Testbeam Measurements with MuPix Sensors

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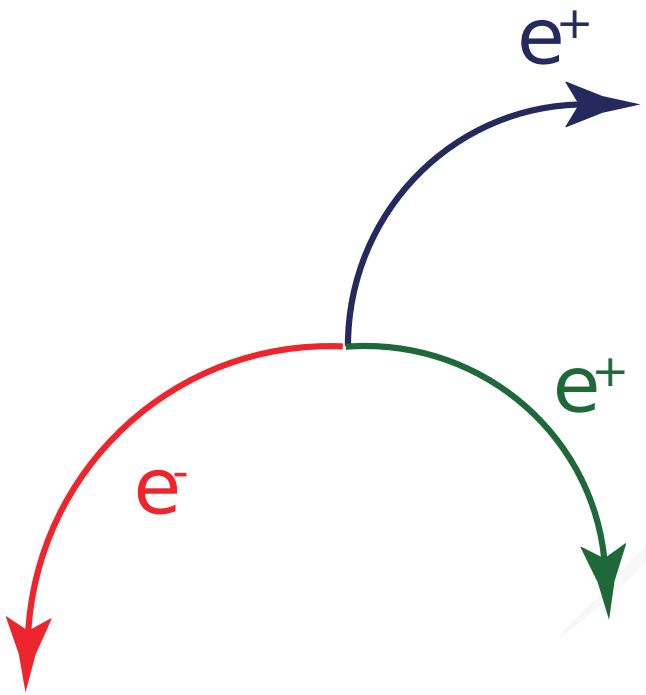
PI Palaver, Heidelberg, 30. April 2014

INTERNATIONAL MAX PLANCK RESEARCH SCHOOL

PT FS FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES

The Mu3e Experiment



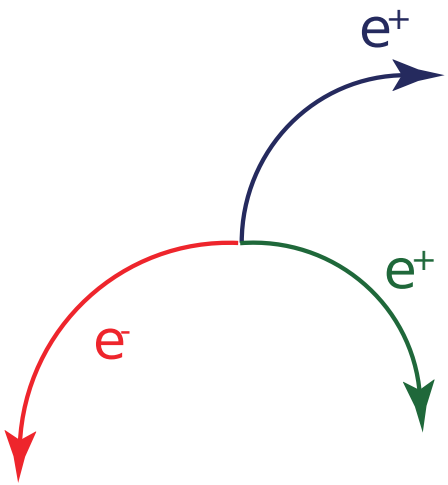
- Precision experiment
- Search for $\mu^+ \rightarrow e^+e^-e^+$
- Sensitivity <1 in 10^{16} decays
- Standard Model $\ll 1$ in 10^{50}

Importance ?

- Indirect new physics search
- High sensitivity

Signals and Backgrounds

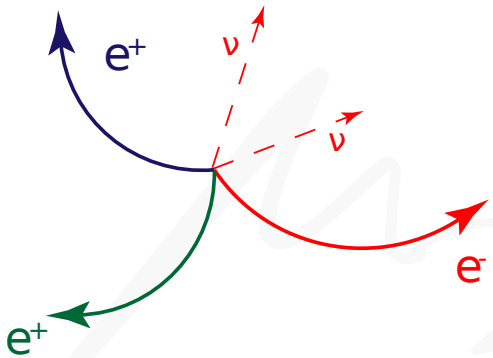
Signal



- Common vertex
- $\sum \vec{p}_i = 0$
- $p < 53\,\text{MeV}$

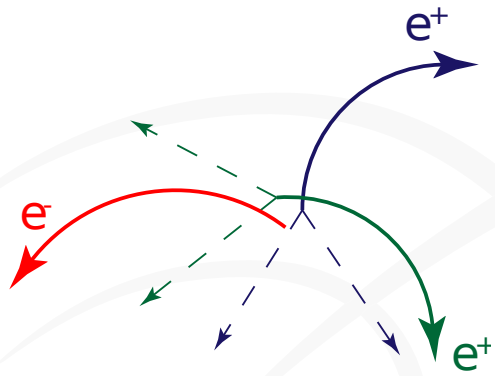
Backgrounds

Internal Conversion



- Common vertex
- $\sum \vec{p}_i \neq 0$
- In-time

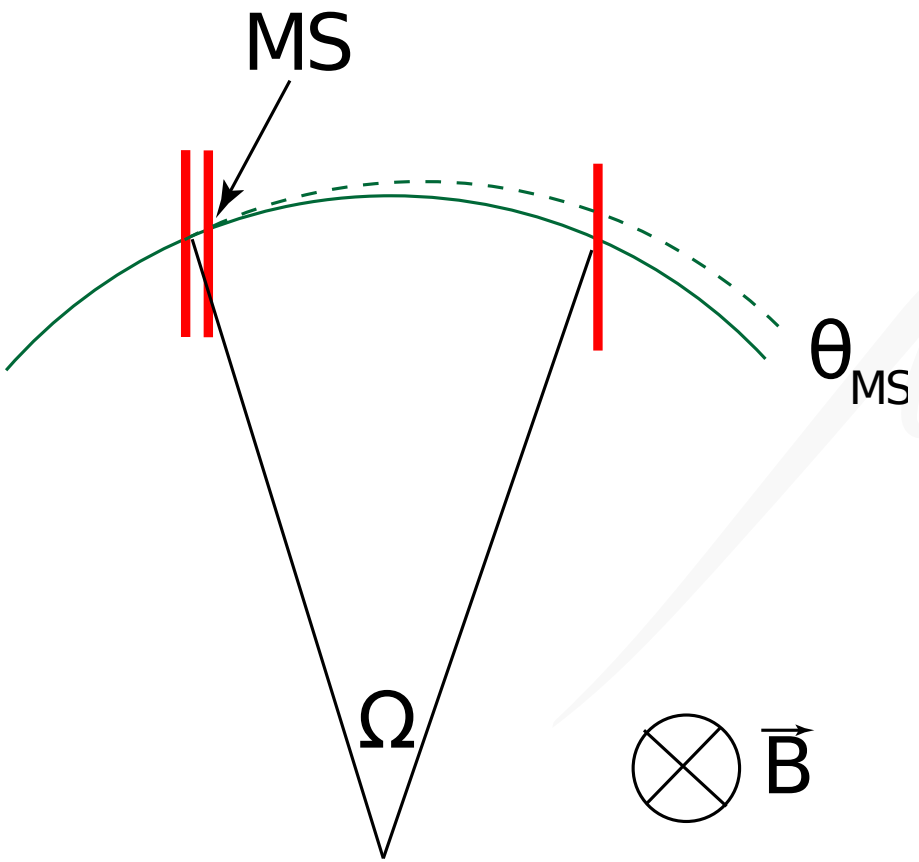
Combinatorial



- No common vertex
- Out-of-time

Requires $\sigma_p < 0.5\,\text{MeV}$
$\sigma_t < 20\,\text{ns}$

Multiple Scattering

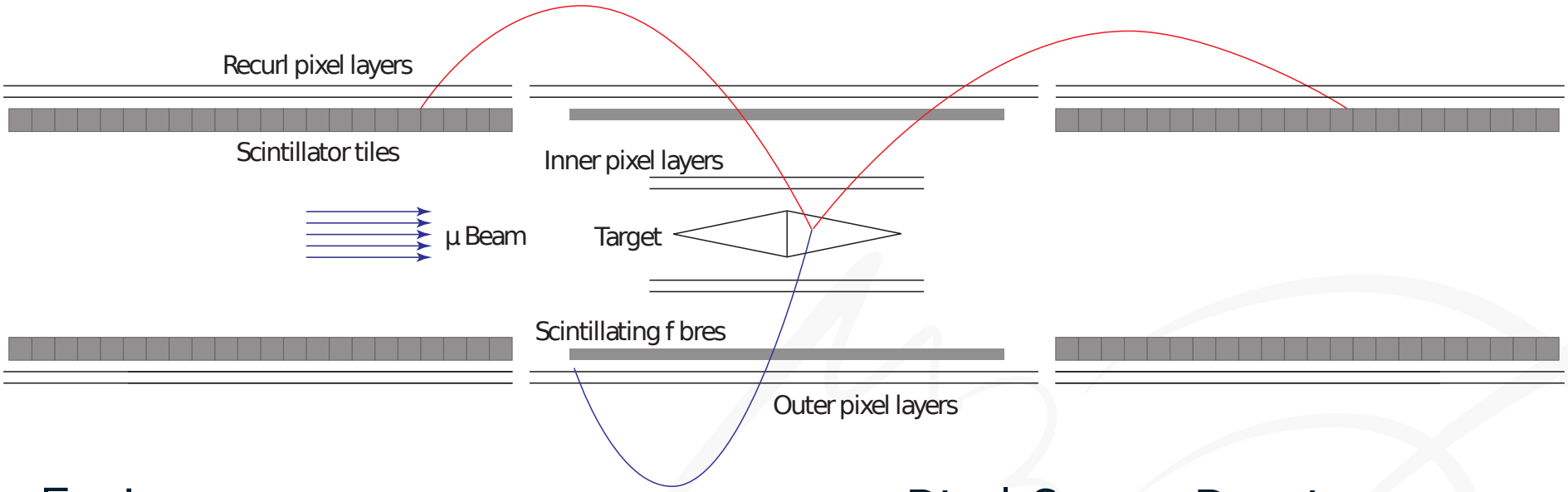


$$\theta_{MS} = \frac{13.6\,\text{MeV}}{p}\sqrt{x/X_0}$$

Example

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

The Mu3e Experiment



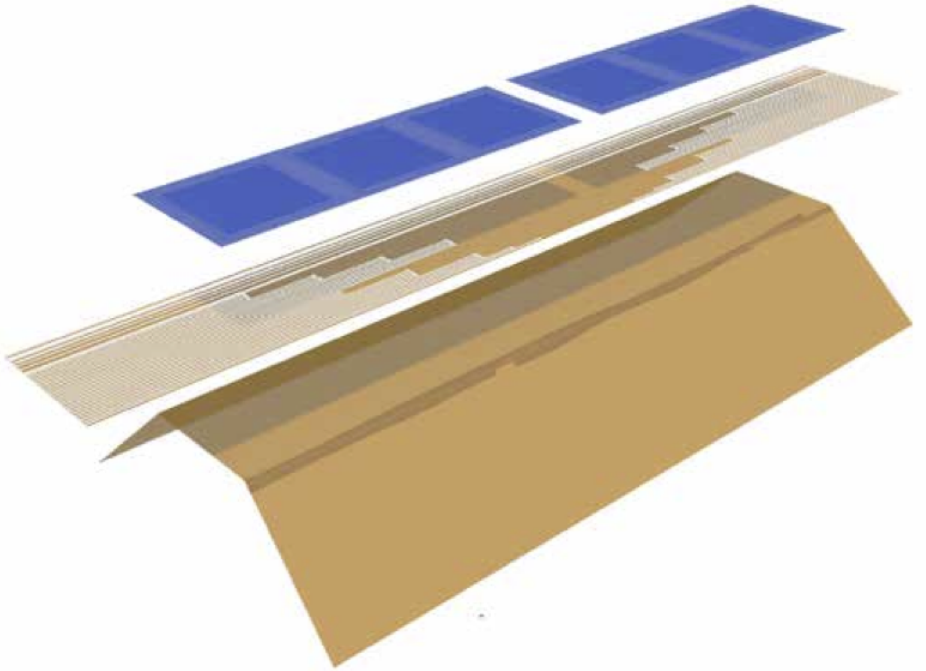
Environment

- $>10^9$ μ^+ Decays/s
- Electrons p $<$53 MeV
- Multiple scattering dominates

Pixel Sensor Requirements

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

Ultra-Lightweight Mechanics

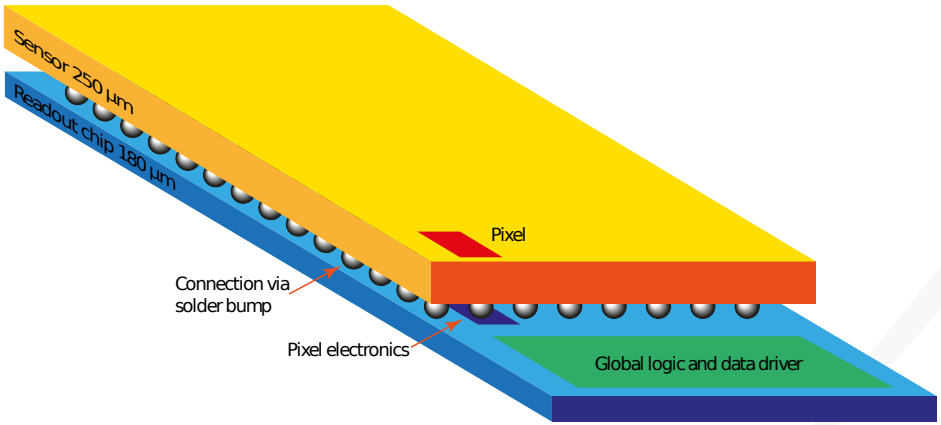


- 50 µm Silicon sensor
- 25 µm Kapton flexprint
- 50 µm Kapton support frame

$\rightarrow$ $<1\,‰$ Radiation length

Silicon Pixel Sensors

Hybrid



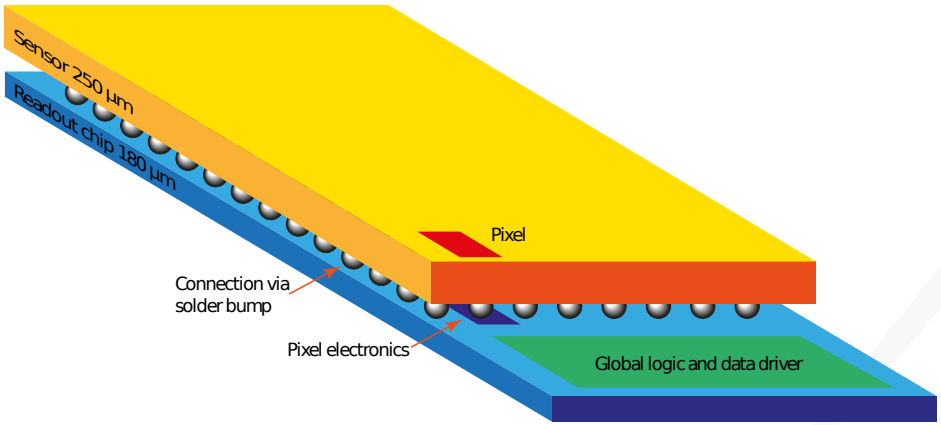
- HV ∼700 V
- Sensor thickness ∼250 µm
- Extra material
- Complex and expensive

Monolithic Active Pixel Sensor

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

Silicon Pixel Sensors

Hybrid



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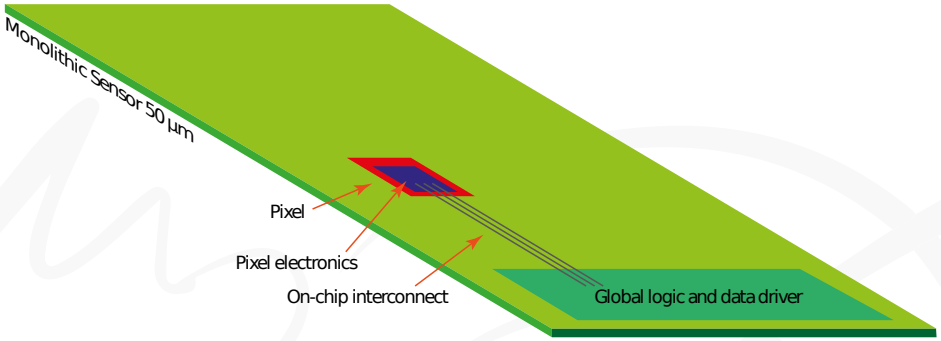

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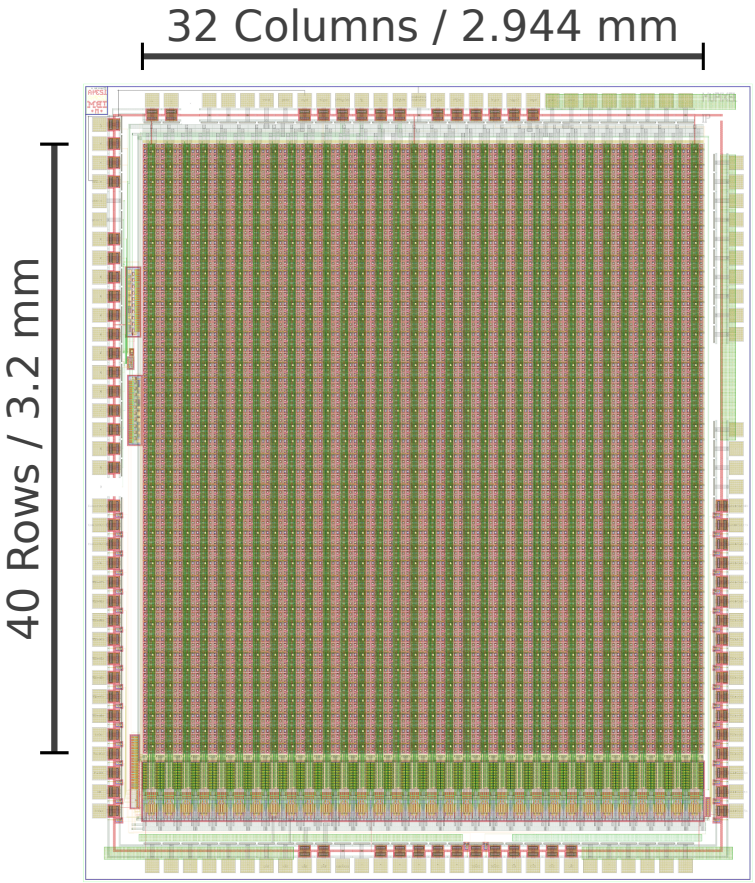
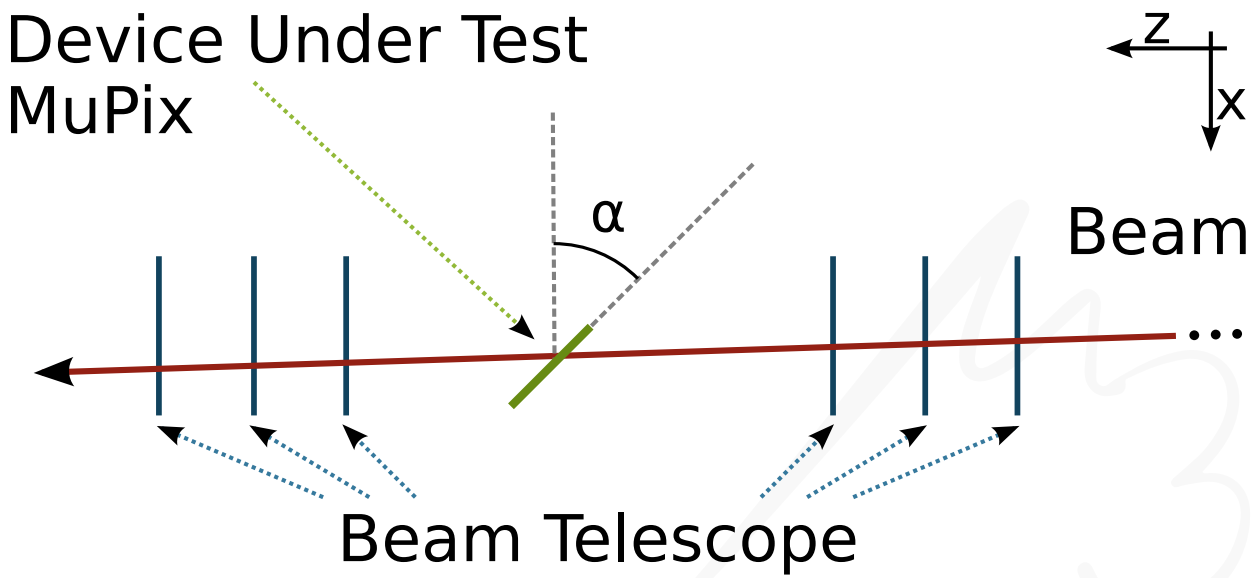
MuPix4 HV-MAPS Prototype



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
- Incorrect address every 2^{nd} double row

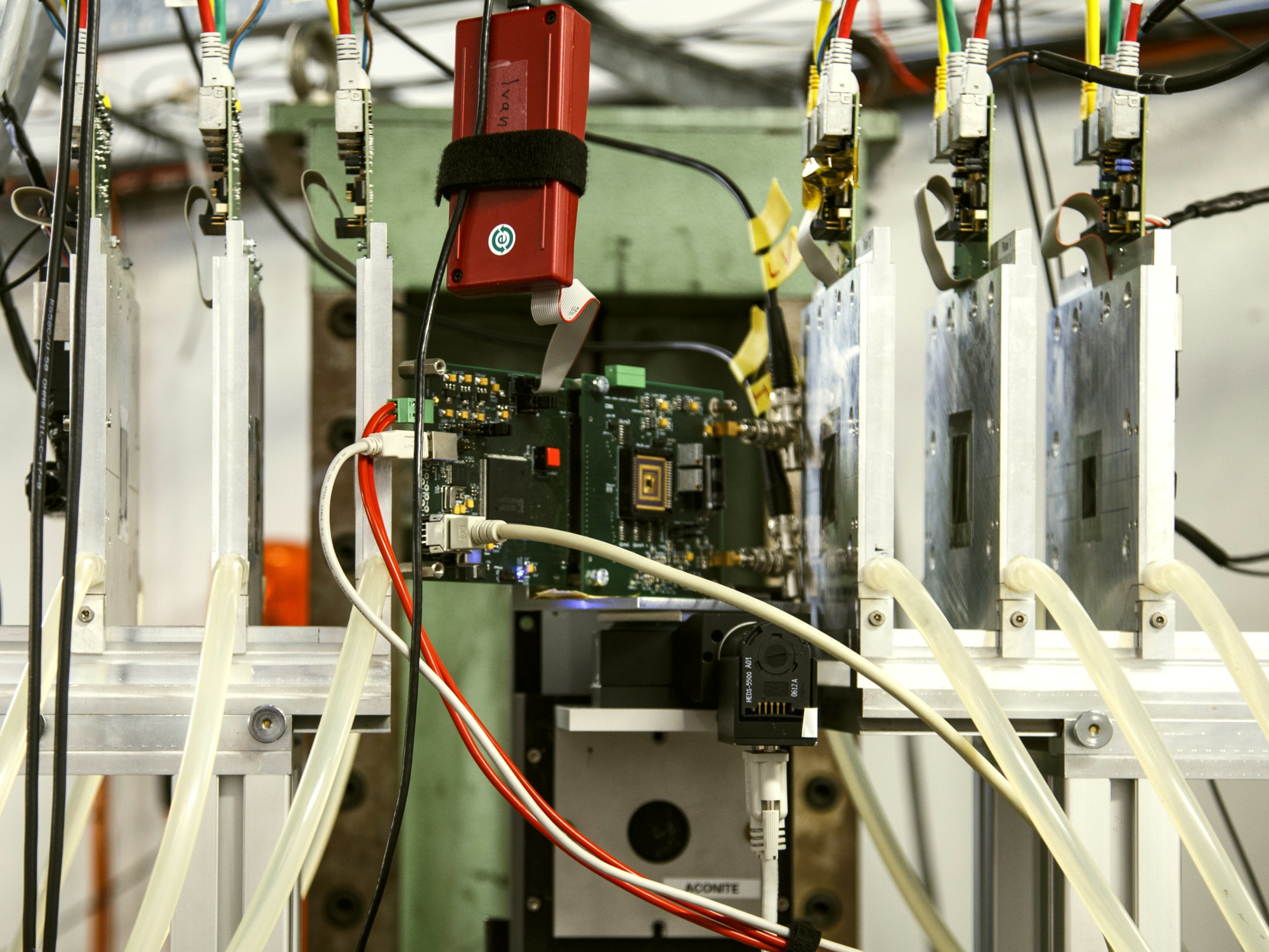
DESY Testbeam



Provided by DESY

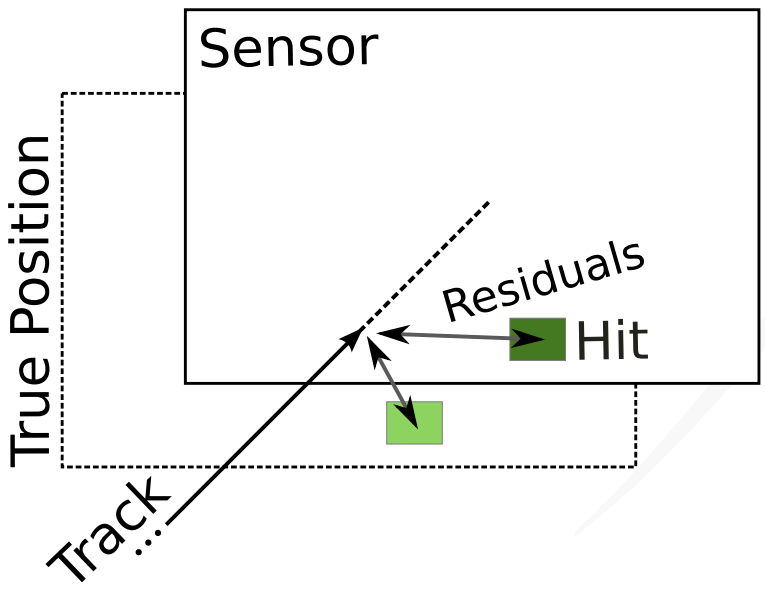
- Beamline T22
- 1 GeV to 6 GeV electrons
- Aconite beam telescope


Hochspannung
Lebensgefahr!
Danger
High voltage!

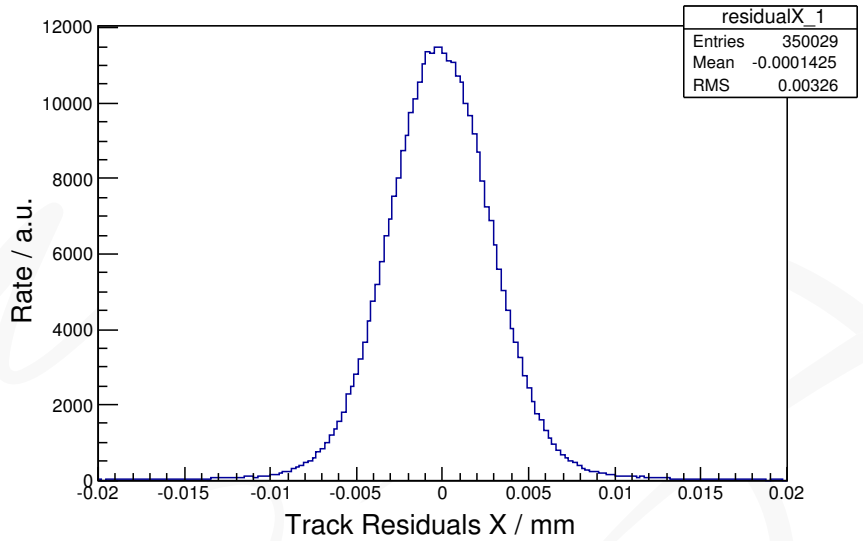

Ivan
MEMS-5500 A01
0612 A
ACONITE

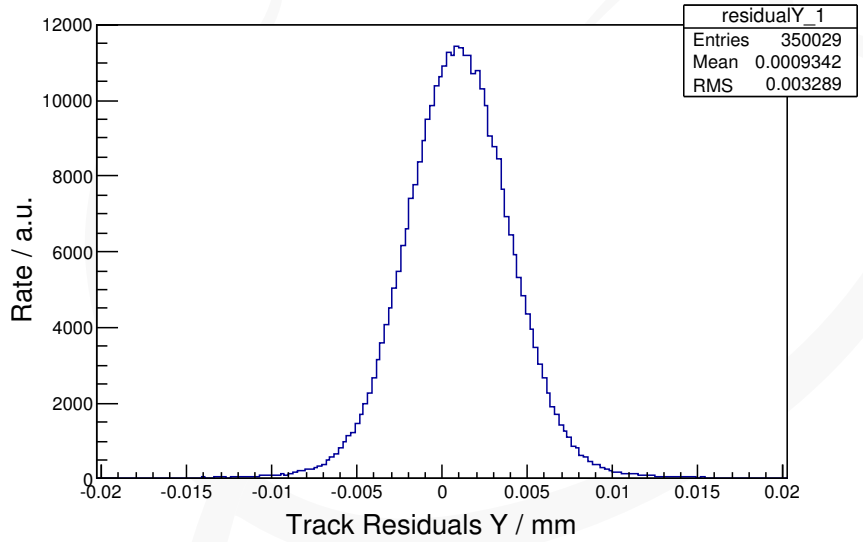
Alignment

With Misalignment

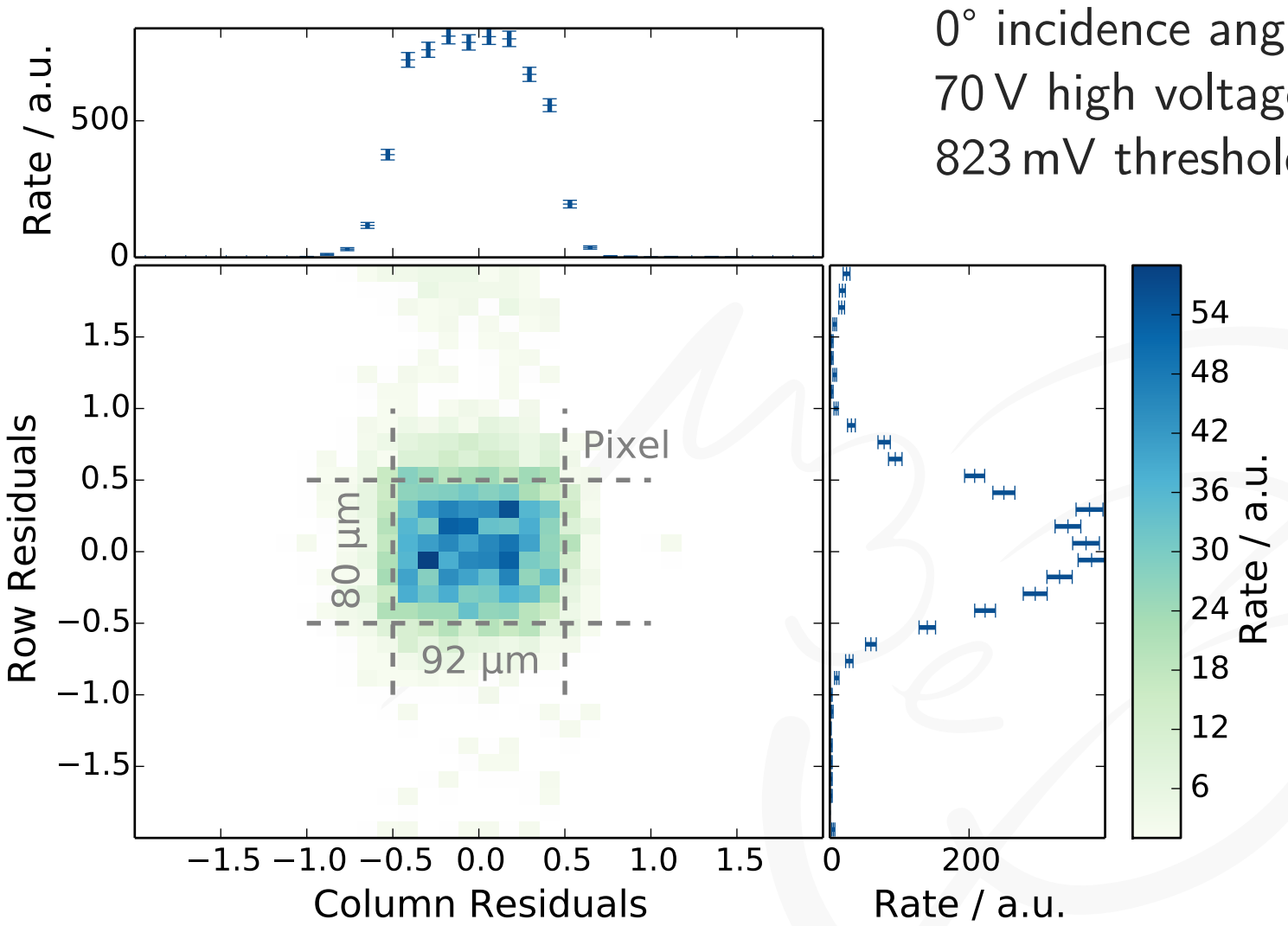


Track Residuals After Alignment

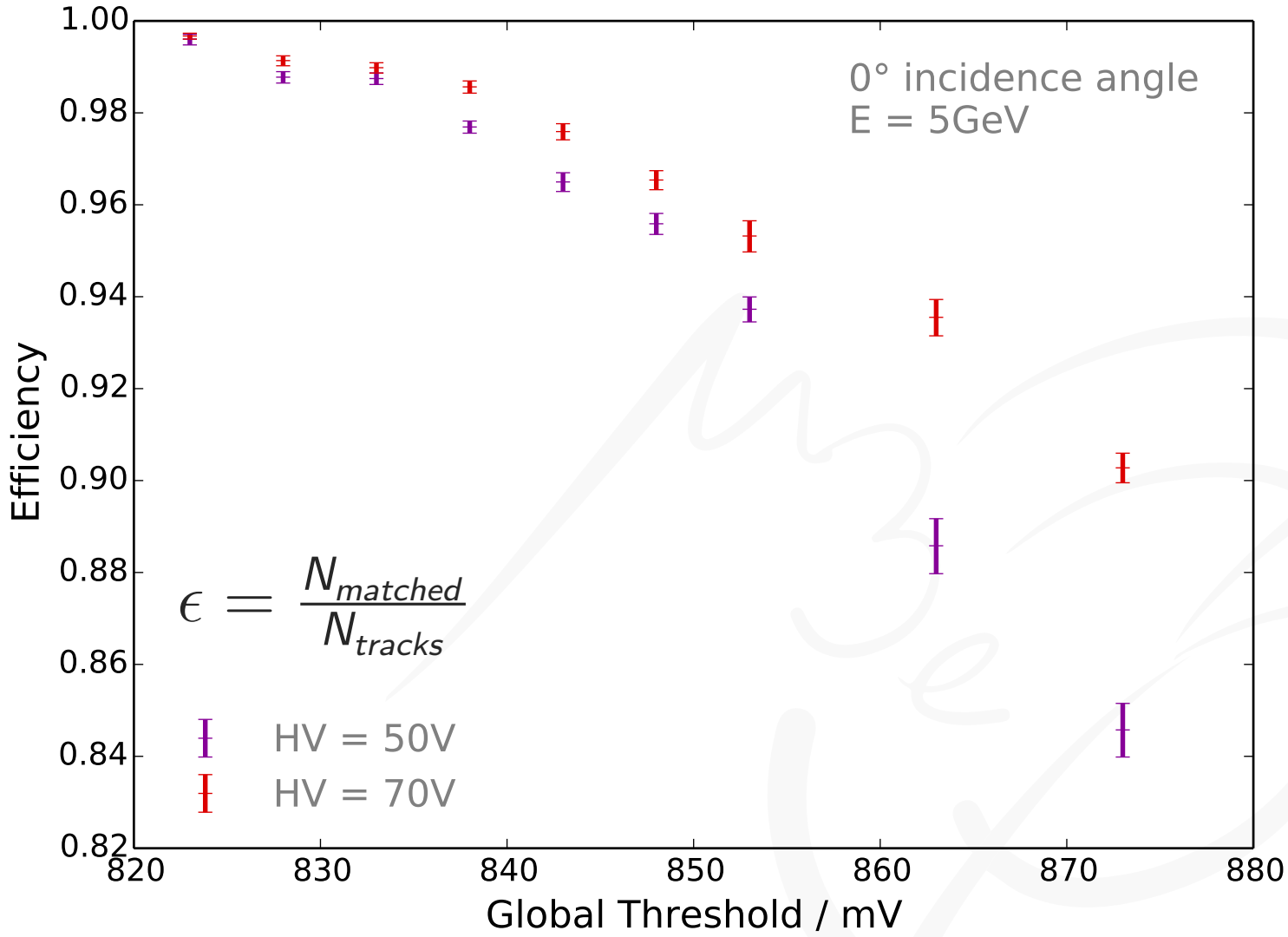




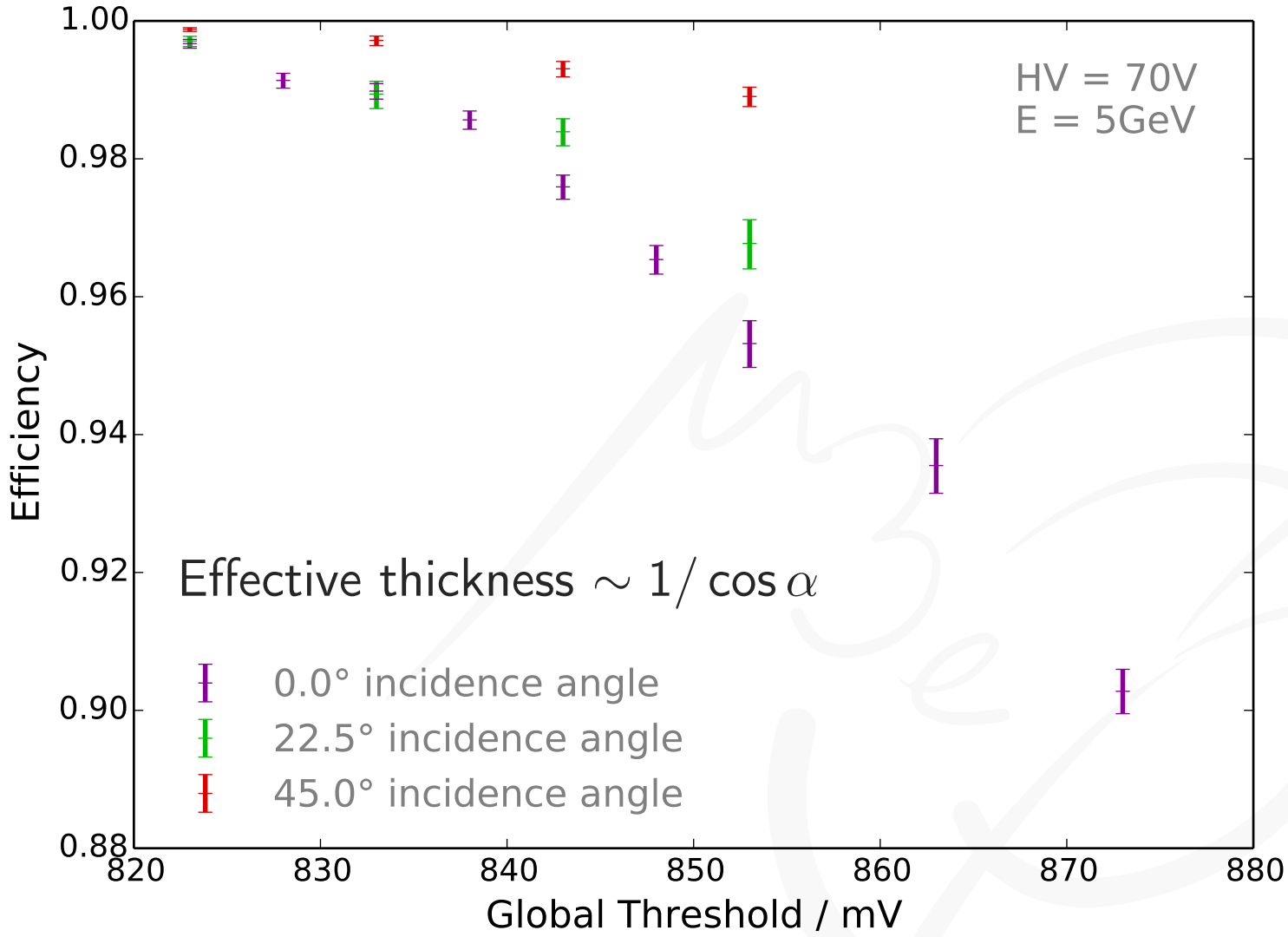
Single Hit Resolution



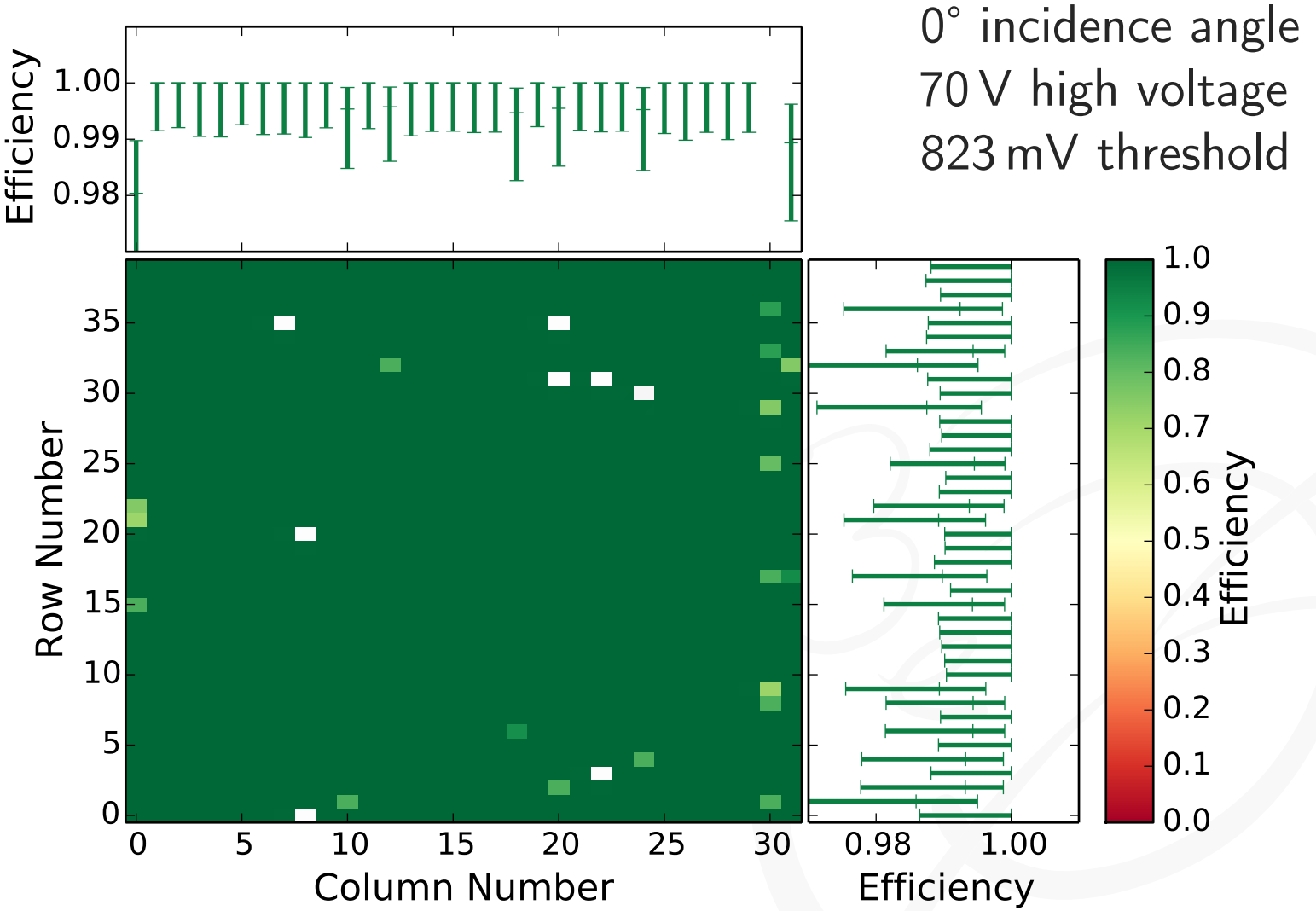
Global Efficiency / High Voltage



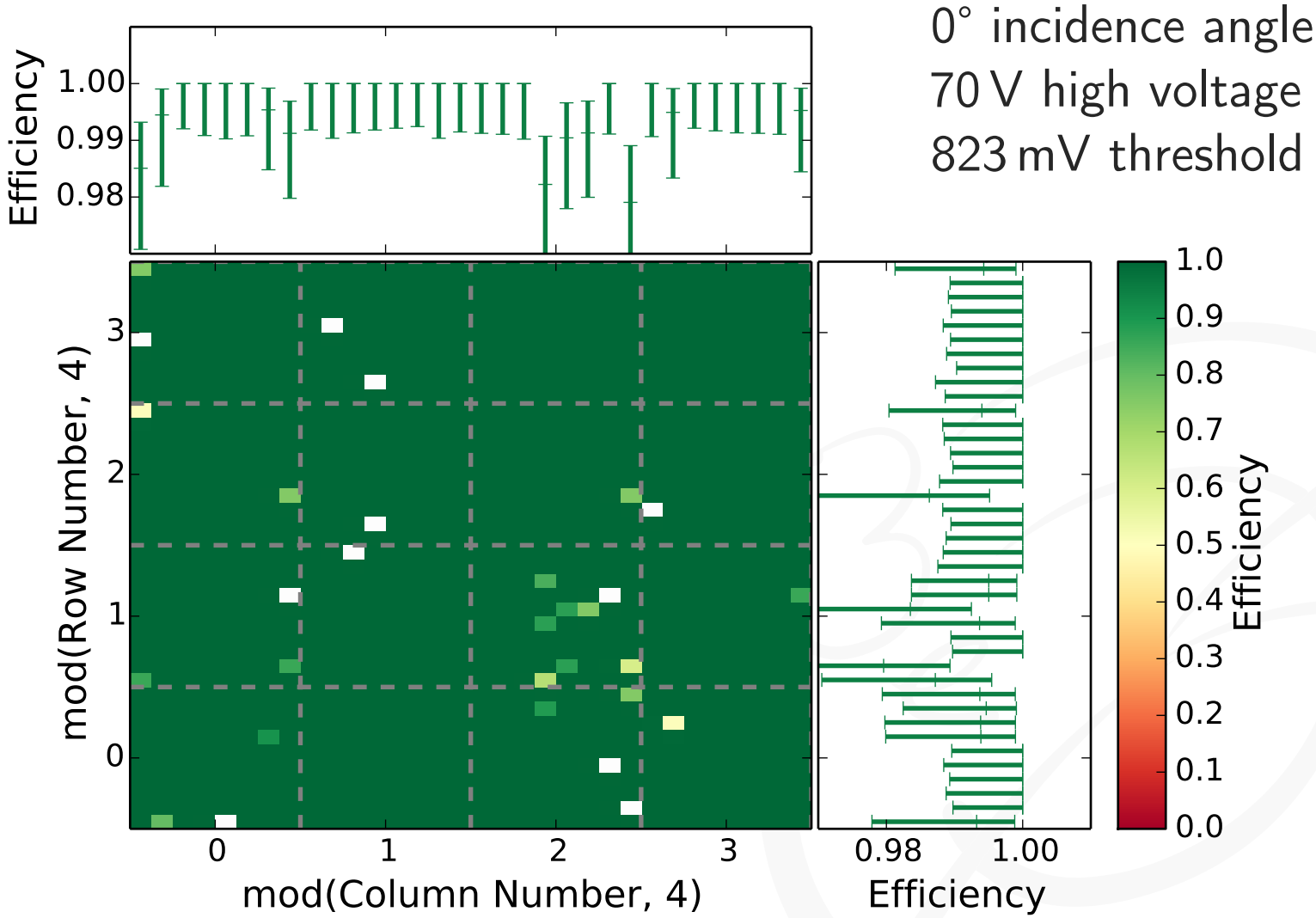
Global Efficiency / Incidence Angle



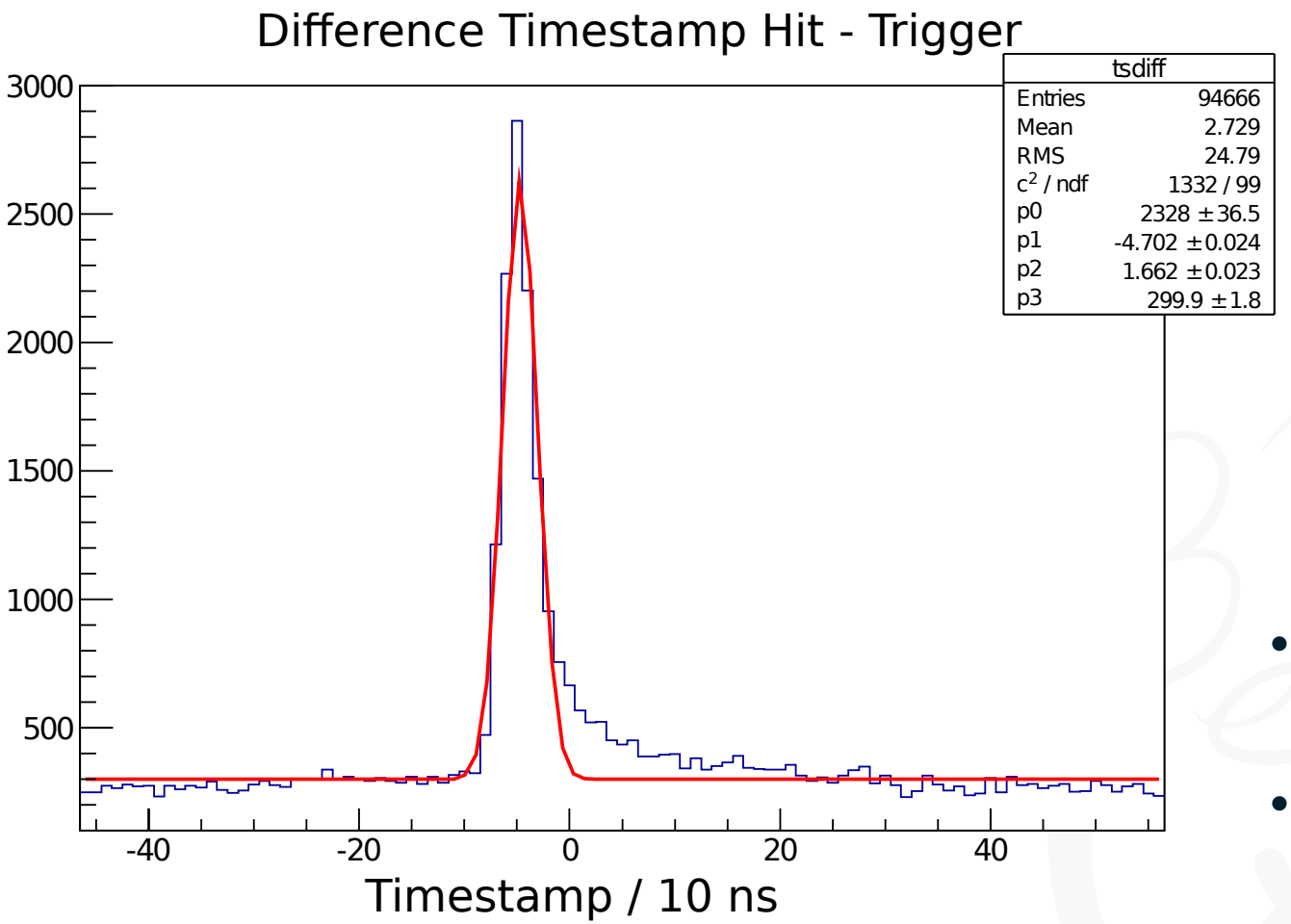
Pixel Efficiency



Subpixel Efficiency / 4x4 Submatrix



Timing



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

Summary & Outlook

Mu3e

- Search for $\mu^+ \rightarrow e^+e^-e^+$
- Fast and precise electron tracker
- Sensitivity 1 in 10^{16} decays

MuPix4 Testbeam

- Efficiency $>$99 %
- Position resolution $\sim$ pixel size
- Time resolution $<$17 ns
- HV-MAPS for Mu3e works

Outlook

- MuPix6 prototype
- Scale size
- Full Integration

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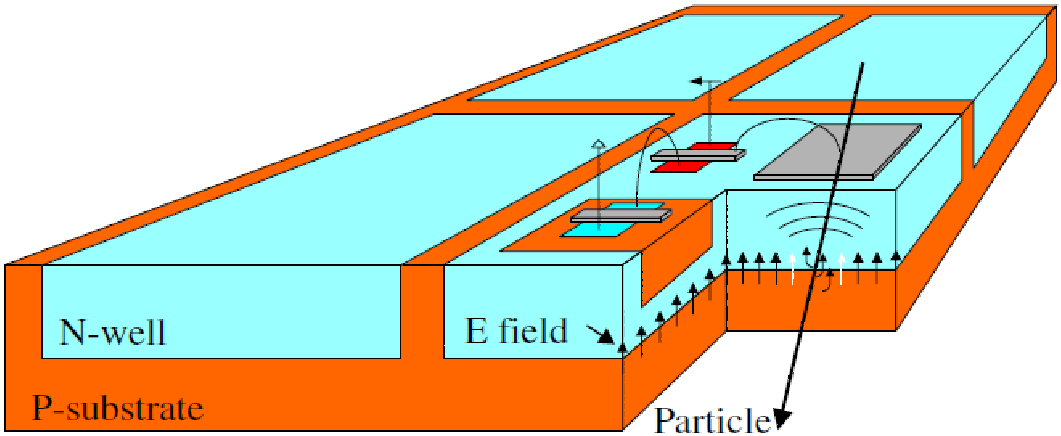
Thank You

Backup

Mu3e Collaboration

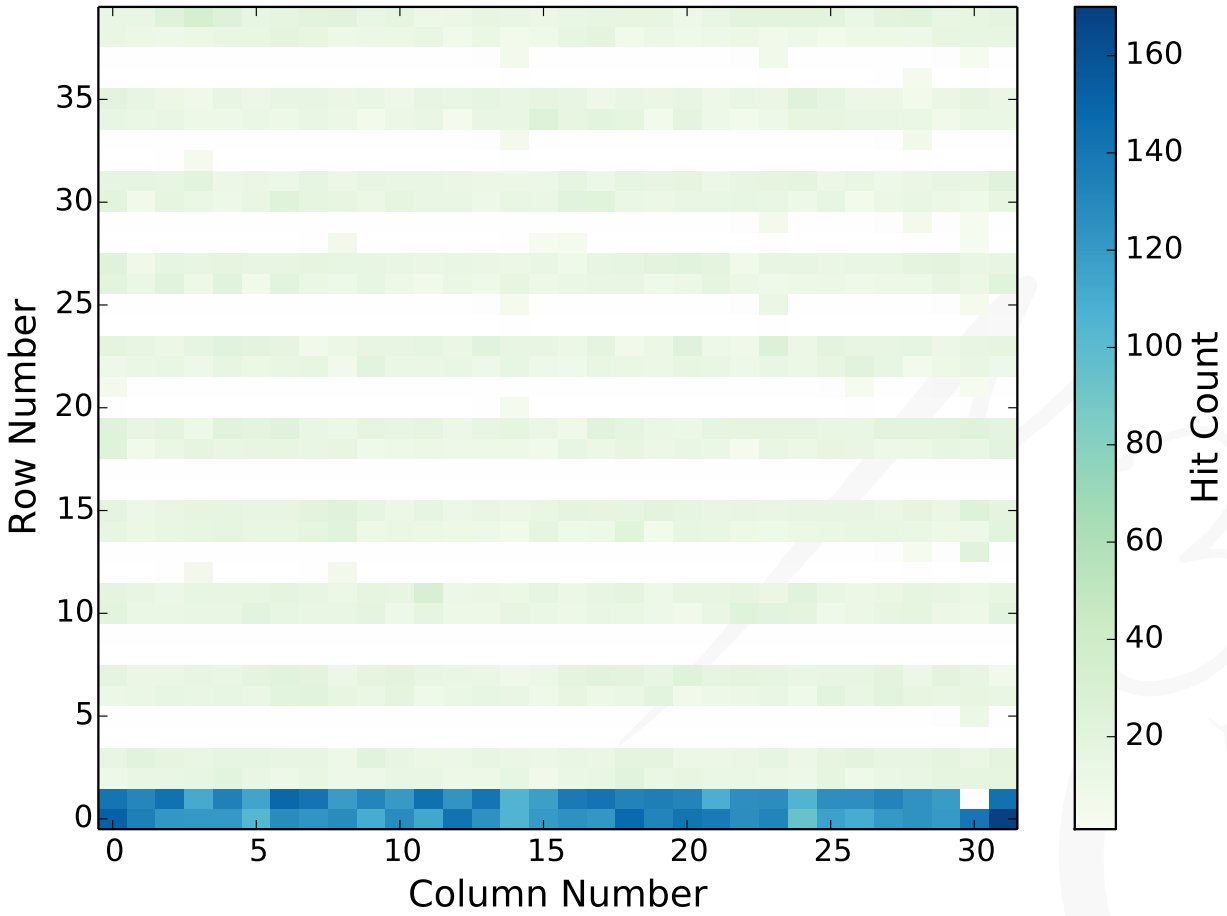
- Paul-Scherrer Institute, Switzerland
- ETH Zürich
- University Zürich
- University Geneva
- Heidelberg University
- ZITI Mannheim

HV-MAPS



- P-N junction between N-well and substrate
- Reverse bias voltage
- Thin depletion zone beneath N-well

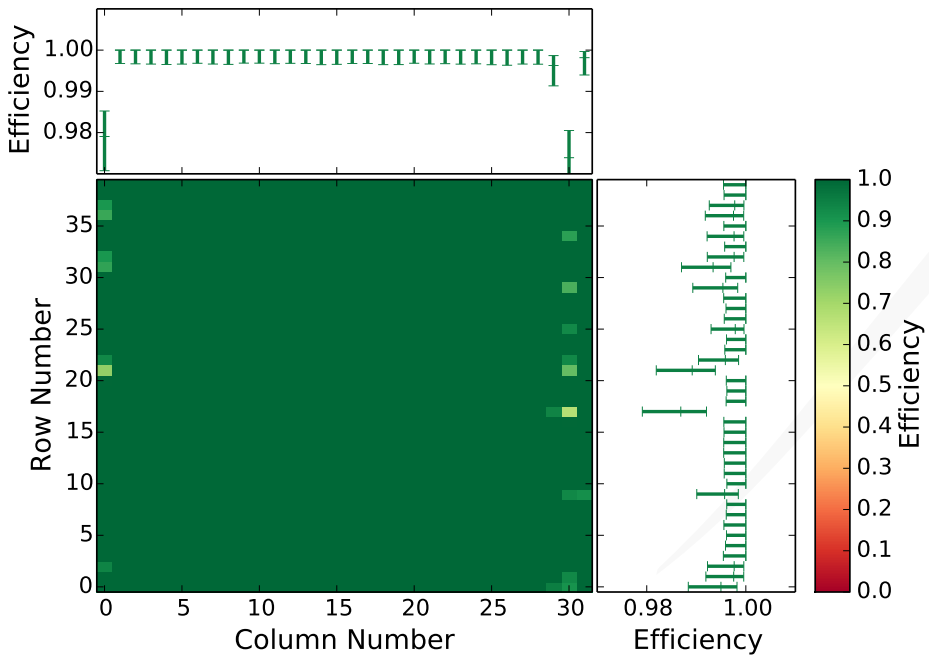
Hitmap a.k.a Hybrid Strixel Sensor



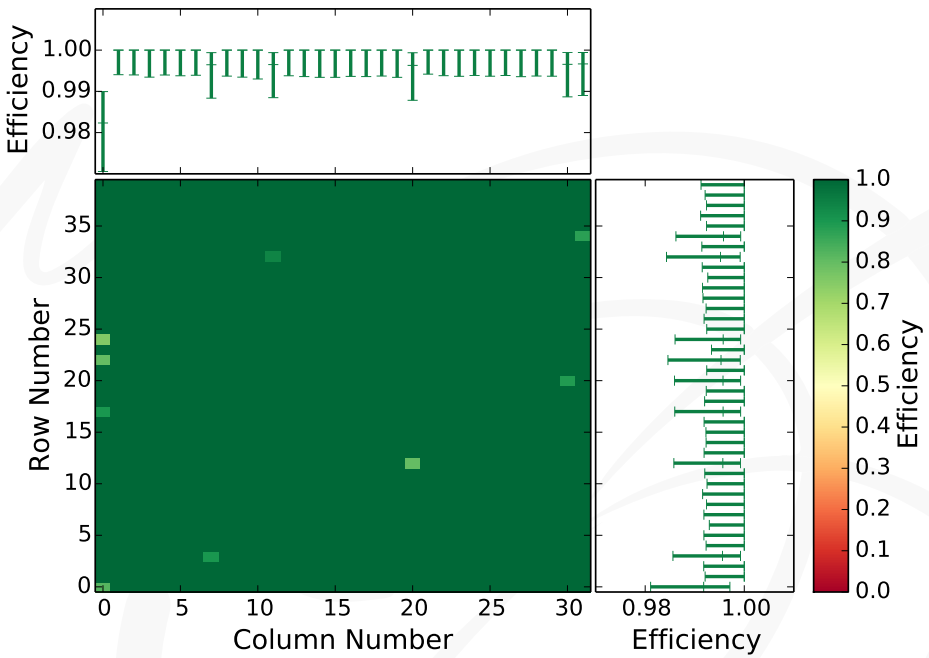
0° incidence angle
70 V high voltage
838 mV threshold
5 GeV beam energy

Pixel Tuning

Before Tuning



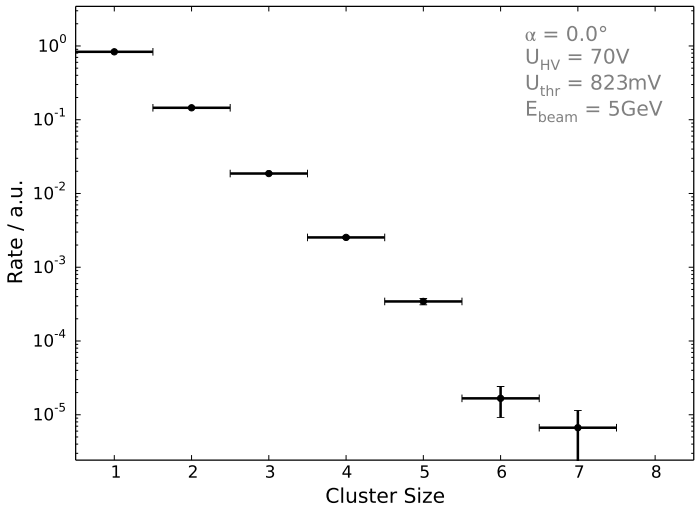
After Tuning



45° incidence angle

Clustering / Charge Sharing

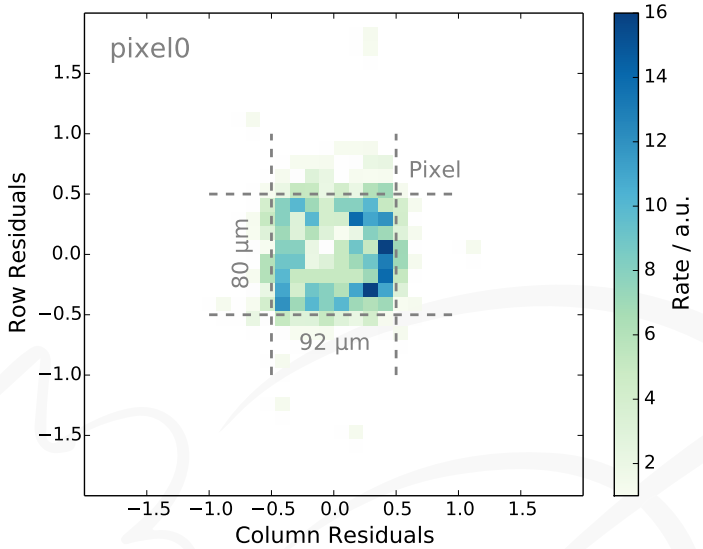
Cluster Size

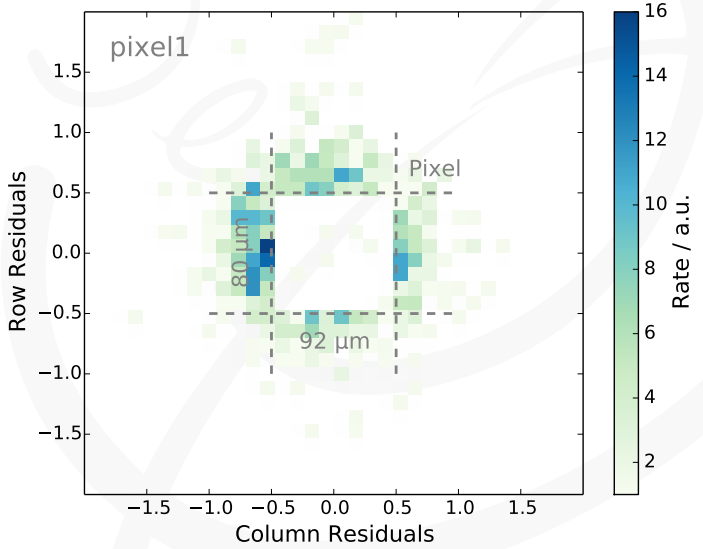


0° incidence angle
70 V high voltage
823 mV threshold
5 GeV beam energy

1-pixel cluster dominate

2-Pixel Cluster





Mu3e Expected Sensitivity over Time