PROCEEDINGS OF SCIENCE

Ultra long-lived particles searches with MATHUSLA

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Many extensions of the Standard Model include particles that are neutral, weakly coupled, and long-lived that can decay to hadronic and leptonic final states. The ATLAS, CMS, and LHCb experiments have performed searches for possible long-lived particles at the LHC and significant exclusion limits have been set in recent years. In this talk, we describe the MATHUSLA surface detector (MAssive Timing Hodoscope for Ultra Stable neutraL pArticles), which can be implemented with existing technology in time for the turn- on of the high luminosity LHC (HL-LHC). We installed a small-scale test stand on the surface above ATLAS IP in autumn 2017 for timing measurements to study efficiency of downward cosmic track rejection. This will provide useful information for the design of the main detector and important inputs for the future physics and detector simulations.

The 39th International Conference on High Energy Physics (ICHEP2018)
4-11 July, 2018
Seoul, Korea

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1. Introduction

Many proposed extensions of the Standard Model (SM) introduce new particles that are neutral, weakly coupled, and long-lived, and can decay to hadronic and leptonic final states. Long-lived particles (LLPs) can be detected at colliders as displaced decays from the interaction point (IP), or missing energy if they escape. All the searches carried out in proton-proton collisions at the LHC have set significant exclusion limits in recent years. The current searches performed at colliders have limitations. An LLP does not interact with the detector and it is only visible once it decays. Unfortunately, no existing or proposed search strategy will be able to observe the decay of non-hadronic electrically neutral LLPs with masses above few GeV and lifetimes near the limit set by Big Bang Nucleosynthesis ($c\tau \sim 10^7 - 10^8$ m). Such ultra-long-lived particles (ULLPs) produced at the LHC will escape the main detector with extremely high probability. During the high-luminosity LHC running time (from 2025 till 2035) about 1.5×10^8 Higgs bosons are expected to be produced [1]. Since LLPs, as described by the above-mentioned models, can be generated in Higgs-boson decays, dedicated experiments searching for LLPs produced in LHC collisions have been seriously considered. LLP searches have to face two basic challenges: first, the frequency of the expected observed LLP decays is proportional to the decay "depth" times the geometrical acceptance of the detector; secondly, it is necessary to overcome the QCD-induced background, particularly in collider experiments such as ATLAS, CMS and LHCb.

2. The MATHUSLA detector

The MATHUSLA surface detector (MAssive Timing Hodoscope for Ultra Stable neutraL pArticles) [2] can be implemented with existing technology in time for the turn-on of the high-luminosity LHC (HL-LHC). The MATHUSLA detector will consist of an air-filled decay volume surrounded by charged particles detectors (top, bottom, and sides) that provide timing, and a robust multi-layer tracking system located in the upper region. The MATHUSLA proposal considers covering a total sensitive area of 200×200 m^2 on the surface in the region near the interaction point of ATLAS or CMS detectors for the beginning of the HL-LHC run. Fig. 1 shows a basic scheme of the possible placement of the MATHUSLA experiment on the ground above an LHC interaction point.

The MATHUSLA detector has been devised in such a way to have geometrical coverage of about 5%, to need minimal instrumentation and to be virtually background free. Basically, the sensitivity of the experiment to LLPs is proportional to the overall volume, while its cost is proportional to the area covered by the detectors. The proposed MATHUSLA layout includes scintillator tiles (top, bottom, and sides) that provide ~ 1 ns timing resolution and ~ 10 cm position resolution, and Resistive Plate Chambers (RPCs) [3] as the multi-layer tracking system (also providing timing information with a sub-ns resolution). The RPC layers act as a directional tracker, while the scintillator tiles give additional veto. The reconstructed vertex and time-of-flight measurement of final states will distinguish LLP decays from passing cosmic rays and neutrino-scattering events. An LLP signature in MATHUSLA is expected to be a reconstructed upward-going vertex with at least two separate decays tracks, compatible with a neutral particle produced at the LHC interaction region, as shown schematically in Fig. 2.

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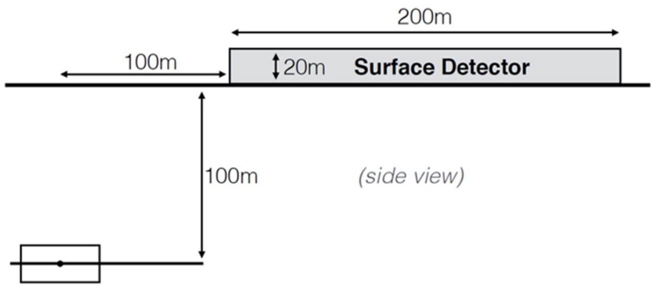

Figure 1: Basic scheme of the possible placement of the MATHUSLA experiment on the ground above an LHC interaction point.

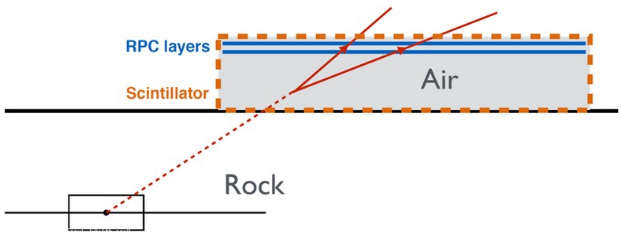

Figure 2: Schematic representation (not in scale) of a possible LLP signature in MATHUSLA.

The cosmic-ray background will be easily rejected by exploiting timing and floor-veto information from the scintillators. Muons coming from LHC collisions will be also rejected with the floor veto. Cosmic-neutrino backgrounds (between 10 and 100 interactions per year above 300 MeV) are also expected to be rejected easily since they would produce non-pointing vertices in the detector, and the rate of neutrinos coming from LHC secondaries is expected to be extremely low (less than 1 event per year). Based on this, the possible reach of a MATHUSLA-like experiment for LLPs is expected to be ~ 3 orders of magnitude better than the expected reach for the LLP ATLAS search during the whole HL-LHC operation time.

3. The MATHUSLA test stand

We installed a small-scale test stand ($\sim$ 6.5 m high, covering an area of 2.5×2.5 m^2) on the surface above the ATLAS interaction point in autumn 2017 that consists of three layers of RPCs used for timing/tracking and two layers of scintillators (top, bottom) for timing measurements to study efficiency of downward cosmic track rejection. The RPCs were provided by the group of Roma Tor Vergata from spares of the ARGO-YBJ experiment [5], while the scintillators and the phototubes were obtained from spares of the D0 experiment at Fermilab [4]. The goal is to estimate cosmic background that mimics upward-going tracks and the proton-proton collision backgrounds from ATLAS during nominal LHC operations. The test stand will resume operation above the ATLAS IP in April 2018 and collect data with pp collisions until December 2018. This will provide useful information for the design of the main detector and important inputs for the future physics and detector simulations. The MATHUSLA collaboration will publish a Letter of Intent before October 2018, and the MATHUSLA project will be evaluated by a board of the LHC Committee before the end of 2018. Based on the outcome of these steps, the future plans will be prepared at the beginning of 2019.

References

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