Spectral Calibration of Photon-Counting Material-Selective Clinical CT Scanners

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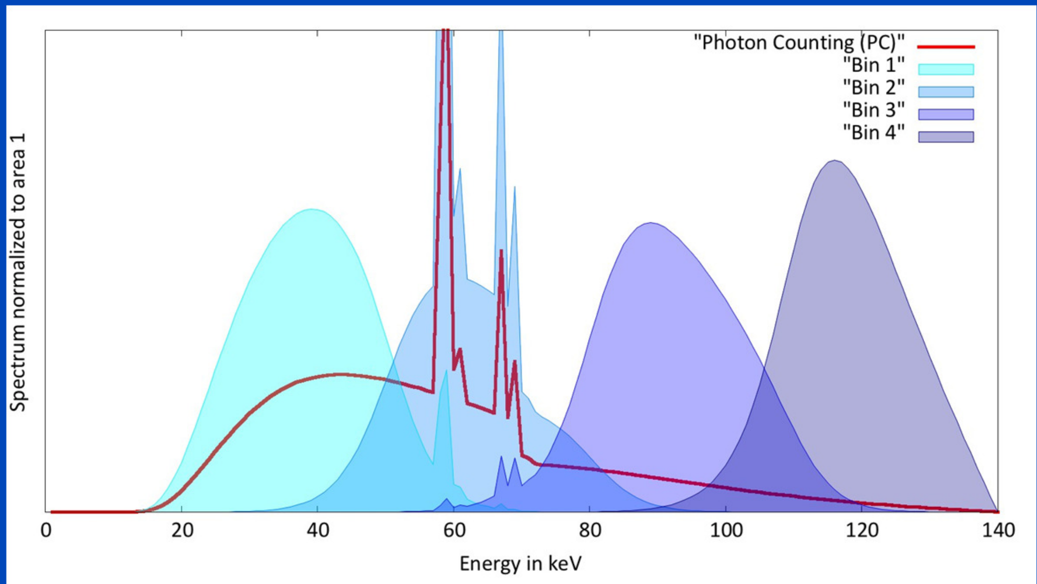
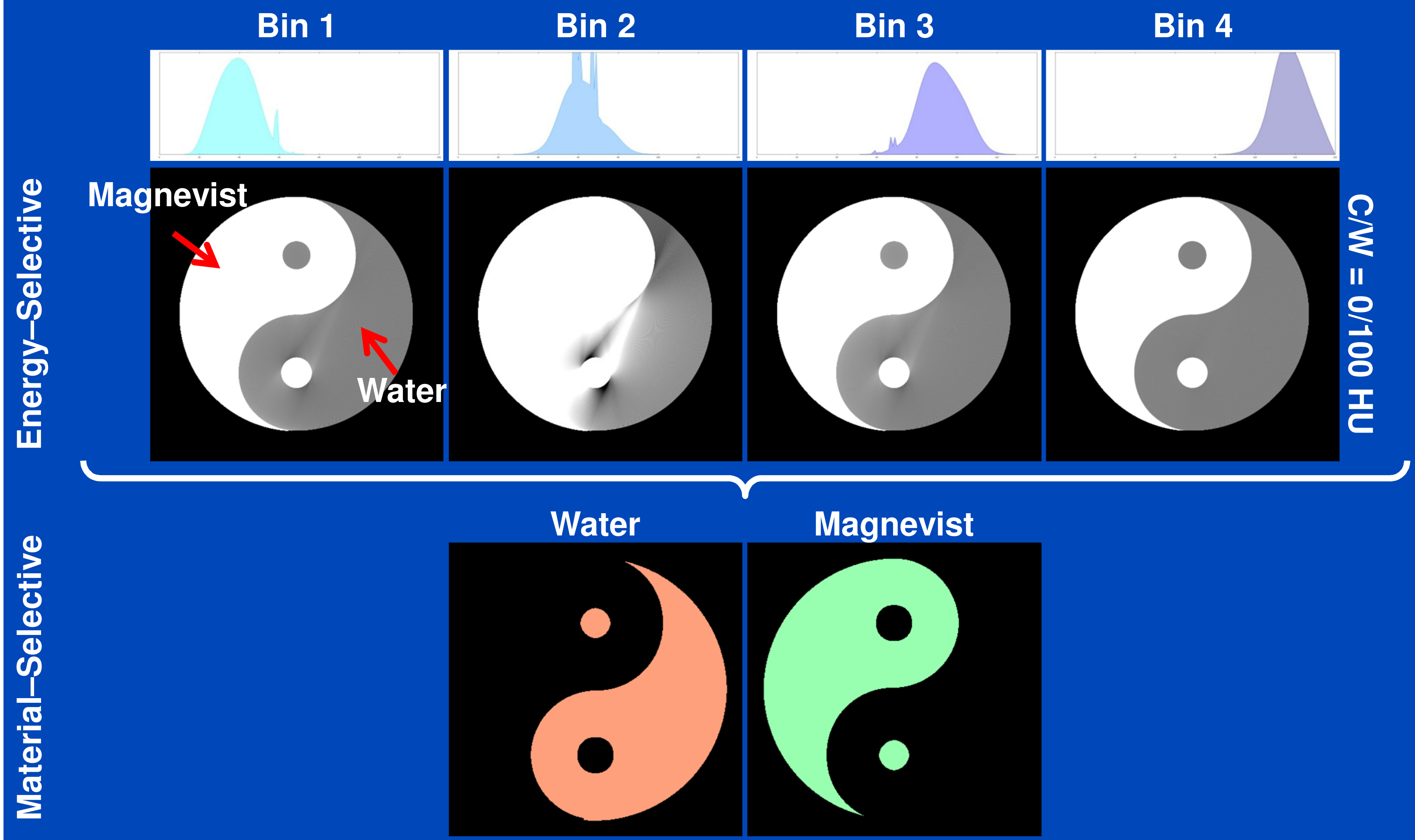
Aim

- To calibrate an energy-selective CT system to be able obtain quantitative images of basis materials
- To find a method that does not require to know the detected spectra or the energy dependence of the materials




Bin 1
Bin 2
Bin 3
Bin 4
Energy–Selective
Magnevist
Water
C/W = 0/100 HU
Material–Selective
Water
Magnevist

FAU

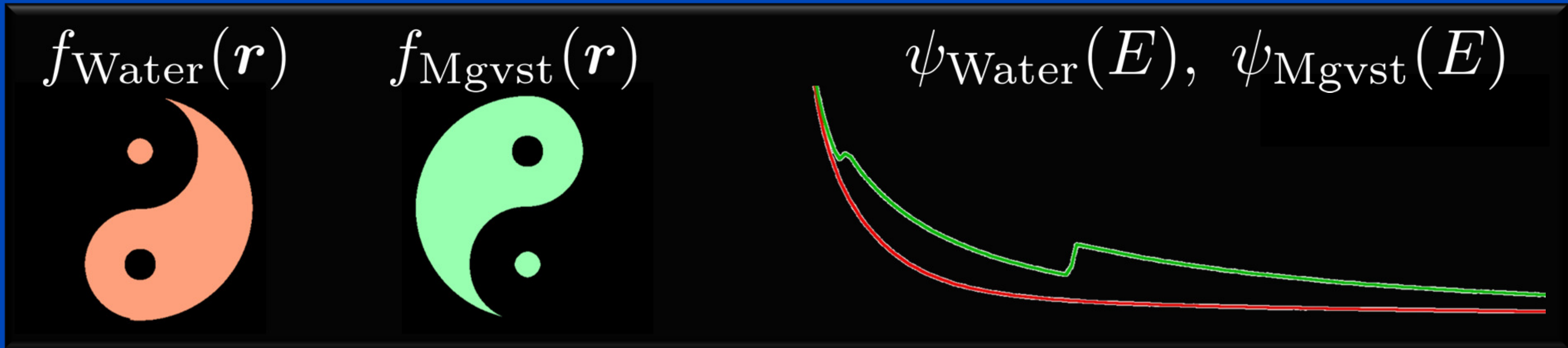
dkfz.

Multiple Energy CT

- **The object consists of *M* independent materials:**

$$\mu(\boldsymbol{r},E)=f_1(\boldsymbol{r})\psi_1(E)+f_2(\boldsymbol{r})\psi_2(E)+...+f_M(\boldsymbol{r})\psi_M(E)$$

- **Example (for *M* = 2)**



- **The CT measurement yields *B* sinograms (*B* ≥ *M*)**

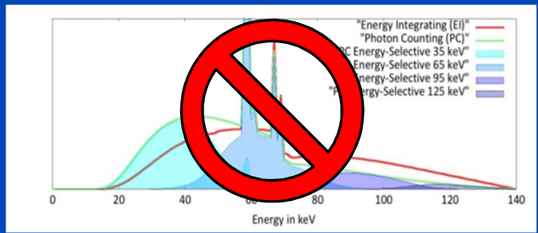
$$q_b=-\ln\int dE\,w_b(E)e^{-p_1\psi_1(E)-p_2\psi_2(E)-\ldots-p_M\psi_M(E)}$$

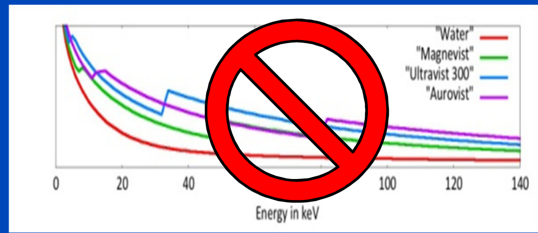
with $p_m=\mathsf{X}f_m(\boldsymbol{r})$.

Inversion Methods

- **Analytical**

$$q_b = -\ln \int dE\, w_b(E)\, e^{-p_1\psi_1(E) - p_2\psi_2(E) - \ldots - p_M\psi_M(E)}$$





- **Empirical: Direct calibration of** $p_m(q_1, q_2, \ldots, q_B)$**.**
- **Prior art:**

ECC	Empirical cupping correction	[MedPhys 33:1269, 2006]
ECCU	ECC with tube voltage modulation	[PMB 55:4107, 2010]
EDEC	Empirical dual energy calibration	[MedPhys 34:3630, 2007]
EMEC	Empirical multiple energy calibration	this work

FAU dkfz.

EMEC Series Expansion

$$p_m(q_1, q_2, ..., q_B) = \sum_{k_1, k_2, ..., k_B} c_{m,k_1,k_2,...,k_B} q_1^{k_1} q_2^{k_2} ... q_B^{k_B}$$

The unknowns $c_{m,k_1,k_2,...,k_B}$ **are calculated from a calibration scan.**

EMEC Calibration

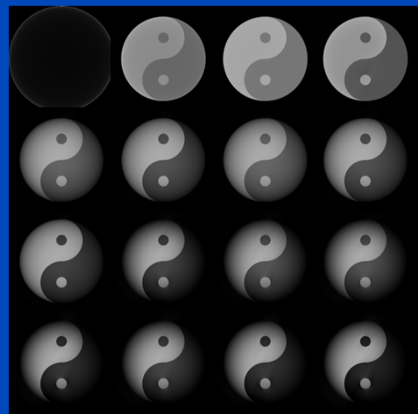
$$p_m(q_1, q_2, \ldots, q_B) = \sum_{k_1,k_2,\ldots,k_B} c_{m,k_1,k_2,\ldots,k_B} q_1^{k_1} q_2^{k_2} \ldots q_B^{k_B}$$

$$\mathsf{X}^{-1} \qquad\qquad\qquad \mathsf{X}^{-1}$$

$$f_m(f_1, f_2, \ldots, f_B) = \sum_{k_1,k_2,\ldots,k_B} c_{m,k_1,k_2,\ldots,k_B} f_{m,k_1,k_2,\ldots,k_B}$$

Template images, can be obtained by thresholding the calibration scan.

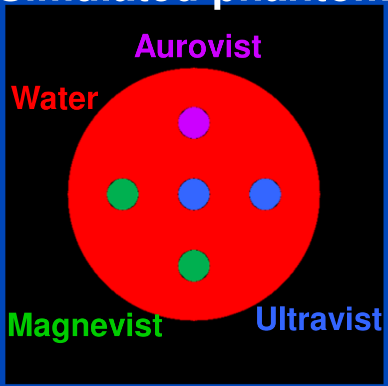
$$= \sum_{k_1,k_2,\ldots,k_B} c_{m,k_1,k_2,\ldots,k_B}$$



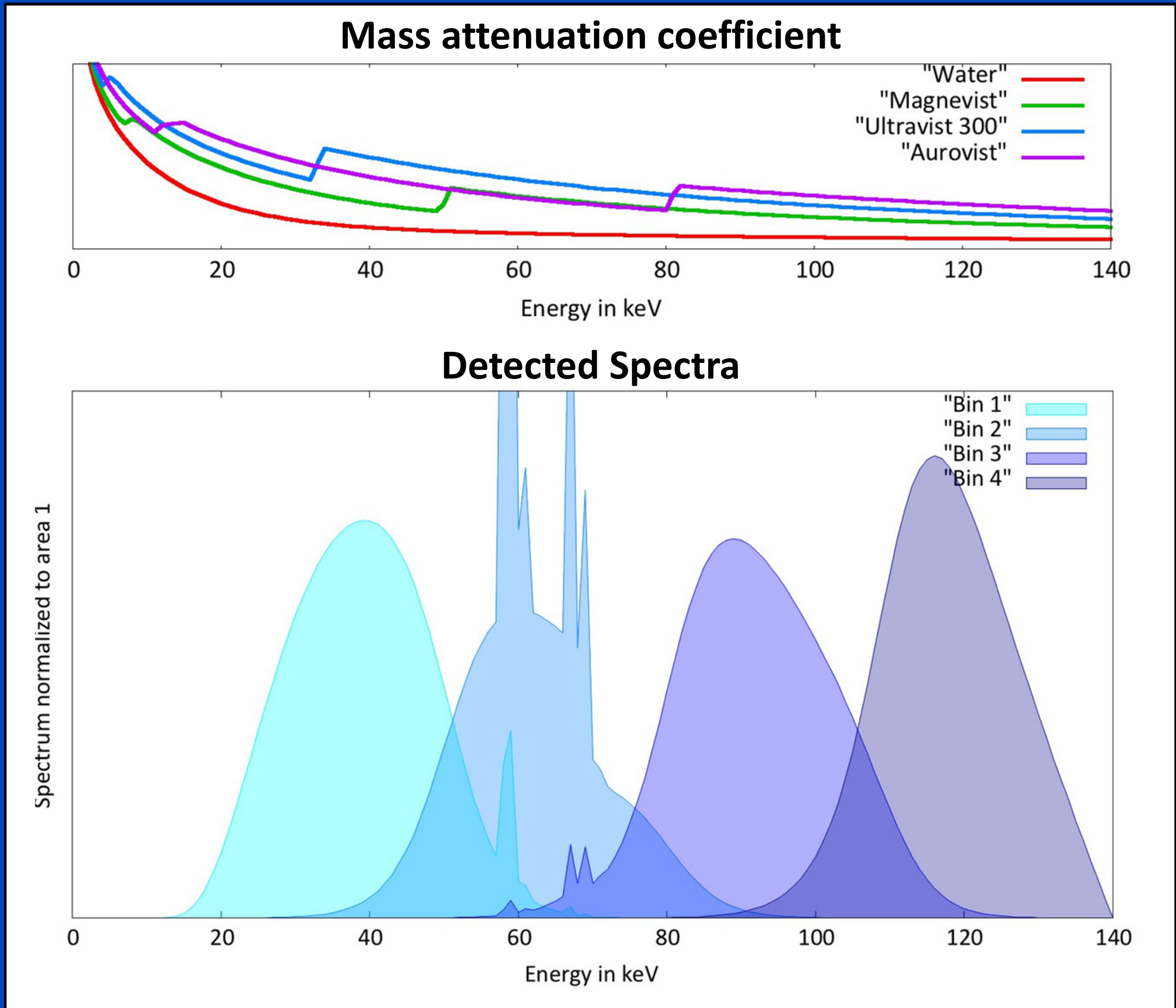
Basis images, obtained by reconstructing the monomials.

Four Material Separation

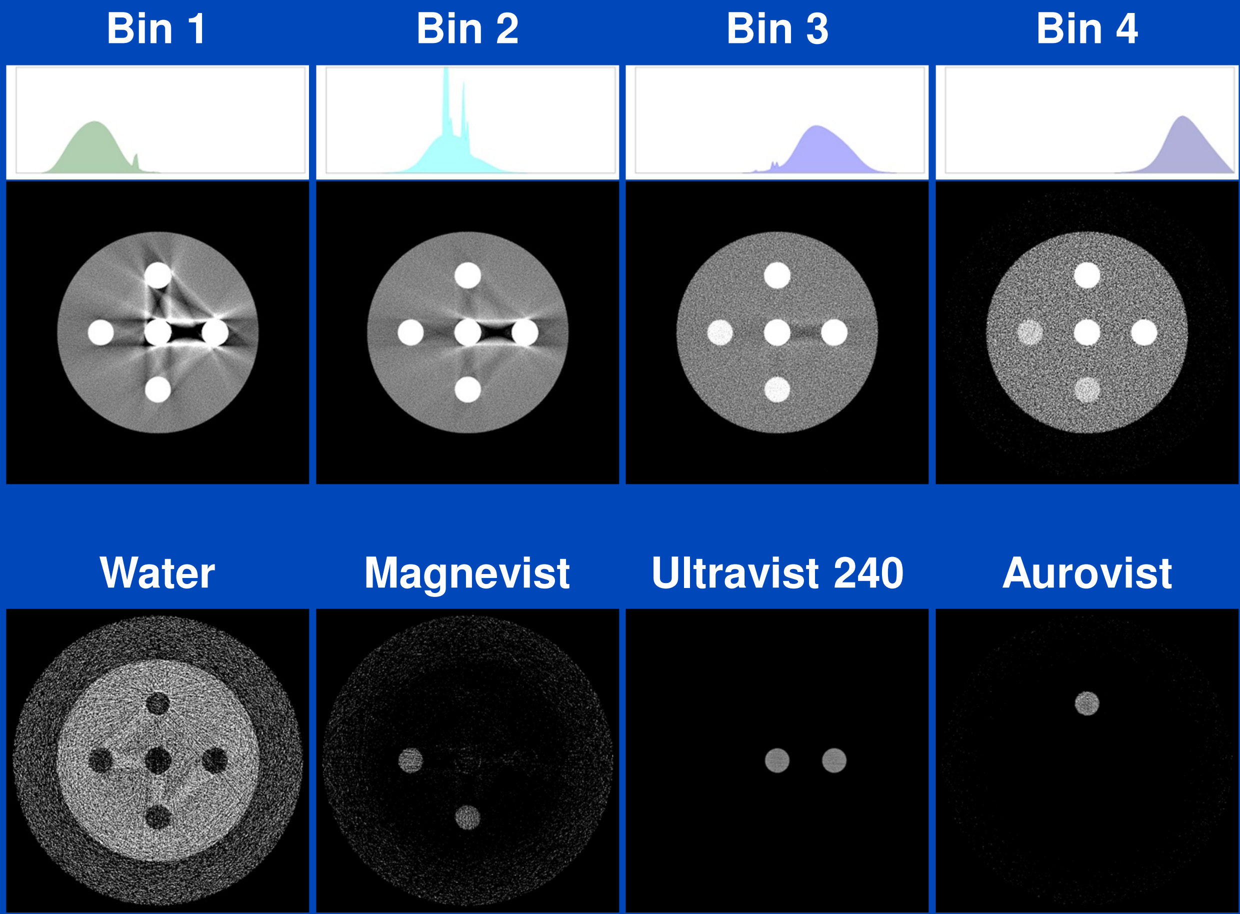
Simulated phantom



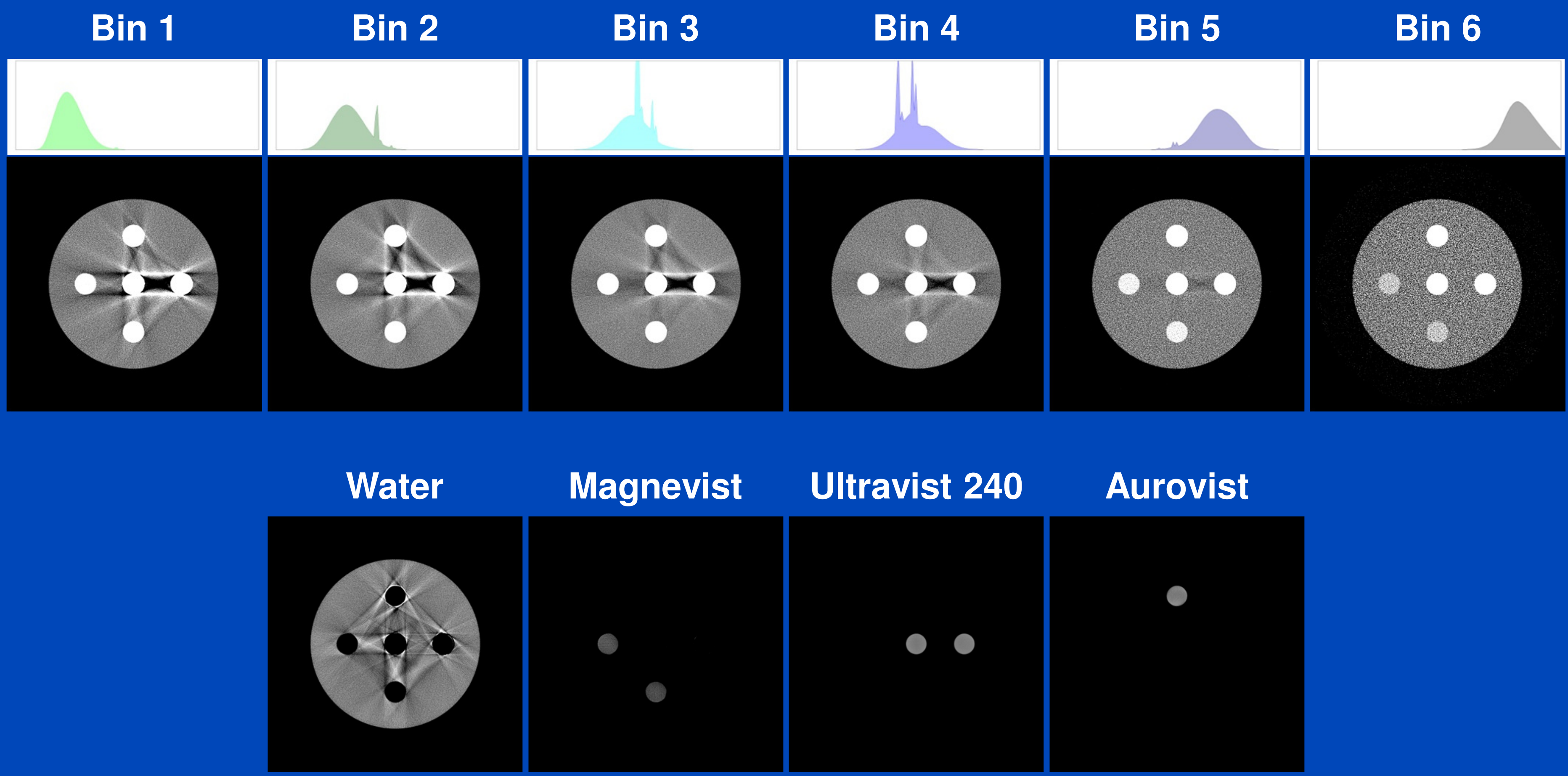
- 140 kV source spectrum
- 2 mm Al prefiltration
- 1.4 mm CdZnTe detector
- Gaussian spectral blur



Results
4 Energy Bins



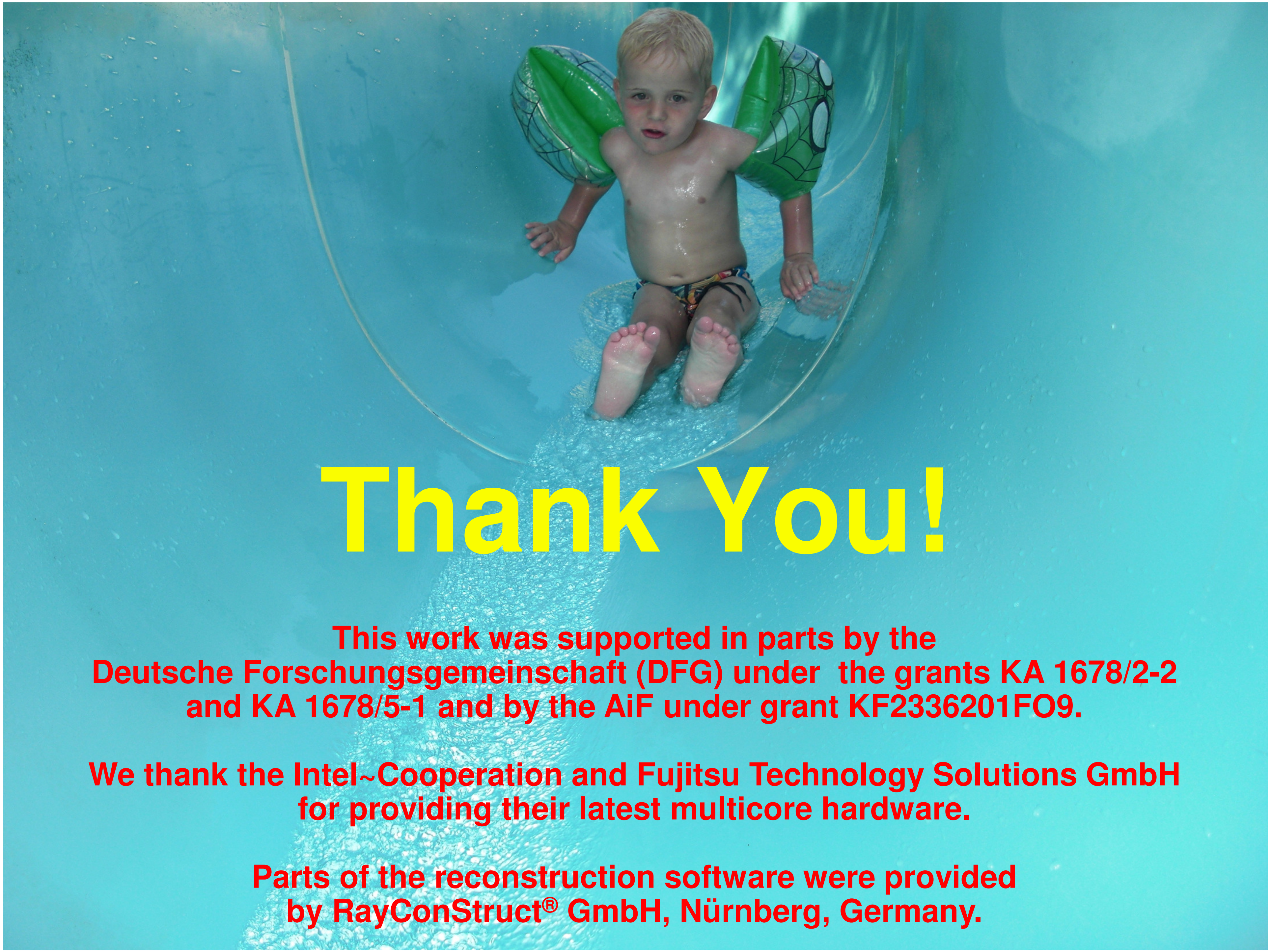
Results
6 Energy Bins



Summary of our Preliminary Results

- Empirical multiple energy calibration (EMEC)
  - enables us to reconstruct quantitative material-selective CT images from energy-selective rawdata
  - does not require to know any spectral properties of the CT system or the materials involved
  - can be easily applied in clinical and pre-clinical routine
  - inherently corrects beam hardening and first order scatter artifacts

Calibrate the system, not the components!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