NLO QCD+EW CORRECTIONS FOR HV AND HV+JET IN THE POWHEG BOX RES

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arXiv:1706.03522

- ✗ NLO QCD+EW HV and HVj production
- ✗ Resonances and the `POWHEG BOX RES` code
- ✗ HVj+ `MiNLO`
- ✗ A few results
- ✗ Conclusions

HV and HVj production

We have computed the NLO QCD+EW corrections to the following processes

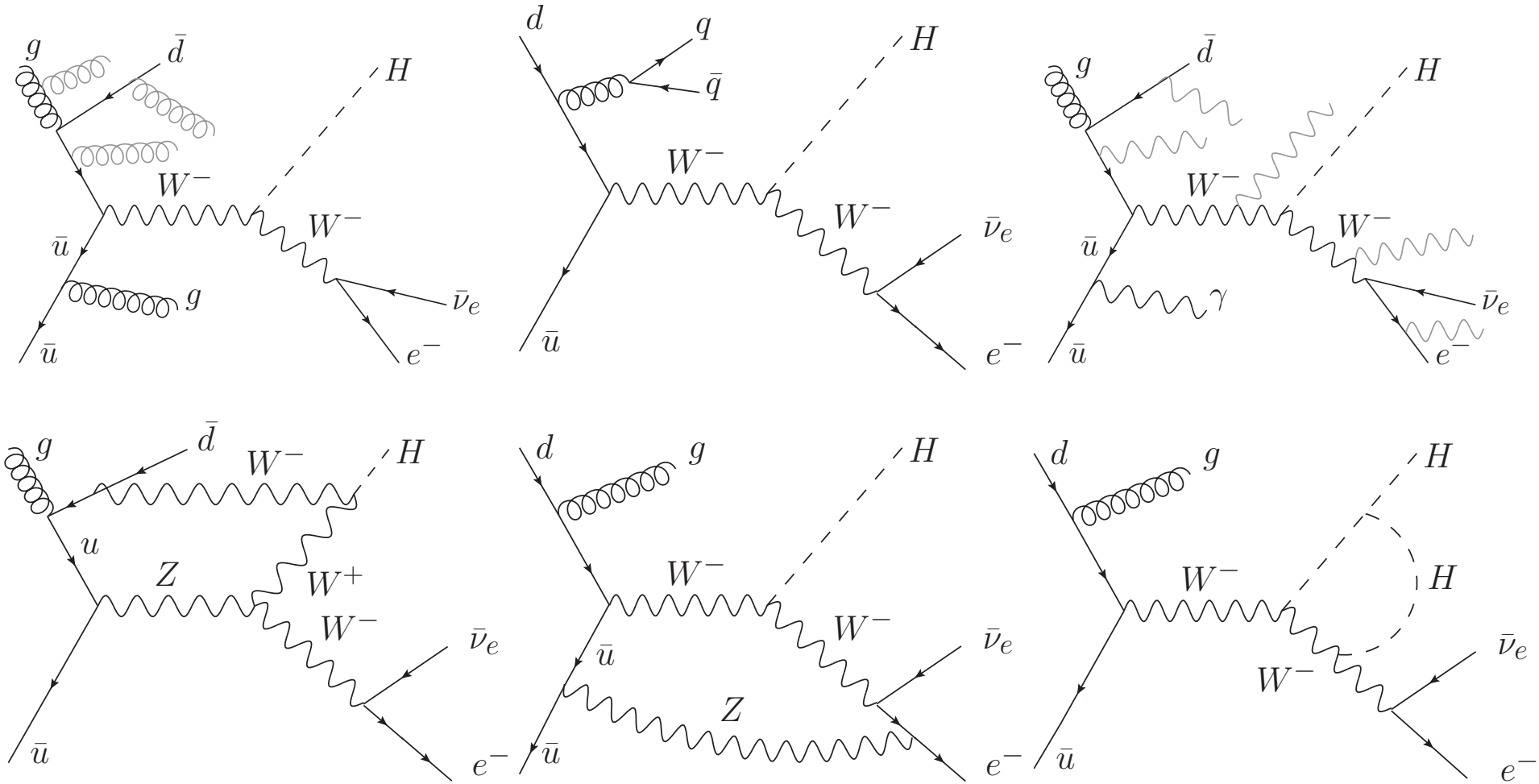
$$pp \to HW^+(j) \to H\ell^+\nu_\ell(j)$$
$$pp \to HW^-(j) \to H\ell^-\bar{\nu}_\ell(j)$$
$$pp \to HZ(j) \to H\ell^+\ell^-(j)$$

including all spin-correlation and off-shell effects

The NLO QCD corrections have been available for a while (Luisoni, Nason, C.O., Tramontano, arXiv:1306.2542)

Only one leptonic generation, and all leptons are treated as massless.

QCD+EW corrections to HVj

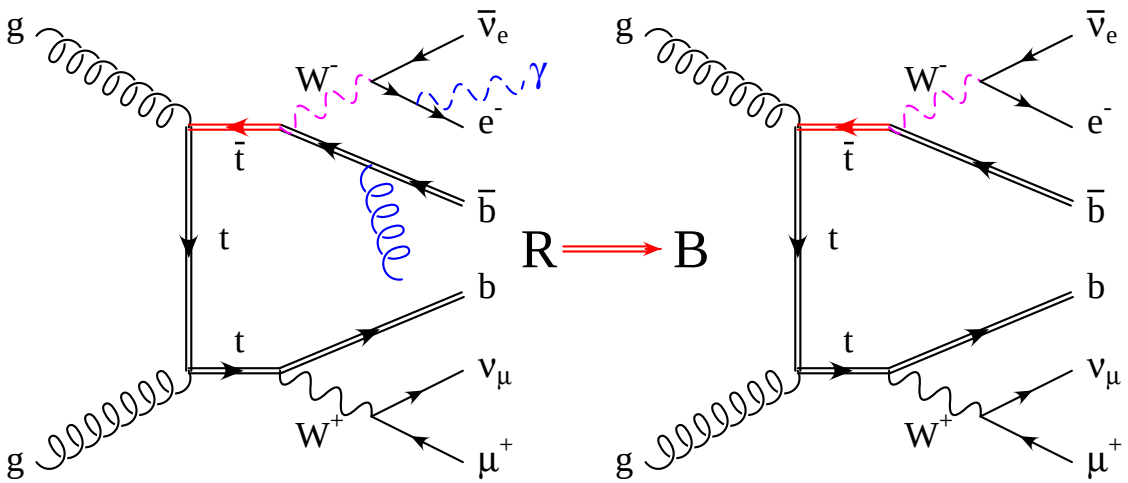


Born: $\mathcal{O}\left(\alpha_S\,\alpha_{EM}^3\right)$ QCD real+virtual: $\mathcal{O}\left(\alpha_S^2\,\alpha_{EM}^3\right)$ EW real+virtual: $\mathcal{O}\left(\alpha_S\,\alpha_{EM}^4\right)$

Sensitive to the trilinear Higgs boson coupling.

Resonances

When dealing with resonances whose decay products can radiate, we have two technical problems to tackle. Consider for example $e^- \bar{\nu}_e \mu^+ \nu_\mu b\bar{b}$



1) Problem at NLO level

   Standard subtraction schemes to construct the counterterms to real diagrams (e.g. Catani-Seymour, Frixione-Kunszt-Signer/FKS) do not preserve the virtuality of the resonances. For example, when the $W^- \bar{b} g$ system is such that the $\bar{t}$ is on-shell, its counterterm is off-shell, spoiling infra-red cancellation in the narrow width approximation.

$$\mathbf{\Phi_R} \Longrightarrow (\mathbf{\Phi_B}, \Phi_{\rm rad}), \qquad \mathbf{\Phi_B} = \text{underlying Born}$$

Resonances

2) Problem at NLO + Parton Shower level

The POWHEG formula is

$$d\sigma = \overline{B}(\mathbf{\Phi_B}) \left\{ \Delta\left(p_T^{(\min)}\right) + \Delta(p_T) \frac{R(\mathbf{\Phi_B}, \Phi_{\rm rad})}{B(\mathbf{\Phi_B})} \, d\Phi_{\rm rad} \right\} d\mathbf{\Phi_B}$$

$$\overline{B}(\mathbf{\Phi_B}) = B(\mathbf{\Phi_B}) + V(\mathbf{\Phi_B}) + \int d\Phi_{\rm rad} \, R(\mathbf{\Phi_B}, \Phi_{\rm rad})$$

$$\Delta(p_T) = \exp\left[- \int d\Phi'_{\rm rad} \frac{R(\mathbf{\Phi_B}, \Phi'_{\rm rad})}{B(\mathbf{\Phi_B})} \theta(p'_T - p_T) \right]$$

The standard FKS POWHEG underlying Born mapping does not preserve resonance virtuality: if R is on shell, B is off shell, and R/B is LARGE. But, in POWHEG, R/B should be small (of the order of α_S), or should approach the Altarelli-Parisi splitting functions, for the method to work.

The POWHEG BOX RES

The solutions have been discussed in Jezo, Nason, arXiv:1509.09071. The output of this has been a major revision of the POWHEG BOX V2 code: the POWHEG BOX RES.

- For each flavour structure, the code automatically finds all the possible resonance histories compatible with the partonic process at hand and keeps track of them, while generating radiation from each resonance, preserving the virtuality of the resonances.
- It is now possible to keep track of all the decay chains, allowing to pass this information to Pythia or Herwig, that can complete the shower by preserving the resonance virtualities...
- ...and to keep the hardest radiation in the decay of each resonance, for every generated event. In this way, an event has several QCD or QED radiations attached to it.

  Pythia and Herwig have then to be instructed not to produce any radiation harder than the one already present at the Les Houches level, for each resonance decay.

Tested on single-top and on the non-trivial $\ell^+\nu_\ell\, l^-\bar{\nu}_l\, b\bar{b}$ production (Ježo, Lindert, Nason, C.O., Pozzorini, arXiv:1607.04538).
Applied now to HV and HVj production, where the virtuality of the V boson is preserved when photon radiation is produced.

Improved MiNLO in HVj production

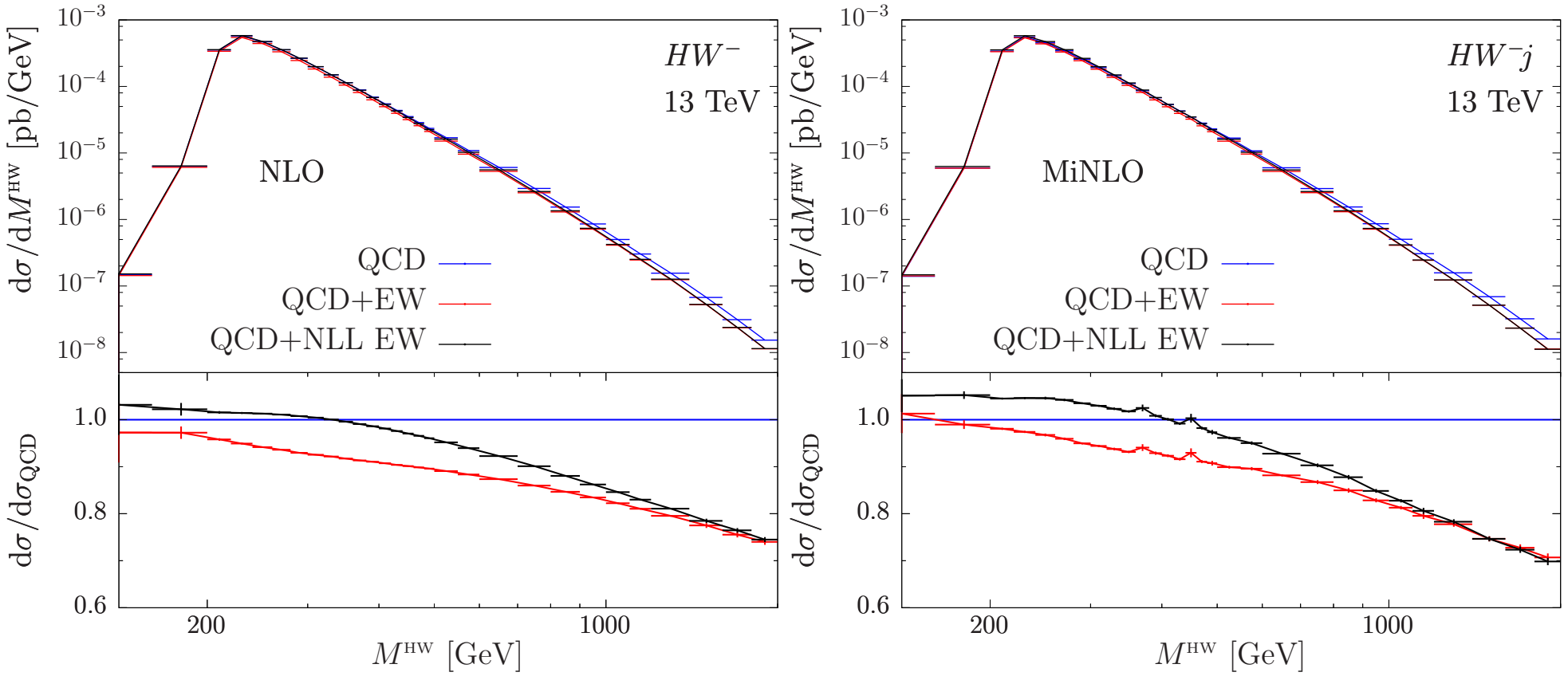
✗ The fixed-order Born cross section for HVj is divergent and, in general, a minimum transverse-momentum cut on the hardest jet is required.

✗ Related to this (at least in the POWHEG BOX), the question of merging samples with different multiplicity, i.e. HV, HVj, ... samples, preserving the good features of each sample in the "appropriate" region of validity.

✓ We deal with the divergent Born cross section and with the merging of samples using an improved version of MiNLO (Multi-scale improved NLO), as described in (Hamilton, Nason, Zanderighi, arXiv:1206.3572).

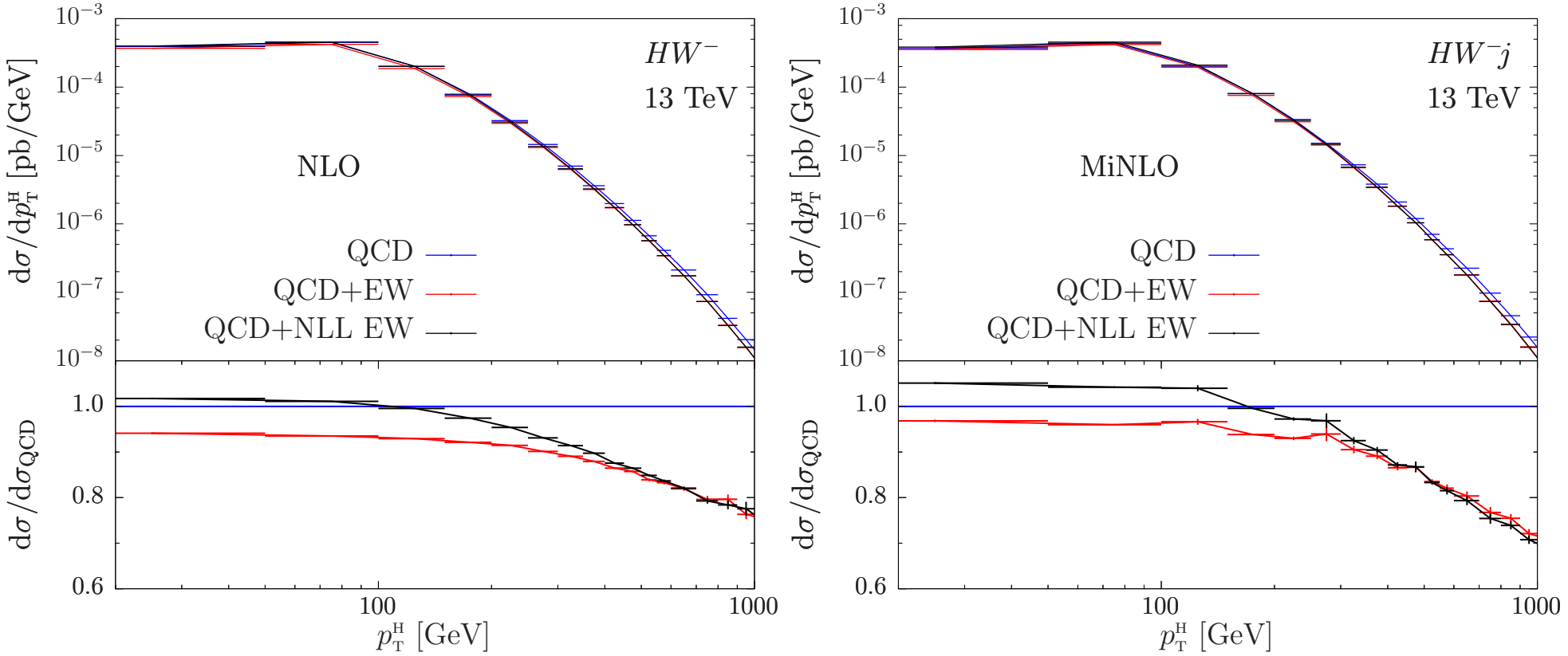
✓ The resulting event sample is NLO accurate in QCD+EW both for inclusive distributions in HV production and for inclusive distributions in HVj.
For the NLO QCD accuracy, there exists a formal proof (Hamilton, Nason, C.O., Zanderighi, arXiv:1212.4504). For the NLO EW accuracy, we have indications that it is correct.

NLO results at fixed order for HW^- and HW^-j production



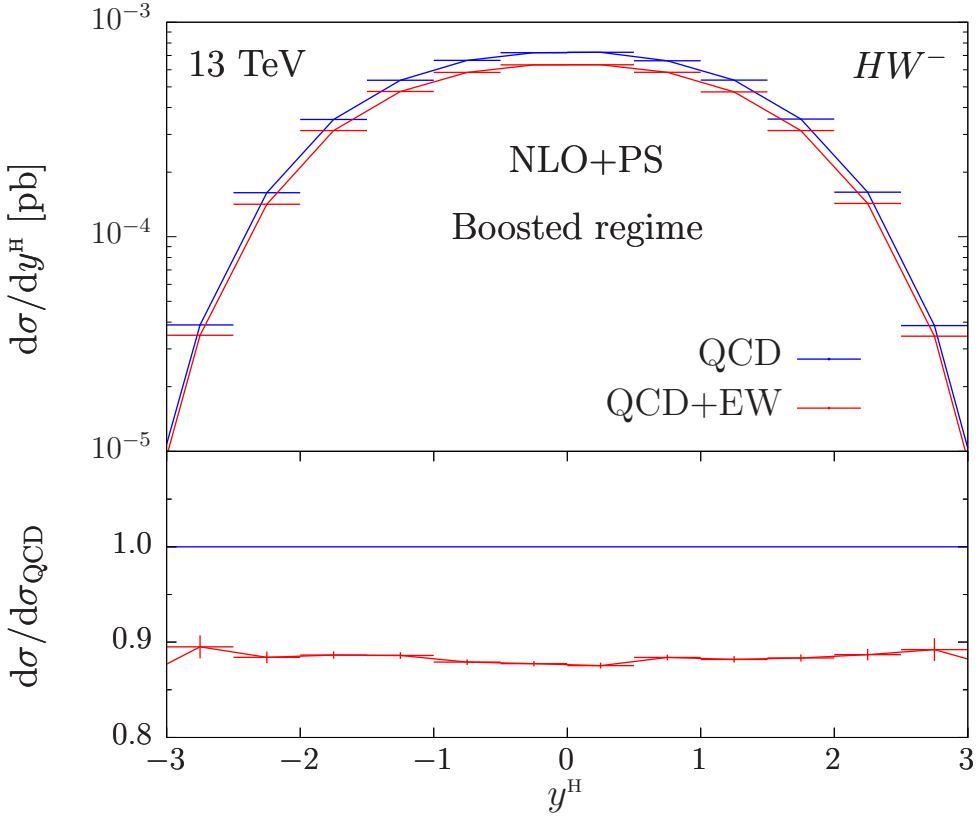
- EW corrections can largely exceed the ten percent level in the high-energy regions, where Sudakov logarithms become dominant.
- An example is the invariant mass of the HV pair in HV and HVj production, where the EW corrections reach -30% around 2 TeV.

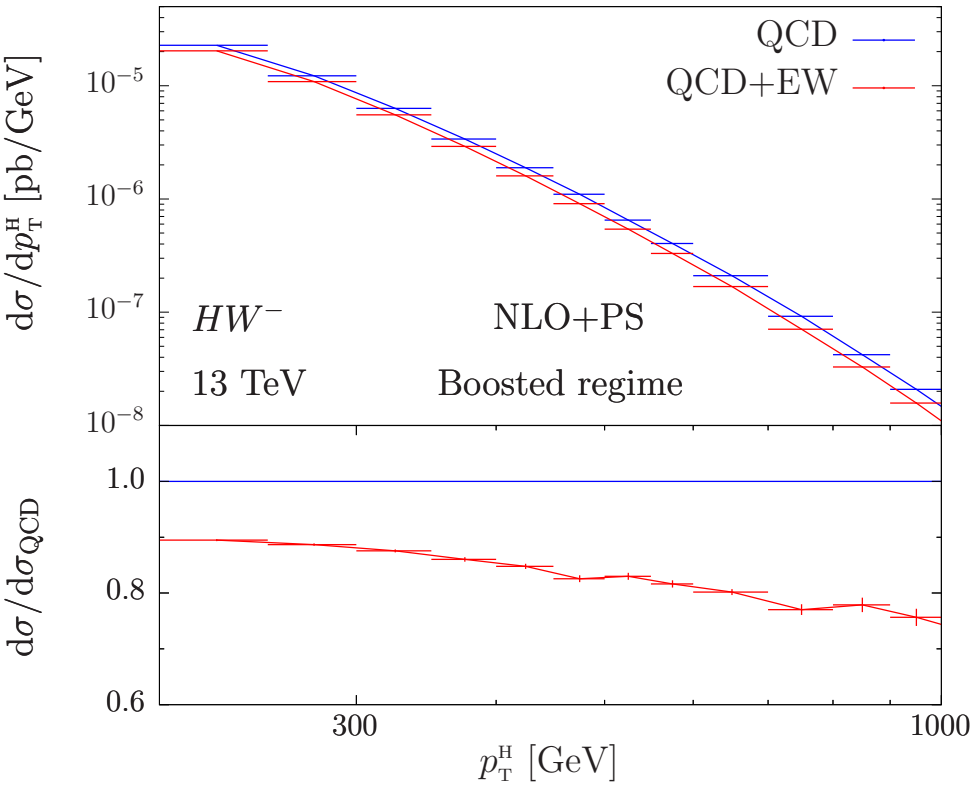
NLO results at fixed order for HW^- and HW^-j production



- Similar conclusions for the transverse momentum of the Higgs boson. The EW corrections reach -30% around 1 TeV in HW^-j production.

NLO + Parton Shower results for HW^- production



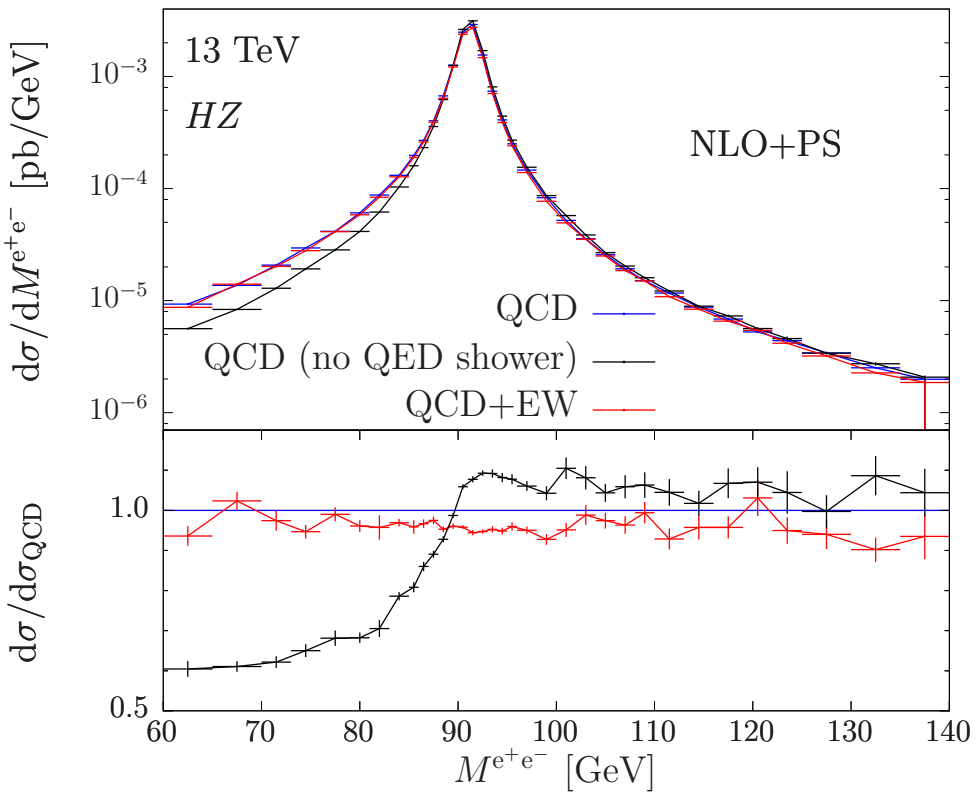


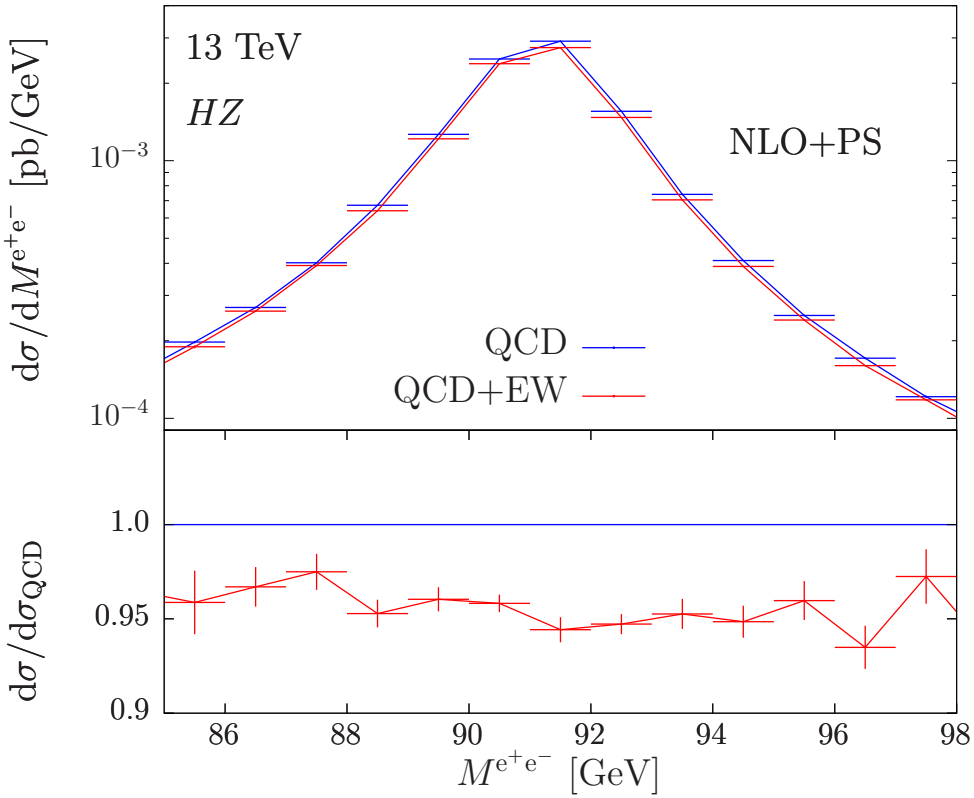
- Shower done by `Pythia 8.1`. The results have NLO+PS QCD+EW accuracy
- Boosted regime to improve the signal-over-background ratio in the $H \to b\bar{b}$ decay channel:

$$p_T^H \geq 200 \text{ GeV} \qquad p_T^V \geq 190 \text{ GeV}$$

- Constant negative EW corrections around 10% for y^H and corrections up to -25% for p_T^H around 1 TeV.

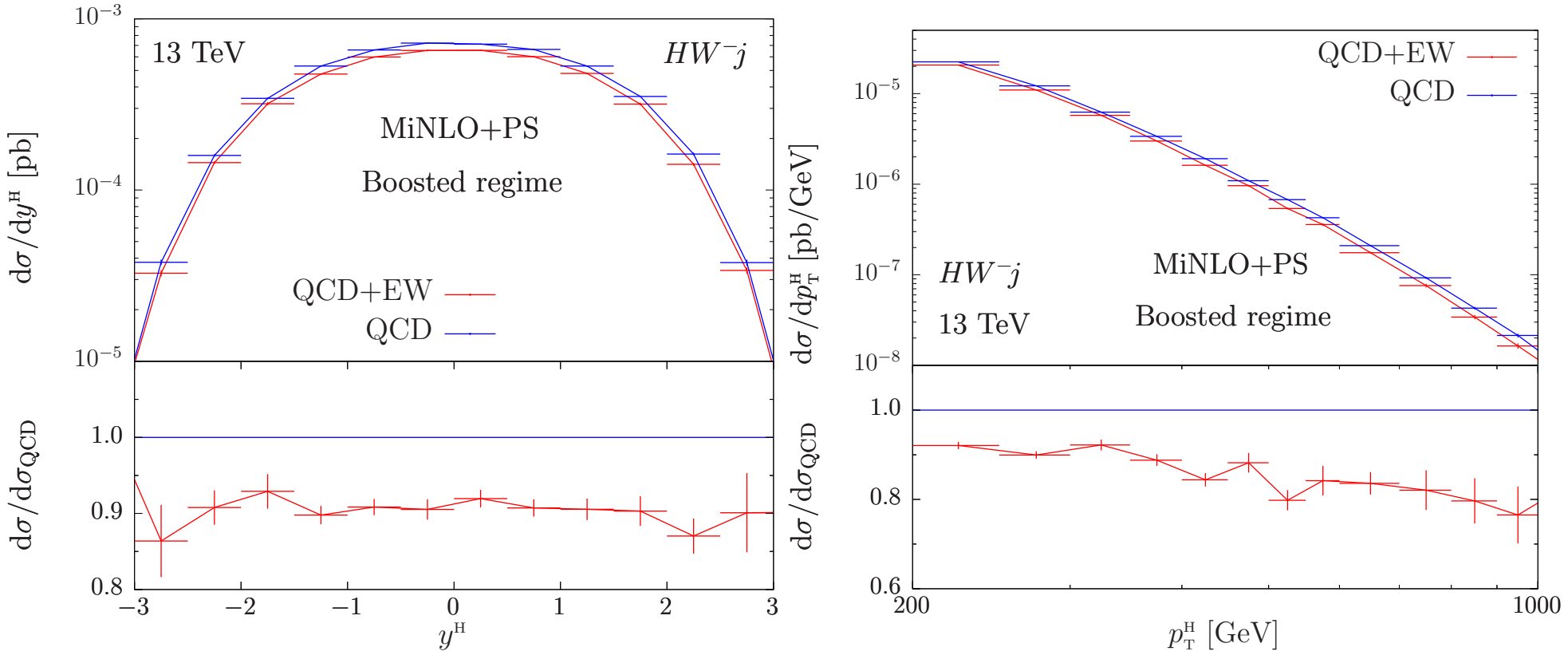
NLO + Parton Shower results for HZ production





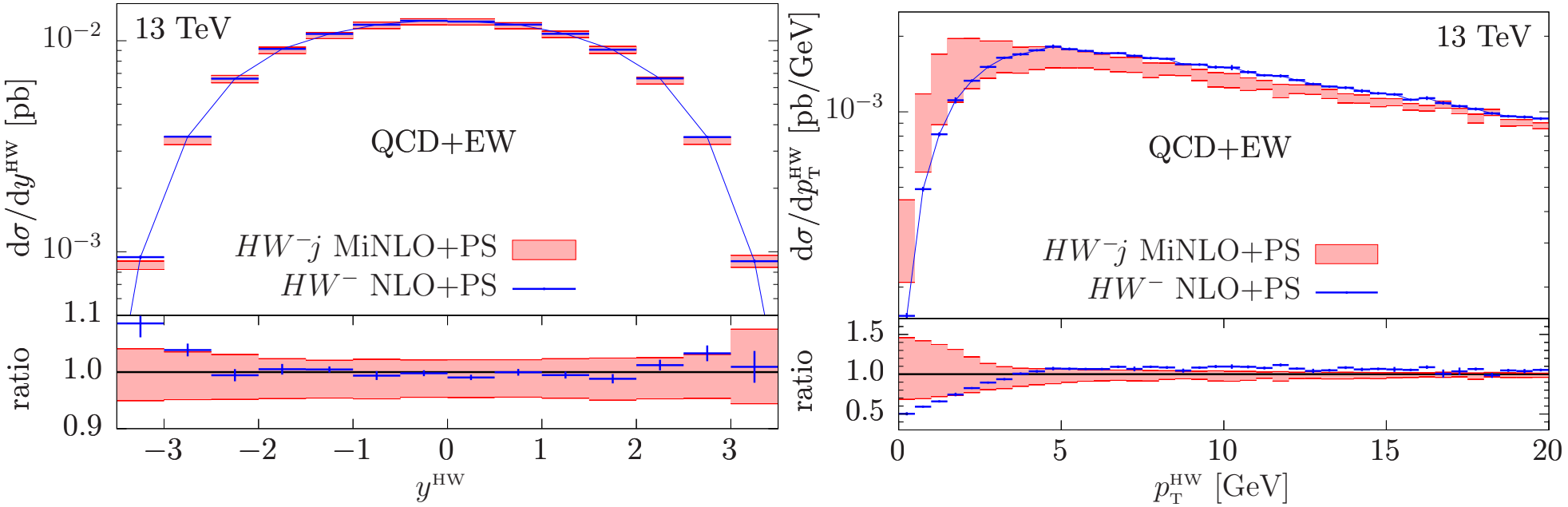
- Dressed leptons: bare leptons recombined with photons with $R_{\gamma\ell} < 0.1$
- `Pythia 8.1` contains exact matrix elements to describe photon radiation from $Z \to e^+e^-$: same shape as `POWHEG`. Different normalization due to EW virtual corrections.
- If the QED shower is switched off in `Pythia 8.1`, distortions up to 40% appear in the region below the Z peak

MiNLO + Parton Shower results for HW^-j production



- These results closely agree with the corresponding ones for HW^- production.
- This supports the fact that the MiNLO predictions for HVj should preserve NLO QCD+EW accuracy for inclusive (with respect to the jet) quantities.

HV vs. *HVj* generators



- Scale variation bands (details in arXiv:1706.03522)
- With `MiNLO`, the y^{HW} and $p_{\mathrm{T}}^{\mathrm{HW}}$ distributions computed with the HWj generator are finite and agree with the results for HW.
- y^{HW} has NLO accuracy both in HV and with HVj.
  $p_{\mathrm{T}}^{\mathrm{HW}}$ has LO accuracy for HV and NLO accuracy for HVj.

Conclusions

✓ In the new release of the POWHEG BOX, the POWHEG BOX RES, the consistent treatment of radiation from resonances has been added.

- Given a list of possible partonic processes contributing to a particular production process, the program automatically finds all the possible resonance histories, and generates radiation by maintaining the virtuality of the decaying resonances.
- In addition, the automated phase-space integrator adapts itself to the given resonance history, in order to perform the correct importance sampling.
- The generation of QED radiation has been fully implemented both from massless and massive particles.
- The POWHEG BOX RES benefits from the interface to three automatic matrix-element generators: MadGraph 4, Gosam and OpenLoops.

Conclusions

- ✓ Using the interface to OpenLoops, we have built a code for HV and HVj production, accurate at NLO in QCD+EW.
- ✓ Electroweak corrections typically lower NLO+PS QCD predictions by 5 to 10% at the level of integrated cross sections and in angular distributions.
- ✓ Due to Sudakov logarithms, EW corrections can be much more sizable in the tails of transverse-momentum and invariant-mass distributions, where their negative contributions reach tens of percent.

`http://powhegbox.mib.infn.it/`