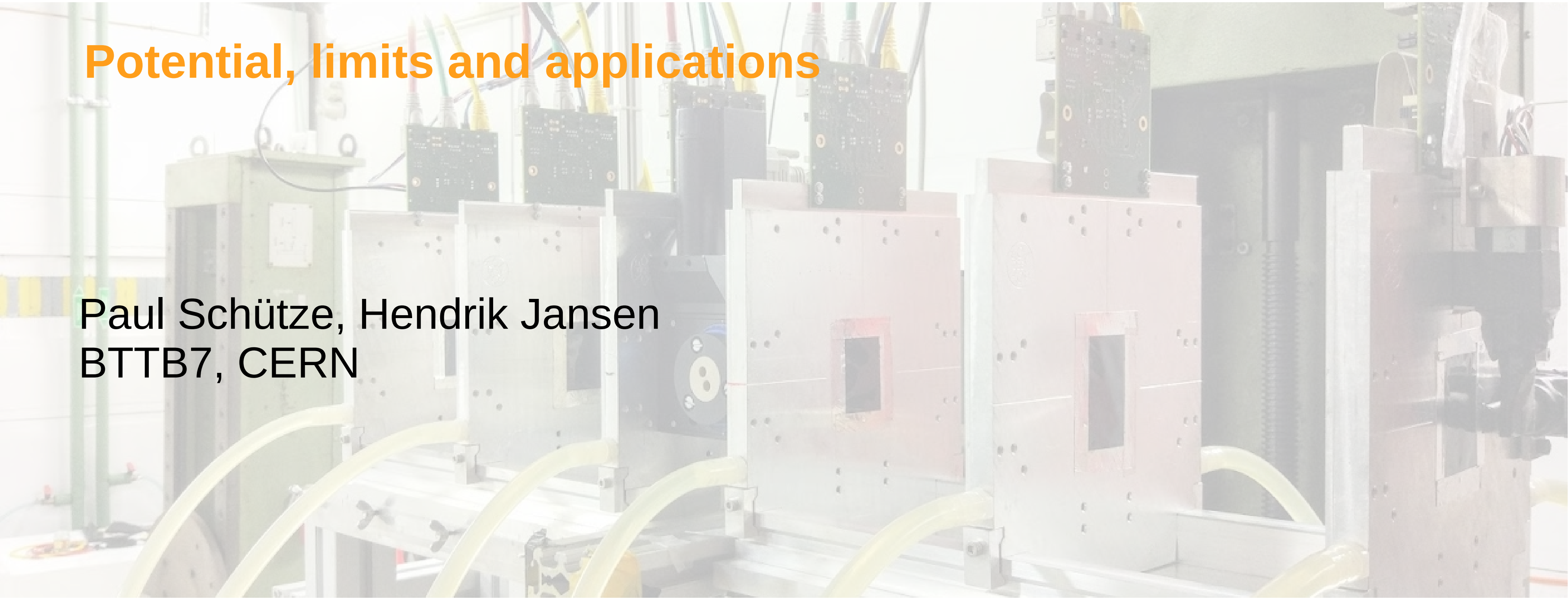
Material Budget Imaging in two and three dimensions



Potential, limits and applications

Paul Schütze, Hendrik Jansen
BTTB7, CERN

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

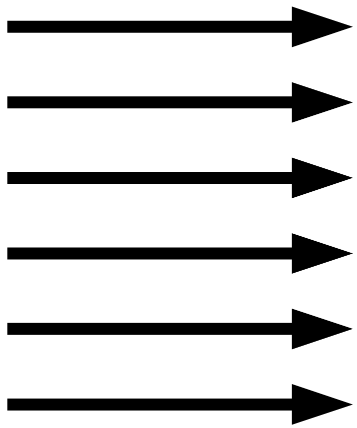
DESY.

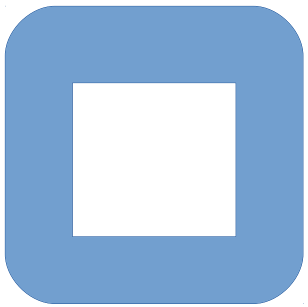
Imaging in a 

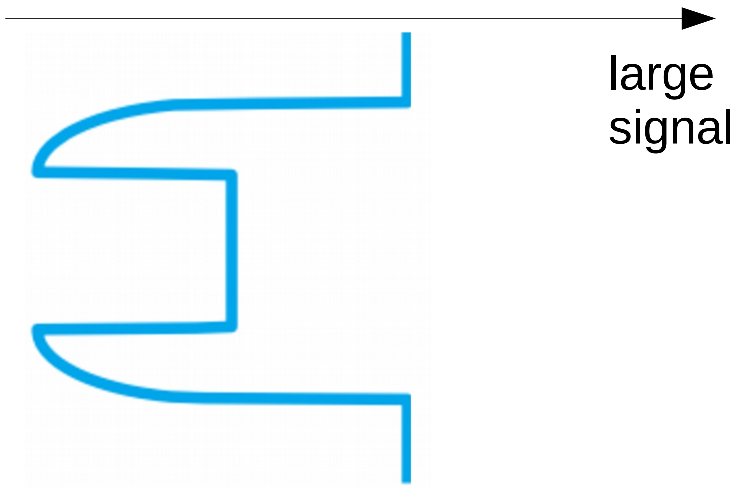
Probe
- x-, y-photon
- charged particle

Interaction with the target
- absorption
- scattering
- ...

Measure physical quantity
- intensity





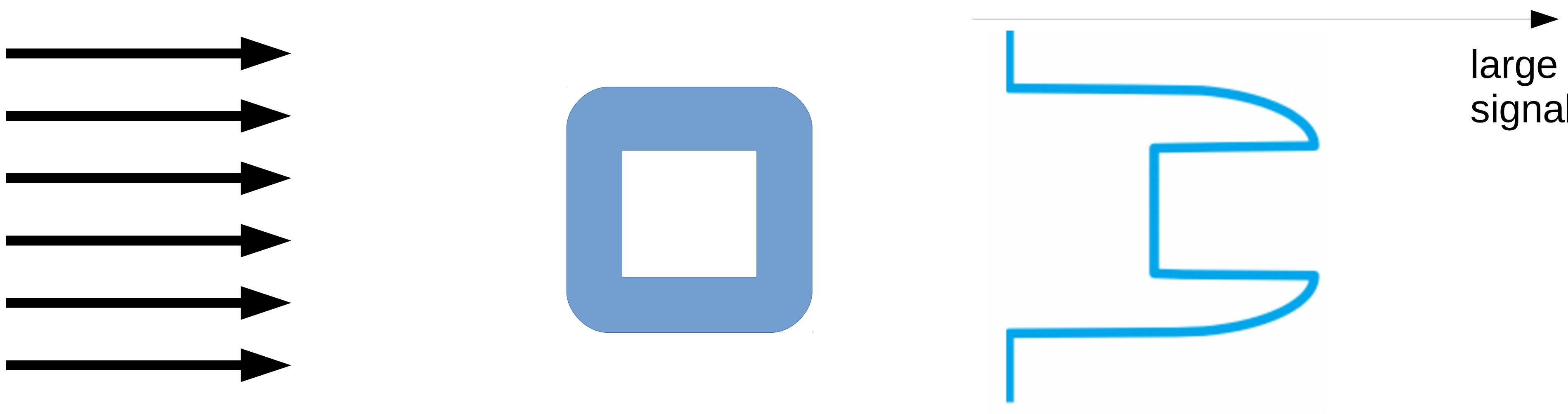


Imaging in a 

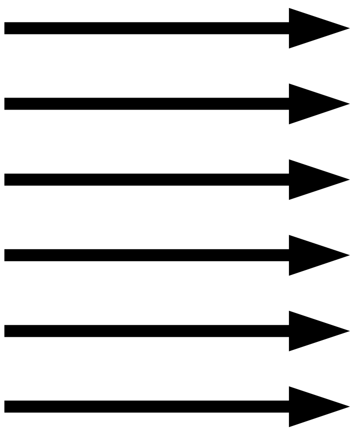
Probe
- x-, y-photon
- charged particle

Interaction with the target
- absorption
- scattering
- ...

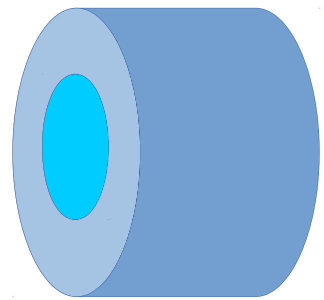
Measure physical quantity
- intensity
- energy loss (delta E)
- variance of displacement
- variance of deflection angle

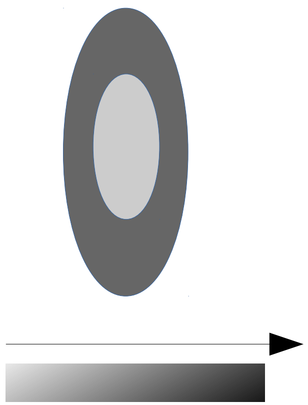


Imaging in a 



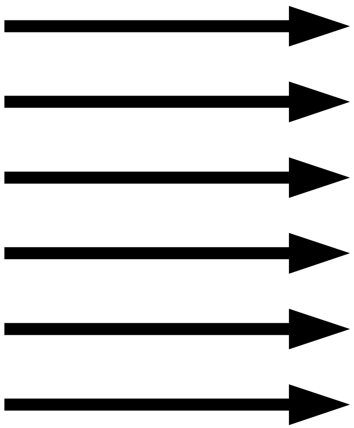
Integral effect over depth



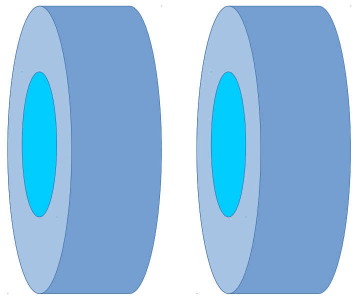


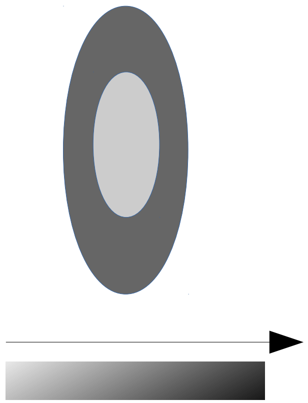
→ no/little information along the depth

Imaging in a 



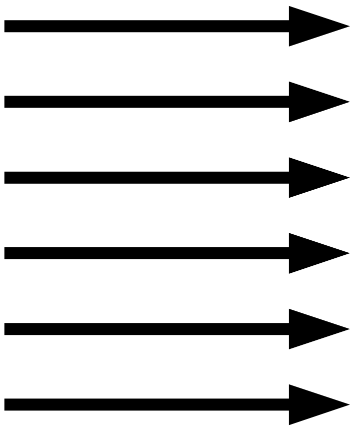
Integral effect over depth



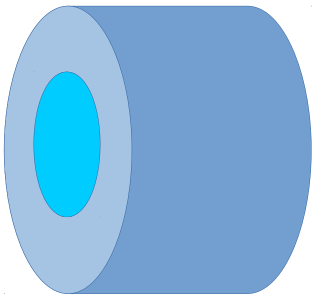


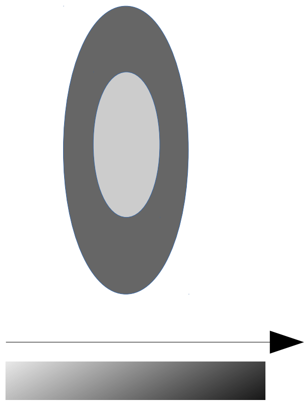
→ no/little information
along the depth

Imaging in a 

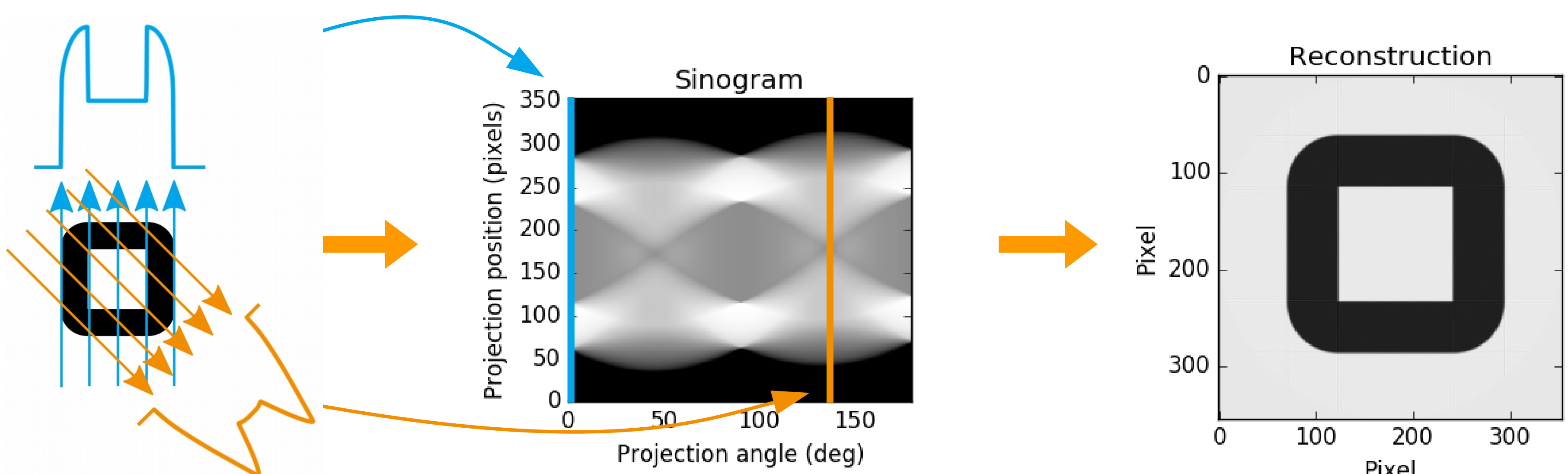


Integral effect over depth



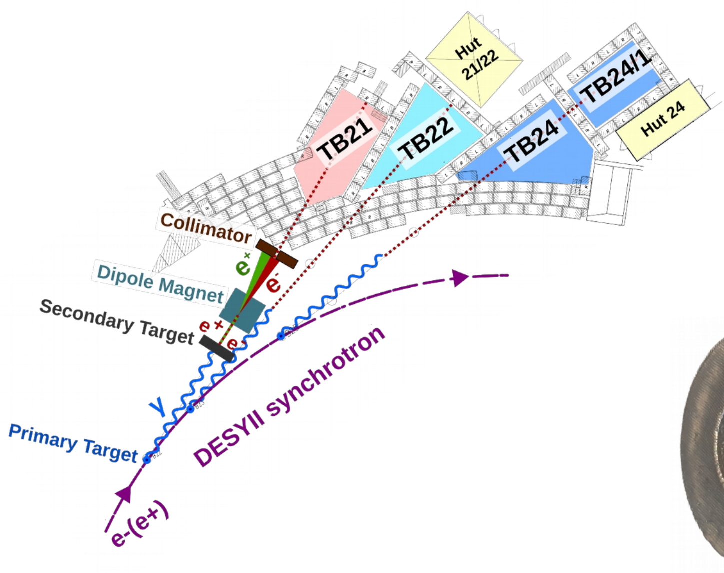


→ no/little information
along the depth



Imaging in a 

Probe source

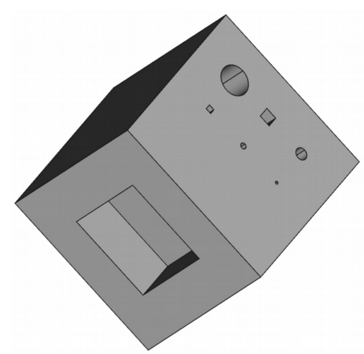


or

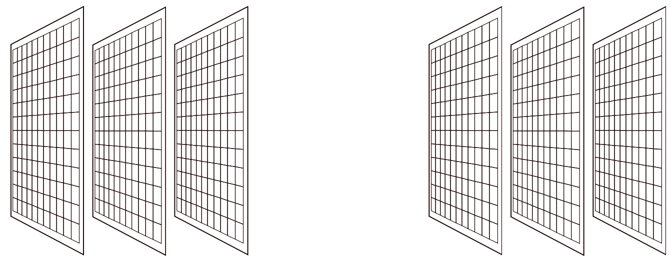
GEANT4

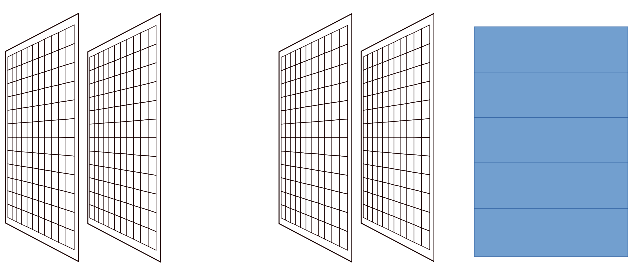
or ...

Target

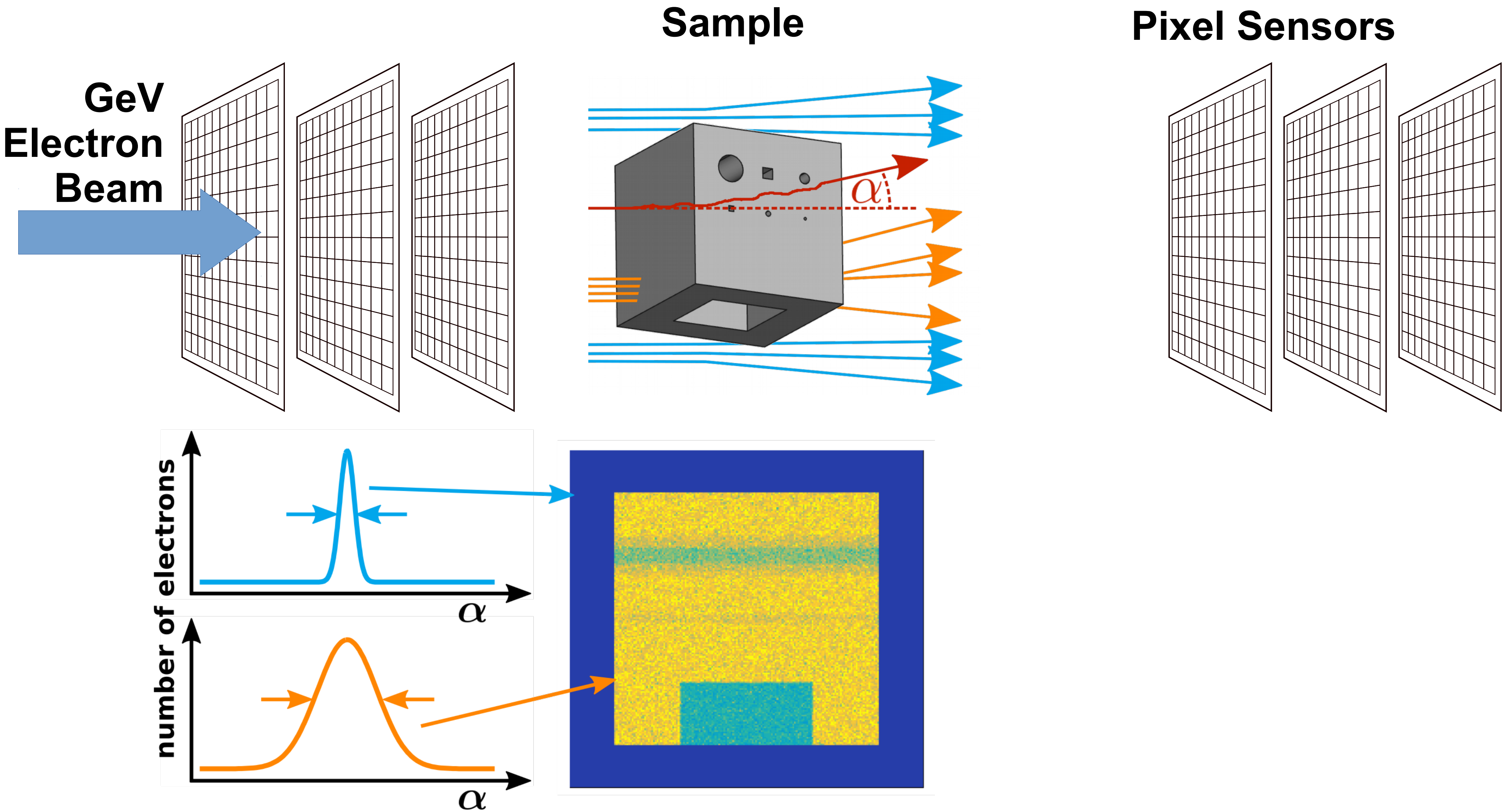


(Set of) Sensor(s)





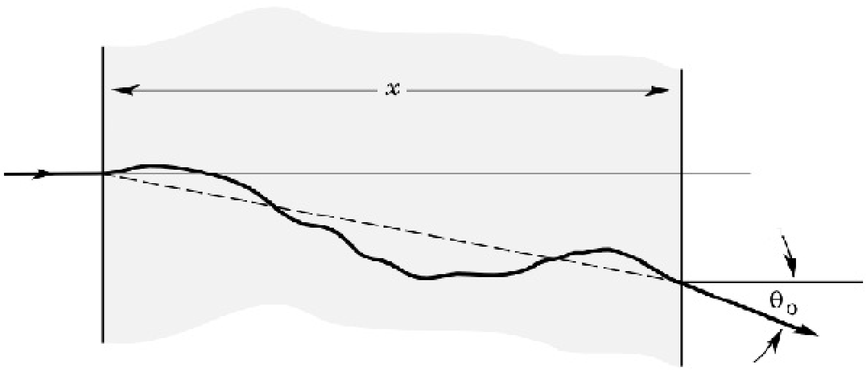
Material Budget Imaging



→ **Repeat measurement for various rotation angles**

Physics of MBI

- High-energy particle undergoes multiple Coulomb scattering when traversing material
  - ➔ Particle is deflected
- Scattering angle distribution: Gaussian-like centre with tails at larger angles



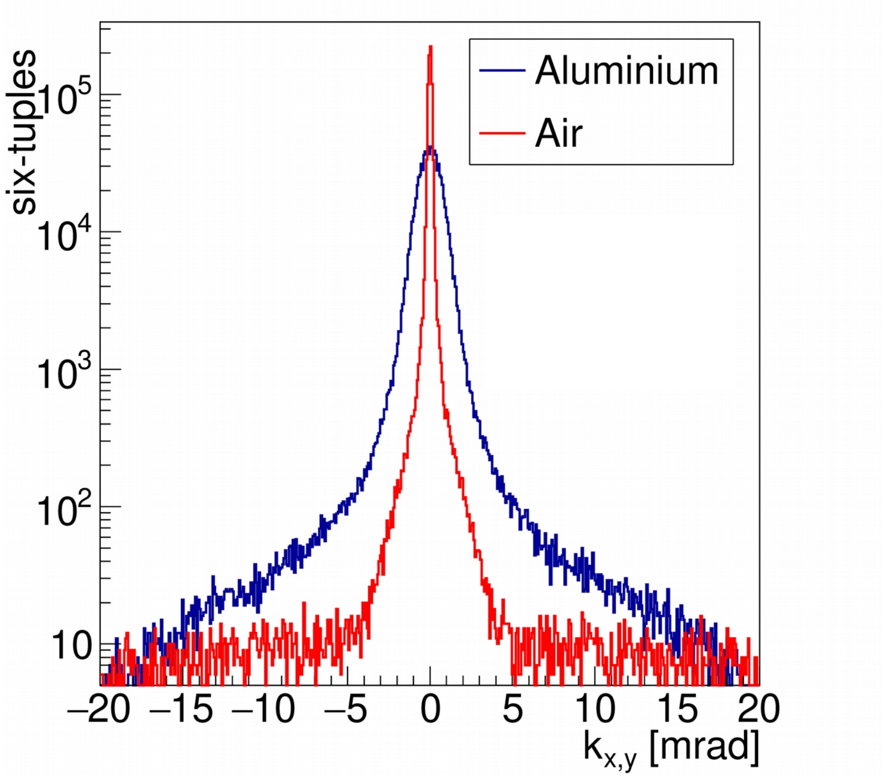
- The Gaussian width predicted by the Highland

$$\Theta_0 = \left(\frac{13.6\,\mathrm{MeV}}{\beta c p} \cdot z\right) \cdot \sqrt{\varepsilon} \cdot (1 + 0.038 \ln \varepsilon)$$

$\varepsilon = x/X_0$: **Material Budget**

x: Path length in the material

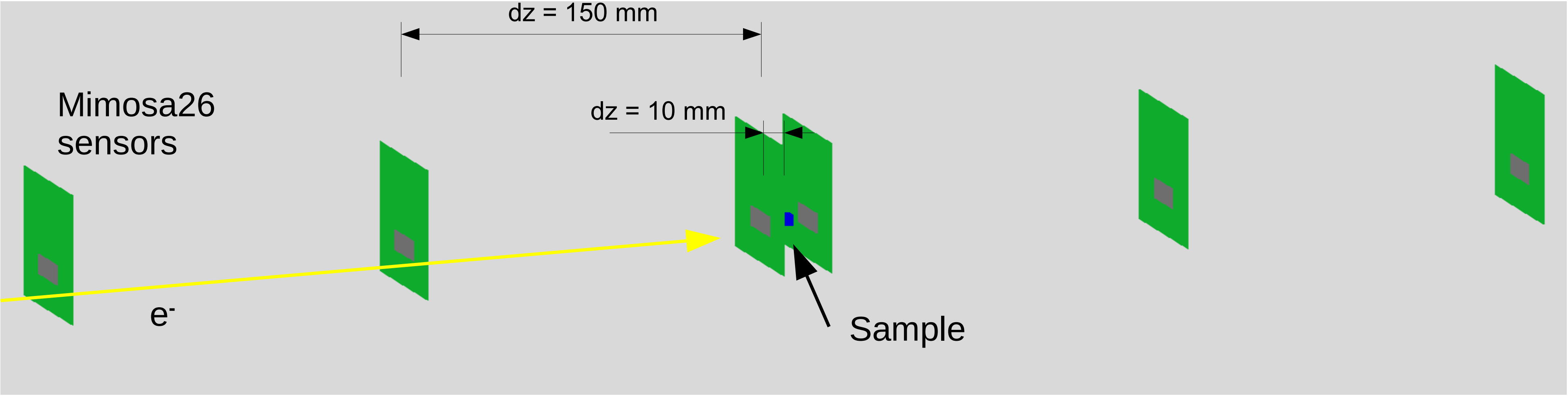
X_0: Material's radiation length



- ➔ Measurement: Scattering angle distribution
- ➔ Characteristic quantity: Material budget

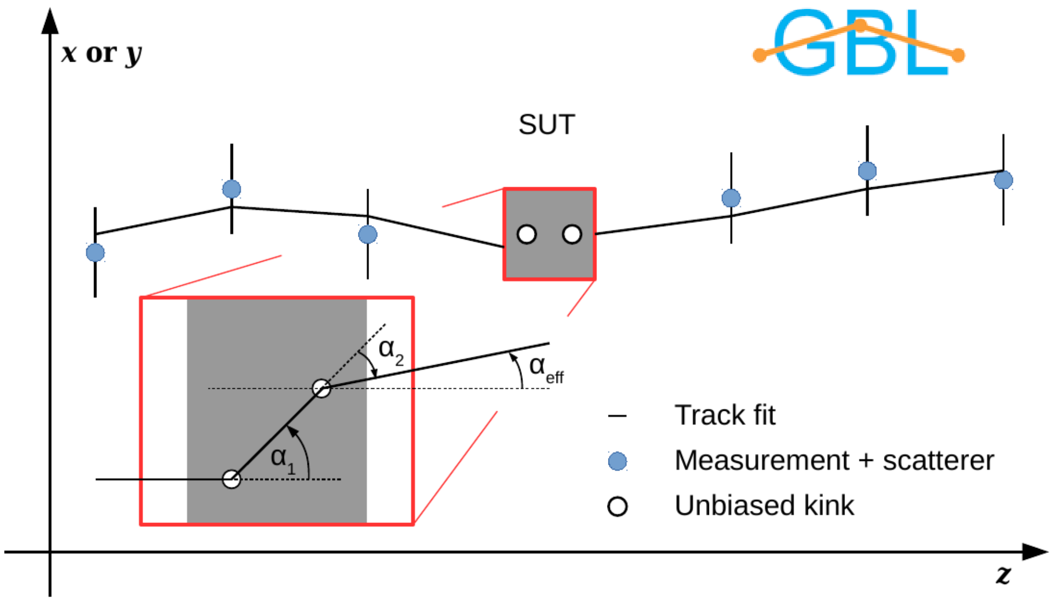
EUDET Beam Telescopes / *AllPix*

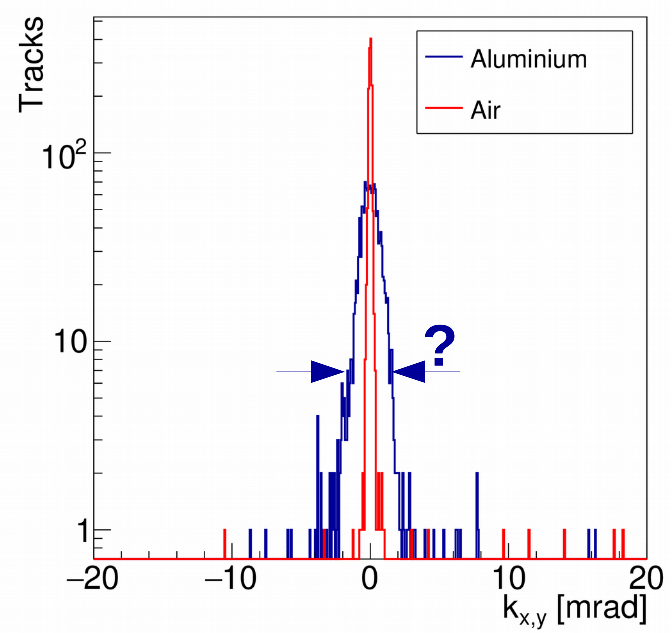
- 6 sensors: Mimosa 26
  - Pixel Pitch: 18.4 μm x 18.4 μm
  - Active area: 10.6 mm x 21.2 mm
  - Intrinsic sensor resolution: > 3.24 μm
- 4 PMTs as coincidence trigger
- Track resolution (this application): σ = 2 – 10 μm
- *AllPix* Detector Simulation Framework (based on *Geant4* libraries)
  - Simulation of the particle propagation and detector response



Track reco and MB estimation

- GBL for track fitting
  - Find the most probable trajectory based on the measured hits
  - Includes multiple scattering
  - Kink angle at the sample: Local, unbiased parameter
- Method for MB estimation:
  - Calculate *Average Absolute Deviation* of the inner 90% quantile
  - Best performance out of 11 tested fitting and statistical methods
  - Conversion to MB via Highland formula
- Challenges:
  - Non-Gaussian tails of the distribution
  - Low statistics





Why MBI?

Considerable interest and potential in MBI

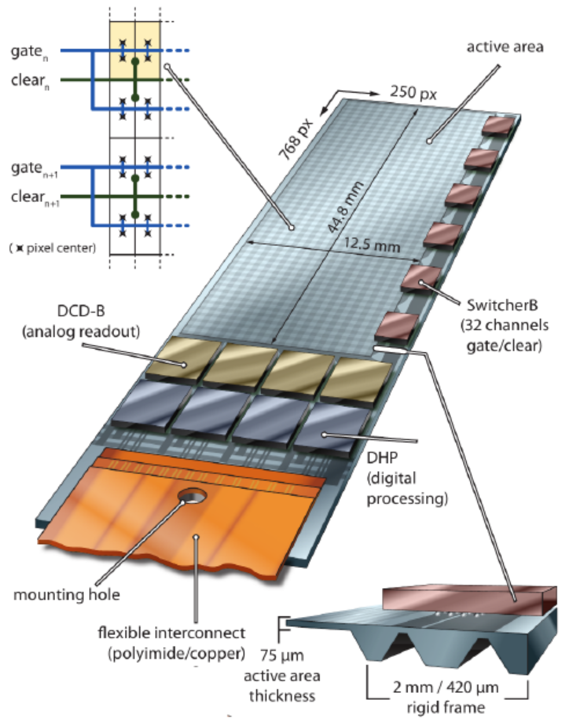
- Various upgrade activities in particle physics
  → Estimate of MB distribution for realistic detector description

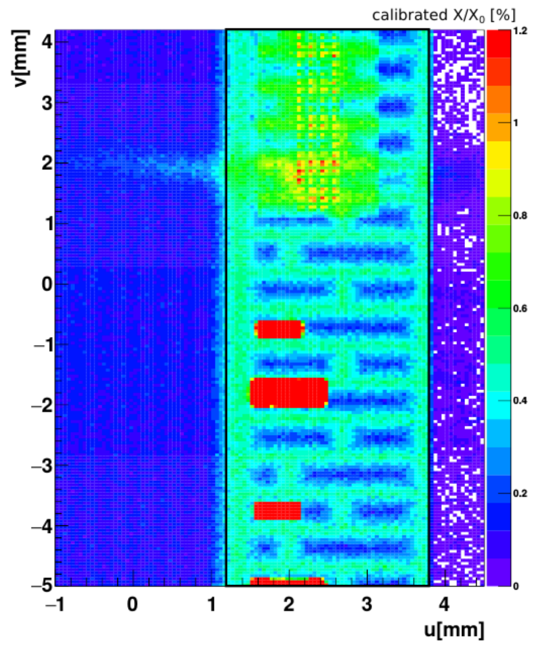
- Non-destructive testing of prototypes
  → e.g. batteries, high-Z material

- Medical imaging
  → possible dose advantage
  → less artefacts

MBI at Belle II / ATLAS

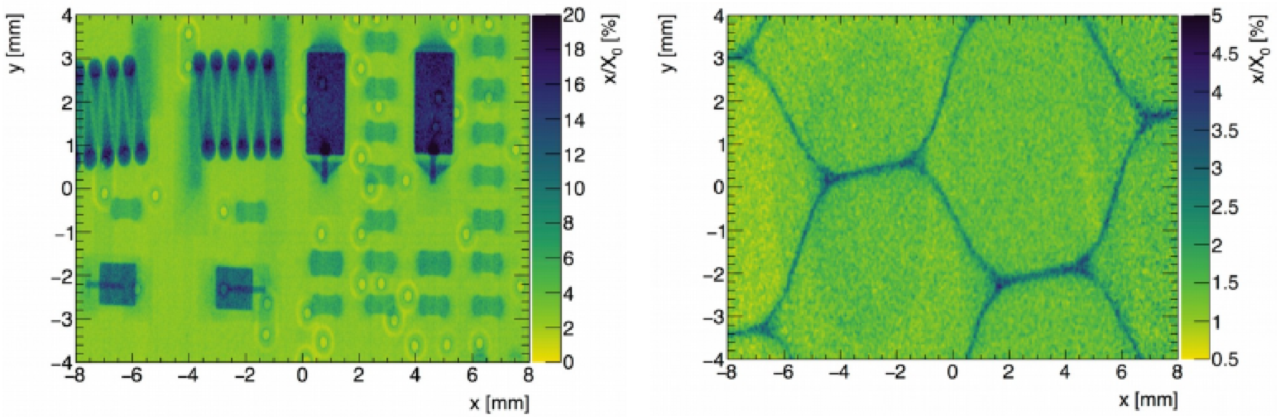
Belle II PXD module





U. Stolzenberg et al.

ATLAS Tracker endcap petal

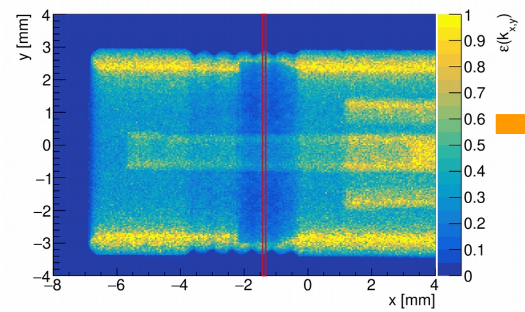


M. Queitsch-Maitland et al.

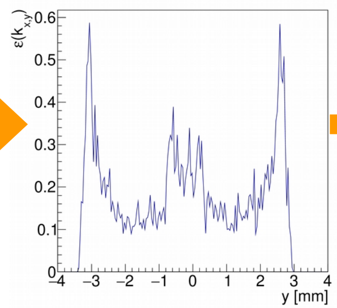
Examples of 3D MBI

Reconstruction

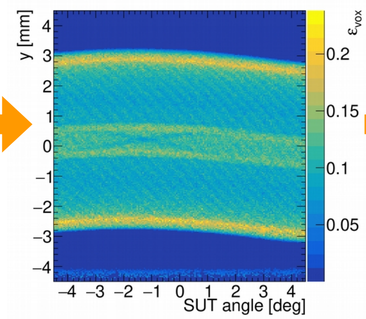
2D Material Budget map

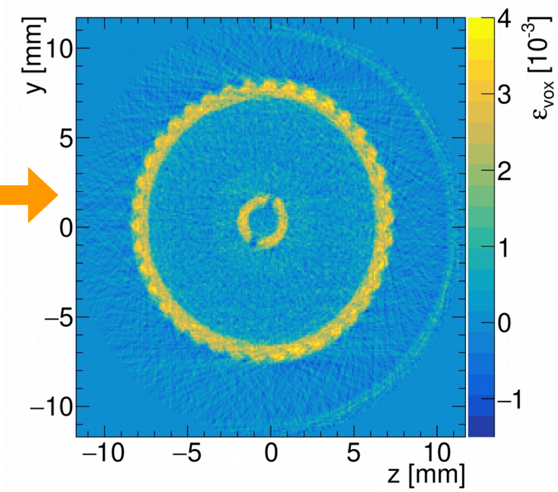


Vert. slice

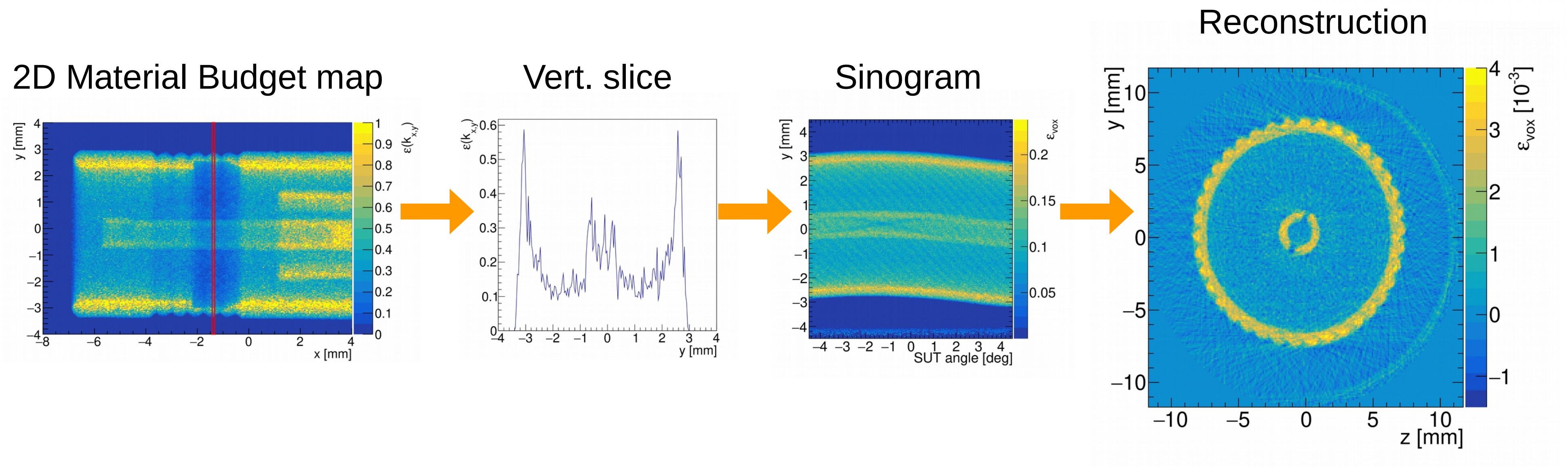


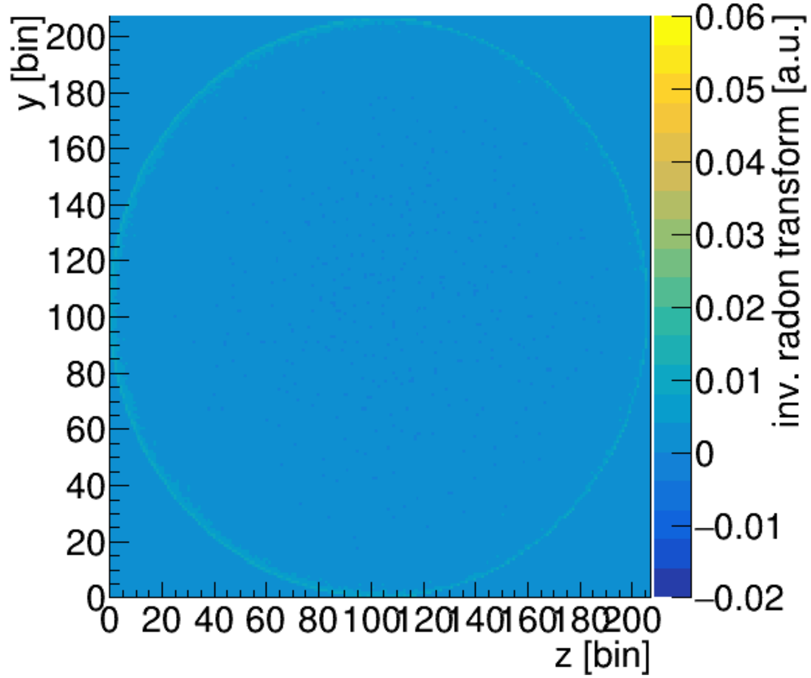
Sinogram



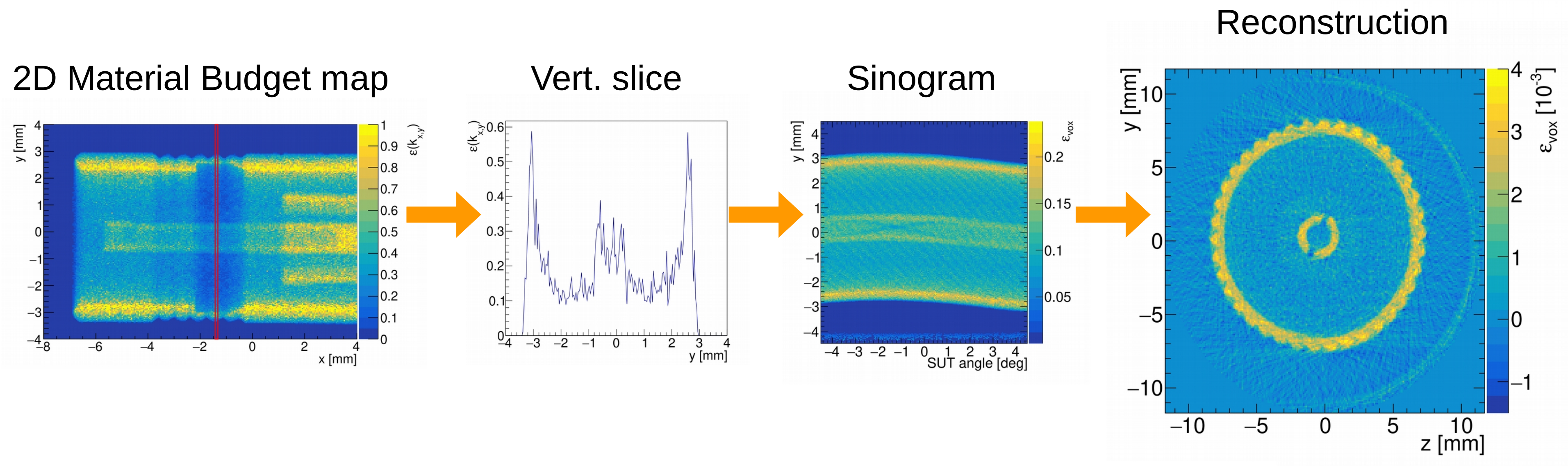


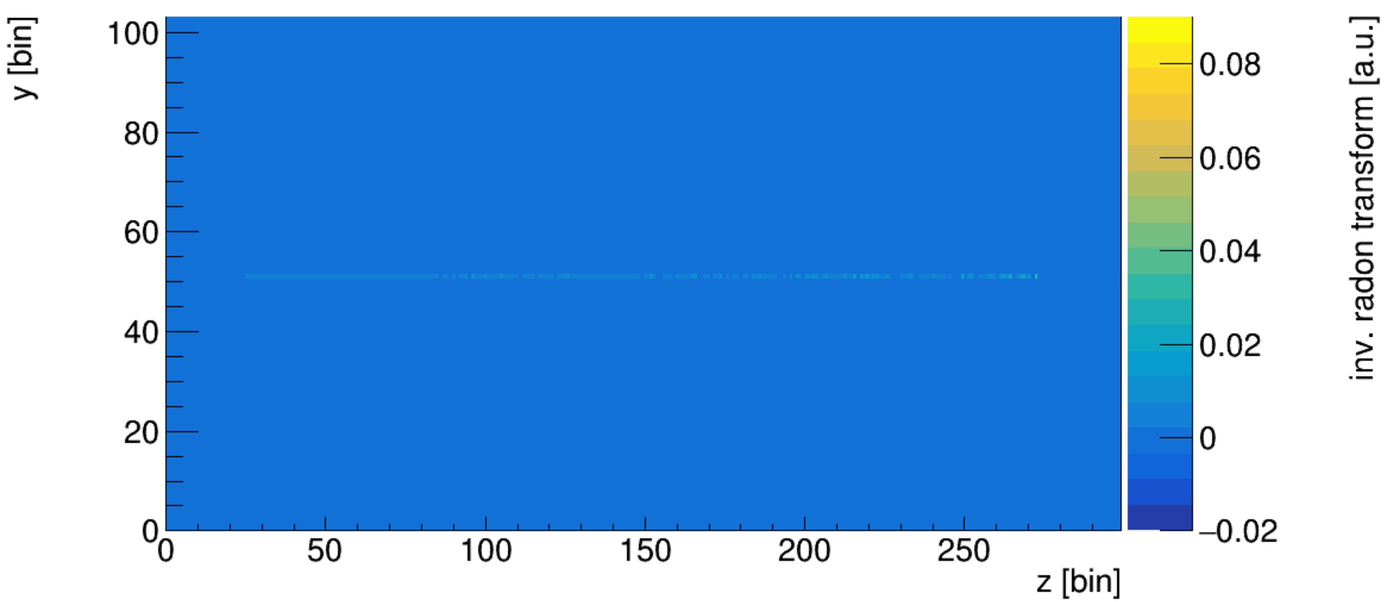
Examples of 3D MBI



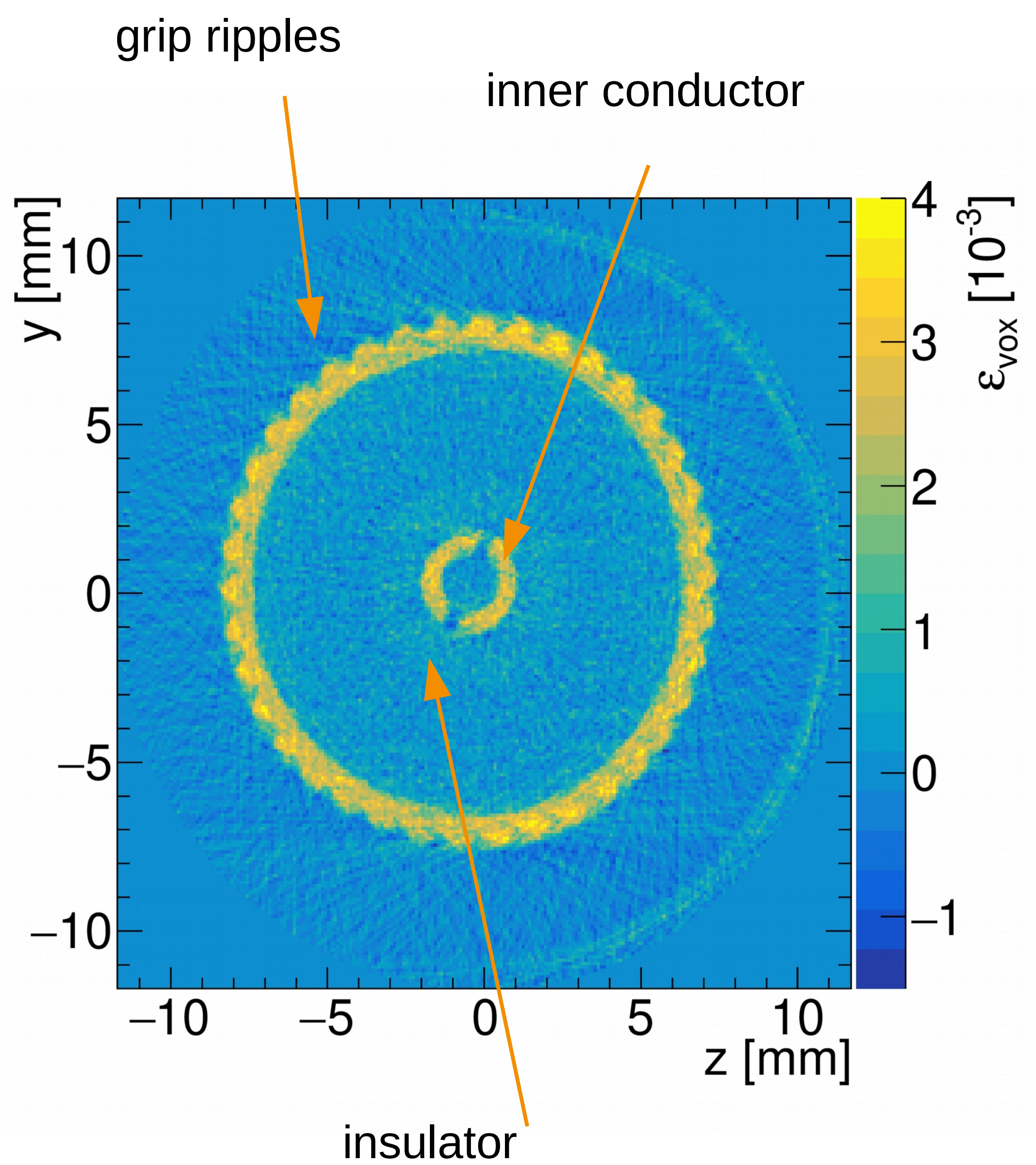


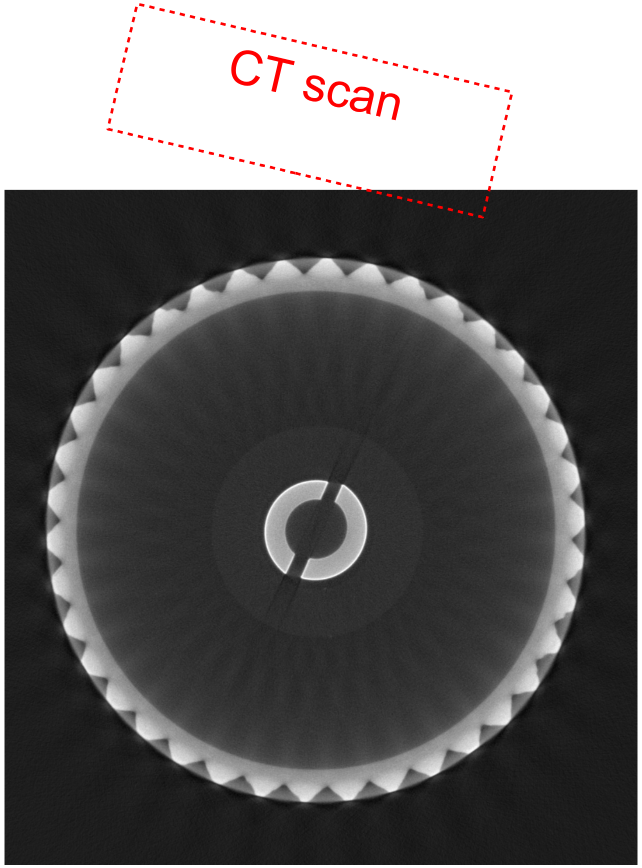
Examples of 3D MBI





Comparison to CT





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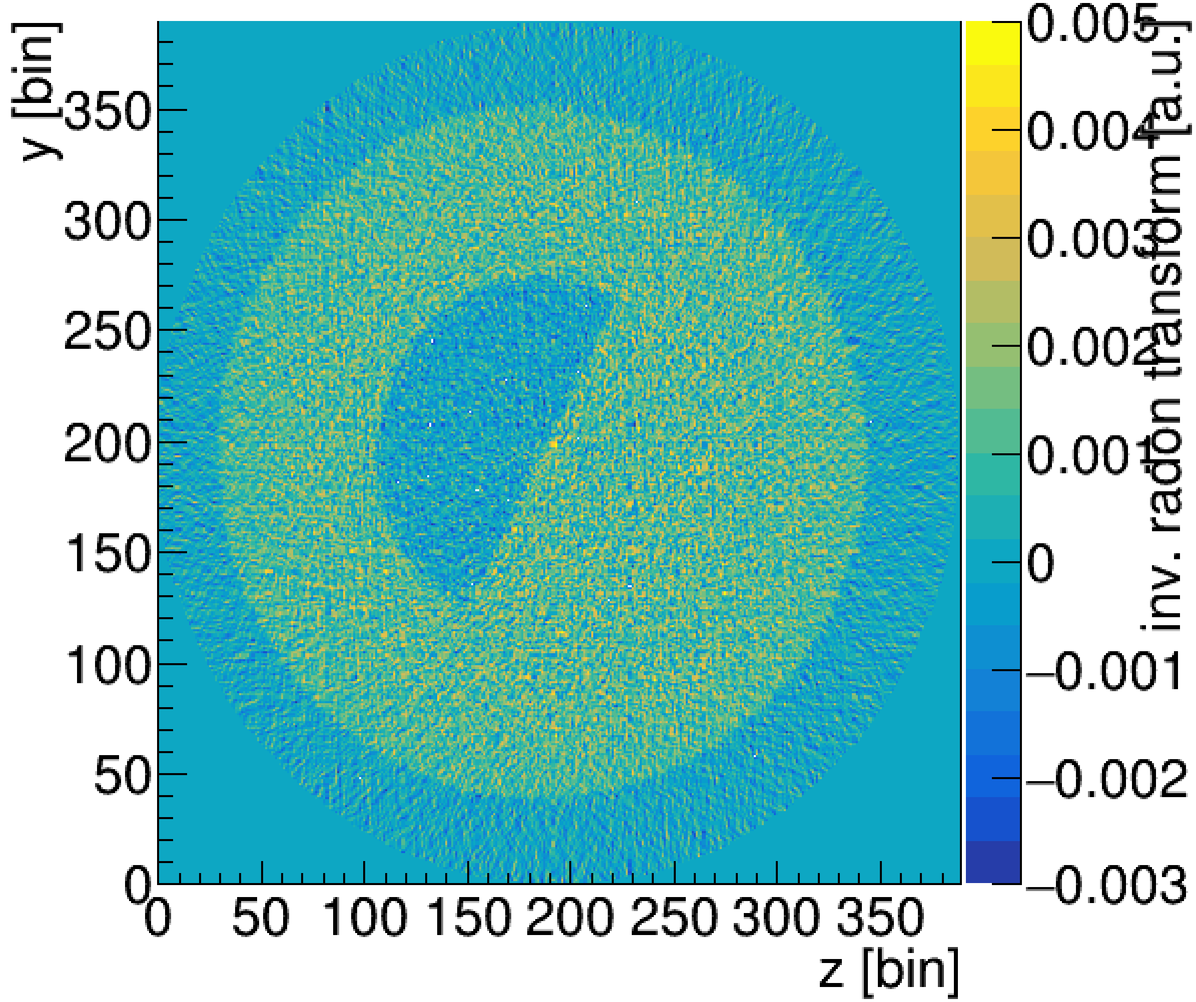
Zentrum für Material- und Küstenforschung

Example of 3D MBI

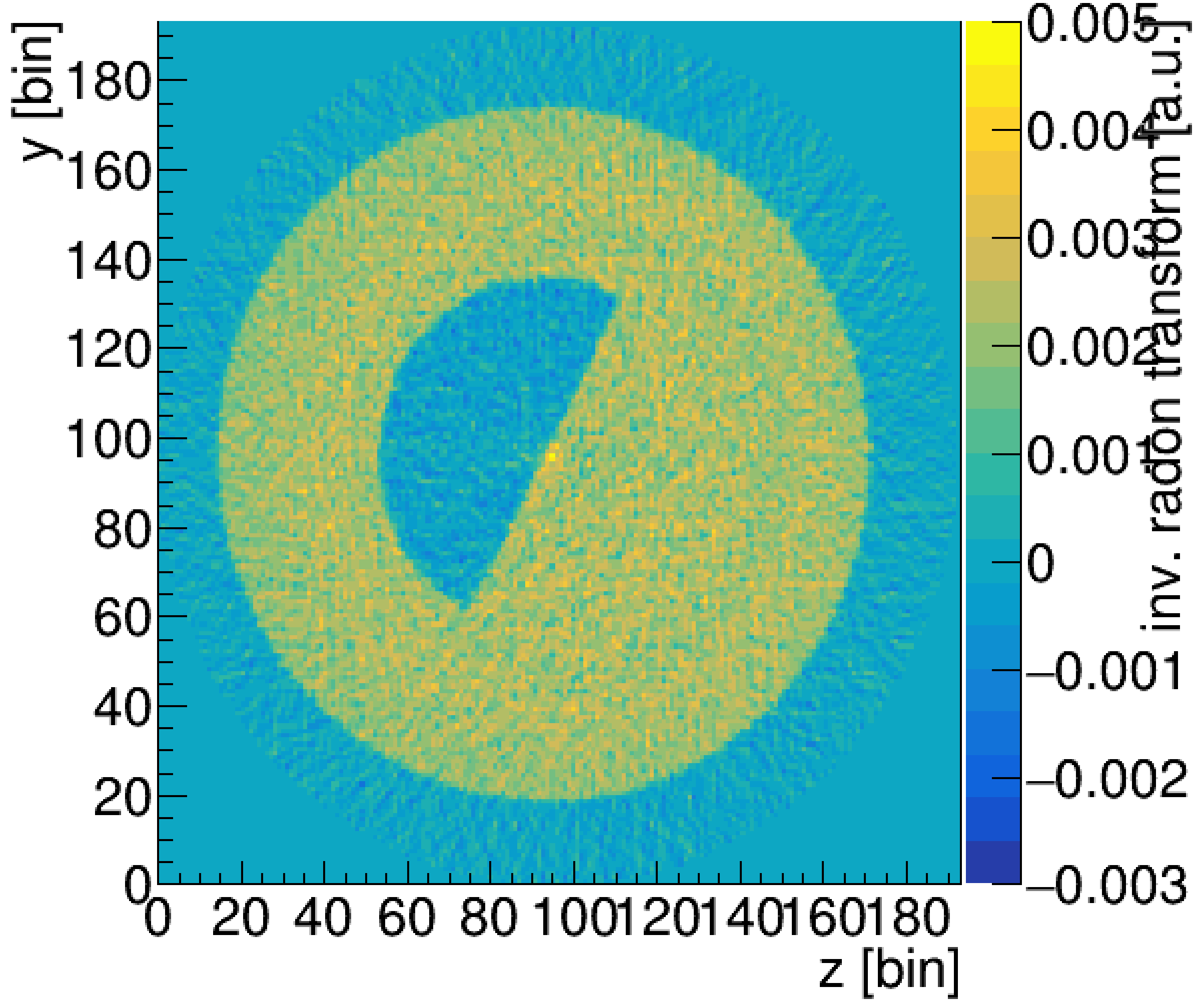
16 mm diameter
3D printed nickel

50 um voxel



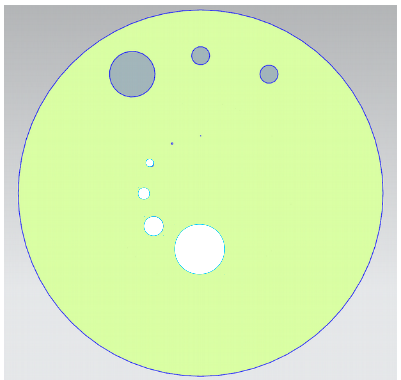
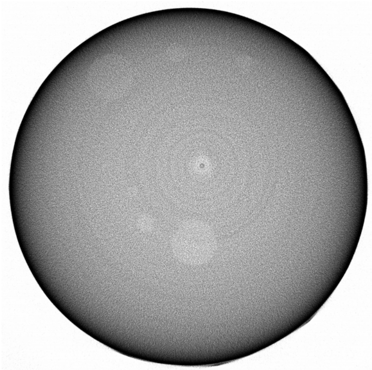
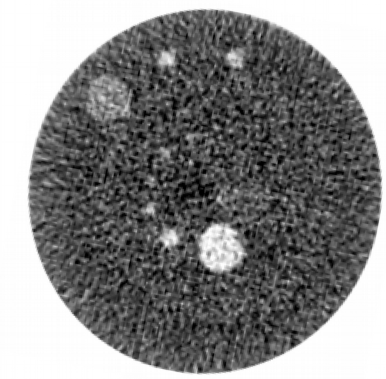
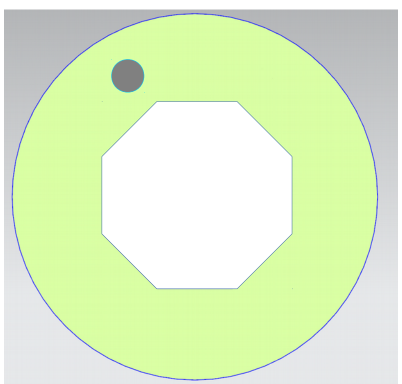
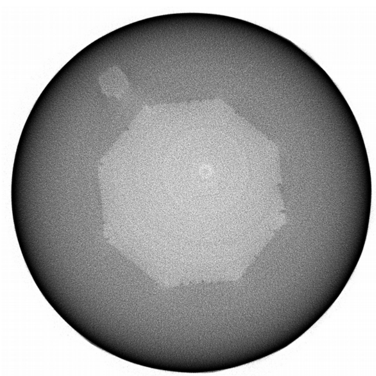
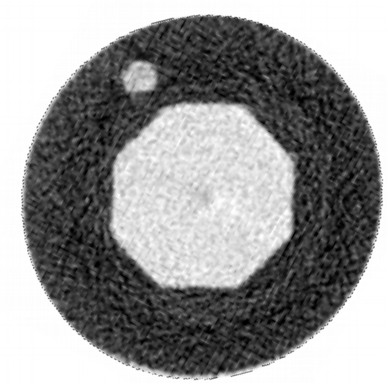
Example of 3D MBI

100 um voxel



16 mm diameter
3D printed nickel

Comparison to CT

Cross-sections	CT scan at 170 kVp (inverted)	MBI
		
		

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Interested?

Conclusion & Outlook

MBI works up to at least ε = 100%

- In simulation up to 200%

Pixel/voxel size limit 5 to 10 µm, practical 50 µm

Improve image reconstruction

Calibration curves for various materials

Understand market potential

Try biological samples

Contrast vs Resolution