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Development of Si Beam Position Detectors for NA61/SHINE experiment

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Abstract. The NA61/SHINE experiment at the CERN SPS is undergoing a major upgrade during the LHC Long Shutdown 2 period (2019-2021). The upgrade is essential to fulfil the requirements of the new open charm measurement program. In this program detector will operate at a beam intensity increased by a factor of 10, which requires an upgrade of current Beam Position Detectors (BPDs). New BPDs should monitor lead and proton beam intensities with up to 10^5 Hz rate. In this paper, progress on design and development of the new BPDs based on Si strip detectors, its front-end and readout electronics, as well as integration with the NA61/SHINE DAQ is presented.

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. It consists of 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 centimetres 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 BPD detectors is measurement of beam particle trajectory on event-by-event basis (particle-by-particle). New BPDs should monitor lead and proton beams at 13A-150A GeV/c momentum, rates up to 10^5Hz and operate in vacuum. Detector requirements include:

- Detector should work with p and Pb beams

- The planed beam intensity is on the level of 100 kHz of Pb or p ions at momentum 13A-150A GeV/c.
- 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).
- The accuracy of the position measurement is expected to be on the level of 250 μm.
- Detector should be installed in the vacuum $(10^{-3} mbar)$.
- Material on the beam line should be minimised.

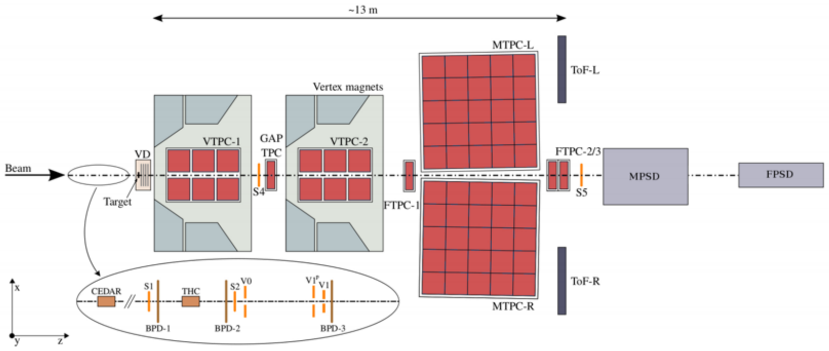

Figure 1. NA61/SHINE experiment scheme after the LS2 upgrades

3. New BPD design

3.1. Detector position on the beam line

Trajectory of the beam in NA61/SHINE is measured by a set of 3 separate detectors with 2-coordinate determination of the particle hit position. Detectors are mounted upstream of the target at the distance of 25 m to optimize the trajectory measurement (see Figure 1).

3.2. Sensitive element selection

In this work, the design of Silicon Strip Detector (SSD) version of the BPDs is presented. In order to fulfil mentioned requirements, a Hamamatsu S13804 detector [3] has been chosen, being the only one meeting constraints on spacial resolution. S13804 is a 9x9 cm Silicon wafer with 1024 diodes etched into it, however, only the 200 inner ones are planned to be used. For this application, SSDs have a set of advantages, including: being an off-the-shelf component and having a sufficient radiation hardness for this application. Such detectors have been already used for similar task at BM@N, LHC, J-PARC and other experiments [2].

3.3. Mechanical design

Each of the 3 BPDs will utilize a 6-way vacuum fitting with 2 of the openings being connected to the beam pipe, 2 having the detector inserts mounted to them and 2 being plugged. (see Figure 2).

Each of the detector inserts consists out of an ISO-K vacuum flange with a seal/centering ring, with two vacuum feedthrough connectors and two optical mounting brackets mounted into the machined openings in it. An aluminium plate with an opening for the beam is mounted onto the brackets to ensure precise positioning of the detector in the beam pipe. A flexible PCB is then mounted onto the aluminium plate, which hosts the detector itself and two mating connectors for the feedthrough. Usage of flexible PCB ensure minimum gas emission and removes the need for

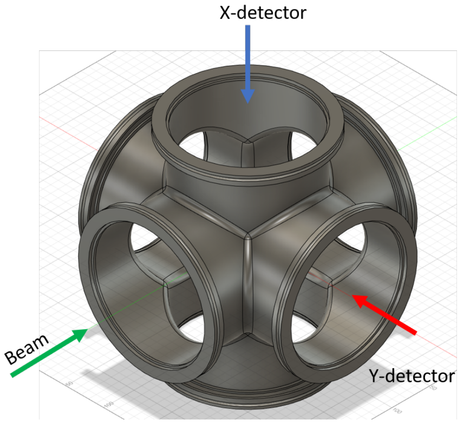

Figure 2. Six-way vacuum fitting, schematic view.

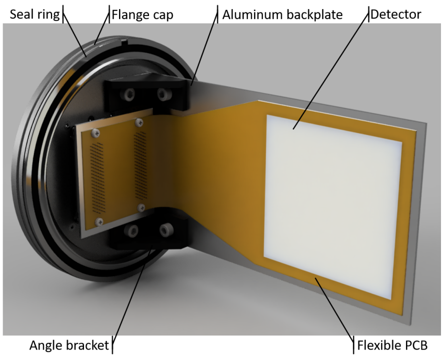

Figure 3. Detector insert, overall view.

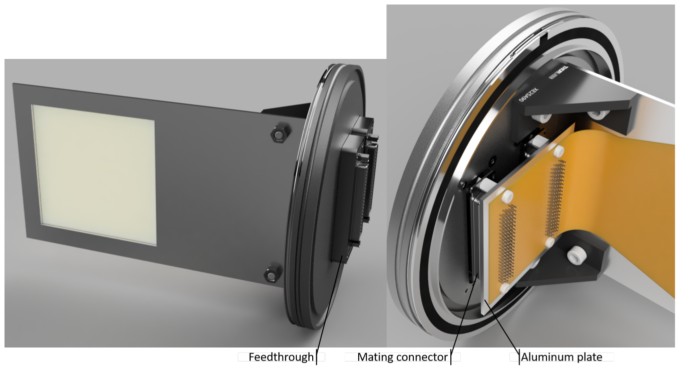

Figure 4. Detector insert, detailed view.

additional connectors between the detector and the front-end amplifiers. Design of the detector is shown in the Figure 3 and Figure 4.

Mounting fixtures are offset, so the beam would hit the middle of the sensitive part of the detector, as the topology illustrations show that the sensitive elements are arranged as two columns with bonding pads in the middle.

4. Front End Electronics design

A design of the front end electronics channel has been developed. Schematic is built entirely with off-the-shelf components, without usage of any custom-manufactured ASICs or other expensive or hard to obtain parts.

Each amplifier consists out of fast and charge-sensitive amplifier, an intermediate amplifier and an output buffer (see Figire 5). An electronically-controlled scale-changing feature has been added later, making the same board usable with both proton and heavy ion beams.

An evaluation board with one front-end channel has been manufactured (see Figure 6) and tested for amplification and noise spectrum with satisfactory results (see Figure 7 and Figure 8).

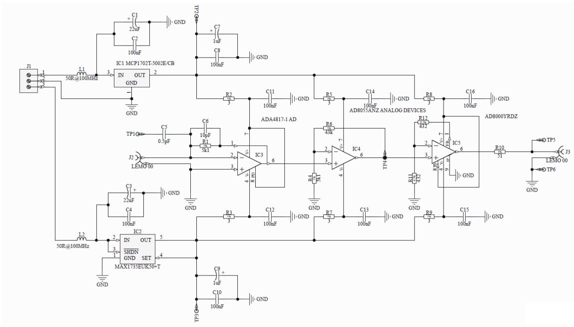

Figure 5. Typical amplifier schematic.

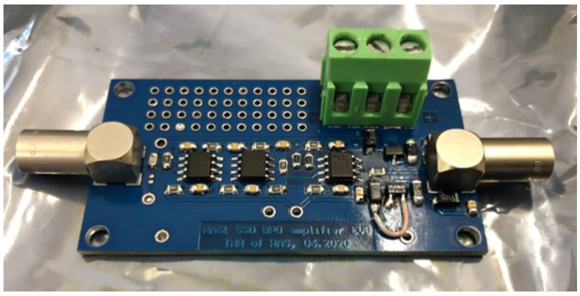

Figure 6. Evaluation board.

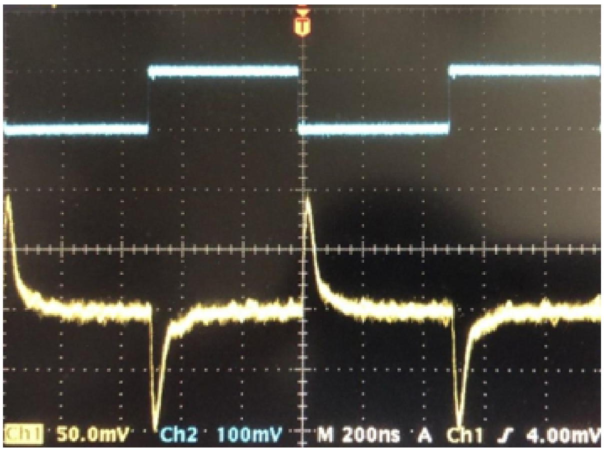

Figure 7. Amplifier output signal with generator input.

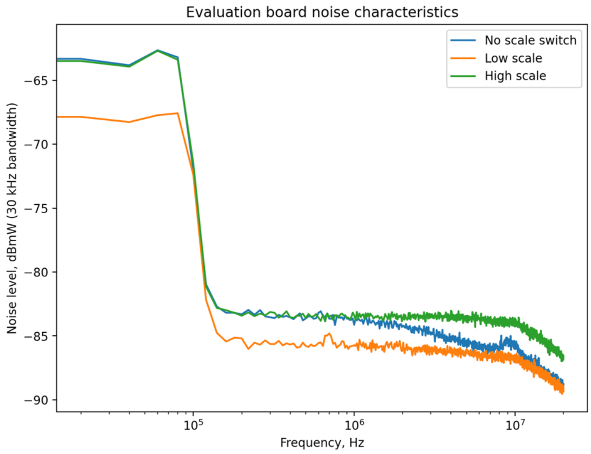

Figure 8. Noise characteristics.

5. 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 is completed and front-end electronics prototype has been developed. First Silicon Strip BPD is expected to be completed and tested at the beginning of 2021.

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