp \rightarrow tbjj$</td>
<td>$m_{\text{top}}/4$</td>
<td>4</td>
<td>8.195 ± 0.002</td>
<td>8.91 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>b.1 $pp \rightarrow (W^+ \rightarrow)e^+\nu_e$</td>
<td>$m_W$</td>
<td>5</td>
<td>5072.5 ± 2.9</td>
<td>6146.2 ± 9.8</td>
<td></td>
</tr>
<tr>
<td>b.2 $pp \rightarrow (W^+ \rightarrow)e^+\nu_e j$</td>
<td>$m_W$</td>
<td>5</td>
<td>828.4 ± 0.8</td>
<td>1065.3 ± 1.8</td>
<td></td>
</tr>
<tr>
<td>b.3 $pp \rightarrow (W^+ \rightarrow)e^+\nu_e j j$</td>
<td>$m_W$</td>
<td>5</td>
<td>298.8 ± 0.4</td>
<td>303.0 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>b.4 $pp \rightarrow (\gamma^*/Z \rightarrow)e^+e^-$</td>
<td>$m_Z$</td>
<td>5</td>
<td>1007.0 ± 0.1</td>
<td>1170.0 ± 2.4</td>
<td></td>
</tr>
<tr>
<td>b.5 $pp \rightarrow (\gamma^*/Z \rightarrow)e^+e^- j$</td>
<td>$m_Z$</td>
<td>5</td>
<td>156.11 ± 0.03</td>
<td>203.0 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>b.6 $pp \rightarrow (\gamma^*/Z \rightarrow)e^+e^- j j$</td>
<td>$m_Z$</td>
<td>5</td>
<td>54.24 ± 0.02</td>
<td>56.69 ± 0.07</td>
<td></td>
</tr>
<tr>
<td>c.1 $pp \rightarrow (W^+ \rightarrow)e^+\nu_e b\bar{b}$</td>
<td>$m_W + 2m_b$</td>
<td>4</td>
<td>11.557 ± 0.005</td>
<td>22.95 ± 0.07</td>
<td></td>
</tr>
<tr>
<td>c.2 $pp \rightarrow (W^+ \rightarrow)e^+\nu_e t\bar{t}$</td>
<td>$m_W + 2m_{\text{top}}$</td>
<td>5</td>
<td>0.009415 ± 0.000003</td>
<td>0.01159 ± 0.00001</td>
<td></td>
</tr>
<tr>
<td>c.3 $pp \rightarrow (\gamma^*/Z \rightarrow)e^+e^- b\bar{b}$</td>
<td>$m_Z + 2m_b$</td>
<td>4</td>
<td>9.459 ± 0.004</td>
<td>15.31 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>c.4 $pp \rightarrow (\gamma^*/Z \rightarrow)e^+e^- tt$</td>
<td>$m_Z + 2m_{\text{top}}$</td>
<td>5</td>
<td>0.003513 ± 0.000003</td>
<td>0.004876 ± 0.000002</td>
<td></td>
</tr>
<tr>
<td>c.5 $pp \rightarrow \gamma t\bar{t}$</td>
<td>$2m_{\text{top}}$</td>
<td>5</td>
<td>0.2906 ± 0.0001</td>
<td>0.4169 ± 0.0003</td>
<td></td>
</tr>
<tr>
<td>d.1 $pp \rightarrow W^+W^-$</td>
<td>$2m_W$</td>
<td>4</td>
<td>29.976 ± 0.004</td>
<td>43.92 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>d.2 $pp \rightarrow W^+W^- j$</td>
<td>$2m_W$</td>
<td>4</td>
<td>11.613 ± 0.002</td>
<td>15.174 ± 0.008</td>
<td></td>
</tr>
<tr>
<td>d.3 $pp \rightarrow W^+W^+ jj$</td>
<td>$2m_W$</td>
<td>4</td>
<td>0.07048 ± 0.00004</td>
<td>0.1377 ± 0.0005</td>
<td></td>
</tr>
<tr>
<td>e.1 $pp \rightarrow HW^+$</td>
<td>$m_W + m_H$</td>
<td>5</td>
<td>0.3428 ± 0.0003</td>
<td>0.4455 ± 0.0003</td>
<td></td>
</tr>
<tr>
<td>e.2 $pp \rightarrow HW^+ j$</td>
<td>$m_W + m_H$</td>
<td>5</td>
<td>0.1223 ± 0.0001</td>
<td>0.1501 ± 0.0002</td>
<td></td>
</tr>
<tr>
<td>e.3 $pp \rightarrow HZ$</td>
<td>$m_Z + m_H$</td>
<td>5</td>
<td>0.2781 ± 0.0001</td>
<td>0.3659 ± 0.0002</td>
<td></td>
</tr>
<tr>
<td>e.4 $pp \rightarrow HZ j$</td>
<td>$m_Z + m_H$</td>
<td>5</td>
<td>0.0988 ± 0.0001</td>
<td>0.1237 ± 0.0001</td>
<td></td>
</tr>
<tr>
<td>e.5 $pp \rightarrow Ht\bar{t}$</td>
<td>$m_{\text{top}} + m_H$</td>
<td>5</td>
<td>0.08896 ± 0.00001</td>
<td>0.09869 ± 0.00003</td>
<td></td>
</tr>
<tr>
<td>e.6 $pp \rightarrow Hb\bar{b}$</td>
<td>$m_b + m_H$</td>
<td>4</td>
<td>0.16510 ± 0.00009</td>
<td>0.2099 ± 0.0006</td>
<td></td>
</tr>
<tr>
<td>e.7 $pp \rightarrow Hjj$</td>
<td>$m_H$</td>
<td>5</td>
<td>1.104 ± 0.002</td>
<td>1.036 ± 0.002</td>
<td></td>
</tr>
</tbody>
</table>
MadSpin
Decay with Full Spin correlation

[P. Artoisenet, R. Frederix, OM, R. RietKerk (2012)]
MadSpin

• WISH-LIST:
  ➡ For a sample of events include the decay of unstable final states particles.
  ➡ Keep full spin correlations and finite width effect
  ➡ Keep unweighted events
MadSpin

- **WISH-LIST:**
  - For a sample of events include the decay of unstable final states particles.
  - Keep full spin correlations and finite width effect.
  - Keep unweighted events.

- **Solution:**

  [Frixione, Leanen, Motylinski, Webber (2007)]

```
<table>
<thead>
<tr>
<th>Read Event</th>
<th>Generate Decay</th>
<th>Unweighting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass</td>
<td>Write Event</td>
<td></td>
</tr>
<tr>
<td>FAIL</td>
<td>RETRY</td>
<td></td>
</tr>
</tbody>
</table>
```

\[ |M_{LO}^{P+D}|^2 / |M_{LO}^{P}|^2 \]
MadSpin

- Fully automatic
  - Fully integrated in MG5 [LO and NLO]
  - Can be run in StandAlone
MadSpin

• Fully automatic
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• we are going to release a speed up version (15x faster)
MadSpin

- Fully automatic
  - Fully integrated in MG5 [LO and NLO]
  - Can be run in StandAlone
- we are going to release a speed up version (15x faster)
- Example $t \bar{t}h$:

\begin{figure}
  \centering
  \begin{subfigure}{0.49\textwidth}
    \centering
    \includegraphics[width=\textwidth]{scalar_higgs.png}
    \caption{Scalar Higgs}
  \end{subfigure}
  \hfill
  \begin{subfigure}{0.49\textwidth}
    \centering
    \includegraphics[width=\textwidth]{scalar_higgs_COS.png}
    \caption{Scalar Higgs}
  \end{subfigure}
\end{figure}

The results for the pseudo-scalar Higgs boson are shown in Figure 6. The effects of the spin correlations on the transverse momentum of the charged lepton are similar as in the case of a scalar Higgs boson: about 10% at small $p_T$, increasing to about 40% at $p_T = 200$ GeV. On the other hand, the $\cos(\phi)$ does not show any significant effect from the spin-correlations. Therefore this observable could possibly help in determining the CP nature of the Higgs boson, underlining the importance of the inclusion of these spin correlations.
DEMO

Is it really automatic?
• 1) Download the code
DEMO

• launch the code 

  ➡ Exactly like MG5 !!!
• You can enter **ANY** process!
  ➡ add [QCD] for NLO functionalities
  ✦ generate p p > t t~ [QCD]
  ✦ generate p p > e+ e- mu+ mu- [QCD]
  ✦ generate e+ e- > t t~ [QCD]

```
mg5> generate e+ e- > t t~ [QCD]
Switching from interface MG5 to aMC@NLO
The default sm model does not allow to generate loop processes. MG5 now loads 'loop_sm' instead.
  import model loop_sm
INFO: load particles
INFO: load vertices
INFO: Restrict model loop_sm with file models/loop_sm/restrict_default.dat.
INFO: Run "set stdout_level DEBUG" before import for more information.
INFO: Change particles name to pass to MG5 convention
Kept definitions of multiparticles l- / j / vl / l+ / p / vl~ unchanged
Defined multiparticle all = g gh gh~ d u s c d~ u~ s~ c~ a ve vm vt e- mu- ve~ vm~ vt~ e+ mu+ b t b~ t~ z w+ h
INFO: Generating FKS-subtracted matrix elements for born process: e+ e- > t t~ [ QCD ]
INFO: Generating virtual matrix elements using MadLoop:
INFO: Generating virtual matrix element with MadLoop for process: e+ e- > t t~ [ QCD ]
INFO: Generated 1 subprocesses with 4 real emission diagrams, 2 born diagrams and 2 virtual diagrams
aMC@NLO>```
• Born

• real

• Virtual
• Create your aMC@NLO code
  ➡ output PATH
• Create your aMC@NLO code

  ➡ output PATH

INFO: Writing out the aMC@NLO code, using optimized Loops
INFO: initialize a new directory: PROD_TT2
INFO: remove old information in PROD_TT2
INFO: Generating real emission matrix-elements...
INFO: Generating Helas calls for FKS process: e+ e- > t t~ [ QCD ]
ALOHA: aloha creates FFV1 routines
ALOHA: aloha creates FFV1 routines
ALOHA: aloha creates FFV1 routines
ALOHA: aloha creates FFV2 routines
ALOHA: aloha creates FFV5 routines
INFO: Processing color information for process: e+ e- > t t~ [ QCD ]
INFO: Writing files in P0_epem_ttx
INFO: Creating files in directory V0_epem_ttx
INFO: Computing diagram color coefficients
INFO: Drawing loop Feynman diagrams for Process: e+ e- > t t~ [ QCD ]
INFO: Generating born Feynman diagrams for Process: e+ e- > t t~ [ QCD ]
History written to /Users/omatt/Documents/eclipse/2.0.0beta4/PROD_TT2/Cards/proc_card_mg5.dat
Export UFO model to MG4 format
ALOHA: aloha creates FFV2 routines
ALOHA: aloha creates FFV1 routines
ALOHA: aloha creates FFV4 routines
ALOHA: aloha creates FFV5 routines
ALOHA: aloha creates FFV2_5 routines
ALOHA: aloha creates FFV2_4 routines
INFO: Use Fortran compiler gfortran
INFO: Generate jpeg diagrams
INFO: Generate web pages
The option group_subprocesses is modified [Auto] but will not be written in the configuration files.
If you want to make this value the default for future session, you can run 'save options --all'
The option complex_mass_scheme is modified [False] but will not be written in the configuration files.
If you want to make this value the default for future session, you can run 'save options --all'
save configuration file to /Users/omatt/Documents/eclipse/2.0.0beta4/PROD_TT2/Cards/amcatnlo_configuration.dat
Type "launch" to generate events from this process, or see /Users/omatt/Documents/eclipse/2.0.0beta4/PROD_TT2/README
Run "open index.html" to see more information about this process.
• Create your aMC@NLO code
  ➡ output PATH
• Run it:
  ➡ launch [PATH]
• Create your aMC@NLO code
  ➡ output PATH

• Run it:
  ➡ launch [PATH]

First Question:

The following switches determine which operations are executed:
1 Perturbative order of the calculation:
   order=NLO
2 Fixed order (no event generation and no MC@[N]LO matching):
   fixed_order=OFF
   shower=ON
   madspin=OFF
3 Shower the generated events:
4 Decay particles with the MadSpin module:
   Either type the switch number (1 to 4) to change its default setting,
   or set any switch explicitly (e.g. type 'order=L0' at the prompt)
Type '0', 'auto', 'done' or just press enter when you are done.
0, 1, 2, 3, 4, auto, done, order=L0, order=NLO, ...
[60s to answer]
> [timer stopped]
- Create your aMC@NLO code
  - output PATH
- Run it:
  - launch [PATH]

Second Question:

INFO: will run in mode: aMC@NLO
Do you want to edit a card (press enter to bypass editing)?
1 / param  : param_card.dat
2 / run     : run_card.dat
3 / madspin : madspin_card.dat
4 / shower  : shower_card.dat
you can also
- enter the path to a valid card or banner.
- use the 'set' command to modify a parameter directly.
  The set option works only for param_card and run_card.
  Type 'help set' for more information on this command.
[0, done, 1, param, 2, run, 3, madspin, 4, enter path, ... ][60s to answer]

- each beam at 250 GeV
• The code runs:

INFO: For gauge cancellation, the width of 't' has been set to zero.
INFO: Compiling source...
INFO: ...done, continuing with P* directories
INFO: Compiling directories...
INFO: Compiling on 8 cores
INFO: Compiling P0_epem_ttx...
INFO: P0_epem_ttx done.

INFO: Checking test output:
INFO: P0_epem_ttx
INFO: Result for test_ME:
INFO: Passed.
INFO: Result for test_MC:
INFO: Passed.
INFO: Result for check_poles:
INFO: Poles successfully cancel for 20 points over 20 (tolerance=1.0e-05)

INFO: Starting run
INFO: Using 8 cores
INFO: Cleaning previous results
INFO: Doing NLO matched to parton shower
INFO: Setting up grid
INFO: Idle: 0, Running: 2, Completed: 2 [ current time: 17h19 ]
INFO: Idle: 0, Running: 1, Completed: 3 [ 1.2s ]
INFO: Idle: 0, Running: 0, Completed: 4 [ 1.3s ]
INFO: Determining the number of unweighted events per channel

Intermediate results:
Random seed: 36
Total cross-section: 6.232e-01 +/- 4.2e-03 pb
Total abs(cross-section): 7.010e-01 +/- 2.5e-03 pb
INFO: Computing upper envelope
INFO: Idle: 0, Running: 2, Completed: 2 [ current time: 17h19 ]
INFO: Idle: 0, Running: 1, Completed: 3 [ 1.3s ]
INFO: Idle: 0, Running: 0, Completed: 4 [ 1.3s ]
INFO: Updating the number of unweighted events per channel

Intermediate results:
Random seed: 36
Total cross-section: 6.183e-01 +- 3.7e-03 pb
Total abs(cross-section): 6.986e-01 +- 1.9e-03 pb

INFO: Generating events
INFO: Idle: 0, Running: 2, Completed: 2 [ current time: 17h19 ]
INFO: Idle: 0, Running: 1, Completed: 3 [ 0.6s ]
INFO: Idle: 0, Running: 0, Completed: 4 [ 1.3s ]
INFO: Doing reweight
INFO: Idle: 0, Running: 1, Completed: 3 [ current time: 17h19 ]
INFO: Idle: 0, Running: 0, Completed: 4 [ 0.74s ]
INFO: Collecting events
INFO: Summary:
Process e+ e-> t t~ [QCD]
Run at l-l collider (250 + 250 GeV)
Total cross-section: 6.183e-01 +- 3.7e-03 pb
Ren. and fac. scale uncertainty: +1.0% -0.8%
Number of events generated: 10000
Parton shower to be used: HERWIG6
decay_events -from_cards
INFO: Running MadSpin
INFO: This functionality allows for the decay of resonances
INFO: in a .lhe file, keeping track of the spin correlation effects.
INFO: BE AWARE OF THE CURRENT LIMITATIONS:
INFO: (1) Only a succession of 2 body decay are currently allowed
*******************************************************************************
  *  WELCOME to MADSPIN  *
  *                        *
*******************************************************************************

Integration
Events Generation
Top Decay
INFO: Estimating the maximum weight
INFO: ******************************
INFO: Probing the first 75 events
INFO: with 400 phase space points
INFO: 
INFO: Event 1/75: 0.18s
INFO: Event 6/75: 1s
INFO: Event 11/75: 1.9s
INFO: Event 16/75: 2.8s
INFO: Event 21/75: 3.8s
INFO: Event 26/75: 4.9s
INFO: Event 31/75: 5.8s
INFO: Event 36/75: 6.7s
INFO: Event 41/75: 8s
INFO: Event 46/75: 8.9s
INFO: Event 51/75: 9.7s
INFO: Event 56/75: 10.8s
INFO: Event 61/75: 11.7s
INFO: Event 66/75: 12.6s
INFO: Event 71/75: 13.6s

INFO: Decaying the events...
INFO: Event nb 1000 2.1s
INFO: Event nb 2000 3.8s
INFO: Event nb 3000 5.6s
INFO: Event nb 4000 7.3s
INFO: Event nb 5000 9.1s
INFO: Event nb 6000 10.8s
INFO: Event nb 7000 12.5s
INFO: Event nb 8000 14.4s
INFO: Event nb 9000 16.1s
INFO: Event nb 10000 17.9s
INFO: Total number of events written: 10000/10000
INFO: Average number of trial points per production event: 10.9322
INFO: Branching ratio to allowed decays: 1
INFO: Number of events with weights larger than max_weight: 0
INFO: Number of subprocesses 8
INFO: Number of failures when restoring the Monte Carlo masses: 1
INFO: Decayed events have been written in /Users/omatt/Documents/eclipse/2.0.
INFO: The decayed event file has been moved to the following location:
INFO: /Users/omatt/Documents/eclipse/2.0.0beta4/PROCNLO_loop_sm_16/Events/rur
INFO: MadSpin Done

INFO: Preparing MCatNLO run
INFO: Compiling MCatNLO for HERWIG6...
INFO: ... done
INFO: Running MCatNLO in /Users/omatt/Documents/eclipse/2.0.0beta4/PROCNLO_lc
INFO: The file /Users/omatt/Documents/eclipse/2.0.0beta4/PROCNLO_loop_sm_16/E
It contains showered and hadronized events in the StdHEP format obtained show
cayed_1/events.lhe.gz with HERWIG6
quit
DEMO

Is it really automatic?
DEMO

Is it really automatic?

As much as LO!
Top-quark pair production at ILC

Preliminary
Offshell effect at NLO

- Diagrams with unstable particles present in general an imaginary part in the Dyson-ressumed propagator:
  \[ P(p) = [p^2 - m_0^2 + Pi(p^2)]^{-1} \]

- Mixing of different perturbative orders breaks gauge invariance. Fine cancellations spoiled, leading to enhanced violation of unitarity

- **No pole cancelation** at NLO for fix-width scheme

- **Solution:** Complex Mass-Scheme: \( M \rightarrow \sqrt{M^2 - iM\Gamma} \),

  \[ c_W^2 = \frac{M_w^2 + iM_W\Gamma_W}{M_Z^2 + iM_Z\Gamma_Z} \]
Gauge dependence at LO

| $|A|^2 - |$Feynman-unitary$|/unitary | complex mass | fixed width |
|----------------|----------------|-------------|
| $e^+e^- \rightarrow uu\bar{u}d$ | 1.5334067678e-15 | 1.2312200197e-09 |
| $uu \rightarrow uu\bar{u}d$ | 2.0862057616e-16 | 2.7696013365e-10 |
| $uu \rightarrow b\bar{b}e^+\nu_e\mu^-\nu_\mu$ (real Yuk) | 1.7934842084e-06 | 2.2832833007e-05 |
| " (complex Yuk) | 8.5986902303e-16 | 2.2832833007e-05 |

| $\sigma (pb)$ for $gg \rightarrow b\bar{b}e^+\nu_e\mu^-\bar{\nu}_\mu$ |
|----------------|---------------------------------|
| gauge - scheme | complex-mass | fix width | no width |
| feynman | 1.796e-05 ± 2.3e-08 | 1.787e-05 ± 2.5e-08 |
| unitary | 1.792e-05 ± 2.1e-08 | 1.778e-05 ± 2.4e-08 | 1.810e-05 ± 2.4e-08 |
Offshell effect at NLO

\[ e^+ e^- \rightarrow w^+ w^- b \bar{b} ~ \]

\[ e^+ e^- \rightarrow t \bar{t} ~ \]

\[ M_{t} \quad \text{NLO} \]

N. of b+ve combinations, \( L = 10 fb^{-1} \)

\[ M \left[ b \ e^+ \text{ve} \right] \text{ (GeV/c}^2\)
• aMC@NLO is public flexible
• MadSpin decay with full spin correlations keep finite width effect
• complex-mass
• This is only the beginning of this Tool!

## Conclusion

<table>
<thead>
<tr>
<th>Process</th>
<th>$\mu$</th>
<th>$n_{lf}$</th>
<th>Cross section (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>LO</td>
</tr>
<tr>
<td>a.1 $pp \to t\bar{t}$</td>
<td>$m_{top}$</td>
<td>5</td>
<td>123.76 ± 0.05</td>
</tr>
<tr>
<td>a.2 $pp \to tj$</td>
<td>$m_{top}$</td>
<td>5</td>
<td>34.78 ± 0.03</td>
</tr>
<tr>
<td>a.3 $pp \to tjj$</td>
<td>$m_{top}$</td>
<td>5</td>
<td>11.851 ± 0.006</td>
</tr>
<tr>
<td>a.4 $pp \to t\bar{b}j$</td>
<td>$m_{top}/4$</td>
<td>4</td>
<td>25.62 ± 0.01</td>
</tr>
<tr>
<td>a.5 $pp \to t\bar{b}jj$</td>
<td>$m_{top}/4$</td>
<td>4</td>
<td>8.195 ± 0.002</td>
</tr>
<tr>
<td>b.1 $pp \to (W^+ \to e^+\nu_e)$</td>
<td>$m_W$</td>
<td>5</td>
<td>5072.5 ± 2.9</td>
</tr>
<tr>
<td>b.2 $pp \to (W^+ \to e^+\nu_e\bar{j})$</td>
<td>$m_W$</td>
<td>5</td>
<td>828.4 ± 0.8</td>
</tr>
<tr>
<td>b.3 $pp \to (W^+ \to e^+\nu_ejj)$</td>
<td>$m_W$</td>
<td>5</td>
<td>298.8 ± 0.4</td>
</tr>
<tr>
<td>b.4 $pp \to (\gamma^*/Z \to e^+e^-)$</td>
<td>$m_Z$</td>
<td>5</td>
<td>1007.0 ± 0.1</td>
</tr>
<tr>
<td>b.5 $pp \to (\gamma^*/Z \to e^+e^-\bar{j})$</td>
<td>$m_Z$</td>
<td>5</td>
<td>156.11 ± 0.03</td>
</tr>
<tr>
<td>b.6 $pp \to (\gamma^*/Z \to e^+e^-jj)$</td>
<td>$m_Z$</td>
<td>5</td>
<td>54.24 ± 0.02</td>
</tr>
<tr>
<td>c.1 $pp \to (W^+ \to e^+\nu_e\bar{b}\bar{b})$</td>
<td>$m_W + 2m_b$</td>
<td>4</td>
<td>11.557 ± 0.005</td>
</tr>
<tr>
<td>c.2 $pp \to (W^+ \to e^+\nu_e\bar{t}\bar{t})$</td>
<td>$m_W + 2m_{top}$</td>
<td>5</td>
<td>0.009415 ± 0.000003</td>
</tr>
<tr>
<td>c.3 $pp \to (\gamma^*/Z \to e^+e^-\bar{b}\bar{b})$</td>
<td>$m_Z + 2m_b$</td>
<td>4</td>
<td>9.459 ± 0.004</td>
</tr>
<tr>
<td>c.4 $pp \to (\gamma^*/Z \to e^+e^-\bar{t}\bar{t})$</td>
<td>$m_Z + 2m_{top}$</td>
<td>5</td>
<td>0.0035131 ± 0.00000004</td>
</tr>
<tr>
<td>c.5 $pp \to \gamma\bar{t}\bar{t}$</td>
<td>$2m_{top}$</td>
<td>5</td>
<td>0.2906 ± 0.0001</td>
</tr>
<tr>
<td>d.1 $pp \to W^+W^-$</td>
<td>$2m_W$</td>
<td>4</td>
<td>29.976 ± 0.004</td>
</tr>
<tr>
<td>d.2 $pp \to W^+W^-\bar{j}$</td>
<td>$2m_W$</td>
<td>4</td>
<td>11.613 ± 0.002</td>
</tr>
<tr>
<td>d.3 $pp \to W^+W^+jj$</td>
<td>$2m_W$</td>
<td>4</td>
<td>0.07048 ± 0.000004</td>
</tr>
<tr>
<td>e.1 $pp \to HW^+$</td>
<td>$m_W + m_H$</td>
<td>5</td>
<td>0.3428 ± 0.0003</td>
</tr>
<tr>
<td>e.2 $pp \to HW^+\bar{j}$</td>
<td>$m_W + m_H$</td>
<td>5</td>
<td>0.1223 ± 0.0001</td>
</tr>
<tr>
<td>e.3 $pp \to H\bar{Z}$</td>
<td>$m_Z + m_H$</td>
<td>5</td>
<td>0.2781 ± 0.0001</td>
</tr>
<tr>
<td>e.4 $pp \to H\bar{Z}\bar{j}$</td>
<td>$m_Z + m_H$</td>
<td>5</td>
<td>0.0988 ± 0.0001</td>
</tr>
<tr>
<td>e.5 $pp \to H\bar{t}\bar{t}$</td>
<td>$m_{top} + m_H$</td>
<td>5</td>
<td>0.08896 ± 0.000001</td>
</tr>
<tr>
<td>e.6 $pp \to H\bar{b}\bar{b}$</td>
<td>$m_b + m_H$</td>
<td>4</td>
<td>0.16510 ± 0.000009</td>
</tr>
<tr>
<td>e.7 $pp \to Hjj$</td>
<td>$m_H$</td>
<td>5</td>
<td>1.104 ± 0.002</td>
</tr>
</tbody>
</table>
Work in Progress in aMC@NLO

What to expect in the future
Perspectives
Perspectives

• FeynRules@NLO:
Perspectives

- FeynRules@NLO:
  - NLO not only for the SM but for New Physics
Perspectives

• **FeynRules@NLO:**
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• **ElectroWeak corrections (matched to the shower)**
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0 → 1 rates in $H^0$ and $t\bar{t}$ production
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• Interface to Pythia8
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• Automation of loop-induced processes

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• Complex mass scheme
MC@NLO properties

- Good features of including the subtraction counter terms
  1. **Double counting avoided**: The rate expanded at NLO coincides with the total NLO cross section
  2. **Smooth matching**: MC@NLO coincides (in shape) with the parton shower in the soft/collinear region, while it agrees with the NLO in the hard region
  3. **Stability**: weights associated to different multiplicities are separately finite. The MC term has the same infrared behavior as the real emission (there is a subtlety for the soft divergence)

- Not so nice feature (for the developer):
  1. **Parton shower dependence**: the form of the MC terms depends on what the parton shower does exactly. Need special subtraction terms for each parton shower to which we want to match