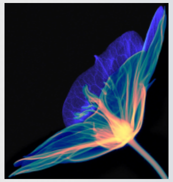
Advanced Radiation Dosimetry European Network Training

Mittuniversitetet

MID SWEDEN UNIVERSITY

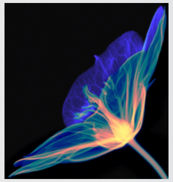


MEDIPIX: COLLABORATION AND DETECTORS

Erik Fröjdh, CERN

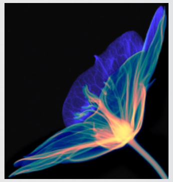
Geneva, Switzerland

R. Ballabriga, J. Alozy, M. Campbell, M. De Gaspari, E.H.M. Heijne, X. Llopart, T. Poikela, L.Tlustos, P. Valerio, W.Wong, D.Krapohl, S. Procz, M. Fiederle, S. Pospisil, J. Jakubek, V. O'Shea, Kenway Smith, Dzmitry Maneuski, Jan Visser, A. Bulter, J. Marchal, I.Horswell, H. Graafsma, E. Hamann, Z. Vykydal, J. Visschers, S. Vahanen, N. Tartoni, C. Ponchut, R. Plackett, S. Petterson, B. Norlin, J. Jungman, T. Koenig, C. Frojdh, N. Andersson, D. Pennicard, G. Anton, P. Butler…



Outline

- A few words about CERN
- Hybrid Pixel Detectors
- Medipix Collaboration
  - Designed chips
- Applications
  - ”Color” X-ray Imaging
  - Mixed Field Dosimetry



CERN

The world's largest particle physics research laboratory

An international effort of:

- 20 European Member States
- 7 Observer or Acceding States
- 28 Non-Member States involved in particular projects

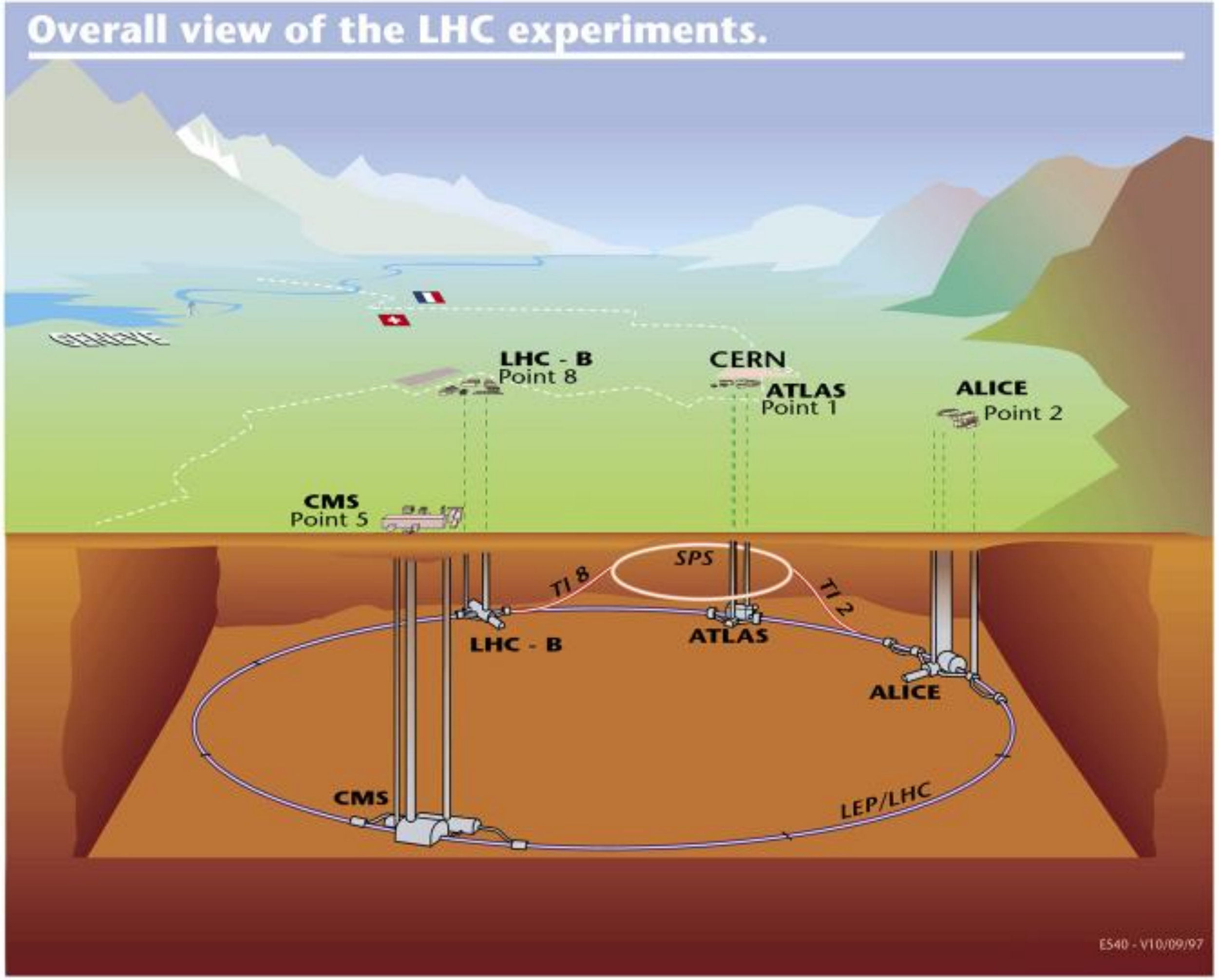
~ 2 400 staff members (75% are applied physicists, engineers and technicians)

~ 11 500 users from all over the world (mostly physicists)

Annual budget ~ USD 1 000 000 000

An aerial view of CERN and the Large Hadron Collider Accelerator Complex

The Large Hadron Collider



Two counter rotating proton beams on 27km circumference ring

Particle bunch crossings 40 M times per second

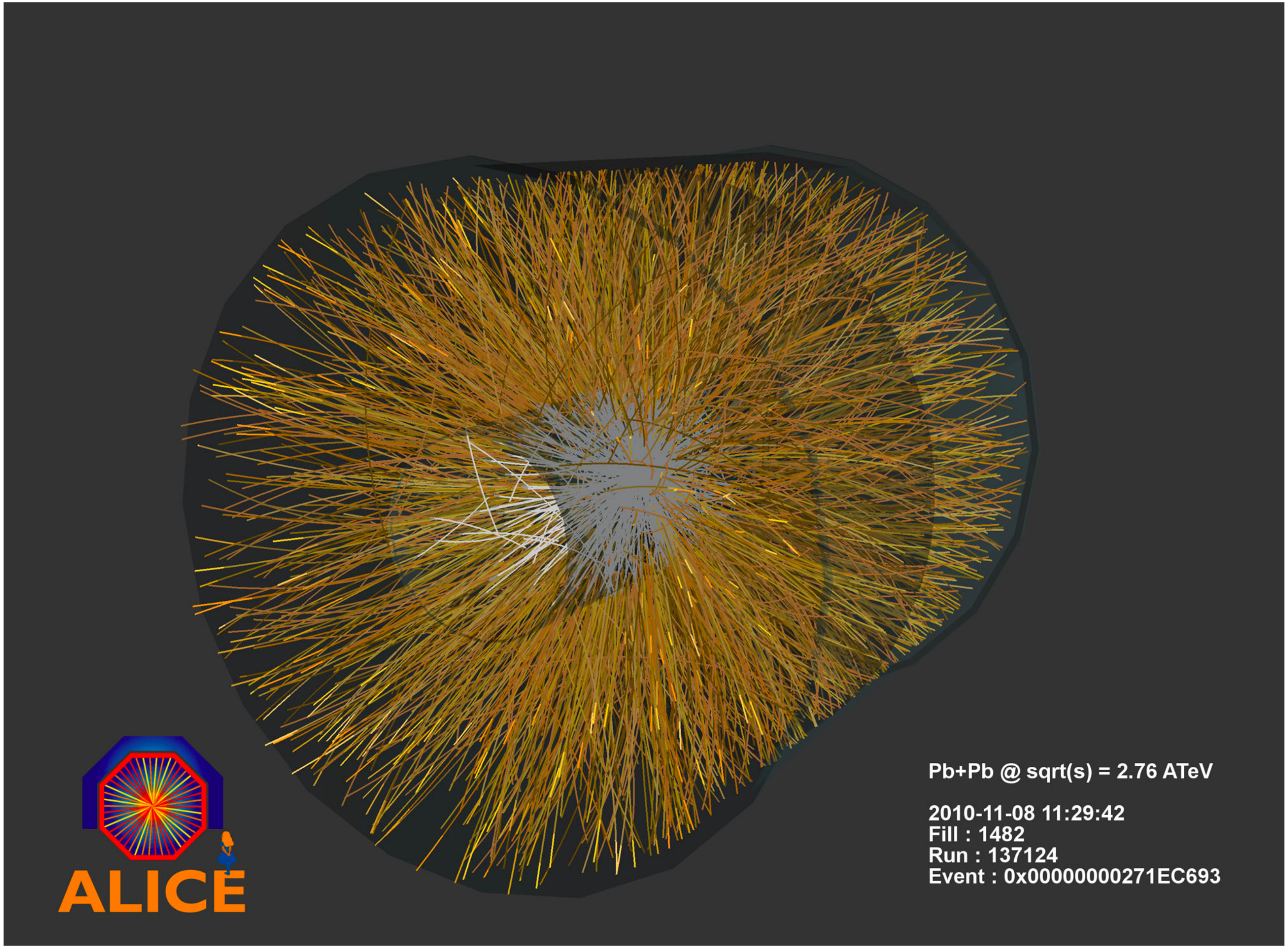
100 billion particles in each bunch

Several 1 000 particles created per bunch crossing

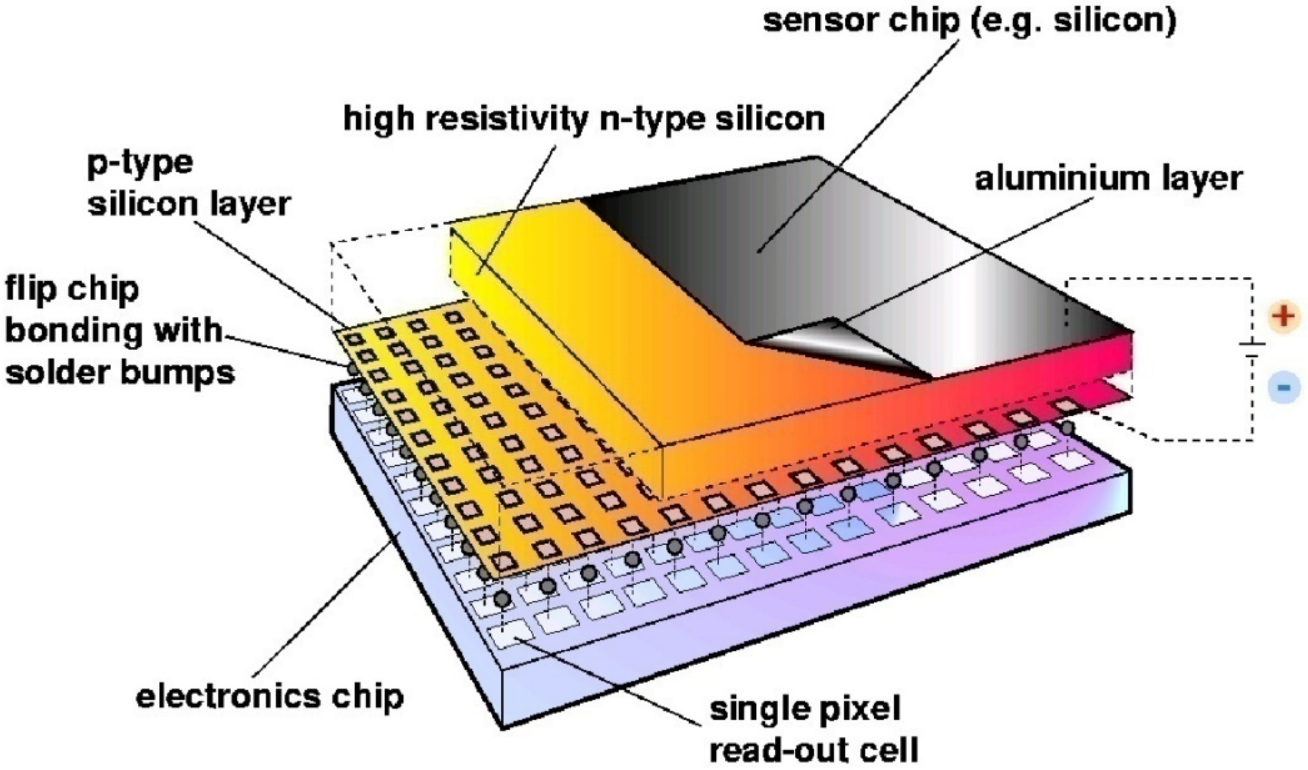
7 TeV on 7 TeV Collisions

Entire magnet ring cooled to 1.8K

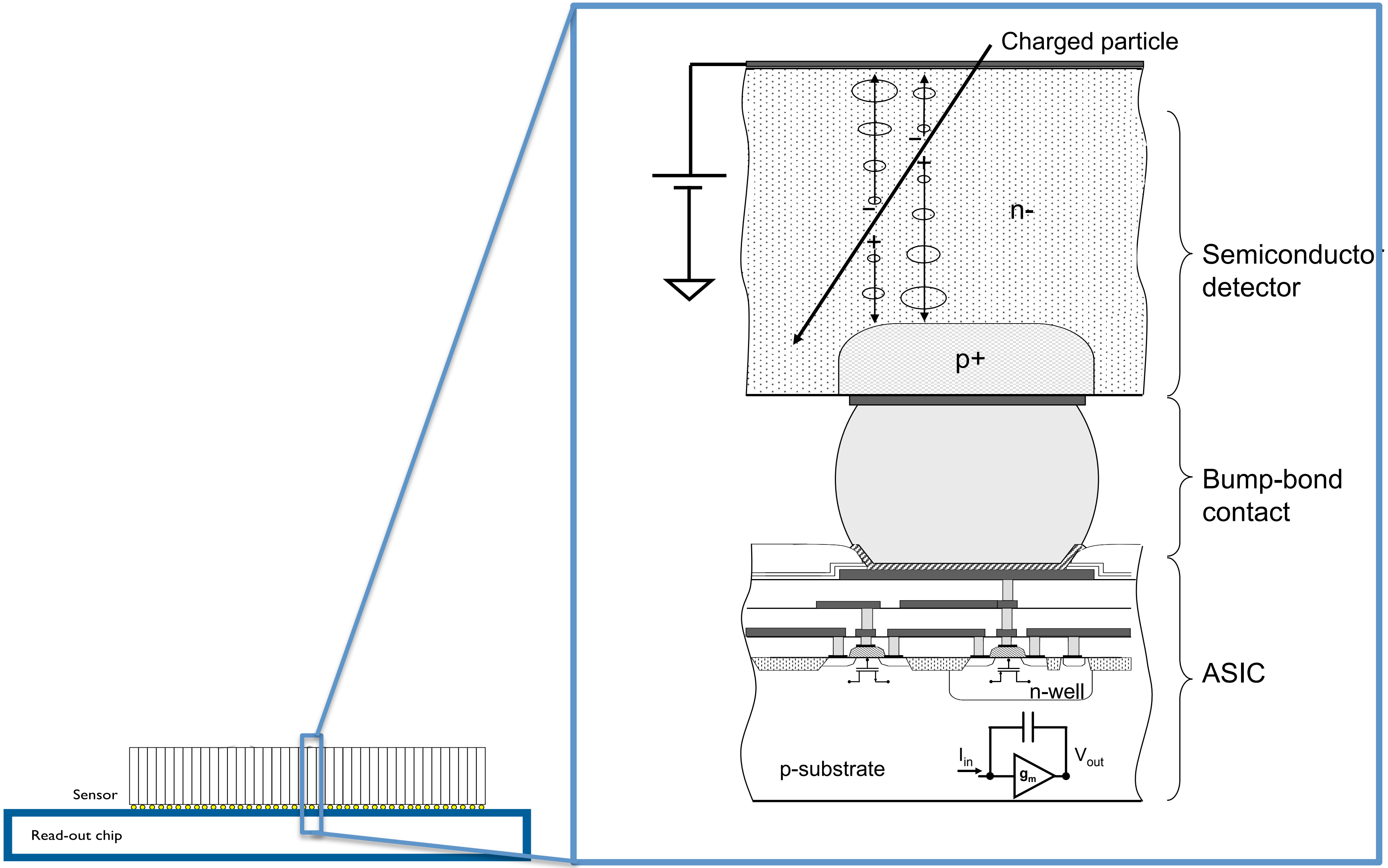
Lead Ion Collision ALICE



Hybrid Pixel Detectors

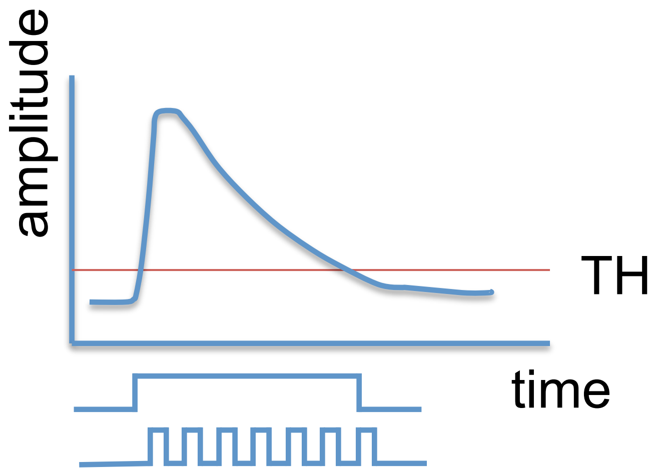


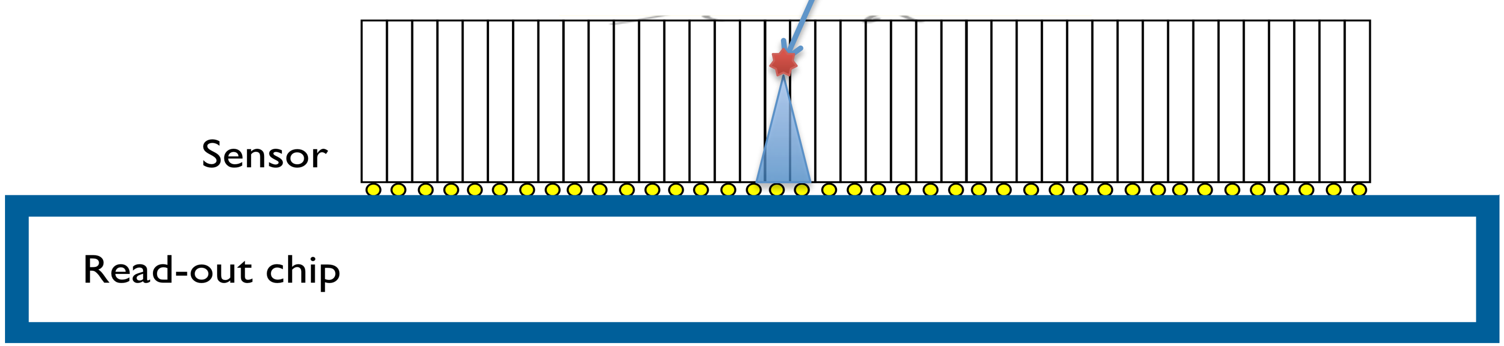
Hybrid Pixel Detectors



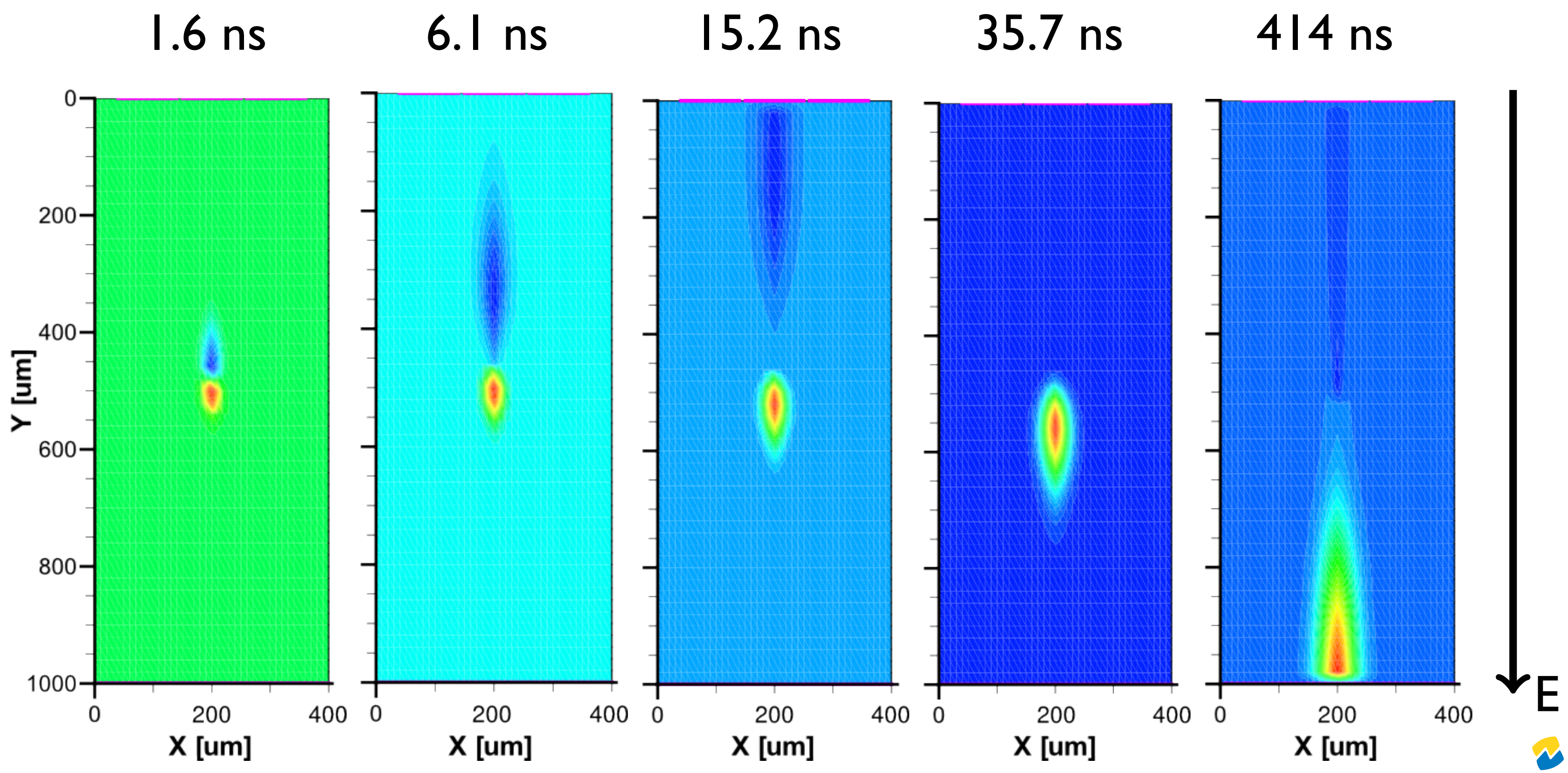
Signal Formation

- Moving charge induces a signal on the read out pad
- Pulse height is proportional to the deposited energy
- In order to detect a particle it has to interact with the sensor material and create electron-hole pairs



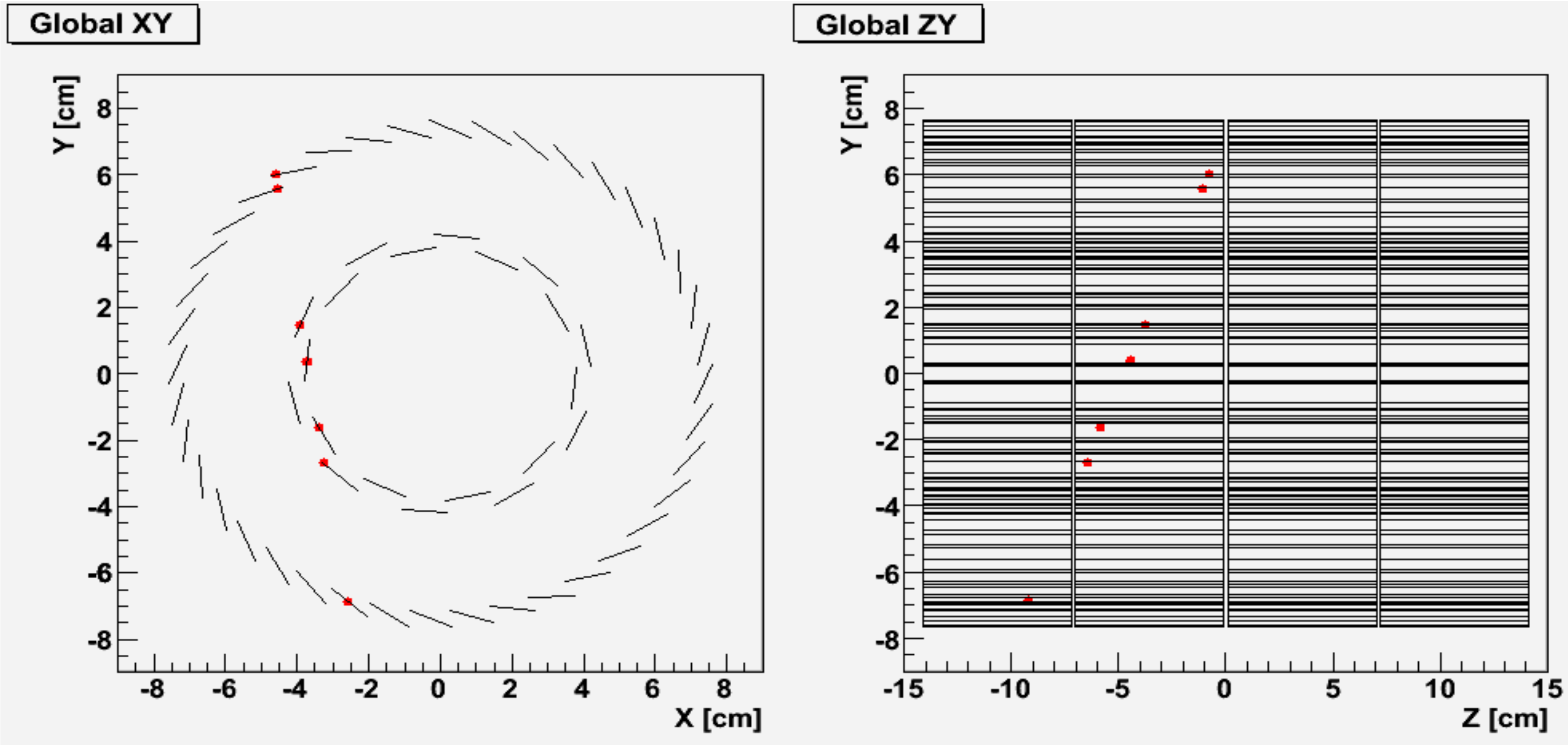


Charge carrier simulation CdTe



By David Krapohl, Mid Sweden University

Cosmic Particles in the Alice Experiment



Can this be used for something else?

- The idea of using the single photon counting principle with hybrid pixel detectors for X-ray imaging dated back to late 80s
- The Medipix collaboration was formed to use the knowledge gained in the design and fabrication of hybrid pixel detectors to make a single photon counting system for X-ray radiography.
- Initial partners of the collaboration were CERN, the University of Freiburg (Germany), the University of Glasgow (Scotland) and the INFN of Pisa and Napoli

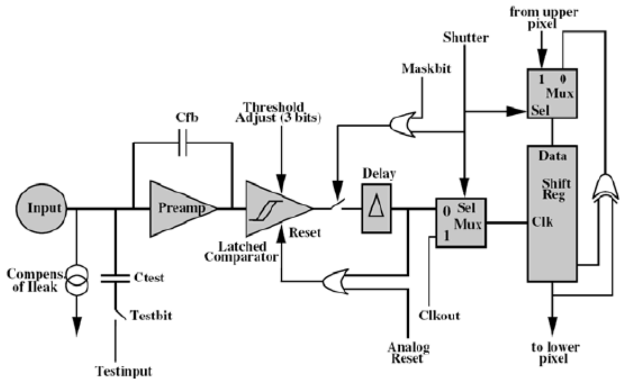
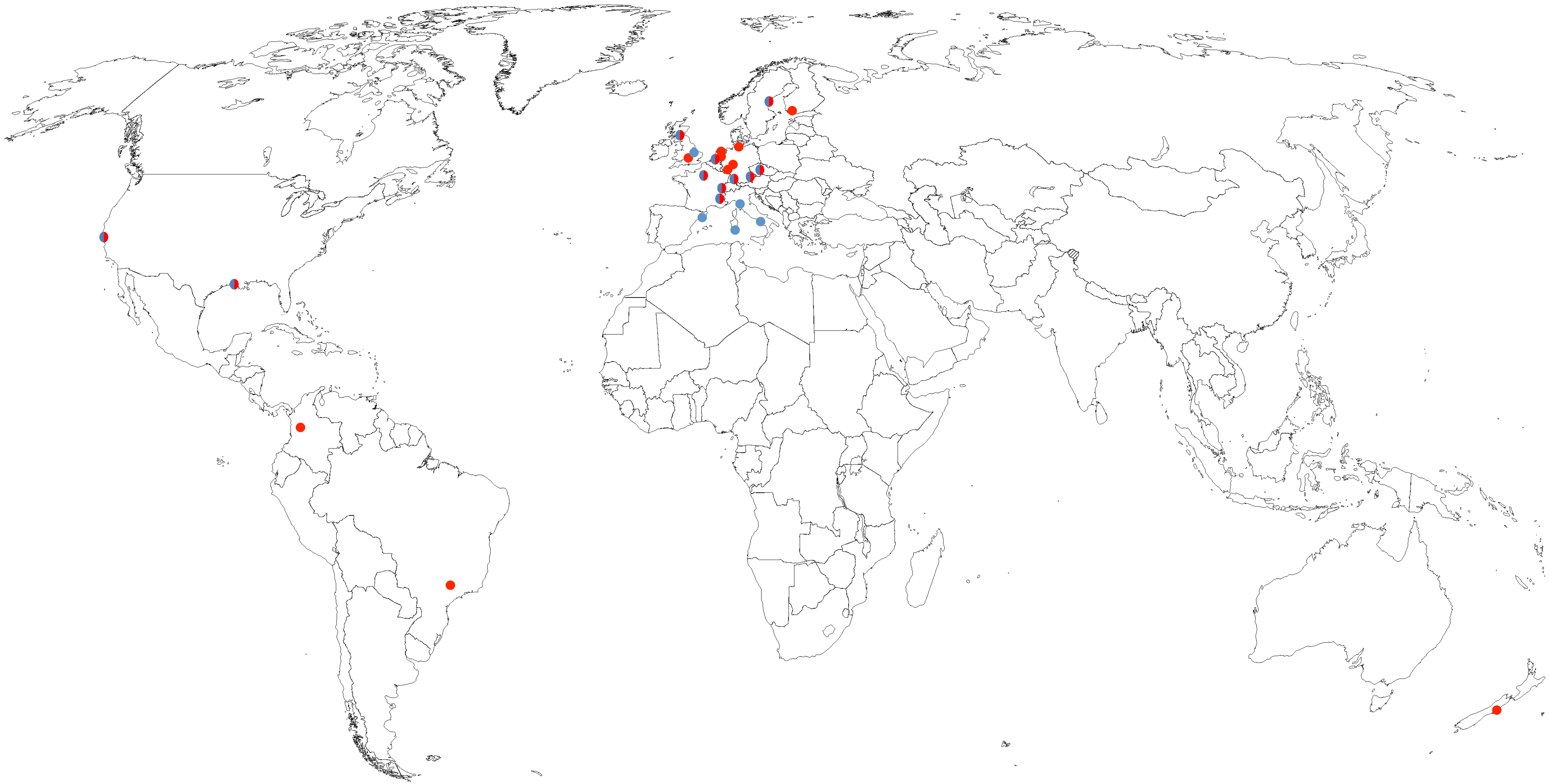


Figure 1.7. The Medipix1 pixel cell schematic.

Medipix 2 and 3 Collaboration



- Medipix2 collaboration member
- Medipix3 collaboration member
- Medipix2 and 3 collaboration member

www.cern.ch/medipix

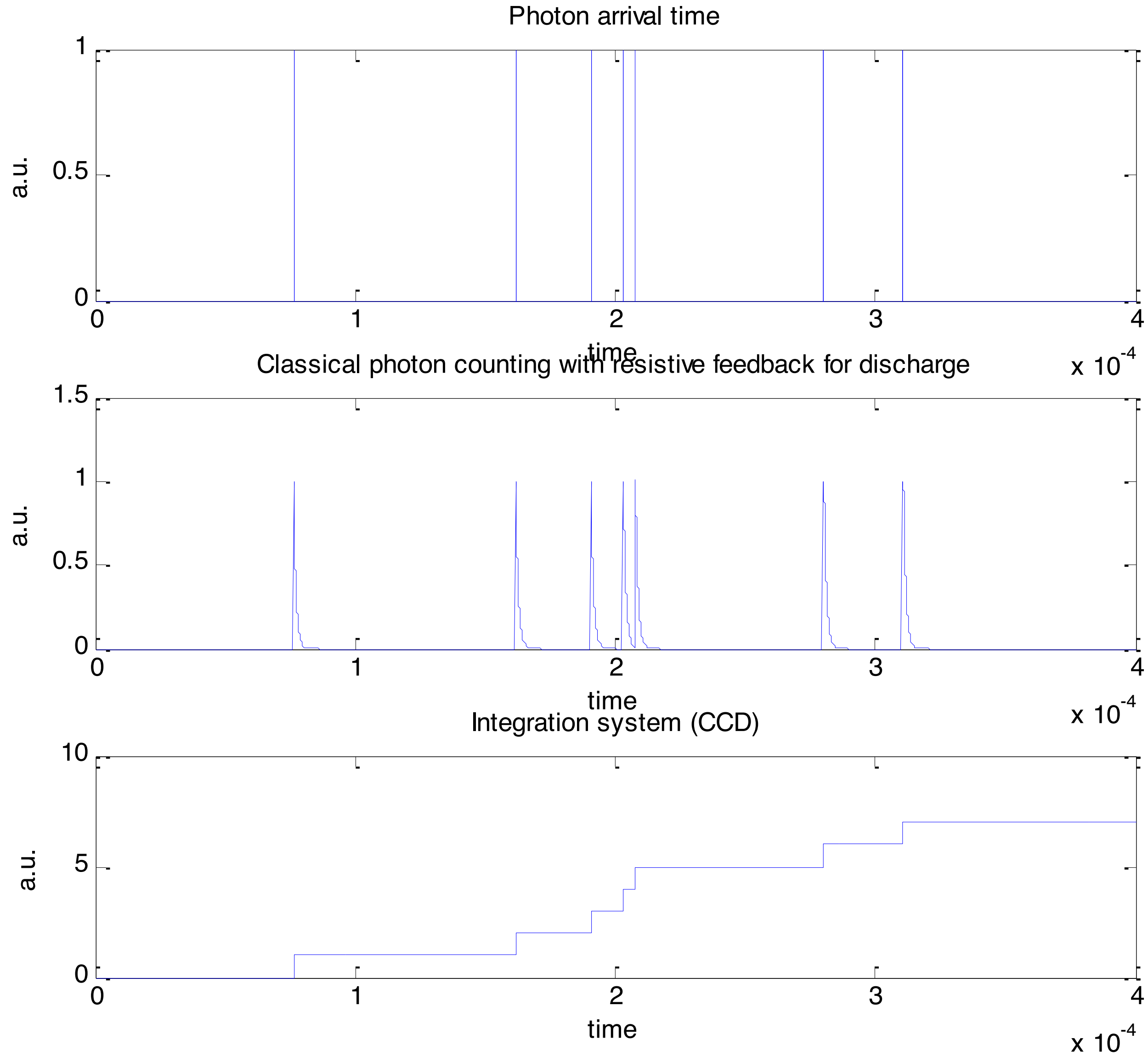
The Medipix2 Collaboration

Institut de Fisca d'Altes Energies, Barcelona, Spain
University of Cagliari and INFN Section thereof, Italy
CEA, Paris, France
CERN, Geneva, Switzerland,
Universitat Freiburg, Freiburg, Germany,
University of Glasgow, Scotland, UK
Universita' di Napoli and INFN Section thereof, Italy
NIKHEF, Amsterdam, The Netherlands
University of Pisa and INFN Section thereof, Italy
Laboratory of Molecular Biology, Cambridge, England, UK
Mid Sweden University Sundsvall, Sweden,
Czech Technical University, Prague, Czech Republic
ESRF, Grenoble, France
Academy of Sciences of the Czech Republic, Prague
Universität Erlangen-Nurnberg, Erlangen, Germany
University of California, Berkeley, USA
University of Houston, Texas, USA

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 Netherlands
Mid Sweden University, Sundsvall, Sweden
IEAP, Czech Technical University, Prague, Czech Republic
ESRF, Grenoble, France
Universität Erlangen-Nurnberg, Erlangen, Germany
University of California, Berkeley, USA
VTT, Information Technology, Espoo, Finland
ISS, Forschungszentrum Karlsruhe, Germany
University of Houston, USA
Diamond Light Source, Oxfordshire, England, UK
Universidad de los Andes, Bogota, Colombia
University of Bonn, Germany
AMOLF, Amsterdan, The Netherlands
ITER, Cadarache, France
Technical University of Munich, Germany

Photon processing versus integrating

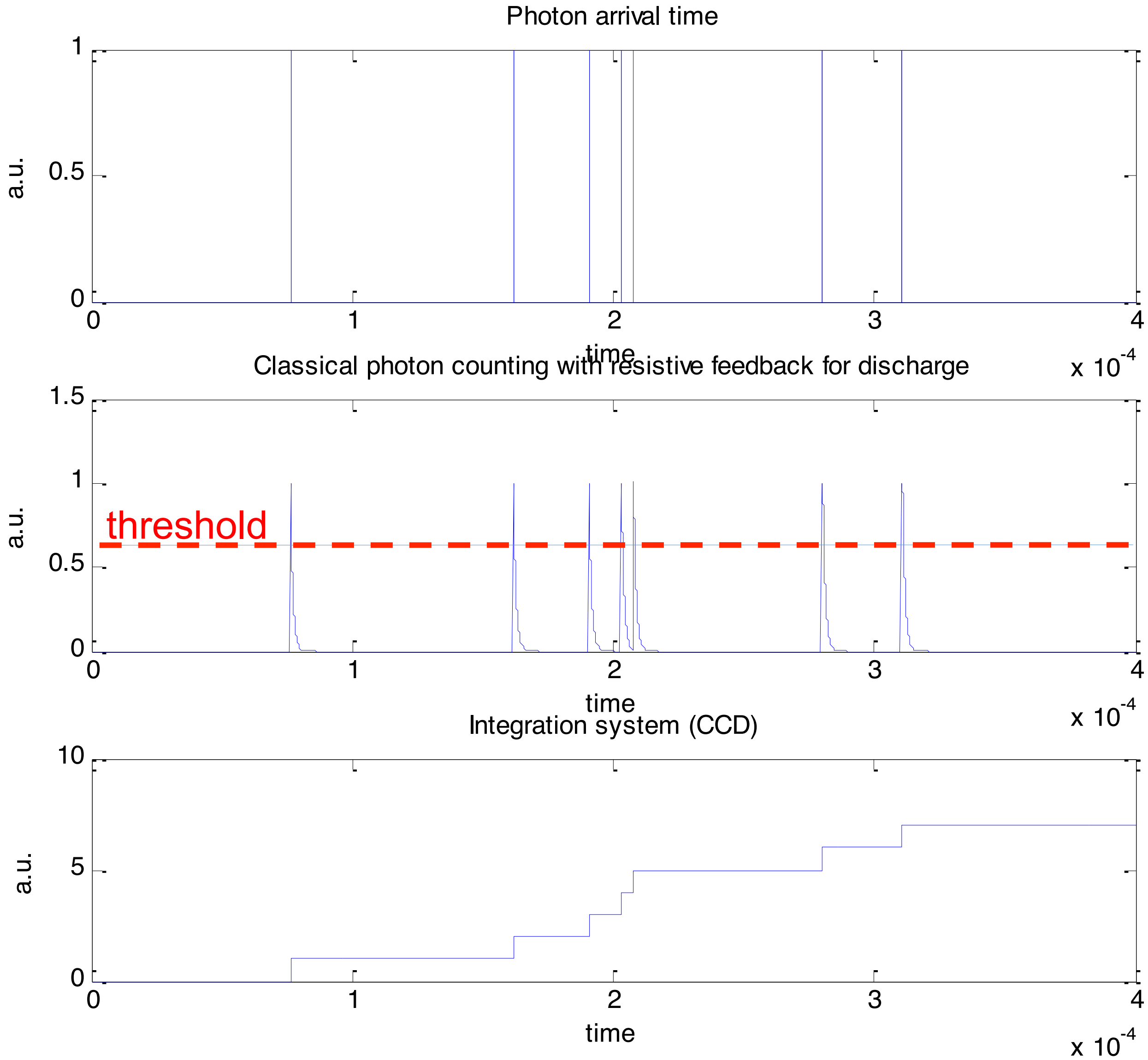


Photon time of arrival follows Poisson statistics

Simulation of preamplifier output (τ=1μs) for a photon counting system

Simulation of the principle of an integration based detector

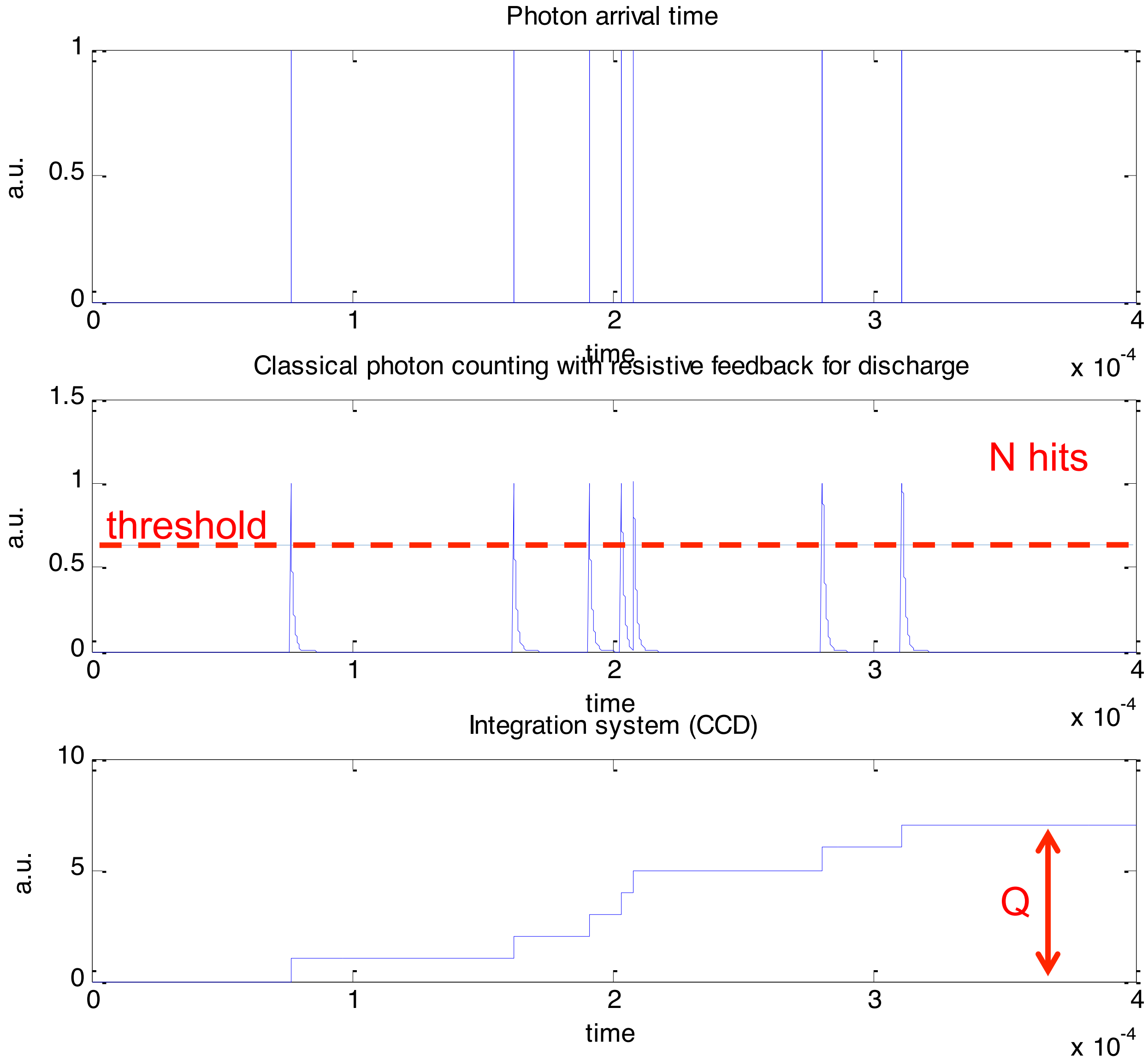
Photon processing versus integrating



Result:
N: hits above threshold

Result:
Q: Total integrated charge

Photon processing versus integrating

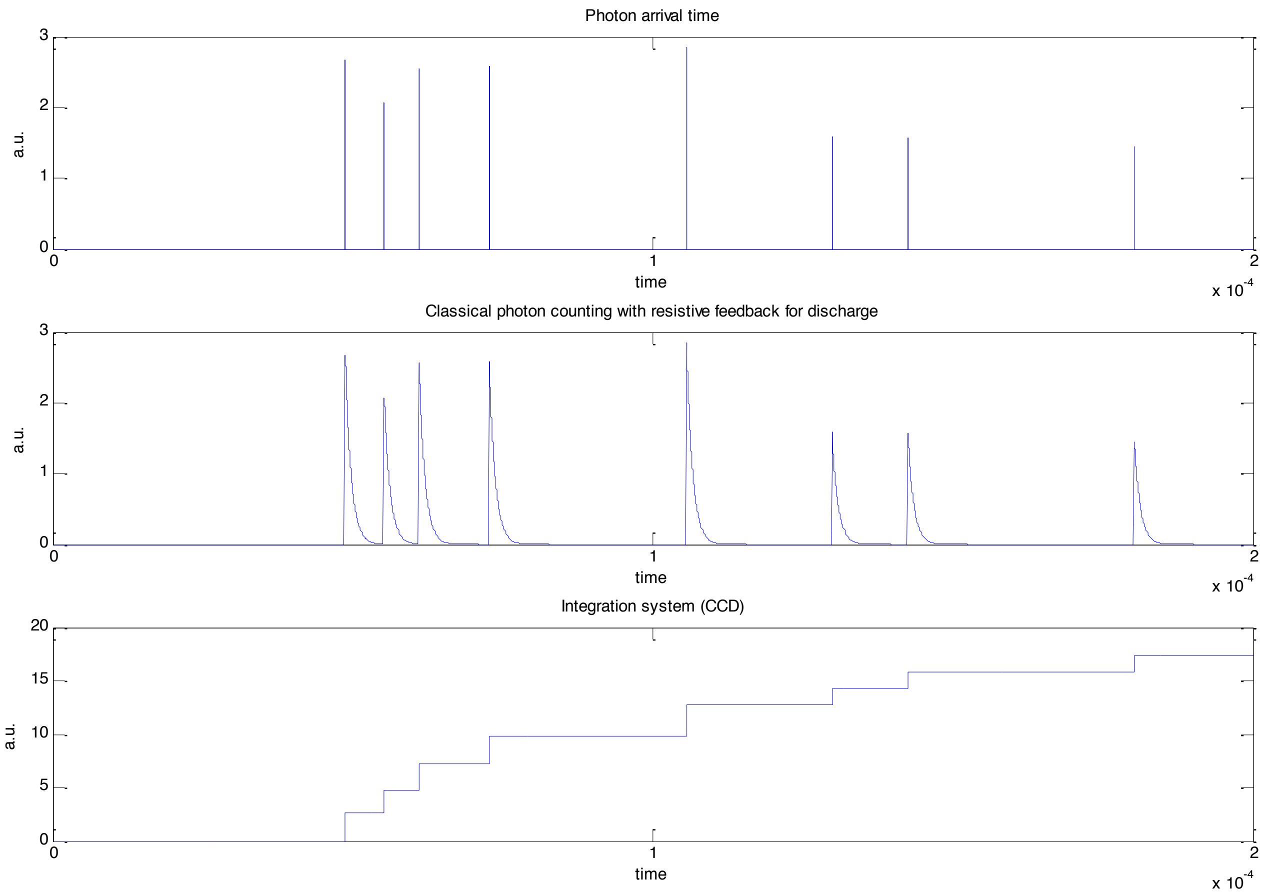


System more robust to noise (noise free images in photon counting independent on shutter time)

Result:
N: hits above threshold
Rejects noise

Result:
Q: Total integrated charge
Integrates noise

Photon processing versus integrating



In integrating detectors, low energy photons information is masked by high energy photons.

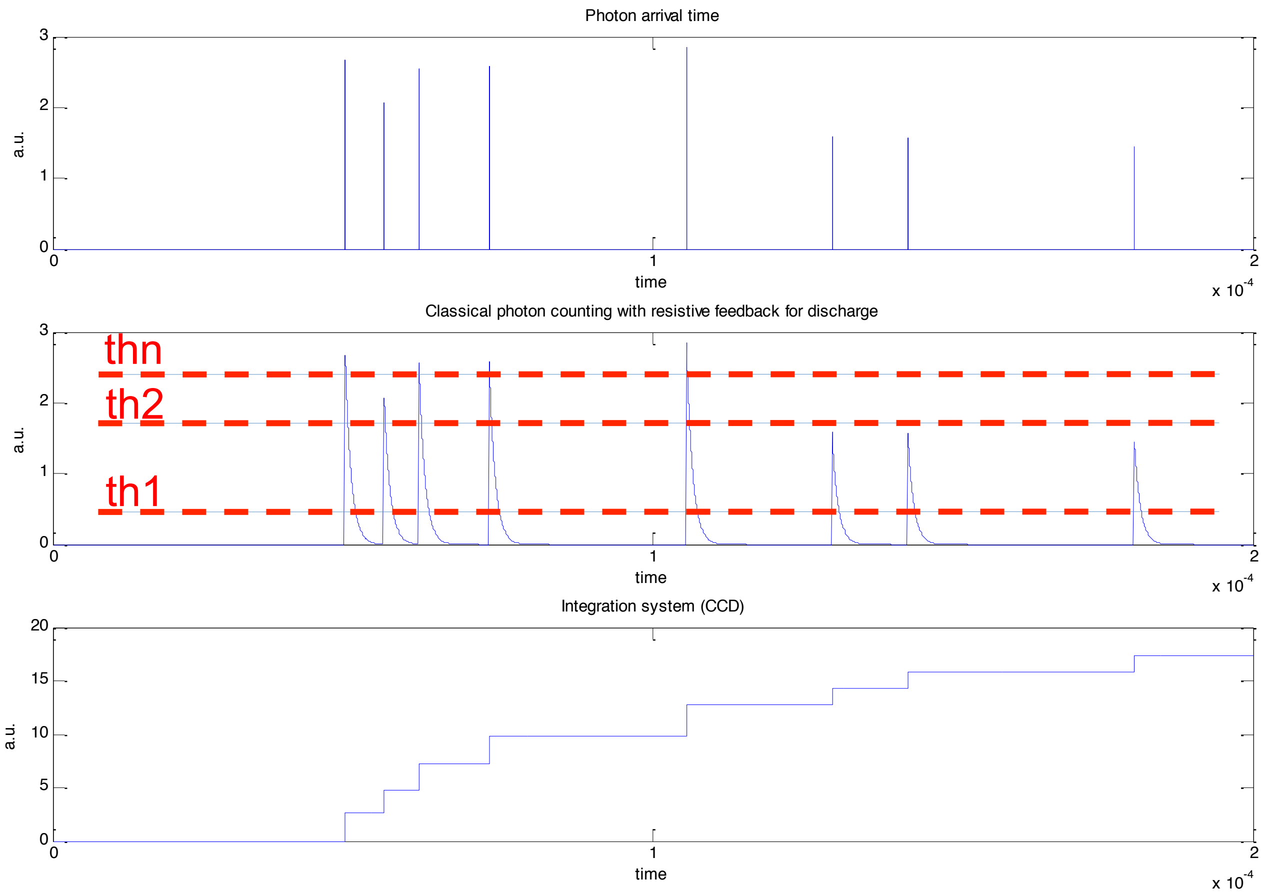
$$W \propto E$$

In Photon Counting with 1 threshold

$$W = 1$$

Photon counting with multiple thresholds allows to optimize the weighting function AND allows k-edge identification

Photon processing versus integrating



In integrating detectors, low energy photons information is masked by high energy photons.

$$W \propto E$$

In Photon Counting

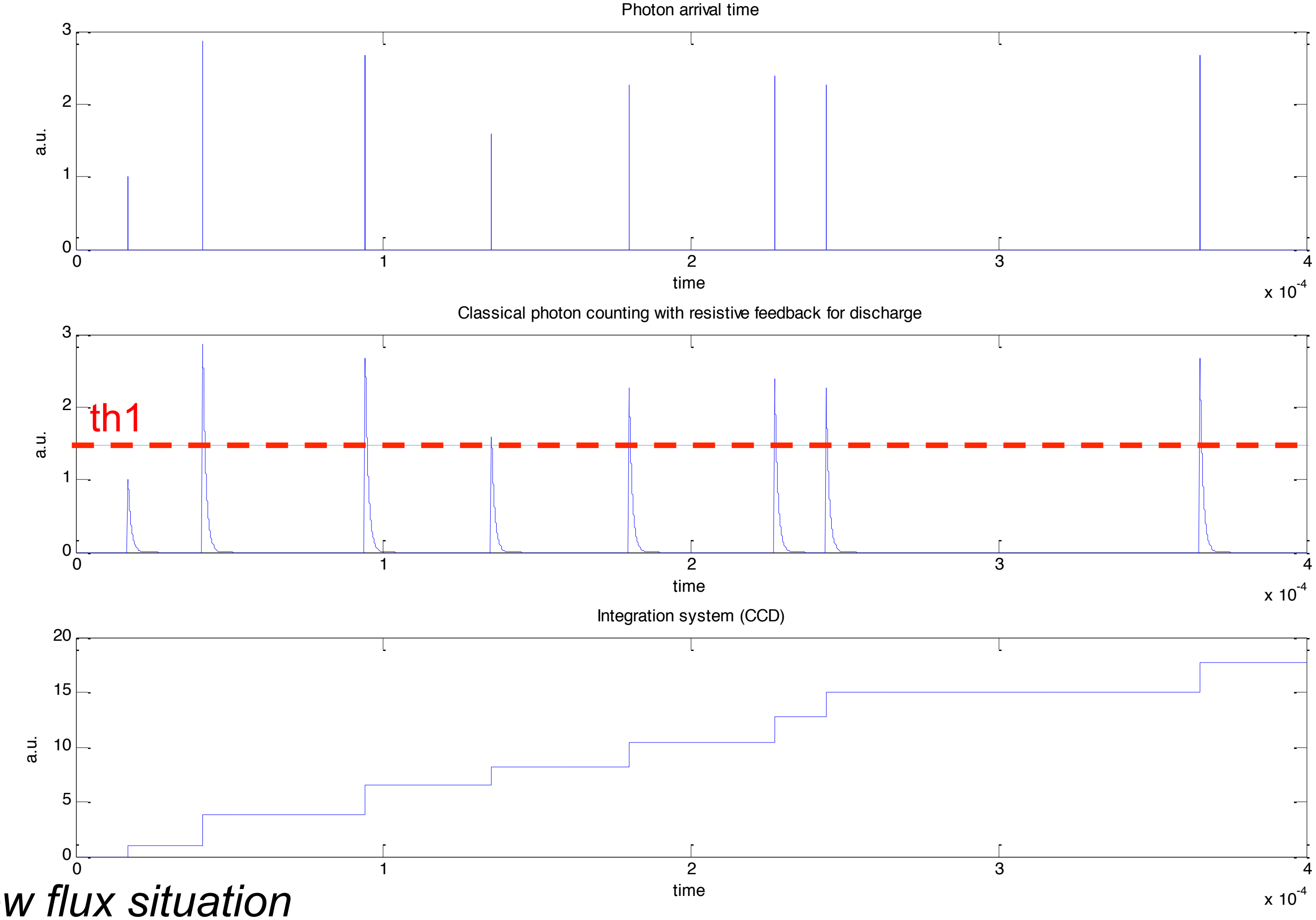
$$W = 1$$

Photon counting with multiple thresholds allows to optimize the weighting function

$$W \sim E^{-3}$$

(optimal function for low contrast objects)

Photon processing versus integrating

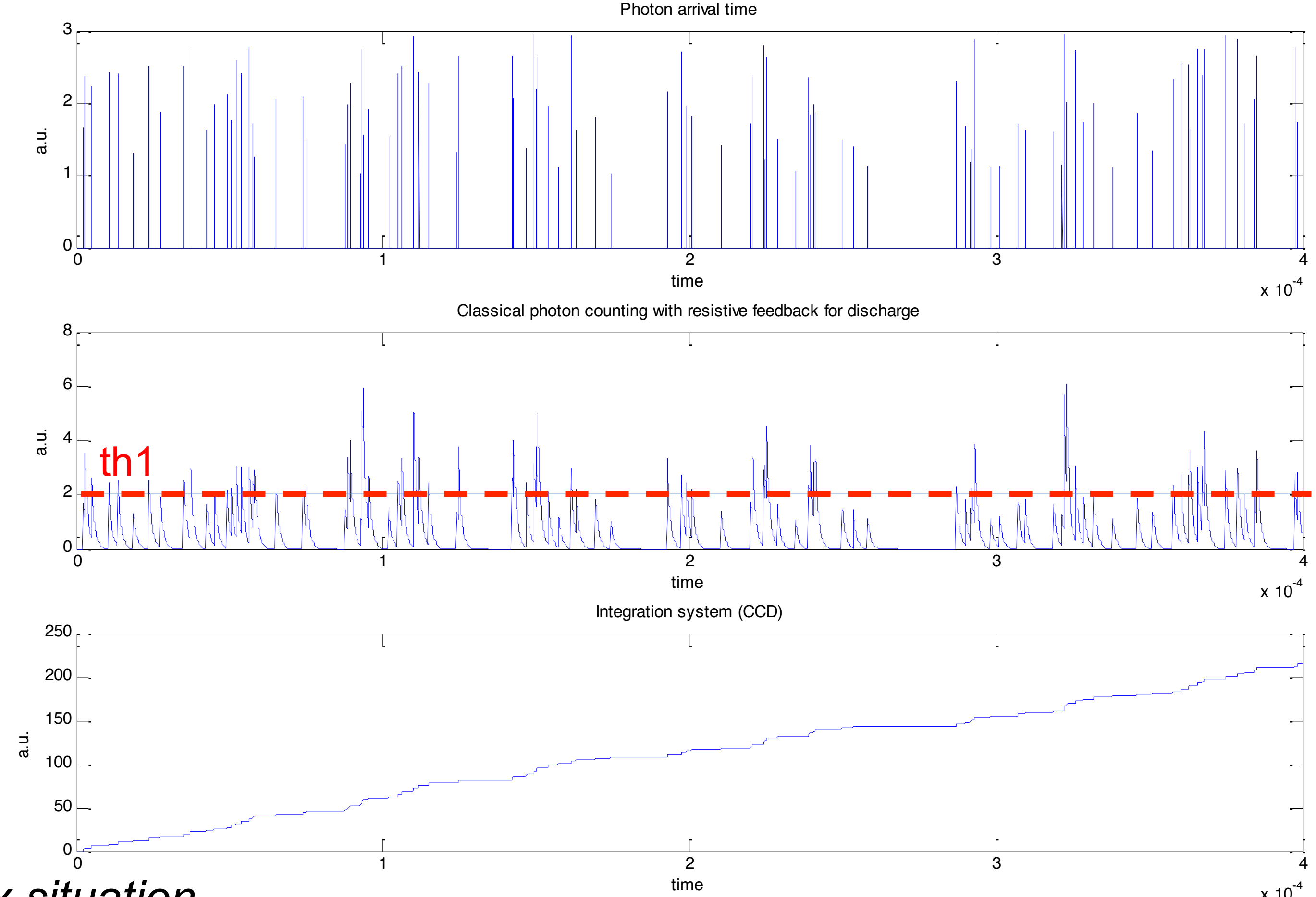


Low flux situation

μ=40μs (mean time constant between the arrival of two consecutive pulses)

τ=1μs (preamplifier reset time constant)

Photon processing versus integrating

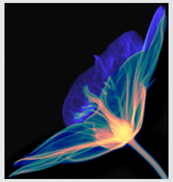


High flux situation

μ=4μs (mean time constant between the arrival of two consecutive pulses)

τ=1μs (preamplifier reset time constant)

The preamplifier output shows "pile up" degrading the performance of the measurement



Designed chips

Medipix1 (1998)	*1μm SACMOS, 64x64 pixels, 170x170μm^2* *PC / Frame based readout*
Medipix2 (2001)	*0.25μm CMOS, 256x256 pixels, 55x55μm^2* *PC / Frame based readout*
Timepix (2006)	*0.25μm CMOS, 256x256 pixels, 55x55μm^2* *PC, ToT, ToA / Frame based readout*
Medipix3 (2009)	*0.13μm CMOS, 256x256 pixels, 55x55μm^2* *PC / Frame based readout* *Event by event charge reconstruction and allocation*
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Timepix3 (2013)	*0.13μm CMOS, 256x256 pixels, 55x55μm^2* *PC; ToT, ToA (simultaneous)/ Data driven readout*
Smallpix	*0.13μm CMOS, 512x512 pixels, 40x40μm^2 (TBD)* *PC, iToT; ToA, ToT1 (simultaneous)/ Frame based (ZC)* *TSV compatible design*
Clicpix prototype	*65nm CMOS, 64x64 pixels, 25x25μm^2* *ToA, ToT1 (simultaneous)/ Frame based (ZC)*

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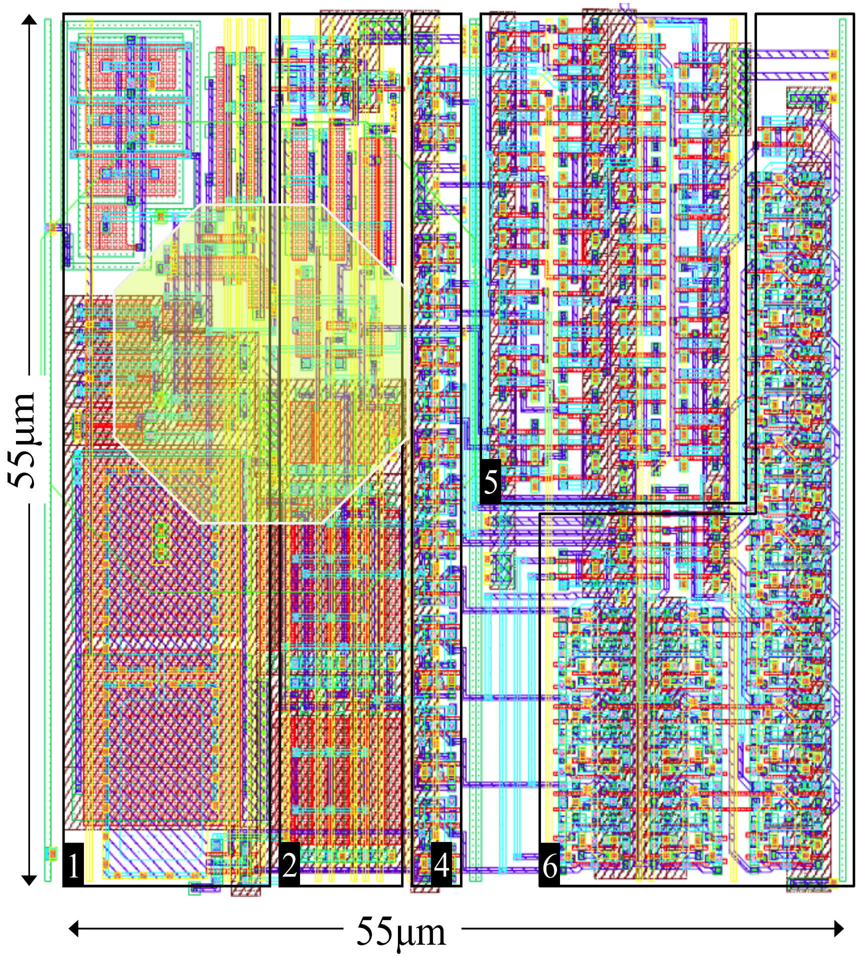
Timepix

- Hybrid Pixel Detector
- 256x256 pixels
- 55um pixel pitch

- Single Photon Processing
  - Time-over-Threshold
  - Time of arrival
  - Photon Counting

Capable of operating in both electron and hole collection mode

Multi purpose chip



~ 500 transistors / pixel

Digital back-end electronics

«Photon counting mode»

Medipix1, 2, 3

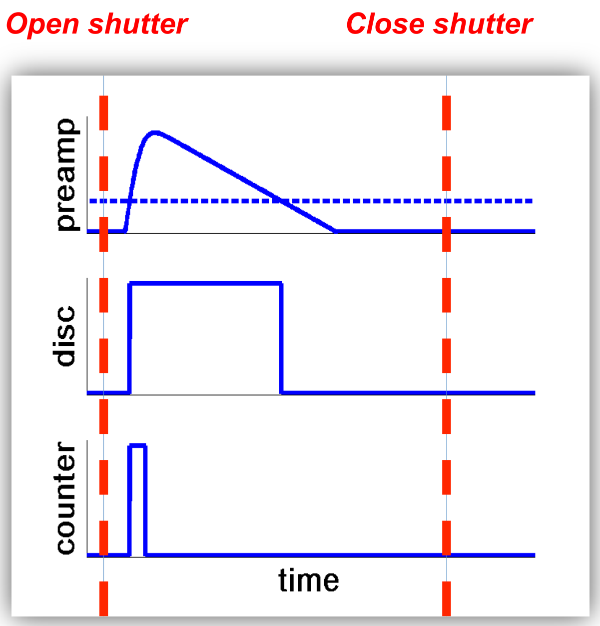
Timepix

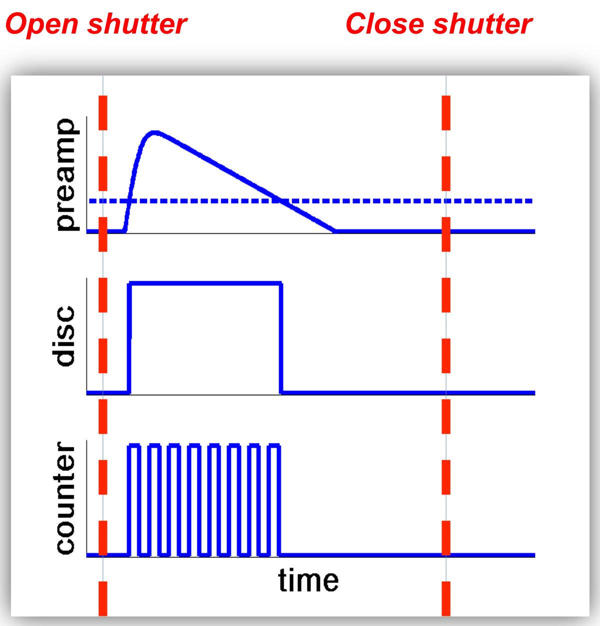
«Time over Threshold mode»

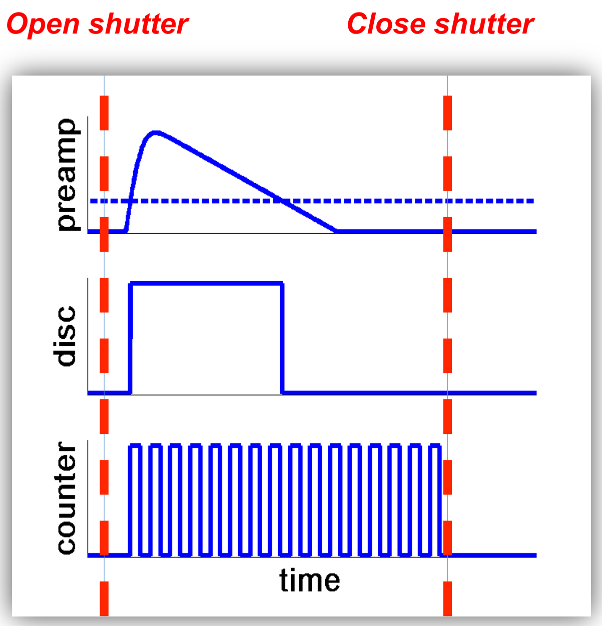
Timepix

«Time of Arrival mode»

Timepix

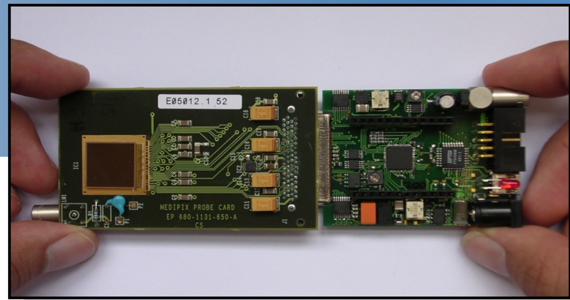






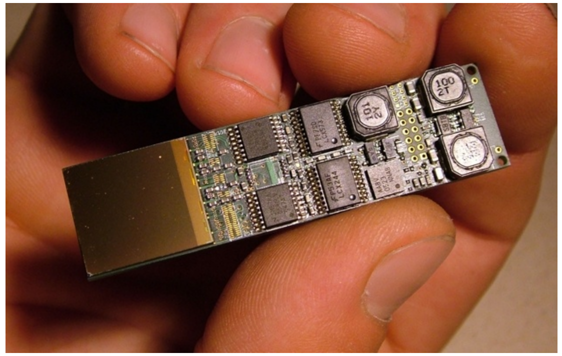
Drawing: W. Wong

Timepix

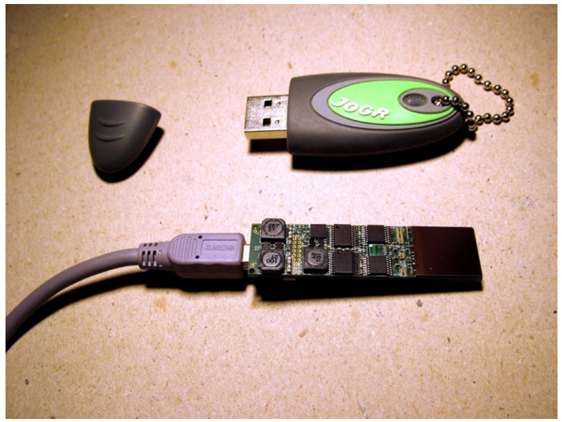


Usb read out

- Compact system 15x60mm for the USB Lite read out including sensor
- USB Connection to standard PC
- Pixelman control software allowing scripting and plugins



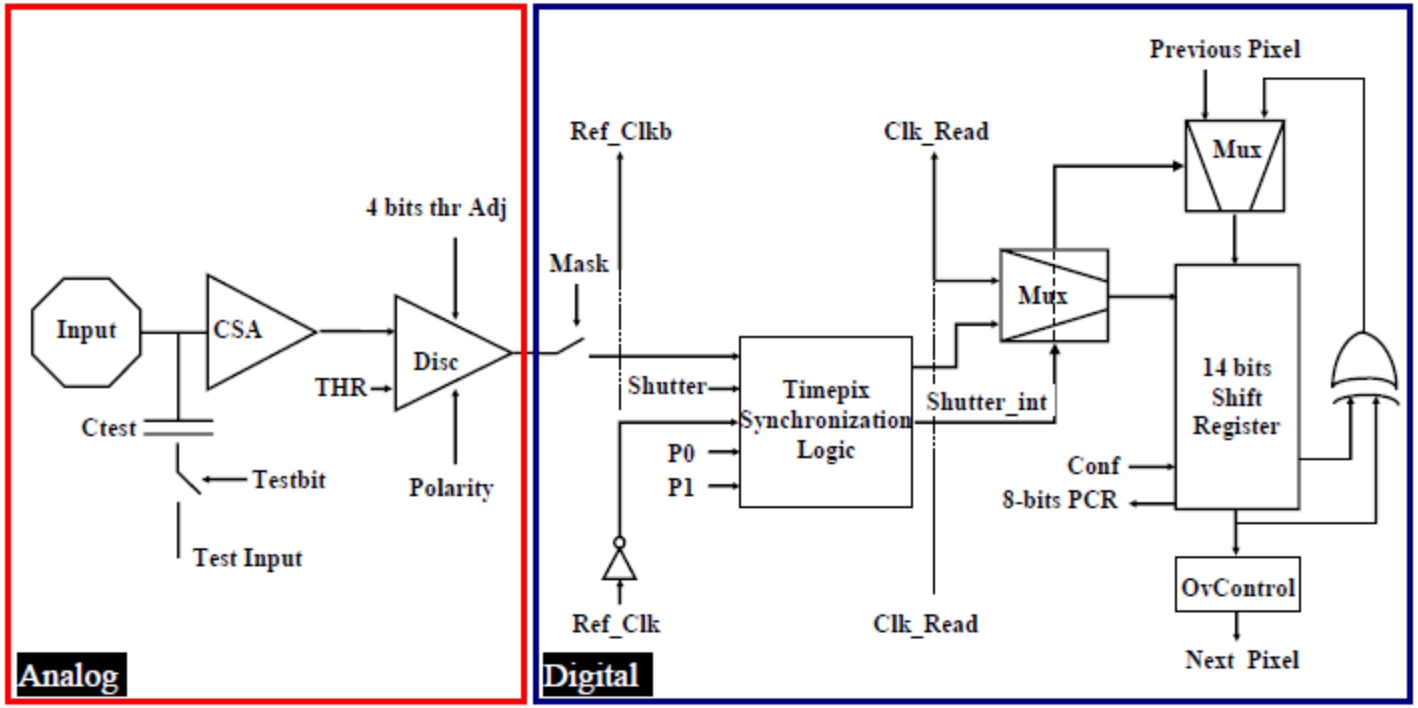
Usb lite



Usb lite

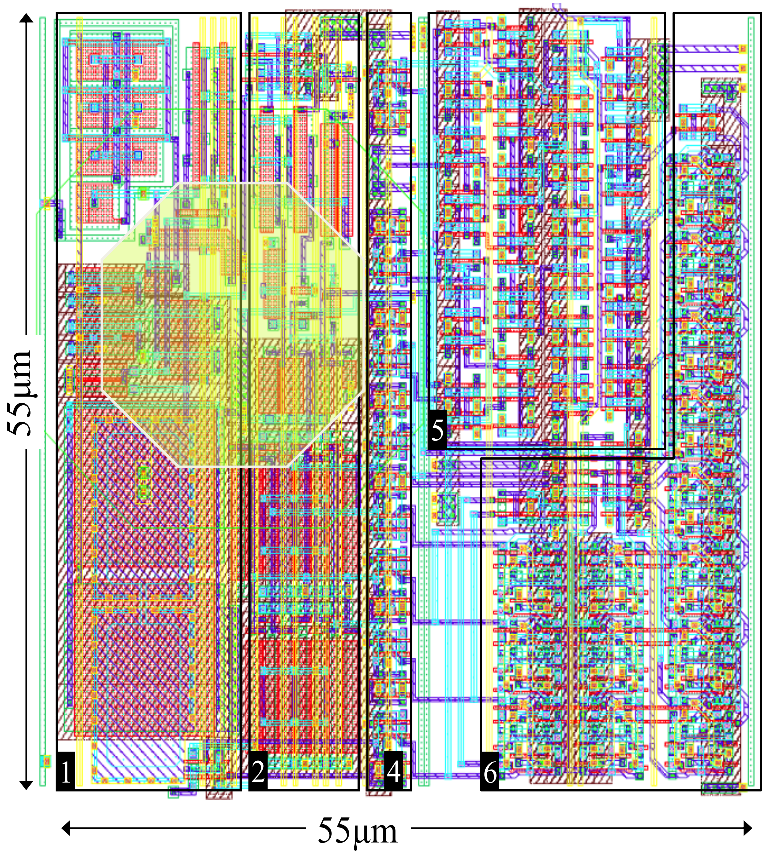
Pictures courtesy of IEAP Prague

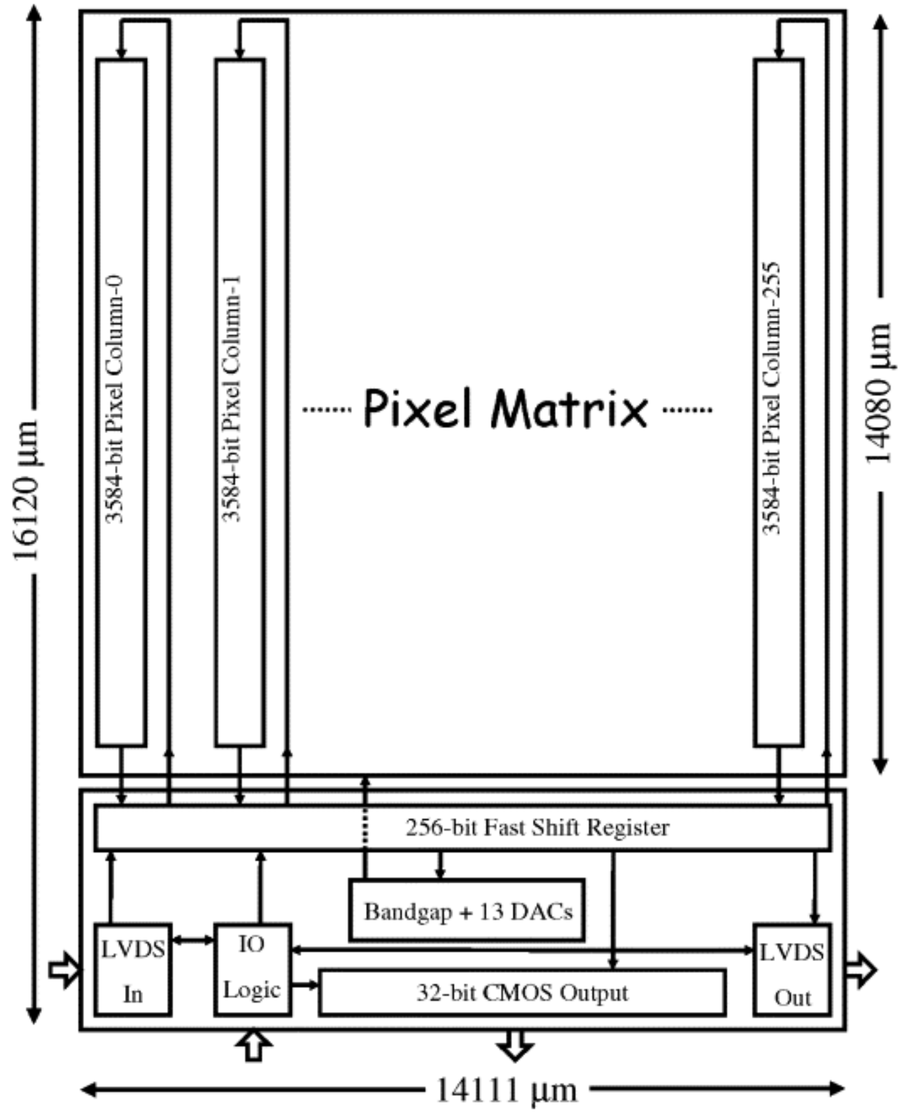
Timepix pixel cell schematic



X. Llopart, et al., "Timepix, a 65k programmable pixel readout chip for arrival time, energy and/or photon counting measurements" NIM A 581 (2007) 485-494.

Timepix pixel layout

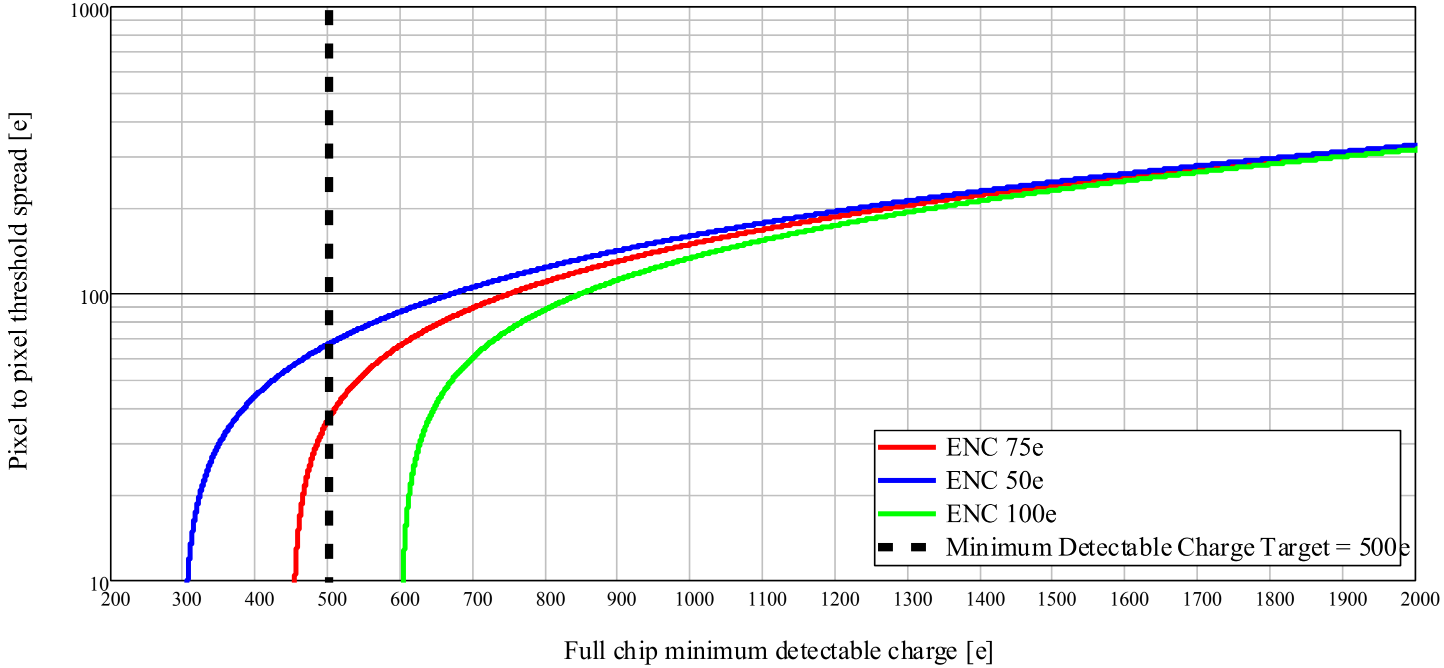




	Holes [h^+]	Electrons [e^-]
Electronic noise	$99.4 \pm 3.8\ e^-$ rms	$104.8 \pm 6\ e^-$ rms
Gain	~16.7 mV/ke⁻	~16.3 mV/ke⁻
Threshold DAC step gain	$24.7 \pm 0.7\ e^-$	$25.4 \pm 1.2\ e^-$
CSA linearity [0-20 ke-]	>99.9%	
TOT dynamic range	> 200 ke⁻ (measured up to ~40 ke⁻)	
ΔTOT/TOT (Qin>Thr + 1 ke-)	<5%	
Time-walk	<50 ns	
Threshold variation before adjustment	~240 e⁻ rms	
Threshold variation after adjustment	~35 e⁻ rms	
Minimum detectable charge	~650 e⁻	
TOT energy resolution after correction	1300 e⁻ FWHM	
Static pixel analog consumption	~6.5 µW	
Static pixel digital consumption	~7 µW @ Ref_Clk =80 MHz	

Full Chip Minimum detectable charge

Minimum Detectable Charge = $6\sqrt{Pixel\_ENC^2 + Threshold\_spread^2}$



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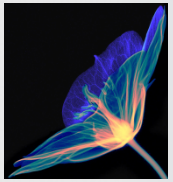

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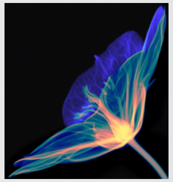

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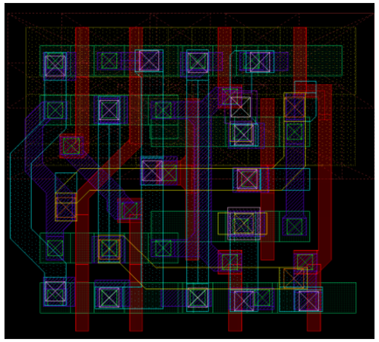
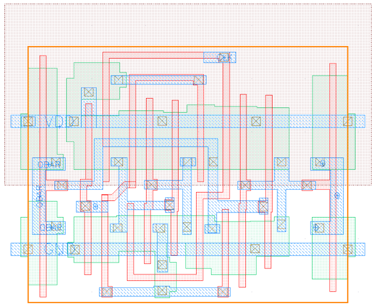
Advantages of scaling



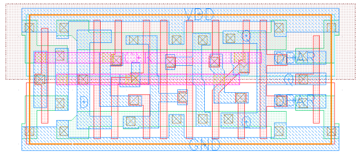
DFF_skt
Medipix2_lib
250nm

1

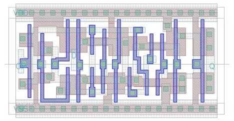


DFF_A
cmos8rf
130nm

1.5x



DFF_A_XL
cern_cmos8rf_hd
130nm
3.2x

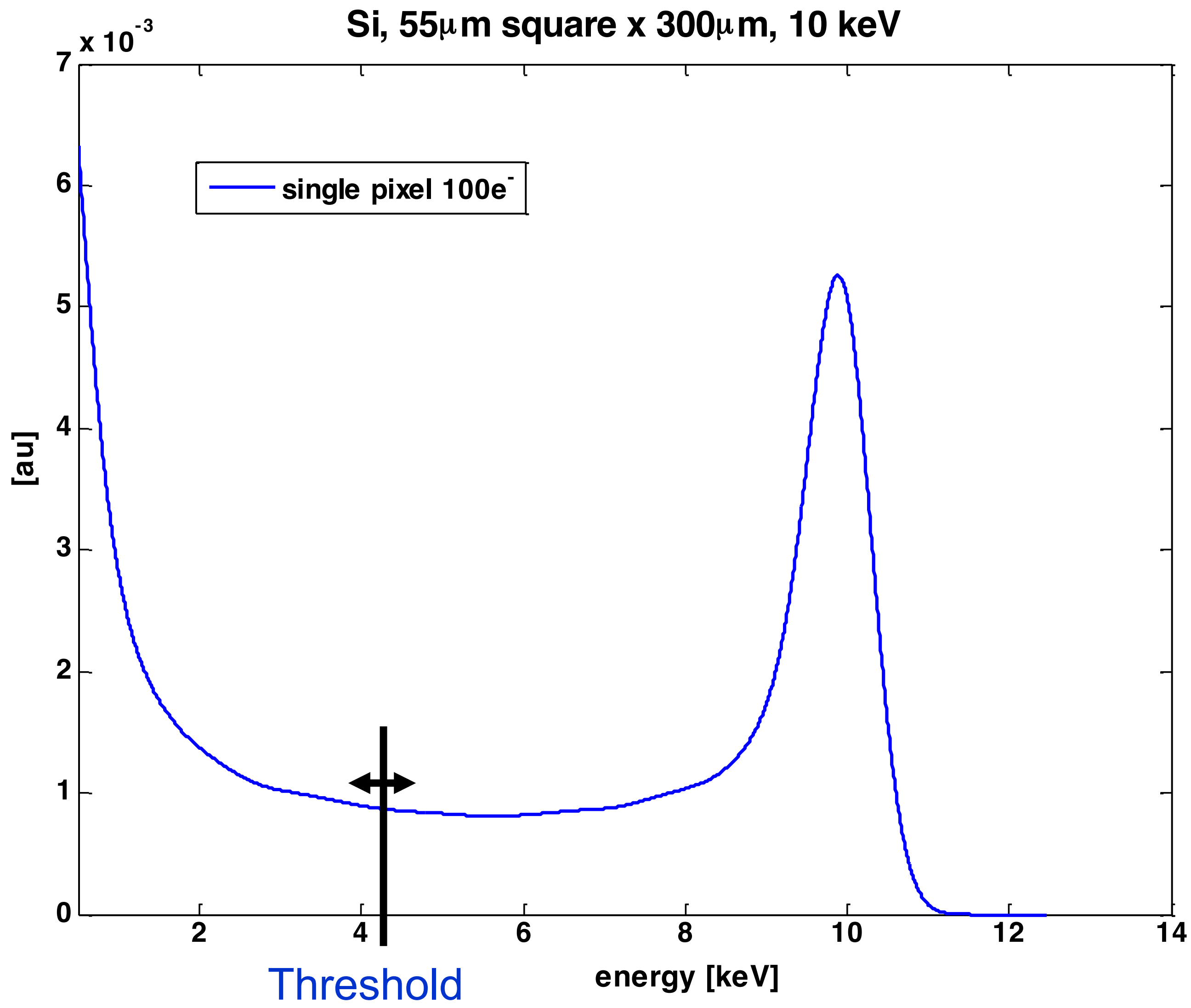


DFQD1
tcbn65lp
65nm

6.4x

This applies only to digital components

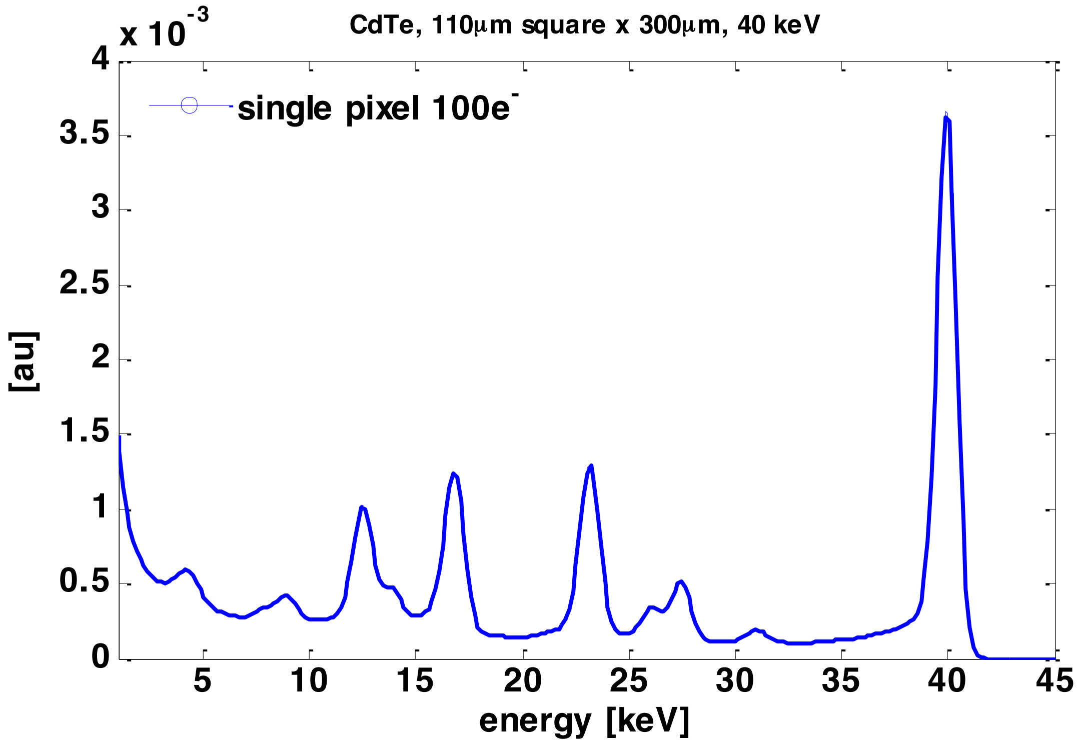
Motivation for the Medipix3 chip



- *Simulated Data*
- *Si 300μm, 55μm pixel*
- *10keV monochromatic photon beam*
- *Charge diffusion produces "charge sharing" tail*
- *Threshold variations produce fixed pattern noise*

Simulation: L. Tlustos

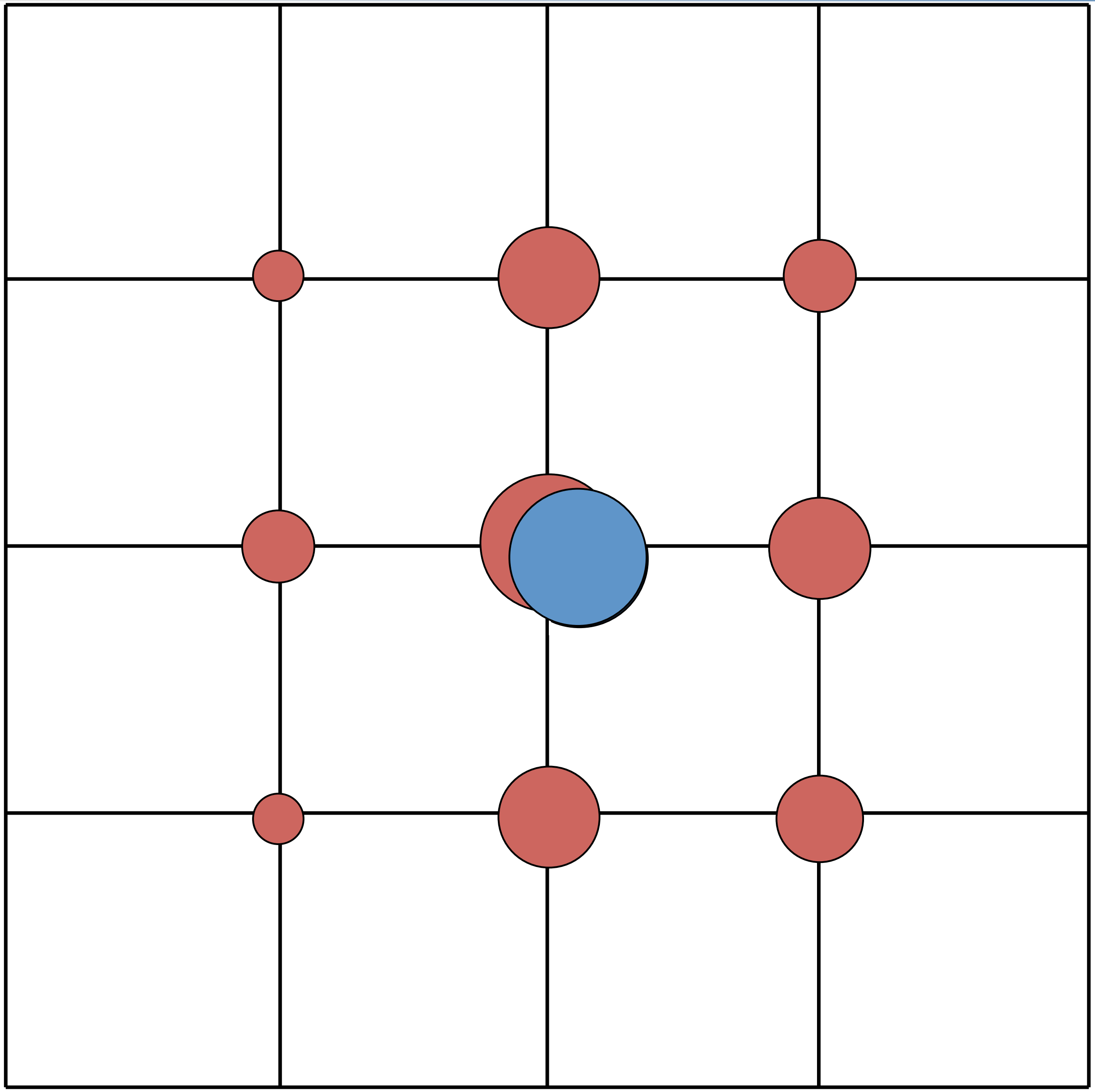
Motivation for the Medipix3 chip



- ***Simulated data***
- ***CdTe 300μm***
- ***110μm pixel pitch***
- ***40keV monochromatic beam***
- ***The influence of fluorescence photons in the energy spectrum is seen***

Simulation: L. Tlustos

The algorithm for charge reconstruction and hit allocation: Charge Summing Mode



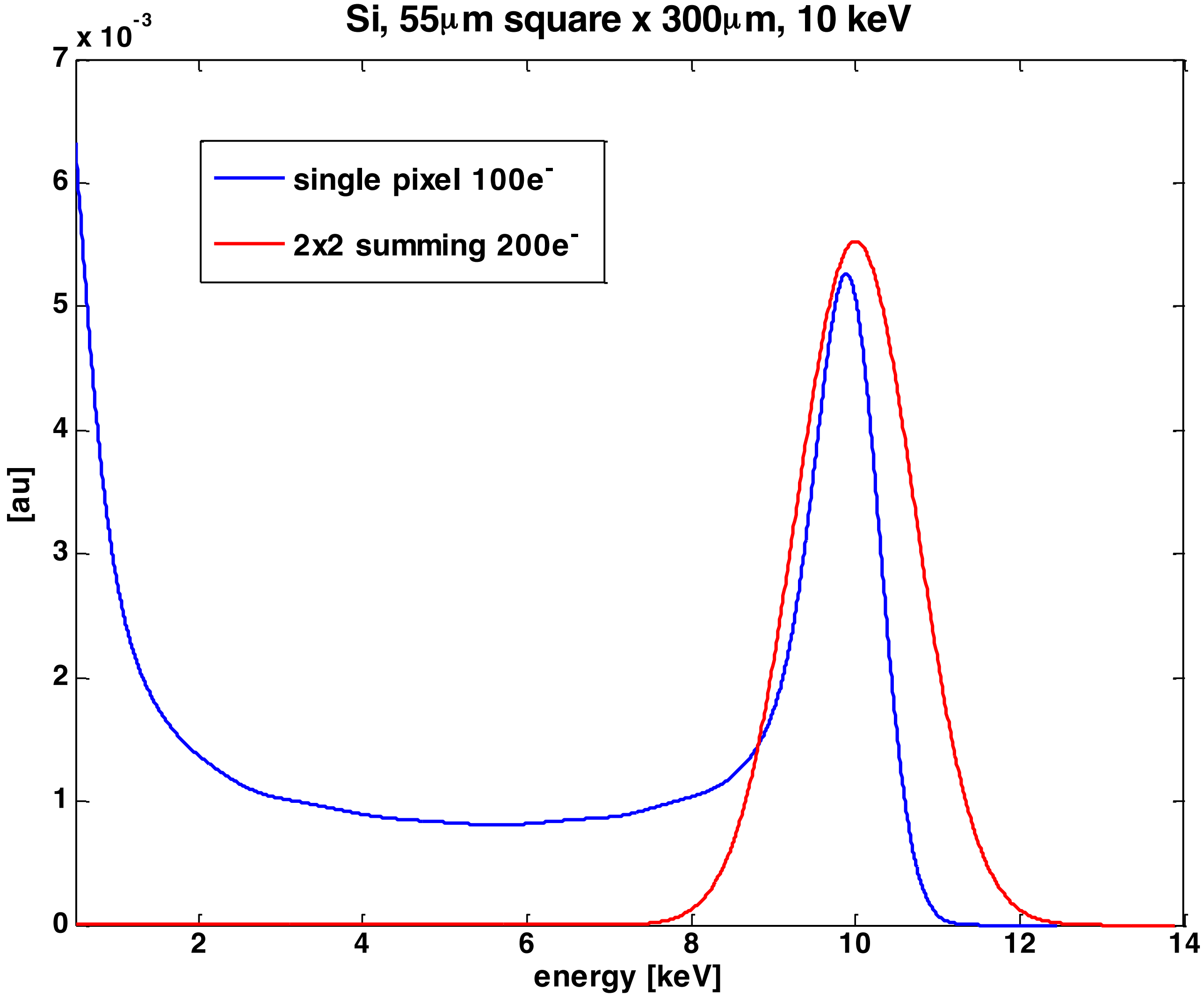
1. TH_0 is applied to the local signal

2. Arbitration circuitry identifies the pixel with largest charge and supresses the pixels with lower signal

3. In parallel, the charge has been reconstructed in the analog summing circuits

4. The pixel with highest charge checks the adjacent summing circuits to see if at least one of them exceeds TH_1

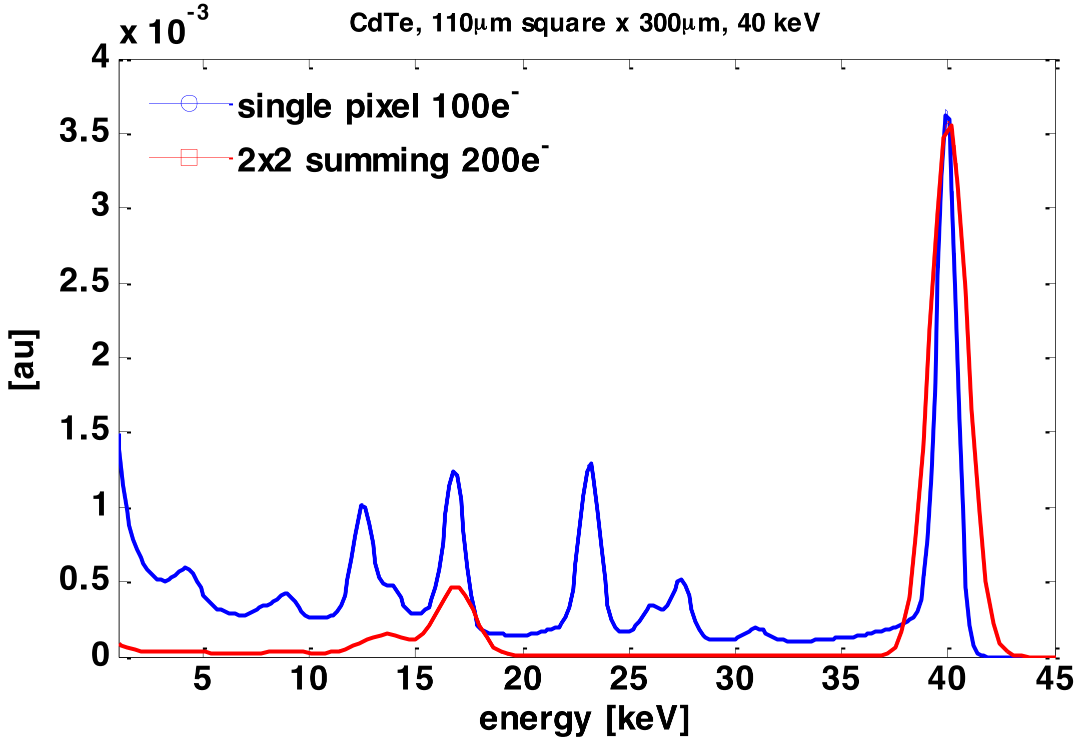
Motivation for the Medipix3 chip



- ***Simulated Data***
- ***Si 300μm, 55μm pixel***
- ***10keV monochromatic photon beam***
- ***In the new architecture charge sharing tail is eliminated***

Simulation: L. Tlustos

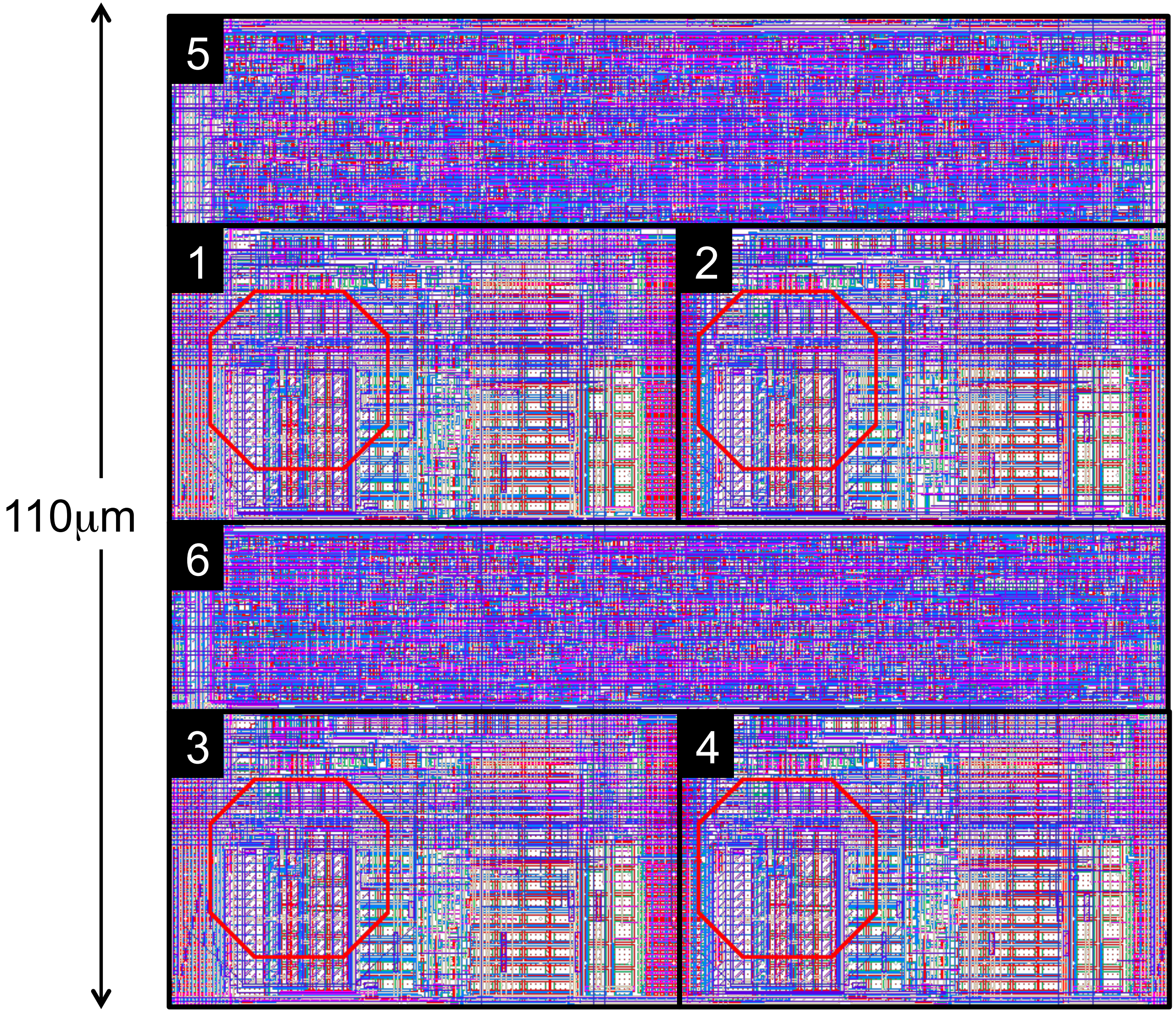
Motivation for the Medipix3 chip



- ***Simulated data***
- ***CdTe 300μm***
- ***110μm pixel pitch***
- ***40keV monochromatic beam***
- ***Fluorescence photons are included in charge sum if their deposition takes place within the volume of the pixels neighbouring the initial deposition***

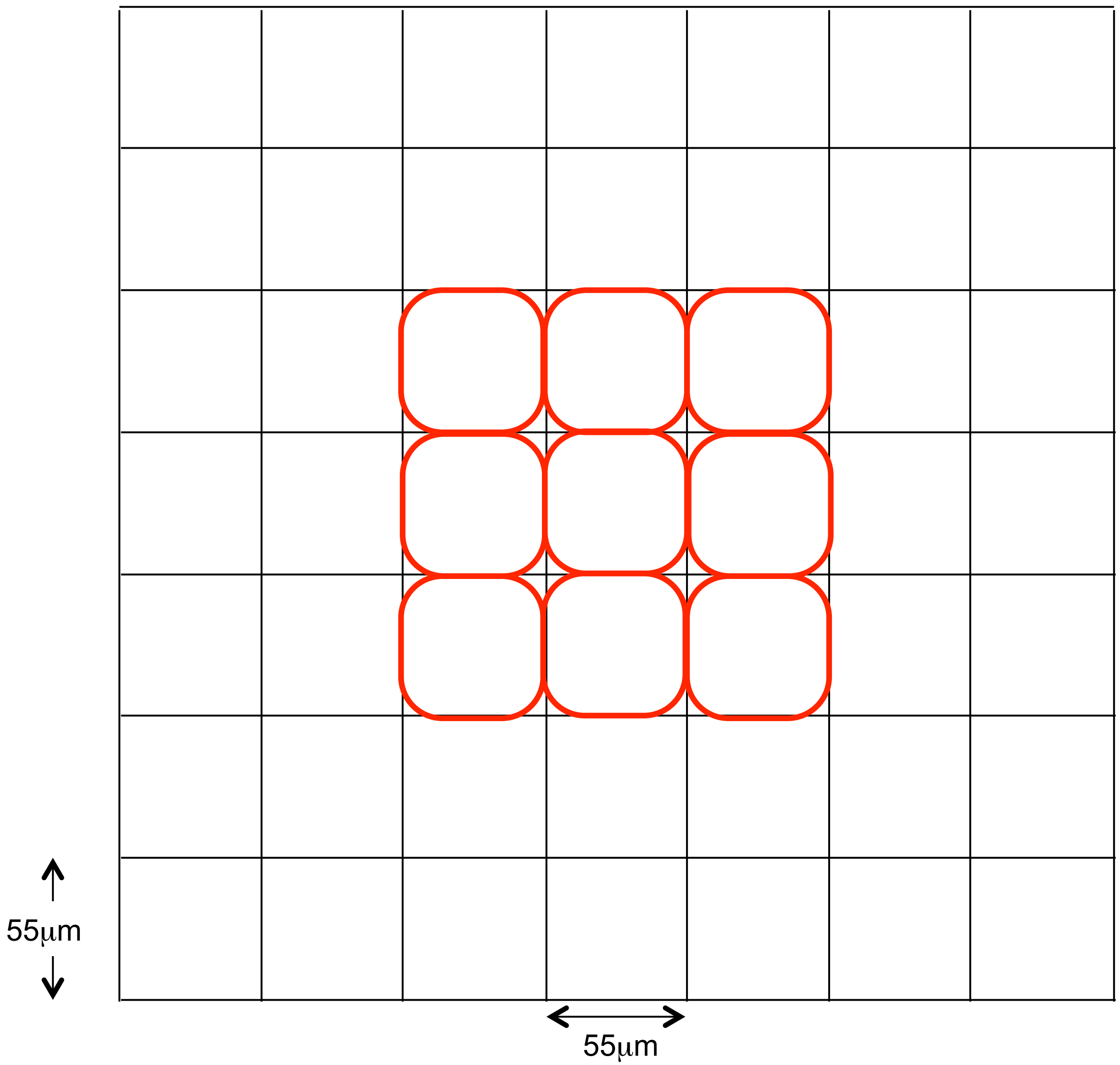
Simulation: L. Tlustos

Medipix3RX Pixel layout



Modes of operation

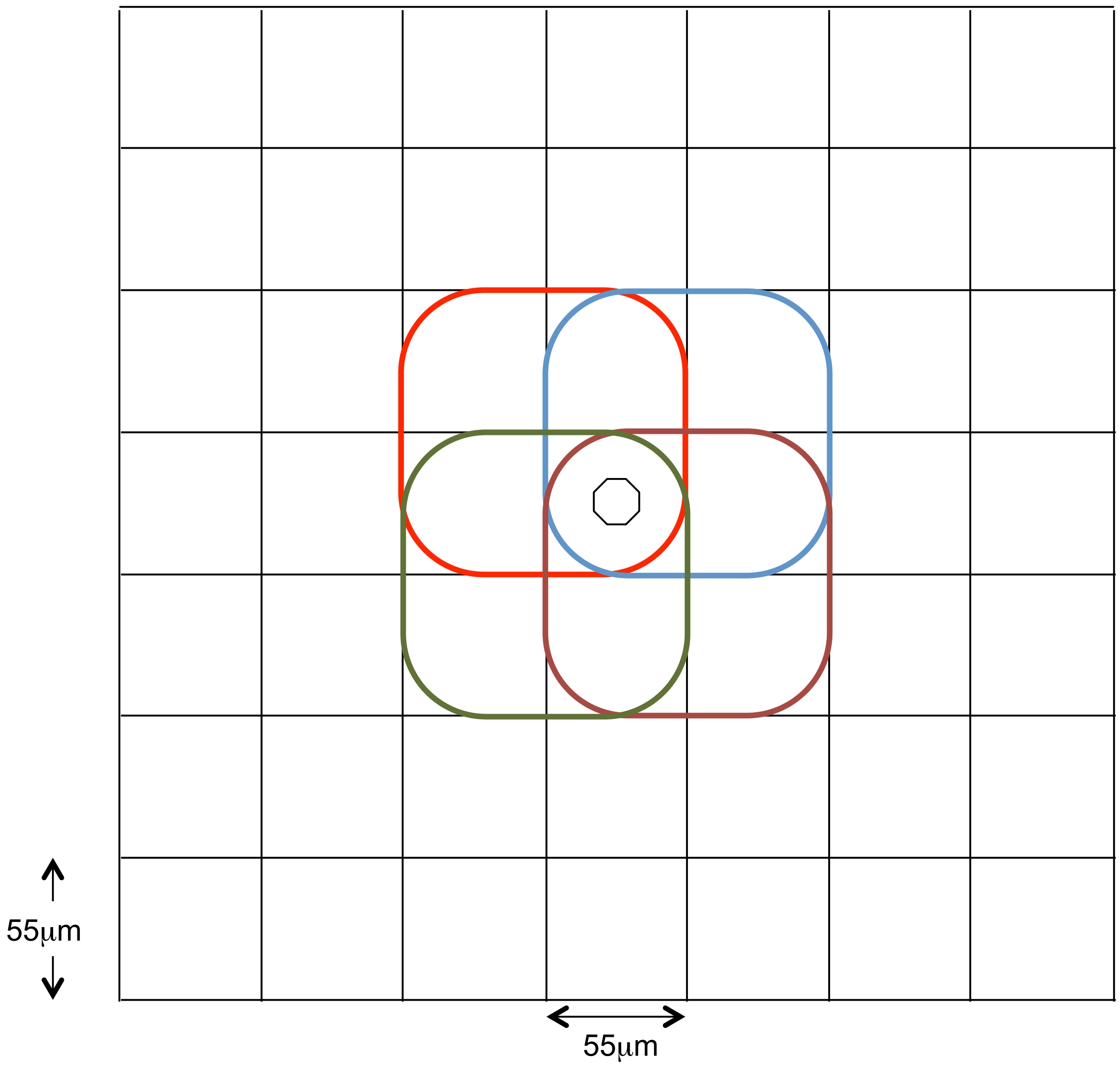
Fine pitch mode, Single Pixel Mode



- ***55μm pixel pitch***
- ***2 thresholds/pixel***
- ***2 counters***

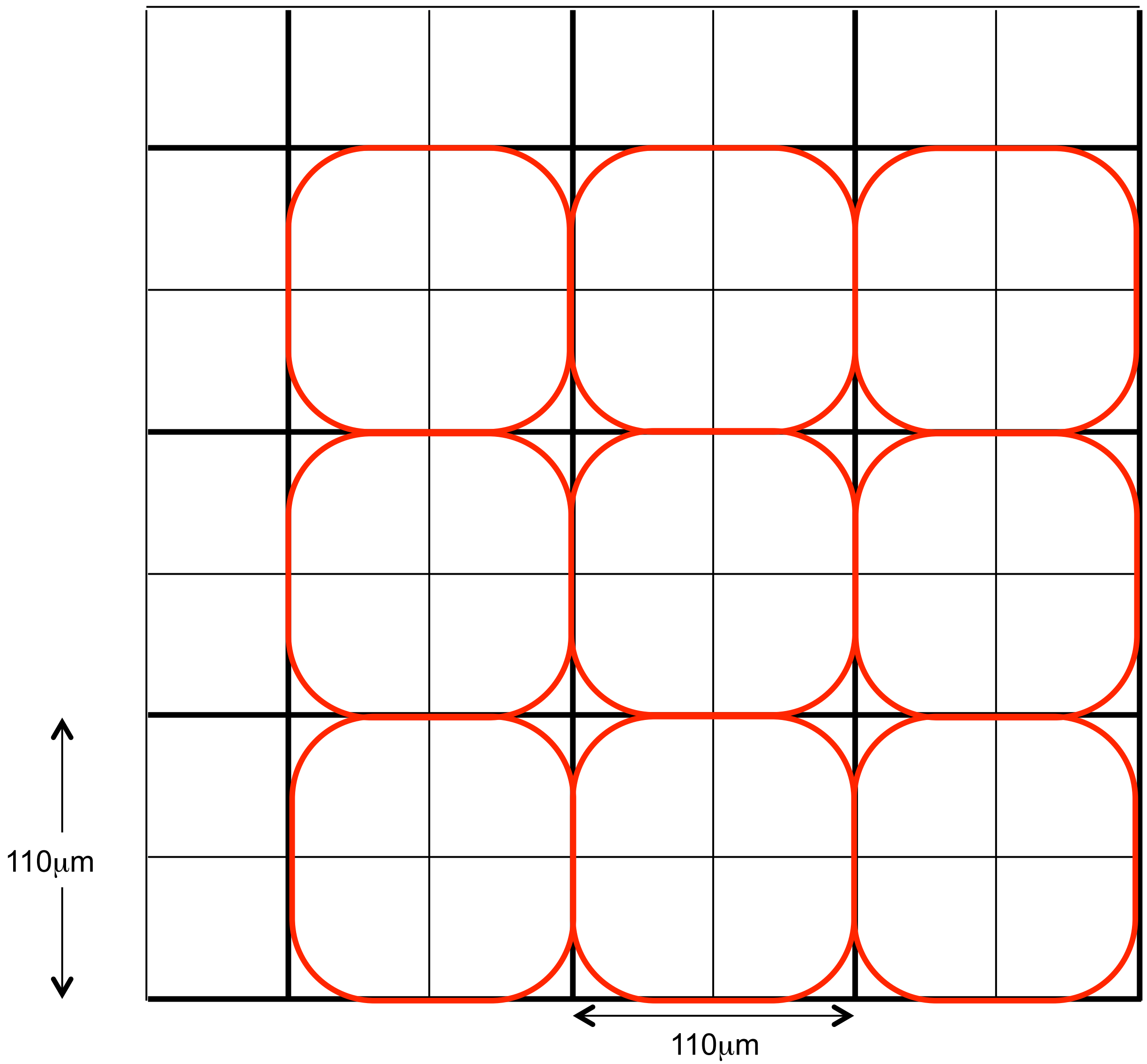
- ***Pixels work independently from one another***

Fine pitch mode, Charge Summing Mode



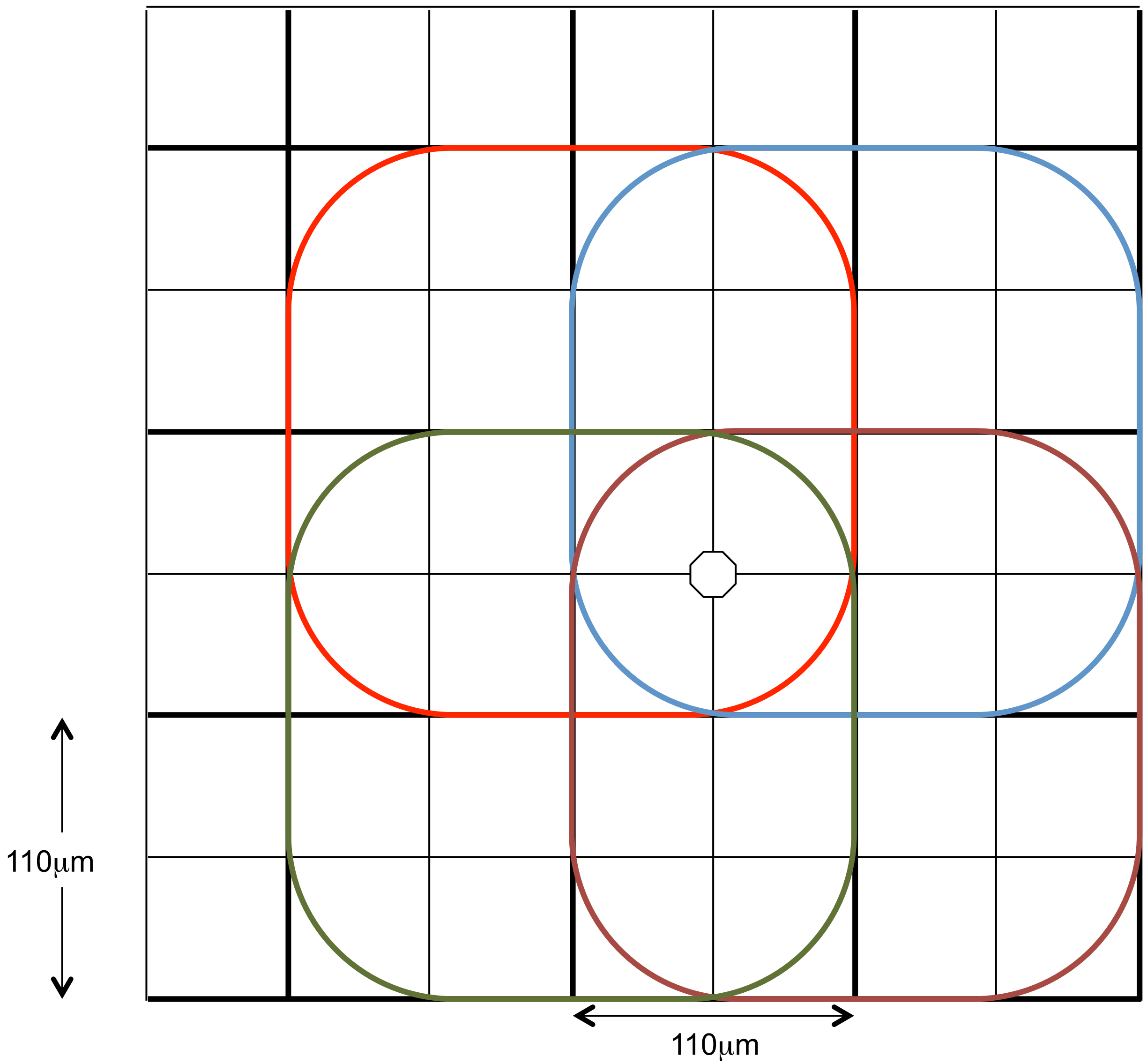
- ***55µm pixel pitch***
- ***Reconstruction over overlapping 110µm x 110µm areas***
- ***2 thresholds/pixel (1 for local charge/1 reconstructed charge)***
- ***2 counters***
- ***Advantage of small pixels without disadvantage of charge sharing***

Spectroscopic mode, Single Pixel Mode



- *110μm pixel pitch*
- *8 thresholds/pixel*
- *8 counters*

Spectroscopic mode, Charge Summing Mode

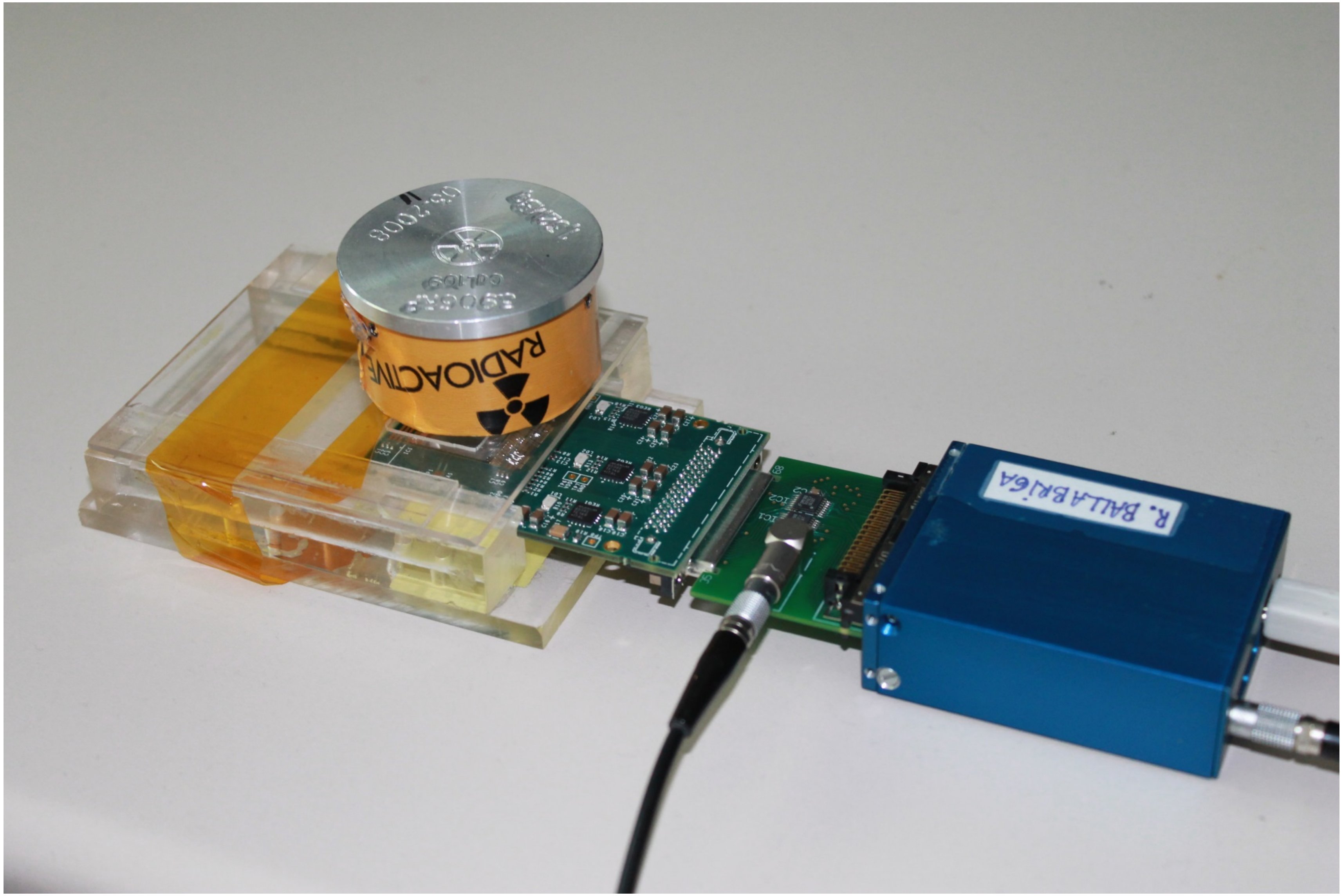


- *110μm pixel pitch*
- *Reconstruction over 220μm x 220μm area*
- *8 thresholds/pixel (4 for local charge/4 reconstructed charge)*
- *8 counters*

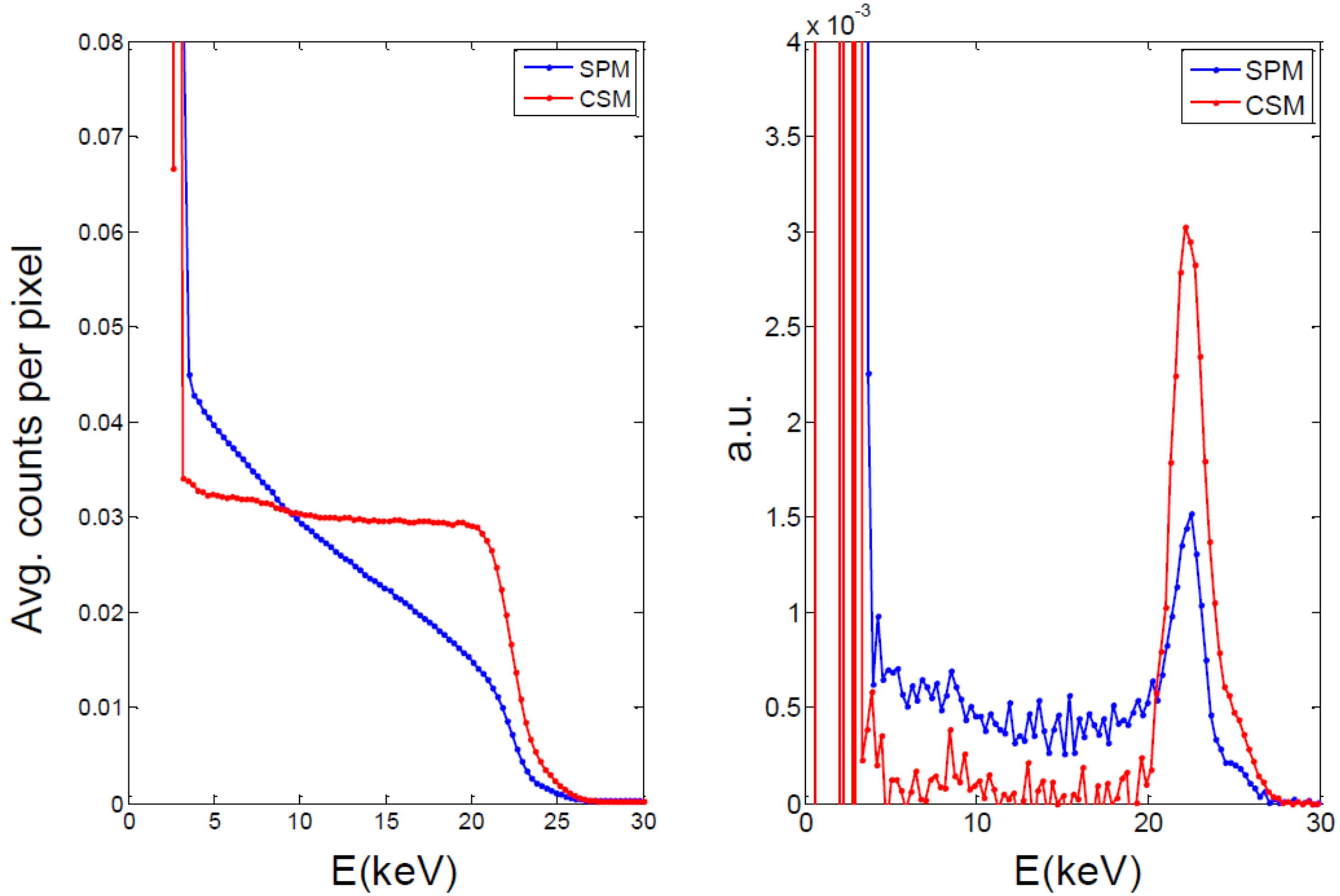
Common to all configurations:

- *4 selectable gain mode*
- *Possibility of Continuous Acquisition/Readout*

Measurements

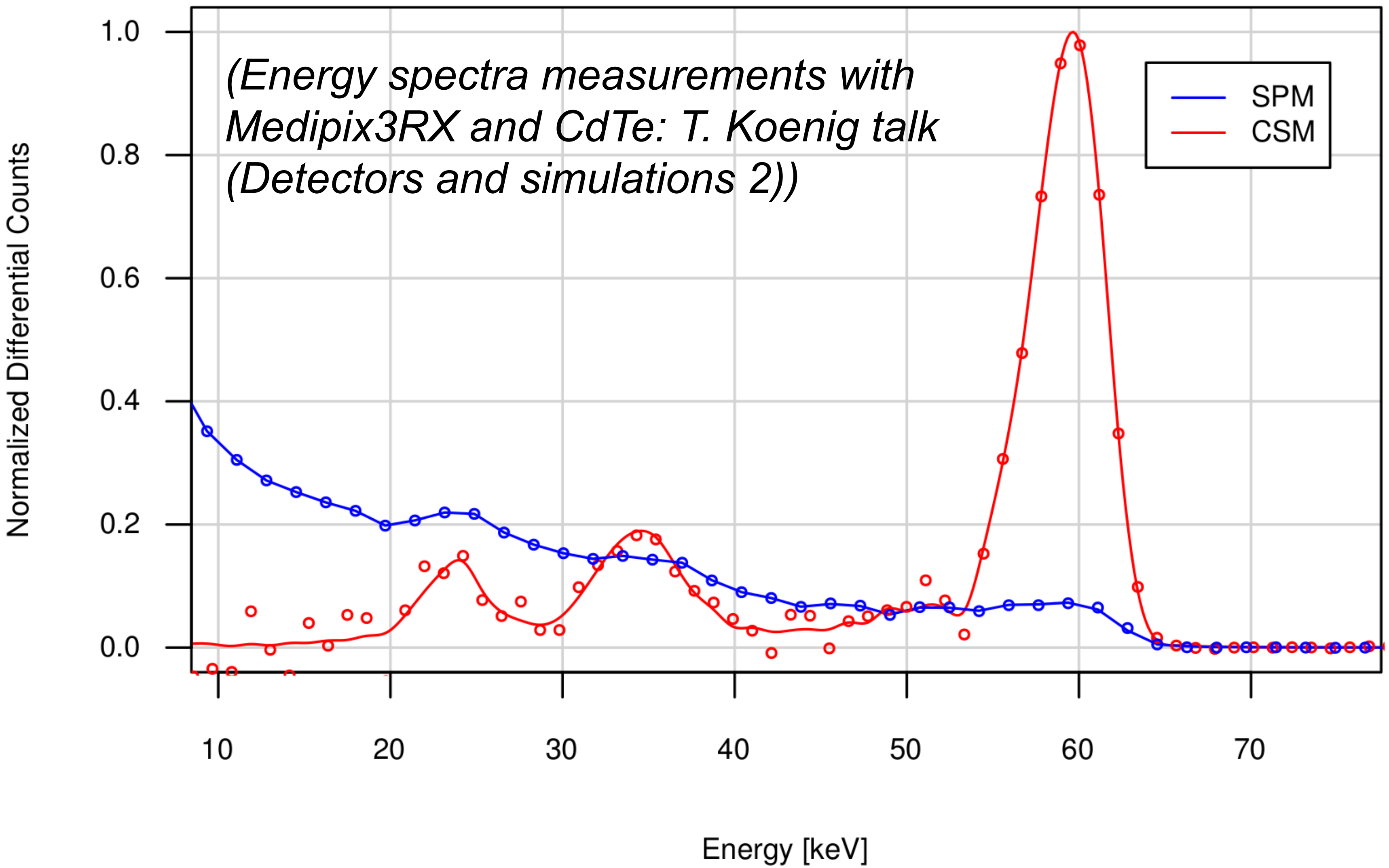


Measurement of ^{109}Cd energy spectrum

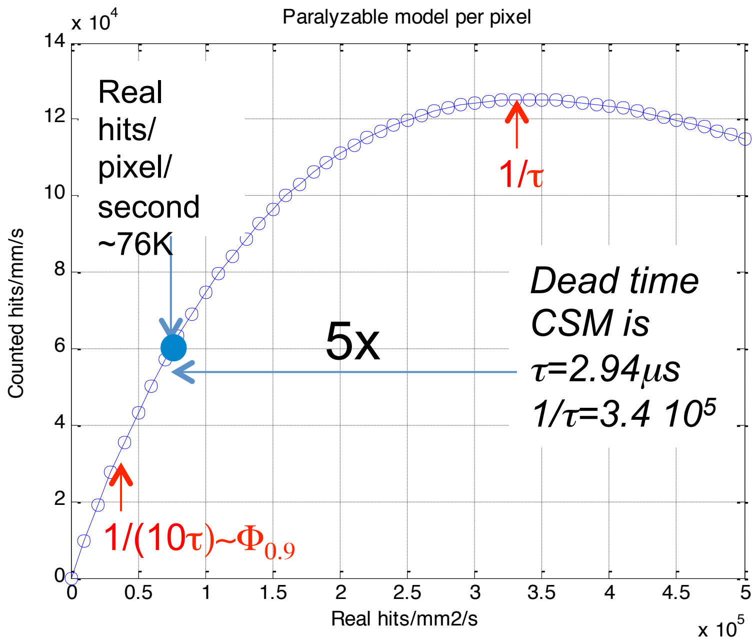


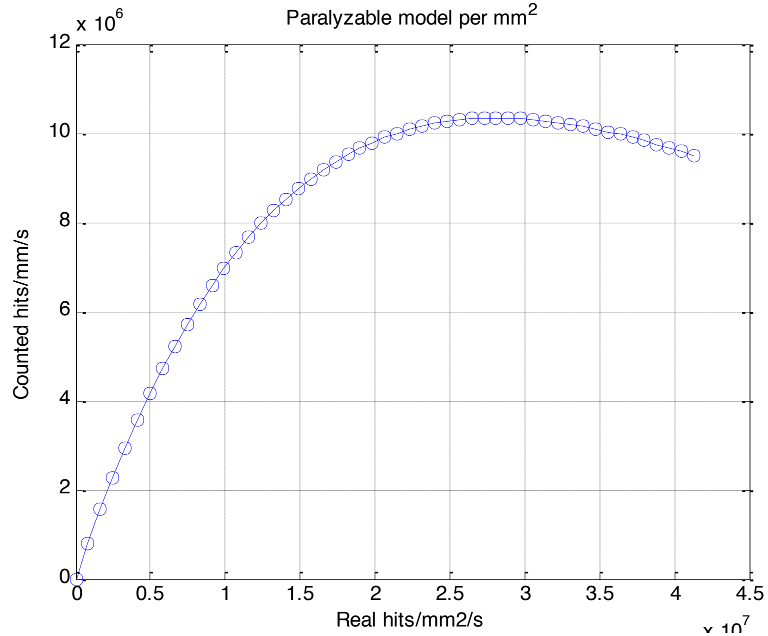
Measurement in HGM @ very low flux conditions
Only 4 pixels masked in the matrix
Raw data, No realignment in data
In Charge Summing Mode each photon is counted once

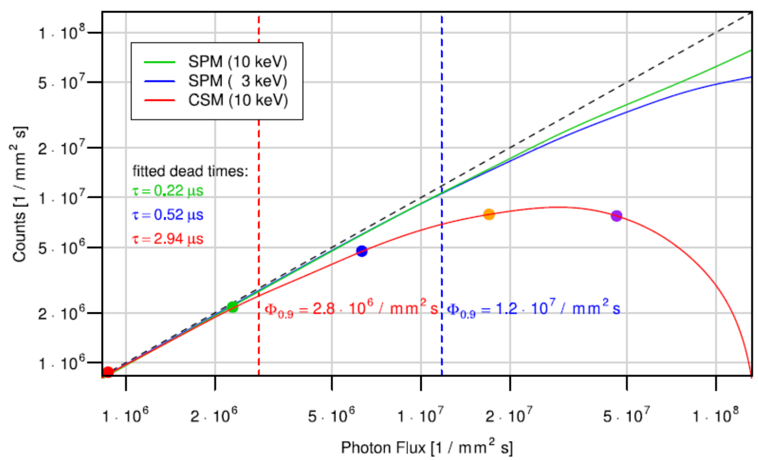
Measurements (60keV, 110μm pitch, 2mm CdTe)

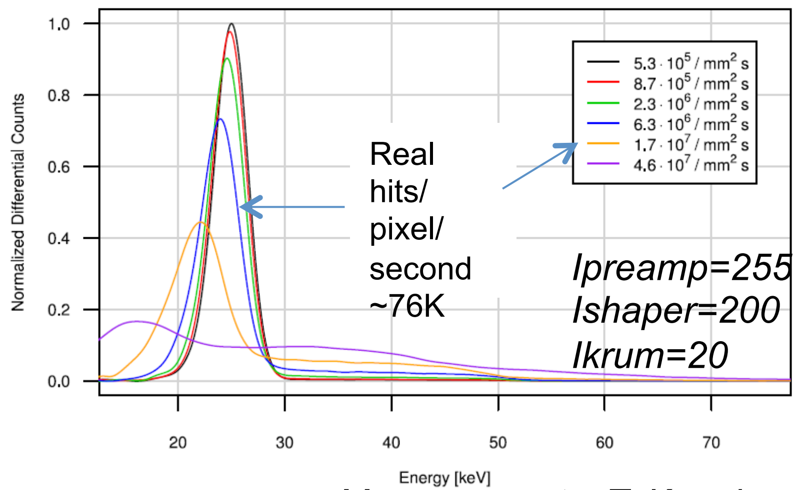


Count rate measurements



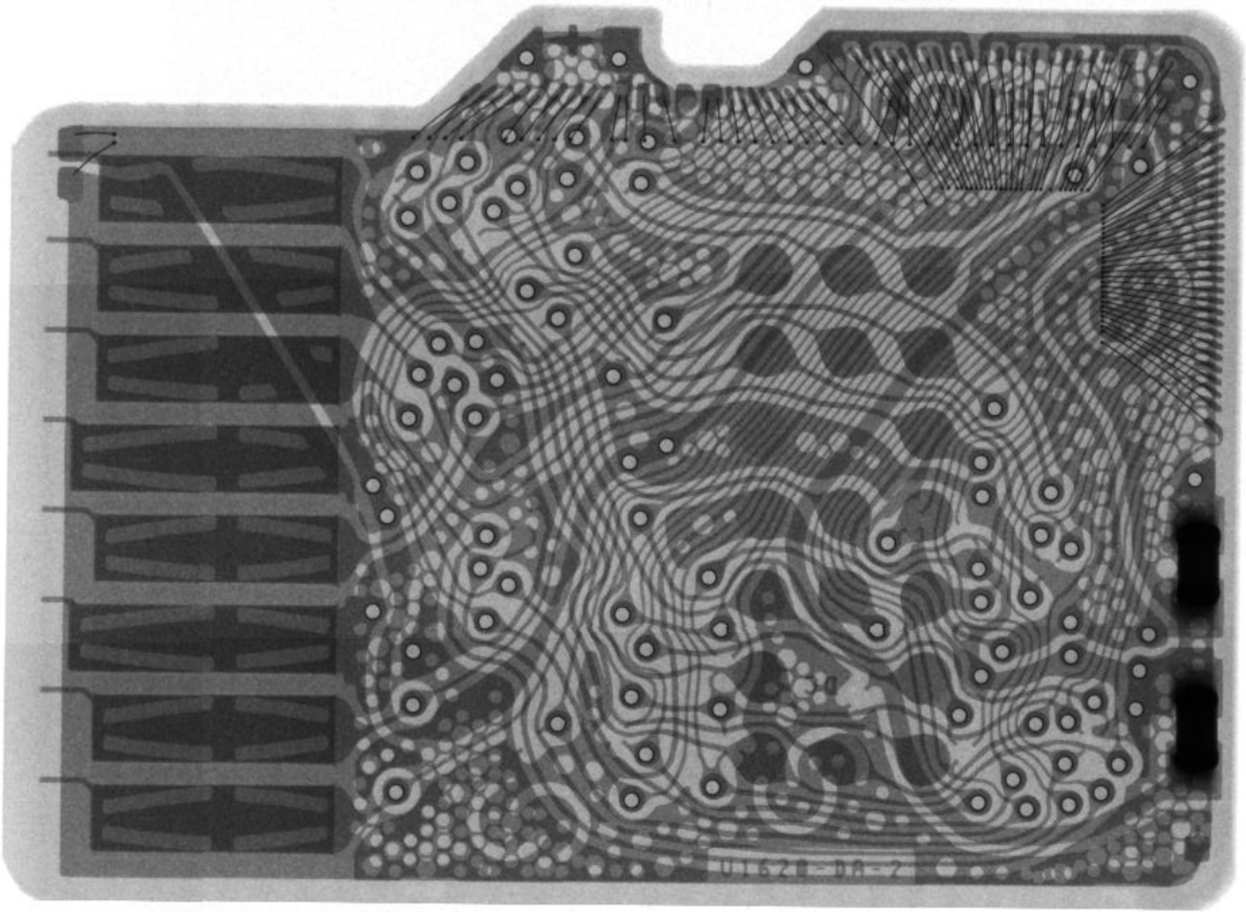






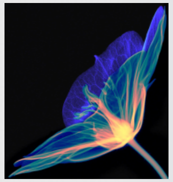
Measurements: T. Koenig

Imaging a μSD card in CSM



μSd card
4x3 tiles, magnification 3.2x
X-ray tube voltage: 30 kVp, Tube current: 100μA, 1mm Al filtering, 5s acquisition

Courtesy of S. Procz (Freiburger Materialforschugszentrum FMF, Germany)



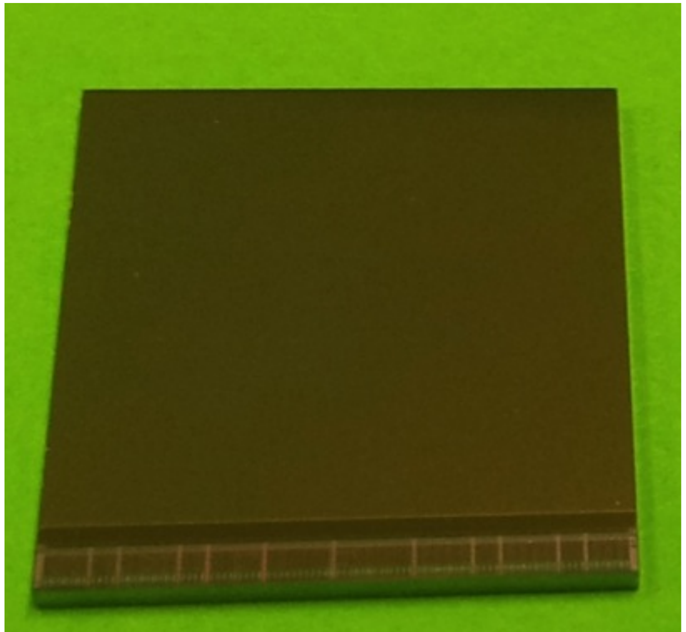
Medipix3RX electrical characterization: measurements obtained (chip with sensor)

	SPM	CSM	Units
Gain (SHGM)	25	55	e^-/DAC step
ENC (SHGM)	75	150	e^- r.m.s.
Threshold dispersion (SHGM)	37.5	85.5	e^- r.m.s.
Peaking time	120	120	ns
Power consumption	0.78	1	W/chip
Dead time/channel*	0.22/4.5	2.94/0.34	μs/MHz
Count rate*	375	28	Mc/mm^{2}s

*Measurements with CdTe, 2mm thick at 110μm pitch (paralizable model fit)

(For more details about count rate and energy spectra measurements with CdTe see T. Koenig's talk (Detectors and simulations 2))

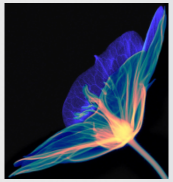
TSV processing on the Medipix3RX


MEDIPIX3 pixel side native thickness

- Through Silicon Via is a vertical electrical connection passing through a silicon wafer
- This eliminates the need for wirebonds

(Active area)/(Total die area) with wire bond connections 88.6%
(Active area)/(Total die area) TSV connections 94.3%

J. Alozy



Medipix3RX Modes of Operation

System Configuration	Pixel Operating Modes	# Thresholds
Fine Pitch Mode → 55 µm x 55 µm	Single Pixel Mode	2
	Charge Summing Mode	1+1
Spectroscopic Mode → 110 µm x 110 µm	Single Cluster Mode	8
	Charge Summing Mode	4+4
Front-end Gain Modes	**Linearity (5% deviation)**	**# Thresholds**
Super High Gain Mode	~5 ke^-	2
High Gain Mode	~9 ke^-	
Low Gain Mode	~12.5 ke^-	
Super Low Gain Mode	~18 ke^-	
Pixel Counter Modes	**Dynamic range**	**# Counters**
1-bit	1	2
6-bit	63	2
12-bit	4095	2
24-bit	16777215	1
Pixel Readout Modes	**# Active Counters**	**Dead Time**
Sequential Count-Read (SCR)	2	Yes
Continuous Count-Read (CCR)	1	No

Medipix3RX electrical characterization: measurements obtained (chip with sensor)

Gain, noise and threshold dispersion measured for two different operating points after energy calibration of the assembly. Chip with sensor 300μm Si, p-on-n.

Gain Mode	Mode	Gain (e^-/ DAC step)	ENC (e^- r.m.s.)	Threshold dispersion (e^- r.m.s.)
SHGM	SPM	37	86	55.5
	CSM	77	203	115.5
HGM	SPM	66	95	99
	CSM	142	200	213
LGM	SPM	94	106	141
	CSM	207	219	310
SLGM	SPM	123	119	184
	CSM	279	247	418

Ipreamp=60, Ishaper=90 (low power)

Gain Mode	Mode	Gain (e^-/ DAC step)	ENC (e^- r.m.s.)	Threshold dispersion (e^- r.m.s.)
SHGM	SPM	25	72	37.5
	CSM	57	148	85.5
HGM	SPM	45	80	67.5
	CSM	107	174	160.5
LGM	SPM	65	93	97.5
	CSM	155	201	232.5
SLGM	SPM	87	107	130.5
	CSM	207	233	310.5

Ipreamp=250, Ishaper=200 (high power)

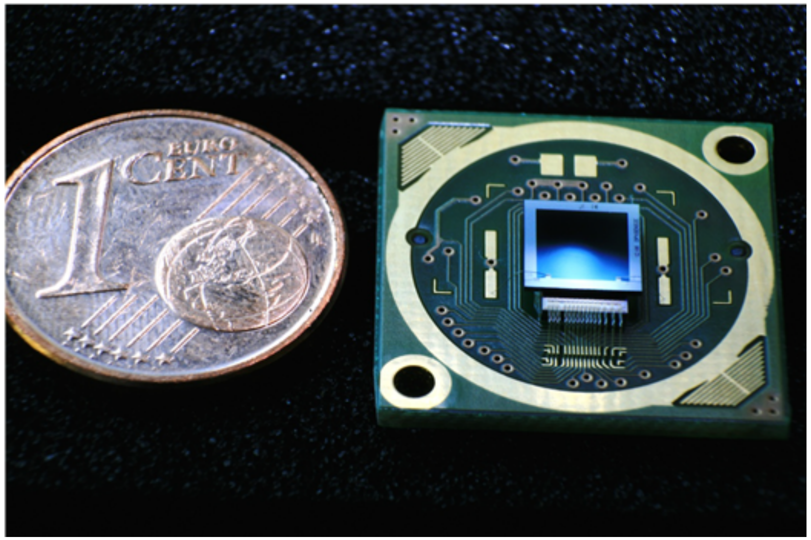
Other characteristics of the chip:
Peaking time ~120ns
Measurements with CdTe, 2mm thick at 110μm pitch show τ_{SPM}=0.22μs and τ_{CSM}=2.94μs (paralizable model fit)

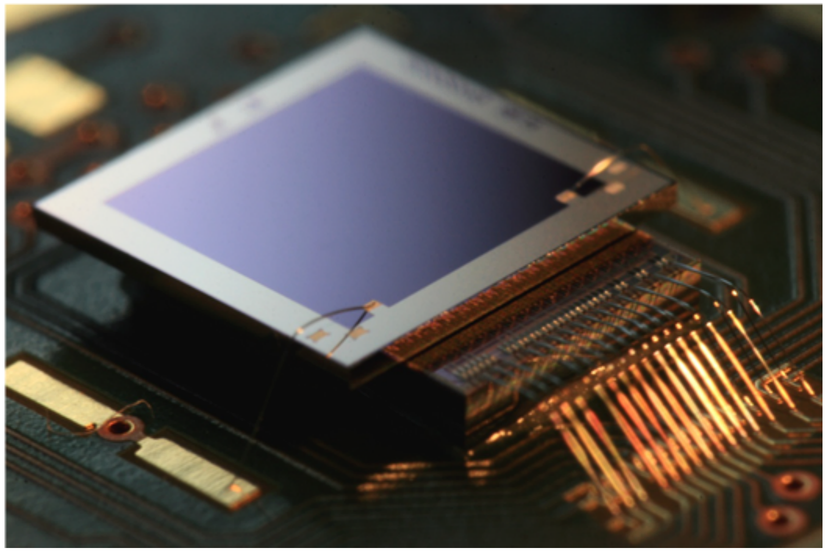
(More details about count rate measurements and measurement of energy spectra with CdTe: T. Koenig talk (Detectors and simulations 2))

Designed chips

Medipix1 (1998)	*1μm SACMOS, 64x64 pixels, 170x170μm^2* *PC / Frame based readout*
Medipix2 (2001)	*0.25μm CMOS, 256x256 pixels, 55x55μm^2* *PC / Frame based readout*
Timepix (2006)	*0.25μm CMOS, 256x256 pixels, 55x55μm^2* *PC, ToT, ToA / Frame based readout*
Medipix3 (2009)	*0.13μm CMOS, 256x256 pixels, 55x55μm^2* *PC / Frame based readout* *Event by event charge reconstruction and allocation*
Dosepix (2011)	*0.13μm CMOS, 16x16 pixels, 220x220μm^2* *ToT, PC / Rolling shutter (programmable column readout)* *Event by event binning of energy spectra (16 digital thrs)*
Timepix3 (2013)	*0.13μm CMOS, 256x256 pixels, 55x55μm^2* *PC; ToT, ToA (simultaneous)/ Data driven readout*
Smallpix	*0.13μm CMOS, 512x512 pixels, 40x40μm^2 (TBD)* *PC, iToT; ToA, ToT1 (simultaneous)/ Frame based (ZC)* *TSV compatible design*
Clicpix prototype	*65nm CMOS, 64x64 pixels, 25x25μm^2* *ToA, ToT1 (simultaneous)/ Frame based (ZC)*

Dosepix





- Developed in the framework of the Medipix2 collaboration
- Main application: dosimetry

- 16x16 pixel matrix, 220x220μm^2 pixels
- CMOS 0.13μm technology
- 15mW full chip consumption
- 1 global analog threshold

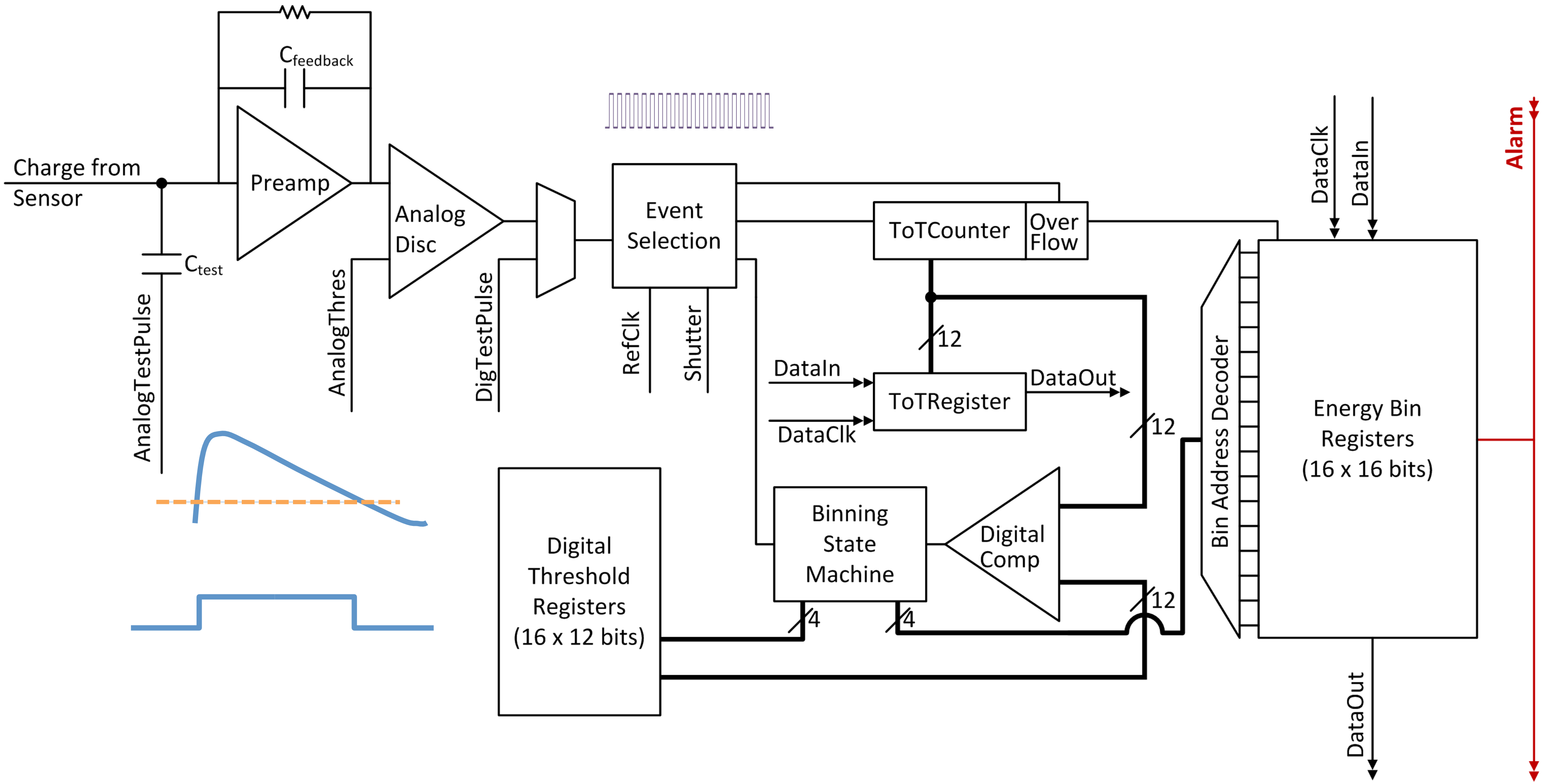
- Operation Modes:
  - Energy binning mode
    - 12 bit ToT measurement @100MHz
    - 16 digital thresholds for event-by-event energy binning
    - 16x16bit counters

  - Photon counting mode (8 bits)

  - Integral ToT (24 bits)

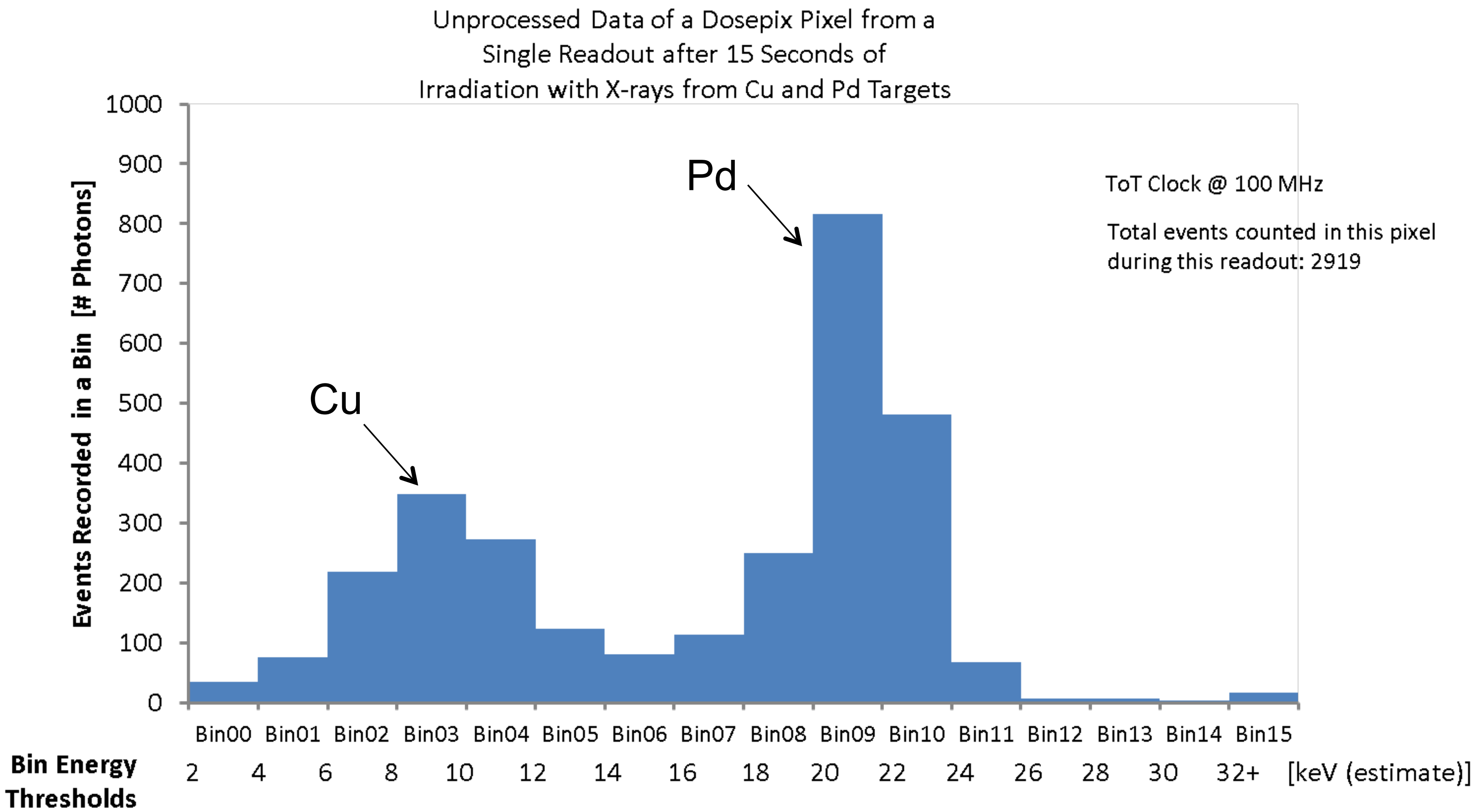
W.S.Wong et al., Electrical measurements of a multi-mode hybrid pixel detector ASIC for radiation detection, JINST 7, 2012.
doi:10.1088/1748-0221/7/01/C01056

Pixel in Dosimetry Mode



Winnie Wong

Dosepix single acquisition unprocessed data



W. Wong

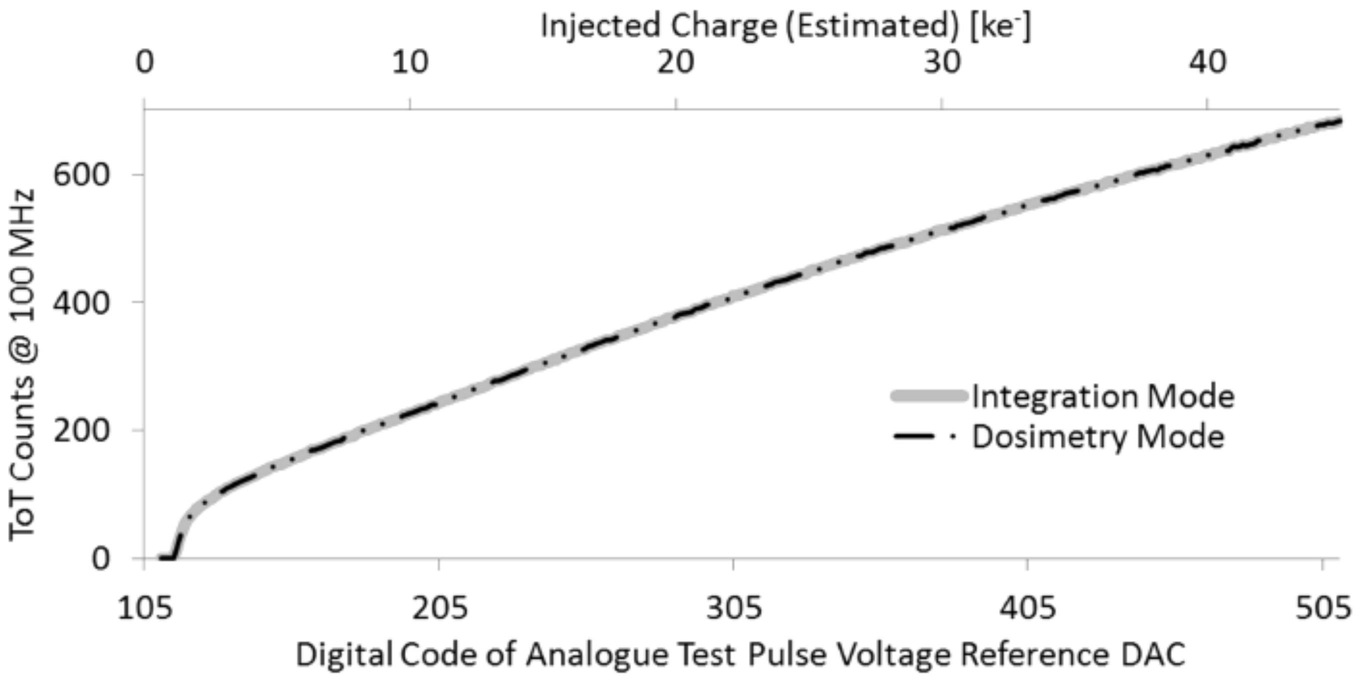


Figure 5. Time over threshold counts vs. injected charge, measured by a single pixel programmed in energy integration mode. The data shown here is the average of 20 measurements per analogue test-pulse voltage setting. The analogue threshold was set at $\sim$1.7 ke$^-$.

Designed chips

Medipix1 (1998)	1μm SACMOS, 64x64 pixels, 170x170μm^2 PC / Frame based readout
Medipix2 (2001)	0.25μm CMOS, 256x256 pixels, 55x55μm^2 PC / Frame based readout
Timepix (2006)	0.25μm CMOS, 256x256 pixels, 55x55μm^2 PC, ToT, ToA / Frame based readout
Medipix3 (2009)	0.13μm CMOS, 256x256 pixels, 55x55μm^2 PC / Frame based readout Event by event charge reconstruction and allocation
Dosepix (2011)	0.13μm CMOS, 16x16 pixels, 220x220μm^2 ToT, PC / Rolling shutter (programmable column readout) Event by event binning of energy spectra (16 digital thrs)
Timepix3 (2013)	0.13μm CMOS, 256x256 pixels, 55x55μm^2 PC; ToT, ToA (simultaneous)/ Data driven readout
Smallpix	*0.13μm CMOS, 512x512 pixels, 40x40μm^2 (TBD) PC, iToT; ToA, ToT1 (simultaneous)/ Frame based (ZC) TSV compatible design*
Clicpix prototype	65nm CMOS, 64x64 pixels, 25x25μm^2 ToA, ToT1 (simultaneous)/ Frame based (ZC)

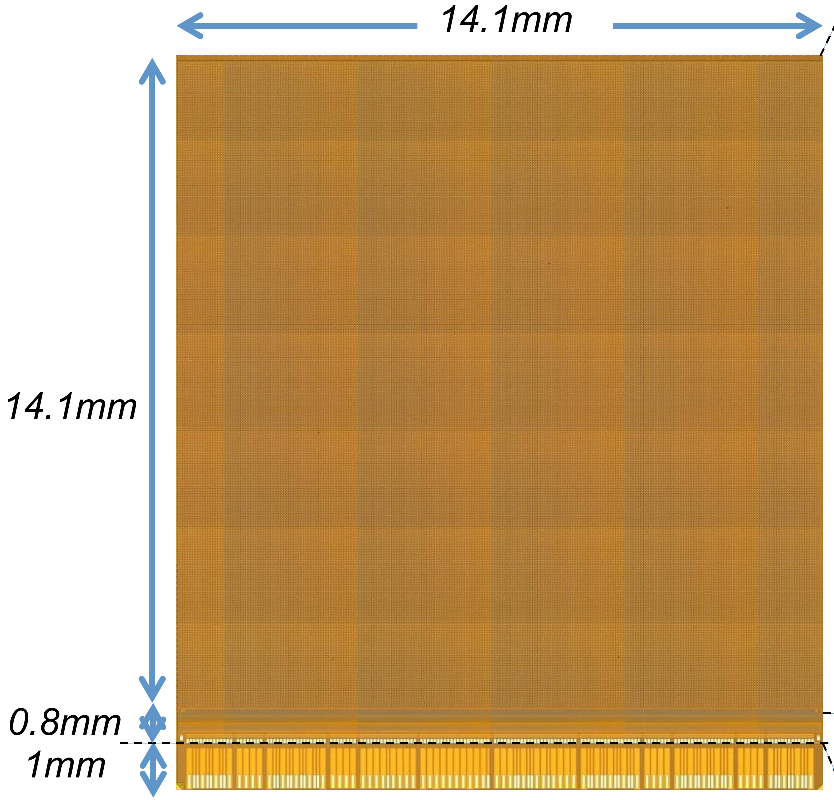
Smallpix

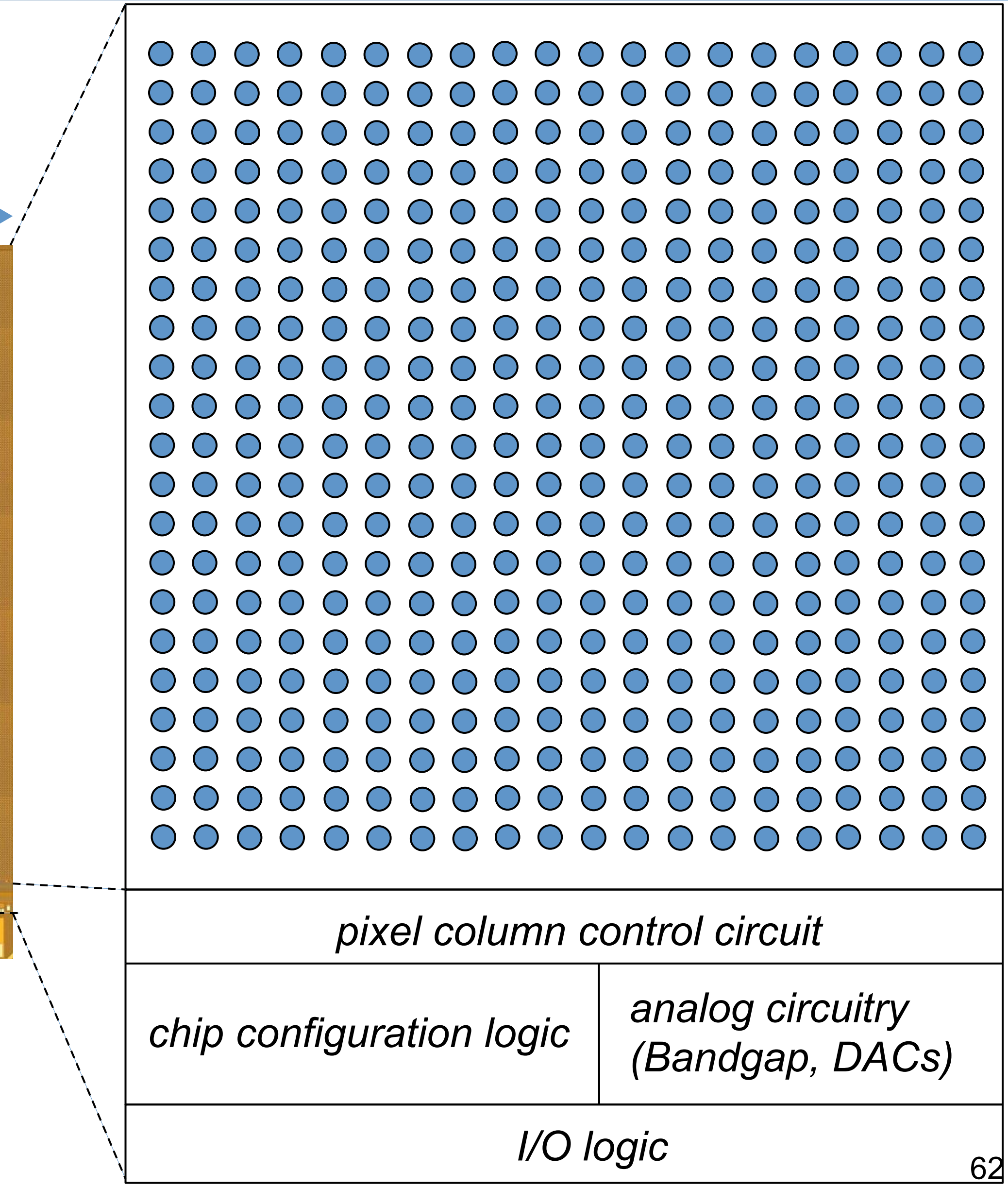
- Developed in the framework of the Medipix3 collaboration
- Applications: Particle tracking by time stamping and total deposited charge measurement (e.g. Radiation and beam monitors, dosimetry, neutron imaging)

- 512x512 pixel matrix, ~40x40μm^2 pixels
- CMOS 0.13μm technology

- Simultaneous measurement of ToA + ToT1 or PC + iToT
- Frame based readout with zero compression (on-pixel and per-column)
- Fast OR
- Shutdown/wake-up feature for the front end
- Design compatible for Through Silicon Via technology

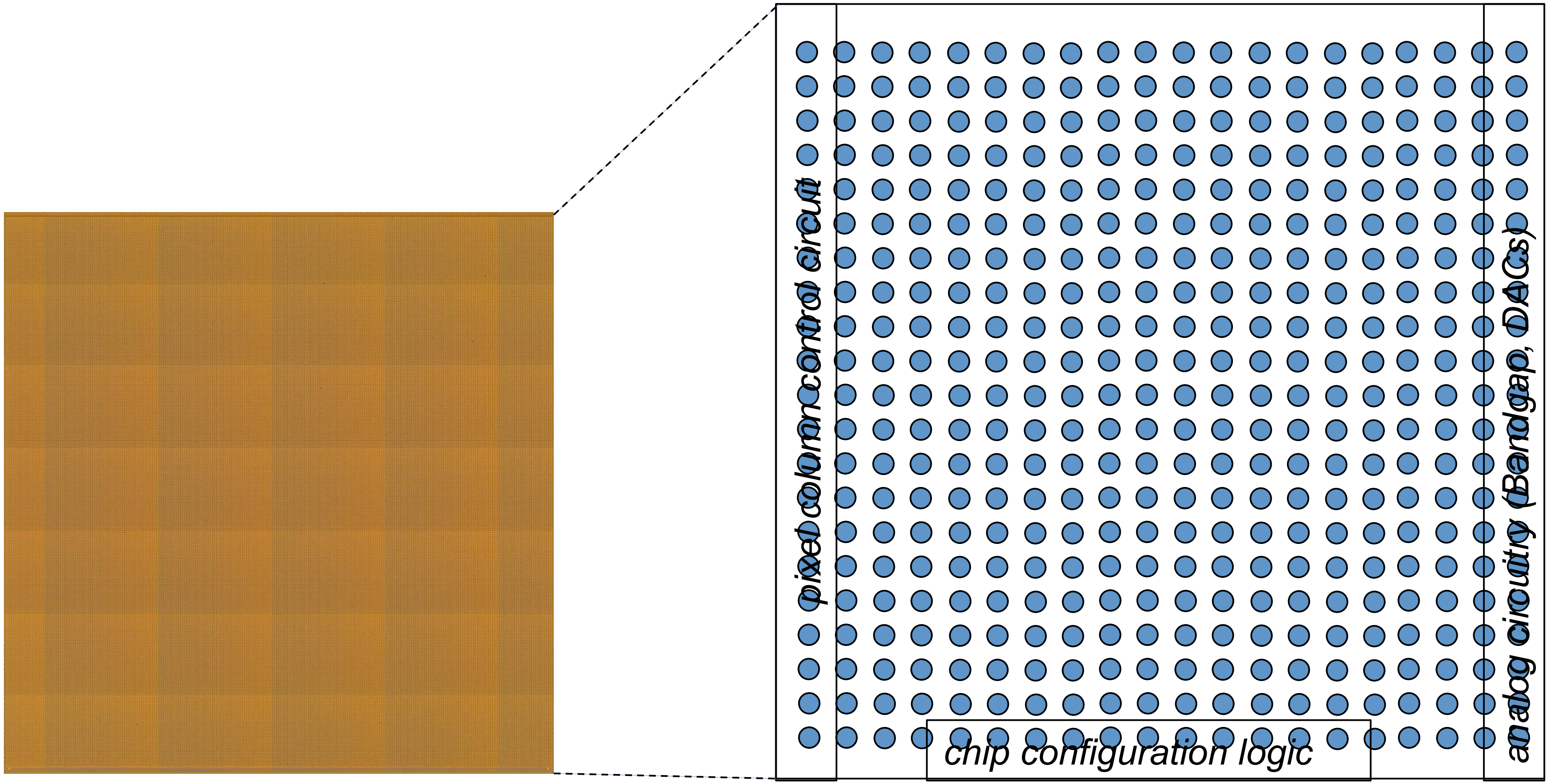
Medipix3 “classical 3-side buttable” architecture





Active area wire bond connections 88.6%
Active area TSV connections 94.3%

Smallpix architecture



Target Active area TSV connections ~100%
Chip can be tiled on 4 sides

Designed chips

Medipix1 (1998)	*1μm SACMOS, 64x64 pixels, 170x170μm^2* *PC / Frame based readout*
Medipix2 (2001)	*0.25μm CMOS, 256x256 pixels, 55x55μm^2* *PC / Frame based readout*
Timepix (2006)	*0.25μm CMOS, 256x256 pixels, 55x55μm^2* *PC, ToT, ToA / Frame based readout*
Medipix3 (2009)	*0.13μm CMOS, 256x256 pixels, 55x55μm^2* *PC / Frame based readout* *Event by event charge reconstruction and allocation*
Dosepix (2011)	*0.13μm CMOS, 16x16 pixels, 220x220μm^2* *ToT, PC / Rolling shutter (programmable column readout)* *Event by event binning of energy spectra (16 digital thrs)*
Timepix3 (2013)	*0.13μm CMOS, 256x256 pixels, 55x55μm^2* *PC; ToT, ToA (simultaneous)/ Data driven readout*
Smallpix	*0.13μm CMOS, 512x512 pixels, 40x40μm^2 (TBD)* *PC, iToT; ToA, ToT1 (simultaneous)/ Frame based (ZC)* *TSV compatible design*
Clicpix prototype	*65nm CMOS, 64x64 pixels, 25x25μm^2* *ToA, ToT1 (simultaneous)/ Frame based (ZC)*

Timepix3 chip (soon to be submitted for fabrication)

- Developed in the framework of the Medipix3 collaboration (design effort between CERN, Bonn university and Nikhef)

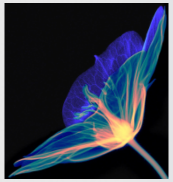
- Applications: Particle tracking by time stamping and total deposited charge measurement (e.g. Radiation and beam monitors, dosimetry, gas detectors, HEP TPC readout)

- 256x256 pixel matrix, 55x55μm^2 pixels
- CMOS 0.13μm technology

- Simultaneous measurement of ToA and ToT per event (48bits/event)
- Packet-based data-driven readout (small readout associated dead time of 375ns)
- Maximum dead time free hit rate of 40 10^6 hits/s cm^2 (randomly distributed hits)
- Programmable shutdown/wake-up feature for the front end (analog domain) and/or general clock gating (digital domain)

Pixel Requirements

Pixel size	55 μm x 55 μm
Global Time stamp (bunchID)	40 MHz (25ns)
Global Time stamp range	14bits (409.6 μs)
Accurate Time stamp per pixel	4bits → 1.56ns resolution (640 MHz)
Local Oscillator frequency	640 MHz (shared by 8 pixels)
On-pixel local oscillator tuning	Locked using periphery PLL
TOT range	10 bits (@ 40 MHz)



Pixel Operation Modes

Readout Operation Modes	Op_mode	
ToA & ToT	00	Fast Time (4b @ 640 MHz) ToA (14b @ 40 MHz) ToT (10b @ 40 MHz) Pixel coordinate 16b
		Double hit resolution: 375ns
Only ToA	01	Fast Time (4b @ 640 MHz) ToA (14b @ 40 MHz) pixel coordinate 16b
		Double hit resolution: 375ns
Event Count & Integral ToT	10	Event count 10b Integral ToT (14b @ 40 MHz) pixel coordinate 16b
		Shutter-controlled operation
		Non-continuous with Zero Suppression
		Full chip readout time: 1.6 ms @ 320MHz and 8 SLVS lines

Designed chips

Medipix1 (1998)	*1μm SACMOS, 64x64 pixels, 170x170μm^2* *PC / Frame based readout*
Medipix2 (2001)	*0.25μm CMOS, 256x256 pixels, 55x55μm^2* *PC / Frame based readout*
Timepix (2006)	*0.25μm CMOS, 256x256 pixels, 55x55μm^2* *PC, ToT, ToA / Frame based readout*
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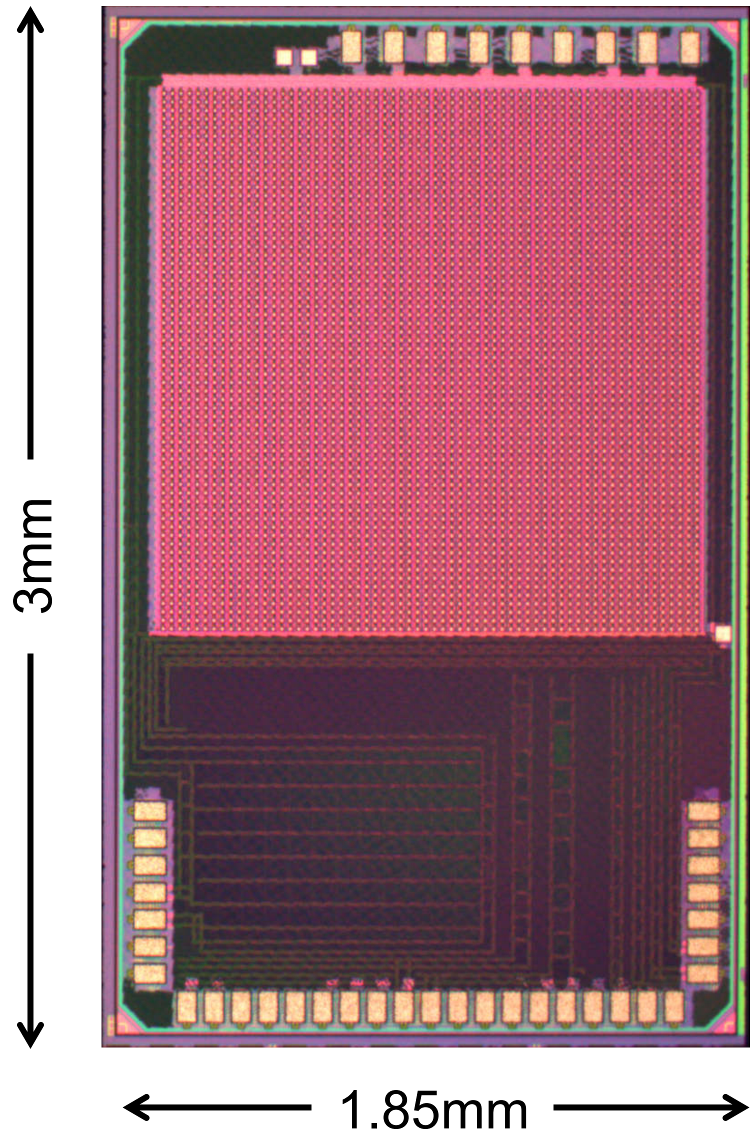
Smallpix	*0.13μm CMOS, 512x512 pixels, 40x40μm^2 (TBD)* *PC, iToT; ToA, ToT1 (simultaneous)/ Frame based (ZC)* *TSV compatible design*
Clicpix prototype	*65nm CMOS, 64x64 pixels, 25x25μm^2* *ToA, ToT1 (simultaneous)/ Frame based (ZC)*

CLICpix prototype



Designed in collaboration with the CERN Linear Collider Detector group

ASIC in 65nm CMOS technology designed to fulfill the specifications for the future CLIC vertex detector

- 25x25 μm^2 pixel, 64x64 pixel matrix
- Simultaneous 4-bit ToA and TOT measurement @100MHz
- Frame based with zero suppression
- Power pulsing

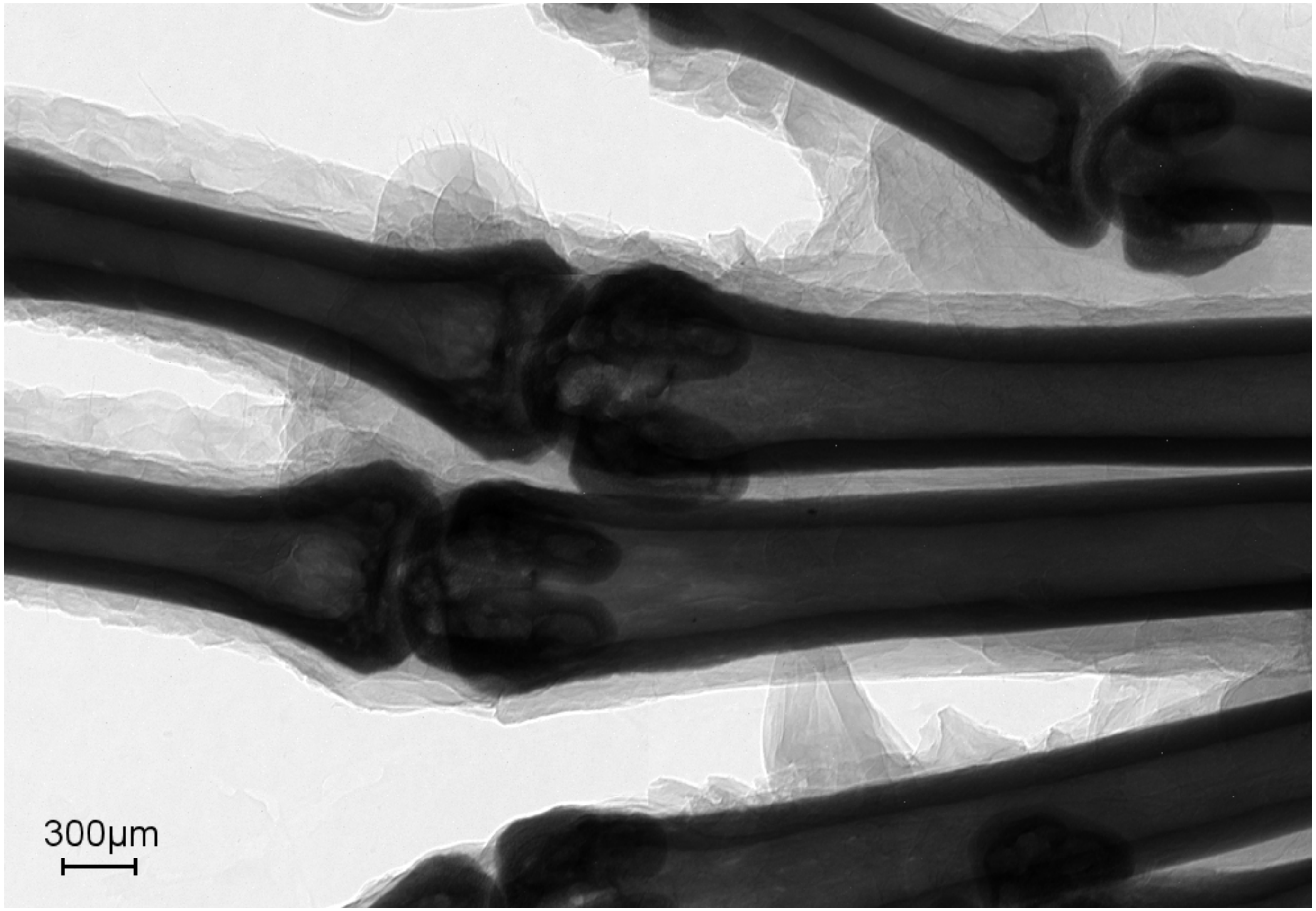
Preliminary characterization on the 65nm CMOS technology done

First prototype chip with full pixel functionality to be tested in coming weeks

Applications

The following slides contain measurements done with Medipix2, Medipix3 and Timepix chips

Imaging in Single Pixel Mode



Mouse paw 10x (25s acq / 15 tiles) (Entire dynamic range)
energy: 30 kVp, power: 3.0 W
threshold 0: 50 (DAC value)
magnification: 10x (~5µm pixel resolution)

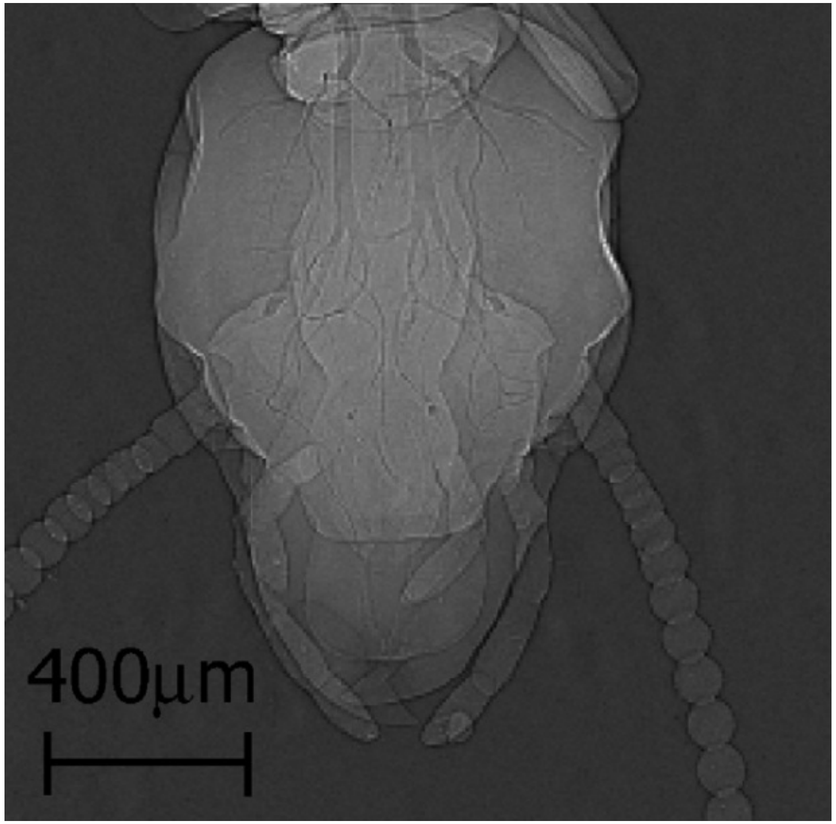
Courtesy of S. Procz *(Freiburger Materialforschugszentrum FMF, Germany*)

Imaging in Single Pixel Mode

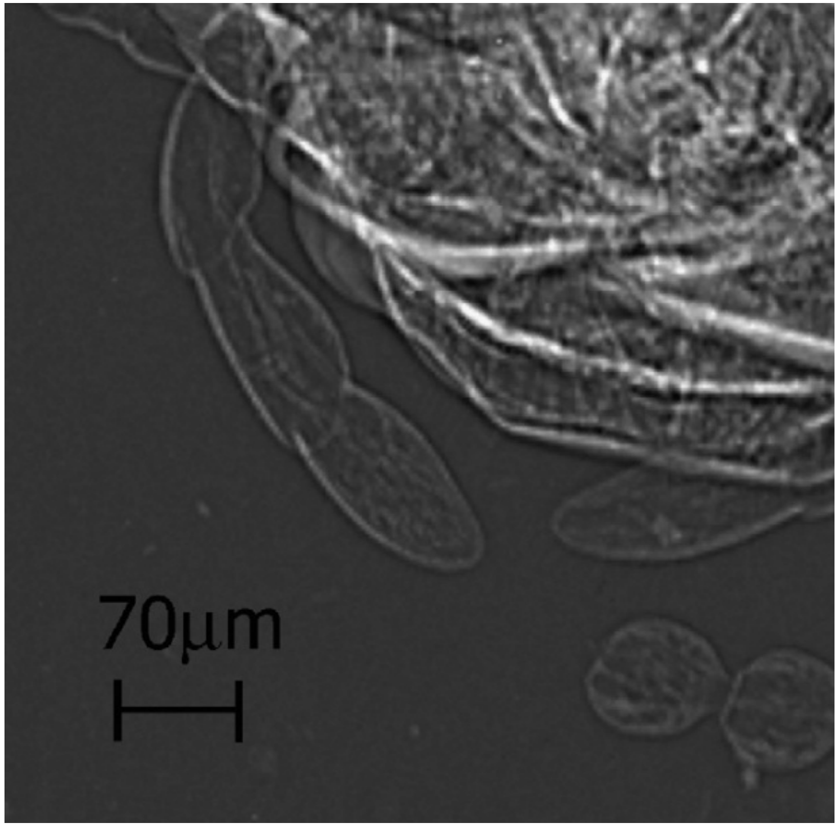
Mouse paw 10x (25s acq / 15 tiles) (High intensity part)
energy: 30 kVp, power: 3.0 W
threshold 0: 50 (DAC value)
magnification: 10x (~5µm pixel resolution)

Courtesy of S. Procz *(Freiburger Materialforschugszentrum FMF, Germany*)

Soft tissue imaging



X-ray image of a termite head.



Detail of termite note the phase contrast enhanced edges making visible fine structure of soft tissue inside the palpus and antenna.

J. Jakůbek et al., NIM A 571 (2007)

<u>First CT reconstruction with CdTe Medipix3 detector</u>

MPX3 55µm
CdTe 1mm

5x4 tiles

CT scan courtesy of S. Procz (Freiburger Materialforschugszentrum FMF, Germany)

Energy selective, planar imaging
MPX3 CdTe 1mm - Spectroscopic Mode 110µm

Piezo Lighter

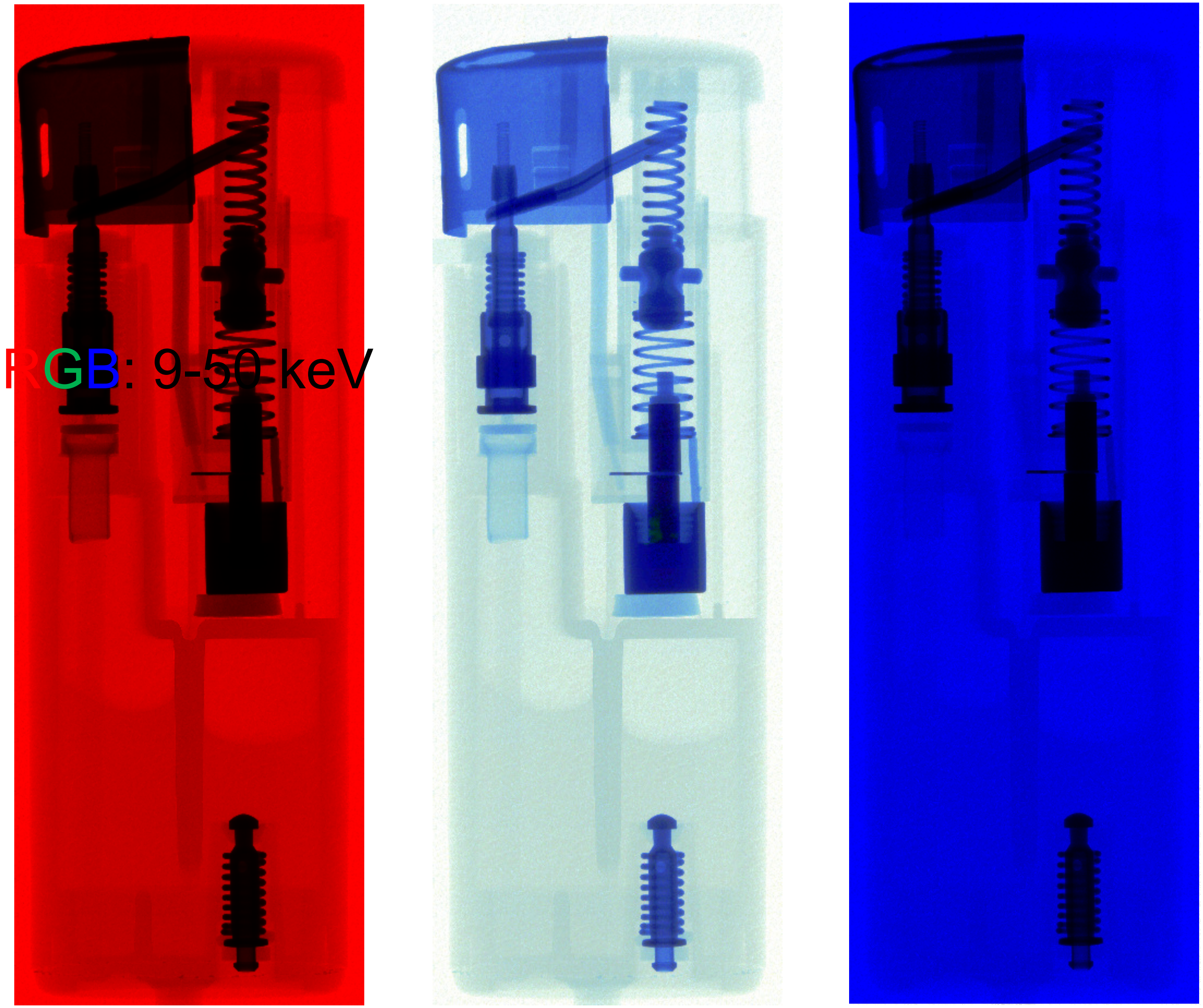
Magnification: 1.3x

Bias: -320V

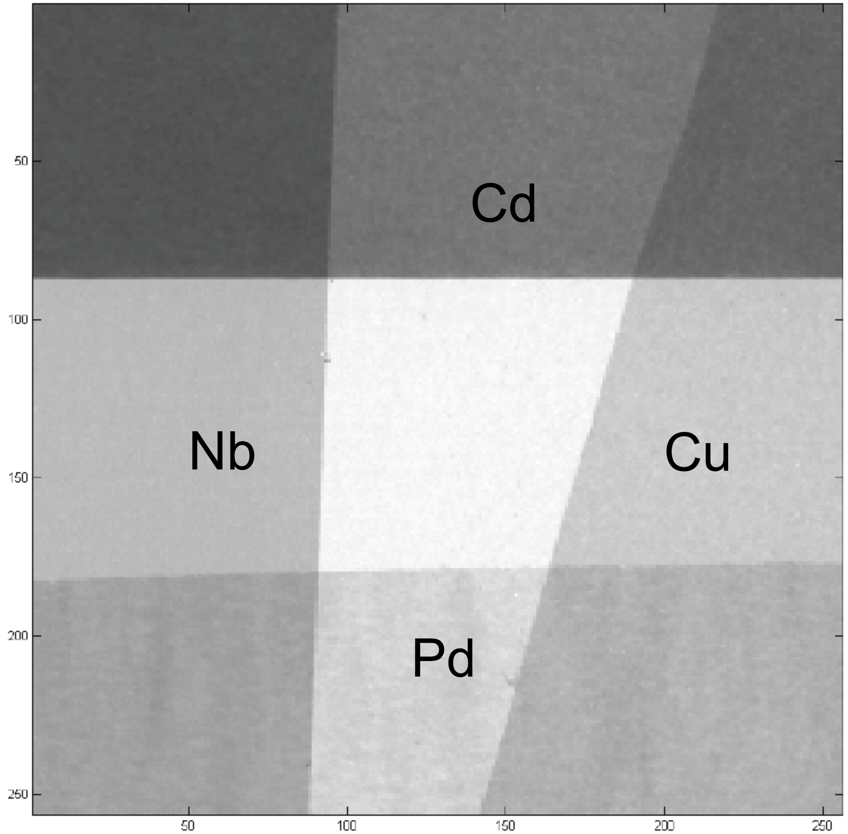
MPX3 CdTe 1mm
Color Mode
4x11 tiles

1 acquisition, 4 thresholds

Courtesy S. Procz



Colour X-ray imaging

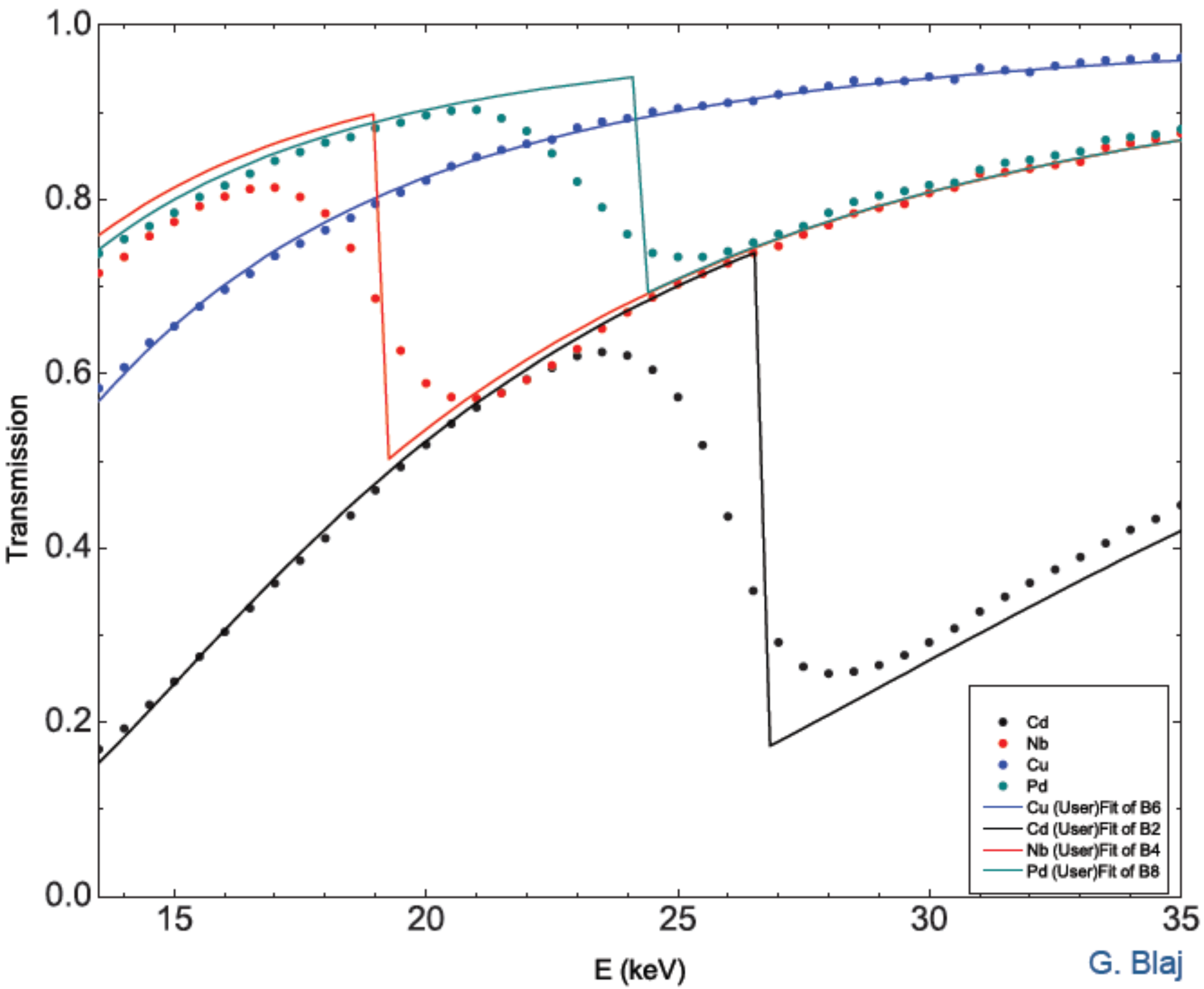


Classical X-ray image: impossible to distinguish between absorption of different materials and absorption of different thicknesses

Colour X-ray image: pixel spectroscopy + multiple thresholds allow material separation

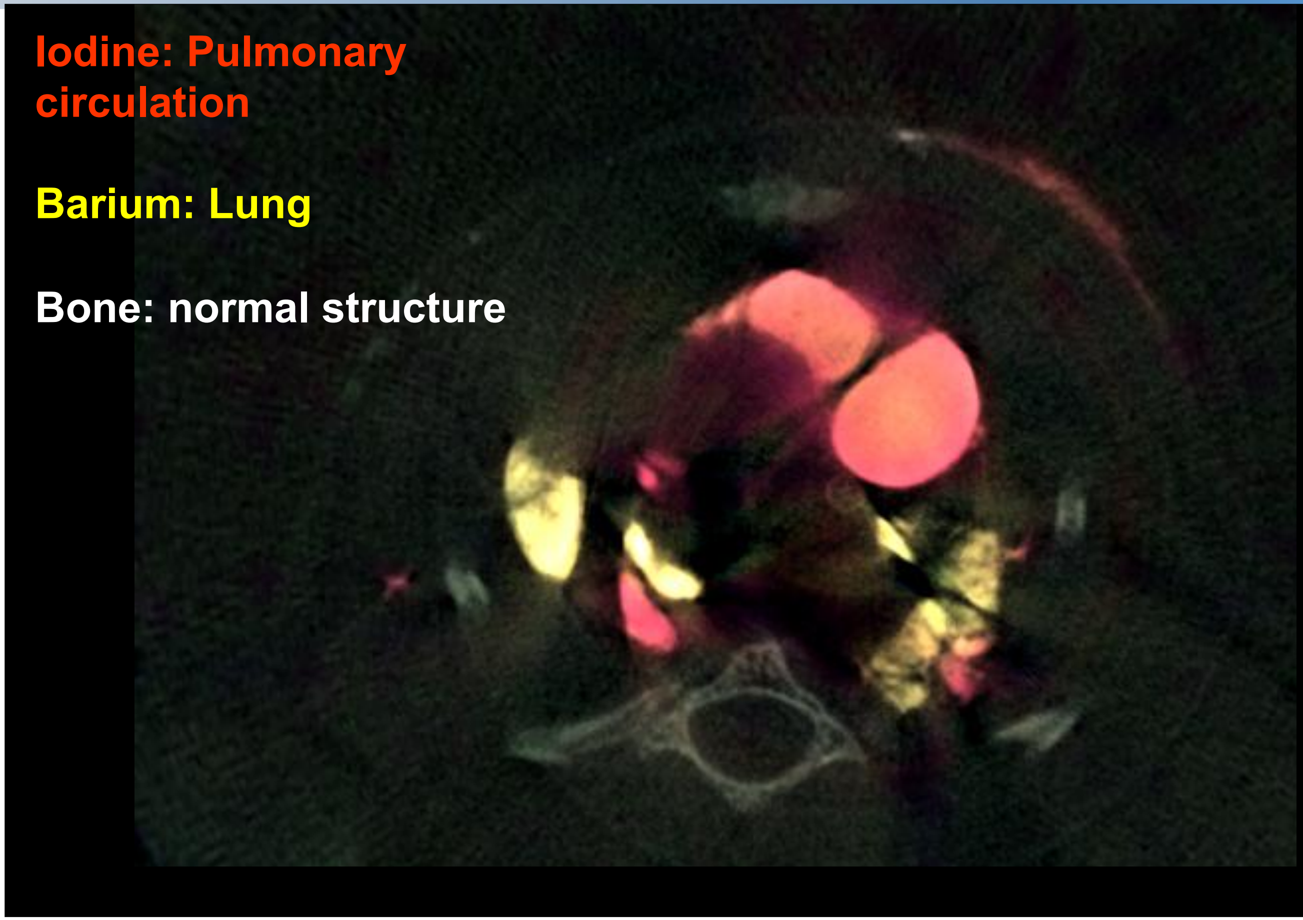
Colour X-ray imaging

- Measured Spectra (dots) vs
- Theoretical model (lines)
  - Excellent agreement
- 2 Routes:
  - Multispectral imaging (several thresholds, fast)
  - Spectroscopic Imaging (accurate)



G. Blaj

Spectroscopic Colour Imaging

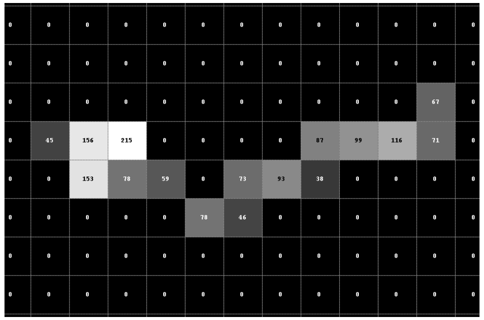


Courtesy: A. Butler

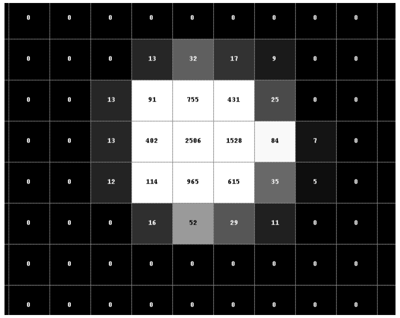
Basic Particle Identification

- Mixed radiation fields poses problems for dosimetric measurements.
- An advantage of a pixelated detectors is that particles can be identified by their track shape.
- This is based on the different ways the particles interact in the sensor.

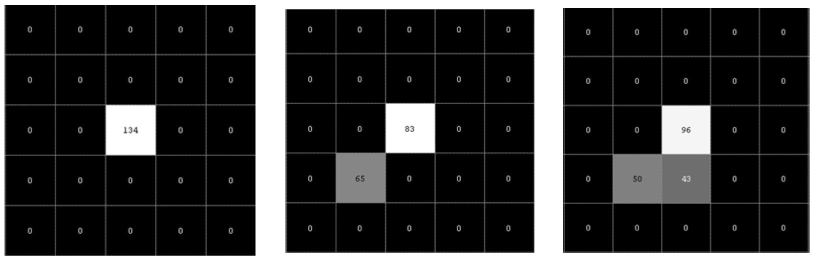
Basic Particle Identification



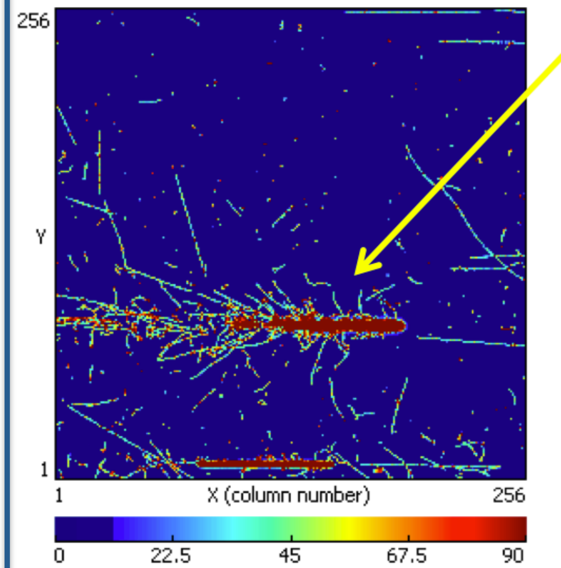
0.5MeV Electron (^{90}Sr)



5.5MeV Alpha (^{241}Am)



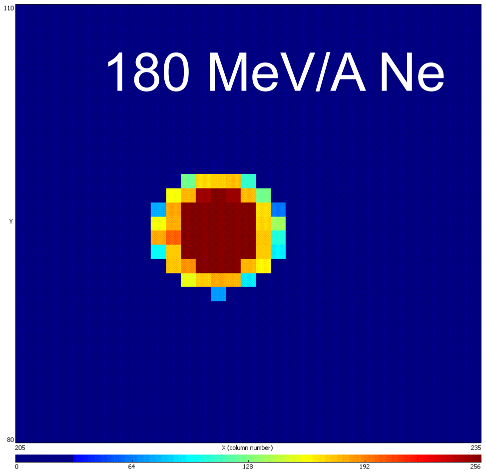
60keV Photons (^{241}Am)

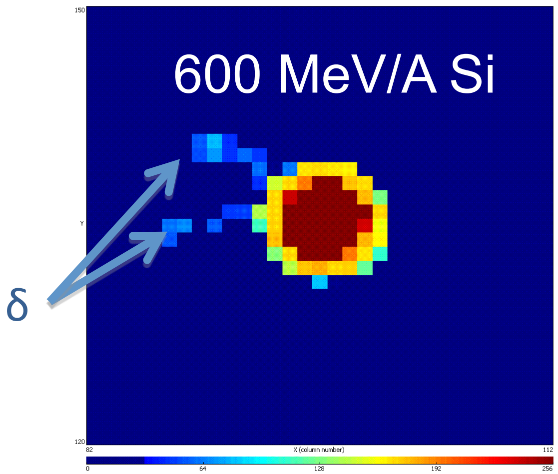


Pb ion with delta rays
Erik Heijne [2]

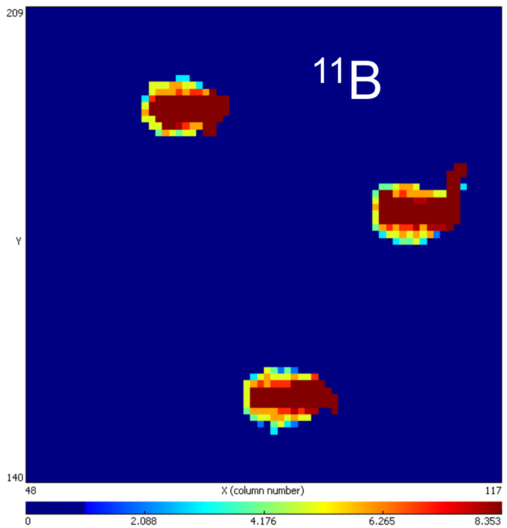
Basic Particle Identification

0°

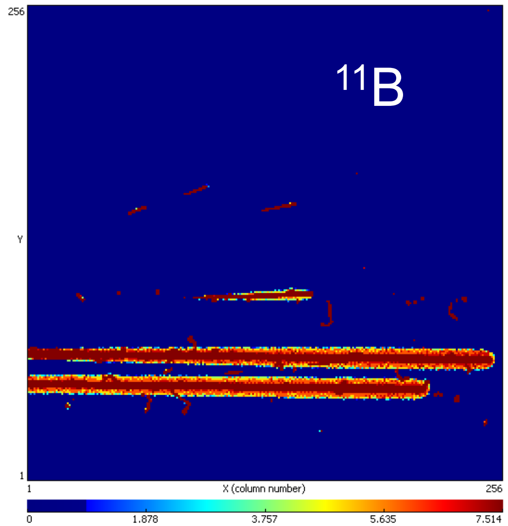




60°



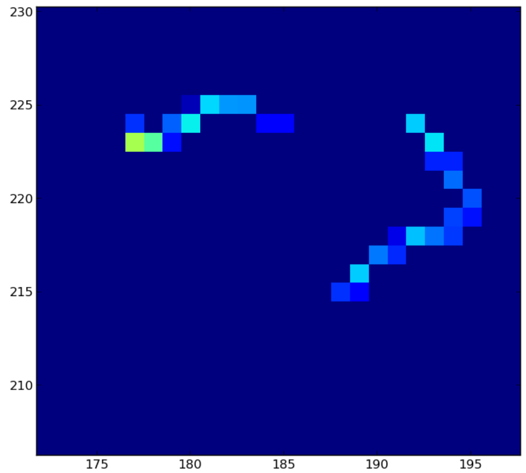
90°



L. Pinsky et al., Proc. IEEE Aerospace Conf., 2007.

Basic Particle Identification

- **Possible to categorize particles using track and energy information**
- **Some types of particles are hard or impossible to separate**
- **Additional convertors and filters improve the detection specificity**



β^- radiation or Compton electrons?

Neutron Detection

- Neutron have no charge and are therefore not directly detectable by Coulomb interactions in the sensor.
- Thermal neutrons are detected by the production of secondary radiation by neutron capture in a convertor layer
- Ex. n + 6Li $\rightarrow$ α (2.05 MeV) + 3H (2.73 MeV)
- Fast neutrons can be detected by elastic scattering in the sensor layer but for increased efficiency and specificity a hydrogen rich converter material as Poly ethylene is used.

Neutron Detection

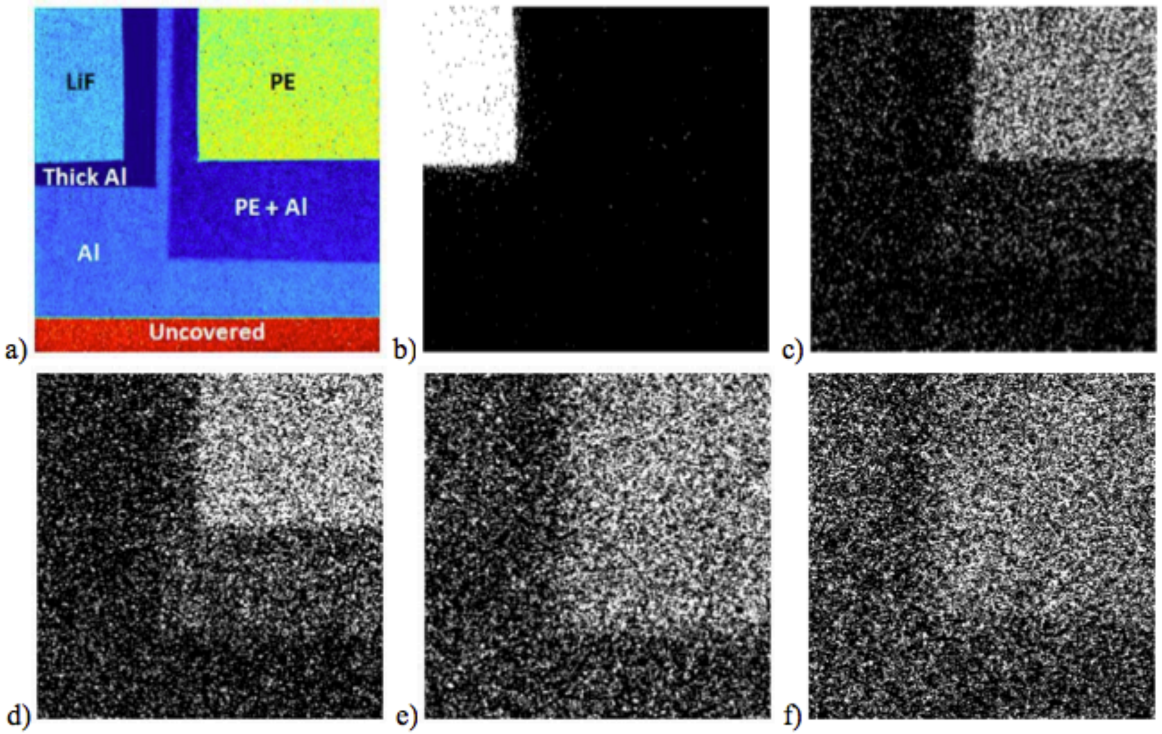
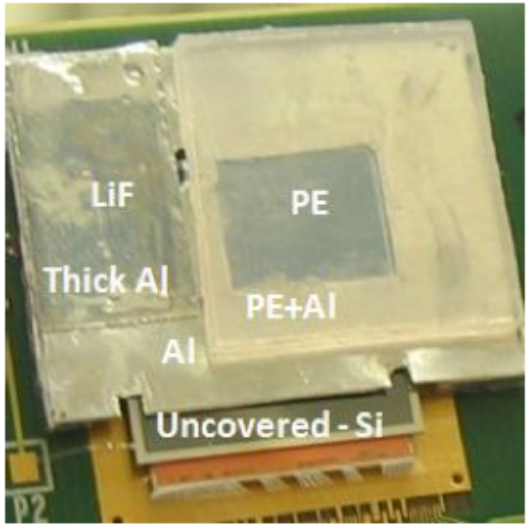


Figure 50. a) X-ray radiogram of conversion layers above one of the ATLAS-MPX devices. Integrated response of the device set to high threshold mode to b) thermal neutrons (25 meV) and to fast neutrons of c) ^{252}Cf (2.1 MeV); d) ^{241}AmBe (4.5 MeV); e) Van de Graaff accelerator (14 MeV) and f) cyclotron (2 - 30 MeV).

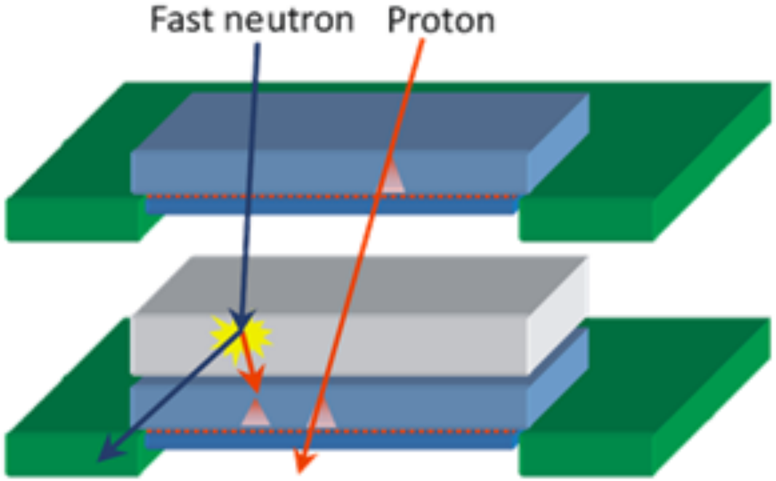


Medipix2MXR with different convertors.

Work done by Z. Vykydal [1]

Improved Neutron Detection

- To separate heavy charged particles form neutron response test have been made with a multi layer detector.
- Interactions registered in both layers
  - Low LET signatures – minimum ionizing charge particles (muons, energetic electrons,...)
  - High LET signatures – highly ionizing charged particles (~10 MeV protons,...)
- Interactions registered in single layer only
  - Low LET signatures – photon interactions in one of the sensitive layers
  - High LET signatures – fast neutron interactions in polyethylene region or thermal neutron interactions in 6Li region



Example of particle identification using a two layer detector

Work done by Z. Vykydal [1]

ATLAS-MPX Network

- 16 Medipix2MXR detectors with neutron convertors
- Placed in the ATLAS experimental cavern
- Installed in 2008 before the first LHC beam
- Proposed upgrade to Timepix detectors

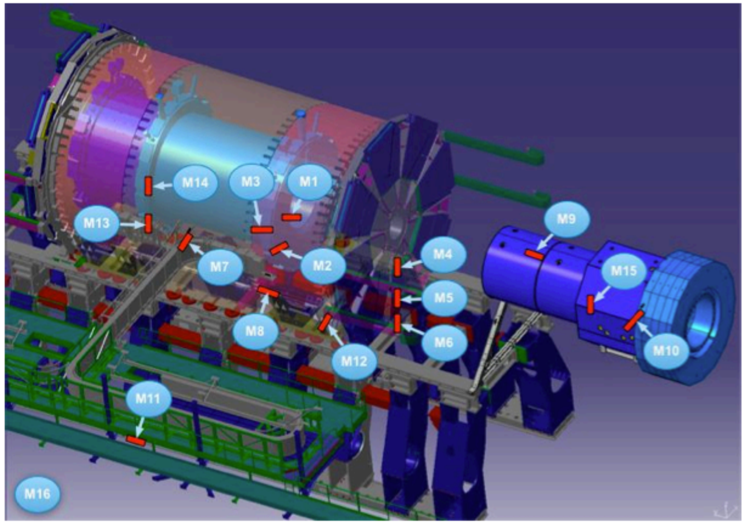
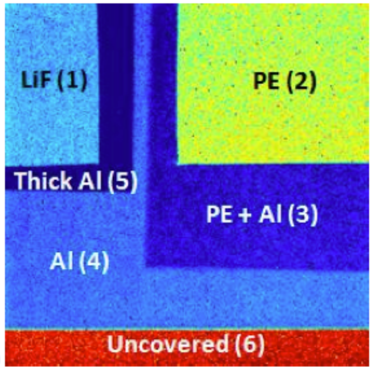
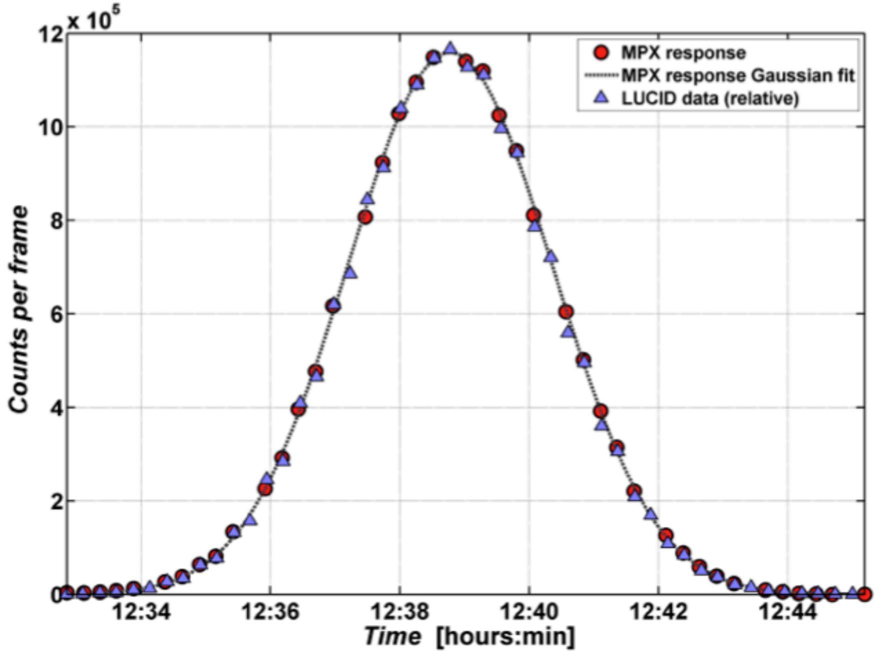


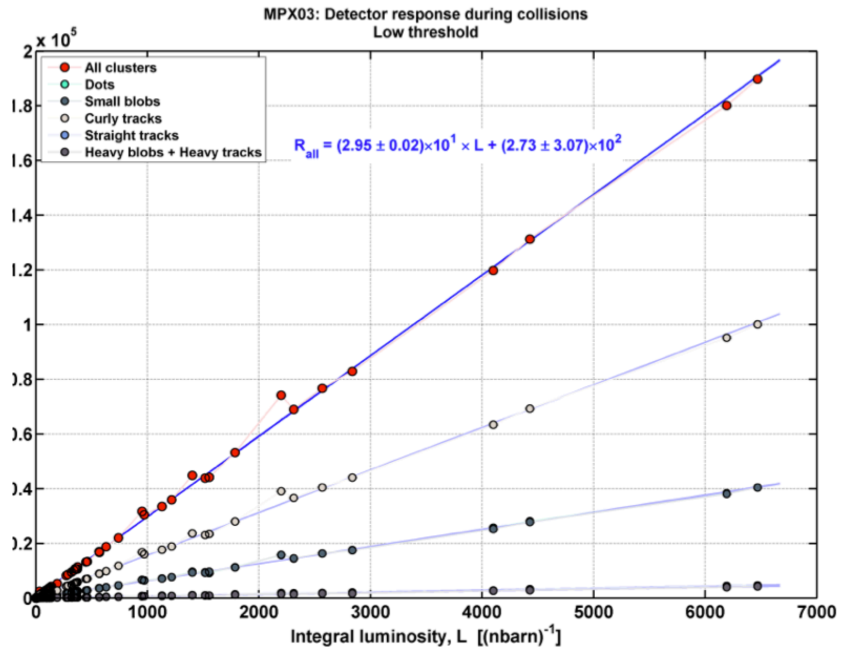
Figure 34. The network of ATLAS-MPX detectors in ATLAS.



Work done by Z. Vykydal [1]

ATLAS-MPX

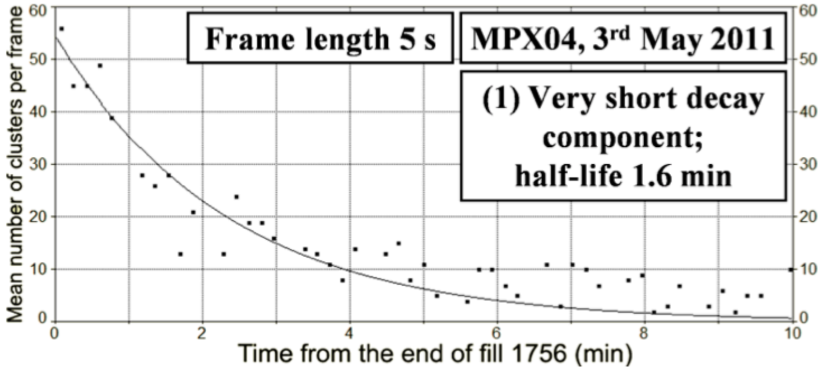




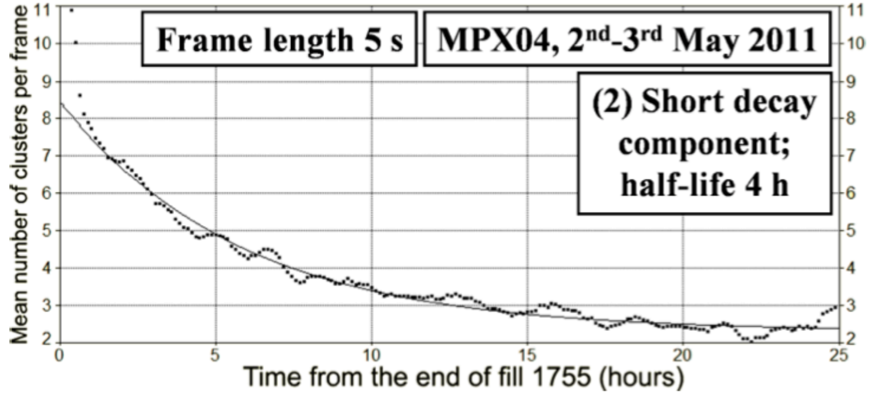
Good agreement with beam luminosity and other instruments

Work done by Z. Vykydal

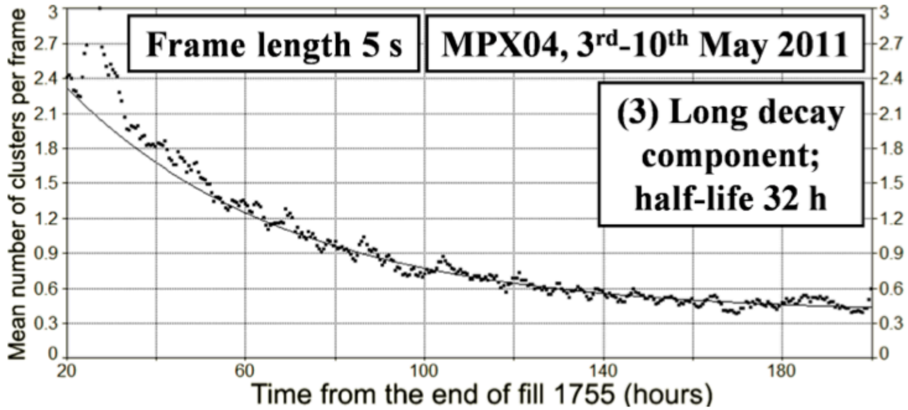
Radioactive Activation



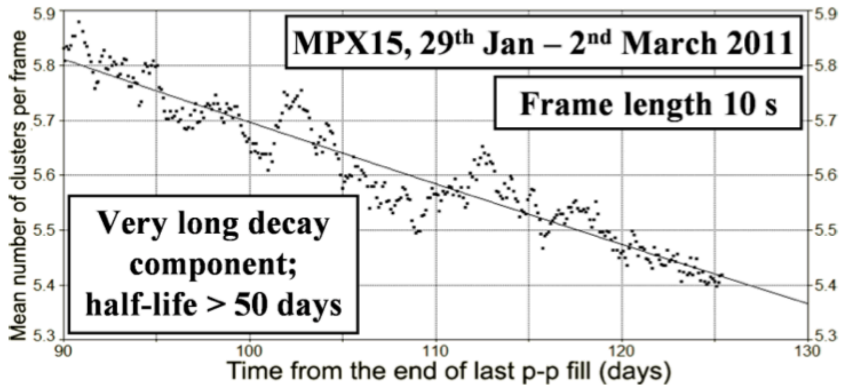
a)



b)



c)

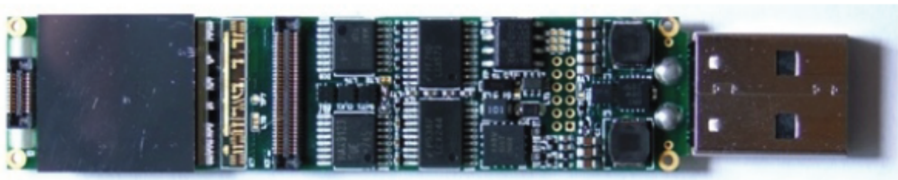


d)

Work done by Z. Vykydal [1]

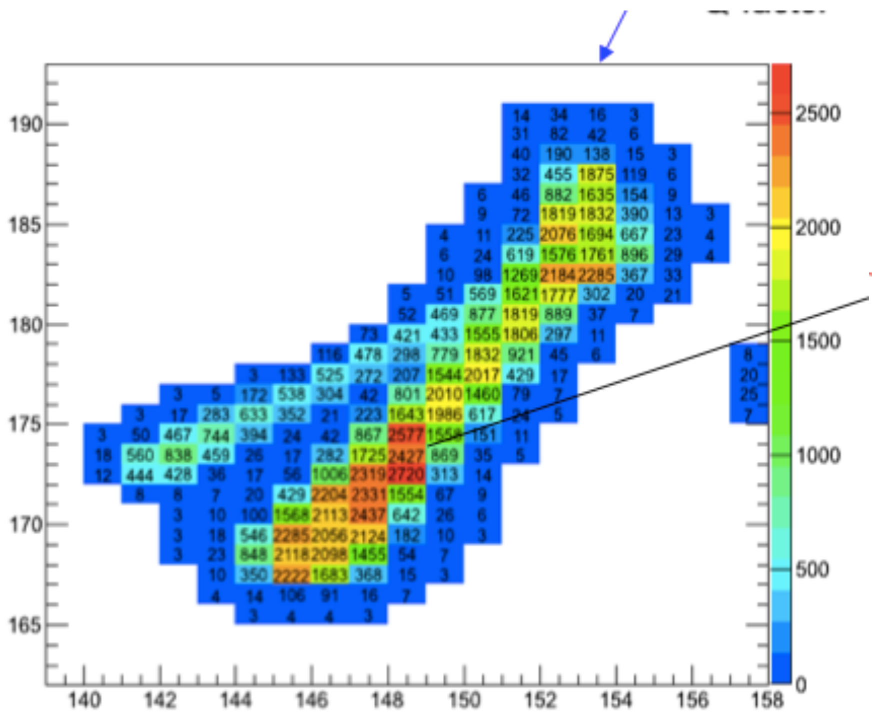
Timepix Detectors at ISS

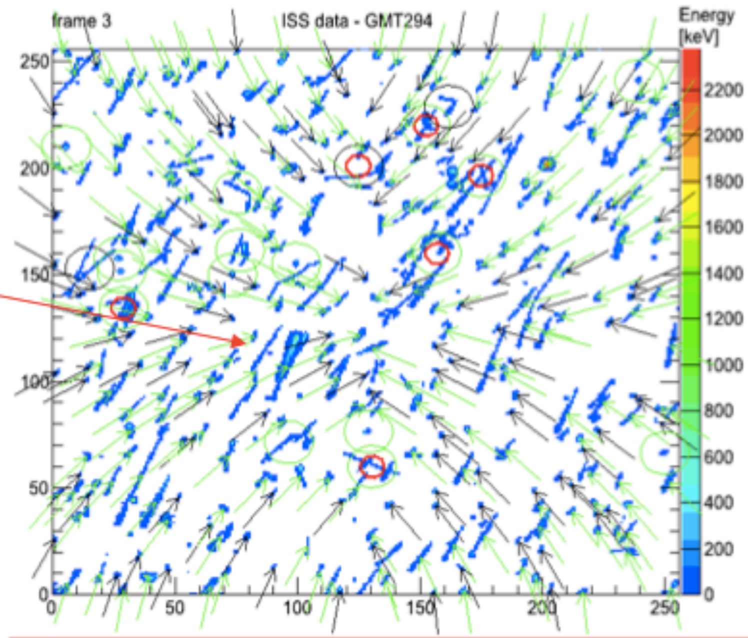
- 5 Timepix Usb Lite detectors with 300um Si sensors are currently in operation at the ISS
- Evaluated as an option for radiation field monitors and personal dosimeters
- Mixed radiation field
- Important to get the right quality factor for heavy ions




EMERGENCY USE
FIRE PORT
NOD1P3_H1
KAVANDI
UF-1

Timepix Detectors at ISS



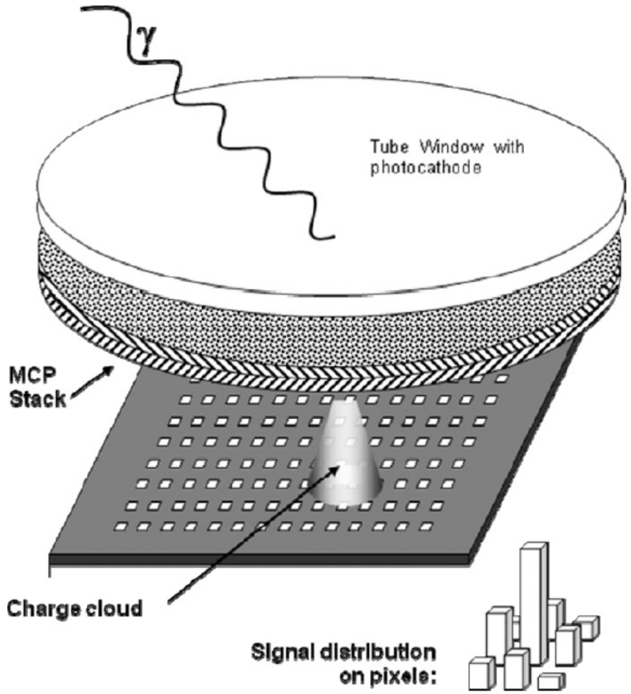


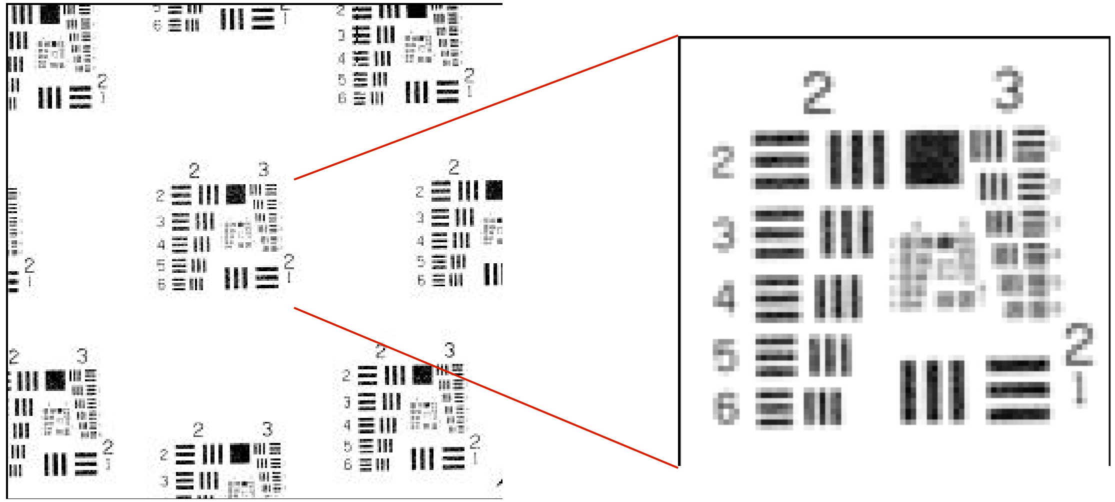
Heavy fragment found in a very busy frame.

Heavy Ion fragment, Q factor ~ 25

Demonstration

Detection of low energy particles

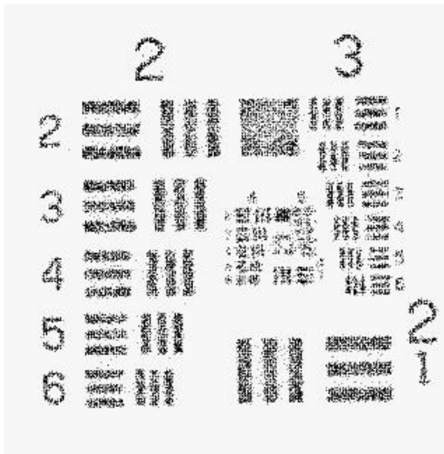




1 s

Group 3-2 visible 9 lp/mm = 55µm

(Nyquist limit)



Calculate centroids of each event

16 lp/mm

Particle tracking with Micromegas

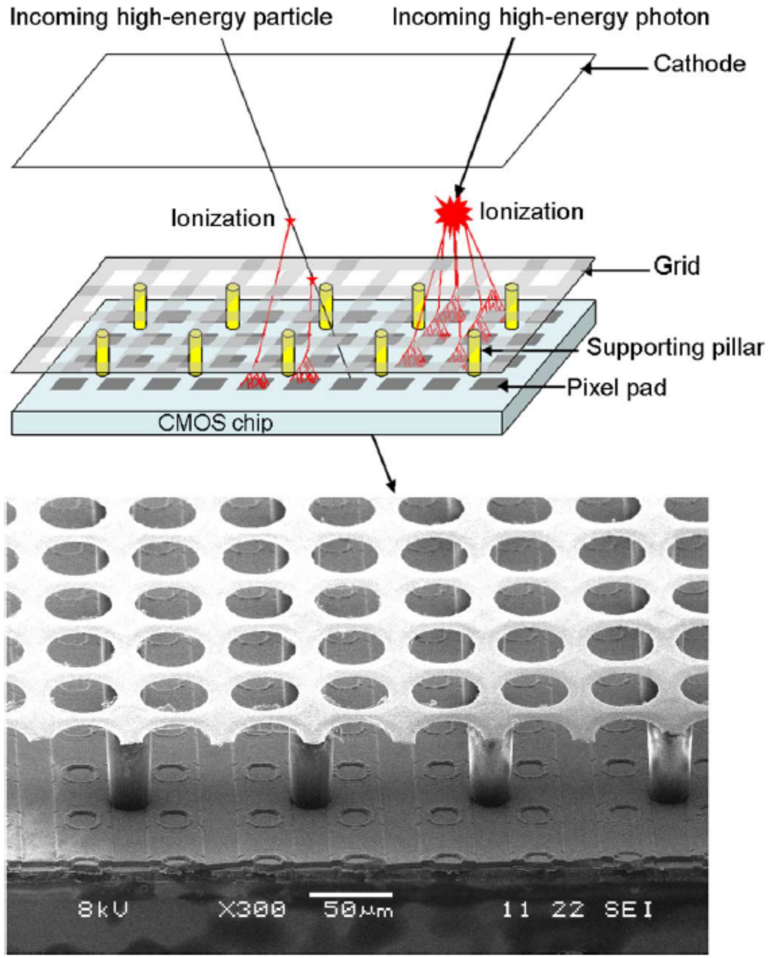


Fig. 1. (Top) Schematic view of the detector. An ionizing particle creates several free electrons that drift toward the CMOS chip and create an avalanche between the grid and the chip. (Bottom) SEM picture of an integrated device.

moderate field (1kV/cm)

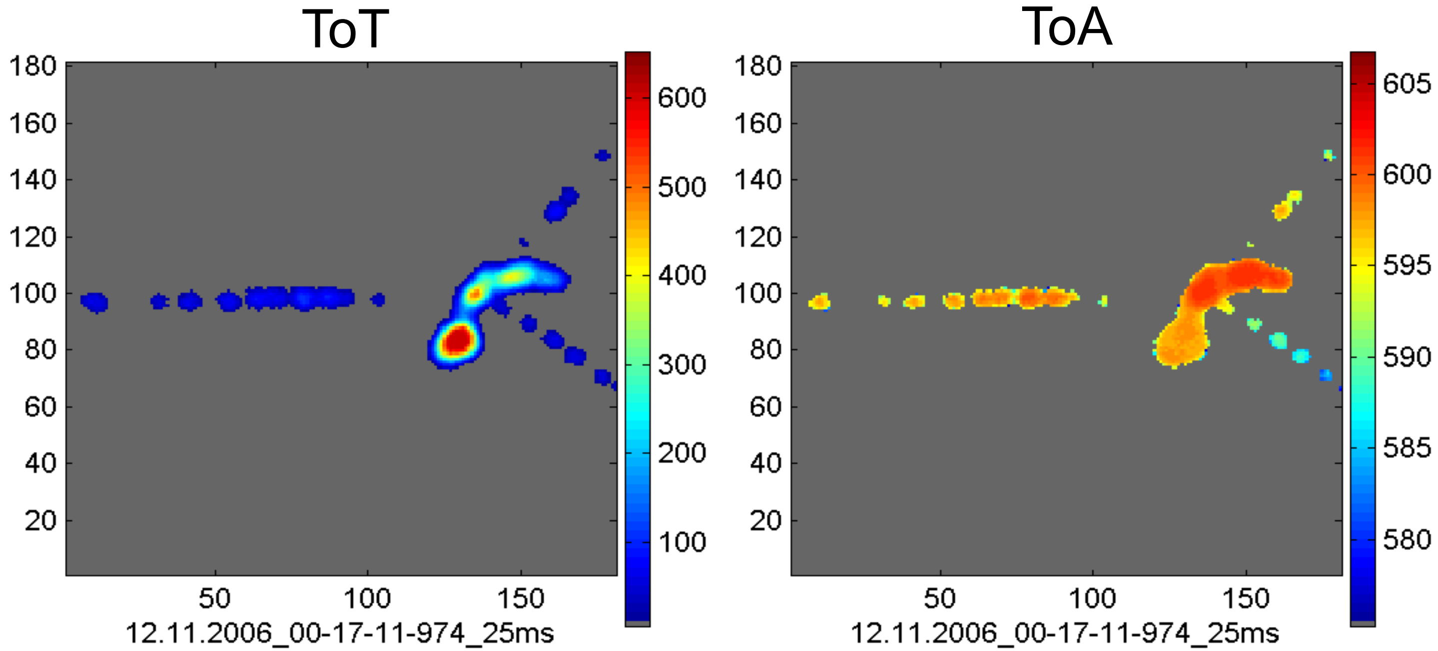
High electric field ~100kV/cm (Avalanche region)

Abstract—An unpackaged microchip is used as the sensing element in a miniaturized gaseous proportional chamber. This letter reports on the fabrication and performance of a complete radiation imaging detector based on this principle. Our fabrication schemes are based on wafer-scale and chip-scale postprocessing. Compared to hybrid-assembled gaseous detectors, our microsystem shows superior alignment precision and energy resolution, and offers the capability to unambiguously reconstruct 3-D radiation tracks on the spot.

Carvallo et al. IEEE electron device letters, Vol. 29, No. 6, June 2008

Particle tracking with GEMs

ToT	ToA	ToT	ToA	ToT	ToA	ToT	ToA
ToA	ToT	ToA	ToT	ToA	ToT	ToA	ToT
ToT	ToA	ToT	ToA	ToT	ToA	ToT	ToA
ToA	ToT	ToA	ToT	ToA	ToT	ToA	ToT
ToT	ToA	ToT	ToA	ToT	ToA	ToT	ToA
ToA	ToT	ToA	ToT	ToA	ToT	ToA	ToT
ToT	ToA	ToT	ToA	ToT	ToA	ToT	ToA
ToA	ToT	ToA	ToT	ToA	ToT	ToA	ToT

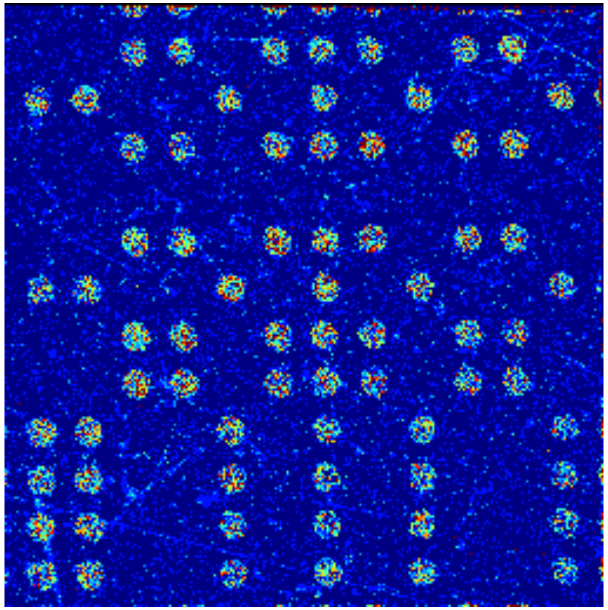


A. Bamberger et al., DESY testbeam, 2006

Gamma imaging

GAMPIX developed by CEA-LIST for localization of hot spots of radioactivity

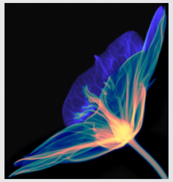
- **CdTe for detection of 59 keV (^{241}Am) – 1,25 MeV (^{60}Co)**



Raw image for ^{241}Am (A=74 Mbq at 1 meter, T=30 min)

Superposition with visible image

M. Gmar et al., NIM A 652 (2011)



Summary and Conclusions

- Medipix (1,2,3) is a successful collaboration using technology from high energy physics for other applications
- The strength of the collaboration is the diversity of users
- The project is completely self funded
- Medipix is now finding its way back into HEP