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 a heavy LLP and a dark matter candidate, 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.

42nd International Conference on High Energy Physics (ICHEP2024)
18-24 July 2024
Prague, Czech Republic

https://pos.sissa.it/

PoS(ICHEP2024)320

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 beneficial for delayed decay searches. 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 selected based on existing constraints on BSM models, but for 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 $A \to Z^*H$, 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. LLPs of four different masses were considered, $m_a = 0.3, 1, 3, 10\,\text{GeV}$, with $c\tau = m_a \cdot 10\,\text{mm/GeV}$. 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 rejection based on 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. Two- and four-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* selection, where track pairs (assuming they are electrons or pions) with invariant mass below 700 MeV are rejected. An isolation criterion is also included in the 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 of

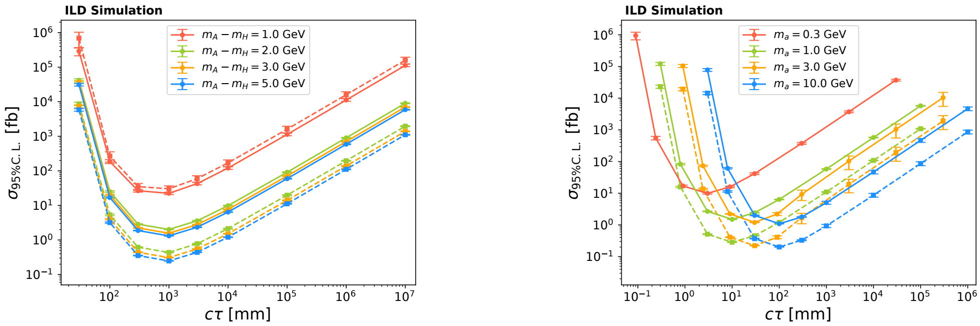

Figure 1: Expected 95% C.L. upper limits on the signal production cross-section for the considered benchmarks and different LLP mean decay lengths, for the scalar pair-production (left) and the light pseudoscalar production (right) at $\sqrt{s} = 250$ GeV. Solid lines corresponds to the standard selection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

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 the 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 displacements higher than about 10 cm the efficiency drops quickly in the the all-silicon tracker, while for the baseline ILD design it remains high almost throughout the whole tracking 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

The work was supported by the National Science Centre, Poland, under the OPUS research project no. 2021/43/B/ST2/01778.

References

[1] ILD Concept Group collaboration, *International Large Detector: Interim Design Report*, 2003.01116.

[2] J. Klamka and A.F. Zarnecki, *Searching for displaced vertices with a gaseous tracker for a future e^+e^- Higgs factory*, 2409.13492.

[3] P. Bambade et al., *The International Linear Collider: A Global Project*, 1903.01629.

[4] N. Alipour Tehrani et al., *CLICdet: The post-CDR CLIC detector model*, .