New Beam Position Detectors for NA61/SHINE experiment

A. Makhnev[1,2], F. Guber[1,2], D. Serebryakov[1], S. Pulawski[3], S. Kowalski[3]

[1]Institute for Nuclear Research RAS, Moscow, Russia
[2]Moscow Institute of Physics and Technology, Dolgoprudny, Moscow Region, Russia
[3]Institute of Physics, University of Silesia, Katowice, Poland

E-mail: makhnev.a@phystech.edu

Abstract. The NA61/SHINE experiment at the CERN SPS is undergoing a major upgrade during the CERN Long Shutdown 2 period (2019-2021). The upgrade is essential to fulfill the requirements of the new open charm and neutrino programs. In these programs the NA61/SHINE will operate with the data acquisition rate increased by a factor of 10, which requires an upgrade of current Beam Position Detectors (BPDs). New detectors should monitor beam particle positions with a frequency up to 10^5 Hz.

This paper presents an overview of the new BPD design, as well as discusses current state of development and prototype production of BPD, including: mechanical design, front-end electronics design and integration with experiment's data aquisition system.

1. Introduction

NA61/SHINE is a fixed-target experiment located in the H2 beam line in the North Area of the CERN Super Proton Synchrotron (SPS) [1]. The multi-purpose detector is optimized to study hadron production in hadron-proton, hadron-nucleus and nucleus-nucleus collisions.

Figure 1 presents a schematic drawing of the detector after the Long Shutdown 2 (LS2) upgrades. The detector is a large acceptance hadron spectrometer with excellent capabilities in charged particle momentum measurements and identification by a set of eight Time Projection Chambers (TPCs) as well as Time-of-Flight (ToF) detectors. The Vertex Detector (VD) is placed 5 cm downstream from the target. It consists of four layers of silicon pixel sensors allowing to reconstruct vertices of short-lived charm particles like D^0 mesons. A forward hadron calorimeter, the Projectile Spectator Detector (PSD), measures energy of spectator (non-interacting) nucleons, and is used for centrality and interaction plane determination. An array of beam detectors identifies beam particles, precisely measures their trajectories and provides trigger signals.

2. New BPD requirements

The main purpose of Beam Position Detectors (PBD) is measurement of beam particle trajectory on event-by-event basis (particle-by-particle).

(i) Detector should work with p and Pb beams

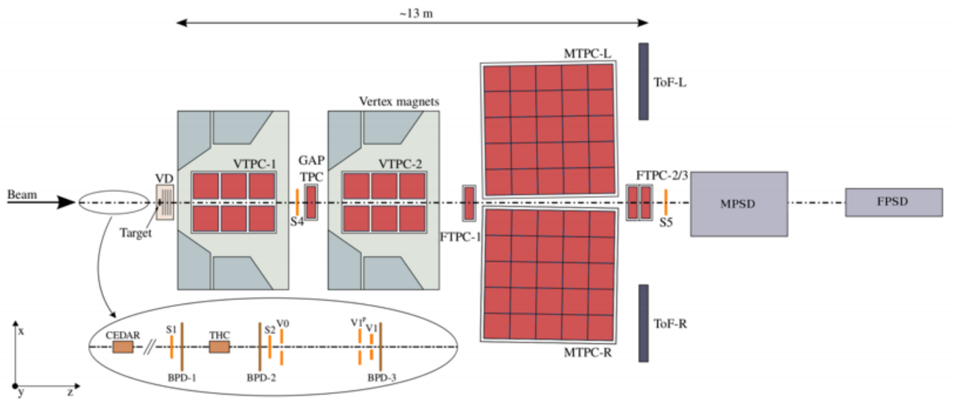

Figure 1. NA61/SHINE experiment scheme after the LS2 upgrades

(ii) The planed beam intensity is on the level of 100 kHz of p and Pb ions at momentum of 13A-150A GeV/c.

(iii) For this purpose detector should be able to determine without doubts the position in X and Y plane of each beam particle (probability of pileup should be minimised).

(iv) The accuracy of the position measurement is expected to be on the level of 250 μm.

(v) Detector should be installed in the vacuum ($10^{-3} mbar$).

(vi) Material on the beam line should be minimised.

3. General BPD design

Trajectory of the beam in NA61/SHINE is measured by a telescope, consisting out of 3 separate detectors with two sensitive elements each, together providing 2-coordinate determination of the particle hit position at 3 points along the beam line (25 meters downstream from the target).

For a sensitive element, a Hamamatsu S13804 Silicon Strip Detector [2] has been chosen. Main advantage of S13804 is being an off-the-shelf part, which also meets the spacial resolution requirements. S13804 is a 9x9cm silicon wafer with 1024 strip-like diodes etched into it. Each of the diodes has a 10 MOhm polysilicon resistor connected for biasing, as well as a decoupling capacitor for readout. All of the diodes are biased from a common source through the corresponding pads and could be accessed via individual readout pads.

Diodes are arranged in a two-column structure (see Fig. 2), but in this application, only the inner 200 diodes from one of the columns will be used.

This kind of detectors have been already used for similar task at BM@N, LHC, J-PARC and other experiments [3].

4. Mechanical design

For mounting the detector inside the vacuum beam pipe, a special fixture has been developed (see Fig. 3). It consists out of:

- A vacuum-sealed cap with a seal centering ring, which provides sealing surfaces alignment and carries the seal material.
- Two electrical feedthroughs of 104-pin D-sub connectors. Feedthroughs are sealed with O-rings and are mounted to the cap with screws in tapped blind holes.
- An aluminium backplate, mounted to the cap on the vacuum side with angle brackets, originally designed for optical hardware. These brackets were chosen to ensure precise positioning of the detector in the beam pipe.

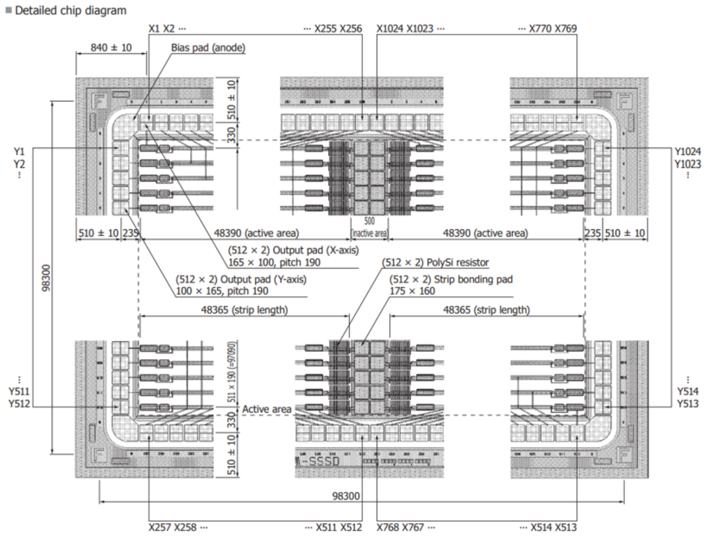

Figure 2. Topology drawing of Hamamatsu S13804 [3].

- A flexible PCB attached to the backplate with locating pins and screws. This PCB carries the detector, which is glued and bonded to it, as well as mating connectors for the feedthrough. Connector mounting area is reinforced with an additional aluminium plate.

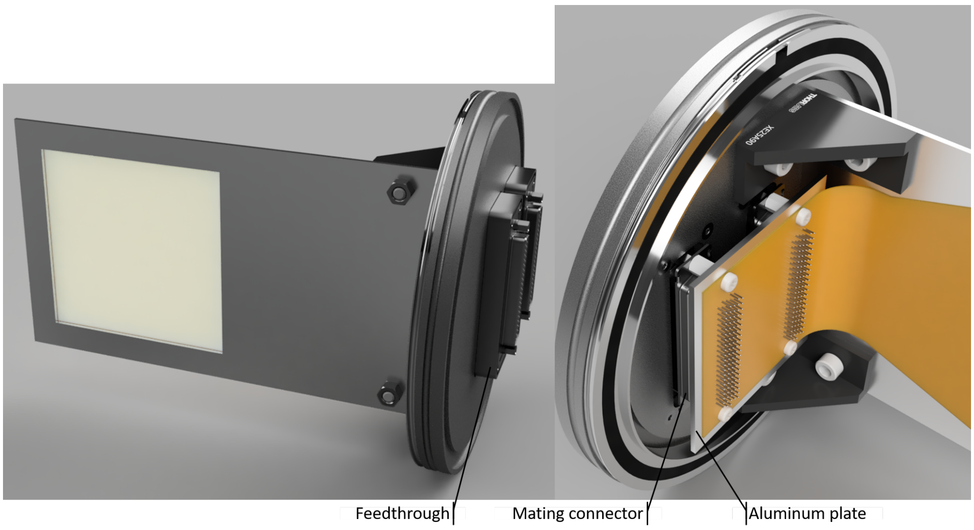

Figure 3. Detailed view of the detector insert.

Two of such fixtures are mounted perpendicularly in a 6-way cross fitting with all the other holes plugged. Resulting assembly is then mounted with cross-standard adapters onto the beam pipe.

On the atmosphere side of the detector, two PCBs with the front-end electronics (see Fig. 4) will be mounted, each consisting out of a motherboard and a mezzanine board, together carrying 100 discrete amplifiers per unit for a 200 channels per detector or 400 channels per assembly.

Prototype of the assembly has been produced (see Fig. 5).

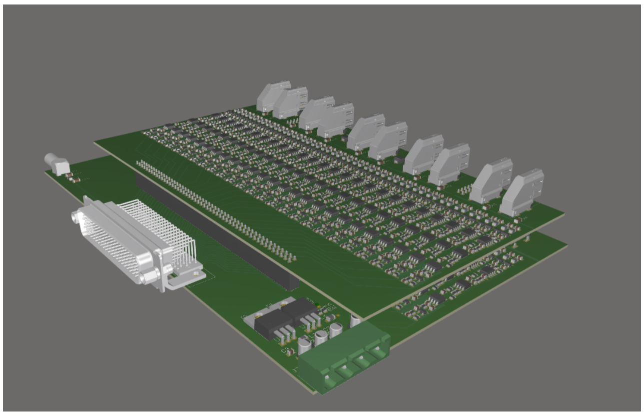

Figure 4. Amplifier board design.

Figure 5. Detector insert prototype.

5. Front-end amplifiers design

Front-end amplifiers are implemented with discrete components, simplifying and lowering the cost of production (a.e. no ASICs are used).

Each amplifier consists out of a charge-sensitive front-end, an intermediate amplifier and an output differential line driver. Each amplifier provides its own power regulation through a linear stabilizer. Output signal is transmitted through HDMI cables to a differential-to-single-ended converter connected to an ADC. Front-end electronics are implemented with a scale-changing feature, allowing operation on both proton and heavy ion beams without altering the setup. Scale changing is achieved by switching the input capacitance of the charge-sensitive amplifier with a FET.

6. Conclusions

Development of the new Silicon Strip BPD, which will be able to operate with beam intensities up to $10^5 Hz$ is presented. At the moment, mechanical design and electronics design are completed. First production prototype of the new detector will be tested at CERN in summer of 2021.

7. Acknowledgements

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