INNOVATIVE ECONOMY
NATIONAL COHESION STRATEGY

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3D reconstruction of point-like sources in a J-PET scanner using total variation regularization

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(J-PET collaboration)

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Agenda:

- Analytic image reconstruction algorithms:
  - TOF back-projection total variation (TV) regularization
  - TOF filtered back-projection (reference method)
- Measurement of 6 point-like sources in 3 layer J-PET scanner
- Results:
  - evaluation of spatial resolution
  - estimation of computational cost

1. TOF back-projection TV regularization (TOF-BPTV)

Subsequent steps of the proposed algorithm:

- List-mode data pre-correction

- TOF back-projection

- Reconstruction with regularization

1. TOF back-projection TV regularization (TOF-BPTV)

Subsequent steps of the proposed algorithm:

- **List-mode data pre-correction** : **randoms and scatter**
  detector efficiency
  attenuation factors

- TOF back-projection

- Reconstruction with regularization

1. TOF back-projection TV regularization (TOF-BPTV)

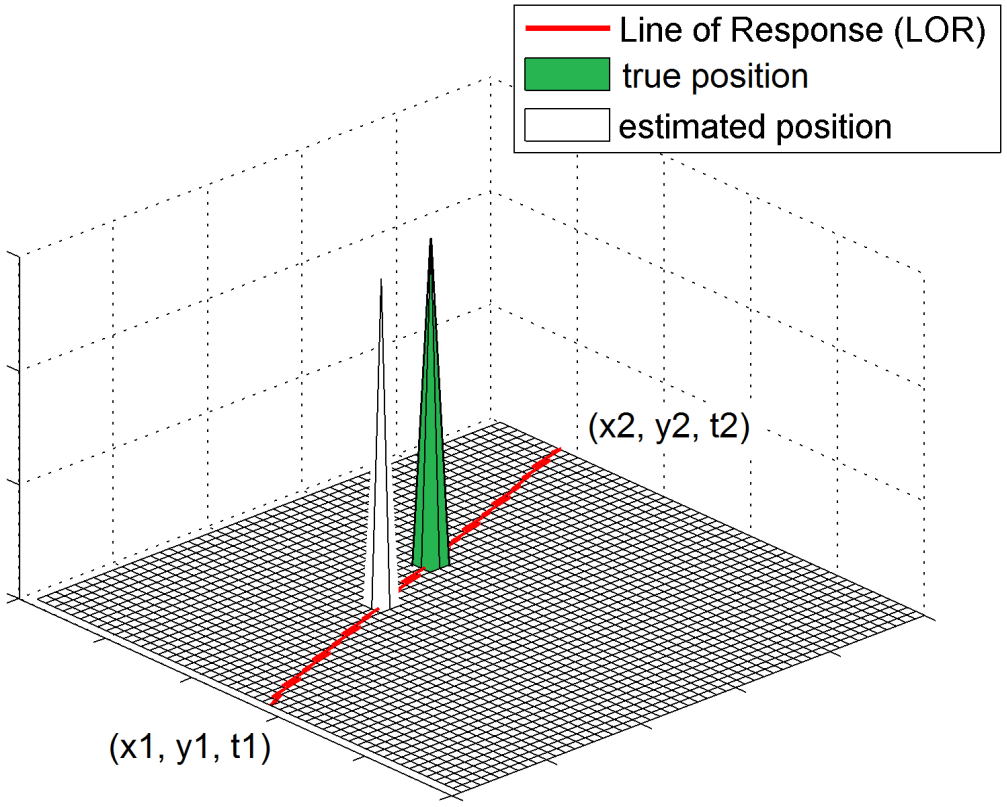
Subsequent steps of the proposed algorithm:

- List-mode data pre-correction

- **TOF back-projection**

- Reconstruction with regularization

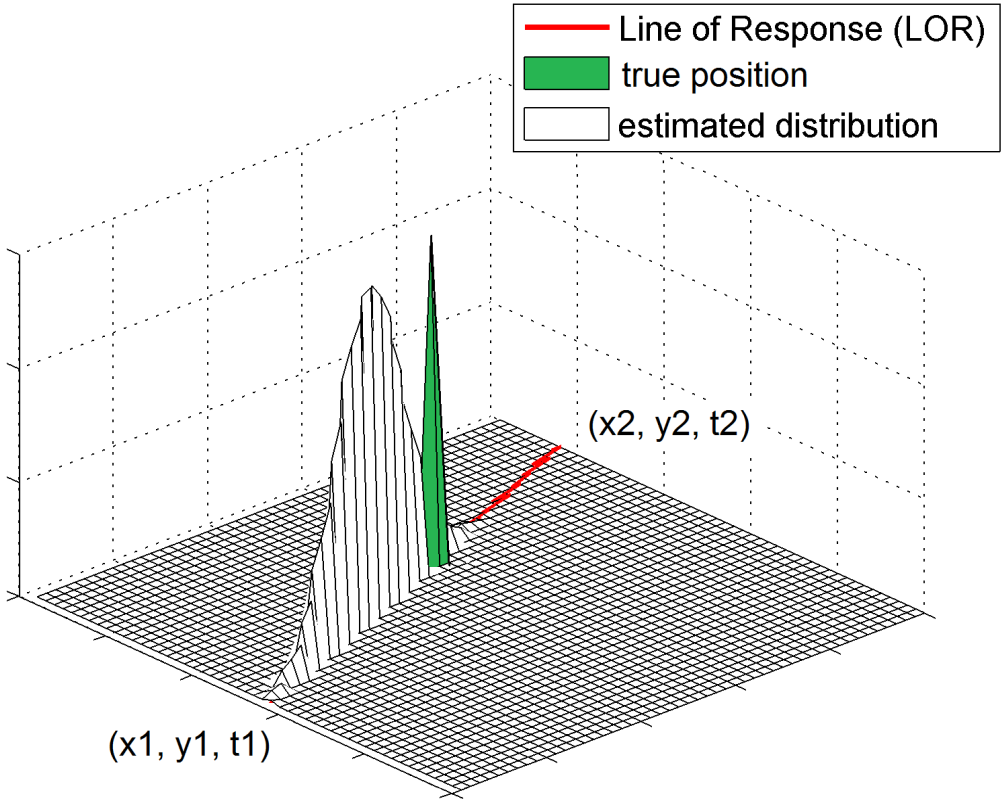
1. TOF back-projection TV regularization (TOF-BPTV)



2-dimensional image space (example)

- TOF information allows us to estimate the position along LOR

1. TOF back-projection TV regularization (TOF-BPTV)



2-dimensional image space (example)

- TOF information allows us to estimate the position along LOR
- We may include the distribution along LOR (TOF kernel) in calculation of TOF back-projected image

1. TOF back-projection TV regularization (TOF-BPTV)

- Deposition of corrected data into TOF back-projected image $\mathbf{b}$; formulation of filtering problem:

$$\mathbf{b} = A\mathbf{f}$$

$\mathbf{f}$: unknown image

A : overall TOF forward and back-projection operator

* bold symbols $\mathbf{b}$ and $\mathbf{f}$ represent the vectorized versions of 3-dimensional images.

** matrix A is finite-dimensional sampling of original operator

1. TOF back-projection TV regularization (TOF-BPTV)

Subsequent steps of the proposed algorithm:

- List-mode data pre-correction

- TOF back-projection $\mathbf{b} = A\mathbf{f}$

- **Reconstruction with regularization**

1. TOF back-projection TV regularization (TOF-BPTV)

- Total Variation (TV) norm of an image can be defined as:

$$\mathrm{TV}(\mathbf{f}) = \sum_i |D_i \mathbf{f}|$$

D : first-order forward finite-difference operator

- Image $\mathbf{f}$ is reconstructed by solving regularization problem:

$$\min_{\mathbf{f}} \ \mathrm{TV}(\mathbf{f}) + \frac{\mu}{2} \|A\mathbf{f} - \mathbf{b}\|_2^2$$

μ : regularization parameter

2. Measurement in 3 layer J-PET scanner

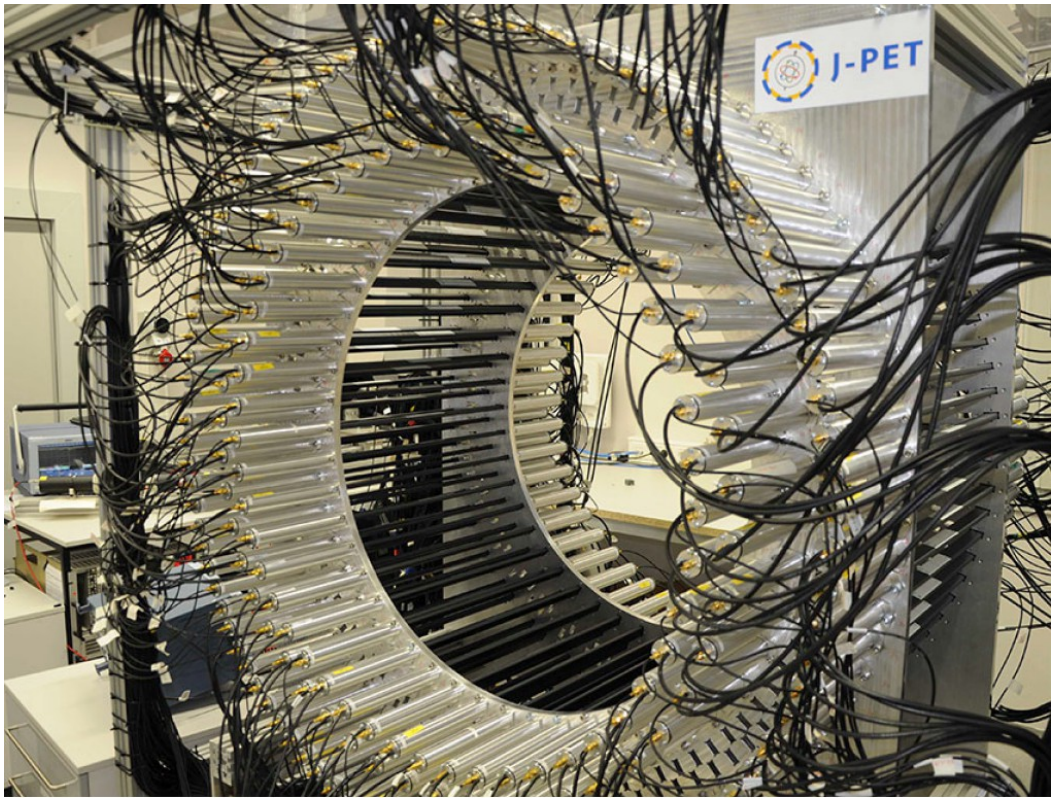
<u>Experimental setup:</u>

Number of layers: 3

Number of strips: 192

Detector length: 50.00 cm

CRT: 500 ps



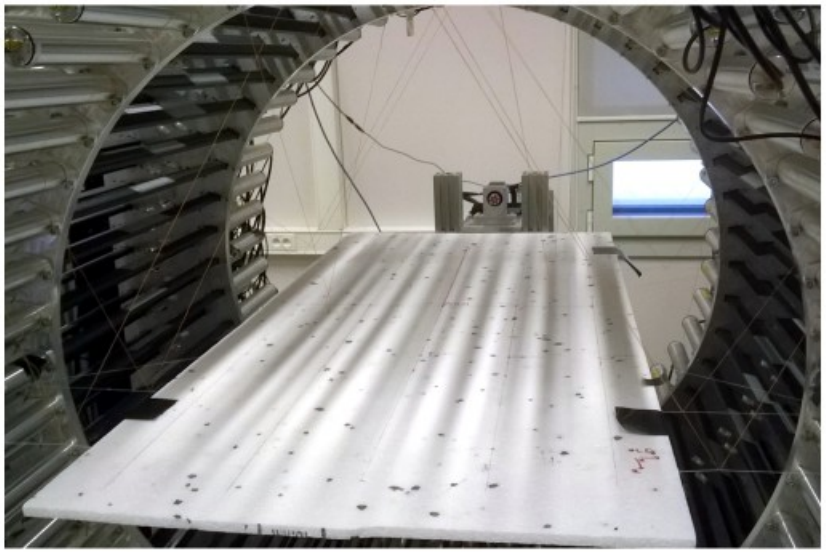
<u>Number of true events:</u>

11.2 million

<u>Voxel size:</u>

x: 4.0 mm, y: 4.0 mm, z: 4.0 mm

2. Measurement in 3 layer J-PET scanner

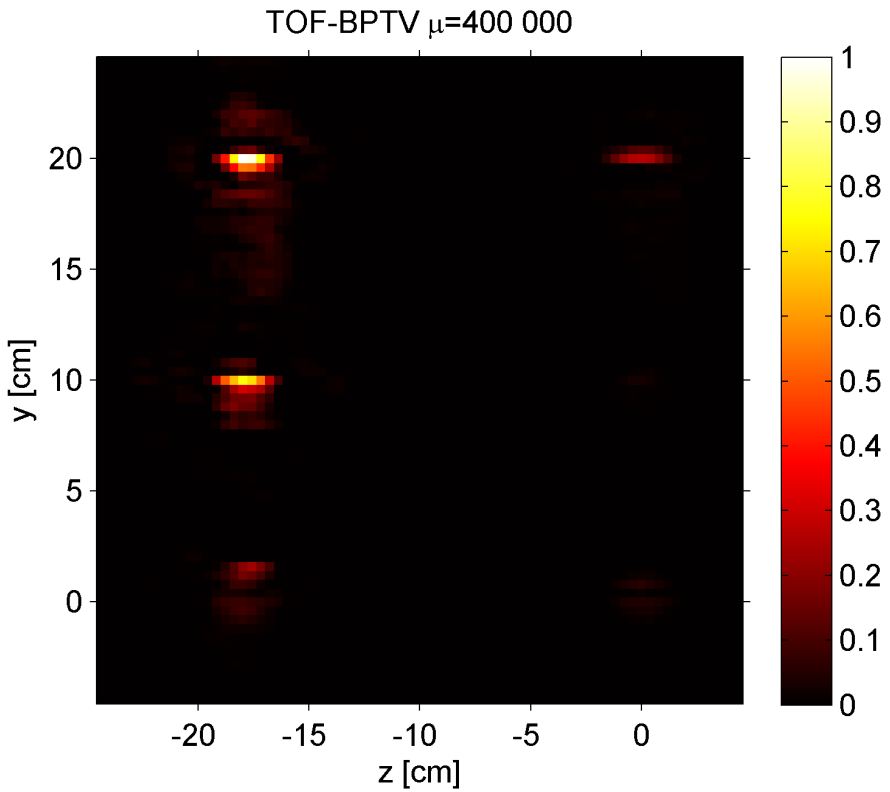


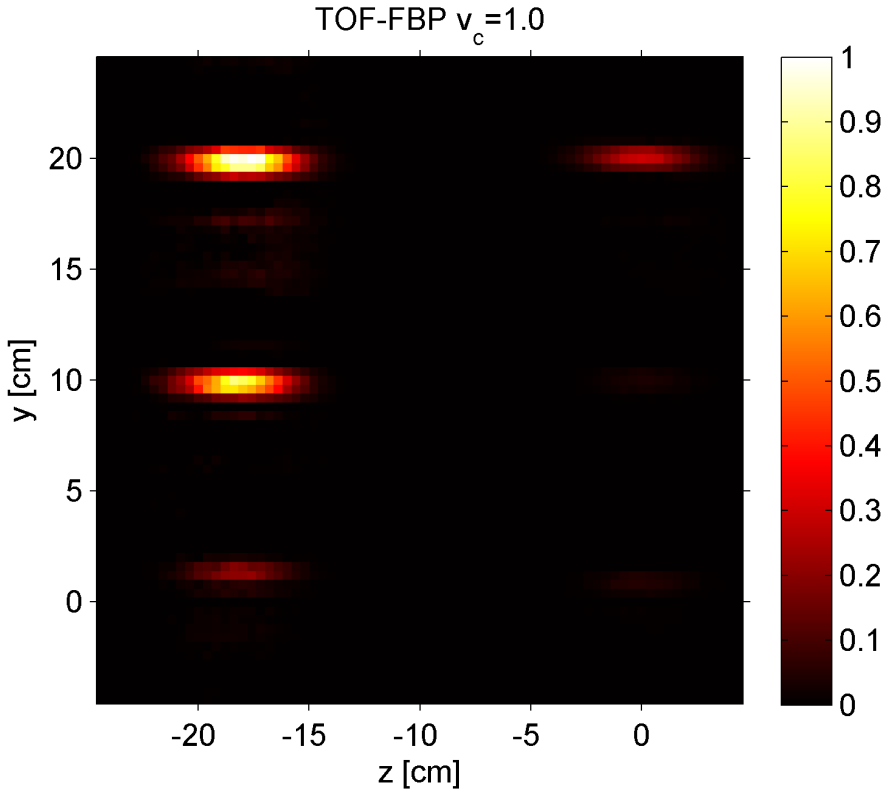
6 sources used in the measurements: serial number (1st column), position in detecting chamber (2nd column) and activity (3rd column).

Source	Position [cm]	Activity [kBq]
37/12	(0,1,0)	204
39/12	(0,10,0)	207
UR450	(0,20,0)	1134
UR451	(0,1,-18.75)	1131
K4-390	(0,10,-18.75)	6198
L2-295	(0,20,-18.75)	7601

- Required corrections:
  - detector efficiency
  - randoms
- Small probability for photons scattering and attenuation (point-like sodium sources were placed on the styrofoam panel)

3. Results: spatial resolution





- Reconstructed images:
  (activity in linear scale)

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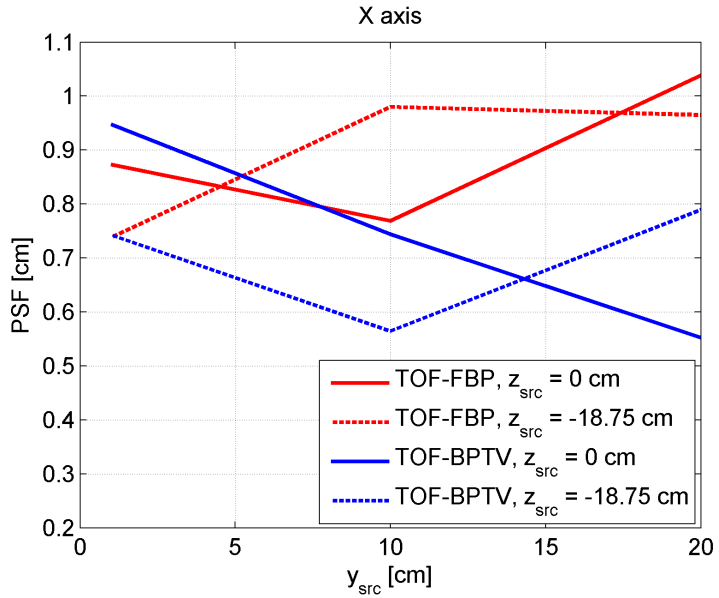
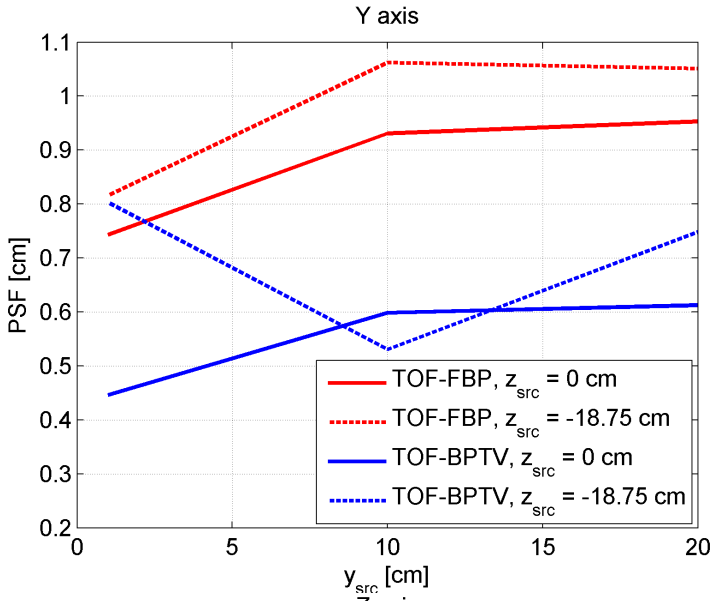
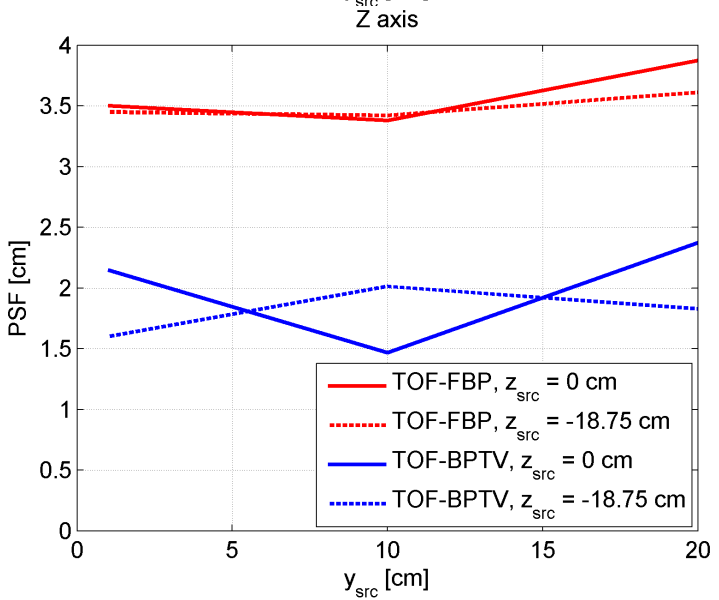
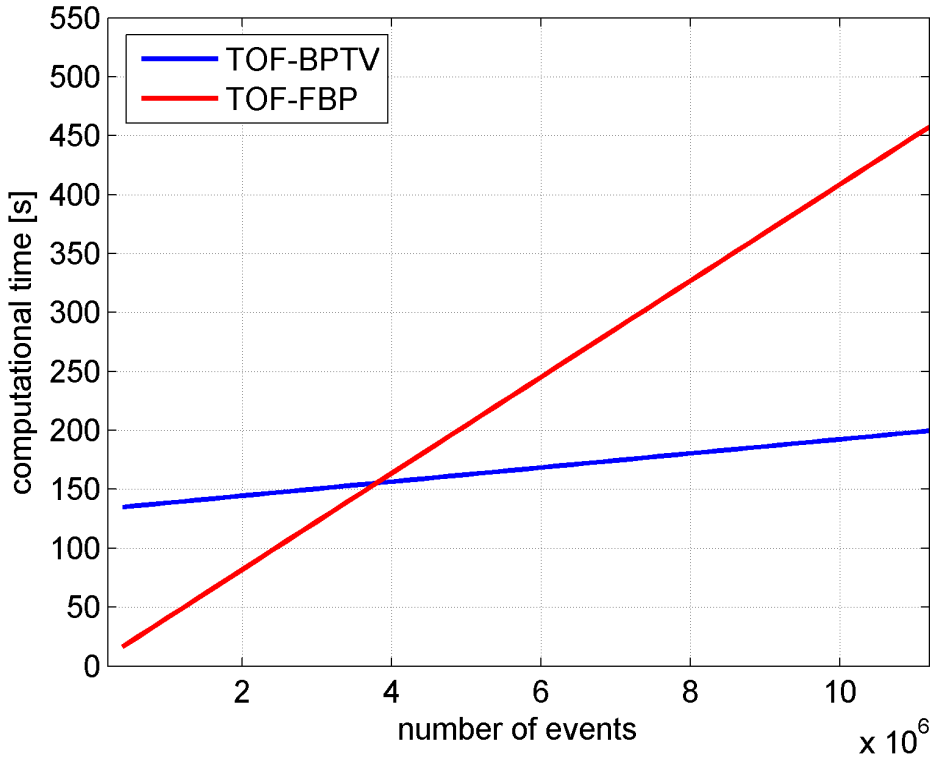






- PSF(x,y,z) values for optimal regularization parameters for both methods
- Much better PSF in z axis for TOF-BPTV than TOF-FBP

4. Results: computational time



For a set of more than 4 million events TOF-BPTV is faster than TOF-FBP

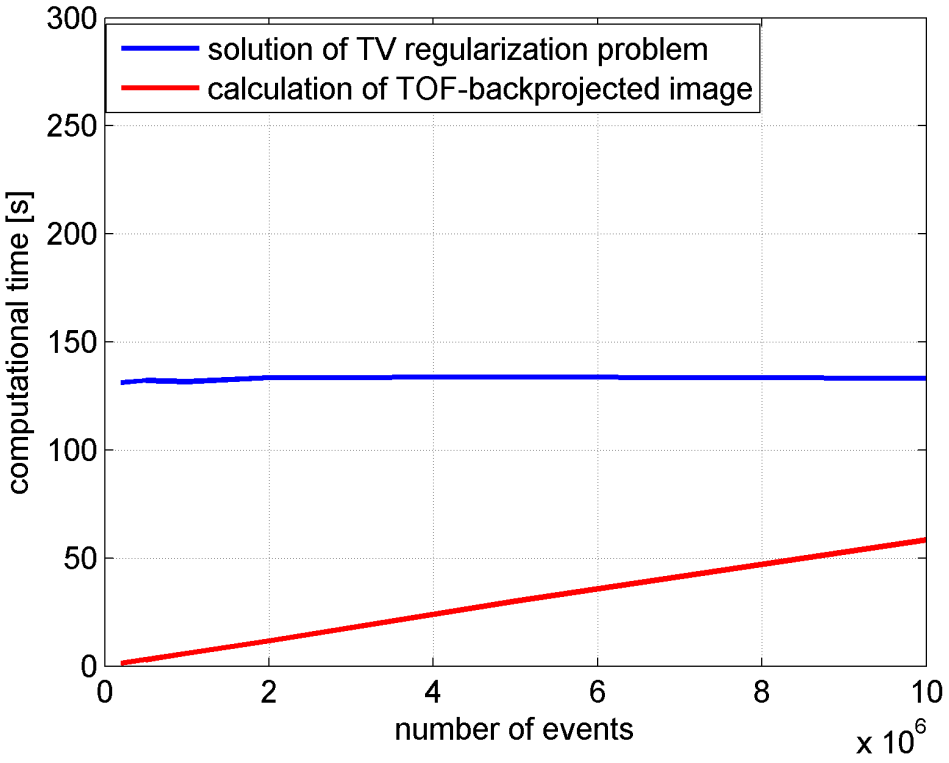
Comparison of computational time of TOF-BPTV and TOF-FBP methods

Reconstructed area:
x,y,z: -24.4 cm; +24.4 cm

Voxel size:
x,y,z: 4.0 mm

Image size:
123 x 123 x 123

4. Results: computational time



Computational time of both stages in TOF-BPTV method

TOF-BPTV method consists of two stages:

1) calculation of TOF back-projected image $(\mathbf{b})$

2) solving of TV problem

$$\min_{\mathbf{f}} \ \mathrm{TV}(\mathbf{f}) + \frac{\mu}{2}\|A\mathbf{f} - \mathbf{b}\|_2^2$$

Time of solving TV problem is independent of number of events.

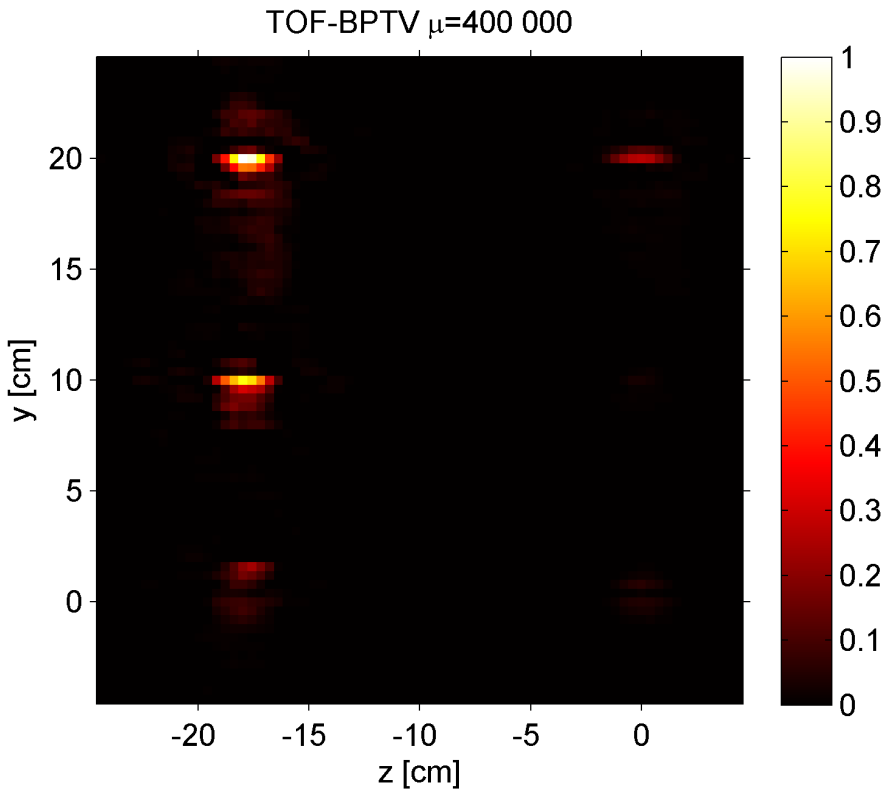
Summary

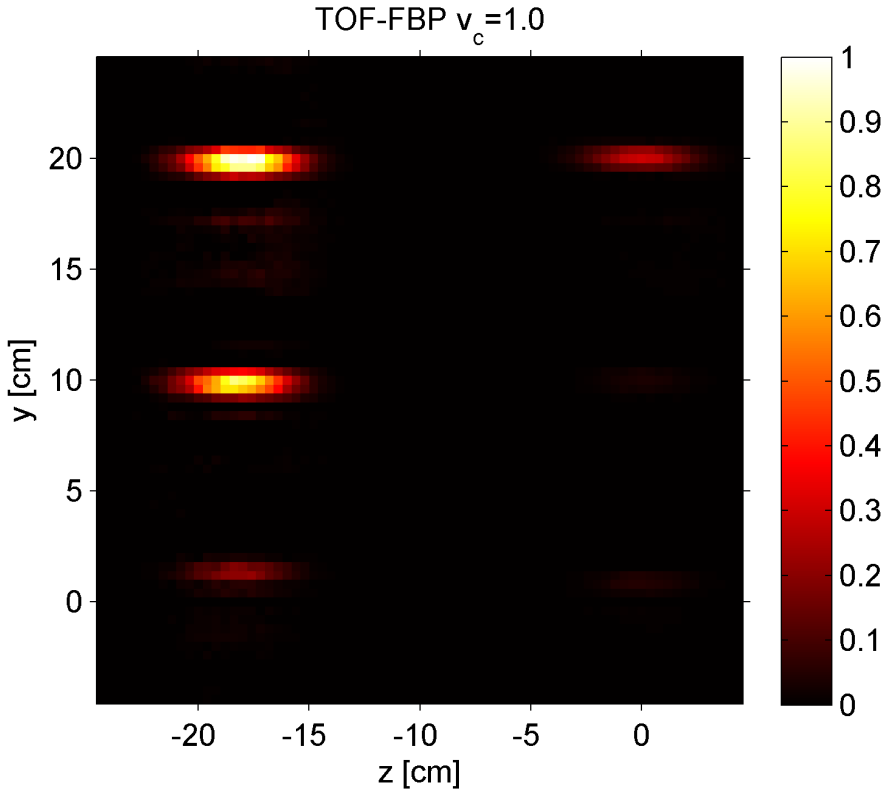
- The spatial resolution of the J-PET scanner was determined by estimation of full width half maximum in three directions of PSF images at six position inside the scanner volume.

- The comparison results shown superior spatial resolution of reconstructed images from the proposed TOF-BPTV method in respect to the TOF-FBP algorithm.

- Simultaneously, reconstruction time in proposed technique was approximately 2.2 times shorter than required by reference method (for full dataset with 11 million events).

3. Results: spatial resolution





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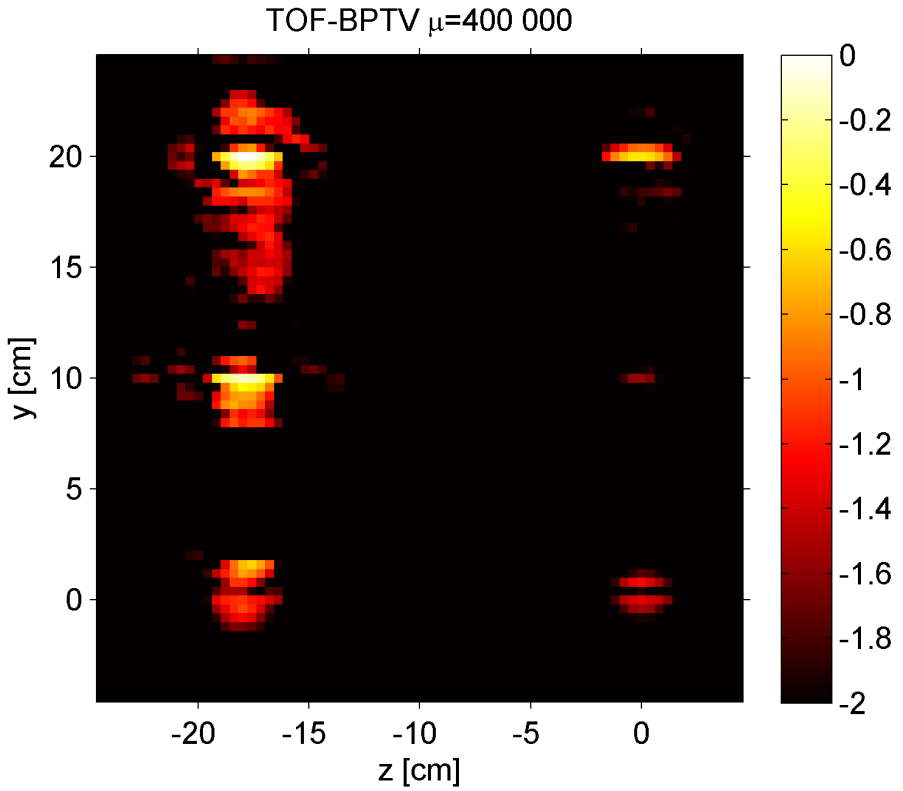

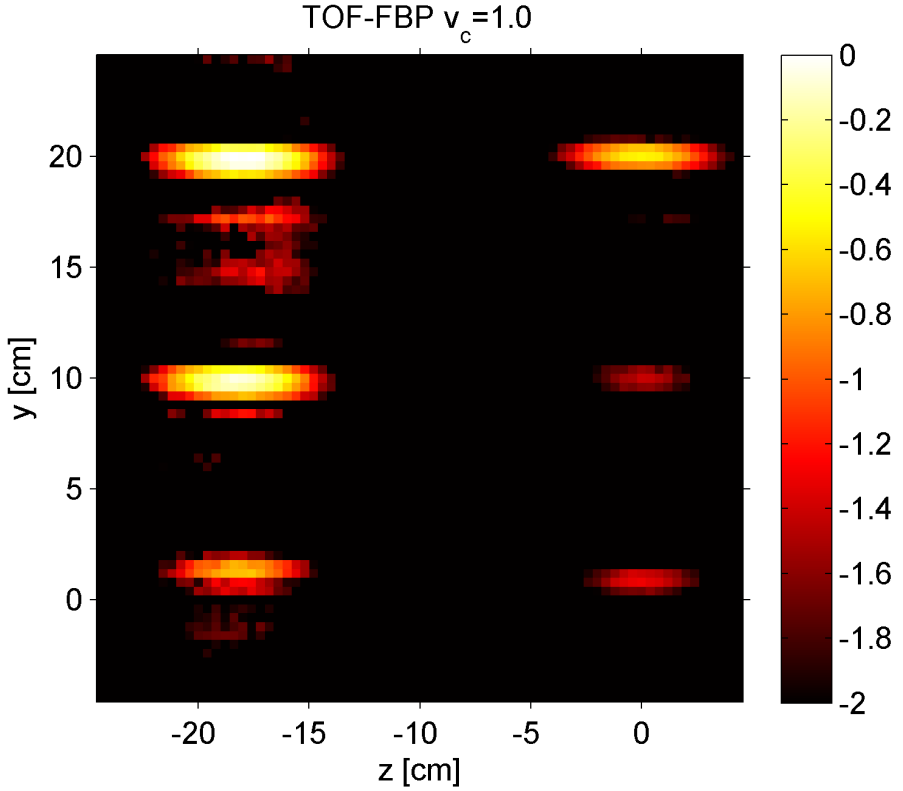

- Reconstructed images:
  (activity in logarithmic scale)

Source	Position [cm]	Activity [kBq]
37/12	(0,1,0)	204
39/12	(0,10,0)	207
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