Development and feasibility studies towards a surrounding background tagger for the SHiP decay volume

TIM MOLZBERGER

Physikalisches Institut, Albert-Ludwigs-Universität,79104 Freiburg im Breisgau

In recent decades, evidence has emerged for the existence of particles beyond the Standard Model. Particles from this "hidden sector" may offer an explanation for phenomena such as dark matter, the neutrino mass hierarchy, and others. An experiment probing the intensity frontier for mass up to a few GeV/c^2 can discover new particles, which are characterised by a low coupling strength to the standard model. Two principal production modes have been identified: Proton bremsstrahlung and heavy flavour decays. The objective of the SHiP experiment at CERN is to produce these feebly interacting particles and to observe their scattering on, or their decay to standard model particles. Building upon this idea, we have designed a new experiment that will be located at the SPS beam dump facility in the North Area underground cavern ECN3 with its high-intensity 400 GeV/c^2 proton beam (see Figure 1).

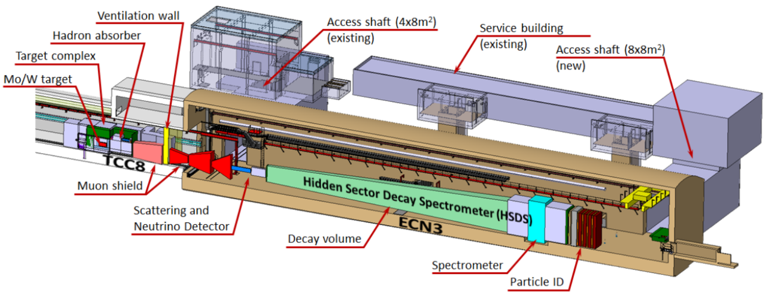

Figure 1: Illustration of the Search for Hidden Particles (SHiP) layout in ECN3.

The setup consists of a high-density proton target, acting as beam dump and absorber, followed by a hadron absorber and a magnetic muon shield immediately downstream. The shield deflects the muons produced in the beam dump in order to reduce the flux in the detector acceptance to an acceptable level. Only neutral particles that interact feebly are permitted to continue undisturbed before penetrating an emulsion-based scattering detector and subsequently a 50 m long decay volume. Here particles from the hidden sector can decay to standard model particles which are detected downstream in a spectrometer equipped with a large aperture dipole magnet, tracking and particle identification. A potential source of background is the inelastic scattering of neutrinos or muons in the cavern walls of the material of the decay volume. The task of the Surrounding Background Tagger (SBT) is to identify and categorize such background events.

The necessity for a light wall structure and a highly efficient background tagger system with optimal timing and spatial resolution for the SBT has been fulfilled by the implementation of a double-wall CORTEN steel structure comprising compartments with a liquid scintillator-based detector system (see Figure 2). Each of the 800 cells is filled with the solvent linear alkylbenzene and the fluor 2,5-diphenyloxazole. Primary and fluorescence light is shifted to the visible and finally collected by two Wavelength-shifting Optical Modules (WOM). Light collection is improved by removing optical impurities from the solvent and reducing the loss of scintillation photons by painting the inner walls of the compartments with a UV-reflecting $BaSO_4$ paint. At the front face of every WOM Silicon Photomultipliers convert the blue light to an electrical signal, which is then amplified and digitized.

The development of the SBT follows an iterative approach with different stages of prototypes, starting with lower complexity and advancing to more complex and larger structures. Each step is subject to extensive characterization with minimum ionizing particles and the findings are incorporated into the ongoing developments (see Figure 2). A recent prototype, comprising a single detector cell, was subject to a testbeam campaign with positron beams of different energies between 1.4 GeV and 5.4 GeV at DESY in autumn 2022. In this setup the detection efficiency for positrons was found better 99.3 % and a spatial resolution of 30 cm was reached with a likelihood-based approach. Further improvement down to 14 cm was achieved by a neural-network-based approach. A time resolution better 1 ns was measured over the entire detector and the energy resolution was found better +25 % and -10 % with respect to the energy of the beam particle.

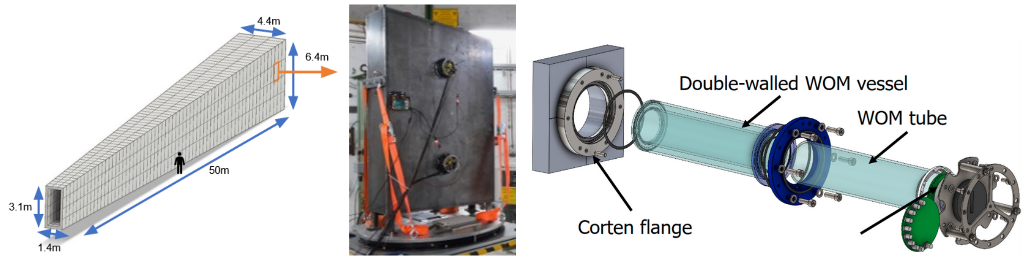

Figure 2: (Left) A schematic of of the SBT with dimensions. (Center) The prototype of one SBT cell at the DESY testbeam in 2022. (Right) Exploded-view drawing of a WOM with readout.

Based on the experience of the DESY testbeam a larger prototype, made of four compartments in a 2×2-cell configuration, was extensively tested in spring 2024 at the CERN T9 test beam facility. Here the objective was to further improve on the light collection efficiency and to assess effects of the sharing of the electromagnetic shower between different compartments. First results show an increase in the wall reflectivity from 68 % in the previous year to 98 %, due to the replacement of a water-based primer by an acrylic primer for the $BaSO_4$ paint. A forthcoming iteration in the prototyping will feature the initial rows of compartments for the final SBT detector.