THE MEDIPIX COLLABORATIONS: PIXEL DETECTORS FOR PHOTON COUNTING AND PARTICLE TRACKING APPLICATIONS

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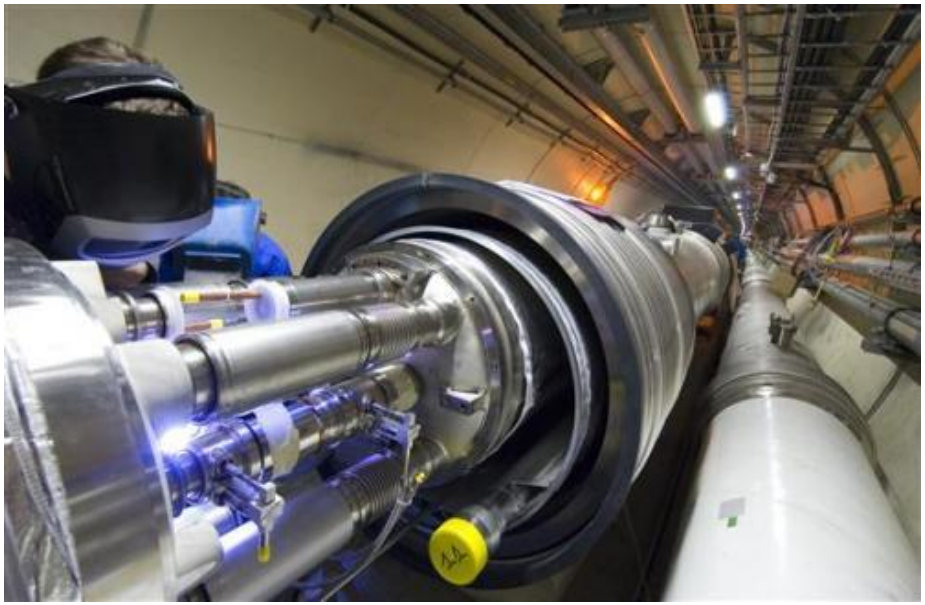
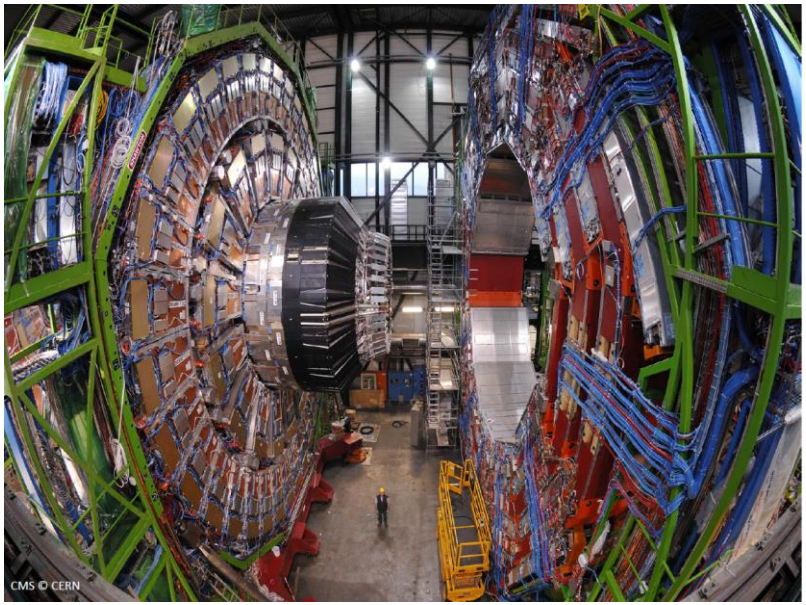
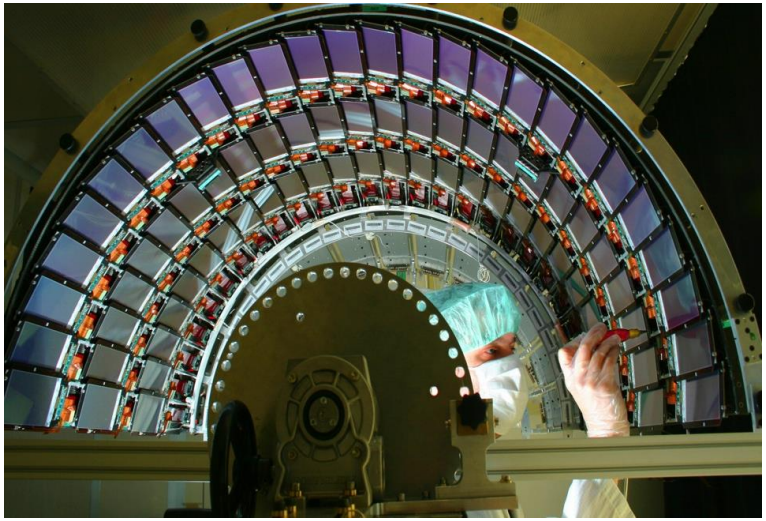




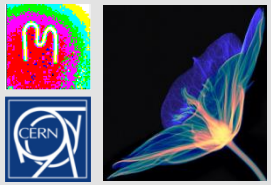


Particle accelerators+Detectors=Attoscope (10^{-18}m)

Tracker detector specifications:

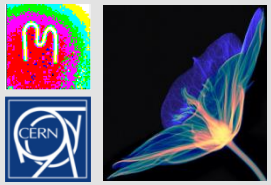
- Tagging of ‘hits’ to single bunch crossings (25ns)
- The ability to distinguish 2 closely separated tracks
- Minimal mass
- Minimal power consumption
- Radiation tolerant detectors and readout electronics

Present day solution: single event processing with Hybrid Pixel Detectors



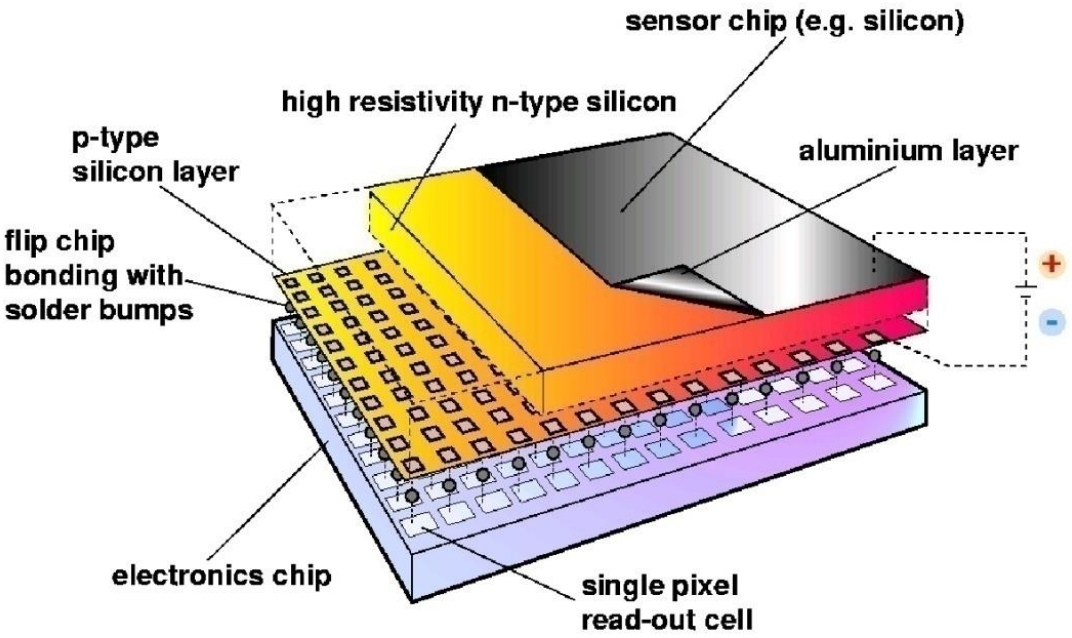
Outline

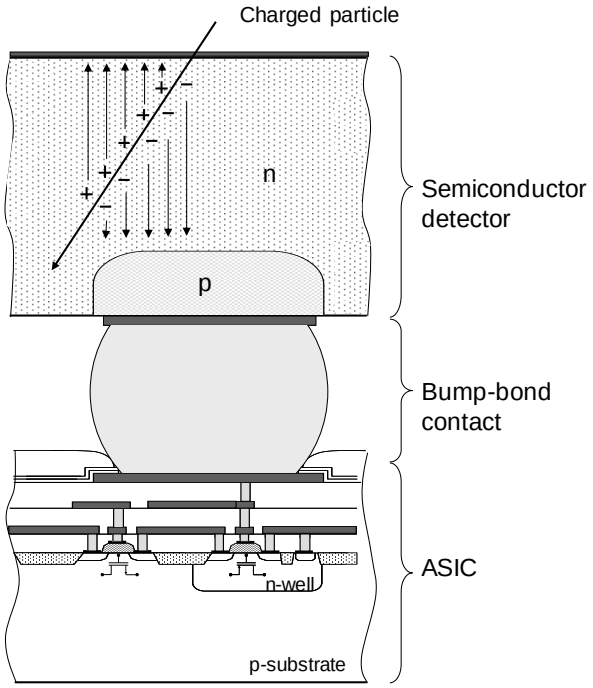
- Introduction to hybrid pixel detectors
- The Medipix Collaborations
- The two families of chips
  - Medipix chips
  - Timepix chips
- Some applications
  - X-ray radiography
  - Carbon beam monitoring
  - Mass spectrometry
- Summary and conclusions



Introduction to hybrid pixel detectors

Hybrid Pixel Detectors



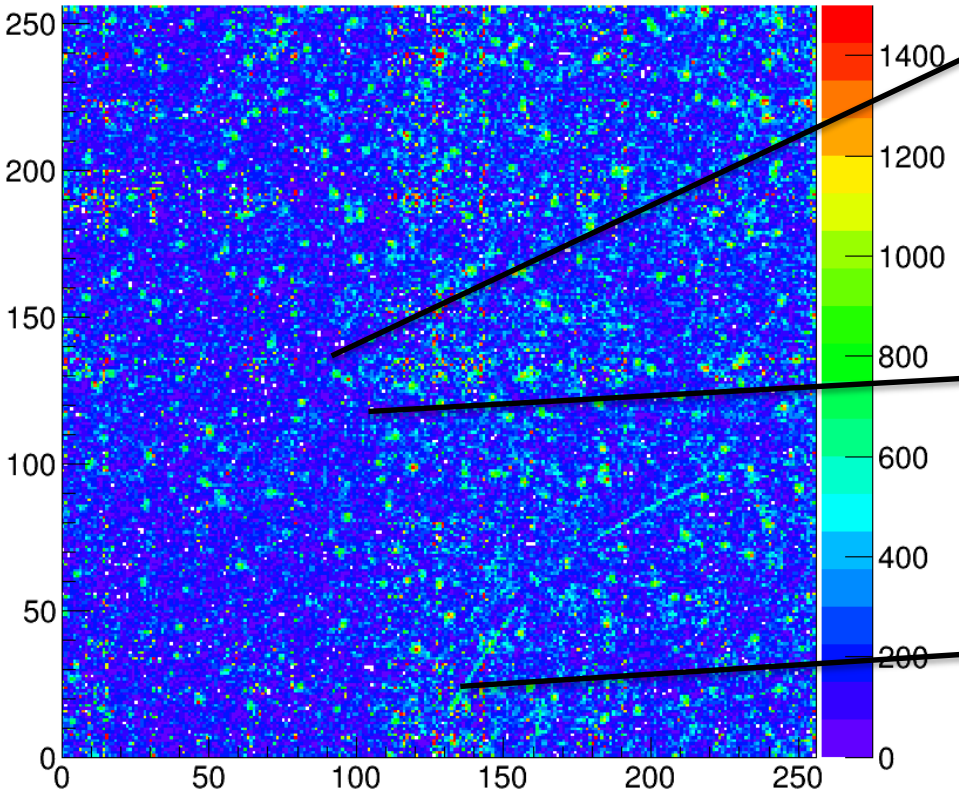


Sensor: Converts energy deposited by a particle into an electrical signal (direct conversion)
Readout Electronics: electrical signal processing to extract information about radiation
Information: Camera / Time of arrival and Energy

- Fill factor is 100 %
- Sensor material can be optimized for the application (Si, GaAs, CdTe..) (other sensors possible (photocathode+MCP))
- Standard CMOS electronics
- Very high SNR
- Noise hit free
- Limitation “dead time”

Energy and time measurements with cosmic particles

Integral frame ~ 72h

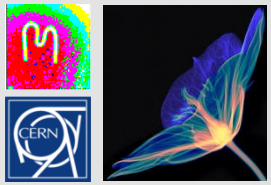


Heavy ionizing particle with short range (α)

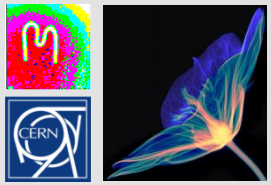
Fast particles high E_K (μ, e^-)

Heavy ionizing particle (protons, ions)

Timepix chip: matrix of 256x256 pixels
Different particles present a different signature in their interaction with the pixelated semiconductor detector



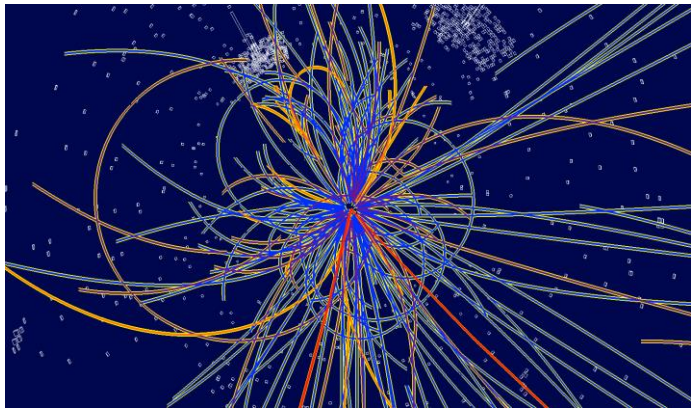
Demonstration

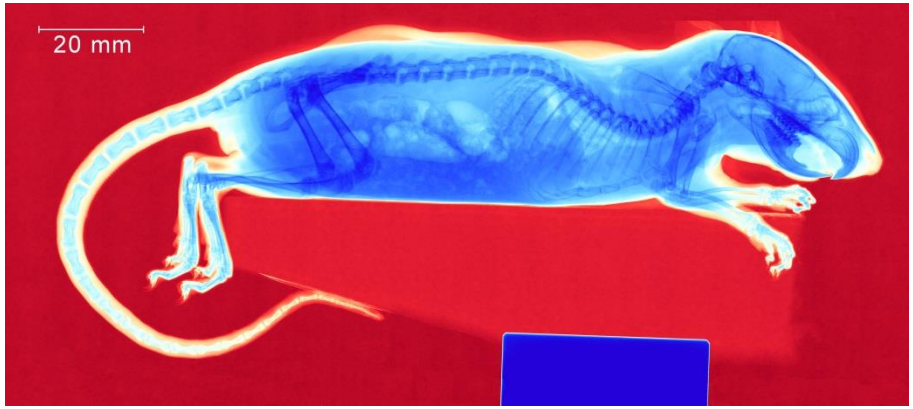


The Medipix Collaborations

Medipix Collaborations

- Created to develop hybrid pixel detectors and their applications
- Readout chips are designed at CERN based on
  - Know how developed for particle detectors in High Energy Physics
  - Feedback from the collaboration members
- Collaboration members develop readout systems and install chips in their applications
- Licenses have been granted to commercial partners
- Example of spin-off and spin-back from/to Physics





Medipix2 Collaboration

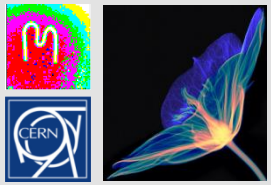
- U INFN Cagliari
- CEA-LIST Saclay
- CERN Genève
- U Erlangen
- ESRF Grenoble
- U Freiburg
- U Glasgow
- IFAE Barcelona
- Mitthoegskolan
- MRC-LMB Cambridge
- U INFN Napoli
- NIKHEF Amsterdam
- U INFN Pisa
- FZU CAS Prague
- IEAP CTU in Prague
- SSL Berkeley

http://medipix.web.cern.ch/MEDIPIX/

The Medipix3 Collaboration

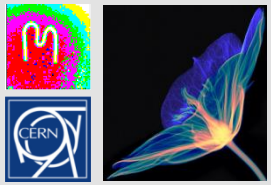
University of Canterbury, Christchurch, New Zealand
CEA, Paris, France
CERN, Geneva, Switzerland,
DESY-Hamburg, Germany
Albert-Ludwigs-Universität Freiburg, Germany
University of Glasgow, Scotland, UK
Leiden University, The Netherlands
NIKHEF, Amsterdam, The Nether
Mid Sweden University, Su
IEAP, Czech Technic epublic
ESRF, Grenob
Universit , Germany
U , USA
gy, Espoo, Finland
gszentrum Karlsruhe, Germany
ouston, USA
d Light Source, Oxfordshire, England, UK
niversidad de los Andes, Bogota, Colombia
University of Bonn, Germany
AMOLF, Amsterdan, The Netherlands
Technical University of Munich, Germany
Brazilian Light Source, Campinas, Brazil

THIS PRESENTATION: MEDIPIX3 and TIMEPIX3



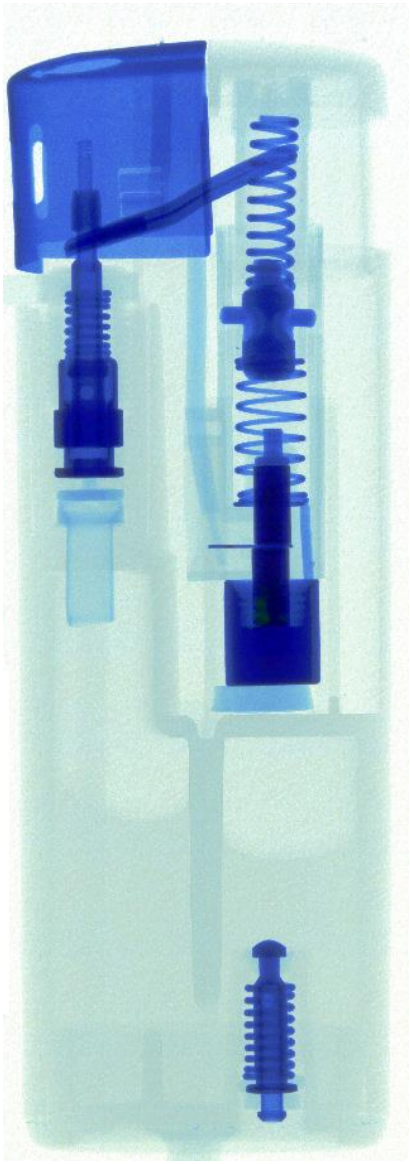
Chips developed by the Medipix3 collaboration:

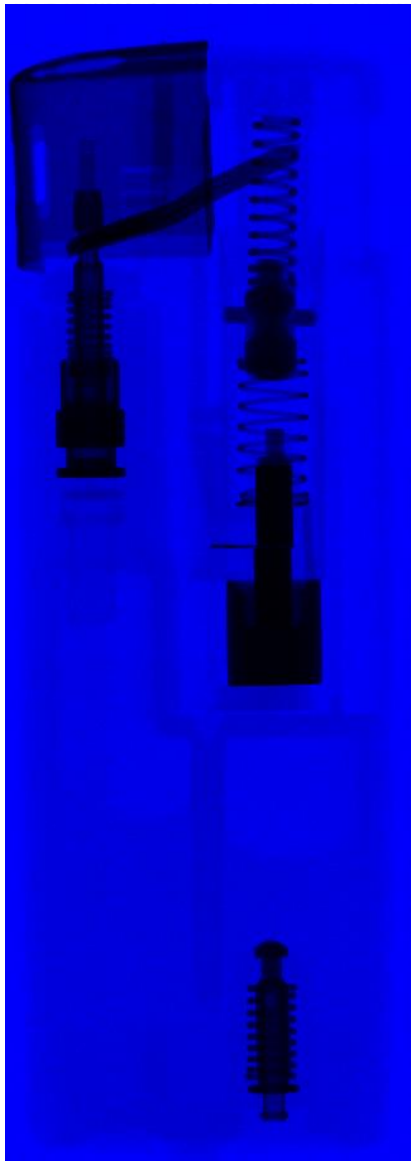
- Medipix3: Camera
- Timepix3: Single Particle Energy and Time of Arrival Measurement



Camera mode: X-ray imaging

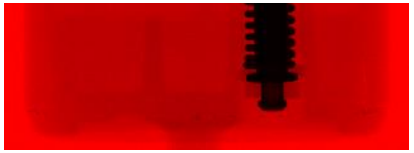
Colour x-ray of a lighter



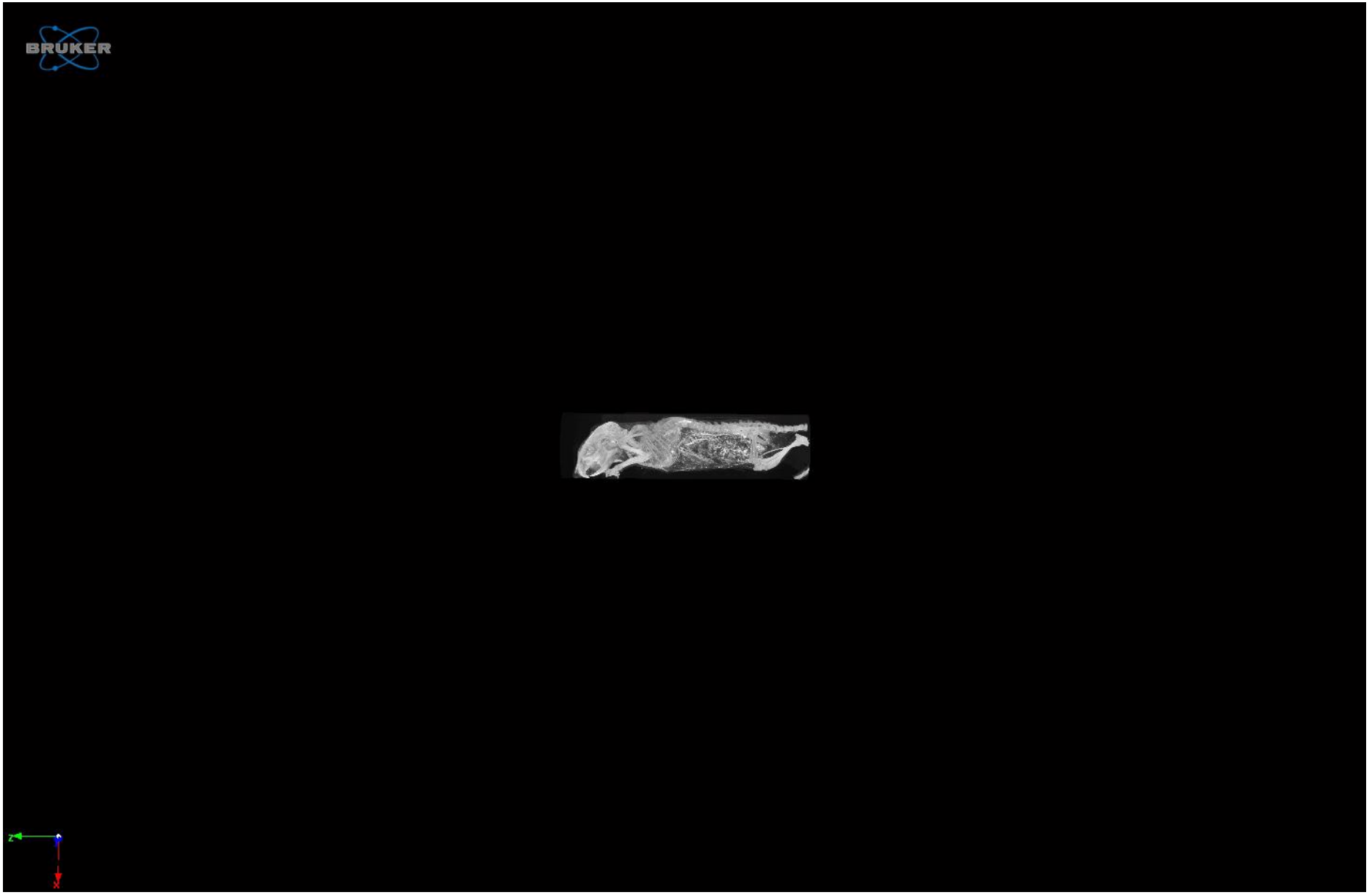


Photon weight in image:

- Integrating technologies: ~E
- Photon counting: 1
- Optimal SNR: Energy weighting ~E^{-3}



Courtesy: S. Procz et al.

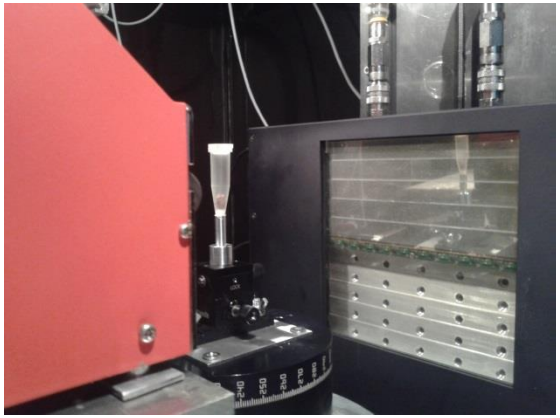


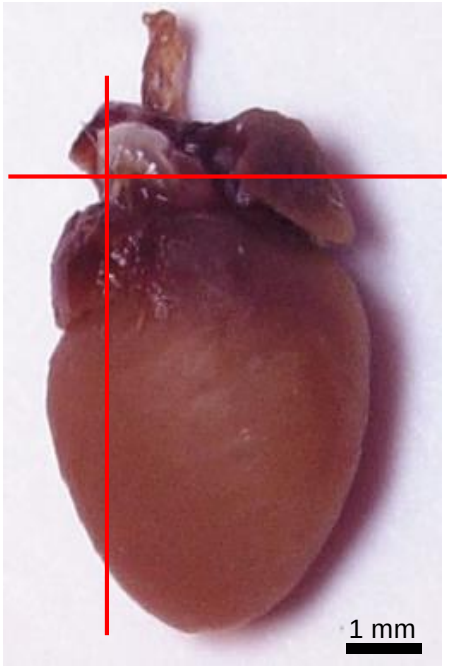
- Micro-CT of a mouse with contrast agent (Au nanoparticles)
- Acquired using small animal CT scanner
- Spatial resolution ca. 45 µm

Timepix, Courtesy J. Dudak

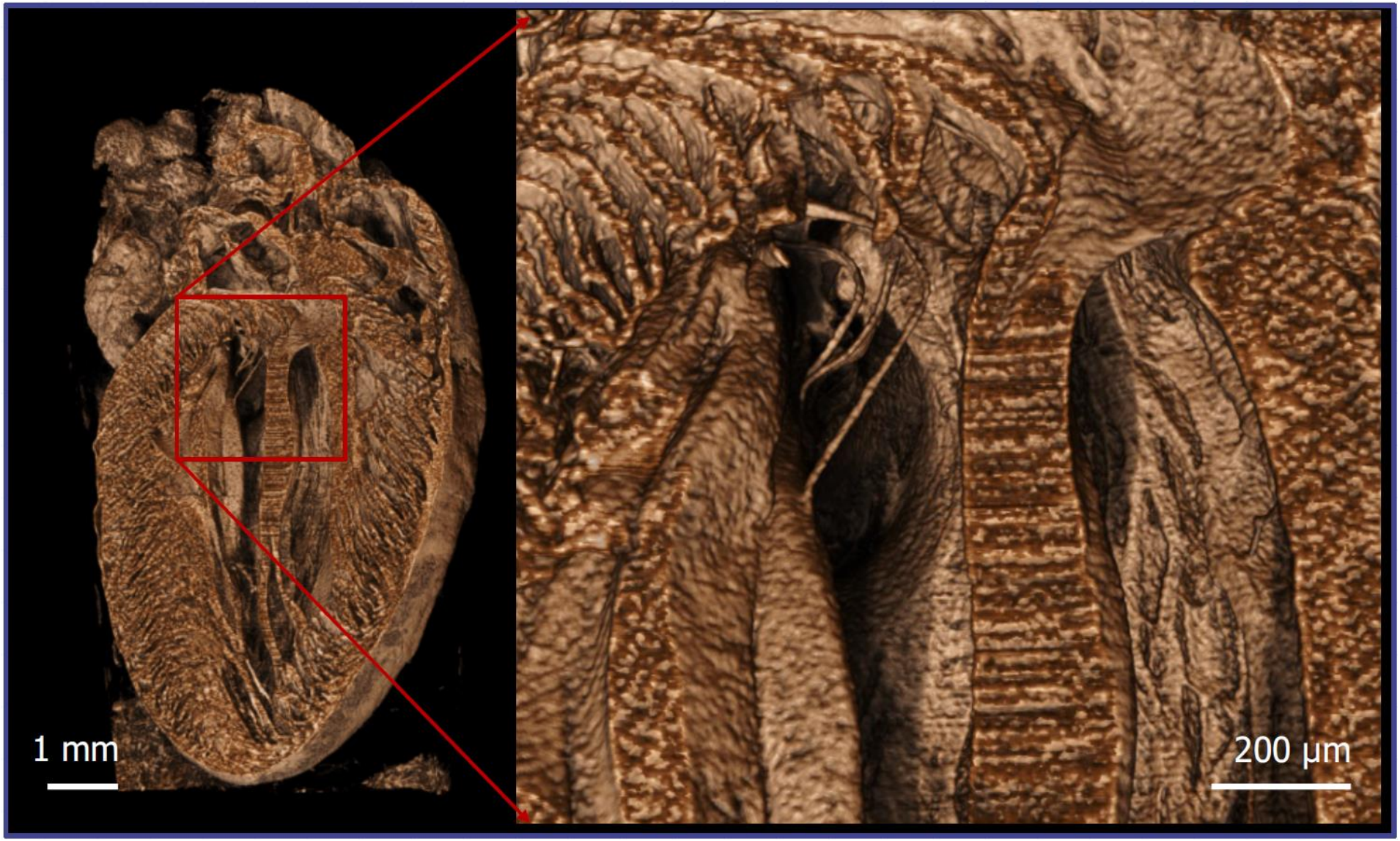
Micro-CT of a mouse heart

- Ethanol-preserved mouse heart scanned using the WidePIX10x5 detector
- 60 kVp tungsten spectrum
- 720 projections, 5 seconds per projection
- Spatial resolution ca. 7 µm
- Reconstructed using Volex, visualized using CTVox and Amide software





Dudak, J. et al. High-contrast X-ray micro-radiography and micro-CT of ex-vivo soft tissue murine organs utilizing ethanol fixation and large area photon-counting detector. Sci. Rep. 6, 30385; doi: 10.1038/srep30385 (2016).



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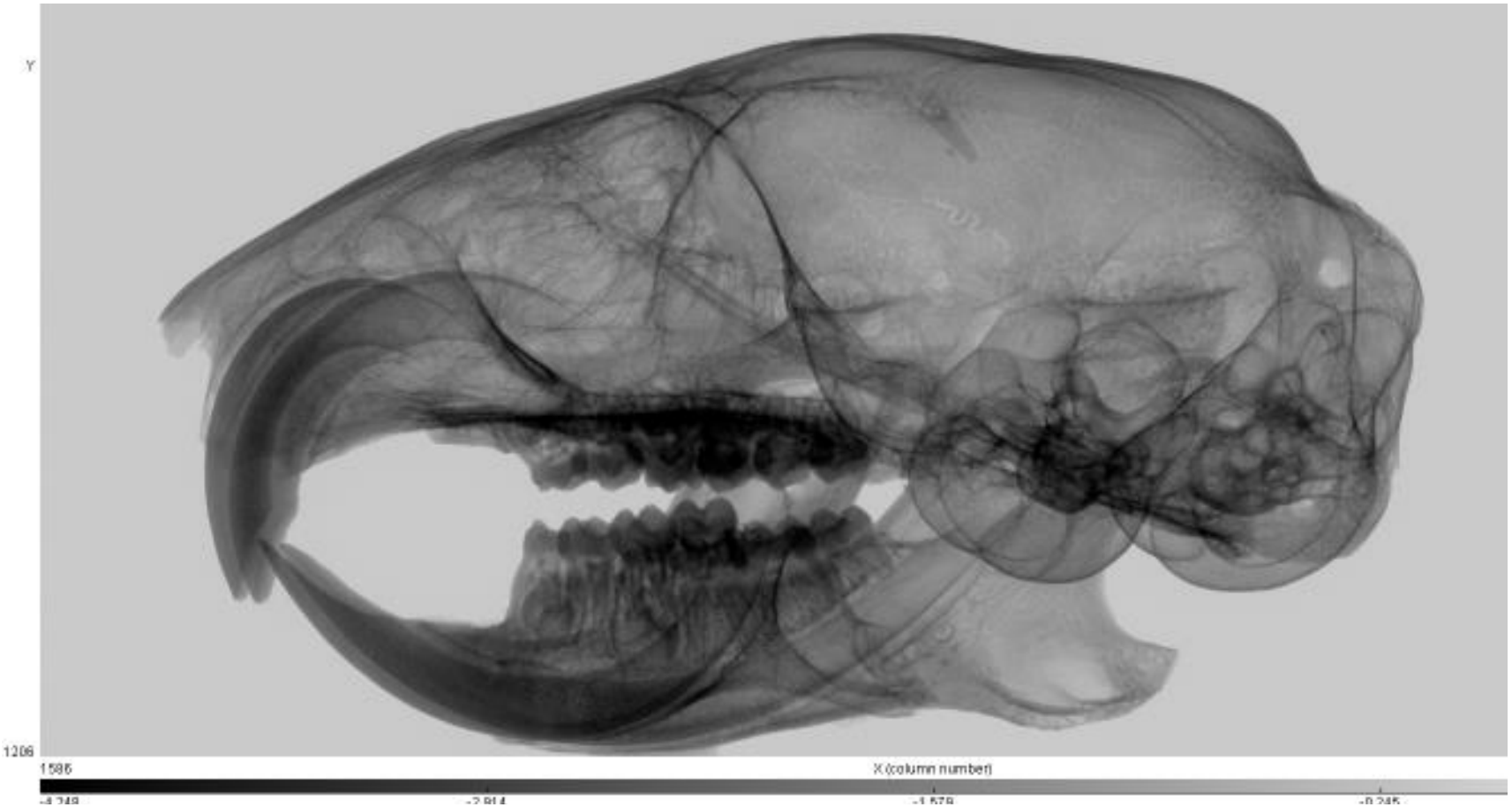
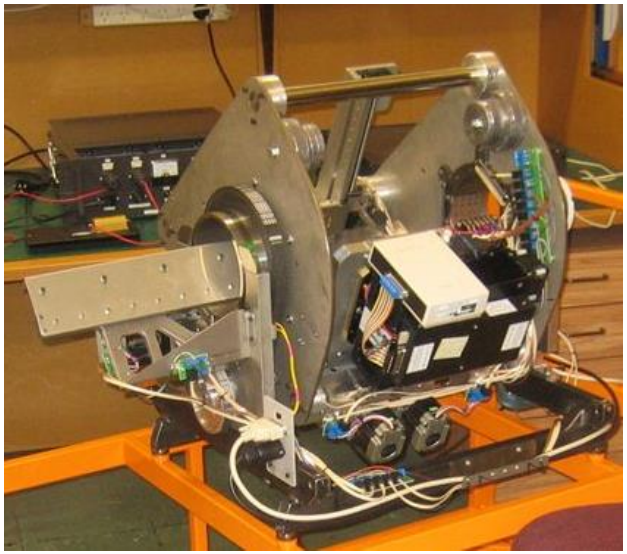
Medipix3 Image (GaAs 55μm/500μm)

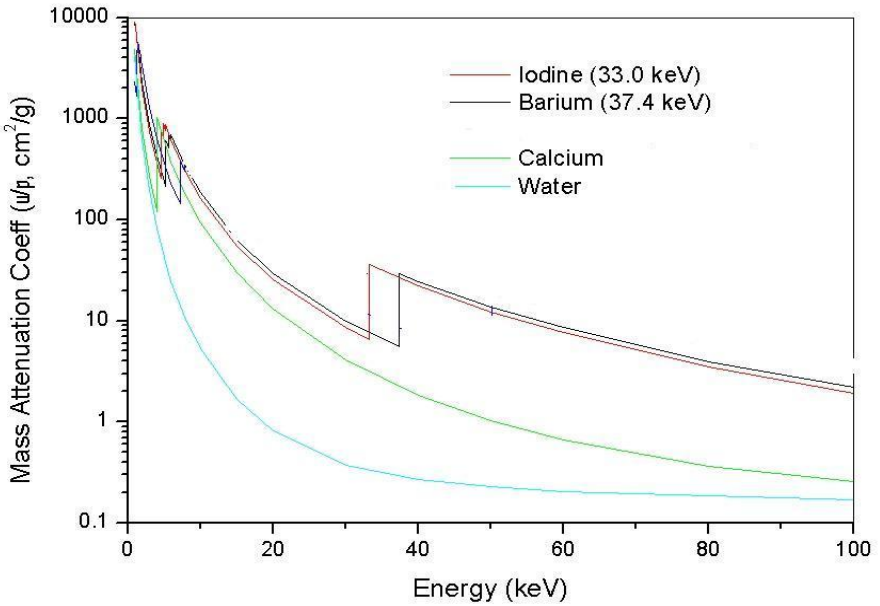


A tiled X-ray image of a mouse skull.

Courtesy S. Procz

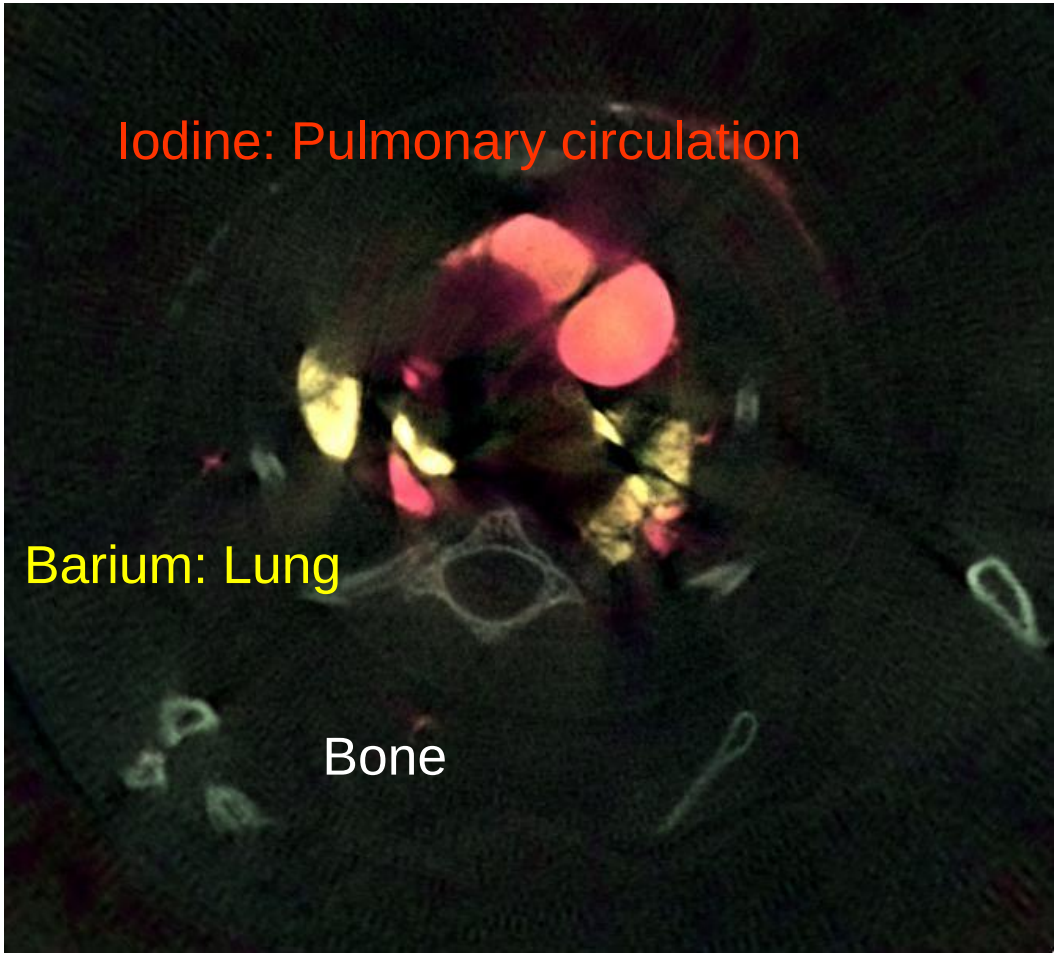
‘Colour’ X-ray Imaging (www.marsbioimaging.com/)



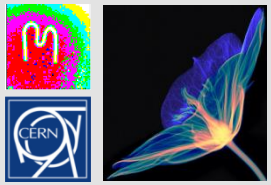


Univ. Canterbury, NZ
Mars bio-imaging
Small animal CT

‘Colour’ X-ray Imaging (www.marsbioimaging.com/)



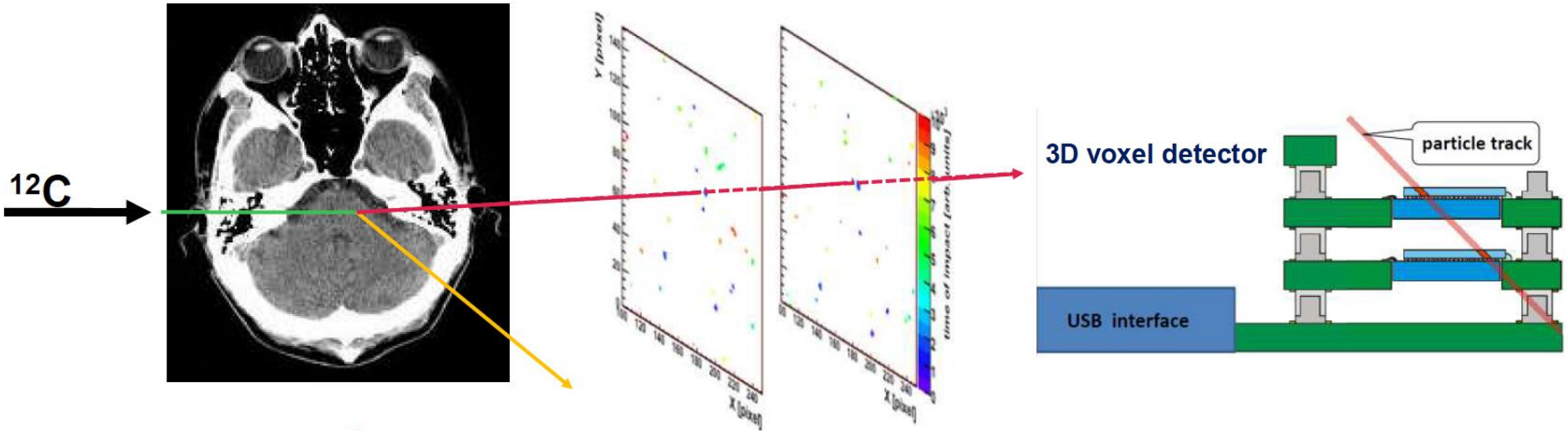
Butler, A., et al., *Processing of spectral X-ray data with principal components Analysis*, IWORID 2009, Prague



Single particle energy and time of arrival measurement:

Beam Monitoring

Carbon Therapy beam monitoring



Hadron Therapy

Precise delivery of radiation dose in a tumor area

Essential to monitor beam in real time

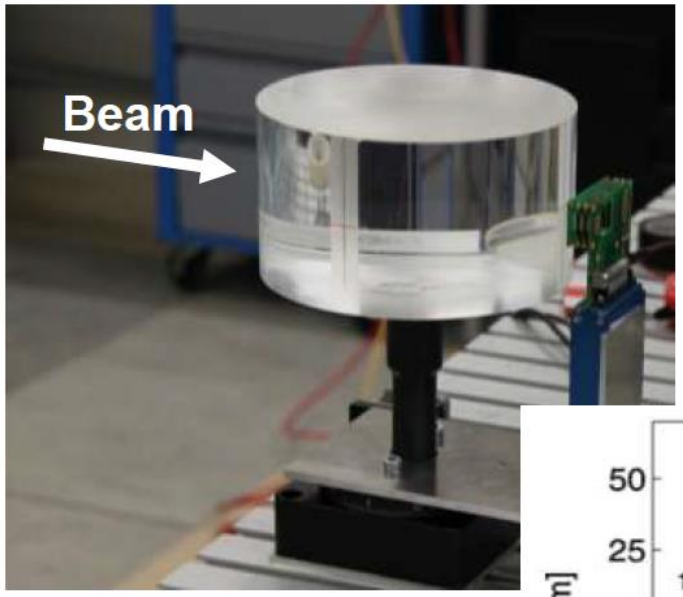
- *To avoid overdose on critical organs or underdose in tumor*

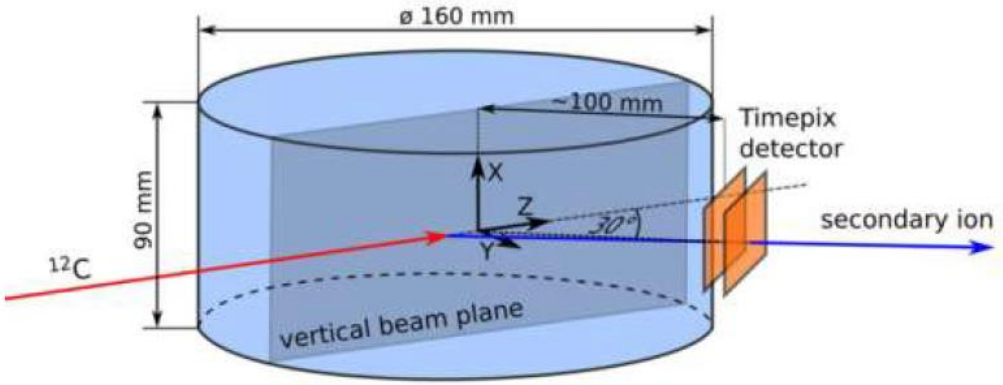
Timepix-based camera allows to reconstruct trajectory of secondary particles

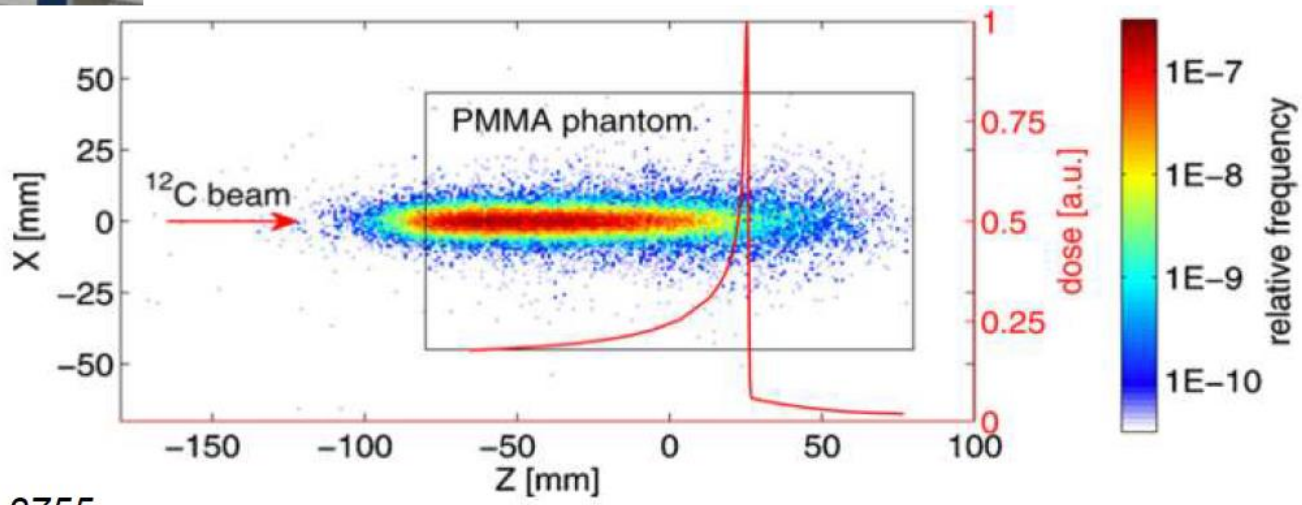
Verification in real time of the beam delivered to the patient: beam range, width and shifts in the lateral direction

Slide courtesy of M. Martisikova, German Cancer Research Centre, Heidelberg

Carbon Therapy beam monitoring

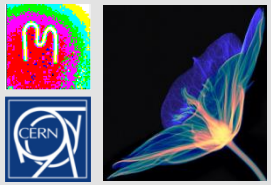






Gwosch et al.: PMB 58 (2013) 3755

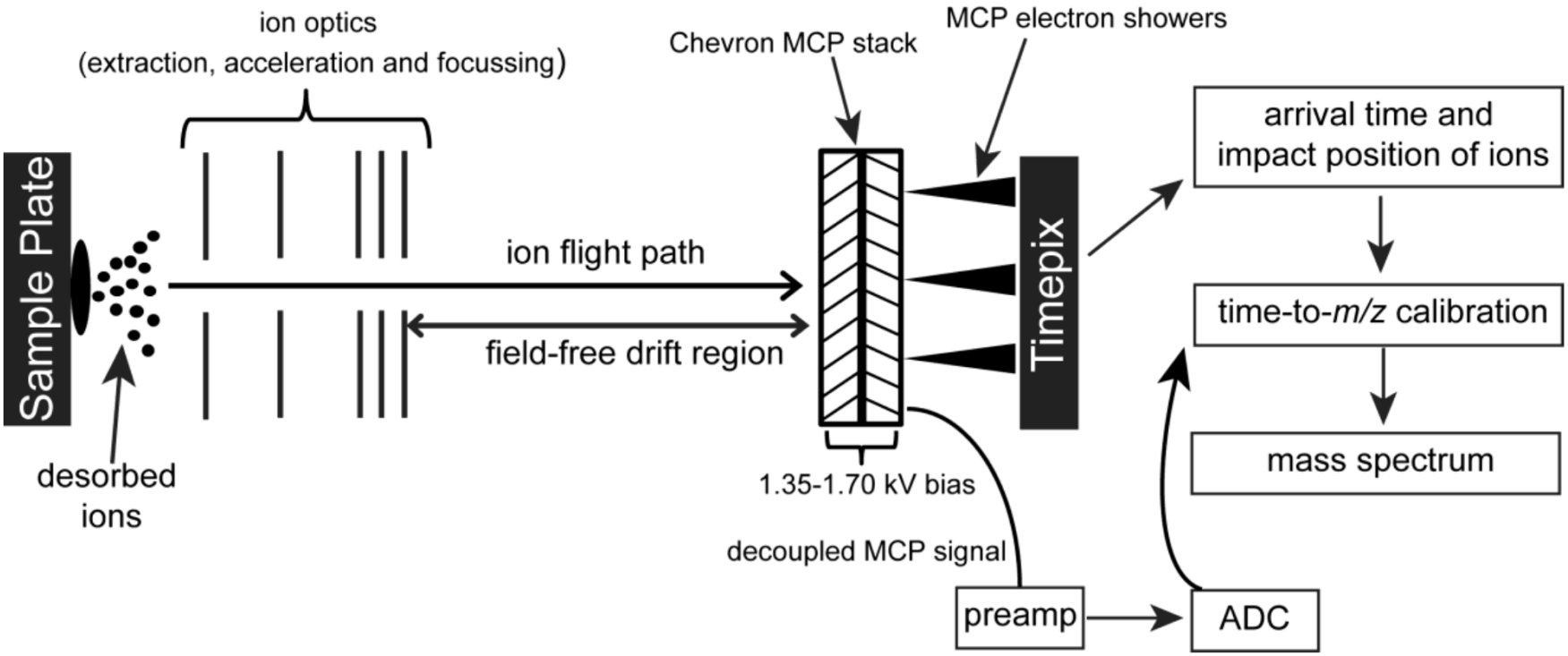
Verification in real time of the beam delivered to the patient: beam range, width and shifts in the lateral direction



Single particle energy and time of arrival measurement:

Mass Spectrometry

Time of Flight Mass Spectrometry



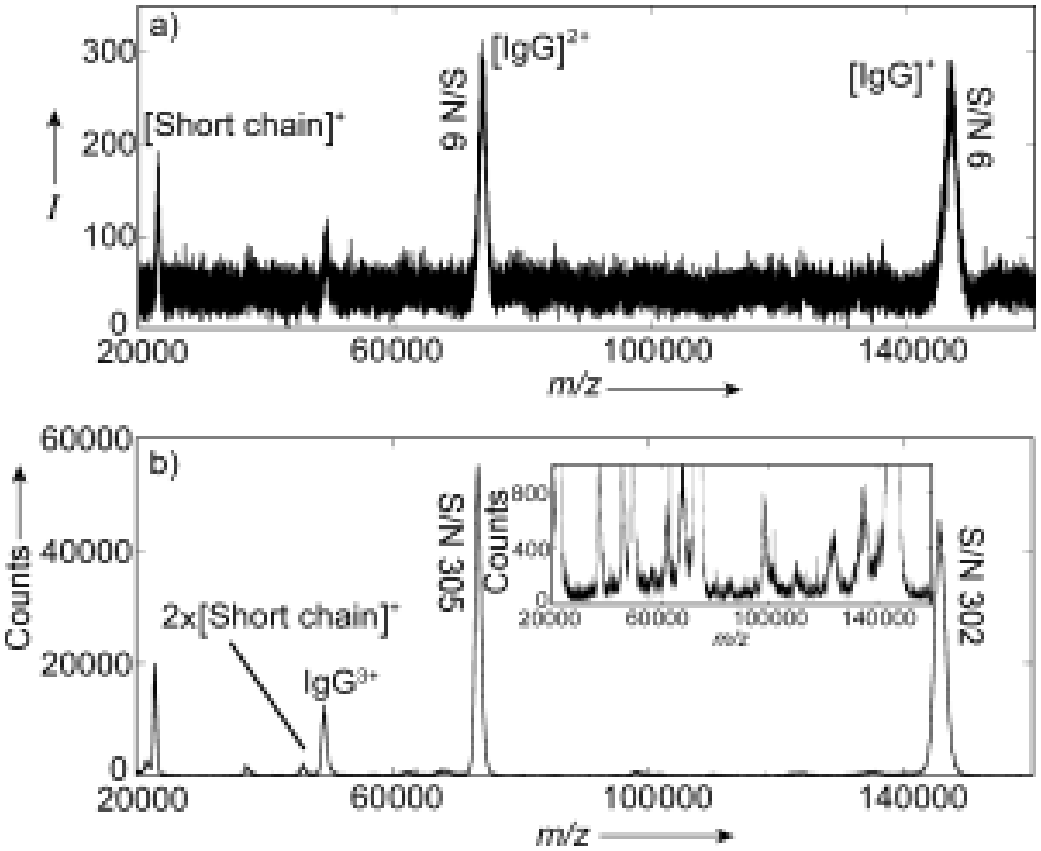
Mass spectrometry imaging visualization of spatial organization and identification of molecular masses from biomolecular surfaces

"Enhanced Detection of High-Mass Proteins by Using an Active Pixel Detector", Shane R Ellis et al, Angewandte Chemie DOI: 10.1002/anie.201305501

Enhanced Detection of High-Mass Proteins by Using an Active Pixel Detector

ADC measurement

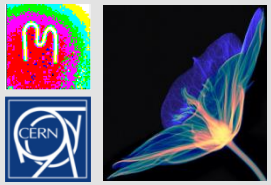
Timepix measurement



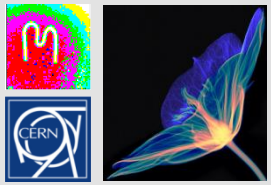
Analysis of the antibody Immunoglobulin G

30 fold improvement in signal to noise ratio

- Every hit is the result of an ion arrival event at the detector
- 512x512 parallel TDCs (segmentation allows dealing with high fluxes)
- Electron shower from MCP falls on a cluster of pixels (Oversampling)



Summary and conclusions



Summary and conclusions

- Hybrid pixel detectors were developed at CERN for particle physics experiments and have been transferred to other fields of science
- The Medipix collaborations have developed 2 architectures for hybrid pixel detectors
  - Cameras (Medipix3)
  - Single particle time and energy measurement (Timepix)
- The electronics in the pixels processes the information on an event by event basis
- The main limitations of the technology are the dead time and the cost (due to relatively low volumes)
- This advantages of the technology make the devices excel in several applications (imaging, dosimetry, beam monitoring, electron microscopy, mass spectrometry, material analysis and others)

Thank you for your attention!

Medipix3RX images: S. Procz et al.