SAFIR-II: Design and Performance of a High-Rate Preclinical PET-MR System

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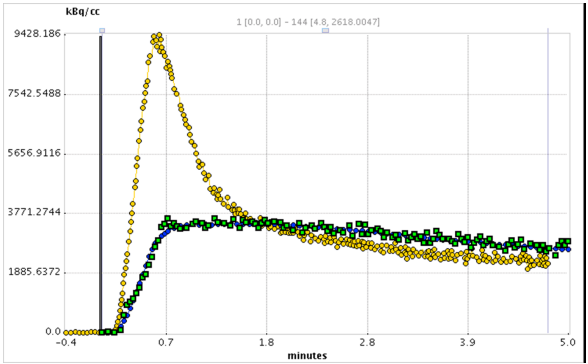
The SAFIR Project

Motivation

- PET Imaging: Slow ($>$10 min)
- Fast kinetic processes: $<$1 min
- Need specialized system

Requirements

- 7 T MRI compatible
- Measurements at 500 MBq
- 2 mm spatial resolution
- Quantitative imaging
- Small-rodent images in 5 s



Simulated Oxygen-15 Time-Activity-Curve (Brain)

The SAFIR-II Positron Emission Tomography Insert

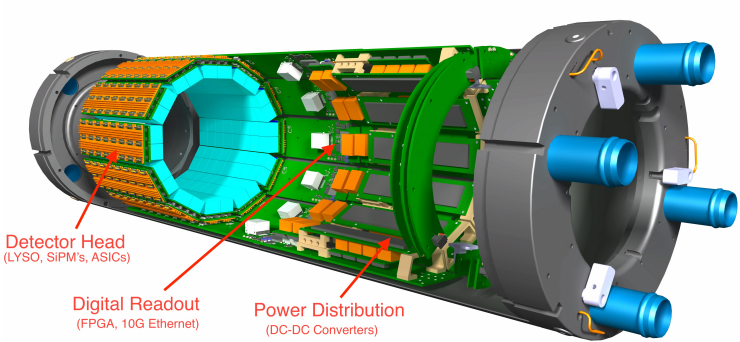
Crystal Geometry

- $2 \times 2 \times 13$mm LYSO
- 2.2 mm pitch
- Al-ESR optical separation
- 64 rings, 12×15 crystals/ring

$\rightarrow$ 11520 crystals total,

145 mm axial FOV

- Hamamatsu SiPM
- 1:1 crystals-SiPM coupling



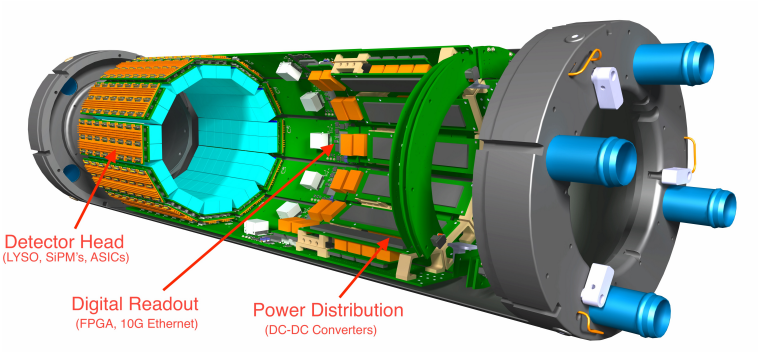
The SAFIR-II Positron Emission Tomography Insert

Digital Electronics

- PETA-8 ASICs
- Kintex-7 FPGA
- 10GBit Optical Ethernet
- MR-compatible DC-DC

Carbon fibre structure

- 199 mm outer diameter
- 114 mm inner diameter
- 70 cm length



MRI Compatibility

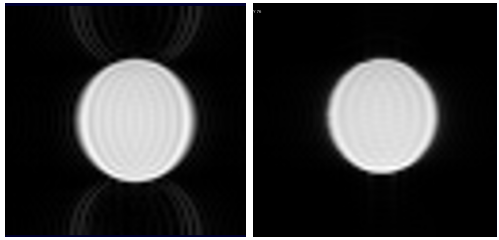
Evaluated using Bruker QA-Sequences and 50 mL QA-phantom

RF-Emissions

- SNR: −9.2 % (full operation)
- **NO** visible artifacts

Switching Gradients (EPI)

- Nyquist-Ghosts visible
- Sequence adjustment removes artifacts



Left: EPI with SAFIR-II: Ghost artifacts

Right: Adjusted, artifact free EPI

MRI Compatibility

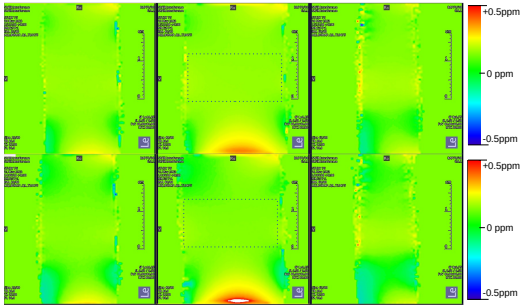
B0-Field

- Homogeneity not disturbed by SAFIR-II

SAFIR-II Operation

- Functional throughout sequences
- Coincidence Rate unaffected

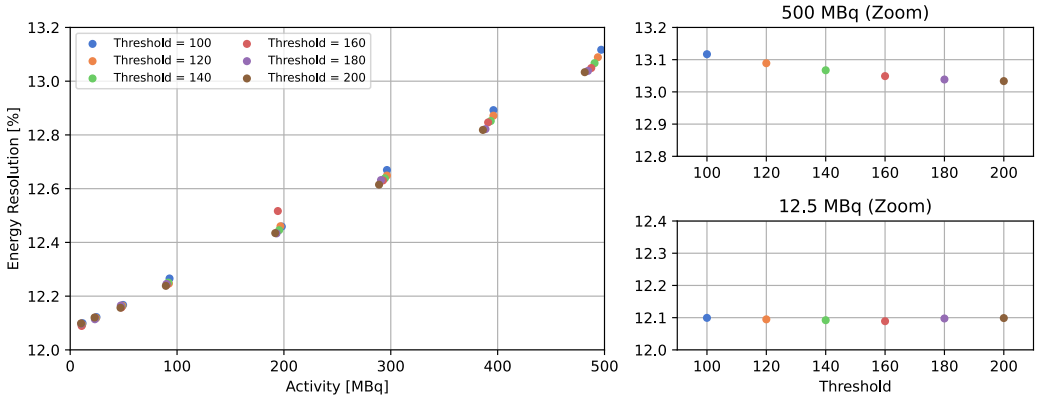
⇒ SAFIR-II is MR-compatible



Top: B0-Map Baseline (after shimming)

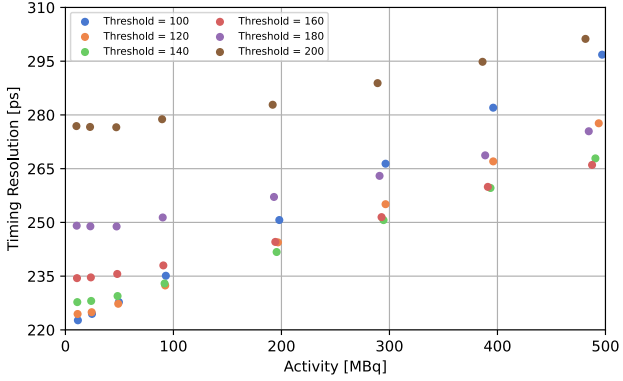
Bottom: B0-Map with SAFIR-II (after shimming)

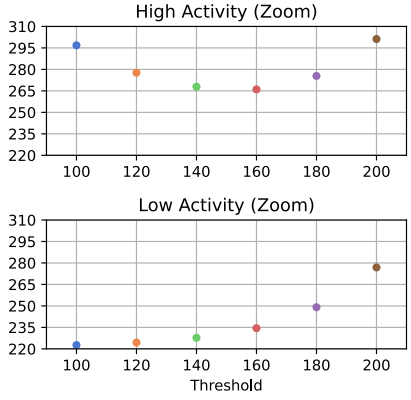
Performance: Energy Resolution



Best: 12.1 % FWHM (^{22}Na point source)

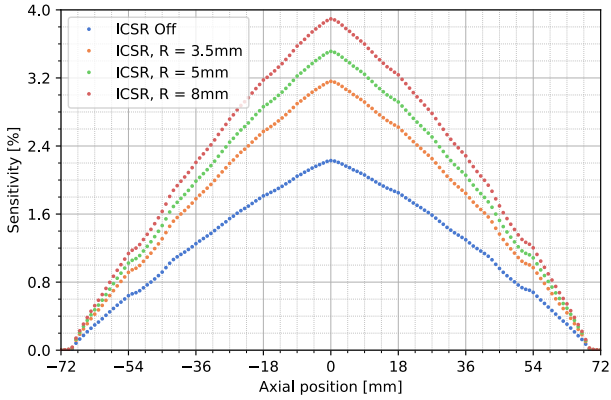
Performance: Timing Resolution





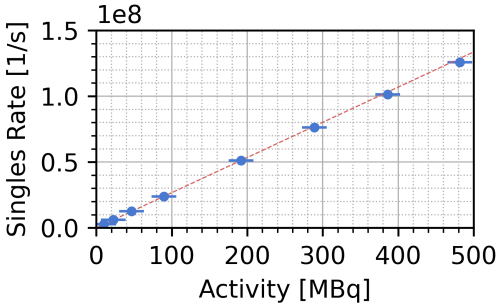
Best: 221 ps (^{22}Na point source)

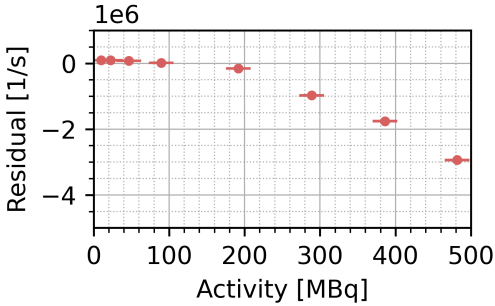
Performance: Sensitivity



Peak: 3.98 %

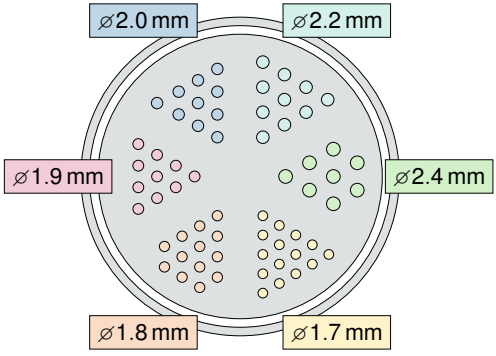
Performance: Data Loss

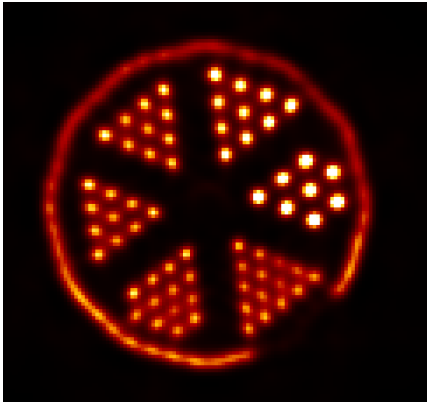




Max: 2.3 % of Singles lost
(Confirmed via Test-Trigger Method)

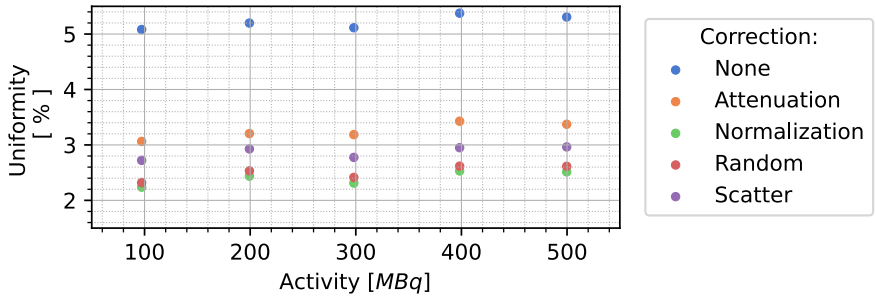
Spatial Resolution: Derenzo-Phantom





Spatial Resolution: <1.7 mm

Image Quality: Uniformity



Recon:

STIR
OSMAPOSL
9 Subsets, 10 Iterations
0.7mm Gauss filter

Corrections:

Attenuation: Manual μ-map
Scatters: Single-Scatter-Sim (STIR)
Normalization: Component-based
Randoms: Singles-Prompt

Image Quality: Spill-Over-Ratio

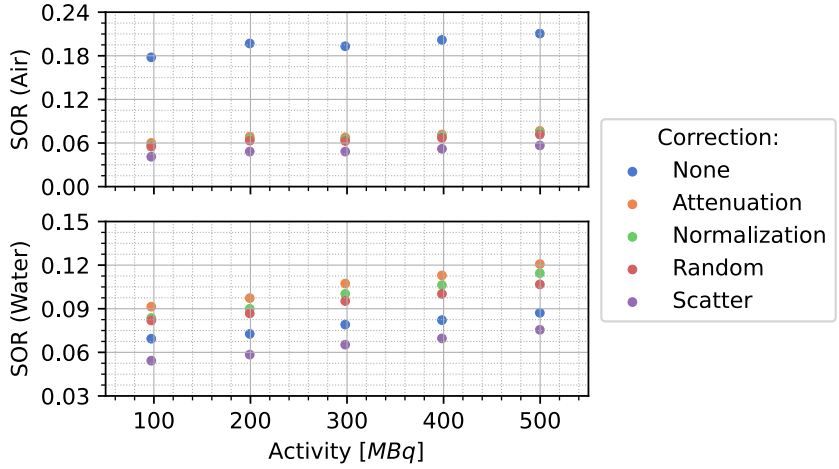


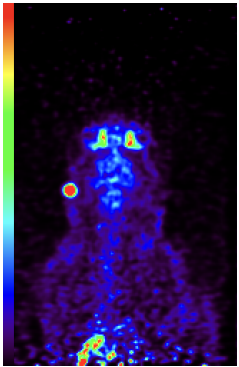
Image Quality: Comparison

Scanner	Uniformity	SOR		RC				
		Air	Water	5 mm	4 mm	3 mm	2 mm	1 mm
SAFIR-II	2.96 %	0.057	0.075	0.92	0.79	0.58	0.32	0.053
SAFIR-I	4.8 %	0.218	0.220	1.08	0.84	0.54	0.28	0.04
nanoScan®	3.52 %	0.058	0.062	1.03	0.98	0.90	0.84	0.26
SimPET-XL™	3.89 %	0.036	0.036	0.95	0.91	0.79	0.62	0.14
Bruker	6.5 %	0.12	0.22	0.94	0.95	0.91	0.64	0.14

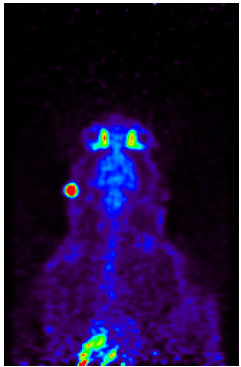
Note: SAFIR-II evaluated at 500 MBq, all others at 3.7 MBq

First Animal Measurements

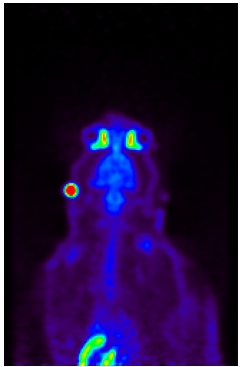
10 seconds



30 seconds



5 minutes

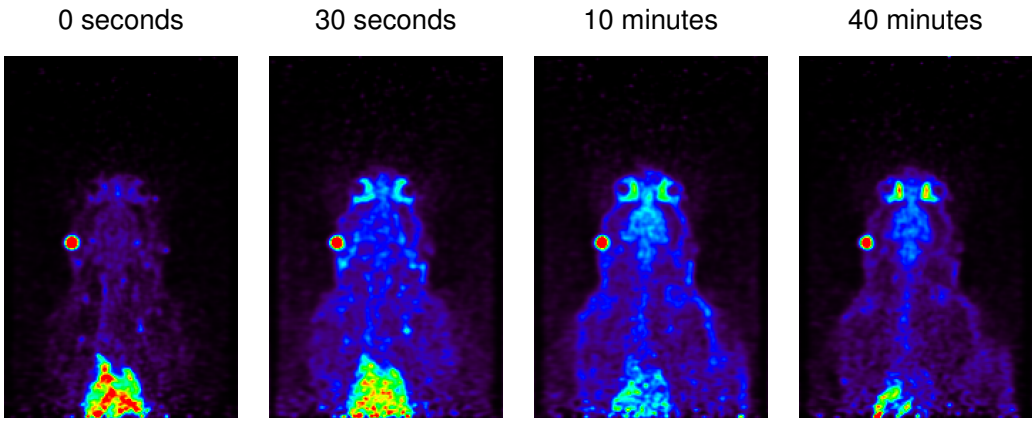


Sprague-Dawley Rat

283 MBq FDG

40 min after injection

First Animal Measurements



Outlook

- SAFIR-II is operational according to specifications
- Few adjustments remaining: Recon-update, recon-speed, air-tubing
- Many potential future studies:
  - NEMA characterization: NECR, spatial resolution
  - Performance optimization: recon filters, analysis adjustments, ...
  - Animal studies: OGI, impact of diets on brain metabolism, cardiac perfusion

Thank you for your attention.