User provided function for PHOTOS

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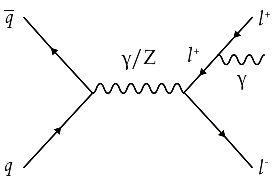
Introduction

Motivation for my talk

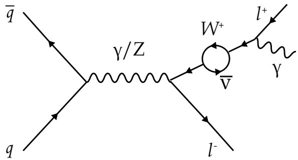
- Last year Viktor Zhabin was analyzing distributions in $Z \to l^+ l^- \gamma$ final states. There was an indication of a dip in $m(l^\pm \gamma)$ distribution at about 80 GeV: https://cds.cern.ch/record/2280876/files/SummerReport.pdf.
- Statistical significance of a dip was estimated at 3.5 σ level. These experimental data require attention, even if nothing public is available to show.
- I am involved in some work on PHOTOS Monte Carlo. This program use matrix element for $q\bar{q} \to l^+ l^- \gamma$ to generate final state bremsstrahlung.
- It was possible to implement into generator a `C++ method` to modify matrix element and observe how modification translates into properties of event sample.
- I will report on results of my activity.

Introduction

- Series of events $pp \to Z/\gamma^* \to l^+l^-$ are generated by PYTHIA[1].
- Then some of two lepton final states are modified with PHOTOS[2] to be $2l\gamma$ states.
- PHOTOS, version allowing user provided modification, is used. Changes to kernel of Fig. 1a (like of Fig. 1b[3]) can be added.



a) Real photon emission: default.



b) Virtual W-ν correction to the real photon emission: user provided.

Figure 1. Corrections to Z decay to lepton pair.

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[1] T. Sjostrand, et al., Comput. Phys. Commun. 178, 852 (2008).
[2] N. Davidson et al., [http://photospp.web.cern.ch/photospp/]; in current study a version of PHOTOS dated 17.11.2017 is used.
[3] Viktor Zhabin, [https://cds.cern.ch/record/2280876/files/SummerReport.pdf].

Example 1.

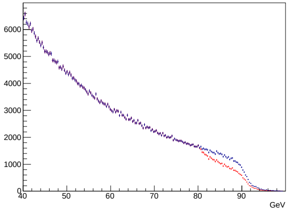
Ansatz of virtual correction inspired by opening of W-ν channel added into PHOTOS. It is roughly what diagram of Fig. 1b may bring[1]:

$$F(M) \;=\; 1 - A\sqrt{\frac{M - M_W}{M_W}} \cdot \Theta(M - M_W), \qquad (1)$$

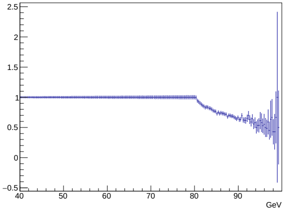
where M is invariant mass of the lepton pair, A is a parameter to be fixed/calculated, M_W is mass of W-boson. Ansatz is somehow following KLN theorem.

[1] Better one is expected soon from Alexey Kharlamov.

Example 1. Test



a) The numbers of the $e^+\gamma$ events with (red) and without (blue) W-ν-like correction depending on invariant mass of the $e^+\gamma$.



b) The ratio of the numbers of the $e^+\gamma$ events with and without W-ν-like correction depending on invariant mass of the $e^+\gamma$.

Figure 2. 10^7 $pp \to Z \to e^+e^-$ events are generated by PYTHIA at 8 TeV. W-ν-like correction code has been tested for unrealistically large A $= 1$ used in formula (1). Radiation was generated by PHOTOS in the single photon mode. PHOTOS setup parameters are:

```
Photos::setPairEmission(false);
Photos::setAlphaQED(1.0*0.00729735039);
Photos::setInfraredCutOff(0.1645);
Photos::maxWtInterference(4.0);
Photos::setDoubleBrem(false);
Photos::setQuatroBrem(false);
Photos::setExponentiation(false);
Photos::setMeCorrectionWtForZ(True);
```

Example 2.

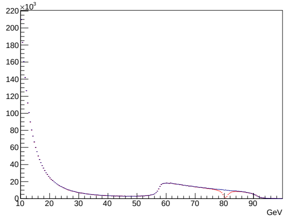
Pole approximation is chosen to incorporate resonance-like correction into PHOTOS. A factorized part of the amplitude writes[1]:

$$F(M) = \left|1 + A\frac{\Gamma_W M e^{i\phi}}{M_W^2 - M^2 - i\Gamma_W M_W}\right|^2, \qquad (2)$$

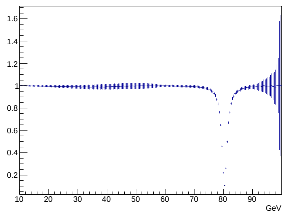
where M is invariant mass of the lepton pair, A and ϕ are parameters, M_W is mass of W-boson, $\Gamma_W = 2.085$.

[1] It is taken from notes of Alexey Kharlamov.

Example 2. Test



a) The numbers of the $e^+\gamma$ events with (red) and without (blue) resonance correction depending on invariant mass of the $e^+\gamma$.

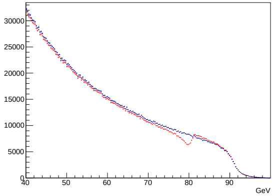


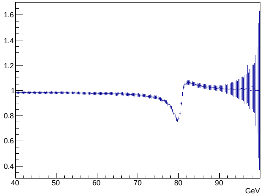
b) The ratio of the numbers of the $e^+\gamma$ events with and without resonance correction depending on invariant mass of the $e^+\gamma$.

Figure 3. 5×10^7 $pp \to Z \to e^+e^-$ events are generated by PYTHIA at 8 TeV. Resonance correction code has been tested for formula (2) and $A = 0.7$, $\phi = \pi/2$. Radiation was generated by PHOTOS in the single photon mode. PHOTOS setup parameters are:

```
Photos::setPairEmission(false);
Photos::setAlphaQED(4.0*0.00729735039);
Photos::setInfraredCutOff(0.4);
Photos::maxWtInterference(4.0);
Photos::setDoubleBrem(false);
Photos::setQuatroBrem(false);
Photos::setExponentiation(false);
Photos::setMeCorrectionWtForZ(True);
```

Example 2. "Real" values





a) The numbers of the $e^+\gamma$ events with (red) and without (blue) resonance correction depending on invariant mass of the $e^+\gamma$.

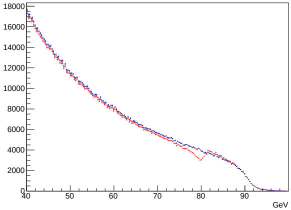
b) The ratio of the numbers of the $e^+\gamma$ events with and without resonance correction depending on invariant mass of the $e^+\gamma$.

Figure 4. 5×10^7 $pp \to Z \to e^+e^-$ events are generated by PYTHIA at 8 TeV. Resonance correction code has been tested for formula (2) and $A = 0.16$, $\phi = 2.514$[a]. Radiation was generated by PHOTOS in the single photon mode. PHOTOS setup parameters are:

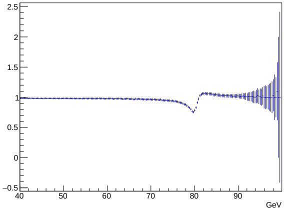
```
Photos::setPairEmission(false);
Photos::setAlphaQED(1.0*0.00729735039);
Photos::setInfraredCutOff(0.1645);
Photos::maxWtInterference(4.0);
```

[a] Values of these parameters are obtained from Alexey Kharlamov.

Example 2. "Real" values



a) The numbers of the $\mu^+\gamma$ events with (red) and without (blue) resonance correction depending on invariant mass of the $\mu^+\gamma$.



b) The ratio of the numbers of the $\mu^+\gamma$ events with and without resonance correction depending on invariant mass of the $\mu^+\gamma$.

Figure 5. 5×10^7 $pp \to Z \to \mu^+\mu^-$ events are generated by PYTHIA at 8 TeV. resonance correction code has been tested for formula (2) and $A = 0.16$, $\phi = 2.514$. Radiation was generated by PHOTOS in the single photon mode. PHOTOS setup parameters are:

```
Photos::setPairEmission(false);
Photos::setAlphaQED(1.0*0.00729735039);
Photos::setInfraredCutOff(0.1645);
Photos::maxWtInterference(4.0);
Photos::setDoubleBrem(false);
Photos::setQuatroBrem(false);
Photos::setExponentiation(false);
Photos::setMeCorrectionWtForZ(True);
```

Installation of user-provided matrix element.

- Into Z NLO ME user factor function can be introduced with the pointer:
- ```
  Photos::setMeCorrectionWtForZ(true);
  PhotosMEforZ::set_VakPol(exampleAnmalousCouplingsZNLO);
  ```
- where declaration format has to follow dummy function:
  ```
  double exampleAnmalousCouplingsZNLO(double qp[4],double qm[4],
  double ph[4],double pp[4],double pm[4],int IDE,int IDF) {return 1.0;}
  ```
- Factor provided by this routine $\frac{|M^{\boldsymbol{new}}|^2}{|M^{\boldsymbol{SM}}|^2}$ multiply internal weight of PHOTOS. User conventions for M^{new} and M^{SM} are allowed.
- Incoming fermions of Z/γ^* productions and outgoing leptons are used: 4-momenta and flavours.
- The spin state of intermediate Z/γ^* is constructed on flight.
  ```

Conclusions and things to do.

- Simulations of "real" spectrum including user-provided W-ν loop-like or resonance-like correction were demonstrated.
- So far I was using single photon mode of PHOTOS because I was testing. It is straightforward to switch multiple photon radiation.
- Then also a detector-response simulation is straightforward. Verification of significance of these modifications is easy.
- Further SM- or non SM-corrections can be introduced into PHOTOS simulation in the same manner.
- Option for PHOTOS where modification is introduced through event weights is envisaged.

THANK YOU FOR YOUR ATTENTION!