

HV-MAPS Tracking Telescope: Alignment and Efficiency Analysis

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for the Mu3e Collaboration

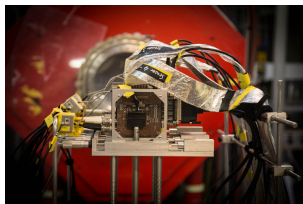
DESY Telescope Workshop

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Physikalisches Institut Heidelberg

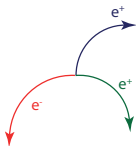
- The Mu3e Experiment
- Mupix Sensors
- Telescope Setup
- Beam Tests
- Alignment
- Efficiency Analysis





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

$$E_e < 53 \text{ MeV}$$



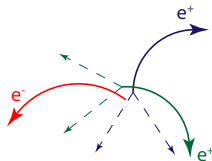
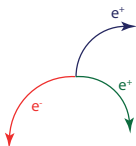
Signal

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



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- Single vertex
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Random Combinations

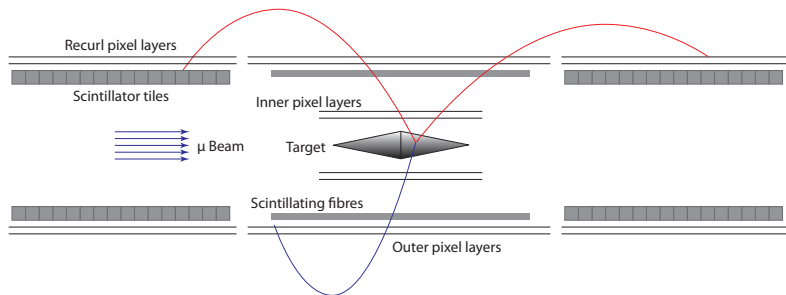
- Not coincident in time
- No single vertex
- $\Sigma \vec{p}_i \neq 0$
- $E \neq m_\mu$

The Mu3e Detector



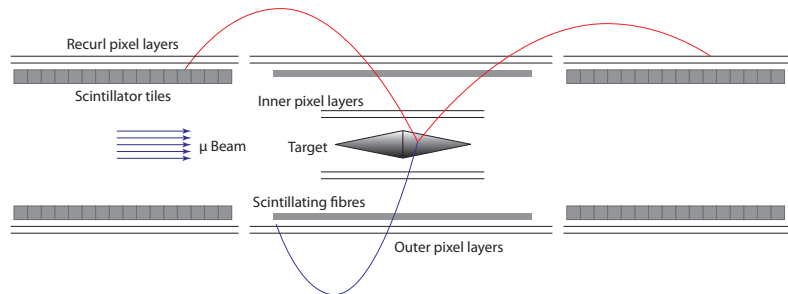
Requirements:

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

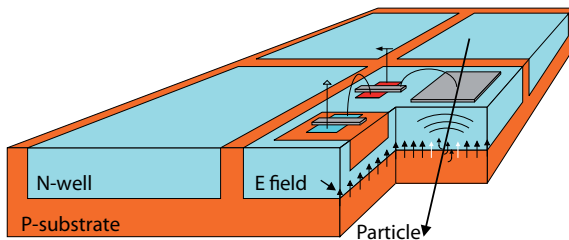


Requirements pixel detector:

- Pixel size: $80\ \mu\text{m} \times 80\ \mu\text{m}$
- Continuous readout frequency: 20 MHz
- Low material budget $\rightarrow 50\ \mu\text{m}$ thickness



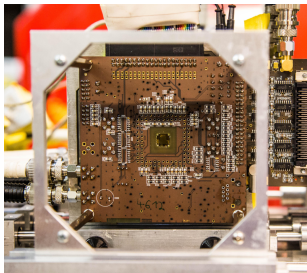
High Voltage Monolithic Active Pixel Sensors



- 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)

Mupix6



- Pixel area: $103 \times 80 \mu\text{m}^2$
- Active area: 9.4 mm^2
- Analog + digital readout
- Double stage amplifier
- Time stamp resolution: $< 17 \text{ ns}$
- $250 \mu\text{m}$ chip
- On $100 \mu\text{m}$ PCB board
- $x/X_0 = 2.5\%$

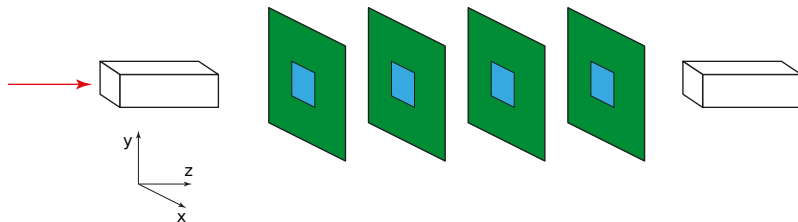
Thinned Mupix4

$50 \mu\text{m}$ sensor on $25 \mu\text{m}$ Kapton foil
 $\Rightarrow 0.6\%$ radiation lengths

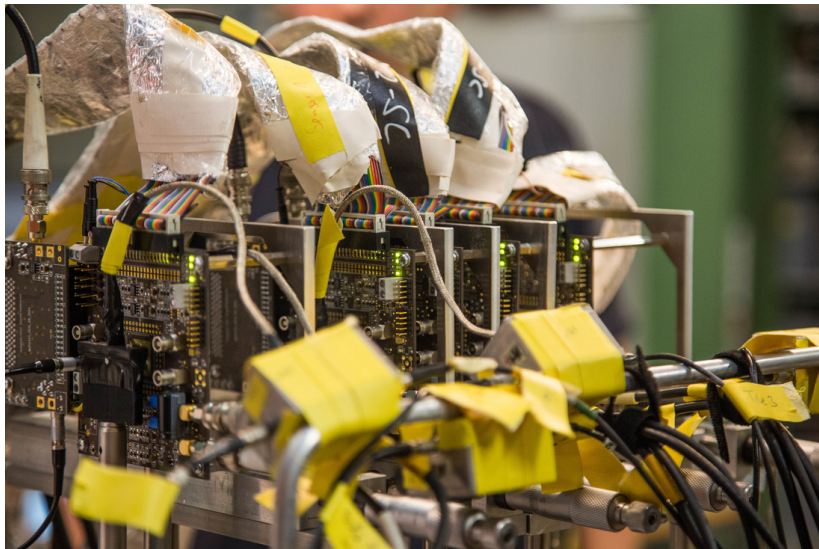
Telescope Setup



- 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	$18.4 \mu\text{m} \times 18.4 \mu\text{m}$	$103 \mu\text{m} \times 80 \mu\text{m}$
Active area	224 mm^2	9.4 mm^2
Material	50 μm sensor	50 μm sensor
	50 μm protective foil	25 μm Kapton
in radiation lengths	0.7 ‰	0.6 ‰
Time resolution	$(115.2 / \sqrt{12}) \mu\text{s}$	17 ns
Frame rate	9 kHz	20 MHz
Maximum track rate	$\sim 100 \text{ kHz}$	$\sim 20 \text{ MHz}$



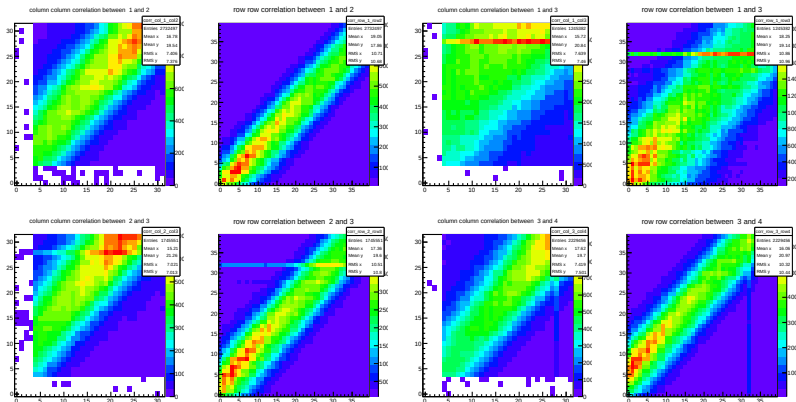
DESY

First test at T22 beamline with Mupix4 chips

PSI

- π M1 beamline
- 250 MeV π , μ , e
- Beam trigger rate of tiles: $> \text{kHz}$
- First test with Mupix6 chips including time stamps
- On one layer (DUT), scans were performed:
 - High Voltage
 - Threshold Voltage

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



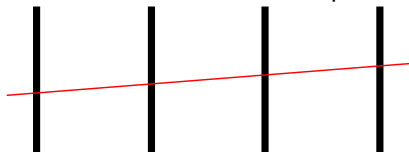


Simple straight track:

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

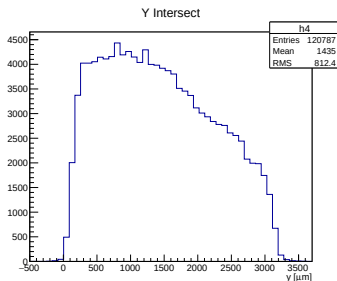
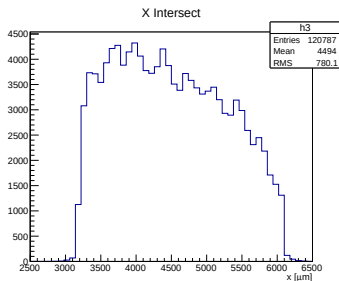
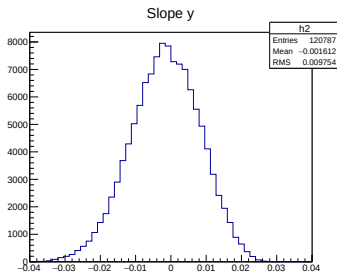
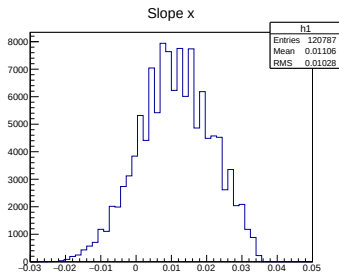
$\vec{x}$: x and y position

$\vec{a}$: two dimensional slope

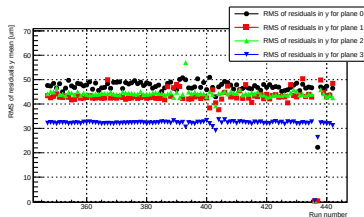
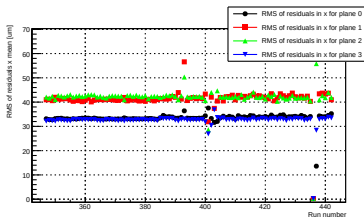
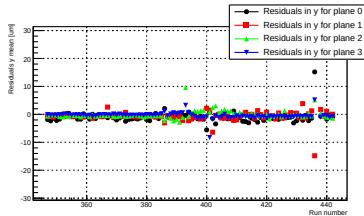
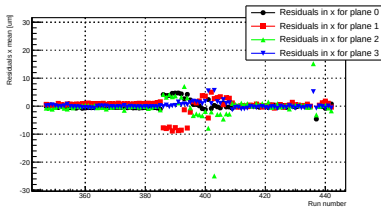


- Loop over all possible hit combinations and fit tracks with
 - 1 hit in each plane
 - $\Delta t < 250$ ns
 - Hot pixels removed
- Calculate residuals
- Adjust alignment manually in several iterations

Fit: Position and Slope

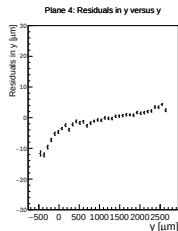
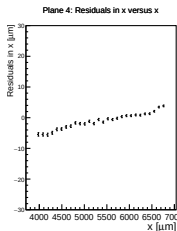
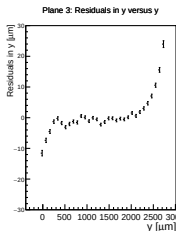
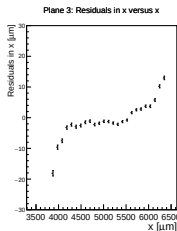
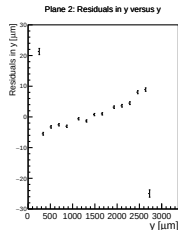
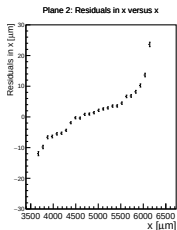
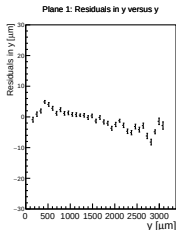
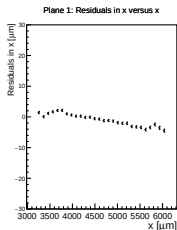


Residuals



Aligned to within 10 μm

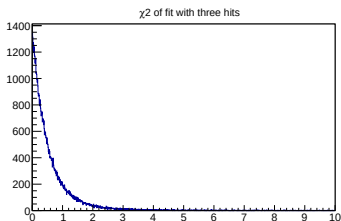
Residuals Versus Position



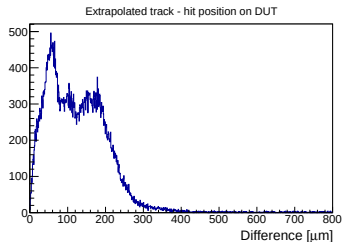
Threshold = 0.68 V, HV = 60 V, single run



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

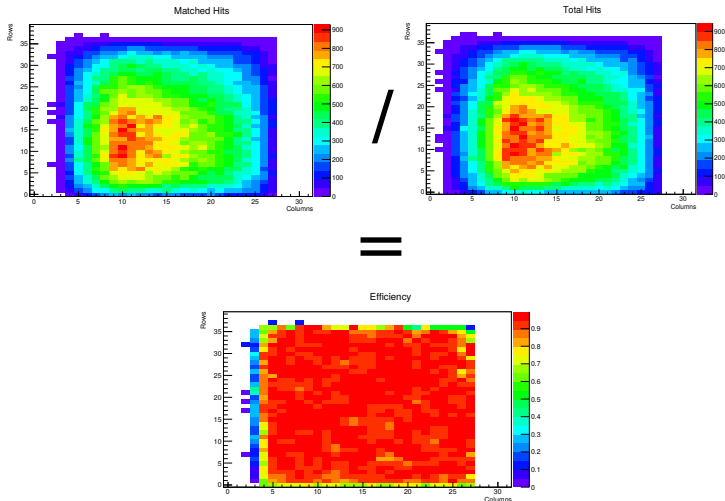


$$\chi^2 < 2$$



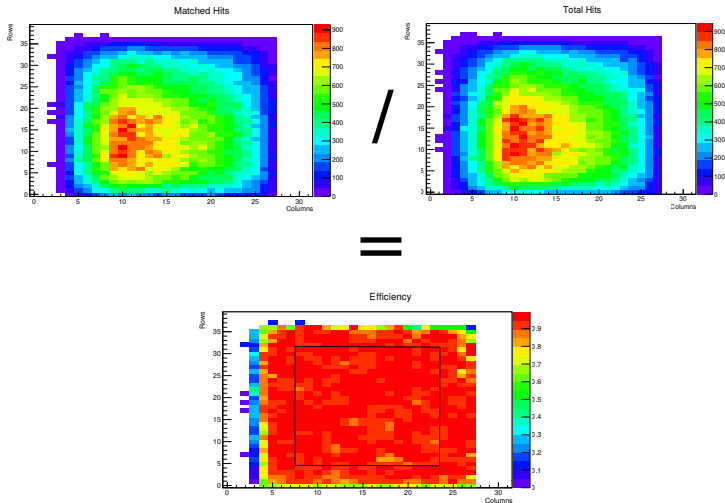
$$\text{Difference} < 400 \mu\text{m}$$

Efficiency Analysis



Threshold = 0.7 V, HV = 60 V

Efficiency Analysis

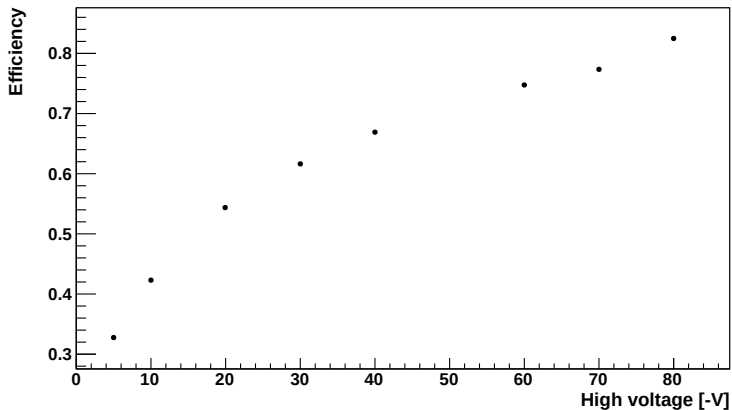


Threshold = 0.7 V, HV = 60 V

High Voltage Scan

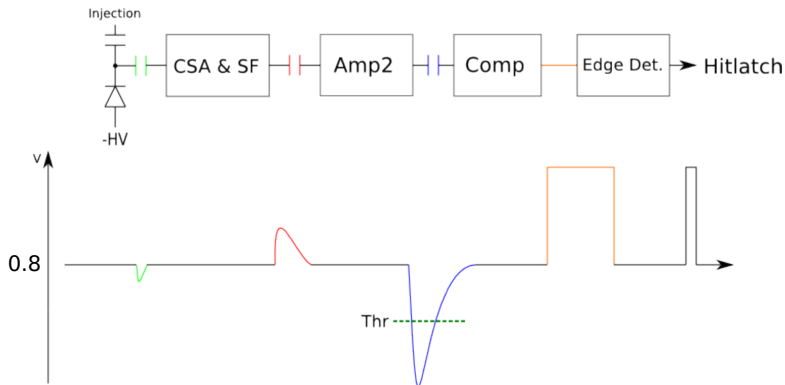


Threshold = 0.65 V



by Jan Repenning

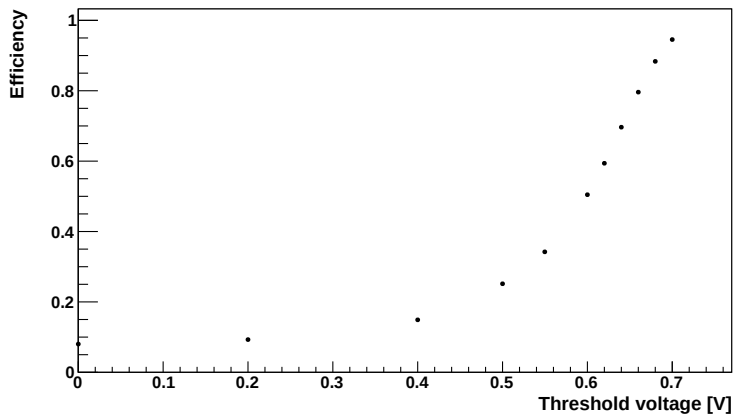
Signal Wave Form



Threshold Scan



HV = 60 V

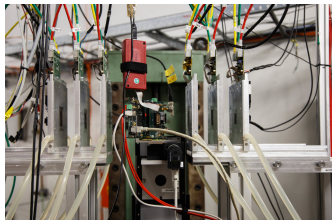


by Jan Repenning

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



- 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
⇒ Test Mu3e DAQ



Thank you for your attention!



Backup Slides

