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The NA62 GigaTracker

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ABSTRACT

The GigaTracker is a hybrid silicon pixel detector built for the NA62 experiment aiming at measuring the branching fraction of the ultra-rare kaon decay $K^+ \rightarrow \pi^+\nu\bar{\nu}$ at the CERN SPS. The detector has to track particles in a beam with a flux reaching 1.3 MHz/mm^2 and provide single-hit timing with 200 ps RMS resolution for a total material budget of less than 0.5% X_0 per station. The tracker comprises three 60.8 mm × 27 mm stations installed in vacuum ($\sim 10^{-6}$ mbar) and cooled with liquid C_6F_{14} circulating through micro-channels etched inside a few hundred micron thick silicon plates. Each station is composed of a 200 μm thick silicon sensor read out by 2 × 5 custom 100 μm thick ASICs, called TDCPix. Each chip contains 40 × 45 asynchronous pixels, 300 μm × 300 μm each and is instrumented with 100 ps bin time-to-digital converters. In order to cope with the high rate, the TDCPix is equipped with four 3.2 Gb/s serialisers sending out the data. We will describe the detector and the results from the 2014 and 2015 NA62 runs.

1. Introduction

The GigaTracker (GTK) has been designed for the NA62 experiment at the CERN SPS which aims to measure the branching fraction of the ultra-rare kaon decay $K^+ \rightarrow \pi^+\nu\bar{\nu}$ [1]. The detector is made of three planes of hybrid pixels, as shown in Fig.1. It has to track particles in a beam with a flux reaching 1.3 MHz/mm^2 and provide single-hit timing with 200 ps resolution for a total material budget of less than 0.5% X_0 per station. In order to maintain good timing performance, it is planned to replace the detectors after 100 days of operation, which would correspond to a fluence of 10^{14} 1 MeV eq. n/cm^2.

We describe here the functionalities of the TDCPix chip designed for the GTK needs, the integration of the bump-bonded modules, and the detector performance.

2. The TDCPix ASIC assembly

The GTK hybrid pixel matrix is made by bump-bonding two rows of five 100 μm thick TDCPix chips to a 200 μ m thick silicon sensor of 60.8 mm × 27 mm as shown in Fig. 2. Both p-in-n and n-in-p sensors can be used. The pixel matrix is organized in 40 columns of 45 pixels each. The pixel size is 300 μm × 300 μm. The chip architecture has been designed to keep the pixel analogue logic separated from the digital logic which is located at the end-of-column region.

Each pixel electrode is connected to a pre-amplifier followed by a discriminator with a tunable threshold. The discriminated signals are then transmitted to the end-of-column where the hit leading time and time-over-threshold (ToT) are measured by time-to-digital-converter (TDC) pairs with 100 ps bins.

Overall the TDCPix chip contains 360 TDC pairs where each TDC pair is shared by five pixels.

In order to cope with the high hit rate, each 10 column-group is equipped with a 3.2 Gb/s serialiser sending out the hit data.

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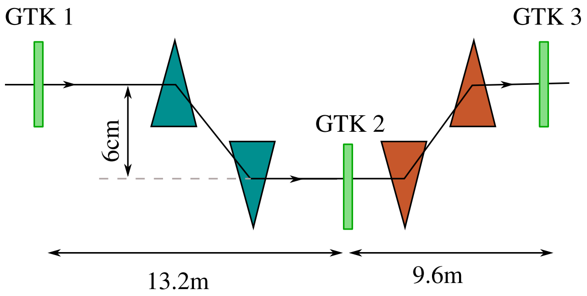

Fig. 1. Layout of the GigaTracker. Three stations (green) are inserted around two pairs of bending magnets. The first one (blue) displaces the beam by 6 cm on average in the vertical plane. The second one (orange) brings the beam back on its original trajectory. The precise measurement of the vertical shift allows to measure the particle momentum. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

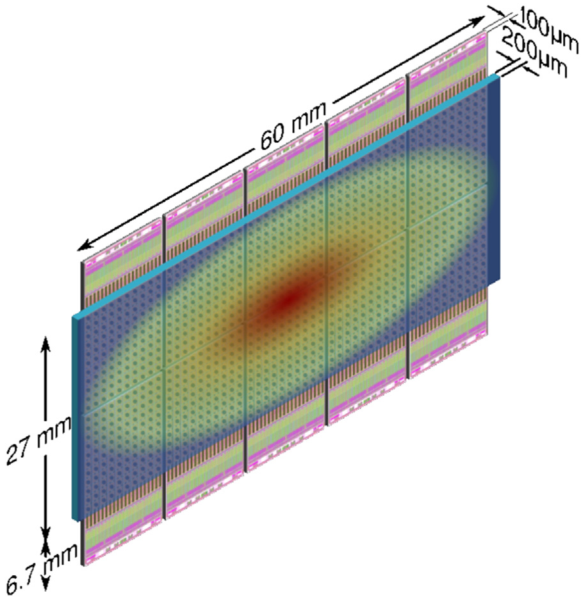

Fig. 2. The TDCPix assembly is composed of a 60.8 mm × 27 mm sensor bump-bonded onto 5 × 2 TDCPix chips. The chip digital and time-to-digital converters logic is located in the 6.7 mm extending outside the sensor.

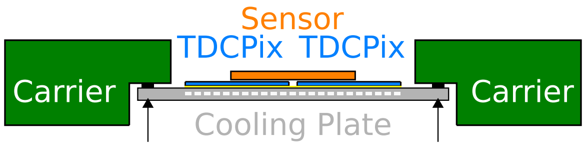

Fig. 3. Cross section of a GigaTracker detector.

3. Detector integration

3.1. Mechanical integration

The GTK mechanical integration is illustrated in Figs. 3 and 4. The detector is glued onto a micro-channel cooling plate which is a few hundred microns thick and is clamped onto the GTK carrier. The GTK carrier is then glued into a frame and a flange. The whole assembly is inserted into the vacuum vessel.

3.2. Electrical Integration

The data sent out with the forty 3.2 Gb/s chip serial links are shipped out of the chip to the GTK carrier through a very dense wire bonding scheme (73 µm pitch). These data are then routed outside the vacuum vessel via 30 cm long strips running inside the 14 internal layers of the GTK carrier. Outside the vessel, the GTK carrier is equipped with optical links connected with 300 m long fibres to data acquisition boards located outside the experimental area. The clock, configuration, resets, and data are transmitted on those links. Each TDCPix is controlled and read out by one DAQ board. These boards are also connected to the experiment trigger system and answer trigger requests by retrieving in their 1 ms buffers all hits within 75 ns around the trigger time stamp.

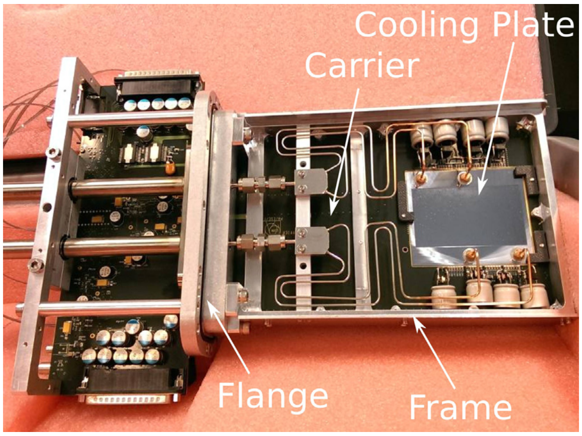

Fig. 4. Picture of the backside (or cooling plate side) of a GigaTracker detector.

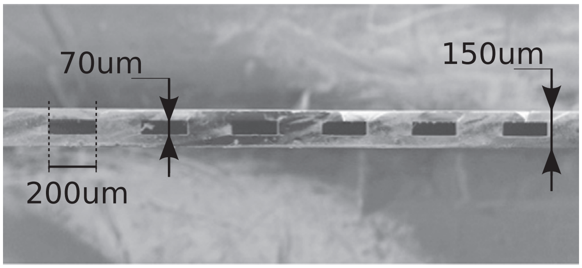

Fig. 5. Picture showing a cross section of the cooling plate.

3.3. Thermal integration

A cooling system is needed to remove the heat dissipated by the chips (3.5 W/chip) and to operate the sensor cold (-25 °C) in order to reduce the radiation damage. In order to keep the material budget below 0.5% X_0 per station, a micro-channel cooling system was developed. The system consists of a silicon plate which is a few hundred microns thick and has two circuits of 70 µm × 200 µm cross section micro-channels etched inside, as shown in Fig. 5. This cooling plate is glued to the chips and cold C_6F_{14} is circulated in its channels at a pressure of 3.5 bars for a flow of 3 g/s. It is the first time such a micro-channel cooling device is used in high-energy physics.

4. Performance

The detector time resolution was first assessed with a demonstrator of the final system containing 45 pixels. The first tests were performed in the laboratory by injecting charge in the pixel with a laser pulse. The time resolution was measured to 70 ps RMS [2] for a charge injected at the pixel centre equivalent to a minimum ionizing particle and with a sensor biased at 300 V, as shown in Fig.6.

In 2010, the same system was tested with a 10 GeV/c π^+ beam from the PS [3]. The time resolution was found to be 160 ps at 300 V sensor bias as shown in Fig. 7.

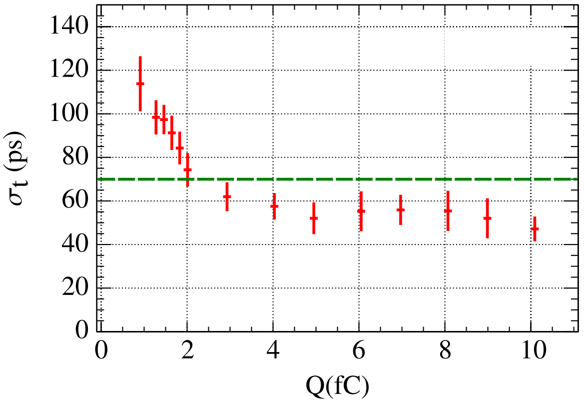

Fig. 6. Hit arrival time resolution as a function of the injected charge [2].

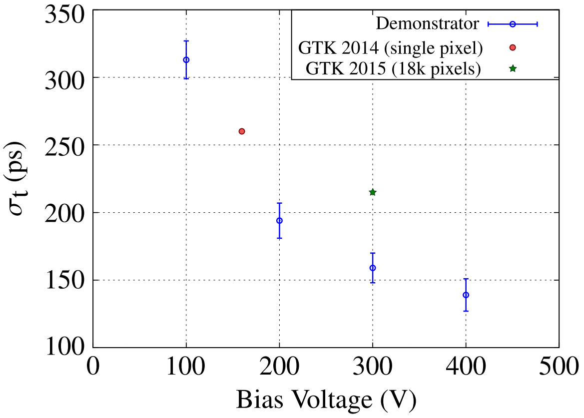

Fig. 7. Hit arrival time resolution as a function of the voltage bias applied to the sensor.

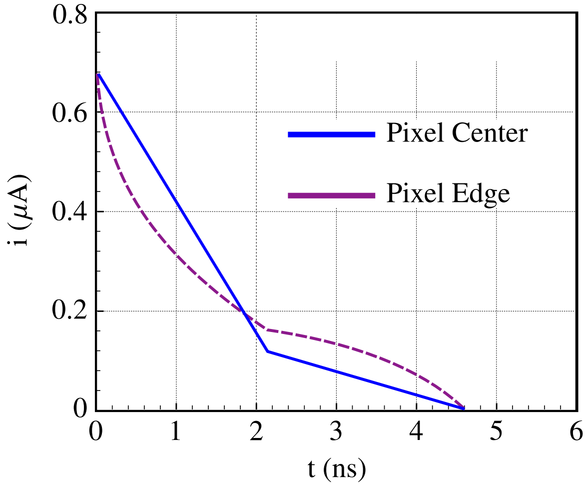

Fig. 8. Sensor current pulse as a function of time.

The resolution degradation with respect to the laser measurement is explained by the contribution of two factors. First, while the laser was shone at the pixel centre, the π^+ were illuminating all the pixel area so the signal pulse shape varied due to the pixel weighting field, as shown in Fig. 8, inducing a resolution degradation of 85 ps. Second, contrary to the laser case, the charge deposited by a particle along its path can vary considerably, which results also in a pulse shape variation degrading the time resolution by another 60 ps.

Finally in 2014, three detector prototypes of the final design were installed in the NA62 experiment and operated until 2015. Fig. 7 shows that the time resolution measured for a single pixel is compatible with the test beam results while it is around 50 ps larger for the full pixel matrix. This degradation is due to the fact that the time walk and time offset corrections were less precise as they had to be derived for groups of pixels to get enough statistics.

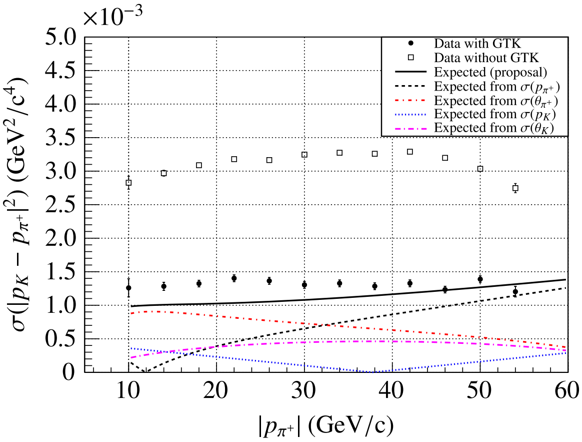

Fig. 9. $K^+ \to \pi^\pm\pi^0$ squared missing mass resolution as a function of the π^+ momentum with and without using the GTK information and the expected contributions from the resolution on the K^+ and π^+ momentum (p_K and p_{π^+}) and on their angle with respect to the beam average direction (θ_K and θ_{π^+}).

Kinematics performance was also studied by measuring the resolution on the squared missing mass, $|p_K - p_\pi|^2$ of the $K^+ \to \pi^\pm\pi^0$ decay where the π^+ is reconstructed with the NA62 Straw spectrometers and the K^+ with the GTK. Fig. 9 shows the $K^+ \to \pi^\pm\pi^0$ squared missing mass resolution as a function of the π^+ momentum with and without using the GTK information and the expected resolution contributions. The agreement of the measured and expected squared missing mass resolution demonstrates the good kinematics performance of the GTK.

5. Conclusions and prospects

The GigaTracker is an ambitious project aiming at measuring the momentum and arrival time of particles in a beam with a flux as high as 1.3 MHz/mm^2. A dedicated chip, the TDCPix, has been designed for this purpose. Tests and first operations in the experiment demonstrate that a resolution as good as 200 ps can be achieved. Moreover, the detector implements for the first time in high energy physics a micro-channel cooling which allows to keep the material budget below 0.5% X_0 per station. The 2016 NA62 run starting at the end of April 2016 will give the opportunity to measure the detector performance after irradiation.

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