Higgs plus Jets with Herwig 7

Peter Schichtel
@ Pheno 2016
Why jets?

traditionally: access production mode via CJV

correlations substantially more information

QCD jet scaling as tool

pT spectra probe loop structure in GF
Outline

- NLO matching
  - HJets and Herwig 7 in EW production
- NLO merging
  - Herwig 7.1 in gluon fusion

Release/Usability
- Herwig 7
- Physics capabilities

Leading order parton shower uncertainties
- Herwig 7

https://herwig.hepforge.org/
New Release

Documentation, Installation and User Support

Documentation re-written from scratch: "Living" sphinx site
Replacing old wiki pages.

Bootstrap script pulling in all dependencies, heavily tested:

```
$ ./herwig-bootstrap /opt/Merwig7

Herwig 7 bootstrap was successful.
$ source /opt/Merwig7/bin/activate
activates all required environment variables.
$ deactivate
returns to the original environment variables.
```

Revised issue tracking for more efficient user response.

easy install
easy use
tutorials online
New Release

Documentation, Installation and User Support

Documentation re-written from scratch: "Living" sphinx site
Replacing old wiki pages.

Bootstrap script pulling in all dependencies, heavily tested:

```
./Herwig-bootstrap /opt/Herwig7

Herwig 7 bootstrap was successful.
```

Revised issue tracking for more efficient user response.

easy install
easy use
tutorials online

Herwig 7 – Usage Example

Old-style input files still work but will become deprecated.
New NLO input files much easier to handle.

Essentials of a new-style input file:

```
read Matchbox/PPCollider.in
set Factory:OrderInAlphaS 1
set Factory:OrderInAlphaEW 2
do Factory:Process p p -> e+ e- j
read Matchbox/MadGraph-OpenLoops.in
read Matchbox/MCatNLO-DefaultShower.in
```

Choose collider setup.
Choose process.
Choose amplitude providers.
Choose shower and matching.

https://herwig.hepforge.org/
Physics capabilities/modules

\[ pp \text{ Event Generator} \]

https://herwig.hepforge.org/
Physics capabilities/modules

pp Event Generator

- automatic NLO matched to PS
- Interfaces to many ME/Loop provider
- two distinct matching schemes
- two distinct parton showers
- spin correlations in shower
- PDF interface via LHAPDF
- cluster hadronisation model
- dedicated MPI model
- (LO)UFO interface for BSM
- Interface to Rivet

https://herwig.hepforge.org/
Shower Uncertainties

LO as benchmark (develop full chain) algorithms (evolution variable, profile)

scale of hard process vs. full phase space

how to approach phase space boundary

- parametric
- algorithmic
- perturbative
- fitting
- numerical/statistical

-- inclusive: reproduce ME
-- logarithmic sensitive: all scales
-- hard PS emission: huge band

NLO effects, used in certain processes


with Johannes Bellm, Graeme Nail, Simon Plätzer, and Andrzej Siodmok
With Johannes Bellm, Graeme Nail, Simon Plätzer, and Andrzej Siodmok

Shower Uncertainties

LO as benchmark (develop full chain)

algorithms (evolution variable, profile)

sources of uncertainty

scale of hard process vs. full phase space

how to approach phase space boundary

-- parametric
-- algorithmic
-- perturbative
-- fitting
-- numerical/statistical

-- inclusive: reproduce ME
-- logarithmic sensitive: all scales
-- hard PS emission: huge band

\[ x(Q^2, q^2) \]

\[ q^2 / \text{GeV}^2 \]

1 2 3 4

0 0.2 0.4 0.6 0.8 1

power shower
theta cutoff
hfact profile
resummation profile
Shower Uncertainties

LO as benchmark (develop full chain)
algorithms (evolution variable, profile)
sources of uncertainty
consistency checks

scale of hard process vs. full phase space

how to approach phase space boundary

-- parametric
-- algorithmic
-- perturbative
-- fitting
-- numerical/statistical

-- inclusive: reproduce ME
-- logarithmic sensitive: all scales
-- hard PS emission: huge band

\[ q_\perp / \text{GeV} \]

\[ \kappa ( Q_\perp^2, q_\perp^2 ) \]

\[ x(Q_\perp^2, q_\perp^2) \]

\[ \text{power shower} \]
\[ \text{theta cutoff} \]
\[ \text{hfact profile} \]
\[ \text{resummation profile} \]
Shower Uncertainties

Separation between H boson and leading jet

Transverse momentum of leading jet (Higgs)

\[ \frac{d\sigma}{dp_{\perp}} \left( \Delta R(H, \text{1st jet}) \right) [\text{pb}] \]

\[ \frac{d\sigma}{dp_{\perp}} \left( \text{jet}_1 \right) [\text{GeV}] \]
Shower Uncertainties

Separation between H boson and leading jet

Transverse momentum of leading jet (Higgs)

reasonable error bands?
ME prediction?
which scales drive uncertainty?
Shower Uncertainties

Separation between H boson and leading jet

Transverse momentum of leading jet (Higgs)

Reasonable error bands?

ME prediction?

which scales drive uncertainty?
Shower Uncertainties

**Separation between H boson and leading jet**

- Herwig 7
- \( pp \rightarrow Hj \)

**Transverse momentum of leading jet (Higgs)**

- \( p_{\perp} (\text{jet 1}) \) [GeV]

Reasonable error bands? ME prediction? which scales drive uncertainty?
Gluon Fusion & merging

Up to 3(2) jets @ (N)LO comparison study
doing well (not trivial)
uncertainty measure
merging: technical challenge (7.1)
background to EW production
loop induced BSM?

theoretical precision limits
LHC analyses!

LHJ: pp \rightarrow h + jets comparison

Scalar sum of jet transverse momenta

<table>
<thead>
<tr>
<th>H_{jet} T [GeV]</th>
<th>BFGLP hj NNLO</th>
<th>GoSam + SHERPA</th>
<th>hij NNLO</th>
<th>hij NNLO</th>
<th>jNNLO</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>0.8</td>
<td>1.2</td>
<td>1.4</td>
<td>1.6</td>
<td>1.8</td>
</tr>
<tr>
<td>0.8</td>
<td>1.2</td>
<td>1.4</td>
<td>1.6</td>
<td>1.8</td>
<td>2.0</td>
</tr>
</tbody>
</table>

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

Peter Schichtel

p. 7/9
Gluon Fusion & merging

Up to 3(2) jets @ (N)LO comparison study doing well (not trivial) uncertainty measure merging: technical challenge \((7.1)\) background to EW production loop induced BSM?

theoretical precision limits LHC analyses!

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plätzer

LesHouches to appear soon with Johannes Bellm and Simon Plátzer
Gluon Fusion & merging

Up to 3(2) jets @ (N)LO comparison study doing well (not trivial) uncertainty measure merging: technical challenge (7.1) background to EW production loop induced BSM?

theoretical precision limits LHC analyses!
Gluon Fusion & merging

Up to 3(2) jets @ (N)LO comparison study doing well (not trivial) uncertainty measure merging: technical challenge \((7.1)\) background to EW production loop induced BSM ?

theoretical precision limits LHC analyses!
EW production @ NLO with HJets

precission Higgs physics
  handcrafted fast MEs
  study shower effects/uncertainties
  test the VBF approximation
  precise jet vetoe studies

ME provider for H7
EW production @ NLO with HJets

- EW production @ NLO with HJets
- precission Higgs physics
- handcrafted fast MEs
- study shower effects/uncertainties
- test the VBF approximation
- precise jet veto studies

Glimpse at current work with Johannes Bellm, Terrance Figy, and Simon Plätzer

**Parton shower vs. fixed order**

- lo-fo-central
- lo-ps-central
- nlo-fo-central
- nlo-ps-central

**pT of the Higgs + tagging jets (2 ME jets)**
EW production @ NLO with HJets

precission Higgs physics
handcrafted fast MEs
study shower effects/uncertainties
test the VBF approximation
precise jet vetoe studies

parton shower vs. fixed order

switching on the VBF cuts

pT of the Higgs + tagging jets (2 ME jets)

third jet pT (3 ME jets)

rapidity diff between third jet and tagging jets (3 ME jets)
**Summary**

**Herwig 7**  
automated NLO matching: Higgs precision physics  
good data description  
many more contributions
Summary

Peter Schichtel

just a glimpse of what is possible
Herwig 7 – Sample Results

[amplitudes built-in or from MGSaMC and OpenLoops]

From LEP ...

YR4 and Les Houches Contributions

EW H+3jets NLO+PS
Belim, Figy, Plätzer, Schichtel

Z+b jets NLO+PS
Nail, Plätzer, Reuschle, Richardson

ttH NLO+PS
Gieseke, Plätzer, Podskubka, Reuschle

q/g tagging
Siodmok, Plätzer, Richardson

shower uncertainties
Nail, Plätzer, Siodmok

just a glimpse of what is possible
Summary

Higgs precision physics
reliable perturbative uncertainties
NLO matched Higgs plus jets
Herwig 7.1 in the pipe
NLO multi-jet merging
Spin correlations at NLO
Top decays in the Dipole shower
UFO model for Matchbox (NLO)
Heavy quark fragmentation

Thanks for listening :)