Design and Simulation of a High-Resolution and High-Sensitivity BrainPET Insert for 7T MRI

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Aim

Within the Helmholtz Validation Fund Project "Next generation BrainPET scanner for 7T MRI", we aim to build a UHF-MRI compatible, high performance BrainPET insert prototype for dedicated human neuroimaging. The combination of the BrainPET 7T insert with an UHF MRI will open up new possibilities for research in neurosciences by obtaining detailed neurochemical information simultaneously with multi-contrast MRI comprising anatomical imaging and high spatial resolution functional imaging. PET compatibility with MRI X-nuclei capabilities was also considered.

Fig. 1 Magnetom Terra 7 T MR (Siemens)

Fig. 2 Magnetom 9.4 T MR Scanner

Single scintillation detector measurements

The multiple staggered scintillator pixel array layer design [1] will be used for depth of interaction detection (DOI, see fig. 5). Displacement of the different scintillator arrays relative to each other (1/2 pixel pitch in one or 2 directions) allows identification of all three layers via the centroid position or scintillation light distribution. The centroid will be used for calibration, and the ML positioning algorithm will be used for crystal pixel identification and γ-ray energies estimation [2].

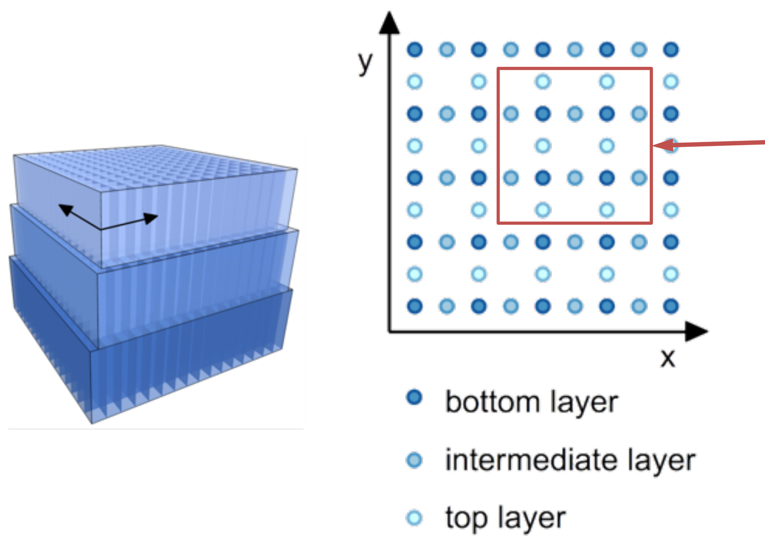

Fig. 5 DOI detection principle

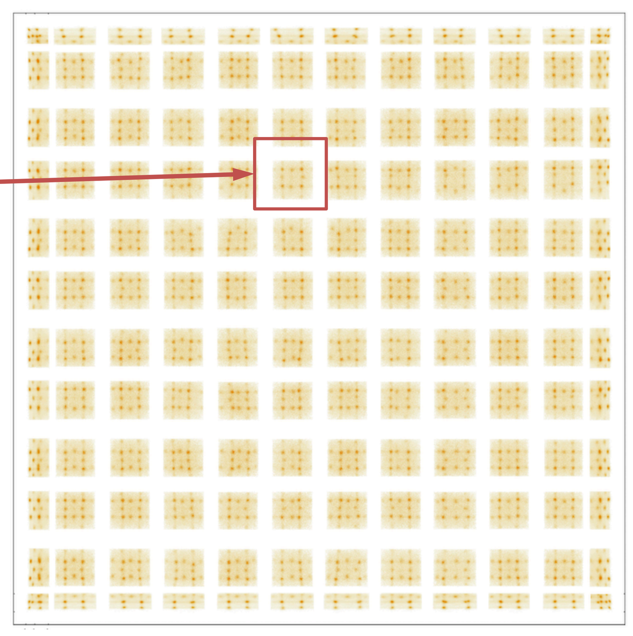

Fig. 6 Flood map (Lu background)

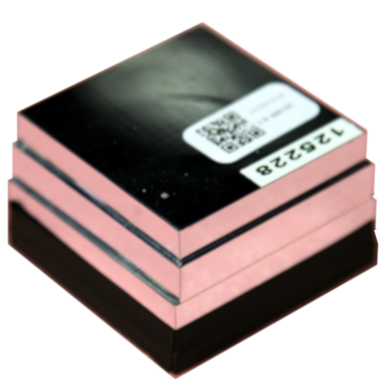

Fig. 7 scintillation detector

Flood map (fig. 6) obtained during 20 minute data acquisition for one of the 120 assembled scintillation detectors using Lu background (no external g source). Fig. 7: scintillation block glued to the light guide and dSiPM array. For computation of the gamma ray impact position, only full 3x3 SiPM neighborhoods where used. dSiPM trigger setting was 4th photon trigger, validation network setting 119 [3]. Overvoltage 1.4 Volt, integration time was set to 325 ns and validation time to 10 ns. SiPM temperature was ≈ 17 degree. All 1634 scintillation pixel can be identified. Flood maps from the other 120 scintillation detector look similar.

System performance simulation

MC simulations with GATE of sensitivity and spatial resolution have been performed, including intrinsic detector energy resolution of 12 %, inter-crystal Compton scatter, CoG of energy deposition, positron range (without B_0 field), γ attenuation and non-collinearity, and a typical energy window of 388-634 keV. A peak sensitivity of ≈ 12% at the isocentre was confirmed by simulating a low-activity point source. Spatial image resolution significantly below 2.0 mm over the whole human brain was confirmed with a simulation of a Derenzo phantom with 20 cm diameter where the sector with a 1.6 mm grid could be resolved (figs. 8 & 9).

Conclusions & Future Work

The simulation study and first measurements confirmed:

- Design allows to reach 12% sensitivity and spatial resolution < 2 mm over entire PET FOV
- All scintillation pixels can be identified
- Assembly and first PET only phantom images expected till end of the year 2020
- First simultaneous MR-PET phantom images expected till spring of 2021

References

[1] M. Ito, et al. "Four-layer DOI detector with a relative offset in animal PET system." 2007 IEEE Nuclear Science Symposium Conference Record. Vol. 6. IEEE, 2007.
[2] C. Lerche et al., *Physics in Medicine & Biology* 61.4 (2016): 1650.
[3] V. Tabacchini, et al., Journal of Instrumentation 9.06 (2014): P06016.
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Key design features

3 layers of LSO with 24 x 24, 23 x 24, and 22 x 23 pixels each, all with pixel pitch of 2.0 mm in both directions, for achieving homogeneous spatial image resolution. Total thickness 24 mm.

511 keV Gamma transparent, 8 channel TX/RX head coil. 18 cm axial FOV and 28 cm transversal opening for head and head holder. .

Digital readout electronic using highly integrated digital SiPMs with 12 x 12 channels per tile, dSiPM pitch is 4 mm in both directions, shielded using a carbon fibre reinforced plastic to avoid interferen-ces with MR.

Gantry with ≈ 40 cm PET opening and ≈ 25 cm PET axial FOV. Integrated UHF MR (figs. 1 & 2) compatible cooling infrastructure, rear opening for visual neurostimulation. Guides for reproducible axial and transversal alignment with MR FOV.

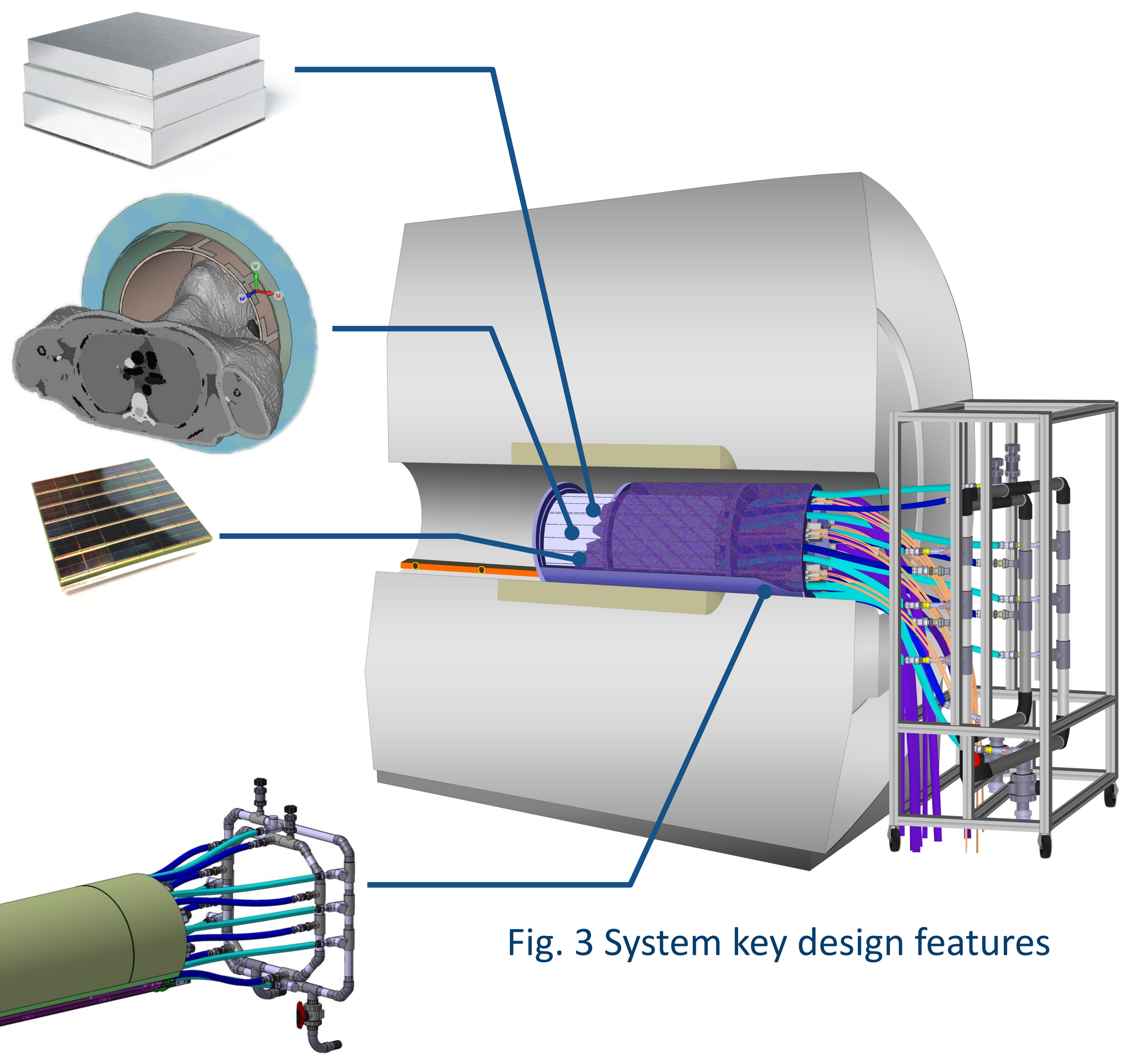


Fig. 3 System key design features

System infrastructure

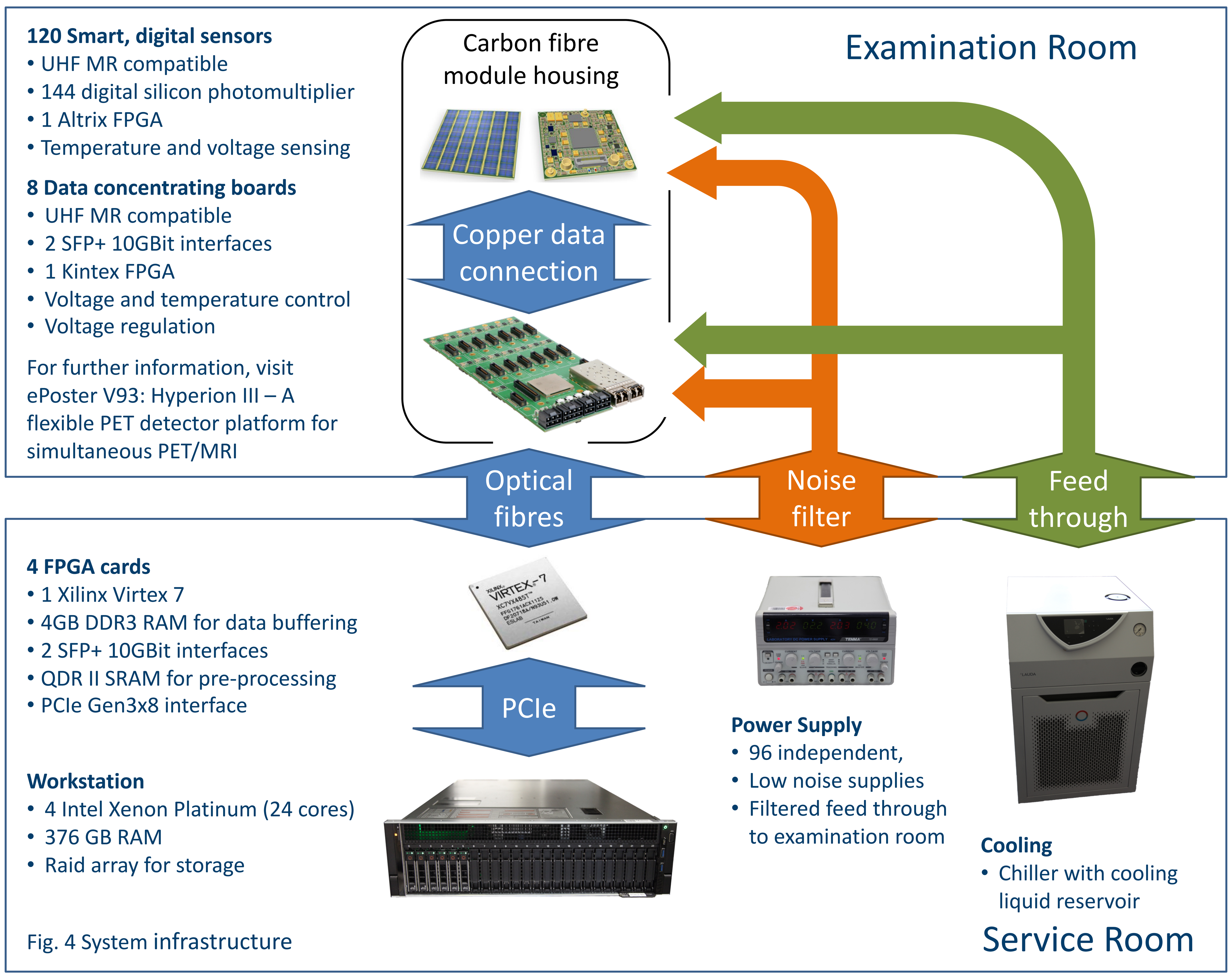
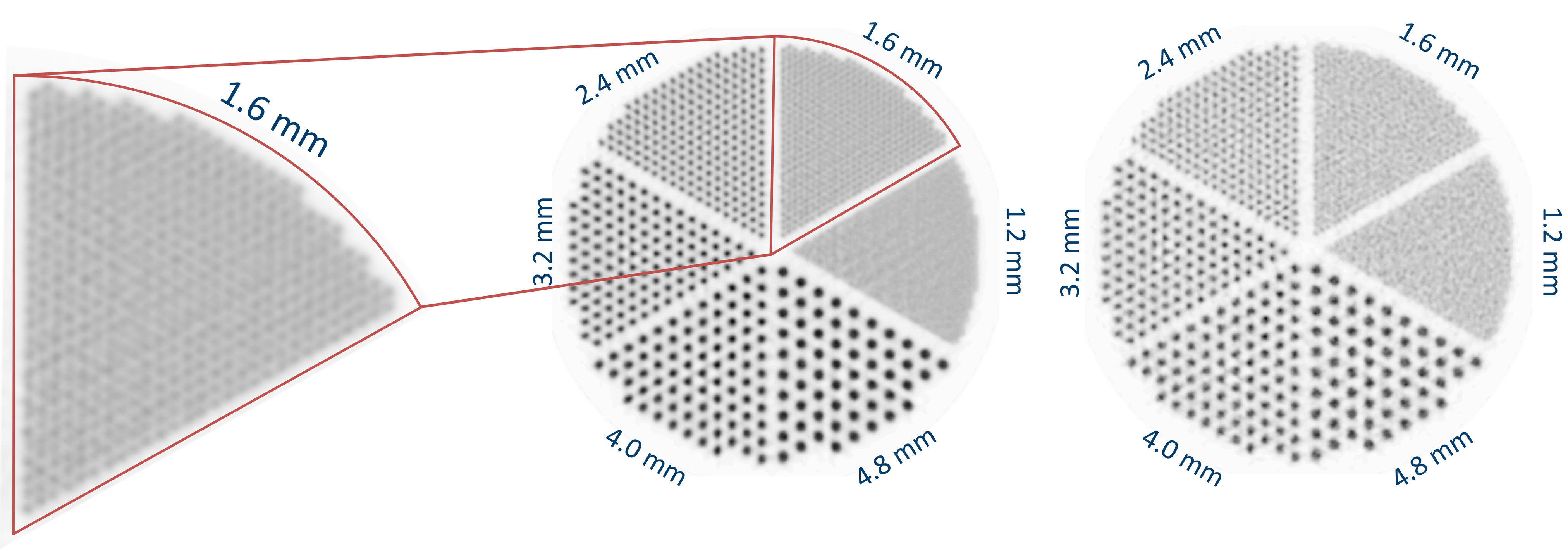


Fig. 4 System infrastructure



Homogeneous spatial resolution < 2 mm over PET FOV allows for significant partial volume effect reduction for entire cortex

Fig 8. High count simulation: 32 MBq, 600s integrated over 64 slices. Reconstruction with PRESTO (OP-OSEM) without smoothing [4]. Voxel size: 0.625 x 0.625 x 1 mm^3, 250 iterations, 2 subsets

Fig. 9 Low count simulation: 32 MBq, 600s single slice. Reconstruction with PRESTO (OP-OSEM) without smoothing [4]. Voxel size: 0.625 x 0.625 x 1 mm^3, 250 iterations, 2 subsets

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