POWHEG-BOX: status and prospects

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ECFA Higgs Factories: 1st Topical Meeting on Generators

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The POWHEG BOX framework

- Main focus: matching of accurate fixed-order predictions with Parton Showers for SM processes, mostly for LHC Physics.
- Designed having QCD corrections in mind, infrastructure to handle EW corrections added later.
- Several BSM applications exist, but not the main focus.

- Organization:
  - Public to all theorists that want to contribute ($\sim$ 100 processes, $\sim$ 100 authors contributed)
  - Some "core" developers, not really a strictly well defined collaboration
  - Fully supported interfaces: `OpenLoops`, `GoSam`, `Madgraph4`, `MG5_aMC@NLO`
  - The Parton Shower is taken care of by `Pythia` or `Herwig`, through provided interfaces (LHE + user hooks when needed)
- All publicly available at

  `powhegbox.mib.infn.it`
- Two main releases
  - distributed through `svn`, webpage with extensive report of bugfixes and revision
  - POWHEG BOX V2: main release, almost all processes are here
  - POWHEG BOX RES: most recent one, created to deal with processes with resonances

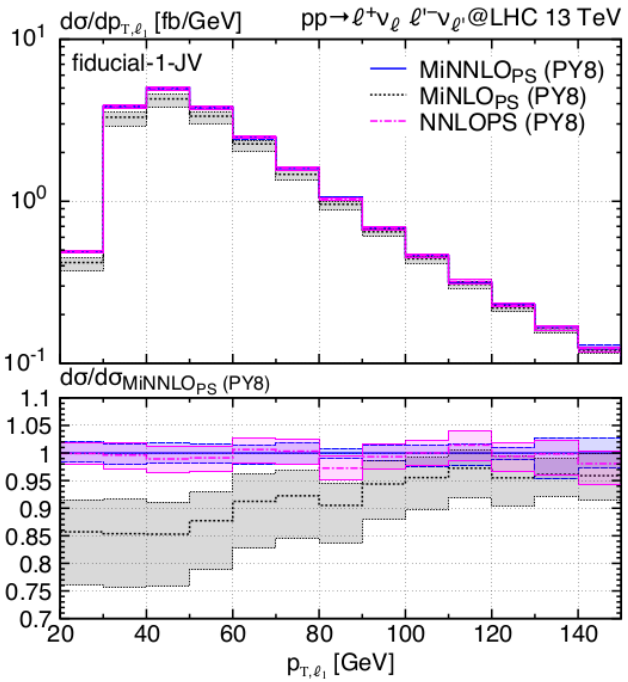
- This talk: quick overview of recent progress for LHC Physics + comments related to e^+e^- Physics.

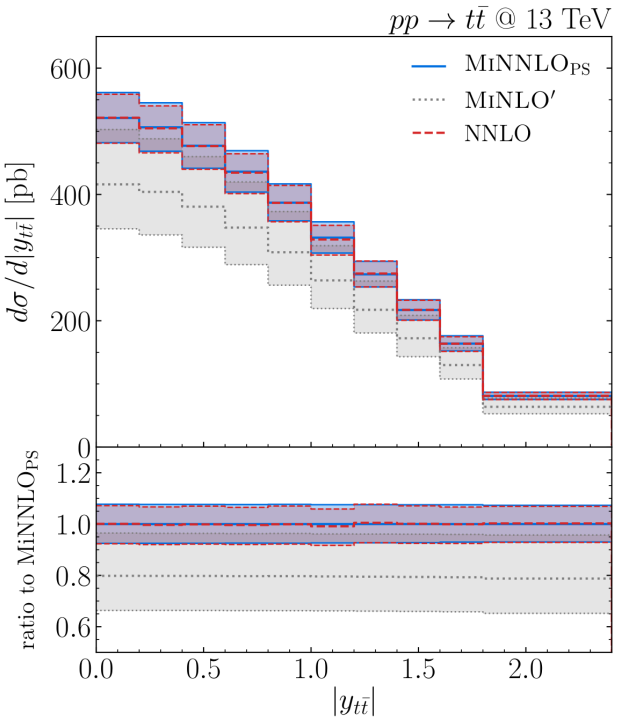
MiNNLO$_{PS}$

- Why? NNLO$_{QCD}$+PS without a-posteriori reweighting, within the `MiNLO` approach.
- Main equation: `POWHEG` $\bar{B}$ function written as

$$\mathrm{d}\sigma \sim e^{-[\tilde{S}(p_T)]}\left\{\alpha_S\,\mathrm{d}\sigma^{(1)}_{FJ}\left(1+\alpha_S\,[\tilde{S}(p_T)]^{(1)}\right)+\alpha_S^2\,\mathrm{d}\sigma^{(2)}_{FJ}+\alpha_S^3\,[D(p_T)]^{(\geq 3)}F^{corr}(\Phi_{FJ})\right\}$$

  where $[D(p_T)]^{(\geq 3)}$ contains the genuine NNLO ingredients, suitably combined.
- Succesfully applied to several color-singlet production processes (DY, ggH, VV, Vγ) & $t\bar{t}$ production. [Monni,Nason,ER,Wiesemann,Zanderighi + Mazzitelli + Lombardi,Buonocore,Rottoli '19-]

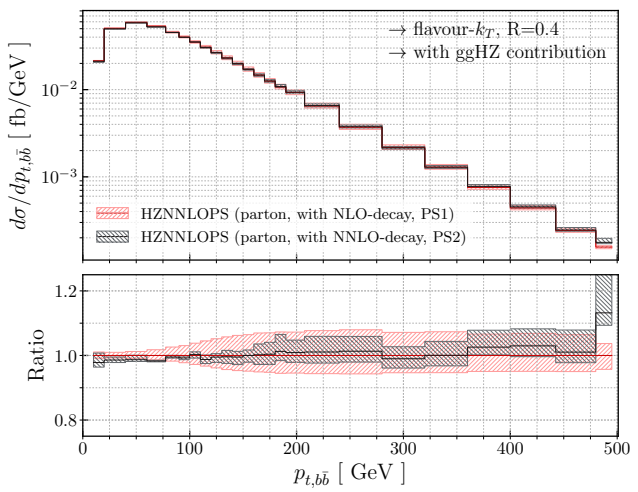


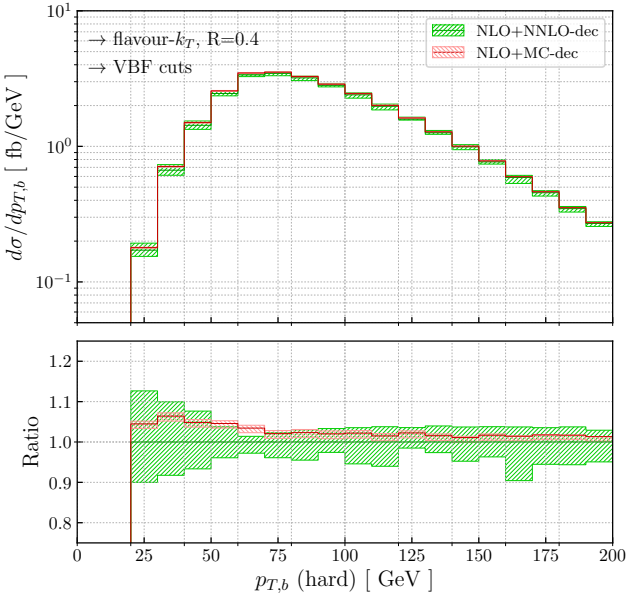


- here plots from [Lombardi, Wiesemann, Zanderighi '21] (WW, left) and [Mazzitelli, Monni, et al. '20] ($t\bar{t}$, right).

$H \to b\bar{b}$: an "e^+e^--like" application

- $H \to b\bar{b}$ with `MiNLO'` [Bizon,ER,Zanderighi, '19]
  - standalone generator, adapted from the main repository with minor changes
  - used to include Higgs decay in VH and VBF [interface working with partonic events (LHE), before PS].
  - NNLOPS from `MiNLO'` : NNLL resummation of 3-jet resolution parameter (CA) from 1607.03111 ($\delta\mathcal{F}_{\mathrm{clust.}}$ and $\delta\mathcal{F}_{\mathrm{correl.}}$)





- adding just QCD corrections to an e^+e^- initiated process: doable without too much effort. This misses many effects, though.

NLO$_{EW}$+PS

- NLO EW calculations for multileg processes: automated 1-loop providers [GoSam, MadLoop/MG5_aMC, NLOX, OpenLoops, Recola] + frameworks to handle integration/subtraction [MG5_aMC, Sherpa, MATRIX, POWHEG BOX, ...], full automation in MG5_aMC.
- (NLO$_{QCD}$+) NLO$_{EW}$+PS: area where progress is being made (matching not conceptually solved in full generality).
- Current approach within POWHEG: exact matching of EW corrections for n- and $n+1$-body contributions

1st papers: [Barze et al. '12,'13, Carloni et al. '16]

- Use the POWHEG BOX RES framework [Jezo, Nason '15]

$$\bar{B}(\Phi_B) = B(\Phi_B) + [V_{\rm QCD}(\Phi_B) + V_{\rm EW}(\Phi_B)] + \int \mathrm{d}\Phi_{\rm rad}\,[R_{\rm QCD}(\Phi_B,\Phi_{\rm rad}) + R_{\rm EW}(\Phi_B,\Phi_{\rm rad})]$$

$$\Delta_{p_{\rm T}}(\Phi_B) = \Delta^{\rm QCD}_{p_{\rm T}}(\Phi_B) \times \Delta^{\rm EW}_{p_{\rm T}}(\Phi_B)$$

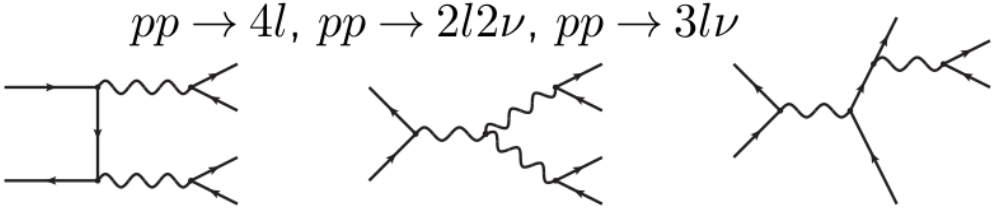
- generate one radiation from each resonance
- requires dedicated interface to Parton Shower
- additive scheme + factorizable & mixed $\alpha_{\rm S}^n \alpha_{\rm EW}^m$ terms, only in collinear limit

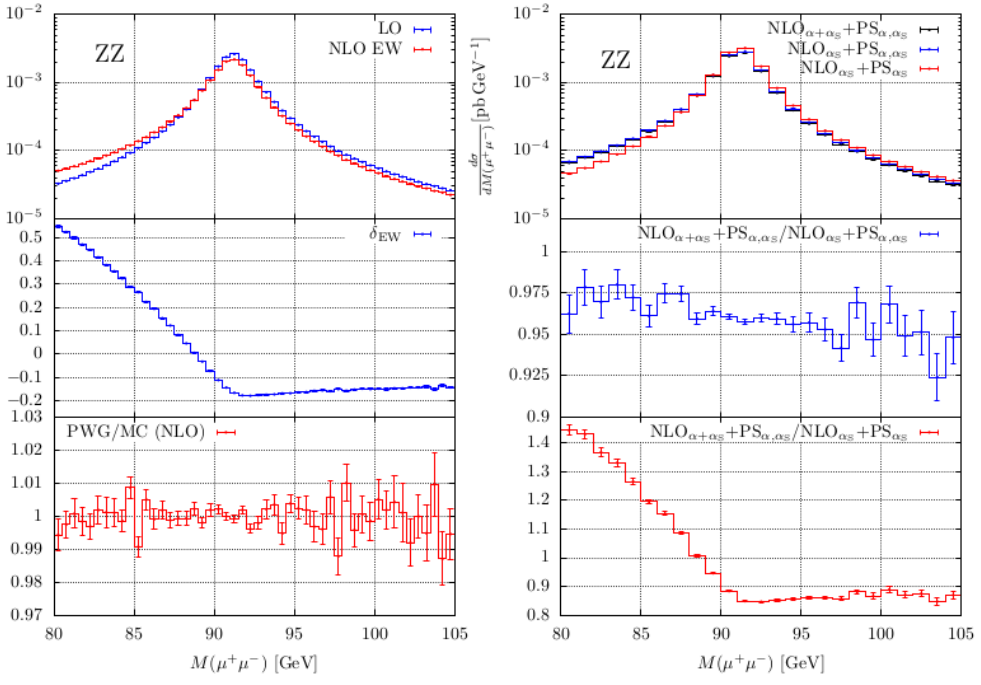
VV: exact NLO$_{\text{QCD}}$+NLO$_{\text{EW}}$+PS$_{\text{QCD,QED}}$

[Chiesa,Oleari,ER '20]

loop amplitudes from `Recola2`

$pp \to 4l,\ pp \to 2l2\nu,\ pp \to 3l\nu$





- possible to have control on few percent effects
- NLO$_{\alpha_S+\alpha}$ + PS$_{\alpha_S,\alpha}$ / NLO$_{\alpha_S}$ + PS$_{\alpha_S,\alpha}$:

  - NLO weak, non-log QED $\mathcal{O}(\alpha)$, mixed
- NLO$_{\alpha_S+\alpha}$ + PS$_{\alpha_S,\alpha}$ / NLO$_{\alpha_S}$ + PS$_{\alpha_S}$:

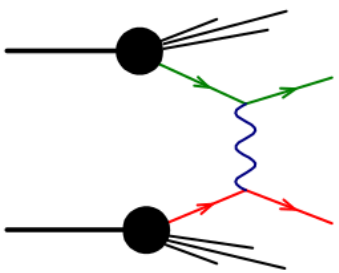
  - NLO weak, QED $\mathcal{O}(\alpha)$, leading-log QED $\mathcal{O}(\alpha^n)$ $(n > 2)$, mixed

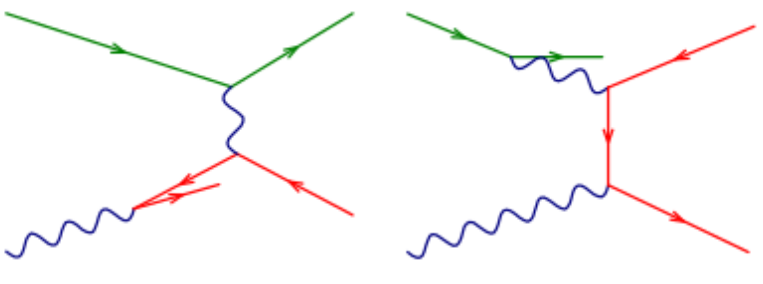
What's missing here: photons in initial state, merging with QCD corrections for $WW + 1$ jet

Handling of initial state leptons/photons in pp collision

[Buonocore,Nason,Tramontano,Zanderighi '21]

- study of NLO corrections for $\gamma\gamma \to \phi$, $\ell\bar{\ell} \to \phi$, non-Drell-Yan pair production.
- some ingredients that would be needed for QED corrections (for γ induced channels) added
- complete handling of IR subtraction for $\gamma \to \ell\bar{\ell}$: counts as $\alpha_{\rm S}$ because originates from q PDF.
- initial-state $\ell \to \ell\gamma$ subleading in the context of [Buonocore,et al. '21]





Comments & conclusions

`POWHEG BOX`: code initially thought for LHC Physics.

For several aspects, certainly not ready for fully realistic e^+e^- simulation.

- Beamstrahlung: FCC, CLIC, ILC
- Beamspot/crossing angle
- polarization

- output format: LHE $\rightarrow$ PS
- code management/availability or source code: currently `svn`.
  - planned discussion within main developers on making communication with EXP users more easily accessible.
- LHE: we rely on it, together with dedicated interfaces to `Pythia` and `Herwig`.
  - when multiple radiation: different starting scales.
- NLO corrections: QCD and EW are part of current development in pp
  - basic ingredients can be adapted for e^+e^-.
- CPU performance: so far, even for more complex processes, we managed to deal with them through “reweighting” + “parallelization”
  - reweighting: minimize calls to CPU-intensive routines / avoid recomputing
  - parallelization: so far, no need of particularly complicated arrangements (that we are aware of), just multicore
  - plans to explore use of GPU

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Thanks for your attention