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Quantum simulation and medical imaging platform for PET scanners

Wojciech Krzemień

07.12 2023

European Funds Smart Growth
Republic of Poland
European Union European Regional Development Fund

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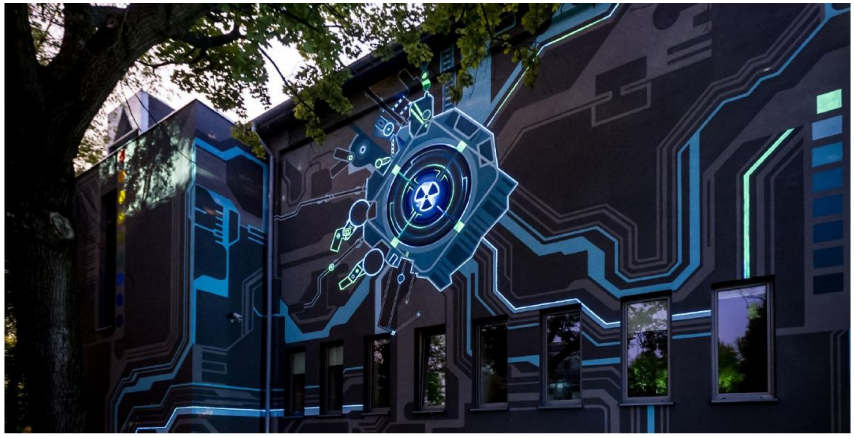
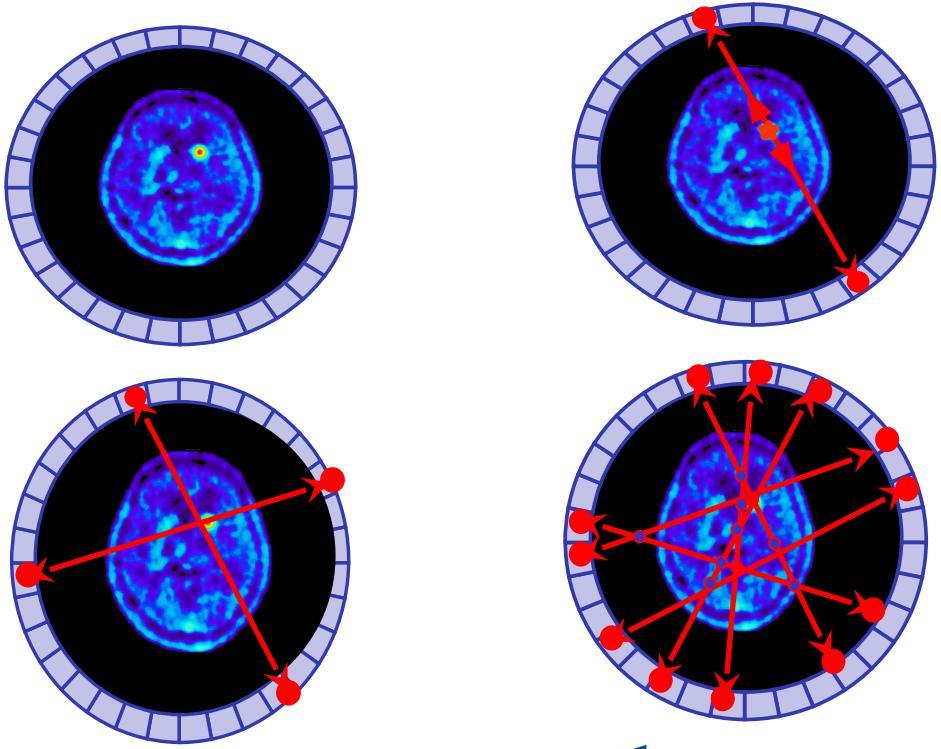
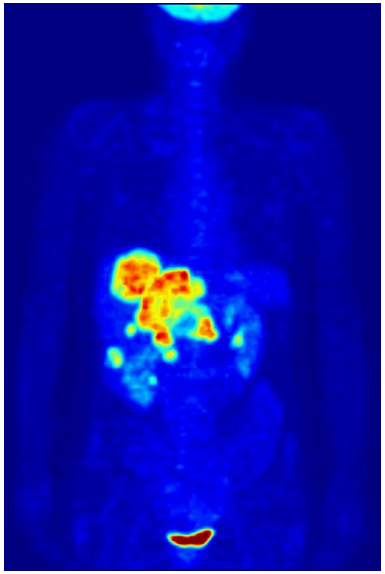
Świerk Computing Centre



- One of the largest research institutes in Poland (1195 employees, incl. 80 prof., 170 PhD, PhD studies: 45 students
- Scientific achievements: ~ 500 reviewed papers, ~16000 per year (5th/4th position in Poland)
- EU project: success rate ~30 %
- Budget/year : 70M euro
- 124 different projects
- Collaboration with the largest laboratories in the world (CERN, DESY, JPark, FAIR, Julich, ESS, T2K) and many universities
- Maria Reactor

Positron Emission Tomography (PET)

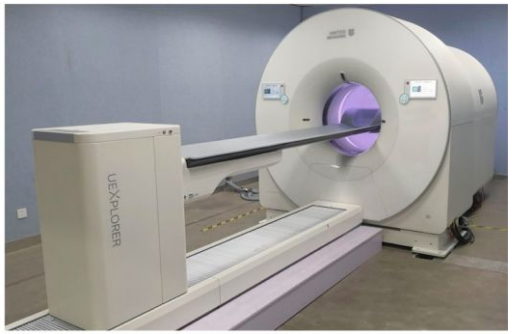


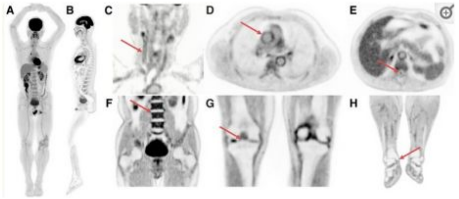


Author: Jens Maus (http://jens-maus.de/)
-Own work, Public Domain,

Towards total-body scanners

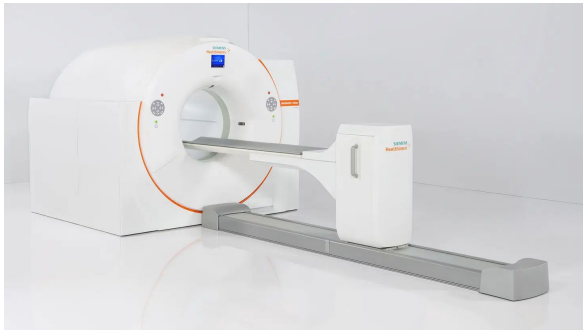
uExplorer





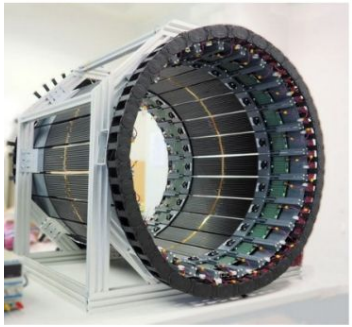
R. Badawi et al.
J Nucl Med. 2019 Mar; 60(3): 299–303.

Biograph-Vision Quadra



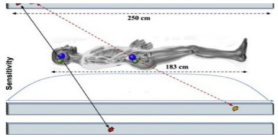
https://www.siemens-healthineers.com/en-us/molecular-imaging/pet-ct/biograph-vision-quadra

Modular J-PET



Total-body J-PET

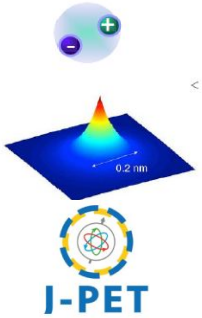
P. Moskal et al. PET Clinics 15 (2020) 439
P. Moskal et al. Phys. Med. Biol. 66 (2021) 175015
J. Baran et al. http://arxiv.org/abs/2212.02285

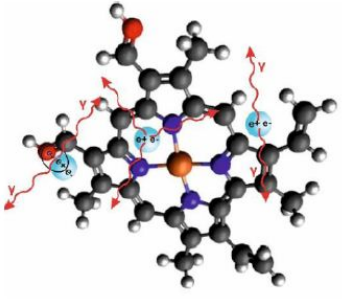


- 250 cm AFOV
- Additional layers of wavelength shifters → better axial resolution

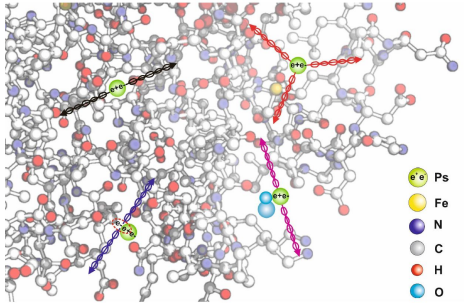
New techniques and imaging algorithms
(*multi-photon imaging, quantum imaging, quantum correlations*)

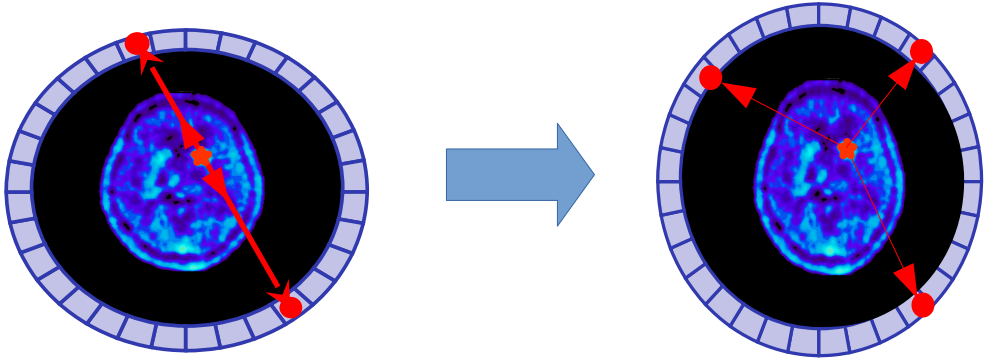
Positronium tomography





Model of the hemoglobin molecule





P. Moskal et al. Nature Reviews Physics 1 (2019) 527
P. Moskal et al. Phys. Med. Biol. 64 (2019) 055017
P. Moskal et al. EJNMMI Phys. 7 (2020) 44
P. Moskal et al. Science Advances 7 (2021) eabh4394
P. Moskal et al. Nature Communications 12 (2021) 5658
S. Bass et al. Rev. Mod. Phys. 95 (2023) 021002

http://koza.if.uj.edu.pl/publications/pet

Group:
- Wojciech Krzemień
- Konrad Klimaszewski
- Mateusz Bała
- Oleksander Fedoruk
- Lech Raczyński
- Aldona Spirzewska
- Damian Trybek
- Dawid Meleszczuk

Quantum simulations and medical imaging software platform

Common API

Services

Simulators

PET Image Reconstructor

Phantom generator

Quatum emulators/ Quantum computer

Quantum simulations

Standard simulations

Image reco.

Quantum Imaging

GAN networks

Libraries

Qiskit

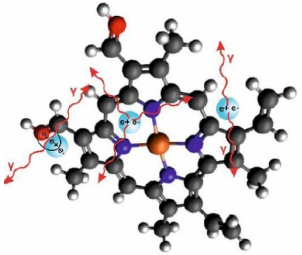
GEANT4 A SIMULATION TOOLKIT

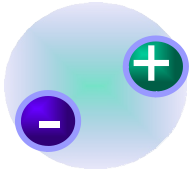
GATE

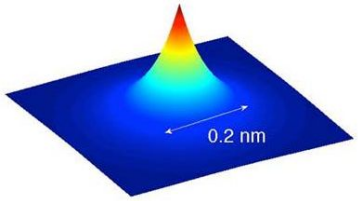
TensorFlow

PYTORCH

(Quantum) Simulators I







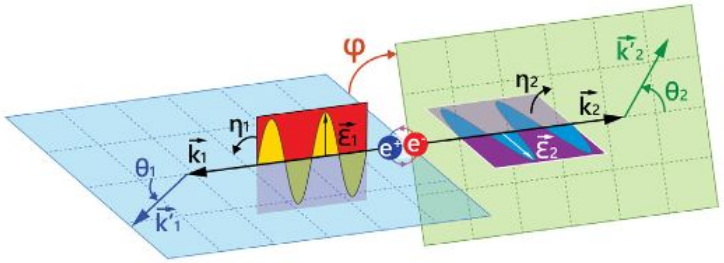
Scientific support:
Prof. B. Hiesmayr, leader of QPW, University of Vienna

B. C. Hiesmayr, P. Moskal Sci. Rep. 7 (2017) 15349

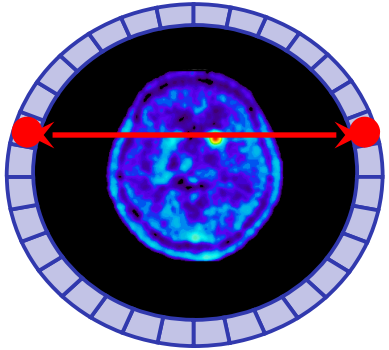
B. C. Hiesmayr, P. Moskal Sci. Rep. 9 (2019) 8166

Physical process simulations (including **quantum** effects) with potential use for the PET tomography applications

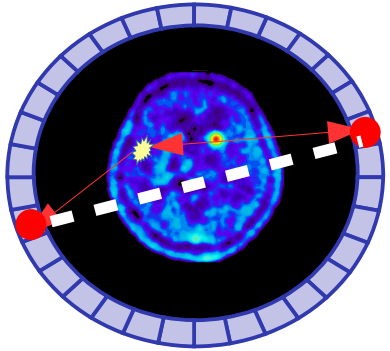
Two-photon quantum correlations



S. Bass et al. Rev. Mod. Phys. 95 (2023) 021002



True events



(Noisy) scattered events

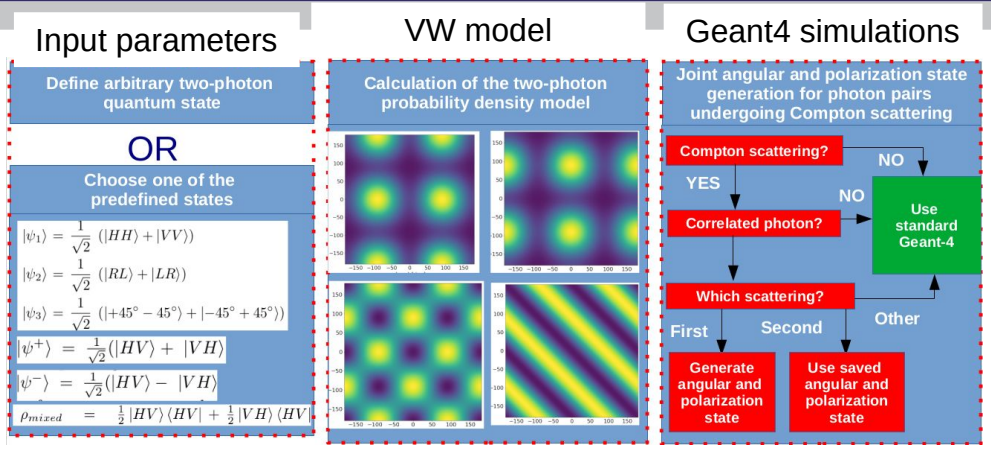
D. Watts et al. Nature Communications 12 (2021) 2646

A. Ivaskhin et al. Scientific Reports 13 (2023) 7559

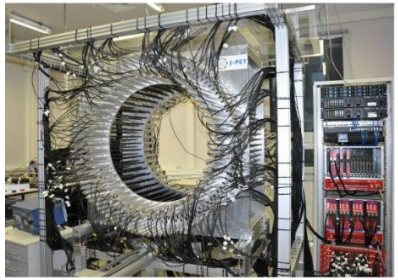
(Quantum) Simulators I

Quantum MC simulator

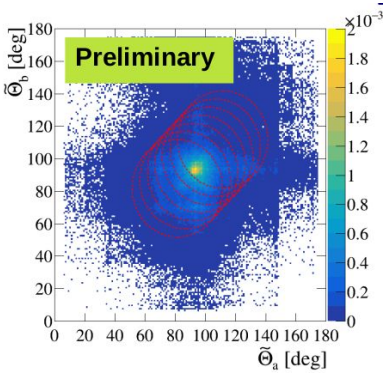
- Geant4 based model with quantum correlations
- Simulations incorporate into platform
- Visualization tools provided as Jupyter-notebooks

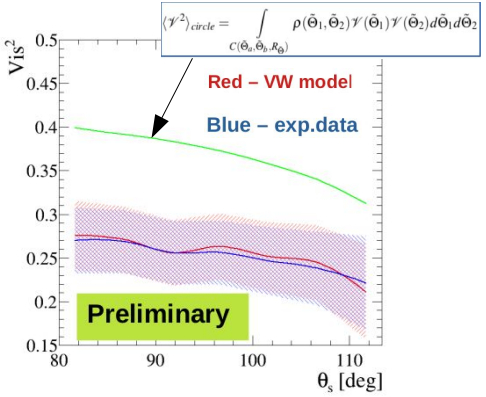


Model validation with data taken by the J-PET scanner

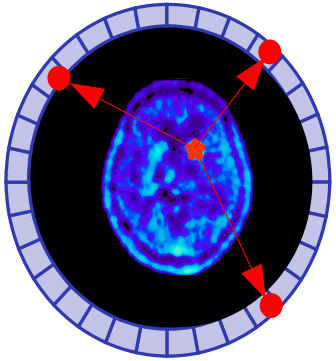


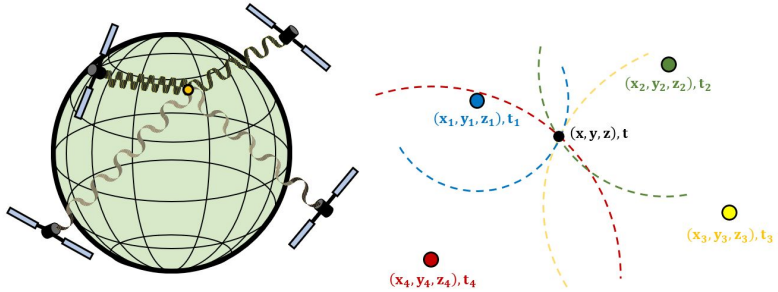
Great agreement with data



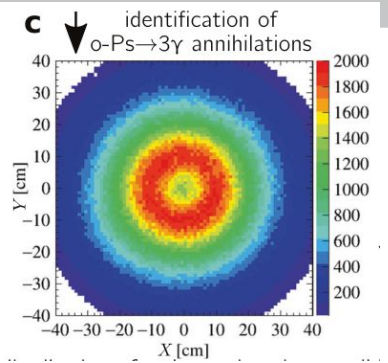


PET Image Reconstructor II





A. Gajos et al., NIM A 819 (2016) 54-59

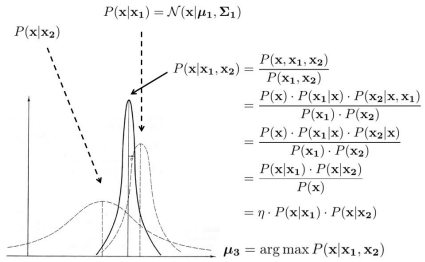


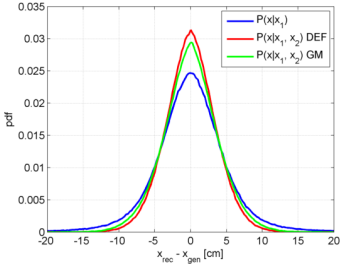
Nature Communications 12 (2021) 5658

Problem → resolution (σ) of about 8 cm

Trilateration "on steroid"

- Set of tools for fast prototyping and algo. comparison
- Three enhanced algorithm implementations
- Jupyter notebook visualizations





Preliminary results:
resolution improvement al least 2x

Phantom generators III

Challenge:

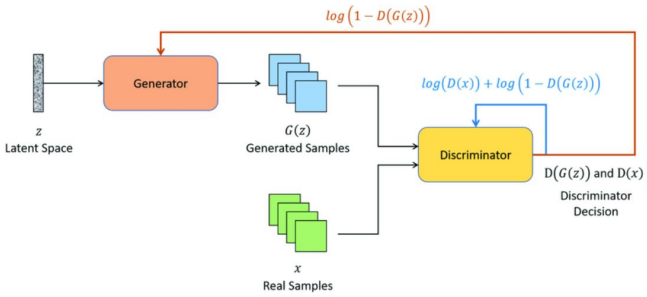
- Small accessibility of the large medical image sets for AI applications e.g. training of deep learning models
- Medical images → sensitive data, privacy issues, limited access due to number of operating facilities

Scientific support:
Dr hab Michał Kruk, SGGW

Proposed solution:

- Service for generation of medical pseudo-images using GAN network models
- Set of tools in form of the Jupyter notebook scripts that can be run in the batch or interactive mode

Generative Adversarial Networks (GANs)



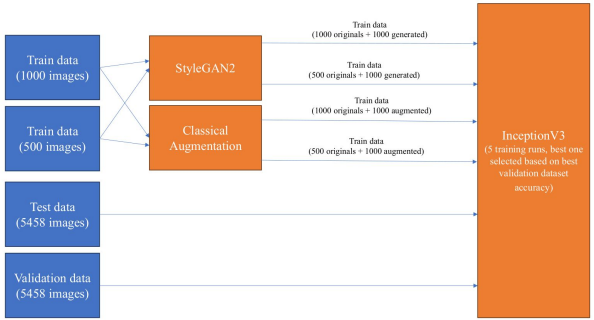
https://github.com/junyanz/CycleGAN

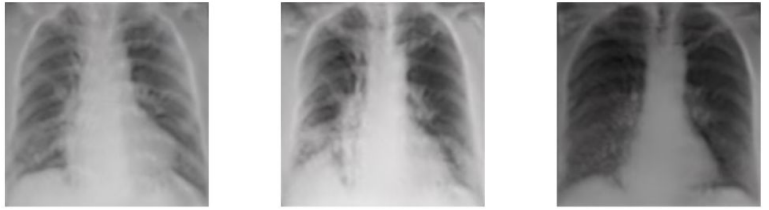
https://arxiv.org/abs/1406.2661,
Ian J. Goodfellow, Jean Pouget-Abadie, Mehdi Mirza, Bing Xu, David Warde-Farley, Sherjil Ozair, Aaron Courville, Yoshua Bengio

Phantom generators III

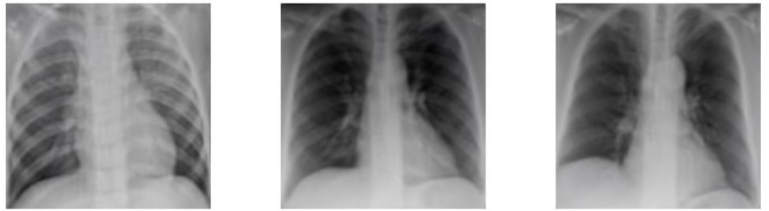
- GAN model trained on COVID-19 dataset:
  - ~3600 Covid-19 images
  - ~10000 healthy images
  - ~6000 lung opacity
  - ~1300 viral pneumonia
- Freschet Inception Distance metric

https://www.kaggle.com/datasets/tawsifurrahman/covid19-radiography-database





GAN trained on 1000 images



GAN trained on 500 images

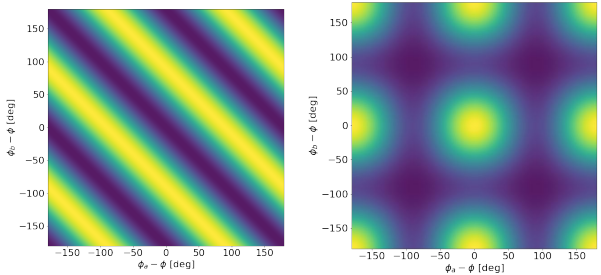
O. Fedoruk et al, accepted for publication "Additional Look into GAN-based Augmentation for Deep Learning COVID-19 Image Classification".

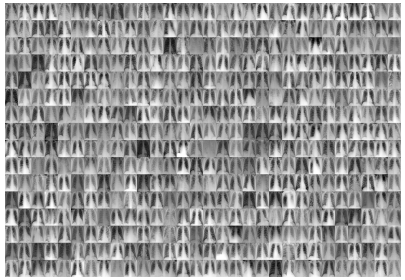
Performance of GAN-based augmentation for deep learning COVID-19 image classification (2023), https://arxiv.org/abs/2304.09067
Oleksandr Fedoruk, Konrad Klimaszewski, Aleksander Ogonowski, Rafał Możdżonek

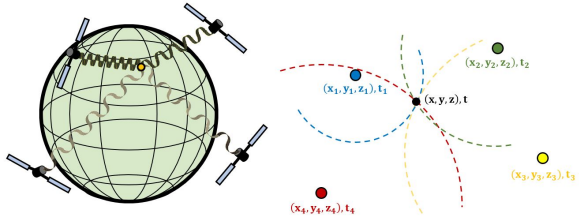
Summary:

- Set of tools and services for scientific community implemented as a platform

- Three main functionalities:
  - **Simulators** → Geant4 Monte Carlo models with quantum correlation included
  - **Phantom generators** → GAN- based service for generation of pseudo medical images for AI support
  - **Image reconstructors** → tools for fast prototyping of multi-photon algorithms







Thank you!

2nd International Workshop on Machine Learning and Quantum Computing Applications in Medicine and Physics

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https://events.ncbj.gov.pl/event/314/

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