RPCs and readout system for the neutrino detector of the SHiP experiment

L. Congedo
Università di Bari,
Bari, Italy
Sezione INFN di Bari,
Bari, Italy
E-mail: liliana.congedo@ba.infn.it

ABSTRACT: SHiP (Search for Hidden Particles) is a proposed experiment to be installed at CERN, with the aim of exploring the high intensity beam frontier to investigate the so-called Hidden Sector. Since the SPS proton beam interacting with the SHiP high density target is expected to produce a large neutrino flux, the experiment will also study neutrino physics with unprecedented statistics. A dedicated Scattering and Neutrino Detector (SND) is thus being designed. It consists of a nuclear emulsion target and a tracking fibres detector in magnetic field followed by a Muon Identification System. The Muon System is composed of iron filters interleaved with tracking planes, instrumented with Resistive Plate Chambers (RPCs) operated in avalanche mode. Each plane consists of three gaps read out by two panels of perpendicular strips. The RPC read-out electronics is being developed. It is based on the use of front-end Field Programmable Gate Arrays (FPGAs) connected to a concentration system, transmitting data serially at high speed via optical link to the data acquisition and control system. A small-scale prototype of the SHiP Muon Identification System, with five RPC planes consisting of one large gap each, has been produced and exposed at CERN H4 facility in a test beam.

KEYWORDS: Resistive-plate chambers; Front-end electronics for detector readout; Neutrino detectors

ArXiv ePrint: 2004.09556
1 The SHiP experiment

Problems unexplained by the Standard Model, such as the nature of dark matter [1], the baryonic asymmetry of the Universe [2] and the neutrino oscillations [3], could hide new physics. Several theories proposed to explain these phenomena suggest the existence of neutral weakly interacting particles, the so-called Hidden Particles.

SHiP (Search for Hidden Particles) [4] is a proposed experiment, to be installed in a beam dump facility [5] at CERN SPS (proton beam energy 400 GeV), with the aim of investigating the Hidden Sector domain (e.g. Heavy Neutral Leptons) [6]. In order to observe Hidden Particles, SHiP will explore the high intensity beam frontier: $4 \times 10^{13}$ p.o.t. per spill are expected (integral p.o.t. $2 \times 10^{20}$ in five years). Since the beam interacting with the fixed target (blocks of titanium-zirconium doped molybdenum alloy, density 10.22 g/cm$^3$), is expected to produce a large neutrino flux, SHiP includes a dedicated program in neutrino physics. In particular, the first direct observation of the tau antineutrino is expected, as well as the study of tau neutrino with unprecedented statistics (about $10^{16}$ $\nu_\tau$ and $\overline{\nu}_\tau$ are expected at the beam dump [7]).

Figure 1. Layout of the SHiP detector (left) and of the SHiP SND (right).

The SHiP detector layout [8] (figure 1) is composed of a hadron absorber and an active muon shield [9], deflecting magnetically muons produced by the beam interactions with the target [10], a
Scattering and Neutrino Detector (SND) and a downstream Hidden Sector (HS) detector. The SND consists of a precision spectrometer, composed of a nuclear emulsion target and a tracking fibres detector in magnetic field (about 1.2 T) [11], followed by a Muon Identification System. Downstream layers consisting of Multigap Resistive Plate Chambers (MRPCs) and acting as background tagger for the Hidden Sector spectrometer, are added to the SND.

2 The SND Muon Identification System

The SND Muon Identification System goal is the identification with high efficiency of the muons produced in the neutrino interactions occurring in the SND emulsion target.

The muon detector, designed by the Bari and Napoli INFN groups, consists of eight tracking planes (dimension $\sim 2 \times 4 \text{ m}^2$), instrumented with Resistive Plate Chambers (RPCs), interleaved with iron walls, acting as hadron filters. The four upstream iron plates are 15 cm thick, while the downstream iron layers have a reduced thickness of 10 cm, in order to minimise interactions inside the Muon System which could be a source of background for the HS detector.

Each tracking plane is equipped with three gaps (active area: $1.9 \times 1.2 \text{ m}^2$ for each) operated in avalanche mode, since the expected rate of charged particles impinging on the detectors is about $200 \text{ Hz/cm}^2$. RPC planes are read out by two panels of perpendicular copper strips ($\sim 1 \text{ cm pitch}$). Their external mechanical structure (figure 2) includes front-end boards, high voltage and low voltage distribution, as well as the gas distribution system, studied to reduce pipes path, minimising the probability of gas leaks due to eventual pipes damages.

In order to compensate for the acceptance loss of each tracking plane due to the dead areas between adjacent gaps, the RPC planes are staggered by $\pm 10 \text{ cm}$. The detector planes are hanging from the top of a Muon System support structure (figure 2) and extracted through upper trails.

![Figure 2. Layout of the designed Muon Identification tracking plane (left) and Muon System support structure (right).](image)

3 RPC prototypes for the SHiP SND

In July 2018, the SHiP Collaboration installed a small-scale replica of the experiment target, collecting about $3 \times 10^{11}$ protons at 400 GeV (1-sigma beam spot width: 2 mm), in the H4 beam line at the CERN SPS, in order to measure the muon flux generated by the SHiP target [12]. The experimental set-up consisted of a spectrometer, instrumented with drift tubes and scintillators, and a muon tagger (figure 3).
A pilot production of five RPCs, prototypes of the SHiP tracking planes, was made for the muon-flux measurement by the Bari, Napoli and Kodel SHiP groups.

Each RPC (active area: $1.9 \times 1.2 \, \text{m}^2$) consisted of 2 mm thick Bakelite electrodes covered with graphite paint and a 2 mm wide gas gap, operated in avalanche mode with standard mixture ($\sim 95\% \, \text{C}_2\text{H}_4\text{F}_4$, $\sim 4.5\% \, \text{C}_4\text{H}_{10}$, $\sim 0.5\% \, \text{SF}_6$). The chambers were read out by two panels of perpendicular copper strips with 1.0625 cm pitch and a maximum length of about 2 m.

The RPCs were tested with cosmic rays at CERN before being exposed to the H4 beam for the muon-flux measurement. In the set-up used to test one chamber with cosmic rays, data acquisition was triggered by the coincidence of the remaining RPCs, positioned both upstream and downstream of the studied detector. These RPCs were also used to reconstruct particle tracks. Test results obtained for one detector are shown in figure 4.

In the set-up for the muon-flux measurement at CERN, the RPCs were interleaved with $1 \times 80 \, \text{cm}$ and $3 \times 40 \, \text{cm}$ iron slabs and used as muon tagger. An additional 80 cm thick iron plate was positioned upstream of the first chamber. Data acquired by RPCs, triggered by scintillators coincidence, were combined to reconstruct particle tracks and matched with drift tube tracks to provide muon identification. The tagged muon momentum varied from a few GeV/c to a few hundreds of GeV/c (muon spectrum peak at $\sim 10 \, \text{GeV/c}$) [12].
RPCs performance during the muon-flux measurement at CERN is shown in figure 5. The detectors efficiency levels measured in this configuration were improved by a few percent with respect to the cosmic rays test results, due to the better alignment of the system during the test beam. The RPCs reached efficiency levels above 98% with a position resolution of about 3 mm.

4 The RPC read-out electronics for SHiP

In order to study very rare Hidden Particle decays, the SHiP read-out system is designed to acquire data continuously during an SPS spill (about 1 s duration), without a hardware trigger system, i.e. in trigger-less mode. Data acquired by each SHiP sub-detector front-end (FE) electronics are collected by a concentration system and transmitted through optical link to a host computer in a central event filter farm for processing.

The read-out electronics for SHiP RPCs (figure 6) is being designed in Bari. It consists of a front-end system, acquiring signals in trigger-less mode and transmitting data serially to the concentrators, interfaced to the SHiP data acquisition (DAQ) and control system.

The front-end electronics for SHiP RPCs is composed of 38 FE boards per tracking plane, each one connected to 16 input channels, hosting two Front-End Electronics Rapid Integrated Circuit (FEERIC) ASIC chips [13] and a FPGA. The FE ASICs acquire, amplify and discriminate signals, which are then transmitted to the FPGA on-board for data timestamping, zero suppression and serialization. The FPGA can be controlled and configured by the user through the DAQ and control system. In order to test the whole system (e.g. with cosmic rays), the trigger mode of operation is also implemented in the FPGA.

The main blocks of the designed FE FPGA are shown in figure 6. Signals are acquired, formed according to the user configuration, zero suppressed, timestamped and stored till transmission by the Data Block. The TX Block manages transmission: it assigns packets priorities, encodes words using 8b/10b code and serializes data. The receiver (RX) Block is designed to decode and identify received data as well as to execute fast commands (e.g. trigger). Received slow control (SC) packets are managed by a dedicated block (SC Block).
5 Conclusions and outlook

A Muon Identification System, equipped with RPCs, is being designed for the SHiP Scattering and Neutrino Detector. A small-scale prototype of the Muon System has been produced, tested with standard gas mixtures and exposed at CERN H4 facility. A position resolution of about 3 mm and efficiency levels above 98% have been measured.

Eco-friendly gas mixtures for SHiP RPCs are currently under study. In order to optimize the RPCs performance with eco-gas, new gaps with reduced thickness will be produced and tested.

A front-end FPGA for the high speed serial transmission of data from the SHiP RPCs to the DAQ system has been designed and fully simulated. A prototype of the front-end board hosting the designed FPGA will be produced and tested.

References

[1] S. Dodelson and L.M. Widrow, Sterile neutrinos as dark matter, *Phys. Rev. Lett.* 72 (1994) 17.
[2] M. Fukugita and T. Yanagida, Barygenesis without grand unification, *Phys. Lett. B* 174 (1986) 45.
[3] S.M. Bilenky and B. Pontecorvo, Lepton mixing and neutrino oscillations, *Phys. Rept.* 41 (1978) 225.
[4] SHiP collaboration, A facility to Search for Hidden Particles (SHiP) at the CERN SPS, CERN-SPSC-2015-016 SPSC-P-350 (2015).
[5] SHiP collaboration, The experimental facility for the Search for Hidden Particles at the CERN SPS, 2019 *JINST* 14 P03025 [arXiv:1810.06880].
[6] SHiP collaboration, Sensitivity of the SHiP experiment to Heavy Neutral Leptons, *JHEP* 04 (2019) 077 [arXiv:1811.00930].
[7] SHiP collaboration, SHiP experiment — Progress Report, CERN-SPSC-2019-010 SPSC-SR-248 (2019).
[8] SHiP collaboration, SHiP experiment — Comprehensive Design Study report, CERN-SPSC-2019-049 SPSC-SR-263 (2019).

[9] SHiP collaboration, The active muon shield in the SHiP experiment, 2017 JINST 12 P05011 [arXiv:1703.03612].

[10] SHiP collaboration, Fast simulation of muons produced at the SHiP experiment using Generative Adversarial Networks, 2019 JINST 14 P11028 [arXiv:1909.04451].

[11] SHiP collaboration, The magnet of the scattering and neutrino detector for the SHiP experiment at CERN, 2020 JINST 15 P01027 [arXiv:1910.02952].

[12] SHiP collaboration, Measurement of the muon flux from 400 GeV/c protons interacting in a thick molybdenum/tungsten target, Eur. Phys. J. C 80 (2020) 284.

[13] P. Dupieux, B. Joly, F. Jouve, S. Manen and R. Vandaële, Upgrade of the ALICE muon trigger electronics, 2014 JINST 9 C09013.