Monte Carlo comparisons VBSCAN Cost Action

Mathieu Pellen, Marco Zaro, Alexander Karlberg, Michael Rauch, Jürgen Reuter, Christopher Schwan

June 21, 2017



Part I Introduction

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

0.1 Input parameters

- Centre-of-mass energy of 13 TeV at the LHC.
- Parton distribution function (PDF): NNPDF-3.0 at NLO with $\alpha_{\rm s}\,(M_{\rm Z})=0.118$ (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, $\mu_R = \mu_F = M_W$.
- α : G_{μ} scheme with:

$$\alpha = \frac{\sqrt{2}}{\pi} G_{\mu} M_{\rm W}^2 \left(1 - \frac{M_{\rm W}^2}{M_Z^2} \right)$$
 with $G_{\mu} = 1.16637 \times 10^{-5} \,\text{GeV}.$ (1)

The numerical value is: $\alpha = 7.555310522369 \times 10^{-3}$.

- Mass and width of the massive particles:

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

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

Hence the numerical values are

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

- 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

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

Contact person	Code	$ \left \begin{array}{c} \mathcal{O}(g_W^6) \\ s/t/u \end{array} \right $	$\mathcal{O}(g_W^6)$ interf.	Off- shell	NF QCD	EW corr. to $\mathcal{O}(g_W^4 g_s^2)$
A. Karlberg	POWHEG	t/u	No	Yes	No	No
M. Pellen	Recola	Yes	Yes	Yes	Yes	Yes
M. Rauch	VBFNLO	Yes	No	Yes	No	No
C. Schwan	PSI	t/u	No	Yes,	No	No
				virt. 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:

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

- Missing energy cut:

$$E_{\rm T,miss} = p_{\rm T,miss} > 40 \,\text{GeV}$$
 (8)

- Jet definition:

$$p_{T,j} > 30 \,\text{GeV}, \qquad |y_j| < 4.5.$$
 (9)

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

$$m_{\rm ij} > 500 \,\text{GeV}, \qquad |\Delta y_{\rm ij}| > 2.5.$$
 (10)

- All jets in the event are required to satisfy

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

0.2 Codes

0.2.1 POWHEG: Alexander Karlberg

VBF approximation?

0.2.2 VBFNLO: Michael Rauch

VBF approximation

0.2.3 WHIZARD: Jürgen Reuter

Full matrix element

0.2.4RECOLA: Mathieu Pellen

Full matrix element

0.2.5MadGraph5_aMC@NLO: Marco Zaro

To be checked what is possible

0.3Observables

- 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).
- $p_{\mathrm{T,j_1,j_2}}$ and $y_{\mathrm{j_1,j_2}}$ of the two tagged jets (not their sum) $p_{\mathrm{T,j_1,j_2}}$: [0; 1 TeV] with bins of size 25 GeV (40 bins). $y_{\mathrm{j_1,j_2}}$: [-5; 5] with bins of size 0.5 (20 bins).
- Invariant mass of the two charged leptons. [0; 4 TeV] with bins of size $100 \,\overline{\text{GeV}}$ (40 bins).
- Zeppenfeld variable for μ^+ and e^+ :
- $z_{\ell}^* = |y_{\ell} (y_{j_1} + y_{j_2})/2|/|\Delta y_{jj}|$

[0; 1.5] with bins of size 0.05 (30 bins).

Numerical results 0.4

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

Code	$\sigma[fb]$		
POWHEG	1.5573 ± 0.0003		
${ m Recola}$	1.5503 ± 0.0003		
VBFNLO	1.5538 ± 0.0002		
PSI	1.5524 ± 0.0002		
${ m MG5_AMC}$	1.542 ± 0.002		

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

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

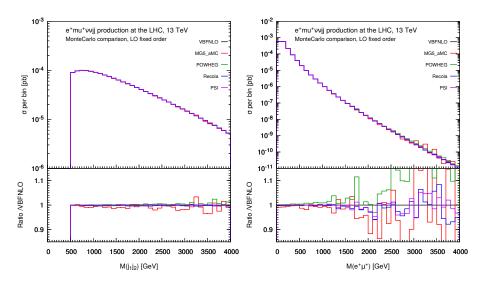


Figure 1: Invariant-mass of the two tagging jets (left) and of the two leptons (right), at LO.

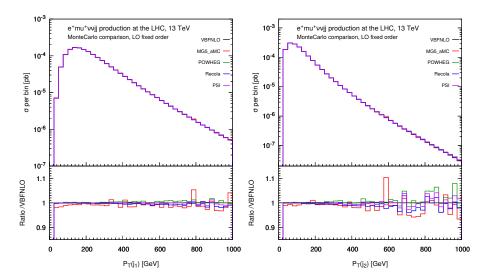


Figure 2: Transverse momentum of the first (left) and second (right) tagging jet, at LO. $\,$

Code	$\sigma[fb]$	$\sigma(n_j = 2)[\text{fb}]$	$\sigma(n_j = 3)[\text{fb}]$
POWHEG			
${ m Recola}$			
VBFNLO	1.3531 ± 0.0003	0.8264 ± 0.0003	0.5267 ± 0.0001
PSI	1.3366 ± 0.0009	0.8199 ± 0.0008	0.51663 ± 0.00007
${ m MG5_AMC}$	1.315 ± 0.003	0.784 ± 0.003	0.5313 ± 0.0009

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

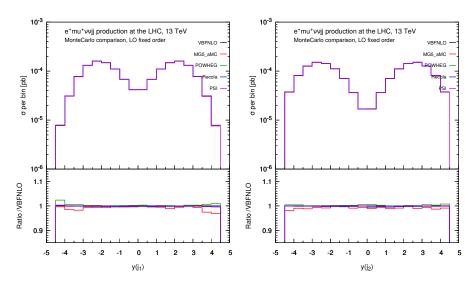


Figure 3: Rapidity of the first (left) and second (right) tagging jet, at LO.

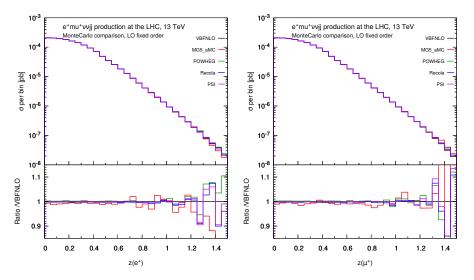


Figure 4: Zeppenfeld variable of the positron (left) and of the muon (right), at LO. $\,$

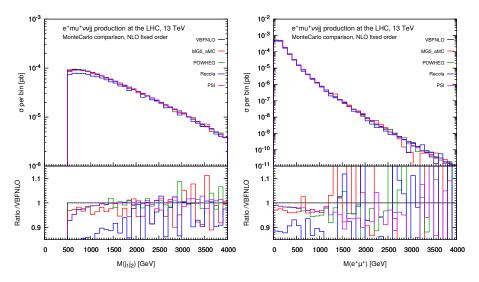


Figure 5: Invariant-mass of the two tagging jets (left) and of the two leptons (right), at NLO.

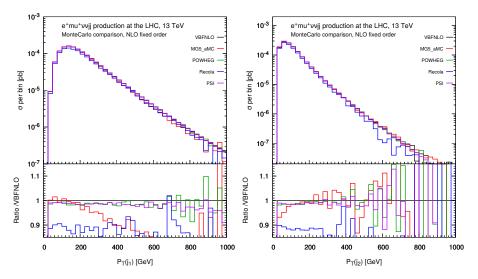


Figure 6: Transverse momentum of the first (left) and second (right) tagging jet, at $\rm NLO.$

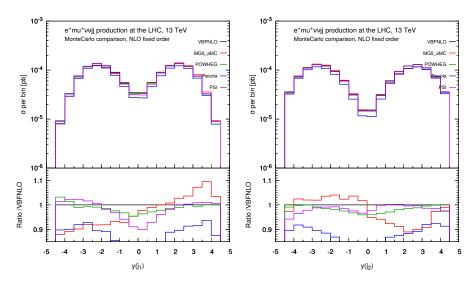


Figure 7: Rapidity of the first (left) and second (right) tagging jet, at NLO.

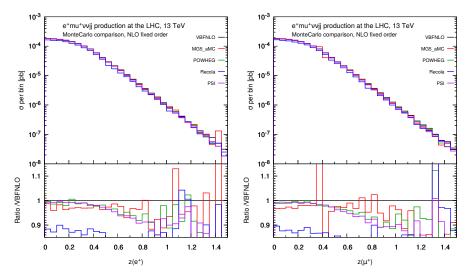


Figure 8: Zeppenfeld variable of the positron (left) and of the muon (right), at NLO.

Part III Conclusion

$\begin{array}{c} {\rm Part\ IV} \\ {\rm Acknowledgments} \end{array}$

Karlsruhe for hosting the documents used for the comparison.