NATIONAL CENTRE
FOR NUCLEAR RESEARCH
ŚWIERK

GATE activities @ NCBJ

Wojciech Krzemień

Gate Scientific Meeting
31.03 2026

National Center for Nuclear Research

Research sector in NCBJ

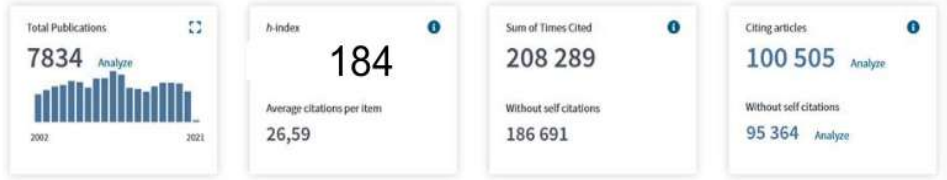
- Nuclear Facilities Operations Department (Reaktor MARIA)
- Material Physics Department (LBM)
- Department of Fundamental Research
- Department of Nuclear Techniques and Equipment
- Complexity Center (CS)
- Radioisotope Centre (POLATOM)
- Division of Nuclear Equipment HITEC
- Science and Technology Park
- International Research Agenda - NOMATEN
- Scientific-and-Industry Centers

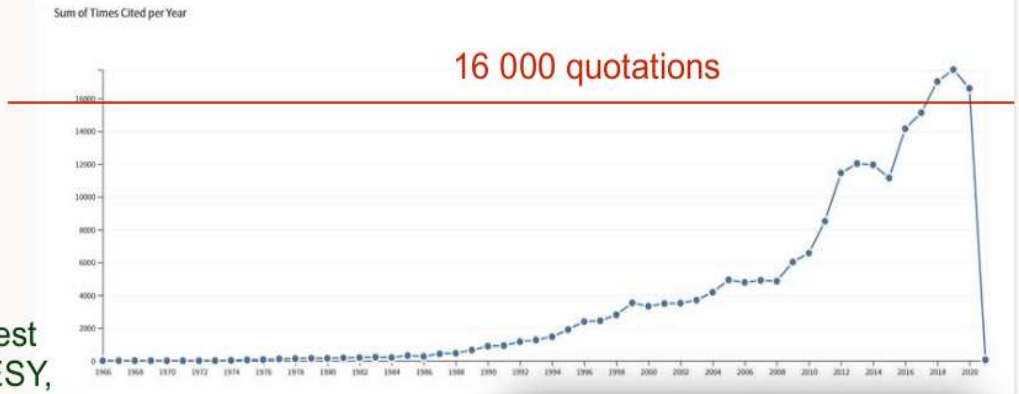
One of the largest research institute in Poland
1195 employees, inc. 80 prof. & 170 PhD
PhD Study: ~45 students

EU projects: success rate: 30%

HR EXCELLENCE IN RESEARCH

Scientific achievements:
~500 reviewed papers,
~16000 quotations each year,
5/4th position in Poland,





budget/year ~ 70 M€

124 different types projects

International collaborations with largest laboratories in the world (CERN, DESY, Grenoble, JParc, FAIR, Julich, ESS, JINR, T2K), cooperation in many universities around the world

POLATOM

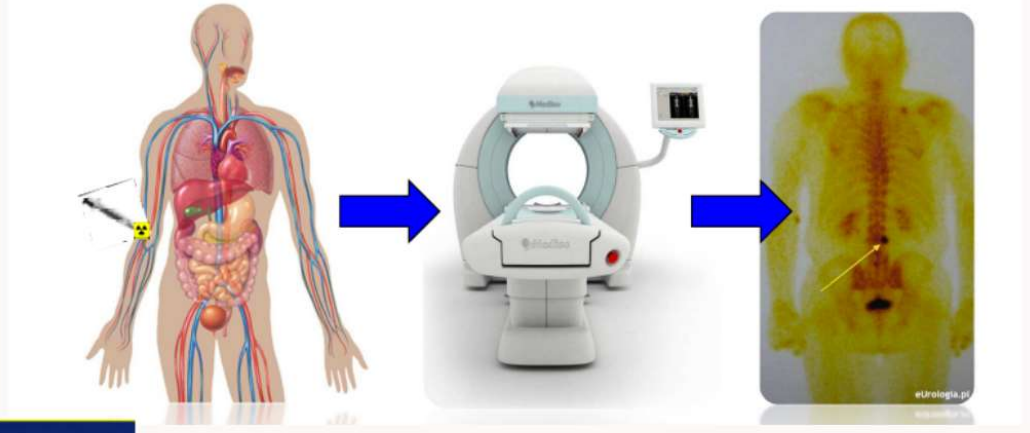
Radiopharmaceuticals with marketing authorisation

Quality Assurance System certified:

ISO: PN-EN ISO 9001:2015-10
cGMP and GLP

Radioisotope Centre POLATOM-NCBJ

POLATOM



Export to 80 countries
100% polish market
(except PET)

Medicines for 17 million
patients a year

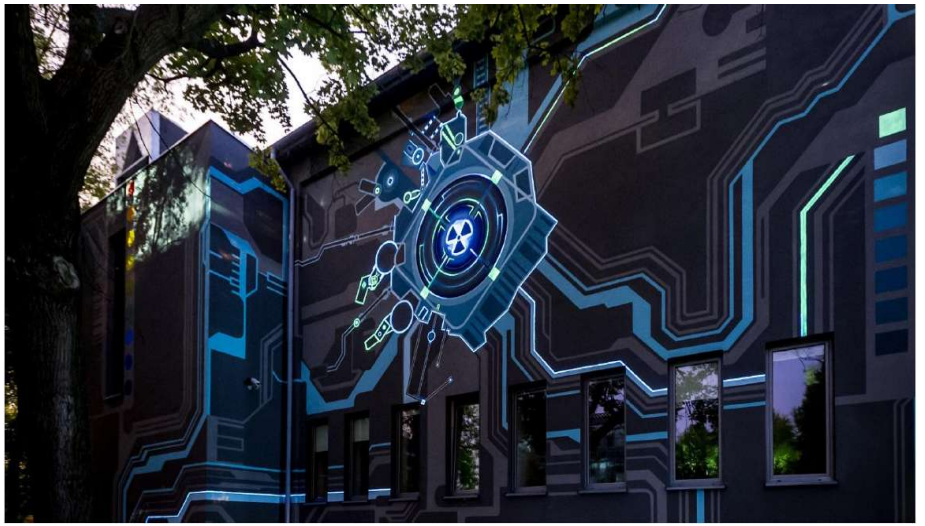
I-131

Mo-99

NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

Department of Complex Systems

Świerk Computing Centre



https://www.ncbj.gov.pl/en/department-complex-systems

- CIS computing cluster (1,4 PFLOPS, ~36 000 cores and 200 TB RAM)
- development of AI and Big Data processing methods
- data analysis in various applications
- development of novel imaging algorithms for medicine and industry

IMPET – Industrial Multiphoton PET Tomography

Objectives:

- **AI-enhanced** solutions for **industrial multiphoton** imaging
- use of **quantum correlation** measurements as complementary information to classical spatial distributions and to PALS methods.
- Development of new **positron emission particle tracking** algorithms
- project of the **industrial scanner** and the library of the **reconstruction methods**

Timeline: **1.02 2025 – 31.01 2028**

contract number: **First Team FENG.02.02-IP.05-0152/23**

Principal Investigator: **Wojciech Krzemień (NCBJ)**

Scientific cooperation:

- **Beatrix Hiesmayr (University of Vienna)**
- **David Sarrut (CREATIS - INSA Lyon)**

Commercial cooperation: **Creotech Instruments S.A.**

Total budget: **~ 940K euro**

Website: **https://pet.ncbj.gov.pl/**

European Funds for Smart Economy
Republic of Poland
Co-funded by the European Union
FNP Foundation for Polish Science

Scientific collaborations

CREATIS Lyon, France

- David Sarrut → Gate development
- Aurelien Coussat → multiphoton image reco algorithms

IT:U interdisciplinary transformation university austria

universität wien

- Beatrix Hiesmayr → quantum correlations in photon systems from Ps decays
- Tobias Sutter

JAGIELLONIAN UNIVERSITY IN KRAKÓW

- Kamil Dulski → positronium lifetime imaging, MC methods

European Funds for Smart Economy
Republic of Poland
Co-funded by the European Union
FNP Foundation for Polish Science

ML-based scatter corrections

Symposium on AI and Reconstruction for Biomedical Imaging, K.Klimaszewski, M.Obara, London, March 9-10, 2026 (Poster)

M. Obara et al., "Data Generation for Machine Learning Classification of Coincidence Events for Siemens Biograph Vision Quadra PET," IEEE EUROCON 2025

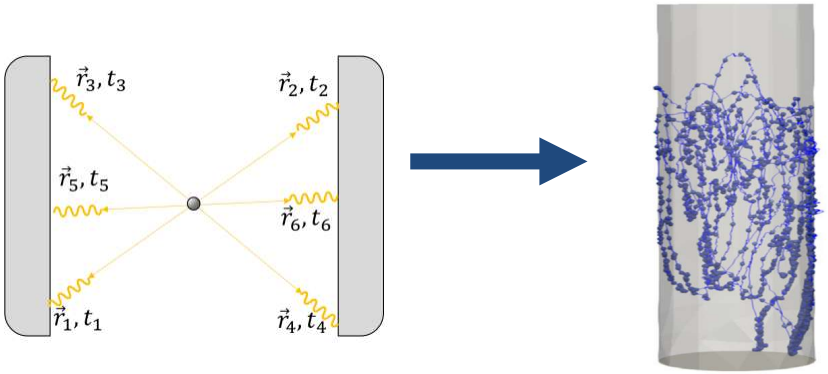
Novel Positronium Lifetime Imaging algo's

Symposium on AI and Reconstruction for Biomedical Imaging, R. Y. Shopa, London, March 9-10, 2026 (Poster)

In collaboration with
Kamil Dulski (Jagiellonian University)

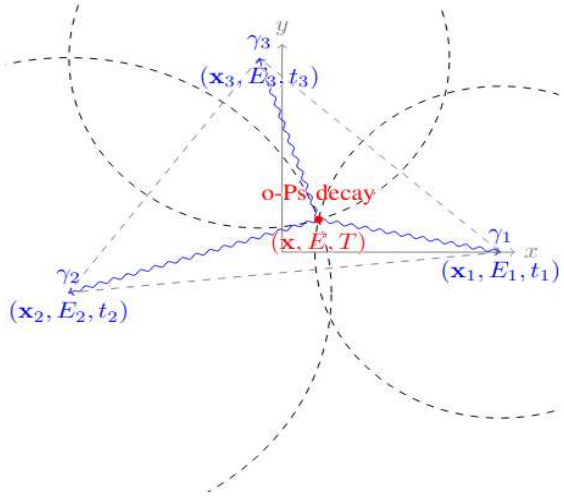
Positron Emission Particle Tracking

L. Raczyński

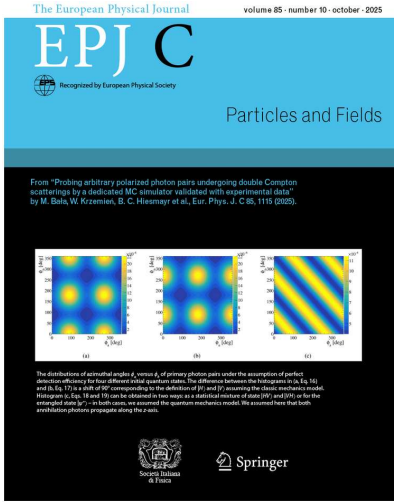


New ortho-positronium vertex reconstruction algo.

L. Raczyński,
W. Krzemień



In collaboration with
Aurelien Coussat
(CREATIS - Lyon)



Models of multi-photon correlations

MC model for arbitrary two-photon intial state:
M. Bała, W. Krzemień, B.C. Hiesmayr, et al. Euro.Phys. J. C 85 (2025)

Multiple scattering formalism in quantum information language:
B. C. Hiesmayr, W. Krzemień, and M. Bała Sci Rep 14, 9672 (2024)

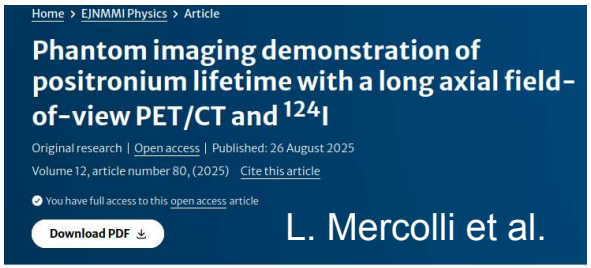
In collaboration with
Beatrix Hiesmayr (IT:U and University of Vienna)
Tobias Sutter (University of Vienna)

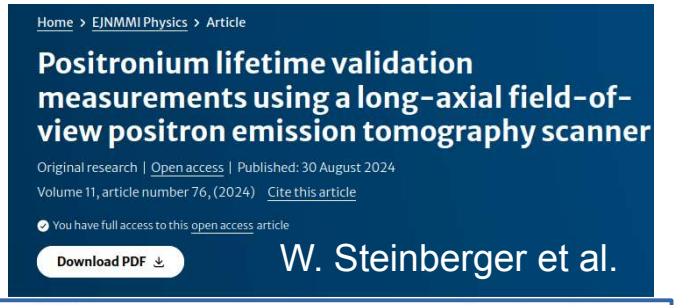
Positronium decay source model with multiple annihilation channels

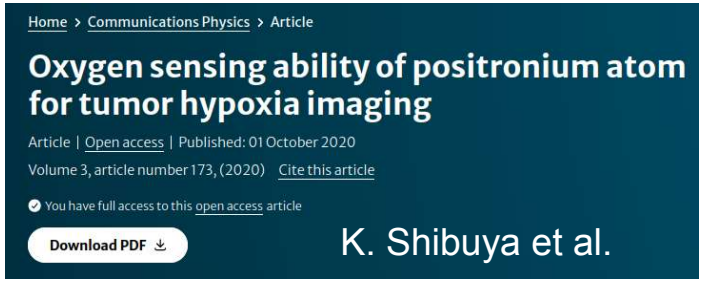
In collaboration with:

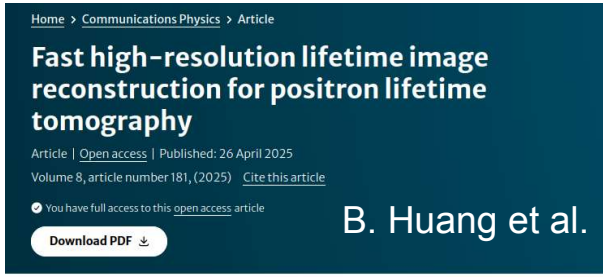
- Mateusz Bała (NCBJ)
- Kamil Dulski (Jagiellonian University)
- Wojciech Zdeb (NCBJ) et al.

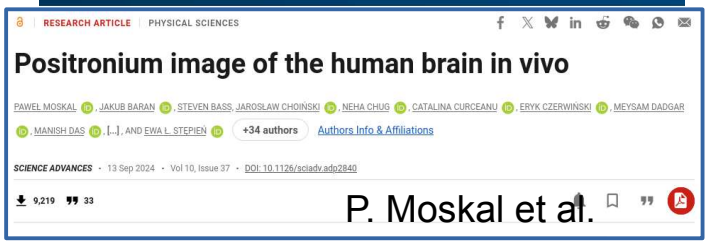
Positronium Lifetime Imaging (+ other markers)











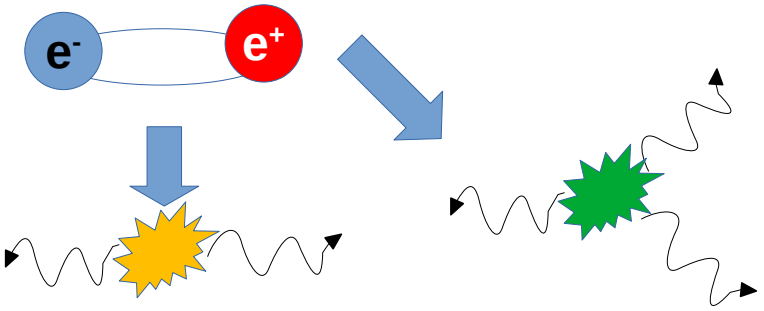
Applications:

- novel medical imaging techniques
- novel industrial imaging techniques

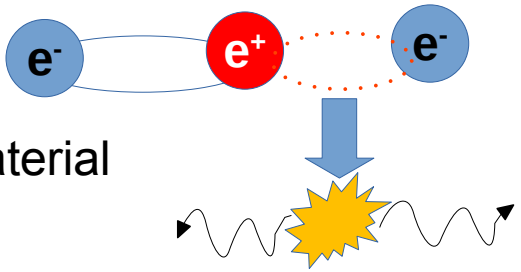
Challenge:
lack of the proper MC tools to perform the simulations

Positronium decay models

Positronium (Ps) decays



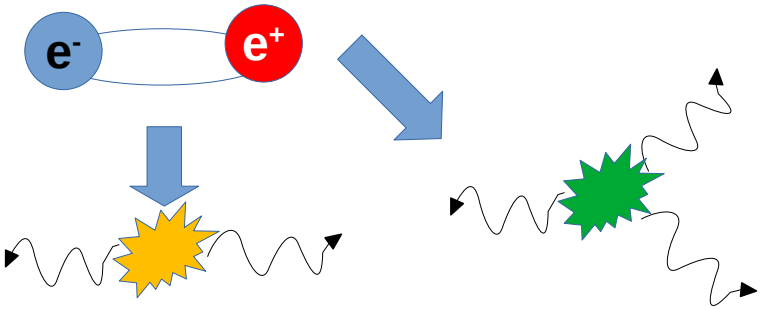
Pick-off



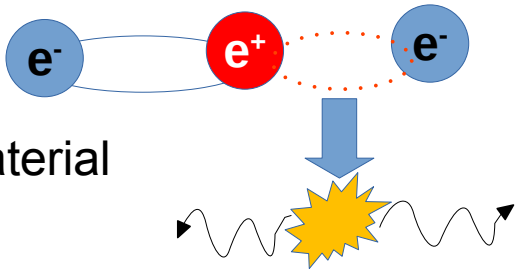
Depends on material surrounding

Positronium decay models

Positronium (Ps) decays

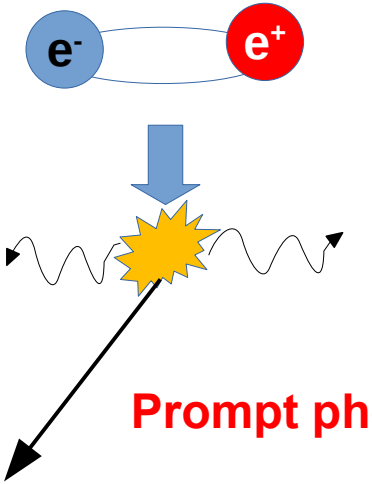


Pick-off

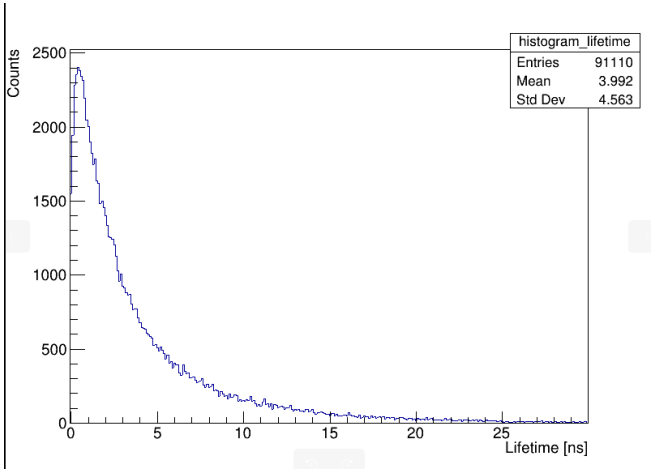


Depends on material surrounding

For PLI non-pure source emitter needed



Prompt photon E*



Start (Ps formation): Emission of prompt photon	Ps Lifetime	Stop (Ps decay): Emission of anihilation photons

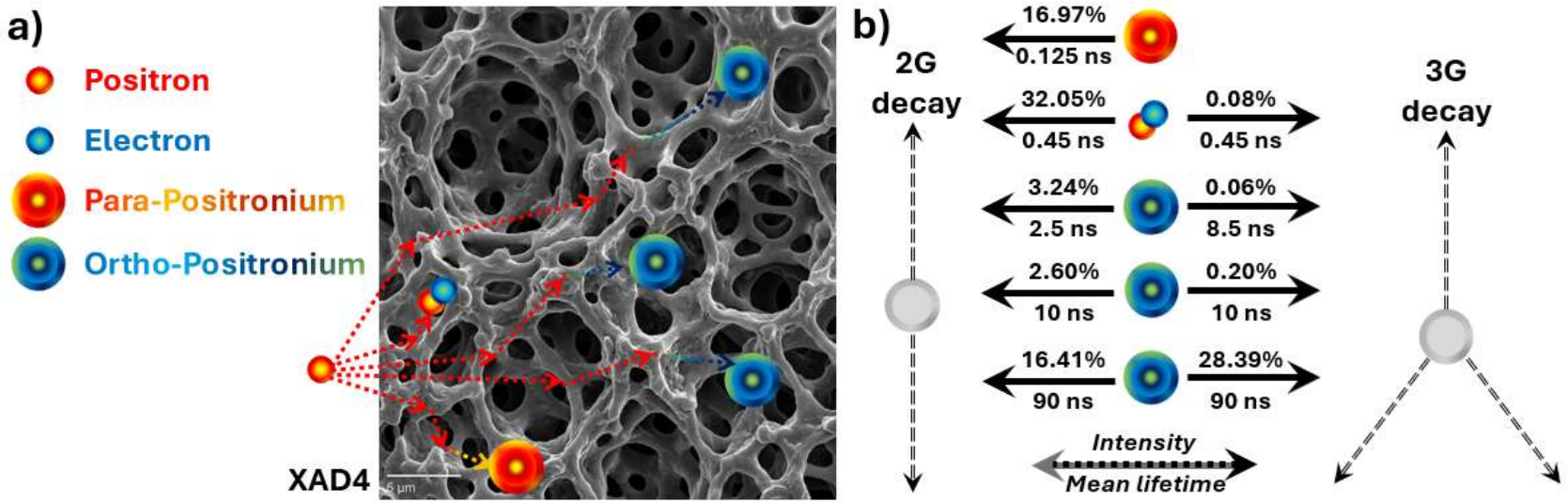
Available implementations

- No native positronium modelling in Geant4

- (Few) Geant4-based „in-house" models developed by some groups
  - Custom solutions for given purposes
  - Code not always „easily" available for the community

- First Ps decay model „**ExtendedVSource"** (GATEv > 9.3) by Mateusz Bała
  - Used by several groups in their researches → published articles.
  - Some (important) limitations:
    - Multi-channel modelling not accesible,
    - simplified prompt photon decay scheme,
    - no positron range modelling

Positronium decay source with multiple annihilation channels

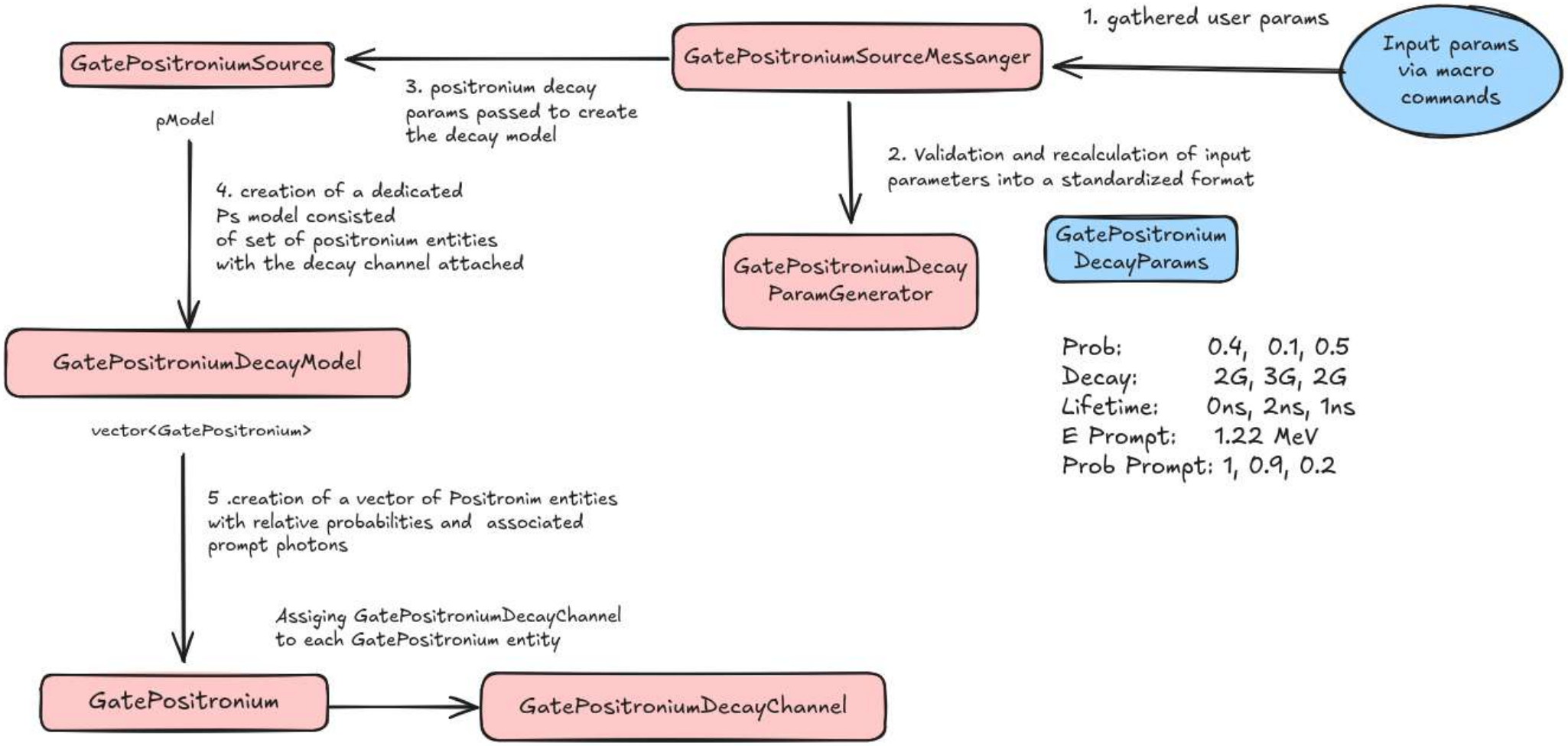


Functionalities

- multi-component decay mode
- complex decay scheme with non-trivial prompt photon emissions
- effective positron range modelling
- Set of helper functions to make the user life easier

Code ported to **GATEv10** but also provided in **Gatev9.4**

Implementation scheme

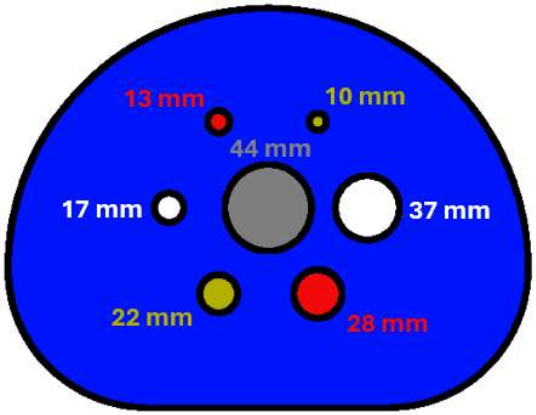


Tests and Benchmarks

Basic tests [done]:

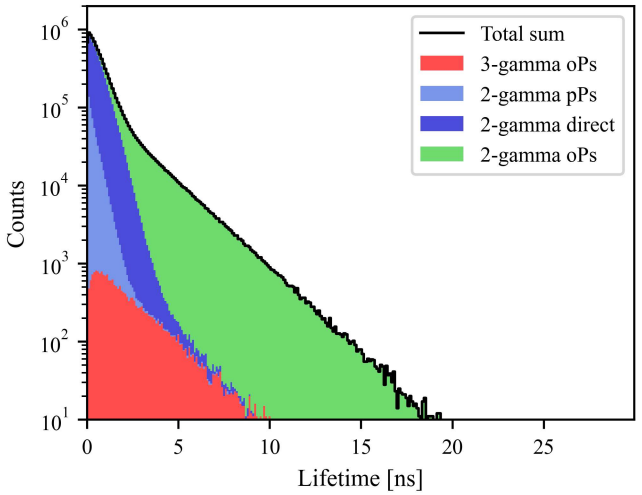
- Set of unit tests for methods developed (**ctest** mecanism used in Gate 9.4)
- Functional backward-compatibilty tests with Gate v9.3
- Self-consistency checks to reproduce expected:
  - fractions of decay channes
  - lifetimes
  - kinematics
  - prompt decay schemes (e.g. using ^{68}Ga, ^{22}Na, ^{124}I sources)
  - 3g-to-2g ratio

Selected „more complex" use cases [almost finished]:

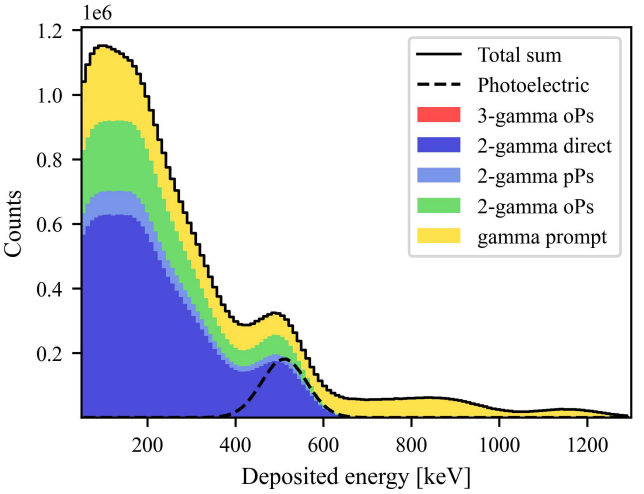


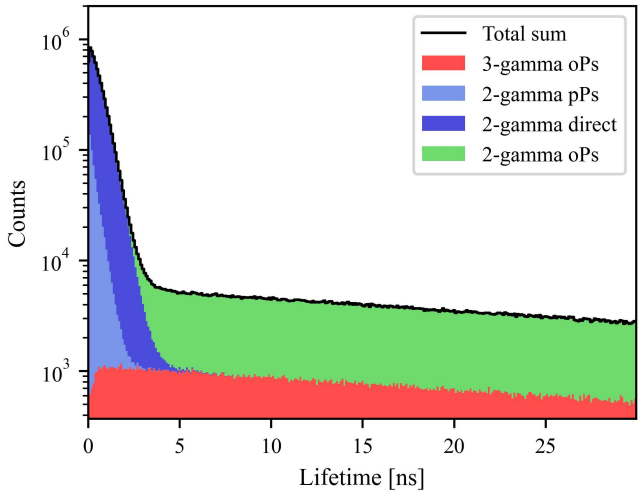
	p-Ps	direct	o-Ps$_1$	o-Ps$_2$	o-Ps$_3$	o-Ps$_4$
Intensity	13%	79%	4.8%	2.7%	2.2%	1.3%
Mean lifetime [ns]	0.125	0.4	2.1	6.3	21	58
Intensity	12%	69.5%	18.5%			
Mean lifetime [ns]	0.152	0.42	2.54			
Intensity	9.2%	76.3%	14.5%			
Mean lifetime [ns]	0.15	0.44	2.04			
Intensity	14%	62%	22%			
Mean lifetime [ns]	0.14	0.4	1.8			

Simulations with a model of Siemens Biograph Vision Quadra (Gate 9.4)

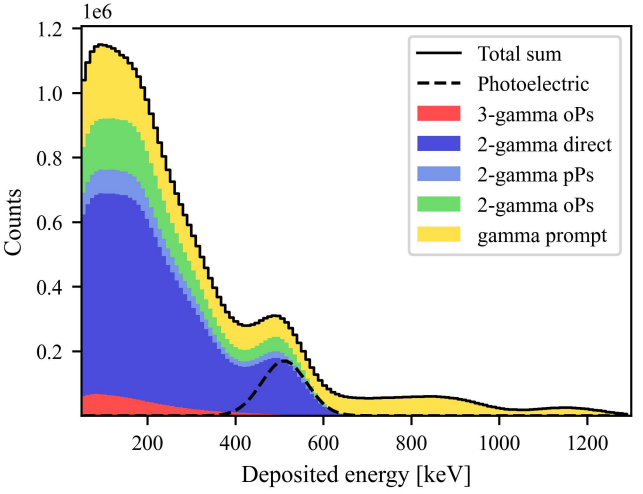


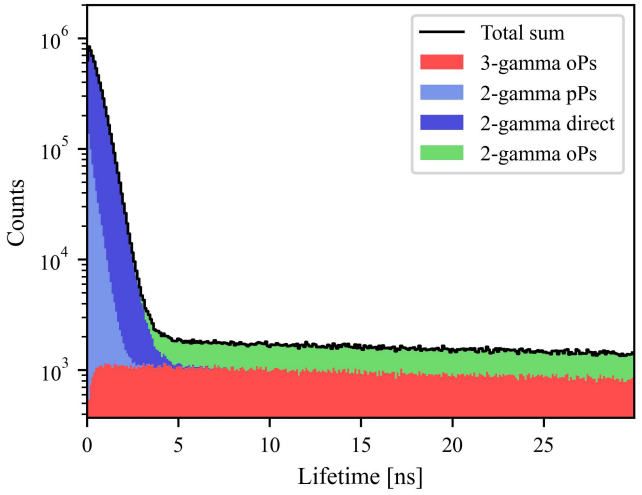
τ(oPs → 3g) = 2 ns



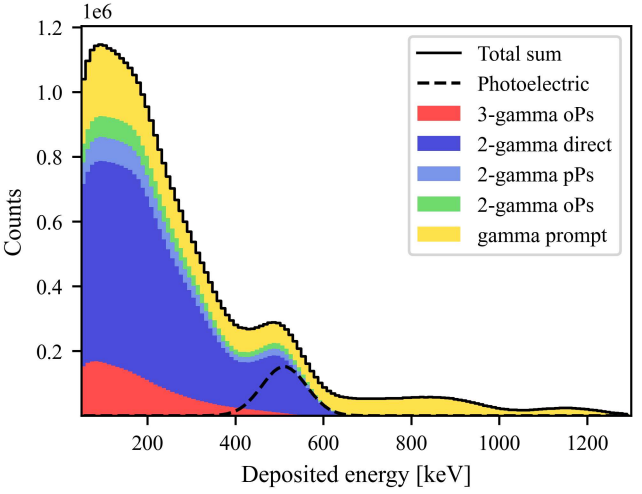


τ(oPs → 3g) = 40 ns





τ(oPs → 3g) = 100 ns



Summary

New multi-channel positronium model for GATE:

- Implementation **[done]**
- Basic tests **[done]**
- Selected „more complex” use cases/benchmarks **[in preparation]**
- **Porting of the code to GATEv10 [done]**

In plans:

- Preparation of PRs **[almost done]**
- Finalization of user parameter handling in Gate 10 **[in progress]**
- Preparation of Docs [:-)]
- Validation with experimental data → in collaboration with M.S. Allen, C. Catana (MIT, MGH Martinos Center) and E. Roncali (UC Davis)

Other Gate-related activities
some memory leaks fixed

Memory leaks fixes + one refactorization by Konrad Klimaszewski for GATE 9v4

- GateVolumeID refactoring (as a thin wrapper to std::vector)
- Fix memory leaks in the digitizer code
- Added as a part of Gate 9v4.2 release

WMLQ2026 is approaching

3rd International Workshop on Machine Learning and Quantum Computing Applications in Medicine and Physics

WMLQ2026

7 to 11 September 2026, Warsaw, Poland

https://events.ncbj.gov.pl/event/468/page/606-home

We acknowledge the support by the Foundation for Polish Science through the FIRST TEAM FENG.02.02-IP.05-0152/23 programme co-financed by the European Union under the European Funds for Smart Economy 2021-2027 (FENG).

European Funds for Smart Economy
Republic of Poland
Co-funded by the European Union
FNP Foundation for Polish Science

Thank you for attention