Filtration and reconstruction of trigger-less data for the whole-body J-PET scanner

Total-Body PET Conference
September 24th 2021

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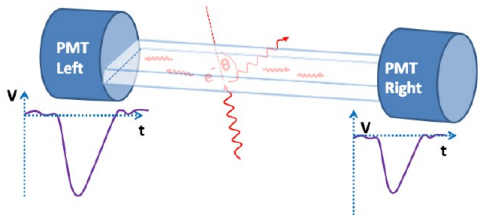
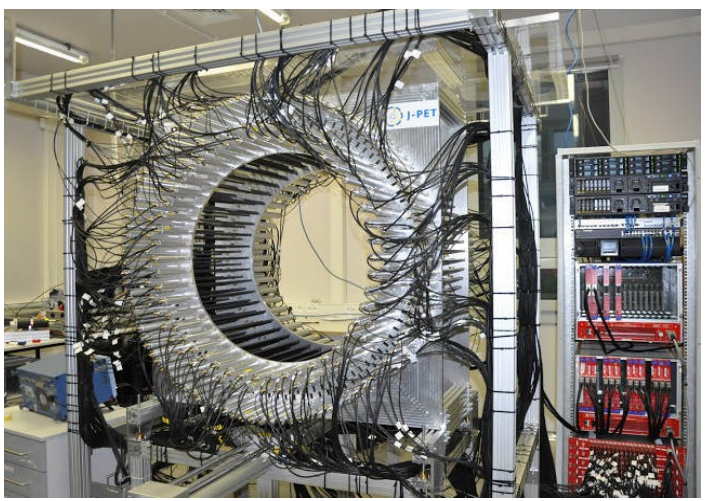
on behalf of the J-PET Collaboration
Jagiellonian University

The Jagiellonian Positron Emission Tomograph (J-PET)

- First PET device using plastic scintillator strips

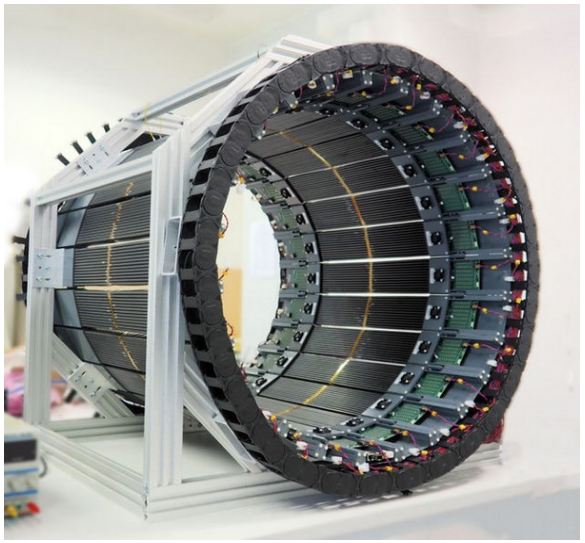


- **Goal: cost-effective whole body PET scanner**



1st full scanner prototype
50 cm AFOV
192 detection modules
(2 vacuum tube photomultipliers each)

Acta Phys. Pol. B 48 (2017) 1567

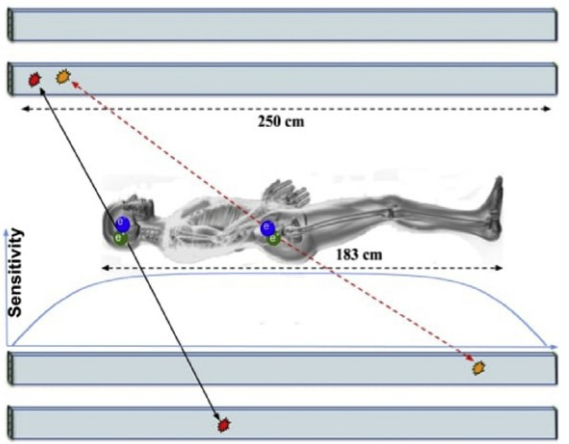


New J-PET prototype with fully digital readout

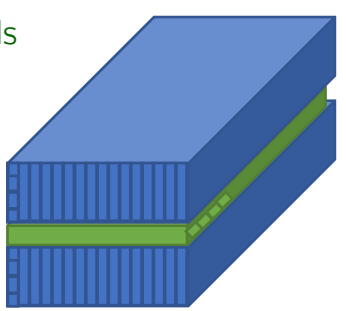
- 50 cm AFOV
- SiPM matrices

→ see the poster by S. Niedźwiecki for details

Future: whole-body J-PET



PET Clinics 15 (2020) 439
Phys. Med. Biol. 66 (2021) 175015



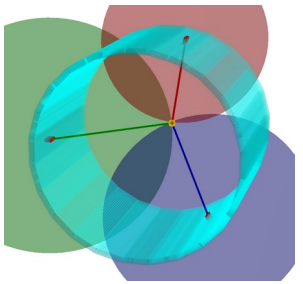
Additional layers of wavelength shifters perpendicular to scintilaltors
→ improved axial resolution
→ see the poster by Shivani

J-PET applications beyond standard PET

Multi-photon imaging modalities

Spatially-resolved determination of properties of positronium (e^+e^-)

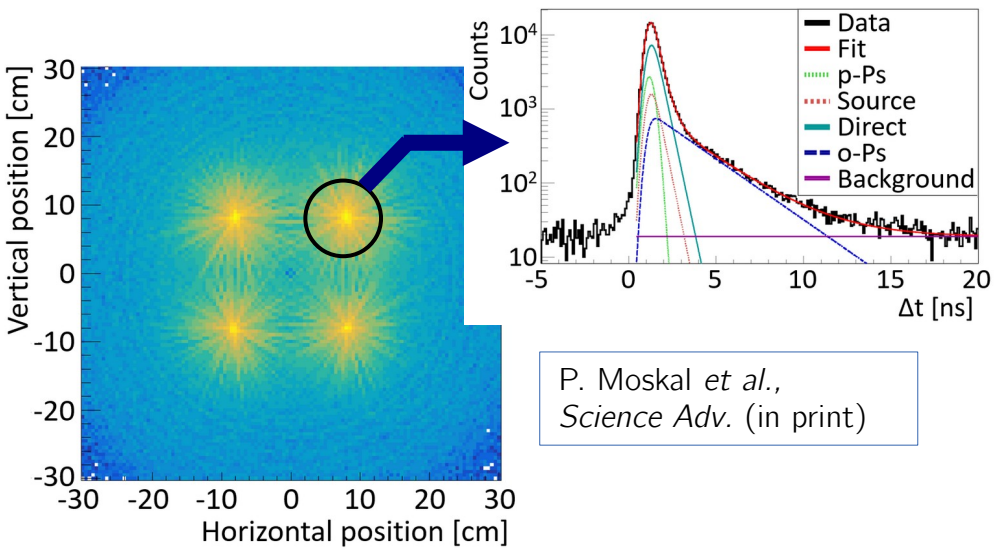
→ **Imaging with three-photon positronium annihilations**



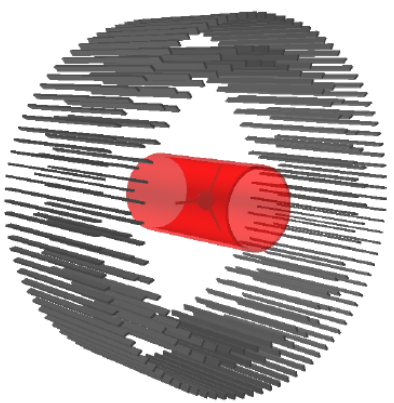
Positronium lifetime

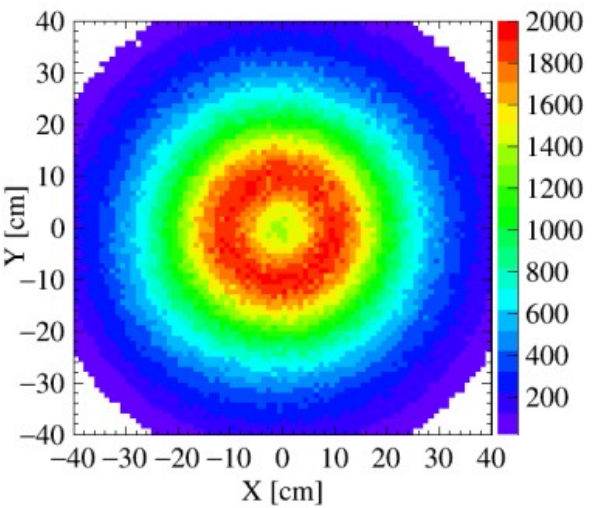
Using back-to-back 2γ pairs

+ 1.275 MeV prompt photons



P. Moskal *et al.*, *Science Adv.* (in print)



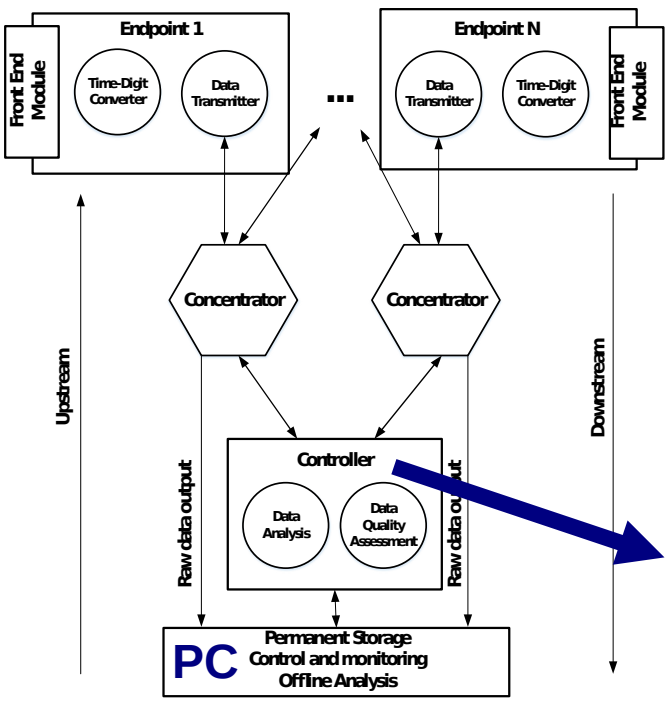


P. Moskal *et al.*, *Nature Comm.* (in print)

Multi-photon imaging requires flexible, minimum-bias data acquisition and processing.

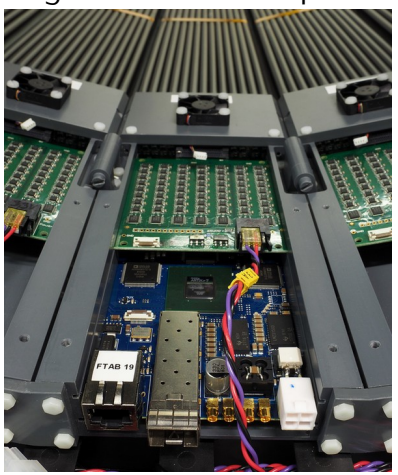
J-PET trigger-less data acquisition system

- Silicon photomultplier matrices read out by custom front-end electronics
- Time-to-Digit Converters implemented in FPGA chips
- Hierarchical, scalable arcitecture



Schemes: courtesy of G. Korcyl

digital J-PET endpoint



Trigger-less measurements:

- no rejection of recorded photon interactions at hardware level
- flexible re-application of different conincidence & filtration criteria in offline analysis
- challenging data flux

Controller based on System-on-a-Chip (SoC) FPGA device

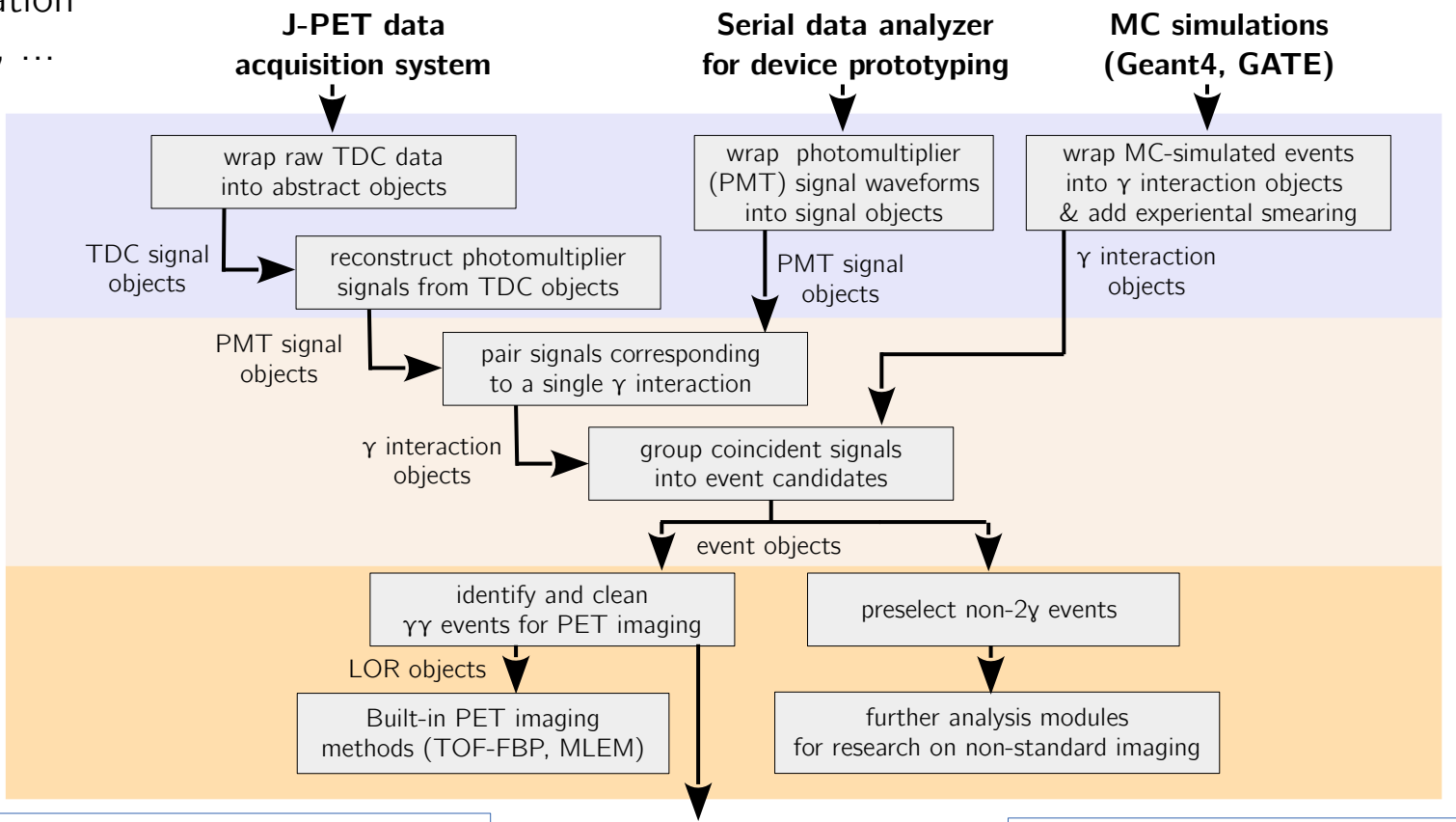
- possibility of reprogrammable filtering of data in hardware
- on-line image reconstruction right on the chip

IEEE Tran. Med. Imag., Vol. 37, No. 11 (2018) 2526

Software reconstruction framework

All filtering and reconstruction is performed in software:

- assembly of photon interactions from single SiPM responses
- coincidence identification
  2γ, 3γ, 2γ+prompt γ, ...



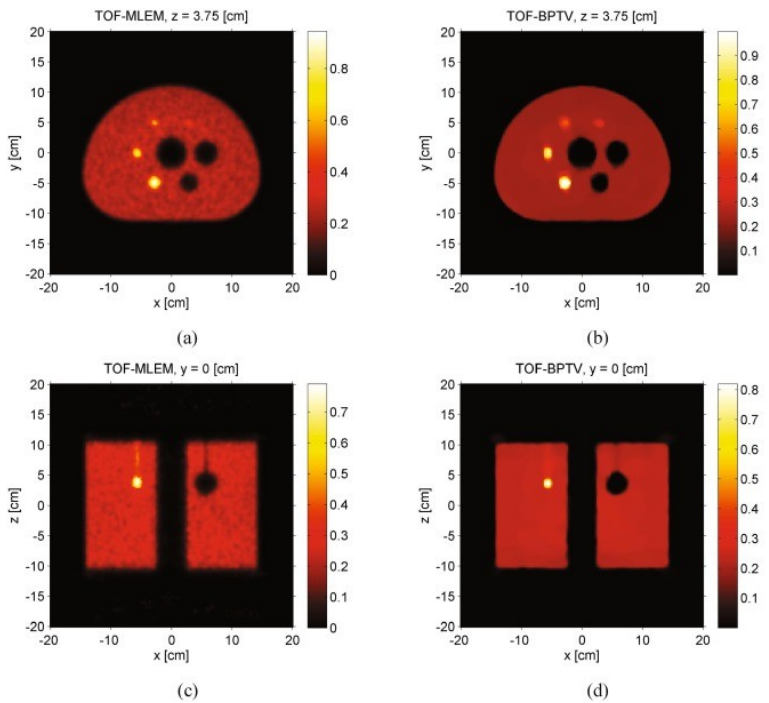
https://github.com/JPETTomography/j-pet-framework

SoftwareX 11 (2020) 100487

Decicated image reconstruction methods

3D TOF-PET image reconstruction using total variation regularization

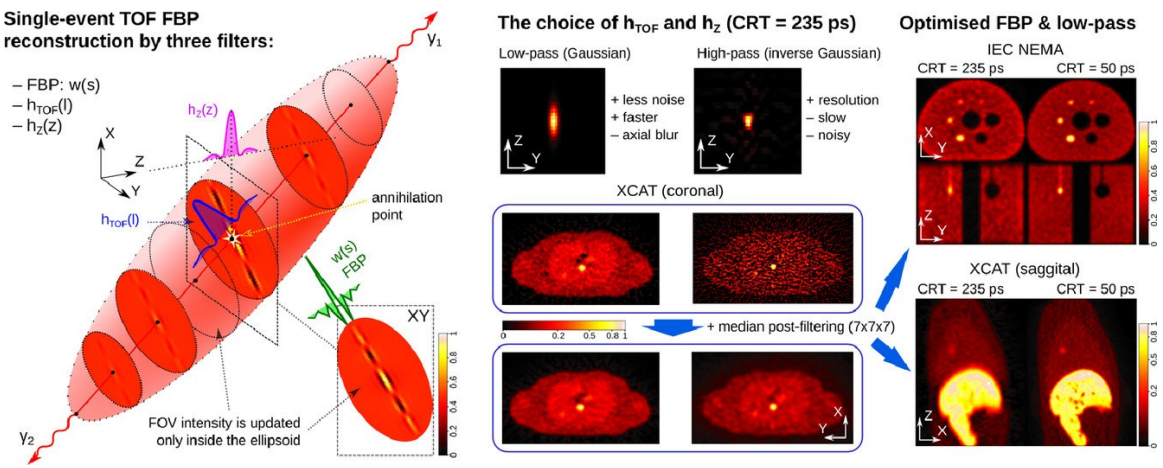
- Semi-analytical algorithm
- TV regularization in image space



Physica Medica 80 (2020) 230

Event-based TOF filtered back-projection for online imaging

- process each LOR) independently **in image space**
- parallelization possibilities
- **Prospects for real-time (online) reconstruction**



Medical Image Analysis 73 (2021) 102199

MLEM reconstruction with MC-based analytical system matrix
→ see the poster by R. Shopa

Towards on-line reconstruction of TB-JPET scans

- **Data flux with the present 50 cm AFOV prototype:**
  - Raw TDC data: ~60 MB/s
    per 10 MBq in the scanner centre
  - Single-core data processing time: 1.7 MB/s
  - Real-time reconstruction of incoming data
    up to the LOR level is feasible with
    a moderate contemporary server computer

Intel® Xeon® Platinum 8168
2 x 24 cores @ 2.7 GHz
(released: 2017)

- **Data flux simulated with GATE for one of the considered TB-J-PET devices:**
  - Raw TDC data: Incoming data: ~2 GB/s
  - Around 30x larger than the current prototype
  - Real-time reconstruction is not precluded with:
    - preliminary coincidencing and filtering of TDC signals in the FPGA SoC system
    - optimized off-line analysis

  at only a moderate increase of the required computing power.

Summary

- The Jagiellonian PET is the first scanner based on plastic scintillator designed with a goal of constructing a cost-effective total body PET.
- J-PET develops a capability of imaging with positronium properties.
- To allow that, all data acquisition is performed in trigger-less mode and analyzed offline.
- FPGA-based electronics allow for adding hardware-level filtration later on.
- The modular data analysis framework of J-PET allows for real-time analysis of data from the 50 cm AFOV prototype with a single contemporary server.

Thank you for your attention!

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