Large-Area CdTe Detector for X-ray Imaging and Overcoming Crystal Imperfections in CdTe Sensors

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International Workshop
26th iWoRiD
on Radiation Imaging Detectors

Funded by
the European Union

Programme **Trend**

T A
C R

OUTLINE

> **X-ray imaging with single-photon counting detectors**

> **Medipix-family detector and its key characteristics**

> **Large-Area CdTe Detector**
> > Introduction + Parameters
> > Large-Area X-ray Imaging

> **Detection stability improvement**
> > Hardware approach = Bias pulsing technique
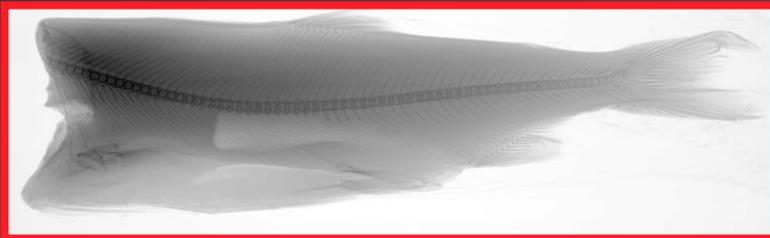> > Software approach = AFF correction

X-RAY IMAGING RADIOGRAPHY WITH SINGLE-PHOTON COUTING DETECTORS

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> ## Imaging parameters
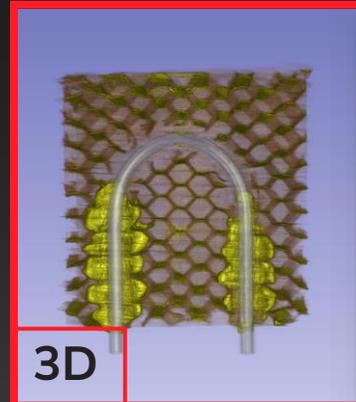
> Photon counting => ultra high contrast

> High spatial resolution

> Ultra high dynamic range

> High signal-to-noise ratio

> Multichannel => material sensitivity

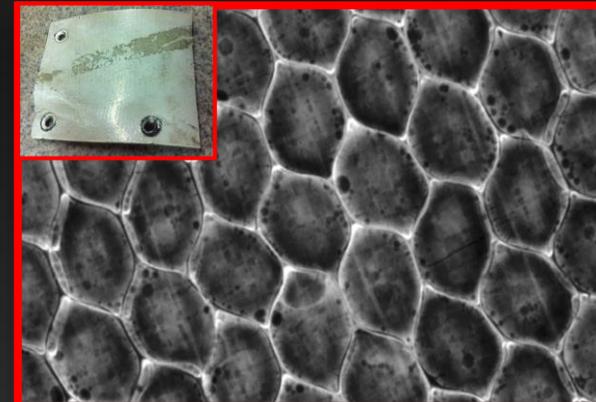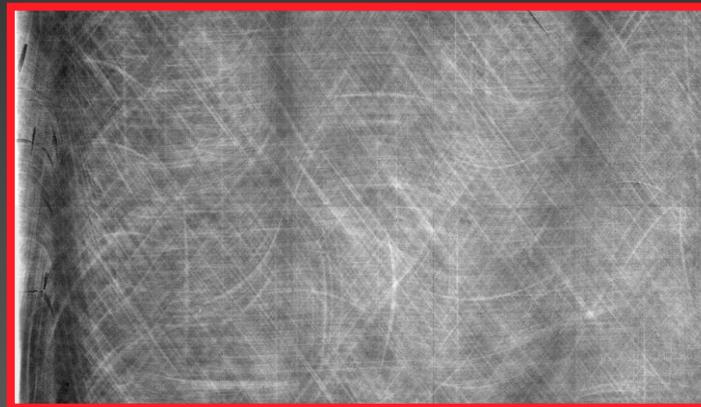**Excellent imaging properties!**

Food safety

3D

NDT: Composite defectoscopy

Medicine
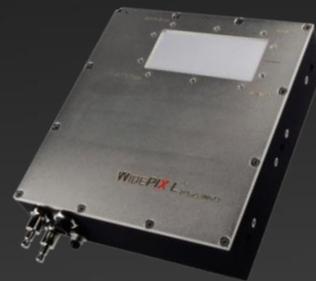

NDT: Detection of fiber undulations

Paintings

MEDIPIX-FAMILY DETECTORS FOR X-RAY IMAGING

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> Technology based on CERN CMOS chips developed within MEDIPIX consortia.

> **Very high signal to noise ratio**

> Single photon counting

> Direct conversion:

>   **COUNT & ENERGY**

> Signal is digital => very high speed

> High resolution: sub 55 μm

> Ultra high dynamic range

> **Energy sensitive imaging**

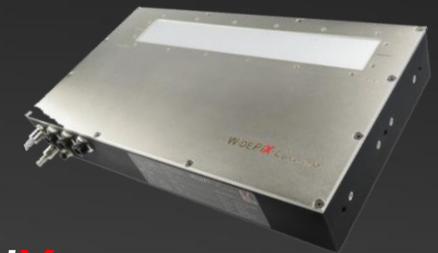> Continuous operating modes for zero deadtime scanning implemented in hardware.
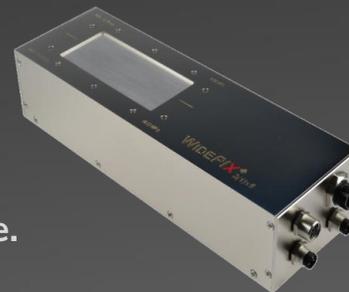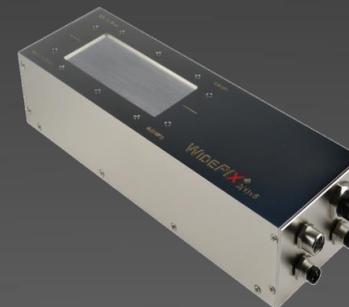
WIDE*PIX* L$_{1X5}$

WIDE*PIX* L$_{1X10}$

WIDE*PIX* L$_{1X15}$

WIDE*PIX* $_{1X5}$

WIDE*PIX* $_{2X5}$

WIDE*PIX*$_{5X5}$
1280x1280

KEY FEATURES OF THE WIDEPIX 5×5 MPX3

DIMENSIONS and CONNECTIVITY

Dimensions:	139.5 x 119 x 227.2 mm
Weight:	4910 g
Connectivity:	5xEthernet
Software:	Pixet Pro

> ## Sensor Configuration
> > 5×5 array of Medipix3 chips (70 x 70 mm, 1.6 Mpixels) => ideal for imaging large areas.

> ## Sensor Material and Thickness
> > CdTe 1000 μm.

> ## Readout Speed = Frame Rate
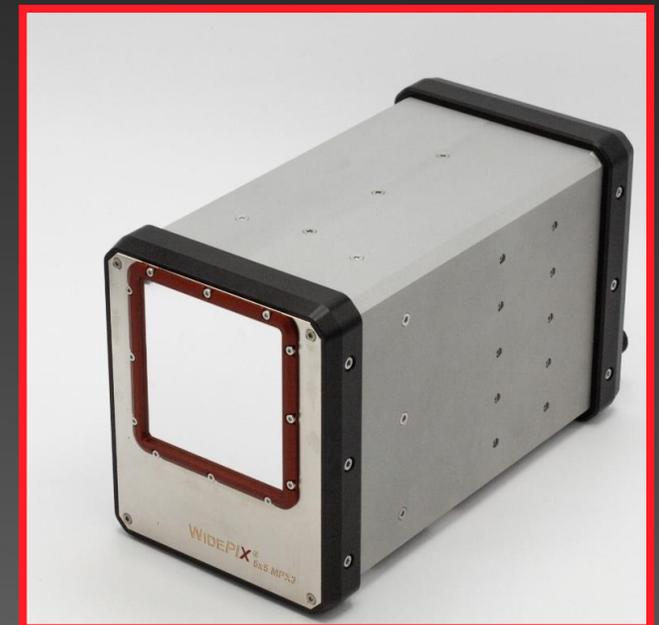> > Capable of capturing up to 170 frames per second (fps).

> ## Data Streaming
> > Designed for high-speed data transmission (3.3 Gbit/s).

> ## Dynamic Range
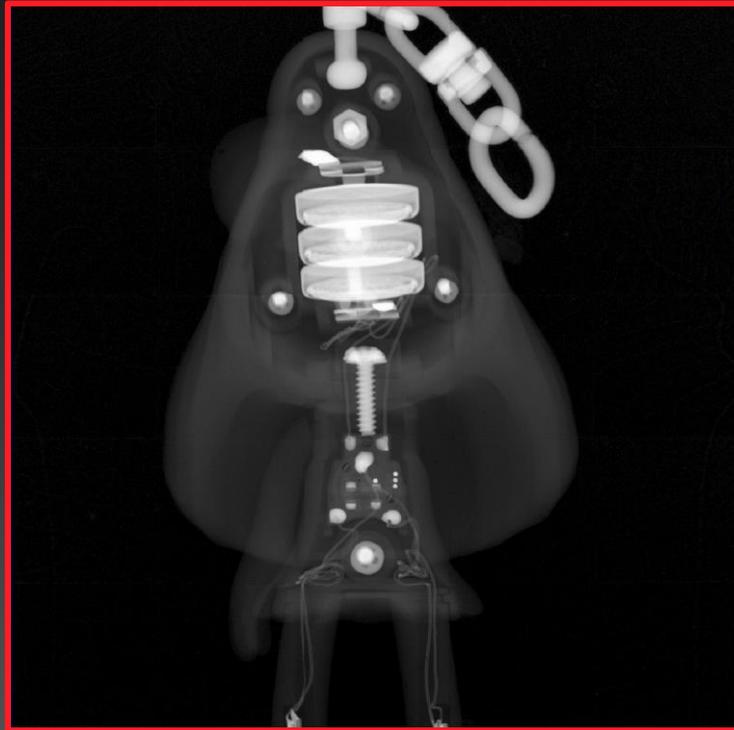> > Offers outstanding dynamic range, making it effective in imaging scenarios with both low and high signal intensities.

MULTICHANNEL „COLOR" RADIOGRAPHS

Can you take a picture?

Standard X-ray

Material sensitive X-ray

Illustration of multichannel "color" radiographs where different materials are identified and imaged in different colors.

APPLICATIONS SUITABILITY OF WIDEPIX 5X5 MPX3

Color X-ray radiography

> **Medical imaging**
>> more precise differentiation of soft tissues,
>> supression of false positive effects

> **Non-destructive testing** @ high energies:
>> thick, dense samples, like:
>>> batteries,
>>> engines of cars,
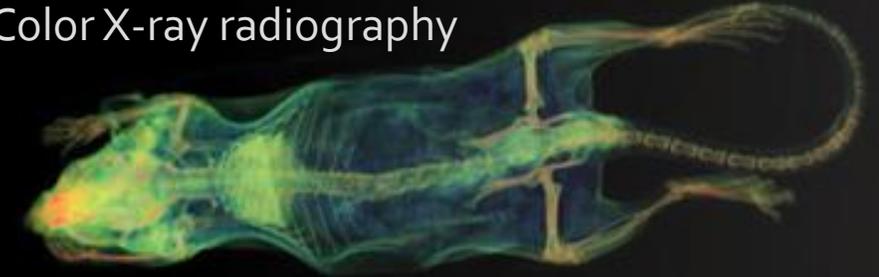>>> basins in nuclear power plants, pipes for oil/gas...

> **XRD**
>> Compatible with X-ray imaging modalities due to Medipix-based detection

> **Research and other potential applications**
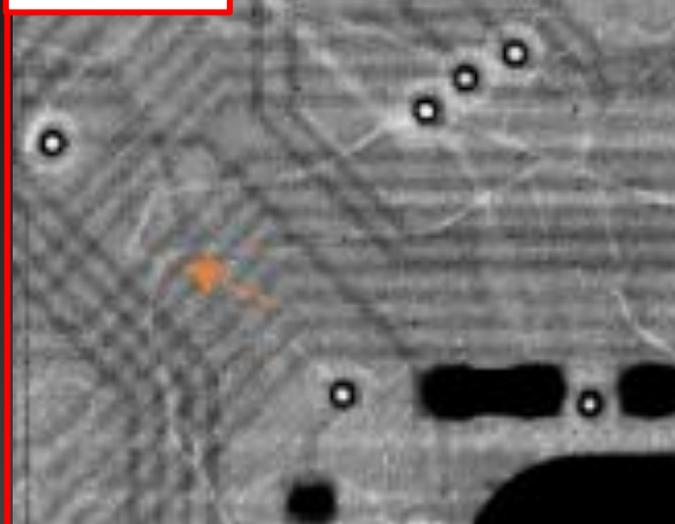>> e.g., space missions, high-energy physics.

CdTe SENSOR

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> Advantages

- > High atomic numbers of components
- > High detection efficiency
- > Wide band gap (~1.45 eV) => no cooling
- > High density (~5.85 g/cm³)
- > Typical detectable energy range for
  X-rays: 5-500 keV
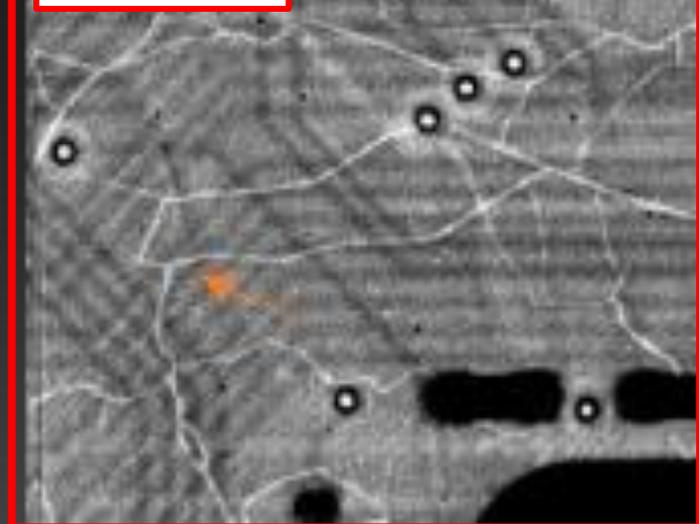
> Disadvantages

- > Material defects and inhomogeneity
- > Low mobility => lifetime product (μτ)
  of charge carriers
- > Polarization at high intensity
- > Poor detection stability
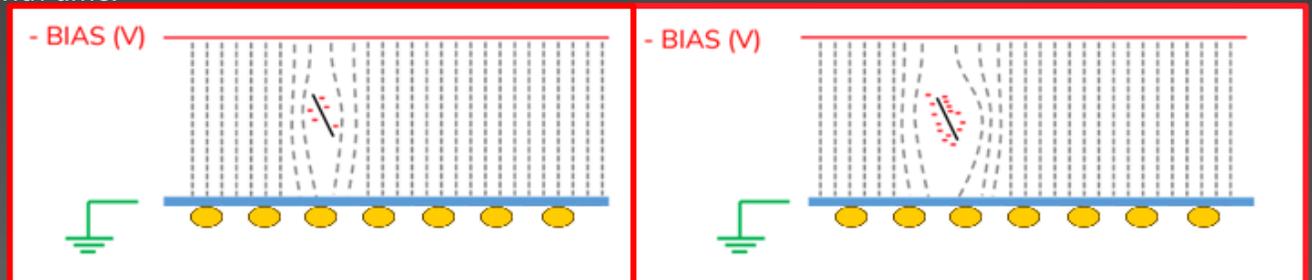- > SNR = 300-500

after 1 sec   **after 10 min**

X-ray radiography of the printed circuit board shows artifacts caused by defects in the CdTe sensor crystal at 1 s (left) and 10 minutes (right). "Vein-like" artifacts, indicated by an arrow, are worsening with time.

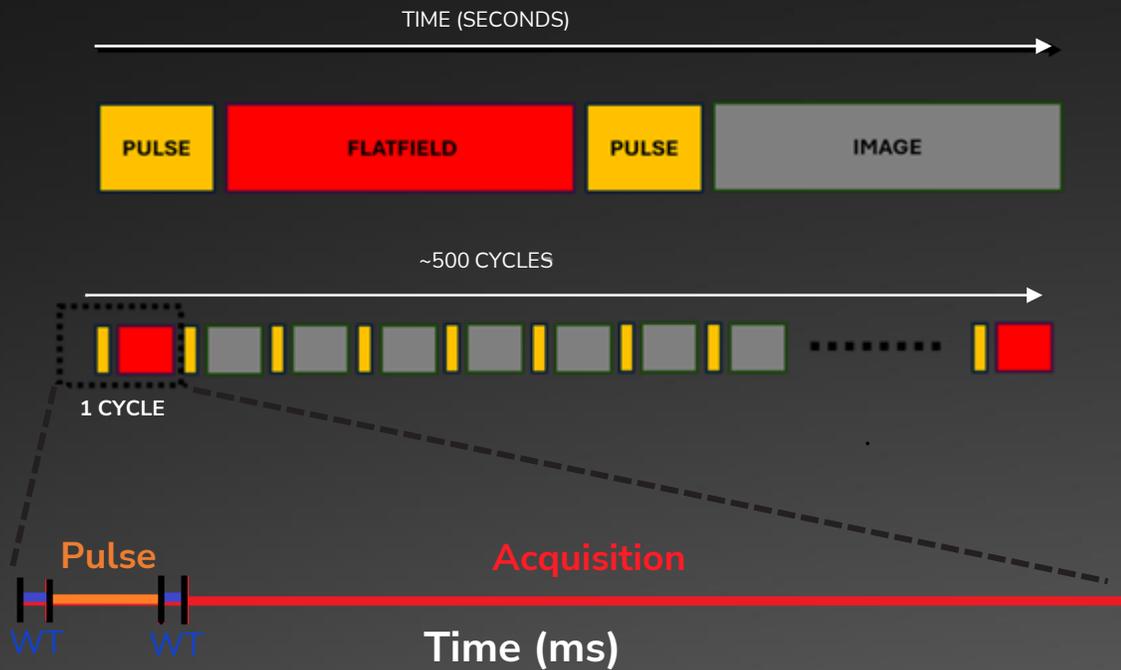- BIAS (V)   - BIAS (V)

WHAT CAN WE DO WITH IMPERFECTIONS?

> **Solution approaches**

Hardware = **PULSED BIAS VOLTAGE SWITCHING** TECHNIQUE

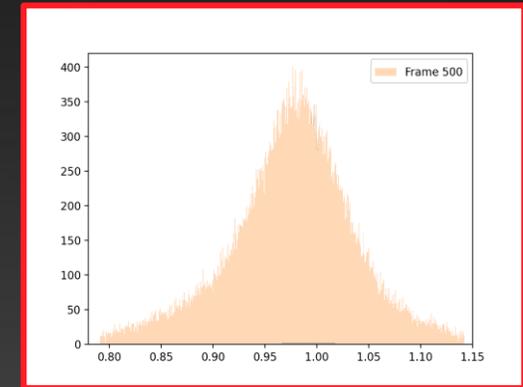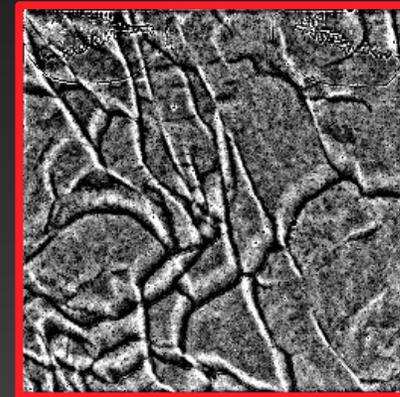Software = **ADAPTIVE FLAT FIELD** (AFF) CORRECTION

PULSED BIAS VOLTAGE SWITCHING TECHNIQUE

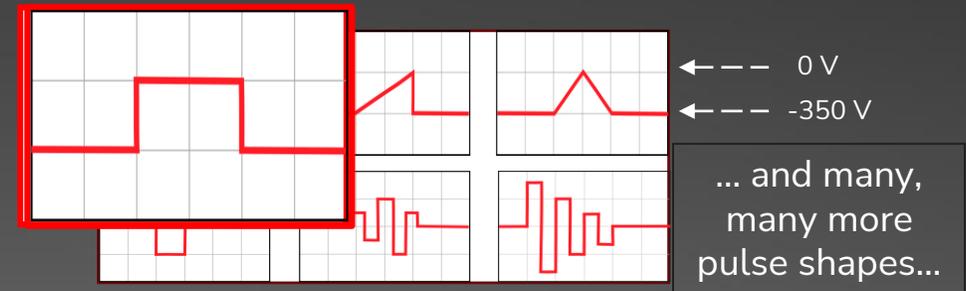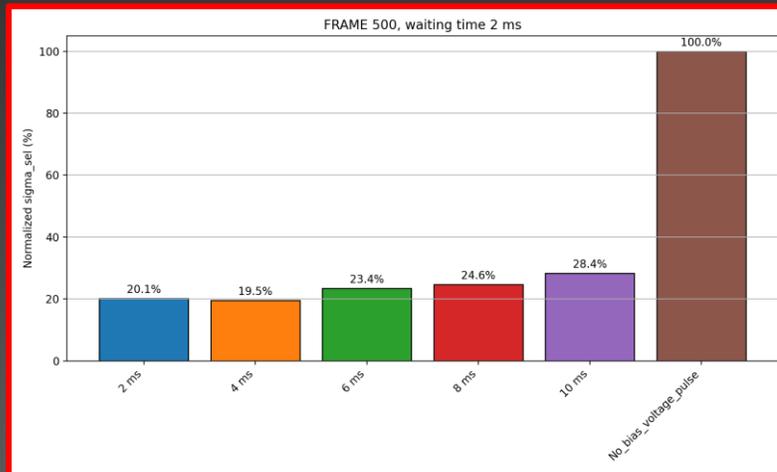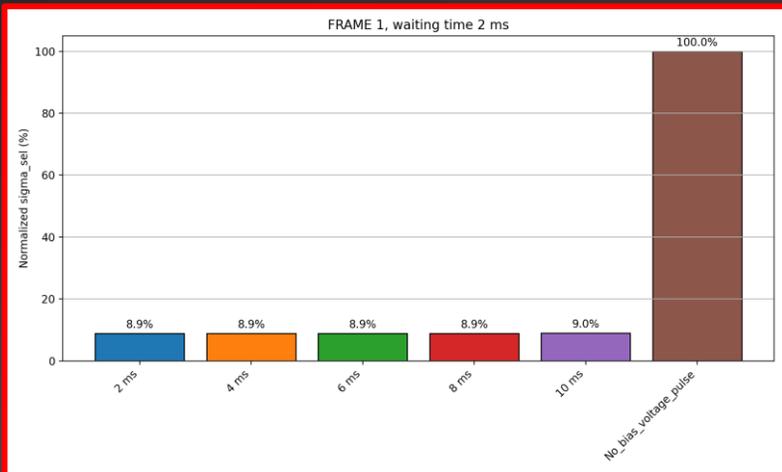**Principle:** Reset the accumulated space charge to a stable "fixed state" before each image.

Without bias refreshing: FRAME 500

TIME (SECONDS)

| PULSE | FLATFIELD | PULSE | IMAGE |

~500 CYCLES

1 CYCLE

Pulse   Acquisition

WT   WT

Time (ms)

WT – waiting time

Distribution of the measured intensity values **μ.**

0 V

-350 V

... and many, many more pulse shapes...

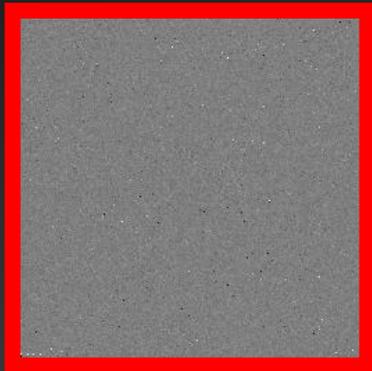# THE BEST SHORT BIAS VOLTAGE PULSE EVALUATION

5.35x better detection stability

σ is calculated only from selected data – specifically, 98% of the sample values that were filtered (most likely by trimming extreme values, i.e., outliers).

The total duration is:
pulse + waiting time = **5 ms**.

An exposure time is extended by 5 ms before each frame
or before a sequence of frames.

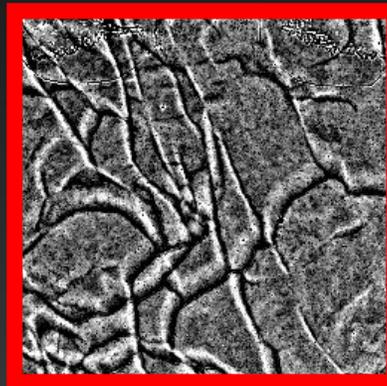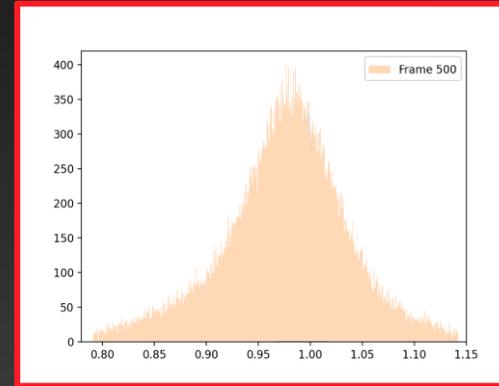# IMAGE COMPARISON: WITHOUT VS. WITH BIAS VOLTAGE PULSE REFRESH

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FRAME 500

Distribution of the measured intensity values **μ.**

FRAME FF (FLAT FIELD)

Without bias refreshing

Ideally:

$$\mu_{[x,y]} = \frac{frame\_x_{[x,y]}}{frame\_FF_{[x,y]}} = 1$$

Wider spread!

5x WORSE

FRAME 500

With bias refreshing
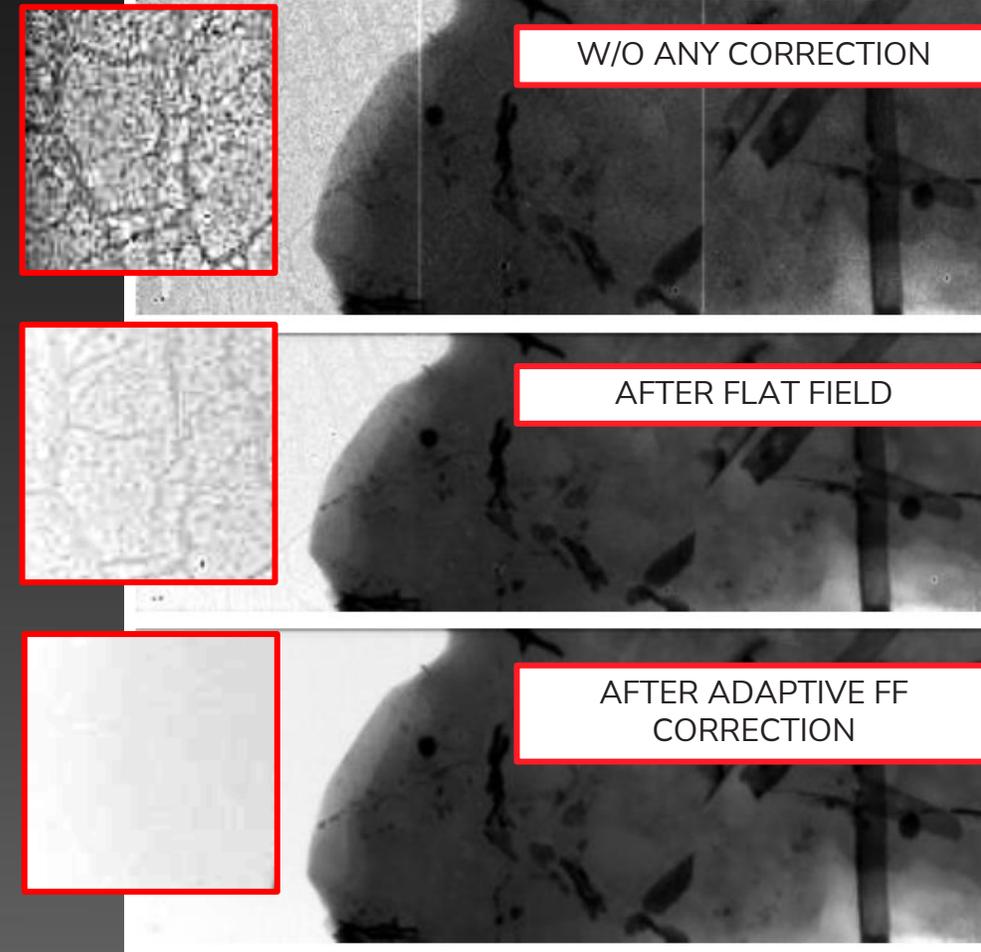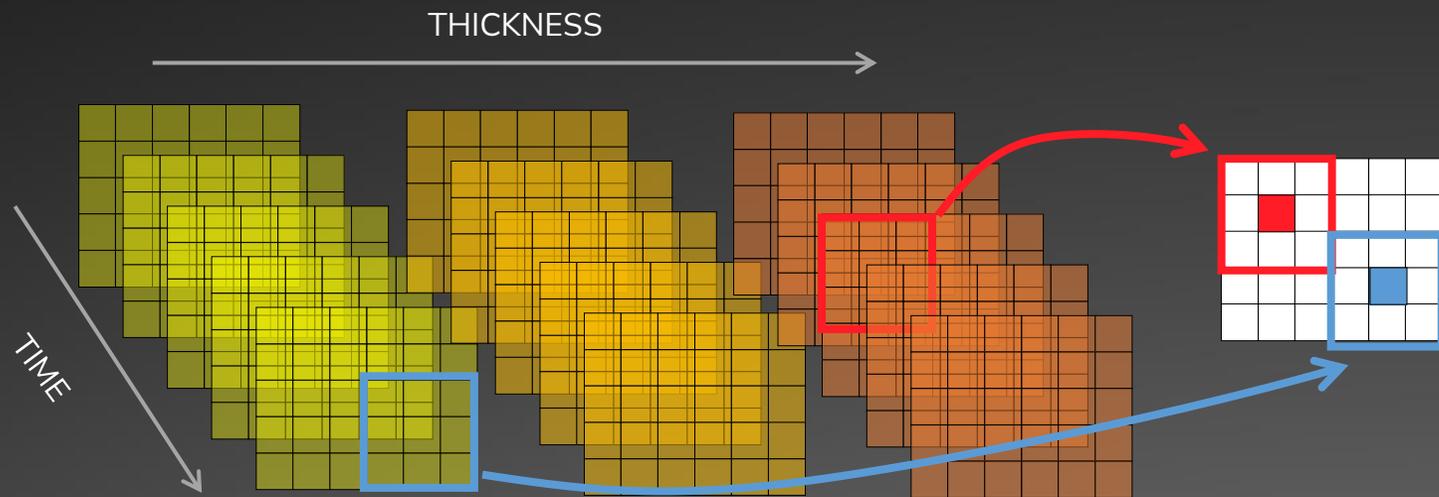

Bias pulse refresh **improves detection stability** of CdTe sensor.

SOFTWARE SOLUTION

> **ADAPTIVE FLAT FIELD CORRECTION FUNCTION**

> IT SELECTS THE **BEST LOCAL** FLAT FIELD **FROM** A **DATABASE** TO COMPENSATE FOR IMAGE ARTIFACTS

> COMPUTATIONALLY DEMANDING

THICKNESS

TIME

W/O ANY CORRECTION

AFTER FLAT FIELD

AFTER ADAPTIVE FF CORRECTION

CONCLUSION

> ## WIDEPI**X** 5x5 MPX3
>> Best suited for material analysis, spectral imaging, CT and NDT applications
>> Large area: 70 x 70 mm
>> 1 638 400 pixels

> ## Bias pulsing
>> Pulsed bias voltage switching offers a low-cost, easily implementable solution.
>> This technique effectively removes accumulated spatial charge and revitalizes the sensor.
>> The best short bias voltage pulse is 4 ms with waiting time 0.5 ms = 5.35x better detection stability.
>> The total duration is: pulse + waiting time = 5 ms.

> ## AFF correction
>> Software post-processing – improves the detection stability.

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