

Commissioning of the EndoTOFPET-US detector

An Asymmetric Time of Flight Positron Emission Tomograph

Ole Brandt¹ and Yonathan Munwes²

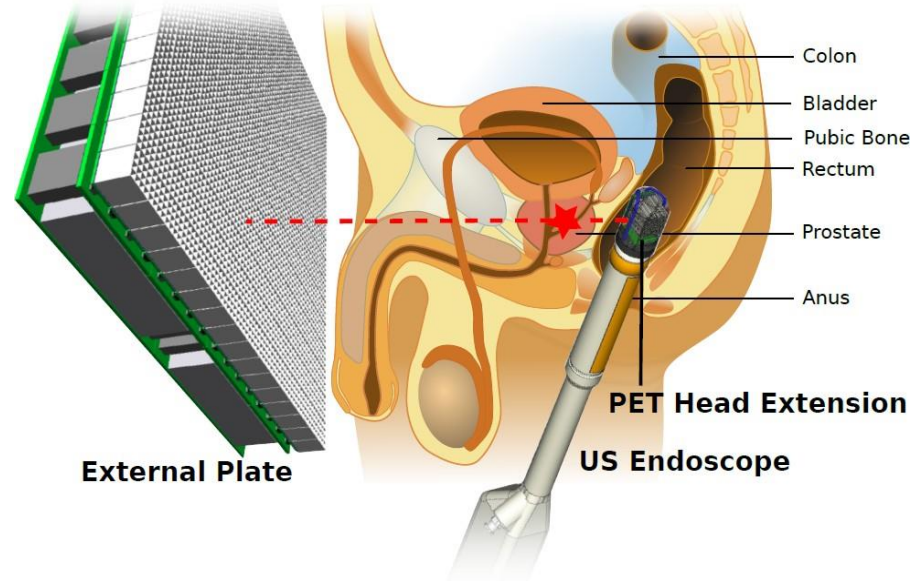
¹ University of Hamburg, Desy

² Kirchhoff Institut für Physik

EndoTOFPET-US

Endoscopic Time of Flight Positron Emission Tomography and Ultra Sound (EndoTOFPET-US):

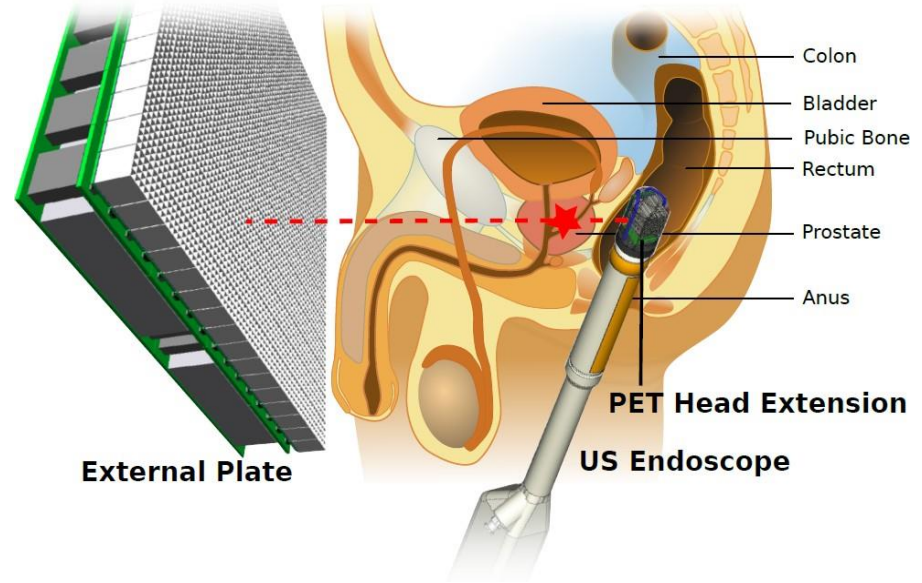
- EU funded project in the FP7 frame
- Development of new biomarkers for pancreas carcinoma
- Intra-operative guidance during prostate surgery
 - Real time imaging



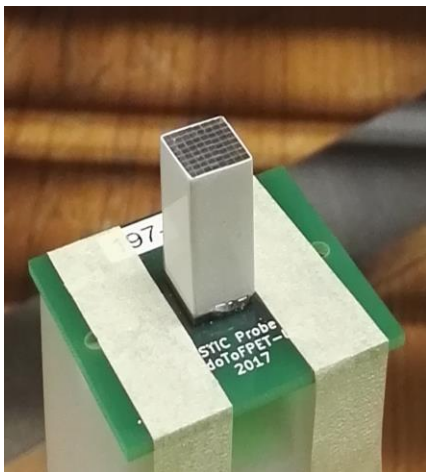
EndoTOFPET-US

Endoscopic Time of Flight Positron Emission Tomography and Ultra Sound (EndoTOFPET-US):

- PET head close to organ under study (reduce background, enhance spatial resolution)
- Plate can be freely moved during acquisition, endoscope can be rotated

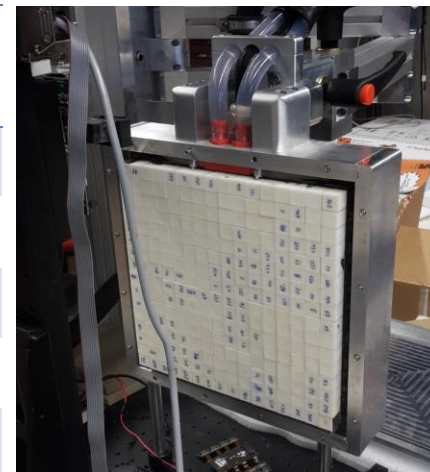


EndoTOFPET-US: Detector



Endoscopic head prototype

	Endoscopic head (prototype)	External plate
Active area	9.6 x 9.6 mm ²	~20 x 20 cm ²
Modules	1	256
# of channels	64	4096
Crystal size	1.2 x 1.2 x 15 mm ³	3.5 x 3.5 x 15 mm ³
Crystal type	LYSO	LYSO
SiPM	S13615-1050PE	S12643-050CN

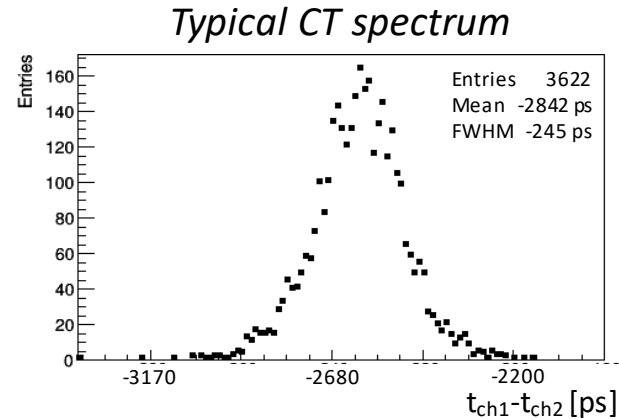
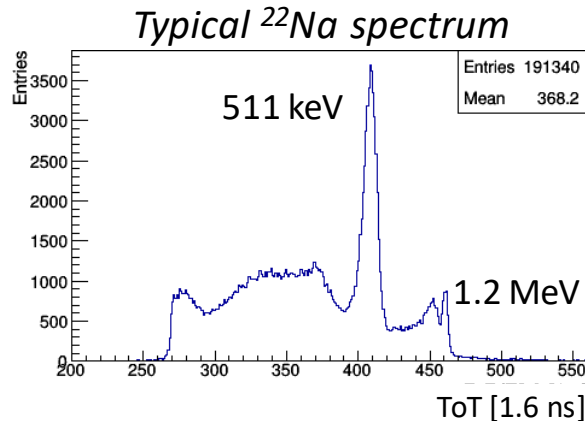


External plate

Analog readout: Silicon Photomultiplier Timing Chip (STiC)
Digital: Daisy chained digital frontend boards

STiC readout ASIC

- Silicon photomultiplier Timing Chip (UMC 180 nm CMOS technology)
- 64 channel ASIC
- Provide picosecond time resolution (single time threshold)
- Energy determined by Linearized time over threshold method

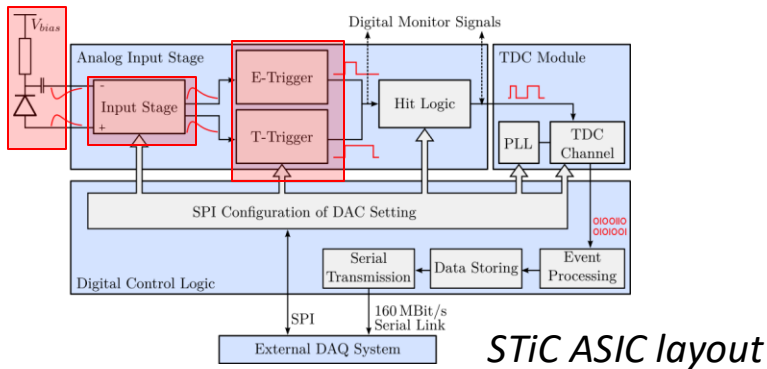


"A Silicon Photomultiplier Readout ASIC for Time-of-Flight Applications Using a New Time-of-Recovery Method,"
in IEEE Transactions on Nuclear Science, vol. 65, no. 5, pp. 1196-1202, May 2018.

Online Coincidence Time Resolution optimization

- Three main readout parameters responsible for the time resolution:
 - SiPM bias voltage
 - Time threshold
 - Input impedance of the chip
- ~82000 possibilities for each channel →
Brute force scan takes ~4 days per channel

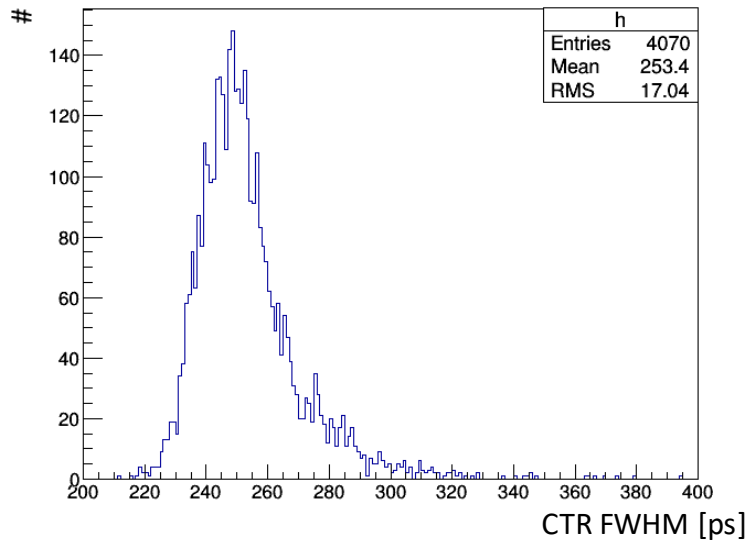
- Optimized using Nelder-Mead method:
 - Numerical method to find minimum of multidimensional function
 - Highly versatile and stable on complex functions



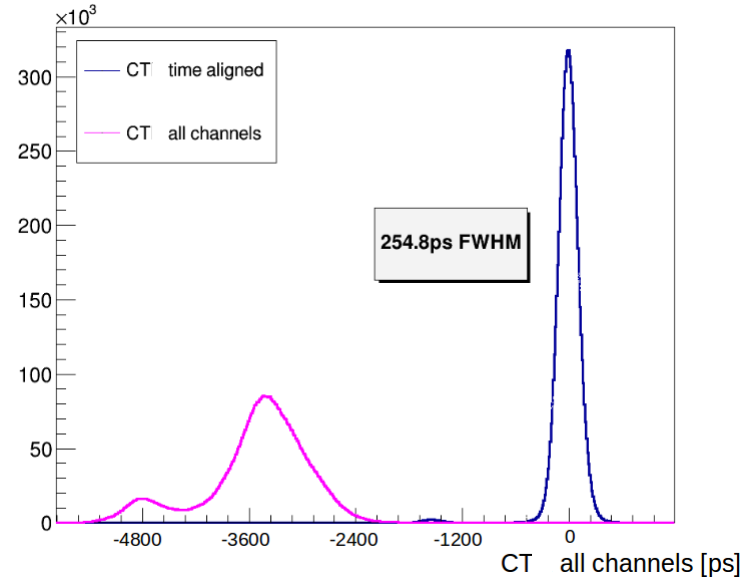
CTR optimization setup

Coincidence Time Resolution optimization: Results

4070 channels calibrated
Mean $\text{CTR}_{\text{FWHM}} = 253 \text{ ps}$

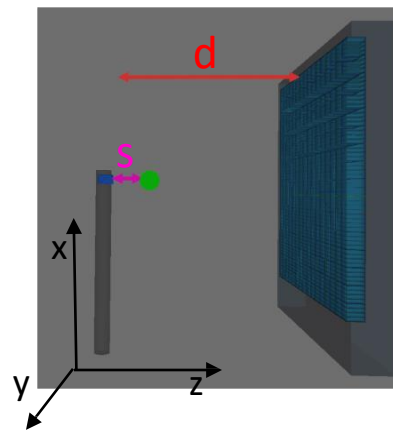
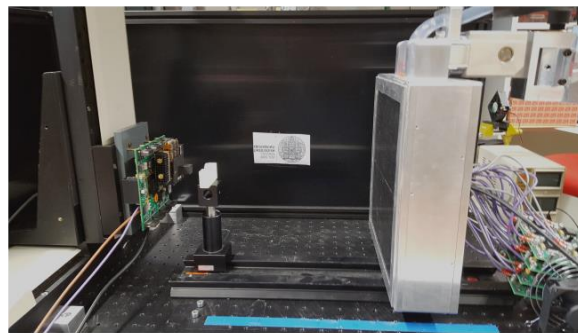


After time alignment:
System CTR_{FWHM} of **255 ps**



Point source measurements: Setup

- First measurements with the full system running were acquired:
 - $d = 200$ mm, 300 mm
 - $s = 20$ mm, 10 mm
- Simulation using GAMOS
 - Geant4 based toolkit
- Digitization using detector parameters:
 - $\text{CTR} = 255$ ps FWHM
 - $\sigma_E/E = 13$ %



d : distance between detectors

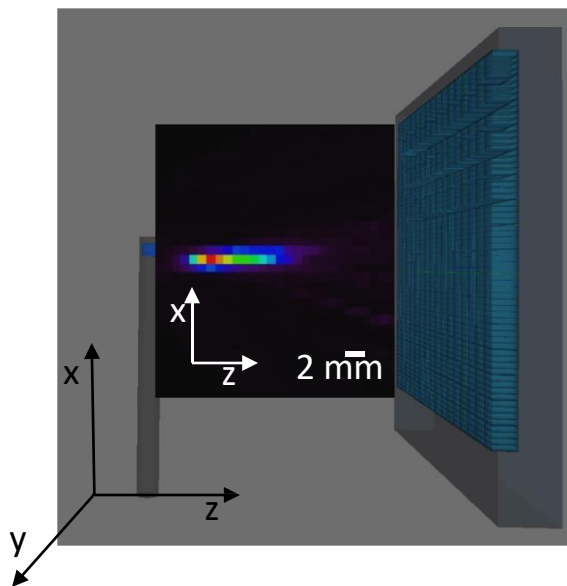
s : distance from endoscopic head to source

^{22}Na point source

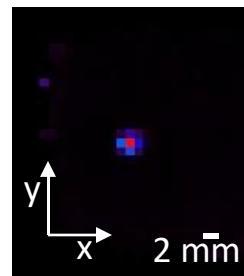
Point source measurements

Reconstruction voxel size: $1 \times 1 \text{ mm}^2$

Coronal view



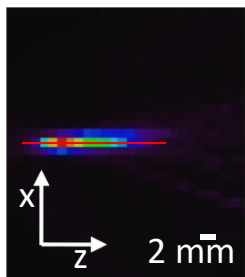
Transverse view



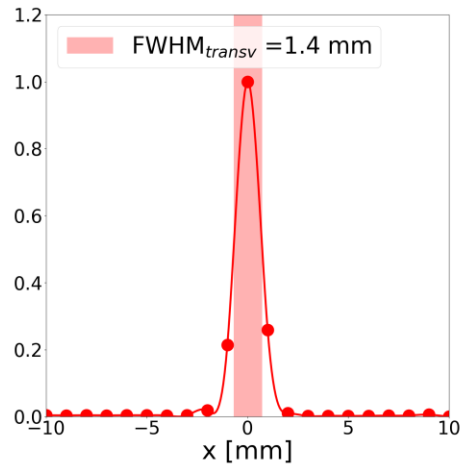
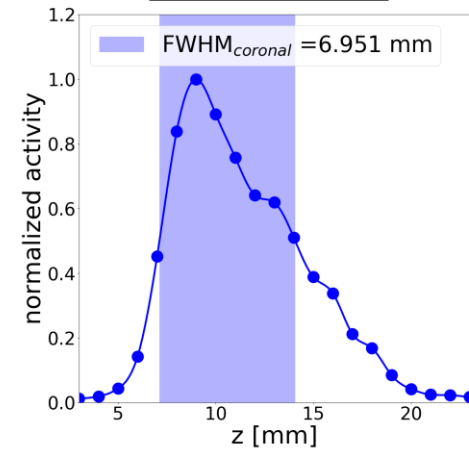
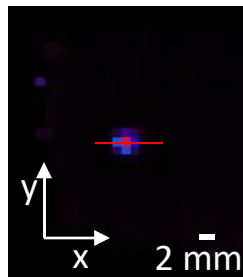
$d = 200 \text{ mm}$
 $s = 10 \text{ mm}$

Point source measurements

Reconstruction voxel size: $1 \times 1 \text{ mm}^2$

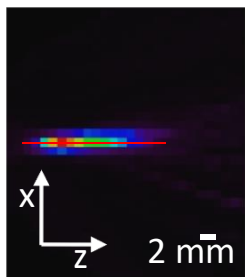


$d = 200 \text{ mm}$
 $s = 10 \text{ mm}$

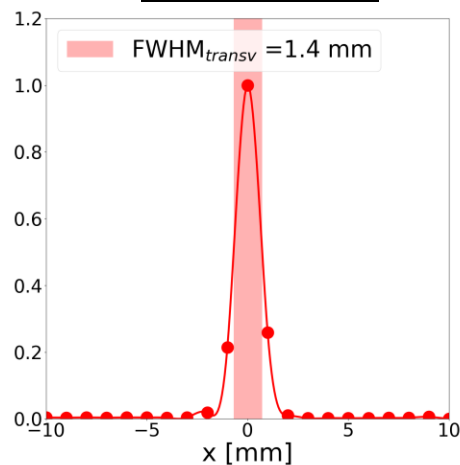
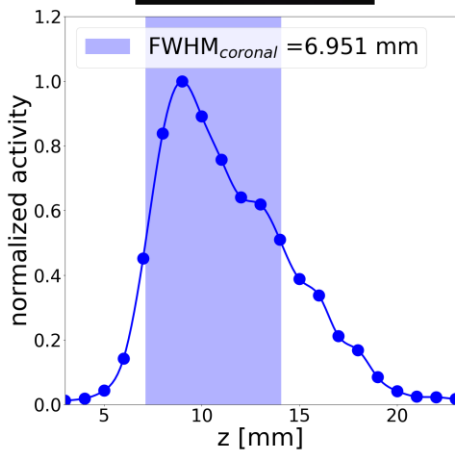
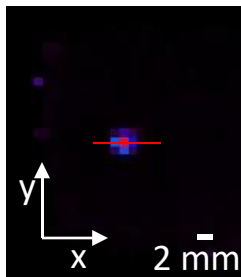


Point source measurements

Reconstruction voxel size: $1 \times 1 \text{ mm}^2$



$d = 200 \text{ mm}$
 $s = 10 \text{ mm}$

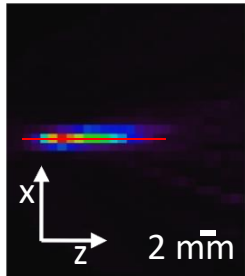


Spatial resolution in z and x - y in mm:

d [mm] \ s [mm]	200	300
10	7.0 1.4	8.9 1.5
20	8.9 1.4	9.0 1.3

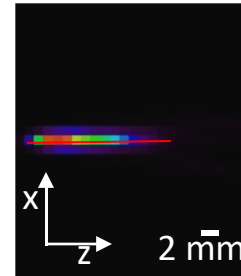
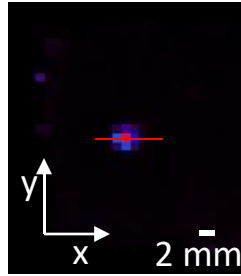
Point source measurements and simulation

Reconstruction voxel size: $1 \times 1 \text{ mm}^2$



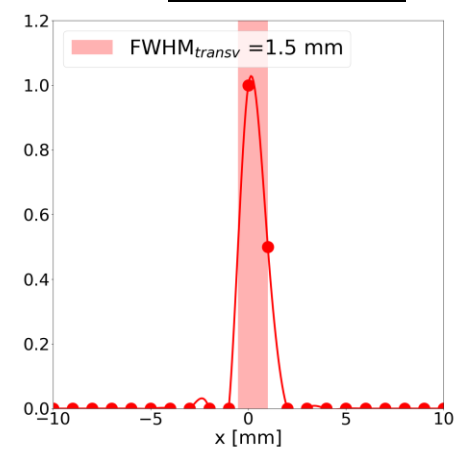
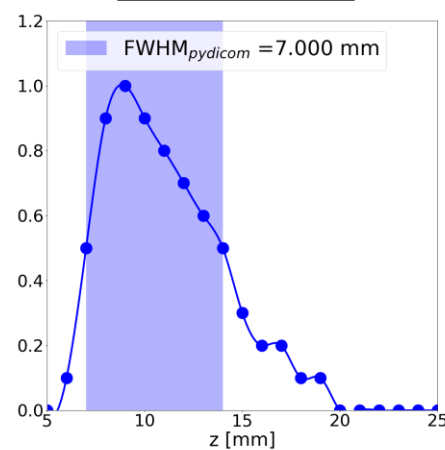
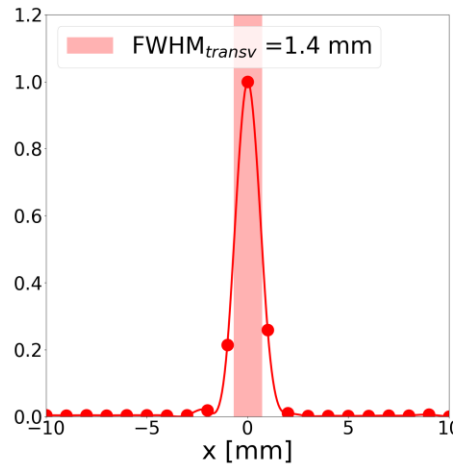
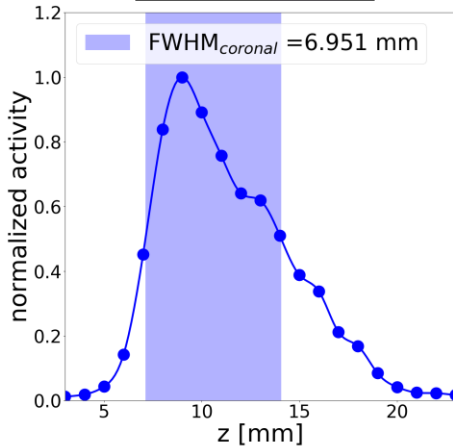
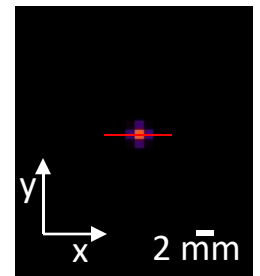
data

$d = 200 \text{ mm}$
 $s = 10 \text{ mm}$



simulation

$d = 200 \text{ mm}$
 $s = 10 \text{ mm}$



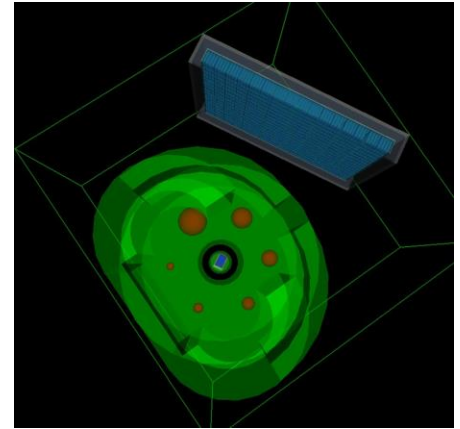
Point source measurements and simulation

Spatial resolution in **z** and **x-y** in mm:

s [mm] \ d [mm]	200		300	
	data	simulation	data	simulation
10	7.0 1.4	7.0 1.5	9.0 1.5	9.0 1.3
20	9.0 1.4	9.0 1.4	9.1 1.3	9.2 1.3

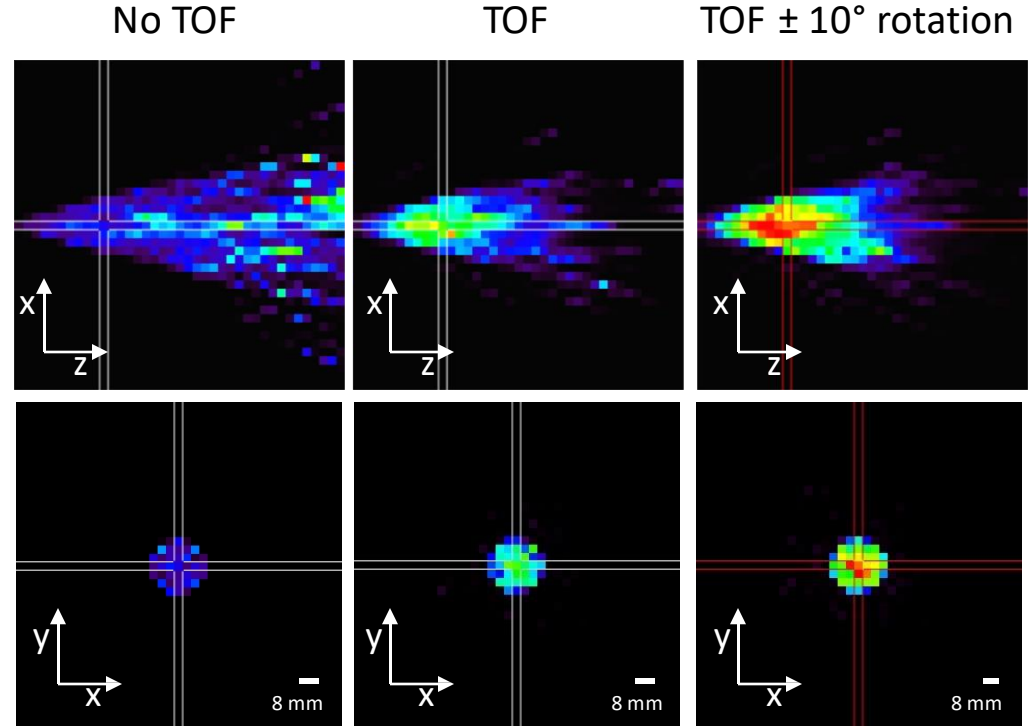
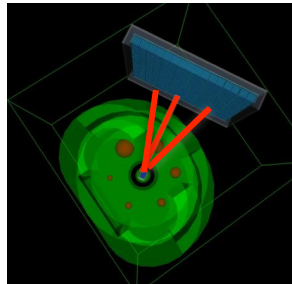
Simulation: NEMA phantom

- So far no TOF and no movement of the detectors
 - Show influence on NEMA body phantom simulation
 - Spheres of varying size (10 mm – 36 mm diameter)
 - Insert endoscopic head into the 51 mm cylindric inlay



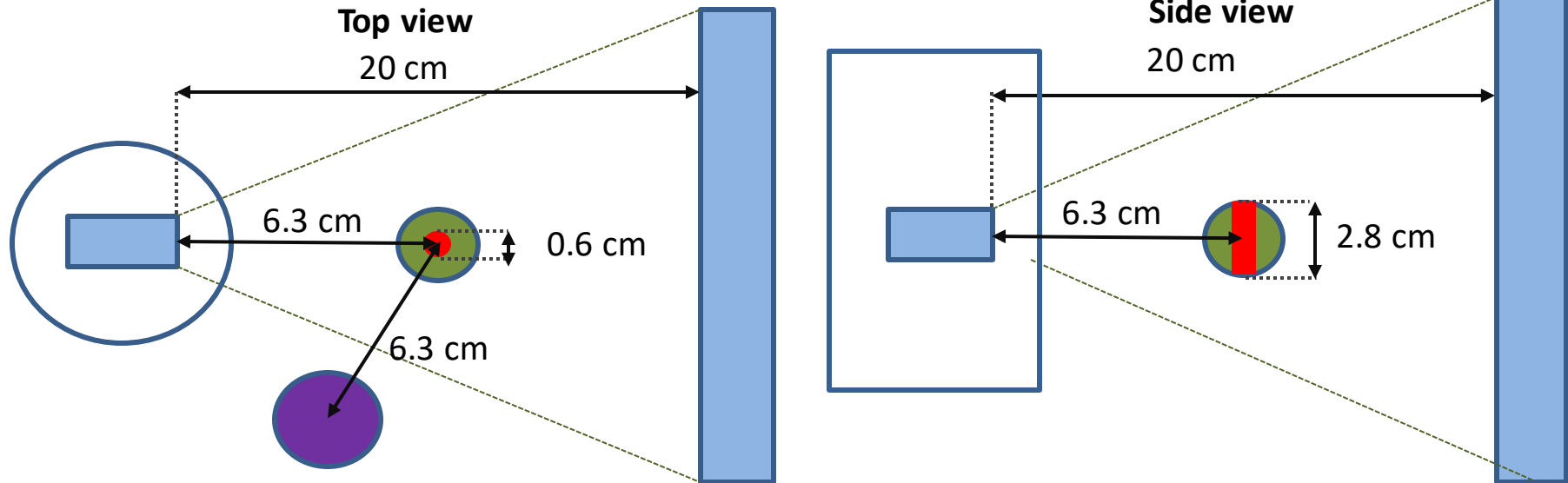
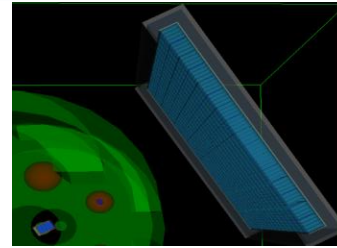
Simulation: NEMA phantom

- 28 mm sphere in center of field of view of the detectors
- 255 ps CTR (3.75 cm)
- Three acquisitions: 0° , -10° and $+10^\circ$ rotation of detectors
- Only 28 mm sphere filled with activity \rightarrow rest filled with water only



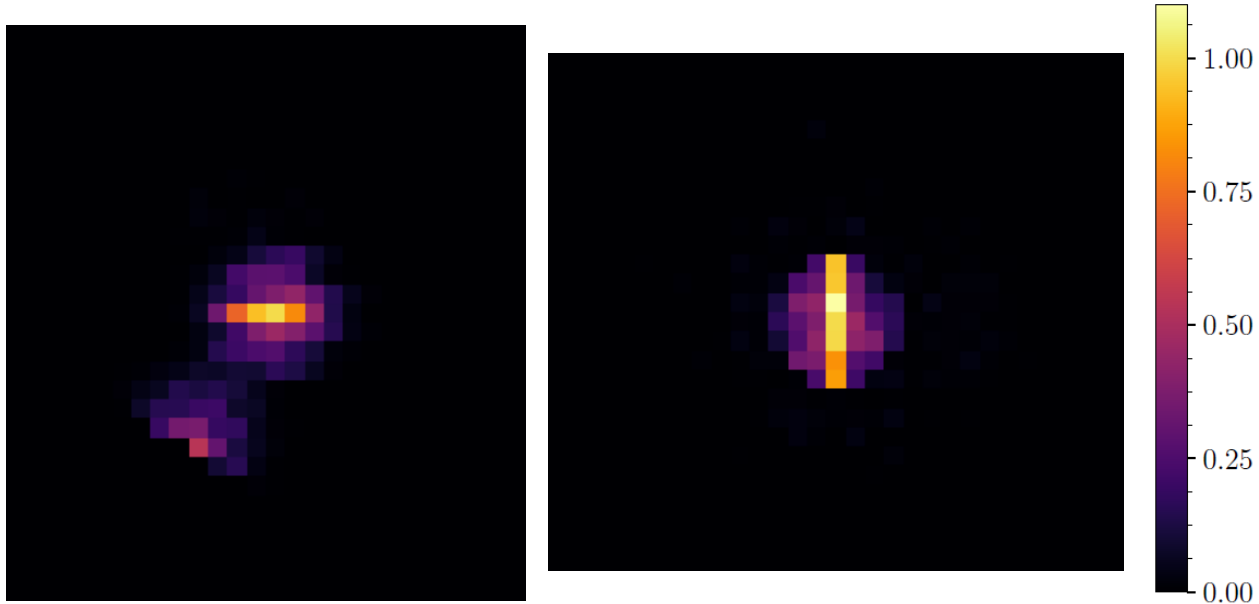
Simulation: NEMA phantom

- Visibility of hot volume inside warm background
- 4.5 kBq/cm³, 0.45 kBq/cm³, 10.4 kBq/cm³



Simulation: NEMA phantom

- Visibility of hot volume inside warm background
 - 4x4x4 mm³ voxels



Conclusion

- System wide CTR FWHM of 255 ps is achieved
- Single point resolution measured:
 - x-y-resolution ~ 1.4 mm
 - z-resolution 7.0 – 9.0 mm } Depending on patient's anatomy
- Detector simulation developed using GAMOS
 - Simulation resolution in agreement with data
- Benefit of TOF and 10° detector rotation demonstrated in simulation
- Hot volume inside warm background can be identified



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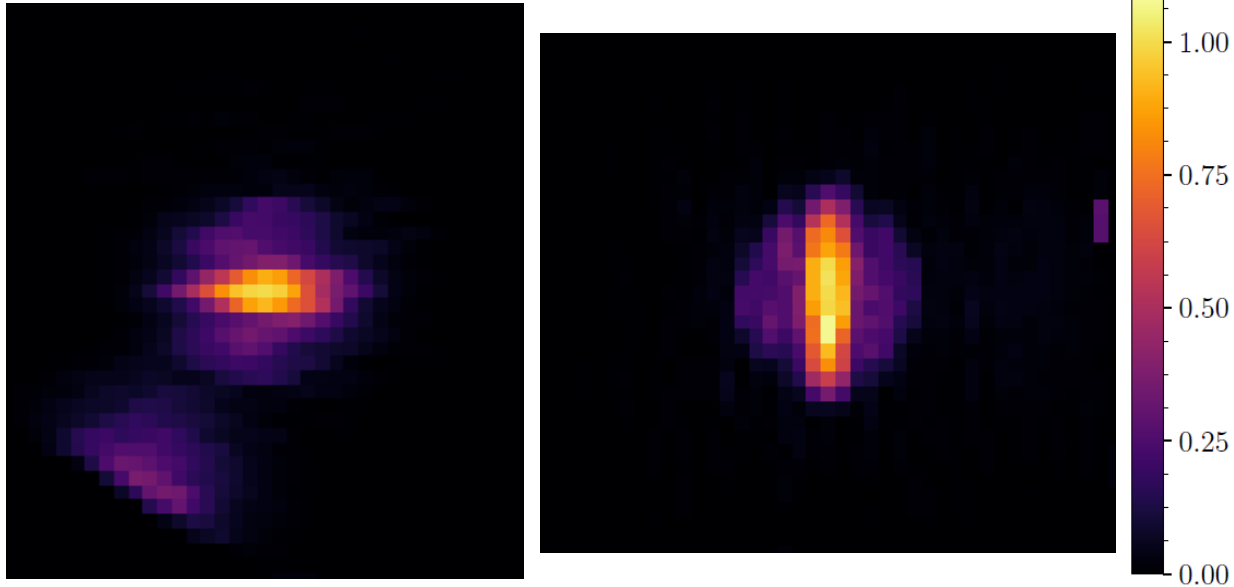


PIER Helmholtz Graduate School
A Graduate Education Program of Universität Hamburg and DESY



ENDO TOFPET US
Endoscopic TOFPET & Ultrasound

- Signal to background 10:1
- $2 \times 2 \times 2$ mm³ voxels



- Signal to background 3:1
- $4 \times 4 \times 4$ mm³ voxels

