Medipix: An application in high energy physics and a spin-off for medical imaging

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CERN, Geneva, Switzerland

University of Otago

University of Canterbury

Medipix3RX[1]

- Developed at CERN. Applications in medical and high energy physics.
- Pixelated hybrid Silicon sensor, a matrix of 256x256 pixels - pixel size of 55μm x 55μm.
- Sensor bump bonded to radiation hard readout ASIC implemented in 250nm CMOS technology.
- Supports single pixel and charge summing modes of operation.
- Measures charge produced by ionizing particles in the sensor.

[1] https://medipix.web.cern.ch/collaboration/medipix3-collaboration

Collaborators from the middle earth

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha

CERN

medipix collaboration

mars
Medipix All Resolution System

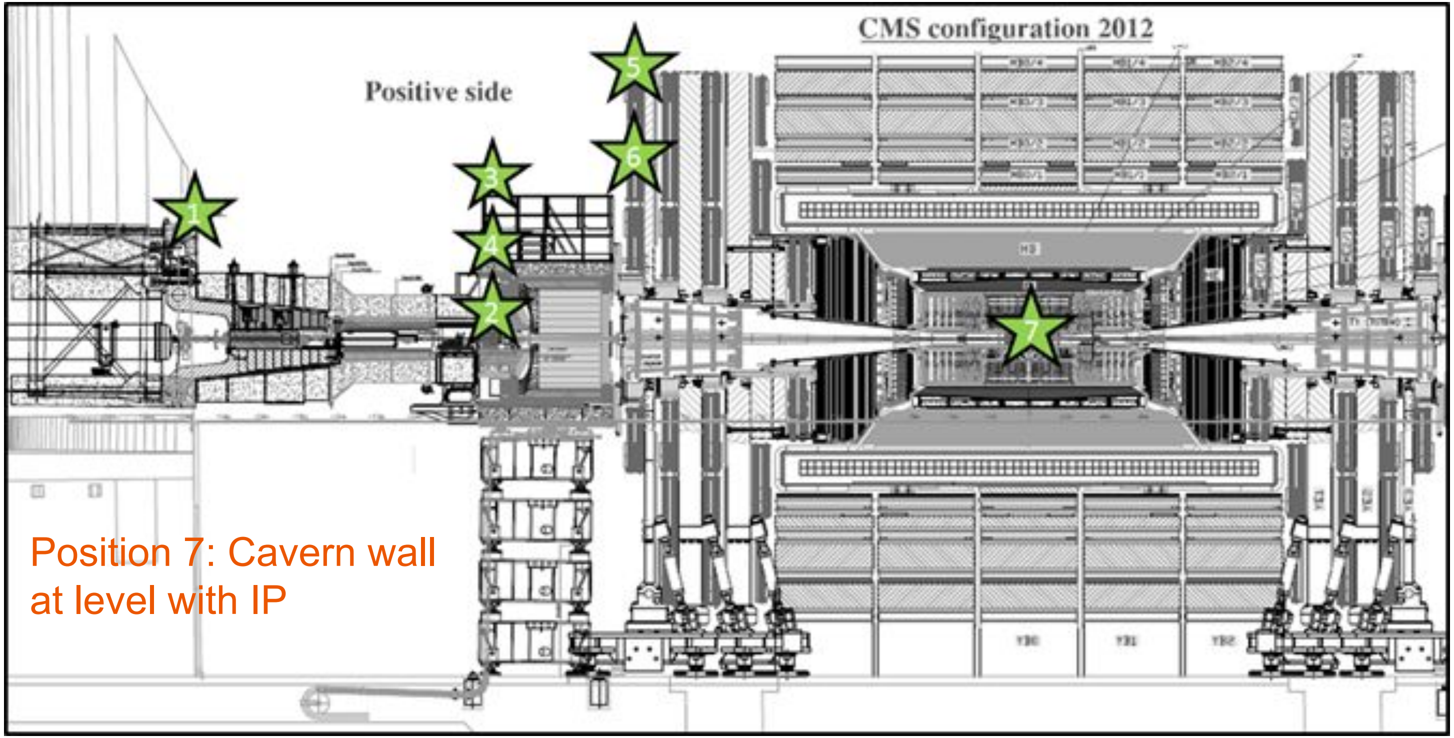
Particle Physics

Project motivation

- Online measurement of neutron fluxes in a mixed radiation field.
- Estimation of residual dose during LHC off periods.
- Provide input to single event upset analysis of the front-end electronics of other sub-detectors.
- Verification of Monte Carlo simulations at low flux locations.
- Validate measurements with RadMon[2] detectors installed on HF platform.

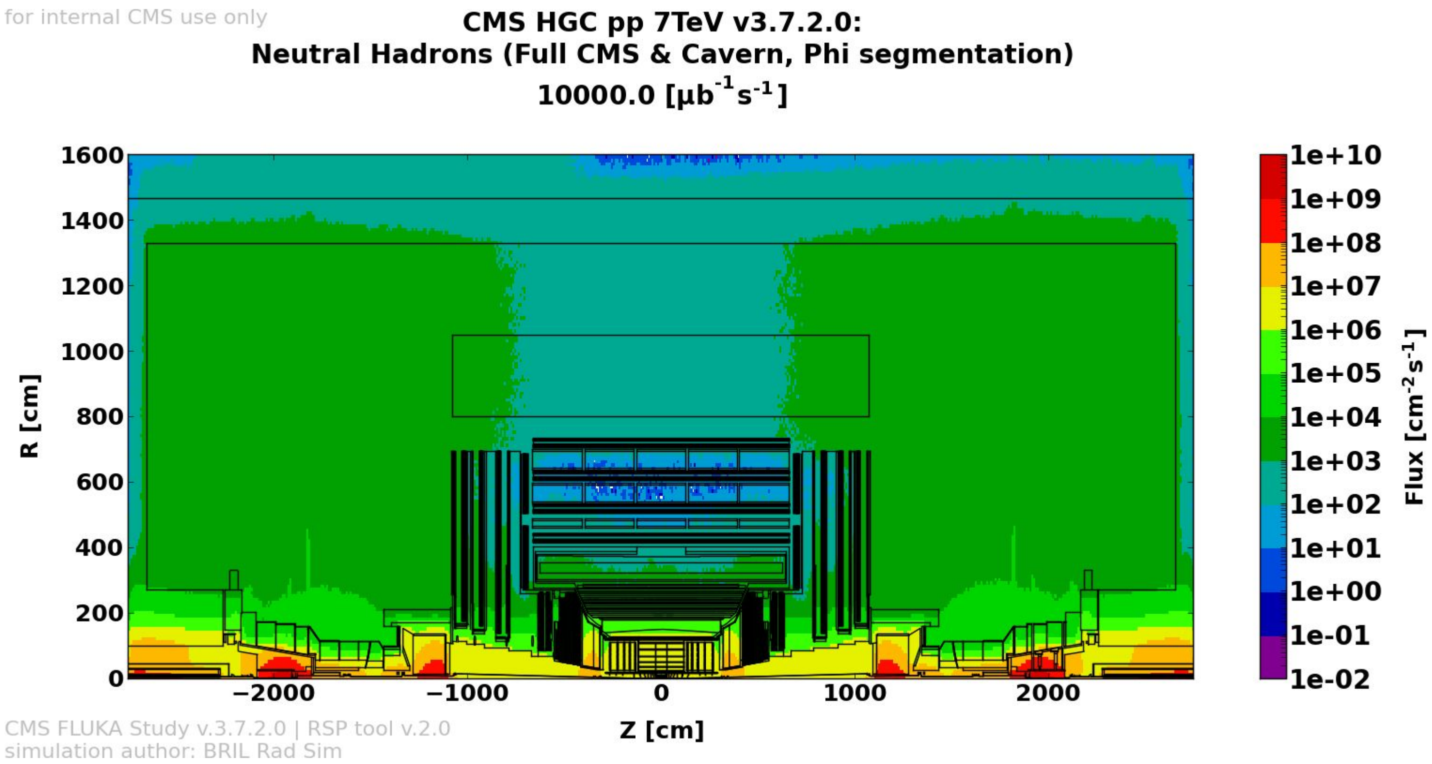
[2] https://ep-dep-dt.web.cern.ch/irradiation-facilities/radmon

Locations of the detectors in the CMS cavern



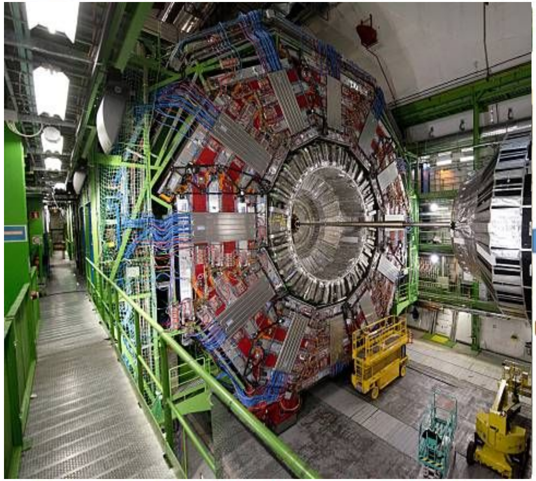
Position 7: Cavern wall at level with IP

Neutron flux in and around the CMS cavern



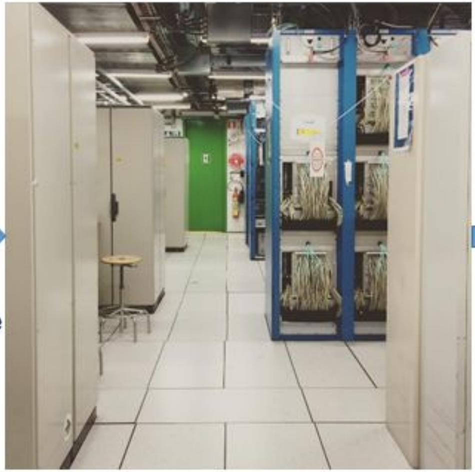
Project layout

UXC (Underground experimental cavern)



80~105m multi-core cable

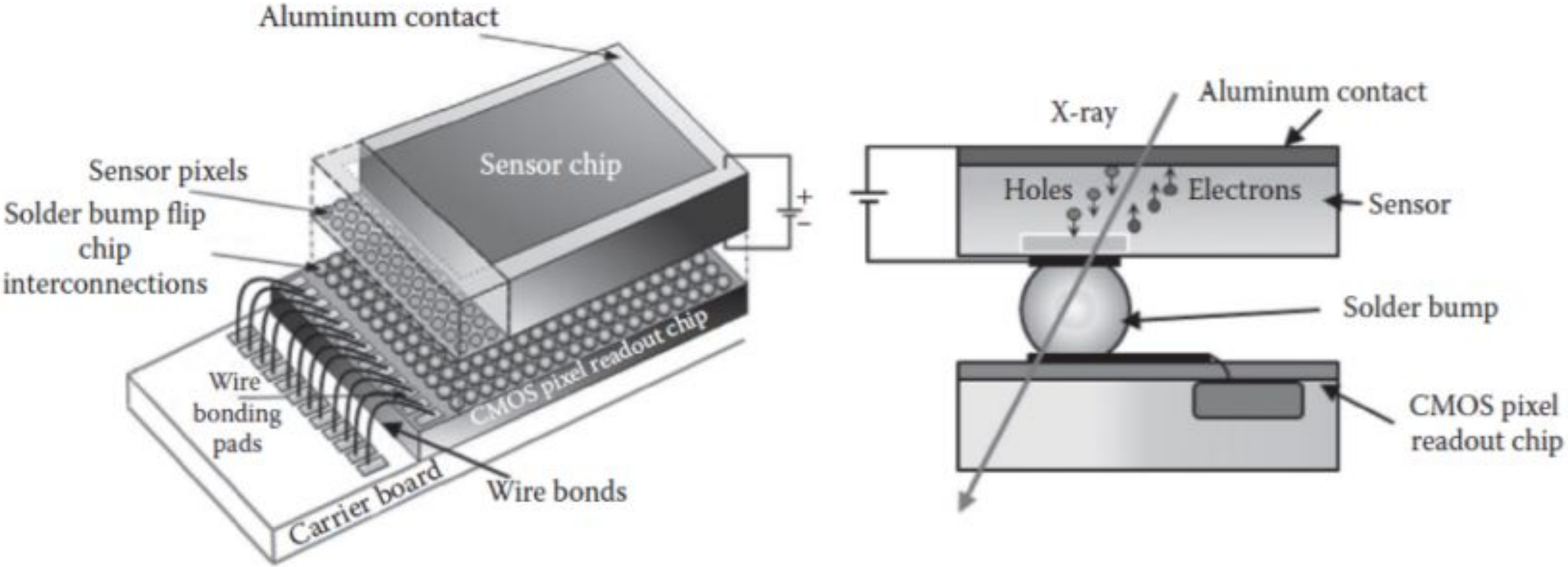
USC (Counting room)



Readout rack (14 readout boards)

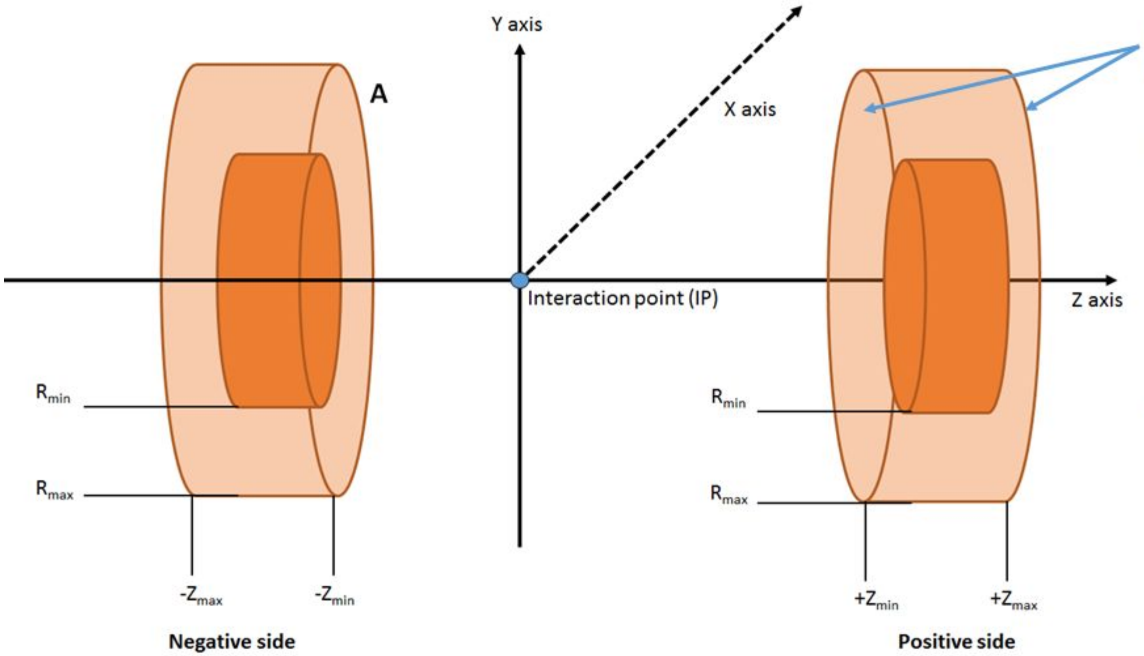
CMS control room (Data analysis)

Architecture of a hybrid pixel detector



Simulations

Simulating CMS cavern radiation environment

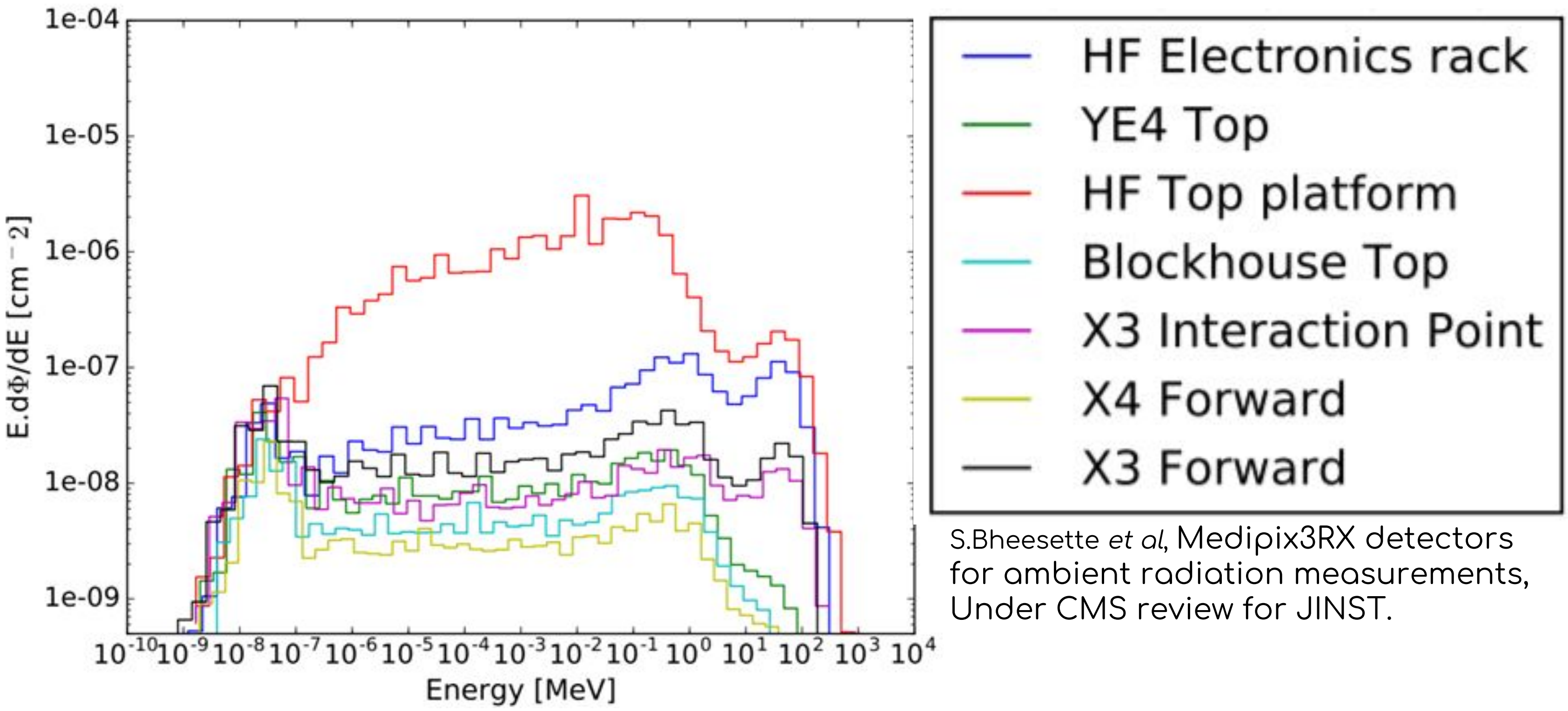


Estimation surface: Considered particles on the two positive faces of the toroid ($+Z_{min}$ and $+Z_{max}$).

- FOCUS is a CMS BRIL developed tool that allows users to simulate with the Monte Carlo FLUKA code record particle parameters crossing the surface of user-defined toroidal volumes within the CMS geometry model.
- The plots in this note only use particle parameters recorded on the flat surfaces of the toroid. The surfaces of the toroid were defined to be at the approximate Z and R locations of the Medipix detectors

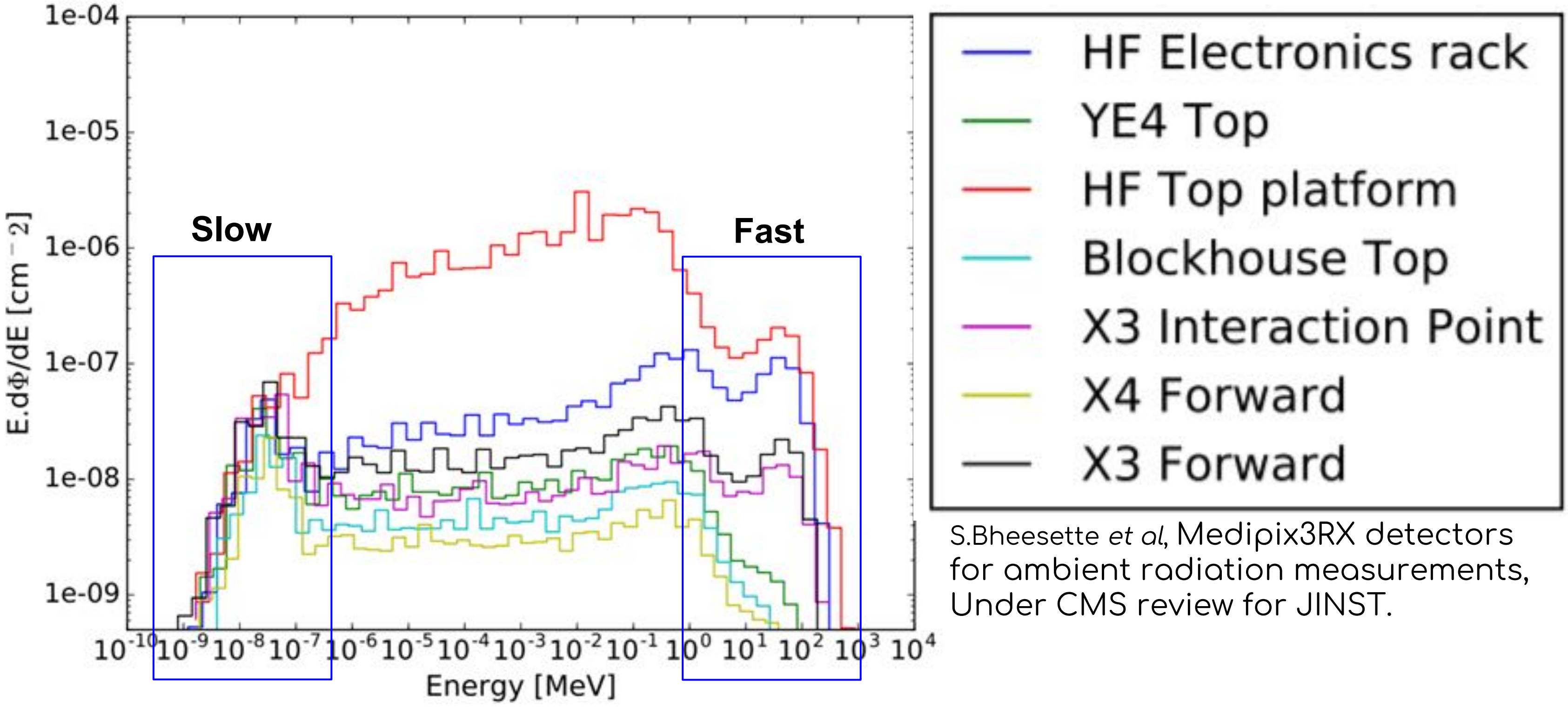
Fluka for CMS Users, https://espace.cern.ch/cms-project-bril/SitePages/FocusBril.aspx

Energy spectra of neutrons in and around the CMS cavern



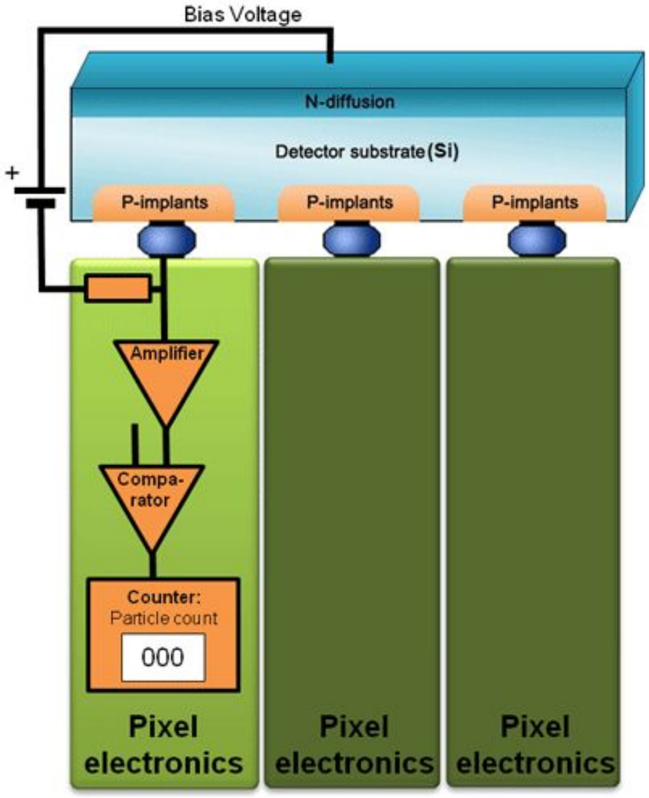
S.Bheesette *et al*, Medipix3RX detectors for ambient radiation measurements, Under CMS review for JINST.

Energy spectra of neutrons in and around the CMS cavern

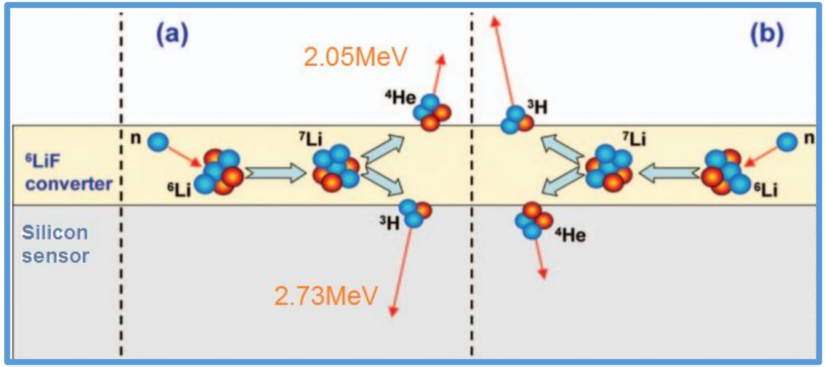


S.Bheesette *et al*, Medipix3RX detectors for ambient radiation measurements, Under CMS review for JINST.

Neutron detection

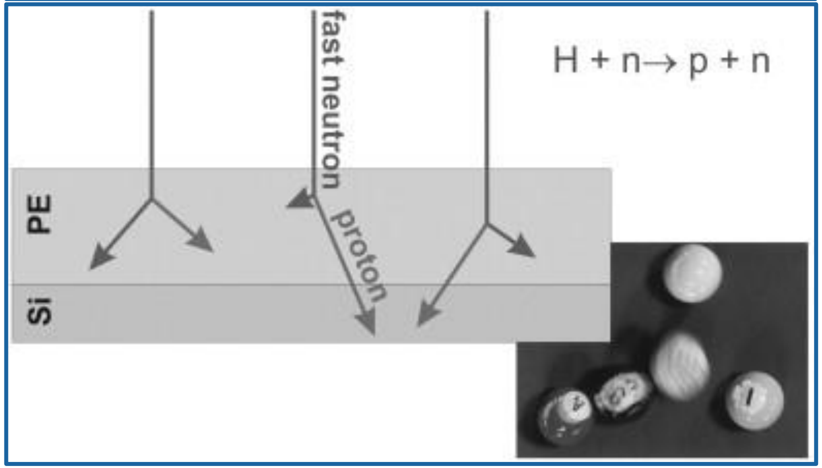


Slow neutrons (few eV to several hundred keV)

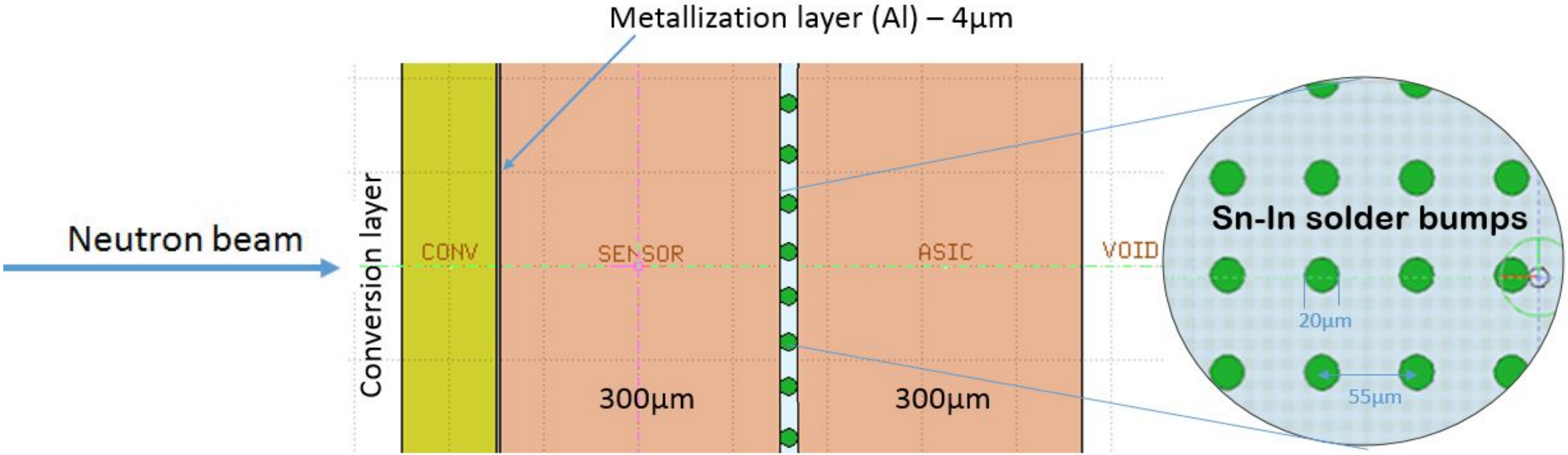


$$
{}^{1}_{0}n + {}^{10}_{5}B \longrightarrow \begin{cases} {}^{7}_{3}Li^{*}\,(1.4721\ \mathrm{MeV}) + {}^{4}_{2}He\,(0.8398\ \mathrm{MeV}) & Q = 2.3119\ \mathrm{MeV}\ (93.7\%) \\ {}^{7}_{3}Li\,(1.7762\ \mathrm{MeV}) + {}^{4}_{2}He\,(1.0133\ \mathrm{MeV}) & Q = 2.7895\ \mathrm{MeV}\ (6.3\%) \end{cases}
$$

Fast neutrons (1-40 MeV)



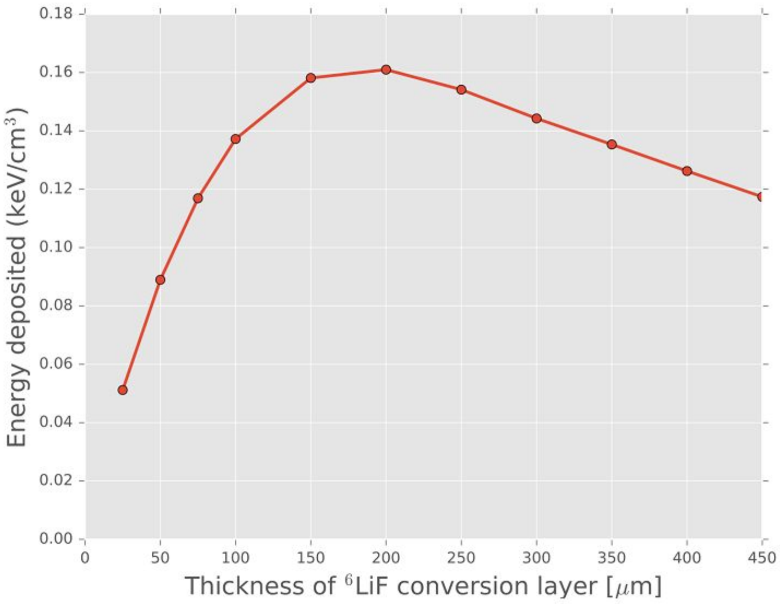
Medipix3RX modelled in FLUKA



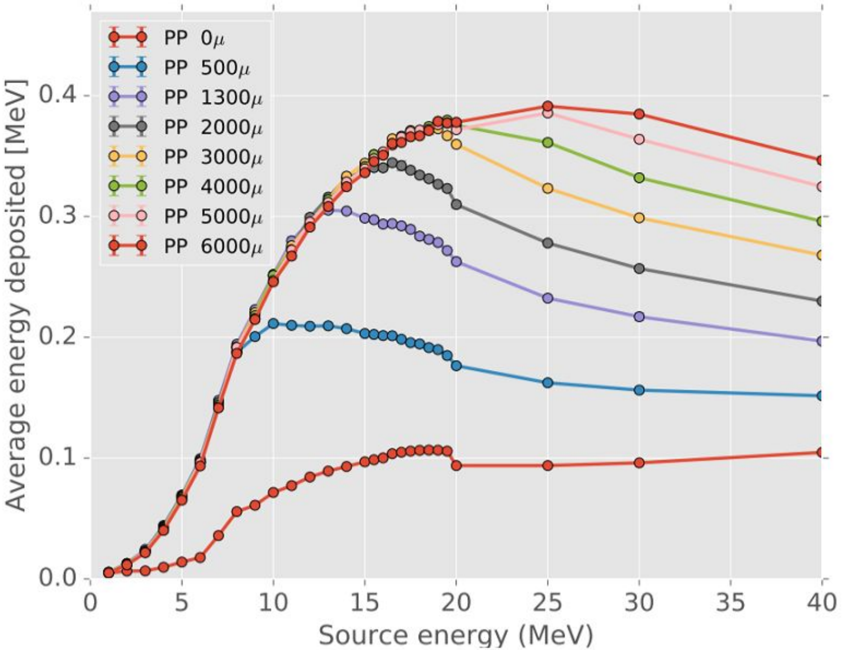
Vlachoudis, Vasilis. "FLAIR: a powerful but user friendly graphical interface for FLUKA." 2009.

A. Ferrari, P.R.Sala, A. Fasso and J. Ranft, **FLUKA**: a multi-particle transport code, CERN-2005-10 (2005).

Thickness optimization of neutron conversion layer



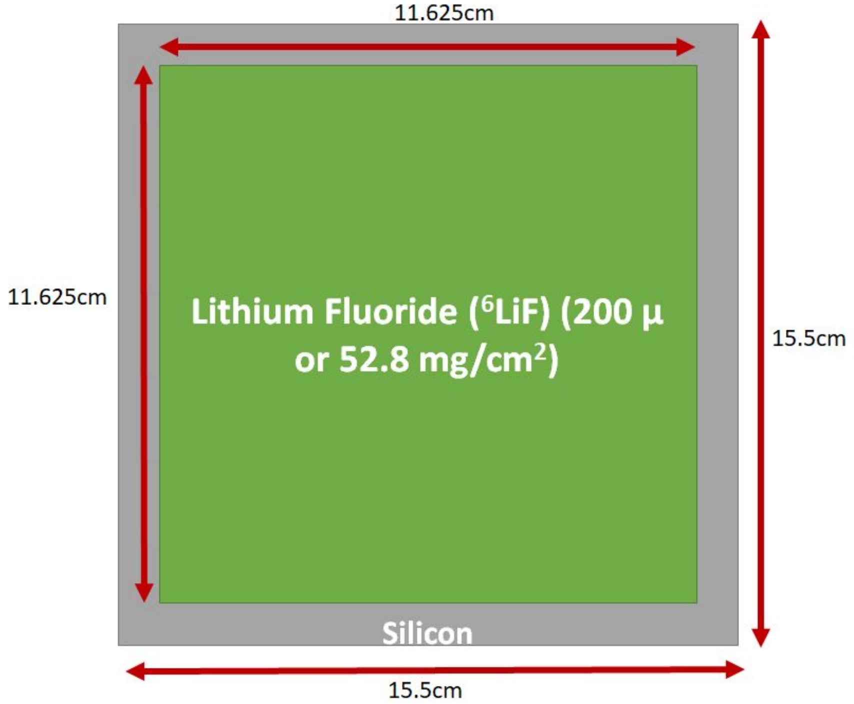
Slow neutrons



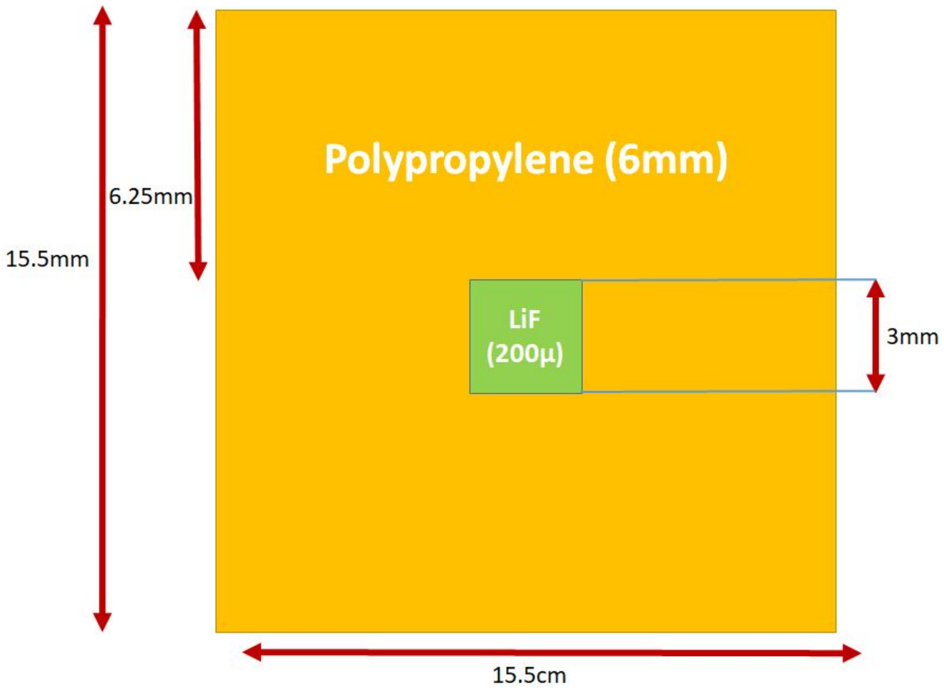
Fast neutrons

S.Bheesette *et al*, Medipix3RX based network of detectors for ambient radiation measurements in the CMS cavern, NSS/MIC 2017, Atlanta, US

Design of neutron conversion layers

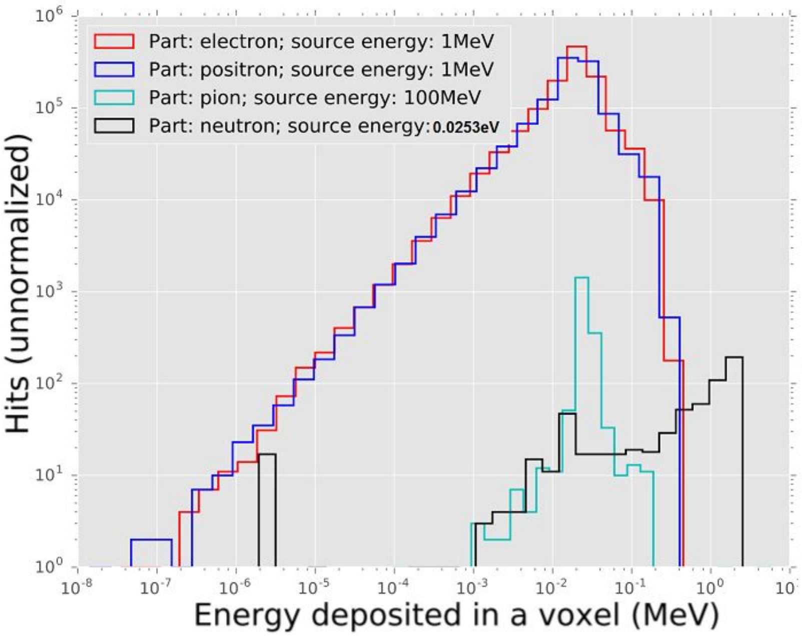


Slow neutrons

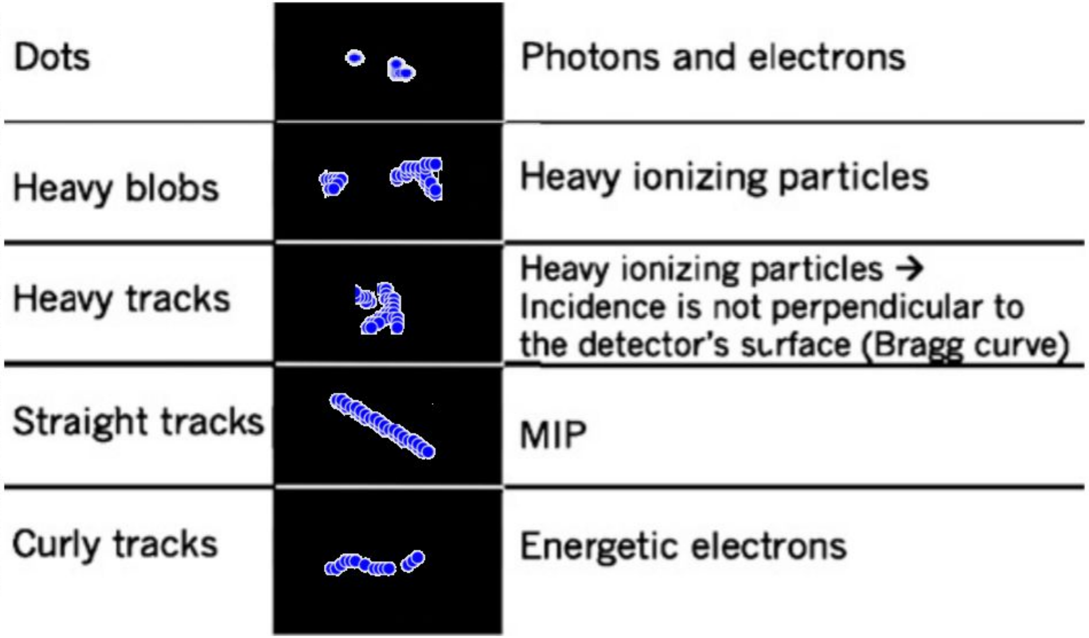


Fast neutrons

Separation of neutron yield from background



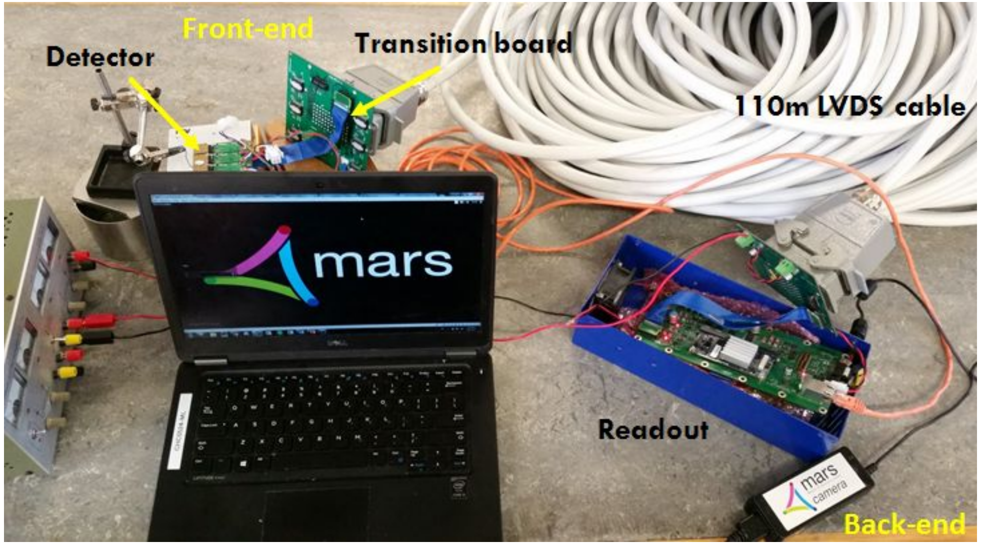
Slow neutrons

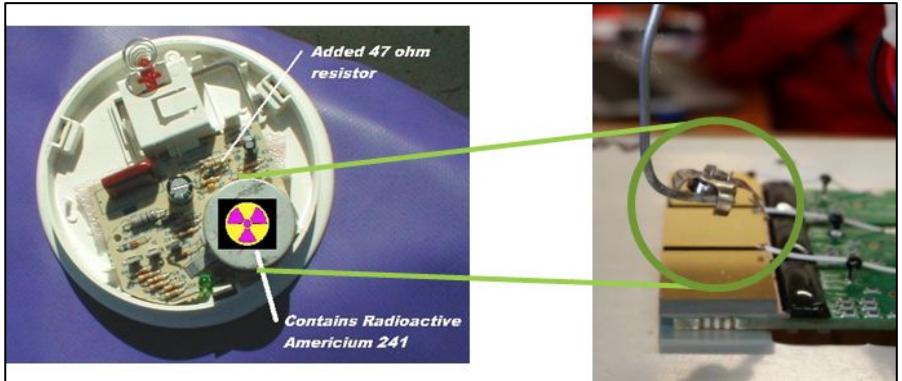


Fast neutrons

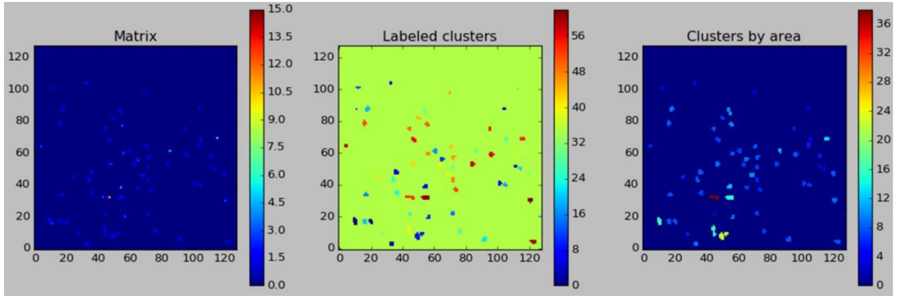
Hardware

CMS-Medipix prototype

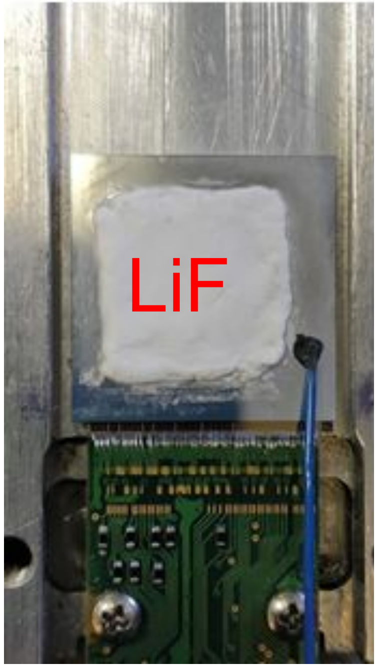




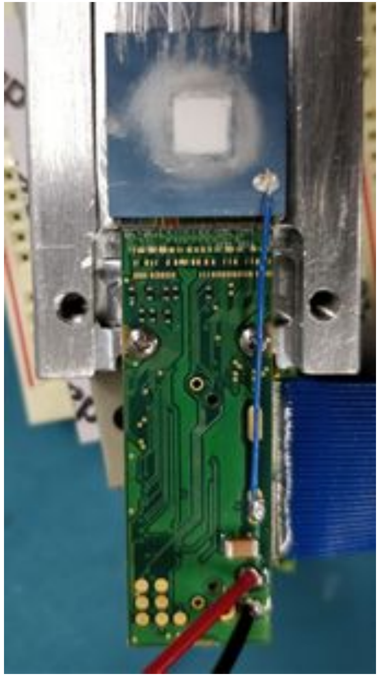
Observing alphas from ^{241}Am

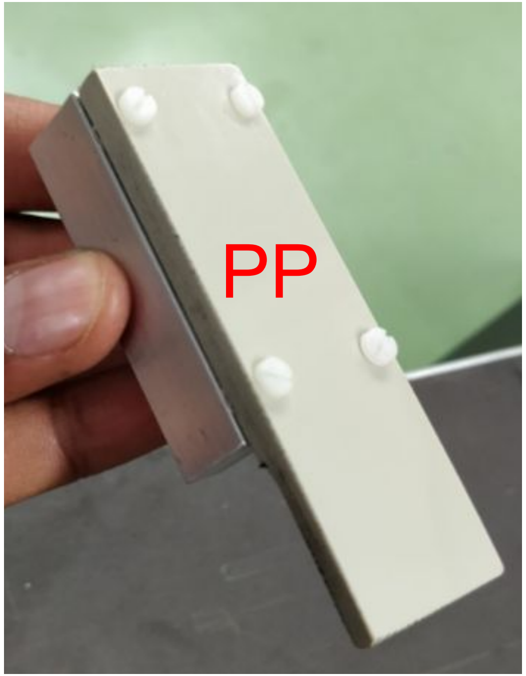


Medipix neutron detector



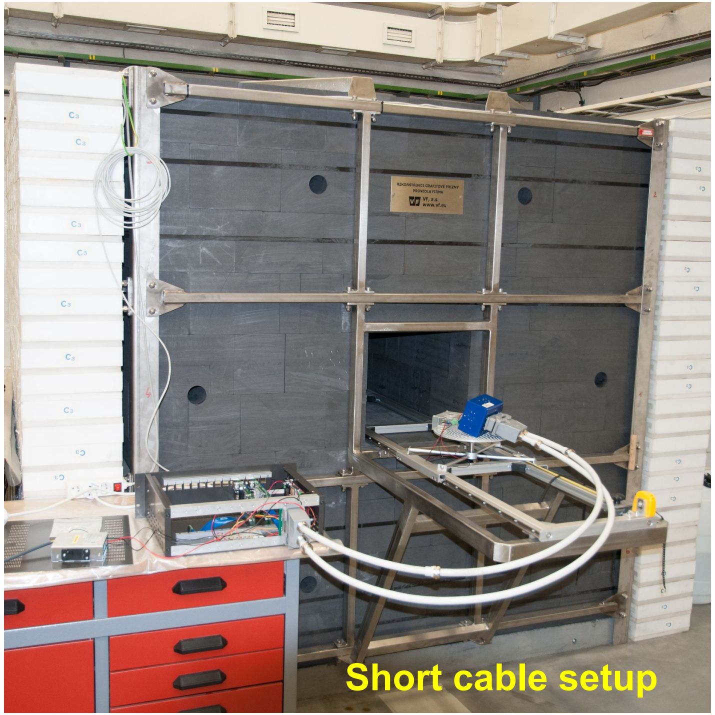
Slow neutron detector

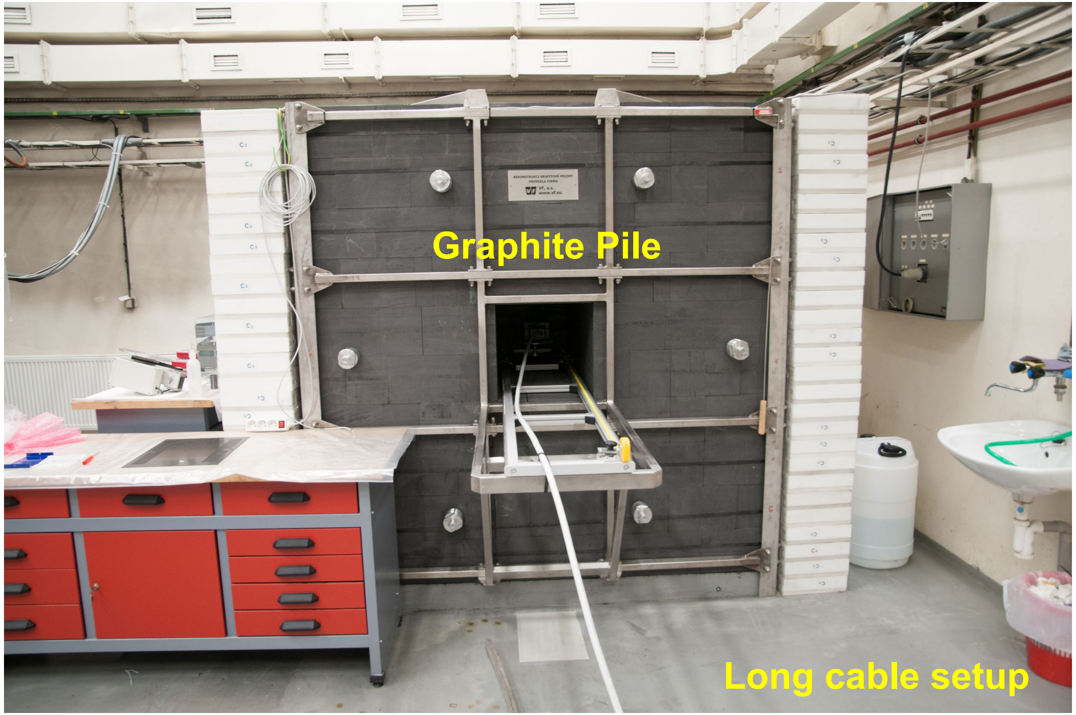




Fast neutron detector (LiF coated with PP)

Calibration of Medipix detector with slow neutrons



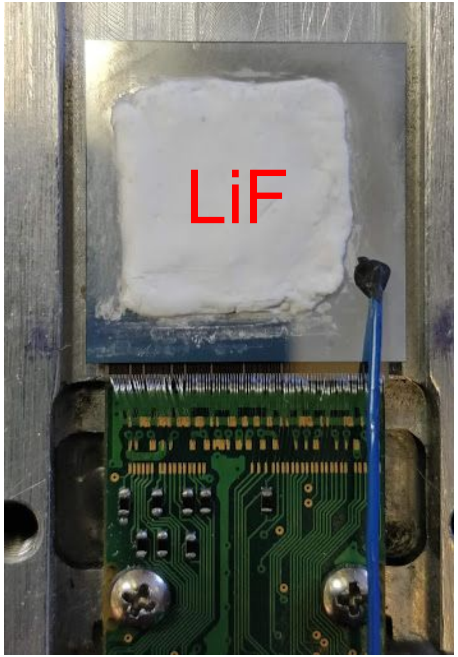


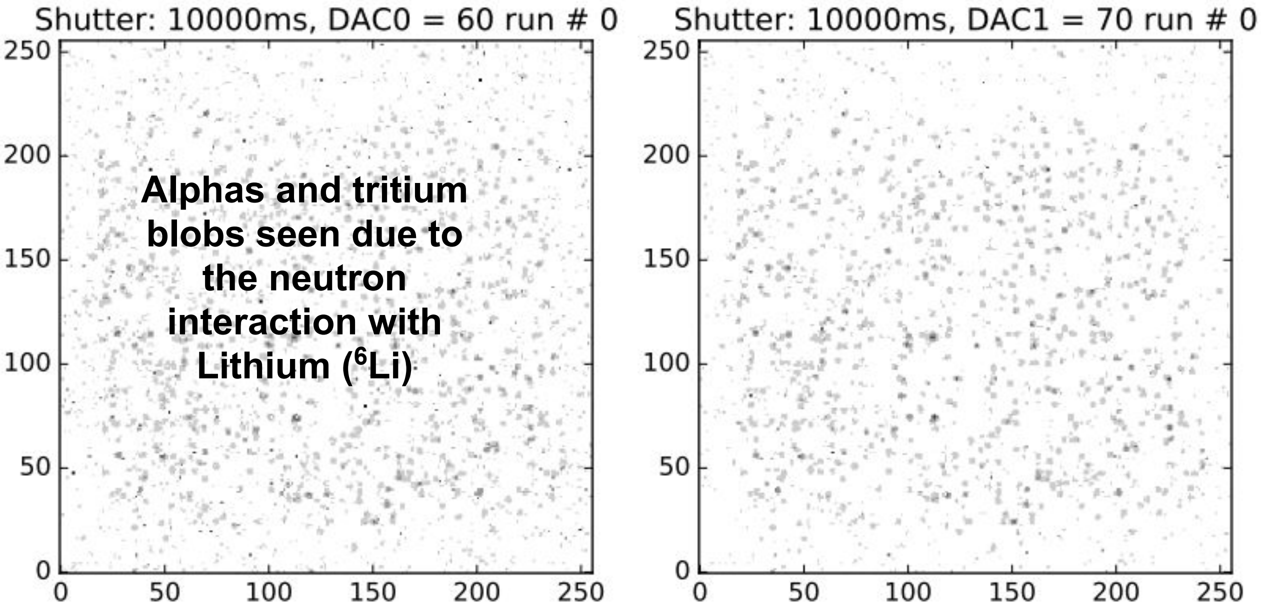
Czech Metrology Institute, Prague

Graphite pile source

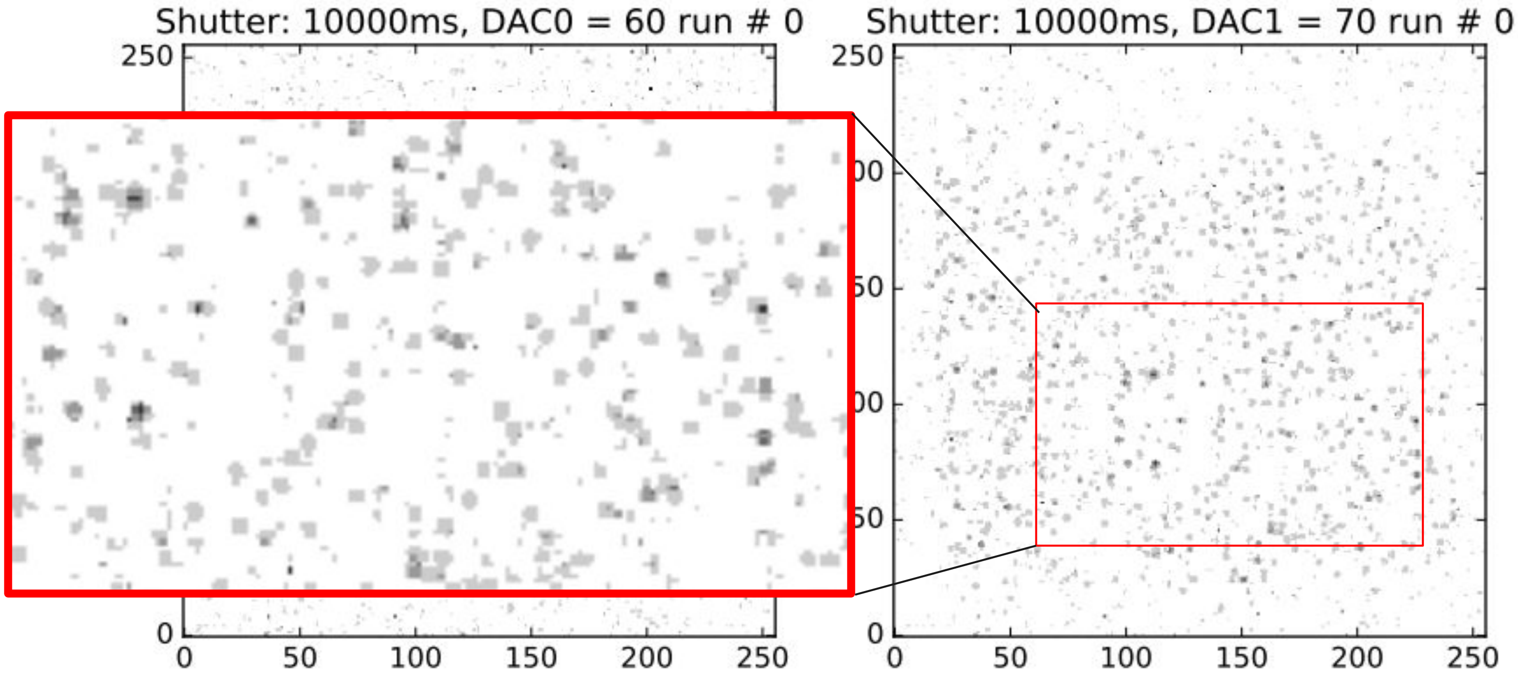
1. Thermal field - isotropic
2. Source: Graphite pile loaded by ^{6}Am-Be and Pu-Be radionuclide sources
3. Reference position: 194 cm => MPX-CMS box center in the center of the graphite pile
4. Mean neutron energy: 2.93E-8 MeV (92% neutrons have energy below E(Cd) = 0.5 eV)
5. Neutron fluence rate @ reference position: 2.913E4 $cm^{-2}.s^{-1}$ ± 3 % (relative standard deviation)

Calibration results

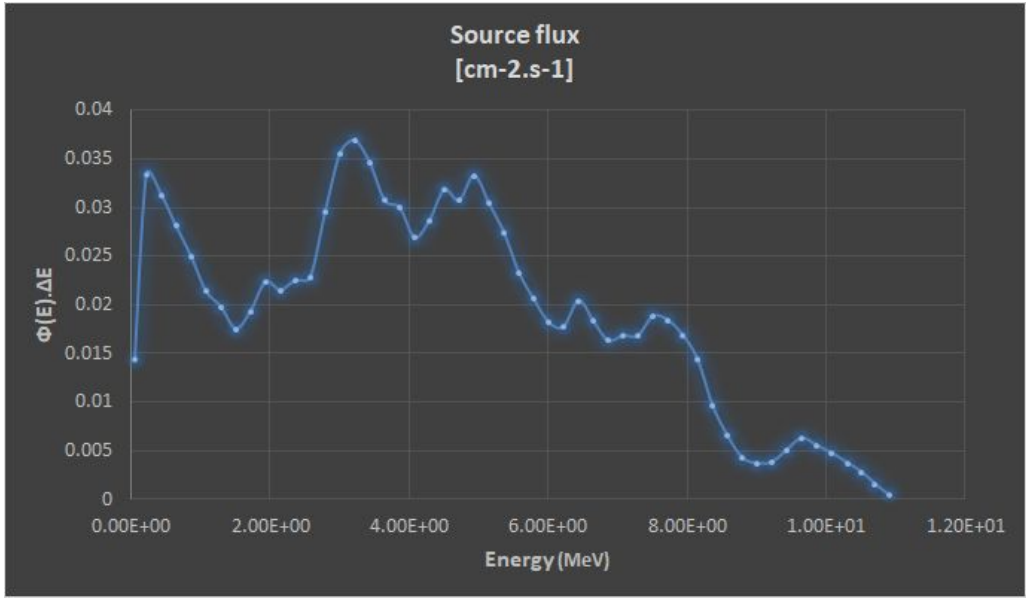


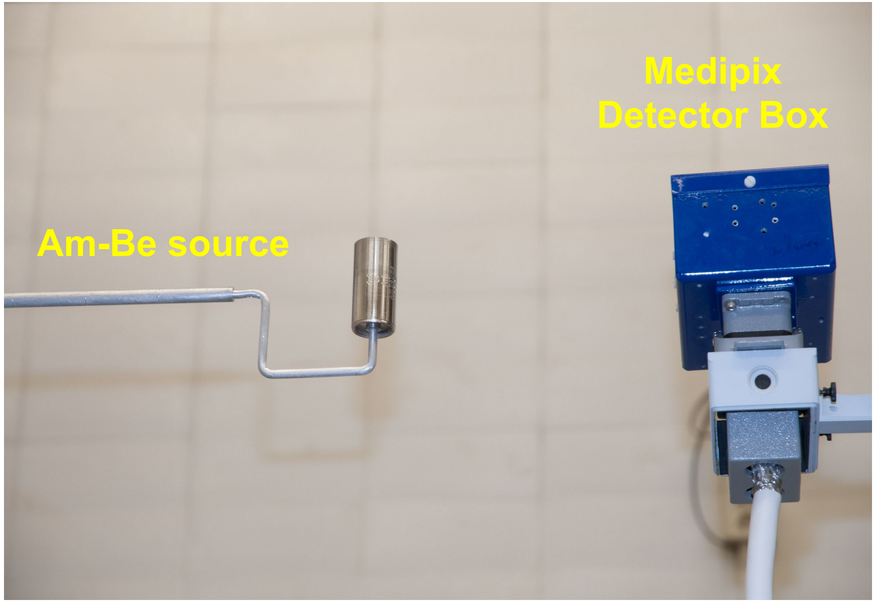


Calibration results



Calibration of Medipix detector with fast neutrons



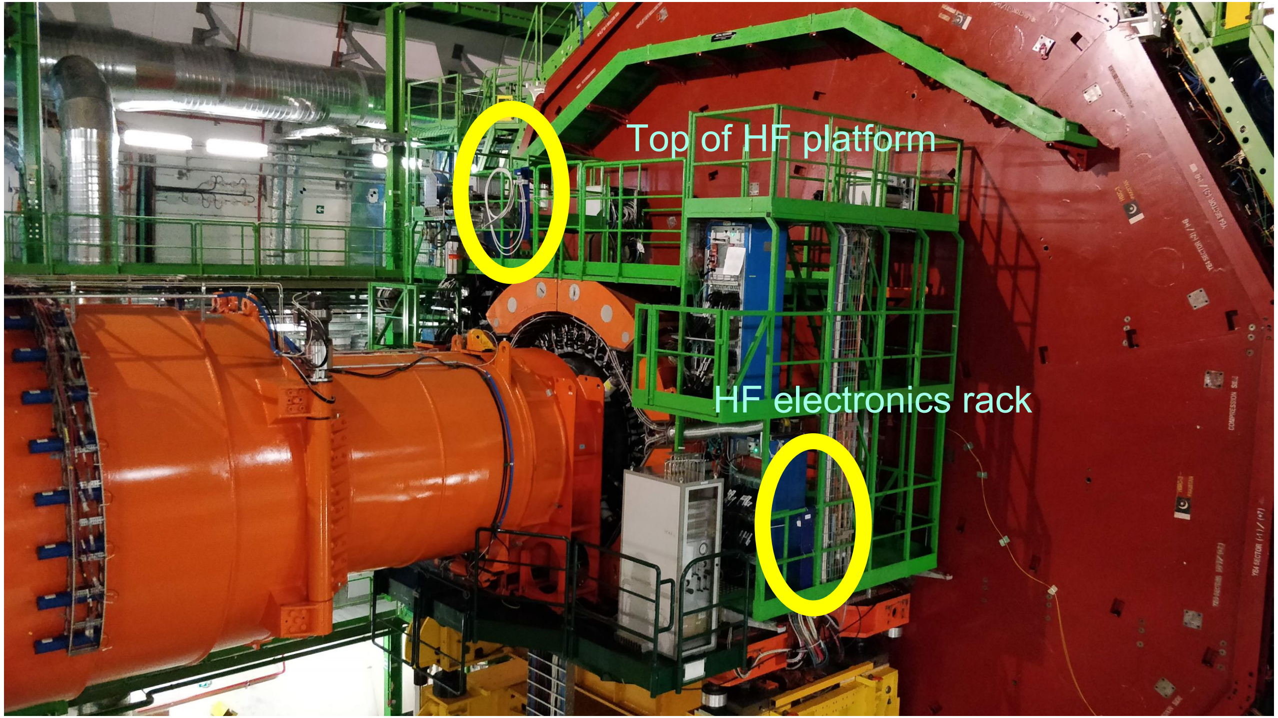


Commissioning at P5

Readout chassis in Underground service cavern (USC) at - 87m

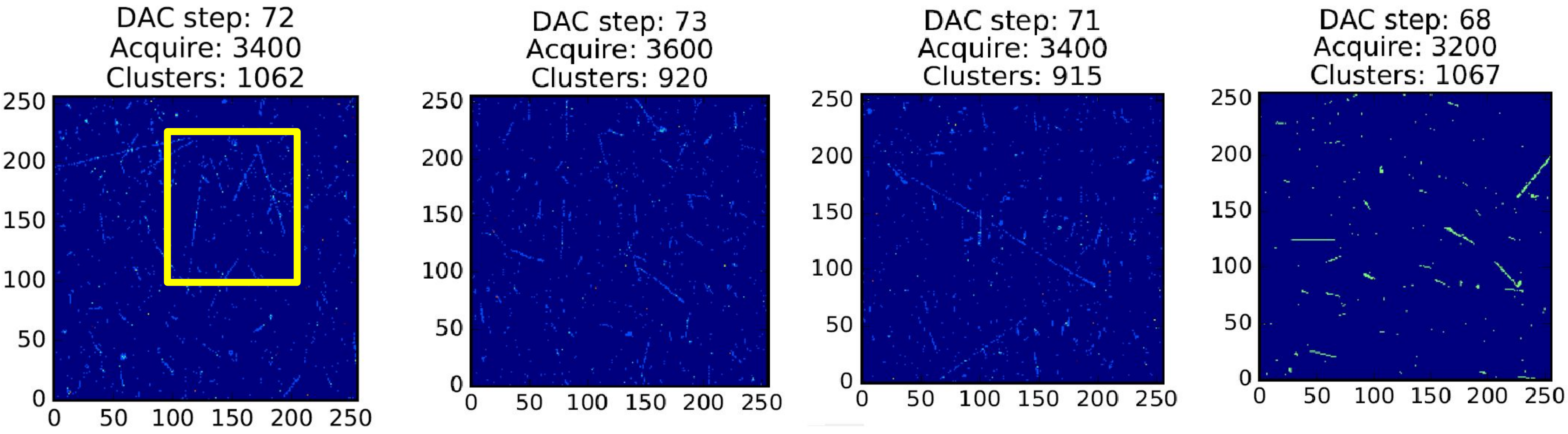
Detector box in Underground experimental cavern (USC) at -100m

Two fast neutron detectors in the CMS cavern



Slow neutron detectors in the CMS cavern

Preliminary results from the fast neutron detectors



These tracks represent recoil protons emitted due to the neutron interaction with the hydrogen atom in PP layer.

Future work at CMS

- Fully commission the remaining neutron detectors (end of Sep 2018).
- Get as much data till the end of this year's run (Dec 2018).
- Port essential Python code to C++ as to run as a part of BRILDAQ which has to be developed using xDAQ framework.
- Upgrade to Timepix3 detectors in the next LHC upgrade for neutron spectroscopy in the CMS cavern and to deliver luminosity results to the LHC.

Medical Imaging

Medipix for Medical imaging

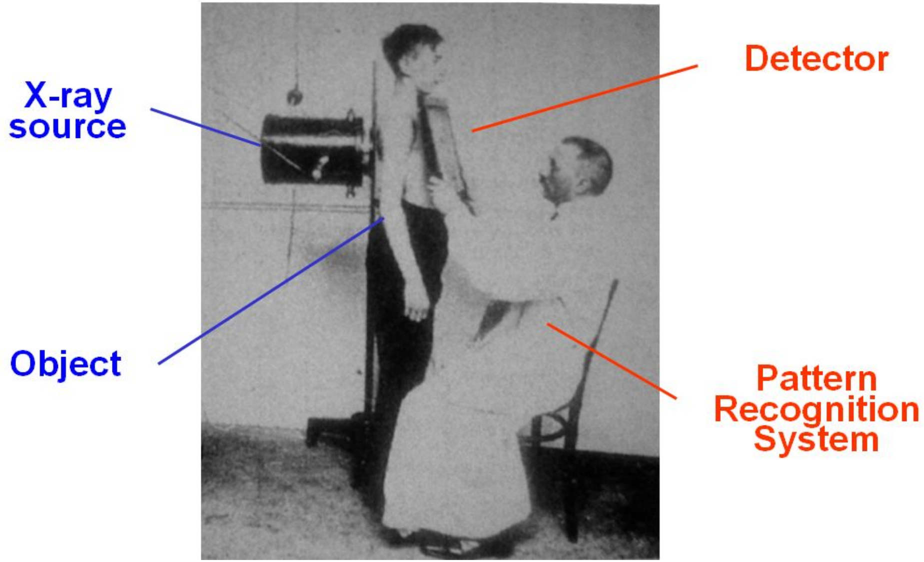
1. Radiography and computed tomography (CT) use X-ray photons to study the human body.
2. The Medipix technology has been applied in X-ray CT and mammography and for beta- and gamma-autoradiography of biological samples.
3. Moreover, with the Medipix3 chip, the images are no longer black and white - they have colours to indicate different energy levels of the photons.
4. The colour X-ray imaging technique produces clearer and more accurate pictures that should help doctors give their patients more accurate diagnoses.
5. High-resolution, high-contrast, very reliable images, making it unique for imaging applications in particular in the medical field.

Mid '90s, Medipix – Michael Campbell

"Various application like Medical Imaging should be profit"

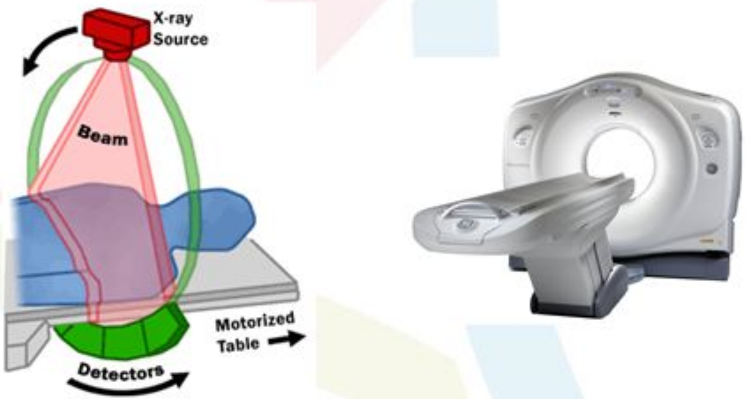
We have come a long way...

X-ray systems



CT – Computed Tomography

"3d X-rays"



Tutankhamun Examined in a CT Scanner

Photo by Kenneth Garrett (National Geographic, 2005)

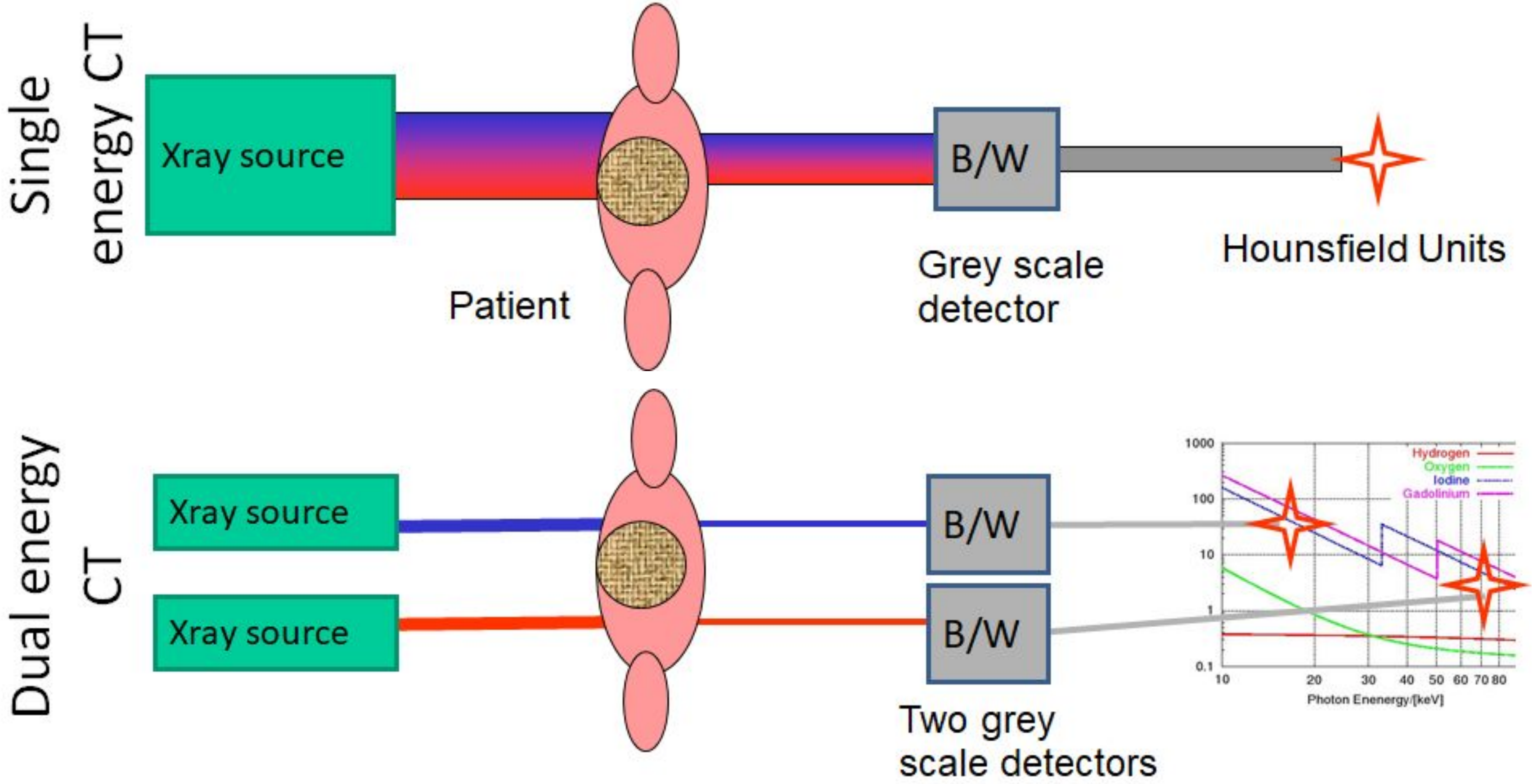
Aims

Molecular imaging is the future

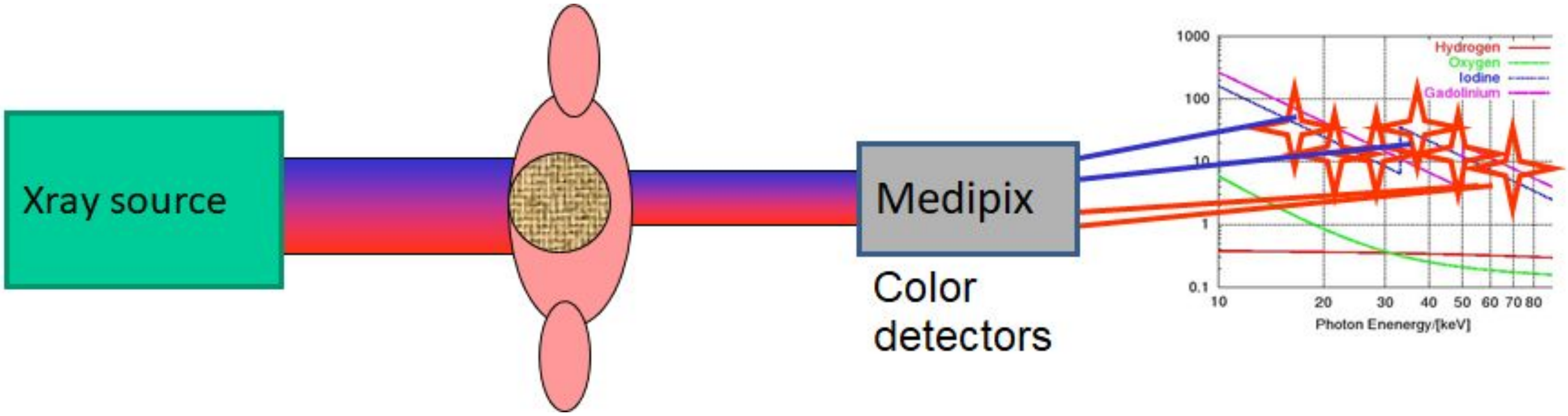
1. What the doctors/radiologists want to know
   a. What is the tissue?
   b. What is its behaviour?
   c. Is the treatment working? (not just size, shape, location)
2. What the researcher wants to know
   a. Constituents (fat, water, Calcium, Iron)
   b. Cancer and pathogen labels

The MARS team

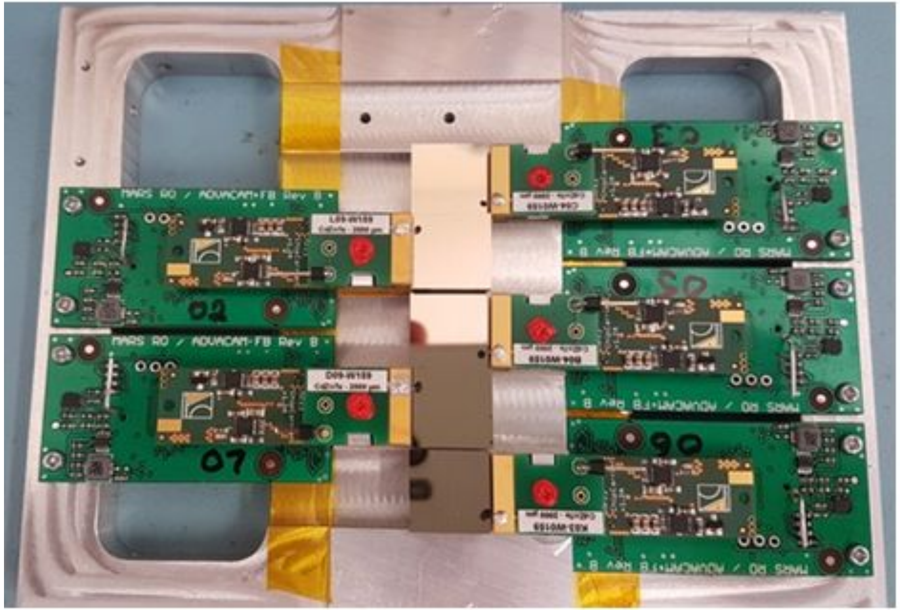
1. NZ university team (30 people)
   a. Canterbury, Otago, Lincoln, Auckland
2. International Partners
   a. CERN, Mayo Clinic, RPI, Notre Dame, OHSU, and many others
3. The commercial partners
   a. MARS Bioimaging Ltd
   b. ILR Ltd, Shamrock, etc.
   c. GE Healthcare

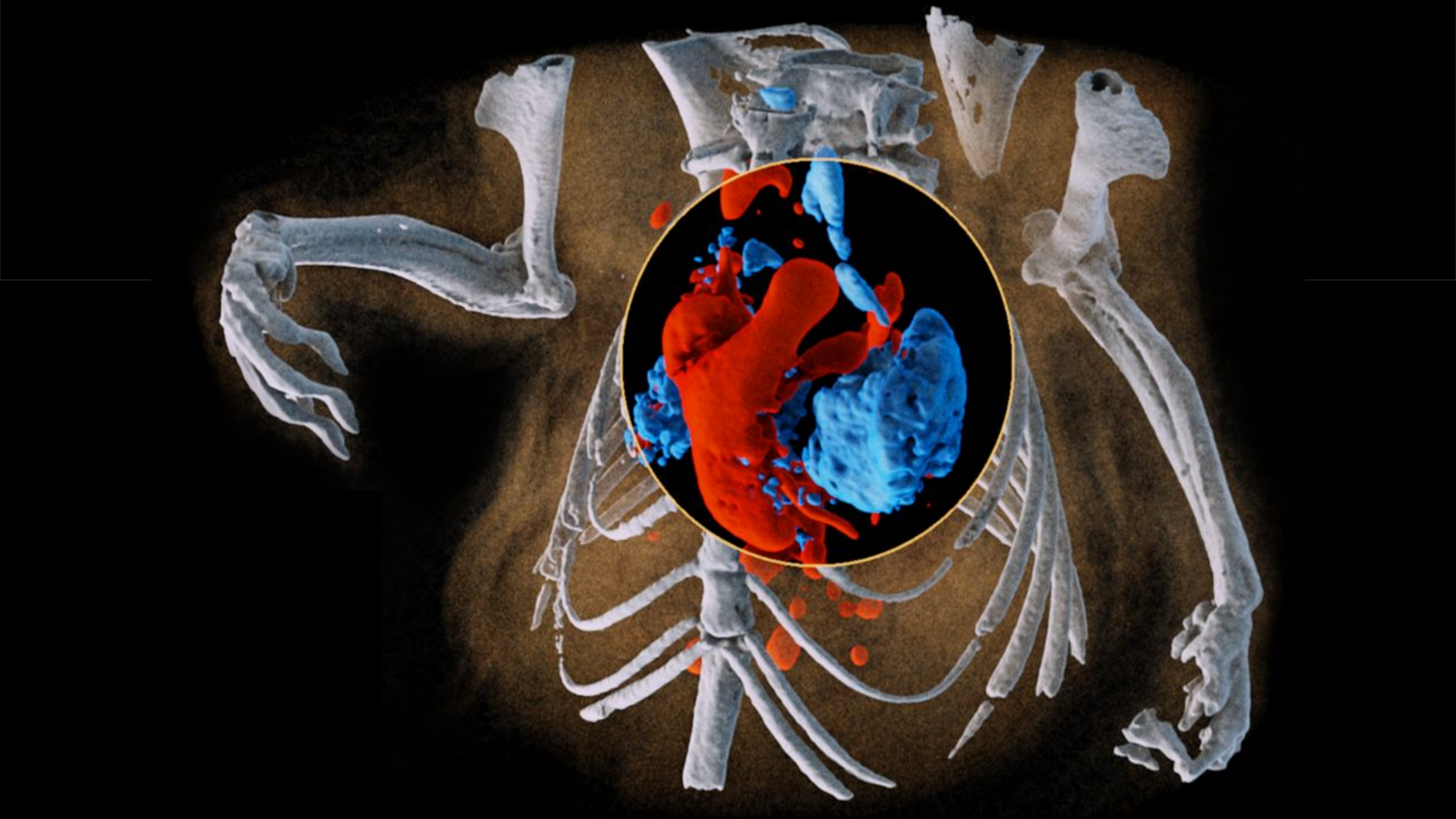

Single energy CT
Xray source
B/W
Patient
Grey scale detector
Hounsfield Units
Dual energy CT
Xray source
Xray source
B/W
B/W
Two grey scale detectors
Hydrogen
Oxygen
Iodine
Gadolinium
1000
100
10
1
0.1
10
20
30
40
50
60
70
80
Photon Enenergy/[keV]

Spectral CT


Xray source
Medipix
Color
detectors
1000
100
10
1
0.1
10
20
30
40
50
60
70
80
Photon Enenergy/[keV]
Hydrogen
Oxygen
Iodine
Gadolinium

MARS scanner V5

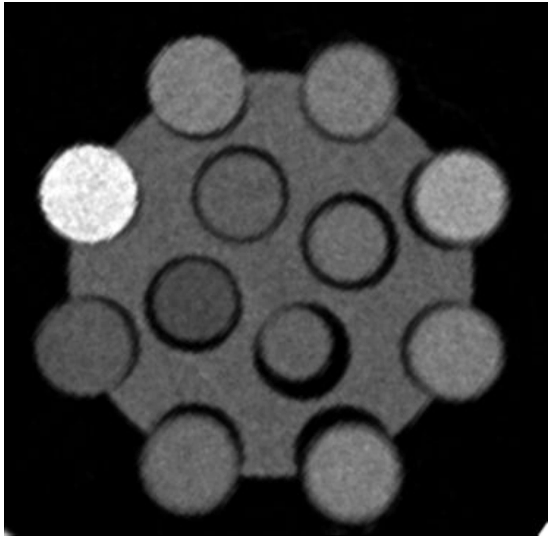




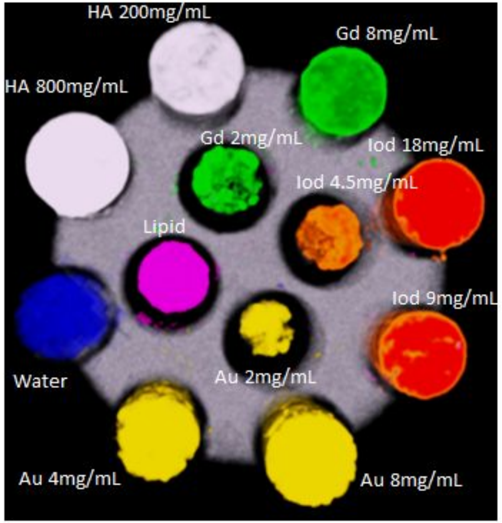
From Grayscale to Colour

Spectral imaging allows to you identify and quantify different materials

- a separate map (data channel) is made for each material
- each map gives partial density (g/cm^3) for that material
- each material is then assigned an unique colour for easy visualisation



Grayscale

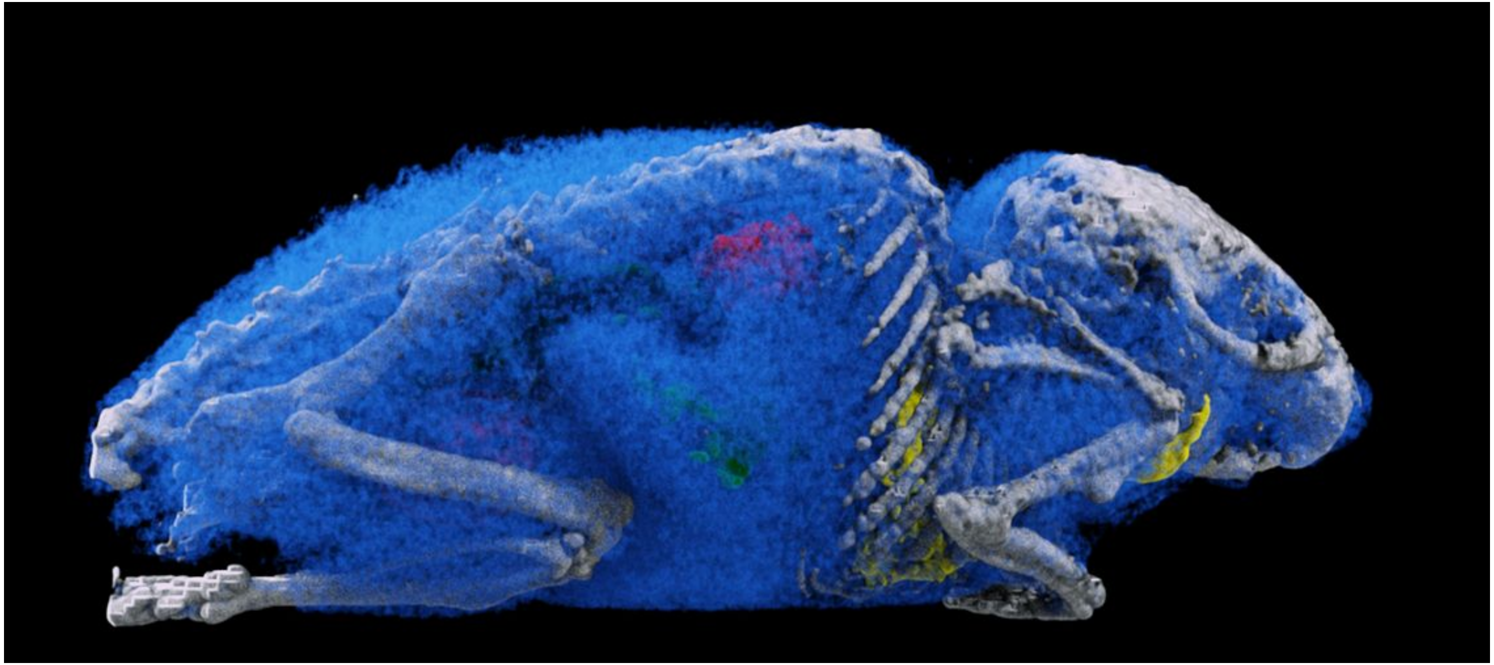


MARS image

Visualization tools

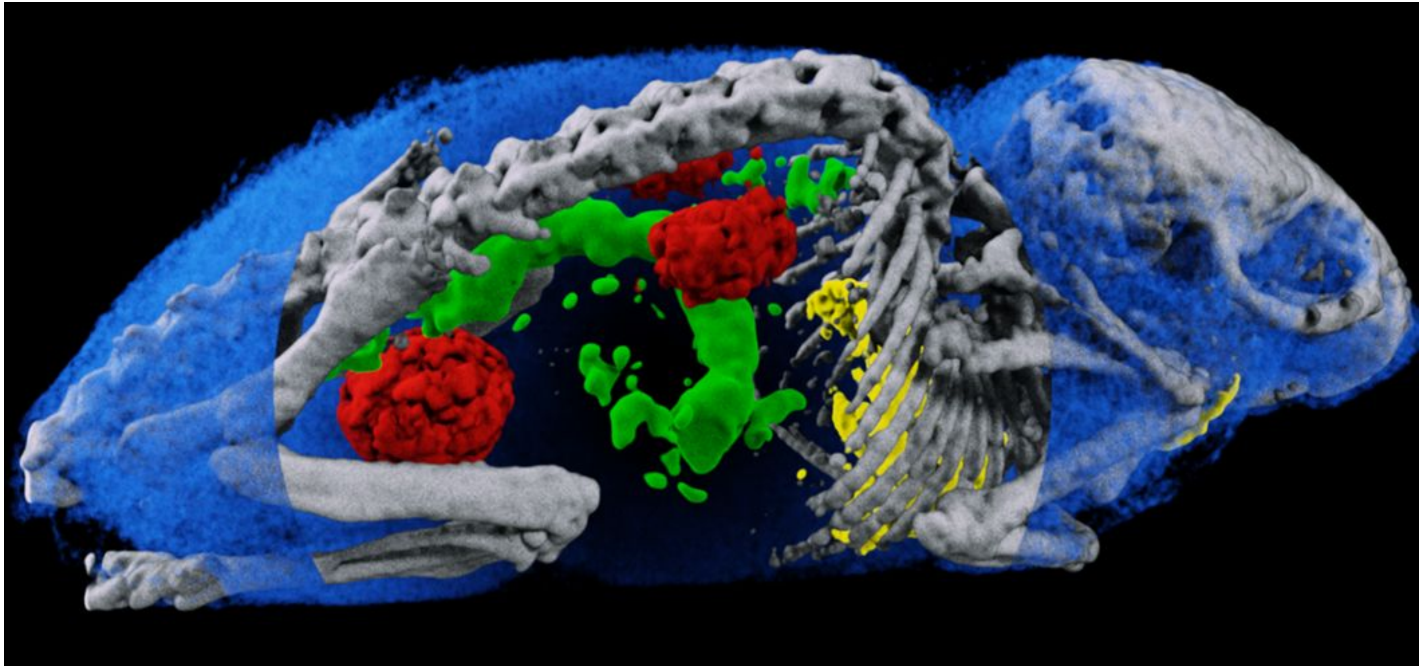
1. Hybrid *zSpace*
2. 2D/3D viewer
   a. 3D for orientation
   b. 2D for detail

A reconstructed MARS image of a mouse



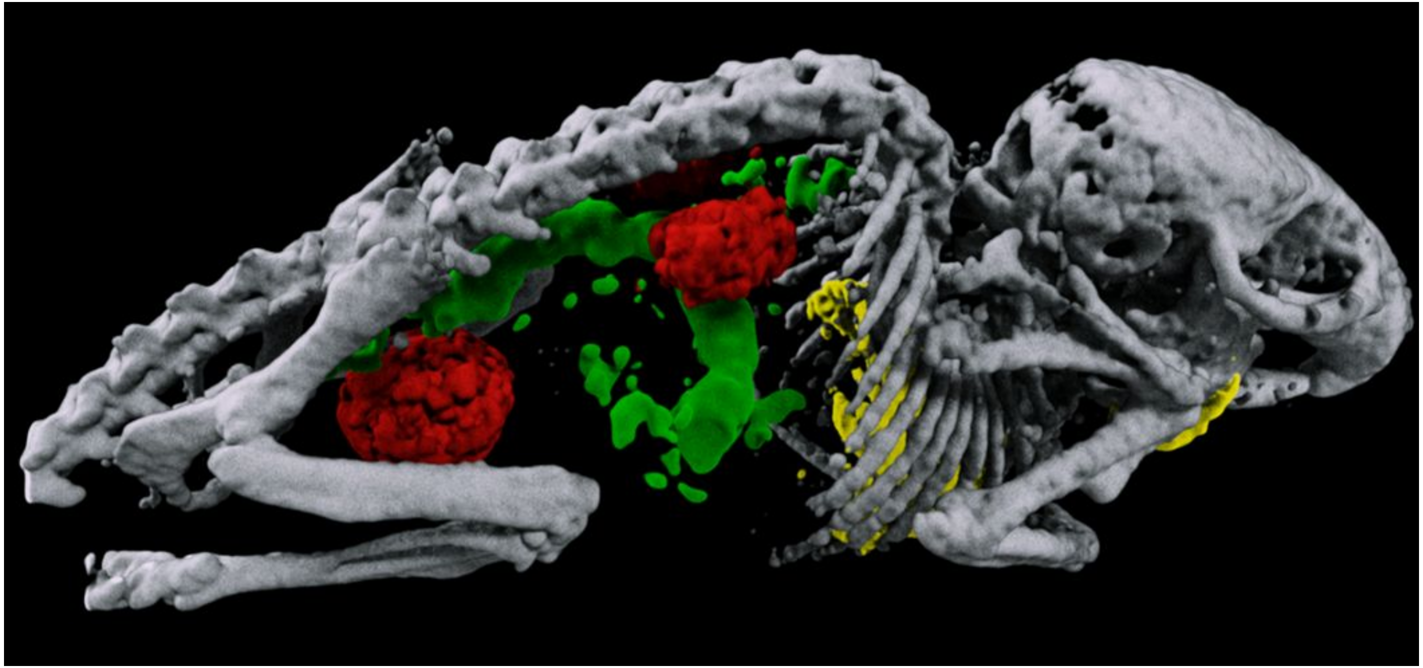
A mouse containing, gold, Gadolinium, and Iodine

A cut open mouse



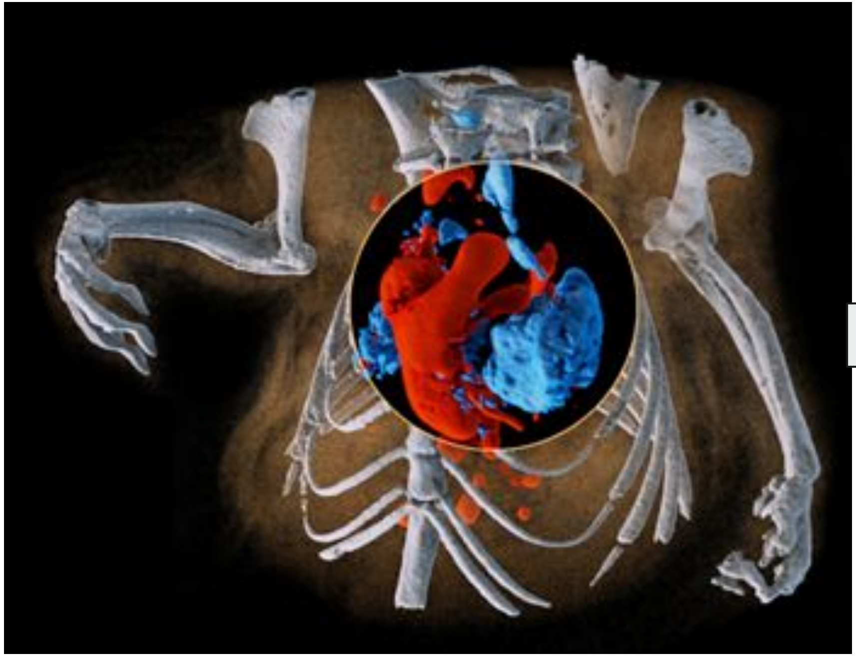
The water has been partly cut away to reveal the bone, gold, Gadolinium and Iodine.

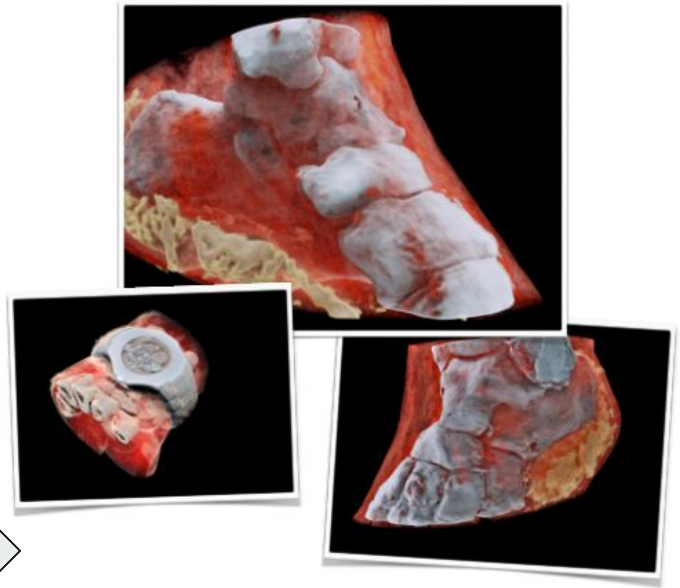
Inside view of the mouse



The water has been completely removed leaving just bone, gold, Gadolinium and Iodine visible.

From preclinical to humans





We made headlines recently!

The New York Times

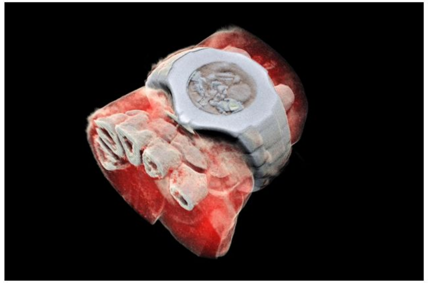
TRILOBITES

3-D Color X-Rays Could Help Spot Deadly Disease Without Surgery

A new medical scanner, derived from technology used by particle physics researchers at CERN, "is like the upgrade from black-and-white film to color," one of its developers said.

By Emily Baumgaertner

July 17, 2018



A three-dimensional scan of physicist Phil Butler's wrist, including watch, made using a new scanner developed by Dr. Butler and his son, Anthony Butler, a radiologist. Mars Bioimaging

Researchers in New Zealand have captured three-dimensional color X-rays of the human body, using an innovative tool that may eventually help diagnose cancers and blood diseases without invasive surgery.

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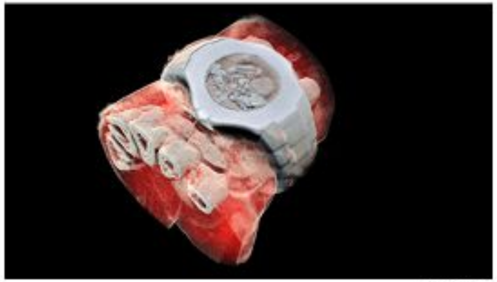

MARS BIOIMAGING

X-rays get upgrade to 3D, full color

By Frankie Schembri | Jul. 18, 2018 , 4:10 PM

the European Organization for Nuclear Research also know as CERN physics lab which contributed imaging technology.

First-Ever Colour X-Ray On A Human Performed In New Zealand

READ IN

The images very clearly show the difference between bone, muscle, and cartilage, for example in the position and size of cancerous tumours: CERN

World | Agence France-Presse | Updated: July 13, 2018 06:36 IST

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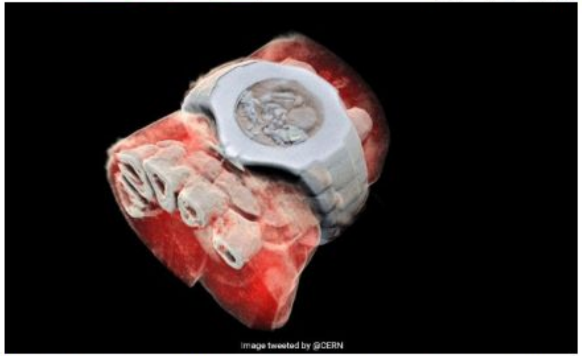


The colour X-ray imaging technique can produce clearer pictures and help doctors better diagnoses. (File)

PARIS, FRANCE: New Zealand scientists have performed the first-ever 3-D, colour X-ray on a human, using a technique that promises to improve the field of medical diagnostics, said the European Organization for Nuclear Research also know as CERN physics lab which contributed imaging technology.

Conclusions

- Radiation in CMS can cause problems with triggering, damage to sub-detectors and electronics, single event effects in electronics and activation which may complicate maintenance and upgrade work.
- We proposed, built and installed a sophisticated radiation monitoring system which is capable of providing quantitative real-time information on the fluxes and the flux distribution of all of the main radiation species in the experiment.
- Multiple movable locations in the CMS cavern to get a precise neutron flux around the CMS cavern.
- This is a successful demonstration of Medipix's micro technology for neutron flux measurement. We plan to work and deploy the Timepix devices next.
- Better spatial and energy resolution makes it the heart of the CT scanners used for molecular and spectral imaging.

Thank you for your attention!

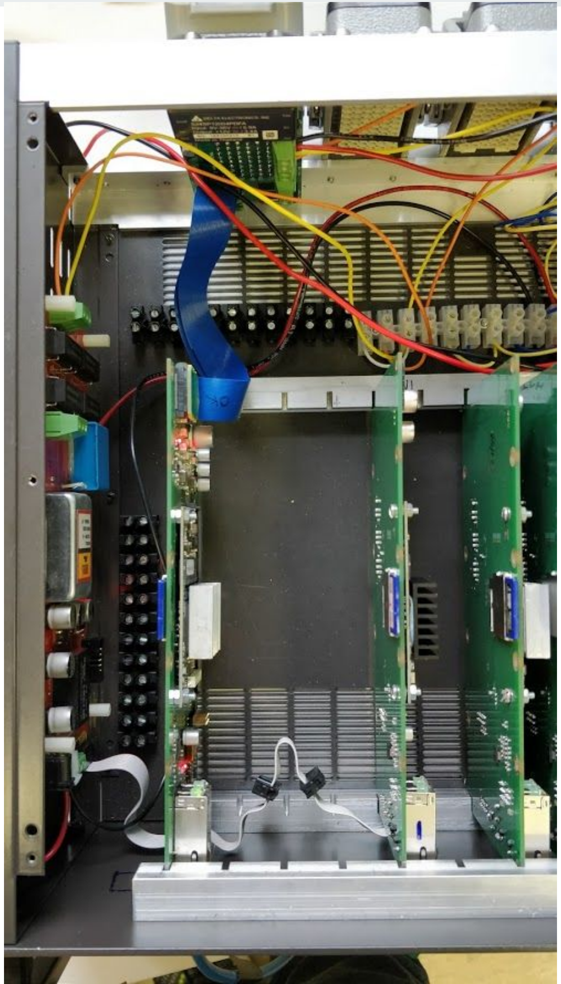
Acknowledgments

Anthony Butler

Philip Butler

Anne Dabrowski

Arkady Lokhovitskiy

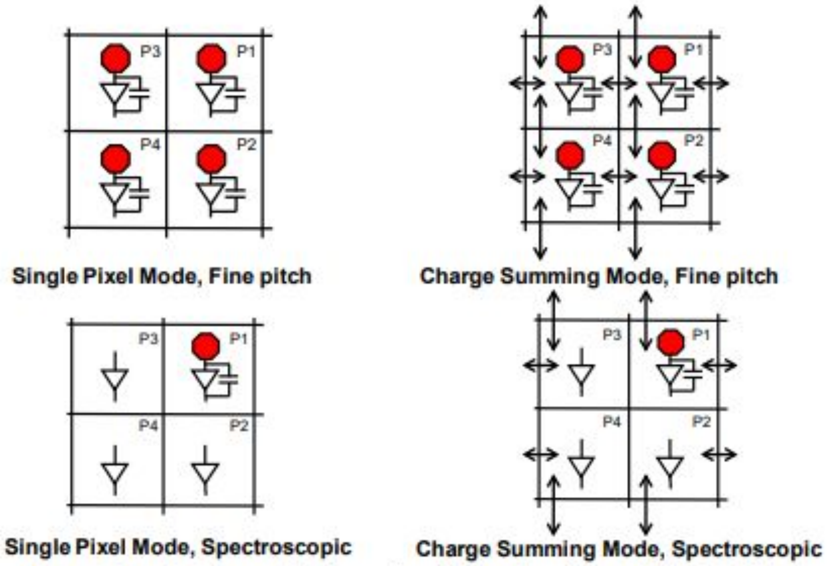


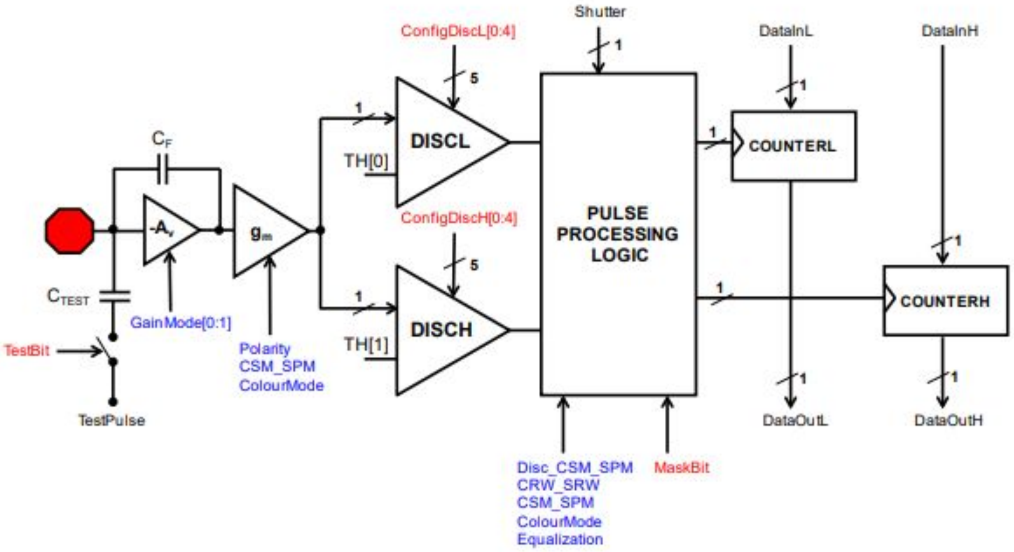
Backup slides

Areas of pre-clinical research in NZ

- Soft tissue quantification
- Bone and cartilage health
- Atheroma characterisation
- Cancer research
- Reduced metal artefacts in implants
- X-ray dosimetry

Operation of individual pixels





MARS Spectral CT

- Multidimensional data with spatial, spectral, temporal components.

  Single energy CT – dual energy CT – *multienergy CT (spectral)*

- Resolving x-ray energies → attenuation spectra of materials → quantification of native tissue types and contrast pharmaceuticals.

- Spectroscopic x-ray detection enabled using Medipix photon-counting detectors developed at CERN.

- Better x-ray detection efficiency (PCD) → low radiation dose.

- Can provide molecular information at high spatial resolution.

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