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Development of a new beam position detectors for NA61/SHINE experiment

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NA61/SHINE is a fixed-target experiment located at the CERN Super Proton Synchrotron (SPS). The development of new beam position detectors is part of the ongoing upgrade of the detector system.

Two types of detectors have been manufactured and are currently being tested. The first one is a scintillating fibers detector with photomultiplier as a readout. The scintillating fibers detector consists of two ribbons, which are arranged perpendicularly to each other. Each ribbon is made of two layers of 250 μm diameter fibers. The grouping of fibers method was used, which allows using of a single multichannel photomultiplier for one detector. The second type of detector is based on the single-sided silicon strip detector (SSD). The Si strips detector produced by Hamamatsu (S13804) was used, where the pitch has a width equal to 190 μm.

The developed detectors must meet several requirements: should work efficiently with proton and lead beams with beam intensity on the level of 100 kHz, the detector's material on the beamline should be minimized, the detectors should be able to determine the position of X and Y hit of each beam particle with maximum possible accuracy.

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1. Introduction

NA61/SHINE is a fixed-target experiment located in the North Area of the CERN Super Proton Synchrotron (SPS) [1]. Developing a new Beam Position Detector (BPD) is part of an ongoing upgrade of the detection system of the experiment. Two alternative BPD designs are described in the paper.

NA61/SHINE detector system includes the 8 Time Projection Chambers (TPCs), Time of Flight detectors (ToF), and Vertex Detector (VD) downstream of the target. The system's primary goal is to measure the particles produced in the interaction of the beam particles with the target. Additionally, upstream of the target is located a set set of beam detectors that provides the identification, timing references, and beam position measurements. The schematic layout of the detector system is shown in Fig. 1.

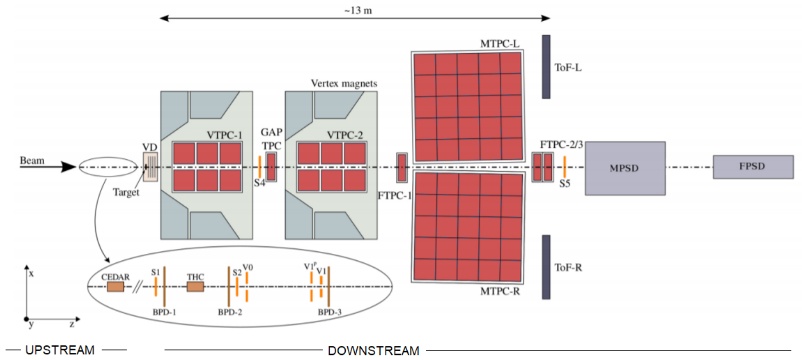

Figure 1: Schematic layout of the NA61/SHINE experiment after the LS2 upgrade.

Beam position detectors (BPD) are used to calculate the trajectory of the incoming beam particle based on its measurement in X and Y planes along the beamline. The new beam position detectors should allow for the measurement of the trajectory of each proton or lead beam particle separately with intensities on the level of 100 kHz with maximum possible accuracy. Additionally, the detector should operate in a vacuum.

Two types of detectors have been designed and manufactured and are currently being tested: scintillating fibers detector and single sided silicon strip detector (SSD).

2. Scintillating fibers detector

The scintillating fibers detector consists of two ribbons placed perpendicularly to each other. Such construction allows measuring the position of the particle passage in the XY plane. Each ribbon is made of two layers of scintillating fibers. Saint-Gobain, round shape, double cladding scintillating fibers (BCF-60) with 250 μm diameter were chosen [3]. The BCF-60 has an extra 3HF formulation which increases its radiation hardness. Layers are shifted relative to each other by a distance equal to the radius of one fiber, which minimizes the detector's dead area. The end of each ribbon is connected to the 256 channel multianode Hamamatsu photomultiplier (H9500) [2]. Finally, grouping of the fibers was implemented, which reduced the number of channels from 480 to 88. Instead of connecting each fibre to one photomultiplier pixel, ten or twelve optical fibers are connected into one group and applied to one pixel. Grouping is as follows: on one side of the ribbon, fibers are grouped into 12 groups of contiguous fibers. The second step of grouping is to read all the first fibers of each such group together, all the second ones together etc. Grouping is carried out separately for the upper and bottom layers of the ribbon. So after the beam particle passes the ribbon, it generates a signal at both ends of the fiber, which allows for precise position measurement. More details of the grouping method may be found in Ref. [5]. The photo of the prototype detector is presented in Fig. 2.

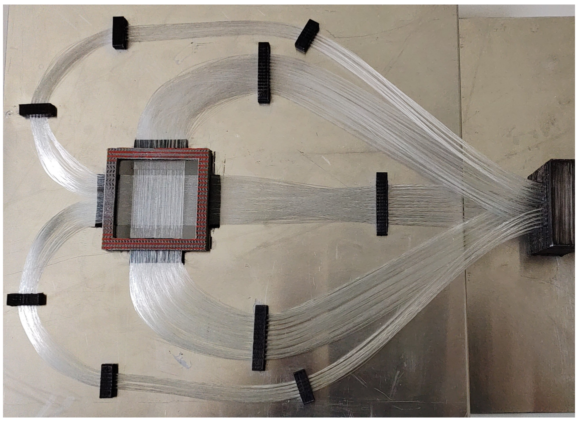

Figure 2: Scintillating fibers detector.

The use of proton and lead beams requires optimizing the detector and its readout for two almost extreme scenarios. The studies show that only approximately 100 photons will reach the end of the fiber after the passage of the proton beam particle. On the other hand, for the lead nuclei, about 7,000 times more photons will be registered. Additionally also the optical cross-talk between the fibers was studied. Analysis was performed for protons and lead nuclei in the energy range from 10 to 150 GeV per nucleon. The simulation showed that for protons, optical cross-talk is negligible. For lead nuclei, the amount of light leaked to the nearest fibers is, at maximum, on the level of 1% of the light recorded in the hit fiber.

3. Silicon strip detector

The second manufactured detector is based on the Hamamatsu S13804 Silicon Strip Matrix [4]. It is a silicon wafer with p-n junctions arranged in a stripe formation. The active area is 97x97 mm^2 in size. The detector has 1024 stripes arranged in two rows. The pitch between the strips is 190 μm. In the final design, two detectors are placed in the 6-way vacuum fitting. One of them determines the position in the X-plane, and the other one rotated by 90°, determines the position in the Y-plane. Detectors are placed on aluminum plates, which stabilize them and ensure that they are in the correct position for the beam. The signal is extracted through ISO-K vacuum flanges with two high-density vacuum feedthrough connectors connected to the detectors through flexible PCB. The schematic layout of a single layer of the BPD detector is presented in Fig. 3.

A dedicated charge amplifier has been manufactured for the detector and is placed outside the vacuum fitting. It consists of a fast and charge-sensitive amplifier, an intermediate amplifier, and an

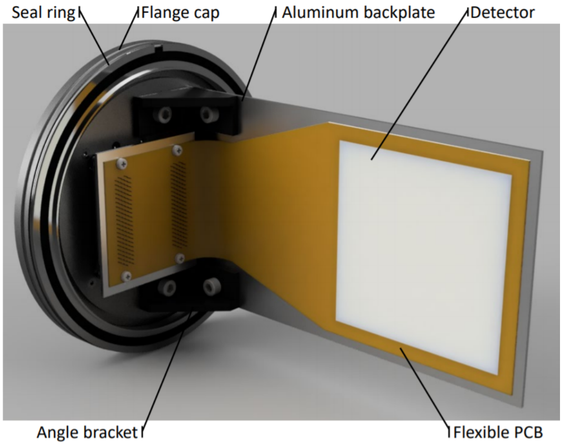

Figure 3: Silicon strip detector.

output buffer. Since it was equipped with an electronically-controlled scale-changing feature, the same board is usable for protons and lead nuclei beams.

4. Summary

In conclusion, two types of beam position detectors for the NA61/SHINE experiment have been manufactured and are currently being tested. New detectors will be commissioned in April-May 2022 and will be used during physics data taking in 2022-2025. It is planned that both detectors will be used depending on the type of measurement. Preliminary results show that the scintillating fiber detector is inefficient for the proton beam, therefore it will be used for measurements with heavy-ions beams. The estimated positional resolution for silicon strip detector is equal to 190 μm and for scintillating fiber detector is equal to 125 μm.

Acknowledgments

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