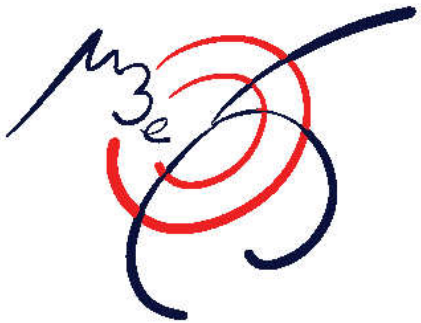
Mu3e Testbeam Measurements at DESY

Moritz Kiehn for the Mu3e Collaboration

Physikalisches Institut, Universität Heidelberg

Telescopes and Testbeams, Hamburg, 30. June 2014

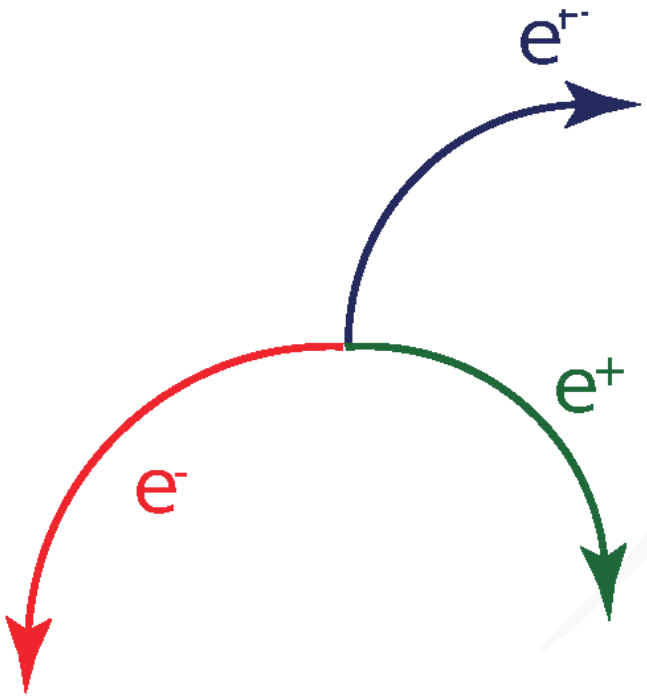


INTERNATIONAL MAX PLANCK RESEARCH SCHOOL

PT FS

FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES

The Mu3e Experiment

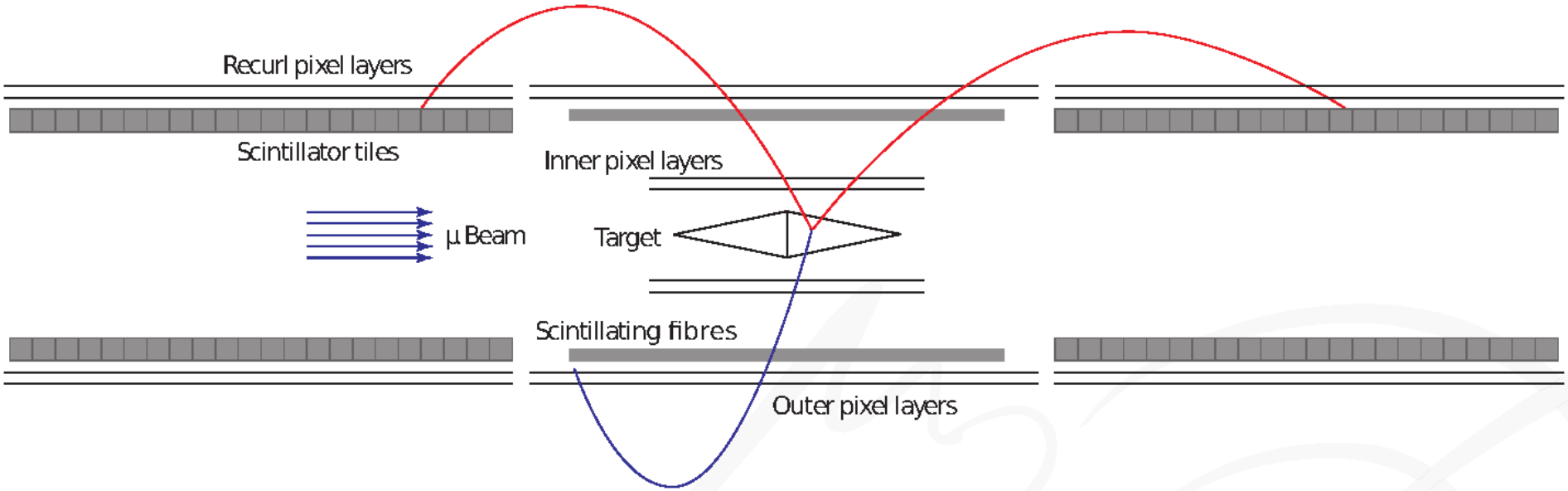


- Precision experiment
- Search for $\mu^+ \rightarrow e^+e^-e^+$
- Sensitivity < 1 in 10^{16} decays
- Standard Model $\ll 1$ in 10^{50}

Importance ?

- New physics search
- High sensitivity

The Mu3e Experiment



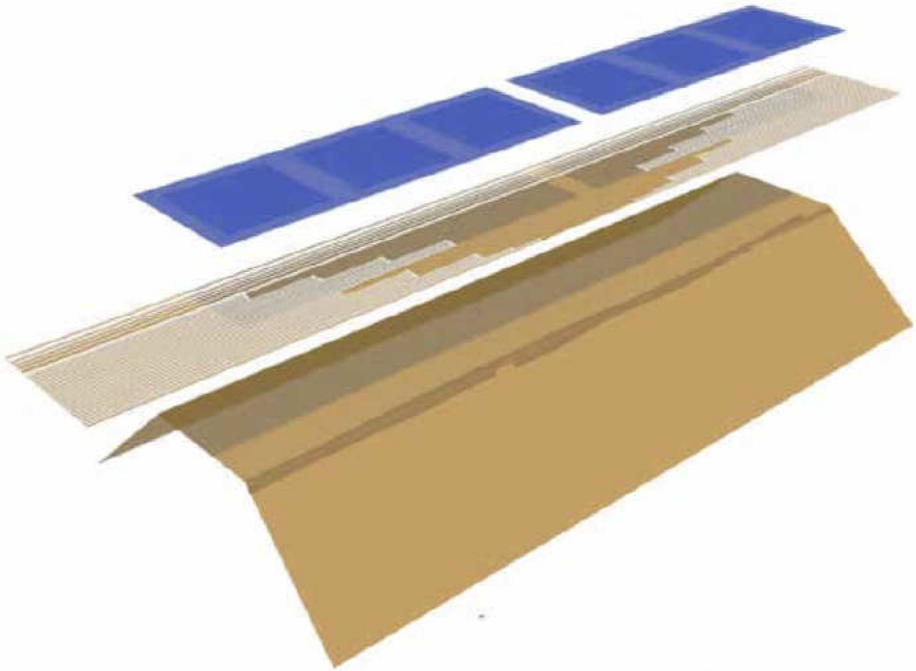
Environment

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

Pixel Sensor Requirements

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

Ultra-Lightweight Mechanics

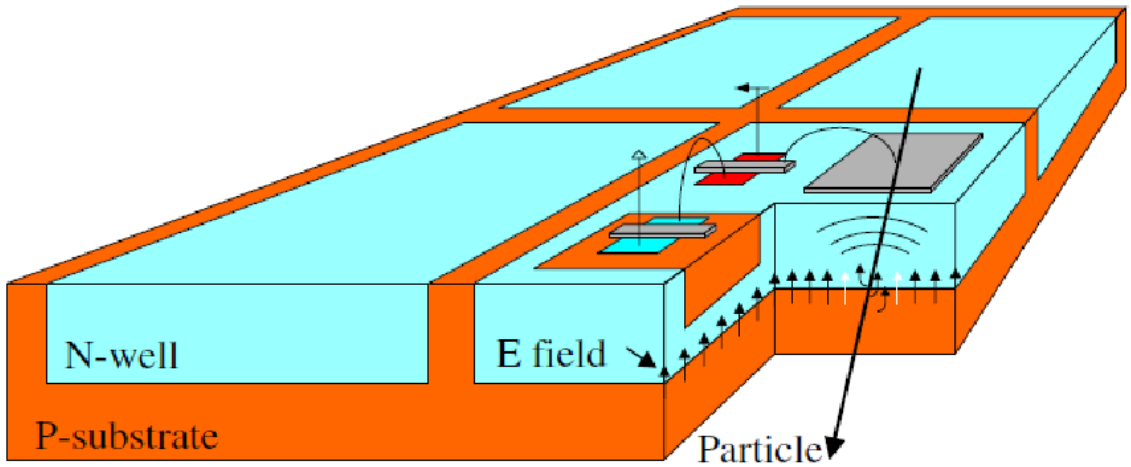


- 50 µm Silicon sensor
- 50 µm Kapton flexprint
- 25 µm Kapton support frame

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

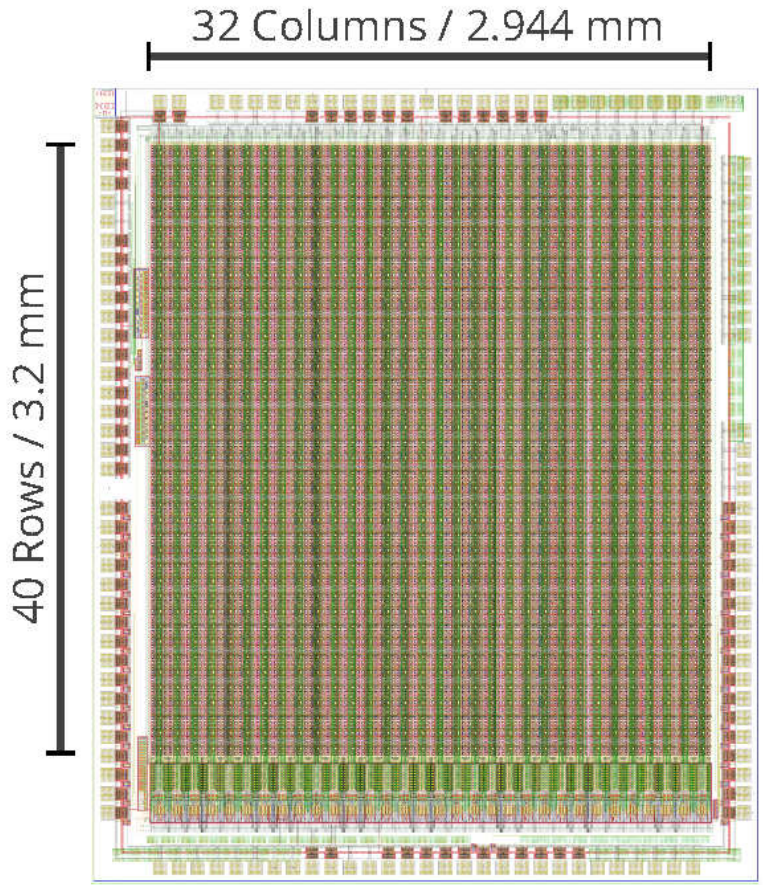
Testing Pixel Sensor Prototypes

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

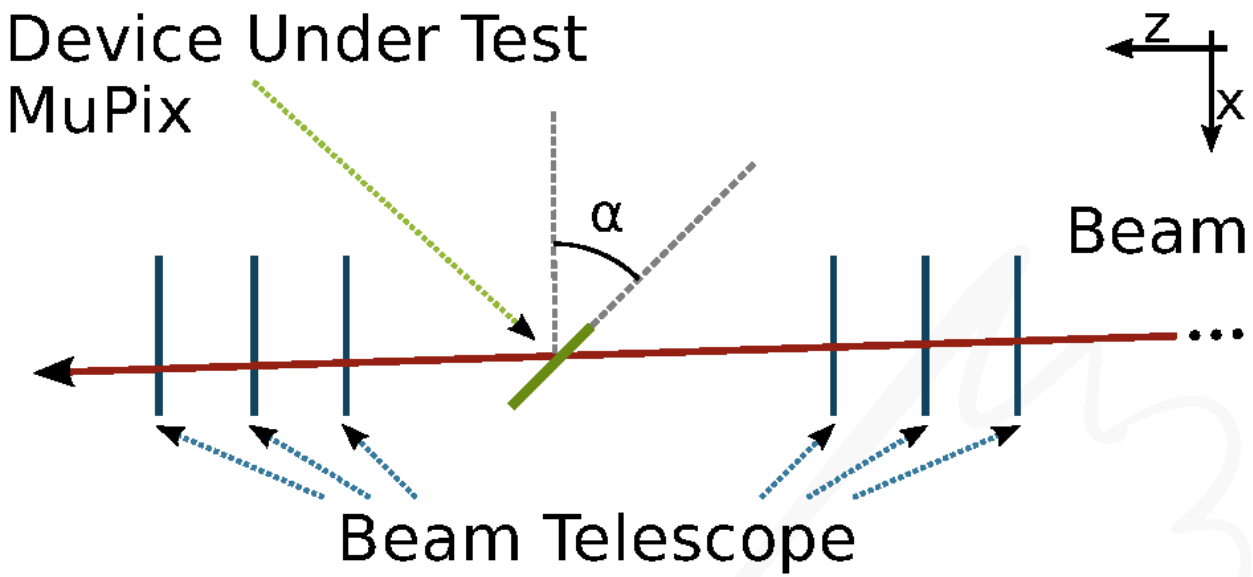
MuPix4 HV-MAPS Prototype



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

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

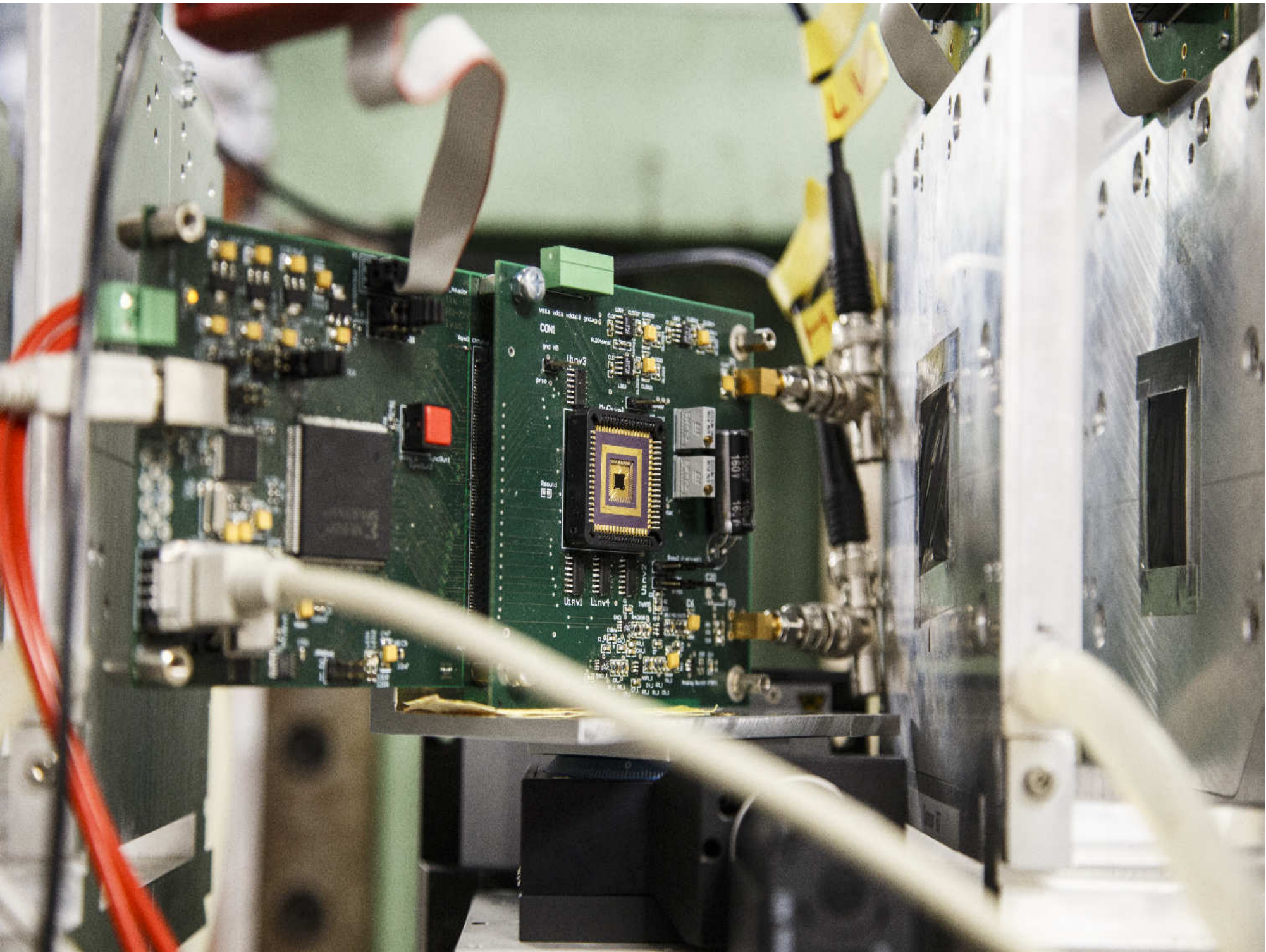
Testbeam Setup w/ MuPix4



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

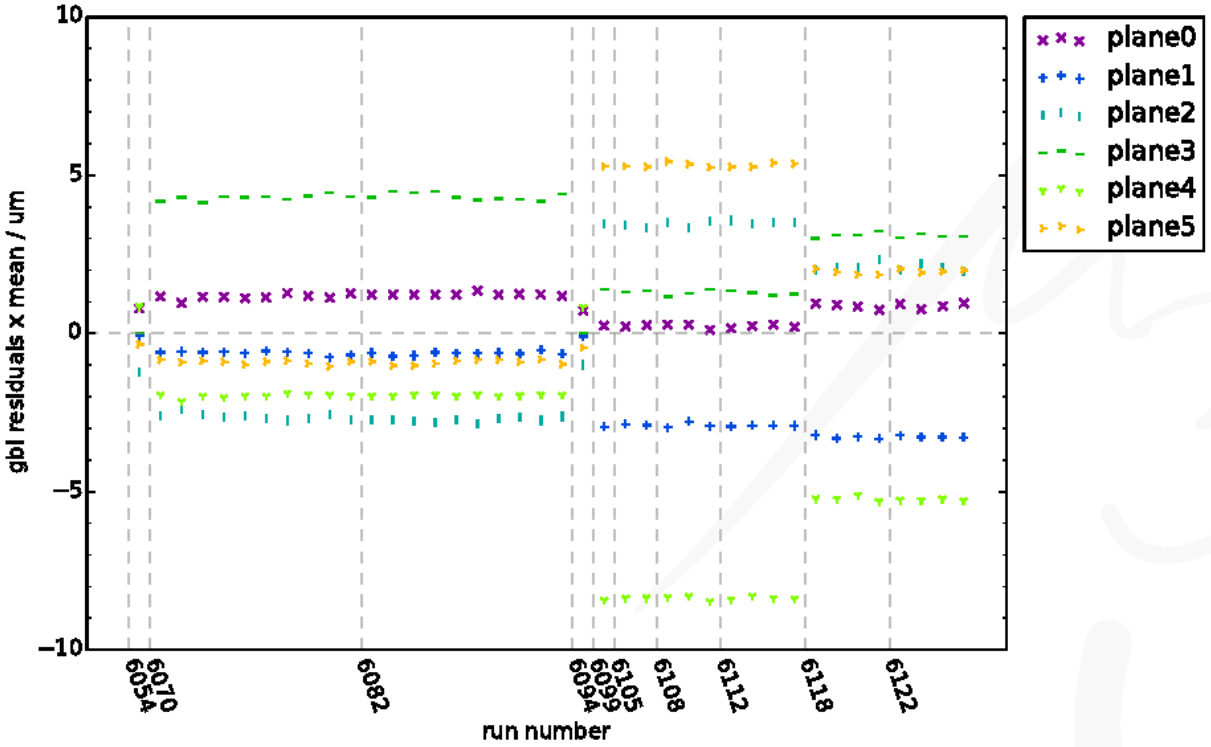
Provided by DESY

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



Telescope (Mis-)Alignment

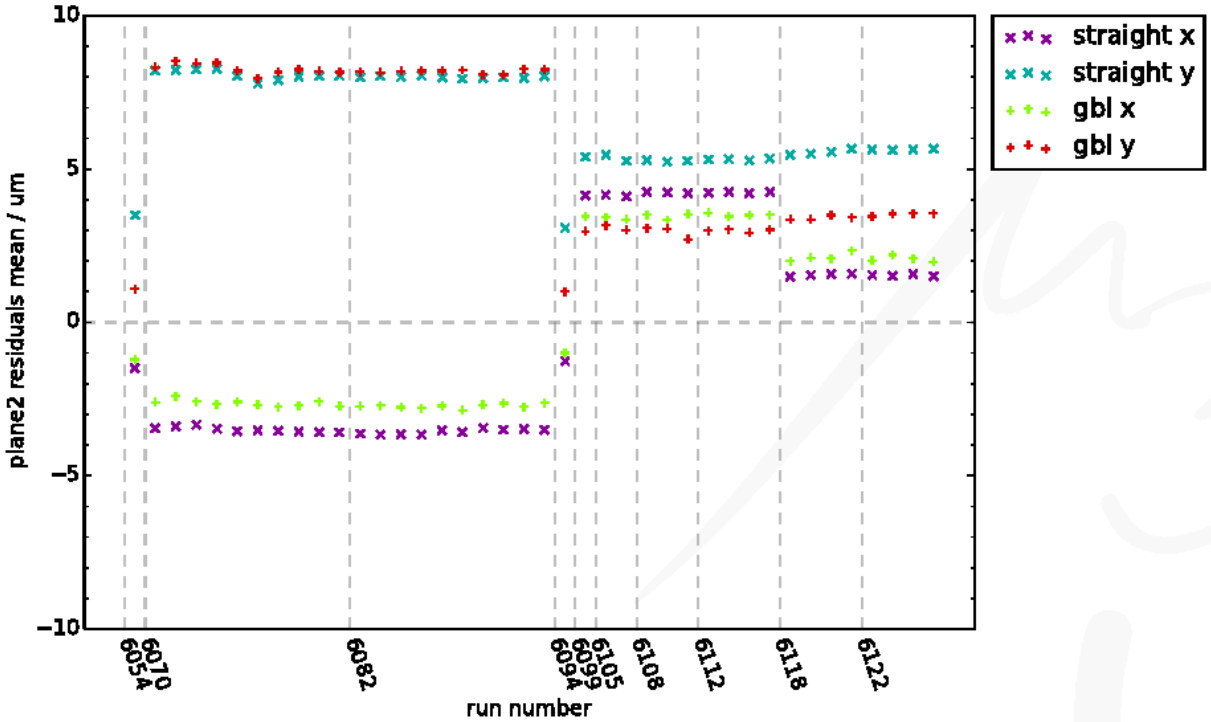
Track Residuals in X / All Planes



- 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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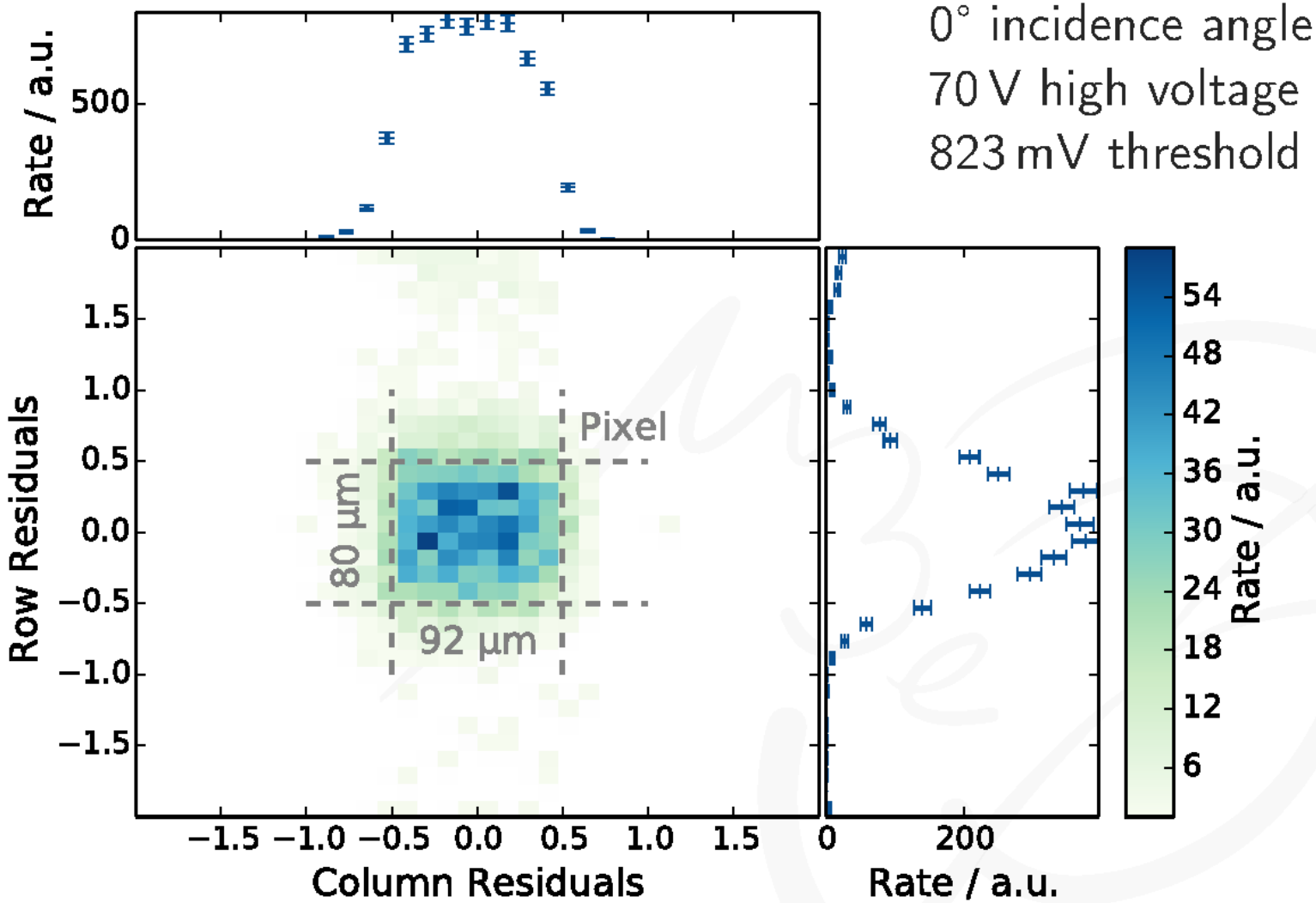
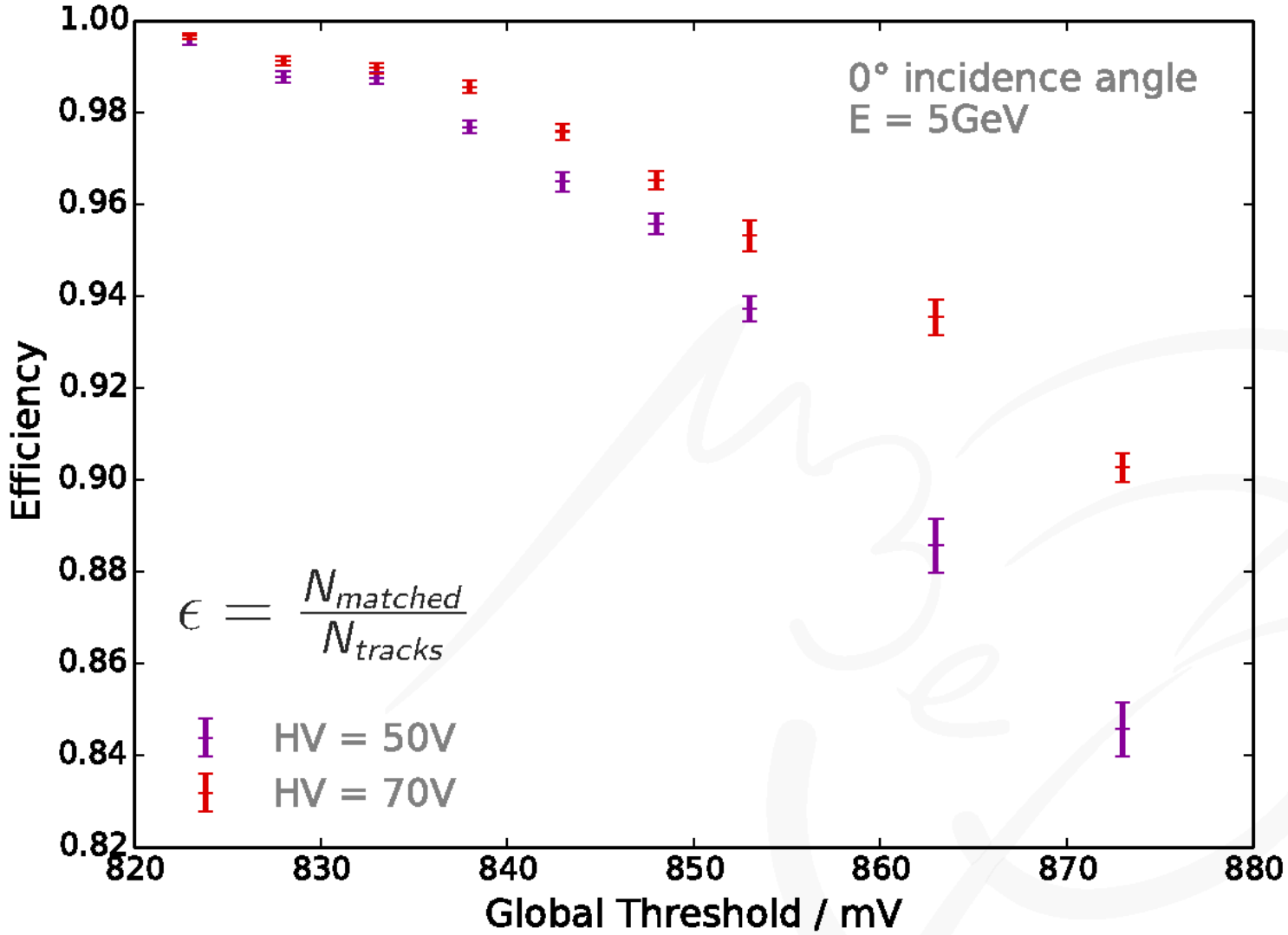
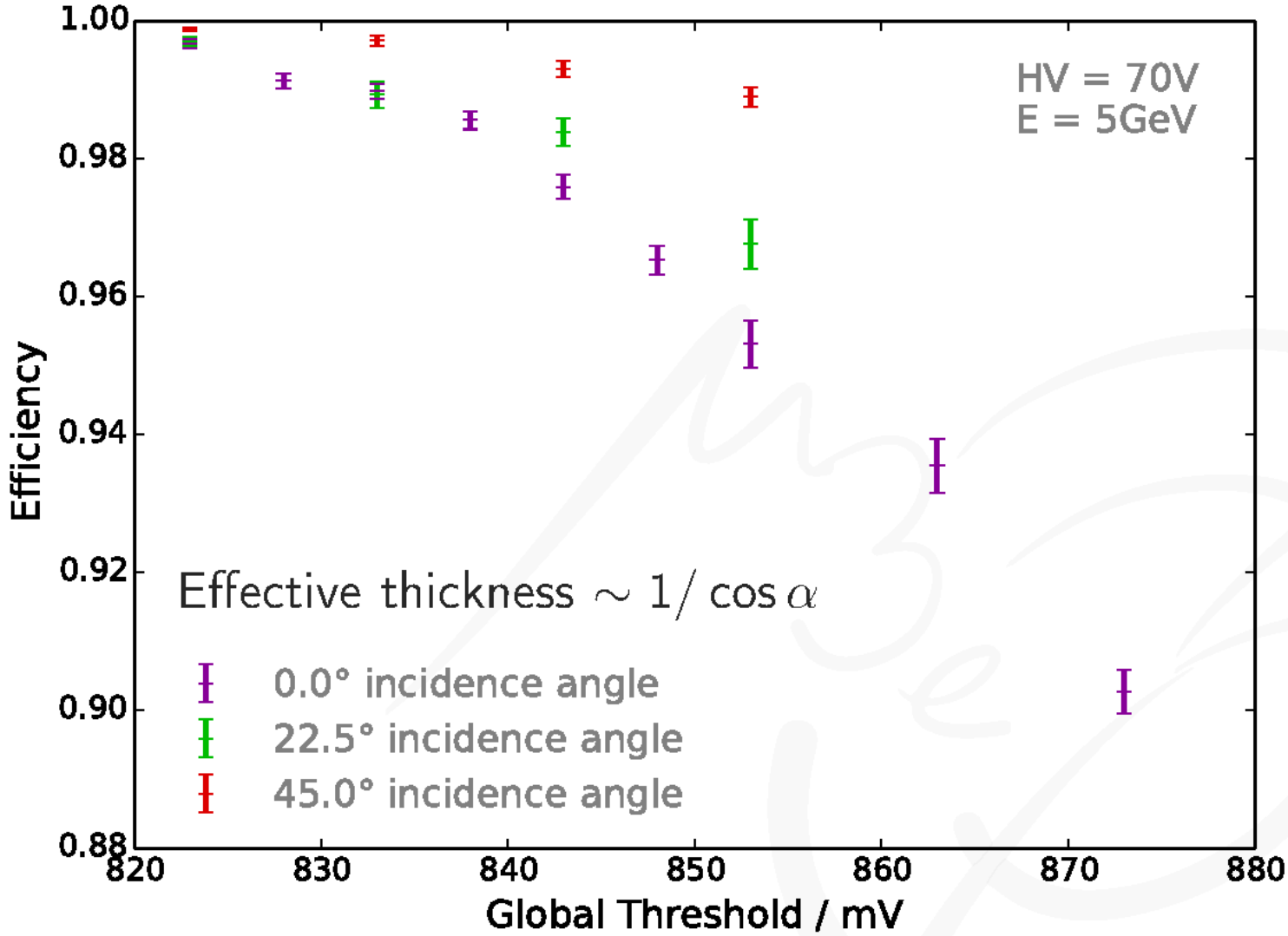
Single Hit Resolution



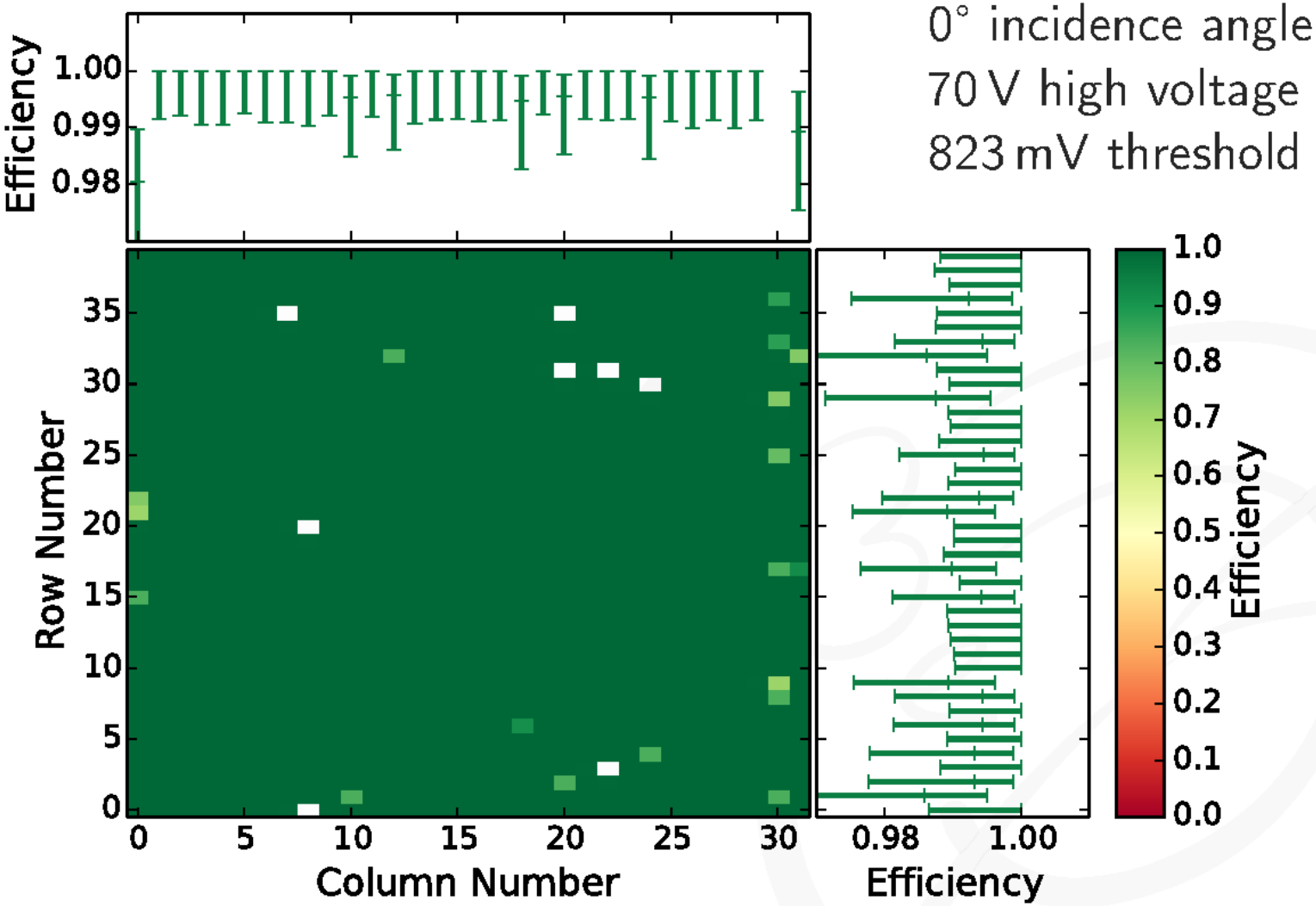
Global Efficiency / High Voltage



Global Efficiency / Incidence Angle



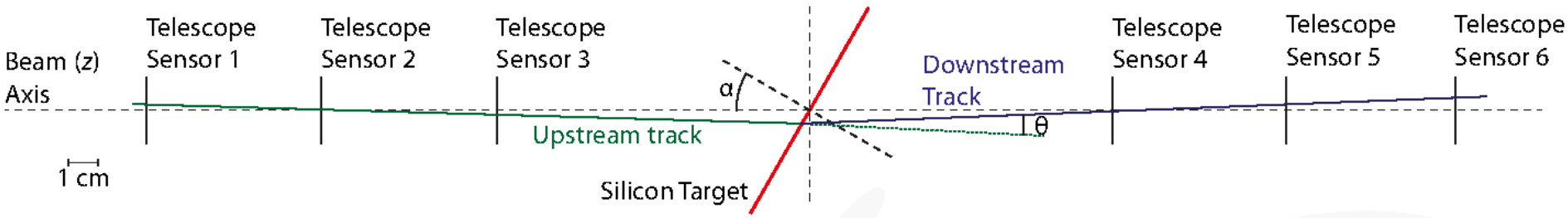
Pixel Efficiency



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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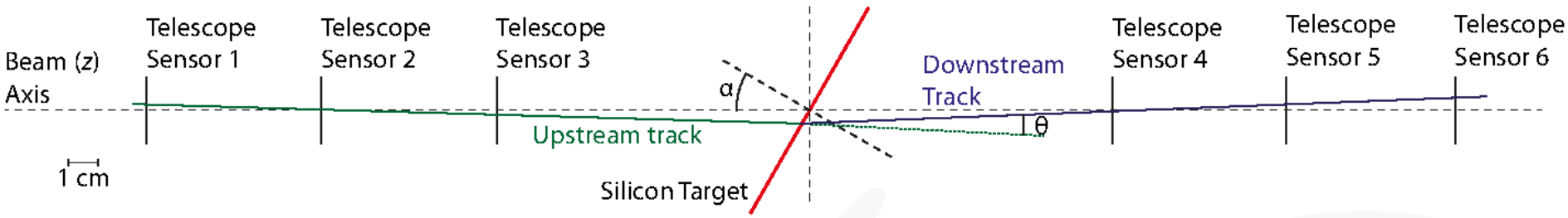


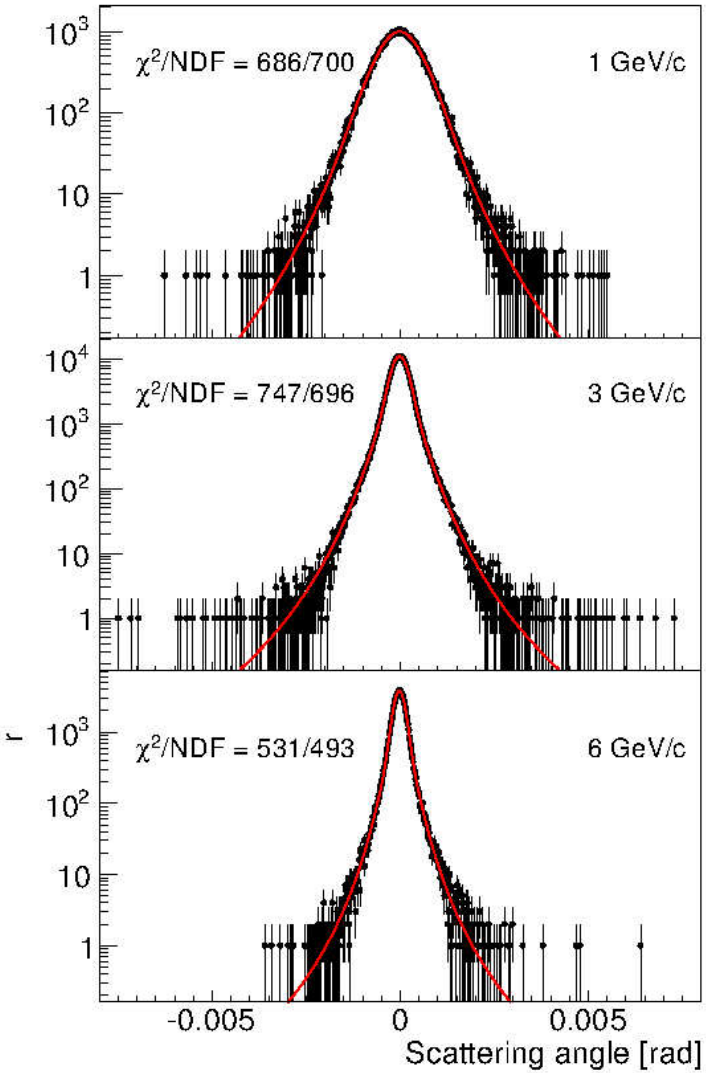
Fitted Scattering Distributions

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

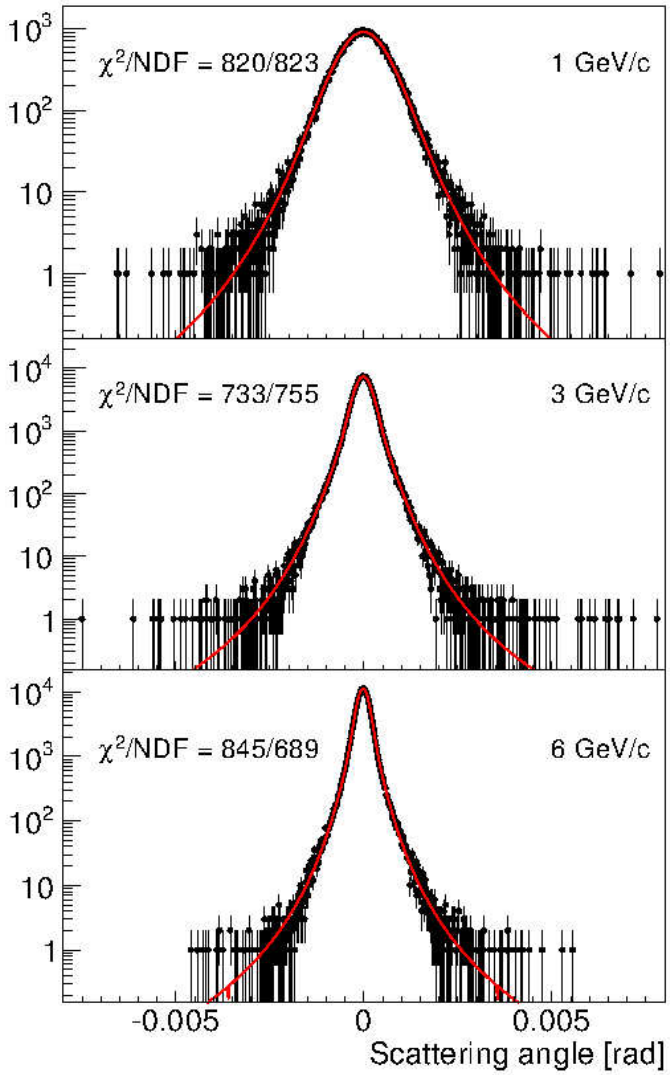
$$s(\theta) \sim t_{\mathit{fixed}} \otimes \mathit{studentt}(\mu, \sigma, \nu)$$

Measured Scattering Distributions

No Silicon

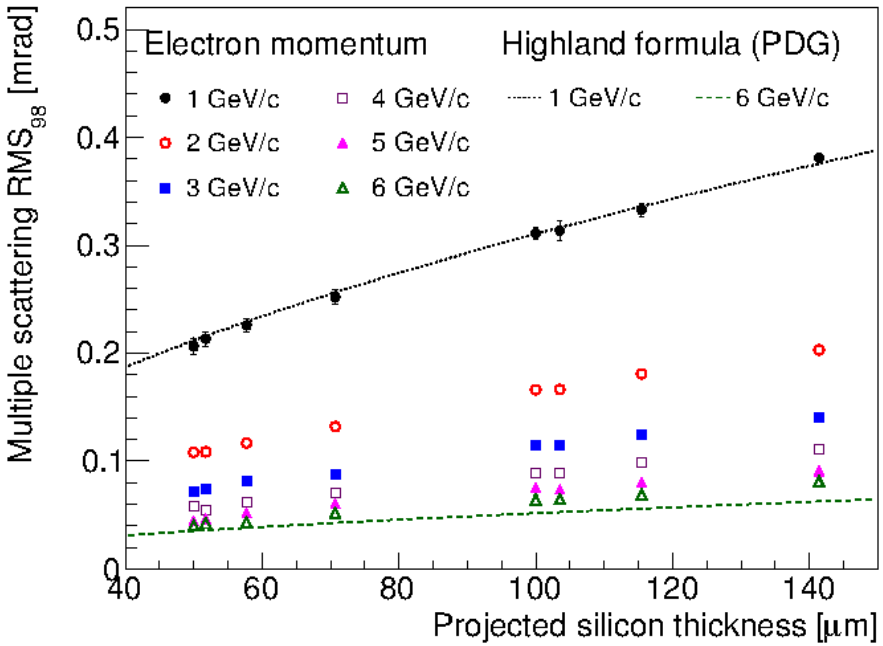


50 µm Si, $\alpha = 15°$

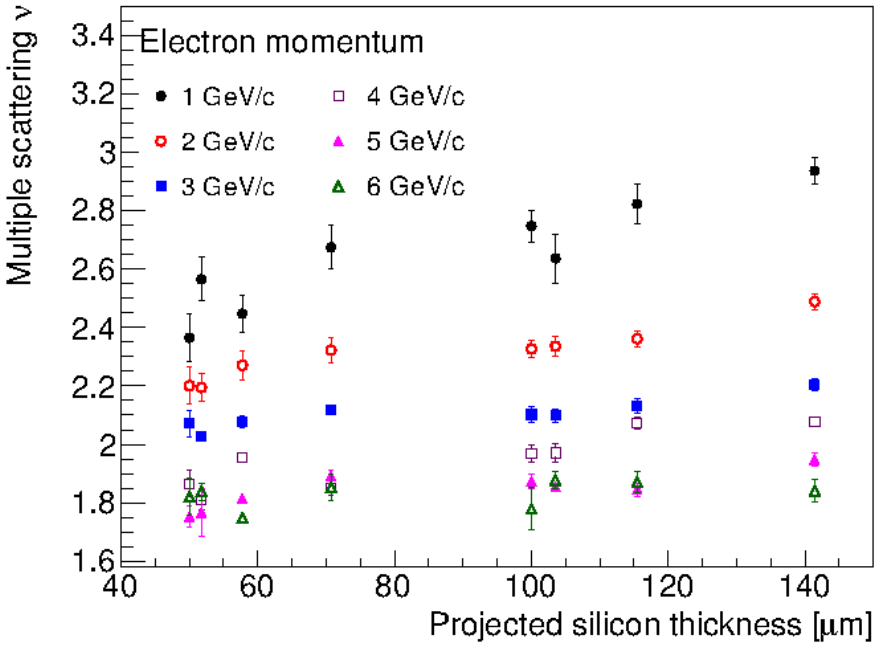


Distribution Parameters

RMS_{98} vs Thickness



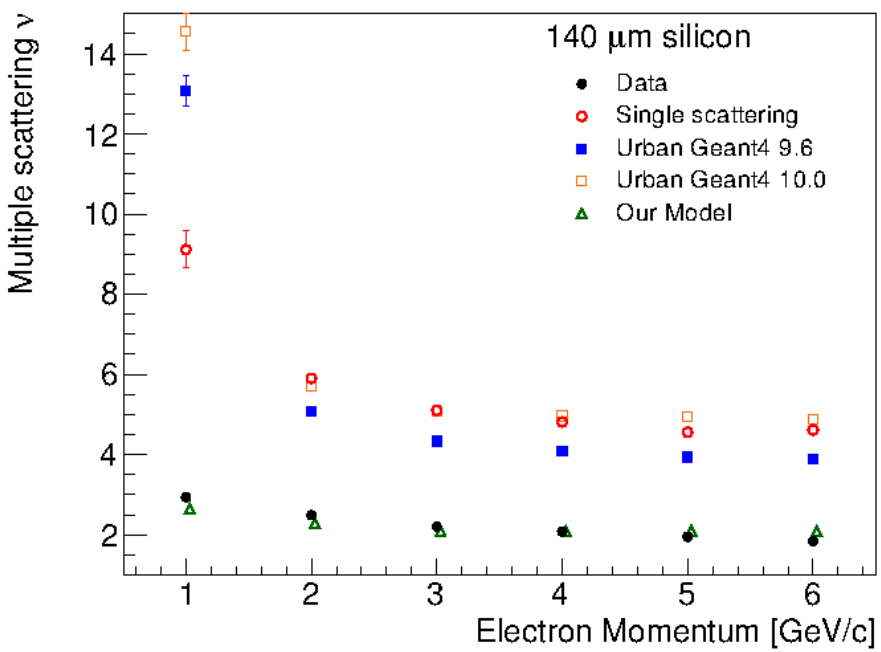
Tail Parameter ν vs Thickness



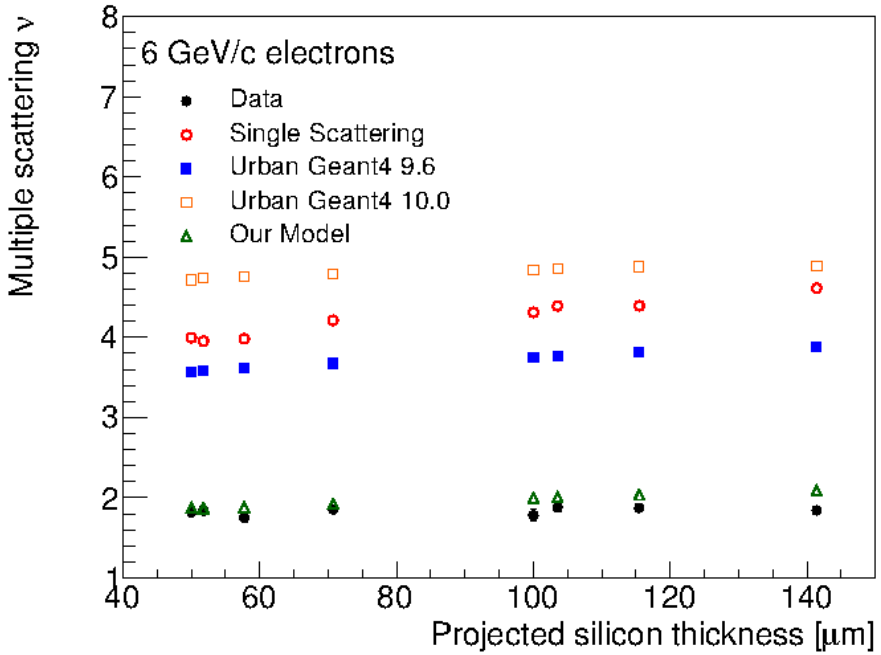
- RMS_{98} is consistent w/ PDG $\sim 1/p\sqrt{t}(1 + 0.038 \ln t)$
- Tail fraction $\sim 1/\nu$

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

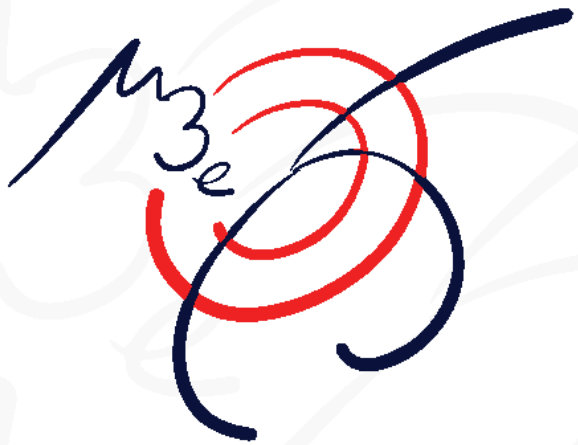
- Search for $\mu^+ \to e^+e^-e^+$
- R&D in progress

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

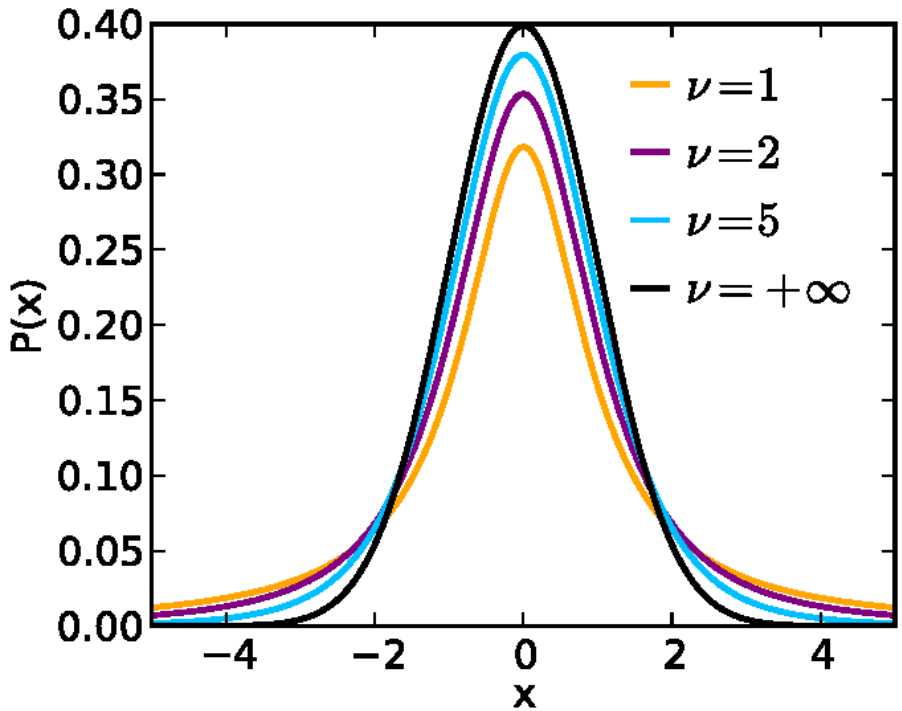
t-Distribution Scattering Model

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

Idea

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

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



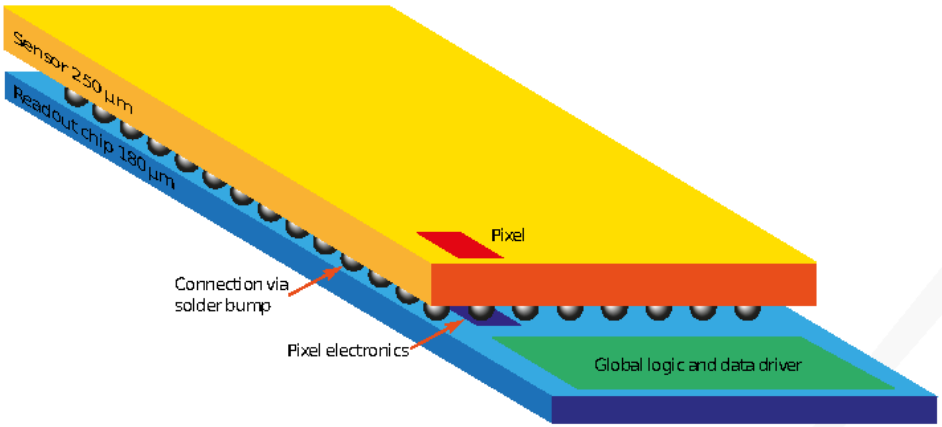
https://en.wikipedia.org/wiki/Student-t

Caveats

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

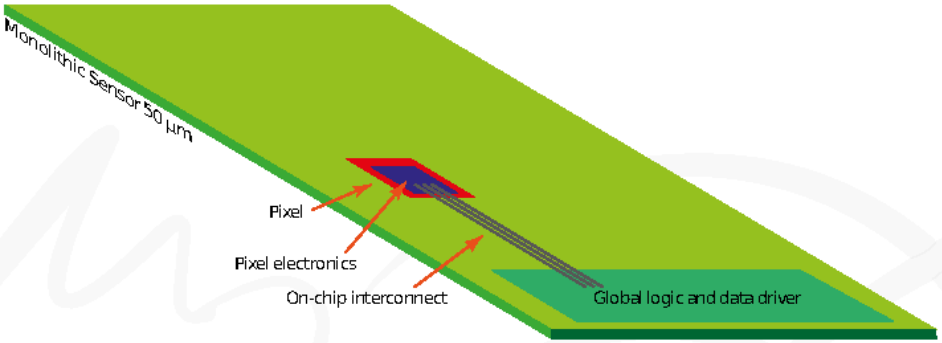
Silicon Pixel Sensors

Hybrid



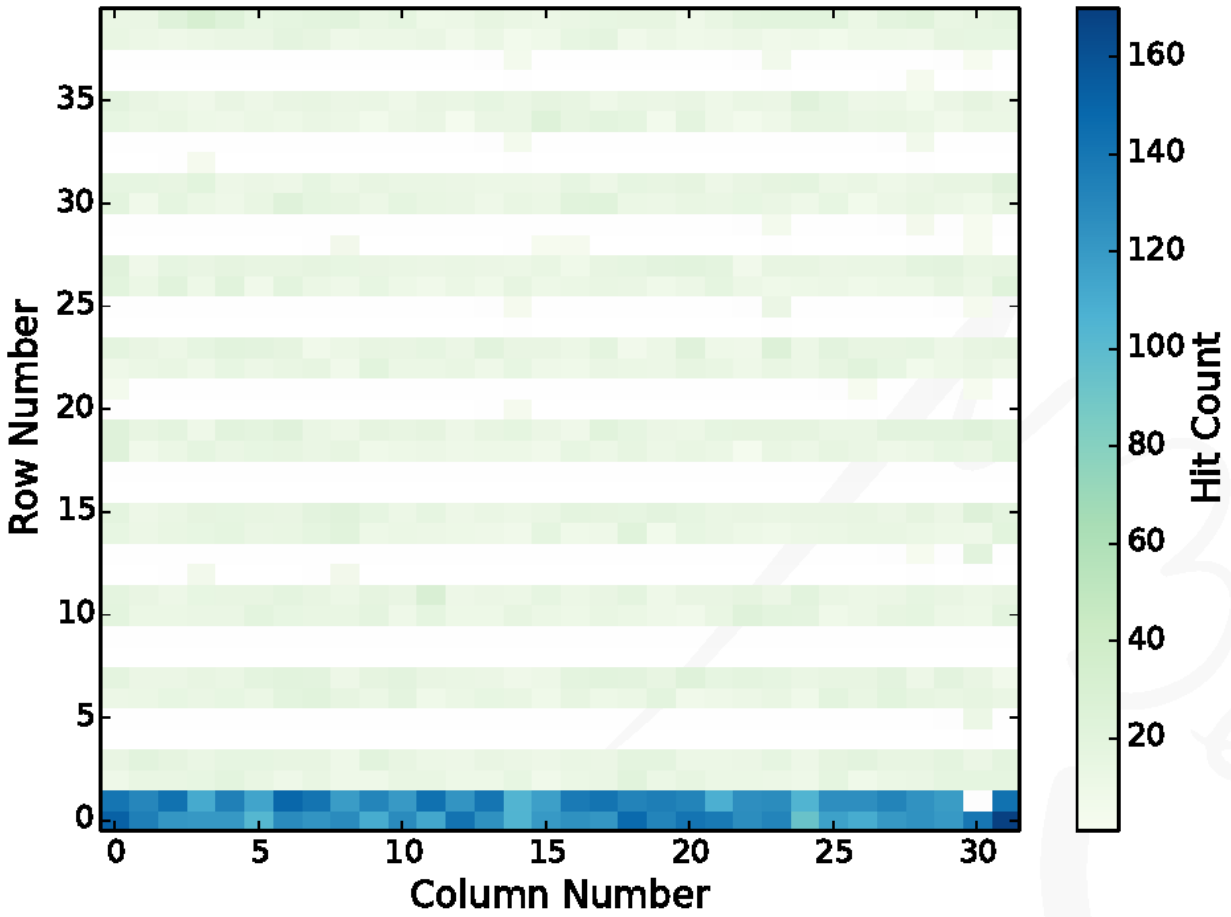
- HV $\sim$ 700 V
- Sensor thickness $\sim$ 250 µm
- Extra material
- Complex and expensive

Monolithic Active Pixel Sensor



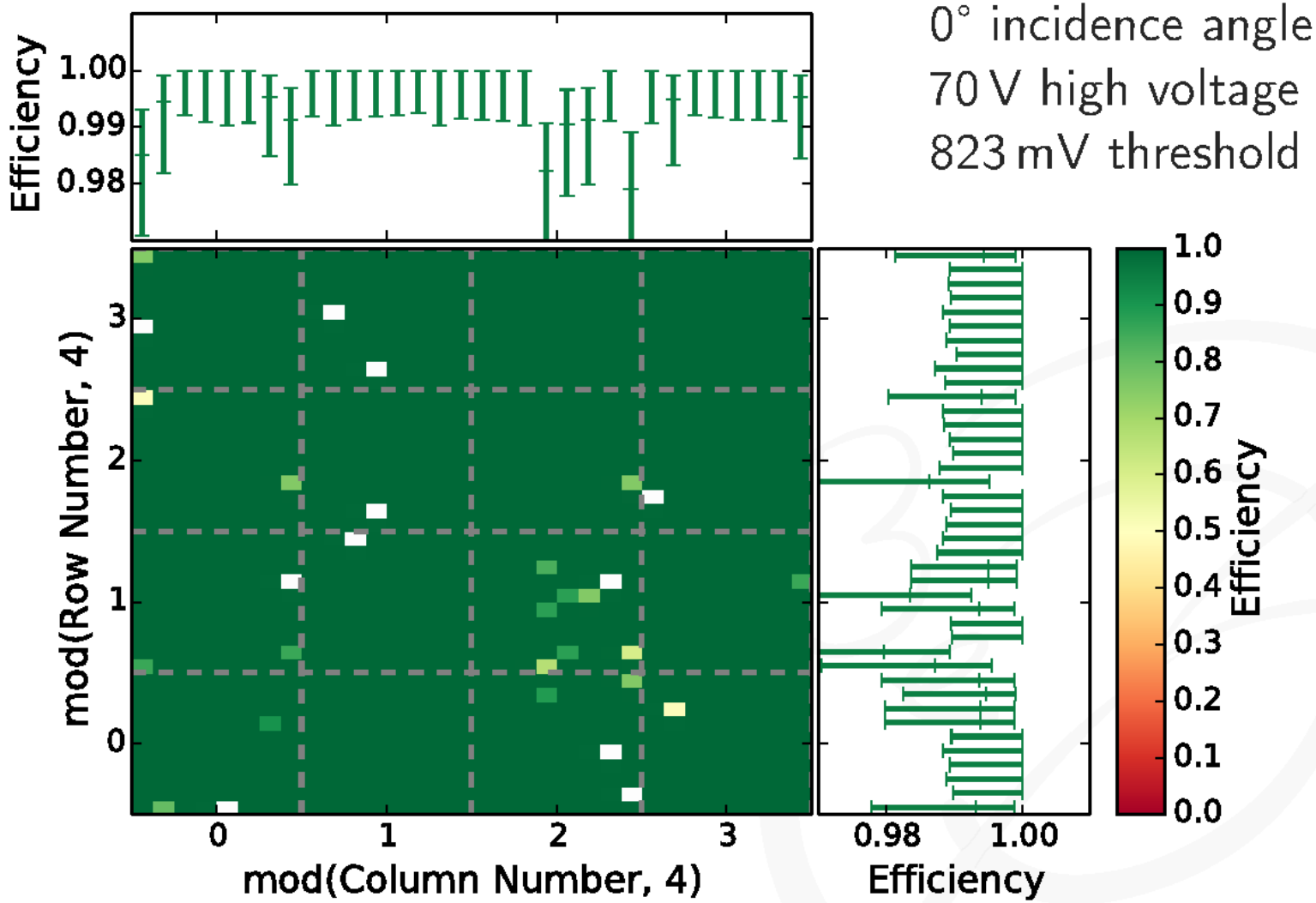
- HV $\sim$ 70 V (HV-MAPS)
- Thin active zone $<$ 20 µm
- Cheap, commercial process

Hitmap a.k.a Hybrid Strixel Sensor



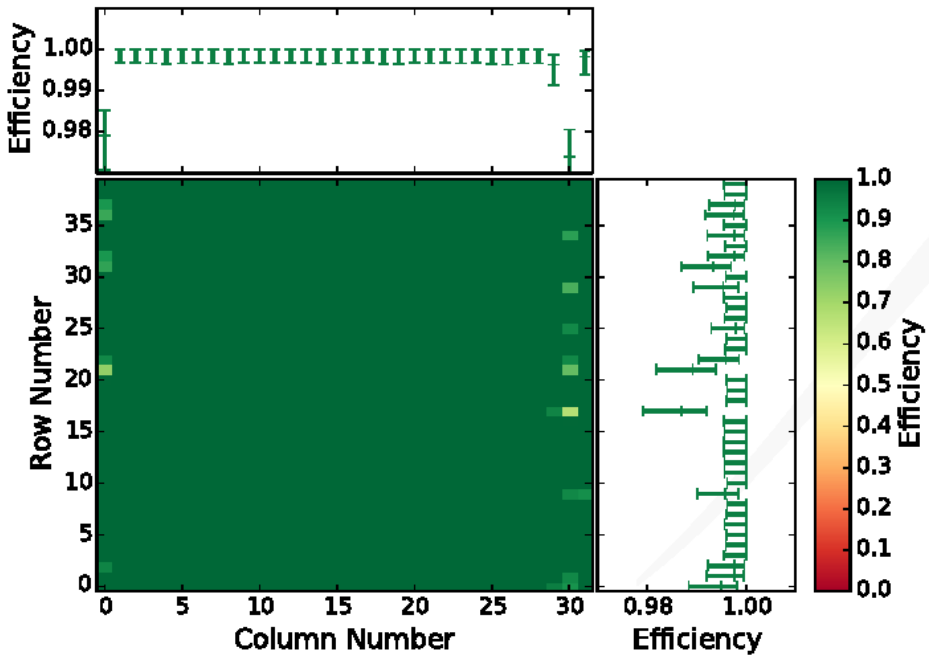
0° incidence angle
70 V high voltage
838 mV threshold
5 GeV beam energy

Subpixel Efficiency / 4x4 Submatrix

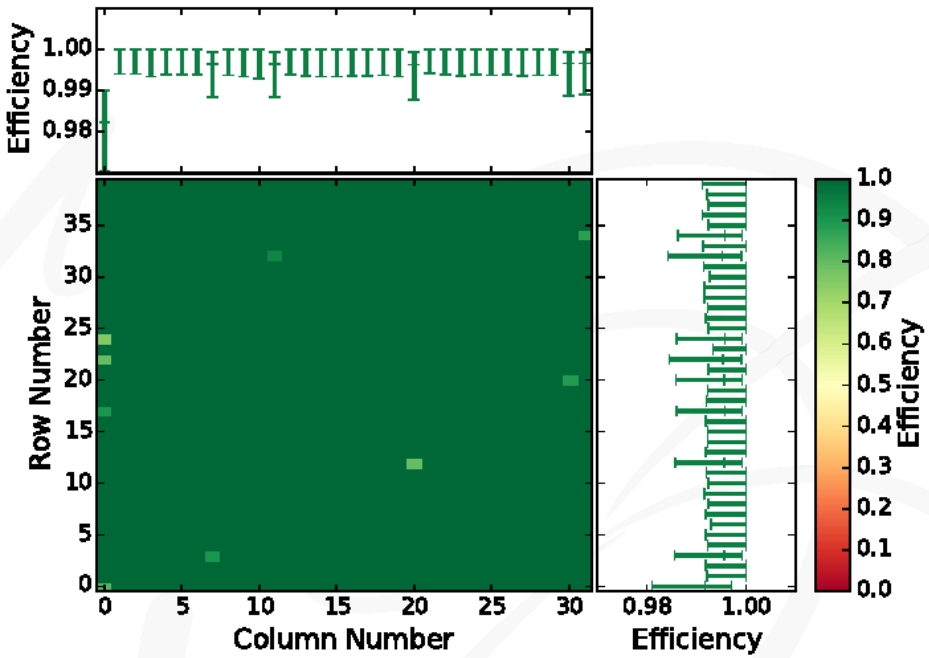


Pixel Tuning

Before Tuning



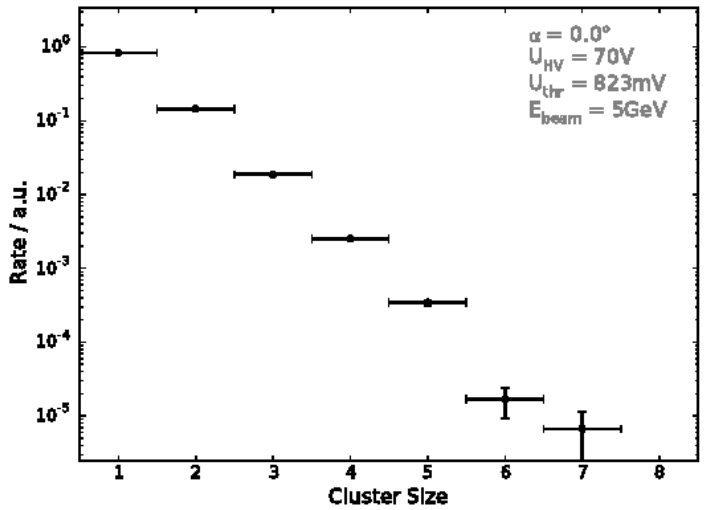
After Tuning



45° incidence angle

Clustering / Charge Sharing

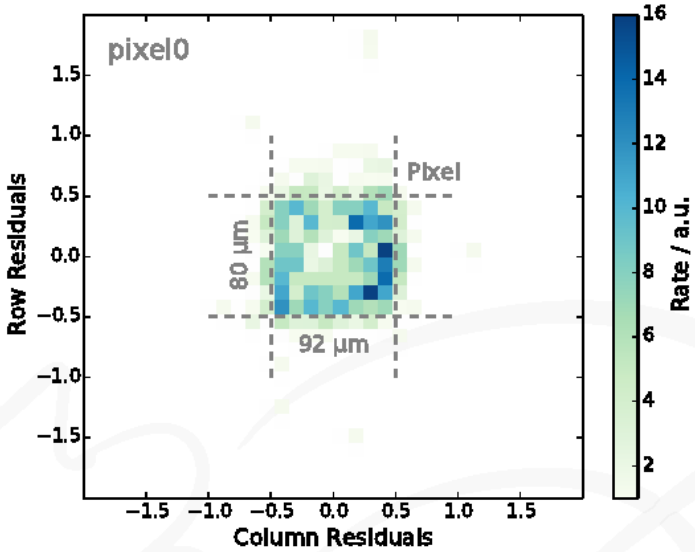
Cluster Size

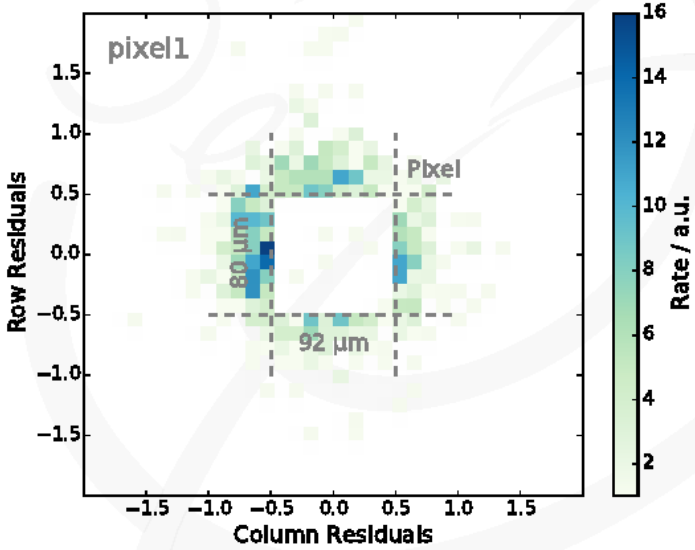


0° incidence angle
70 V high voltage
823 mV threshold
5 GeV beam energy

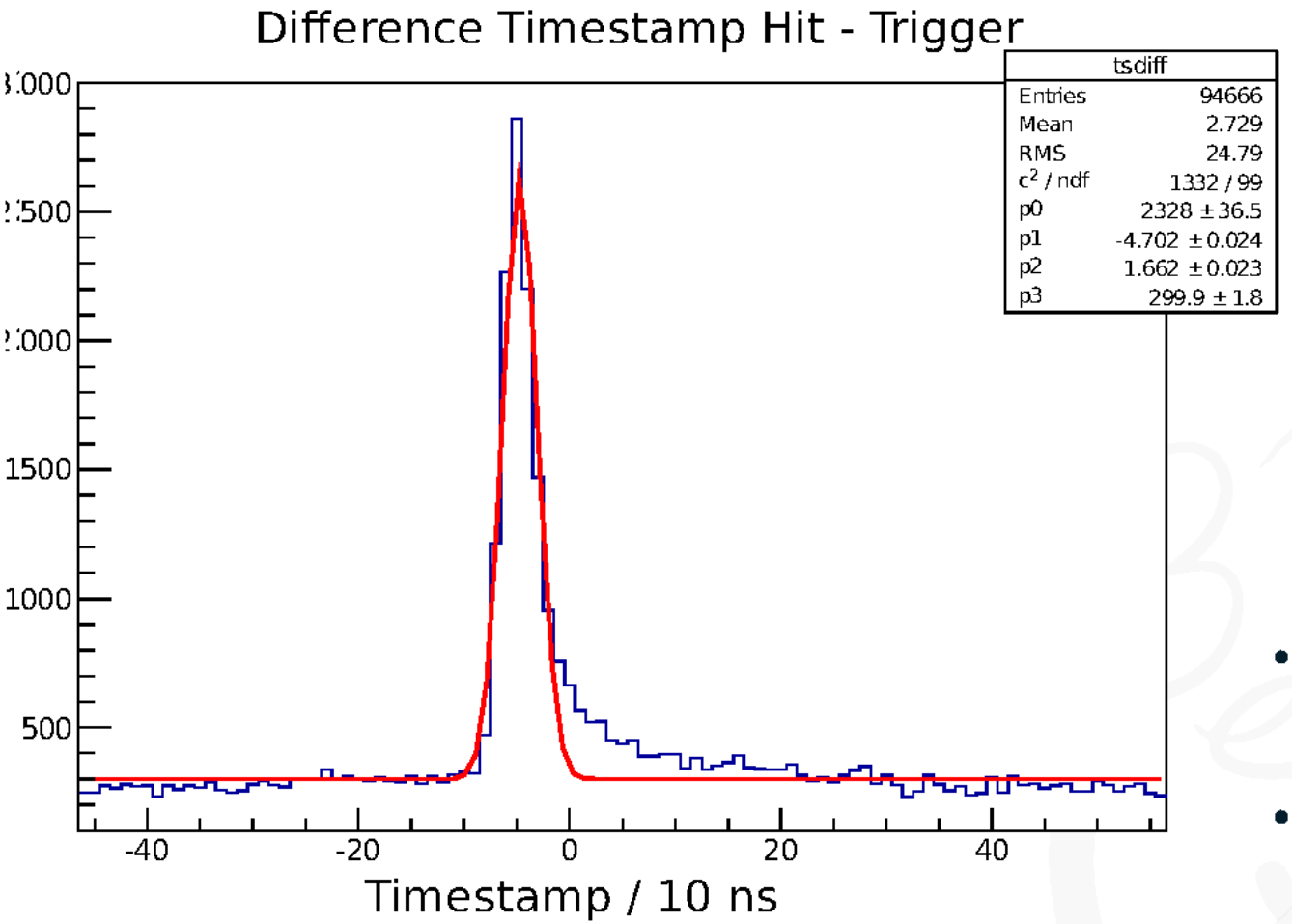
1-pixel cluster dominate

2-Pixel Cluster



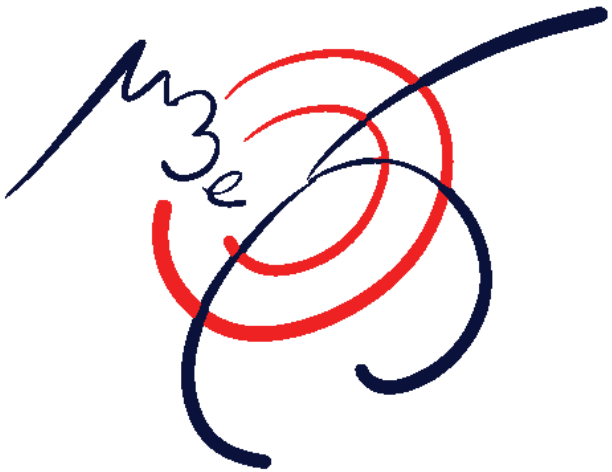


Timing



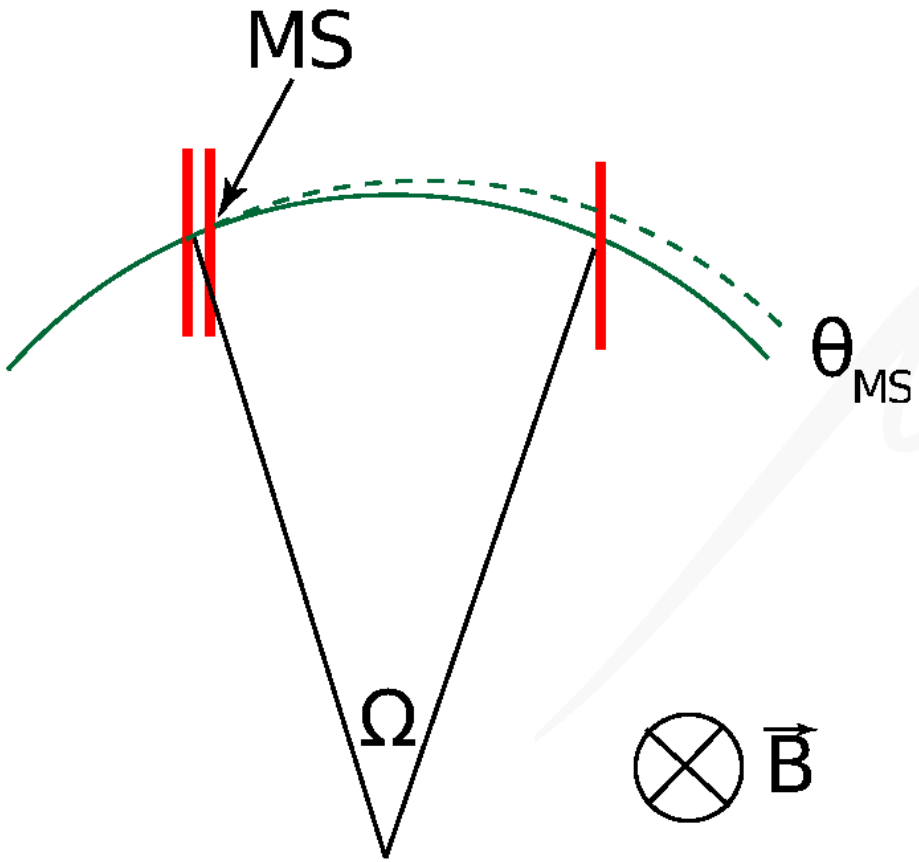
- External timestamp 100 MHz
- Time resolution 17 ns (Sensor + DAQ)

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

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