

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

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1st September 2016
Symposium in Kiev

NEMA – National Electrical Manufacturers Association

NEMA-NU-2 – Performance Measurements of Positron
Emission Tomographs

0. Introduction

1. Spatial Resolution

2. Scatter Fraction

3. Sensitivity

0. Introduction

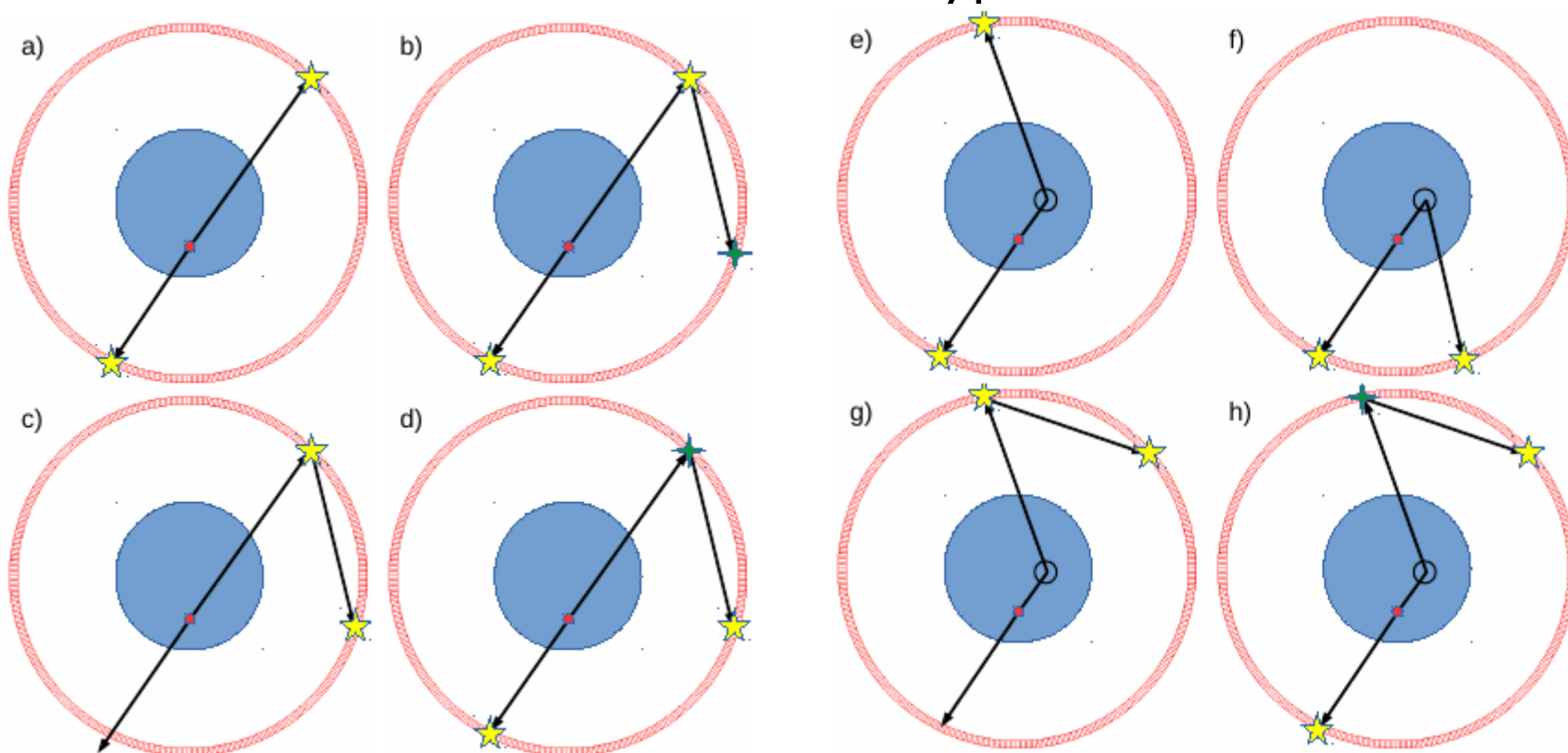
Coincidence:

- time window 3 ns
- exactly 2 or 3 scatterings with deposited energy bigger than noise threshold equal 10 keV
- exactly 2 scatterings with deposited energy bigger than fixed energy threshold equal 200 keV

Types of coincidences: true, scattered (in the phantom or in the detector), random (accidental)

0. Introduction

Pictorial definitions of different types of coincidences



a,b – true coincidences; c,d – detector-scattered coincidences,
e-h – phantom-scattered coincidences

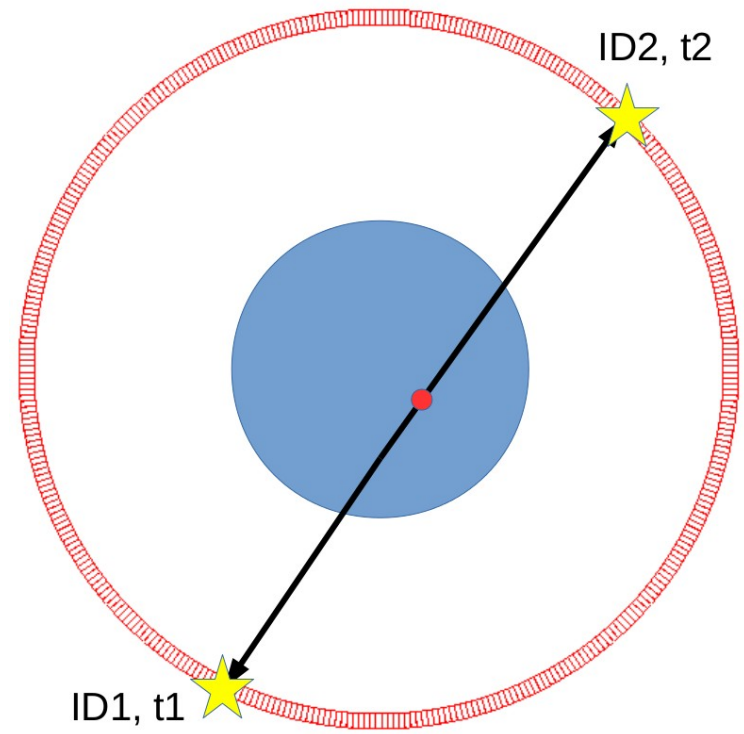
0. Introduction

Part of coincidences may be rejected at this level using selection based on time and identifiers differences between subsequent hits.

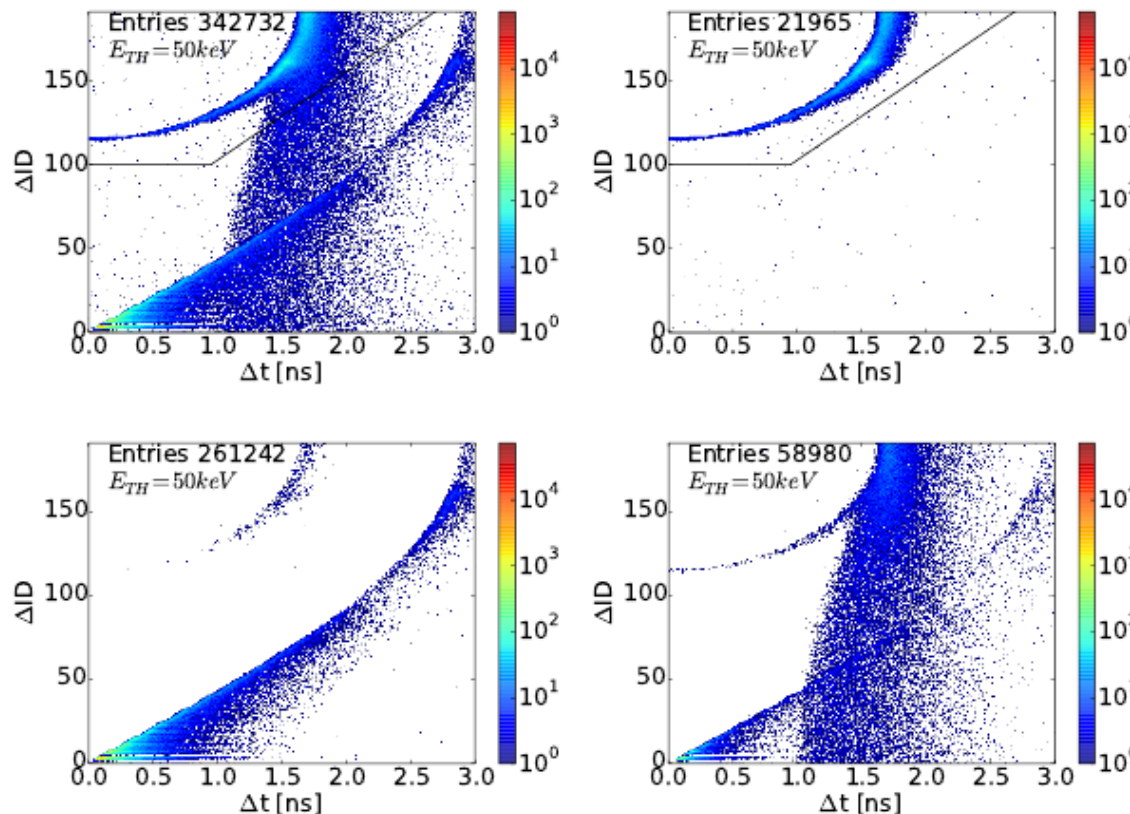
Definitions:

$$Did = \min(|ID1-ID2|, 384-|ID1-ID2|)$$

$$Dt = |t1-t2|$$



0. Introduction



Coincidences for fixed energy threshold equal to 200 keV. Left top – all coincidences, right top – true, left bottom – detector-scattered, right bottom phantom-scattered.

Source moved to the radial distance of 25 cm. Second level selection: $\Delta ID < 100$ and point is below the line connecting points (0 ns, 50) and (2.7 ns, 192). True coincidences lie above this line.

1. Spatial resolution

Spatial resolution – ability of the system to distinguish between two points after image reconstruction

Algorithm of obtaining the Spatial Resolution:

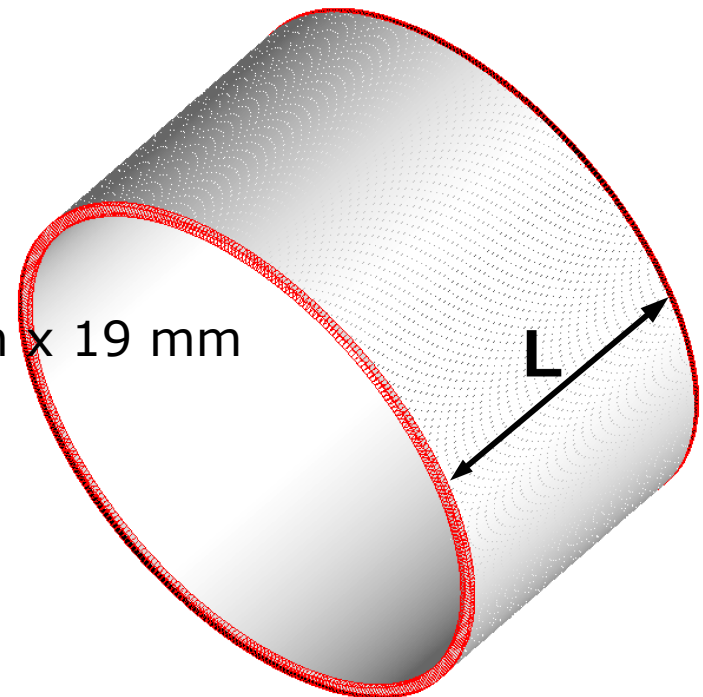
- 1) point source of F18 is located at 6 points inside the Axial Field of View of the system
- 2) at least 100.000 **prompt** counts is acquired in each position
- 3) image reconstruction is performed for each of locations
(algorithm of reconstruction should be FBP [Filtered Back Projection] but actually the used algorithm is MLEM [Maximum Likelihood Estimation Method])
- 4) FWHM is calculated for 1D profiles crossing voxel of the reconstructed image in all three dimensions for each position of the source

1. Spatial resolution

Simulated source: back-to-back gamma quanta with energies 511 keV; shape of source was sphere with radius 0.5 mm; activity 370 kBq (according to the NEMA norm, number of random coincidences was smaller than 5% of all coincidences detected)

Geometry:

- 384 strips with size,
- cross-section of the scintillator 7 mm x 19 mm
- lengths of scintillator strips:
 - 1) $L = 20$ cm
 - 2) $L = 50$ cm
 - 3) $L = 100$ cm



1. Spatial resolution

According to NEMA norm, point source was placed in 6 fixed positions (x,y,z) in cm:

- | | |
|---------------|---------------|
| 1) (1, 0, 0) | 4) (10, 0, a) |
| 2) (1, 0, a) | 5) (20, 0, 0) |
| 3) (10, 0, 0) | 6) (20, 0, a) |

$a = 3/8 * \text{AFOV}$ from the centre of the scanner

*) $L = 20 \text{ cm}$, $a = 7.5 \text{ cm}$

**) $L = 20 \text{ cm}$, $a = 18.75 \text{ cm}$

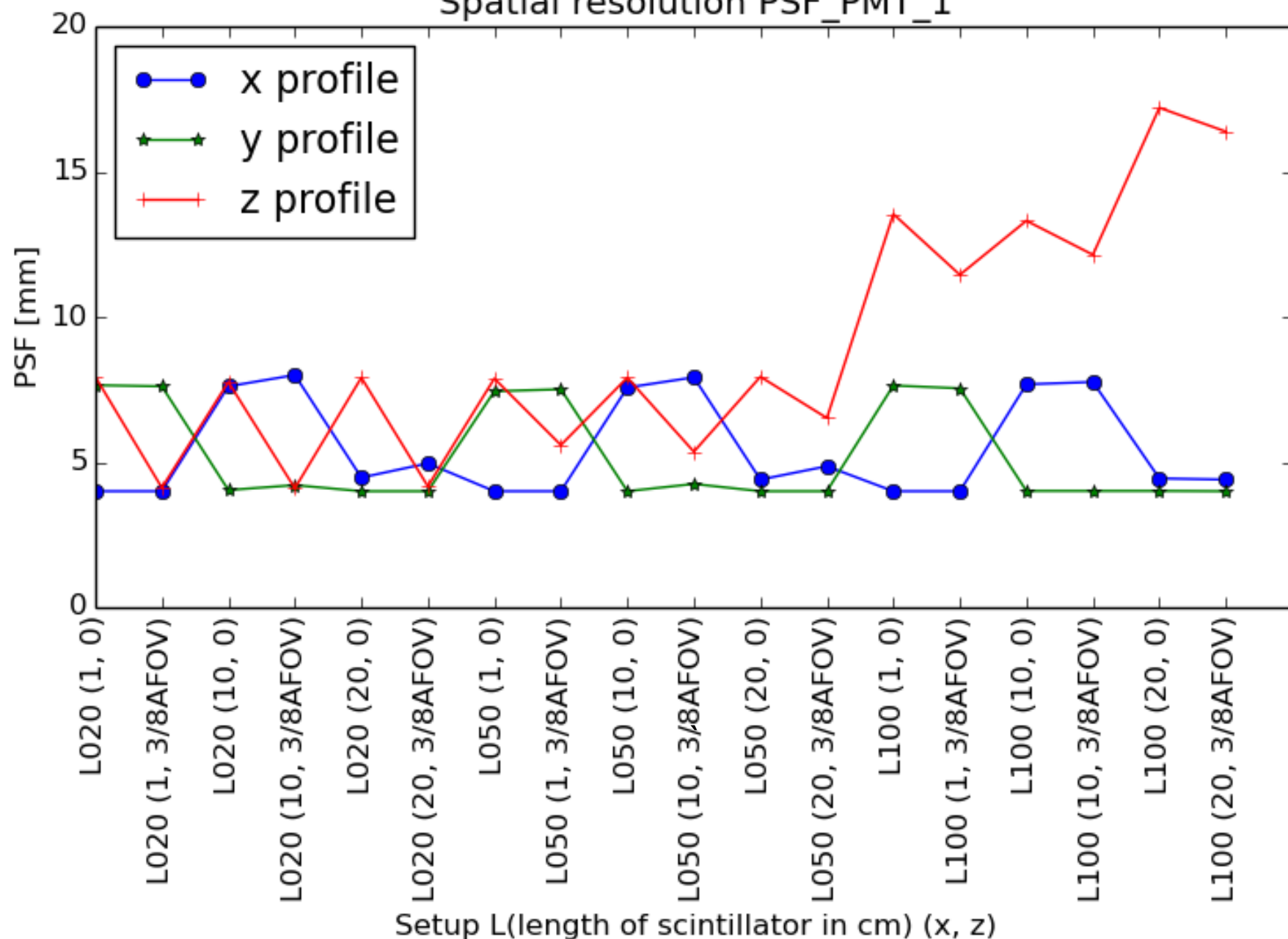
***) 1) $L = 20 \text{ cm}$, $a = 37.5 \text{ cm}$

1. Spatial resolution

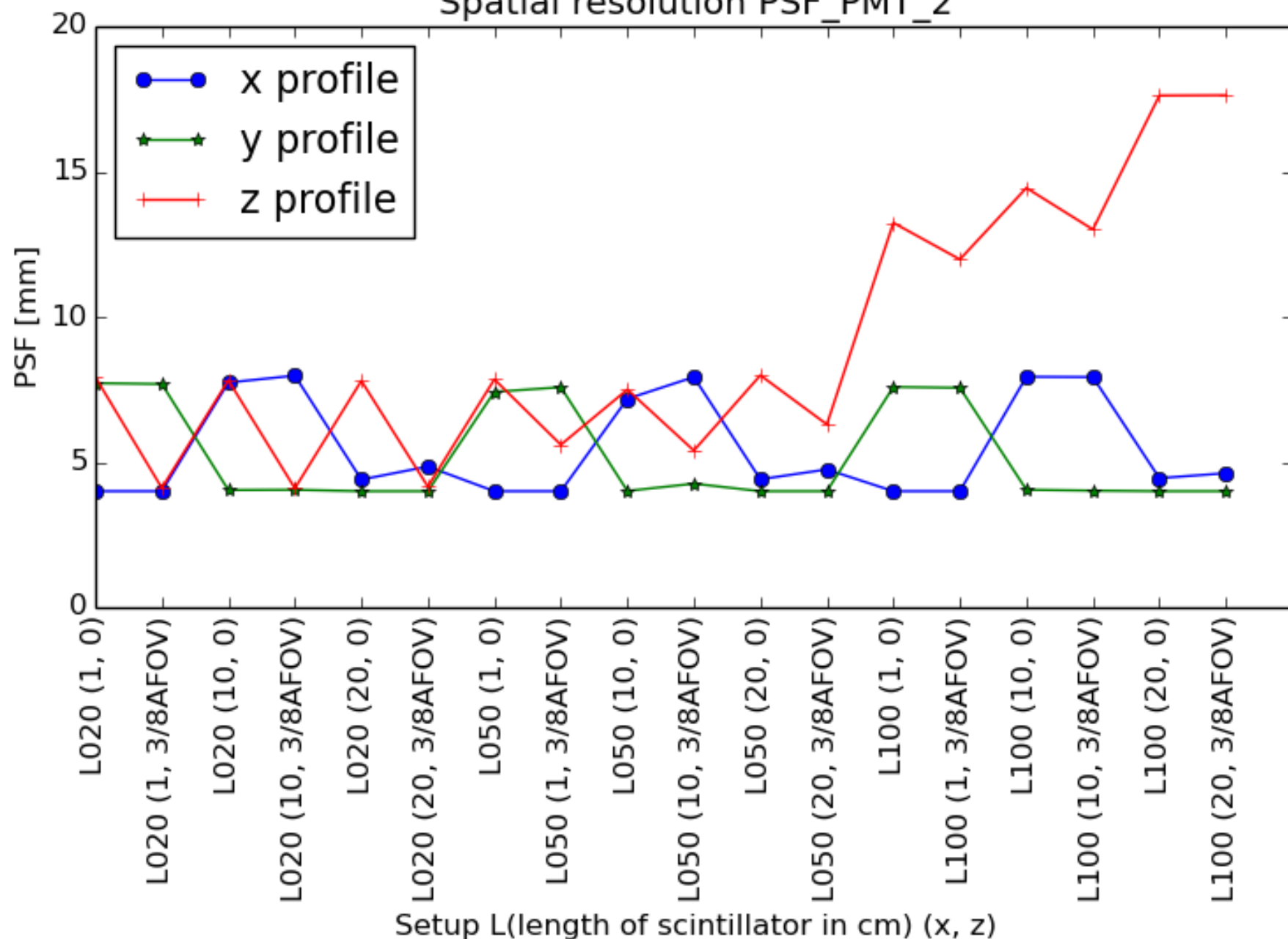
Variants of calculations:

- 1) Different parameters of reconstruction:
 - a) Voxel with size 4 mm, only real true events
 - b) Voxel with size 4 mm, all events selected using criterion based on Did vs. Dt
 - c) Voxel with size 3 mm, all events selected using criterion based on Did vs. Dt
- 2) Different time resolutions CRT (Coincidences Resolving Time) for:
 - a) Photomultiplier R4998
 - b) Silicon photomultiplier
 - c) Theoretical values

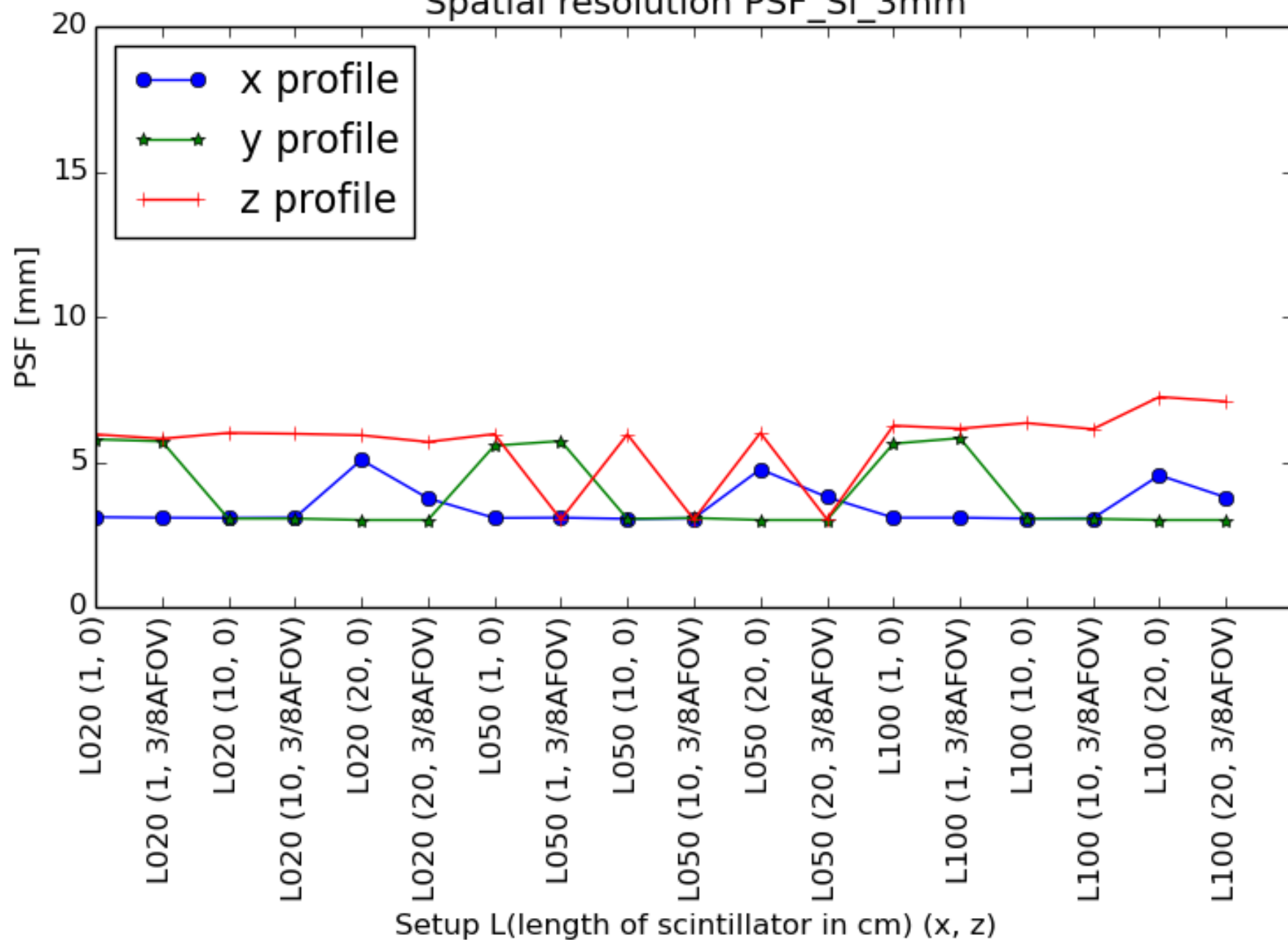
Spatial resolution PSF_PMT_1



Spatial resolution PSF_PMT_2



Spatial resolution PSF_Si_3mm



2. Scatter Fraction

Scatter Fraction (SF, pol. *frakcja rozproszeniowa*) –
a dimensionless ratio of scattered coincidence events
to the sum of scattered and true coincidence events in
a defined region of interest (ROI) in the scanner's field
of view (Definition from NEMA norm)

$$SF = S/(S+T)$$

S – number of scattered coincidences

T – number of true coincidences

2. Scatter Fraction

In the J-PET scanner there are not only coincidences scattered in the phantom but also scattered in the scintillating strips.

Types of coincidences:

true – true coincidence

psca – phantom-scattered coincidence

dsca – detector-scattered coincidence

acci – accidental coincidence

$$\text{SF1} = \text{psca} / (\text{true} + \text{psca})$$

$$\text{SF2} = (\text{psca} + \text{dsca}) / (\text{true} + \text{psca} + \text{dsca})$$

2. Scatter Fraction

Details of measurements from the NEMA norm:

1. Phantom – solid cylinder composed of polyethylene with a gravity 0.96 ± 0.01 , outside diameter 203 ± 3 mm, length 700 ± 5 mm; hole with diameter 6.4 mm is drilled parallel to the central axis of the cylinder at a radial distance of 45 mm
2. Source – line source; polyethylene tube with diameter 4.8 mm filled with a known activity
3. Data collection – 500.000 counts
4. Data Processing using analysis of sinograms



2. Scatter Fraction

Algorithm of obtaining the Scatter Fraction:

- 1) Space inside the detector is divided into N virtual slices
- 2) Oblique sinograms (N^2) are obtained for all combinations between each pair of virtual slices
- 3) Single Slice Rebinning (SSRB) algorithm is used to obtain $2N-1$ rebinned sinograms
- 4) All rebinned sinogram are summed
- 5) For the summed sinogram all projections are aligned to put maximum values at zero and they are summed
- 6) After summing, values of obtained profile at distances ± 2 mm from zero are calculated
- 7) The area of the profile over the line crossing two points at ± 2 mm is treated as true coincidences, below this line as scattered coincidences

2. Scatter Fraction

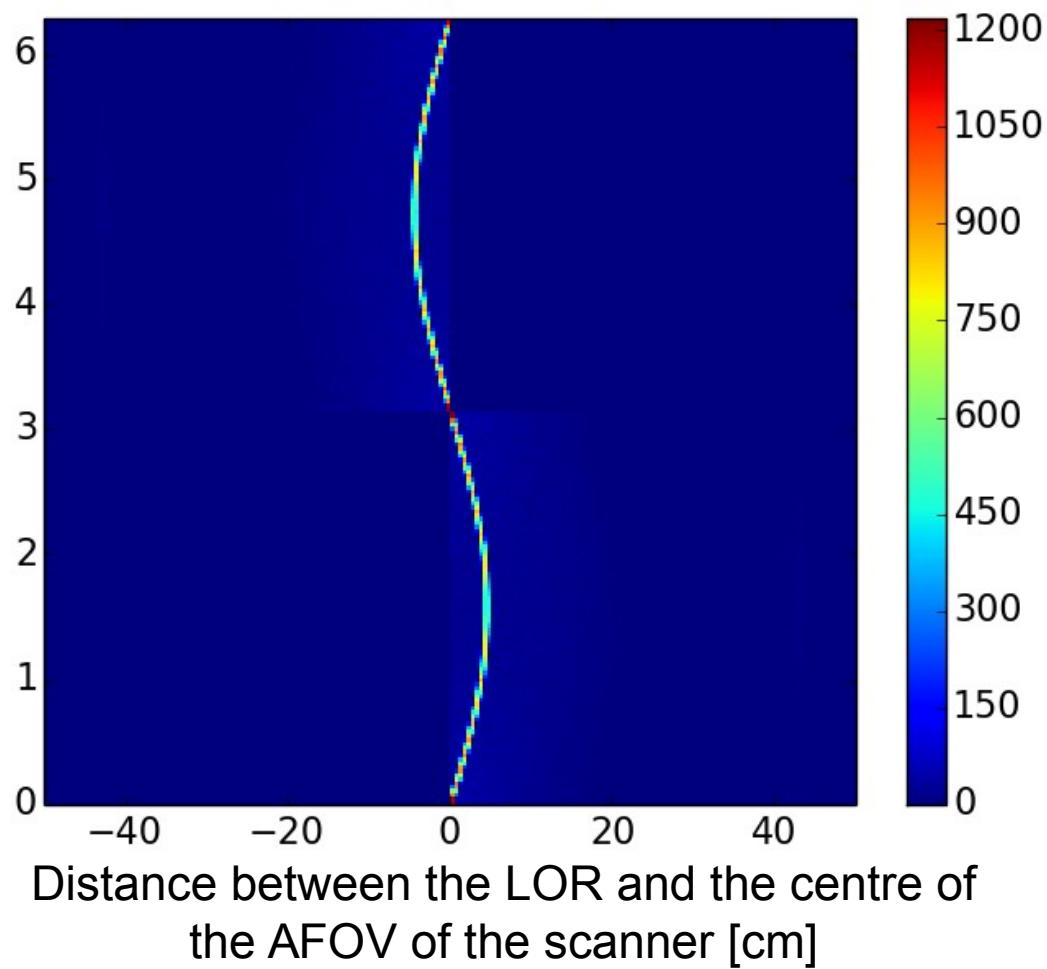
Details of simulation:

- geometry of 384-strip scanner (1 layer with radius 437.3 mm; size of single strip: 7 mm x 19 mm x 500 mm)
- linear source of back-to-back gamma quanta with energy 511 keV

2. Scatter Fraction

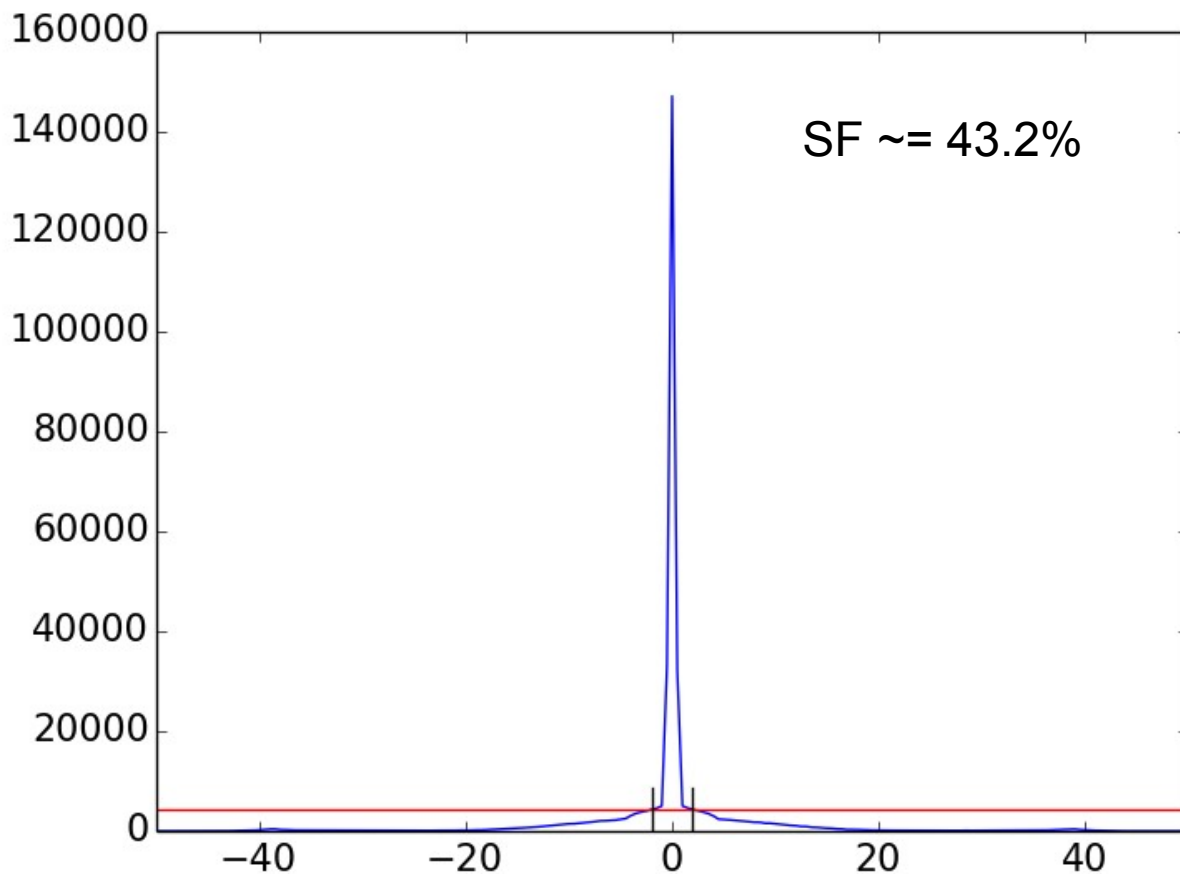
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Angle between
the LOR and
the x axis
[radians]



FINAL
SUMMED
SINOGRAM

2. Scatter Fraction



Distance between the LOR and the centre of
the AFOV of the scanner [cm]

2. Scatter Fraction

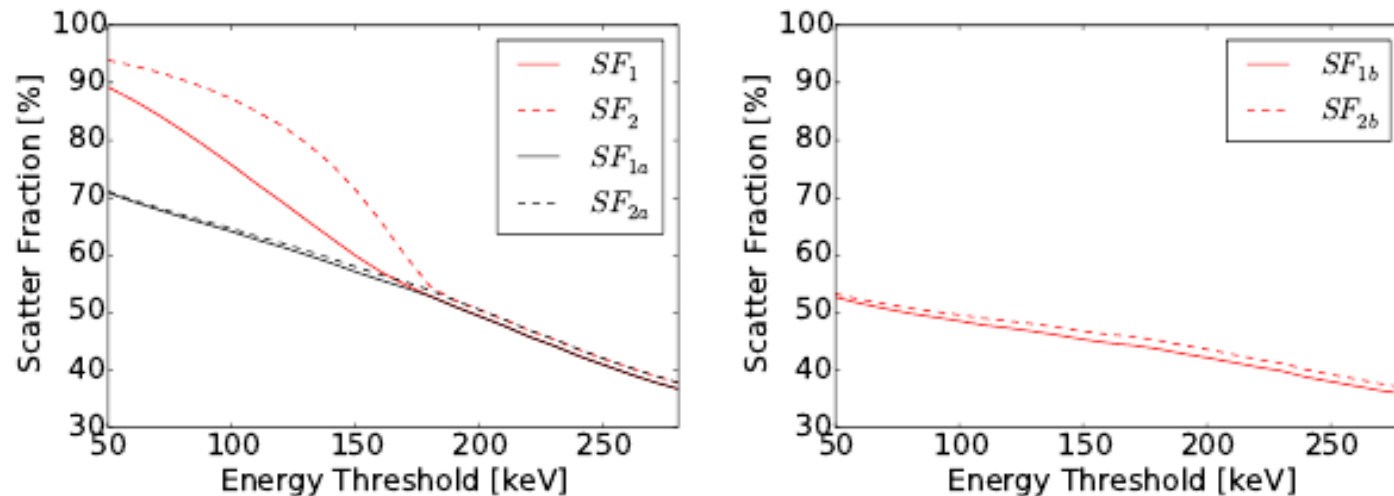


Fig. 5: Scatter fraction of the 384-strip J-PET detector as a function of energy threshold calculated using uncut data from GATE simulation. The left panel shows the dependencies of scattered fraction calculated after the first level selection (lines SF_1 and SF_2) and after the second level selection using a ΔID vs Δt correlation (lines SF_{1a} and SF_{2a}). The SF determined based on the NEMA norm (lines SF_{1b} and SF_{2b}) are shown in the right panel. More detailed description in the text. The result shown is based on 10^8 simulated annihilations.

3. Sensitivity

Sensitivity of a positron emission tomograph is expressed as the rate in counts per second that true coincidence events are detected for a given source strength

In simulation we can use simple linear source:

- linear with length 50 cm in the centre of the Axial Field Of View

Then Sensitivity may be calculated as:

$$\text{Sensitivity} = T/\text{time}/\text{activity}$$

3. Sensitivity

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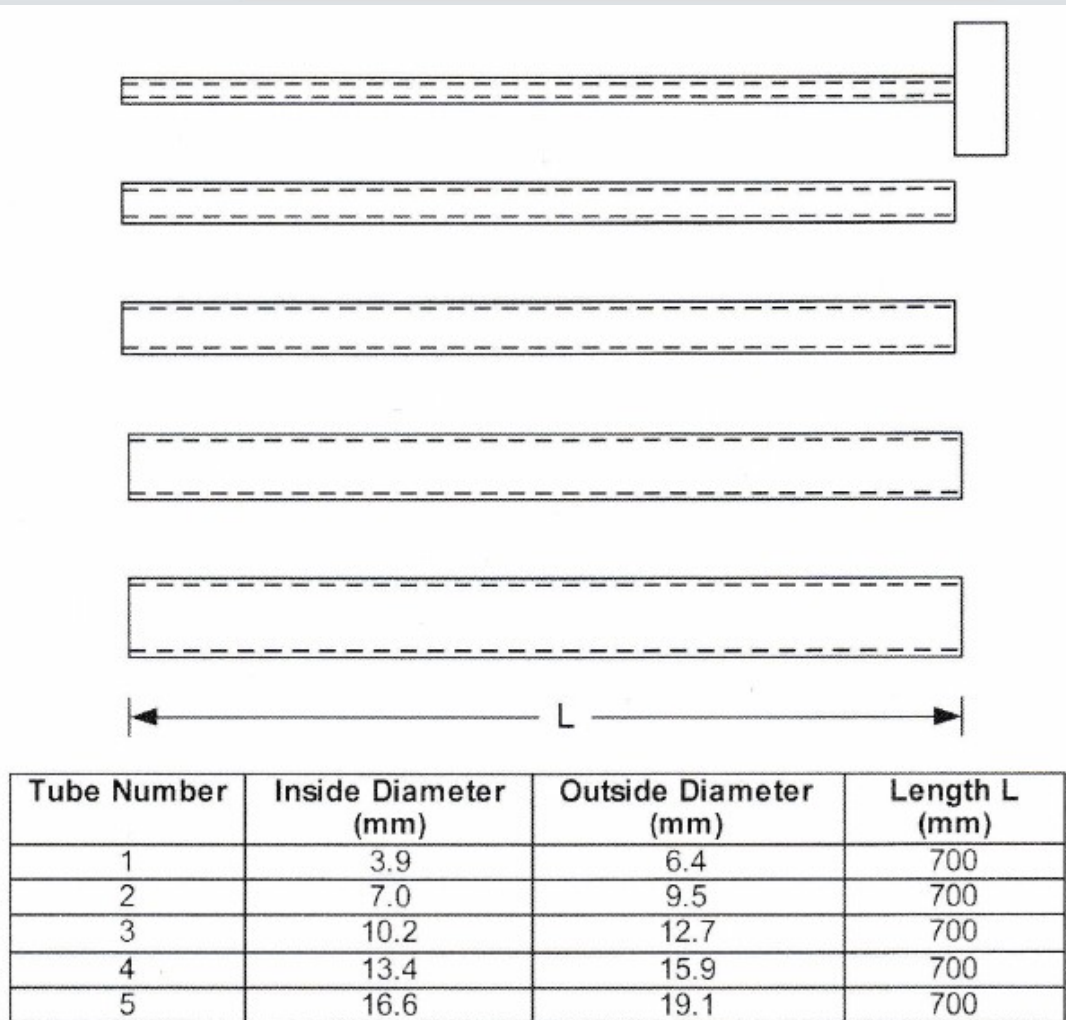
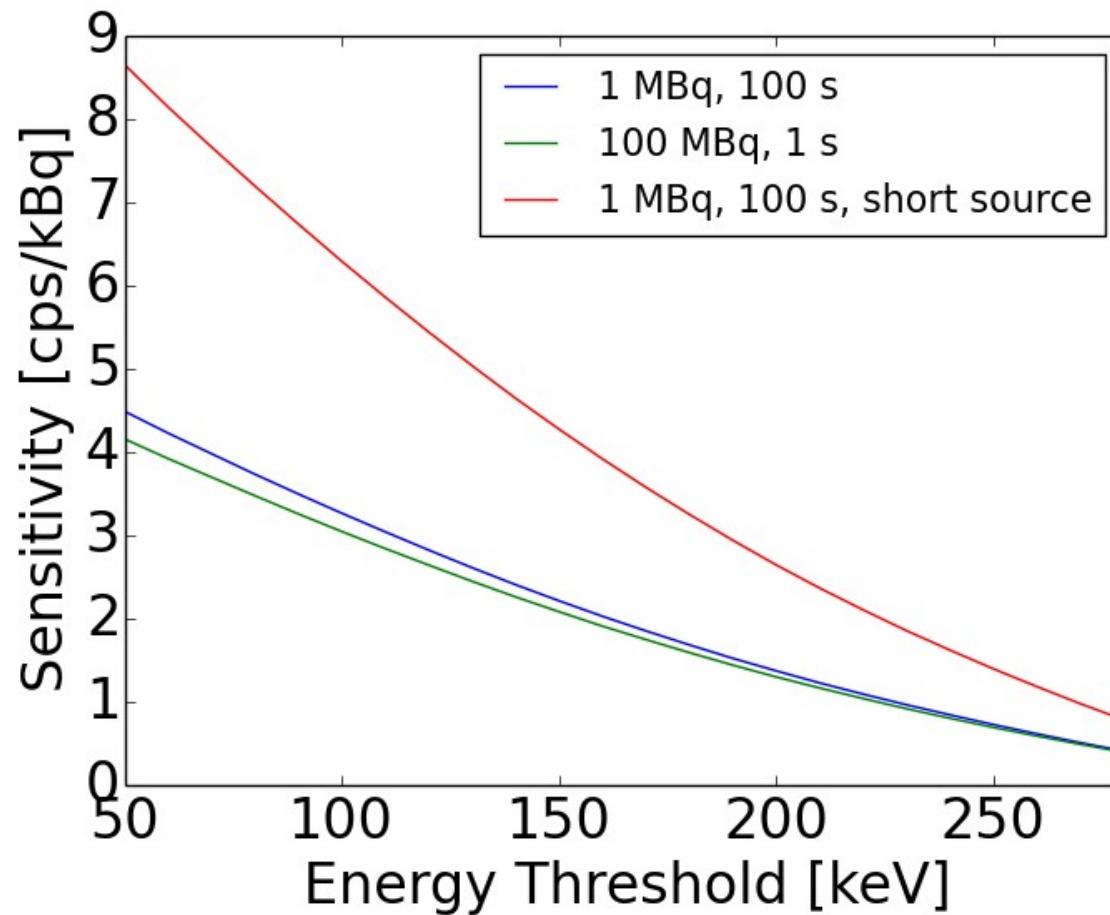


Figure 5-1
SENSITIVITY MEASUREMENT PHANTOM

3. Sensitivity



Summary

Comparison to commercial PET scanners:

PET SCANNER	Spatial Resolution	Scatter Fraction	Sensitivity
GE Discovery	About 5 mm	34% in 3D mode	8.8 cps/kBq
Philips Gemini	About 5 mm	27% to 45%	7 cps/kBq
Siemens Biograph	About 5 mm	31% to 34%	4.2 cps/kBq
384-strip J-PET	About 4-8 mm in x,y direction, 13 mm in z direction (3 layers)	About 45% for energy threshold 200 keV (1 lay, 384 str)	1.5 to 2.5 cps/kBq (1 lay, 384 str)

Thank you for
your attention

Accidental coincidences

Ratios between true and accidental coincidences for time window 3 ns and minimum difference between IDs of the hit scintillator strips equal to 96

