# Developing a BLHA interface for VBFNLO

MCNet Meeting Karlsruhe 2017

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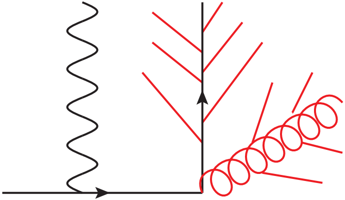
# Motivation

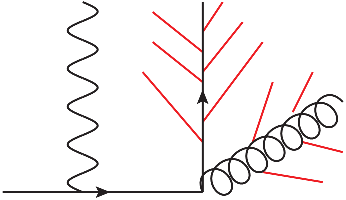
- Fixed order calculations provide a good description of hard jets
  - NLO calculations using subtraction or slicing methods
  - Only applicable for inclusive variables
  - Complexity of computation increases rapidly for many particle final states and higher order corrections
- Parton shower are good at describing most features of common events
  - Evolution down to hadronization scale $\rightarrow$ important for event reconstruction
  - Relies on soft & collinear approximation
    $\rightarrow$ poor description of hard jets and large angle distributions
  - Normalization usually at LO accuracy
- The aim is to combine both methods using the benefits of both

# Matching PS to NLO fixed order calculations

Problem: Naive showering of final states from fixed order calculations would result in double counting:



vs.



Solutions: different matching schemes:

- MC@NLO: Subtractive Method
- POWHEG: Multiplicative Method
- many others (KrkNLO, . . . )

However, all schemes need basically the same building blocks

# BHLA Interface

NLO cross section:

$$d\sigma^{NLO} = d\Phi_n\mathcal{B} + \alpha_S d\Phi_{n+1}[\mathcal{R} - \mathcal{S}] + \alpha_S d\Phi_n \left[\mathcal{V} + \alpha_S \int d\Phi_1 \mathcal{S}\right]$$

- Problem: Calculation of some parts can become very complex and time-consuming
- Goal: Incorporate results from specialized fixed-order parton-level programs
- Benefit: Event generator can use for each process a suitable matrix element provider (MEP)

$\Rightarrow$ Standard interface between MC and MEP developed during Les Houches 2009:

Binoth Les Houches Accord (BLHA)

$\rightarrow$since 2013: **BLHA2**

[Binoth et al., Alioli et al.]

# BLHA - Pre-Runtime Phase

Agreement on setup and subprocesses to calculate
$\Rightarrow$ Generating an Order and a Contract-File

```
# OLP order file created by
Herwig/Matchbox

InterfaceVersion BLHA2

Model SM
CorrectionType QCD
IRregularisation CDR
Extra HelAvgInitial no
Extra ColAvgInitial no
Extra MCSymmetrizeFinal no

AlphasPower 2
AlphaPower 4
AmplitudeType tree
-1 -1 → -13 -11 -2 -2 12 14
-1 2 → -13 -11 -2 1 12 14
-1 2 → -13 -11 -4 3 12 14
```

Order-File

(created by Herwig)

```
# OLP order file created by
Herwig/Matchbox

InterfaceVersion BLHA2 | OK

Model SM | OK
CorrectionType QCD | OK
IRregularisation CDR | OK
Extra HelAvgInitial no | OK
Extra ColAvgInitial no | OK
Extra MCSymmetrizeFinal no | OK

AlphasPower 2 | OK
AlphaPower 4 | OK
AmplitudeType tree | OK
-1 -1 → -13 -11 -2 -2 12 14 | 1 1
-1 2 → -13 -11 -2 1 12 14 | 1 2
-1 2 → -13 -11 -4 3 12 14 | 1 3
```

Contract-File

(signed by VBFNLO)

# BLHA - Runtime Phase

- Run Initialisation Phase
  $\rightarrow$ Setup of MEP, passing of static parameters
  (e.g. $m_W$, $\sin^2(\theta_W)$, ...)
- Actual Runtime Phase
  - Setting of phasespace-dependent parameters (e.g. $\alpha_S(\mu_R)$, ...)
  - Requesting matrix element from MEP via function call
    $\rightarrow$ MC passes subprocess label and momenta
    $\rightarrow$ MEP returns computed results
  - Different Amplitude - Types:

| Type | Return values | |
|---|---|---|
| tree | $\lvert\mathcal{M}\rvert^2 = \langle\mathcal{M}\lvert\mathcal{M}\rangle$ | tree amplitude |
| loop | $A_2, A_1, A_0, \lvert\mathcal{M}_{Born}\rvert^2$ from $2\Re(\mathcal{M}_B^*\mathcal{M}_V)$ $\propto \left(\frac{A_2}{\epsilon^2} + \frac{A_1}{\epsilon} + A_0\right)$ | one-loop amplitude |
| cctree | $C_{ij} = \langle\mathcal{M}\lvert\mathbf{T}_i \cdot \mathbf{T}_j\rvert\mathcal{M}\rangle$ | colour-correlated tree amplitude |
| sctree | $S_{ij} = \langle\mathcal{M}_{i,-}\lvert\mathbf{T}_i \cdot \mathbf{T}_j\rvert\mathcal{M}_{i,+}\rangle$ | spin-correlated tree amplitude |

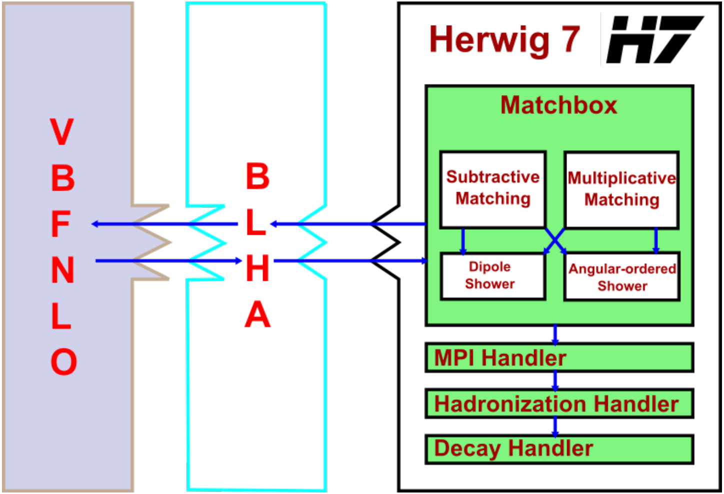
# VBFNLO Introduction

- Vector-Boson-Fusion at Next-to-Leading Order
  [arXiv:1404.3940, arXiv:1107.4038, arXiv:0811.4559]
- Parton-level Monte Carlo program for vector-boson physics processes
  - includes both signal and background processes
  - includes decays of electroweak bosons
  - is able to deal with a high number of final-state particles
- Huge flexibility (cuts on final-state particles, various choices for renormalization and factorization scales, different sets of PDF's)
- BSM options (anomalous couplings, Higgsless and spin-2 models, Two-Higgs models)
- BLHA interface for selected processes

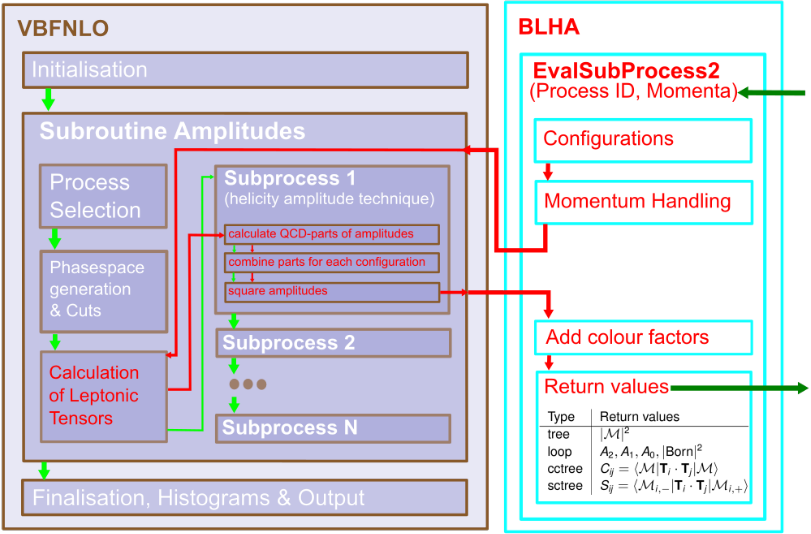
# VBFNLO Process list

- Vector Boson Fusion processes
  $\rightarrow$ *Hjj*, *Hjjj*, *H*, *Vjj*, *HHjj*, $S_2jj$, *VVjj*
- Diboson and Triple vector boson production
  $\rightarrow$ *VV*, *VVV*, *VVj*, *VVVj*
- W / WH production
  $\rightarrow$ *WH*, *W*, *WHj*, *Wj*
- QCD induced vector boson production
  $\rightarrow$ *Vjj*, *VVjj*
- Higgs boson production via Gluon Fusion
  $\rightarrow$ *Hjj*
- Gluon induced diboson production
  $\rightarrow$ *VV*, *VVj*

# BLHA interfacing Herwig7 & VBFNLO



# VBFNLO-BLHA Interface - Concept

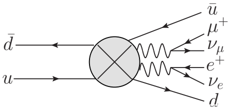


# VBFNLO-BLHA Implementation

- Momentum mapping from BLHA string to VBFNLO process (including selection of the relevant subprocess)

$$\begin{array}{cccccccccc} \texttt{-1} & \texttt{2} & \rightarrow & \texttt{-13} & \texttt{-11} & \texttt{-2} & \texttt{1} & \texttt{12} & \texttt{14} \\ (\bar{d} & u & \rightarrow & \mu^+ & e^+ & \bar{u} & d & \nu_e & \nu_\mu) \end{array}$$

$$\Downarrow$$




- Interface C++ $\leftrightarrow$ Fortran
  (Set of functions as defined in BLHA)
- Adjustment of the Common-Block of VBFNLO
  $\rightarrow$ Storage of parameters and results
  $\rightarrow$ Conventions from BLHA and/or Order File

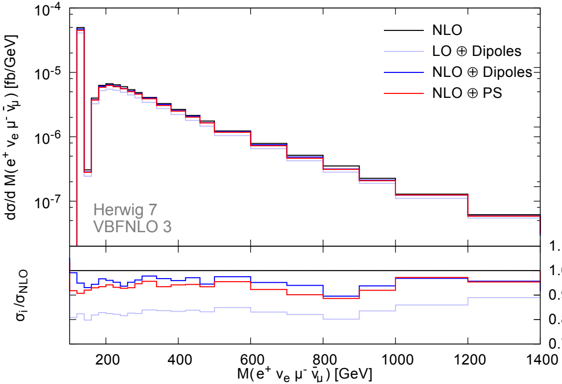
# VBFNLO-BLHA Interface Features

- Available processes:
  - VBF/VBS processes
  - VBF-H with three jets
  - QCD induced $W^{\pm}jj$, $W^{\pm}Zjj$, $W^{\pm}\gamma jj$
- Provides VBFNLO phasespace generator
- Anomalous couplings

**Application:**

Four lepton invariant mass for $pp \to (Hjj) \to e^{+}\nu_e\mu^{-}\bar{\nu}_\mu jj$

[S.Plätzer, M.Rauch]



# Conclusion

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- Several Methods for Matching at NLO
- Complex and time-consuming calculation of different parts
- BLHA interface to use results of FO programs in Event Generators
- VBFNLO - flexible parton-level MC-program for vector-boson physics processes
- VBF/VBS processes available via BLHA interface in VBFNLO 3.0 (stay tuned for more in future releases)