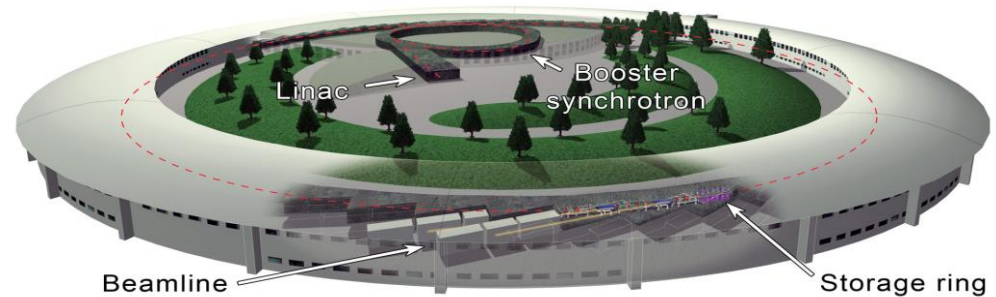


Control instrumentation and X-ray detectors for synchrotron radiation facilities

Pablo Fajardo (fajardo@esrf.fr)

Detector & Electronics Group - ESRF



The European Synchrotron



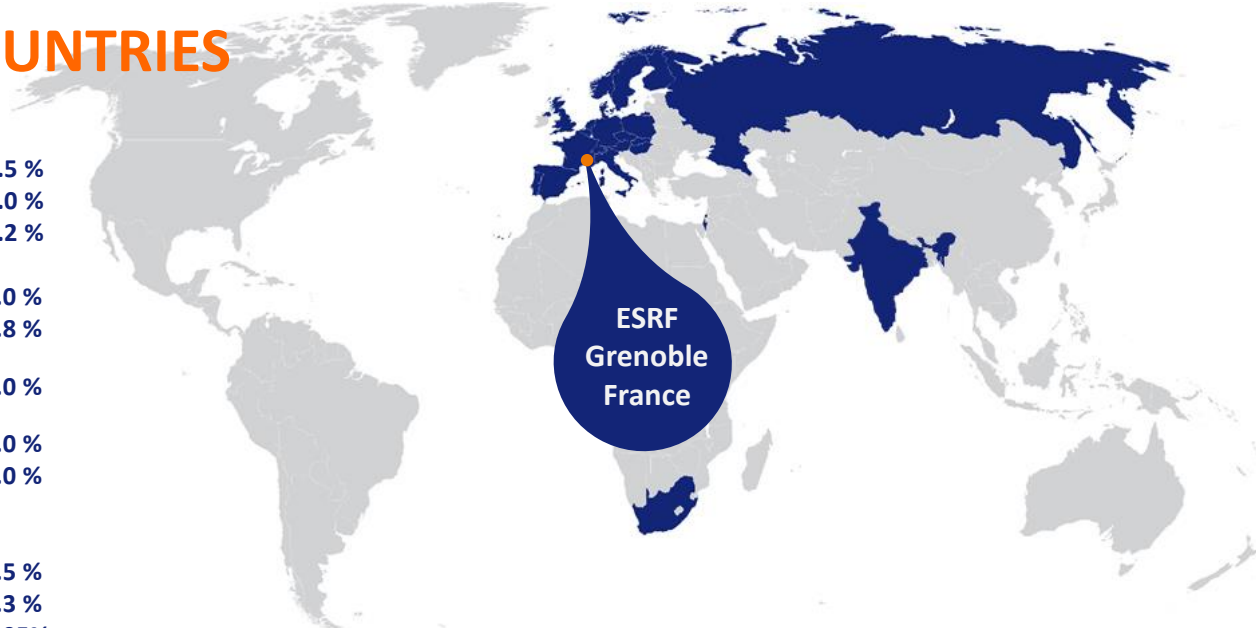
22 PARTNER COUNTRIES

13 Member states:

France	27.5 %
Germany	24.0 %
Italy	13.2 %
United Kingdom	10.5 %
Russia	6.0 %
Benesync	5.8 %
(Belgium, The Netherlands)	
Nordsync	5.0 %
(Denmark, Finland, Norway, Sweden)	
Spain	4.0 %
Switzerland	4.0 %

8 Associate countries:

Israel	1.5 %
Austria	1.3 %
Centralsync (Czech Republic, Hungary, Slovakia)	1.05%
Poland	1.0 %
Portugal	1.0 %
India	0.66%
South Africa	0.3 %



ESRF is an international collaboration founded on an intergovernmental convention (1988)

Annual budget: 100 million euros
Staff: 630 of 40 different nationalities
Legal status: Private civil company subject to French law

30 YEARS OF SCIENCE AT THE EUROPEAN SYNCHROTRON



1988 – 2018



World Leader in
Enabling Science



22

partner countries



10 000

scientific visits per year



44

beamlines



4

Nobel Prizes



2000

publications
per year



330 M€

over 2009-2022

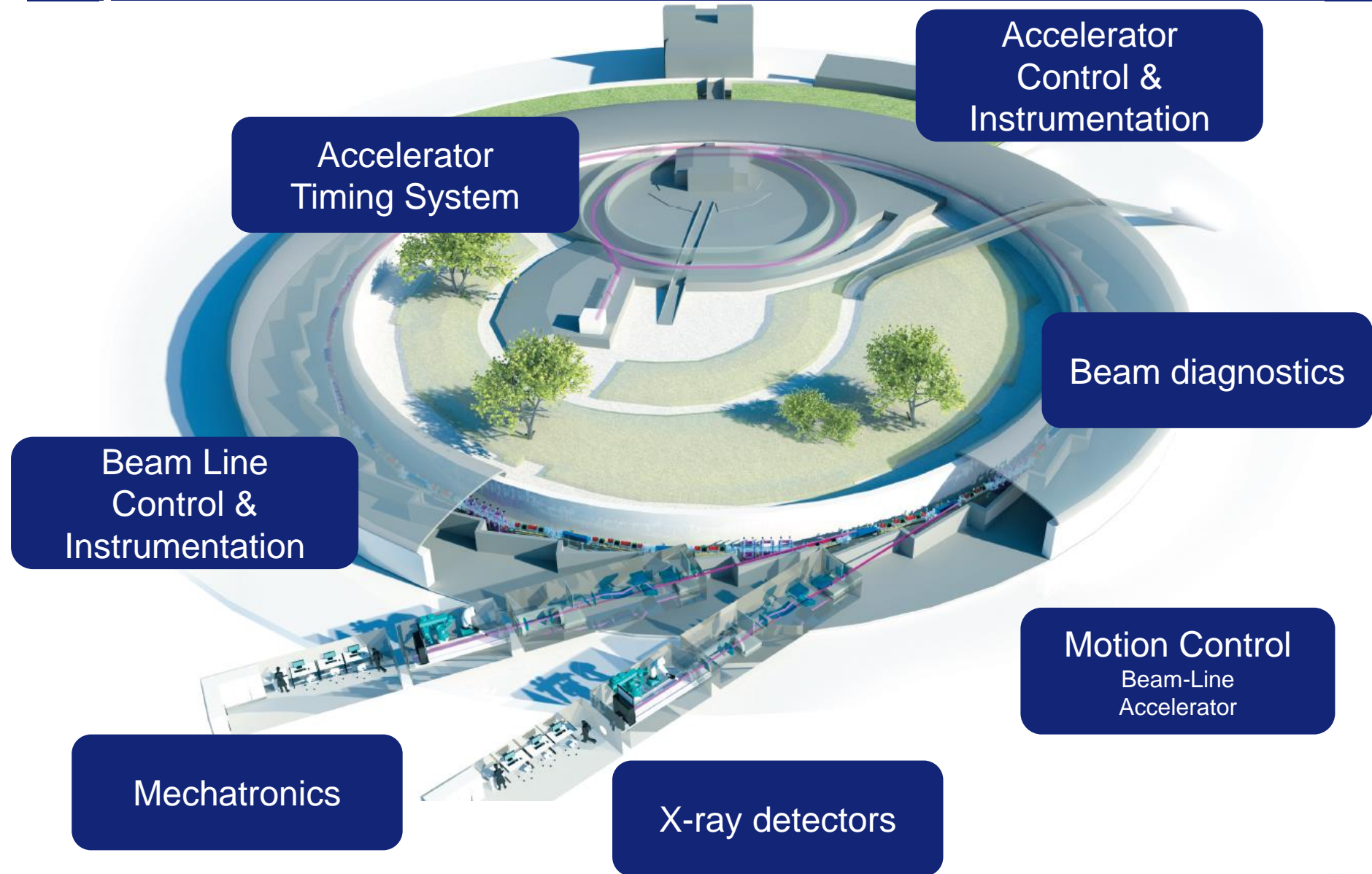
2009-2022: delivery of a new portfolio
of beamlines

2015-2022: construction of a new
generation of synchrotron, EBS

DELIVERABLES OF THE ESRF-EBS PROJECT



CONTROL ELECTRONICS AND DETECTORS



- ❖ Increase of Ethernet connected devices / Field buses replaced by Ethernet
- ❖ Linux based – very few Windows systems (for “standard” equipment)
- ❖ Obsolescence management is a permanent issue
- ❖ Software / Control systems:



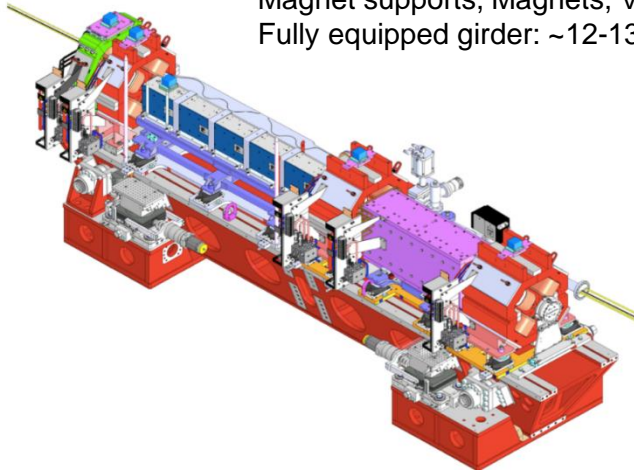
for accelerator complex

BLISS for experiment control

MOTION CONTROL – SOME EXAMPLES

4 Accelerator GIRDERS per storage ring cell (129 total)

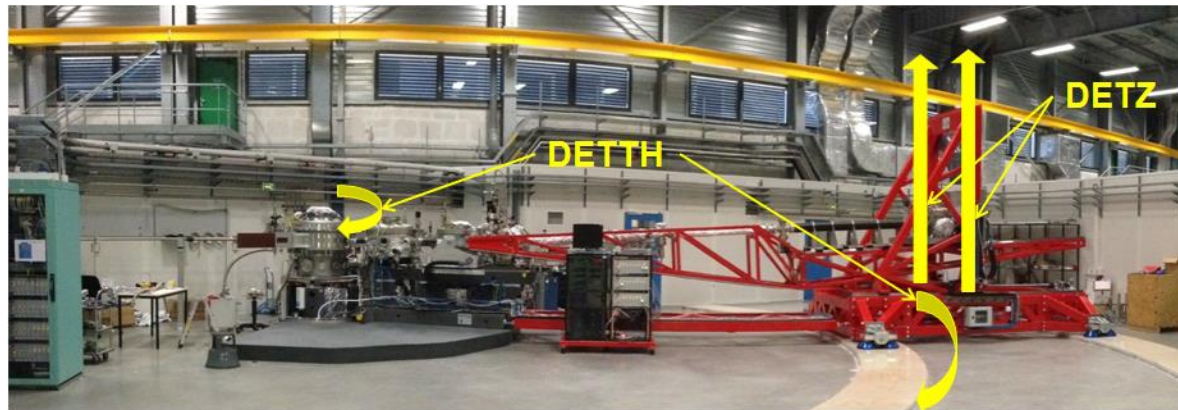
Magnet supports, Magnets, Vacuum equipment, Diagnostics
Fully equipped girder: ~12-13t



4 adjustable feet with motorised wedges
Total: 512 axes + 512 sensors



Raman spectrometer – ID20
~250 motorized axes



ID32 RIXS Station – ID32
6 tons, 11m long scattering arm
micrometer resolution

MOTION CONTROL – THE ESRF STANDARD

In-house development

- Interface of choice for the ESRF control system
- High performance stepper motor control
- Cost effective solution

Icepap

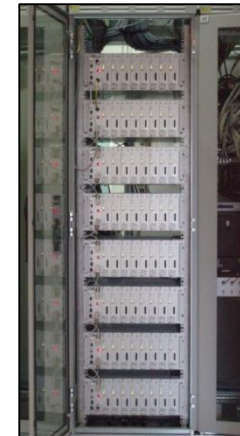
- 8 axes per crate
- 1 controller board
- System up to 128 axes

Also used for other types of motors with adequate interfaces



- About 7000 axes at the ESRF
- Collaboration with ALBA & MAX IV
- Close to 10000 in total

- . Call for tender – Technical & Economic criteria
- . Multi-annual contracts (typically 3 years)
~ 200 crates per CFT
- . Next ESRF CFT potentially in 2021

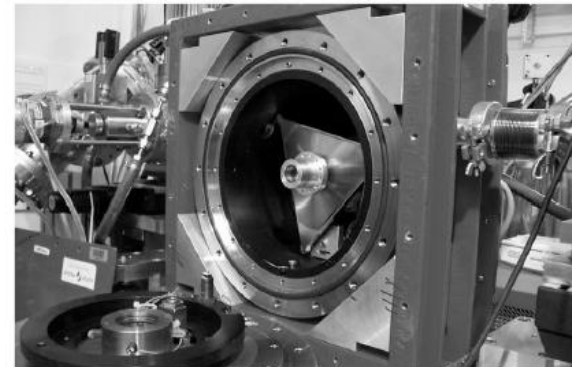


OTHER MOTION CONTROLLERS

- For applications where ICEPAP does not do the job (e.g. power > 300W)
 - ✓ **COTS controllers** - interfaced or not with IcePAP
 - ✓ Specified or/and chosen or/and validated by ESRF
 - ✓ Directly bought by ESRF or, more frequently, procured by the subcontractors in charge of instrument/mechanics design and production
 - ✓ Quantities over 5 years: #20 units
- For very demanding and specific applications such as fast chopper control :
 - ✓ Specified / validated by the ESRF)
 - ✓ Provided with the mechanics by the subcontractors in charge of the instrument
 - ✓ Quantities over 5 years: few units

High-speed chopper

[up to 100 krpm]



- Nanopositioners: devices capable of positioning objects in the nanometer range
- Technologies: most commonly, piezo actuators/motors (specific controllers)
- Sensors and metrology: capacitive sensors, interferometers
- Procurement:
 - ✓ Off-the-shelf turn-key solutions (hexapods, translation stages)
 - ✓ Actuators and sensors to be integrated by the ESRF
 - ✓ Quantities over 5 years: few dozens



BL CONTROL – IN-HOUSE DEVELOPED ELECTRONICS

- . **Stand-alone**
- . Ethernet control
- . Highly Standardized:
Hardware, Firmware, Software
- . Reduce development lead time



- . A range of instruments for **Beamline control**
 - ➔ Counting, sequencing, encoder processing, ...
 - ➔ supports FMC mezzanines
- . And also **Accelerator** specific applications

DAnCE

Data Acquisition & Control Electronics platform

ESRF “standard” hardware modules



10 layers
class 8
120 diff. pairs

- . Standard Digital board (FPGA + ARM)
- . Standard or customized carrier board
- . Embedded in 19” case

Qseven ARM® processor SBC



FPGA and tool chain.



CAD



. Design Phase:

- Subcontracting Design/Schematic of electronic boards based on ESRF specifications
- Place & Route
 - . *Expertise in digital - High demanding applications*
 - . *Know-how & tools: FPGA Xilinx, Altium CAD*
 - . *Mechanical design*
 - . *Project management*

. Prototyping:

- PCB + components - embedded or not in mechanical frame
- Cabling, integration, ...
 - . *Good reactivity, low cycle time*
 - . *Process & supply-chain adapted to prototyping*
 - . *Know-how, advice*

. Production:

- Procurement process depends on quantities/total estimated price: Call for Tender or Request for quote
 - . *Capability & Quality & Prices*
 - . *Testing capabilities*
 - . *Respect of lead times*

. In the coming 5 years:

- PCB design outsourcing: > 5 per year
- Few hundred units embedding our “standard” digital board
- 50% with standard carrier | 50% with specific carrier
- # 100 FMC-like electronic boards

OTHER INTERFACE MODULES – DEVELOPED IN-HOUSE



Voltage to frequency converters **100 MHz**



Voltage to SSI and SSI to Voltage interfaces

Regularly procured by medium quantities (20 to 50 units) depending on the needs



Positioning Encoder Processing Unit



IcePAP - Encoder interface
Sin-Cos, EnDAT, Bissc

ACCELERATOR TIMING & SYNCHRONISATION SYSTEM

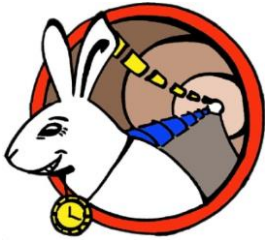
. Open HardWare modules:



- . SPEC boards
- . WR Switches
- . Firmware Features



- . **WHIST:** A module developed by the ESRF
- . Entered in operation in the 2nd half of 2018
- . Already a dozen of modules manufactured



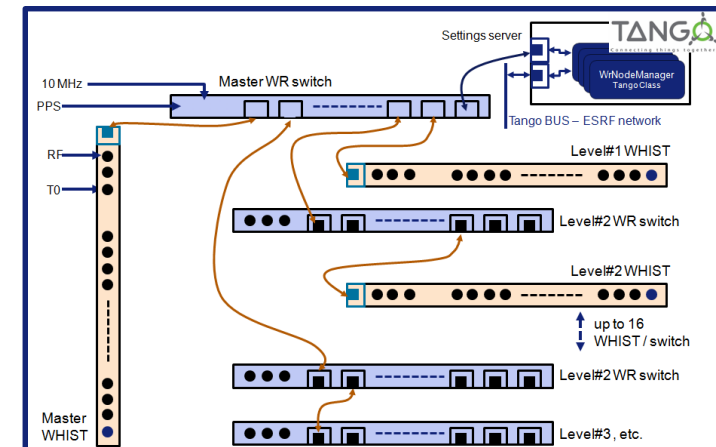
White Rabbit based network [CERN technology]

Complete White Rabbit network built on WR switches

Carrier board (ESRF) + SPEC board
embedded in a 19" case



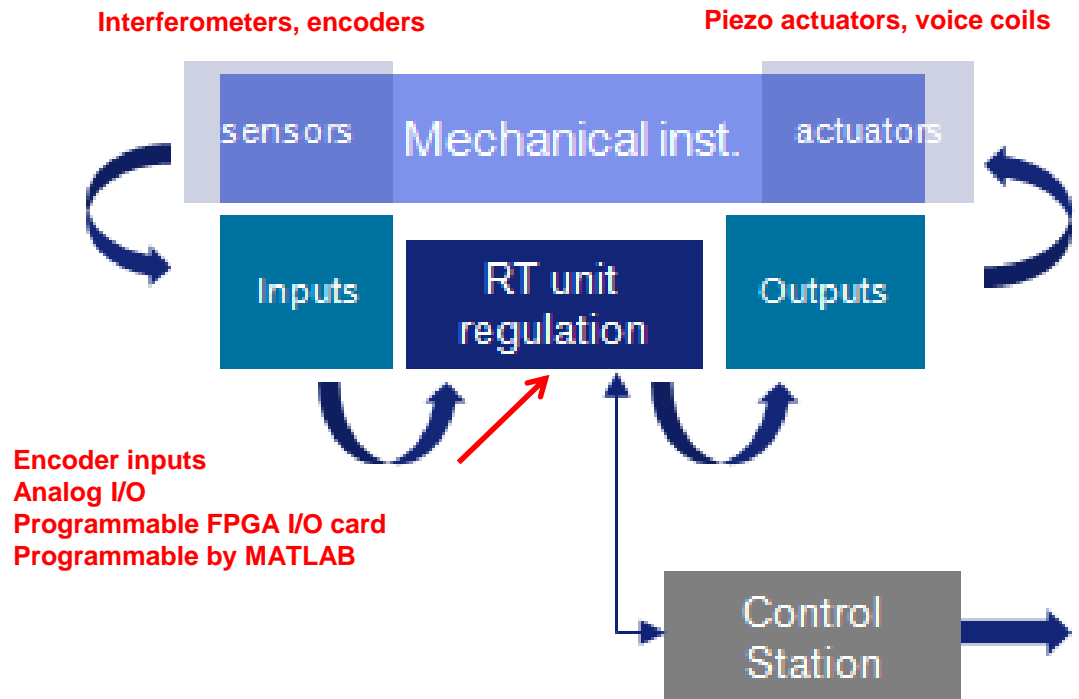
- . In the coming 5 years:
 - around 20 switches
 - > 50 WHIST modules



- Enhance the performance of new experimental stations:

Stability, Accuracy, Speed

- ➔ Fast feedback loop [\times kHz]
- ➔ Deterministic



- Developments already on-going based on a COTS solution for the RT unit
- Some # 20 systems foreseen in the coming 5 years

A diversity of off-the-shelf and customised instruments

Selection based on:

- Technical characteristics / performance
- Cost

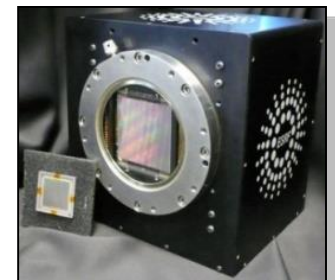
Constraints

- Software integration
- Support / maintenance
- Quick diagnostic
- Availability of components

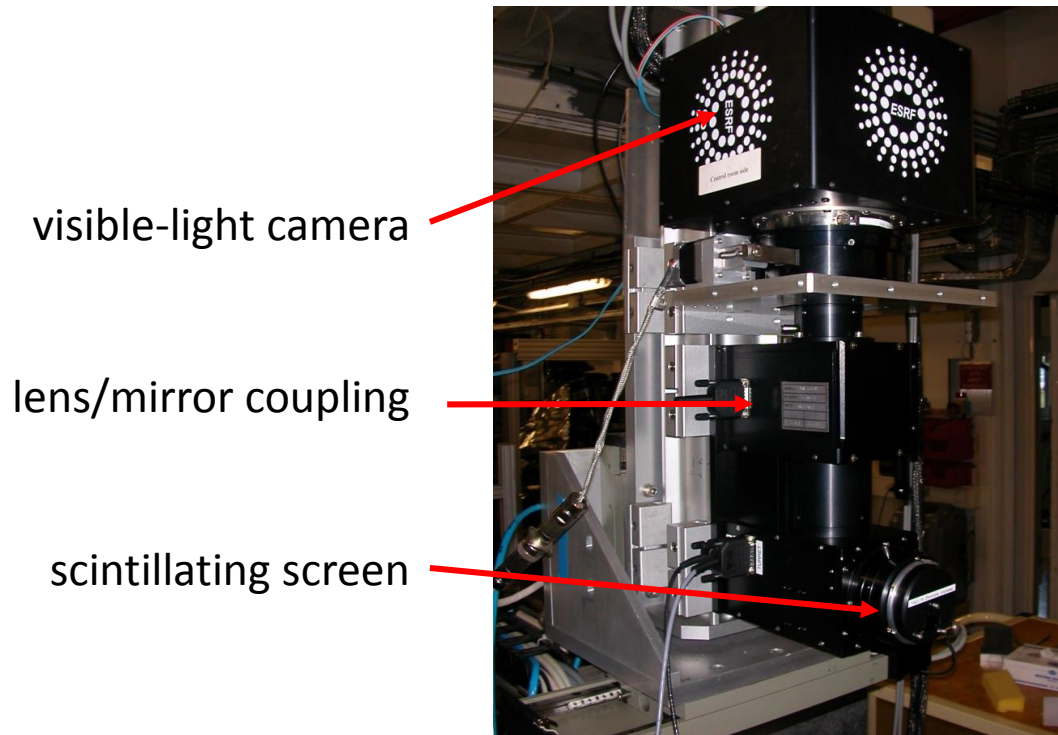
Estimated expenditure in detectors at ESRF

2019-2023: 10 to 15 M€

Usually via CFT (Call-for-Tender)



IMAGING DETECTORS (X-RAY CAMERAS)

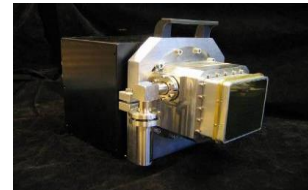


Usually always custom detectors based on standard cameras + customised optics
Price depends on the choice of the camera and complexity of the optical design
Variable price from 30 k€ to 200 k€

Main technologies

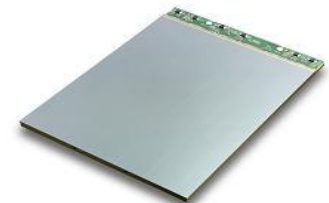
❑ **CCD based**

Indirect (hard X-rays) or direct (soft X-rays) detection schemes
Mature technology (little room for improvement)



❑ **Flat panels** (medical imaging)

a:Si (TFT technology)
CMOS flat panels (tiling or CMOS image sensors)



❑ **Hybrid pixel detectors**

Photon counting operation
Modular devices



Examples of detector systems in operation (not only at ESRF)

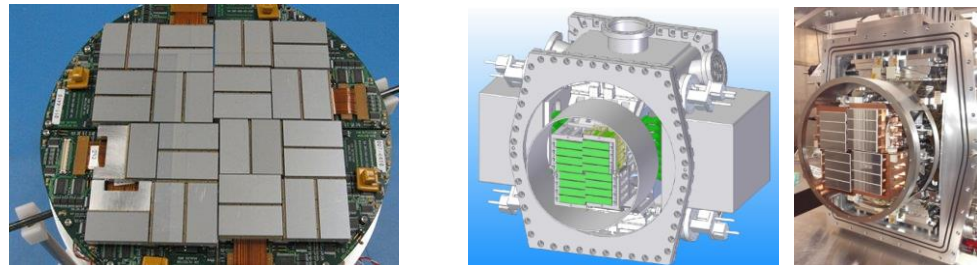
Photon counting

- Few megapixel devices
- Now standard devices at synchrotrons



Charge integrating

- Designed for X-ray free-electron lasers
- Can cope with very intense pulses



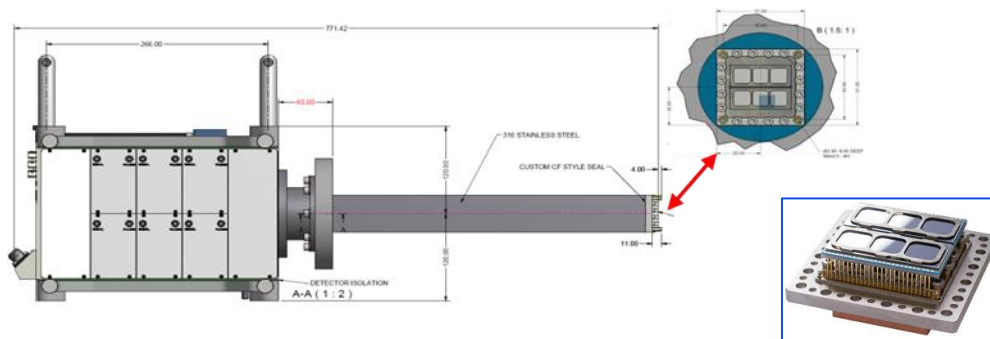
Typical price of “catalog” pixel detectors: from 100 k€ (small module)
to 2 M€ (large format)

Off-the-shelf detectors (most used in practice in SR experiments):

- Silicon drift diodes (SDDs)
- High purity germanium detectors (HPGe)



Customised instruments (multielement and special devices):



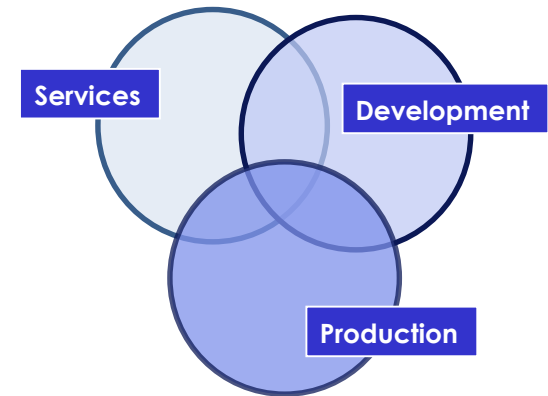
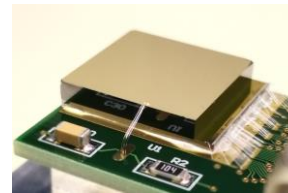
ESRF/ID16A

- SDD 6 element arrays = $2 \times 540\text{mm}^2$
- Energy range $\sim 2\text{...}20\text{keV}$

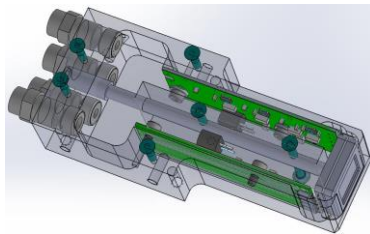
Price range : from 20 k€ (simple single element module)
to 300 k€ (multielement based on standard components)

• Partners for technology development

- X-ray sensor developments, specially high-Z material
- Optics for indirect detection

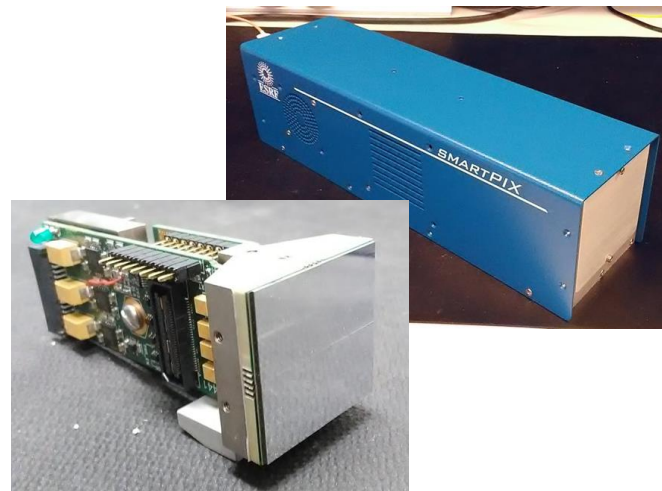


• Licenses



• Production

- Hybrid pixel detector (Maxipix)
- CCD camera (Frelon)
- Scintillator (GGG:Eu, LSO:Tb)
- X-ray beam viewers



THANK YOU FOR YOUR ATTENTION

