ILD-PHYS-PUB–2024-005
18 October 2024

Light mediator searches with mono-photon signature

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High energy e^+e^- colliders offer unique possibility for the most general dark matter (DM) search based on the mono-photon signature. Analysis of the energy spectrum and angular distributions of photons from the initial state radiation can be used to search for hard processes with invisible final state production. While most studies in the past were focused on scenarios assuming heavy mediator exchange, we introduced an alternative approach, where the experimental sensitivity to light mediator production was defined in terms of both the mediator mass and width. It was first used to study the expected sensitivity to dark matter production of experiments at 500 GeV International Linear Collider (ILC) and 3 TeV Compact Linear Collider (CLIC). Presented in this contribution are results from the extension of the study to 250 GeV ILC, which were shown at the first ECFA workshop in Hamburg. Also included are results demonstrating the importance of beam polarization for the DM search sensitivity and reduction of systematic uncertainties.

This work was carried out in the framework of the ILD Concept Group

1 Introduction

There are many hints for the existence of physics Beyond the Standard Model (BSM) and many theoretical scenarios are considered, with wide range of masses and couplings for dark matter particles. With no direct evidence within the LHC energy reach, we should also consider models where new particles are light, but their couplings to SM are very small. High energy e^+e^- colliders are considered perfect tools for the most general search for pair-production of DM particles with a mono-photon signature, when only single hard photon radiated from the initial state is observed in the detector. This contribution focuses on the DM pair production at 250 GeV ILC. For more details on the analysis and higher energy results the reader is referred to [1–4].

2 Analisis framework

For consistent simulation of BSM processes and of the SM background processes with mono-photon signature in WHIZARD [5, 6], a new procedure was invented [1] which allows for proper matching of the soft ISR radiation with the matrix element (ME) level simulation of detectable hard photons. A dedicated model [7] was encoded into FEYNRULES [8, 9] for calculating the DM pair-production cross section and generating signal event samples. Presented results are based on the fast detector simulation framework DELPHES [10] with generic ILC detector model including detailed description of the calorimeter systems in the very forward region.

While radiation of one or more photons (at the ME level) is expected in up to 50% of DM pair-production events, most of these photons go along the beam line and only a small fraction is reconstructed as mono-photon events in the detector. The fraction of “tagged” events depends significantly on the mediator mass and width, as shown in Figure 1 (left).

The analysis focuses on setting the DM pair-production cross section limits as a function of the mediator mass and width, assuming DM particles are light (the mass of fermionic DM is fixed to 1 GeV for all results presented for 250 GeV ILC). Considered are two-dimensional distributions of the reconstructed mono-photon events in pseudorapidity and transverse momentum for background and signal events. Cross section limits for DM pair-production are extracted from the combined analysis of data taken with different beam polarisations, resulting in the strongest limits, also reducing the impact of systematic uncertainties.

3 Results

Presented in Figure 1 (right) are cross section limits expected from the combined analysis of 250 GeV ILC data for vector mediator exchange and different fractional mediator widths. The strongest limits are obtained for processes with light mediator exchange and for narrow mediator widths, whereas for heavy mediator

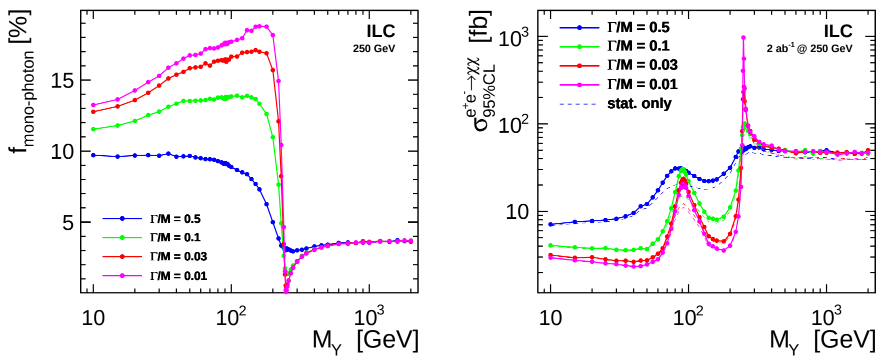

Figure 1: Left: fraction of dark matter pair-production events, which are reconstructed as mono-photon events in the detector. Right: cross section limits for light fermionic DM pair-production with s-channel vector mediator exchange. Results for the ILC running at 250 GeV are presented as a function of mediator mass for different fractional mediator widths.

exchange ($M_Y \gg \sqrt{s}$) cross section limits no longer depend on the mediator width. Limits are significantly weaker for narrow mediator with $M_Y \approx \sqrt{s}$, when photon radiation is significantly suppressed and at $M_Y \approx M_Z$, when signal events are similar to radiative Z return events.

Shown in Figure 2 are expected limits on the mediator coupling to electrons for different mediator widths (left) and for different coupling scenarios (right). For heavy mediator exchange, the coupling limits increase with the mediator mass squared, $g_{eeY} \sim M_Y^2$, as expected in the effective field theory (EFT) approach. As shown in [11], results of the presented approach [2] are in very good agreement with the limits from the ILD analysis [12] based on the full detector simulation and EFT formalism.

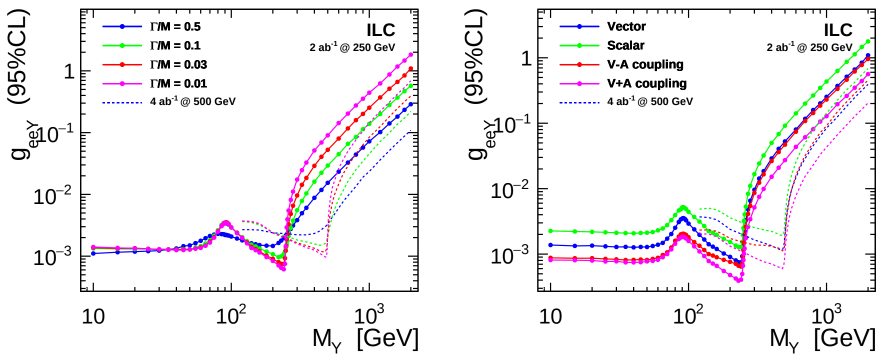

Figure 2: Limits on the mediator coupling to electrons for the ILC running at 250 GeV (solid lines) and 500 GeV (dashed lines), as a function of mediator mass. Left: for vector mediator and different relative mediator widths. Right: for different mediator coupling scenarios and relative mediator width, Γ/M = 0.03.

4 Impact of polarisation

The sensitivity to processes of radiative DM production is mainly limited by the "irreducible" background from radiative neutrino pair-production events, $e^+e^- \rightarrow \nu\bar{\nu}+\gamma$. As the structure of mediator couplings is unknown, data taken with different polarisation combinations needs to be combined to obtain the best sensitivity in all possible scenarios. Moreover, by combining four independent data sets the impact of systematic uncertainties is significantly reduced. This is shown in Figure 3, where expected limits from mono-photon analysis are compared for the combined analysis of polarised data and for an unpolarized data set with the same integrated luminosity, without and with systematic uncertainties taken into account. When beam polarisation is not used,

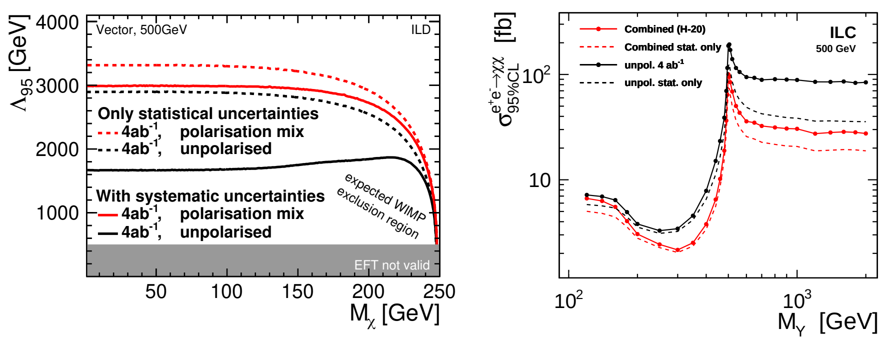

Figure 3: Impact of the systematic uncertainties on the expected limits from the mono-photon analysis at 500 GeV ILC. Left: EFT mass scale limits as a function of the DM particle mass [12]. Right: limits on the DM pair-production cross section as a function of mediator mass [2]. Limits from the combined analysis of data collected with different beam polarisations (red) are compared with limits expected for unpolarised data set with the same integrated luminosity (black).

systematic uncertainties reduce the ILC reach in EFT mass scale by almost a factor of two. When combining data taken using different polarisation combinations, systematic effects can be significantly constrained based on the predicted polarisation dependence of the SM backgrounds. The impact of the systematic uncertainties on the EFT mass scale is reduced to about 10%. For scenarios with light mediator exchange, the impact of systematic uncertainties is significantly reduced. Still, combined analysis of data taken with different polarisation combinations results in significant limit improvement.

5 Conclusions

Future e^+e^- colliders offer many complementary options for DM searches. Searches based on the mono-photon signature are believed to be the most general and least model-dependent way to look for DM production. A future Higgs factory will be able to test light mediator coupling to electrons down to $g_{eeY} \sim 10^{-3}$ up to the kinematic limit, $M_Y \leq \sqrt{s}$. For processes with light mediator exchange, limits expected from the analysis of mono-photon spectra on the mediator couplings to SM fermions are stronger than those expected from the direct searches in SM decay channels. If discovered, the new mediator can be precisely studied at e^+e^- colliders. Its coupling structure can be easily determined at the ILC thanks to the polarisation of both electron and positron beams.

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