New approach to DM searches with mono-photon signature

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1. MOTIVATION

One of the important goals of the proposed future e^+e^- collider experiments is the search for dark matter particles using different experimental approaches. The most general one is based on the mono-photon signature, which is expected when production of the invisible final state is accompanied by a hard photon from initial state radiation. We proposed the procedure[1] which allows for consistent, reliable simulation of mono-photon events in WHIZARD,[2,3] for both BSM signal and SM background processes, based on merging the matrix element calculations with the lepton ISR structure function.

2. MERGING PROCEDURE

For precise kinematic description of photons entering the detector, we need to include hard photon emission directly in the process matrix element (ME) calculation. On the other hand, very soft and collinear photons should still be simulated with the parametric approach, taking into account proper summation of higher order corrections. A dedicated procedure for merging between the two regimes was proposed, exploiting variables[1] q_- and q_+ to describe kinematics of each emitted photon. For the single photon emission these variables correspond to the virtuality of the electron or positron after (real) photon emission. Pair of values (q_-,q_+) gives the information on both the energy and scattering angle of a given photon, and determines if the photon can be reconstructed in the detector, see Fig. 1 (left). The phase space for photon radiation is divided into ME (hard) emission and ISR (soft) regions, as indicated with red dashed line for default merging scale $q_{min} = 1$ GeV.

Main SM background contributions to mono-photon searches are expected to come from the radiative neutrino pair production process and the radiative Bhabha scattering. Only for a small fraction of these events the radiated photon can be measured in the detector. We assume the final signal selection requires photon to be reconstructed in the angular range $7° < \theta^\gamma < 173°$ and with the transverse momentum $p_T^\gamma >= 5\,\text{GeV}$. After imposing these requirements, expected distribution of the photon transverse momenta is no longer sensitive to the choice of the merging parameter q_{min}, see Fig. 1 (right) for the example of radiative neutrino pair production at 380 GeV.

Cross sections and kinematic distributions of photons in radiative neutrino pair-production events were also compared with predictions of the $\mathcal{KK}$MC,[4,5] a Monte Carlo generator providing perturbative predictions for SM and QED processes, which has been widely used in the analysis of LEP data. Results of WHIZARD simulation implementing the proposed merging procedure agree very well with corresponding $\mathcal{KK}$MC predictions, see Fig. 2.

3. PLANS FOR SNOWMASS 2021

We plan to exploit the proposed procedure[1] in estimating the sensitivity of future e^+e^- colliders to different DM scenarios. We would also like to propose a novel approach, where the experimental sensitivity is defined in terms of both the mediator mass and mediator width. This approach is more model independent than the approaches presented so far, assuming given mediator coupling values to SM and DM particles. Limits on the light DM production cross section can be set as a function of the mediator mass and width based on the expected two-dimensional distributions of the reconstructed mono-photon events, see Fig. 3.

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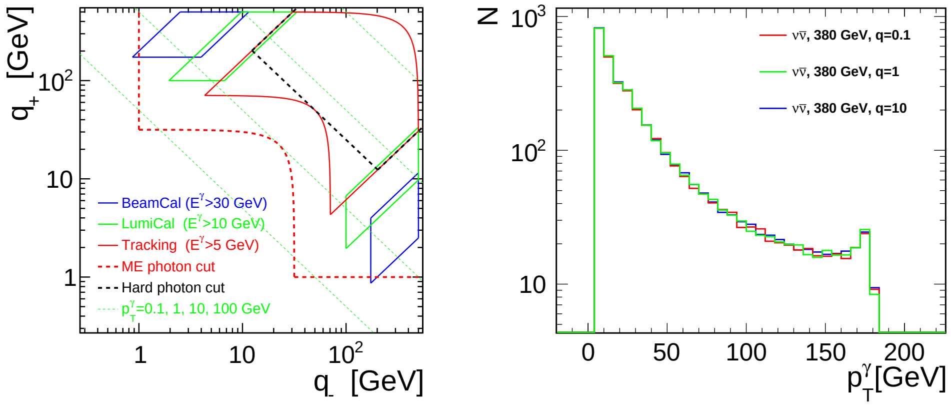

Figure 1. Left: detector acceptance expected for the future experiments at e^+e^- colliders in the (q_+, q_-) plane, for collision energy of 500 GeV; red dashed line indicates a default cut used to restrict the phase space for ME photon generation. Right: distribution of the hard photon transverse momenta for radiative neutrino pair production at 380 GeV in WHIZARD, for different values of the merging parameter q_{min}. Distributions are normalised to the number of events expected for integrated luminosity of 1 fb^{-1}.

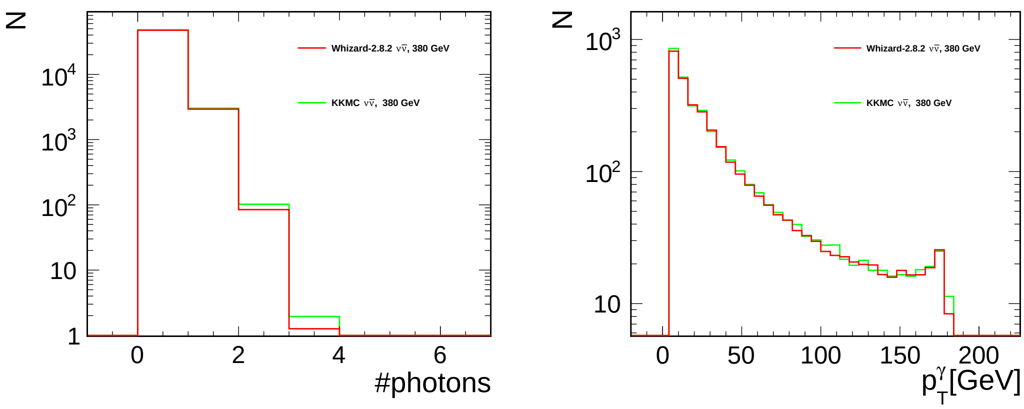

Figure 2. Distributions of the number of reconstructed photons (left) and the photon transverse momentum (right) in the neutrino pair production events generated by WHIZARD (red) and the $\mathcal{KK}$MC (green). for collision energy of 380 GeV. Acceptance cuts on the photon angle and transverse momentum are applied. Distributions are normalised to the number of events expected for integrated luminosity of 1 fb^{-1}.

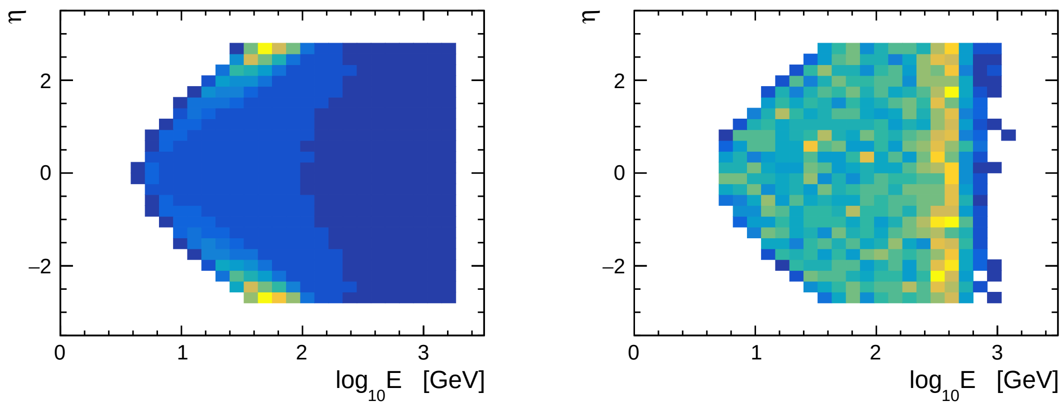

Figure 3. Pseudorapidity vs energy distributions for mono-photon events at 3 TeV CLIC, expected for SM background processes (left) and signal of radiative DM pair-production, for DM mass of 50 GeV, mediator mass of 2.5 TeV and mediator width of 200 GeV (right).