Karlsruhe Institute of Technology

Automated NLO Matching

Ken Arnold

Institute for Theoretical Physics

What is NLO matching?

Matchbox

Results for Hjj via VBF

Summary

What is NLO matching?

- NLO approximation: Holds for hard emissions away from soft/collinear regions
- Parton shower approximation: Correct in soft/collinear limits

How to combine the two?

Observable O at NLO:

$$\langle O\rangle_{NLO} = O(0)\,[B+\alpha V] + \int_0^1 \mathrm{d}x\, O(x)\alpha\frac{R(x)}{x}$$

with

B : Born cross-section

V : Virtual cross-section

$\frac{R(x)}{x}$: Real differential cross-section

x : Phase space variable of additional emission; $x = 0$ for no emission

α : Coupling constant

Divergencies in V cancel against those stemming from the integration of $\frac{R(x)}{x}$.

$\rightarrow$ Do subraction to render both parts seperately finite.

Subtraction formalism:

$$\langle O\rangle_{NLO} = O(0)\left[B + \alpha V + \int_0^1 \frac{A(x)}{x}\right] + \int_0^1 \mathrm{d}x\,\alpha\left[O(x)\frac{R(x)}{x} - O(0)\frac{A(x)}{x}\right]$$

Rewrite this as

$$\langle O\rangle_{NLO} = O(0)\left[B + \alpha\tilde{V}\right] + \int_0^1 \mathrm{d}x\,\alpha\left(\frac{O(x)R(x) - O(0)A(x)}{x}\right)$$

where $\tilde{V}$ and $\int_0^1 \mathrm{d}x\,(...)$ are separately finite.

Parton shower approximation with Sudakov form factor

$$\Delta(x_0, x_1) = \exp\left\{-\int_{x_0}^{x_1} \mathrm{d}x\, \alpha \frac{P(x)}{x}\right\} \approx 1 - \int_{x_0}^{x_1} \mathrm{d}x\, \alpha \frac{P(x)}{x}$$

acting on LO calculation generates terms of order α.

$$\begin{aligned}\langle O \rangle_{PS} &= O(0) B \Delta(\mu, 1) + \int_{\mu}^{1} \mathrm{d}x\, \alpha O(x) B \frac{P(x)}{x} \Delta(\mu, x) \\ &\approx O(0) B \left[1 - \int_{\mu}^{1} \mathrm{d}x\, \alpha \frac{P(x)}{x}\right] + \int_{\mu}^{1} \mathrm{d}x\, \alpha O(x) B \frac{P(x)}{x}\end{aligned}$$

$\rightarrow$ Double counting when acting on NLO calculation.

Subtract terms before showering:

$$\langle O\rangle'_{NLO} = O(0)\left[B+\alpha\tilde{V}\right] + \int_0^1 \mathrm{d}x\,\alpha\left(\frac{O(x)R(x)-O(0)A(x)}{x}\right)$$

$$+\,O(0)B\int_\mu^1 \mathrm{d}x\,\alpha\frac{P(x)}{x} - \int_\mu^1 \mathrm{d}x\,\alpha O(x)B\frac{P(x)}{x}$$

Matched observable:

$$\langle O\rangle_{MC@NLO} = O(0)\left[B+\alpha\tilde{V}+\int_0^1 \mathrm{d}x\,\alpha\frac{BP(x)-A(x)}{x}\right]$$

$$+\int_0^1 \mathrm{d}x\,\alpha O(x)\frac{R(x)-BP(x)}{x}$$

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$$\langle O\rangle_{MC@NLO} = O(0)\left[B + \alpha\tilde{V} + \int_0^1 \mathrm{d}x\,\alpha\,\frac{BP(x) - A(x)}{x}\right] + \int_0^1 \mathrm{d}x\,\alpha\,O(x)\,\frac{R(x) - BP(x)}{x}$$

- Events with Born-type and with real emission configuration are seperately finite
- Expanding the formula above with parton shower recovers correct NLO cross section
- We have dropped terms of the form

$$\int_0^{\mu} \mathrm{d}x\,\alpha\,[O(0) - O(x)]\,B\,\frac{P(x)}{x}$$

$$\langle O\rangle_{MC@NLO} = O(0)\left[B+\alpha\tilde{V}+\int_0^1 \mathrm{d}x\,\alpha\frac{BP(x)-A(x)}{x}\right] + \int_0^1 \mathrm{d}x\,\alpha O(x)\frac{R(x)-BP(x)}{x}$$

Possible simplifications:

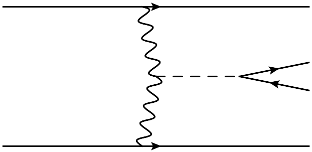
- $R(x) - BP(x) = 0$: Use exact real emission ME for first PS splitting (POWHEG)
- $BP(x) - A(x) = 0$: PS uses the same splitting functions as subtraction scheme (e.g. dipole shower)

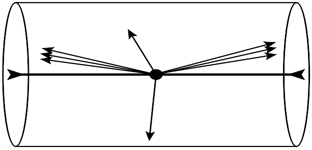
Matchbox [KA, J. Bellm, S. Gieseke, J. Kotanski, S. Plätzer, M. Stoll]:
NLO framework within ThePEG and Herwig++

- Automated CS dipole subtraction
- Automated NLO matchings both MC@NLO (with dipole shower) and POWHEG (with dipole and default shower) type
- Efficient automated phasespace generation
- Adaptive sampler for Sudakov type distributions
- External matrix elements can be interfaced in two ways: Either via squared matrix elements or via colour ordered amplitudes
- User sees only the Herwig input file he is used from LO + parton shower calculations!

Matchbox was released as part of Herwig++ 2.6!

Results for Hjj production via vector boson fusion @ LHC



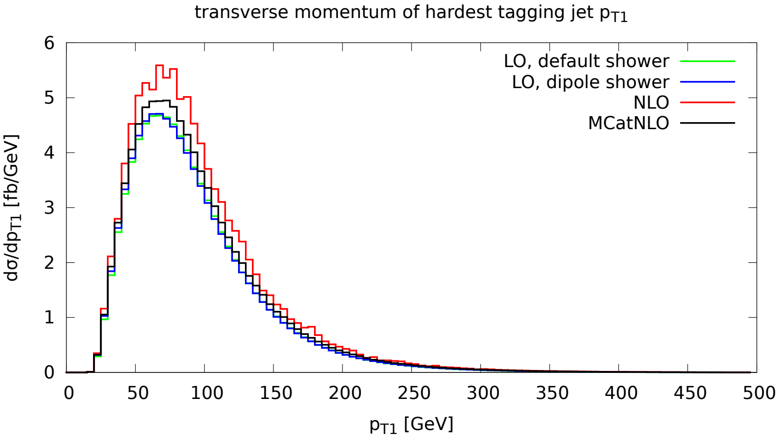


Analysis cuts:

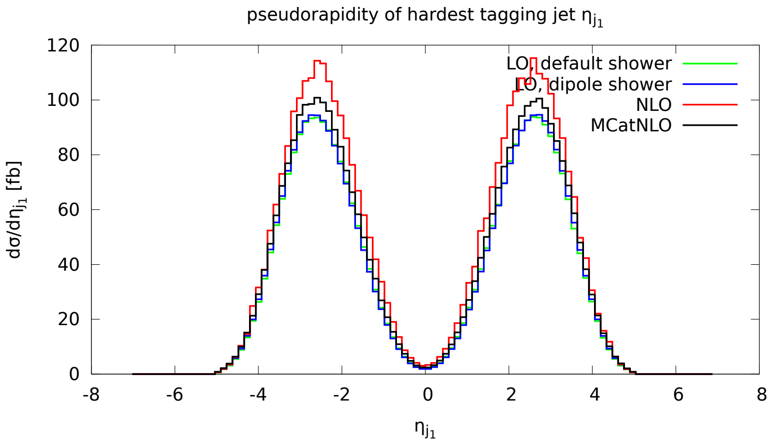
$$p_{Tj} > 20\,\mathrm{GeV} \qquad m_{jj}^{\text{tag}} > 600\text{GeV}$$

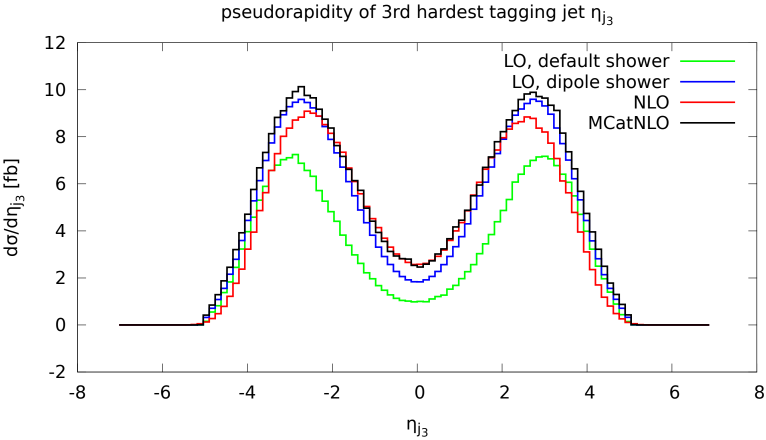
$$\eta_j < 5 \qquad |\eta_{j1} - \eta_{j2}| > 4$$

$$R_{jj} > 0.7 \qquad y_{j1} \cdot y_{j2} < 0$$

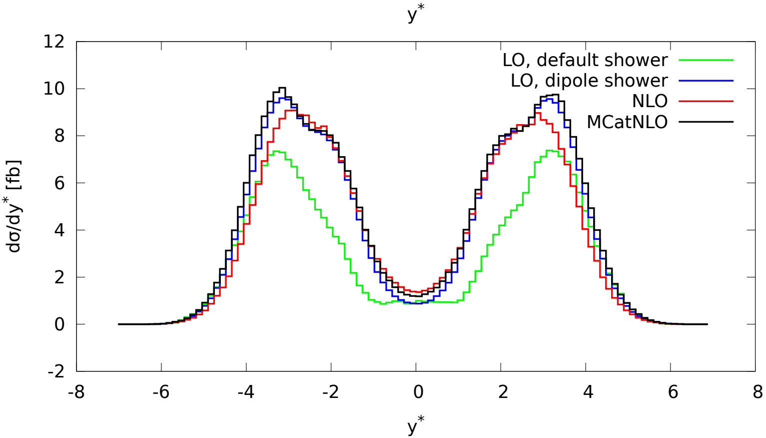


transverse momentum of hardest tagging jet p_{T1}
LO, default shower
LO, dipole shower
NLO
MCatNLO
$d\sigma/dp_{T1}$ [fb/GeV]
p_{T1} [GeV]
0
1
2
3
4
5
6
0
50
100
150
200
250
300
350
400
450
500


pseudorapidity of hardest tagging jet η_{j_1}
LO, default shower
LO, dipole shower
NLO
MCatNLO
$d\sigma/d\eta_{j_1}$ [fb]
η_{j_1}
120
100
80
60
40
20
0
-8
-6
-4
-2
0
2
4
6
8


pseudorapidity of 3rd hardest tagging jet η_{j_3}
LO, default shower
LO, dipole shower
NLO
MCatNLO
$d\sigma/d\eta_{j_3}$ [fb]
η_{j_3}
12
10
8
6
4
2
0
-2
-8
-6
-4
-2
0
2
4
6
8

$$y^* = y_3 - \frac{1}{2}(y_1 + y_2)$$



Summary:

- NLO matching is required to combine parton shower approximation with NLO matrix elements consistently
- Shower based on Catani-Seymour subtraction leads to a better approximation of the NLO results and makes MC@NLO type matching easier
- Matched observables are correct in hard and soft/collinear phasespace regions