Overview of detector development at ESRF

Ongoing activities and strategy for future instruments

Pablo Fajardo, Jean Susini
Outline

Present: Ongoing activities
- Overview of in-house capabilities and achievements
- Beamline specific development projects
- Collaboration activities

Future: Detector Development Programme
- Preparatory work
- Overall picture
- Key technologies
- New long-term advanced detector projects
Contributions from ESRF staff

Many ISDD members
Thierry Martin
Cyril Ponchut
Jean Claude Labiche
Jean Marie Rigal
John Morse
Paul Antoine Douissard
Marie Ruat
Menyhert Kocsis
Joël Clément
Christian Hervé
Laurent Siron
Jacques Cérrai
Alejandro Homs
Laurent Claustre
Emmanuel Papillon
Sebastien Petitdemange
Roberto Homs
Christophe Jarnias
Jean Jacques Thevenin
Emmanuel Collet
Eric Mathieu
Daniel Pothin
Jacques Borrel
Patrick Duboc
Jean François Ribois
…
Isabelle Kieffer [- 2009, now FAME]
Nicolas Janvier [- 2010]

and even more from EXPD
Beamline scientists and BLOMs from all the ESRF beamlines
X-ray Detectors at the ESRF

• A diversity of off-the-shelf and customised instruments

• ESRF driven developments:
  • Strongly **application oriented** (user facility)
  • But as **generic** as possible

• In-house developments
  • **technology** and **know-how**:
    - Optics, mechanics, electronics, software
    - X-ray detector testing and characterisation
  • Focus on **detector integration** projects
MAXIPIX: high frame rate hybrid pixel detector

- **55 x 55 µm²** pixel size
- **5-20 keV energy range** (500µm Si sensor)
- **> 10⁵ counts/pixel/s**
- **1400 frames per second**

Detection geometries and packaging

11 systems in operation @ ESRF
+ PETRAIII and Diamond
+ requests from:
  NSLS, Soleil, LNLS, …

Main applications:
- Inelastic scattering
- XPCS
- SAXS, GISAXS
- Surface and interface diffraction
## FReLoN camera

**CCD camera optimised for synchrotron experiments**

- Combines high speed and sensitivity
- Emphasis on linearity and stability
- Beamline integration (data acquisition, operating modes)

<table>
<thead>
<tr>
<th>CCD chip (no binning)</th>
<th>Readout freq. (Mpixels/s)</th>
<th>Dynamic Range</th>
<th>Frame rate (frames/sec)</th>
<th>Noise (e- rms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH7899 (ATMEL/e2v)</td>
<td>20 (4 x 5)</td>
<td>18800 14.2 bits</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>40 (4 x 10)</td>
<td>13800 13.8 bits</td>
<td>8</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>80 (4 x 20)</td>
<td>9090 13.1 bits</td>
<td>15</td>
<td>26</td>
</tr>
<tr>
<td>CCD230-42 (e2v)</td>
<td>10 (4 x 2.5)</td>
<td>13200 13.7 bits</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>20 (4 x 5.0)</td>
<td>8200 13.0 bits</td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td>KAF4320 (KODAK)</td>
<td>10 (4 x 2.5)</td>
<td>37800 15.2 bits</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>20 (4 x 5.0)</td>
<td>27500 14.7 bits</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>40 (4 x 10)</td>
<td>16600 14.0 bits</td>
<td>6</td>
<td>27</td>
</tr>
</tbody>
</table>

> 20 systems in operation @ ESRF beamlines
Optics for indirect detection

BM05
Folded, 1.9x

ID06
In-line, 20x/0.5

ID15
Reflective
10x/0.4

ID15
Folded, 1x
Polychromatic

ID19
3 motorized objectives
4 eyepieces

ID18F, In-line, 10x/0.4

Folded
4x/0.16

~35 custom optical systems installed at ESRF beamlines
Very high spatial resolution scintillators

- Epitaxial single crystal films (SCF)
- Key components for high resolution imaging

![Spatial resolution (MTF)](image)

Objective with NA=0.55

MTF vs Cycles (LP/mm)

Epitaxial layer e.g. Gd₃Ga₅O₁₂

Transparent substrate

SCF + substrate thickness < 25 µm

Commercial scintillators
- Free-standing > 25µm
- Fragile
Facility for in-house production of SCF scintillators
*Liquid Phase Epitaxy (LPE)*

Continuous Improvement of thin crystal film scintillators:

- YAG:Ce ($Y_3Al_5O_{12}$)
- LAG:Eu,Tb ($Lu_3Al_5O_{12}$)
- LuGG:Eu ($Lu_3Ga_5O_{12}$)
- GGG:Eu, GGG:Tb ($Gd_3Ga_5O_{12}$)
- LSO:Tb ($Lu_2SiO_5$)

16µm thick GGG:Eu on 500µm undoped GGG, 1” diameter.
**Ongoing beamline specific developments**

The current detector development effort focuses on upgraded beamlines:

<table>
<thead>
<tr>
<th>Beamline</th>
<th>Detector developments</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPBL4 / NINA</td>
<td>- New imaging optics</td>
</tr>
<tr>
<td></td>
<td>- Very high dynamic range combo cSAXS detector</td>
</tr>
<tr>
<td>Nano-imaging &amp; Nano-analysis</td>
<td></td>
</tr>
<tr>
<td>UPBL6</td>
<td>- Custom MAXIPIX pixel detectors (Si and CdTe)</td>
</tr>
<tr>
<td>Inelastic X-ray scattering</td>
<td></td>
</tr>
<tr>
<td>UPBL9a</td>
<td>- High sensitivity USAXS FReLoN detector</td>
</tr>
<tr>
<td></td>
<td>- Ge microstrip XH detector (STFC)</td>
</tr>
<tr>
<td></td>
<td>- New optics for EDXAS FReLoN</td>
</tr>
<tr>
<td></td>
<td>- FReLoN camera Hamamatsu</td>
</tr>
<tr>
<td>UPBL11 / TEXAS</td>
<td>- Field fiber optics coupling tomography camera</td>
</tr>
<tr>
<td>Energy Dispersive XAS</td>
<td></td>
</tr>
<tr>
<td>Palaeontology project</td>
<td></td>
</tr>
</tbody>
</table>

In addition to specific developments, the UPBLs will be equipped with a number of commercial state-of-the-art detectors (e.g. Rayonix, PILATUS, energy dispersive, …)
Optics developments for UPBLs

Semitransparent cameras (UPBL4 / NINA)
- Custom design eyepieces (3.1x and 4x)
- Vitreous carbon mirror

Larger formats:
- 4k×4k pixels **X-ray imaging** optics (UPBL4 / NINA)
  - Custom made lenses

- Wider input field (100 mm) for **EDXAS** (UPBL11 / TEXAS)
  - Optical/lens coupling to FReLoN camera

- Wider input field for **tomography** (**Palaeontology project**)
  - Fibre optics ‘flexible ‘ coupling to a CCD camera

(U. Bologna, INFN)
New CCD/FReLoN cameras for UPBLs

Fast linear CCD camera for EDXAS (UPBL11 / TEXAS)

- FReLoN camera based on the CCD *Hamamatsu S11156-2048*
- 2048 pixels (14×1000 μm)
- 5000 frames/sec @ 14bit

High sensitivity/resolution USAXS detector (UPBL9a)

- Backilluminated CCD e2v 230-84
- 4096×4096 pixels (15μm×15μm)
- Direct fiber optics (faceplate) coupling
Very high dynamic range combo detector for **coherent SAXS** (**UPBL4 / NINA**)  
A combination of:  

- A **photon counting** pixel detector  
- An **integrating** imaging detector (CMOS)
UPBL developments: Time resolved 1D detector

Ge microstrip detector for time resolved EDXAS (UPBL11 / TEXAS)

Upgrade of existing detector developed by STFC (UK)

Ge monolithic sensor
- 1024 strips, 50 µm pitch
- Built at LBNL (Berkeley)

New readout chip (XCHIP3)
- Improved ASIC
- Developed at RAL (STFC)

Time resolved experiments:
- 150 ns gating time
- 1.6 µs readout time
- Irreversible and stroboscopic experiments

XH detector head with heat shield removed (STFC and LBNL, courtesy J. Headspith)
Ongoing collaborations

- Technicality
  - Pan-European Consortium for Detector Development
- Synergy
  - LiMA
  - XNAP
  - hiZpad

* Initiated and/or coordinated by the ESRF
Pan-European Consortium for Detector Development 2011-... 

Goals:
- Set a common ground for collaboration and promote synergy for new R&D programmes
- Create the necessary critical mass to steer developments in industry and to influence EU programme definition

Consortium official kick-off in January 2012, but some activities initiated in 2011

First initiatives:

**X-ray beam position monitors – BPM**
- Survey + topical workshop
- Ongoing activities
- Common goals and interests
- 2 working groups:
  - White beam monitors (HZB)
  - Diamond based BPMs (ESRF)

**ESRF development proposal:**
- A custom 16 Mpixel CCD to build
  - a soft X-ray area detector
  - a hard X-ray imaging camera

Based on FReLoN electronics:
- Low technological risk
- Short development time (~3 years)
HIZPAD collaboration (ELISA JRA)

High-Z (CdTe) semiconductor sensors for pixel detectors
SR facilities ESRF, DESY, DLS, ELETTRA, SLS, SOLEIL
+ CNRS, RAL, U. Freiburg, U. Surrey, DECTRIS

Resolution measurements @ 50 and 90 keV (ID15)

Diffraction of Yb$_2$O$_3$ nanopowder @ 50keV (ID11)

2009 – 2011
http://hizpad.esrf.eu
Goals:
- Speed up the development of EIGER at PSI
  (next generation of counting pixel detector at PSI)
- Early availability of modules at the ESRF beamlines
- Deep in-house knowledge of the detector at ESRF
- Improved beamline integration

- First module at ESRF expected in 2012
XNAP: ns time resolution 2D detector

- 1 kpixel sensor: pixellated avalanche Photodiode (APD)
  - active area: \( \sim 1 \text{ cm}^2 \)
  - pixel size: 280\( \mu \text{m} \times 280\mu \text{m} \)

- 2 different readout modes:
  - **counting mode**: 1 Mfps
  - **list mode** (event by event) up to \( 10^9 \) photons/sec:
    \( \sim 1\text{ns} \) resolution

- Target applications:
  - Nuclear resonance scattering
  - XPCS
  - Time resolved scattering
  - High rate counting

2009 - 2012
http://xnap.esrf.eu
LImA: Library for Image Acquisition

Framework for detector data acquisition that provides:
- Common command interface → reuse of code
- Image processing and data reduction functionalities
- Software fallback for features missing in the detector hardware:
  - regions of interest, binning, frame accumulation, …

LImA Core
Configuration/control/processing

Detector specific configuration

Camera plugins
- Frelon
- Maxipix
- ADSC
- Pilatus
- PCO
- Basler
- And more: MYTHEN
  XPAD
  Prosilica
  Roper
  …
LLmA as a collaborative project

- An open source project (GPL license):
  
- External contributor for detector plugins:
  -SOLEIL
  -DESY
  -ADSC (commercial)

- Currently being tested by various labs and possible future contributors:
  -ALBA
  -FRM II
  -ILL
  -NEXEYA SYSTEMS (commercial)

http://forge.epn-campus.eu
Detector programme

The preparatory work was carried out through ESRFUP/WP6.
Technology survey

- Technology prospect by ESRF staff
  Detailed review of the state-of-the-art of detection technologies relevant to ESRF applications

- Visits to laboratories leading key detector technologies

- On-site meetings with invited external experts
  From both research labs and industry

- Topical workshop:

- Preliminary/feasibility studies on two topics:
  - Design of CMOS sensors for X-ray imaging detectors
  - Large format sensors with extended dynamic range for high energy X-ray diffraction
## Beamline survey: Detector questionnaires

### Short questionnaire distributed to all beamlines:

**Very good:**
- Excellent exercise to get an initial overall picture
- Useful information about certain important requirements

**Less good:**
- Inhomogeneous approach and answers.
- Rather short-term view (limited future vision).

### Some outcome:
- Emphasis on area detectors (2D) even for classical 1D or 0D applications
- Interest on high photon energies
  - 50% of the 2D detectors to operate above 35 keV
  - 30% of the 2D detectors to operate above 50 keV
- Clear request for extensive in-house support

### Beamline expectations
(graded from 0 to 5)

<table>
<thead>
<tr>
<th>Detector Feature</th>
<th>Avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic range</td>
<td>4.3</td>
</tr>
<tr>
<td>In-house support</td>
<td>4.2</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>4.2</td>
</tr>
<tr>
<td>Efficiency</td>
<td>4.0</td>
</tr>
<tr>
<td>Larger area</td>
<td>3.8</td>
</tr>
<tr>
<td>Single-photon sensitivity</td>
<td>3.8</td>
</tr>
<tr>
<td>Higher counting rate</td>
<td>3.8</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>3.6</td>
</tr>
<tr>
<td>Readout speed</td>
<td>3.6</td>
</tr>
<tr>
<td>Deadtime-free readout</td>
<td>3.3</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>ms time resolution</strong></td>
<td><strong>3.0</strong></td>
</tr>
<tr>
<td>Sub-ms time resolution</td>
<td>2.3</td>
</tr>
</tbody>
</table>
Detailed survey on future detector requirements

A large number of meetings and discussions (individuals, groups)

Looking into present and future requirements

Identification of “detector cases”:
• Grouping together applications with common detector requirements

• Whenever appropriate:
  • Several detector cases for a single beamline
  • Several beamlines (applications) included in the same detector case

31 different detector cases identified

Detectors @ ESRF: overall picture and foreseen evolution

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**CURRENT DETECTORS**
- a:Si Flat Panels
- Large Field CCDs
- APD
- MAXIPIX, PILATUS
- Direct Detection CCDs
- FReLoN (CCDs)
- Commercial CMOS
- SDD, Multielement Si, Ge

**NEW DETECTORS**
- Mini Flat Panel
- Very small pixel detector
- Fast imaging Camera
- New MAXIPIX
- EIGER
- Next generations
- Custom FReLoN
- Ultra-fast cameras
- Monolithic multielement arrays

**UNDERLYING KEY TECHNOLOGIES**
- High Energy Scintillators
- MEDIPIX3 Edgeless sensors
- High Z Semiconductors
- Optics
- High Resolution Scintillators

**Fast Data Acquisition and Management**
Detector programme

ESRF Detector Programme

- TDRs
- Application/BL specific (short term projects)
- Key technologies
- New advanced detector systems (long term developments)
High-Z semiconductors for hybrid pixel detectors

Crucial issue to overcome the limitations of silicon sensors and enable the use of hybrid pixel detectors in experiments with high energy X-rays

The HIZPAD JRA finished in Summer 2011

New JRA included the CALIPSO FP7 proposal (successor of ELISA)
- Submission in November 2011
- 1.1 M€ requested for the JRA

Among the future goals:
- Improvement of CdTe sensors
  - Better understanding of the material
  - Improved sensor processing
- Develop correction procedures
- Evaluation of other materials: CdZnTe, GaAs
New scintillators (light converters)

<table>
<thead>
<tr>
<th>Applications</th>
<th>Large field of view (cm)</th>
<th>High resolution (µm)</th>
<th>High Energy (&gt;30keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Today</strong></td>
<td>Mammography and custom Gadox screens</td>
<td>Bulk crystals (YAG, LuAG)</td>
<td>Mammography screens Semistructured, CsI(Tl)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single crystal films (GGG, LSO)</td>
<td></td>
</tr>
<tr>
<td><strong>Future</strong></td>
<td>New deposition process</td>
<td>Bulk Crystal (Ceramic)</td>
<td>Structured new materials filled with CsI(Tl) or nano powders</td>
</tr>
<tr>
<td></td>
<td>Higher density, smaller grain</td>
<td>SCF (LuAlO₃, Lu₄Hf₃O₁₂, HfO₂)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Faster phosphors</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Applications**
- **Today**
  - Mammography and custom Gadox screens
  - Bulk crystals (YAG, LuAG)
  - Single crystal films (GGG, LSO)
- **Future**
  - New deposition process
  - Higher density, smaller grain
  - Faster phosphors
  - Bulk Crystal (Ceramic) SCF (LuAlO₃, Lu₄Hf₃O₁₂, HfO₂)
  - Structured new materials filled with CsI(Tl) or nano powders

**Powder screen:**
- Good absorption
- Poor spatial resolution

**Crystal screen:**
- Poor absorption
- High spatial resolution

**Structured Screen:**
- Good absorption
- Good spatial resolution
## Optics for imaging detectors

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Past</th>
<th>Present</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High</strong></td>
<td>1 mag. 1 scint.</td>
<td>Custom optics</td>
<td>Custom optics for enhancement of imaging contrast and speed in UV-blue band</td>
</tr>
<tr>
<td><em>Refractive optics</em></td>
<td>200 – 500nm</td>
<td></td>
<td>16 Mpxels</td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>Custom optics</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Reflective optics</em></td>
<td>1 – 3 µm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td>Custom optics</td>
<td></td>
<td>Custom optics for larger fields of view</td>
</tr>
<tr>
<td><em>Tandem lens</em></td>
<td>5 – 30µm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td>dem. = 3.6</td>
<td>dem. = 2</td>
<td>Fibre optics fan</td>
</tr>
<tr>
<td><em>Fibre optics</em></td>
<td>20 – 50µm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Photon counting hybrid pixel technology

**Keep up-to-date** and **develop** the in-house capabilities to integrate improved photon counting hybrid pixel detectors at the ESRF beamlines

- Extension of MAXIPIX detectors to the **Medipix3** chip
  - **Medipix3** = **Medipix2 +**
    - suppression of charge sharing
    - deadtime-free readout
    - 4-side stitching for large areas
    - from 300 to 30000 fps
    - multiple energy thresholds

- Develop access and expertise in related technologies
  - **Edgeless sensors** (reduction of dead areas)
  - **Advanced interconnect**: through-Si vias (TSV), 3D, ...

- Exploit time resolution capabilities (i.e. TIMEPIX, XNAP)

*Courtesy L.Tlustos, CERN*
High Throughput Data Acquisition

Advanced detector systems require **high throughput data transfer** mechanisms.

The performance of current high performance detectors is already **severely limited** by the data transfer systems (fast CMOS cameras, MAXIPIX, PILATUS, …)

Maintaining and developing the ESRF expertise in the field is fundamental

The ESRF coordinates the work package “**High-throughput Detector Data Streaming**” in the **CRISP FP7 project** that aims to:

- Provide maximum data transfer rates to off-the-shelf computing back-end platforms
- Reduce development efforts and implementation costs in future developments with no compromise in performance.
Proposals for new advanced detector systems

Three main development lines identified:

- **High dynamic range mini flat panels for high energy diffraction**
  
  *Indirect detection integrating detector with very high dynamic range*

- **Small pixel hybrid detectors for scattering/diffraction**
  
  *25 µm pixel with single photon sensitivity (integration mode)*

- **Fast / high dynamic range X-ray imaging detectors**
  
  *> 100 fps CMOS MAPS cameras with 14 bit dynamic range*

No proactive effort foreseen on:

- Solid state **spectroscopy detectors** (multielement Si and Ge array ED detectors)
  - Few experiments potentially impacted by specific developments
  - Several active R&D programs outside the ESRF (e.g. MAIA)

- Pixel detectors for **time resolved experiments**
  - Could provide <100ns resolution with efficient operation
  - Readout schemes to be optimised for each type of application
2D detectors with active pixels

Active pixels: signal **processing** at the **pixel level**: 

- High dynamic range → **high detection sensitivity**
  - Direct detection (hybrid detectors)
  - High energy indirect detection with scintillators

- **Fast readout**: intrinsic parallelisation

Photon counting hybrid detectors (MAXIPIX, PILATUS, XPAD) are good examples, but integrating detectors can benefit as well of active pixels.

Two techniques to achieve high dynamic range with active pixel integrating detectors:

- Signal amplification with variable gain at each pixel
- Partial accumulation of the signal during the exposure period
Microelectronics for active pixel 2D detectors

Two families of CMOS technologies are used in 2D detectors:

- **“standard” CMOS**
  - Highest density of integration
    - Current designs make use 130nm technologies
  - Chip size limited by fabrication reticles
    - The largest chips are about 2cm size

- **“imaging” CMOS**
  - Includes optical detection (built-in photodiodes)
  - Lower integration density
  - Large chip sizes are possible (wafer scale)
  - Other names: MAPS = Monolithical Active Pixel Sensors
    - CIS = CMOS Image Sensors
High dynamic range mini flat panels for high energies

A variant of large pixel (~100µm) CMOS panels developed for medical imaging (i.e. mammography) but optimised for synchrotron diffraction experiments

Medical imaging CMOS panels use simple pixel structures, are limited in dynamic range (~12 bits) and not adequate for diffraction experiments

Similar detectors built around wafer scale CMOS sensors with extended dynamic range (~20 bits) with ‘smart’ pixels would be excellent high energy diffraction detectors.
High dynamic range mini flat panel: target specifications

Example of realistic (although challenging) target values for a CMOS panel optimised for high energy diffraction (>30keV):

- **Basic module**: 12 cm × 12 cm (larger areas require tiling of modules)
- **Scintillator**: CsI:Tl (directly coupled or through fiber optics plate)
- **Pixel size**: 100 – 150 µm
- **RMS noise**: less than 1 photon @ 30 keV (~500 e-)
- **Dynamic range**: > 20 bits
- **Frame rate**: 10 – 100 fps

Main technology challenges/risks:
- Production yield (large format sensor)
  - Special design techniques (redundancy)
- Radiation damage (complex pixels)
  - Radiation hard design
  - Sensor shielding (rad-hard faceplates)
Small pixel hybrid detectors for scattering/diffraction

Scattering applications that will benefit from small pixel size (5 - 30µm):

- Scattering with coherent beams (CDI, XPCS)
  - Angular sampling depends on object/sample size
  - Limited distance sample-detector (diffractometer arm)

- Inelastic scattering with wavelength dispersive setups
  - Position information increases the energy resolution

Both cases require single photon sensitivity (low photon fluxes)

Direct detection in silicon:

- 10keV photon \( \Rightarrow 2800 \) electrons

But the size of the electron cloud prevents photon counting with very small pixels

A silicon hybrid pixel detector in integration mode would be a good candidate
Small pixel hybrid detector: target specifications

Possible goals for a hybrid detector with small pixels:

- **Active area:** 30×30mm² (2×2 readout chips)
- **Energy range:** 5 – 15 keV
- **Pixel size:** 25 µm
- **Integrating readout:**
  - **RMS noise:** ~0.2 X-ray (10keV) (~550 e-)
  - **Dynamic range:** >14 bits
  - **Readout time:** 10 – 100 ms

Main technology challenges/risks:
- Very high density microelectronics
- 25 µm seems a quite challenging but an achievable value
- Relies on progress and availability of high density interconnect technologies (trend is favourable)
Fast / high dynamic range X-ray imaging detectors

CMOS sensors for X-ray imaging (indirect detection schemes):

Some of the advantages of CMOS sensors:
- Electronic shutter
- Random address pixels (ROIs)
- Negligible readout deadtime (few µs per row)
- Highly parallel readout schemes (frame rates)

The weakest point being the reduced dynamic range (with respect to CCDs)

But dynamic range can be extended for instance by using multiple gains in the pixel (subpixels):
CMOS sensor for fast imaging: target specifications

A CMOS sensor for X-ray imaging should be designed to fill the gap between the slower “high image quality” detectors (< 10 fps) and the faster low/medium image quality commercial CMOS cameras:

- **Quantum efficiency:** > 80% (backillumination)
- **Pixel size:** ~10 µm
- **Dynamic range:** >14 bits (single frame readout)
- **RMS noise:** 10 e^-
- **Full well:** > 200000 e^-
- **Line rate:** ~4 µsec
- **Frame rate:**
  - > 100 fps for 2048 x 2048 pixels
  - > 400 fps for 512 x 2048 pixels

**Main technology challenges/risks:**
- Specifications are tight with respect to the state-of-the-art (today)
- Compensate/correct properly for pixel dispersion
Proposals for new advanced detector systems

Higher priority: 2D detectors
With preference for **high energy detectors:**

*High dynamic range mini flat panel*
*Fast X-ray imaging cameras*

Substantial investments
Typical figures: **2 to 5 M€** and **5 to 10 years**

An option – proceed with an incremental strategy:
1. Start with **small scale demonstrators**
   - ✓ Compare and validate technological options
   - ✓ Select adequate partners
   - ✓ Evaluate risks and final feasibility

2. Look for **additional financial resources:**
   - o EU Framework Programmes (Horizon 2020)
   - o Collaborations with other labs

3. Go for **full scale systems**
Detector programme

ESRF Detector Programme

TDRs

Capitalisation of know-how

- High level of customisation
- UPBL driven
- Short term, moderate resources
- Approved case by case

Application/BL specific
(short term projects)

Preventing the "after-Upgrade"

- Priority on area detectors
- Generic developments
- Long term planning and investment
- Sizeable depending on available resources
- Technology challenges and risks

ESRF Detector Programme

Strategic investment

- High-Z semiconductors
- Scintillators
- Optics
- Pixel detectors
- Data acquisition
- Data management

New advanced detector systems
(long term developments)