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GATE Simulation of the J-PET 24 Modular and image reconstruction

Plovdiv, Bulgaria, September 2019

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

Jagiellonian University Old Building

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J-PET Idea

the cost-effective device enabling a simultaneous metabolic and positronium imaging of the whole human body (*Nature Reviews Physics 1 (2019) 527*)

To achieve this goal:

Plastic scintillator is a solution

The primary aim of the group is to develop a technology for:

- **the cost effective Total-body PET,**
- **the MR and CT compatible PET**
- **a modular and transportable PET**

J-PET Group 2018

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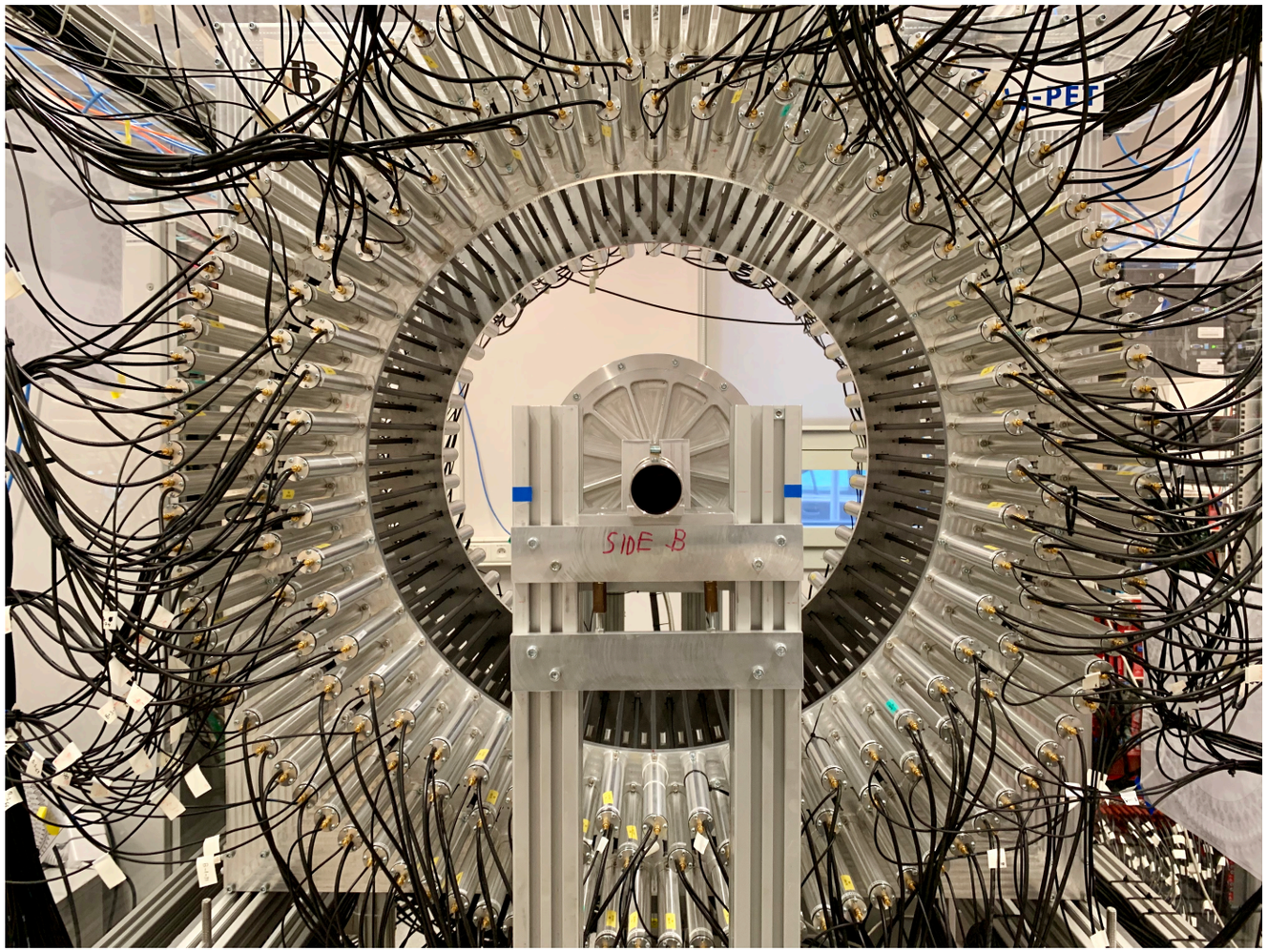
Geometry

- 3 Layers Geometry
- Plastic scintillators EJ230 with 7 × 19 × 500 mm dimension
- 192 Strips, PMT in each ends in 3 layers.



J-PET, Big Barrel

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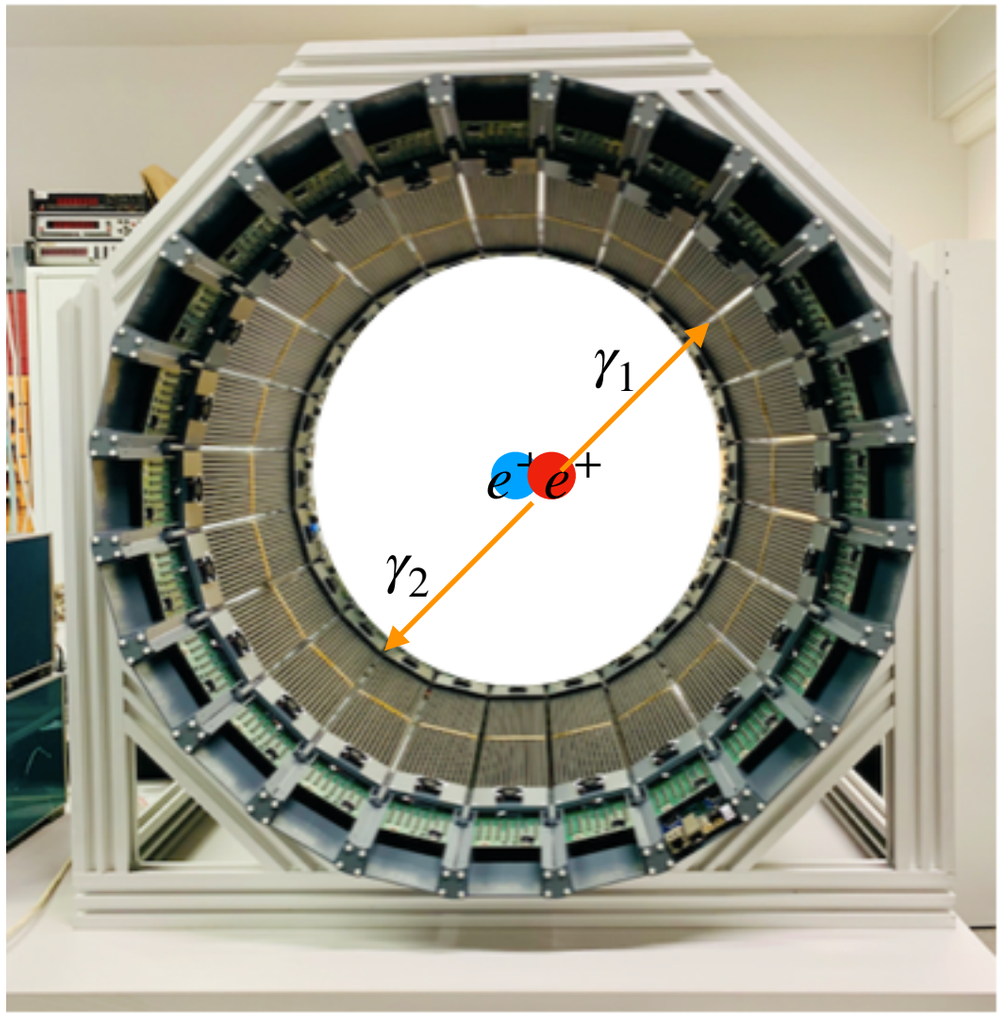
24 Modular J-PET

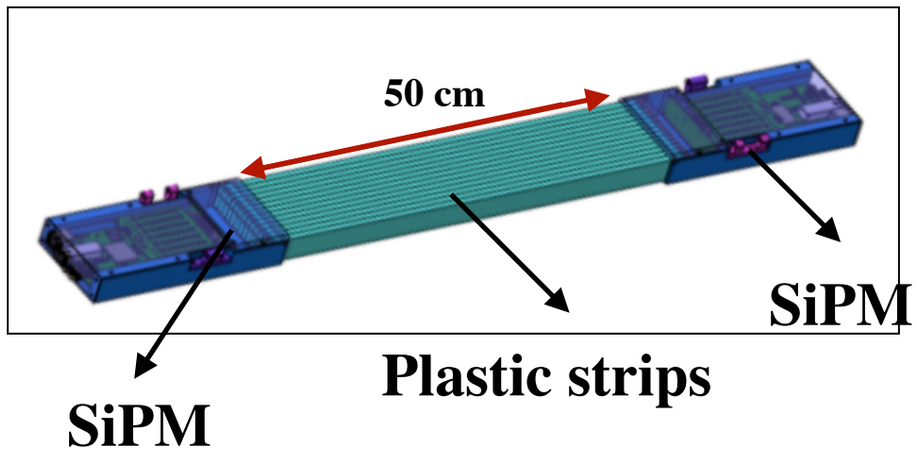
- 24 Modules
- Each modules include 13 strips
- SiPM at each ends of Modules

Advantages:

- Low weight
- Easy connect and disconnect able modules → Adjustable diameter



24 Modular J-PET



Schematic view of Module

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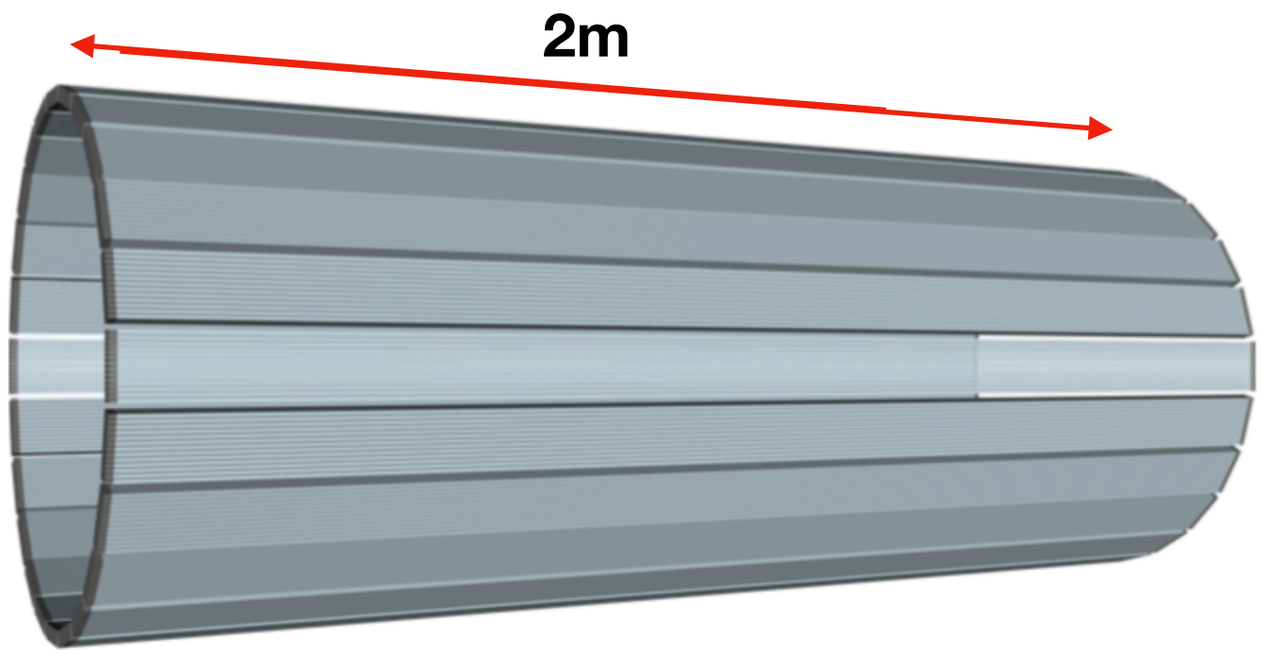
Long FOV J-PET

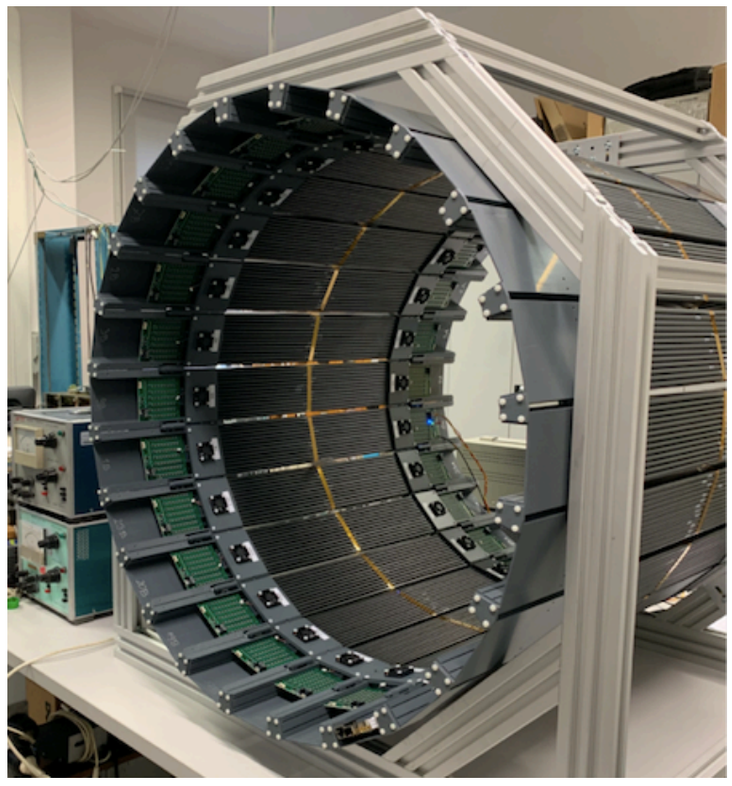
24 Modules 2m
48 SiPM



24 Modular J-PET 2m Long FOV

Many benefits

24 Modules 50cm
48 SiPM



24 Modular J-PET

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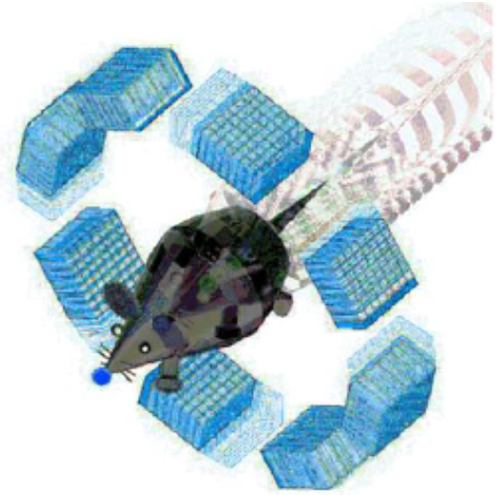
Introduction to GATE



Geant4 Application for Tomographic Emission (GATE)

strong tools for PET, SPECT, CT, RT simulation

Based on Mont Carlo.

Why we need to do simulation?

- Faster than experimental.
- Essential step before doing experimental to design ideal geometry (Saving money)
- To compare the experimental results with simulations

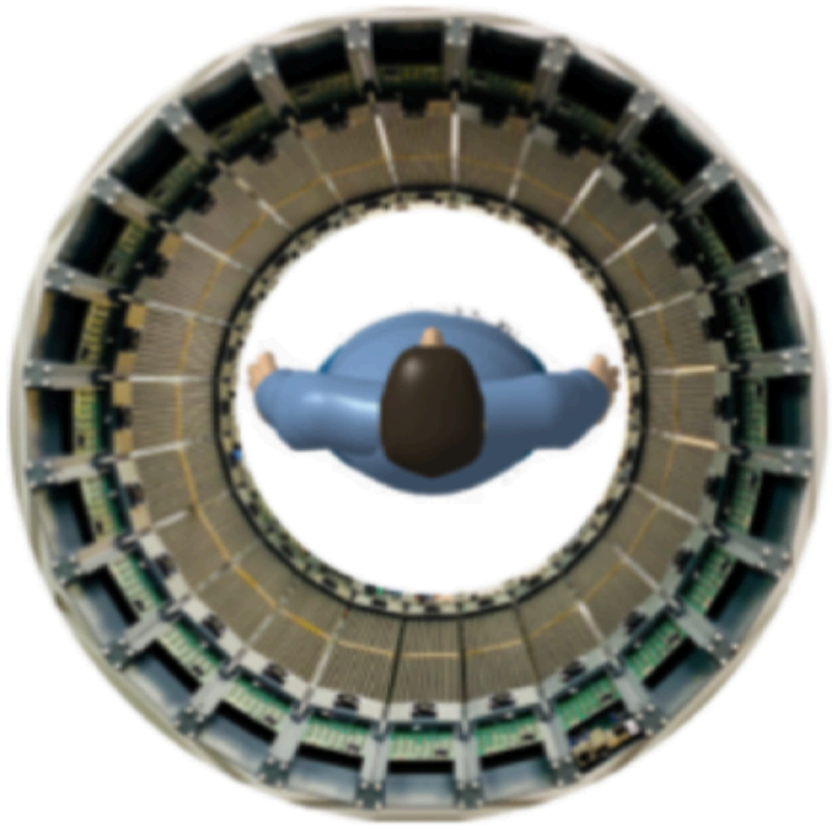
Highly recommended for the young researcher and student to learn and understand the principle of the Medical imaging machines

You can find some examples in https://github.com/OpenGATE/Gate

GATE

- User friendly
- No need for high level programing knowledge
- Well documented and supported by the developers
- Full examples in simulations of PET, SPECT …
- Validated tools in data analysis …

Open Gate Collaboration



Perspective view of the 24 Modular J-PET

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How to access GATE and fall in love with it

- Gate collaboration website http://www.opengatecollaboration.org
- GATE user guides based on the which version you use
- Git hub with the search key of GATE (PET, SPECT..)
- GATE Users emails services (to ask your questions or your developments the others)
- So many presentations about GATE specially in indico.cern

You can also use one of my presentation:

https://indico.cern.ch/event/542674/contributions/2252808/attachments/1314069/1967792/MD_Presentation_maysam.pdf

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Simulation Steps in GATE

Define World	Where all the simulation is going on in it
Define Scanner	Simulating the scanner from smallest part to largest
Define Source	Simulating the source, shape, activity, location
Define Phantom	Simulating the phantom from smallest part to largest
Define physics	To define physics of the simulation regards to the system
Define output	Different type of out put regards kind of scanner
Define Digitizer	To define simulation parameters to select the events

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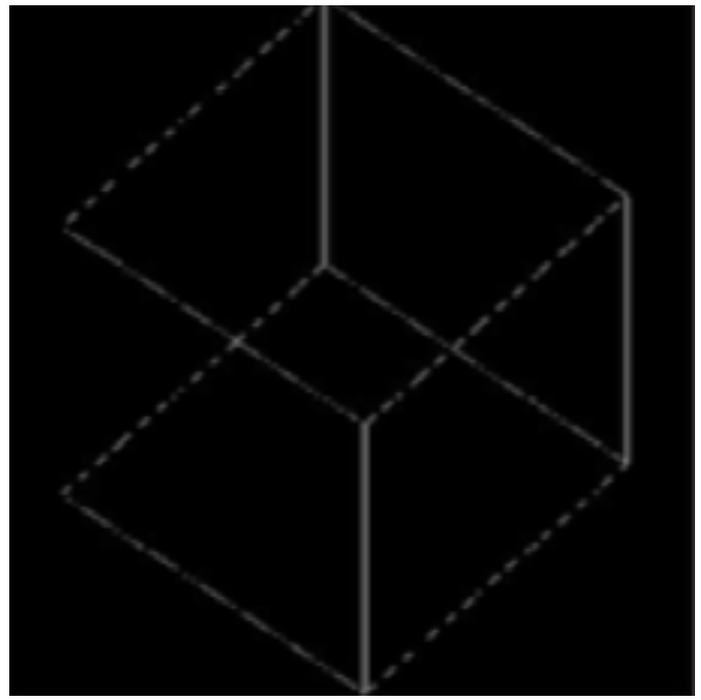
Define World

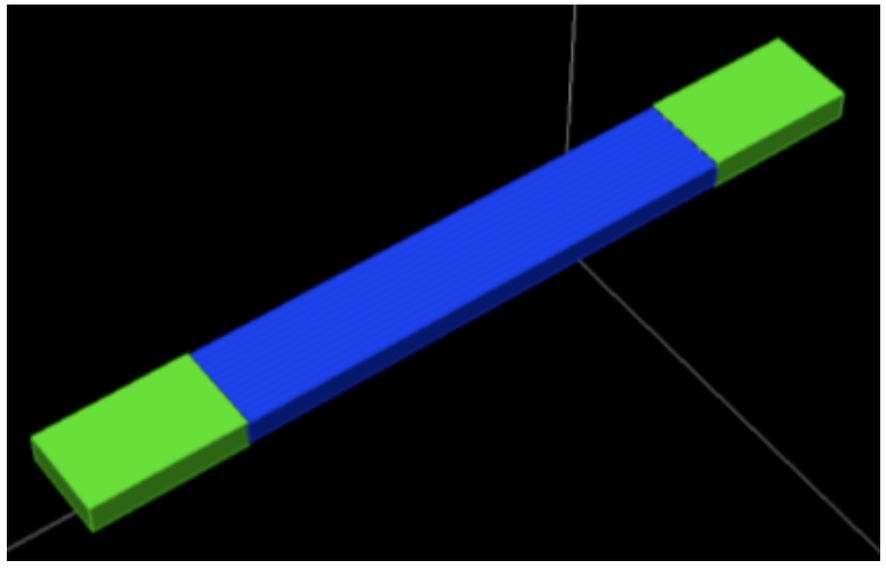
WORLD is a Volume in GATE environment that let you to create your geometry and your physics process, everything will occur in the World



World in GATE Visualisations

Define Scanner

Scanner is your detection part which will let you to design your own geometry include scintillators PMT, …



A single Module simulation before repetition

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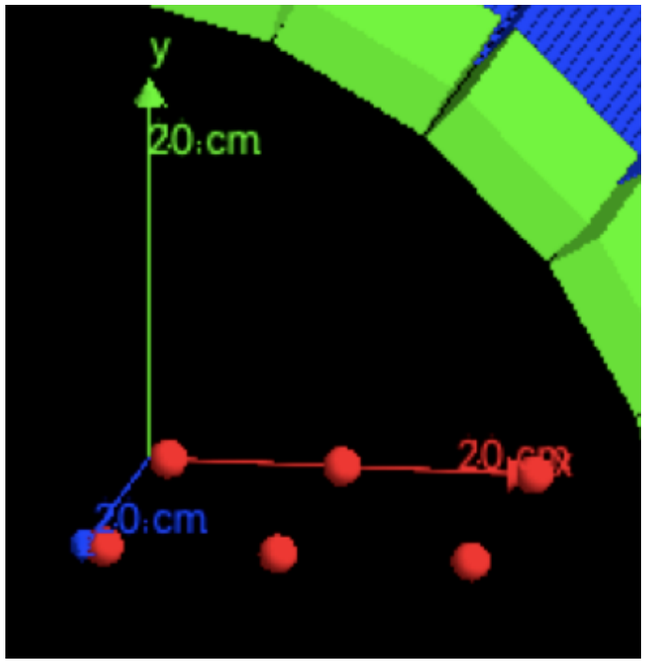
Define Source

Source is another essential part of the simulation, depend on the purpose we can define source in so many shape and activities.



6 Point sources

Define Phantom

Phantom is another part of simulation which can give more accurate information. By means of **materialdatabase.db** we can define any part of body for simulation

```
Kidney: d=1.05 g/cm3 ; n=11
        +el: name=Hydrogen   ; f=0.103
        +el: name=Carbon     ; f=0.132
        +el: name=Nitrogen   ; f=0.03
        +el: name=Oxygen     ; f=0.724
        +el: name=Sodium     ; f=0.002
        +el: name=Phosphor   ; f=0.002
        +el: name=Sulfur     ; f=0.002
        +el: name=Chlorine   ; f=0.002
        +el: name=Potassium  ; f=0.002
        +el: name=Calcium    ; f=0.001
        +el: name=Scandium   ; f=0.0
```

Define Digitizer

Thee most important part of to have a correct simulation is digitizer, Where you should define The Blurring, threshold, upholder, type of particle, coincidences properties …

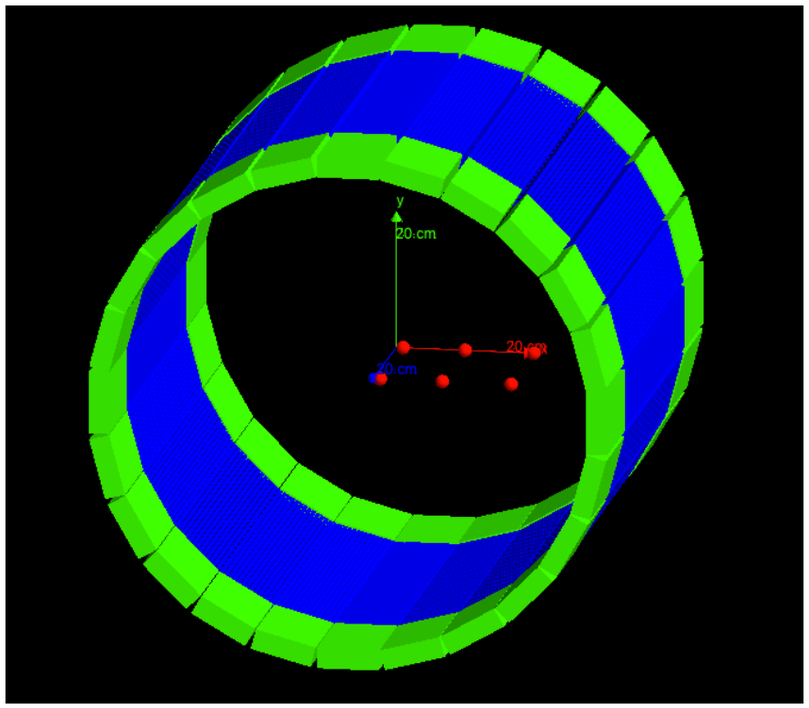
```
# ENERGY BLURRING
/gate/digitizer/Singles/insert blurring
/gate/digitizer/Singles/blurring/setResolution 0.19
/gate/digitizer/Singles/blurring/setEnergyOfReference 511. keV

# ENERGY WINDOW
/gate/digitizer/Singles/insert thresholder
/gate/digitizer/Singles/thresholder/setThreshold 350. keV
/gate/digitizer/Singles/insert upholder
/gate/digitizer/Singles/upholder/setUphold 650. keV
```

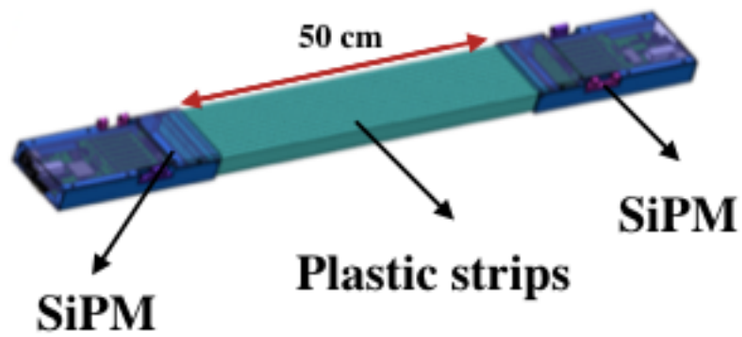
More information:
http://wiki.opengatecollaboration.org/index.php/Users_Guide:Digitizer_and_readout_parameters

GATE simulation of the 24 Modular J-PET

- Most of the steps in J-PET GATE simulation are same as standard
- J-PET is using “**Plastic scintillator**” (**EJ230**) **==>** material database.db need to update
- We are not using digitizer, we have our own solution → we take all the events



24 Modular J-PET include 6 sources by GATE visualization



GATE material Database & way to upgrade

There are elements also a list of materials by default in GATE.

In case if you need to add your own material you need density, list of elements and their numbers in molecular structure

Material name

Density

State

```
[Materials]
NaI: d=3.67 g/cm3; n=2;  state=solid
       +el: name=Sodium ; n=1
       +el: name=Iodine ; n=1

PWO: d=8.28 g/cm3; n=3 ; state=Solid
       +el: name=Lead; n=1
       +el: name=Tungsten; n=1
       +el: name=Oxygen; n=4
```

List of the elements

Element Example *GateMaterials.db*:

```
[Elements]
Hydrogen:    S= H   ; Z=  1. ; A=   1.01  g/mole
Helium:      S= He  ; Z=  2. ; A=   4.003 g/mole
Lithium:     S= Li  ; Z=  3. ; A=   6.941 g/mole
Beryllium:   S= Be  ; Z=  4. ; A=   9.012 g/mole
Boron:       S= B   ; Z=  5. ; A=  10.811 g/mole
Carbon:      S= C   ; Z=  6. ; A=  12.01  g/mole
```

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DATA analyzing and List_Mode preparation In J-PET

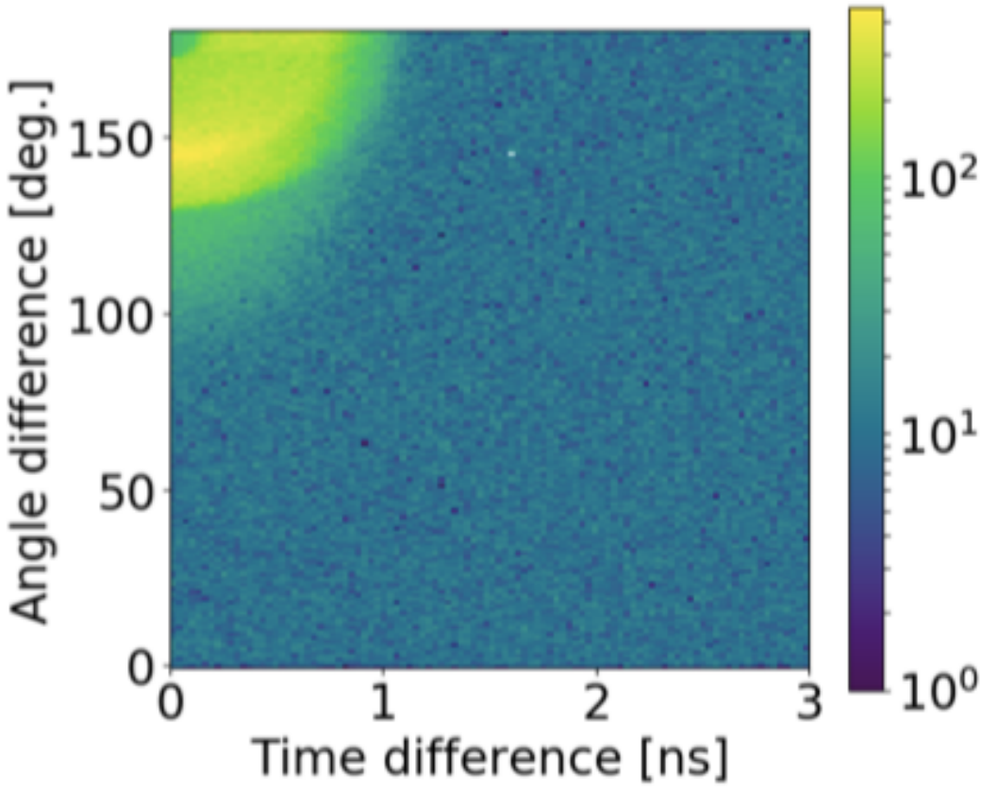
GOJA (GATE Output J-PET Analyzer) By Pawel Kowalski (J-PET)

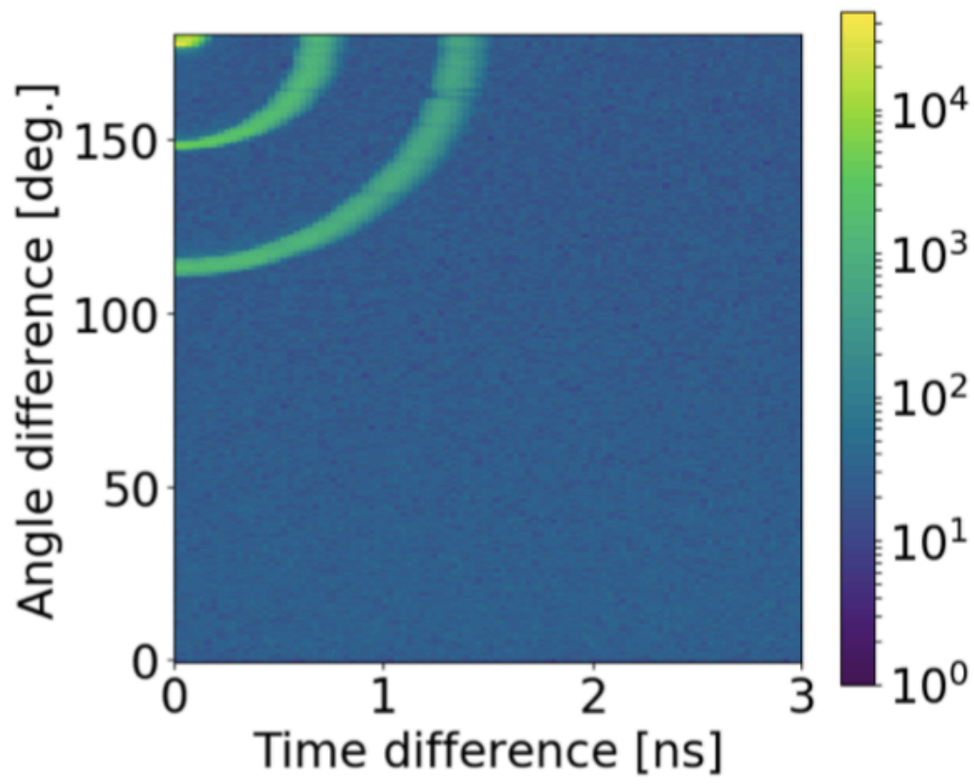
- GATE root output (as raw data) ==> GOJA

What GOJA do==> 1. Preparation of List_Mode for Image reconstruction

2. Categorizing events as true scatter or randoms

3. Able to generate sensitivity map





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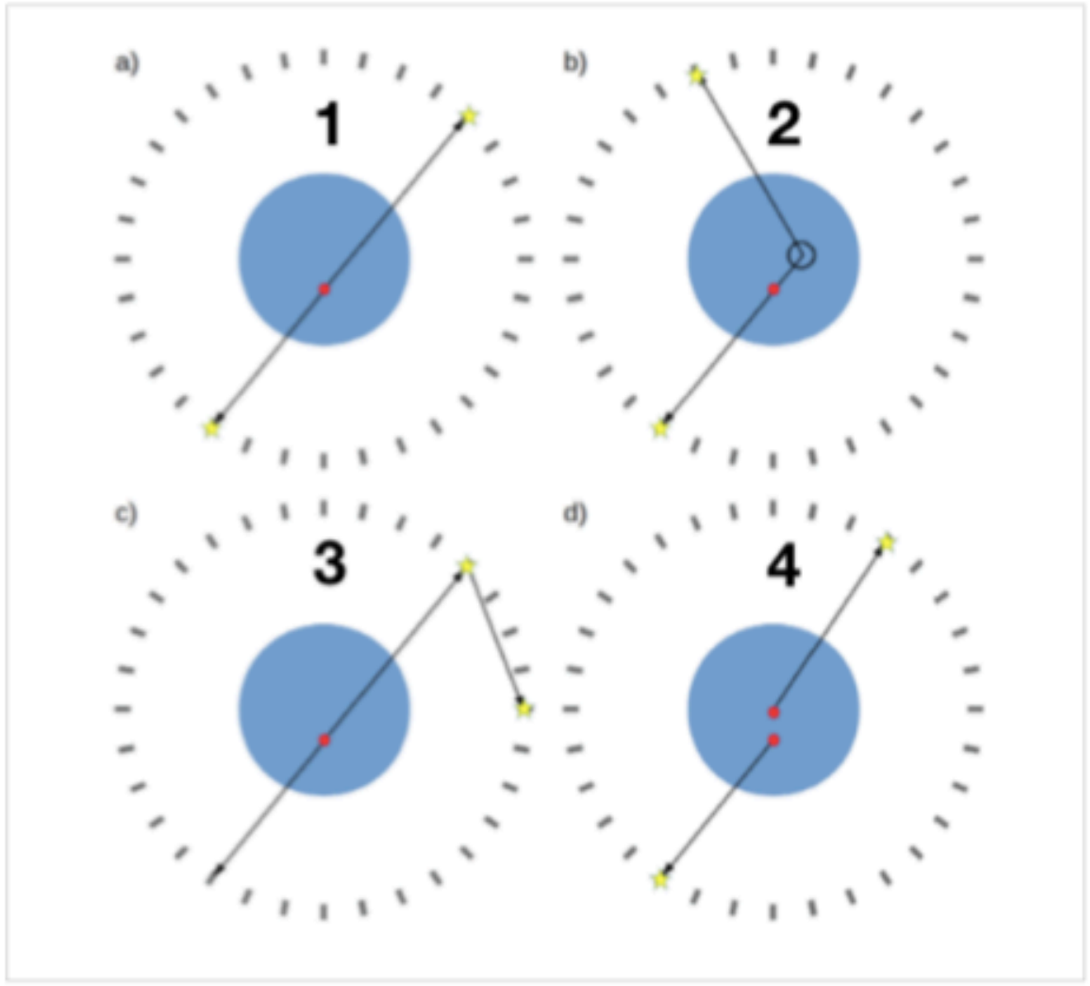
GOJA (GATE Output J-PET Analyzer)

1- true coincidences
2- phantom scatter
3- detector scatter
4- accidental coincidences



Categorizing events as true

scatter, …

16.80	-32.90	18.75	32401356.2	-13.25	33.90	-19.32	32401397.5	15	2	328.60	315.66	1	2.00	0.00	0.00	2.00	0.00	0.00
-18.57	30.65	19.74	202301238.6	13.41	-32.69	-20.49	202301557.0	3	14	339.39	222.42	2	0.00	0.00	10.00	0.00	0.00	10.00
36.31	8.21	1.92	210701179.6	-36.16	-8.73	-17.26	210701426.9	20	8	215.43	329.15	2	2.00	0.00	0.00	2.00	0.00	0.00
25.49	24.42	-6.35	245901183.7	-26.09	-24.99	-13.73	245901211.5	22	10	267.71	304.17	1	0.00	0.00	-10.00	0.00	0.00	-10.00
-31.95	14.67	-15.34	382701224.5	36.00	8.78	8.11	382701342.1	5	20	234.05	216.31	2	-2.00	0.00	0.00	-2.00	0.00	0.00
-22.10	-29.74	-22.70	421001412.5	23.37	28.67	23.55	421001507.1	11	22	201.86	257.26	3	0.00	-2.00	0.00	0.00	-2.00	0.00
-31.30	-19.41	11.98	466101238.7	29.96	21.17	-13.06	466101351.0	9	21	236.59	333.89	1	-2.00	0.00	0.00	-2.00	0.00	0.00
-32.50	15.56	-4.76	742301214.5	32.81	-15.71	-15.29	742301226.1	5	17	291.87	288.97	1	0.00	0.00	-10.00	0.00	0.00	-10.00
17.44	31.31	-19.14	847101233.7	-17.90	-32.14	-0.62	847101266.4	23	11	203.99	301.67	1	0.00	0.00	-10.00	0.00	0.00	-10.00
31.21	-16.31	1.91	1110001147.0	-33.81	13.50	-2.07	1110001242.7	17	6	233.24	225.99	1	0.00	-2.00	0.00	0.00	-2.00	0.00

GOJA List_Mode

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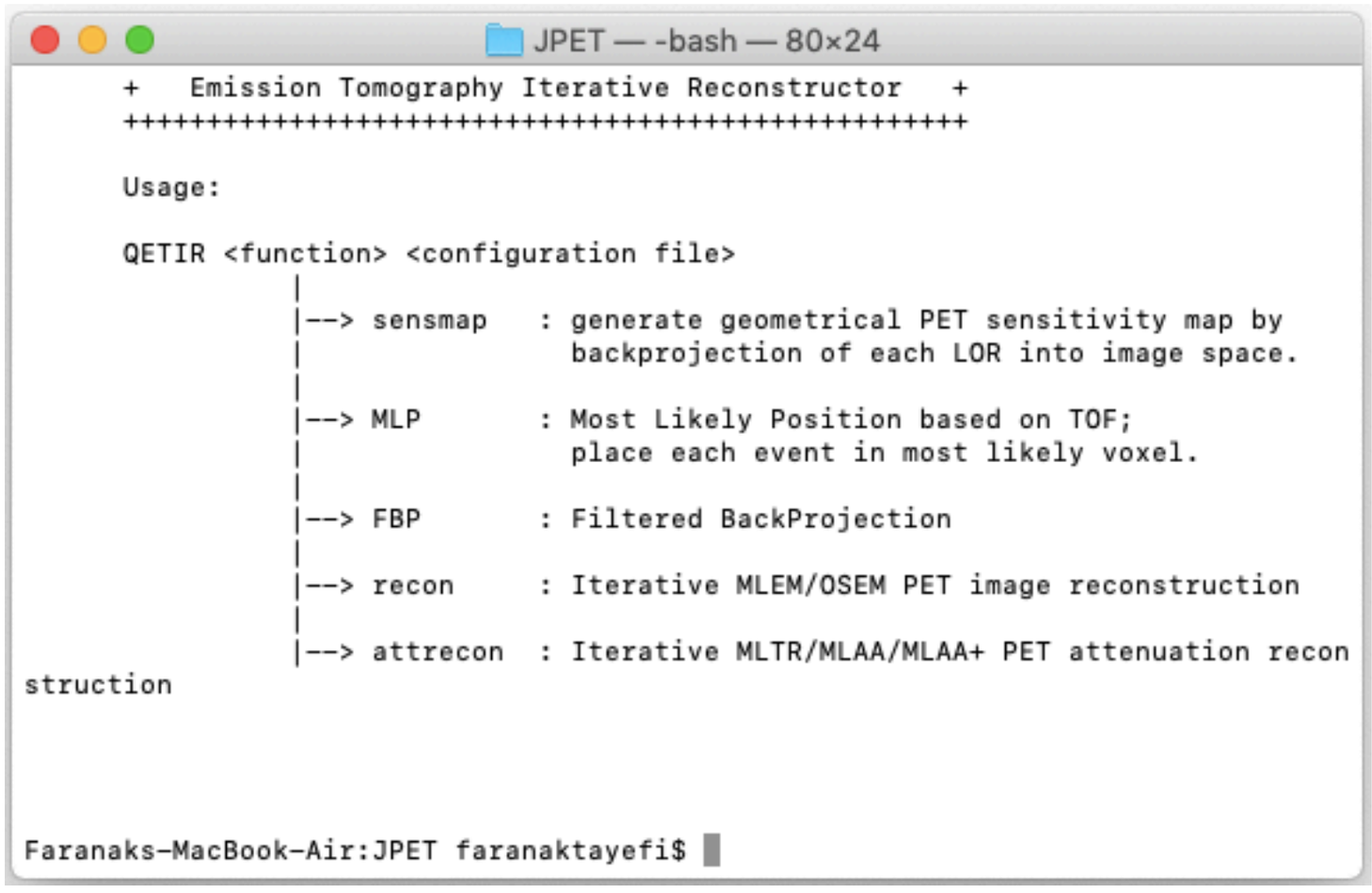
QETIR

Quantitative Emission Tomography Iterative Reconstruction (QETIR)

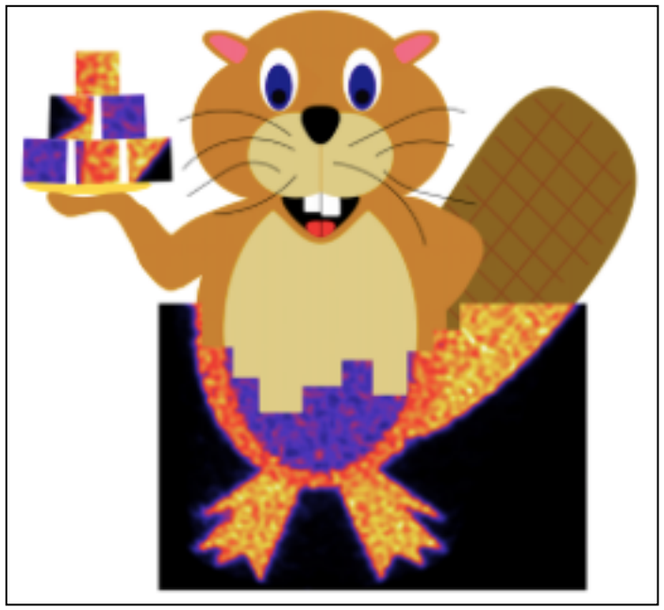
Is an image reconstruction software which developed in Medisip and adapted

For J-PET Group for reconstruction propose.



Other image reconstruction software

- **STIR.** http://stir.sourceforge.net
- **CASTOR.** http://www.castor-project.org



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Thank you for your attention

Special thanks for the support by The Polish National Center for Research and Development through grant TEAM POIR.04.04.00-00-4204/17.

Wawel Castel and Vistula river, Krakow, Poland