Scintillator Extrusions for Mega-detectors: MATHUSLA Letter of Interest for Snowmass 2021

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The MATHUSLA experiment at CERN will be a detector to search for long-lived particles. To achieve the desired production cross section sensitivity the detector is required to be very large. The active elements of this detector will be based on scintillator extrusions. In this paper we discuss the conceptual idea of the detector and plans to optimize the extrusions to improve light yield and timing accuracy.

In the late 1990's, the extruded plastic scintillator concept developed at Fermilab made possible the construction of very large scintillator calorimeters [1, 2]. A series of large experiments using scintillator extrusions have been built, including MINOS [3], MINERva [4], and Mu2e [5]. The MINOS detector is the largest user of extrusions to date, about 300 tons. MATHUSLA [6–8] will be built using scintillator extrusions and will have the most extrusions of any HEP experiment, with an anticipated use of up to 2000 tons. We are pursuing a program to improve the extrusion performance in MATHUSLA by increasing the light yield and improving the time resolution. These improvements will be important to MATHSULA and also to any other new experiments that use the scintillator extrusion technology.

The LHC detectors ATLAS, CMS and LHCb have active LLP searches that have excluded $c\tau \sim 100$ m for many models [9]. Extensions of their searches to very long lifetimes is severely limited by the large SM backgrounds in the LHC main detectors, making it impossible to search for LLPs to the Big Bang Nucleosynthesis (BBN) life-time limit.

To be able to reach the BBN limit at the high luminosity LHC (HL-LHC), the MATHUSLA (MAssive Timing Hodoscope for Ultra-Stable neutraL pArticles) detector was proposed [7, 8]. The plan is to locate a large LLP detector on the surface above or slightly displaced from the *pp* interaction point (IP). The $\sim$ 80m of rock between the IP and the surface detector absorbs the SM backgrounds and allows MATHUSLA to operate in a SM background free environment.

Figure 1 shows the overview of the MATHUSLA experiment. It will be a 100 m × 100 m × 30 m active volume, to be sited near the CMS detector at the LHC. MATHUSLA will be composed

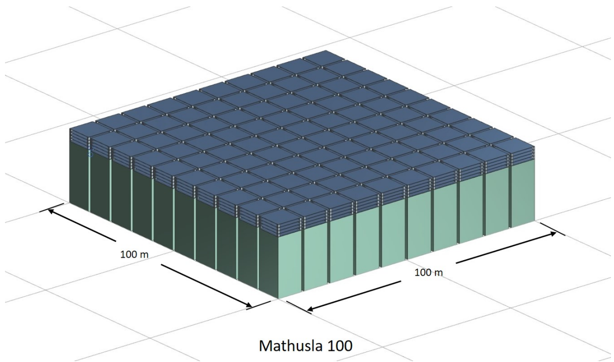

FIG. 1. Overview of MATHUSLA. In the MATHUSLA experiment there will be 100 identical modules in an array. Each module is 10 m × 10 m × 30 m.

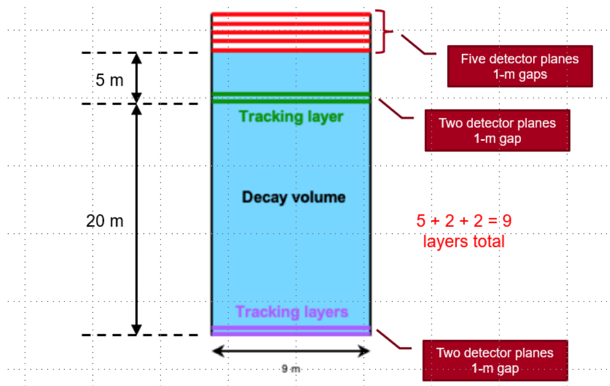

FIG. 2. One of the 100 identical MATHUSLA modules. 9 layers of scintillator are shown.

of 100 identical modules, 10 m × 10 m × 30 m. Figure 2 shows details of a module. There will be 9 layers of scintillators in the module, com-

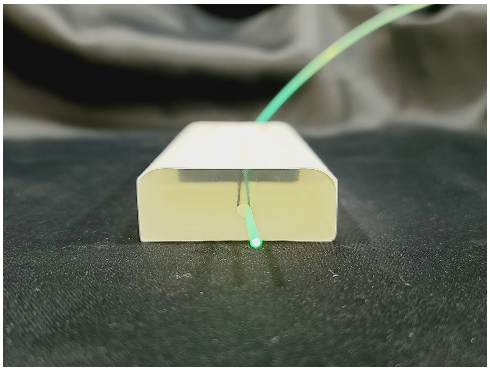

FIG. 3. An extrusion with one central fiber running through a co-extruded hole. Note the co-extruded white reflective coating surrounding the scintillator.

posed of pieces of extrusion 4.5 cm wide by 2 cm thick by 4.5 m long. The extrusions will be read out by wavelength-shifting (WLS) fibers coupled to SiPMs, as is done for instance in Mu2e. Figure 3 shows a representative extrusion with fiber inserted into a co-extruded hole running along the middle of the extrusion. The extruded scintillator bars provide the XY coordinates of a charged particle that traverses the bar. One coordinate is provided by the 4.5 cm segmentation of the extrusion. The other coordinate is provided by the arrival time difference between the light pulses hitting the SiPMs on each end of the extrusion.

The scintillator extrusion facility at Fermilab is shown in Figure 4. It is an in-line process where polystyrene pellets are mixed with the appropriate amount of fluorescent organic compounds and extruded through a die to create a scintillator bar of the profile required by the experiment. Many custom shapes and sizes of extrusion have been made. The extrusion can have a co-extruded hole or holes for wavelength-shifting fiber. Holes of different sizes can be formed to accommodate different diameter WLS fibers. Additionally reflective cladding can be co-extruded on the scintillator.

FIG. 4. The scintillator extrusion facility at Fermilab.

Issues we are pursuing to improve the extrusion include:

- Optimize production/QC with robotics
- Improve light-yield/timing by:
  - Choice of SiPM
  - Choice of Fiber
  - Reflector on the extrusion
  - Geometry of the extrusion
  - Front end electronics / signal shaping

Ongoing studies include evaluation of the wrapping material; evaluation of different fiber diameters and numbers; and shapes of the extrusion. Our goal for timing resolution is less than 1 ns for measurement of the arrival time difference between the SiPMs on each end of the fiber.

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