The NA62 GigaTracker Detector

A. Gianoli, G. Aglieri Rinella, R. Arcidiacono, S. Bonacini, A. Ceccucci, S. Chiozzi, E. Cortina Gil, A. Cotta Ramusino, M. Fiorini, E. Gamberini, J. Kaplon, A. Kluge, A. Mapelli, F. Marchetto, E. Minucci, M. Morel, J. Noel, M. Noy, M. Perrin-Terrin, P. Petagna, F. Petrucci, K. Poltorak, G. Romagnoli, B. Velghe, H. Wahl

***Abstract*—The GigaTracker (GTK) system is a magnetic spectrometer made of 3 hybrid silicon pixel detector stations and 4 achromat magnets for the NA62 experiment (fig. 1). NA62 aims to measure the branching ratio of the ultra-rare decay $K^+ \rightarrow \pi^+\nu\bar{\nu}$ at the CERN SPS. The detector measures the momentum, direction and crossing time of all the secondary beam charged particles. The detector has to cope with a non-uniform beam rate as high as 750 MHz, with a an expected peak rate of 1.3 MHz/mm^2 around the centre and provide a time resolution better than 200 ps.**

I. Introduction

The GigaTracker (GTK) is a magnetic spectrometer made of 3 hybrid silicon pixel detectors and 4 achromat magnets, and it is part of the NA62 experiment. NA62 aims to measure the branching ratio of the ultra-rare decay $K^+ \rightarrow \pi^+\nu\bar{\nu}$ at the CERN SPS. The decay is a good probe for physics beyond the Standard Model and to measure the CKM matrix element V_{td}[1].

The experiment is designed to identify the π^+ from the decay, with the ν and $\bar{\nu}$ escaping undetected; the π^+ is then matched with the K^+ from which it came. The GTK is the high performance tracker in charge of providing the kinematic informations of the passing K^+ before they decay. It is placed along the beam line, inside the vacuum tank, and it sees the entire beam. Table I shows the requirements that the detector must match.

II. The sensor-readout chip assembly

Each GTK station is made of a hybrid pixel detector, with a single sensor element measuring 27×60 mm^2 (it covers the entire beam area). The sensor element can be both a P-on-N or a N-on-P silicon piece, 200 μm thick. This is enough to generate a sufficient signal, while keeping the timing requirements as well as the material budget within the limits. The sensor is operated with a bias voltage between 300 and 600 V. For minimum ionizing particles, the most probable charge deposited in the sensor is 2.4 fC.

The signal is readout by 2×5 custom ASIC chip (TDCPix), bump-bonded to the sensor (see fig. 2). The chips are built using standard 130 nm CMOS technology and follow an ”end-of-column” architecture[2].

A. Gianoli, S. Chiozzi, A. Cotta Ramusino, M. Fiorini, E. Gamberini, F. Petrucci, H. Wahl are with Univ. of Ferrara and INFN, Italy

G. Aglieri Rinella, S. Bonacini, A. Ceccucci, J. Kaplon, A. Kluge, A. Mapelli, M. Morel, J. Noel, M. Noy, M. Terrin-Perrin, P. Petagna, K. Poltorak, G. Romagnoli are with CERN, CH-1211 Geneva 23, Switzerland

R. Arcidiacono, F. Marchetto are with Univ. Torino and INFN, Italy

E. Cortina Gil, E. Minucci, B. Velghe are with Universit cathlique de Louvain, Louvain-la-Neuve, Belgium

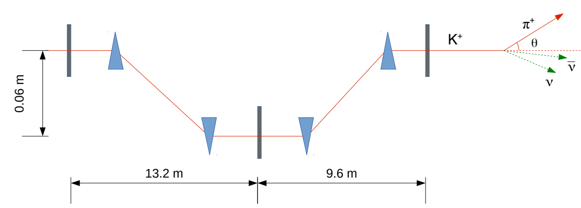

Fig. 1. Sketch of the Gigatracker (GTK) layout viewed from the side. The four triangles represents the achromatic magnets.

TABLE I
Requirements for the Gigatracker

Beam Rate	800 MHz - 1 GHz 1.3 MHz/mm^2
Radiation	$10^1$4 1MeV eq. n /cm^2 /y
Efficiency	99%
Momentum resolution	0.2%
Angular resolution	16 μrad
Hit time resolution	200 ps RMS
Material budget	$3 \times 0.5\% X_0$
Detector size	60.8 mm $\times$ 27 mm

Each TDCPix contains 40×45 asynchronuous pixels, each one 300μm$\times 300\mu$m. The TDCPix is designed to keep as much separate as possible the analog logic from the digital one: the analog logic resides with the pixels, while the digital logic resides in the so called ”end of column”, a part of the chip which exceed the sensor edge by 5 mm.

Each pixel has a fast pre-amplifier, a shaper and a discriminator. The signal is then routed to the end-of-column area where it is converted by a pair of time over threshold TDC, to have both leading and trailing edge. Each pair of TDCs serve five same column, not neighbouring pixels, in order to reduce the number of TDCs needed. The data are sent to a serializer and then off-chip using one of the four 3.2 Gb/s optical link that each TDCPix is provided.

III. Cooling

Each TDCPix dissipates around 3.5 W, and since the detector is in vacuum we need to deal with around 35 W per GTK station of heat. Moreover, considering that the damage due to beam radiation can be reduced by operating the sensor at low temperature, we looked for a solution that could keep the system at a temperature around -25°C, while keeping the total thickness of the GTK station under 0.5 mm silicon equivalent. For this reasons we developed a micro-channel silicon cooling plate, a technology never used before in particle physics.

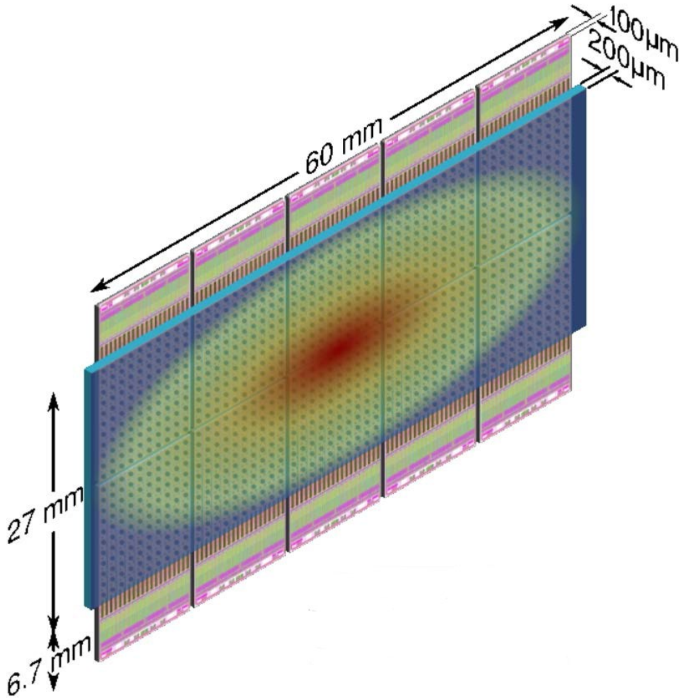

Fig. 2. The TDCPix assembly is composed of a 60 mm × 27 mm sensor bump-bonded onto 5 × 2 TDCPix chips. The chip digital and time-to-digital converters logic is located in the 6.7 mm extending outside the sensor

Micro-channels are made etching small grooves into the silicon wafer. The channels are covered by another silicon wafer and joined together. Top and bottom wafers are then thinned down and inlet connectors are soldered. The thickness in the area illuminated by the beam is around 150 μm.

IV. Off detector readout electronics

To cope with the high beam rate, each TDCPix is readout via four 3.2 Gb/s serialisers sending continously data to custom FPGA made off-detector read-out boards (GTK-RO) placed outside of the experimental area. Each boards receives the data of one chip and buffers them while waiting L0 trigger decision which arrives with a maximum latency of 1 ms. Upon reception of a trigger decision, the boards select the data that fall in a 75 ns time window around the selected timestamp. The selected date are then sent to sub-detector PCs using UDP packets over two 1 Gb links.

The purpose of the sub-detector PCs is to merge the data fragments coming from the 10 GTK-RO boards serving one GTK station and send complete events to the online farm. Since the foreseen rate for each GTK-RO is of the order of 1 Gbps, we use an ethernet switch with 24 gigabit ports and 2×10 Gb ports as a multiplexer: each PC uses one 10 Gb link to receive the data coming from 10 GTK-RO boards, and a second 10 Gb link to send the data to the online farm. Each PC runs Linux, and to achieve the full 10 Gbps throughput we use the ”zero copy” module of the PF_RING library to avoid unnecessary memory-to-memory copy.

V. Current status

The GigaTracker has been installed and commissioned during 2015. First operations in the experiment have been successful and demonstrated that the target resolution of 200 ps can be achieved. Moreover, for the firts time in high energy physics, micro channel cooling has been successfully used. This allowed us to keep the material budget of each station to less than 0.5 X_0. In the 2016 run the system will be pushed to maximum rates and the effect of radiation induced sensor aging will be studied.

References

[1] A. Ceccucci et al., *CERN-SPSC-2005-013*

[2] A. Kluge et al., *The TDCPix readout ASIC: a 75 ps resolution timing front-end for the NA62 Gigatracker*, Nucl. Instrum. Meth. A 06 (2013) 086