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General-Purpose Solution for Timepix3 – Katherine Readout

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INTRODUCTION

The Katherine – *Ethernet Embedded Readout Interface for Timepix3* – is an universal readout device for Timepix3 readout chip. Timepix3 is the latest generation of hybrid particle pixel detectors of the Medipix family. It offers a lot of advanced features, such as high hit-rate, time resolution of 1.56ns, event-data-driven mode and mainly the capability to measure Time-over-Threshold (ToT – energy) and Time-of-Arrival (ToA – time-stamps) simultaneously. The designed Katherine readout device makes it possible to use Timepix3 for a wide range of applications and tasks. This fact meets original idea and effort of authors that could be summarized by phrase "one device – all tasks". Presently the Katherine readout can be already used for sophisticated coincidence measurements in laboratories as well as for complex measurements in pulsed mixed radiation fields applying simultaneously ToT for particle identification and ToA as an input for ToF method, e.g. with more synchronized detectors arranged as particle telescope. It is important to note that the Katherine is rather a platform open to users than final device. There still remains many possibilities to implement new operational functionalities and features.

Timepix3 Detector Description:

- Hybrid pixel detector: readout chip + bump-bonded sensor (Si, CdTe, GaAs etc.)
- Resolution 256x256 pixels; pixel pitch 55μm
- Developed within Medipix3 Collaboration
  (POIKELA, T., et al. Timepix3: a 65K channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout. *Journal of instrumentation*, 2014.)
- Designed in 130nm CMOS technology
- Measuring ToT (energy) and ToA (time-stamping) simultaneously
- ToA measurement:
  - Coarse ToA clock = 40MHz => 25ns
  - Fine ToA clock = 640MHz (ring oscillator) => 1.56ns
  - Global time stamp range 14 bits => 409.6μs
- Readout modes:
  - Frame-based mode with zero-suppressed (max ~1300 fps)
  - Data-driven mode (~40Mhits/s); dead time per pixel min. 475ns
- Acquisition modes: ToA & ToT, Only ToA, Event Count & Integral ToT
- Output data: up to 8 serial lines @ 640MHz => max. data rate = 5.12Gbps

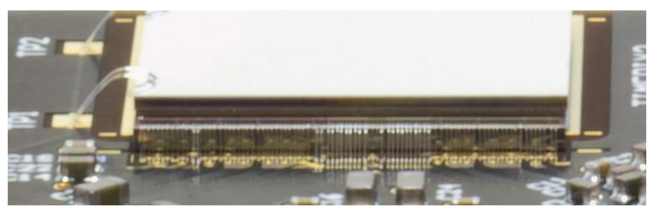
Fig. 1: Timepix3 Detector/Assembly

Katherine Readout for Timepix3:

- Embedded computer + Timepix3 interface (CERN's chipboard)
- Bias voltage source – both polarities (±300V)
- Gigabit Ethernet Interface – max. 16 million events/s (hit/s)
- Dimension: roughly 100x80x28


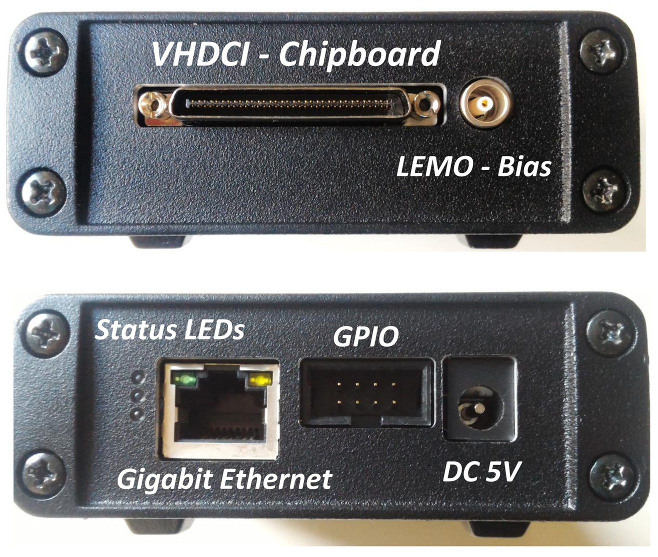

Fig. 2: The Katherine readout for Timepix3

- GPIO Port: 1x single-ended input (possible to use as external clock), 1x single-ended BiDir port, 1x LVDS input, 1x LVDS output
- ToA overflow in data-driven mode => Overall 50-bit (32 extra, 14 ToA, 4 fToA) time-stamping => overflow period is ~20 days (with resolution 1.56ns)
- All data from Timepix3 are converted from LFSR and Gray to binary code in the device
- Enough computing power for user purpose – 8000 ALMs in FPGA free + dual-core ARM Cortex-A9 processor, 1 GB DDR3 RAM
- Communication with a sensor: 2x fast line => 2x 640Mbs or 4x slow line => 4x 160/80/40Mbs
- Communication with a computer/server:
  - P-2-P communication with computer (based on UDP datagrams; TCP/IP in development)
  - 36 control/status commands
  - Automatic/independent sending data to server (via SSH connection)

Control and Acquisition Software:

- Completely new control software tool with GUI supporting more detectors in a network
- Basic functionality is ensured: chip equalization, threshold scans, internal DAC scans, data acquisition, temperature monitoring, internal test pulses, trigger settings, test pulses etc.
- Console multiplatform application for data acquisition

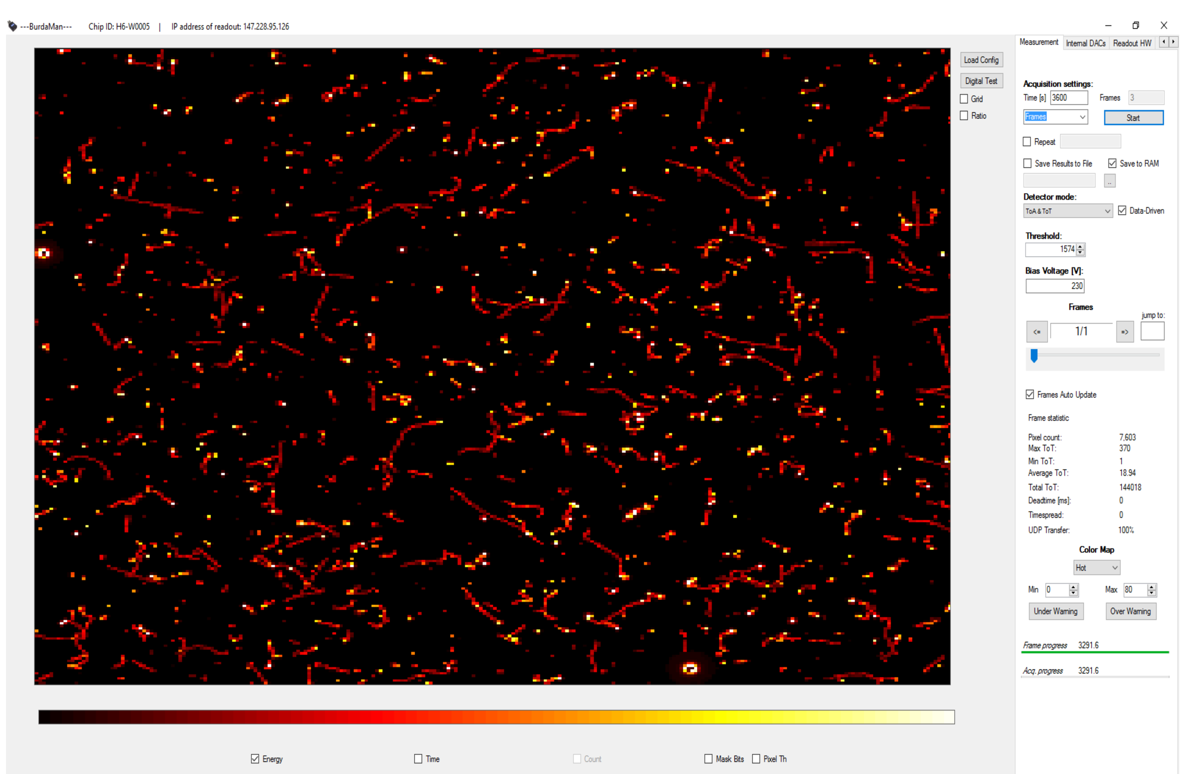
Fig. 3: Control SW – frame with the response of Timepix3 to mixed radiation field (gammas, electrons, alphas)

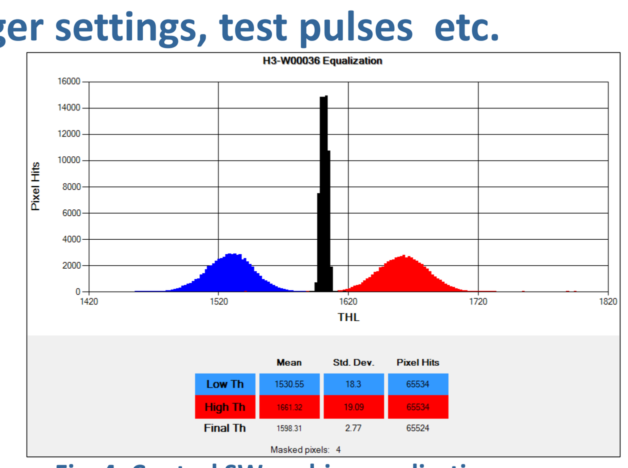
Fig. 4: Control SW – chip equalization process

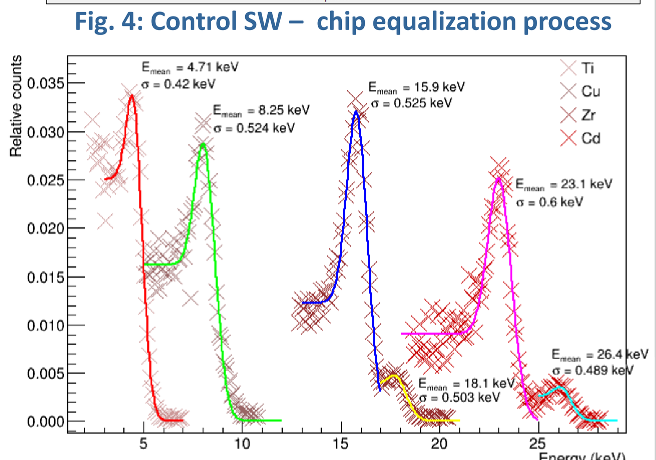

Fig. 5: The energy spectra determined by THL scans for different X-ray flourescences

Detector Stacking and Synchronization:

- Possibility to connect up to 5 detectors to chain with consistent time-stamping
- Common clock signal distribution for all detectors plus measuring differences in phases by the TDC device

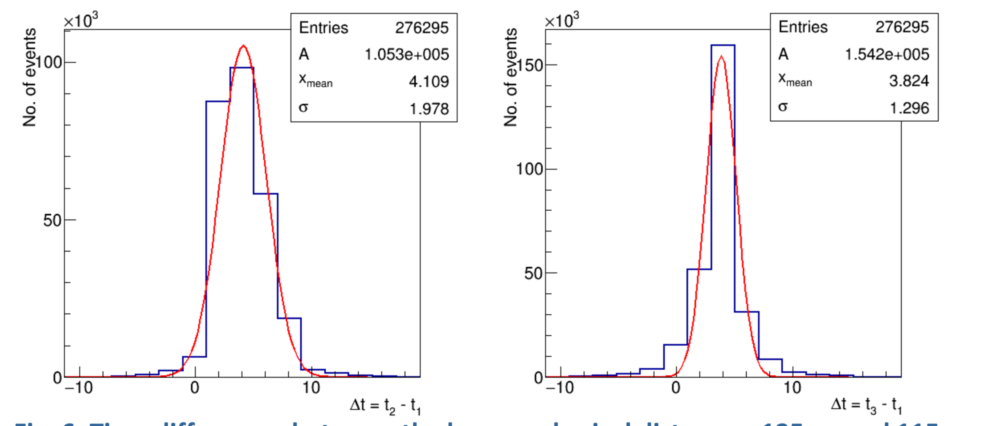

Fig. 6: Time differences between the layers - physical distances: 125cm and 115cm.

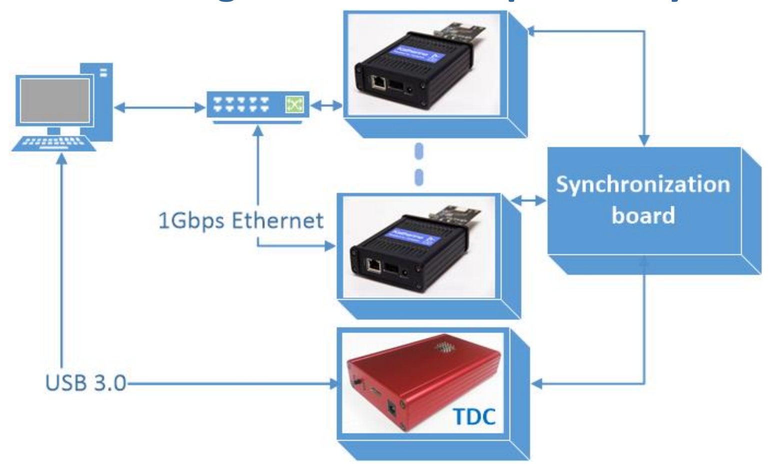

Fig. 7: Synchronization of more detectors - setup

Long-Distance Access:

- Long distance between readout and back-end computer – up to 100m (because of Ethernet)
- Distance between Timepix3 detector and Katherine readout device:
  - VHDCI extending cable => meters (3.5m => 2x 640Mbs, 10m => 4x 160Mbs)
  - Passive ethernet cable extender => tens of meters (e.g. 20m => 2x 640Mbs)
  - Active ethernet cable extender => up to 100m (with decrease in communication speed)
- Assume that detector part is rad. hard. => completed rad. hard. solution for Timepix3


Fig. 8: Usage of extending cable

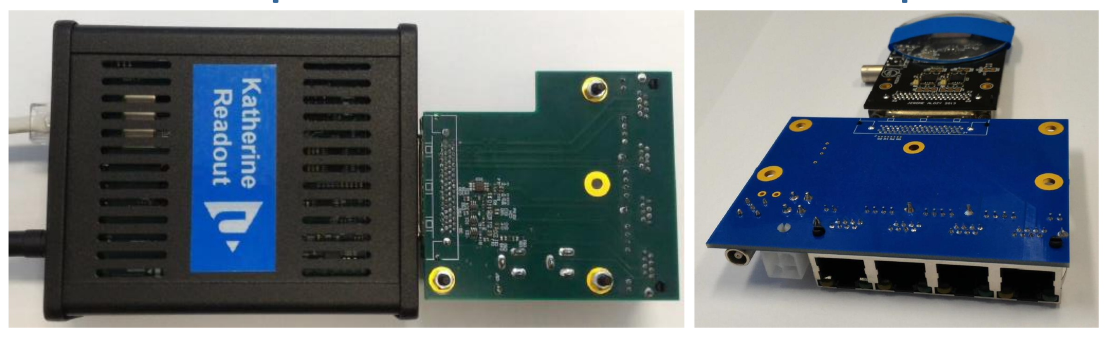

Fig. 9: Ethernet cable extender (readout and sensor side)

Test in ATLAS Environment:

- Detector unit: radiation hardened chipboard with rad. hard. power supplies, Timepix3 assembly with Si-500μm sensor, ethernet cable extender
- Detector unit position - the wall of side A, above beam pipe, with angle 45° to the beam pipe
- Readout device placed in "safety area" in USA15 rack room
- Distance between Timepix3 detector and readout device approximately 80m
- Connection: 4x ethernet cable cat.7, 1x power supply cable, 1x bias voltage cable
- Maximum hit-rate ~5Mhits/s

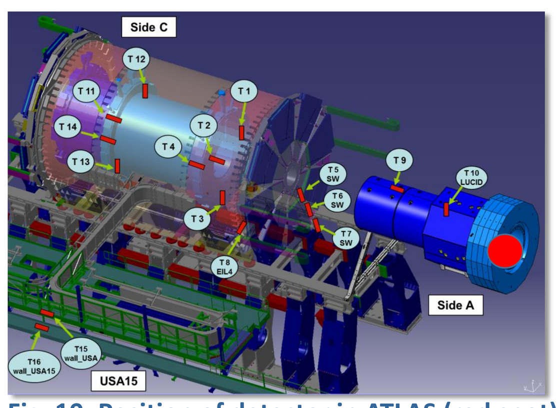

Fig. 10: Position of detector in ATLAS (red spot)

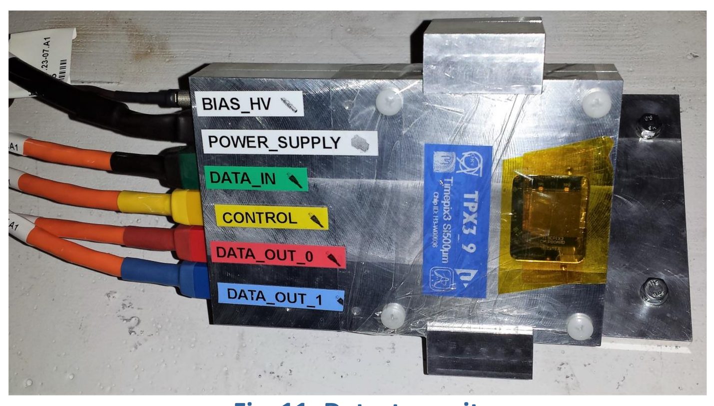

Fig. 11: Detector unit

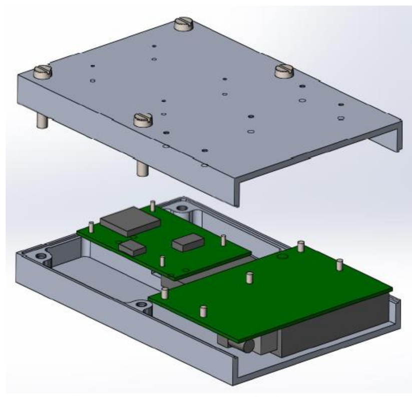
Fig. 12: Drawing of detector unit (chipboard + extender)

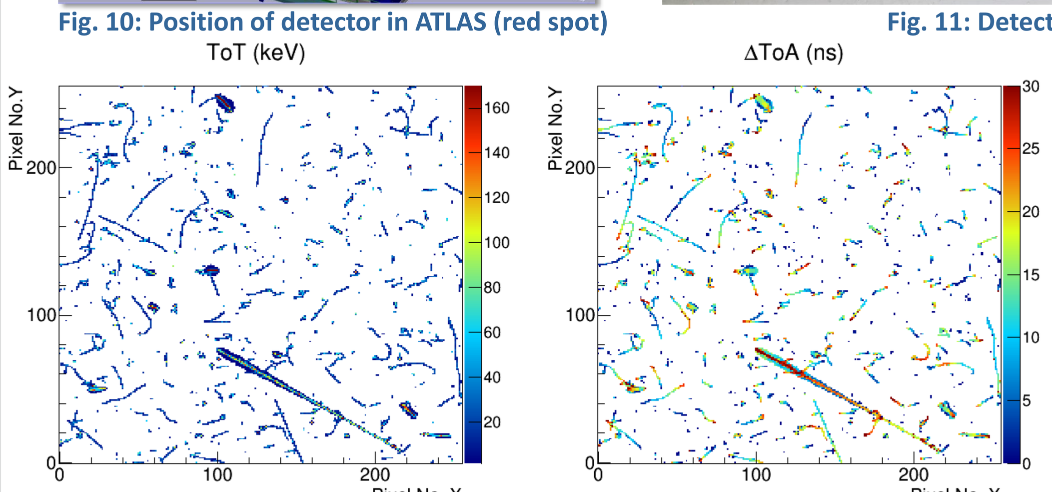

Fig. 13: Visualization of particle tracks accumulated within 10 s in a collision period

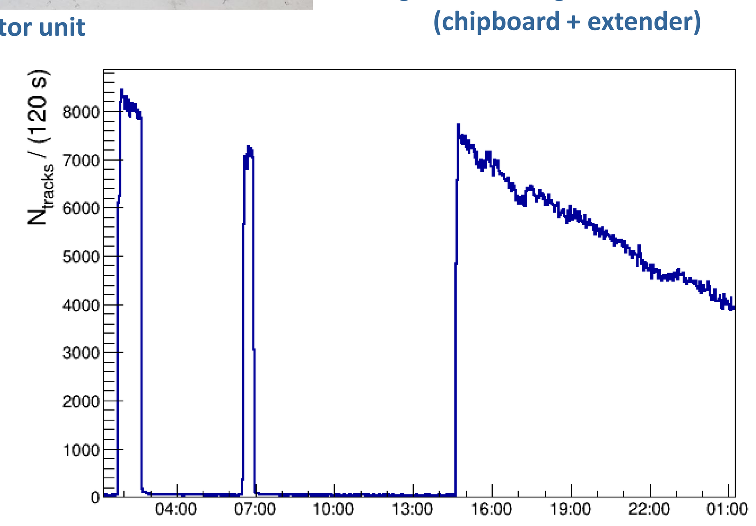

Fig. 14: Count rate measured on the 20th of July 2017 (Runs: 330203, 330166, and 330160)

CONCLUSION

The designed readout device was used and verified within a lot of measurements. Its response was tested by means of X-ray, radiation sources, pions at SPS or by the deployment at ATLAS cavern. The Katherine supports stacking, it means the interconnection of more devices together to set up the particle telescope. With good time resolution of Timepix3 and using TDC device (for time-stamping synchronization enhancement) we can get a tool for Time-of-Flight measurement with resolution below 2ns. Using ethernet cable extenders, sensor can be placed far enough (up to 100m) from readout electronics. Along with rad. hard. chipboard it forms comprehensive solution to apply Timepix3 devices for complex characterization of large variety of radiation fields. This concept has been already successfully tested in ATLAS cavern environment where it is running without faults for five months.