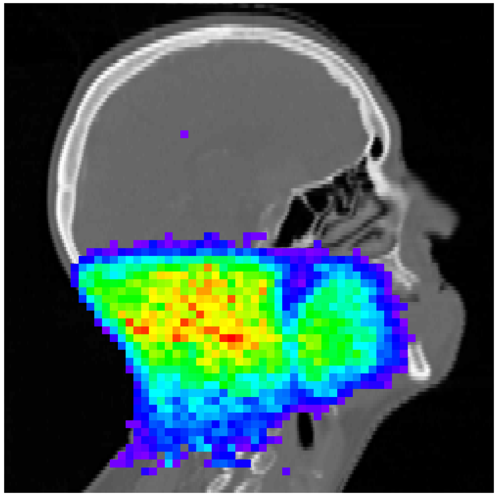
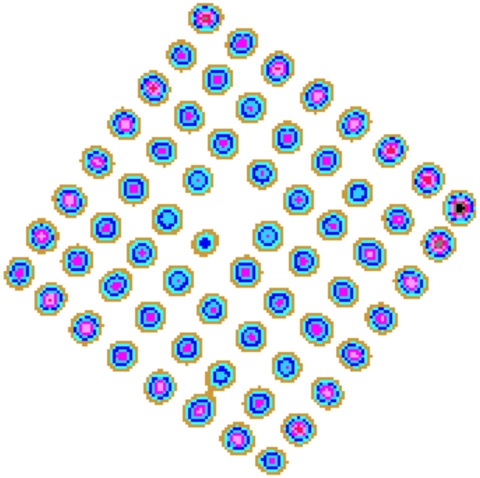
Sensory and imaging technology in science, health and security
CERN, 30 June 2015

Sensors for gamma ray vision

Peter Dendooven





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Contents

- Gamma ray vision ?
- Application to health and nuclear safeguards
  - molecular/functional imaging
  - imaging of spent nuclear fuel
- Improved sensor technology leads to better and new images

Gamma ray vision ?

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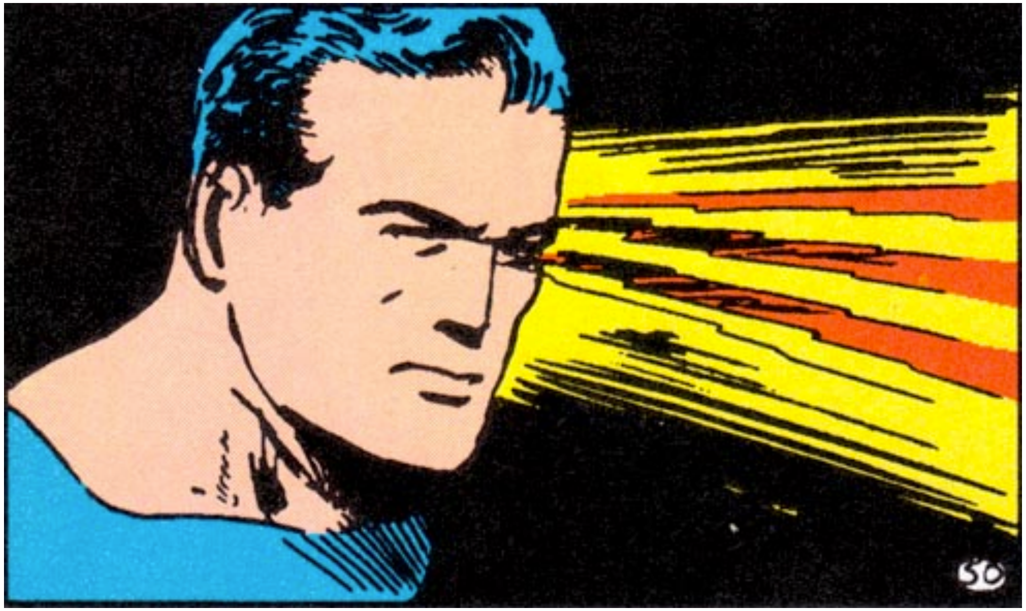


- transmission imaging: external radiation source (e.g. CT)
- **emission imaging**: internal radiation source

Gamma ray emission imaging

object emitting gamma rays from within

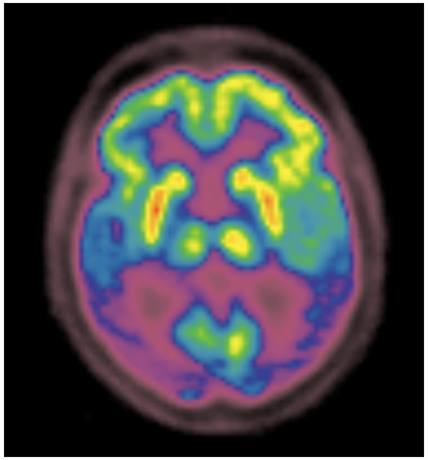
gamma ray
imaging device
(“camera”, “scanner”)

3D distribution of gamma ray emission ?

- camera/scanner measures a 2D image
- looking from all angles provides “depth”
  3D images = **tomography**

Imaging in nuclear medicine



radiotracer biomolecule related to biological function:
“molecular” or “functional” imaging

(medical) imaging techniques must be
sensitive and **specific**

“if there is something,
you should see it”

“if you see something,
it should be there”

technology must aim at improving these

Functional imaging: brain activity

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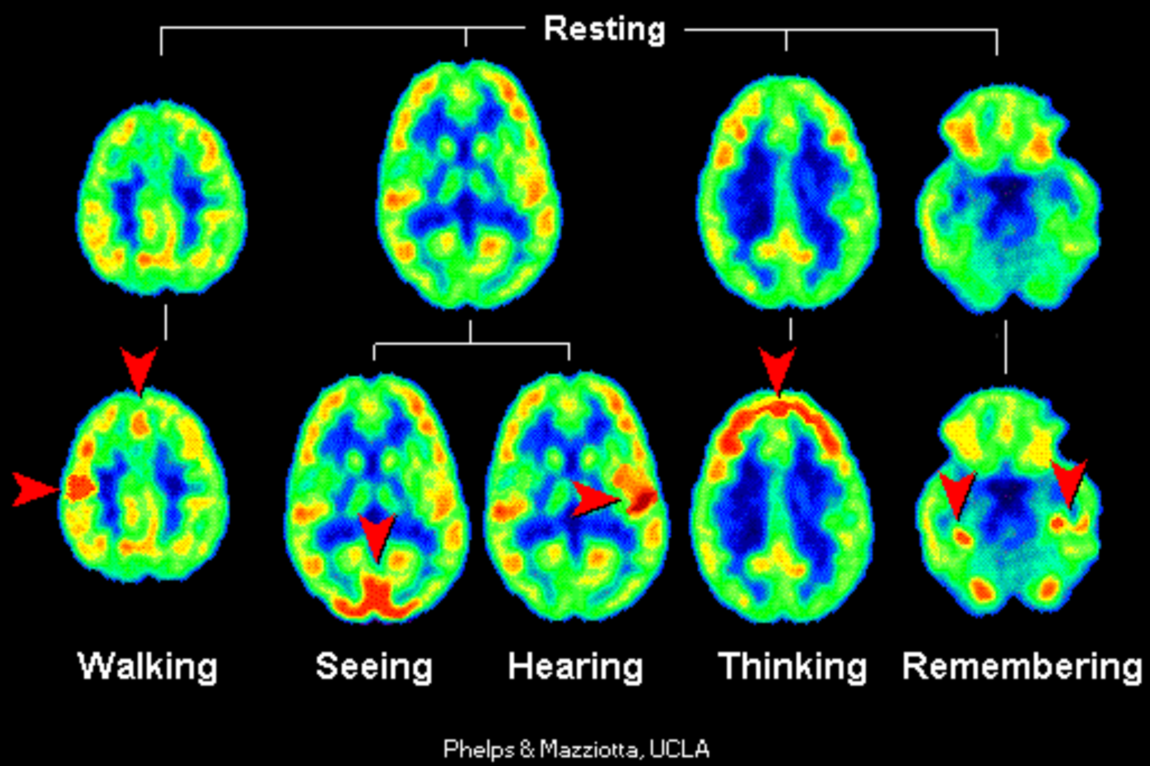
^{18}FDG (fluorodeoxyglucose) relates to cell activity



Nuclear safeguards

IAEA
International Atomic Energy Agency

nuclear safeguards: to deter the proliferation of nuclear weapons

an essential component of the international security system

two ways:

- by providing credible **assurances** that States are honouring their international obligations, thus helping to build international **confidence**
- by being able to **detect** any misuse of nuclear material or technology early on, thereby alerting the world to potential proliferation

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better objective methods (technology) to detect misuse help to build international confidence

Verification of spent nuclear fuel

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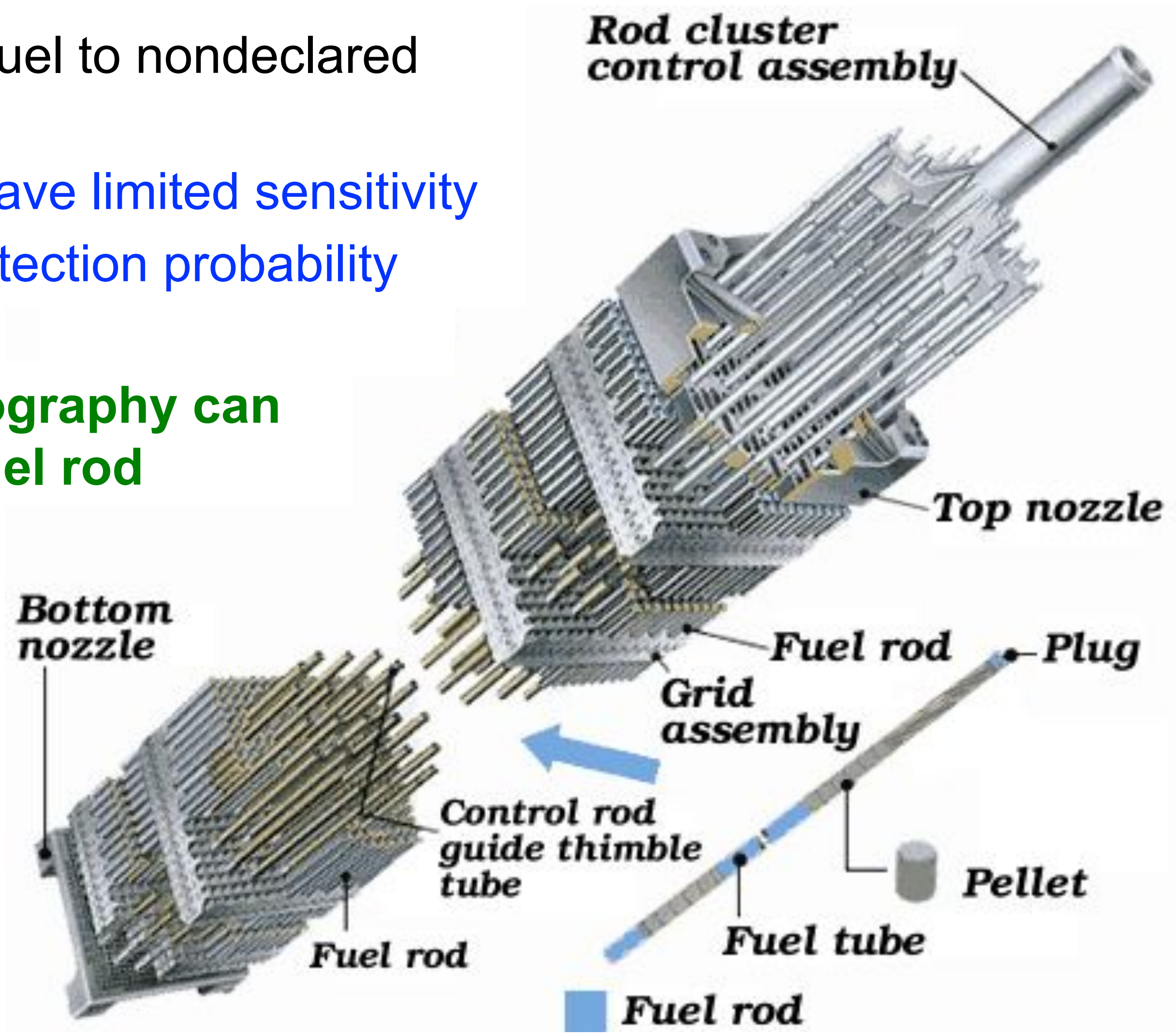
- testing for **partial defects**
  diversion of part of the fuel to nondeclared purposes
- current verification tools have limited sensitivity
- IAEA policy: need high detection probability

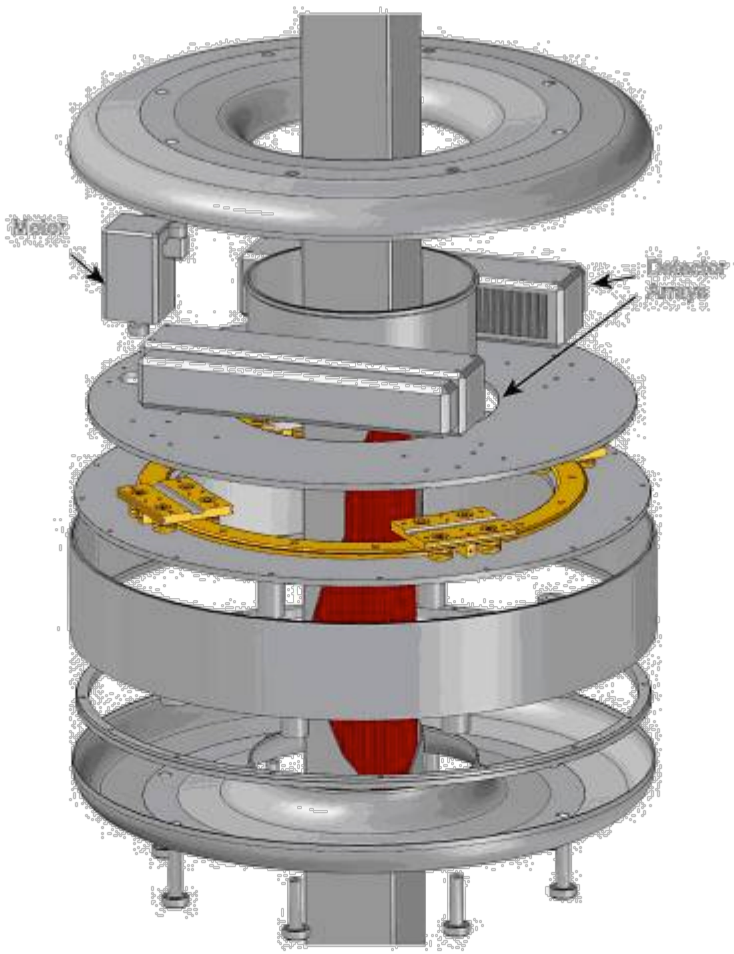
gamma ray emission tomography can detect a single replaced fuel rod



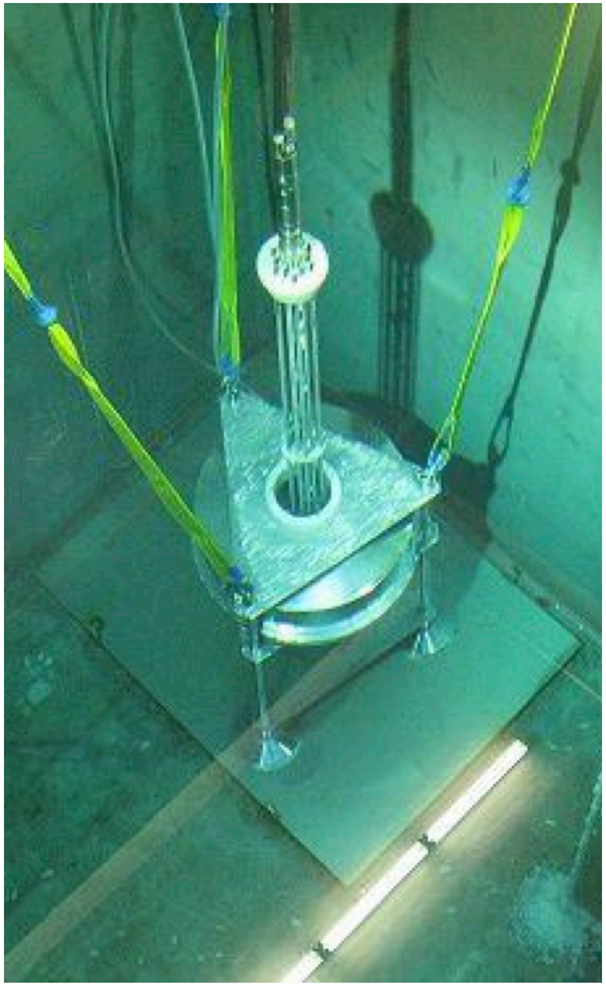
www.world-nuclear.org

A tomograph for spent nuclear fuel

passive gamma emission tomograph (PGET)



T. Honkamaa, STUK



Spent nuclear fuel tomography

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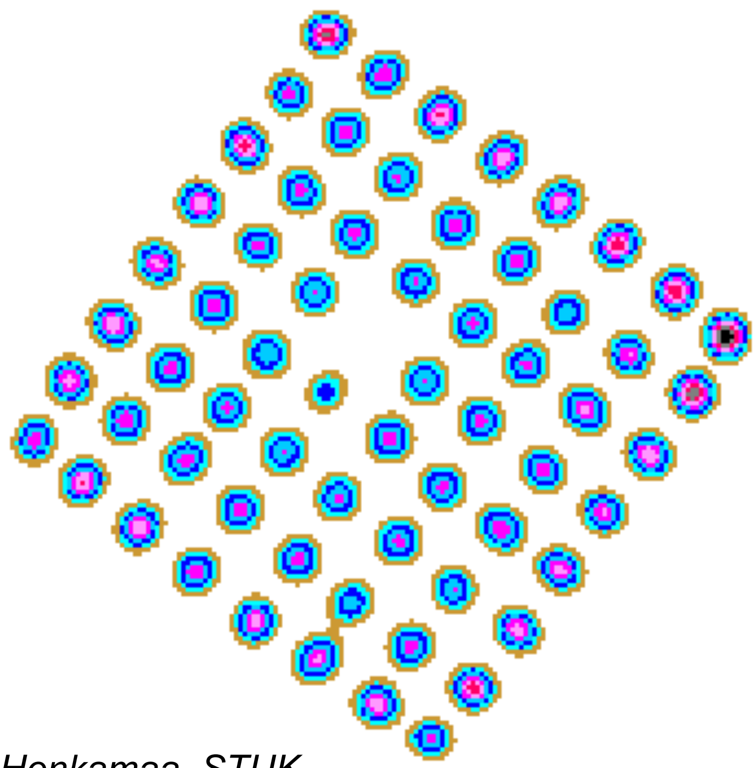
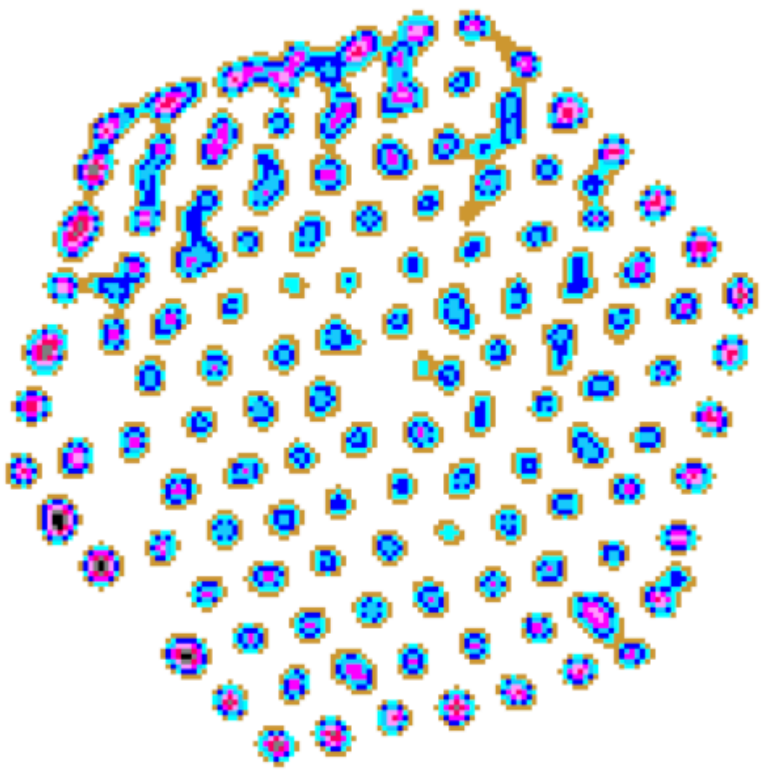
passive gamma emission tomograph (PGET)

STUK

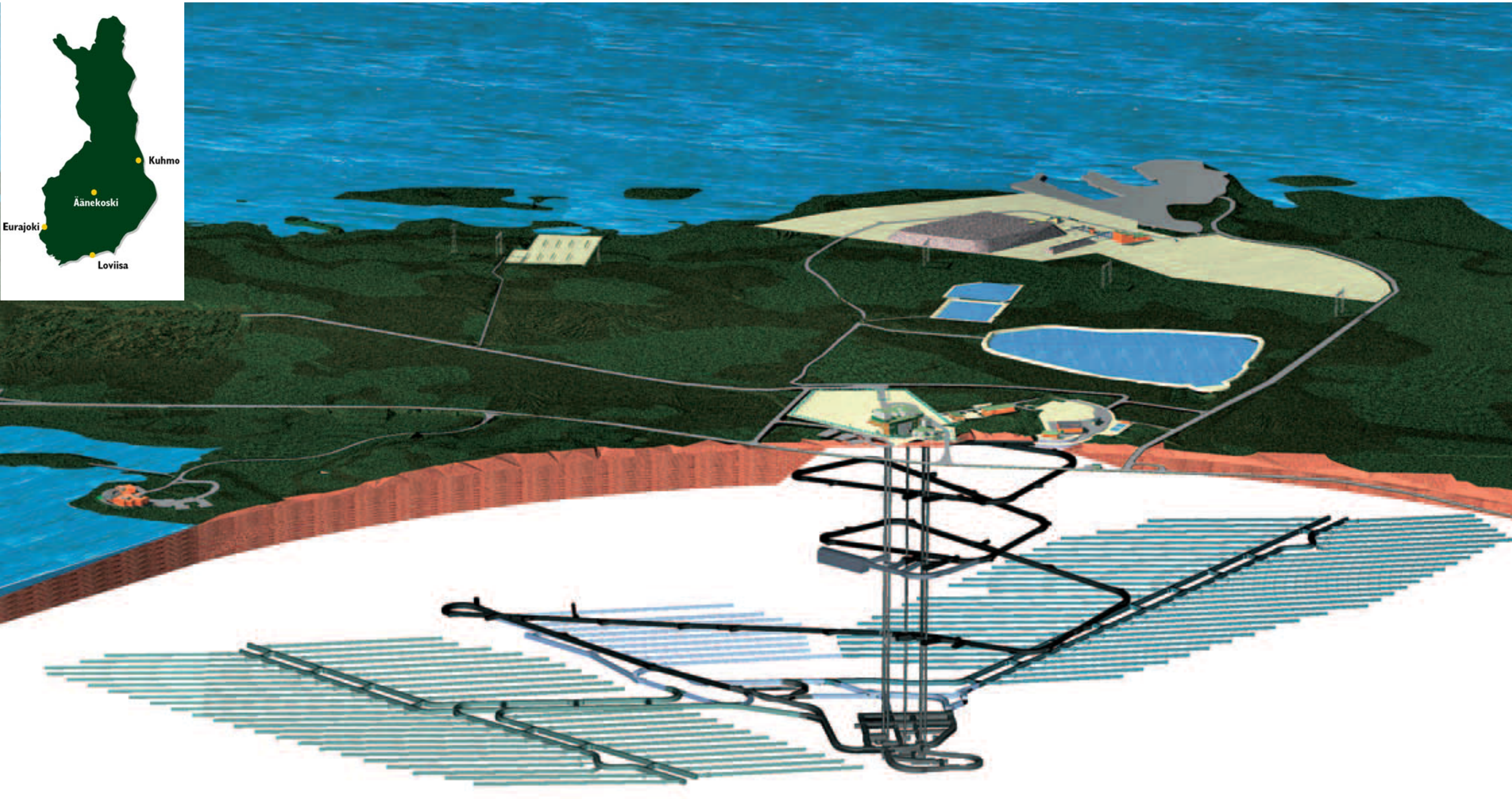




T. Honkamaa, STUK

further development is ongoing in the NINS3 project based at the Helsinki Institute of Physics (research.hip.fi/hwp/nins3/)

Final disposal of spent nuclear fuel



www.posiva.fi/en/final_disposal

Molecular imaging technology

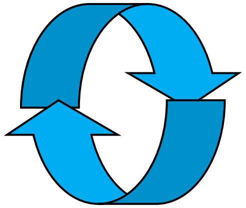
molecular imaging is technologically very advanced…

…but there is room for improvement,
e.g. on gamma ray sensor technology

Benefit of technological progress

improved scanner performance leads to:

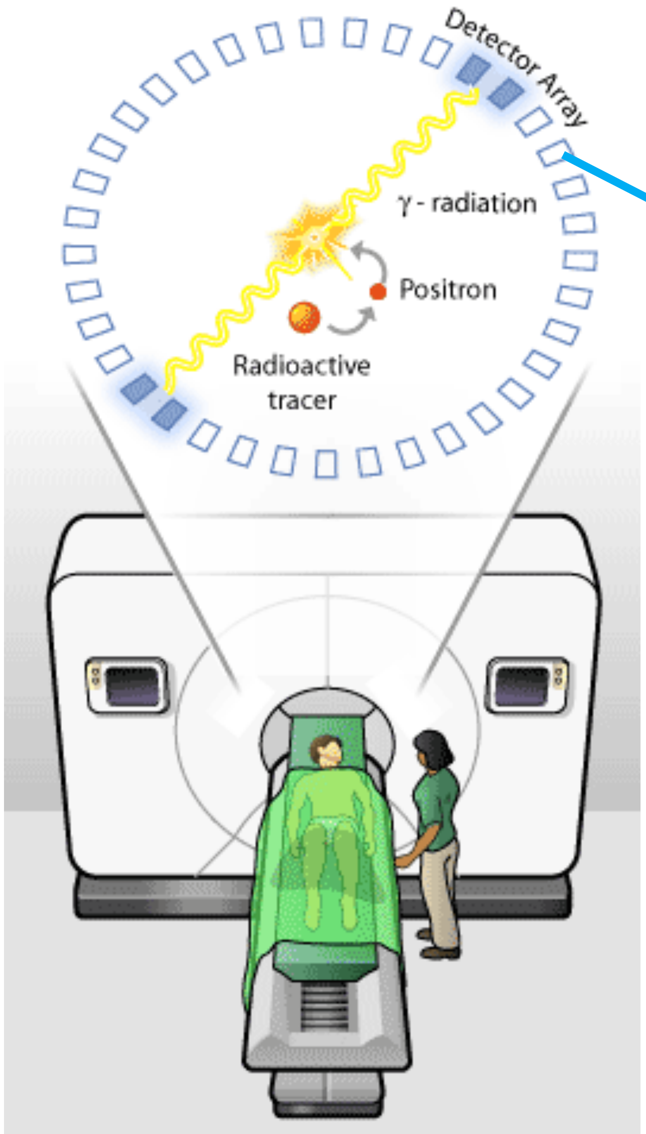
- reduced scan time
- better image quality
- reduced radiation dose to patient and personnel



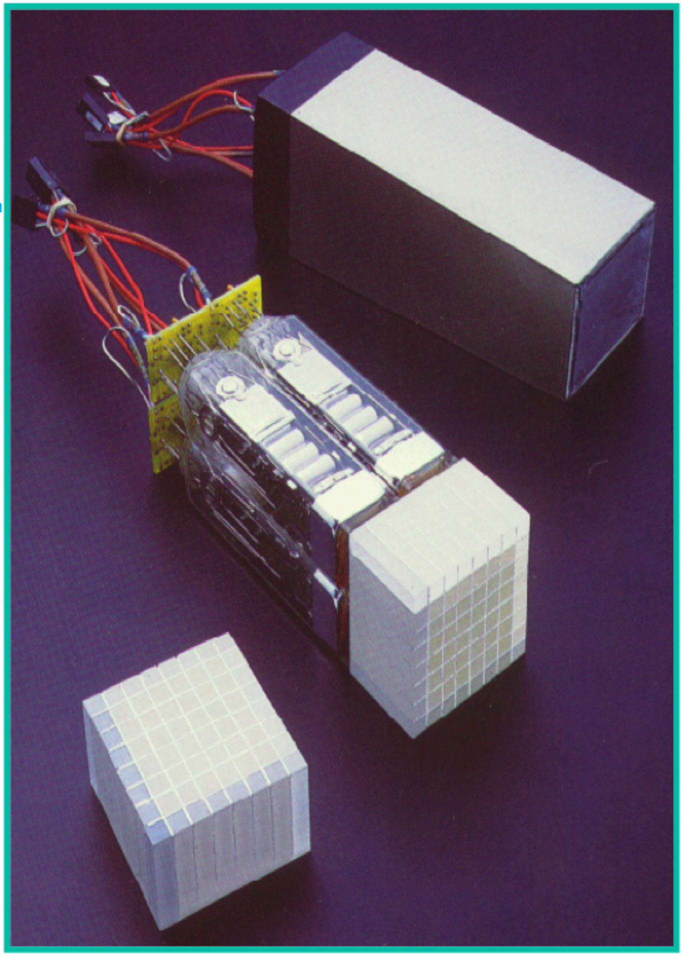
- **new applications**

At the heart of a PET scanner

PET: positron emission tomography



www.bioteach.ubc.ca



The traditional gamma ray sensor

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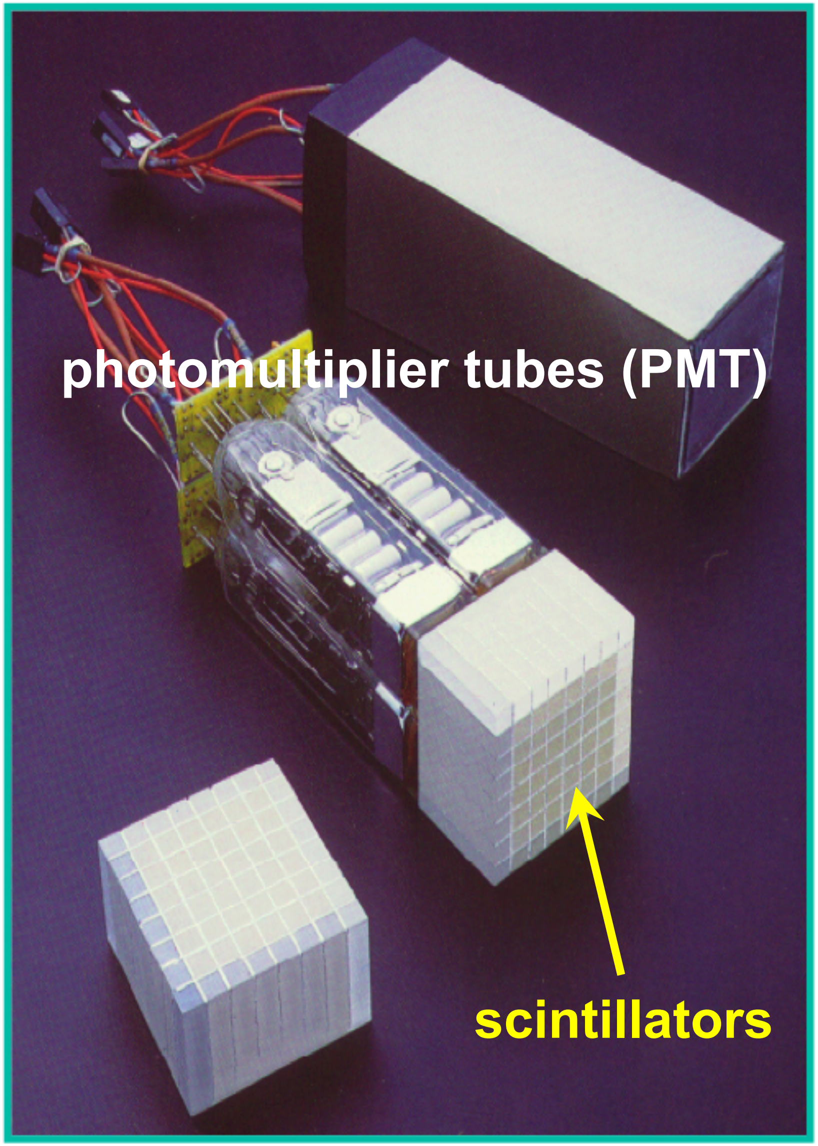

2-step process

gamma ray energy

↓ **scintillator**

light

↓ **photosensor**

electric signal

Benefit of technological progress

better images

being able to see weaker and/or smaller structures
(contrast and resolution)

example: time-of-flight (TOF)
precise time measurement provides **more information** per detected gamma ray

TOF improves image contrast

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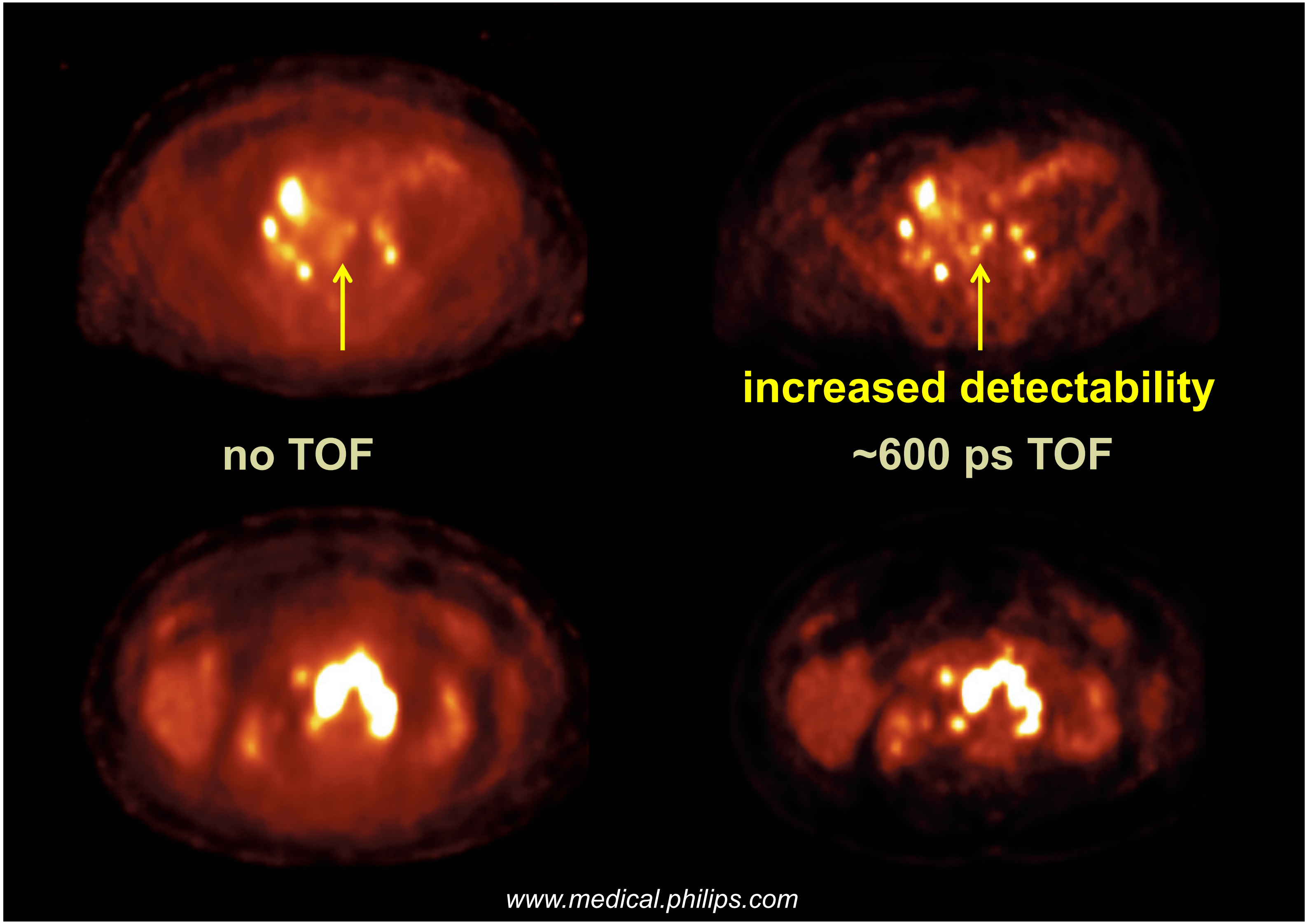

Benefit of technological progress

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new imaging techniques

example: simultaneous functional and anatomical imaging

positron emission tomography (PET)

+

magnetic resonance imaging (MR)

Benefit of technological progress

new imaging techniques

example: simultaneous functional and anatomical imaging

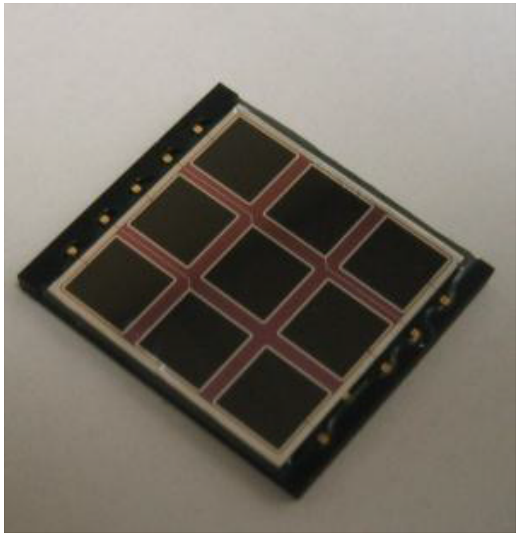
positron emission tomography (PET)

\+

magnetic resonance imaging (MR)

traditional photosensor does not work in a magnetic field

➡ **silicon photosensor**



B.J. Pichler et al,
J Nucl Med 47(2006)639

Silicon photodiodes for PET-MR

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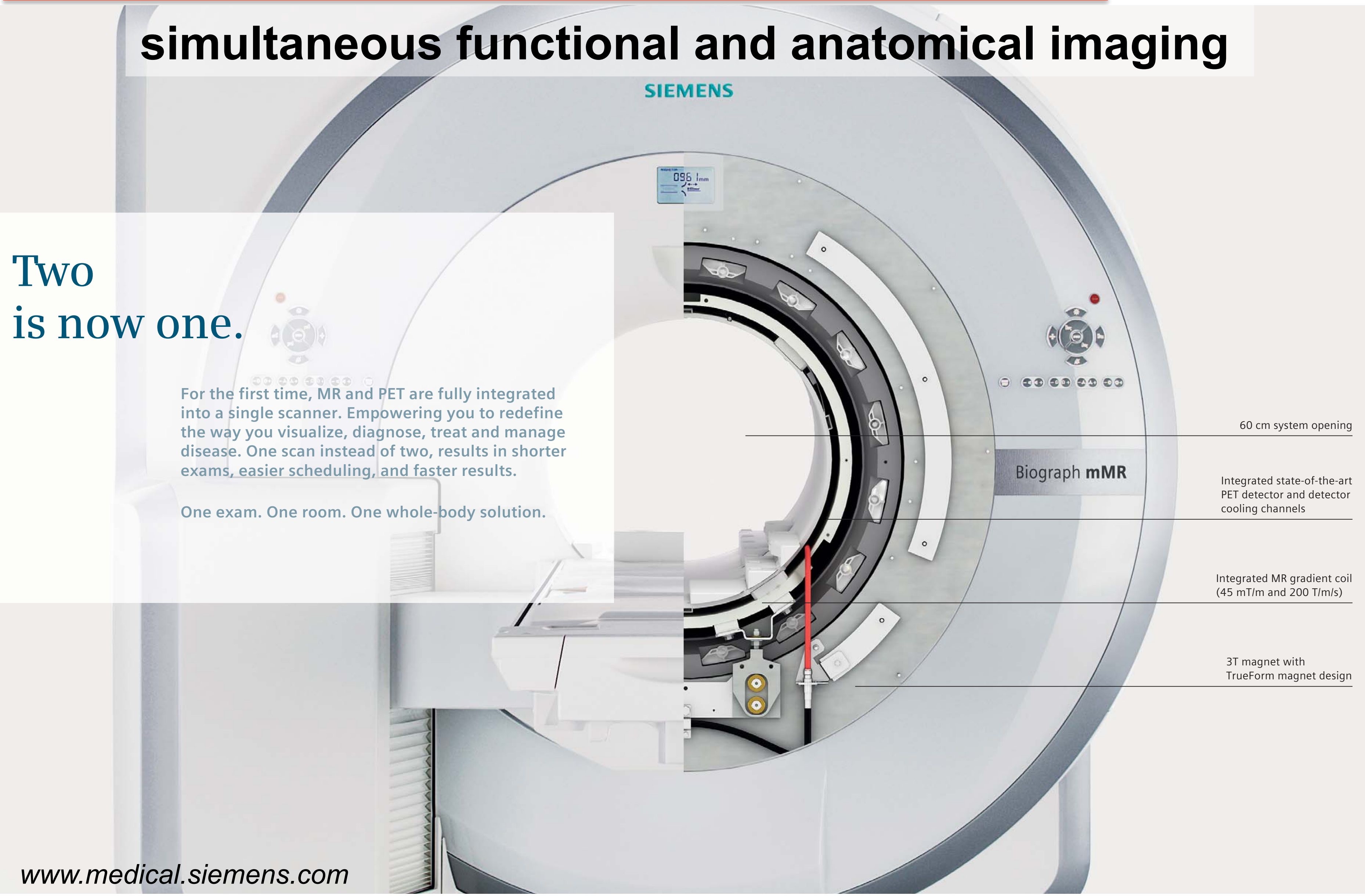
simultaneous functional and anatomical imaging



www.medical.siemens.com

Silicon photodiodes for PET-MR

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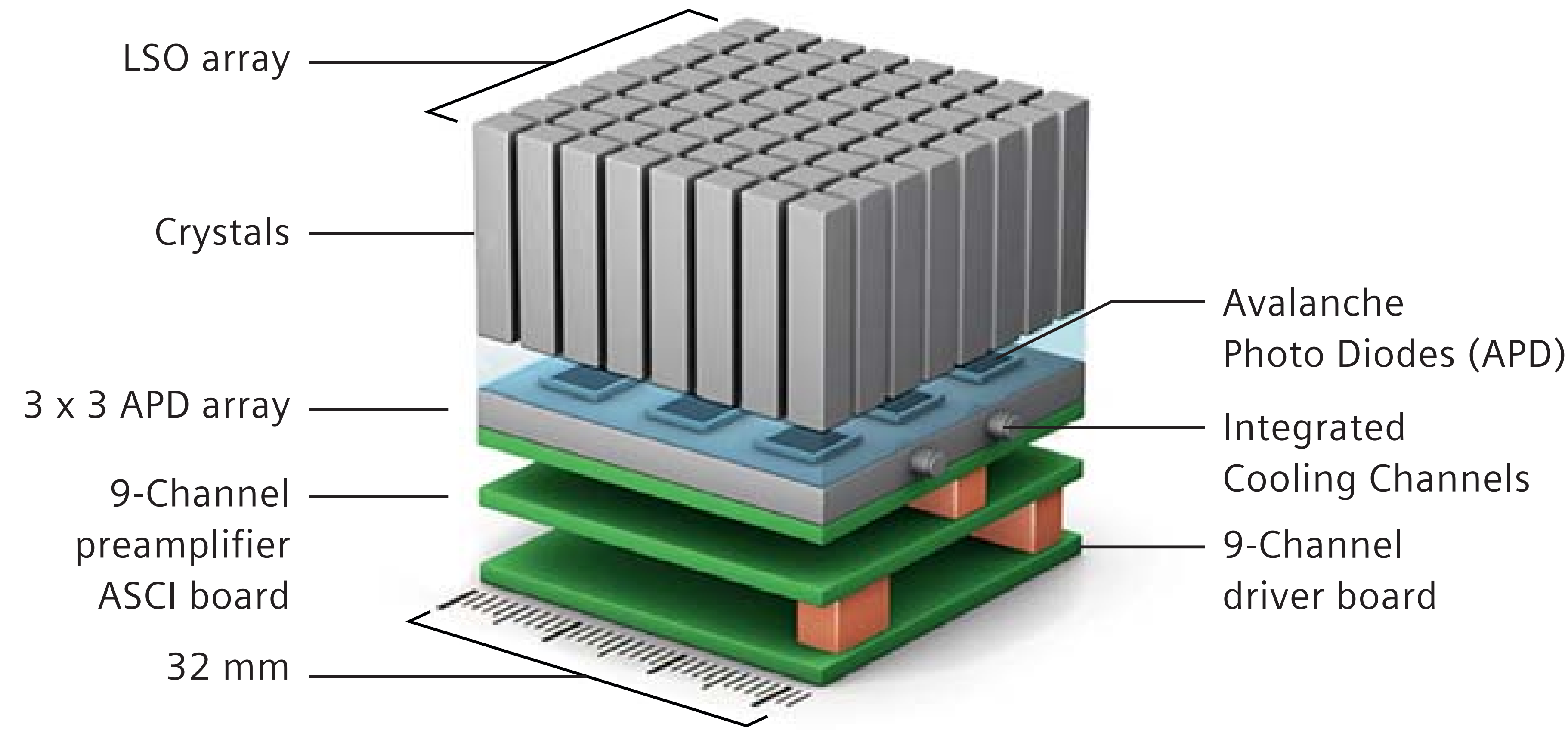

sensor and electronics/data processing are tightly integrated

www.medical.siemens.com

Silicon photodiodes for PET-MR

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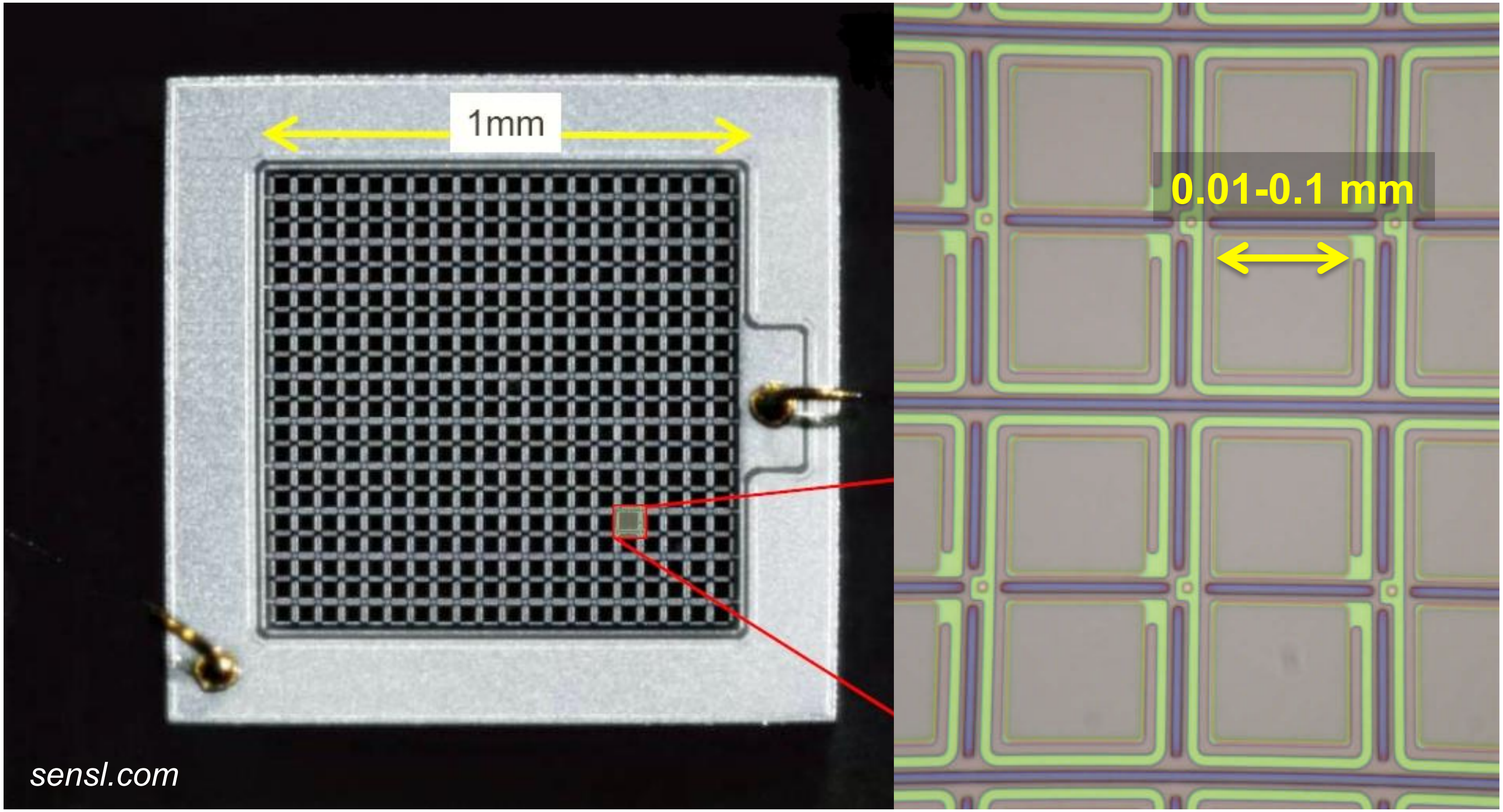
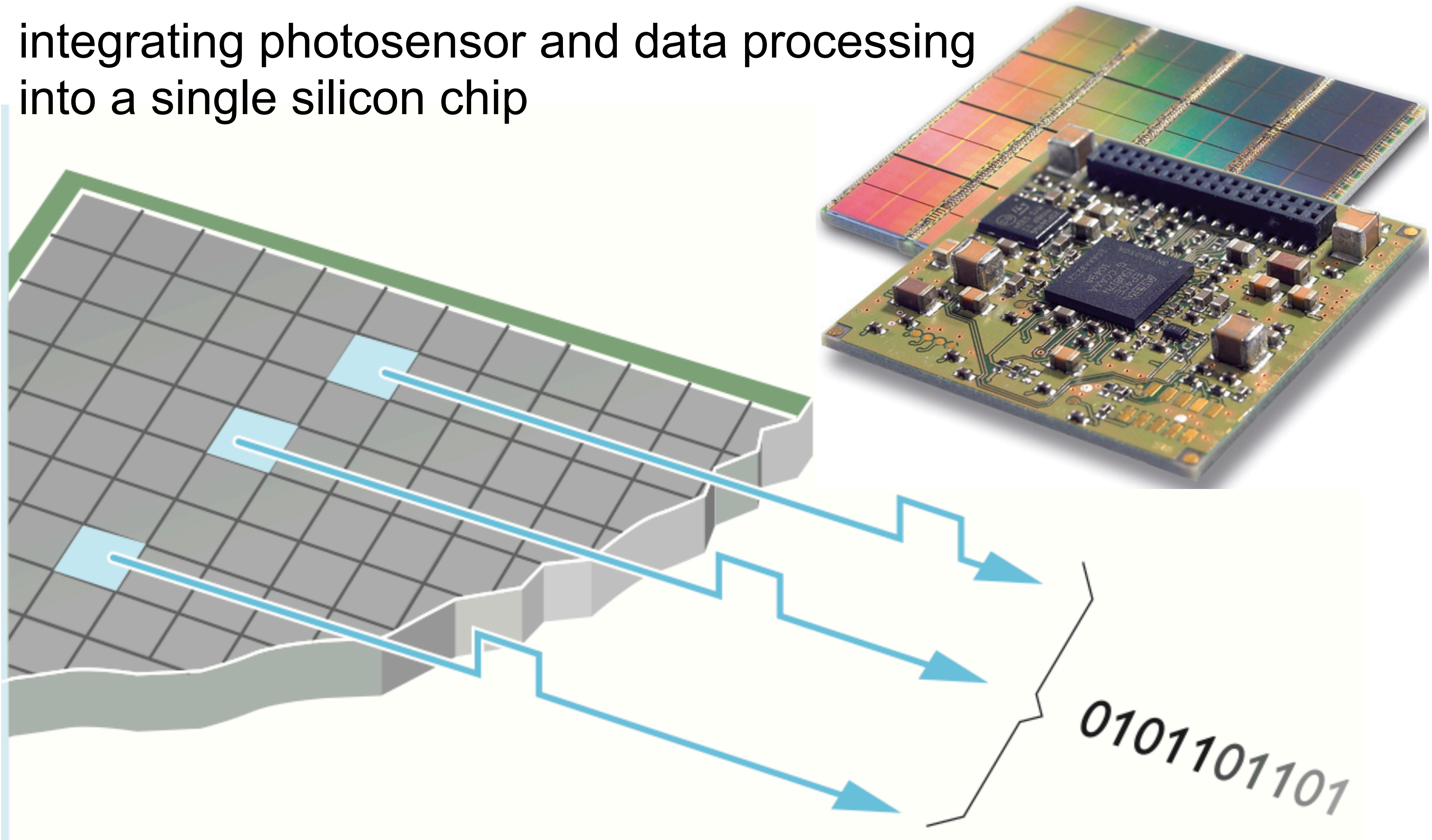
www.medical.siemens.com

SPAD: single-photon avalanche diode



Digital SPADs

integrating photosensor and data processing into a single silicon chip



www.research.philips.com/initiatives/digitalphotoncounting/

Vereos PET/CT (end 2013)

www.healthcare.philips.com

Vereos PET/CT (end 2013)

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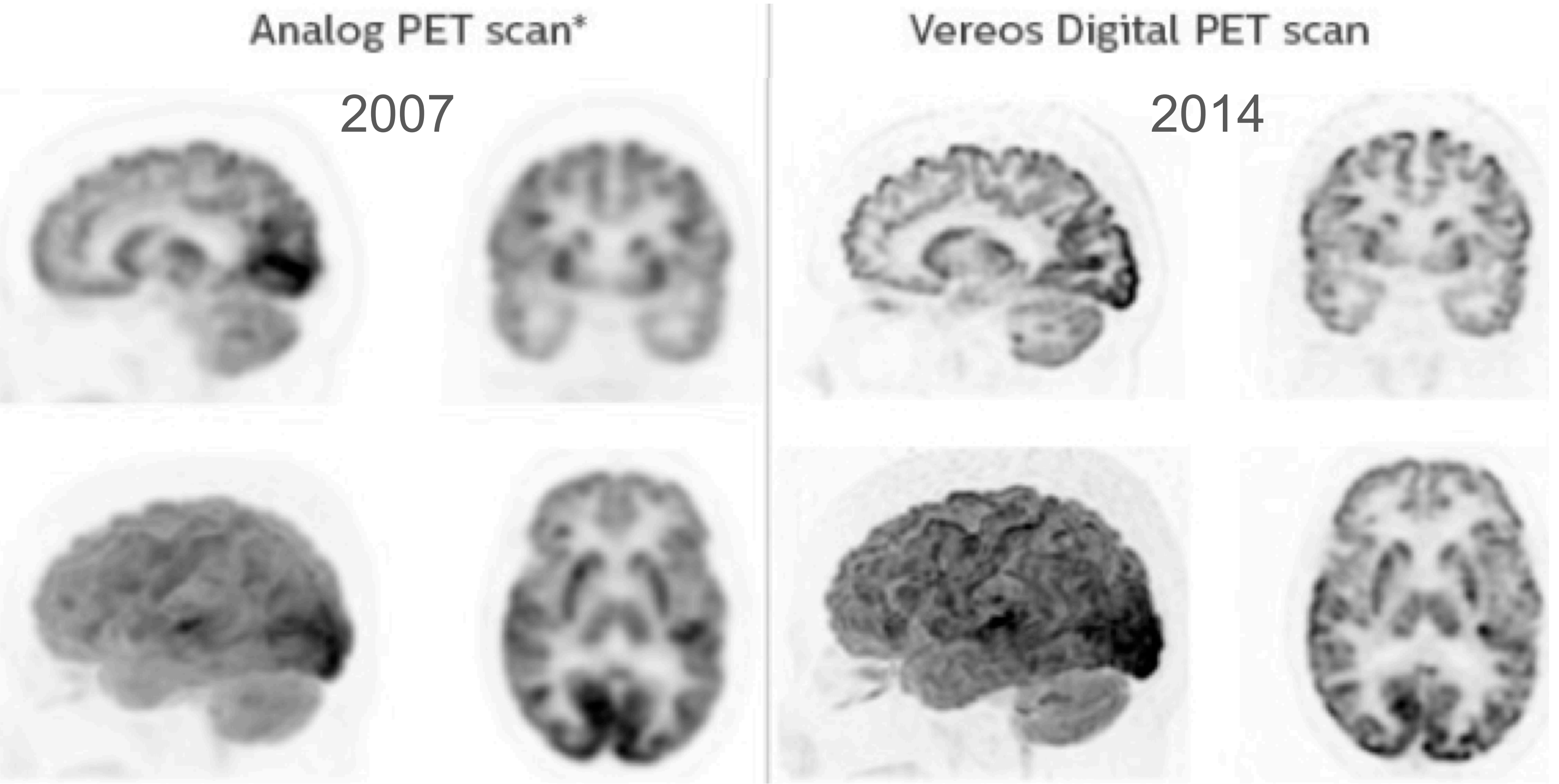

www.healthcare.philips.com

CMOS-based photosensor technology

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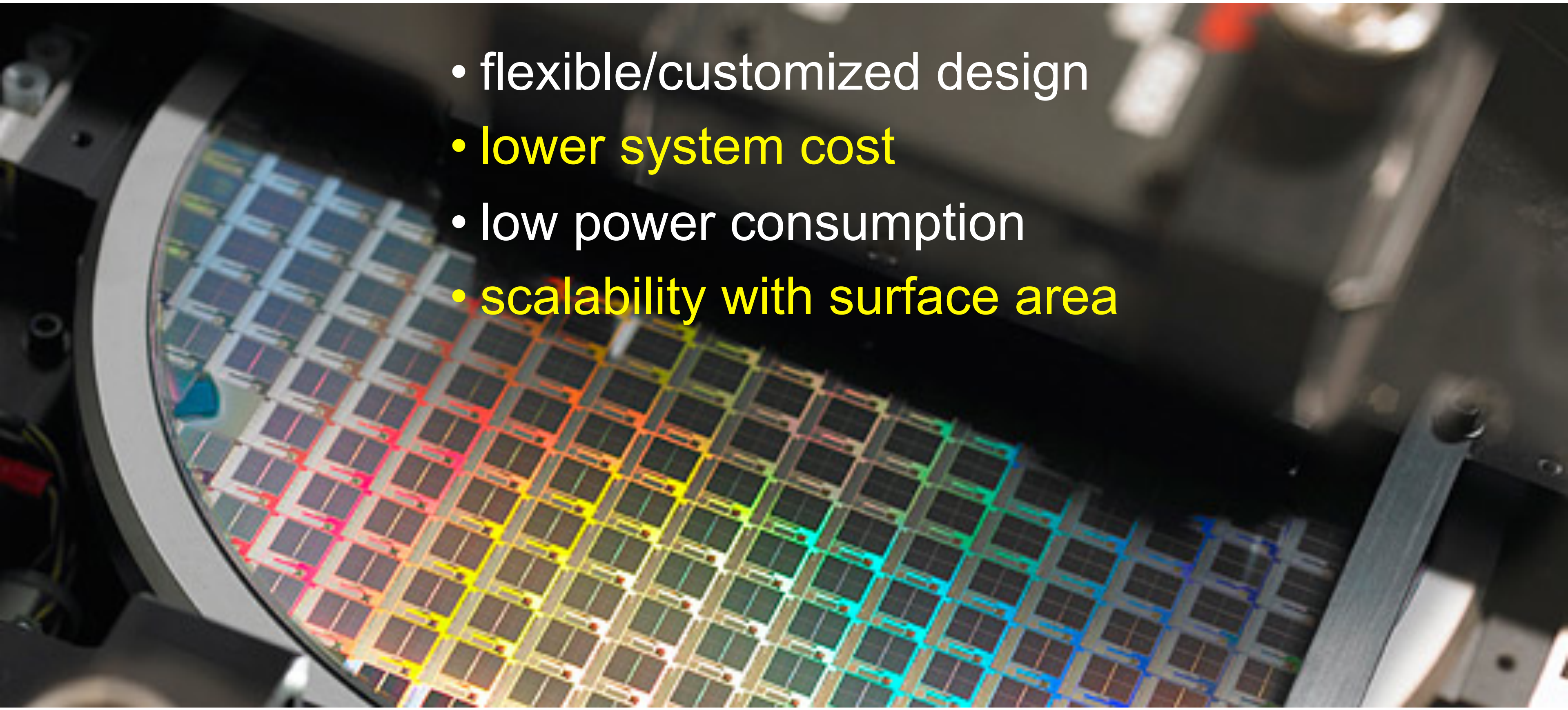
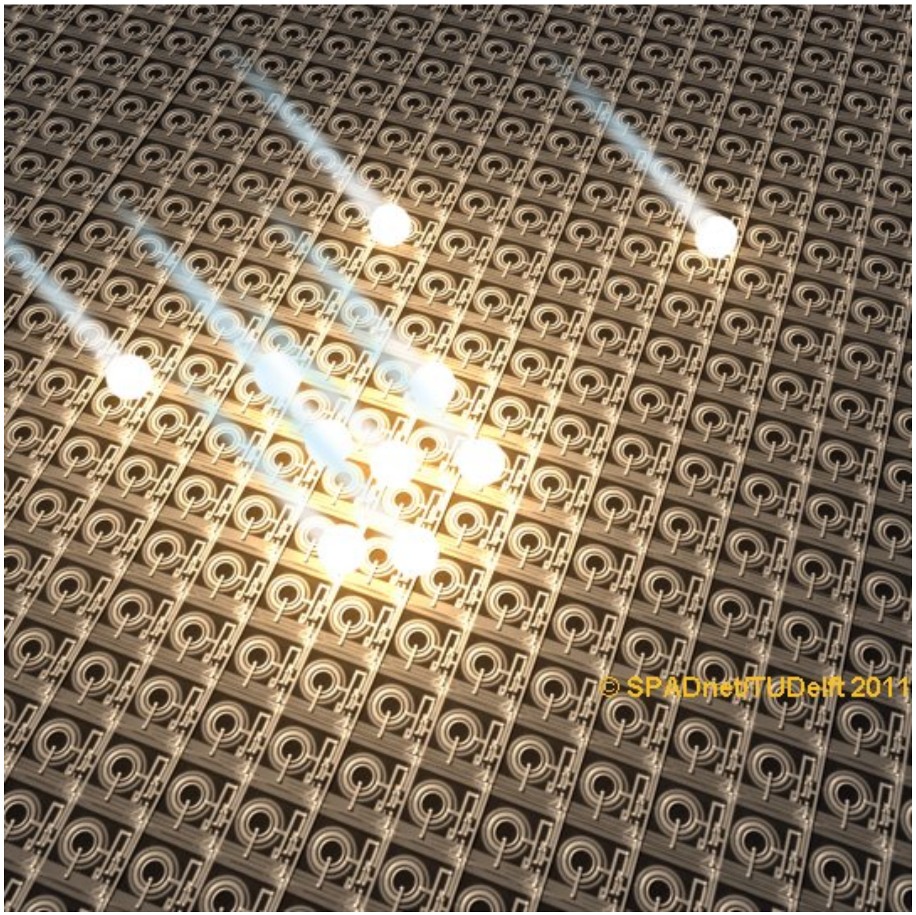
combining high performance SPADs and conventional CMOS logic on the same silicon substrate

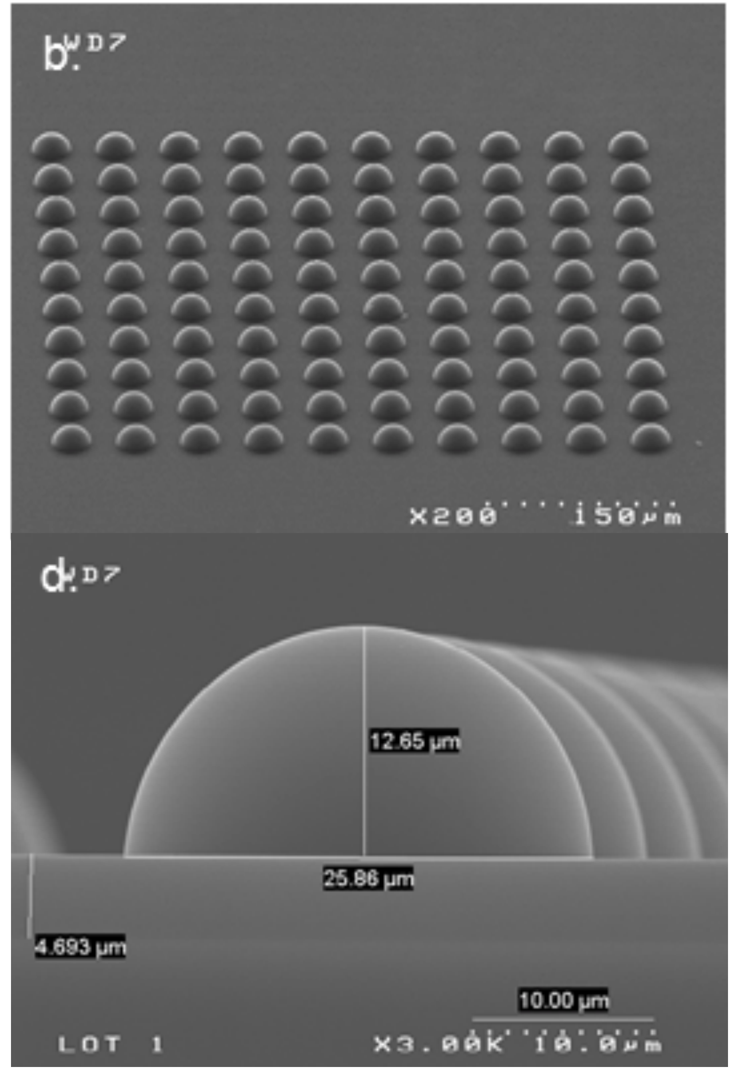


www.research.philips.com/initiatives/digitalphotoncounting/

Further development of SPADs

- improved efficiency





www.spadnet.eu

Further development of SPADs

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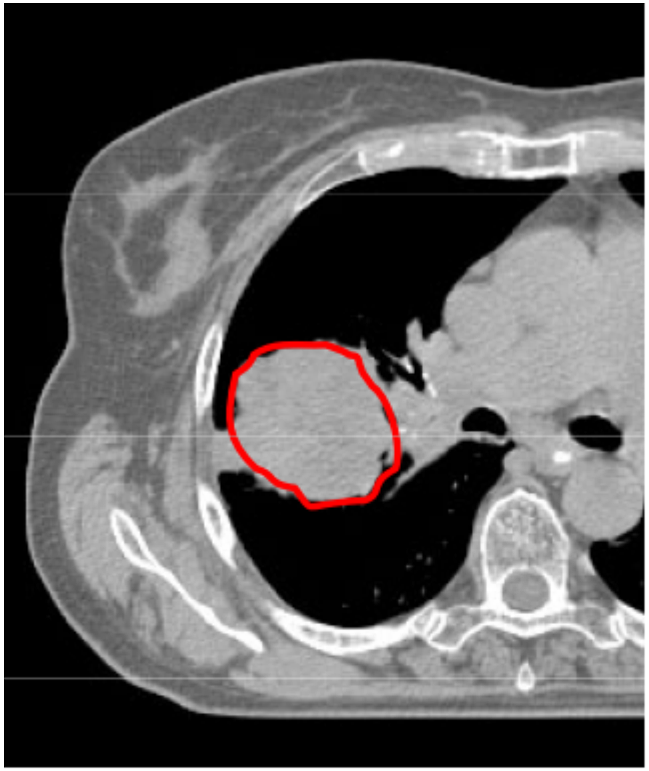
- improved efficiency
- for certain applications: radiation hardness
  e.g. verification of particle beam radiotherapy (“hadron therapy”)

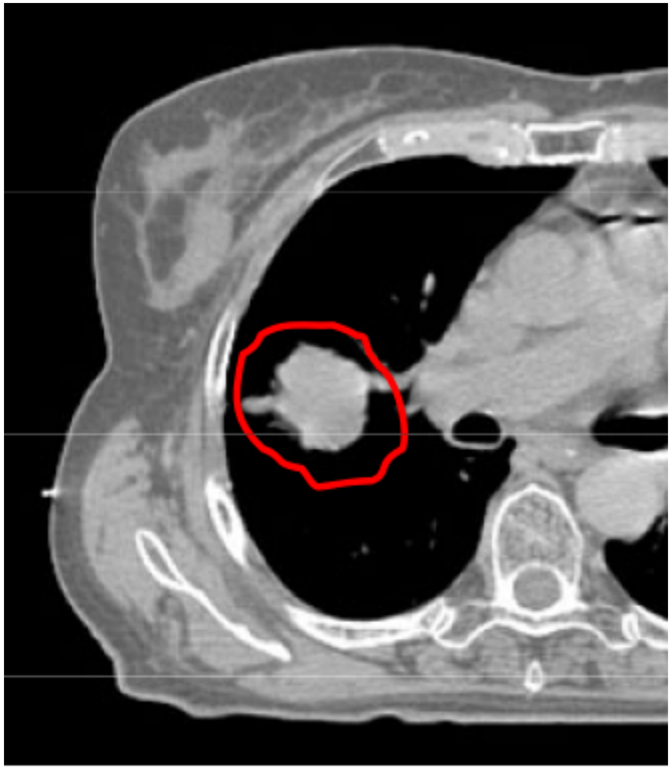
The need for verification of hadron therapy

an example

source: S. Mori en G.T.Y Chen, MGH



before treatment



after 5 weeks

The need for verification of hadron therapy

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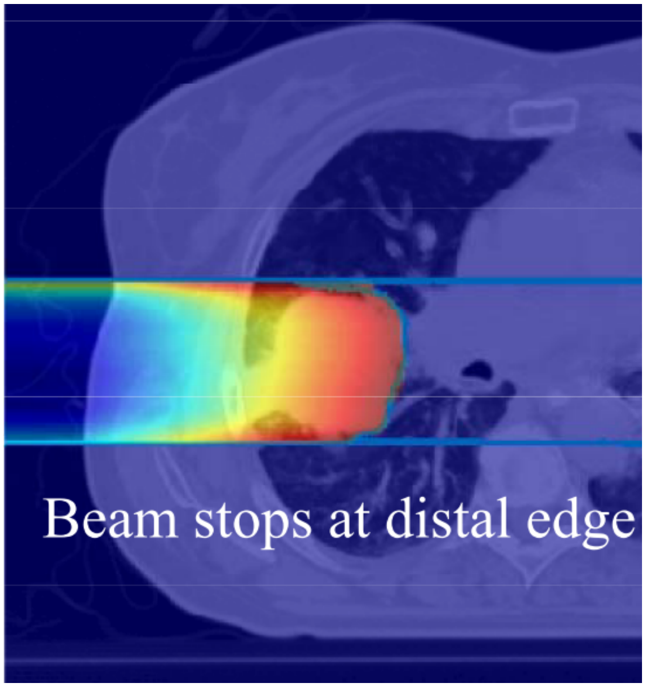
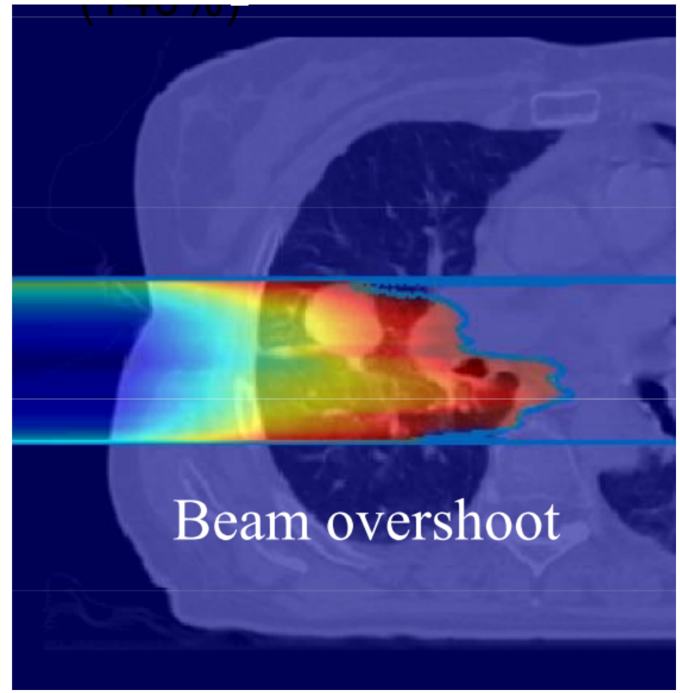
an example

source: S. Mori en G.T.Y Chen, MGH



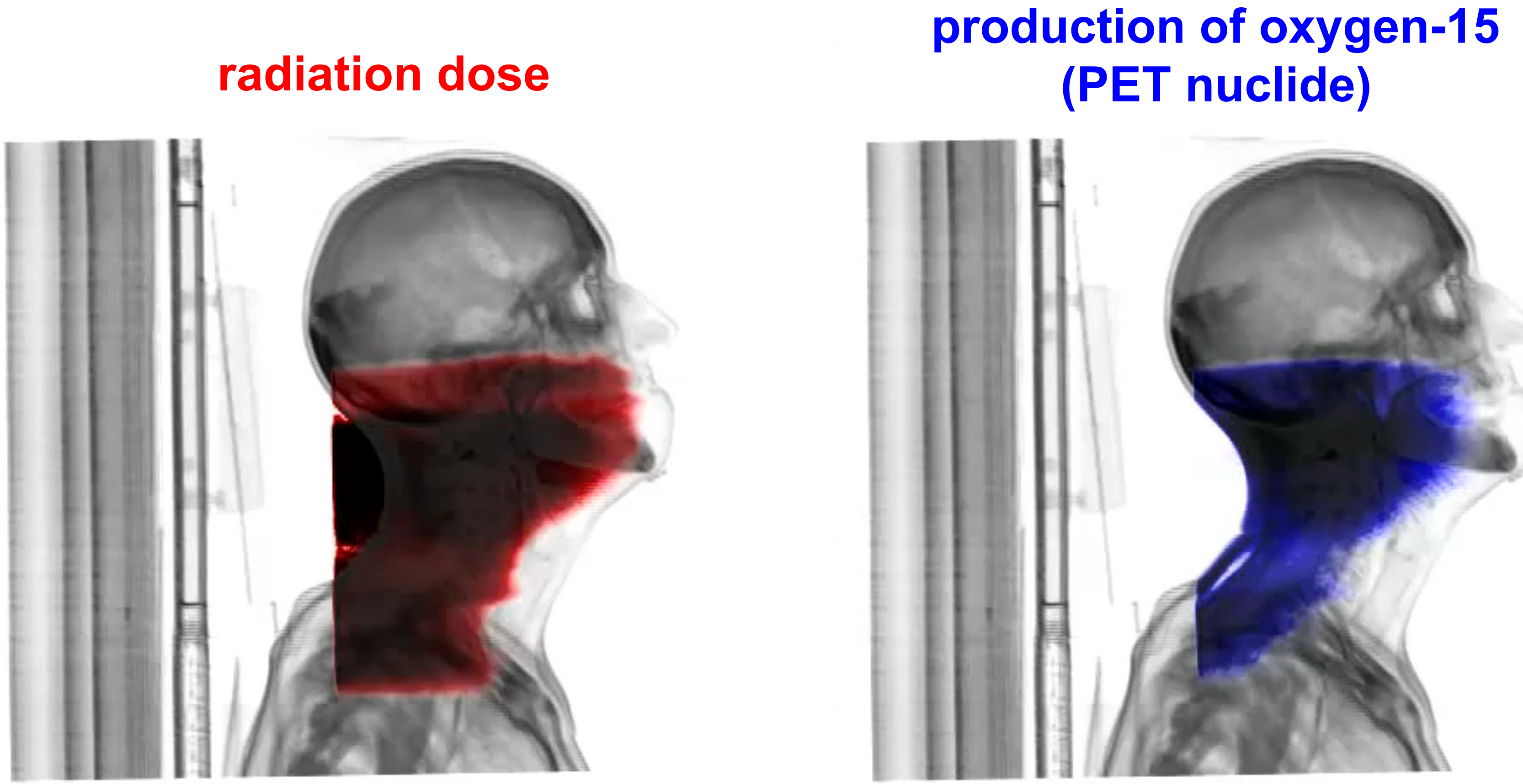
before treatment



after 5 weeks

Verification of hadron therapy

a particle beam creates gamma ray emission from the patient



simulations: KVI-CART, patient input: University Medical Center Groningen

Concluding remarks

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improving gamma ray imaging for health and security

- sensor technology
- image processing and analysis
- combining information from different imaging modalities

applications of gamma ray tomography

- in medicine: high tech but still evolving at a steady pace
- for nuclear safeguards: in its infancy

better technology leads to

- existing applications get better
- new (and unexpected !) applications are possible