WZ production at large transverse momenta beyond NLO in QCD

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[1] F. Campanario and SS, arXiv:1209.4595 [hep-ph]

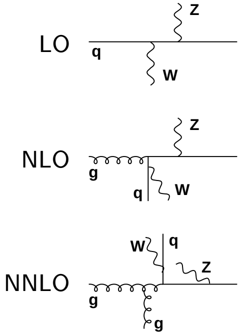
WZ production process

$$pp \rightarrow W^{\pm} Z + X \rightarrow \ell_1^{\pm} \overset{(-)}{\nu_1} \ell_2^{+} \ell_2^{-} + X$$

Beyond NLO in QCD: motivation

- NLO QCD corrections turned out to be sizable [Ohnemus; Frixione, Nason, Ridolfi]
  - new production channels
  - new topologies
- further new subprocesses and topologies expected at NNLO

Using only the NLO results is risky and may lead to misinterpretation of data!



WZ at $\bar{n}$NLO (approximate NNLO)

To compute approximate NNLO QCD correction to WZ we use:

VBFNLO + LoopSim

VBFNLO provides:

- WZ at NLO and WZj at NLO

LoopSim provides:

- consistent way to use the above results and supplement them with approximate 2-loop corrections

LoopSim summary

- use unitarity to simulate the divergent part of 2-loop diagrams

LoopSim procedure

input: event with n final state particles	LoopSim →	output: all $n-k$ final state particle events (equivalently all k-loop events)

- notation:

  $\bar{n}$**LO** – simulated 1-loop
  $\bar{n}$**NLO** – simulated 2-loop and exact 1-loop

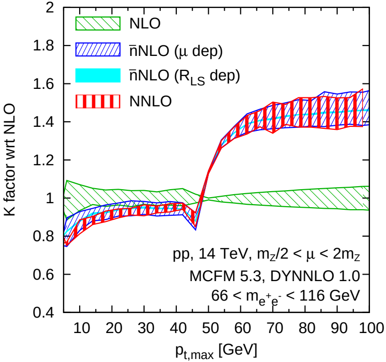
- this will work very for well for the processes with large K factors e.g.

$$\sigma_{\bar{n}\text{NLO}} = \sigma_{\text{NNLO}} \left(1 + \mathcal{O}\left(\frac{\alpha_s^2}{K_{\text{NNLO}}}\right)\right) , \quad K_{\text{NNLO}} \gtrsim K_{\text{NLO}} \gg 1$$

- LoopSim has one parameter R_{LS} (we shall vary it to probe uncertainties of the method related to nonsingular terms of the loop diagrams)

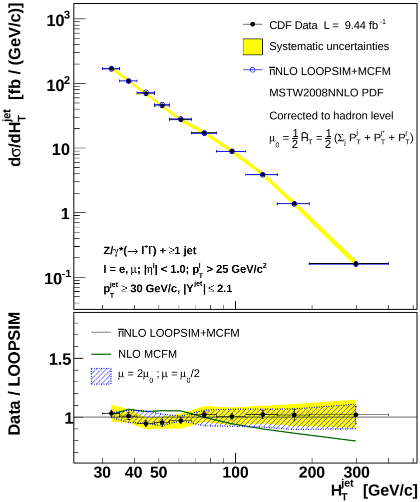
LoopSim has been shown to work

Drell-Yan at NNLO



- excellent agreement with DY at NNLO
- accounts very well for H_T distributions at Tevatron

Z+jets at Tevatron



WZ at $\bar{n}$NLO: details of the computation

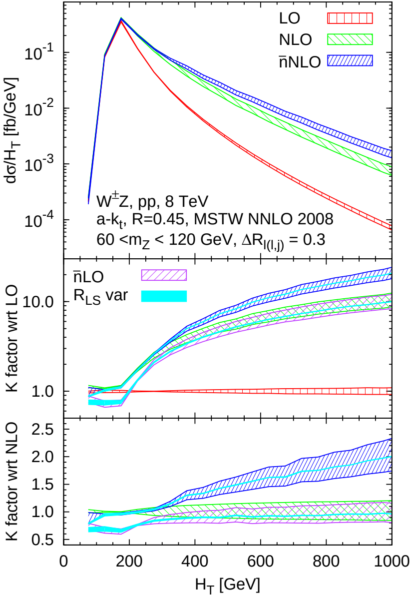
All results correspond to:

- both W^+Z and W^-Z production channels
- two unlike-flavour decay channels: $ee\mu\nu_\mu$ and $\mu\mu e\nu_e$
- MSTW NNLO 2008 at all orders
- $\mu_{F,R} = \frac{1}{2}\left\{\sum p_{T,\text{partons}} + \sqrt{p_{T,W}^2 + m_W^2} + \sqrt{p_{T,Z}^2 + m_Z^2}\right\}$

Cuts:

- $|y_\ell| \leq 2.5$, $p_{T,\ell} \geq 15\,(20)$, for ℓ coming from Z (W)
- $E_{T,\text{miss}} > 30\,\text{GeV}$
- $60 < m_{\ell^+\ell^-} < 120\,\text{GeV}$
- jets from anti-k_t, $R = 0.45$,
- for observables involving jets: $|y_\text{jet}| \leq 4.5, p_{T,\text{jet}} \geq 30\,\text{GeV}$
- $\Delta R_{\ell\,(\ell,j)} > 0.3$, $\Delta R = \sqrt{\Delta\phi^2 + \Delta y^2}$

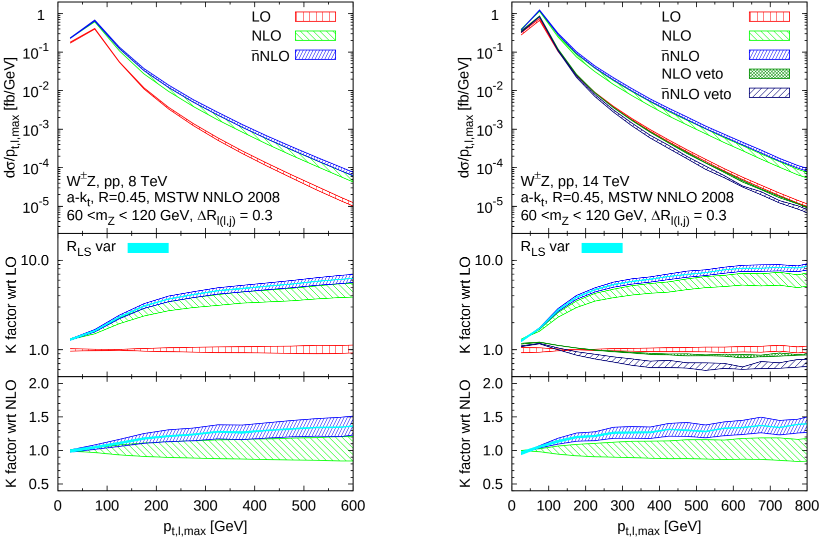
H_T distribution



$$H_T = \sum p_{T,\text{jets}} + \sum p_{T,\ell} + E_{T,\text{miss}}$$

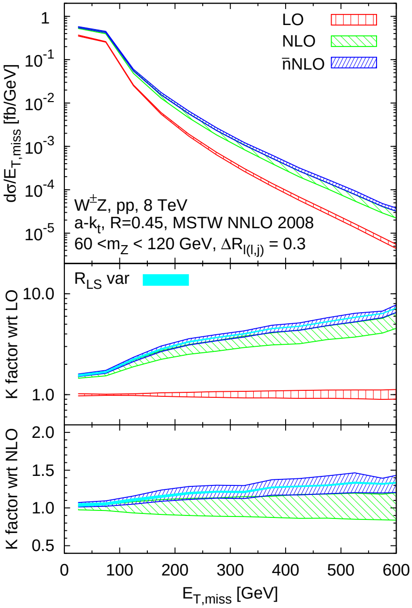
- huge K-factor from LO to NLO, distribution very sensitive to new channels and new topologies
- very good agreement between $\bar{n}$LO and NLO at large H_T
- $\bar{n}$NLO corrections as large as 100% w.r.t. NLO
- small R_{LS} uncertainties at large H_T
- marginal reduction of scale uncertainties at $\bar{n}$NLO (new topologies which dominate computed only at LO)

p_t of the hardest lepton

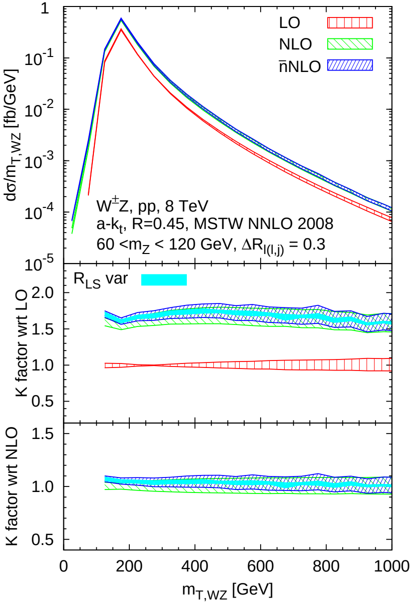


- $\bar{n}$NLO corrections beyond NLO scale uncertainties for $p_t > 200$ GeV
- $\bar{n}$NLO with $p_{t,\text{veto}} = 50$ GeV: large corrections, larger scale uncertainties

missing E_T distribution



- again, huge K-factor from LO to NLO
- large $\bar{n}$NLO of the order of 30%
- $\bar{n}$NLO correction exceeds NLO scale uncertainty
- reduced scale uncertainty at $\bar{n}$NLO



$$m^2_{T,WZ} = (E_T^W + E_T^Z)^2 - (p_x^W + p_x^Z)^2 - (p_y^W + p_y^Z)^2$$

- example of an observable for which $\bar{n}$NLO corrections are small
- finite loop terms of large importance (hence larger R_{LS} uncertainty)
- favoured configurations with W and Z back-to-back and both with sizable p_t; those do not have logarithmic enhancements

Summary

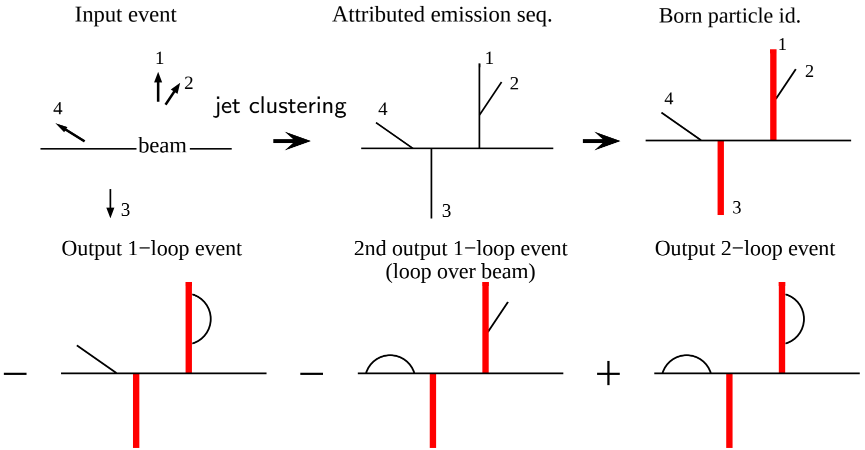
- We used LoopSim + VBFNLO to compute approximate NNLO QCD corrections to the process $pp \to WZ \to \ell_1^{\pm} \overset{(-)}{\nu}_1 \ell_2^{+} \ell_2^{-} + X$

- We found that these corrections are sizable for a number of observables at high p_t, that is: H_T, $p_{T,\ell,\max}$ and $E_{T,\text{miss}}$

- It is therefore important to take them into account in physics analyses within and beyond the Standard Model

BACKUP SLIDES

The LoopSim method: $\bar{n}$LO, $\bar{n}\bar{n}$LO etc.



- jet clustering $ij \to k$ is reinterpreted as the splitting $k \to ij$
- weight of an event $\sim (-1)^{\text{nb. of loops}}$ and all weights sum up to zero (unitarity)
- beware: the loops above are just a shortcut notation!

Including exact loops

$E_{n,l}$ – input event with n final state particles and l loops
U_l^b – operator producing event with b Born particles and l loops
$U_\forall^b$ – operator generating all necessary loop diagrams at given order

How to introduce exact loop contributions?

$$U_\forall^b(E_{n,0}) \quad + \quad U_\forall^b(E_{n-1,1}) \quad - \quad U_\forall^b(U_1^b(E_{n,0}))$$

- generate all diagrams from the tree level event
- generate all diagrams from the 1-loop event
- remove all approximate diagrams from $U_\forall^b(E_{n,0})$ that have exact counterparts provided by $U_\forall^b(E_{n-1,1})$

- inclusion of exact loops helps reducing scale uncertainties
- straightforward generalization to arbitrary number of exact loops