Recent Progress and Next Steps for the MATHUSLA LLP Detector

Snowmass 2021 Letter of Interest

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Thematic Areas:
■ (EF09) BSM: More General Explorations
■ (EF02) EW Physics: Higgs Boson as a portal to new physics
■ (EF10) BSM: Dark Matter at colliders
■ (EF08) BSM: Model specific explorations
■ (NF03) BSM
■ (RF06) Dark Sector Studies at High Intensities
■ (AF05) Accelerators for PBC and Rare Processes
■ (IF3) Solid State Detectors and Tracking
■ (IF4) Trigger and DAQ
■ (IF7) Electronics/ASICs

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Abstract

We outline recent progress on the MATHUSLA LLP detector proposal, including further details on the design, Long Lived Particle (LLP) sensitivity, backgrounds and their rejection, and the cosmic ray physics potential. We also discuss the next steps required to make this detector a reality, which include study of rare backgrounds, further detector and hardware R&D, cosmic ray reconstruction studies, and optimization of the detector geometry. There is ample opportunity for new members, in particular with expertise in detector design, simulation studies, and cosmic ray physics, to contribute to the MATHUSLA design effort.

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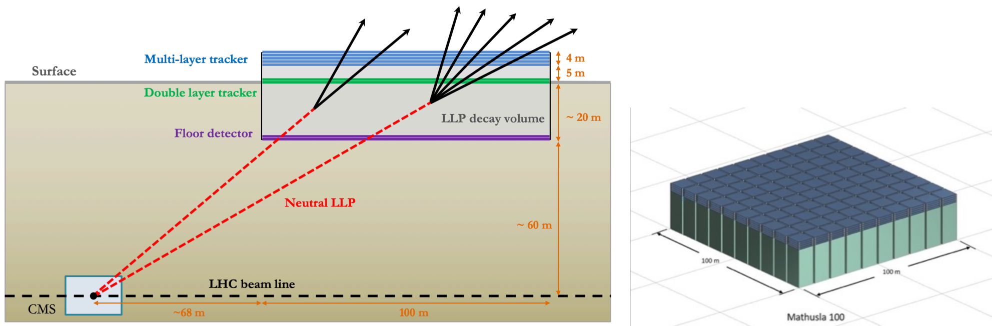

FIG. 1. Left: MATHUSLA detector location near CMS. Right: Schematic view of the MATHUSLA modular detector concept, shown as 100 units of area $9\text{m} \times 9\text{m}$.

I. INTRODUCTION

MATHUSLA (Massive Timing Hodoscope for Ultra-Stable neutraL pArticles) [1, 2] is a proposed large-scale dedicated Long-Lived Particle (LLP) detector to be situated at CERN near CMS. It will be able to reconstruct the decay of neutral LLPs, produced in HL-LHC collisions at CMS, as displaced vertices (DV) in a near-zero-background environment. The geometry of the detector [3] is shown in Fig. 1. The LLP physics case of MATHUSLA was explored in detail in [4], showing orders of magnitude better sensitivity than the main detectors alone. MATHUSLA can be integrated into the CMS L1 trigger system for detailed characterization of any discovered LLPs [5, 6].

Significant progress has been made in the last several years towards a realistic modular detector design and understanding backgrounds at MATHUSLA in detail. This lays the groundwork for the next steps in making MATHUSLA a reality. The immediate goal is the preparation of a Technical Design Report and a robust cost estimate. To this end, several experimental and simulation studies need to be conducted over the timeline of the Snowmass 2021 process.

II. MATHUSLA DETECTOR LOCATION AND MODULAR DESIGN

An updated MATHUSLA design, situated on CERN-owned land near CMS, will be presented shortly in [3]. The location relative to CMS is shown in Fig. 1 (left). The detector has area $100\text{m} \times 100\text{m}$, with a partially excavated decay volume of height 25m. This design achieves the same LLP sensitivity as the original benchmark [1, 4] with $\frac{1}{4}$ the area due to the smaller distance from the collision point [3]. In addition to 5 tracking layers above the decay volume, there are two layers 5m below the ceiling as well as two layers acting as a floor detector.

The detector can be assembled as a modular design. Fig. 1 (right) shows a schematic view of 100 identical detector modules providing coverage of the decay volume. Each of the $9\,\text{m} \times 9\,\text{m}$ detector planes consists of an assembly of extruded scintillating bars whose length, width and thickness is 4.55 m, 4.5 cm, 2 cm, respectively. Each bar is extruded with a hole at the centre into which a wave-length shifting (WLS) fibre is inserted and connected to an SiPM.

The above design represents the current benchmark, but significant R&D is still needed to design and optimize the detector hardware itself (scintillators, fibre, and SIPMs) as well as the trigger and data-acquisition system. This will be conducted as part of the effort to produce a Technical Design Report in 2021. New member contributions will be highly welcome.

III. LLP SEARCHES

The physics case white paper [4] studied the sensitivity of MATHUSLA extensively, demonstrating the wide-ranging reach for LLPs with long lifetimes $c\tau \gtrsim 100m$ and masses ranging from

$\lesssim$ GeV to TeV. MATHUSLA would improve reach for hadronically decaying LLPs produced in exotic Higgs decays by three orders of magnitude compared to ATLAS or CMS searches, and probe TeV-scale LLPs like RPV superpartners or Higgsinos in GMSB to greatly extend the reach of the main detectors. MATHUSLA also has sensitivity for tiny LLP mixing angles in simplified minimal low-scale LLP models like SM+S and Right-Handed Neutrinos, complementing the reach of proposed intensity-frontier experiments like SHiP [7]. Finally, MATHUSLA's LLP reach is vital in completing the DM search program at the LHC, providing unique sensitivity to DM produced in LLP decays in models where the properties of an LLP dictate DM abundance in the plasma of the early universe [3].

IV. INTEGRATION WITH CMS

MATHUSLA can use geometrical information to reconstruct the boost of the decaying LLP [5] and constrain its decay mode. It has recently been shown [6] that this can be used together with information from the main detector to diagnose the LLP production, LLP mass, and parent particle mass, allowing the hidden sector to be characterized in detail. This relies on the fact that MATHUSLA can supply a L1 trigger signal to CMS [2], ensuring that the LLP production event is written to tape regardless of main detector trigger thresholds.

V. BACKGROUNDS AND SIMULATION

Recent progress in detailed background simulations of upward going muons, cosmic rays and atmospheric neutrinos will be presented in [3], greatly aided by measurements taken at the MATHUSLA test stand detector [8]. These simulations support the earlier conclusion that most backgrounds can be effectively vetoed. They also focus attention on rare production of upward-traveling SM particles like neutral Kaons due to cosmic rays hitting the floor. Veto strategies are available, but these rare processes are challenging to simulate and are the subject of ongoing study. Another current focus is the development of realistic LLP reconstruction algorithms in the unique detector environment of MATHUSLA.

VI. COSMIC RAY SCIENCE PROGRAM

MATHUSLA's large detection area and highly granular tracking system makes it an excellent cosmic-ray (CR) telescope to study extended air showers (EAS) and performing CR measurements up to the PeV scale. Highly detailed measurements of EAS arrival time, particle multiplicity, and spatial distributions allow reconstruction of EAS core and direction and would be greatly aided by installing a hybrid digital-analogue tracking layer of Resistive Plate Chambers (RPC) similar to the ARGO-YBJ experiment. This possible upgrade is now being closely investigated, since CR measurements constitute a guaranteed physics return on the investment of building MATHUSLA. This is an area where new members with cosmic ray expertise could make significant contributions.

VII. NEW COLLABORATORS AND TIMELINE

Detector R&D will be conducted over the next few years, with the construction and comissioning of a single prototype module planned around 2024 or 2025. This prototype module would already be able to set leading limits on some LLP processes and perform important CR measurements during the shut-down prior to HL-LHC first beam to calibrate the simulation frameworks. We then plan to have the full detector operational in time for HL-LHC turn-on.

We are excited to welcome new collaborators to aid in realizing this timeline. Many experimental, design and simulation studies need to be conducted in the next 1-2 years, as outlined above. If interested, please send an email to `mathusla.experiment@cern.ch`.

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