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Dark matter searches with mono-photon signature at future e^+e^- colliders

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One of the important goals of the proposed future e^+e^- collider experiments is the search for dark matter (DM) 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. Reviewed in this contribution are recent results on the sensitivity to DM pair production of the International Linear Collider (ILC) which is under consideration to be built in Japan and Compact Linear Collider (CLIC) at CERN.
The ILC design is based on the technology of superconducting accelerating cavities which allows to reach centre-of-mass energies of up to 500 GeV with a footprint of 31 km. The baseline design includes polarisation for both e^- and e^+ beams, of 80% and 30%, respectively. At 500 GeV, ILC is expected to deliver the integrated luminosities of about 4 ab^{-1}.
CLIC is based on the two-beam acceleration scheme which, with an RF gradient of 100 MV/m, should allow to reach 3 TeV centre-of-mass energy at the final construction stage. Only the electron beam polarisation is included in the CLIC baseline design and an integrated luminosities of 5 ab^{-1} is expected at 3 TeV.
Expected exclusion limits are presented for DM pair-production at 500 GeV ILC and at 3 TeV CLIC, for scenarios assuming heavy mediator exchange, as well as for light mediator scenarios, when very small mediator coupling to SM particles is assumed.

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1. Introduction

It is usually assumed that dark matter (DM) particles are pair-produced in e^+e^- collisions via exchange of a new mediator particle, which couples to both Standard Model (SM) particles and DM states. The produced final state is invisible unless it is accompanied by an additional particle(s) (photon, Z, jet etc.). At e^+e^- colliders most promising are mono-photon events, with an energetic photon radiated from the initial state leptons. Main SM background contributions come from the radiative neutrino pair production, $e^+e^- \to \nu\,\bar{\nu}\,\gamma$, and radiative Bhabha scattering, $e^+e^- \to e^+e^-\,\gamma$.

2. Simulating mono-photon events in WHIZARD

For reliable simulation of mono-photon events in WHIZARD [1] a dedicated procedure was proposed, based on merging the matrix-element (ME) calculations required for proper simulation of photons entering the detector with the lepton initial state radiation (ISR) structure function taking into account resummation of higher order corrections [2]. To restrict the phase space for ME photon generation, cuts are imposed on variables q_- and q_+, corresponding to the virtuality of the electron or positron after (real) photon emission. In Fig. 1, cuts used in the matching procedure are compared with the expected detector acceptance for ILC running at 500 GeV and CLIC at 3 TeV.

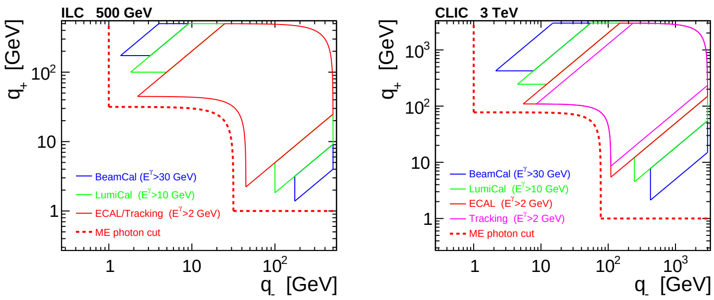

Figure 1: Detector acceptance in the (q_+, q_-) plane (solid lines) expected for the future experiments at 500 GeV ILC (left) and 3 TeV CLIC (right). Red dashed lines indicate the cut used to restrict the phase space for ME photon generation. Figure taken from [3].

3. Dark Matter searches at 3 TeV CLIC

Potential for detecting DM at the Compact Linear Collider (CLIC) running at 3 TeV was investigated using fast detector simulation [4]. The best limits on the DM pair-production cross section can be set when considering the ratio of the mono-photon energy distributions for left-handed and right-handed polarised electron beams, as shown in Fig. 2 (left), as most systematic uncertainties cancel out. These limits can be then translated, using simplified DM models, into exclusion limits for DM and mediator masses, as shown in Fig. 2 (right).

4. WIMP Dark Matter at the ILC

A corresponding study was performed with full detector simulation for the International Large Detector (ILD) concept at the 500 GeV ILC [5]. Radiative Bhabha scattering events can be very

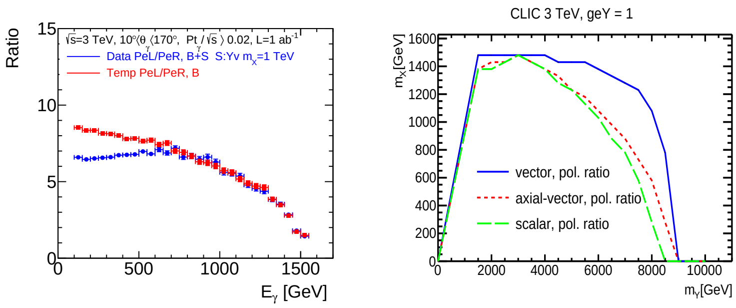

Figure 2: Results of the mono-photon study for CLIC at 3 TeV [4]. Left: ratio of photon energy distributions measured for left-handed and righ-handed electron beam polarisation, for SM background (red) and after including DM production contribution with vector mediator exchange (blue points). Right: exclusion limits in the DM vs mediator mass plane (m_Y,m_χ) for mediator coupling to electrons, $g_{eY} = 1$.

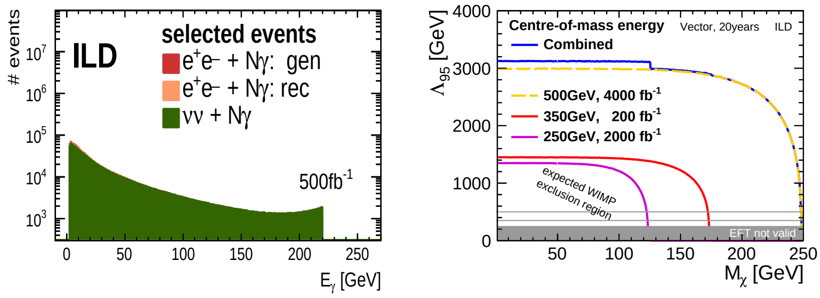

Figure 3: Results of the full-simulation study for the ILD [5]. Left: photon energy distribution for ILC running at 500 GeV and unpolarised beams, after the event selection cuts. Right: expected 95% C.L. limits for the vector operator mass scale, for subsequent stages of the H20 running scenario.

effectively suppressed by the selection cuts and the remaining SM background is dominated by the radiative neutrino pair production events as shown in Fig. 3 (left). In the effective field theory (EFT) approach scales of up to 3 TeV can be tested for different operator types and DM masses almost up to half the collision energy, see Fig. 3 (right). Combining data with different polarisation configurations results in significant reduction of systematic uncertainties.

5. Sensitivity to light mediator exchange

Pair-production of DM particles at the ILC and CLIC was also studied for scenarios with light mediators and small mediator couplings to the SM particles [3]. Limits on the production cross section can be extracted from the two-dimensional distributions of the reconstructed mono-photon events in pseudorapidity and transverse momentum, as shown in Fig. 4. Expected limits on the total DM pair-production cross section are shown in Fig. 5, for different fractional vector mediator widths, for the ILC running at 500 GeV and for different mediator coupling scenarios, for CLIC running at 3 TeV and relative mediator width, $\Gamma/M = 0.03$. Expected cross section limits correspond to the limits on the mediator coupling to electrons of the order of $10^{-3} - 10^{-2}$. For mediator masses up to the centre-of-mass energy of the collider, limits expected from the mono-photon analysis are more stringent than the limits from direct resonance search in SM decay channels.

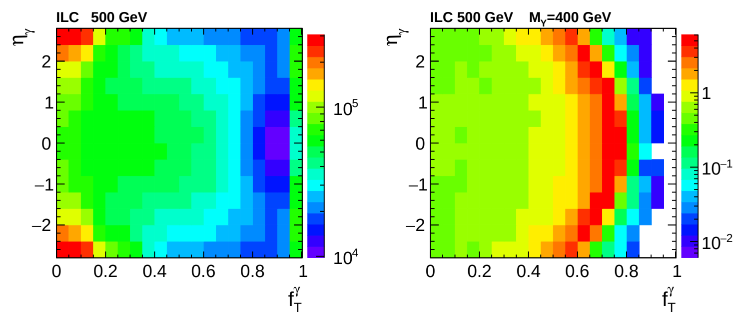

Figure 4: Pseudorapidity vs transverse momentum fraction for mono-photon events at 500 GeV ILC running with –80%/+30% electron/positron beam polarisation and integrated luminosity of 1.6 ab^{-1}. Left: for sum of considered SM backgrounds. Right: for pair-production of Dirac fermion DM particles with m_χ = 50 GeV and vector mediator mass of M_Y = 400 GeV, assuming total production cross section of 1 fb [3]. Momentum fraction, f_T^γ, is a logarithm of the transverse momentum scaled to span the range between the minimum and maximum photon transverse momentum allowed for given rapidity.

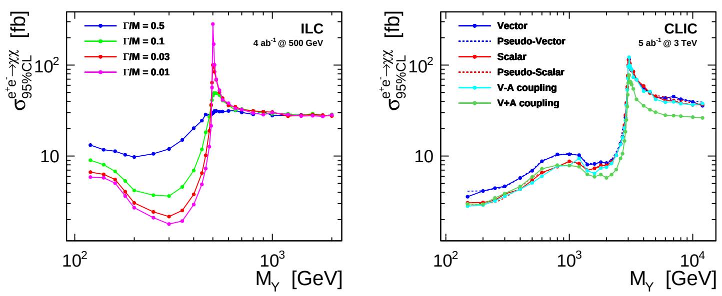

Figure 5: Limits on the cross section for light fermionic DM pair-production processes with *s*-channel mediator exchange. Left: for different fractional vector mediator widths, for the ILC running at 500 GeV. Right: for relative mediator width, Γ/M = 0.03 and different mediator coupling scenarios, for CLIC running at 3 TeV (right). Presented are combined limits with systematic uncertainties taken into account [3].

References

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