# HV-MAPS Tracking Telescope

## For High Rates and Low Momentum Particles

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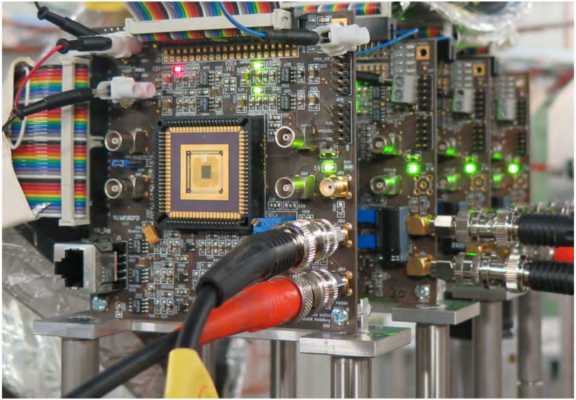
on Behalf of the Mu3e Collaboration

DESY Telescope Workshop

30.06.2014 - 02.07.2014

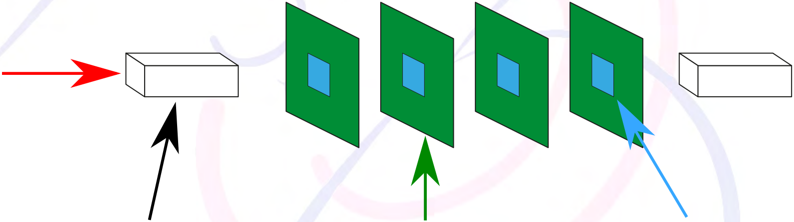
# Outline



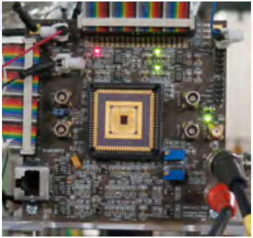


# The MuPix Telescope

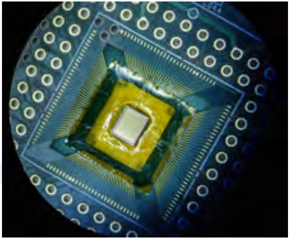
**Idea:** Build a tracking telescope out of Mu3e parts:



**Scintillating Tiles**



**MuPix PCB**



**MuPix 6 sensor**

# Comparison

**Table 1:** *Comparison of existing beam telescopes and the proposed project.*

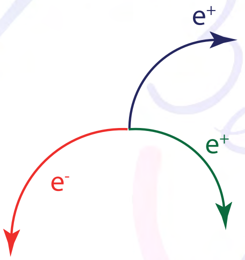
| | Timepix Telescope [5] | EUDET Telescopes [6] | **HV-MAPS Telescope** |
|---|---|---|---|
| Pixel size | 55 μm | 18.4 μm | 80 μm |
| Pointing resolution (180 GeV π) | 2 μm | **1.8 μm** | ≈ 12 μm |
| 50 MeV $e^-$ (1) | 400 μm | 180 μm | **150 μm** |
| Material | 300 μm sensor | 50 μm sensor | 50 μm sensor |
| | 700 μm readout | 50 μm protective foil | 25 μm Kapton foil |
| in radiation lengths | 2.8% | 0.7 ‰ | **0.6 ‰** |
| Time resolution | **1 ns** (in special plane) | 115.2 μs | 17 ns |
| | 16 ms otherwise | | |
| Frame rate | 60 Hz | 9 KHz | **20 MHz** |
| Maximum track rate | 15.5 KHz | ≈ 100 KHz | **≈ 20 MHz** |
| Track reconstruction | mostly offline | offline | **online** |

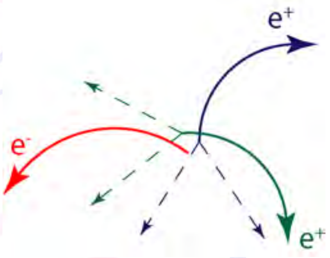
(1) Assuming 1 cm flight distance and dominating multiple scattering effects.

| Test beams | T4-H8A @ CERN | T22 @ DESY | $\pi$M1 @PSI |
|---|---|---|---|
| Energy [GeV] | 180 | 1-6 | ≈0.25 |
| Particles | $\pi^+$ | $e^-$ | e, $\pi$, $\mu$ |
| Rate | | 1 kHz | >GHz |

# New Physics and Mu3e

Search for LFV decay: $\mu^+ \rightarrow e^+ e^+ e^-$ with sensitivity of 1 in $10^{16}$




**Signal Decay**

- $10^9$ $\mu$/s
- precise timing
- $E_{max} = 53$ MeV

**Random Combinations**

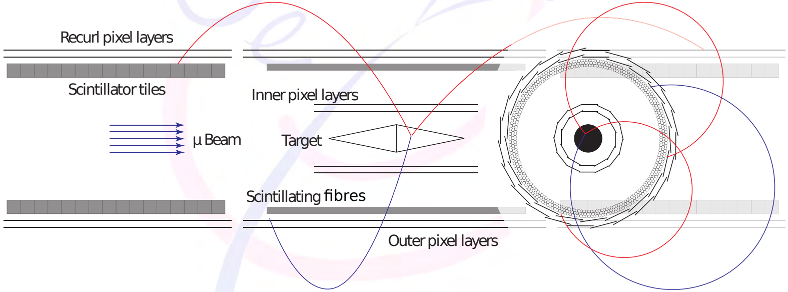
- high momentum resolution
- high vertex resolution
- high time resolution

→ Use new detector technologies for high rates, good vertex and momentum resolution

→ Low momentum particles → avoid multiple scattering

# Mu3e

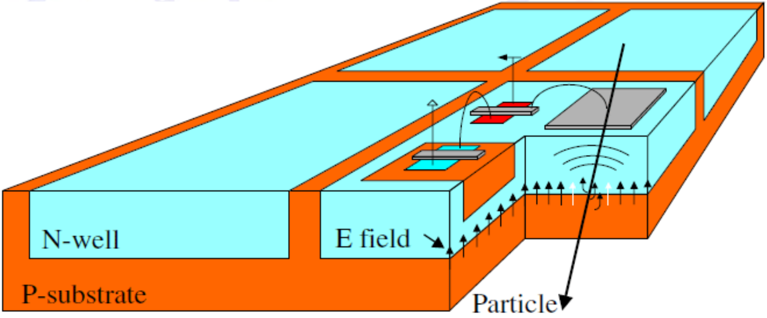
**Concept:** Stop muons at target and measure decay particles
$\rightarrow E_{max} = 53$ MeV




**1 m$^2$ pixel detector**

# HighVoltage - MonolithicActivePixelSensors (HV-MAPS)

(I.Peric, P. Fischer et al., NIM A 582 (2007) 876 )




- Zero suppressed
- 8 bit Time stamp
- 80 x 80 $\mu m^2$

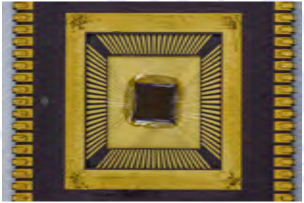
more details: M. Kiehn 17:05 today

- Time resolution < 17 ns
- Efficiency > 99 %
- 50 $\mu$m thin

# MuPix Prototypes

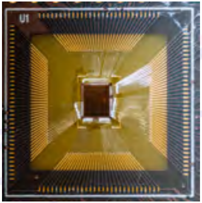
| Prototype | Active Area | Functionality | Bugs | Improvements |
|---|---|---|---|---|
| MuPix1 | 1.77 $mm^2$ | Sensor + analog | Comparator **"ringing"** | First MuPix prototype |
| MuPix2 | 1.77 $mm^2$ | Sensor + analog | **Temperature** dependence | **No ringing** |
| MuPix3 | 9.42 $mm^2$ | Sensor, analog, dig. | bad pixel **on/off**, | **First** part of **dig.** readout |
| MuPix4 | 9,42 $mm^2$ | Sensor, analog, dig. | Zero time-stamp and **row address** for 50% of pixels | First working digital readout, **first timestamp**, temperature stable |
| MuPix6 | 10.55 $mm^2$ | Sensor, analog, dig. | ? | Removed zero time-stamp and address bug |

# Sensor Development



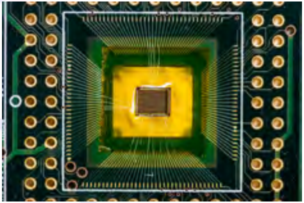
On Carrier

- 2.2 mm ceramic
- 1.7 mm PCB board
- 250 $\mu m$ chip
- $x/X_0 = 23‰$




On Board

- No ceramic
- 100 $\mu m$ PCB board
- 250 $\mu m$ chip
- $x/X_0 = 2.5‰$

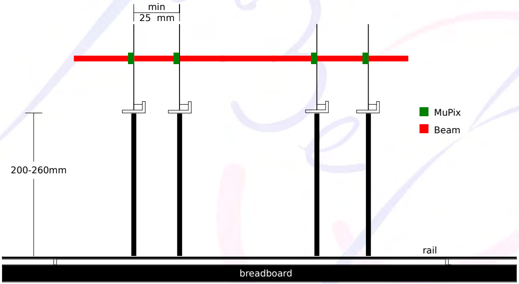


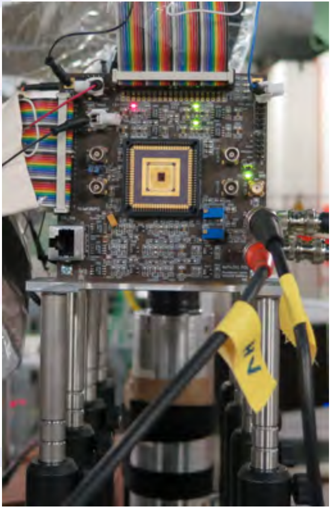
On Kapton

- No ceramic + PCB
- 25 $\mu m$ Kapton
- 250 $\mu m$ chip
- $x/X_0 = 2.1‰$

**Final Goal:** 50 $\mu$m Si + 25 $\mu$m Kapton $\rightarrow X_0 =$**0.6‰**

# Mechanical Structure

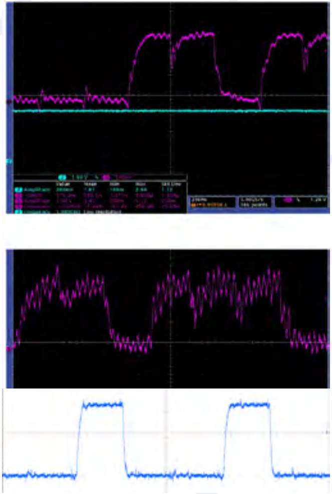


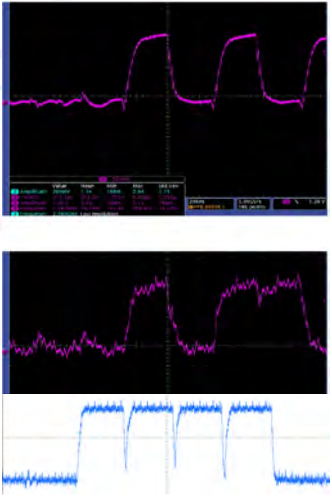

- Mounted on optical rail
- Layers move independently
- Compact system
- Most components: Thorlabs

# Signal Transmission

Plain ribbon cable



AL shielded ribbon cable



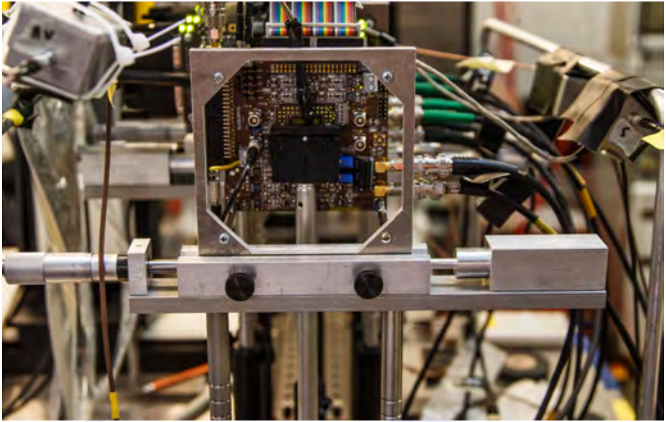
# Readout Chain

1

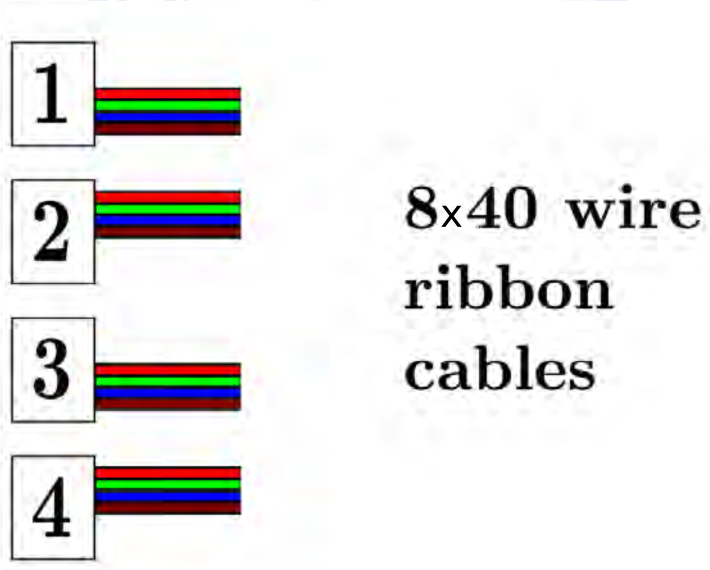
2

3

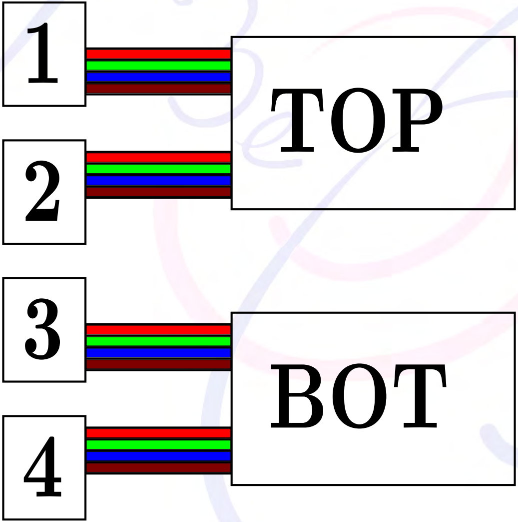
4



# Readout Chain

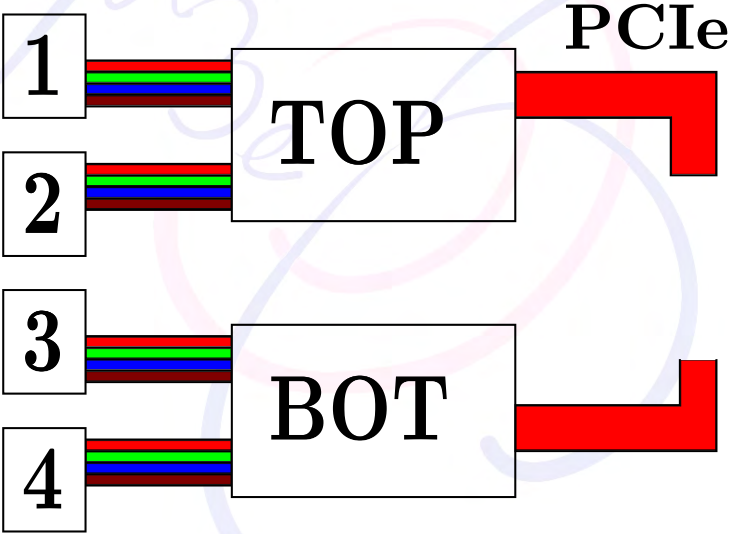


# Readout Chain

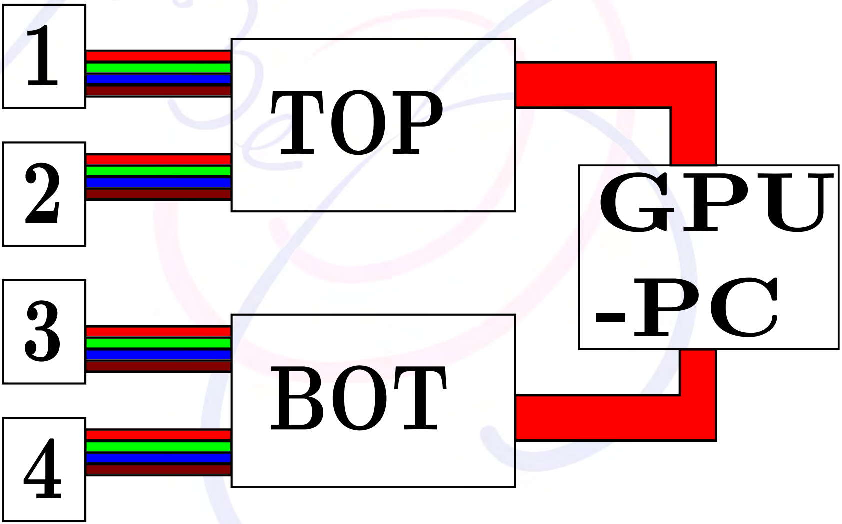



**2 FPGAs**

# Readout Chain



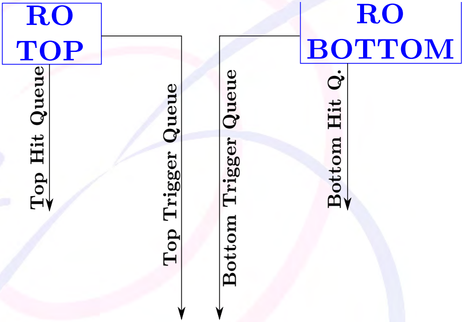
# Readout Chain



# Concept

- Telescope is operating in streaming mode at high particle rates
  $\rightarrow$ Continuous data readout, no trigger and a lot of data
  $\rightarrow$ Need a lot computing power
  $\rightarrow$ Share the work
- Several Threads
  $\rightarrow$ Readout, monitoring, time sorting, storing, tracking $\rightarrow$ Synchronization, coordination, communication
- Data handling via lock-free spsc fifo queues
- Reconstruct the tracks online

# Readout Software




**readout threads**

**copy data from FPGA**

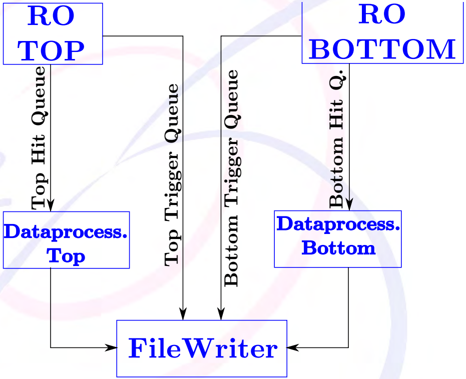
**fill hit and trigger queues**

# Readout Software

**Data sorting**

**Frame creation**

**data storing**



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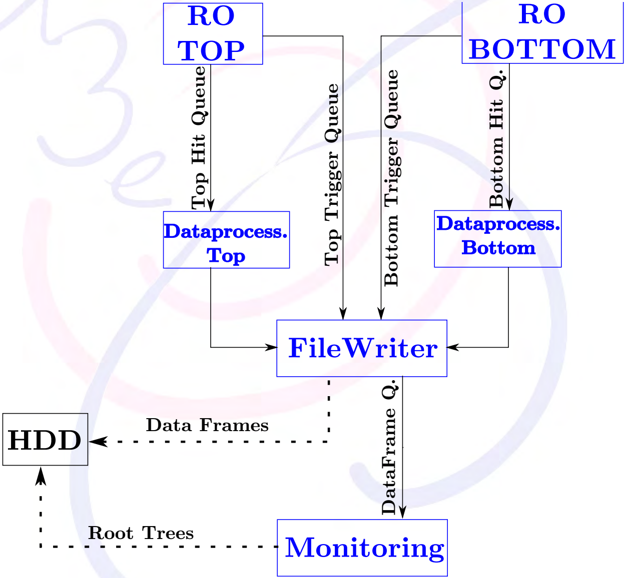

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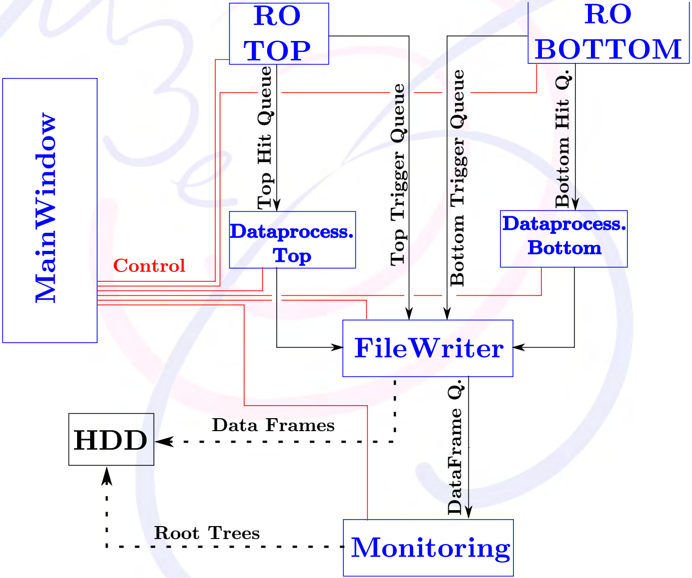

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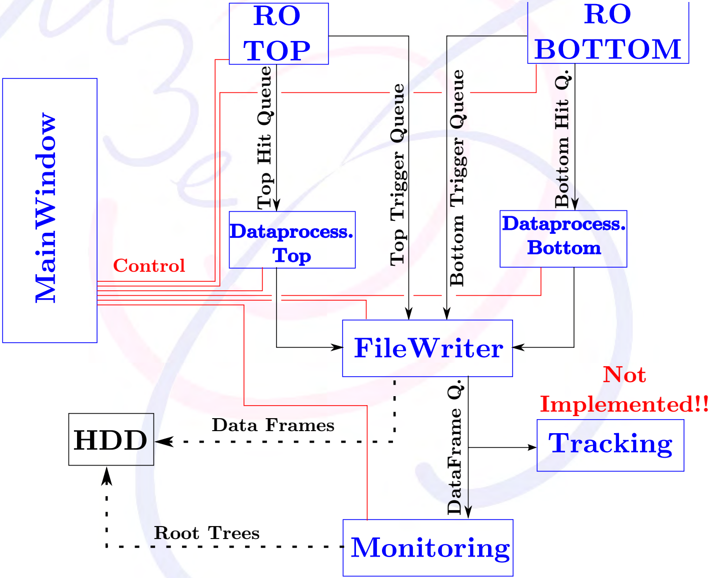
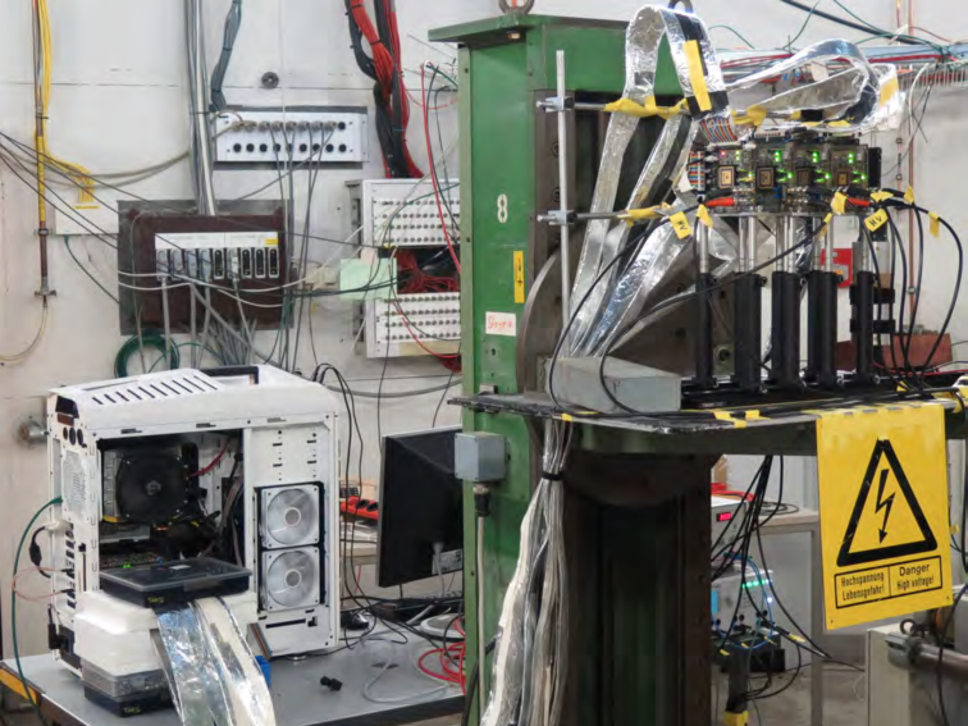


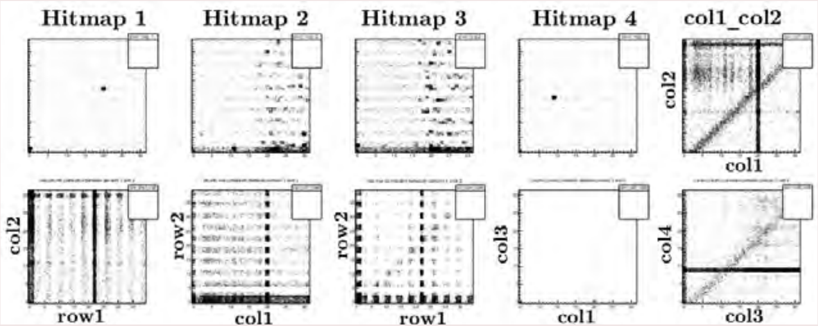

8
Hochspannung
Lebensgefahr!
Danger
High voltage!

# Performance

## Data Taking

- 2.5 days data taking w/o crash at 5 GeV electron energy
- highest rate with noise: 755 k hits/s per plane

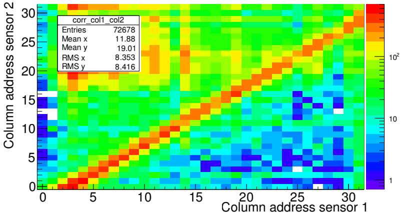
## Online Monitoring

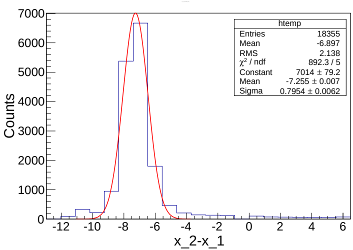


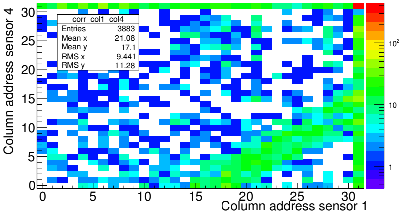
# Correlations & Alignment & Resolution

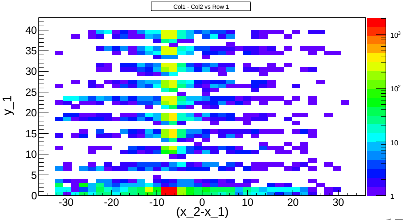
MuPix 4: Pixelsize 92x80 $\mu m^2$

Intrinsic resolution $= 0.28$ Pixel $< 0.79$ Pixel $=$ distribution width

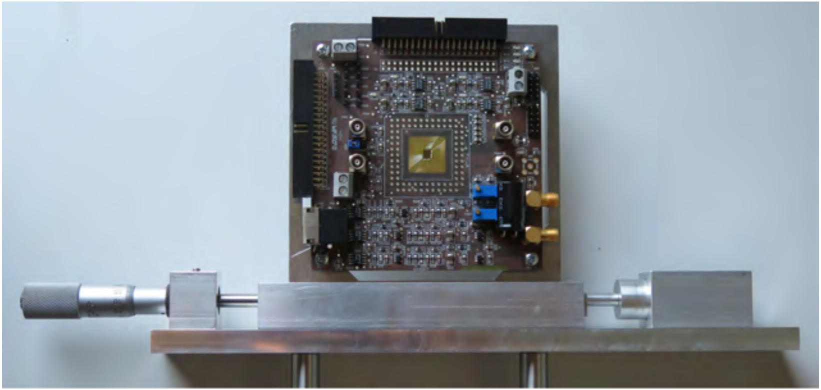


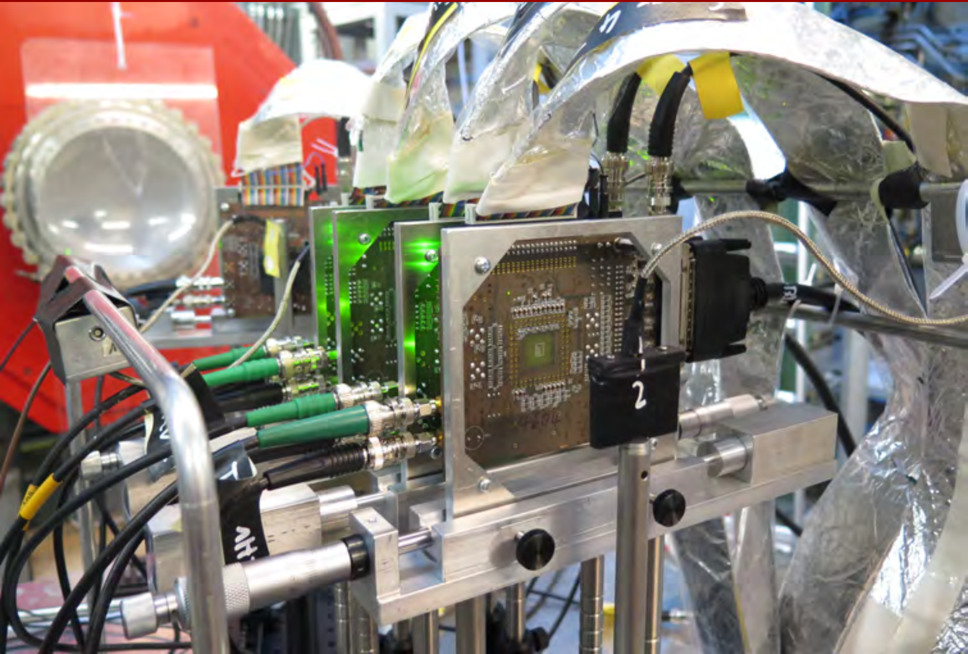
# PCB Holder - Development



# Lessons Learned

- First HV-MAPS telescope in operation
- Chip DAC settings must be improved
- Software is stable and working
- Improve mechanics
- Data format can be improved
- Ribbon cables introduce a lot of digital crosstalk

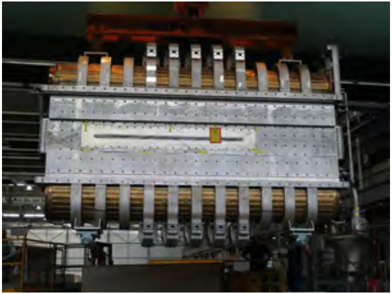
# PSI test beam June 14



# PSI Test Beam

## Goals

- Test new Software and LVDS links
- Take high statistics to test track reconstruction
- Test time stamp influence
- Use the new sensor prototype MuPix 6

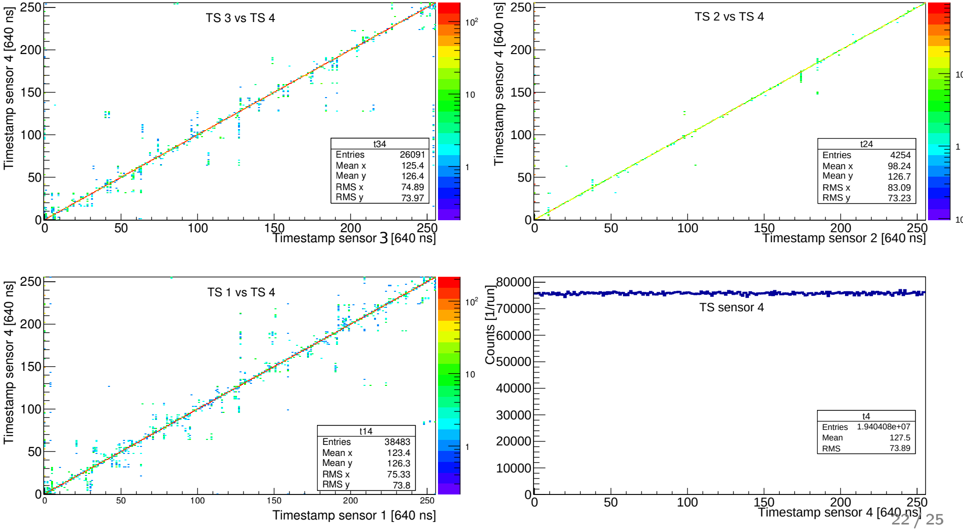


PSI accelerator cavity

- No beam due to accelerator maintenance complications
- Only source tests performed

# Timing with 3.7 MBq $^{90}$Sr-source

## MuPix 6 prototype



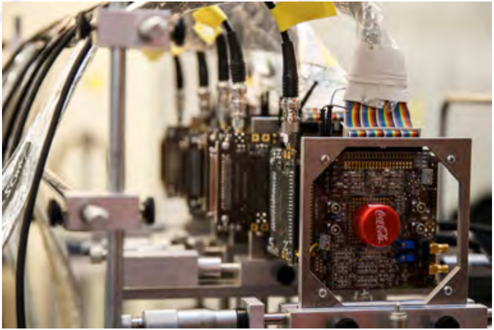
# Summary

- First HV-MAPS telescope tested successfully
- Track reconstruction under test
- High rates ($\approx$1 MHz) can be handled
- New MuPix sensor is under test
- Time stamps are working and system is synchronized

# Outlook

- Next Testbeam: July @ PSI
- Online track reconstruction
- Thin sensors
- Final chip $\mathcal{O}$ (cm$^2$)
- Increase time resolution up 5 ns

- **Thanks to the DESY testbeam group**
- Looking forward to autumn beam




Thank you!