

## The NA62 first level trigger

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**Summary.** — The NA62 experiment is designed to measure the ultra-rare decay  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  branching ratio. The Standard Model prediction requires an extreme beam intensity to make the measurement. Such an intense flux of particles needs a high-performance trigger and data acquisition system, ensuring a high acceptance for the signal events together with a powerful rejection of the decays accounting for most of the rate. The L0 Trigger Processor (L0TP) is the first layer of the trigger chain. It is hardware implemented using programmable logic (FPGA). It is fully digital, based on standard Gigabit Ethernet communication between detectors and L0TP Board. The L0TP Board is a commercial development board provided by Terasic. Data generated by different detectors are sent asynchronously using the UDP protocol to the L0TP during the entire beam spill period ( $\sim 5$  seconds). The L0TP realigns in time the information coming from different sources looking for patterns characteristic of the event as energy, multiplicity, position of hits. The selection of good events is provided by an associative memory based on preset masks. The input rate is higher than 10 MHz for each detector, reduced to a maximum output rate of 1 MHz. L0TP should guarantee a maximum latency of 1 ms. The final version of the system has been used from 2016, and it is currently working for the 2017 data taking. A review of the trigger performance will be presented.

### 1. – Introduction

NA62 is a fixed target experiment [1] located at CERN, operating on the 400 GeV/ $c$  proton beam supplied by the CERN Super-Proton-Synchrotron (SPS). The aim of NA62 is to measure the branching ratio of the rare decay  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  in order to check the Standard Model prediction. In the Standard Model the branching ratio can be computed with extreme accuracy, making this process sensitive to new physics, being

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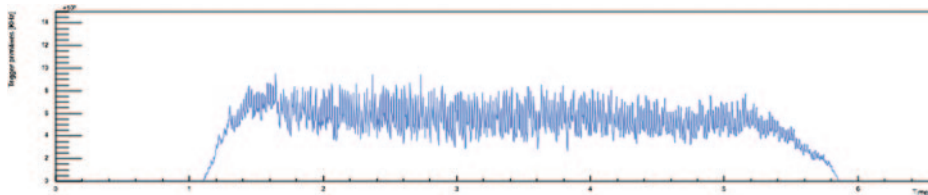


Fig. 1. – NA62 beam profile as a function of time.

strongly suppressed by GIM mechanism. The most recent estimation of the branching ratio is  $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = 8.4 \times 10^{-11}$  [2]. NA62 is designed to collect about one-hundred events in about two years of data taking, with a signal-to-background ratio of 10:1.

This implies an environment characterized by a total flux of incoming particles of about 750 MHz and a total event rate of  $\sim 10$  MHz, which has to be filtered by three different trigger levels. Such intensity requires a high performance Trigger and Data Acquisition (TDAQ) system, in order to collect a reasonable amount of data, minimizing the dead time and random veto effects. The system has been designed to be very reliable, with an adequate bandwidth to cover the kaon-decay rate without introducing biases into measurement.

In this work the trigger processor, called Level-0 Trigger Processor (L0TP), of the first level of the NA62 trigger logic is presented. It has been designed to select candidate events at  $\sim 10$  MHz input rate coming from six different sources (which can be extended to seven) and to reduce the output trigger rate to 1 MHz. It is the only trigger level implemented in hardware by using programmable logic (FPGA). Two higher trigger levels based on software algorithms follow it.

The development of the L0TP has been performed concurrently with the construction of the experiment, growing in complexity from a preliminary version commissioned during the first pilot run in 2014 to the state-of-the-art system used in the 2017 data taking.

## 2. – The logic of the trigger

As expected for a fixed target experiment, the beam delivery lasts for  $\sim 5$  seconds, as shown in fig. 1.

In this interval of time, six different detectors send raw data (primitives) collected in ethernet packets using standard UDP datagrams. Primitives contain both the time and the characteristics of the event such as energy, multiplicity and so on. Data are sent asynchronously and, depending on the source, each connection is characterized by a rate which is different from the others. The L0TP receives the primitives realigning them in time and looking for characteristics that match with required pattern of interesting events. These patterns are set up from the NA62 Run Control by users in form of logic masks. Ethernet packets are sent in variable length frames with a period of  $6.4 \mu\text{s}$ . The frame is transmitted even if it is empty. The fixed time structure of the transmission simplifies the task of the L0TP, which can then proceed to search for coincidences after a fixed latency, absorbing any possible delay of the inputs. Delays from the primitive production are due mostly to two contributions:

- the intrinsic detector average processing time;
- the random fluctuation of the processing time due to the event complexity.

In the first case, an offset could be present between two different systems because of the different time intervals that firmwares spend to generate primitives. As a result, a primitive relating to a certain time could be stored in the packet  $N$  for a faster detector, while it could be in the packet  $M$  for a slower one, where  $N < M$ . This delay is measurable and can be compensated by the L0TP with a Delay Generator Module, made of a series of buffers storing the fastest sources of data and waiting for the others. With an input of 10 MHz the programmable latency is  $\sim 800 \mu\text{s}$ . In the second case, L0TP should be able to absorb time differences between events coming from the same sub-system having large buffers in which the primitives wait a programmable time interval before being processed.

To align the primitives in the L0TP, data are addressed in these buffers using the time of the primitive.

The number of time bits used in the address is a parameter that can be set externally, matching a RAM location to a time interval. Depending on this value, the maximum input latency changes from  $400 \mu\text{s}$  to  $50 \mu\text{s}$ . In other words, generating the address with the primitive time immediately aligns them up to the time length defined by the RAM address. A further cut with respect to a time reference detector is applied before looking for the matching patterns.

The matching patterns are found by an associative memory implemented directly on the FPGA, which allows to program up to 16 different trigger masks together. Furthermore, each mask can be downscaled to fit the maximum output rate.

Finally, triggers are sent with a fixed programmable latency to detectors for the data acquisition, and to the NA62 PC-Farm to store all the useful information and reconstruct the trigger conditions offline.

### 3. – Conclusion

The Level-0 Trigger Processor worked in a stable way during the 2016 first data taking dedicated to the  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  sample collection. Data collected in 3 months are enough to reach the Standard Model sensitivity. From May 2017, a second data taking dedicated to the rare kaon decays is ongoing.

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### REFERENCES

- [1] NA62 COLLABORATION, *JINST*, **12** (2017) P05025.
- [2] BURAS A. J., BUTTAZZO D., GIRRBACH-NOE J. *et al.*, *JHEP*, **11** (2015) 33.