Karlsruhe Institute of Technology

NLO merging with Herwig++

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Johannes Bellm | 2.12.2013

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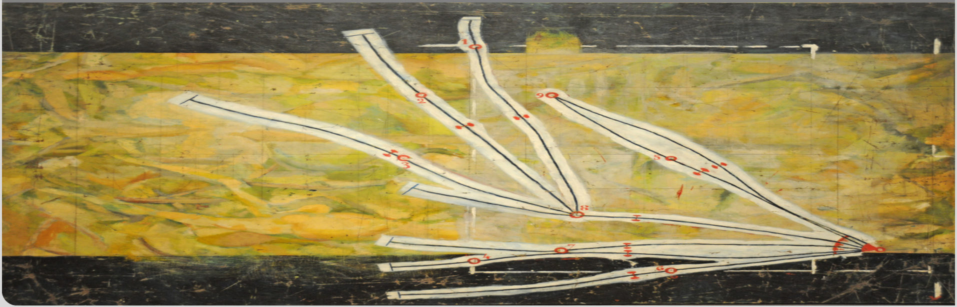

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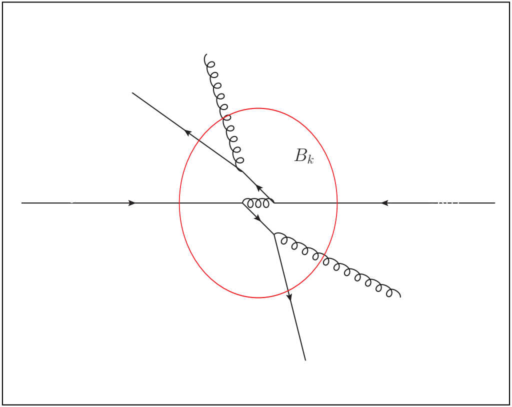
Tree-level merging

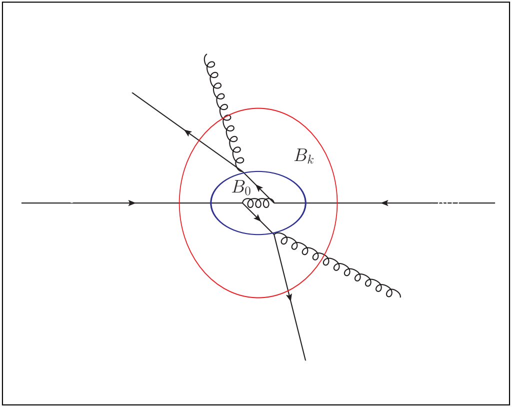
$$PS_\rho\left[d\sigma_{N,\rho}^{merged}\right]=\sum_{k=0}^{N-1} B_k\Delta_\rho^k\Delta_k^0+PS_\rho\left[B_N\Delta_N^0\right]$$



Above the merging scale ρ we want to describe with LO-accuracy, dressed with some PS-history.

Tree-level merging

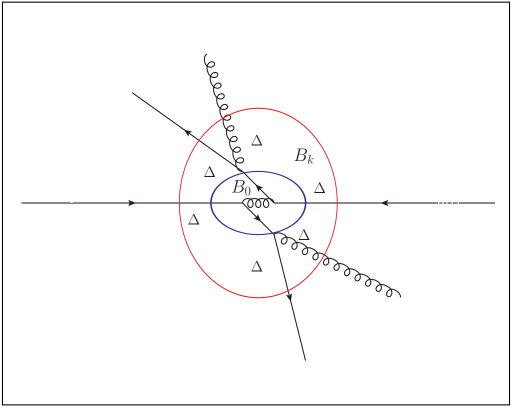
$$PS_\rho\left[d\sigma^{merged}_{N,\rho}\right] = \sum_{k=0}^{N-1} B_k \Delta^k_\rho \Delta^0_k + PS_\rho\left[B_N \Delta^0_N\right]$$



Find the underlying process with a cluster algorithm, providing scales of the splittings.

Tree-level merging

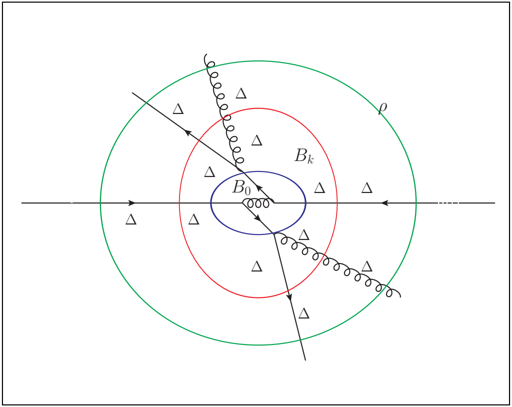
$$PS_\rho\left[d\sigma^{merged}_{N,\rho}\right] = \sum_{k=0}^{N-1} B_k \Delta^k_\rho \Delta^0_k + PS_\rho\left[B_N \Delta^0_N\right]$$



Δ^0_k accumulates the sudakov-,α_s- and pdf-reweighting, of the past.
'What would the shower do?'

Tree-level merging

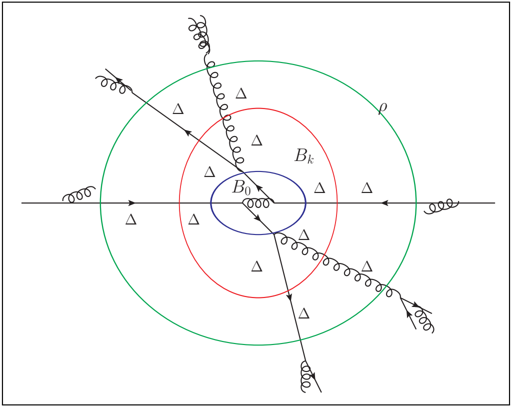
$$PS_\rho\left[d\sigma^{merged}_{N,\rho}\right] = \sum_{k=0}^{N-1} B_k \Delta^k_\rho \Delta^0_k + PS_\rho\left[B_N \Delta^0_N\right]$$



Δ^k_ρ accumulates the sudakov-reweighting, of the future.
'What would the shower do?'

Tree-level merging

$$PS^{\rho}_{\mu}\left[PS_{\rho}\left[d\sigma^{merged}_{N,\rho}\right]\right] = PS^{\rho}_{\mu}\left[\sum_{k=0}^{N-1} B_k \Delta^{k}_{\rho} \Delta^{0}_{k} + PS_{\rho}\left[B_N \Delta^{0}_{N}\right]\right]$$



When we reach the merging scale the parton shower is free to do his job towards the infrared cutoff μ.

Tree-level merging

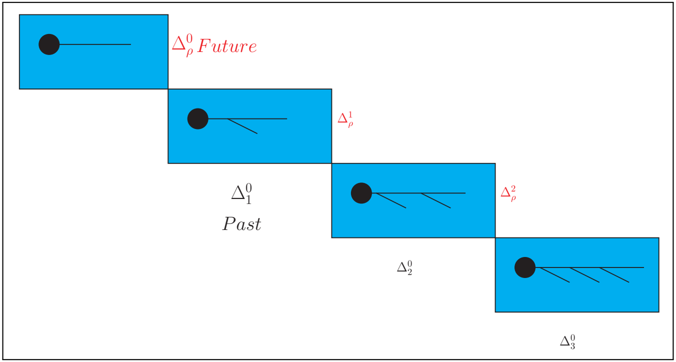
CKKW(-L)[0109231][0112284] and MLM [0611129] are recipes to get $\Delta_{\rho}^{k}\Delta_{k}^{0}$.

Our tasks:

- Get something similar working in Herwig++.
- Repair inclusive Observables (unitarisation).[1211.5467][1211.4827]
- Include local K-factors to get NLO-accuracy.

Repair inclusive Observables

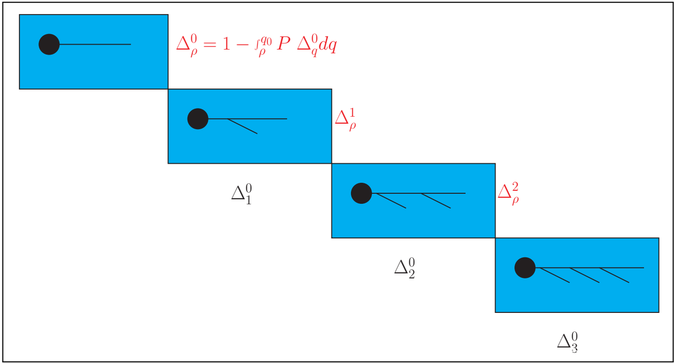
$$PS_\rho\left[d\sigma^{merged}_{N,\rho}\right] = \sum_{k=0}^{N-1} B_k \Delta^k_\rho \Delta^0_k + PS_\rho\left[B_N \Delta^0_N\right]$$



The Futur has been changed for each $B_{k<N}$.

Repair inclusive Observables

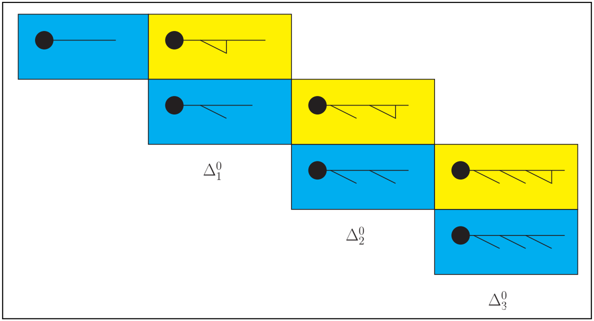
$$PS_\rho\left[d\sigma^{merged}_{N,\rho}\right] = \sum_{k=0}^{N-1} B_k \Delta^k_\rho \Delta^0_k + PS_\rho\left[B_N \Delta^0_N\right]$$



No emission = 1 - at least one emission

Repair inclusive Observables

$$PS_\rho\left[d\sigma^{merged}_{N,\rho}\right] = \sum_{k=0}^{N-1}\left[B_k 1 - \int_\rho^{q_k} dq_{k+1}\frac{B_{k+1}}{dq_{k+1}}\Delta^k_{k+1}\right]\Delta^0_k + PS_\rho\left[B_N\Delta^0_N\right]$$

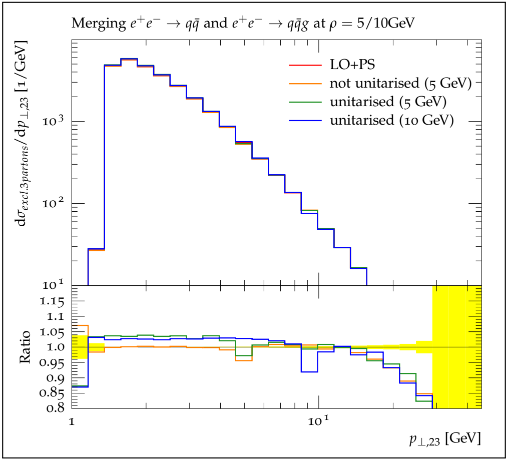


Inclusive Observables stay the same.
Exclusive Observables are discribed with LO-accuracy.

Technicalities: Implementing in Herwig++

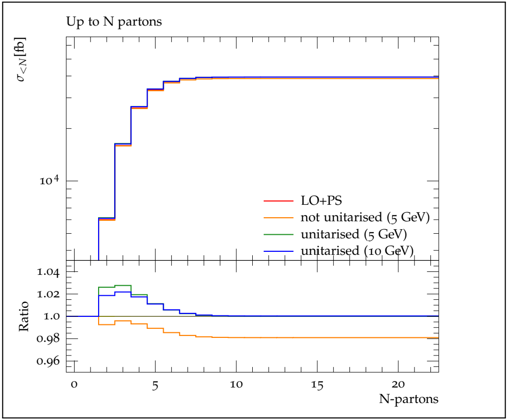
- Framework: Matchbox, Dipole Shower.[0909.5593]
- Clustering via Tildekinematics (Catani-Seymour).[9605323]
- Scales of ordered histories stored in 'clusternodes'.
- Watch for singularities of clustered kinematics.
- Stay independent of the process.
- Every process available in Matchbox automatically can be merged.(BLHA2!)
- Sudakov weight with trial showering.
- Evolving beneath merging scale with a vetoed shower.
- α_s and pdf-reweighting.

Repair inclusive Observables based on [1211.5467]



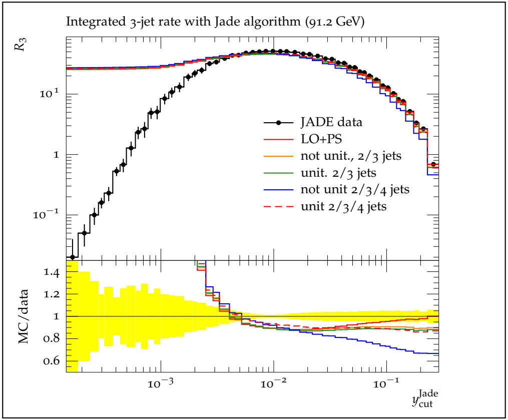
- $e^+e^- \to 2/3$ jets
- Here: not physical exclusive three parton $p_{T,23}$-distribution.
- Divide above and beneath merging scale.
- Sudakov 'works'.

Repair inclusive Observables



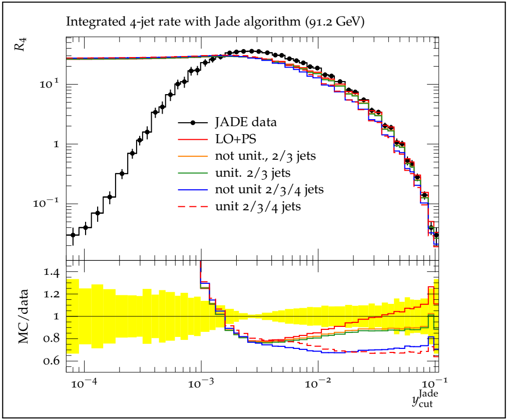
- $e^+e^- \to 2/3$ jets
- Here: Up to N-parton cross section (not physical).
- Full inclusive ($N \to \infty$) is unitarised.
- The difference to the not unitarised merging is $\mathcal{O}(\alpha_s)$ since $B_1 \neq PB_0$.

Repair inclusive Observables



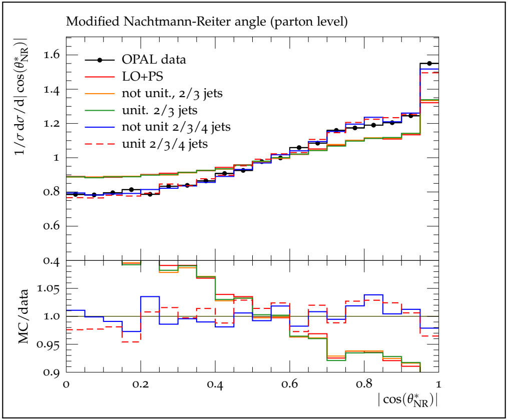
- Here: parton level (no hadronisation).
- Flat ratio distribution in hard region. [JADE_OPAL_2000_S4300807]
- The ununitarised 2/3/4 distribution fails.

Repair inclusive Observables



- Here: integrated 4-jet rate.
- Flat ratio distribution in hard region.

Repair inclusive Observables



- Here: 4 jet Observable.
- Pure parton level.
- Good angular distributions.[OPAL_2001_S4553896]
- $\theta_{NR} = \angle[\vec{p_1} - \vec{p_2}, \vec{p_3} - \vec{p_4}]$

Including NLO-calculations

One way to include NLO-Corrections:

$$d\sigma_{k,\rho}^{1,incl}(VR)_k = V_k + \int_0^{q_k} dq_{k+1} \frac{B_{k+1}}{dq_{k+1}} \theta(q_k - \rho)$$

Gives a local K-factor for B_k.

In the unitarisation we only subtract ordered histories. So the real emission contributions where $q_{k+1} > q_k$ is already included.

$$\int_0^{q_k} dq_{k+1} \frac{B_{k+1}}{dq_{k+1}} \left[\theta(q_k - \rho) - \Delta_{k+1}^{k} \theta(q_{k+1} - \rho)\right]$$

First part from real emission, second from unitarisation procedure brings a sudakov motivated continuation from $\mathcal{O}(\phi_k)$ to $\mathcal{O}(\phi_{k+1})$

Including NLO-calculations

$$PS_\rho\left[d\sigma^{merged}_{N,\rho}\right] = B_0 - \int_\rho^{q_0} dq_1 \frac{B_1}{dq_1}\Delta_1^0 + B_1\Delta_1^0 - \int_\rho^{q_1} dq_2 \frac{B_2}{dq_2}\Delta_2^0 + B_2\Delta_2^0 - \int_\rho^{q_2} dq_3 \frac{B_3}{dq_3}\Delta_3^0 + PS_\rho\left[B_3\Delta_3^0\right]$$

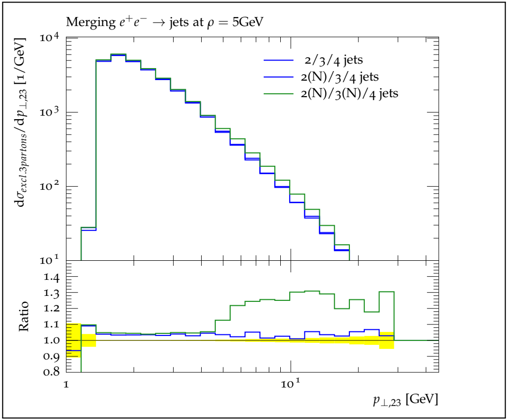
$(VR)_k$ is not produced by the shower!
So we can just add it as an ununitarised shower.(It's already $\mathcal{O}(\alpha_s^{n+1})$)

$$PS_\rho\left[d\sigma^{merged}_{N,\rho}\right] = B_0 - \int_\rho^{q_0} dq_1 \frac{B_1}{dq_1}\Delta_1^0 + B_1\Delta_1^0 \quad \ldots \quad + (VR)_0\Delta_\rho^0 + PS_\rho\left[(VR)_1\Delta_1^0\right]$$

At the Merging Scale

	$p_T < \rho$		$p_T > \rho$	
>3LO	B_0	$\Delta^{\rho}_{p_T} P_{p_T} \Delta^{p_T}_{\mu}$		
	$- \int_{\rho}^{q_0} dq_1 \frac{B_1}{dq_1} \Delta^0_1$	$\Delta^{\rho}_{p_T} P_{p_T} \Delta^{p_T}_{\mu}$	$+B_1(p_T)\Delta^0_{p_T}$	Δ^{ρ}_{μ}
			$- \int_{\rho}^{p_T} dq_2 \frac{B_2}{dq_2} \Delta^0_2$	Δ^{ρ}_{μ}
1NLO	$+(VR)_0$	$\Delta^0_{\rho} \Delta^{\rho}_{p_T} P_{p_T} \Delta^{p_T}_{\mu}$	$+(VR)_0$	$\Delta^0_{p_T} P_{p_T} \Delta^{p_T}_{\rho} \Delta^{\rho}_{\mu}$
2NLO	$+(VR)_0 \Delta^0_{\rho}$	$\Delta^{\rho}_{p_T} P_{p_T} \Delta^{p_T}_{\mu}$		
			$+(VR)_1 \Delta^0_{p_T}$	$\Delta^{p_T}_{\mu}$
	reweighted MEs	Shower	reweighted MEs	Shower

At the Merging Scale

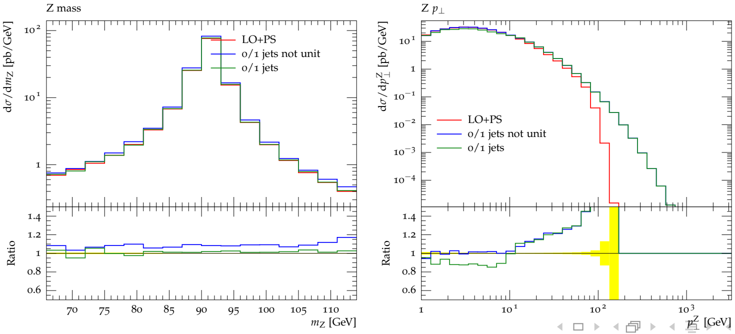


- Same behaviour beneath the merging scale.
- The $(VR)_1$ kicks in at the merging scale.
- $(VR)_0$ is also pushed for $[2(N)/3/4]$ above the merging scale.

Towards LHC-physics (very recent)

$$PS_\rho\,[f_1(Q,x)B_n(Q)]_{2Spl.} = \frac{f_3(q_2,x_2)}{f_2(q_2,x_1)} P(q_2)\Delta_{q_2}^{q_1} \frac{f_2(q_1,x_1)}{f_1(q_1,x)} P(q_1)\Delta_{q_1}^{Q} f_1(Q,x)B_n(Q)$$

$$PS_\rho\,[f_1(Q,x)B_n(Q)]_{2Spl.} = \frac{f_2(q_1,x_1)}{f_2(q_2,x_1)} \Delta_{q_2}^{q_1} \frac{f_1(Q,x)}{f_1(q_1,x)} \Delta_{q_1}^{Q} \underbrace{f_3(q_2,x_2)P(q_2)P(q_1)B_n(Q)}_{\frac{\alpha_S(q_1)}{\alpha_S(q_2)}\left(\frac{\alpha_S(Q)}{\alpha_S(q_2)}\right)^n f_3(q_2,x_2)B_{n+2}(q_2)}$$



Summary

- We implemented an unitarized (N)LO-Merging in Herwig++/Matchbox.
- We are looking into Observables sensitive to the effects at the merging scale.
- Outlook: With the interface standard BLHA2 an automatized NLO-merging seems possible.

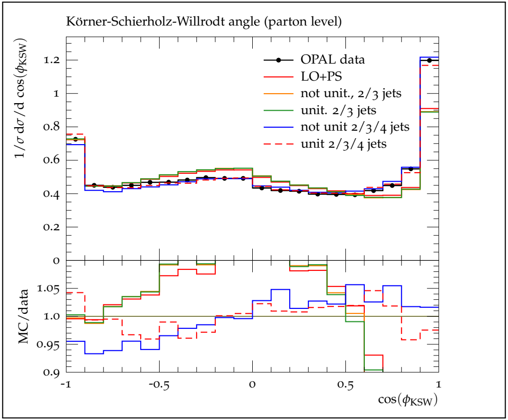
The end

Thanks for your attention!

The end

Backup

Repair inclusive Observables



- Here: 4 jet Observable.
- Pure parton level.
- Good angular distributions.[OPAL_2001_S4553896]
- $\Phi_{KSW} = \frac{1}{2}(\angle[\vec{p_1} \times \vec{p_4}, \vec{p_2} \times \vec{p_3}] + \angle[\vec{p_1} \times \vec{p_3}, \vec{p_2} \times \vec{p_4}])$

LoopSim

LoopSim - algorithm:

1. Get some Event for B_1.
2. Fill histograms with $+1$-kinematic.
3. Find way to cluster the particles by a jet-algorithm.
4. Cluster $+1 \to 0$.
5. Fill $-1\times$weight in histograms with 0-kinematic.

but:

- For later usage we need for the shower one event with one kinematic.
- An event with zero weight is not 'healthy' to every sampler.

LoopSim

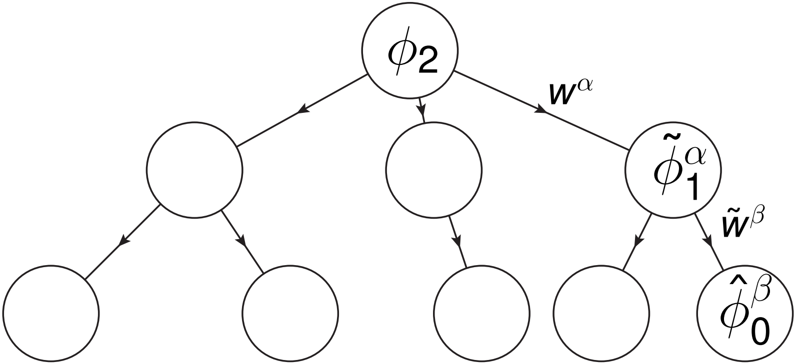
We need:

- Way to cluster from $N + 2 \rightarrow N + 1 \rightarrow N$.
- Find kinematics.
- Make it MC-integrable.

The Matchbox framework:

- Dipoles to find appropriate clusterings ✓
- The tilde-kinematics ✓
- Subtraction ✓

Clusternode



- process independent cluster finder
- full information on cluster-steps (scales, kinematics)

Clusternode - w^α

$$\overbrace{V_1 u(\phi_1) + B_2 u(\phi_2)}^{\text{finite}} = \left[V_1 + \sum_\alpha \int_1 D_\alpha \right] u(\phi_1) + \left[B_2 u(\phi_2) - \sum_\alpha D_\alpha u(\tilde{\phi}_1^\alpha(\phi_2)) \right]$$

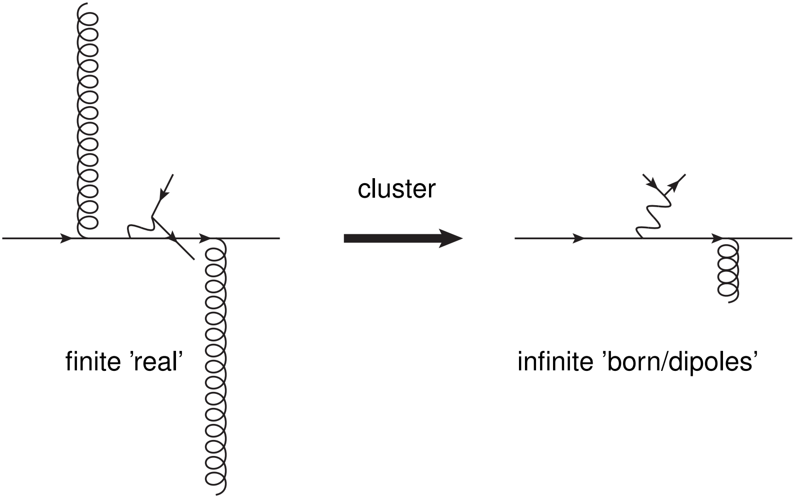
Clustering $\phi_2 \to \phi_1^\alpha$:

$$\sum_\alpha w^\alpha B_2 u(\tilde{\phi}_1^\alpha) - \sum_\alpha D_\alpha u(\tilde{\phi}_1^\alpha)$$

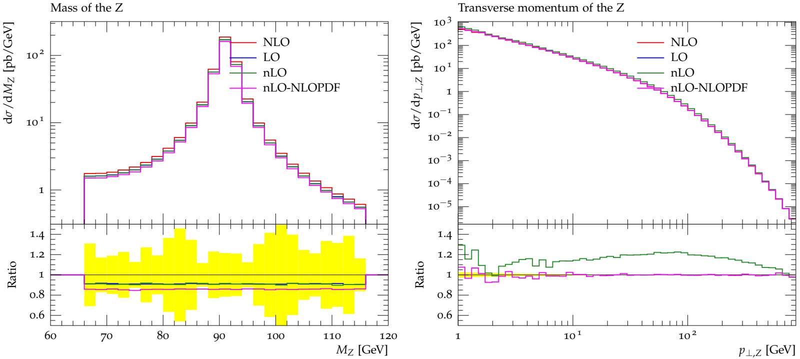
$$\Rightarrow \sum_\alpha \overbrace{\left(B_2 - \sum_\gamma D_\gamma \right)}^{\text{finite}} \frac{D_\alpha}{\sum_\gamma D_\gamma} u(\tilde{\phi}_1^\alpha)$$

as in POWHEG

Clusternode



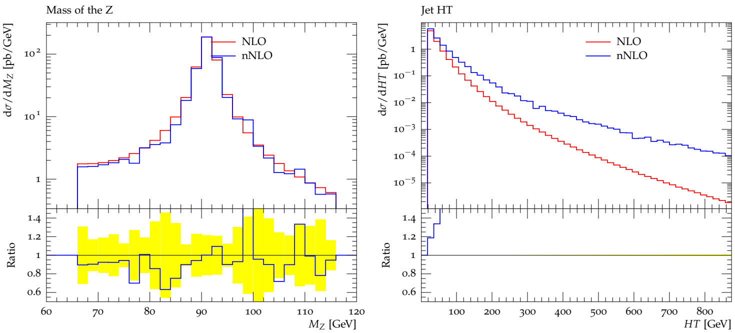
Z-production @ nLO



inclusive vs. exclusive

The PDF choice is an open question. $\mathcal{O}(\alpha_s)$

Z-production @ nNLO



$P_T^{dip} > 3$ GeV.

Back-to-back configurations are not logarithmic enhanced but have huge phase space. → Cluster them? → We think the ordering of the cluster scales give us the answer.→ Unordered histories are seen as new hard processes.

Z-production @ nNLO on Data