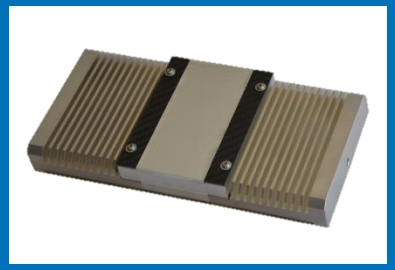
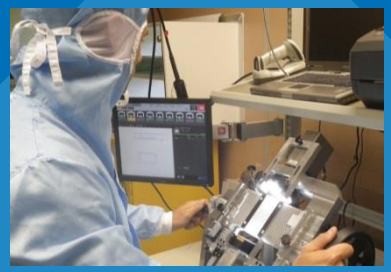
MULTIX®
Xray Spectrometric Imaging

X-ray Multi Energy detectors in security applications

Journés thématiques réseau détecteurs à semiconducteurs IN2P3-IRFU

P. Radisson





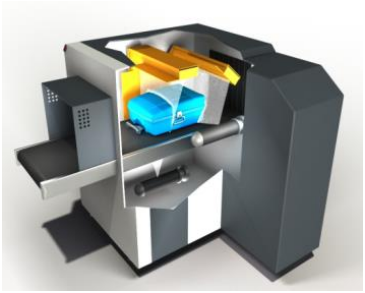
Ref MLX

May 31st, 18

Executive summary

- **MultiX:** French start-up company incorporated in 2010. Spin off from Thales and venture capital backed. Located in Grenoble-France

- **Technology:** Energy Resolved Photon Counting X-ray detector (Multi-Energy /ME) & Methods. Based on Mature building blocks and a major partnership with CEA/LETI French public Lab, patent portfolio.



- **Market:** X-ray scanner manufacturers (conventional, CT and XRD), new build or retrofit to meeting existing and future regulations. To improve threat detection performance for ALL x-ray based detection systems Introducing a new metric for discrimination with high resolution multi-energy detection

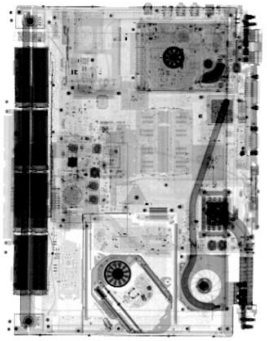
- **Maturity:** Team engaged in the project since 2007.
  - COTS product : ME100 for DAS retrofit & new build
  - In Progress: High Flux ME capability for CT applications and High Energy Resolution for low flux scatter applications

ME100 retrofitted to a Rapiscan 620XR

MultiX Technology

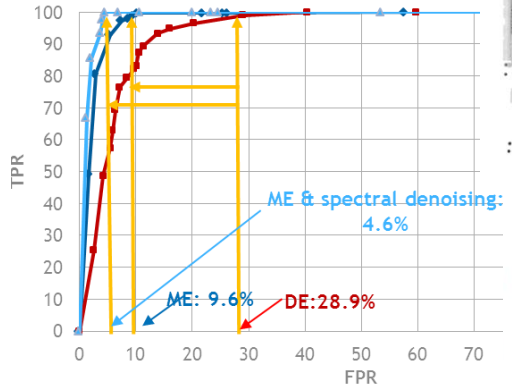
A complete Spectrometric X-ray DAS consisting of:

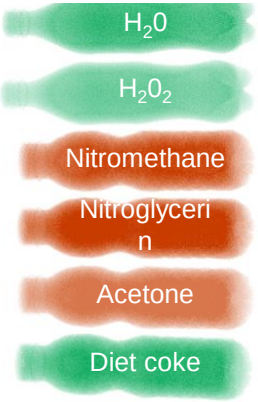
- An energy resolving sensor for spectrometric analysis(CdTe/CZT)
- High-speed front-end electronics for real-time photon counting and precise photon energy measurement
- Dedicated spectrometric real-time signal processing & method for identification of materials

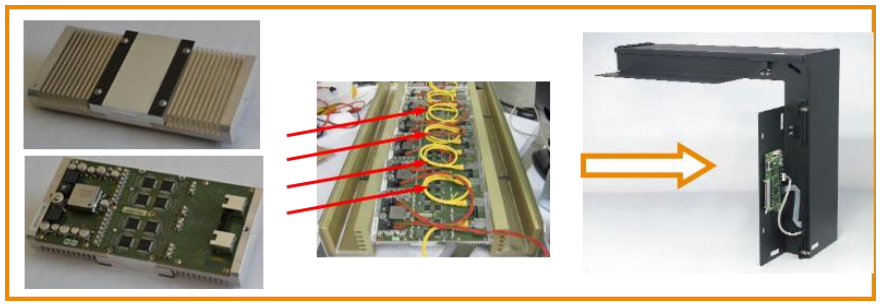


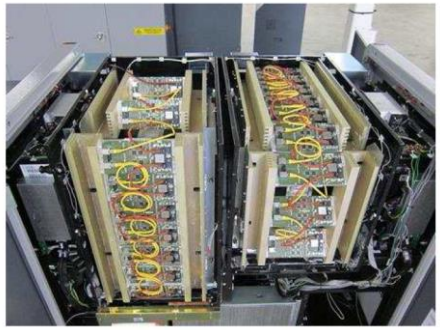
Capabilities

- Improved spatial resolution
- Improved signal to noise ratio
- Improved threat identification
  - High probability of detection (PoD) with reduced false alarm rate (FAR)



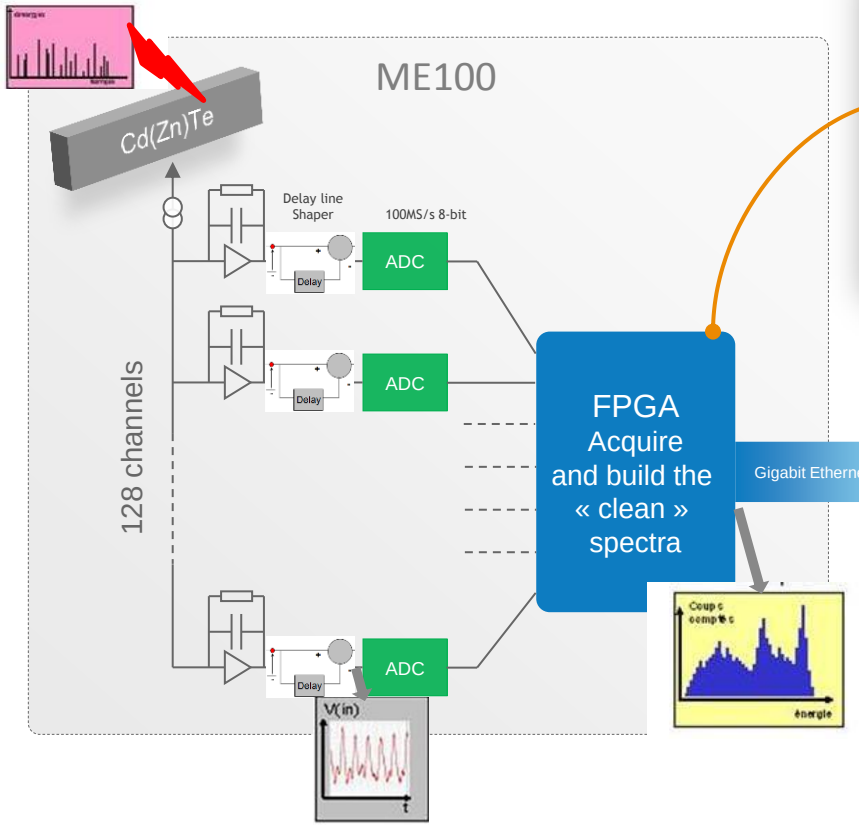




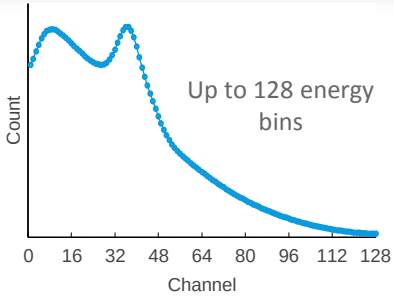


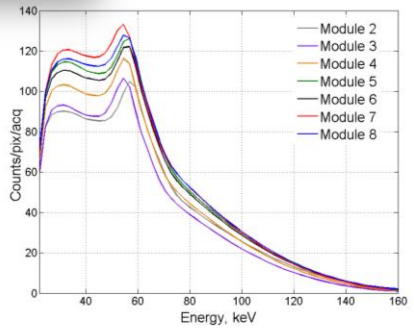
ME100- key architecture

- **Advanced high-speed electronics and advanced signal (pulse) processing for real time:**
  - **Low-noise ASIC + Delay line shaper and ADC→ reduced dead time+ full photon pulse information**
  - **FPGA for advanced digital signal processing.**



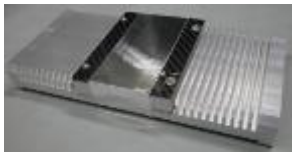
Digital signal processing allows :
- Pile-up rejection
- Charge sharing correction
- Charge induction correction
- Clean and stable spectra(flux, temperature …)

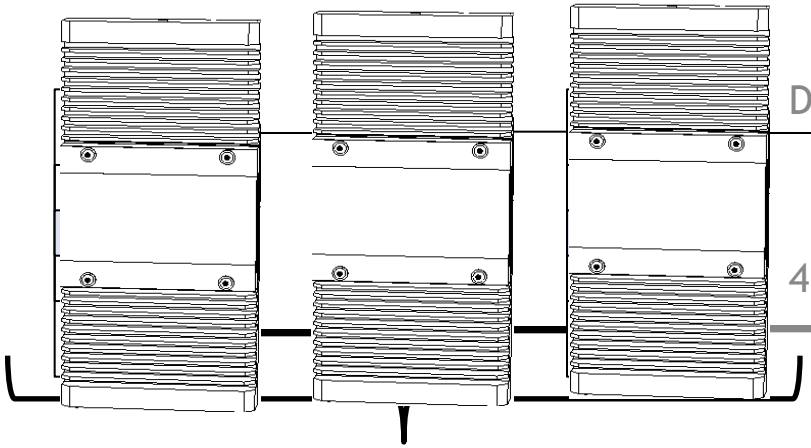




- Linear array, N modules 128 pixels
- Pixel pitch: 800 µm
- Material: CdTe or CdZnTe
- Energy range: 20 - 160 keV expanded to 250-300keV (Cargo & NDT)
- Spectrometry up to 128 energy bins within a single acquisition
- Acquisition time from 0.5 ms to a few 100 ms

MultiX multi-energy (ME) upgrade

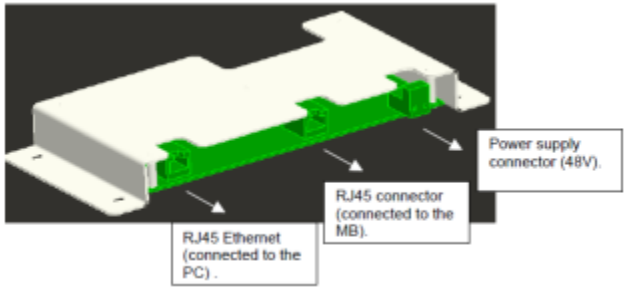




DATA

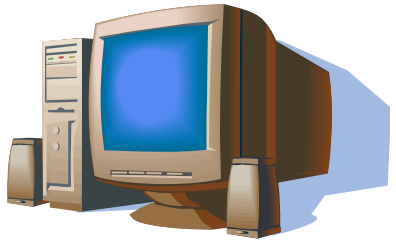
48V

INTERFACE BOX



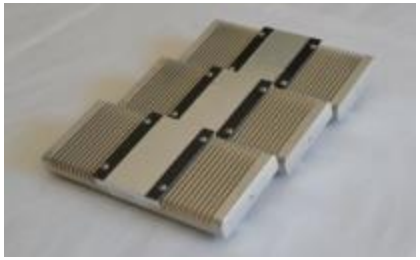
GigaEthernet Link

POWER Supply(1)



ME 100 Modules in daisy chain
Up to 20 modules →

2 meters of detection line (2560Pixels)



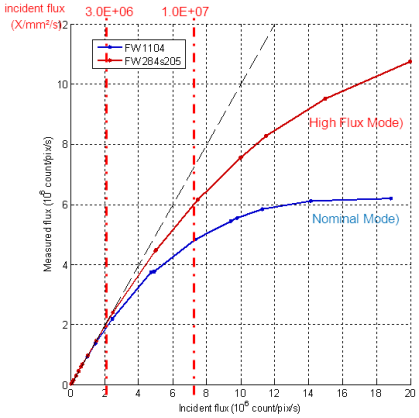
API ready for OEM integration
+
MTT Visualisation SW

(1) Not part of the delivery

ME100 DAS Specifications

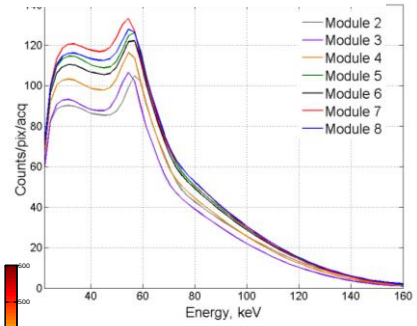
Main features:

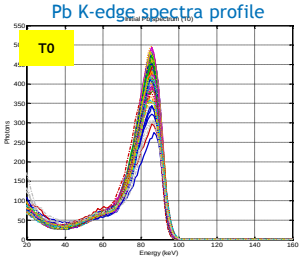
- Linear array, N modules 128 pixels
- Pixel pitch: 800 µm
- Material: CdTe or CdZnTe
- Energy range: 20 - 160 keV expanded to 250-300keV (Cargo & NDT)
- Spectrometry up to 128 energy bins within a single acquisition
- Acquisition time from 0.5 ms to a few 100 ms
- Power consumption : 35W (V2) & 23W (V3)/module (-48V)

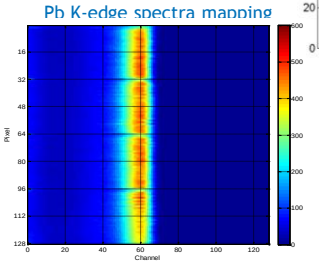


Typical Characteristics:

- Counting at saturation: >6 x10^6 count.s-1
- Global dead time: typ.50-60ns
- Linearity loss versus incident flux : 8% @ 3.0x106 ph.mm-2.s-1
- Energy resolution DE(fwhm)/E:
  - 9-10keV @ 60keV & 3.106 ph.mm-2.s-1 (incident flux)
  - 6-7keV @60-122keV & low incident flux
- Energy calibration in factory: <0.5keV
- Low temperature drift: <0.03keV/°C





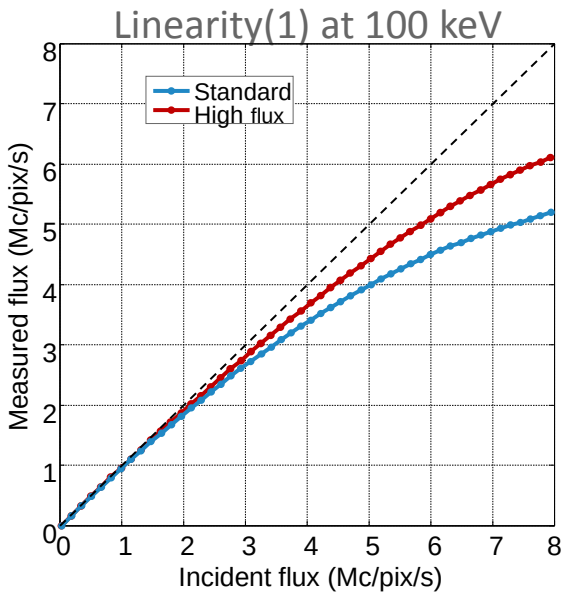


ME100 configurations

➢ **ME 100 configurations:**

Configurations	Flux
Low-flux	$< 10^5$ ph/mm^2/s
Standard	$3 \cdot 10^6$ ph/mm^2/s
High-flux	$> 3 \cdot 10^6$ ph/mm^2/s

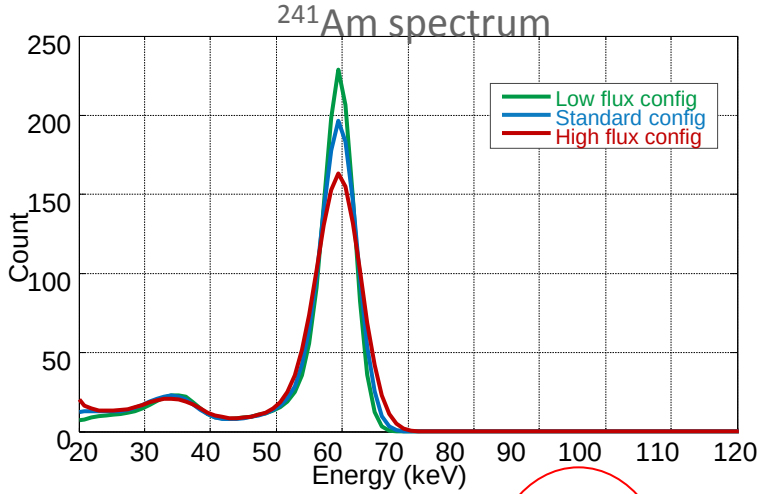
- High-flux mode achieves 25 ns dead time.



Mode	Dead time	2Mph deviation	Saturation
Standard	55 ns	8 %	6 Mph/pix/s
High-flux	25 ns	4 %	11 Mph/pix/s

(1) Linearity with 100 keV monochromatic X-ray beam (ESRF synchrotron).

- Energy resolution at 60 keV (241Am).
- Low-flux configuration achieves <6 keV FWHM.
- Tradeoff between energy resolution and counting rate. Depends on customer applications.



Configuration	FWHM
Low flux	5.5 keV
Standard	6.9 keV
High-flux	9.1 keV

ME100 -Multi Energy benefits for security linescan

- **Small pixels, no lag and no crosstalk →Improved image quality, segmentation and faster clearing (by operators)**

Thanks to Multi Energy dedicated algorithms & methods:

- **Improved Zeff precision and Accuracy → reduced FAR**
- **Material overlap processing → reduced FAR**
- **Spectral Denoising** (Partnership with Grenoble University)

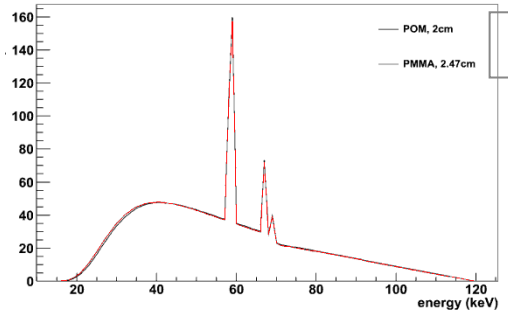
→ additional FAR reduction in real environment thanks to Image segmentation and Material (Zeff,..) discrimination improvements

- **ME "Material Stripping"** Patent pending
  - ME algorithm with unmixed material decomposition

→ additional FAR reduction and POD increase

Material Separability Results review

Evaluation of Separability Criterion with photons statistics(1)



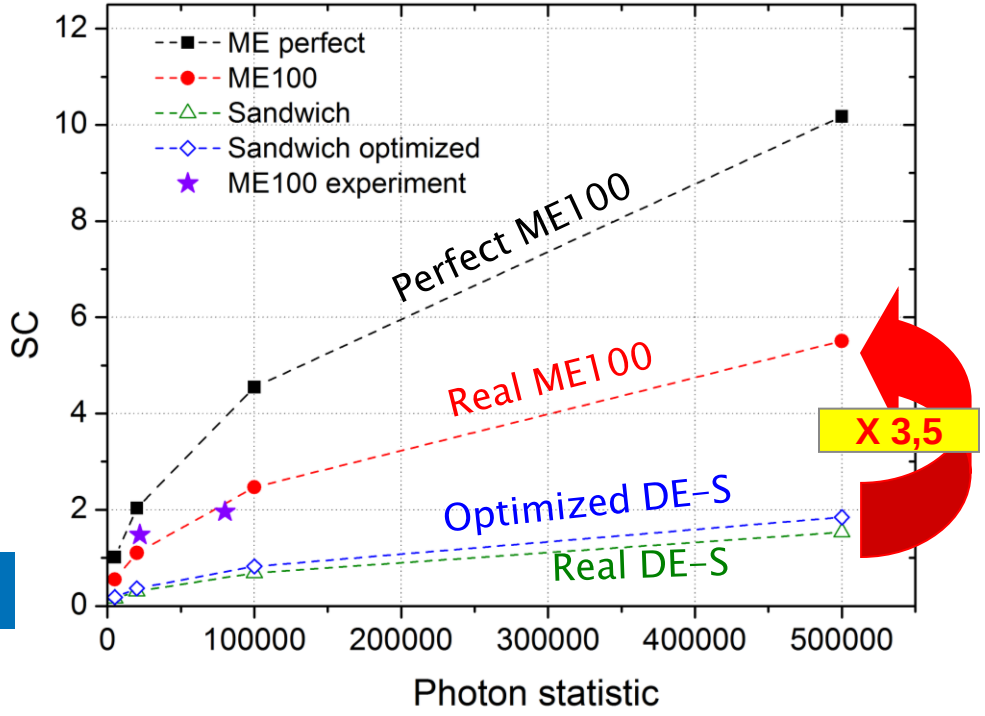
POM :Zeff 7,4

PMMA : Zeff 6,9

$$SC^2 = \sum_{i=1}^{k} \frac{(att_i^1 - att_i^2)^2}{(\sigma_i^1)^2 + (\sigma_i^2)^2}$$

SC ⇔ Z separability

$$Separation = \frac{|Z_1 - Z_2|}{\sqrt{\sigma^2(Z_1) + \sigma^2(Z_2)}}$$



Considering two materials with close X-ray absorption properties:

- Multi-energy detector separability is 3.5 times higher than Dual Energy detector
- ME100 performance can be improved further and thus enhance the ME/DE-S difference

(1) JINST . Gorecki, et al, Comparing performances of a CdTe X-ray spectroscopic detector and an X-ray dual-energy sandwich detector (2013) Journal of Instrumentation, 8 (11), art. no. P11011,

Material discrimination improvements (FAR)

- **Material/objects**
  - 24 benign items in plastic containers, ranging from water, detergent, toilet, milk, alcohol ab. 11 scans each => DE (238) ME (243)
  - 3 threats, ab 100 scans each : NM-real, HP-sim, NG-sim => DE (310) ME (305)
- **Experimental ROC curves(POD/FAR) based on Zeff parameter only**

- POD of 99%:

-DE=> FAR 28,9 %

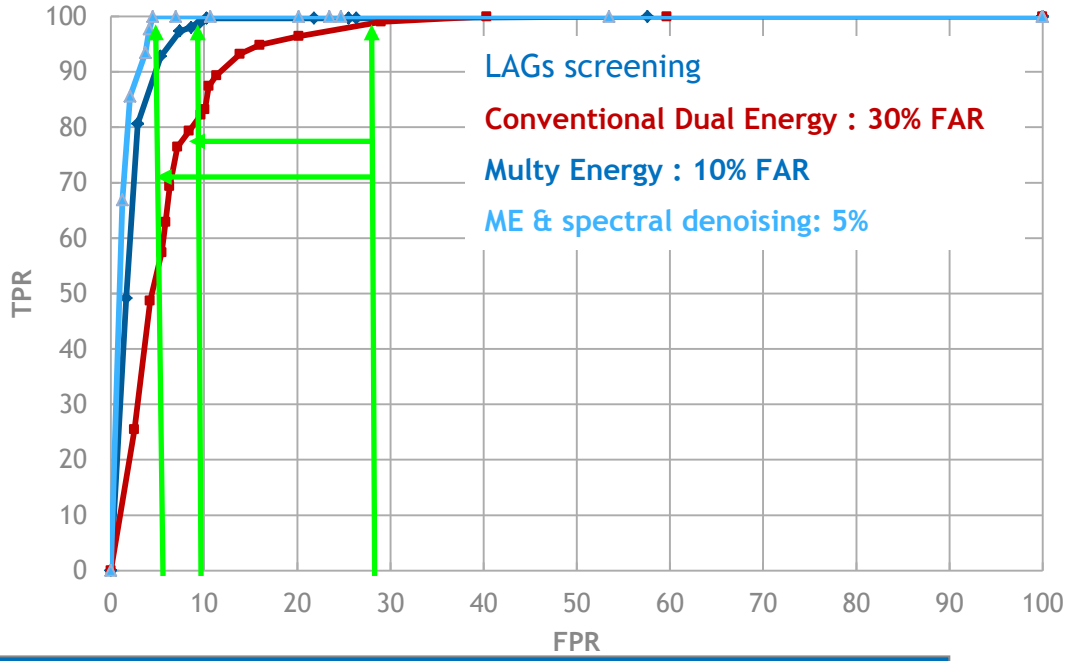
-ME=> FAR 9,6 %

-ME "denoising": 4,6%

Factor 3

Factor 6

-**NM**: real nitromethan (500ml),
-**OP**: Hydrogen peroxide 70% simulant (500ml),
-**NG**: nitroglycerin simulant (500ml)

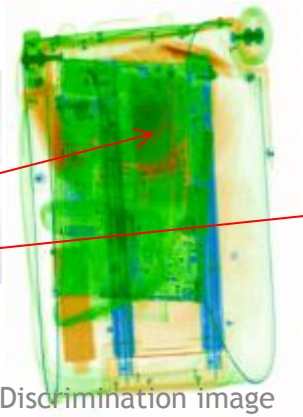


With Multix solution, reduction in FAR (Zeff discrimination)
→factor 3 vs DE
→with spectral denoising, factor 6 vs DE

ME material decomposition-Laptop in Bag

Laptop in bag plus explosive simulant

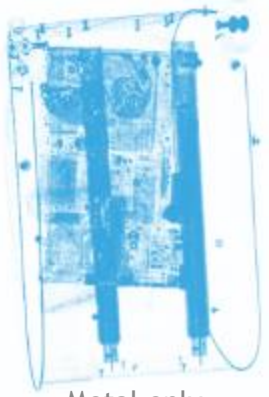
Explosive simulant



Discrimination image

Multi Energy material stripping

Organic only

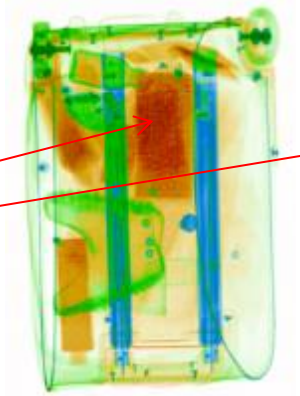


Metal only

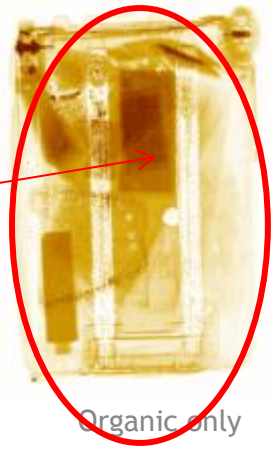
ME material decomposition allows overlap recovery even with laptop: Recovered Organic image reflects very much the one without Laptop

Bag plus explosive simulant (without Laptop)

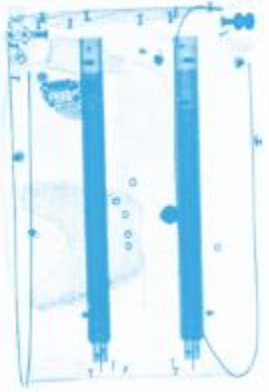
Explosive simulant



Discrimination image



Organic only



Metal only

ME benefits for linescan Summary

- **Contrast to noise in material discrimination is improved**
- **The closer the material the higher the gain (ex NM/water,..) in discrimination**
- **FAR reduction by a factor 3 liquid threats vs. benign liquids (stream of commerce)**
- **Improved segmentation and faster clearing (by operators) thanks to:**
  - Small pixels , lack of lag and lack of crosstalk
  - ME “spectral denoising” in particular in complex bags /laptops..
- **Multix specific material decomposition highlights plastics explosives even in laptop/PED.**

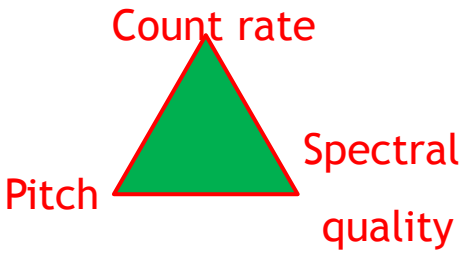
High Flux & Multilinear detectors for security CT

Challenges for Energy Resolved Photon counting in Security CT:

- Higher count rates : x10 vs. regular linescan
- Spectral quality to be maintained for material discrimination
- 2D array detector →integration of the electronic chain
- Speed + large number of pixels →ME data-flow and data processing

Key trade-offs

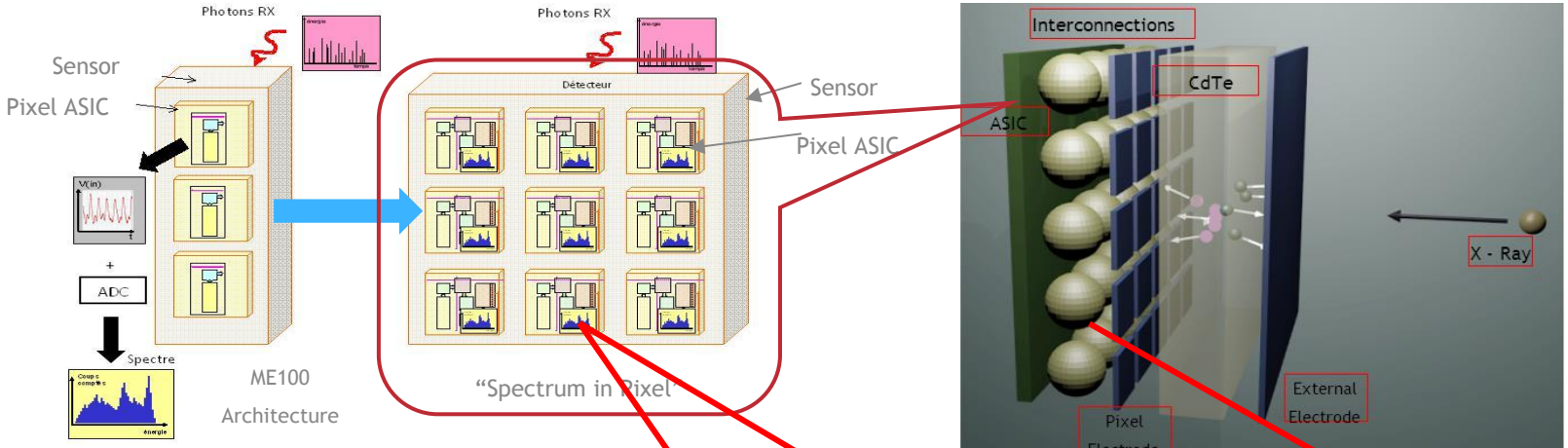
- Pixel size reduction down to 500µm -300µm → to reach higher Mph/mm2/s capabilities
- Degradation of spectral quality with pixel reduction→ require a huge amount of advanced very fast signal processing ahead of the spectrum builder

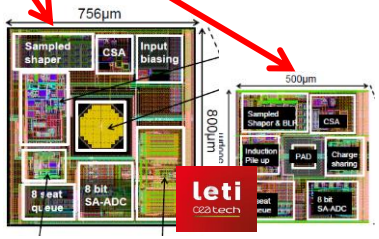


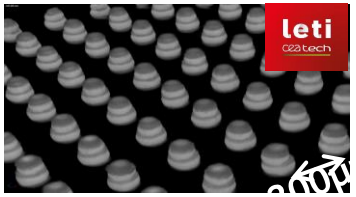
Target & Holy Graal: to integrate the complete Spectrometric chain into the pixel maintaining benefits of ME architecture and performances

High Flux for CT & Multilinear (ME2D) detectors

- **Breakthrough developments at CEA LETI :Very first 2D multi-array x-ray hybrid integrating the complete spectrometric chain in the pixel (SPECTIN: SPECTrum In Pixel):**
  - CSA + delay line shaper +pulse processing + 8bit ADC and spectrum builder
  - charge induction & pile-up rejection, charge sharing correction







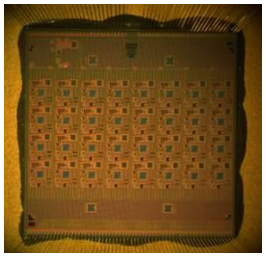
- **500µm & 800µm(1) pixel ASICS**
- **CMOS 0.13µm technology**
- **Low pitch device level flip chip**

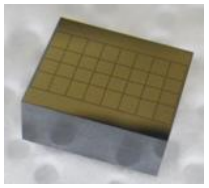
(1): work supported by French funded project FUI-AAP15 projet PIXCSI

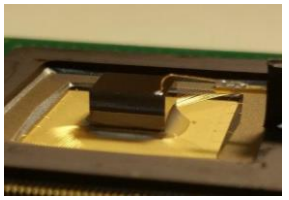
High Flux for CT-ASIC & hybrid results

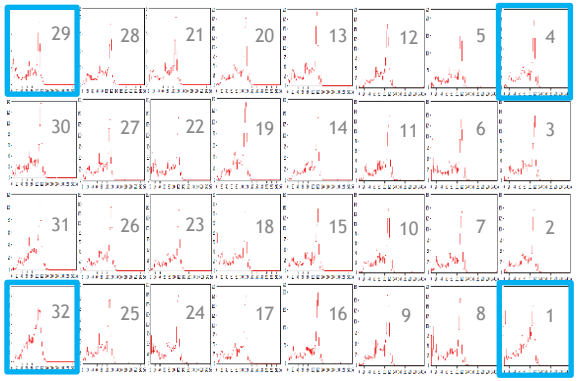
Proven performances

- ASIC 8x4 –pixel 0.8x0.8mm2
- 2 sides “butable”
- 128 energy bins-real time
- Energy resolution 7 to 9% @122keV
- Max count rate : 8Mpcs/pixel
- Count rate Linearity @ 2-3Mph/pix/s: 100%→ improved vs. ME100 (ab. 90-80%)
- Spectral quality improved with charge sharing correction (4 neighbouring pixel)
- Significantly Reduced power per pixel ab. 10 mW vs. 150-180 mW (ME100)
- Demonstrator :128*4 pixels

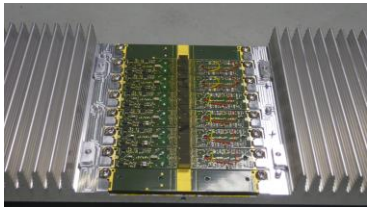


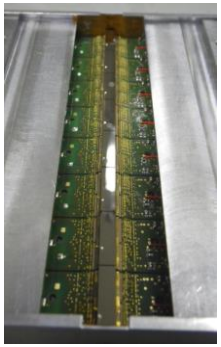


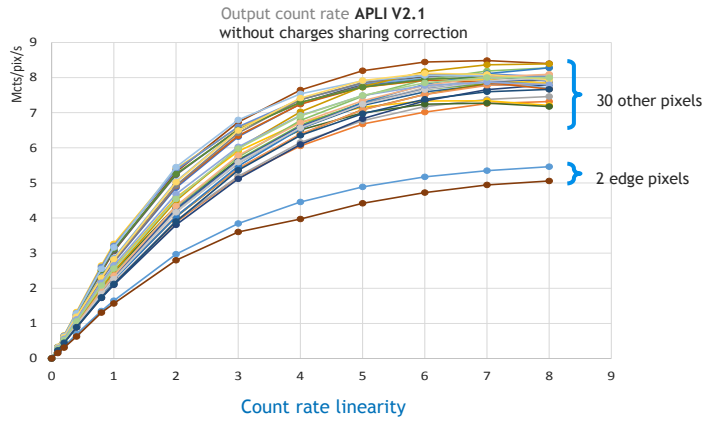




Pixel response uniformity with Co source 122keV





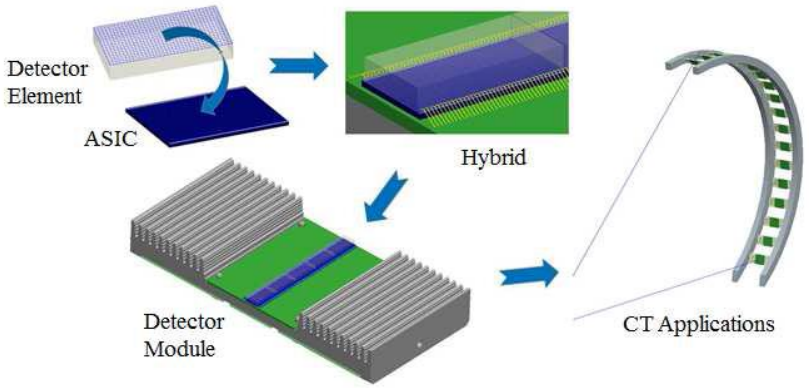


(1): work supported by French funded project FUI-AAP15 projet PIXCSI

High Flux CT & Multilinear (ME2D) in progress

Product development :

- Security CT detector requirements for check point
- Multi-rows configuration, > 8 rows (max 15) , pixel size 1x1mm2
- 20 to 30 Mph/pix/s @10% loss,
- Max OCR: 50Mcps/pix (at saturation)
- Sub-pixel down to 500 µm pitch (400µm to be considered)→ 4 sub-pixel per pixel
  - ASIC geometry 40x16 “sub pixels”
- Spectral quality: FWHM 7-9keV @60keV and low valley/peak ratio (idem ME100)
- Data transfer & processing : NxM pixels x 4 to 64 Energy bins per acquisition (OEM dependent) target 10 to 16 energy bins
- Prototype: module 128x8 pixels→ Mid 2020



ME benefits for security

- **X-ray ME real time spectrometric for transmission security and industrial applications**
  - ME100 is a COTS
  - Demonstrated benefits for security linescan
  - Demonstrated producibility with high level performances and quality
  - Integrated by several OEMs for certification (new build and retrofit)

- **Second generation**
  - Complete spectrometric chain within the pixel
  - 2D arrays configuration
  - Higher flux x10 ph/pix/s
  - Mandatory for Security CT (20 cm/s) and fast industrial applications (belt speed 3m/s)

Contact

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