

# A Thin Silicon Pixel Tracker for the Mu3e Experiment

Adrian Herkert

on behalf of the Mu3e collaboration

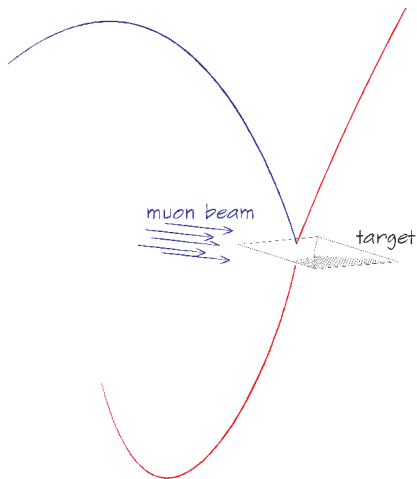
Physics Institute Heidelberg

29.03.2017



# The Mu3e Experiment

Search for the decay  $\mu^+ \rightarrow e^+ e^- e^+$



$B = 1\text{ T}$

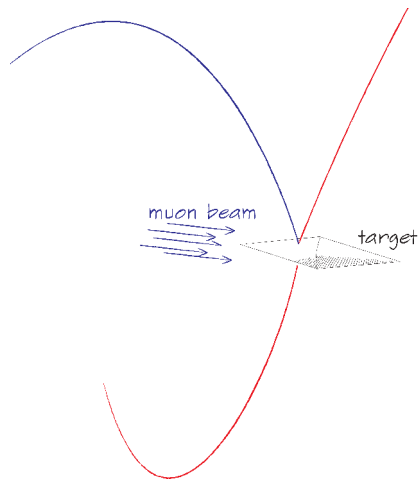
- Standard Model:  
 $\text{BR} < 10^{-54}$
- Current upper BR limit:  
 $1.0 \times 10^{-12}$  at 90% CL  
(SINDRUM, 1988)

[U. Bellgardt et al., Nucl. Phys. B 299 1, 1988.](#)

- Mu3e sensitivity goal:  
1 in  $10^{16}$   $\mu$ -decays
- $\mu$ -rate:  
 $\sim 10^9 \frac{1}{\text{s}}$

# The Signal

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



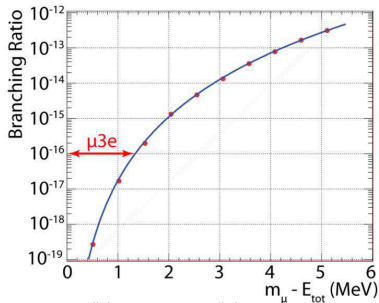
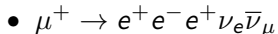
B = 1 T

- Common vertex
- Coincident in time
- $\left(\sum_{i=1}^3 p_i\right)^2 = m_\mu^2$
- $\left|\sum_{i=1}^3 \vec{p}_i\right| = 0$

# Background



## Internal Conversion

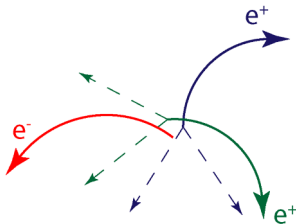


R. M. Djilkibaev, R. V. Konoplich,  
Phys. Rev. D 79, 073004, 2009.

→ High momentum resolution  
needed

## Accidentals

- Ordinary Michel decays  
plus additional  $e^-$

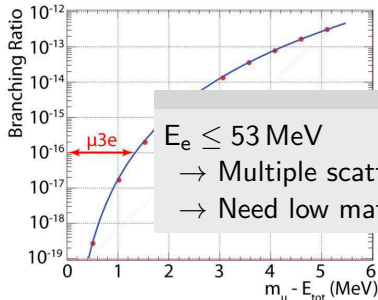
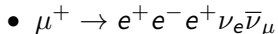


→ High momentum, time, and  
vertex resolution needed

# Background



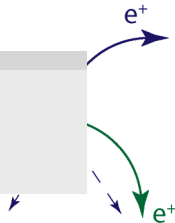
## Internal Conversion



R. M. Djilkibaev, R. V. Konoplich,  
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## Accidentals

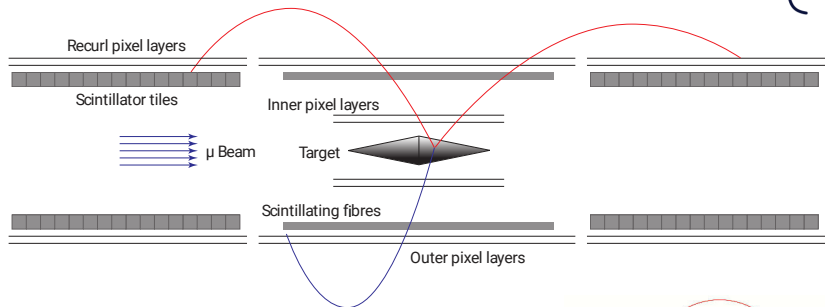
- Ordinary Michel decays plus additional  $e^-$



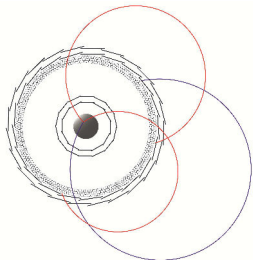
→ High momentum resolution needed

→ High momentum, time, and vertex resolution needed

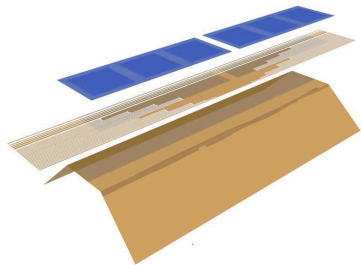
# Detector Design for Minimum Material Budget



- Pixel tracker: 4 barrels of thin pixel sensors
- Timing detectors:
  - Fibre tracker inside central detector
  - Scintillating tiles inside recurl stations
- 1 T solenoid

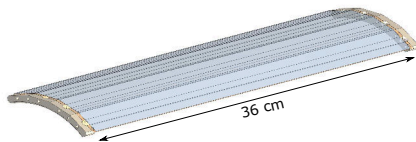


# Pixel Tracker Mechanics

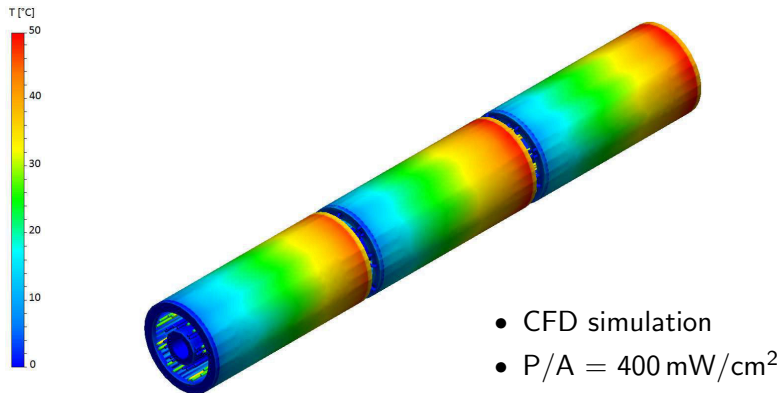


$$\rightarrow x/X_0 \approx 0.1\%$$

- HV-MAPS
  - thinned to 50  $\mu\text{m}$
- Flexprint ([T46.6](#))
- Kapton support structure
  - 25  $\mu\text{m}$  thin

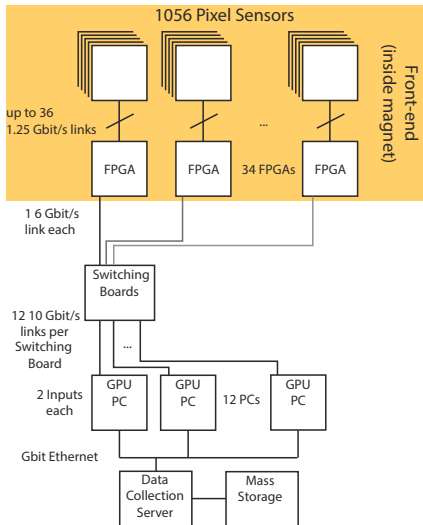


# Helium Gas Cooling System

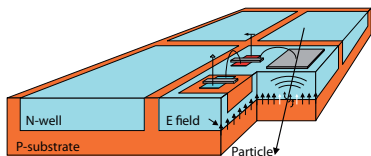




# Detector Readout (T94.9) and Online Track Reconstruction (T46.5, T116.1)



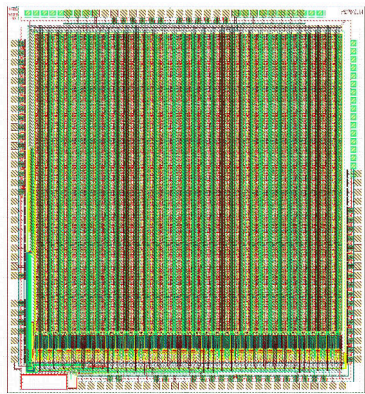
# High-Voltage Monolithic Active Pixel Sensors



I. Perić, NIM A 582, 3, 2007.

- Deep n-well in p-substrate
- Reverse bias voltage (-85 V)
- Depletion zone: ca. 10 - 20  $\mu\text{m}$  (20  $\Omega\text{cm}$  substrate)
- Can be thinned to  $< 50 \mu\text{m}$
- Fast charge collection via drift

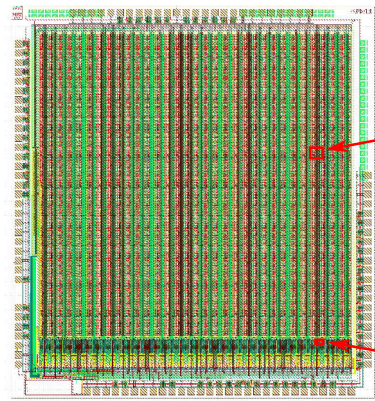
# The MuPix7



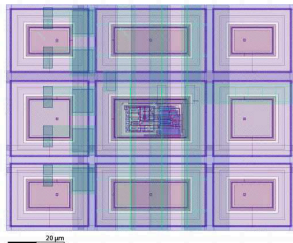
- Commercial 180 nm High-Voltage CMOS process
- Thinned to 50  $\mu\text{m}$
- Active area: 3.3 x 3.2 mm<sup>2</sup>
- 32 x 40 pixels
- Pixel size: 103 x 80  $\mu\text{m}^2$
- Readout state machine on chip
- Clock generation on chip
- Fast serial output of up to 1.6 Gbits/s

# The MuPix7

## Layout



### Pixel

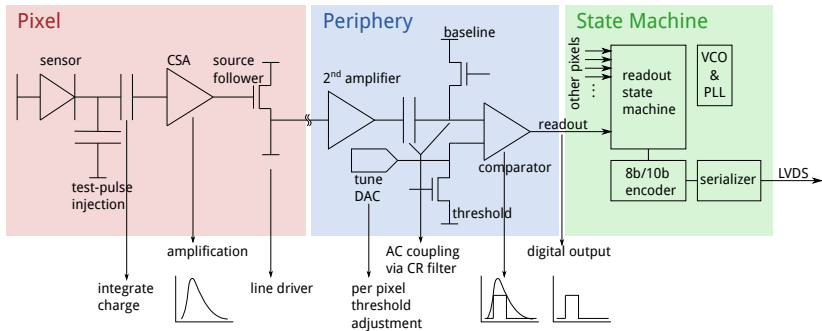


### Digital cell

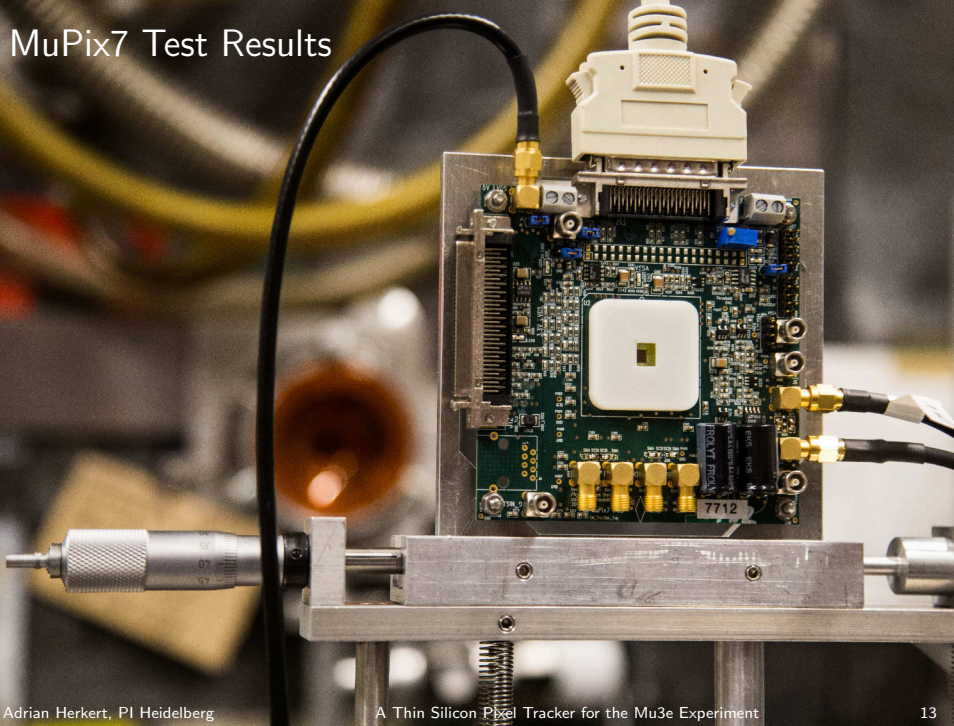


# The MuPix7

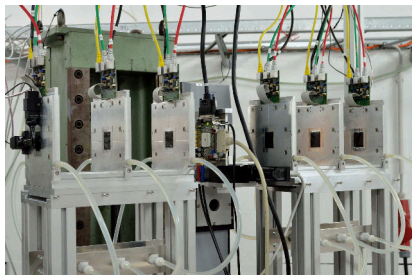
## Full readout system on chip



# MuPix7 Test Results



# EUDET Telescope at DESY

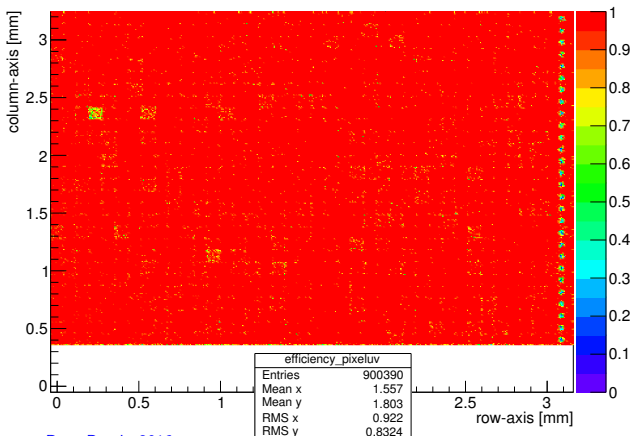


- $E_e = 4 \text{ GeV}$
- 6 MIMOSA planes
- Scintillator triggers in front and back
- DUT: MuPix7 on rotation stage
- Analysis:
  - Straight tracks fit to MIMOSA hits
  - Matched hits from DUT

# Efficiency Map with Sub-Pixel Resolution



Mupix7, 735 mV threshold, HV = -85 V



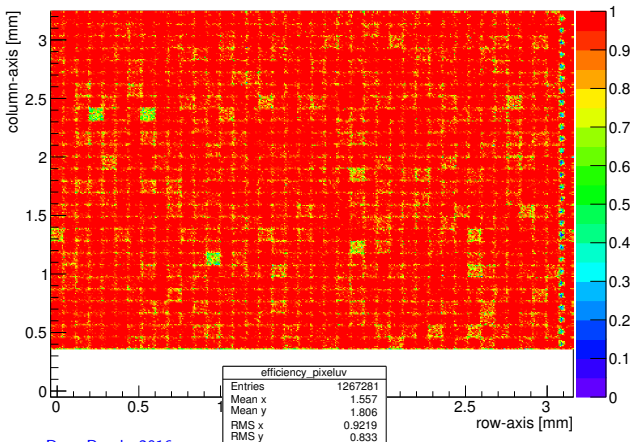
D. v. Bruch, 2016.



# Efficiency Map for Reduced Bias Voltage



Mupix7, 730 mV threshold, HV = -40 V

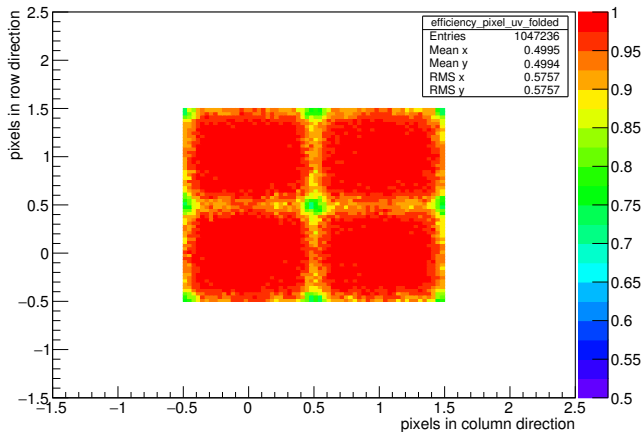


D. v. Bruch, 2016.

# Efficiency Map for Reduced Bias Voltage Folded on 2x2 Pixels



Mupix7, 730 mV threshold, HV = -40 V

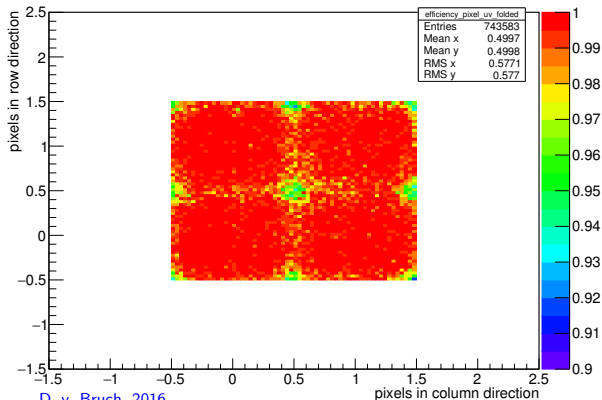


D. v. Bruch, 2016.

# Efficiency Map for Nominal Bias Voltage Folded on 2x2 Pixels



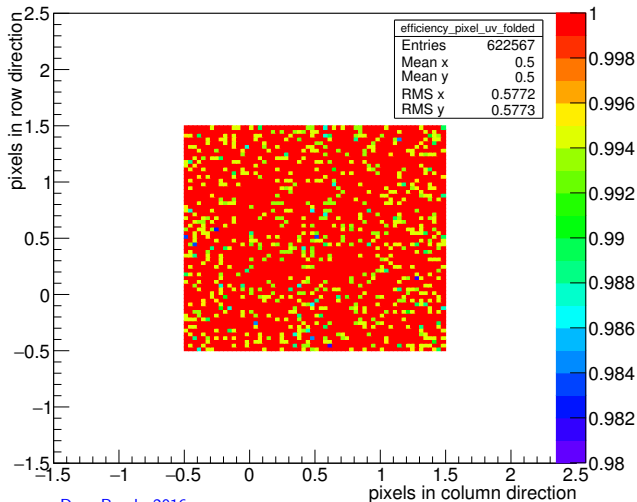
Mupix7, 735 mV threshold, HV = -85 V



# Efficiency Map Folded on 2x2 Pixels for DUT Rotated by 45°

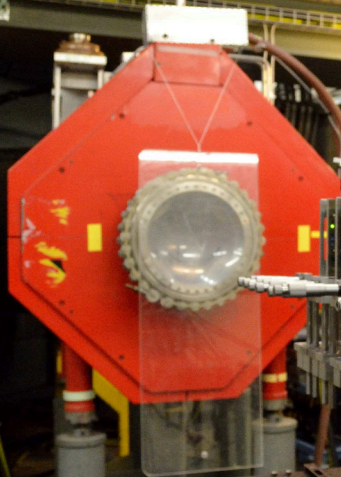


Mupix7, 730 mV threshold, HV = -85 V, rotated by 45 degrees

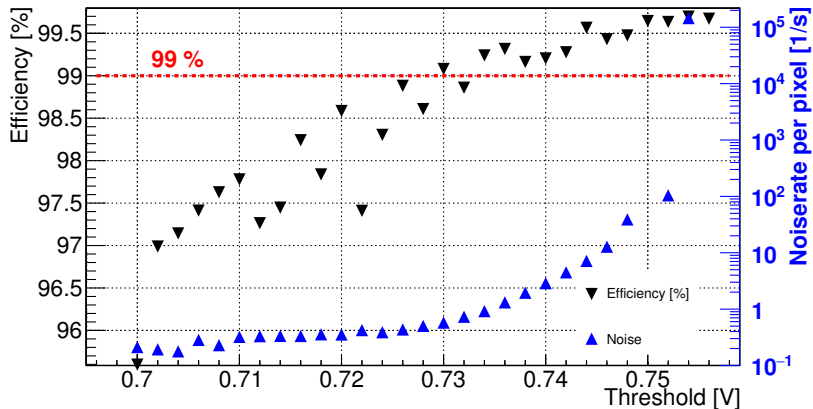


D. v. Bruch, 2016.

# The MuPix Telescope

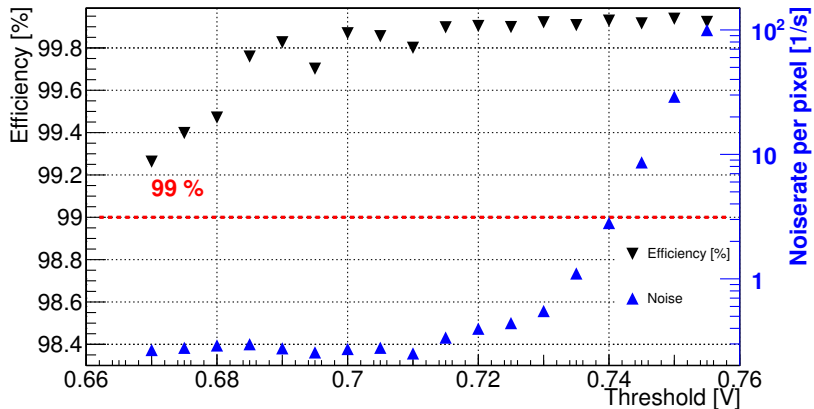


# Efficiency Averaged over Full Sensor



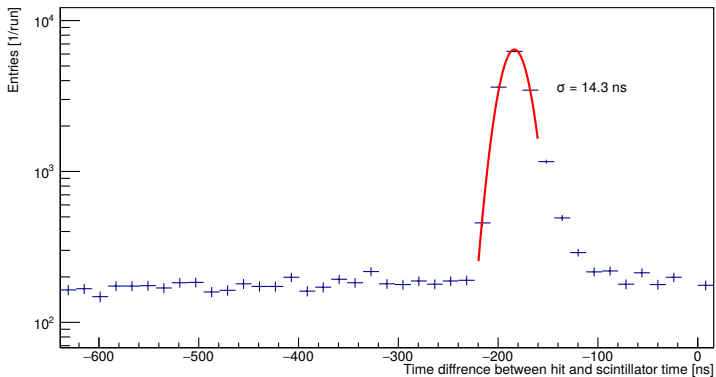
L. Huth, 2016.

# Efficiency at 60° Rotation



L. Huth, 2016.

# MuPix7 Time Resolution



L. Huth, 2016.



# Summary and Outlook



	Specification	MuPix7	MuPix8
Sensor size [mm <sup>2</sup> ]	20 × 22	3.2 × 3.3	10.7 × 19.5
Sensor thickness [μm]	50	50, 63, 75, 250	50, 100
LVDS links	3	1	4
Bandwidth [Gbit/s]	3.75	1.6	6.4
Power consumption [mW/cm <sup>2</sup> ]	≤ 350	≈ 300	250 – 300
Time resolution [ns]	≤ 20	≈ 14	≈ 5 – 10
Efficiency at 20 Hz noise [%]	≥ 99	99.5	≥ 99.9
Substrate resistance [Ωcm]	no spec.	≈ 20	≈ 80

# Acknowledgements



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

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