Data Acquisition at the Front-End of the Mu3e Pixel Detector

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on behalf of the Mu3e Collaboration

Physikalisches Institut, Heidelberg

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UNIVERSITÄT
HEIDELBERG
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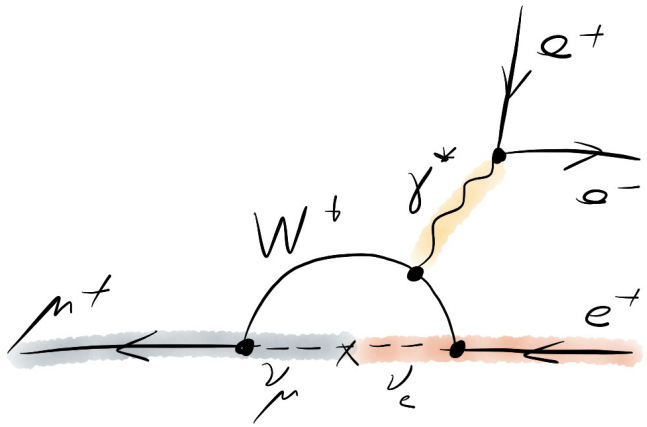
SEIT 1386

The Mu3e Experiment

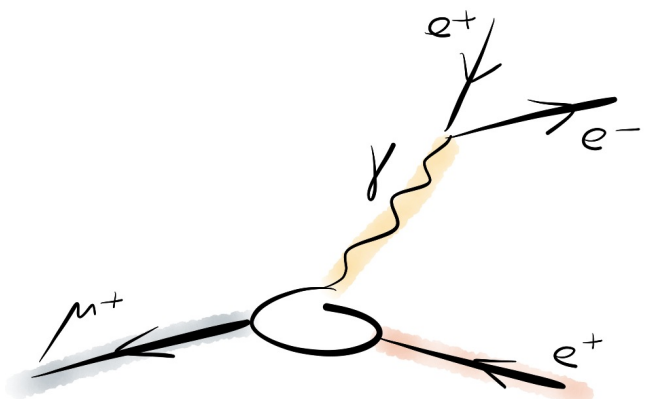
Charged lepton flavour violating decay: $\mu^+ \to e^+e^-e^+$

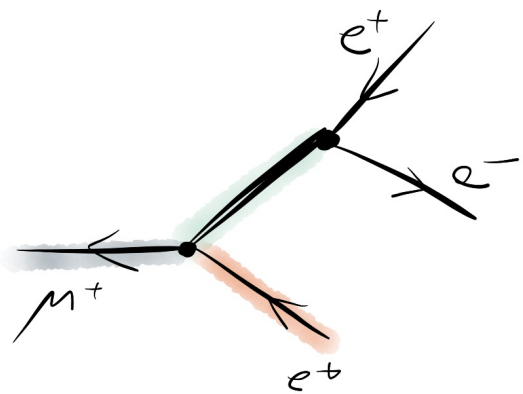
Expectation from lepton mixing:

$$BR_{\mu \to eee} \sim \left(\frac{\Delta m_\nu^2}{m_W^2}\right)^2 < 10^{-54}$$



Observation of $\mu \to eee$ is a clear sign for New Physics
SUSY, extra heavy vector bosons (Z′), ...





The Mu3e Experiment

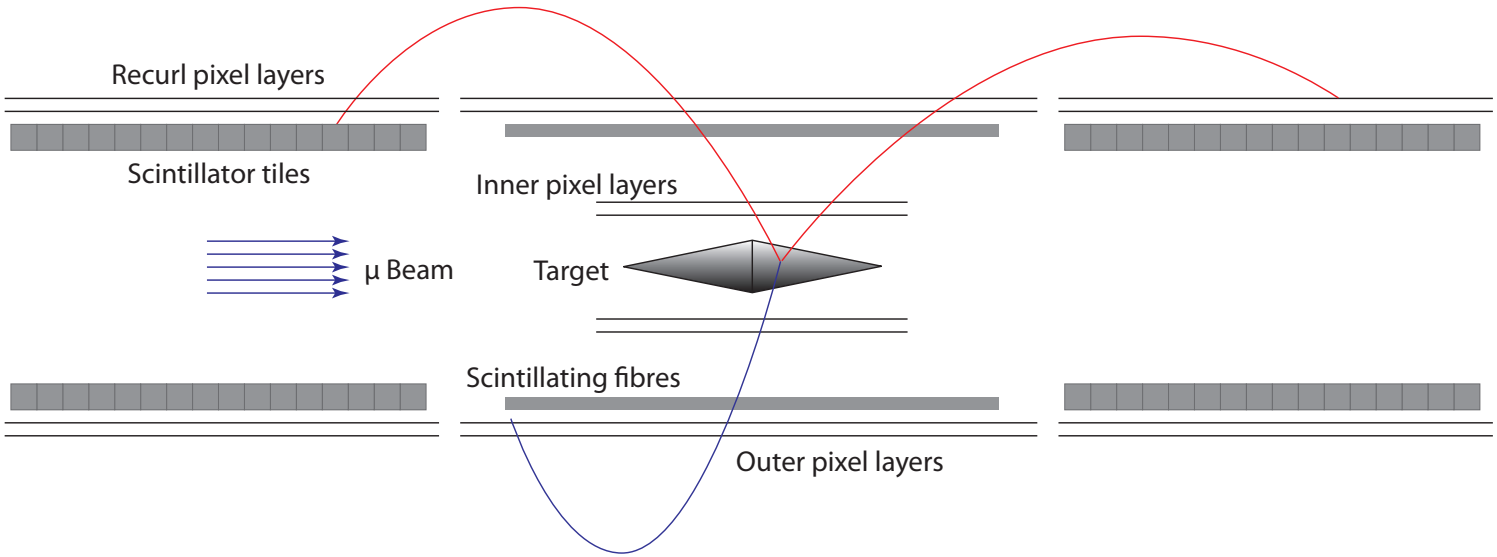
Mu3e: Search for $\mu \to eee$ down to BR $< 10^{-16}$ (90% CL)

- High muon stopping rates $\sim 2 \cdot 10^9$ muons/s
- Background from SM decay $\mu \to eee\nu\overline{\nu}$ and accidental combinations
  - Excellent momentum and vertex resolution
  - Precise timing
- Momentum of decay electrons: $\sim 15 - 53$ MeV/c
  - Low material budget to reduce scattering

The Mu3e Experiment

Tracking detector:
Thinned Si pixel sensors

+ Timing detector:
Scintillating fibres and tiles



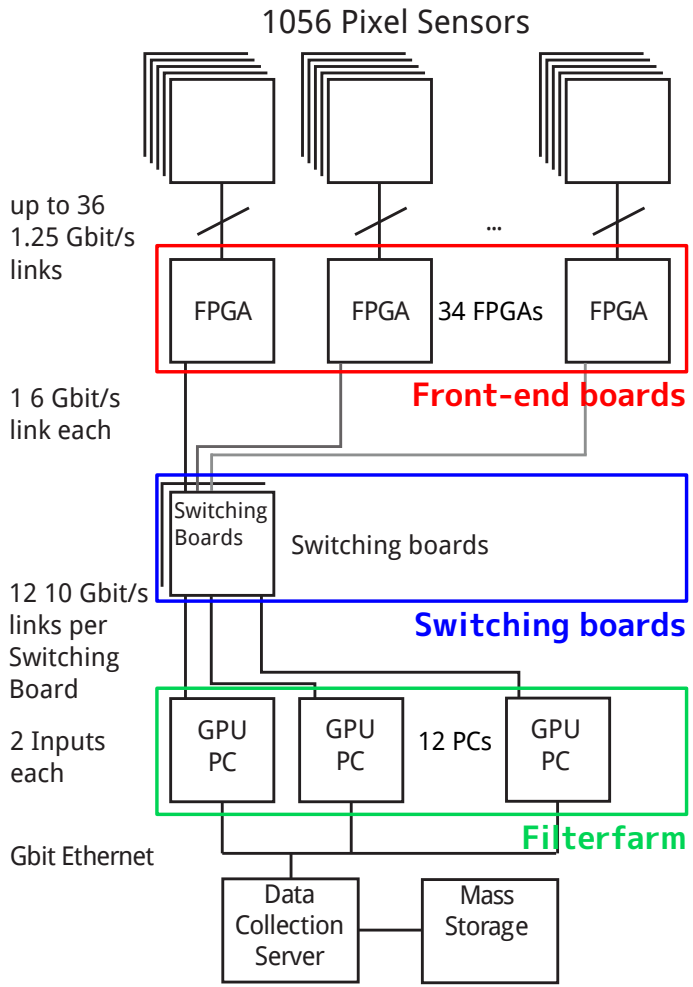
Currently:
Research and development

In 2018:
Commissioning and first data

DAQ Concept

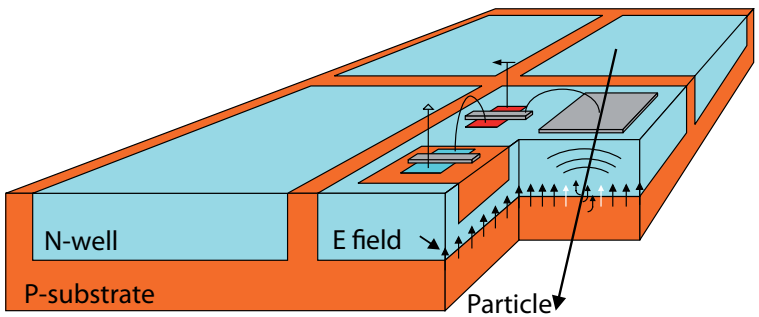
Triggerless data acquisition

- Front-end board (this talk)
  - Decode and merge data of ~ 15 (36) sensors
  - Time-sorting
- Switching board (T22.5)
  - Switch between front-end and filterfarm
  - Merge data of sub-detectors
- GPU filterfarm (T42.5, T42.6)
  - Fast track finding and online reconstruction
  - Reduce data rate by a factor ~ 1000



MuPix7 Prototype

- High Voltage Monolithic Active Pixel Sensor (T72.1 - 72.3)
- Integrated signal processing
  - Amplification and signal shaping
  - Hit detection
- Internal state machine
  - Column-wise readout
    time structure is 'lost'
  - 8b/10b encoded data:
    hit: time stamp, pixel address
    or counter
  - LVDS link at up to 1.25 Gbit/s
    Up to 30 Mhits/s can be read out
    Expected ≤ 8 Mhits/s on busiest sensor at 10^8 μ/s



I. Perić, NIM A 582 (2007)

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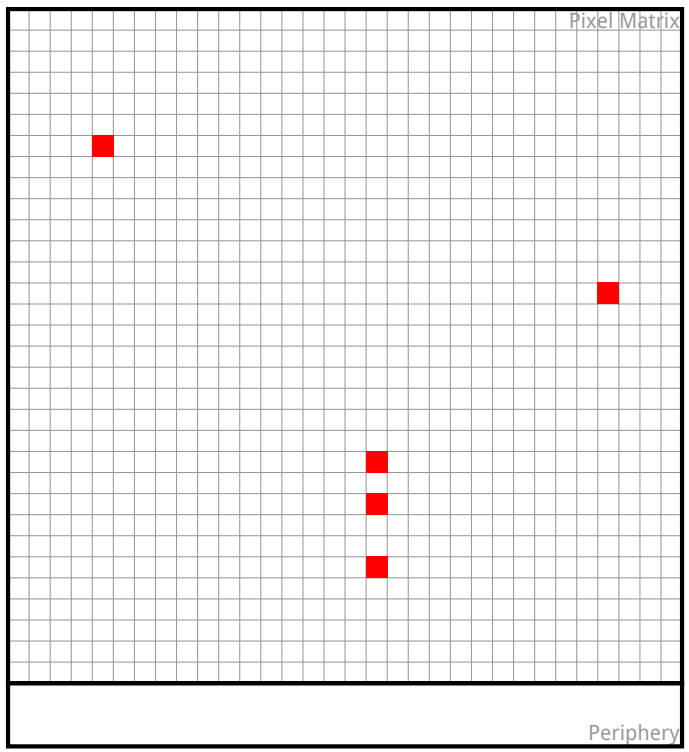

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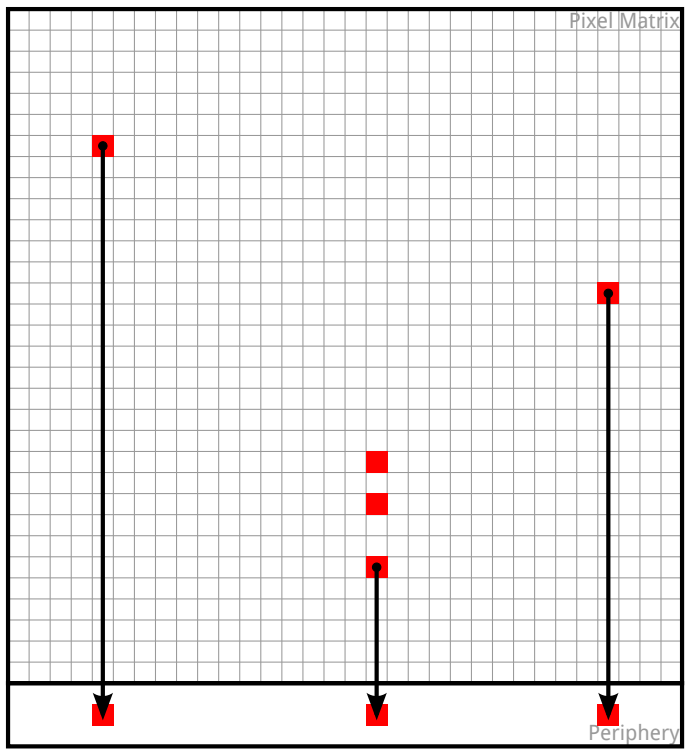

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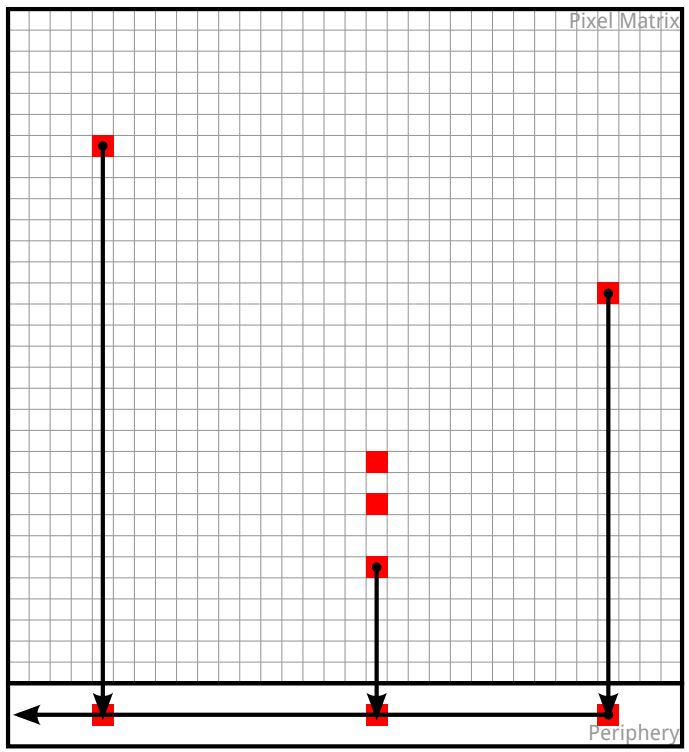

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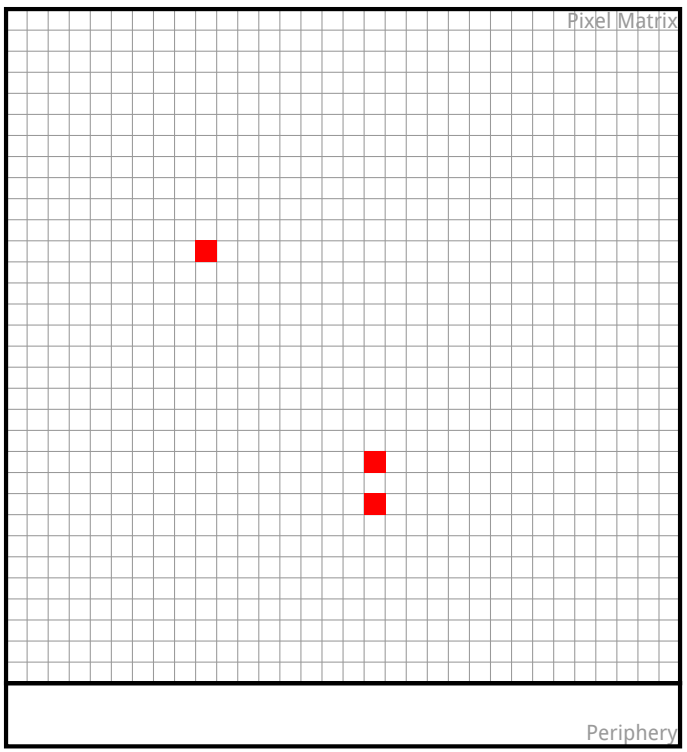

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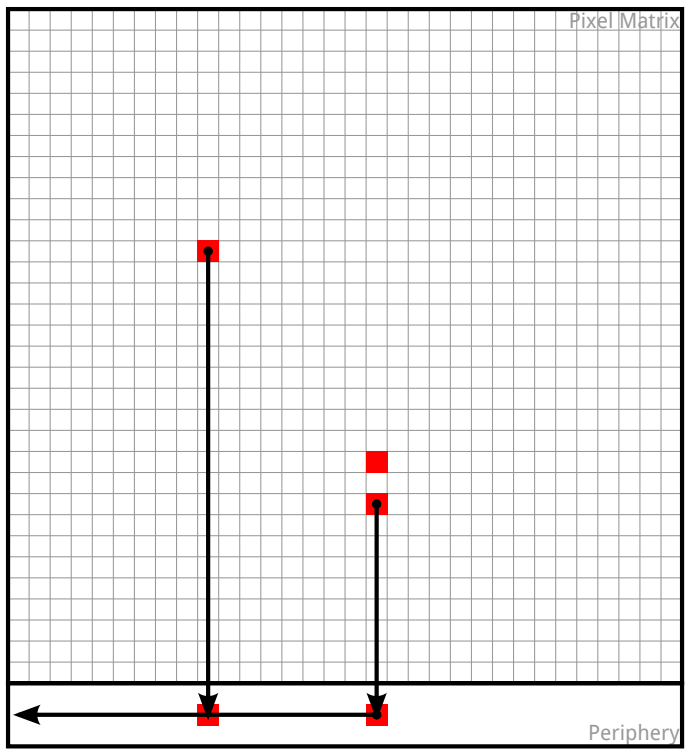

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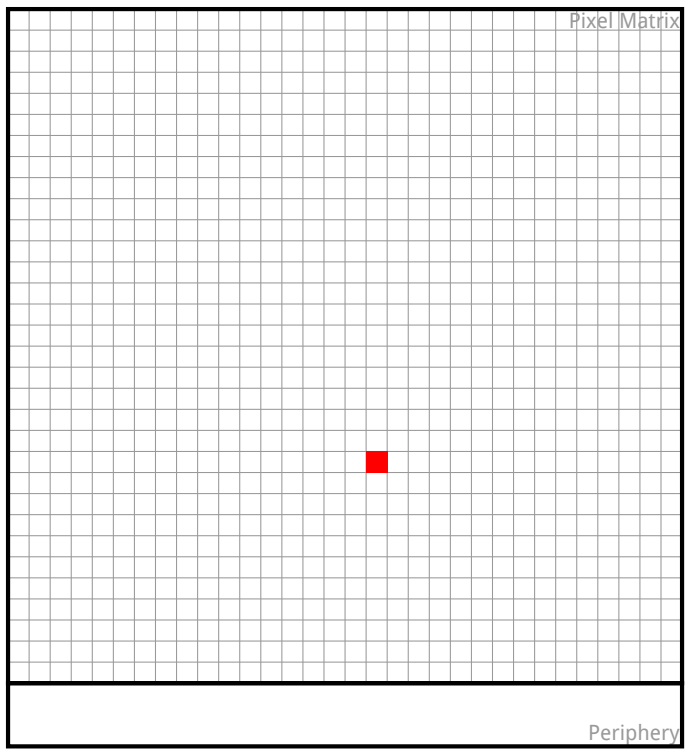

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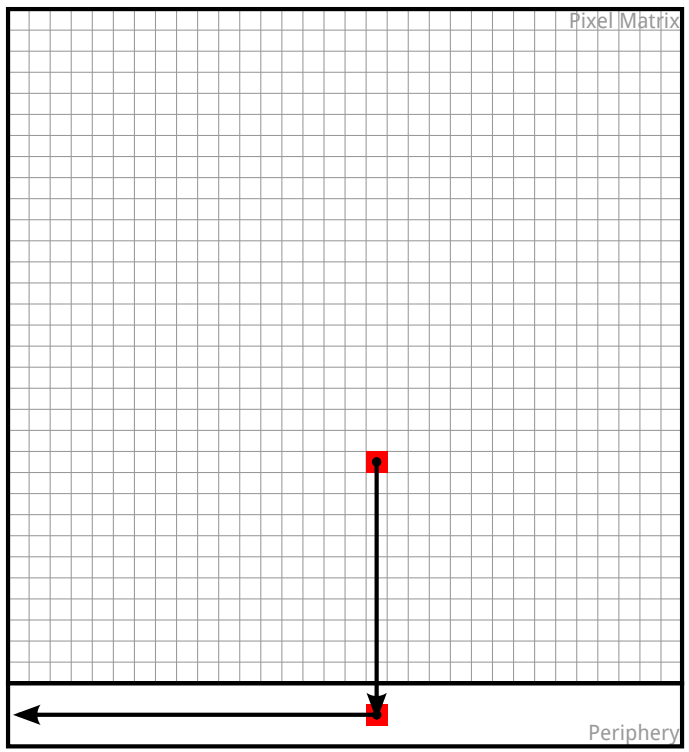

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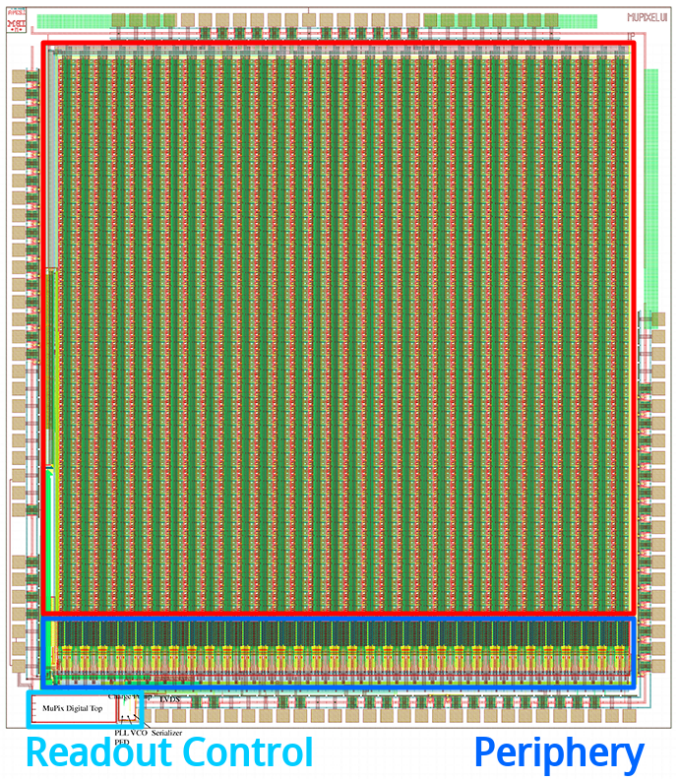
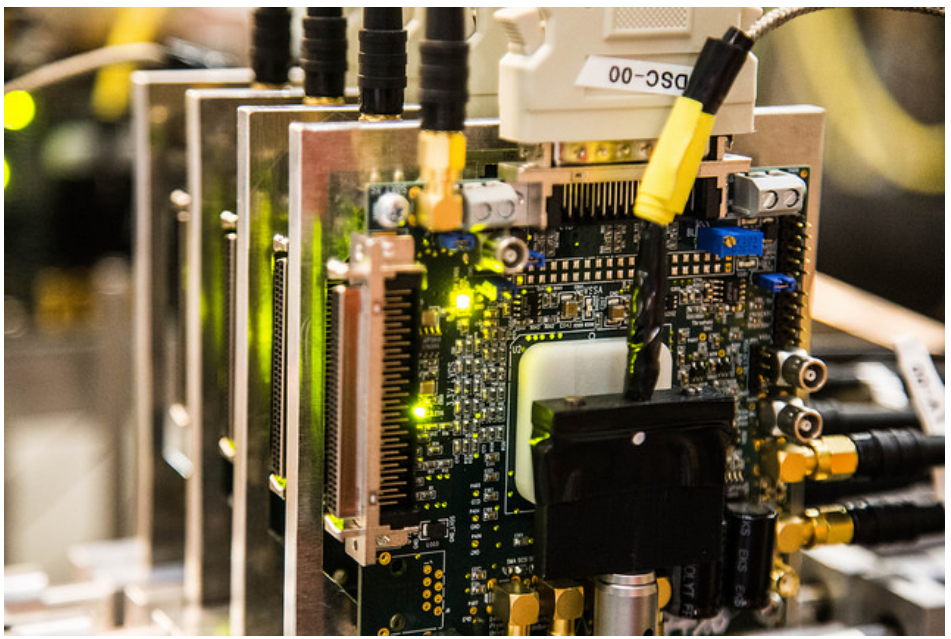


Front-End for the MuPix Telescope

MuPix telescope (T99.5)

- Tests of new prototypes and system integration
- 4 planes of MuPix7
- Readout via Altera Stratix IV development boards
- Test beam at DESY, PSI, SPS, MAMI in 2015



Front-End for the MuPix Telescope

Receiver

- Receive data via LVDS at 1.25 Gbit/s
- Align to word boundary using K-words
- 8b/10b decoding

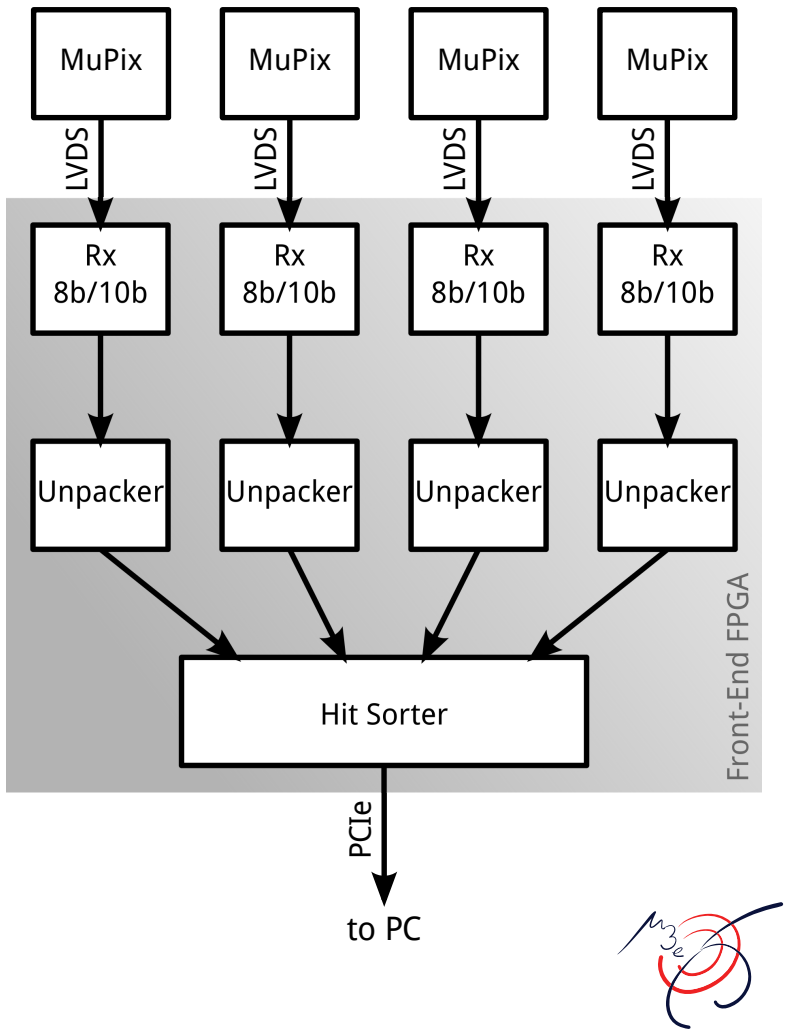
"Unpacker"

- Disentangle hit and counter data
- Remove K-words

Hit sorter

- Merge data from 4 sensors to one datastream
- Sort hit data by time stamp

Data transfer to PC via PCIe



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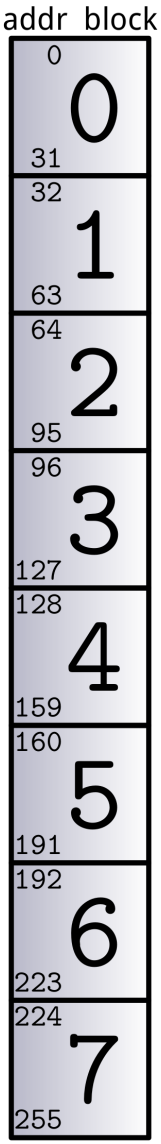

Sort hits by time stamp on FPGA

- Dual-port RAM (74 kbit)
- Continuously write and read
- Address: 8b time stamp + 4b counter
- Divide memory in 8 blocks
- Simultaneous read & write on the same block forbidden

- Possible difficulties
  Read/write conflict: ~ µs 'old' hits
  Overflow: > 15 hits per TS

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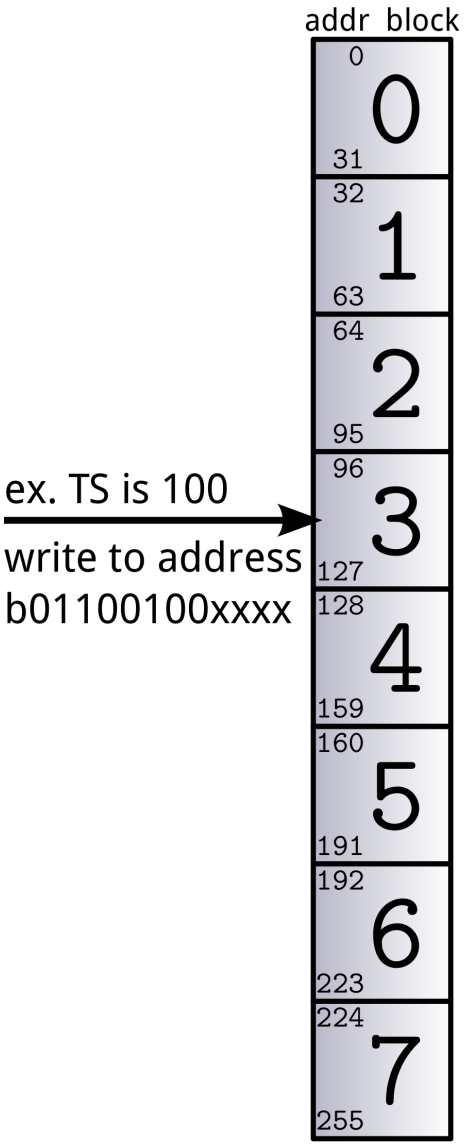

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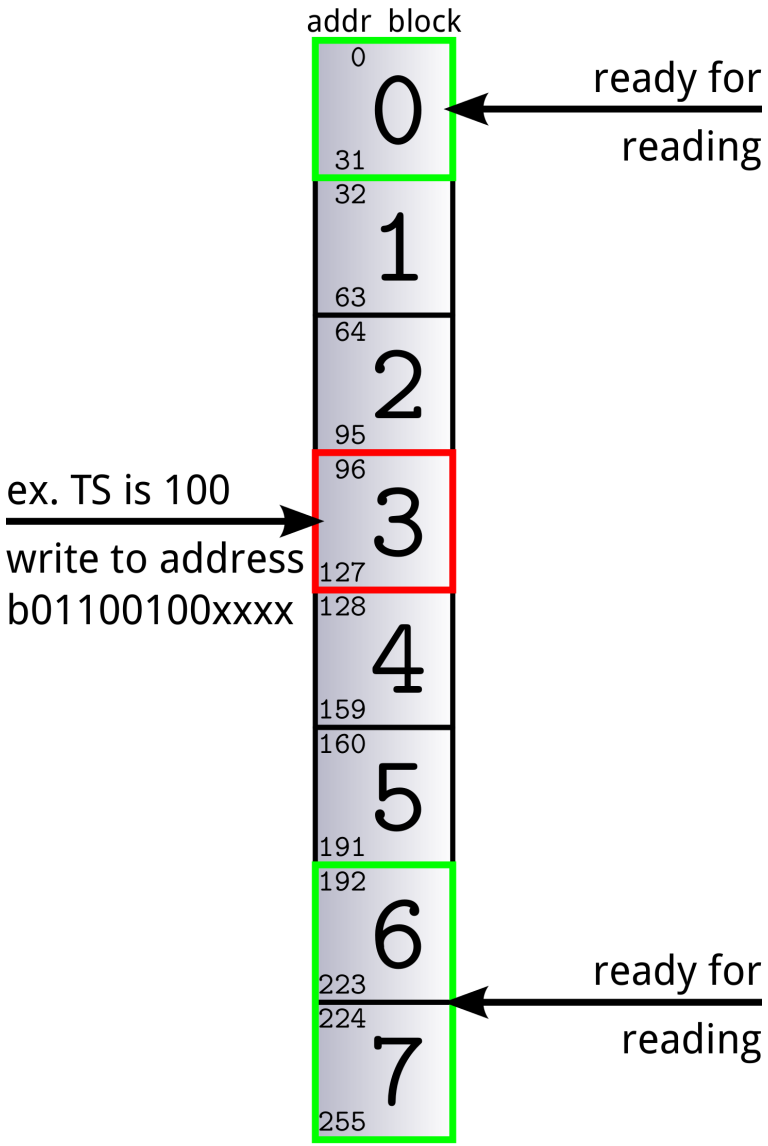

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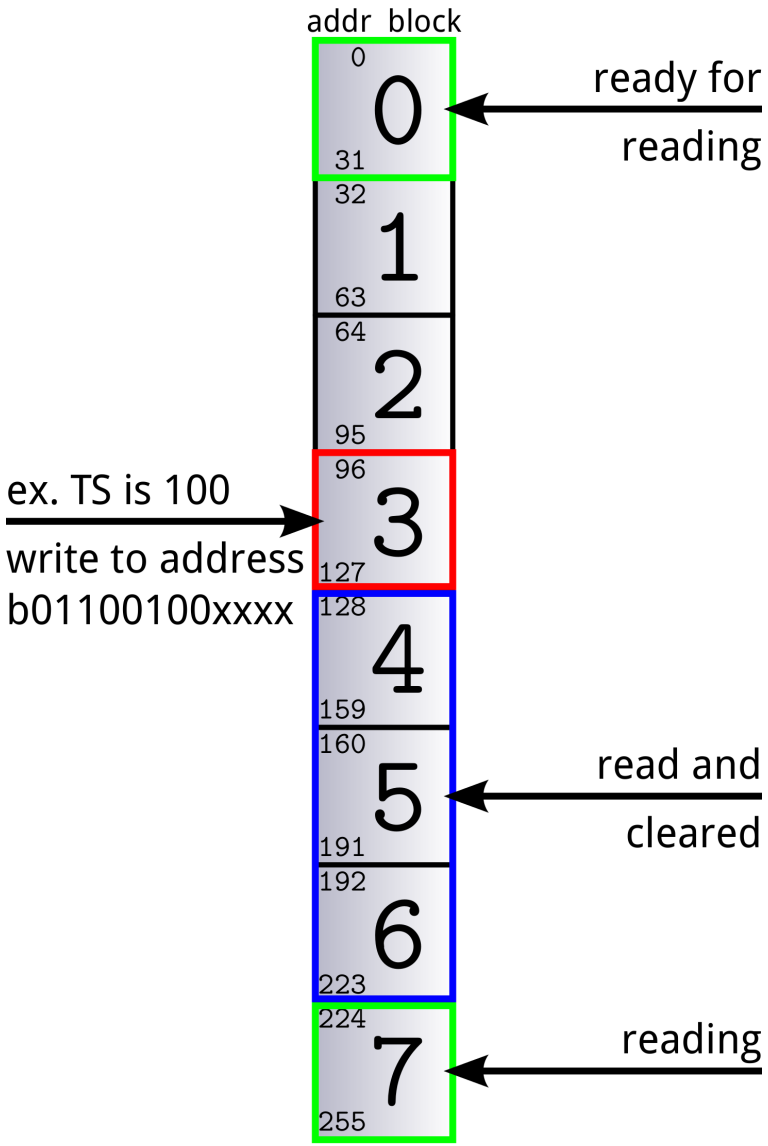

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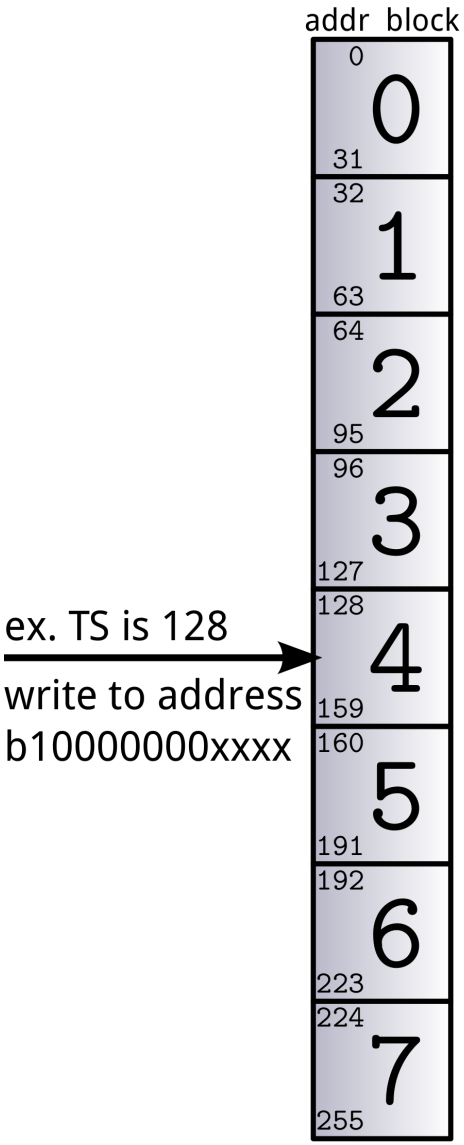

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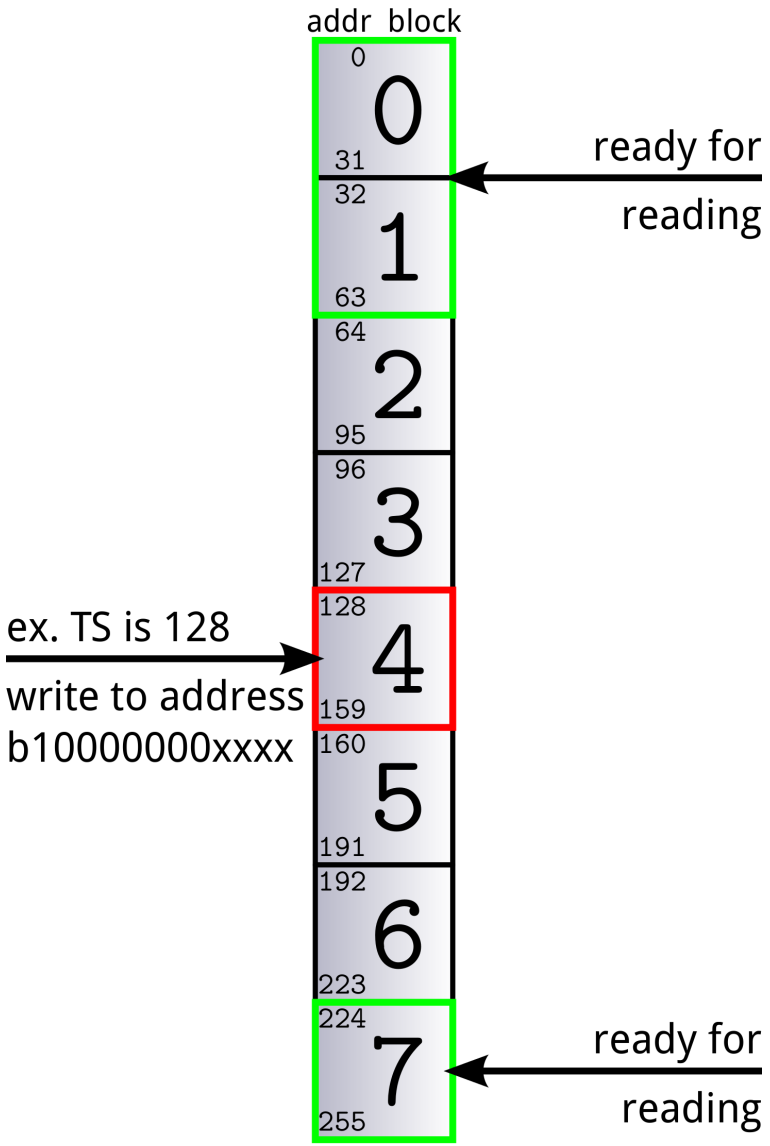

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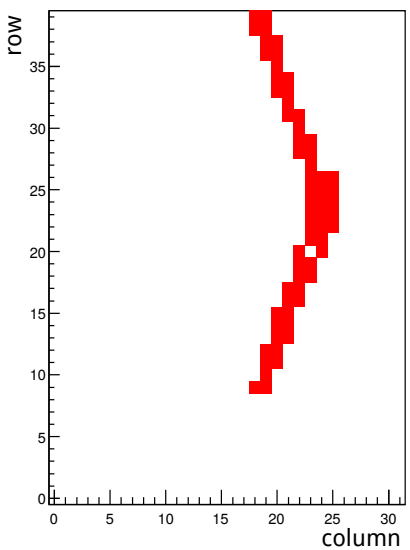
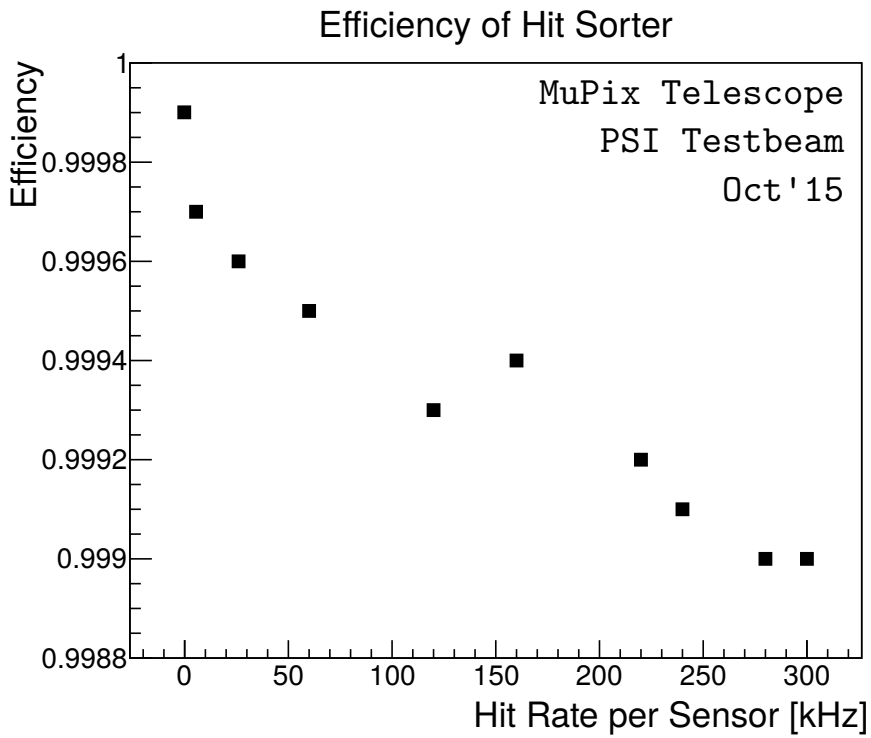
Front-End for the MuPix Telescope

- Successfully tested MuPix readout via fast serial link
- Hit sorting has proven suitability in lab and at test beam
- Data loss $\lesssim 1\,‰$ due to delta electrons
- No overflow observed





Acknowledgements

The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).

We would like to thank PSI for providing high rate test beams under excellent conditions.

We owe our SPS test beam time to the SPS team and our LHCb colleagues, especially Heinrich, Kazu and Martin.

We thank the Institut für Kernphysik at the Johannes Gutenberg University Mainz for giving us the opportunity to take data at the MAMI beam.

Summary

Mu3e Search for LFV decay $\mu \to eee$ with a sensitivity of BR $< 10^{-16}$ (90% CL)

MuPix7 Thinned active pixel sensor (HV-MAPS)

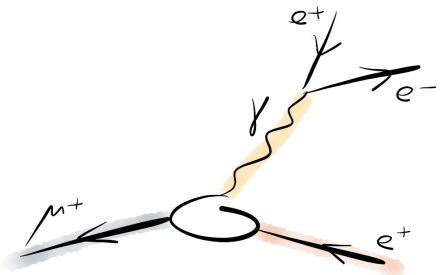
Fast serial data transmission

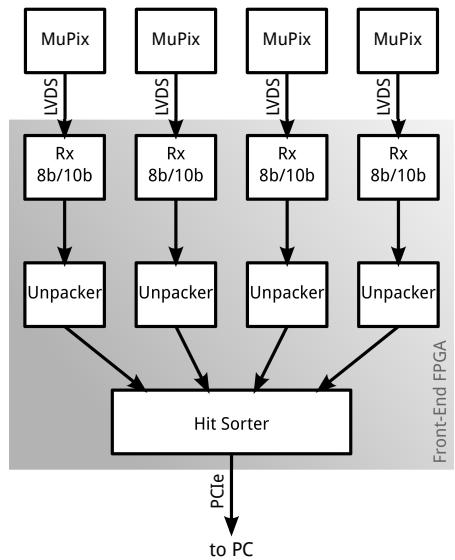
DAQ First implementation of front-end firmware successfully tested in MuPix telescope

Continuous data sorting by time stamp on FPGA working

Outlook Adapt to next MuPix prototype

Scale up to read out ~ 15 sensors





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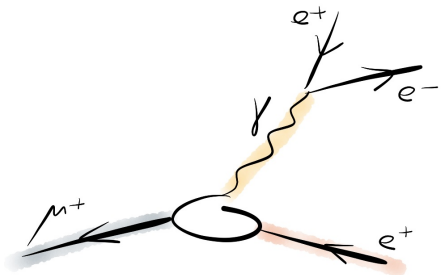

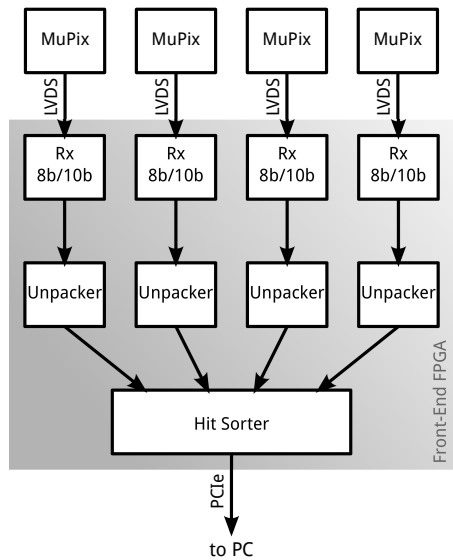

Further talks on Mu3e/MuPix:

Mu3e Experiment:	T22.5, T42.5-7, T43.3, T75.7, T98.1 & 5
MuPix:	T72.1-3
MuPix Telescope:	T99.5