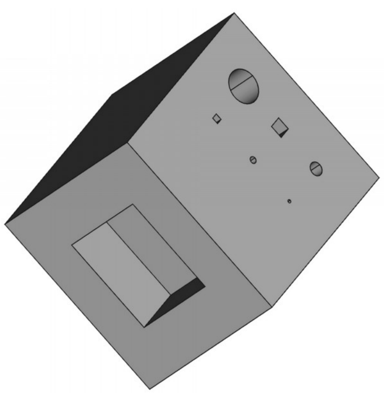
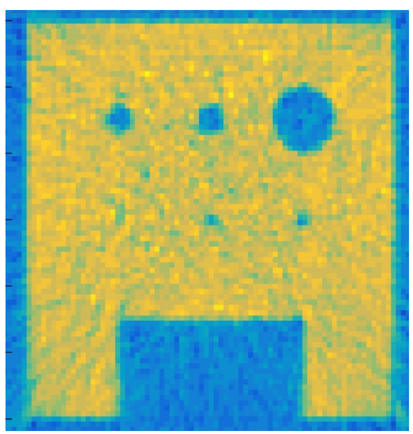
# Track-based Multiple Scattering Tomography

## A feasibility study – concept and simulation





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TIPP’17, Beijing
23.05.2017

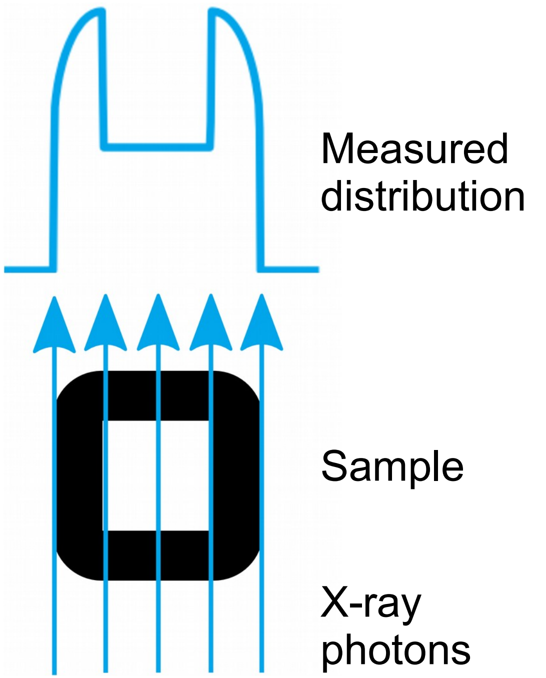
HELMHOLTZ ASSOCIATION

DESY

# Tomography

## Goal:

- Measure the internal structure of a sample
- Reconstructing a two-dimensional density distribution by combining multiple one-dimensional projections




## Standard Method:

- Computed Tomography
- Use X-ray photons traversing the sample to measure a one-dimensional projection of the density distribution

→ Measurement is ambiguous regarding the sample's internal structure

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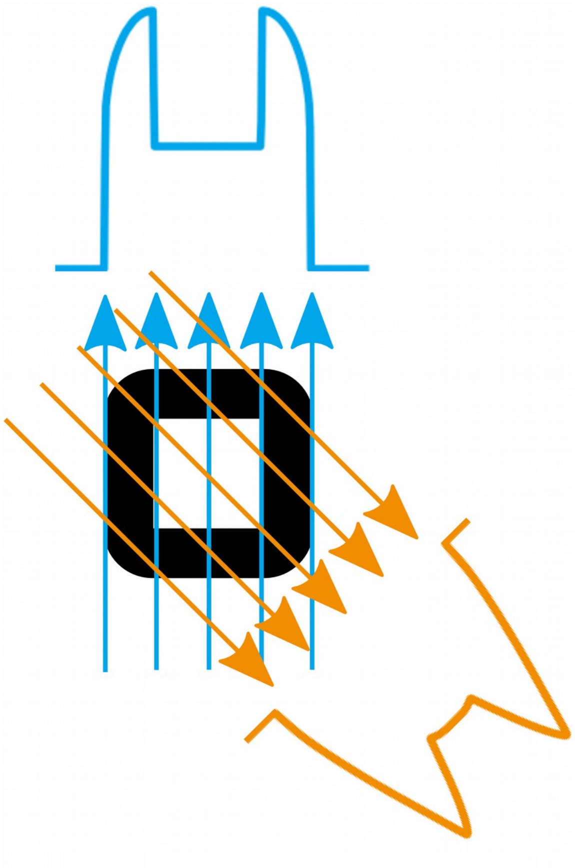


- Standard Method:
  - Computed Tomography
  - Use X-ray photons traversing the sample to measure a one-dimensional projection of the density distribution

  → Measurement is ambiguous regarding the sample's internal structure

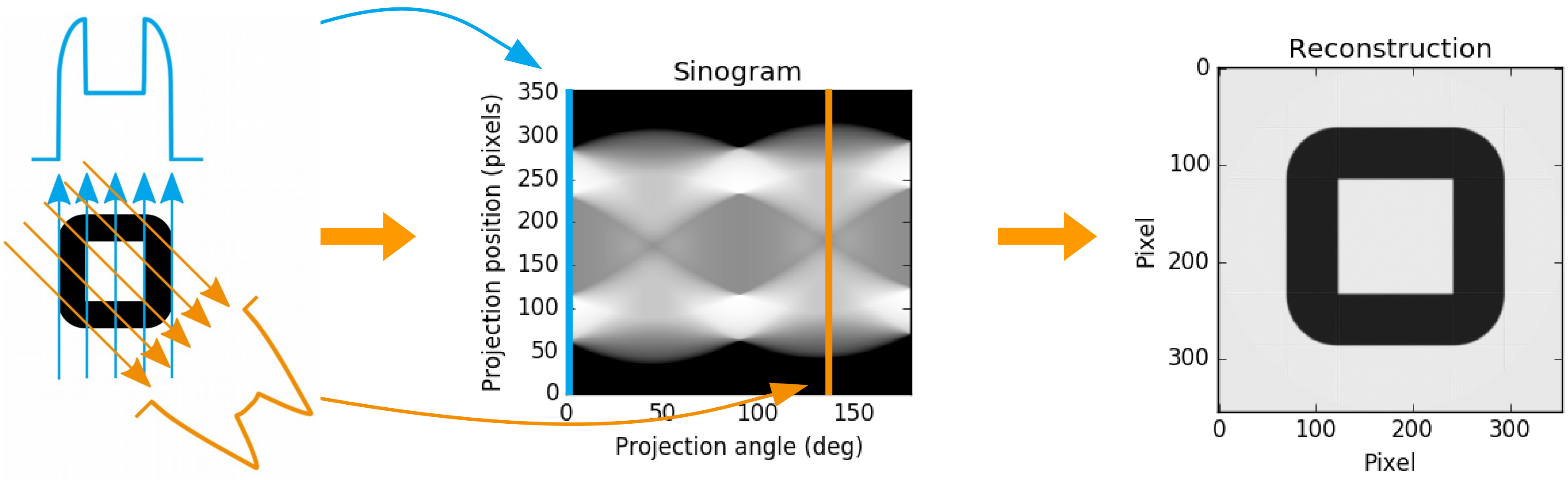
  - Repeat measurement for different angles

  → Two-dimensional structure can be reconstructed

# Tomography – Reconstruction

- Combination of 1D projections for multiple rotation angles
  - ➔Form sinogram as the projected signal over position and angle

- Perform an inverse radon transform [1] to reconstruct the 2D density distribution




- Reconstructing multiple 2D projections enables 3D imaging


[1]: S.R. Deans, *The Radon Transform and some of its applications*

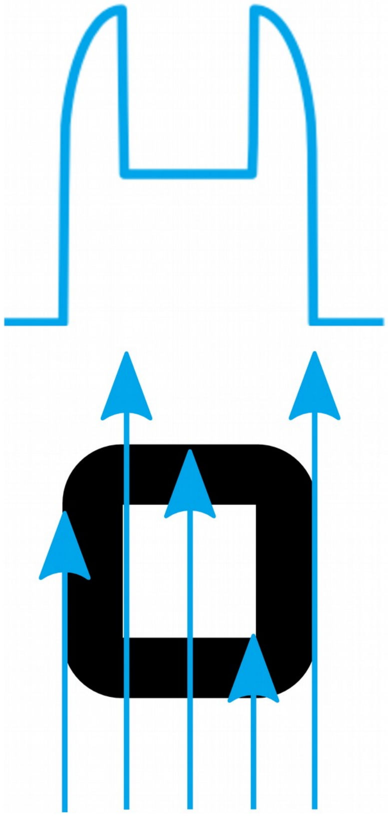
# Tomography – Computed Tomography

- Computed Tomography (CT)
  - Standard technique for material mapping
  - Based on X-ray beam attenuation
  - Measurement:
    Photon counting
  - Characteristic quantity:
    Amount of material and
    it’s radiation length

    ➔ Material budget

- Limitation:
  - Very high absorbing materials
    limited in size due to full absorption

  ➔ Alternative method needed



# Tomography – New technique

## Track-based multiple scattering tomography

- Investigating on a new technique
- High energy (~ GeV) electron beam undergoes multiple Coulomb scattering when traversing a sample
- RMS scattering angle well predicted by the Highland formula [2]:

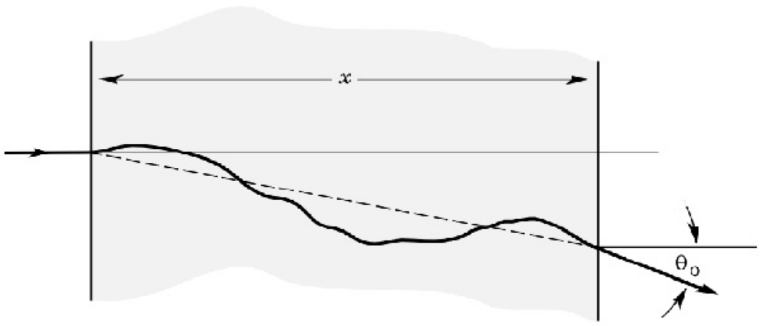
$$\theta_{x,y} = \frac{13.6\,MeV}{\beta cp}\sqrt{\frac{x}{X_0}}\left(1 + 0.038\ln\left(\frac{x}{X_0}\right)\right)$$

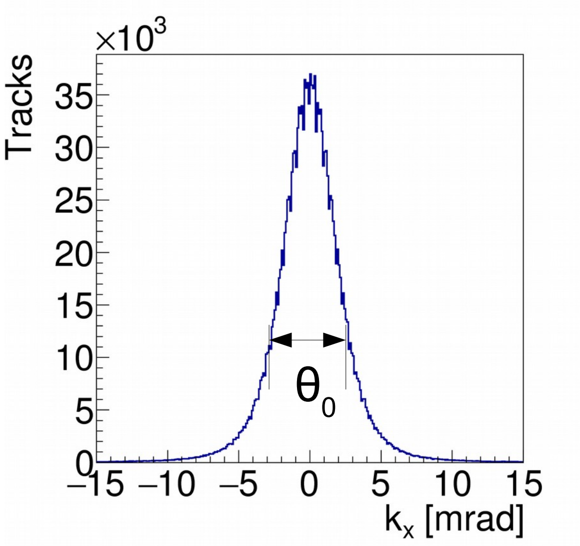
x: Path length in material
$X_0$: Material's radiation length

> See talk by H. Jansen, Thursday, R1

→ Measurement:
Scattering angle distribution

→ Characteristic quantity:
Material budget

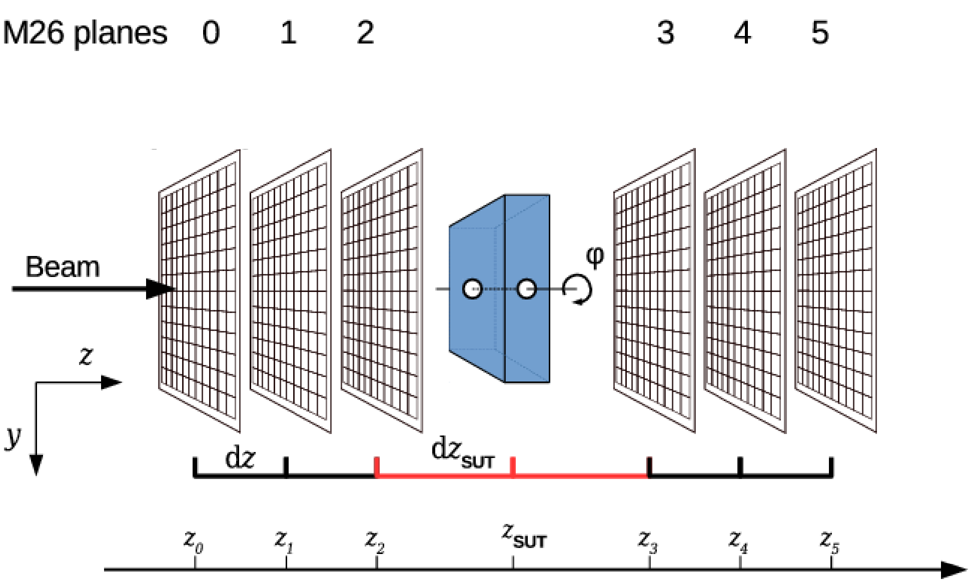


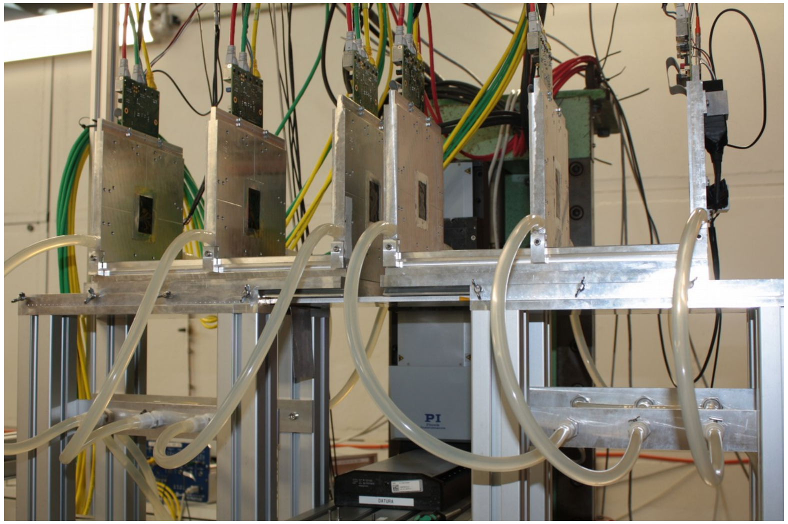




[2]: PDG, *Review of particle physics*

# Tomography – New technique

- Required:
  - Measurement of the scattering angle at the sample
  - Extrapolation of the track to the position of the sample
- Track information from high resolution pixel detectors for HEP
  - DATURA Beam Telescope [3]
  - 6 pixel sensor planes: Mimosa26

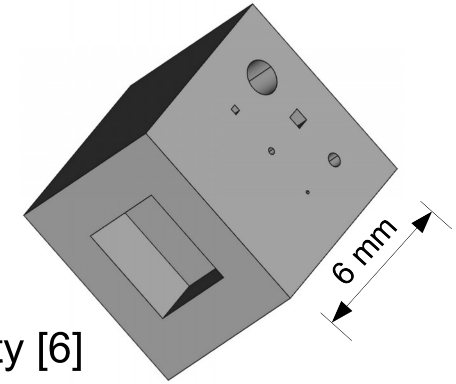


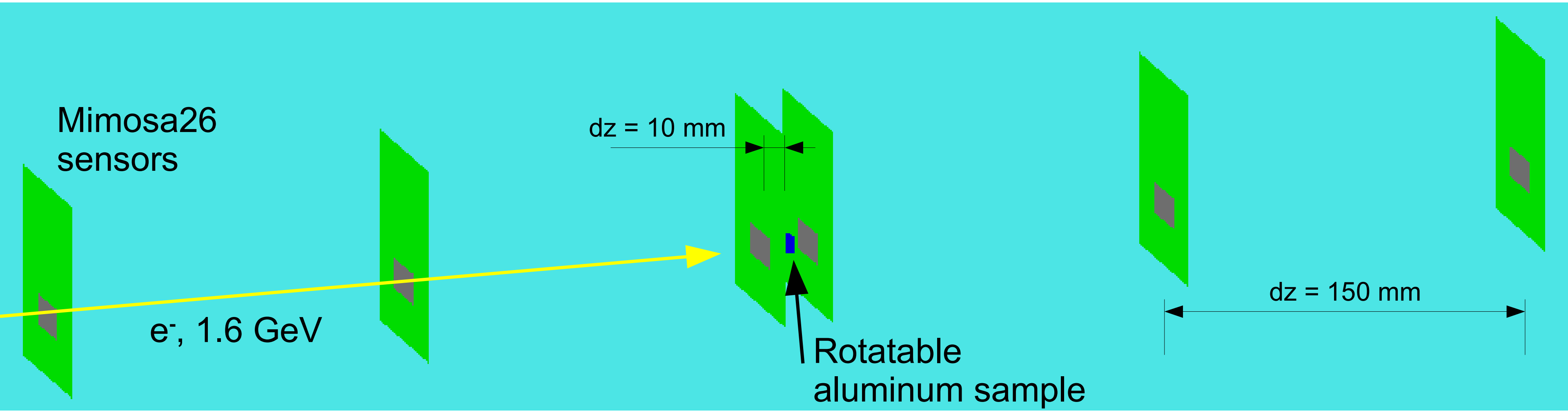



[3]: http://telescopes.desy.de

# Simulation

- Use *AllPix* Detector Simulation Framework [4]
  - Particle propagation and energy deposition from *Geant4* [5]
  - Includes multiple scattering in sensors and sample
  - Simulates the detector response
  - Setup adapted to the conditions at the DESY Test Beam Facility [6]
  - 180 data samples for rotation angles from 0° – 179°

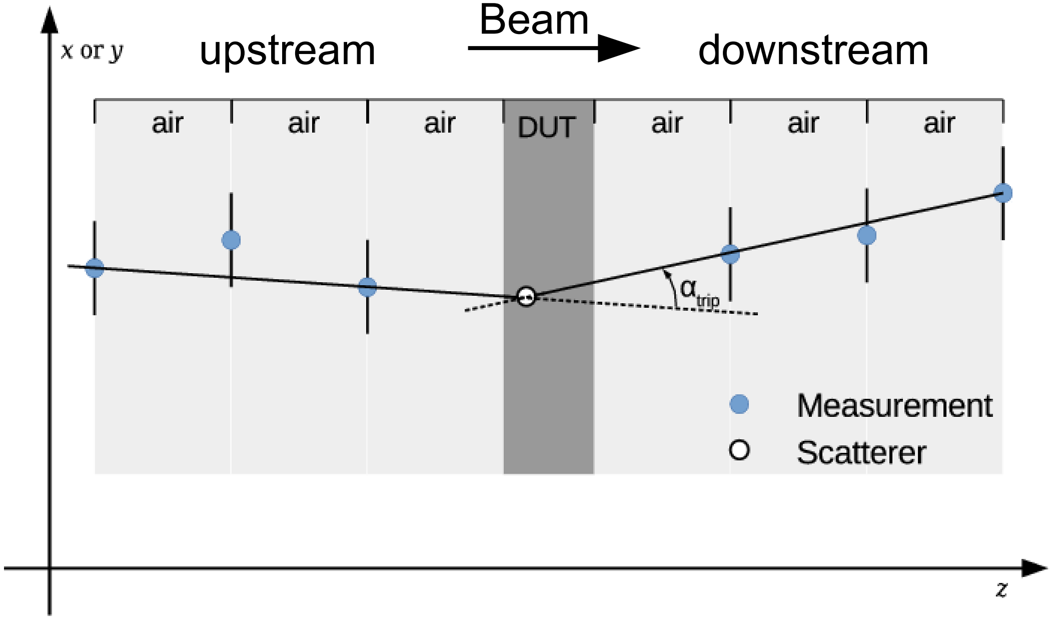



[4]: https://github.com/ALLPix/allpix
[5]: http://geant4.cern.ch/
[6]: http://testbeam.desy.de

# Kink angle reconstruction

- Triplet method:
  - Matching hits in upstream (*downstream*) planes form **triplets**
  - Matching upstream and downstream triplets form **track** candidates
  - Kink angle at the sample: Difference of upstream and downstream slopes



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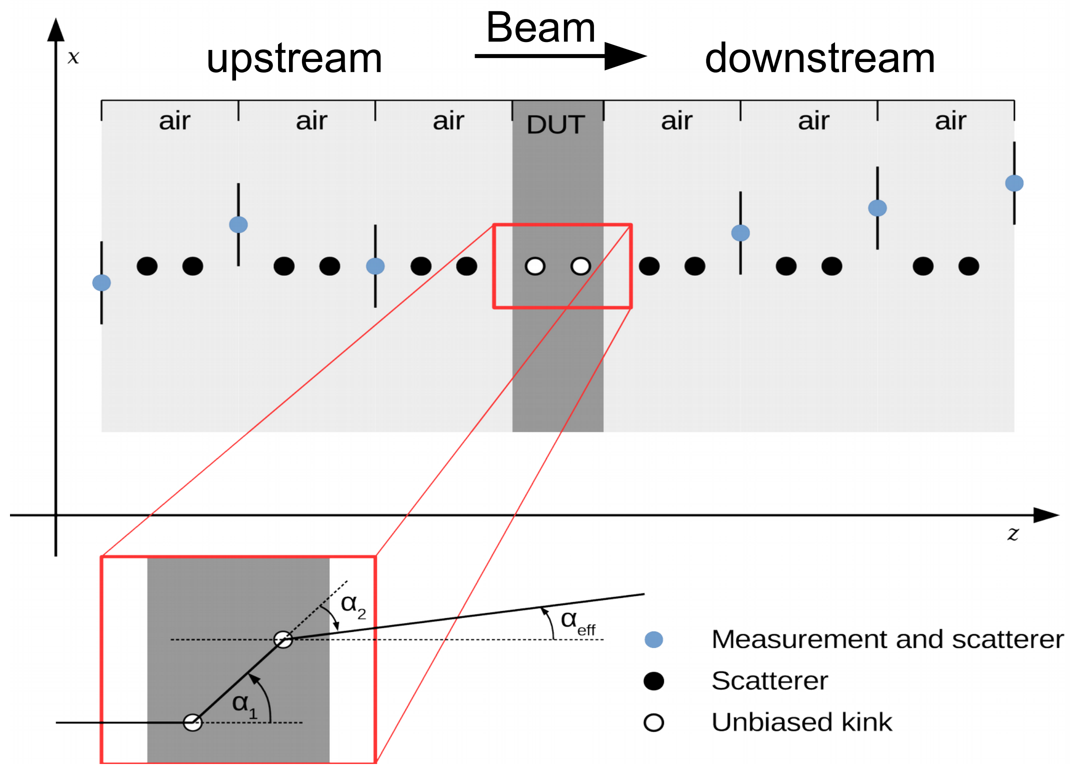
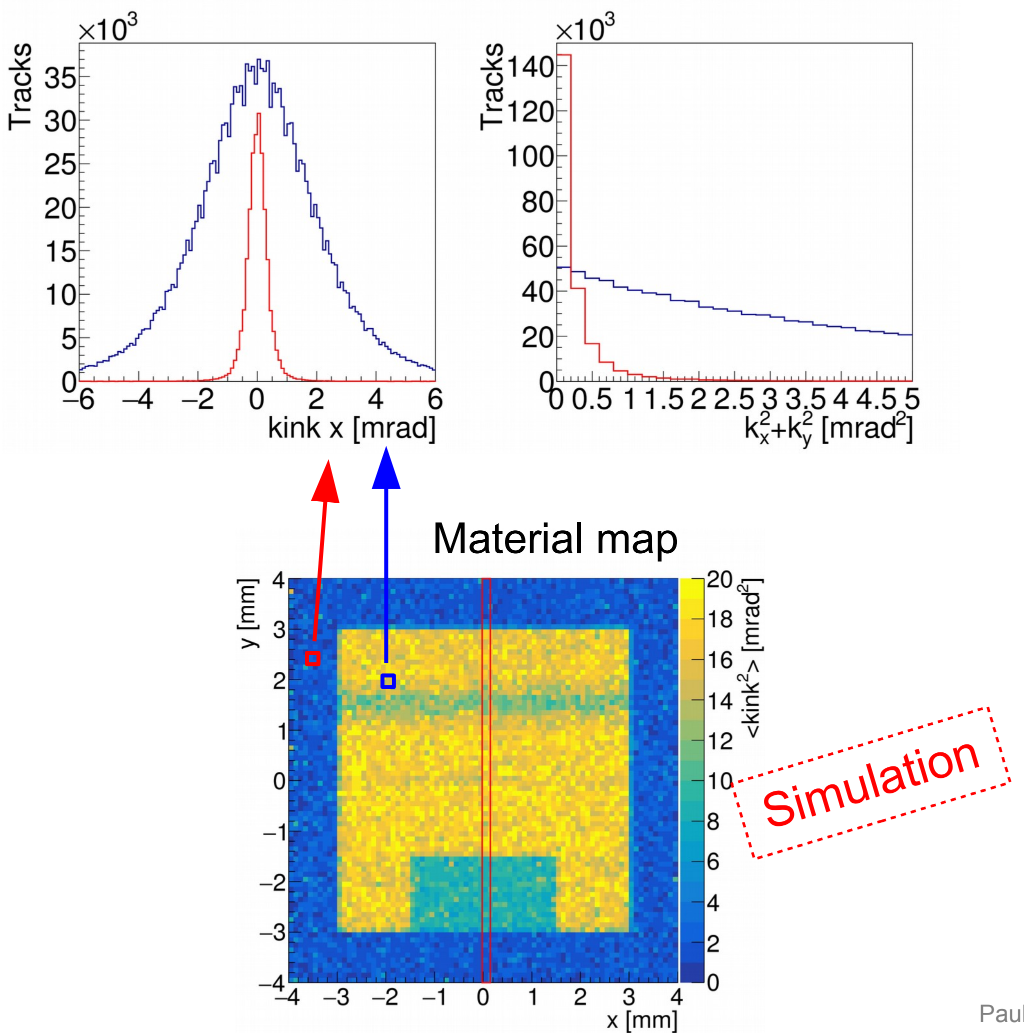


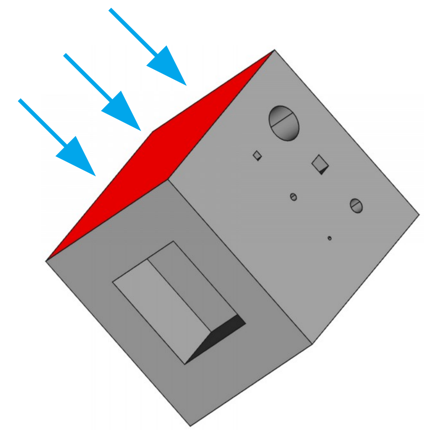

- GBL [7] for track fitting
  - Optimizing the trajectory
  - Allows for scattering
  - Kink angle at the sample: Local parameter in the track model

[7]: C. Kleinwort, *General broken lines as advanced track fitting method*

# Image reconstruction

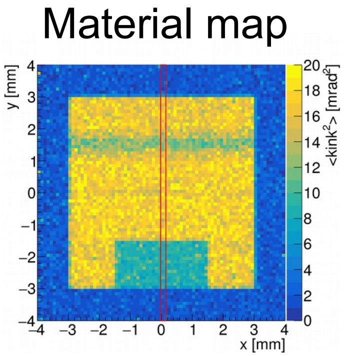
- Mapping of the squared kink angle for one rotation angle (from triplets)
  - Representation of a projection of the sample's material budget

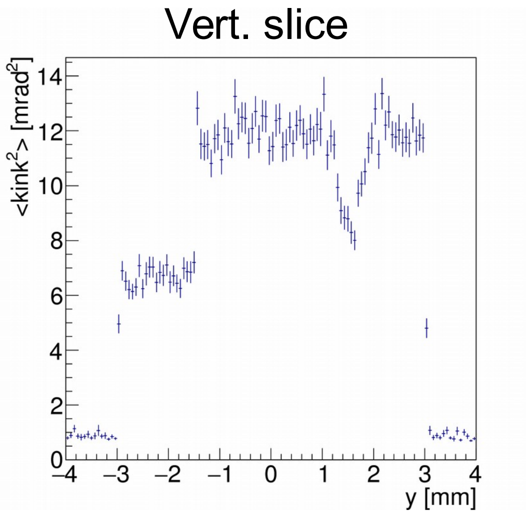


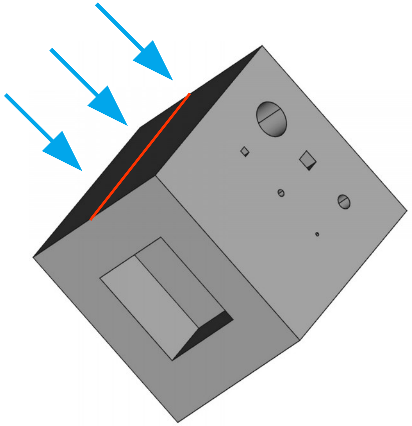



# Image reconstruction

- Mapping of the squared kink angle for one rotation angle (from triplets)
  - Representation of a projection of the sample's material budget
- Extract a slice perpendicular to the rotational axis



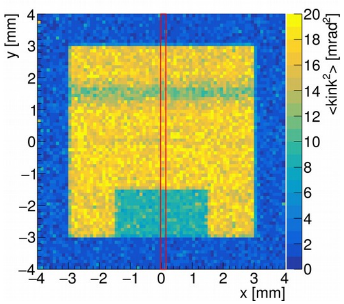



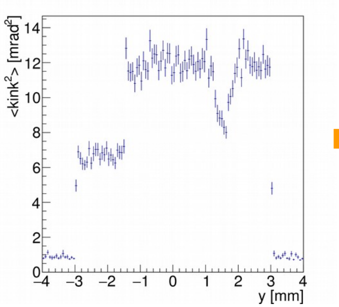
# Image reconstruction

- Mapping of the squared kink angle for one rotation angle (from triplets)
  - Representation of a projection of the sample's material budget
- Extract a slice perpendicular to the rotational axis
- Slices from multiple angles form the sinogram

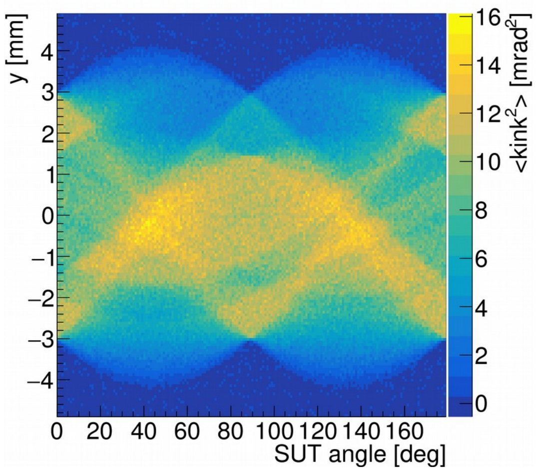
Material map




Vert. slice

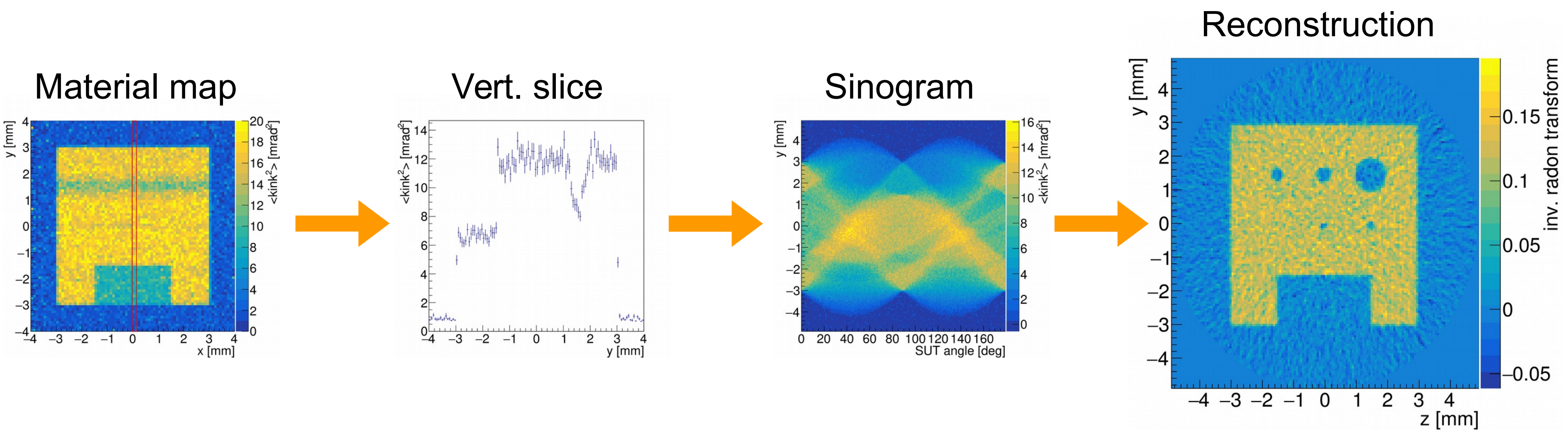



Sinogram



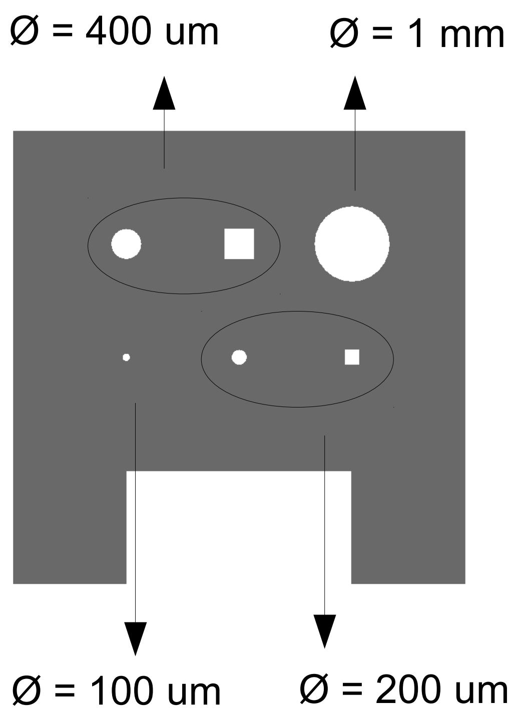
# Image reconstruction

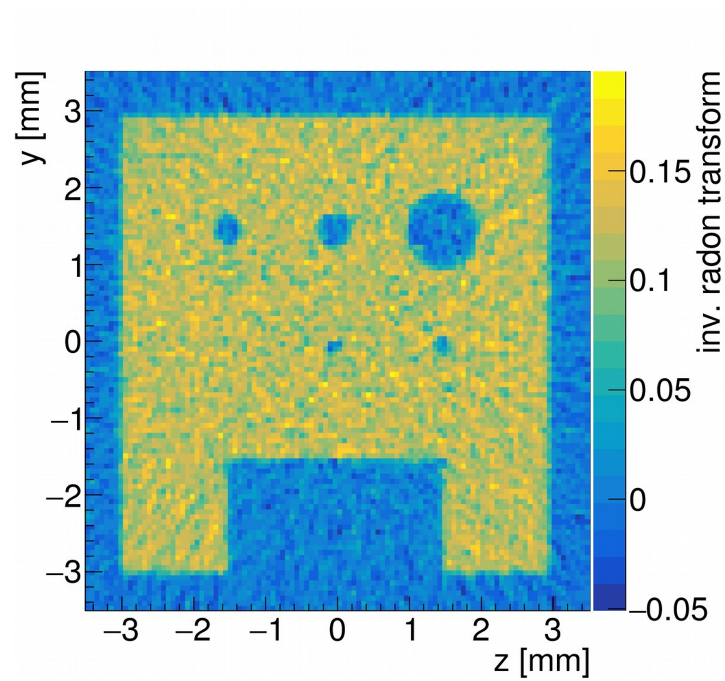
- Mapping of the squared kink angle for one rotation angle (from triplets)
  - Representation of a projection of the sample's material budget
- Extract a slice perpendicular to the rotational axis
- Slices from multiple angles form the sinogram
- Filtered back projection yields the reconstructed density distribution



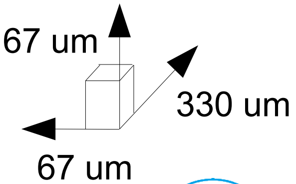
# Evaluation

- First successful simulated tomographic image reconstruction



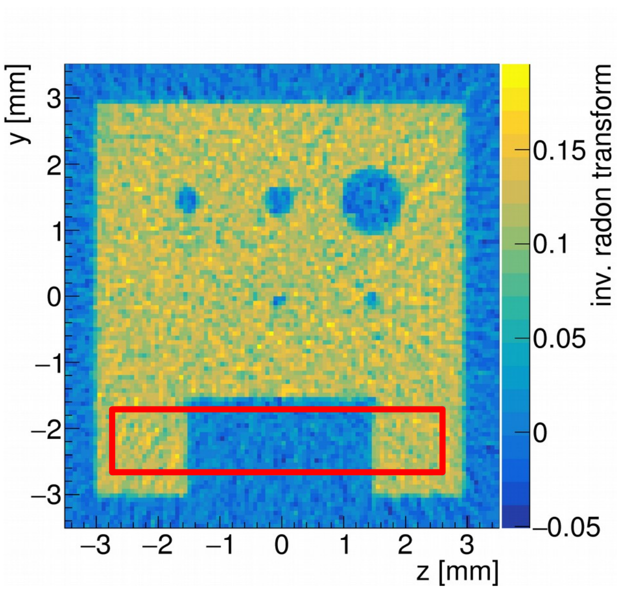

- 3D bin: “voxel”

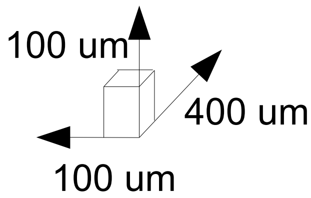


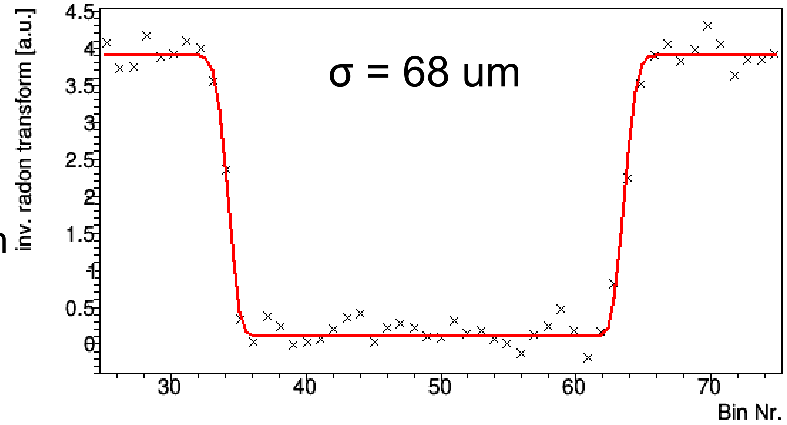
# Resolution

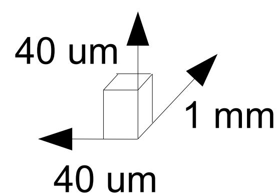
- Introduce transfer function fitted to edges
  - Modified error function with width σ
  - Evaluatated for different voxel sizes

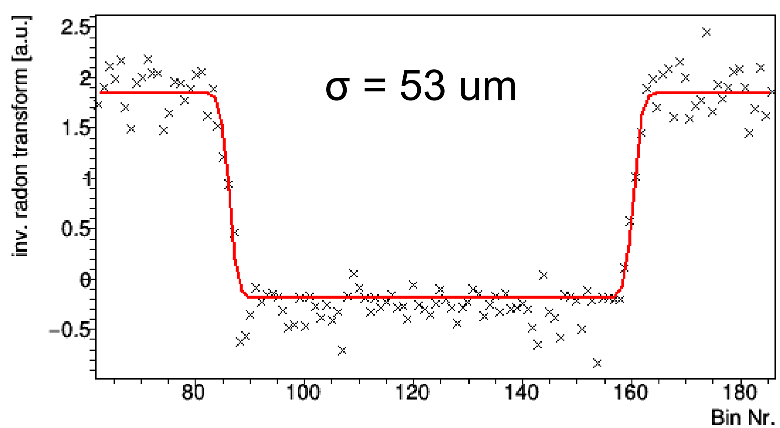
$$f(x) = C \int_0^x e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$



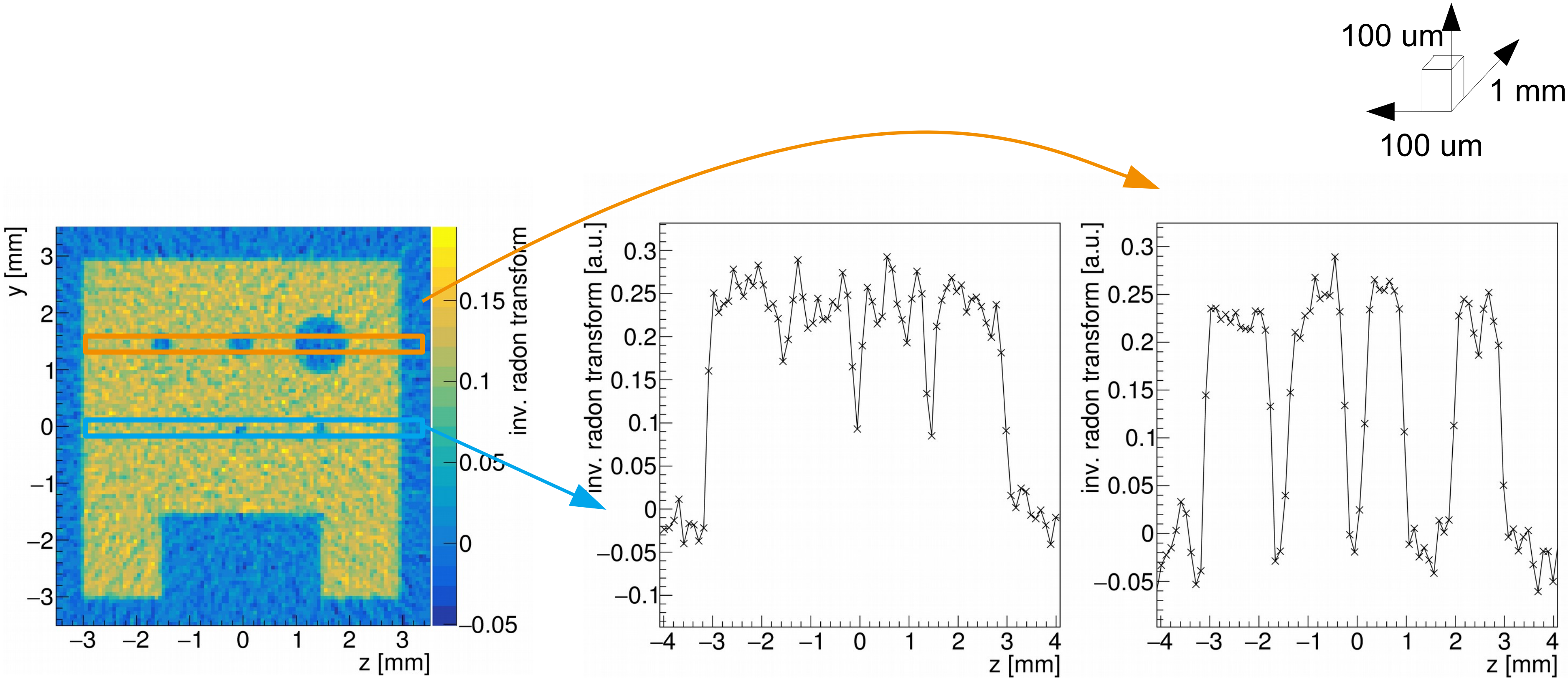



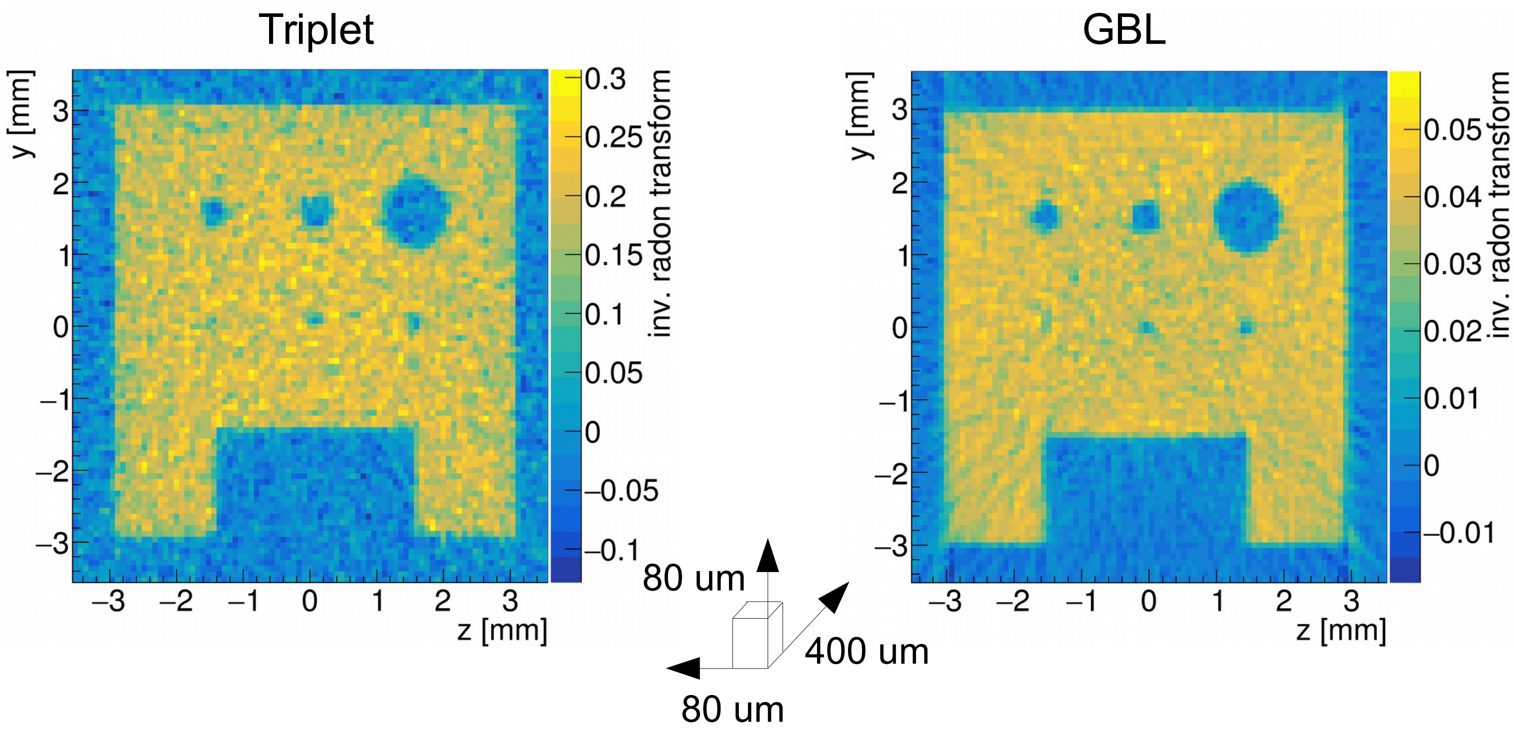
# Resolution

- For structures smaller than ~3σ the transfer functions overlap
  - ➔Structure not fully reconstructed
- Larger structures yield the full contrast



# Triplet / GBL method

- Compare kink angle estimation by triplet method and GBL




- Contrast: $C = \frac{|\mu_{alu} - \mu_{air}|}{\sqrt{\sigma_{alu}^2 + \sigma_{air}^2}}$

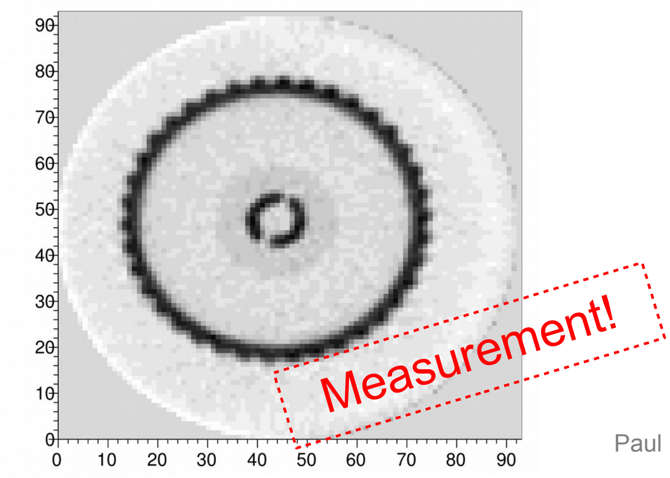
| Triplet | GBL |
|---|---|
| 4.5 ± 0.2 | 6.9 ± 0.2 |

- Higher contrast for GBL method

# Conclusion & Outlook

- Alternative tomographic technique using the measurement of multiple coulomb scattering of charged high energy particles
- Simulations performed based on Geant4 physics models
  - Corresponding measurements possible at the DESY Test Beam Facility
- Successful reconstruction of sample's geometry

- Test beam measurements performed recently – analysis ongoing
- Optimization of reconstruction and imaging ongoing



# Backup

# EUDET-type Pixel Telescopes

- High precision tracking of particle beams
- Mostly used for detector tests for HEP purposes
  - Device under test (DUT) placed in the middle of the telescope
- 6 Sensors: Mimosa26
  - Pixel pitch: 18.4 um x 18.4 um
  - Active area: 10.6 mm x 21.2 um
  - Intrinsic resolution: σ = 3.24 um
- Pointing resolution: σ > 1.86 um
- Replace DUT by a passive scatterer