Monte Carlo simulations for the J-PET scanner

J-PET

Wojciech Krzemień
On behalf of the J-PET collaboration

Gate Technical Meeting
Wuppertal, 23.01. 2020

NATIONAL CENTRE
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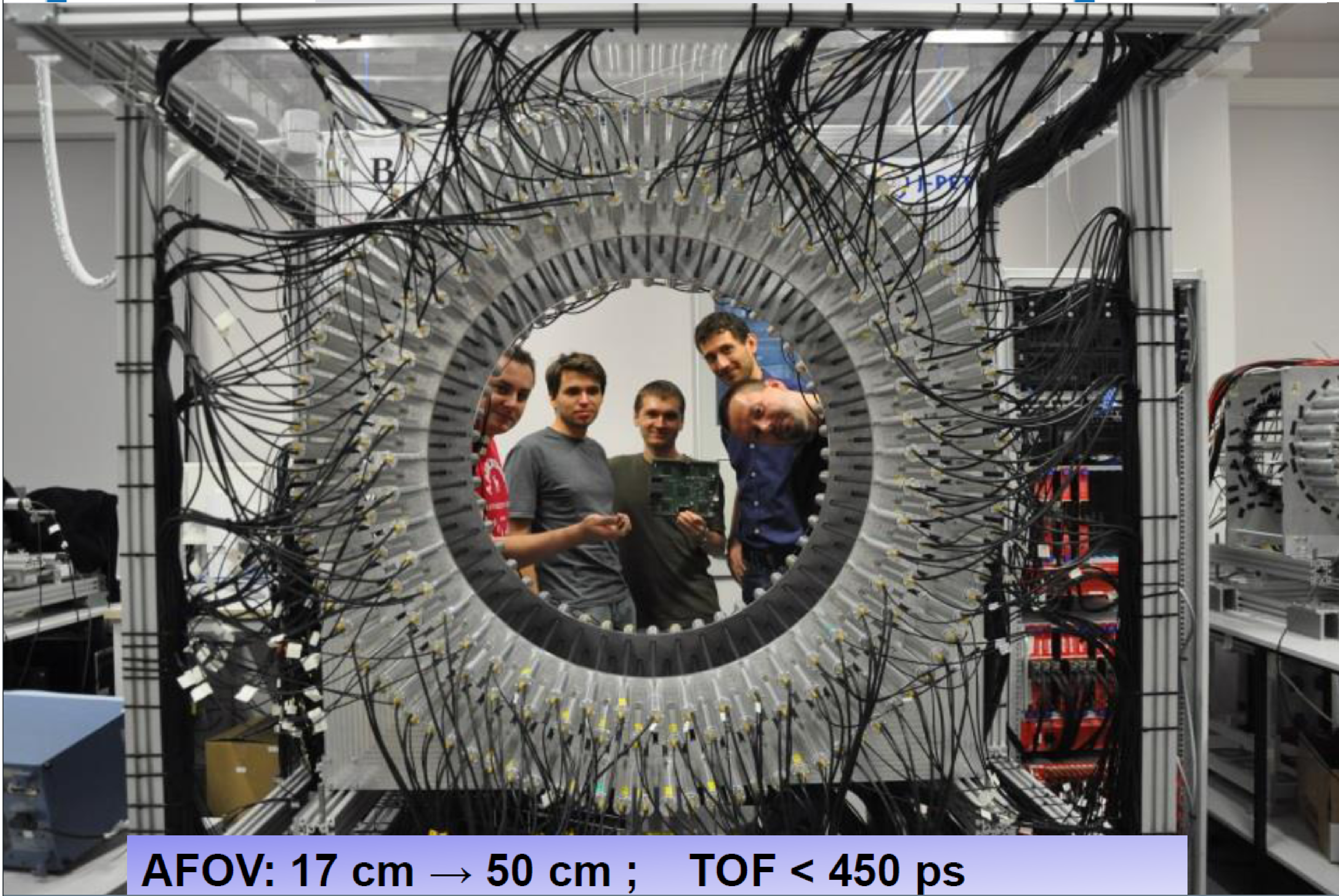
ŚWIERK

Outline

- J-PET project
- **Monte Carlo applications and extensions:**
  - **Scanner performance studies according to NEMA norms**
  - **Positronium imaging**
  - **Image reconstruction**
  - Quantum entanglement/polarization studies
  - Discrete symmetries studies
  - **Application of ML to classification**
  - Proton therapy monitoring

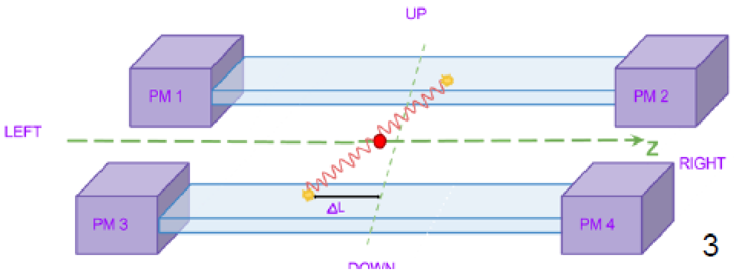
Jagiellonian PET



AFOV: 17 cm → 50 cm ; TOF < 450 ps

Cost-effective total body scanner

$$\Delta l = \frac{(t_2 - t_1) \cdot v}{2} \cong \frac{(t_2 - t_1) \cdot c}{4}$$



$$\Delta x = \frac{(t_l - t_r) \cdot c}{2} \Longrightarrow \Delta x = \frac{\Delta t}{2} \cdot c$$

P. Moskal, P 388 555 [WIPO ST 10/C PL388555] (2009), PCT/PL2010/00062 (2010), WO2011008119, US2012112079, JP2012533734, EP2454612.

J-PET: P. Moskal et al., Nucl. Inst. and Meth. A 764 (2014) 317-321
J-PET: P. Moskal et al., Nucl. Inst. and Meth. A 775 (2015) 54-62
J-PET: P. Moskal et al., Phys. Med. Biol. 61 (2016) 2025-2047

Cost-effective total body solution

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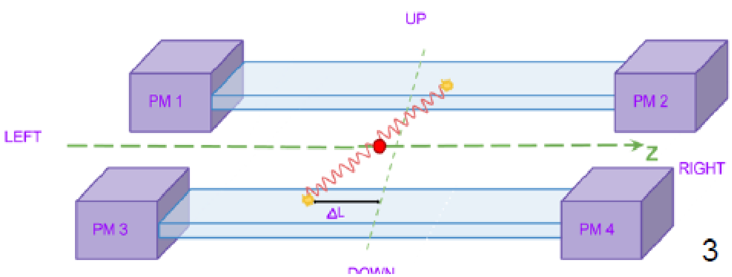

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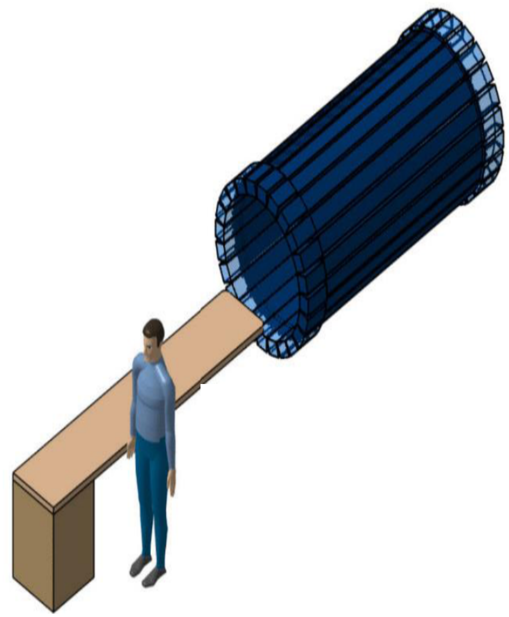

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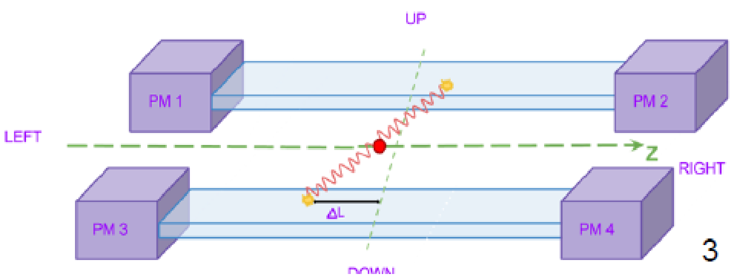
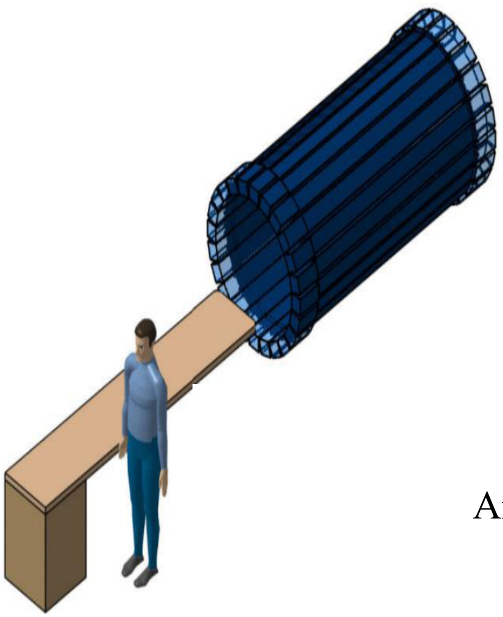


3

$$\Delta x = \frac{(t_l - t_r)\cdot c}{2} \Longrightarrow \Delta x = \frac{\Delta t}{2}\cdot c$$



Change of the paradigm

Crystal	→	**Plastic**
Energy	→	Time
High efficiency	→	Low efficiency
Photoeffect	→	Compton scattering
Low acceptance	→	High acceptance
Analog electronics	→	Digital electronics
Triggering	→	No master trigger

P. Moskal, P 388 555 [WIPO ST 10/C PL388555] (2009), PCT/PL2010/00062 (2010), WO2011008119, US2012112079, JP2012533734, EP2454612.

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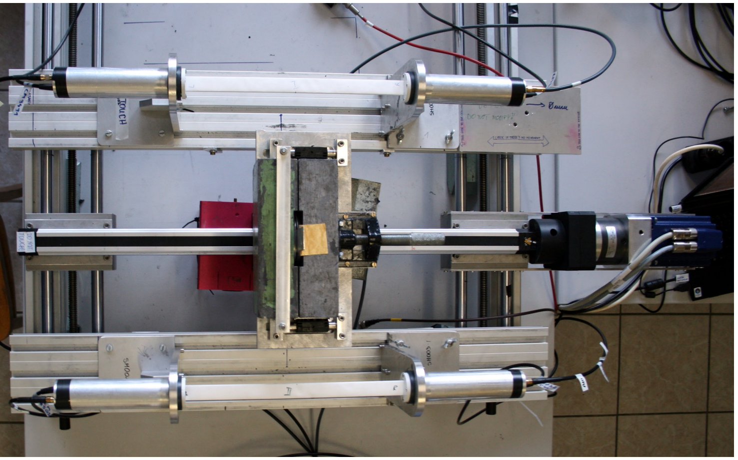
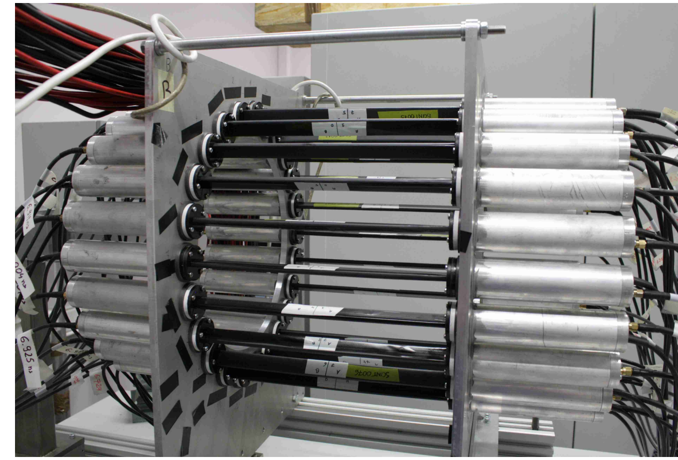
2012

2 strips

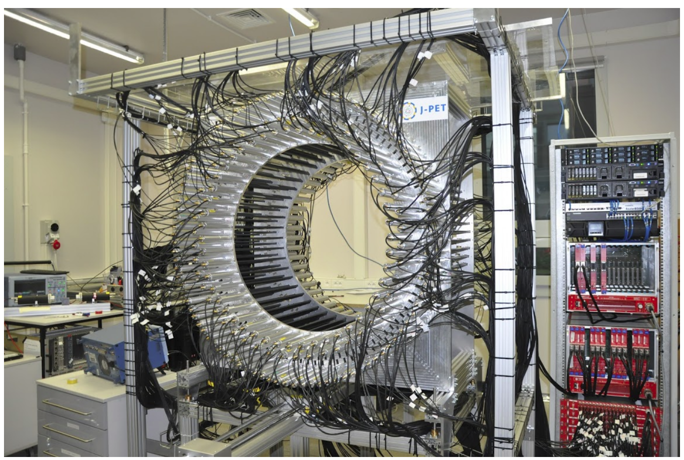


2014

48 plastic strips



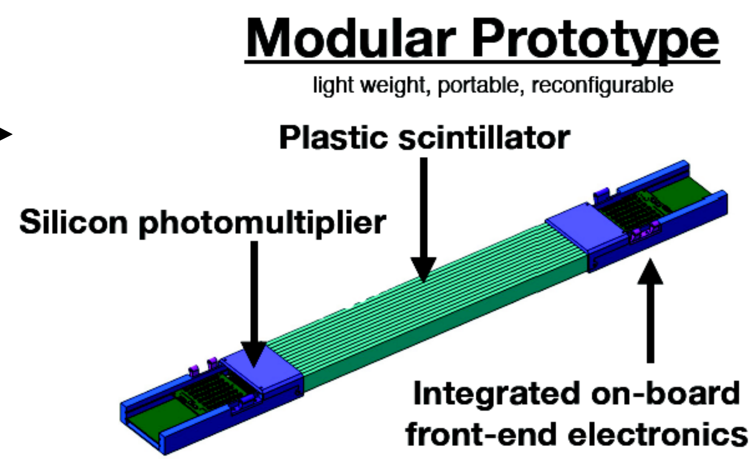
192 plastic strips



2016

- Three cylindrical layers of EJ-230 plastic scintillator strips (7x19x500 mm^3)
- Vacuum tube photomultipliers

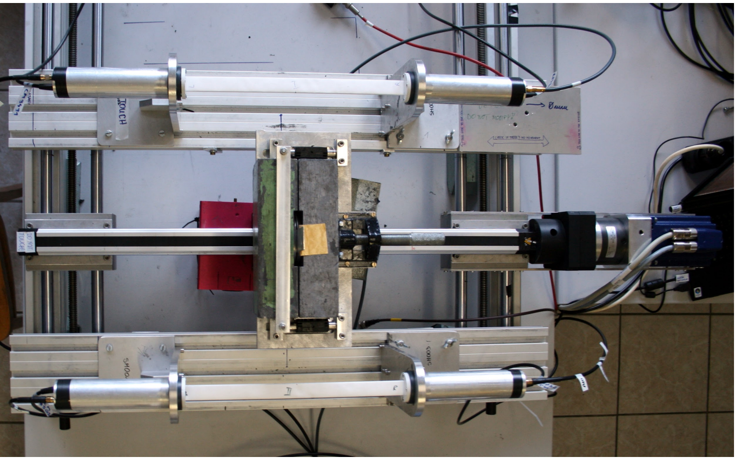
24 modules
312 strips



2018

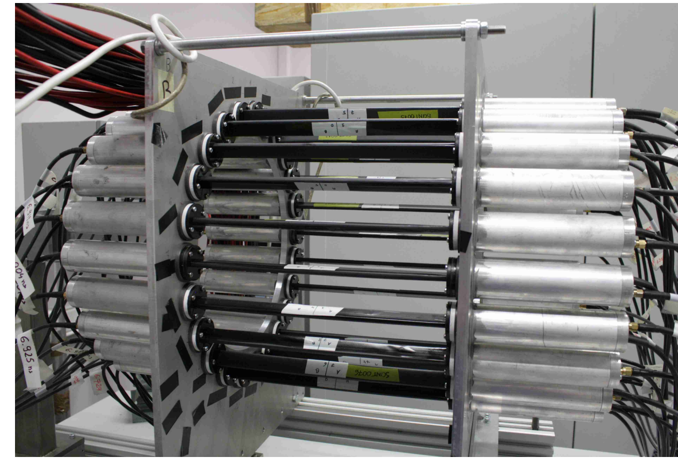
2012

2 strips

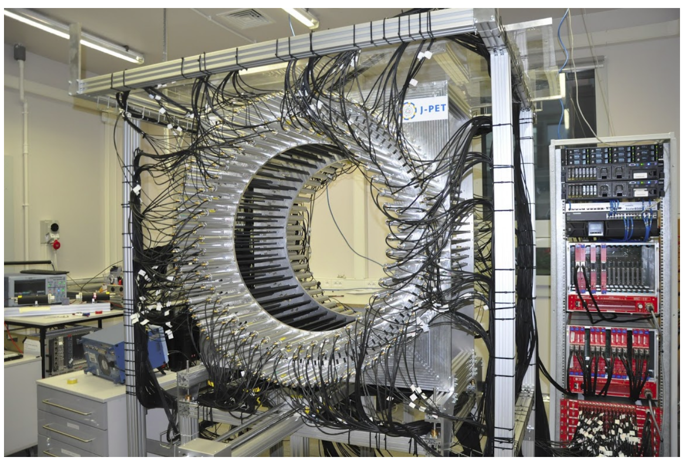


2014

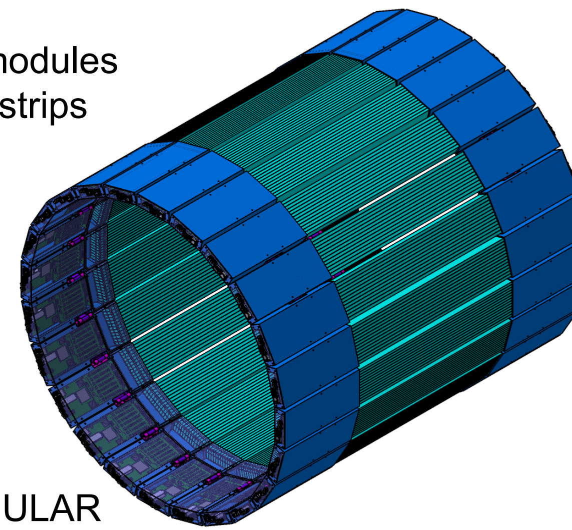
48 plastic strips



192 plastic strips



24 modules
312 strips



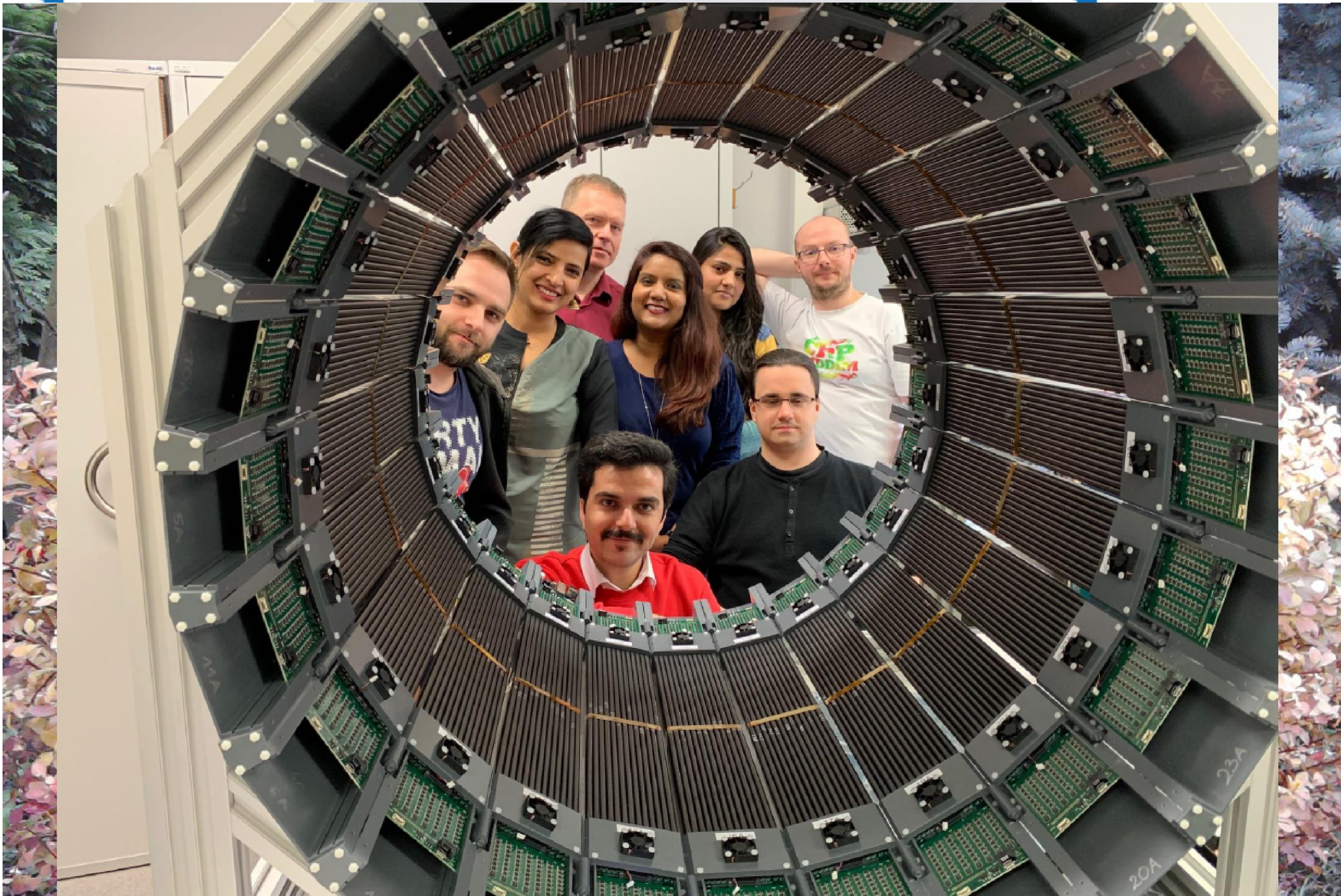
MODULAR

2016

2018

- Three cylindrical layers of EJ-230 plastic scintillator strips (7x19x500 mm^3)
- Vacuum tube photomultipliers

Jagiellonian PET



J-PET Software@GitHub

J-PET collaboration

http://koza.if.uj.edu

https://github.com/JPETTomography

your organization's avatar

22 repositories

Repositories 21 | Packages | People 23 | Teams | Projects | Settings

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J-PET-geant4

Forked from daria137/jpetmc

MC simulations for J-PET using the modified Geant4 package

C++ · Apache-2.0 · 10 · 0 · 0 · 1 · Updated 8 hours ago

-pet-framework-examples

Example analyses based on the J-PET Analysis Framework

C++ · Apache-2.0 · 19 · 1 · 0 · 3 · Updated 15 hours ago

RectangularScintillator

Library for Monte Carlo simulation of photons movement in scintillator of rectangular shape (C++11)

C++ · 1 · 0 · 0 · 0 · Updated 3 days ago

Gate

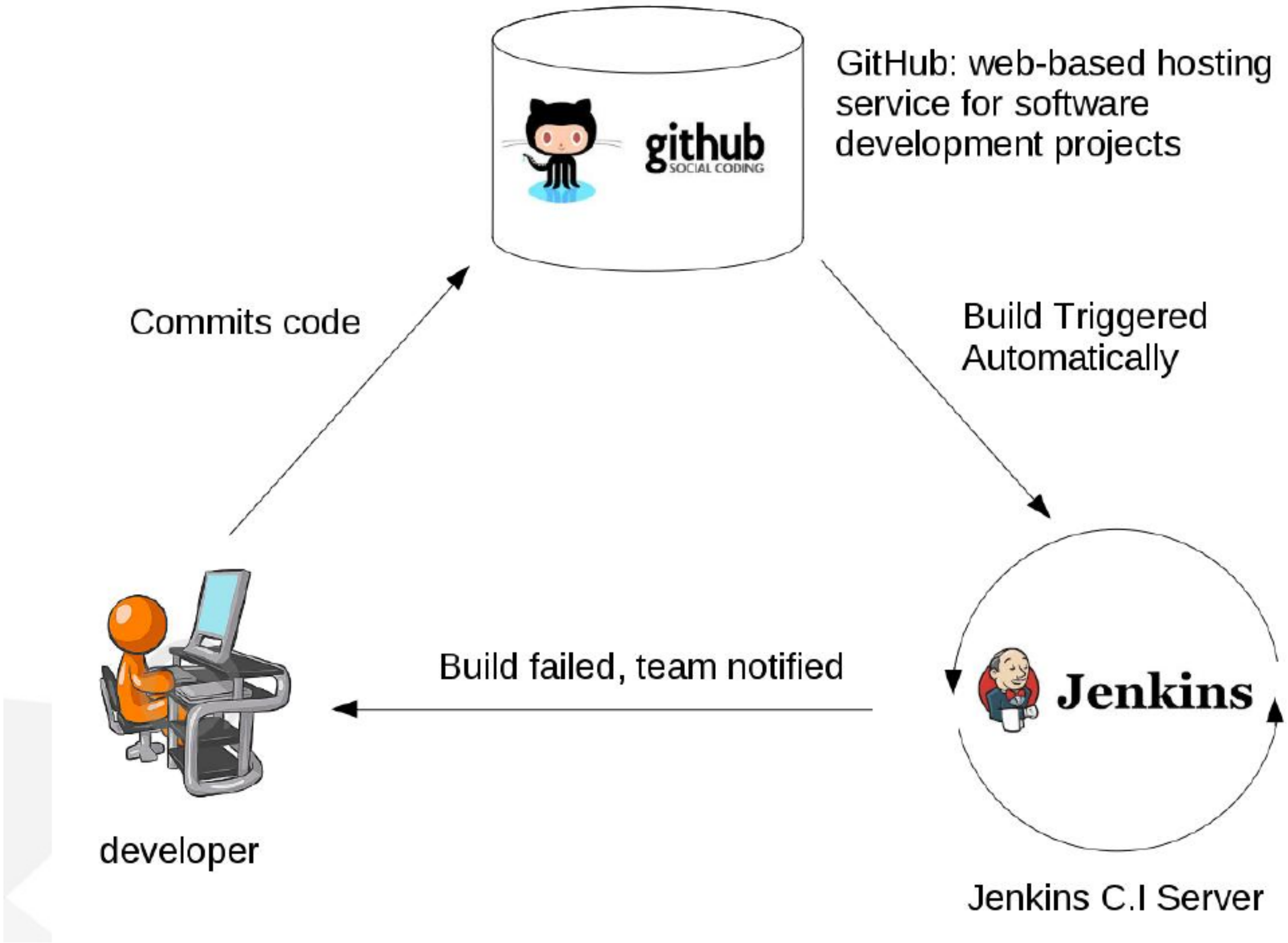
Top languages

C++ · Python · Haskell · R · Mathematica

People 23

0 seats left — Buy more

Continous integration and testing



Travis CI

J-PET software workshops & tutorials

- Third J-PET Framework Workshop, UJ, Kraków, 10.10.2019
- Gate Output J-PET Analyzer(GOJA) Worshop, 23.24 05. 2019
- STIR FBP 3D Workshop, NCBJ, Warszawa, 22.03.2018
- GATE and Reconstruction Workshop, NCBJ, Warszawa, 22.03.2018
- Second J-PET Framework Workshop, UJ, Kraków, 20-21.03.2017
- J-PET Software Workshop, UJ, Kraków, 07-08. 07.2016
- First J-PET Framework Workshop, NCBJ, Warszawa, 09.04.2015

Detector performance studies with GATE

Performance studies of the J-PET scanner according to the NEMA norms

IOP Publishing *Phys. Med. Biol.* **63** (2018) 165008 (17pp) https://doi.org/10.1088/1361-6560/aad29b

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IPEM Institute of Physics and Engineering in Medicine

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PAPER

Estimating the NEMA characteristics of the J-PET tomograph using the GATE package

P Kowalski[1], W Wiślicki[1], R Y Shopa[1], L Raczyński[1], K Klimaszewski[1], C Curceanu[3], E Czerwiński[2], K Dulski[2], A Gajos[2], M Gorgol[4], N Gupta-Sharma[2], B Hiesmayr[5], B Jasińska[4], Ł Kapłon[2], D Kisielewska-Kamińska[2], G Korcyl[2], T Kozik[2], W Krzemień[6], E Kubicz[2], M Mohammed[2,7], S Niedźwiecki[2], M Pałka[2], M Pawlik-Niedźwiecka[2], J Raj[2], K Rakoczy[2], Z Rudy[2], S Sharma[2], S Shivani[2], M Silarski[2], M Skurzok[2], B Zgardzińska[4], M Zieliński[2] and P Moskal[2]

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3 INFN, Laboratori Nazionali di Frascati, 00044 Frascati, Italy
4 Institute of Physics, Maria Curie-Skłodowska University, 20-031 Lublin, Poland
5 Faculty of Physics, University of Vienna, 1090 Vienna, Austria
6 High Energy Physics Division, National Centre for Nuclear Research, 05-400 Otwock-Świerk, Poland
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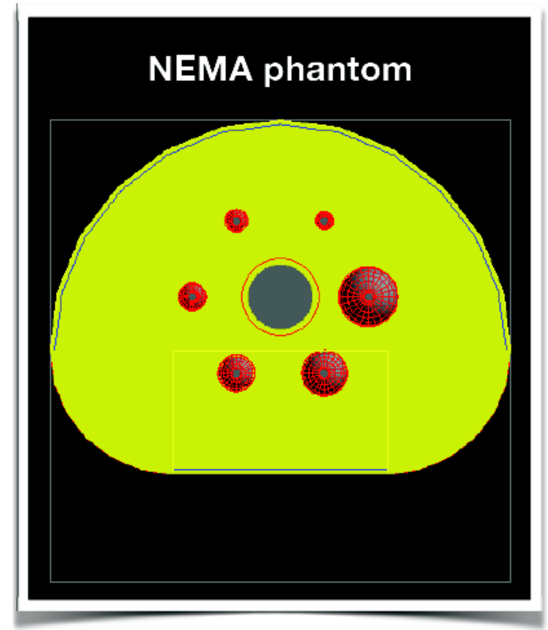
Keywords: NEMA norms, J-PET, positron emission tomography, plastic scintillators

Performance studies of the J-PET scanner according to the NEMA norms

Geometry optimization of the prototype device

- **J-PET detector setup configurations**
  - Plastic length: L (20, 50, 100cm)
  - Diameter: D (75, 85, 95cm)
  - Number of detection layers (1 or 2)
  - Thickness of plastic strips ($20x4cm^2$ or $20x7cm^2$)
  - Readout: PMT, SiPM and SiPMs combined with wavelength shifters

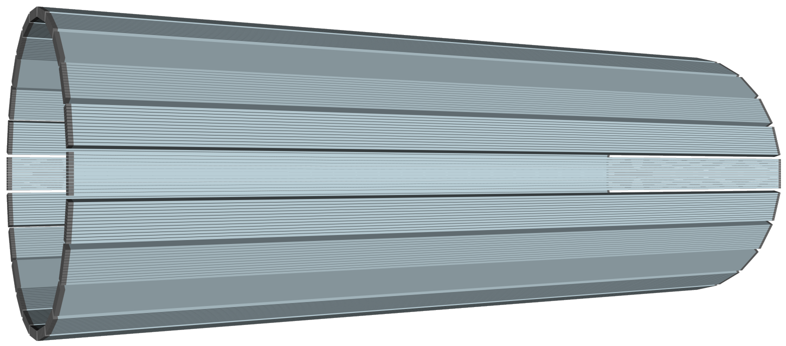
- **National Electrical Manufacturers Association norm (NEMA)**
  - spatial resolution (100cm): **3mm (radial, tangential) and 20mm (axial)**
  - sensitivity (2-layer, 100cm): **14.9 cps/kBq^{-1}**
  - scatter fraction (sin. method): **35%**
  - noise equivalent count rate (NECR): **110 kcps @63 kBq cc^{-1}** (2 layers)



The above studies confirmed that the PET scanner based on plastic scintillator strips may achieve NEMA characteristics comparable to those obtained for commercially used PET scanners. We believe that the presented results may be improved.

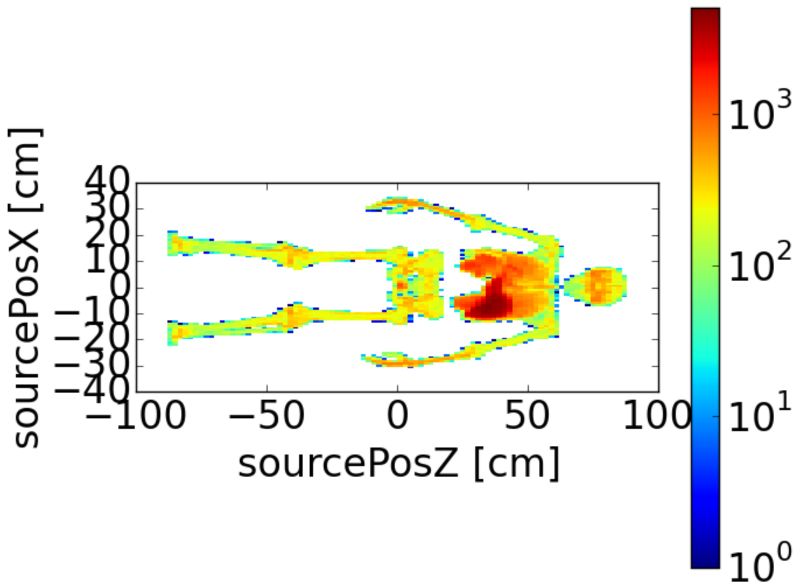
Performance studies of 2 m J-PET scanner

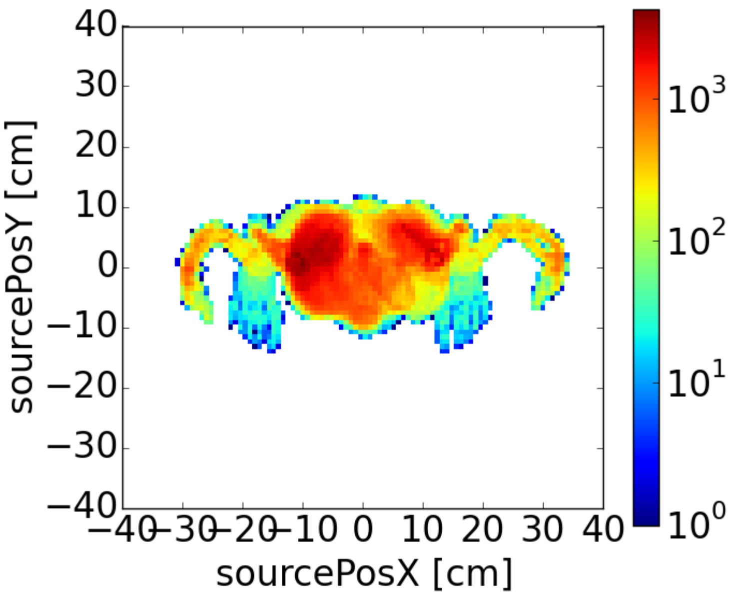
Geometry: 2 m AFOV, 24 or 48 modules, diameter of about 80 cm



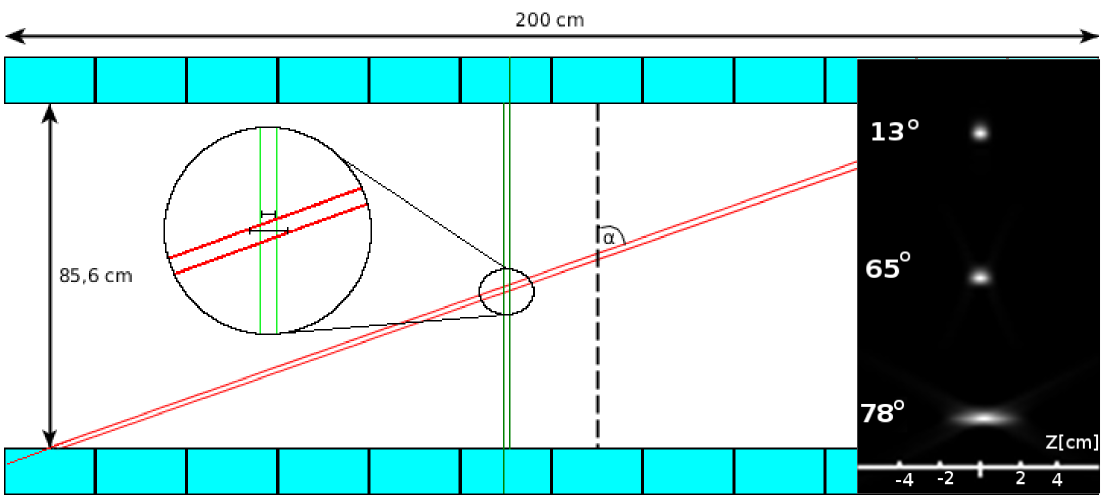
NEMA norms: spatial resolution, sensitivity, scatter fraction, NECR, image quality

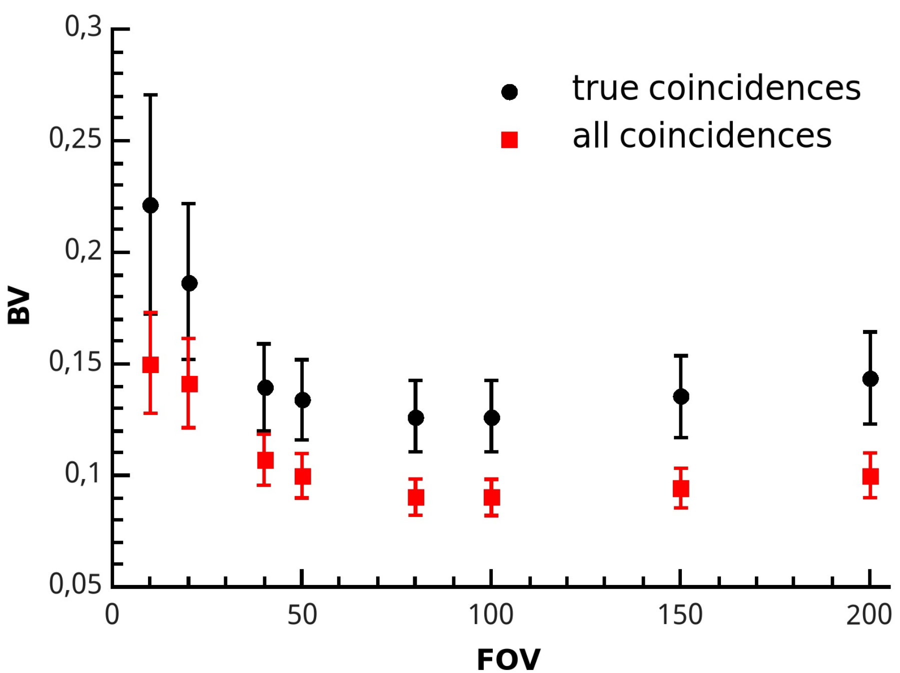
XCAT phantom simulations





Influence of the scanner size on the image quality





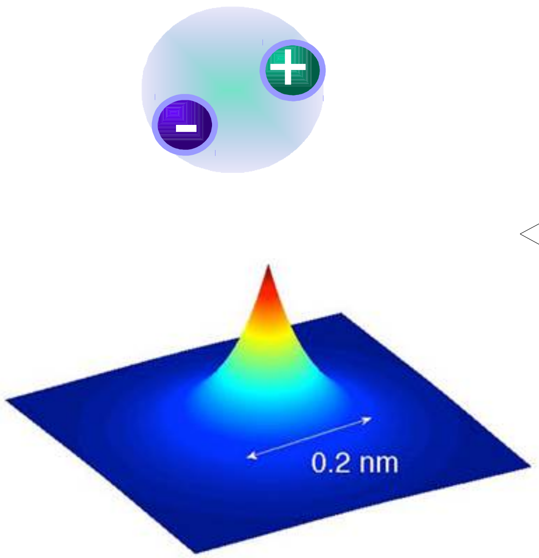
Reconstruction of the NEMA IEC Body Phantom from J-PET Total-body Scanner Simulation Using STIR

[K.Klimaszewski, P.Kopka, DOI:0.5506/APhysPolB.51.357]

- J-PET (GATE) simulation
  - 1 layer – 384 scintillanting strips
  - Strips artificially divided into 2000 "crystals" along axial coordinate
  - Diameter: 85cm, **Length: 200 cm**
  - Point source (gama backtoback 511keV , 100kBq Activity), NEMA IEC Phantom
- FBP 3DRP (STIR) reconstruction without ToF
- Verification of the scanner size influence on the image quality:
  BV – Background Variablity
  CRC – Contrast Recovery Coefficient
- Resolution FWHM:
  - X/Y: ~5 mm,
  - Z ~6÷23 mm
- Optimal image quality for **FoV ~100cm**

Positronium tomography

Implementation of ortho-positronium decays



Para-positronium:
- **lifetime ~125 ps**
- **two-photon decay**

Ortho-positronium:
- **lifetime ~142 ns**
- **three-photon decay**

Positronium tomography

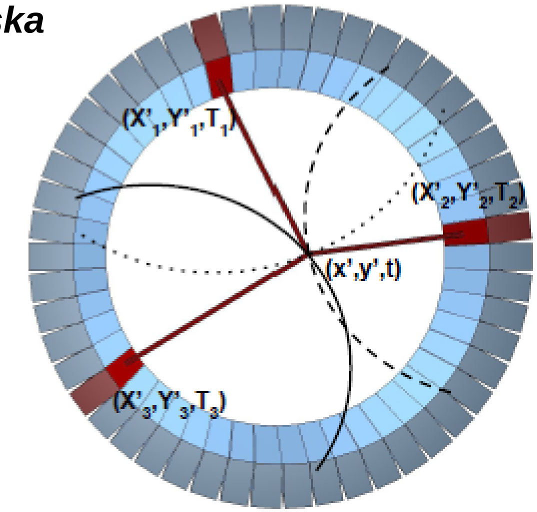
Fundamental physics studies (symmetries)

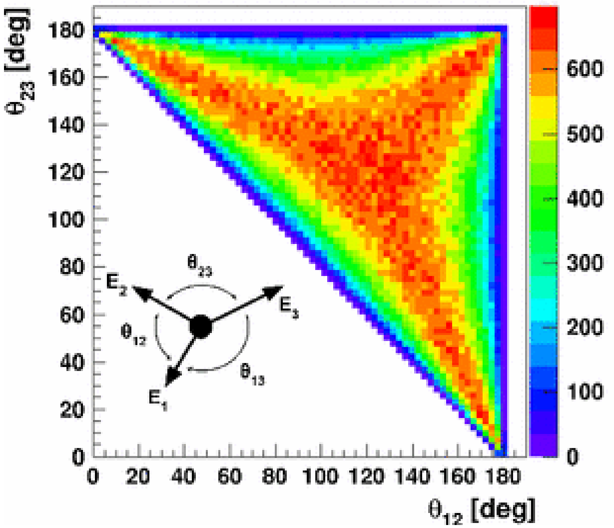
Quantum entanglement tomography

1) P. Moskal et al., Phys. Med. Biol. 64 (2019) 055017
2) P. Moskal et al. Eur. Phys. J. C 78 (2018) 970
3) D. Kaminska et al., Eur. Phys. J. C (2016) 76:445

Implementation of ortho-positronium decays

Daria Kisielewska





Implementation of QED-complient description of orto-positronium decay

Positronium tomography

Fundamental physics studies (symmetries)

Quantum entanglement tomography

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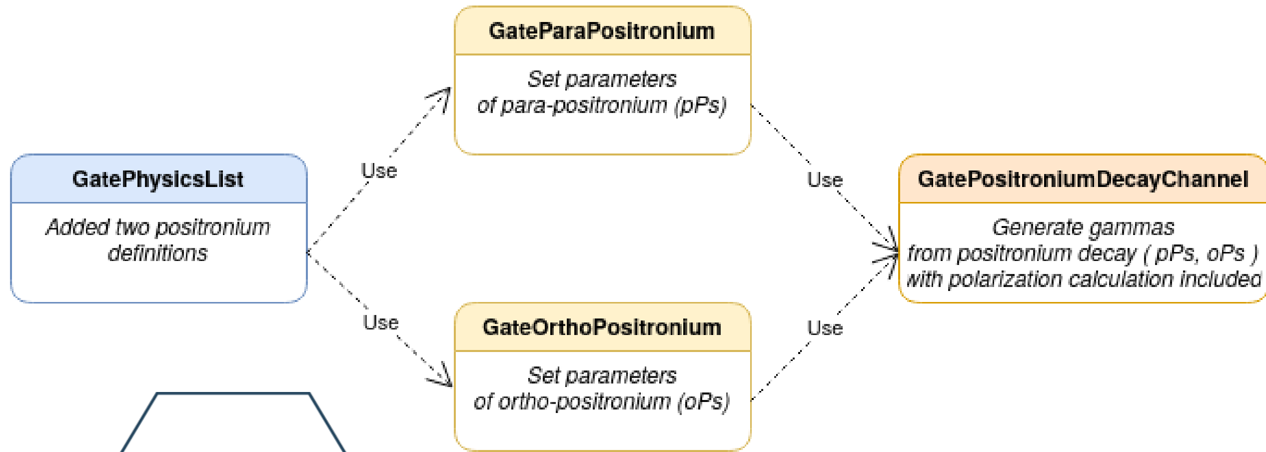
Source extensions in GATE

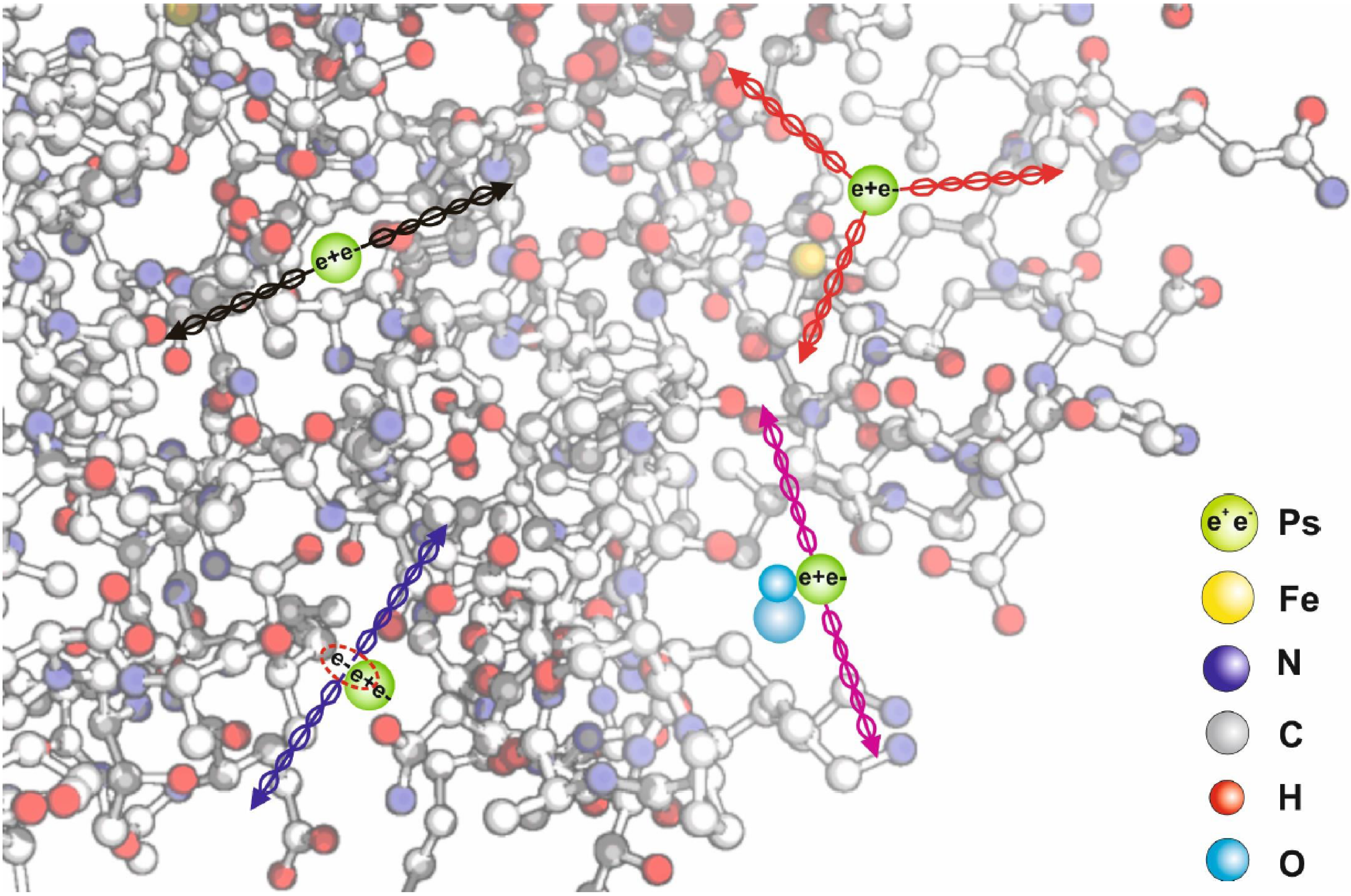
Mateusz Bała

- Ortho-positronium
- Para-positronium
- Non-pure emitters (e.g. scandium sources)
- Polarization degrees of freedom



Merged to GATE develop branch

Model of the hemoglobin molecule



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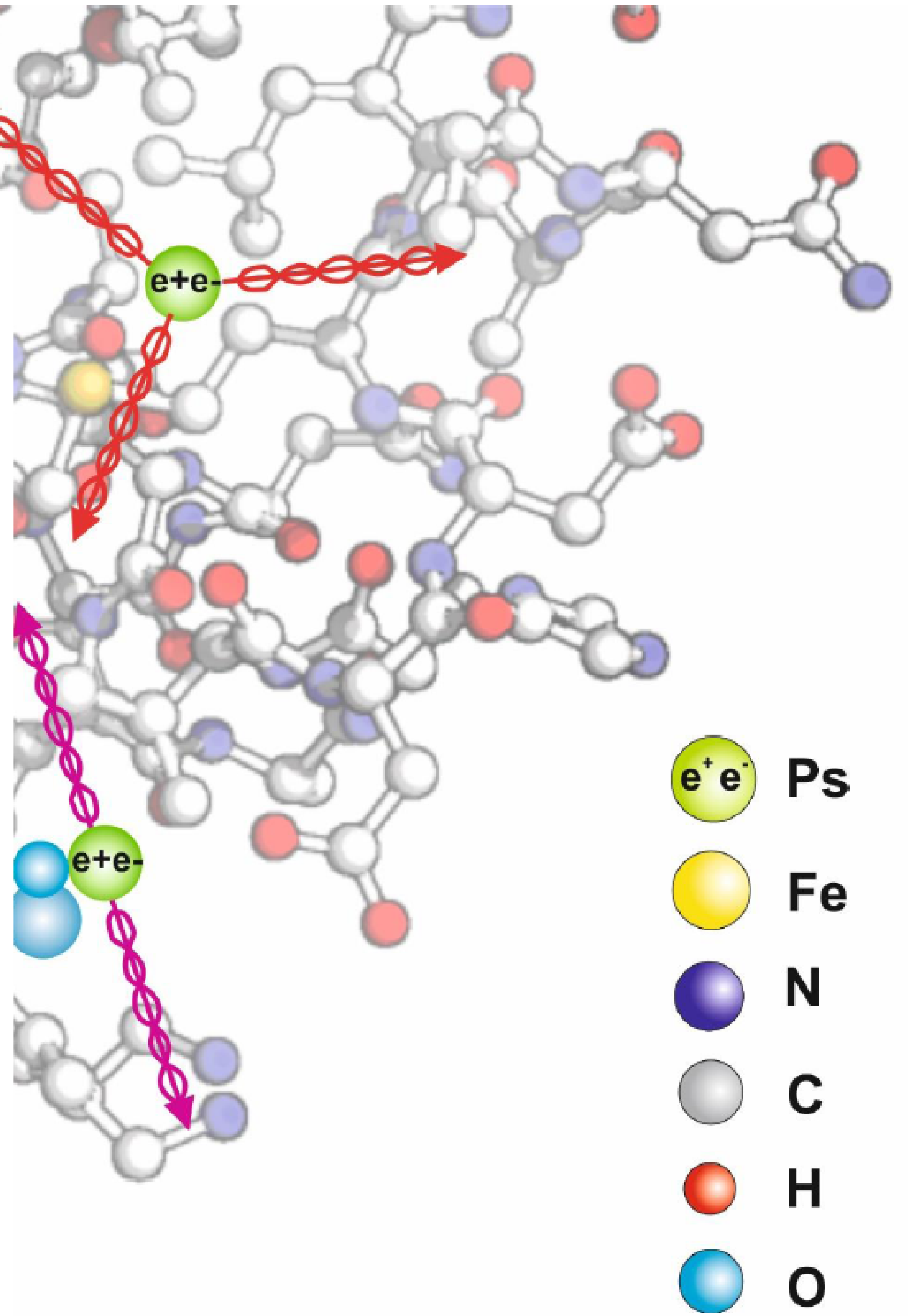

https://www.nature.com/articles/s42254-019-0078-7

Nature Reviews Physics

COMMENT

Positronium in medicine and biology

Paweł Moskal[1], Bożena Jasińska[2]*, Ewa Ł. Stępień[1]* and Steven D. Bass[1,3]**

In positron emission tomography, as much as 40% of positron annihilation occurs through the production of positronium atoms inside the patient's body. The decay of these positronium atoms is sensitive to metabolism and could provide information about disease progression. New research is needed to take full advantage of what positronium decays reveal.

Positronium Physics

Positronium atoms are bound states of an electron and its antiparticle, the positron. Positronium has two ground states, which are distinguished by their decay processes and their lifetimes, which differ by a factor of more than 1,000. Spin-zero para-positronium is even under charge conjugation symmetry — that is, exchanging all particles with their anti-particles results in the same atom — and in vacuum has a lifetime of 125 ps, decaying to two photons. Spin-one ortho-positronium is odd under charge conjugation and in vacuum has a lifetime of 142 ns, decaying to three photons. More details of the fundamental physics of positronium are given in BOX 1.

Positronium decays in biological material

However, inside biological materials, the picture is more complicated. In that setting, positronium mean lifetime and formation probability depend on the healthiness of the material, its nanostructure and concentration of bio-active molecules; these factors are indicative of the stage of development of metabolic disorders of human tissues.

typically of similar strength, with the details dependent on the size of intermolecular voids and the concentration of bio-active molecules. Key observables are the positronium lifetime in the medium, the ratio of two-photon to three-photon decay rates and the probability of positronium production in the biomaterial.

Measuring positronium lifetimes

The fate of the positronium atom is investigated by positron annihilation lifetime spectroscopy (PALS). The advantage of using PALS to investigate the structural transformations and micro-environmental changes of a biological sample is that PALS is nondestructive and preserves the structural characteristics of the sample. In particular, PALS can test for structural changes in biological polymeric systems such as chitosan, bilayer interphases (emulsions, liposomes and micellar systems) or self-assembled biomimetic systems as bio-membranes. In terms of specific membrane diffusion and permeability properties, PALS is sensitive to the nanostructural changes caused by the formation of bioactive nano-

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PAPER

Feasibility study of the positronium imaging with the J-PET tomograph

P Moskal[1], D Kisielewska[1], C Curceanu[2], E Czerwiński[1], K Dulski[1], A Gajos[1], M Gorgol[3], B Hiesmayr[4], B Jasińska[3], K Kacprzak[1], Ł Kapłon[1], G Korcyl[1], P Kowalski[5], W Krzemień[6], T Kozik[1], E Kubicz[1], M Mohammed[1,7], Sz Niedźwiecki[1], M Pałka[1], M Pawlik-Niedźwiecka[1], L Raczyński[5], J Raj[1], S Sharma[1], Shivani[1], R Y Shopa[5], M Silarski[1], M Skurzok[1], E Stępień[1], W Wiślicki[5] and B Zgardzińska[3]

1 Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, 30-348 Cracow, Poland
2 INFN, Laboratori Nazionali di Frascati, 00044 Frascati, Italy
3 Institute of Physics, Maria Curie-Skłodowska University, 20-031 Lublin, Poland
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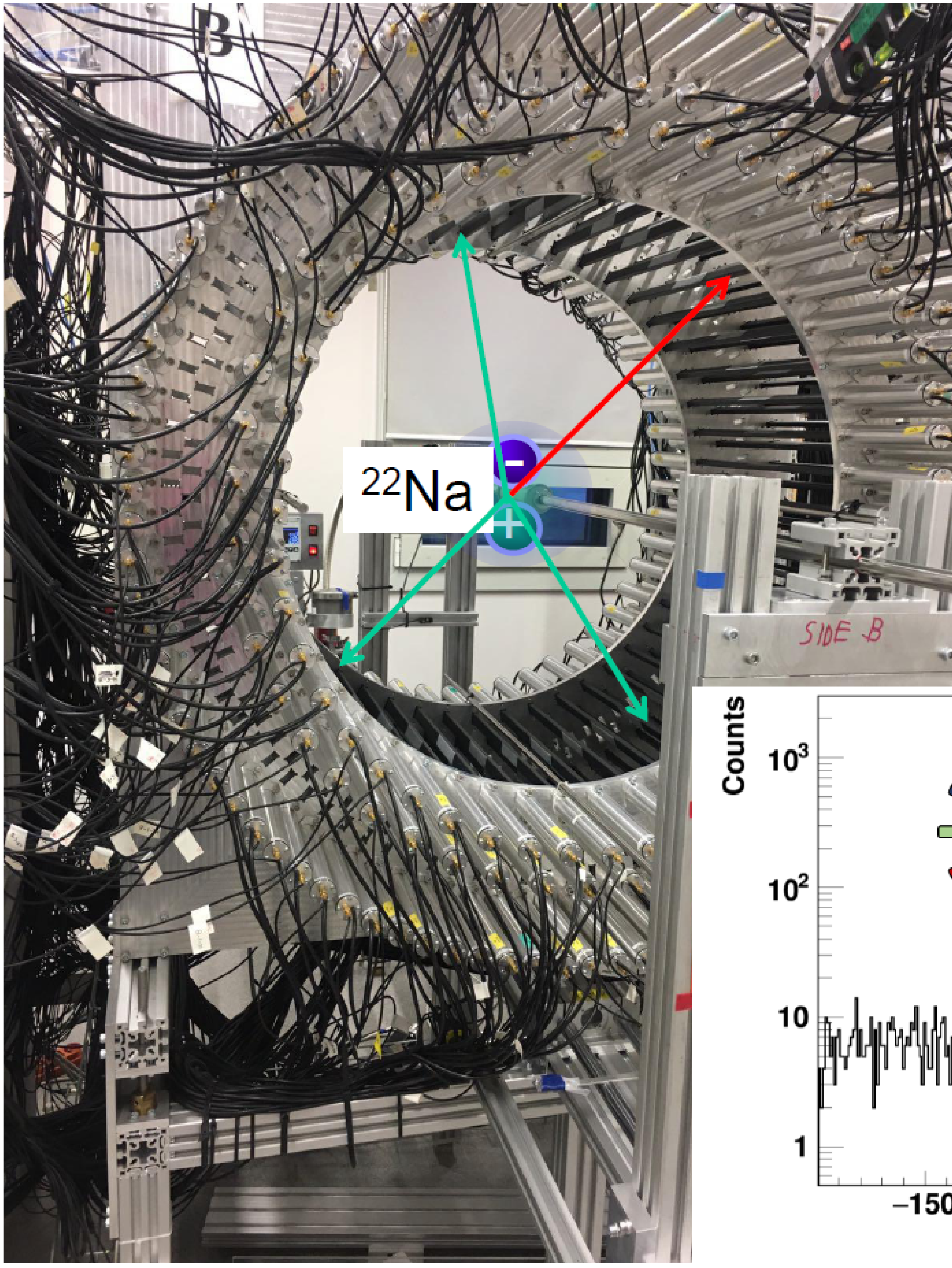
6 High Energy Physics Division, National Centre for Nuclear Research, 05-400 Otwock-Świerk, Poland
7 Department of Physics, College of Education for Pure Sciences, University of Mosul, Mosul, Iraq

E-mail: daria.kisielewska@uj.edu.pl

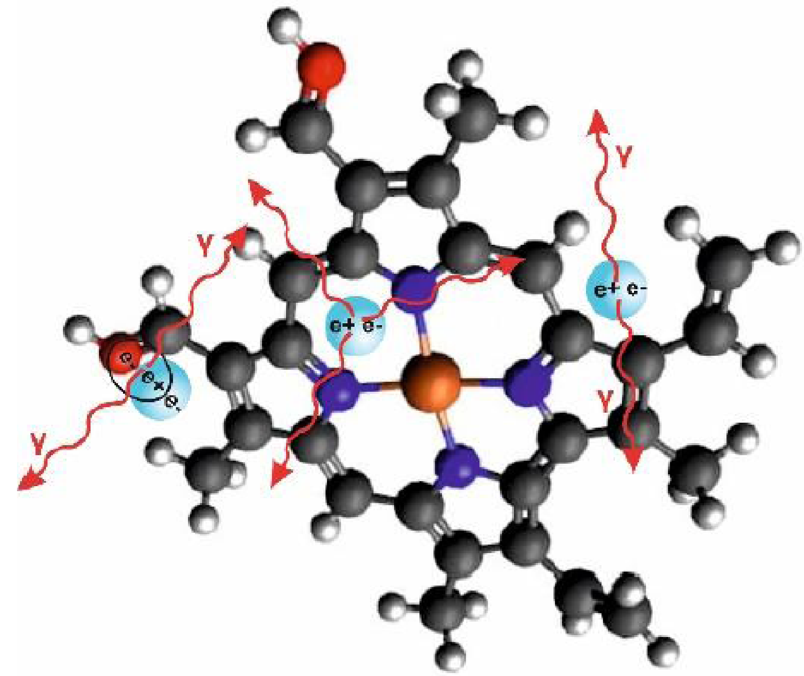
Keywords: positron emission tomography, positronium atom, J-PET

Abstract

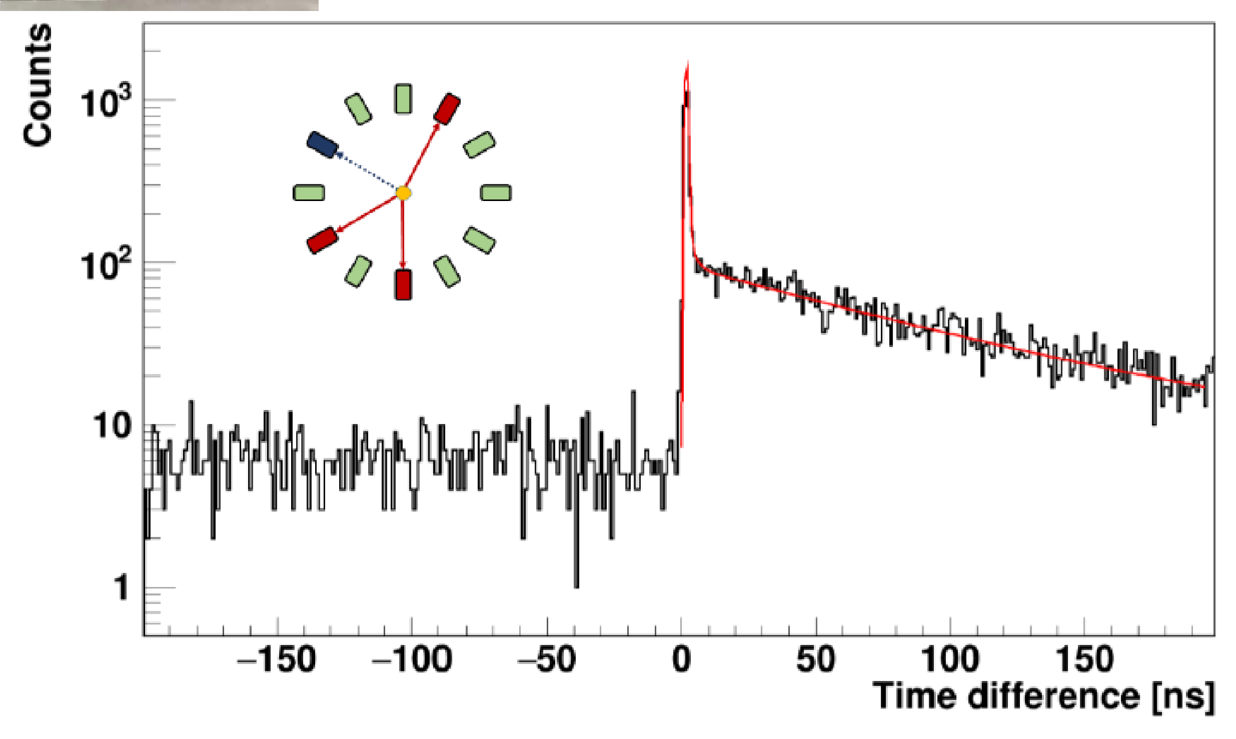
A detection system of the conventional PET tomograph is set-up to record data from e^+e^- annihilation into two photons with energy of 511 keV, and it gives information on the density distribution of a radiopharmaceutical in the body of the object. In this paper we explore the possibility of performing the three gamma photons imaging based on ortho-positronium



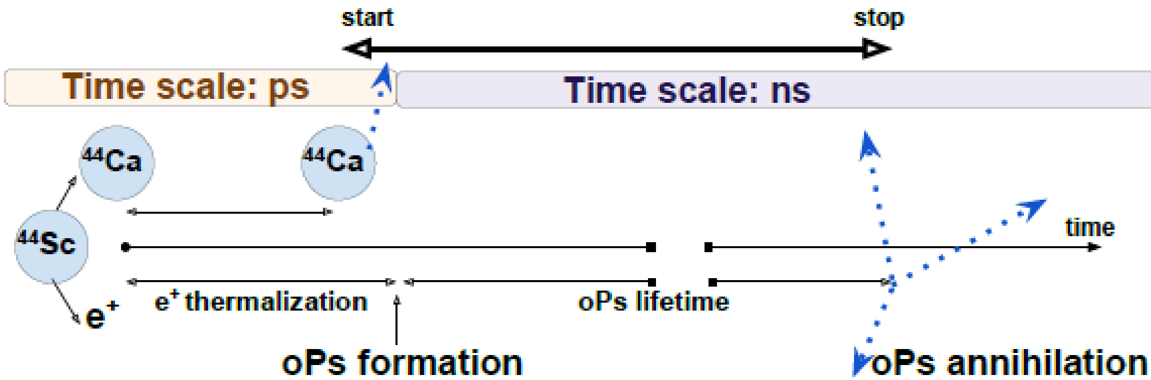
^{22}Na
SIDE B

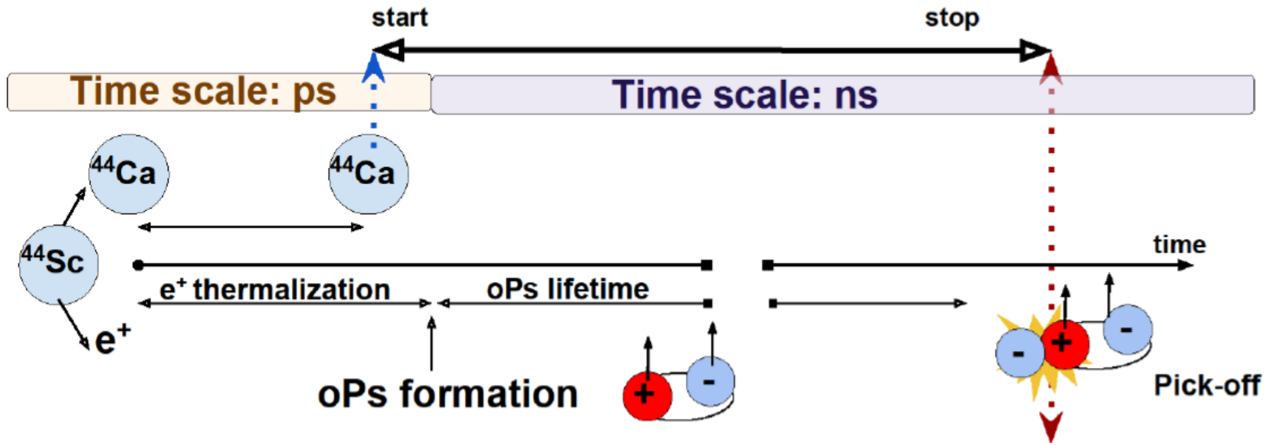


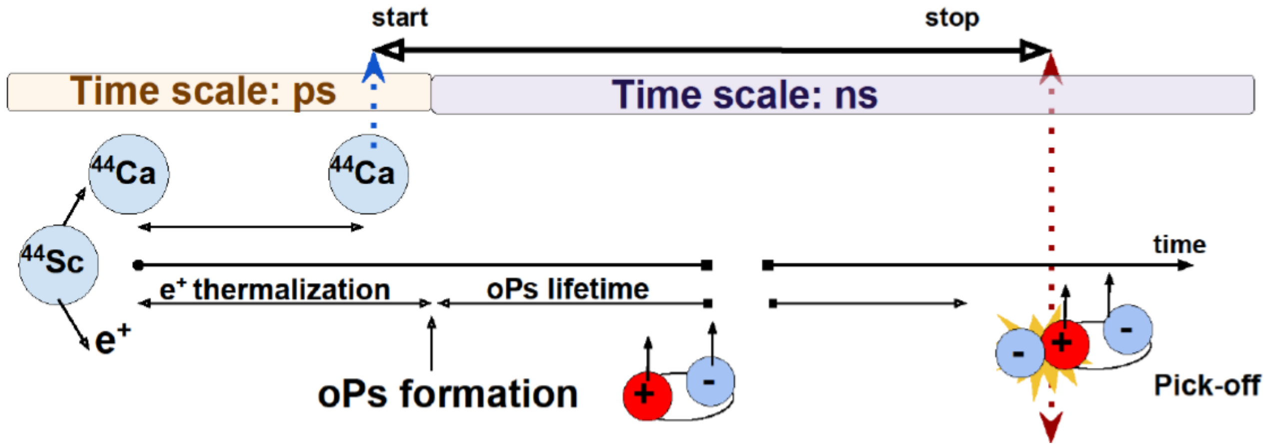
γ
e+ e-

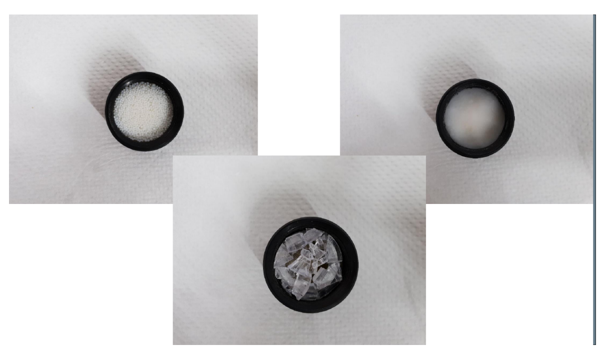


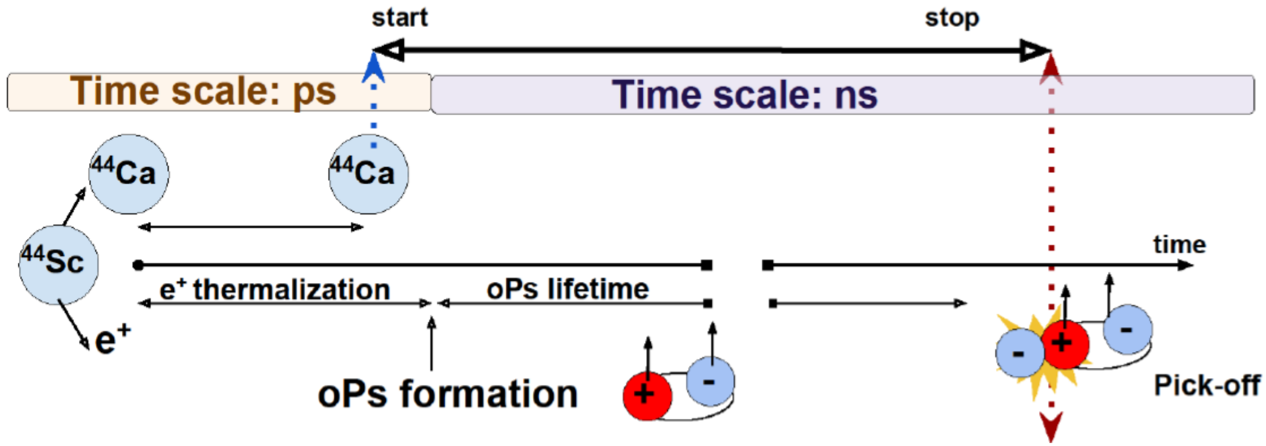
Counts
10^3
10^2
10
1
−150
−100
−50
0
50
100
150
Time difference [ns]

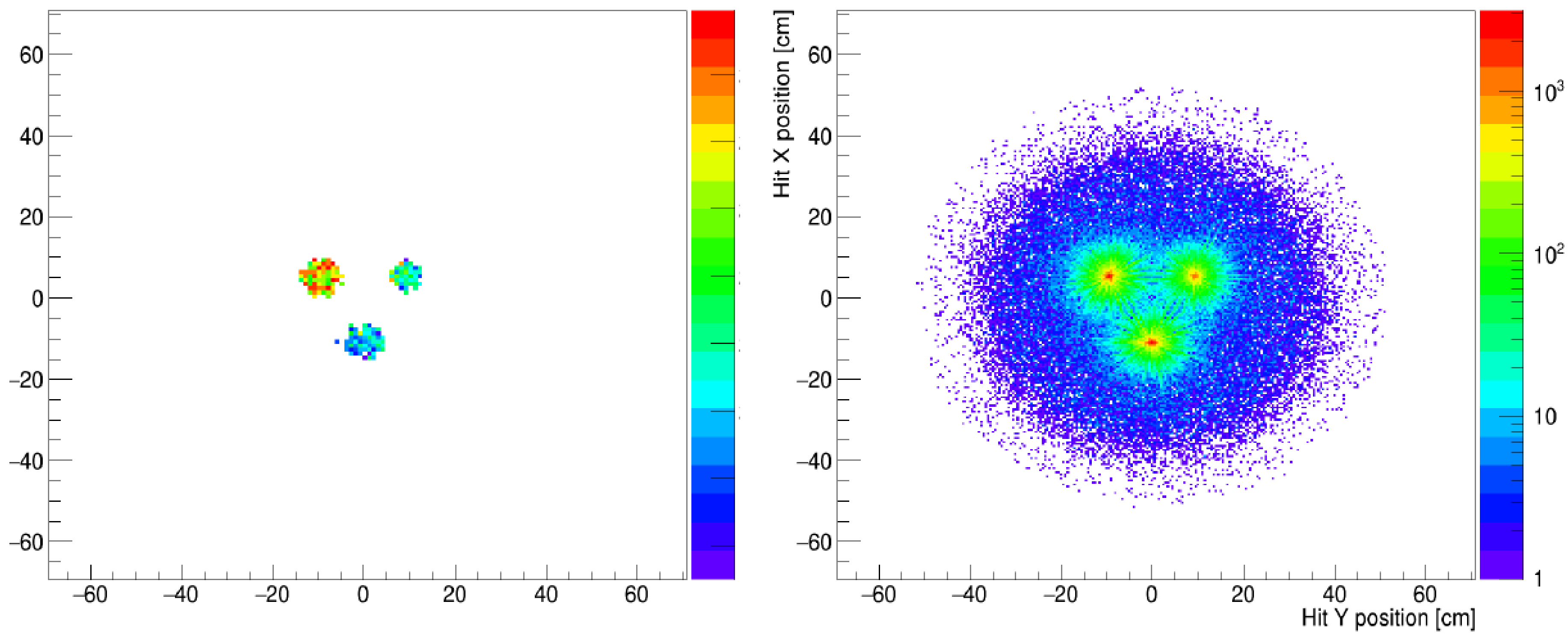

start
stop
Time scale: ps
Time scale: ns
44Ca
44Ca
44Sc
time
e+
e+ thermalization
oPs lifetime
oPs formation
oPs annihilation


start
stop
Time scale: ps
Time scale: ns
44Ca
44Ca
44Sc
e+
time
e+ thermalization
oPs lifetime
oPs formation
+
-
-
+
-
Pick-off


start
stop
Time scale: ps
Time scale: ns
44Ca
44Ca
44Sc
time
e+ thermalization
oPs lifetime
e+
oPs formation
Pick-off




start
stop
Time scale: ps
Time scale: ns
44Ca
44Ca
44Sc
e+
time
e+ thermalization
oPs lifetime
oPs formation
Pick-off


Hit X position [cm]
Hit Y position [cm]
60
40
20
0
−20
−40
−60
10^3
10^2
10
1

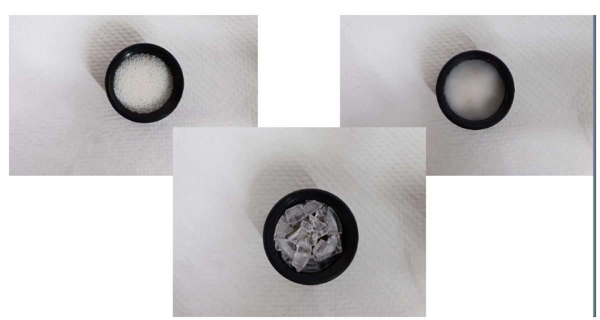


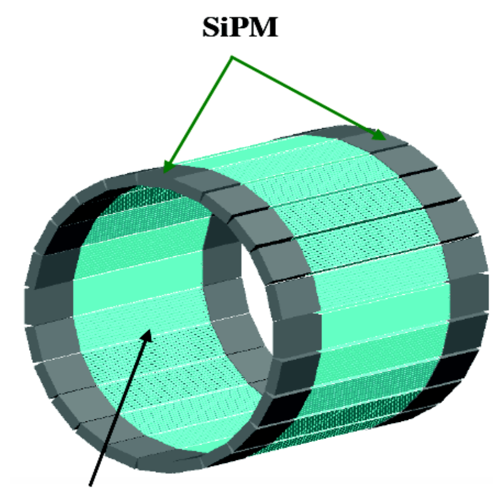
Image reconstruction

Validation of various (TOF-) MLEM implementations

J. Baran
M. Dagdar
K. Klimaszewski
P. Kopka
M. Pawlik-Niedzwiecka

Requirements:

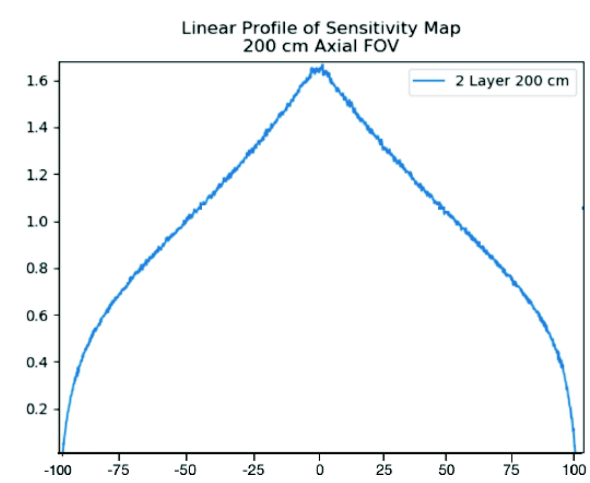
- Multi-layer geometry
- Large AFOV
- Very good TOF information



Tests on:

- GATE-based simulations
- Experimental data (NEMA-like measurements)

- CASTOR
- QETIR
- STIR (TOF version available as pending PR)



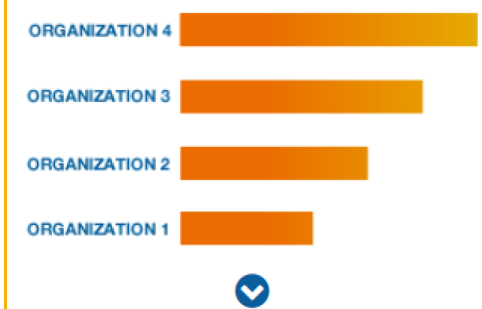
Evaluation of Single-Chip, Real-Time Tomographic Data Processing on FPGA SoC Devices

Publisher: IEEE

39 Author(s) G. Korcyl ; P. Białas ; C. Curceanu ; E. Czerwiński ; K. Dulski ; B. Flak ; A. Gajos ; B. Głowacz ; M. Gor… **View All Authors**

Abstract:
A novel approach to tomographic data processing has been developed and evaluated using the Jagiellonian positron emission tomography scanner as an example. We propose a system in which there is no need for powerful, local to the scanner processing facility, capable to reconstruct images on the fly. Instead, we introduce a field programmable gate array system-on-chip platform connected directly to data streams coming from the scanner, which can perform event building, filtering, coincidence search, and region-of-response reconstruction by the programmable logic and visualization by the integrated processors. The platform significantly reduces data volume converting raw data to a list-mode representation, while generating visualization on the fly.

Published in: IEEE Transactions on Medical Imaging (Volume: 37 , Issue: 11 , Nov. 2018)



Real-Time image reconstruction on FPGA

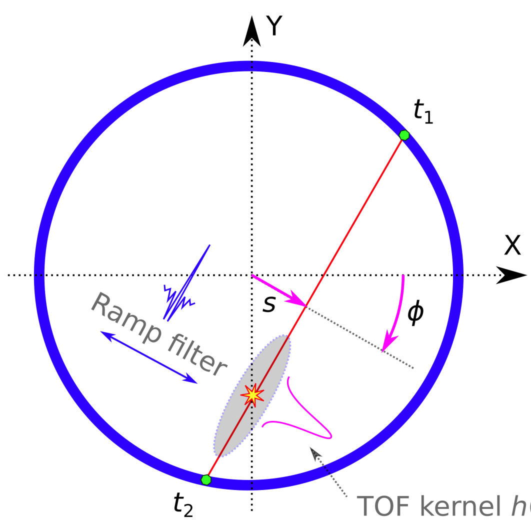
Roman Y. Shopa

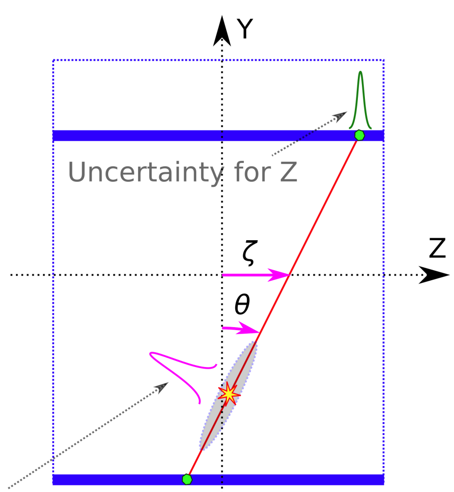
TOF FBP in image space

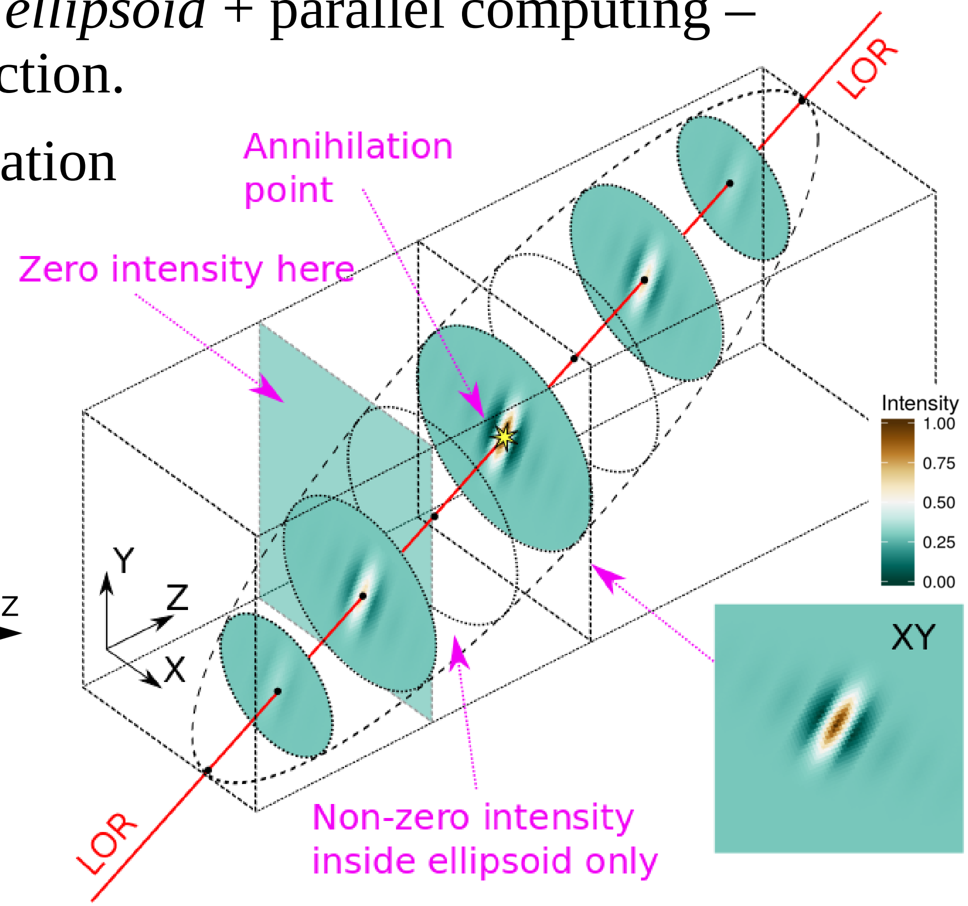
The idea – proceed each line-of-response (LOR) independently in image space using 3D kernel: ***Ram-Lak filter*** normal to LOR in XY, ***Gaussian or high-pass*** – for TOF kernel along LOR and small one along Z (uncertainty for axial position of hit).

Update intensity *within a small volume of ellipsoid* + parallel computing – a prospect for real-time (online) reconstruction.

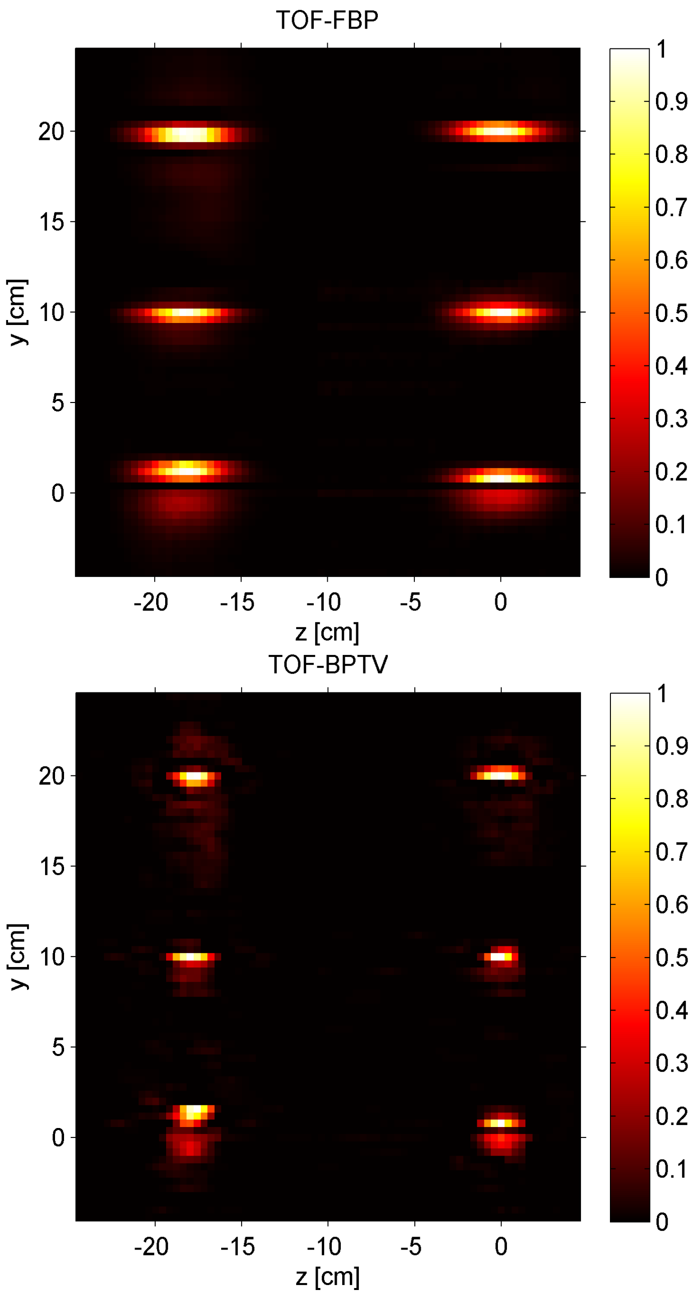
The model resembles kernel density estimation (KDE), but for the asymmetrical case.







PET image reconstruction using TV regularization

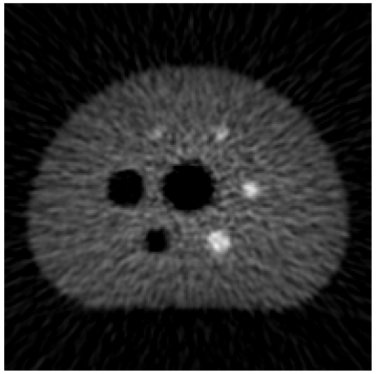


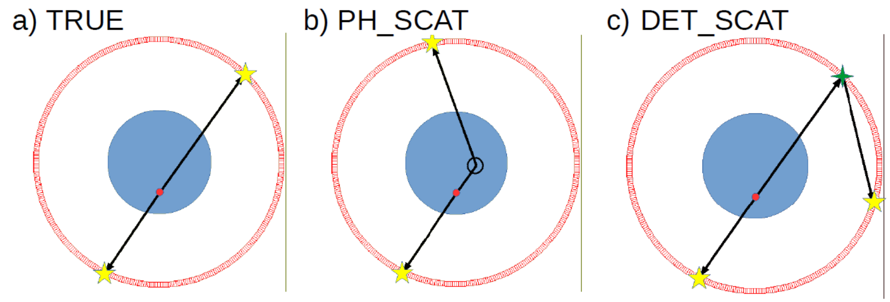
- The spatial resolution of the J-PET scanner was determined by estimation of full width half maximum of PSF images at six position inside the scanner volume.
- The comparison results shown superior spatial resolution of reconstructed images from the proposed TOF-BPTV method (bottom) in respect to the TOF-FBP algorithm (top).

[L. Raczyński APPB 2020]

Reconstruction of experimental data of the Jagiellonian-PET (J-PET) scanner from measurement of six point-like sources.

Machine Learning techniques for event classifications

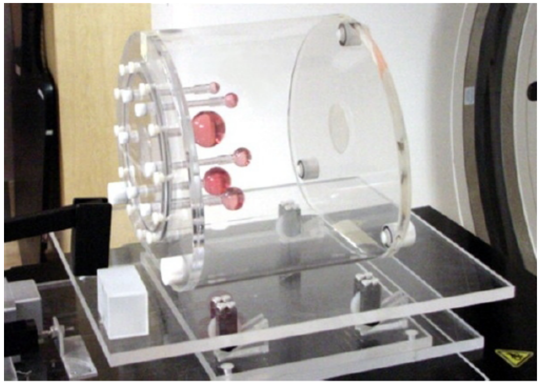




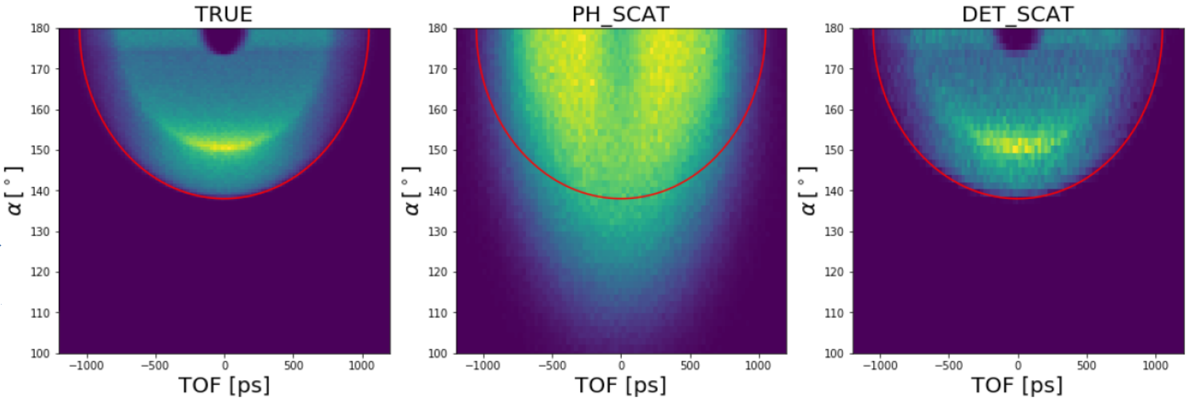
Jan Bielecki, W.K,

Konrad Klimaszewski

Discrimination of the scattering and random coincidences background



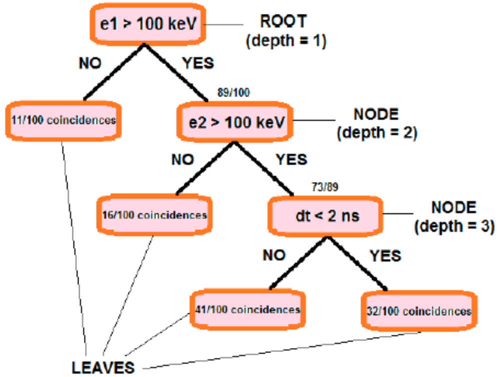
GATE simulations



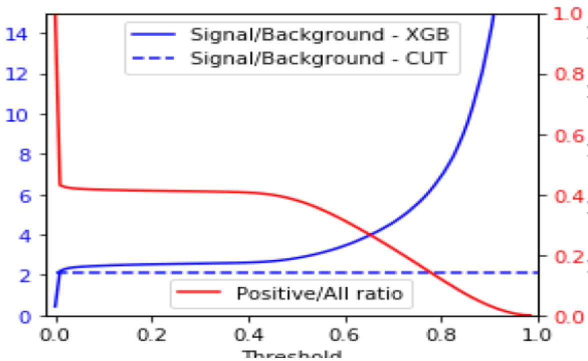
IEC-NEMA phantom

$18 * 10^7$ coincidences:

29% TRUE, 19% PH-SCAT, 2% DET_SCAT – 50%, RNDM



Decison Tree



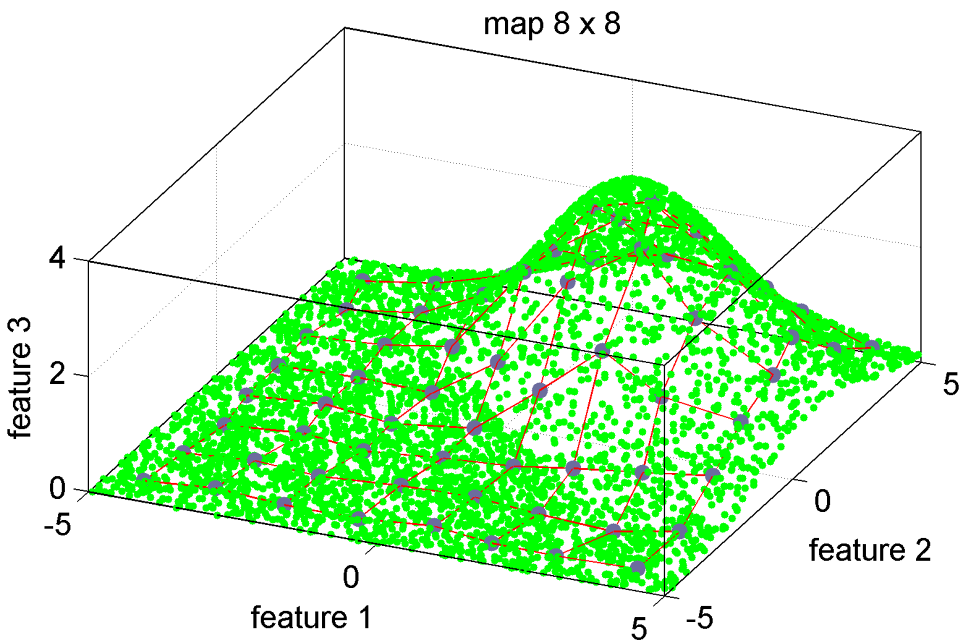
XGBoost & AdaBoost

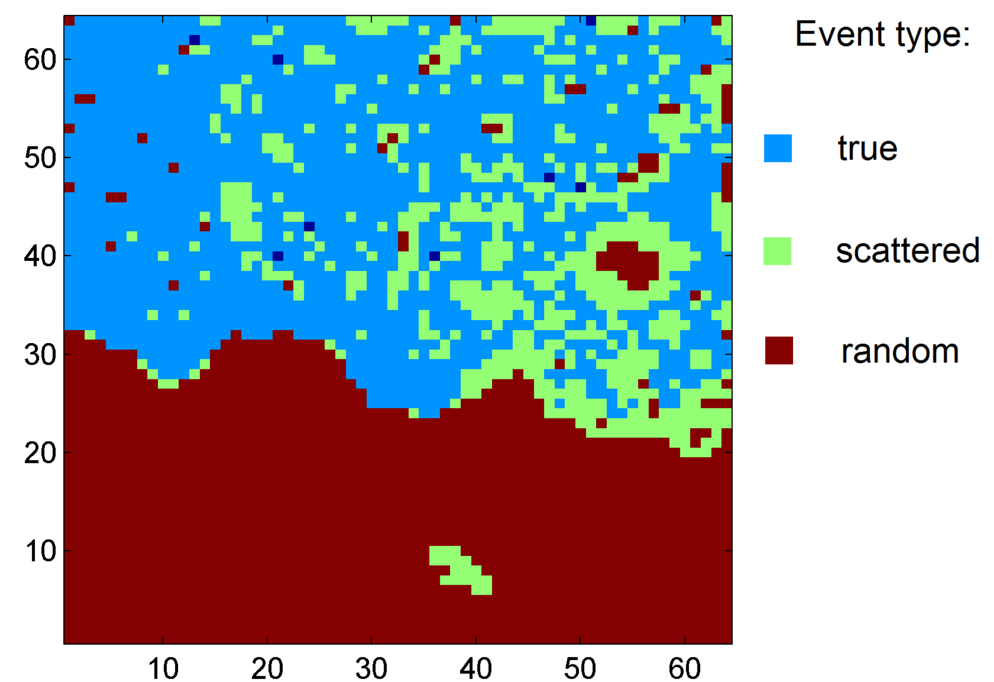
Lech Raczyński

Event classification in J-PET detector using Self-Organized Maps

• Analysis and visualization of multi-dimensional data describing events type in J-PET detector using Self Organizing Map (SOM).

Example of visualisation of 3D synthetic data using 2D SOM map



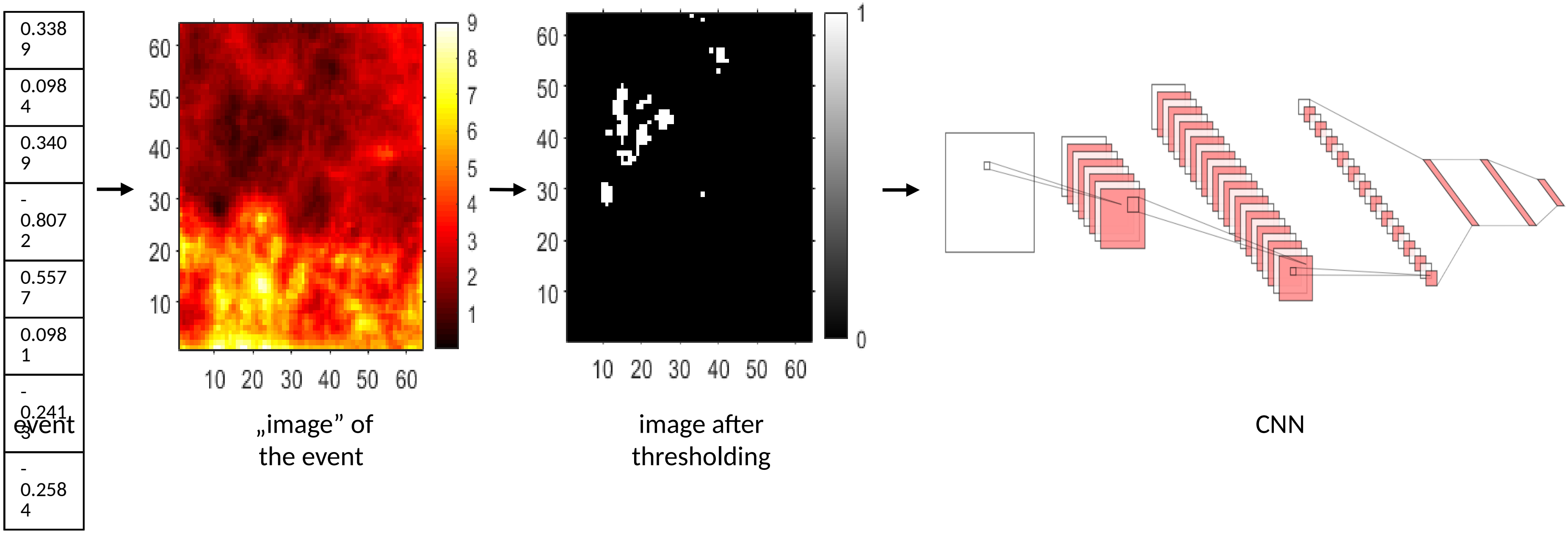


Trained SOM map on J-PET data

• Identification of class labels using training data from GATE simulation (on the top) helps to visualize classes distributions.

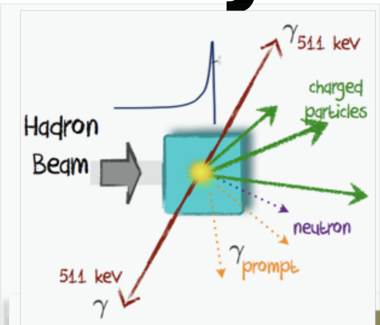
Convolutional neural network

- Creating self-organizing map (Kohonen map)
- Converting each event to „image” (matrix) by calculating distances between event and each node of the Kohonen map
- Thresholding – for N closest nods distance equal to 1, for rest 0

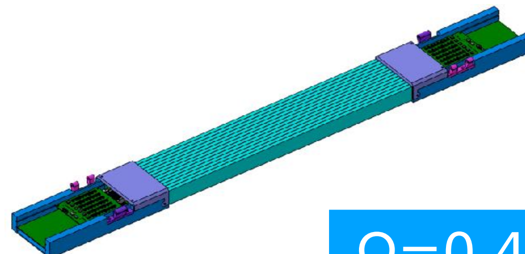


event → „image” of the event → image after thresholding → CNN

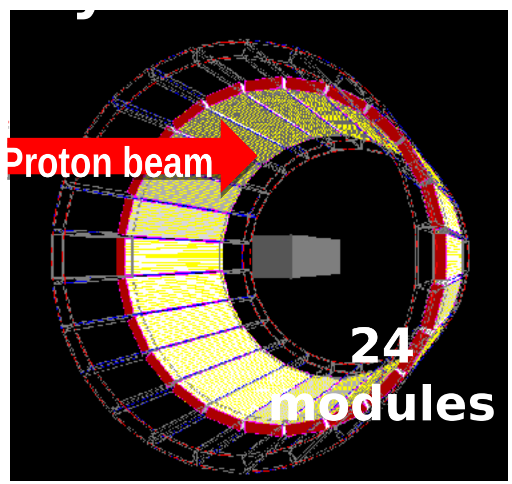
J-PET technology for proton beam therapy range monitoring

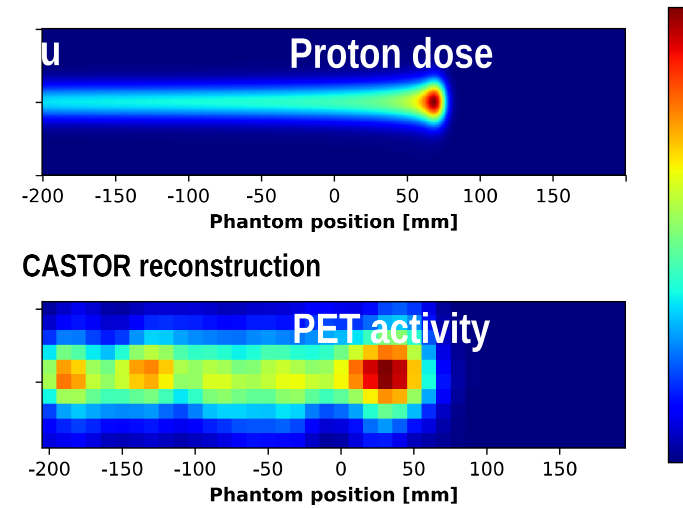


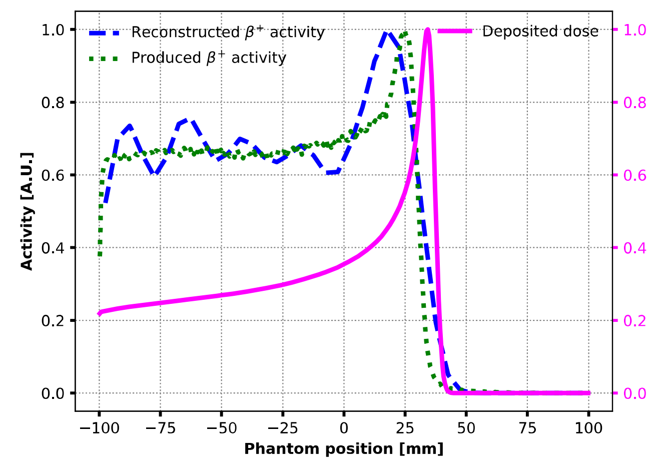
GATE MC simulations



$\Omega=0.4$
$\varepsilon_{det}=0.1$



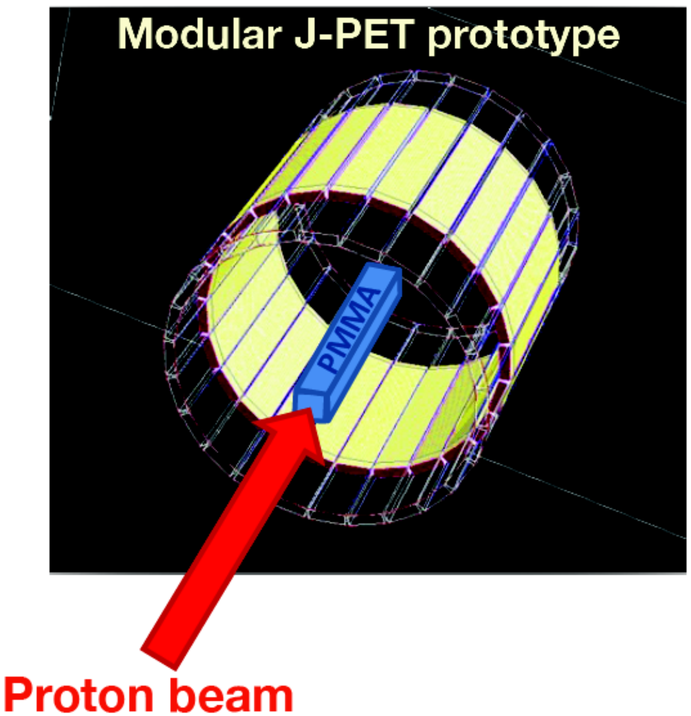




Students:
Jakub Baran, Monika Pawlik-Niedźwiedzka

The National Centre for Research and Development · LIDER · European Funds Smart Growth · Republic of Poland · FNP Foundation for Polish Science · European Union European Regional Development Fund

Simulation setup



Settings:

- GATE/Geant4
- Physics list: QGSP_BIC_HP_EMY
- Full simulation
- in-room design
  (in-beam in the future)
- PMMA phantom 10x10x40cm^3
- Protons at 150 MeV
- 10^7 primary protons
- Clinical proton beam model
  used in Krakow for patient treatment

Scoring:

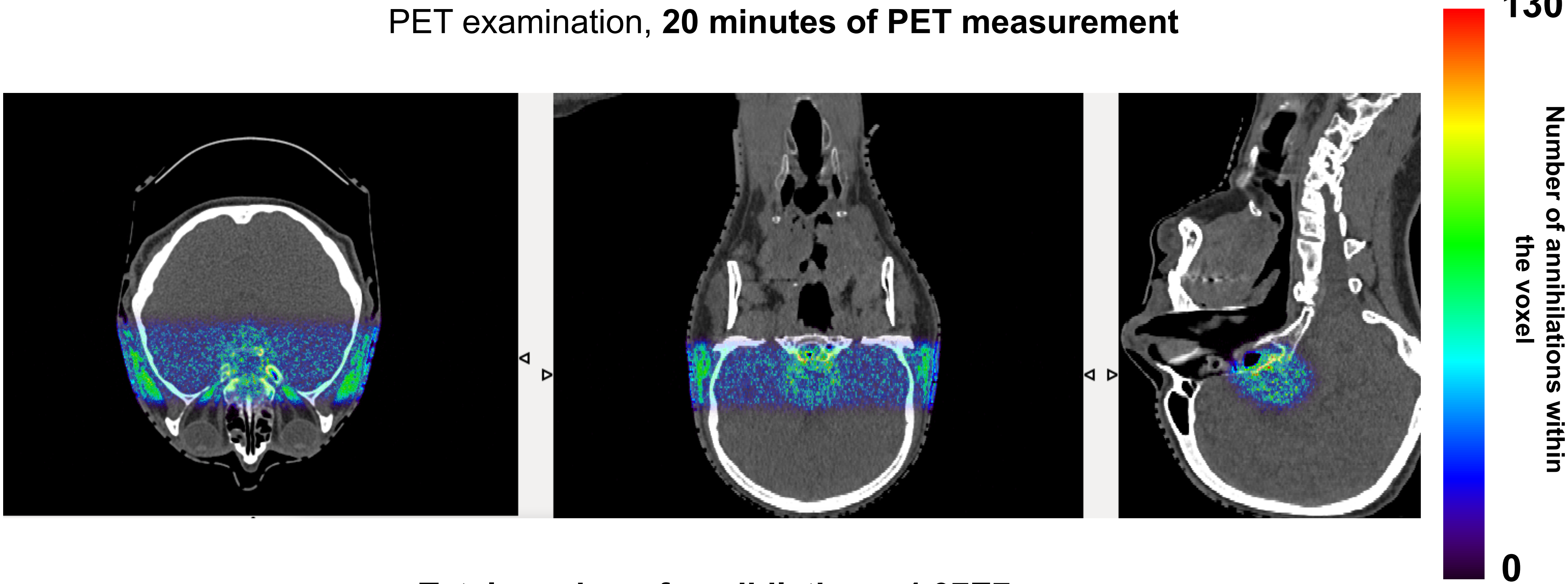
- # of annihilations in the PMMA
- # of detected singles
- # of detected coincidences

Antoni Ruciński's group

Simulated β⁺ activity map – 1ˢᵗ step

From Jakub Baran presentation

SCENARIO: 10 minutes of irradiation, 10 minutes preparation for the PET examination, **20 minutes of PET measurement**



Total number of annihilations: 1.97E7

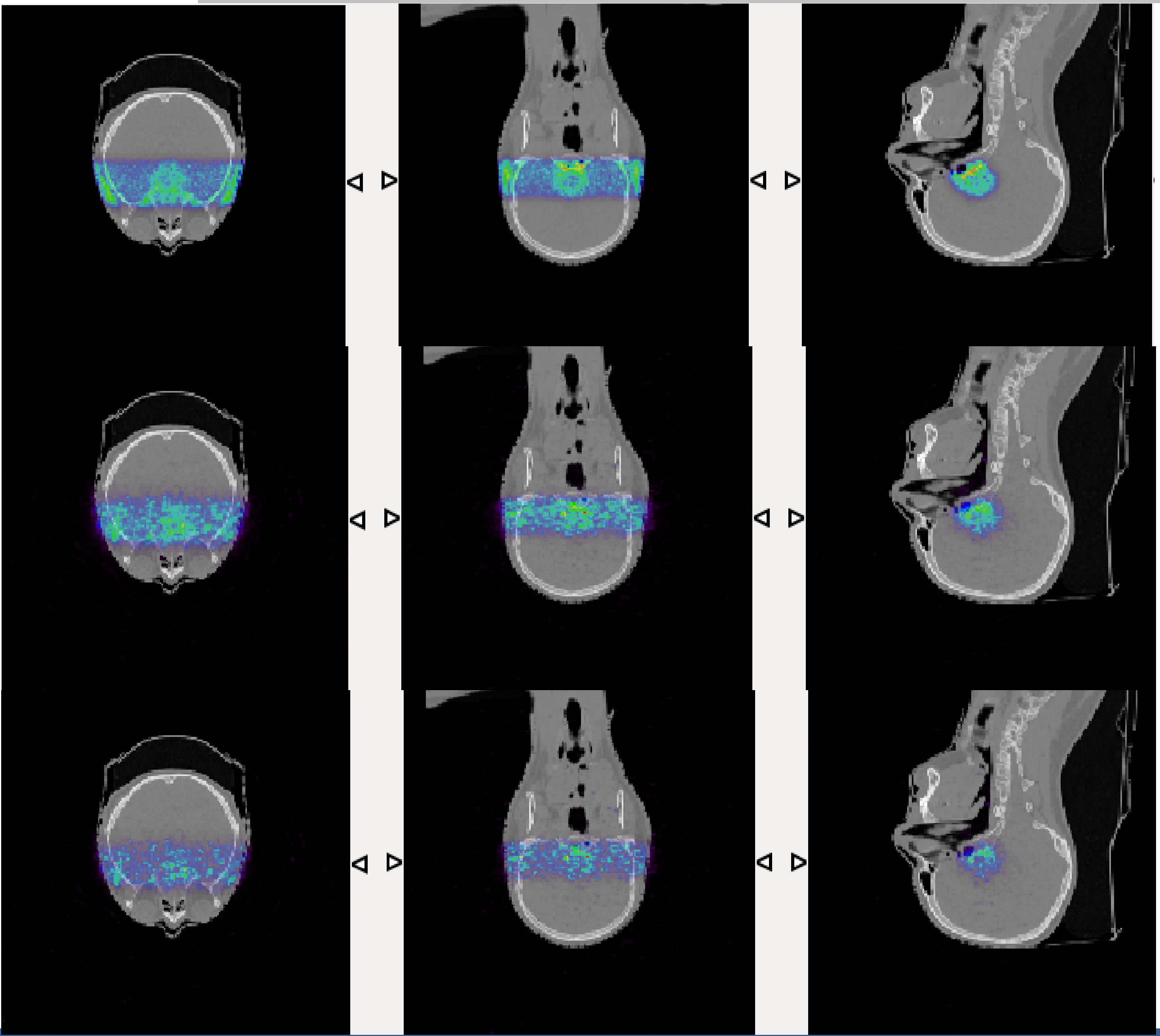
Maximum number of annihilations within the voxel: 130

Voxel size (as in CT): $0.69 \times 0.69 \times 1.2\ mm^3$

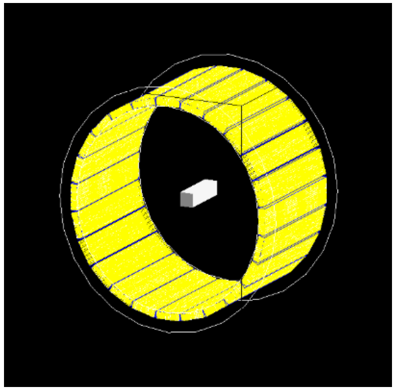
THIS SETUP WAS SIMULATED IN THE 2nd STEP

Reconstructed PET image – 2nd step

From Jakub Baran presentation



BARREL



TOP: Monte Carlo activity (resolution was rescaled to the PET resolution)

CENTER: Reconstructed off-beam activity (TOF-MLEM – 2 iterations)

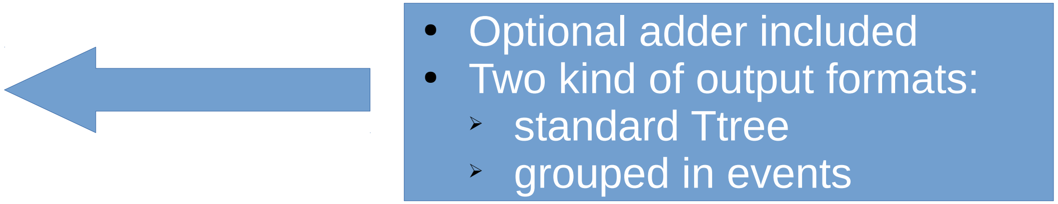
BOTTOM: Reconstructed off-beam activity (TOF-MLEM – 3 iterations)

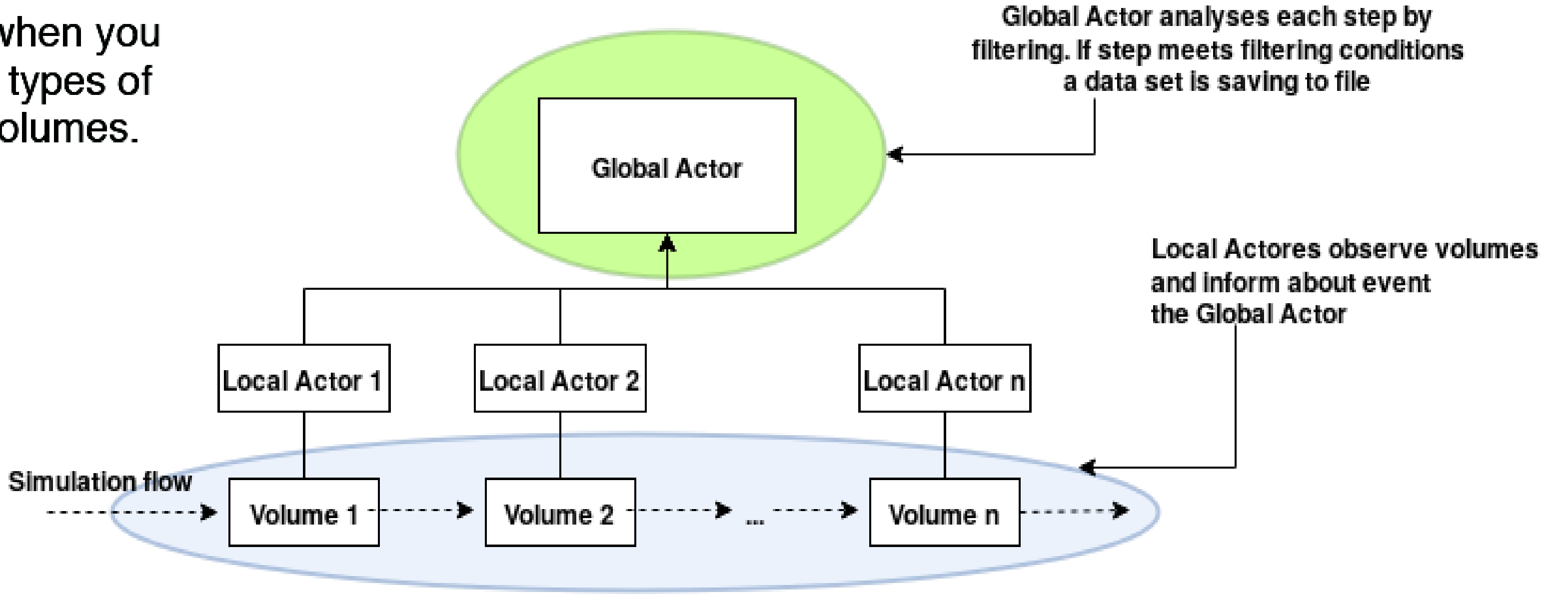
(Near) future GATE contributions

Mateusz Bała

Extension of Actor concept

- **Local Actor (LA)**: a standard actor attached to a volume
- **Global Actor (GA)** can collect data from many volumes
- GA with LA attached, can collect chronologically data from any number of volumes to single ROOT file
- Use GA and LA always when you want to collect the same types of information from many volumes.





Gate Output J-PET Analyzer (GOJA)

Paweł Kowalski

Python

Several extra tools such e.g job splitter and coincidence maker :

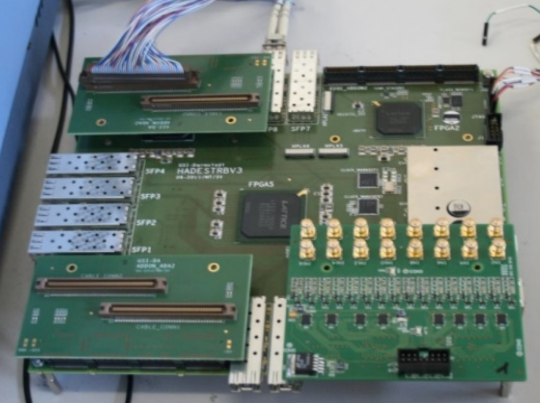
https://github.com/JPETTomography/j-pet-gate-tools

Thank you for attention

J-PET

More materials available at:

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



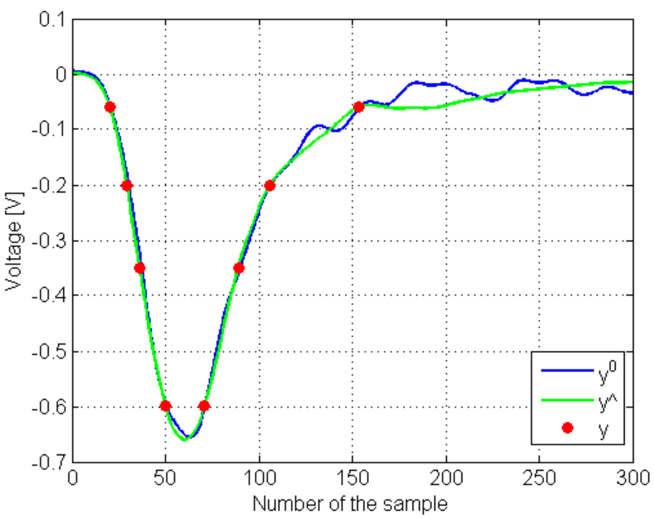
ONLY DIGITAL in triggerless mode

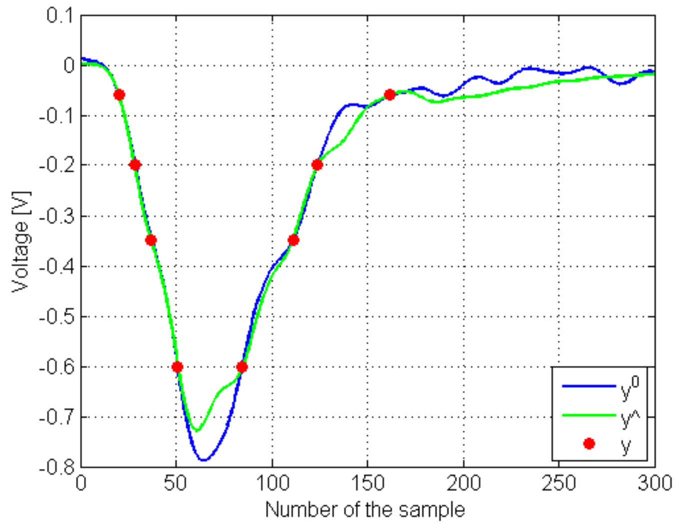
FFE sampling & Readout electronics

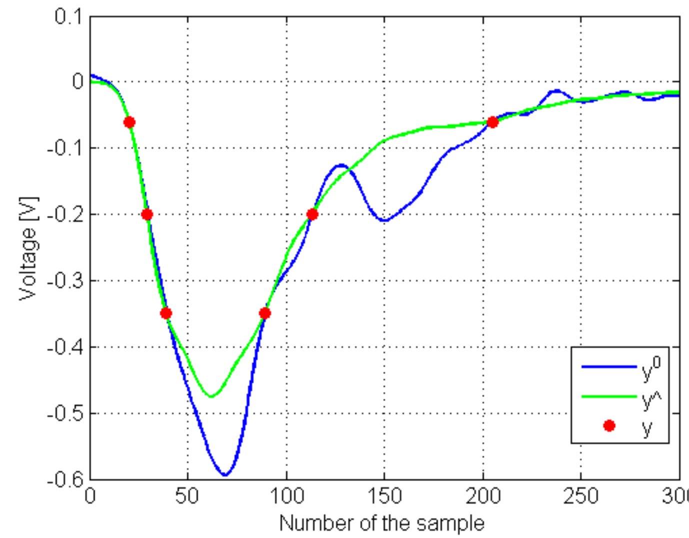
precision of 20ps (sigma) for 10 Euro per sample

M.Pałka, P.M., **PCT/EP2014/068367**

G. Korcyl, P. M., M. Kajetanowicz, M. Pałka, **PCT/EP2014/068352**







Library of signals; Principal Component Analysis; Compressive Sensing;
J-PET: L. Raczyński et al., Nucl. Instr. Meth. A786 (2015) 105
J-PET: P. M. et al., Nucl. Instrum. Meth. A775 (2015) 54

Reconstruction

Detector	FrontEnd electronics	Electronics controller	Hit along strip	Annihilation point	Image

J-PET: M.Palka et al., JINST 12 (2017) P08001 J-PET: W. Krzemień et al., Acta Phys. Pol. B47 (2016) 561 J-PET: G. Korcyl et al., IEEE TMI 2018 in press J-PET: P. Bialas et al., Bio-Alg. and Med-Sys. 10 (2014) 12

G. Korcyl -> poster session

Type: LSO / LYSO / BGO / polymer scintillator

Price per cm^3: 86 / 86 / 35 / 1

Plastic scintillators can be easily produced
in large sizes and various shapes

Why plastics were not considered
so far as a material for PET detectors ?

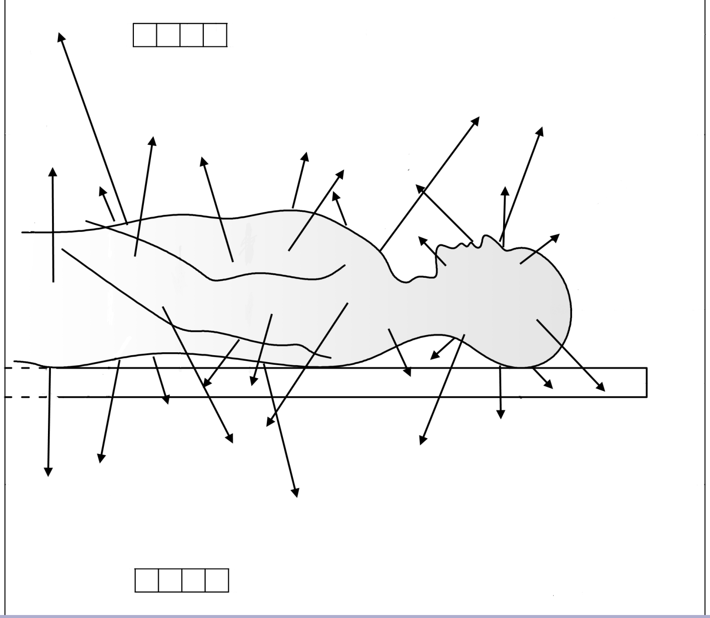
→ **Low detection efficiency**
and no photeffect !

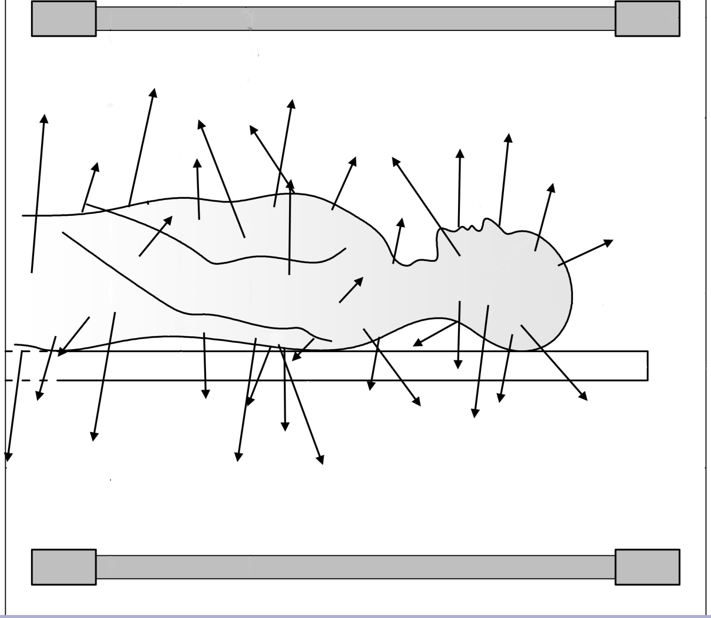
Sensitivity ?
Scatter fraction ?
Accidental coincidences?
...

for the 2.5 cm layer the efficiency for the registration of events selected to reconstruct the image is for the plastic scintillator by

a factor of about 20 smaller in relation to the BGO crystals and about 40 times less compared to the LSO crystals

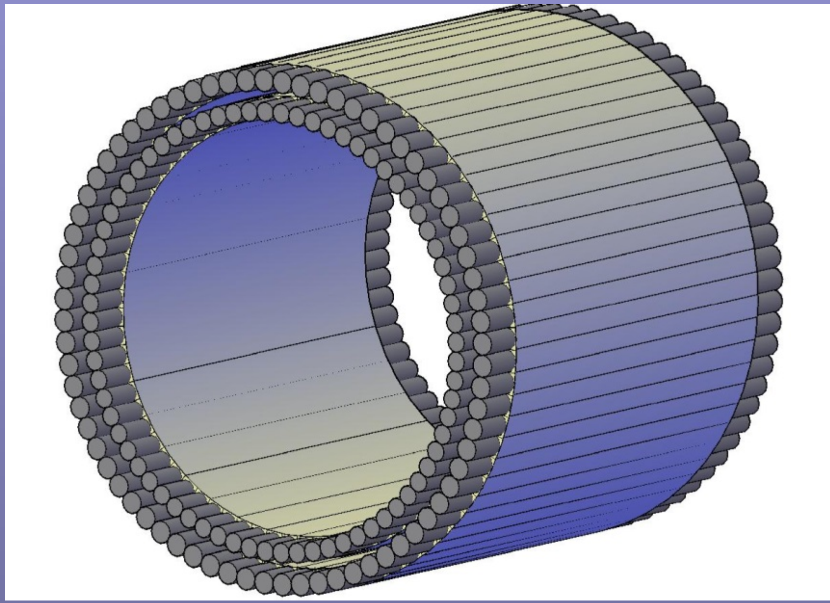
name	type	density [g/cm^3]	decay time [ns]	photons/ MeV	mean free path [cm]
BGO	crystal	7.13	300	6000	1.04
GSO	crystal	6.71	50	10000	1.49
LSO	crystal	7.40	40	29000	1.15
NE102A	polymer	1.032	2.4	10000	10.2
BC404	polymer	1.032	1.8	10000	10.2
RP422	polymer	1.032	1.6	10000	10.2





It is important to note that the cost of J-PET does not increase with the increase of the FOV

epsilon^2 = 20 to 40 smaller efficiency

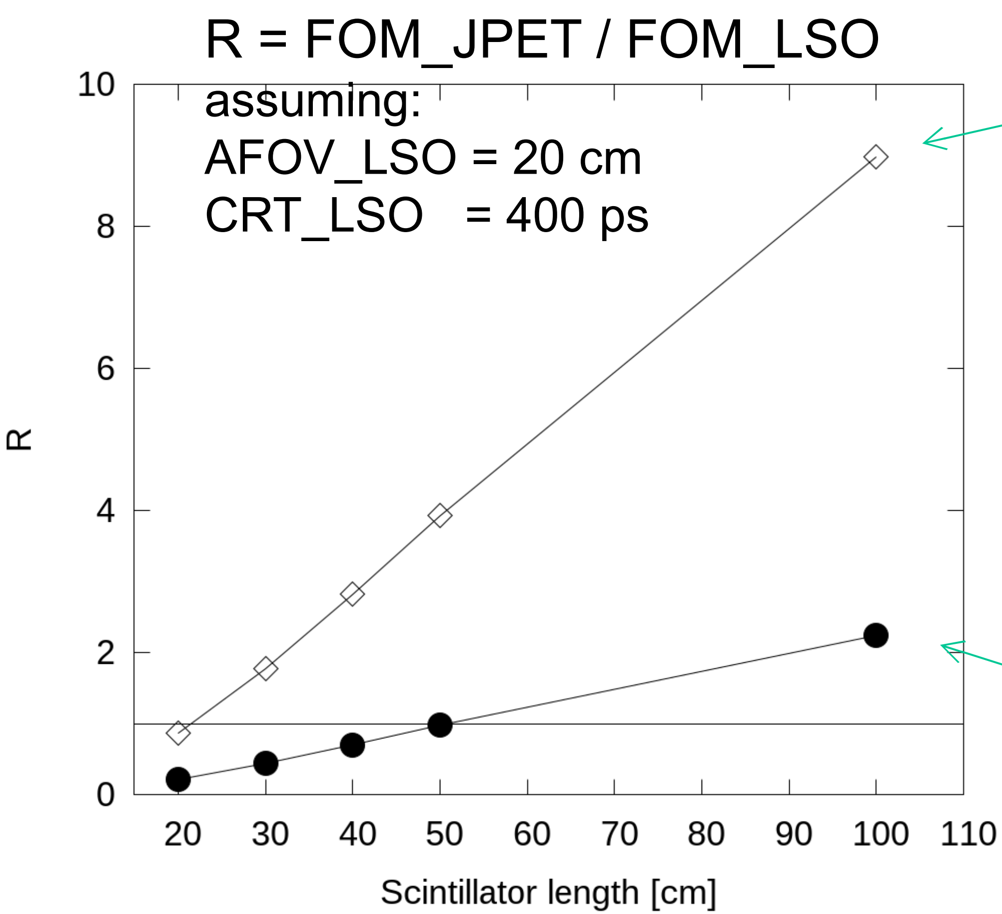


But

Solid angle -------------------- > factor of ~5
600 ps --> 200ps – 300ps --> factor of 3 -- 2
1m instead of ~17 cm ---------> factor of 10
N layers in the strip-PET ----> factor **N^2**

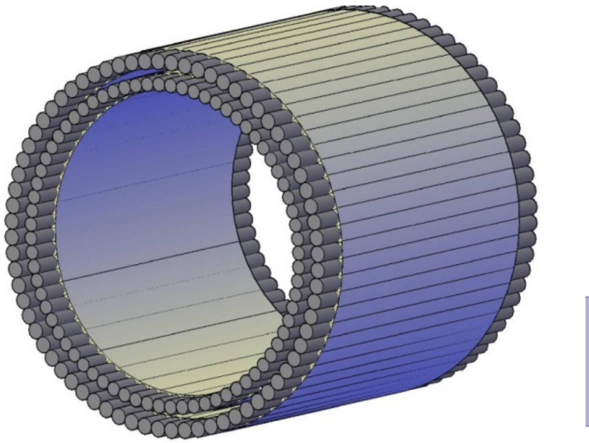
Conservatively:
for N=1 ----> total factor of ~ 100
Lower dose by factor of 3 (100 better / 30 worse)

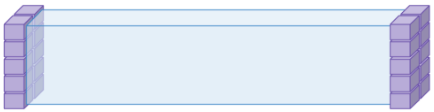
TOTAL-BODY
850 strips, 6800 SiPM



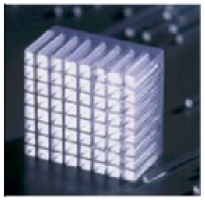
N_JPET_layers = 2

N_JPET_layers = 1





$$R = \frac{FOM\_JPET}{FOM\_LSO}$$



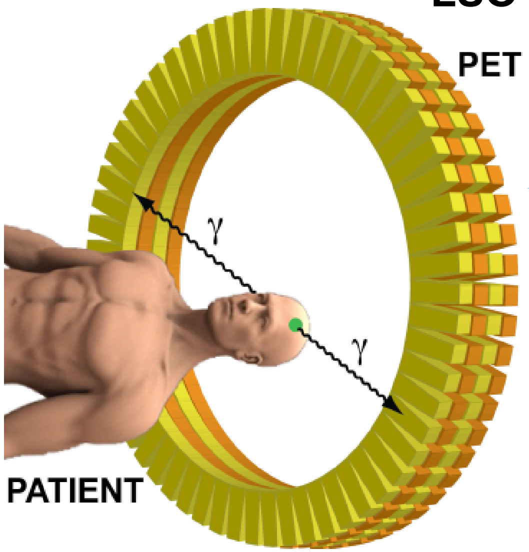
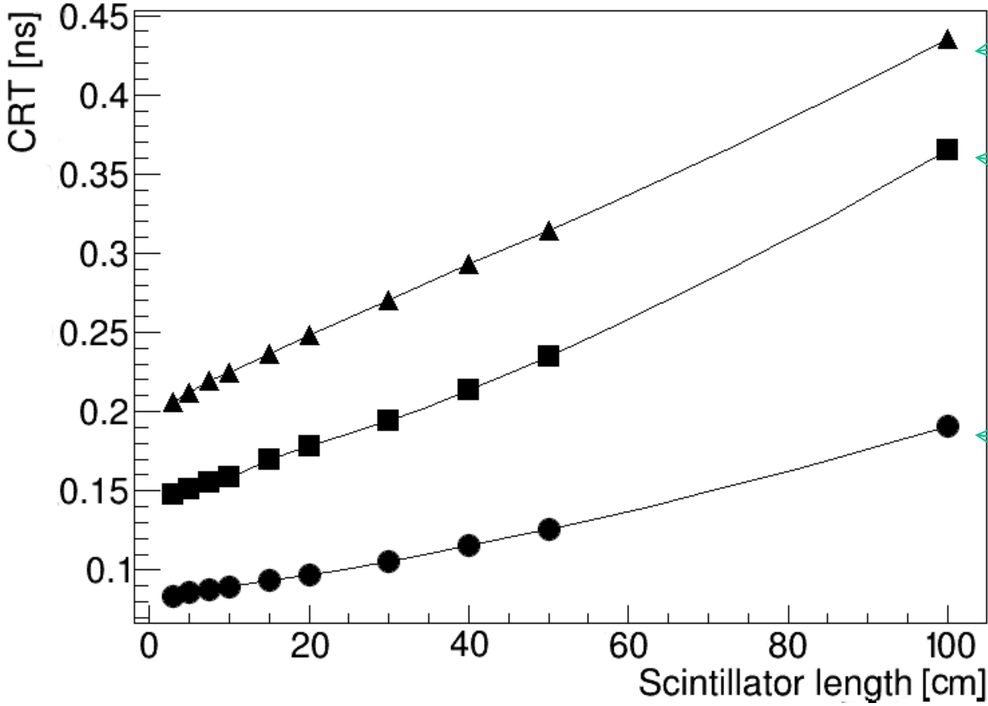
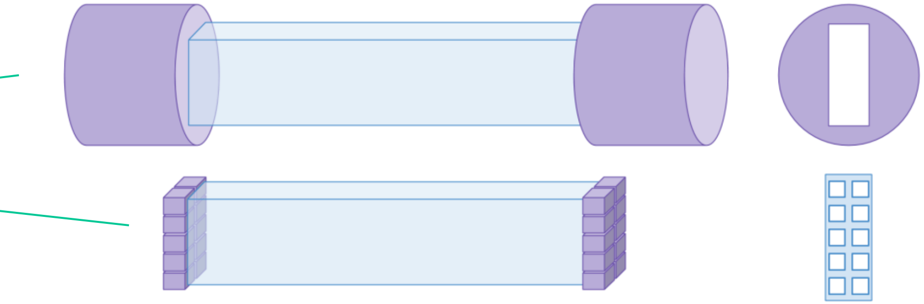


Figure of Merit for whole body imaging (FOM):

$$FOM \cong \frac{(\text{detection effi.})^2 \bullet (\text{selection effi.})^2 \bullet \text{acceptance}}{CRT \bullet \text{Number\_of\_bed\_positions}}$$

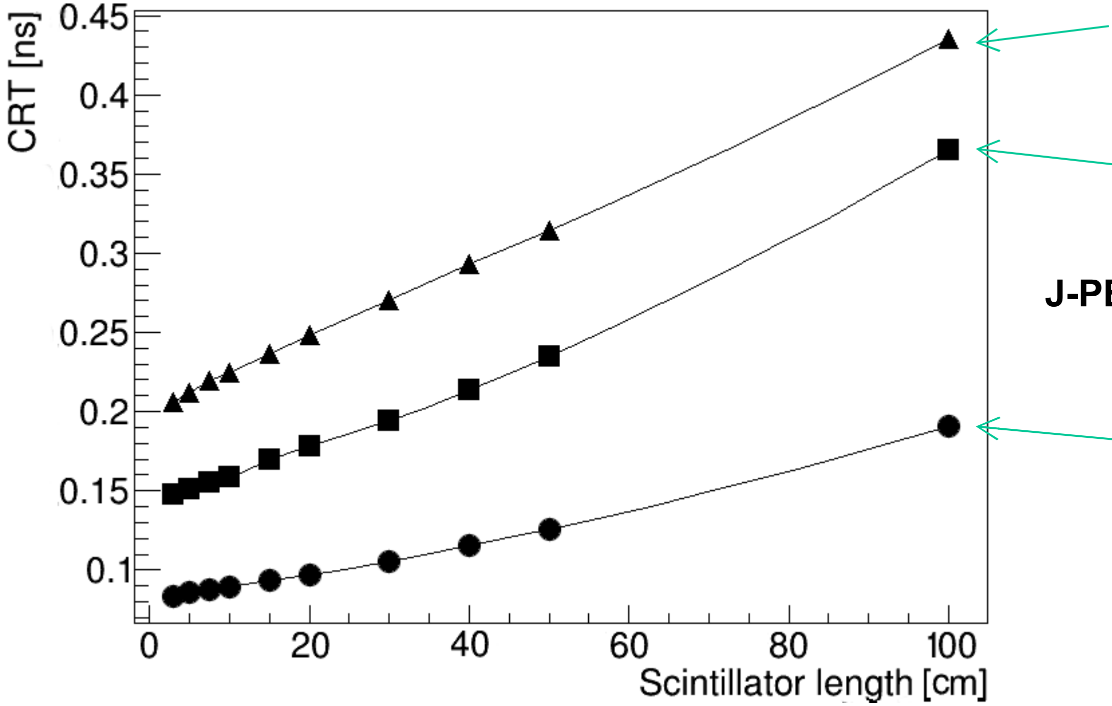
J-PET: P.M. et al., Phys. Med. Biol. 61 (2016) 2025; arXiv:1602.02058

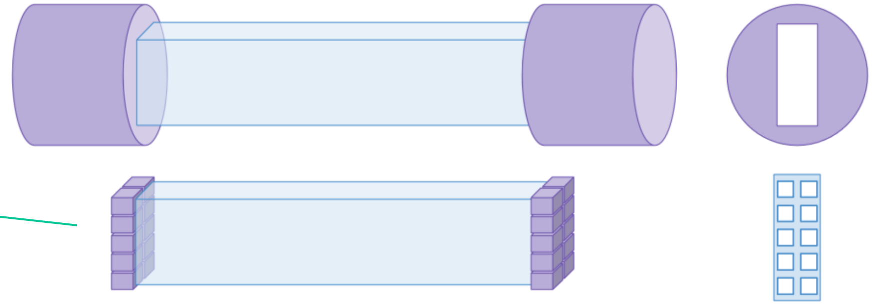




J-PET: P.M. et al., Phys. Med. Biol. 61 (2016) 2025

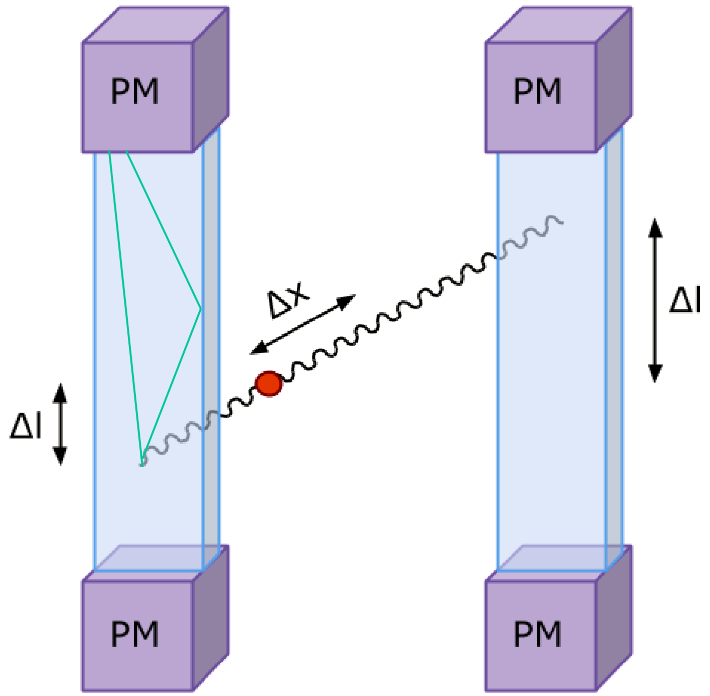
Limit of the J-PET





J-PET: P.M. et al., Phys. Med. Biol. 61 (2016) 2025

Limit of the J-PET



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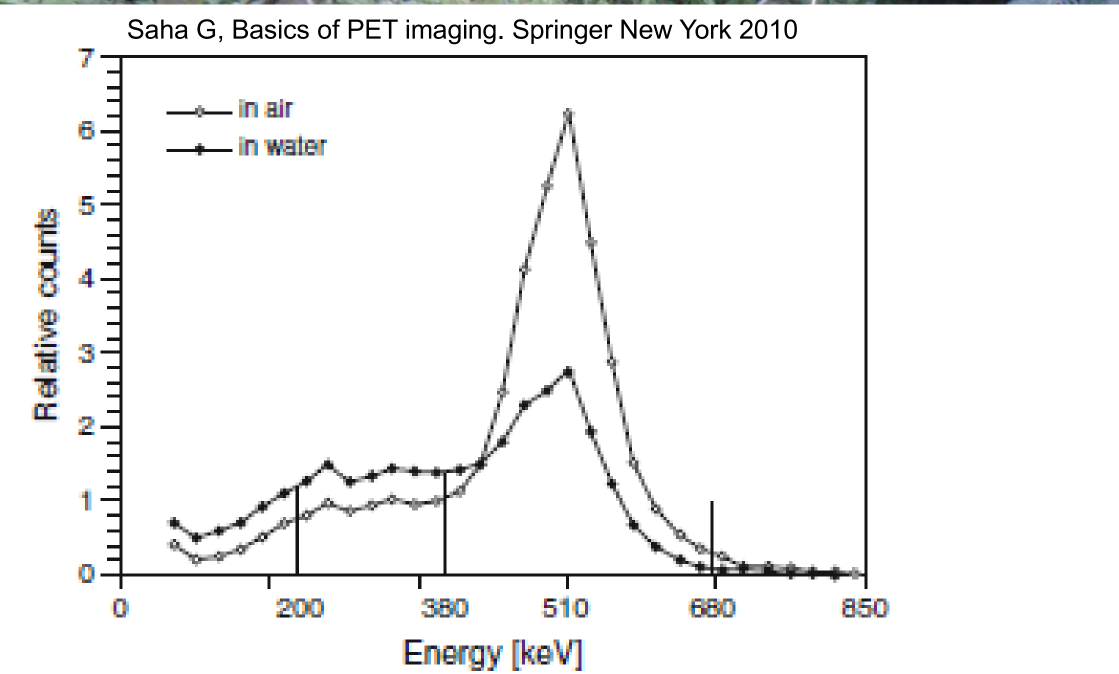
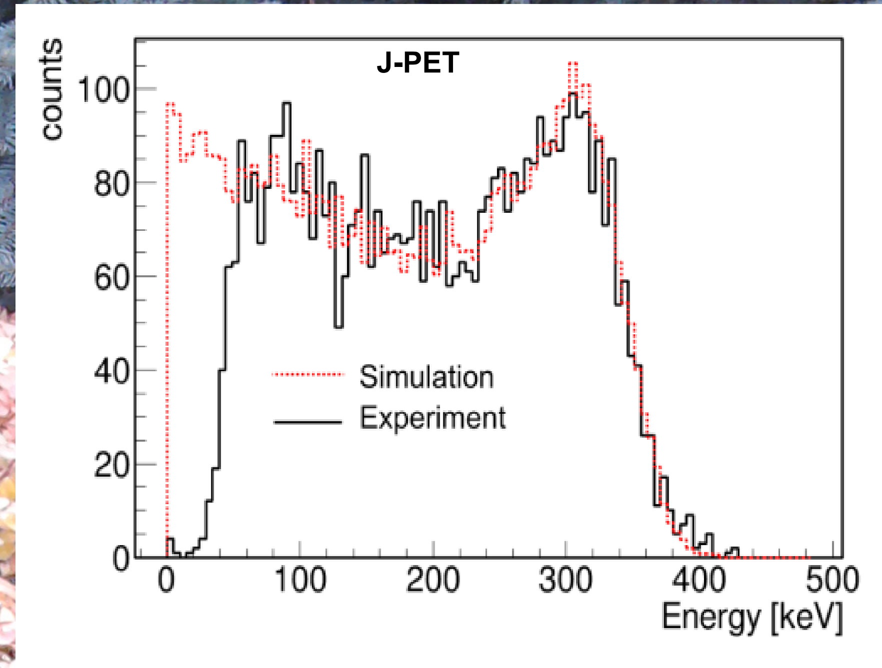
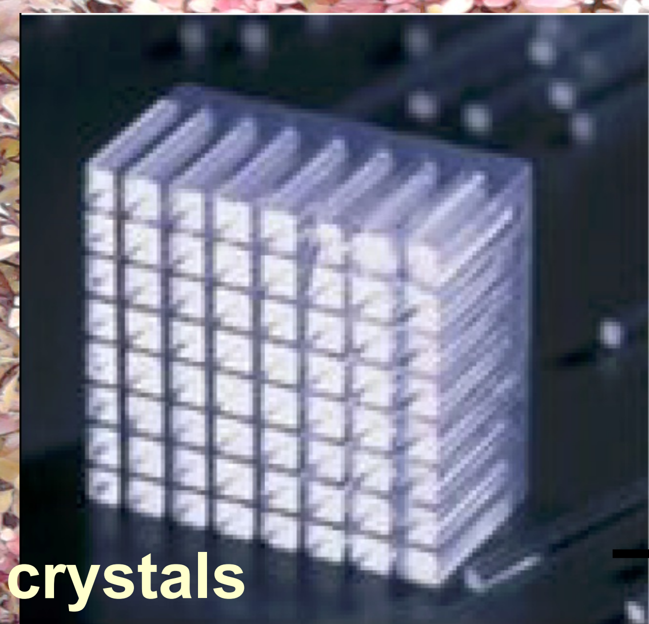
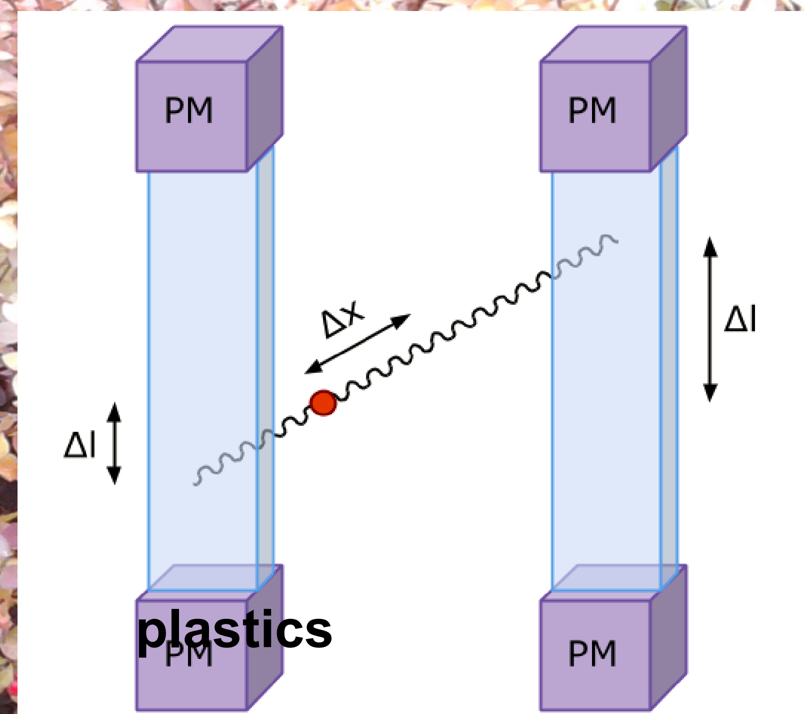
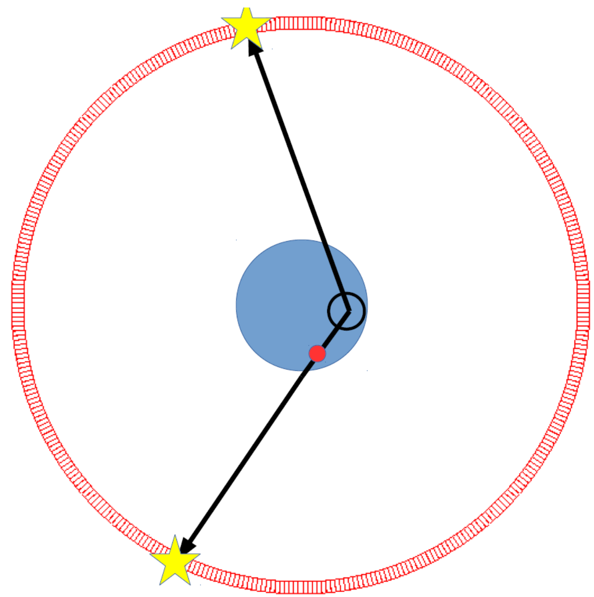

Saha G, Basics of PET imaging. Springer New York 2010
in air
in water
Relative counts
Energy [keV]
0
200
380
510
680
850
0
1
2
3
4
5
6
7

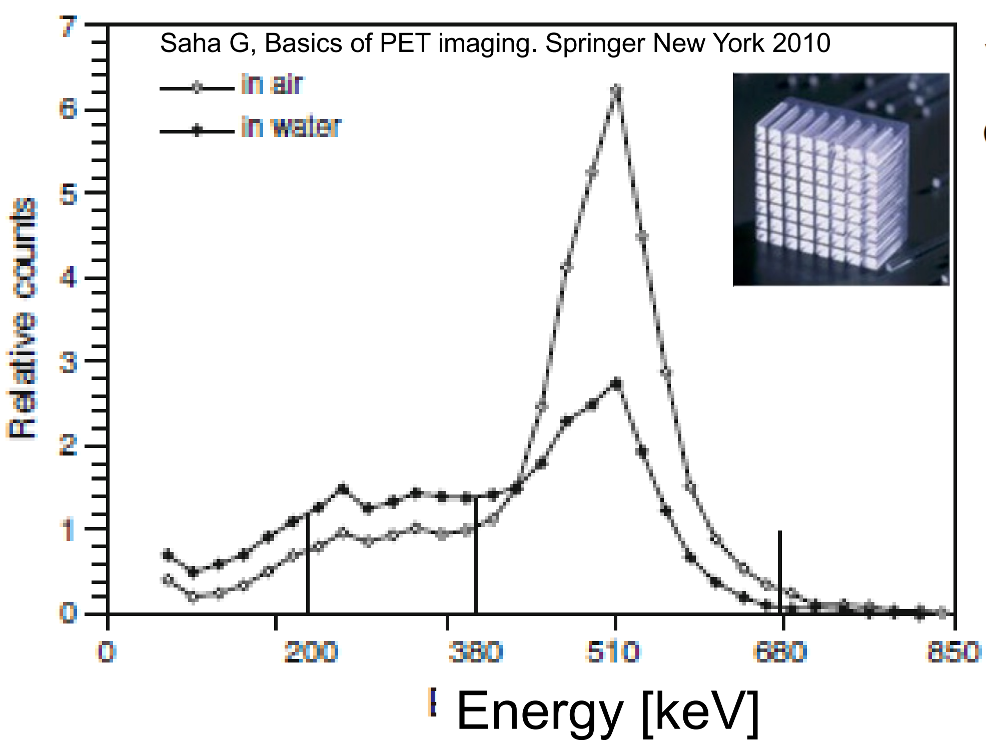

J-PET
counts
Simulation
Experiment
Energy [keV]
0
100
200
300
400
500
0
20
40
60
80
100

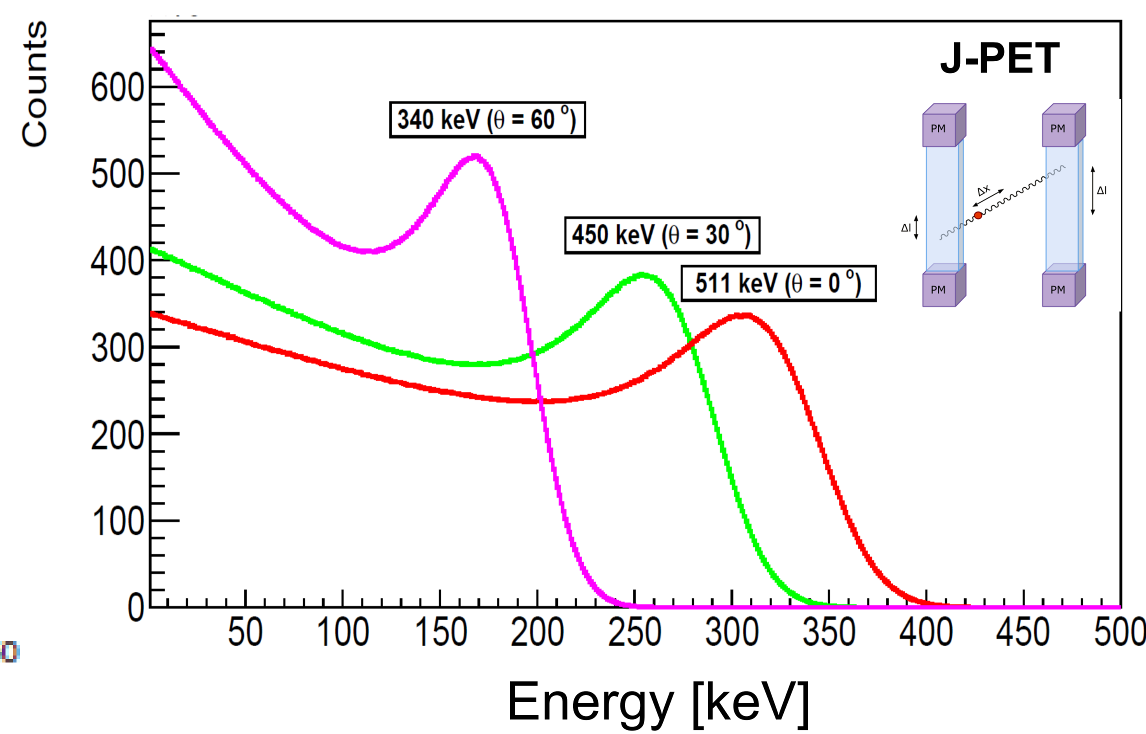

crystals


PM
PM
PM
PM
Δx
Δl
Δl
plastics

scattering in the patient



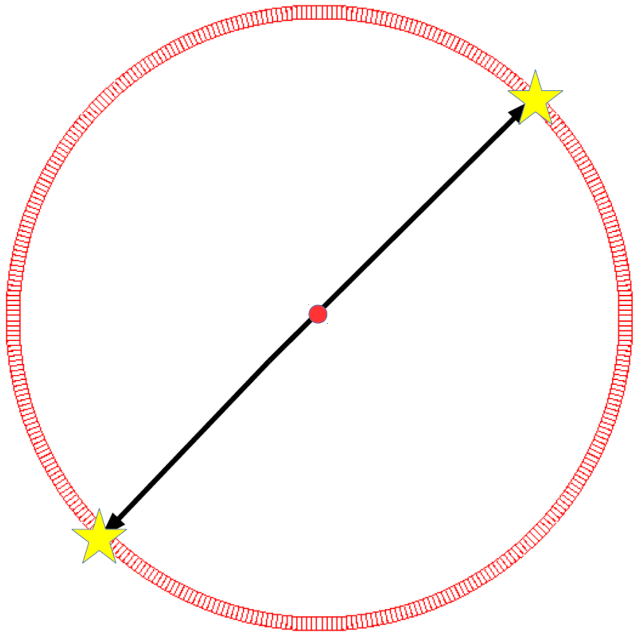


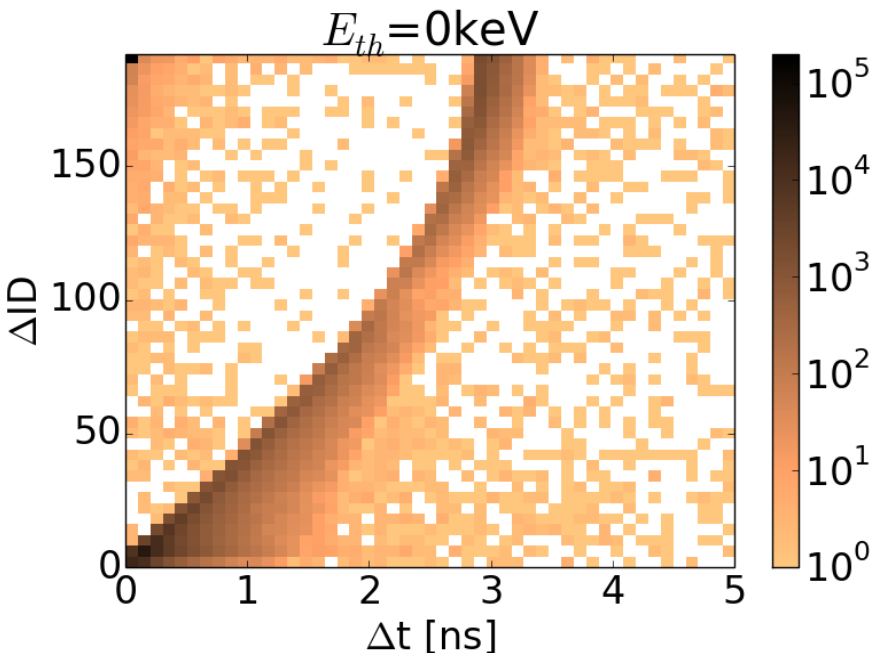


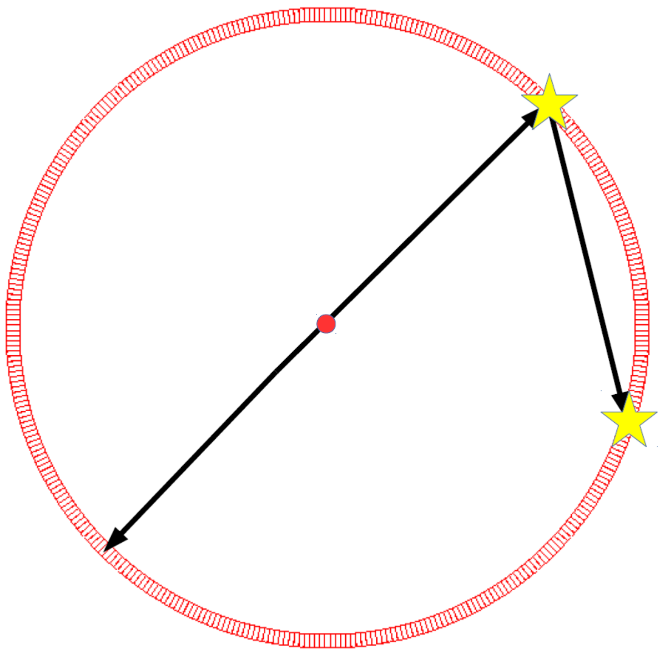
secondary scattering in the detector

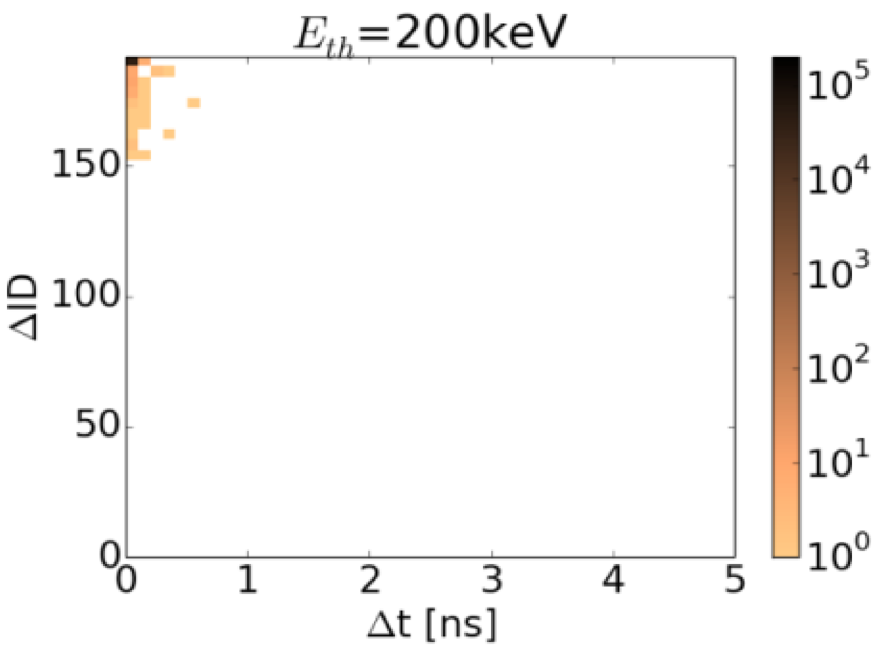
J-PET: P. Kowalski et al., Phys. Med. Biol. submitted

J-PET: P. Kowalski et al., Acta Phys. Pol. A127 (2015) 1505 and Acta Phys. Pol. B47 (2016) 549



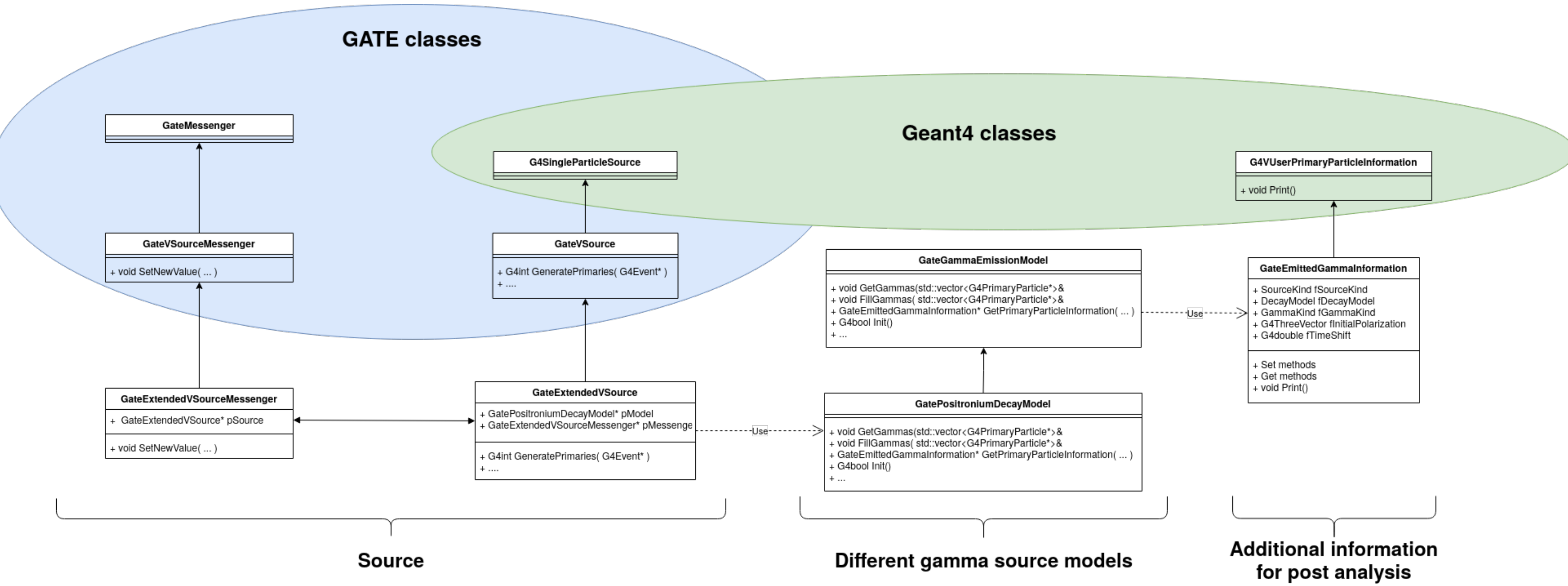






Mateusz Bała

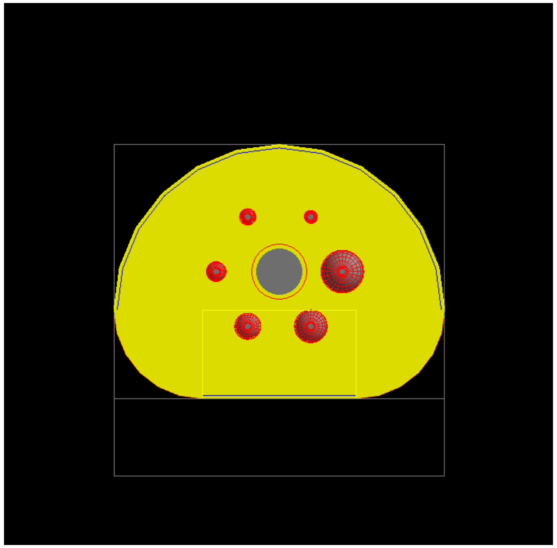
Source extensions

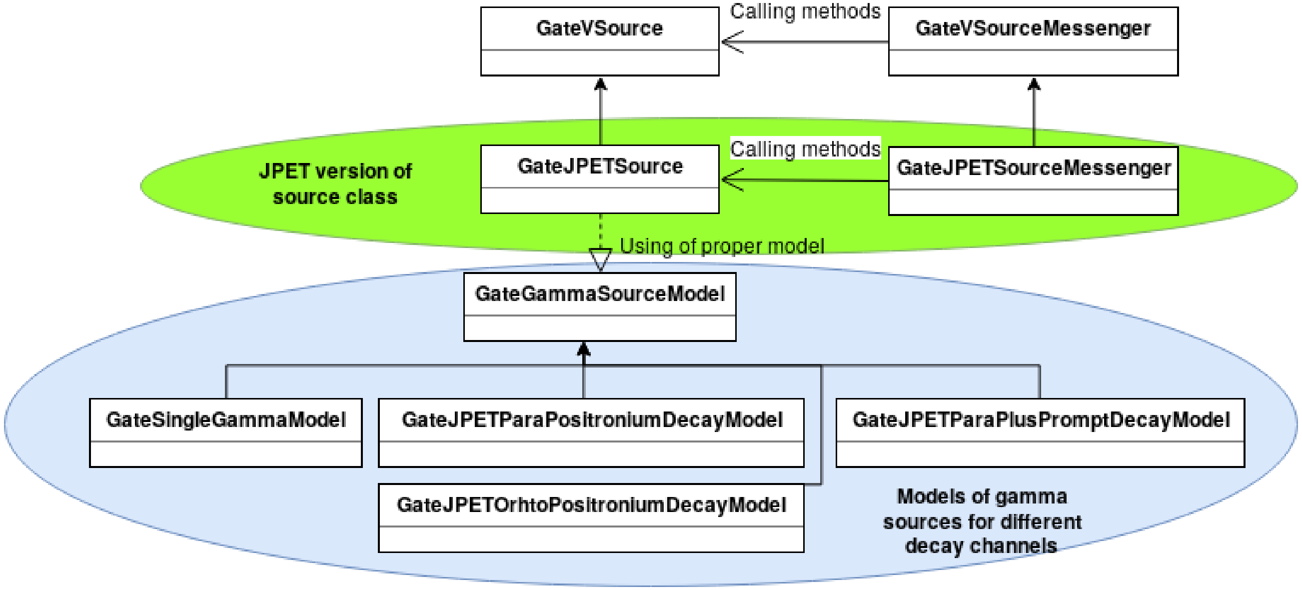


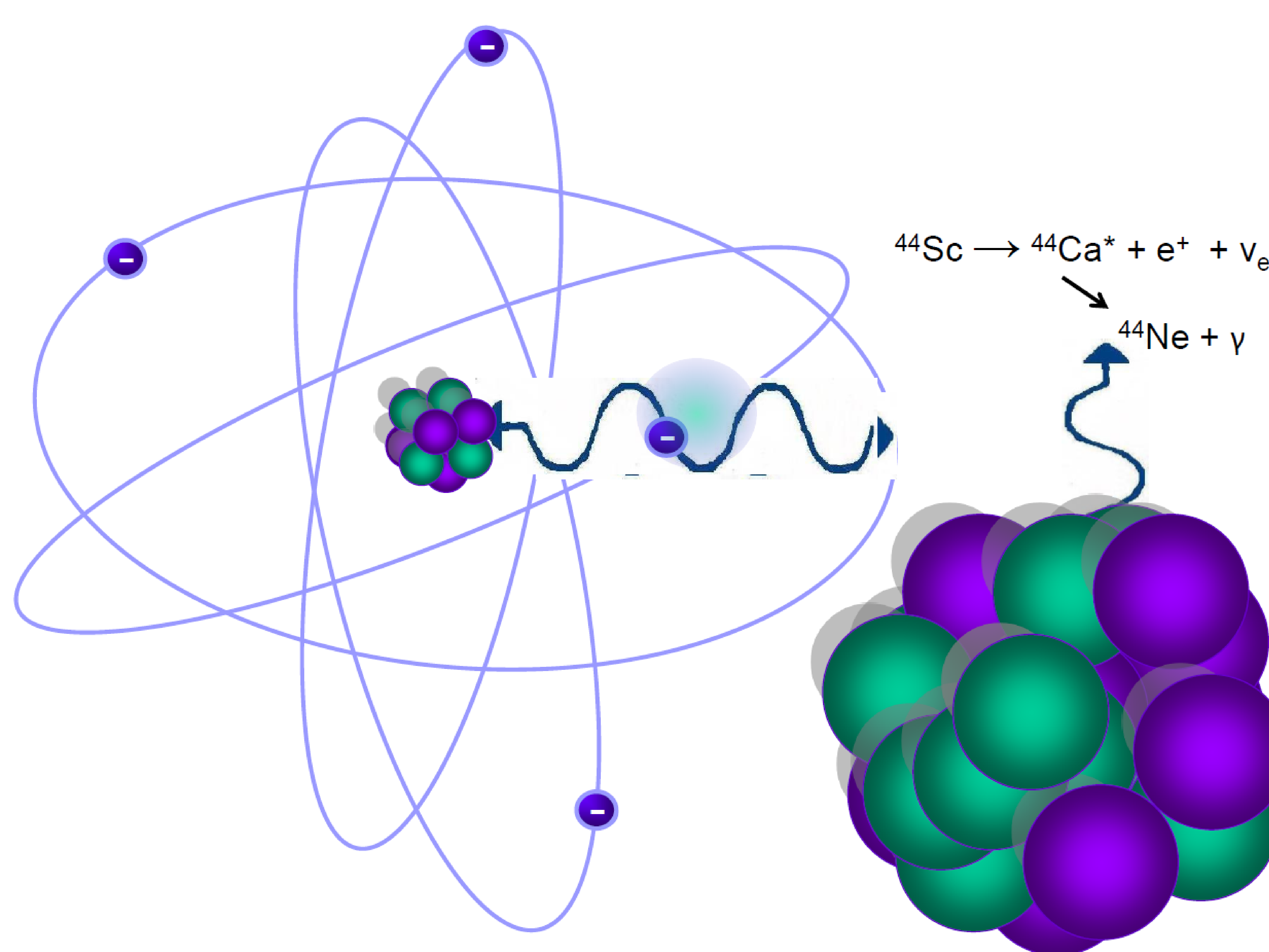
Mateusz Bała

Extension to new sources and decays

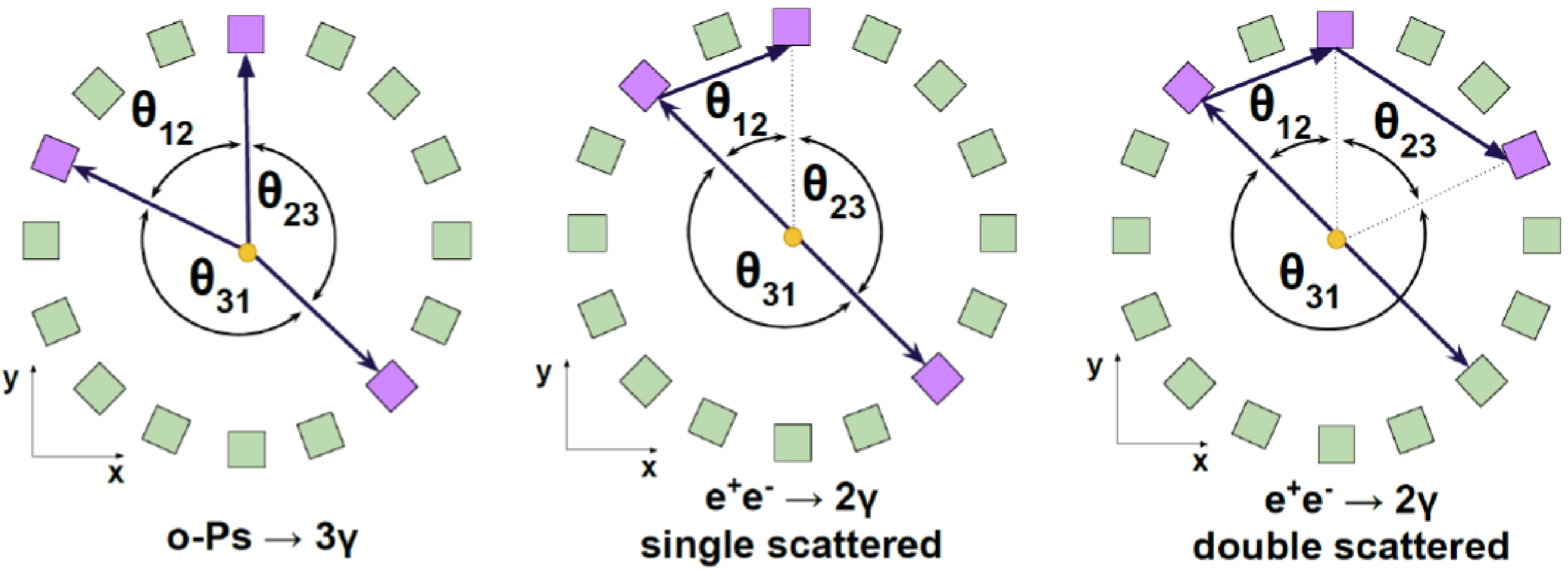
- Ortho-positronium
- Para-positronium
- Non-pure emitters
  (e.g. scandium sources)
- Polarization degrees of freedom



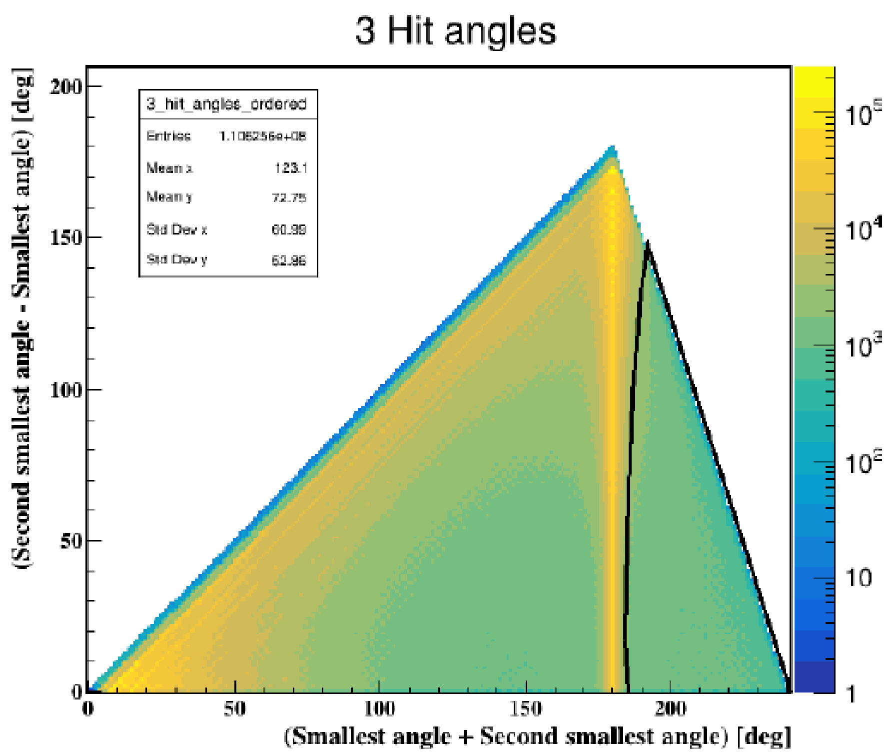


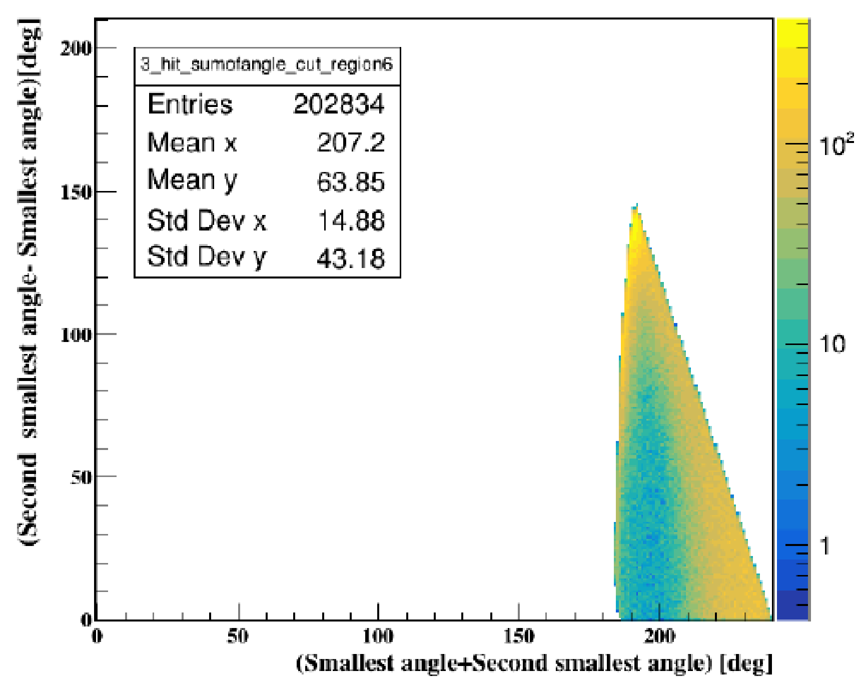


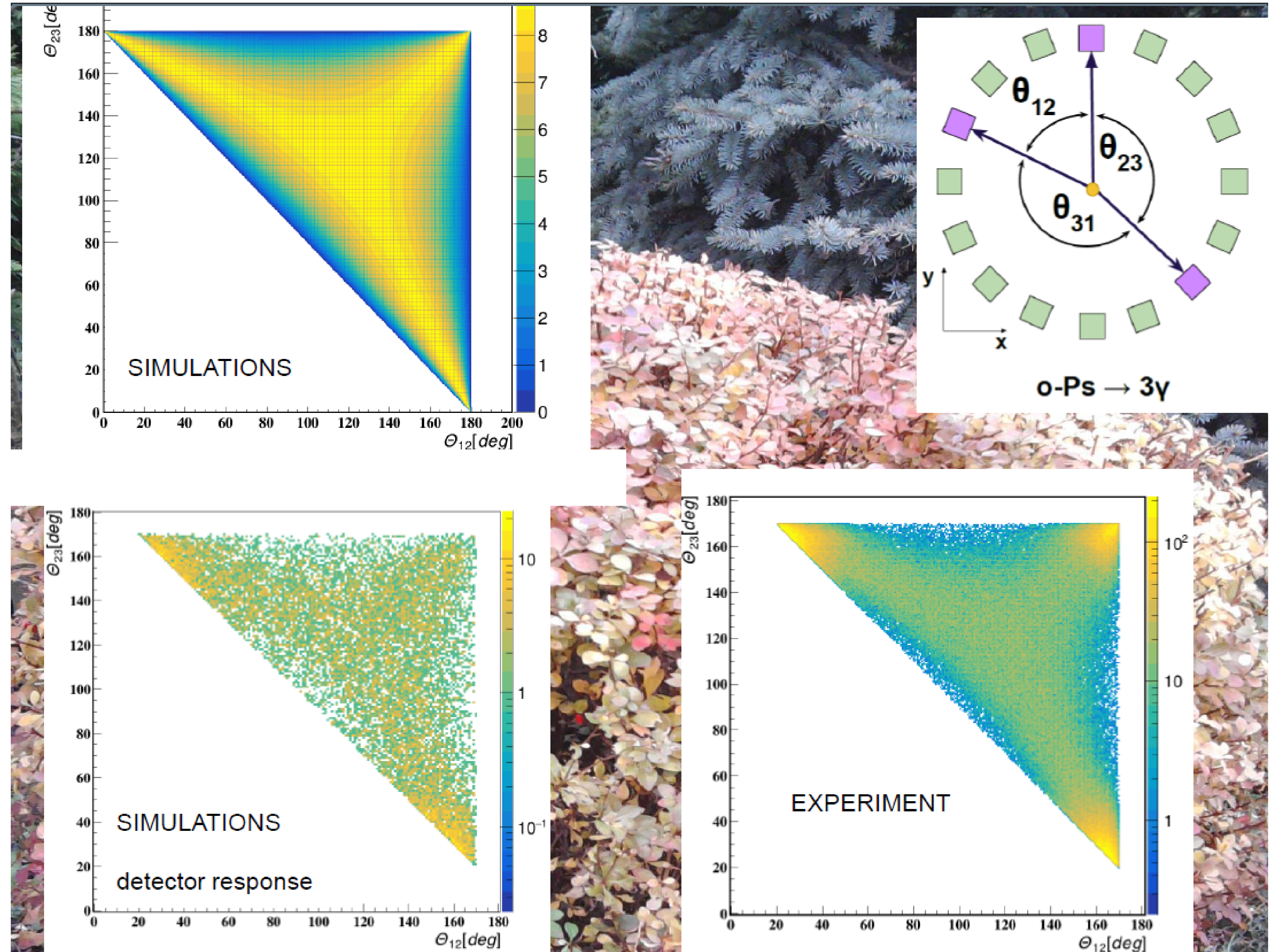
$^{44}Sc \longrightarrow {}^{44}Ca^{*} + e^{+} + \nu_{e}$
$^{44}Ne + \gamma$



$\theta_{23} + \theta_{12} > 180$ $\theta_{23} + \theta_{12} = 180$ $\theta_{23} + \theta_{12} < 180$

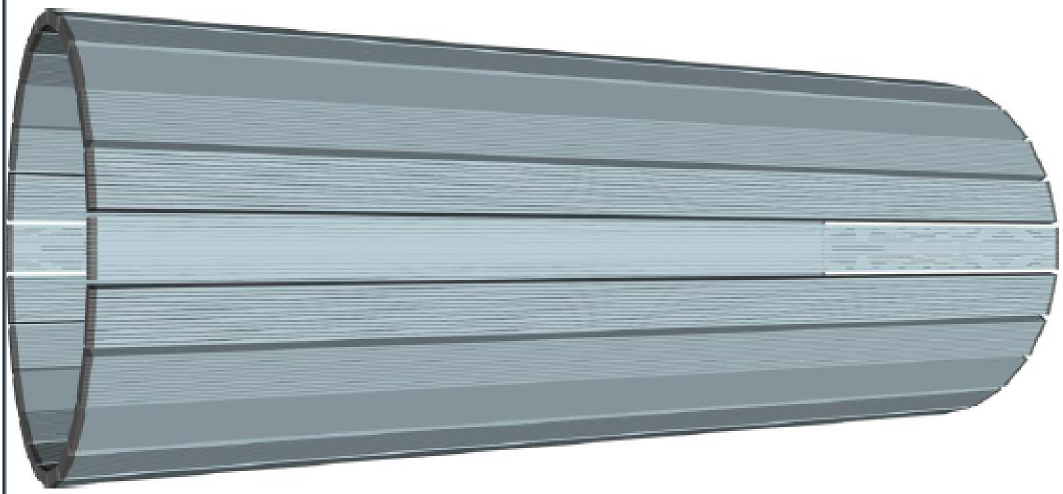




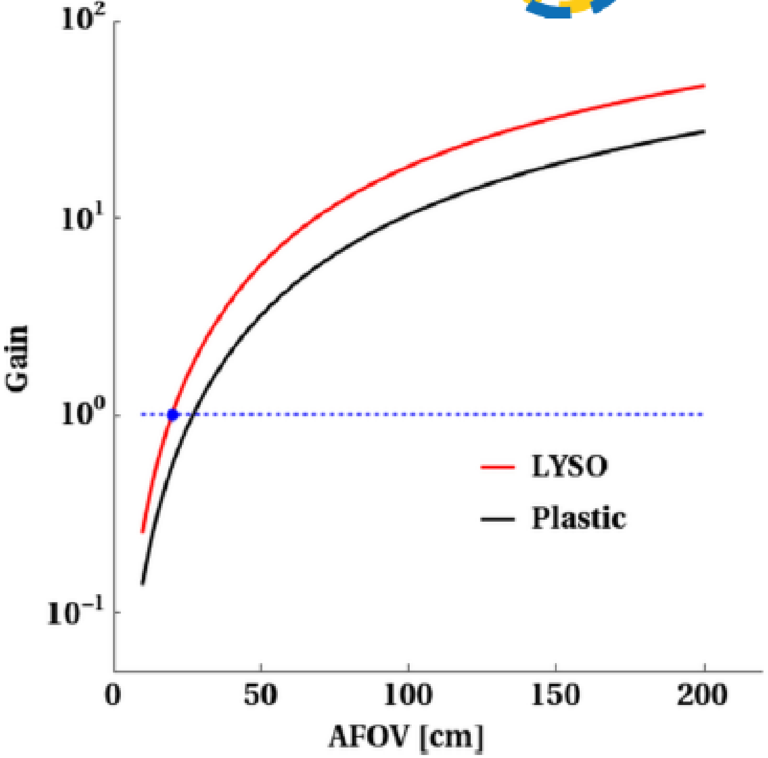


$\Theta_{23}[deg]$
$\Theta_{12}[deg]$
SIMULATIONS
θ12
θ23
θ31
y
x
o-Ps → 3γ
$\Theta_{23}[deg]$
$\Theta_{12}[deg]$
SIMULATIONS
detector response
$\Theta_{23}[deg]$
$\Theta_{12}[deg]$
EXPERIMENT

Expected performance



24 modules
single scintillator: 6 x 30 x 2000 mm^3



Gain is relative to LYSO PET with AFOV = 20 cm

Technology landscape

- Data analysis framework,
- MC simulations,
- Image reconstruction algo,
- MC/data postprocessing

J-PET **Framework**

C++

GATE

GEANT4
A SIMULATION TOOLKIT

ROOT
Data Analysis Framework
6

Technology landscape

- Data analysis framework,
- MC simulations,
- Image reconstruction algo,
- MC/data postprocessing

GATE

J-PET Framework

C++

Python

ROOT
Data Analysis Framework

Technology landscape

- Data analysis framework,
- MC simulations,
- Image reconstruction algo,
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GATE

GEANT4
A SIMULATION TOOLKIT

J-PET **Framework**

ROOT
Data Analysis Framework
6

C++

Python

- Image reconstruction prototyping,
- validation studies,
- simple MC simulations

R

MATLAB
The Language of Technical Computing

Wolfram
Mathematica

Technology landscape

- Data analysis framework,
- MC simulations,
- Image reconstruction algo,
- MC/data postprocessing

GATE

J-PET **Framework**

C++

Python

- Image reconstruction prototyping,
- validation studies,
- simple MC simulations

perl
Programming Language

ba&sh

+ many more

Wolfram Mathematica

MATLAB
The Language of Technical Computing

J-PET Analysis Framework

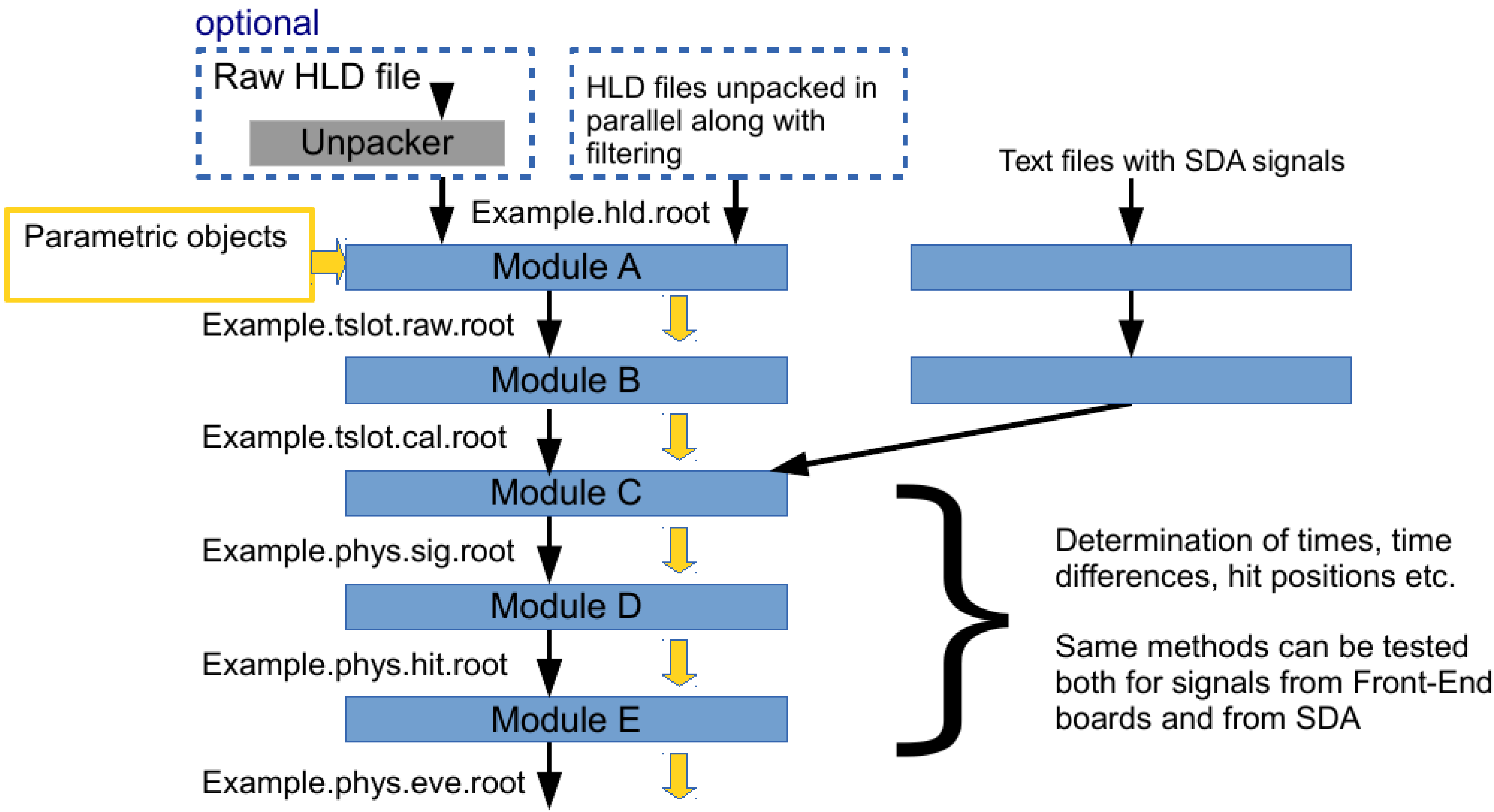
Open-source platform for J-PET data analysis

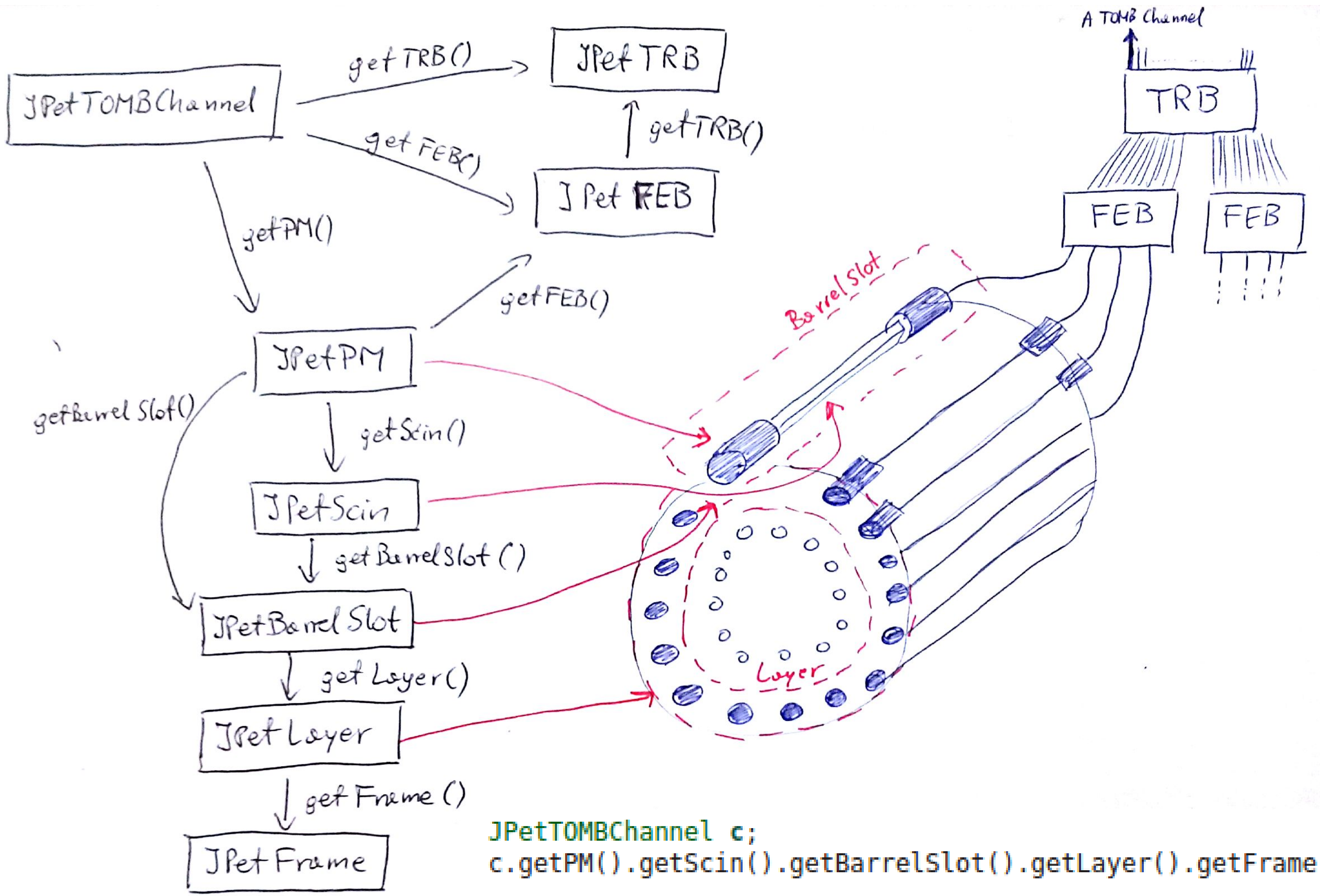
Technicalities

- Open source project
- So far 7 releases (v8 very soon :-))
- Mainly developed in C++11
- ROOT-based data structure (ROOTv6)
- All configuration parameters stored in JSON files.
- Heavy usage of BOOST library,
- Quality ensured by automatic set of tests (Jenkins & Travis)

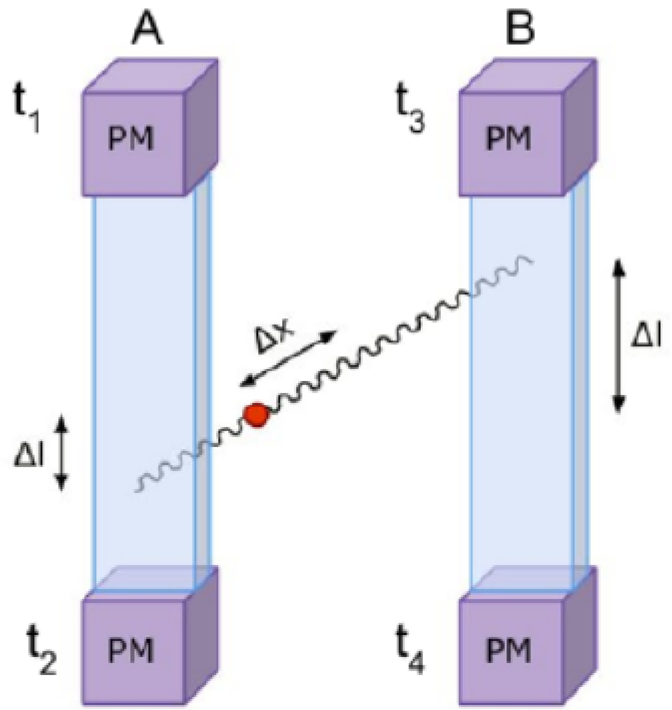
Scheme of the analysis with J-Pet framework

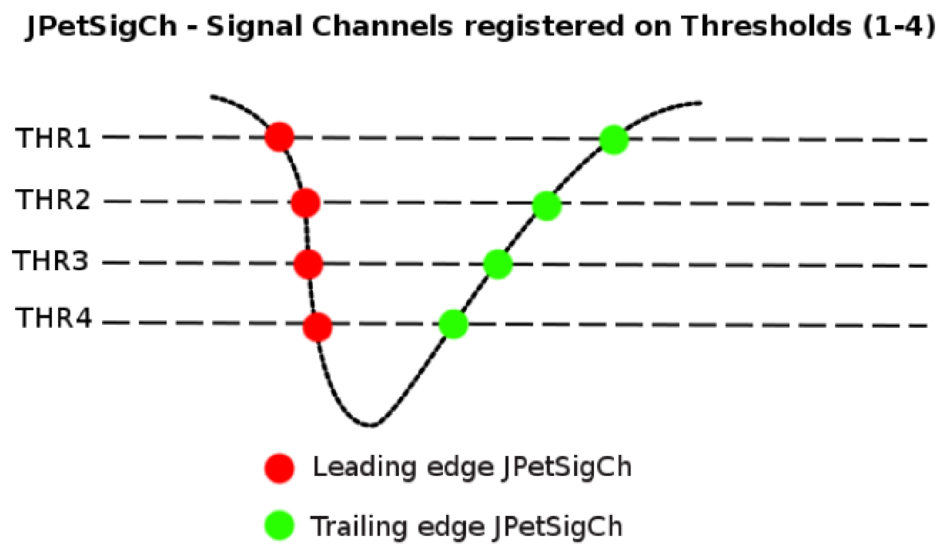
Each analysis module is a separate C++ class.

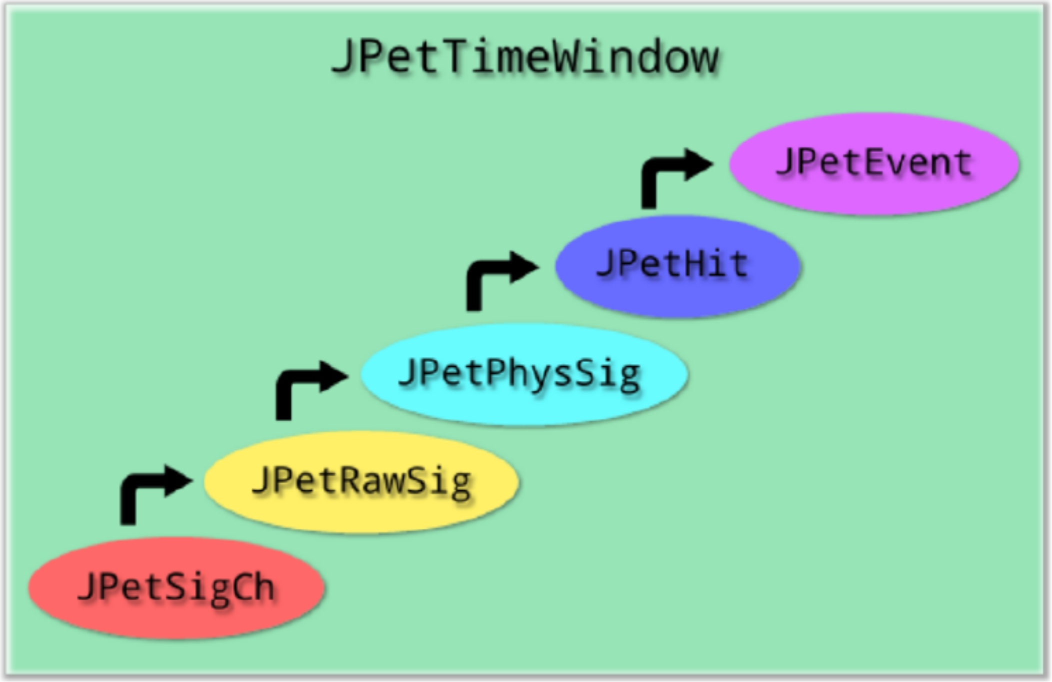




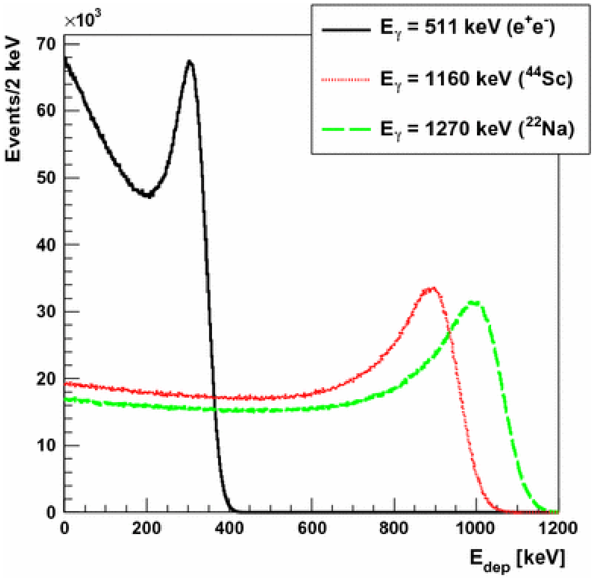

```
JPetTOMBChannel c;
c.getPM().getScin().getBarrelSlot().getLayer().getFrame()
```


A
B
t_1
t_2
t_3
t_4
PM
PM
PM
PM
Δx
Δl
Δl

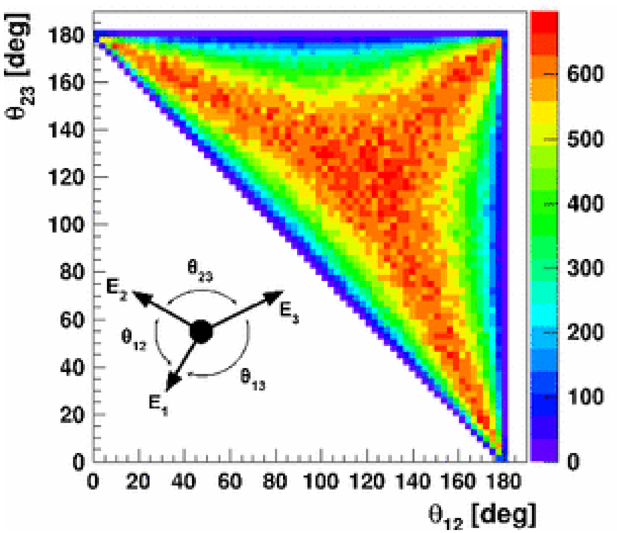

JPetSigCh - Signal Channels registered on Thresholds (1-4)
THR1
THR2
THR3
THR4
Leading edge JPetSigCh
Trailing edge JPetSigCh


JPetTimeWindow
JPetEvent
JPetHit
JPetPhysSig
JPetRawSig
JPetSigCh

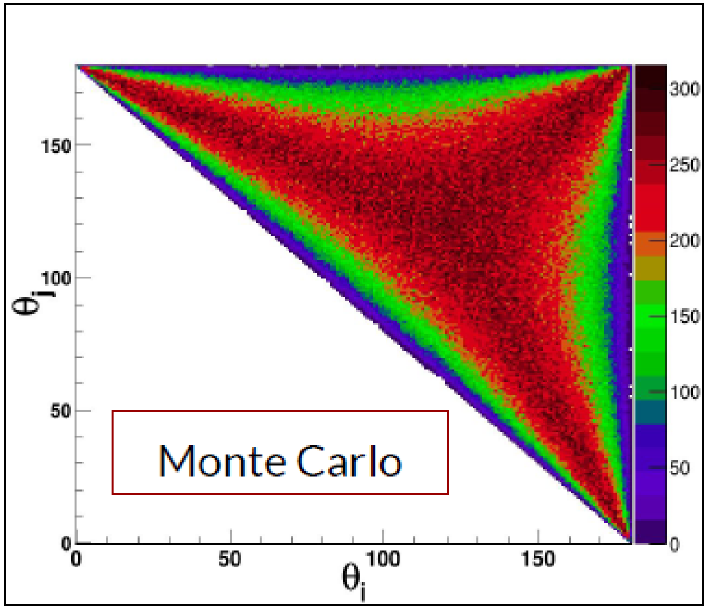
Analysis and MC simulations in action



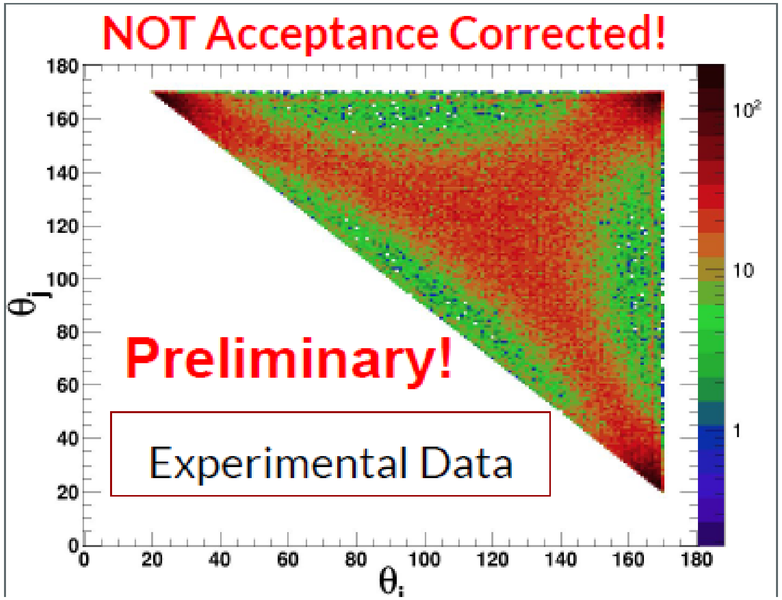
D. Kaminska et al., Eur. Phys. J. C (2016) 76:445



D. Kaminska et al., Eur. Phys. J. C (2016) 76:445



From Juhi Raj's talk



From Juhi Raj's talk

☐	961	Rozszerzenie	New	Low	Check the acceptance map output from MLEM package	Kamil Rakoczy	2018-07-02
☐	960	Blad	Answer	Normal	Update includes for current Framework version in Event Display	Kamil Rakoczy	2018-06-27
☐	959	Rozszerzenie	New	Normal	Improve LargeBarrel example	Aleksander Gajos	2018-06-20
☐	953	Blad	In progress	Normal	Problem with Unpacker	Aleksander Gajos	2018-05-17
☐	947	Wsparcie	In progress	Normal	Verify that the incomplete setups (missing TRef-s) are harmless for Examples' UT-s	Krzysztof Kacprzak	2018-04-30
☐	945	Rozszerzenie	New	Low	MC implementation of small annihilation chamber		2018-04-26
☐	944	Rozszerzenie	New	Low	MC implementation of collimator		2018-04-26
☐	943	Rozszerzenie	Answer	Normal	MC Implementation of missing DecayVertex structures	Wojciech Krzemien	2018-04-26
☐	942	Rozszerzenie	In progress	Normal	MC time optimization -> Energy cuts	Sushil Sharma	2018-04-26

Recommended way to report a bug

J-PET Analysis Framework

Authors

J-PET Analysis Framework is being developed by Wojciech Krzemien, Aleksander Gajos, Kamil Rakoczy, Szymon Niedźwiecki and Krzysztof Kacprzak. The former developers are Karol Stola, Damian Trybek, Andrzej Gruntowski, Klara Muzalewska, Oleksandr Rundel and Tomasz Kisielewski.

Citation

In case you want to refer to J-PET Analysis Framework you can use this reference:

> W. Krzemien et al.
> Analysis framework for the J-PET scanner
> Acta Phys. Polon. A127 (2015) 1491-1494 DOI: 10.12693/APhysPolA.127.1491
> e-Print: arXiv:1503.00465

All the data analyses, calibration procedures performed in J-PET use J-PET Framework