Abstract

The SHiP experiment has been proposed in conjunction with a new high-intensity Beam Dump Facility (BDF) at the CERN SPS complex in order to search for neutral “hidden” particles with masses up to a few GeV and feebly interacting with Standard Model particles. Unprecedented sensitivities are expected due to the high intensity of the 400 GeV SPS proton beam ($4 \cdot 10^{19}$ protons on target per year), a large acceptance detector and careful suppression of background, in particular by using a magnetic Muon Shield behind the production target. A crucial role in the reconstruction of the decays of the signal candidates is played by the Hidden Sector (HS) decay spectrometer of SHiP.

The main subsystem of the HS decay spectrometer is the spectrometer straw tracker (SST) consisting of four tracking stations and a dipole magnet. The SST is a tracking detector conceived to reject background and detect signal events by measuring precisely charged particle momenta, reconstruct decay vertices and the impact parameters to the point of production of hidden particle candidates. The SST needs to cover a large acceptance of $5\,\text{m} \times 10\,\text{m}$ providing at least $120\,\mu\text{m}$ spatial resolution of track hits and must be made with a minimum amount of material in the acceptance. To satisfy these requirements, an in-vacuum drift detector based on ultralight 5 m long and 2 cm diameter straw tubes was proposed.

Building on a technology developed by the NA62 collaboration, the cathode straw tubes are made of $36\,\mu\text{m}$ thick biaxially-oriented PET coated with copper and gold on the inner surface of the tube. The anode is a $30\,\mu\text{m}$ diameter wire made of gold-plated tungsten-rhenium alloy. The tube is filled with Ar/CO_2 70%/30% gas mixture at 1 bar absolute pressure. An applied high voltage of 2.2 kV provides a gas gain between 10^4 and 10^5. This design allows to achieve 0.5% of a radiation length per tracking station. However, it brings important challenges in terms of mechanical rigidity and stability of the tubes. The straw tubes undergo significant gravitational sagging, which leads to a non-negligible wire displacement from the tube center, and cannot operate without pretensioning or external supporting structures. Several mechanical designs of the tracking stations are being explored to minimize the magnitude of the sagging of the tubes, while keeping minimal the material amount in the acceptance. The studies presented in this thesis address various aspects related to the characteristics of the straw tubes and their performance within the SST and are intended to guide the engineering design.

One chapter of this thesis covers some key mechanical and electrical properties of the straw tubes. This includes gravitational sagging, 3-dimensional surface scanning, elongation, creep measurements and signal attenuation. Prototypes were built and measurements were performed in the laboratory. The results are compared to theoretical predictions.

A chapter is devoted to the test beam experiment preformed with a straw tube prototype and to the associated data analysis. A 2 m prototype straw tube was tested with a 150 GeV pion beam at CERN. The goal of the test beam experiment was to measure the spatial resolution of the straw tube with respect to different wire displacement values. The results show that the spatial resolution of the straw tube does not depend significantly on the magnitude of the wire displacement, and a spatial resolu-

tion of less than 110 μm was obtained. However, the shape of the isochrone relation of the straw tube (the V-shape) depends significantly on the wire eccentricity, indicating that the electric field distortions due to the wire displacement are important. The possibility to extract the wire eccentricity from the drift time spectrum alone, using edge finding algorithms, was also considered and elaborated in this chapter based on the test beam results. Apart from providing a direct measurement of the local wire eccentricity, these algorithms could help to understand the actual straw tubes geometry in SHiP and could provide input to a future geometry-correcting algorithm.

In the last chapter, the results of a few simulation studies are discussed. As already mentioned, the suppression of the backgrounds is essential for the SHiP physics reach. The Muon Shield was developed to deflect out of the acceptance the muons coming out of the production Target and Hadron Absorber of the BDF, thereby keeping as low as possible the background rates in the SHiP detectors. The description of the experiment in the simulation framework was improved to take into account a more realistic field map of the spectrometer magnet and the equivalent mass model of SST frames. The rates of background hits in the SST were verified with this new description. The maximum occupancy in the SST per straw tube obtained for the nominal values of the magnetic fields of the SHiP Muon Shield is $\approx$ 10 kHz/tube, which corresponds to an average of 0.01 hits/tube for a 1 μs time window. This ensures smooth operation of the tubes without saturation under nominal conditions and leaves room to increase significantly the hit rate for the tracker alignment runs, for example, by reducing the Muon Shield field. It was also found that the hit rates are dominated by low energy e^+/e^- particles (from photon conversions) in the two stations before the dipole magnet, while real muons are the dominant cause of hit rates in the two stations behind the magnet.

An initial simulation study of the effect of straw tube sagging and, hence, of non-zero wire eccentricity was performed in the SHiP simulation framework. The results show that the track fitting quality depends significantly on the spread of the wire eccentricity across the SST, while it is less sensitive to the mean value of this eccentricity. These studies should be elaborated further in order to specify more precisely the acceptable tolerance to the variation of the maximum wire displacements in the straw tubes.

The last simulation study is devoted to the influence of the pile-up in time of the muon background events. So far, SHiP simulation events corresponded to one generated proton interaction and the subsequent Geant4 particle production through the experimental setup. In the real experiment, the data stream will be subdivided in time frames containing detector hits from various sources (several proton interactions, cosmic ray showers, noise, etc). As part of this thesis, a pile-up simulation algorithm was proposed and implemented into the digitization procedure of the SHiP simulation framework. The robustness of the track pattern recognition algorithms was checked on the muon background events without any adaptation of the algorithm. Adding pile-up within a 3 μs time window provoked a relative drop of the tracks recognition efficiency by 9%, indicating that some adaptation is required.

In summary, a characterization of several aspects of the SHiP straw tubes was performed and studied within the SHiP simulation framework. The results obtained in this work not only confirm the viability of the proposed SST detector concept for the

SHiP experiment, in particular the choice of increasing the straw diameter to 2 cm, but also provide a guidance for further development of the engineering design.