Performance studies of SBT prototypes

Alessia Brignoli

Humboldt Universität zu Berlin

SHiP (Search for Hidden Particles) is an experiment to search for light feebly interacting particles. The project was proposed and accepted, in March 2024, to be built at a dedicated CERN SPS Beam Dump Facility. The high intensity of the SPS 400 GeV proton beam allows probing a wide variety of models containing light long-lived exotic particles with masses below O(10) GeV/c^2[1]. The operation in an almost background-free enviroment is a fundamental characteristic of the experiment. For this reason, a critical component of the experiment is the Surrounding Background Tagger (SBT). This detector, designed to envelop the large decay volume of the SHiP Hidden Sector (HS) detector, plays a vital role in identifying background events caused by muons and neutrinos.

The SBT is designed to detect minimum ionizing particles (MIPs) with an efficiency of at least 99%. To achieve this, the detector is constructed using liquid scintillator (LS), made from LAB+PPO at 2g/L, to cover the entire decay vessel structure. The LS is contained within numerous cells created by the support structure of the SHiP decay vessel, with each cell being instrumented with Wavelength-shifting Optical Modules (WOMs). WOMs are innovative, low-cost, large-area photodetectors originally proposed for the IceCube neutrino telescope[2]. The WOMs are coated with a wavelength-shifting dye in which scintillation light is absorbed and remitted at a longer wavelength, and detected by an array of 40 SiPMs coupled at one of the end of the WOM tube. This ensures a high photon collection effiency and provide good timing and spatial resolution.

As of today, several advancements have been implemented and tested to improve the performance of the SBT:

- Purification of the LS: This increases the light attenuation length in the scintillator, particularly within the crucial wavelength range for PPO light emission.
- Enhanced Reflectivity: The inner walls of the LS detector cells are painted with a reflective coating to better reflect scintillation photons, thereby increasing the amount of detected light.
- Optimized WOM Coating: The absorption probability of scintillation photons in the WOM coating was increased, enhancing the detector's sensitivity.
- Improved Optical Coupling: The coupling between the SiPM arrays and the WOMs was refined to ensure maximum light collection.

These improvements were validated through a series of tests, including a full-size one-cell prototype, tested at the DESY test beam facility with a positron beam, in 2022, and a four-cells prototype, tested at PS area at the CERN with muons and electrons, in spring 2024. The results of these tests were compared to Monte Carlo simulations, which helped in fine-tuning the detector's response and characterizing its performance in the simulation. Additional laboratory measurements were conducted to optimize the WOM coating procedures and to demonstrate the detector's ability to reconstruct the location of light sources based on the light yield distribution measured by the SiPM arrays.

This research focuses on testing the detectors response and the development of Monte Carlo simulations for predictions and comparisons. For both the tested prototypes, the detector efficiency was estimated and resulted in a value higher than 99.5% all over the cell, above the required performance [3]. Moreover, a data analysis to estimate the time performance of the detectors was developed. The time resolution for the both the prototypes was estimated to be of ± 1 ns. Lastly, a likelihood method to estimate the possibility of reconstracting the position of a particle passing through the detector was implemented.
In addition, as previously mentioned, two Monte Carlo simulations of the two detectors prototypes, in the Geant4 enviroment, were built. The accuracy of the used material properties and of the geometry, allowed to make predictions above the collected light yield and, throught the comparison with data, to estimate the goodness of the realized prototype. Moreover, the implementation of the digitization of the collected signal in the simulation allowed to realize predictions on the time and space resolution achievable in the real detector.

References

[1] SHiP Collaboration (2015), *A Facility to Search for Hidden Particles (SHiP) at the CERN SPS.* arXiv:1504.04956

[2] IceCube Collaboration (2021), *The Wavelength-shifting Optical Module (WOM) for the IceCube Upgrade.* arXiv:2107.10194

[3] SBT Collaboration (2023), *Performance of a first full-size WOM-based liquid scintillator detector cell as prototype for the SHiP Surrounding Background Tagger.* arXiv:2311.07340