FACULTY OF ENGINEERING AND ARCHITECTURE

Innovative Molecular Imaging and Therapy

DEVELOPMENTS IN TOTAL BODY PET SYSTEMS

Stefaan Vandenberghe

Christian Vanhove, Vincent Keereman, Roel Van Holen

Research professor, Innovative Molecular Imaging and Therapy

MEDISIP -Infinity lab-Molecubes NV, UGent Belgium

Stefaan.Vandenberghe@ugent.be

☏ 0032 93325854

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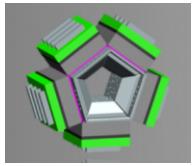
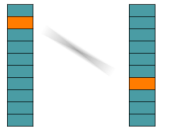
Penn
University of Pennsylvania

University of Pisa

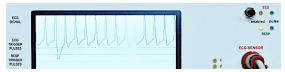
HARDWARE DETECTOR AND SYSTEM DEVELOPMENT IN MEDISIP

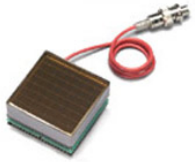


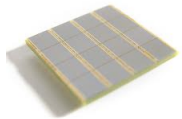


- MEDISIP software experience
  - Iterative reconstruction
  - System design with Monte Carlo simulations

- Infinity lab
  - Direct access to phantom animal and tracer
  - Strengths and limitations of current imaging systems







- MEDISIP high res detectors
  - Electronics
  - Silicon photomultipliers
  - Positioning algorithms
  - Collimator production

- MEDISIP systems
  - High resolution detectors
  - Compact design
  - Iterative reconstruction

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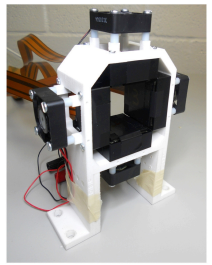
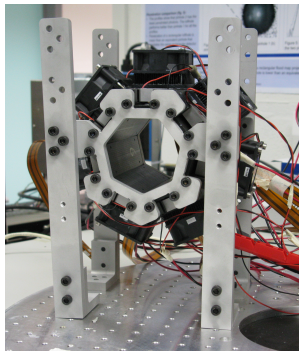
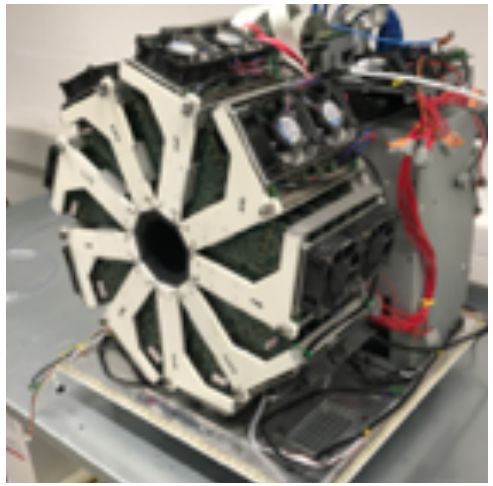
MICRO PET DEVELOPMENT IN GHENT



2014
DigiPET v1

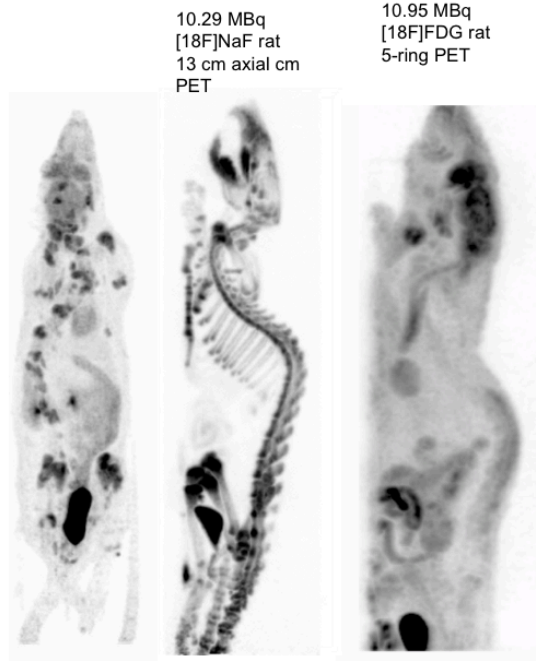


2015
DigiPET v2



2016
Beta Cube v1

2017
Molecubes Beta + X Cube
8 mm thick LYSO
13 cm axial FOV
still sub mm



FIRST PET-CT installed in February 2017

MOLECUBES

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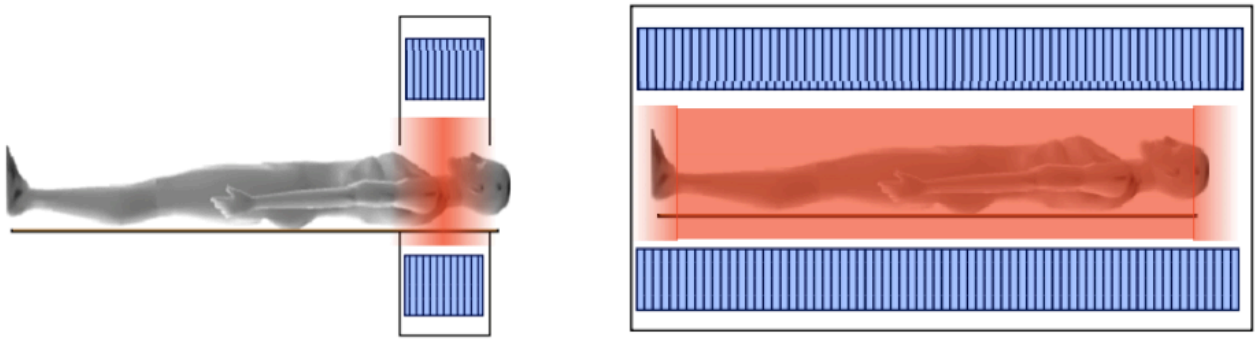
TOTAL BODY PET CONCEPT

From current 15-25 cm to 1-2 m long PET



Courtesy of Simon Cherry

Point peak Sensitivity: 4-6%	X 3-5 →	Point peak Sensitivity: 12-24 %
Body imaging sensitivity (NECR): 7-21 cps/kBq	X 30-50 →	Body imaging sensitivity (NECR): 200-500 cps/kBq
Acquisition time for total body 20 min	20-40 x faster →	Acquisition time for total body 0.5 min

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Options

Quality

NEW

Improved images (reduce Poisson noise)

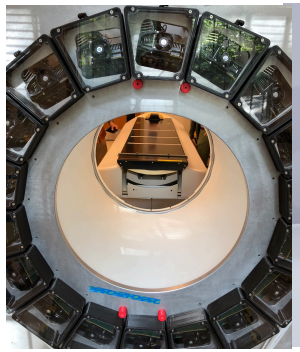
Dynamic imaging (multiple images after each other)

Reduce dose to patients and cost of tracer production

Faster imaging more patients on same day

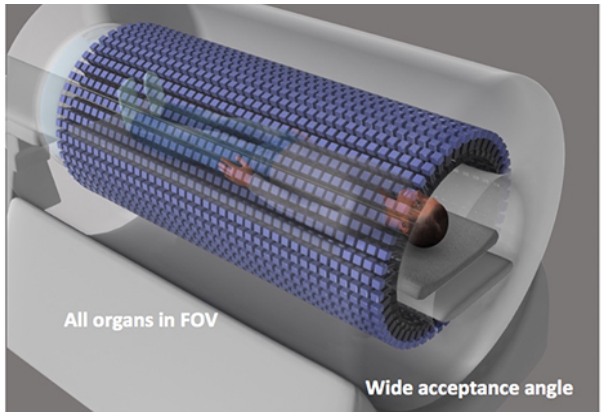
NEXT STEPS: TOF, SPATIAL RESOLUTION AND DOI

Improve effective sensitivity by better TOF



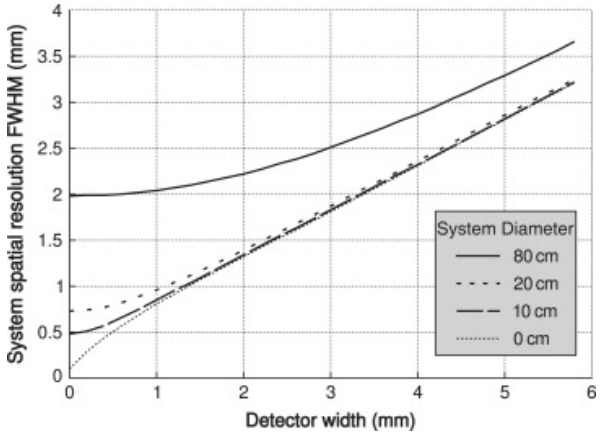
PennPET Explorer
250 ps

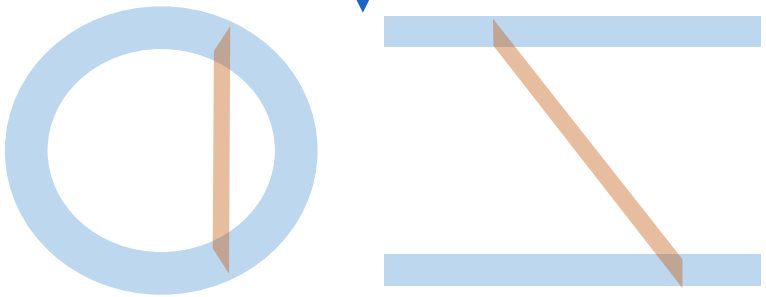
Siemens Biograph Vision
214 ps



Full body coverage → geometric sensitivity maximal
About 400 ps TOF
2.8 mm crystals
no DOI

Towards the 2mm limit of spatial resolution in clinical PET





Transverse and axial DOI in TB-PET

The promise of nuclear medicine technology: Status and future perspective of high-resolution whole-body PET,Physica Medica, Klaus P.Schäfers

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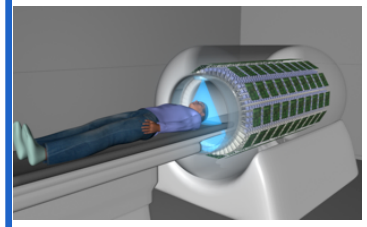
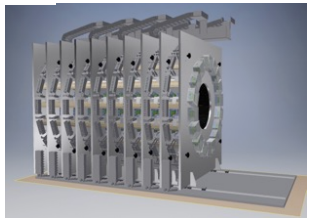
UC DAVIS
UNIVERSITY OF CALIFORNIA

EXPLORER

Penn
University of Pennsylvania



15.5 M US$



Advancing the Potential and Promise of Total-Body PET Imaging
NIH, National Cancer Institute, Apr 7 2017

Neue Einblicke ins Körperinnere [New insights into the inner body]
Deutschlandfunk [Germany-Radio], Mar 31 2017, [Article only in German]

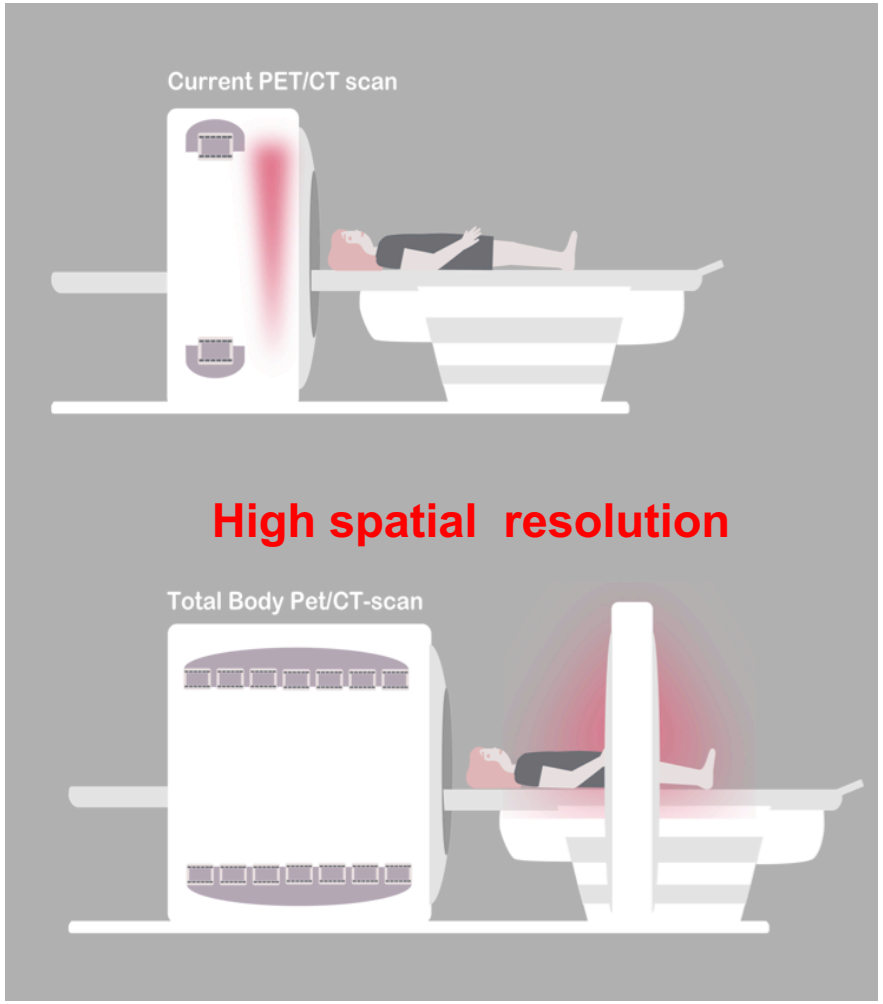
World's first full-body PET scanner could aid drug development, monitor environmental toxins
Science AAAS, Mar 17 2017, Get the journal article here

First Total Body PET Scanner Could Change Biomedical Research
Bioscience Technology, Mar 16 2017

NIH
National Institutes of Health

University of California, Davis
Project Title: EXPLORER: Changing the Molecular Imaging Paradigm with Total Body PET
Grant ID: R01-CA-206187

PET 2020
EUROPEAN EXPLORER IN GHENT



Medical cyclotron map Europe

Belgium = heart of Europe

Unique HR PET tech in Ghent

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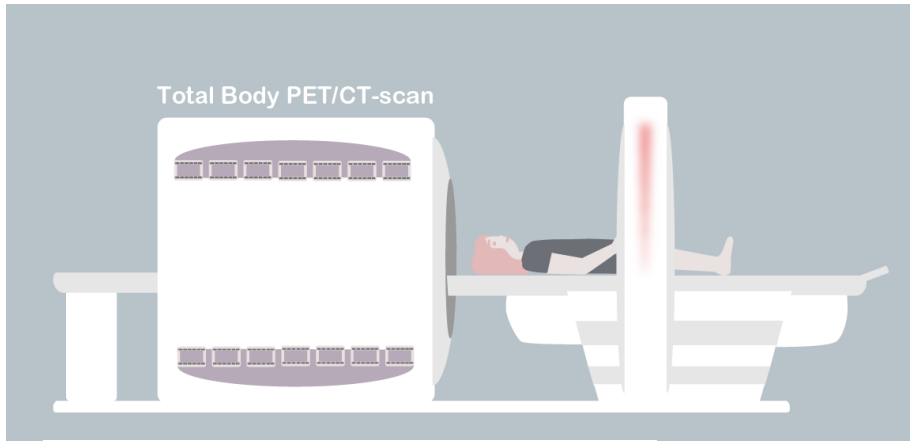
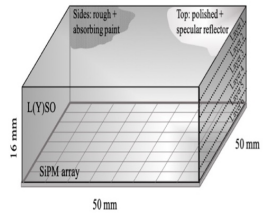
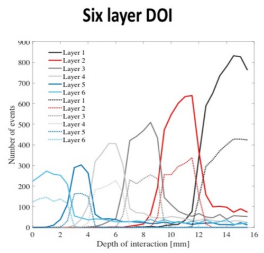
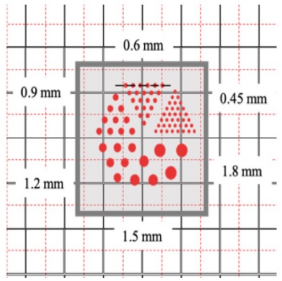
Slides courtesy of Stefaan Vandenberghe, Boudewijn Brans, Simon Cherry, Joel Karp

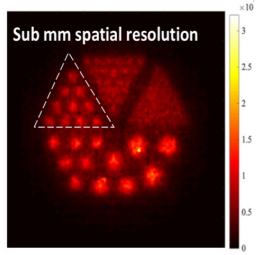
PET-2020











16 mm thick LYSO
6 layers DOI
Submm resolution
1Mcps

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Submitted to PMB, Mariele Stockhoff, PhD Ugent

Detector
Monolithic 16 mm thick LYSO
Readout by analog SiPMs

Detectors have **sub mm intrinsic spatial resolution**
Light sharing + fine sampling + Advanced positioning
6 layer DOI

Cost effective base geometry
70 cm long - 70 cm bore

System performance
2-2.5 mm system spatial resolution over whole FOV
3-4 times faster for single organ imaging
9-10 x faster for routine clinical FDG body PET imaging

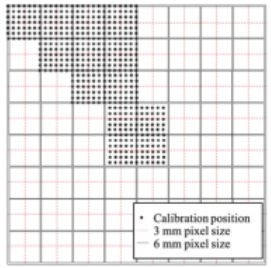
OPTICAL SIMULATION STUDY ON THE SPATIAL RESOLUTION

MATERIALS AND METHODS

Optical Simulation

Gate Monte Carlo Simulation
→ Validated LUT Davis reflection model

Detector Calibration



Positioning

k- Nearest Neighbors

$$\text{Distance}_{i,j} = \sqrt{\sum_{k=1}^{K} (\text{scaledCharge}_{i,k} - \text{calibrated scaledCharge}_{j,k})^2}$$

Performance evaluation

Investigated parameters

- Pixel Size
- Photon Detection Efficiency (PDE)
- Reduction of readout channels (Multiplexing*)

M. Stockhoff, S. Jan, A. Dubois, S. R. Cherry, and E. Roncali, "Advanced optical simulation of scintillation detectors in GATE V8 . 0 : First implementation of a reflectance model based on measured data," *Phys. Med. Biol.*, vol. 62, pp. L1–L8, 2017.

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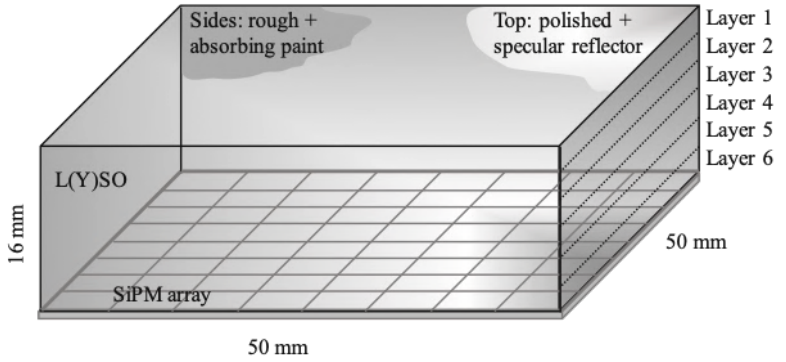
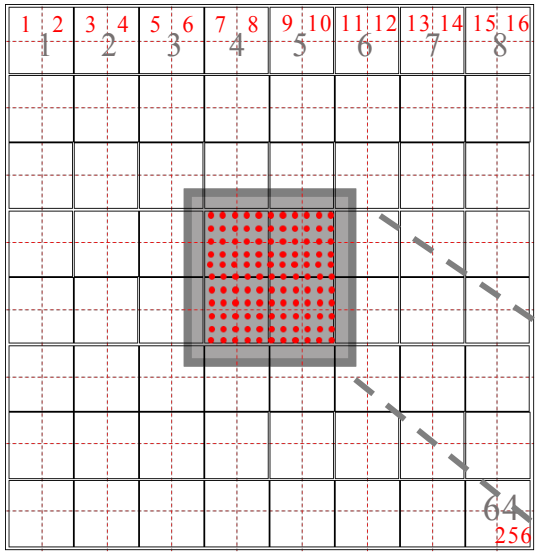
mariele.stockhoff@ugent.be

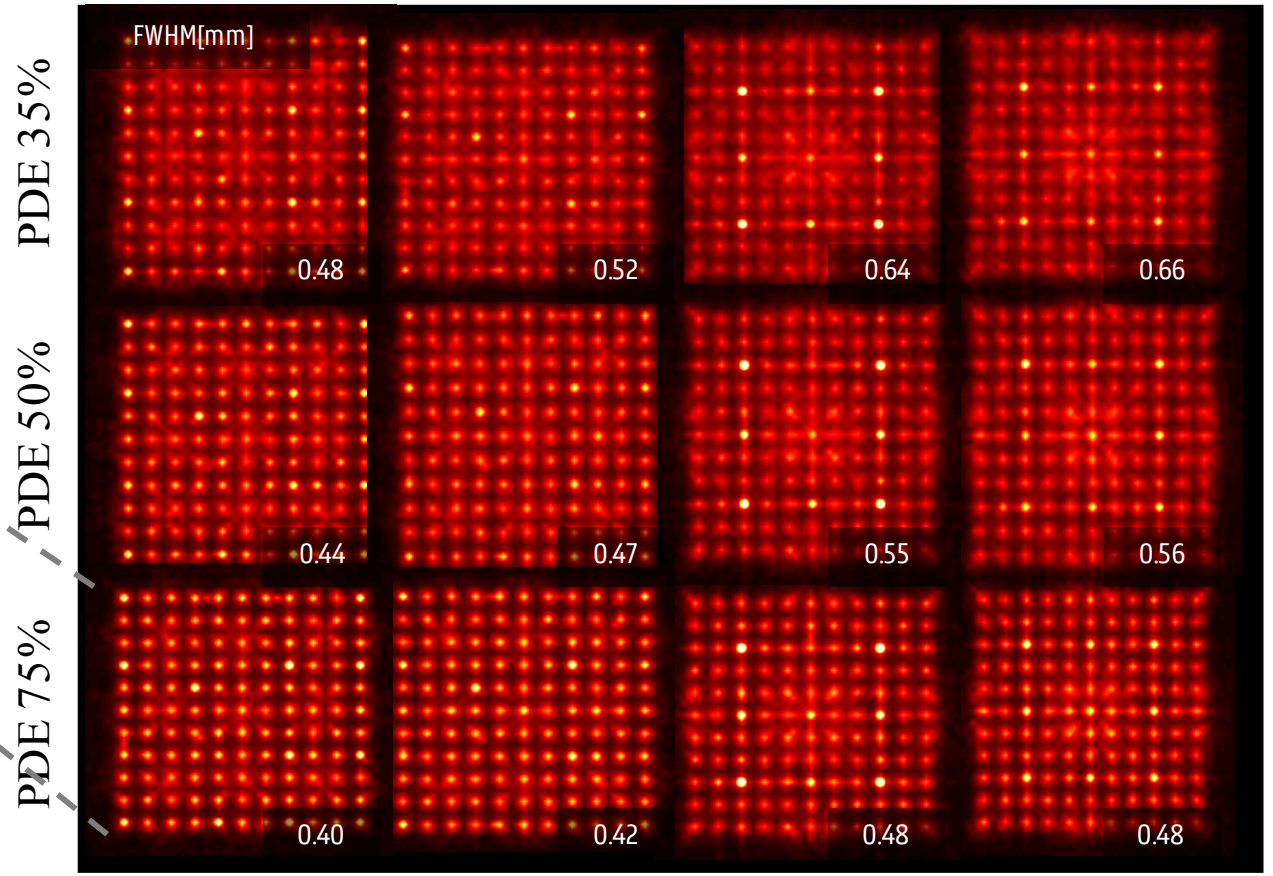


▸ Optical simulation of a monolithic LYSO scintillation crystal coupled to an array of SiPMs.

RESULTS

- Spatial resolution in the center





*combined channels (multiplexed)

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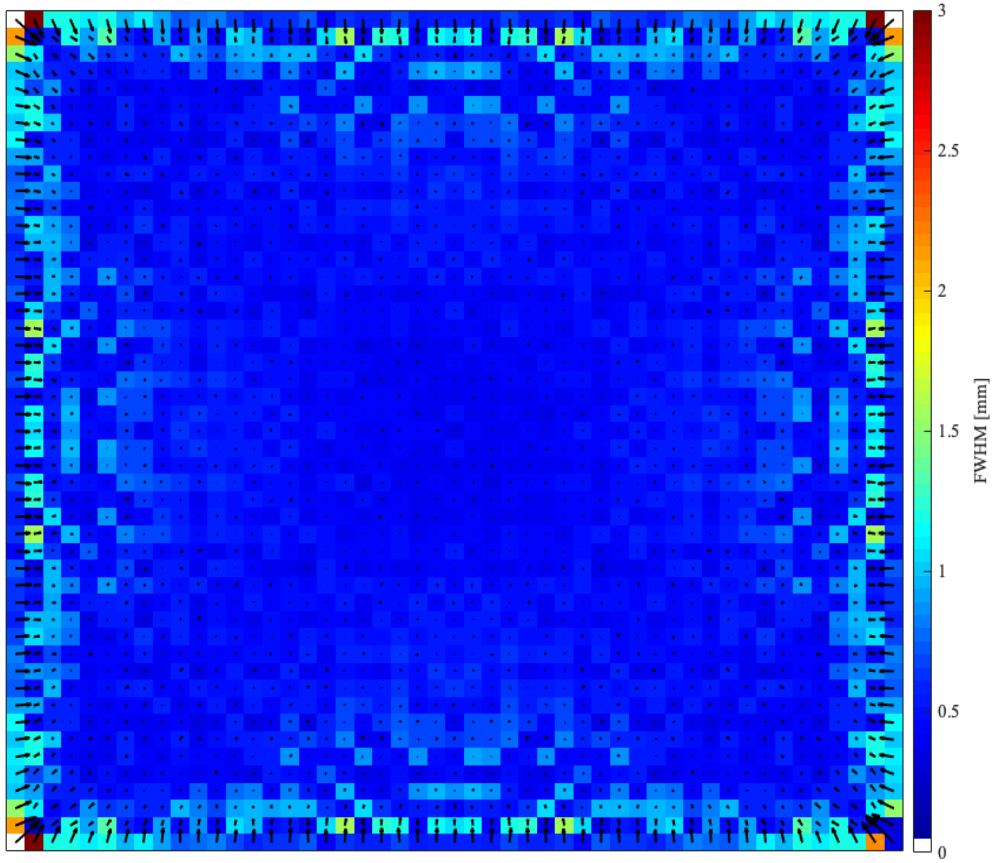
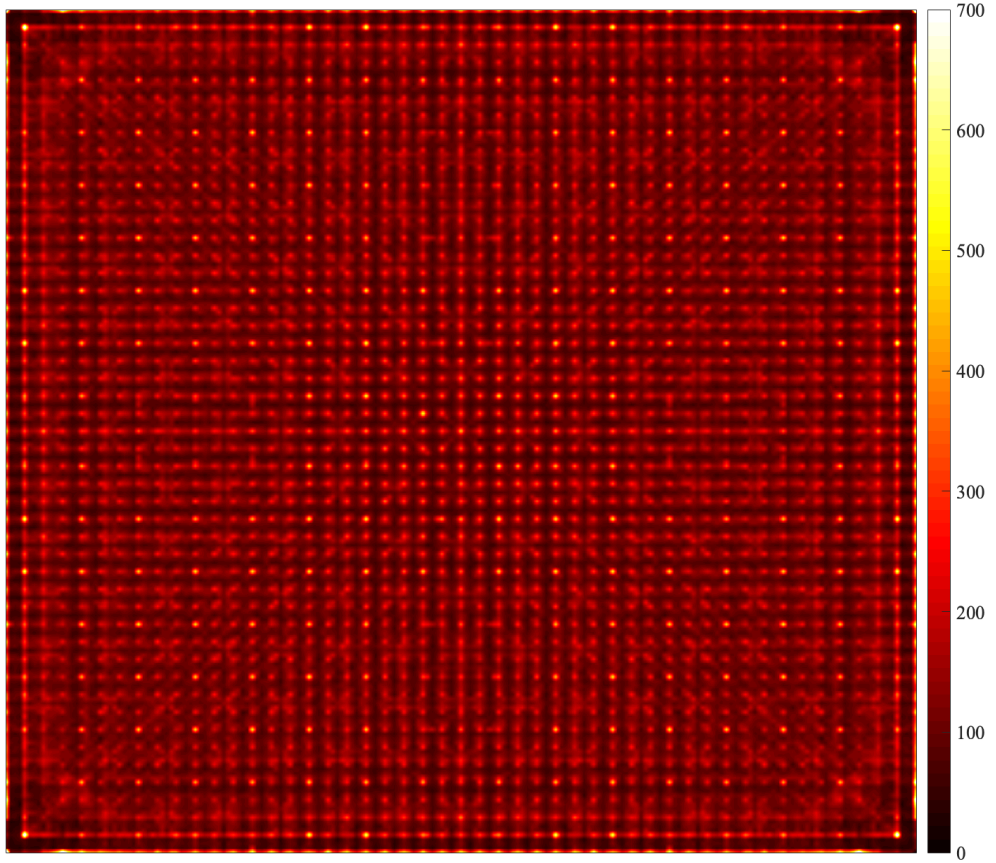
Whole detector resolution





Small degradation at edges

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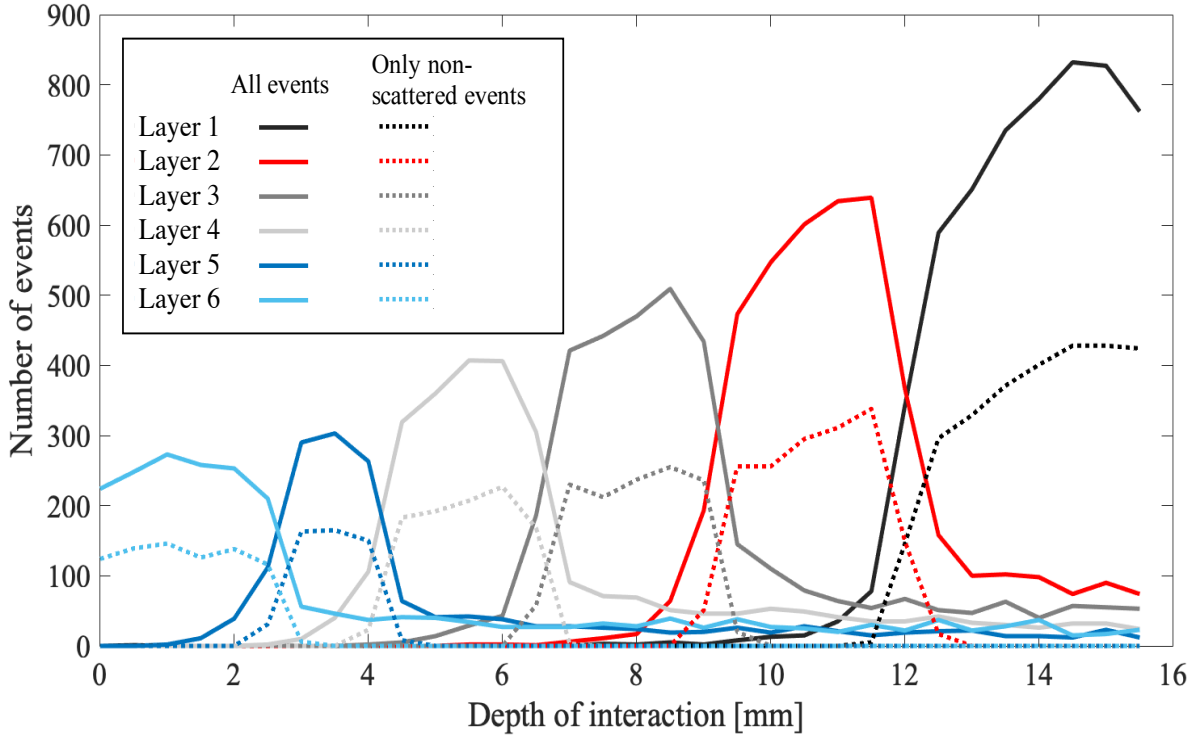
- DOI resolution: real DOI dependent on the determined depth layer



Layer	Layer Accuracy [%]	Mean absolute error [mm]
1	96.6	0.99
2	70.7	1.18
3	66.4	1.58
4	58.4	1.91
5	50.7	2.3
6	54.6	3.0
Overall	**72.2**	**1.6**

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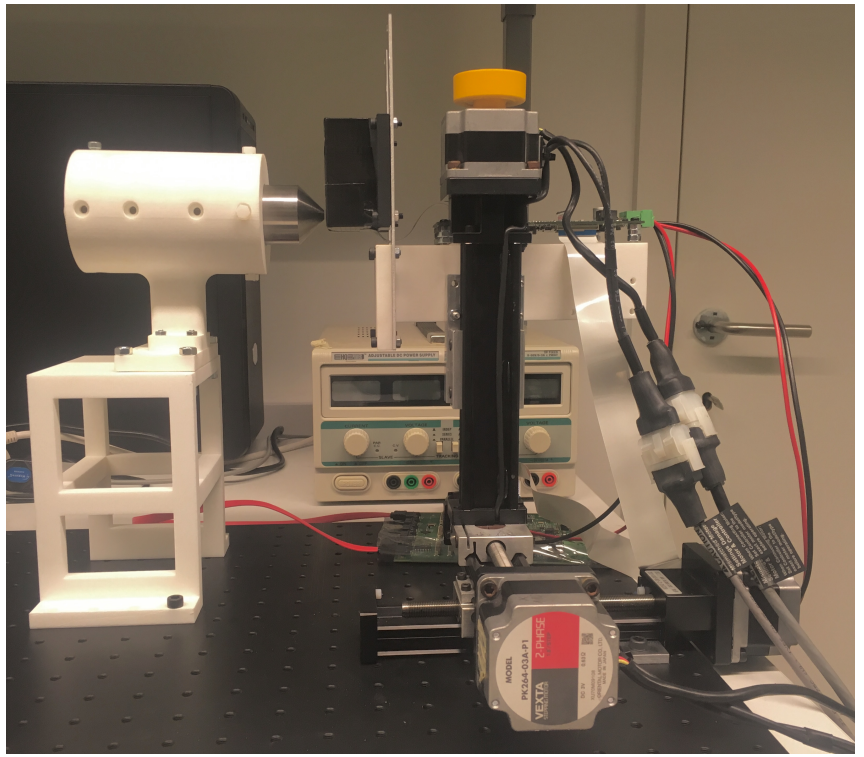
NEXT: EXPERIMENTAL VALIDATION



Degradation factors:

- Non-Perfect calibration beam
- Lu176 background

USE SIMULATION DATA FOR POSITIONING

- Precise optical reflection model
- Much simpler geometry to simulate than pixelated detectors

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GE discovery MI 4-ring- 20 cm

Pixelated
25 mm thick LYSO
20 cm long - 85 cm bore
13 Liter-94 kg LYSO

0.5 m² SiPM

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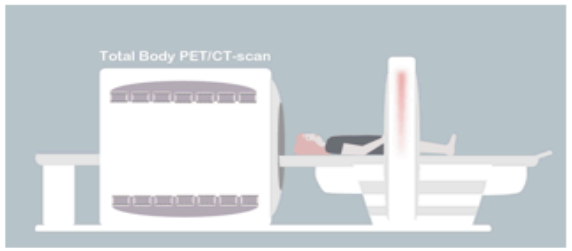
1.9 x more Scintillator

3x more Light Detector

PET-2020



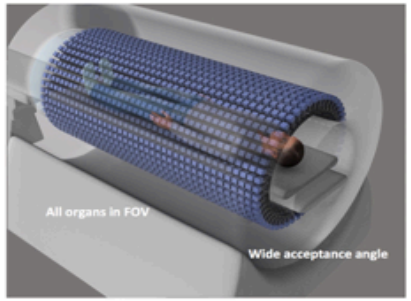
Monolithic
16 mm thick LYSO
70 cm long - 70 cm bore
25 Liter-180 kg LYSO *

1.5 m² SiPM

3.5 x more Scintillator

1.5-3.3x more Light Detector

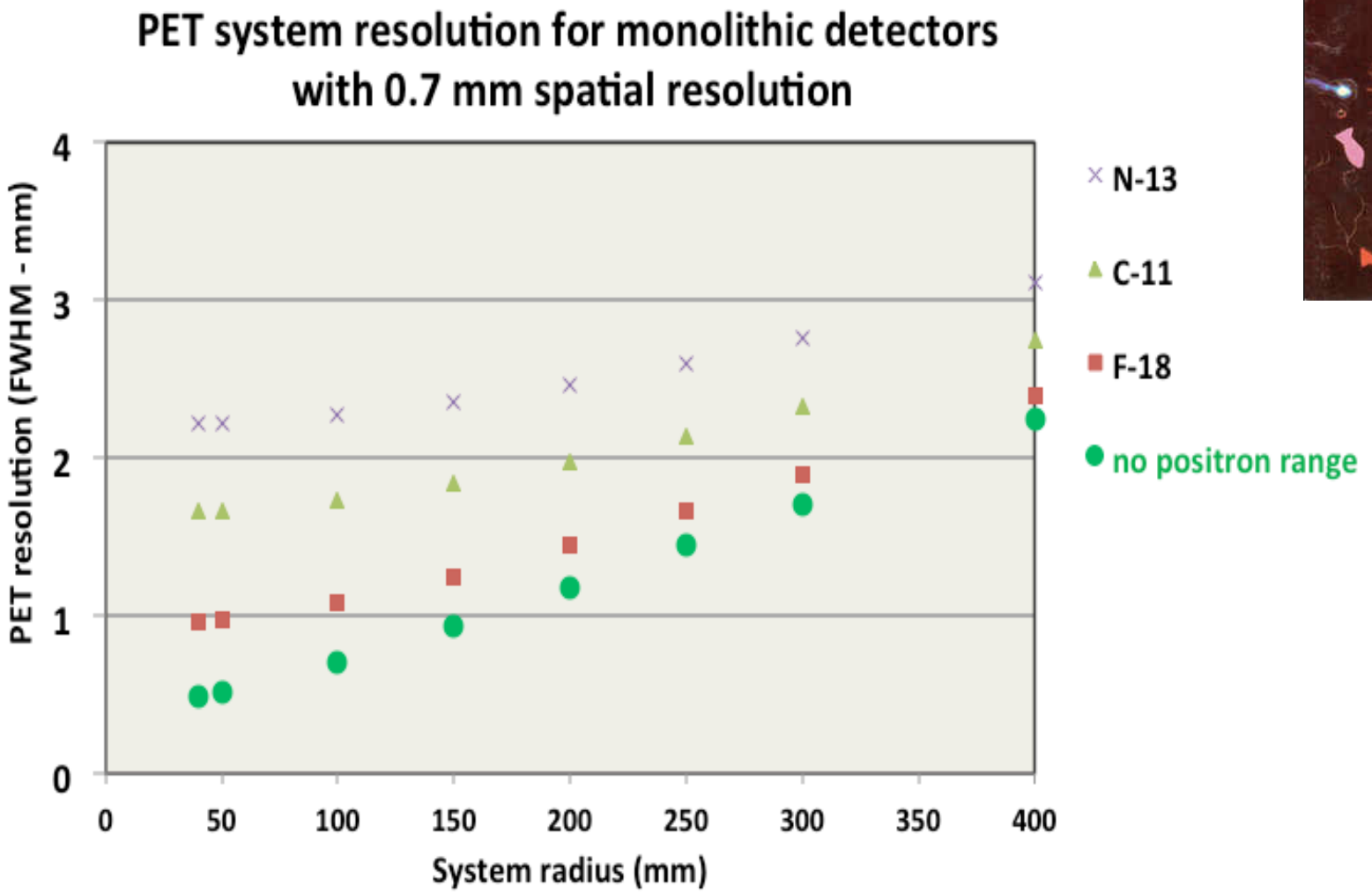
Explorer



Pixelated
18 mm thick LYSO
198 cm long – 78.6 cm bore
88 Liter-624 kg LYSO

5 m² SiPM **

ACOLINEARITY DOMINATES CLINICAL PET IN THE LIMIT



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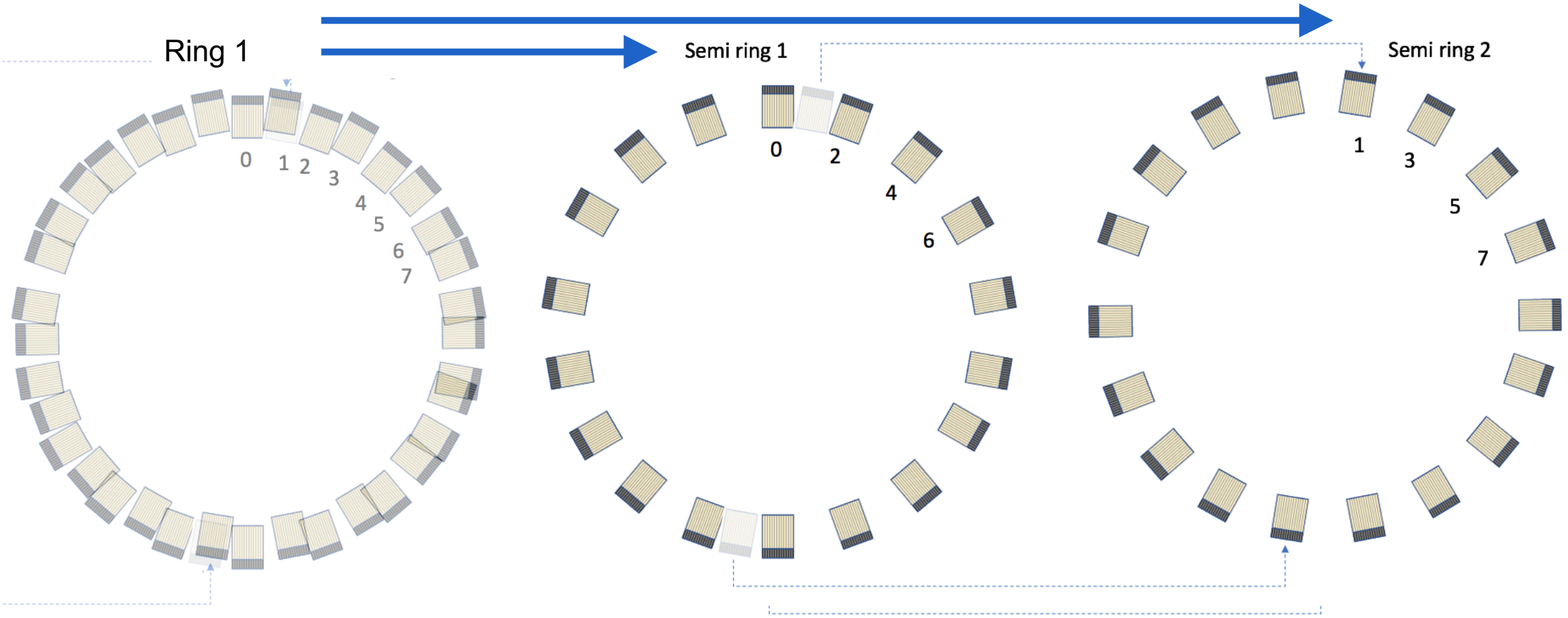
ONE RING IS/ARE TWO SEMI-RINGS BY AXIAL SPLITTING



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High sensitivity single organ imaging
Fast continuous static body scans
Easier access

Speed vs 20 cm
9-10x faster (for body imaging)
3-4 for single organ imaging

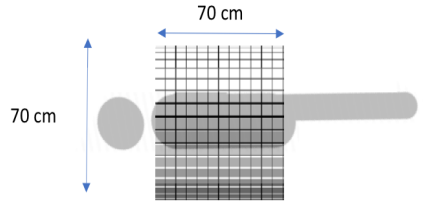
Spatial resolution of 2 mm
with monolithic

Total body imaging
Fast continuous body scans
Long axial FOV

Speed vs 20 cm
9-10x faster (for body imaging)

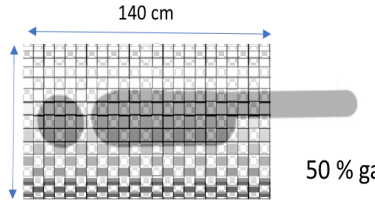
Spatial resolution of 2 mm
with monolithic

Adaptive per ring based on one motor and camera aperture principle



Compact,
Routine mode

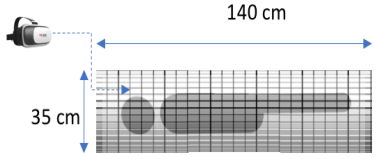
Axial splitting of rings



50 % gaps

Large, Research
mode

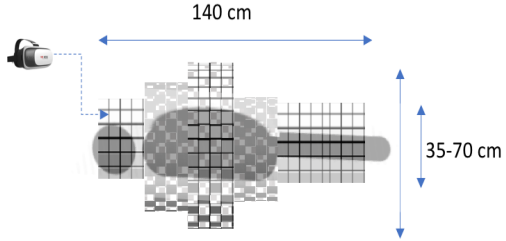
Radially inwards movement of detectors



No gaps

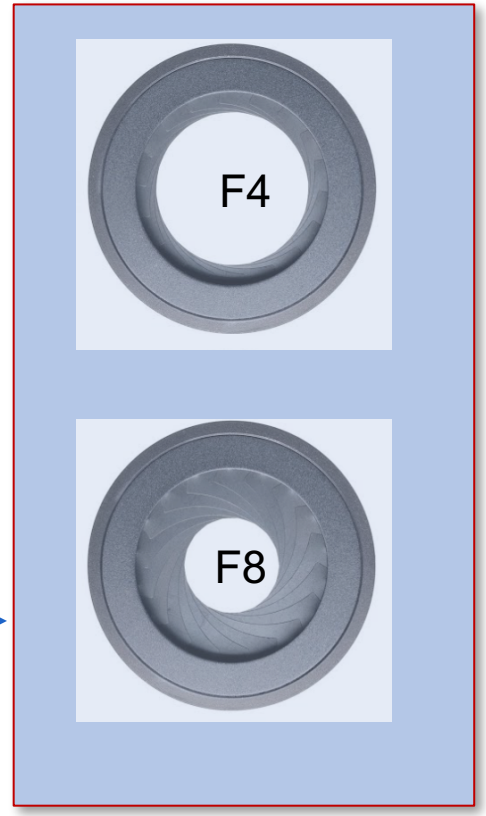
Paediatric mode

Full radially inwards movement of detectors



Adaptive mode

0-50 % gaps



Total body imaging of small object (paediatric)
Fast dynamic scans

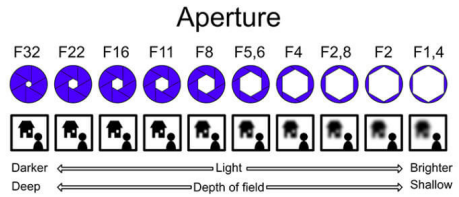
Speed vs 20 cm
30-40 x faster (for body imaging)

High spatial resolution with 1 mm monolithic
+ 6 layer DOI
→ < 1.5 mm

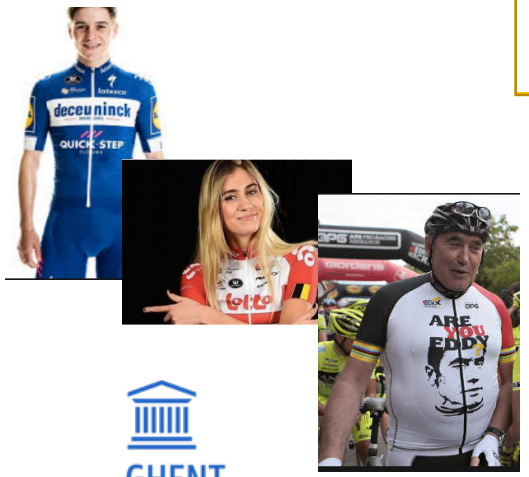
Adapts to patient body
Fast dynamic body scans
Brain body interactions

Speed vs 20 cm
15-25 x faster (for body imaging)

High spatial resolution with 1 mm monolithic
+ 6 layer DOI
--> < 1.5 mm



ADAPTIVE APERTURE PET



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Small bore ?

Hypothyroid in cats

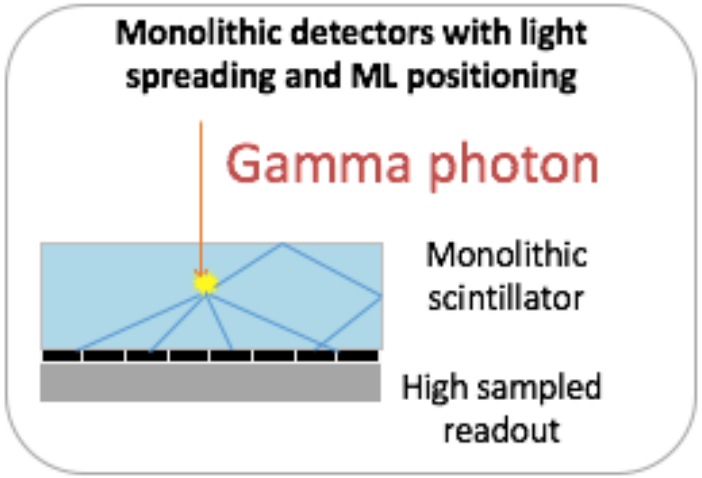
Please, no CAT scan again

I better fit in here !

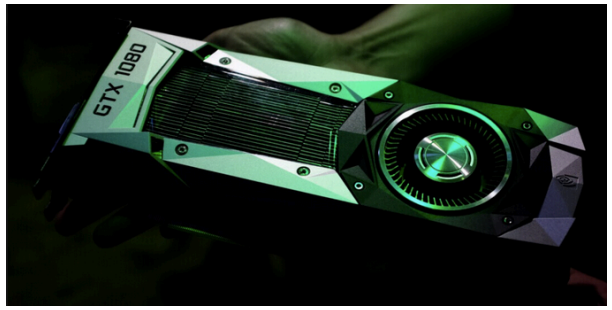
Lion Columbus zoo, Ohio imaging center, refurbished GE LightSpeed 16-slice CAT scanner

PET2020 IS VERY STRONG COST-EFFECTIVE COMBO

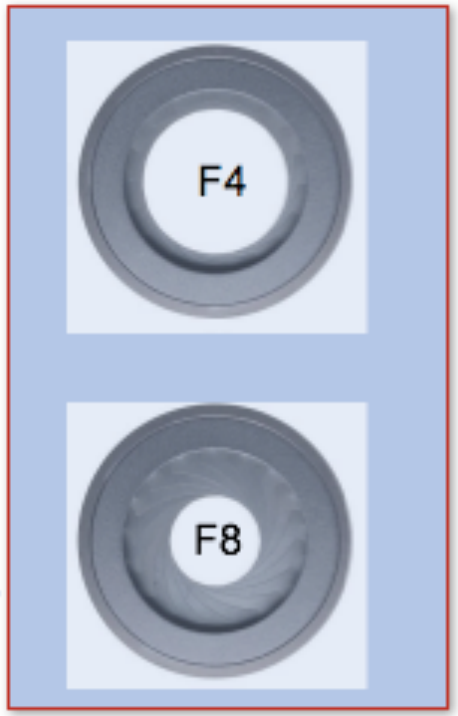
3D detector



Compact parallel computing



Simple Adaptive Mechanical design



Real time positioning

3D listmode TOF acquisition and reconstruction

University of Pisa

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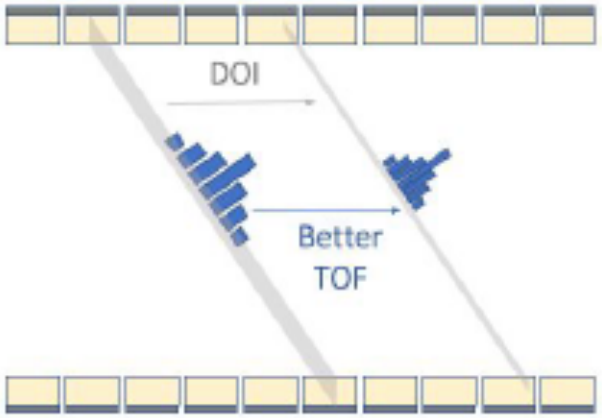
https://www.labworld.it/utofpet-sviluppera-nuove-tecnologie-per-rivelatori-pet/

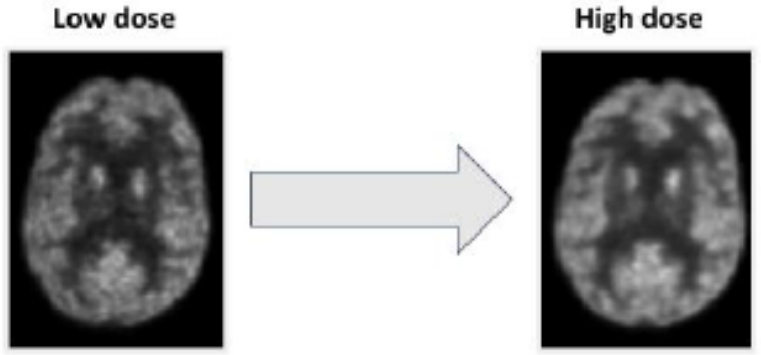
DEEP LEARNING (WELL DEFINED TASKS) AT DIFFERENT LEVELS

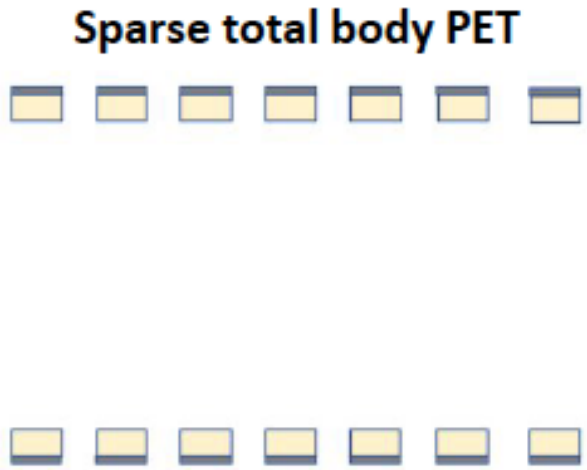
ACQUISITION

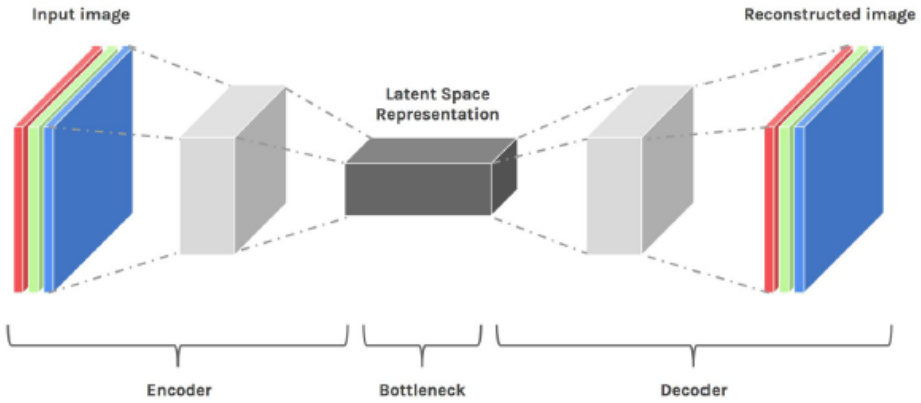
LOW NOISE RECONSTRUCTION

SYSTEM DESIGN









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SUMMARY

1. High resolution detectors (sub mm intrinsic) are the basis of this innovative Total Body system
2. Unique high resolution (2 mm system limit)
3. Optimal length for routine PET imaging (90 % of studies are FDG body)
4. Fast throughput for routine imaging
5. Adapts in a simple mechanic transformation to smaller or longer objects
6. Cost-effective (only 2-3 x detector material of current PET-CT)
7. Adapts to a wide range of subjects-One PET fits all
   - axially: standard 70 up to 140 cm axial length
   - transverse to subjects of 35 to 70 cm diameter

Future projects

- In-beam imaging
- Lifetime Positronium imaging

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TOTAL BODY PET 2020: FIRST ANNOUNCEMENT

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Penn

UCDAVIS
UNIVERSITY OF CALIFORNIA

THE UNIVERSITY OF EDINBURGH

FACULTY OF ENGINEERING AND ARCHITECTURE

Thank You!

INTERESTED IN COST EFFECTIVE TOTAL BODY PET

Stefaan.Vandenberghe@ugent.be
☎ 0032 93325854

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