



The MuPix Telescope

A Thin, High Rate Particle Tracking Telescope

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INTERNATIONAL MAX PLANCK RESEARCH SCHOOL PTFS FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES

Abstract

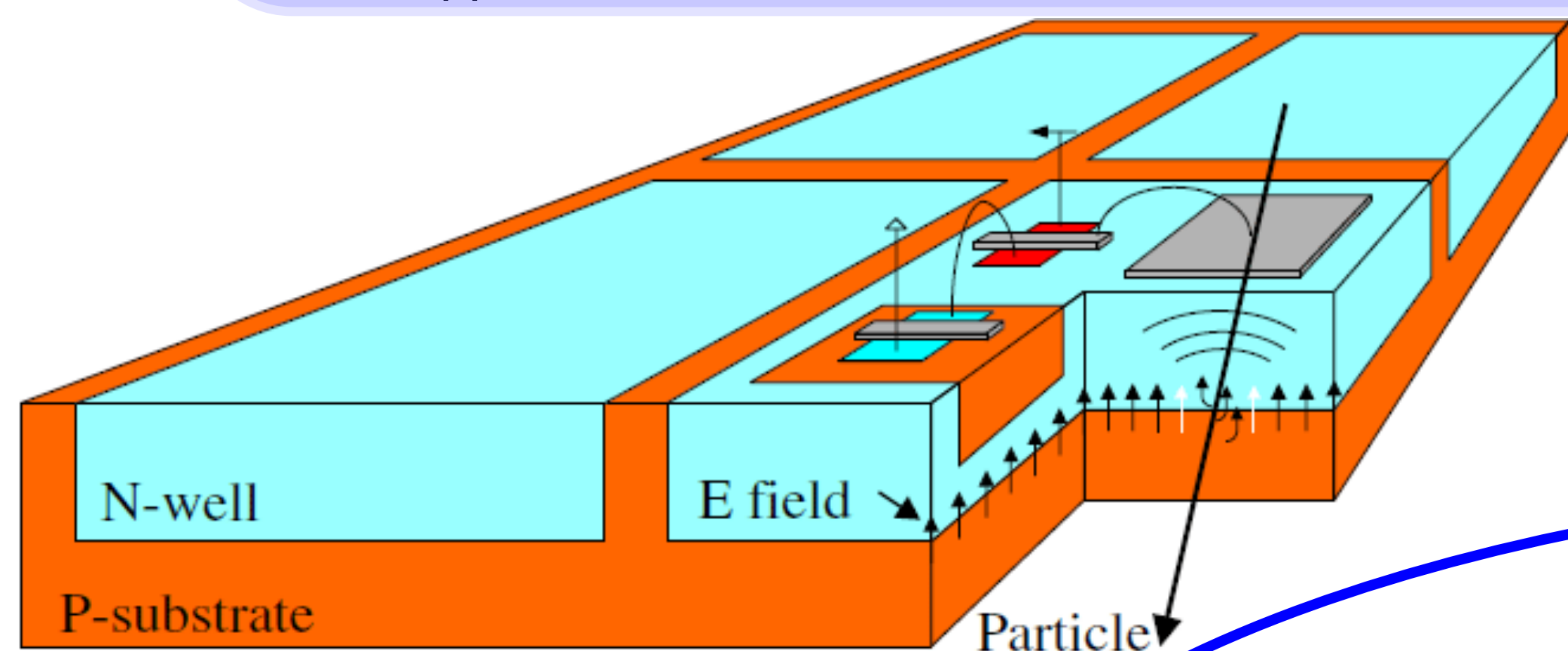
The Mu3e experiment is going to search for the Lepton Flavor Violating decay $\mu^+ \rightarrow e^+e^+e^+$, aiming for a sensitivity of 1 in 10^{16} decays, an improvement of four orders of magnitude to the previous limit¹⁾. The high decay rate and the low momentum of the particles put strong constraints on the detector technology: High vertex and momentum resolution require a thin pixel tracker. In combination with the required time resolution, a novel pixel technology is needed. High-Voltage monolithic active pixel sensors (HV-MAPS) are chosen.

To characterize HV-MAPS in testbeam campaigns, test the readout concept and integrate the main detector components into a tracking system, a beam telescope was developed. It consists of four layers of HV-MAPS for precise position resolution and two tile scintillators as reference timing sensors. The DAQ system is based on a Stratix IV development board, controlled by a standalone GUI.

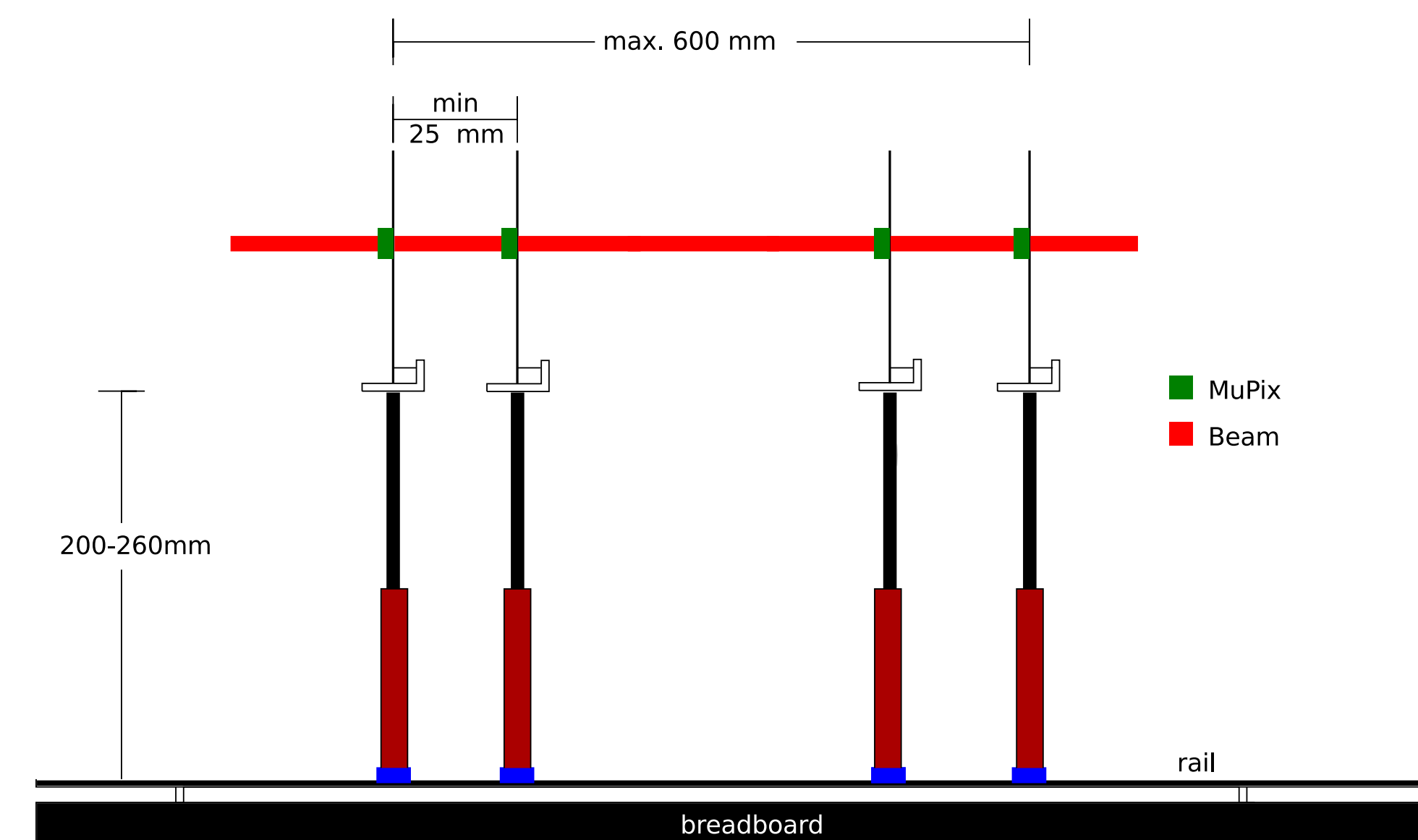
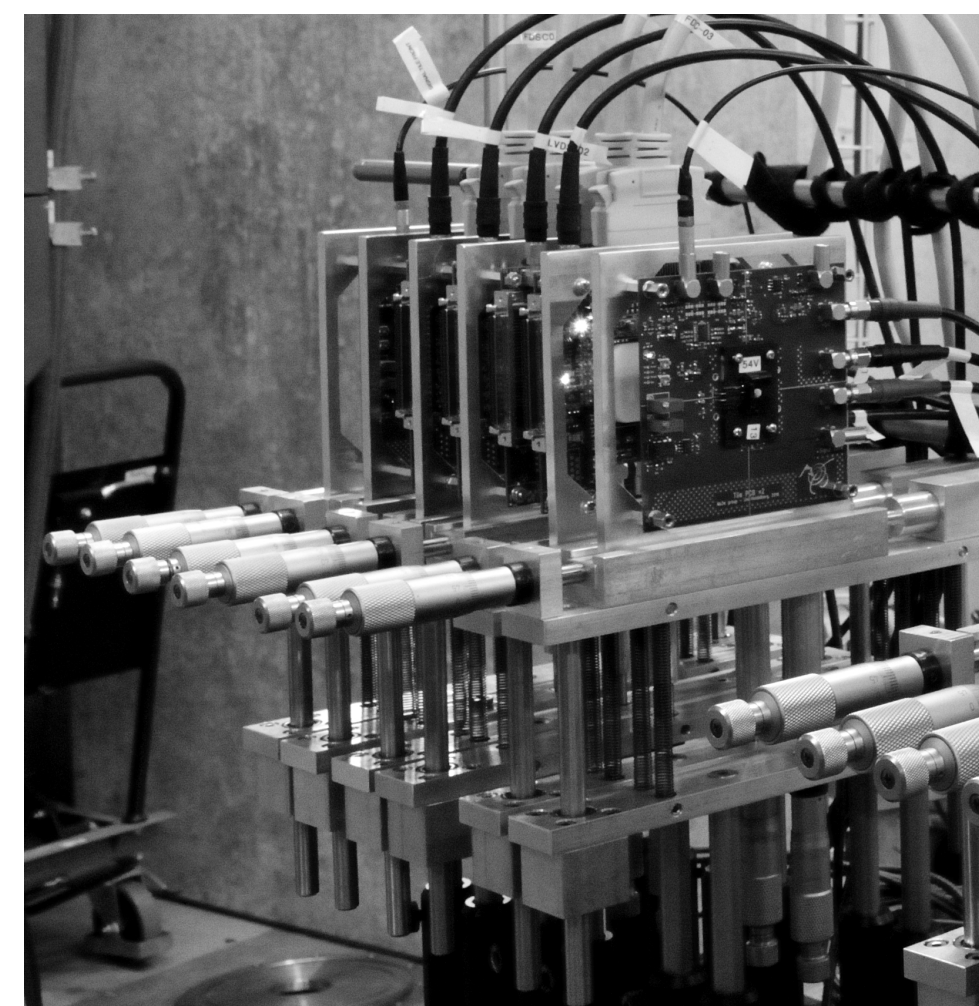
¹[SINDRUM Collaboration] Search for the decay $\mu \rightarrow e e e$ Nucl. Phys., B299 1,1988

HV-MAPS

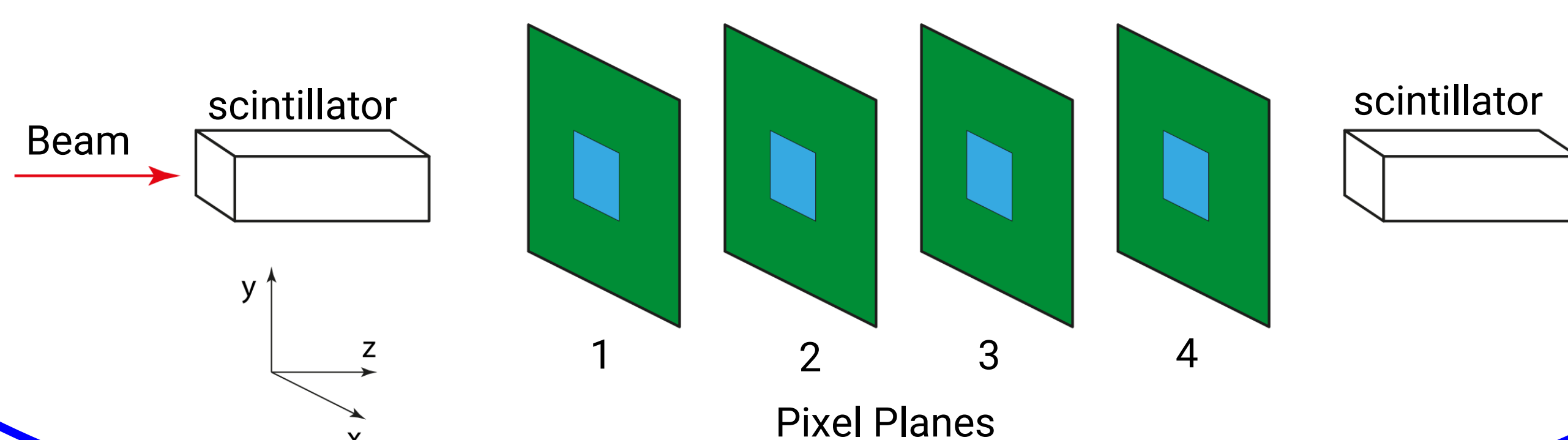
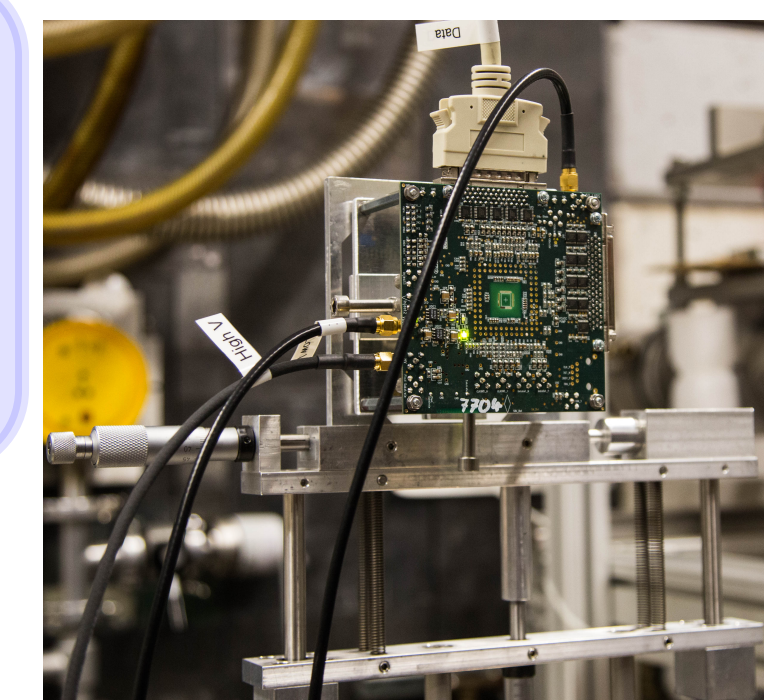
- Monolithic design
- Combines advantages of MAPS with fast charge collection in reverse biased diode
- Commercial HV-CMOS process
- Depletion zone $\sim 15 \mu\text{m}$
- Can be thinned to $50 \mu\text{m}$
- Amplification in pixel
- Readout controlled on chip
- Zero suppression



Mechanics

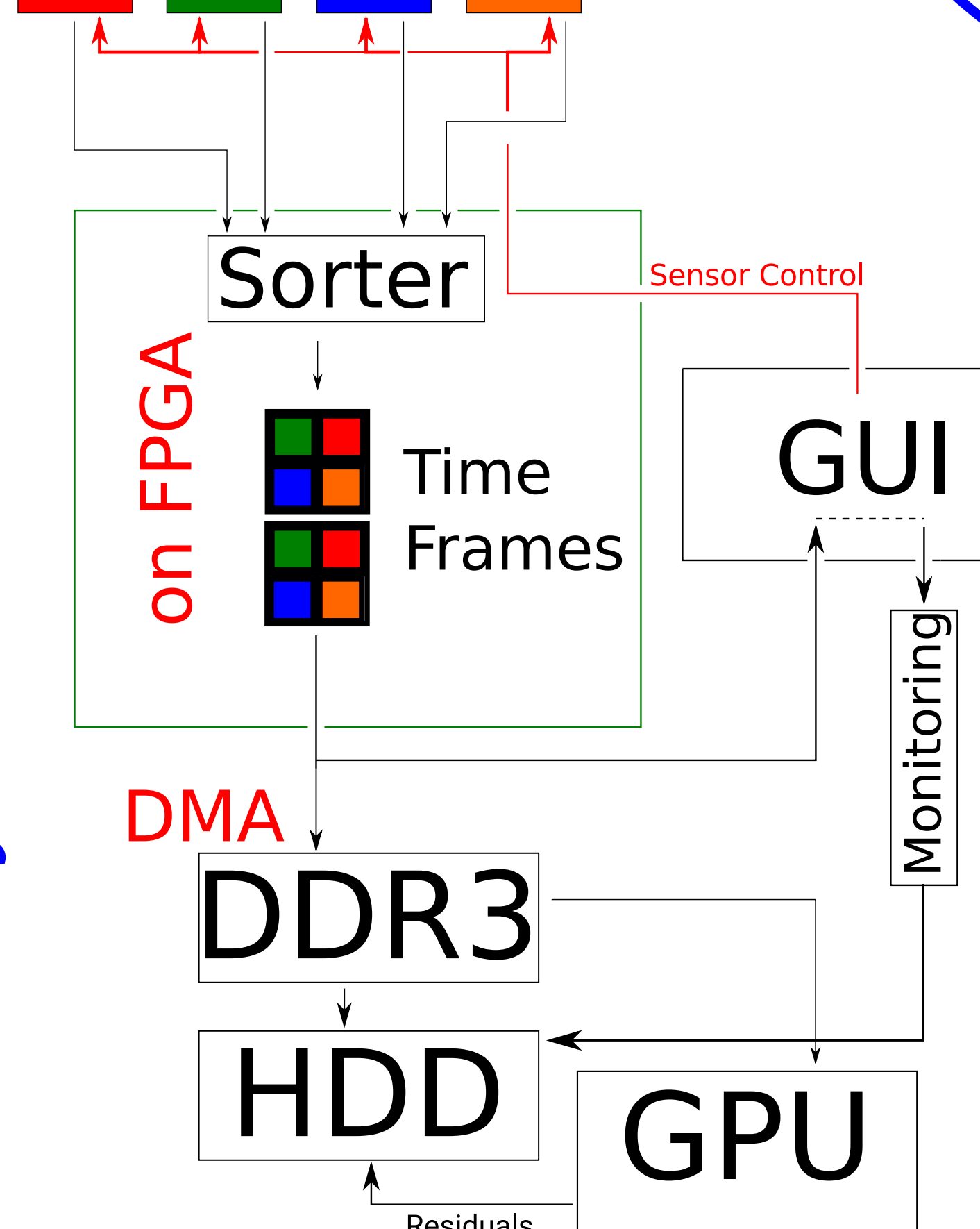


- Based on ThorlabsTM components
- PCB holder custom design
- $10 \mu\text{m}$ precision in x/y
- Stable and compact



DAQ System

1 2 3 4 Sensors



- 4 HV-MAPS per FPGA
- Time sorting on FPGA
- PCIe connection to main memory
- Polling and direct memory accesses (DMA) possible
- optional DMA to GPU
- GPU and CPU online tracking
- Online monitoring
- Up to 60 MByte/s to disk

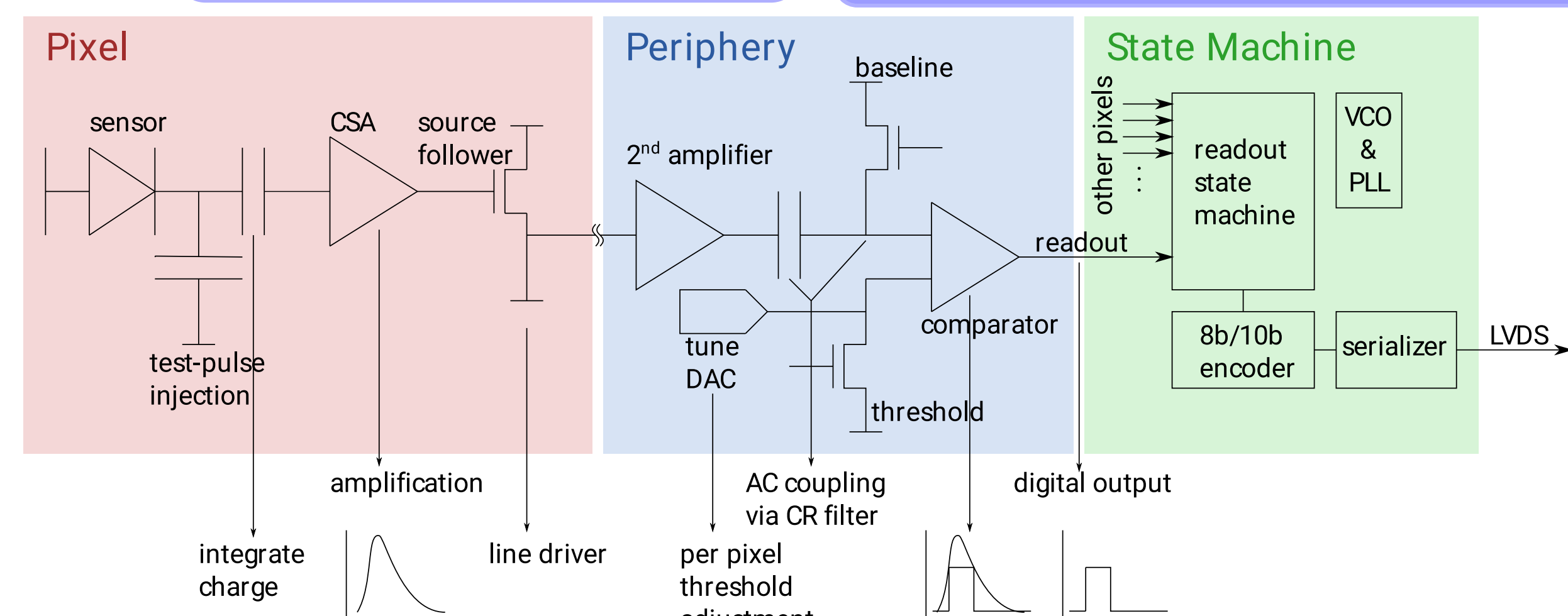
Design Goals

- $< 20 \text{ ns}$ time resolution
- Efficiency $> 99\%$
- Max 30 MHits/s
- $50 \mu\text{m}$ thin

Features

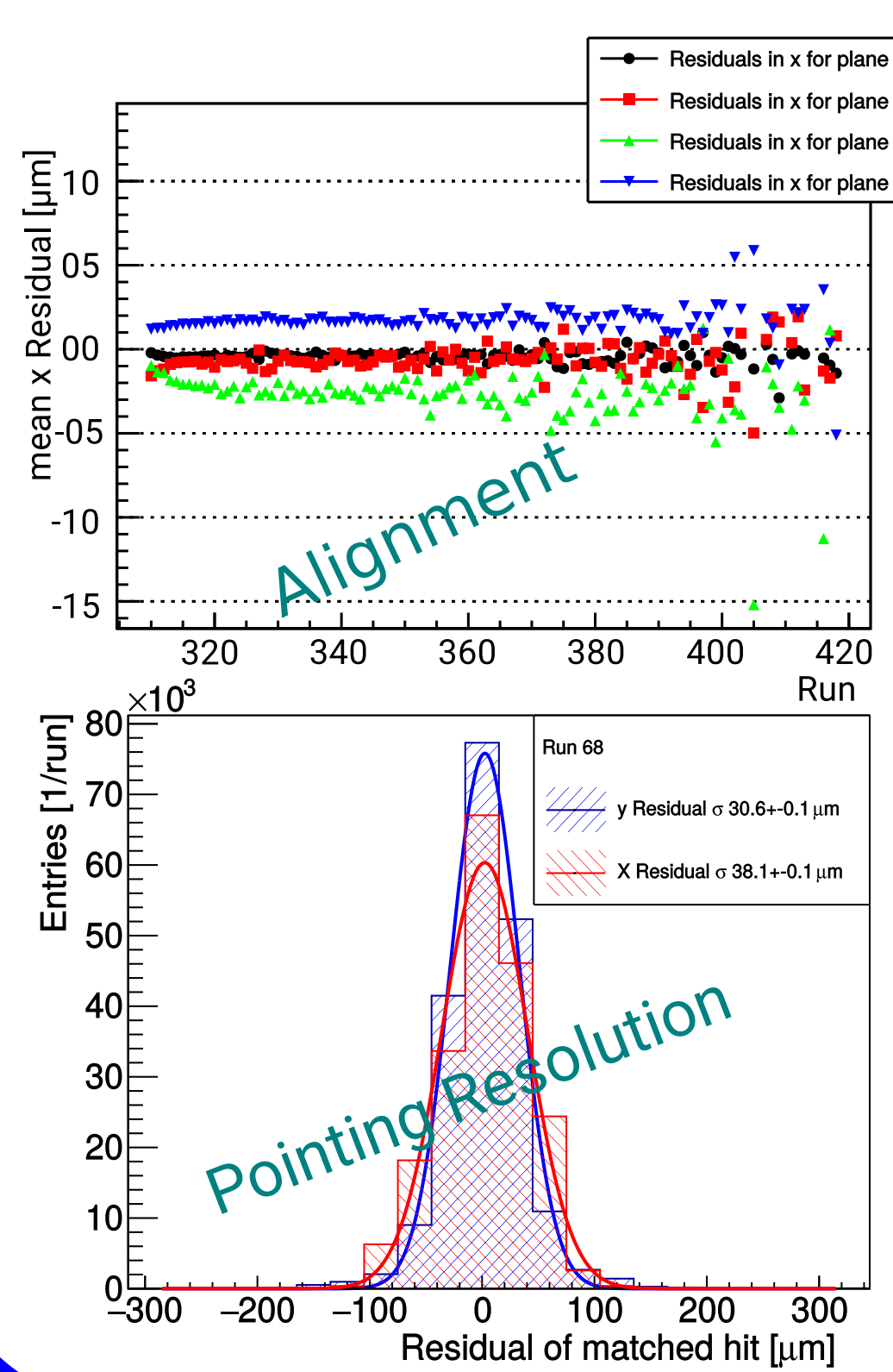
- HV-MAPS technology
- 32×40 pixel ($80 \times 103 \mu\text{m}^2$)
- Fully integrated readout on-chip
- 1.25 GBit/s serial LVDS output
- Up to -85 V bias
- Individual pixel tuning
- Self triggered non shuttered readout

MuPix 7 prototype



Testbeam Results

MuPix Telescope performance

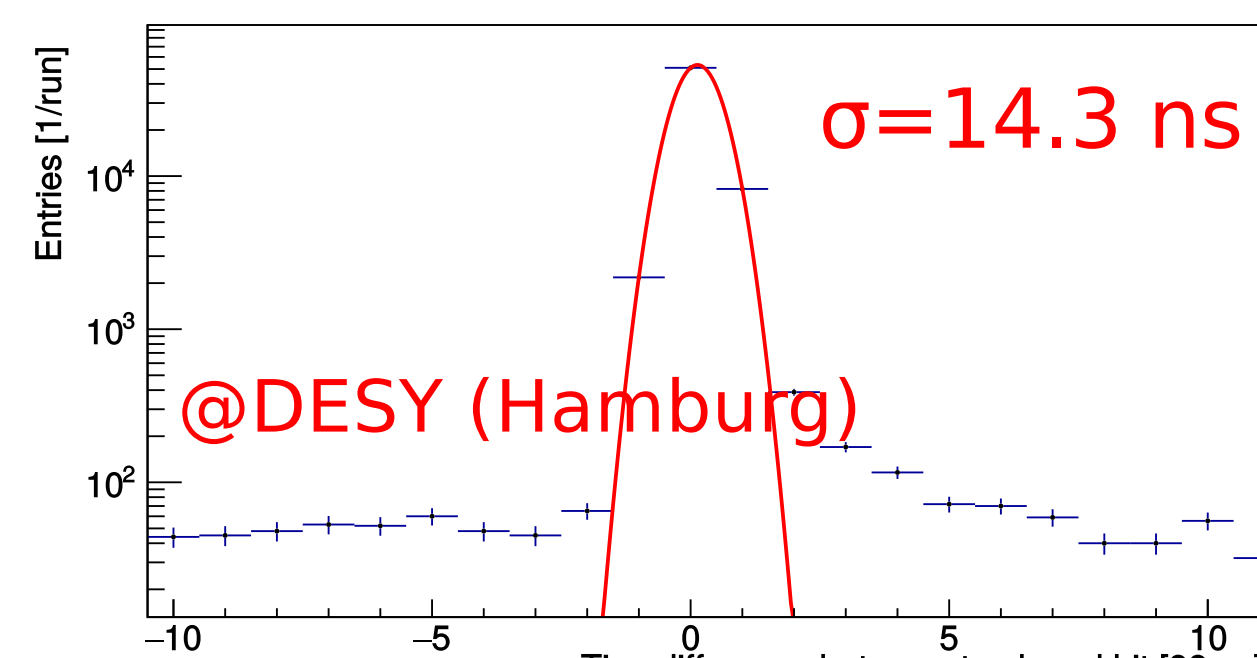


- 2 MHz track rate
- Tracking efficiency $\sim 85\%$
- Time Resolution $\sim 15 \text{ ns}$
- Position resolution ($5 \text{ GeV } e^-$) $150 \mu\text{m}$
- DMA, GPU/CPU tracking implemented
- $100 \mu\text{m}$ mechanical alignment precision

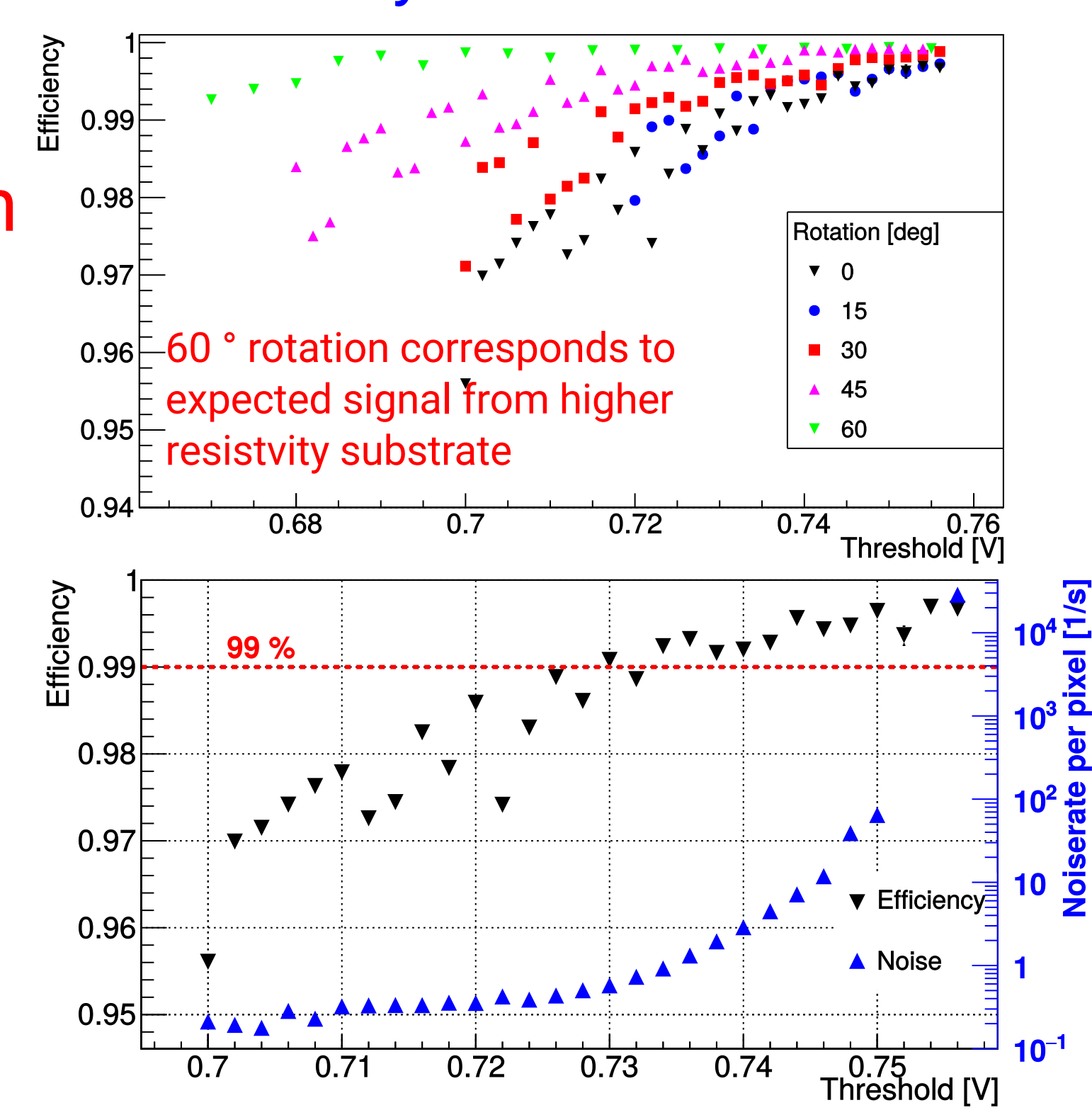
MuPix7 performance

All features fulfill the design goals for Mu3e

Time Resolution



Efficiency Studies



Summary

- HV-MAPS**
 - Concept validated
 - Most requirements for Mu3e fulfilled
 - On chip readout under control
- MuPix Telescope**
 - Useful tool for integration test and testbeams
 - High system efficiency ($\approx 99\%$)

Outlook

- HV-MAPS**
 - $2 \times 2 \text{ cm}^2$ prototype on the way
- MuPix Telescope**
 - Evaluate next sensor prototypes
 - Integrate alternative DUTs

Acknowledgements

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