Testbeam Characterization of the MuPix7

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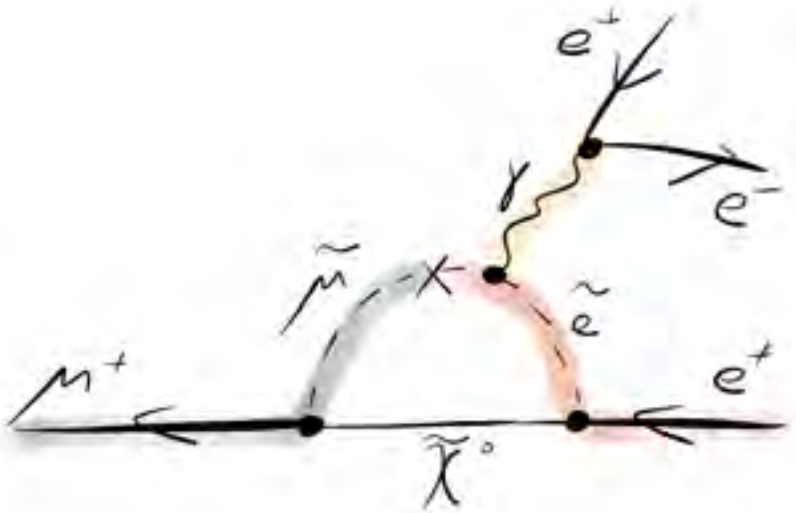
INTERNATIONAL MAX PLANCK RESEARCH SCHOOL

PT FS FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES

Motivation

What's beyond the SM?

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



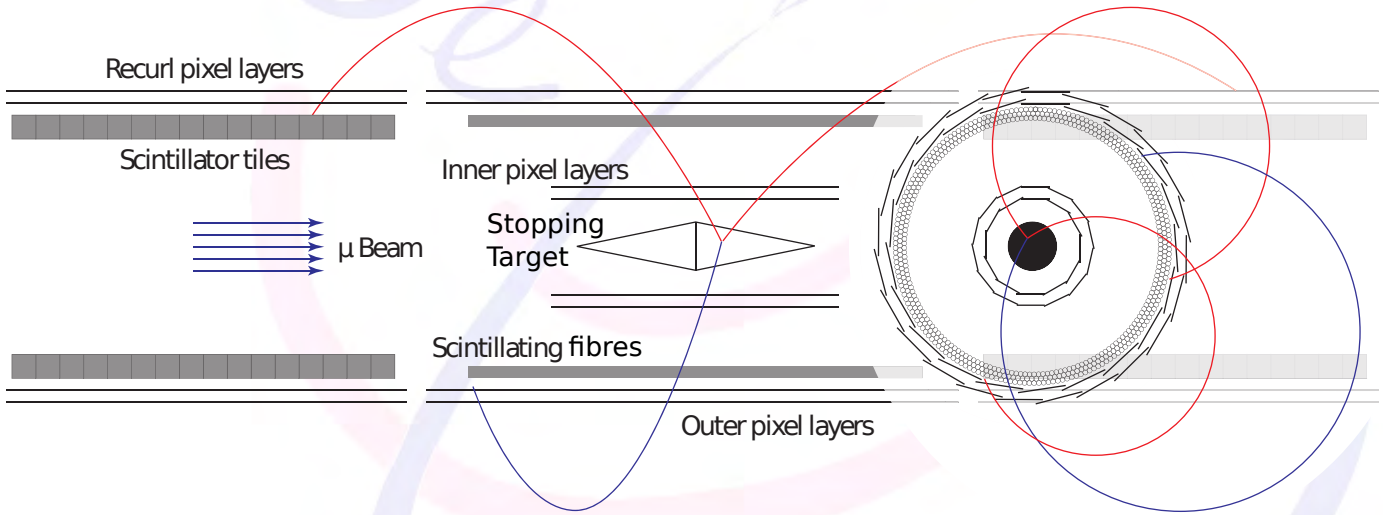
The decay $\mu^+ \rightarrow e^+e^-e^+$

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

Background

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

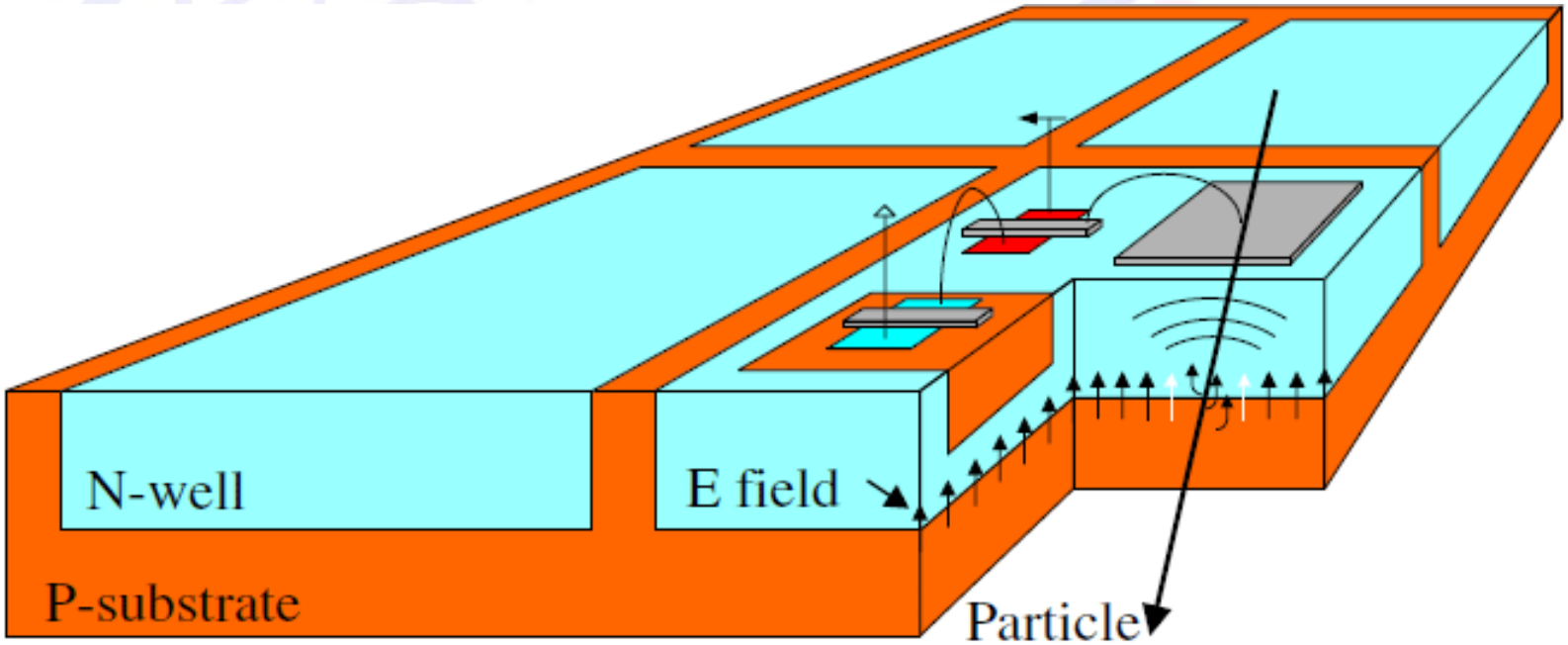
The Mu3e Experiment - Searching for $\mu^+ \rightarrow e^+e^-e^+$ with a sensitivity of BR$< 10^{-16}$



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)

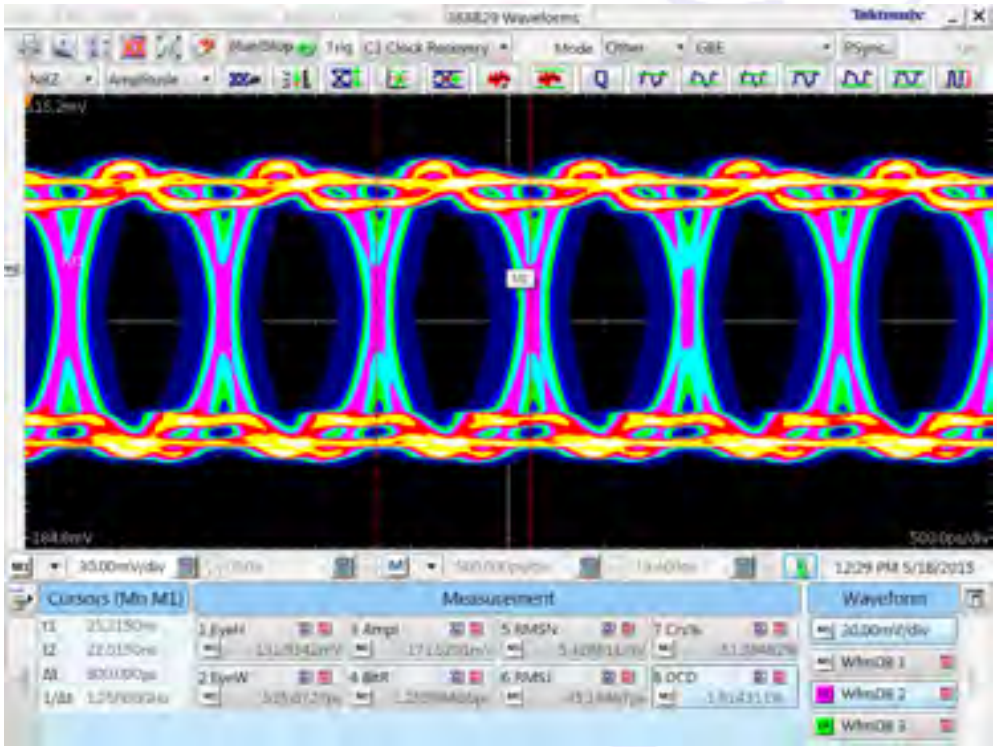


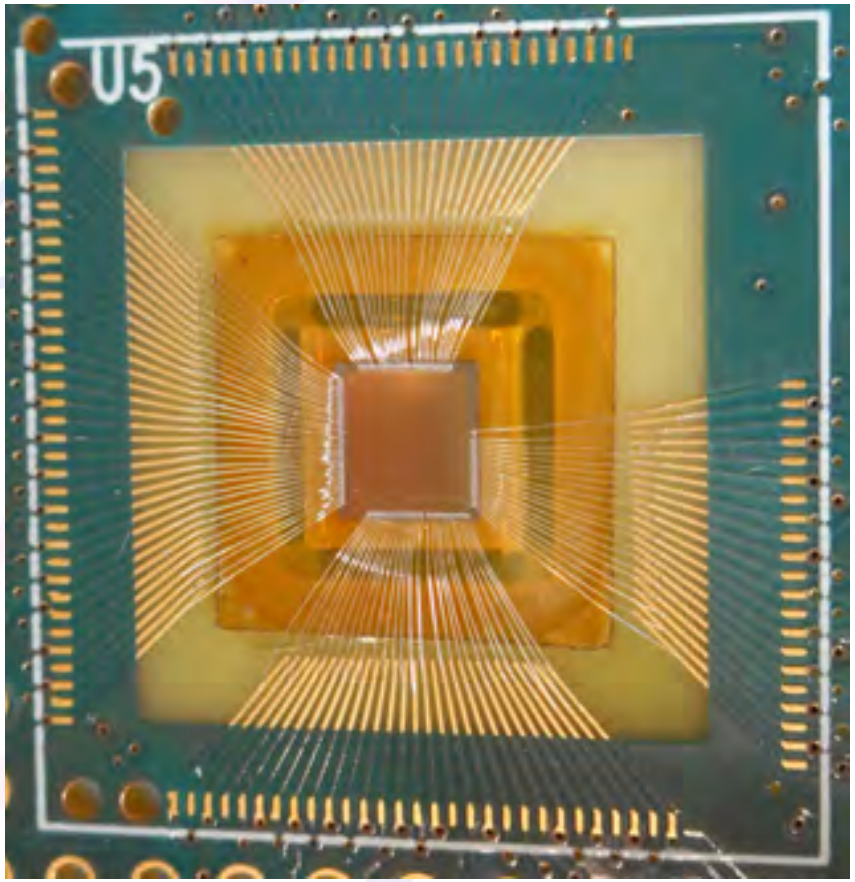
Design Goals

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

The MuPix 7

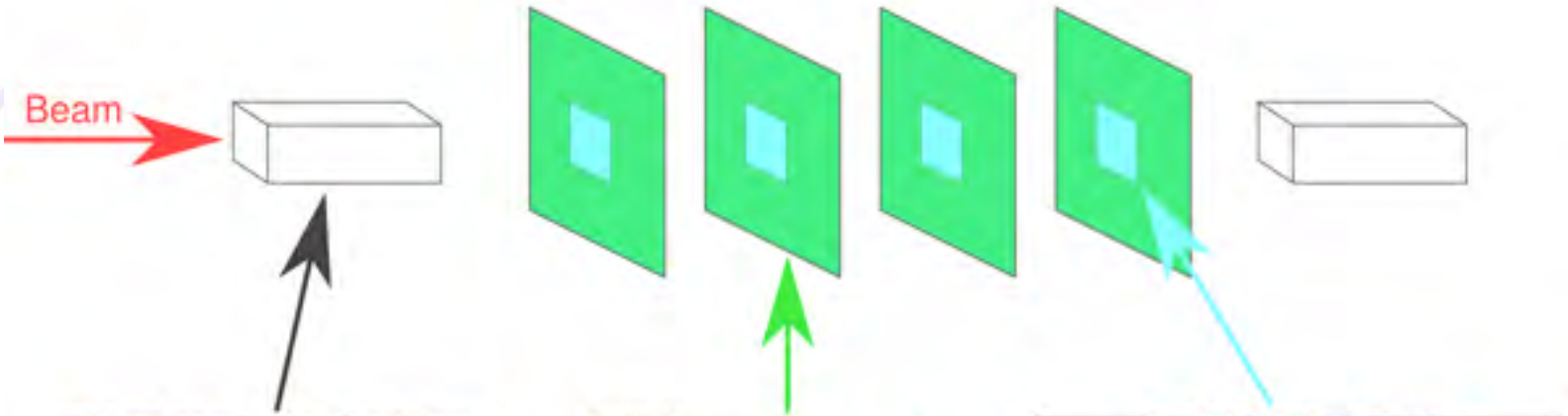
- Latest prototype
- Fully integrated readout on the chip
- On chip PLL & VCO
- 1.25 GBit/s data $\approx$ 33 MHits/s





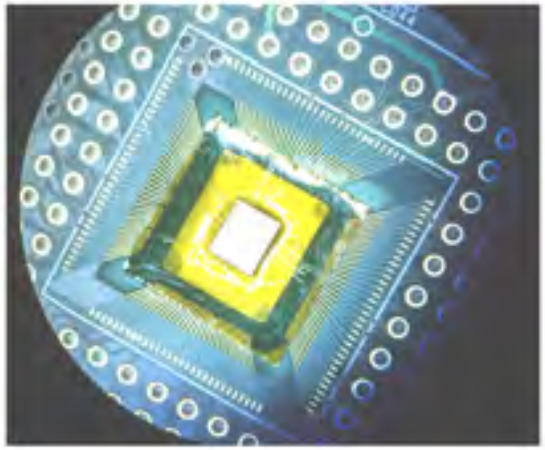
The MuPix Telescope

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



Scintillating Tiles

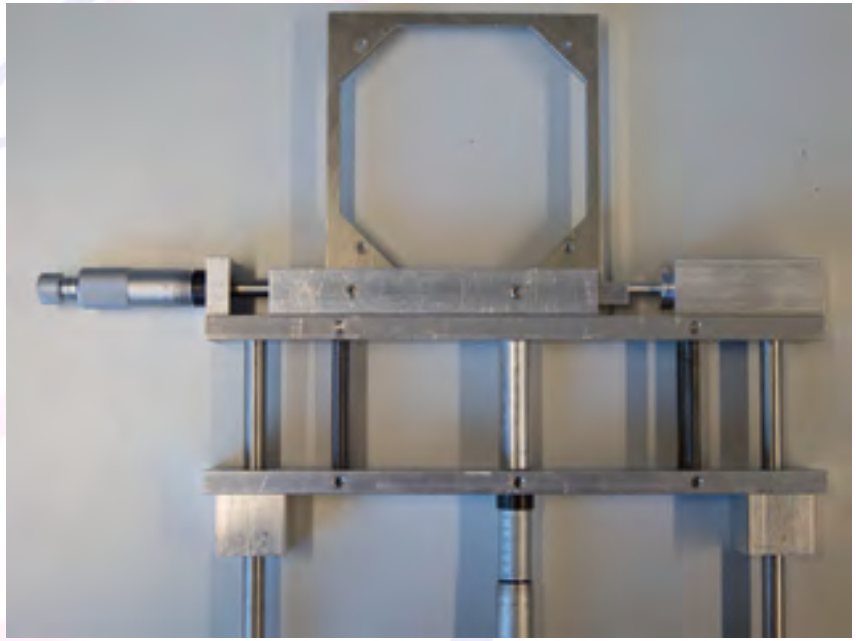
MuPix PCB



MuPix sensor

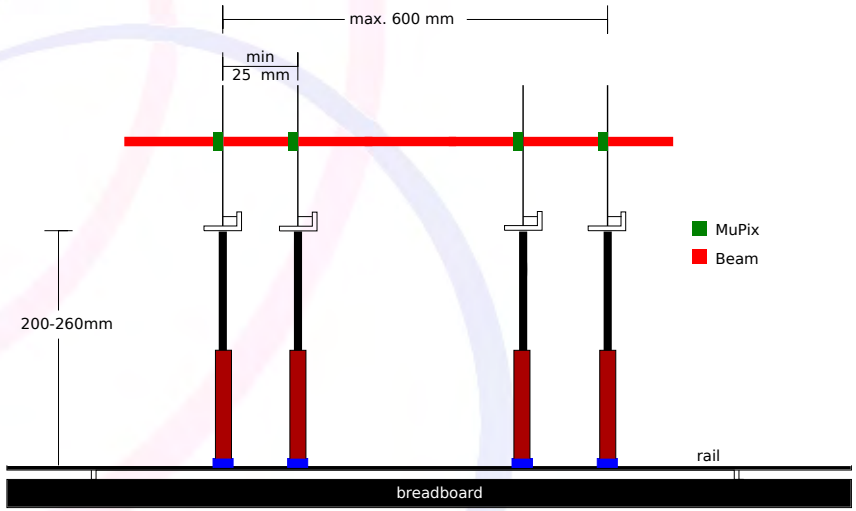
Mechanics, Readout & DAQ

- Custom PCB holder with 10 μm precision



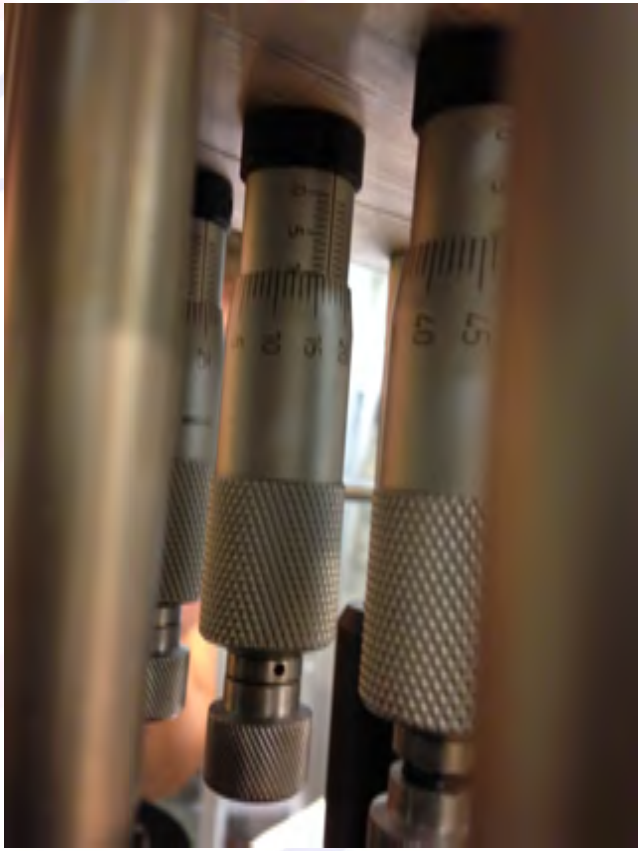
Mechanics, Readout & DAQ

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



Mechanics, Readout & DAQ

- Custom PCB holder with 10 μm precision
- Commercial mechanical support
- Readout and data transfer - next talk by Dorothea

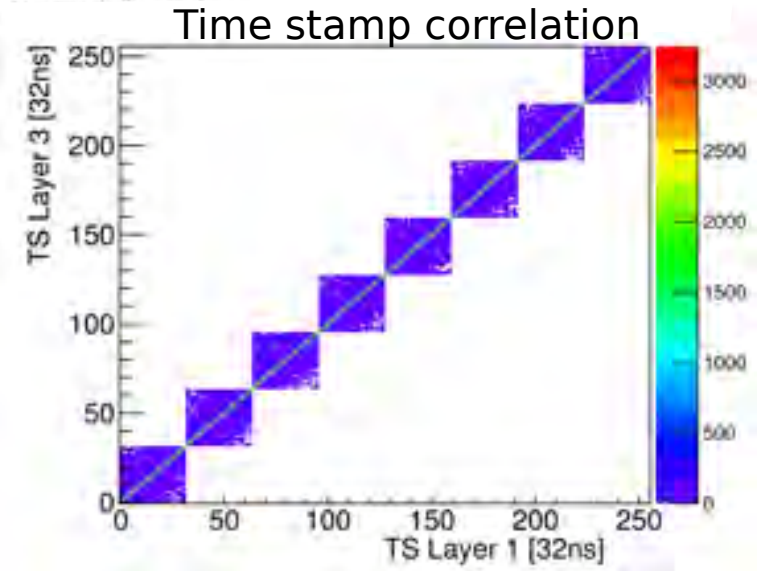


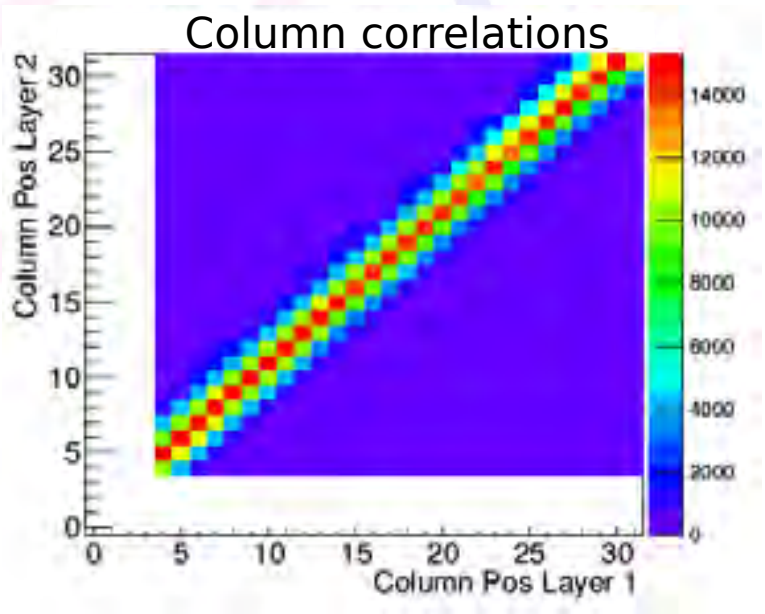
Mechanics, Readout & DAQ

- Custom PCB holder with 10 μm precision
- Commercial mechanical support
- Readout and data transfer - next talk by Dorothea
- Versatile graphical control interface

Mechanics, Readout & DAQ

- Custom PCB holder with 10 μm precision
- Commercial mechanical support
- Readout and data transfer - next talk by Dorothea
- Versatile graphical control interface
- Online monitoring, tracking and efficiency calculation

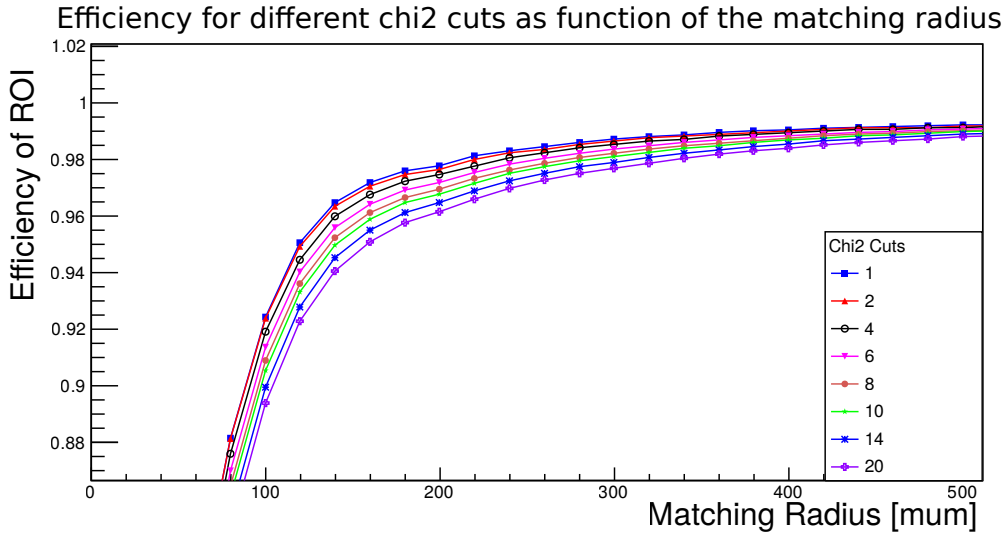




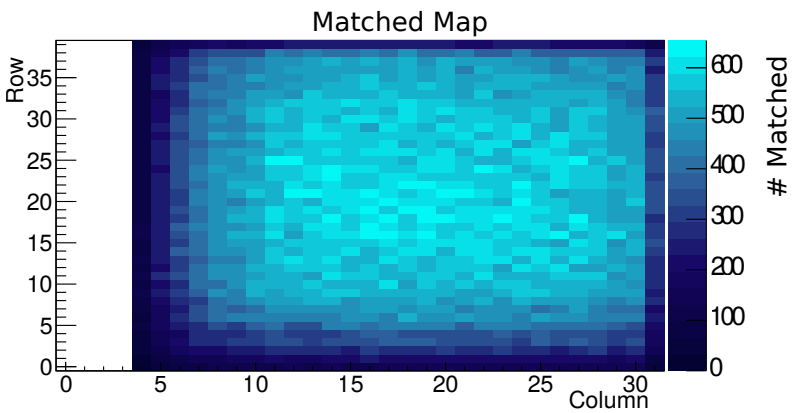
Analysis Concept

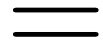
Analysis Procedure

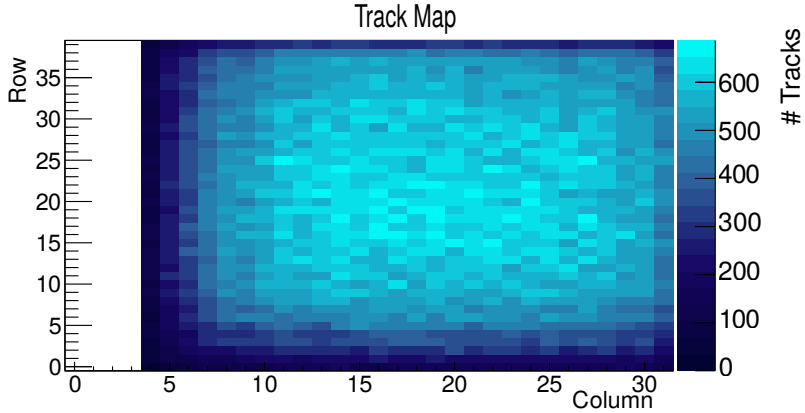
- Align the system
- Extrapolate track and check hits on DUT
- Match DUT hits
- Analyze cut-effects
- Extract the relevant parameters



Efficiency Analysis







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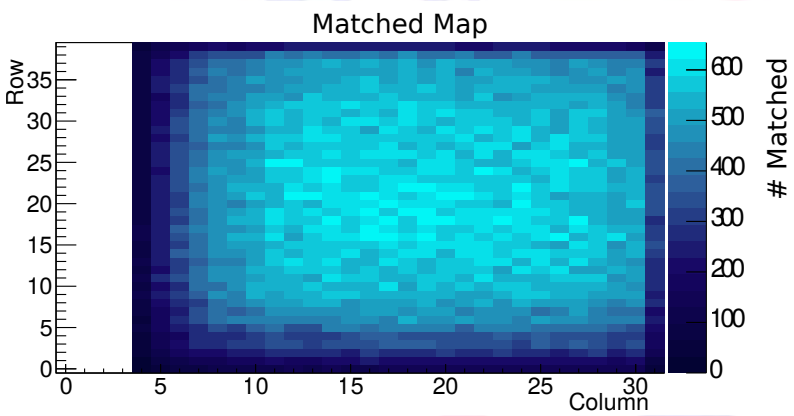
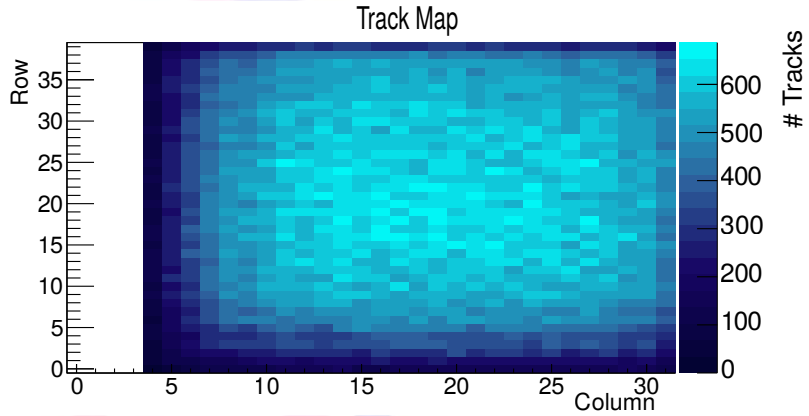
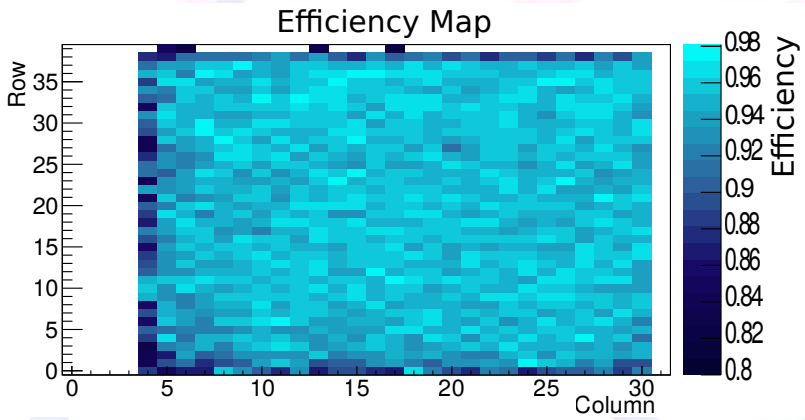


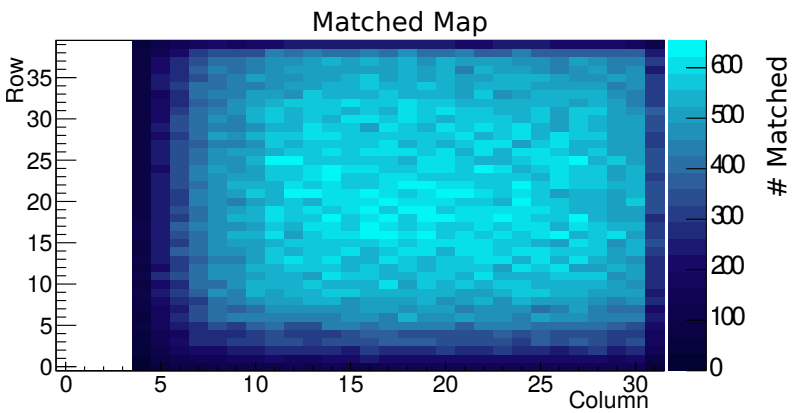




$$\text{Eff} = \frac{\#\text{ matched}}{\#\text{ tracks}}$$

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

Efficiency Analysis



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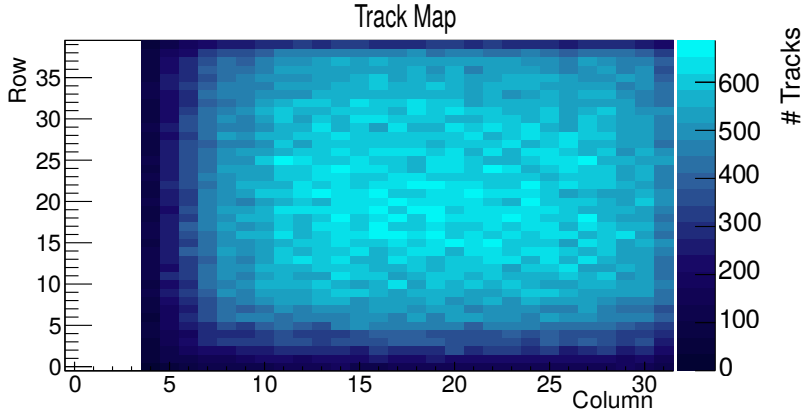

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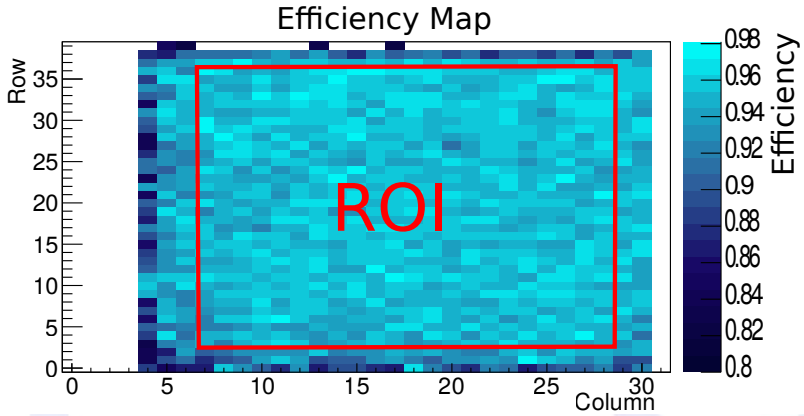
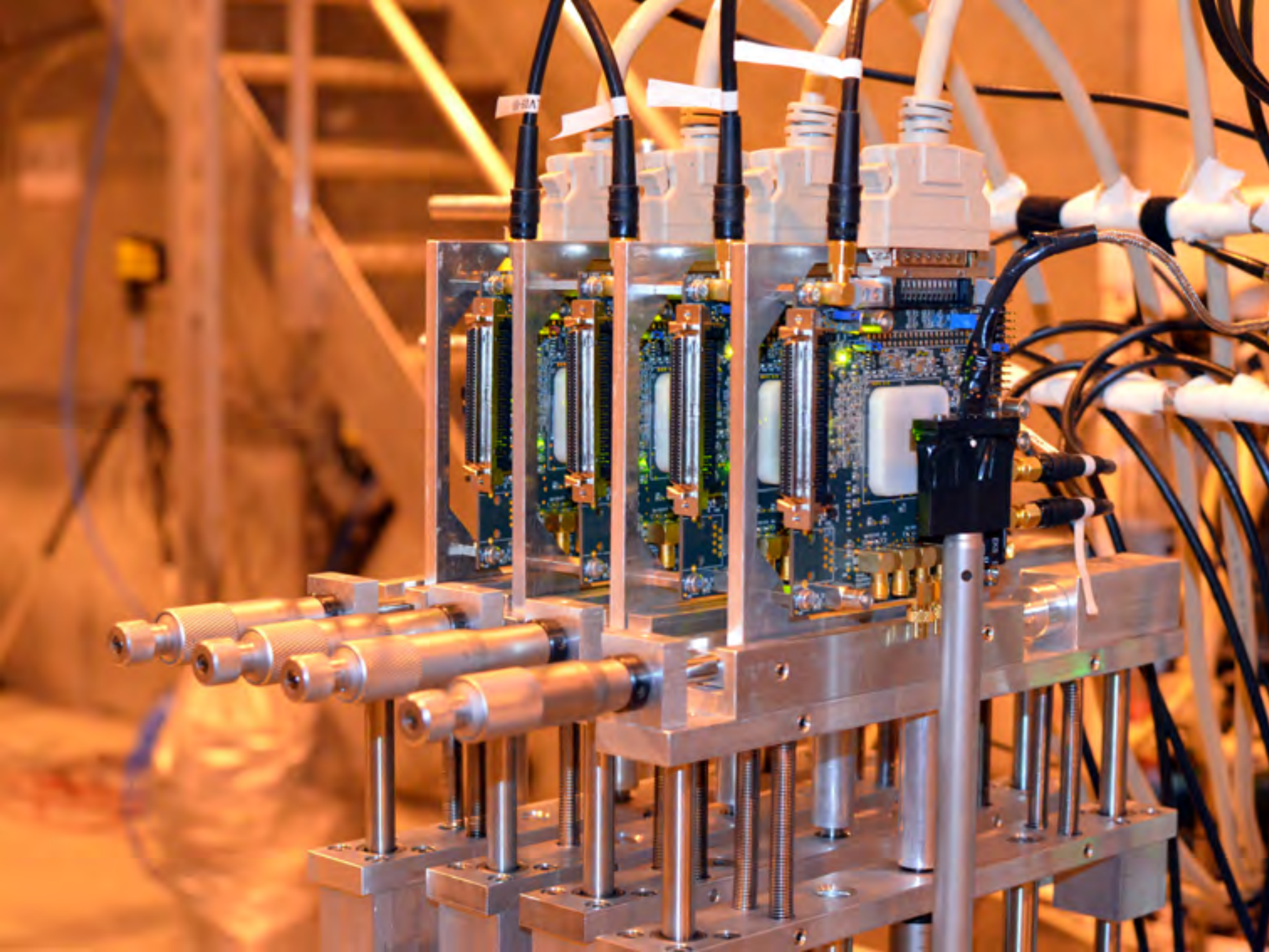


$$\text{Eff} = \frac{\#\ \text{matched}}{\#\ \text{tracks}}$$

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

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

Testbeam Campaigns



SPS Testbeam

Goal:

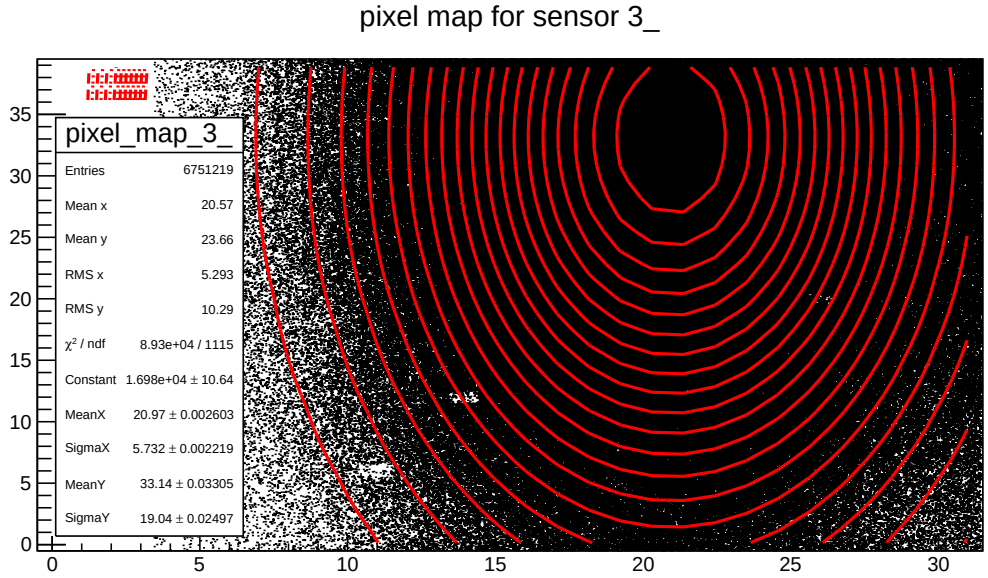
- Show functionality of MuPix7
- Integrate it into the Telescope

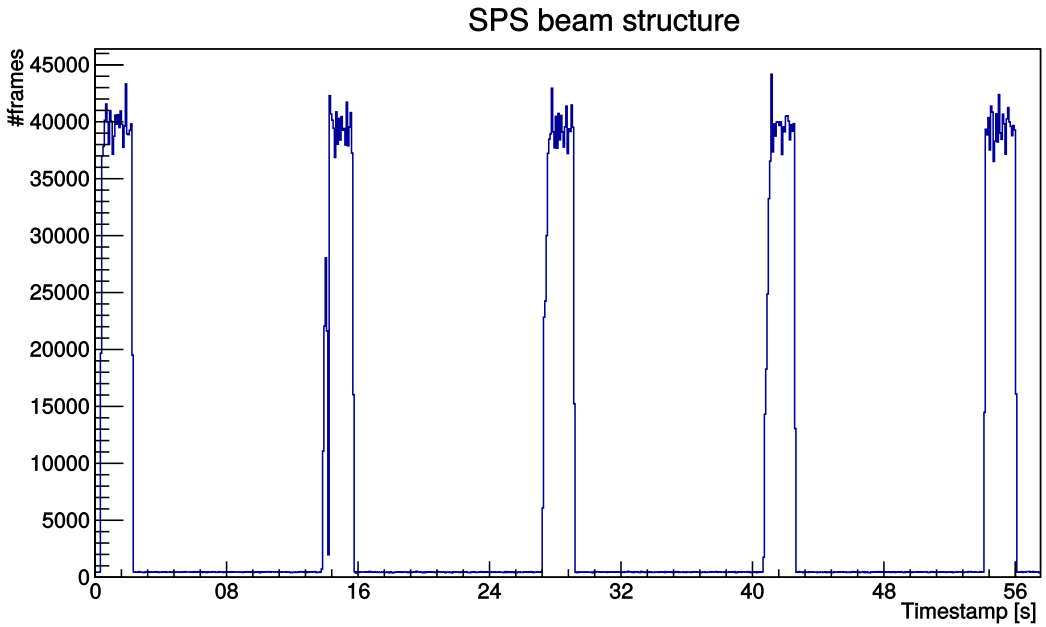
Beam:

- Pions
- 160 GeV
- High intensity spills

Setup:

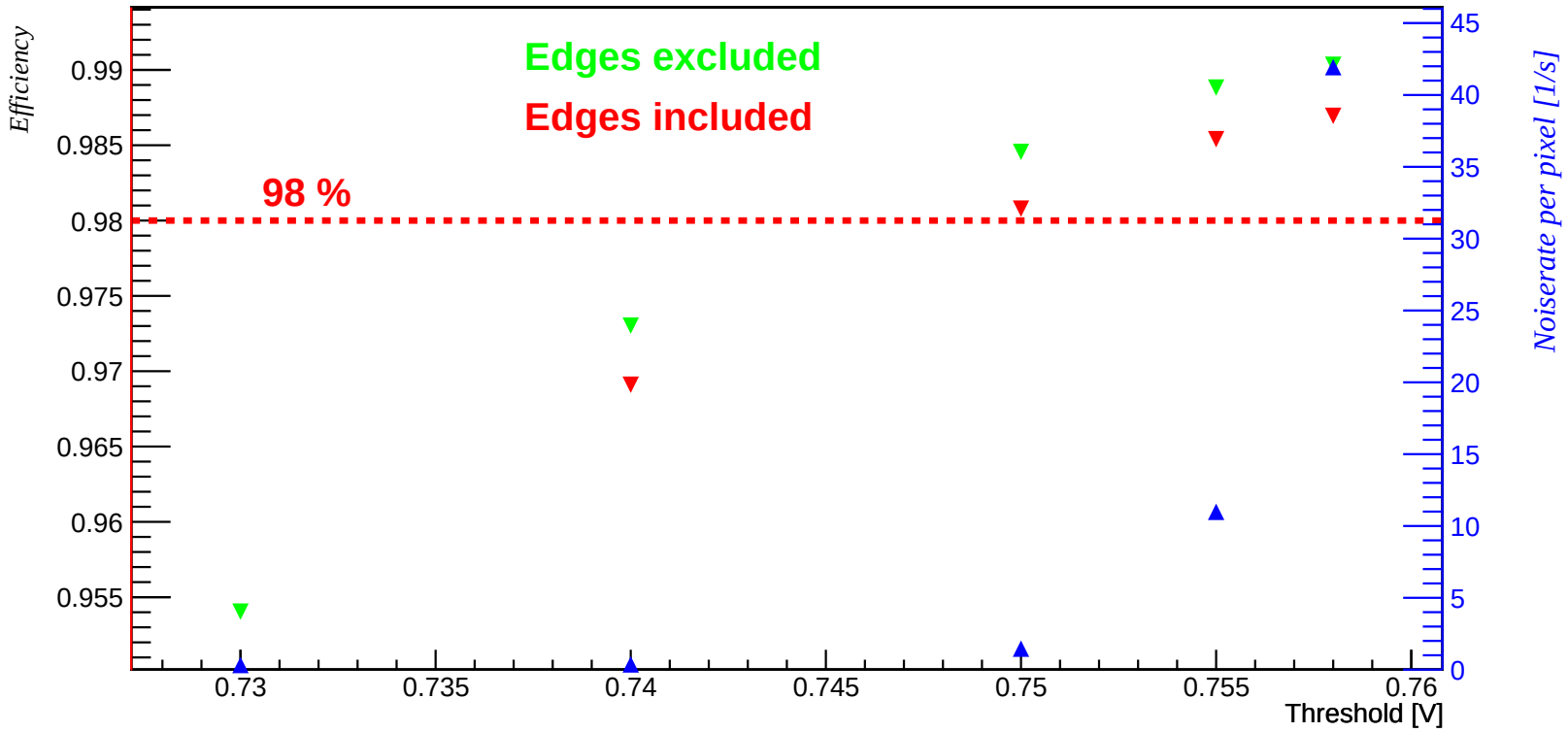
- 4 planes MuPix7
- Time Sorting on FPGA

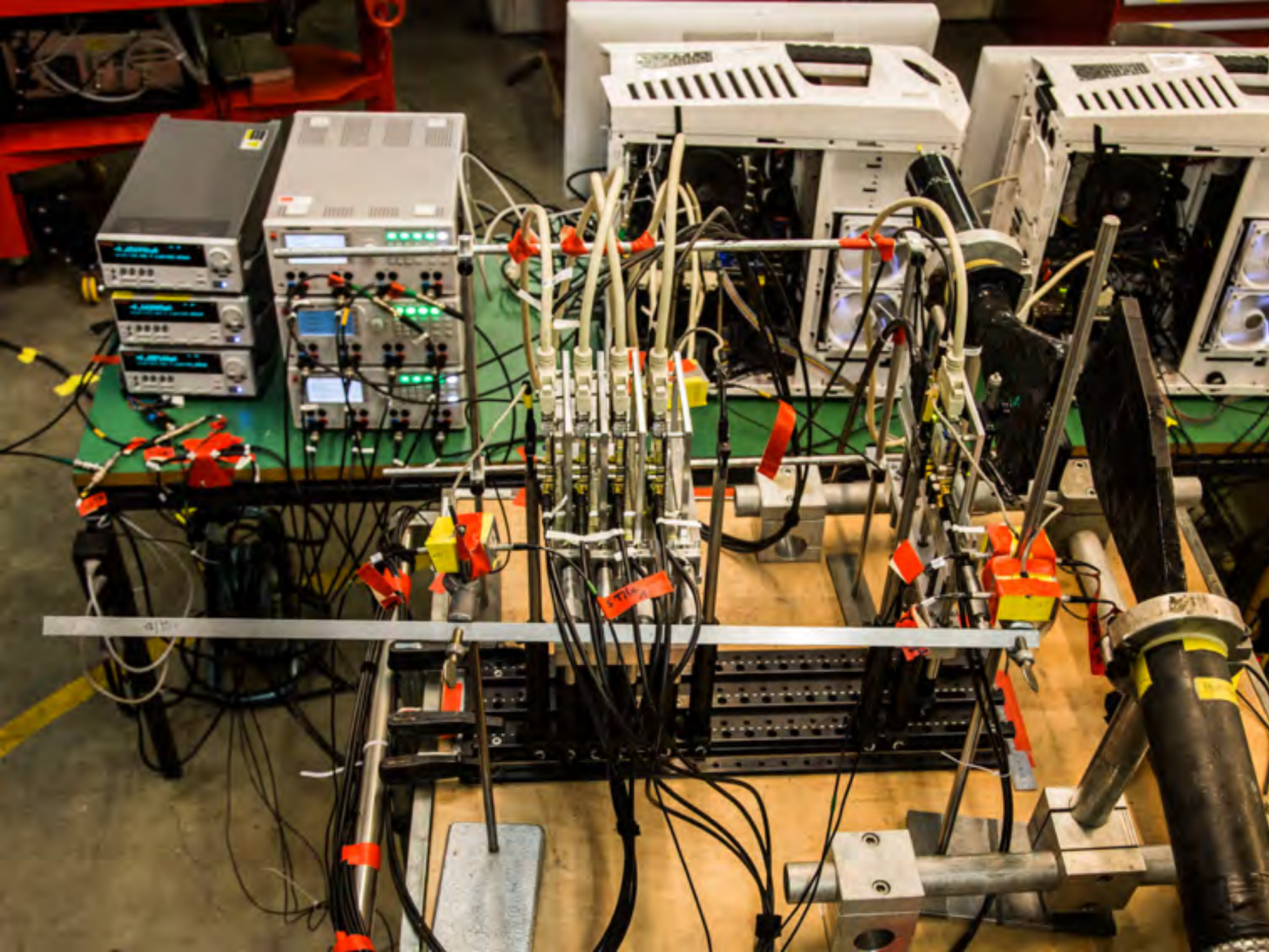




Result

Efficiency probably limited by saturated DAQ during spills!





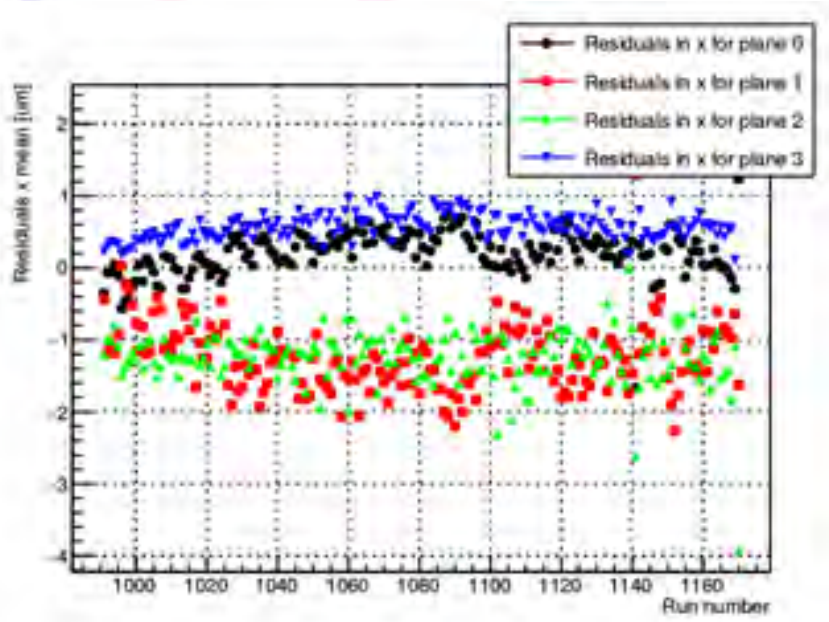
PSI Testbeam

Goals: Measure

- Efficiency
- Noise
- Compare different power settings
- Time resolution

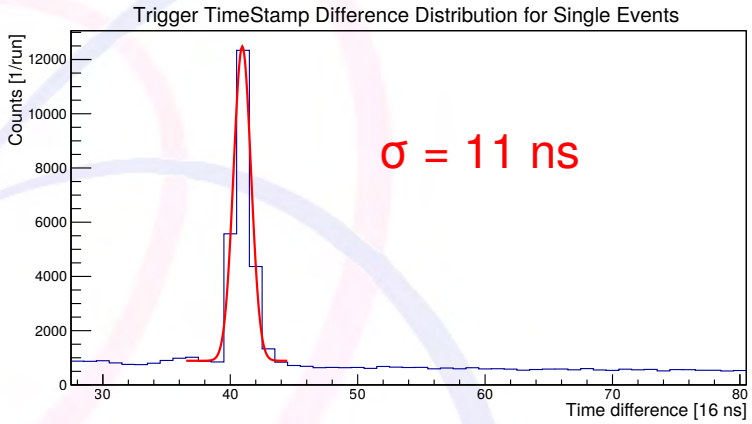
Beam:

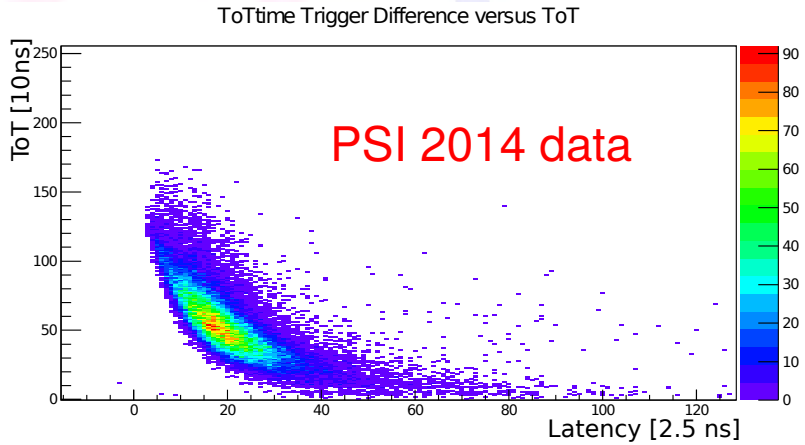
- Positrons, muons, pions
- $\approx$ 220 MeV/c
- Trigger rate $<$ 2 MHz
- On sensor rate 380 kHz



Time Resolution

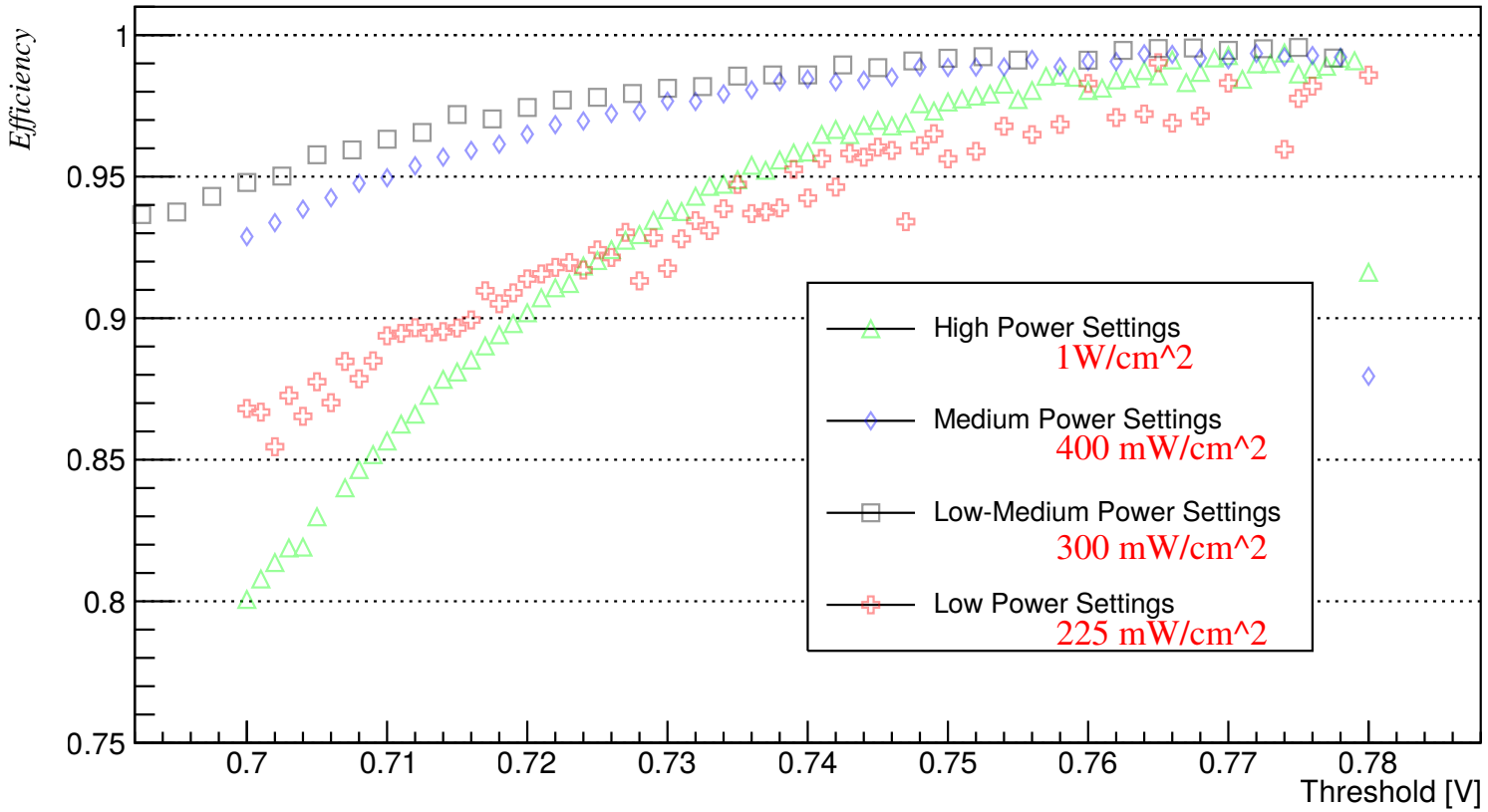
- Selected only events with reference scintillator coincidence
- Required time resolution < 20 ns
- Measured in a separate setup - no tracking information

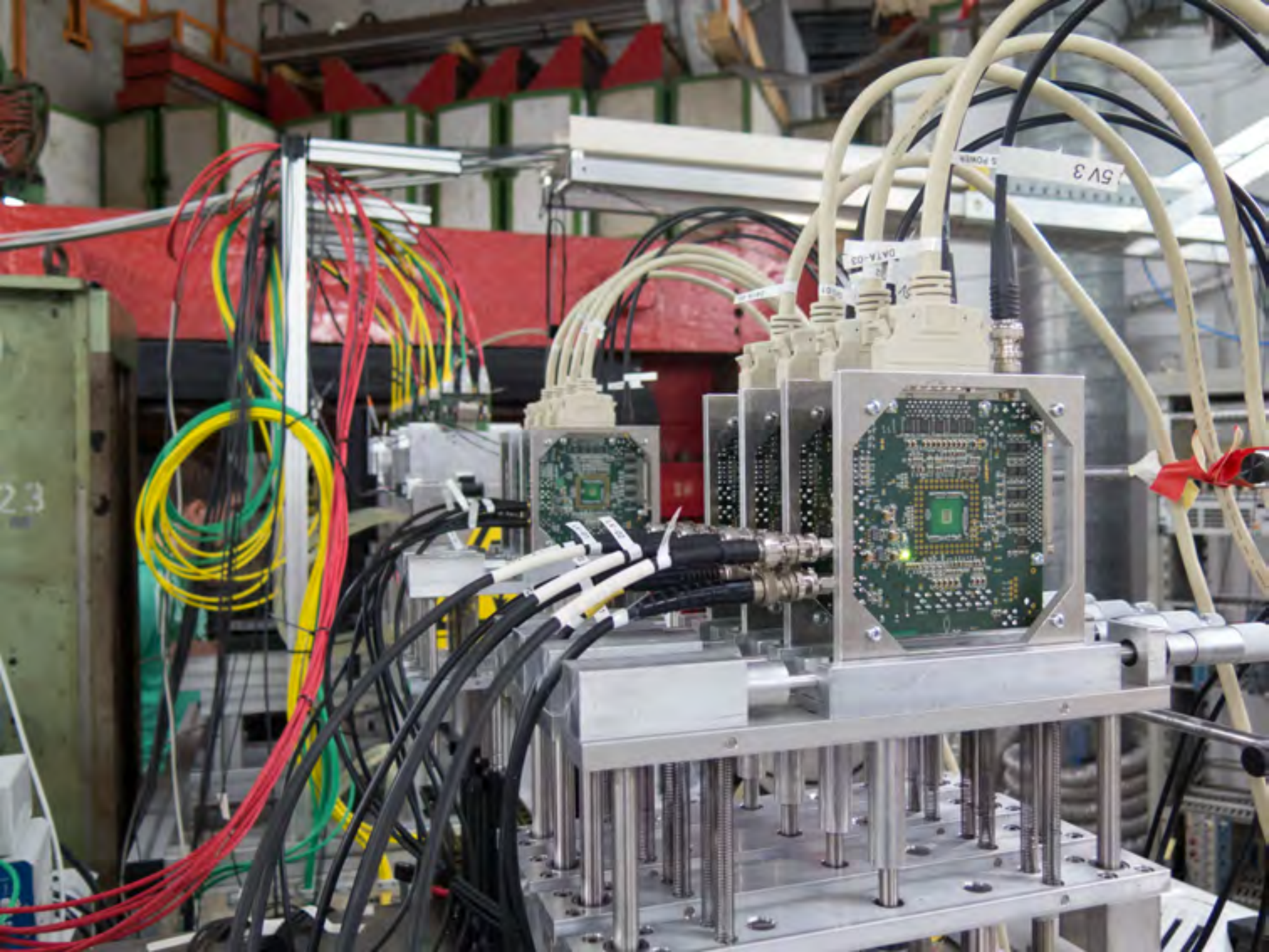




Comparision of Power Settings

maximal cooling power: 400 mW/cm^2





DESY Testbeam

Goals: Measure

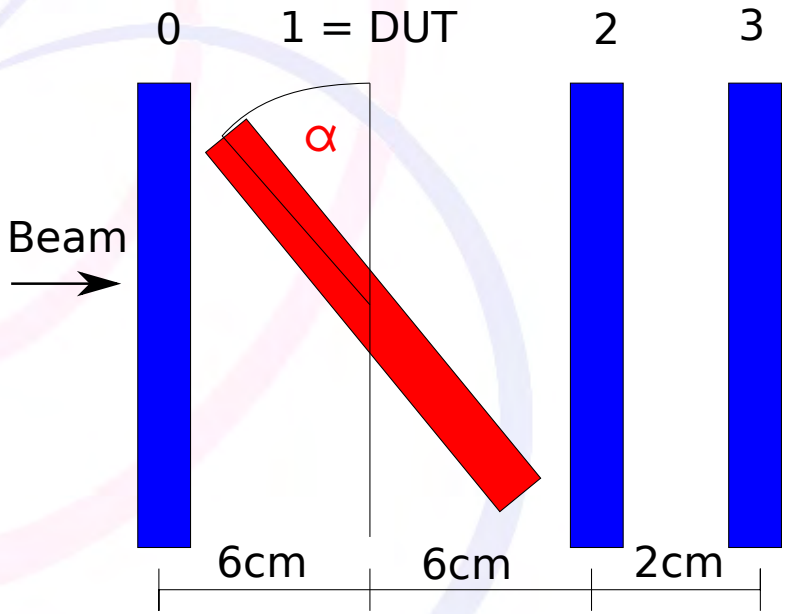
- Efficiency
- Noise
- Cross talk
- Sub pixel effects

Beam:

- Positrons
- 4-6 GeV/c
- Rate $<$ 10 kHz

Setup:

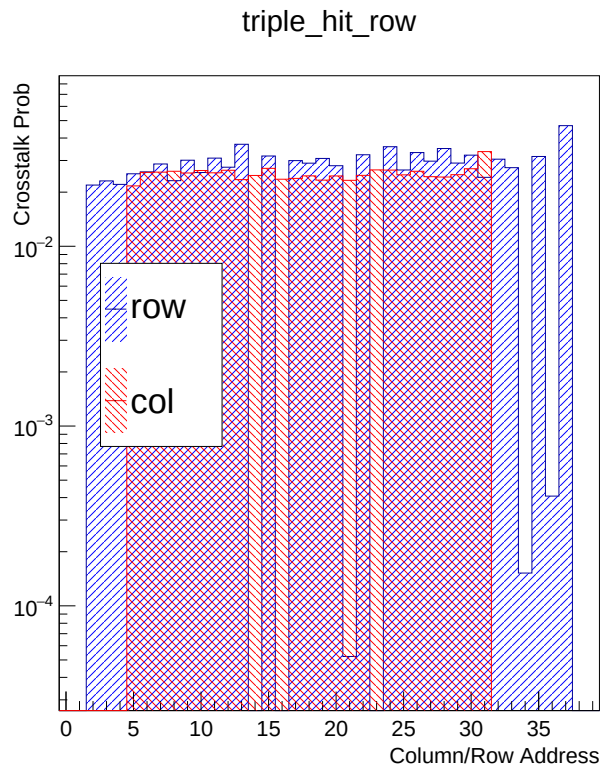
- Rotated device under test
- DMA and GPU tests
- 2nd telescope for long term stability measurements



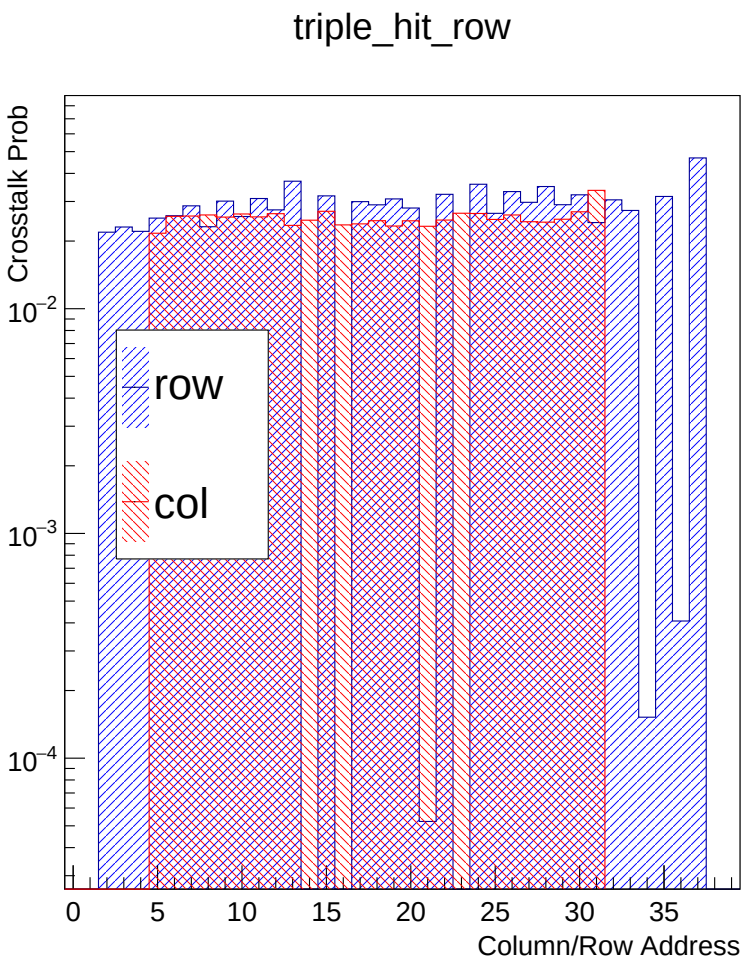
Crosstalk I

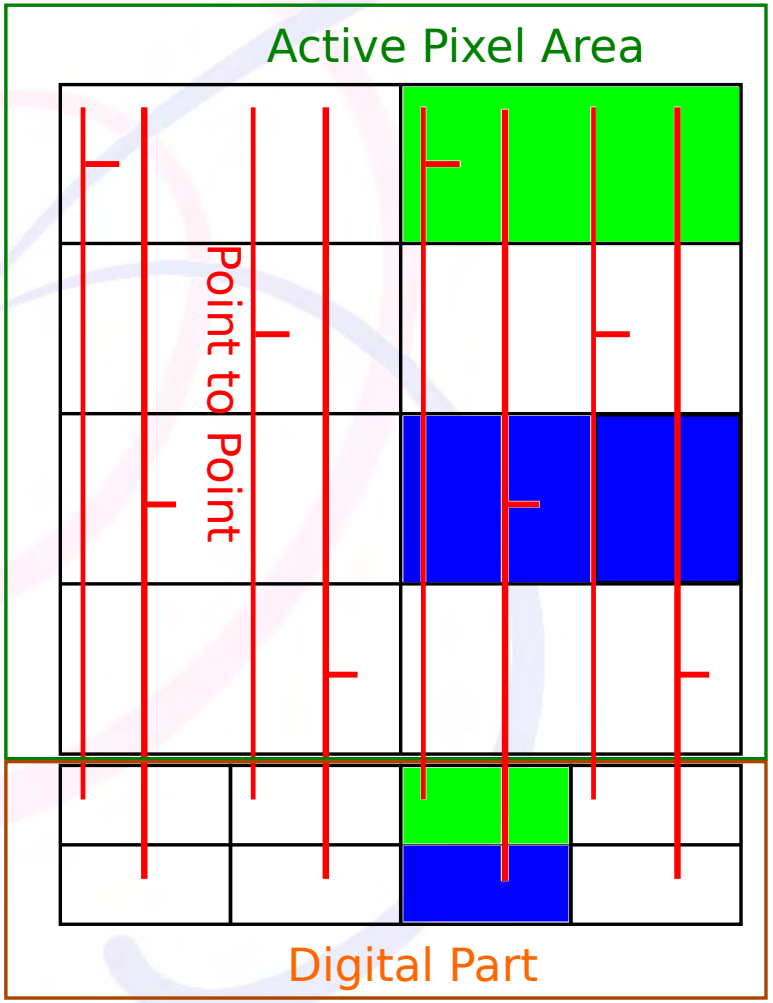
Selection Criteria

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

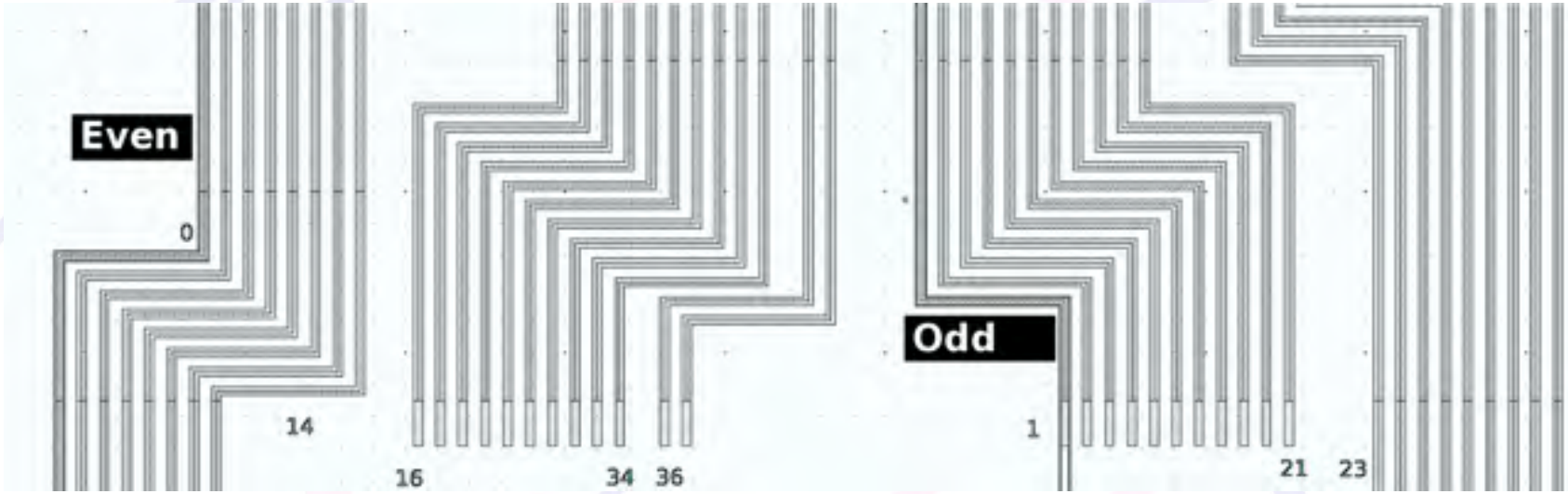


Crosstalk II

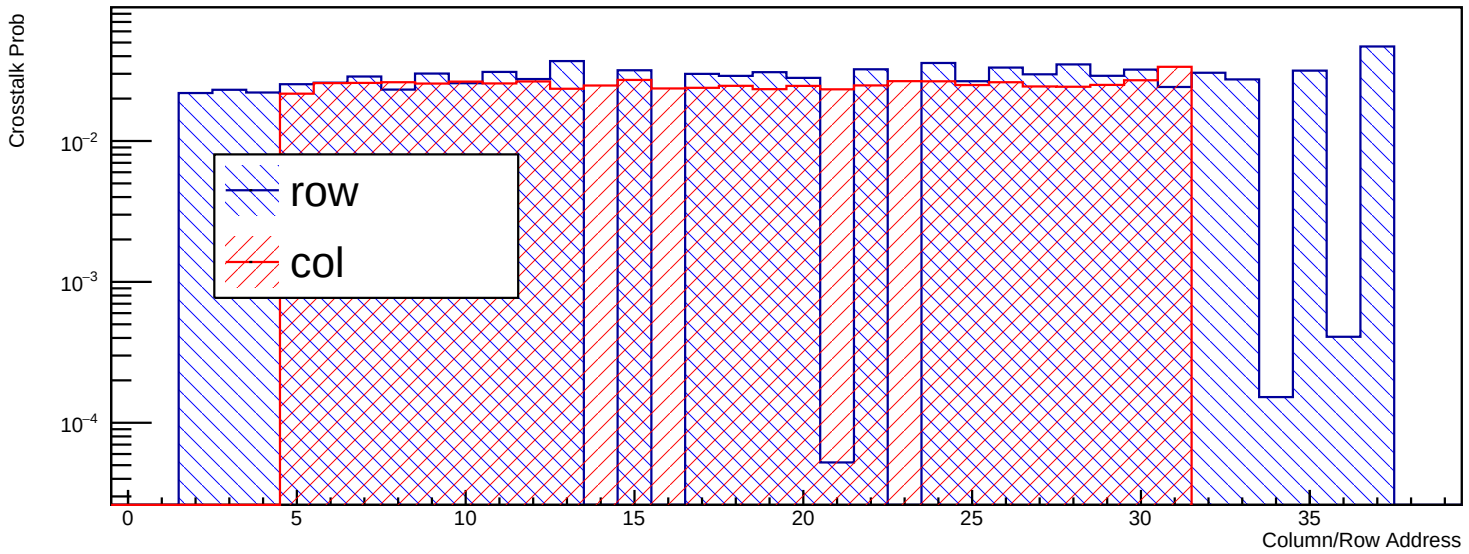




Crosstalk III



triple_hit_row



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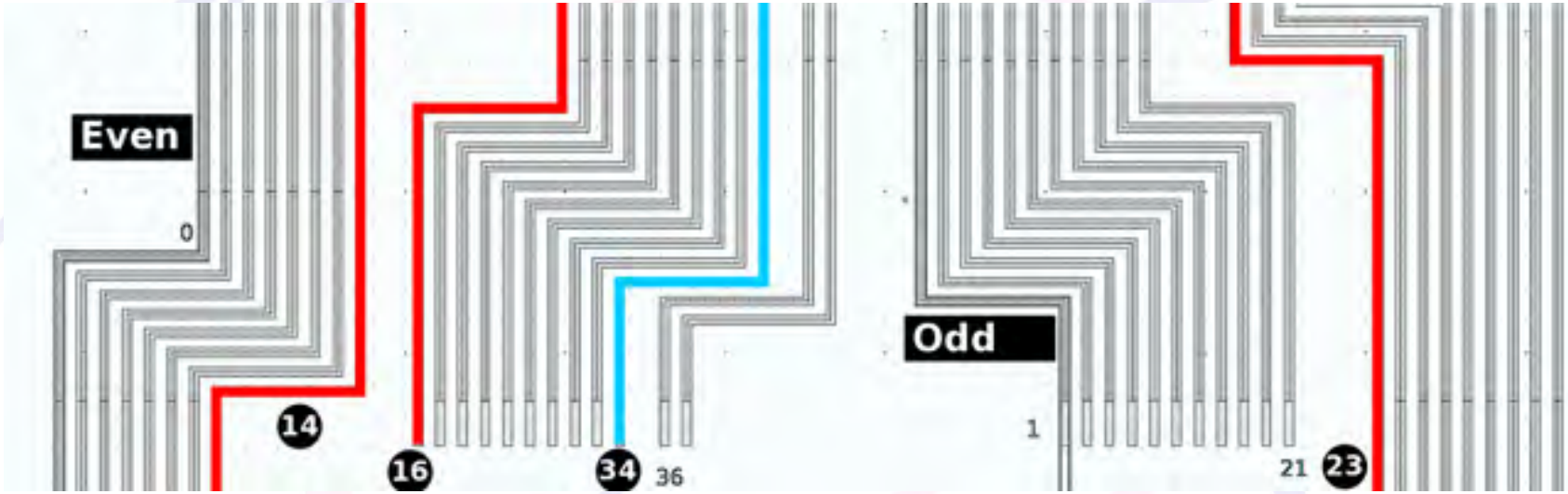
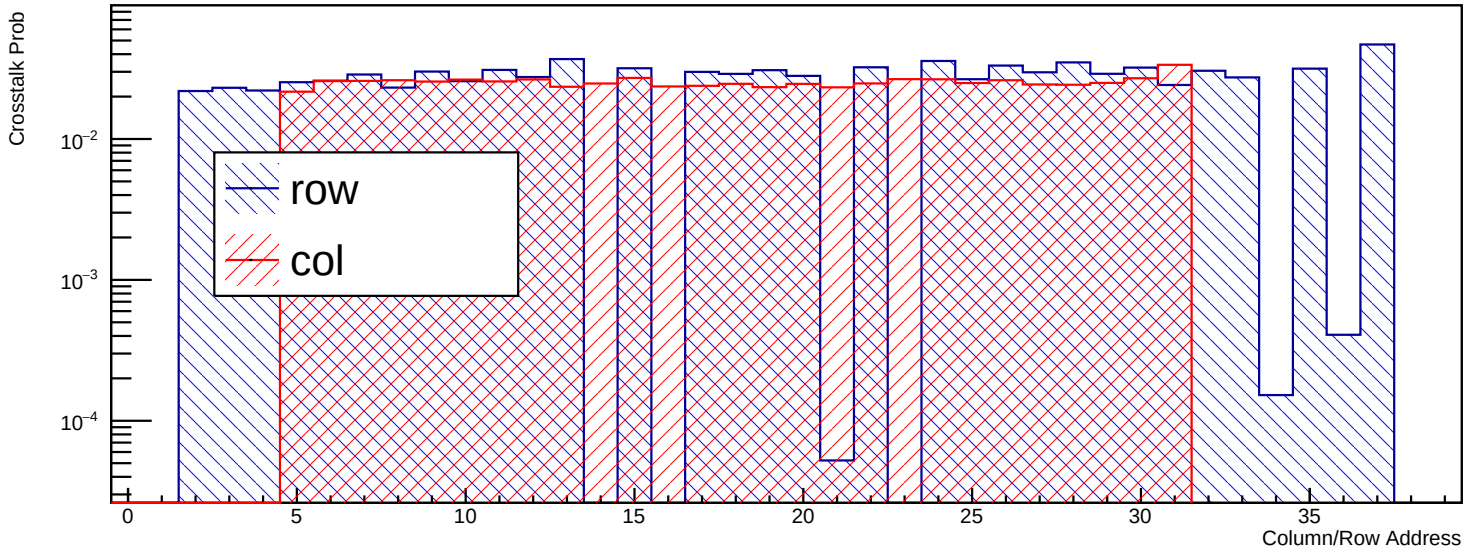
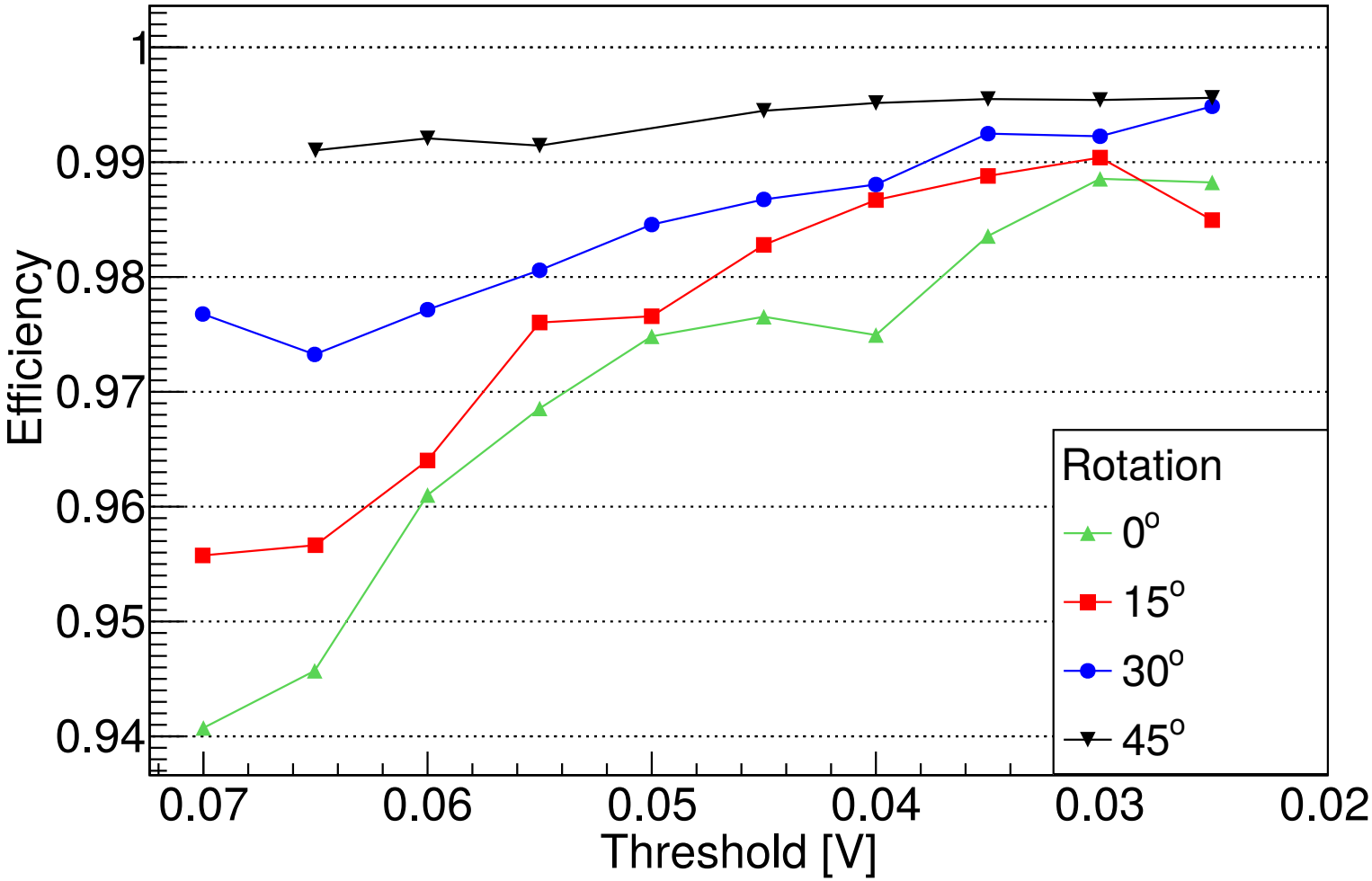


triple_hit_row



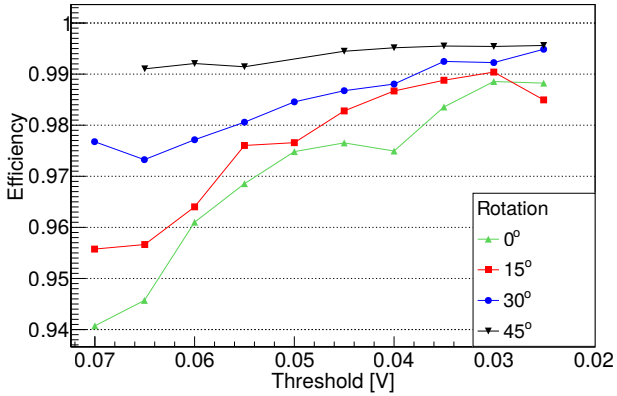
Efficiency Summary

Larger rotation → more signal → Higher efficiency at higher thresholds



Conclusion

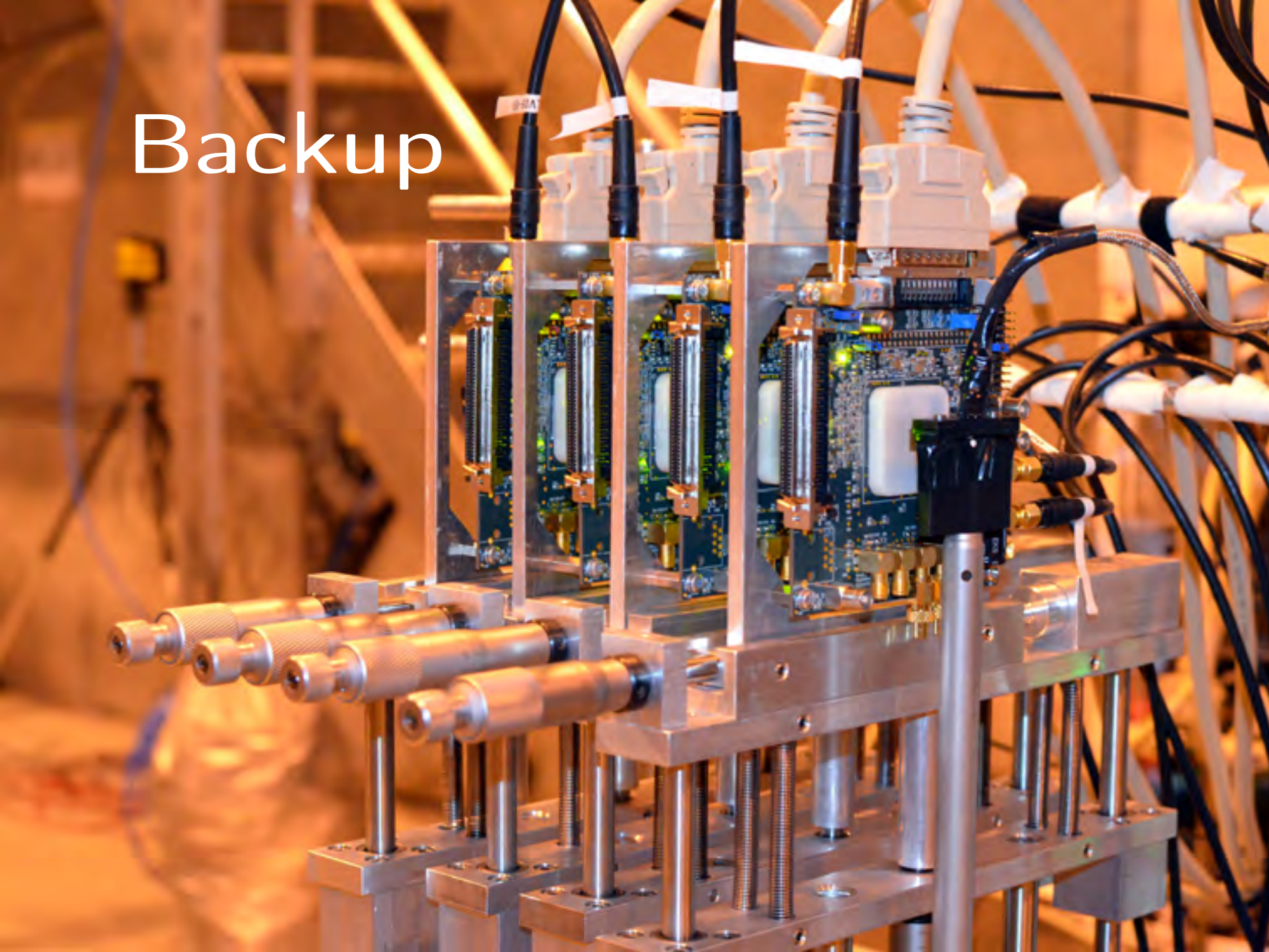
- First running integrated HV-MAPS system
- High Rate capabilities $\mathcal{O}$ (1MHz)
- Important tool to test scaling
- High system efficiency > 99 %
- Time resolution < 11 ns
- Cross talk and clustering analysis ongoing
  $\rightarrow$ cross talk issue, should be fixed in MuPix8



Thanks to the Helmholtz alliance for providing beam time!

Outlook

- 8 planes
- Improve DUT integration
- Use existing DAQ to develop module tests and readout
- Next prototype with a size of $> 1 \times 1$ cm^2
- Better timing: timestamps created by faster clock


Backup

Track Model

Trackmodel: Straight track without scattering

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

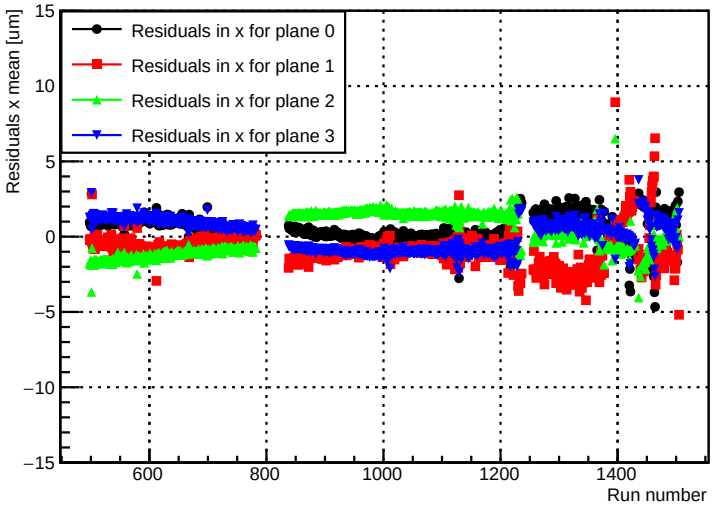
$\rightarrow \mathcal{X}^2$ can be analytically minimized

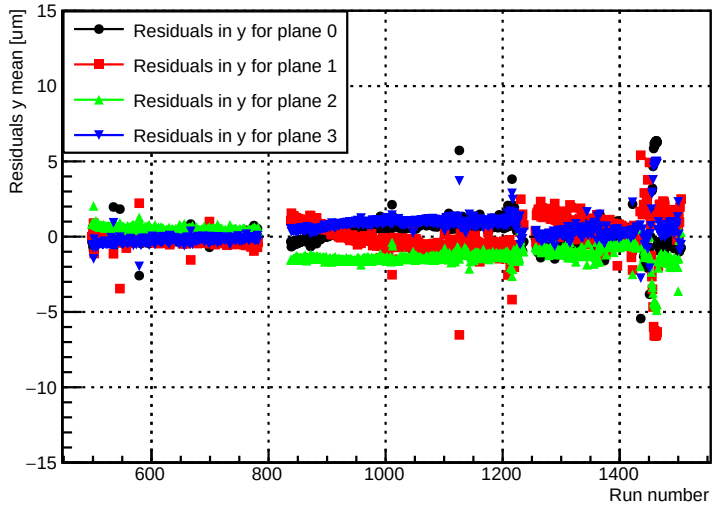
$$\mathcal{X}^2 = \sum_{i=1}^{n} \left(\frac{(x_i - (x_0 + a_x \cdot z_i))^2}{\sigma^2_{x_{m_i}}} + \frac{(y_i - (y_0 + a_y \cdot z_i))^2}{\sigma^2_{y_{m_i}}} \right)$$

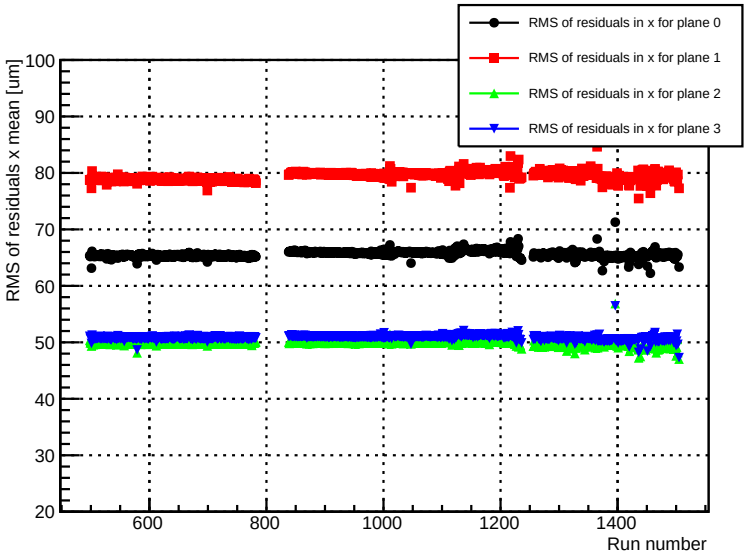
$$\text{assuming } \sigma_{x/y_{m_i}} = \text{pixel resolution} = \frac{\text{pixel size}}{\sqrt{12}}$$

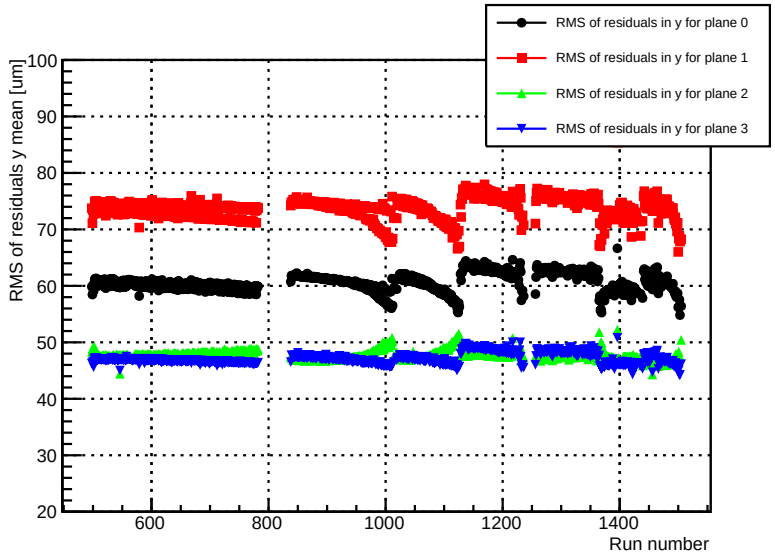
$\rightarrow$ Fast and robust track model!

Alignment @ DESY

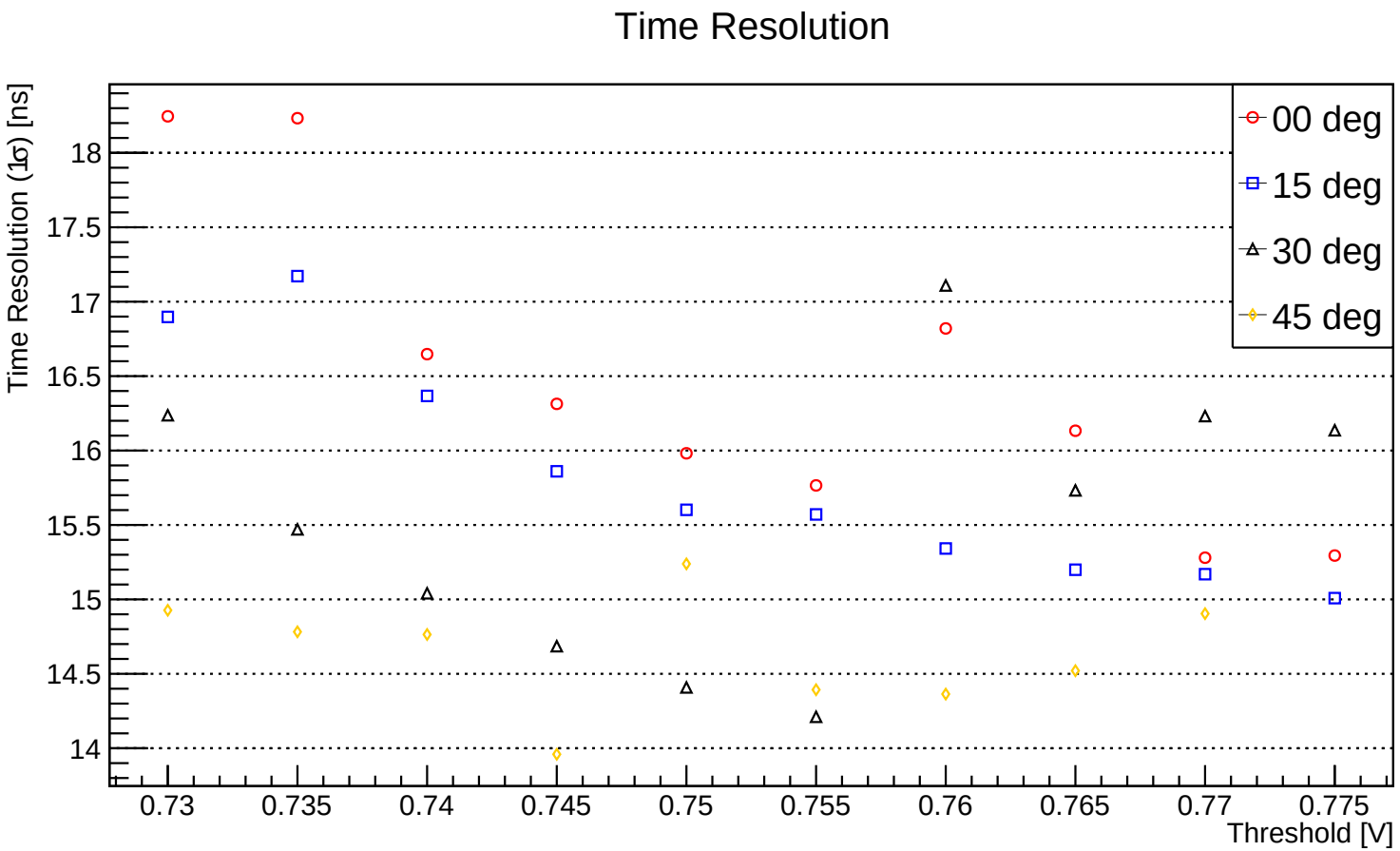




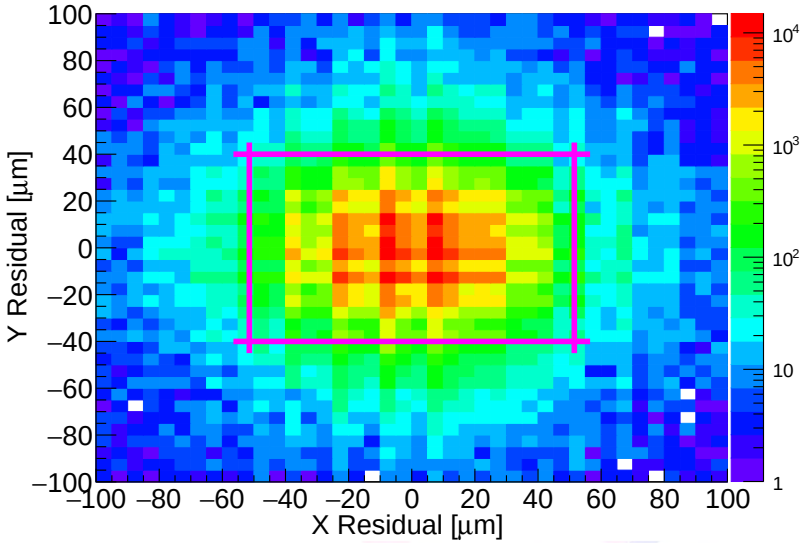


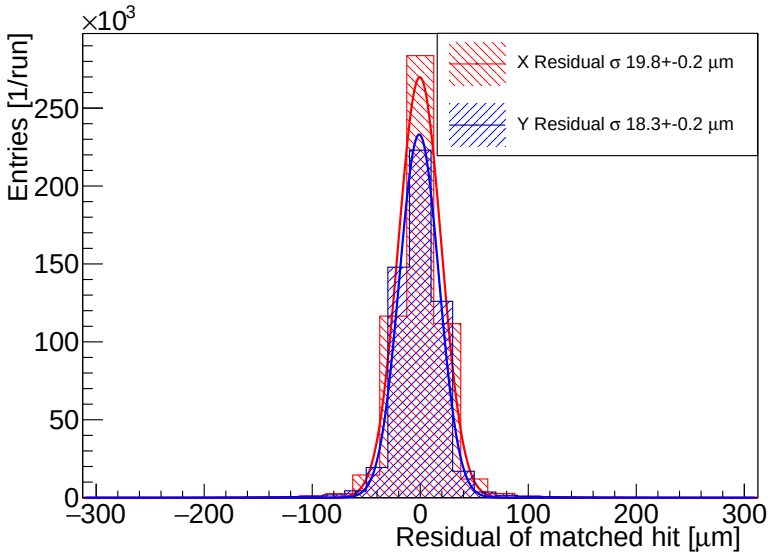


Telescope Timing @ DESY



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