

Fixed-order and merged parton-shower predictions for WW and WWj production at the LHC including NLO QCD and EW corrections

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→ Based on [arXiv:2005.12128](#), [JHEP 2010 \(2020\) 159](#)

In collaboration with:

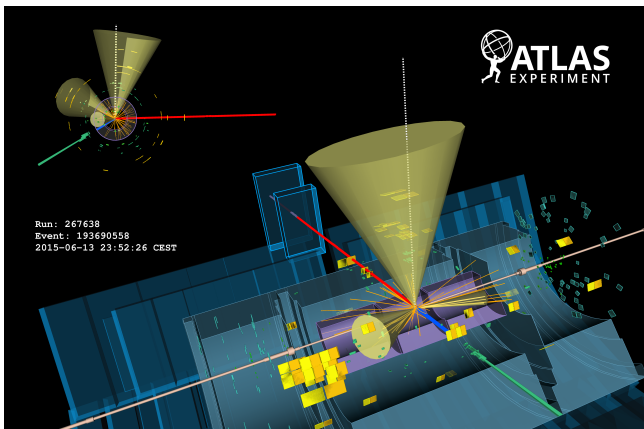
Stephan Bräuer, Ansgar Denner, Marek Schönherr, Steffen Schuman

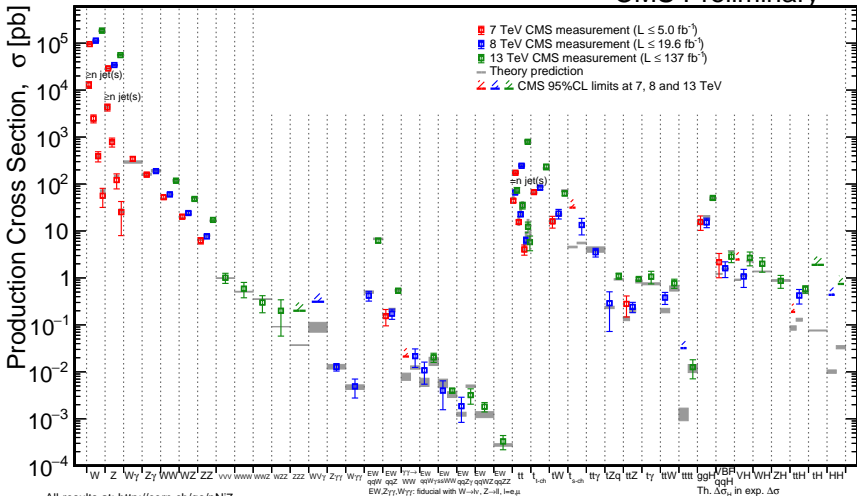
LHCEWWG-MB: Dibosons
CERN, Geneva, Switzerland

28th of May 2021



LHC: Great tool to probe fundamental interactions at high energies
→ Great to measure jets and bosons leptons

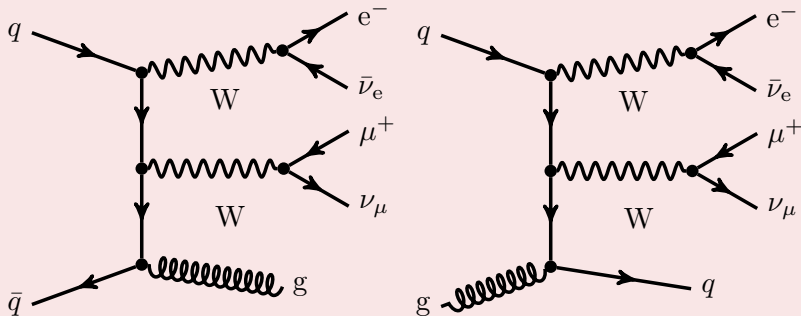




→ $VV + \text{jet}$ processes not yet on the (CMS) plot...

- What is $WW+\text{jet}$...
... and why you want to compute it
- Fixed-order results
 - WW production
 - WWj production
 - Ratios of WW and WWj
- Multi-jet merged results
 - Fixed-order vs. merged results at NLO QCD
 - Including EW corrections via the virtual approximation
 - Ratios of WW and WWj

LO diagrams and motivations



- Simply WW production in association with one jet
 - Search for anomalous triple gauge-boson couplings (as for diboson)
 - Different kinematic / complementary
 - First measurement of $pp \rightarrow W^+W^-j$ by ATLAS [1608.03086]

⚠ Need for precise predictions!

- $pp \rightarrow WW$ (see previous talk)
- $pp \rightarrow WWj$
 - NLO QCD: [Dittmaier, Kallweit, Uwer; 0908.4124], [Cascioli et al.; 1309.0500]
 - Merged predictions: [Hamilton et al.; 1606.07062]
 - NLO EW: [Li et al.; 1507.07332] (on-shell)
 - no NNLO QCD predictions

This work

Inclusion of EW corrections in (QCD) merged predictions

→ Merged PS effects with approximate EW corrections
(included via virtual EW approximation)

[Kallweit et al; 1511.08692], [Gütschow, Lindert, Schönherr; 1803.00950]

NB: [Chiesa, Oleari, Re; 2005.12146], similar intention but restricted to WW

Features of the computation

- Fixed-order analysis at NLO QCD+EW
 - for off-shell pp → $\mu^+ \nu_\mu e^- \bar{\nu}_e$
 - for off-shell pp → $\mu^+ \nu_\mu e^- \bar{\nu}_{ej}$
- Inclusive sample with:
 - merged predictions + PS + approximate EW corrections
 - pp → $\mu^+ \nu_\mu e^- \bar{\nu}_e + 0, 1j@NLO + 2, 3j@LO$
(MEPS@NLO/MENLOPS method)
[Höche et al.; 0903.1219, 1009.1127, 1207.5030, 1207.5031, 1403.7516]
 - Can be studied with $n_j = 0$ (WW) or $n_j = 1$ (WWj)

- $pp \rightarrow \mu^+ \nu_\mu e^- \bar{\nu}_e$

$$p_{T,\ell} > 20 \text{ GeV}, \quad |y_\ell| < 2.5, \quad \Delta R_{\ell\ell'} > 0.1$$

$$m_{\ell\ell} > 10 \text{ GeV}, \quad p_{T,\text{miss}} > 20 \text{ GeV}$$

Jet-veto:

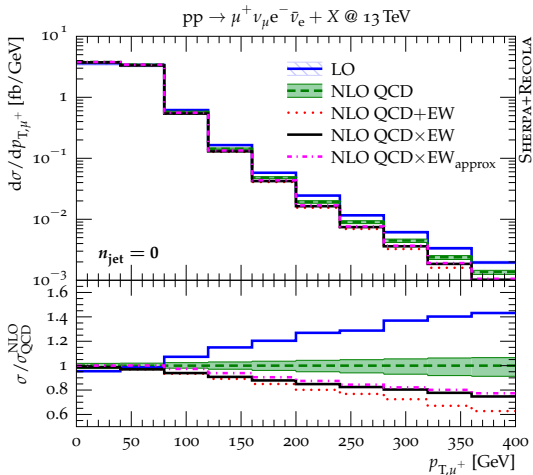
$$p_{T,j} > 25 \text{ GeV} = p_{T,j,\text{cut}} \quad \text{and} \quad |y_j| < 2.5$$

- $pp \rightarrow \mu^+ \nu_\mu e^- \bar{\nu}_e j$

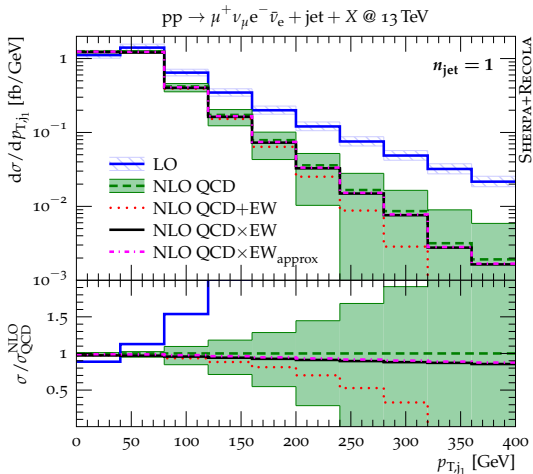
- Same lepton cuts
- $p_{T,j} > 25 \text{ GeV}$ and $|y_j| < 2.5$ + $\Delta R_{\ell\pm j} > 0.4$
- Same jet veto for extra jets

Fixed-order results NLO QCD+EW

- for off-shell $pp \rightarrow \mu^+ \nu_\mu e^- \bar{\nu}_e$
- for off-shell $pp \rightarrow \mu^+ \nu_\mu e^- \bar{\nu}_e j$
- Ratios

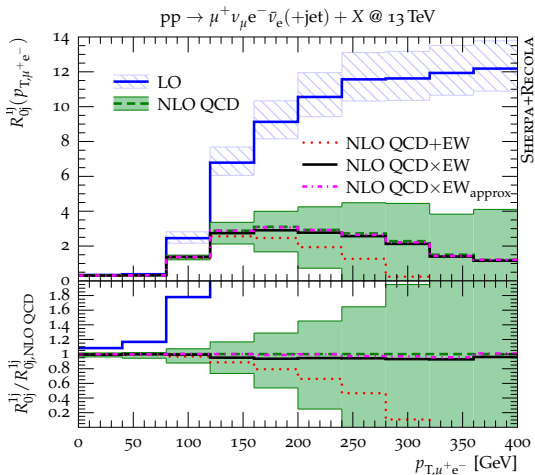


- Two consistent prescriptions (additive and multiplicative)
- EW virtual approximation reliable in high-energy limit



- Large QCD corrections: effect of the jet veto
- EW corrections: Sudakov logarithms

Ratio between W^+W^-j and W^+W^- @ fixed order



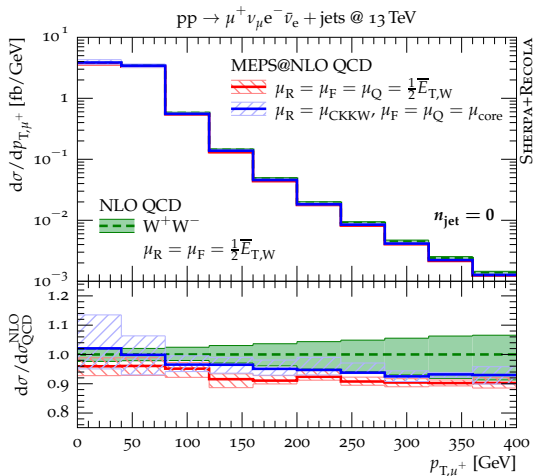
- Very large ratios between WWj and WW (sensitive to jet veto)
 \rightarrow Ratio motivated by ATLAS measurement [1608.03086]
- Multiplicative approach favoured

(identical leading-logarithmic corrections [Denner, Pozzorini; hep-ph/0010201])

Multi-jet merged results

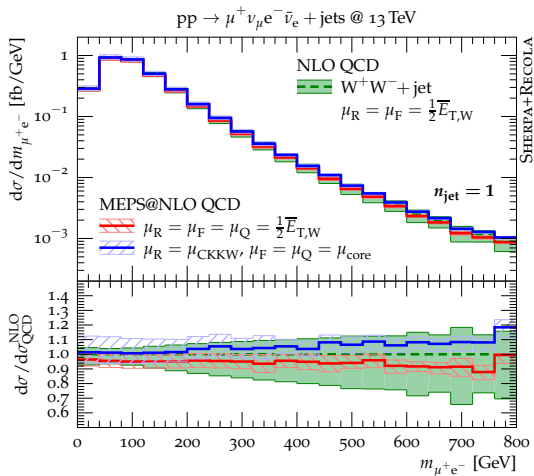
- Fixed-order vs. merged results at NLO QCD
- Including EW corrections via the virtual approximation
- Ratios of WW and WWj

pp $\rightarrow W^+W^-$ fixed order vs. merged PS

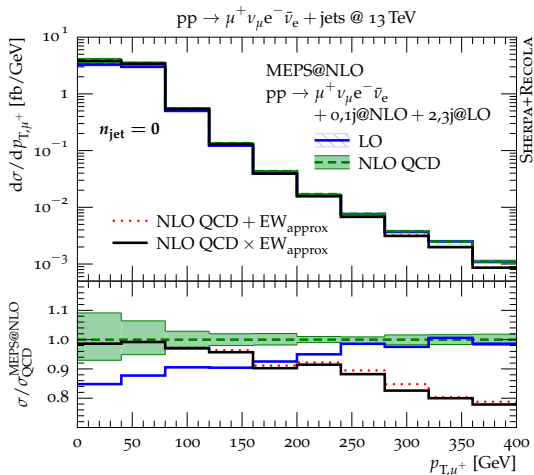


- Two prescriptions for the merged results (red curve: inconsistent merging)
- Consistent result between fixed-order and merged predictions

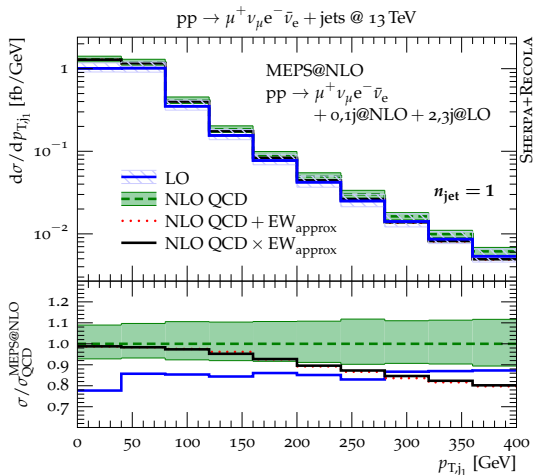
pp $\rightarrow W^+W^-j$ fixed order vs. merged PS



- Same picture as in the WW case

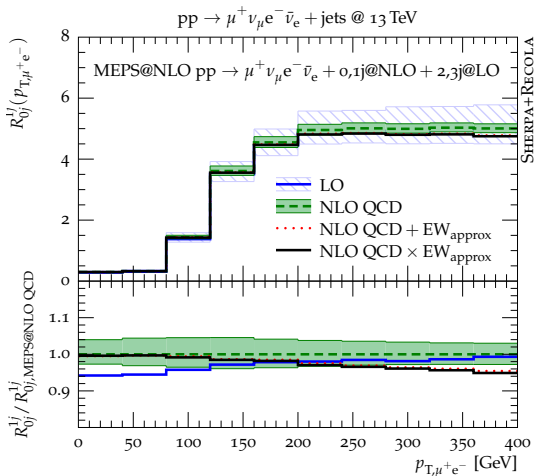


- Two prescriptions consistent



- Same picture as for pp $\rightarrow W^+W^-$

Ratio between W^+W^-j and W^+W^- beyond fixed order



- For multi-jet merged parton-shower: much more stable ratios

- New computation for $pp \rightarrow W^+W^-$ and $pp \rightarrow W^+W^-j$
→ [Bräuer, Denner, MP, Schönherr, Schumann; 2005.12128]
- Fixed-order analysis at NLO QCD+EW
→ for off-shell $pp \rightarrow \mu^+\nu_\mu e^- \bar{\nu}_e$
→ for off-shell $pp \rightarrow \mu^+\nu_\mu e^- \bar{\nu}_{ej}$
- Inclusive sample with:
 - merged predictions + PS + approximate EW corrections
→ $pp \rightarrow \mu^+\nu_\mu e^- \bar{\nu}_e + 0, 1j @ \text{NLO} + 2, 3j @ \text{LO}$
 - Can be studied with $n_j = 0$ or $n_j = 1$

Possible directions

- Comparison against experimental data ...
 $pp \rightarrow W^+W^-j$ and ratios to $pp \rightarrow W^+W^-$
- Comparison against other theoretical predictions for ...
... $pp \rightarrow W^+W^-$ and $pp \rightarrow W^+W^-j$

Thank you