NA62 Charged Particle Hodoscope. Design and performance in 2016 run

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Abstract: The NA62 experiment at CERN SPS aims to measure the branching ratio of the ultra-rare decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ with 10% accuracy. The experiment operates with a 75 GeV/c high intensity (750 MHz) secondary beam. A new detector, named Charged Particle Hodoscope (CHOD), designed to produce an input signal to the L0 trigger processor for events with charged particles produced in kaon decays, has been assembled, installed, integrated into NA62 Data Acquisition System (DAQ) and commissioned in 2016. During the whole 2016 run the detector has been in continuous operation. Design and performance features of the detector are presented.

Keywords: Detector design and construction technologies and materials; Overall mechanics design (support structures and materials, vibration analysis etc); Scintillators and scintillating fibres and light guides; Trigger detectors

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1 Introduction

The NA62 experiment [1] is located at CERN North Area High Intensity Facility and aims to measure the branching ratio of the ultra-rare decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ with 10% accuracy [2]. The experiment operates with a 75 GeV/c positive hadron beam that has a total particle rate of 750 MHz, of which about 6% is from $K^+$. The schematic view of the experimental setup is shown in figure 1. The hardware Level-0 (L0) trigger processor, the first step of the multi-level trigger system [3] is designed to reduce the trigger rate from 10 MHz to 1 MHz. A new detector, named Charged Particle Hodoscope (CHOD), provides an input to the L0 trigger based on the number of charged particles. The CHOD has been assembled and commissioned in 2016 and was in continuous operation during the whole 2016 data-taking period.

2 NA62 CHOD detector

The CHOD is comprised of 152 scintillator tiles that cover an annular area of radius $140 < R < 1070$ mm centred around the beam pipe (see figure 2). Scintillation light from the tiles is collected with Wave-Length Shifting (WLS) fibres, with silicon photomultipliers (SiPMs) used for readout. The detector is located along the beam axis, between the RICH and LAV12 (Large Angle Veto station 12) detector support frame.

The scintillating tiles are all 30 mm thick. Tiles have transverse dimensions of either $267.5 \times 108$ mm$^2$ or $133.75 \times 108$ mm$^2$ in the central region, whereas peripheral tiles typically have a special shape to fit the circular acceptance area. Tiles are made of polymerized polystyrene scintillator SC-301 produced at IHEP (Protvino, Russia) [4] and fixed on a 3 mm thick G10 support plane. The tiles are organized in rows. The rows are placed alternately on the upstream and downstream side of the support plane and overlap each other by 1 mm (figure 2). The efficiency to detect cosmic rays has been measured for each tile to be above 99%, including edge effects [5, 6].

The tiles are wrapped with a Tyvek sheet with the exception of faces adjacent to another tile which are interlaid with 70 µm thick double-Aluminized Mylar [7].
The scintillation light from each tile is read by \( \phi 1 \) mm wave-length shifting (WLS) fibres Y11(200) type S that are organized in two bundles of interleaved fibres. Each fibre is glued with EPO-TEK 301 Optical glue in 1.7 mm deep grooves that run parallel to the 108 mm side of the tile. The distance between fibres in the same bundle is 33.42 mm (the tile readout is schematically shown in figure 3). The fibres were machined flat with a diamond milling tool at the two ends and sputtered with aluminum at the far end to increase the amount of light reaching the SiPM. To minimize the loss of light, four WLS-fibre lengths from 1350 mm to 2000 mm were chosen depending on the tile position.
To obtain good light collection uniformity the fibres in each bundle are organized into groups of four fibres per SiPM (see figures 4 and 5). Each group of four WLS-fibres are optically coupled to SensL MicroFC-30035 [9] silicon photomultipliers (SiPMs) with $3 \times 3$ mm$^2$ active area, which are installed on the outside periphery of the detectors active area (the photograph of the bottom part of the CHOD is shown in figure 6). To measure the total light transmitted by each bundle of fibres (see figure 3) two SiPMs are used with output in analog OR. The two ORs from a tile are separately preamplified and directed to LeCroy 4413 discriminators. The ECL output of the discriminators are translated to LVDS and read by TEL62 TDC boards [3], which are used by the data acquisition system of the NA62 experiment.

During the 2016 data-taking period, the detector was operated with a bias voltage of 4.5 V above breakdown and the discriminator thresholds were set at 45 mV, equivalent to nine excited pixels.

### 3 Performance during the 2016 data-taking period

Data samples collected by a minimum-bias trigger independent of the CHOD were used for efficiency and timing studies. Positive muons produced by $K_{\mu2}$ decays ($K^+ \rightarrow \mu^+\nu$) were reconstructed from the spectrometer data and extrapolated to the CHOD plane.
Figure 6. Bottom half of the NA62 CHOD after assembly in the clean room and before transport to experimental hall.

Figure 7. Efficiency of a single tile as a function of the muon track extrapolated position on the CHOD surface: X coordinate (left) and Y coordinate (right). The dashed (red) lines correspond to the fits using two Fermi functions.

The efficiency as a function of the transverse coordinates (X, Y) for a typical tile are presented in figure 7. The dashed red lines are fits with Fermi functions to the edges of the tiles. The plateau efficiency obtained as a Fermi function parameter is (99.5 ± 0.1)%. Reconstructed tile sizes were estimated to be $\Delta X = (133.96 \pm 0.05)$ mm and $\Delta Y = (108.11 \pm 0.05)$ mm assuming the edge of the tile as the point of 50% efficiency. The physical size of the tile is 133.75 × 108 mm$^2$.

The overall average efficiency for the fiducial sensitive area of the detector was found to be (98.6 ± 0.1)%.
For the time resolution measurements the differential Cherenkov counter (KTAG) was used as a reference detector [1]. Figure 8 shows the average signal arrival time distribution of the A and B bundles of a tile with respect to the KTAG time. From the Gaussian fit, the time resolution ($\sigma$) is $(1.01 \pm 0.01)$ ns for the selected tile. The resolution of each tile is given in figure 9 according to its position on the CHOD surface. The time resolution of the detector using all 152 tiles is obtained to be $(1.1 \pm 0.1)$ ns.

4 Conclusion

After installation and commissioning the CHOD operated reliably during the whole NA62 2016 data-taking period. The CHOD was mainly used to provide the L0 trigger information on the multiplicity of tiles per event, with time resolution of $(1.1 \pm 0.1)$ ns and an efficiency averaged over $3.5 \, \text{m}^2$ sensitive area of $(98.6 \pm 0.1)\%$. Both parameters satisfy the requirements of the experiment. A significant improvement of the time resolution is expected to be obtained by replacing the classical threshold discriminators by constant fraction discriminators (CFDs) with the possibility of adjusting thresholds channel by channel. The prototype of the new CFD module has already been tested successfully.

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