NA62 data acquisition upgrade

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The NA62 experiment at CERN

NA62 is located at the CERN Super Proton Synchrotron

Aims at measuring the extremely rare kaon decay: 
\[ K^+ \rightarrow \pi^+ \nu \nu \]  
\[ \text{BR}(K^+ \rightarrow \pi^+ \nu \nu) = (8.4 \pm 1.0) \times 10^{-11} \]

10^{13} kaon decays need to be collected to measure it with a 10% precision

<table>
<thead>
<tr>
<th>Data-taking</th>
<th>% of nominal intensity(*)</th>
<th>Decays recorded</th>
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<tbody>
<tr>
<td>2016</td>
<td>40%</td>
<td>5 \times 10^{11}</td>
</tr>
<tr>
<td>2017-2018</td>
<td>60%</td>
<td>8 \times 10^{12}</td>
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<tr>
<td>2021</td>
<td>100%</td>
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100% of nominal intensity: kaon rate = 45 MHz
The NA62 trigger system

To reduce the data rate at a manageable level, NA62 uses two levels of triggers:

The **Level-0 (L0)**: a hardware trigger implemented in an FPGA board called **L0TP** (Level-0 Trigger Processor).

Simple detectors associations.

Maximum trigger rate output: 1 MHz

The **Level-1 (L1)**: a software trigger running on the DAQ-farm.

Complex algorithms.

Events rate reduction: 1 MHz → 100 kHz
Current NA62 data acquisition system

A subset of detectors produce the trigger primitives, the input of L0TP.

The readout generates the trigger primitives. The computation algorithm must not exceed 100 $\mu$s.

L0TP distributes the L0 triggers via TTC (Timing Trigger and Control system)

A partial event is built in the DAQ-farm.

The detectors that contribute the most in the event size are read out only after a positive L1 decision.
The TEL62 readout board

The TEL62 is an integrated trigger and data acquisition board used by the larger part of the detectors.

It can host up to four high-performance TDC boards

- Developed from the TELL1 board for the LHCb experiment (2006)
- Not designed to be radiation tolerant
- Has limitations at 100% of intensity especially for high rate detectors
The TEL62 readout concept

The TEL62 needs to perform lots of operations:

- Time To Digital conversion
- buffer the data (limited)
- produce the trigger primitives
- perform trigger matching
- pack the events in UDP data frames and send the to the DAQ-farm

Internal buffer limited to the readout memory.

For that reason the L0 trigger must arrive within 1 ms.
The new readout concept

On-detector:
- Time To Digital conversion
- send out the data via optical fibers

Off-detector:
- receive the data via optical fibers
- buffer the data (all the data can be cached)
- produce the trigger primitives
- perform trigger matching
- pack the events in UDP data frames and send them to the DAQ-farm

minimise the electronic exposed to radiation

Sitting on a readout server located in a protected environment
The Front-End Link eXchange board

FELIX

The FELIX hardware platform has been developed for the final implementation in the ATLAS Run 3 upgrade.

FELIX is designed to:

- act as a data router, receiving data from detector front-end electronics and sending on a commodity network through the readout server.
- be detector agnostic.
The FELIX system

The FELIX system consists of: the PCI express board, the firmware and the software that run on a Linux server.

Connectivity 2x MTP24/48 optical links. Optional TTC mezzanine board.

- FELIX -> Front-End: GBT (GigaBit Transceiver)
  - TTC clock distribution
  - Synchronous command distribution
  - runtime parameter loading
- Front-End -> FELIX
  - GBT
  - lightweight FULL mode designed for maximum throughput
On-detector: Custom TDC board

The design includes:

- 64 channels with 780 ps bin or 32 channels with 390 ps bin
- 2x CYCLONE10 FPGA
- 2x SFP links per FPGA:
  - 2x FULL mode: data to FELIX and slow control responses
  - 1x GBT for TTC and slow control request
Timeline and goals

NA62 will restart the data-taking in 2021 after the LS2.

Goals:

- Equip KTAG and CHANTI, two high rate detectors, with new TDC and FELIX full readout.
- Demonstrate the capability to read data at 100% intensity
- Add NA62-specific trigger matching capabilities (L0 or L1) in the FELIX host.

The TDC inputs plug is the same, will be possible to switch back to the old readout.

Will provide extra TEL62 spares for other detectors.
KTAG read with the Level-0 trigger

KTAG data are used to evaluate the L1 decision in the DAQ-farm

384 channels - 16x TDC boards 32 channels / 390 ps bin resolution - 3x FELIX servers
CHANTI is not used in the trigger can be read at any level.

CHANTI read with the Level-1 trigger

576 channels - 9x TDC boards 64 channels / 780 ps bin resolution - 2x FELIX servers
TDC prototype acquisition test during 2018 data-taking

Test done on 1 out of the 6 CHANTI stations with beam at 100% intensity.

CHANTI station channels duplicated and sent to the TEL62

- The test validated the new TDC
- Full raw output saved
Trigger matching software

The trigger matching software uses:

- the raw data collected during TDC test (**words**)
- the L0 triggers

It is a C++ application that:

- loads the words into memory
- sorts the words in intervals of 100 ns (**sorting**)
- performs the **trigger matching** with the L0 triggers (75 ns window)
Trigger matching software

L0 triggers: $2 \times 10^6$

Average trigger rate: 520 KHz

4 seconds of data at 100% intensity.

1 out of 6 CHANTI stations

- Sorting: ~3.3 s
- Trigger matching: 0.3 s

Using 1 thread of an Intel Xeon Silver 4214 @2.2 GHz CPU
Conclusions

- I showed you the design of the NA62 data acquisition upgrade
- This is the first step towards a completely asynchronous readout system
- The first results with trigger matching software using data at full intensity show that it is possible to cope with the event rate
- FELIX software can handle the L1 triggers from the DAQ-farm

What’s next?

- TDC prototypes will arrive in November
- Start testing the communication between FELIX and the TDC board
- Prepare the FELIX software to handle L0 triggers