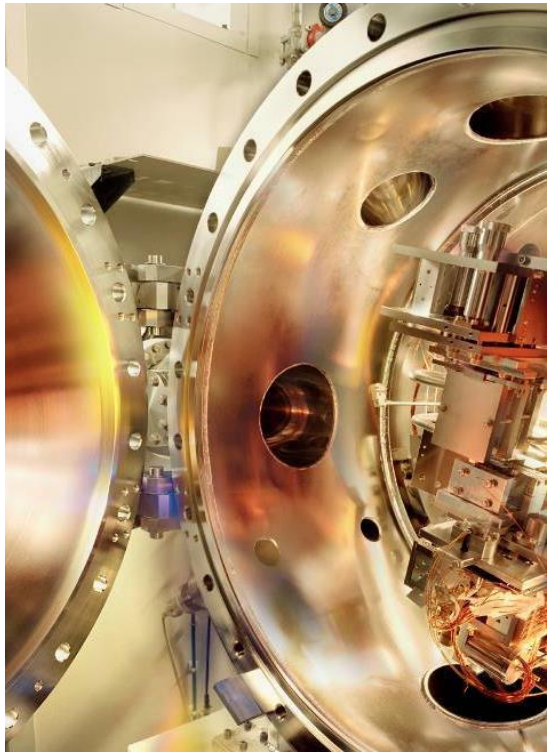
07th Eiroforum School on Instrumentation

Grenoble 07-11 June 2021

The European Synchrotron



ESRF

Photons and Instrumentation

On behalf of ISDD team

- ESRF
- EBS overview
- Instrumentation programme

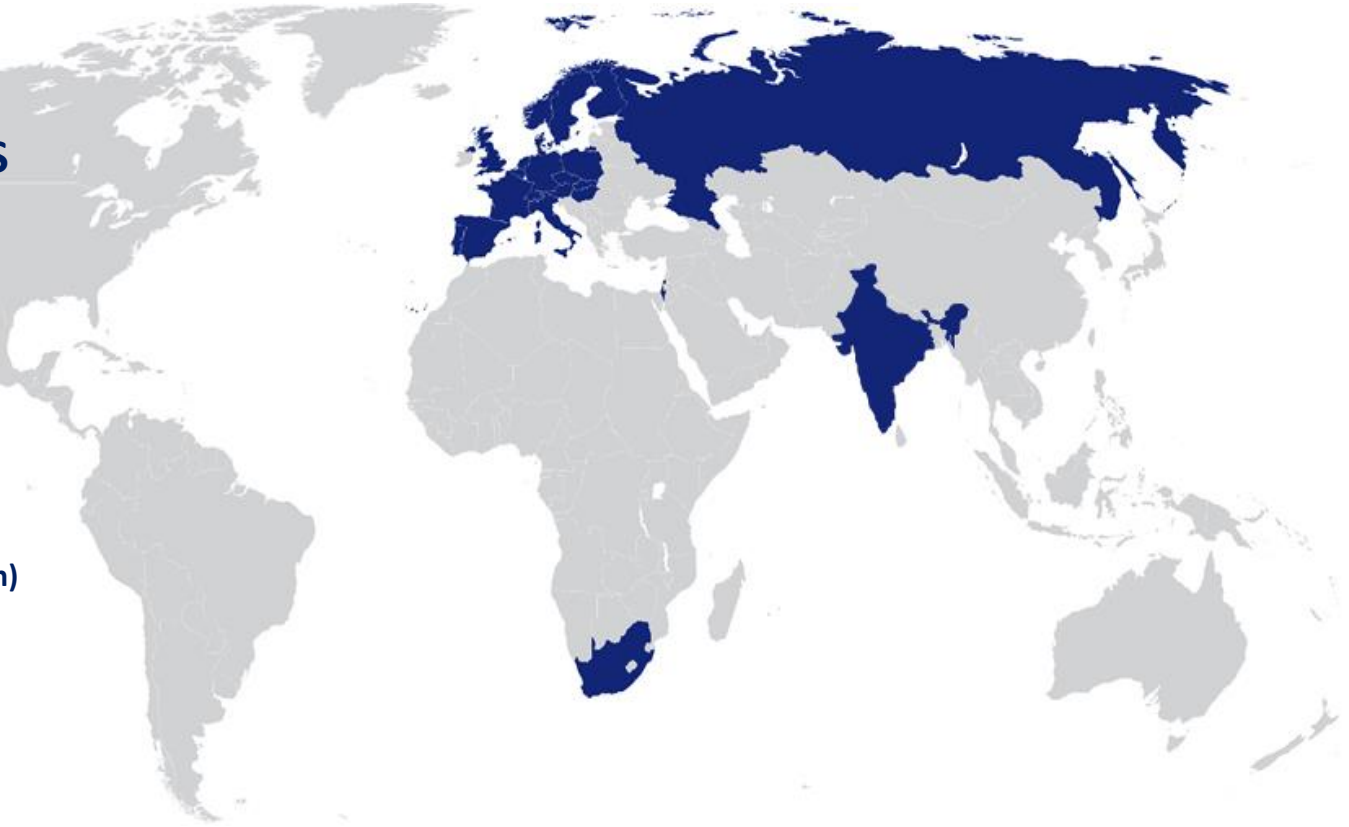
22 PARTNER COUNTRIES

13 Member states:

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

9 Scientific Associate countries:

Israel	1.75 %
Austria	1.75 %
Centralsync (Czech Republic, Hungary, Slovakia)	1.05%
Poland	1.0 %
Portugal	1.0 %
India	0.66 %
South Africa	0.3 %



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

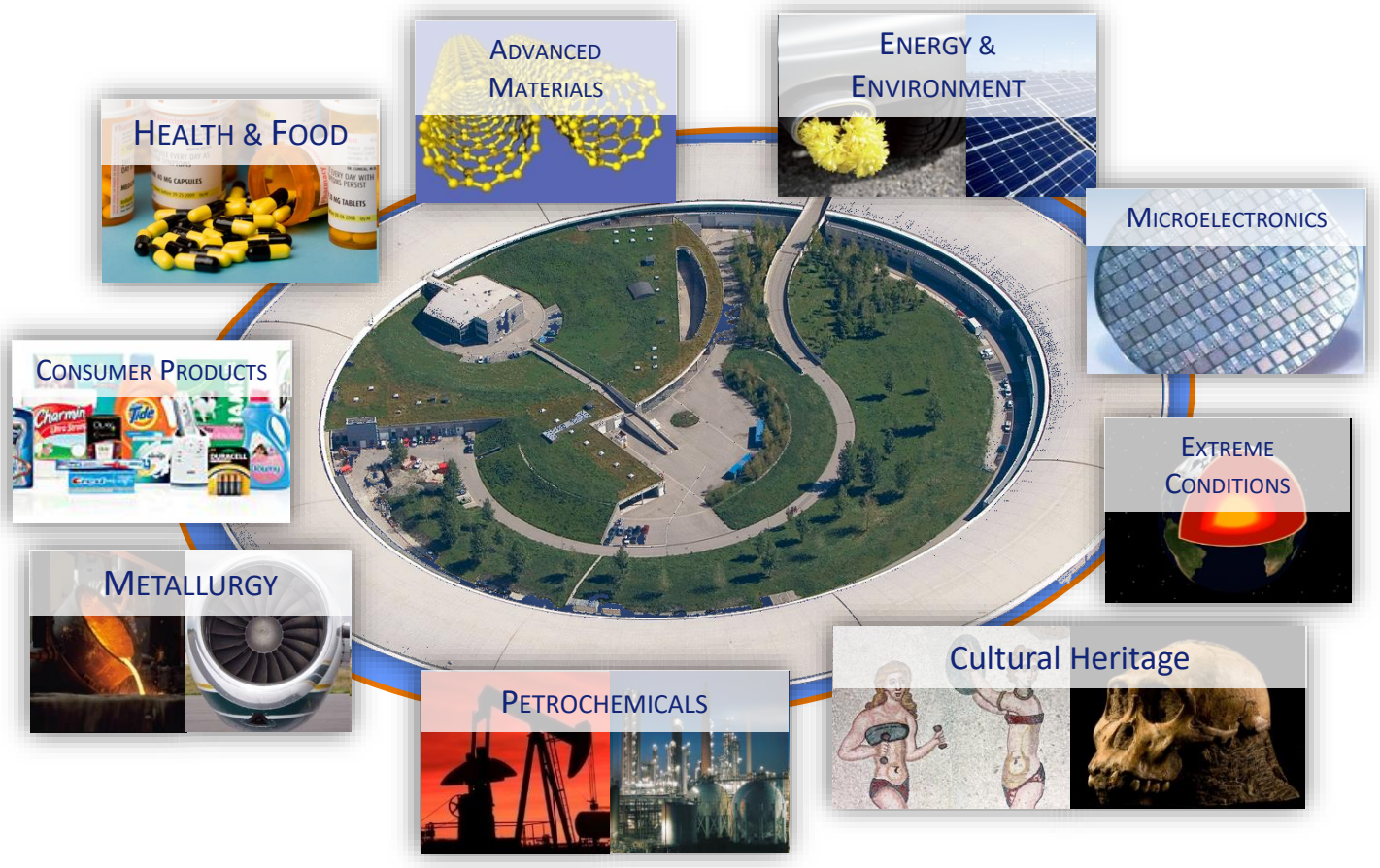
The ESRF produces the most intense synchrotron generated light in the world

ESRF - France

A research facility unique worldwide

- ✓ **44 Beamlines**
- ✓ **9 000 scientific visitors** every year
- ✓ **2 000 proposals** per year: **900 accepted,** 1 550 experimental sessions
- ✓ **30%** of the research involves **industrial developments**
- ✓ **2000 publications** per year

Synchrotron radiation science



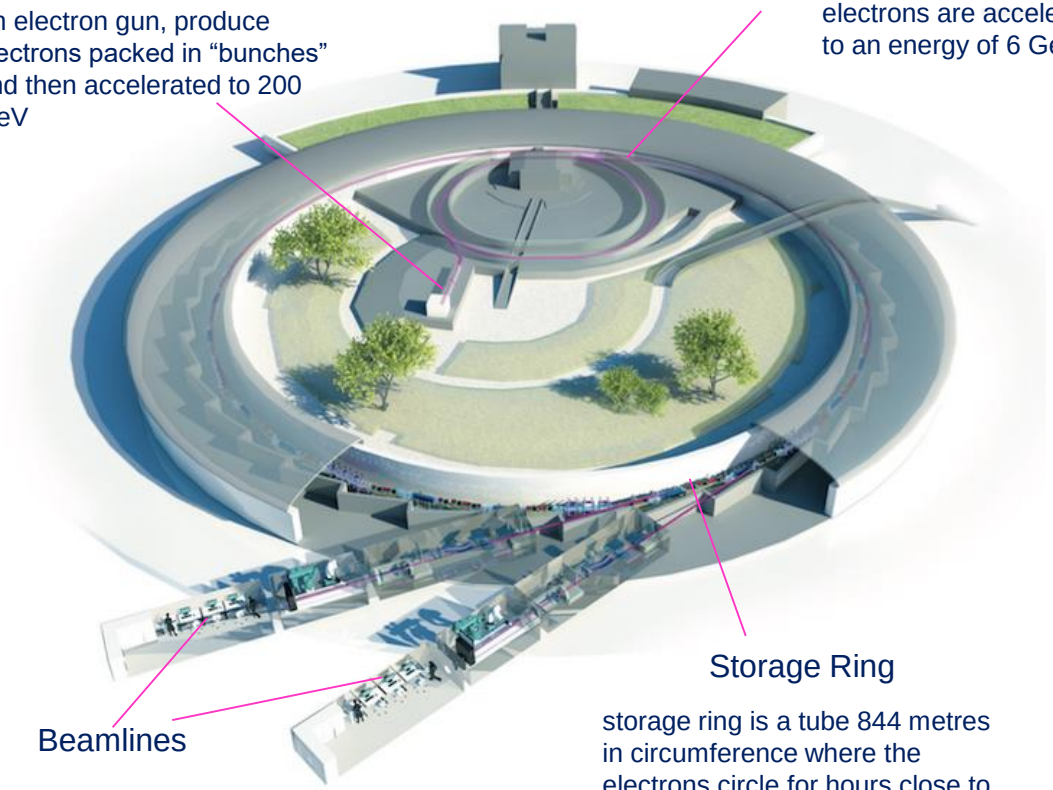
ESRF

Linac

An electron gun, produce electrons packed in “bunches” and then accelerated to 200 MeV

Booster synchrotron

electrons are accelerated to an energy of 6 GeV



Storage Ring

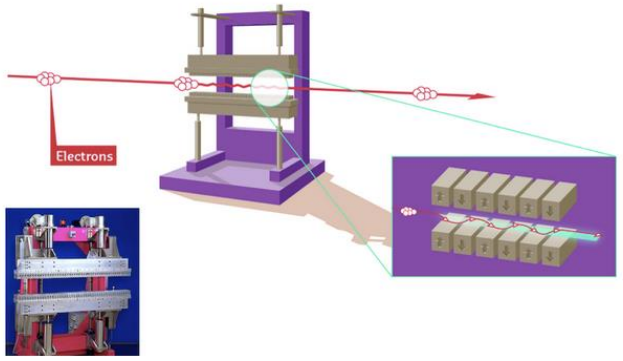
storage ring is a tube 844 metres in circumference where the electrons circle for hours close to the speed of light

Beamlines

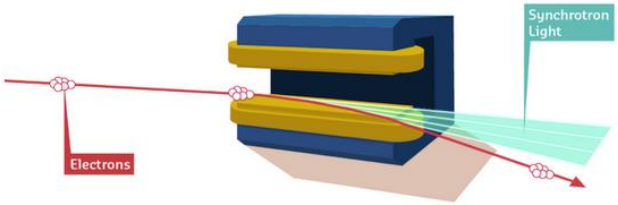
X-ray beams emitted by the electrons are directed toward "beamlines"

synchrotron light from:

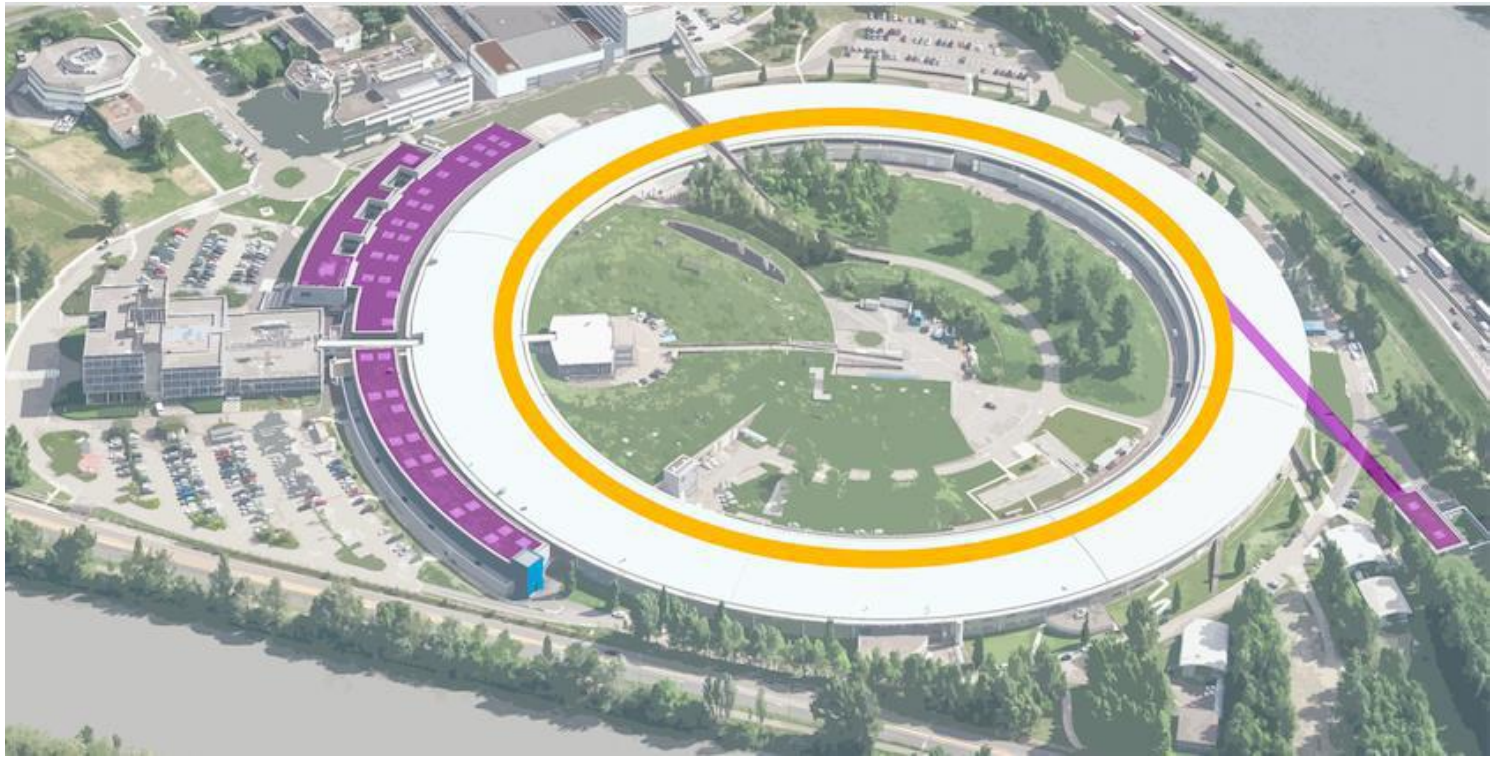
Insertion Devices: (undulators)



Bending magnets



ESRF UPGRADE PROGRAMME



Phase I -180M€ (2009-2015)

- 19 new endstations and beamlines
- New 8000m2 experimental hall
- Improvement of overall infrastructure and Accelerator systems

EBS -150M€ (2015-2022)

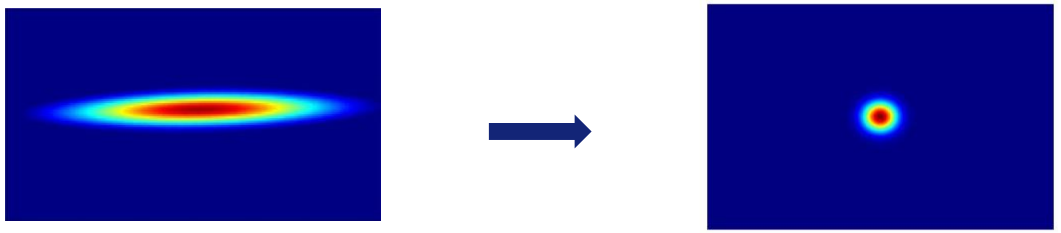
- A new high energy low-emittance source
- A new portfolio of unique instruments
- An innovative scientific instrumentation programme

EBS OVERVIEW

ESRF **E**xtremely **B**rilliant **S**ource

The first high-energy fourth-generation synchrotron

- Substantially decrease the Storage Ring Equilibrium Horizontal Emittance
- Increase the source brilliance
- Increase its coherent fraction

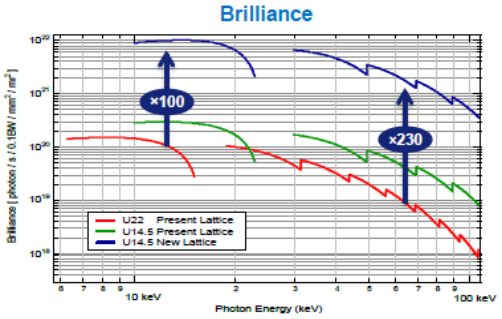


E-beam properties	2018	Now (EBS)
Energy (GeV)	6.04	6
Multibunch current (mA)	200	200
Circumference (m)	844.39	843.98
Horizontal emittance (pm.rad)	4000	140
Vertical emittance (pm.rad)	4	5

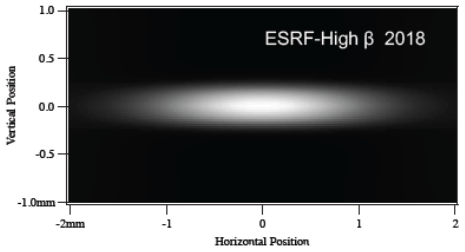
EBS OVERVIEW

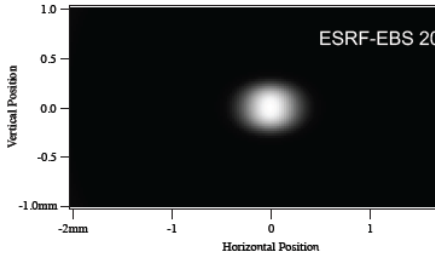
Parameter	2018		EBS: H7BA lattice	
Energy [Gev]	6.03		6	
Current [mA] (multibunch mode)	200		200	
Rel. Energy spread [%]	0.1		0.094	
Energy loss /turn [Mev/turn]	4.9		2.6	
Emittance [pm]	4000	5	134 (no IDs)	5
Tunes	36.44	11.39	76.21	27.34
Beta at IDs	37.6/0.35	3	6.8	2.9
Dispersion at IDs [mm]	134/3.1		2	
R.m.s electron beam size [µm]	385/37	3.9	29.7	3.8
R.m.s electron beam div. [µrad]	10/107	1.3	4.4	1.3
	Horizontal	Vertical	Horizontal	Vertical

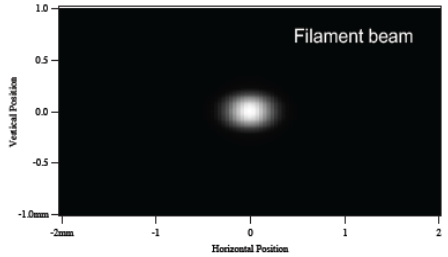
- Substantial increase of brilliance at X-ray sources
- use of transverse coherence
- High flux micro-nano X-ray beams



Photon beam @ 30 m
- Undulator 110 periods of 18mm
- E= 23 keV (n=3)



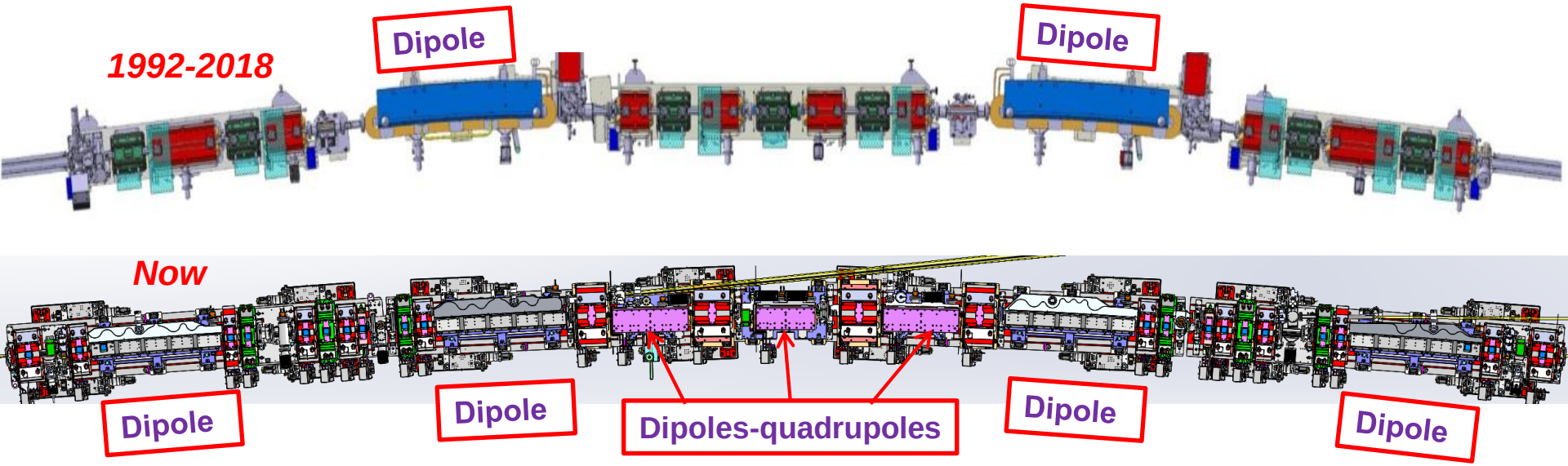




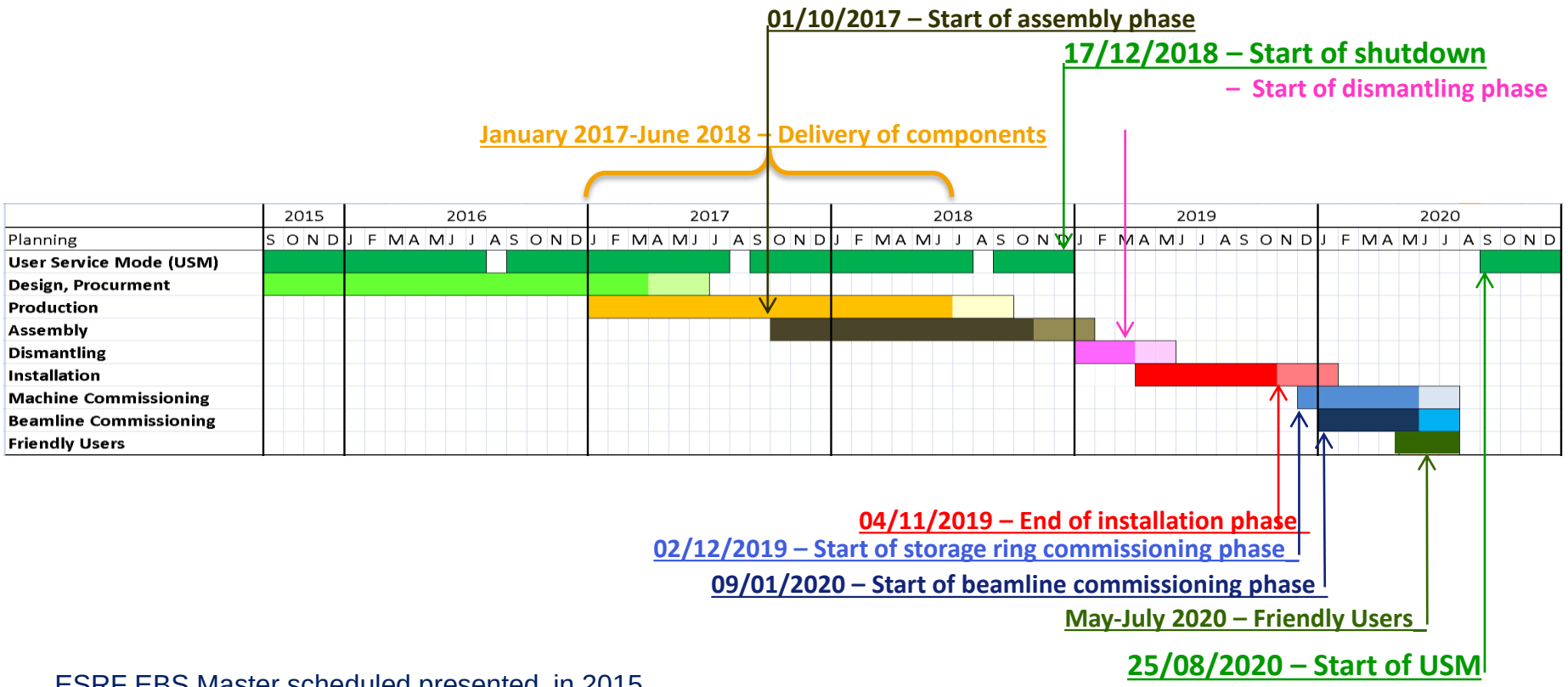
EBS OVERVIEW

- **Old ESRF lattice**
  Double Bend Achromat = (2 dipoles + 15 quad. sext.) per cell
  ID length = 5 m (standard) / 6m / 7m

- **ESRF EBS lattice**
  Hybrid 7 Bend Achromat = (4 dipoles + 3 dipoles-quad + 24 quad., sext., oct.) per cell
  ID length = 5 m



EBS OVERVIEW



ESRF EBS Master scheduled presented in 2015

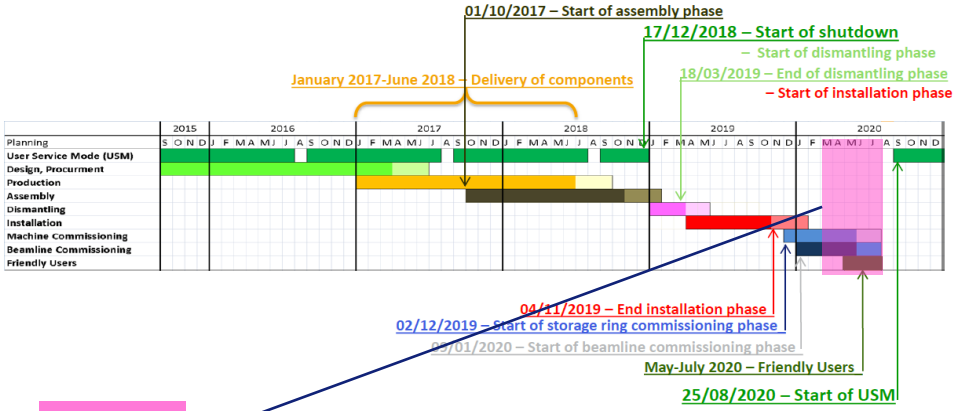
2020: It has not been moved by a single day!

Electron beam:

- 28/11/2019 First three turns in EBS storage ring
- 06/12/2019 First beam stored

EBS OVERVIEW

Master Plan and Major Milestones



Handling crisis from pandemics to climate change… ?

2020:
- COVID-19 crisis

2020

30 January | 2 March | 16 March | 11 May | 1 June | 25 August

LONG-SHUTDOWN

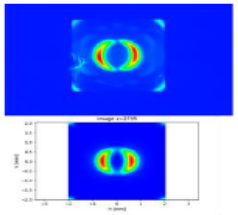
BEAMLINE RESTART

COVID-19 lockdown

BEAMLINE COMMISSIONING

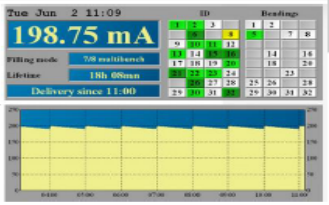
USM OPERATION

First EBS beam on 27 beamlines



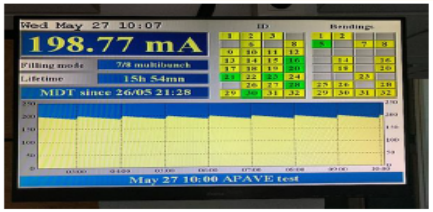
At 9mA

At 200mA



Resuming User Service Mode

- 5 BLs operational for COVID-19 research



- 25/27 ID beamlines ready for full scale commissioning

ESRF - HANDLING CRISIS

CLOSURE	1st WAVE	2nd WAVE	RESUME FULL OPERATION	USM OPERATION
Less than 10 people on site	Less than 100 people on site	Gradual Increase of people on site	Complete USM preparation	Back to USM
16 March – 11 May Closure & implementation of the ESRF continuity plan for pandemic: Teleworking	**12 May – 1 June** Resume gradually storage ring commissioning, beamline restart and COVID-19 research	**2 June – 10 July** Ramp-up number of people on site: commissioning activities restart	**13 July – 24 August** Back to full operation and complete USM preparation	**From 25 August** Back to USM with strict COVID-19 prevention policy New confinement, 30-10→13-12-2020

- Anticipate possible different travel mobility restrictions
- Ensure a fair access for all members and scientific associates

- Only mail-in samples
- Experiments have to be performed by ESRF staff
- Or
- Remote connection with/by users
- Beam time availability reduced

April 2020
Decision by Management
to do only
remote experiments

- Start with simple experiments
- Increase complexity at the end of 2020

- Issues and challenges:
  - safety, logistics
  - workload
  - IT, cyber security…

ESRF - HANDLING CRISIS

Remote experiments - Remote access

Issues and challenges remote experiments/remote access :

- Safety, logistics
  - Sample transport/safety approval via ICAT/ISPyB

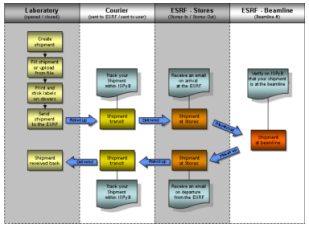
- IT Infrastructure
  - BLISS (new beamline control system)
  - Guacamole/MXCuBE3
    - Network speeds to/from ESRF
    - Data transfer to/from home lab (ICAT, rsync)
    - Experiment Tracking (ICAT/ISPyB)

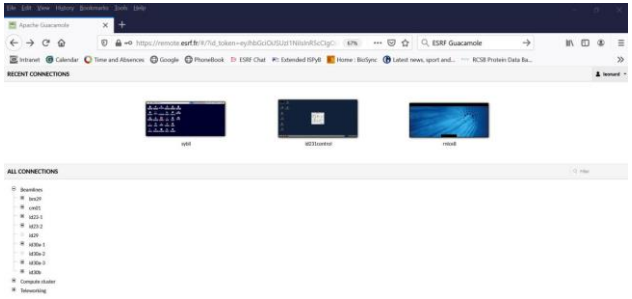
- On-line data reduction/analysis
  - Data transfer to NICE

- Post-experiment processing @ ESRF

- Work load
  - Much heavier than for normal operation
  - For everybody at ESRF, not just for beamline staff
  - Reduction in Beam time

- Difficult, not all planned/allocated experiments can be done with no users on site





A lot of software development ready for the User Service Mode on 25th August 2020

EXPERIMENTAL PROGRAMME OVERVIEW

ISDD Division: Support to Accelerators and Beamlines

ESRF Instrumentation Services and Development Division (ISDD)

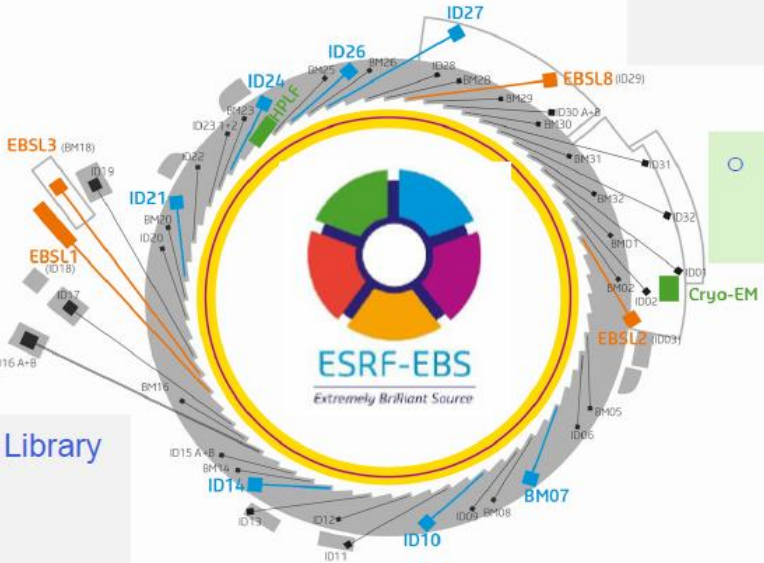
Software | Detectors & Electronics | X-Ray Optics | Mechanical Engineering

- Four new beamlines fully optimized for EBS
  - EBSL3-BM18: *High throughput large field phase-contrast tomography beamline*
  - EBSL8-ID29: *Serial crystallography beamline*
  - EBSL1-ID18: *Beamline for coherence applications*
  - EBSL2-ID03 *Beamline for hard X-ray diffraction microscope*

- **Refurbishment Programme**
  ID18 (ID14), ID21, ID24, BM23, ID27, ID32

- New Insertion Devices + small gaps

- ESRF Data Policy on all beamlines



- 10 new high-end 2D detectors

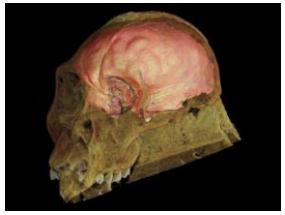
- New Beamline Control software Bliss

- New access modes *e.g.* BAG, mail-in, etc…

- Scientific Software Library silx

NEW BEAMLINE EBSL3 (BM18)

BM18: Multiscale phase-contrast Tomography for large objects



EBSL3
A Beamline for High Throughput
Large Field Phase-contrast Tomography

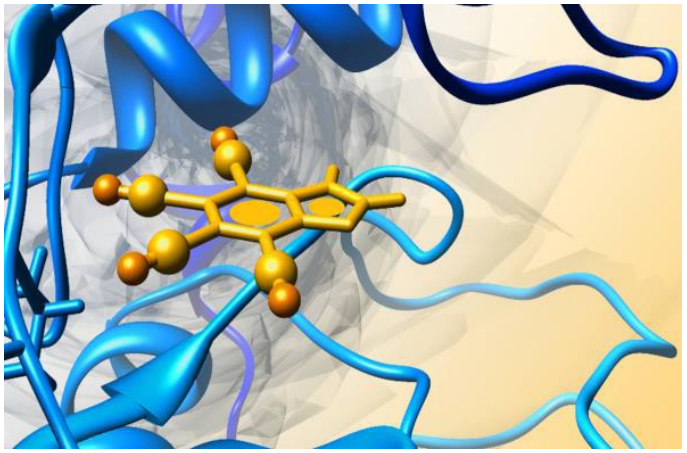
- **Hard X-ray energy, high X-ray coherence, large field-of-view , high throughput tomography** is ideally suited to non-destructive study of large objects with sub-micrometre resolution

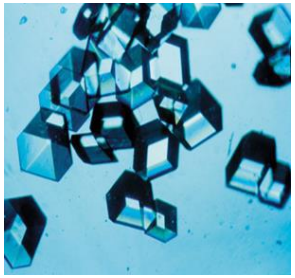
- **New perspective** for research in palaeontology, archaeology and characterisation of engineered materials by providing the largest high-energy and high-coherence synchrotron beam worldwide for **hierarchical imaging** and automated tomography

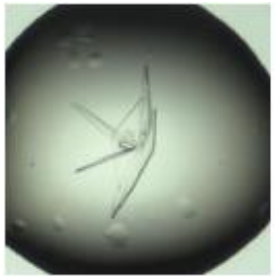
- **3D-imaging research applications:**
  - -materials for space, aeronautics, automotive, etc.
  - -micrometre scale anatomy of entire organs
  - -hierarchical imaging of large specimens, e.g. Mummies
  - -3D-virtual reconstruction of fossils and unique artefacts

up to 40 m of phase propagation @ 400 keV

NEW BEAMLINE EBSL8 (ID29)







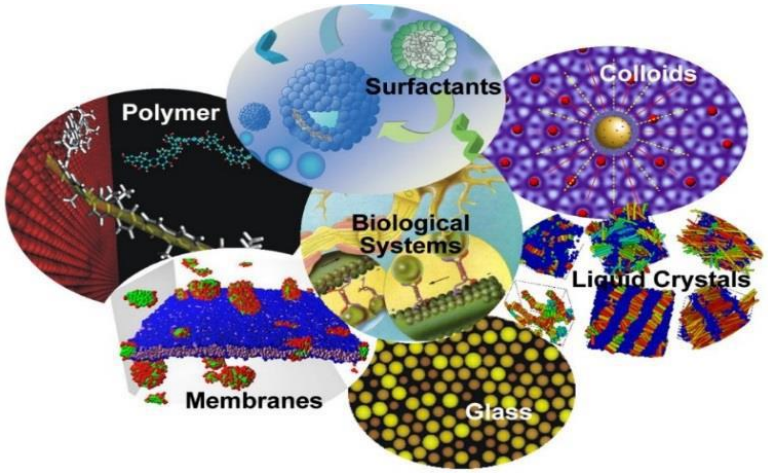
EBSL8
A Beamline for
Serial Macromolecular Crystallography

- **Serial crystallography** is emerging as a unique technique to solve structures of important classes of proteins available only in sub-micron crystals, whilst monitoring radiation damage

- **New perspectives** for the Life Sciences by providing a unique (flux, flux-density, stability) facility worldwide with capabilities for **room temperature** and **time-resolution** macromolecular crystallography

- **Research applications:**
  -fundamental problems such as enzyme kinetics
  -drugs effects into target proteins
  -determinants neutralizing human antibodies against viruses

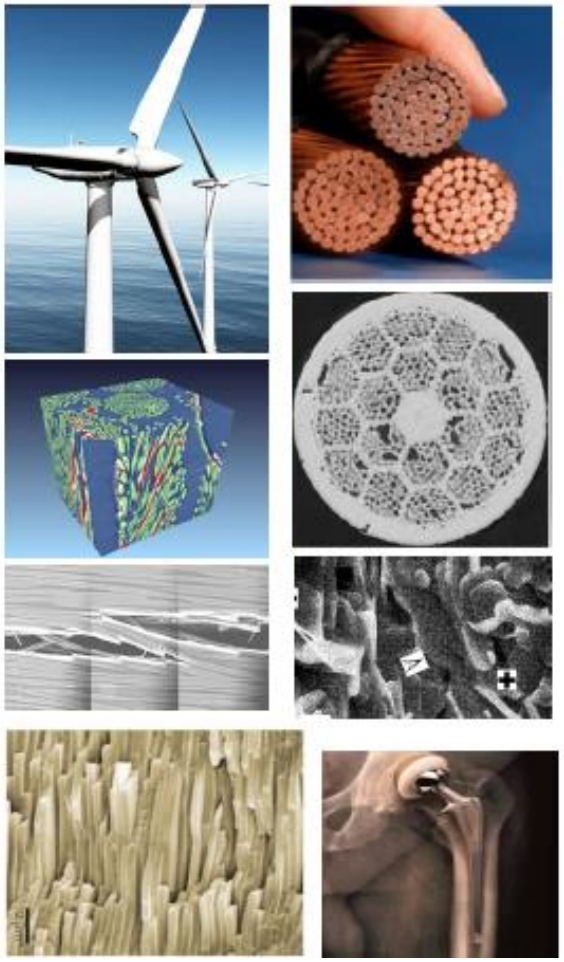
NEW BEAMLINE EBSL1 (ID18)



EBSL1
A Beamline for
Coherent X-ray Dynamics &
Imaging Applications

- **Coherent X-rays** are ideal to study the complex and unknown correlations in materials and living matter in 3D-space and in time under ***operando*** **conditions**
- **New perspectives** to observe dynamical processes under real conditions down to the single atom by exploiting the EBS worldwide unrivalled **X-ray coherent flux at high energies** with **temporal resolution, down to 100ns**
- **Research applications:**
  - -dynamics and structure of muscle deformation
  - -bio-mineralisation processes
  - -image formation in photonic devices
  - -glasses & melts under real conditions

NEW BEAMLINE EBSL2 (ID03)



EBSL2
A Beamline for
Hard X-ray Diffraction Microscopy

- **Hard X-ray diffraction microscopy** is a unique tool to study the hierarchical correlations of structures in materials from millimetre down to tens of nanometres
- **New perspectives** for better understanding of properties of nano-structured and non-homogeneous materials under real conditions by providing a unique (hard X-ray penetration, flux-density, resolution, stability) facility worldwide
- **Research applications:**

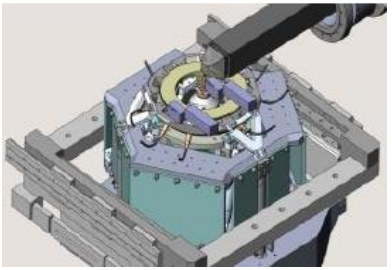
  -multi-scale characterization of modern engineered materials -biomaterials
  -environmental agent effects and control
  -material fatigue in transportation, industrial plants, etc.

INSTRUMENTATION PROGRAMME OVERVIEW

Beamline control & Data Management

- Beamline control: BLISS
- Data Management & Analysis
- New simulation tools

High precision Engineering



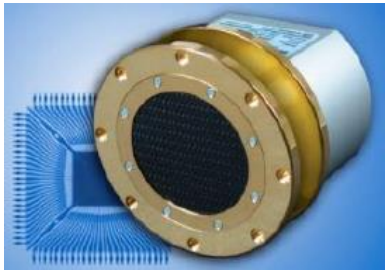
- Spectroscopy monochromator
- Highly-integrated end stations
- Mechatronics

EBS Enabling Technology

X-Ray Optics

- New Instruments
- New manufacturing methods
- New simulation tools

X-Ray Detectors



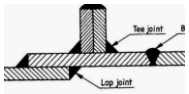
- New detectors
- Sensors, DAQ, software
- Exploratory R&D

HIGH PRECISION ENGINEERING

Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation

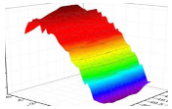
Mechanical

- Design
- Manufacturing
- Material



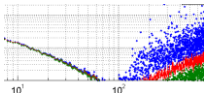
High Heat load

- Design
- Cooling
- material



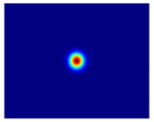
Stability

- Thermal
- Vibration



X-ray Physics

- e-beam
- x-ray Source

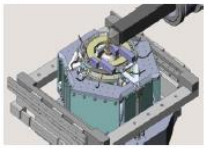


Optics

- New instruments
- New manufacturing methods

High precision

- New spectroscopy monochromator
- Sample positioning



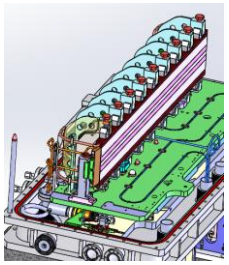
Many skills required for Mechanical Engineering

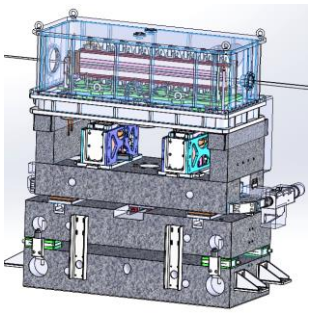
HIGH PRECISION ENGINEERING

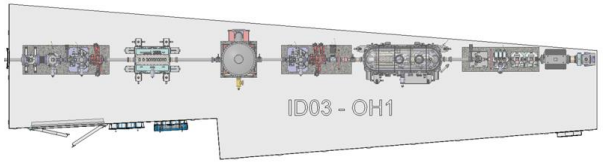
Mechanical Engineering

Main activities

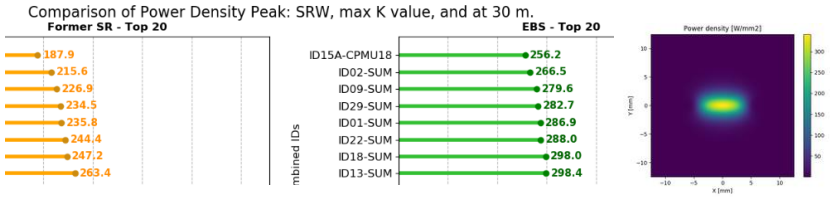
- **Support for installation and start-up** of the EBS accelerator and of new beamlines equipment.
- Mechanical design and procurement of instrumentation for New beamlines **EBSL3-BM18, EBSL8-ID29, ID21, ID24, and ID27**.

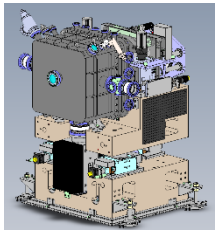






- **Double Crystal Monochromator**:
  - ✓ Contribution to prototype commissioning at ID21. Investigations to further improve crystals angular stability.
  - ✓ Production of 2 DCMs.
- **Beamline heat load review** from EBS source and former SR, available on intranet Confluence





- Reception of new generation **cryocoolers** with features to reduce LN2 vibrations on monochromators crystals.

Spectroscopy Double –Crystal monochromator

Mechanical Engineering

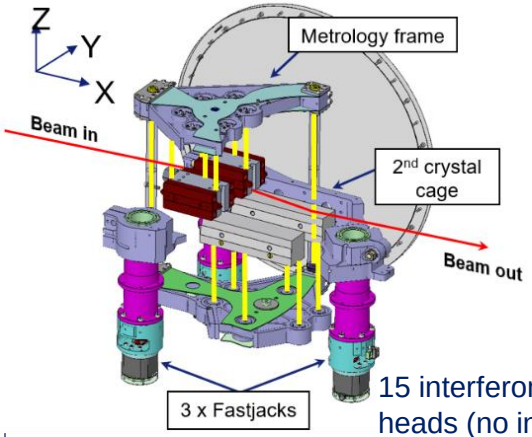
Online metrology

Theoretical performance

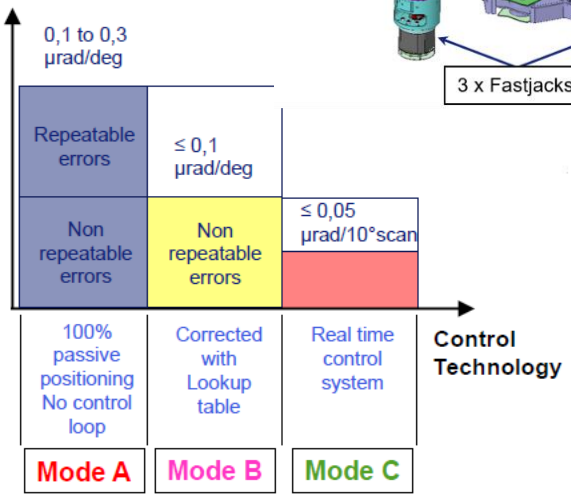
Movement	Resol.	Repeat.
ΔRX nrad	<8	<110
Δ RY nrad	<3	<42
Δ TZ nm	0.3	5

2nd Crystal specs

Movement	Parallelism
ΔRX nrad	100
Δ RY nrad	14
Δ TZ nm	200

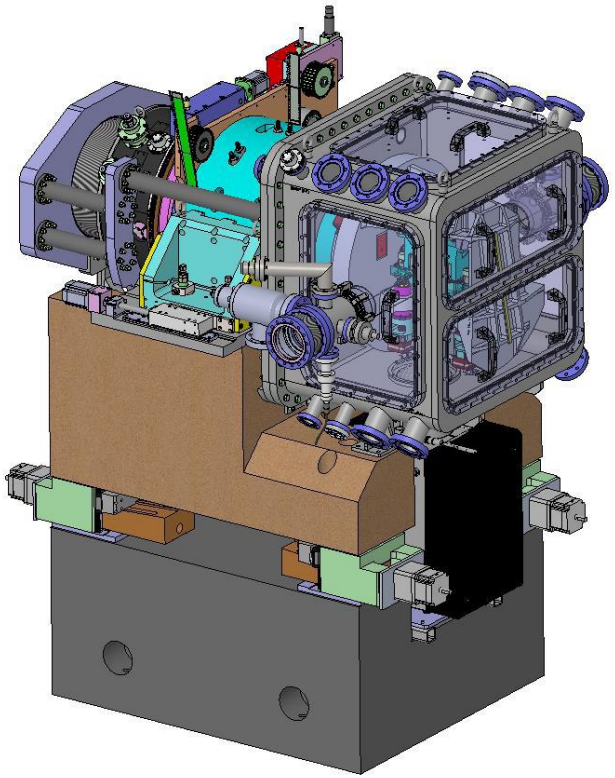


15 interferometer heads (no in-vacuum electronics)



3 operation modes

- **A: no correction**
- **B: correction of repeatable errors (lookup table)**
- **C: real-time correction**



DCM project team:
Delphine BABOULIN, **Bob BAKER**, Ray BARRETT, Pascal BERNARD, Gilles BERRUYER, Julien BONNEFOY, Maxim BRENDIKE, Philipp BRUMUND, Yves DABIN, Ludovic DUCOTTE, Hervé GONZALEZ, Olivier MATHON, Thomas ROTH, Remi TUCOULOU

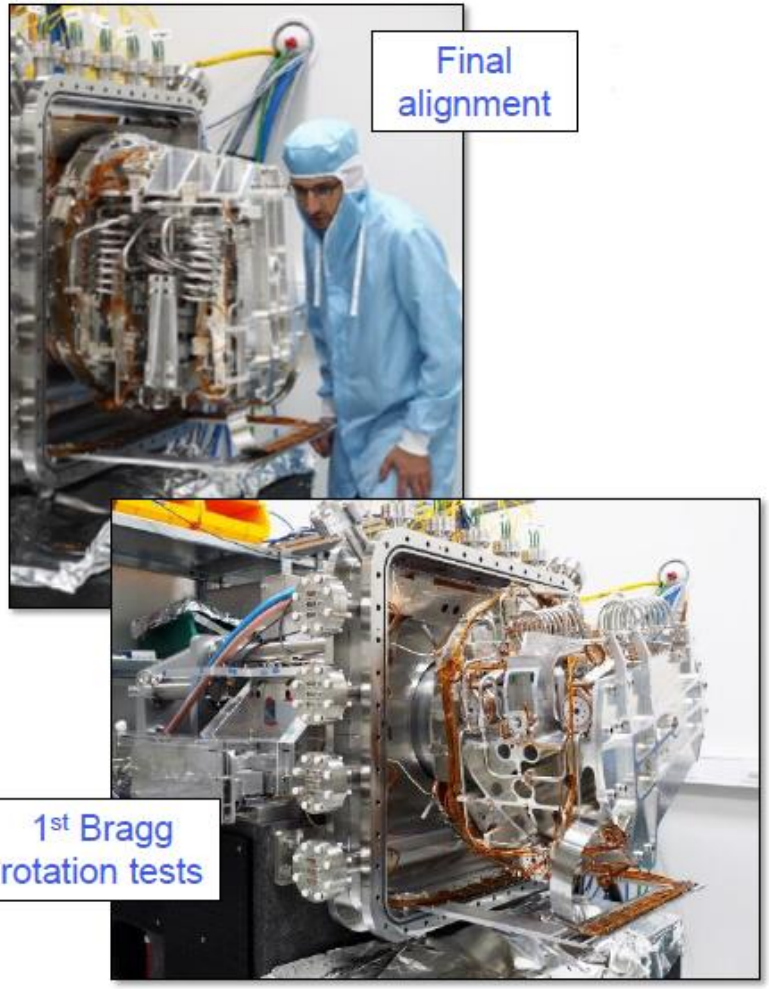
-> Vladimir Krotov video

HIGH PRECISION ENGINEERING

Spectroscopy Double –Crystal monochromator

Mechanical Engineering

Measurements



Installation

SOFTWARE

Accelerator control | Beamline control | Data Analysis

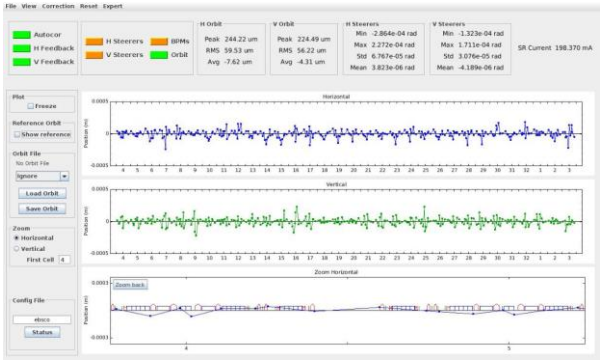
Software development

- Hot Swap Manager
- Timing system
- History database
  - HDB web interface
- Interaction with beamlines
  - Energy scans
  - Insertion devices synchronization with monochromators
  - Connect beamlines to accelerator timing system

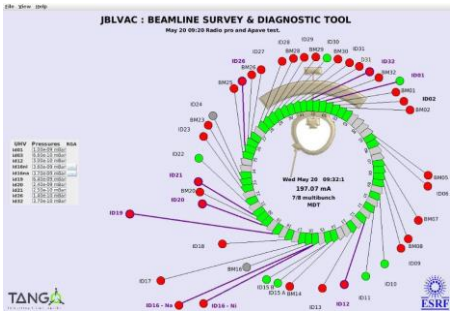
- TANGO
  - Web development framework

- Digital twin
  - Accelerator simulator

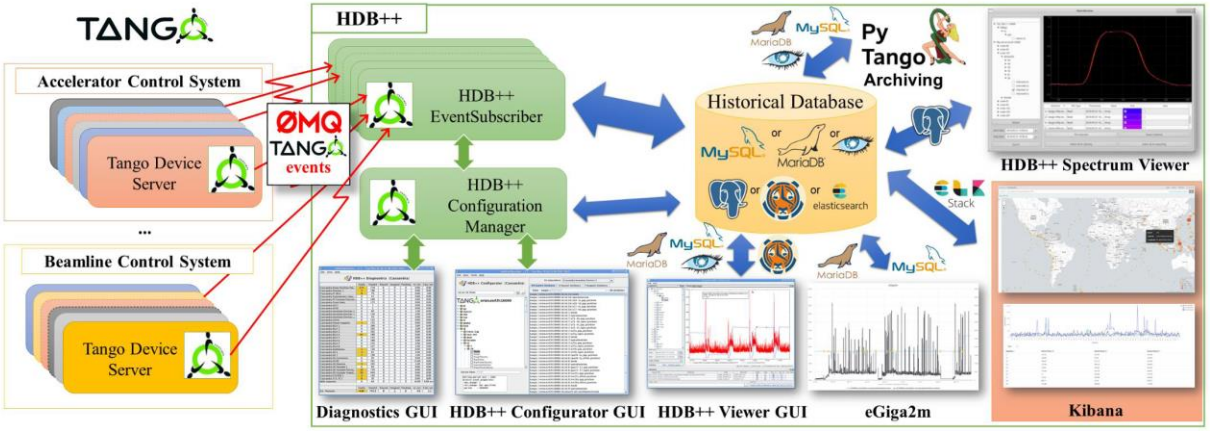
- ~8000 parameters archived
- Disk cluster 10TB/year
- Time To Leave feature (TTL)
  - Data decimation to optimize network traffic
  - Some data automatically discarded…



E-beam orbit



Beamlines survey & diagnostic tools



Archiving system

Courtesy JM Chaize

SOFTWARE

Accelerator control | Beamline control | Data Analysis

Bliss - development & deployment of BLISS (new beamlines control system

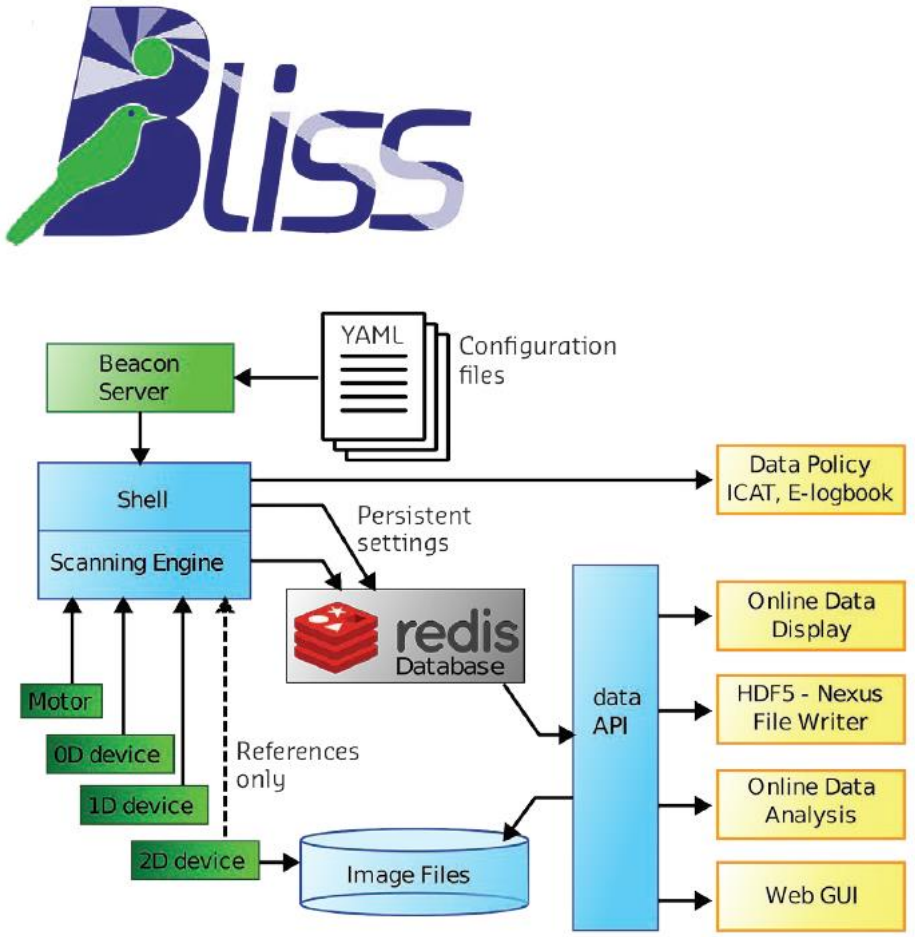
Operation - beamline commissioning

Web GUIs - MxCube3 in production on all SB beamlines, BsxCube + ID21 + BM05 GUI under commissioning

New High level software framework for 2D detectors:
LIMA1 – Bliss and HDF5 saving, Eiger2 validation of set-up, adaptation to changing supplier SDK

LIMA2 - On-going implementation, planning for Jungfrau detector

Data Policy - set-up of experiment registration in ICAT for all beamlines under commissioning

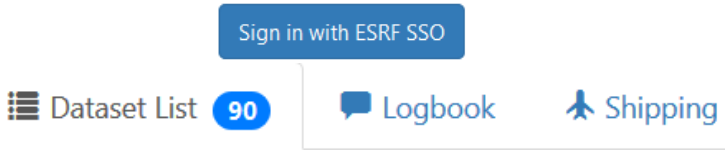


Courtesy M Guijarro

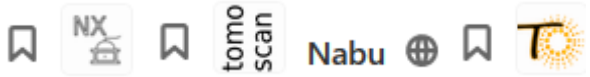
SOFTWARE

Accelerator control | Beamline control | Data Analysis

Data Policy (https://data.esrf.fr)
- Datasets of 43 beamlines in ICAT
- Single Sign On implemented
- Sample Tracking implemented

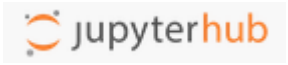


Tomography
- New pipeline for volume reconstruction



SB pipelines completed migration from OAR to SLURM and to Ubuntu 20.04

Jupyter service for remote analysis operational. https://jupyter-slurm.esrf.fr



New Acquisition System contributions
- NexusWriter in operation.
- PyMca:

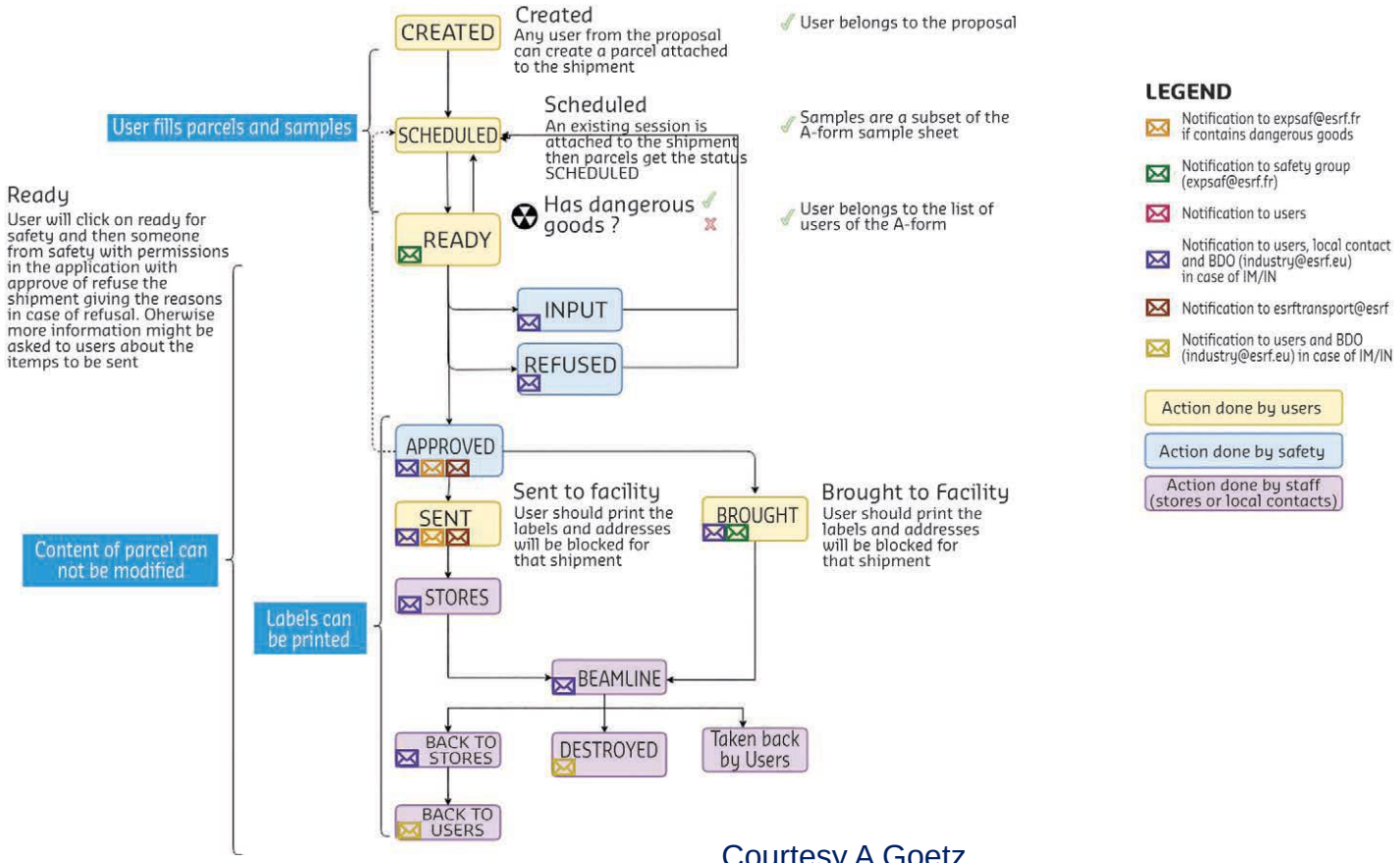
HDF5. Implemented ZFP lossy compression (adapted to floating point data).

New detectors support

Courtesy A Goetz

SOFTWARE

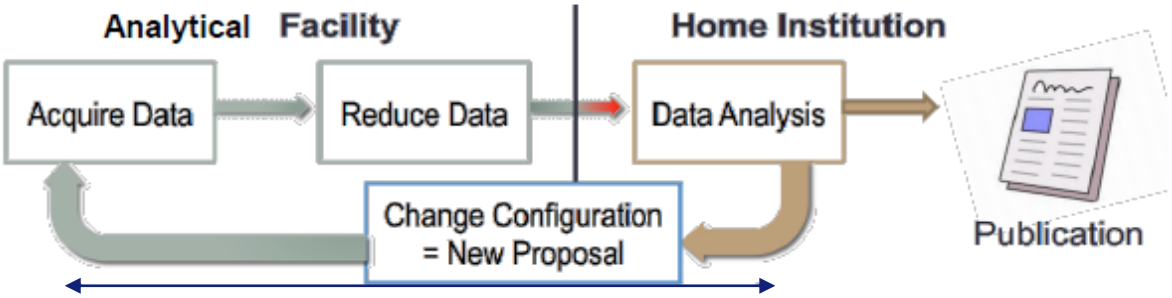
The COVID-19 pandemic has accelerated the need for large-scale remote and mail-in access solutions for user experiments, and especially the ability to accurately track large numbers of samples and tools transiting through the facility. In only a few months, a sample tracking module has been developed and implemented in an existing module (ICAT+) of the metadata catalogue ICAT.

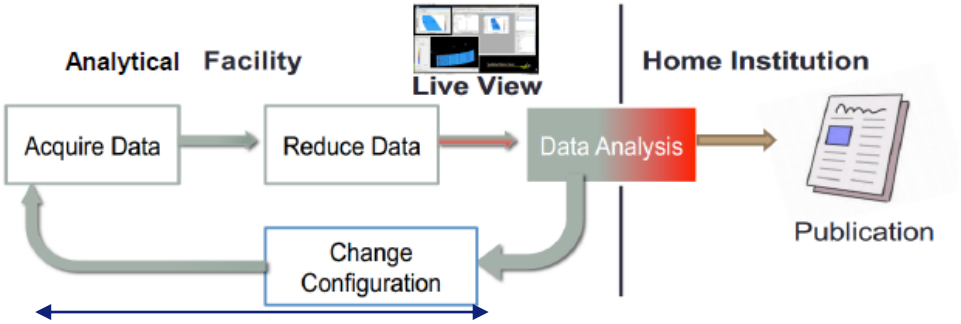


Courtesy A Goetz

ON-LINE & OFF-LINE DATA ANALYSIS

Data Management !





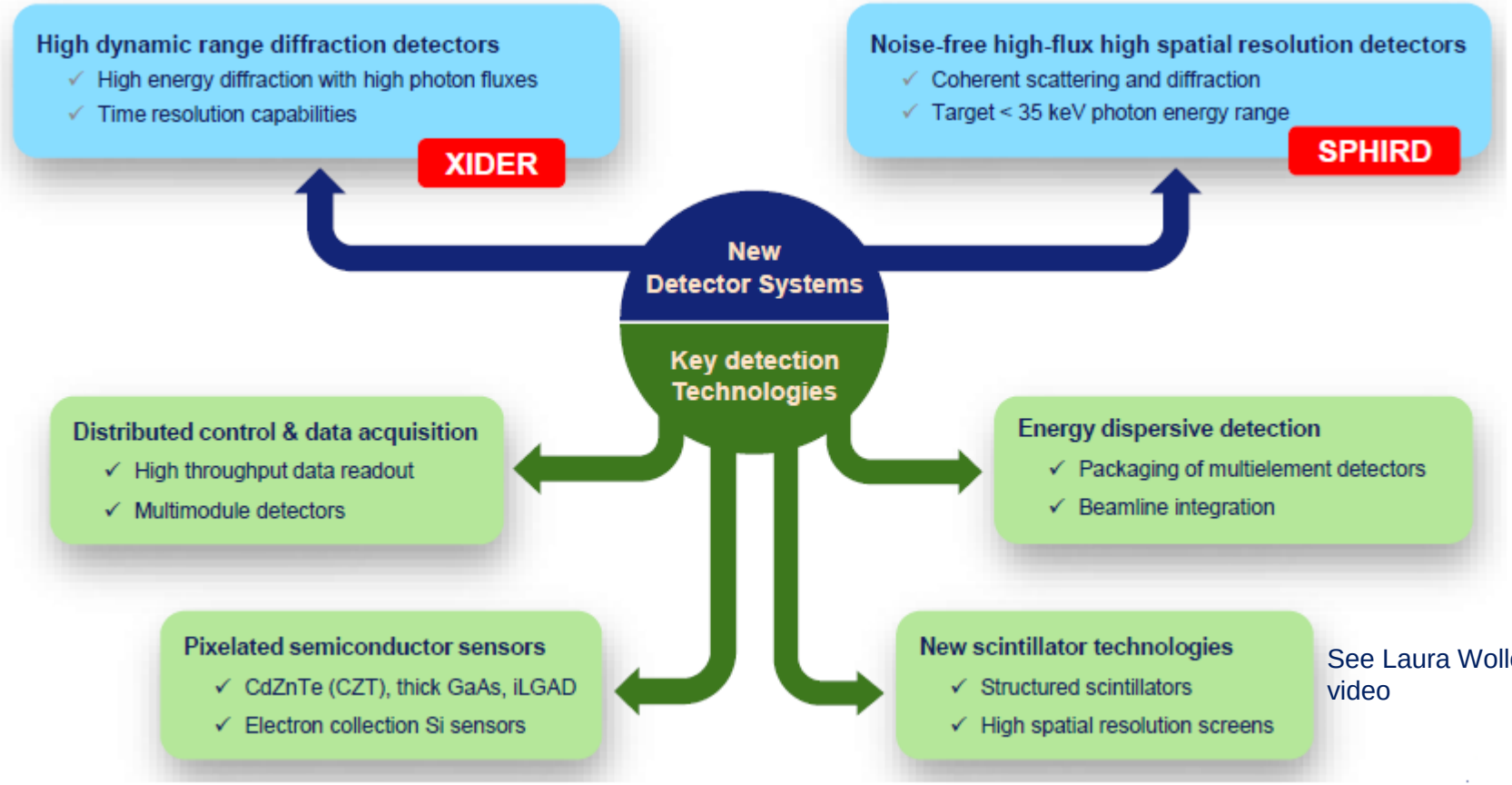
Courtesy: T. Proffen/M. Hagen

- Strategy
- Infrastructure
- Resource
- data sustainability
- …

→ **Andy Goetz presentation**

Detectors & Electronics

EBS Detector Development Plan (DDP)



See Laura Wollesen video

Courtesy P Fajardo

- *XIDER : detector for time resolved and high energy diffraction applications*
- *SPHIRD : high count rate detector with small pixels*

projects in R&D phase

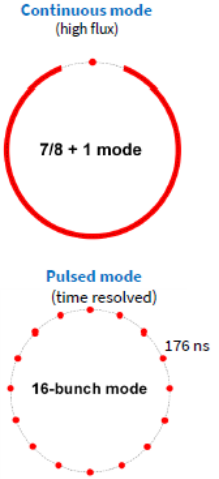
DETECTORS & ELECTRONIC

SPHIRD : A high-rate photon counting detector with small pixels

- For optimal use of **intense coherent beams**
- Designed to operate with **high-Z compound semiconductors** (hybrid pixels)
  - to reach high energies: optimised in the 15 - 30 keV range, usable in a wider range
  - to minimize parallax effects (important with small pixels)
- With a sensor pixel pitch **≤ 50 µm**, target in the 30 to 40 µm range
- Able to reach very high count rates: **>15 Mcps** per pixel (at 10% of pileup)
  ×4 (**> 60Mcps**) with 2×2 binning
- Investigate the possibility of achieving **higher spatial resolution**
- Microelectronics technology node: CMOS 40 nm

XIDER: A Very fast high dynamic range digital integrating detector

- 2D hybrid pixel detector for **high energy** and **time-resolved** diffraction experiments with ESRF-EBS
- Based on the concept of **incremental digital integration**
- Main targets:
  - ✓ Operation with **high-Z sensors** (30-100 keV)
  - ✓ **100 µm pixel pitch**, 200 µm (2×2) configurable pixels
  - ✓ Able to manage very high photon fluxes (up to **1 Gcps/pixel**)
  - ✓ **100% duty cycle**, deadtime free readout
  - ✓ Burst mode up to **5.68 Mframes/s** (ESRF 16-bunch frequency)
  - ✓ **Fully digital** readout and enhanced functional **versatility**



Courtesy P Fajardo

DETECTORS & ELECTRONIC

Detectors & Electronics

Distributed control & high throughput data acquisition

Generic tool to facilitate the setup/building of distributed data acquisition and processing environments

- Fully scalable multi-node computing infrastructure
- Various kind of data receiving & processing nodes (CPU,GPU, FPGA processors)
- Optimised for multimodules detectors

Rashpa:

- High performance data transfer architecture from the detectors (hardware & low level software)

Lima2:

- New high level software framework for 2D detectors control and data acquisition
- Supports in-house developments & commercial detectors

Pixelated semiconductors

Investigation of various kind of pixelated sensors

- CdZnTe (CZT) pixelated sensors from REDLEN and IMEM (Parma)
- Thick GaAs: Cr pixel sensors (700 & 1000 µm) from TSU (Tomsk)
- Pixelated iLGAD (low gaim APD) Si sensors (CNN)
- Electron collection (n on p) Si sensors (shorter time, polarity compatibility with high Z)

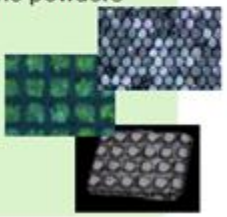
Scintillator technologies

Structured scintillators

- ✓ Improvement of micro-columnar screens: *CsI (Tl,Sm), ZnSe (Te), CeBrI, LuI$_3$*
- ✓ Micro-structured screens (micropore-arrays, MCPs, Si matrices) filled with micro and nano powders
- ✓ Simulation studies

High spatial resolution screens

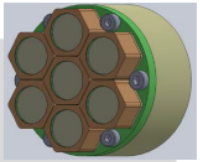
- ✓ Single-crystal films (SCF) of new high density scintillating materials: (Pb,Sr)TiO3, HfO2
- ✓ Epitaxial growth of structured (micropillar-shaped) SCFs (LYSO:Ce)



Integration of energy dispersive detectors

Development of improved packaging of multielement detectors (SDDs)

- ✓ Optimised modular vacuum-compatible packaging
- ✓ Improve the maintainability and performance of the detectors



Beamline integration

- ✓ Build and validate in-house expertise for the development of beamline custom detectors

Ge detection

- ✓ Survey and characterization of available HPGe detector technologies
- ✓ Participation in the development of a new monolithic multielement Ge detector (LEAPS initiative)

Courtesy P Fajardo

X-RAY OPTICS

NEW BEAMLINE AND REFURBISHED BEAMLINE PROJECTS

Horizontal deflecting optics

- White beam mirrors (in-house design, water-cooled)
- Multilayer monochromators (in-house design, water-cooled)
- Double crystal monochromators

Fixed curvature focusing mirror systems
Wavefront preserving optics

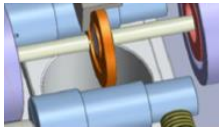
1nm and 0.1 µrad scale figure/slope errors

Crystal spectrometers (in-house design)

- Bent spherical crystal arrays
- von Hamos spectrometers

Refractive lenses

In-house production of Aluminium lenses



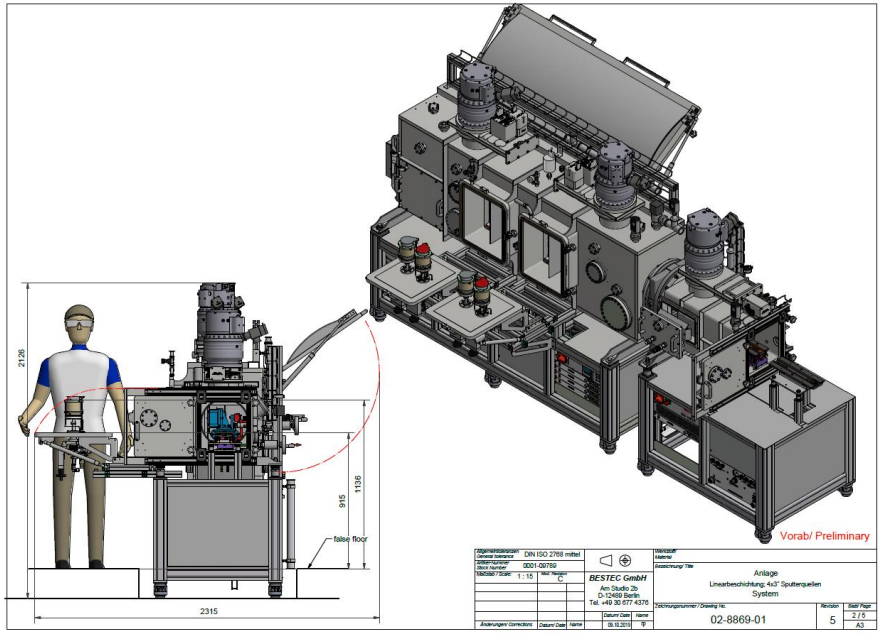
- Installation of a New Compact Multilayer Deposition System (CMCS)
- Thin-film coating of optics optimised for EBS applications (coherent, hard X-rays, substrate correction)

High importance of metrology

X-RAY OPTICS

New deposition system optimised for EBS applications:

- Coatings for use with coherent hard X-ray
- Accurate positioning of shorter optics
- Optimised motion control for improved coating thickness precision (*correction of imperfect substrates*)



Courtesy Ray Barrett

X-RAY OPTICS

X-Ray Optics

Mirrors & Metrology
optical metrology, mirror systems design, assembly, characterization & simulation

Monochromator systems
design, assembly: channel cut monochromators, polychromators, bent-Laue, fixed-exit, cryocooling

Crystals
design, manufacture, characterization –X-ray topography (BM05)

Multilayers
design, manufacture, characterization & simulation

Plasma cleaning
KB mirrors contamination removal

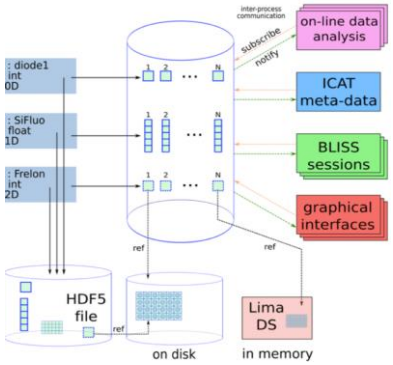
Crystal Analysers
design, manufacture, characterization & simulation

Refractive Lenses
design, manufacture, characterization & simulation

Simulation/ BL design
Shadow, XOP, Oasys(pyXOP, ShadowOUI, SRW), …

-> Ray Barrett presentation

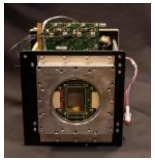
CHALLENGES



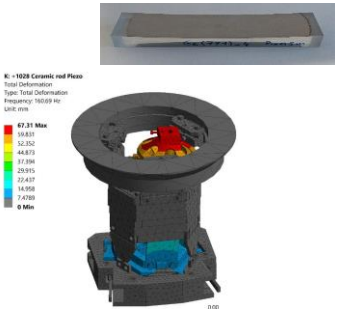
Beamline Instrumentation control

On-line data analysis
- Data pre-processing
- Tomographic reconstruction
- Crystallographic analysis

Machine learning, AI

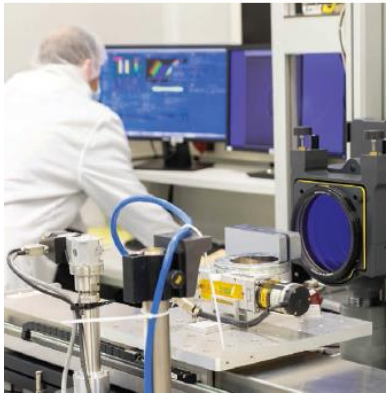


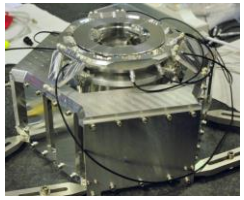
Detector technology
Scintillators
Electronic (timing, FPGA…)



Optics
- Manufacturing & preparation techniques
- Power management
- measurement

Cryo undulators with minimum gap
- Power
- Power density





Nano imaging Beamline Instrumentation:

- faster nano positioning
- vibration control

MANY THANKS FOR YOUR ATTENTION