ESRF

Update on detector development activities

T. Martin on behalf of ISDD/Detector Unit

Monday 18 March, 2024

Thanks to:

Beamline Control Unit
Mechanical Engineering
Network Unit
External collaborators
Colleagues from Experiments Division

ESRF The European Synchrotron
D&E Detector & Electronics Group
Instrumentation Services and Development Division

FAMILIES OF X-RAY DETECTOR AT ESRF

2D detectors

X-ray imaging detectors

Intense beams and high spatial resolution

- Scintillators + optics + visible light cameras
- sCMOS cameras

Scattering/diffraction detectors

Large area & single photon sensitivity

- Hybrid pixel detectors
- Photon counting or charge integrating

Energy dispersive detectors

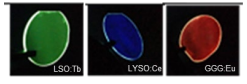
Discrete and monolithic devices

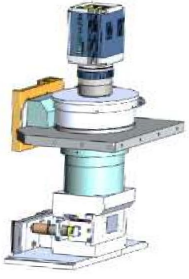
- Silicon Drift Diodes (SDD)
- HPGe detectors
- Digital Pulse Processors

Point detectors

Beam intensity and diagnostics

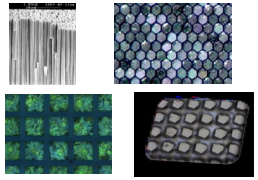
- Avalanche Photodiodes
- Ion chambers, PIN diodes
- Diamond, SiC beam monitors





X-RAY IMAGING DETECTORS

- **Scintillators**

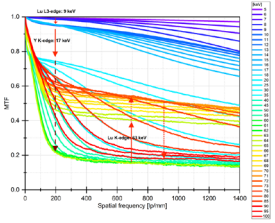


  - ✓ **Microstructure scintillator:** *identify micro-structured (30-50µm resolution) scintillators with improved properties, especially stability under radiation, high DQE, low afterglow*

    CeBrI, ZnSe:Te, LuI_3:Ce, co-doped/undoped/low moisture CsI

  - ✓ **High resolution scintillator:** *development of high spatial resolution scintillators with higher efficiency than current available screens (LuAG:Ce, LSO:Tb. GGG:Eu)*

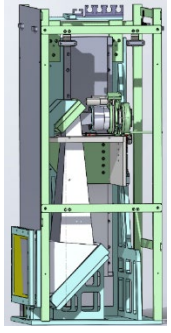
    - ➢ **High density hafnate scintillators ($Lu_2Hf_2O_7$)**
    - ➢ **Tool for simulation of energy deposition and spatial resolution**



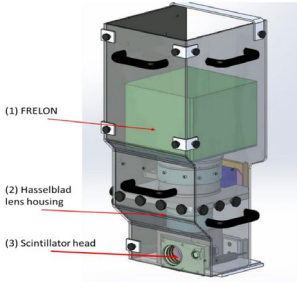
- **Optomechanics developments**

BM05: Microscope Topo

  - ✓ **Large Field of View Detector**, BM05 (20cm), BM18 (40cm)
  - ✓ **Compact white beam microscope**, BM05
  - ✓ **XRI heat load**, temperature up to 300ºC, ID19
  - ✓ **Detector systems**, high collection efficiency, rad hard., blue eraser, 1x, 2x, 4x mag., BM18
  - ✓ **Optical components:** thin and perforated mirrors, Al coating, BM18



BM18: large FOV



ID19: XRI heat load

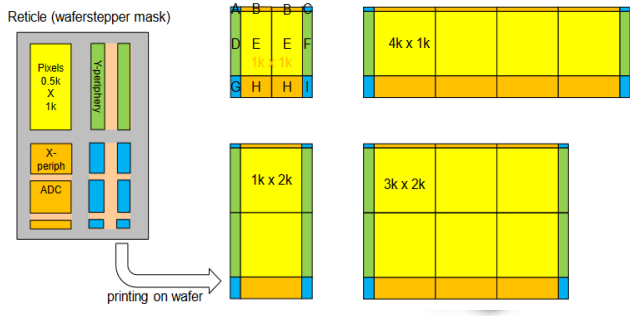
sCMOS FRELON? - INVESTIGATION PHASE - : HORNET PROJECT

The Frelon camera

- More than 40 cameras produced at ESRF
- Excellent performance (at the time)
- Platform: different CCD sensors and optics

What's next: sCMOS Frelon?

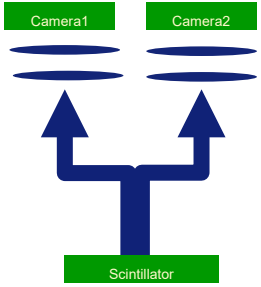
A family of customisable sCMOS cameras for synchrotron X-ray imaging?

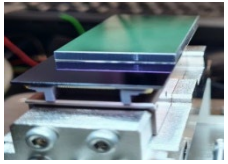


Stitching technology

ELFIS2 sensor

- Developed for ESA by Caeleste (Be)
- Interesting detection performance:
  - ✓ Pixel size: 15 µm
  - ✓ Full-well capacity up to 320 ke$^-$ (ITR mode)
  - ✓ Readout noise down to 2.5 e$^-$ r.m.s. (HG mode)
  - ✓ Frame rate for 4Mpixel: 140 fps





Well suited for taper/FOP coupling

- And some key "uncommon" features:
  - ✓ Global shutter with deadtime-free readout
  - ✓ Backside illumination (QE > 90%)
  - ✓ Radiation hardened
  - ✓ Hardware binning
  - ✓ Scalable size up to 8k×8k pixels (64M) by "stitching" of 512×1024 pixel blocks
  - ✓ Family sensor (6.5µm pixel size)

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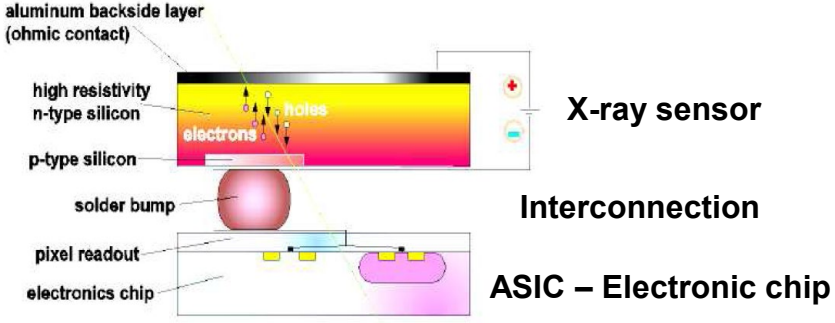


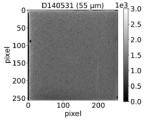
X-ray sensor

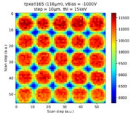
Interconnection

ASIC – Electronic chip

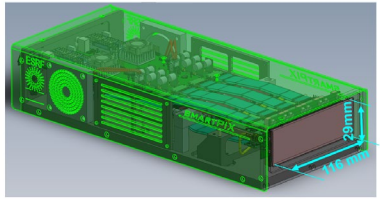
SCATTERING/DIFFRACTION DETECTORS

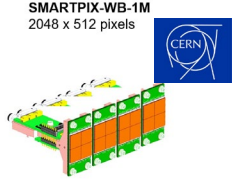
- **Characterization of pixelated semiconductors**
  - ✓ High-flux **CdZnTe**, CdTe, GaAs

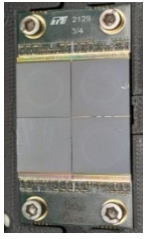




- **SMARTPIX: In-house** development based on the CERN Medipix3-RX chip (2011)
  - ✓ Pixel 55 µm. Compatible with Si, CdTe, CZT, GaAs,… sensors (bipolar)
  - ✓ Mounting, calibration, commissioning and maintenance in-house
  - ✓ Max 2 kHz frame rate (target 4 kHz in 6-bit mode)
  - ✓ Low latency distributed DAQ: Lima2 & RASHPA
  - ✓ Deployment in 2024-2025 (8 systems)







- **JUNGFRAU, Developed by PSI**
  - ✓ **One Jungfrau 4M** commissioned in 2022 at ID29, now in user operation
  - ✓ **One 1M Jungfrau** on-going order for ID09

- **CITIUS, Developed for the SPring8-II** Upgrade Program
  - ✓ **Available at the ESRF** for evaluation
  - ✓ In-house development of a **bonding station** to coupling a Fiber Optic Plate (FOP) to imaging sensors
  - ✓ **Presentation Monday** at 11:15 and **Wednesday** at 10:00

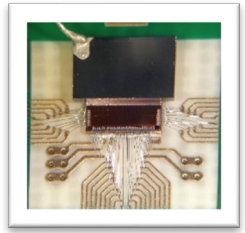
- **XIDER, ESRF and University of Heidelberg,** moving to XIDyn collaboration
  - ✓ High dynamic range digital integrating detector, 100 µm and 200 µm pixel pitch, CdTe and CZT sensors
  - ✓ **Presentation Monday** at 15:00 by M. Wilson

ESRF ISDD Instrumentation Services and Development Division

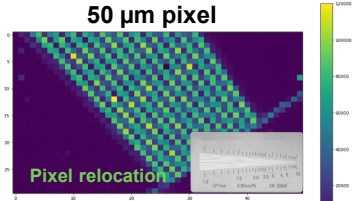
SCATTERING/DIFFRACTION DETECTORS

SPHIRD

- R&D collaboration with AGH University of Science and Technology (Krakow)
- A high quality **high-rate X-ray photon counting detector**
- Design and test of **two** test readout ASICs:
  - Microelectronics technology node: **TSMC CMOS 40 nm**
  - With a sensor pixel pitch of **50 µm** (prototype), target in the **30 - 40 µm** range
- Prototype detectors: **CdTe**, **high-flux CZT**, **Si**
- Maximise the count rate capabilities: **> 60 Mcps/pixel** with full pixels (at 10% pile-up)
  > 15 Mcps/pixel with small pixels
- X-ray hit relocation (arbitration algorithm) prevents count losses at the pixel corners
- Investigate the possibility of achieving **higher spatial resolution** (subpixel relocation)

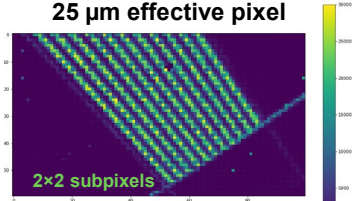


Pixel Relocation
50 µm pixel



10 lp/mm

2×2 Relocation
25 µm effective pixel



3×3 Relocation
16.7 µm effective pixel

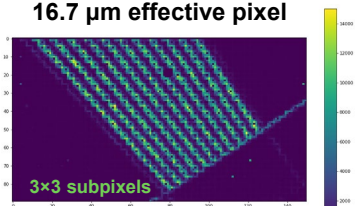


Image of an X-ray resolution test pattern (Si sensor, 16 keV)

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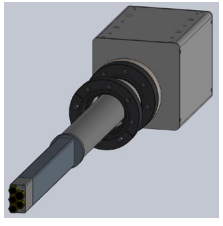

Point detectors

Beam intensity and diagnostics

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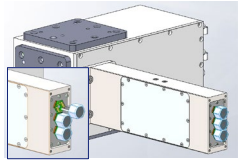
INTEGRATION AND STUDY OF ENERGY DISPERSIVE DETECTORS

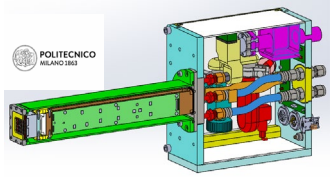
- **Development of compact SDD (Silicon Drift Detector) modules**
  - ✓ **Optimized modular version** (hexagonal geometry), vacuum-compatible
  - ✓ Sensor fabricated by Mirion

Commercial system

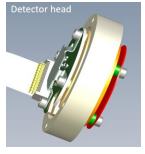

In-house system

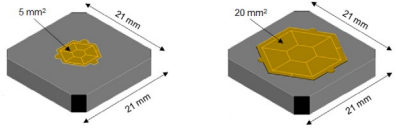
- **Monolithic sensors**
  - ✓ **Development of two ARDESIA 16–channel optimized with ESRF/Politecnico di Milano**:
    - ➢ *ID16a* : In vacuum version, integration and design of mechanics
    - ➢ *ID24:* Integration of **1mm thick** SDDs sensor, in air

16 × 25mm²
1mm thick SDDs

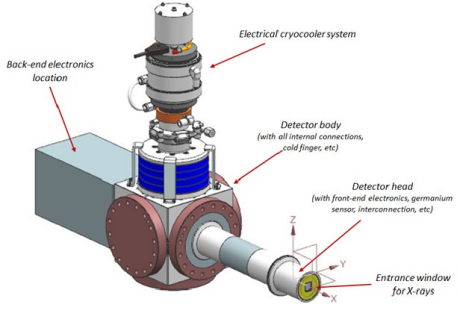


  - ✓ **Design a new generation of Germanium detectors for X-ray spectroscopy applications in the energy range 5 keV to 100 keV**
    - ➢ Horizon Europe : 10 partners, Synchrotrons and industrial partners
    - ➢ Monolithic crystal of 7-element (5mm²/elt and 20mm²/elt variants)
    - ➢ Custom readout ASICS with 3 gains to optimize performance in ranges:
      5-15 keV / 15-37.5 keV / 37.5-100 keV
    - ➢ DPP: Xpress4





Sensors fabricated, MIRION



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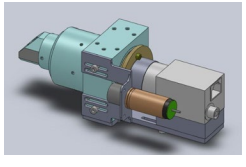
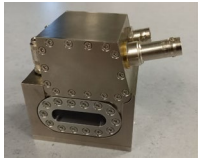
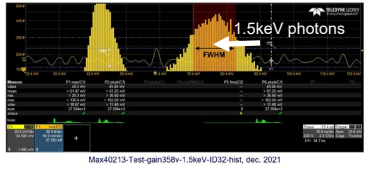


BEAM INTENSITY AND DIAGNOSTIC

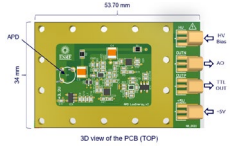
- **“FAST” Ionization Chamber: Development of a high flux version**
  - ✓ 5 kV high voltage compatible
  - ✓ Adaptive absorption, **Easy maintenance**



- **Extend the energy range of APD system to lower energy:** New preamplifier design
  - ✓ Based on MAX40213 amplifier (low-noise device for LiDAR ‘Light Detection and Ranging’)
  - ✓ Noise level decreased, to operate at working energy from 0.5keV (~3keV on the actual version)



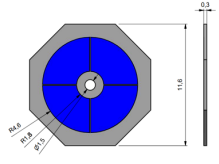
Max40213-Test-gain358v-1,5keV-ID32-hist, dec. 2021



3D view of the PCB (TOP)

- **Beam viewers:**
  - ✓ CCD → CMOS: Evaluation & **upgrade** with new CMOS Ace Basler (acA1440-73gm)
  - ✓ Improvement of **spatial resolution** with thin film scintillator

- **Compact 4-quadrant photodiode**
  - ✓ Vacuum compatible
  - ✓ Sensor fabricated by Mirion



60mm² (4 × 15mm²)
Ø 1.5mm aperture

21mm × 14mm

ACKNOWLEDGEMENT

DETECTOR UNIT STAFF

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LEAPS

Emmanuel COLLET
Frelon
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LPE
HPD-PSI

Pablo FAJARDO
Group Head
Sphird

Christophe JARNIAS
Opto-mechanics
Indirect detection

Menyhert KOCSIS
Team Head
Ipool

Thierry MARTIN
Unit Head
Diagnostic

Eric MATHIEU
Mechanics
Diagnostic

Julien MATHIEU
LPE, Polishing
Scintillators

Leila NIONGUI
Physical measurement

Kristof PAUWEL
Indirect detection
Citius

Marie RUAT
HPD-Dectris
SC sensor

THANK YOU FOR YOUR ATTENTION