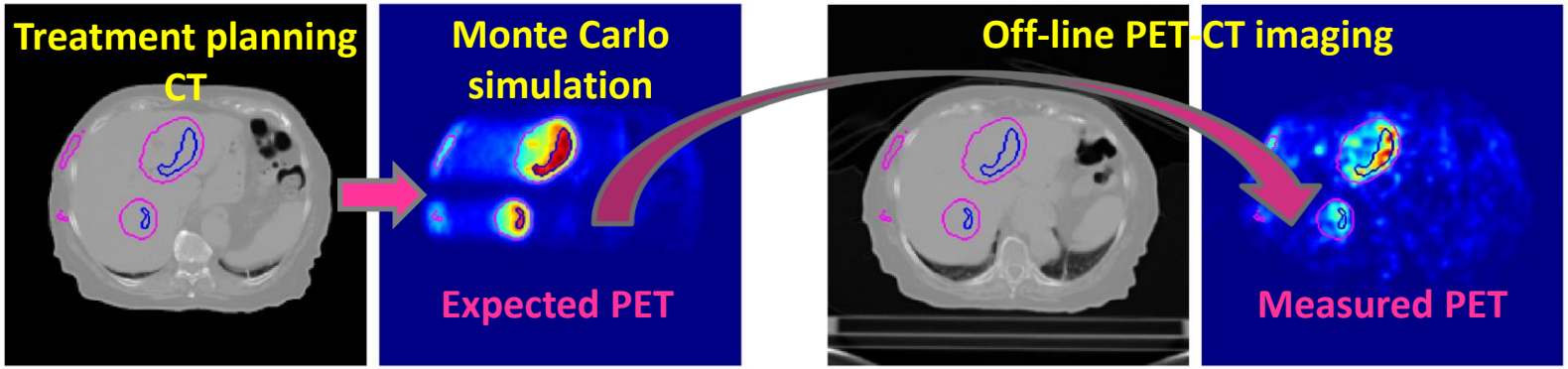
Tuning of a 4D ML reconstruction strategy for PET-based treatment verification in ion beam radiotherapy

Elisabetta De Bernardi[1], Katia Parodi[2], Rosalinda Ricotti[3], Marco Riboldi[4], Guido Baroni[4], Chiara Gianoli[2,5]

[1] Medicine and Surgery Department – Tecnomed Foundation, University of Milano-Bicocca, Milan, Italy
[2] Department of Experimental Physics - Medical Physics and Department of Radiation Oncology, Ludwig Maximilian University of Munich, Germany; Department of Radiation Oncology, Heidelberg University Hospital, Germany
[3] Department of Radiation Oncology, European Institute of Oncology, Milano, Italy
[4] Dipartimento di Elettronica, Informazione e Bioingegneria (DEIB), Politecnico di Milano, Italy
[5] Department of Radiation Oncology, Ludwig Maximilian University of Munich, Germany

PET-based treatment verification in ion beam therapy

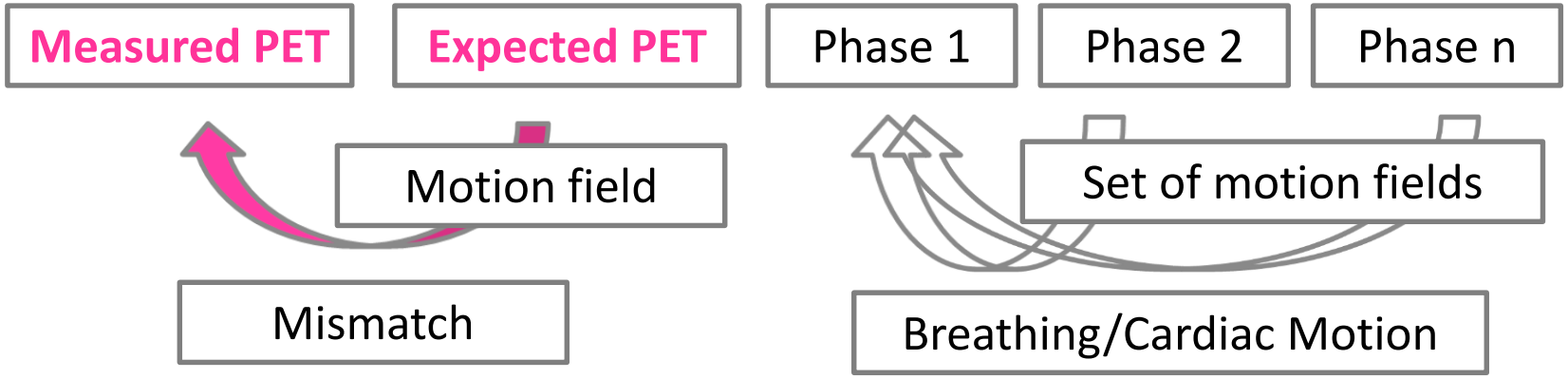
- Detect possible mismatches with respect to the treatment planning (i.e., patient positioning, intra- and inter-fractional anatomical changes)
- Imaging of secondary radiation of the ion beam treatment
- PET-CT comparison in terms of activity-anatomy



- Poor image quality of the Measured PET (i.e., time delay and washout in *off-line PET*) (Kurz et al. 2015 Med Phys)
- Quantification of the mismatch is performed as *range difference* along the beam direction (1D) (Bauer et al. 2013 Radiother Oncol)

The idea

- Interpret the Expected PET and the Measured PET as different motion states of a 4D PET dataset
- Adapt a 4D Maximum Likelihood (ML) reconstruction algorithm developed for 4D PET imaging to PET-based treatment verification



De Bernardi et al., Med Phys, 2015

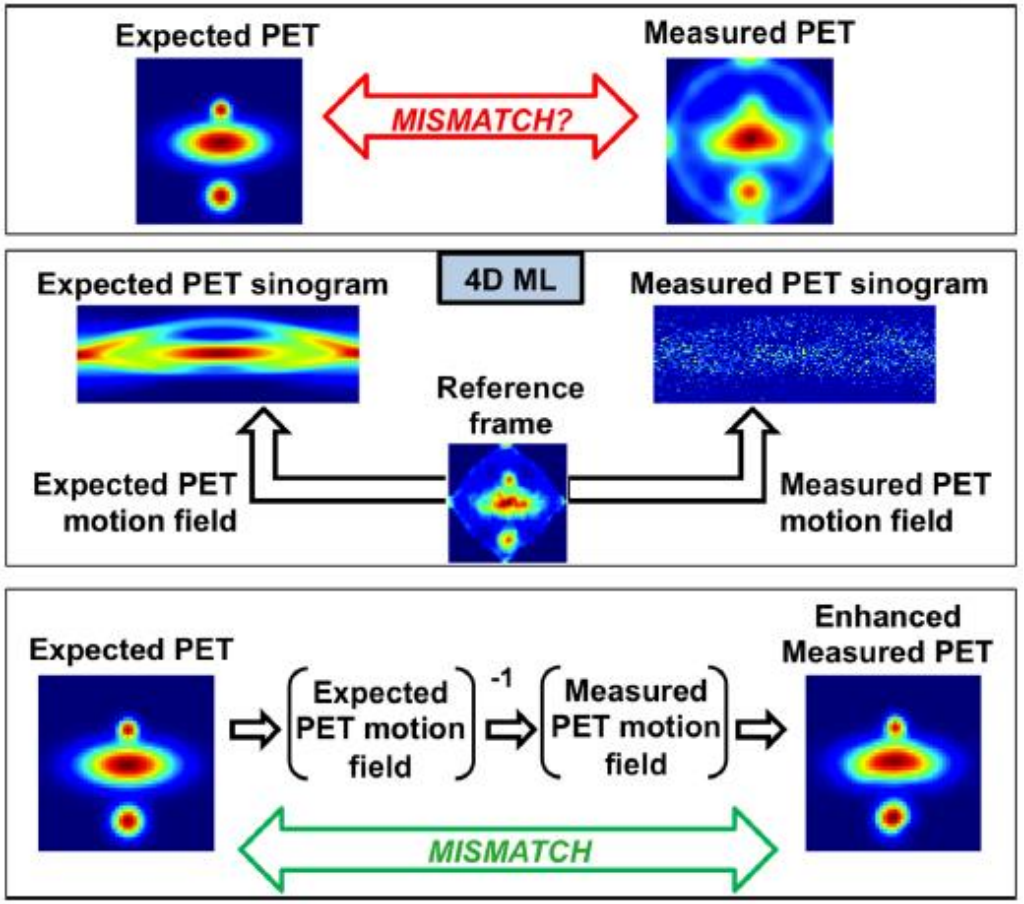
Blume et al., IEEE Trans Med Imag, 2010;
Blume et al., Phys Med Biol, 2012

Extensive testing on analytical phantom

Sensitivity to:
- Mismatch

Robustness against:
- Activity complexity
- Washout inaccuracy
- Noise

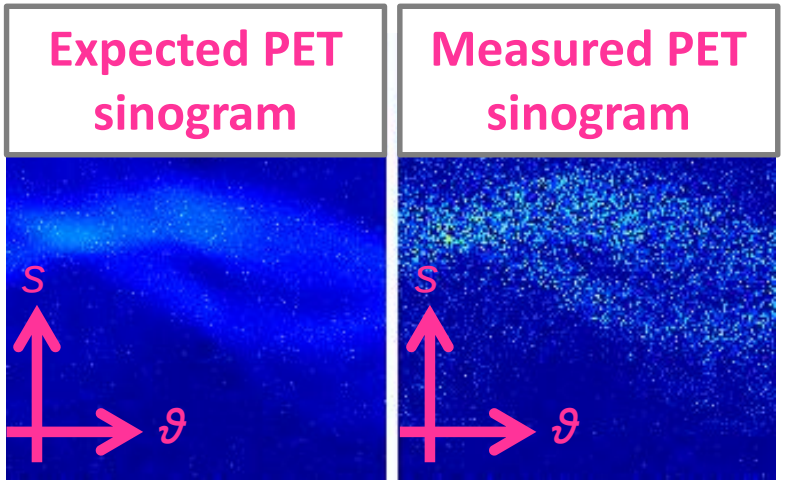
Limitations:
- ↑ Noise ↑ Smoothing



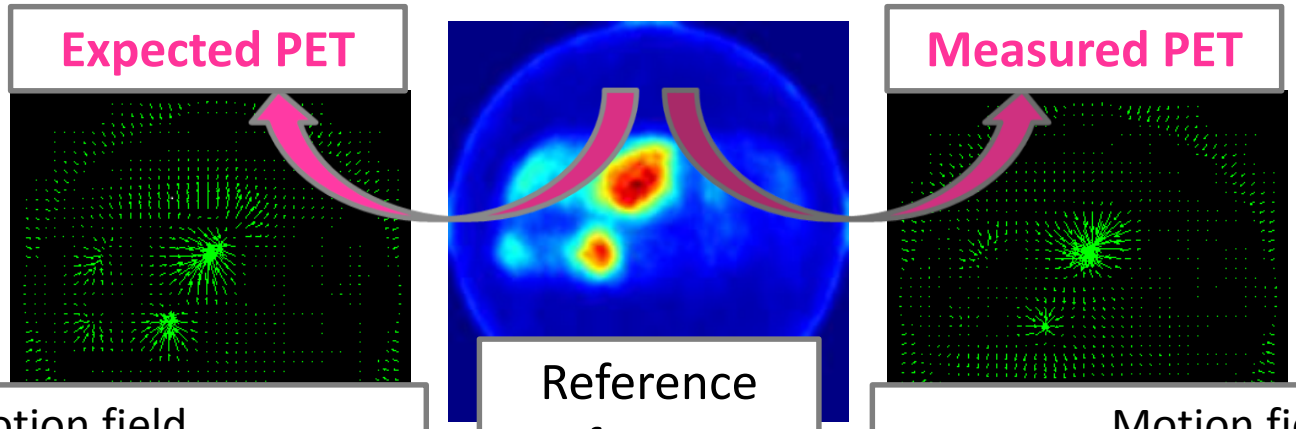
De Bernardi et al., Med Phys, 2015

On clinical datasets

Algorithm input



Algorithm output



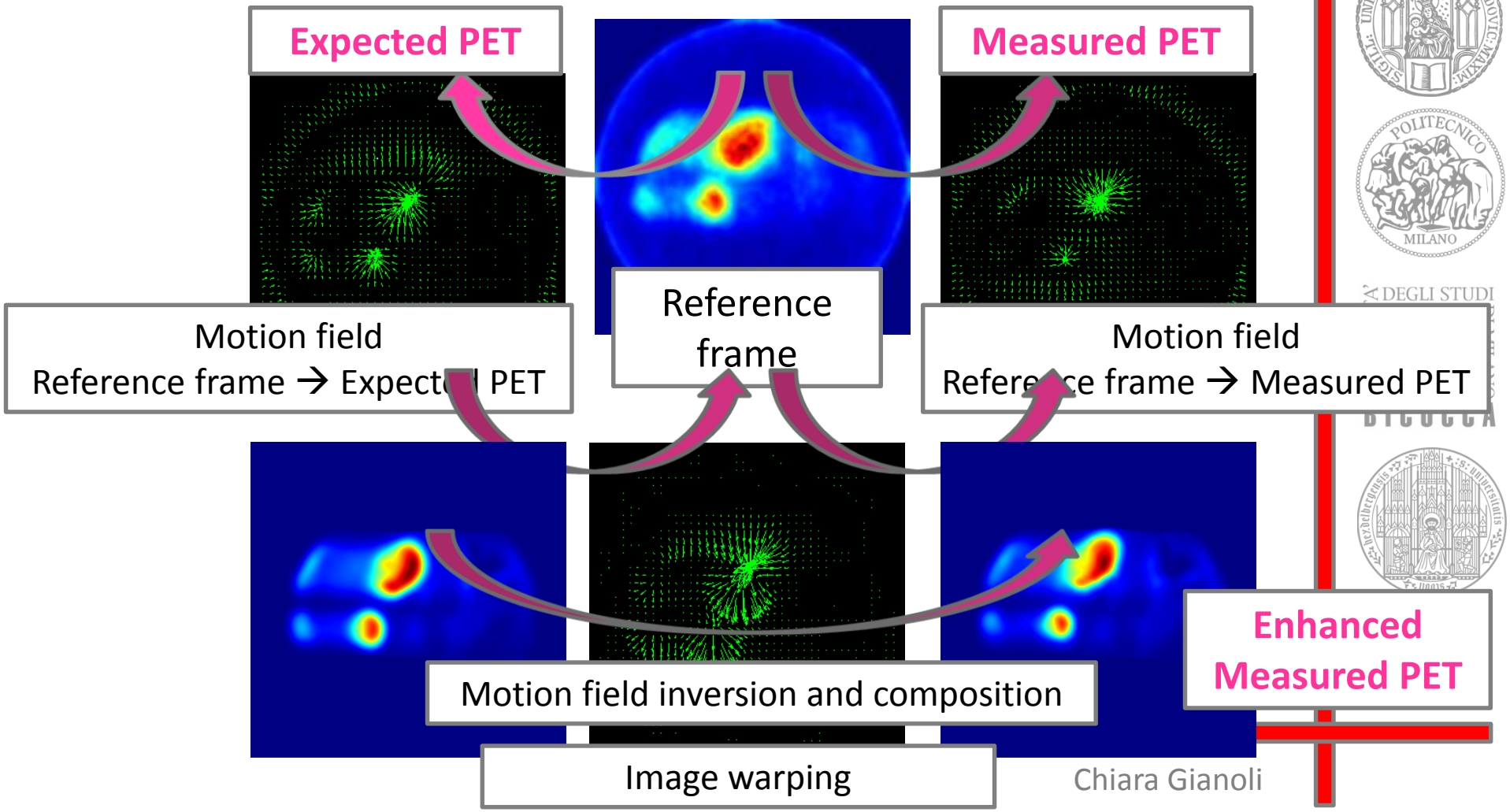
Motion field
Reference frame → Expected PET

Reference frame

Motion field
Reference frame → Measured PET

On clinical datasets

Algorithm output



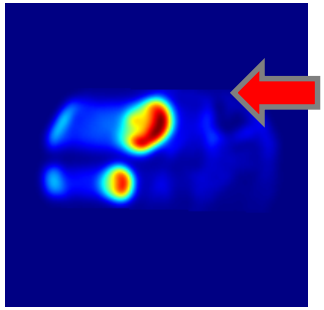
The aim of the work

Optimize the framework of the algorithm for clinical datasets by:

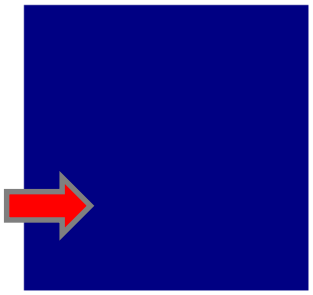
- Reducing the number of unknown variables (deformation fields)

Motion field
Expected PET → Measured PET

- Investigating two different initializations for the reference frame:
  - Uniform activity
  - Expected PET (as prior knowledge)

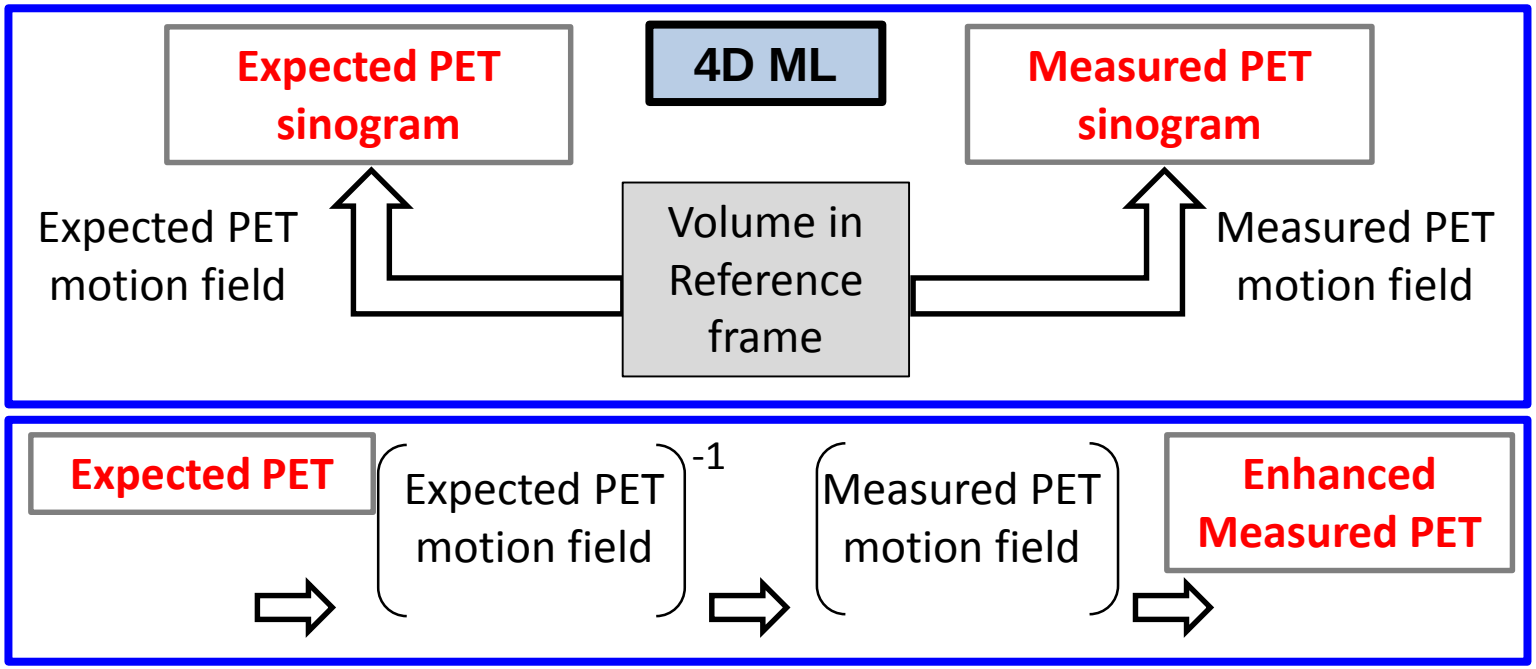


Reference frame *Init.*



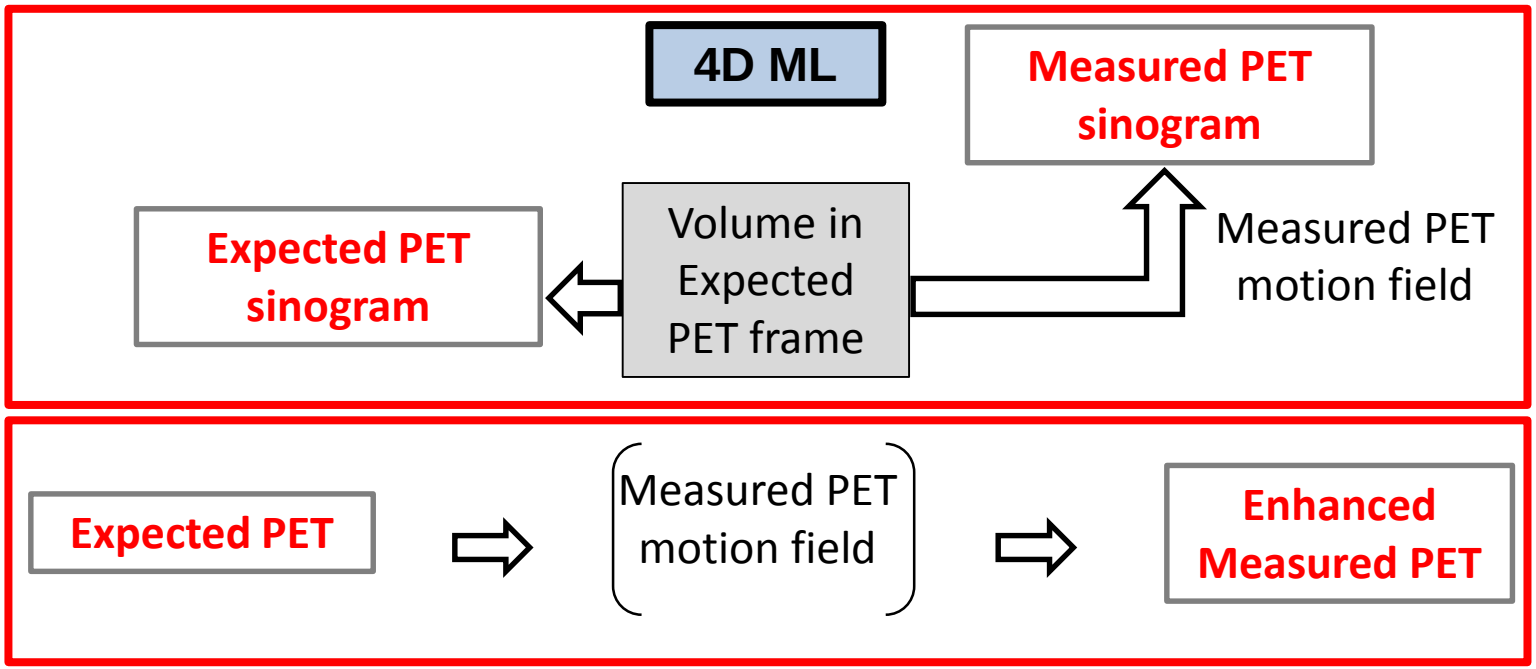
The aim of the work

- Original method (Method 1): reference frame is an intermediate state between the Expected PET and the Measured PET



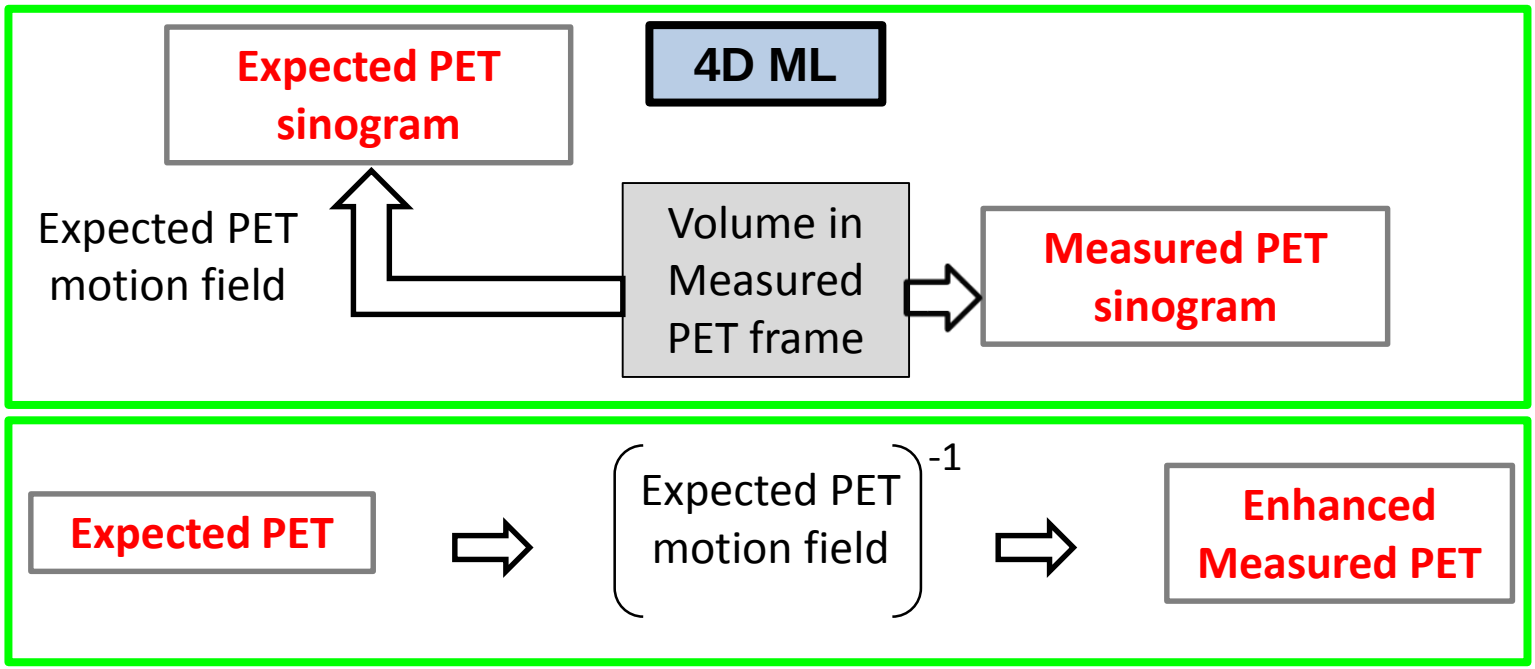
The aim of the work

- Method 2: reference frame is the Expected PET frame



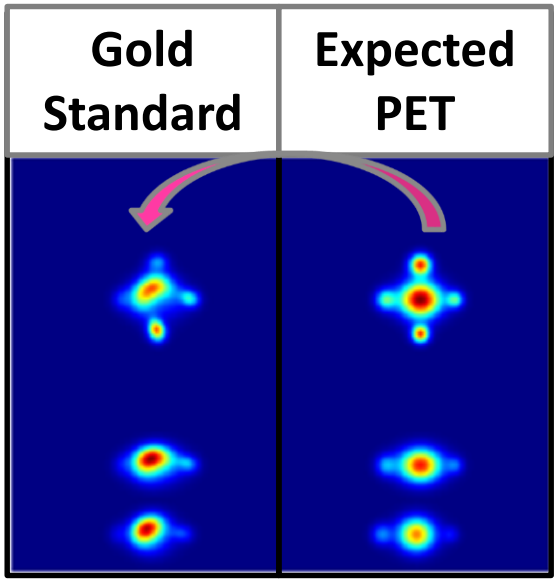
The aim of the work

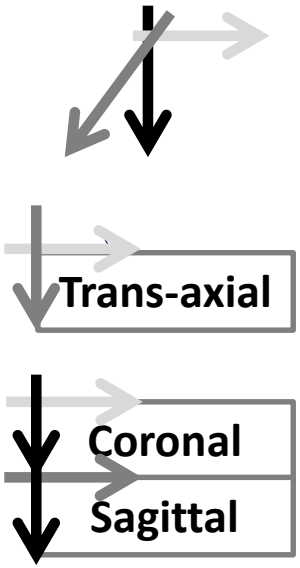
- Method 3: reference frame is the Measured PET frame



Analytical phantom

- Expected PET: combination of six Gaussian spots
- Measured PET: deformation of the Expected PET according to known motion fields



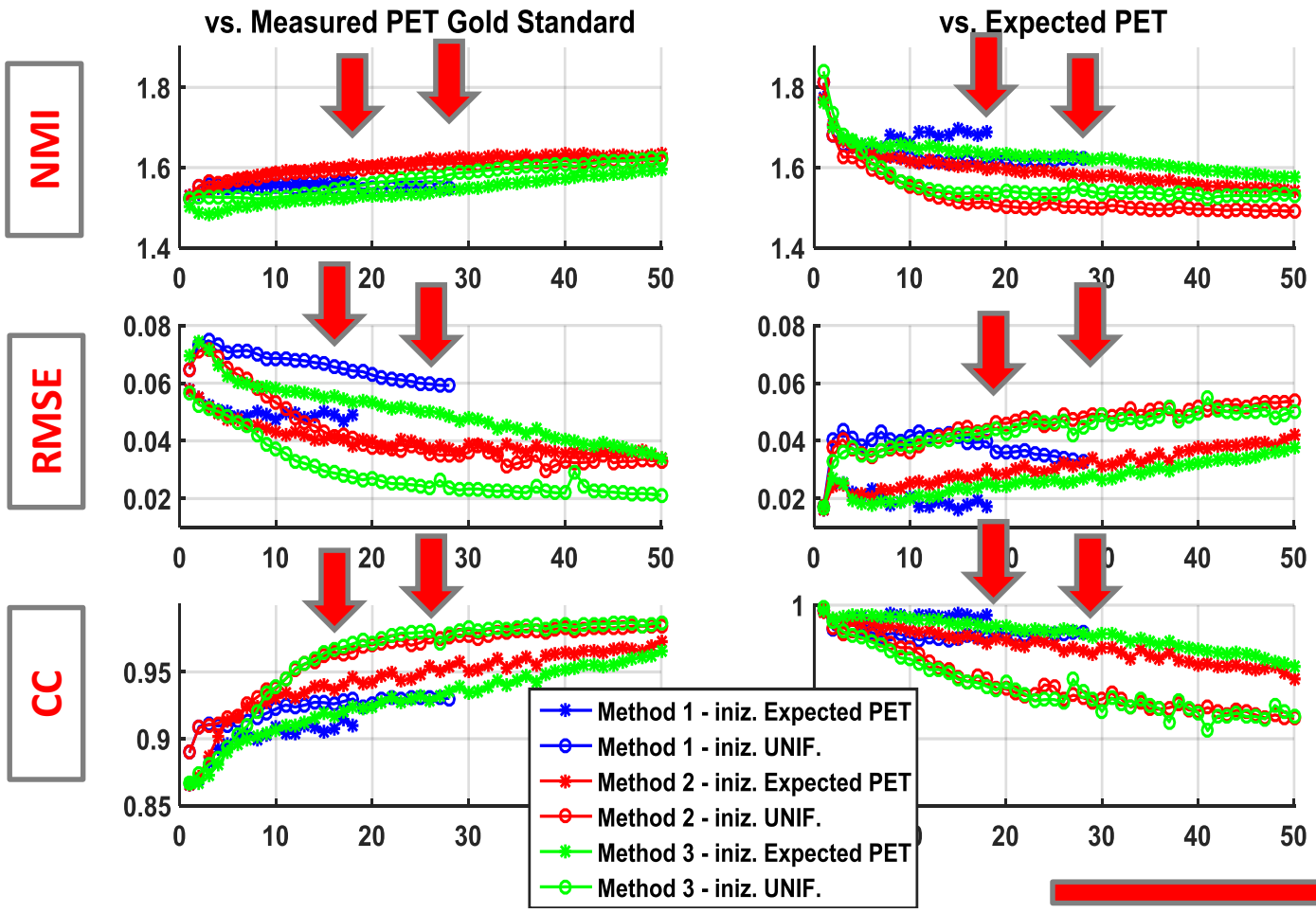


gold standard for both image and motion field

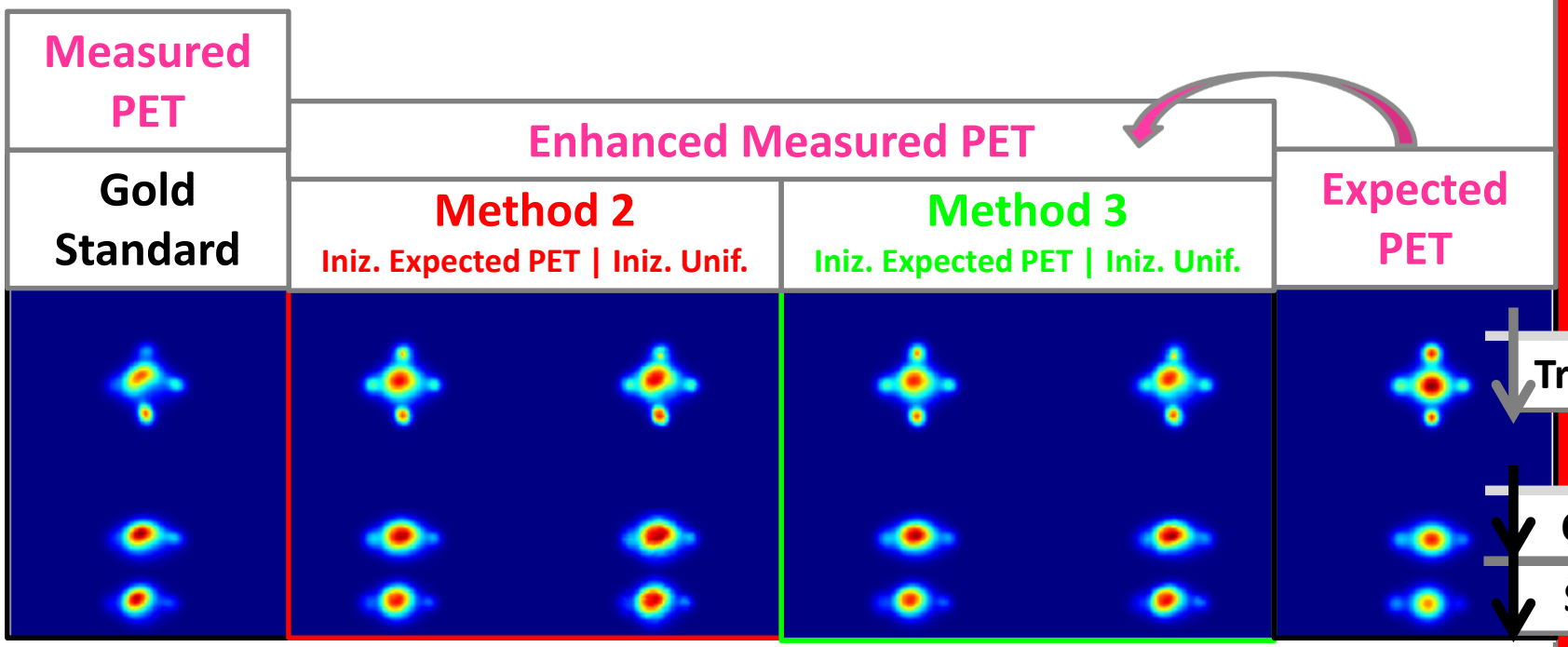
- Washout inaccuracy (66% activity scaling for 2 spots)
- Poisson noise simulation (maximum 2 counts/voxel) + LSO random noise

Analytical phantom: convergence assessment

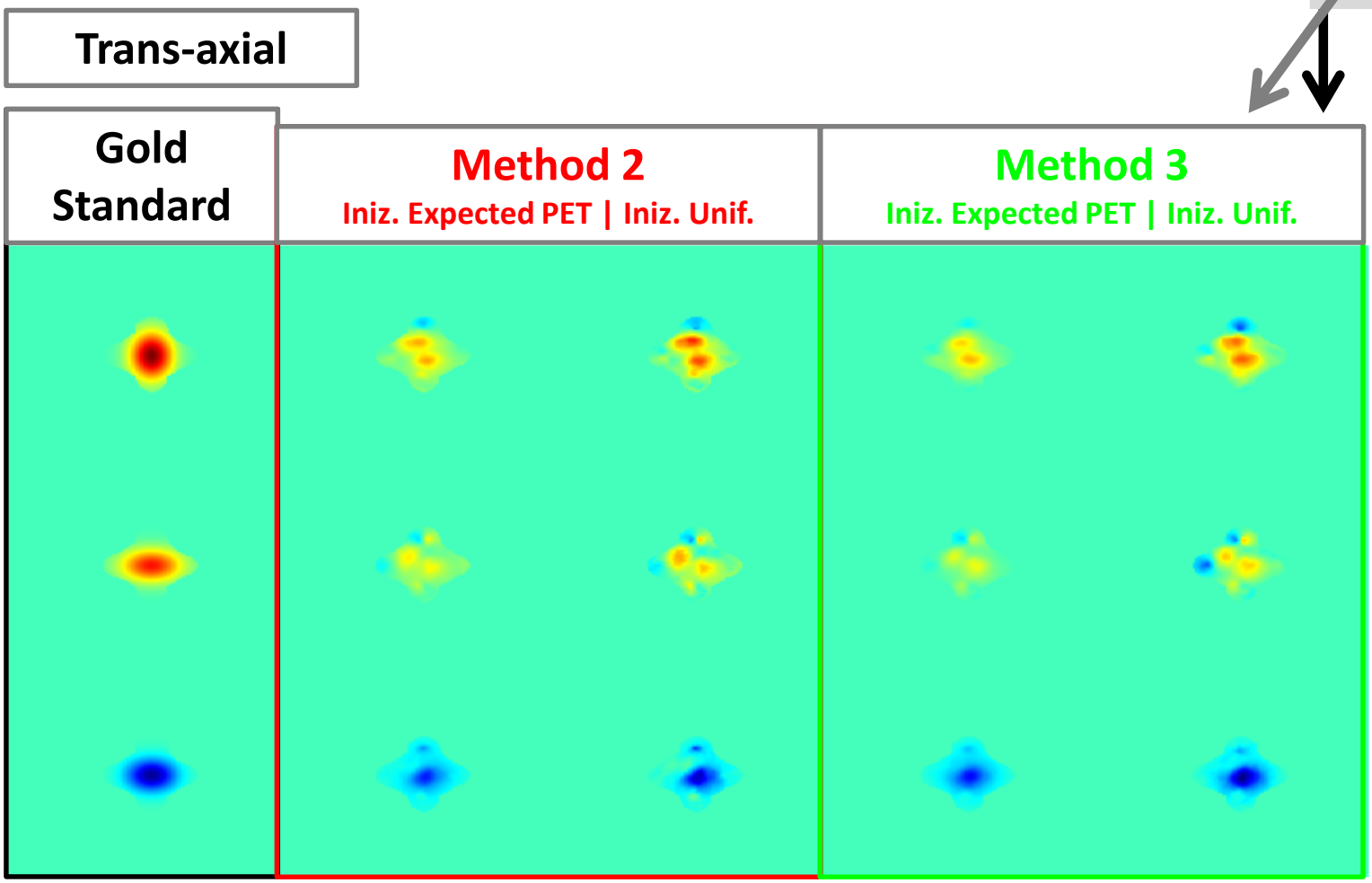
Similarity vs. Measured PET (Gold Standard) and vs. Expected PET



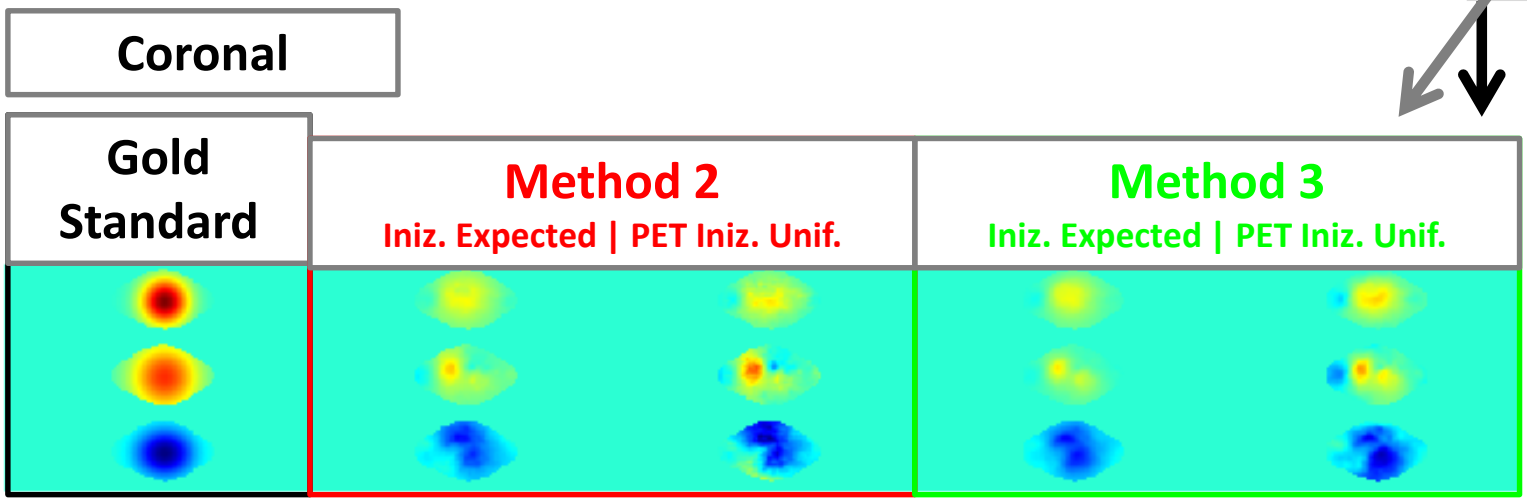
Analytical phantom: reconstructed images

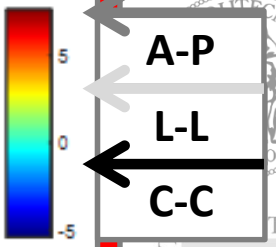


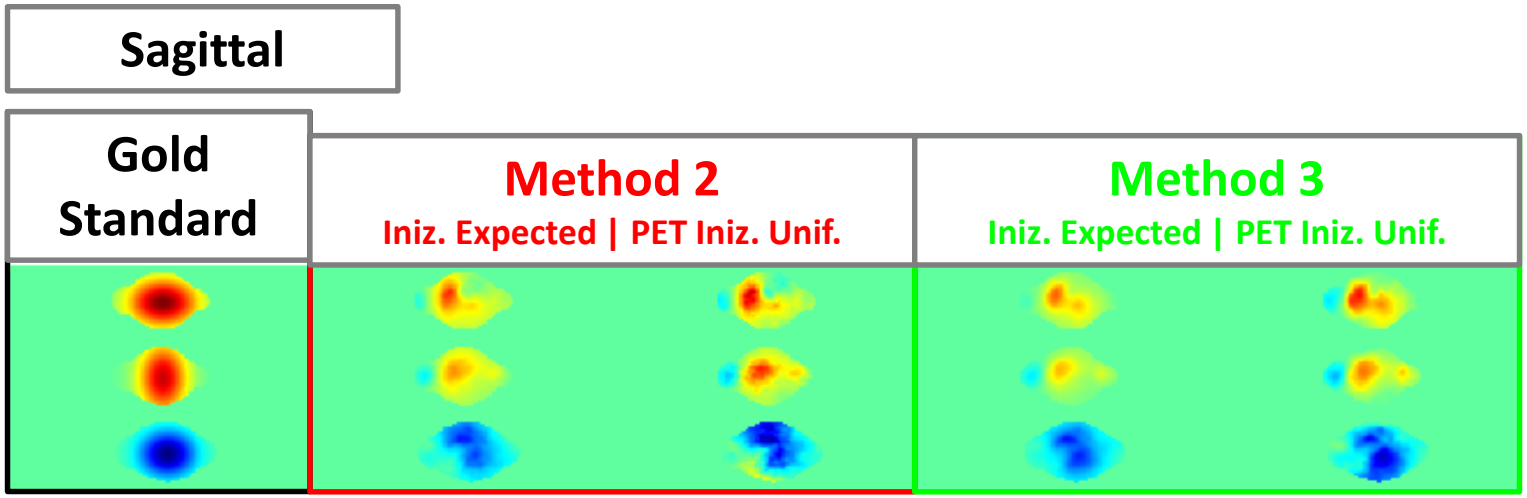
Analytical phantom: motion fields

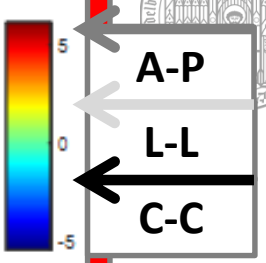


Analytical phantom: motion fields







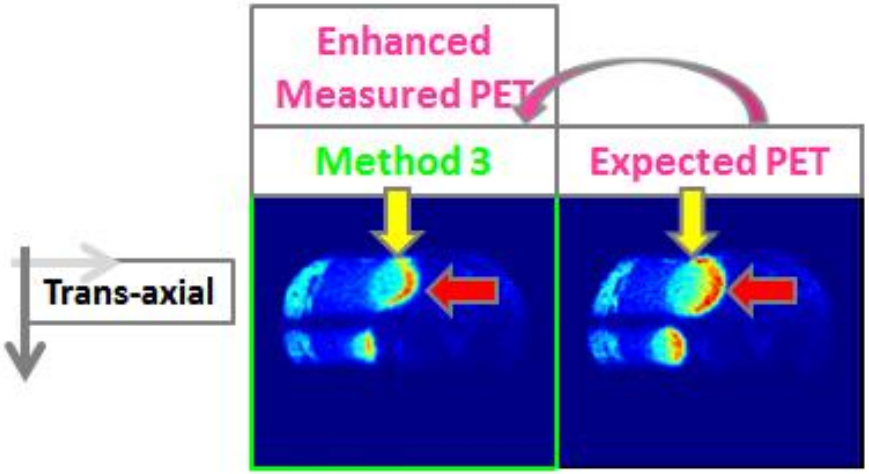


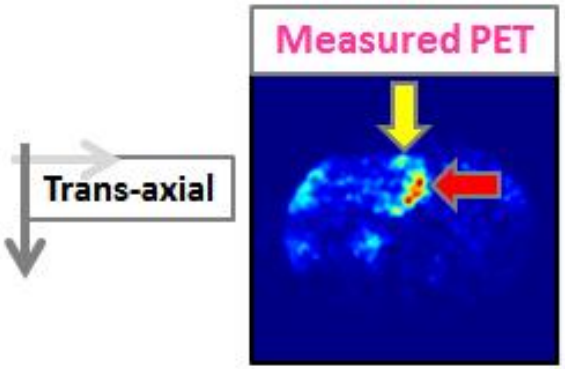
Outcomes

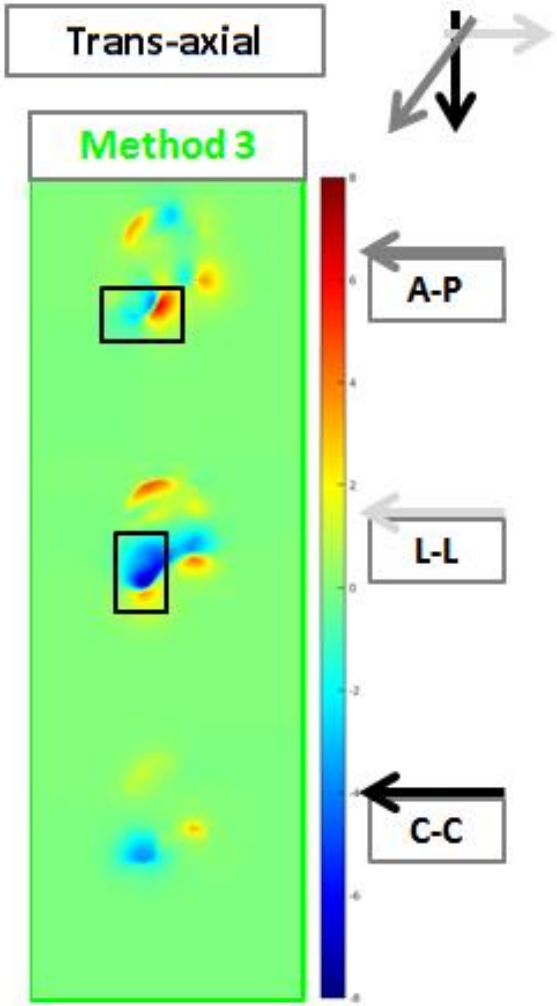
- Application of method 3 with uniform initialization on clinical datasets
- Improvement of noise mitigation technologies and methodologies to better tackle the LSO random noise
  - Time of Flight reconstruction
  - Targeted reconstruction for computational optimization (GE patent 2010)

Gianoli et al. ICTR-PHE 2016 Proffered papers – Emerging technologies (Wednesday)

Outlook on clinical dataset







Discussions

- Refinement of the simulation of the washout inaccuracies (not only spot scaling but generation of pattern of washout inaccuracies)
- Inclusion of Jacobian-based as “washout compensation index” on the motion field
- Disentangle washout compensation from the actual mismatch

Acknowledgments

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- Jürgen Debus
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