PROCEEDINGS OF SCIENCE

Long-lived particle searches with the ILD experiment

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An interesting concept that could explain why the new physics evades detection is a potential existence of Beyond the Standard Model (BSM) long-lived particles (LLPs). Such states, just like many particles in the SM, could travel macroscopic distances before decaying, making it very challenging to observe them. However, the main mechanisms responsible for an enhancement of particle lifetime include reduced couplings to the SM sector or small mass differences in a particle decay chain. This, by definition, makes it very difficult to search for such states in the busy environment of a hadron collider. Therefore, future e^+e^- colliders provide a unique opportunity for LLP searches. This study focusses on neutral LLP searches using the International Large Detector (ILD), a detector concept for a future Higgs factory. The signature considered is a displaced vertex inside the ILD's Time Projection Chamber. We study challenging scenarios involving small mass splittings between heavy LLP and dark matter, resulting in soft displaced tracks. As an opposite case, we explore light pseudo-scalar LLPs decaying to boosted, nearly collinear tracks. Backgrounds from beam-induced processes and physical events are considered. Various tracking system designs and their impact on LLP reconstruction are discussed. Assuming a single displaced vertex signature, model-independent limits on signal production cross-section are presented for a range of LLP lifetimes, masses, and mass splittings. The limits can be used for constraining specific models, with more complex displaced vertex signatures.

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1. Introduction

The ILD [1] is one of the experiments proposed for operation at a future Higgs factory. Its tracking systems include a pixel vertex detector and a silicon inner tracker, surrounded by a time projection chamber (TPC), which is promising in case of searches for delayed decays. This contribution, based on Ref. [2], presents prospects for a detection of a neutral LLPs with the ILD, using International Linear Collider (ILC) [3] operating at $\sqrt{s} = 250\,\text{GeV}$ as a reference collider.

2. Analysis strategy and benchmark scenarios

Benchmark scenarios considered were not points in a parameter space of particular BSM models, but involved signatures challenging from experimental perspective. Two opposite classes of benchmarks were chosen, with the first one involving a very soft displaced track pair in the final state. We used pair-production of heavy neutral scalars, A and H, where the former is the LLP and the latter is stable (and escapes undetected). The LLP decay channel is $\text{A} \to \text{Z}^*\text{H}$, and its mass and proper decay length were fixed to $m_A = 75\,\text{GeV}$ and $c\tau = 1\,\text{m}$. Four mass splitting values between A and H were considered: $m_A - m_H = 1, 2, 3, 5\,\text{GeV}$. The second class features production of a very light and highly boosted LLP with strongly collimated final-state tracks. It was generated using the associated production of a pseudoscalar LLP, a, with a hard photon. Four masses of LLP were considered, $m_a = 0.3, 1, 3, 10\,\text{GeV}$, with $c\tau = 10 \cdot m_a$ mm/GeV. Only decays to muons of Z^* and a were simulated. The analysis relied on vertex-finding algorithm designed for this study and was performed in a model-independent way, considering only the displaced vertex signature in the TPC, ignoring any other activity in the detector. The study was carried out using full detector simulation.

3. Background reduction

Two types of background have been taken into account – soft, beam-induced (low-p_T) processes and hard (high-p_T) processes. The beam-induced processes occurring in each bunch-crossing constitute a significant standalone background if one wants to consider soft signals. To reject fake vertices, a set of quality cuts was applied on the variables describing kinematic properties of tracks. The main background sources that remain include V^0 particles and secondary interactions of particles with the detector material. In addition to matching with a dedicated ILD software for V^0 identification, cuts corresponding to masses of different V^0s are applied. Further cuts on the total p_T of tracks forming the vertex, and on variables describing track-pair geometry, provide the total reduction factor of $1.26 \cdot 10^{-10}$ for beam-induced backgrounds. 2-fermion and 4-fermion production with hadronic jets in the final state was considered as the high-p_T background. To improve the high-p_T background rejection, in addition to the *standard* selection described above, we consider also *tight* cuts, where track pairs (assuming they are electrons or pions) with invariant mass below 700 MeV are rejected. An isolation criterion is also included in tight selection.

4. Results

Vertex finding rates for the signal and the background were used to obtain the expected 95% C.L. upper limits on the signal production cross section, $\sigma_{95\%\text{C.L.}}$, assuming integrated luminosity

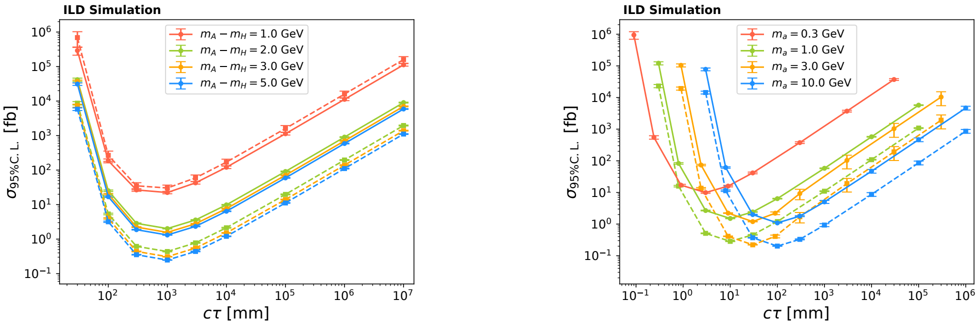

Figure 1: Expected 95% C.L. upper limits on the signal production cross-section for the considered benchmarks and different LLP mean decay lengths, for the scalar pair-production (left) and the light pseudoscalar production (right) at $\sqrt{s} = 250$ GeV. Solid lines corresponds to the standard selection and dashed lines to the tight set of cuts. The uncertainties are statistical.

of 2 ab^{-1}. An event re-weighting was also performed to obtain the limits for a range of LLP lifetimes without generating and processing a large number of event samples. The limits are presented in Fig. 1 as a function of LLP proper decay length $c\tau$. For tight selection, the sensitivity to $m_a = 300$ MeV scenario is lost because of the tight cuts on the invariant mass.

5. Impact of the detector design

Impact of the detector design on the sensitivity to LLP decays to soft final states was also tested. For that purpose, an alternative ILD design was used, in which the TPC was replaced by an all-silicon outer tracker, modified from the detector model proposed for the Compact Linear Collider (CLICdet) [4]. The analysis has shown that for decays close to the interaction point, where both detector models are identical, the performance is very similar. However, for higher displacements the efficiency drops quickly in the the all-silicon tracker (reaching almost zero at 1 m), while for the baseline ILD design it remains high almost throughout the whole detector volume. The reason is a limited number of layers in the silicon tracker, as at least 4 hits are required to reconstruct a track.

Acknowledgments

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