La Photodétection avec les Semi-conducteurs

Résumé des Journées Thématiques co-organisées par les réseaux instrumentaux IN2P3-IRFU :

Photodétection (coord. Sara Marcatili)

Semi-conducteurs (coord. Ana Torrentó)

La photodétection avec les semi-conducteurs

3–4 juin 2024
LPSC
Fuseau horaire Europe/Paris

Entrer le texte à rechercher

- Accueil
- Ordre du jour
- Liste des contributions
- Liste des auteurs
- Inscription
- Liste des participants

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The R&D instrumentation networks dedicated to photodetectors and semiconductors created in 2012 with the aim of promoting exchanges between the different laboratories active in the fields, are organising a two half-days meeting on **June 3 and 4, 2024 at LPSC** (Grenoble) on the topic : ""Photodetection with semiconductors". Talks will covers direct detection of light, from visible to infrared, of X-rays, as well as the detection of gamma-rays using converters.

This event will bring together IT, researchers and doctoral student working on intrumentation and wishing to discover and understand the latest technologies, their performances and their limits.

Submissions for oral presentations are now closed. You can still submit a poster contribution by sending an e-mail to the organizers. An international audience is expected: the presentation material will therefore be in English.

A visit to the XBIC beamline at ESRF will be organized at the end of the second day. The number of participants is limited. **Registrations to the ESRF visit are now closed.** A lunch box will be provided on June 4th to the people participating to the ESRF visit.

Introduction

- Disclaimer: the purpose is showing a glimpse of the Journées, not an exhaustive summary
- 58 registered people; approx. 40-50 participants
- Timetable (one keynote presentation in each session) :
  - Session 1: Gamma Detectors
  - Session 2: From visible to mm wavelength detectors
  - Session 3: X-ray detectors
  - Session 4: Detectors for synchrotron radiation
- Visits to plasma and ion sources platforms + ESRF (limited to 16 people)
- Poster session
- Industrial participants :

CAEN Tools for Discovery

High/Low Voltage Power Supply systems and Front-End/Data Acquisition modules which meet IEEE Standards for Nuclear and Particle Physics.

SiCLADE TECHNOLOGIES

Conception, development, manufacturing and marketing of particles sensors in extreme conditions, in high technology domains: medical, nuclear, spatial, geoprospecting, military and internal security.

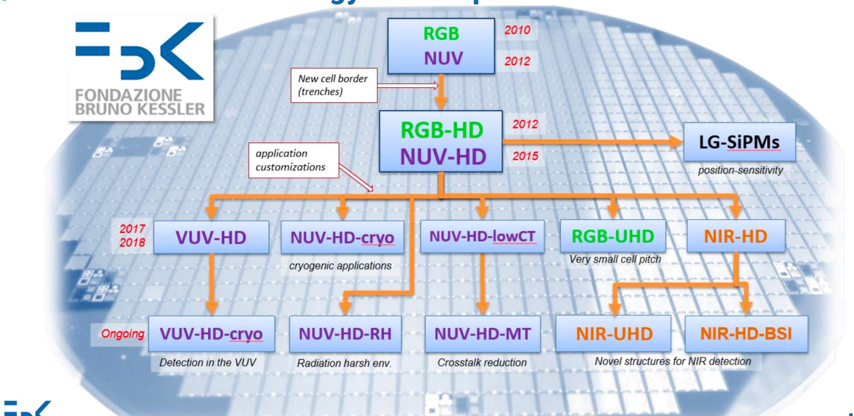
Session 1: Gamma detectors

14:00	**Introduction**	*Ana Sofia Torrento et al.*	*Amphithéâtre, LPSC*	14:00 - 14:15
	Overview of LPSC activities	*Laurent Derome*	*Amphithéâtre, LPSC*	14:15 - 14:30
	Development of Silicon Photomultiplier Technologies at FBK for scientific and Industrial Applications	*Alberto Gola*	*Amphithéâtre, LPSC*	14:30 - 15:05
15:00	**Prompt gamma detection with Cherenkov radiators coupled to SiPMs**	*Mme Adélie André*	*Amphithéâtre, LPSC*	15:05 - 15:25
	Amplificateurs faible bruit et large bande pour les SiPMs et les Diamants	*Christophe Hoarau*	*Amphithéâtre, LPSC*	15:25 - 15:45
	Caméra SPID-X, imagerie gamma avec masque codée.	*Abel Vanel*	*Amphithéâtre, LPSC*	15:45 - 16:05
16:00				

Session 1: Gamma detectors

SiPM development at FBK

Fondazione Bruno Kessler
Custom SiPM technology roadmap



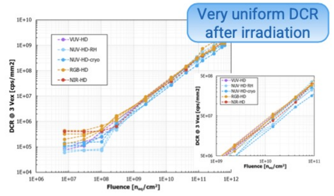
Alberto Gola - FBK SiPM roadmap - Photodetection with semiconductors - LPSC meeting 03/06/2024 | 5

Single SPAD switch-off
Effectiveness in reducing the DCR after irradiation

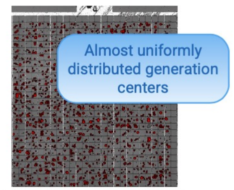
Whether switching off "screamer" SPAD is effective to reduce DCR after irradiation depends on whether the increase of DCR is caused by:

a. *few, very rare, very "bad" bulk damage events*, each one causing a large increase of the DCR → single SPAD switch-off is useful.

b. *the sum of many, uniformly distributed, smaller events*, each one responsible for smaller DCR increments → single SPAD switch-off is not very useful.



DCR vs Fluence for different FBK technologies: all plots converge to similar values above approximately 1e8 n_{eq}/cm^2



Emission microscopy measurement on a NUV-HD SiPM irradiated at $1 \cdot 10^{11}$ n_{eq}/cm^2, at 4V excess bias, showing *almost uniform cell activation*.

Additional R&D ongoing to characterize SPAD population after irradiation: **AIDAinnova SiPM run**

Reports on non-uniform SPAD DCR after irradiation presented at NSS2023 by L. Ratti

Alberto Gola - FBK SiPM roadmap - Photodetection with semiconductors - LPSC meeting 03/06/2024 | 30

2.5D and 3D Integration
FBK IPCEI clean-room upgrade

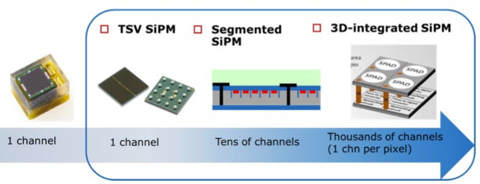
IPCEI on Microelectronics

FBK is part of the *IPCEI on microelectronics* project (Important Project of Common European Interest - €1.75 billion total public support, 12 M€ to FBK).

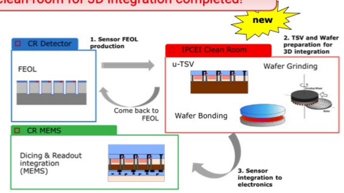
The goal for FBK is upgrading its optical sensors technologies, by *developing TSVs, micro-TSV and Backside Illuminated SiPMs*. This will allow high-density interconnections to the front-end and high-segmentation.

Customized TSVs will be optimized to preserve the NUV-HD electro optical and timing performance.

New clean-room for 3D integration completed! new



Range of technologies being developed within IPCEI



The FBK system composed of 3 research clean-rooms in FBK.

Alberto Gola - FBK SiPM roadmap - Photodetection with semiconductors - LPSC meeting 03/06/2024 | 35

Light concentration
Metasurfaces and Metamaterials

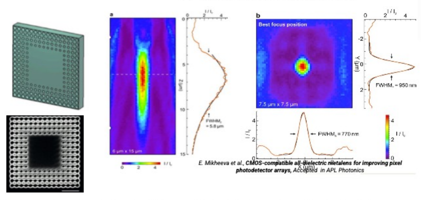
Multiwave Metacrystal · Institut Fresnel Marseille · Università degli Studi di Milano Bicocca · CERN

FBK investigated the possibility of *using nanophotonics to enhance SiPM performance* in the context of the PHOTOQUANT ATTRACT project.

Metalens-based light concentrators can work similarly to microlenses *to enhance SiPM radiation hardness*.

- Advantages: rad-hard metalens material (TBC), compatibility with CMOS planar processing.

93% of incident light concentrated
In < 1μm spot diameter or <5% of total area



ATTRACT

Experimental metalens designed and fabricated 4x4μm Nb_2O_5 metalens with refractive index gradient introduced by holes of varying diameter, (joint ATTRACT project CERN, FBK, Institut Fresnel.)

E. Mikheeva et al., CMOS-compatible all-dielectric metalens for improving pixel photodetector arrays, Accepted in APL Photonics

Session 1: Gamma detectors

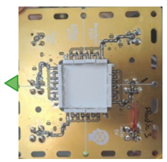
Proton therapy monitoring based on Prompt Gamma TOF measurement

Context – PGTI (Prompt Gamma Time Imaging)

TOF measurement between Plastic scintillator beam monitor and Prompt gamma detector TIARA to determine proton range

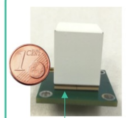
3rd version of the prototype (18 month R&D)

Article in preparation

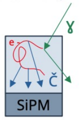


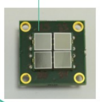
- Plastic scintillator (EJ-204) 1x25x25 mm³
- Read-out by 16 Silicon Photomultipliers (Hamamatsu SiPM 3x3 mm²)

Final version of the prototype (18 month R&D)



Cherenkov radiator 2 x 1.5 x 1.5cm³ lead fluoride cristal (PbF_2)

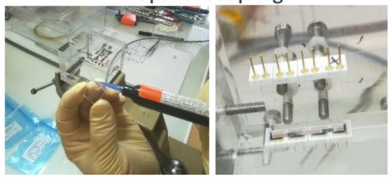




Read-out by 4 Silicon Photomultipliers (SiPM)

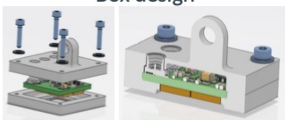
Detectors and electronics are developed at LPSC (SDI, SE)

Optical coupling

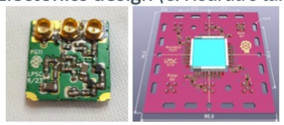


Reflective paint covering

Box design

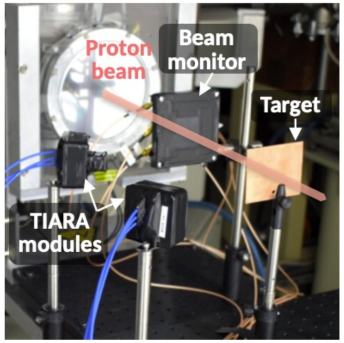


Electonics design *(C. Hoarau's talk)*



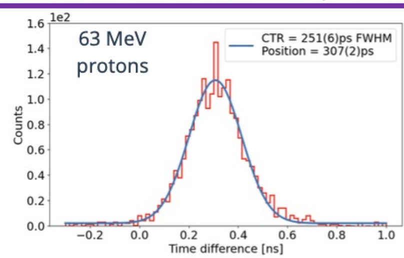
Same reflective paint, optical glue and electronics used for TIARA modules and plastic monitor

Time resolution characterization set-up



The thin copper target is used as a point-like PG source

Coincidence Time Resolution = 251ps FWHM

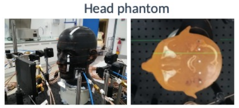


Last version of the TIARA module (March 2024)

Gamma detector time resolution = 220 ps FWHM

8-channels detection system to measure an anatomical change in a clinical phantom

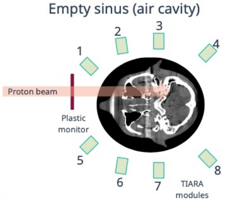
Head phantom



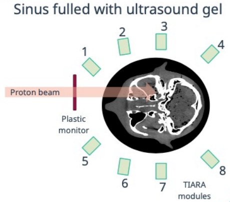
Clinical proton beam (IBA ProteusOne)

Set-up realized

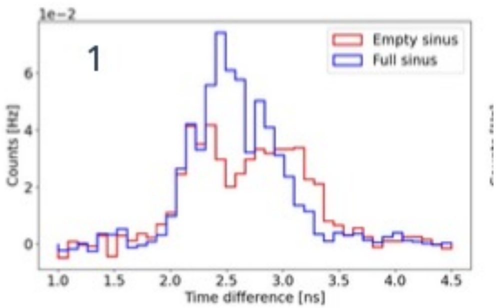
Empty sinus (air cavity)



Sinus fulled with ultrasound gel



Sensitivity to anatomical changes



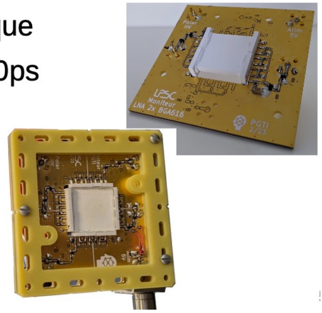
Session 1: Gamma detectors

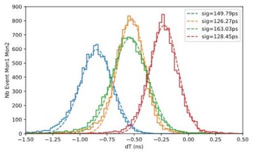
Low-noise large-band amplifiers for SiPM and diamond detectors

PGTI TOF

T_{START} Moniteur Faisceau

- Détecteurs SiPM-Plastique
- Mesure CAL : Jitter ~100ps

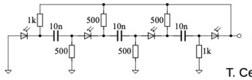




- Diamètre de faisceau
  20 mm → 25 mm

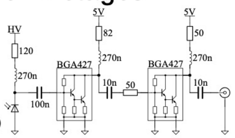
T_{STOP} Détecteur & Amplificateur

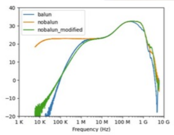
- Détecteurs 4x SiPM – Scintillateur :



T. Cervi et al 2017 JINST 12 C03007
Lukas Nies, et al, arXiv:1811.02680

- Pré-Amplificateur 2 étages
  - 33 dB
  - 80 – 980 MHz





J W Cates et al Phys. Med. Biol. 63 (2018)

4

Diamond hodoscope

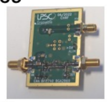
Amplificateur

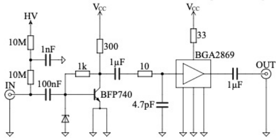
Montage à émetteur commun d'un transistor à hétérojonction (SiGe:C) NPN RF BFP740, et second étage à MMIC BGA2869

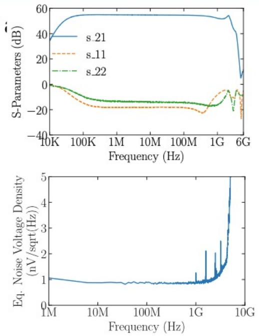
Grand gain 56 dB

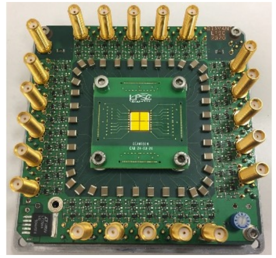
Faible bruit NF=0,85 dB

C. Hoarau, et al., JINST 16 (2021)

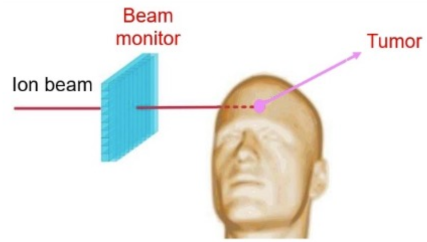




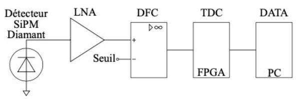


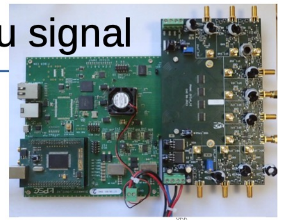


- 40 channels
- σ_{coinc} < 100 ps
- Ampl ~ 100 mV (p @ 50 MeV)

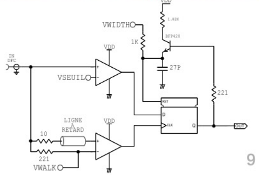


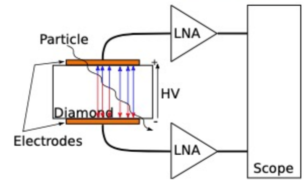
Mise en forme du signal





- Discriminateur à fraction constante t_m~650ps
- TDC (time to digital converter) jitter ~ 25 ps
- Interface c++ / QT





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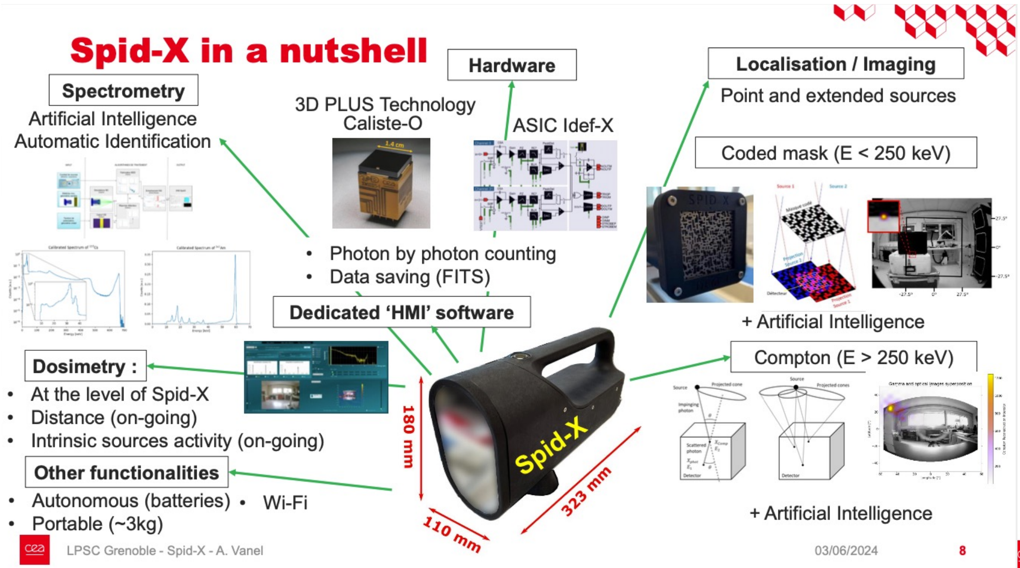
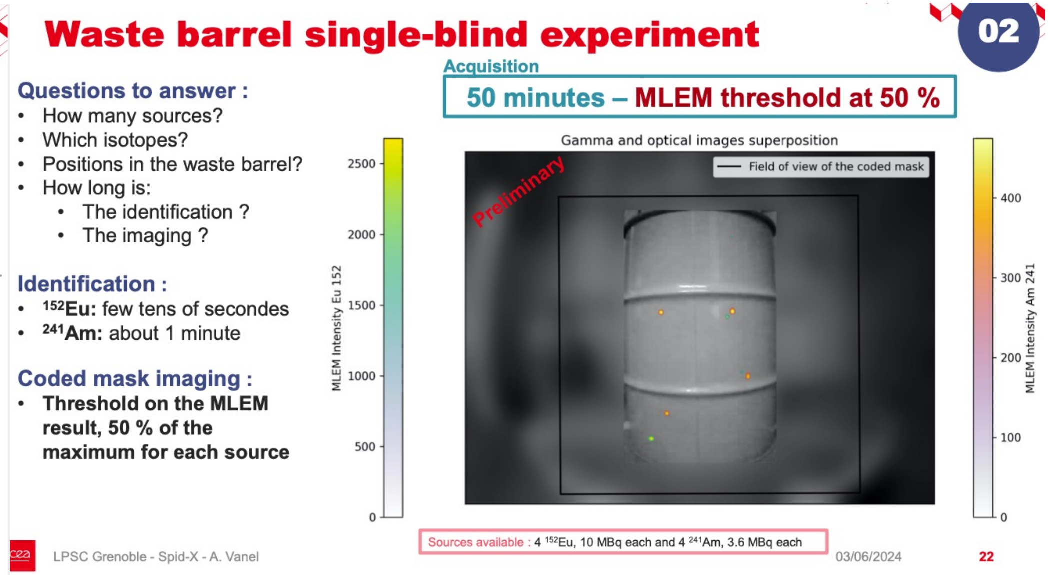
Session 1: Gamma detectors

SPID-X: RX – gamma camera for nuclear applications





- **Summary**

Promising first in-situ results confirming spectro-identification, imaging and dosimetry capabilities of Spid-X in unknown environments:

- **Spectrometry:** correct identification of all source(s) in presence
- **Imaging:** coded mask localisation of up to 4 same sources (up to 2x4 total), with a precision of 1° with respect to the true positions
- **Dosimetry:** « simple » model with deatime correction for high dose rates already implemented and giving good results

Ongoing and Outlooks

Spid-X DEM-2 (pre-industrial model) caracterised in laboratory

- All spectrometry, imaging and dosimetry specifications validated
- Schedule of water ingress and solid particule protection tests ongoing

ALB3DO Astro to Industry = cea irfu + 3D plus

Sensitivity tests, in less than 1 min, on axis, and without obstacle :

- **^{241}Am, 407 kBq :**
  - 1 m (1.5 nSv/h)
- **^{137}Cs source, 3.39 MBq :**
  - 1.75 m (83 nSv/h).

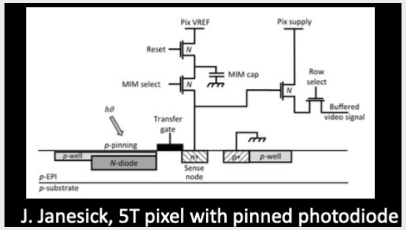
Session 2: From visible to mm wavelength detectors

	New developments in CCD detectors for astronomical observatories	*Claire JURAMY-GILLES*	*Amphithéâtre, LPSC*	17:35 - 18:10
18:00	**Observations of the Early Universe at millimetre wavelengths: the Grenoble GIS contribution**	*Sofia Savorgnano*	*Amphithéâtre, LPSC*	18:10 - 18:30
	Détecteurs infrarouges : des détecteurs classiques vers les APD	*Thibault Pichon*	*Amphithéâtre, LPSC*	18:30 - 18:50
19:00	**PICMIC: The first results**	*Henso ABREU*	*Amphithéâtre, LPSC*	18:50 - 19:10

New developments in CCD detectors

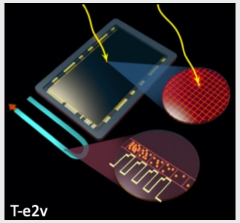
CMOS sensors for UVOIR imaging

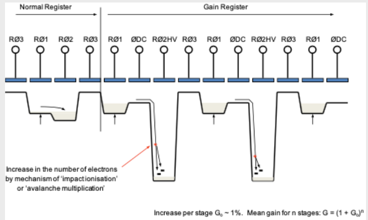

T-e2v COSMOS-66 (64Mpix)


J. Janesick, 5T pixel with pinned photodiode

1 amplifier / pixel, multiplexed readout, electronic shutter (rolling/global), high dynamic range
High energy consumption, dark current, inter-pixel capacitance

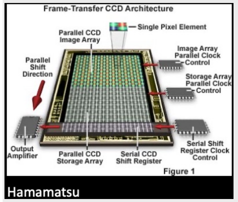
EMCCD for photon counting

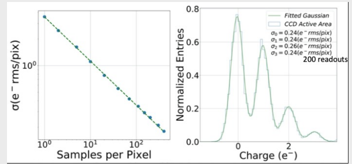

T-e2v



Addition of an Electron Multiplication register (‘gain register’ between the usual serial shift register and the output amplifier). Supress read noise, amplifies dark current

Skipper CCD for noise below 1 e-

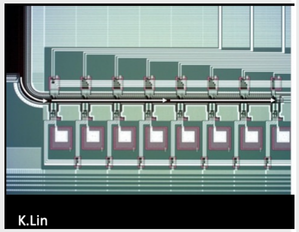

Hamamatsu



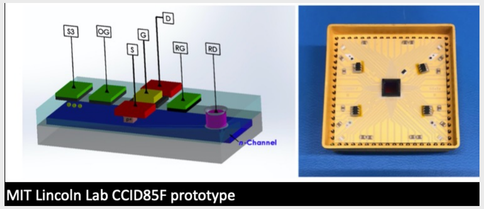
Reading back and forth several N times reduces the noise in sqrt(N); readout during exposure; choose skipper region

Multi-Amplifier Sensing (MAS) CCD

- Repeated readout of the same charge... in sequential amplifiers
- Average (or weighted average) on 8, 16, 32 channels
- Complicated Readout system
- Correlated noise suppression: read the same value at different times


K.Lin

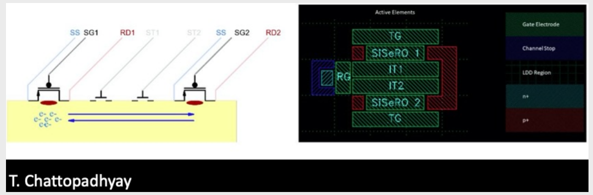
SiSeRO (Single electron Sensitive ReadOut) CCD


MIT Lincoln Lab CCID85F prototype

Pixel charge modulates current in readout transistor
- Faster readout (X-ray), high conversion gain, no kTC, compact
- Expect 1e noise at 1 MHz for 1500 pA/e

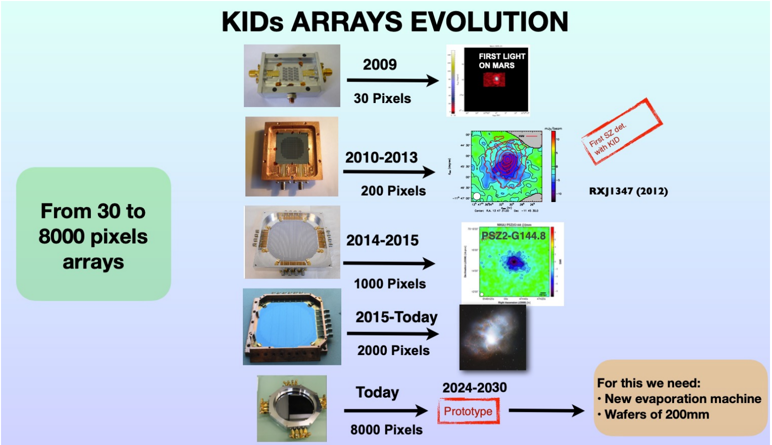
Other

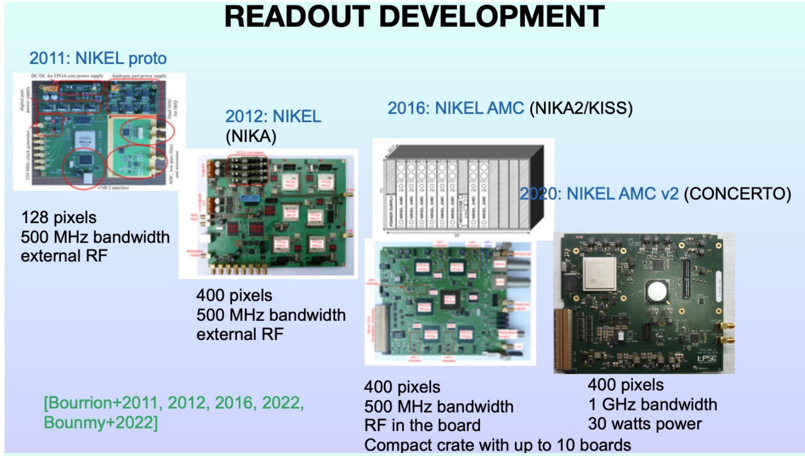
- Skipper CMOS
- Active Pixel sensor with 2 SiSeROs per pixel

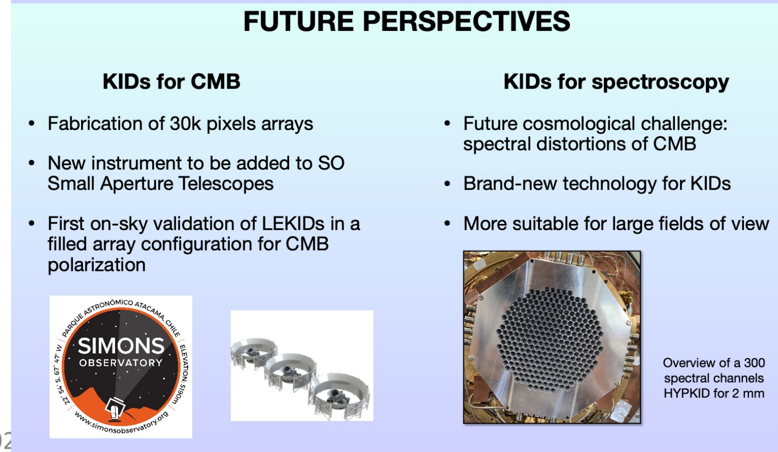

T. Chattopadhyay

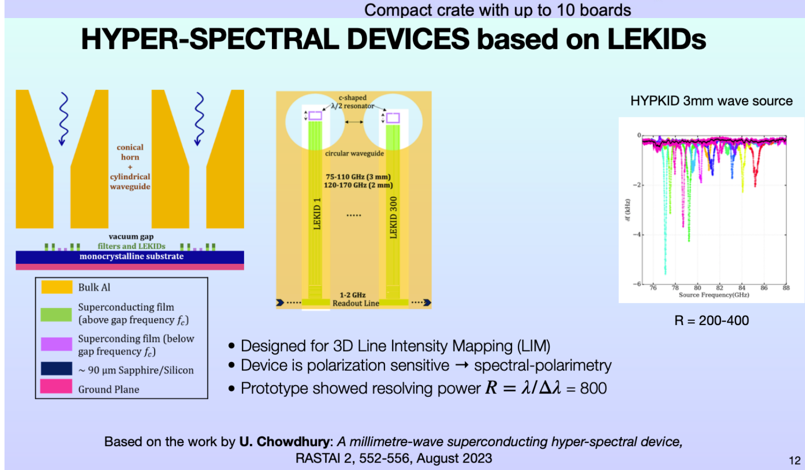
LPSC contribution to GIS KIDS

Expertise in design and fabrication of KIDS and associated optics, electronics, and analysis chain









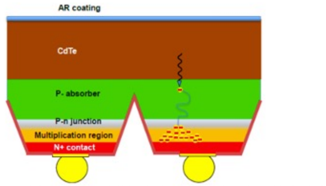
IR detectors in Astronomy

HgCdTe-based APD: basic principles

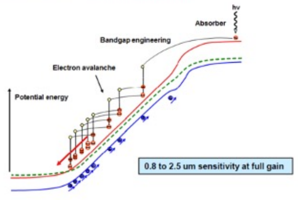
Why HgCdTe is a good material for APD ? [2]

1. This is due to the HgCdTe band structure. **Only electrons are multiplied**. The holes are too heavy and loose most of their energy interacting with phonons.
2. HgCdTe material presents low dark current

State of the art HgCdTe APD, demonstrates a gain of 100 with an excess noise factor lying between 1.1 and 1.4 with moderate applied biases (dozen of volts).



Schematic view of a HgCdTe-based avalanche photodiode



Band diagram of an avalanche photodiode. Taken from [1]

[1] CLAVEAU, Charles-Antoine, BOTTOM, Michael, JACOBSON, Shane, *et al.* First tests of a 1 megapixel near-infrared avalanche photodiode array for ultra-low background space astronomy. In : *X-Ray, Optical, and Infrared Detectors for Astronomy X*. SPIE, 2022. p. 330-346.
[2] ROTHMAN, Johan. Physics and limitations of HgCdTe APDs: A review. *Journal of Electronic Materials*, 2018, vol. 47, no 10, p. 5657-5665.

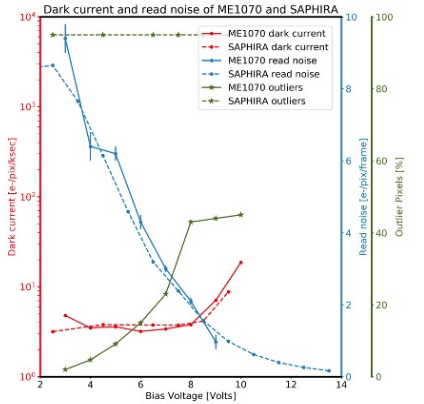
On the use of APD for low flux applications

In astronomy APDs are used mainly for adaptative optics, but not for low flux applications. No science grade devices already exist. Yet developments are ongoing funded by:

- NASA (IkePono development, 1024x1024 array)
- ESA (IBEX development, 2048x2048 array)
- University of Hawaï (IkePono development, 1024x1024 array)

Current development demonstrates sub-electron readout noise but still has to face main limitations [1]:

1. Glow of the readout circuit
2. Maintain low dark current while applying high biases
3. Persistence
4. Loss of QE at low bias voltage

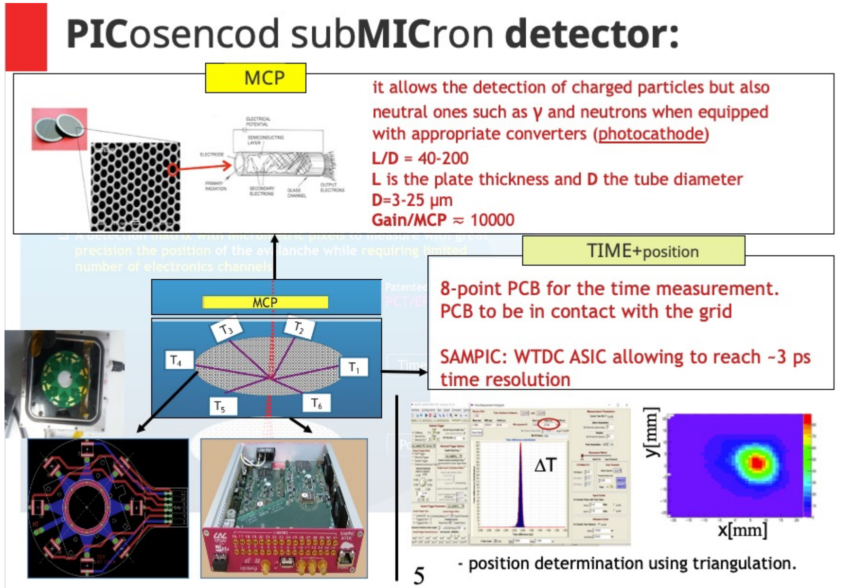


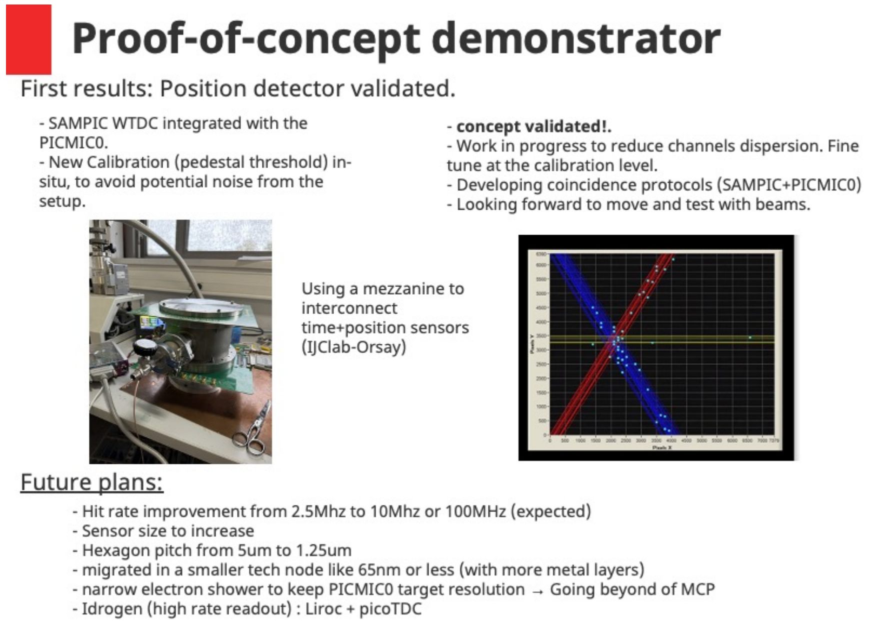
Taken from [1]

[1] CLAVEAU, Charles-Antoine, BOTTOM, Michael, JACOBSON, Shane, *et al.* First tests of a 1 megapixel near-infrared avalanche photodiode array for ultra-low background space astronomy. In : *X-Ray, Optical, and Infrared Detectors for Astronomy X*. SPIE, 2022. p. 330-346.

- HgCdTe based IR detectors are widely used in the most up to date IR instruments and serve very well astronomers.
- However in photon-starved applications, we are interested in increasing the detector sensitivity. As shown APD sounds to be promising candidates as they allow sub-electron readout noise. Yet these detectors are still under development.
- **IR Photon counting arrays with HgCdTe-based APD ?**
  An excess noise factor below 1.02 would allow us to operate in a photon counting mode. We would reach an almost noiseless multiplication. This could bring major changes in IR astronomy.

PICMIC: The First Results



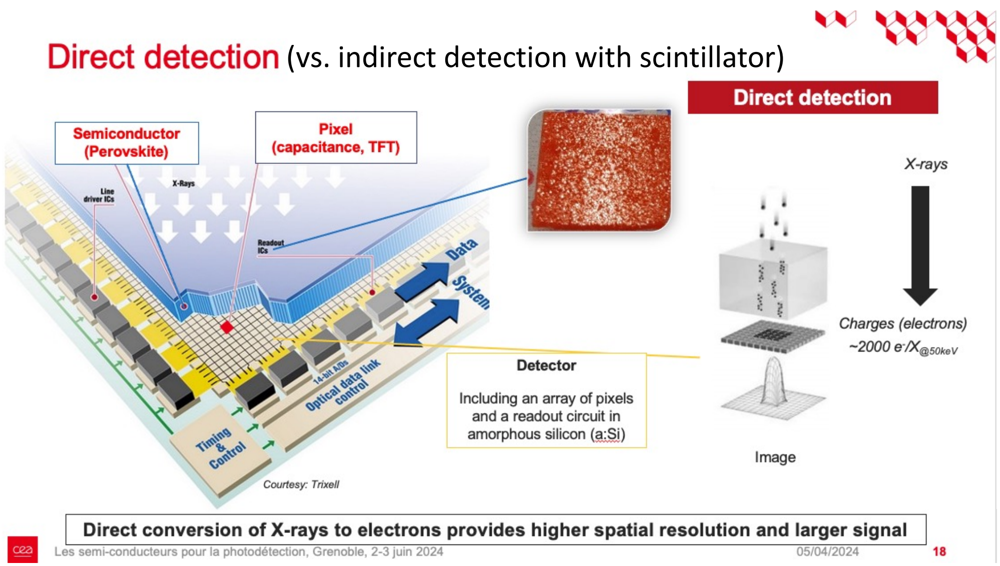


- PICMIC concept **validated**:
  - Principle of very precise time measurement already validated; now principle of very precise positions validated.
- A first demonstrator using SAMPIC for time measurement and combining both time and position measurements based on SAMPIC DAQ is being used to combine both very precise time and position measurements.
- A new detector NCP is being developed to reach unprecedented resolutions in both time and position.
- A board integrating a low-jitter timing preamplifier and discriminator (LIROC-OMEGA) as well as a precise TDC (piciTDC-CERN).

Session 3: X-ray detectors

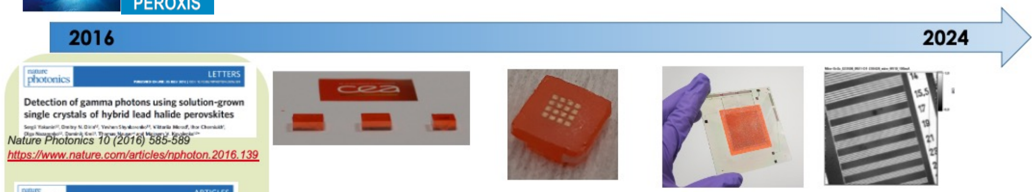
09:00	**Introduction to X-ray and gamma-ray detection**	*Aline Meuris*	*Amphithéâtre, LPSC*	09:00 - 09:35
	Large-area X-ray detectors based on organic and perovskite films	*Andrea Ciavatti*	*Amphithéâtre, LPSC*	09:35 - 09:55
10:00	**Lead Halide Perovskites semiconductors for X-ray imaging**	*Éric Gros-Daillon*	*Amphithéâtre, LPSC*	09:55 - 10:15
	Imagerie CT spectrale avec le XPAD3.2/AsGa sur le PIXSCAN-FLI	*Yannick Boursier*	*Amphithéâtre, LPSC*	10:15 - 10:35
	Monolithic CMOS pixel sensors for low energy X rays	*Elio SACCHETTI*	*Amphithéâtre, LPSC*	10:35 - 10:55

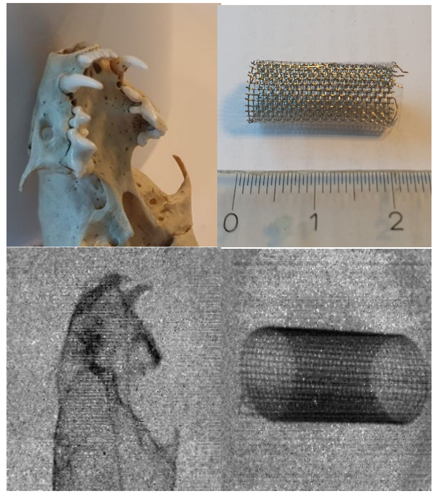
Perovskites for RX and Gamma detection



X-ray imagers development at CEA Grenoble

https://peroxis-project.eu/





Achievements :

- ✓ Spatial resolution
- ✓ Sensitivity (signal)

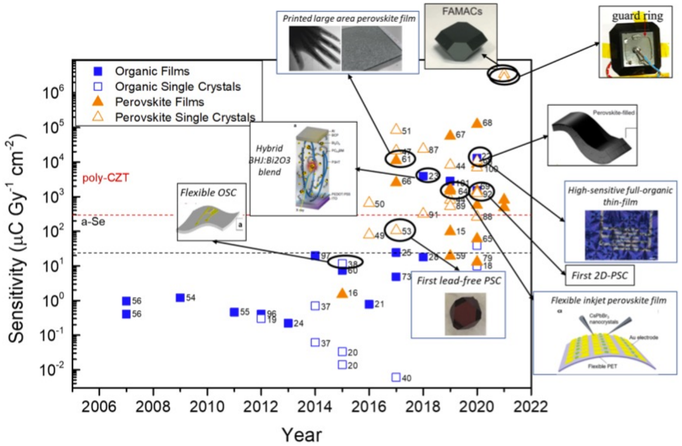
- Layer thickness
- Surface

- ✗ Dark current value/stability
- ✗ Process compatibility with backplane technology

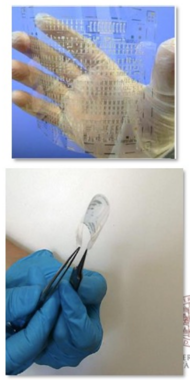
- PV have achieved in few years the same cell efficiency as silicon and it is still increasing.
- PV are used for solar cells in space, tolerance to radiation very high respect to silicon (which is destroyed very soon)
- Gamma-ray detector with energy resolution comparable to CdZnTe (3.2%@122keV, 1.6%@662keV) was obtained thanks to Bridgman growth of $CsPbBr_3$ (Northwestern university)
- X-ray imagers were made at CEA and meet high spatial resolution and large signal

Large-area RX detectors based on perovskite films

ORGANIC/HYBRID MATERIALS FOR X-RAY RADIATION DETECTION

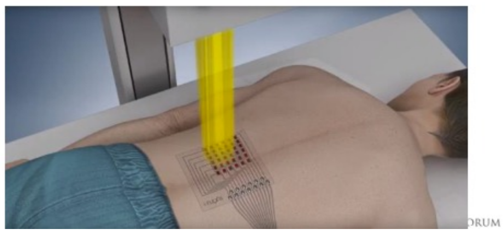


Sensitivity: 10^6 μC/Gy cm² @ 0.2V @ RT
>> than polyCZT or a-Se

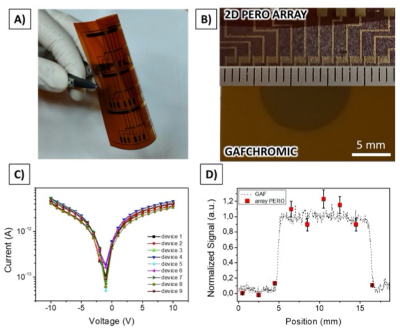


8 L. Basiricò et al., *Adv. Mater. Technol.* **2020,** 2000475

- **In-situ** dose evaluation thank to conformability human tissues

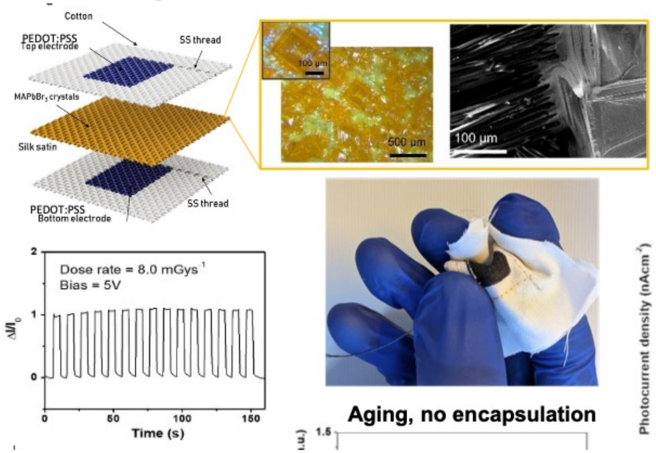


FLEXIBLE X-RAY BEAM MONITOR ARRAY

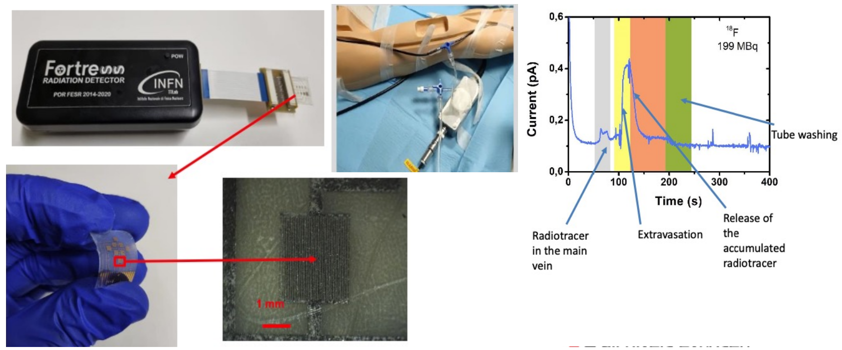


I. Fratelli et al., Advanced Science (2024), in publication

Direct detection by 3D perovskites on textiles



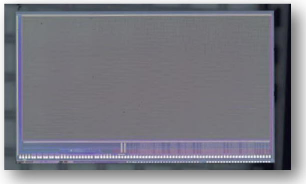
Wearable wireless X-ray sensor (up to 150keV) based on 2D perovskite thin films



Session 3: X-Ray detectors

MAPS for soft RX detection

A sensor for low energy X-ray detection : "Monolithic Imager 1"



- 256 x 512 pixels
- Pixel pitch: 20 µm
- Total area: 10.5 x 6.2 mm²
- Rolling or global shutter operation
- Analog readout with programmable MUX (32/16/8/4)

Specifications

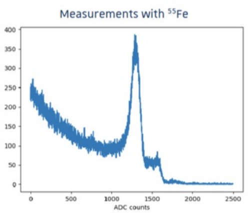
[1 - 10] keV X-ray detection, designed for spectroscopic applications

Operation mode:
- High frame rate (max. 40 kHz)→ energy resolution on each impinging photon
- Low frame rate (min. 1 kHz) → integration over several photons/pixels (each pixel dynamics is important !)

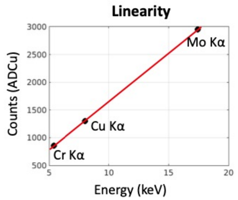
Next version:
Higher dynamics (actual dynamics : 15 ke)
+ will integrate a 12 bits ADC (IPHC + LPSC + APC development)

Signal resolution - Spectroscopy

Signal dynamics - Particle counting



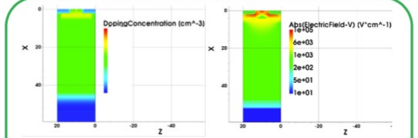
Energy resolution ~ 180 eV @Mn(Kα)
(room temperature)



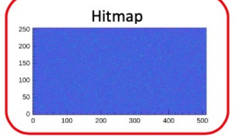
Measurements with X-ray generator

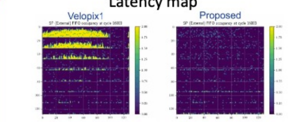
Developing a physics-electronics integrated simulation based on MI-1

From the particle interaction with the sensor… → Sentaurus TCAD / Synopsys: Sensing element design → ap²: Charge deposition, collection, digitization → PixESL: Readout architecture sizing → cadence: Integrated circuits design → … to the chip digital output

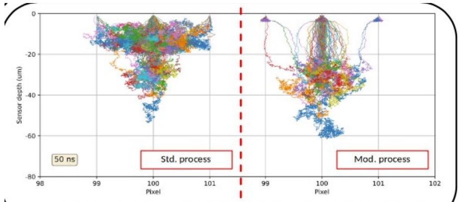


Doping concentration and electric field maps

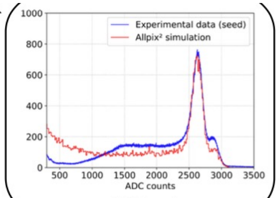




From "PixESL: A virtual Electronic System Level prototyping framework", Jashandeep Dhaliwal, 25/09/2023, p.5



Charge collection comparison between std. and mod. process



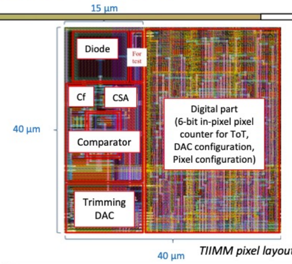
Fe55 spectrum

Technology transfer: "TIIMM" sensor

- TIIMM: Tracking and Ions Identifications with Minimal Material budget
- European funding: H2020-INFRAIA / STRONG-2020
- **Designed for position and energy measurement**

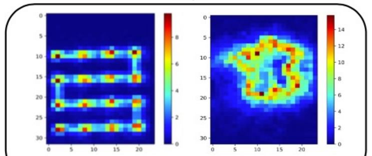
Maximum linear range of ToT:
- TIIMM0 : 110ke-
- TIIMM1 : 250ke-
- TIIMM1B : up to 700 ke- (current maxi. of MI-1: 15 ke-)

Digitizing already integrated (6 bits ToT) => useful for signal dynamics



TIIMM pixel layout

Improvements on MI-1 ⇄ **Pooling of developments** ⇄ Improvements on TIIMM

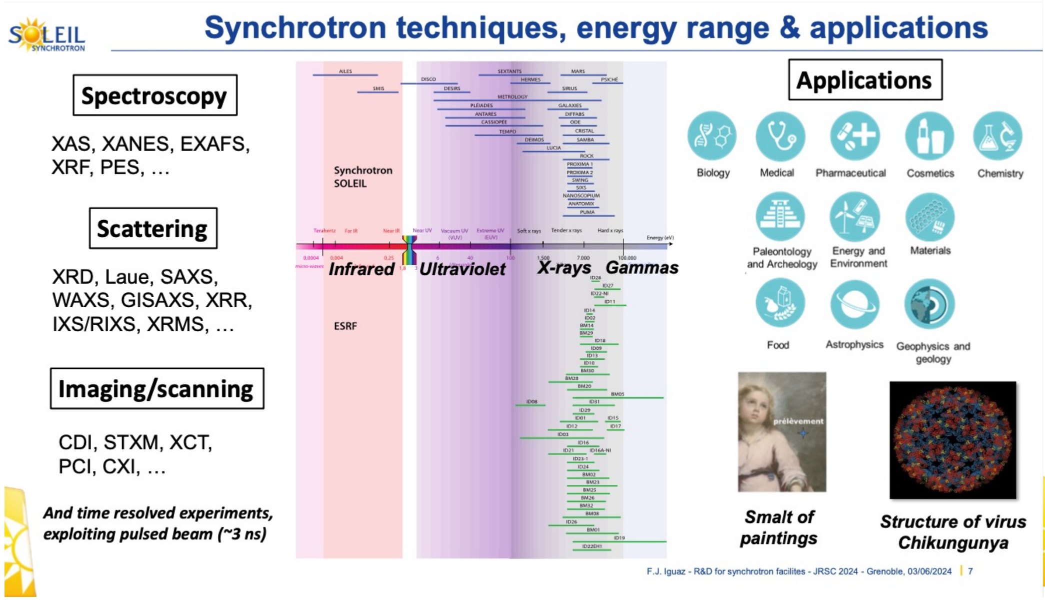


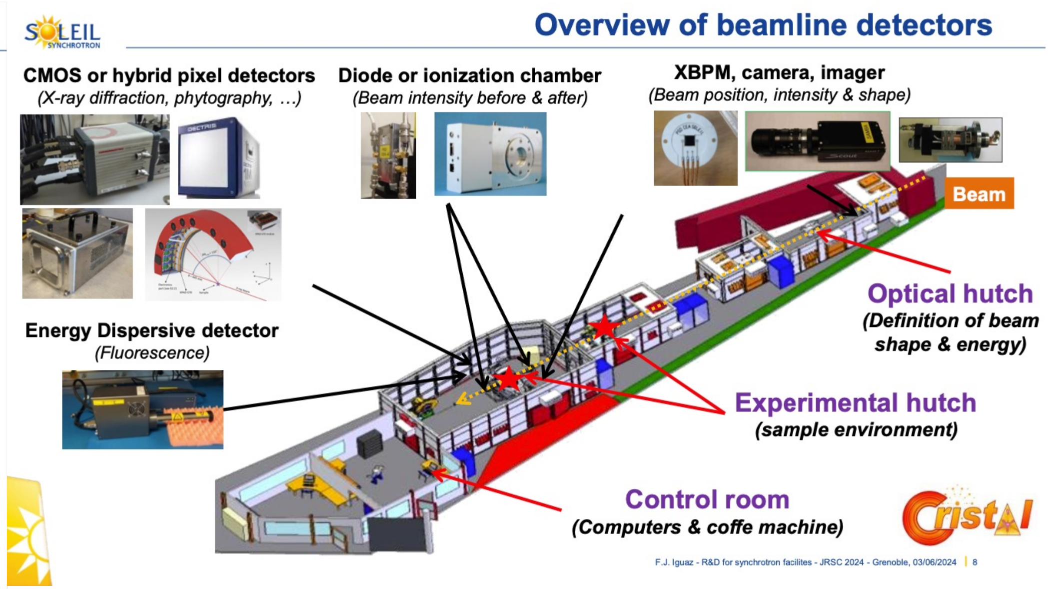
Proof of concept @AIFIRA (LP2iB) in April 2024

Session 4: Detectors for synchrotron radiation

Time	Contribution	Speaker / Room	Time slot
	Detectors overview in synchrotron experiments	*Francisco Jose (Paco) Iguaz Gutierrez*	
	Amphithéâtre, LPSC		11:25 - 12:00
12:00	**Soft X-ray Synchrotron cameras based on Back Side Illuminated CMOS sensor at SOLEIL**	*Kewin Desjardins*	
	Amphithéâtre, LPSC		12:00 - 12:20
	Micro-beam radiation therapy avec diamant pour détecteur des rayons X de haute intensité	*Jayde Livingstone*	
	Amphithéâtre, LPSC		12:20 - 12:40
	Advanced synchrotron radiation based techniques (Bragg diffraction imaging, XBIC) for the characterization of semi	*J. Baruchel*	

Detector R&D for synchrotron facilities

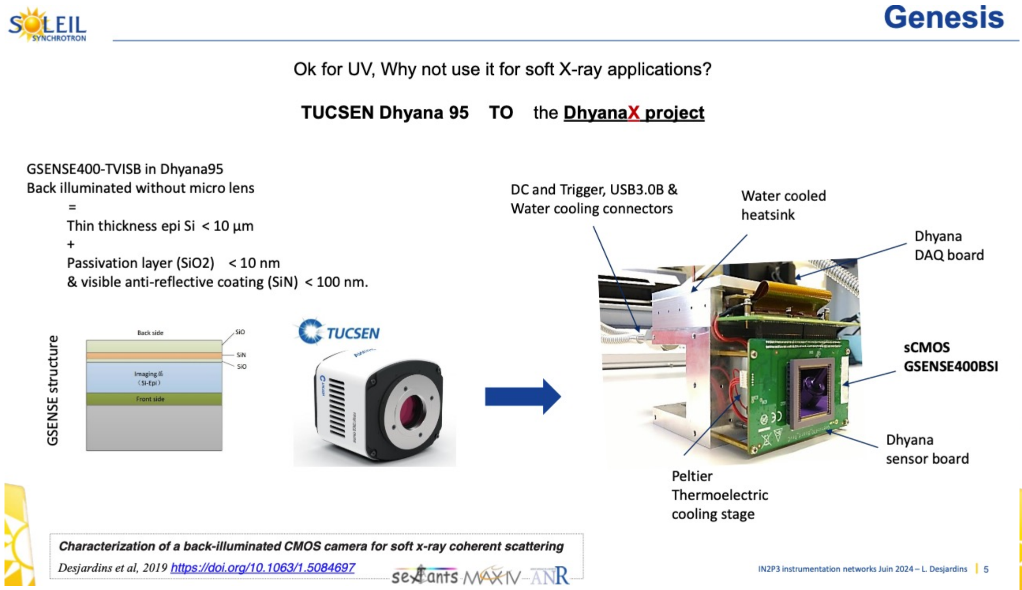


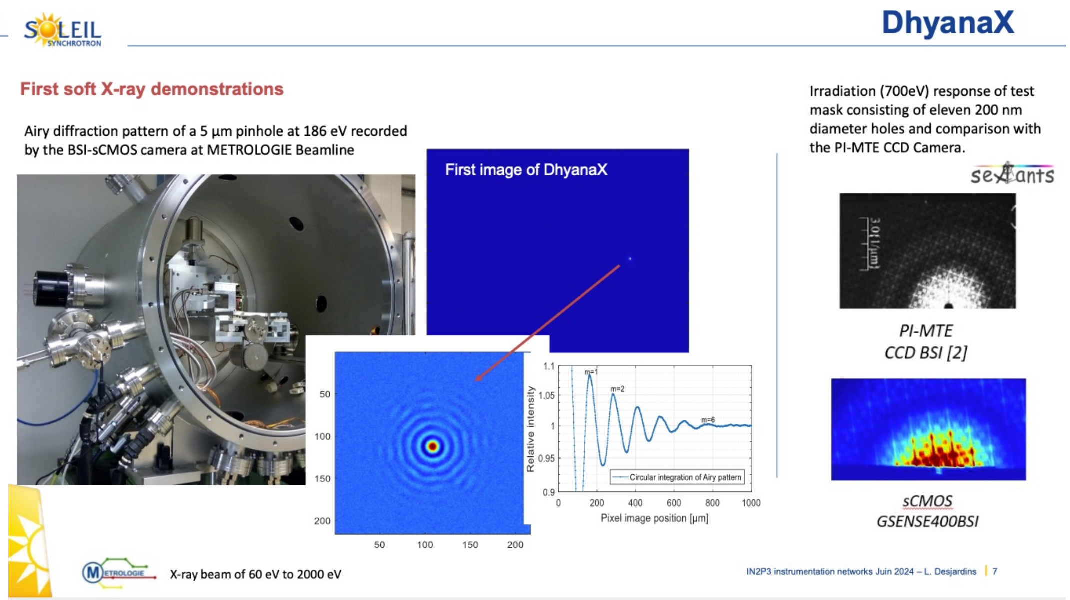


- Big development of detector based on semiconductor for Synchrotron facilities
  - Sensor -> Uniform response & radiation hardness
  - ASIC -> Small pixels and large dynamic range
  - Firmware -> Reduction of charge sharing for spectroscopy
  - Readout system -> Large area covering, high frame rate
- Detector development is made by synchrotron facilities, research laboratories and private companies
- Synchrotron are pushing detector limits for facilities upgrades

Session 4: Detectors for Synchrotron radiation

Soft RX CMOS BSI camera

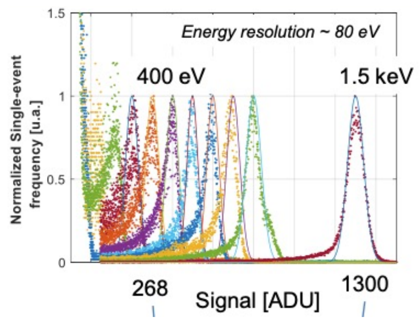


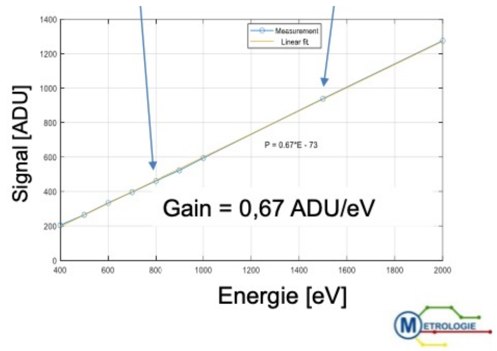


Adaptation of a commercial UV camera to soft RX detection to improve frame rate.

Application of the concept to upgrade other beam lines.

Trend is to have larger area detectors with smaller pixels.

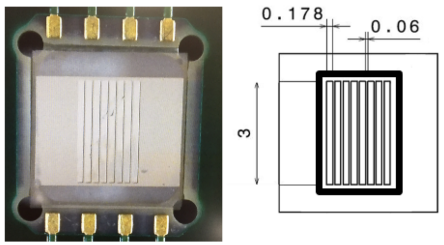




Microstrip diamond detector for microbeam therapy

Session 4: Detectors for Synchrotron radiation

LPSC MICROSTRIP DIAMOND DETECTOR

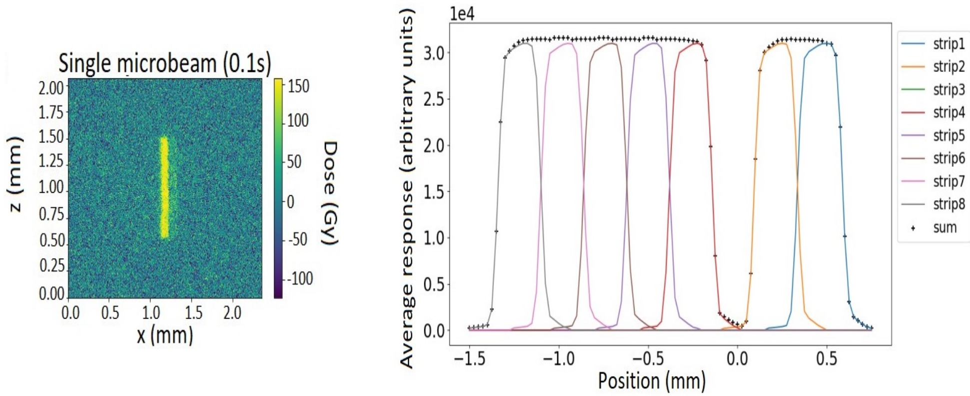


LPSC 8-microstrip diamond detector prototype. All measurements in mm.

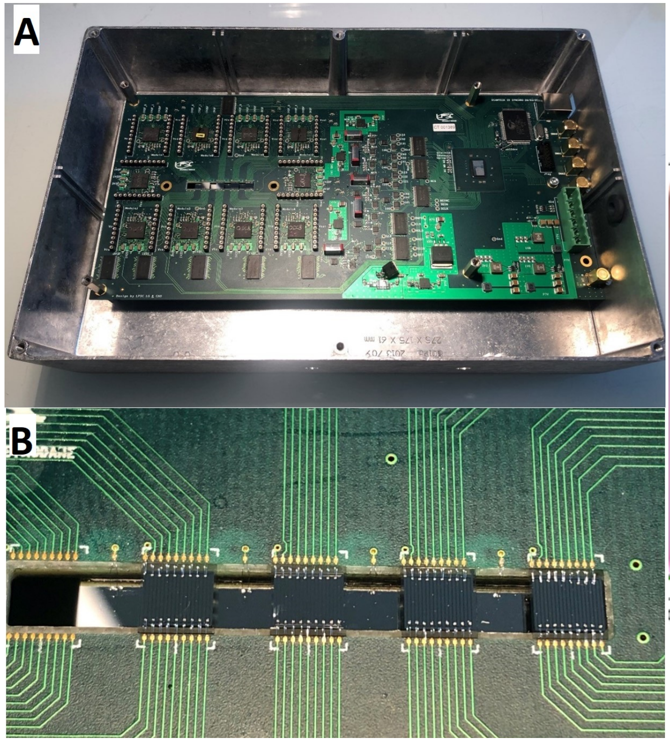
JAYDE LIVINGSTONE - PHOTODETECTION WITH SEMICONDUCTORS JUNE 4TH 2024

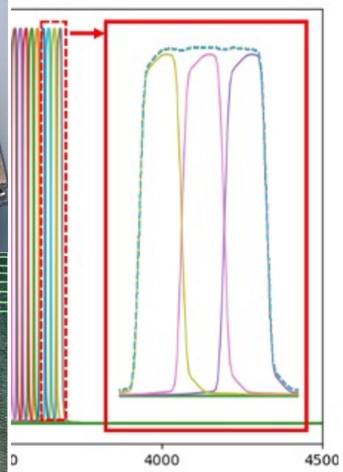
8-strip prototype device

- 550 µm thick monocrystalline CVD diamond
- 8 strips: 3 mm high, 178 µm wide, 60 µm between adjacent strips
- 100 nm thick Al metallisation layers
- 1 V/µm electric field
- Guard-ring surrounding strips
- Simultaneous integrated charge readout
- Aluminium housing with aluminised mylar beam window



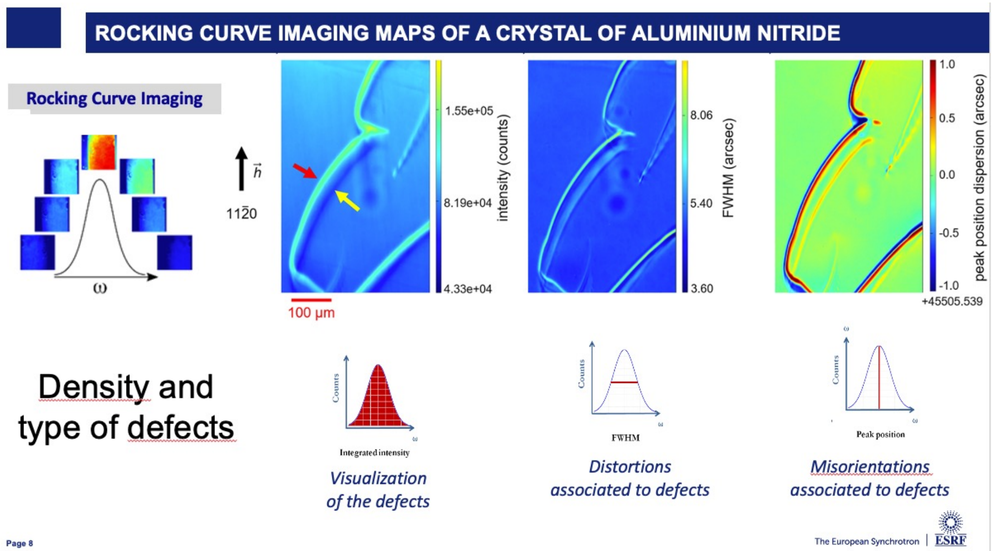
A single microbeam (as visualised using Gafchromic ® film, left) was scanned horizontally across the microstrip detector.

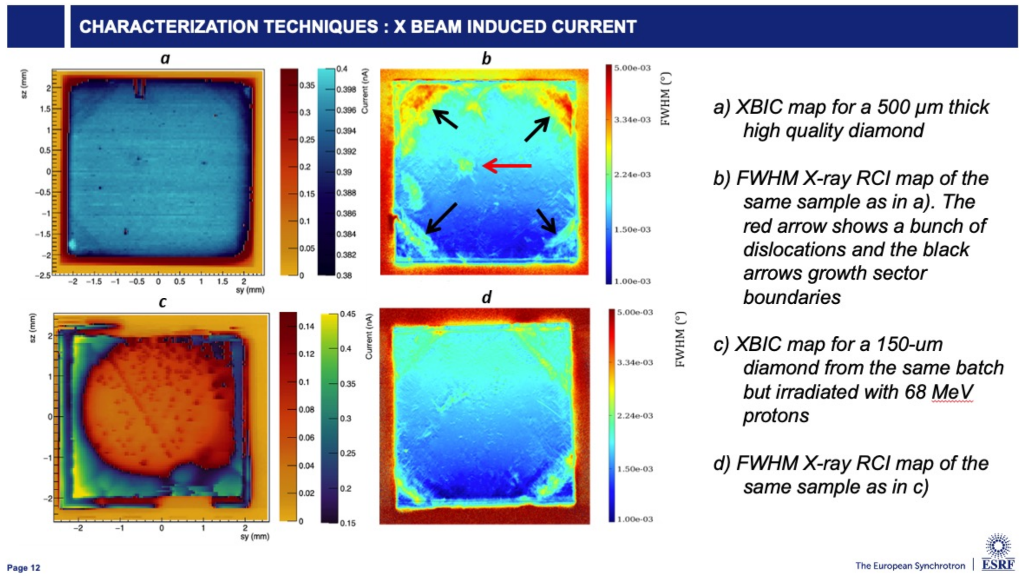


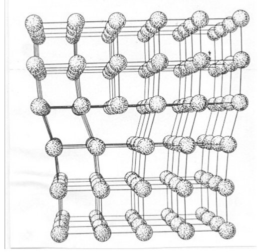


- Juxtaposition of 9 x 17-strip diamond detectors: 150 µm thick monocrystalline diamond substrate
- Tests with veterinary patients

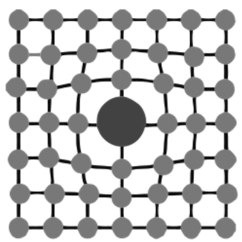
XBIC, Bragg diffraction imaging for semiconductor characterisation at ESRF







Linear defect: dislocation



« Punctual » defect: precipitate / inclusion

Au plaisir de nous revoir !!!

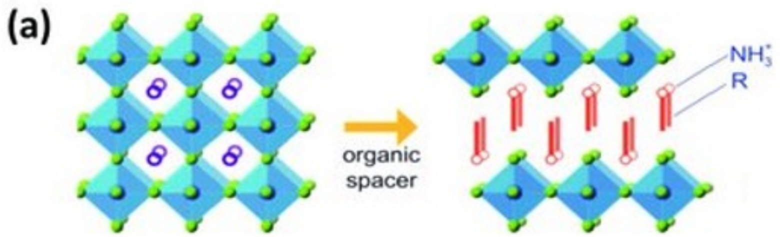
Back-up

Perovskites

The perovskite family

3D

2D



E. Abd El-Samad A, Mixed 2D-3D Halide Perovskite Solar Cells 2021

3D lattice of BX6 octahedra.
A cations located in the interstices between the octahedra.

Excellent **optoelectronic properties**, good electrical conductivity, wide band gap

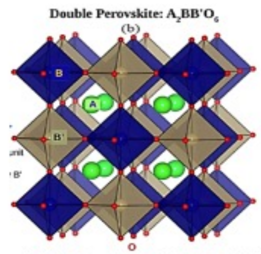
Solar cells, Photodetectors, Light-emitting diodes, Lasers

BX6 octahedra separated by layers of organic ions.

Greater **stability** in ambient air
More intense photoluminescence

Lasers, display

Double perovskite



Rehman, M.U.; Crystals 2022, 12, 1597.

B and B' are different metal cations

And many others

Vacancy ordered double perovskies, Ruddlesden−Popper, Chalcogenide; Rudorffites (ex: AgBi2I7) etc.

Perovskites

2D layered Perovskites

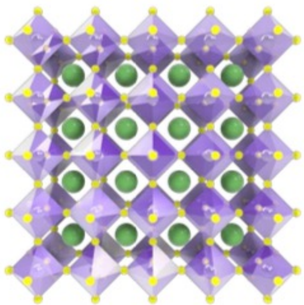
PEA_2PbBr_4 ($PEA = C_6H_5C_2H_4NH_3^+$)

3D vs. 2D

$APbX_3$

Organic cation (MA, FA)

Halogen anion (I, Br, Cl)

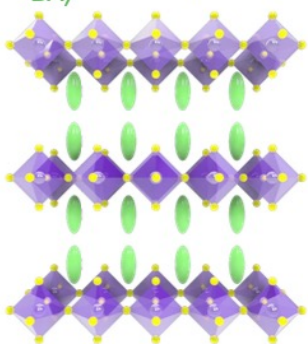


- High X-ray stopping power 10 cm^{-1}, comparable to CZT.
- High carriers diffusion length >1μm in polycrystalline films.
- Low cost, low temperature <150 ℃ deposition from solution.
- Optoelectronic properties tuning by controlling the relative amounts of the components

A_2PbX_4

Organic cation (PEA, BA)

Halogen anion (I, Br, Cl)



- High X-ray stopping power.
- **Lower mobility**
- **Lower Ion migration**
- **Better stability**
- Low cost, low temperature <150 ℃ deposition from solution.
- Optoelectronic properties tuning by controlling the relative amounts of the components

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