The MuPix Telescope

Tracking Low Momentum Particles at High Rate

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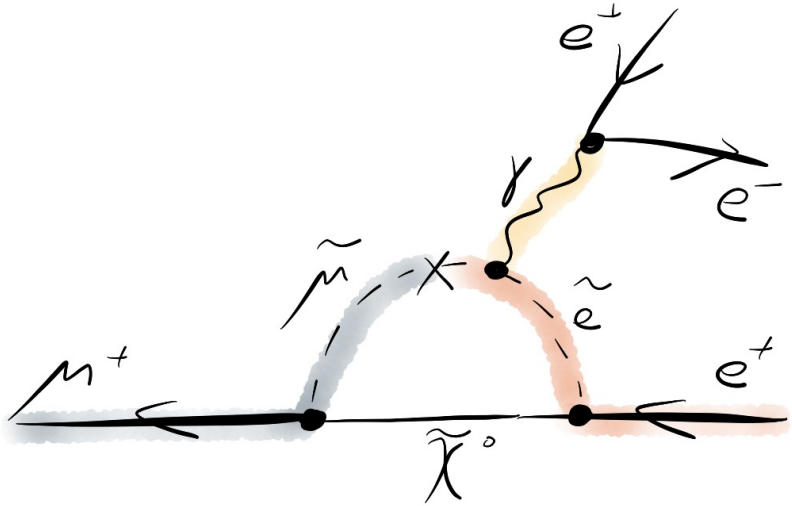
INTERNATIONAL MAX PLANCK RESEARCH SCHOOL
PT FS
FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES

Motivation

Motivation

What's beyond the SM?

- Charged Lepton Flavour Violation?
- Introduced by BSM theories
- Measurable branching ratios predicted



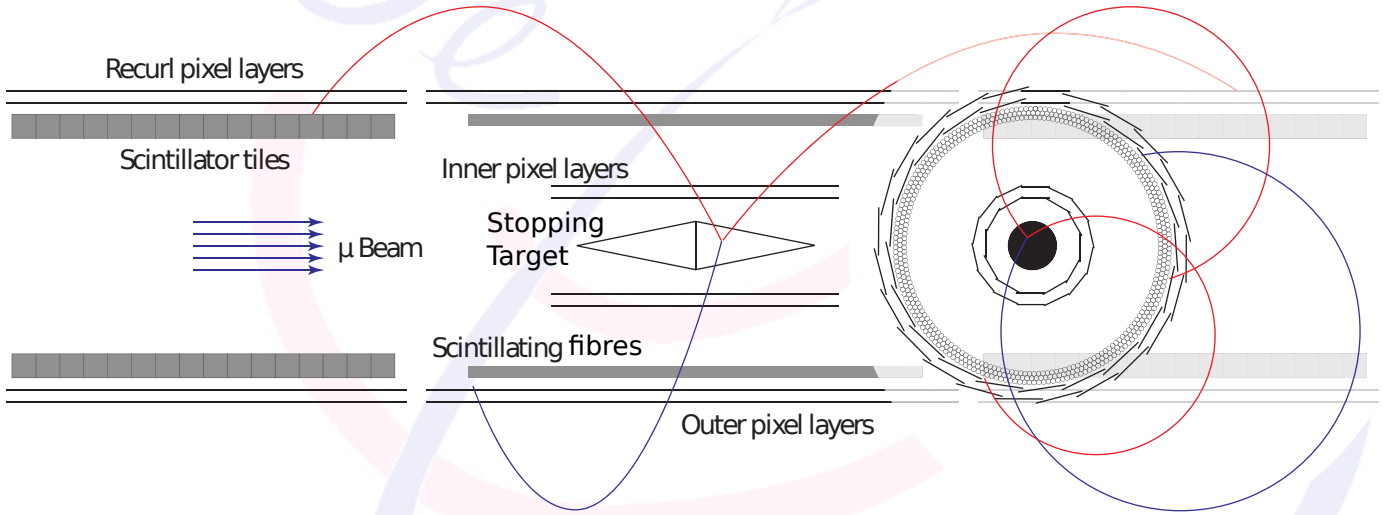
The decay $\mu^+ \to e^+e^-e^+$

- SM - BR $< 10^{-54}$
- $\sum \vec{p} = 0$
- Coincident in space and time
- $E_{max} < 53$ MeV

Background

- Radiative decay with internal conversion: $\sum \vec{p} \neq 0$

The Mu3e Experiment - Searching for $\mu^+ \rightarrow e^+e^-e^+$ with a sensitivity of BR$< 10^{-16}$

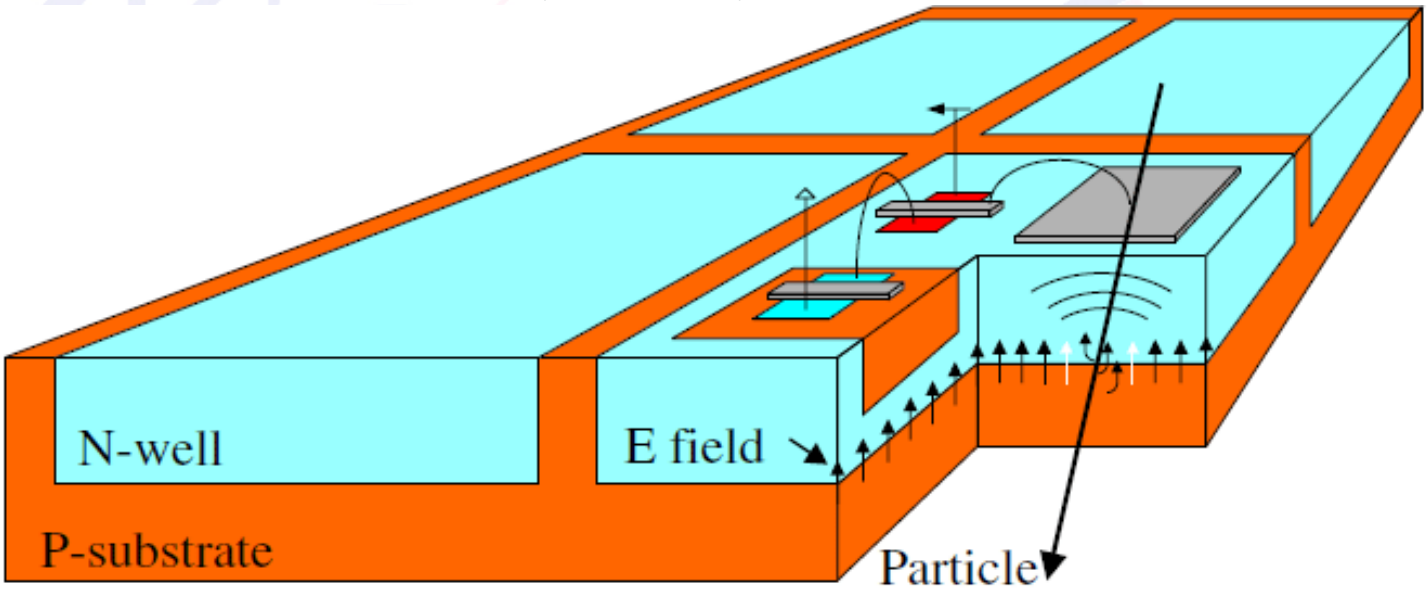


Multiple scattering regime and high rate

$\rightarrow$ Fast and thin pixel sensor

HighVoltage - MonolithicActivePixelSensors (HV-MAPS)

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

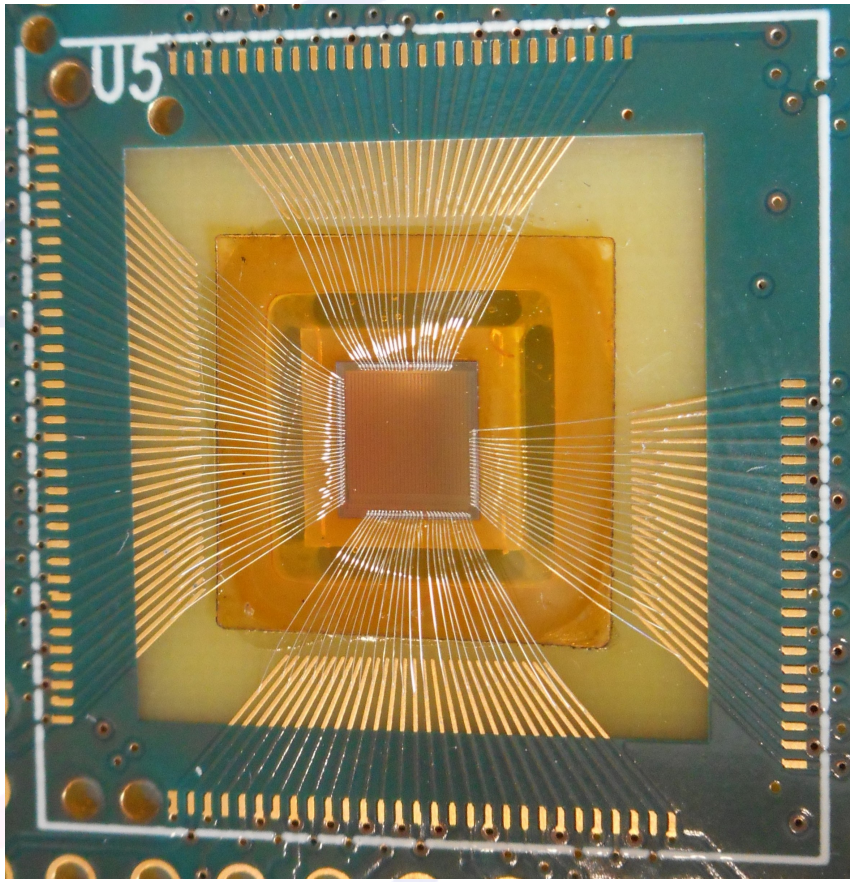


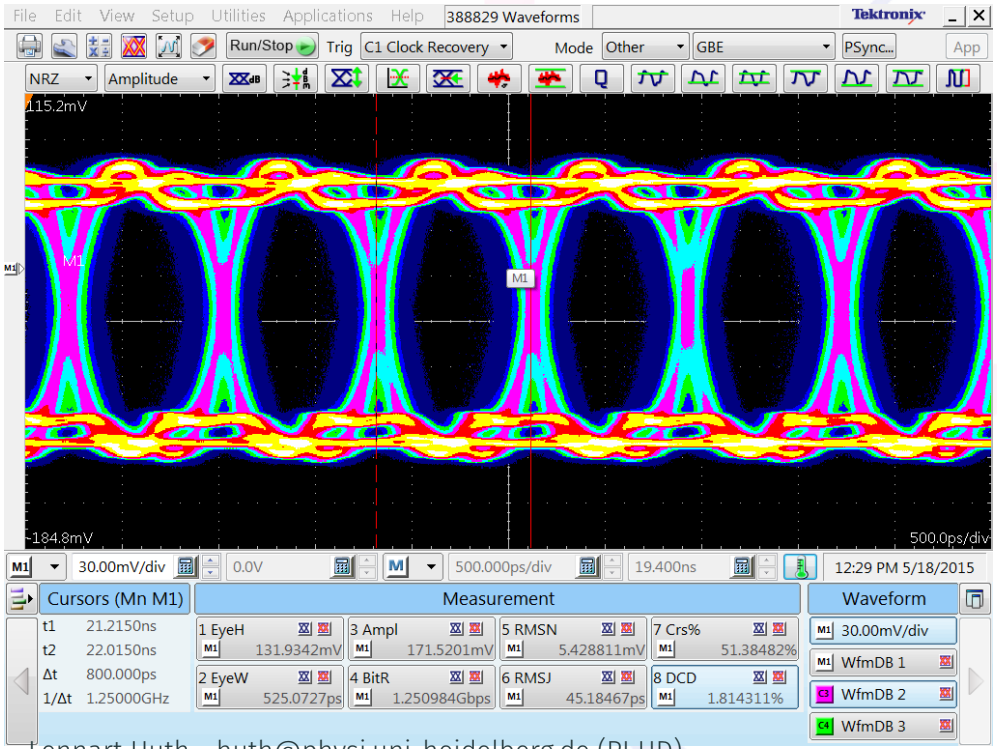
Design Goals

- Binary readout
- Pixel size: 80 x 80 μm^2
- 256 x 256 pixel
- 8 ns time stamps
- Time resolution < 20 ns
- Efficiency > 99 %
- 50 µm thin $\approx$ 0,05 % radiation length

The MuPix 7

- Latest prototype
- Fully integrated readout on the chip
- On chip PLL & VCO
- 1.25 GBit/s data ≈ 33 MHits/s
- Details: T 72.1/2/3

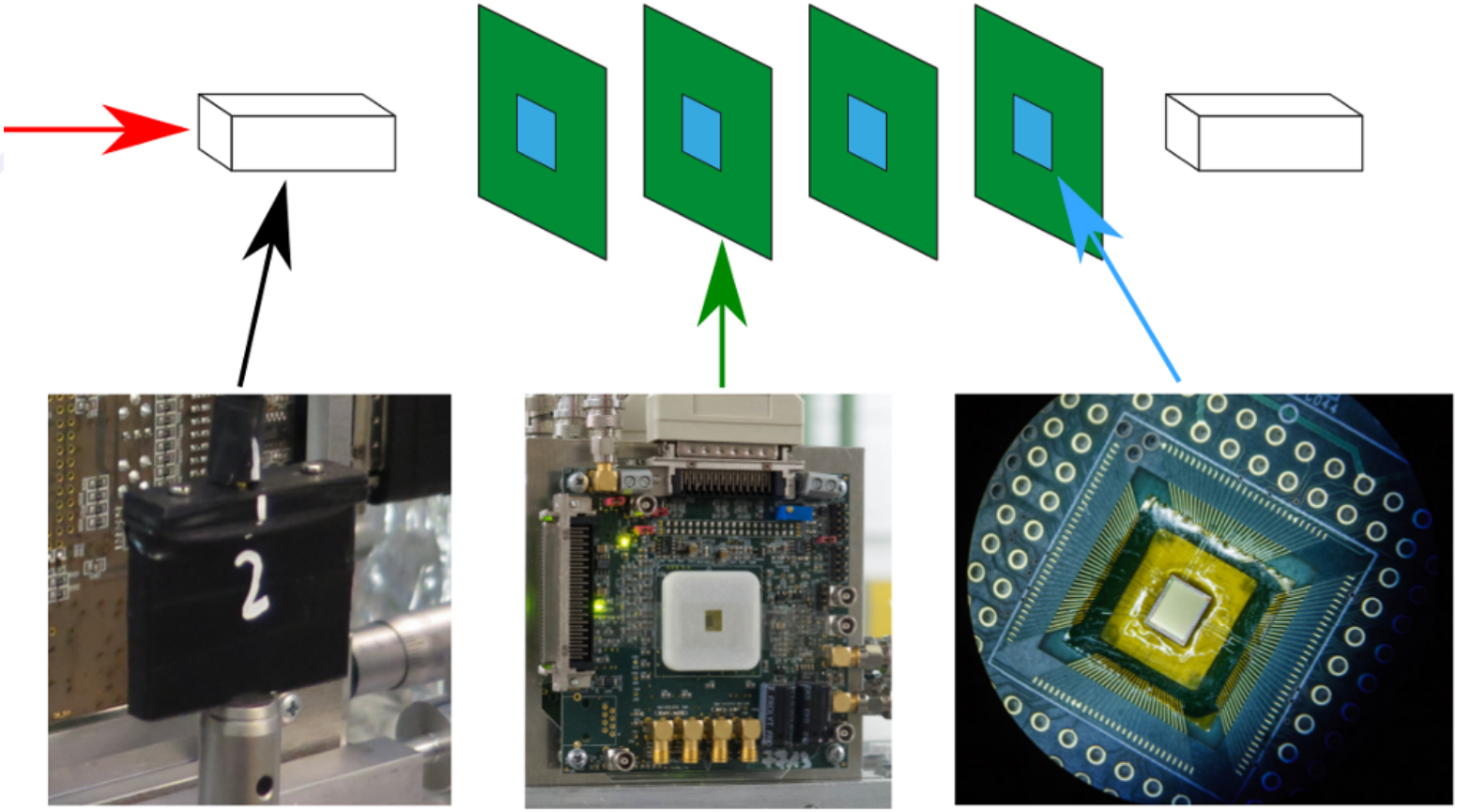




The MuPix Telescope

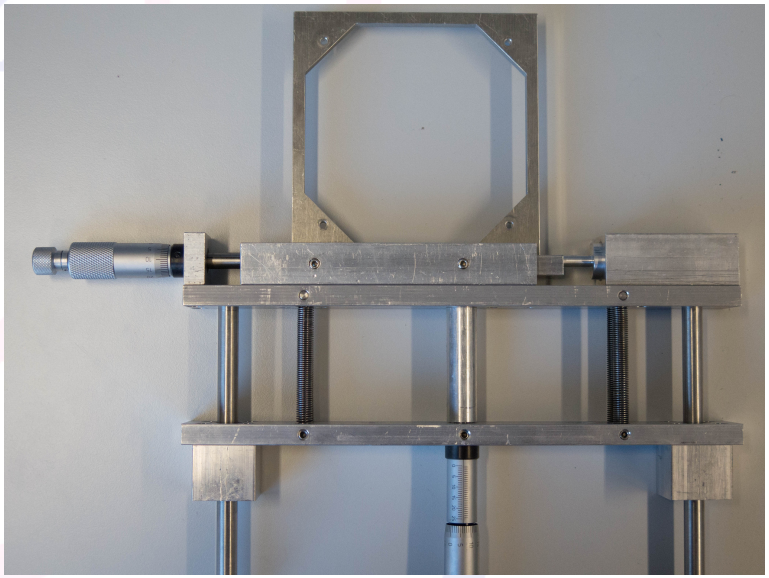
The MuPix Telescope

Idea: Build a tracking detector out of Mu3e parts as integration test and fill a gap in the choice of existing beam telescopes:



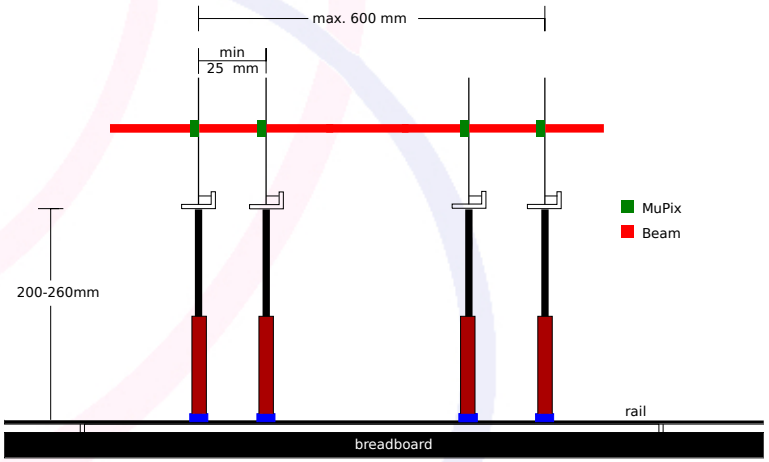
Concept, Readout & DAQ

- Custom PCB holder with 10 µm precision



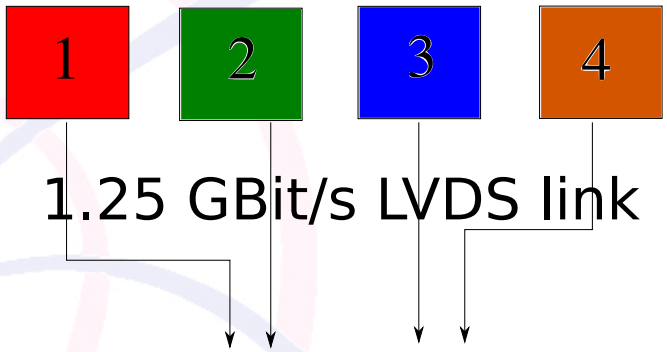
Concept, Readout & DAQ

- Custom PCB holder with 10 µm precision
- Commercial mechanical support



Concept, Readout & DAQ

- Custom PCB holder with 10 µm precision
- Commercial mechanical support
- Differential high speed links: 1.25 GBit/s
- Online time sorting (T 22.4)



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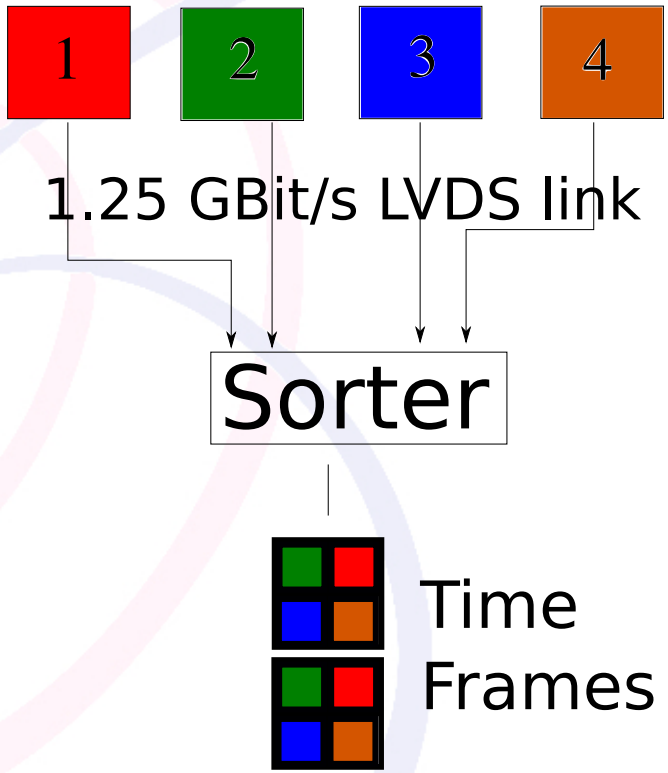
- GByte/s data transfer to PC



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- Custom PCB holder with 10 µm precision
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- Differential high speed links: 1.25 GBit/s
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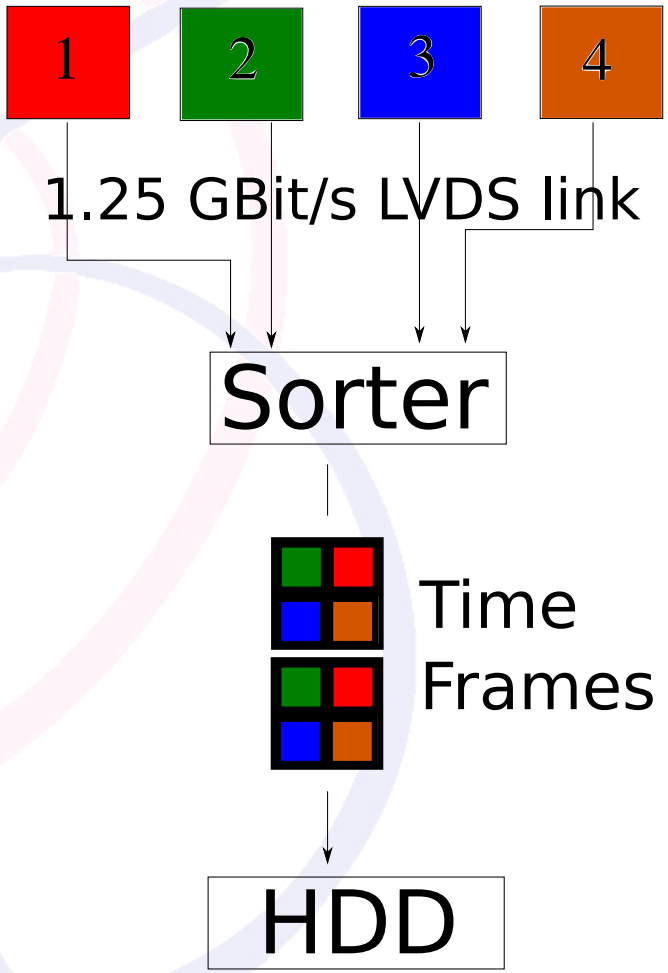
- GByte/s data transfer to PC
- Up to 60 MByte/s final data storage



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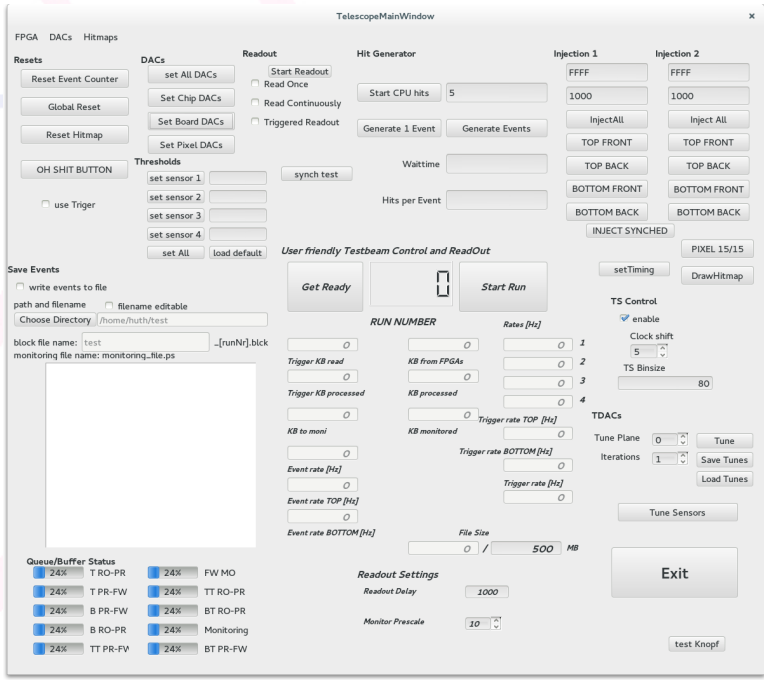
- User friendly control interface



Concept, Readout & DAQ

- Custom PCB holder with 10 µm precision
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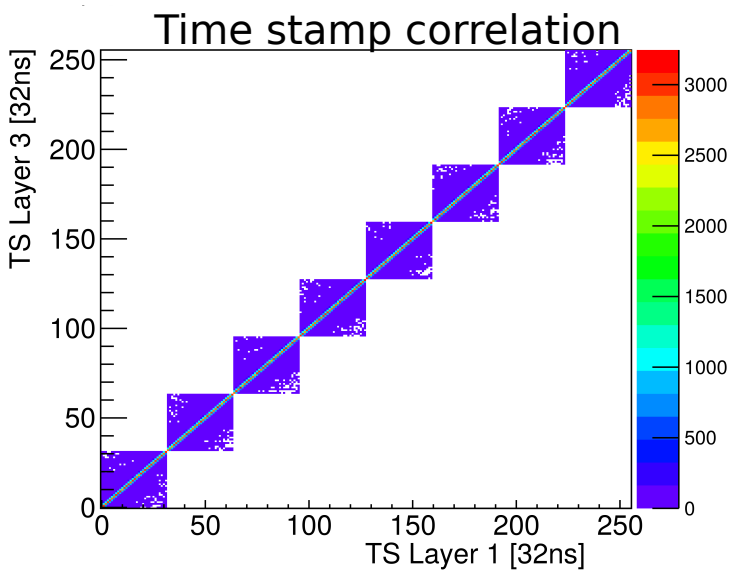
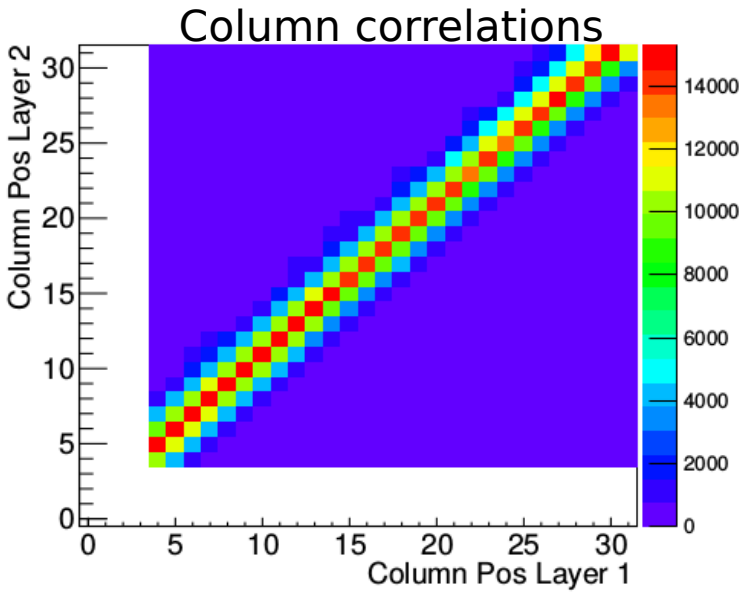
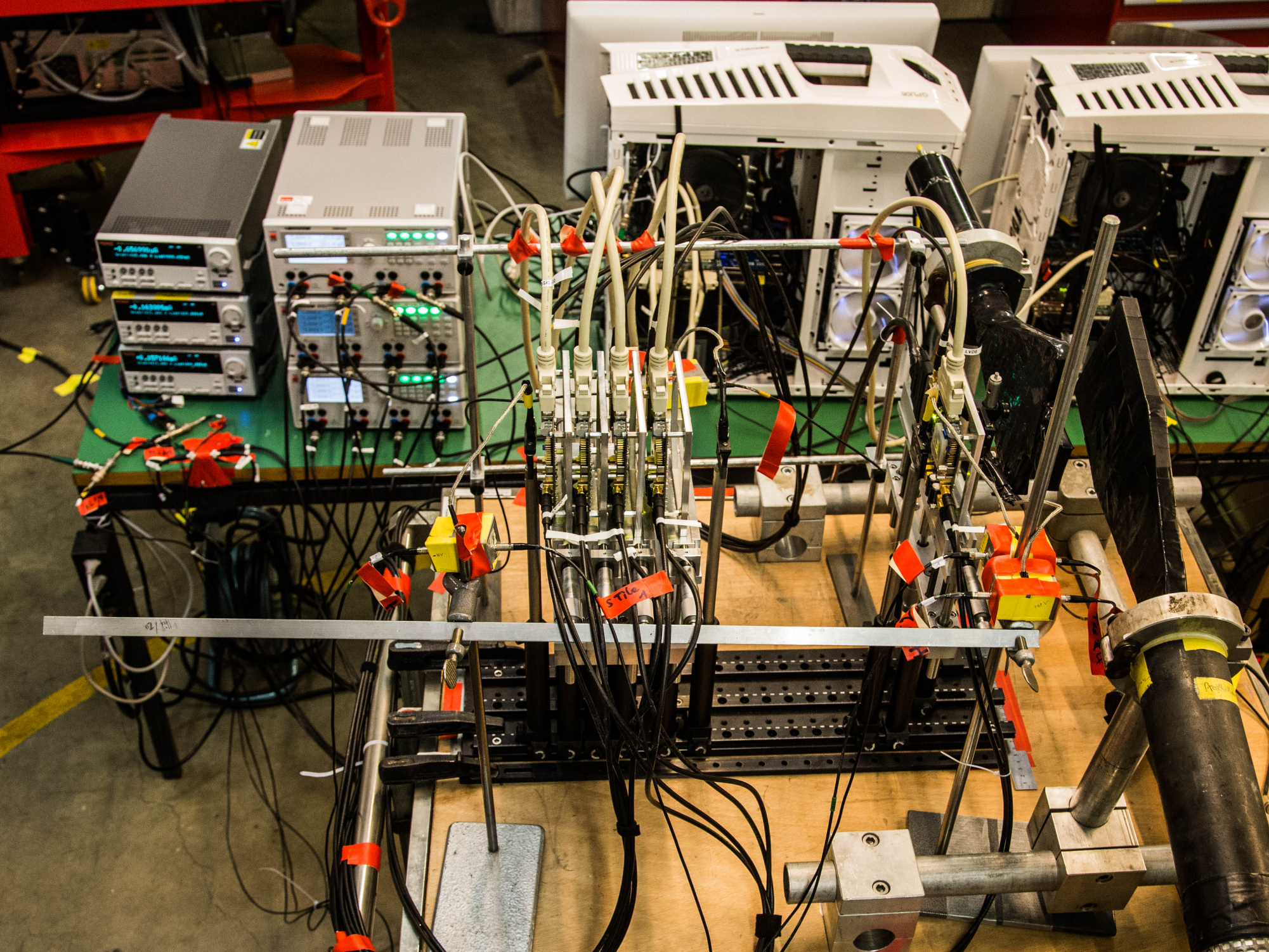
- Differential high speed links: 1.25 GBit/s
- Online time sorting (T 22.4)
- GByte/s data transfer to PC
- Up to 60 MByte/s final data storage
- User friendly control interface
- Online monitoring, tracking and efficiency calculation
- GPU Online Tracking and direct memory access (T 42.5/6)



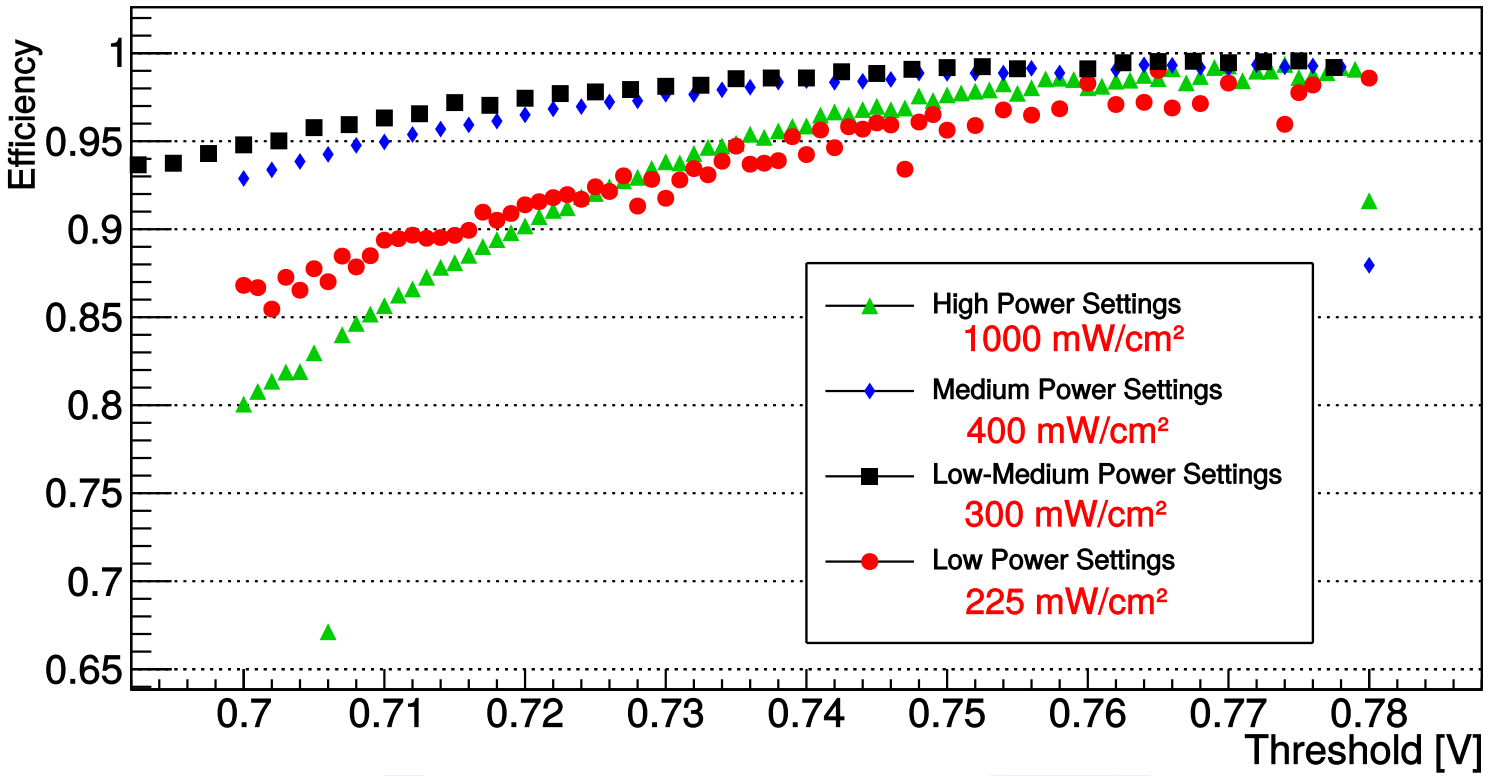


Testbeam Results



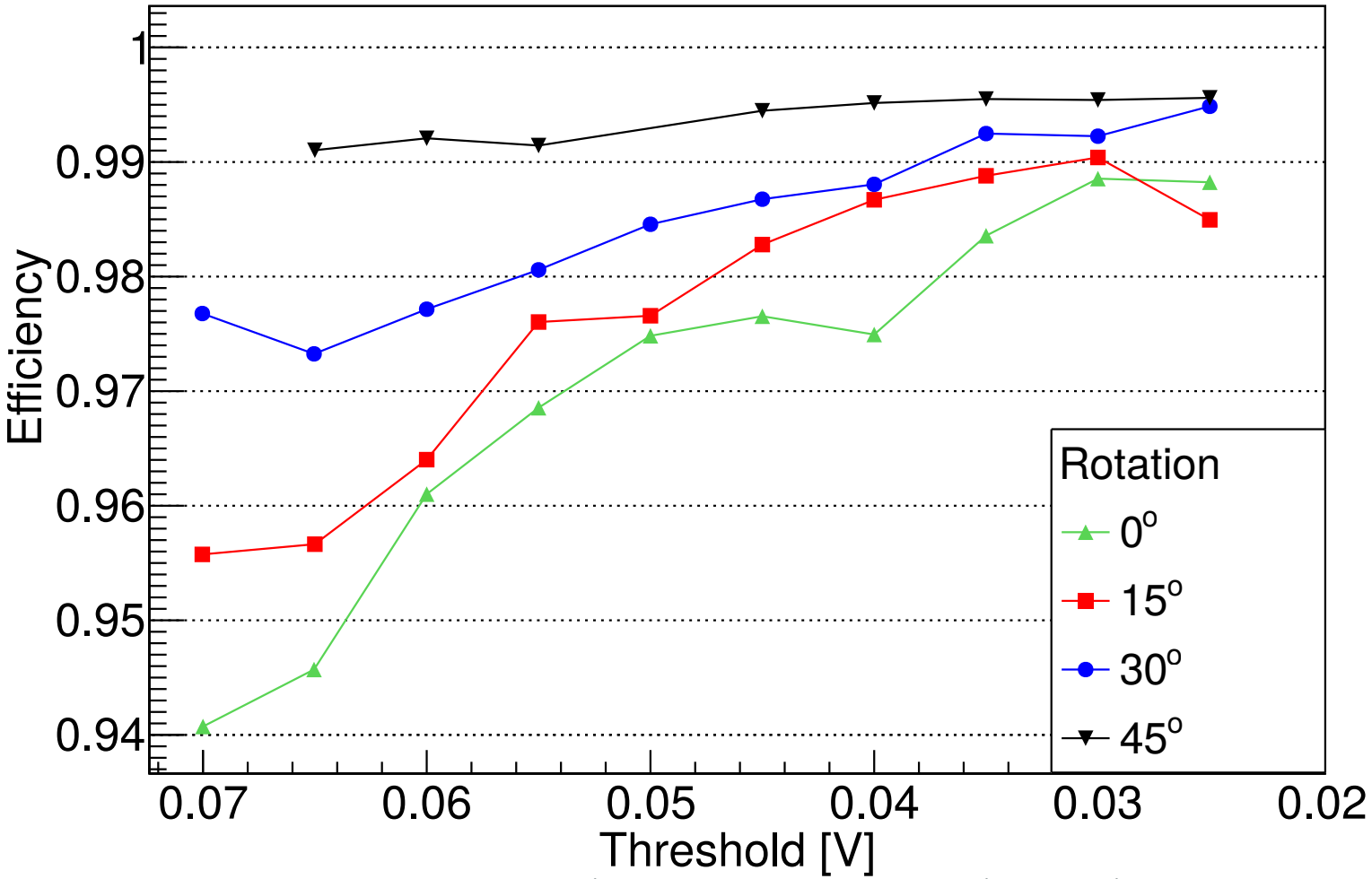
Comparison of Power Settings

Maximal cooling power: 400 mW/cm^2



Efficiency Summary

Larger rotation → more signal → Higher efficiency at higher thresholds

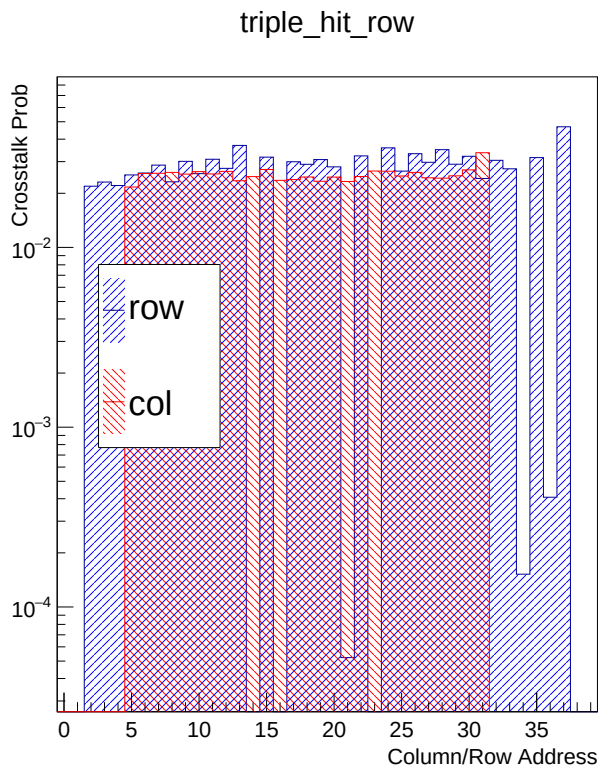


800 µm search window and 64 ns time window

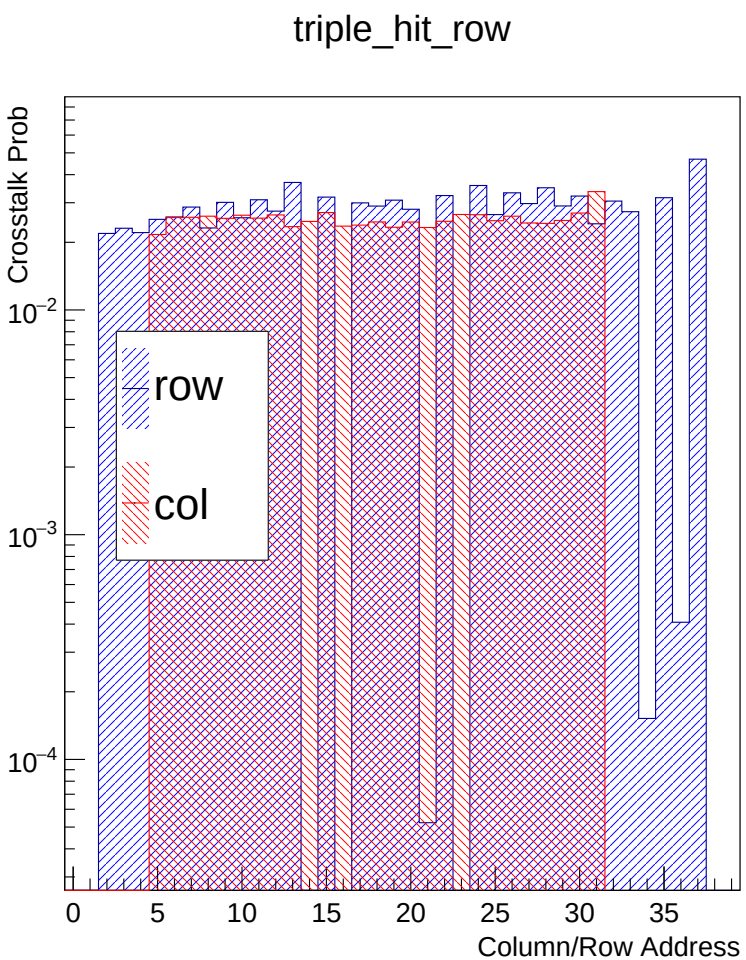
Crosstalk I

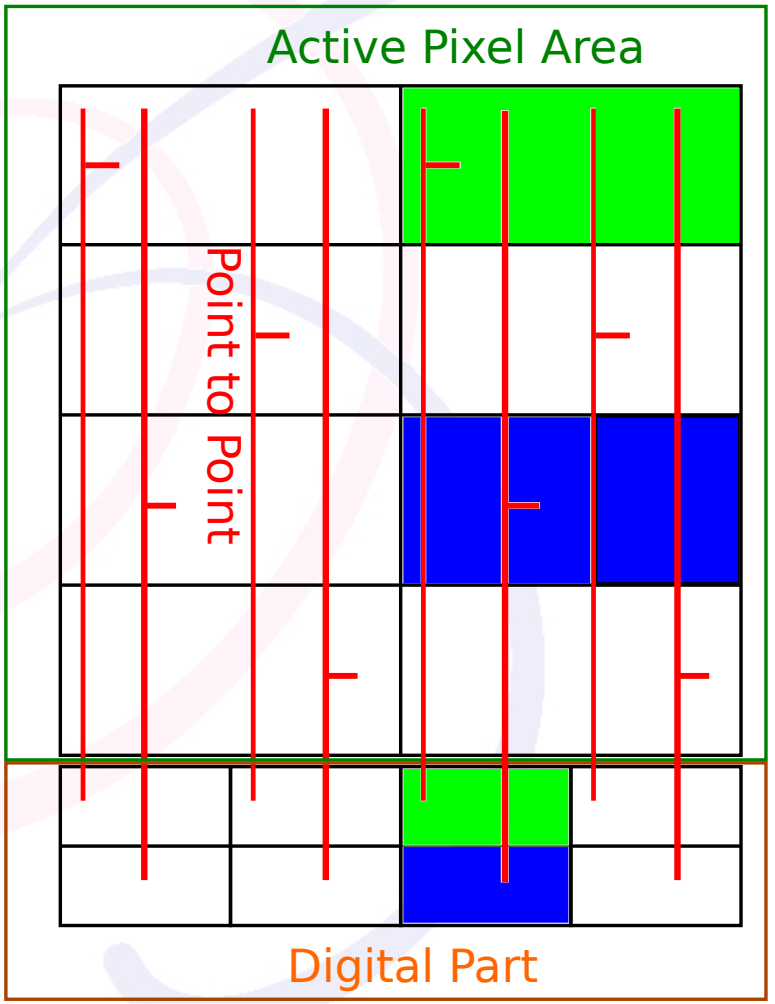
Selection Criteria

- Single track
- Count hits on DUT
- Select events with only 2/3 hits
- Same column, row +/-2

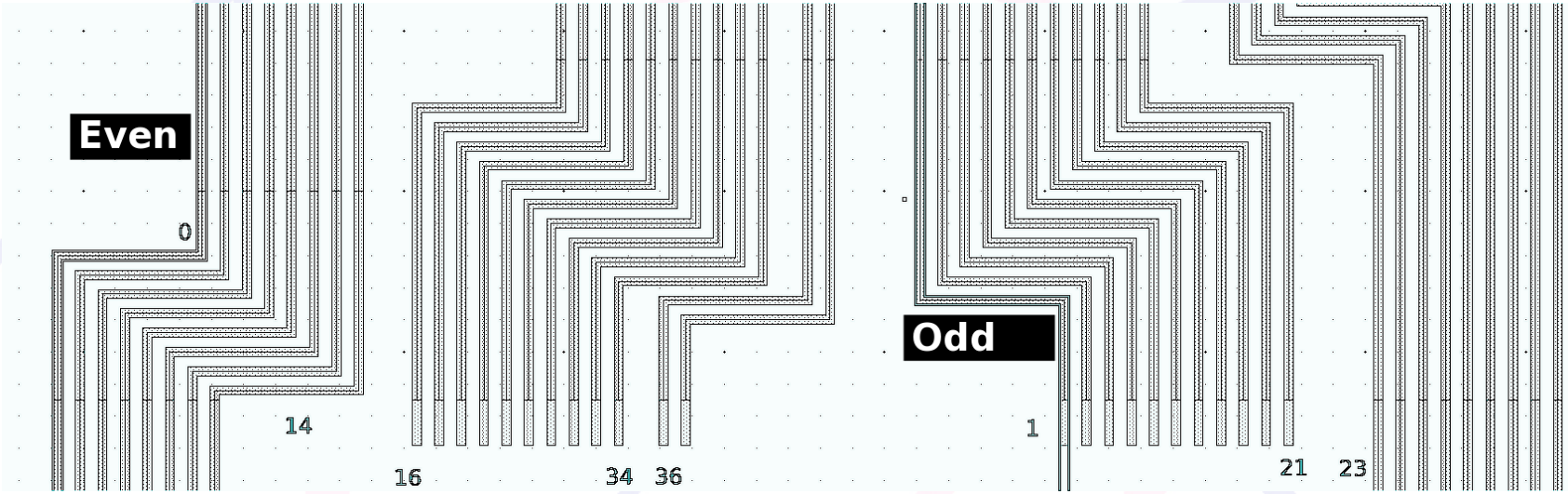


Crosstalk II

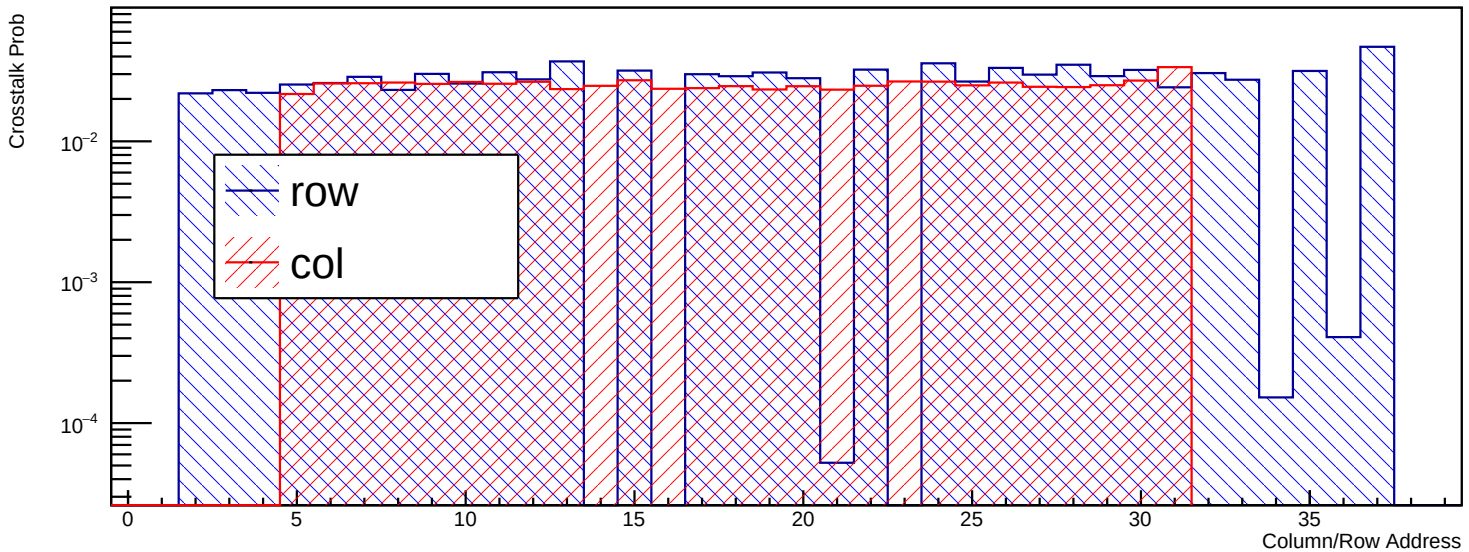




Crosstalk III



triple_hit_row



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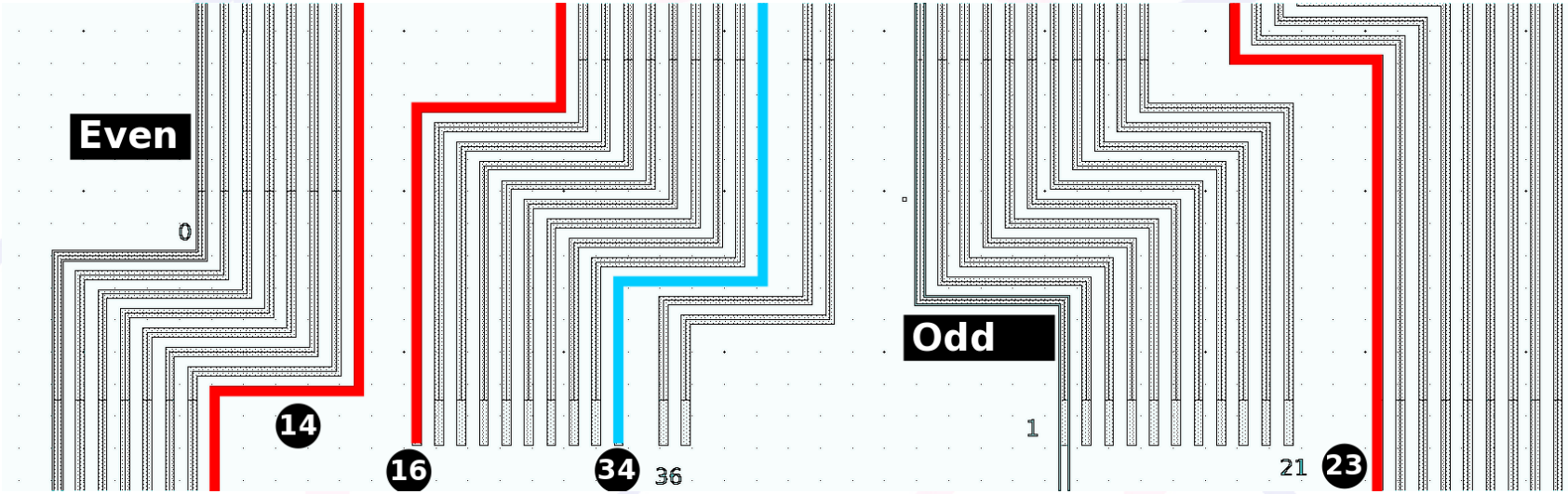

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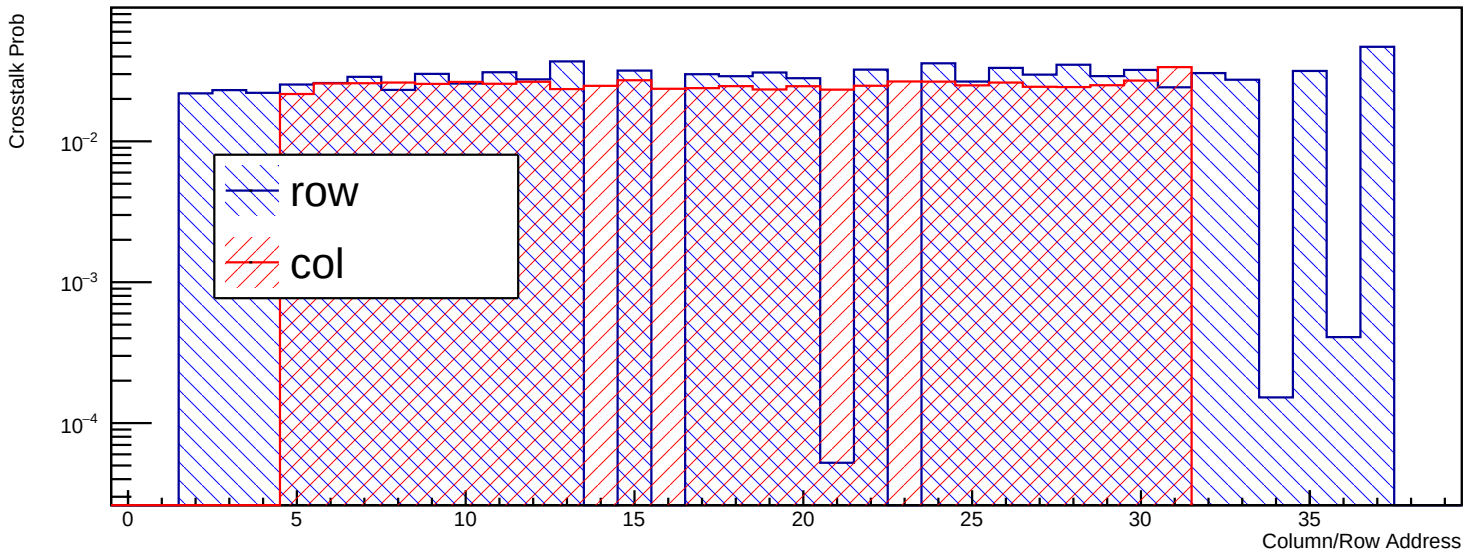
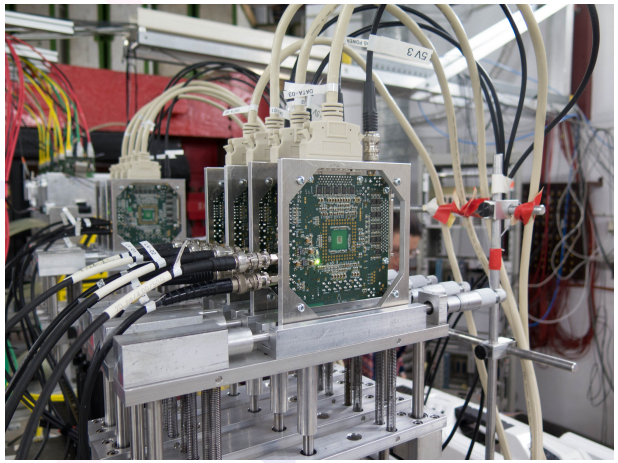
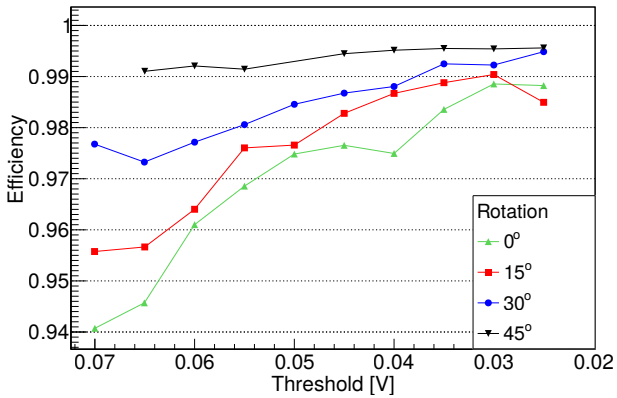


Conclusion

- First running integrated HV-MAPS system
- High Rate capabilities $\mathcal{O}$ (1MHz)
- Important tool to test scalability
- High system efficiency > 99 %
- Time resolution < 11 ns
- Cross talk and clustering analysis ongoing
  $\rightarrow$ cross talk issue, should be fixed in MuPix8





Acknowledgments

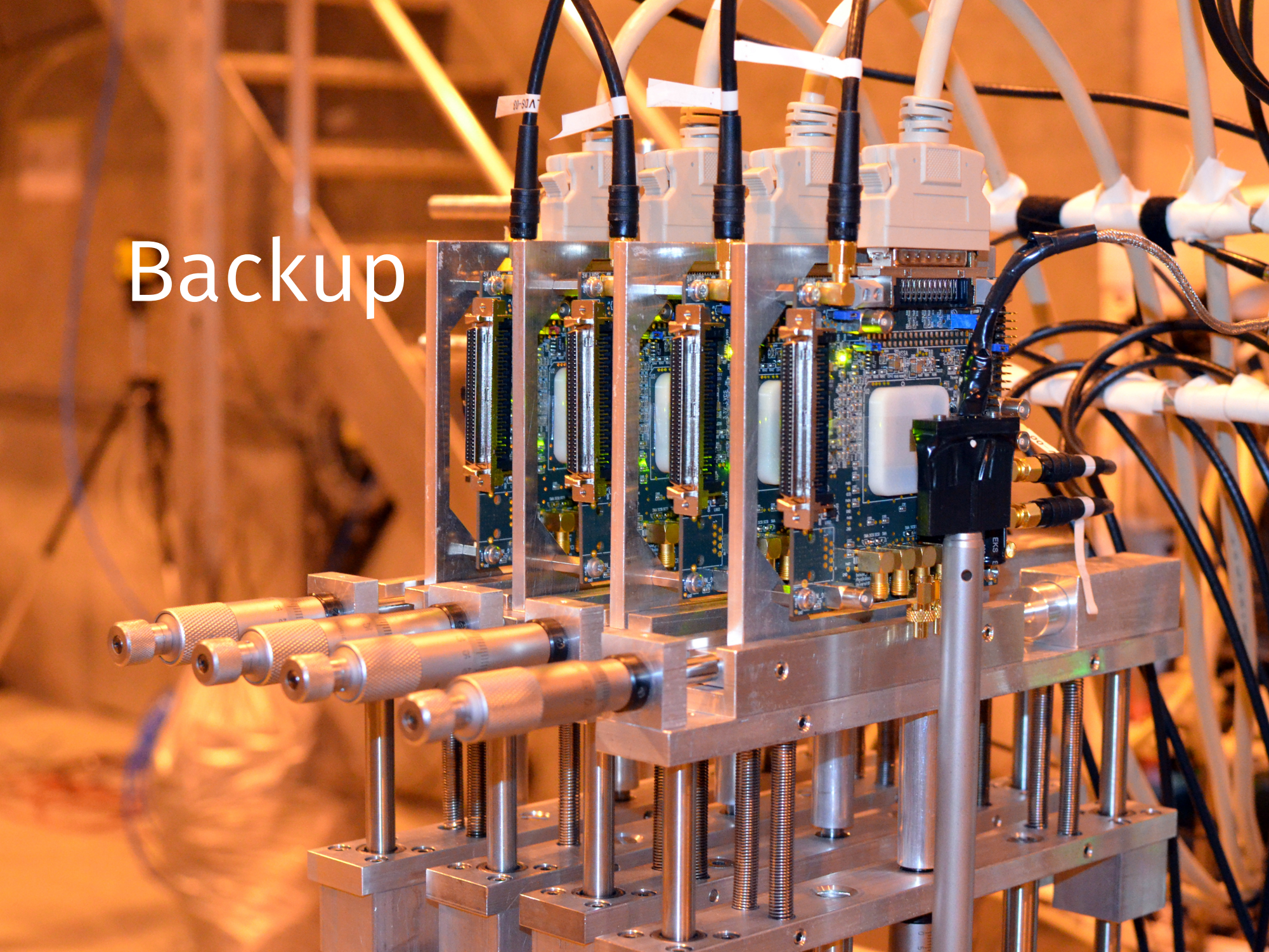
The measurements leading to the rotated DUT results have been performed at the Test bEam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).

We would like to thank the 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 JGU Mainz for giving us the opportunity to take data at MAMI.

Backup



Track Model

Trackmodel: Straight track without scattering

$$\vec{x}(z) = \vec{x_0} + \vec{a} \cdot z$$

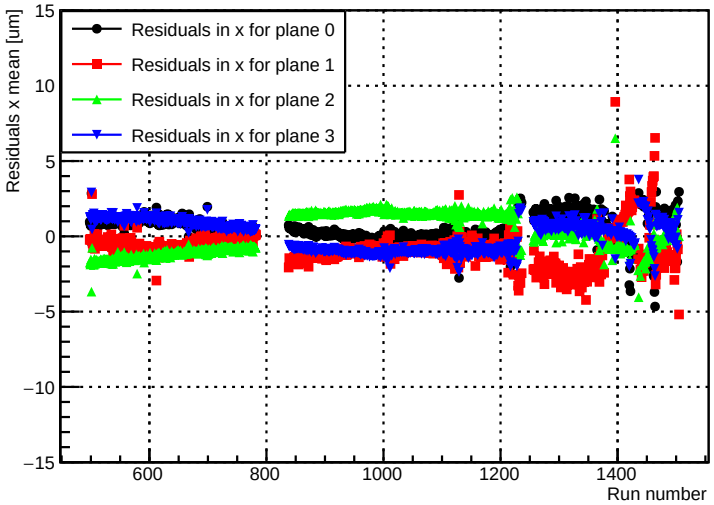
$\rightarrow \mathcal{X}^2$ can be analytically minimized

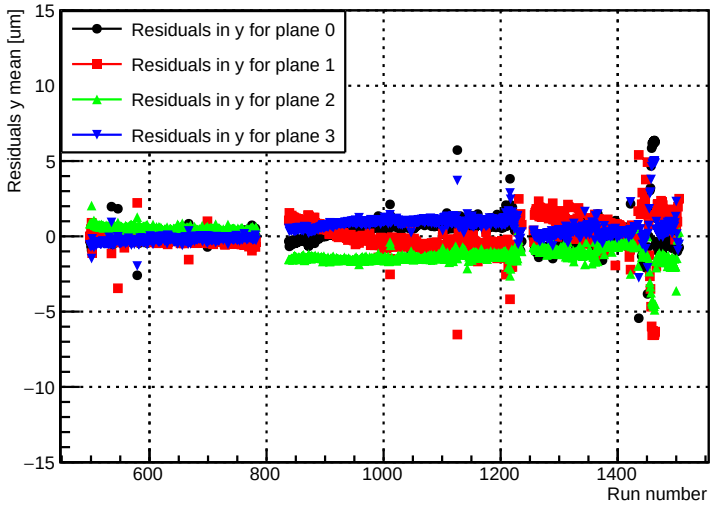
$$\mathcal{X}^2 = \sum_{i=1}^{n} \left(\frac{(x_i - (x_0 + a_x \cdot z_i))^2}{\sigma^2_{x_{m_i}}} + \frac{(y_i - (y_0 + a_y \cdot z_i))^2}{\sigma^2_{y_{m_i}}} \right)$$

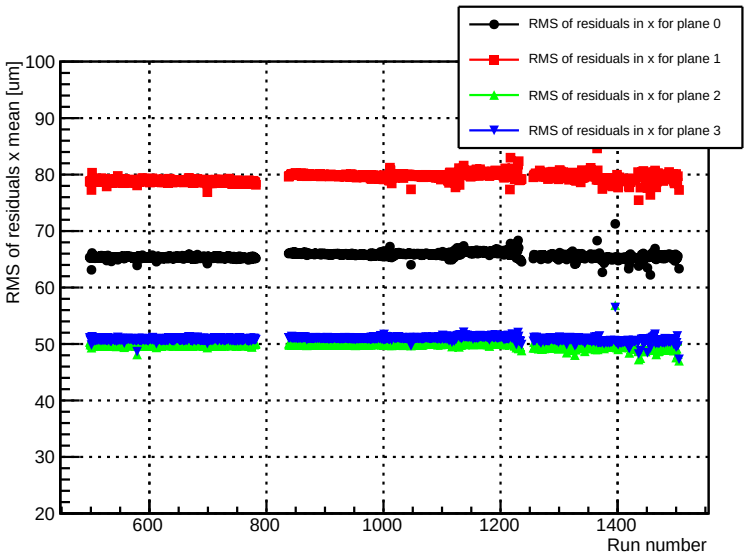
$$\text{assuming } \sigma_{x/y_{m_i}} = \text{pixel resolution} = \frac{\text{pixel size}}{\sqrt{12}}$$

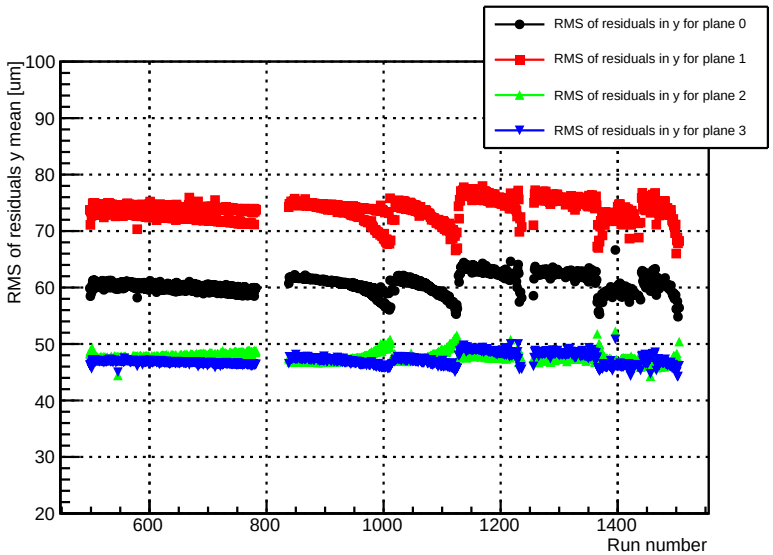
$\rightarrow$ Fast and robust track model!

Alignment @ DESY

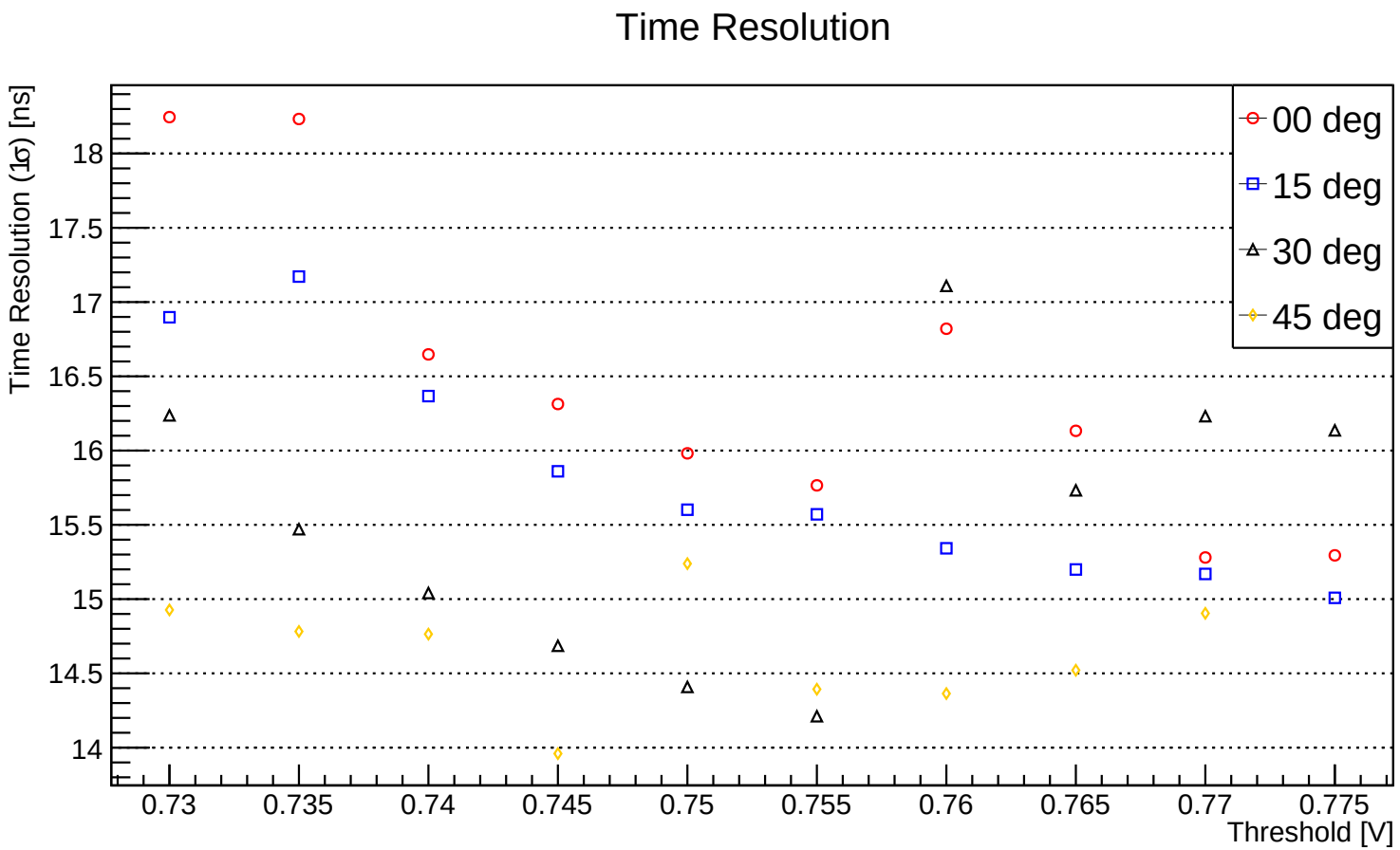




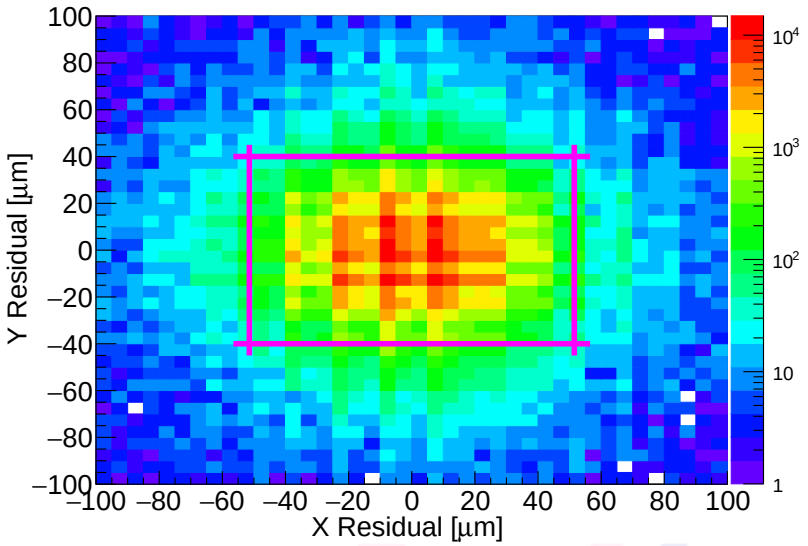


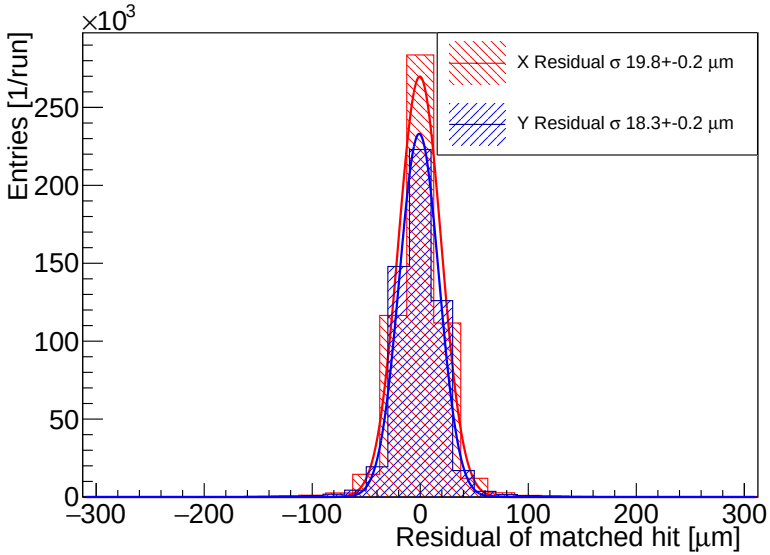


Telescope Timing @ DESY



MuPix7 Spatial Resolution



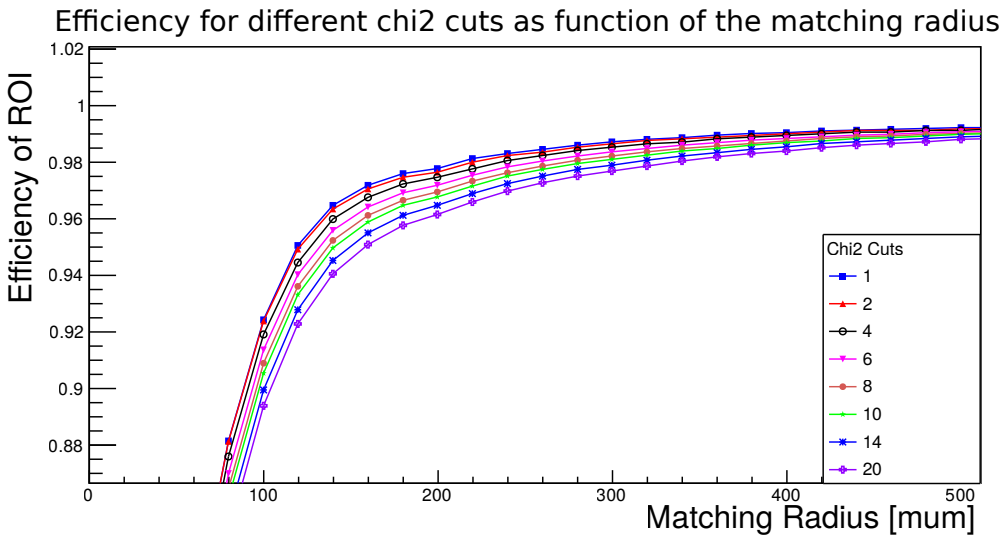


- Resolution is dominated by the pixel size!
- Multiple Scattering small enough for 4 GeV/c electrons
- Resolution in x slightly worse than in y: Feature of pixel size

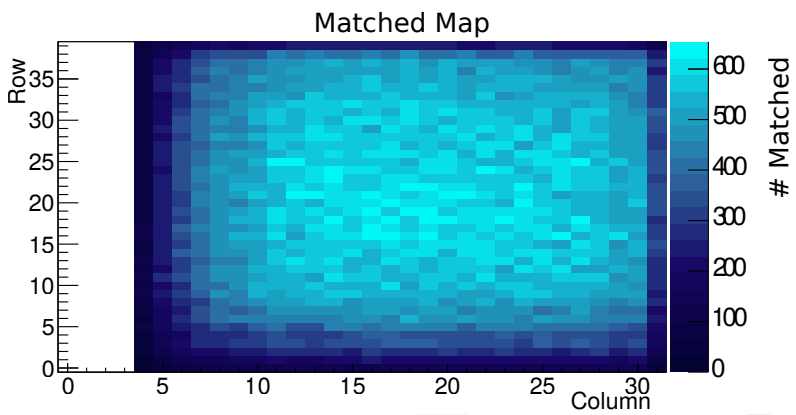
Analysis Concept

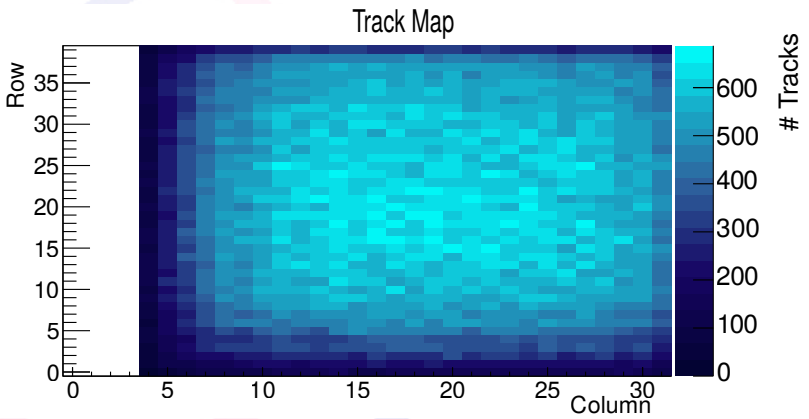
Analysis Procedure

- Align the system
- Extrapolate track and check hits on DUT
- Match DUT hits
- Analyze cut-effects
- Extract the relevant parameters



Efficiency Analysis





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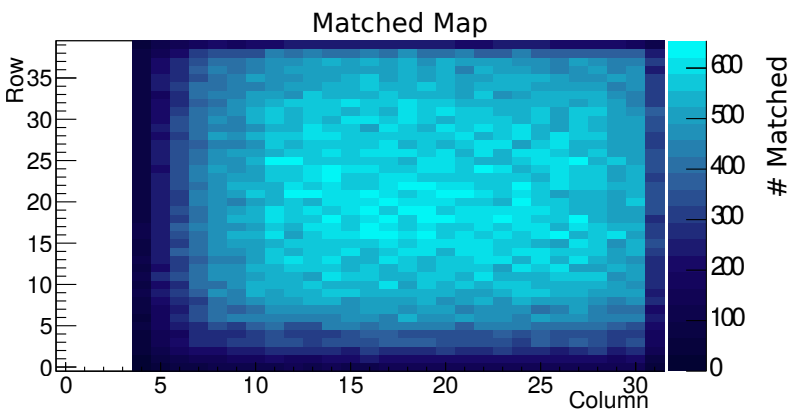

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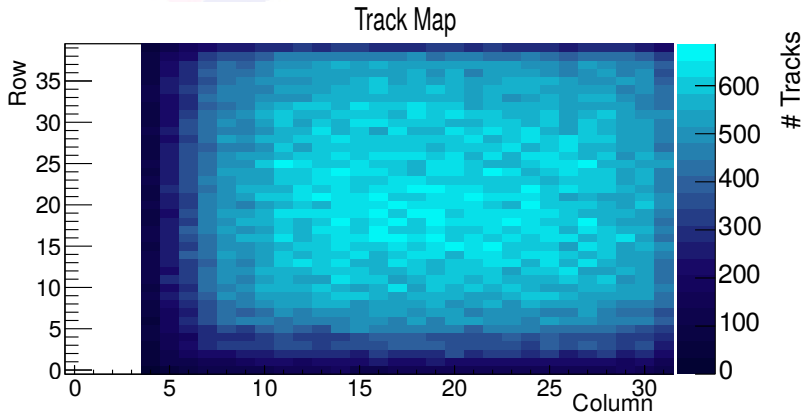

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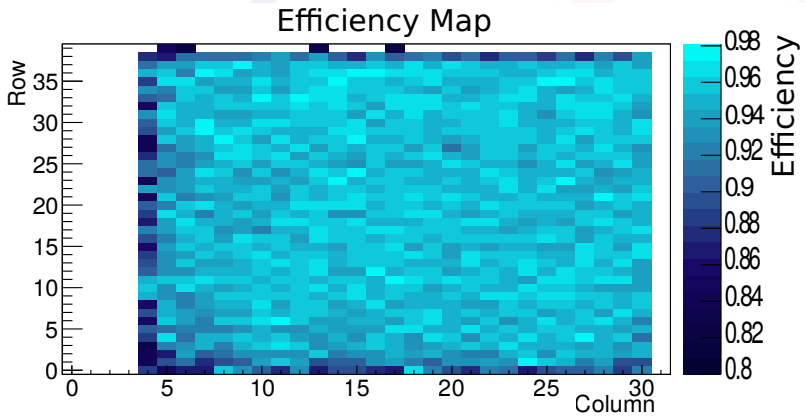
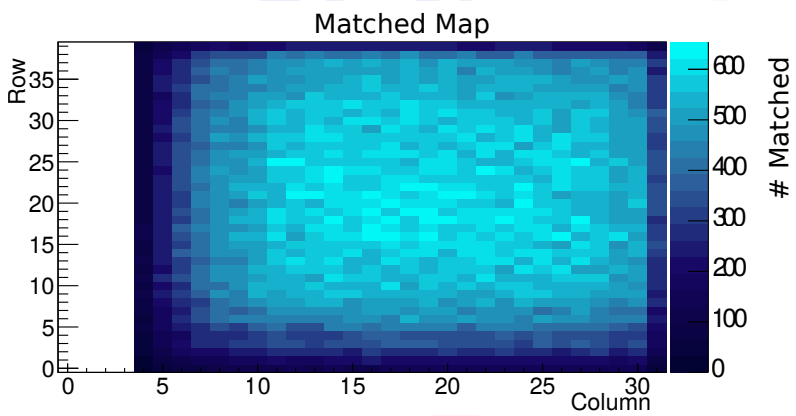


$$\text{Eff} = \frac{\#\ \text{matched}}{\#\ \text{tracks}}$$

$$\text{Noiserate}_{\text{pixel}} = \frac{\#\text{hits} - \#\ \text{matched}}{\#\ \text{runtime} \cdot \#\ \text{pixel}}$$

Efficiency Analysis



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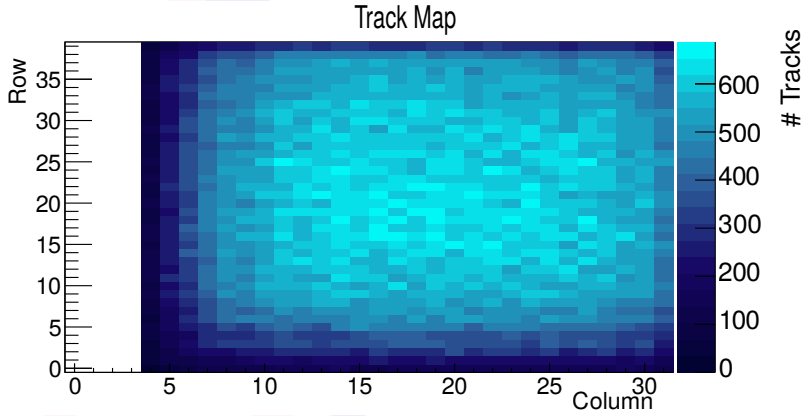

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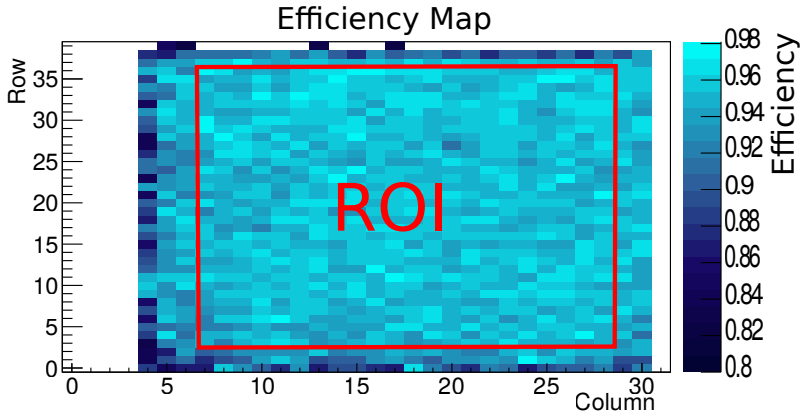

$$\text{Eff} = \frac{\#\ \text{matched}}{\#\ \text{tracks}}$$

$$\text{Eff}_{\text{ROI}} = \frac{\#\ \text{matched}_{\text{ROI}}}{\#\ \text{tracks}_{\text{ROI}}}$$

$$\text{Noiserate}_{\text{pixel}} = \frac{\#\text{hits} - \#\ \text{matched}}{\#\ \text{runtime} \cdot \#\ \text{pixel}}$$