Anwendungen (in) der Teilchenphysik (Medizin/Medizintechnik)

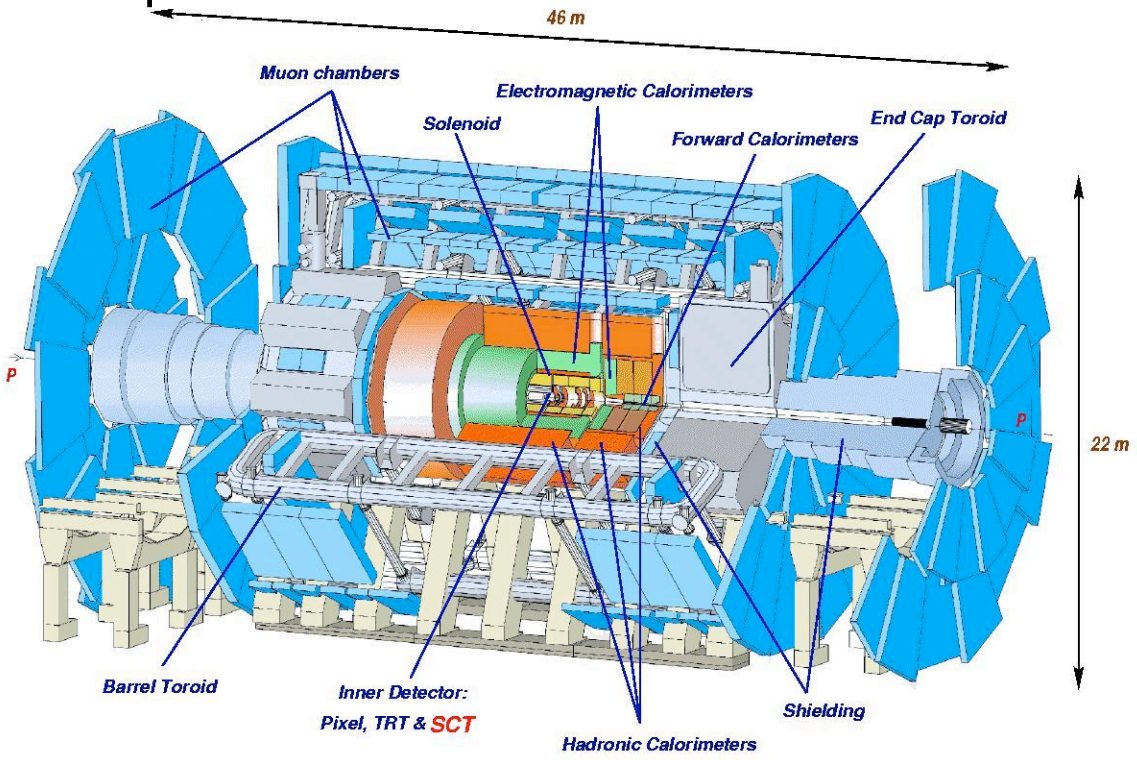
Outline

- Pixeldetektoren am CERN
- Medipix, Anwendungsbeispiele
  - Medipix2 chip & readout System
  - X-ray-, Neutronenbildgebung, ...
- „Spin back“ in HEP:Timepix
- Medipix3
- Zusammenfassung
- Demo

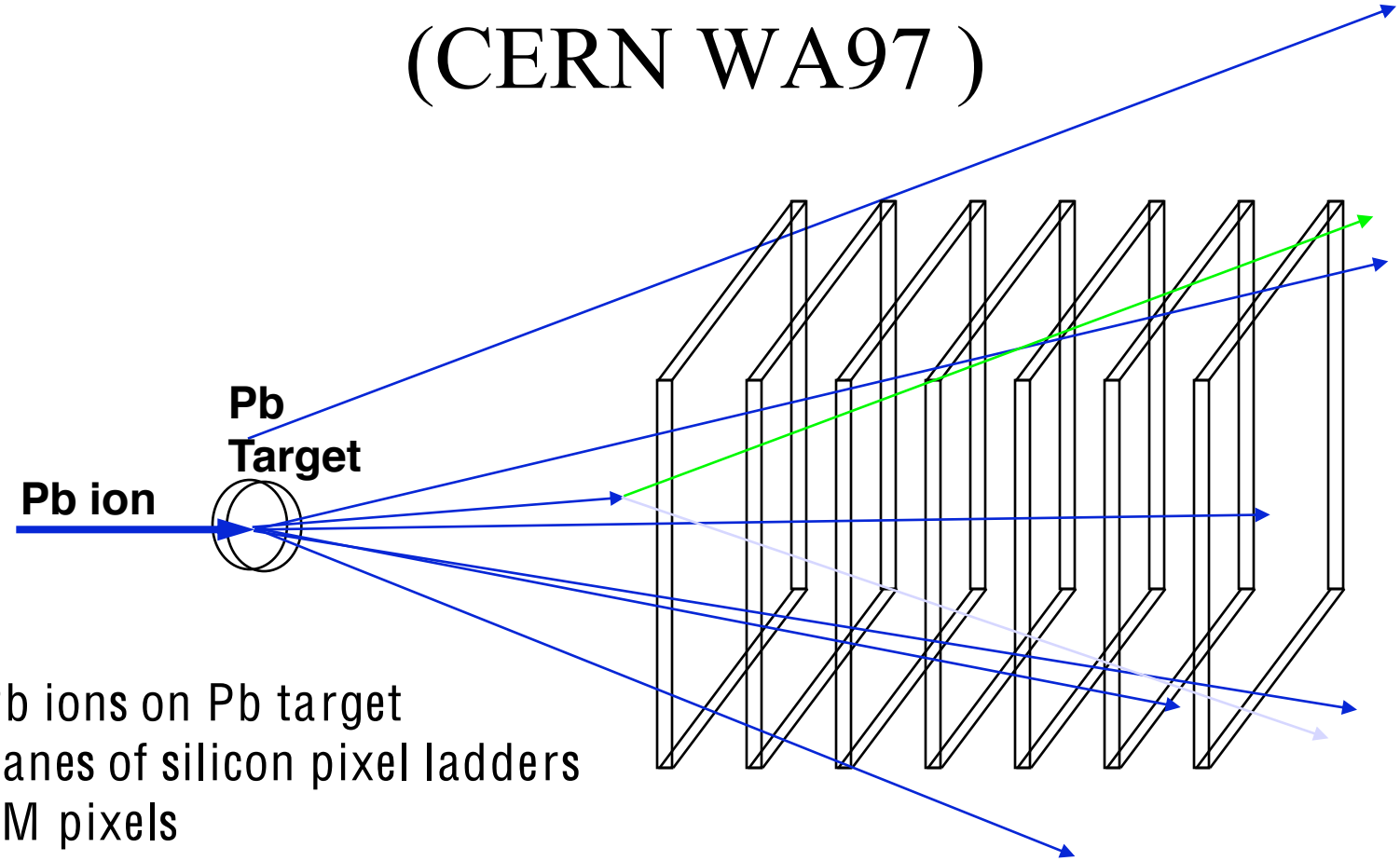
Pixel Detectors at CERN

- Used in LHC experiments to obtain precise spatial information of particle tracks

Example: ATLAS



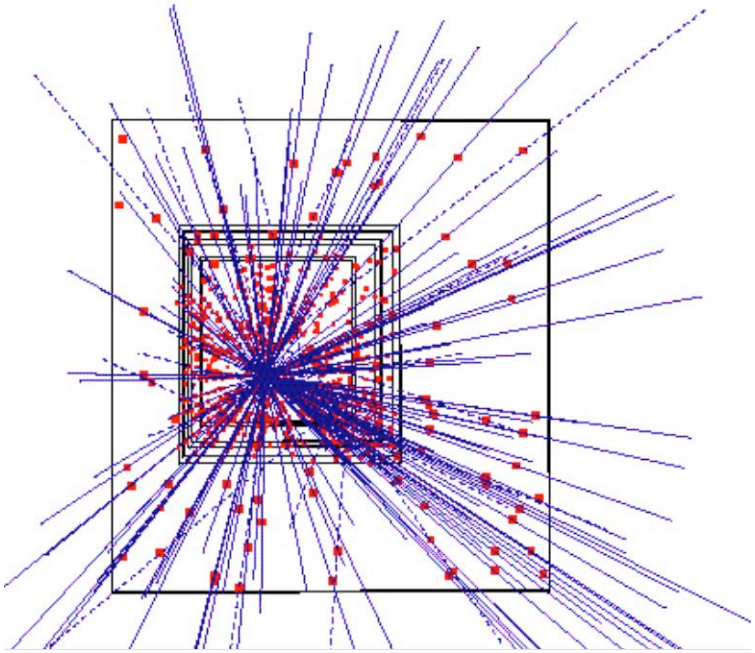
Hybrid pixel detector arrangement in a fixed target heavy ion experiment (CERN WA97)



^{208}Pb ions on Pb target
7 planes of silicon pixel ladders
1.1 M pixels

Tracking

- unambiguous reconstruction of particle patterns with micrometer precision
- low input noise due to tiny pixel capacitance



WA97, RD19 (CERN):

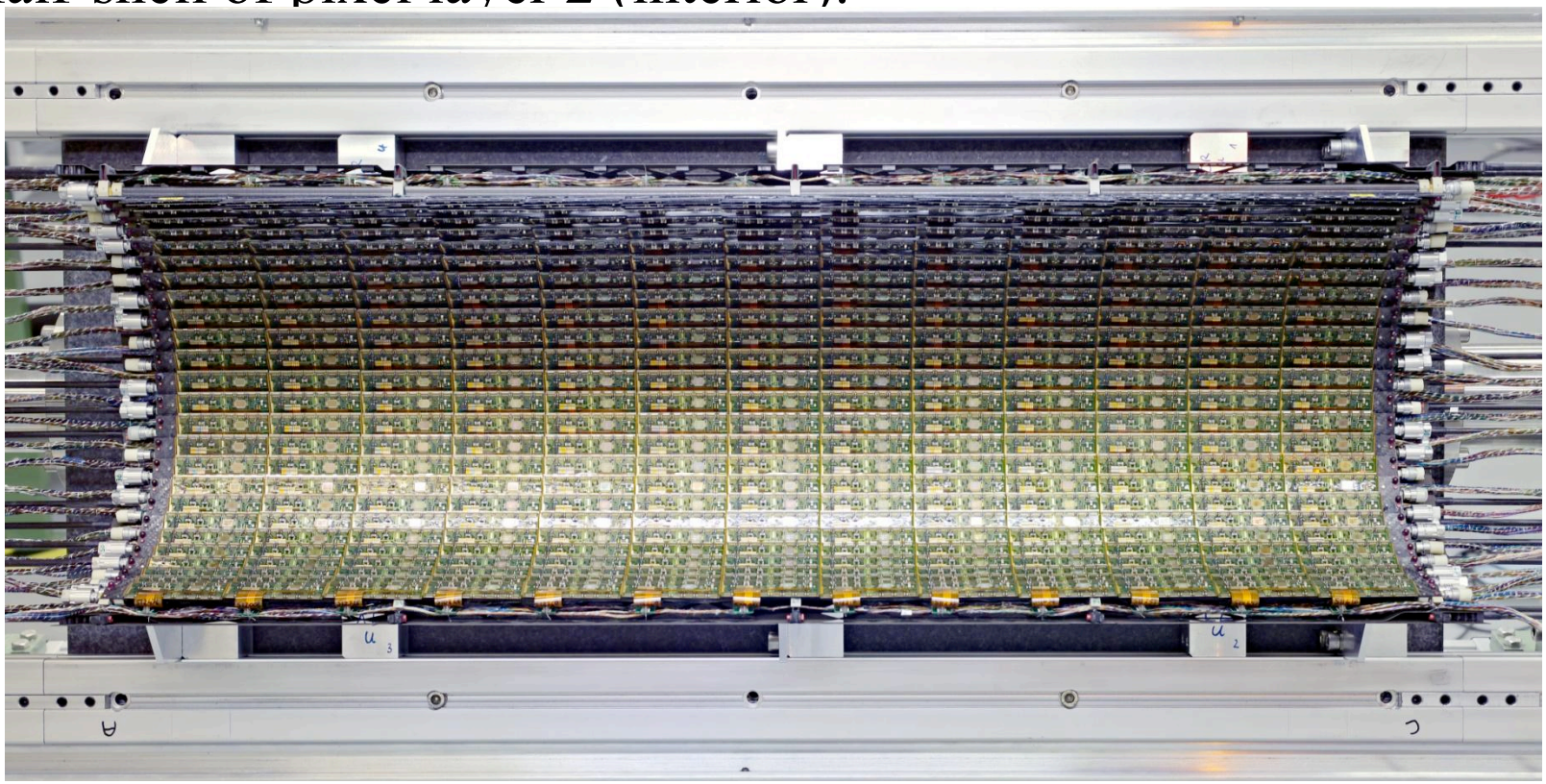
All hits associated with particle tracks; clean and fast images.

First large-scale CMOS pixel system.

ATLAS Pixels

- ATLAS, CMS Pixel Layer bestehen aus ~15 000 pixel Chips

Half-shell of pixel layer 2 (interior):



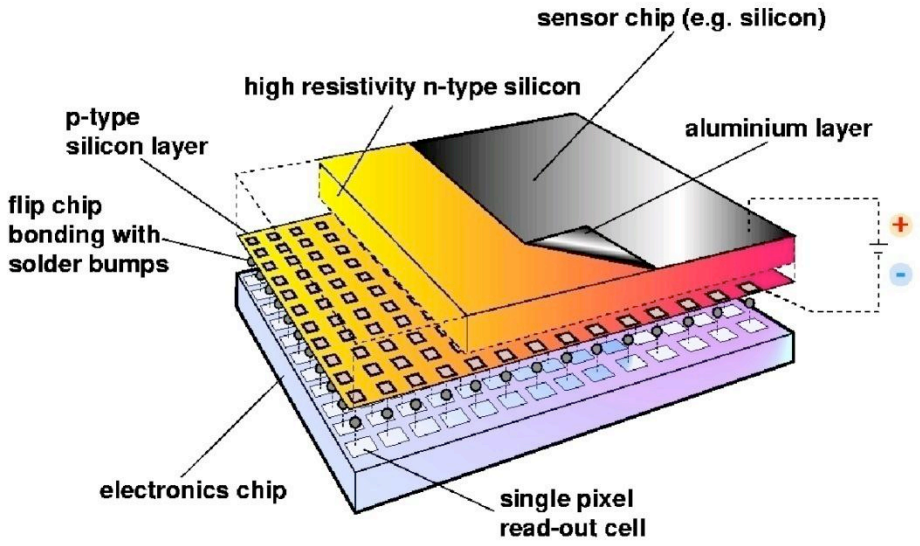
Anforderungen in HEP Tracking fuer LHC (Kurzfassung)

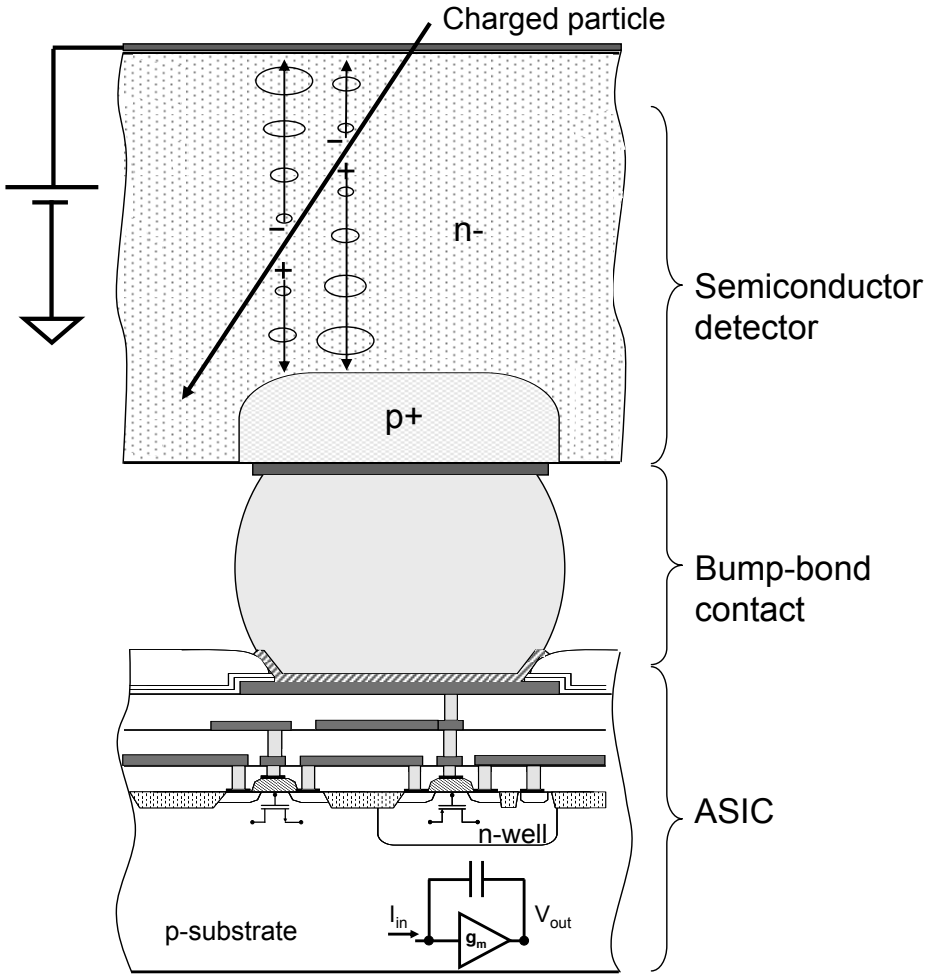
- Teilchen muessen einzelen bunch crossings zugeordnet werden (25ns)
- Information muss gespeichert werden bis Auslesetrigger gegben wird
- Hohe Ortsaufloesung – eng beieinanderliegende Teilchenspuren muessen in r and phi separiert werden koennen
- Minimal Masse
- Minimaler Energieverbrauch
- Strahlungharte Detektoren and Ausleseelektronik
- ……..

Single Event Processing

HYBRID SILICON PIXEL DETECTORS

Hybrid-Pixel Detektor





Motivation für das Medipix Projekt

- Technology entwicklet fuer HEP: offensichtlich auch einsetzbar in anderen Bereichen. Anforderungprofile in Bildgebung zT. stark ueberlappend
- Fortschritt in CMOS Technologie ermöglicht Implementierung
  - kompletter real-time Signalverarbeitung von einzelnen Photonen im Pixel Maβstab
    - Photon/Teilchen Energie dient als Selektionskriterium
      - Rauschunterdruckung (→ zB. Leckströme)
    - Digitalisierung bereits im Pixel (!= CCD, AMFPI)
      - Linearer dynamischer Bereich
      - Limitiert nur durch die Anzahl der Bits im Zähler
      - Kein Ausleserauschen
  - Keine Wichtung der Photonen nach Energie -> Verbessertes SNR (eg. bei schwachem Kontrast in med. Radiography)

→ Quantum Imaging

MEDIPIX2 PARTNERS

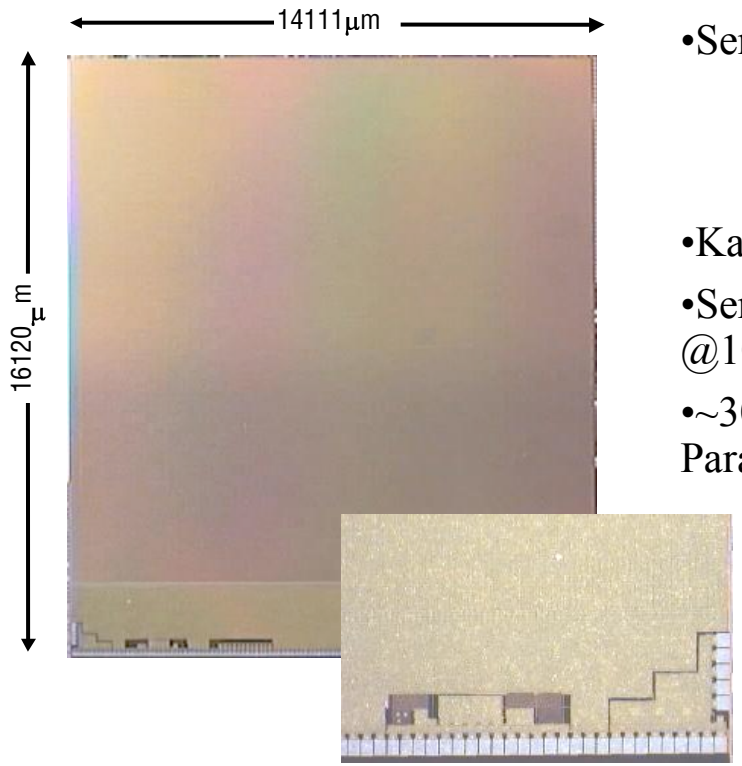
- U INFN Cagliari
- CEA-LIST Saclay
- CERN Genève
- U d'Auvergne Clermont
- U Erlangen
- ESRF Grenoble
- U Freiburg
- U Glasgow
- IFAE Barcelona
- Mitthoegskolan
- MRC-LMB Cambridge
- U INFN Napoli
- NIKHEF Amsterdam
- U INFN Pisa
- FZU CAS Prague
- IEAP CTU in Prague
- SSL Berkeley

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

Medipix2 collaboration

- **Applications:**
  - **Dental radiography**
  - **Mammography**
  - **Angiography**
  - **Dynamic autoradiography**
  - **Tomosynthesis**
  - **Synchrotron applications**
  - **Electron-microscopy**
  - **Gamma camera**
  - **X-ray diffraction**
  - **Neutron detection**
  - **Dynamic defectoscopy**
  - **Adaptative optics**
  - **Radiation monitor**
- **> 100 publications in the last 5 years** (http://www.cern.ch/Medipix**)**
- **Medipix3 collaboration started last September (“*The Medipix3 Prototype, a Pixel Readout Chip Working in Single Photon Counting Mode with Improved Spectrometric Performance”, R.Ballabriga, IEEE NSS-MIC 2006*)**
- **Collaboration spokesman Michael Campbell (michael.campbell@cern.ch)**

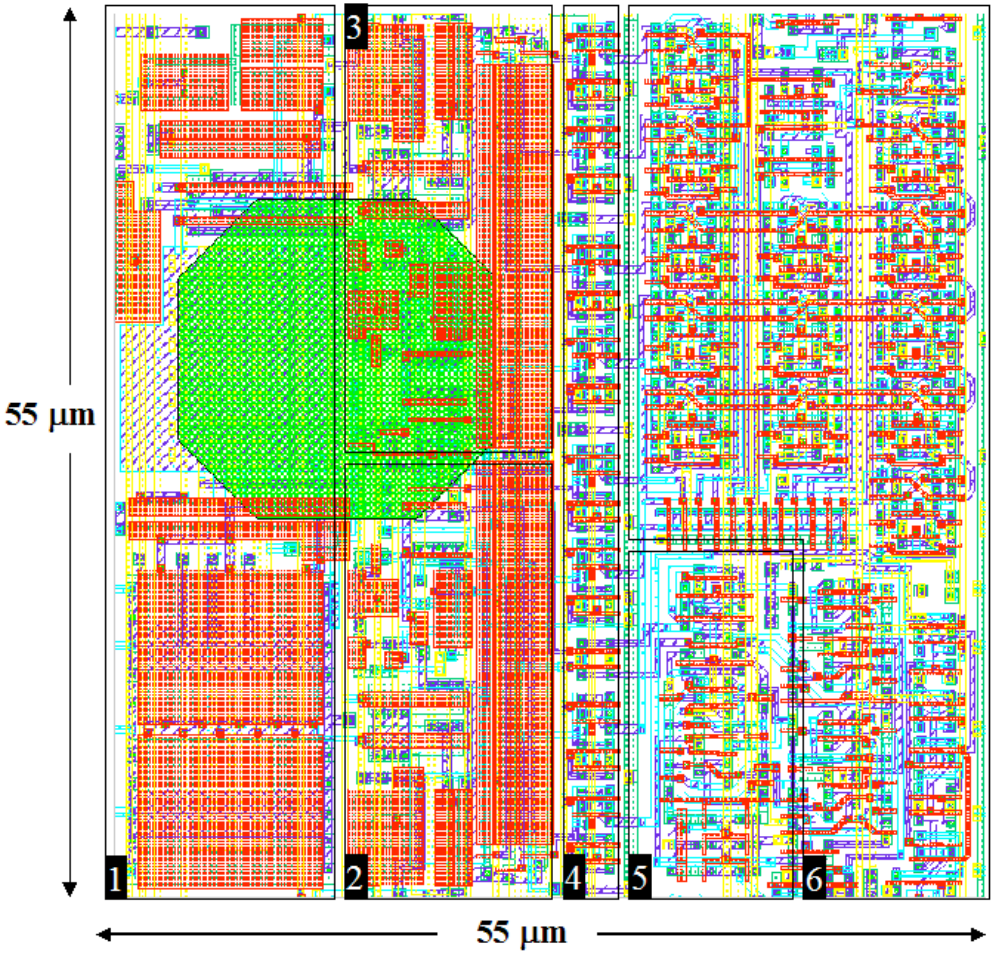
Medipix2 Chip



- Sensitive Fläche ~2 cm^2
  - 55 µm Pixel
  - 256 x 256 Pixel
- Kachelbar / Daisy-chain
- Serielle Auslese ~ 9.2ms @100MHz Clock
- ~300µs 32bit CMOS Parallel Port

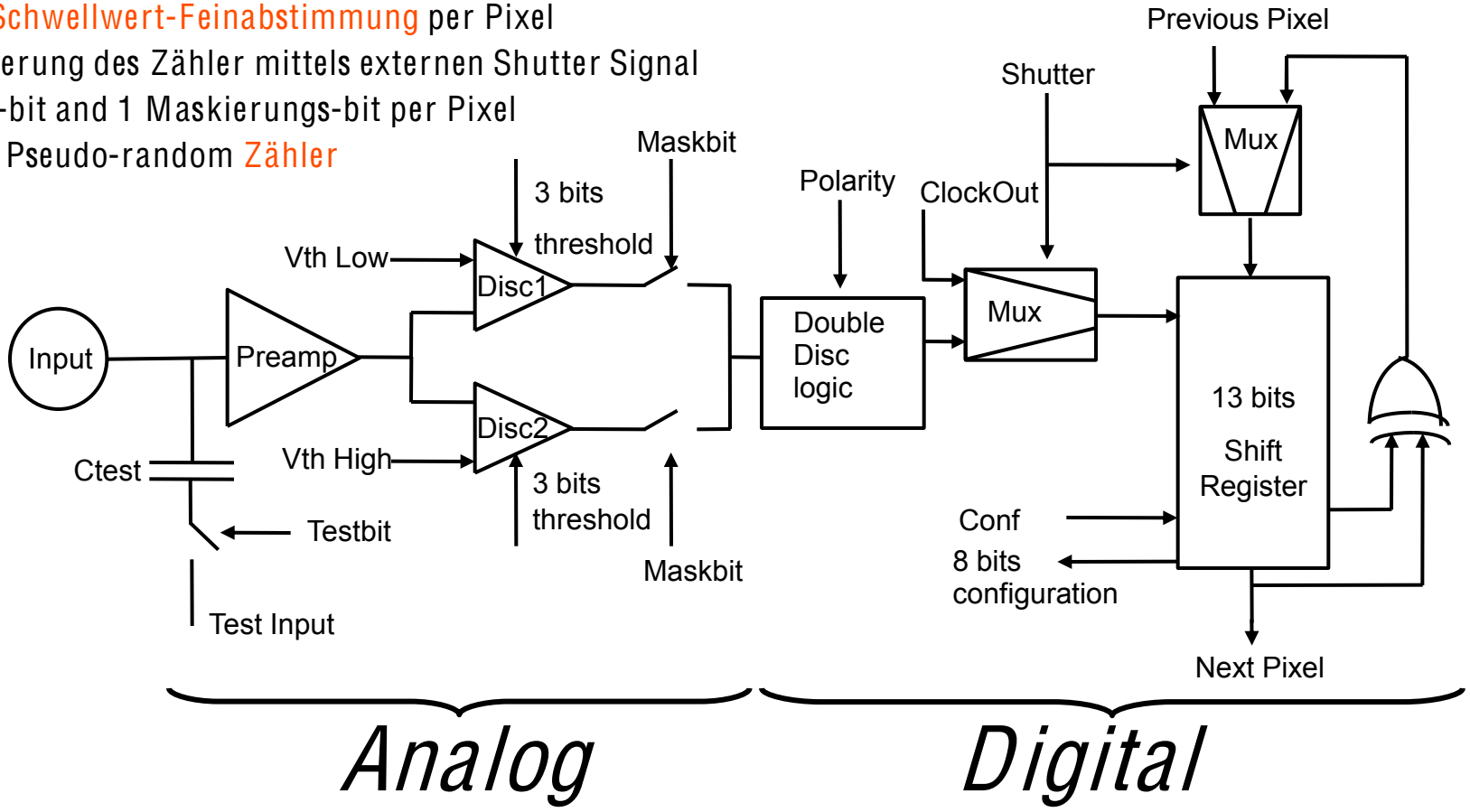
Medipix2 Pixel Cell Layout

- 256 x 256 Pixel
- 55 µm Pixel
- 503 Transistoren/Pixel
  ~33Mio /Chip

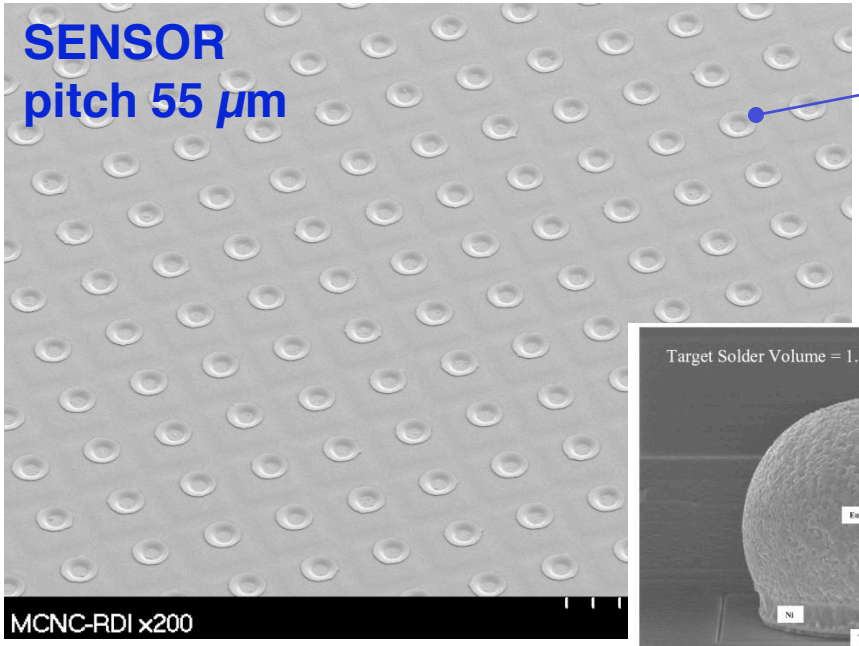


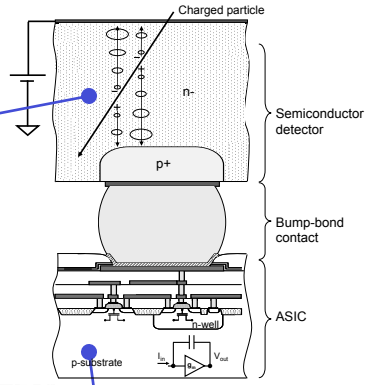
Medipix2 Pixel

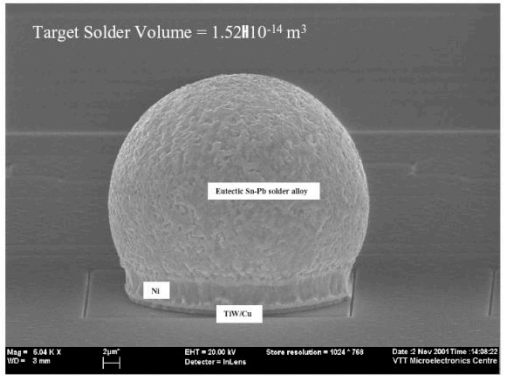
- Positives und negatives Eingangssignal → **alternative Detekormaterial möglich**
- Ladunssensitiver Vorverstärker mit Dunkelstromkompensation pro Pixel
- 2 Diskriminatoren mit global einstellbarem Schwellwert
- 3-bit Schwellwert-Feinabstimmung per Pixel
- Aktivierung des Zähler mittels externen Shutter Signal
- 1 Test-bit and 1 Maskierungs-bit per Pixel
- 13-bit Pseudo-random Zähler

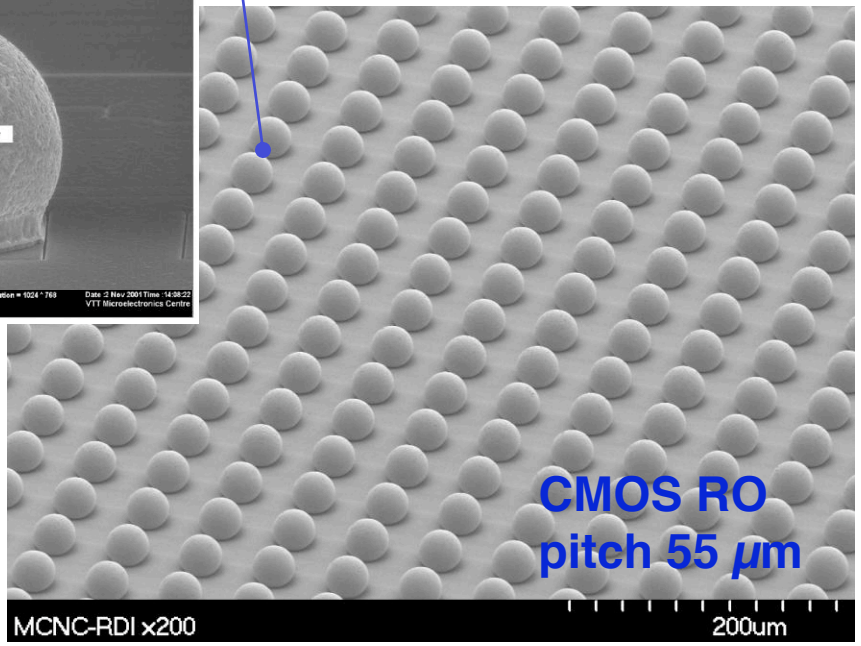


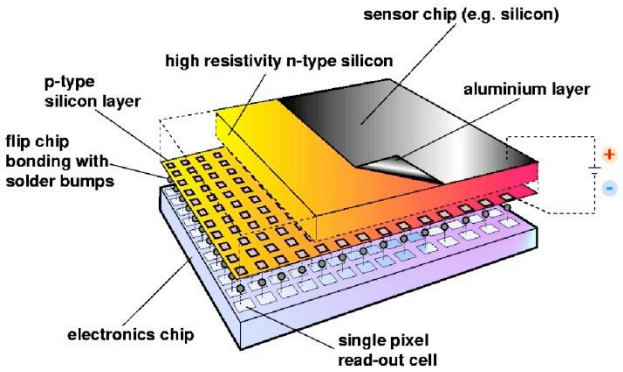
Medipix2 bump bonding



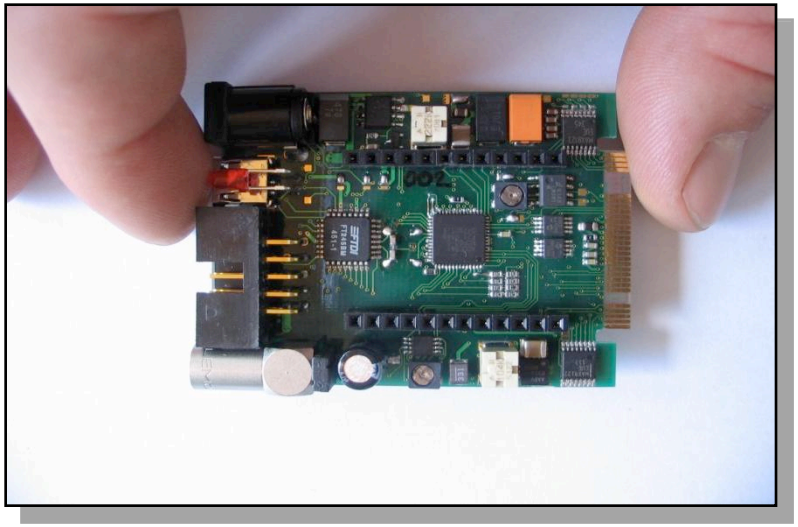


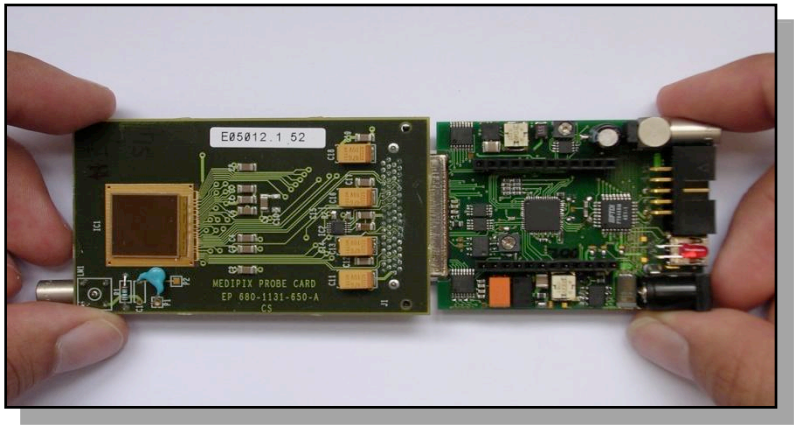




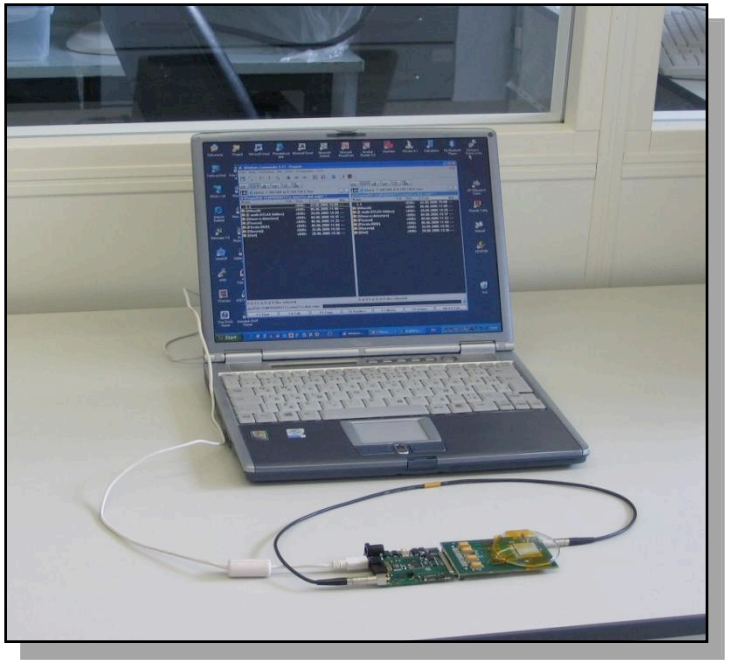


USB based Medipix2 Readout System



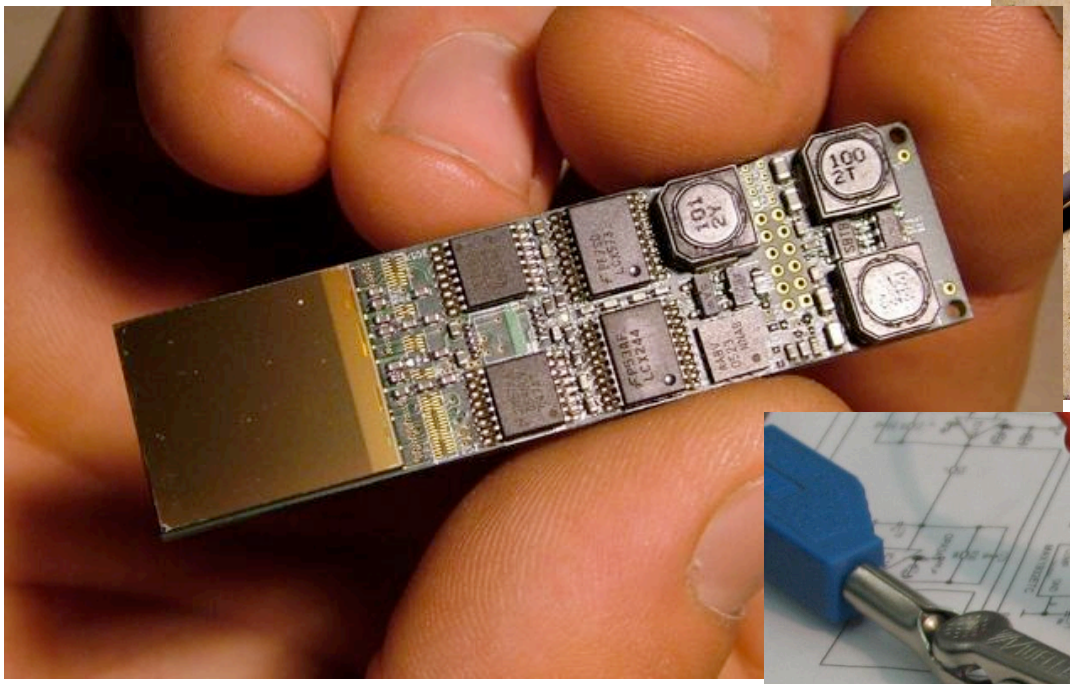


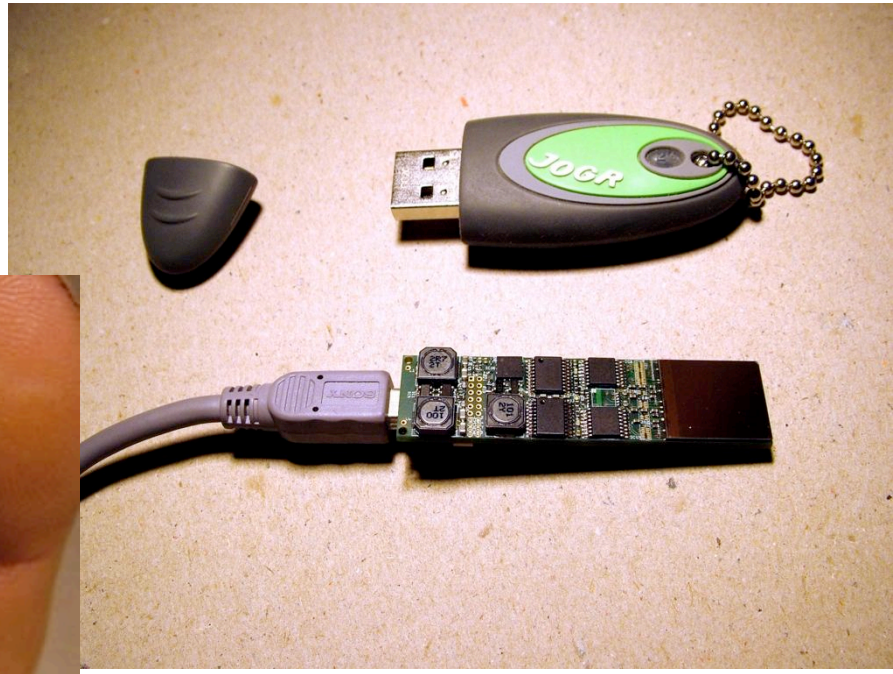
USB1 compatible
Includes Pixelman readout software
Developed by S. Pospisil et al. CTU, Prague

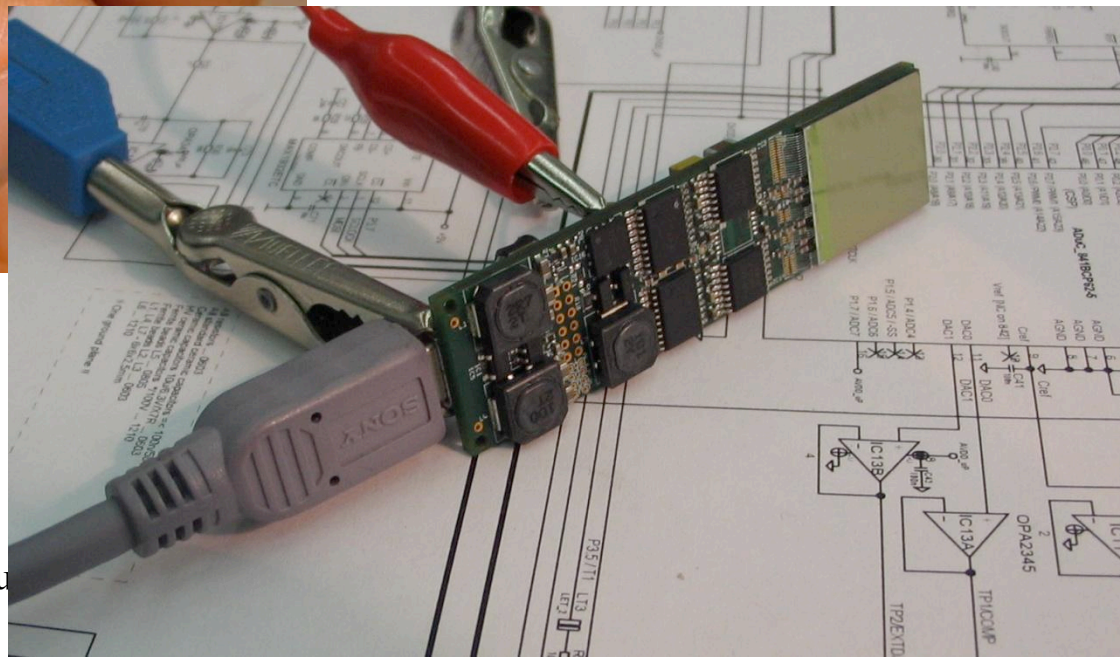


USB Lite

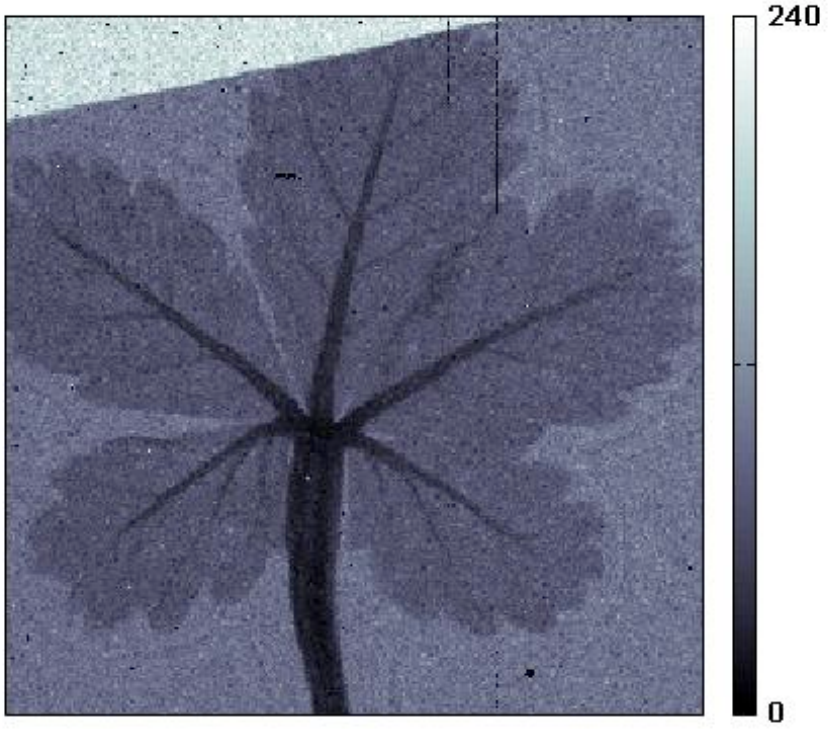
with bonded bare chip







^{55}Fe – 5.9 keV



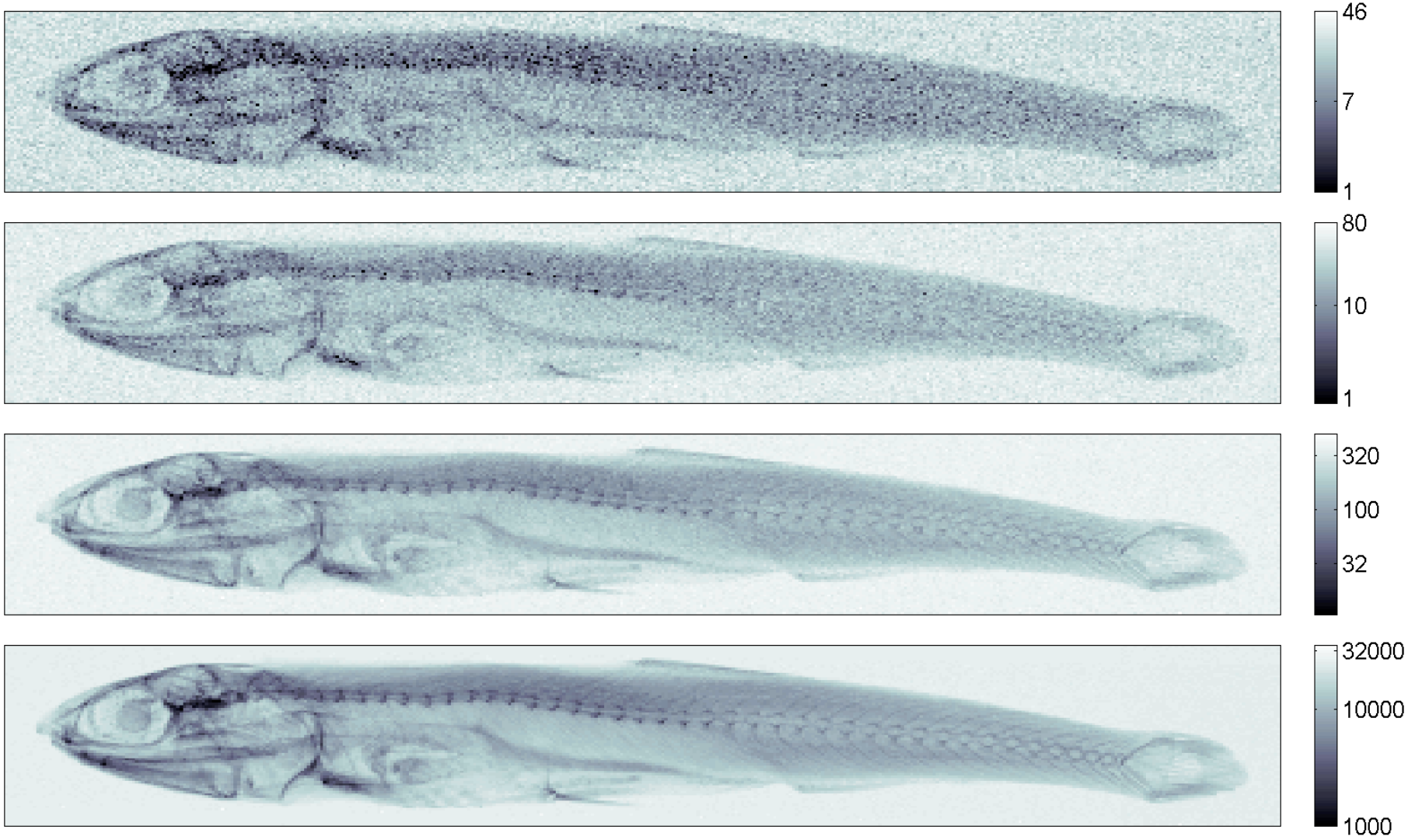
Geringe Intensität ~240 Photonen im Hintergrund

Niedriger Schwellwert ~3.5 keV

14 Stunden Aufnahme

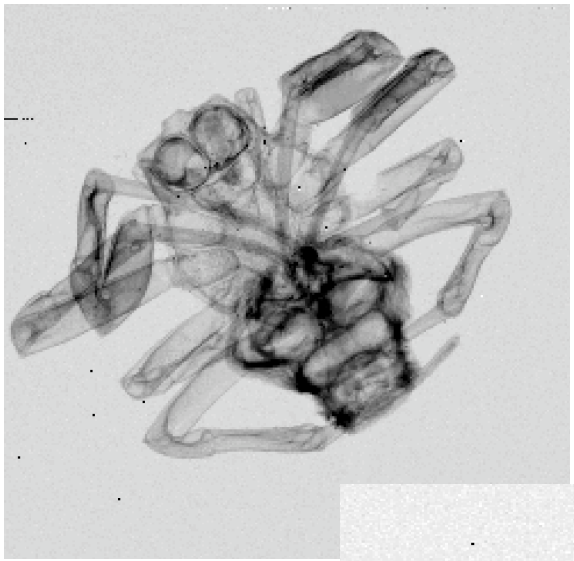
- Kein Dunkelrauschen

Anchovy - Mo 17kV (MPX1)

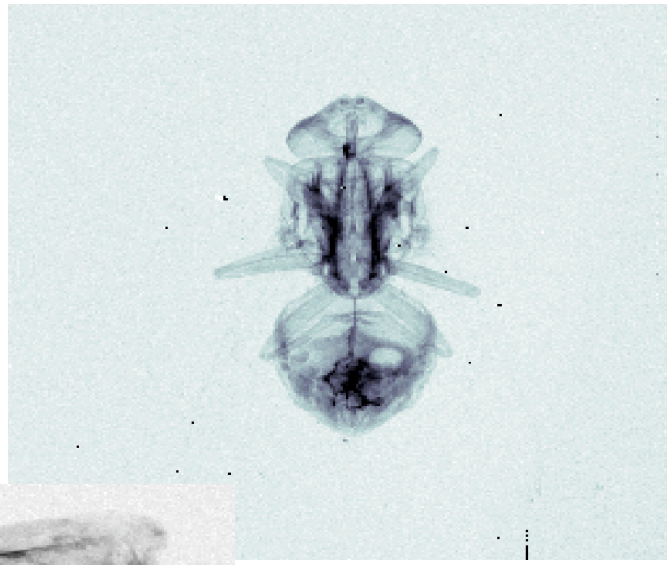


Lukas Tlustos, Medipix Collaboration, CERN

Hohe Kontrastaufloesung (MPX2)

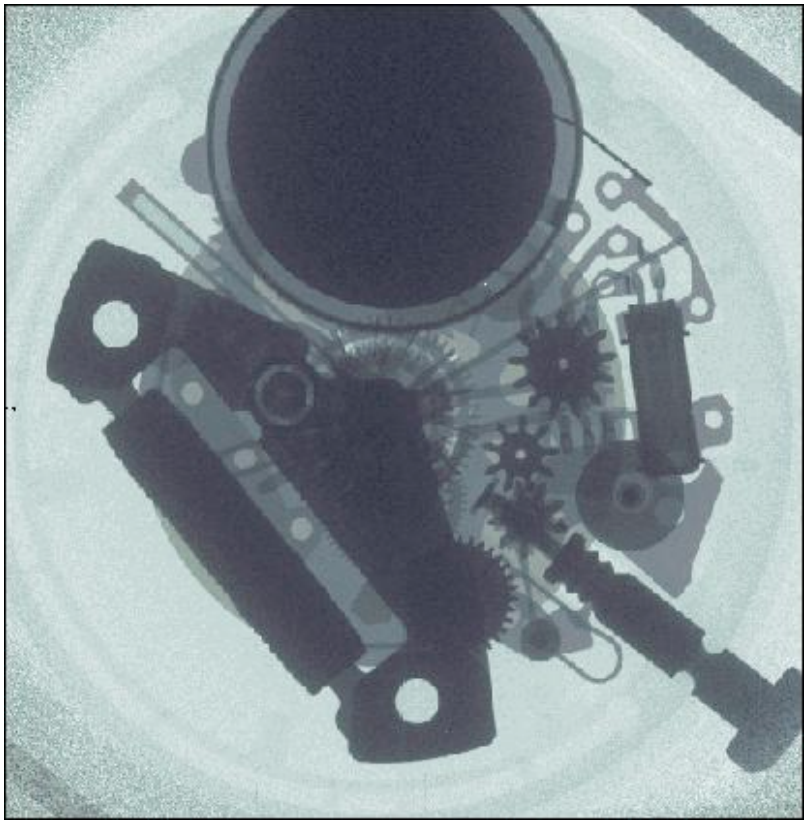


W 14kV
125 μm Al
5mm PMMA



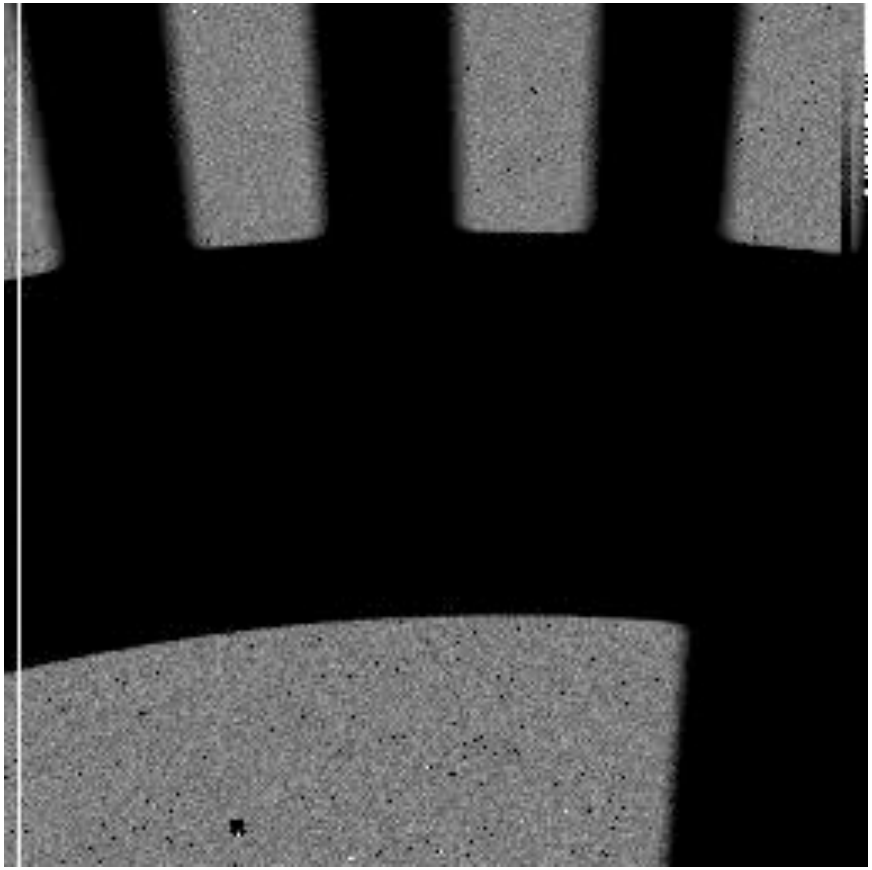
W 35 kV
2.5 mm Al

“High” rate images



X-Ray movie at 5.5fps 512x512 pixels, uses 4-chip Quad detector

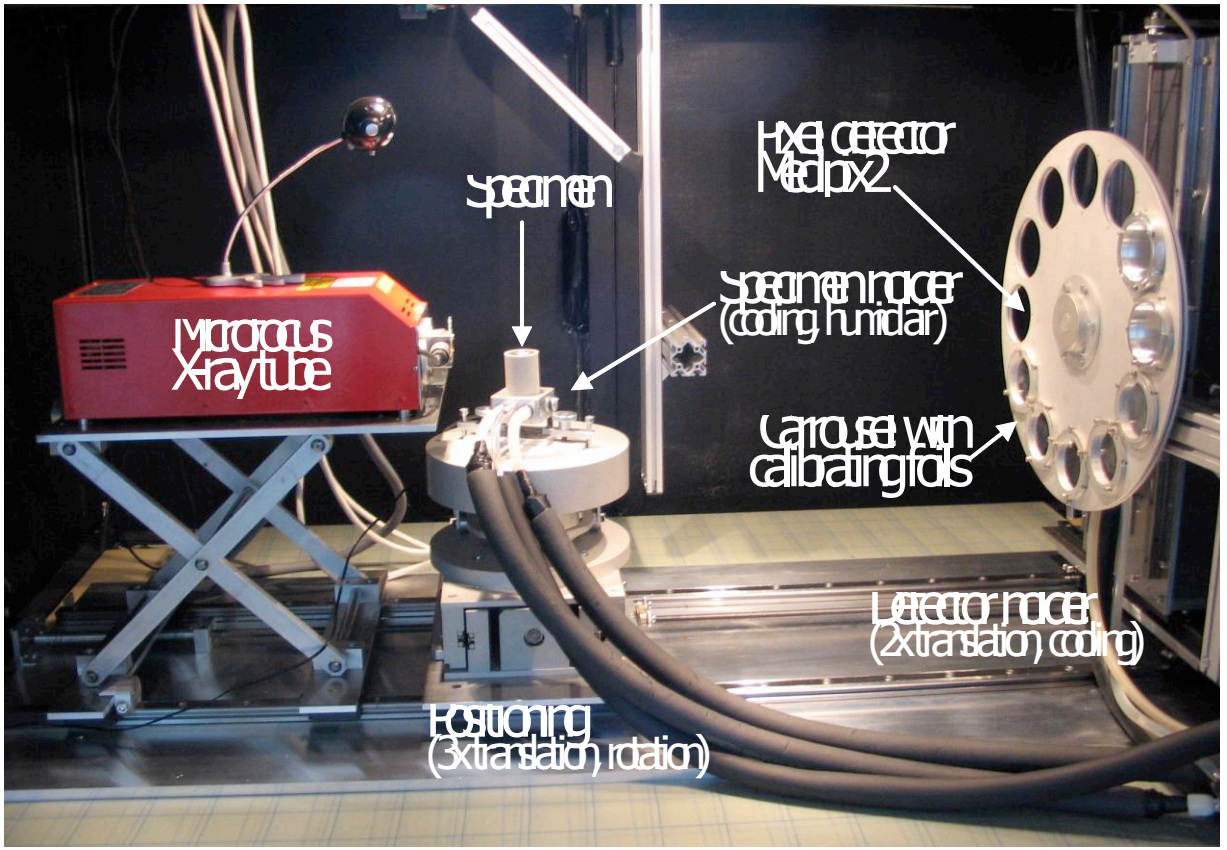
Real high rate images



- Application required development of a new fast readout system (ESRF Grenoble)
  - 1 kHz frame rate imaging could be achieved turning chopper wheel

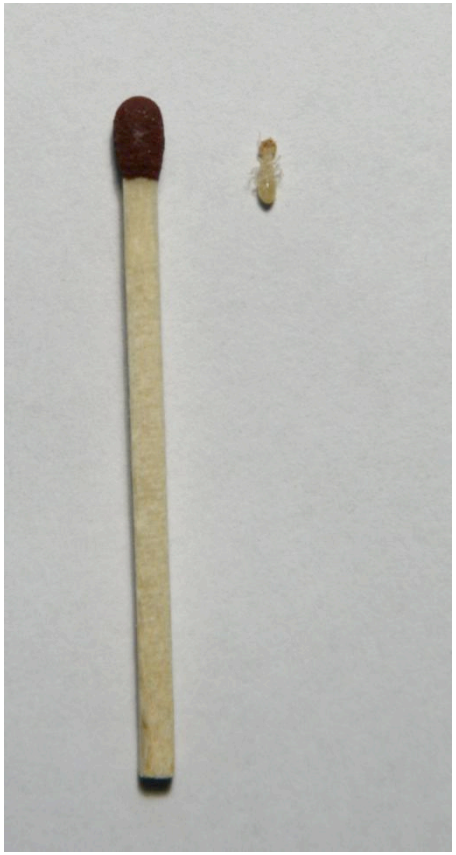
X-ray Transmission Radiography and Tomography

- High-resolution X-ray radiography using a <u>microfocus X-ray source</u> →low photon flux



High-resolution X-ray Radiography

- Imaging of termites



Imaging of termites as an example for a **soft tissue organism**

Particularly difficult due to their **poorly sclerotized** cuticle.

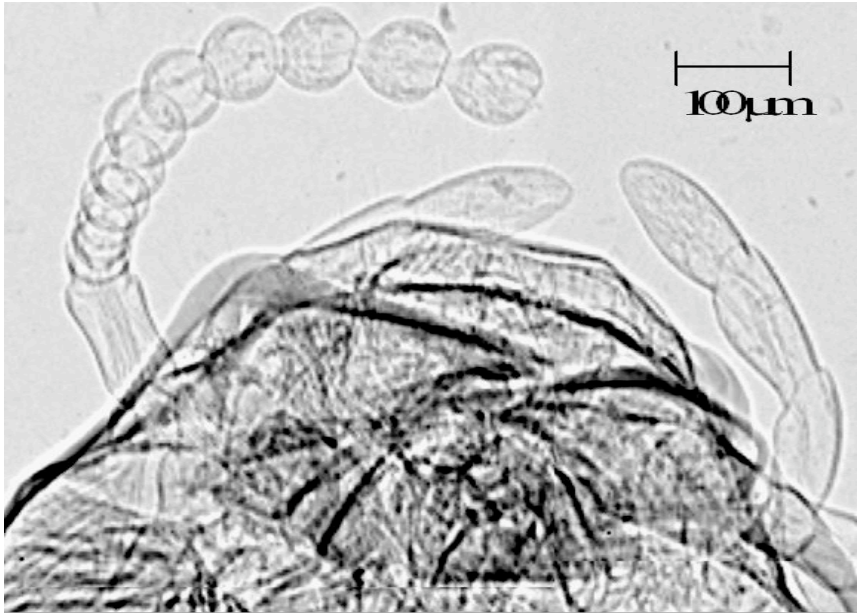
Vulnerable to damage when manipulated during sample preparation.

High-resolution X-ray Radiography

- Imaging of termites

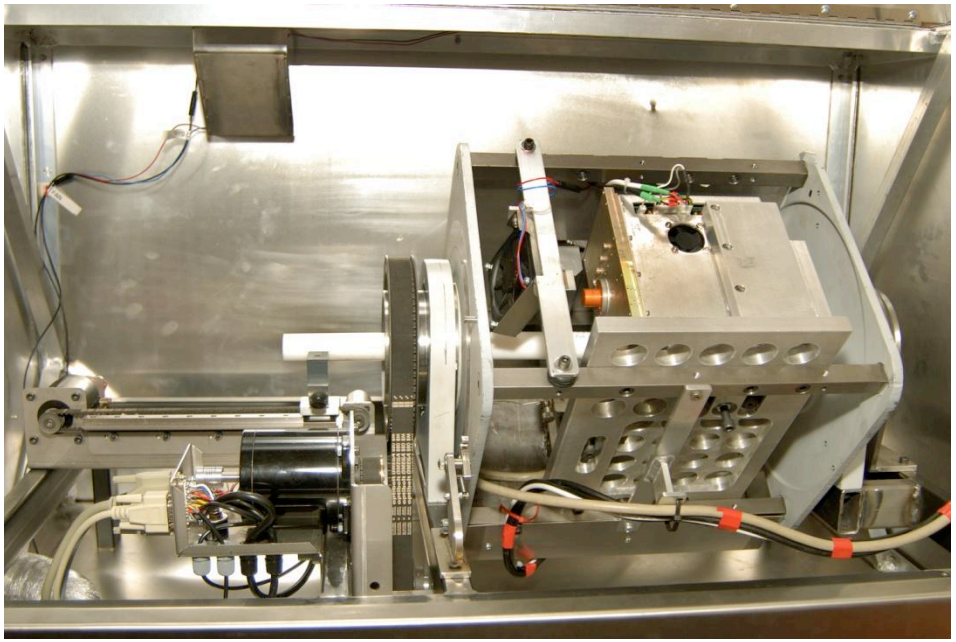
X-ray transmission image of a termite worker body (left) and detail of its head (bottom). Even the fine internal structure of the antennae is recognized.

(Magnified 15x, time=30 s, tube at 40 kV and 70 mA)



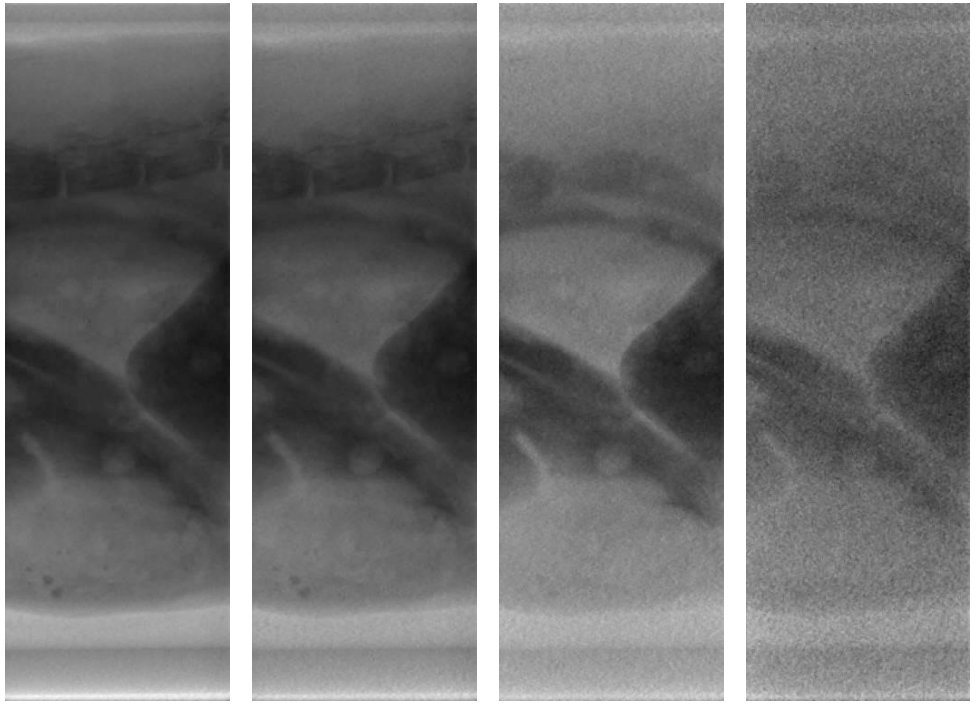
MARS scanner

- Spinout company Univ. Canterbury, NZ
- Goal is to develop clinical applications
- Cost / technology limit what can be done
- Small animal / pathology specimens



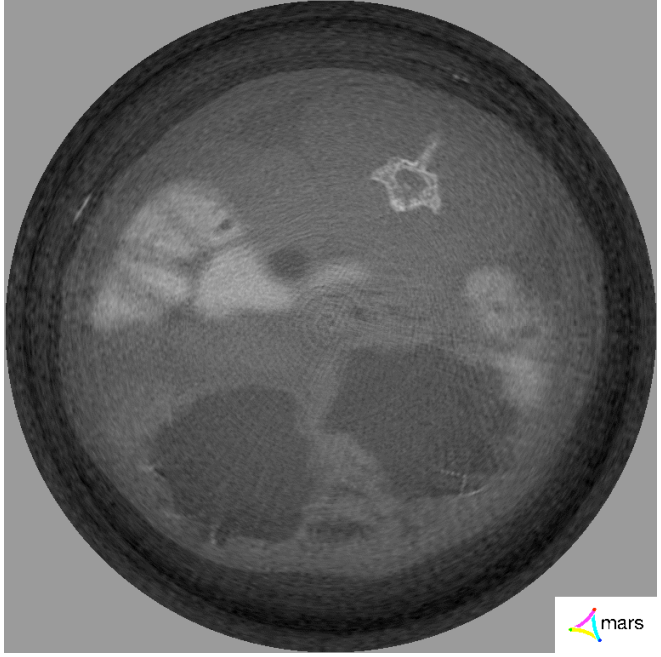
First MARS medical scan

W @ 75 KeV

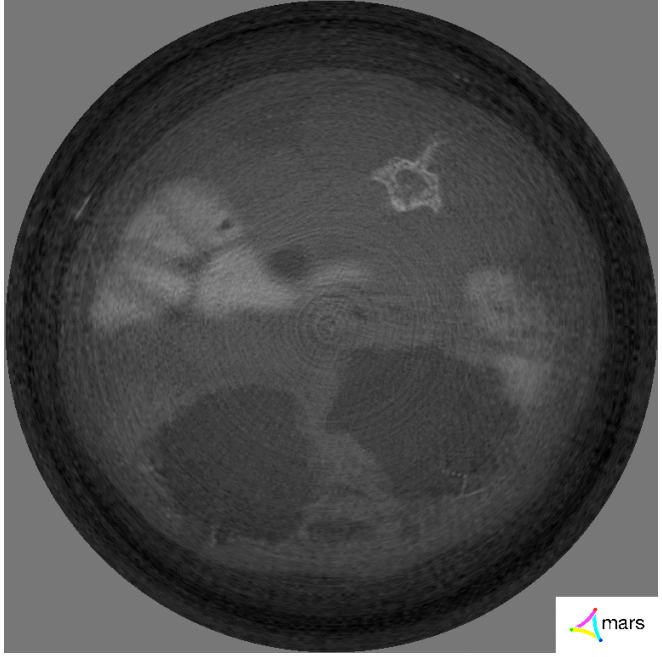


12 keV 17 keV 33 keV 42 keV

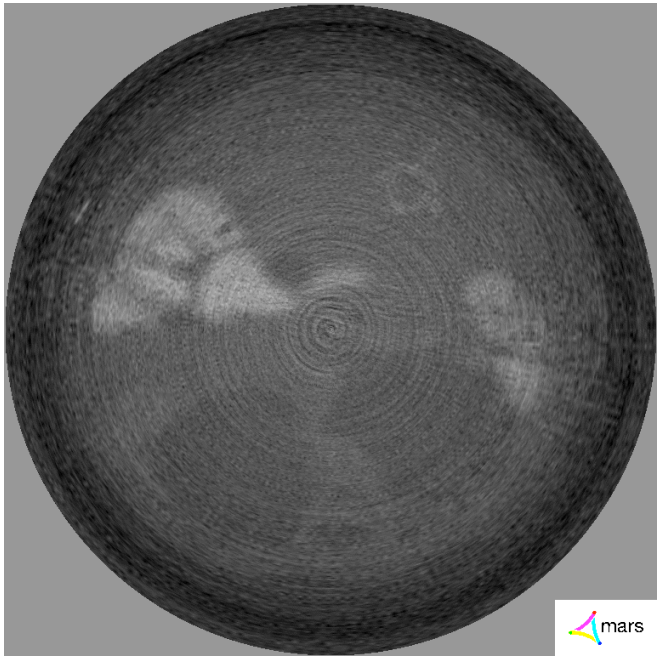
Iodine contrast



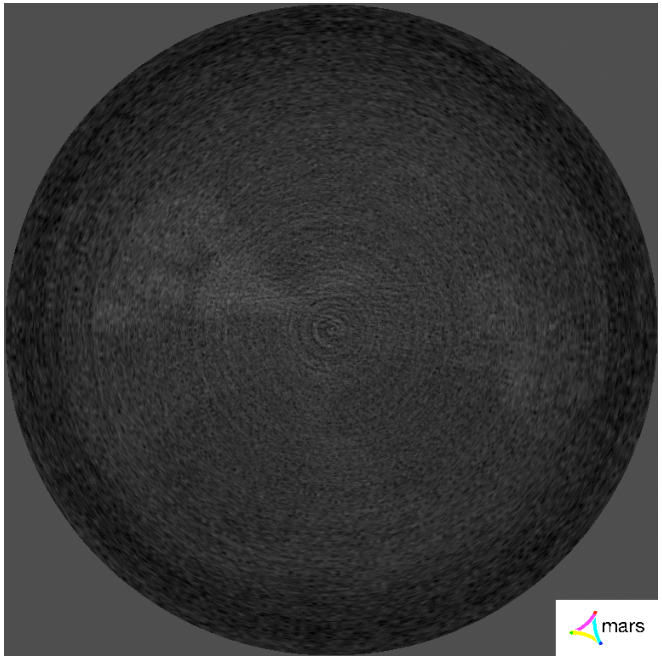
12keV



17keV

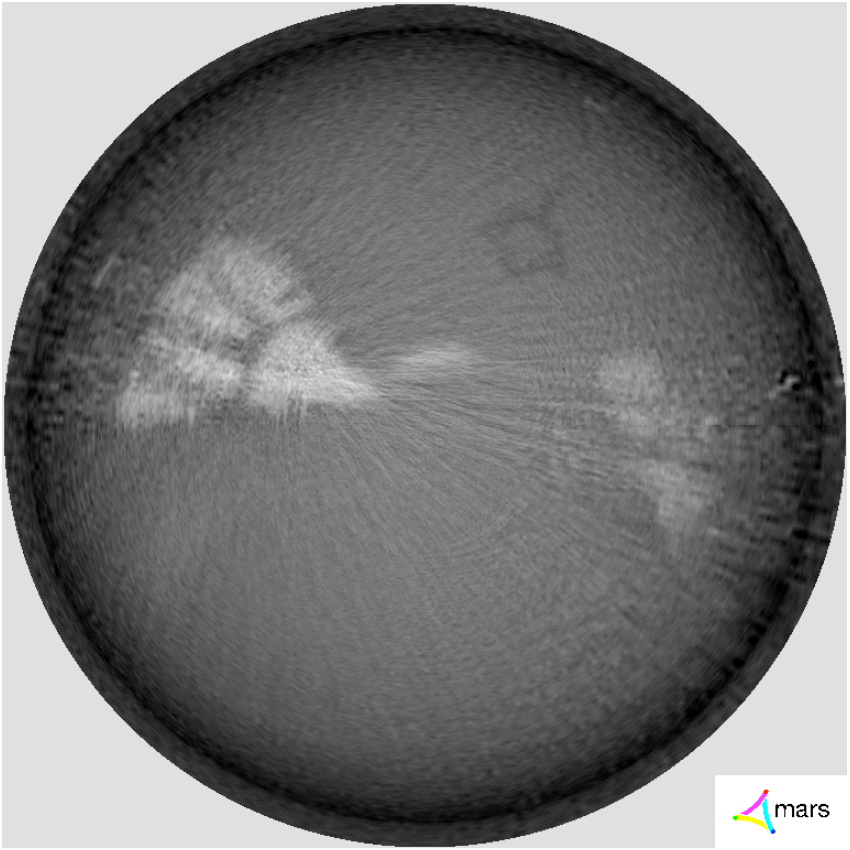


33keV

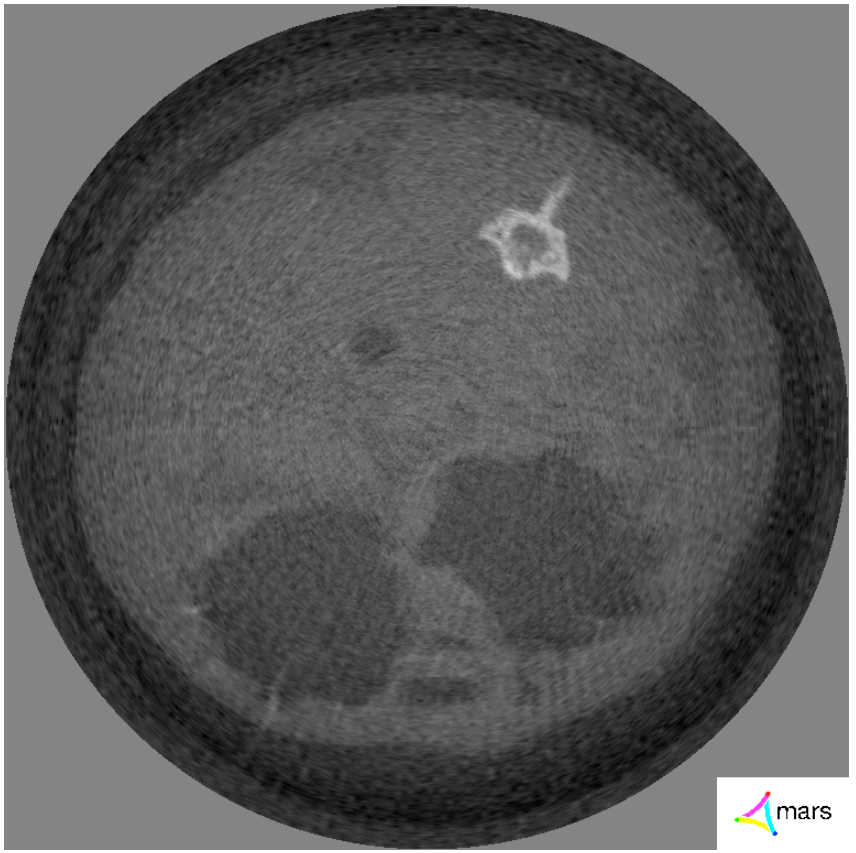


42keV

Results: Spectral Imaging



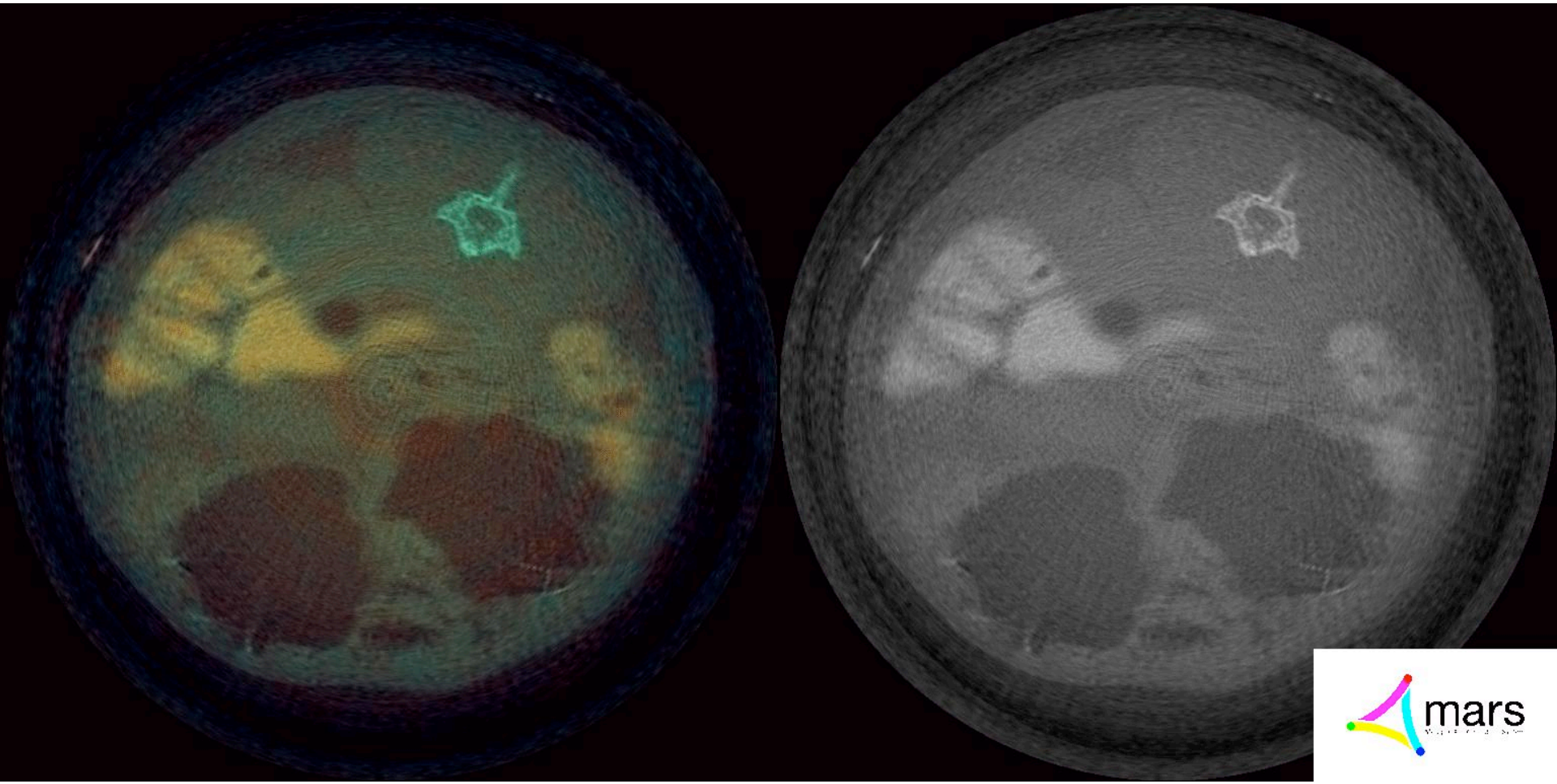
Iodine



Non-iodine

Useful for heart and cancer imaging

Results: Spectral Imaging



Triple Phase Protocol

CT

1) Scan (C-)
2) Give iodine
3) Scan (C+ PV)
4) Wait 15 minutes
5) Scan (C+ delayed)

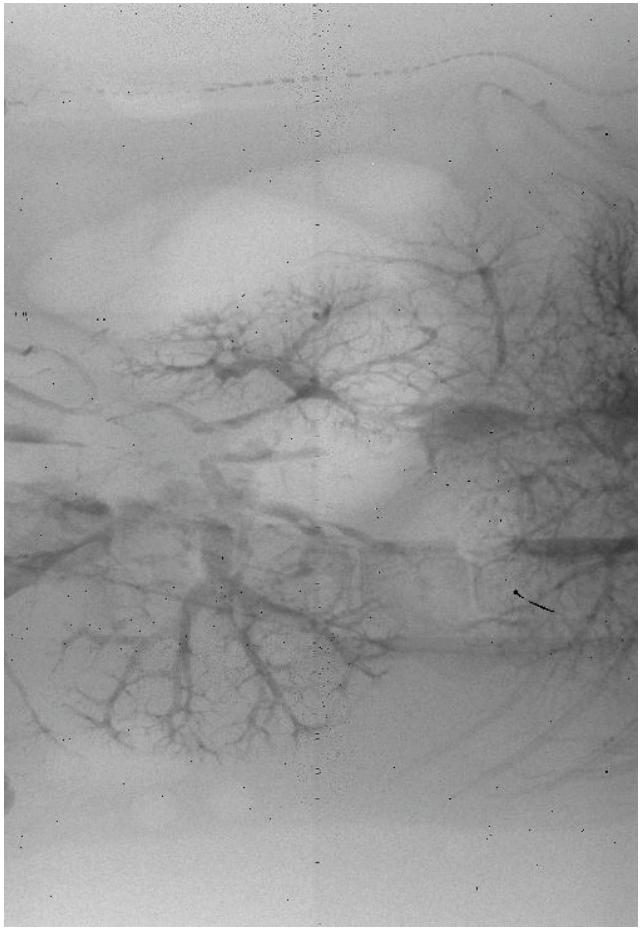
- 3 scans
- Twice on table

MARS

1) Give iodine
2) Wait 15 minutes
3) Give gadolinium
4) Scan

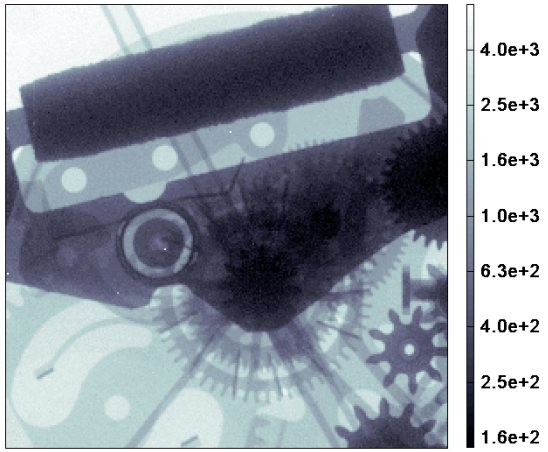
- 1 scan
- Once on table

Mouse kidneys

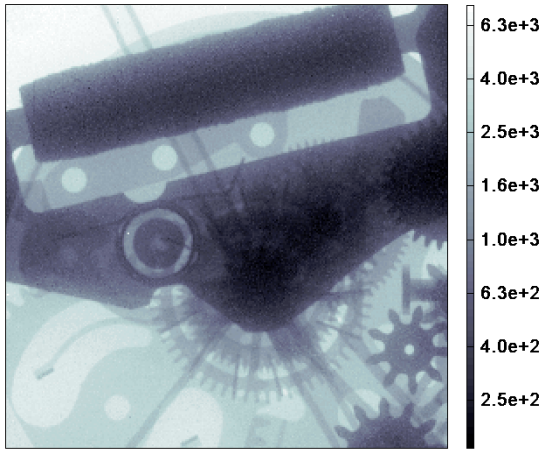


Energiefenster (→ MPX3)

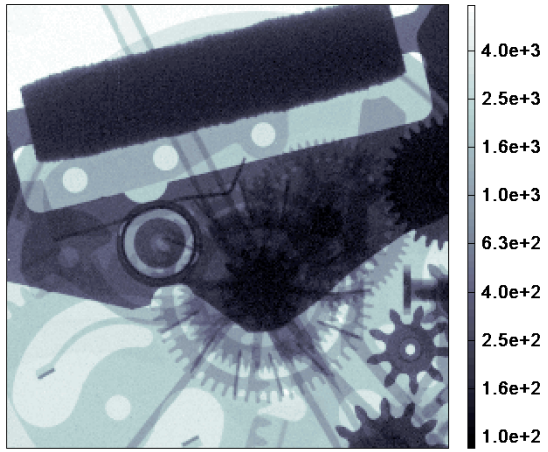
16.1-19.6 keV



21.6-25.1 keV



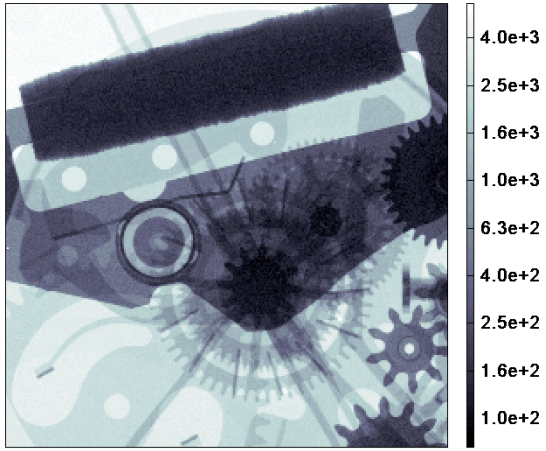
29-33.5 keV



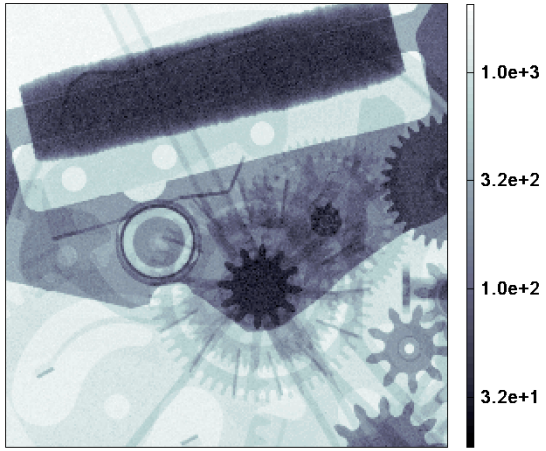
W-Röhre 50 kV
2.5 mm Al

ΔE=3.5 keV

36.9-40.4 keV

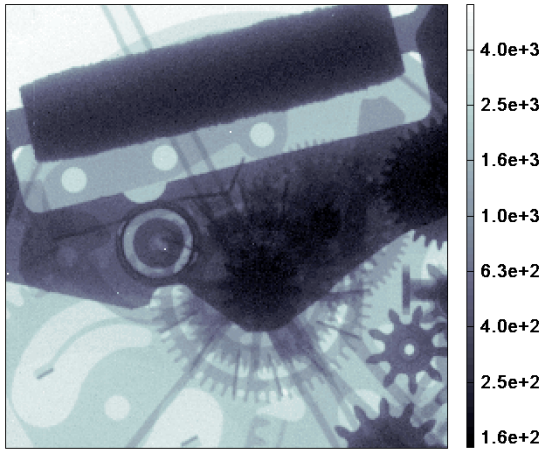


43.1-46.6

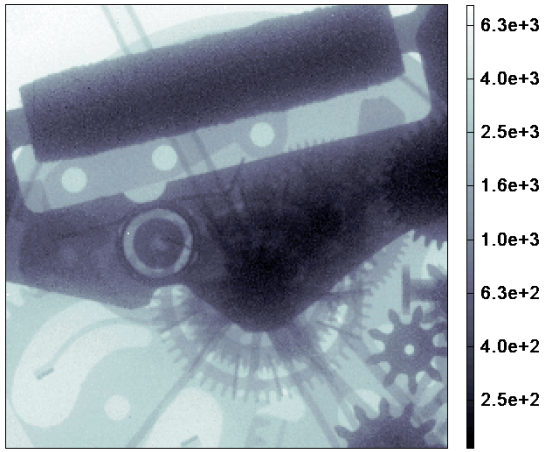


Energiefenster (→ MPX3)

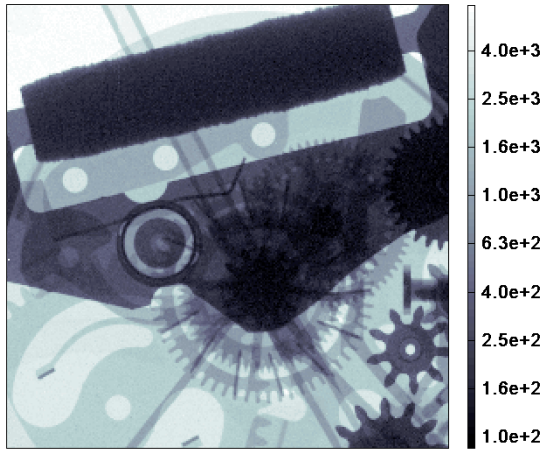
16.1-19.6 keV

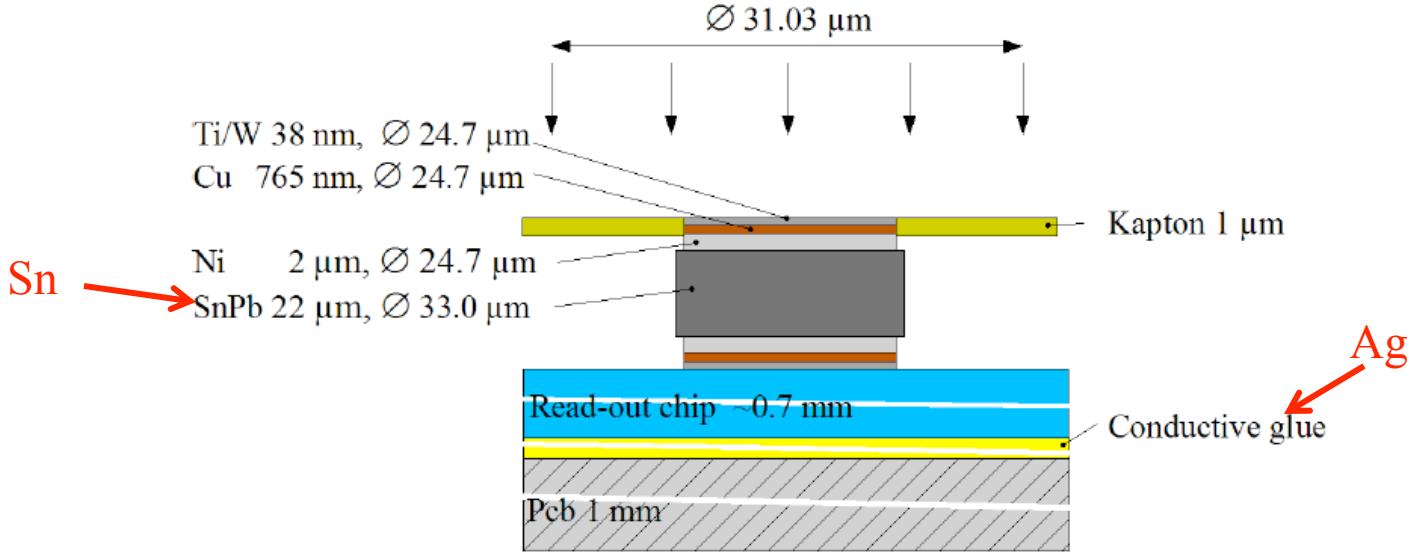


21.6-25.1 keV

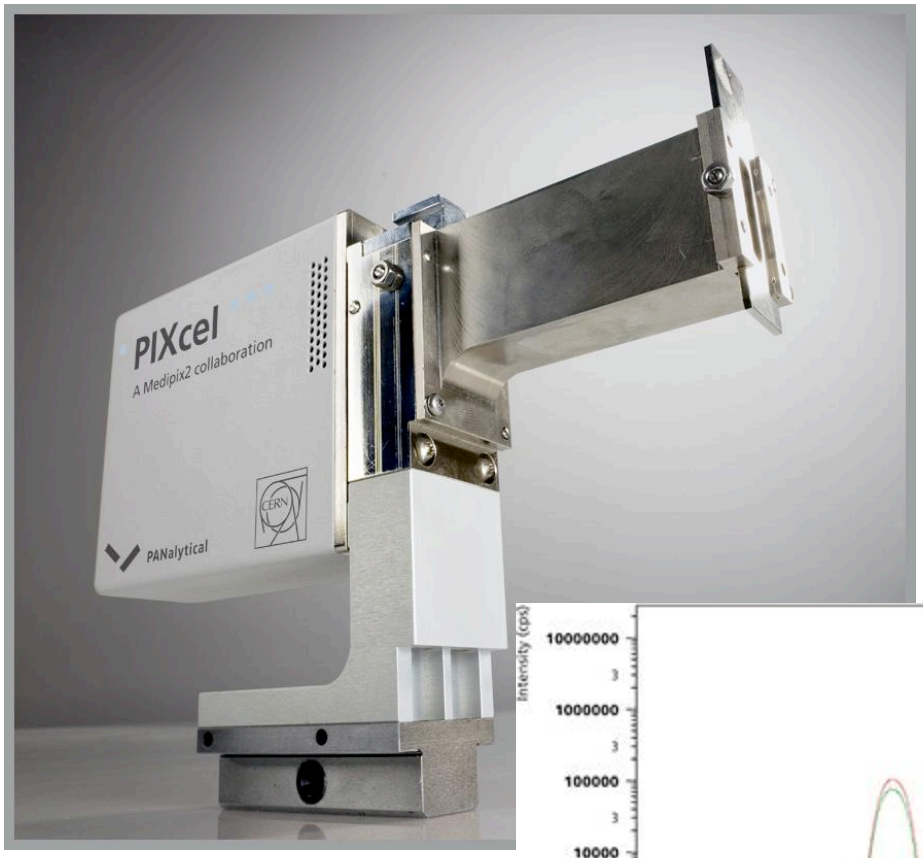


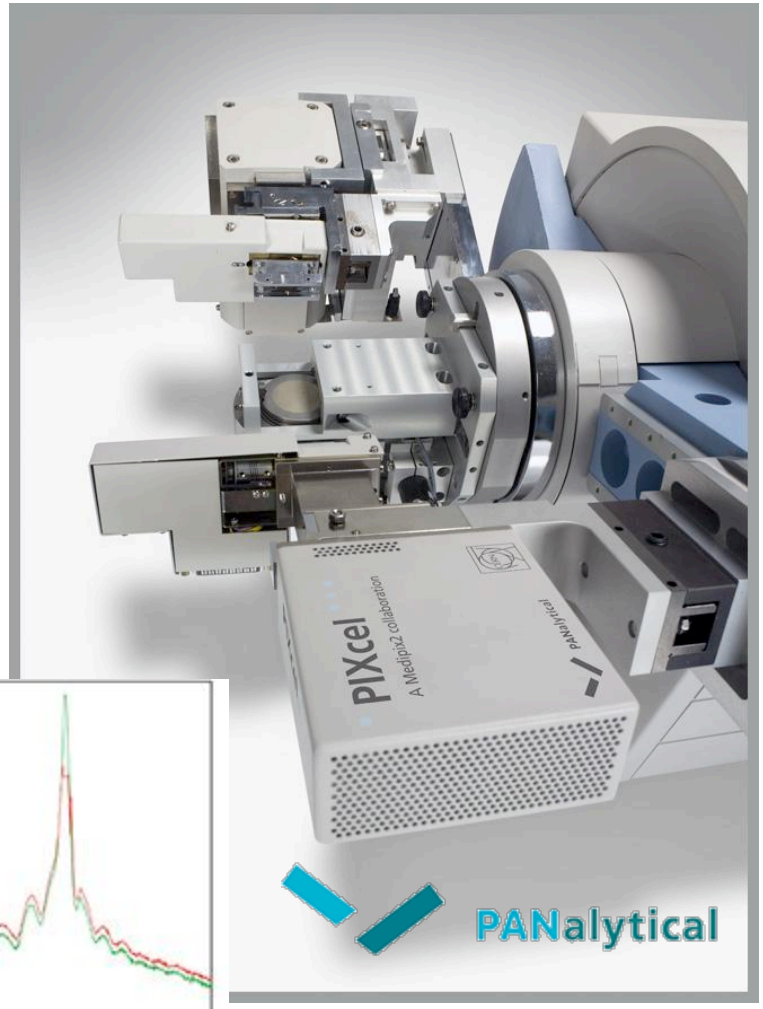
29-33.5 keV

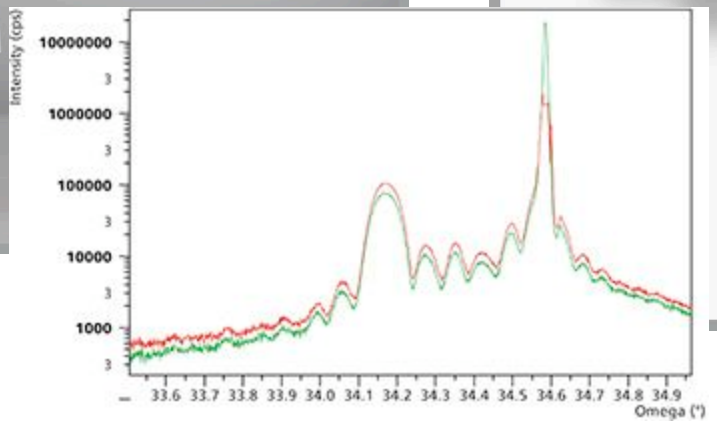




TT to industry- PANalytical



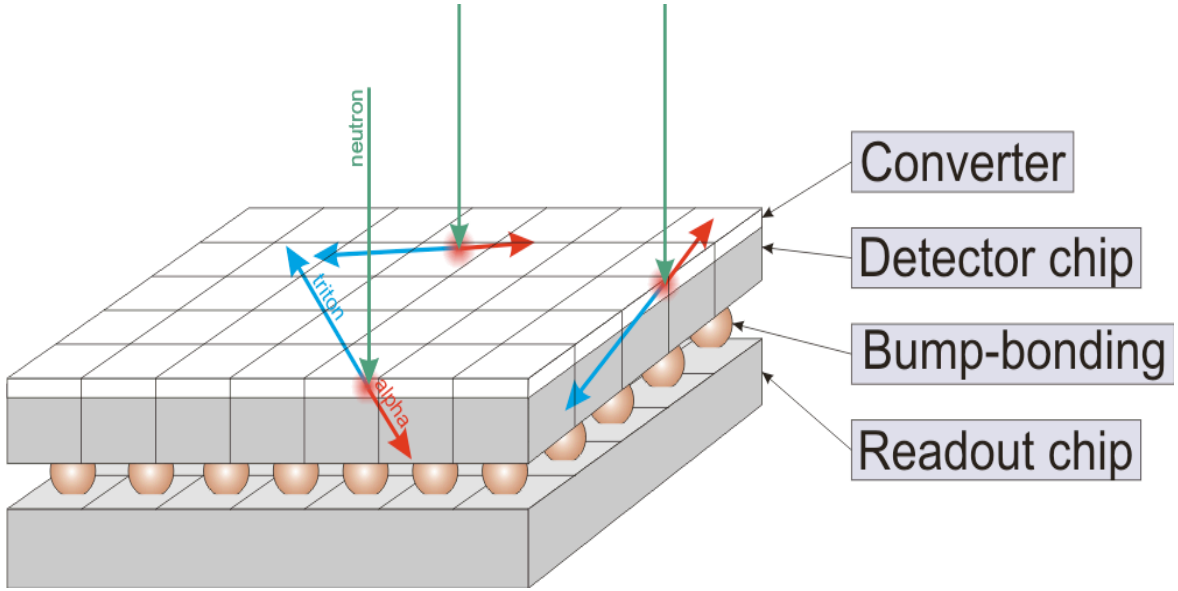




Neutronography

Czech Technical University, Prague

- Detection of light elements due to different attenuation of neutrons in matter, strong attenuation by H -> organic materials
- Conversion of thermal neutrons to heavy charged particles in ^{6}Li converter layer
- Reaction: $^{6}Li + n \rightarrow \alpha\ (2.05\ MeV) + {}^{3}H\ (2.72\ MeV)$
  Cross section: 940 barns (0.0253 eV)



Neutron tomography

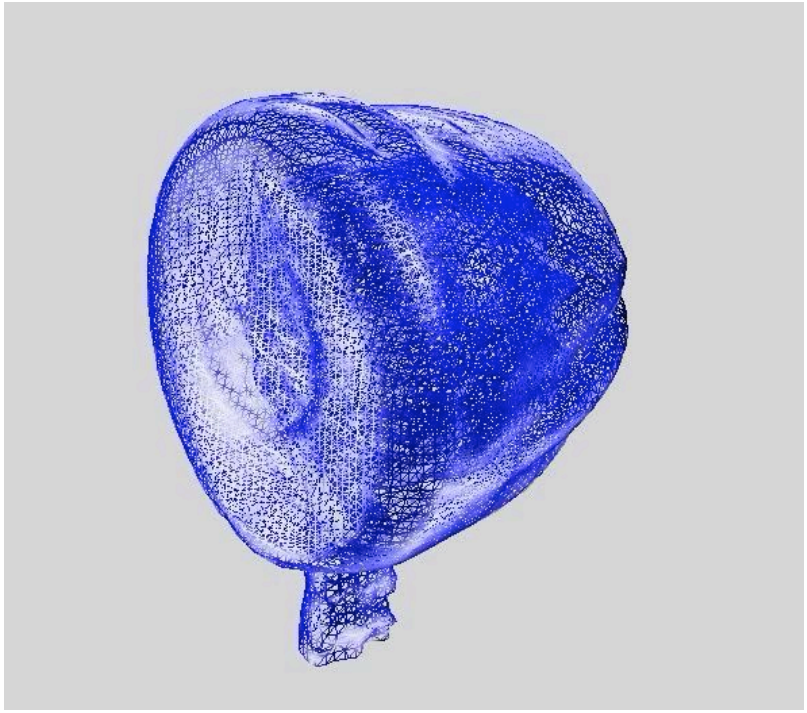
Czech Technical University, Prague

Neutron vs. X-ray tomography

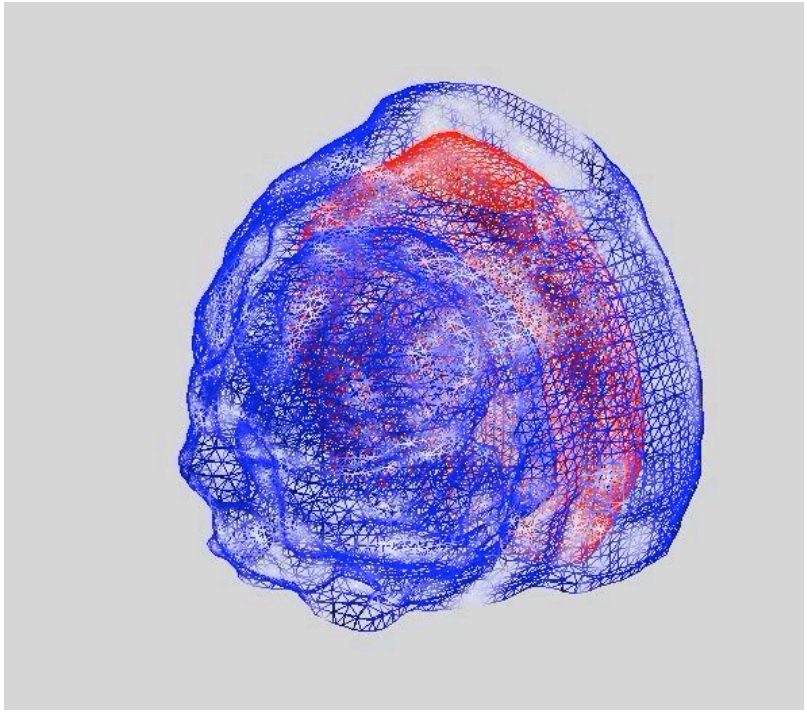
3D-reconstruction of blank cartridge

Filtered back-projection algorithm

X-ray



Neutron

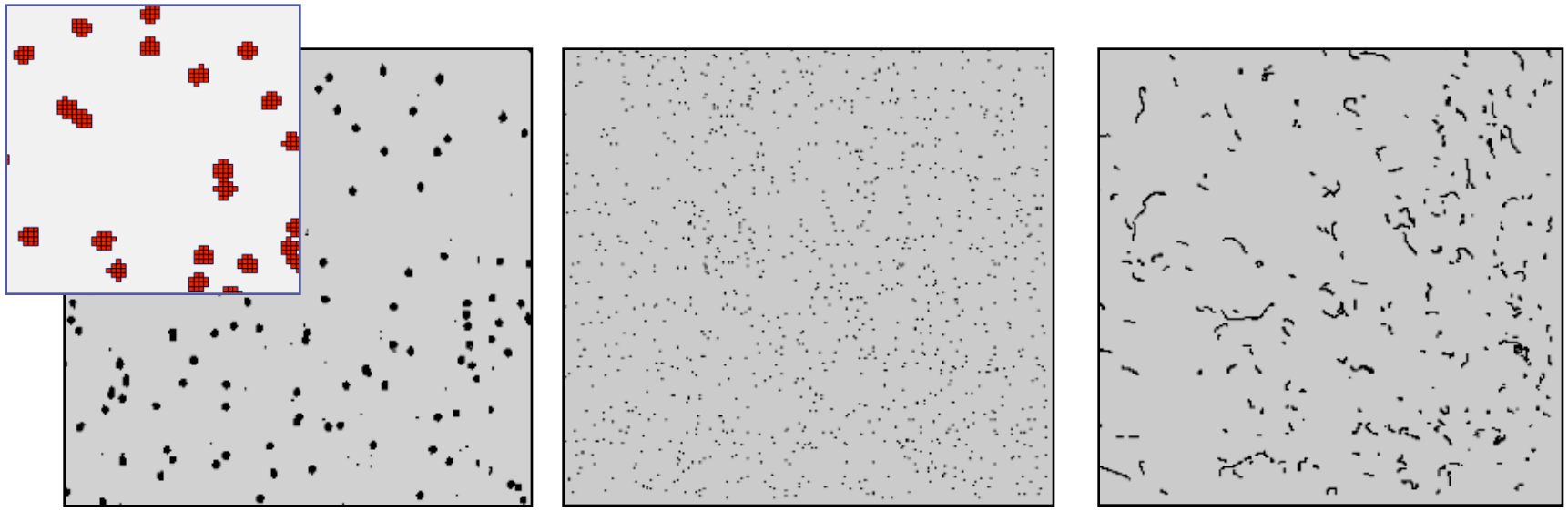


Back to Tracking / HEP (1)

- Different particles have different event signatures ⇒ use cluster finding algorithms and decoding of event morphology
- Vary energy threshold ⇒ spectroscopic information

✓ New application: online dosimetry

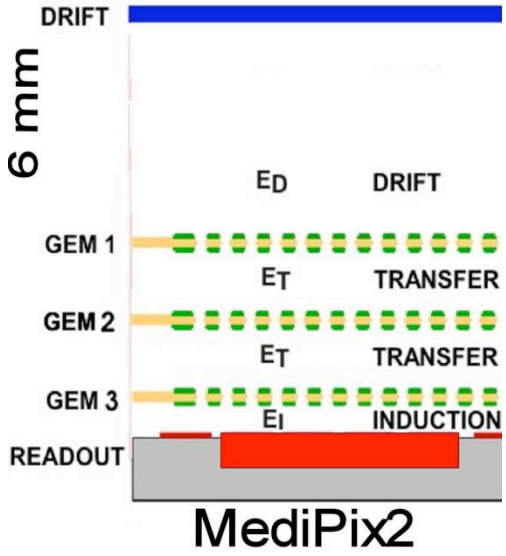
✓ Will be installed in ATLAS to cross-check dose simulations

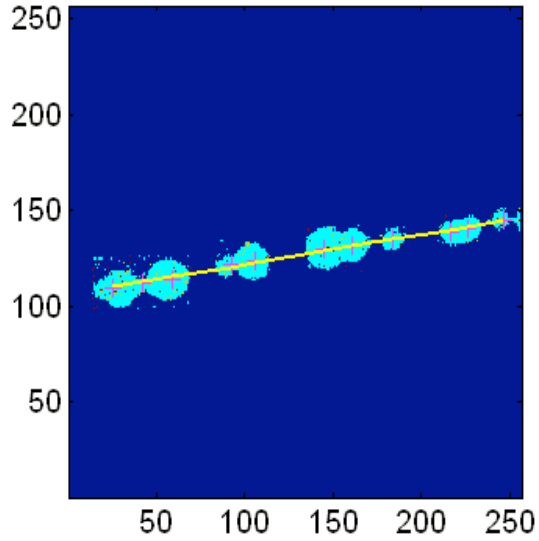


^{241}Am alpha source ^{55}Fe X-ray source ^{90}Sr beta source

Spin back to HEP (2)

- A novel approach for the readout of a TPC at the future linear collider is to use a CMOS pixel detector combined with some kind of gas gain grid
- Using a *bare* photon counting chip Medipix2 coupled to GEMs (A.Bamberger, M.Titov, Freiburg) or Micromegas (J.Timmermans, NIKHEF) demonstrated the feasibility of such approach

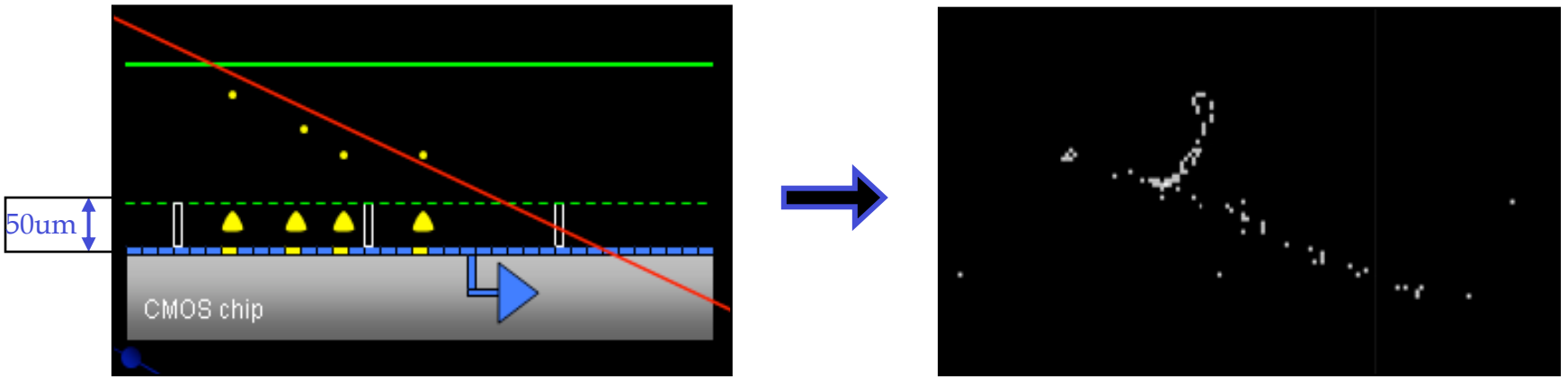




GEM

Spin back to HEP (2)

- A novel approach for the readout of a TPC at the future linear collider is to use a CMOS pixel detector combined with some kind of gas gain grid
- Using a *bare* photon counting chip Medipix2 coupled to GEMs (A.Bamberger, M.Titov, Freiburg) or Micromegas (J.Timmermans, NIKHEF) demonstrated the feasibility of such approach

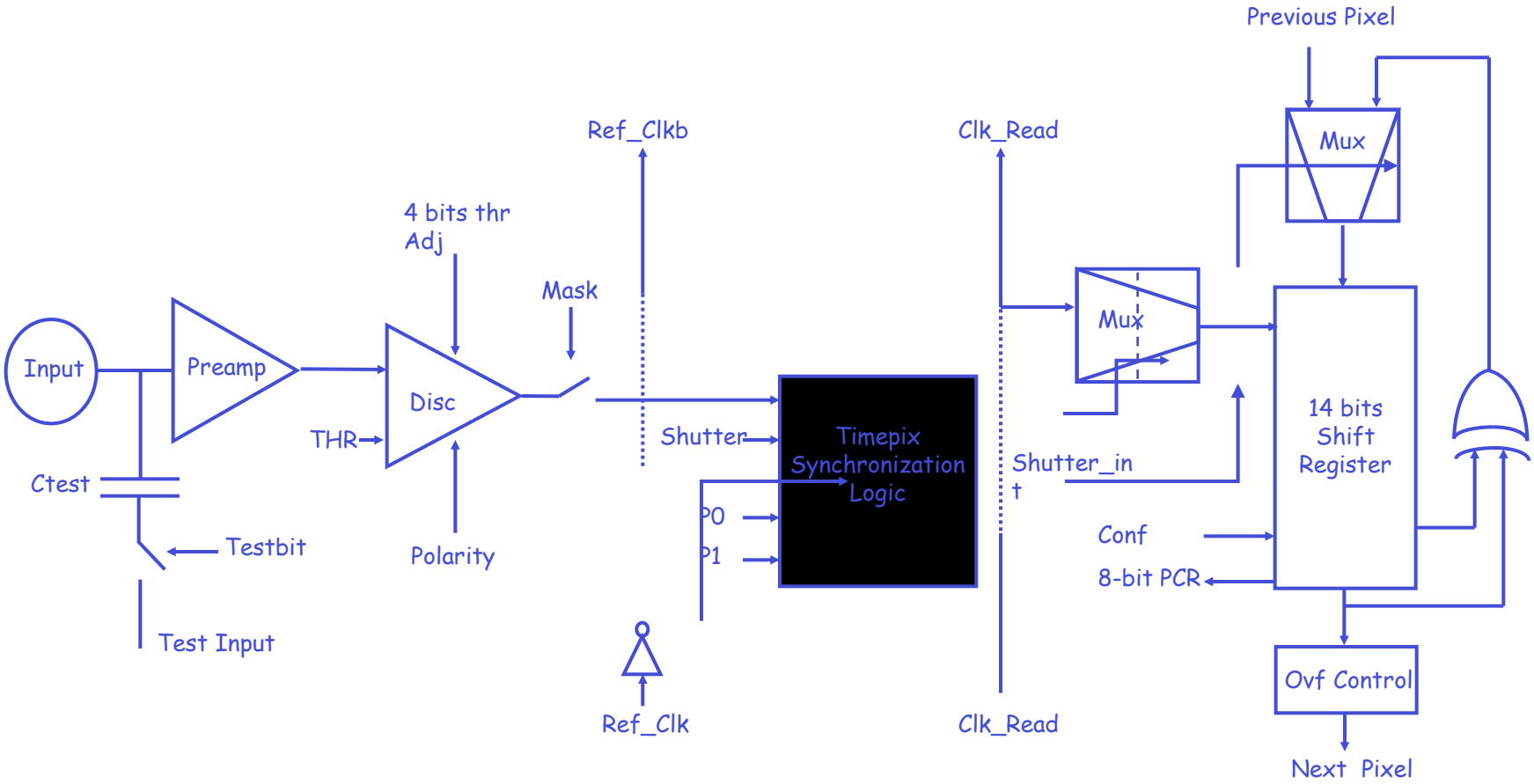


Micromegas

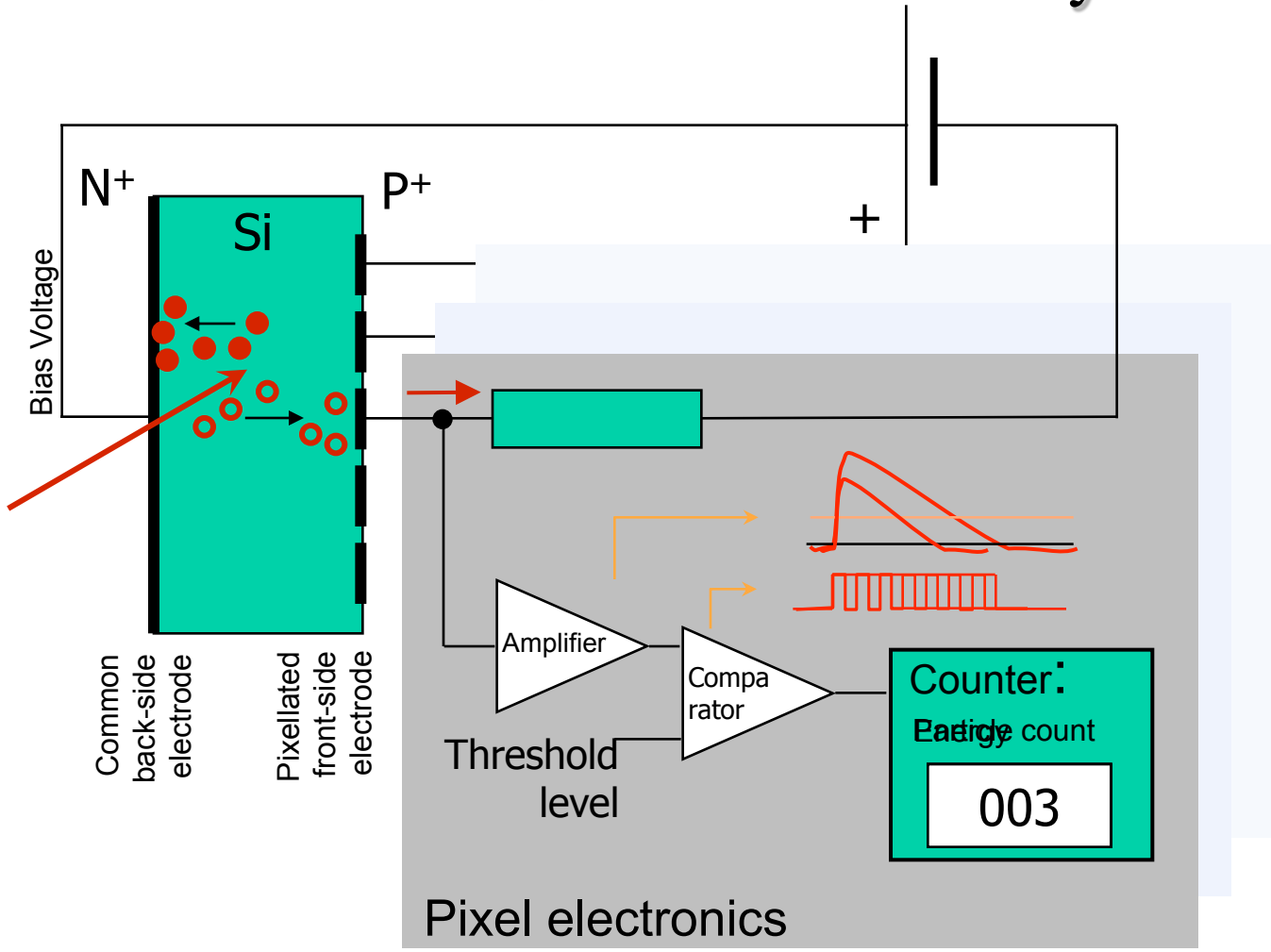
Timepix

- New readout chip fully compatible with Medipix2 electronics/software
- 3 operational modes
  - Counting (= Medipix2)
  - Arrival time
  - Time over threshold mode (~ energy deposited)
- Mode can be set in each pixel independently, allowing for concurrent energy and arrival time measurements

Timepix Pixel Schematic



TimePix TOT (ADC) Mode with Silicon Detector Layer



Threshold level >> electronic noise
⇒No false counting.

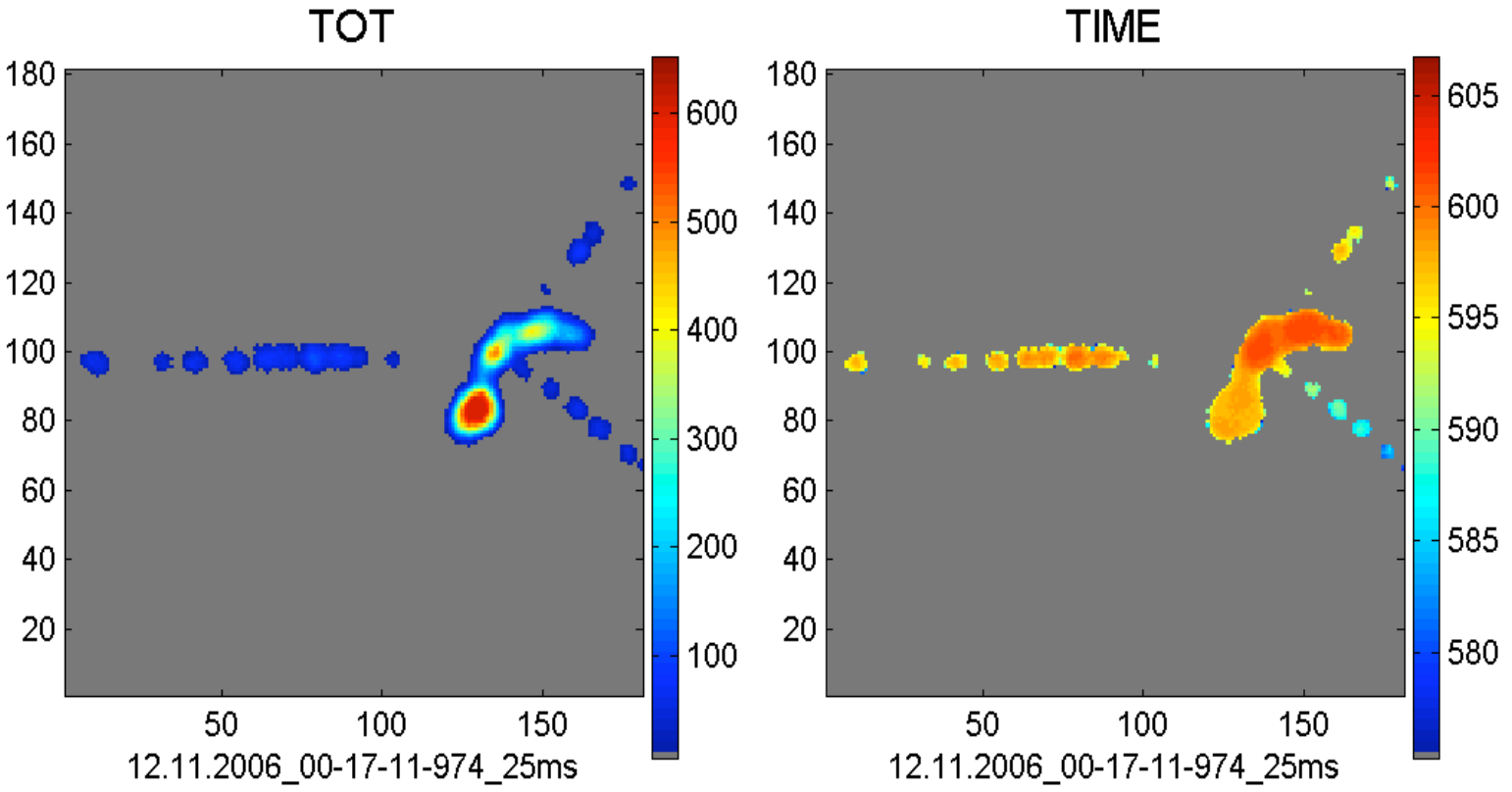
Digital integration (counting)
⇒ No dark current.

Unlimited dynamic range and exposure time.

Detected count obeys poissonian distribution

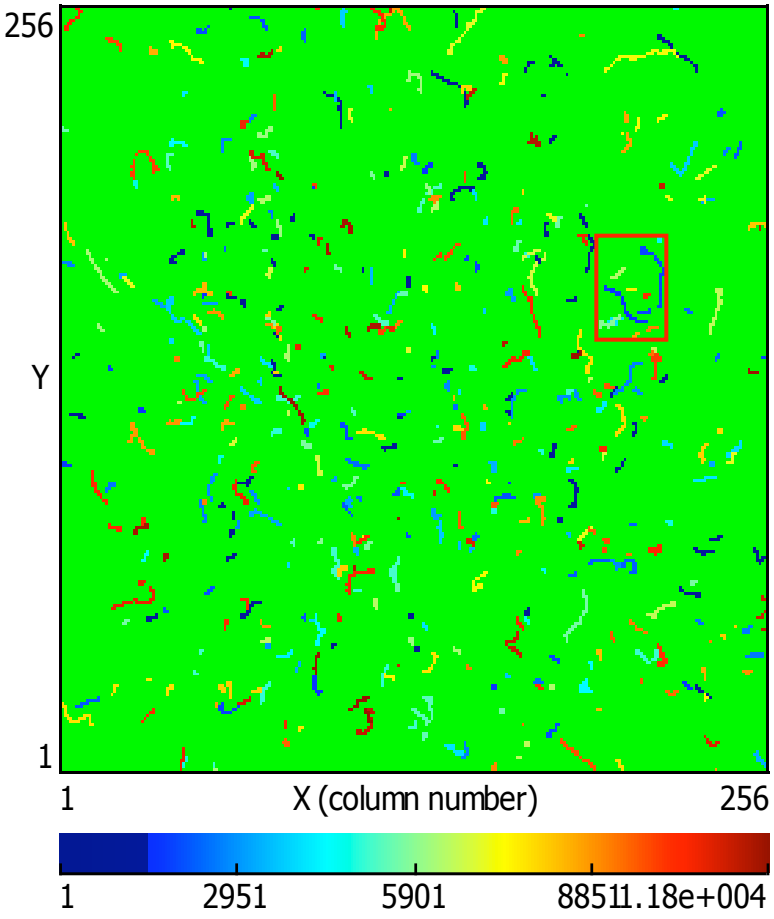
Timepix with 3-GEM detector

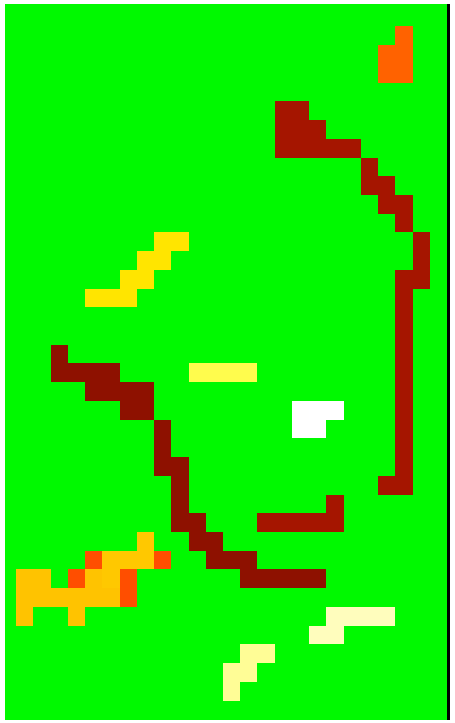
- DESY testbeam in November 2006 (A.Bamberger, M.Titov)

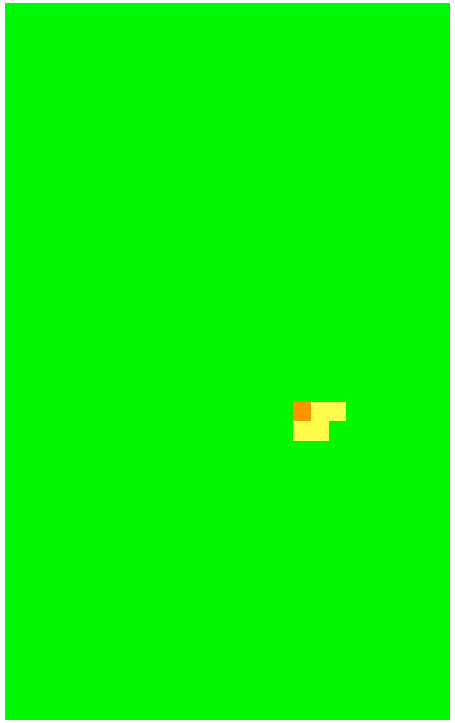


^{90}Sr

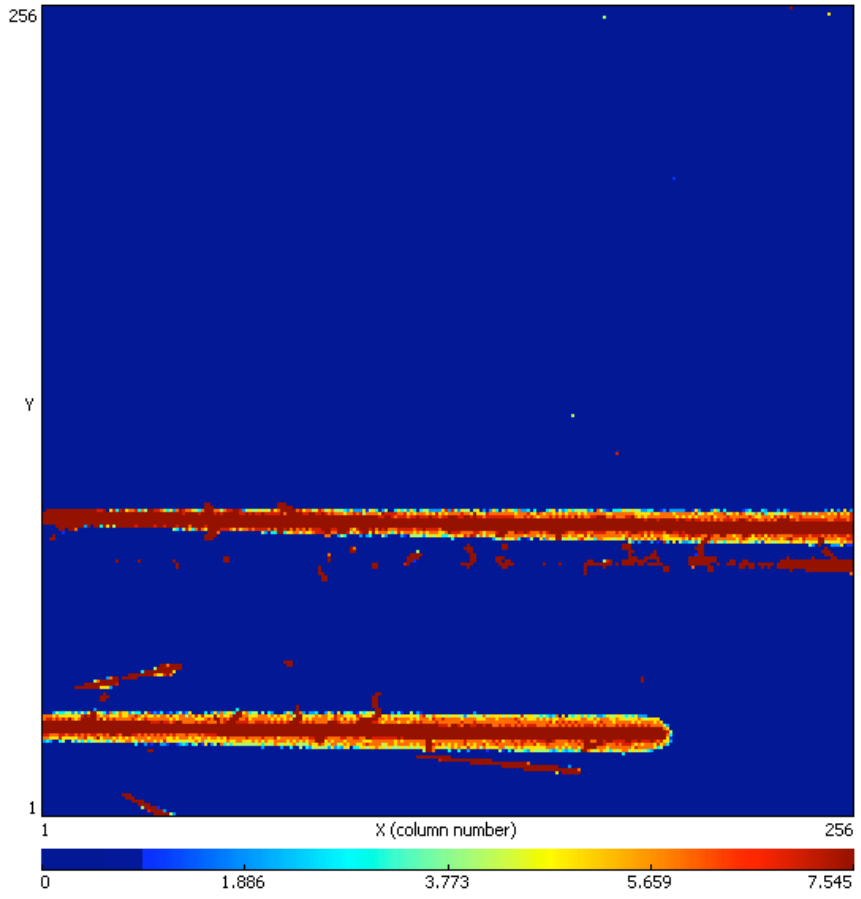
- ^{90}Sr 11 µs exposure time and *Clk_Ref*=6.27 MHz (159.3ns)
- Maximum acquisition time dynamic range of 1.88 ms

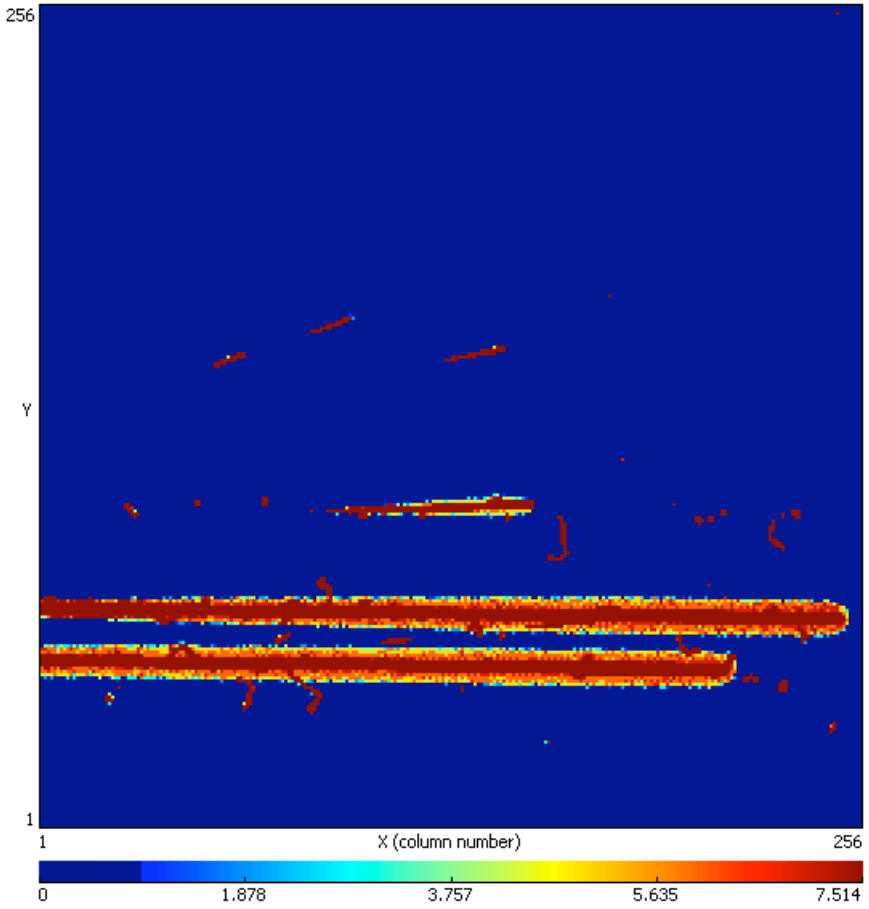






→ Hadron therapy: ^{11}B @ ~90°





Zusammenfassung

- Technologie entwicklet im HEP Kontext erfolgreich in weitem (und staendig wachsendem) Anwendungsbereich eingesetzt
  - Auslesechip universell einsetzbar, Adaption an die zu detektierenden Teilchen im Sensorteil
- Erfolgreicher TT in europaeische Industrie

- Transfer nicht einseitig – Ideen entwicklet im Rahmen des Medipix Projekts zurueck in HEP

Outlook

New IC design to deal with charge sharing

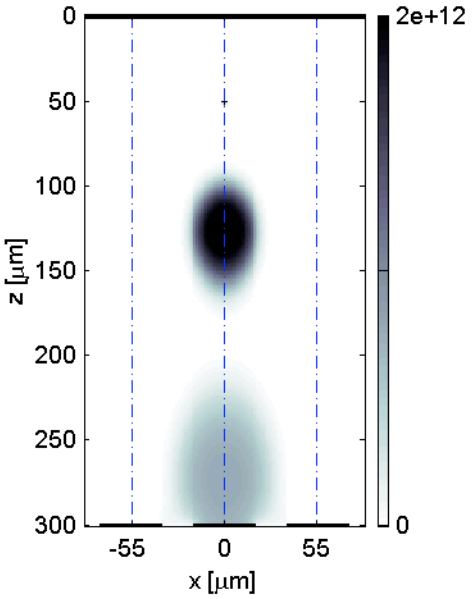
spectroscopic & spatial resolution

Edgeless / 3D sensor (edgeless readout)

for large area tiling

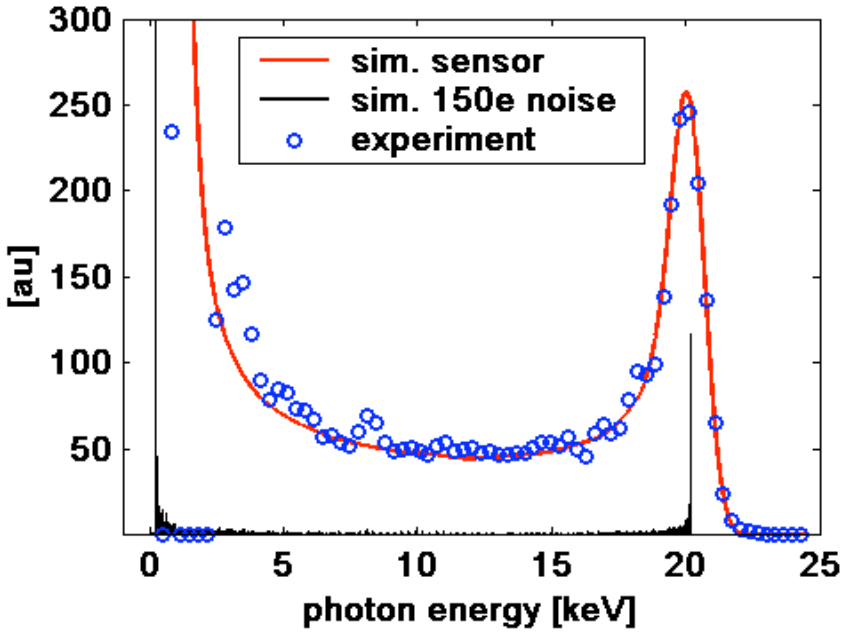
Uniform high Z sensor

Simulation Ladungstransport



20 keV Photonen
300 µm Si Sensor
55 µm Pixelgrösse
120 V Sensorspannung

Monoenergetische Photonen 20 keV

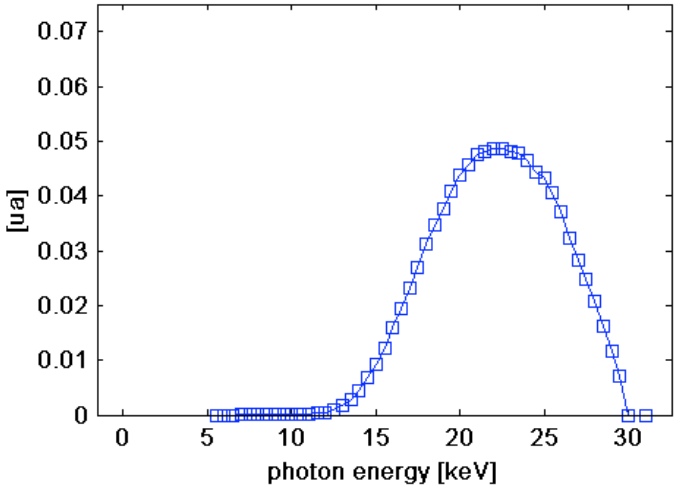


- Monoenergetisches Photonenspektrum → kontinuierliches Spektrum mit ± konstantem Untergrund und starkem Anteil niedriger Pulshöhen

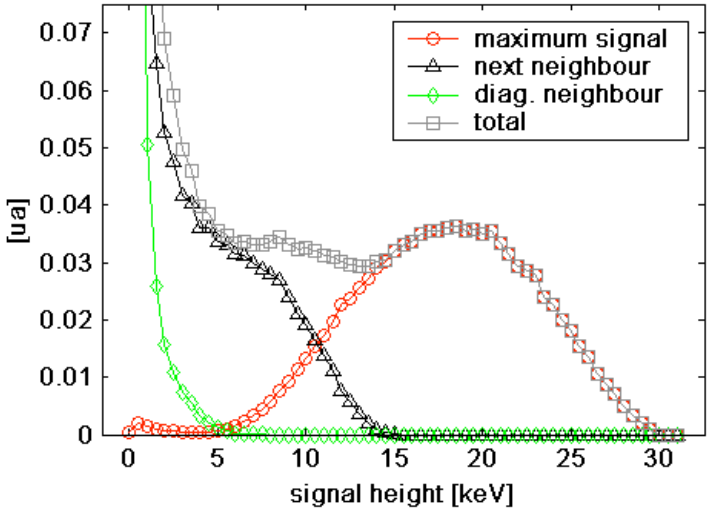
Spektrale Röntgenquelle

Simulation des effectiven Signalspektrums an der Pixelelektrode

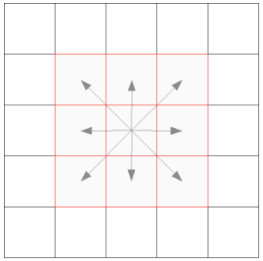
Photonen Spektrum



Detektiertes Spektrum

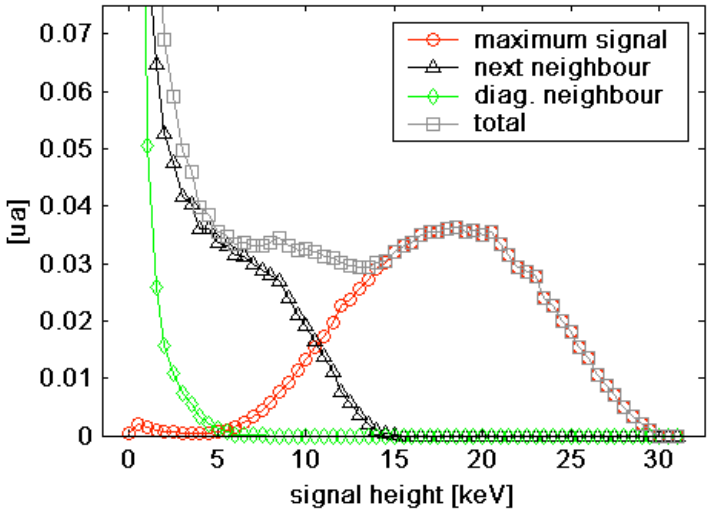


Charge-sharing Korrektur

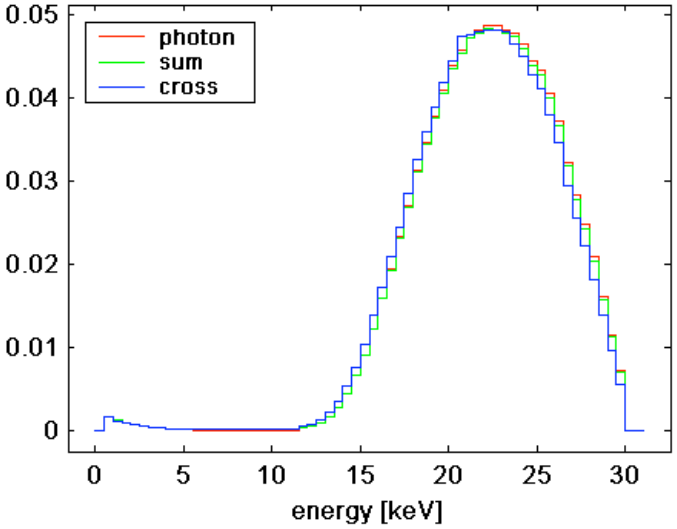


Simulation: Summation der Signale aus 3x3 Pixeln

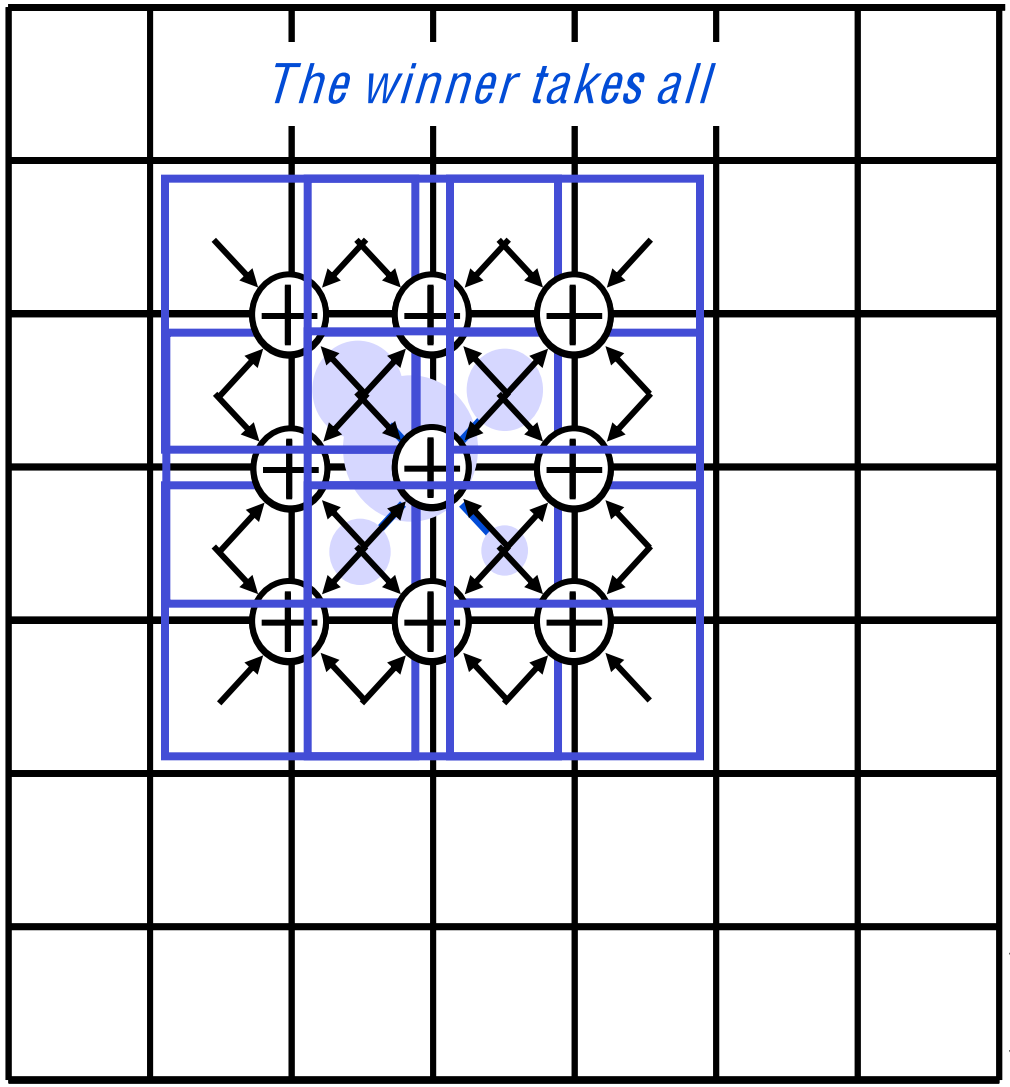
Deformiertes Pixel Spektrum



Korrigiertes Pixel Spektrum



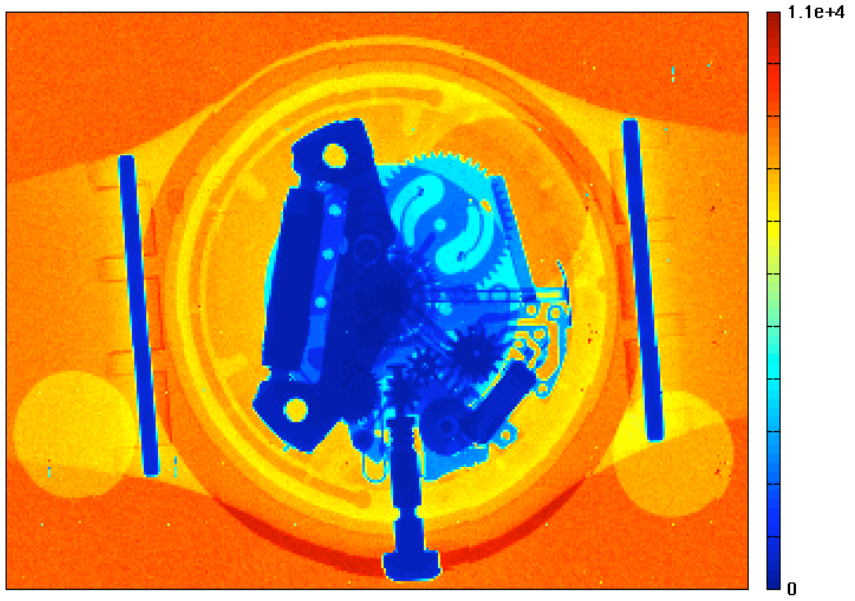
Medipix3 - Charge Summing Architecture



- *Charge is summed in every 4 pixel cluster on an event-by-event basis*
- *The incoming quantum is assigned as a single hit*

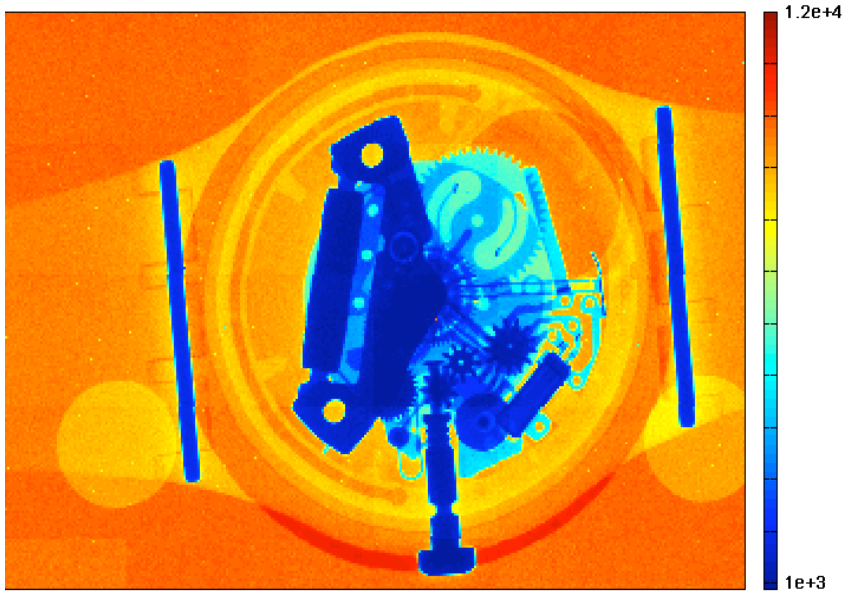
Uniform high-Z material

Medipix1 with Si and GaAs



300 mm Si

22-Jul-2004 - swatch_si_corr_b



150 mm GaAs

22-Jul-2004, swatch_gaas_corr_b

Acknowledgements

Fellow members of the Medipix Consortium
www.cern.ch/medipix

Members of the CERN Medipix team

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Winnie Wong