GPU Accelerated Time-of-Flight PET Reconstructions via STIR Integration of Parallelproj

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Introduction

Time of Flight (TOF) functionalities integrated into STIR[1] master since v. 6.0

Traditional STIR Ray-Tracing projector does not support GPU utilization

Parallelproj[2]: (independent) CUDA + C + Python library allowing use of CUDA GPUs for fast tomographic projection

Since STIR v. 5.0: wrapper for parallelproj projector into STIR for non-TOF reconstructions

This work

Extends the wrapper's functionality to support TOF data processing

[1] K. Thielemans et al., 'STIR: software for tomographic image reconstruction release 2', Physics in Medicine and Biology, Feb. 2012.
[2] G. Schramm and K. Thielemans, 'PARALLELPROJ—an open-source framework for fast calculation of projections in tomography', Front. Nucl. Med., Jan. 2024.

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Materials & Methods (I)

PET phantom scans

Siemens Biograph Vision 600 [3, 4]

NEMA IEC Body phantom

Data generation – Siemens research software e7tools

Unlist LM data into sinograms

Estimate TOF scatter & randoms

Data generation – Prepare for use with STIR

Create STIR – readable headers (correct data order,…)

Use of Script to deal with this (STIR workshop at IEEE MIC 2023)

Conversion script to process e7tools output will be made available

[3] Casey, M.E., Osborne, D.R. (2020). Siemens Biograph Vision 600. In: Zhang, J., Knopp, M. (eds) Advances in PET. Springer, Cham.
[4] van Sluis J et al. Performance Characteristics of the Digital Biograph Vision PET/CT System. J Nucl Med. 2019 Jul; 60(7):1031-1036.

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Materials & Methods (II)

Reconstructions

- Using STIR via SIRF
- MLEM, 10 iterations
- For STIR Ray-Tracing: set number of LORs per bin to 5

Timing tools

- Individual steps: STIR Timings Utility (stir_timings)
- Full reconstructions: Using line-profiler [5]

A note on file sizes

- prompts: 1.4 GB (signed integer)
- randoms, scatter: 2.8 GB (single float)
- Due to large file sizes: Caching switched off

[5] https://pypi.org/project/line-profiler/

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System Specifications

CPU

- **Model**: Intel Xeon W2295
- **Cores/Threads**: 18 Cores / 36 Threads
- **Base/Boost Clock**: 3.0 GHz / 4.6 GHz

GPU

- **Model**: NVIDIA RTX A4000
- **CUDA Cores**: 6144
- **VRAM**: 16 GB GDDR6
- **Memory Bandwidth**: 448 GB/s
- **Base/Boost Clock**: 735 MHz / 1560 MHz

RAM

- **Size**: 64 GB DDR4 (2 x 32 GB modules)
- **Speed**: 2666 MT/s
- **Form Factor**: DIMM
- **ECC**: Supported

SW Versions

- **STIR:** 6.3
- **Parallelproj**: 1.9
- **OS**: Ubuntu 22.04.5 LTS (Jammy Jellyfish)
- **gcc**: 11.4.0
- **CUDA:** 12.1

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A note on overhead

STIR: procedure for forward projection - copying data from CPU to GPU

- If image stored non-contiguously in memory, copy to contiguous memory block (rarely occurs!)
- Copy image from host to device (GPU)
- Call parallelproj (for all data, i.e. NOT subset-wise)
- Copy projection data from device to host
- Parallelproj and STIR projection data: different data order
  - Transpose TOF and spatial dimensions (on host) to internal ProjDataInMemory
- STIR is setup to forward project directly to a file
  - When data is accessed, it is copied from file into memory

Consequences:

- Double memory needed
  - Forward_project uses an internal buffer, but transposing uses its own buffer!
- Overhead in memory copies
- Overhead when only needing a subset of the data
  - can be avoided in SIRF (or STIR Python) by constructing one AcquisitionData per subset

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Results – Timings

	RT [min]	PP [min]
forward projection	4.92	0.55
back projection	14.97	0.44
Full acquisition model set-up	16.67	1.50
Full reconstructions	133.33	5.00

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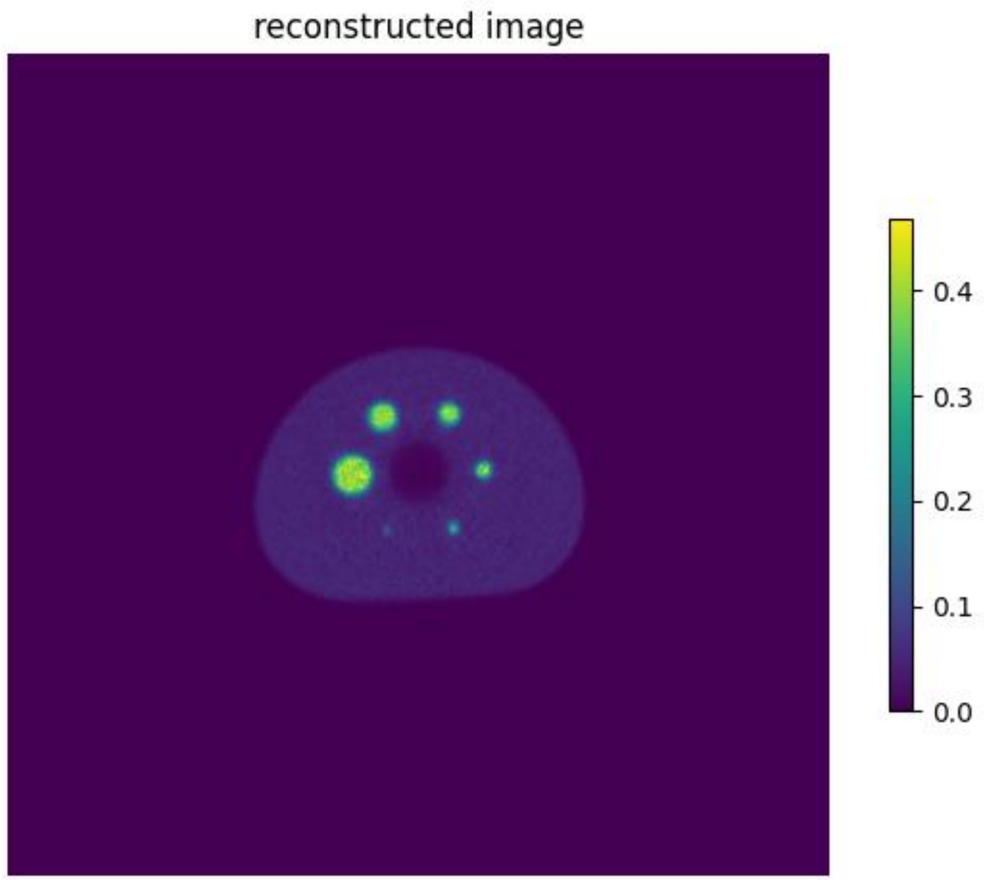
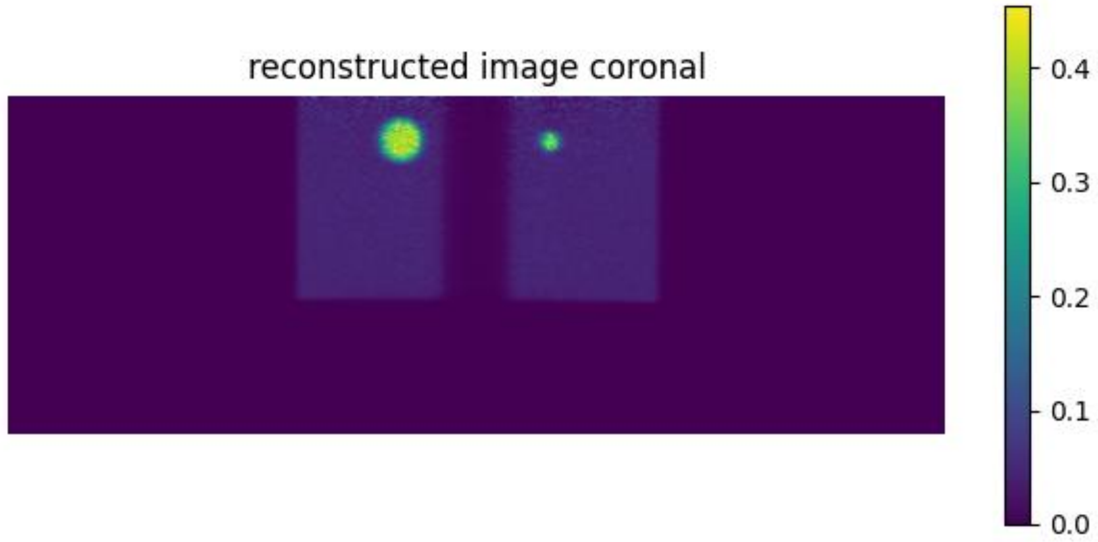
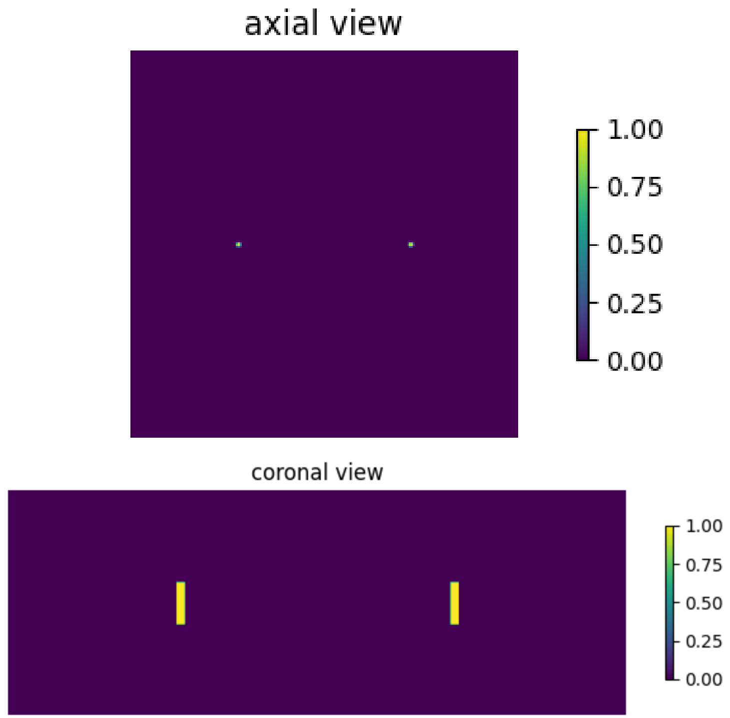
Results – (STIR) Reconstructed Images

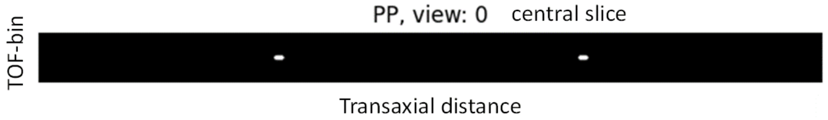


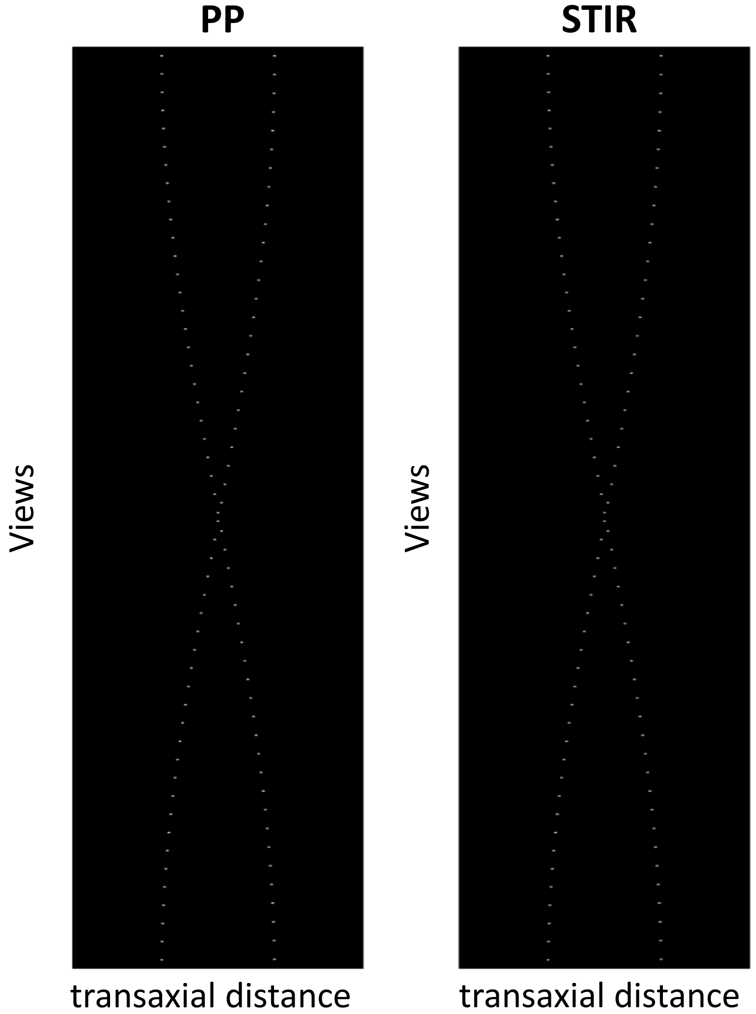


Results – PP vs RT Forw. Projections



Simulated line-sources were forward projected





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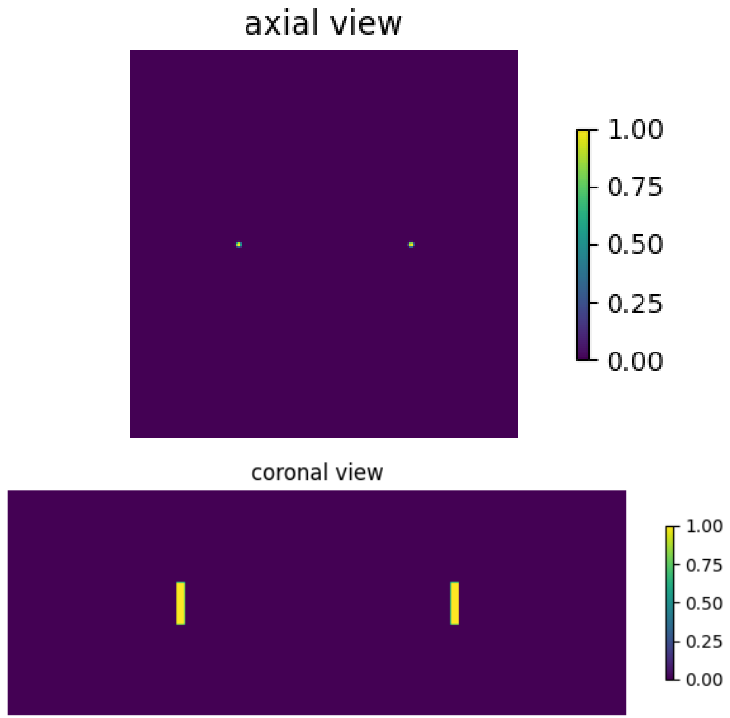
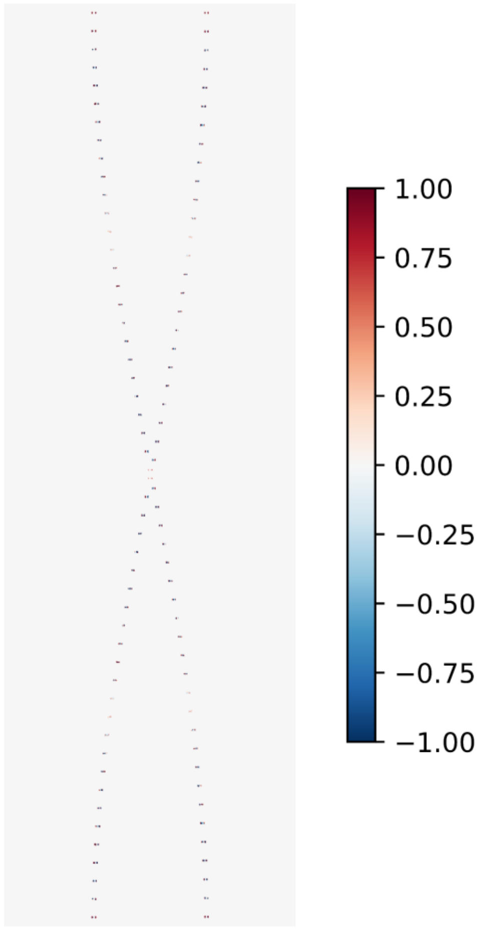
Results – PP vs RT Forw. Projections



Simulated line-sources were forward projected

Relative Difference



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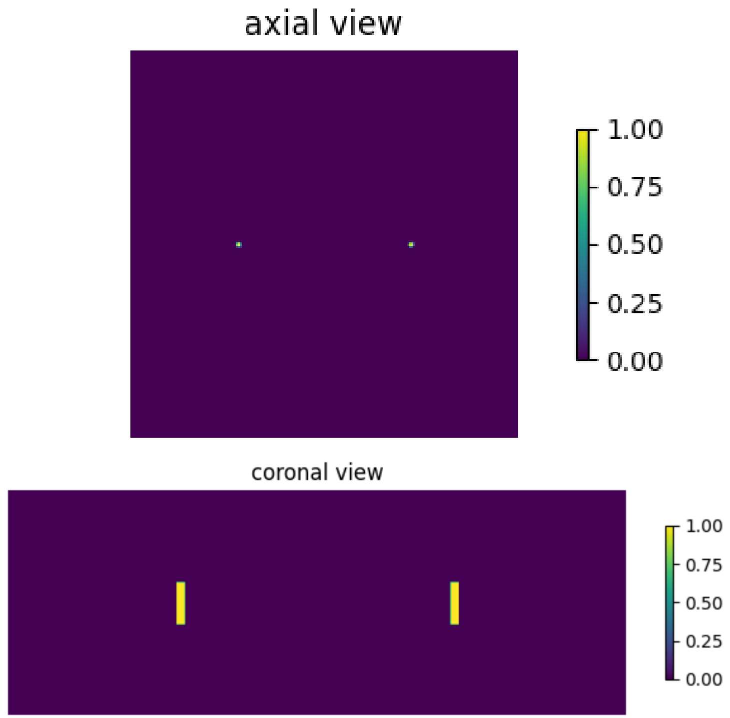
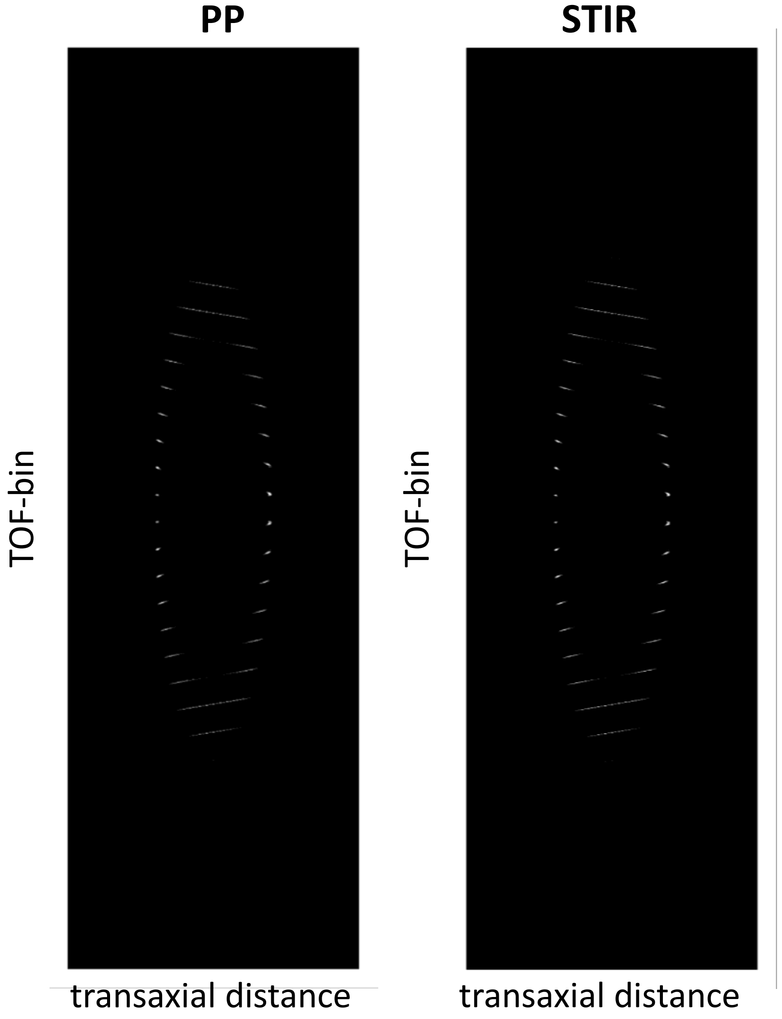
Results – PP vs RT Forw. Projections



Simulated line-sources were forward projected



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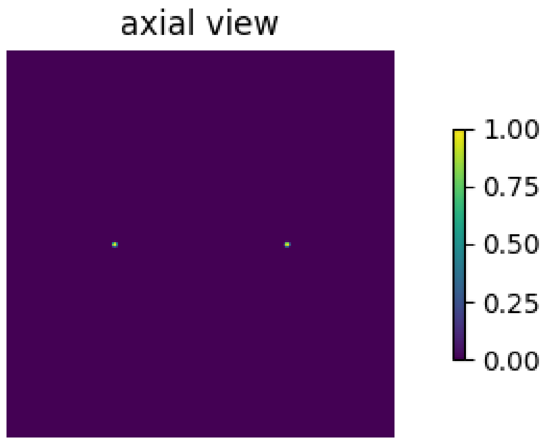
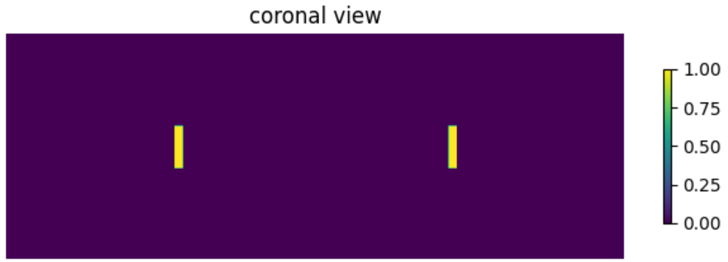
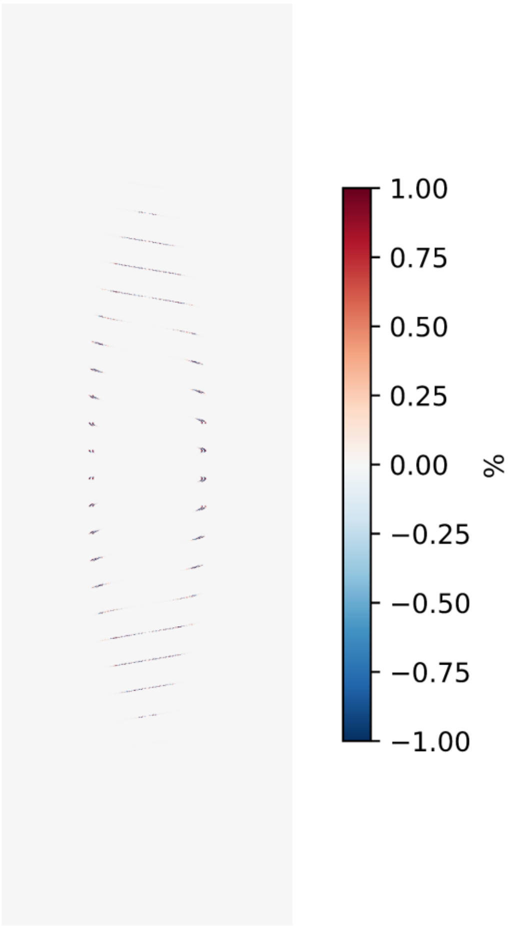
Results – PP vs RT Forw. Projections





Simulated line-sources were forward projected



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References

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[2] G. Schramm and K. Thielemans, ‘PARALLELPROJ—an open-source framework for fast calculation of projections in tomography’, Front. Nucl. Med., vol. 3, Jan. 2024, doi: https://doi.org/10.3389/fnume.2023.1324562.

[3] M. E. Casey and D. R. Osborne, ‘Siemens Biograph Vision 600’, in Advances in PET: The Latest in Instrumentation, Technology, and Clinical Practice, J. Zhang and M. V. Knopp, Eds., Cham: Springer International Publishing, 2020, pp. 71–91. doi: https://doi.org/10.1007/978-3-030-43040-5_6 .

[4] J. van Sluis et al., ‘Performance Characteristics of the Digital Biograph Vision PET/CT System’, J Nucl Med, vol. 60, no. 7, pp. 1031–1036, Jul. 2019, doi: 10.2967/jnumed.118.215418.

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