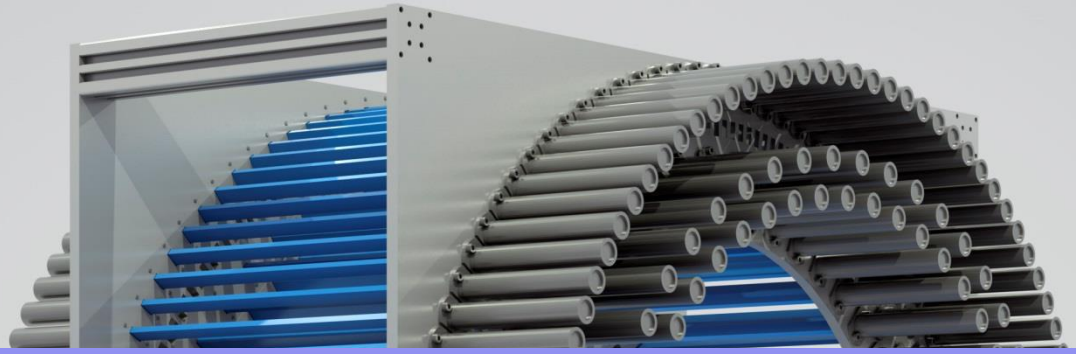
J-PET: a novel TOF-PET scanner based on plastic scintillators

ICTR-PHE-2016, 15-19 February 2016

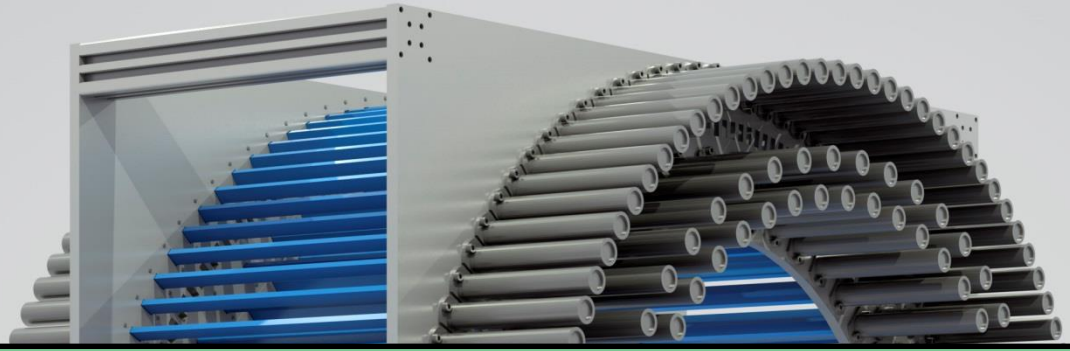
Paweł Moskal, Jagiellonian University
on behalf and for the J-PET Collaboration
http://koza.if.uj.edu.pl

Jagiellonian PET



- Jagiellonian PET
- NEMA characteristics
- Towards simultaneous J-PET and MRI imaging

Jagiellonian PET



- **Jagiellonian PET**

WHOLE BODY

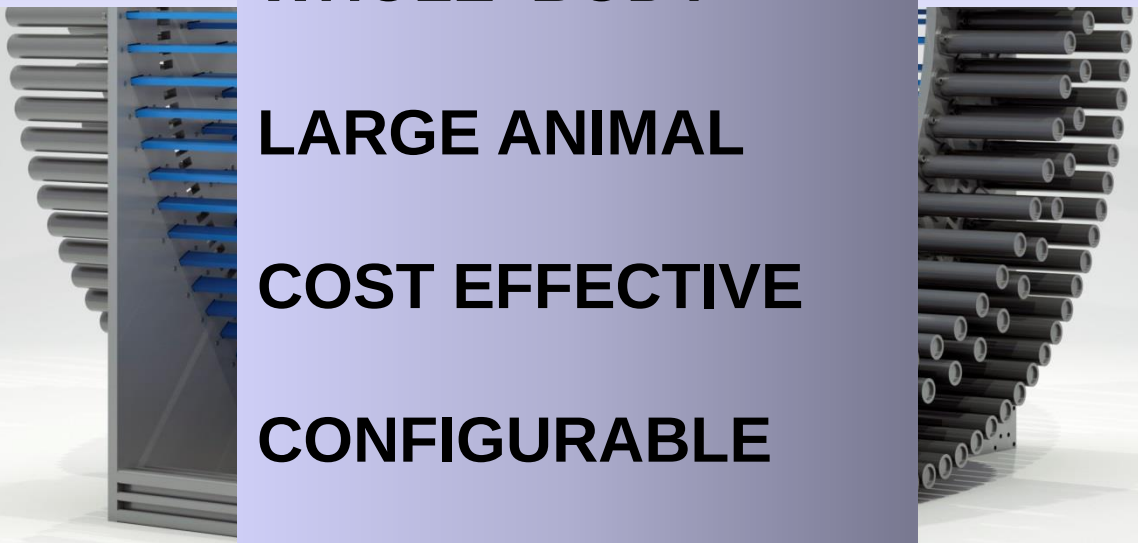
LARGE ANIMAL

COST EFFECTIVE

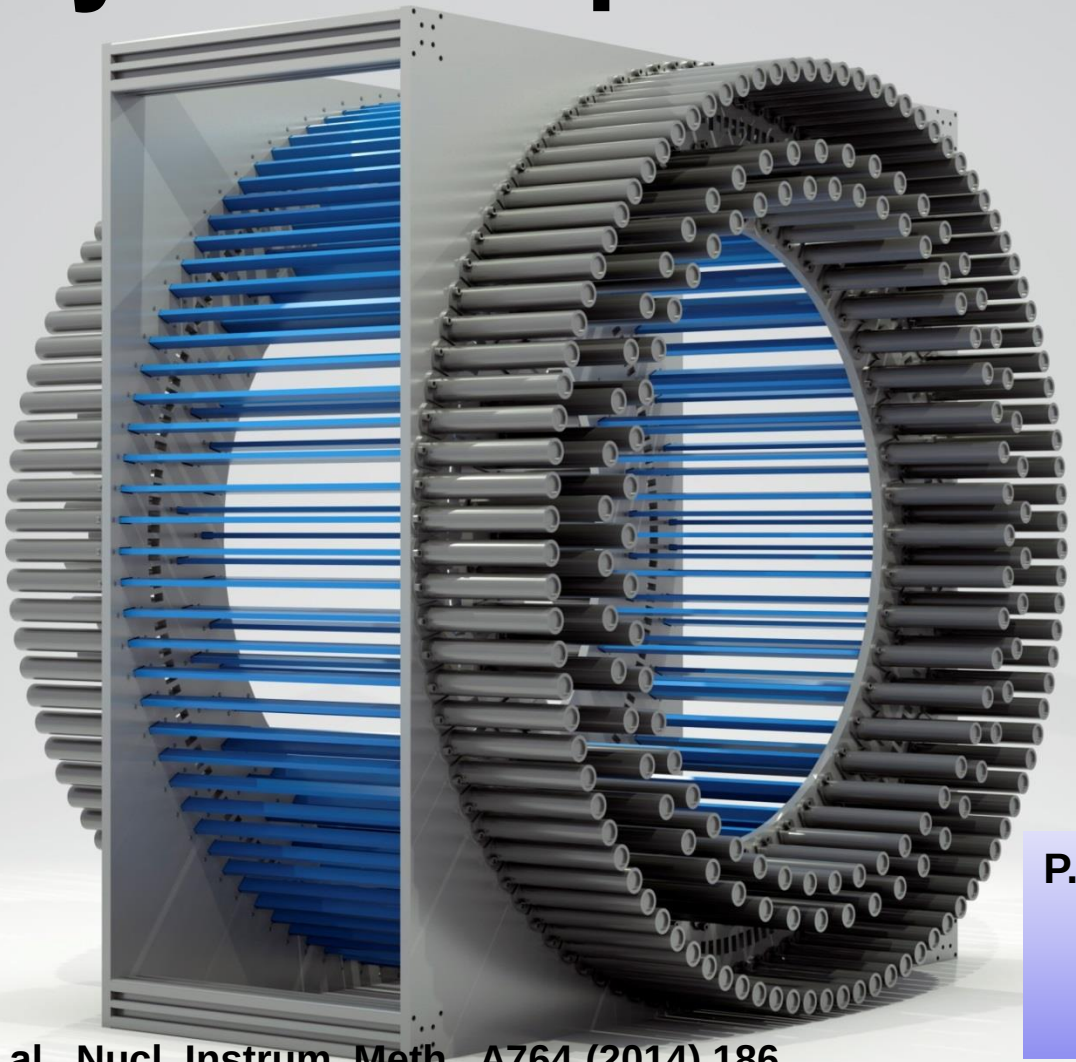
CONFIGURABLE

MRI COMPATIBLE

...



crystals → plastics

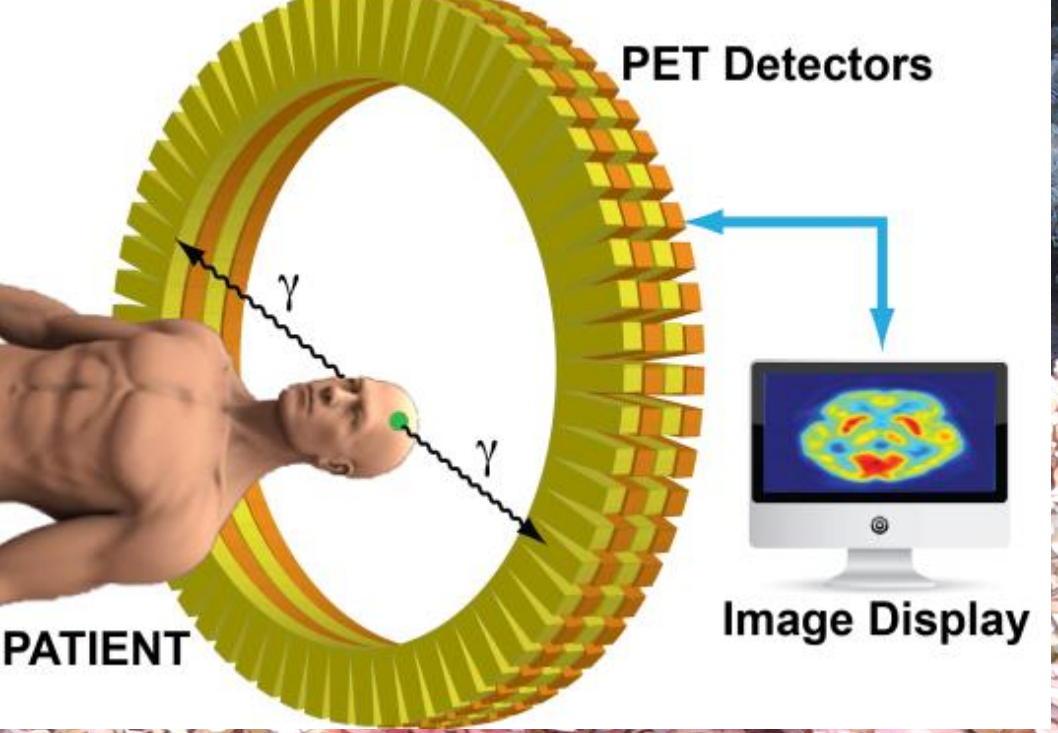


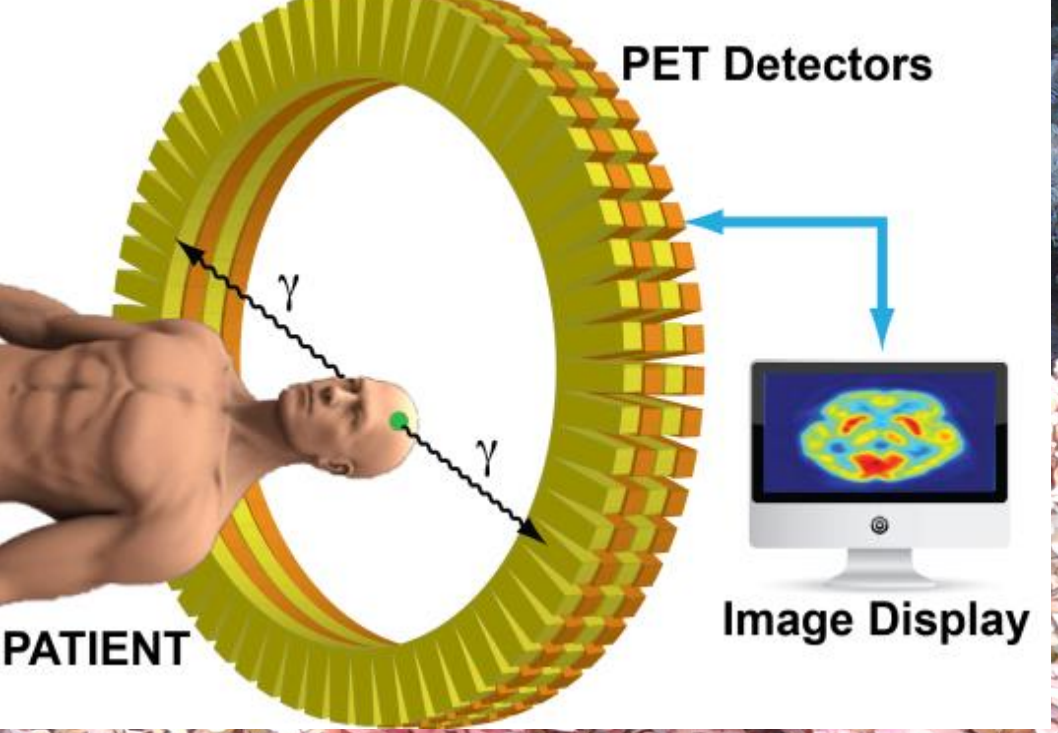
P. M., Patents (2014)
WO2011008119,
WO2011008118
EU, JP, US.

J-PET: L. Raczyński et al., Nucl. Instrum. Meth. A764 (2014) 186
J-PET: P. M. et al., Nucl. Instrum. Meth. A764 (2014) 317
J-PET: P. M. et al., Nucl. Instrum. Meth. A775 (2015) 54
J-PET: L. Raczyński et al., Nucl. Instrum. Meth. A786 (2015) 105
J-PET: P. M. et al., Phys. Med. Biol. (2016) in print; arXiv:1602.02058

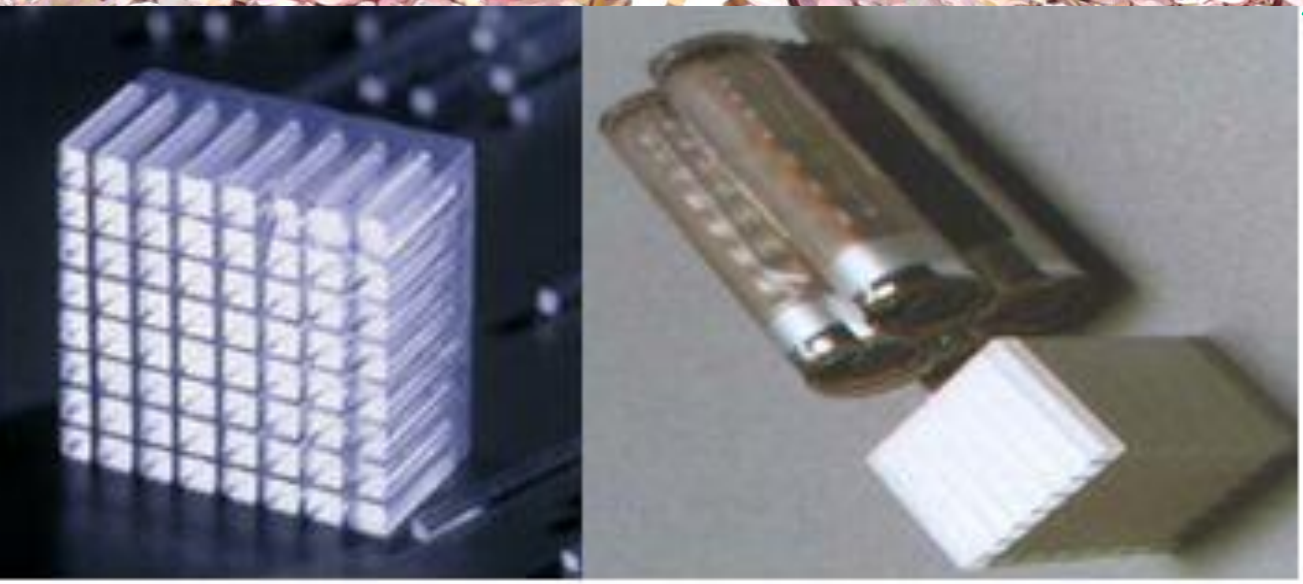
34 articles and 16 International patent applications

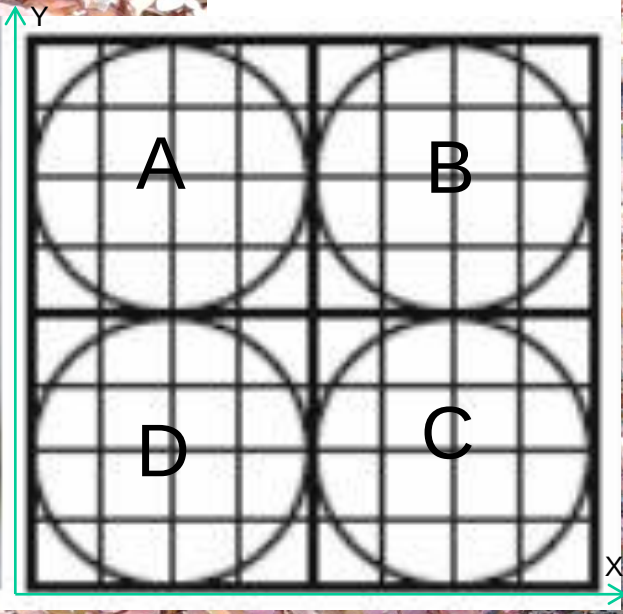
J-PET

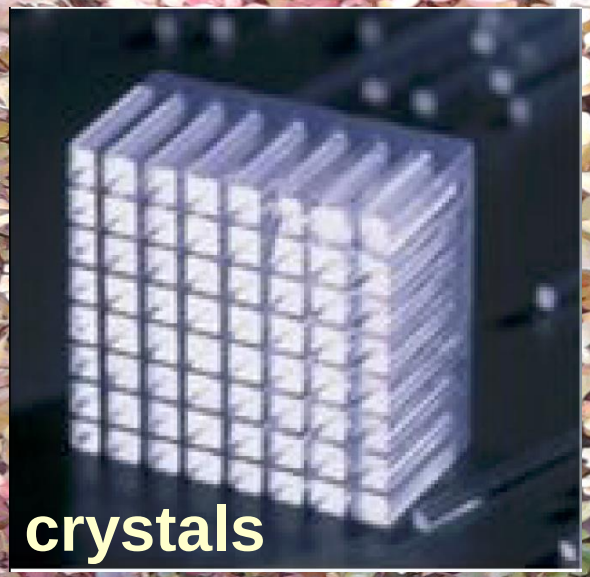

PET Detectors
γ
γ
Image Display
PATIENT

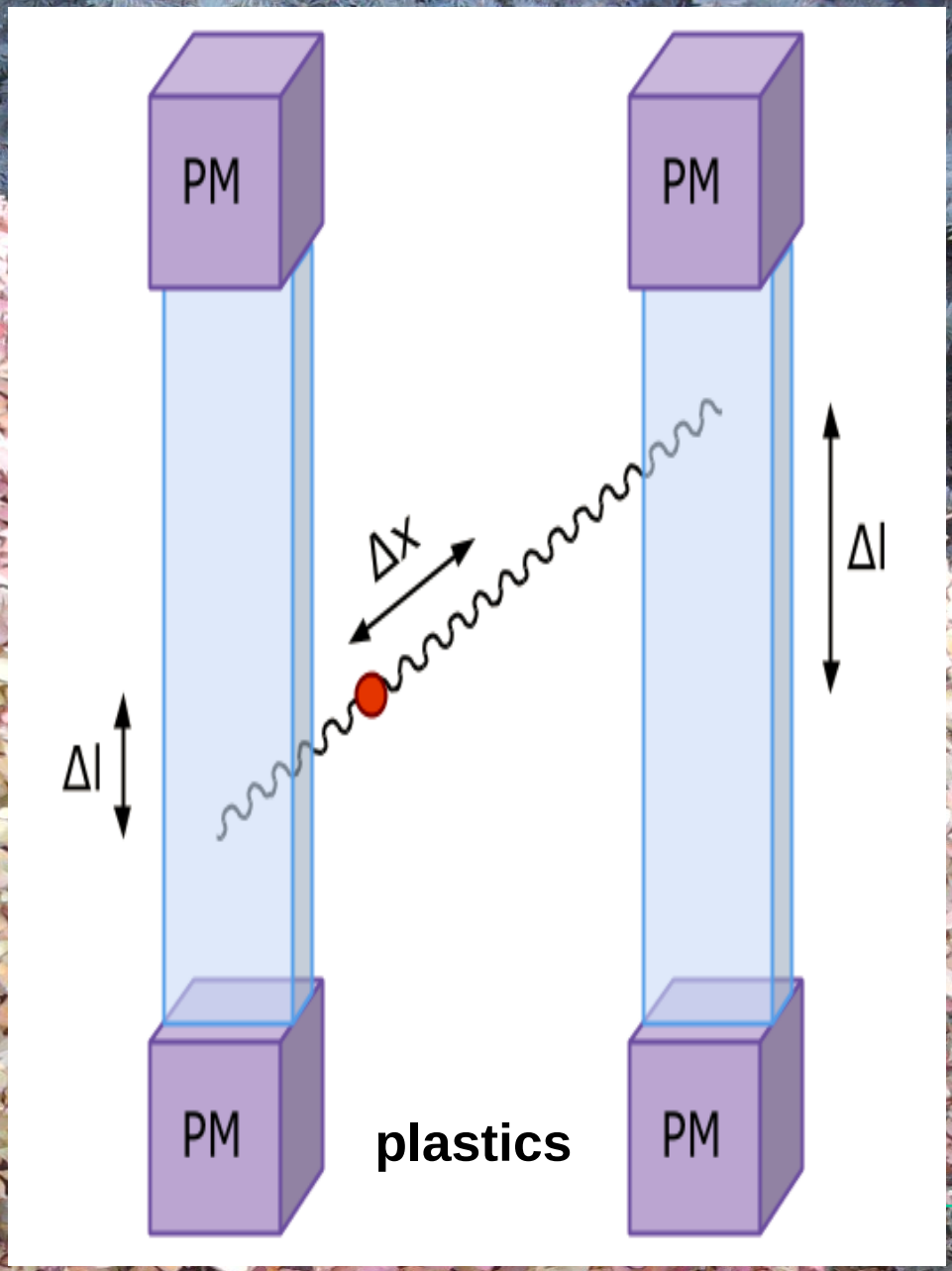


$$X = \frac{(B+C)-(A+D)}{A+B+C+D},$$

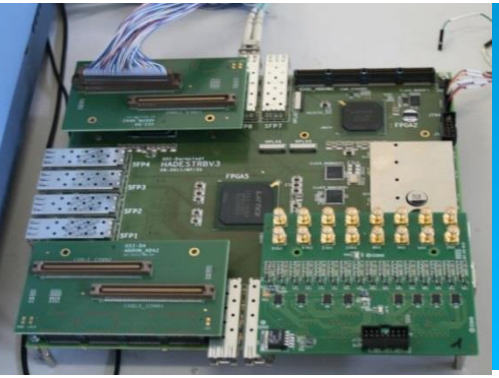





crystals


PM
PM
Δx
Δl
Δl
PM
plastics
PM

New idea… BREAK THROUGH



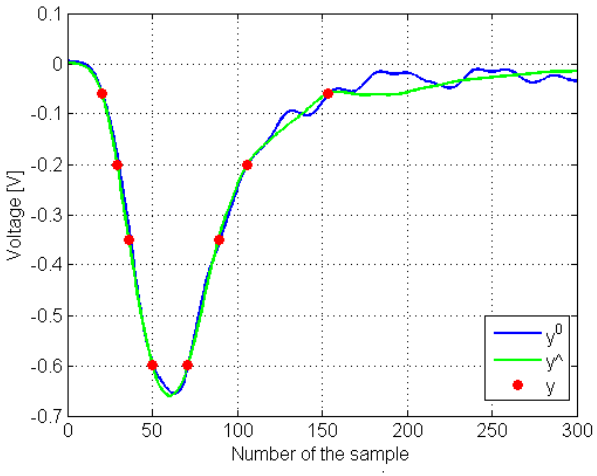
ONLY DIGITAL in triggerless mode

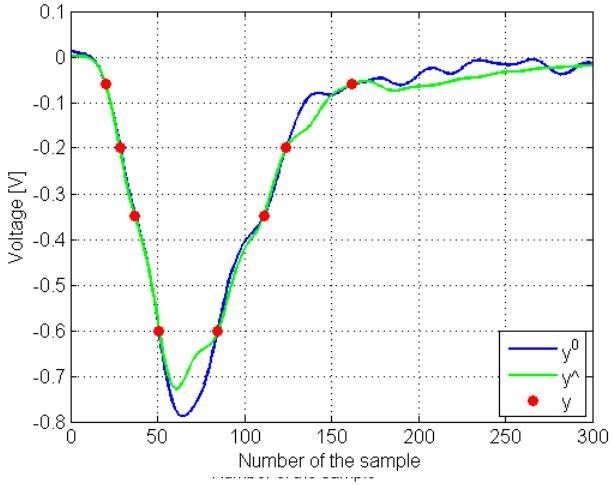
FFE sampling & Readout electronics

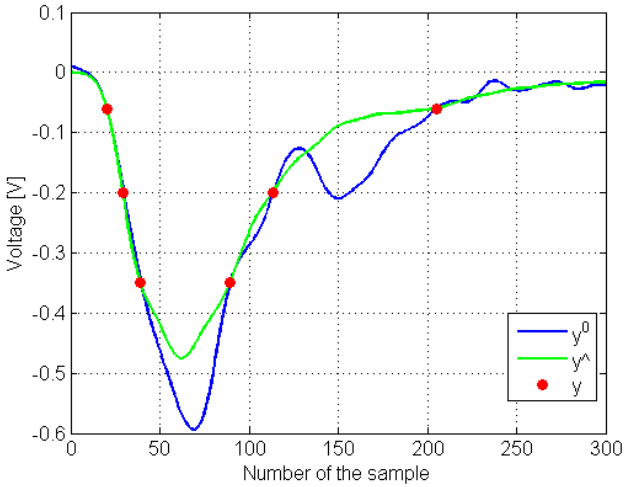
precision of 21ps (sigma) for 10 Euro per sample

M.Pałka, P.M., **PCT/EP2014/068367**

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







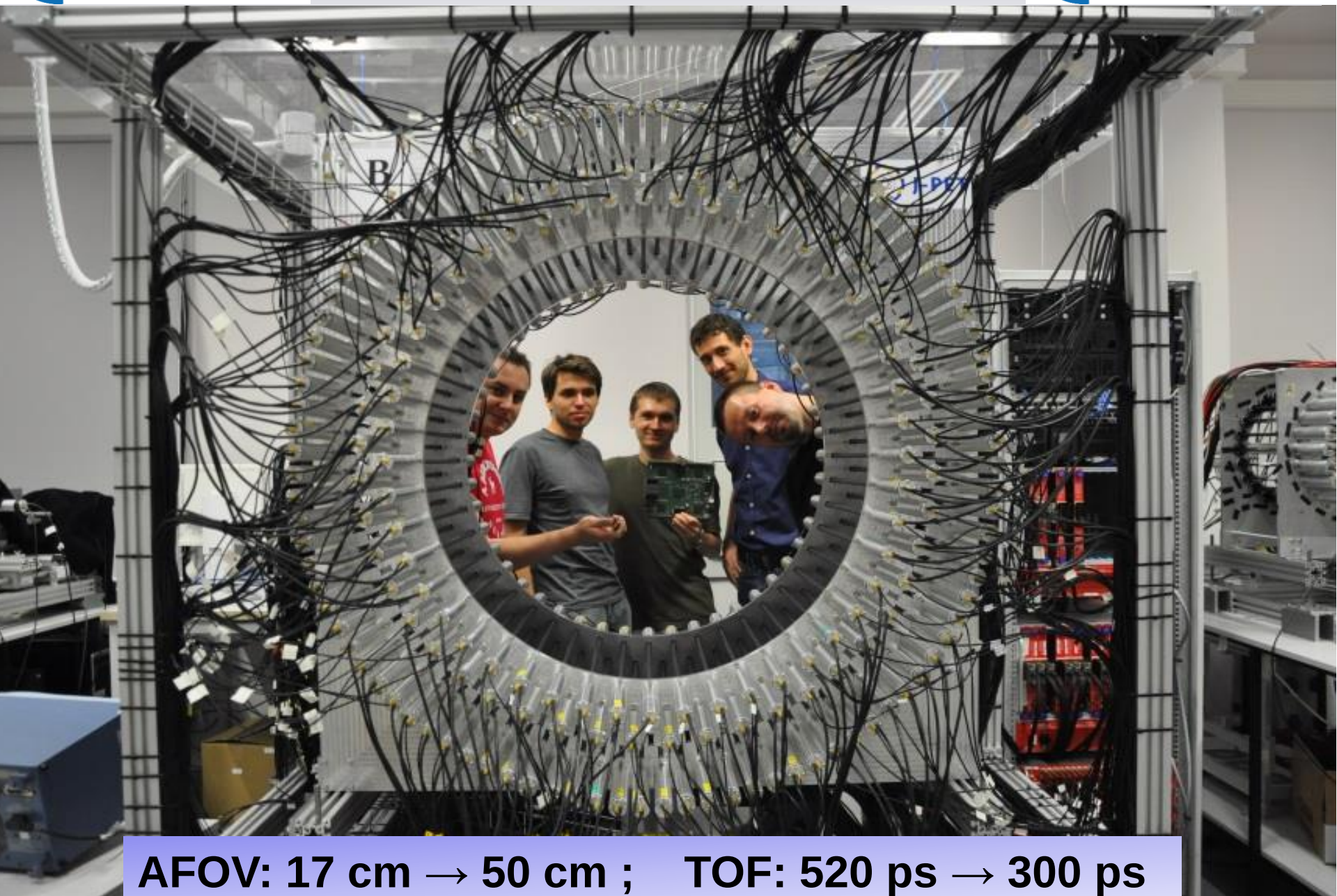
Library of signals ; Principal Component Analysis; Compressive Sensing;
J-PET: L. Raczyński et al., Nucl. Instr. Meth. A786 (2015) 105
J-PET: P. M. et al., Nucl. Instrum. Meth. A775 (2015) 54

Reconstruction

Detector | **FrontEnd electronics** | **Electronics controller** | **Hit along strip** | **Annihilation point** | **Image**

J-PET: W. Krzemień et al., Acta Phys. Pol. B47 (2016) 561

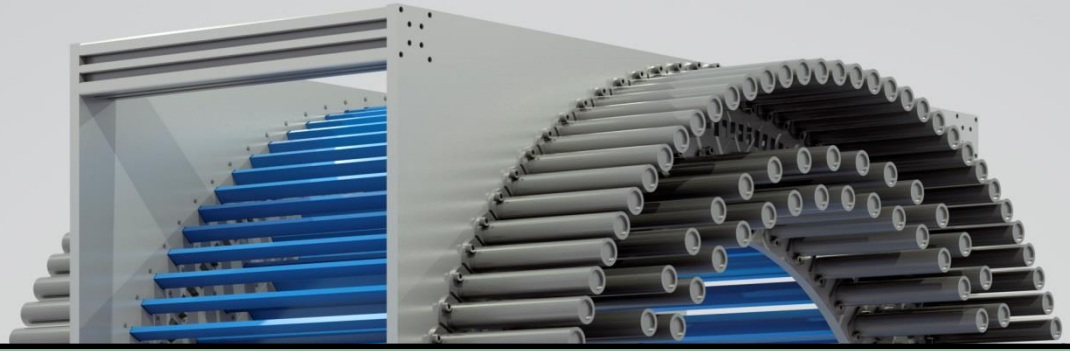
Jagiellonian PET



AFOV: 17 cm → 50 cm ; TOF: 520 ps → 300 ps

Jagiellonian PET

Jagiellonian PET



- Jagiellonian PET
- NEMA characteristics
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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 ?

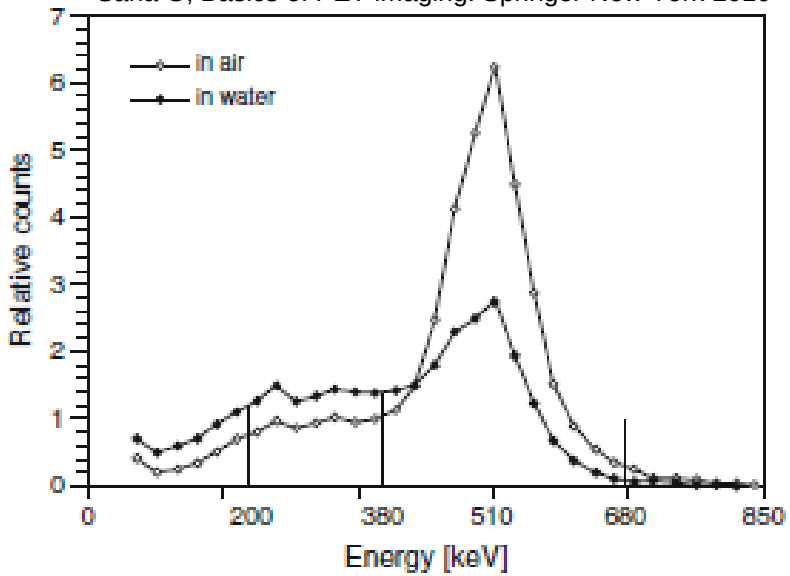
→ Low detection efficiency and no photeffect !

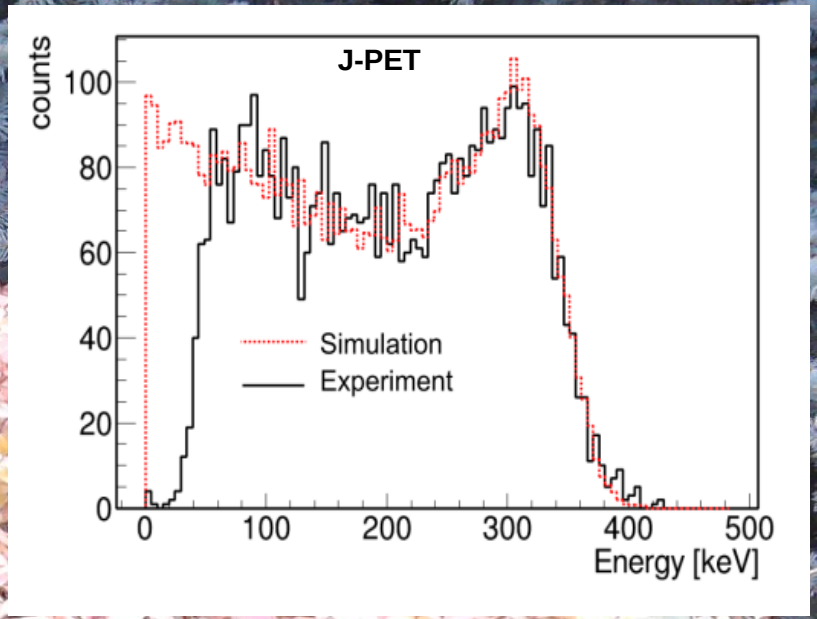
Sensitivity ?

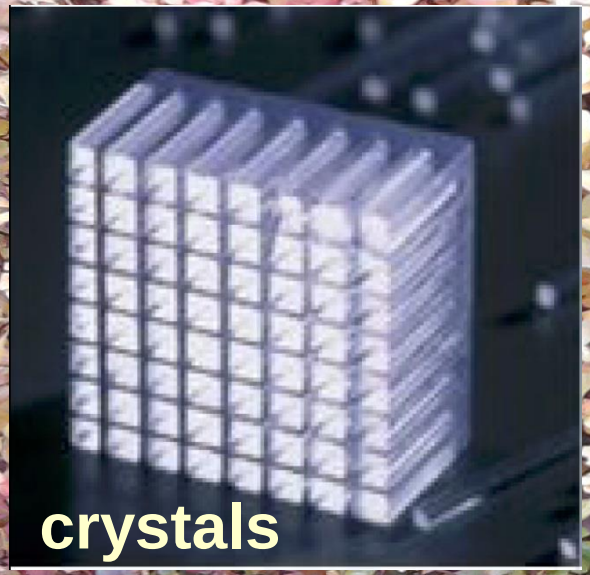
Scatter fraction ?

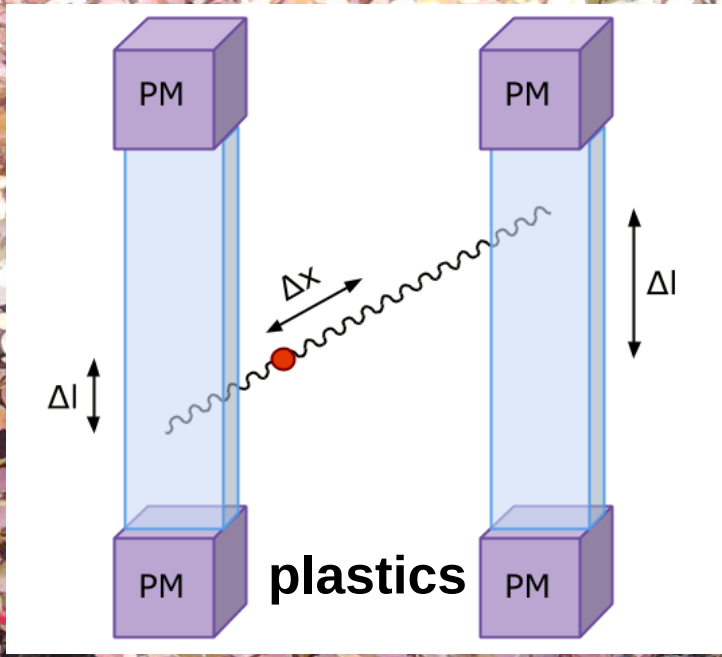
Accidental coincidences?

Saha G, Basics of PET imaging. Springer New York 2010





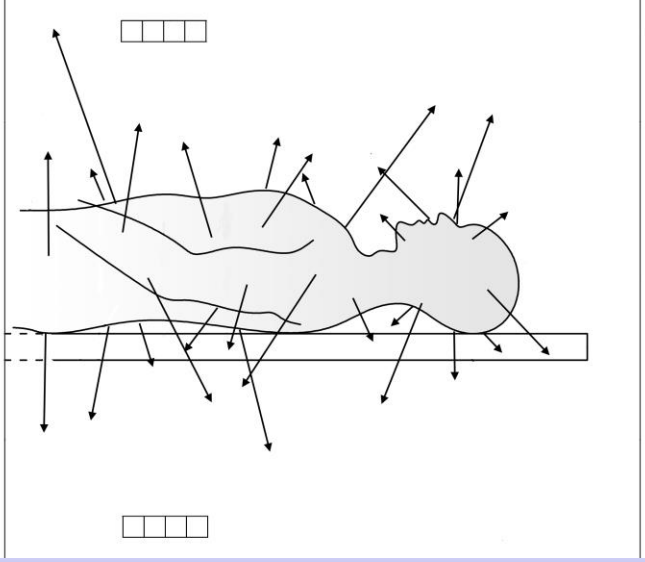


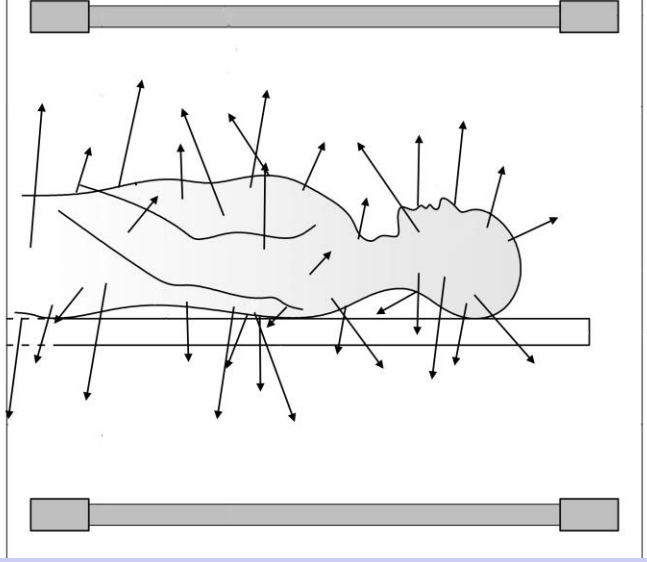


for the 2.5 cm layer the efficiency for the registration of events selected to reconstruct the image is for the plastic scintillator by

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

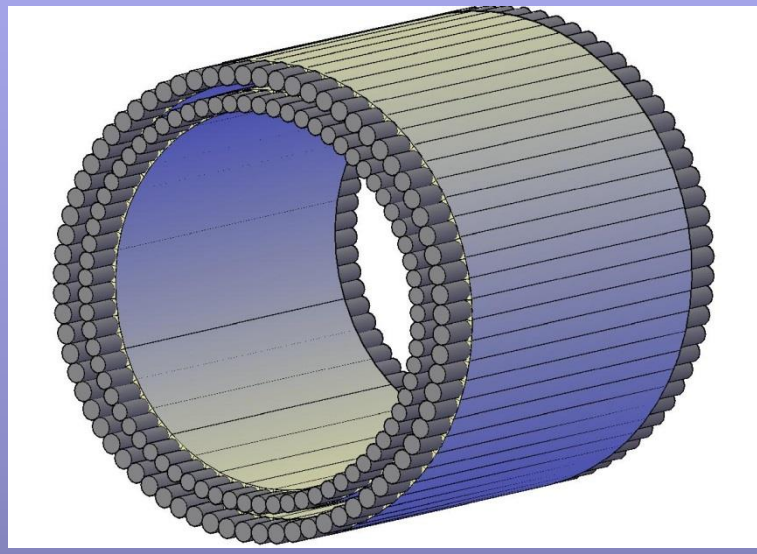




It is important to note that the cost of J-PET does not increase with the increase of the FOV

epsilon^2 = 20 to 40 smaller efficiency

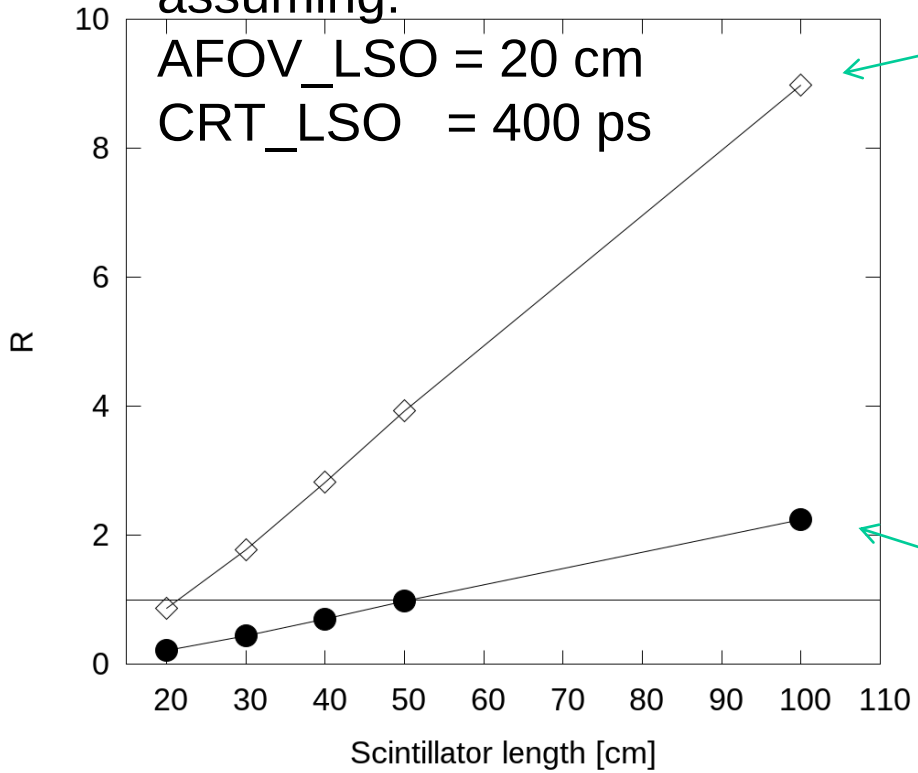
But



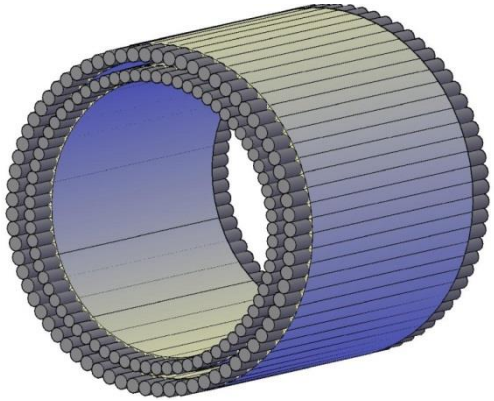
Solid angle ---------- > factor of ~5
600 ps --> 200ps – 300ps --> factor of 3 -- 2
1m instead of ~17 cm ---------> factor of 10
N layers in the strip-PET ----> factor **N^2**

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

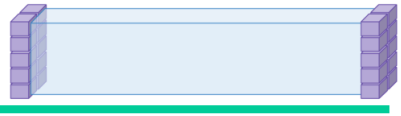
R = FOM_JPET / FOM_LSO
assuming:
AFOV_LSO = 20 cm
CRT_LSO = 400 ps

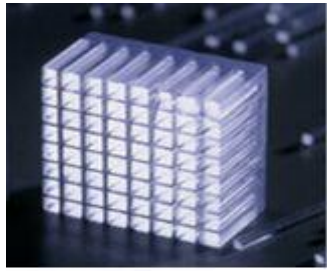


N_JPET_layers = 2



R = FOM_JPET / FOM_LSO





N_JPET_layers = 1

LSO

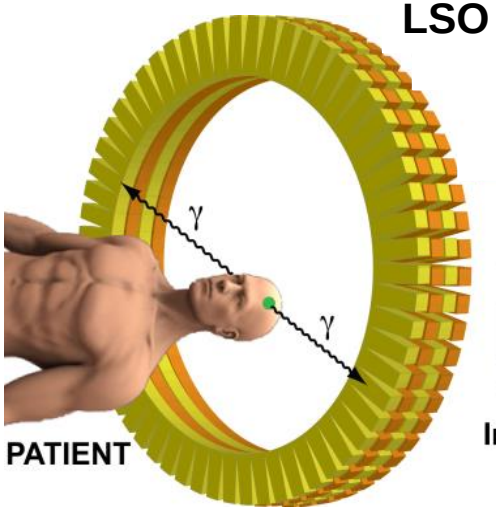
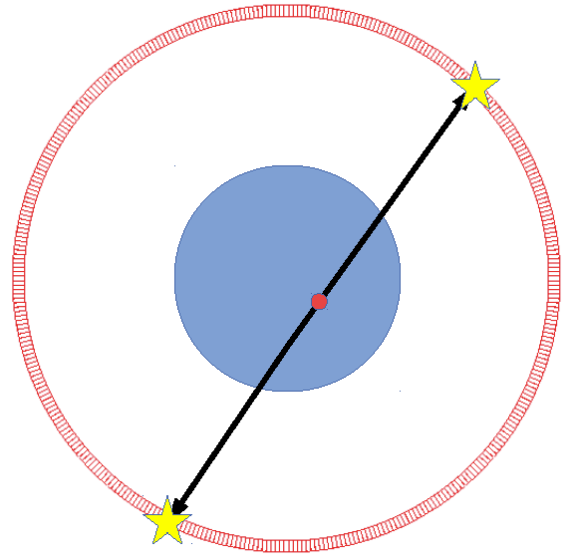


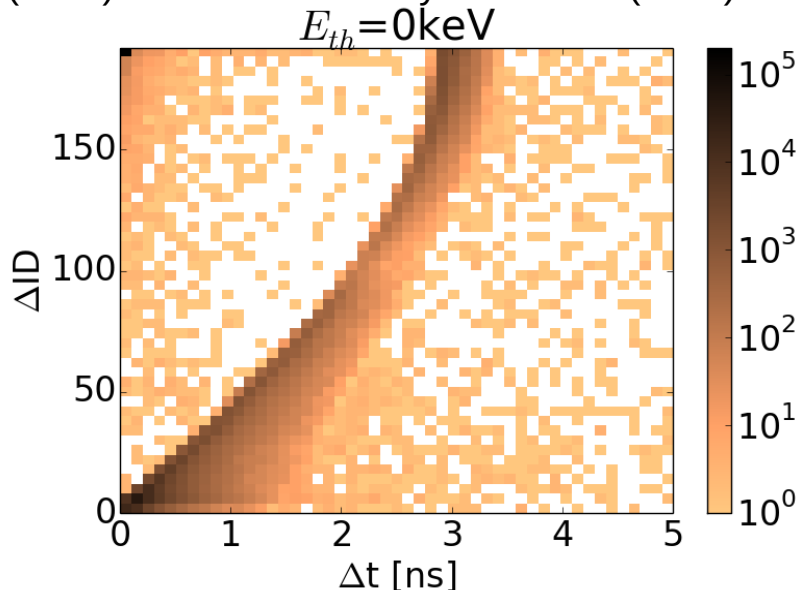
Figure of Merit for whole body imaging:
FOM = ϵ_detection^2 · ϵ_selection^2 · Acc / (CRT N_steps)

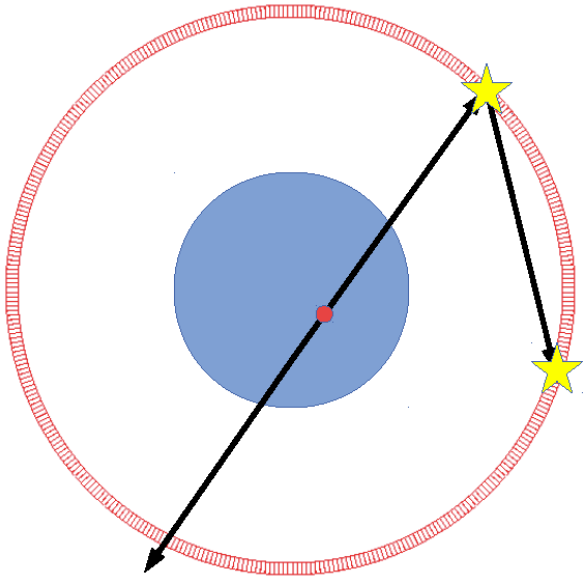
J-PET: P.M. et al., Phys. Med. Biol. (2016) in print ; arXiv:1602.02058

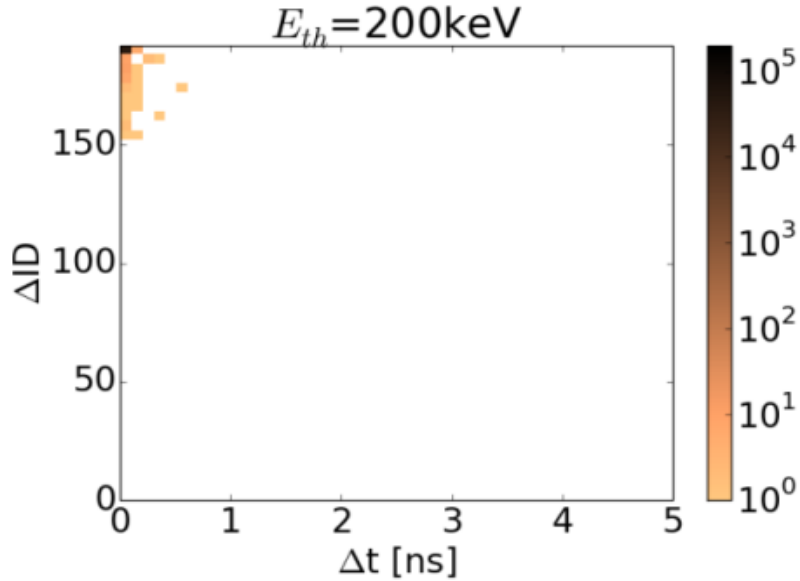
J-PET
secondary scattering in the detector

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









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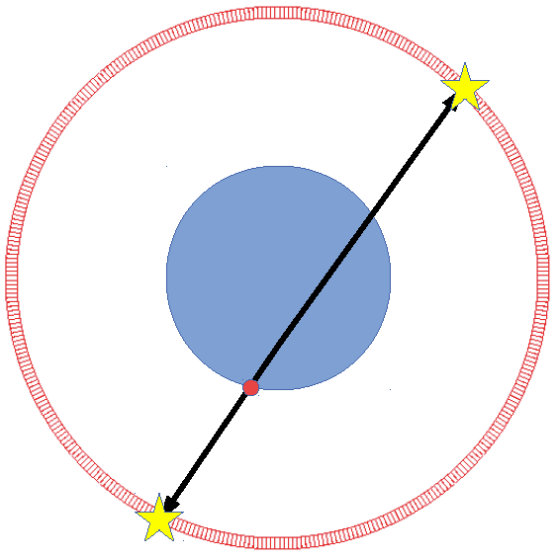

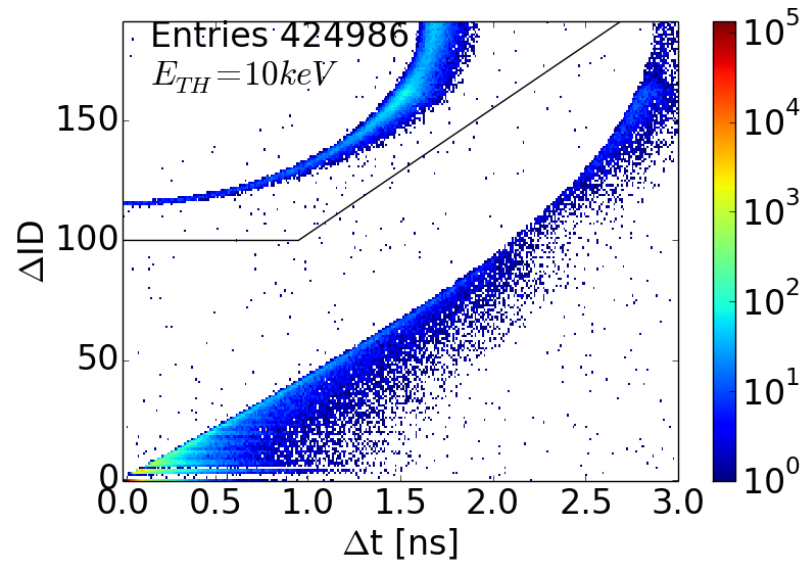

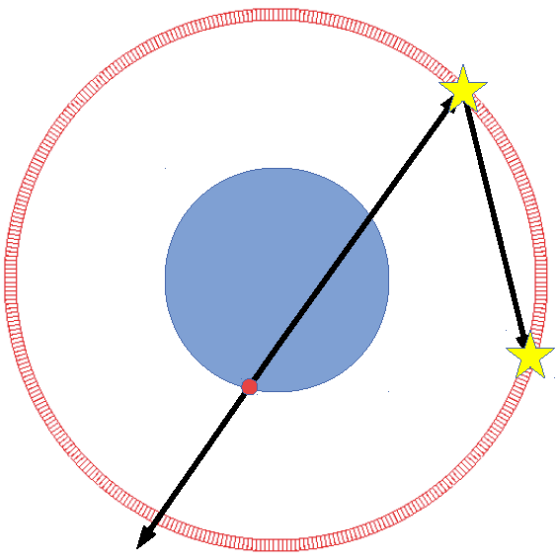

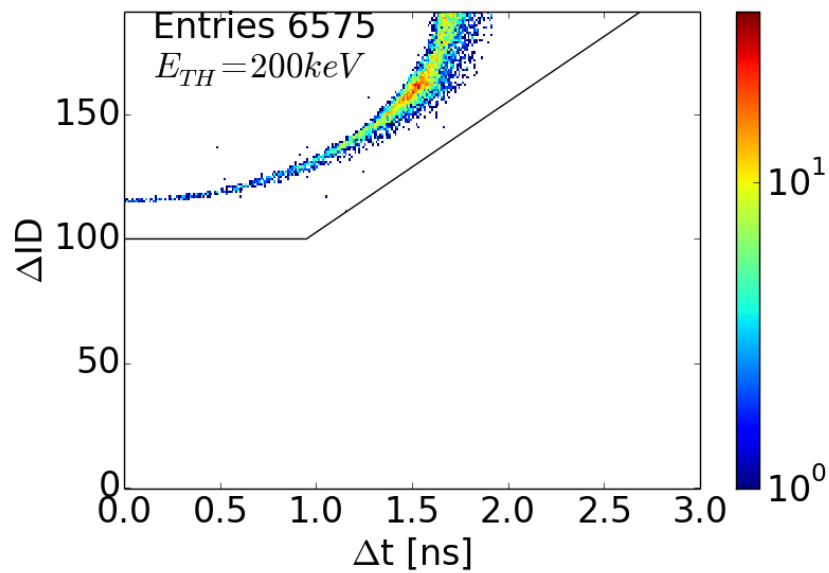

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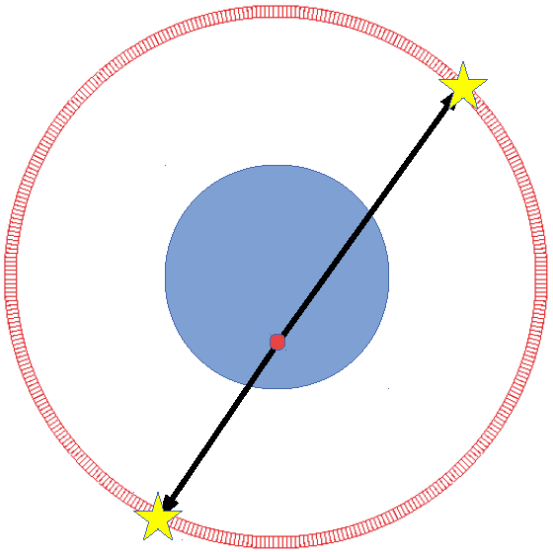
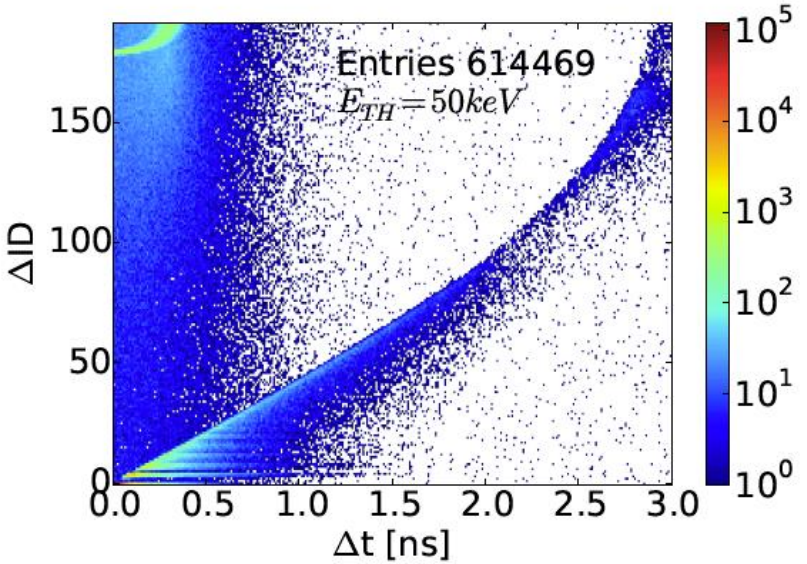
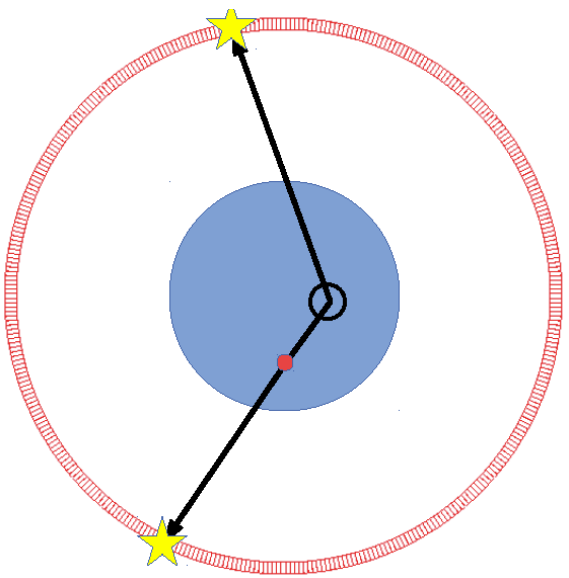
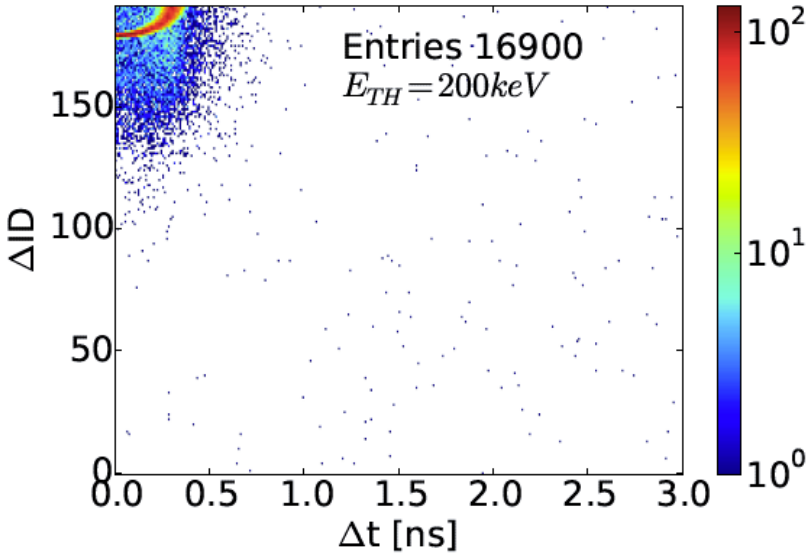
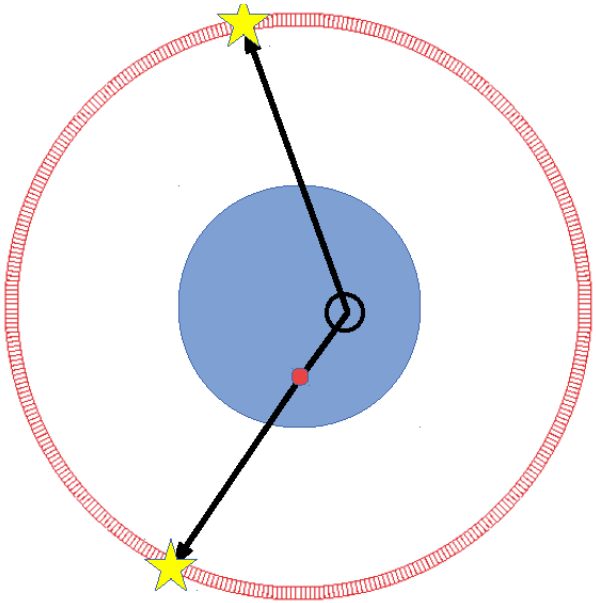


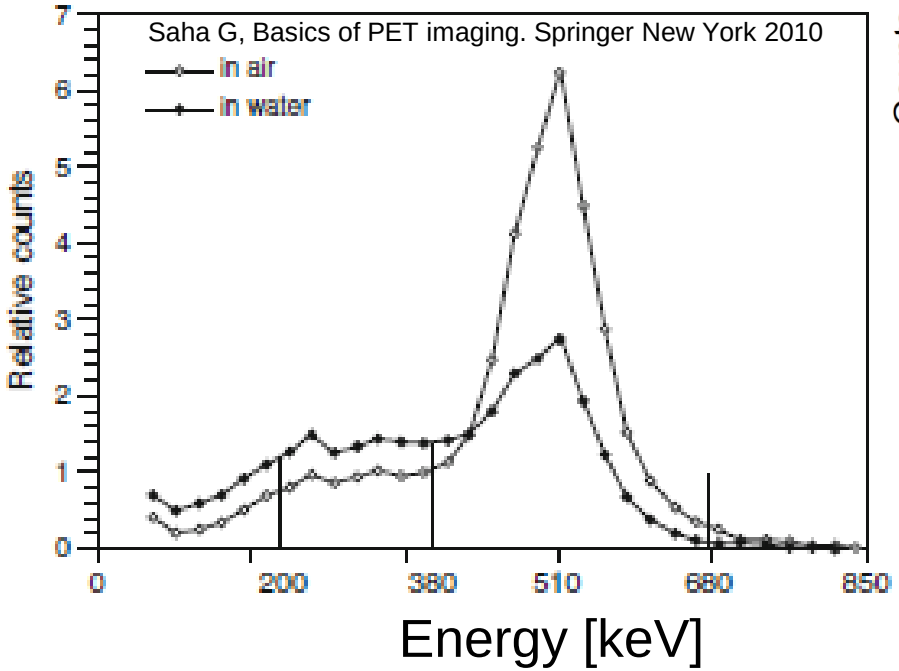


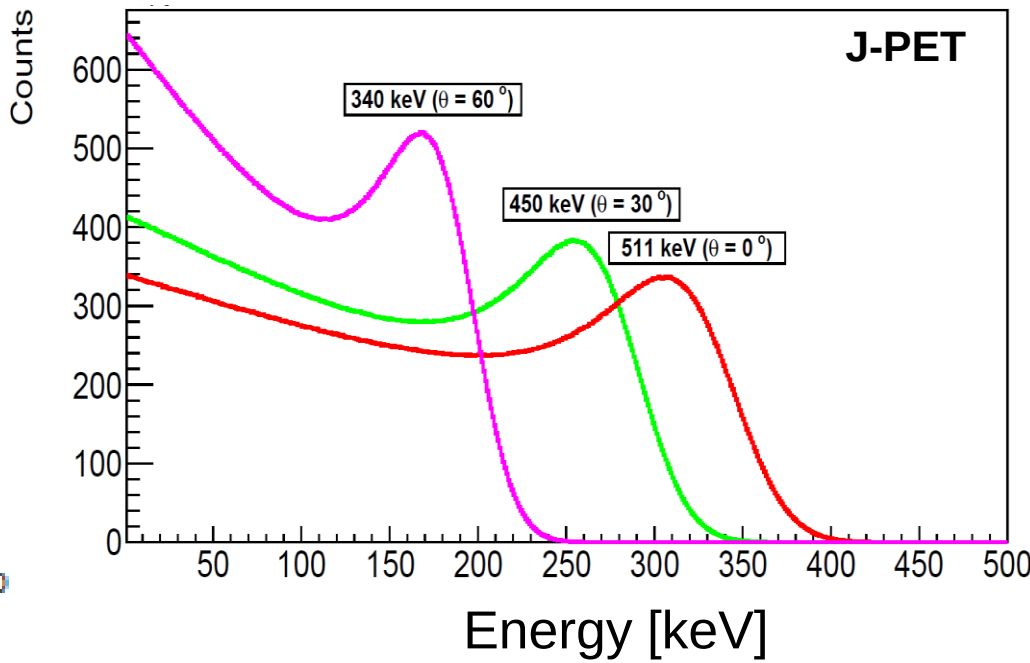




J-PET scattering in the patient

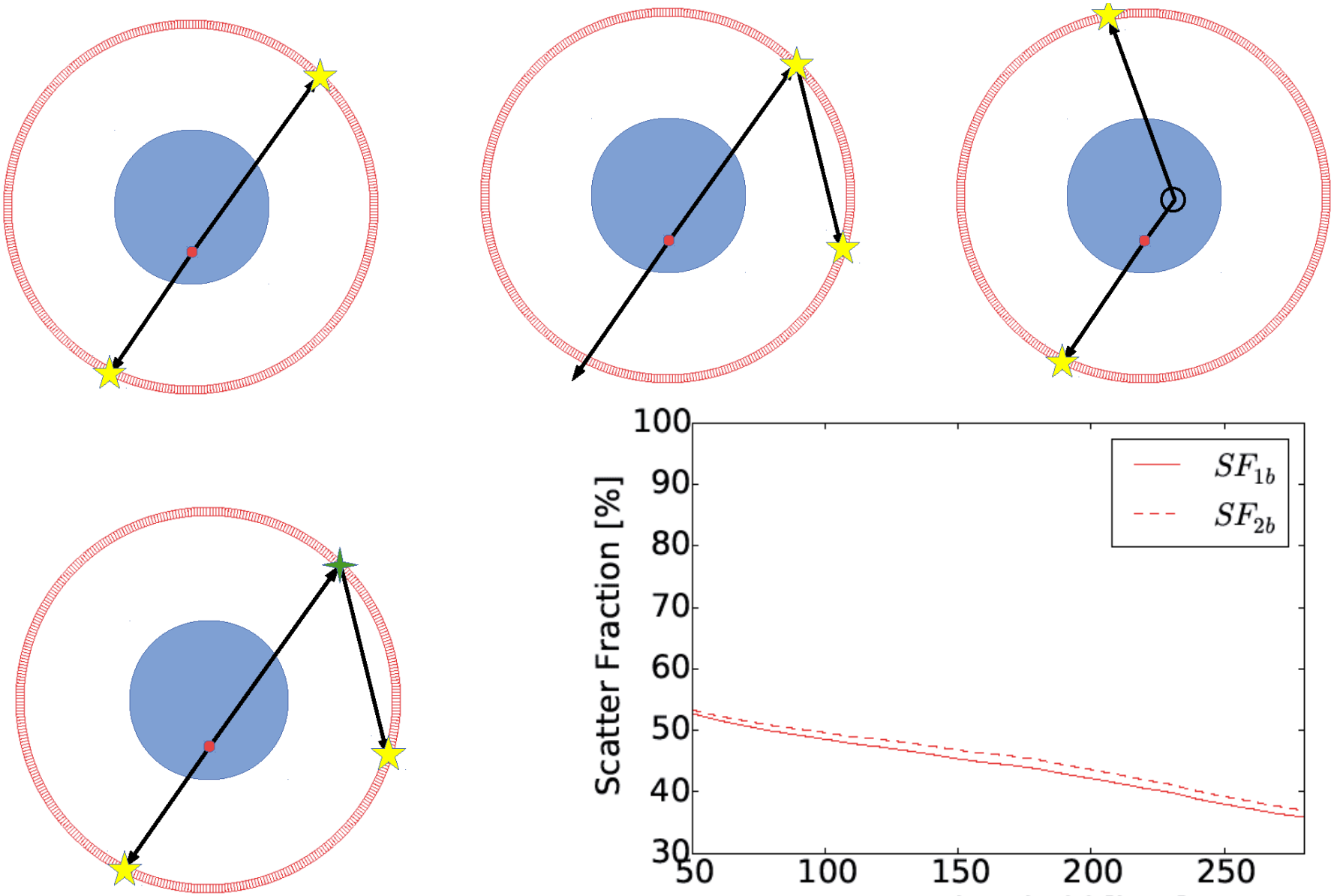






J-PET Scatter Fraction

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



J-PET CHARACTERISTICS

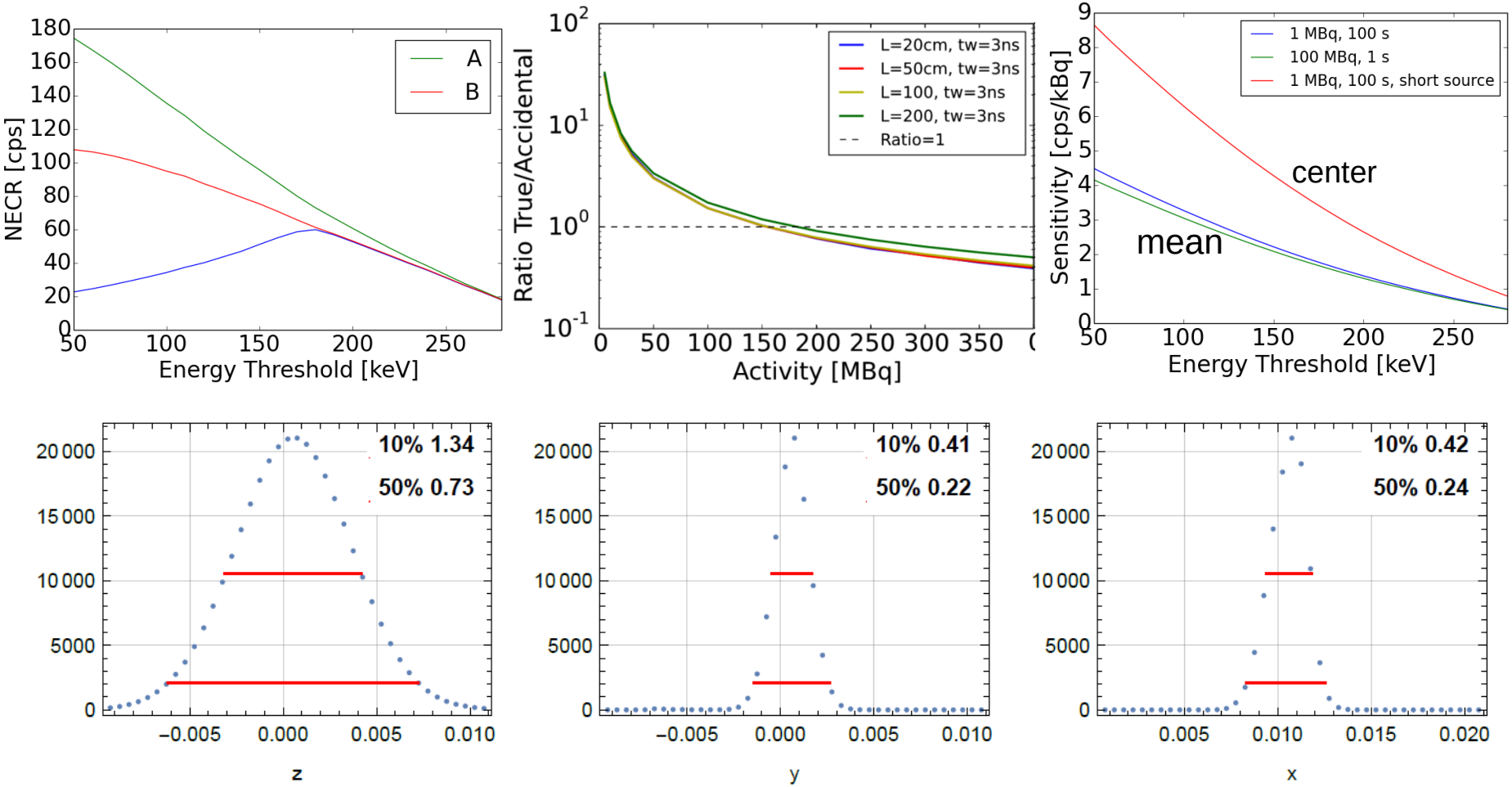
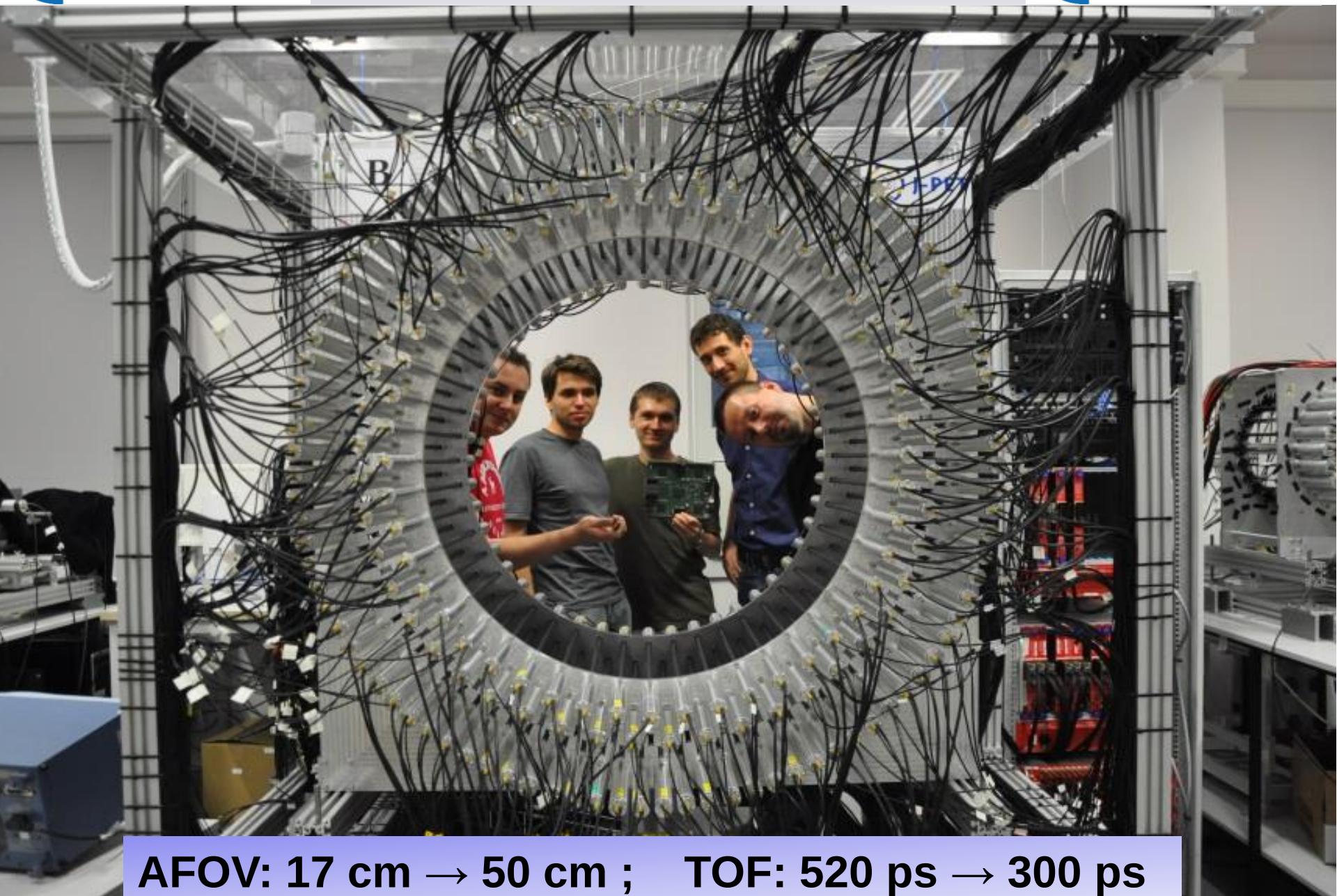


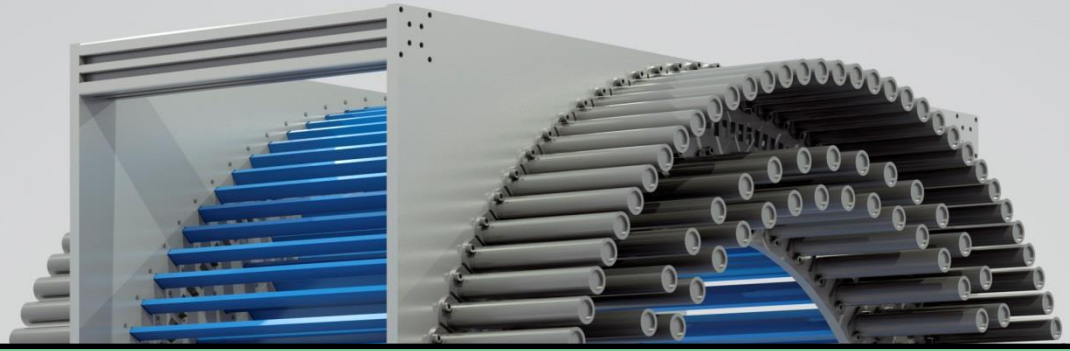
Figure 27: Reconstruction of the 1mm source located at $(1, 0, 0)$ cm after 020 iterations. FullRing length 050 cm.

Jagiellonian PET



AFOV: 17 cm → 50 cm ; TOF: 520 ps → 300 ps

Jagiellonian PET



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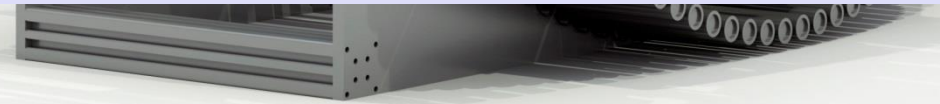
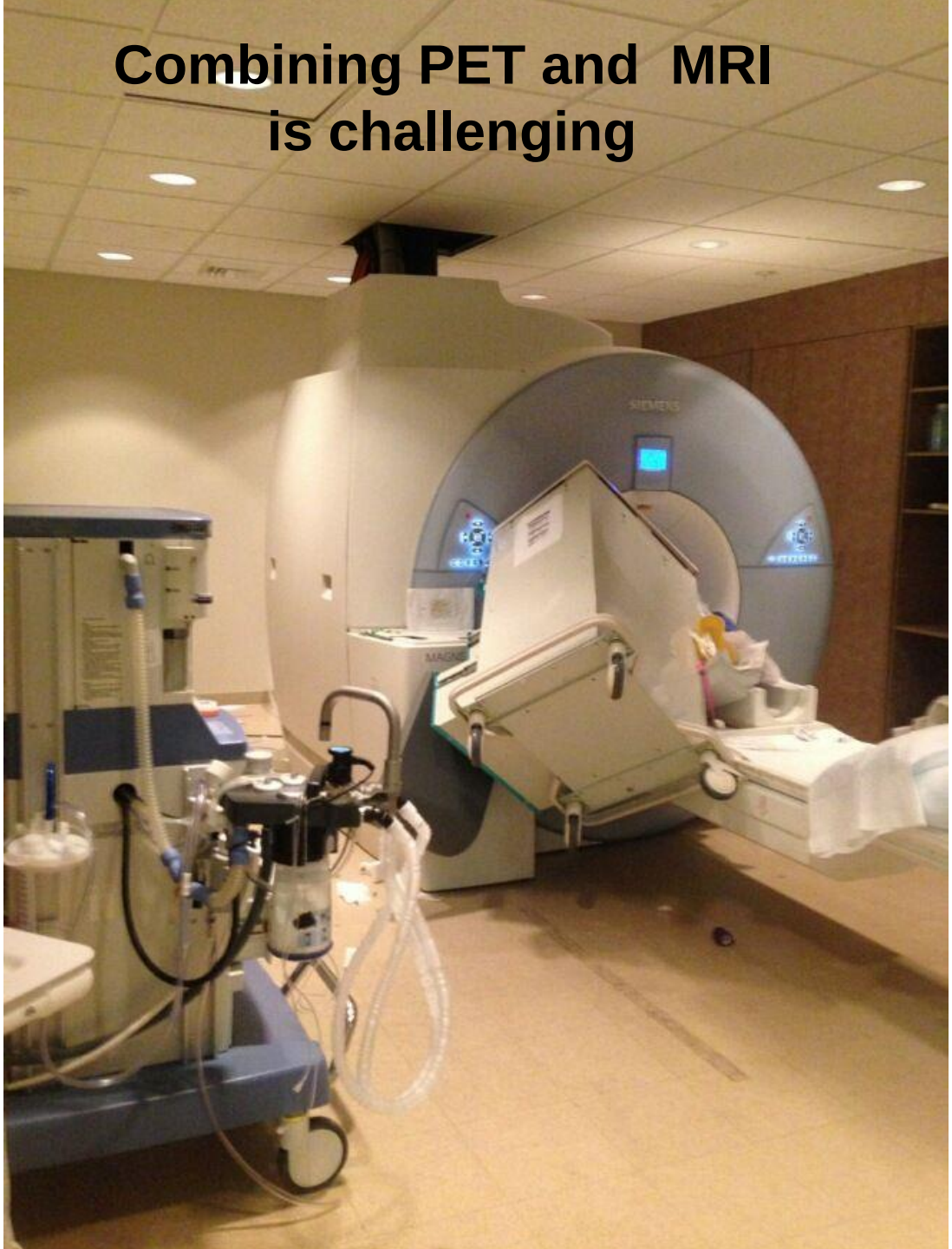
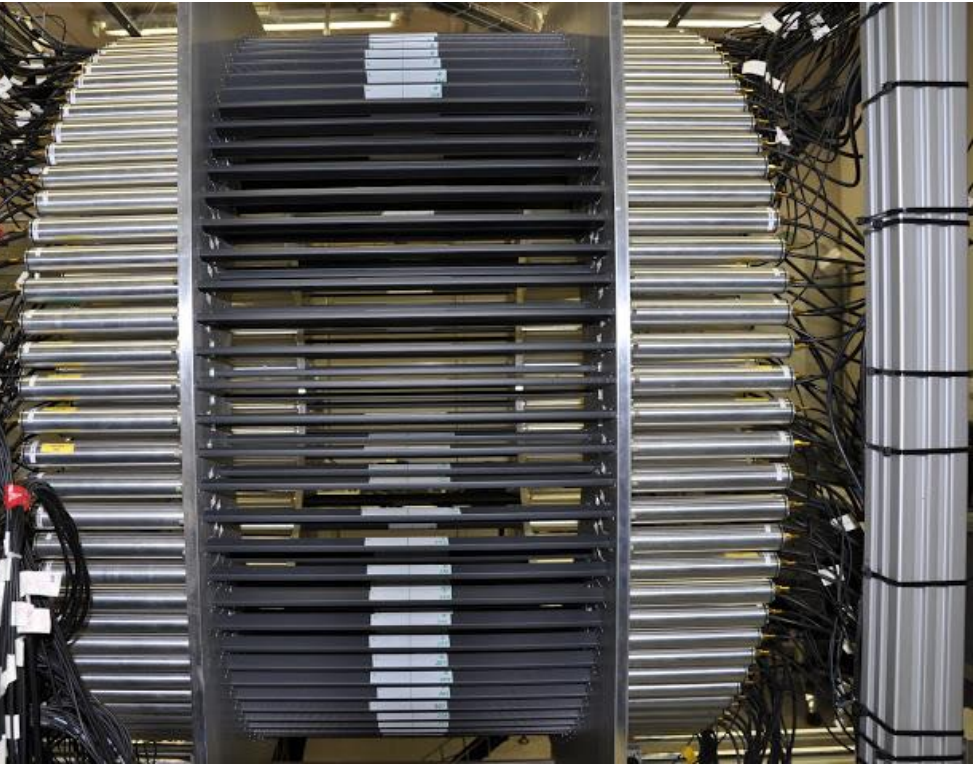
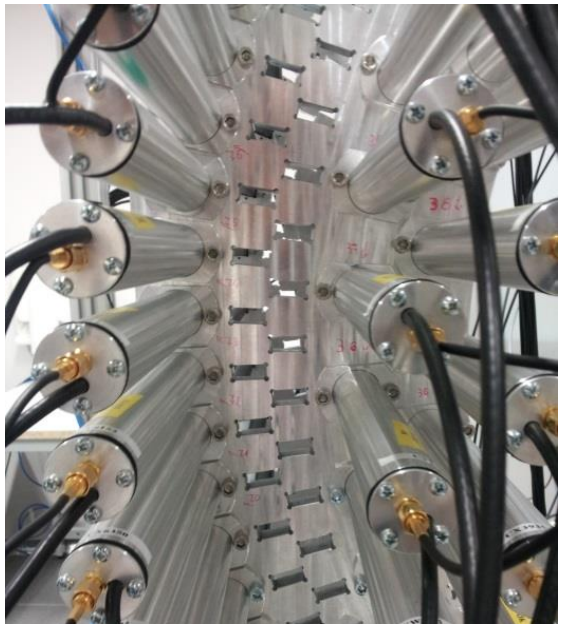
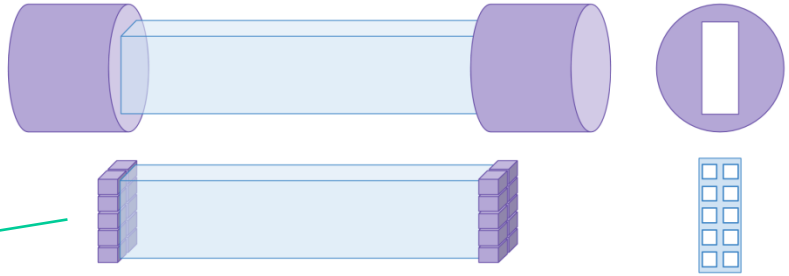


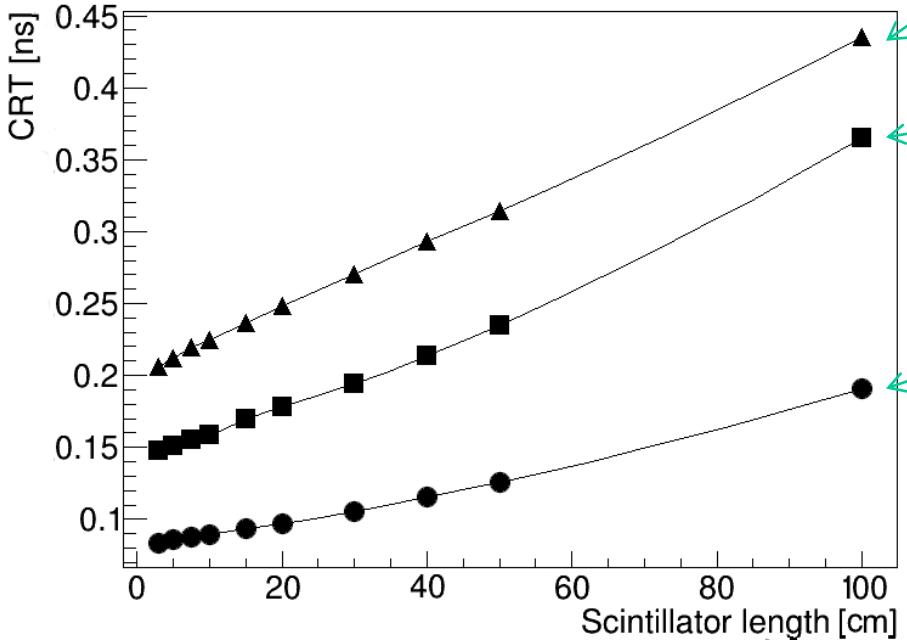
Combining PET and MRI is challenging





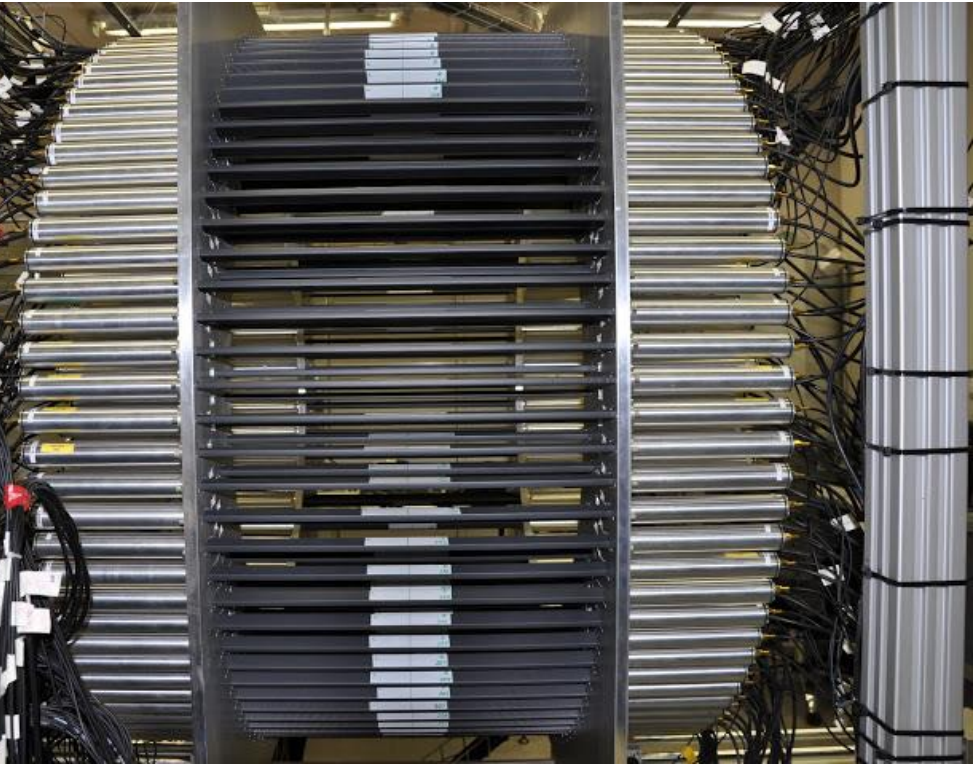


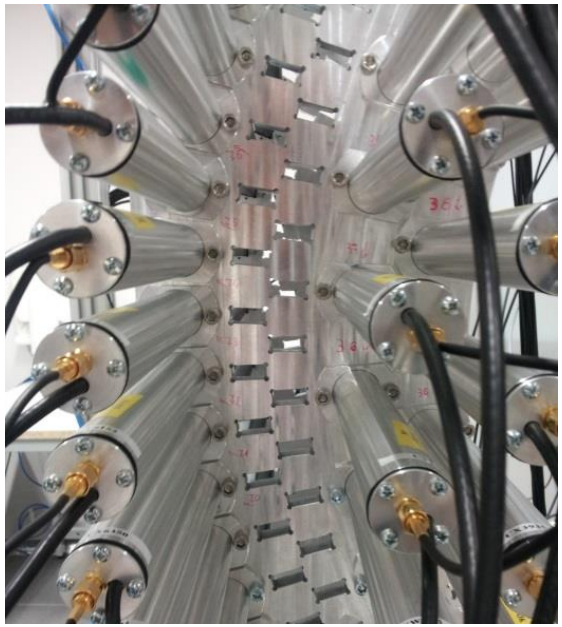


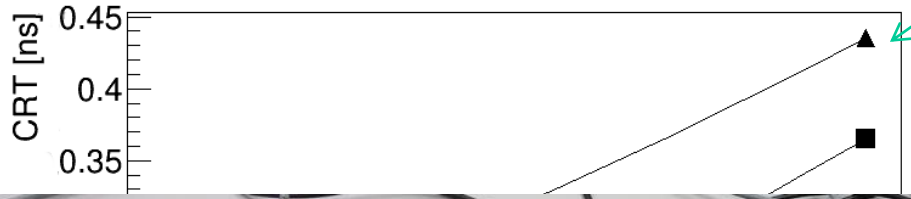


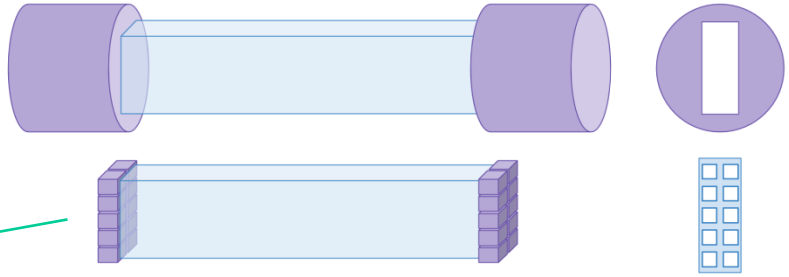
J-PET: P.M. et al., Phys. Med. Biol. (2016) in print ; arXiv:1602.02058

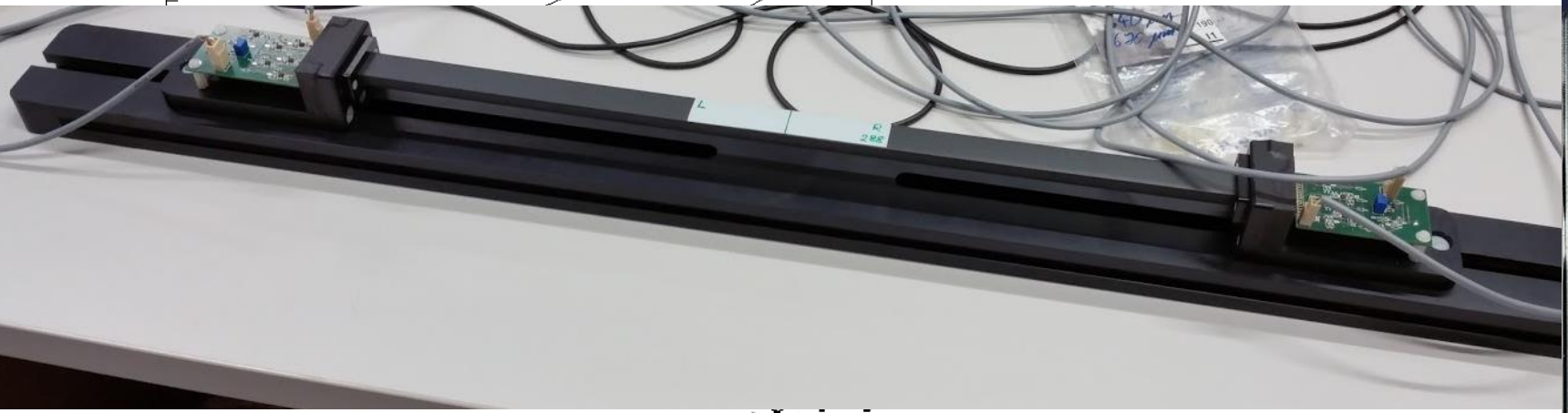
Limit of the J-PET






CRT [ns]
0.45
0.4
0.35

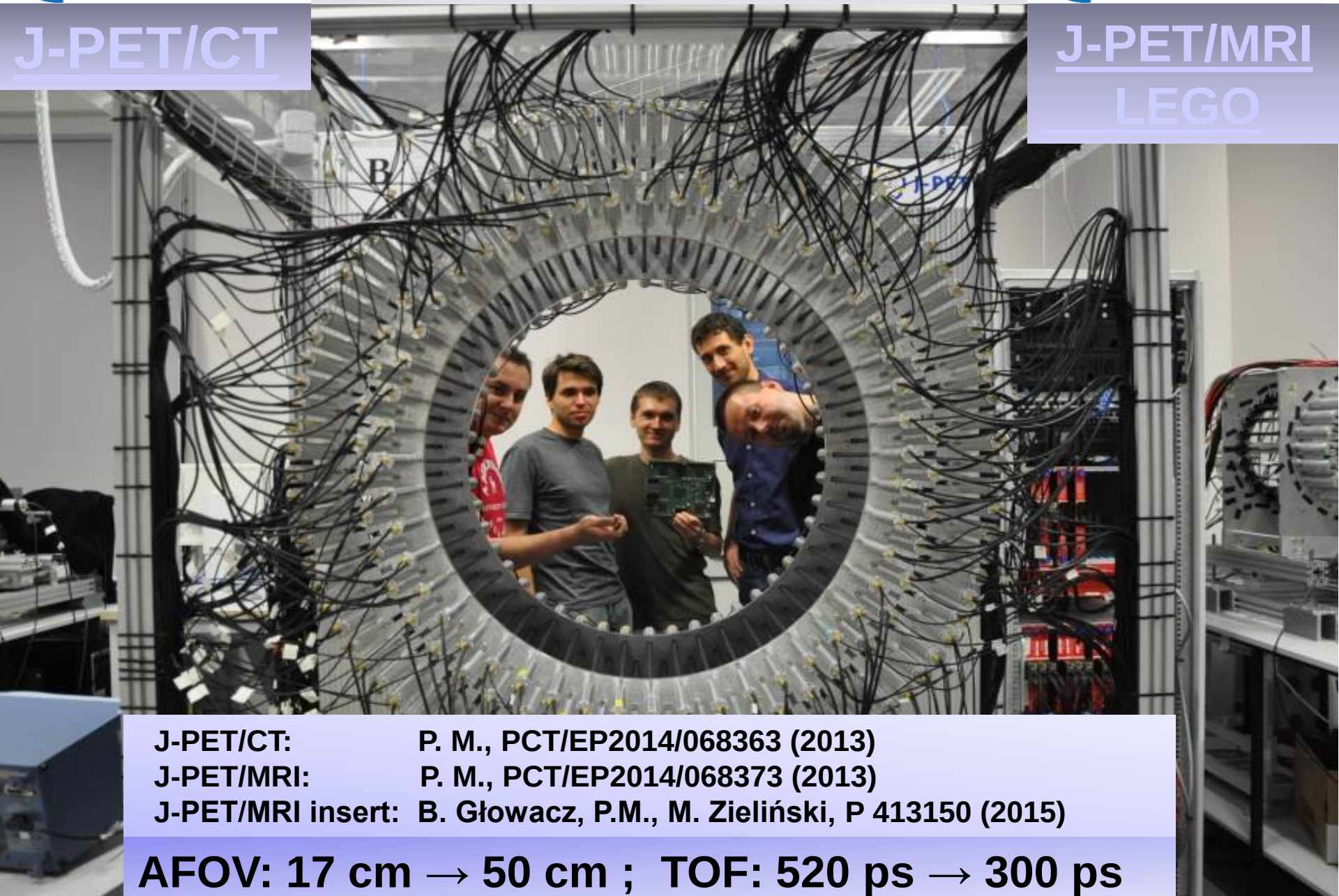




Jagiellonian PET

J-PET/CT

J-PET/MRI
LEGO



J-PET/CT: P. M., PCT/EP2014/068363 (2013)
J-PET/MRI: P. M., PCT/EP2014/068373 (2013)
J-PET/MRI insert: B. Głowacz, P.M., M. Zieliński, P 413150 (2015)

AFOV: 17 cm → 50 cm ; TOF: 520 ps → 300 ps

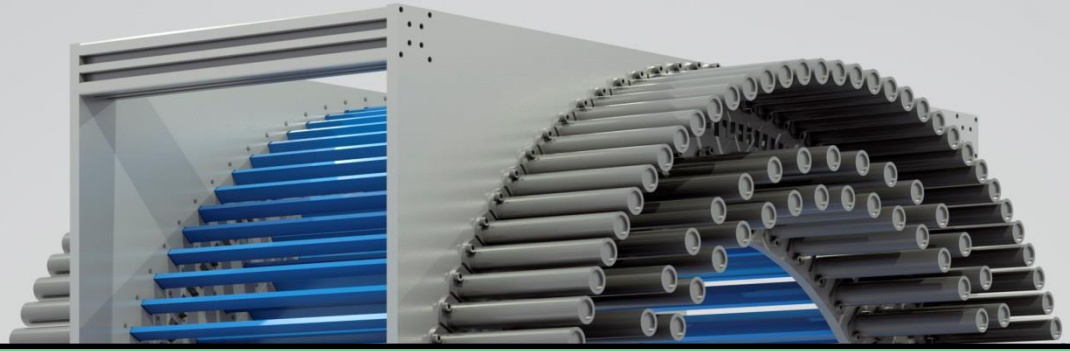
Jagiellonian PET

KING SIZE PET FOR LARGE ANIMALS

THANK YOU
FOR YOUR ATTENTION

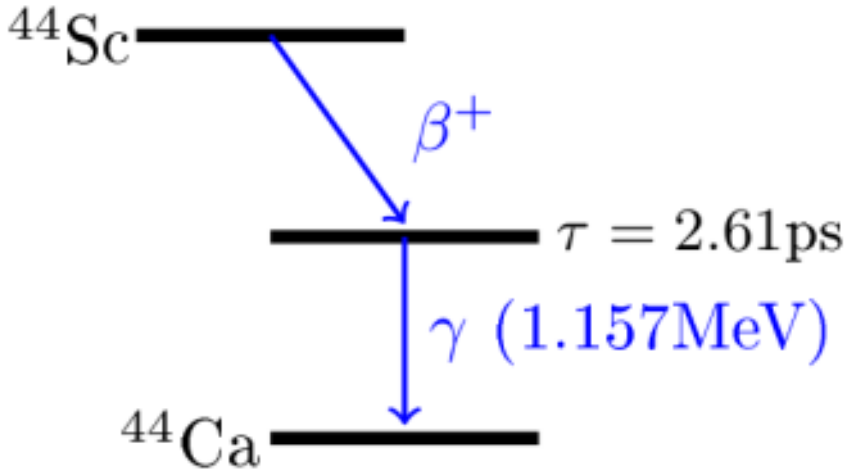
AFOV: 17 cm → 50 cm ; TOF: 520 ps → 300 ps

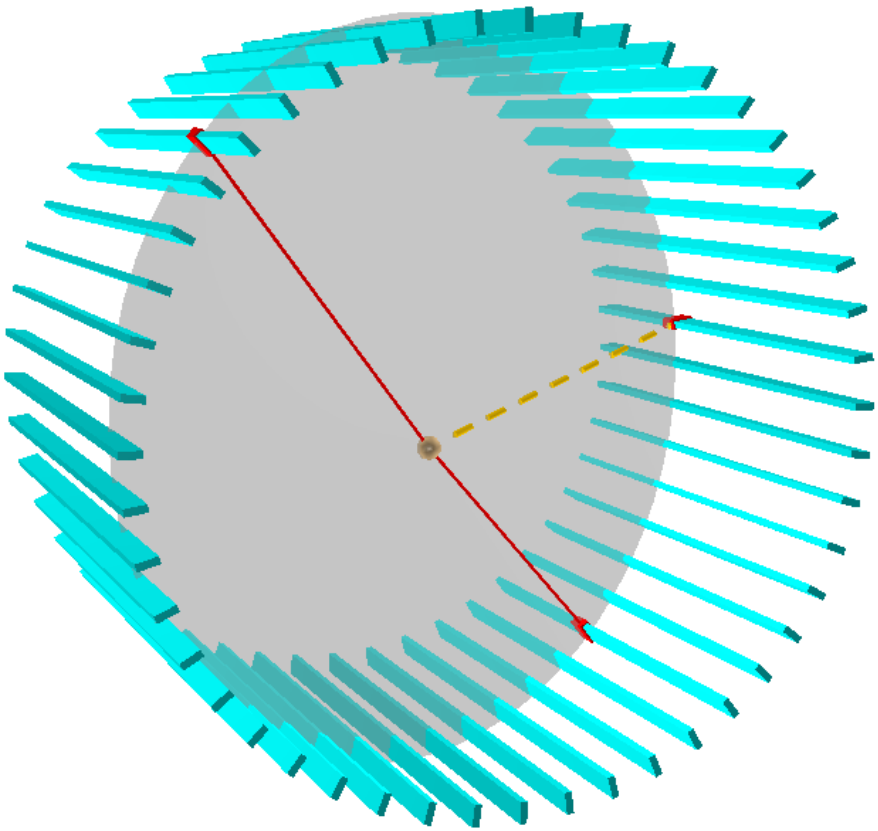
Jagiellonian PET

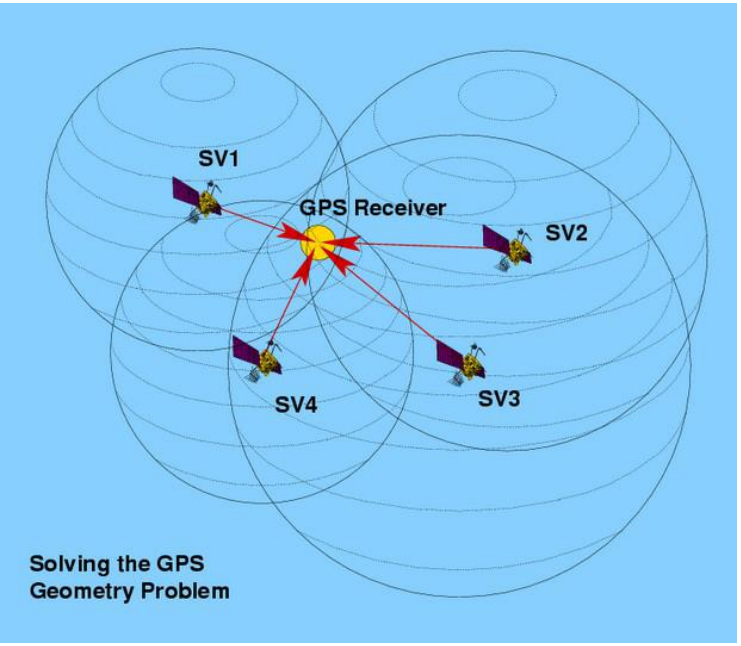


- Jagiellonian PET
- NEMA characteristics
- Towards simultaneous J-PET and MRI imaging
- MULTI-PHOTON PET

3-gamma tomography



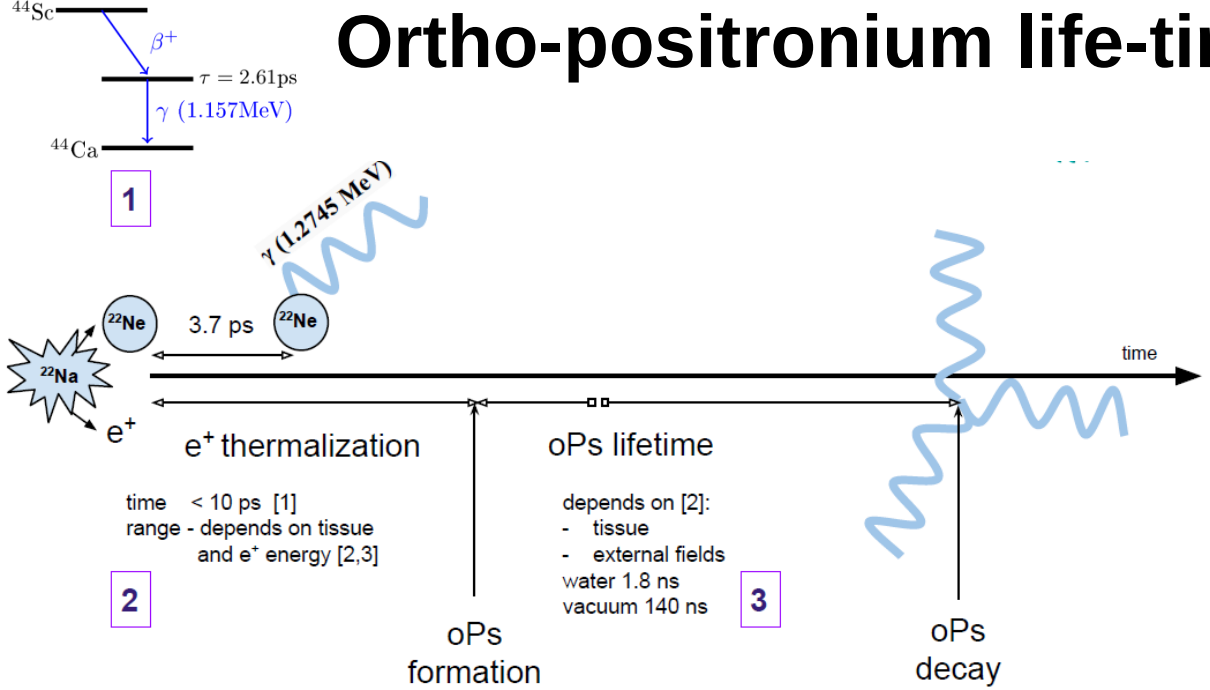


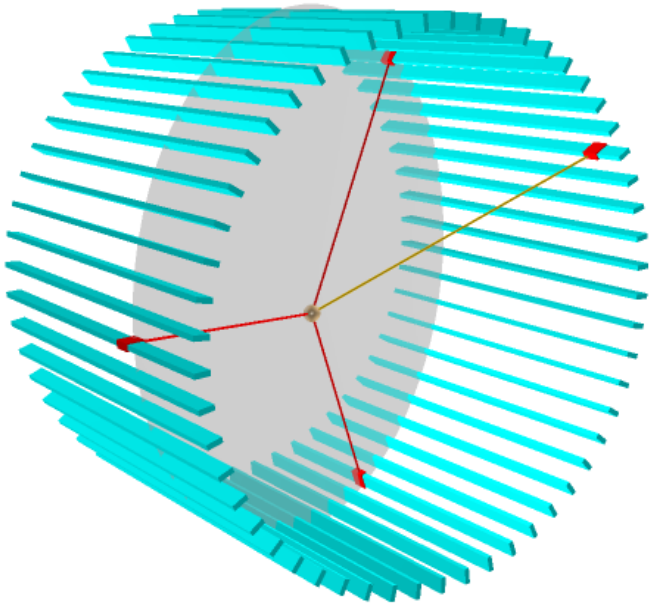


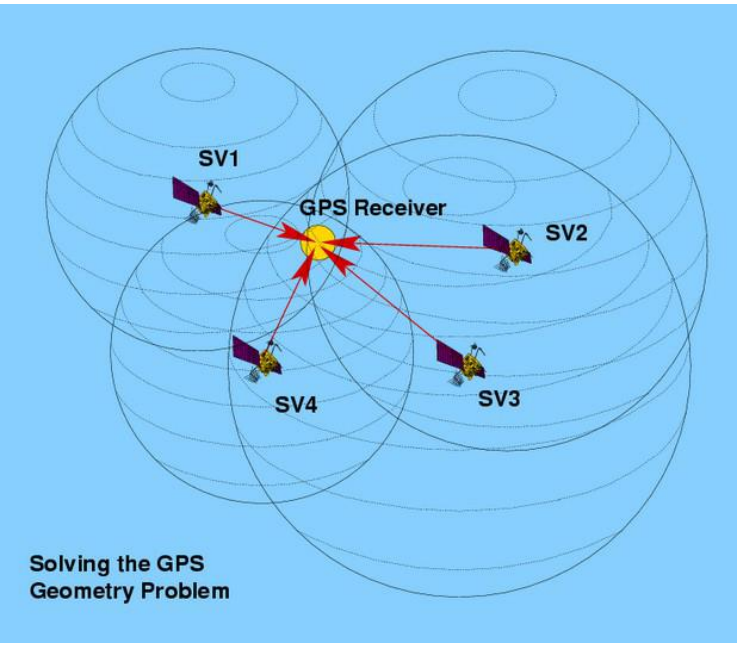
GPS-based trilateration reconstruction
J-PET: A. Gajos et al.,
Nucl. Instr. and Meth. (2016) submitted

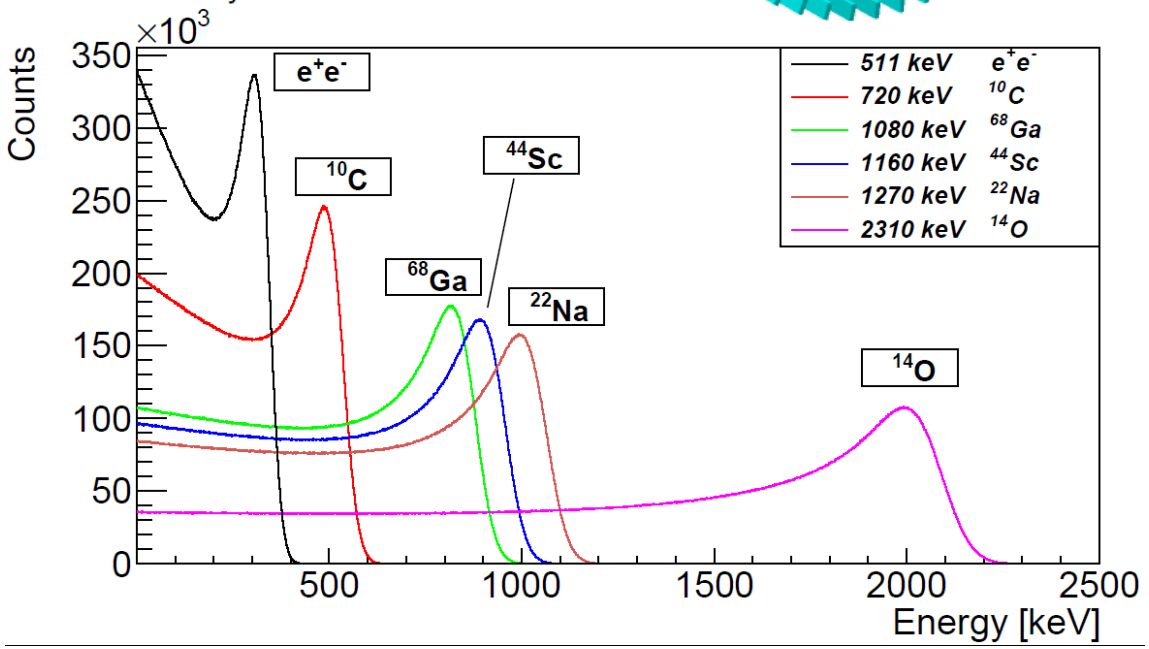
P. M., **PCT/EP2014/068374 (2013)**
A. Gajos, E. Czerwiński, D. Kamińska, P. M., **PCT/PL2015/050038 (2015)**

Ortho-positronium life-time tomography









P. M., PCT/EP2014/068374 (2013)

A. Gajos, E. Czerwiński, D. Kamińska, P. M., PCT/PL2015/050038 (2015)

Jagiellonian PET

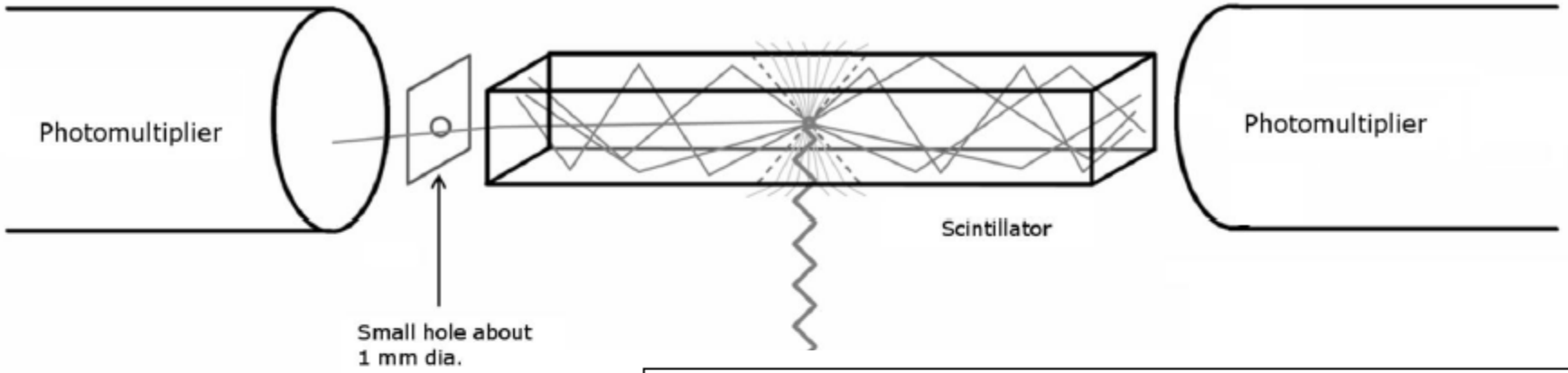
KING SIZE PET FOR LARGE ANIMALS

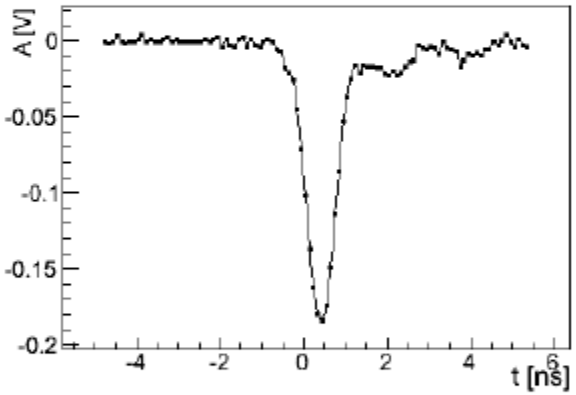
THANK YOU
FOR YOUR ATTENTION

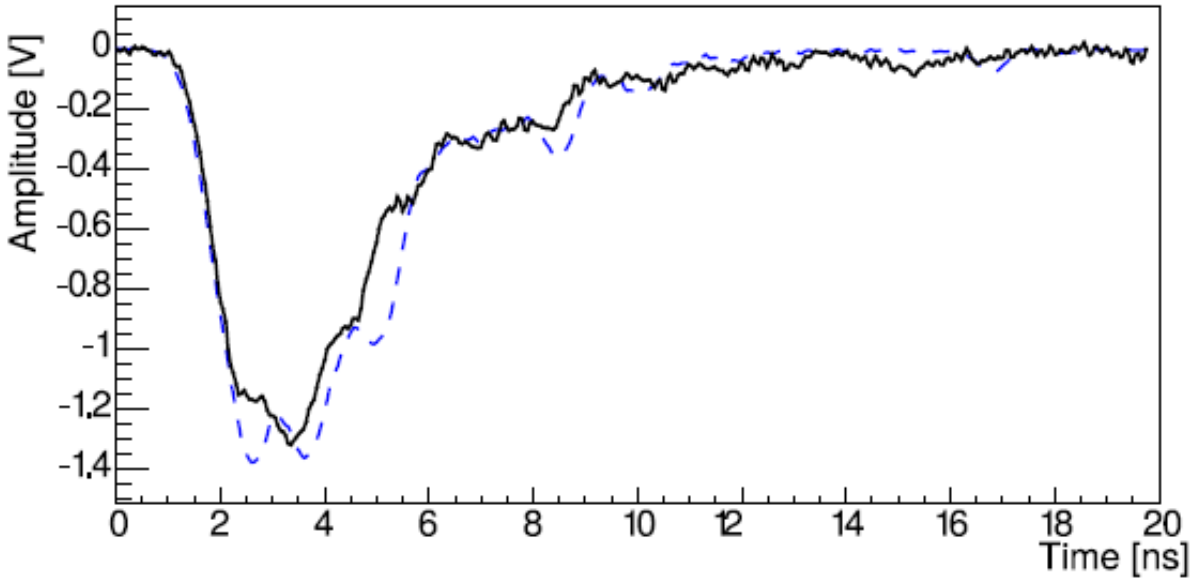
AFOV: 17 cm → 50 cm ; TOF: 520 ps → 300 ps

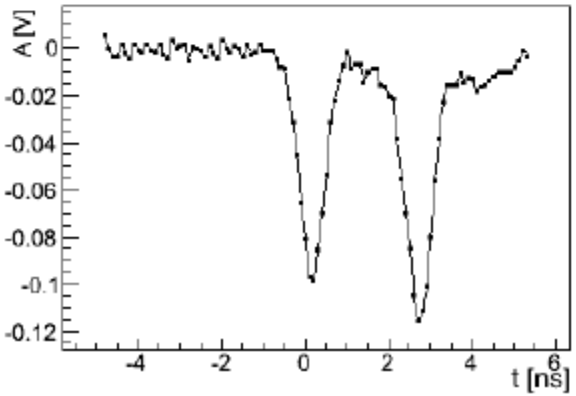
Device	Sensitivity	SF	NECR	PSF	Diameter	AFOV
GE Discovery STE and VCT	2.3 cps/kBq (8.8 cps/kBq) (R0, centre of field of view) and 2.3 cps/kBq (8.9 cps/kBq) (R10) [1]	The system scatter fraction was 21.4% in 2D at an energy of 375 keV (33.9% in 3D mode at a higher energy of 425 keV).[1]	84.9 kcps at 43.9 kBq/ml (2D) and 67.6 kcps at 12.1 kBq/ml (3D) [1]	Transaxial resolution FWHM for 2D(3D) mode at 1 cm offset from the centre of the field of view (R1) was 4.87 mm (5.12 mm) and at 10 cm off centre (R10) radially 5.70 mm (5.89 mm) and tangentially 5.84 mm (5.47 mm). The axial resolutions were 4.4 mm (5.18 mm) (R1) and 5.99 mm (5.86 mm) (R10). [1]	88.6 cm [2]	15.7 mm [2]
Philips Gemini TF PET/CT	7 cps/kBq (NEMA) and > 14 cps/kBq (TOF) [3]	From 27% to 45% [4]	110 kcps (NEMA) and > 220 (TOF) [3]	FWHM r=1cm: transverse 4.8 mm axial 4.8 cm r=10cm: radial 5.2 mm tangential 5.2 mm axial 4.8 [4]	90 cm [4]	18 cm [5]
Siemens Biograph TM	4.2 cps/kBq [6]	From 31% to 34% [7]	9 kcps at 1 kBq/ml [7]		83 cm [7]	21.8 cm [5]

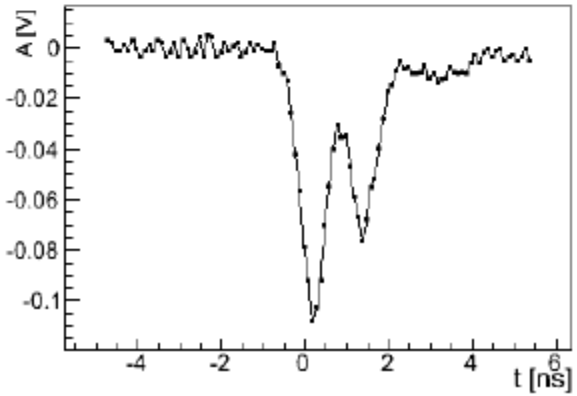
[1] Eur J Nucl Med Mol Imaging. 2007 Oct;34(10):1683-92. Epub 2007 Jul 28., http://www.ncbi.nlm.nih.gov/pubmed/17661031
[2] http://www.medwow.com/med/petct/ge-healthcare/discovery-ste-16-petct/67494.model-spec
[3] http://www.usa.philips.com/healthcare/product/HC882471/gemini-tf-pet-ct-scanner
[4] S. Surti et al., J Nucl Med. 2007 Mar;48(3):471-80
[5] https://www.aapm.org/meetings/08SS/documents/Townsend.pdf
[6] http://www.activexray.com/pdf/Siemens_Biograph.pdf [7] P. Gonias et al., Nucl. Instrum. Methods Phys. Res. A, 571 (2007), 263


Photomultiplier
Photomultiplier
Scintillator
Small hole about
1 mm dia.

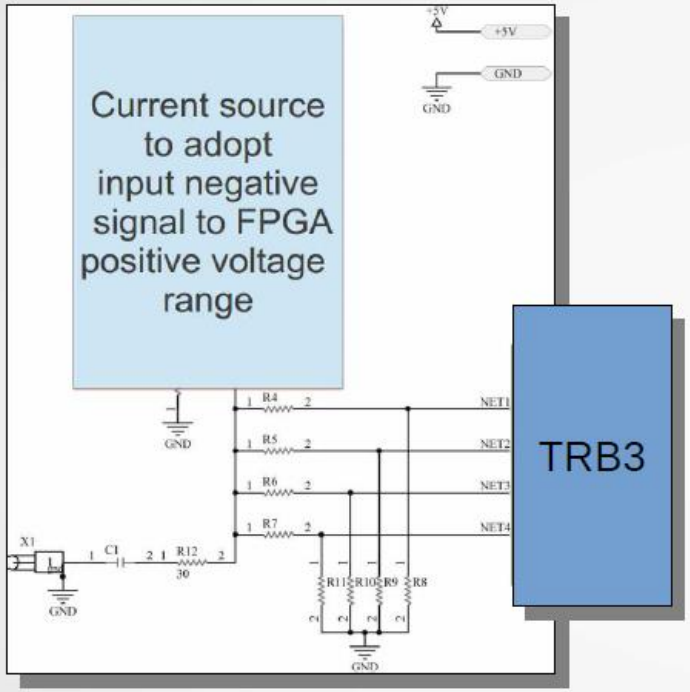

A [V]
t [ns]

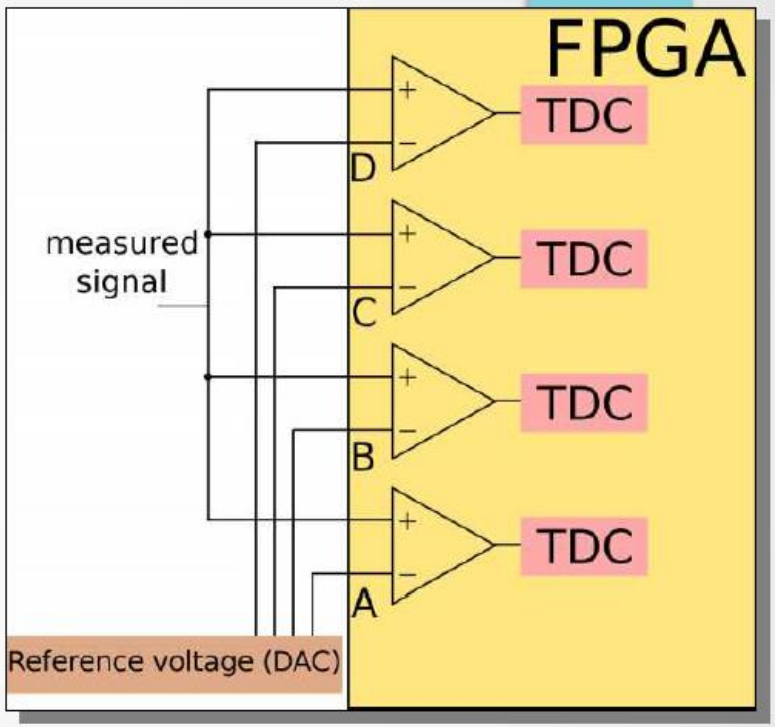

Amplitude [V]
Time [ns]


A [V]
t [ns]

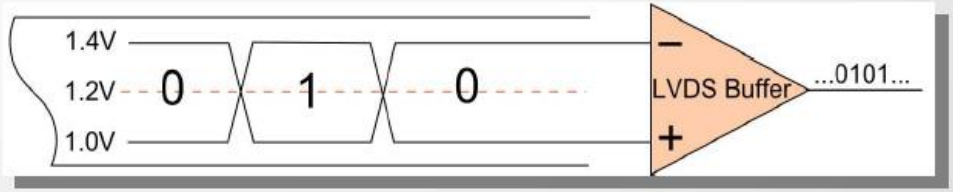

A [V]
t [ns]

FEE dive in



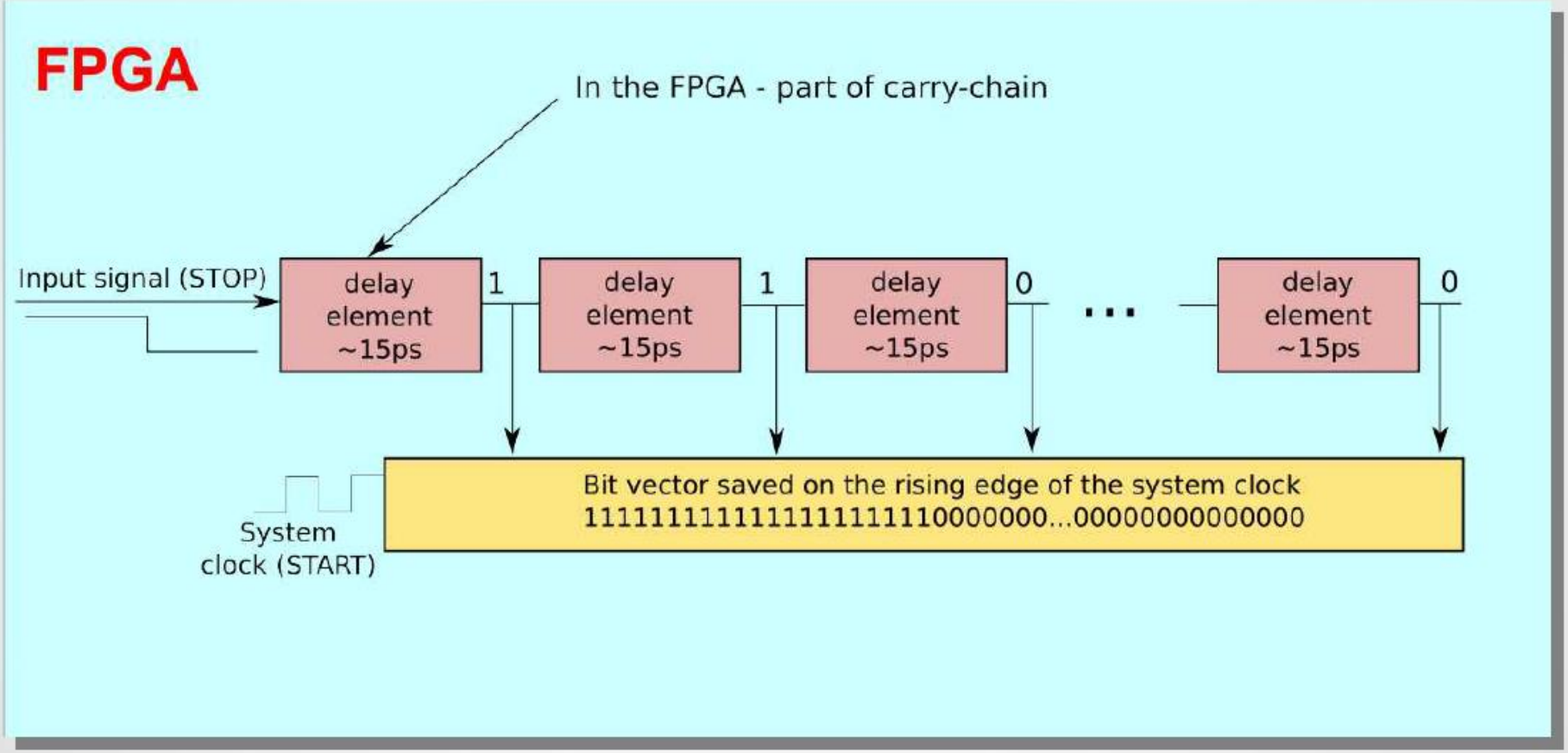


Discrimination of the signal is done with LVDS buffer which acts as a comparator. This innovative approach is the subject of **patent application**



PCT/EP2014/068367 (2014)

TDC in FPGA


FPGA
In the FPGA - part of carry-chain
Input signal (STOP)
delay element ~15ps
1
delay element ~15ps
1
delay element ~15ps
0
...
delay element ~15ps
0
Bit vector saved on the rising edge of the system clock
11111111111111111111110000000...00000000000000
System clock (START)