

# Accuracy of a helium-beam radiography system based on thin silicon pixel detectors

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Universitätsklinikum Heidelberg  
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Medizinische Fakultät Heidelberg

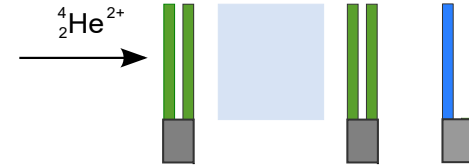
# Idea of our detection system

Many systems measure residual energy / range [1]

Our idea:

## Thin detector

- Very small and light
- Measuring energy deposition **in the steep rising edge of Bragg peak**



# Detector

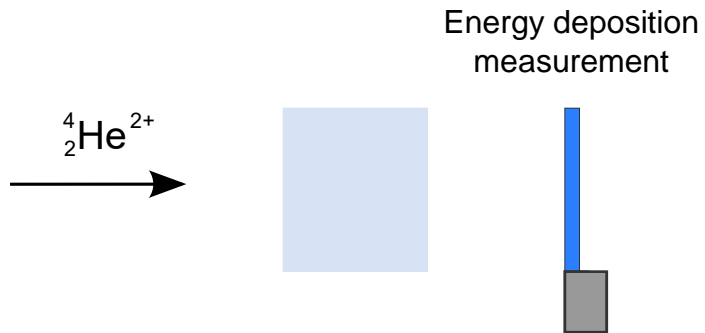


[2]

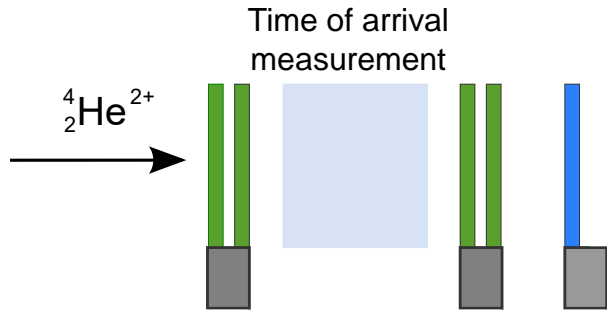
Timepix [3], a semiconducting detector:

- Sensor layer: 300  $\mu\text{m}$  silicon
- Pixelated (256x256, 55  $\mu\text{m}$  pixel size)
- Single particle detection
- Each of the 65k pixels operable in 2 modes:
  - Time of Arrival
  - Energy deposition
- Background-free

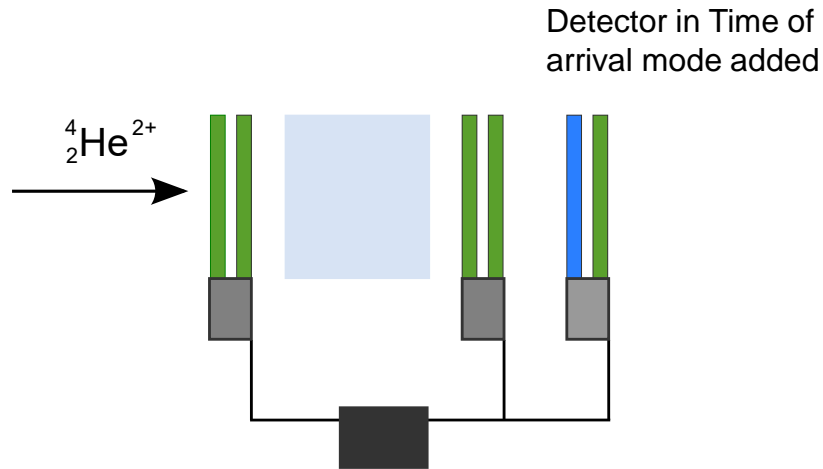
# Detection System [4]



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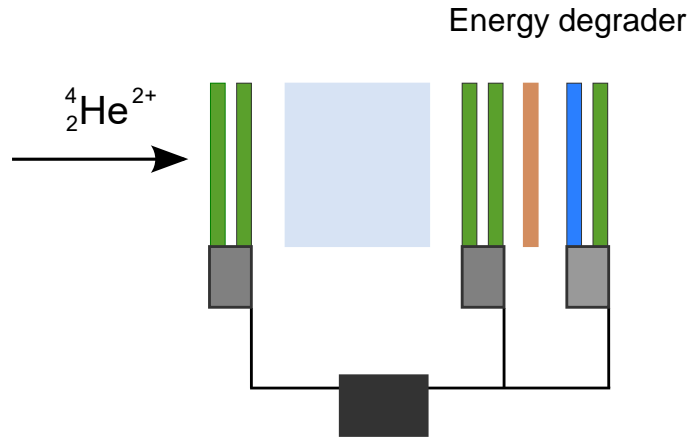
# Detection System [4]



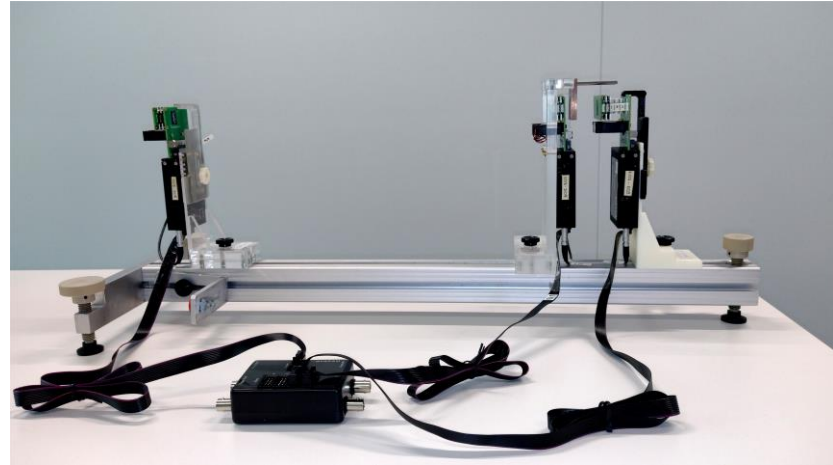
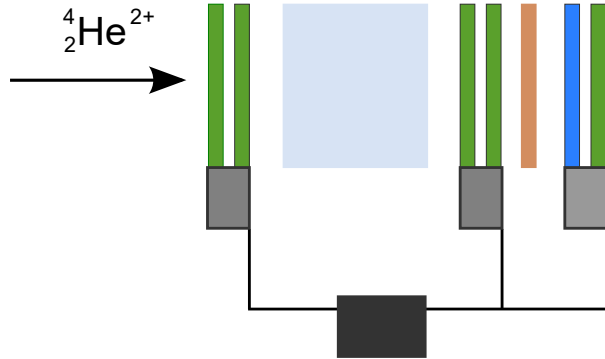
Synchronization:

- Search for temporal coincidences
- Cubic Spline path [5,6]

# Detection System [4]

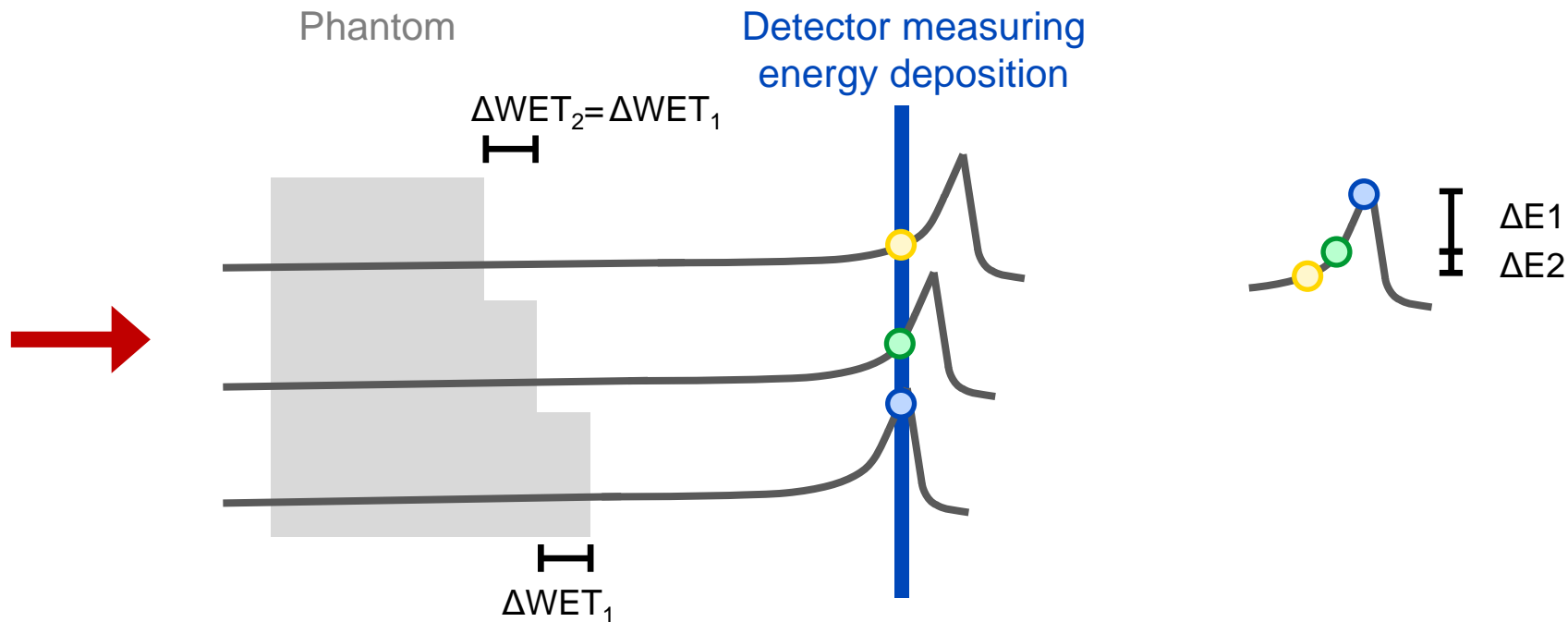


# Detection System [4]



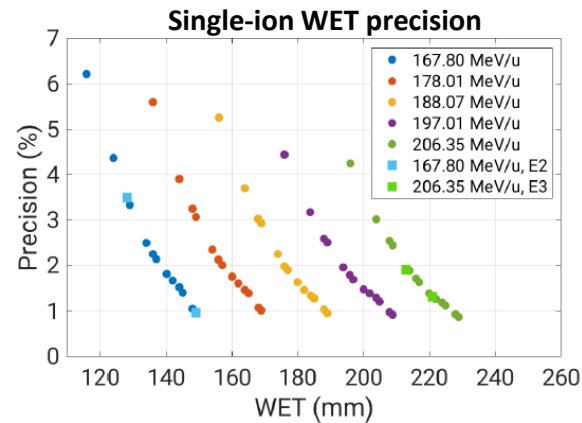
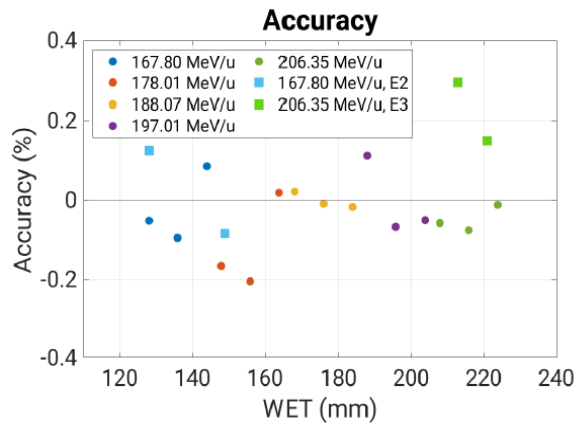
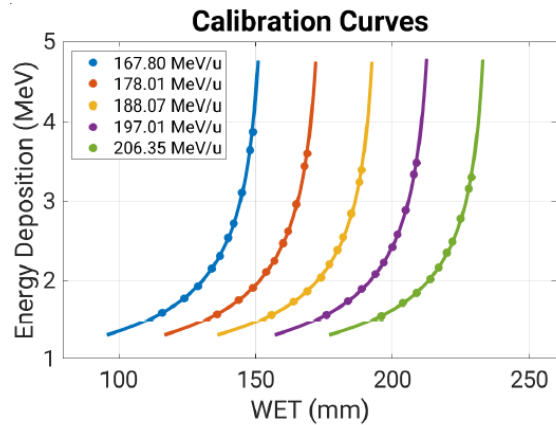
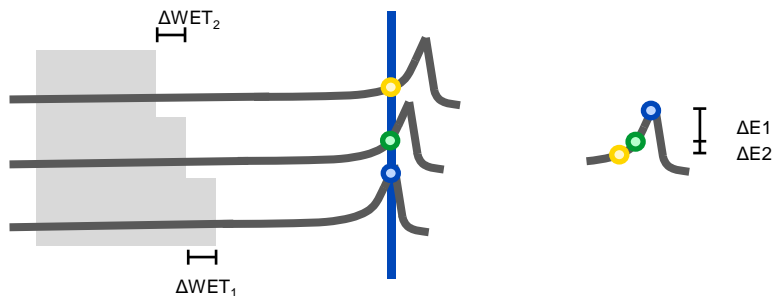


# Energy painting [7]



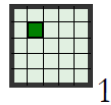
→ combination of several energies

# Energy painting [7]



# Energy painting [7]

Mono-energetic  
Image



1



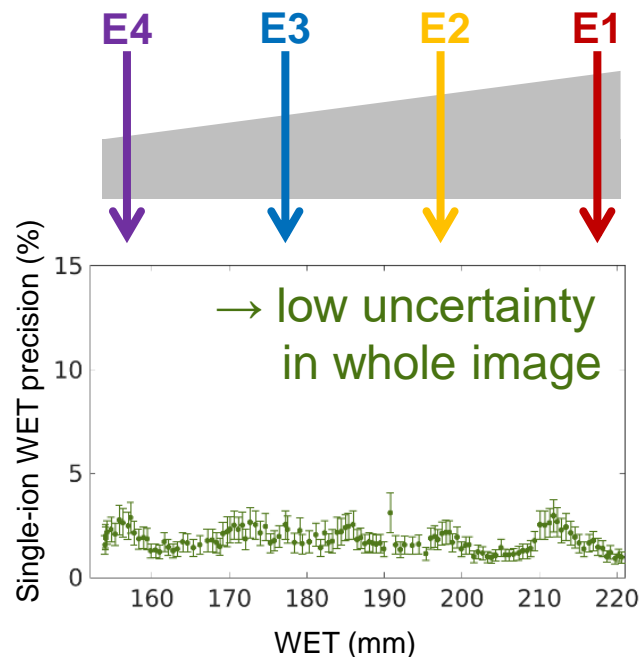
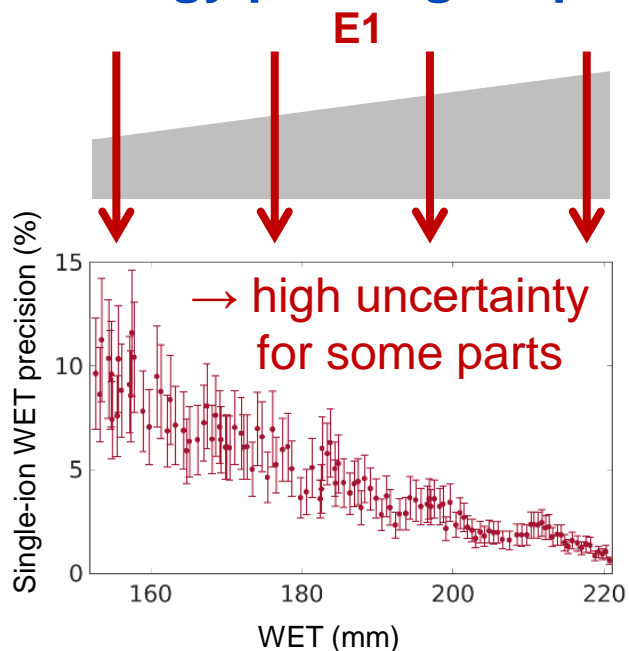
2

⋮



K

## Energy painting: Experimental results [7]



→ factor 2.5 improvement of single-ion WET precision

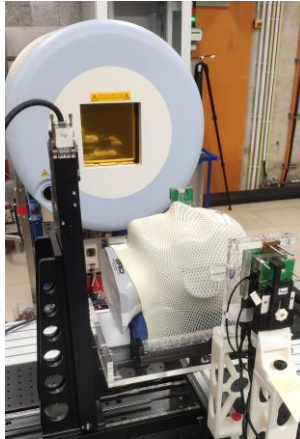
→ mean SIWP of around 2% competitive with US pCT system (Dickmann et al. 2019)

[7] Metzner et al. *PMB* 69.5 (2024): 055002.

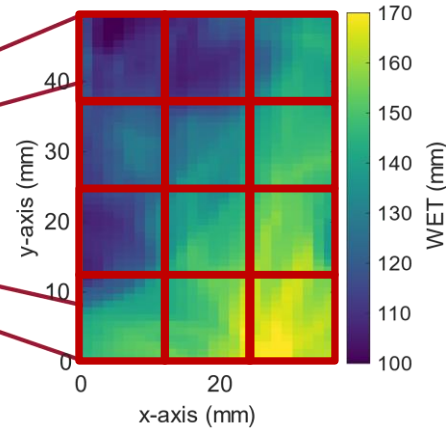
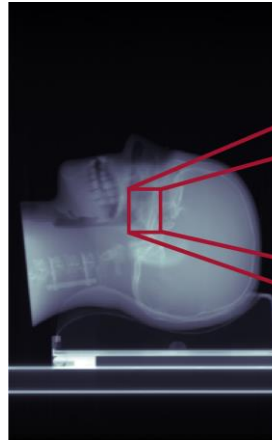
[8] Dickmann et al., *PMB* 64.14 (2019): 145016.

# Imaging of anthropomorphic phantom

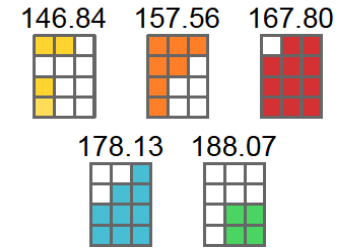
X-ray CT (HU)



X-ray CT (WET)



Energies (MeV/u)



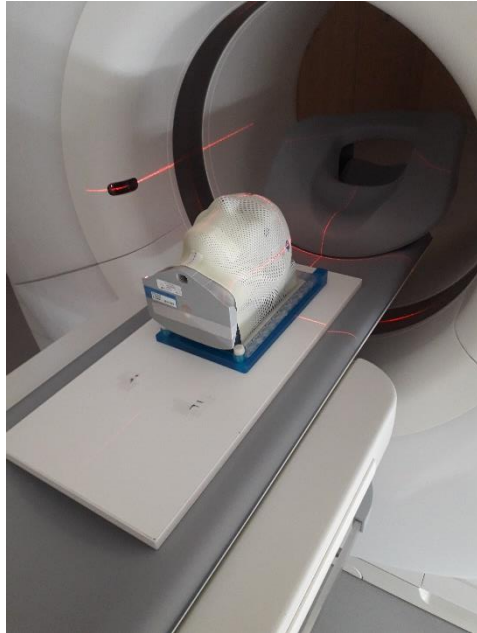
[9]



Region at the skull base:

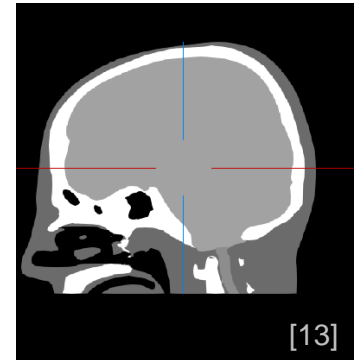
- Clinically relevant
- Heterogeneous
- Severe anatomical changes can occur

# Imaging of anthropomorphic phantom



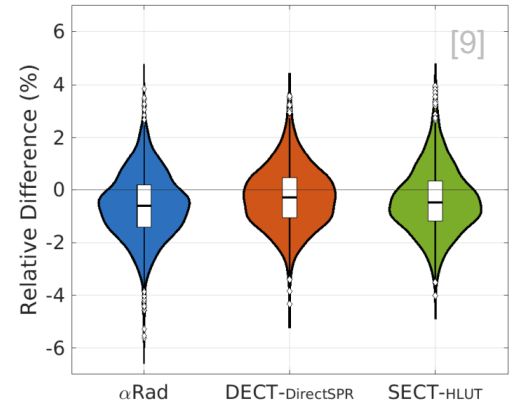
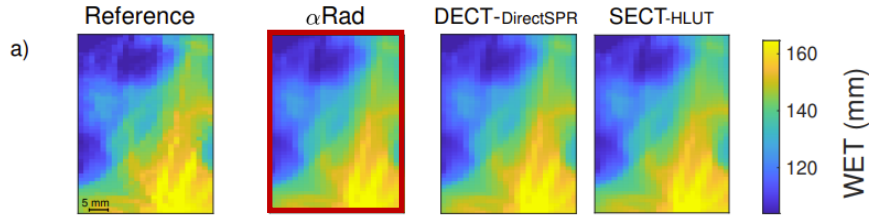
Comparison to projections of:

- Single-energy CT scan (converted to RSP with clinical protocol)
- Dual-energy CT scan (converted to RSP with clinical protocol)
  
- Similar to Dedes et al. [10], Volz et al. [11] and Bär et al. [12]  
For **our detection system**, determining **WET accuracy** in an **anthropomorphic phantom**
  
- Reference data set of Wohlfahrt et al. [13]:
  - RSP measurement of all 9 materials present in head phantom
  - Segmentations of high resolution X-ray CT scan ( $0.5\text{mm}^3$ )
  - Assignment of RSP values to all segmented volumes



# Imaging of anthropomorphic phantom: Results

WET maps of the anthropomorphic phantom

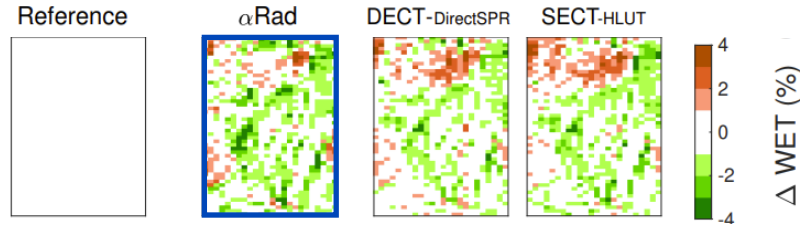


RMSE [9] :

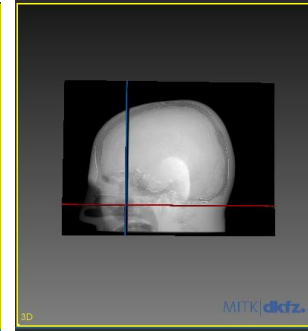
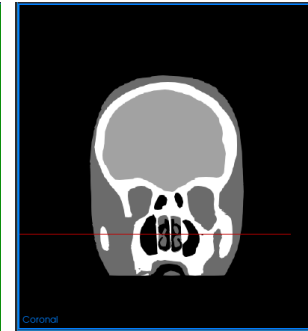
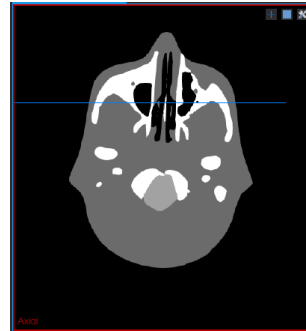
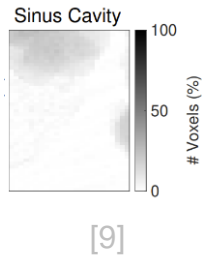
- $\alpha$ Rad: 1.43%
- DECT: 1.19%
- SECT: 1.30%
- (SECT with simpler HLUT: ~1.5%)
- (RMSE of reference scan ~1.0%)

[9]

# Imaging of anthropomorphic phantom: Results



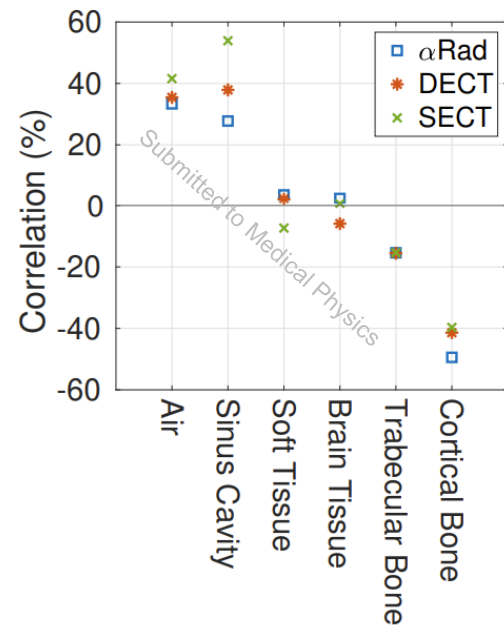
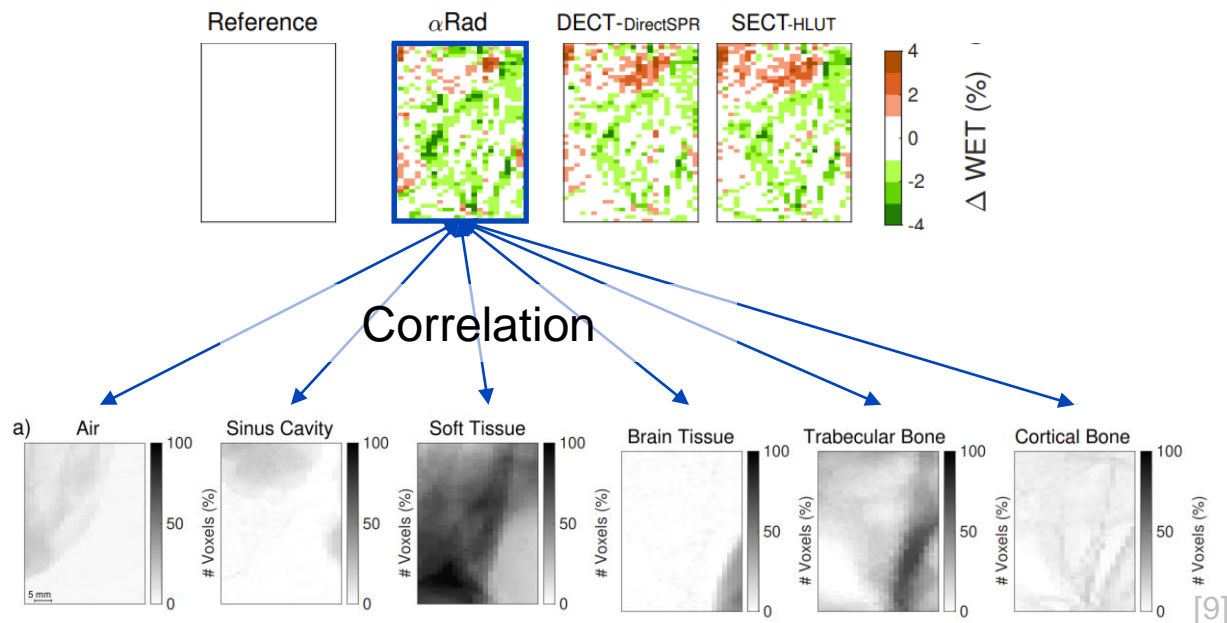
Where do deviations from Reference stem from?





# Imaging of anthropomorphic phantom: Results

[9]



→ Results for SECT and DECT agree with findings in Wohlfahrt et al. [13]

0%: no correlation  
 100%: maximum correlation  
 -100%: maximum anticorrelation

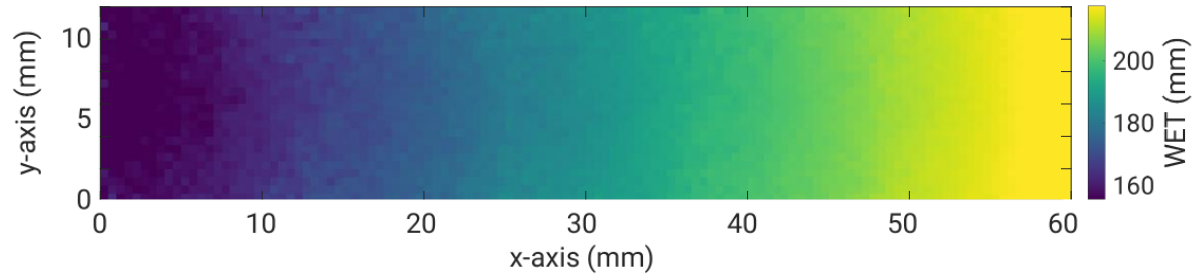
# Summary

- **Energy painting** overcomes the limitation in WET range of thin detectors
- Also in **anthropomorphic phantoms** we reached **accurate WET values**  
(RMSE ~1.4% compared to 1.0% of reference)
- **Competitive** with X-ray CT modalities in terms of WET accuracy

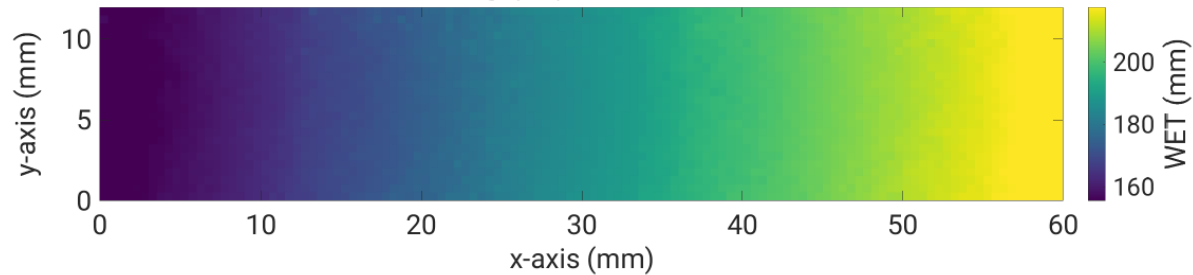
# Appendix

# Methods: Energy Painting

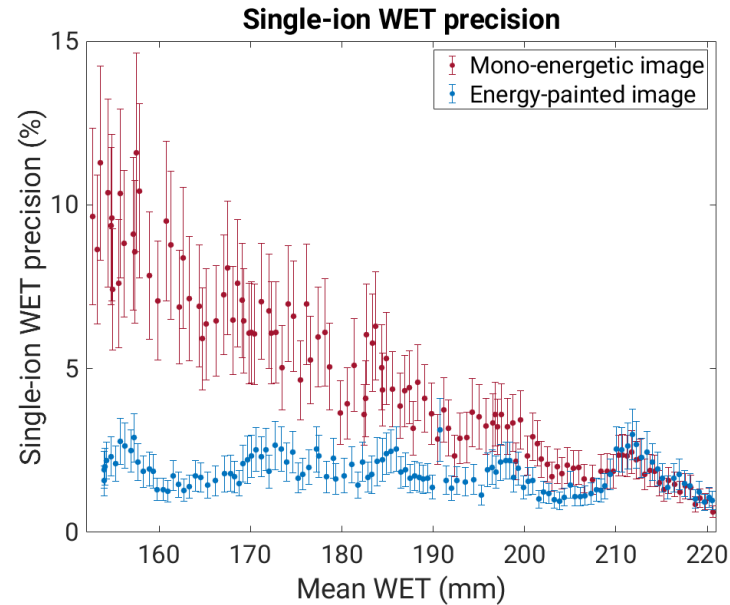
## Mono-energetic



## Energy painted



# Assessment of Energy Painted Image of wedge phantom



Metzner et al., PMB 69.5 (2024)