Dead Time Effects and Image Quality Evaluation at High Activities for the SAFIR Dual Ring Prototype

A closer look at challenges faced by a high rate PET system

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Elba, Italy

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for the SAFIR collaboration

The SAFIR Project

Motivation:

- Preclinical PET insert for quantitative kinetic modeling, e.g. ^{15}O-water time-activity curves
- Fully MR-compatible, simultaneous image acquisition in mere seconds

➔ **S**mall **A**nimal (mice and rats) **F**ast (image times ~ seconds) **I**nsert for M**RI** (**SAFIR**)

Requirements:

- PET insert operating within a Bruker BioSpin 70/30 MRI scanner (7T)
- Spatial resolution: ~2 mm, Image acquisition times: ~5 s,
- Target activity of 500 MBq in mice and rats

➔ **Result:** SAFIR Dual Ring Prototype (DRP), reduced FOV prototype, completed in 2019

The system: SAFIR DRP

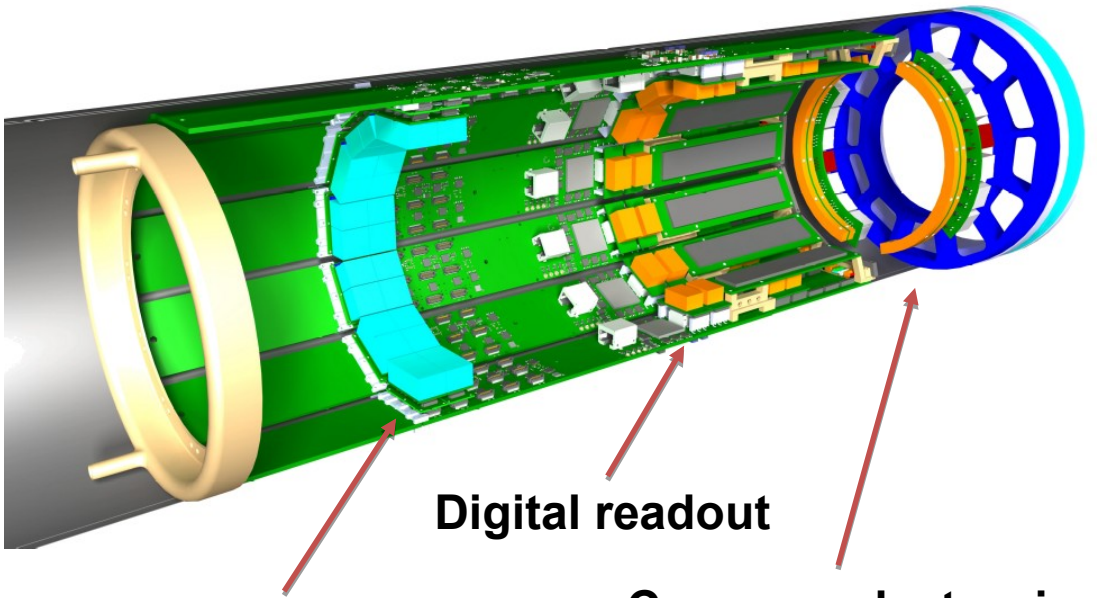
Scanner Layout

- 199 mm outer, 114 mm inner diameter
- Carbon fibre structure, fully air cooled
- 12 sectors, each sector RF screened

Crystal Geometry

- 2.1x2.1mm LYSO crystals, 2.2mm pitch
- Crystals 1:1 coupled to SiPM Matrices
- SiPM digitization using PETA6-SE ASIC
- 16 rings,12 x 15 crystals per ring

➔ **2880** crystals in total, 35.6mm Axial FOV



Topics

Operating at 500MBq:

- SAFIR DRP characterized according to NEMA NU-4, including NECR @ 500MBq
- NEMA requires evaluation of Image Quality Phantom at 3.7 MBq

➔ Of course, Image Quality at higher activities of interest

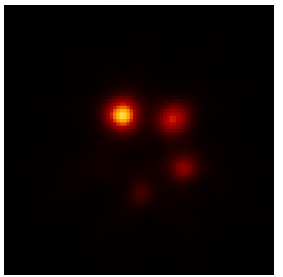
IQ Evaluation at high activities

Measurements:

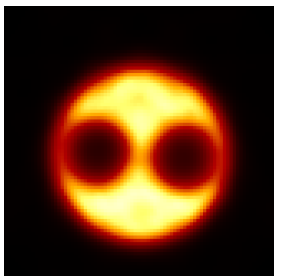
- NEMA Image Quality Phantom at 100 MBq up to 500 MBq
- Evaluation of Spill-over-Ratios, Recovery Coefficients and Uniformity according to NEMA

Data processing:

- Data calibration & coincidence sorting performed offline (custom software)
- Coincidence timing window: **500 ps**
- Coincidence energy window: **391 keV – 601 keV**
- Recon: **STIR, OSMAPOSL, 12 Subsets, 30 Iterations**
- Corrected for randoms, scatters, normalization, attenuation



Recovery Coefficient (RC)



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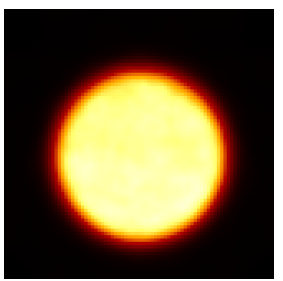

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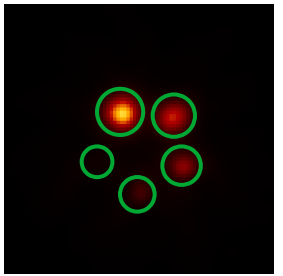

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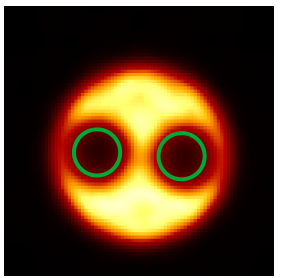

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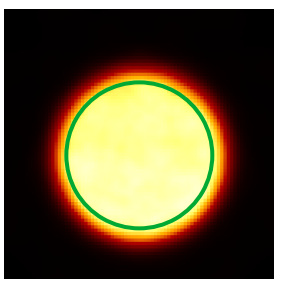

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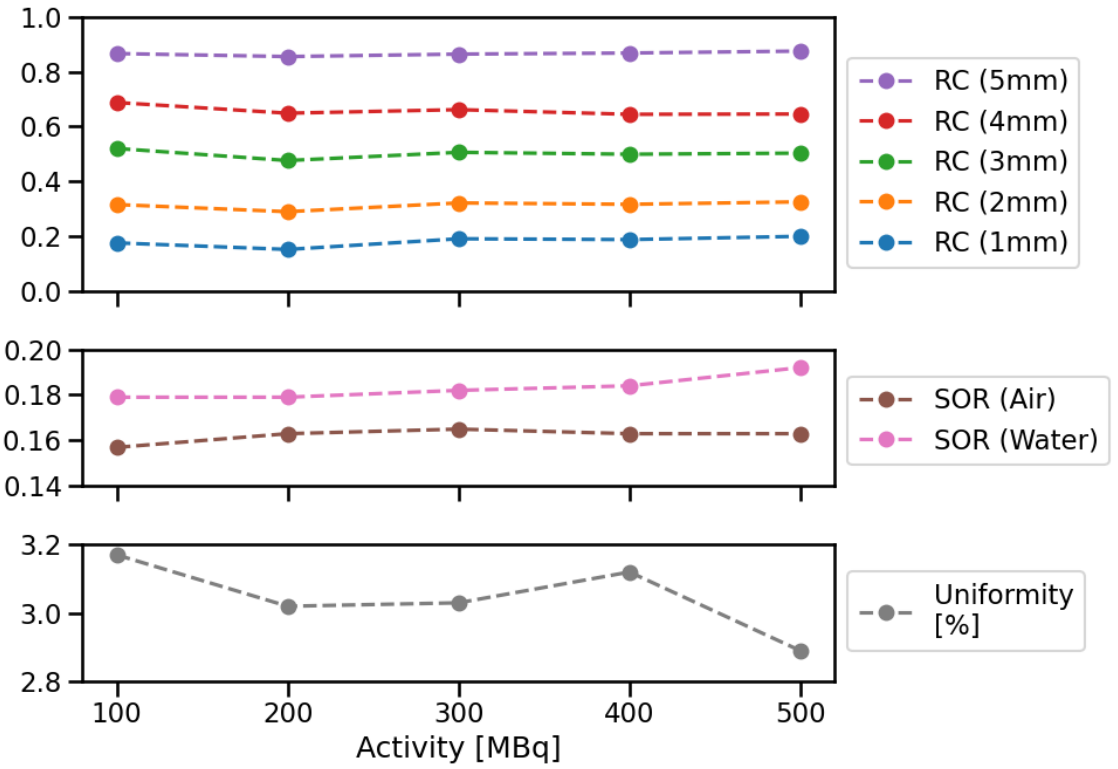

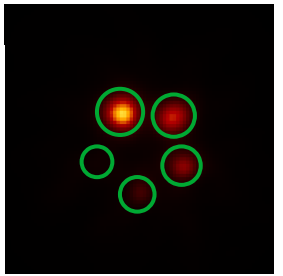

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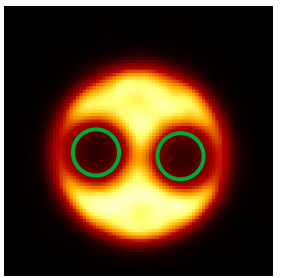

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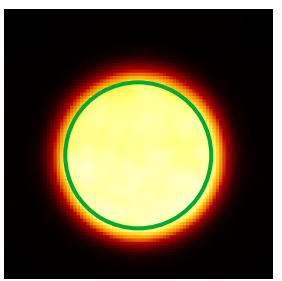

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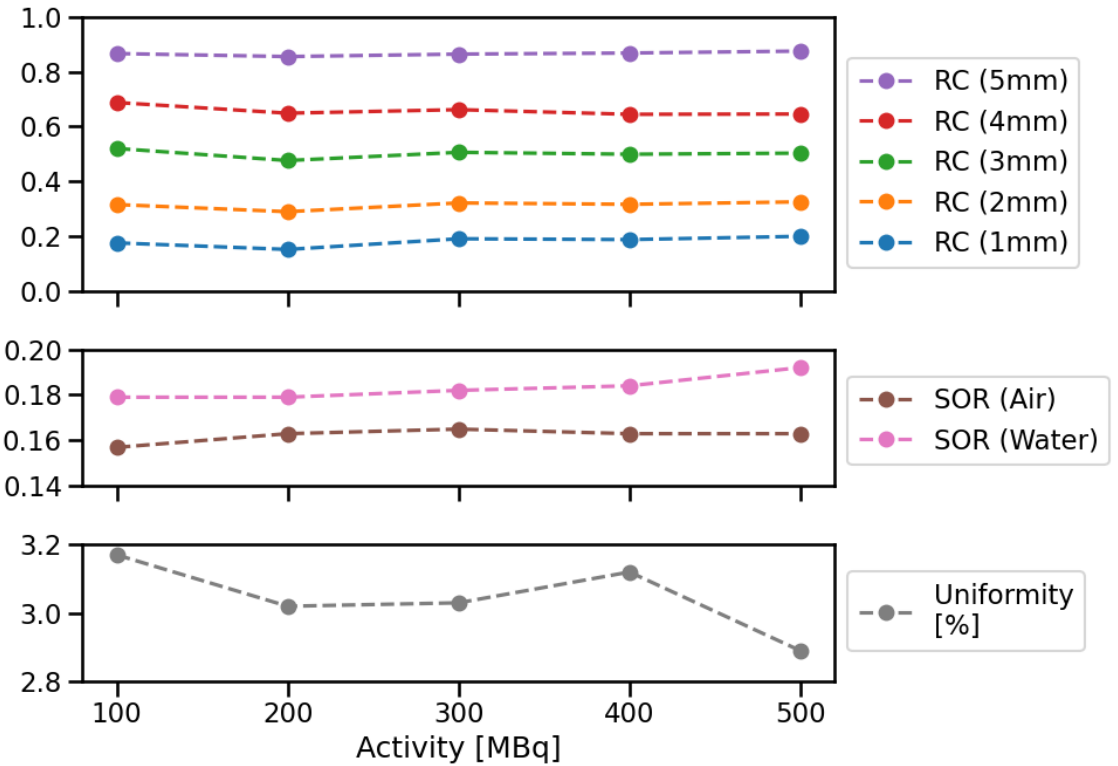

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- Measurement error due to mechanical movement possible

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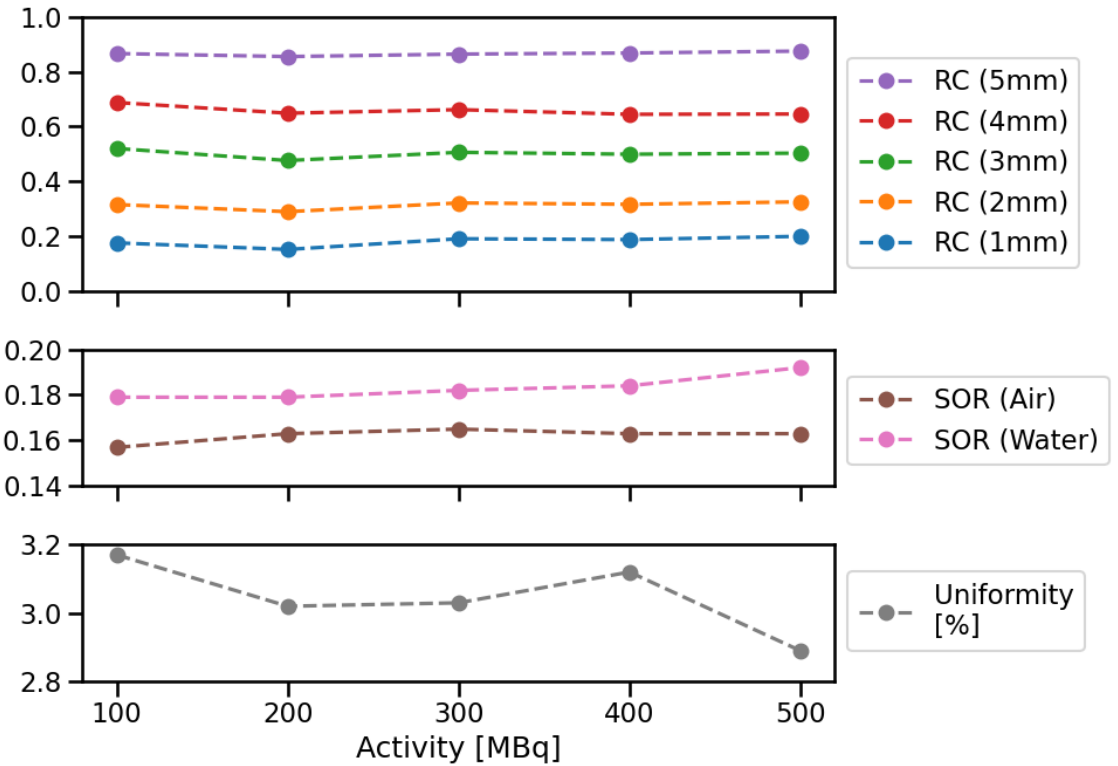

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Conclusions:

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- No significant degradations detected

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On the topic of Data Loss:

- Measured count rates at 500MBq lower than simulated
- Dead-Time effects of detector channels suspected to cause data loss

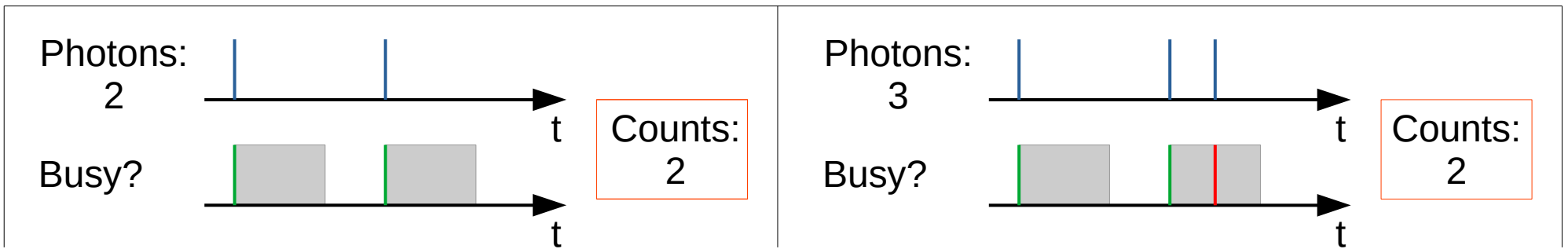
➔ Investigate Dead-Time effects at higher activities

On the topic of Data Loss

Detector Dead time:

- Readout channels enter ‘busy’ period after hit
- Photons arriving during that time are not registered
- ‘Deadtime’ ranges from 450 ns to 2.4 µs for PETA6
- Cross-talk, noise & intrinsic Lutetium activity can trigger channels as well
- At high event rates this can can be a significant factor

➔ <u>Increased loss of singles & coincidences</u>



Analyzing & Correcting for Dead Time Effects

Test-Trigger Events:

- PETA-6 supports injection of ‘dummy’ signals for all channels
  - ➔ Will only be read out if channel is not ‘busy’, else lost
- Injection at e.g. 100 Hz, then recording the number received
  - ➔ Estimate percentage of real events lost per channel per second
  - ➔ Averaging over the entire detector to estimate data loss

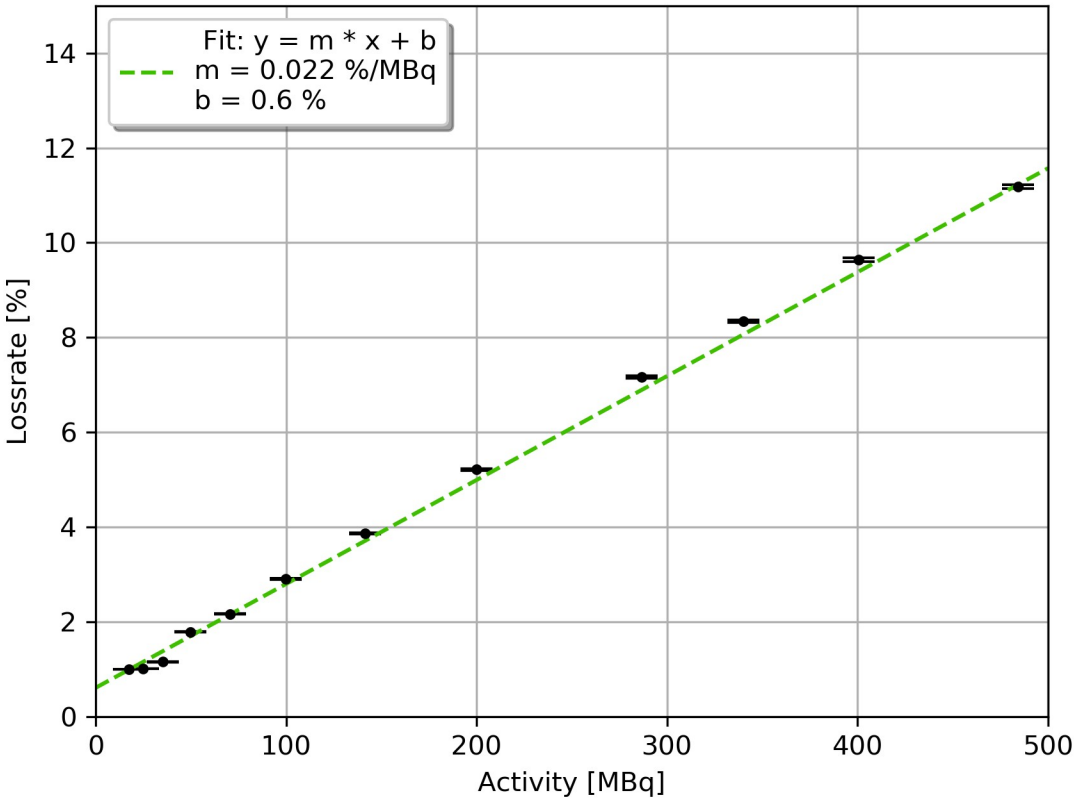
Measurement:

- Cylindrical Calibration Phantom (40 mm x 20 mm)
- Activity: F18 in water, 484 Mbq to 17 MBq

Data Loss % vs Activity

Single Event Loss:

- At 484 Mbq, an average of **11.2 %** of single events were lost
- Near linear dependency



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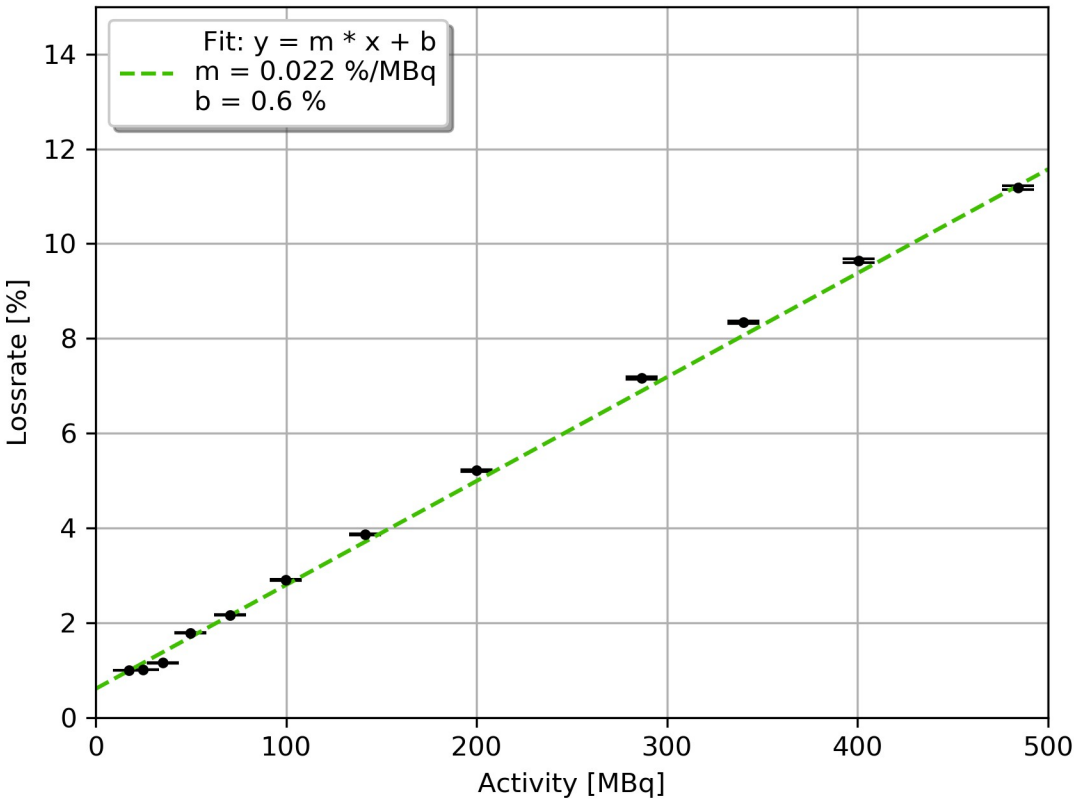
Coincidence Loss:

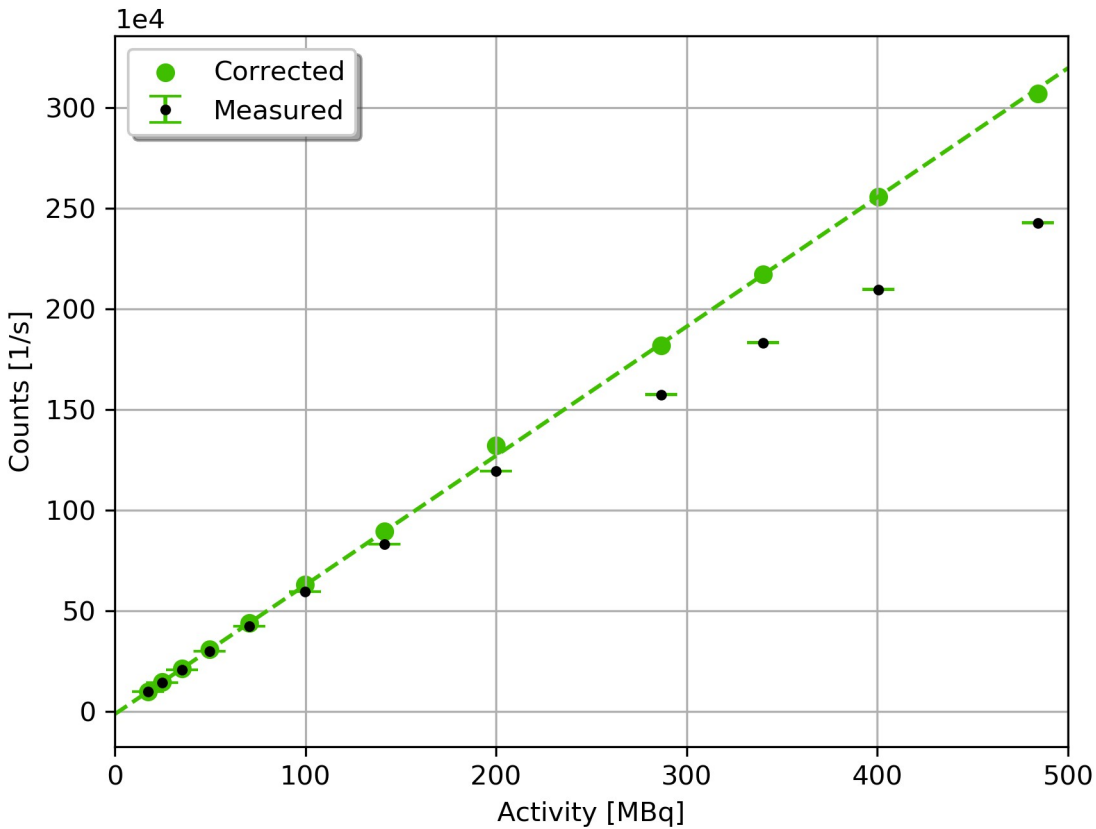
- For each LOR, channel loss rates multiply
  - ➔ 21% coincidence loss at 500MBq



Coincidence Count Rate vs Activity

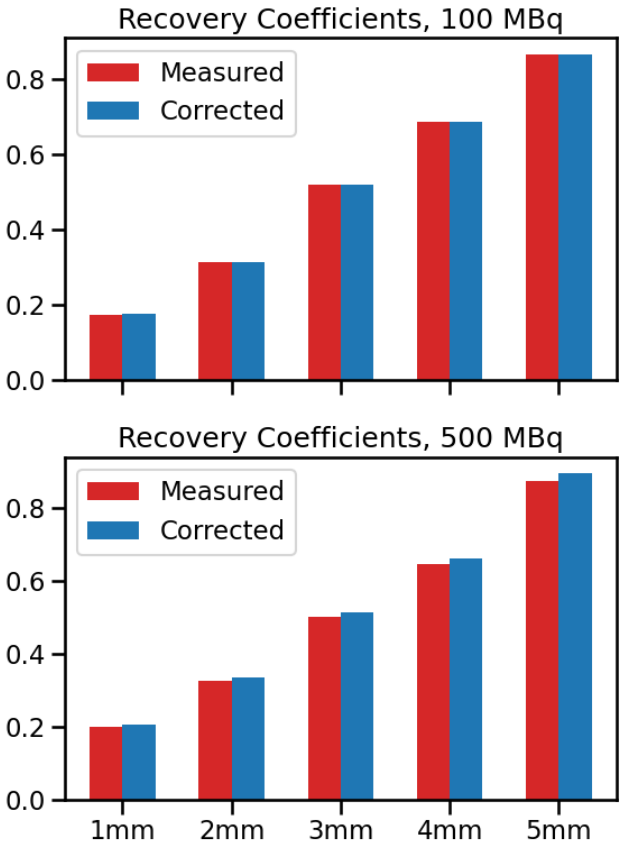
Coincidence Loss Correction:

- Multiply individual channel loss rates for each LOR
- Use results as correction factor for LOR count rates
- Correction restores linear dependency of count rate and measurement activity



Impact on Image Quality

- Evaluation of Image Quality Phantom measurement performed before and after correcting for data loss
- Comparison of parameters at 100 and 500 MBq shows almost no deviations



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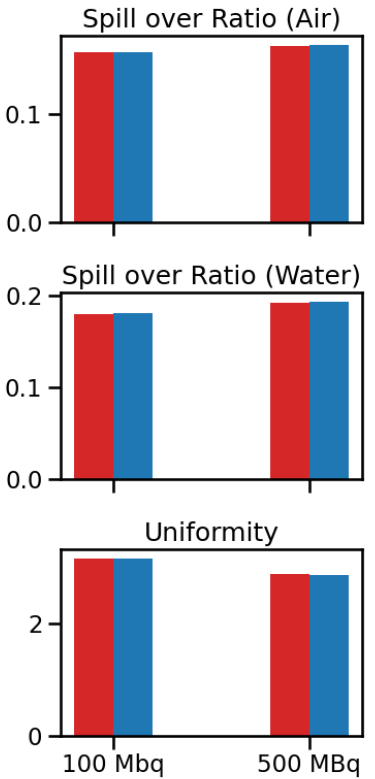

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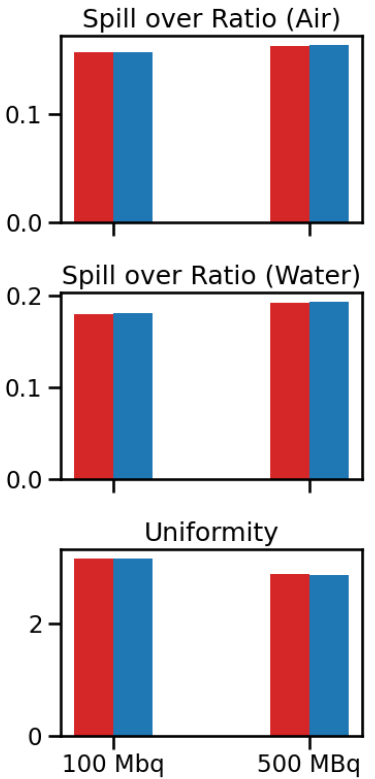
➔ **Correction yields important benefits for quantitative PET measurements with varying activities while not degrading Image Quality**



Outlook

SAFIR-I built & in use

- Dual Ring Prototype was upgraded
- Axial FOV increased by 50%
- First Time-Activity curves measured

SAFIR-II under construction

- Increased Axial FOV of 142.4 mm (~ x4)
- **New ASIC:** PETA6 → PETA8, reduces power consumption by 50%
- Adjustments to crystal reflectors, reduced cross-talk

Continued Dataloss Investigations

- PETA-8, featuring improved readout logic, decreases deadtime
- Measurements with SAFIR-II, impact on In-Vivo Data
- Integration of deadtime into simulations
- Investigation on count-rate performance after deadtime-correction

Thank you

The SAFIR Collaboration

- Institute for Particle Physics and Astrophysics, ETH Zürich
- Institute for Pharmacology and Toxicology, University of Zürich
- Department of Nuclear Medicine, University of Zürich
- Institute for Biomedical Engineering, ETH Zürich
- Institute of Computer Engineering, University Heidelberg
- University Medical Center, Groningen

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SPARE

Impact on Image Quality

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- Comparison of parameters at 100 and 500 MBq shows almost no difference

Activity	100 MBq		500 Mbq	
Corrected?	no	yes	no	yes
SOR (Air)	0.157	0.157	0.163	0.164
SOR (Water)	0.179	0.180	0.192	0.193
Uniformity [%]	3.17	3.17	2.89	2.87
RC (1 mm)	0.175	0.176	0.199	0.205
RC (2 mm)	0.315	0.315	0.325	0.334
RC (3 mm)	0.520	0.520	0.503	0.515
RC (4 mm)	0.688	0.688	0.646	0.661
RC (5 mm)	0.867	0.867	0.876	0.896

IQ Evaluation at high activities

Activity [MBq]	100	200	300	400	500
Meas. Time [s]	48	24	16	12	10
SOR (Air)	0.157	0.163	0.165	0.163	0.163
SOR (Water)	0.179	0.179	0.182	0.184	0.192
Uniformity	3.17%	3.02%	3.03%	3.12%	2.89%
RC (1 mm)	0.175	0.151	0.190	0.187	0.199
RC (2 mm)	0.315	0.289	0.321	0.316	0.325
RC (3 mm)	0.520	0.476	0.506	0.499	0.503
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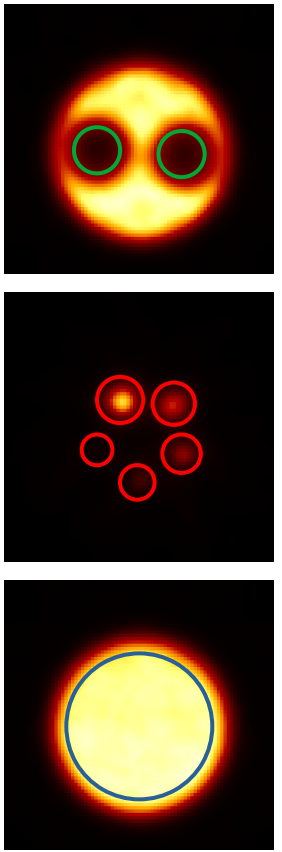

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