Final-state QED radiation in single Z and W production

Renat Sadykov and Andrej Arbuzov

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Outline

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- Results for neutral current
- Results for charged current
- Summary

Motivation

- The effect of final-state QED radiation in Drell-Yan processes is large (up to 200% for invariant mass distribution in single Z production). The standard tool for simulation of QED FSR in ATLAS is `PHOTOS` program.

Our goas are:

- to perform the comparison between `SANC` and `PHOTOS` in the single and multiple photon mode for FSR radiation in Drell-Yan like processes both for neutral (NC) and charged (CC) currents
- to check if QED FSR is properly installed in the two programs
- to tune a separation of the FSR QED corrections from a complete EW NLO corrections in CC case

Realization of FSR in PHOTOS and SANC

- In `PHOTOS` the bremsstrahlung corrections to decays of W and Z bosons is calculated separately from other effects. In standard Monte-Carlo simulation the PHOTOS is interfaced to PYTHIA program through HepMC interface
- In `SANC` the complete EW corrections at one-loop is calculated for single W and Z production. The FSR QED corrections can be separated from the rest of EW corrections.

Setup for numerical comparison

We use CTEQ6L1 pdf set with running scale $Q^2 = s$. The `C++` version of `PHOTOS` programs was used together with `Pythia8` program which provide the Born-level events in HEPevt format that subsequently passed to `PHOTOS` for addition of photon radiation off final leptons. `PHOTOS` was running in single and multiple photon mode with matrix-element corrections turned on.

We use the following notations for QED corrections:

- effect of single-photon radiation:

$$\delta = \frac{\mathcal{O}(\alpha)FSR - Born}{Born}$$

- effect of multi-photon radiation:

$$\delta_{h.o.} = \frac{h.o.FSR - \mathcal{O}(\alpha)FSR}{Born}$$

Setup for NC

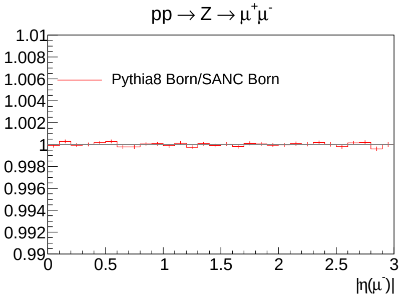
CM energy: $\sqrt{s_0} = 7$ TeV,
PDF set: CTEQ6L1 — LO with LO α_s,
factorization scale: $Q^2 = \hat{s} = s_0 x_1 x_2$,
EW scheme: G_μ,
input parameters: $M_Z = 91.1876$ GeV, $\Gamma_Z = 2.4952$ GeV,
cuts:

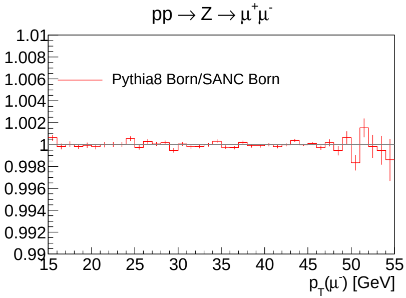
$$|\eta(\ell^+)| < 10, \quad |\eta(\ell^-)| < 10,$$
$$p_T(\ell^+) > 0.1 \text{ GeV}, \quad p_T(\ell^-) > 0.1 \text{ GeV},$$
$$70 \text{ Gev} < M(\ell^+\ell^-) < 110 \text{ GeV},$$

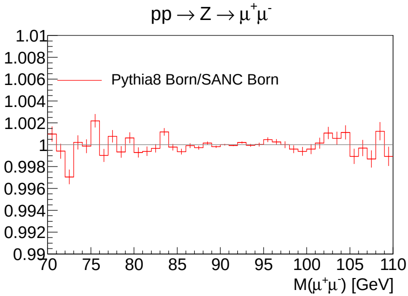
the minimum allowed value of photon energy in real emission is determined by the auxiliary parameter ϵ, so that $E_\gamma > \epsilon\sqrt{\hat{s}}/2$.

For electrons we have an option when electron and photon momenta are combined into an effective electron momentum if $\Delta R = \sqrt{(\Delta\eta(e,\gamma))^2 + (\Delta\phi(e,\gamma))^2} < 0.1$.

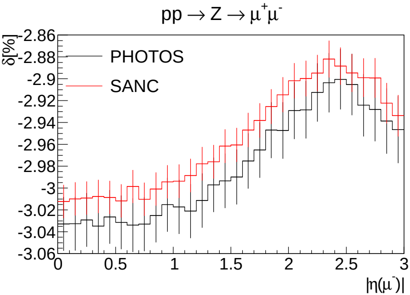
NC. Born

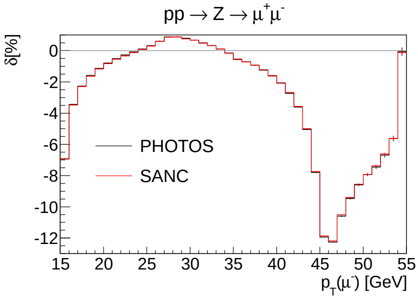

pp → Z → μ+μ-
1.01
1.008
1.006
1.004
1.002
1
0.998
0.996
0.994
0.992
0.99
Pythia8 Born/SANC Born
0
0.5
1
1.5
2
2.5
3
|η(μ-)|

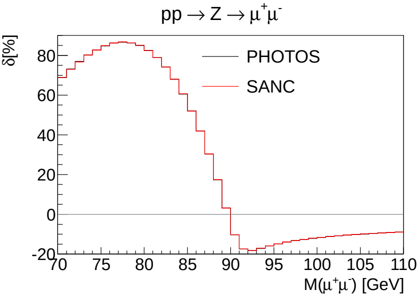

pp → Z → μ+μ-
1.01
1.008
1.006
1.004
1.002
1
0.998
0.996
0.994
0.992
0.99
Pythia8 Born/SANC Born
15
20
25
30
35
40
45
50
55
pT(μ-) [GeV]


pp → Z → μ+μ-
1.01
1.008
1.006
1.004
1.002
1
0.998
0.996
0.994
0.992
0.99
Pythia8 Born/SANC Born
70
75
80
85
90
95
100
105
110
M(μ+μ-) [GeV]

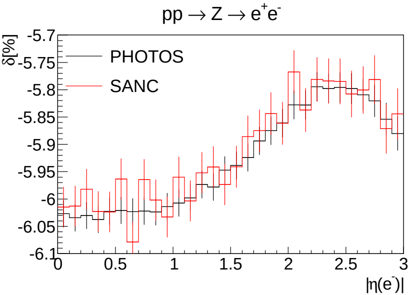
NC. Single-photon mode. Muons

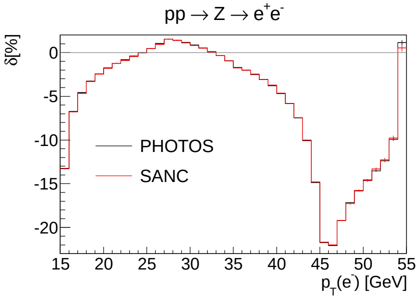


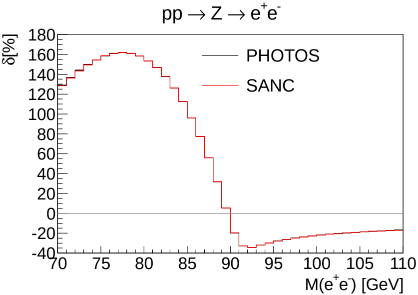




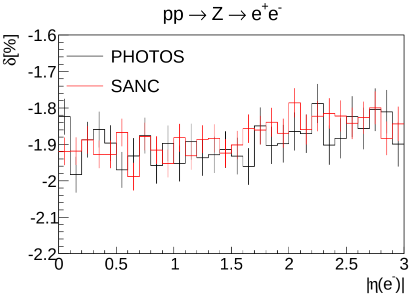
NC. Single-photon mode. Bare electrons

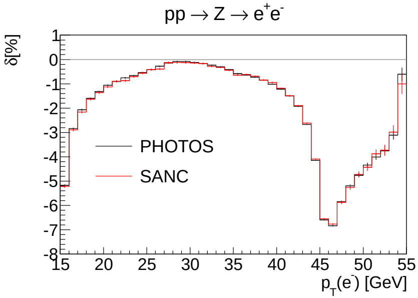


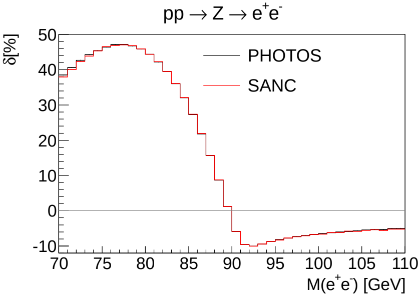




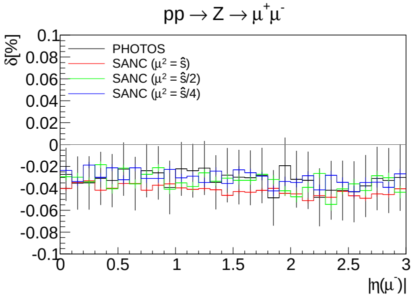
NC. Single-photon mode. Recombined electrons

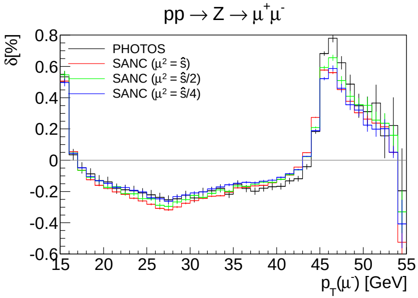


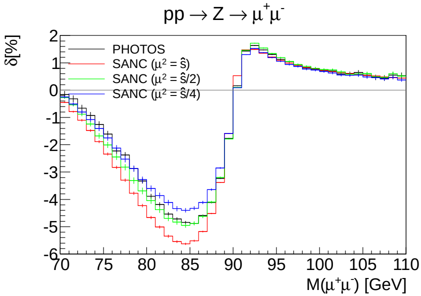




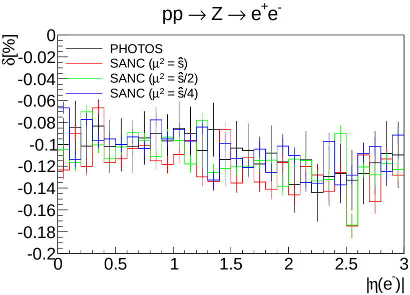
NC. Multi-photon mode. Muons

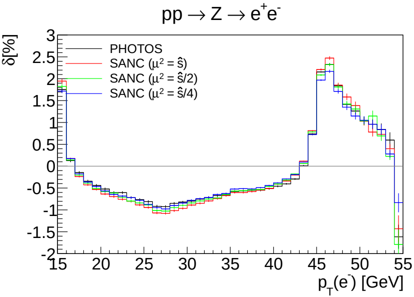


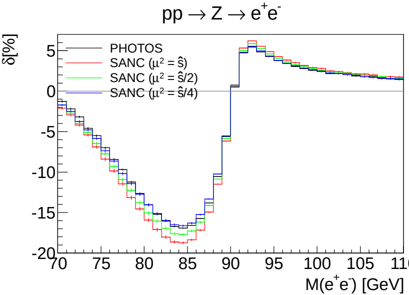




NC. Multi-photon mode. Bare electrons







Setup for CC

CM energy: $\sqrt{s_0} = 7$ TeV,
PDF set: CTEQ6L1 — LO with LO α_s,
factorization scale: $Q^2 = \hat{s} = s_0 x_1 x_2$,
EW scheme: G_μ,
input parameters: $M_W = 80.403$ GeV, $\Gamma_W = 2.141$ GeV,
cuts:

$$|\eta(\ell^-)| < 10,$$
$$p_T(\ell^-) > 0.1 \text{ GeV}, \quad p_T(\bar{\nu}_\ell) > 0.1 \text{ GeV}$$

the minimum allowed value of photon energy in real emission is determined by the auxiliary parameter ϵ, so that $E_\gamma > \epsilon\sqrt{\hat{s}}/2$.

Tuning of SANC FSR scale

The total $W \to u + d$ decay width

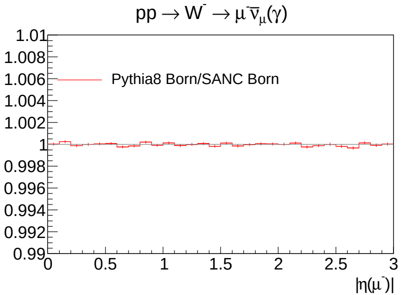
$$\Gamma_W^{PW+QED} = \Gamma^{LO}(\delta^{PW} + \delta^{QED}).$$

- *QED/EW* separation is not gauge-invariant
- 6 *QED* diagrams with virtual photons and 3 — with real photons:

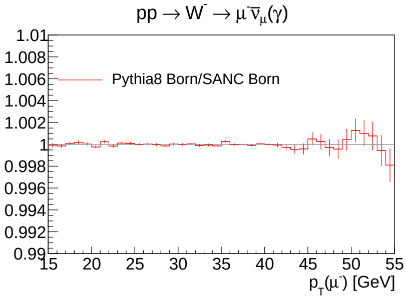
$$\delta^{QED} = \frac{\alpha}{\pi}\left[Q_W^2\left(\frac{11}{6} - \frac{\pi^2}{3}\right) + (Q_u^2 + Q_d^2)\left(\frac{11}{8} - \frac{3}{4}\log\frac{M_W^2}{\mu^2}\right)\right]$$

- Why ud-channel? δ^{QED} contains only charges squared
- Natural and u, d symmetric expression. Clear *ISR/FSR* separation
- Setting $\mu = M_W \exp(-\frac{11}{12})$ annulates the FSR in δ^{QED} as `PHOTOS` does

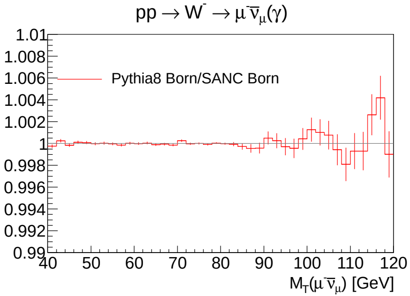
CC. Born



$pp \to W^- \to \mu^-\bar{\nu}_\mu(\gamma)$
Pythia8 Born/SANC Born
$|\eta(\mu^-)|$

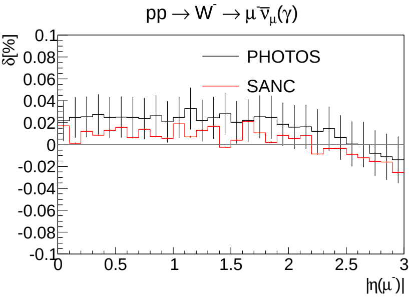


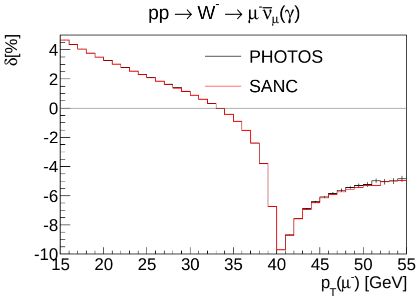
$pp \to W^- \to \mu^-\bar{\nu}_\mu(\gamma)$
Pythia8 Born/SANC Born
$p_T(\mu^-)$ [GeV]

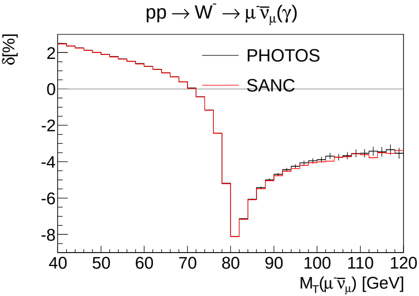


$pp \to W^- \to \mu^-\bar{\nu}_\mu(\gamma)$
Pythia8 Born/SANC Born
$M_T(\mu^-\bar{\nu}_\mu)$ [GeV]

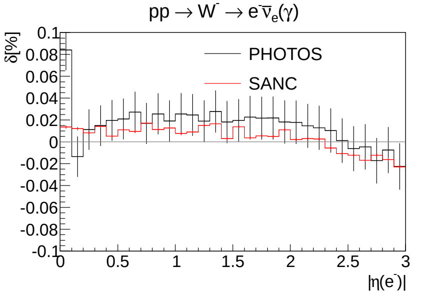
CC. Single-photon mode. Muons

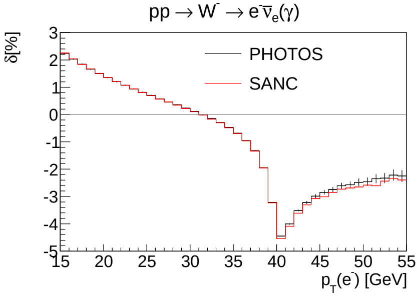


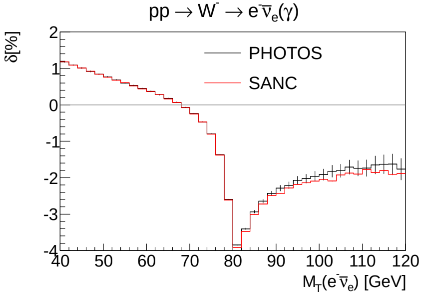




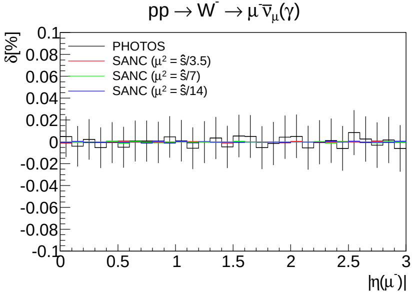
CC. Single-photon mode. Recombined electrons

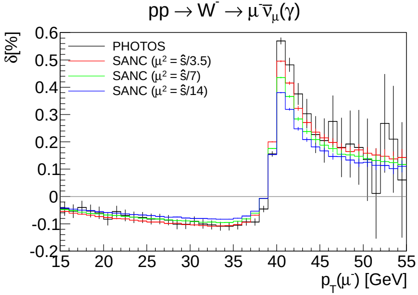


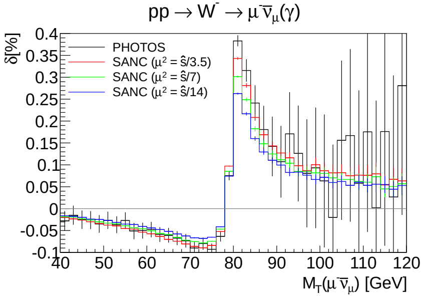




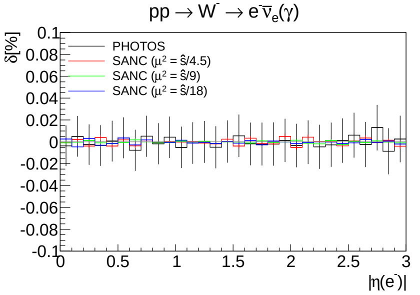
CC. Multi-photon mode. Muons

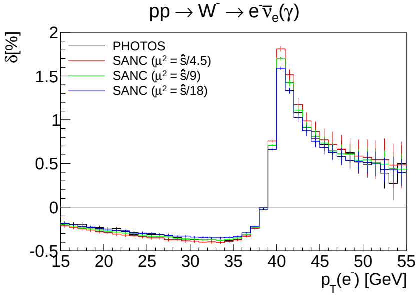


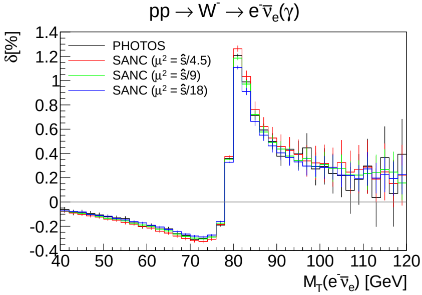




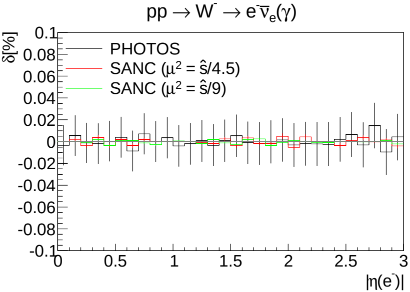
CC. Multi-photon mode. Bare electrons

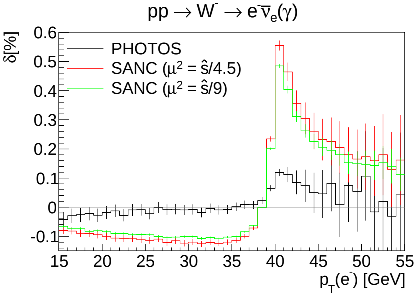


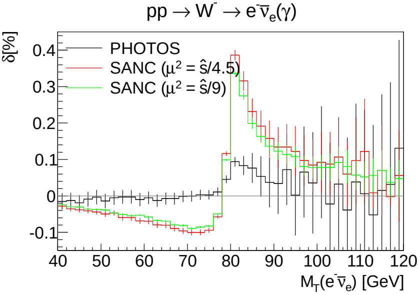




CC. Multi-photon mode. Recombined electrons







Summary

- PHOTOS was running in the single (for which it was not designed) and multiple photon mode.
- We found a good agreement between SANC and PHOTOS (within 0.02%) in single photon mode for both neutral and charged currents (for the same values of ϵ parameter).
- The comparison for multiple-photon mode was also performed for NC and CC. The results agree within 0.1% for mouns and bare electrons. For recombined electrons there is a 0.5% disagreement for p_T and m_T distributions.
- PHOTOS can be used for simulation chains at LHC aiming at 0.5% precision tag for bremsstrahlung in single Z or W production.