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NA61/SHINE DETECTOR UPGRADE*

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The NA61/SHINE detector, at the CERN SPS, is undergoing a major upgrade during the LHC Long Shutdown 2 period (2019–2021). The upgrade is essential to fulfill the requirements of a new open charm measurement program. It is necessary to stress that this New Physics goal can be only achieved when the readout rate will be increased by a factor of 10 and the resolution of the secondary vertex in the high multiplicity tracks environment of Pb+Pb events will be improved. The following elements of the experiment are parts of the upgrade: Time Projection Chambers (TPC), Vertex Detector (VD), Beam Position Detectors (BPD), Particle Spectator Detector (PSD), and Time-of-Flight detectors (TOF). On top of the detectors, a new Trigger and Data Acquisition (TDAQ) system is being developed. In this contribution, the progress on design and development of new detectors and TDAQ system for NA61/SHINE experiment will be presented.

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1. Introduction

The NA61/SHINE experiment [1] is based on a large acceptance fixed target hadron spectrometer, located in CERN (North Area), and uses the H2 beamline coming from Super Proton Synchrotron (SPS). Currently, it is the only experiment at CERN providing hadron production data as a function of energy, reaction type and centrality in the SPS regime of the phase diagram of strongly interacting matter, Ref. [2]. The main interest of the experiment concerns studying properties of the onset of deconfinement, searching for the critical point of strongly interacting matter and providing precise reference measurements for neutrino physics experiments as also for improving simulations of cosmic-ray air showers.

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Technical details concerning beamlines and sub-detectors of the experiment are presented in Ref. [1]. During the Long Shutdown 2 (LS2), the main goal of the upgrade is to increase the recorded event rate from about 80 Hz, which was the practical upper limit for the previous data acquisition system [3] to 1 kHz. This is important for the charm measurement program which requires a tenfold increase of the data-taking rate. This means that the experiment needs to construct a new vertex detector, change readout electronics of time projection chambers, and completely redesign the Data Acquisition system — preparing distributed event building system, which will be capable of checking incoming data (quality assurance), reducing data, and sending them to external storage. Also, a new Trigger system is needed, a new Projectile Spectator Detector (PSD) and also a replacement of deteriorated Time-of-Flight detector. The NA61/SHINE upgrade assumptions are described in detail in [4].

2. The upgrade

As depicted in Fig. 1, going from the left side (following the beam direction), first are start detectors, such as S1, S2 using BC-420 plastic scintillators. They will be upgraded with quartz 99.9% active materials. Inspection of photomultipliers (PMT) will be performed and necessary corrections for possible amplitude loss will be applied. In the case of veto detectors, a new detector (capable of beam shift detection) will be added for safety reasons. This safety system may protect the Vertex Detector pixel sensors from a direct hit by high-intensity beam. For beam position detectors upgrade, two possible technologies were chosen: Scintillating Fibers and Silicon Strip detectors. Both of these have their strong sides and the final decision will be based on feasibility of readout systems and integration with the rest of data acquisition system. Possibly both solutions will be built.

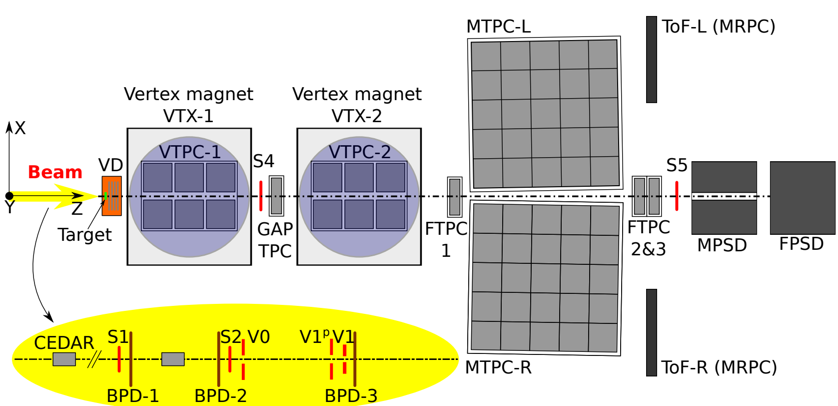

Fig. 1. NA61/SHINE detector subsystems after LS2 upgrade.

Next is Vertex Detector, which becomes the most important detector for the NA61/SHINE physics program beyond 2020. To meet the 1 kHz readout rate, only the ALPIDE pixel sensors together with MOSAIC readout boards fulfill the requirements. These sensors were already tested on beam and proved a much better performance (low noise) than previously used MIMOSA-26 in Small Acceptance Vertex Detector (SAVD).

The following detectors are Time Projection Chambers (TPC). They have proven to sustain high trigger rate operation, however, their bottleneck was readout electronics, hence all readout electronics was dismantled and a new one adopted from the ALICE experiment is being installed. Since these printed circuit boards (PCBs) differ in shape and connector types from previously used in NA61/SHINE, a lot of work with adapters and cables preparation and also redesigning the mechanical suspension is performed. Such tasks are realized in an iterative way with checking of prototypes on-site. Following the electronic and mechanical works, also new readout software needs to be implemented. In Table I, there is calculated distribution of the ALICE readout electronics boards per specific TPC detector at the NA61/SHINE experiment.

TABLE I

Planned distribution of Front-End Cards (FECs), Readout Control Units (RCU-2s) and Common Readout Receiver Cards (C-RORCS) in Readout Nodes at NA61/SHINE experiment TPC readout scheme.

<table>
<tr><th></th><th>VTPC 1,2</th><th>MTPC HR</th><th>MTPC SR</th><th>GTPC</th><th>FTPC 1</th><th>FTPC 2,3</th><th>Σ</th></tr>
<tr><td>FECs</td><td>432</td><td>270</td><td>720</td><td>8</td><td>12</td><td>36</td><td>1478</td></tr>
<tr><td>RCUs</td><td>24</td><td>20</td><td>40</td><td>1</td><td>1</td><td>2</td><td>88</td></tr>
<tr><td>C-RORCs</td><td>4</td><td>4</td><td>7</td><td colspan="3">1</td><td>16</td></tr>
</table>

The next sub-detector is the Time-of-Flight detector — completely replaced with the Multigap Resistive Plate Chamber (MRPC) technology. Previously, ToF used scintillators and photomultipliers with a Fastbus-based readout system coupled with VME and finally read via the Universal Serial Bus (USB) by the Central Data Acquisition System. Fastbus crates used old and unsupported technology, which consumed much power and emitted a lot of heat. A new idea of using MRPC technology comes from the NICA BM@N experiment. The MRPC system, designed for NA61/SHINE is based on the TOF400 detector planned for BM@N experiment. Tests showed that the new system is versatile and can successfully replace the old one.

The last sub-detector being upgraded is Particle Spectator Detector (PSD), which is a calorimeter, used mainly to measure the centrality of collisions. PSD is now divided into two parts: Main (MPSD) and Forward (FPSD). MPSD has a thru-hole in the center, which allows collision spectators to go thru to the FPSD. This allows to get a better dynamic range for measurements and finally get a better radiation resistance.

On top of detectors, a new Data Acquisition system is being developed. There are 168 event-building server nodes, each with 12 CPU cores. Assuming that the SPS supercycle will consist of two 5 s spills released in a 30 s period, we can set up a 1/3 duty cycle, and using the 1 kHz event rate, we can estimate the average event rate on the level of 1 kHz/3 $\sim$ 333 events/s. Total computing parallel tasks will be $168 \times 12 = 2016$, so we can spend no more than $2016/333 \approx 6.05$ s per event. Most consuming algorithms with tracking take 4.42 s per event, so this assures that we still have some margin. For sustaining high network data throughput 100 GbE and 25 GbE technologies will be used together with advanced switches and trunk connections. Software is currently in a development stage and final tests are expected in Q3 2020.

Another important part of the upgrade is the new Detector Control System (DCS) with time-series databases and the efficient and modern monitoring software.

3. Conclusions

The NA61/SHINE experiment upgrade is being performed during the LS2 period. A lot of effort is put into the adoption of electronics from ALICE: TPC readout electronics interfacing and mechanical suspension of PCBs above TPC chambers. Every task is on schedule. The first data taking is expected to be started in spring 2021.

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