The Gigatracker detector of the NA62 experiment at CERN SPS

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Frontier Detectors for Frontier Physics
14th Pisa Meeting on Advanced Detectors
May 27 – June 2 2018 • La Biodola, Isola d'Elba (Italy)

Abstract

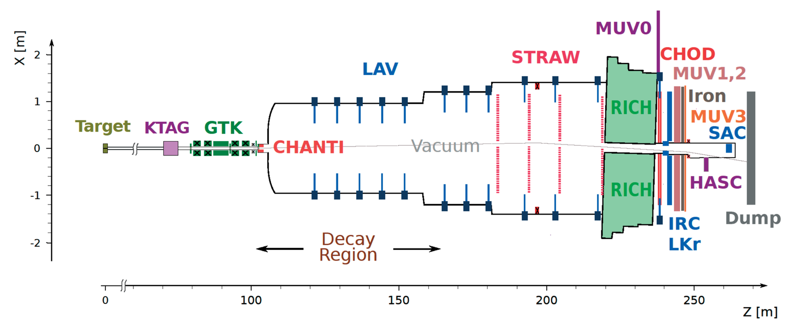
The NA62 experiment at the CERN SPS is a fixed target experiment designed to measure the branching ratio of the ultra-rare Kaon decay $K^+ \to \pi^+ \nu \nu$. The experiment uses a high-momentum K^+ decay in flight to increase the rejection power of the main background: $K^+ \to \pi^+ \pi^0$. The Gigatracker is a hybrid silicon pixel detector, exposed to a 750 MHz high-energy charged hadron beam, built to give an accurate measurement of K^+ momentum and direction together with a high precision measurement of the beam particle arrival time (better than 200ps RMS resolution). It is made by three stations placed right before the K^+ decay region and inserted around two achromats. The detector works in vacuum (~10^{-6} mbar) at about -10°C. Each station is made by a 200 um thick silicon sensor readout by 10 TDCPix, custom 100 um thick ASICs, and cooled by an innovative double circuit silicon micro-channel cooling system. All these parts are designed to minimize the total material budget which, in the final detector, amounts to less than 1.5% X_0 for the three stations. In order to sustain the high rate of incoming particles each TDCPix, operating in a self triggered mode, is equipped with four 3.2 Gb/s serializers sending data to the detector DAQ system based on a read-out card per TDCPix chip sending trigger-matched hits to 6 PC servers. I will describe the whole detector and present some of the results from data collected during the 2016 and 2017 NA62 runs.

The NA62 Experiment

A fixed target experiment designed to measure with an innovative decay in flight technique, with a 10% precision, the branching ratio highly suppressed decay $K^+ \to \pi^+ \nu \bar{\nu}$ (flavour changing neutral current process)

This decay is very clean theoretically and sensitive to physics beyond the Standard Model (SM).

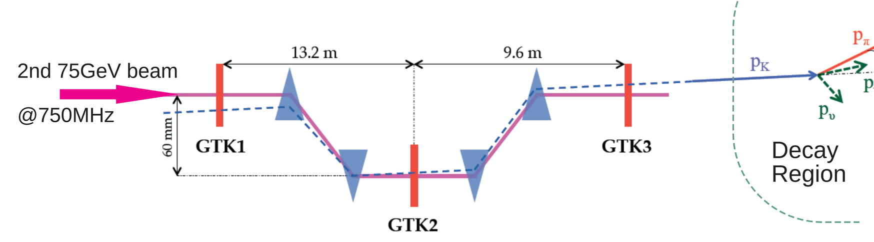
The theoretical SM prediction is $BR(K^+ \to \pi\nu\bar{\nu}) = (0.84\pm0.1)\times10^{-10}$



400 GeV/c primary SPS p beam on Be target

secondary charged particles(6% kaons) of (75.0±0.8) GeV/c momentum at 750MHz

across the gigatracker (GTK) 3 planes (stations) Si pixel detector in achromat bending magnets



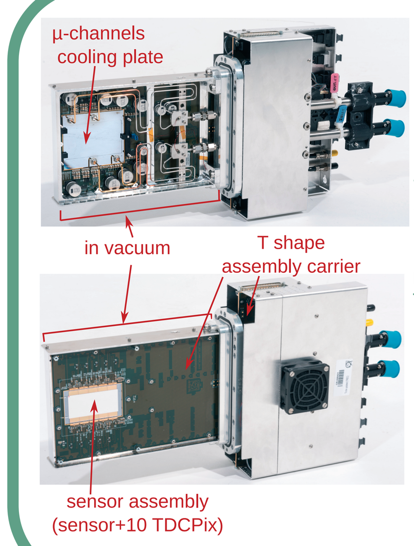
One candidate signal event found in the 2016 dataset is in agreement with the SM prediction and previous measurements.

The analysis of the 2016 data set proves that the decay-in-flight technique works.

More signal events expected in 2017 and 2018 data sets.

ongoing data taking in 2018 since April

The Gigatracker Requirements



Measure :

- momentum
- time
- angle

of all beam tracks

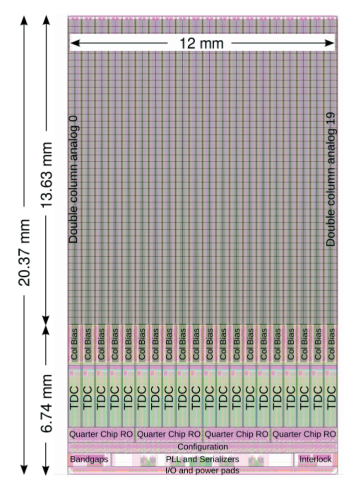
Sustain high non-uniform rate
- ~1.5 MHz/mm² (center)
- 750 MHz (total)

Reduce
- multiple scattering
- beam hadronic interactions

- X/X_0 ~0.5% per station
- $\sigma(p_K)/p_K$ ~0.2%
- $\sigma(\theta_K)$ ~16 µrad
- 300 × 300µm² pixel size
- < 200ps Δt on single hit

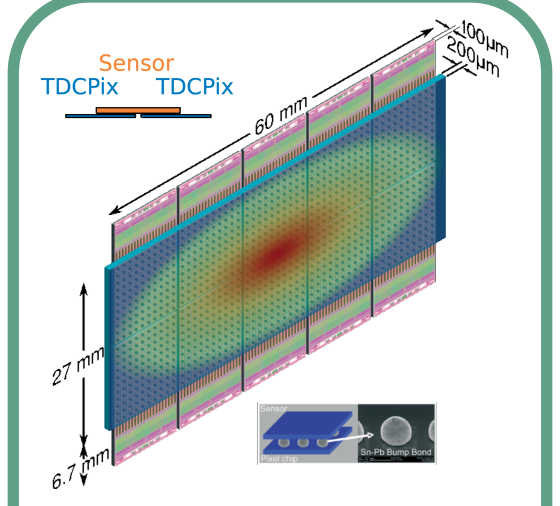
The TDCPix

- Custom Read Out ASIC
- 300x300 µm² pixel size
- 1800 pixels (40 columns x 45 pixels)
- dissipated power: 3.5 W
- peaking time: 5ns
- 360 TDC dual channels
- TDC bin size: 98ps
- ToT measure
- input signal, thickness
- data bandwidth: 4x3.2Gb/s
- on-pixel fast preamplifier and discriminator
- asynchronous transmission lines from pixels to reduce noise and power consumption.
- Polarity control
- 5 bit DAC threshold trimmer
- IBM 130nm CMOS technology



- SEU protection (x3)
- Self triggered operation: 210 MHits/s 4x3.2 Gb/s serializers

The Sensor Assembly

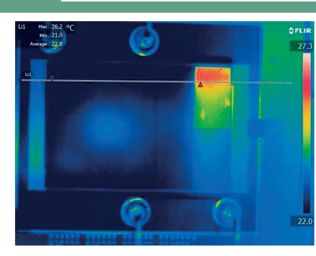


n-on-p and p-on-n (FBK, CiS)
10 read-out TDCPix per sensor in 2 rows

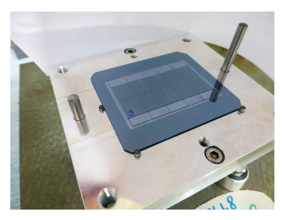
Sn-Ag bump-bonding, BCB deposition and thinning of the ASIC down to 100 µm (IZM)

The Cooling System

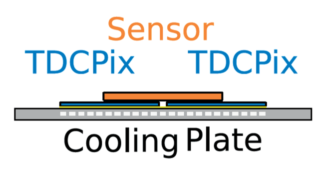
- 35 W per station
- Very low material budget (~0.15% X_0) in the active beam area
- In vacuum (~ 10^{-6} mbar)

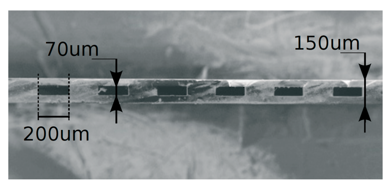


First application in HEP



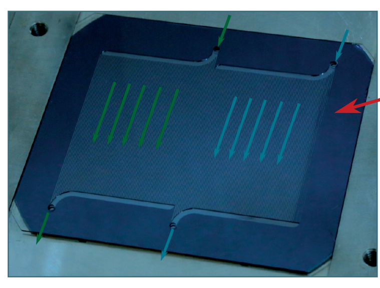
glued to bump-bonded assembly





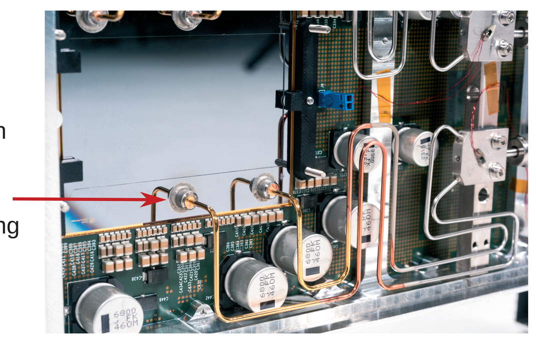
- Micro-channels cooling plate
- Fabricated by CEA Leti
- 150 Etch channels (+ openings for inlets/outlets and distribution manifold)

- Circulate coolant (C_6F_{14}) in micro-channels
- 3.5 bar pressure, 3 g/s flow
- Two cooling circuits
- Temperature down to -25°C

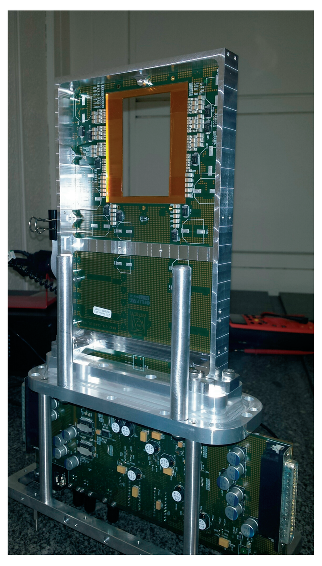


Fluid brought in with capillaries

Kovar connectors soldered onto cooling plate



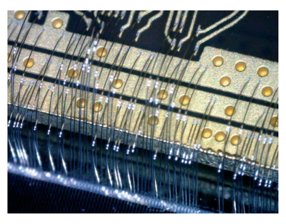
Electro-mechanical integration



The Assembly Carrier is a PCB board with mechanical support and alignment with the beam.

constructed using a mixture of FR4 and Kaplon based on sequential build up (SBU) technology.

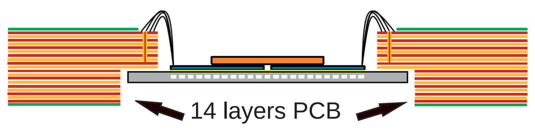
The SBU provides 80µm vias allowing the high signal density requirements close to the ASICs to be accommodated.



Cooling plate clamped on PCB, then TDCPix wired bonded to PCB (14 layers)

Serving power, clock, config. and receiving data

40 differential 3.2 Gb/s signals over 30 cm
73 µm bonding pitch on chip



The GTK Assembly carrier also act as vacuum feedthrough

Mechanical guides assure precise alignment of the assembly carrier, and thus the silicon assembly, with the vessel.

A flange with O-ring tightly glued around the PCB and screwed to the vacuum vessel

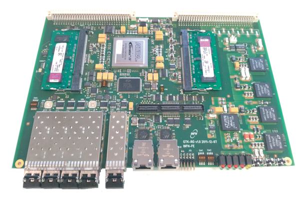
The assembly carriers optical components outside the vacuum vessel.

One GTK module, the assembly and its services can be inserted and removed with minimal intervention.

High temperature variation in the cooled operation mode and in the uncooled stand-by mode --> silicon components are not glued to the GTK assembly carrier, but are placed in a precisely machine opening and held by carbon fibre clips to maintain the position.
This arrangement will avoid mechanical stress due to the different thermal expansion coefficients of silicon and FR4

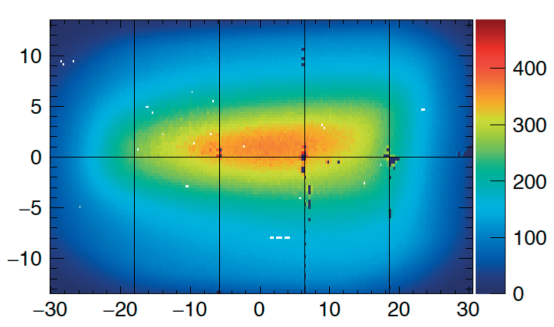
DAQ and Read Out

- TDCpix sends out every hit: trigger matching needed
- GTK-RO board must:
  - Buffer data, waiting for level-0 trigger decision
  - (maximum level-0 trigger latency is 1 ms)
- Retrieve data in a 75 ns time window upon trigger request
- Send data to the sub-detector PCs (2PCs/chip)
- GTK-RO built using FPGA (Altera Stratix IV)
- Each GTK-RO made of two decked cards: daughter card handles interface with TTC
- Each TDCpix is connected to:
  - one GTK-RO through 4 optical links (one per 3.2 Gb/s serializer):
  - 1 configuration link



Operation

- 3 independent vacuum sector (1 per station) for easier and faster intervention
- detector connected to the Detector Safety System with continuous monitoring of temperature (station and ASICs), vacuum, current and voltage of HV and LV channels
- Station to be replaced every ~100 day (~2×10^{14} 1MeV n_{eq} /cm²)



Detector Profile

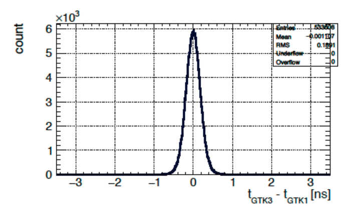
Physics Performances

single-hit time resolution:

σ_{GTK1} =132 ps

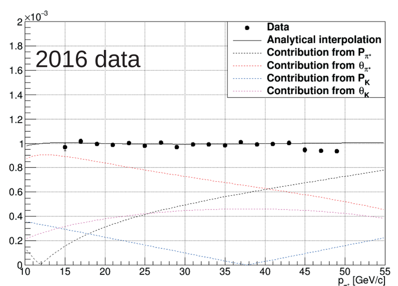
σ_{GTK2} =126 ps

σ_{GTK3} =129 ps



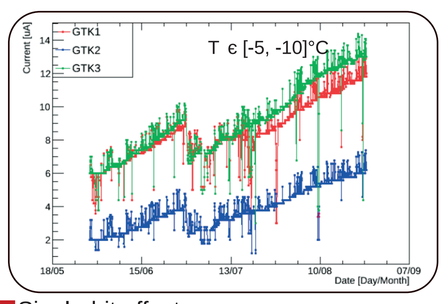
time resolution per track = 74ps

Improvement of the missing mass resolution thanks to the GTK



Irradiation Effects

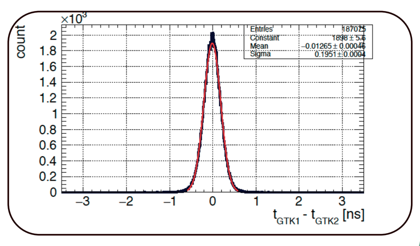
Exposed to a high radiation fluence (1/2 year at nominal beam intensity)
TID(average) = 7kGy → φ_{eq}(average)=1.5×10^{13} 1MeV n_{eq}/cm²
TID(peak)=35kGy → φ_{eq}(peak)=7×10^{13} 1MeV n_{eq}/cm²



Leakage current increases

- Single-hit effect:
  σ_{GTK1} =139 ps
  σ_{GTK2} =137 ps
  σ_{GTK3} =142 ps
- Small deterioration of time resolution per track:

Δt_{2016} 74ps → Δt_{2017} 78ps



Conclusions

- Detector fully operational since 2016
- Performance better than expectations
- Innovative and very-low mass cooling plate based on micro- channels (first implementation in HEP experiment)
- Approaching a phase of operations of the detector in an environment with an unprecedented level of radiation
- Careful monitoring of the performance
- new station building and calibration for periodic replacement and future use

References

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