Mu3e Testbeam Measurements at DESY

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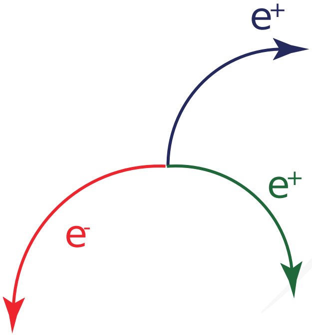
Physikalisches Institut, Universität Heidelberg

Telescopes and Testbeams, Hamburg, 30. June 2014

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

The Mu3e Experiment

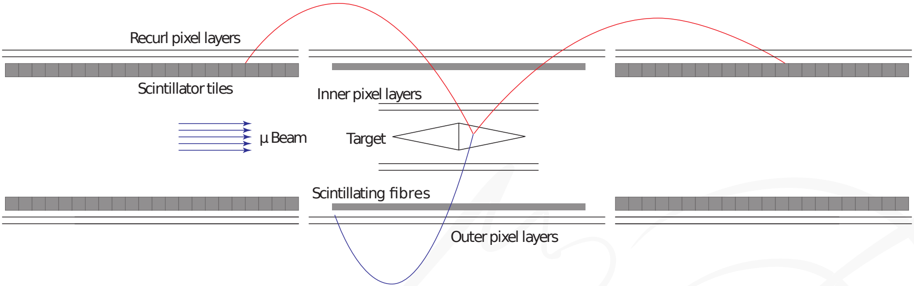


- Precision experiment
- Search for $\mu^+ \to e^+e^-e^+$
- Sensitivity < 1 in 10^{16} decays
- Standard Model $\ll 1$ in 10^{50}

Importance ?

- New physics search
- High sensitivity

The Mu3e Experiment



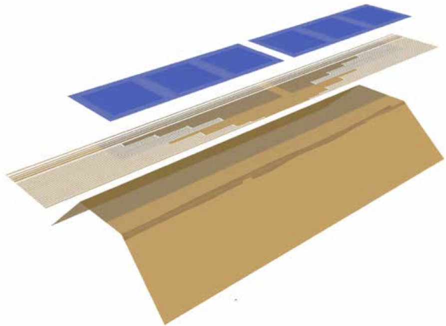
Environment

- $> 10^9$ μ^+ Decays/s
- Electrons p $< 53\,\mathrm{MeV}$
- Dominated by multiple scattering

Pixel Sensor Requirements

- Fast $< 20\,\mathrm{ns}$
- Thin $\leq 1\,‰\,X_0$
- Pixel $80 \times 80\,\mathrm{\mu m}^2$

Ultra-Lightweight Mechanics

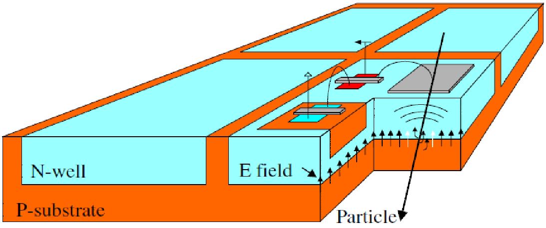


- 50 µm Silicon sensor
- 50 µm Kapton flexprint
- 25 µm Kapton support frame

→ ≤ 1 ‰ Radiation length

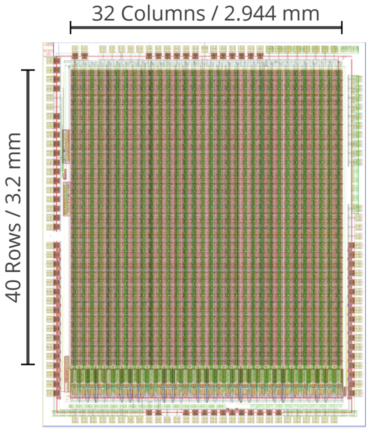
Testing Pixel Sensor Prototypes

Monolithic Active Pixel Sensors



- HV $\sim 70\,\mathrm{V}$ (HV-MAPS)
- Fast charge collection by drift
- Thin active zone $< 20\,\mu\mathrm{m}$
- Cheap, commercial process

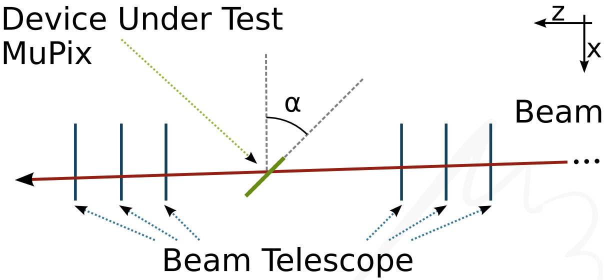
MuPix4 HV-MAPS Prototype



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

- $92 \times 80\,\mu m^2$ pixel size
- Global threshold
- Zero-suppressed digital readout
- Timestamps
- 93 % active area

Testbeam Setup w/ MuPix4

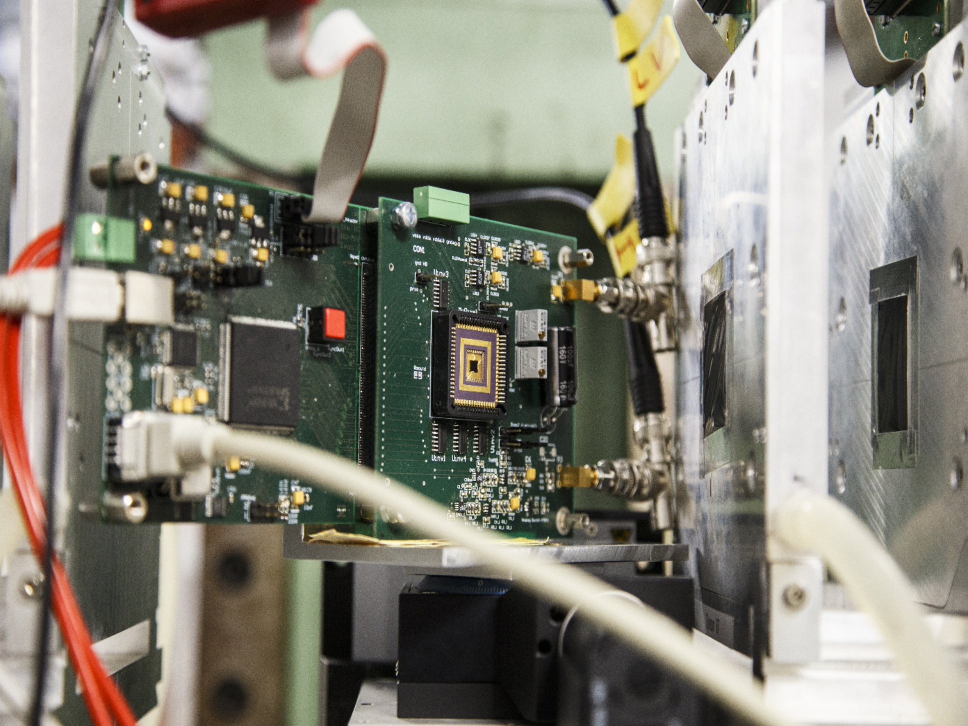


- Full EUDAQ (v1.1) integration
- Reconstruction w/ EUTelescope (v00-09-xx)

Provided by DESY

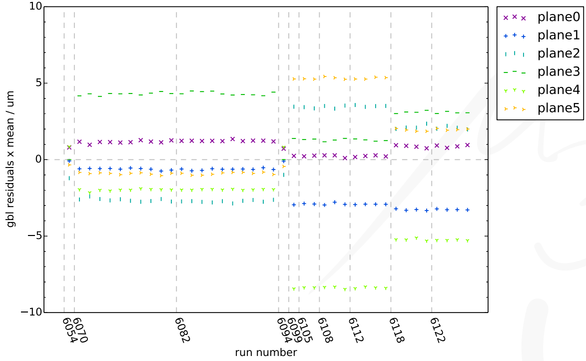
- Beamline T22
- 1 GeV to 6 GeV electrons
- Aconite beam telescope


Danger


CON1
Uinv3
Uinv1
Uinv4

Telescope (Mis-)Alignment

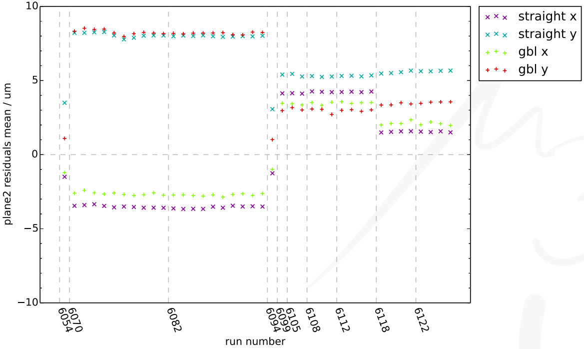
Track Residuals in X / All Planes



- GBL / Millepede Alignment
- Systematic Shift
- Complimentary before / after DUT
- Not visible in alignment runs

Telescope (Mis-)Alignment

Track Residuals / Plane 2



- GBL / Millepede Alignment
- Systematic Shift
- Complimentary before / after DUT
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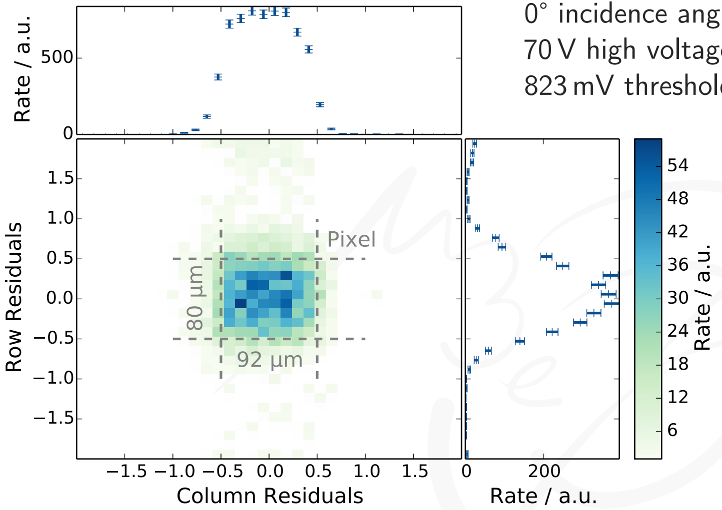
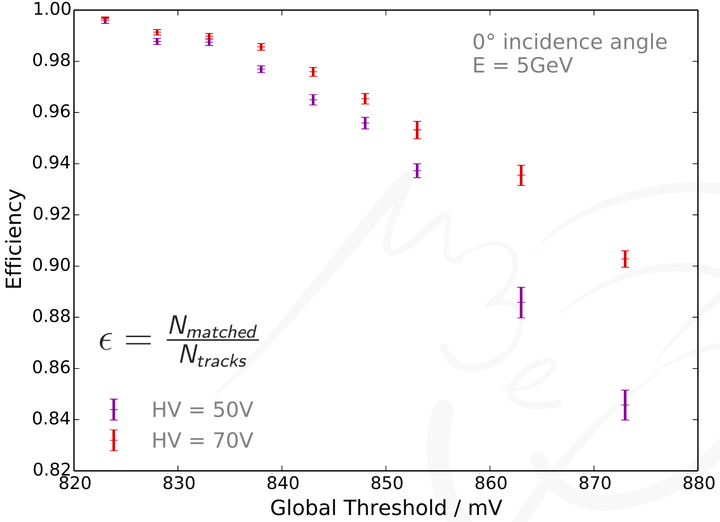
Single Hit Resolution

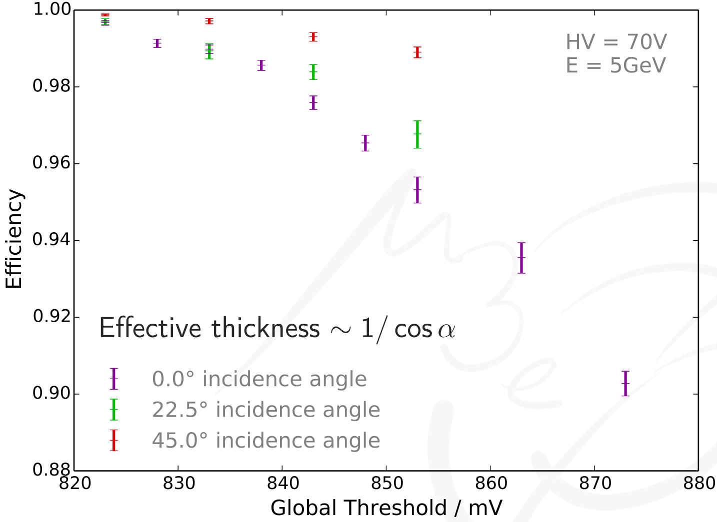


0° incidence angle
70 V high voltage
823 mV threshold

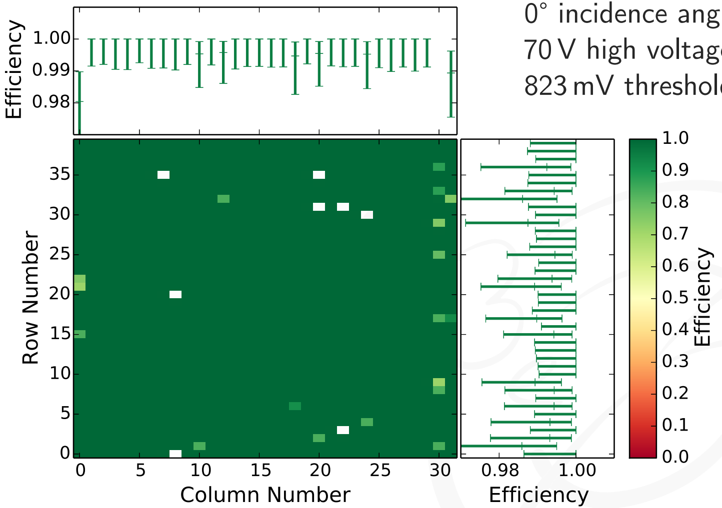
Global Efficiency / High Voltage



Global Efficiency / Incidence Angle



Pixel Efficiency



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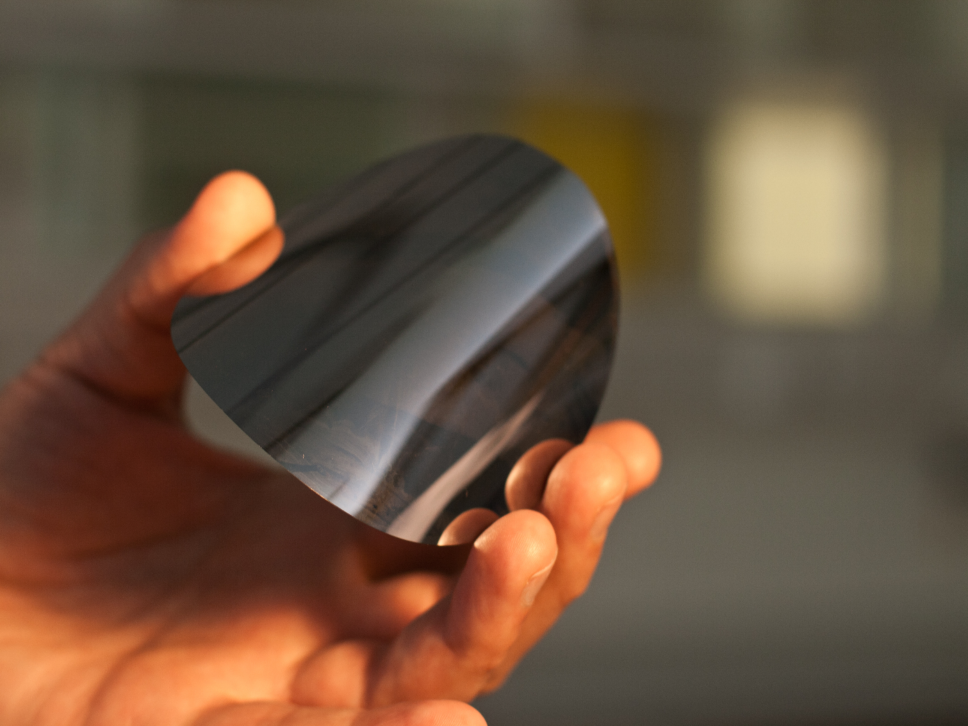
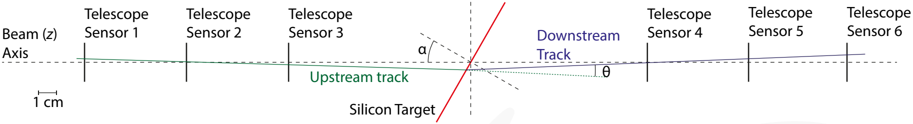
Multiple Scattering in Thin Silicon



Testbeam Setup w/ Silicon Wafer

N. Berger, M. Kiehn, et.al. arXiv:1405.2759 (accepted by JINST)



Measured Scattering Distributions

$$t(\theta) = f_{upstream} \otimes f_{downstream}$$

$$s(\theta) = f_{upstream} \otimes f_{Si} \otimes f_{downstream}$$

$$= (f_{upstream} \otimes f_{downstream}) \otimes f_{Si}$$

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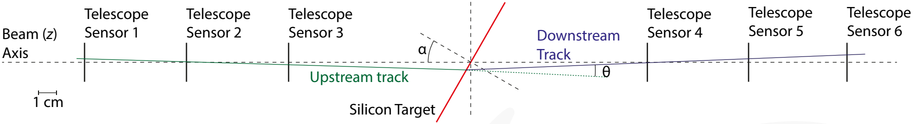


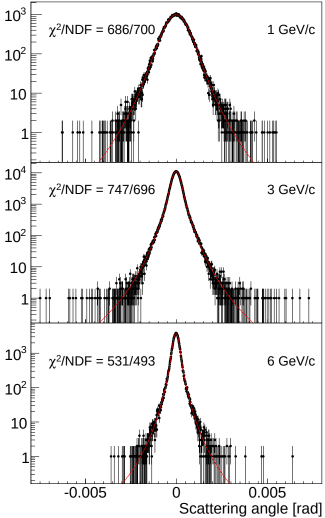
Fitted Scattering Distributions

$$t(\theta) \sim normal(\mu, \sigma_1) + \epsilon \cdot studentt(\mu, \sigma_2, \nu_2)$$

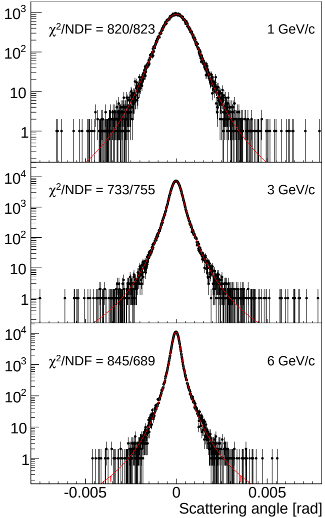
$$s(\theta) \sim t_{fixed} \otimes studentt(\mu, \sigma, \nu)$$

Measured Scattering Distributions

No Silicon

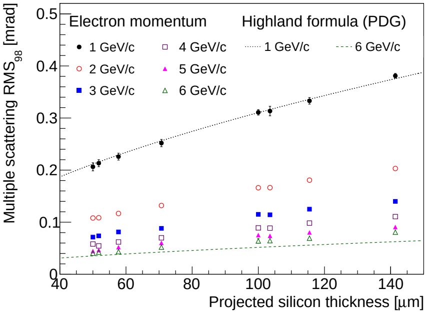


50 μm Si, $\alpha = 15°$

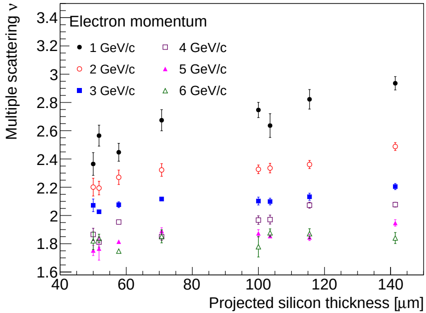


Distribution Parameters

RMS_{98} vs Thickness



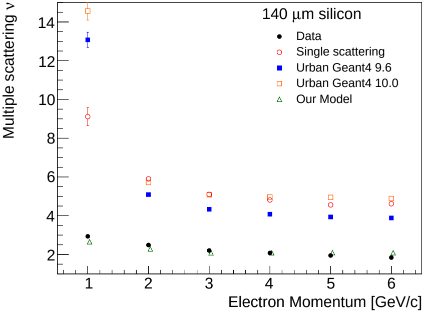
Tail Parameter ν vs Thickness



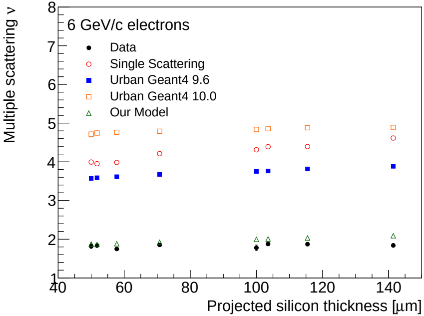
- RMS_{98} is consistent w/ PDG $\sim 1/p\sqrt{t}(1 + 0.038 \ln t)$
- Tail fraction $\sim 1/\nu$

GEANT4 Validation

Tails vs Momentum



Tails vs Thickness



- GEANT4 simulation of Telescope Setup
- RMS_{98} is well described (not shown)
- Default models underestimate tails
- Shape is not described

Summary & Outlook

Mu3e

- Search for $\mu^+ \rightarrow e^+e^-e^+$
- R&D in progress

Testbeams at DESY

- MuPix HV-MAPS prototype
- Scattering in thin silicon
- Scintillating tiles / fibres
- ...

Outlook

- MuPix6 prototype
- Next Testbeam in Oct./Nov. ?

Impossible w/o DESY Testbeam Group. Thank You.

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Backup

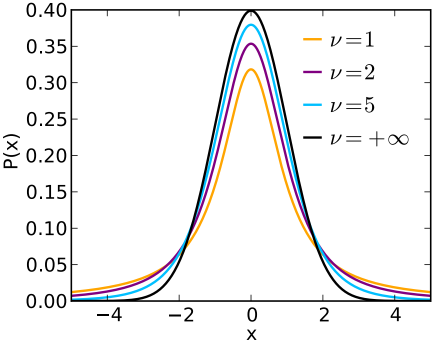
t-Distribution Scattering Model

N. Berger, M. Kiehn, et.al. arXiv:1405.2759

Idea

- Based on Urban model
- Angles from t-distribution
- ν from fit to data

$$\nu(p, t) = A + B\frac{1}{p - D} + Cd$$



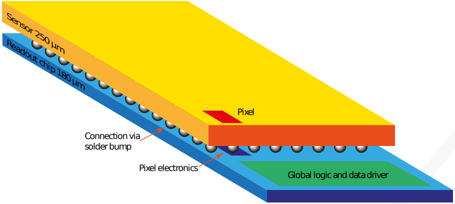
https://en.wikipedia.org/wiki/Student-t

Caveats

- Purely empirical
- Valid only for
  1 GeV to 6 GeV electrons
  50 μm to 141 μm Si

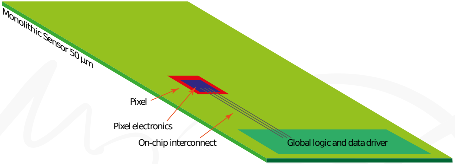
Silicon Pixel Sensors

Hybrid



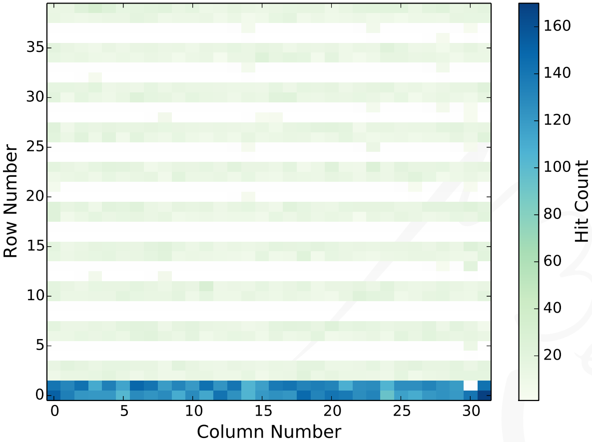
- HV $\sim$ 700 V
- Sensor thickness $\sim$ 250 µm
- Extra material
- Complex and expensive

Monolithic Active Pixel Sensor



- HV $\sim$ 70 V (HV-MAPS)
- Thin active zone $<$ 20 µm
- Cheap, commercial process

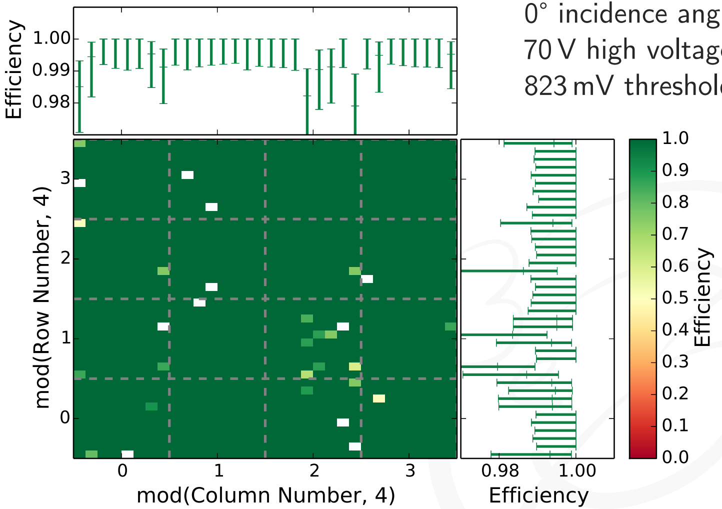
Hitmap a.k.a Hybrid Strixel Sensor



0° incidence angle
70 V high voltage
838 mV threshold
5 GeV beam energy

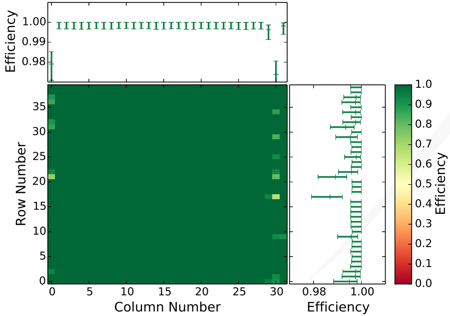
Subpixel Efficiency / 4x4 Submatrix

0° incidence angle
70 V high voltage
823 mV threshold

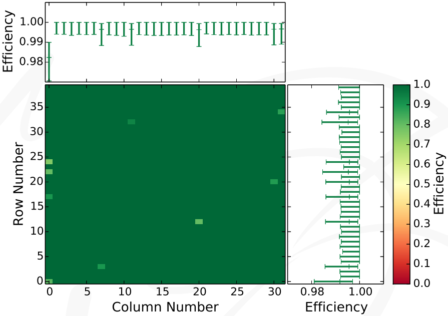


Pixel Tuning

Before Tuning



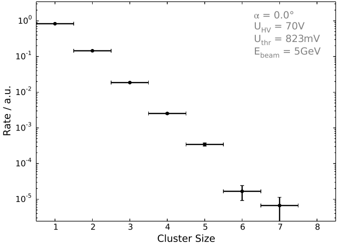
After Tuning



45° incidence angle

Clustering / Charge Sharing

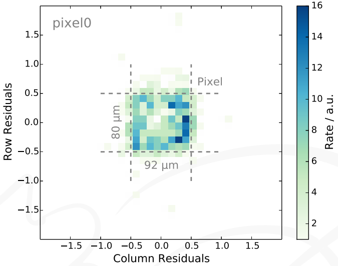
Cluster Size

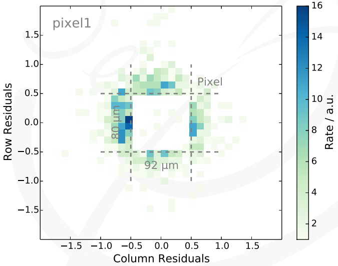


0° incidence angle
70 V high voltage
823 mV threshold
5 GeV beam energy

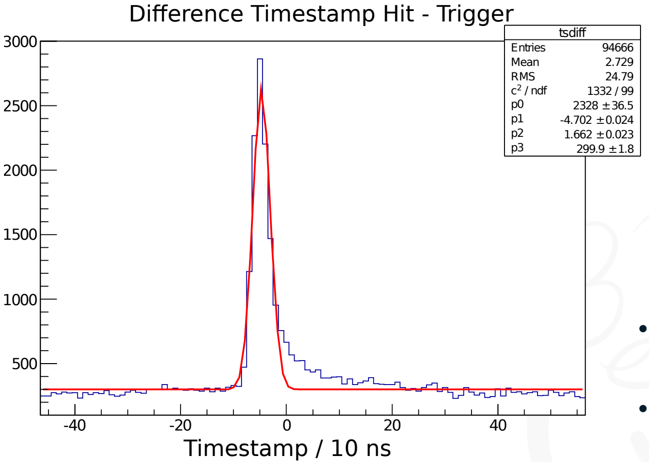
1-pixel cluster dominate

2-Pixel Cluster





Timing

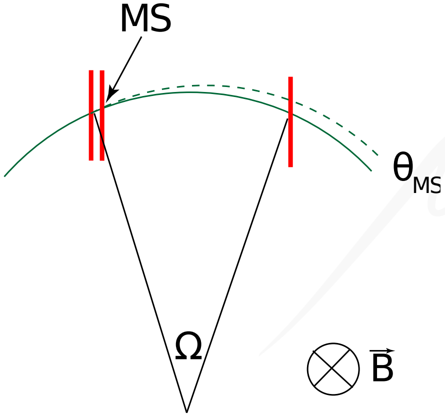


- External timestamp 100 MHz
- Time resolution 17 ns (Sensor + DAQ)

Mu3e Collaboration

- Paul-Scherrer Institute, Switzerland
- ETH Zürich
- University Zürich
- University Geneva
- Heidelberg University
- ZITI Mannheim

Multiple Scattering



$$\theta_{MS} = \frac{13.6\,\text{MeV}}{p}\sqrt{x/X_0}$$

Example

- $p = 35\,\text{MeV}$
- 200 µm Si
- $\Omega R = 5\,\text{cm}$
- $\Delta y \approx 1\,\text{mm}$