From particle physics to medical applications – multispectral photon counting detectors in medical imaging

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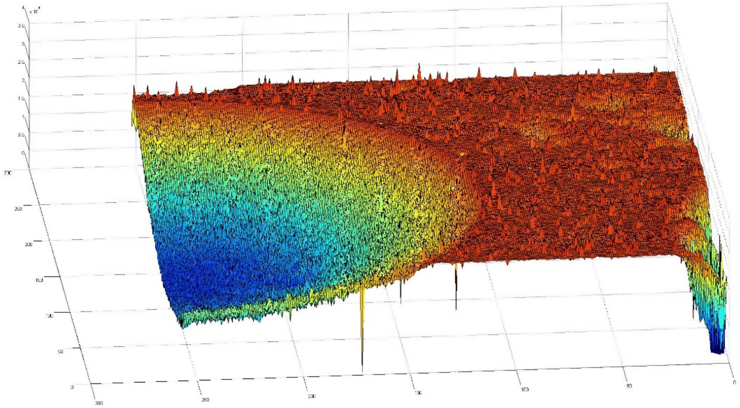
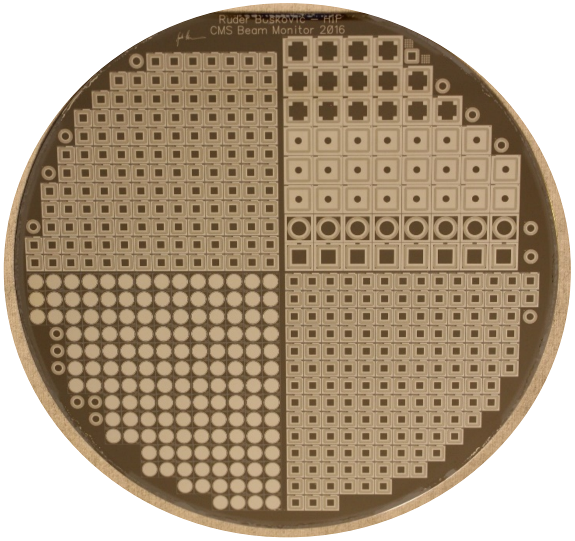




Consortium and collaborators

Consortium members:

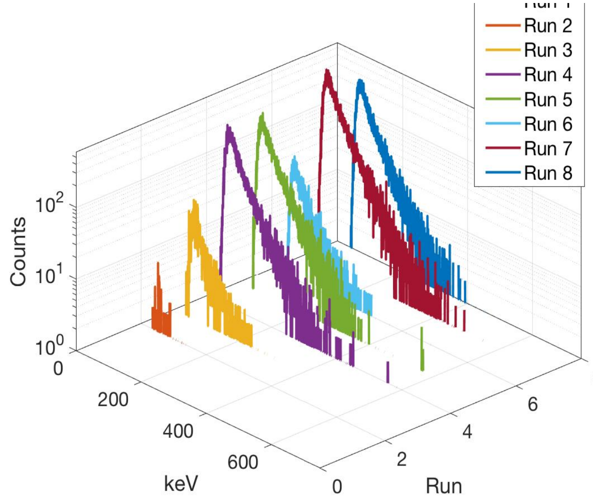
- Helsinki Institute of Physics (**H**)
- Aalto University (**A**)
- Lappeenranta University of Technology (**L**)
- Radiation and Nuclear Safety Authority (STUK) of Finland (**S**)

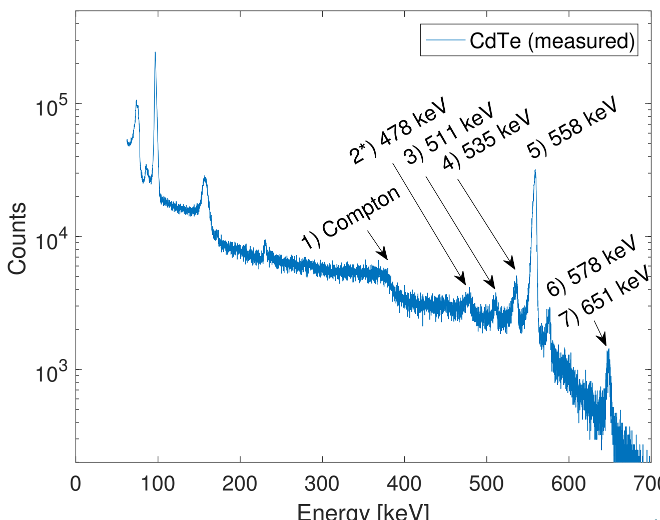
Collaborators:

- Harvard Medical School
- California Institute of Technology
- Ruđer Bošković Institute
- University of Oulu
- Varian Medical Systems Finland
- Detection Technology Plc

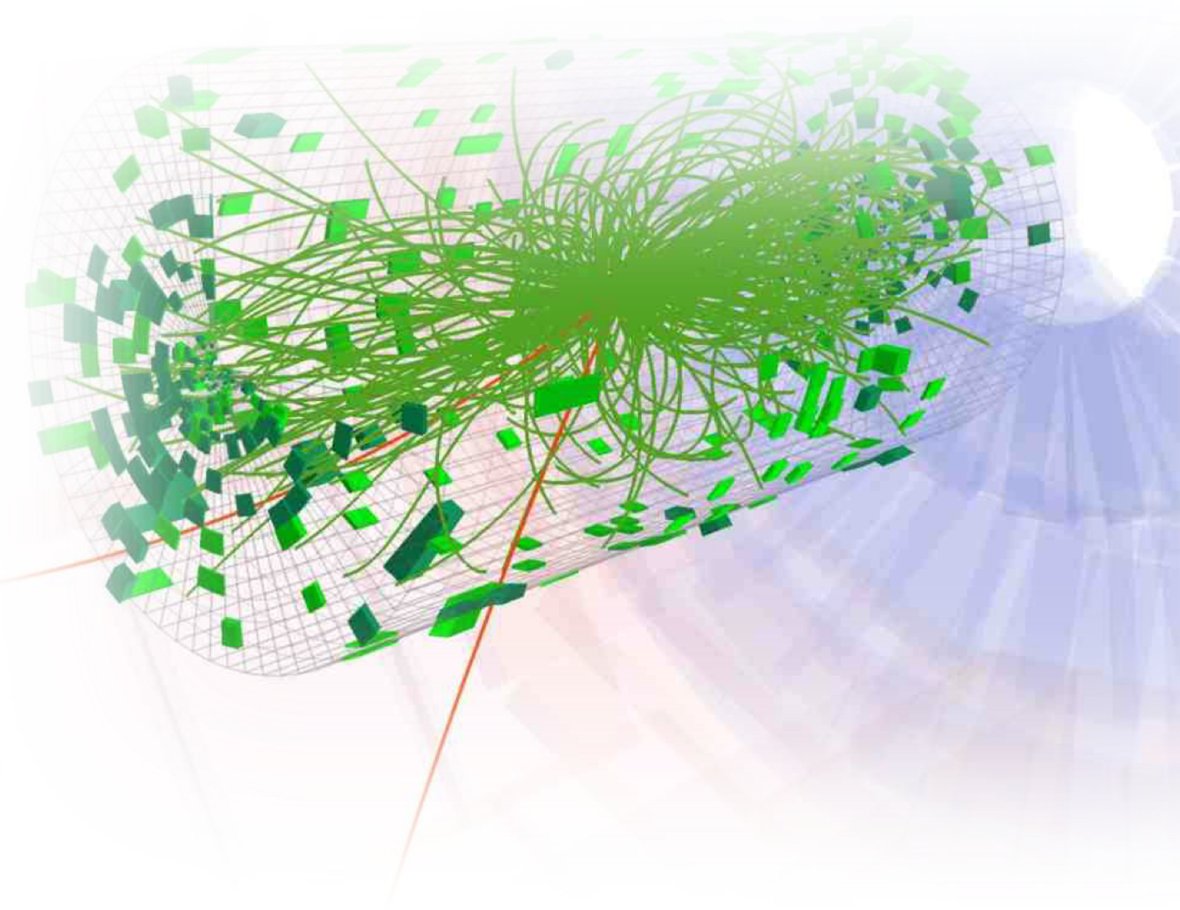
Aim of the project

- In this project funded by Academy of Finland the aim is to develop next-generation medical imaging detection system capable of multispectral imaging.
- Such a system will fundamentally change the way how imaging is done in medical and industrial applications.
- Our approach is to employ a direct detection system based on photon counting, which would open possibilities for new diagnostic procedures due to:
    - superior efficiency
    - contrast
    - image quality and
    - lower patient dose

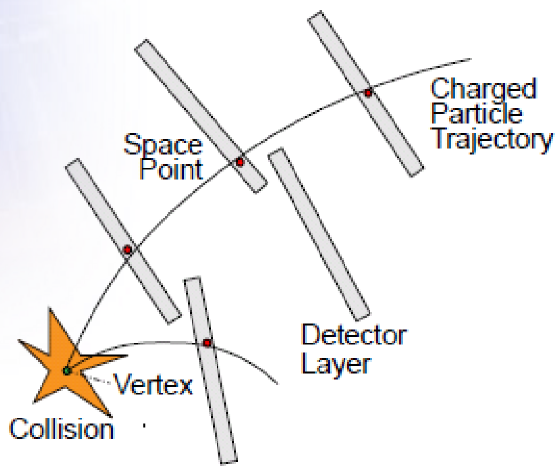


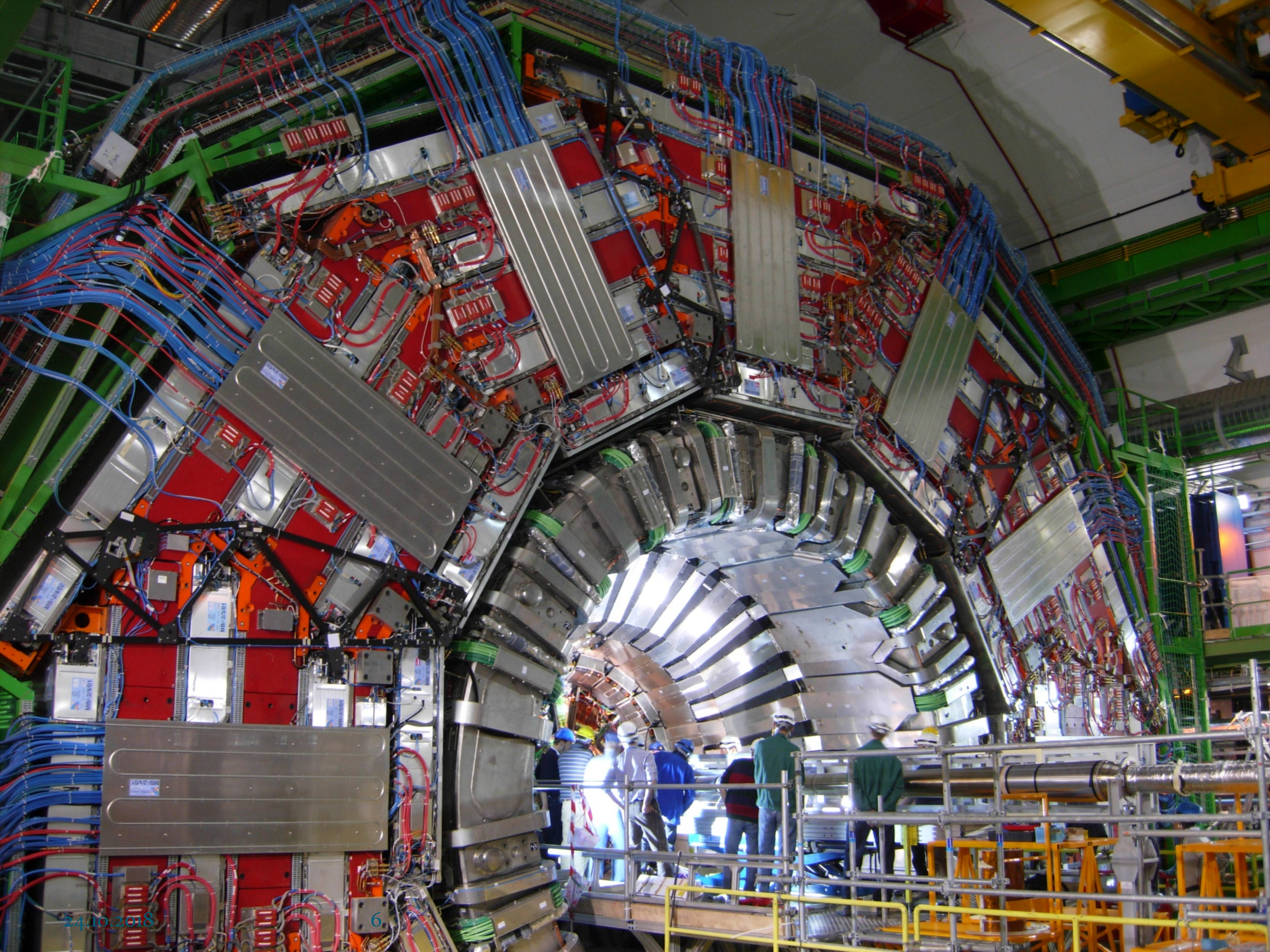


Background



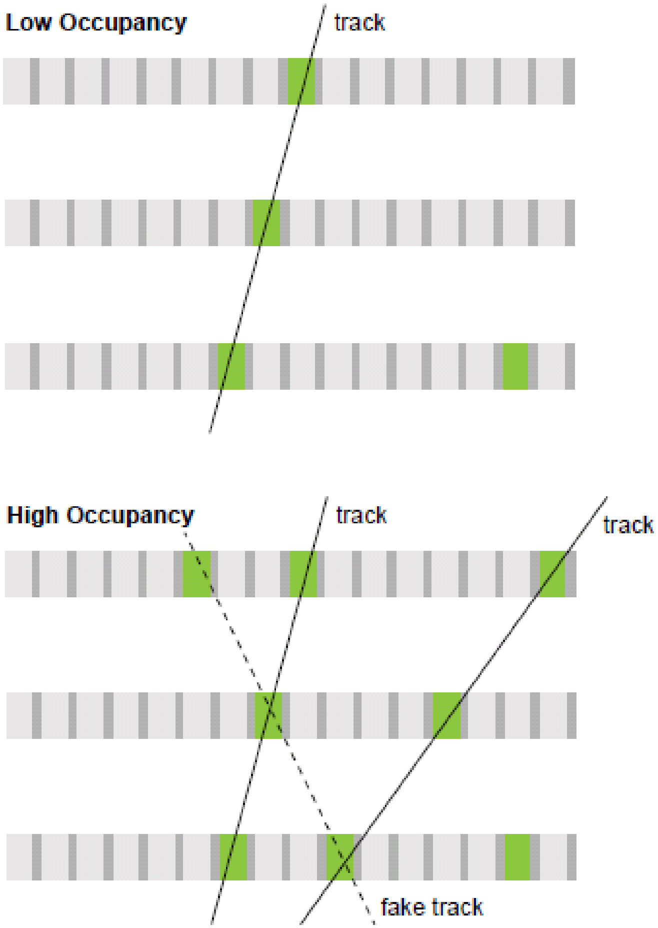
- The idea started from high energy particle physics, where we need very precise pixel detectors on the innermost layers of the tracking systems.





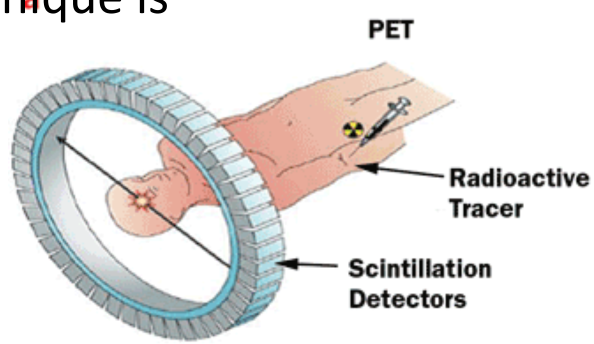
And why pixel detectors?

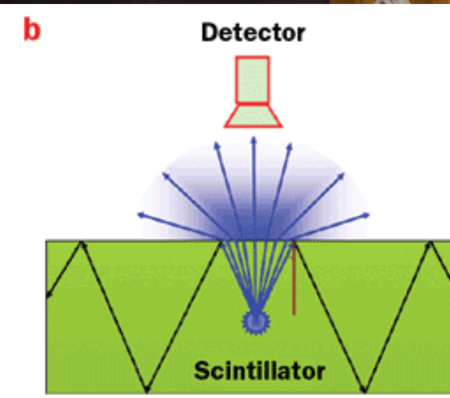
- Resolution and material budget:
  - Small pixels → high hit resolution → high track and vertex resolution
  - Material budget: 3D space point with a single detector layer
- Tracking advantages of highly segmented detectors:
  - Low hit occupancy → low hit combinatorics
  - "Track seed" from region with smallest probability for wrong assignment of hits to tracks
- **Many of these are also requirements needed from medical imaging detectors.**



Detectors with high quantum efficiency

- In medical applications, bulk of the imaging systems are based on scintillation detectors with limited energy resolution → lower image quality and longer exposure times.
- Detectors with higher quantum efficiency allow superior image quality by producing more signal per ionizing event
- Very efficient detection technique is direct conversion of radiation into electrical signal, so-called photon counting (PC).

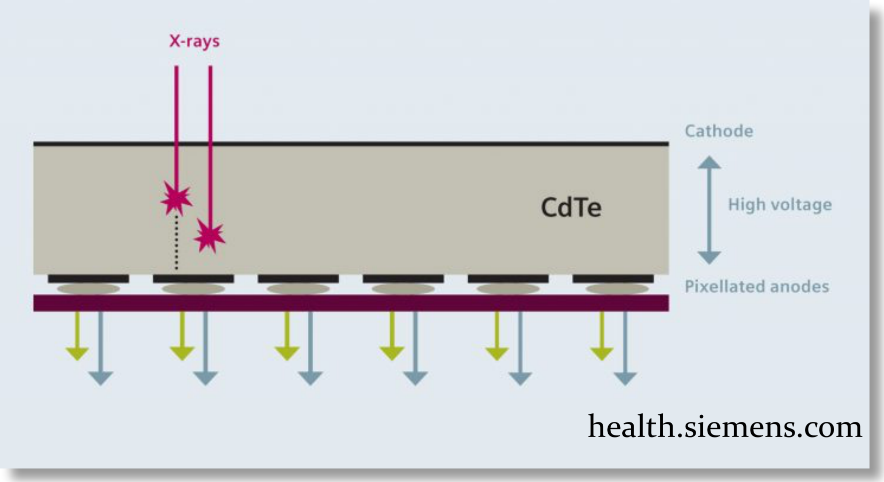




www.photonics.com

Photon counting

- In photon counting, analysis of the spectral composition of the data can be used to efficiently separate different tissue types of similar density.
- This enables new diagnostic possibilities and increases the accuracy.
- The higher efficiency and thus lower patient dose, can further be improved by employing direct conversion in combination with thick (>1mm), or high-Z materials.



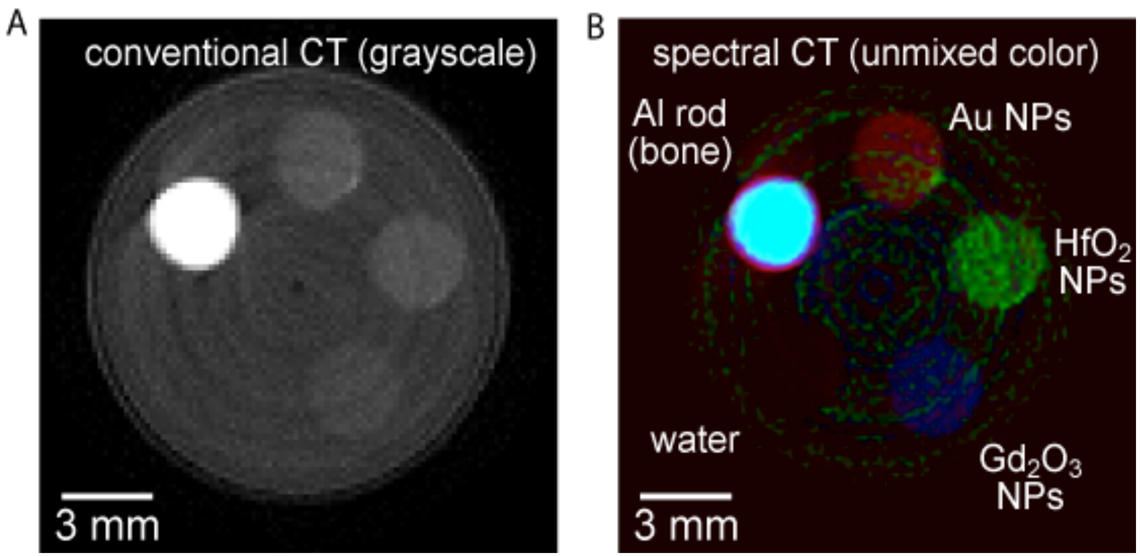
- Certain materials like CdTe can directly convert X-rays into electrical current.
- Thus, each photon can be detected individually and its energy can be measured.

Multispectral imaging

- A detector capable of PC operation can also be operated in multispectral mode.
- This refers to the simultaneous detection of more than one radiation type (photon-, proton-, or neutron radiation).
- Such capability will have immediate impact on radiation therapy, dosimetry and patient safety.

Higher efficiency
= lower dose
Better contrast
"Colored X-rays" - spectral resolved images

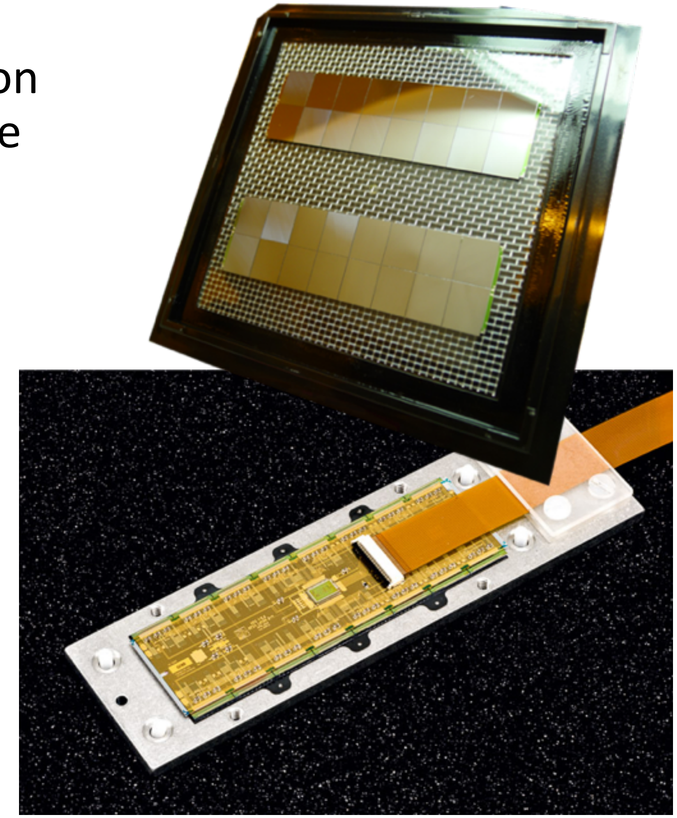
Direct conversion detectors can "see" X-ray colors

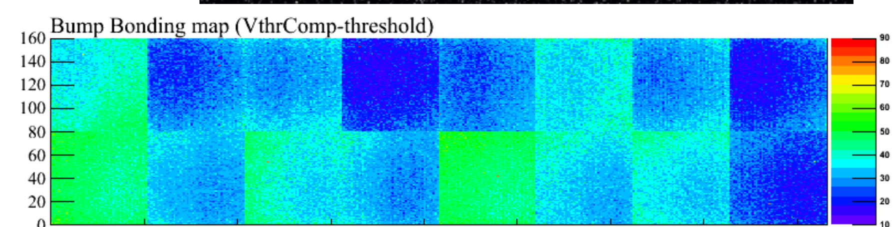


[Accessed: 11.10.2017; adapted from http://www.pion.cz/_sites/pion/upload/images/a14cf10a5583d19f7cfdebd63cf64382_electromagnetic-spectrum.png]

How to achieve this?

- Reliable detector production techniques and photon counting mode of the read-out chips (ROCs) are the main challenges.
- Fortunately, these have already been addressed in high energy particle physics.
- Now we are bringing this technology to the medical field.
- The plan is to combine quantum efficient detector materials (Cd(Zn)Te and thick silicon with the readout electronics used in the Compact Muon Solenoid (CMS) experiment at CERN.
- The resulting detection system will be capable of preserving the full energy spectrum of the applied radiation (PC mode) and will be capable of multispectral operation.





Semiconductor processing and electronics

- As a group we have access in the Micronova semiconductor processing facility that includes 2600 m^2 of cleanrooms and processing lines for silicon CMOS, MEMS, III-V optoelectronics and thin film devices.
- Thus, we are rather rare research group in that sense that we can actually process all the detectors for our research “in house” within our group.
- I.e. we do everything from detector design up to the fully functional detector.

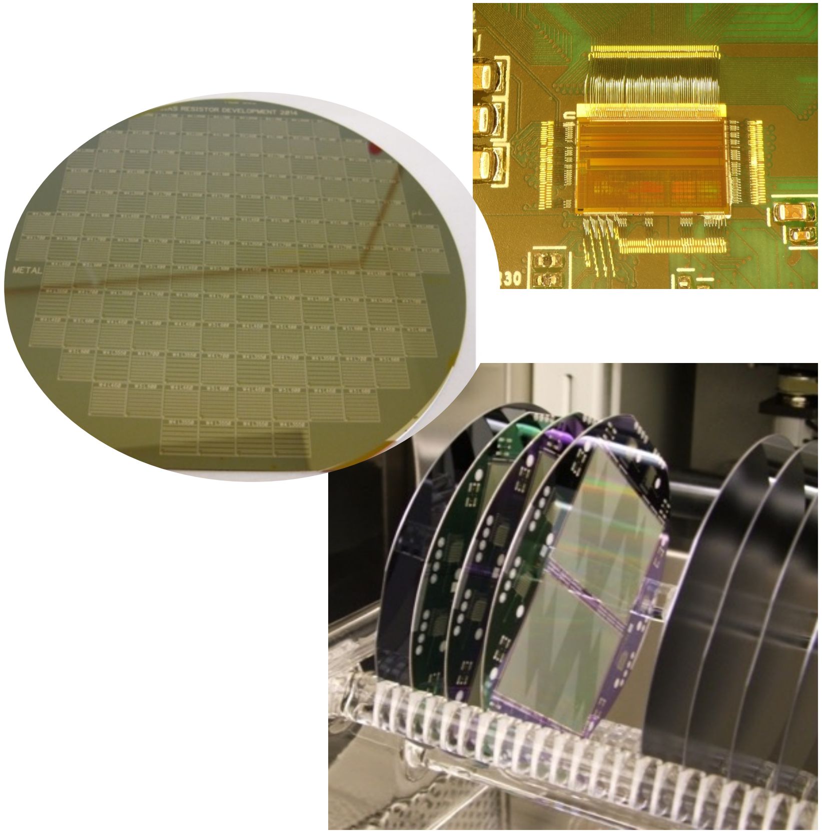
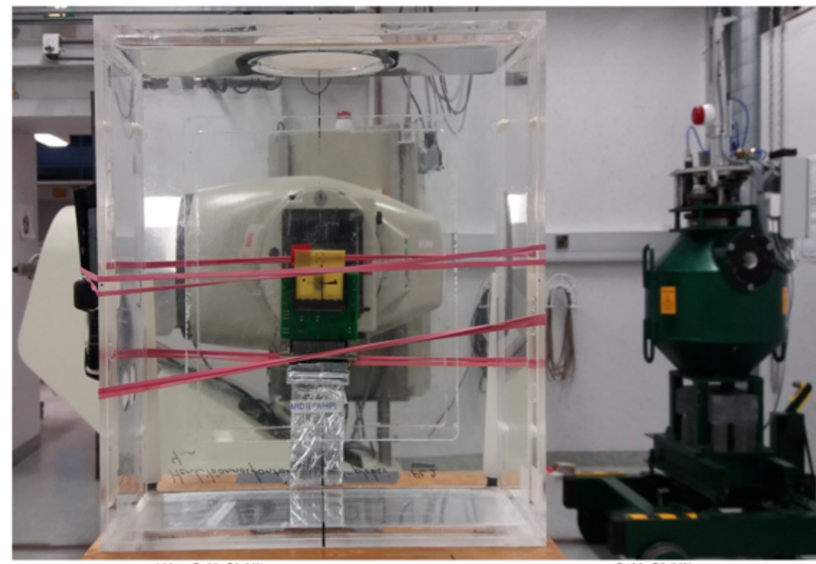
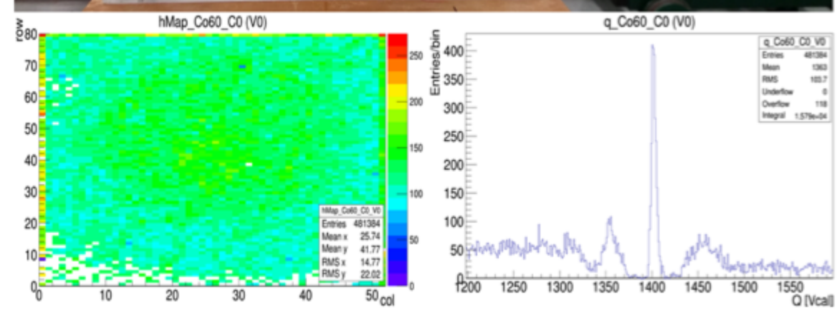


Image reconstruction and verification

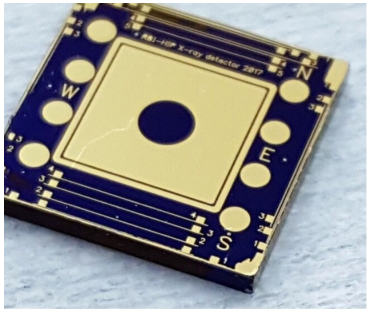
- Data processing and image reconstruction will require entirely new mathematical methods.
- Our consortium members from Aalto University have strong experience in the state-of-the-art methods derived from the theory of Bayesian statistical inverse problems and statistical signal processing .
- The final verification of the concept will be done at the national standards laboratory of Radiation and Nuclear Safety Authority (STUK).

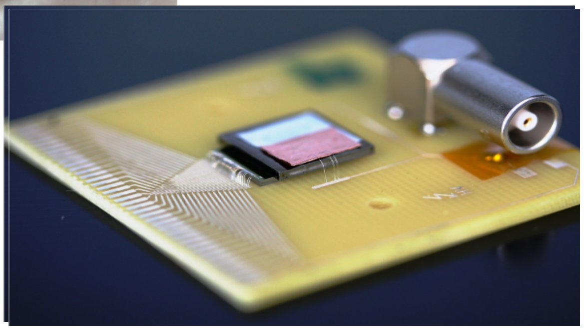


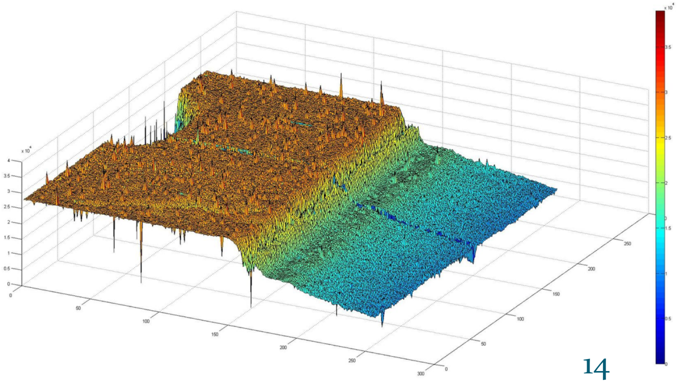


First detector prototypes

- We have already processed our first CdTe prototype sensors.
  - Diode detector without position resolution.
  - A pixelated device suitable for the CMS experiment readout electronics
- Next we will start the full characterization campaign for the sensors.
  - This will include laboratory tests with laser and x-rays.
  - Tests at the STUK national validation laboratory
- First premilinary results from the Ruđer Bošković Institute focused ion beam test facility indicate that the detector homogenity is very good.
- This is very important quality for medical imaging sensors.







Summary

- The aim of the project is to produce a novel detection system for medical imaging.
- The detection system is based on multispectral photon counting detectors that allow preserving the energy spectrum of the used radiation (e.g X-rays).
- The proof of concept includes, in addition to the detector and readout circuit, also the electronics to drive the hardware, the software to analyze the data, and verification tests against established dosimetry equipment.