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A new generation of fast X-ray and particle imagers with single-quantum analysis for applications non-destructive testing and space

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Abstract: Semiconductor pixel detectors, originally developed for high energy particle tracking at the CERN Large Hadron Collider, have demonstrated very interesting properties for applications out of the field of accelerator physics. After 3 decades of development the principle of "quantum counting" or "photon counting" imaging detectors became well established. This technology was elaborated and modified for a range of practical applications such as medical imaging, nondestructive testing, computed tomography, electron microscopy, mineral analysis, dosimetry or even space weather forecasting. The principle of the single quantum tracking detectors is a direct detection and digitization of the complete information for each quantum (e.g. X-ray photon). The incident quanta generate signals in a cluster of pixels, from which one can recognize characteristics of the quantum including its energy (calibrated in keV), time of arrival (~100 ps), precise impact position (subpixel). Different particle types such as X-ray or gamma photons, electrons, ions, etc. produce distinctive patterns allowing very effective suppression of unwanted background in images. Identification of coincidences (e.g. Compton scattering or XRF) improves the image quality even further. The full suppression of the electronic noise brings outstanding image quality in radiographic applications. The ultrahigh dynamic range enabled by excellent signal to noise ratio (>thousands) is limited only by intensity of radiation and exposure time. The multichannel or even fully spectroscopic energy information helps to resolve a material composition of samples. The parallel signal processing in pixels and the data-driven, multi-port readout enable fast imaging, including observation of sub-ms dynamic processes. Examples will be presented for use in non destructive testing.

A new generation of fast X-ray and particle imagers with single-quantum analysis for applications non-destructive testing and space

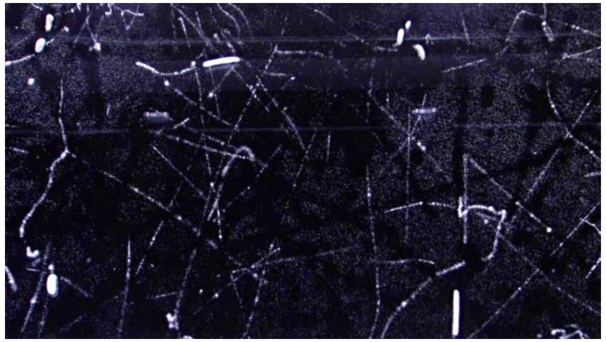
Jan Jakůbek, Erik H.M. Heijne

Dr. Erik Heijne

Supersight: See invisible

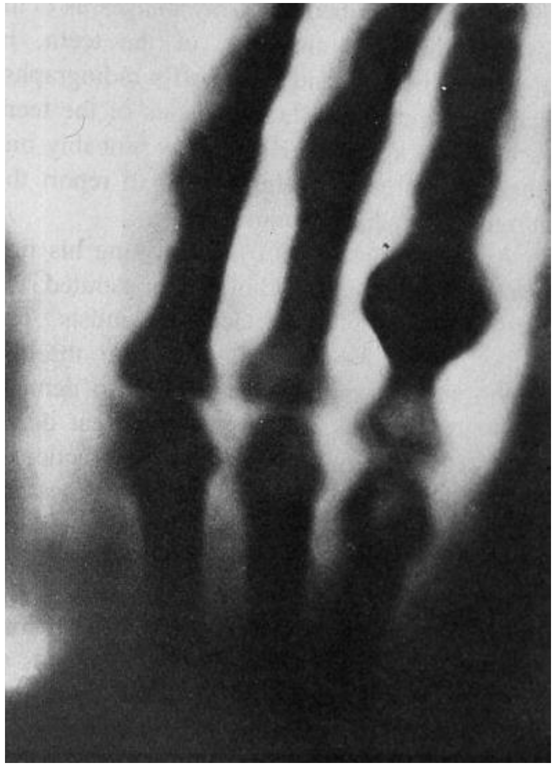
- Particle physics pre-history:
- penetrating radiation discovery …

Cloud Chamber 1911
Wilson, Cavendish Lab,
Cambridge, Nobel Prize 1927



Bubble Chamber 1955
Fermilab

Wilhelm Conrad Roentgen
X-ray image of his wife's hand, 1895



Nuclear emulsions:
Various invisible particles discovered

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Most precise, most revealing
identified many of the elementary particles

...but by far the slowest:
takes ~a week to see
an exposure

Radium decay

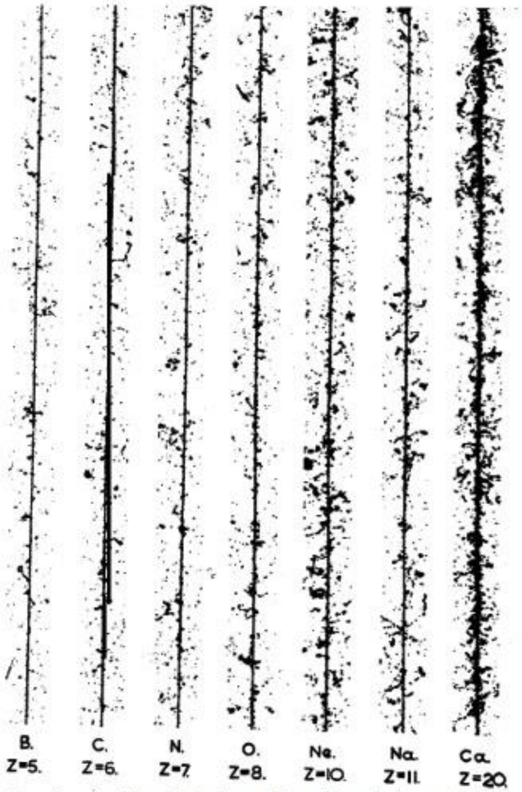
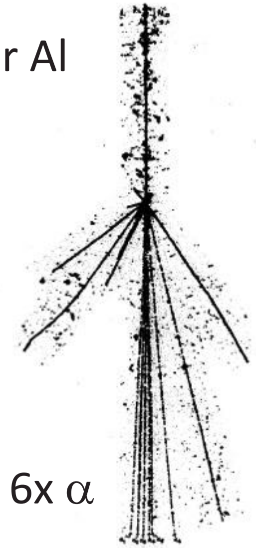


Fig. 2. Examples of the tracks in photographic emulsions of primary nuclei of the cosmic radiation moving at relativistic velocities.

- > **1935 – 1965 Illford Ltd Kodak**
  "nuclear emulsion"
- > **Cecil Powell : 1947 pion discovery, Nobel 1950**

Mg or Al



6x α

π-μ-e

Fig. 3. A nucleus of magnesium or aluminium moving with great velocity, collides with another nucleus in a photographic emulsion. The incident nucleus splits up into six α-particles of the same speed and the struck nucleus is shattered.

Much higher detection speed needed
Silicon diodes …

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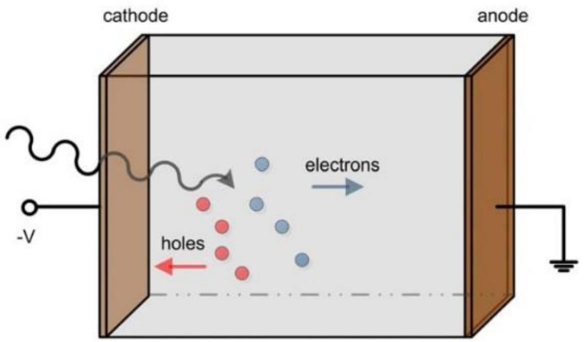
March 1973: Si diode detectors for muon flux monitoring 10^2 – 10^8 cm^{-2} in the shield of the East Area neutrino beam



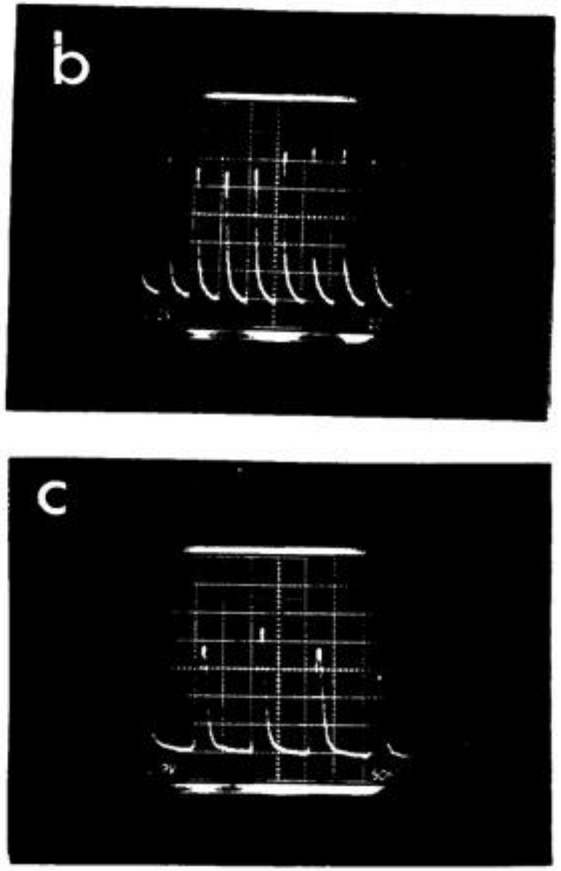


Fig. 4.1 Current pulses, induced by the muon flux in a 500 μm thick detector, measured over a 50 Ω termination as a function of time. The current in individual pulses shows variations, related to the variation of the number of accelerated protons. The duration of each proton bunch is 10 ns.
(a) A complete PS extraction; 18 pulses were directed to the neutrino area. Horizontal divisions 500 ns.
(b) At 70 V bias there is no total depletion; not all charge is collected, as can be seen from the still decreasing current, when the next pulse begins. Horizontal division 100 ns.
(c) At 270 V bias all charge is collected after 70 ns (50 ns per division).

PS beam has 18 or 20 bunches of 10ns: protons ->pions->muons

Higher speed? ...

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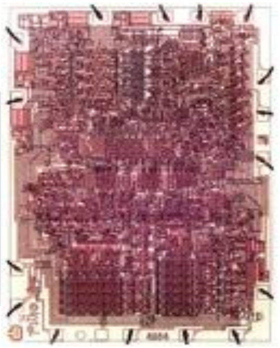
- 1920 – 1965 electronics based on electrodes in vacuum tubes
  - radio also uses 'crystal oscillator' as frequency reference
- 1940 – 1960 study of semiconductors & growth of monocrystals
  - selenium, GaAs, then Ge, but Si is difficult and comes late
- 1943 AgCl crystal is first semiconductor detector (electrons)
  - Utrecht, P. van Heerden recorded electron energy spectrum
- 1960 – 1970 first complex integrated circuits; Moore's law 1965
  - R&D worldwide (Kooi, 1966 LOCOS), stronger manufacturing in USA
  - East: IBM, BellLabs, Texas, RCA,.. West: Fairchild, Intel,...

Laben-Milano ~1955
nuclear pre-amplifier

Si monocrystal 1"
Montecatini (IT) ~1955
-> Monsanto

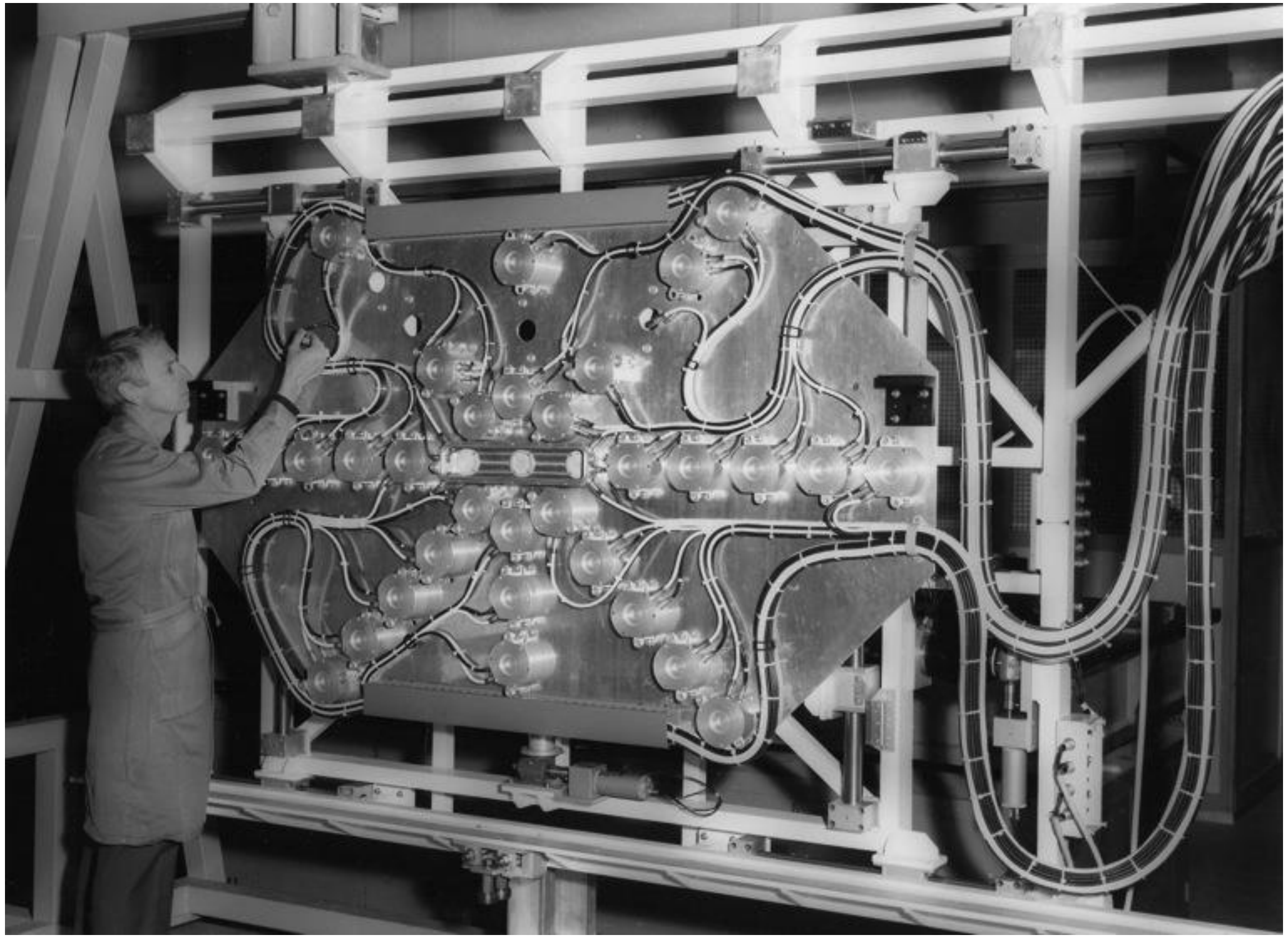


4 bit CPU 1971
Intel 4004 10µm nMOS

Imaging with Si diodes?
Neutrino beam profile monitors

The only option:

Diode Array



6 planes

calibration by moving box

IEEE symposia: where new things begin

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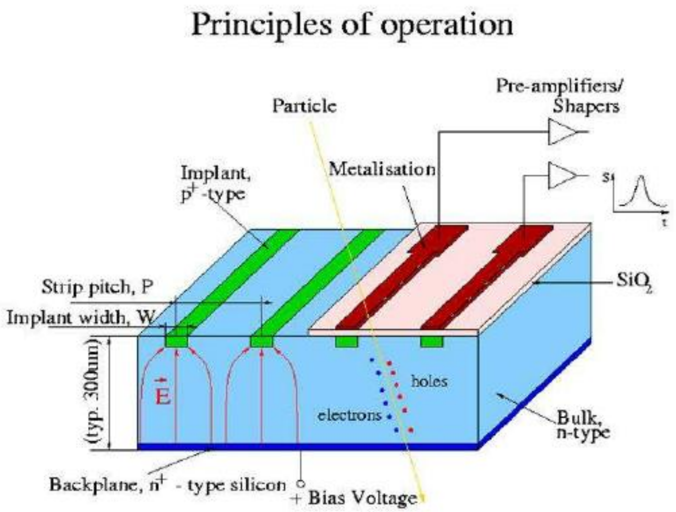
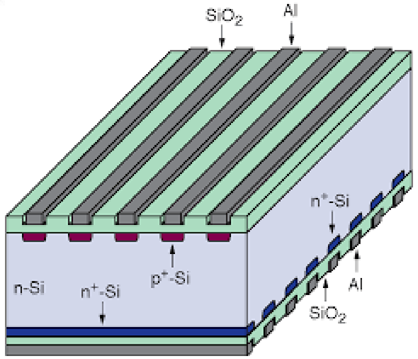
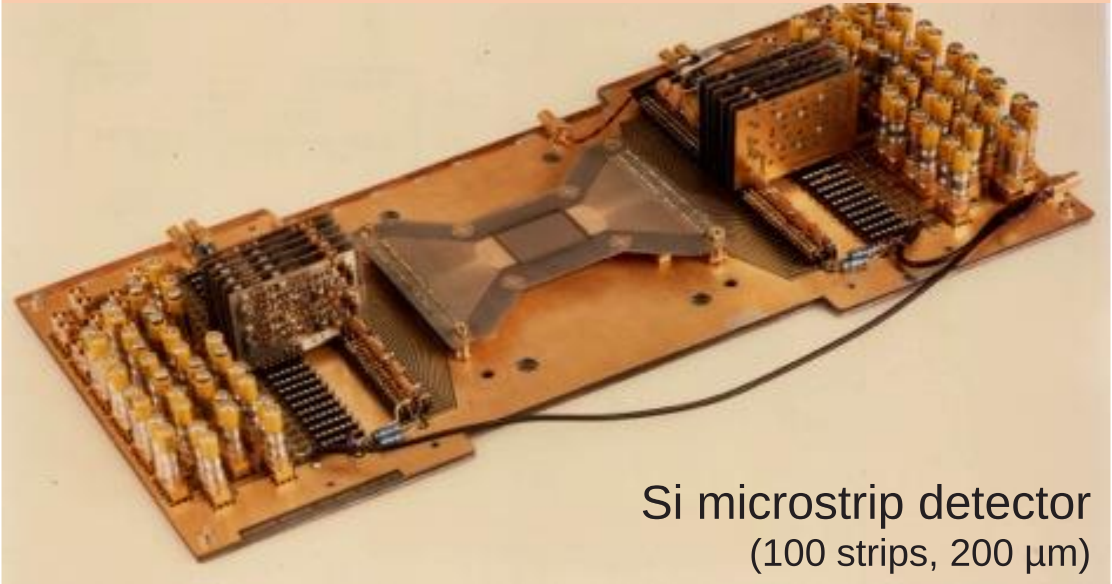
- 1979 IEEE-Nuclear Science Symposium in San Francisco resulted in:
- Project for silicon microstrip detector, implemented by April 1980



Cross strips:
2D information



The fabrication of the first silicon microstrip detector was demonstrated nearly simultaneously by a team with Erik H.M. Heijne and independently by Robert Klanner and Gerhard Lutz.



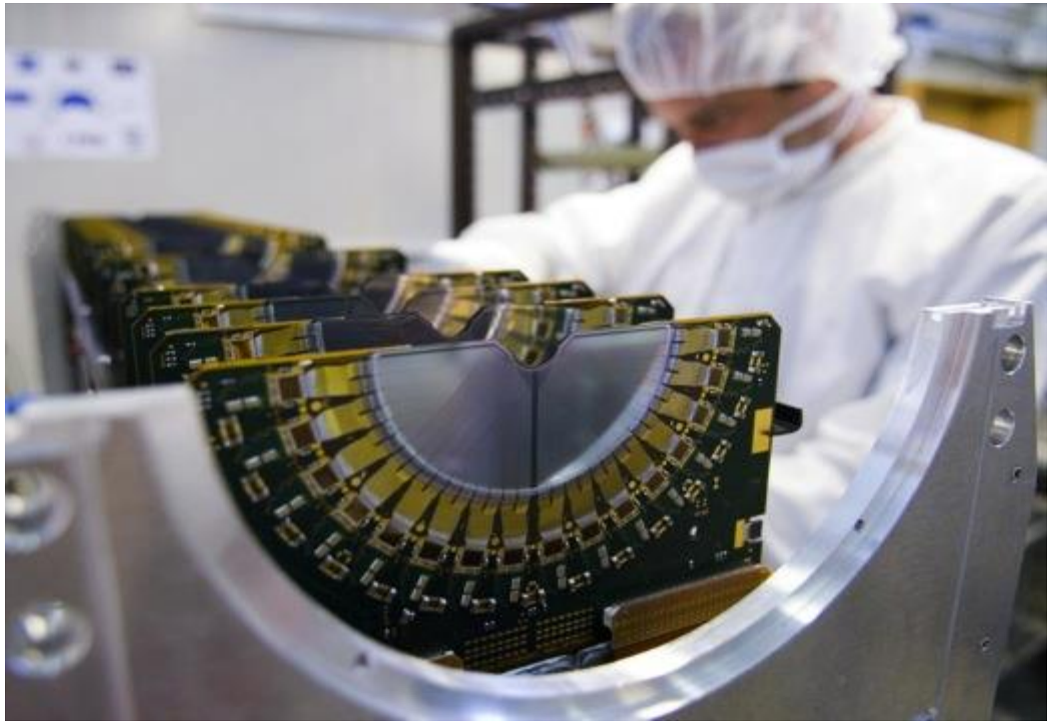
Si microstrip detector
(100 strips, 200 µm)

2nd result of IEEE:

Little box with sequoia seeds, bought at the Muir Woods museum shop.

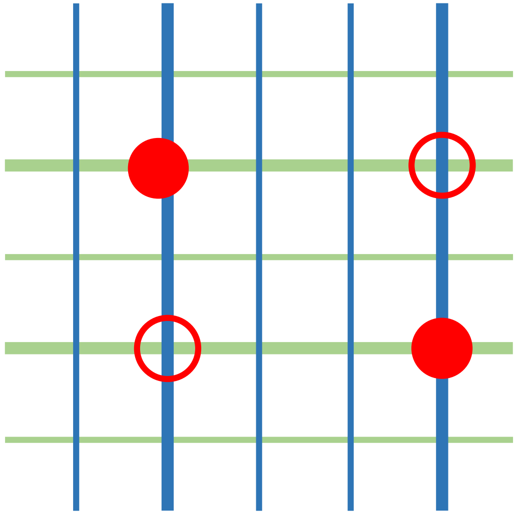
45 years later

Silicon microstrip detectors now major instruments in LHC. Example: Vertex Locator LHCb (the lower half of it)



But still not finished:

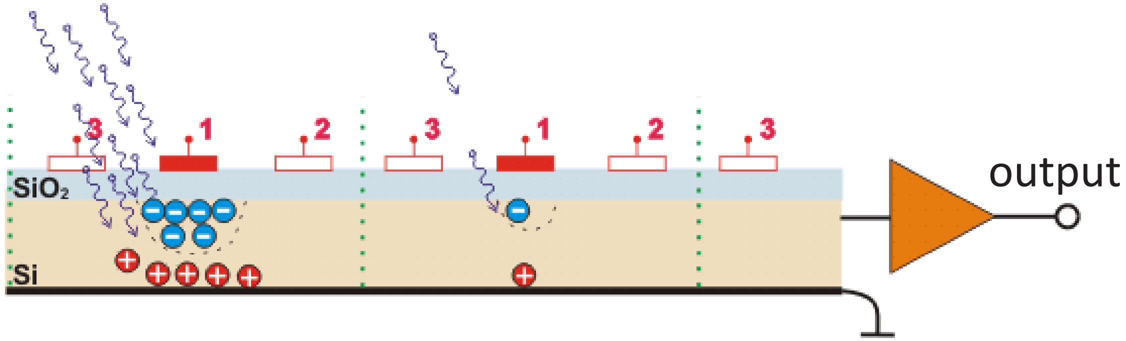
- Ambiguities when more particles cross the detector simultaneously
- Hardly usable for imaging



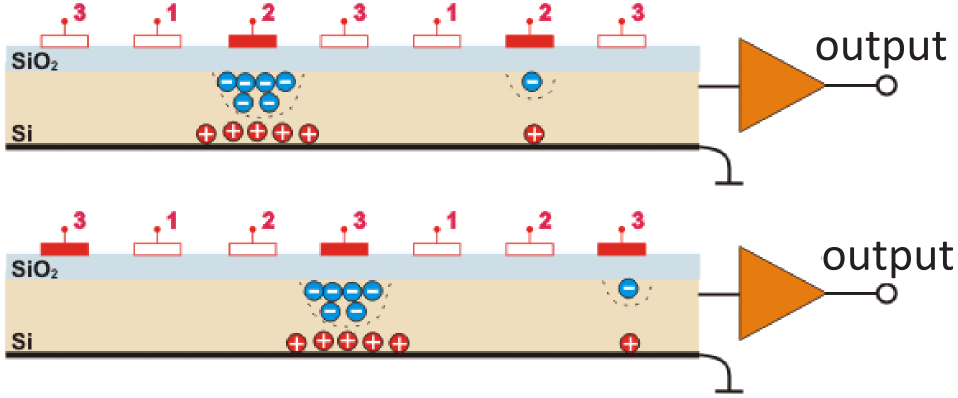
Erik Heijne and his sequoia tree in the garden

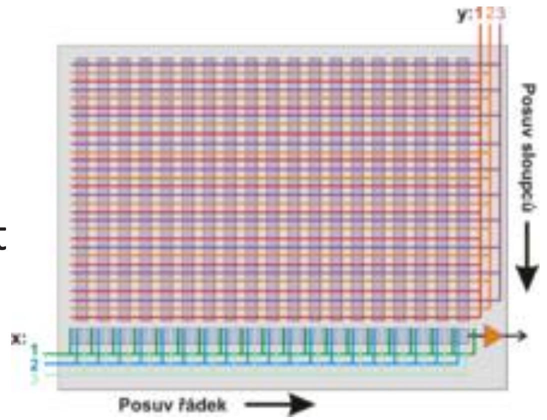
Prehistory of imagers: CCD (1969)

Exposure: Potential well accumulates ionization charge



Read-out: altering potentials on electrodes charges are moved to output





In the late 1960s, Willard Boyle and George E. Smith at Bell Labs were researching MOS technology while working on semiconductor bubble memory. They realized that an electric charge was the analogy of the magnetic bubble and that it could be **stored on a tiny MOS capacitor**. As it was fairly straightforward to fabricate a series of MOS capacitors in a row, so that the charge could be stepped along from one to the next.[3] This led to the invention of the **charge-coupled device** by **Boyle and Smith in 1969.**

Pixel Workshops Leuven 88-90 & Bari 96

ADVACAM Imaging the Unseen

> **expose & develop ideas, inspiration**

> **confront IC & sensor specialists**

> academy: IMEC, EPFL, ETHZ, TU Delft, PoliMilano

> industry: Philips, CSEM, LETI, Canberra, ..

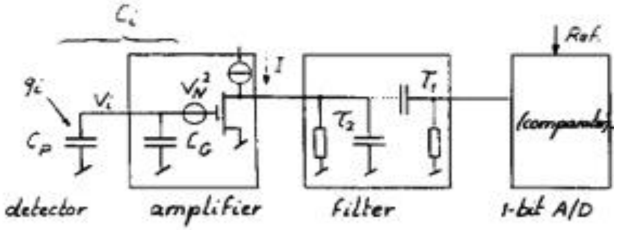
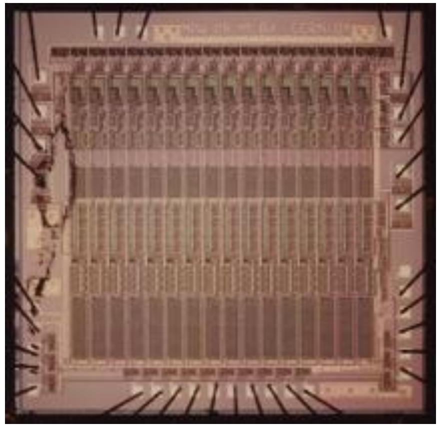


Fig. 1. Schematic drawing of the analog front end

> **learn about projects of other teams**

> RAL, SLAC, LBL, MPI, INFN, Penn, CEA, LAL, ...

1986 - 1988



16 CHANNELS
COLLABORATION
IMEC LEUVEN

Vittoz CSEM-EPFL — Nucl.Instr.Meth.A275-3(1989)

in-pixel circuit — Nucl.Instr.Meth.A305-3(1991)

Nucl.Instr.Meth.A395-3(1997)

Combination of both principles? (1988)

Basic idea:

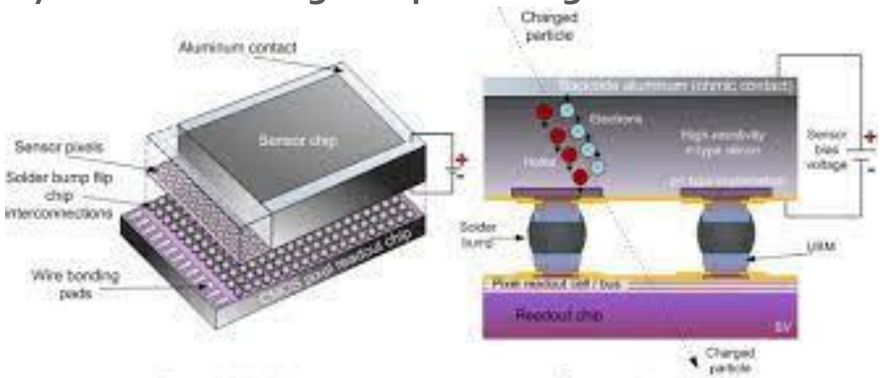
2D array of diodes connected to Independent chip for signal processing.

=> 2 chips: Hybrid technology

1st chip: pixelated sensor

2nd chip: CMOS readout - separate channel for each pixel

Hybridization using bump-bonding



Generic pixel detector   Cross-sectional cut

'Dream' proposal

processing of the quantum signal in each single pixel

The Silicon Micropattern Detector

A Dream ?

aim: see cluster patterns and identify particles/quanta

Erik Heijne — CERN-EF
Pierre Jarron
Nicola Redaelli

Alf Olsen — SI Oslo

Quantum dosimetry
US Patent 8168953
Heijne-Pospisil subm 2007

London Conference on Position-Sensitive Detectors
7-11 sept 1987

Silicon Micropattern Detector
tentative characteristics
E. HEIJNE — LONDON Conf. 1987

- 2-dimensional array of detecting elements

just 35 years ago

- granularity of 20-100 μm
- no insensitive regions between segments
- in situ signal processing, giving digital output zero suppression, local ADC — BINARY or DIGITAL
- memory function until external trigger/clear
- hierarchical information structure using mosaic of devices
- recognition of useful data (patterns)
- active area per device > 100 mm^2

  $1 m^2 = 10^4$ devices

- boundary conditions in:
  power dissipation < .1 W/cm^2
  radiation tolerance 10^7 rad
  10^{14} neutrons

M — A DREAM ? — NIM A 273 (1988) 615

RD19 project

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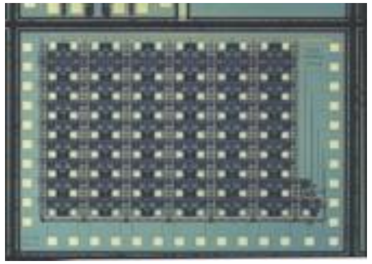
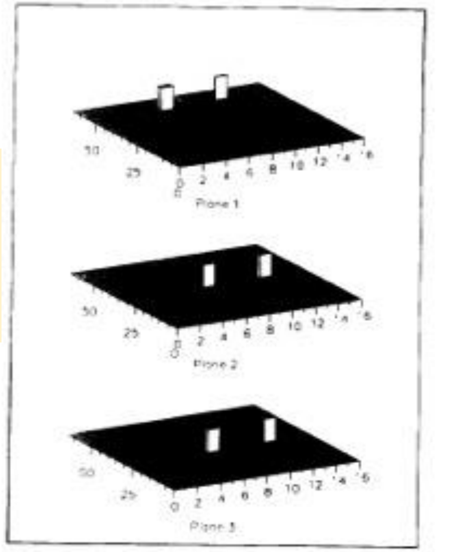
> **First matrix tested 1989, CERN+EPFL & ETHZ (Faselec SACMOS3µm)**



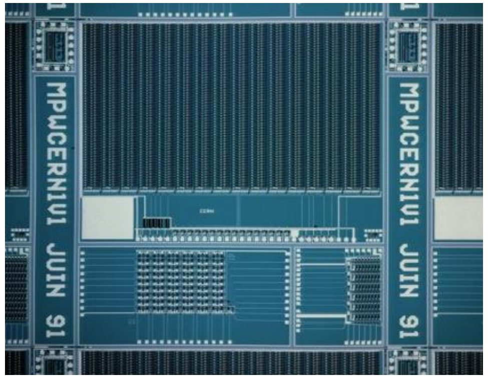
- synchronous amplifiiers, 10MHz
- wirebond pads left no space
  for sensor guardrings -> repeat

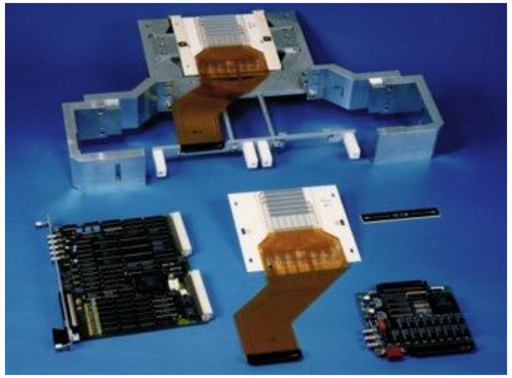
RD19 collaboration: starting point for LHC experiments



13 A nice event seen in the 3 pixel planes. Note the dip angle of the tracks.

> **1991 Omega chip 16x63 pixels, 75x500µm,** strobed binary



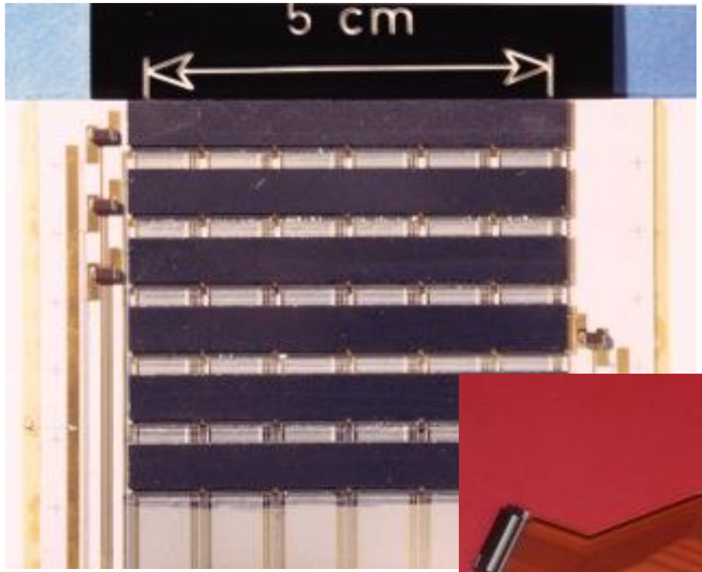


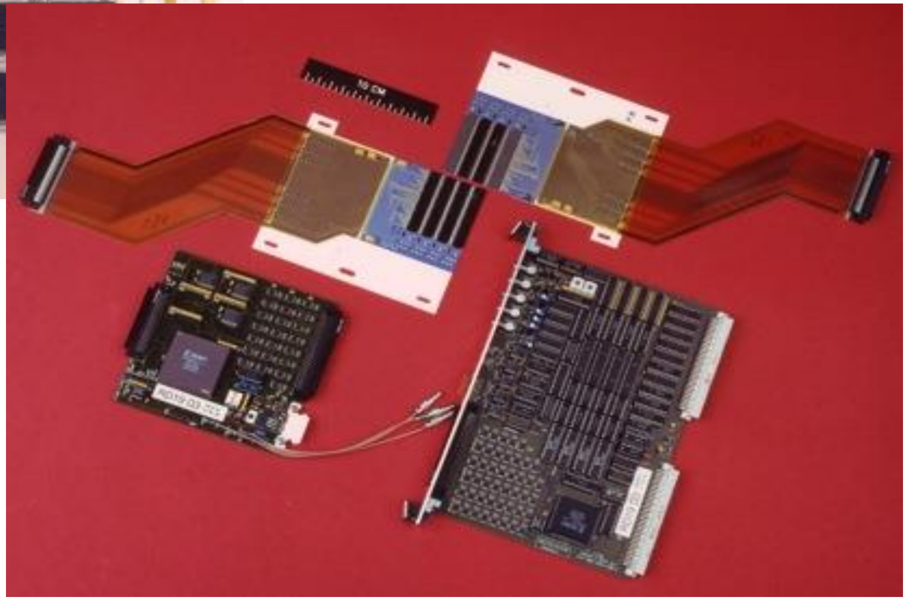
F. Anghinolfi[1‡], P. Aspell[1‡], K. Bass[12], W. Beusch[1], L. Bosisio[10], C. Boutonnet[2], P. Burger[11], M. Campbell[1‡], E. Chesi[1], C. Claeys[5], J.C. Clemens[3], M. CohenSolal[3], I. Debusschere[5], P. Delpierre[2], D. Di Bari[14], B. Dierickx[5], C.C. Enz[13], E. Focardi[10], F. Forti[10], Y. Gally[3], M. Glaser[1], T. Gys[1], M.C. Habrard[3], E.H.M. Heijne[1], L. Hermans[5], R. Hurst[7], P. Inzani[8], J.J. Jæger[2], P. Jarron[1], F. Krummenacher[*13], F. Lemeilleur[1], V. Lenti[14], V. Manzari[14], G. Meddeler[1‡], M. Morando[9], A. Munns[12], F. Nava[6,15], F. Navach[14], C. Neyer[4], G. Ottaviani[6,15], F. Pellegrini[9], F. Pengg[1], R. Perego[8], M. Pindo[8], R. Potheau[3], E. Quercigh[1], N. Redaelli[8], L. Rossi[7], D. Sauvage[3], G. Segato[9], S. Simone[14], G. Stefanini[1], G. Tonelli[10], G. Vanstraelen[+5], G. Vegni[8], H. Verweij[1], G.M. Viertel[4], J. Waisbard[2]

CERN[1], Collège de France[2], CPPM Marseille[3], ETHZ[4], IMEC[5], INFN and University of : Bari[14], Bologna[6], Genova[7], Milano[8], Modena[15], Padova[9], Pisa[10], Canberra Semiconductor NV[11], GEC-Marconi(Caswell)[12], Smart Silicon Systems SA [13]

Anghinolfi et al.. IEEE NS-39(1992) 654-661

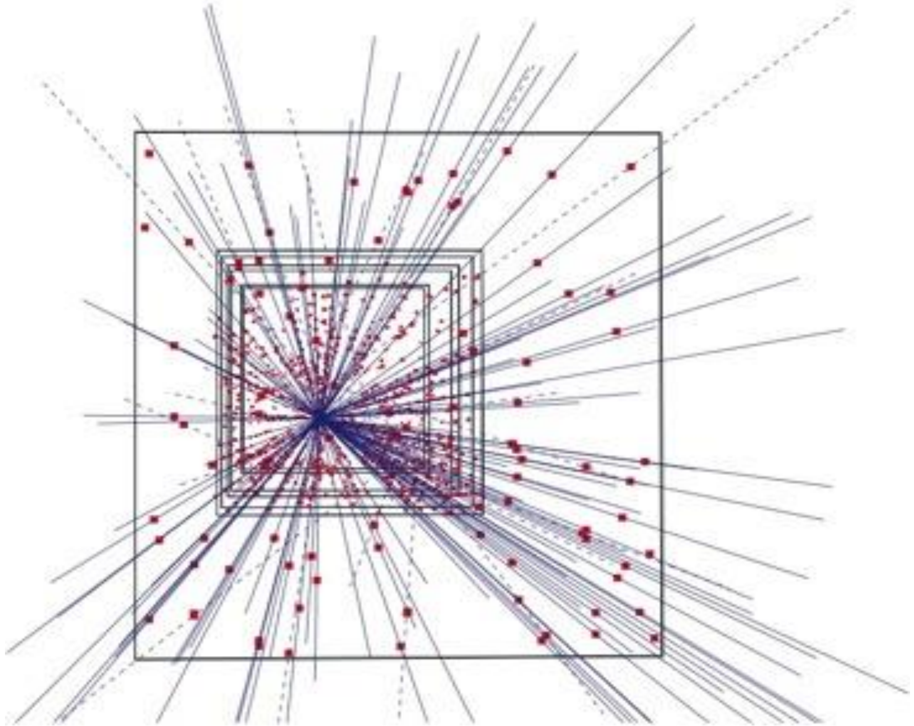
RD19 telescope in Omega WA94





7 detector layers

No false events: Each event in each layer assigned to particle track originating in interaction point



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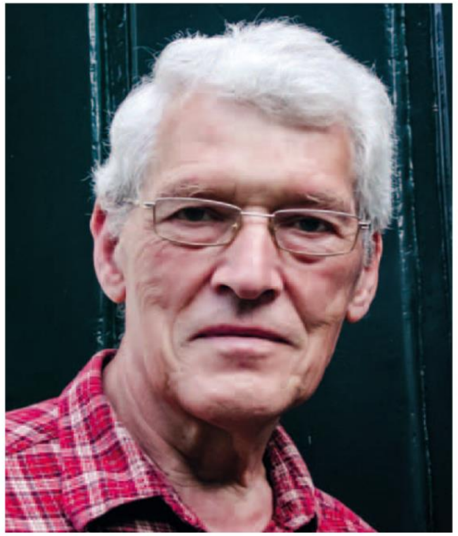


Erik Heijne
Initiator and the first leader

Michael Campbell
Chip designer and current leader of Medipix collaboration

Stanislav Pospisil
Founder and the first director of IEAP CTU

EUROPE ... EAR RESEARCH

CERN DRDC/94-51
RD19 Status Report
6 January 1995

RD19: Status report on 1994
Development of hybrid and monolithic silicon micropattern detectors

Spokesman: Erik H.M. Heijne

CERN[1], Collège de France[2], CPPM Marseille[3], EPFLausanne[4], ETH Zurich[5], IMEC Leuven[6], INFN and University of Bari[7], Catania[8], Genova[9], Milano[10], Modena[11], Padova[12], Perugia[13], Pisa[14], Roma[15], Trieste[16], University GHS Wuppertal[17], Technical University Athens[18], Group Praha[19], Univ. of Glasgow[20], Canberra Semiconductor NV[21¶], GEC-Marconi Materials Technology(Caswell)[22¶] and Smart Silicon Systems SA[23¶]

F. Antinori[1], C. Arrighi[3], H. Beker[15], D. Barberis[9], G. Batignani[14], K.H. Becks[17], W. Beusch[1], G. Bilei[13], L. Blanquart[3], V. Bonvicini[16], V. Bonzom[3], L. Bosisio[16], U. Bottigli[14], C. Boutonnet[2], P. Burger[21¶], M. Campbell[1], E. Cantatore[1,7], M.G. Catanesi[7], B. Checcucci[13], E. Chesi[1], J.C. Clemens[3], M. Cohen Solal[3], G. Darbo[9], J.C. Da Silva[3], S. D'Auria[20], C. Da Via[1], P. Delpierre[3], D. Di Bari[7], S. Di Liberto[15], B. Dierickx[6], D. Elia[7], C.C. Enz[4], A. Fallou[3], M. Fantacci[14], E. Focardi[14], F. Forti[14], Y. Gally[3], M. Garg[17], M. Glaser[1], S. Glitza[17], E. Grigoriev[3], T. Gys[1], M.-C. Habrard[3], G. Hallewell[3], E.H.M. Heijne[1], L. Hermans[6], J.M. Heuser[17], A. Jacholkowski[1,7], J.J. Jæger[2], J. Jakubek[19], P. Jarron[1], P. Jirousek[19], S. Kavadias[18], S. Kersten[17], P. Kind[17], F. Krummenacher[23*¶], R. Leitner[19], F. Lemeilleur[1], V. Lenti[7], G. Lenzen[17], M. Letheren[1], M. Lokajicek[19], L. Lopez[1], D. Loukas[18], M. LoVetere[9], M. Macdermott[5], G. Maggi[7], P. Martinengo[1], G. Meddeler[1], F. Meddi[15], A. Mekkaoui[3], P. Middelkamp[1,17], K. Misiakos[18], M. Morando[12], T. Mouthuy[3], A. Munns[22¶], P. Musico[9], P. Nava[11], V. O'Shea[20], M. Pallavicini[9], F. Pellegrini[12], F. Pengg[1†], M. Pindo[9], S. Pospisil[19], R. Potheau[3], E. Quercigh[1], N. Redaelli[10], J. Ridky[19], I. Ropotor[17], U. Röser[5], L. Rossi[9], K. Safarik[1], S. Saladino[7], D. Sauvage[3], G. Segato[12], P. Sicho[19], S. Simone[7], K. Smith[20], W. Snoeys[1], B. Sopko[19], G. Stefanini[1], P. Tempesta[7], Z. Tomsa[19], G. Tonelli[14], G.M. Viertel[5], V. Vrba[19] and J. Waisbard[2]

* Also with EPF Lausanne, Switzerland,
† Fellowship Austria
¶ The companies Canberra, GEC-Marconi and SSS are not formally member of the collaboration

History: CERN, CTU and IEAP …

Stanislav Pospisil
the first director
of of IEAP CTU

2011 Seminar of Erik Heijne in IEAP CTU

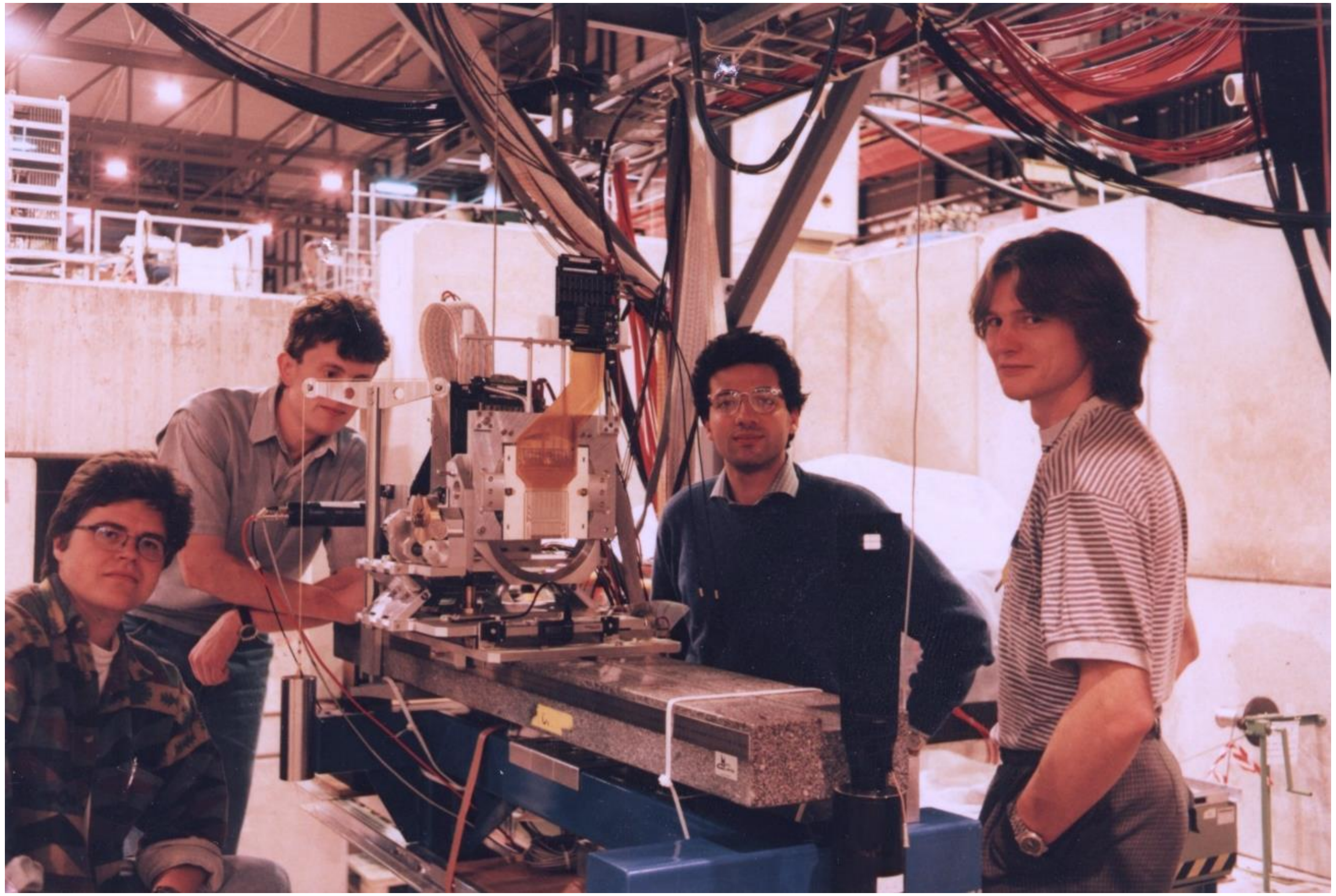
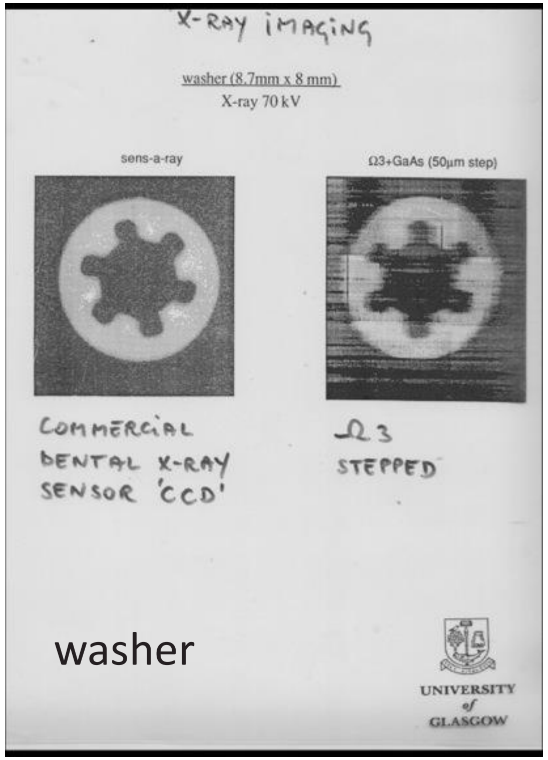


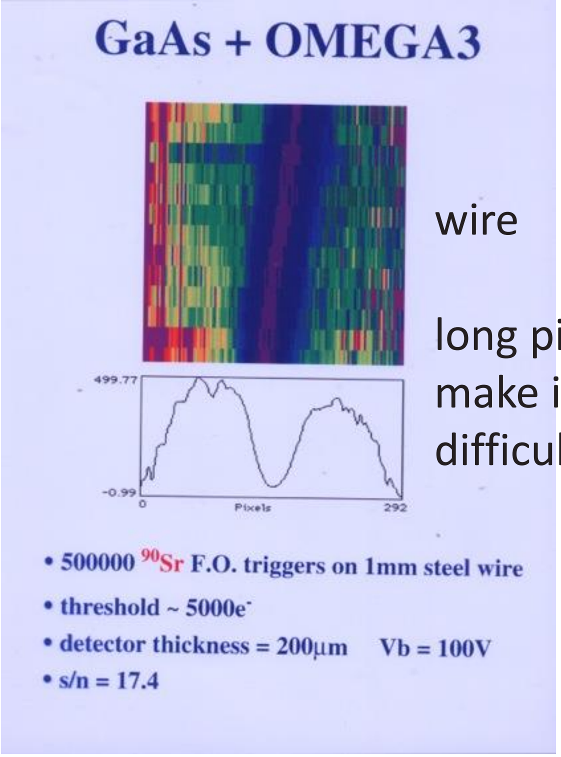
Photo by Cinzia Da Via: one of early beam test periods within RD19 in 1993

Results 1991-1999 from RD19

- **Started with Hybrid & Monolithic-SOI**
  - SOI abandoned because difficult+expensive
- **Complete hybrid telescopes produced**
- **Exploited immediately in Omega ion experiments**
  - **high occupancy from ion interactions needs pixels**
- Soon also in Delphi forward tracker (CdF&Marseille)
- First radhard-by-design pixel circuit for ALICE
  - this first version (1999) was used without iteration
  - a 2nd version made for LHCb RICH imaging tubes
- **Results convinced LHC community** **ATLAS, CMS**

Instead of just recording particles, use radiation to analyze objects?



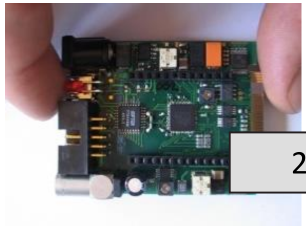


wire

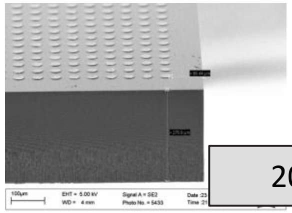
long pixels make it difficult

Current technology origin

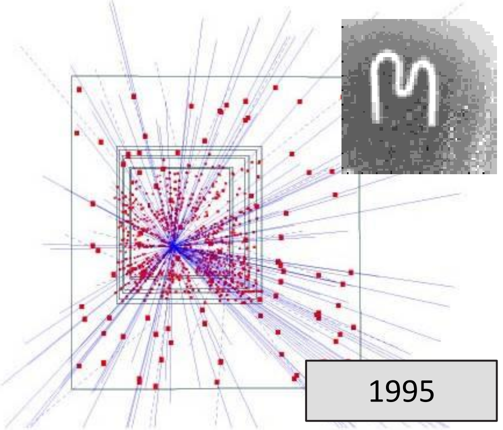
- The story started in CERN: RD19 group and **Omega** chip in 90's
- Development of pixel detectors continues within **Medipix collaborations**
- Establishing Institute of Experimental and Applied Physics IEAP under CTU in Prague in 2002

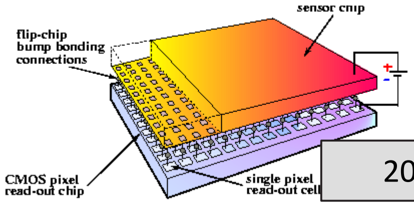

2005

- Miniaturized USB based readout system and software enabled rapid development of many new applications methods and technologies
- Combining Medipix technology with technology of edgeless silicon sensors developed in VTT


2010

- Development of the first large area pixel detector with continuous sensitivity in 2013
- **ADVACAM** company established (Finland 2012, Czech Rep. 2013)


1995



2001


2013

>Results of this long journey

Current technology status …

ADVACAM

Bringing technology out of the lab

ADVACAM
Imaging the Unseen

> IMAGING THE UNSEEN

We design and produce cameras for material analysis, non-destructive testing, color radiography, or radiation safety

> 30 YEARS OF DEVELOPMENT

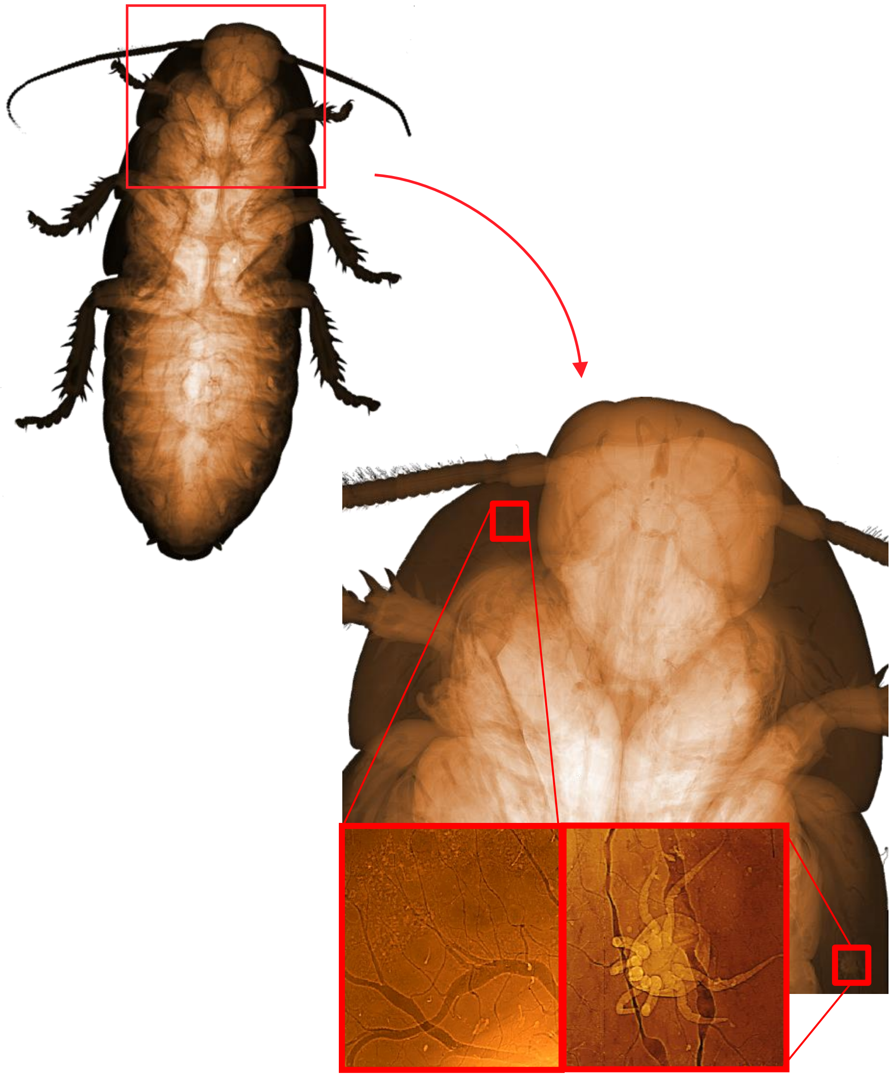
Based on CERN single-photon counting technology, our cameras revolutionize a range of industries, from space to medicine

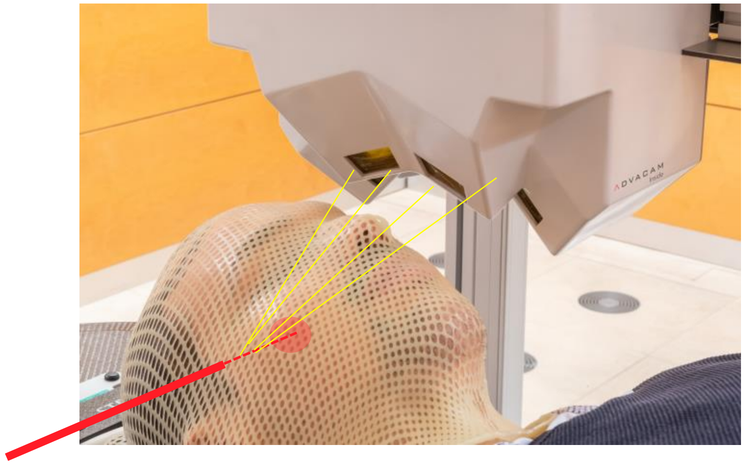
> CONTINUOUS RESEARCH

Experienced team of researchers. New imaging methods are instantly being developed.

> OEM integration

Customized cameras are integrated to devices of our customers and partners in various industries.



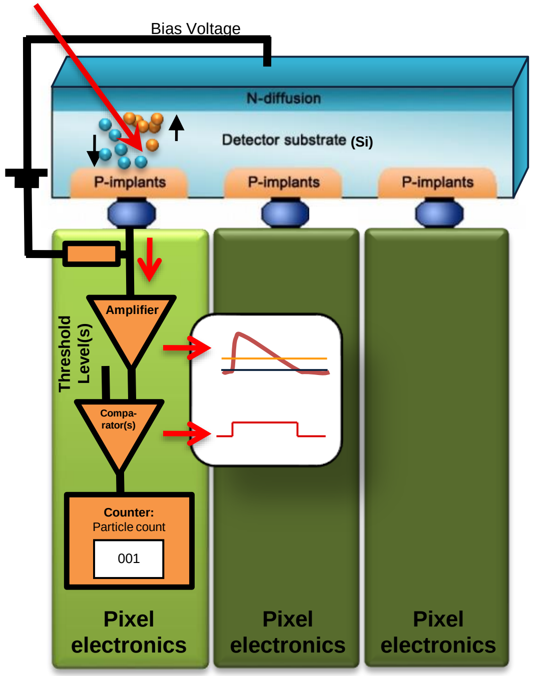


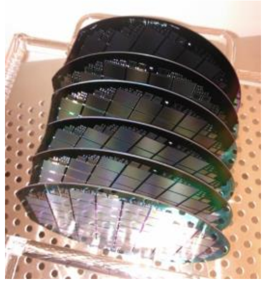
Basic principle:
Digital signal processing in every pixel

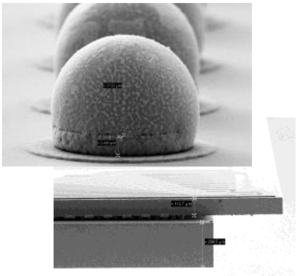
ADVACAM
Imaging the Unseen

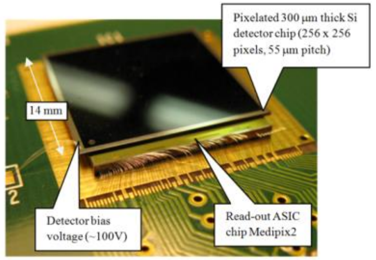
Advantages:

- **Direct conversion:** Radiation quantum => electric pulse => digital count + energy + time
- **High resolution: 55 microns (or better see later)**
- **Provides energy sensitive imaging (spectral too)**
- Very high signal to noise ratio (theoretically unlimited) => **Ultra high dynamic range**
- Signal is digital => Very high speed.
- **Continuous operating modes for zero deadtime scanning** implemented in hardware.

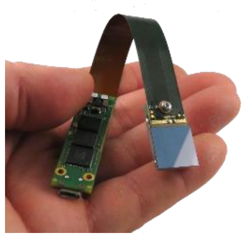








Small

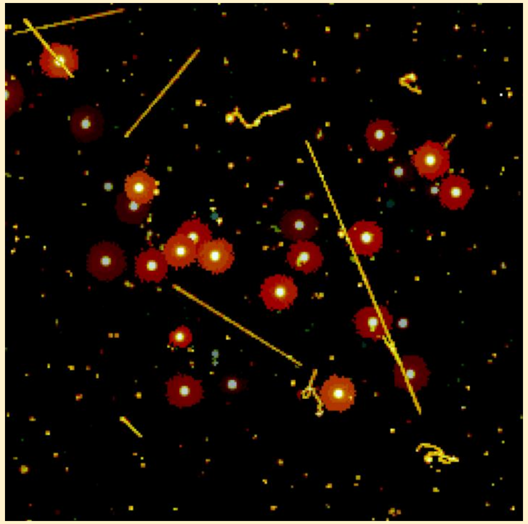


Bigger

Large

Photon counting & Particle tracking

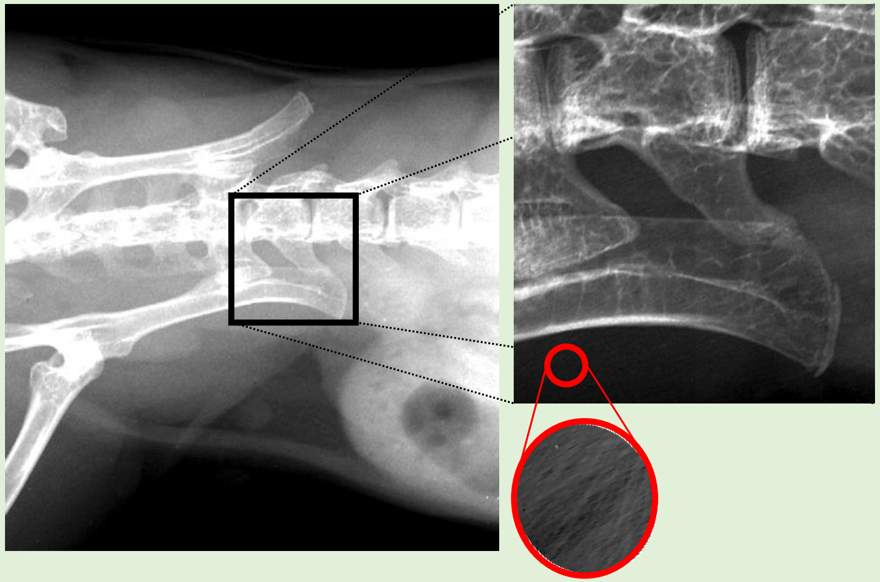
… in your pocket



Natural radiation recorded in the office

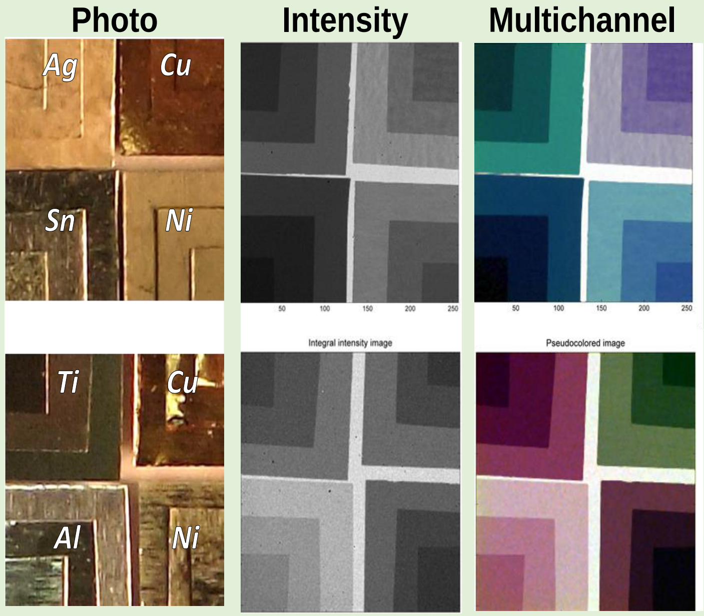
Example: High resolution, high dynamic range X-ray radiography

Photon counting: Ultra-high contrast



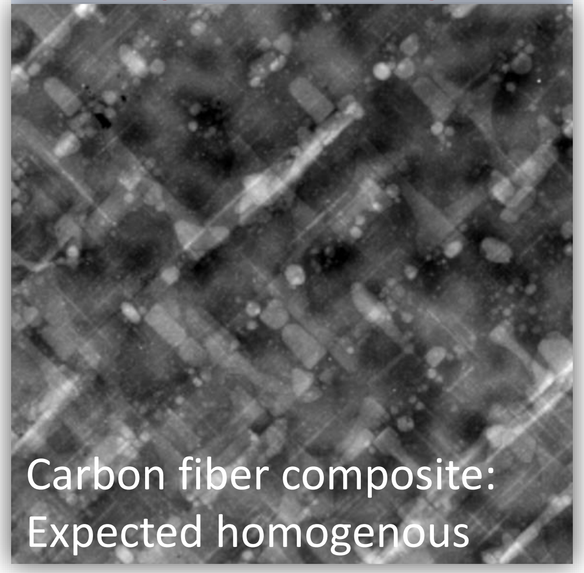
Mouse: hair fibers are resolved through its body !

Multichannel: Material sensitivity



Material differences are identified !

X-ray radiography:
Ultra high dynamic range!



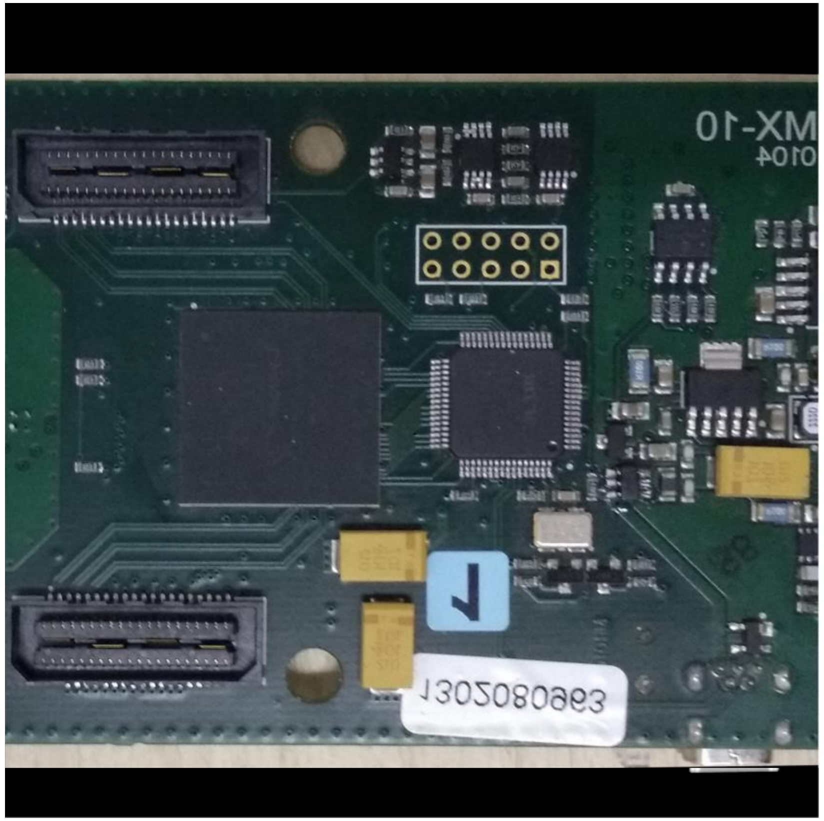
Excellent imaging properties!

Noise obeys Poissonian statistics even at very high counts:

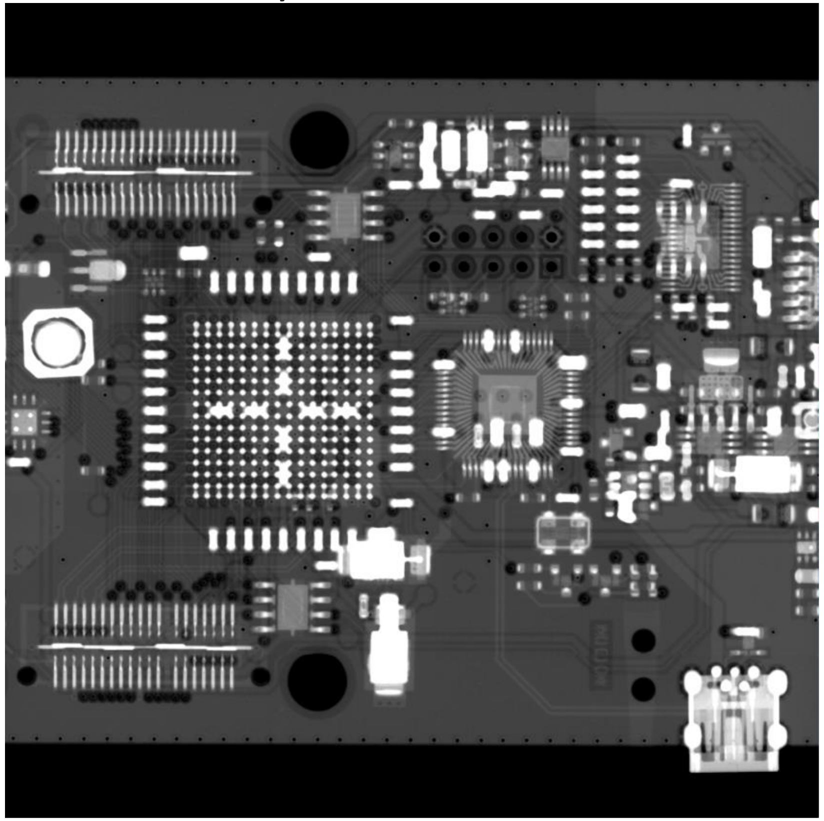
- Global stability over 30 minutes:
  SNR = 5000
- Local stability over 1 hour:
  SNR = 2000

Industrial sample: PCB

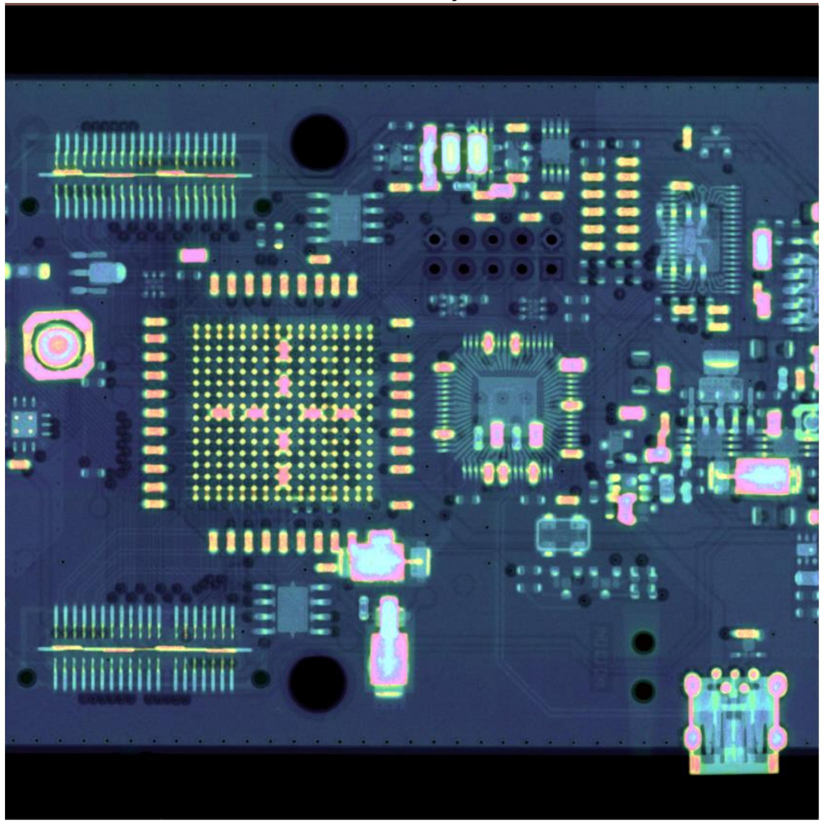
Photo



Standard X-ray



Material sensitive X-ray



Fully digital => Very high speed

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High-speed modes:

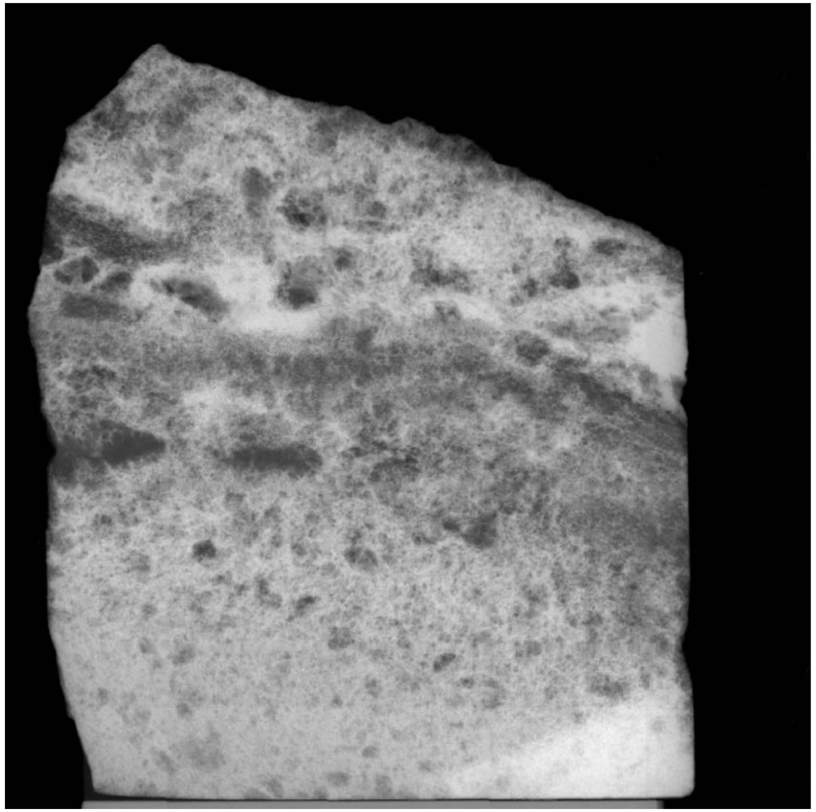
- **Single frame readout in 250 µs**

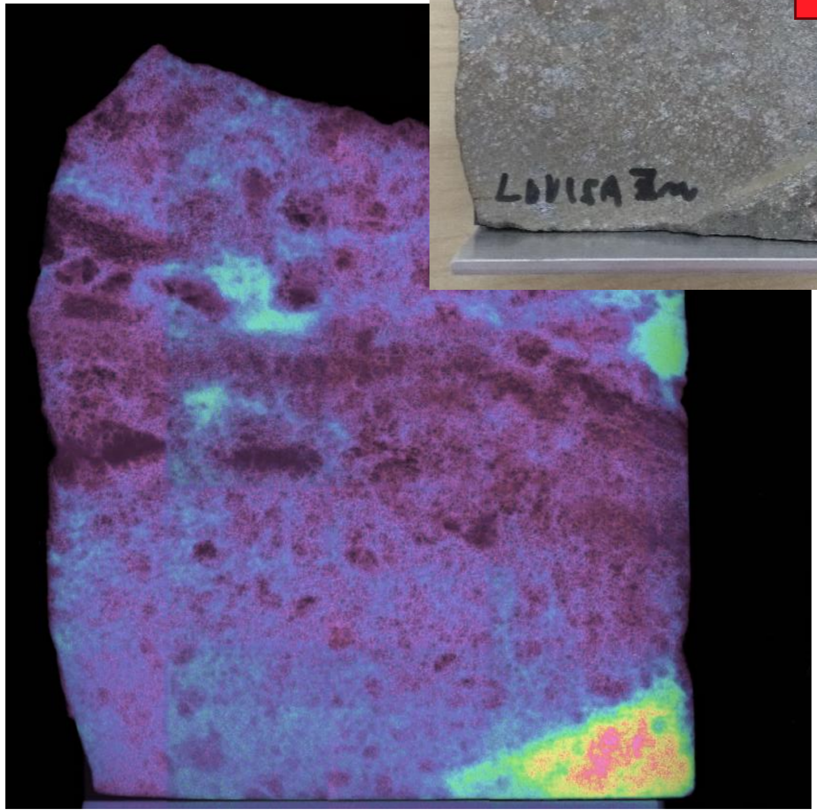
- **Continuous exposure:**
    - When the actual frame is being exposed
    - The previous frame is transferred to PC
    - => no dead time

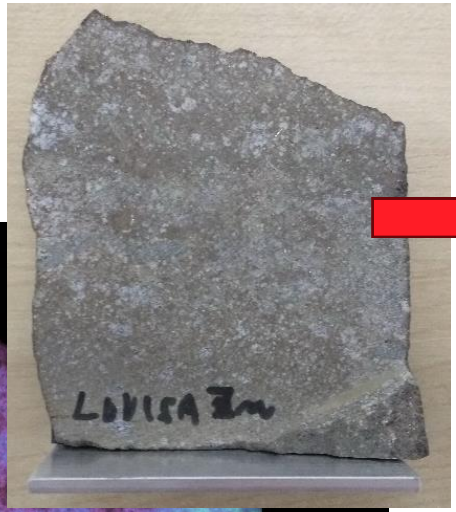
- **Special mode for moving objects: Time-delayed-integration (TDI mode):**
    - For continuously moving objects (scanning)
    - Image is being shifted within the chip synchronously with the object => **no motion blurr**

Mining: Mineral ore sample

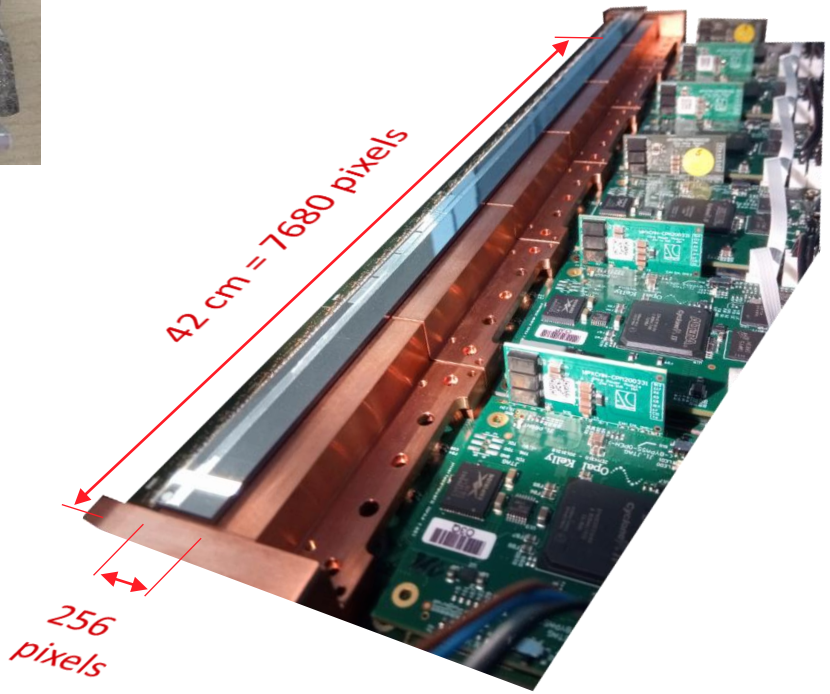
Zinc and lead content to be visualized in ore samples:



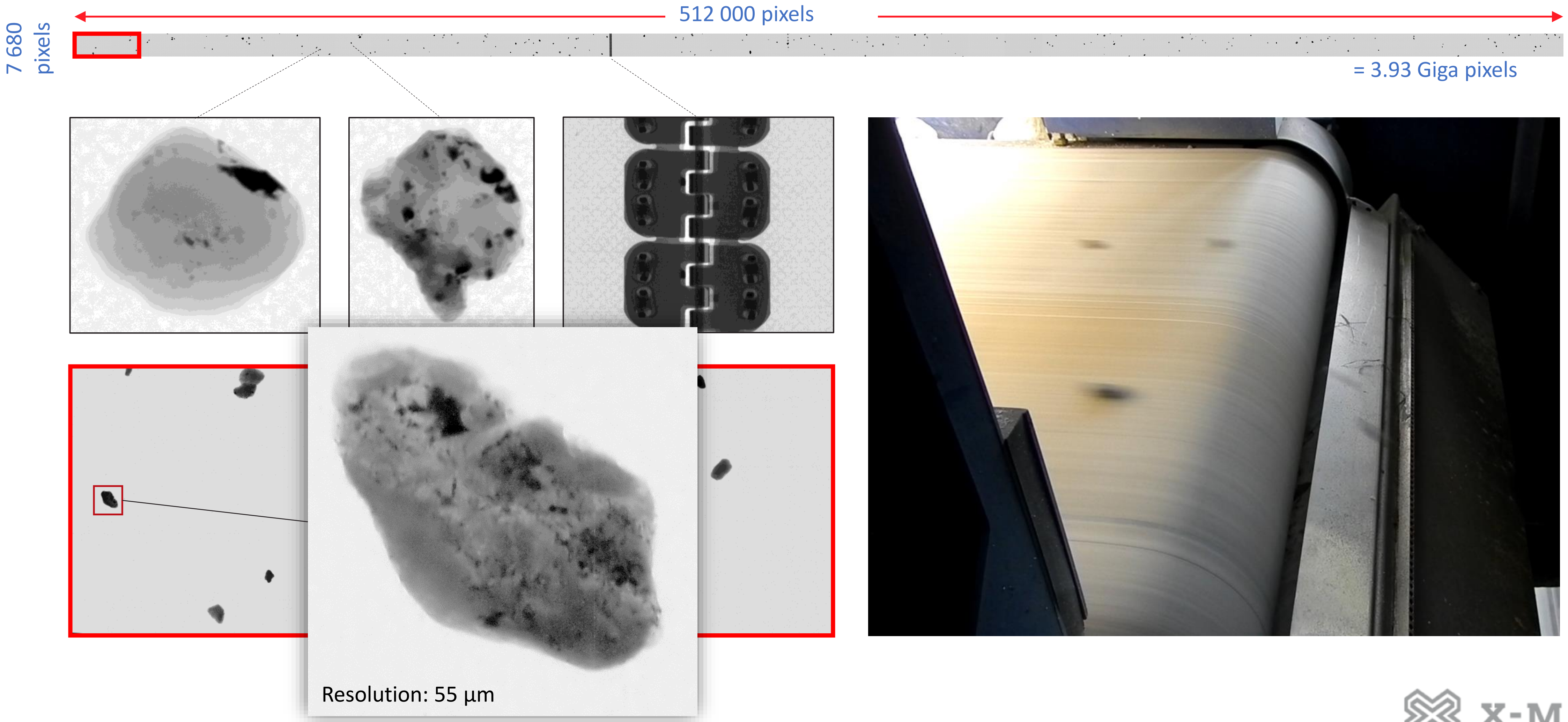




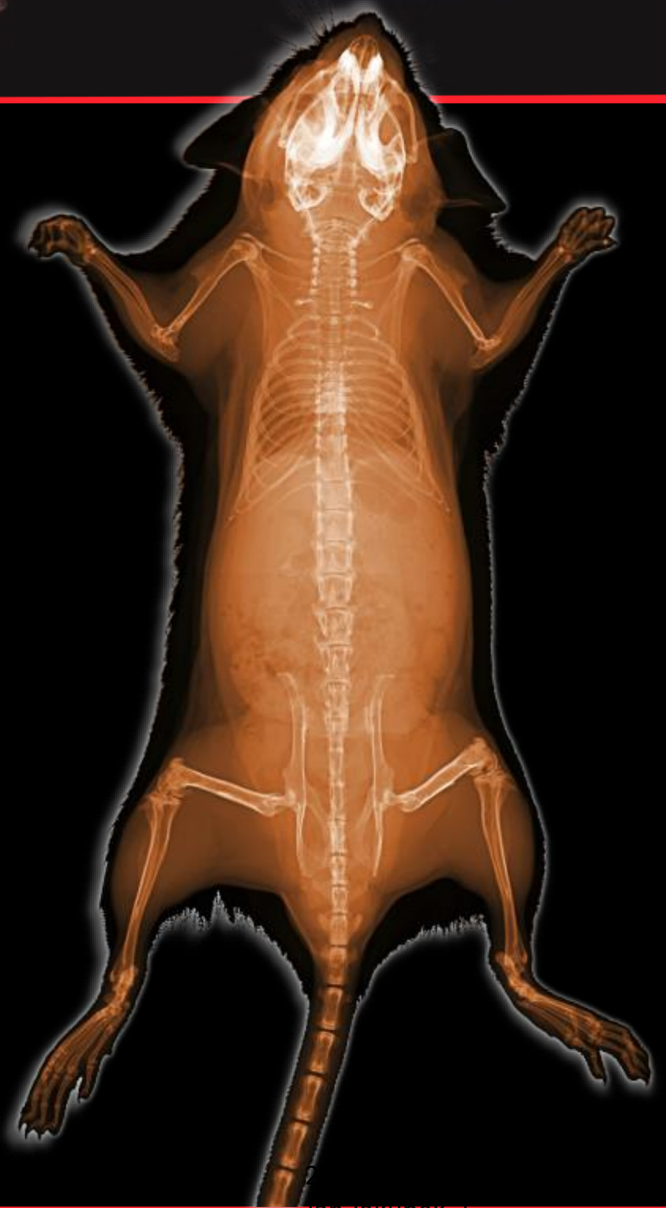
Mineral sorting for mining industry: Fast and long detector for conveyor belts …

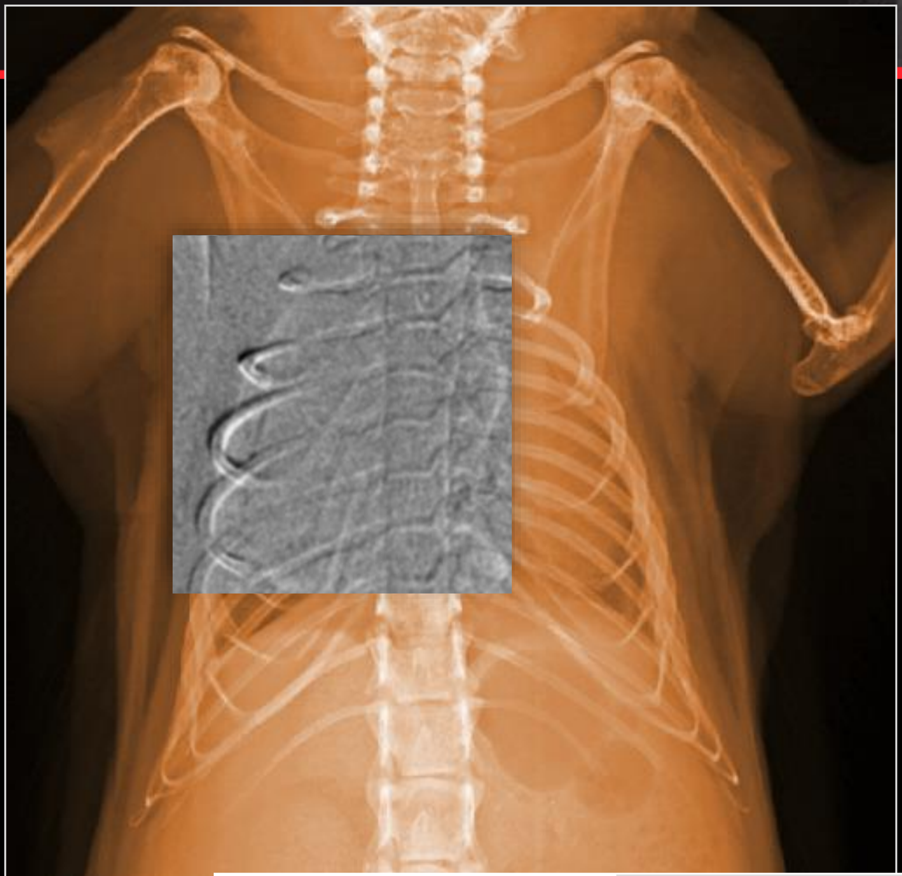


Continuous fast scanning:
12 m^2 in 10 seconds shown here



Mouse Heartbeat …

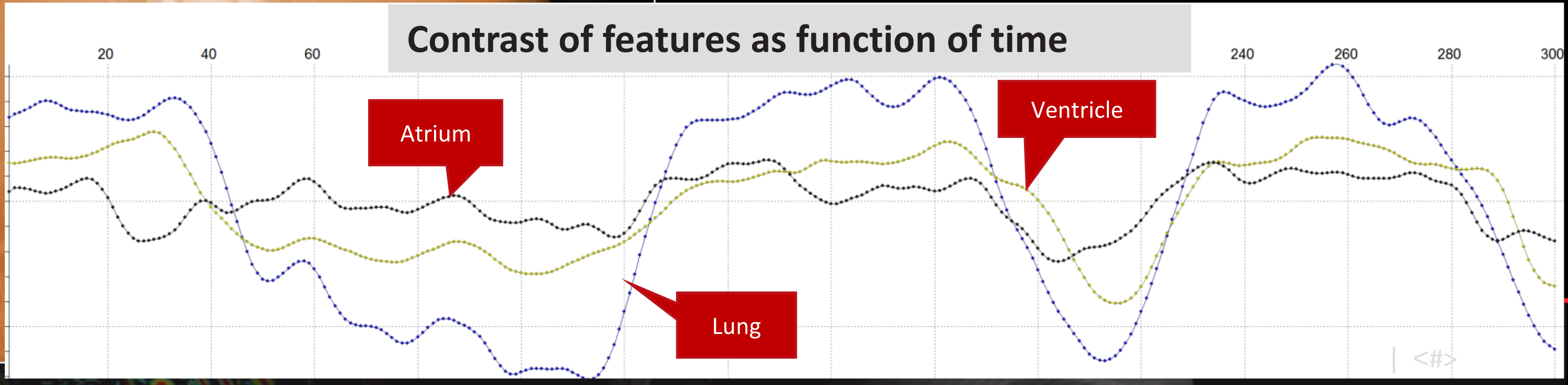




Mouse heartbeat: 670 bpm

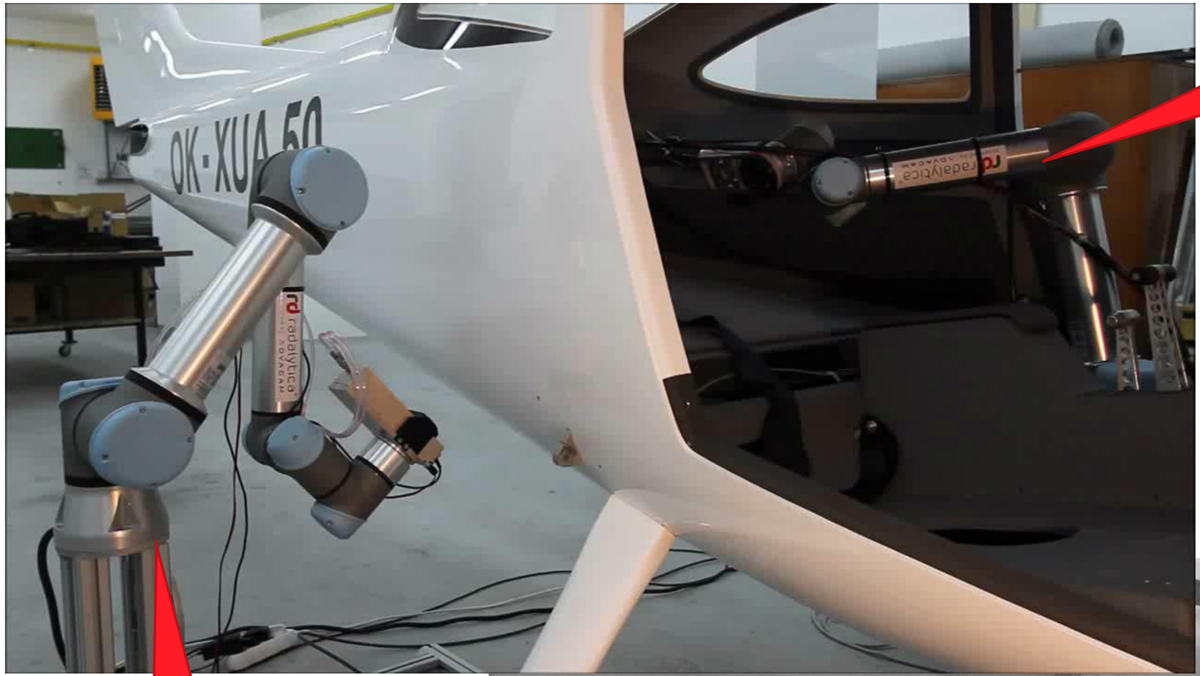
=> 1000 frames per second

Contrast evolution
corresponds to
blood transfers



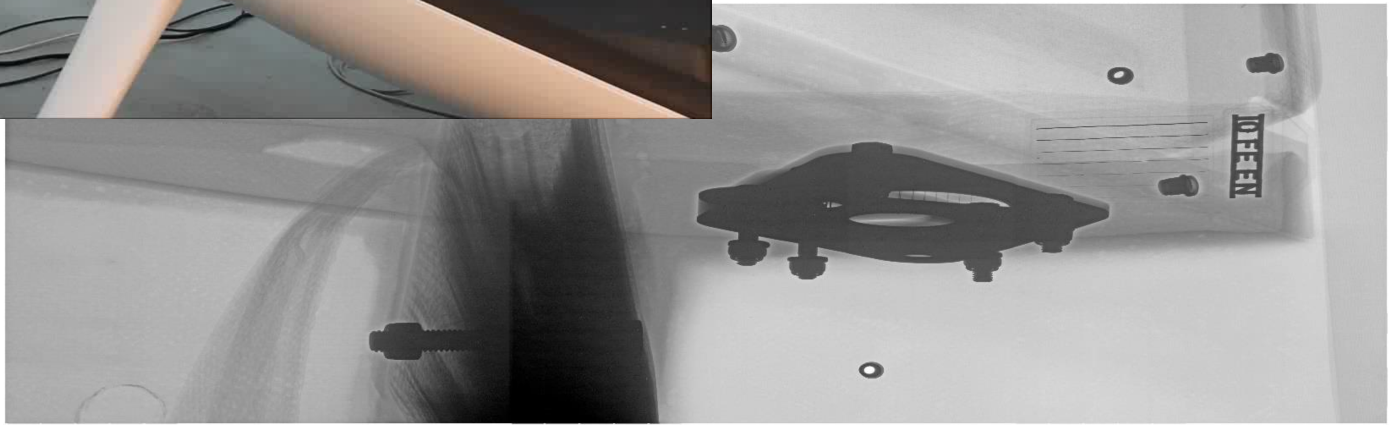
Easy to integrate: Robotic CT

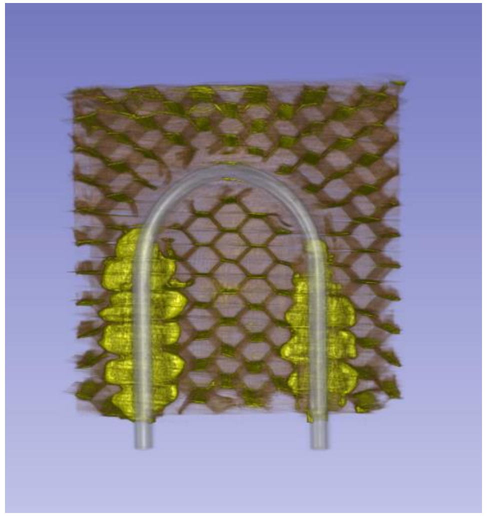
To be checked:
Bottom part of fuselage of ultralight plane



Robot with X-ray trube

Robot with detector





Authentication of art

ADVACAM
Imaging the Unseen

Signed
Vincent van Gogh

La Crau with Montmajour in the backgroud

~1888

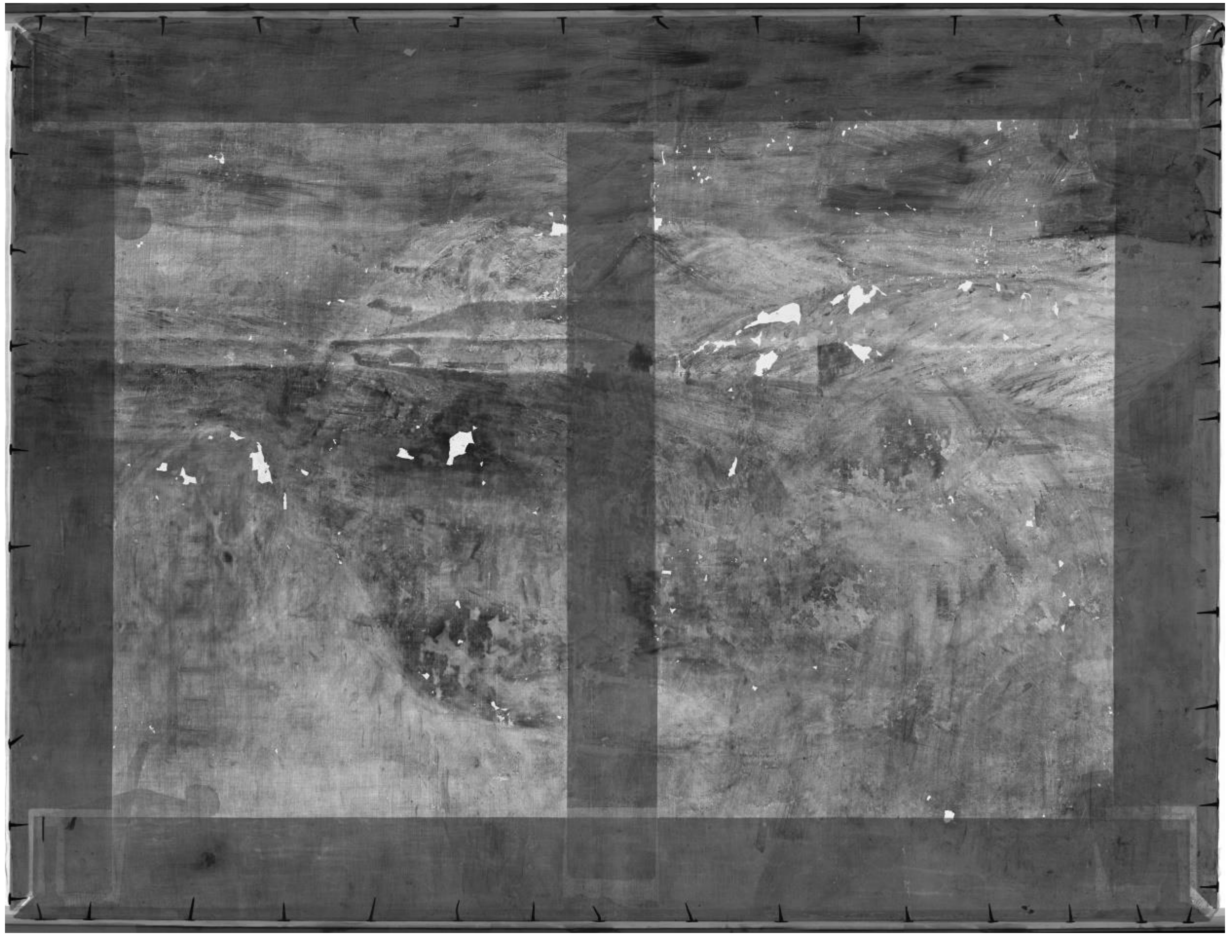
Authentication of art

ADVACAM
Imaging the Unseen

Signed
Vincent van Gogh

La Crau with Montmajour in the backgroud

~1888



Standard X-ray image

Authentication of art

Signed
Vincent van Gogh

La Crau with Montmajour in the backgroud

~1888

Multichannel (14 channels)

Mixed to RGB

Authentication of art

Signed
Vincent van Gogh

La Crau with Montmajour in the backgroud

~1888

Subtracting pigments seen on the surface

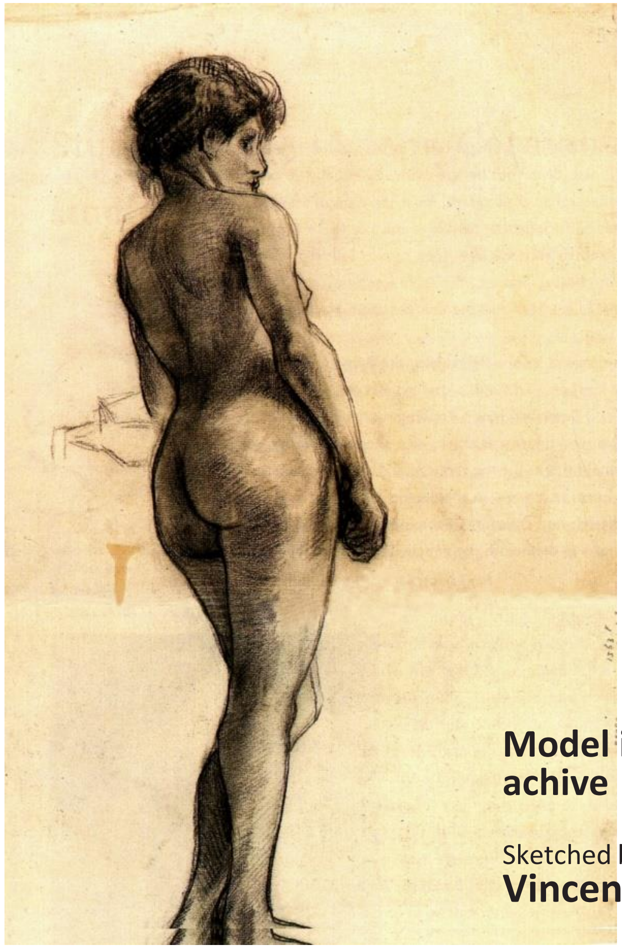
=> Underpaint

Autentication of art

Signed
Vincent van Gogh

La Crau with Montmajour in the backgroud

~1888



Model identified in Louvre achive

Sketched by
Vincent van Gogh

Fully spectral imaging

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> Full spectrum can be measured by every pixel

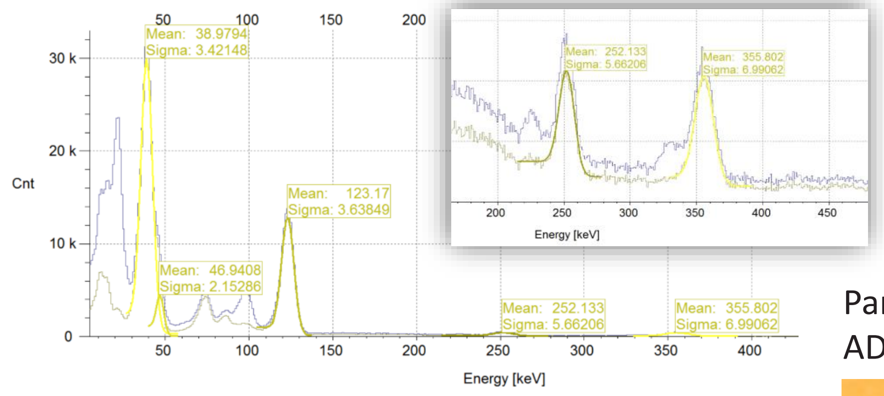
Timepix3 (and new Timepix4):

- **Event based readout** (Not frame based as for Timepix): Each hit pixel transmits the hit information immediately.

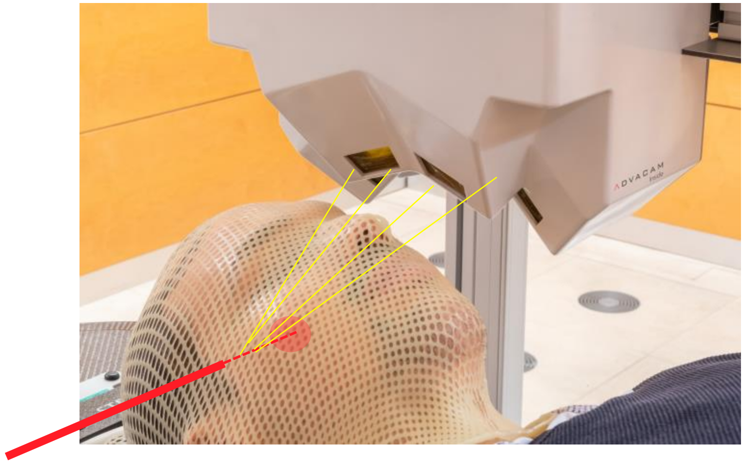
⇒ No dead-time for readout of complete frame.

- **Each pixel measures Energy and Time** of arrival concurrently.
- Time is measured with precision of 1.56 ns (or ~130 ps)
- Chip can produce data stream of 5 Gbit/s (or 160 Gbit/s).

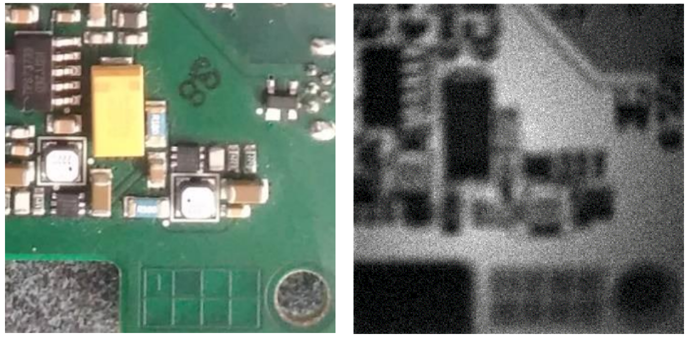
Eu-152 (Bias=500 V)



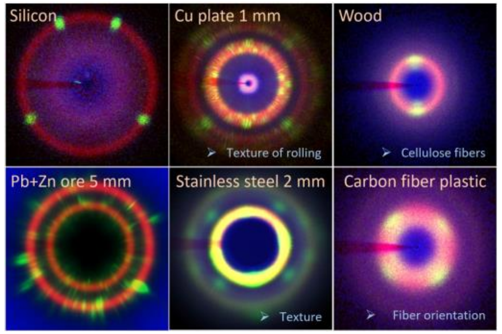
Particle tracker for hadron therapy by ADVACAM (28x Timepix3)



Example: X-ray fluorescence (XRF) imaging



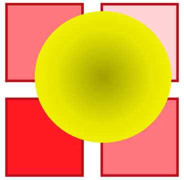
Example: Fast X-ray diffraction (XRD)



Deeply subpixel resolution

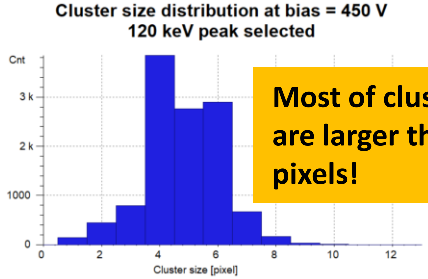
Principle:

1. Single photon is creates signal in several adjacent pixels => cluster
2. The energy is measured by each hit pixel
3. Position can be calculated with better precission

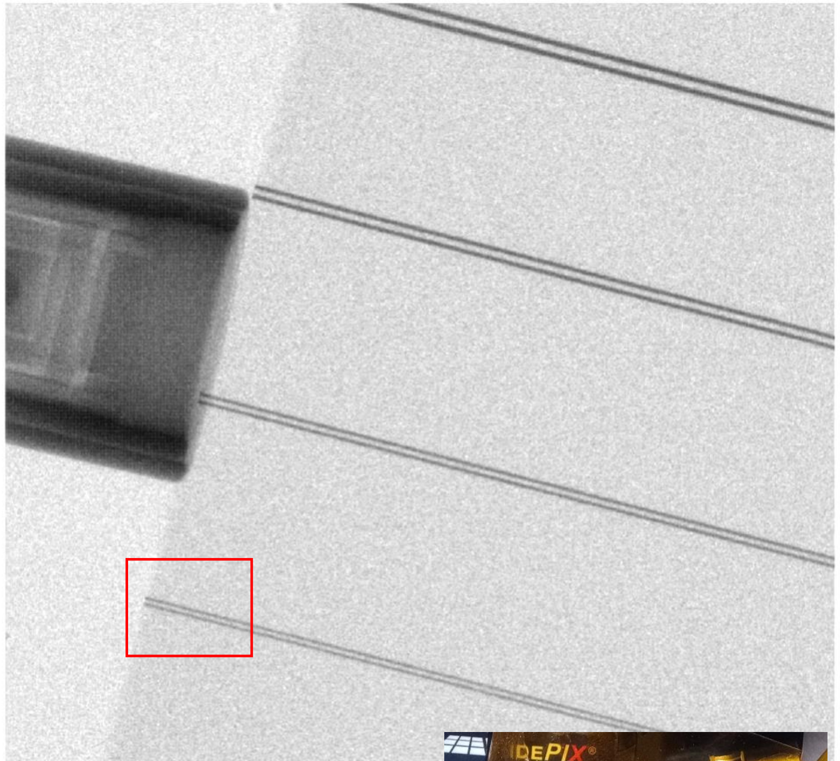


Real case:

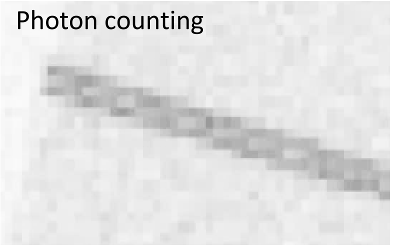
At 160 kVp trough **5 mm steel plate**
⇒ Effective energy is 100-120 keV
⇒ Average cluster of 5 pixels

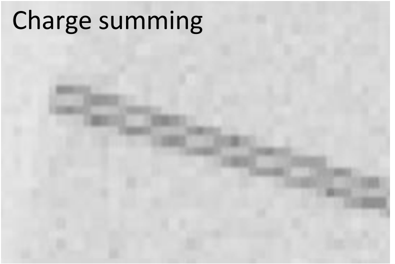


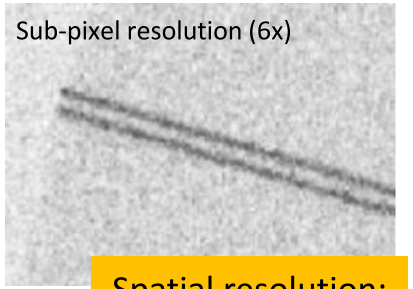
Most of clusters are larger than 3 pixels!



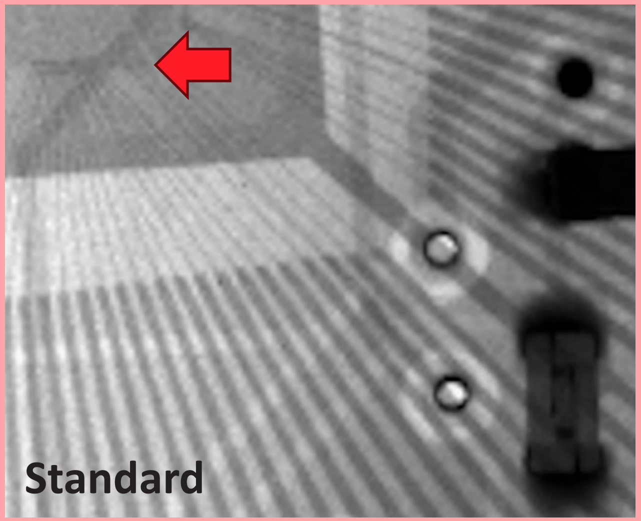
2.3 Mega pixels, pixel size 9.2 µm

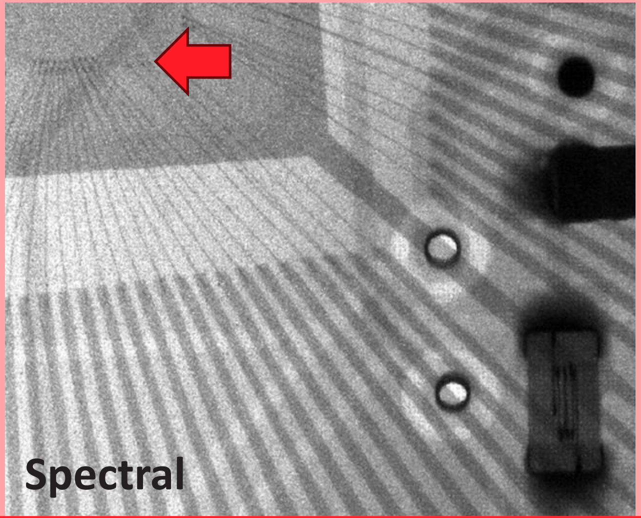






Spatial resolution:
9 µm (RMS)





Subpixel resolution test with the **Newest Duplex Image Quality Identifier**

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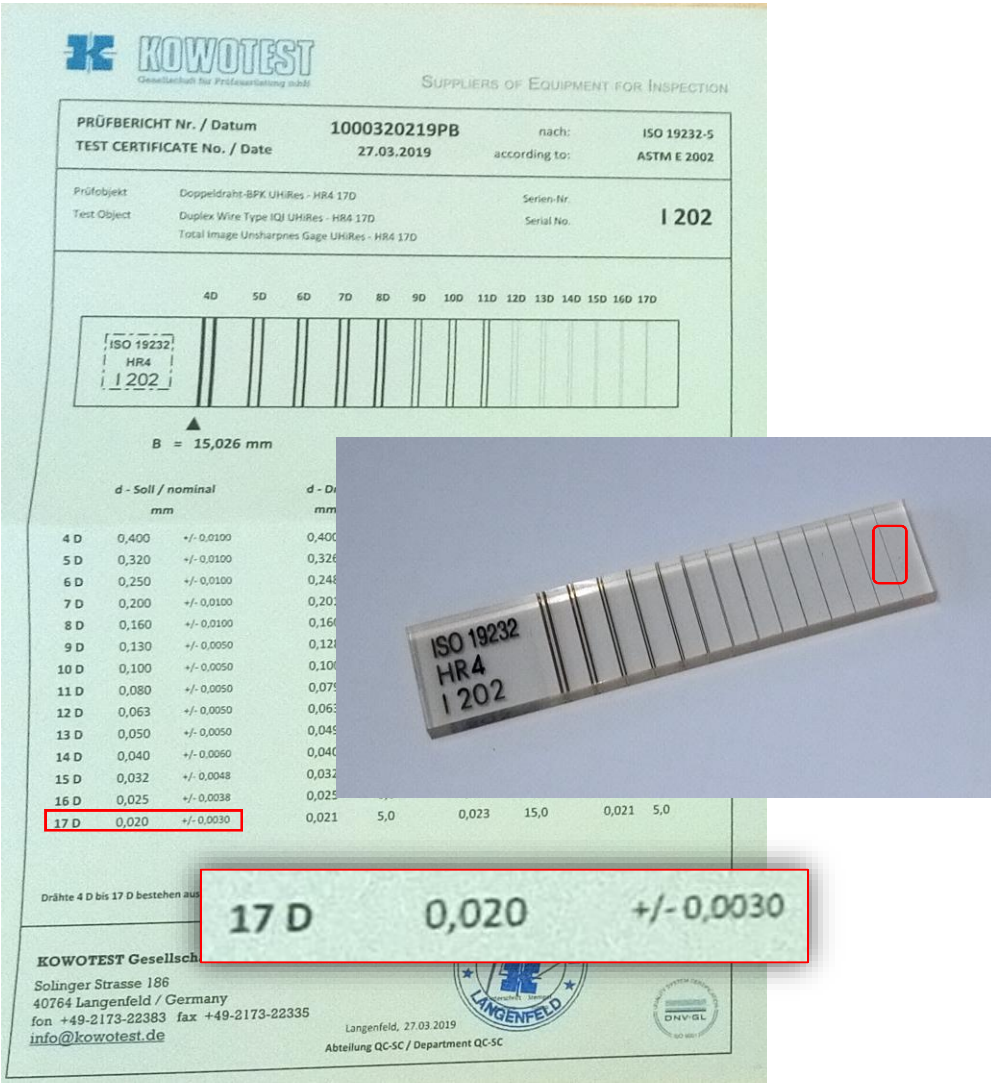


KOWOTEST
Gesellschaft für Prüfausrüstung mbH
SUPPLIERS OF EQUIPMENT FOR INSPECTION

PRÜFBERICHT Nr. / Datum
TEST CERTIFICATE No. / Date
1000320219PB
27.03.2019
nach:
according to:
ISO 19232-5
ASTM E 2002

Prüfobjekt
Test Object
Doppeldraht-BPK UHiRes - HR4 17D
Duplex Wire Type IQI UHiRes - HR4 17D
Total Image Unsharpnes Gage UHiRes - HR4 17D
Serien-Nr.
Serial No.
I 202

B = 15,026 mm

d - Soll / nominal mm			d - D… mm
4 D	0,400	+/- 0,0100	0,400
5 D	0,320	+/- 0,0100	0,320
6 D	0,250	+/- 0,0100	0,248
7 D	0,200	+/- 0,0100	0,201
8 D	0,160	+/- 0,0100	0,160
9 D	0,130	+/- 0,0050	0,128
10 D	0,100	+/- 0,0050	0,100
11 D	0,080	+/- 0,0050	0,079
12 D	0,063	+/- 0,0050	0,063
13 D	0,050	+/- 0,0050	0,049
14 D	0,040	+/- 0,0060	0,040
15 D	0,032	+/- 0,0048	0,032
16 D	0,025	+/- 0,0038	0,025
17 D	0,020	+/- 0,0030	0,021 5,0 0,023 15,0 0,021 5,0

Drähte 4 D bis 17 D bestehen aus

17 D 0,020 +/- 0,0030

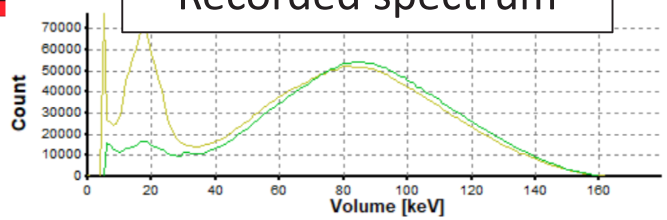
KOWOTEST Gesellsch…
Solinger Strasse 186
40764 Langenfeld / Germany
fon +49-2173-22383 fax +49-2173-22335
info@kowotest.de

Langenfeld, 27.03.2019
Abteilung QC-SC / Department QC-SC

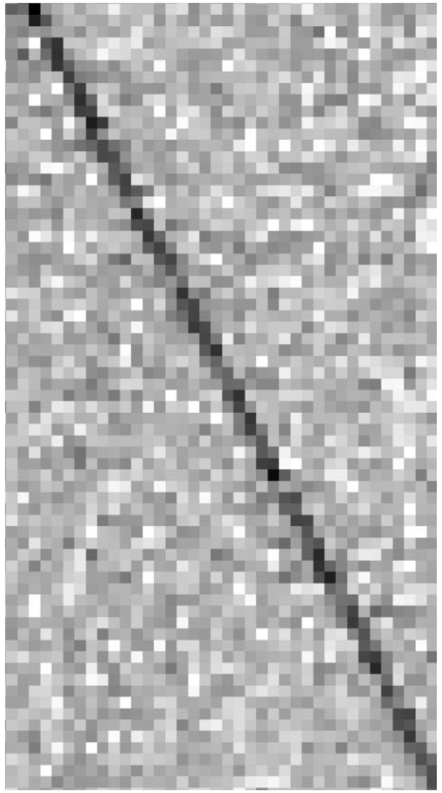
Conditions:

160 kVp, 0.5 mA,
Through 5 mm Fe plate,
100 s exposure

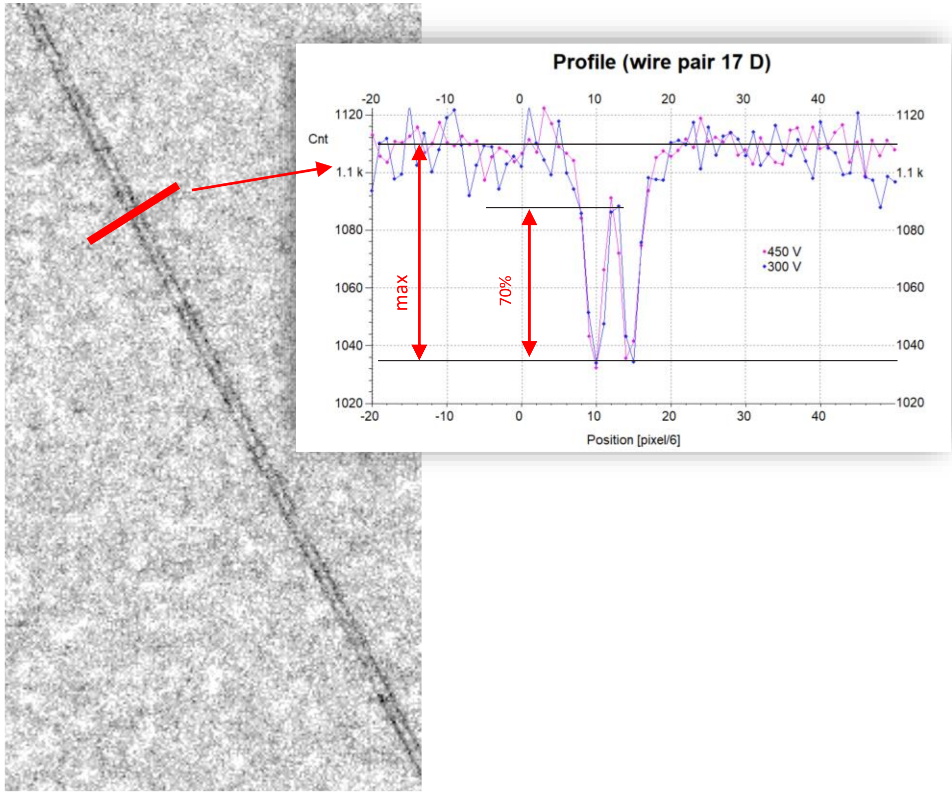
Recorded spectrum



Photon counting



Subpixel 6x (9 µm):



Gamma camera
Visualization of radioactive sources

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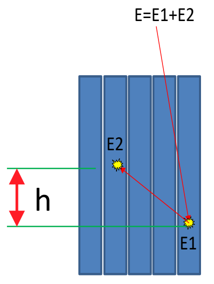
Imaging the Unseen

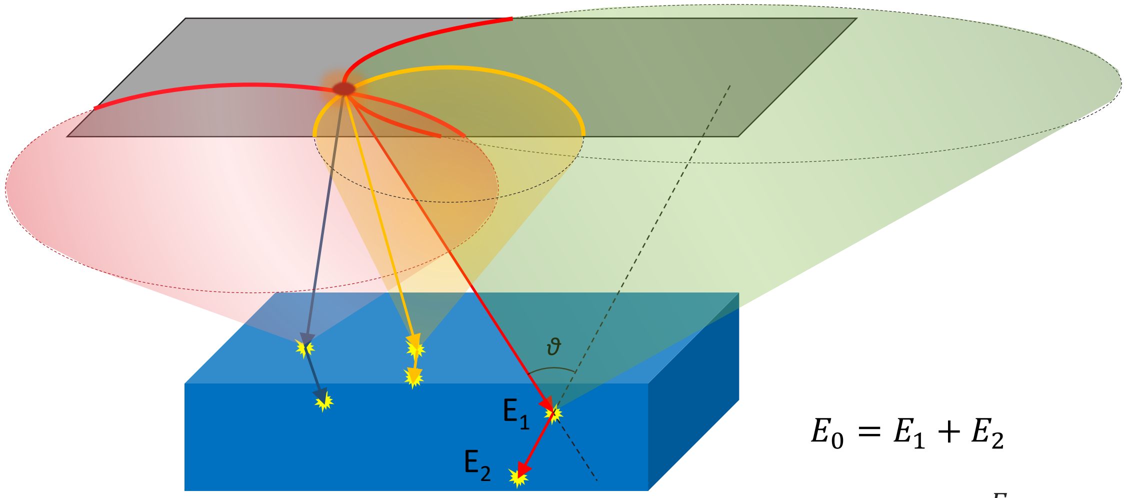
Based on Compton scattering in the sensor

For each Compton scattering event we can:
- Detect coincidence
- Measure both energies: E_1 and E_2
- Measure both positions in 3D

=> We can reconstruct Compton cone:



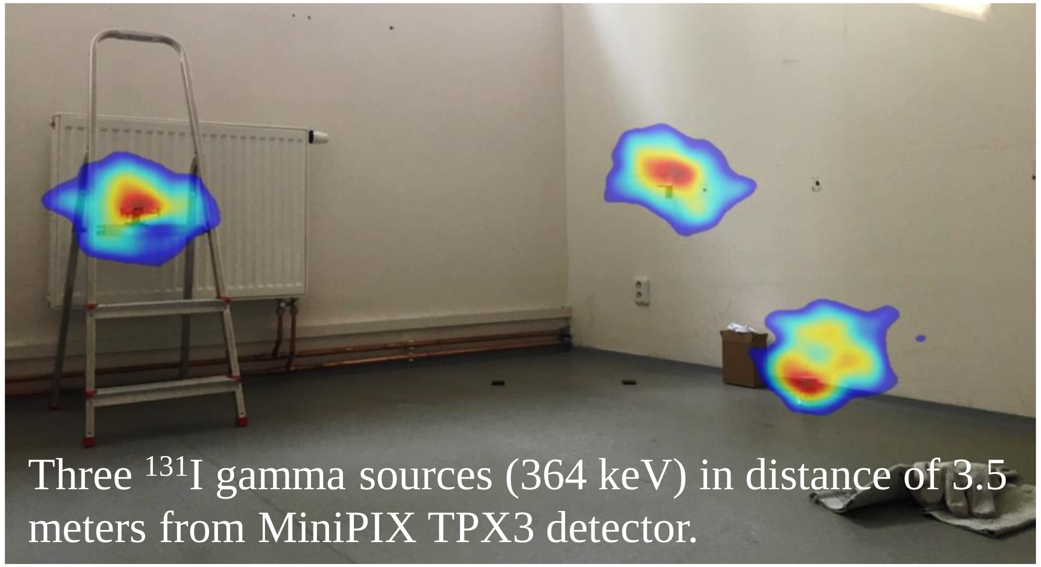
Compton scattering

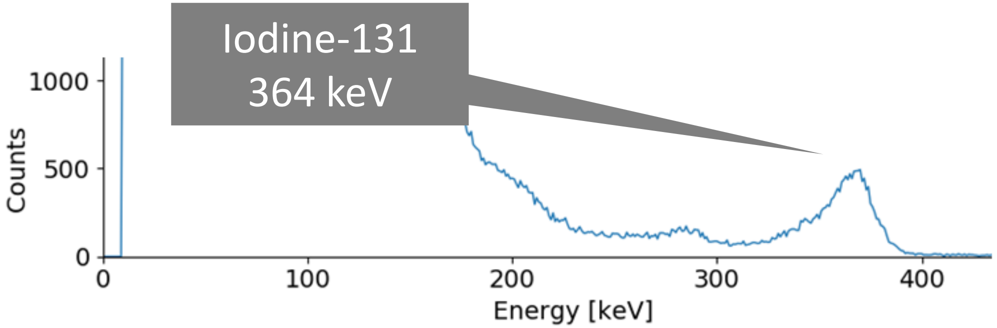


Timepix3 CdTe detector

$$E_0 = E_1 + E_2$$

$$\cos\theta = 1 - m_e c^2 \frac{E_1}{E_2(E_1 + E_2)}$$

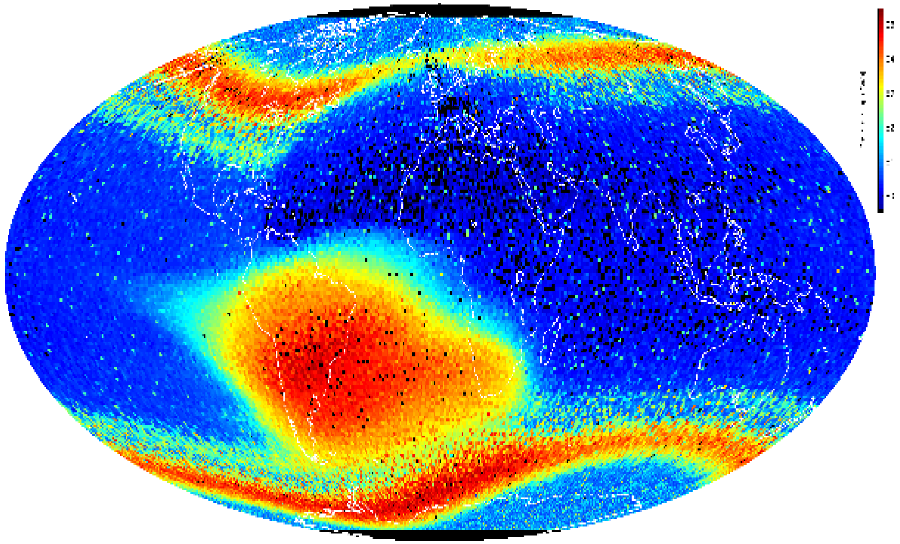

Three ^{131}I gamma sources (364 keV) in distance of 3.5 meters from MiniPIX TPX3 detector.

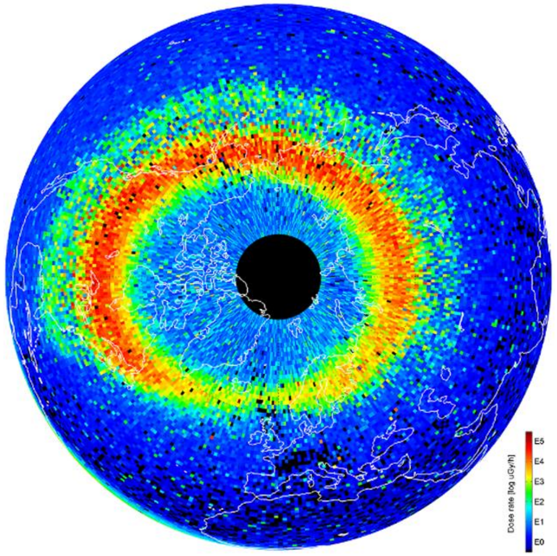


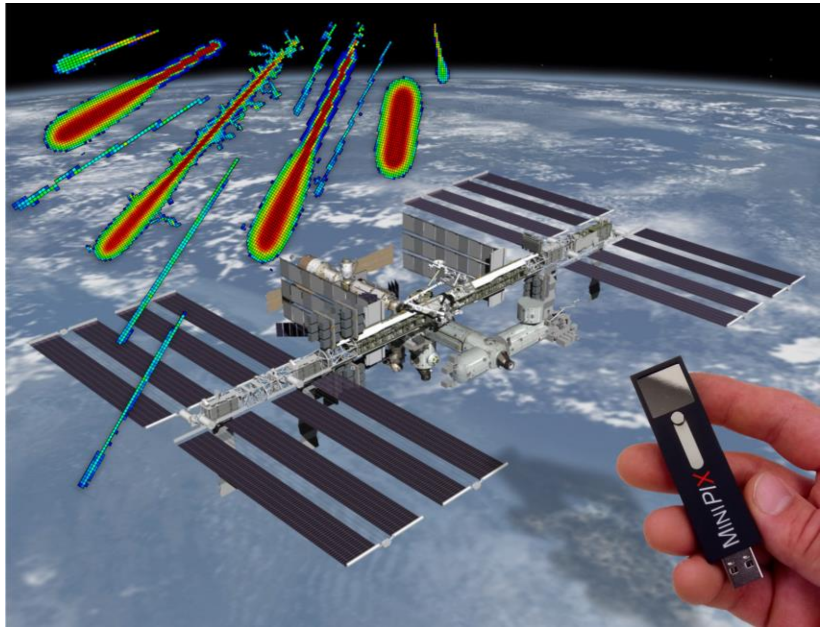
… the original purpose is still there

The largest object imaged by our technology (in 3D)

Using smallest detector we do:







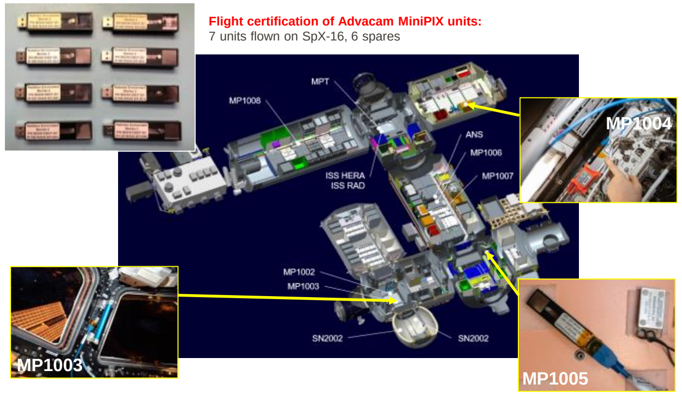


Image of so-called space weather: Charged particles directed by magnetic field of earth.
Recorder by our detectors orbiting earth on board of ISS.

MiniPIX EDU in classrooms
Simplified version of detectors used in space

ADVACAM Imaging the Unseen

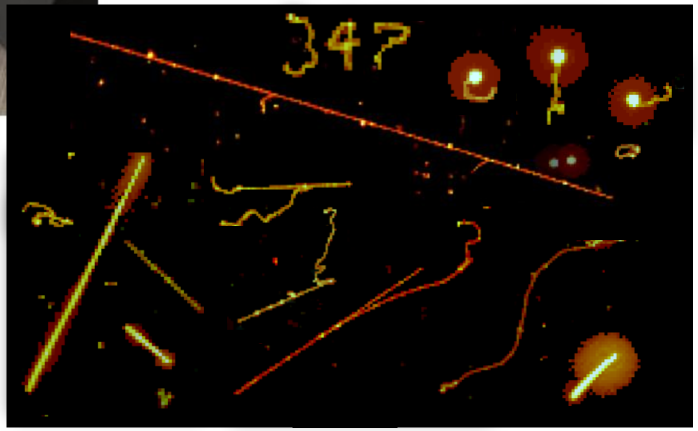
MiniPIX EDU for Education, physics teaching and basic radiation experiments.

Based on earlier projects: of IEAP CTU and CERN such as "CERN technology in schools" by Becky Parker.

Many processes can be directly observed in normal environment of common classroom.

No accelerator is needed to watch principles of particle physics!

It is small …
… and less expensive.



Example: Inhaled radioactivity

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Imaging the Unseen

Did you know that even simple face mask used against CORONA virus significantly reduce the amount of inhaled radioactivity?

Use the MiniPIX detector

1. Measure Fresh mask

2. Use it for 5 min

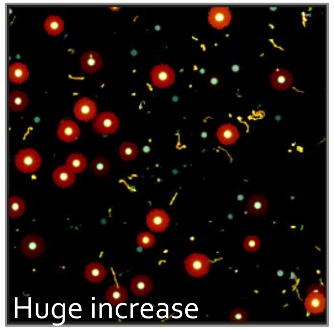
3. Measure Used mask

Why?

- Radon decay products are ionized.
- They stick to dust and aerosols.
- Mask filters them out greatly.
- **Exhaled air is filtered in lungs!!!**

Fresh mask

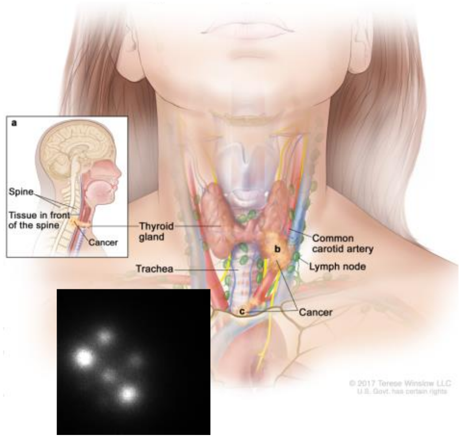
Used mask

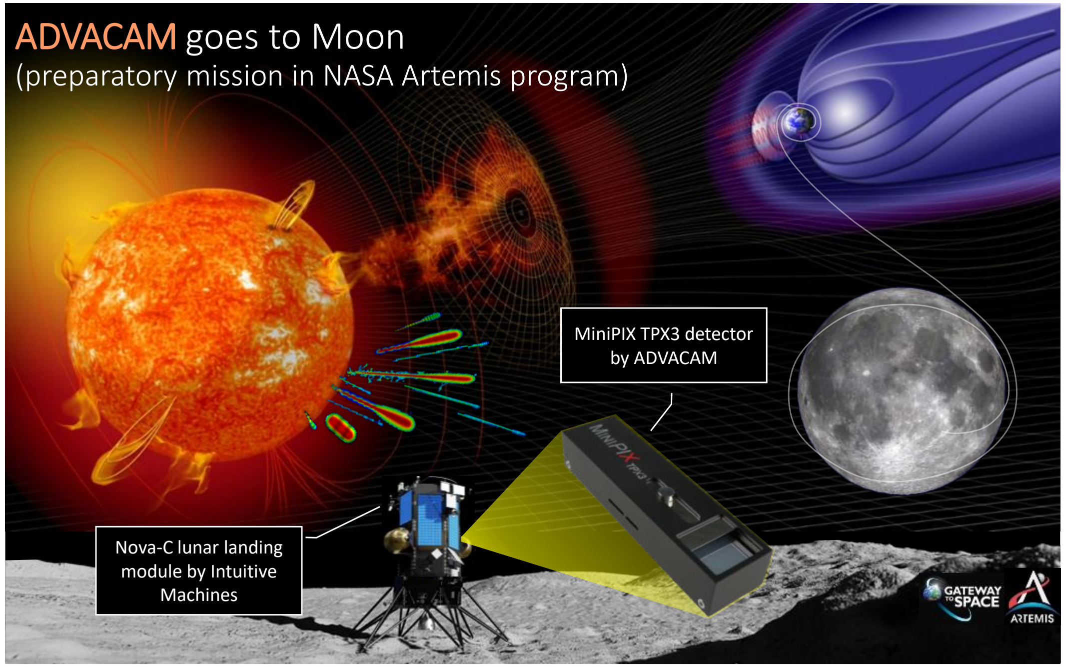


Exhaling only

… and much more

- **Photon counting imaging technology is applied in many other fields:**
  - Nondestructive testing
  - Electron microscopy
  - X-ray diffraction
  - Medical
  - Radio therapy
  - Space
  - Science





- **Future:**
  - Exploitation of excellent time resolution ~100 ps => solid state Lidars …
  - **Extent sensitivity range** through the XUV, UV, Visible **down to Near Infra Red** (partners?) => Lasers
  - Implement track processing into the chip

Thank you for attention