university of groningen

kvi - center for advanced radiation technology

HELSINKI INSTITUTE OF PHYSICS

Positron emission tomography without image reconstruction

Peter Dendooven / Aleksandra K. Biegun

p.g.dendooven@rug.nl

KVI – Center for Advanced Radiation Technology
University of Groningen
&
Helsinki Institute of Physics
University of Helsinki

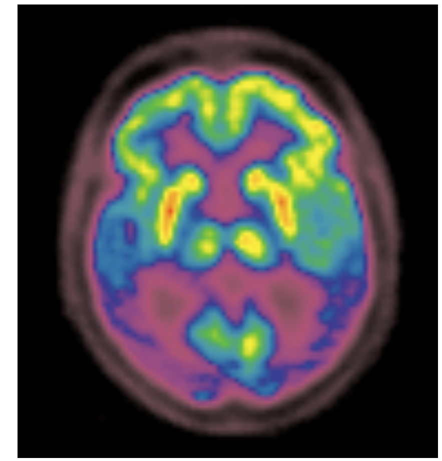
ATTRACT NL Kick-off event
Amsterdam, February 9, 2017

Contents

university of groningen
kvi - center for advanced radiation technology

- **time-of-flight positron emission tomography (TOF-PET)**
- **the concept: Cherenkov TOF-PET**
- **technology needed**
- **potential impact and market**

Molecular imaging



- **radiotracer related to a biological/physiological process**
- **imaging of biological processes: functional, molecular imaging**

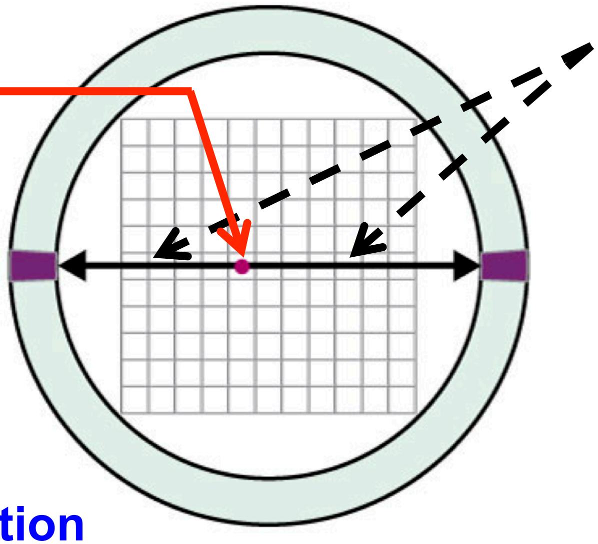
if the radioactive label is a positron emitter:

positron emission tomography (PET)

The principle of PET

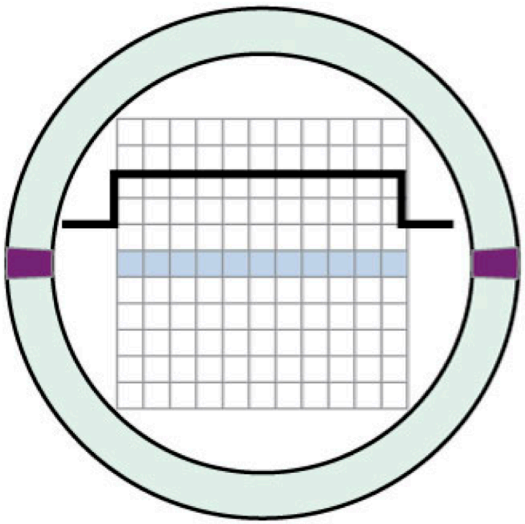
university of groningen
kvi - center for advanced radiation technology

positron annihilation



2 back-to-back 511 keV photons

image reconstruction



The principle of time-of-flight PET

university of groningen
kvi - center for advanced radiation technology

positron annihilation

2 back-to-back 511 keV photons

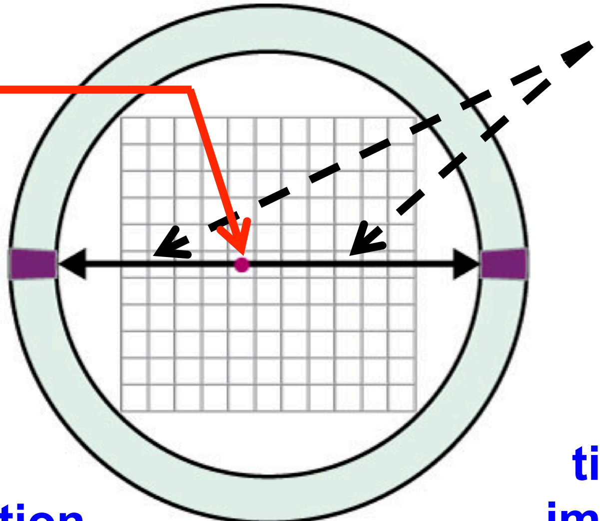
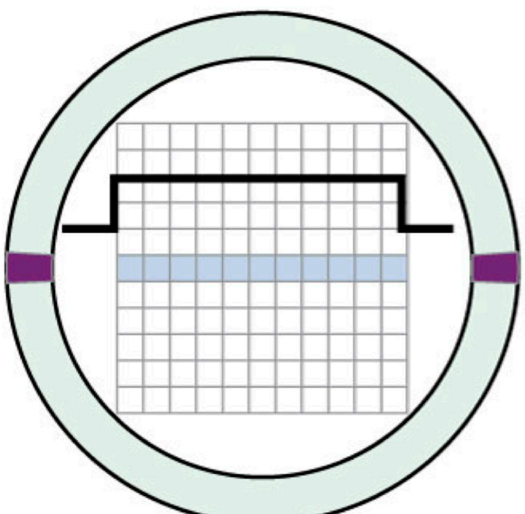
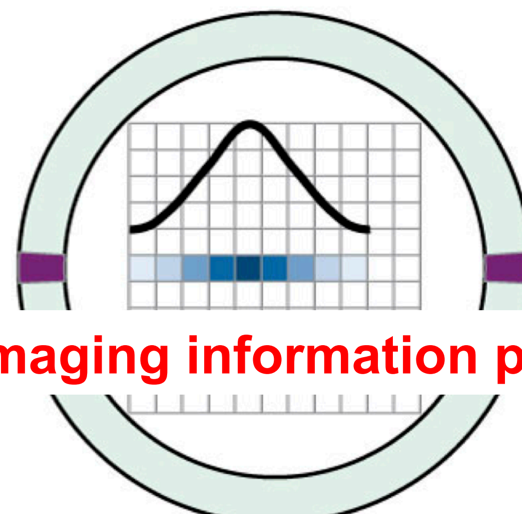


image reconstruction



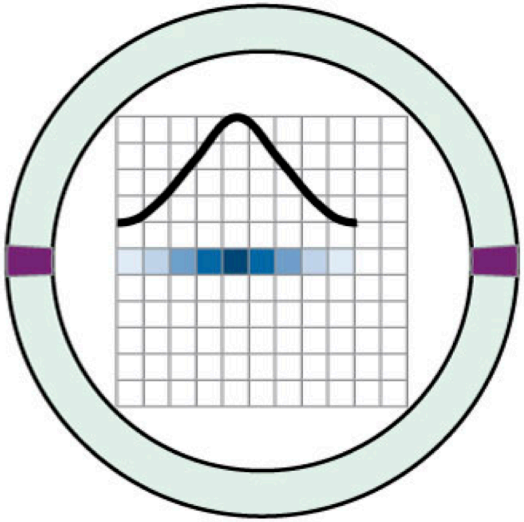
time-of-flight (TOF) image reconstruction



more imaging information per count

Time-of-flight PET (TOF-PET)

university of groningen
kvi - center for advanced radiation technology



$$\Delta x = c \, \frac{CRT}{2}$$

state-of-the-art TOF-PET

- image spatial resolution = **4-5 mm**
- scanner coincidence resolving time:
  $CRT \approx 350$ ps $\rightarrow \Delta x \approx$ **50 mm**

holy grail

$CRT \approx 20$ ps $\rightarrow \Delta x \approx 3$ mm

→ no tomographic image reconstruction needed
paradigm shift !

Coincidence resolving time

university of groningen
kvi - center for advanced radiation technology

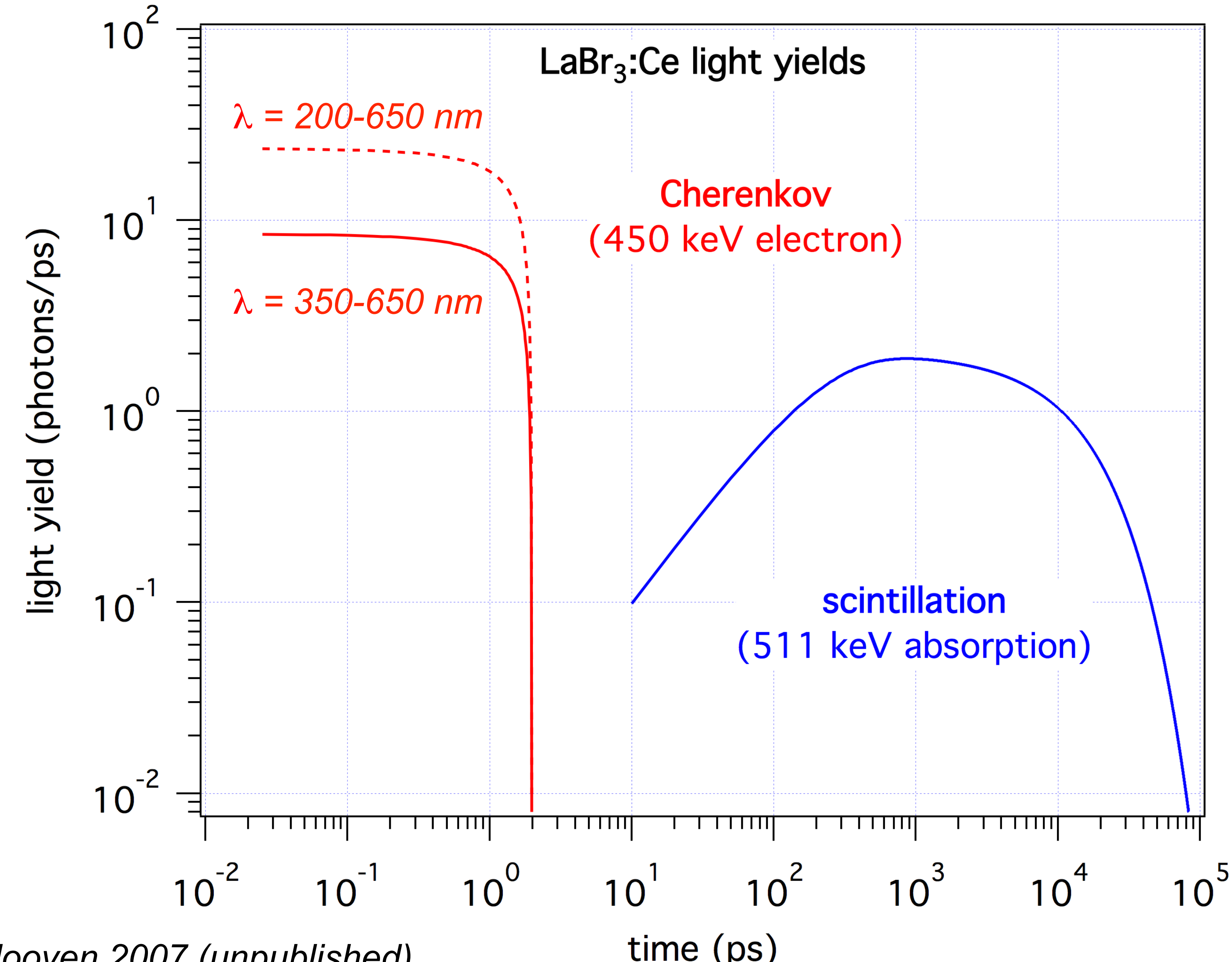
PET detectors are almost always scintillation detectors.

gamma ray energy converted into light

CRT improves as more ~~scintillation~~ photons are detected very soon after the gamma-ray interaction.

The fastest light response of a material to the interaction of gamma rays is Cherenkov light.

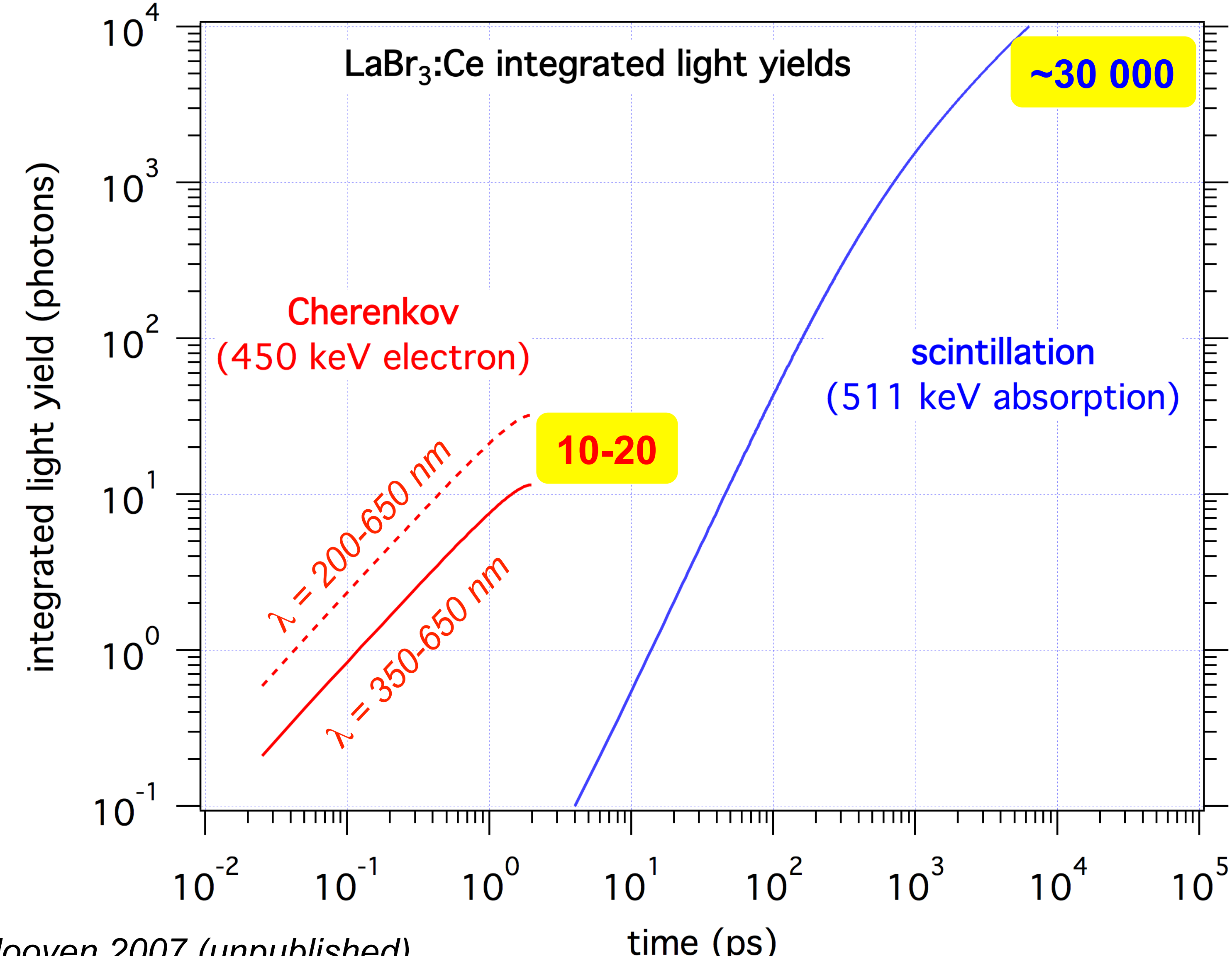
Light yields vs. time



P. Dendooven 2007 (unpublished)

Integrated light yields vs. time

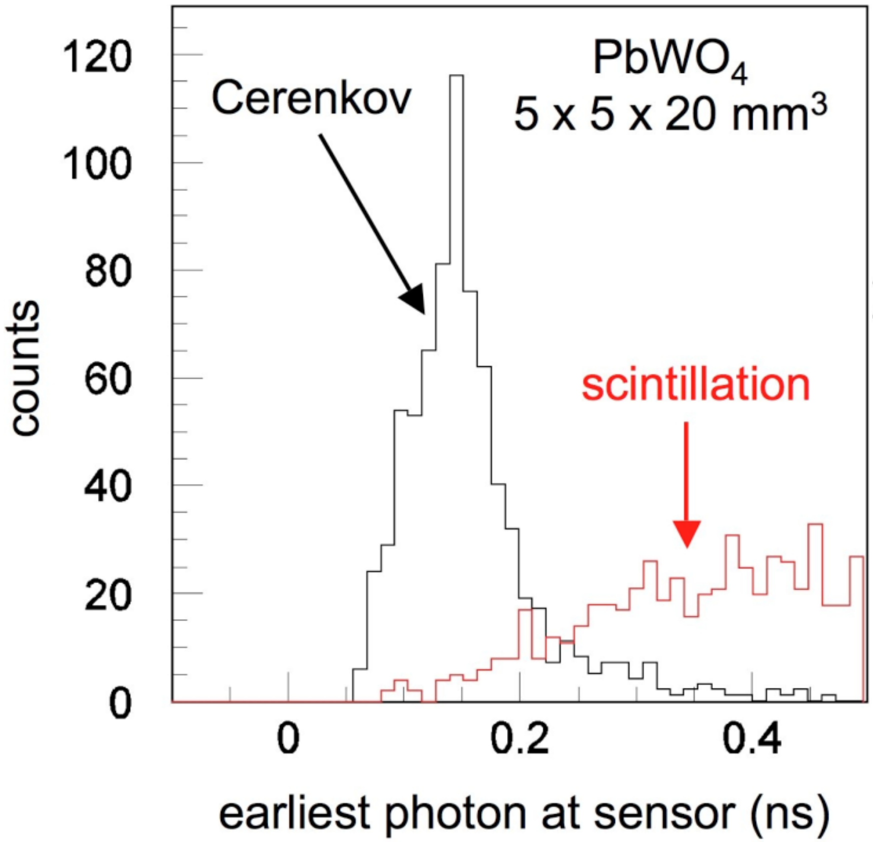
university of groningen
kvi - center for advanced radiation technology

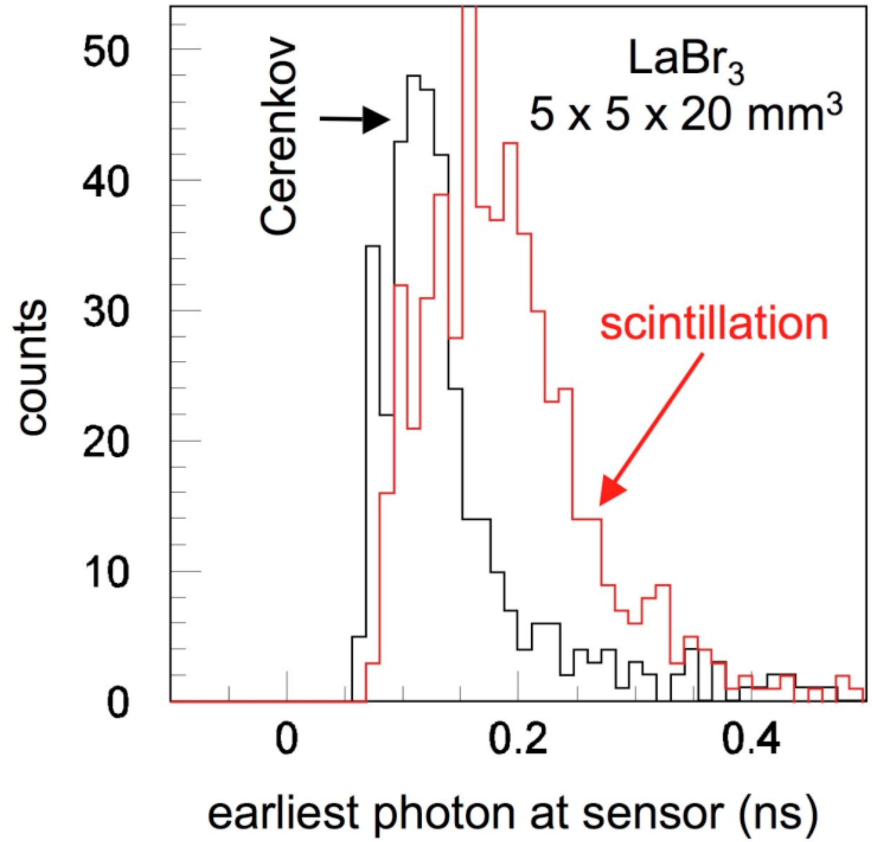


P. Dendooven 2007 (unpublished)

Photons arriving at the sensor

university of groningen
kvi - center for advanced radiation technology





- Geant4 Monte Carlo simulation
- arrival time distribution of the first photon

P. Dendooven et al., abstract/summary submitted to 2008 IEEE NSS-MIC (unpublished)

Combine Cherenkov & scintillation

Cherenkov light for timing and scintillation light for other purposes

Dendooven P.G., "Time-of-flight positron emission tomography using Cerenkov radiation", patent no. WO/2010/085139, filed 26 January 2009, issued 29 July 2010

decoupling of the timing from other information

allows e.g. TOF-PET using slow scintillators (such as BGO)

Progress in Cherenkov TOF-PET

university of groningen

kvi - center for advanced radiation technology

Cherenkov from silica aerogel

Ooba T. et al. 2004 IEEE Nucl. Sci. Symp. Med. Imag. Conf. Record M10-4
Kawai H. et al. 2009 IEEE Nucl. Sci. Symp. Med. Imag. Conf. Record M13-270

Cherenkov from scintillators and heavy glasses

Miyata M. et al. J. Nucl. Sci. Techn. 43 (2006) 339-343
Lecoq P. et al. IEEE Trans. Nucl. Sci. 57 (2010) 2411
Brunner S.E. et al. IEEE Trans. Nucl. Sci. 61 (2014) 443
Dolenec R. et al. IEEE Trans. Nucl. Sci. 63(2016)2478
Kwon S.I. et al, Phys. Med. Biol. 61 (2016) L38

and references therein

Technological progress needed

find and/or engineer optimized scintillation materials:

- high density – high atomic number (efficiency for 511 keV)
- high index of refraction (production of Cherenkov light)
- low density (production of Cherenkov light)
- transparent to UV (transport of Cherenkov light)

develop photosensors:

- superior timing
- UV sensitive

efficient coupling of scintillator and sensor

Potential impact & market

university of groningen
kvi - center for advanced radiation technology

impact in positron emission tomography:

- bright but slow scintillators are useful for TOF-PET
- novel TOF-PET detector concepts and detector materials
- PET without image reconstruction
- cheaper PET imaging

impact in general:

improved technology for any application where ultrafast and efficient detectors for gamma-ray detection and imaging are needed

PET scanner market:

- about 1 billion $ in 2015
- predicted to grow at about 5% per year