HV-MAPS Tracking Telescope: Alignment and Efficiency Analysis

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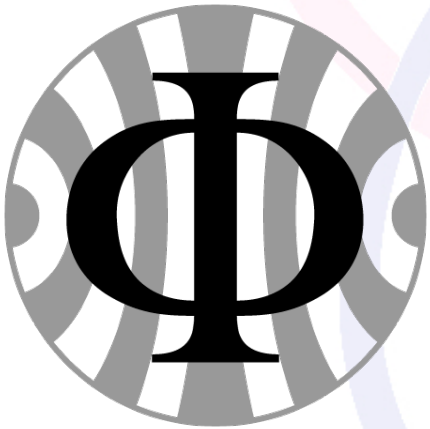
for the Mu3e Collaboration

DESY Telescope Workshop

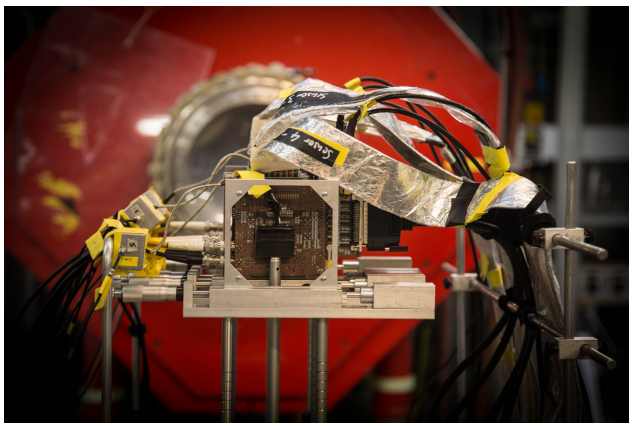
January 20, 2015



Physikalisches Institut Heidelberg

Outline

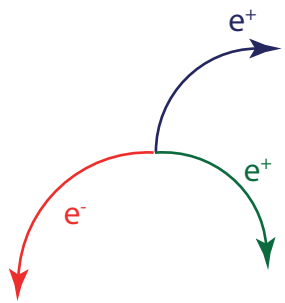
- The Mu3e Experiment
- Mupix Sensors
- Telescope Setup
- Beam Tests
- Alignment
- Efficiency Analysis



The Mu3e Experiment

Mu3e searches for the charged lepton-flavour violating decay $\mu^+ \to e^+e^+e^-$ with a sensitivity better than 10^{-16}

$$E_e < 53\,\mathrm{MeV}$$



Signal

- Coincident in time
- Single vertex
- $\Sigma \vec{p_i} = 0$
- $E = m_\mu$

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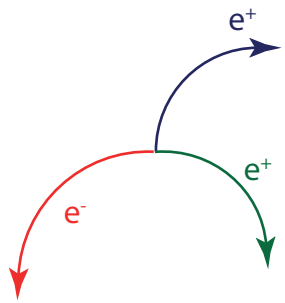
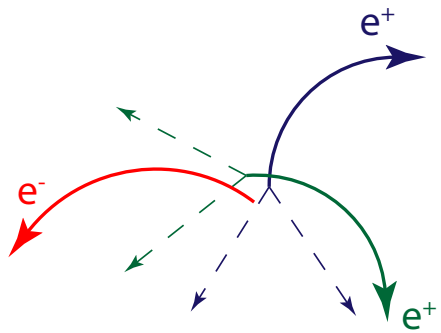




Signal

- Coincident in time
- Single vertex
- $\Sigma \vec{p_i} = 0$
- $E = m_\mu$

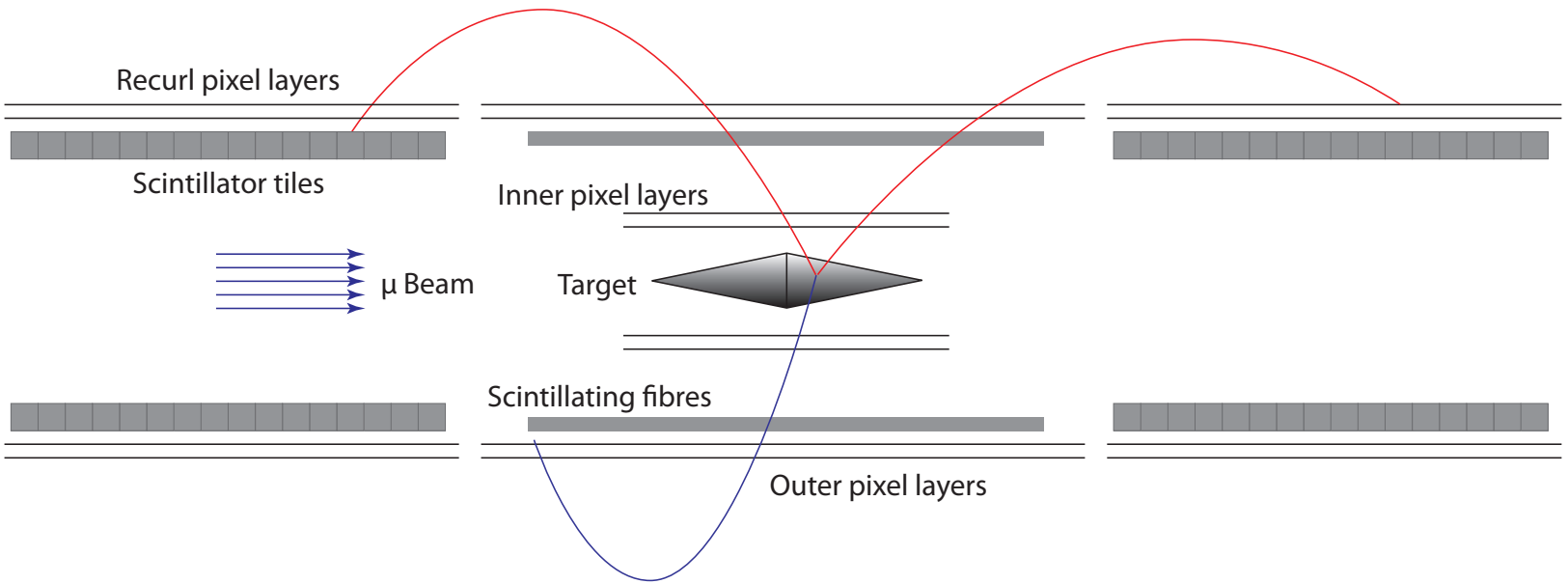
Random Combinations

- Not coincident in time
- No single vertex
- $\Sigma \vec{p_i} \neq 0$
- $E \neq m_\mu$

The Mu3e Detector

Requirements:

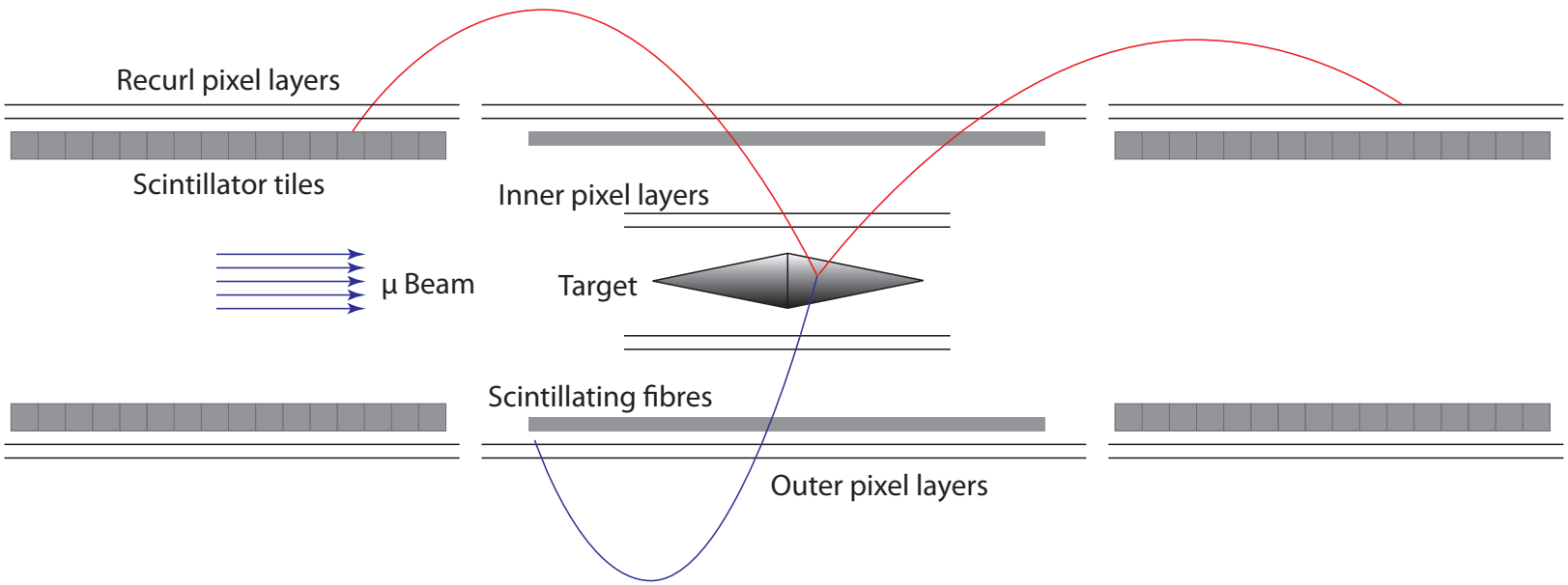
- Excellent momentum resolution: $< 0.5\,\mathrm{MeV/c}$
- Good timing resolution: 100 ps for tiles, 1 ns for fibres, 20-50 ns for pixels
- Good vertex resolution: 100 μm



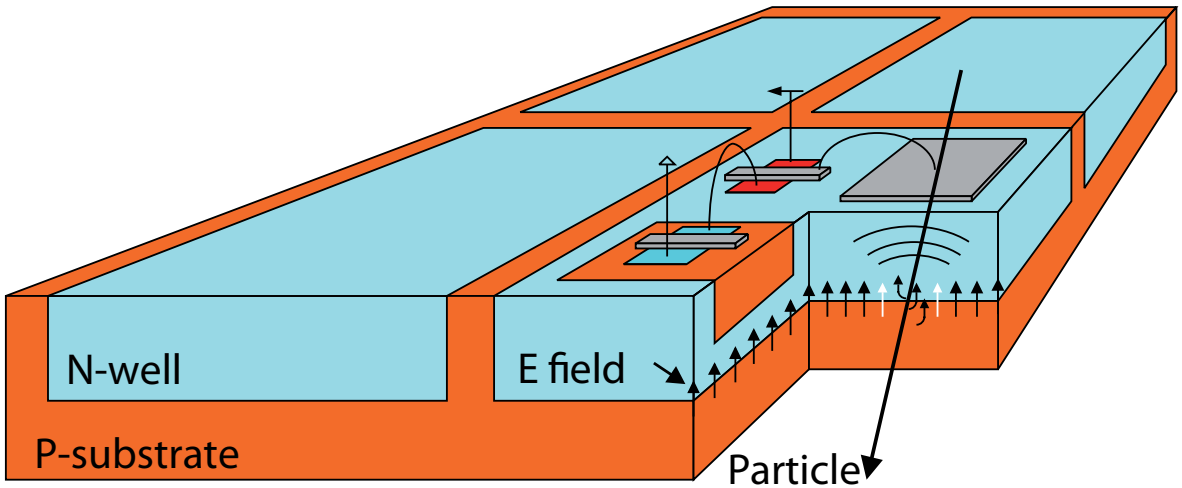
The Mu3e Detector

Requirements pixel detector:

- Pixel size: 80 μm x 80 μm
- Continuous readout frequency: 20 MHz
- Low material budget $\rightarrow$ 50 μm thickness



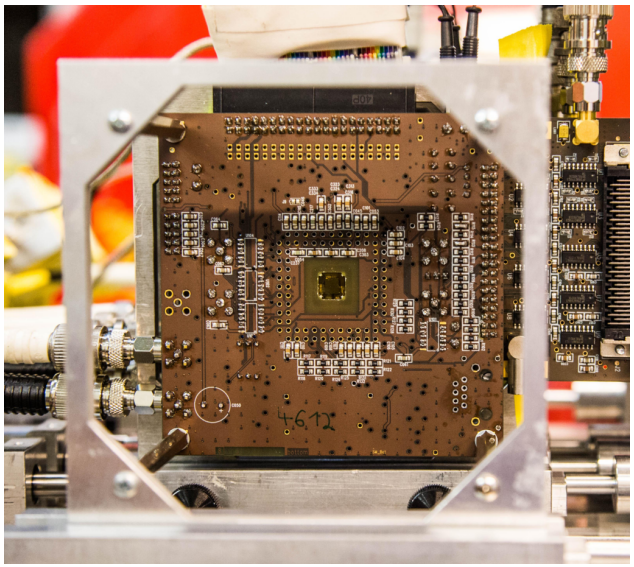
High Voltage Monolithic Active Pixel Sensors



- Zero suppressed readout
- 8 bit timestamps
- HV applied: 50 - 90 V
- Charge collection via drift

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

Mupix Prototypes



Mupix6

- Pixel area: 103 x 80 μm^2
- Active area: 9.4 mm^2
- Analog + digital readout
- Double stage amplifier
- Time stamp resolution: < 17 ns

- 250 μm chip
- On 100 μm PCB board
- $x/X_0 = 2.5‰$

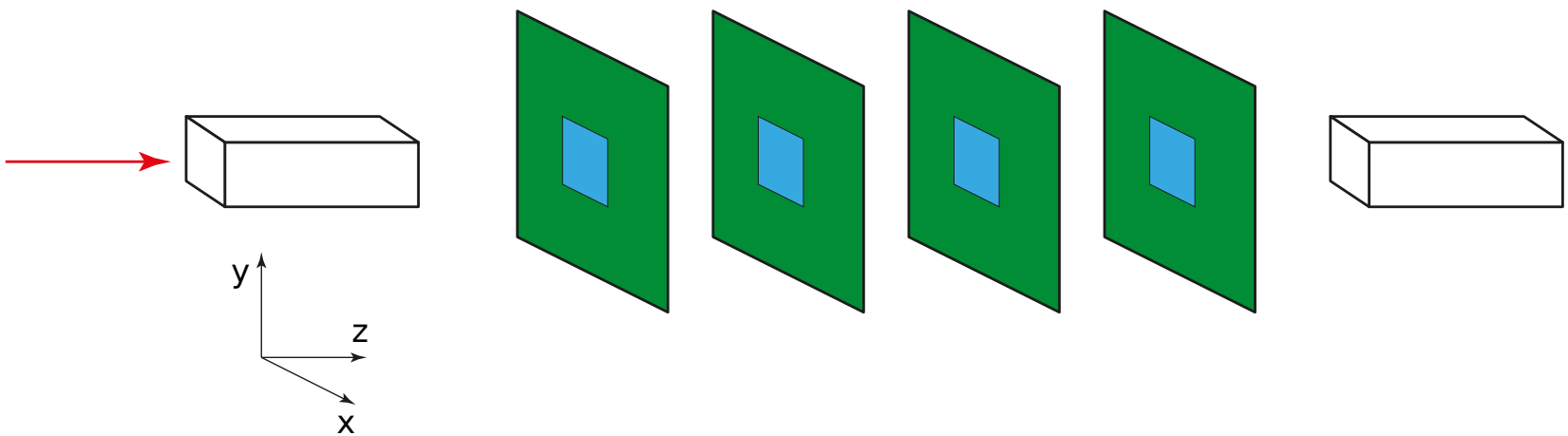
Thinned Mupix4

50 μm sensor on 25 μm Kapton foil

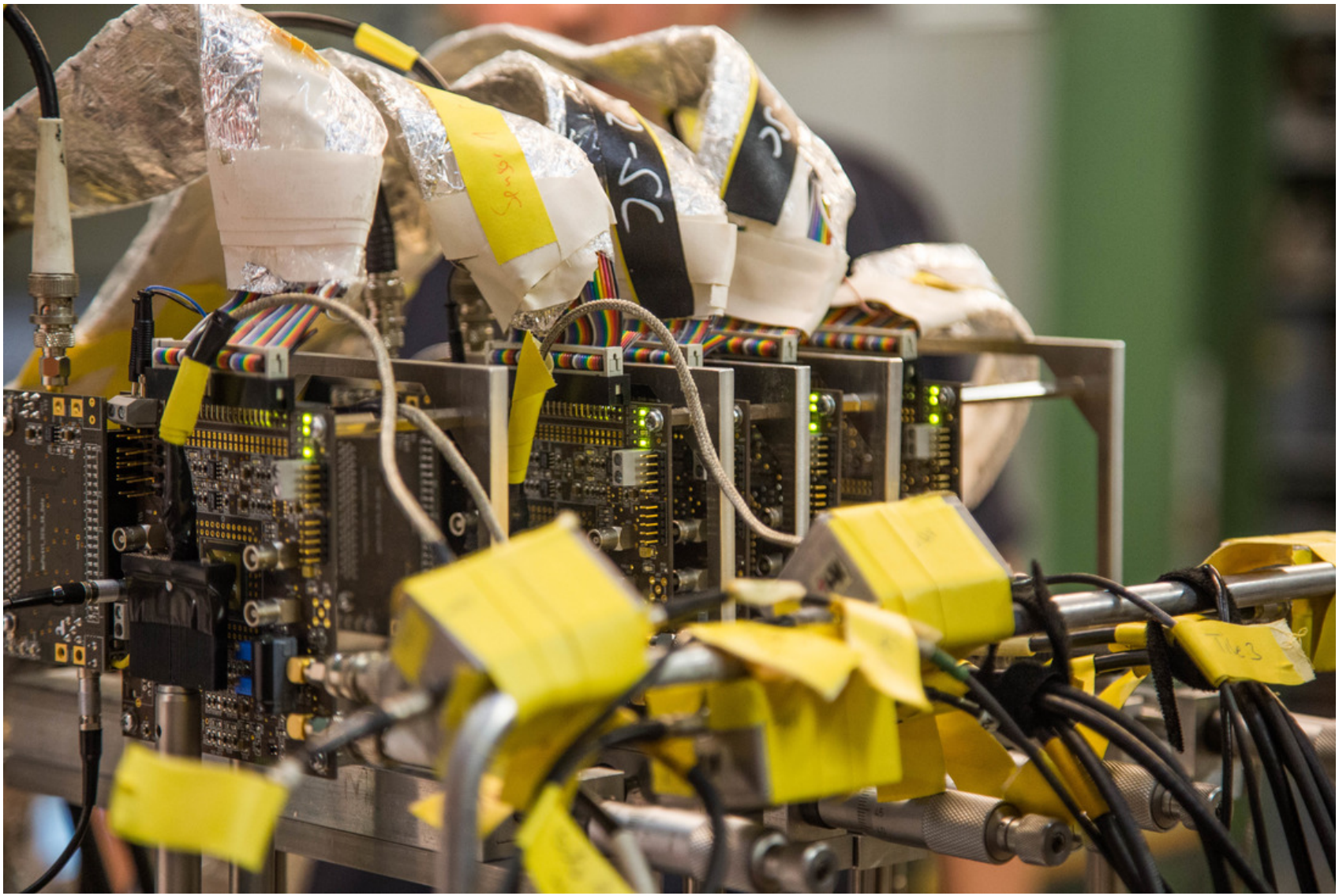
$\Rightarrow$ 0.6 ‰ radiation lengths

Telescope Setup

- 4 layers of Mupix6 sensors
- Read out by two FPGAs
- Scintillating tiles in front and back



Telescope Setup



Comparison with EUDET Telescope

	EUDET Telescope	HV-MAPS Telescope
Pixel size	18.4 μm x 18.4 μm	103 μm x 80 μm
Active area	224 mm^2	9.4 mm^2
Material	50 μm sensor 50 μm protective foil	50 μm sensor 25 μm Kapton
in radiation lengths	0.7 ‰	0.6 ‰
Time resolution	(115.2 / $\sqrt{12}$) μs	17 ns
Frame rate	9 kHz	20 MHz
Maximum track rate	$\sim$ 100 kHz	$\sim$ 20 MHz

Beam Tests

DESY

First test at T22 beamline with Mupix4 chips

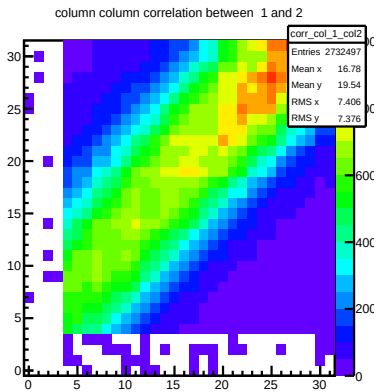
PSI

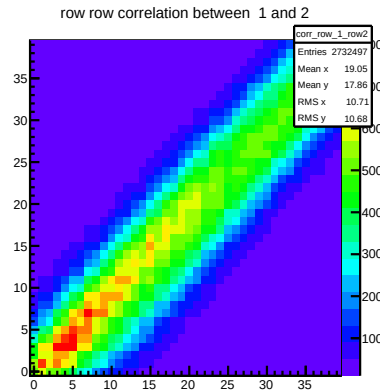
- πM1 beamline
- 250 MeV π, μ, e
- Beam trigger rate of tiles: $>$ kHz

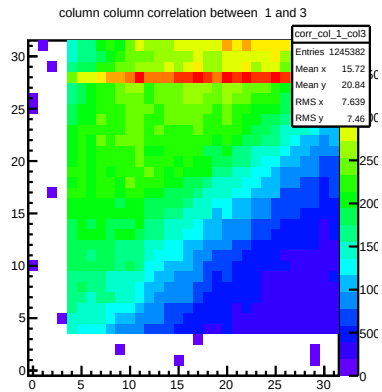
- First test with Mupix6 chips including time stamps
- On one layer (DUT), scans were performed:
  - High Voltage
  - Threshold Voltage

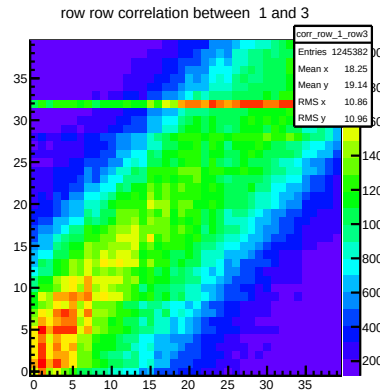
Online Alignment

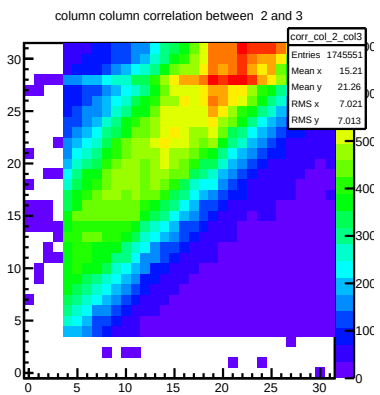
- Adjust planes mechanically with help of laser
- Study correlations between hits on different planes
  $\rightarrow$ Improve mechanical adjustment

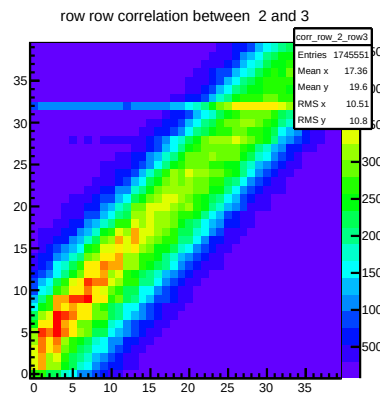


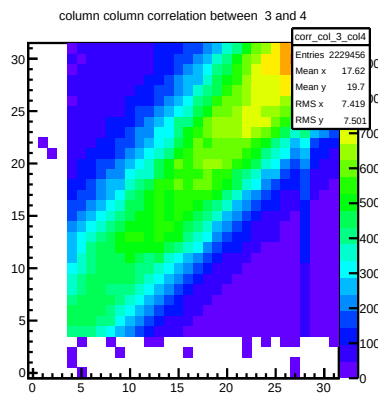


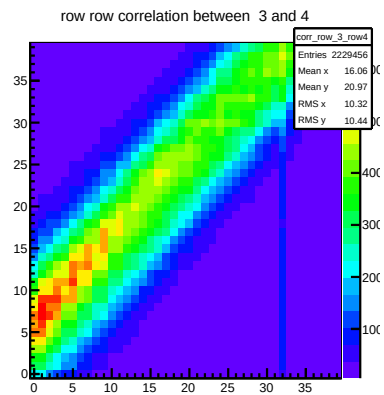












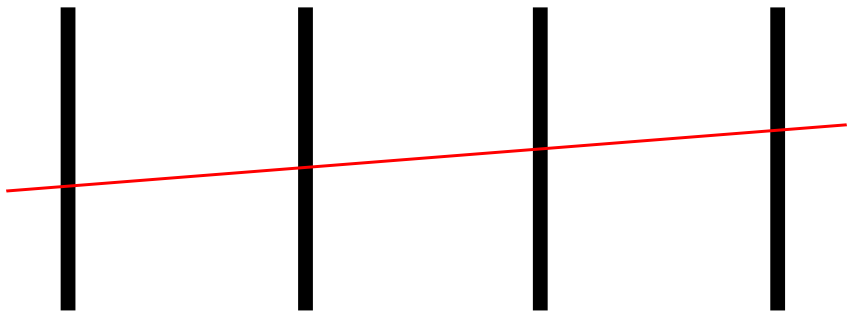
Straight Track Fit

Simple straight track:

$$\vec{x}(z) = \vec{x}_0 + \vec{a} \cdot z$$

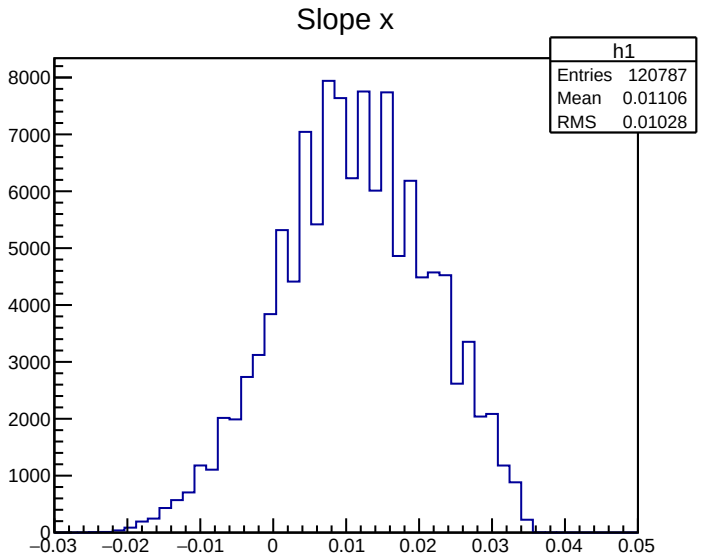
$\vec{x}$: x and y position

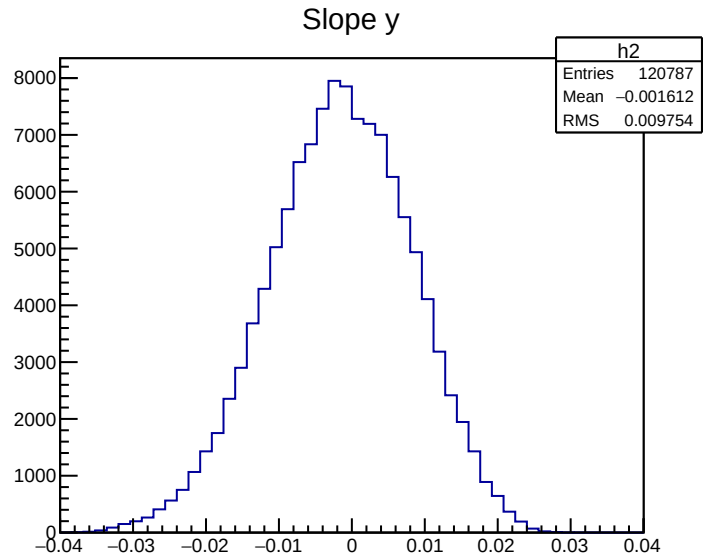
$\vec{a}$: two dimensional slope

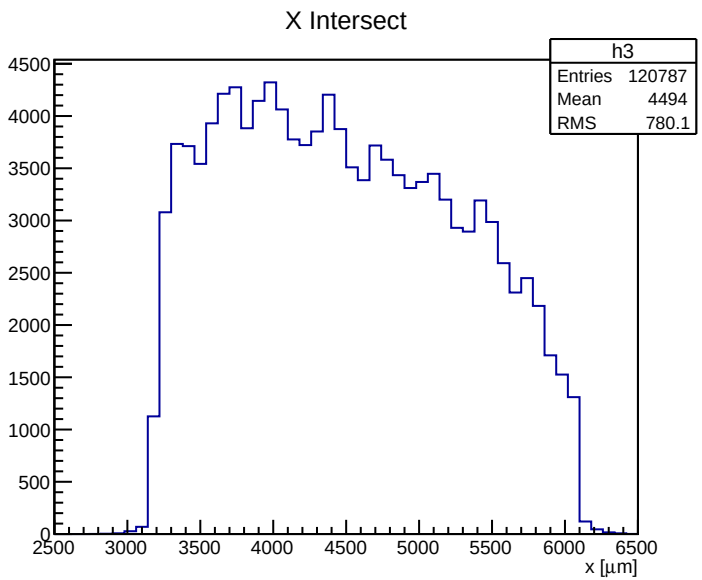


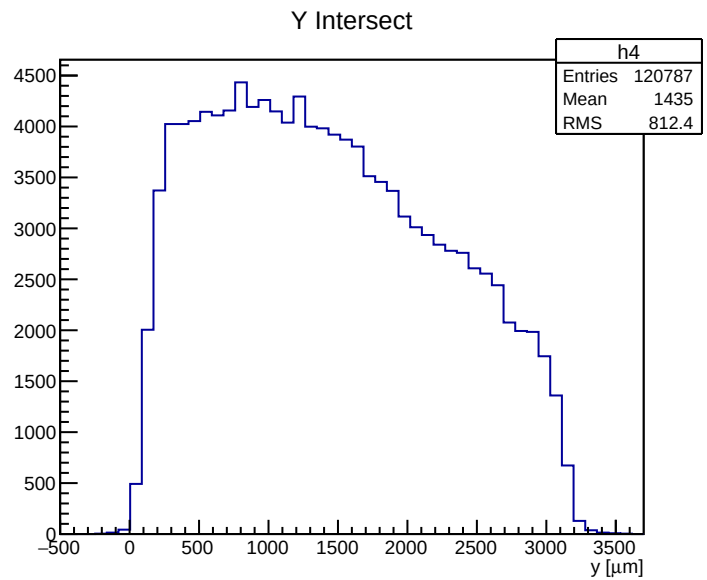
- Loop over all possible hit combinations and fit tracks with
  - 1 hit in each plane
  - $\Delta t < 250\,\text{ns}$
  - Hot pixels removed
- Calculate residuals
- Adjust alignment manually in several iterations

Fit: Position and Slope

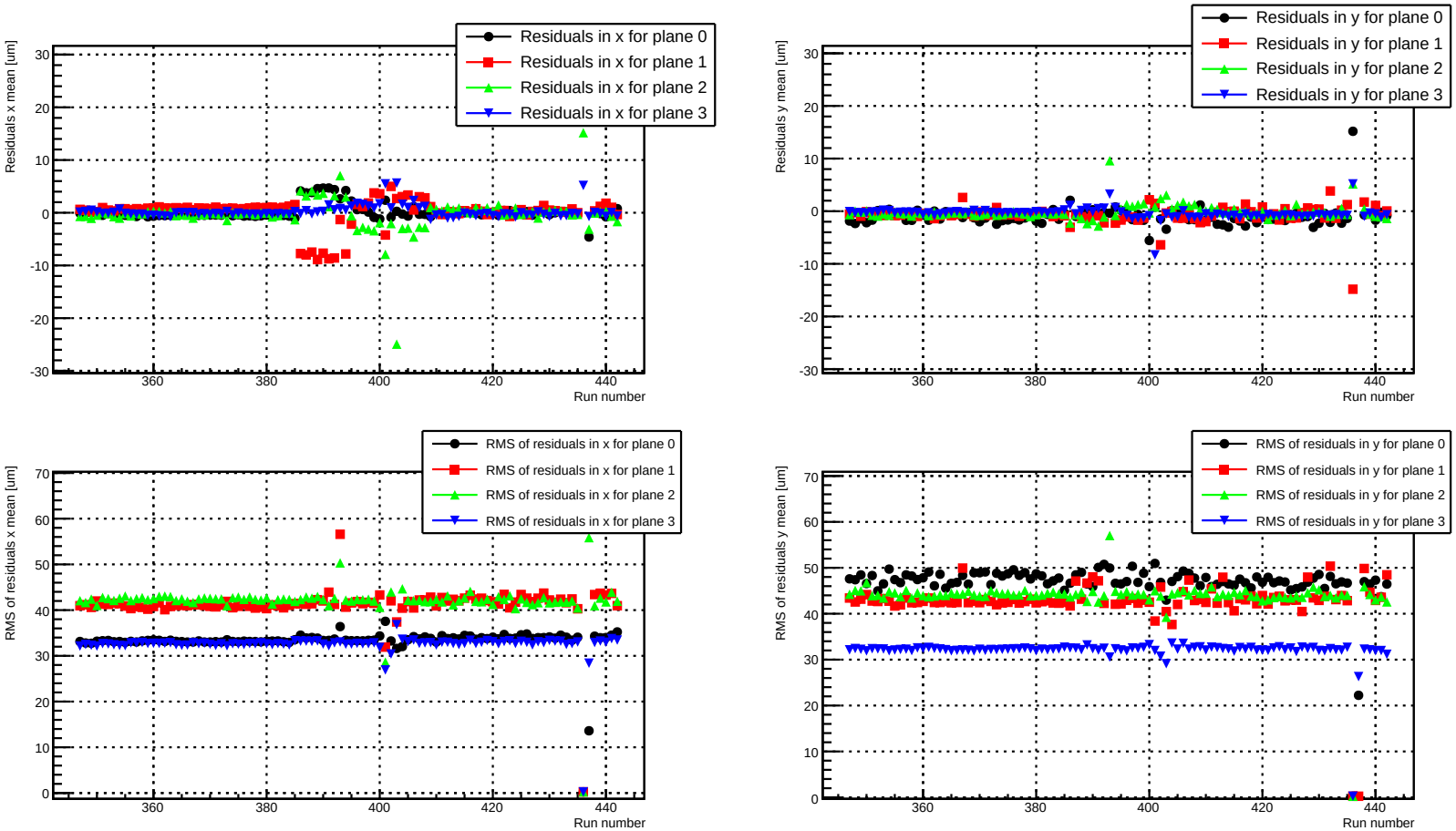






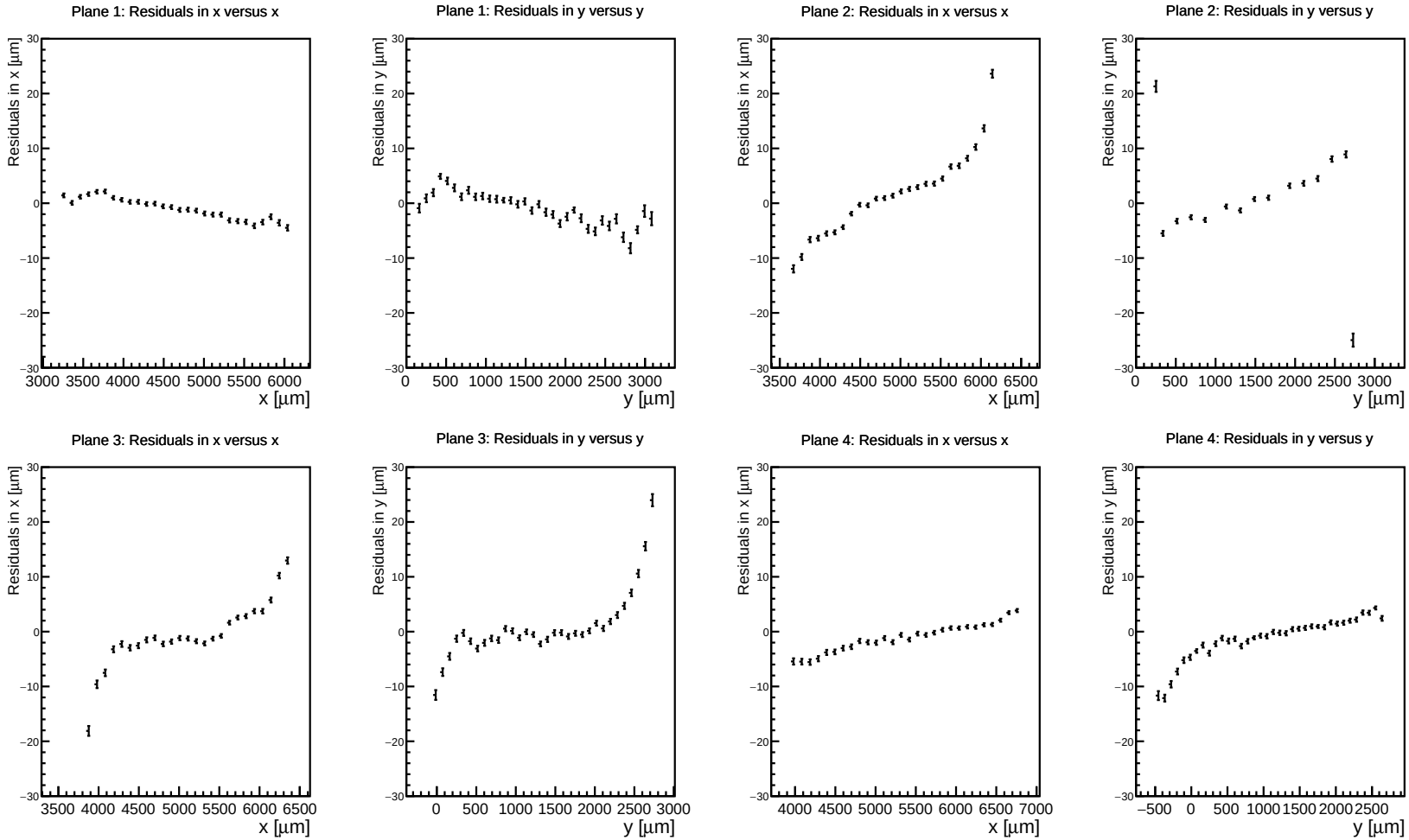


Residuals



Aligned to within 10 μm

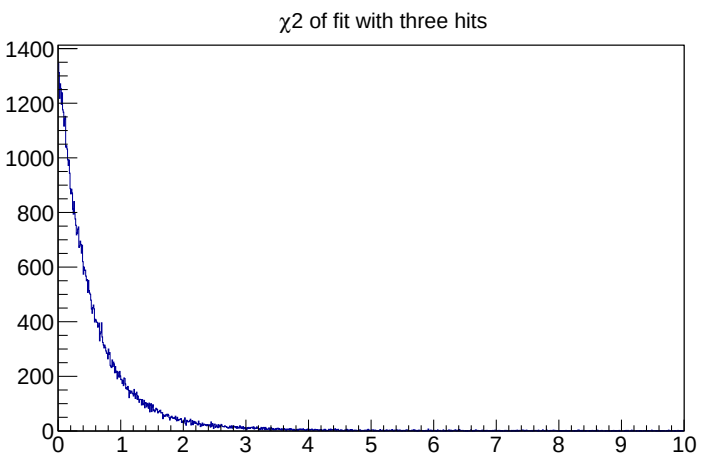
Residuals Versus Position

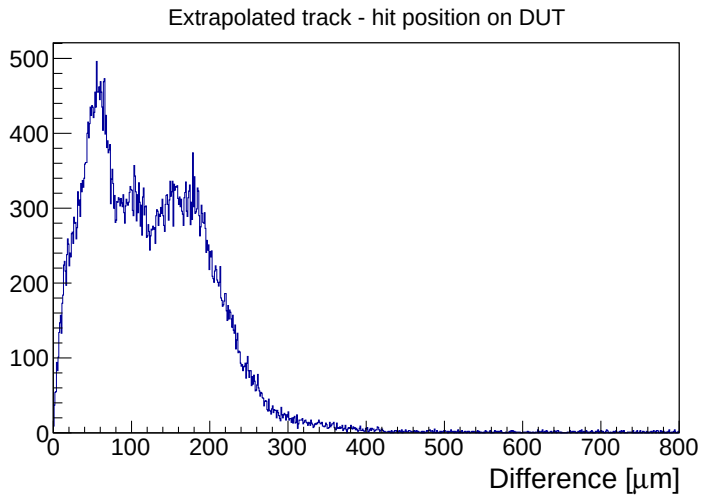


Threshold = 0.68 V, HV = 60 V, single run

Efficiency Analysis

- Fit tracks from three hits without DUT
- Extrapolate tracks onto DUT
- Match extrapolated tracks to hits on DUT

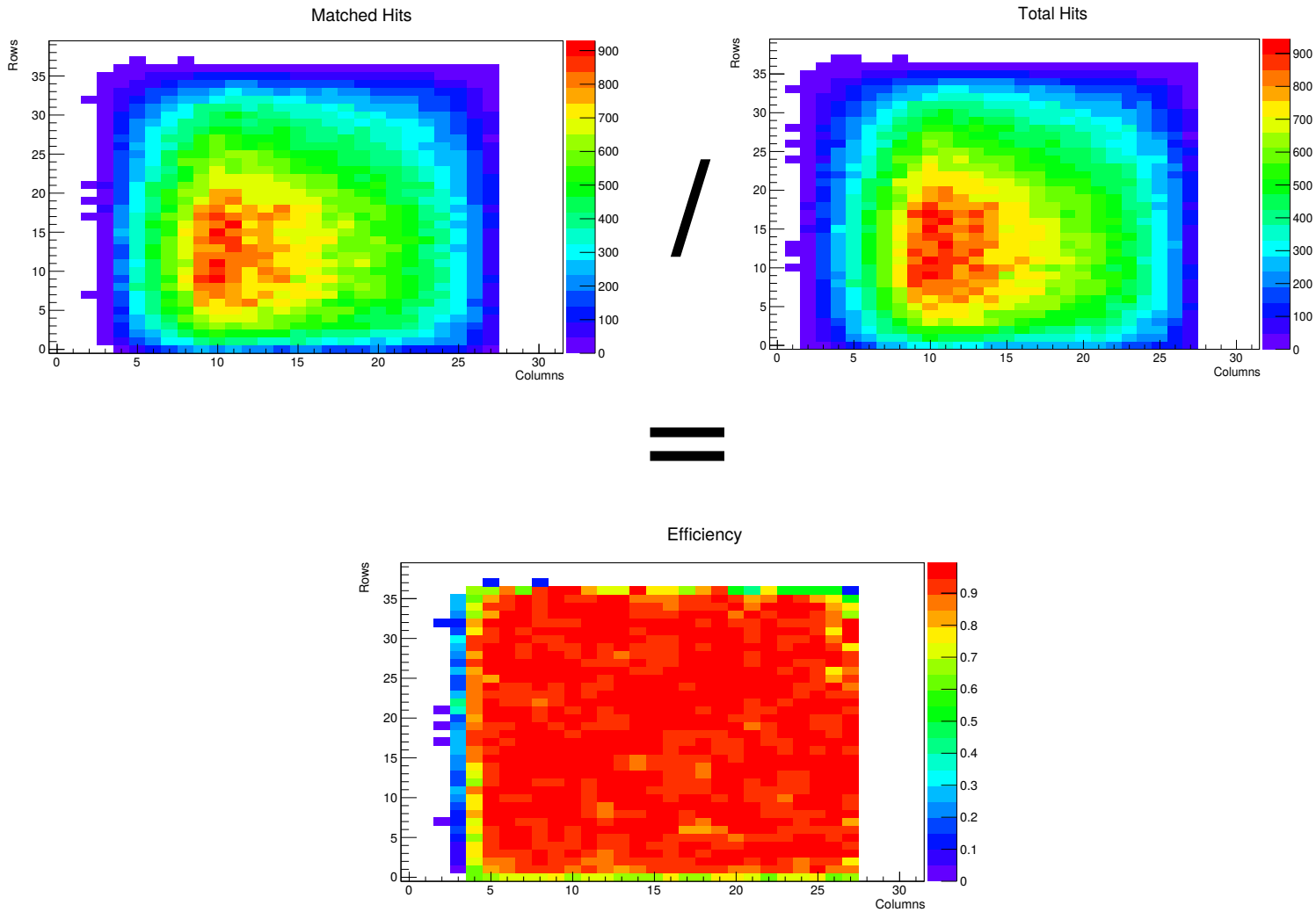




$\chi^2 < 2$

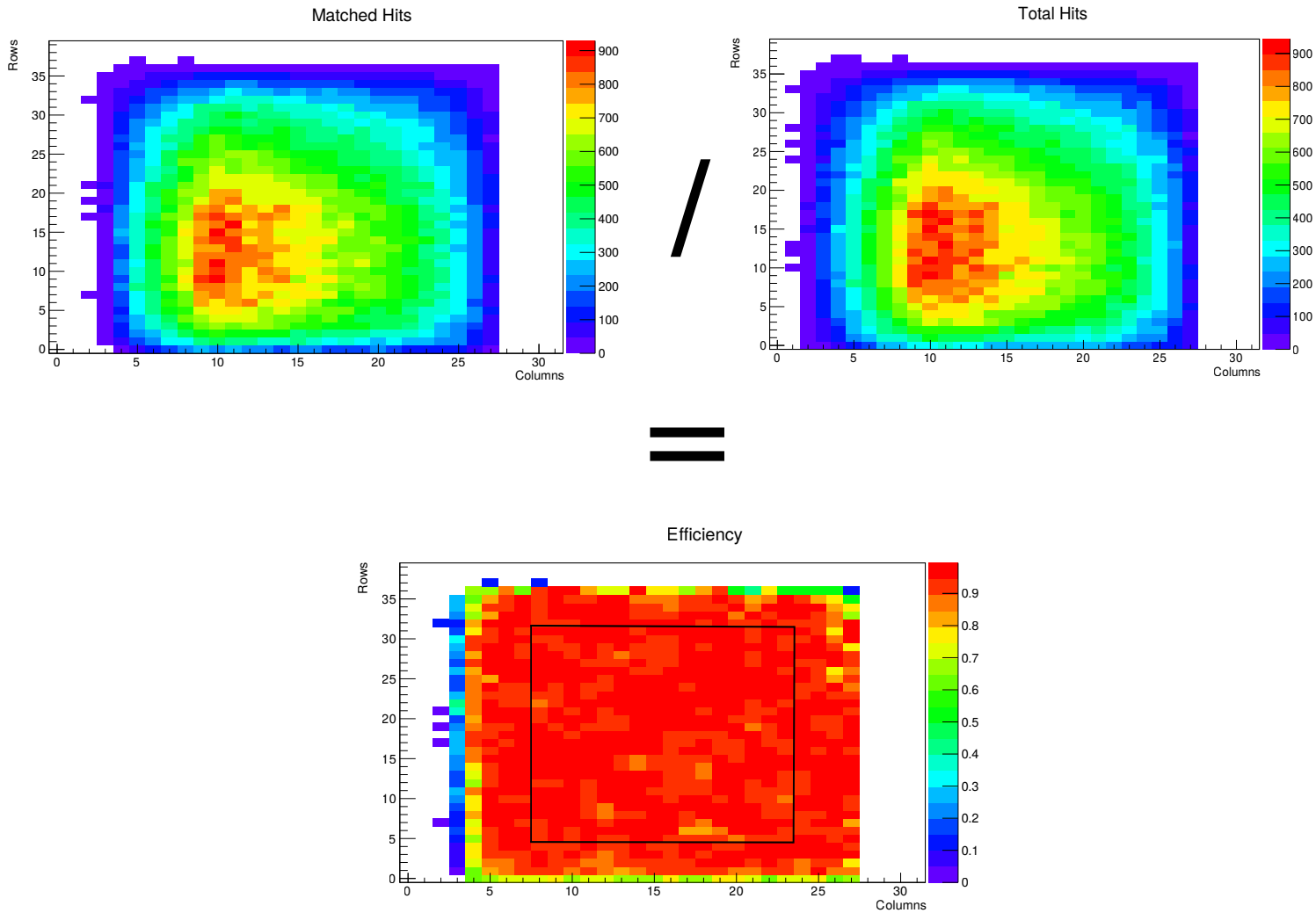
Difference $< 400\,\mu$m

Efficiency Analysis



Threshold = 0.7 V, HV = 60 V

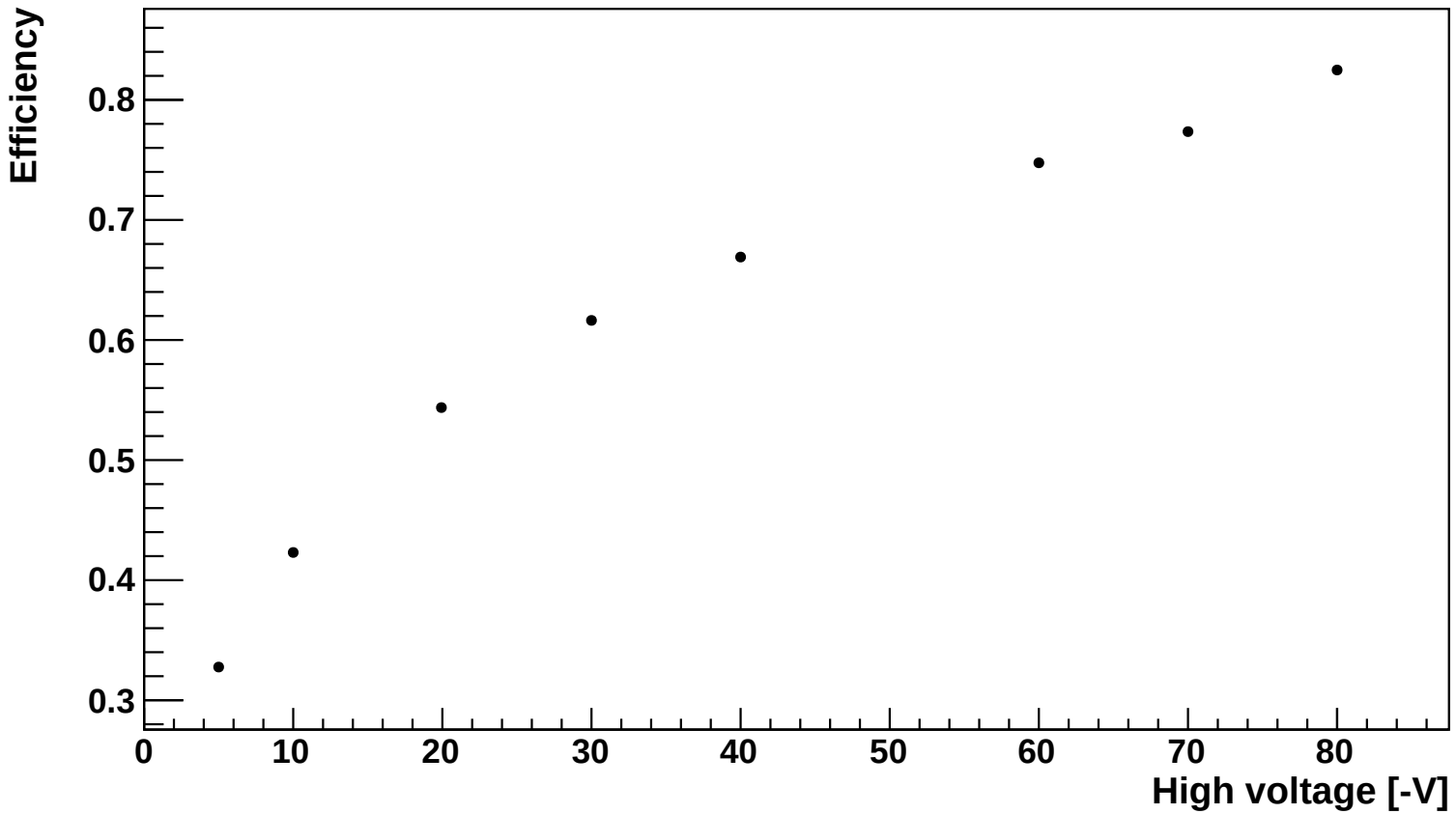
Efficiency Analysis



Threshold = 0.7 V, HV = 60 V

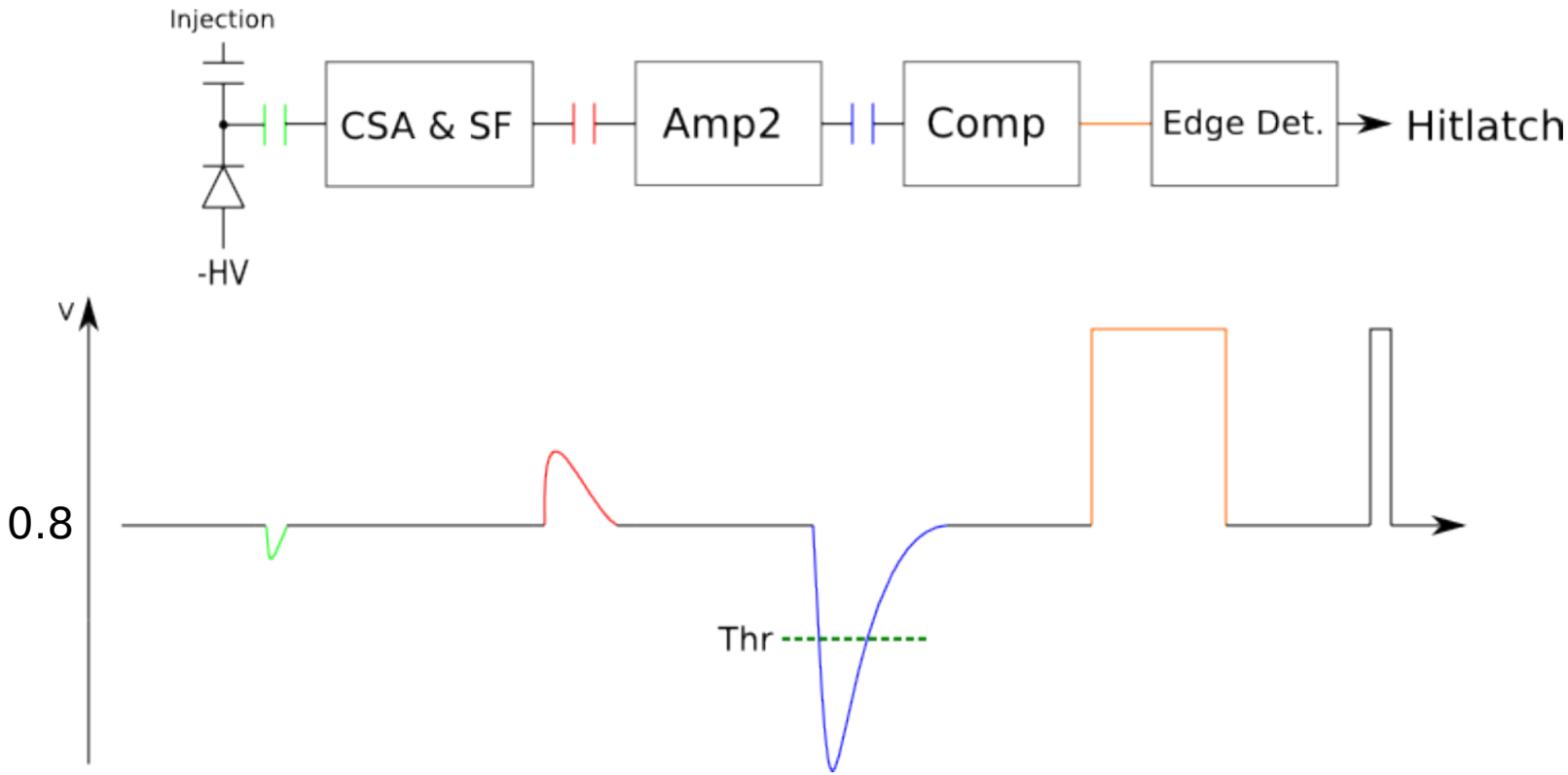
High Voltage Scan

Threshold = 0.65 V



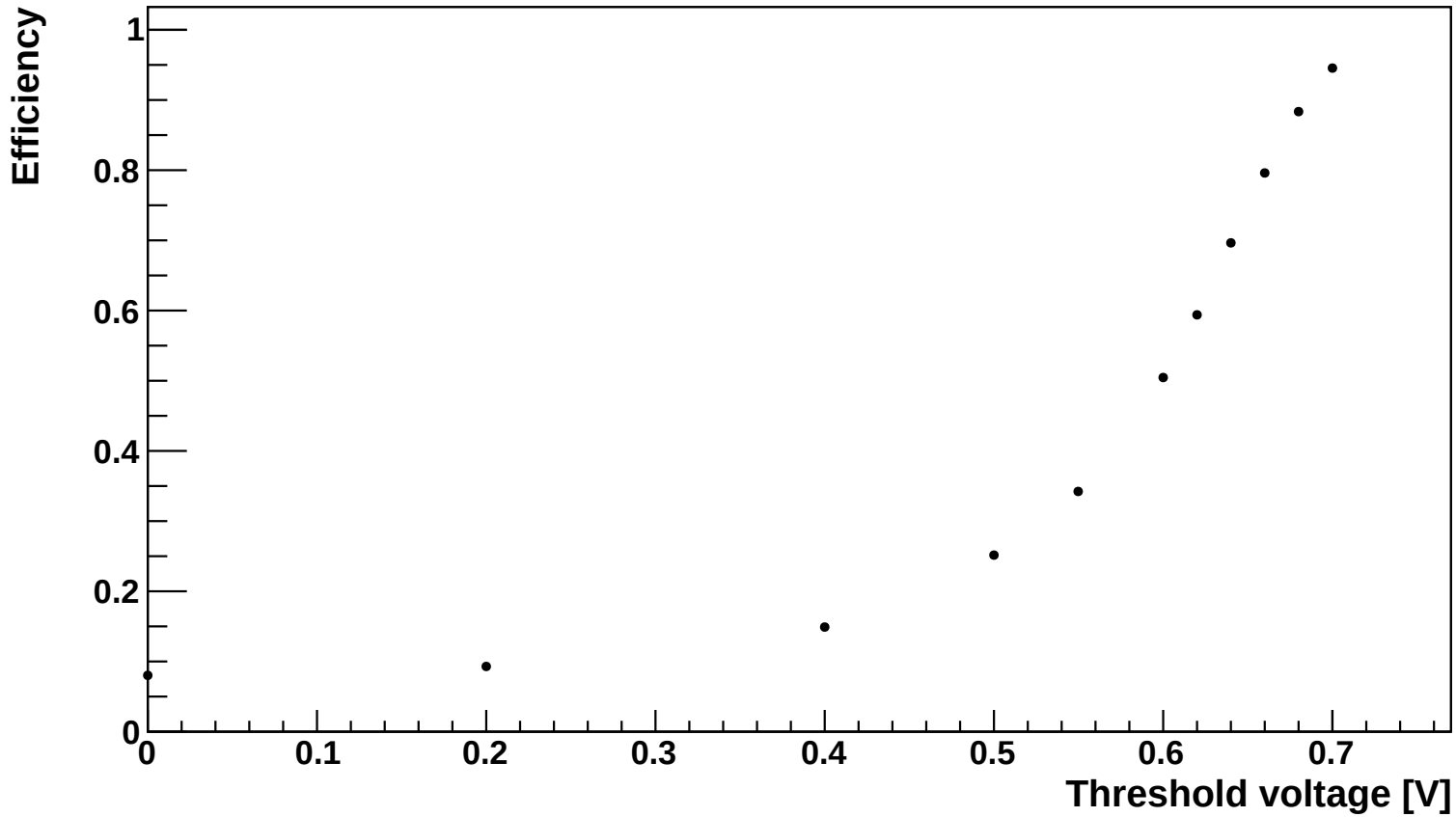
by Jan Repenning

Signal Wave Form



Threshold Scan

HV = 60 V



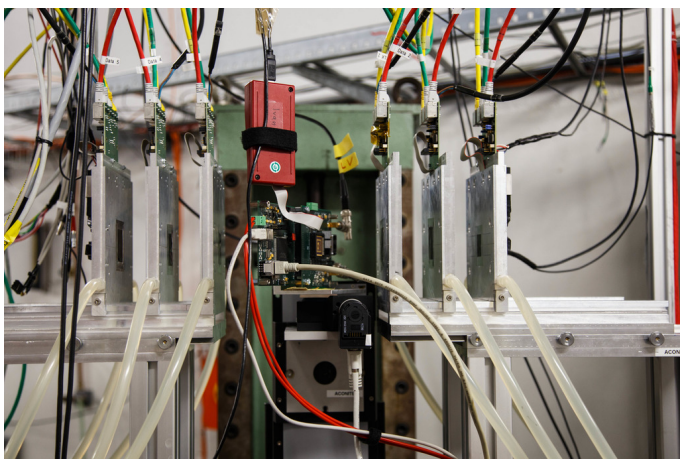
by Jan Repenning

Conclusions

- First test of Mupix6 telescope
- Achieved alignment:
  - to within 10 μm
  - minimized rotations of planes
- Straight track model works
- Efficiency of Mupix6 determined to $> 94\,\%$
- Voltage and threshold dependency studied

Outlook

- Improve mechanics:
  - Adjust y-position more precisely
  - Integrate tiles as triggers with movable posts
- Possibly use software for minimization of residuals and alignment, such as Millepede



Next beam test at DESY in March:

- Further measurements at other thresholds
- Test new prototype Mupix7

Final goal: Working telescope with online reconstruction, streaming readout
$\Rightarrow$ Test Mu3e DAQ

Thank you for your attention!

Backup Slides

Time Resolution