# Joint Hardware and Patient Attenuation Correction for Hybrid PET/MR Imaging

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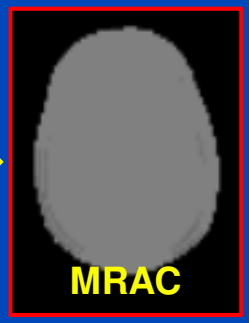
# Aim

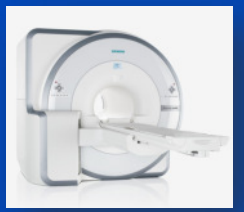
- **Current PET/MR status**


Gold Standard


- **Aim: To improve patient AC for non-TOF PET/MR.**

- **Algorithms (all based on MLAA[1])**
  - **MR-MLAA** Emission-based patient AC for PET/MR
  - **xMLAA** Emission-based hardware AC for PET/MR
  - **xMR-MLAA** Combination of MR-MLAA and xMLAA



Biograph mMR (non TOF)

[1] J. Nuyts, P. Dupont, S. Stroobants, R. Benninck, L. Mortelmans, and P. Suetens, "Simultaneous maximum a posteriori reconstruction of attenuation and activity distributions from emission sinograms.," IEEE Trans. Med. Imaging 18(5):393–403, 1999.

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# MR-MLAA

- **Joint estimation of attenuation and activity**
  - Using PET emission data
  - Incorporating MR-based prior information
- **Iterative approach**
  - Update attenuation and activity in an alternating manner
- **Objective function**

$$Q(\lambda, \mu) = \underbrace{L(\lambda, \mu)}_{\text{Log-likelihood}} + \underbrace{L_{\mathrm{S}}(\mu) + L_{\mathrm{I}}(\mu)}_{\text{Prior terms}}$$

$\lambda$ = activity
$\mu$ = attenuation

- **Intensity prior $L_{\mathrm{I}}$**
  - Voxel-dependent probability distribution of attenuation values
  - Derived from diagnostic $T_1$-weighted MR images

T. Heußer, C.M. Rank, M.T. Freitag, A. Dimitrakopoulou-Strauss, H.-P. Schlemmer, T. Beyer, and M. Kachelrieß, "MR-Consistent Simultaneous Reconstruction of Attenuation and Activity for non-TOF PET/MR," *IEEE Trans. Nucl. Sci.* 63(5):2443-2451, 2016.

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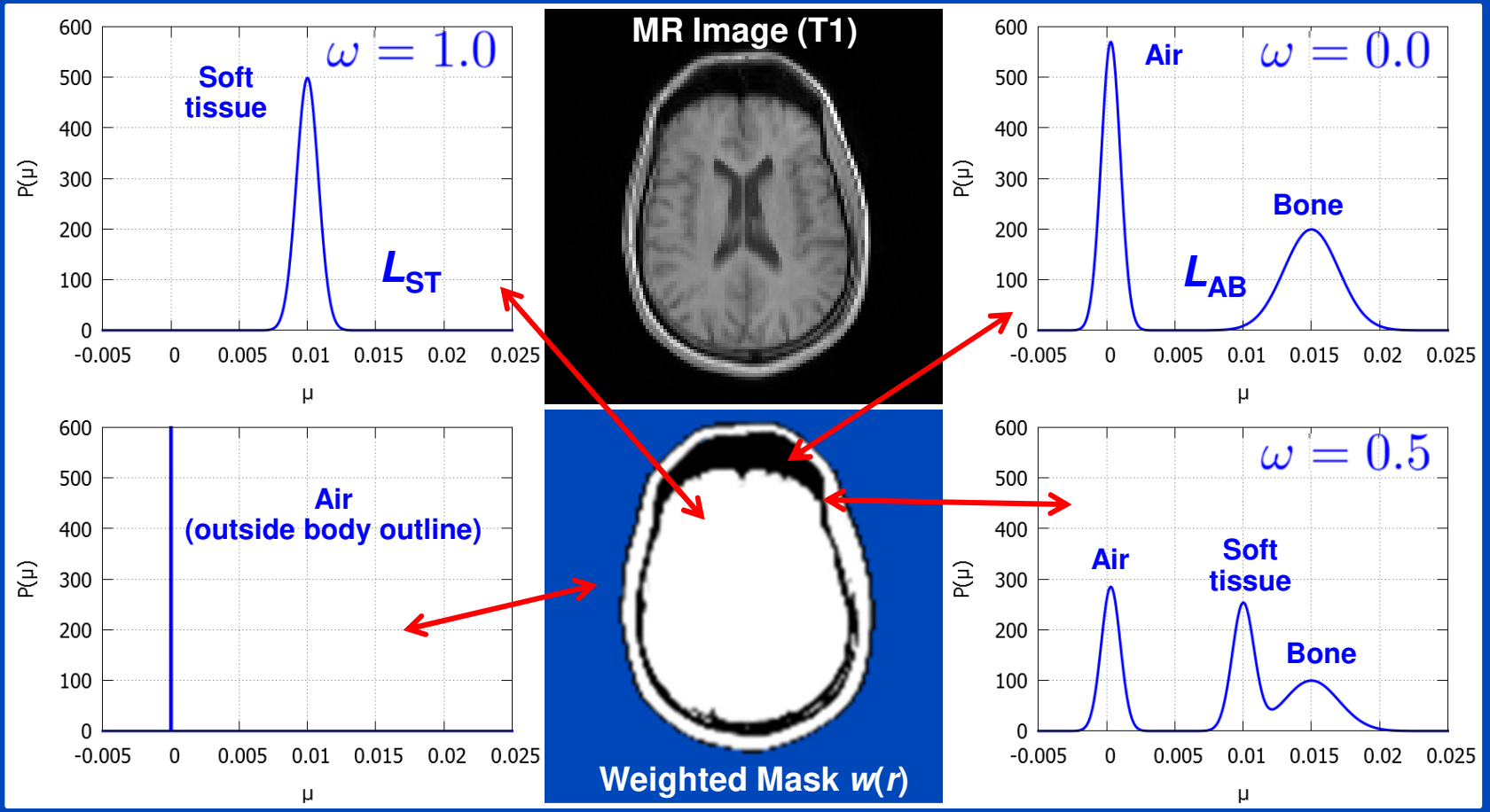
# MR-MLAA's Intensity Prior




$$L_{\mathrm{I}}(\mu) = \omega(r)\beta_{\mathrm{ST}}L_{\mathrm{ST}}(\mu) + (1-\omega(r))\beta_{\mathrm{AB}}L_{\mathrm{AB}}(\mu)$$

We use $\beta_{ST}$ = 0.1 and $\beta_{AB}$ = 0.6 throughout this presentation.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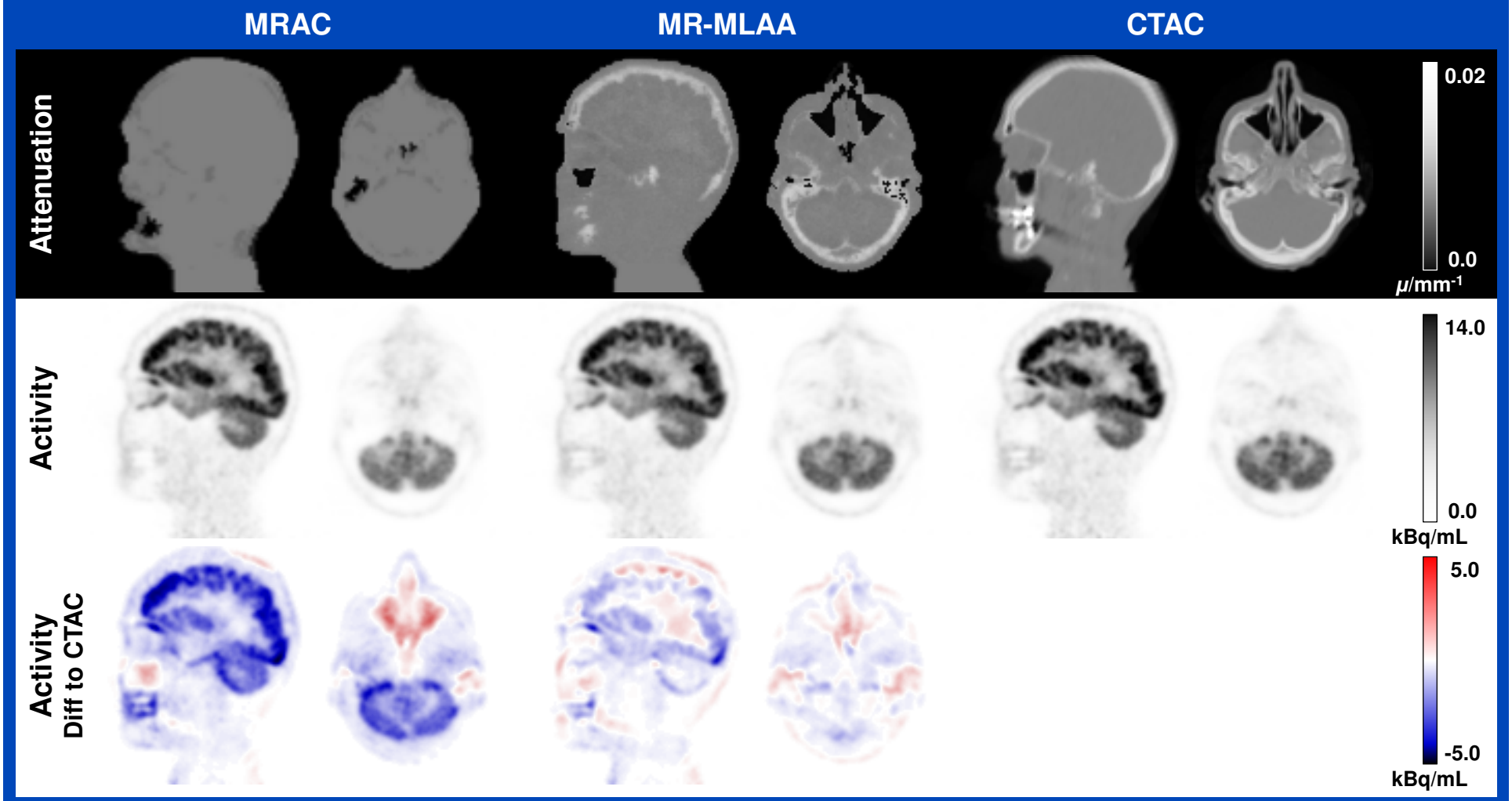
# MR-MLAA Patient Example

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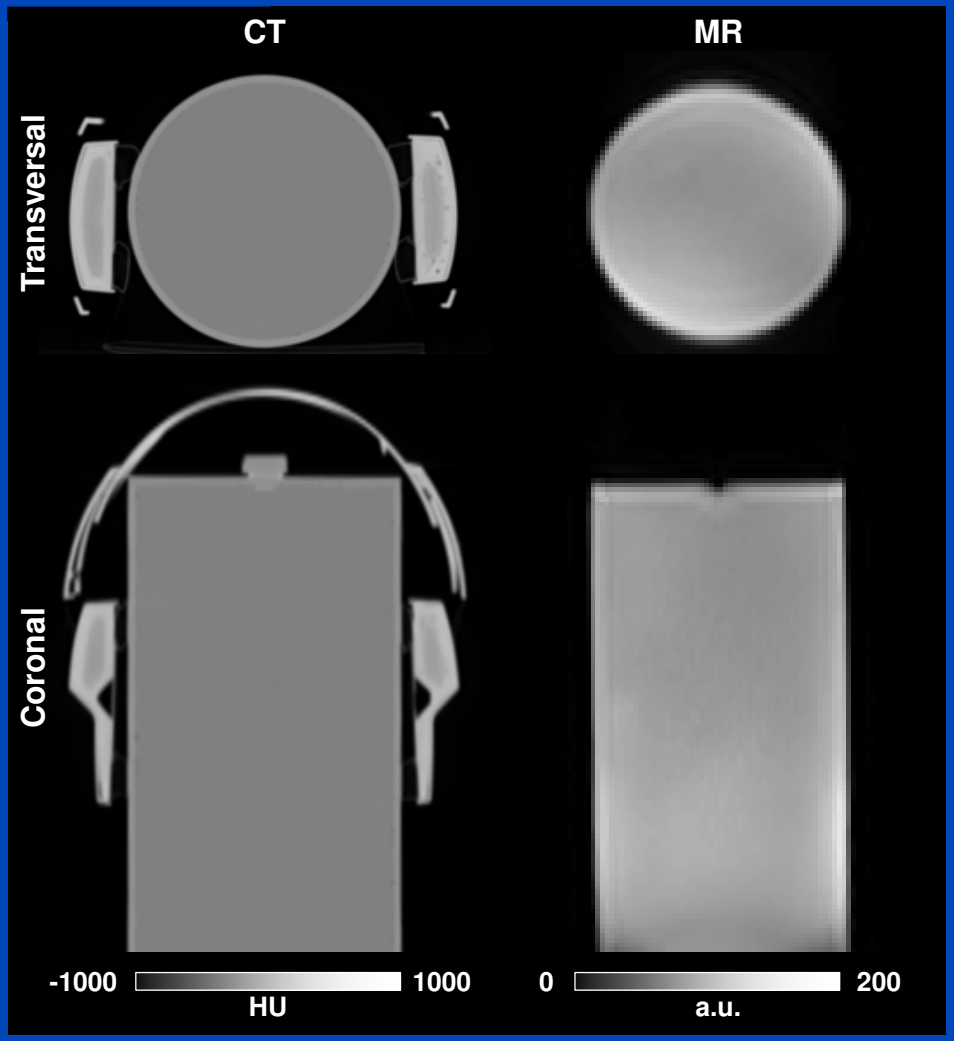
# xMLAA

- Flexible hardware components are currently neglected in MR-based AC
  - MR-safe headphones
  - Radiofrequency torso surface coils
  - Positioning aids
  - …
- Aim
  - Estimate attenuation of flexible hardware components from the PET emission data




T. Heußer, C.M. Rank, Y. Berker, M.T. Freitag, and M. Kachelrieß, "MLAA-based Attenuation Correction of Flexible Hardware Components in Hybrid PET/MR Imaging," *EJNMMI Physics* 4:12 (23 pages), 2017.

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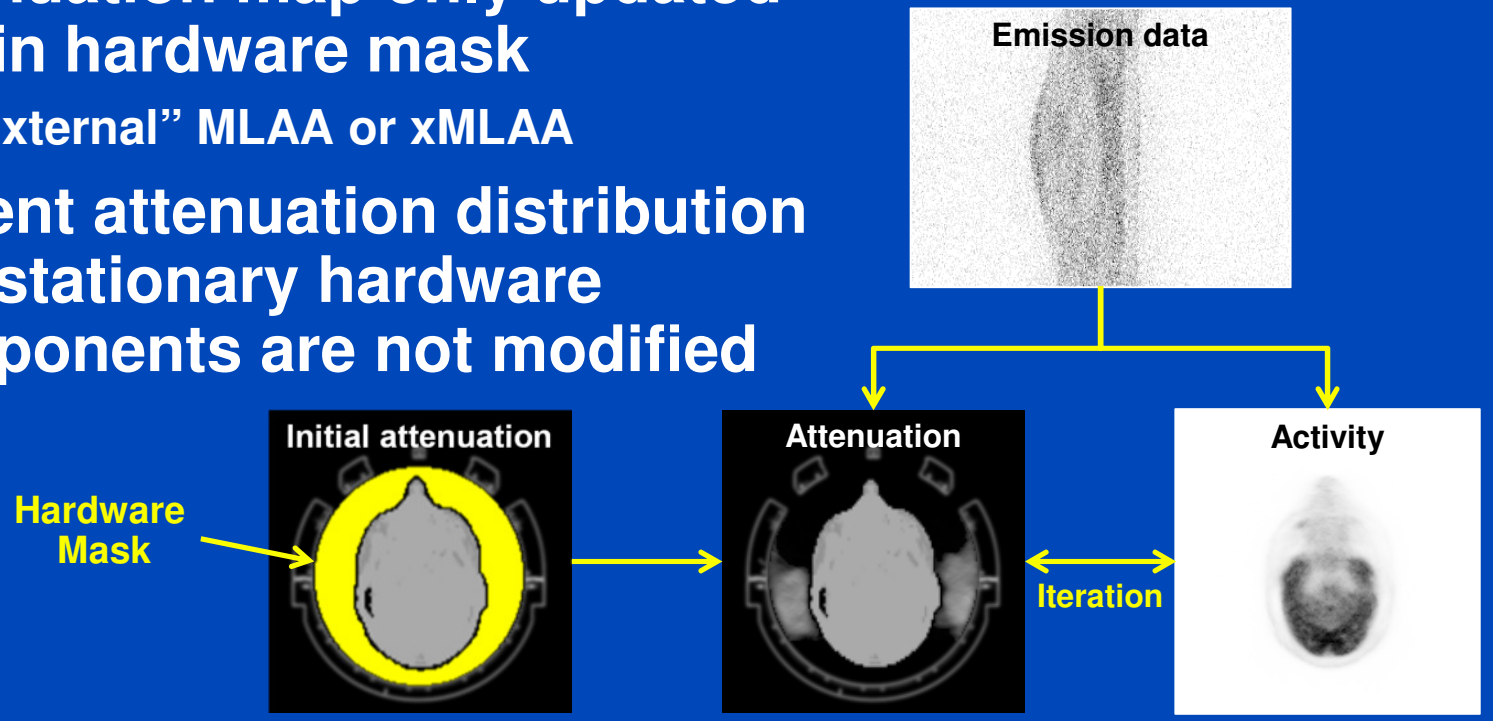
# xMLAA

- Joint estimation of attenuation and activity
  - Based on the MLAA algorithm
- Attenuation map only updated within hardware mask
  - "External" MLAA or xMLAA
- Patient attenuation distribution and stationary hardware components are not modified

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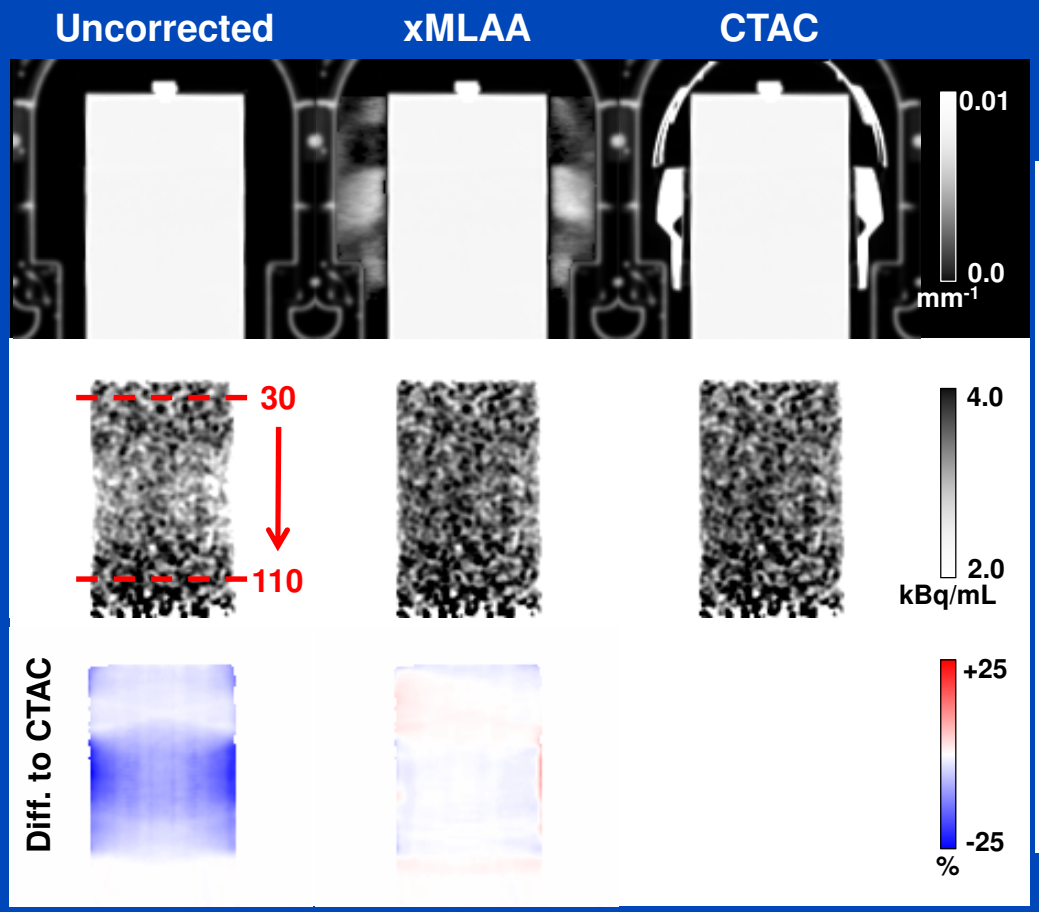
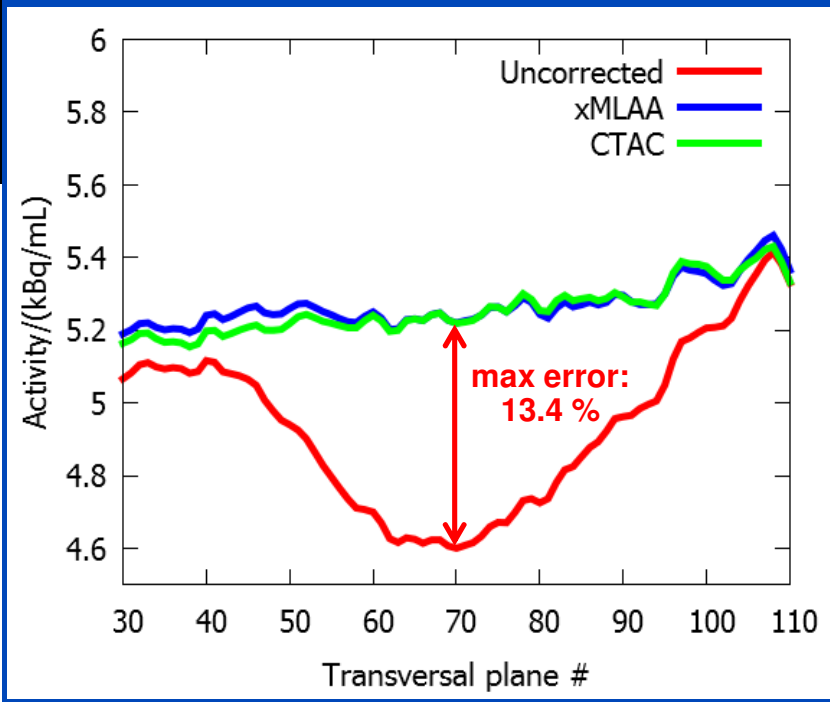
# xMLAA with Headphones

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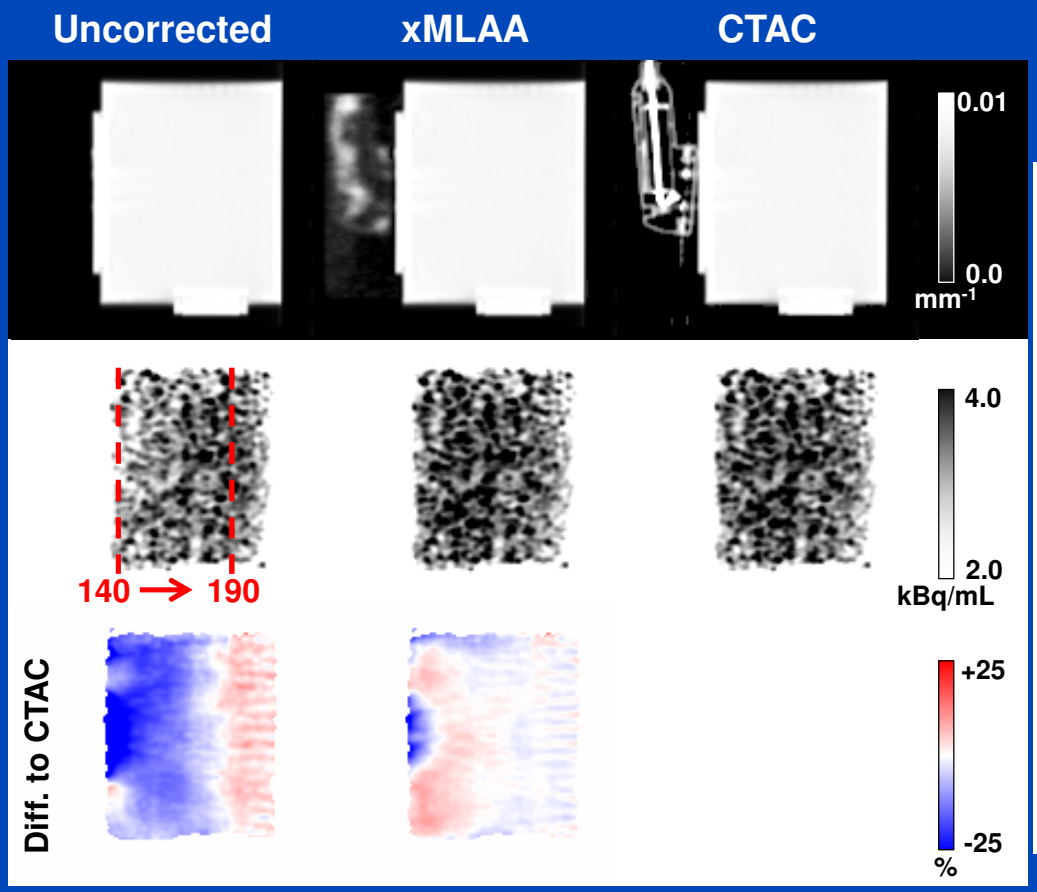
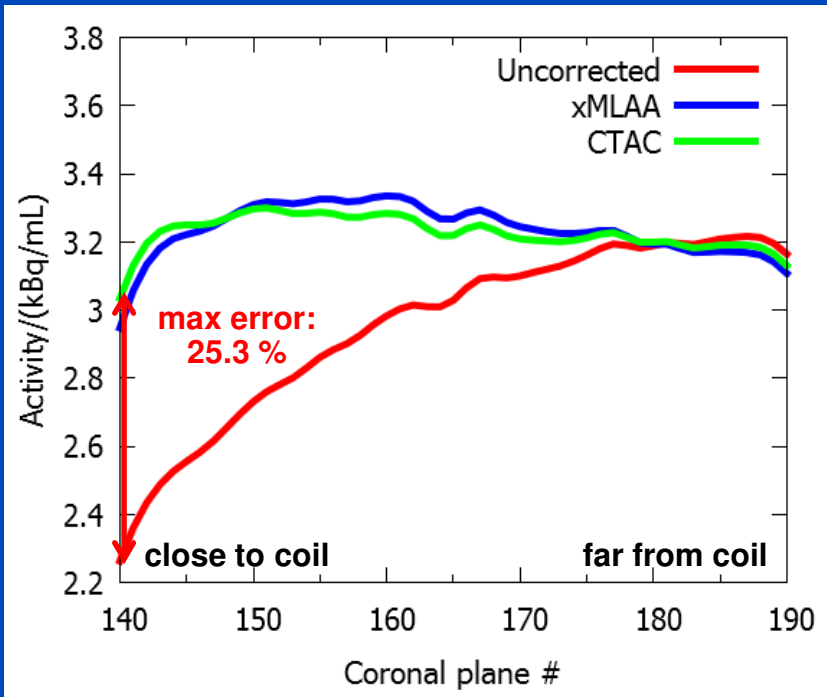
# xMLAA with Torso Coil

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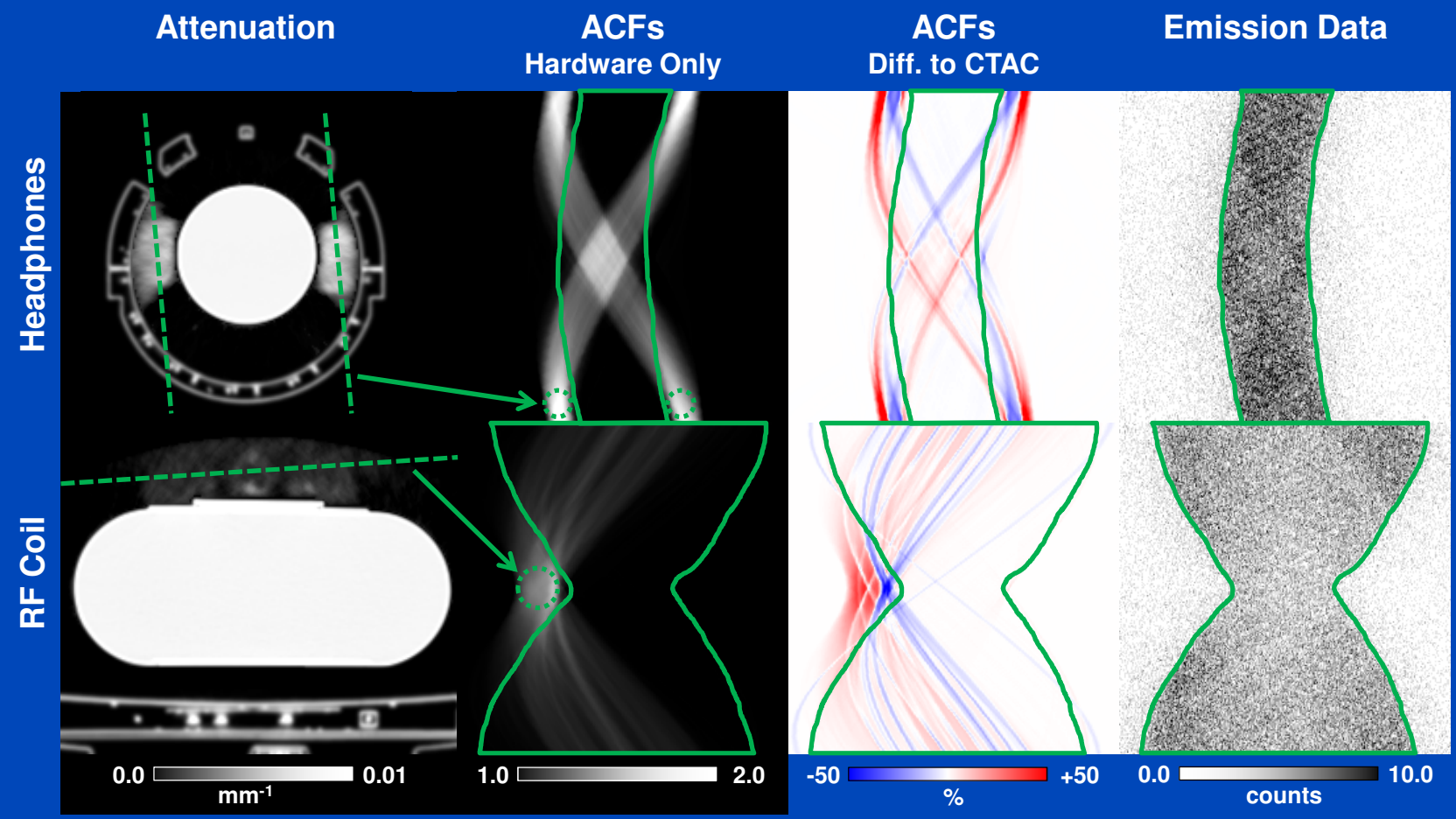
# xMLAA
# Attenuation Correction Factors

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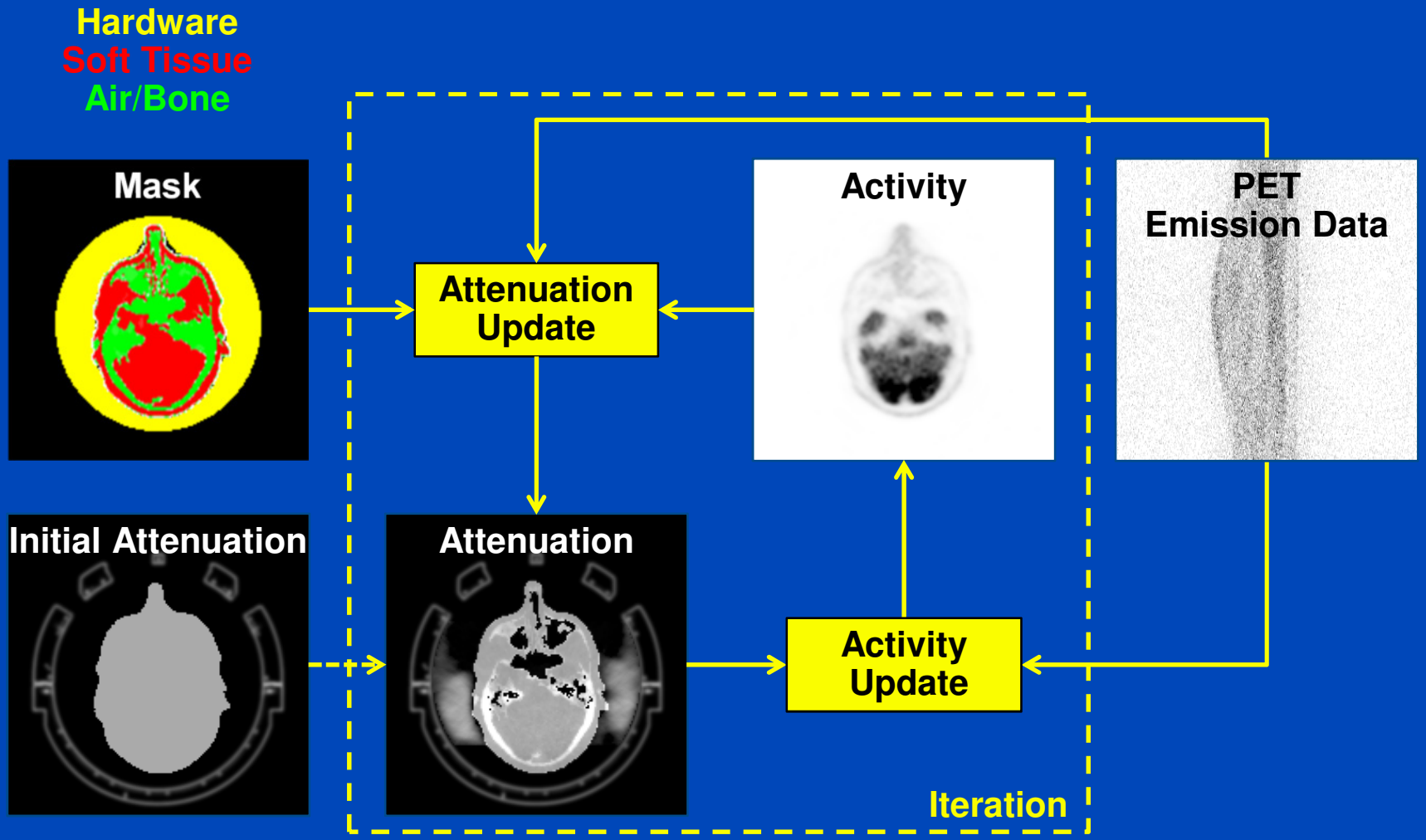
# xMR-MLAA
# Combination of MR-MLAA and xMLAA

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# xMR-MLAA Algorithm

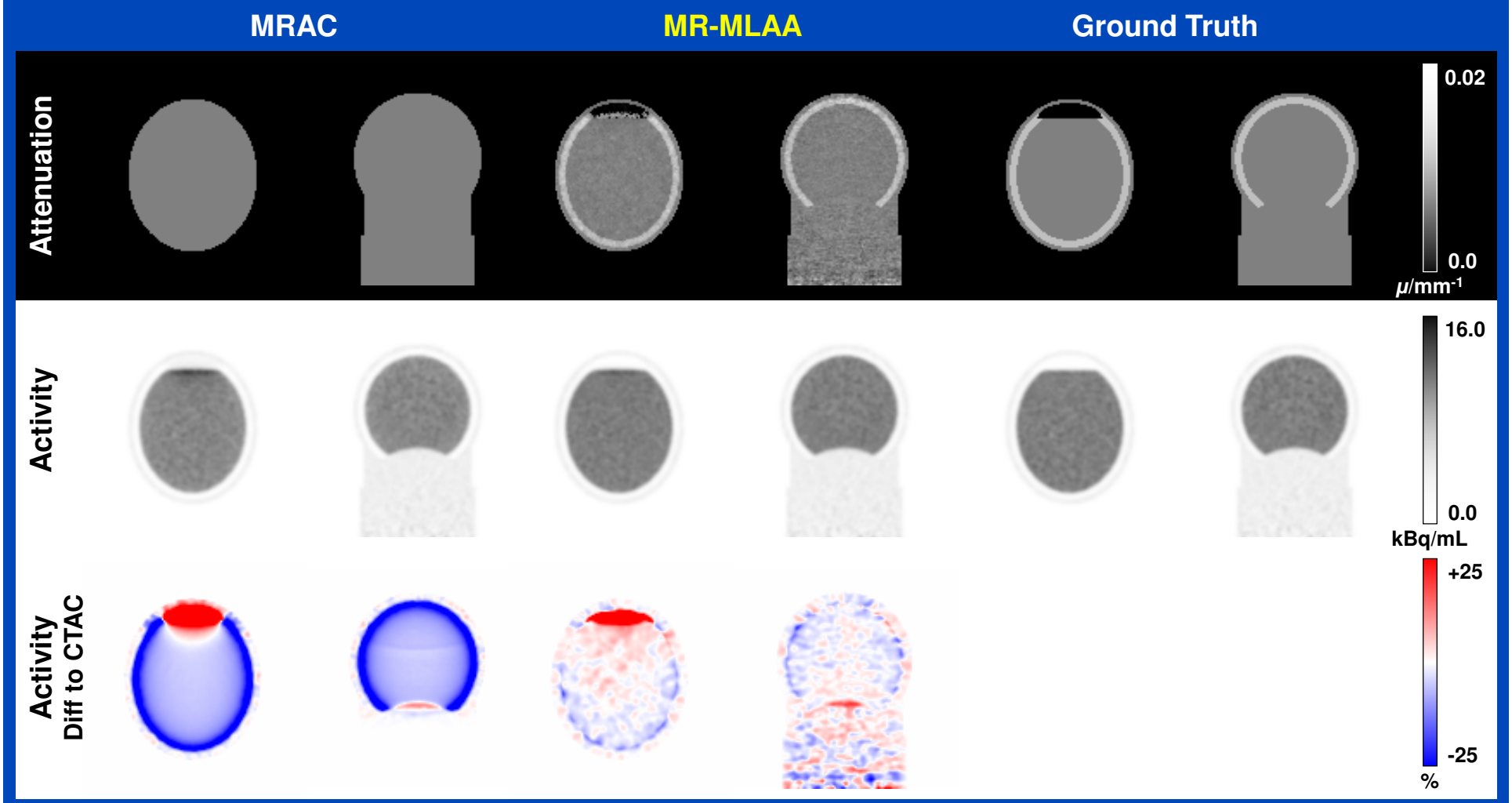
- Hardware and patient attenuation are updated sequentially
- Hardware update
  - xMLAA
  - 2 iterations, 21 subsets
- Patient update
  - MR-MLAA
  - 3 Iterations, 21 subsets
- Intensity prior


Hardware
Soft Tissue
Air/Bone

$$L_{\mathrm{I}}(\boldsymbol{\mu}) = \omega_{\mathrm{x}}(\boldsymbol{r})\beta_{\mathrm{x}}L_{\mathrm{x}}(\boldsymbol{\mu}) + (1-\omega_{\mathrm{x}}(\boldsymbol{r}))L_{\mathrm{MR}}(\boldsymbol{\mu})$$

$$L_{\mathrm{MR}}(\boldsymbol{\mu}) = \omega(\boldsymbol{r})\beta_{\mathrm{ST}}L_{\mathrm{ST}}(\boldsymbol{\mu}) + (1-\omega(\boldsymbol{r}))\beta_{\mathrm{AB}}L_{\mathrm{AB}}(\boldsymbol{\mu})$$

# Simulation without Hardware

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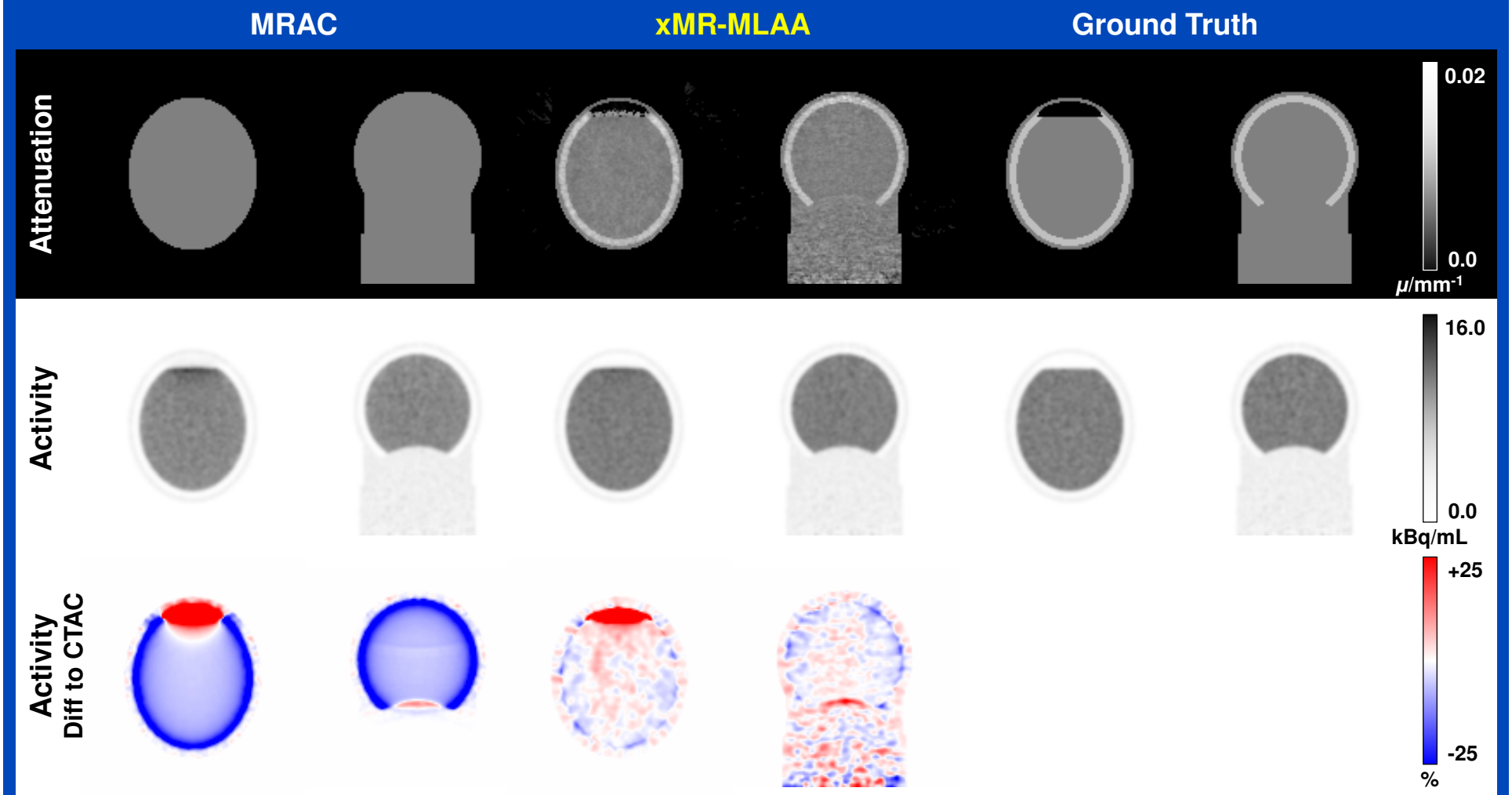
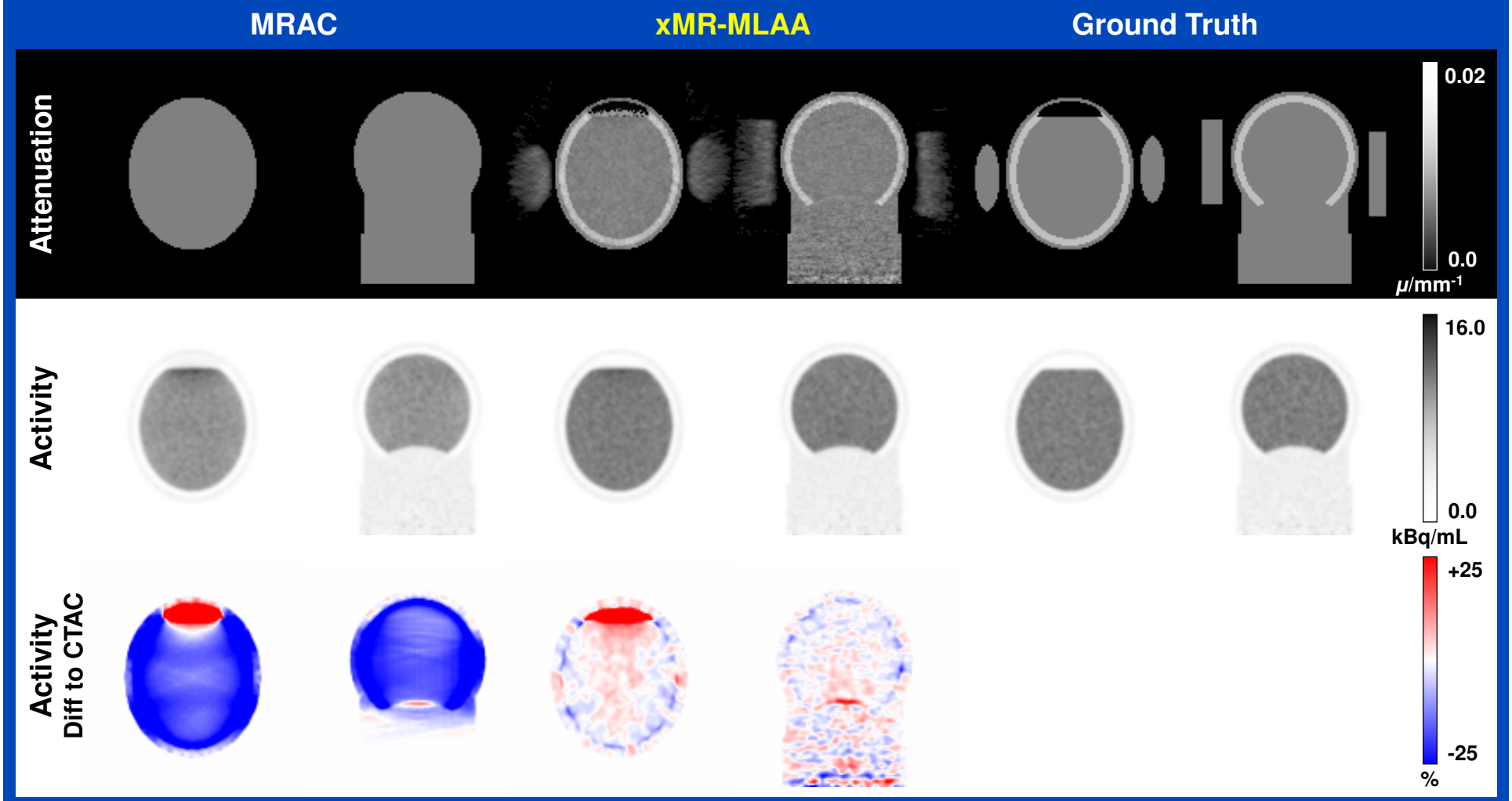
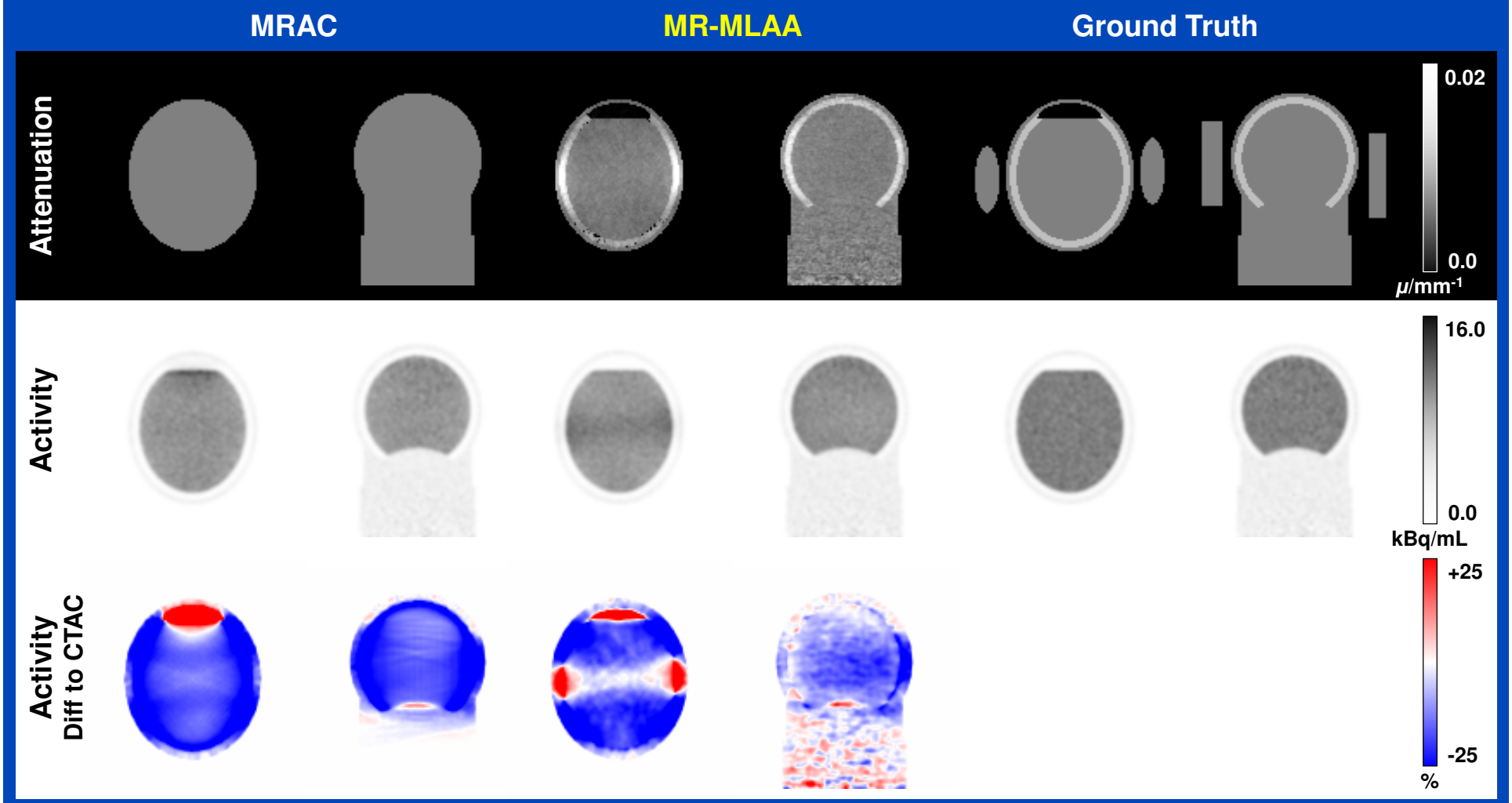
# Simulation without Hardware



# Simulation with Hardware



# Simulation with Hardware

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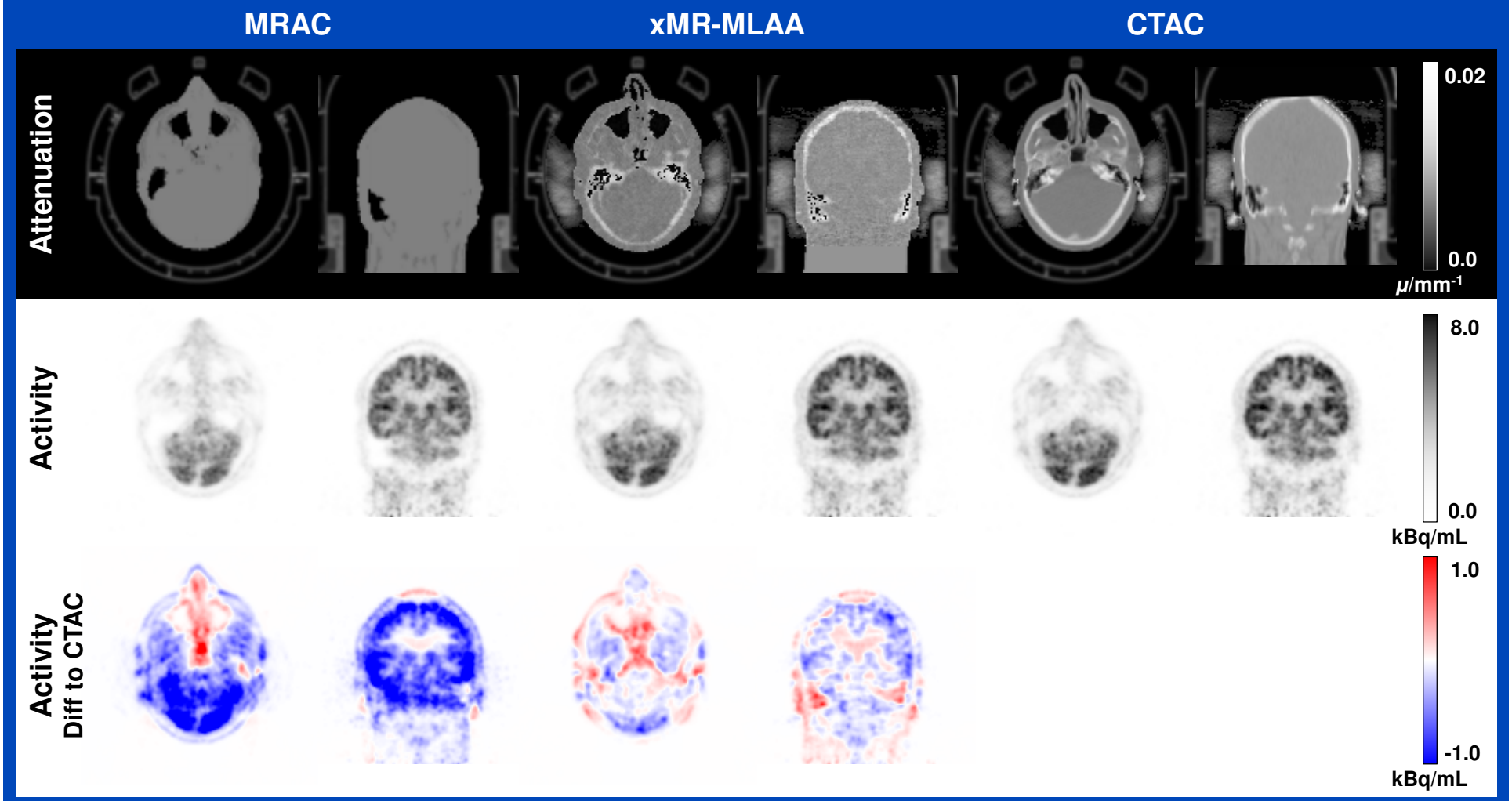
# xMR-MLAA Patient Study

- Clinical non-TOF $^{18}$F-FDG-PET/MR data of the head region acquired with a Siemens Biograph mMR
- Attenuation correction
  - MRAC: standard MR-based AC
  - xMR-MLAA: proposed method
  - CTAC: CT-derived AC
- Perform OSEM reconstructions using
  - 3 iterations
  - 21 subsets
  - Gaussian post-smoothing ($\sigma$ = 2.0 mm)
- Limitation
  - MR hardware components are not present in the CT-based attenuation maps.
  - Therefore, we added the xMLAA-based hardware estimates to the CT-based attenuation maps.

# xMR-MLAA Patient Example 1




Deviations in region of paranasal sinuses due to MR misclassification, not due to xMR-MLAA.

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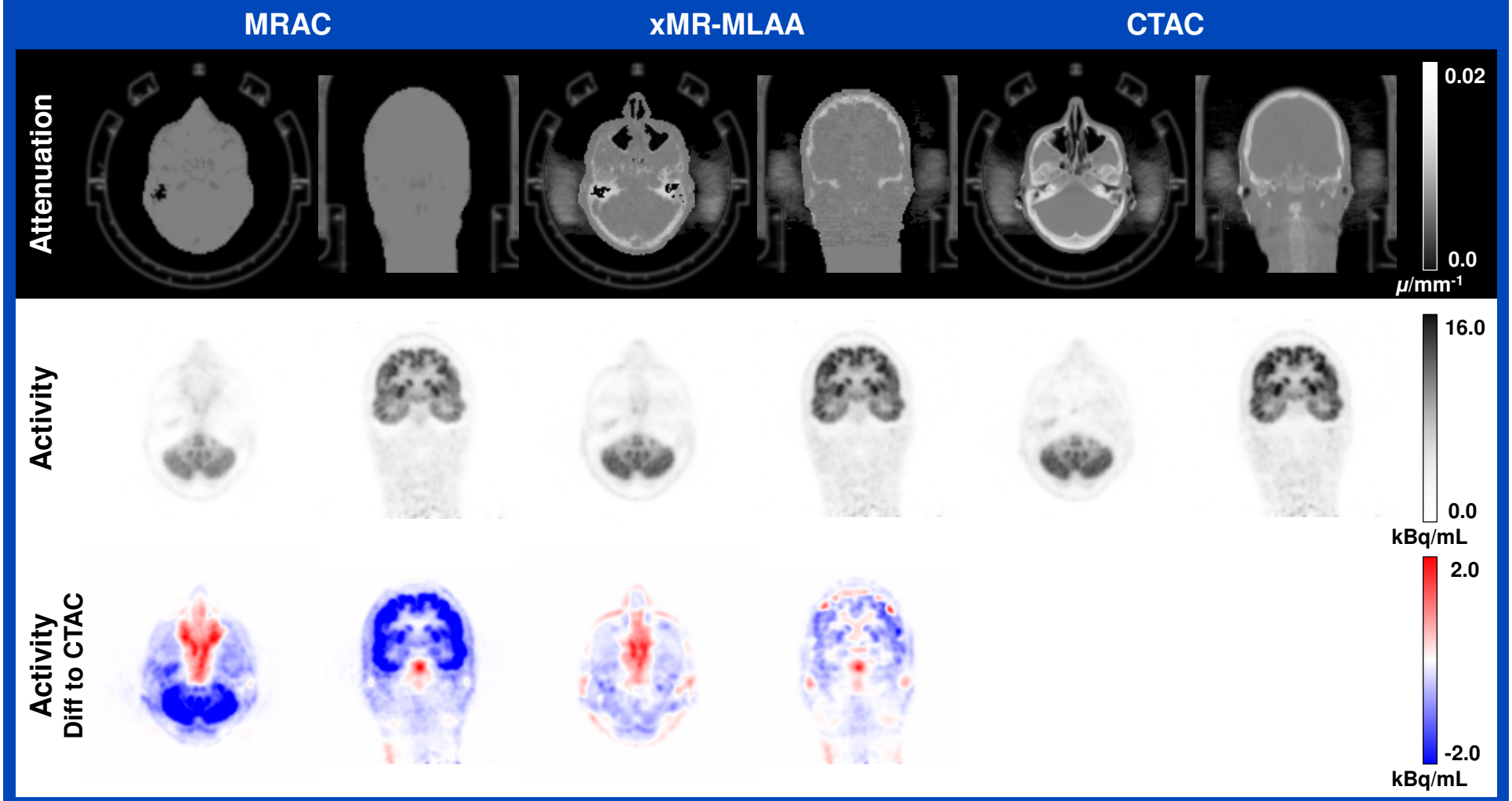
# xMR-MLAA Patient Example 2




Deviations in region of paranasal sinuses due to MR misclassification, not due to xMR-MLAA.

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# Conclusions on xMR-MLAA

- Jointly estimates hardware and patient attenuation from the non-TOF PET/MR data.
- Has the potential to reduce the activity underestimation from around 15% to below 5%.
- Outlook: Including TOF information should yield even better performance.


• Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs (www.dkfz.de), or directly through marc.kachelriess@dkfz.de.
• This work was supported by the Helmholtz International Graduate School for Cancer Research, Heidelberg, Germany. Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.
• This presentation will soon be available at www.dkfz.de/ct.
Thank You!