Scale variations in $W/h/t\bar{t}$ production at NLO

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Workshop on Scale Choices

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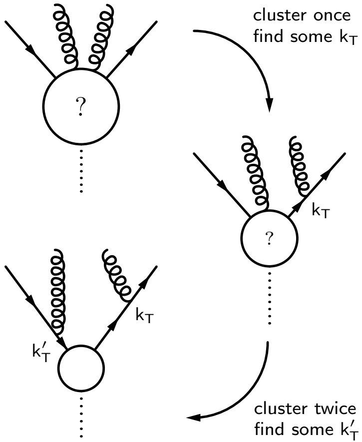
H_T' vs MINLO

- Renormalization/factorization scale typically used at very high multiplicity: sum of transverse mass $H_T = \sum p_\perp$
- Criticized for being too large and insensitive to dynamics of process
- Very different scale defined by MINLO [Hamilton,Nason,Zanderighi] arXiv:1206.3572
  - Interpret event in terms of QCD branchings, like in a parton-shower
  - Assign transverse momentum scales to splittings, evaluate one α_s at each of these scales
  - Multiply with NLL Sudakov factors, subtract first-order expansion
- MINLO probes detailed dynamics, typically very different from H_T
  $\rightarrow$ good candidate for comparison



Details of the MINLO procedure

[Hamilton,Nason,Zanderighi] arXiv:1206.3572

- Perform k_T clustering of flavor-compatible partons, determine scales $q_1, \ldots, q_M, Q$ (and q_0 in real corrections), set $Q_0 = q_1$
- Evaluate M powers of α_s at the scales $\mu_1, \ldots, \mu_M$, with $\mu_i = K_R q_i$
  Evaluate $N-M$ powers of α_s at $\mu_{\mathrm{core}} = K_R Q$, vary scales using K_R

$$[\alpha_s(\mu_{\mathrm{core}})]^{N-M} \prod_{i=1}^{M} \alpha_s(\mu_i)$$

- Define α_s to be used in the $(N+1)^{th}$ power at NLO as

$$\alpha_s^{(N+1)} = \frac{1}{N}\left[(N-M)\,\alpha_s(\mu_{\mathrm{core}}) + \sum_{i=1}^{M} \alpha_s(\mu_i)\right]$$

- Set renormalization scale explicitly appearing in virtual corrections to

$$\mu_R = \left[\mu_{\mathrm{core}}^{N-M} \prod_{i=1}^{M} \mu_i\right]^{1/N}$$

  Set factorization scale to $K_F q_1$, vary using K_F
- Dress configuration with NLL Sudakov form factors $\Delta_a(Q_0, Q)$
- Subtract NLO contribution present in the dressed Born term as

$$B \to B\left[1 - \sum_{q_j < q_i} \left[\Delta_{f_{ij}}^{(1)}(Q_0, q_i) - \Delta_{f_{ij}}^{(1)}(Q_0, q_j)\right] - \sum_{\mathrm{external}} \Delta_{f_l}^{(1)}(Q_0, q_{k_l})\right]$$

Details of our implementation

- Sudakov factors are probabilities, defined as

$$\Delta_a(Q_0,Q) = \exp\left\{-\int_{Q_0}^{Q}\frac{\mathrm{d}q}{q}\frac{\alpha_s(q)}{\pi}\sum_{b=q,g}\int_0^{1-\frac{q}{Q}}\mathrm{d}z\left[z\,P_{ab}(z)+\delta_{ab}\frac{\alpha_s(q)}{2\pi}\frac{2C_a}{1-z}K\right]\right\}$$

where $K(q) = \left(\frac{67}{18}-\frac{\pi^2}{6}\right)C_A - \frac{10}{9}T_R\,n_f(q)$

- Renormalization scale for explicitly μ_R dependent terms from

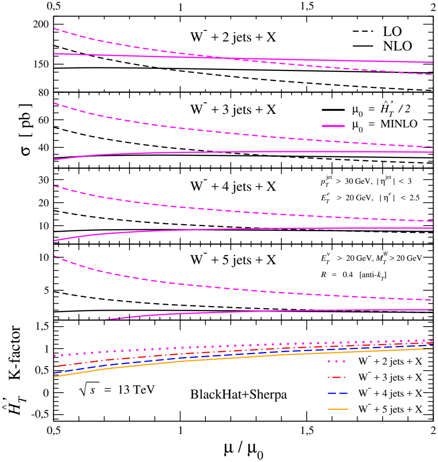
$$[\alpha_s(\mu_R)]^N = [\alpha_s(\mu_{\text{core}})]^{N-M}\prod_{i=1}^{M}\alpha_s(\mu_i)$$

- Unordered configurations are treated differently:
  - Demand strong ordering of nodal scales in k_T clustering
  - If ordering violated, skip recombination and move to next pair
  - If no other combination, consider as Born $\to$ set scale Q
  - If Q violates ordering, undo last clustering
- Massive Sudakovs to account for top quark mass
  [Catani,Dittmaier,Trocsanyi] hep-ph/0011222, [Krauss,Rodrigo] hep-ph/0303038
- In processes with non-trivial color structure at LO:
  Assume all logarithms of Sudakov type (no soft function)

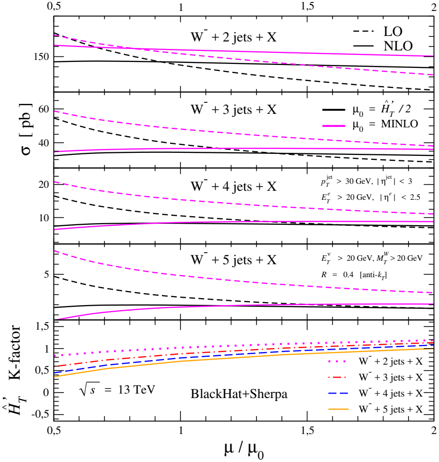
$W^{\pm}$+5 jets at (MI)NLO

[Bern,Dixon,Febres Cordero,Ita,Kosower,Maître,Ozeren,SH] arXiv:1304.1253
[Anger,Febres-Cordero,Maître,SH] in preparation

- $W^{\pm}$+jets has new flavor (& kinematics) channels beyond (N)LO
- Often not possible to find ordered history, unordered can correspond to high-energy limit or large EW log → QCD MINLO not appropriate



- Ordered & unordered histories



- Ordered histories only

$W^{\pm}$+5 jets at (MI)NLO - p_T spectra

[Bern,Dixon,Febres Cordero,Ita,Kosower,Maître,Ozeren,SH] arXiv:1304.1253
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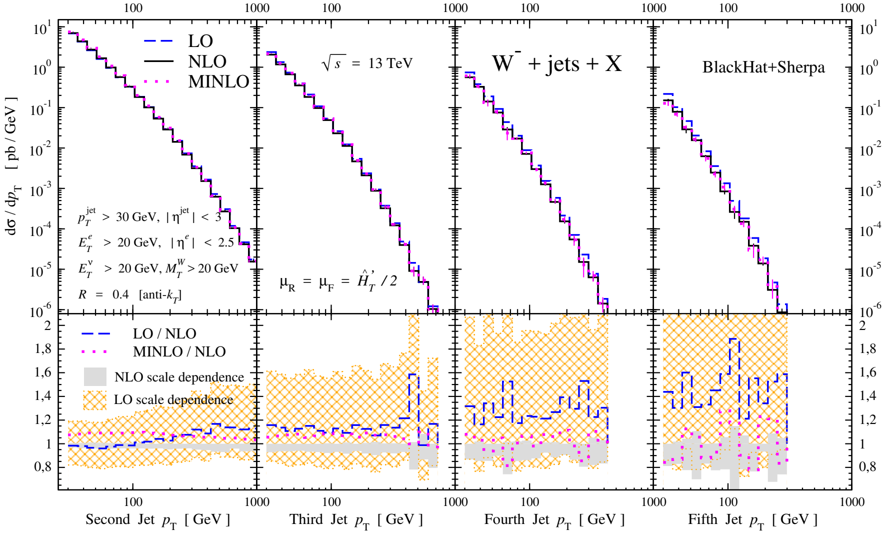
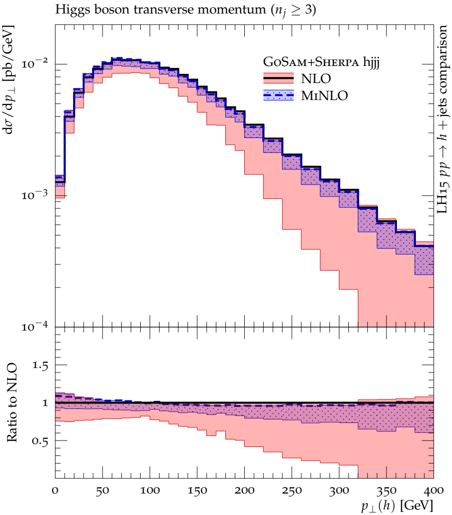
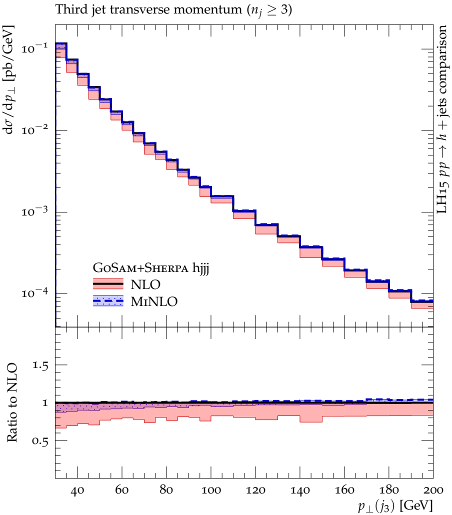


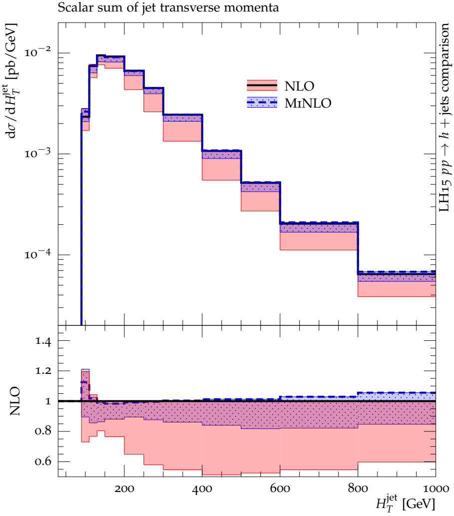
H+3jets at (MI)NLO

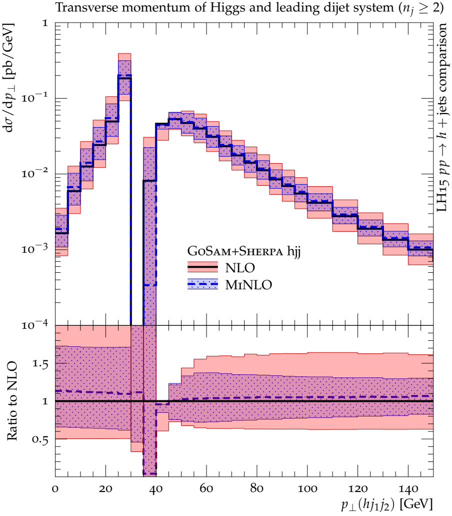




- Higgs transverse momentum
- 3rd jet transverse momentum

H+3jets at (MI)NLO - $H_{T,j}$ spectra

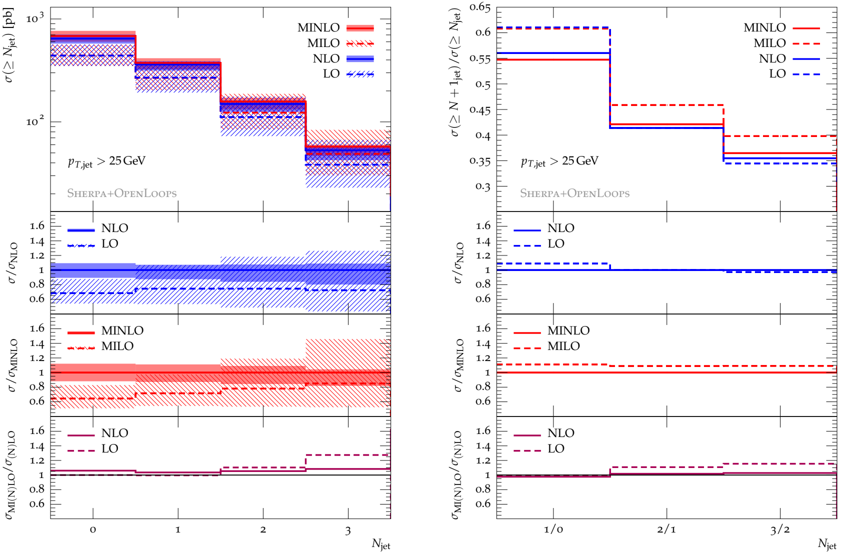




- H_T spectrum
- Higgs-dijet transverse momentum

$t\bar{t}$+3jets at (MI)NLO - Jet multiplicity

[Maierhöfer,Moretti,Pozzorini,Siegert,SH] arXiv:1607.06934



$t\bar{t}$+3jets at (MI)NLO - $p_{T,t}$ spectra

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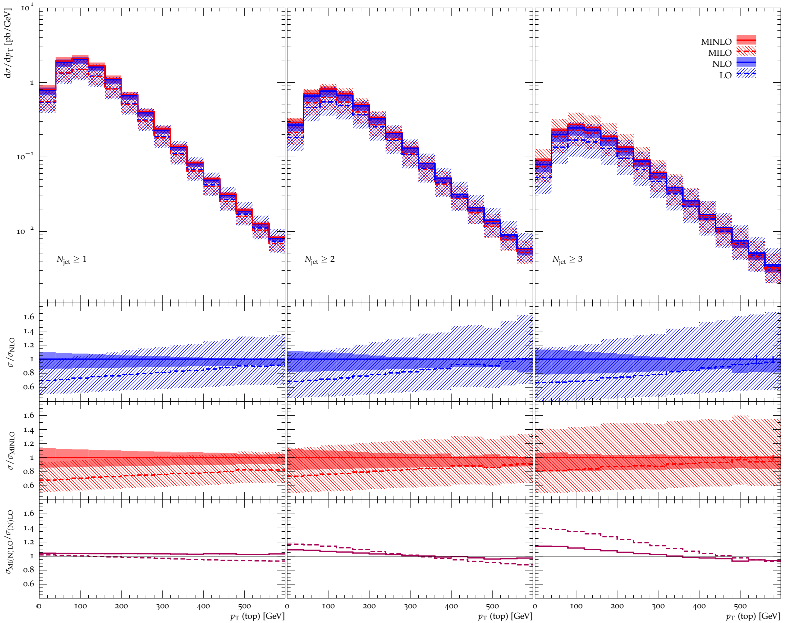

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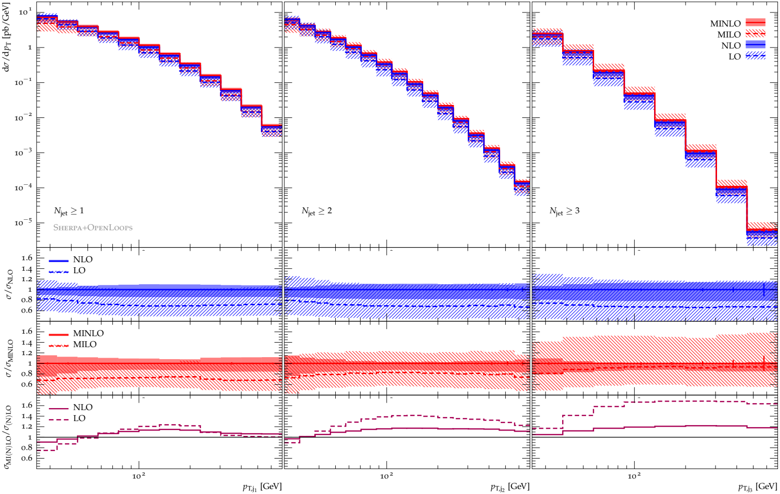

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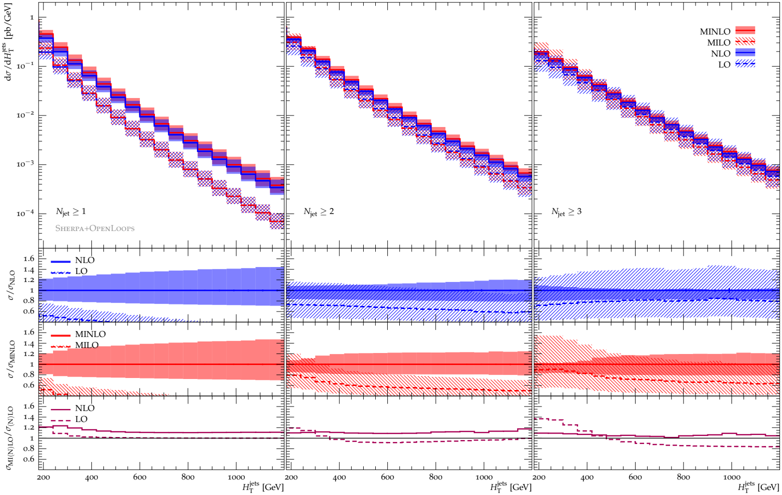

Conclusions?

- Tested MINLO vs fixed-order NLO using $H_T'/2$
- Generally at least fair if not good agreement at NLO
- Should also vary MINLO algorithm within uncertainties
  - Jet radius dependence
  - Ordered vs unordered clustering
  - Choice of Born scale
- Further ideas & suggestions welcome