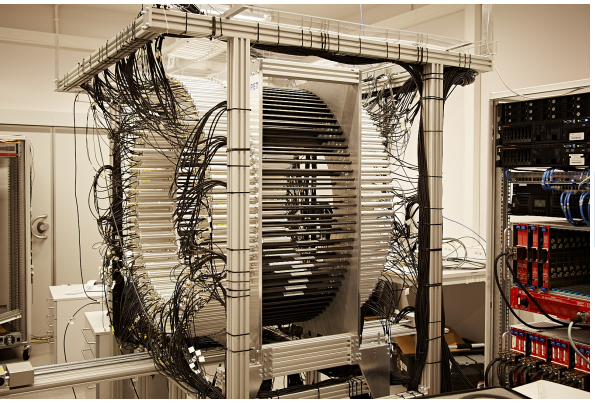
Overview of the J-PET analysis and simulation software

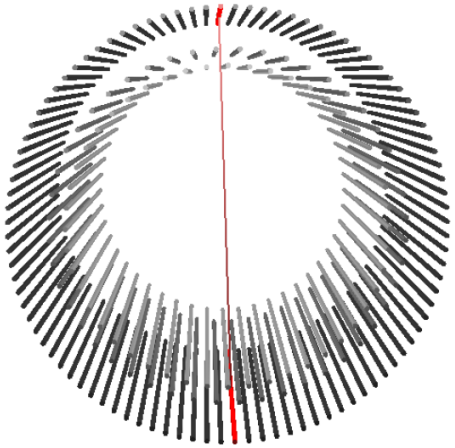
Wojciech Krzemień

3rd Jagiellonium Symposium on Fundamental and Applied Subatomic Physics
Kraków, 27.06. 2019

J-PET software



Experiment



MC simulations

„raw" data

Line of response (LOR)

DAQ

low-level reco

Image reco. algorithms

Image

Model

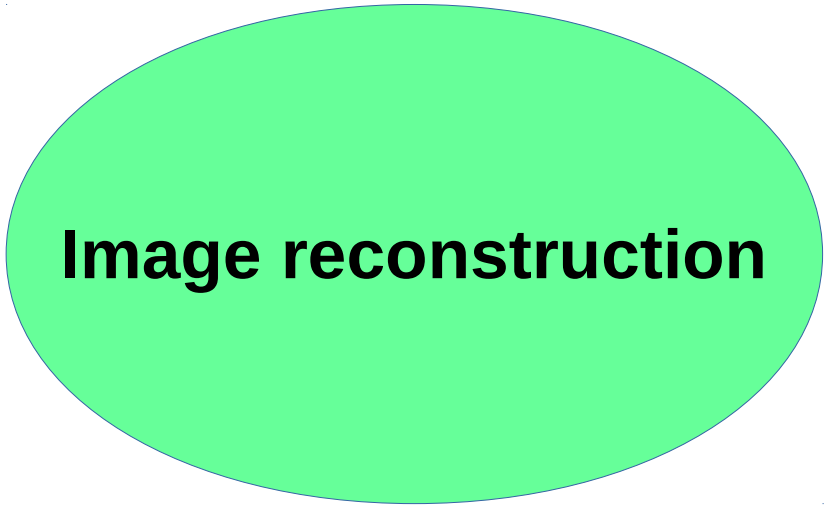
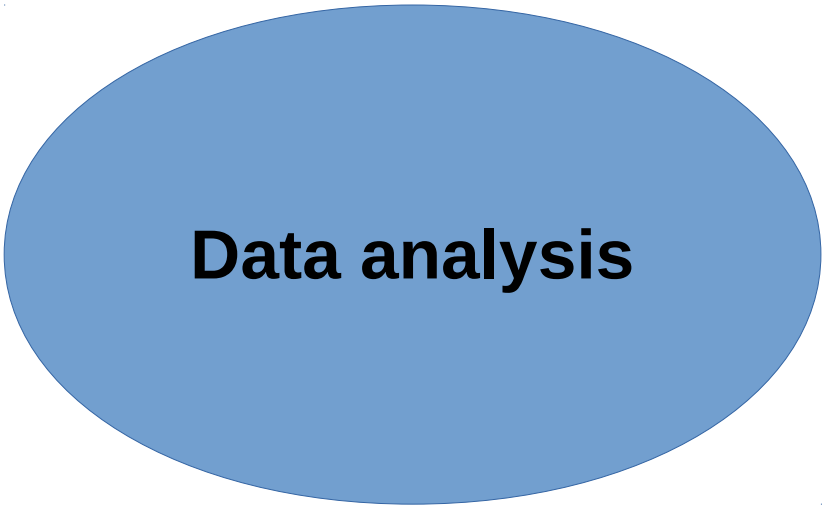
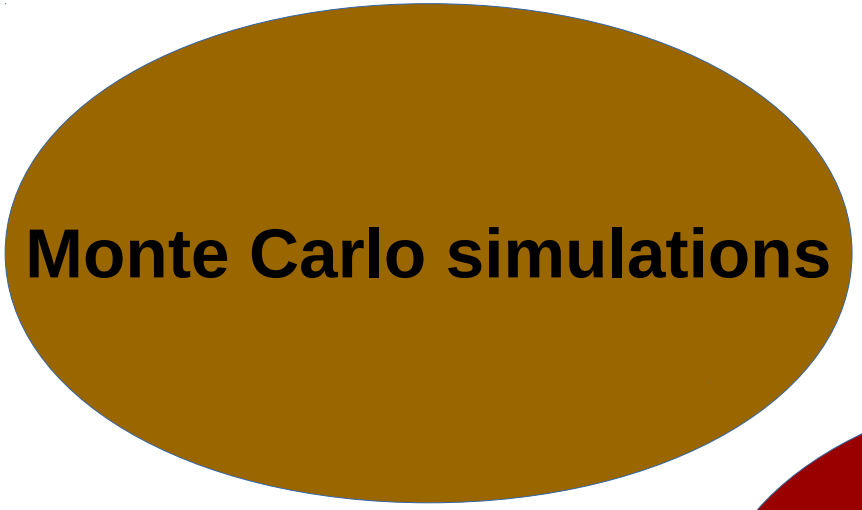


Image reconstruction


Data analysis


Monte Carlo simulations


Detector calibrations


Data Acquistion System

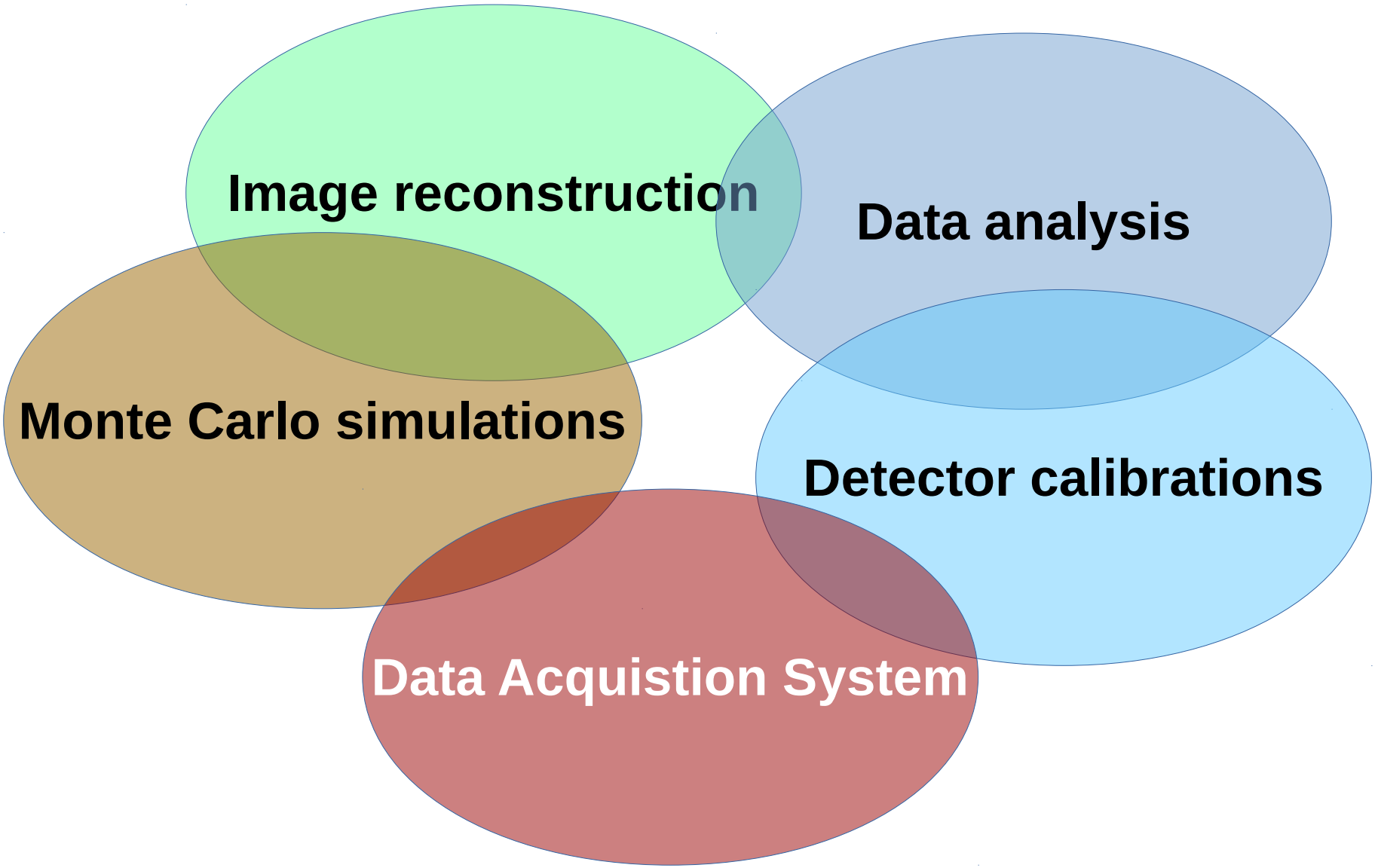


Image reconstruction
Data analysis
Monte Carlo simulations
Detector calibrations
Data Acquistion System

J-PET Software@GitHub

https://github.com/JPETTomography

J-PET collaboration

http://koza.if.uj.edu

your organization's avatar

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

21 repositories

Find a repository… | Type: All | Language: All | Customize pins | New

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 ectangular 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

Technology landscape

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

J-PET **Framework**

C++

GATE

GEANT4
A SIMULATION TOOLKIT

Technology landscape

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J-PET **Framework**

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Python

GATE

GEANT4
A SIMULATION TOOLKIT

ROOT
Data Analysis Framework

Technology landscape

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J-PET Framework

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GATE

GEANT4
A SIMULATION TOOLKIT

ROOT
Data Analysis Framework

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

MATLAB
The Language of Technical Computing

Wolfram Mathematica

Technology landscape

- Data analysis framework,
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- Image reconstruction algo,
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J-PET **Framework**

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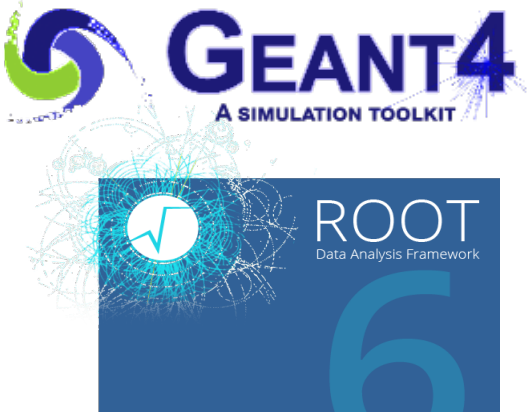
GATE



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

ba&sh

+ many more

Image reconstruction - challenges

Conventional tomography

Adapt known algorithms to take advantage of (or at least not deteriorate) the J-PET scanner features:

- timing resolution
- modular, multiple-layer setup
- large Field-of-View
- Fast and Efficient Data Acquisition system

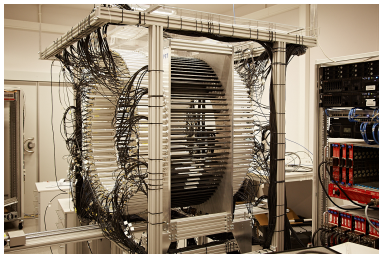


Image reconstruction - challenges

Conventional tomography

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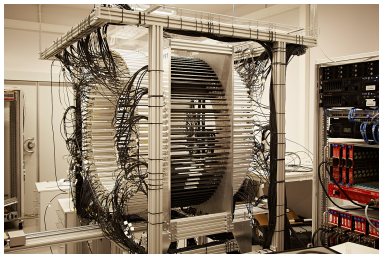


Unconventional tomography

Develop new methodologies and techniques

- Three-photon tomography,
- 2+1 tomography
- Positronium lifetime tomography
- Quantum entanglement imagining

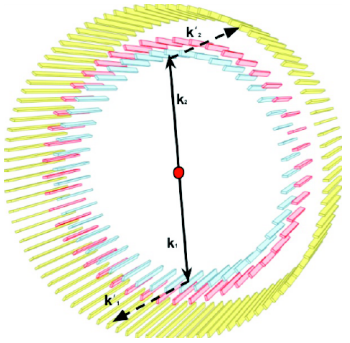
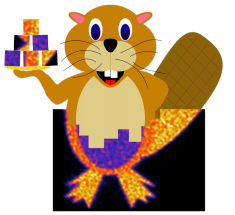


Image reconstruction algorithms & packages

Packages being used/ under test:

- Software for Tomographic Image Reconstruction (**STIR**) (used in [2], [3])
- Tomographic Reconstruction in Python (**TomoPy**) (used in [3])
- Customizable and Advanced Software for Tomographic Reconstruction (**CASTOR**)
- Quantitative Emission Tomography Iterative Reconstruction (**QETIR**)(*)



1) G. Korcyl et al. IEEE Transactions On Medical Imaging, Vol. 37, No. 11 (2018) 2526
2) P. Kowalski et al. Physics in Medicine and Biology 63 (2018) 165008
3) R. Y. Shopa et al. Acta Phys. Polon. B48 no. 10, 1757 (2017)
4) L. Raczyński et al. Acta Physica Polonica B Vol. 48, pp. 1611, (2017)
5) M. Pawlik-Niedźwiecka et al. Acta Phys. Polon. A 132, no. 5, 1645 (2017)
6) A. Strzelecki PhD thesis, Jagiellonian University (2016)
https://github.com/JPETTomography/j-pet-mlem

(*)by courtesy of prof. Vandenberghe

Image reconstruction algorithms & packages

- Real time image reconstruction based on Field Programmable Gate Array (**FPGA**)[1] – **see G. Korcyl's talk**
- (Time-of-Flight) Filtered Backprojection (**TOF-FBP/FBP**)[3][4] – **see R. Y. Shopa's talk**
- Maximum Likelihood Expectation Maximization (**MLEM**) [5][6] - **see P. Kopka & K. Klimaszewski poster**
- TOF Back Projection Total Variation Regularization (**TOF-BPTV**)[4] – **see L. Raczyński talk**

Python

C++

1) G. Korcyl et al. IEEE Transactions On Medical Imaging, Vol. 37, No. 11 (2018) 2526
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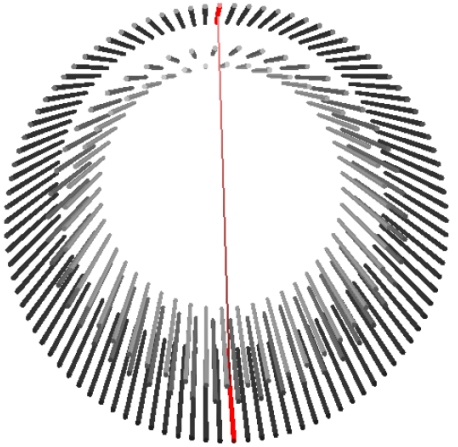
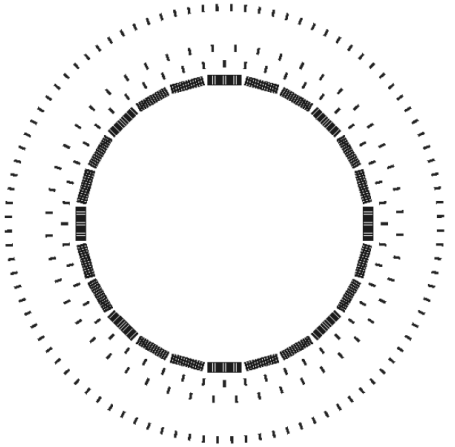
Monte Carlo simulations

- Experimental sensitivity studies
- Calibration procedure development
- Selection criteria during data analysis
- Testing of image reconstruction algorithms
- Studies of optimal detector setups





1) P. Moskal et al., Phys. Med. Biol. 64 (2019) 055017
2) P. Moskal et al. Eur. Phys. J. C 78 (2018) 970
3) P. Kowalski et al., Phys. Med. Biol.(2018) 63, N.16
4) D. Kaminska et al., Eur. Phys. J. C (2016) 76:445
5) A. Gajos, et. al. Nucl. Instrum. Meth. A819, 54 (2016)

Monte Carlo simulations

https://github.com/JPETTomography/J-PET-geant4

GATE

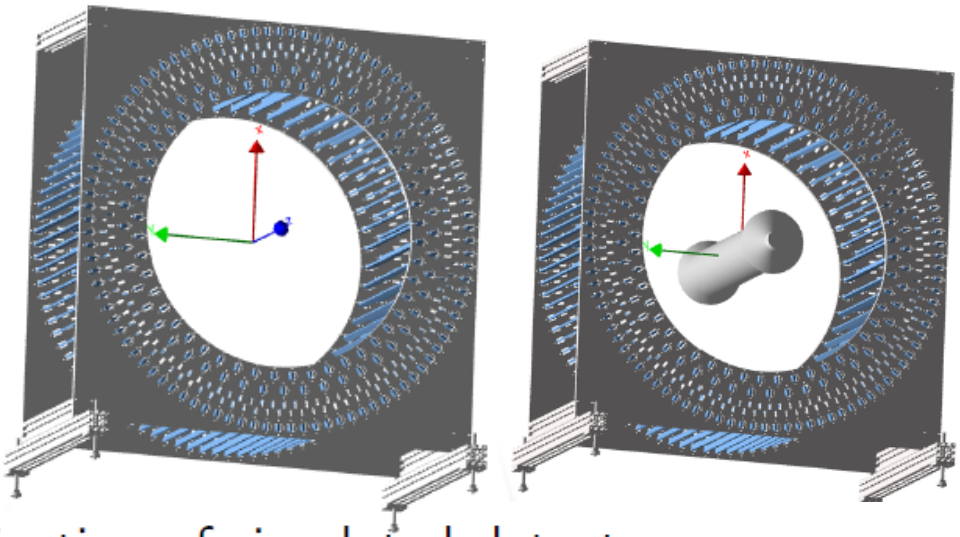
Simulations of Preclinical and Clinical Scans in Emission Tomography, Transmission Tomography and Radiation Therapy

https://github.com/JPETTomography/Gate

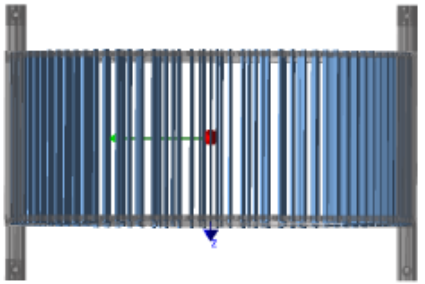
J-PET Geant 4

Daria Kisielewska
Sushil Sharma

- code available at GitHub
  `https://github.com/JPETTomography/J-PET-geant4.git`
- required packages: geant.10.4, root6, cadmesh, cmake
- physics list: G4EmLivermorePolarizedPhysics (Livermore physics models with polarized photon models)
- the Monte Carlo simulations account for:
  - angular and energy distributions of gamma quanta originating from direct or ortho-positronium annihilation,
  - Compton interactions of emitted gamma quanta in the detector built from plastic scintillators,
  - determination of gamma quanta hit-position and hit-time in the detector with experimentally determined resolutions,
  - multiple scattering and accidental coincidences,



⇳ Visualization of simulated detector

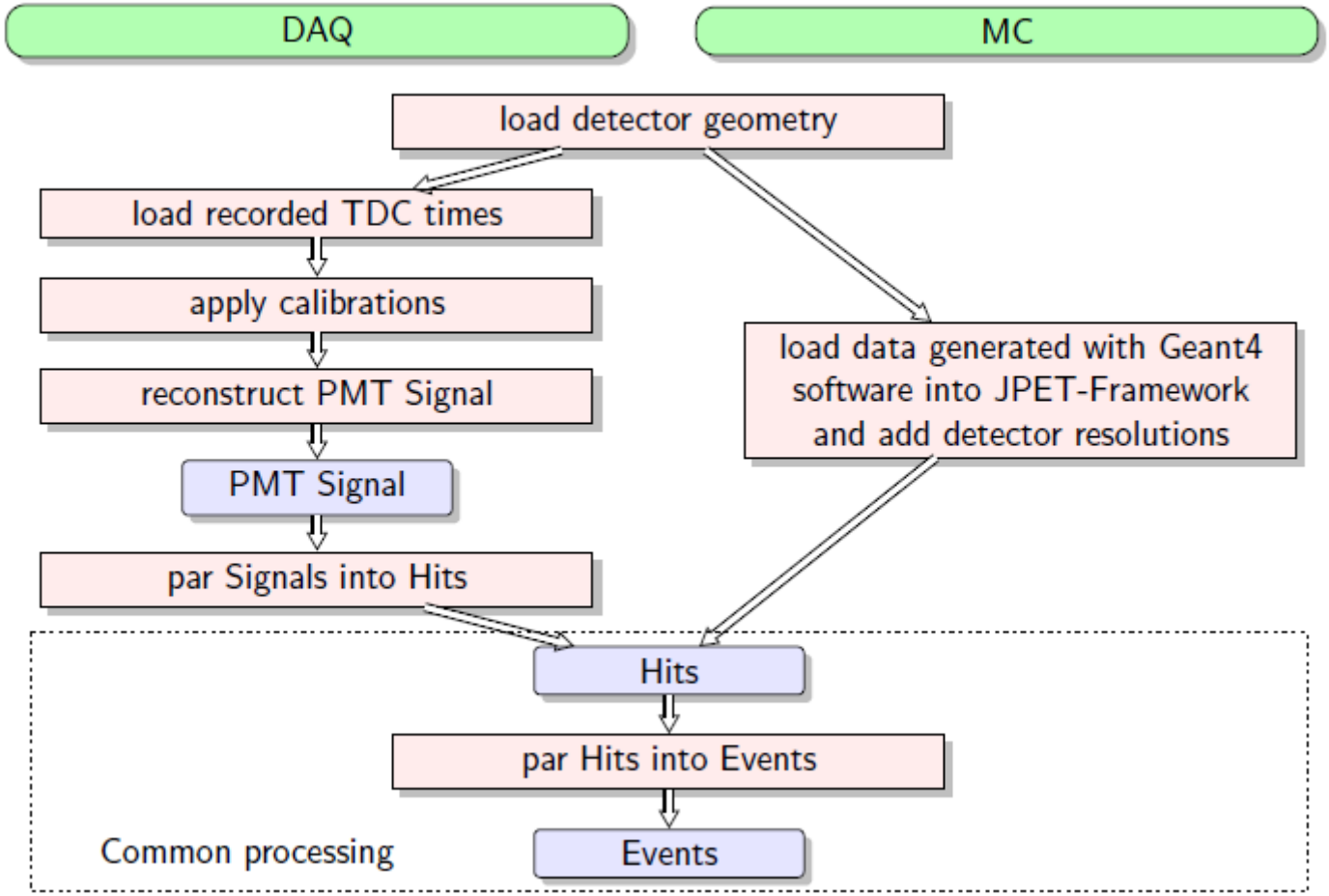


Layer number	Layer radius with respect to the center of scintillator	Number of scintillators in the layer
1	42.50 cm	48
2	46.75 cm	48
3	57.50 cm	96

Taken from Daria Kisielewska's talk „J-PET Monte Carlo simulations with the GEANT package."

J-PET Geant 4 integration with J-PET Framework

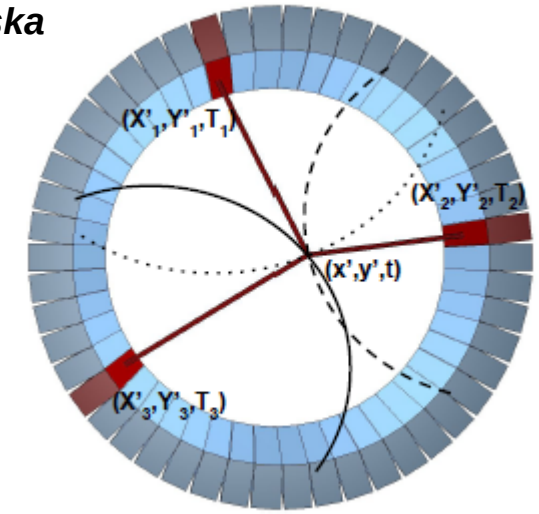
Daria Kisielewska

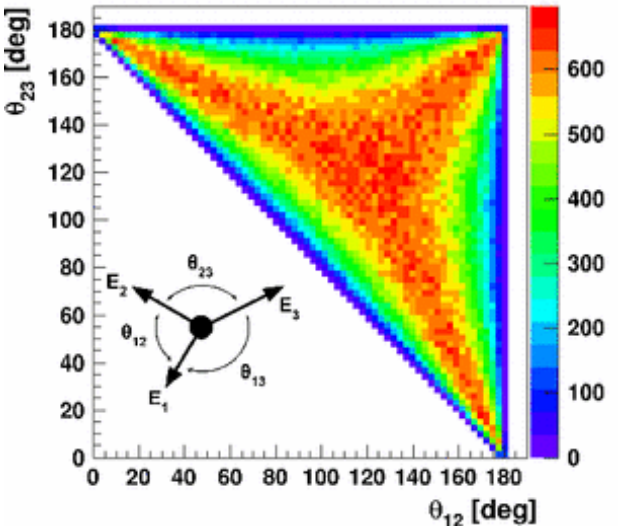


Taken from Daria Kisielewska's talk „J-PET Monte Carlo simulations with the GEANT package."

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

1) P. Moskal et al., Phys. Med. Biol. 64 (2019) 055017
2) P. Moskal et al. Eur. Phys. J. C 78 (2018) 970
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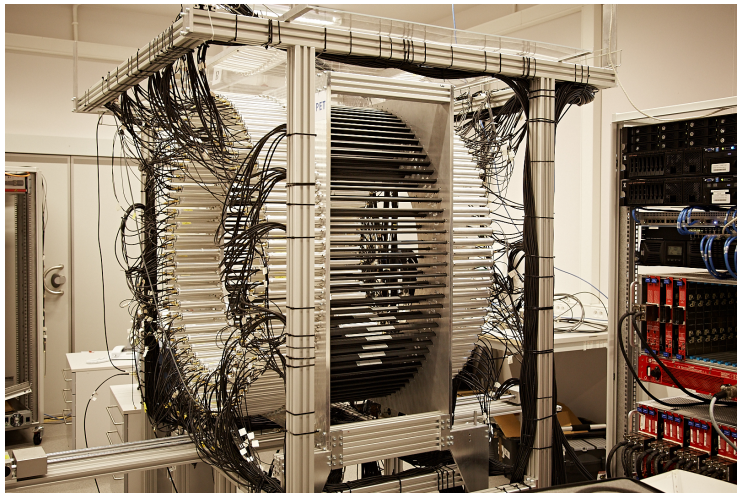
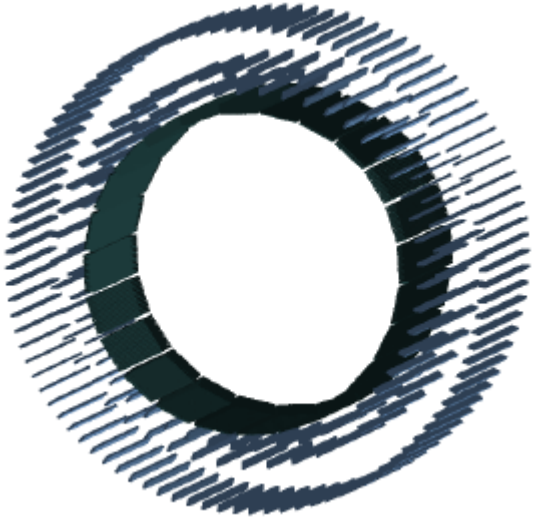
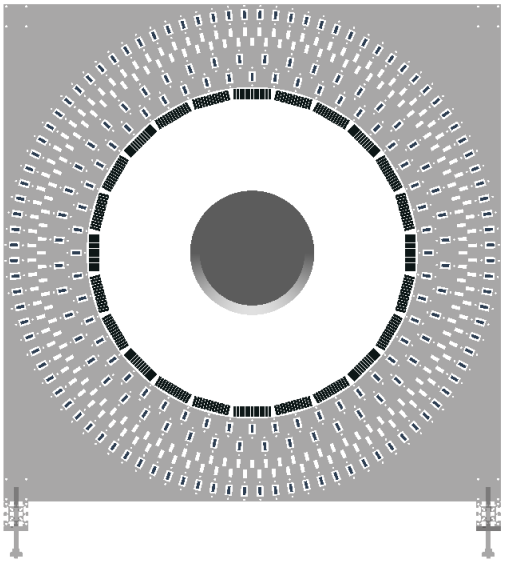
Towards modular PET







J-PET GATE

https://github.com/JPETTomography/Gate

Mateusz Bała,
Jakub Baran
Nikodem Krawczyk
Paweł Kowalski
Meysam Dadgar

- Experimental sensitivity studies
- Testing of image reconstruction algorithms
- Studies of optimal detector setups
- Polarization studies
- PET for hadron therapy

https://github.com/JPETTomography/Gate/tree/master/JPET_GATE_Use_Examples/Example_6

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

Physics in Medicine & Biology

IPEM Institute of Physics and Engineering in Medicine

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PUBLISHED
10 August 2018

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[6,7], 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]

1 Department of Complex Systems, National Centre for Nuclear Research, 05-400 Otwock-Świerk, Poland
2 Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, 30-348 Kraków, Poland
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
7 Department of Physics, College of Education for Pure Sciences, University of Mosul, Mosul, Iraq

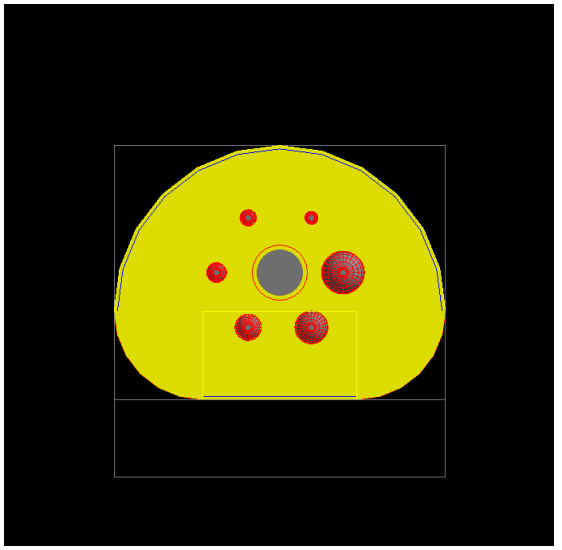
E-mail: pawel.kowalski@ncbj.gov.pl

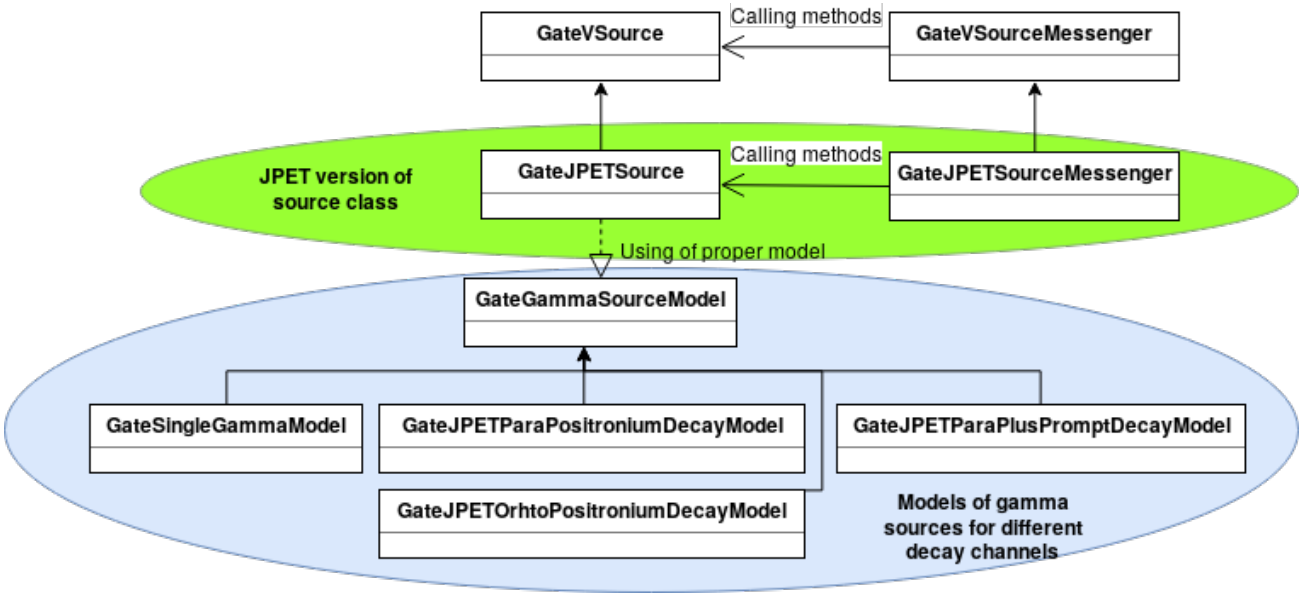
Keywords: NEMA norms, J-PET, positron emission tomography, plastic scintillators

Also - see S. Niedzwiecki's talk

Extension to new sources and decays

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

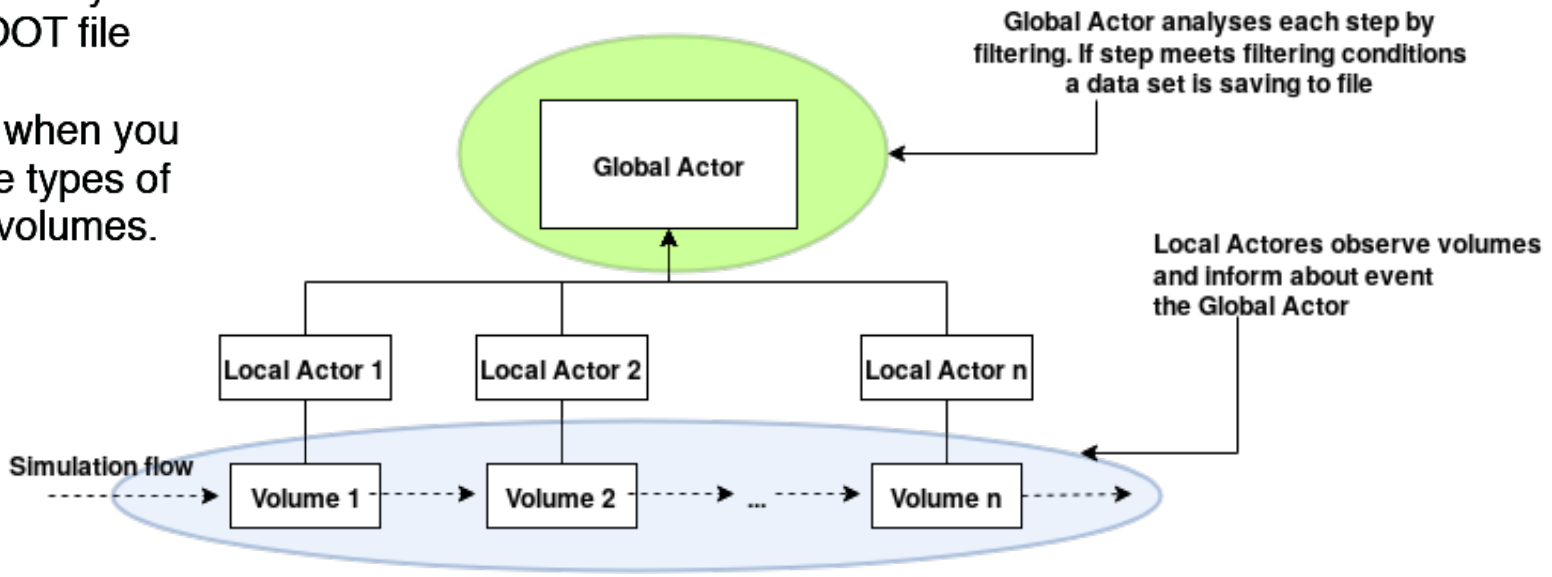




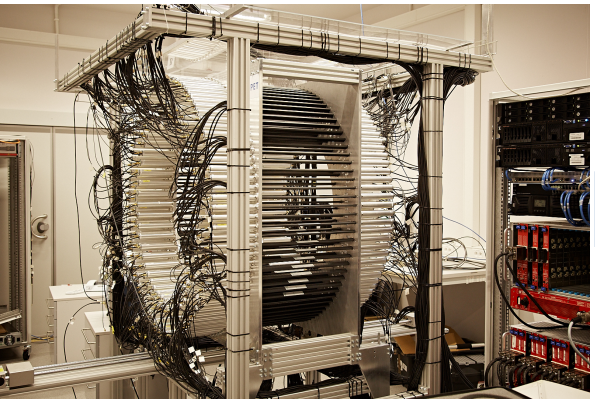
Mateusz Bała

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.



J-PET software



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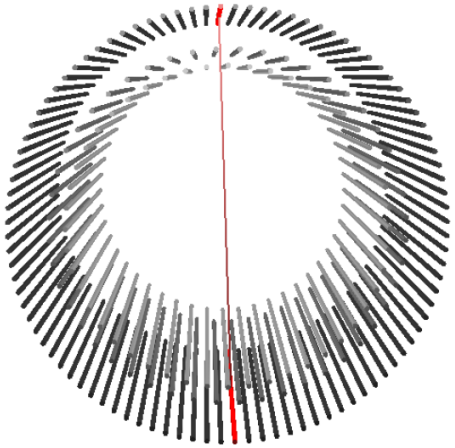


MC simulations

„raw" data

Line of response (LOR)

DAQ

low-level reco

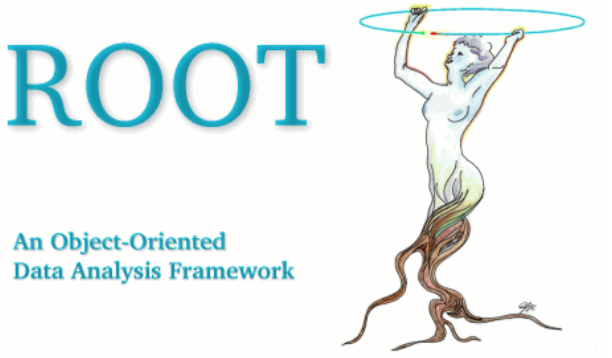
Image reco. algorithms

Image

Model

J-PET Analysis Framework

Open-source platform for J-PET data analysis

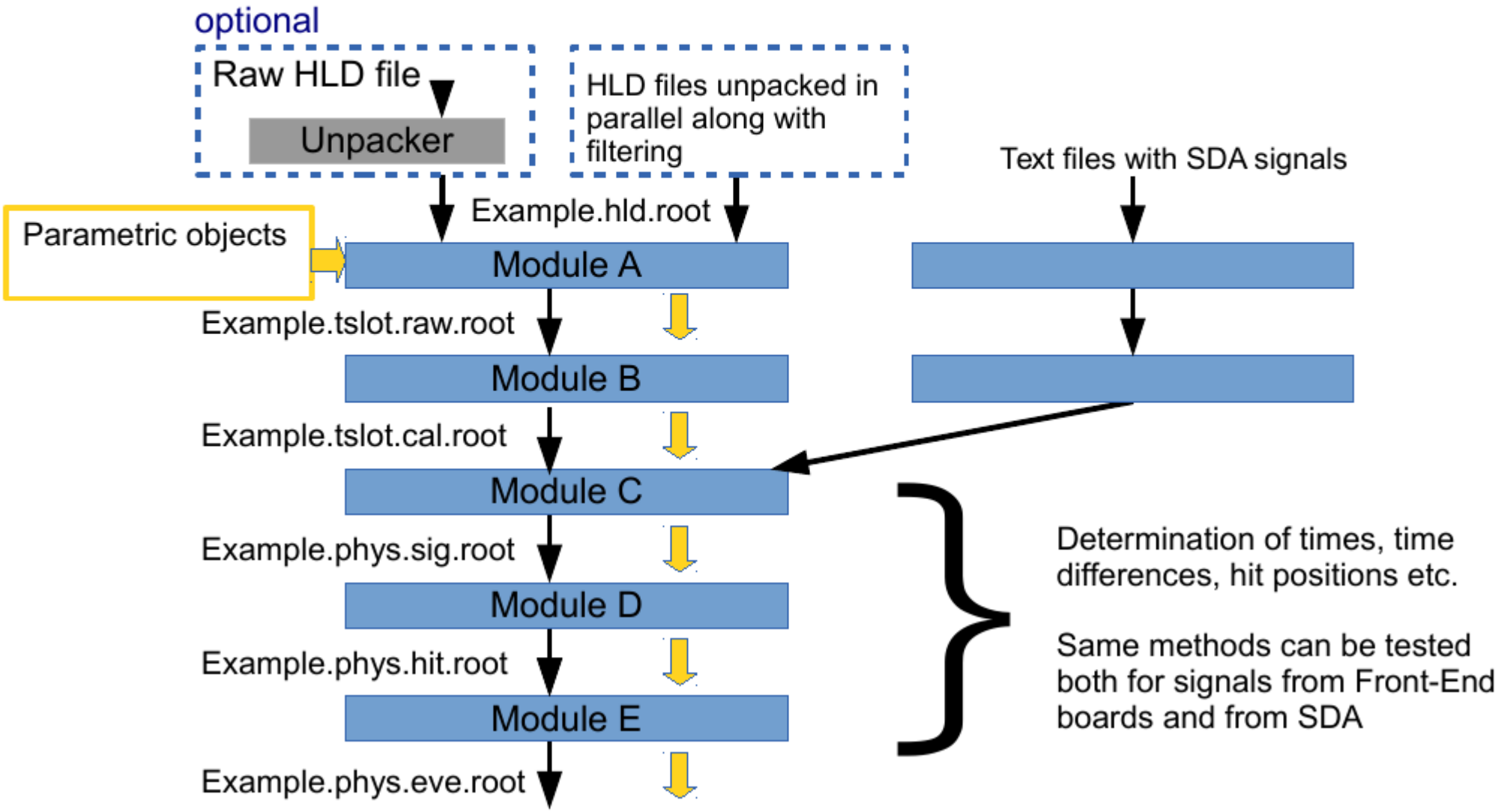


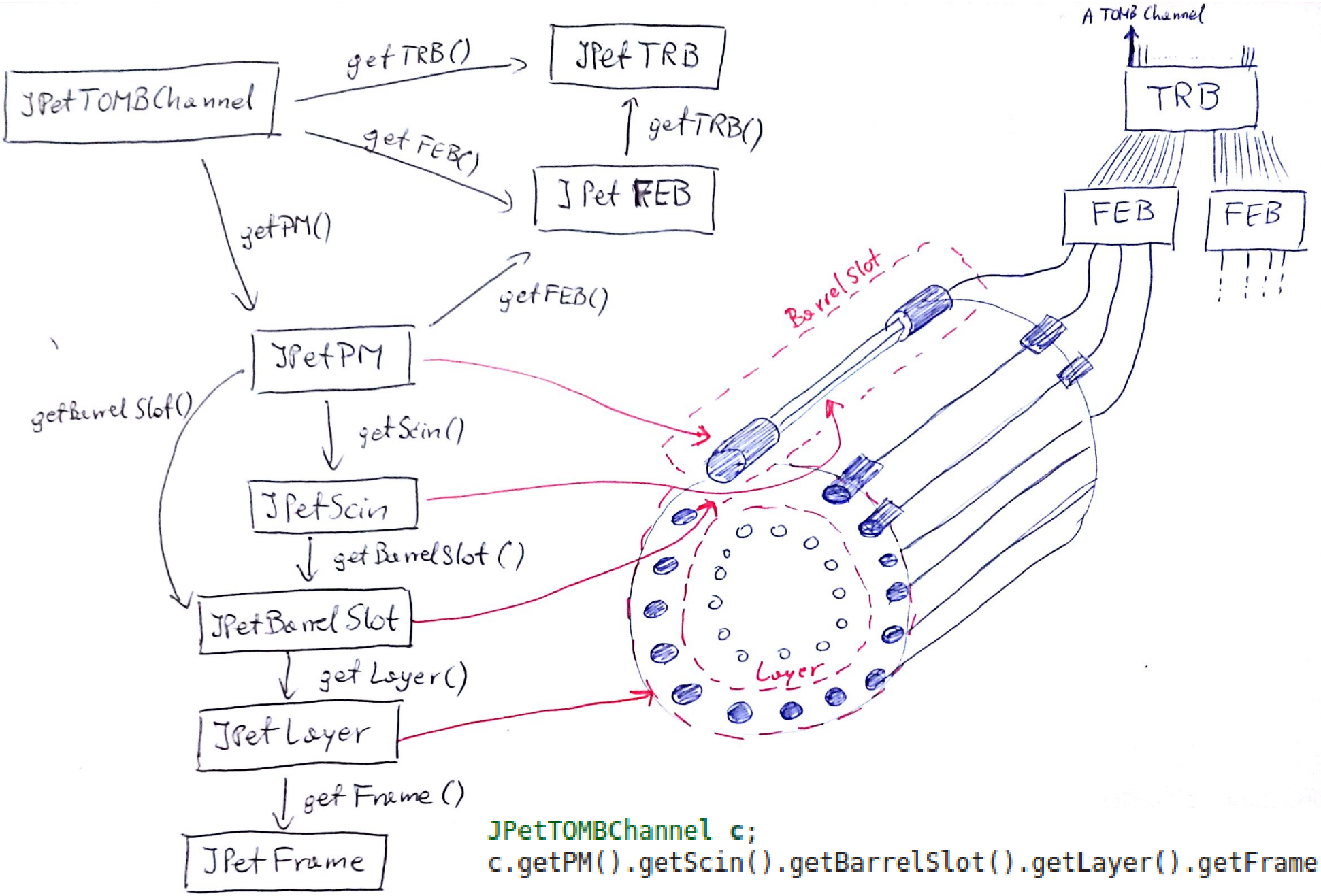
Technicalities

- 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)

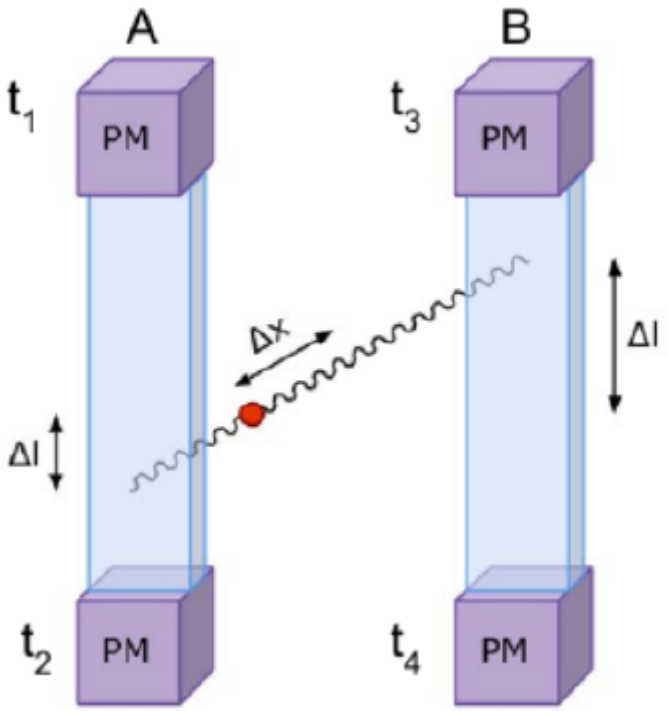
Scheme of the analysis with J-Pet framework

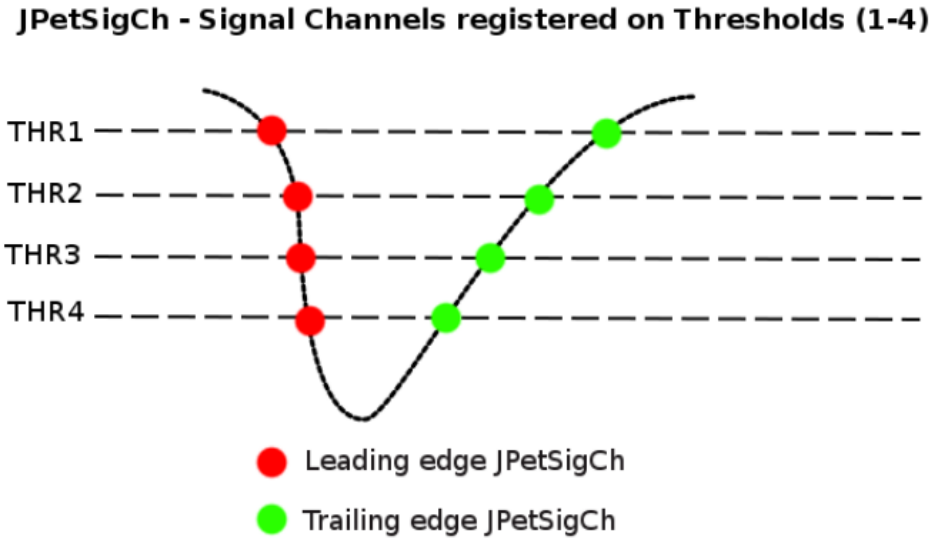
Each analysis module is a separate C++ class.

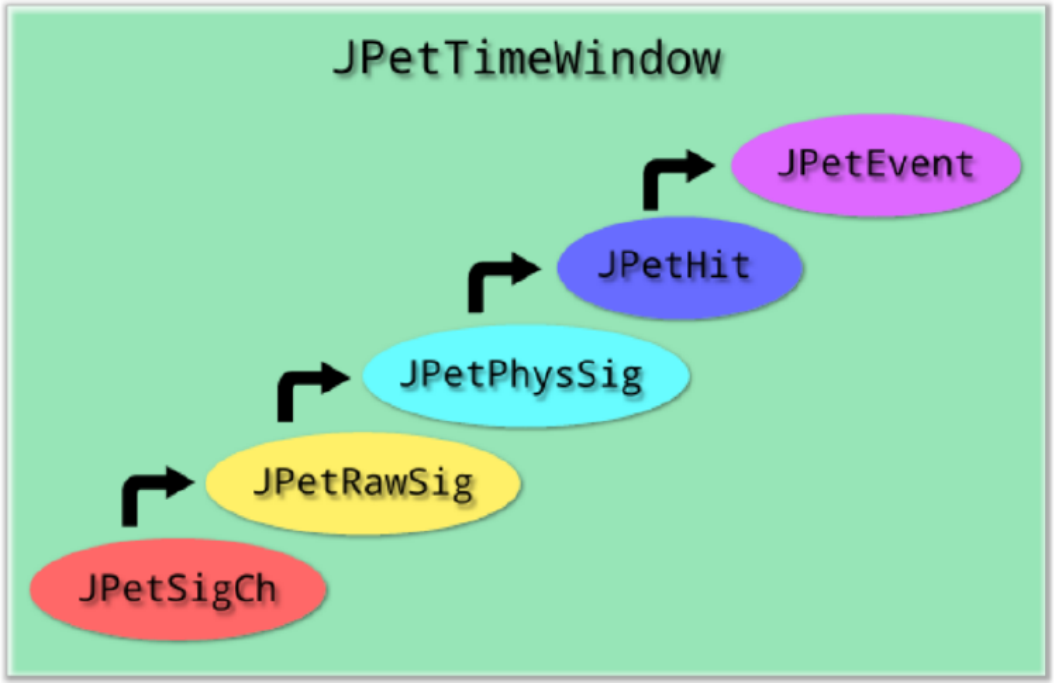




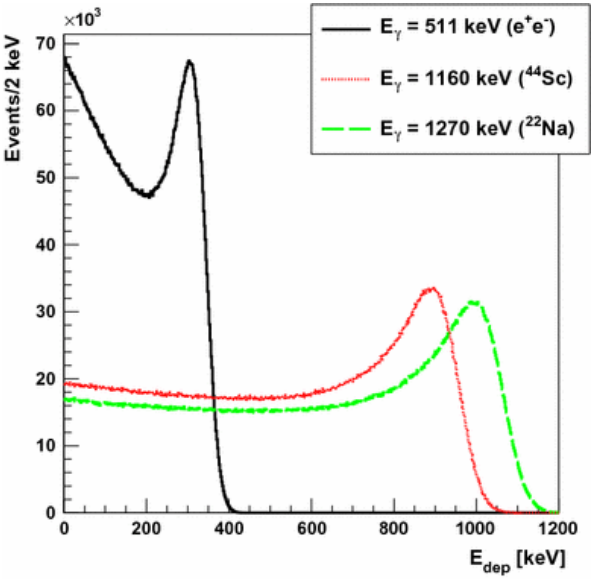

```
JPetTOMBChannel c;
c.getPM().getScin().getBarrelSlot().getLayer().getFrame()
```


A
B
t1
t2
t3
t4
PM
PM
PM
PM
Δx
Δl
Δl

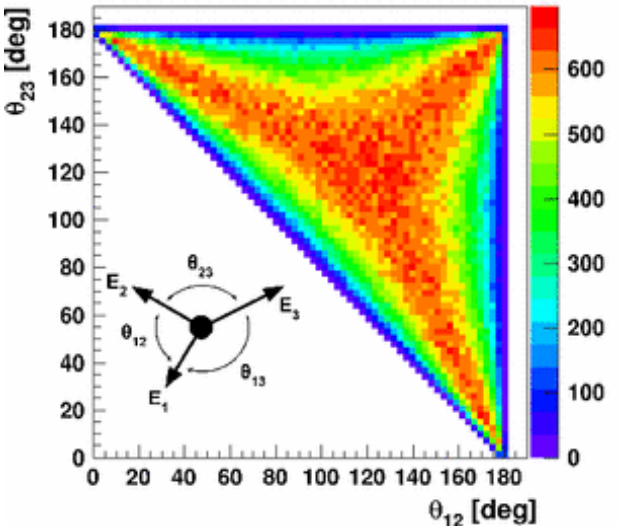

JPetSigCh - Signal Channels registered on Thresholds (1-4)
THR1
THR2
THR3
THR4
Leading edge JPetSigCh
Trailing edge JPetSigCh


JPetTimeWindow
JPetEvent
JPetHit
JPetPhysSig
JPetRawSig
JPetSigCh

Analysis and MC simulations in action



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



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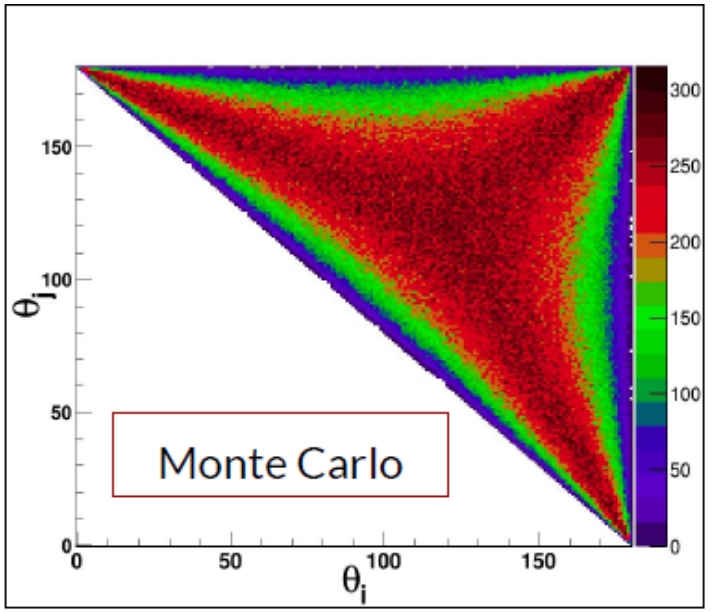
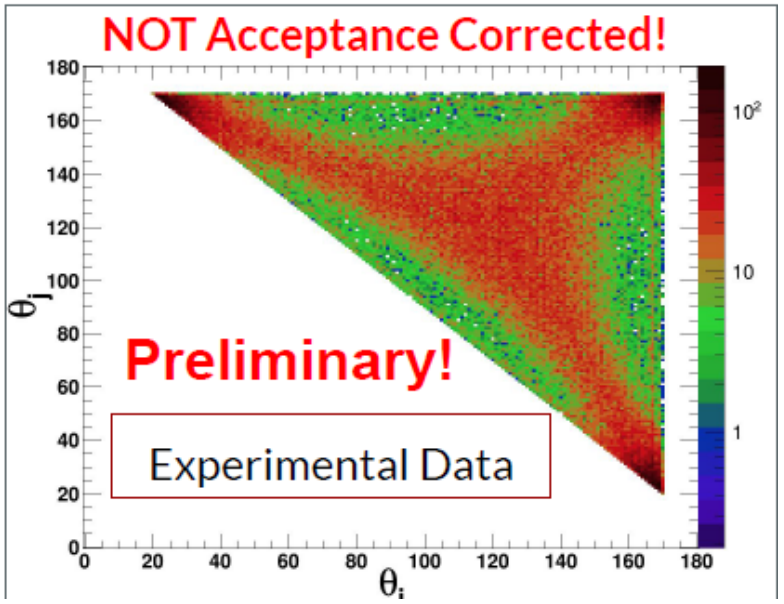
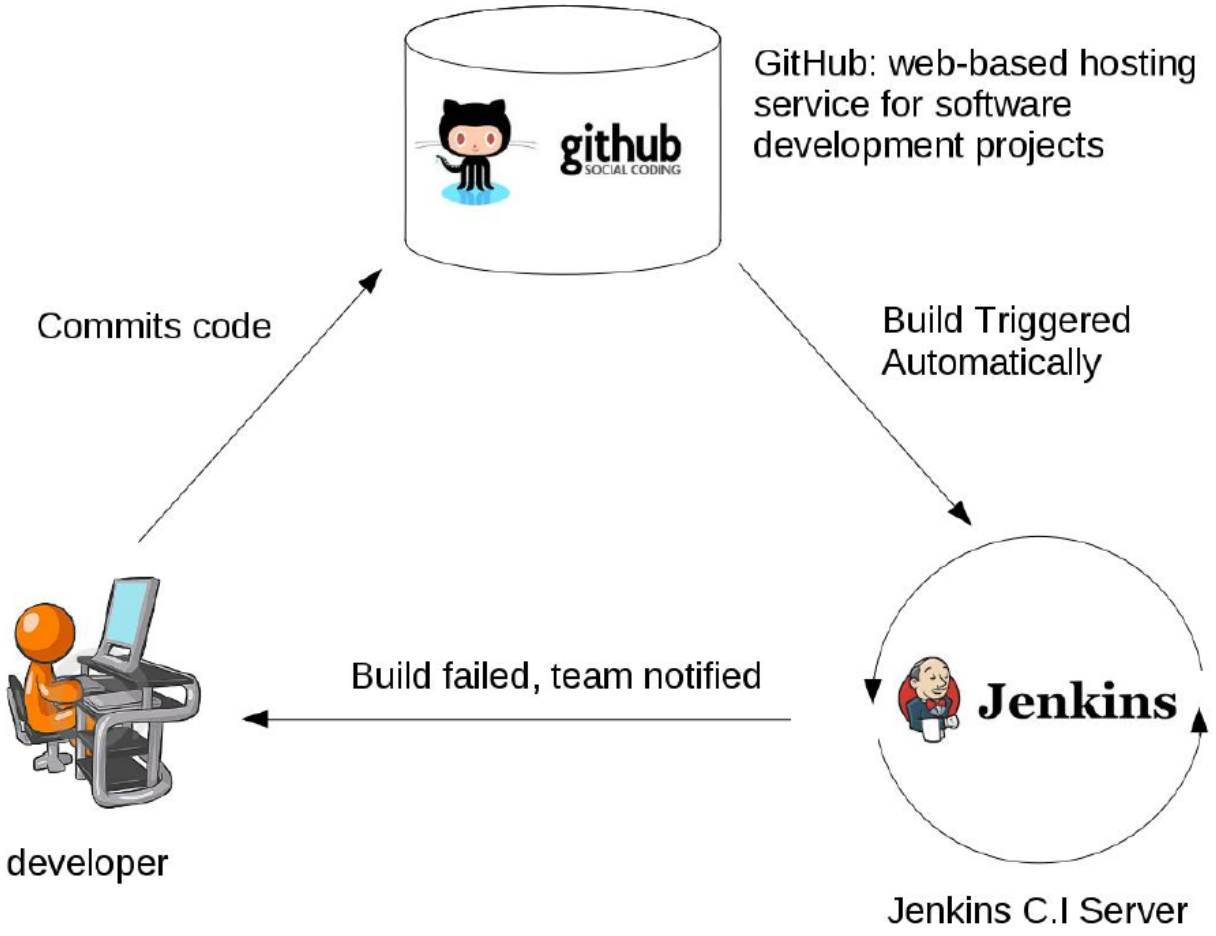


From Juhi Raj's talk



From Juhi Raj's talk

Continous integration and testing



Travis CI

☐	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

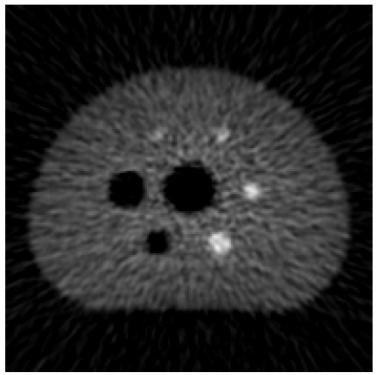
In case you want to refer to J-PET Analysis Framework you can use this reference:

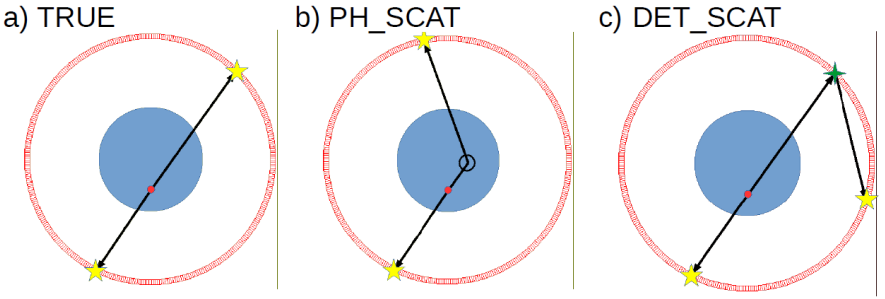
> W. Krzemien et al.
> Analysis framework for the J-PET scanner
> Acta Phys. Polon. A127 (2015) 1491-1494 DOI: 10.12693/APhysPolA.127.1491
> e-Print: arXiv:1503.00465

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

J-PET software workshops & tutorials

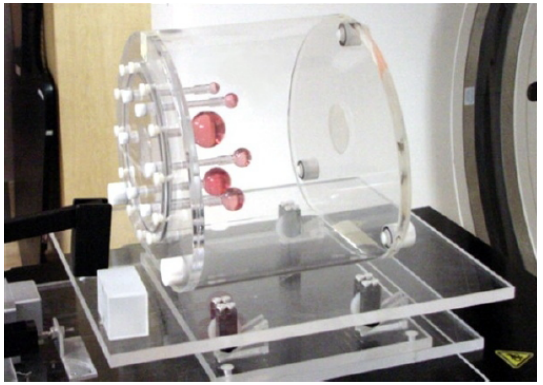
- Gate Output J-PET Analyzer(GOJA) Worshop, 23.24 05. 2019
- STIR FBP 3D Workshop, NCBJ, Warszawa, 22.03.2018
- GATE and Reconstruction Workshop, NCBJ, Warszawa, 22.03.2018
- Second J-PET Framework Workshop, UJ, Kraków, 20-21.03.2017
- J-PET Software Workshop, UJ, Kraków, 07-08. 07.2016
- First J-PET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



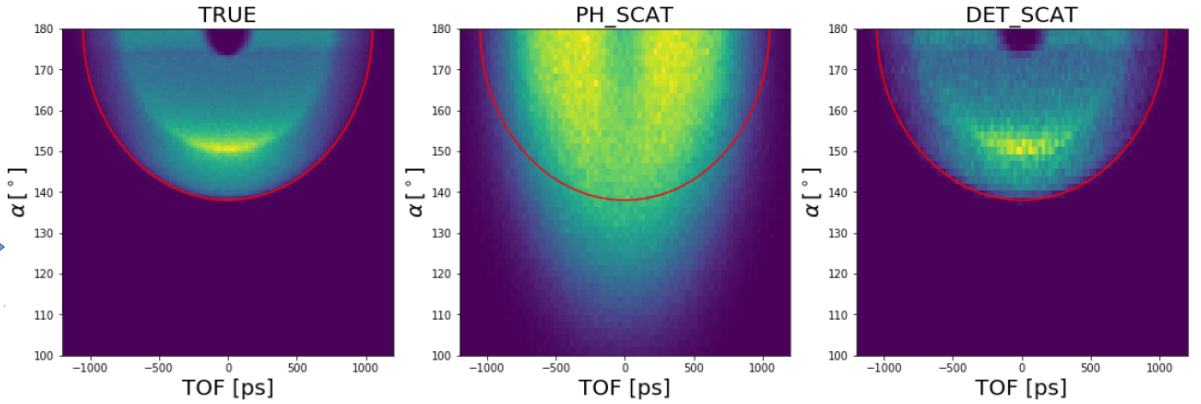


Jan Bielecki & W.K

Discrimination of the scattering and random coincidences background



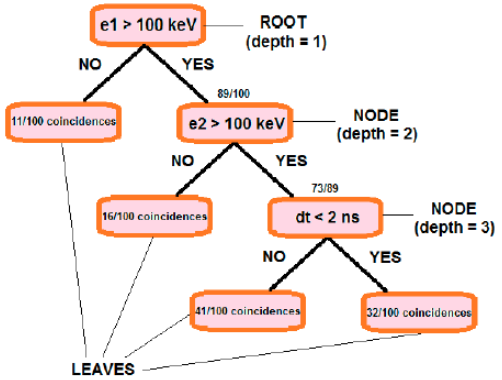
GATE simulations



IEC-NEMA phantom

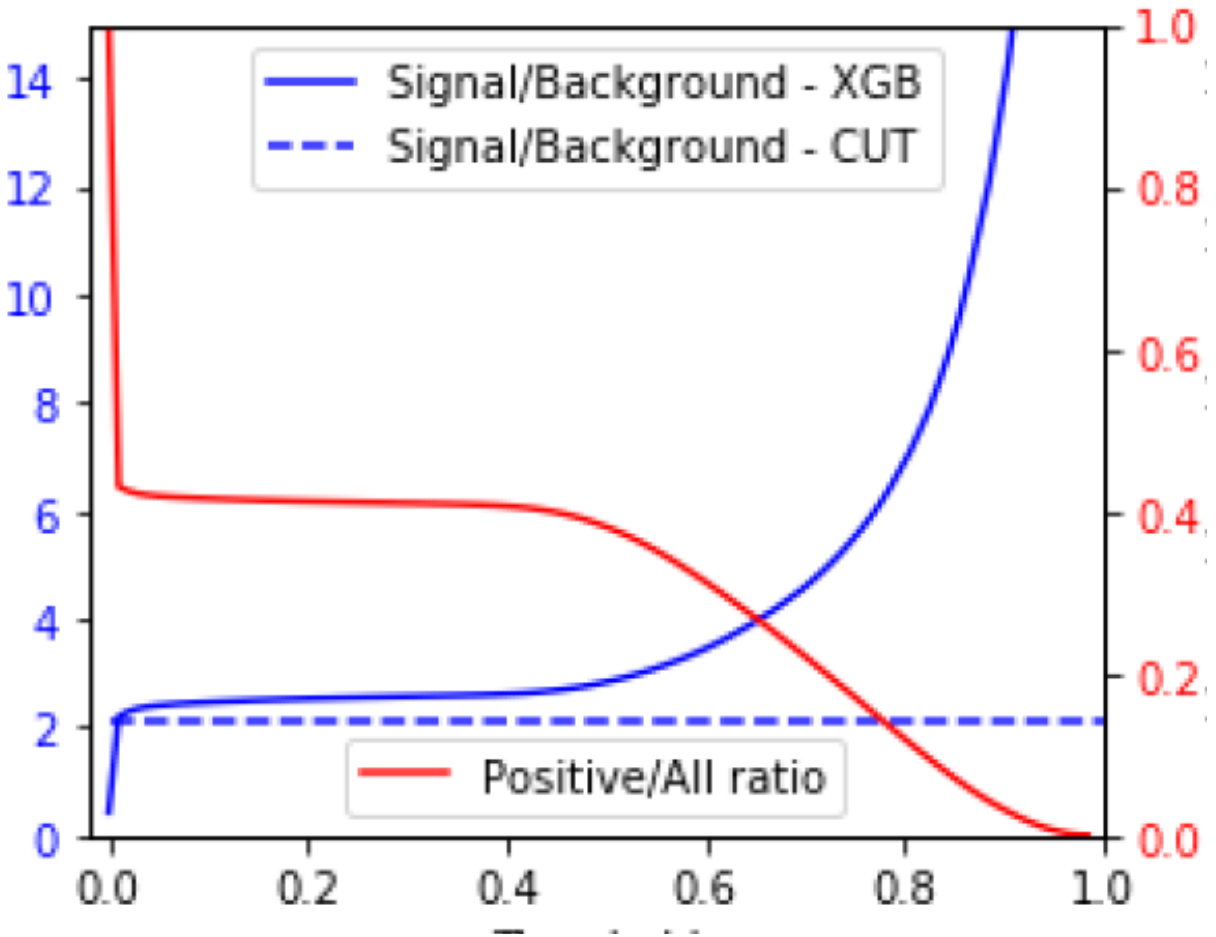
18 *10^7 coincidences:

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



Decison Tree

XGBoost & AdaBoost



	ACC	TPR	PPV	FPR
XGB	88.43%	95.35%	73.17%	14.42%
ADA	88.50%	95.66%	73.19%	14.45%
CUT	85.64%	99.63%	67.12%	20.13%

First application of Machine Learning techniques in J-PET

Thank you for attention

New contributors are welcome!!!
Framework developers meetings ~2 weeks:

http://koza.if.uj.edu.pl/petwiki/index.php/Framework_developers_meetings

J-PET Framework at GitHub

Framework core (library):
https://github.com/JPETTomography/j-pet-framework

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

Image reconstruction – current status

Home-made implementations:

- MLEM (A. Strzelecki)
- 2-D FBP (K. Rakoczy)
- „Naive” online reconstruction (G. Korcyl)

- BPF + regularization methods (L. Raczyński)

Software for Tomographic Image Reconstruction

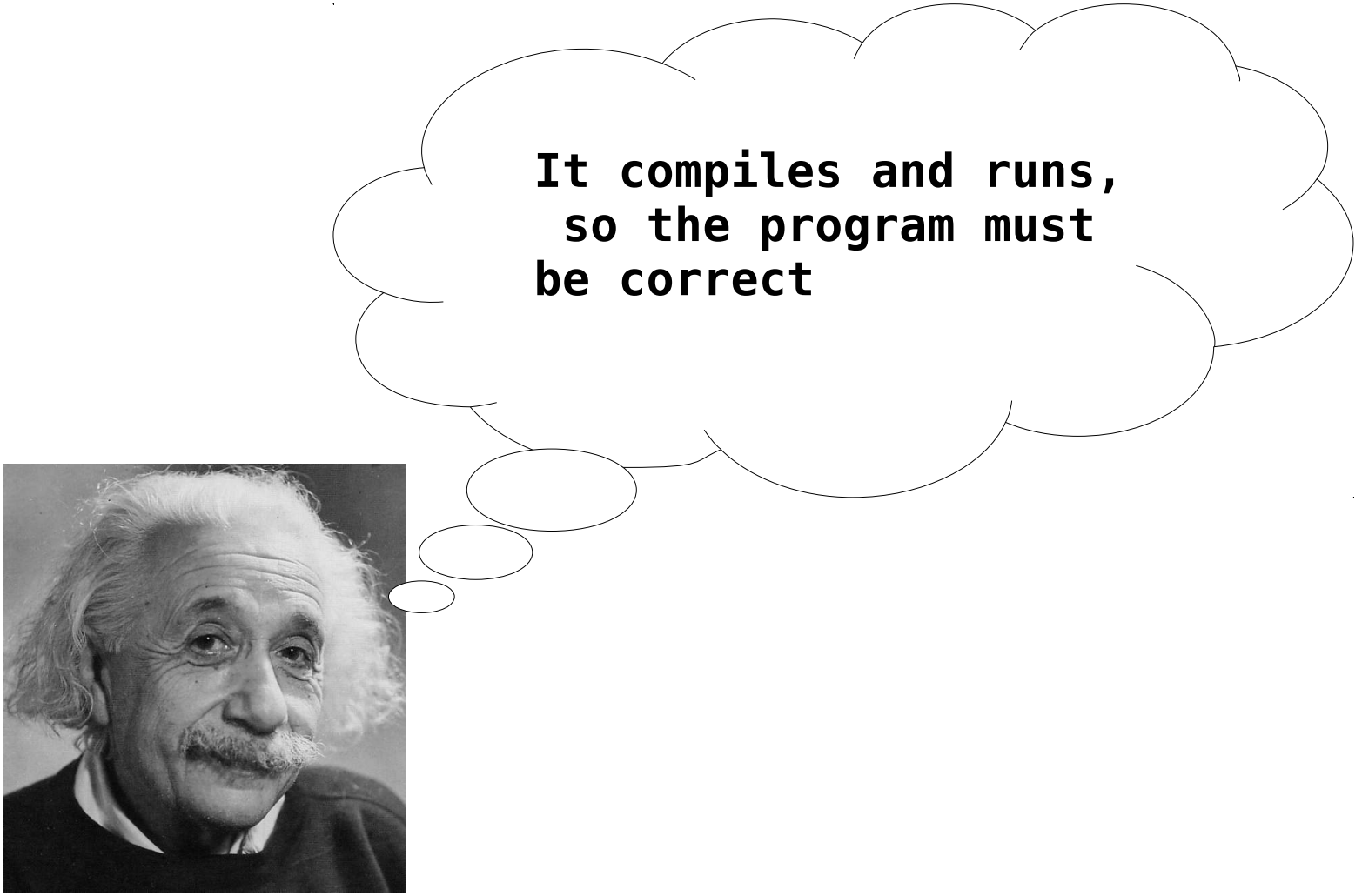
FBP
(P. Kopka, K. Klimaszewski)

FBP +KDE
(R. Shopa)

Data analysis is hard

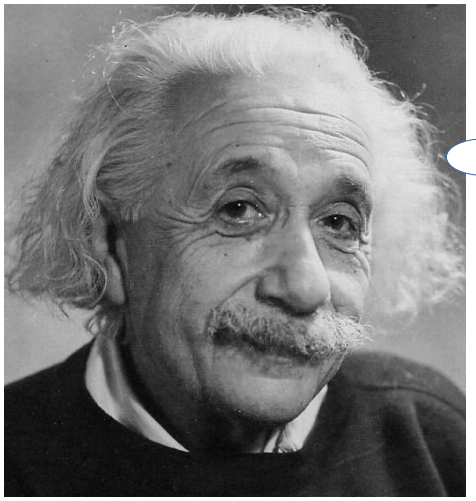
dealing with the complexity

Physicist vs Programmer



Physicist vs Programmer

The best solution is to put my 10000 lines of code in one function

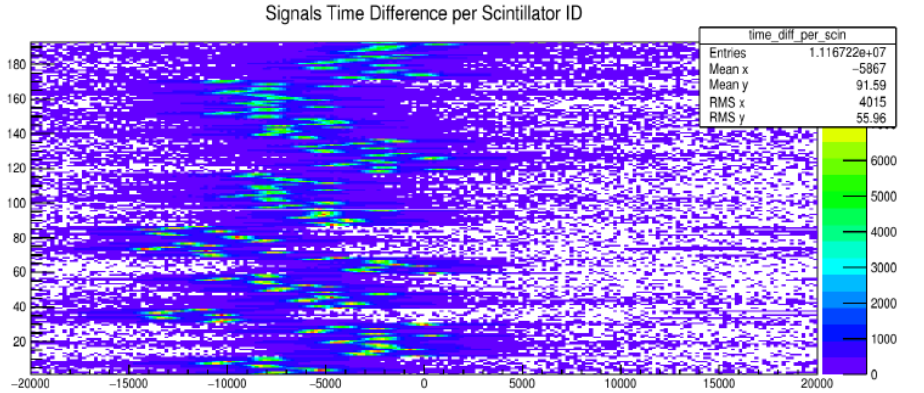


Nowy PMB Daria → symulacje

Calibrations

Way to „fix” imperfection of the real world :-)

Calibrations



- See the dedicated session 5
- All calibrations implemented
- as Tasks in the J-PET Framework

Way to „fix” imperfection of the real world :-)

***Stolen from very old presentations of M. Skurzok and M. Silarski