

Electroweak radiative corrections to Drell-Yan processes in SANC

Part 2. QED FSR corrections. SANC vs PHOTOS.

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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 goals 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: $\sqrt{s_0} = 7 \text{ TeV}$,

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: $M_Z = 91.1876 \text{ GeV}$, $\Gamma_Z = 2.4952 \text{ GeV}$,

cuts:

$$|\eta(\ell^+)| < 10, \quad |\eta(\ell^-)| < 10,$$

$$p_T(\ell^+) > 0.1 \text{ GeV}, \quad p_T(\ell^-) > 0.1 \text{ GeV},$$

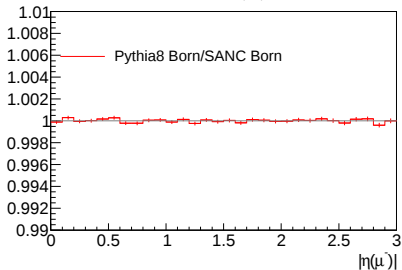
$$70 \text{ GeV} < M(\ell^+ \ell^-) < 110 \text{ GeV},$$

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

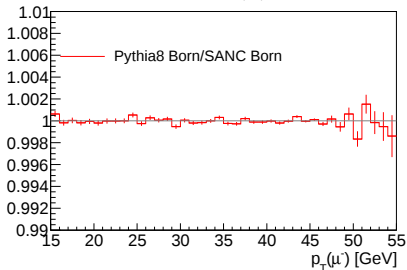
For electrons we have an option when electron and photon momenta are combined into an effective electron momentum if $\Delta R = \sqrt{(\Delta\eta(e, \gamma))^2 + (\Delta\phi(e, \gamma))^2} < 0.1$.

NC. Born

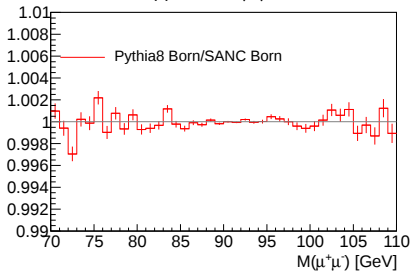
$$pp \rightarrow Z \rightarrow \mu^+ \mu^-$$



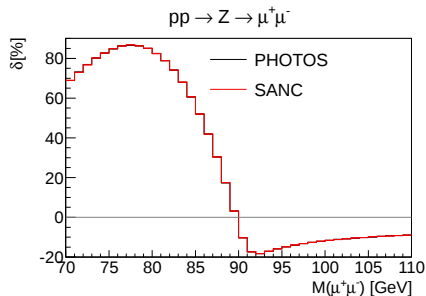
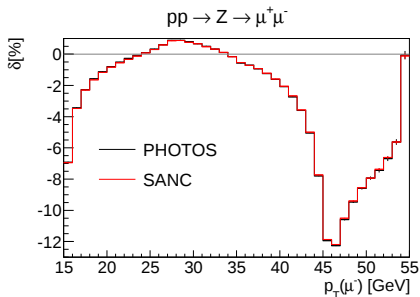
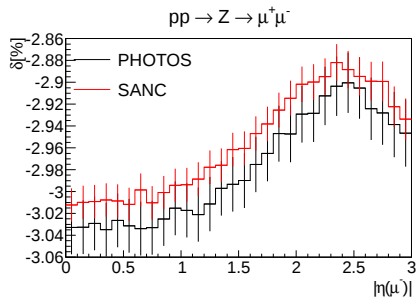
$$pp \rightarrow Z \rightarrow \mu^+ \mu^-$$



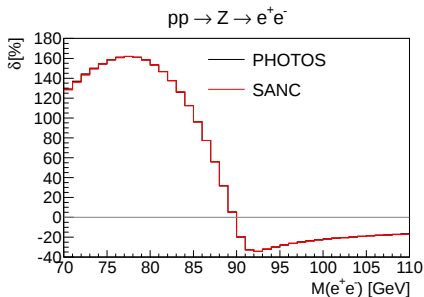
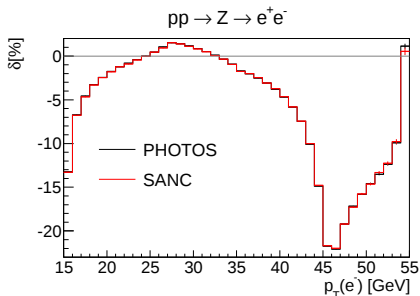
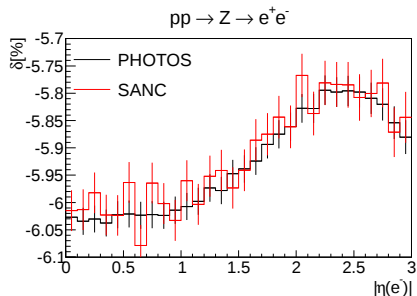
$$pp \rightarrow Z \rightarrow \mu^+ \mu^-$$



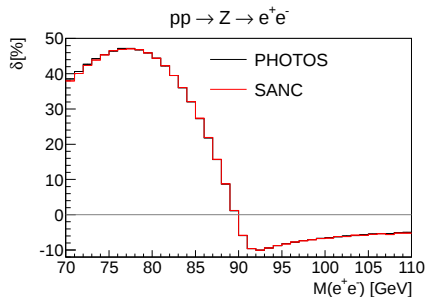
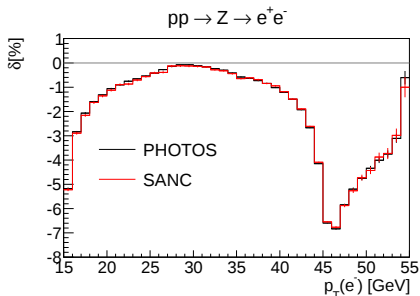
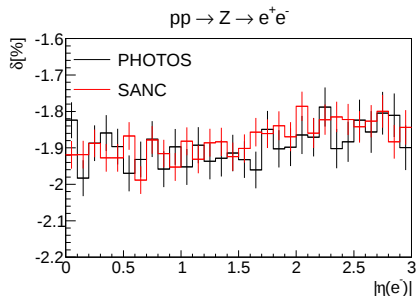
NC. Single-photon mode. Muons



NC. Single-photon mode. Bare electrons

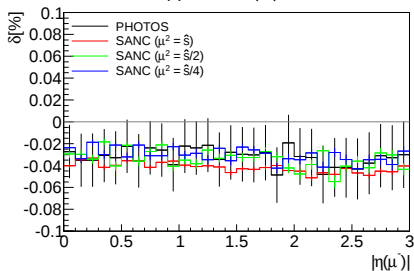


NC. Single-photon mode. Dressed electrons

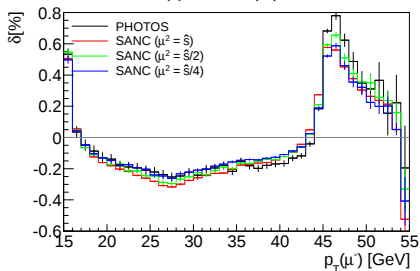


NC. Multi-photon mode. Muons

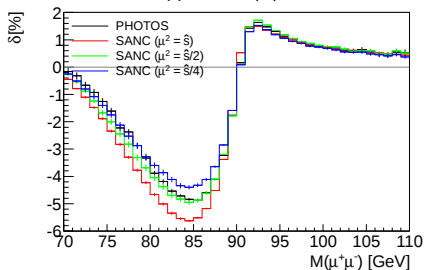
$$pp \rightarrow Z \rightarrow \mu^+ \mu^-$$



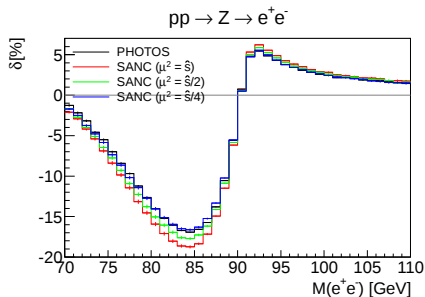
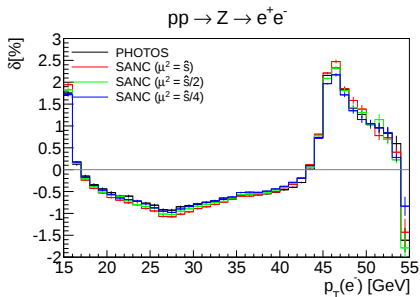
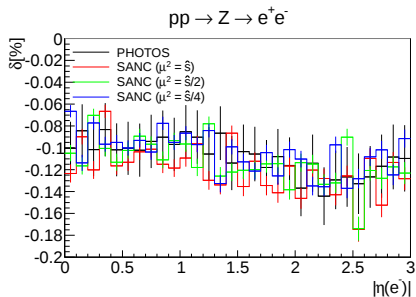
$$pp \rightarrow Z \rightarrow \mu^+ \mu^-$$



$$pp \rightarrow Z \rightarrow \mu^+ \mu^-$$



NC. Multi-photon mode. Bare electrons



Setup for CC

CM energy: $\sqrt{s_0} = 7 \text{ TeV}$,

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: $M_W = 80.403 \text{ GeV}$, $\Gamma_W = 2.141 \text{ GeV}$,

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 $W \rightarrow u + d$ decay width

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

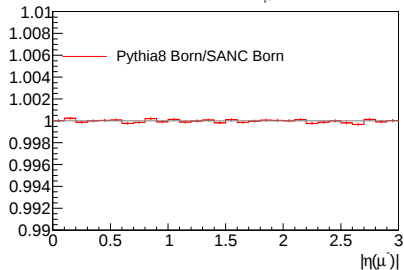
- QED/EW separation is not gauge-invariant
- 6 QED diagrams with virtual photons and 3 — with real photons:

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

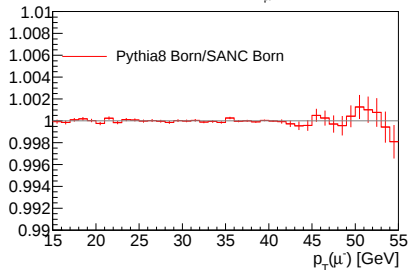
- Why ud -channel? δ^{QED} contains only charges squared
- Natural and u, d symmetric expression. Clear ISR/FSR separation
- Setting $\mu = M_W \exp(-\frac{11}{12})$ annulates the FSR in δ^{QED} as PHOTOS does

CC. Born

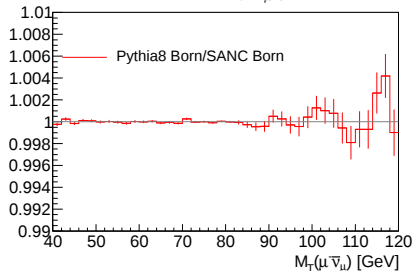
$$pp \rightarrow W^- \rightarrow \mu^- \bar{\nu}_\mu (\gamma)$$



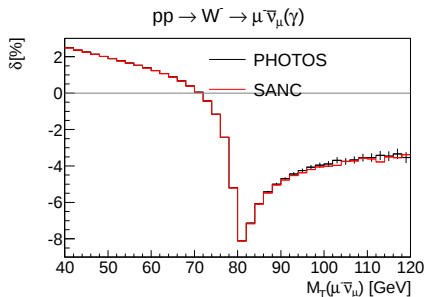
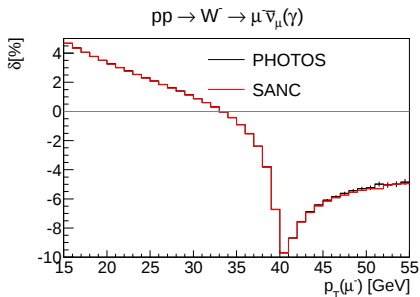
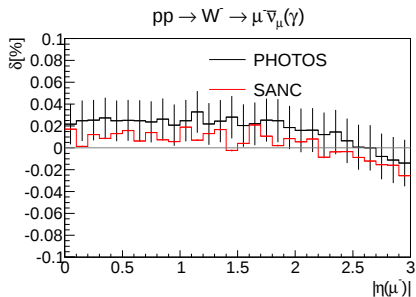
$$pp \rightarrow W^- \rightarrow \mu^- \bar{\nu}_\mu (\gamma)$$



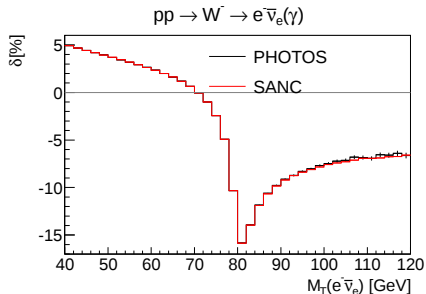
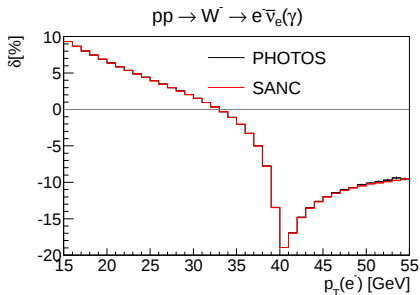
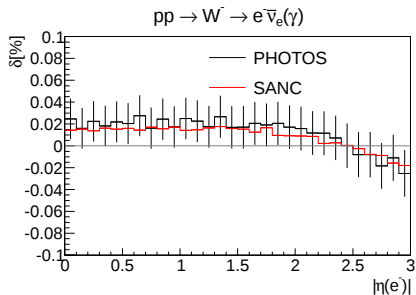
$$pp \rightarrow W^- \rightarrow \mu^- \bar{\nu}_\mu (\gamma)$$



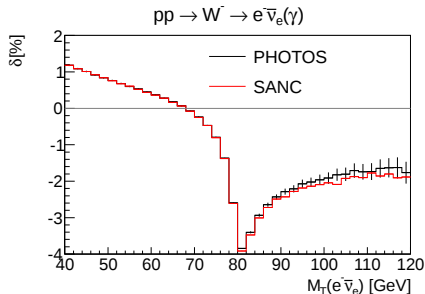
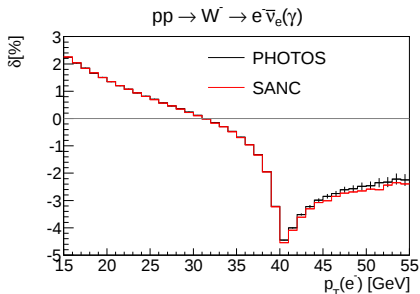
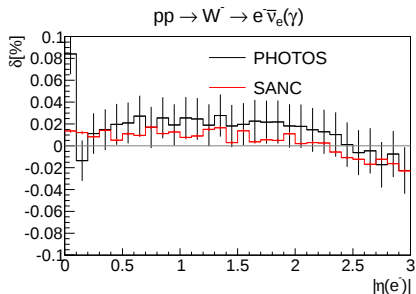
CC. Single-photon mode. Muons



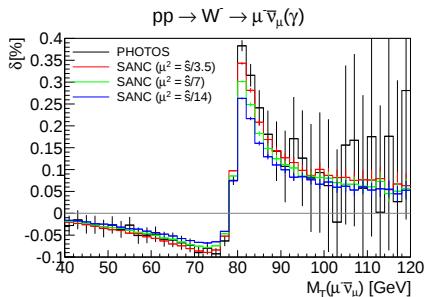
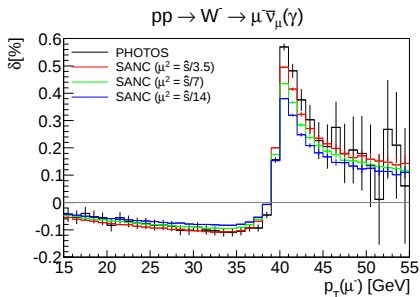
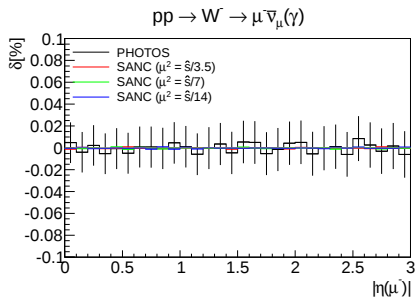
CC. Single-photon mode. Bare electrons



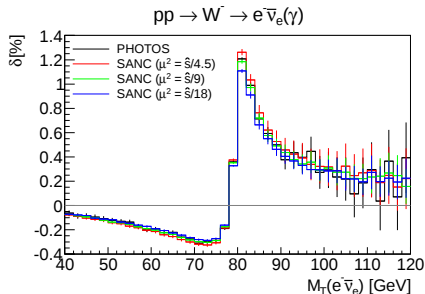
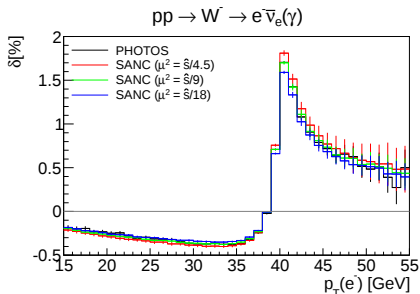
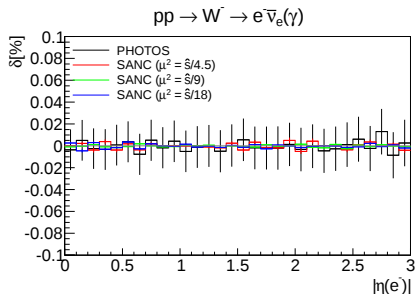
CC. Single-photon mode. Dressed electrons



CC. Multi-photon mode. Muons



CC. Multi-photon mode. Bare electrons



Setup for ϕ^* comparison

We begin the comparison of SANC and PHOTOS for the distribution of ϕ^* variable, which is defined as (see arXive:1009.1580 [hep-ex])

$$\phi^* = \tan\left(\frac{\phi_{acop}}{2}\right) \sin\theta^*, \quad \cos\theta^* = \tanh\left(\frac{\eta(\ell^-) - \eta(\ell^+)}{2}\right).$$

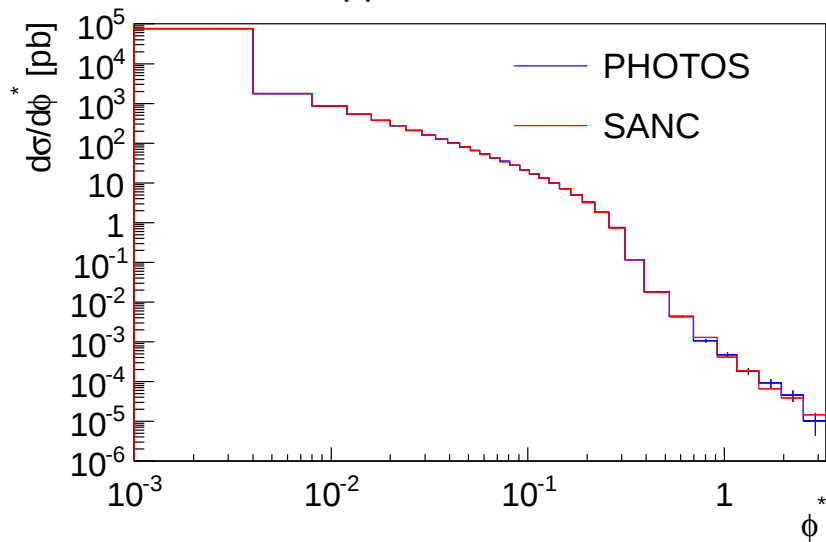
The following cuts are applied:

$$\begin{aligned} |\eta(\ell^+)| &< 2.4, \quad |\eta(\ell^-)| < 2.4, \\ p_T(\ell^+) &> 20 \text{ GeV}, \quad p_T(\ell^-) > 20 \text{ GeV}, \\ 66 \text{ GeV} &< M(\ell^+\ell^-) < 116 \text{ GeV}, \\ \ell &= e, \mu. \end{aligned}$$

ϕ^* . Single-photon mode. Bare electrons

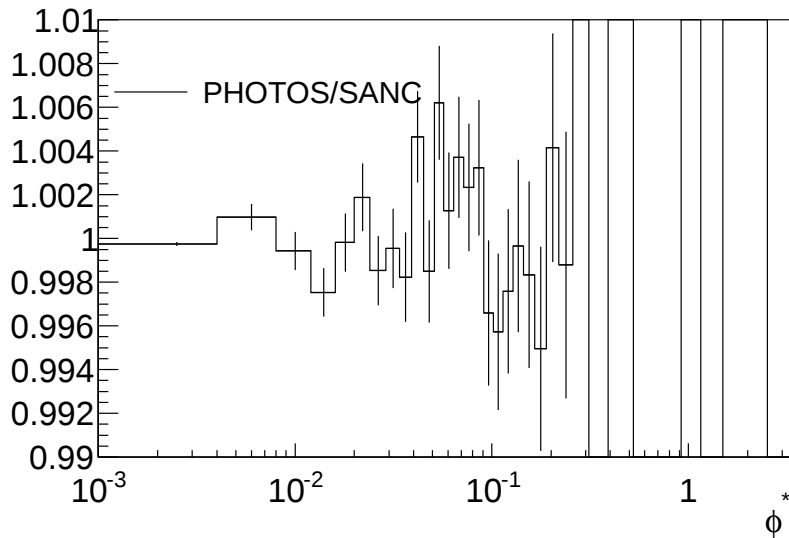
Cross-section

$$pp \rightarrow Z \rightarrow e^+e^-$$



ϕ^* . Single-photon mode. Bare electrons Ratio

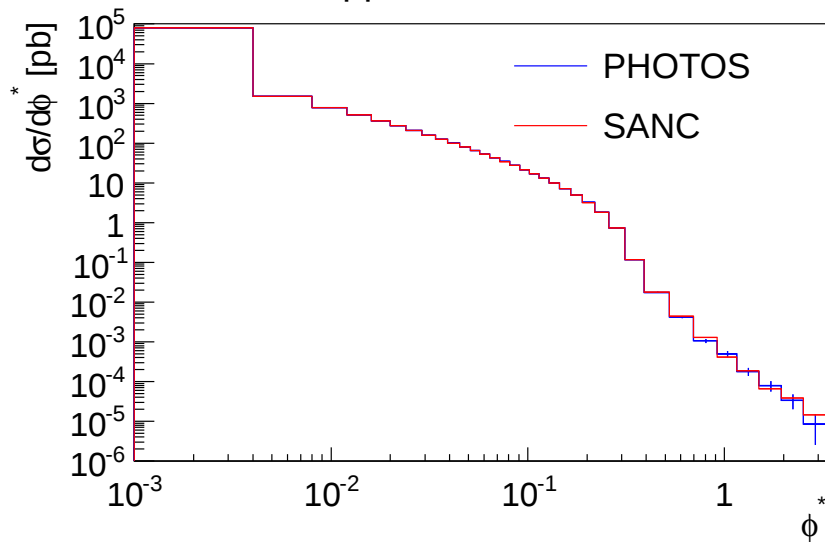
$$pp \rightarrow Z \rightarrow e^+e^-$$



ϕ^* . Single-photon mode. Dressed electrons

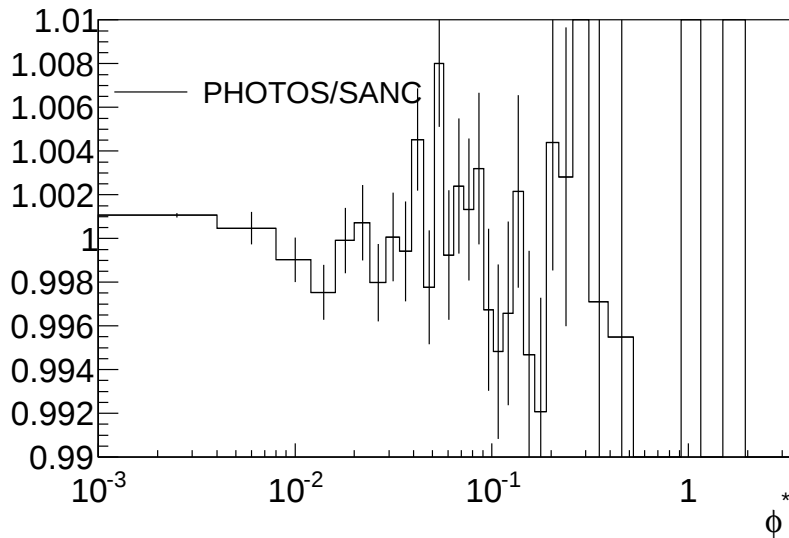
Cross-section

$$pp \rightarrow Z \rightarrow e^+e^-$$



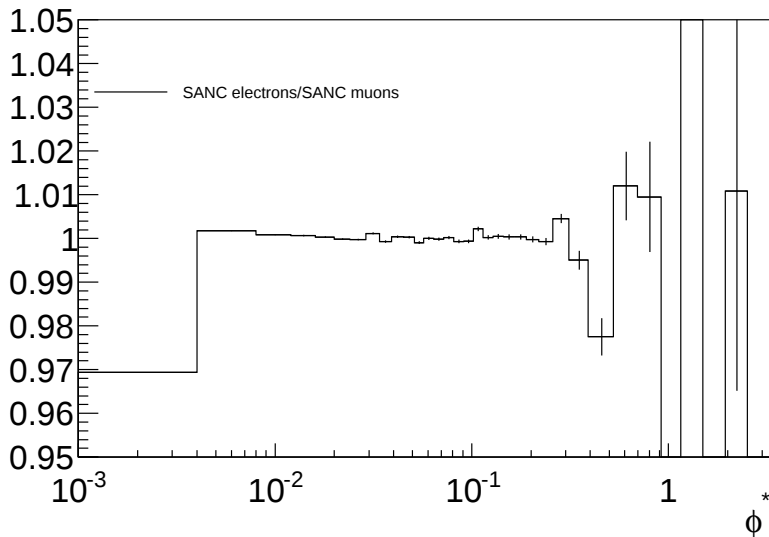
ϕ^* . Single-photon mode. Dressed electrons Ratio

$pp \rightarrow Z \rightarrow e^+e^-$



ϕ^* . Single-photon mode. Bare electrons vs muons Ratio

$$pp \rightarrow Z \rightarrow e^+e^- (\mu^+\mu^-)$$



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.
- PHOTOS can be used for simulation chains at LHC aiming at 0.2% precision tag for bremsstrahlung in single Z or W production.
- We begin to study the uncertainty in ϕ^* distribution due to treatment of QED FSR radiation.