Effect of emission of extra lepton pair for precise measurement of W-boson mass

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- One of the purposes of LHC experiments is to improve precision of the W boson mass measurement[1]
- That relies on understanding of Z boson production and decay processes[2]
- Precise calculations include radiative corrections
- Such corrections are usually calculated with a help of MC generators
- PYTHIA generates series of events
  $pp \to Z/gamma^*\ jets, Z \to \ell^+\ell^-$
- PHOTOS modifies final states and with certain probability replaces $\ell^+\ell^-$ pair with four lepton system: $\ell^+\ell^-\ell'^+\ell'^-$

[1] T. Aaltonen *et al.*,Phys. Rev. Lett. 108, 151803 (2012).

[2] A. B. Arbuzov, R. R. Sadykov, Z. Was, Eur. Phys. J. C 73, no. 11, 2625 (2013).

Goal

Our goal is to derive analytically the correction to the Z boson decay due to the emission of extra lepton pair and to compare this prediction with the previous one which is made by the MC generator[1].

[1] N. Davidson, T. Przedzinski and Z. Was, Comput. Phys. Commun. 199, 86 (2016).

Real pair correction

One can describe the amplitude of emission of extra lepton pair from final state, i.e. $Z \to \ell^+\ell^- + (\ell^+\ell^-)$, like the Born amplitude multiplied by a factor of $\widetilde{B_f}$

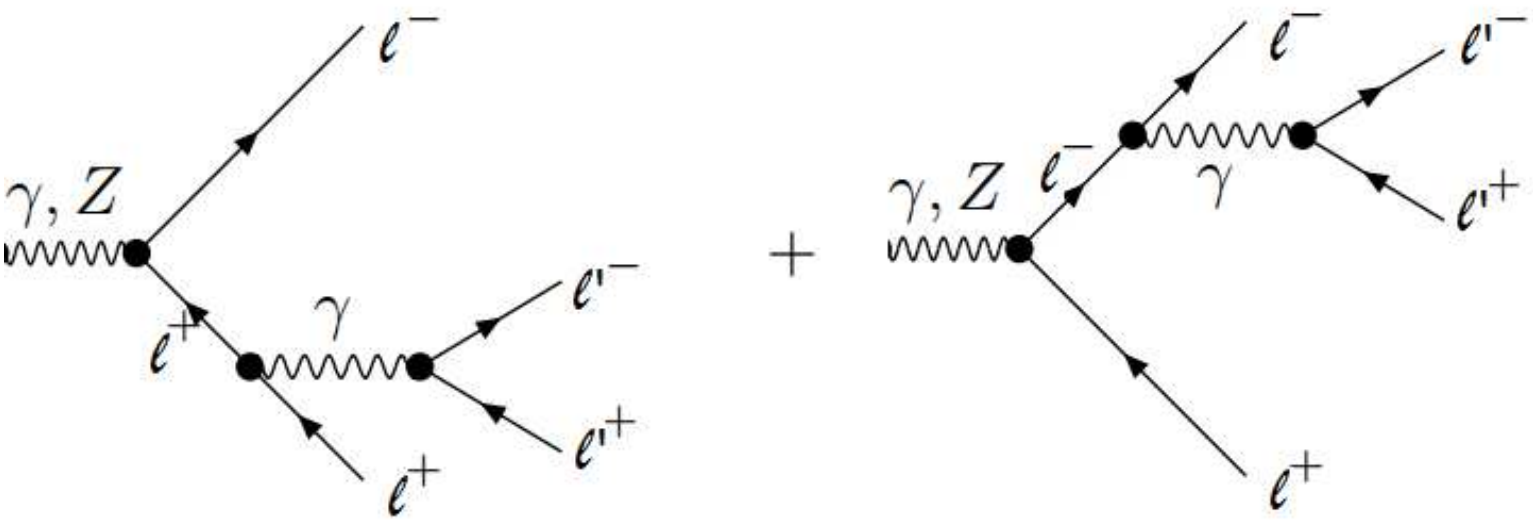

Figure 1. Real pair correction.

Real pair correction

$$\begin{aligned}\widetilde{B_f} &= (\frac{\alpha}{\pi})^2 \frac{4}{\pi^5} \int \left(d^4q\delta^4(q-q_1-q_2)\right)\left(d^4k\delta^4(k-p-p')\right) \times \\ &\times \delta^4(P_z-k-q)\frac{d^3q_1}{2(q_1)_0}\frac{d^3q_2}{2(q_2)_0}\frac{d^3p}{2p_0}\frac{d^3p'}{2p'_0} \times \\ &\times \left(\frac{p'}{p'q}-\frac{p}{pq}\right)_\mu \left(\frac{p'}{p'q}-\frac{p}{pq}\right)_\nu \frac{4q_1^\mu q_2^\nu - q^2 g^{\mu\nu}}{2q^4},\end{aligned}$$

where p^μ, $(p')^\mu$ denote the 4-moments of outgoing leptons, and q_1^μ, q_2^μ - of additional emitted leptons; P_z is the 4-moment of ingoing Z-boson; $q^\mu = q_1^\mu + q_2^\mu$; $k^\mu = p^\mu + (p')^\mu$; $q_1^2 = q_2^2 = \mu^2$; $p^2 = (p')^2 = m^2$.

Real pair correction

$$\widetilde{B_f} = -(\frac{\alpha}{\pi})^2 \frac{2}{3\pi^2} \int_{4m^2}^{(M_Z-2\mu)^2} dM_{LL}^2 \int_{4\mu^2}^{(M_Z-M_{LL})^2} dM_{ll}^2 \frac{M_Z^2 + M_{LL}^2 - M_{ll}^2}{M_{LL}^2} \times$$

$$\times \sqrt{1-\frac{4\mu^2}{M_{ll}^2}} \frac{1}{M_{ll}^2} \left(1+\frac{2\mu^2}{M_{ll}^2}\right) \left(\frac{m^2\sqrt{\lambda}\sqrt{1-\frac{4m^2}{M_{LL}^2}}}{M_{LL}^4 M_{ll}^2 + m^2\lambda} + \right.$$

$$\left. + \frac{1-\frac{2m^2}{M_{LL}^2}}{(M_Z^2 - M_{ll}^2 - M_{LL}^2)} \ln \left| \frac{M_Z^2 - M_{ll}^2 - M_{LL}^2 - \sqrt{1-\frac{4m^2}{M_{LL}^2}}\sqrt{\lambda}}{M_Z^2 - M_{ll}^2 - M_{LL}^2 + \sqrt{1-\frac{4m^2}{M_{LL}^2}}\sqrt{\lambda}} \right| \right),$$

where M_Z is mass of incoming Z boson, M_{LL} is invariant mass of the lepton pair, M_{ll} is invariant mass of the additional lepton pair, m is mass of single lepton of first kind, μ is mass of single additional lepton of second kind,
$\lambda = (M_Z^2 + M_{ll}^2 - M_{LL}^2)^2 - 4M_Z^2 M_{LL}^2$.

Numerical results

- We use PYTHIA to generate events that correspond to $pp \to Z \to e^+e^-$ production and decay of Z boson and we use PHOTOS to evaluate the effect of emission of additional electron-positron pair.
- Energy of beam is set to be 14 TeV.
- The allowed mass range is starting 10 GeV up to 200 GeV for PYTHIA run.

Numerical results

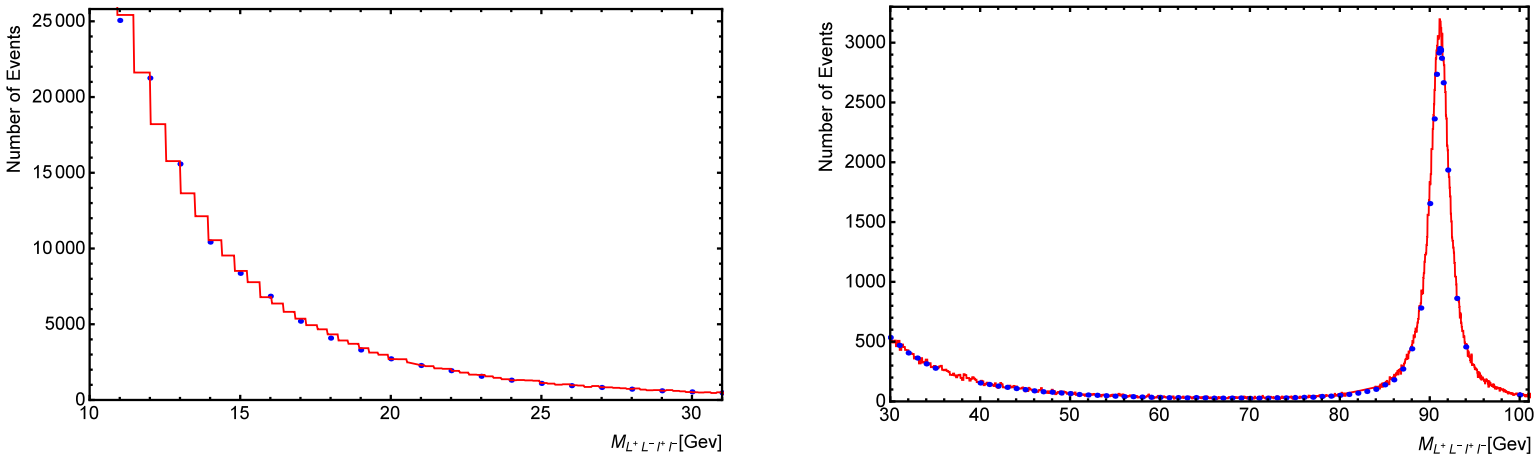

Figure 2. Distribution of number of $pp \to Z \to e^+e^- + e^+e^-$ events as a function of invariant mass of two electron-positron pairs. Solid line corresponds to output by PHOTOS, points correspond to semi-analytical evaluation.

Numerical results

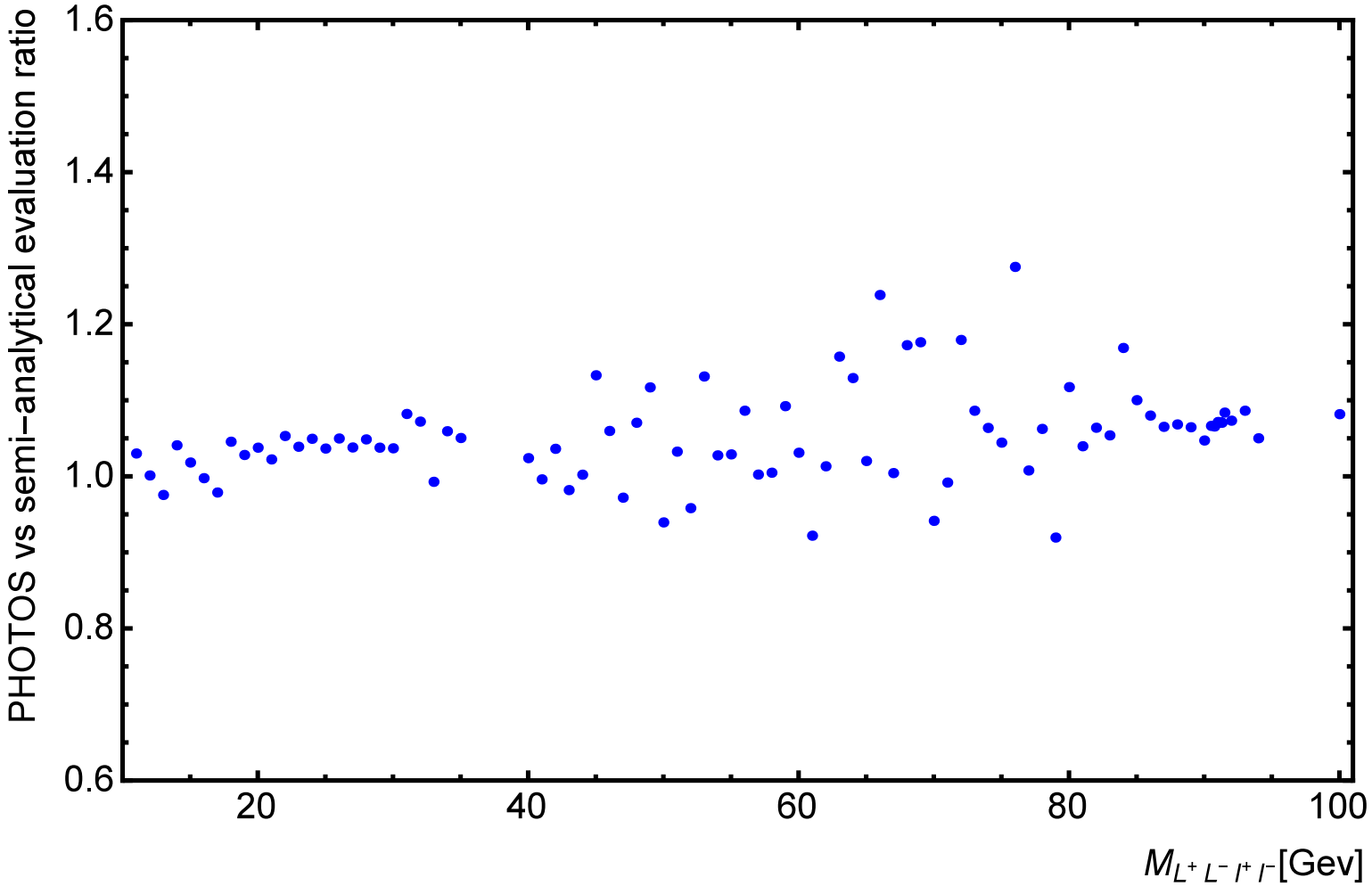

Figure 3. Ratio of two distributions (by PHOTOS and semi-analytical) of number of $pp \to Z \to e^+e^- + e^+e^-$ events as a function of invariant mass of two electron-positron pairs.

Conclusions

- Computation of distribution of the number of emissions of additional electron-positron pair in the process $pp \to Z \to e^+e^-$ on the invariant mass of two electron-positron pairs by PHOTOS is in good agreement with such computation by rigorous analytical formula.
- My calculation is an extension of previous calculation[1], where soft approximation for emission of pairs was used.
- I am still working on test when phase space constraint is used.
- My test supplement test of PHOTOS comparison to results for pair emission obtained from KORALW[2] Monte Carlo for Z boson decay to 4 fermions, where extremely narrow width of intermediate Z boson is used to block emission of pairs from initial state.

[1] S. Jadach, M. Skrzypek and B. F. L. Ward, Phys. Rev. D 49, 1178 (1994).

[2] S. Jadach, W. Placzek, M. Skrzypek, B. F. L. Ward and Z. Was, Comput. Phys. Commun. 119, 272 (1999).

Thank you for your attention!