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Model-independent WIMP Characterisation at the International Linear Collider

Jenny List[*†]
DESY
E-mail: jenny.list@desy.de

We investigate the prospects for detecting WIMP dark matter and for measuring its parameters in a model-independent way at the International Linear Collider. The signal under study is direct WIMP pair production with associated initial state radiation $e^+e^- \to \chi\chi\gamma$. The analysis accounts for the beam energy spectrum of the ILC and the dominant machine-induced backgrounds. The influence of the detector parameters are incorporated by full simulation and event reconstruction within the framework of the ILD detector concept. By using polarised beams, the detection potential is significantly increased due to the reduction of the dominant SM background of radiative neutrino production $e^+e^- \to \nu\nu\gamma$. It will be shown that the ILC can observe WIMP pair production even if only a few percent of the primordial WIMPs annihilate into e^+e^- pairs. The dominant sources of systematic uncertainty are the precision of the polarisation measurement and the shape of the beam energy spectrum. With an integrated luminosity of 500 fb^{-1}, the helicity structure of the interaction involved can be inferred, and the masses and cross sections can be measured with a relative accuracy of a few percent.

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[*] Speaker.
[†] On behalf of the ILD Detector Concept Study

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1. Introduction

According to cosmological observations, about 25% of the energy content of today's universe consists of Dark Matter. One of the most popular candidates for this yet unknown type of matter are *Weakly Interacting Massive Particles*, WIMPs. These can be searched for in three complementary ways: Direct detection of primordial WIMPs when they hit the earth and scatter off nuclei, indirection detection via annihilation products of primordial WIMPs and production of WIMPs in the laboratory at colliders, eg. in proton-proton collisions at the LHC. Direct detection and the LHC are very powerful in probing the interaction of WIMPs with quarks (and gluons). Indirect detection could find signals of WIMP annihilations into photons or leptons as well as to hadrons. However the interpretation of signals is challenging due to astrophysical sources and uncertainties in the signal propagation. WIMP searches at a future e^+e^- Linear Collider like the ILC allow to test the WIMP-lepton coupling under laboratory conditions, analoguously to the LHC exploring the WIMP-quark couplings. Indepently of a future discovery or further exclusions from the above type of experiments, the ILC can add fully complementary information, since a priori WIMP-quark and WIMP-lepton interactions could be governed by different operators at different scales.

Assuming that today's relic density value is determined by WIMP pair annihilation, the cross-section for this annihilation sets the scale for the reverse process: WIMP pair production at colliders. The cross-section for $e^+e^- \to \chi\chi$ is completely determined by the WIMP mass M_χ and spin S_χ, the spin-averaged fraction of annihilations to e^+e^-, κ_e, and the corresponding fractions for the four possible chiral combinations $e^+_R e^-_L$, $e^+_L e^-_R$, $e^+_L e^-_L$, $e^+_R e^-_R$ as well as the dominant partial wave J_0 of the annihilation process [1]. While the WIMPs themselves don't leave signals in collider detectors, initial-state photon radiation can be used to detect these events.

The baseline design of the ILC [2] forsees a tunable center-of-mass energy between 200 and 500 GeV, upgradable to 1 TeV, an integrated luminosity of 500 fb^{-1} in the *first* 4 years, and then every 2 years (at 500 GeV) and beam polarisations of $|P(e^-)| \geq 80\%$ and $|P(e^+)| \geq 30\%$. The results presented here are based on full simulation of the ILD detector concept [3] for signal and all relevant background processes. For a full description of the analysis and more results see [4].

2. Results

Assuming the cosmologically required total WIMP-WIMP annihilation cross-section, the observability of WIMP production in e^+e^- collisions depends on the fraction κ_e of these annihilations which results in electron-positron pairs. Figure 1 shows the lower limit on κ_e, for which an observation at a level of 3σ is still possible for a Spin-1 WIMP and a dataset with $P(e^-,e^+) = (+80\%, -30\%)$ and an integrated luminosity of 500 fb^{-1} as a function of the WIMP mass for three different assumptions on the helicity structure of the WIMP-fermion coupling. It can be seen that the annihilation into e^+e^- does not have to be dominant, but that percent-level fractions are sufficient for not too heavy WIMPs. Even for WIMP masses 30 GeV below the kinematic limit, a κ_e of about 10% would still be sufficient.

The measurement of the polarised cross-sections gives access to the helicity structure of the WIMP-fermion couplings. The achievable precision and separation power has been evaluated for three benchmark cases, assuming that the total luminosity of 500 fb^{-1} is split such that 200 fb^{-1}

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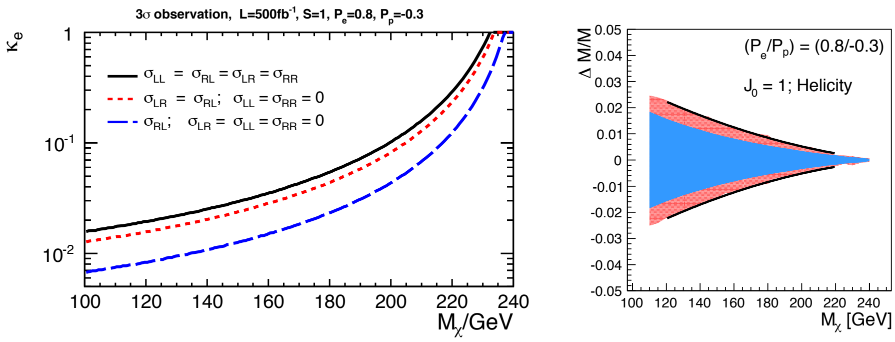

Figure 1: Left: 3σ-observation reach in terms of κ_e vs the mass of a spin-1 WIMP for three different assumptions on the helicity structure of the WIMP-fermion coupling. Right: relative uncertainty on the WIMP mass for the case of helicity and parity conserving couplings (blue: systematic uncertainty, red: statistical contribution to total uncertainty).

are accumulated for each of the opposite sign configurations and $50\,\mathrm{fb}^{-1}$ for each of the like-sign configurations, which are less interesting eg. for Standard Model physics. The precision of the result is limited by the assumed precision of the polarisation measurement, where we conservatively assume $\delta P/P = 0.25\%$. In a χ^2 test between the three helicity scenarios depicted in Figure 1 (left), the wrong hypotheses obtain p-values of less than 10^{-8} and thus can clearly be rejected. The measurements of the polarised cross-sections can be combined to determine the total unpolarised cross-section σ_0. With $|P(e^+)| = 30\%$, σ_0 can be determined to precisions between 3 and 5%, depending again on the helicity structure of the WIMP-fermion coupling.

The dominant partial wave of the WIMP-WIMP annihilation process can eg. indicate whether the WIMP is a majorana fermion or a boson. It is observable through it's influence on the ISR photon energy spectrum near the endpoint: In a template fit to the photon energy spectrum after detector simulation, the correct hypothesis yields the lower χ^2/ndf. The discrimination becomes less significant at lower WIMP mass far from threshold. If a WIMP signal is observed in a mass range where the distinction is not significant, dedicated data-taking near the production threshold can easily overcome this issue.

The WIMP mass M_χ can be determined from the endpoint of the photon energy spectrum - or by a template fit to the whole spectrum once the dominant partial wave has been determined. The right plot of figure 1 shows $\Delta M_\chi / M_\chi$ vs M_χ for the case of $\sigma_{RL} = \sigma_{RL}$, $\sigma_{LL} = \sigma_{RR} = 0$. The precision ranges from 2.5% to 0.4% and receives a significant systematic contribution (blue band). The dominant source is the knowledge of the shape of the beam energy spectrum, which has been estimated in a very conservative way in this study, thus further improvements are expected.

References

[1] A. Birkedal, K. Matchev and M. Perelstein, Phys. Rev. D **70** (2004) 077701 [hep-ph/0403004].

[2] C. Adolphsen *et al.*, arXiv:1306.6328 [physics.acc-ph].

[3] T. Behnke *et al.*, arXiv:1306.6329 [physics.ins-det].

[4] C. Bartels, M. Berggren and J. List, Eur. Phys. J. C **72** (2012) 2213 [arXiv:1206.6639 [hep-ex]].

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