Summer Student Work Report

GTK Beam Test 2017

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1. Introduction

NA62 is a fixed target kaon experiment installed at the CERN Super Proton Synchrotron. The main goal of NA62 is to measure the branching ratio of the ultra-rare kaon decay \((K^+ \rightarrow \pi^+ \nu\bar{\nu})\) which is of the order \(10^{-12}\) with a precision of 10 % (same as Standard Model prediction), by detecting 80 decay candidates with a signal to background ratio of 10 [1]. In order to achieve this measurement various experimental techniques are used, in particular, low-mass 4D tracking with the beam spectrometer called Gigatracker (GTK).

The GTK is in operation at NA62 since 2014 and is among the few silicon pixel detectors performing 4D tracking. This summer, a beam test was conducted to study the phenomena determining the detector time resolution. The project described here contributed to the beam test preparation, data taking and data analyses. One of the main goals of the test was to understand the weight field contribution to the detector time resolution. This field is distorting the signal pulse shape at the edge of the pixel. Hence, to study this effect, the position of the hits inside the pixel has to be determined. An external telescope was therefore used for this purpose.

In the next two chapters it will be described primary devices that were being used in the beam test setup. Chapter 4 is describing the online monitor software and in chapter 5 are represented the plots obtained from TDCPix beam test data. In chapter 7 is made a conclusion about the beam test.

2. GigaTracker (GTK)

The GTK is a spectrometer that provides precise measurements of momentum, time and angle of the incoming kaon beam. The GTK is composed of three stations mounted around four magnets [1]. In figure 1 is pictured the sensitive part of GTK module.

Each station is made of one hybrid silicon pixel detector with a total size of 63.1 mm x 29.3 mm containing 18000 300 μm x 300 μm pixels arranged in a matrix of 90 x 200 elements. The 18000 pixels are read-out by 10 TDCpix ASICs, in two rows of 5, complemented by a thin microchannel cooling system. With this configuration the detector matches the expected beam dimensions of \(~60 \text{ mm} \times 27\text{ mm}\). The pixel dimensions and the distances between stations are adapted to deliver the required momentum and direction resolution \((\sigma(pK)/pK \sim 0.2 \%, \delta \theta = 16 \mu\text{rad})\) [1].

The 2 x 5 read-out chips were designed to deliver a time resolution better than 200 ps for single pixel hit, allowing to achieve a track resolution better than 150 ps.
Figure 1: Drawings of Gigatracker module. On the left side is presented the detecting module and its position relative to the beam. On the right side is typified a cross section of the constituting elements: a) Support frame, b) Cooling plate, c) TDCPix, d) Silicon pixel sensor.

2.1. The TDCPix (A High Time Precision Pixel Chip for the NA62 GTK)

The TDCPix is a hybrid pixel detector readout ASIC designed for the NA62 GTK detector. The chip requirements are a single-hit timing resolution better than 200 ps RMS. The discriminator time walk effect is compensated using a time-over-threshold (TOT) approach with off-chip look-up tables. The principle of the time measurement using the TOT is shown in Figure 2.

The pixel array is connected to 720 TDC channels which provide time to digital conversion with 97 ps binning. The TDCpix processes up to 210 Mhits/cm$^2$ and provides the hit data without the need of a trigger in a continuous data stream via four 3.2 Gb/s serialisers [2].
3. The Timepix3 Telescope

The Timepix3 particle tracking telescope has been developed as part of the LHCb VELO Upgrade project, supported by the Medipix Collaboration and the AIDA framework.

It is a primary piece of infrastructure for the VELO Upgrade project and is being used for the development of new sensors and front end technologies for several upcoming LHC trackers and vertexing systems. The telescope is designed around the dual capability of the Timepix3 ASICs to provide information about either the deposited charge or the timing information from tracks traversing the 14×14 mm matrix of 55×55 µm pixels. Results of tests conducted in the SPS North Area beam facility at CERN show that the telescope typically provides reconstructed track rates during the beam spills of between 3.5 and 7.5 kHz, depending on beam conditions. The tracks are time stamped with 1 ns resolution with an efficiency of above 98% and provide a pointing resolution at the centre of the telescope of ~1.6 µm. The core of the telescope comprises eight Timepix3 silicon hybrid detectors arranged into two `arms' of four about a central DUT (Device Under Test) station together with a ninth plane which provides timing information. The eight pixel planes are angled to nine degrees in both horizontal and vertical axes to optimize the spatial resolution that can be obtained from the system [3].
The spatial resolution of TimePix3 beam telescope is about 2 µm in the centre of the telescope, and time resolution is the order of 1 ns. The best pointing resolution (figure 4), $\sigma = (1.54 \pm 0.11)$ µm, is achieved by a symmetric arrangement of the two telescope arms with the device under test at the centre. These results are quoted for normal running conditions in the SPS with track momentum of $180 \frac{\text{GeV}}{c}$ [3].

Figure 3: Layout of the Timepix3 Telescope mechanics, pixel planes and scintillators with respect to the beam axis.

Figure 4: Resolution as function of the z position in the telescope [3].
4. Online Monitor

The online monitor is a program that shows the distributions of key variables in the real time. A screen shot of the program output is presented in figure 5. It is written in C++ using ROOT [5]. This program consists of two parts: a set of clients (one per device under test) and a server. The clients are building histograms and send them regularly to the server that displays them. The code for online monitor program can be found on site: https://github.com/svostini/Online-Monitor.

![Online Monitor Screen Shot](image)

Figure 5: Display of online monitor program. On the left side is the Hit Map and on the right side is the time profile.

5. Data analysis

This chapter describes the first analyses of the beam test data. The main goal of these analyses was to check the synchronization of devices clock and to estimate the device time resolution. We analyzed the data taken in Run 24450 during which n-in-p type devices were tested at a bias voltage of 300 V.

In Figure 6 is shown Hit Map. It could be seen from the plots in figure 6 that some pixels are missing, but from 1800 pixels, only 5-7 pixels is missing and this is good result.

![Hit Map](image)
Figure 6: Hit Map.

In figure 7 is shown the TOT distribution. From this plot one could notice the second peak which originate from nuclear interaction of particles with detector material.

Figure 7: TOT distribution.

Time difference between hits in two different planes is shown in figure 8. From this plot we can notice that two TDCPix are well synchronized and we can estimate time resolution of the detector without any time corrections. In our case, time resolution of detector is 810 ps.
Figure 8: Time difference between hits in the same frame. One frame is 6.4 µs.

Time difference versus TOT is shown in figure 9. This plot is very important, because from this plot we can derive time walk correction.

Figure 9: Time difference between the hit in chip 1 and the hits in chip 2 in the same frame versus the Time Over Threshold in chip 1.

A rough estimate of the time resolution can be obtained by selecting the most illuminated pixel and requiring a fixed TOT such that we can neglect the time walk correction.

Time difference distribution is shown in figure 10.
From this distribution we can obtain that the time resolution for one TDCPix plane is 170 ps. This value is slightly worse but compatible with previous results [4].
6. Conclusion

This summer, my assignments were to write a code for online monitor and to analyze the data from the beam test. The monitoring tools were used during data taking and helped to align the detectors with the beam. The analyses showed that the devices clocks were synchronized. A first estimate of the time resolution was performed and the results obtained are in agreement with the values measured previously at NA62.

The next steps should be to derive the TDCPix time walk corrections, reconstruct tracks using the Timepix3 telescope data. Extrapolating these tracks to the TDCPix, one could then study how the time resolution varies across one pixel.

Bibliography


