Monte Carlo comparisons
VBSCAN Cost Action

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August 2, 2017

Abstract

Part I

Introduction

Part II

$\mathbf{pp} \to \mu^+ \nu_\mu \mathbf{e}^+ \nu_\mathbf{e} \mathbf{jj}$

0.1 Input parameters

- Centre-of-mass energy of 13 TeV at the LHC.
- Parton distribution function (PDF): NNPDF-3.0 at NLO with $\alpha_{\rm s}\left(M_{\rm Z}\right)=0.118$ (we use it at both LO and NLO). The LHAPDF ID for this set is 260000.
- Flavour scheme: fixed $N_{\rm F}=5$ flavour scheme (no bottom quark appear in the final or initial state). This means that the bottom quark is considered massless.
- Photon induced are neglected (for now).
- Renormalisation scheme: complex-mass scheme if possible. If other schemes are used, we have to estimate the possible differences. - Factorisation scheme: $\overline{\rm MS}$ as for NNPDF.
- Scales: factorisation and renormalisation scale, $\mu_R=\mu_F=M_{\rm W}$.
- α: G_μ scheme with:

$$\alpha=\frac{\sqrt{2}}{\pi}G_\mu M_{\rm W}^2\left(1-\frac{M_{\rm W}^2}{M_{\rm Z}^2}\right)\qquad\text{with}\qquad G_\mu=1.16637\times10^{-5}\,{\rm GeV}. \tag{1}$$

The numerical value is: $\alpha=7.555310522369\times10^{-3}$.
- Mass and width of the massive particles:

$$\begin{aligned} m_{\rm t}&=173.21\,{\rm GeV}, & \Gamma_{\rm t}&=0\,{\rm GeV},\\ M_{\rm Z}^{\rm OS}&=91.1876\,{\rm GeV}, & \Gamma_{\rm Z}^{\rm OS}&=2.4952\,{\rm GeV},\\ M_{\rm W}^{\rm OS}&=80.385\,{\rm GeV}, & \Gamma_{\rm W}^{\rm OS}&=2.085\,{\rm GeV},\\ M_{\rm H}&=125.0\,{\rm GeV}, & \Gamma_{\rm H}&=4.07\times10^{-3}\,{\rm GeV}. \end{aligned} \tag{2}$$

The pole masses and widths entering the calculation are expressed in terms of the measured on-shell (OS) values for the W and Z bosons according to

$$M_V=M_V^{\rm OS}/\sqrt{1+(\Gamma_V^{\rm OS}/M_V^{\rm OS})^2}\,,\qquad \Gamma_V=\Gamma_V^{\rm OS}/\sqrt{1+(\Gamma_V^{\rm OS}/M_V^{\rm OS})^2}. \tag{3}$$

Hence the numerical values are

$$\begin{aligned} M_{\rm Z}&=91.1534806191827\,{\rm GeV}, & \Gamma_{\rm Z}&=2.494266378772824\,{\rm GeV},\\ M_{\rm W}&=80.3579736098775\,{\rm GeV}, & \Gamma_{\rm W}&=2.084298998278219\,{\rm GeV}. \end{aligned} \tag{4}$$

- Experimental signature: two equally charged leptons, missing transverse energy and at least two jets.
- Clustering: QCD partons are clustered into jets using the anti-$k_{\rm T}$ algorithm with jet-resolution parameter $R=0.4$. Photons from real radiation are recombined with the final-state quarks into jets or with the charged leptons into dressed leptons, in both cases via the anti-$k_{\rm T}$ algorithm and a resolution parameter $R=0.1$ (this applies only when computing the EW corrections).
- Rapidity definition: $y=\frac{1}{2}\ln\frac{E+p_z}{E-p_z}$ where E is the energy of the parton and p_z the component of its momentum along the beam axis.
- Distance definition:

$$\Delta R_{ij}=\sqrt{(\Delta\phi_{ij})^2+(\Delta y_{ij})^2}, \tag{5}$$

with

$$\Delta\phi_{ij}=\begin{cases}|\phi_i-\phi_j| & \text{if } |\phi_i-\phi_j|<\pi\\ 2\pi-|\phi_i-\phi_j| & \text{else}\end{cases} \tag{6}$$

Contact person	Code	$\mathcal{O}(\alpha^6)$ $\lvert s\rvert^2$/ $\lvert t\rvert^2/\lvert u\rvert^2$	$\mathcal{O}(\alpha^6)$ interf.	Off-shell	NF QCD	EW corr. to $\mathcal{O}(\alpha^5\alpha_s)$
A. Karlberg	POWHEG	t/u	No	Yes	No	No
M. Pellen	RECOLA +MOCANLO	Yes	Yes	Yes	Yes	Yes
M. Rauch	VBFNLO	Yes	No	Yes	No	No
C. Schwan	BONSAY	t/u	No	Yes, virt. No	No	No
M. Zaro	MG5_AMC	Yes	Yes	Yes	No	No

Table 1: Summary of the different properties of the codes employed in the comparison.

being the positive azimuthal-angle difference and $\Delta y_{ij} = |y_i - y_j|$ being the positive rapidity difference.
- Definition of the missing transverse energy: transverse momentum of the sum of the two neutrinos momenta.
- Cuts on the leptons:

$$p_{\mathrm{T},\ell} > 20\,\mathrm{GeV}, \qquad |y_\ell| < 2.5, \qquad \Delta R_{\ell\ell} > 0.3. \tag{7}$$

- Missing energy cut:

$$E_{\mathrm{T,miss}} = p_{\mathrm{T,miss}} > 40\,\mathrm{GeV} \tag{8}$$

- Jet definition:

$$p_{\mathrm{T,j}} > 30\,\mathrm{GeV}, \qquad |y_{\mathrm{j}}| < 4.5, \qquad \Delta R_{\mathrm{j}\ell} > 0.3. \tag{9}$$

- Out of these 2/3 jets, the two hardest in pT (tagged jets)are required to have:

$$m_{\mathrm{jj}} > 500\,\mathrm{GeV}, \qquad |\Delta y_{\mathrm{jj}}| > 2.5. \tag{10}$$

- Isolation of the lepton, all jets in the event (also the one of the real radiation) are required to satisfy

$$\Delta R_{\mathrm{j}\ell} > 0.3. \tag{11}$$

0.2 Codes

0.2.1 POWHEG: Alexander Karlberg

VBF approximation?

0.2.2 VBFNLO: Michael Rauch

VBF approximation

0.2.3 WHIZARD: Simon Brass, Jürgen Reuter, Pascal Stienemeier

Full matrix element

0.2.4 Recola +MoCaNLO: Mathieu Pellen

Full matrix element

0.2.5 MadGraph5_aMC@NLO: Marco Zaro

To be checked what is possible

0.2.6 BONSAY: Christopher Schwan

0.3 Observables

- Cross section within cuts.
- Distribution in the number of jets.
- Invariant mass of the two hardest jets (two tagged jets).
[0; 4 TeV] with bins of size 100 GeV (40 bins).
- $p_{\mathrm{T},\mathrm{j}_1,\mathrm{j}_2}$ and $y_{\mathrm{j}_1,\mathrm{j}_2}$ of the two tagged jets (not their sum)
$p_{\mathrm{T},\mathrm{j}_1,\mathrm{j}_2}$: [0; 1 TeV] with bins of size 25 GeV (40 bins).
$y_{\mathrm{j}_1,\mathrm{j}_2}$: $[-5; 5]$ with bins of size 0.5 (20 bins).
- Invariant mass of the two charged leptons.
[0; 4 TeV] with bins of size 100 GeV (40 bins).
- Zeppenfeld variable for μ^+ and e^+:
$z^*_\ell = |y_\ell - \left(y_{\mathrm{j}_1} + y_{\mathrm{j}_2}\right)/2|/|\Delta y_{\mathrm{jj}}|$
[0; 1.5] with bins of size 0.05 (30 bins).
- $|\Delta y_{\mathrm{jj}}|$: $[-5; 5]$ with bins of size 0.5 (20 bins).

0.4 Numerical results

0.4.1 LO $\mathcal{O}(\alpha^6)$

Code	σ[fb]
POWHEG	1.5573 ± 0.0003
Recola +MoCaNLO	1.5503 ± 0.0003
VBFNLO	1.5538 ± 0.0002
BONSAY	1.5524 ± 0.0002
WHIZARD	1.5539 ± 0.0004
MG5_aMC	1.547 ± 0.001

Table 2: LO rates within VBS cuts from the different codes.

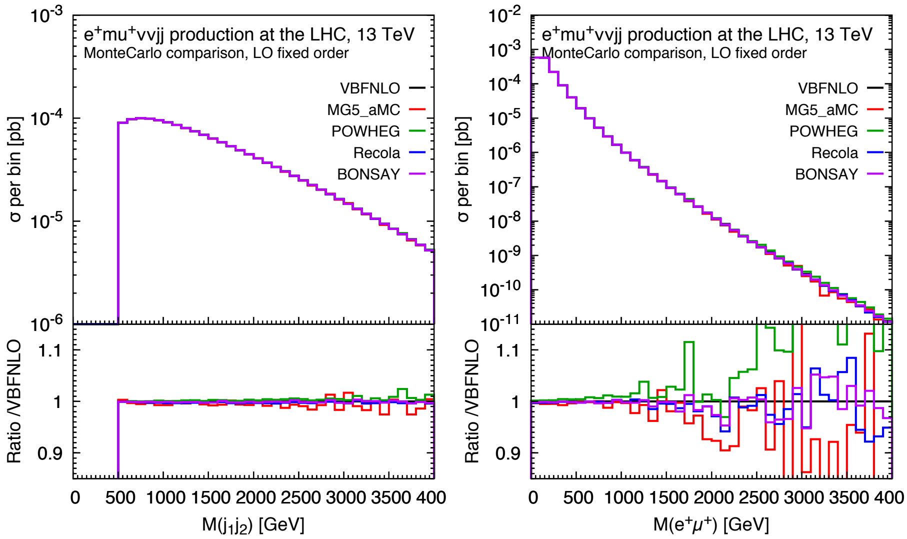

Figure 1: Invariant-mass of the two tagging jets (left) and of the two leptons (right), at LO.

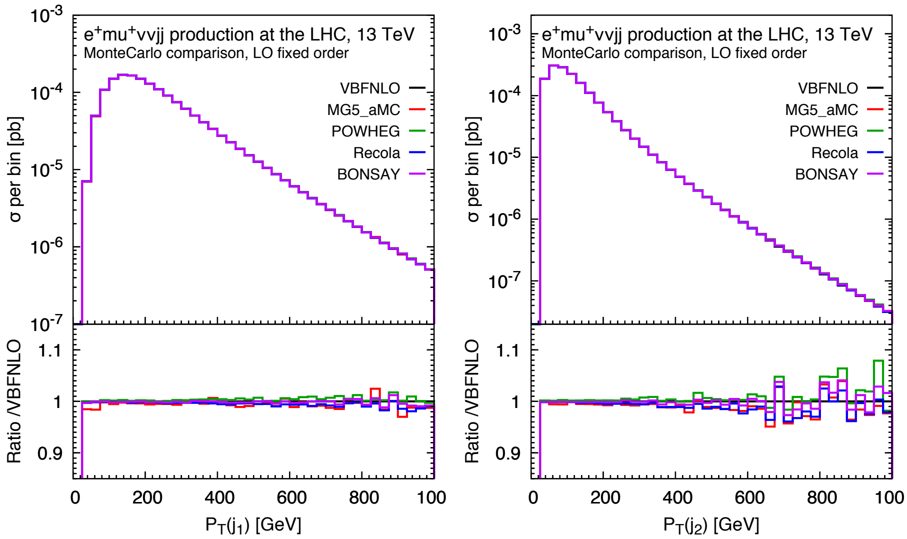

Figure 2: Transverse momentum of the first (left) and second (right) tagging jet, at LO.

0.4.2 NLO $\mathcal{O}\left(\alpha^6\alpha_s\right)$

0.5 Plan

The plan is:
- Scan in m_{jj} and $|\Delta y_{jj}|$ at LO and compute the EW, QCD and interference (for the one who can) contribution.

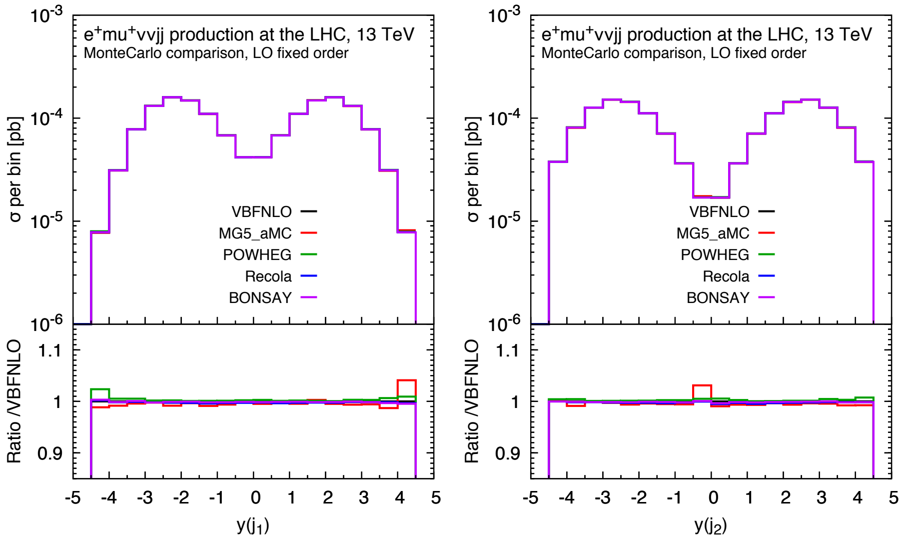

Figure 3: Rapidity of the first (left) and second (right) tagging jet, at LO.

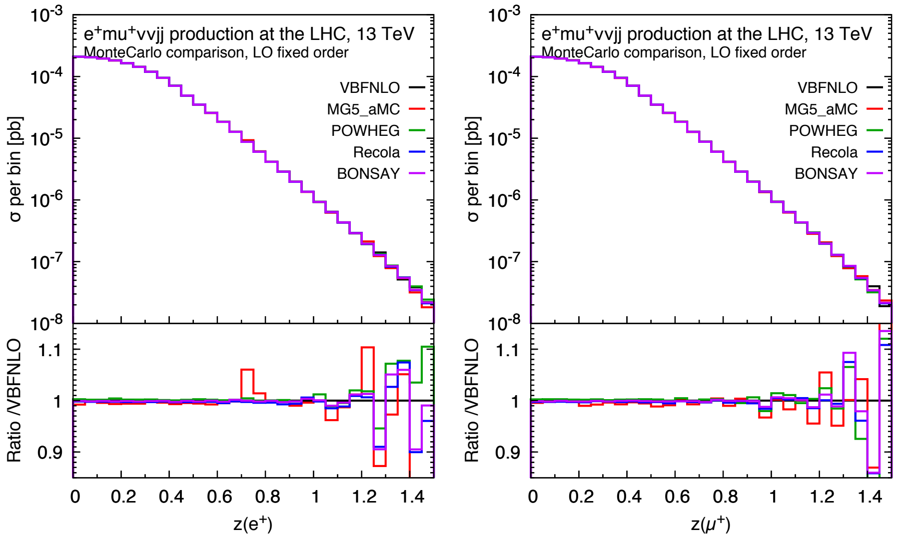

Figure 4: Zeppenfeld variable of the positron (left) and of the muon (right), at LO.

The binning in $m_{\rm jj}$ is $[0, 50, 100, ..., 450, 500, 600, 700, 800]$.
The binning in $|\Delta y_{\rm jj}|$ is $[0, 0.5, 1.0, 1.5, ..., 4.5, 5.0]$.
- Based on this, define a "control region" and a "signal region" (should be the one we have identified already). - Compute the QCD correction to QCD-induced and EW in these two regions. - Add PS to these computations (for those who can). - Add EW on top (probably only Mathieu).

Code	σ[fb]	$\sigma(n_j = 2)$[fb]	$\sigma(n_j = 3)$[fb]
POWHEG	1.334 ± 0.0003	0.808 ± 0.001	0.5260 ± 0.0005
RECOLA +MOCANLO	1.317 ± 0.004		
VBFNLO	1.3531 ± 0.0003	0.8264 ± 0.0003	0.5267 ± 0.0001
BONSAY	1.3366 ± 0.0009	0.8199 ± 0.0008	0.51663 ± 0.00007
MG5_AMC	1.318 ± 0.003	0.781 ± 0.004	0.5374 ± 0.0016

Table 3: NLO rates within VBS cuts from the different codes.

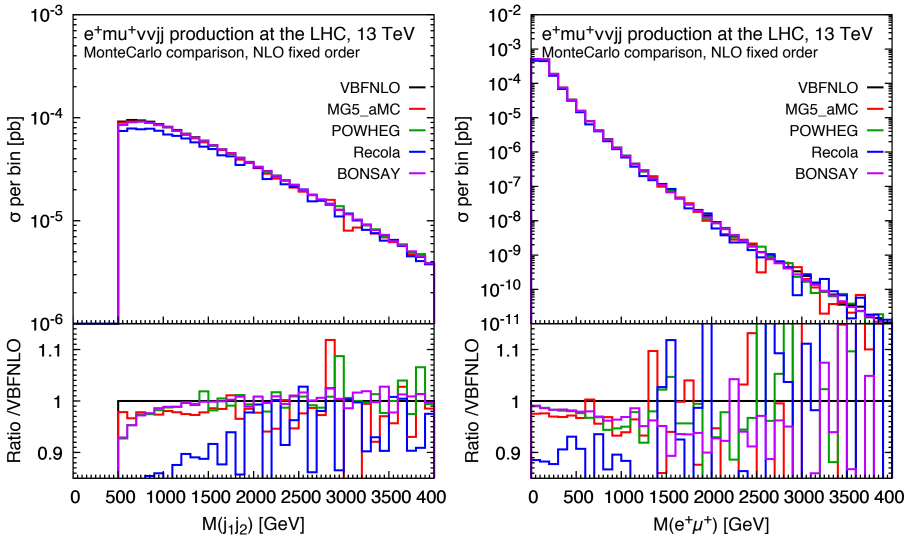

Figure 5: Invariant-mass of the two tagging jets (left) and of the two leptons (right), at NLO.

0.6 Remarks

- [MP: Do we want to keep the cuts as they are or do we want to update to the recomandation of WG2?]
- [MP: In particular we should write the report/article as we go further in the project in order to save time.]

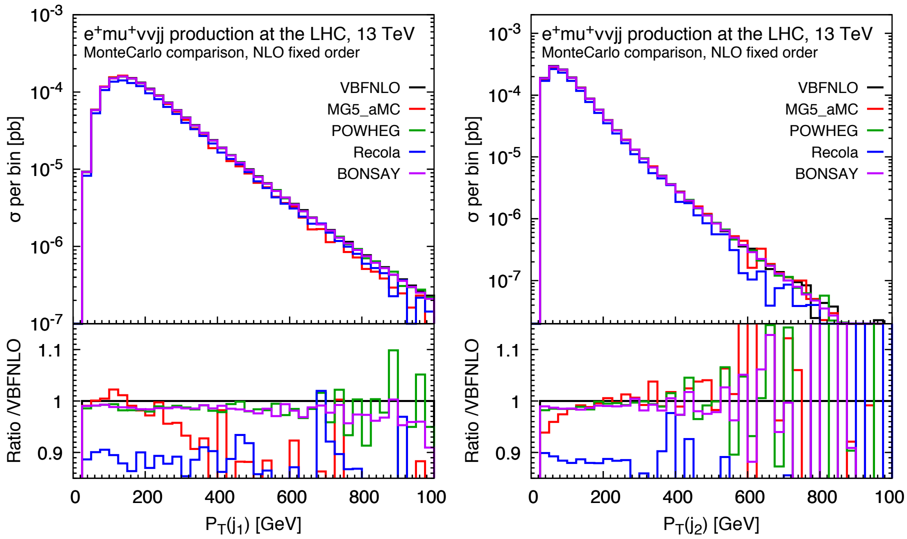

Figure 6: Transverse momentum of the first (left) and second (right) tagging jet, at NLO.

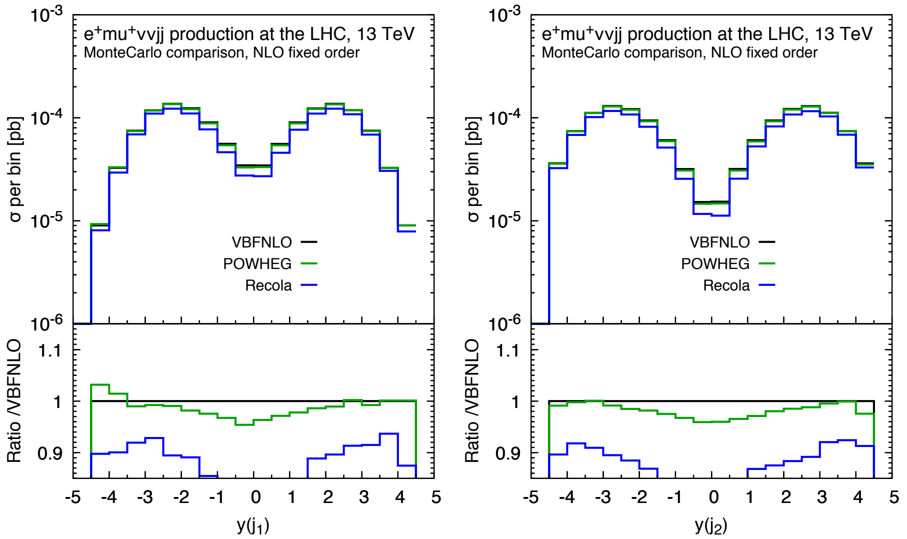

Figure 7: Rapidity of the first (left) and second (right) tagging jet, at NLO.

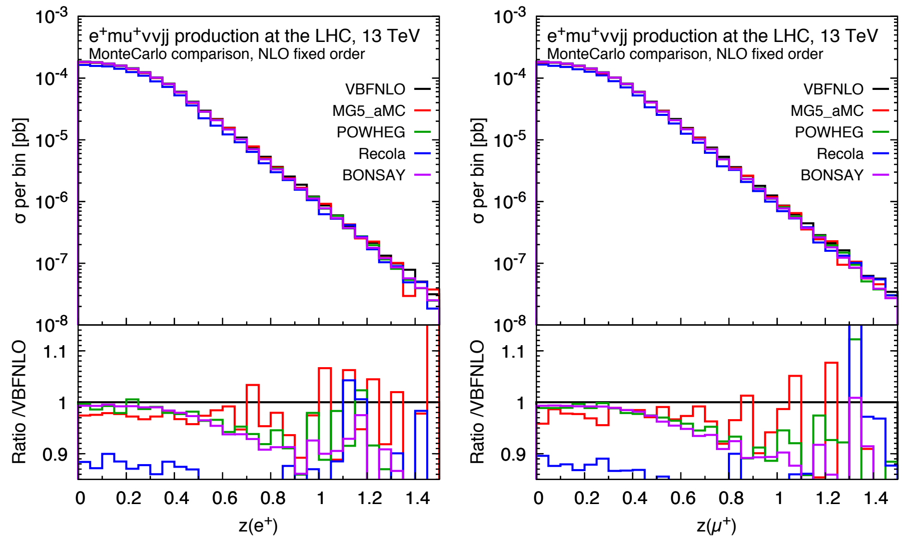

Figure 8: Zeppenfeld variable of the positron (left) and of the muon (right), at NLO.

Part III

Conclusion

Part IV

Acknowledgments

Karlsruhe for hosting the documents used for the comparison.