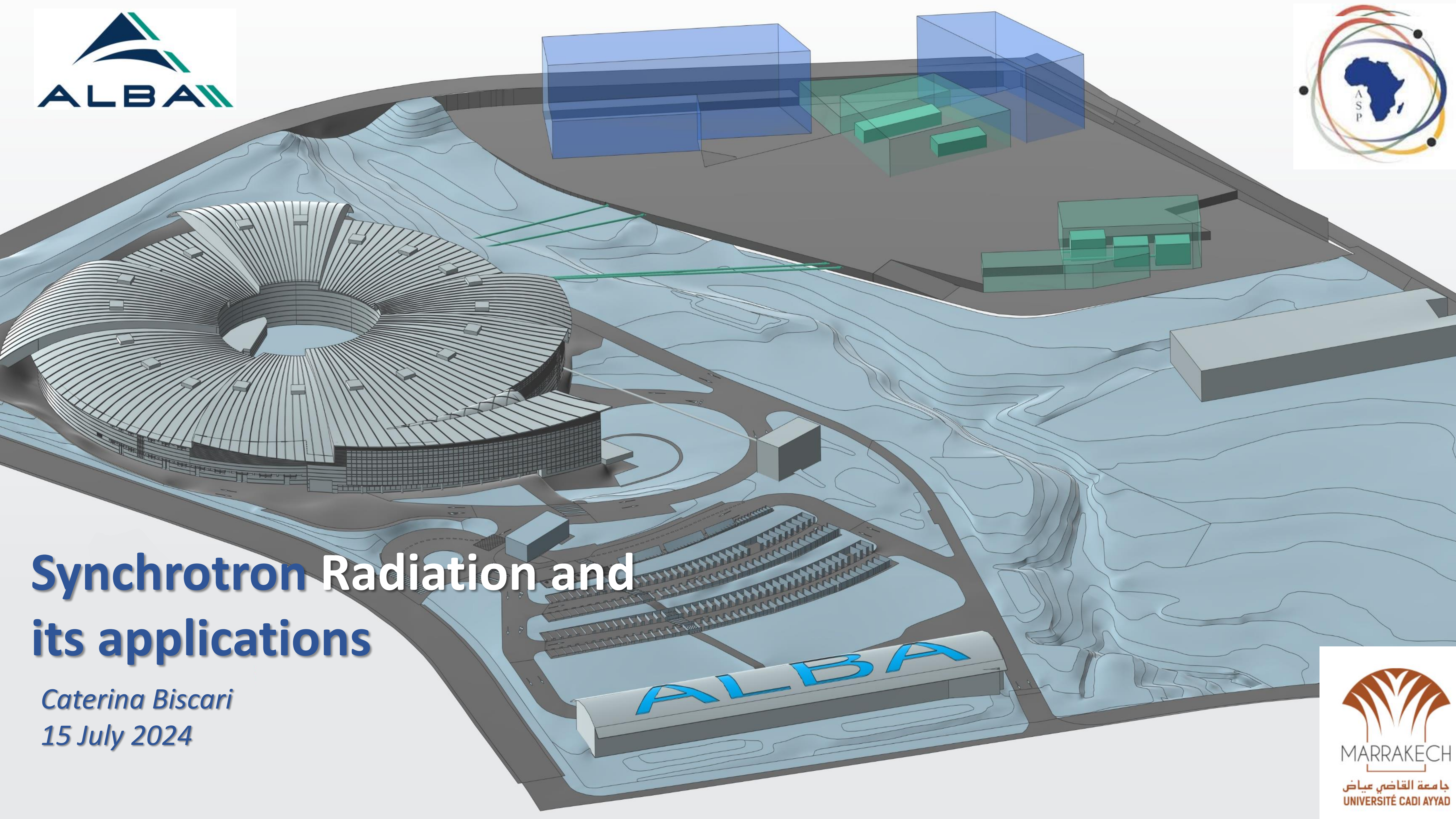
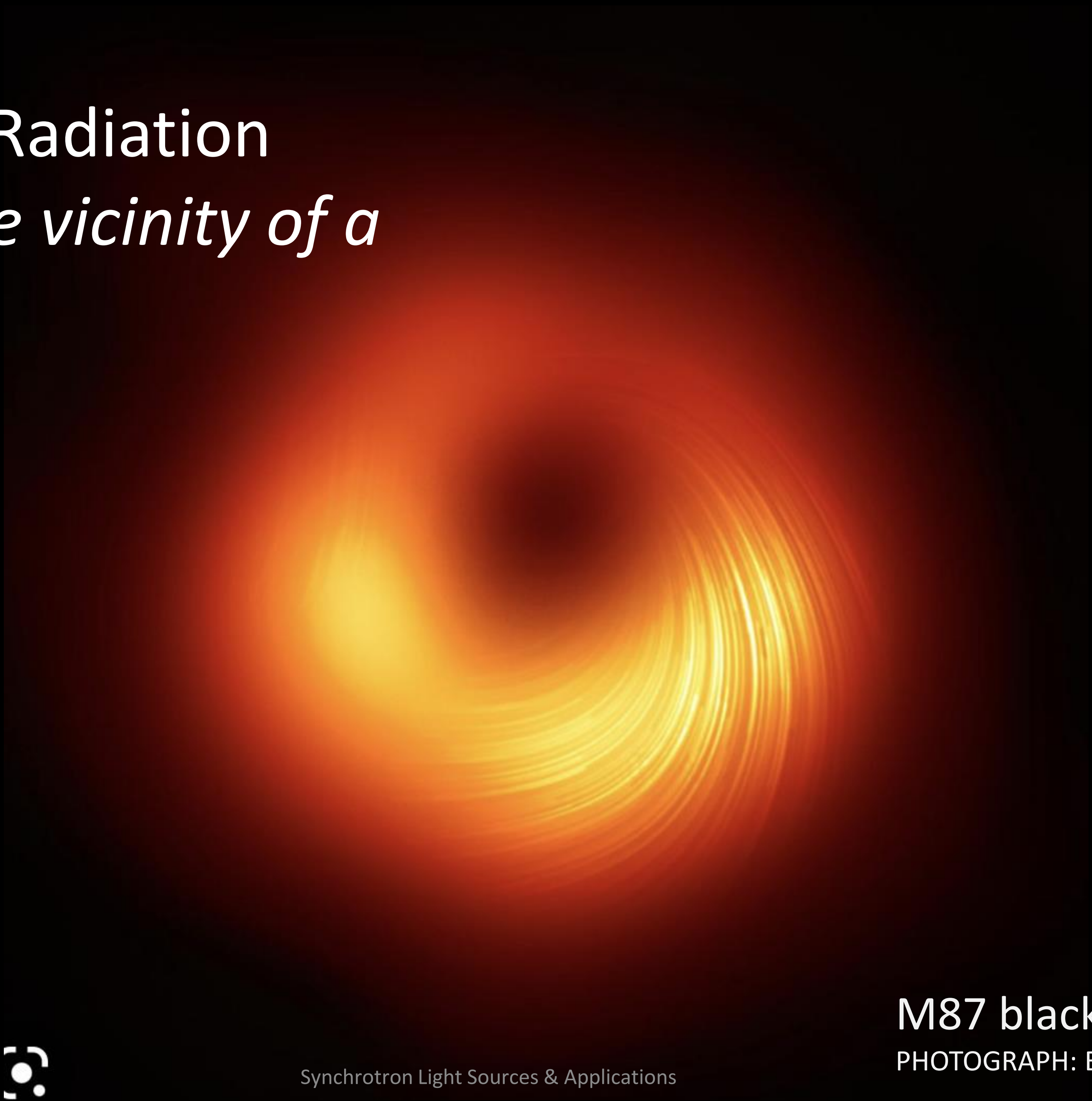


Synchrotron Radiation and its applications

Caterina Biscari
15 July 2024

Synchrotron Radiation

Emitted in the vicinity of a black hole

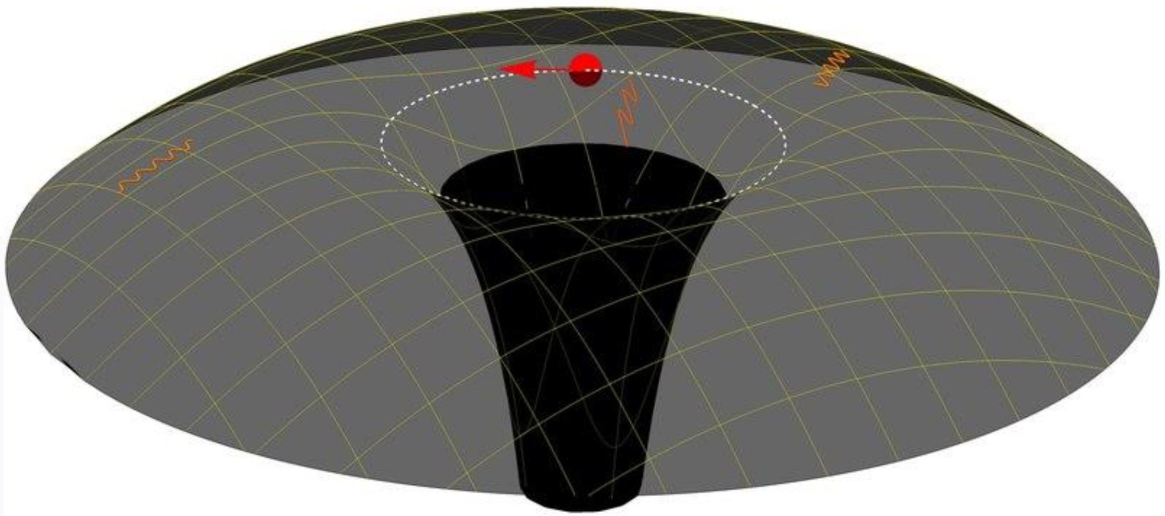


M87 black hole

PHOTOGRAPH: EHT COLLABORATION

Synchrotron Radiation

In the universe *and in our particle accelerators*



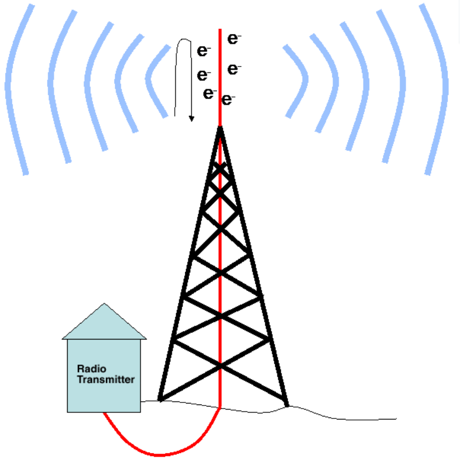
Credit Wikipedia - Joao Paulo Bessa Brito

Black hole representation

ALBA Synchrotron

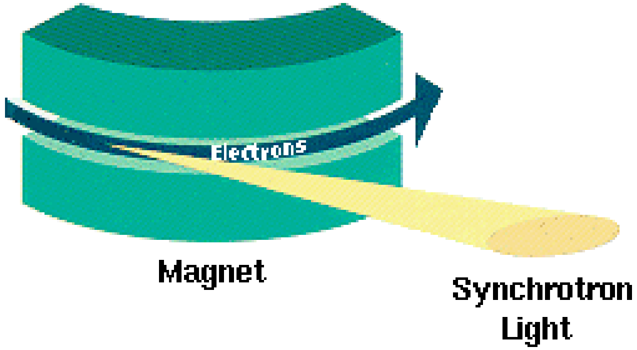
What is synchrotron radiation

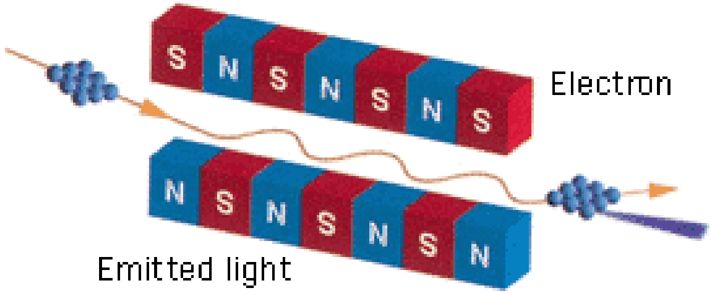
Electromagnetic radiation is emitted by charged particles when accelerated

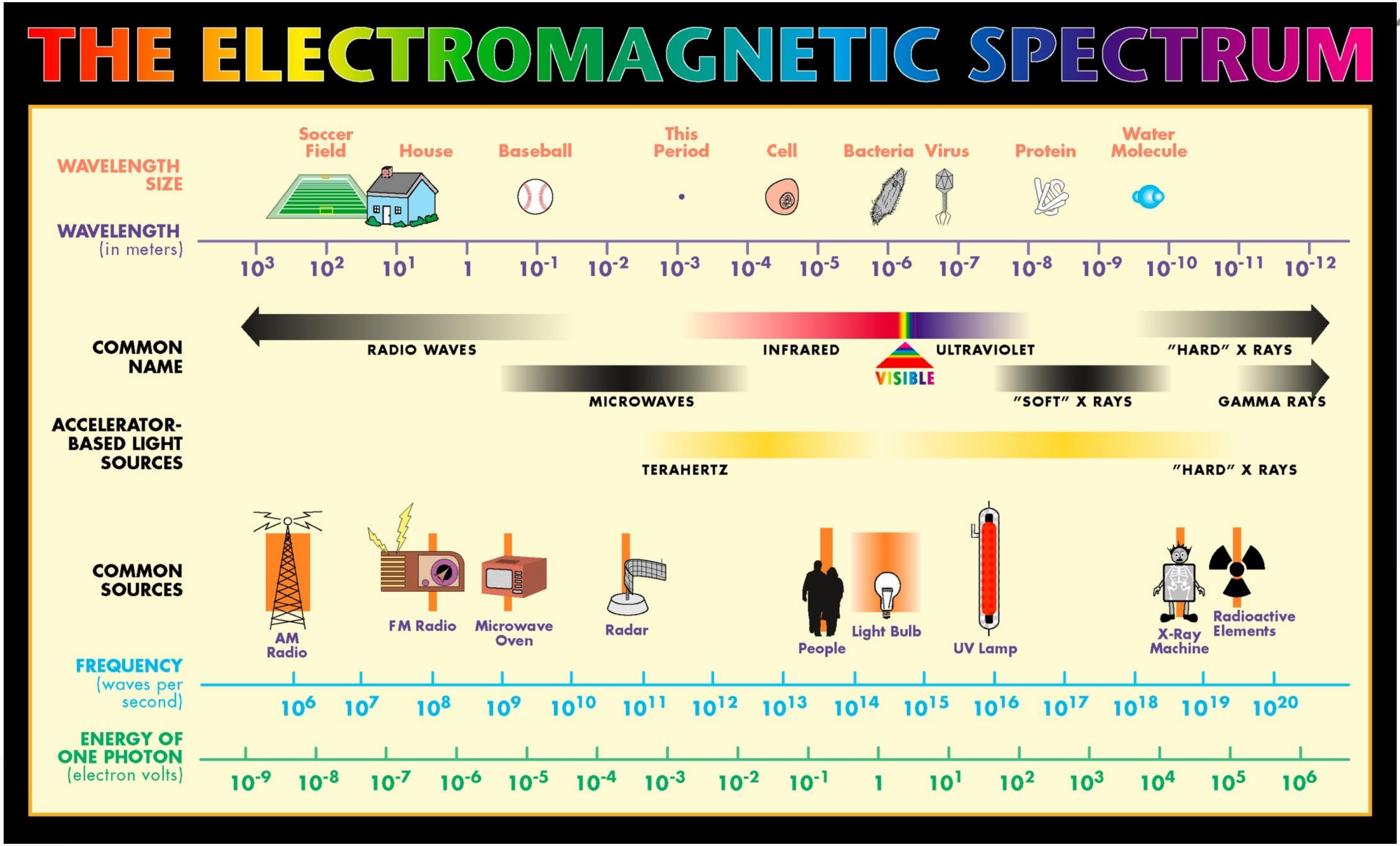


The electromagnetic radiation emitted when the charged particles are accelerated radially (v ⊥ a) is called synchrotron radiation

It is produced in the storage rings using bending magnets, undulators, and wigglers



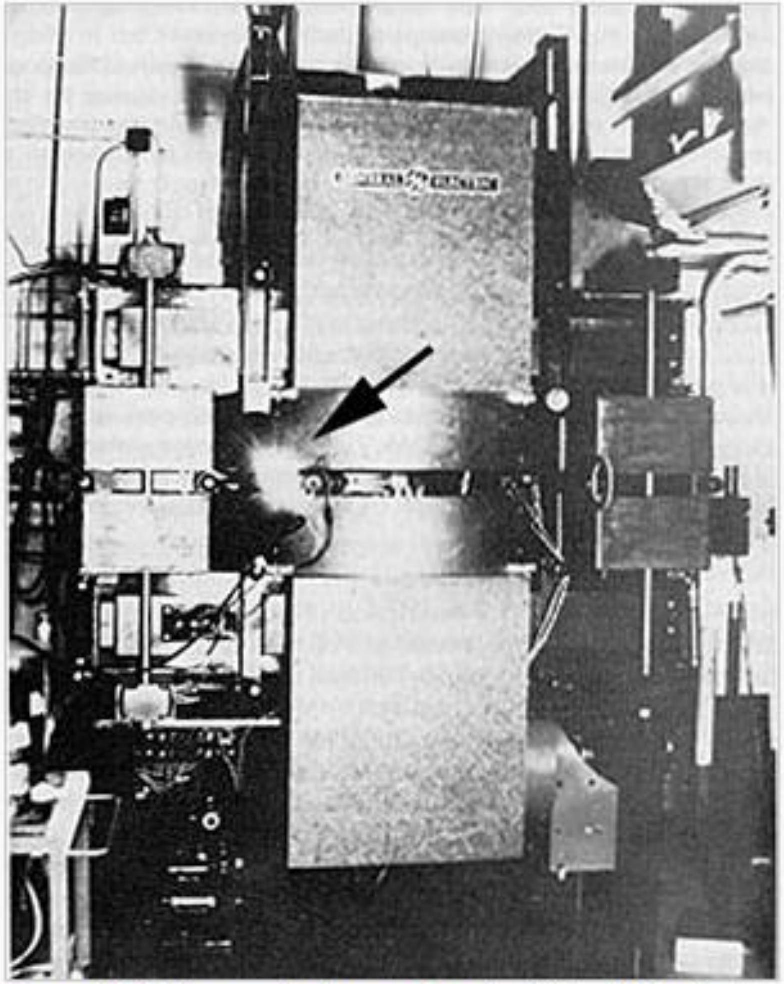




Sources on earth

Discovery of synchrotron radiation (1946)

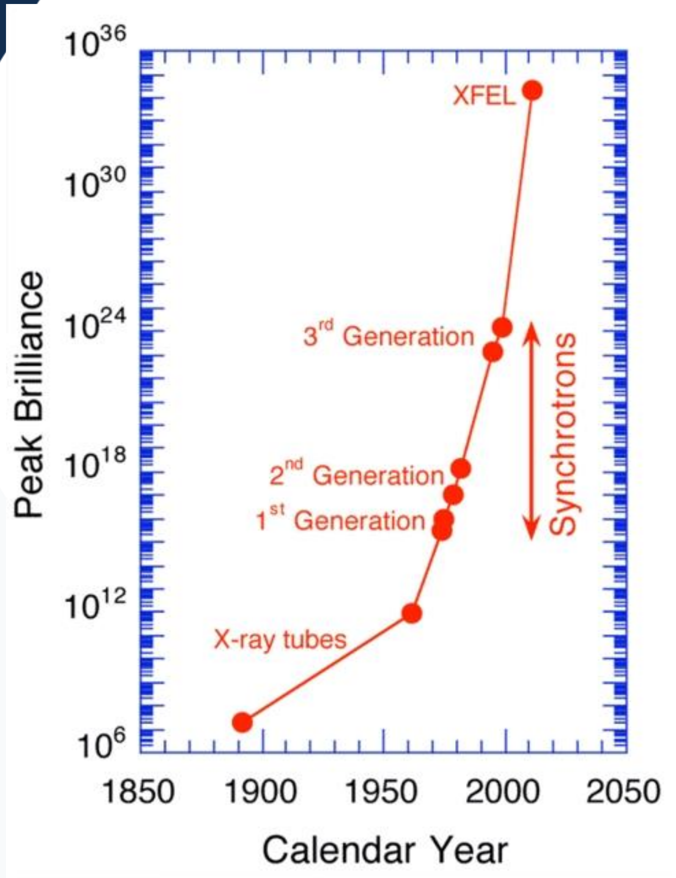
General Electric
Electron synchrotron accelerator - 300 MeV
2nd synchrotron ever built
Visible light through the glass vacuum chamber
SR had been predicted, but its frequency was not known

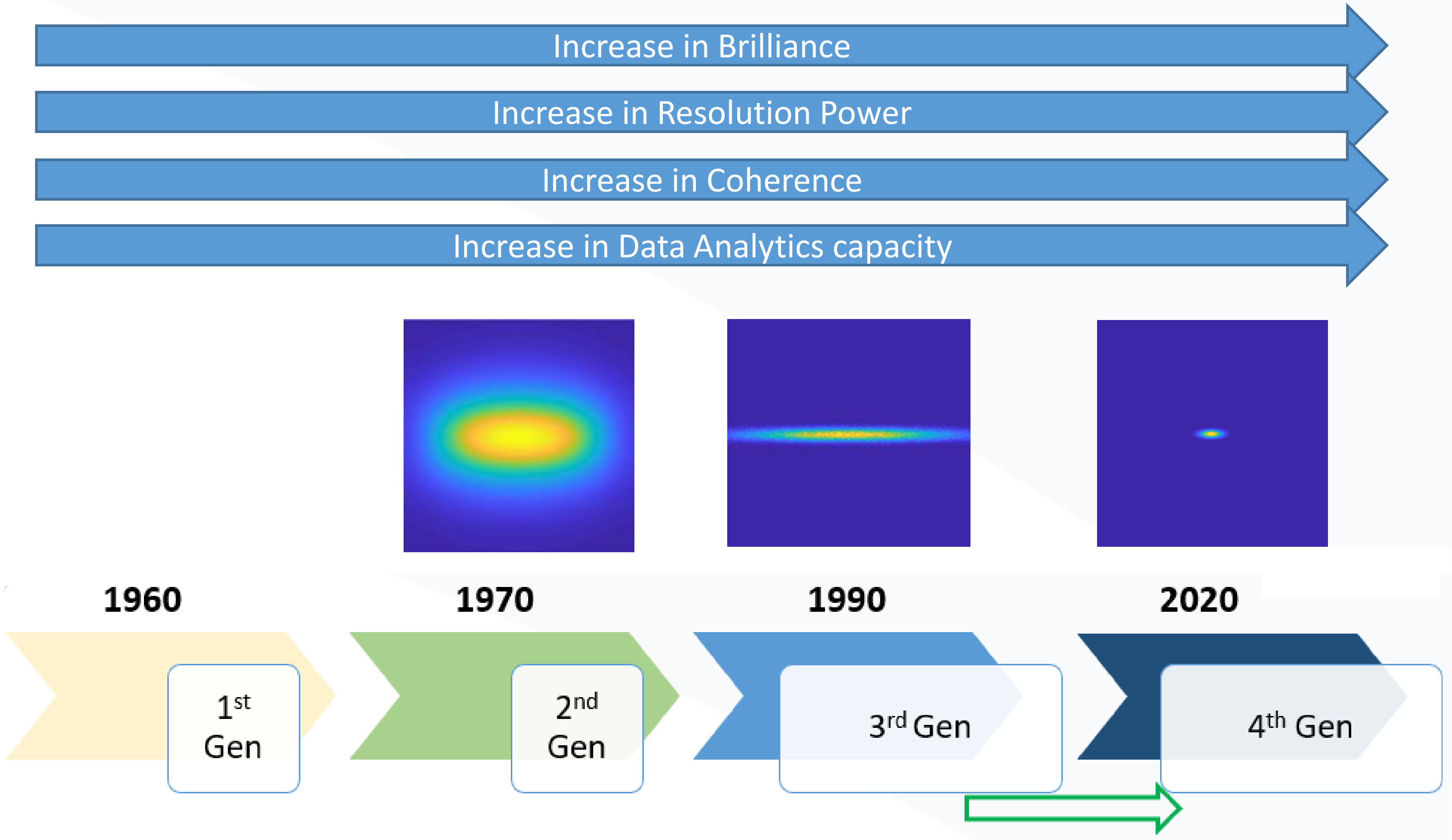


General Electric synchrotron accelerator built in 1946, the origin of the discovery of synchrotron radiation. The arrow indicates the evidence of radiation.

Evolution of Synchrotron Radiation Sources

Light source brilliance
photons/s/mm²/mr²/0.1%BW
photons per time, space, energy definition





1 - Parasitic use of HEP accelerators

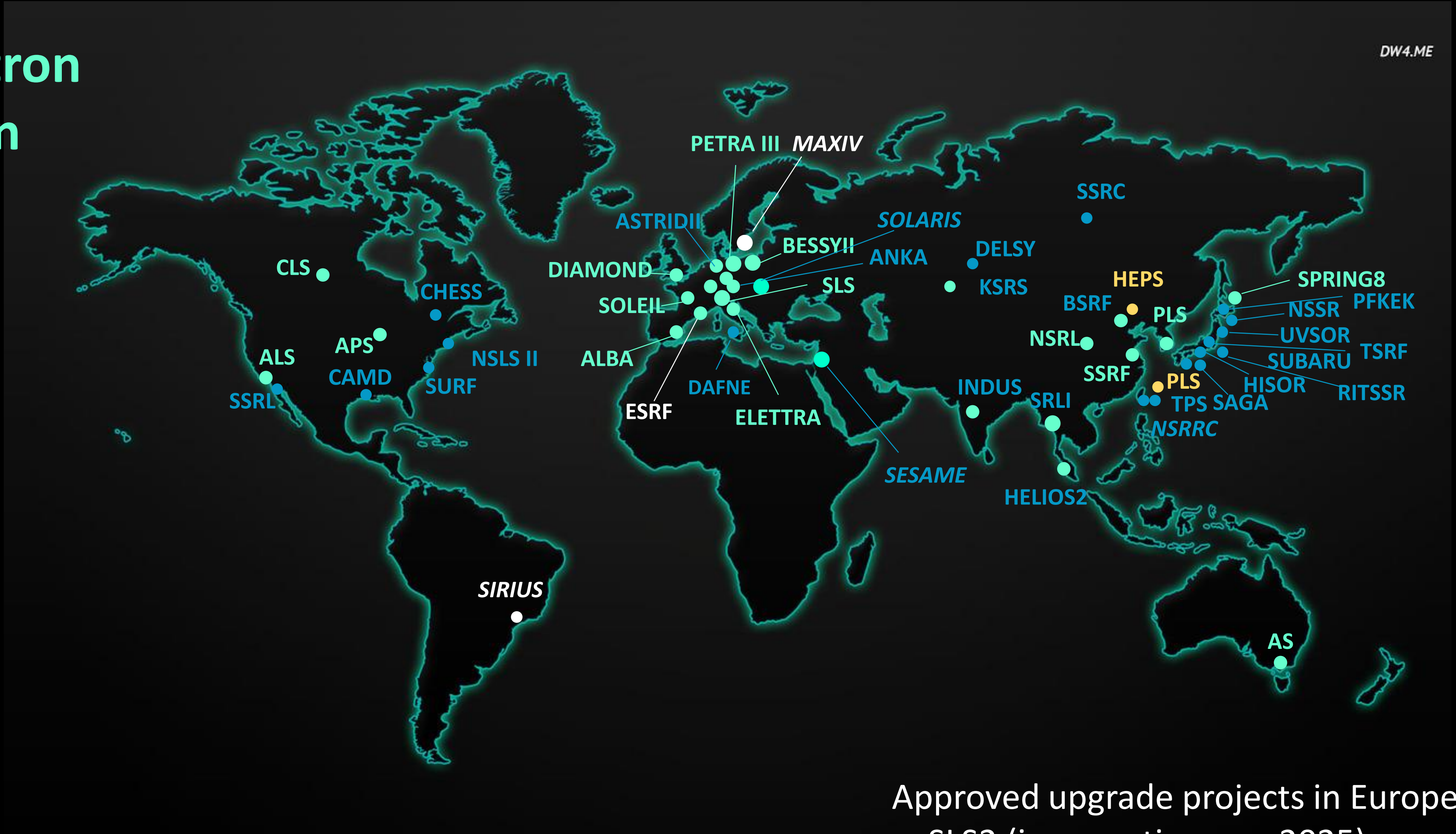
2 - Dedicated X-ray sources

3 - Radiation facilities with wigglers, undulators, high brilliance

4 - Ultimate Storage Rings (USR) – Diffraction limited

2000s: Free Electron Lasers driven by Linacs

Synchrotron Radiation Facilities



- 4th Generation IN OPERATION
- 4th Generation *in construction*
- Upgrading or planning upgrade from 3rd to 4th generation
- 3rd generation

Approved upgrade projects in Europe:

- SLS2 (in execution; op: 2025)
- Elettra2 (in execution; op: 2026)
- Diamond2 (in execution; op: 2027)
- Soleil2 (in execution; op: 2028)

Outstanding characteristics of synchrotron radiation

High brilliance and flux (combined with high collimation)

Wavelength tunability (depending of source & optics)

Beam size tunability (depending of source & optics)

(Partially) coherent radiation

Polarization (linear, elliptical or circular)

Time structure

Synchrotron Light Sources key parameters

Photon beam property	Accelerator property
Photon energy range	Energy, magnetic field, insertion device parameters
Photon flux	Energy, current
Brightness	Energy, current, emittance
Polarization	Magnetic field orientation
Time structure	Rf frequency
Stability	Feedback, beam lifetime, injection system
Beamline capacity	Dipoles, insertion devices

Energy and power emitted in a ring

$$P_{SR} = \frac{2cr_e}{3\left(m_0c^2\right)^3}\frac{E^4}{\rho^2} = \frac{2r_e c m_0 c^2}{3\rho^2}\gamma^4$$

Larmor formula:
Instantaneous power emitted by an electron travelling in a circle of radius ρ (by integrating the Poynting vector)

$$U_0 = \int_{finite\ \rho} P_{SR}\, dt = \frac{2}{3} r_e m_o c^2 \beta^3 \gamma^4 \oint \frac{ds}{\rho^2} = C_\gamma \frac{E^4\left(GeV^4\right)}{\rho(m)} \propto \gamma^4 I_2$$

$$C_\lambda = \frac{4\pi}{3}\frac{r_e}{\left(mc^2\right)^3} = 8.846 \cdot 10^{-5}\frac{m}{GeV^3} \quad for\ e^-, e^+$$

Energy emitted per turn by every particle. Note the strong dependence on γ

Emitted power per turn by N_{tot} electrons (positrons) and protons (antiprotons)

$$P_e(kW) = \frac{e\gamma^4}{3\varepsilon_0\rho} I_b = 88.46\frac{E(GeV)^4 I(A)}{\rho(m)}$$

$$P_p(kW) = \frac{e\gamma^4}{3\varepsilon_0\rho} I_b = 6.03\frac{E(TeV)^4 I(A)}{\rho(m)}$$

$$I_2 = \oint \frac{ds}{\rho^2}$$

$$r_e = \frac{e^2}{4\pi\varepsilon_o m_o c^2}$$

$$N_{tot} = \frac{I \cdot T_o}{e}$$

Energy and power emitted in a ring

$$P_{SR} \propto \frac{\gamma^4}{\rho^2}$$

$$U_o \propto \frac{\gamma^4}{\rho}$$

$$P_e(kW) = 88.5\,\frac{E(GeV)^4 I(A)}{\rho(m)}$$

$$P_p(kW) = 6.0\,\frac{E(TeV)^4 I(A)}{\rho(m)}$$

Emitted power per turn by electrons (positrons) and protons (antiprotons)

Electrons are the particles used for synchrotron light production

Critical energy

The photon energy at which the SR emitted power is higher is the critical energy, which is obtained from the critical frequency

$$\varepsilon_c = \hbar\omega_c = C_c \frac{E^3}{\rho} \qquad C_c = \frac{3\hbar c}{2(mc^2)^3}$$

For electrons we can write

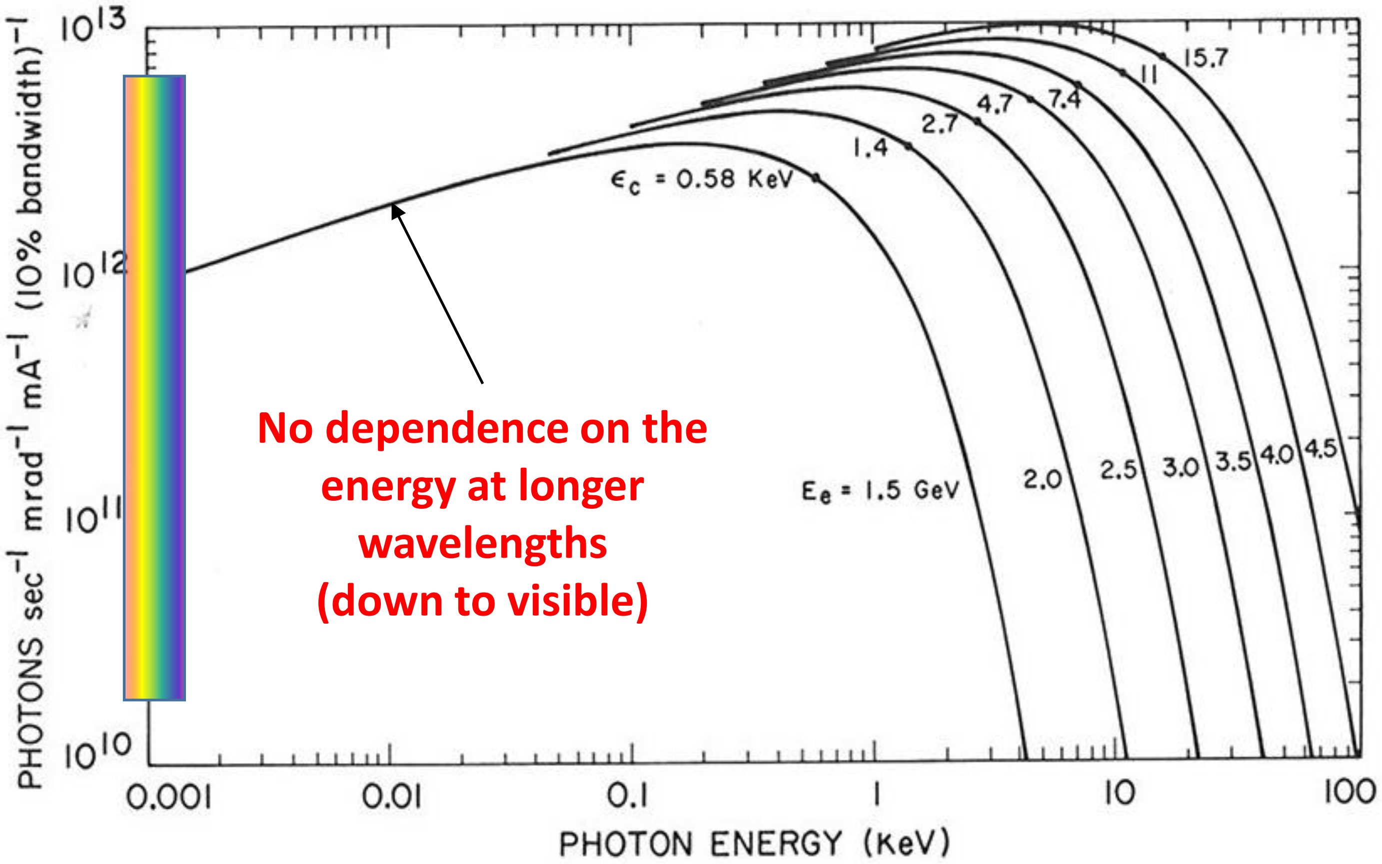
$$\varepsilon_c(keV) = 2.2183 \frac{E^3(GeV^3)}{\rho(m)} = 0.665 E^2(GeV^2)B(T)$$

The higher the bending field the higher the SR photon critical energy

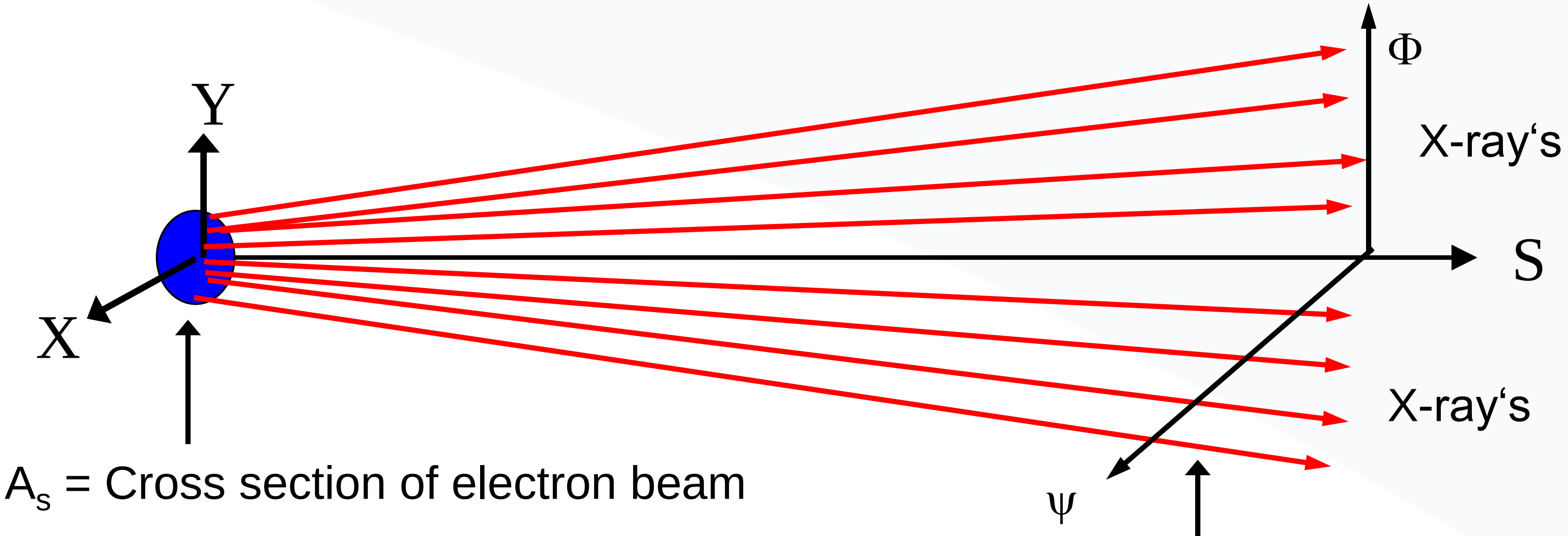
The SR spectrum in a circular accelerator is made up of harmonics of the particle revolution frequency up and beyond the critical frequency, not much separated and with beamline spread, so that the spectrum appears continuous.

Synchrotron radiation emission as a function of beam energy

Dependence of the frequency distribution of the energy radiated via synchrotron emission on the electron beam energy (same ρ)



Brilliance and emittance



A_s = Cross section of electron beam

$\Delta\phi$ / $\Delta\psi$ = Opening angle in vert. / hor. direction

Flux = Photons / (s • BW)

Brilliance = Flux / (A_s • $\Delta\Phi$ • $\nabla\psi$) , [Photons / (s • mm^2 • $mrad^2$ • BW)]

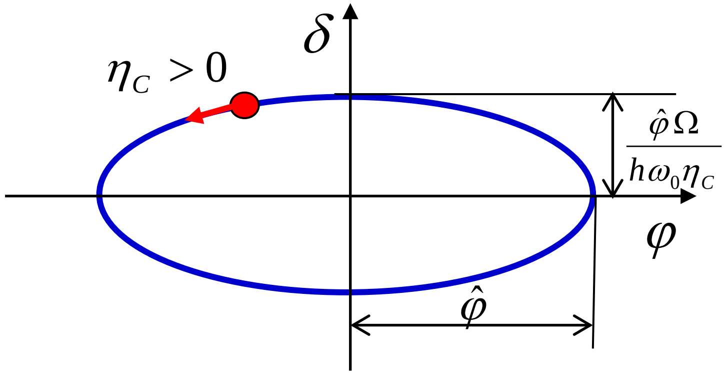
$$\text{brilliance} = \frac{\text{flux}}{4\pi^2 \Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}}$$

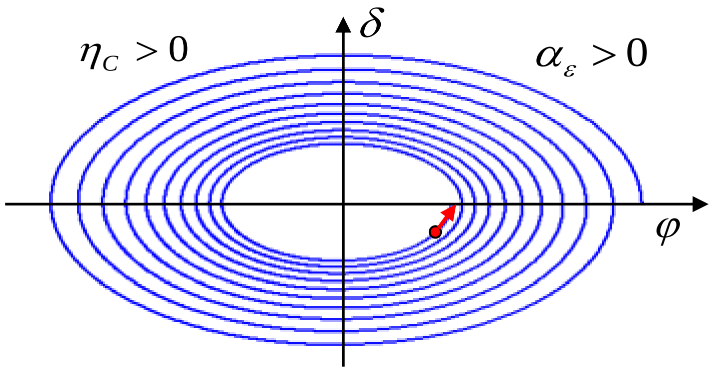
$$\Sigma_x = \sqrt{\sigma_{x,e}^2 + \sigma_{ph,e}^2} \qquad \sigma_x = \sqrt{\varepsilon_x \beta_x + (D_x \sigma_\varepsilon)^2}$$

$$\Sigma_{x'} = \sqrt{\sigma_{x',e}^2 + \sigma'^2_{ph,e}} \qquad \sigma_{x'} = \sqrt{\varepsilon_x \beta_x + (D'_x \sigma_\varepsilon)^2}$$

The brilliance represents the number of photons per second emitted in a given bandwidth that can be refocused by a perfect optics on the unit area at the sample.

Damping of betatron and synchrotron oscillations thanks to emission of synchrotron light





The equations of motion without synchrotron radiation emission are those of a harmonic oscillator, with varying amplitude (Hill's equation)

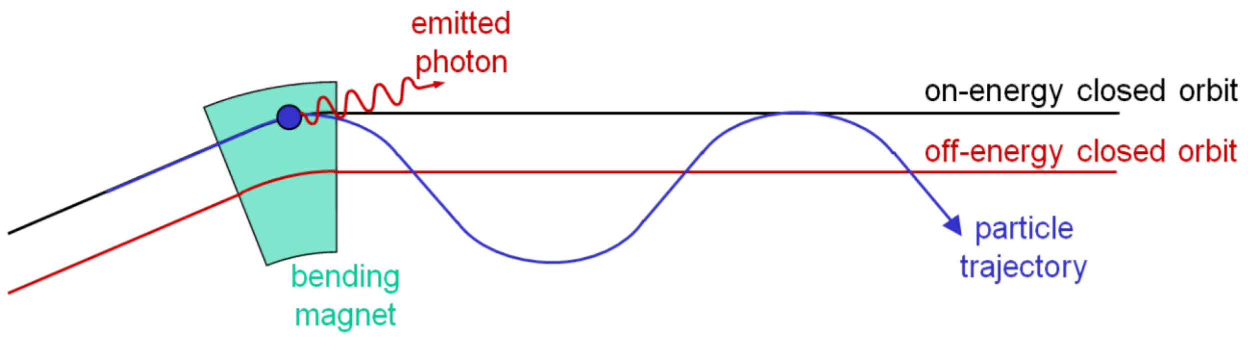
When adding the emission of photons, they become damped oscillations

This is true in the three phase spaces (horizontal, vertical, longitudinal)

Emitted radiation – damping times

		E (GeV)	ρ (m)	Uo (GeV)	τ_x (# turns)
DAΦNE	$e^+ e^-$	0.51	1.4	$5\ 10^{-06}$	200000
LEP	$e^+ e^-$	100	6086	1.5	130
LHC	p p	7000	2800	$7\ 10^{-06}$	$2\ 10^{09}$
ALBA	e-	3.	7	$1.\ 10^{-03}$	3600

Excitation of the motion in the horizontal and in the longitudinal planes



- When particles emit photons, they change their energy, and start moving around a different trayectory, whose distance from the nominal one is proportional to the dispersion function and to the lost energy
- Also the invariant in the longitudinal plane is modified, increasing in a term which is proportional to the number of emitted photons and to their rms energy

Radiation damping

Emittance going versus zero

Quantum nature of radiation

Quantum excitation

Emittance equilibrium distribution

Natural bunch length

Natural energy spread

Emittance in an e- storage ring

The emittance is determined by a balance between two competing processes: quantum excitation of betatron oscillations from photon emission and longitudinal re-acceleration within the RF cavities

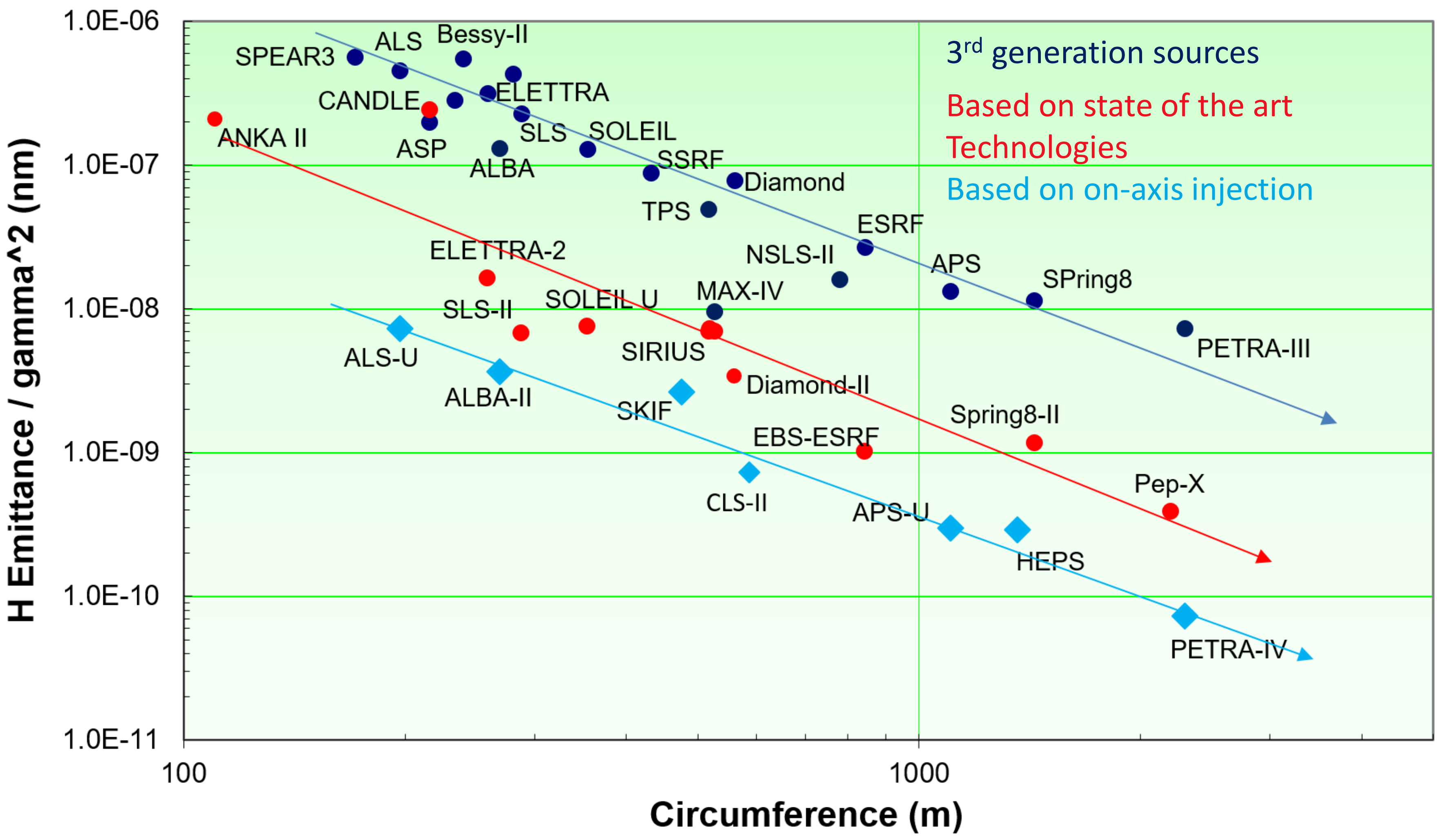
The emittance (size x divergence) depends on the dispersion and on the betatron functions in the dipoles, and on the energy

$$\varepsilon_x = \frac{55}{32\sqrt{3}} \frac{\hbar}{mc} \frac{\gamma^2}{J_x} \frac{\langle H/\rho^3 \rangle}{\langle 1/\rho^2 \rangle}$$

J_x is the Robinson partition number evaluated for the horizontal plane
The emission of photons is done in bendings, where there is dispersion. The electron amplitude oscillation afterwards is given by the dispersion, the original amplitude oscillation and energy loss

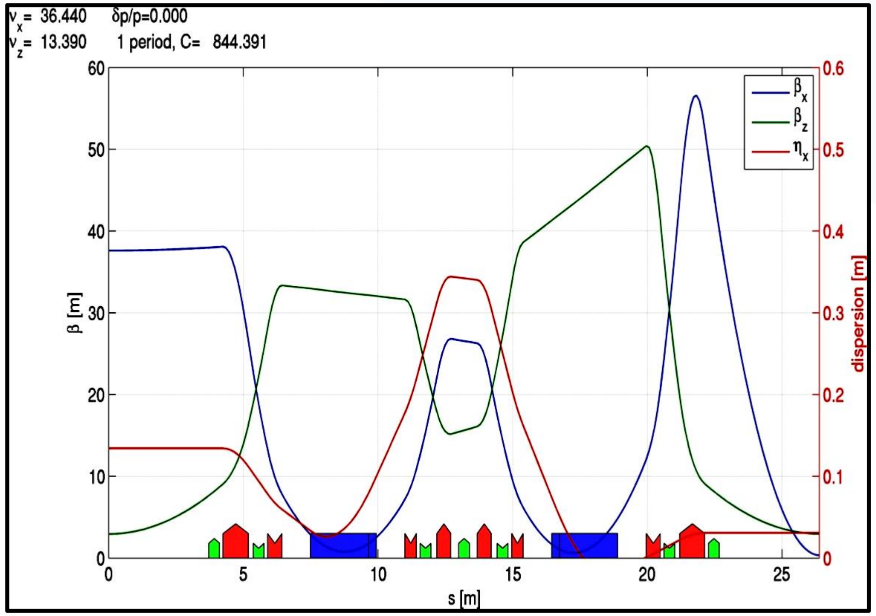
The smaller the dispersion the smaller the final equilibrium emittance:
increasing the n. of dipoles in a ring the dispersion decreases and so does the emittance

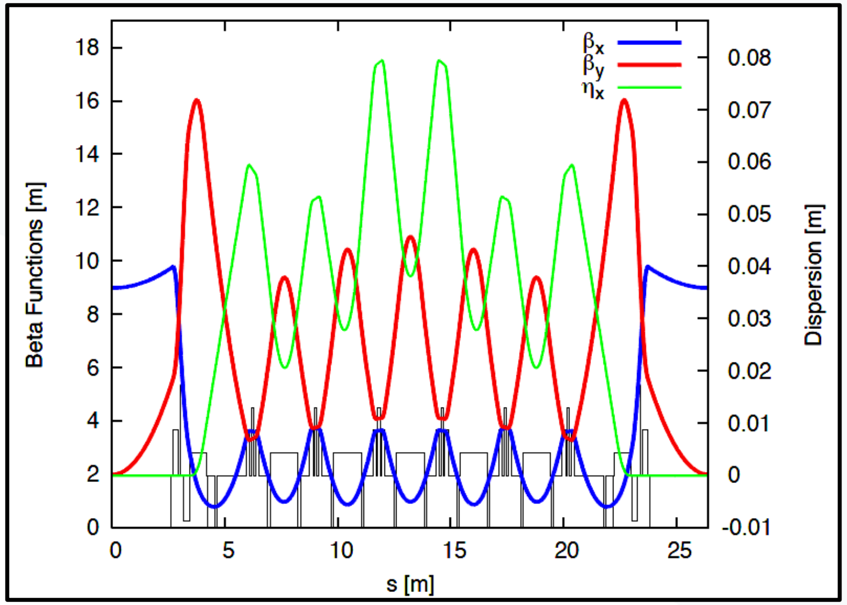
Low Emittance Rings Trend



Synchrotron Light Sources & Applications

The evolution to Multi-Bend Lattice





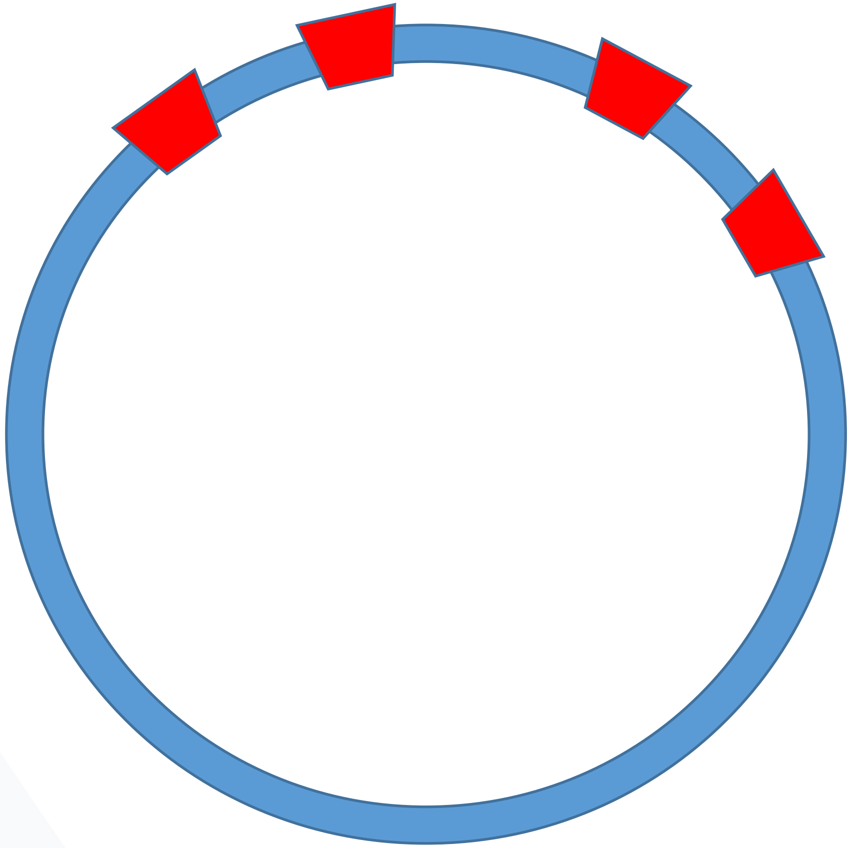
Double-Bend Achromat (DBA)

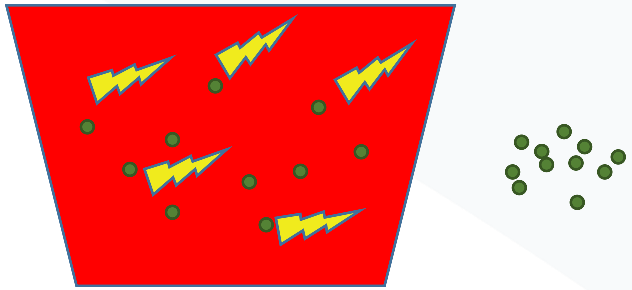
- Many 3rd gen. SR sources
- Local dispersion bump (originally closed) for chromaticity correction

Multi-Bend Achromat (MBA)

- MAX IV and other USRs
- No dispersion bump, its value is a trade-off between emittance and sextupoles (DA)

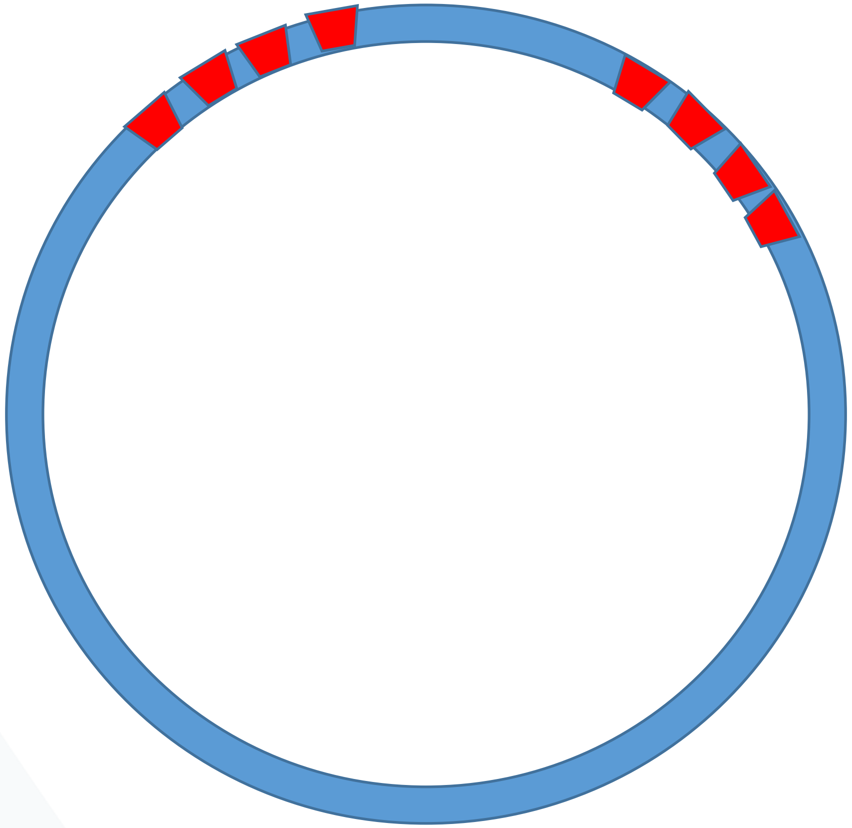
3rd generation light source

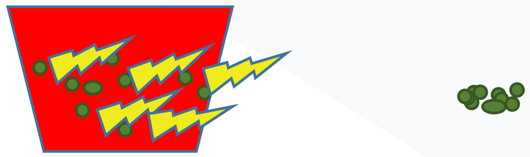




*The electron beam has an average size of ~**50 μm***
(Like one hair dimension)

4^{th} generation light source



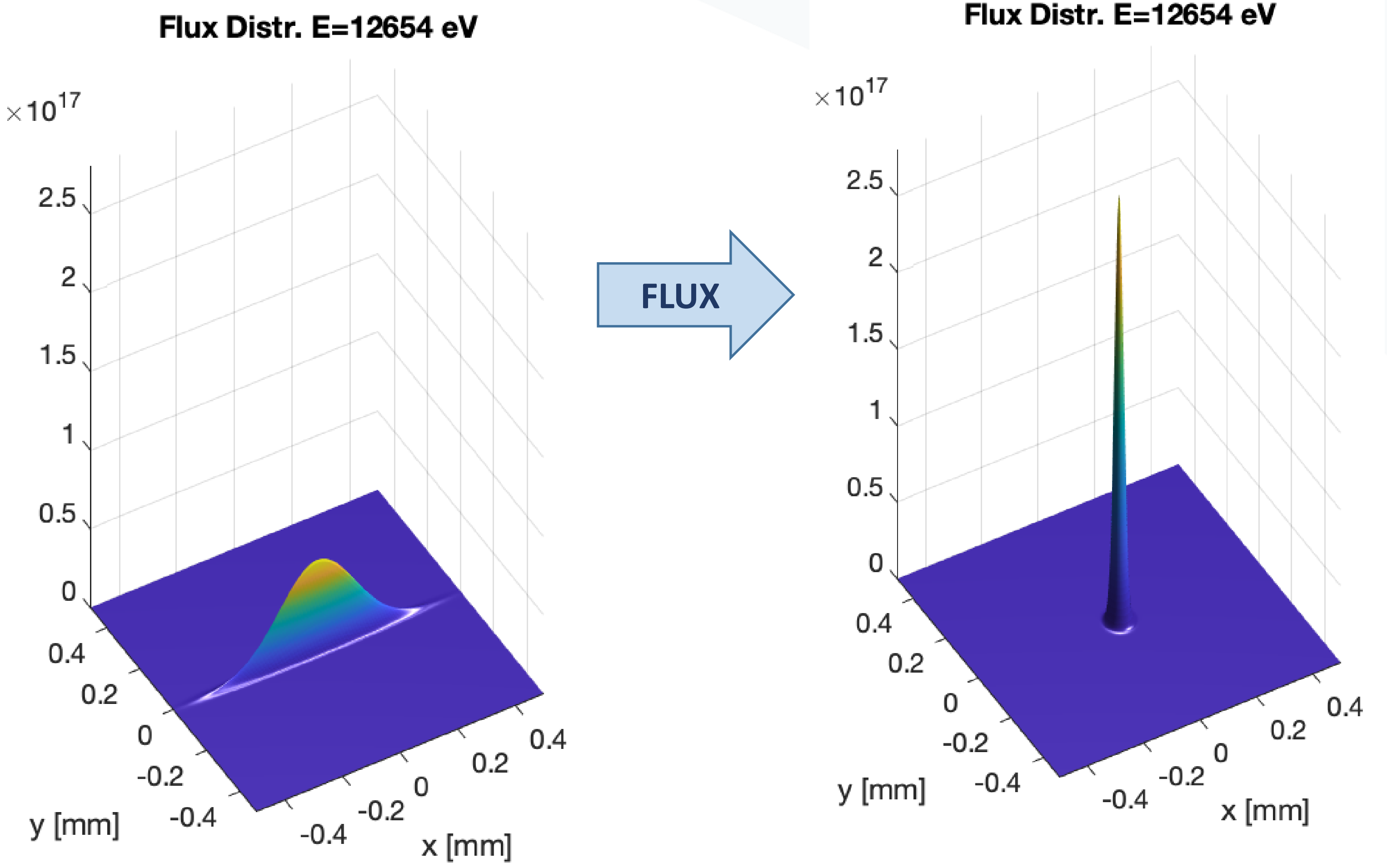


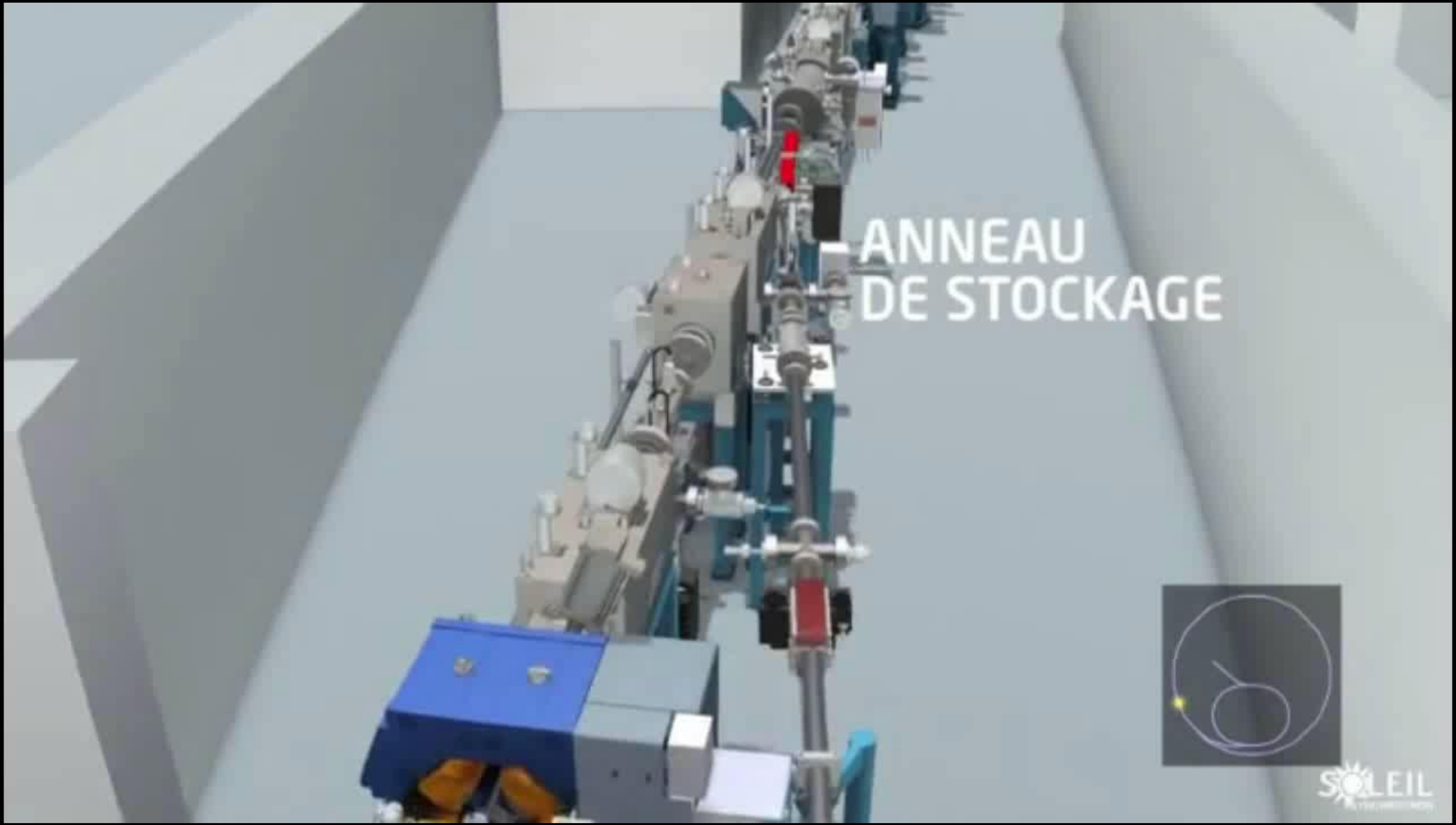
The electron beam has a horizontal dimension of ~ ***5 μm***

The produced photon beam is much more intense and with a much higher resolution

Evolution from 3rd to 4th generation synchrotrons

increase in Brilliance, flux, coherence of synchrotron light by orders of magnitude – boosted by long photon paths

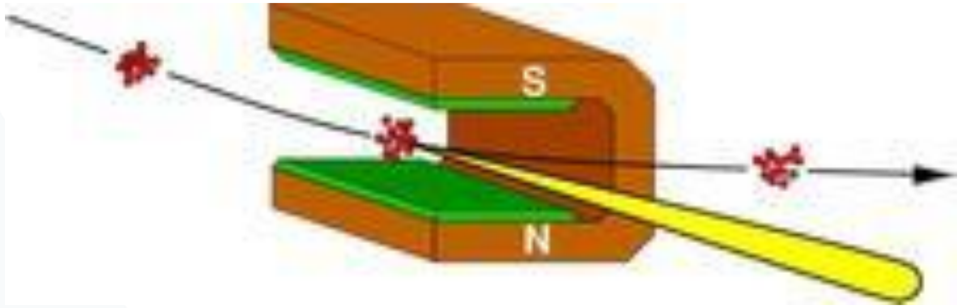



ANNEAU
DE STOCKAGE
SOLEIL

Photon sources: dipole fields

Dipoles determine:

- Property of SR from dipoles
- Natural energy spread and bunch length of beam
- Rf parameters
- Main energy loss per turn



Usually normal conducting dipoles are used

B_{max} = 1.8 T

B_{usual} = 1-1.5 T

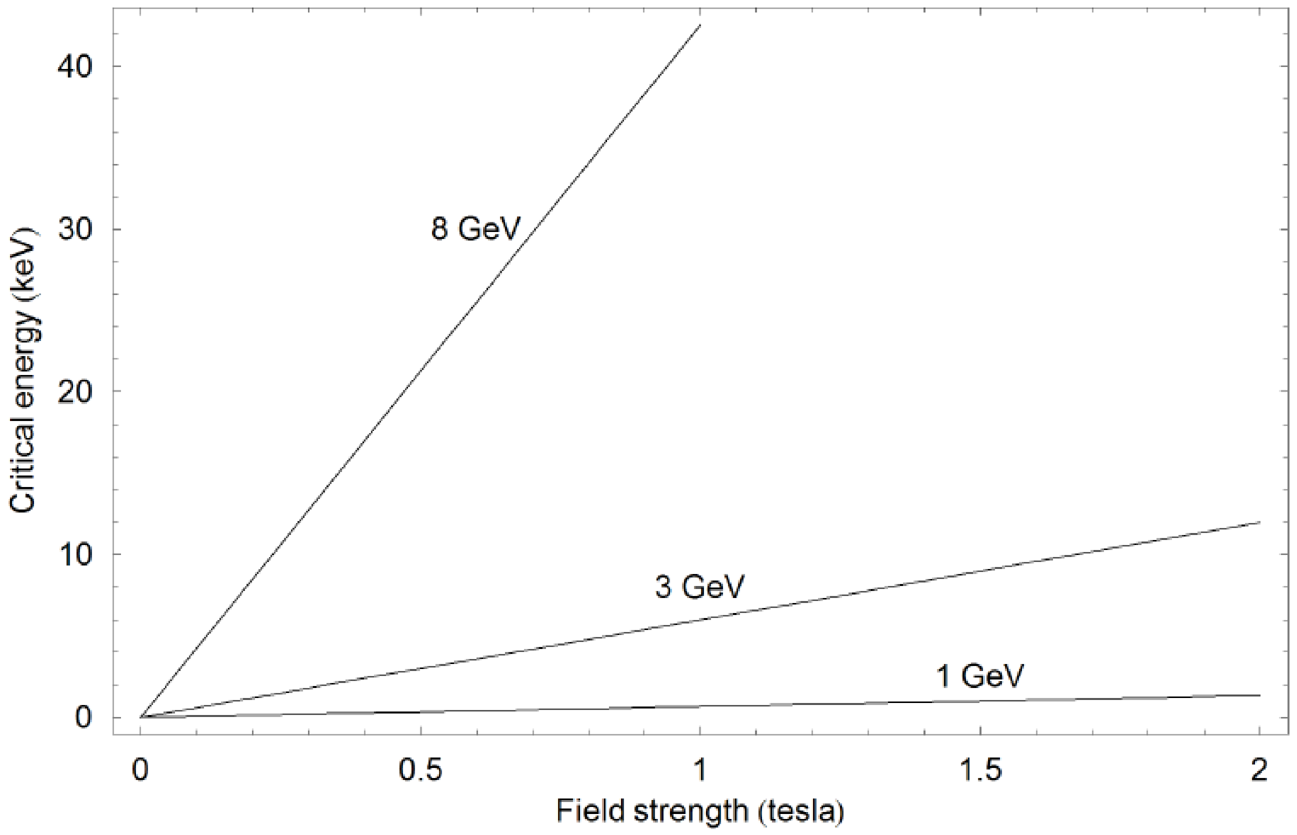
E = 3 GeV

Bρ ~ 10 Tm => ρ = 6-7 m

Critical energy:

$$E_{cr} = \frac{3}{2}\hbar c \frac{\gamma^3}{\rho} \approx 8 - 10\ keV$$

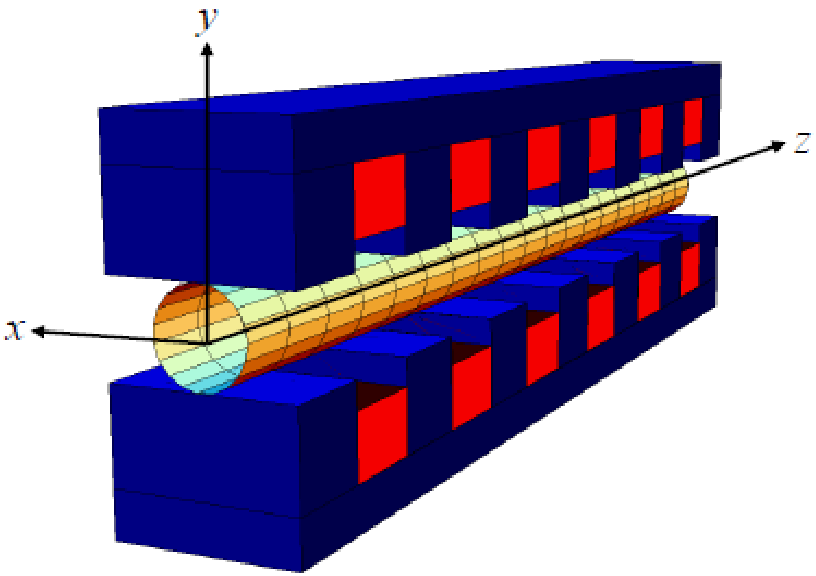
Critical energy and magnetic field



$$E_c = \frac{3}{2}\frac{\hbar c}{\rho}\gamma^3$$

$$E_c[eV] = 665.0255\, B[T].\, E[GeV]^2 = \frac{1239.842}{\lambda_c[nm]}$$

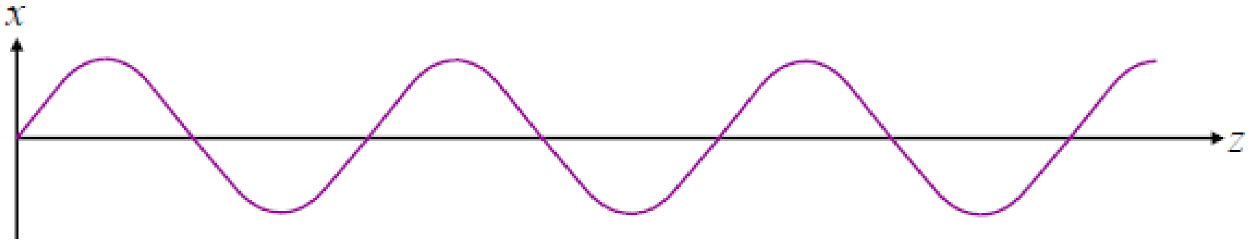
Insertion devices



$$B_y = B_w \sin(k_z z)$$

Peak field = B_w

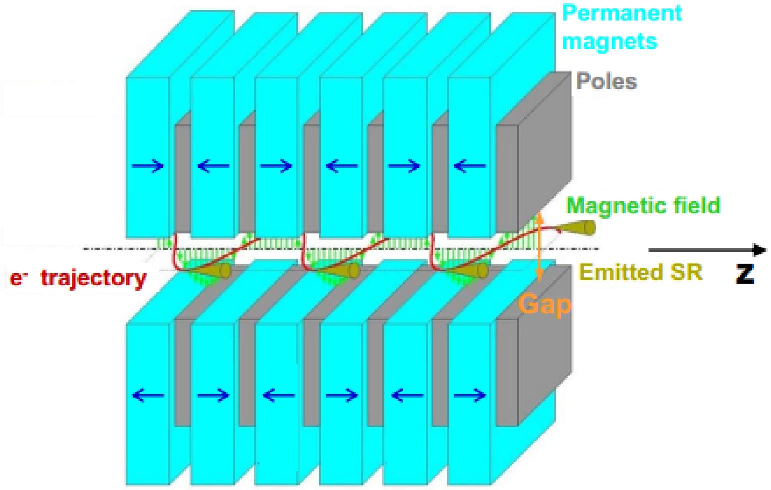
Period = $\lambda_w = \frac{2\pi}{k_z}$



Deflection parameter K:

$$K = \frac{e}{2\pi m_o c} B_W \lambda_w = 0.934\ B_W[T]\ \lambda_w[cm]$$

Wigglers



- Alternating magnetic field

$$B(z) = B_0 \sin\left(\frac{2\pi}{\lambda_U} z\right)$$

Period length λ_U (typ. 10-30cm)
Peak field B_0 (typ. >1.5T)
Number of periods $N=L/\lambda_U$ (typ. 5-100)

- *K*-parameter: $K >> 1$, typ. $K > 10$

Opening angle of the emitted SR $\delta = \pm K/\gamma$

→ spatial power distribution (typ. ~mrad)

Intensities of all poles add up (incoherently)

$Flux_{Wiggler} = 2 \cdot N \cdot Flux_{Dipole}$ (for equal E_c)

→High intensities

→High photon energies

Critical energy:

E_c [keV] = $0.665 \cdot E_e^2$[GeV] $\cdot B_0$[T]

Emitted total power of a wiggler or undulator with length $L=N\cdot\lambda_U$: (typ.: 50kW)

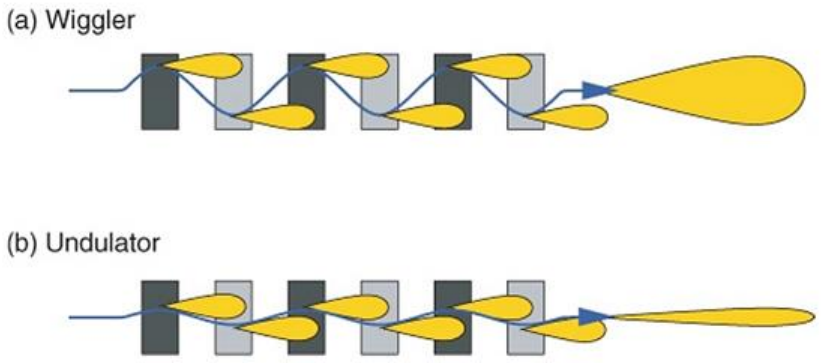
$P_{tot} = 0.633 \cdot B_0^2$ [T] $\cdot L$ [m] $\cdot E_e^2$ [GeV] $\cdot I_e$ [A]

Polarisation of wiggler radiation:
linearly polarised in the orbit plane ψ=0,
unpolarised out of plane

M. Tischer | Insertion Devices | CAS Chios Sep. 2011 | Page 10

Undulators

Insertion devices with short periods, such that K<1



wiggler - incoherent superposition K > 1
Max. angle of trajectory > 1/γ

undulator - coherent interference K < 1
Max. angle of trajectory < 1/γ

$$\lambda_n = \frac{\lambda_u}{2n\gamma^2}\left(1+\frac{K^2}{2}\right) \approx \frac{\lambda_u}{n\gamma^2}$$

n = harmonic

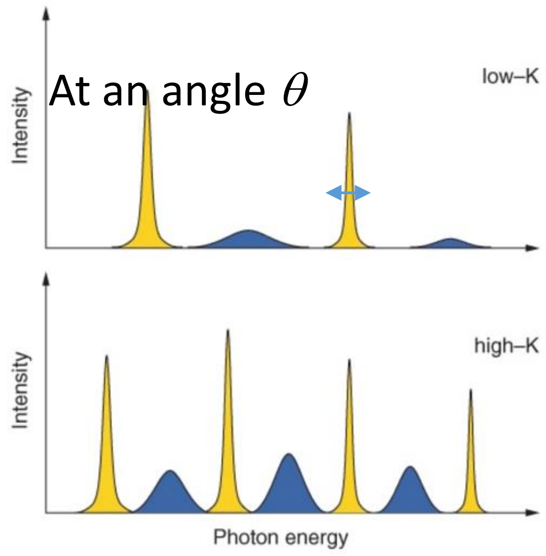
$$\varepsilon_n(eV) = 9.496\frac{nE[GeV]^2}{\lambda_u[m]\left(1+\frac{K^2}{2}\right)}$$

On axis

$$\varepsilon_n(eV) = 9.496\frac{nE^2[GeV]}{\lambda_u[m]\left(1+\frac{K^2}{2}+\theta^2\gamma^2\right)}$$

At an angle θ

At an angle θ

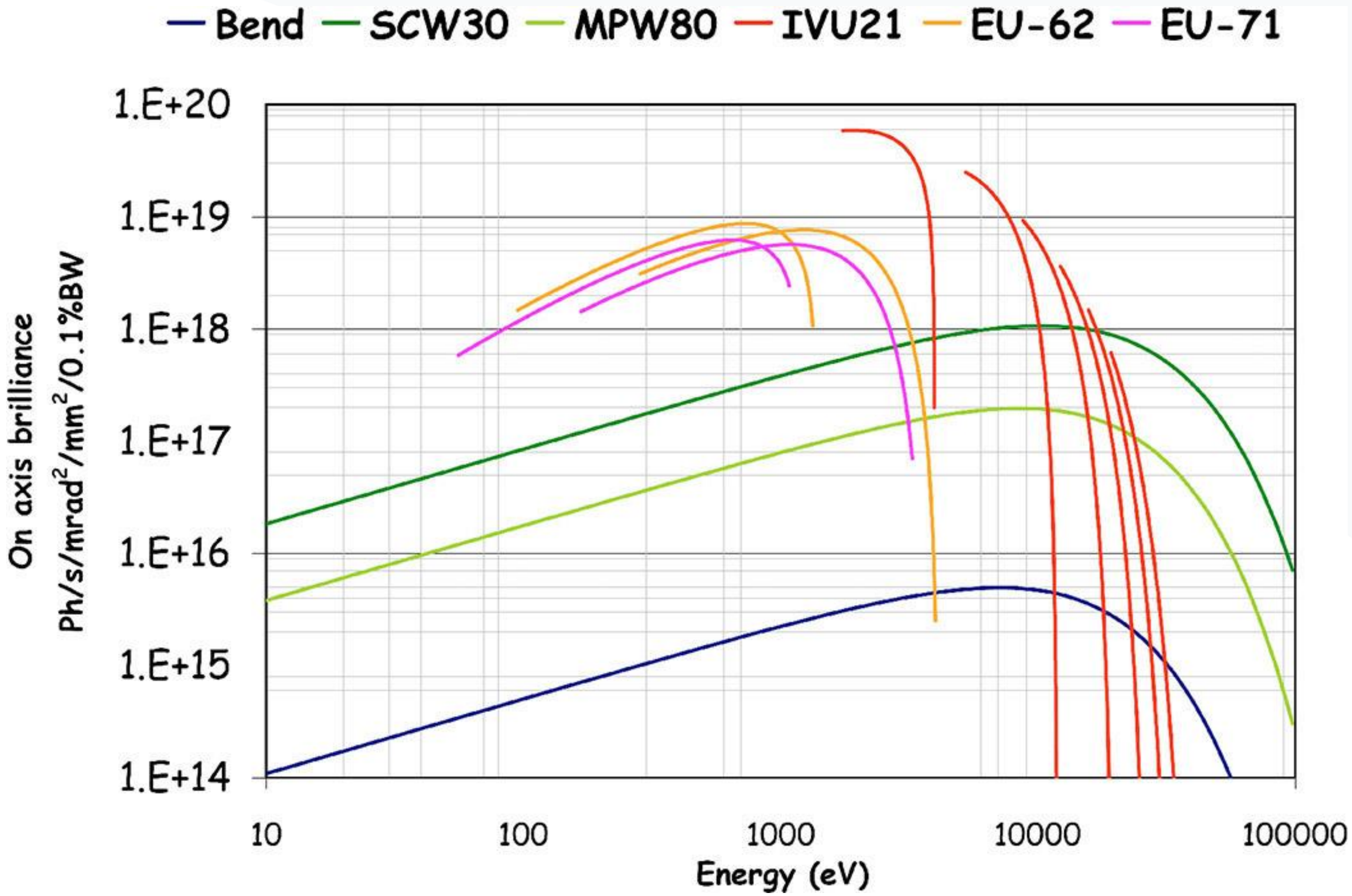


Bandwidth

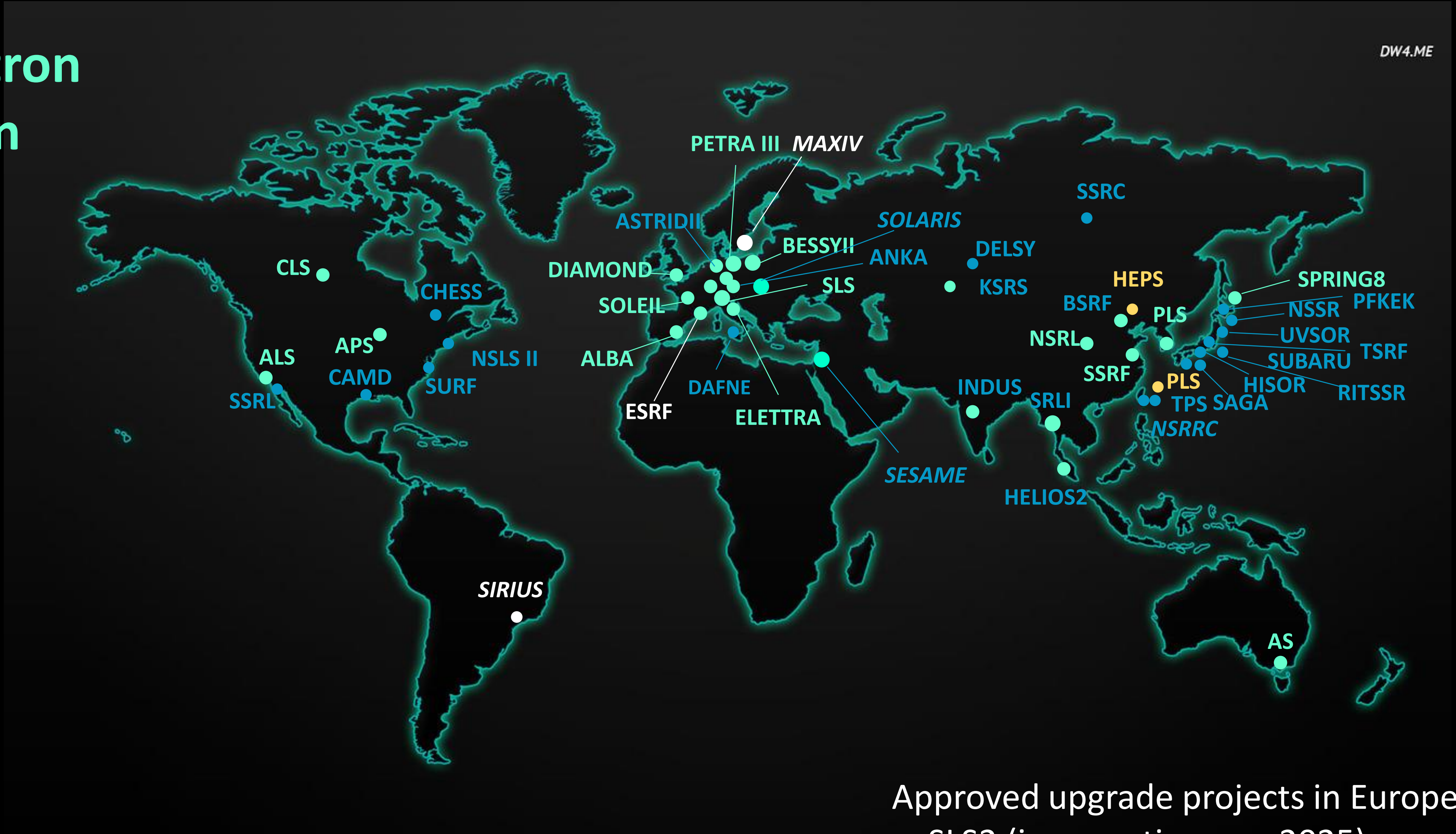
$$\frac{\Delta\omega}{\omega} = \frac{1}{nN_u}$$

Quasi-monochromatic spectrum with peaks at lower energy than a wiggler

ALBA photon spectra



Synchrotron Radiation Facilities



- 4th Generation IN OPERATION
- 4th Generation *in construction*
- Upgrading or planning upgrade from 3rd to 4th generation
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Approved upgrade projects in Europe:

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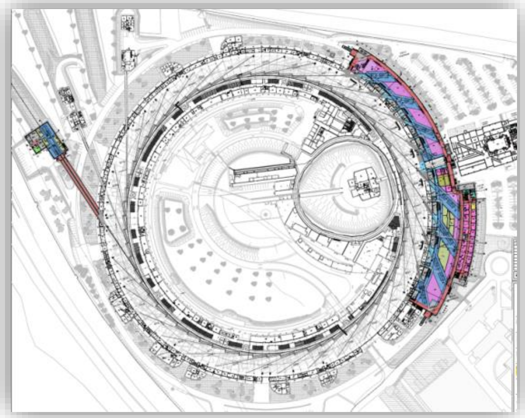
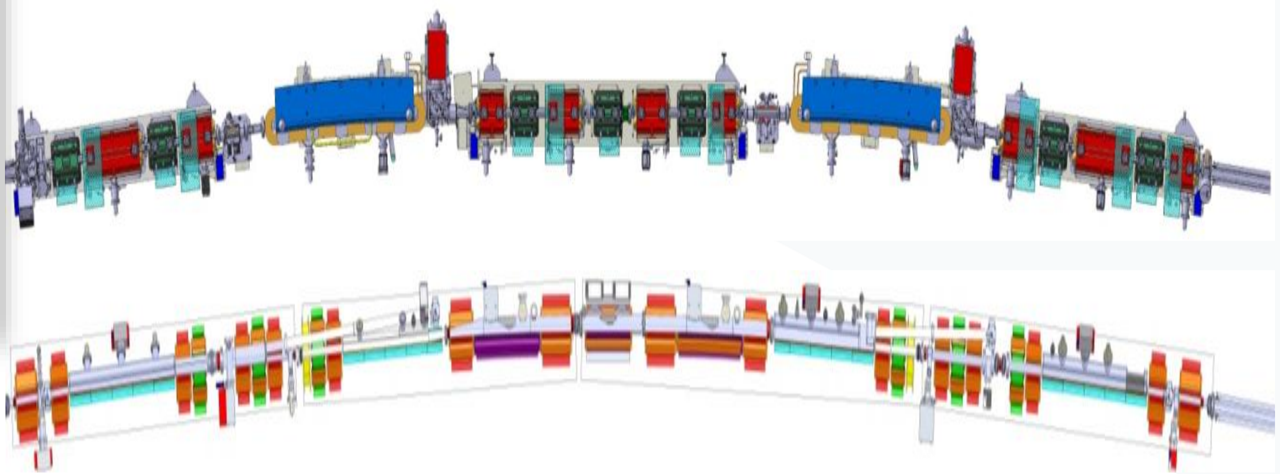
- Soleil2 (in execution; op: 2028)

First 4th generation synchrotrons

ESRF-EBS, the first upgrade from 3rd to 4th generation



Old ESRF Arc Layout: ε_x=4nm



New Low Emittance Layout: ε_x =0.135nm

The 844m Accelerator ring consists of 32 identical Arcs.

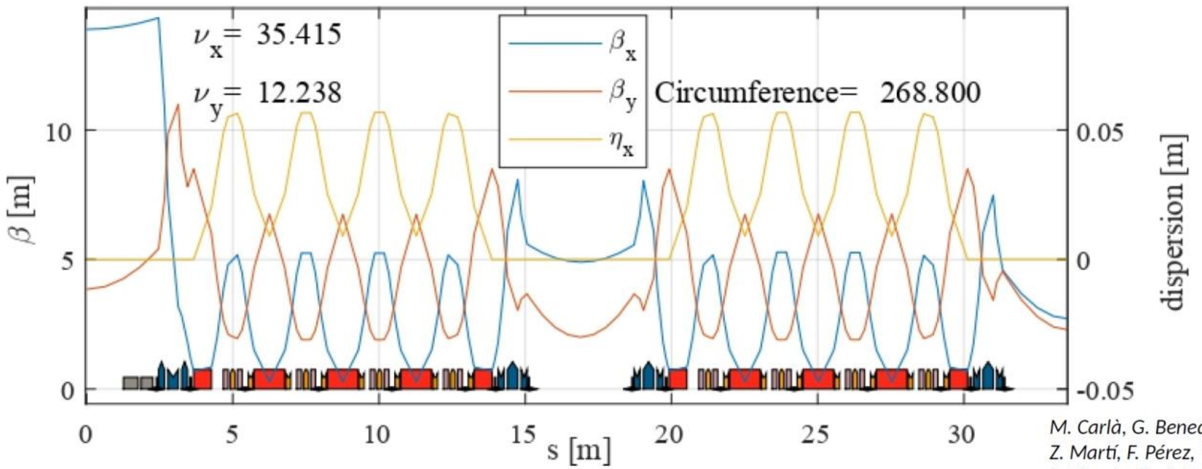
Each Arc is composed by a well defined sequence of Magnets, Vacuum Components (vacuum vessel, vacuum piumps etc), sensors (diagnostic) etc.

All the Arcs have been replaced with a completely new Layout

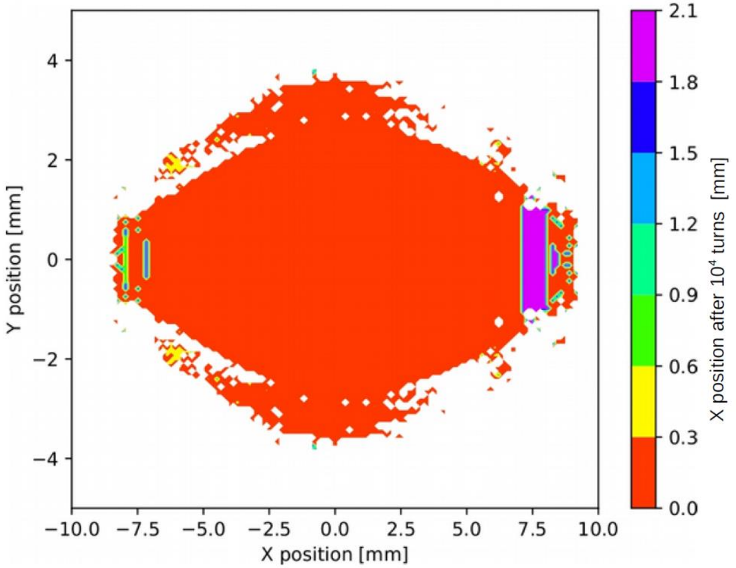
At ALBA: starting the process of upgrading the storage ring towards ALBA II

Design and simulations

5BA lattice A2L004a (May 2024)



M. Carlà, G. Benedetti, O. Blanco Garcia, Z. Martí, F. Pérez, "Status of the ALBA-II lattice studies", IPAC 2024

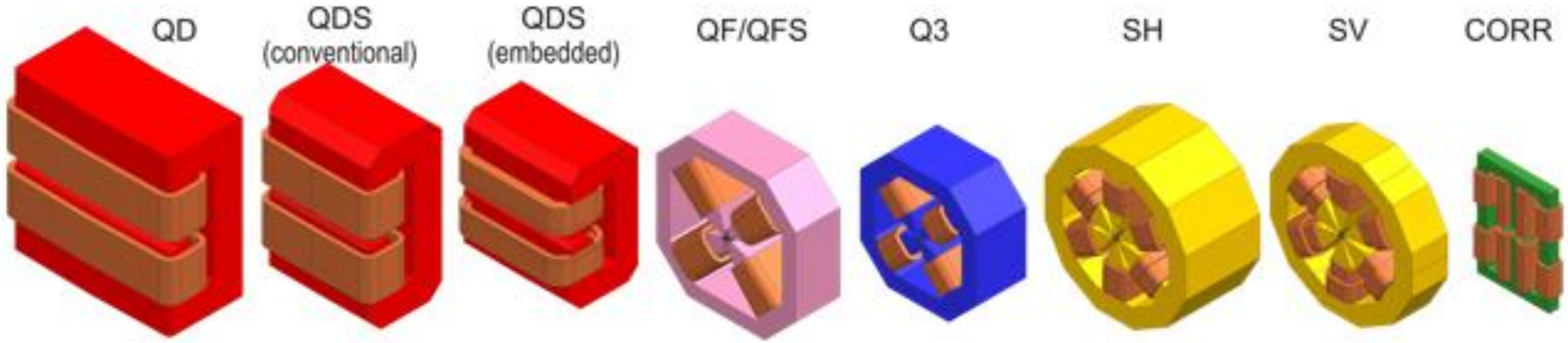


Dynamic aperture

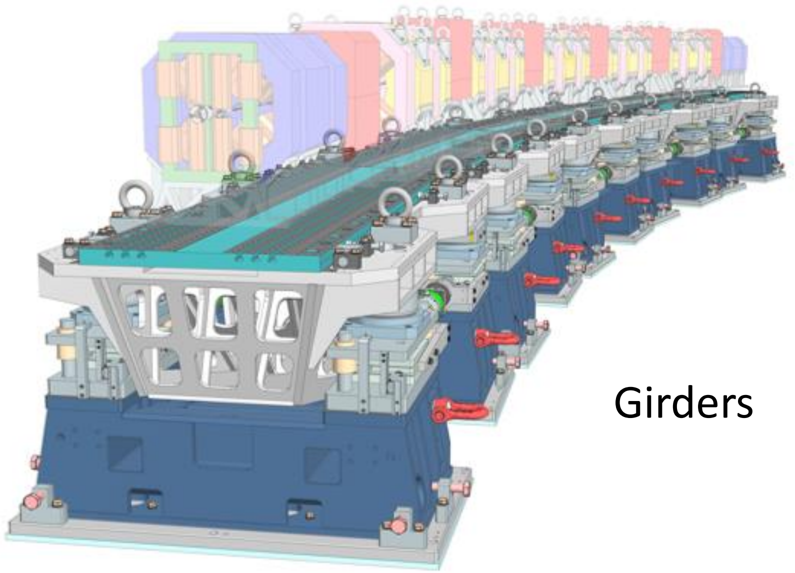
4-fold symmetry, SS length = 4.7m / 3.5m / 4.4m, 11 families of sextupoles (4 SH + 7 SV)

- **Emittance**: 240 pm·rad (170 pm·rad full coupling)
- **Mom. Compaction:** $1.3 \cdot 10^{-4}$
- **Energy loss**: 910 MeV/turn
- **$\beta_{x,y}$ at ID**: 14m / 4.9m / 2.7m
  3.8m / 2.0m / 2.3m
- **Tunes**: 35.41 / 12.24
- **Chromaticity**: -76 / -35

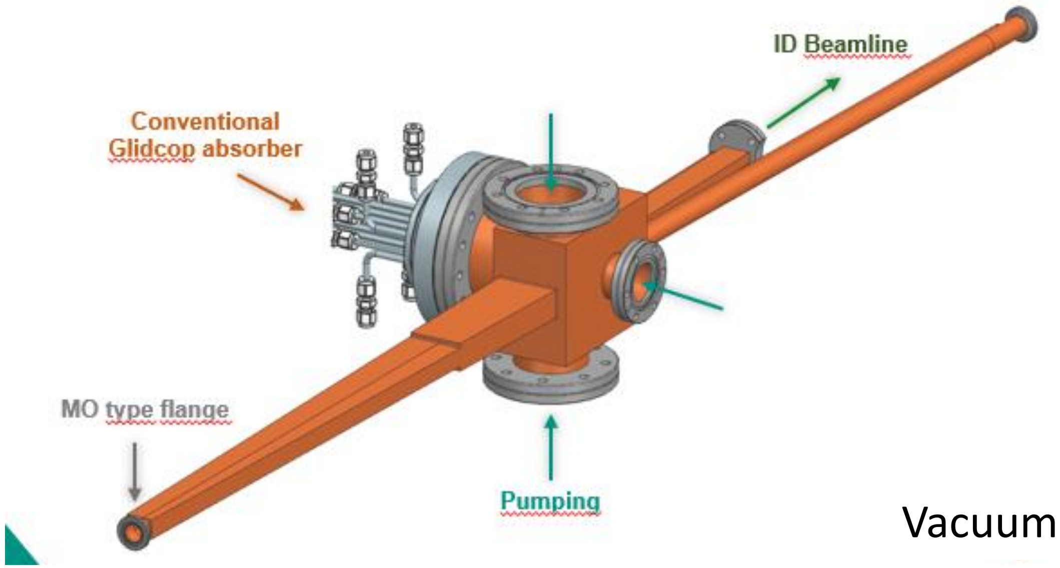
Prototyping all systems of the storage ring



Magnets



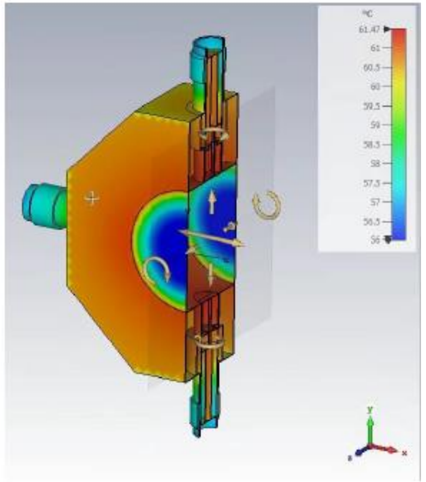
Girders



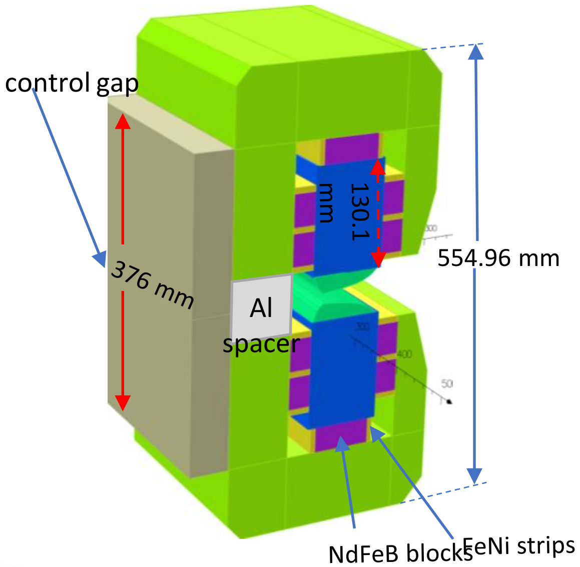
Vacuum

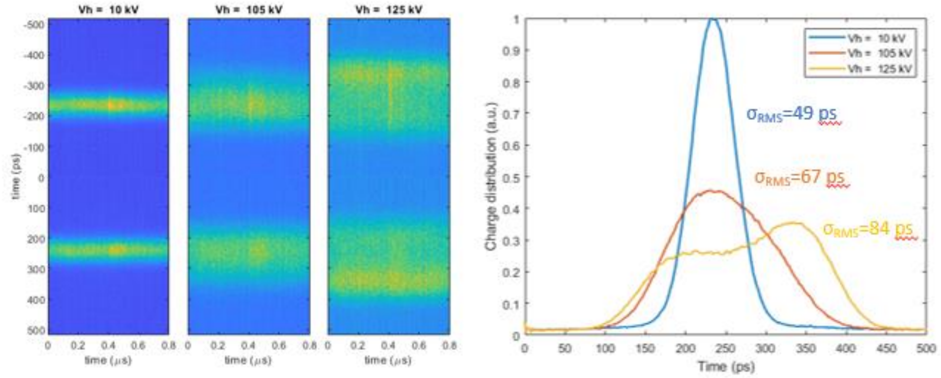
Prototyping all systems of the storage ring and testing 3rd HC at BESSY

Diagnostics

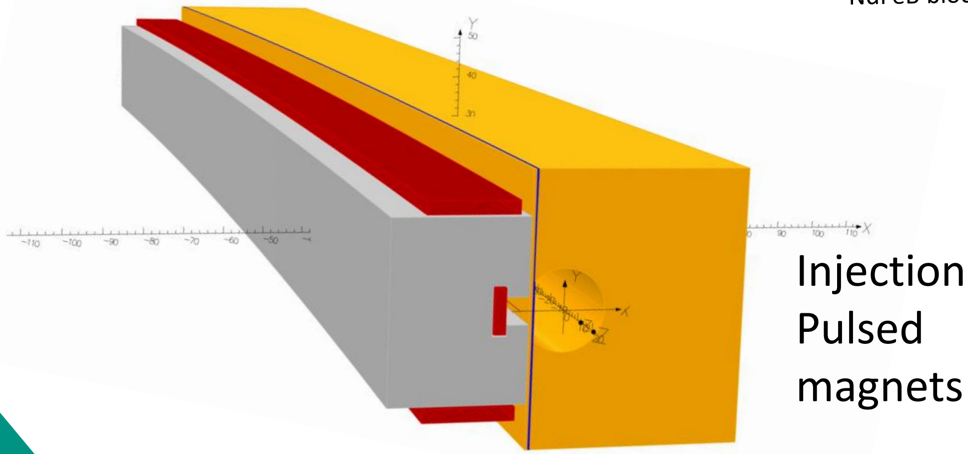


Super Bend

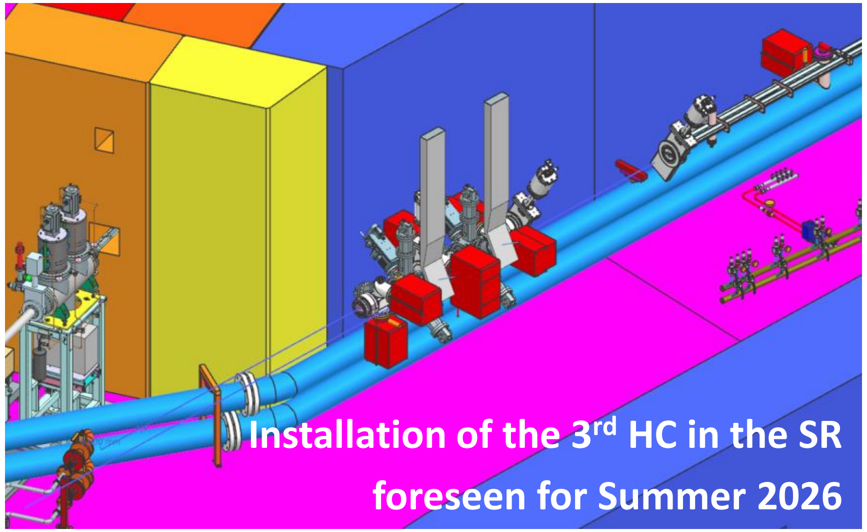




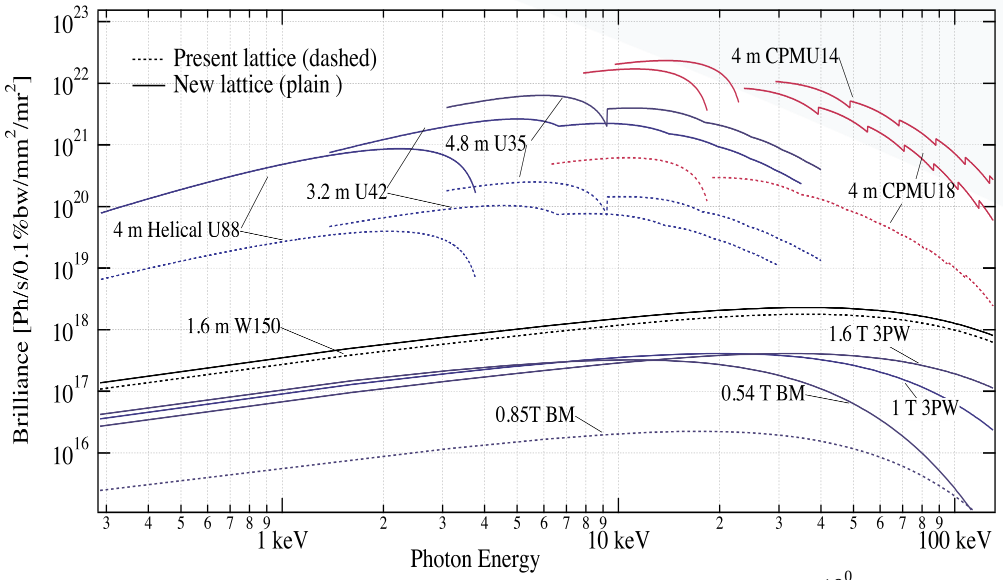
Streak camera images and profiles for 14 mA homogeneous filling pattern with 400 kV main RF at BESSY II



Injection Pulsed magnets



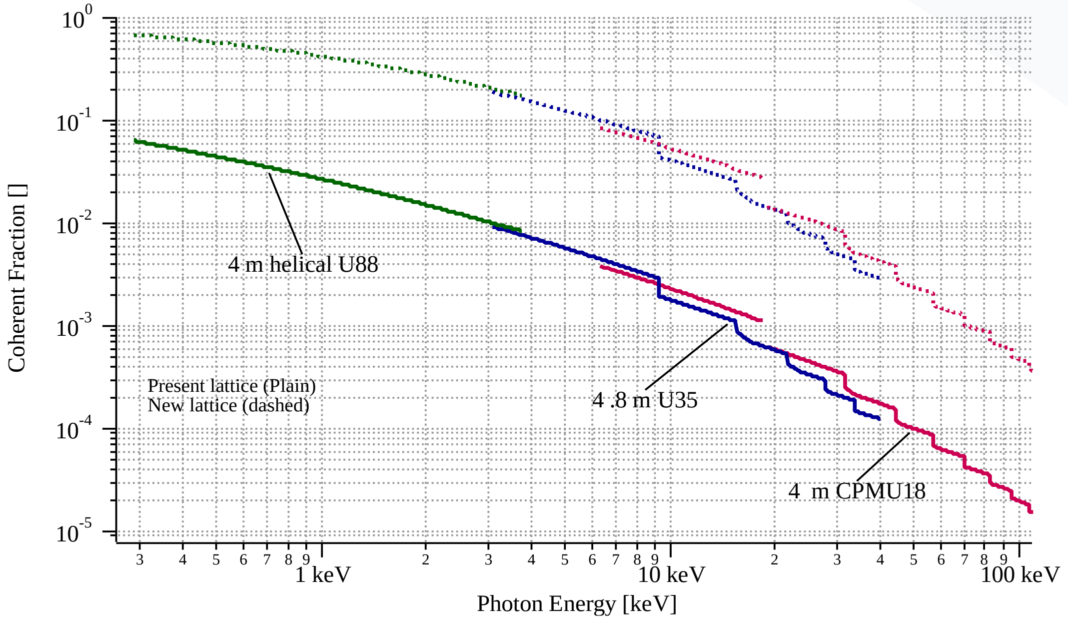
BRILLIANCE AND COHERENCE INCREASE



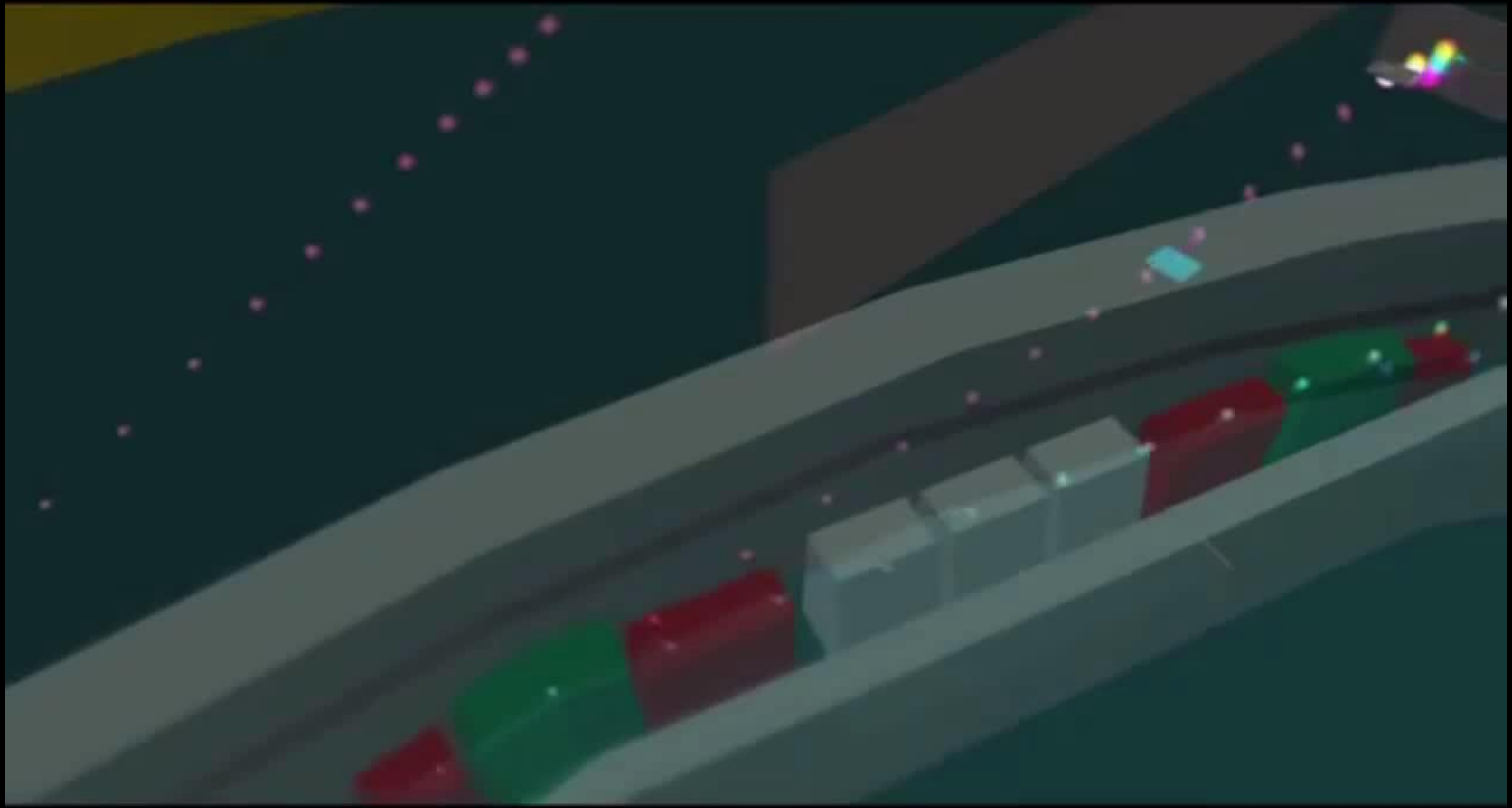
Brilliance

Source performances will improve by a factor 50 to100

Hor. Emittance [nm]	4	0.15
Vert. Emittance [pm]	3	2
Energy spread [%]	0.1	0.09
β_x[m]/β_z [m]	37/3	4.3/2.6



Coherence



Interaction between the light and the matter

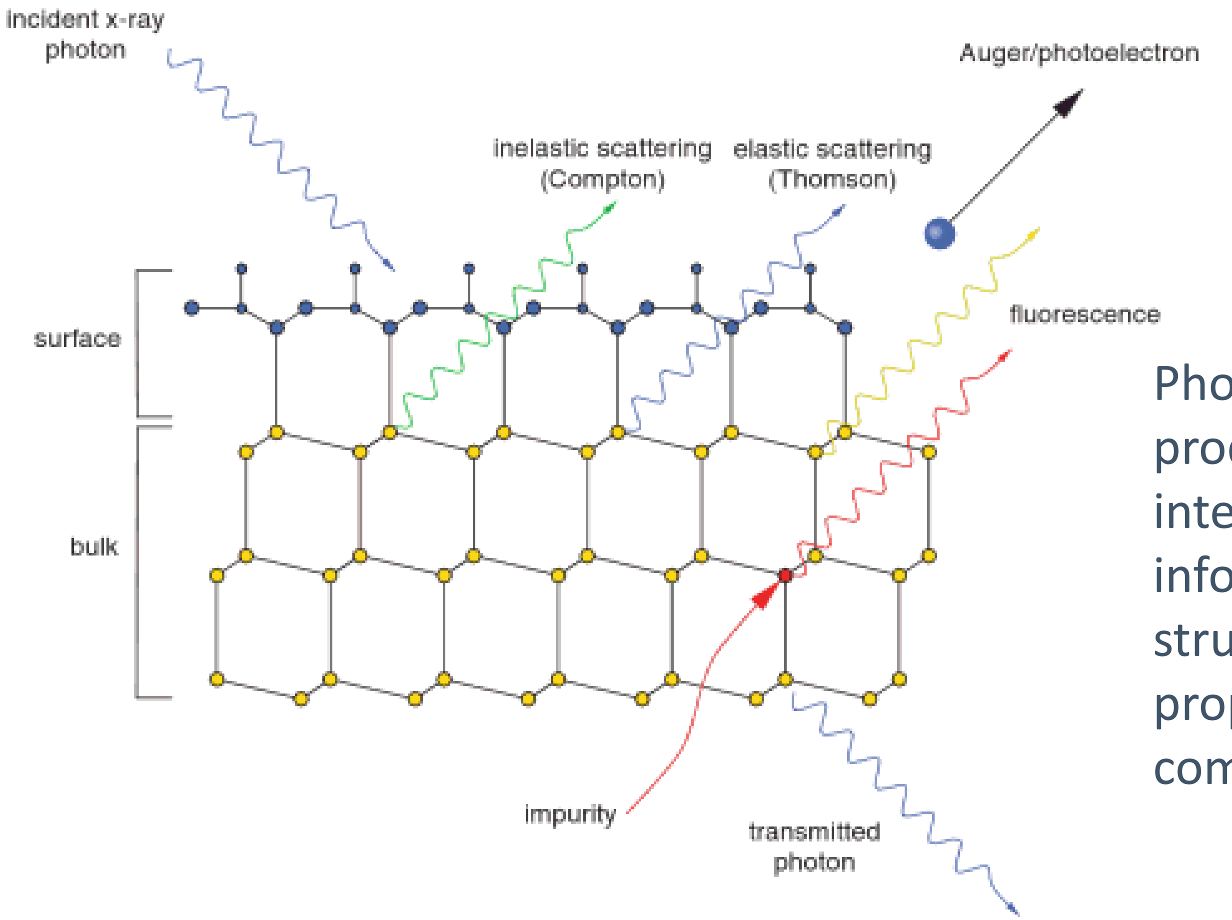
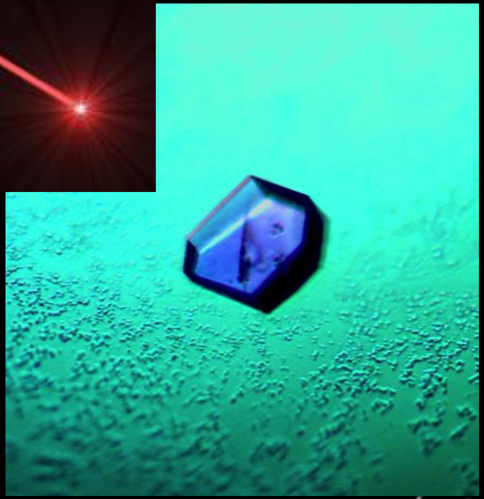


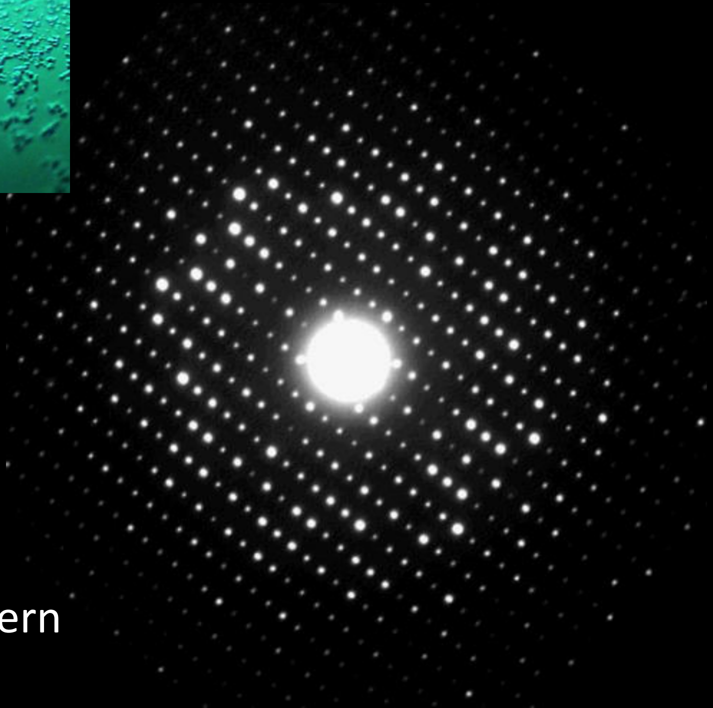
Figure 2.1 The interaction of x-rays with matter. Surface (and interface) regions of a solid or liquid material are characterized by physical properties and structures that may differ significantly from those of the bulk structure. The x-rays may be elastically or inelastically scattered, or absorbed, in which case electrons or lower-energy photons can be emitted. If none of the above occur, the photon is transmitted through the sample.

Photons and electrons produced during the interaction contain information on the structure of matter, its properties and composition

From 'An Introduction to Synchrotron Radiation' Philip Willmott

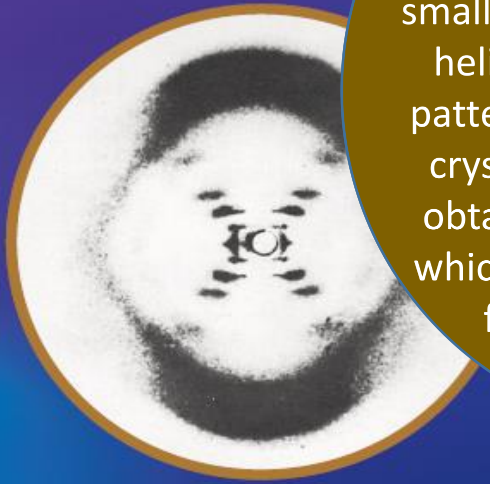
Scattering - Diffraction





Diffraction pattern

DNA and X Rays

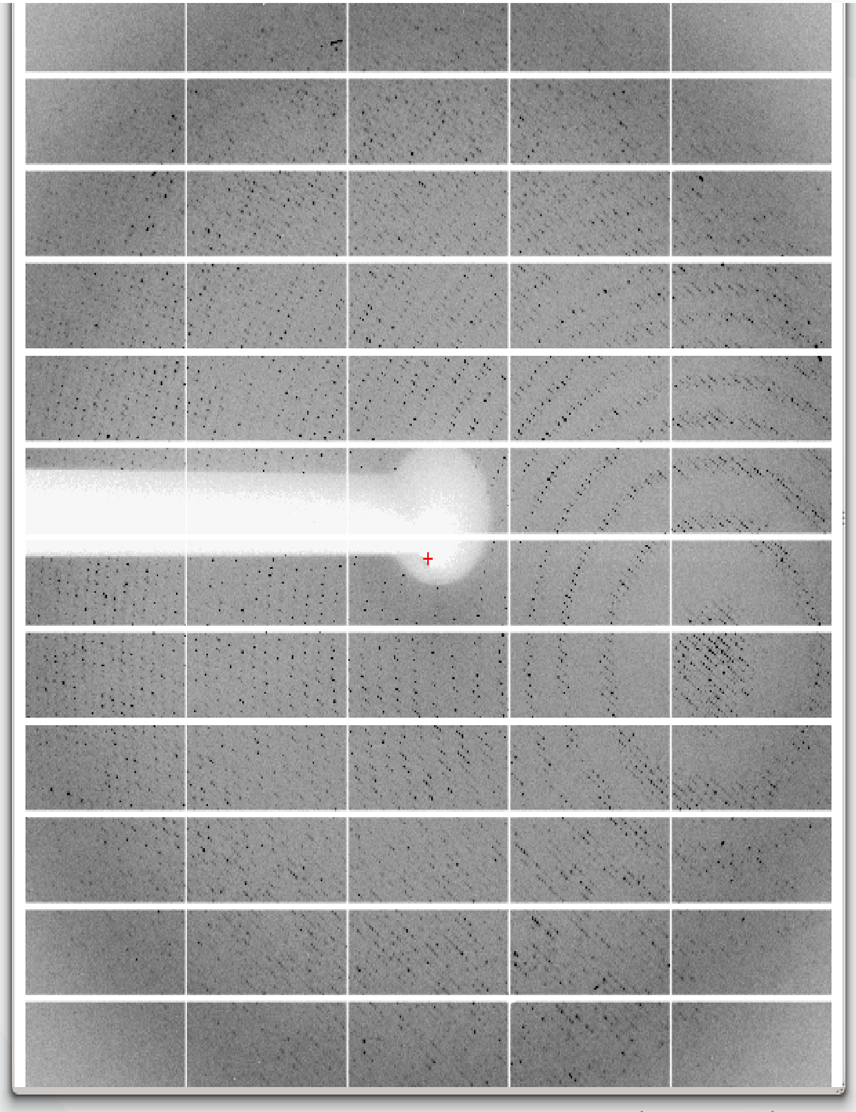


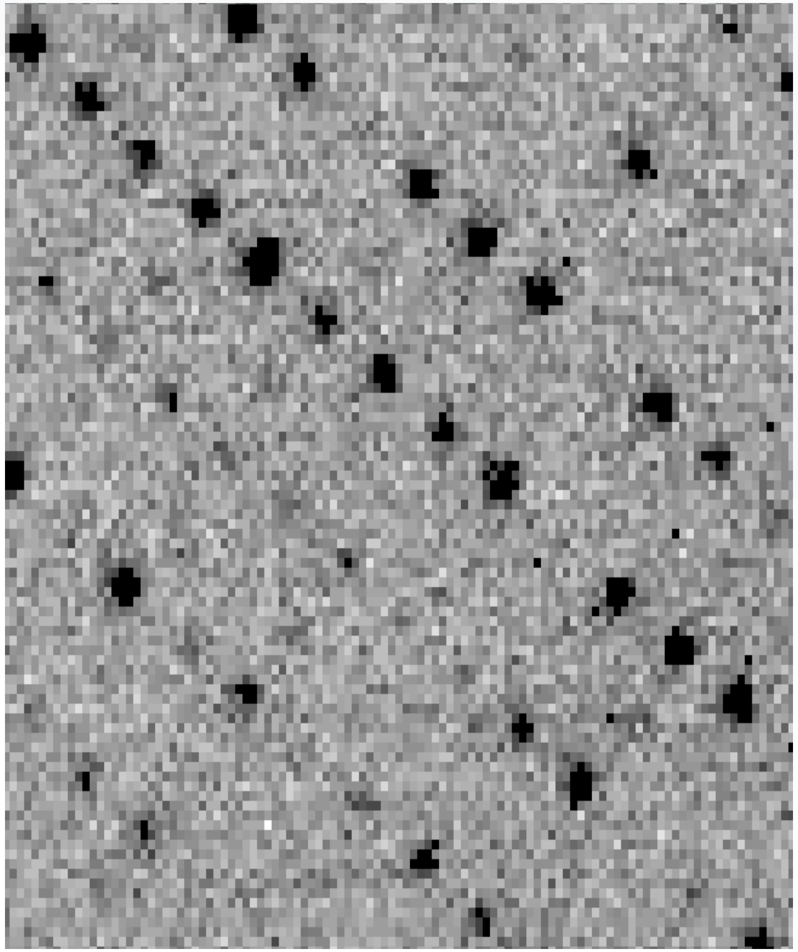
1952
Photo 51:
first image by X-ray diffraction

DNA
is constituted by two complementary filaments formed by regular sequences of small molecules, forming double helixes. It was the diffraction pattern of X rays from a pseudo crystal formed by DNA fibers, obtained by Rosalind Franklin, which allowed determining the form of this molecules.

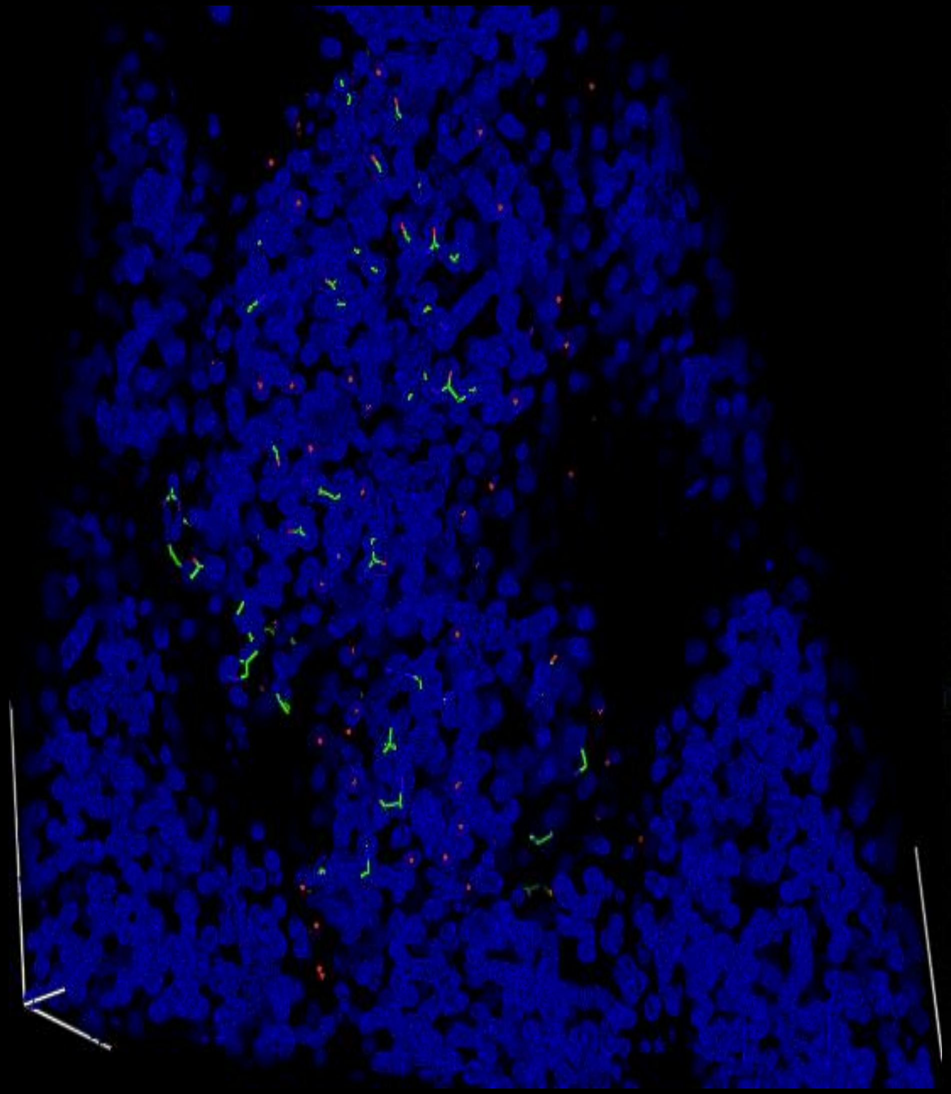
Diffraction pattern of a protein crystal.

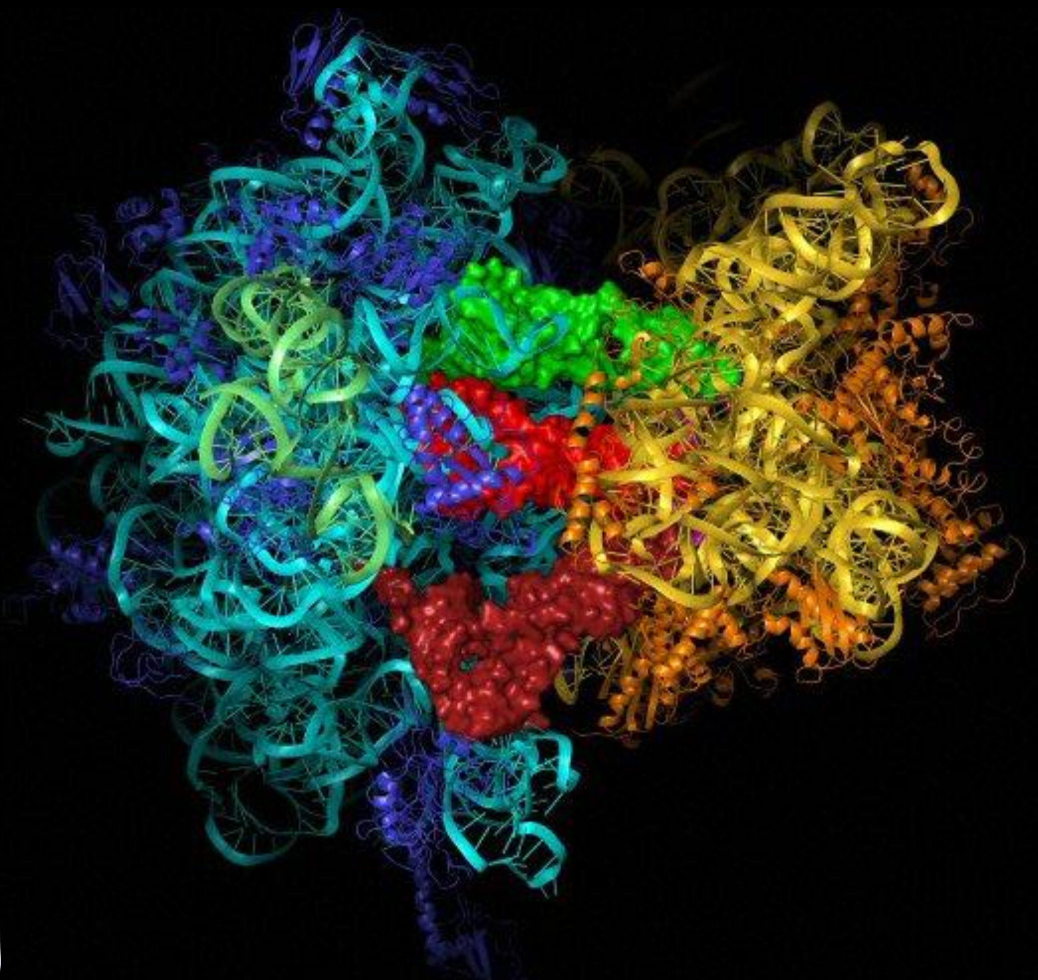
From position and intensity of the spots the protein structure can be defined





Electronic density from which the 3D representation of the protein can be obtained down to atomic resolution

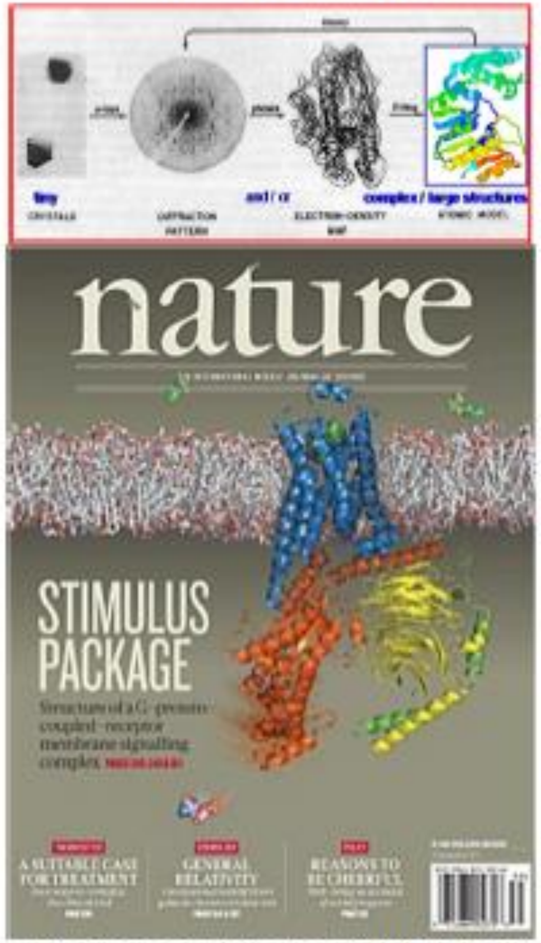




High brilliance and flux

The Nobel Prize in Chemistry **2012** is awarded to Brian K. Kobilka and Robert J. Lefkowitz for studies of G-protein–coupled receptors

G-protein–coupled receptors (GPCRs) form a remarkable modular system that allows transmission of a wide variety of signals over the cell membrane, between cells and over long distances in the body



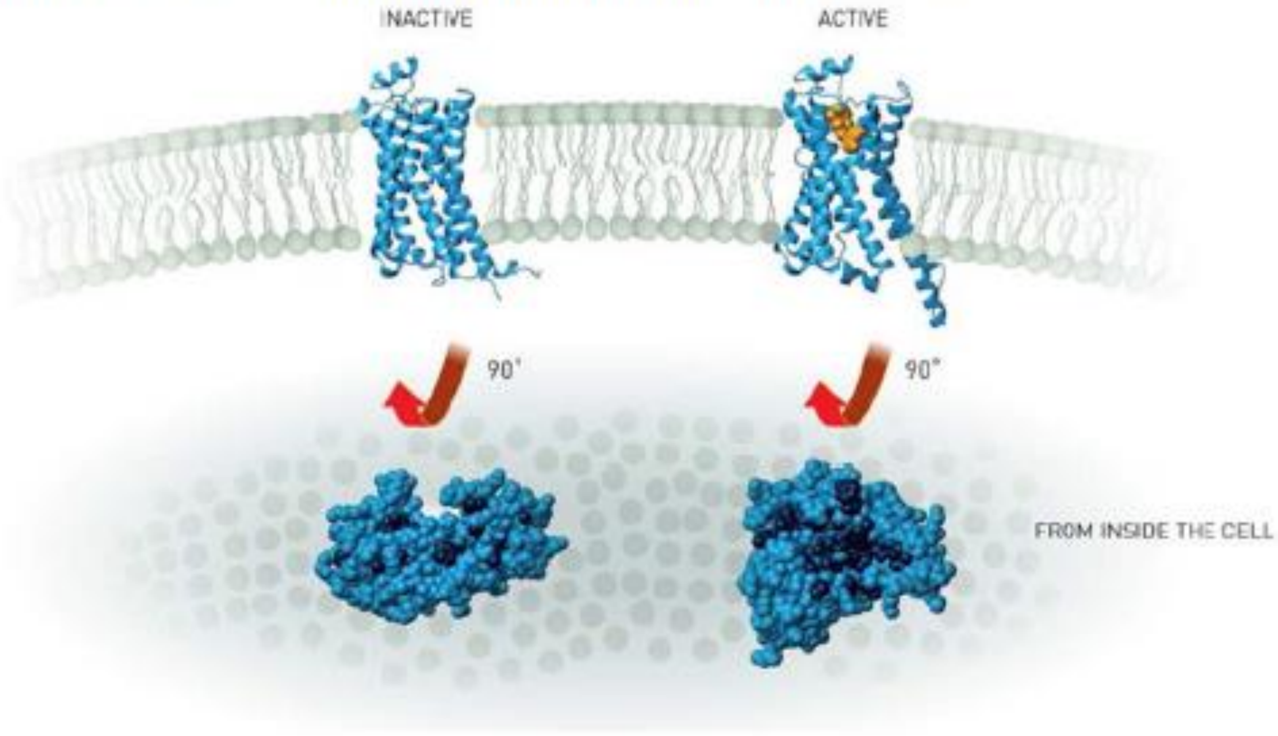
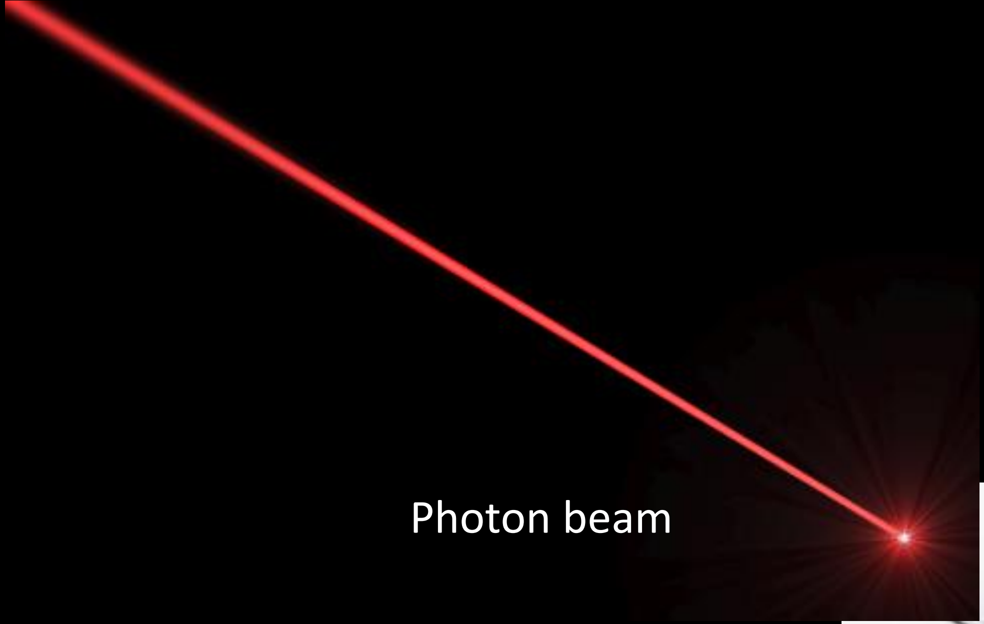
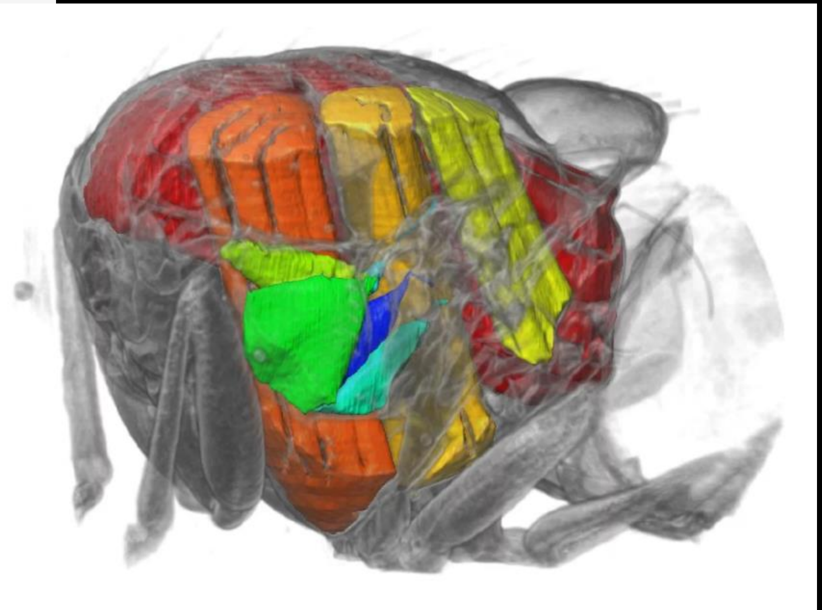


Figure 4. Structural basis of the GPCR signalling mechanism. Non-activated βAR (2bar.pdb) is shown to the left, and activated βAR bound to ligand and G-protein (3sn6.pdb) to the right. At the top, the receptor in the membrane is drawn with blue ribbon that traces the backbone. The bottom view is from the inside of the cell membrane, with the receptor shown using a space-filling model with hydrophobic side chains in dark blue.

Rasmussen SG; et al. (2011) Crystal structure of the human beta2 adrenergic receptor-Gs protein complex. *Nature* 477, 549-555

Imaging

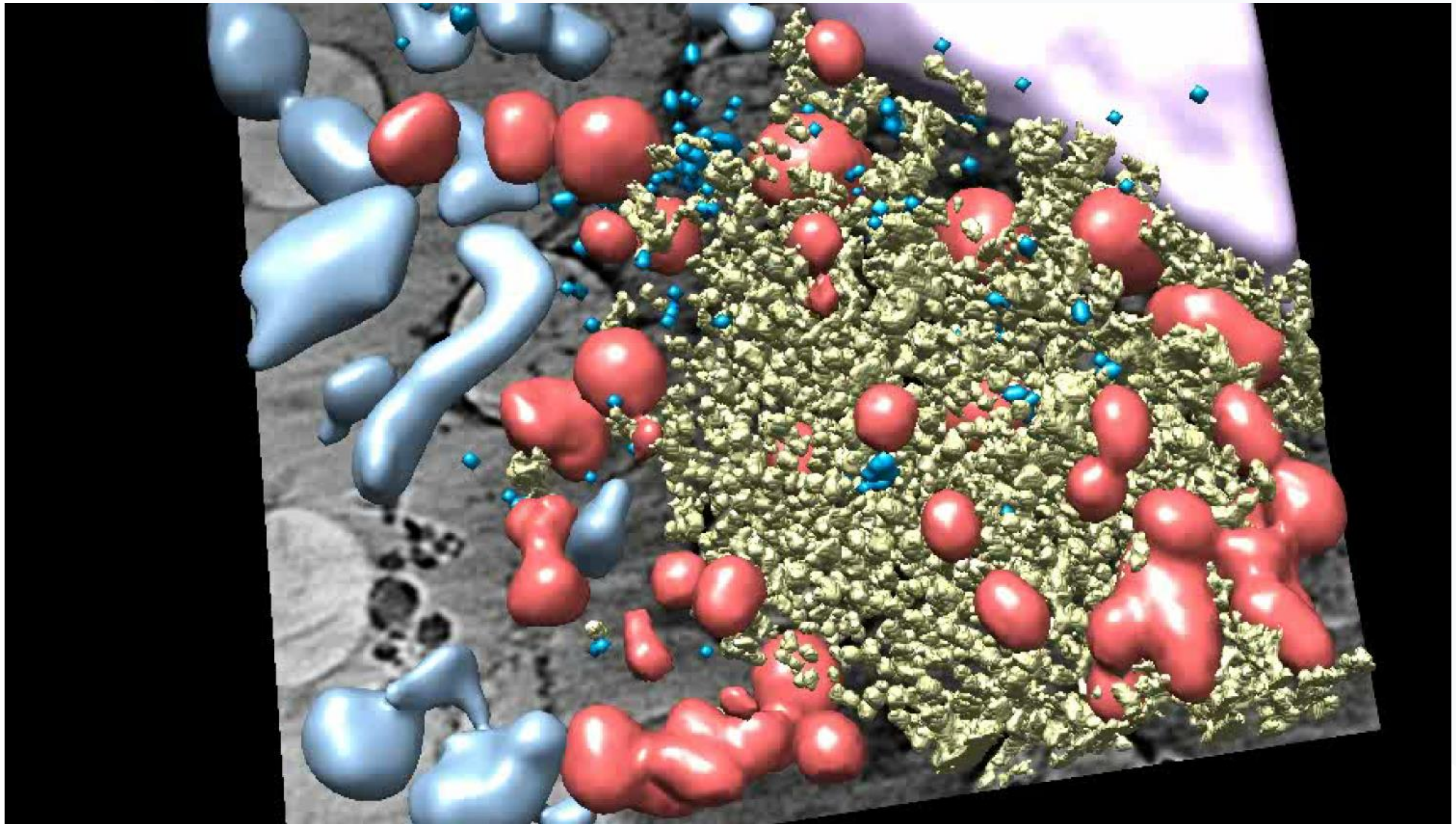




VISUALIZATION IN 3D HOW SARS-COV-2 REPLICATES IN CELLS

National Centre of Biotechnology (CNB-CSIC) and ALBA Synchrotron

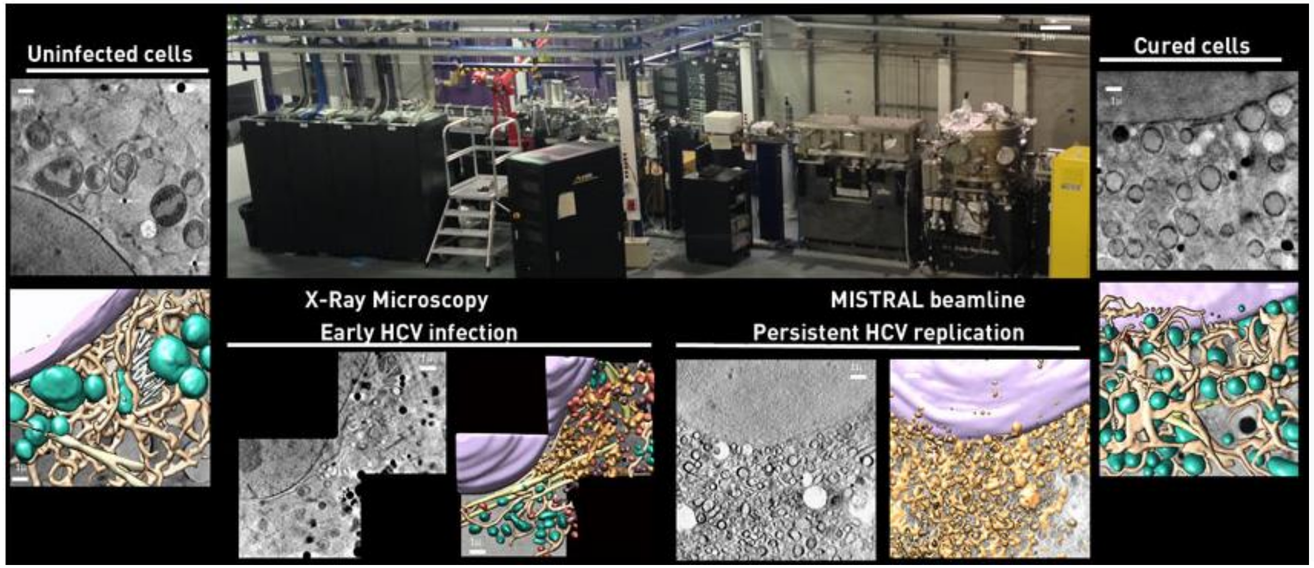
When **comparing an uninfected cell with an infected one**, we can see that the virus multiplication machinery forms vesicles and tubules as well as **remarkable signs of stress on cellular organelles** such as mitochondria and the endoplasmic reticulum."

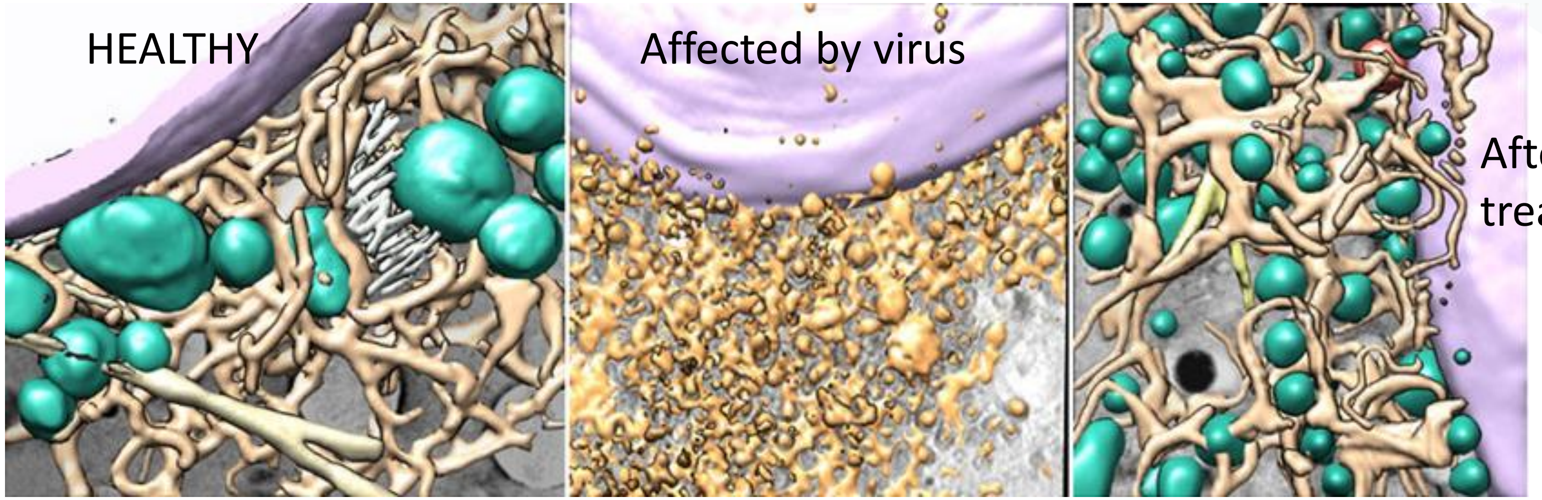


A549 cell (adenocarcinomic human alveolar basal epithelial cells) infected with SARS-CoV-2

3-D Modeling of SARS-2 CoV2-Infected Cells Revealed by Cryogenic 3 Soft X-ray Tomography. *ACS Nano*. DOI: 10.1021/acsnano.3c07265

Hepatitis C Virus effect on a cell



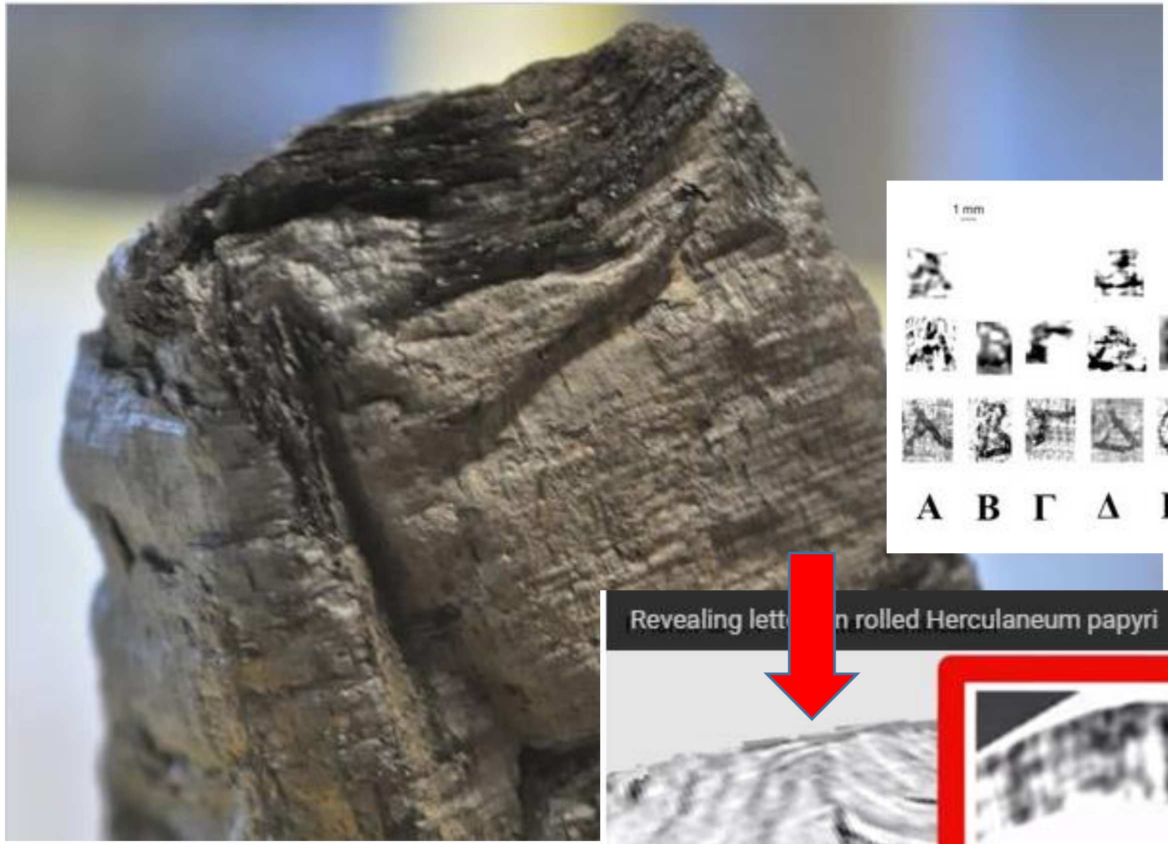


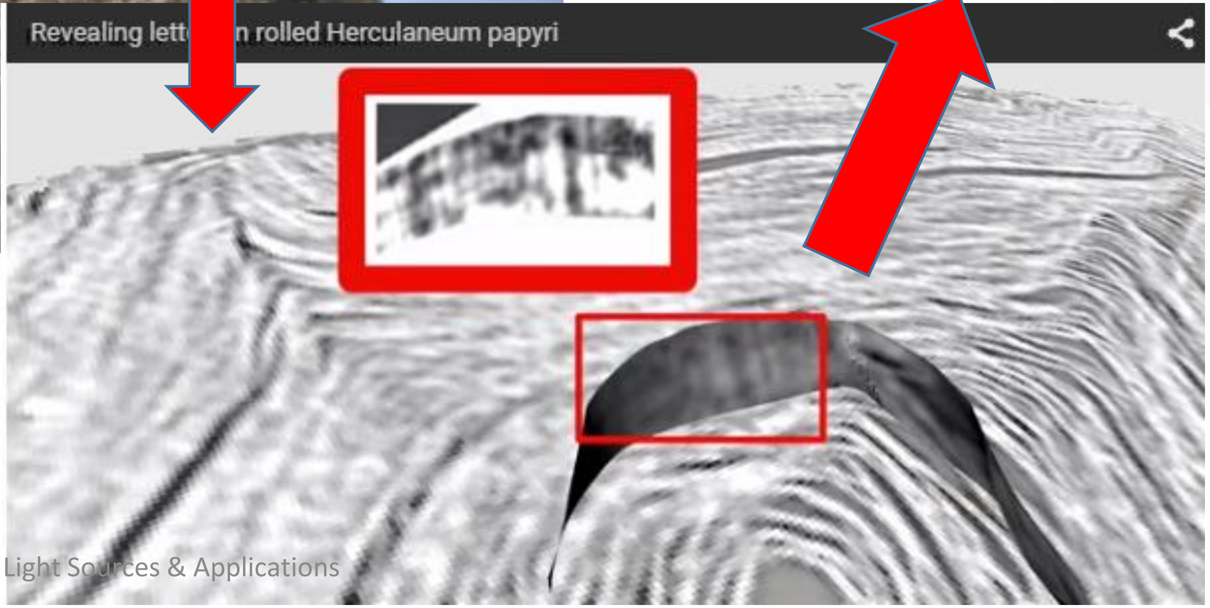
Violet: cell nucleus, green: healthy mitochondria, beige: healthy endoplasmic reticulum, yellow: altered endoplasmic reticulum

Reference: AJ Pérez-Berná, MJ Rodríguez, FJ Chichón, M Friederike Friesland, A Sorrentino, JL Carrascosa, E Pereiro, and P Gastaminza. Structural Changes In Cells Imaged by Soft X-Ray Cryo-Tomography During Hepatitis C Virus Infection. ACS Nano 2016 DOI: 10.1021/acsnano.6b01374

ESRF: Villa di Ercolano papiri

Transmission microscopy





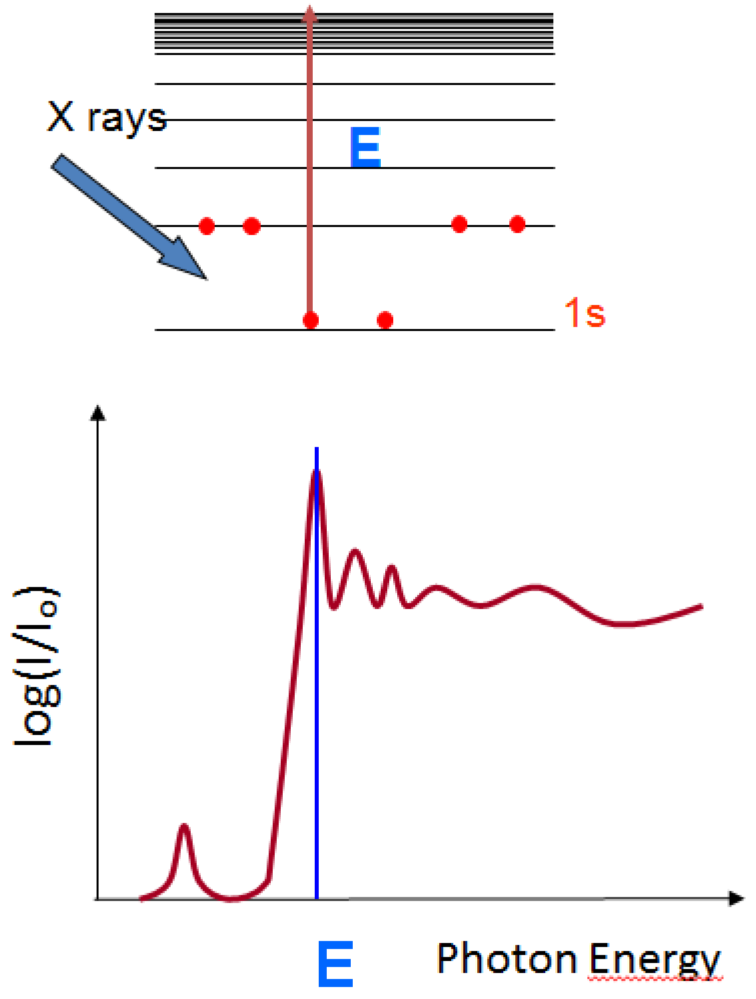
Works of epicureo Filodemo, teacher of Siron, teacher of Virgilio and Oratium

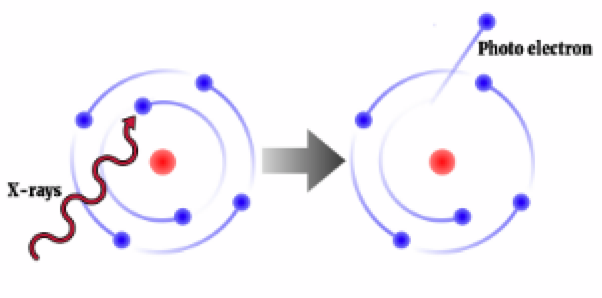
Spectroscopy

Dependence on energy of incident photons of the absorption, emission or fluorescence

Deduction of composition, status, etc.

The absorption energy and the fine structure of the absorption spectra are sensitive to the valence state of the absorbing atom





Photoemission

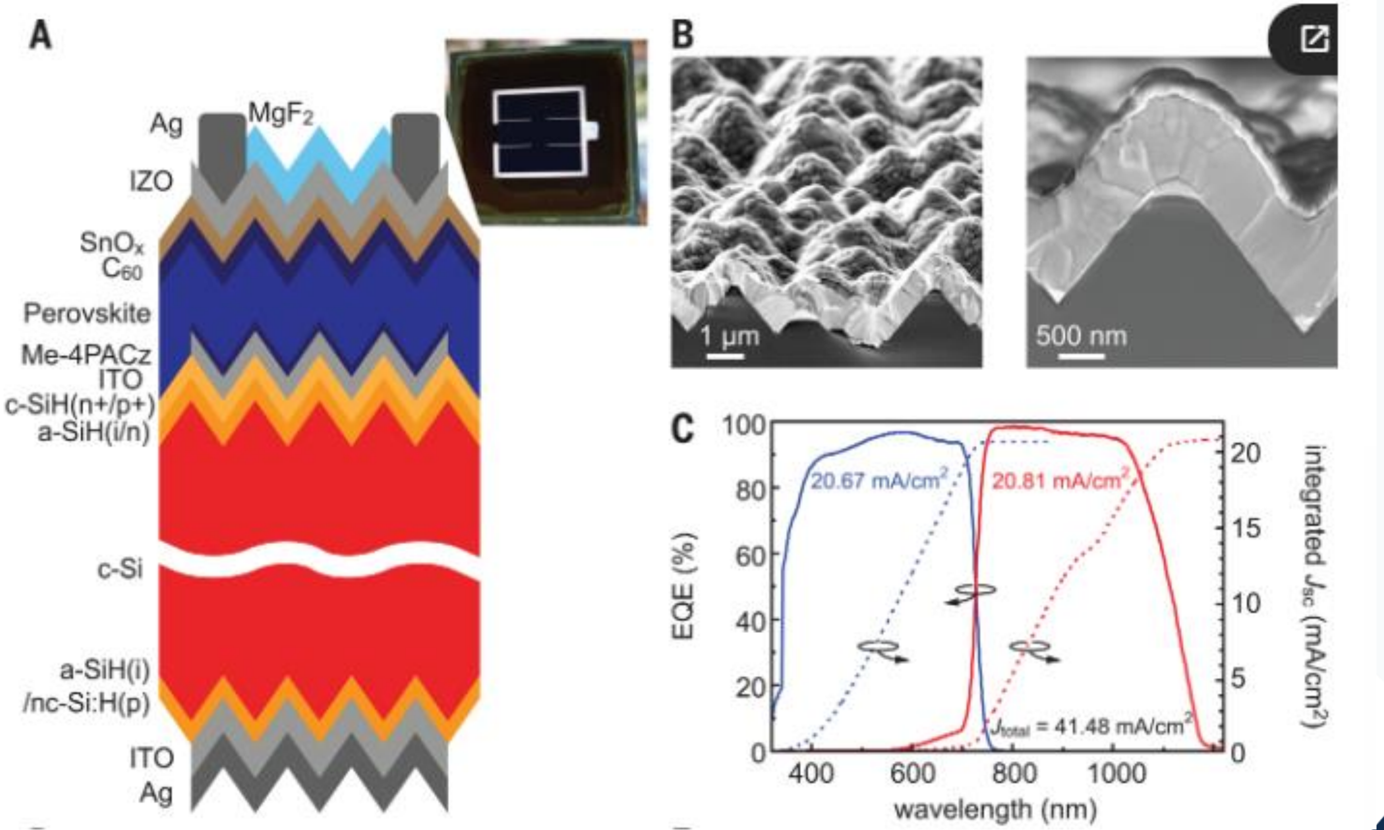
BREAKTHROUGH TOWARDS CHEAP AND EFFICIENT SOLAR CELLS

EPFL's PV-Lab and CSEM

An efficiency of 31.25% by stacking silicon and perovskite cells in a so-called tandem structure. This achievement marks the first time a low-cost technology has surpassed the 30% efficiency milestone (usual efficiency is ~24%.)

Analysis of the impact of the additive on the perovskite crystallization process, **grazing incidence wide-angle x-ray scattering (GIWAXS) was performed at the** NCD-SWEET BL.

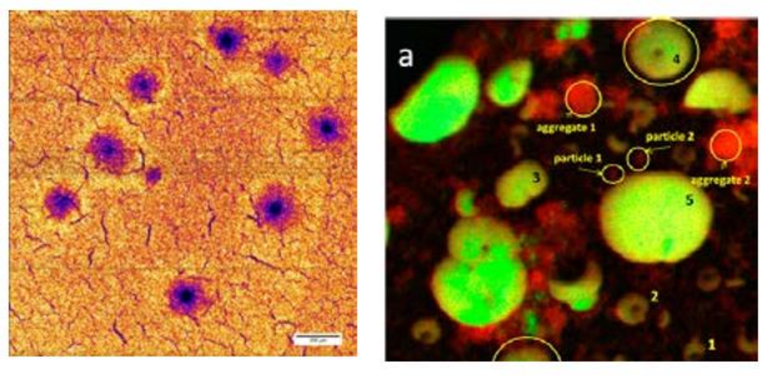
GIWAXS provides detailed information about the **crystallographic structure, orientation, and phase transitions** within the material



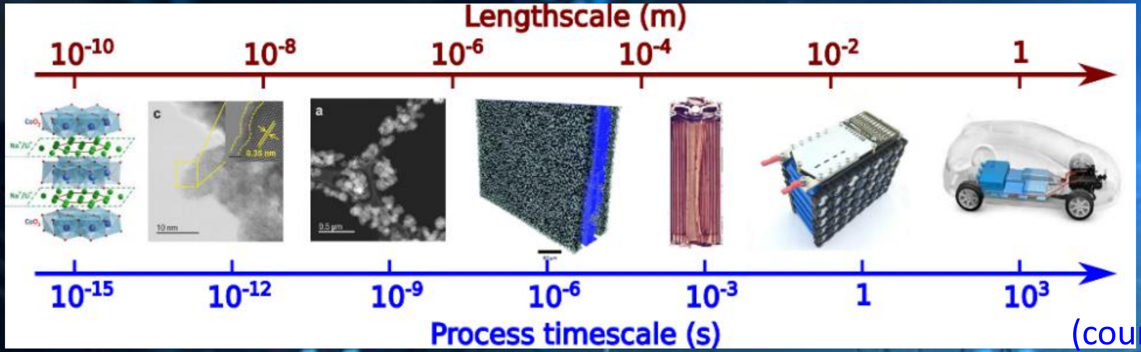
Interface passivation for 31.25%-efficient perovskite/silicon tandem solar cells. *Science* 381, 59-63 (2023). DOI: 10.1126/science.adg0091

Materials for sustainable generation of energy, its storing, transport and conversion

Research on batteries, also based in other materials, like sodium or calcium



Synchrotron X-ray studies of Li battery materials
MISTRAL BL, ALBA



(courtesy: ESRF)

Length scale challenge in battery research
Bridging spatial, temporal and chemical information

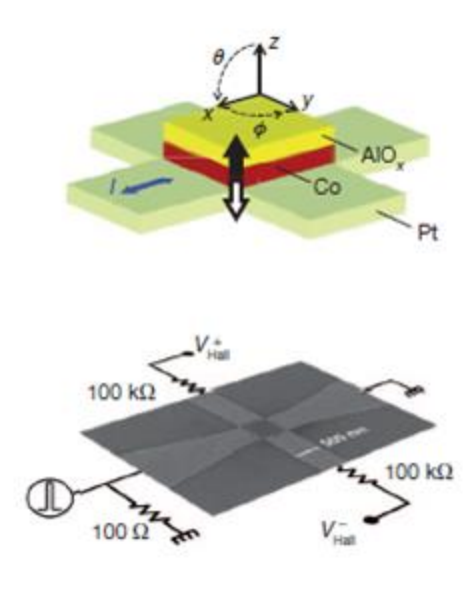
Electronic and Magnetic Structure of Matter

@ BOREAS

Materials for batteries

Spin-orbit fields mechanisms for in-plane current induced magnetization reversal of magnetic tunnel junctions, and their optimization

Fieldlike and antidamping spin-orbit torques in as-grown and annealed Ta/CoFeB/MgO layers



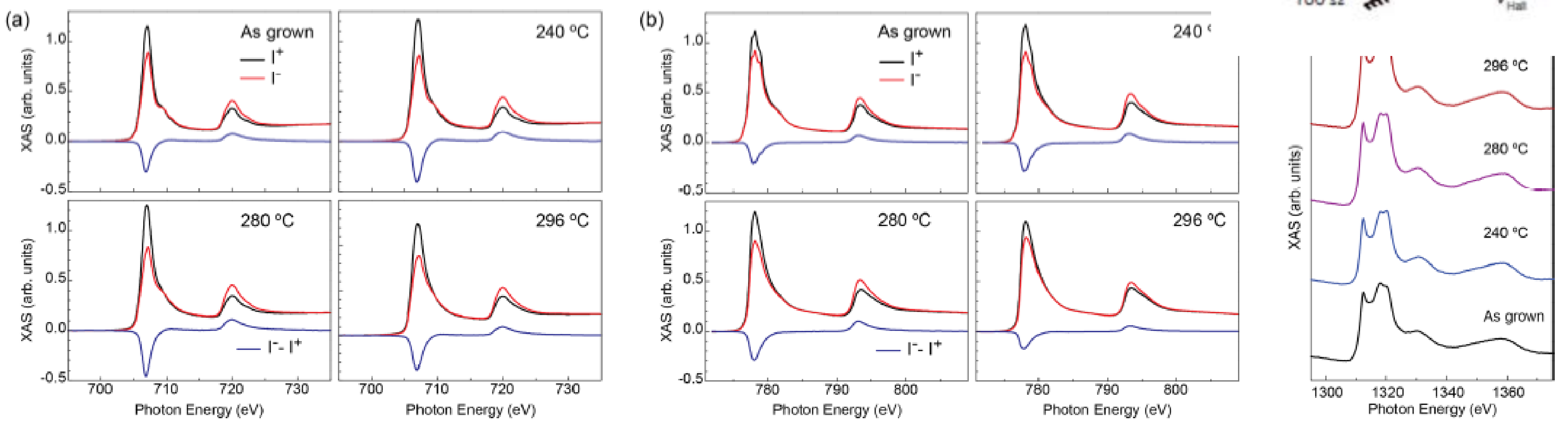
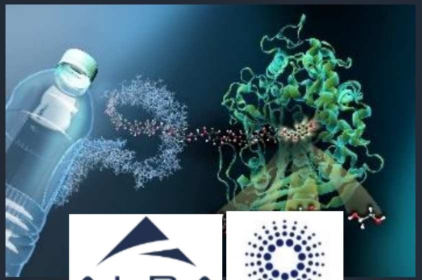


FIG. 4. (Color online) X-ray-absorption and magnetic circular dichroism spectra of as-grown and annealed Ta/CoFeB/MgO trilayers measured at the Fe $L_{2,3}$ edges (a), Co $L_{2,3}$ edges (b), and Mg K edge (c). The spectra were recorded at normal incidence at room temperature in a magnetic field of 1 T.

Physical review **B 89** 214419 (2014)

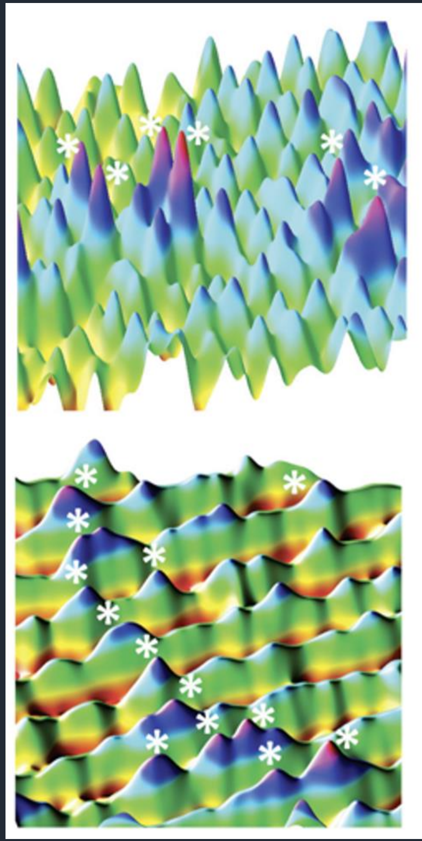
Working for the environment

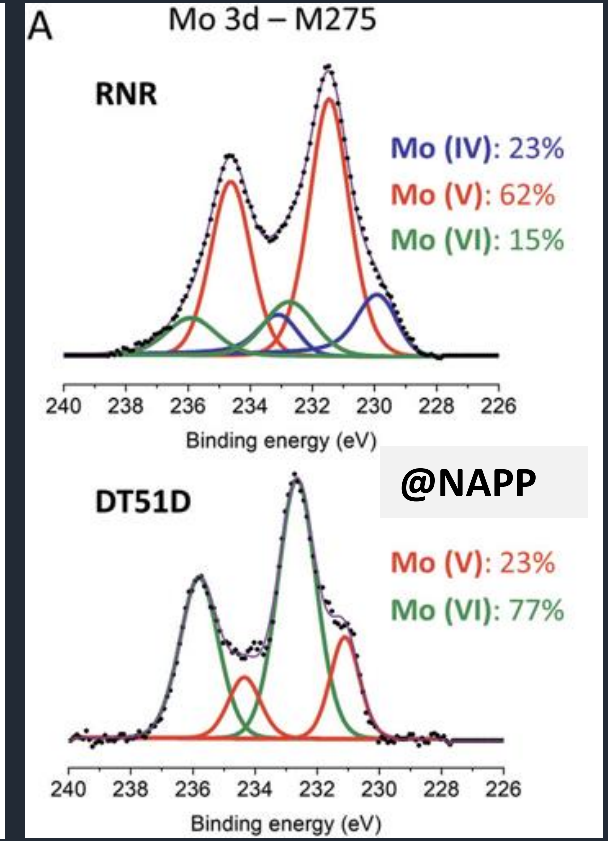
Developing new catalists for green fuels, new polimers, PET digesting bacteria, also using TEMs



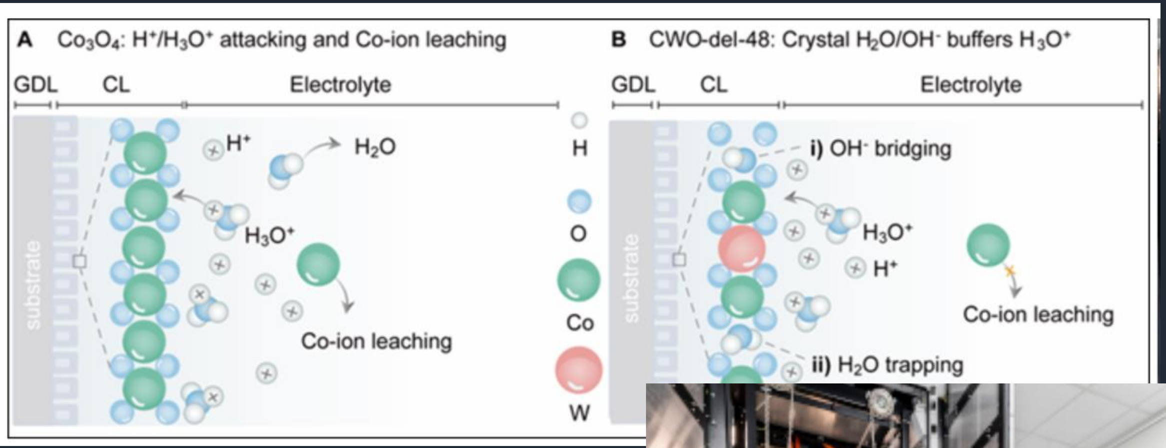
ENVIRONMENT

Low-Temperature Activation of CO_2 to Methane





Hydrothermal Synthesis of Ruthenium Nanoparticles with a Metallic Core and a Ruthenium Carbide Shell for Low-Temperature Activation of CO_2 to Methane, . *Am. Chem. Soc.* 2019, 141, 49, 19304–19311, A. Corma et al.

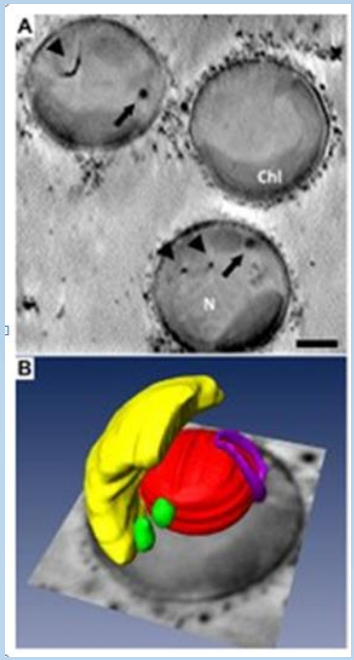


Water-hydroxide trapping in cobalt tungstate for proton exchange membrane water electrolysis. *Science* (2024). https://doi.org/10.1126/science.adk9849

Environmental science – some example from ALBA

Speciation of selenium in wheat to know the Se level in comestibles plants

Analysis of Arsenicum in the soil of an old mine near Madrid for treating and recovering the contaminated soil

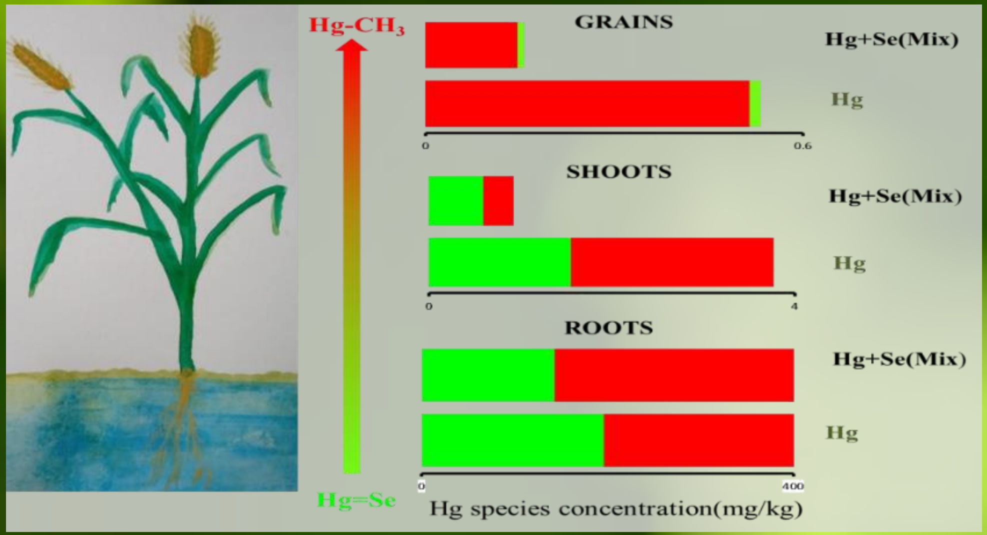


Study the spatial distribution of Calcium in marinae algae to understand effect of climate changes

Develop better catalists for industrial processes, electric cars, etc

www.albasynchrotron.es

Food science: understanding how to grow, enrich, make draught and contaminants resistant,…
Developing new materials for food packaging



Monitorizar la capacidad de las plantas de enriquecimiento con minerales (Selenio)

Characterization of wheat plants with Se: Se(+4), Se(+6), Se(organic). Selenium benefits: helps to prevent common forms of cancer, to fight off viruses, defend against heart disease, and to slow down symptoms correlated with other serious conditions like asthma.

Wine production residues as biopesticides in agriculture

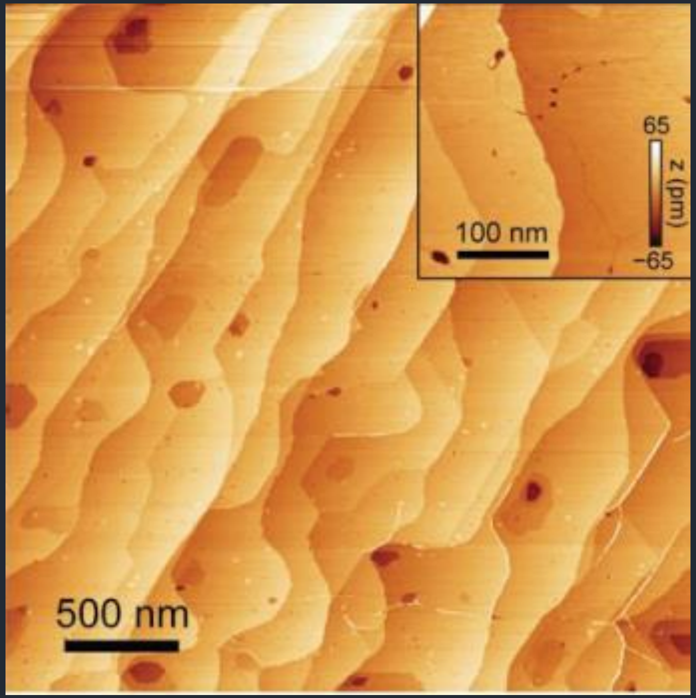
Biochar (2023) 5:30.
https://doi.org/10.1007/s42773-023-00228-8

Helping to understand and preserve our cultural heritage
Ejemplo: retablos del MNAC

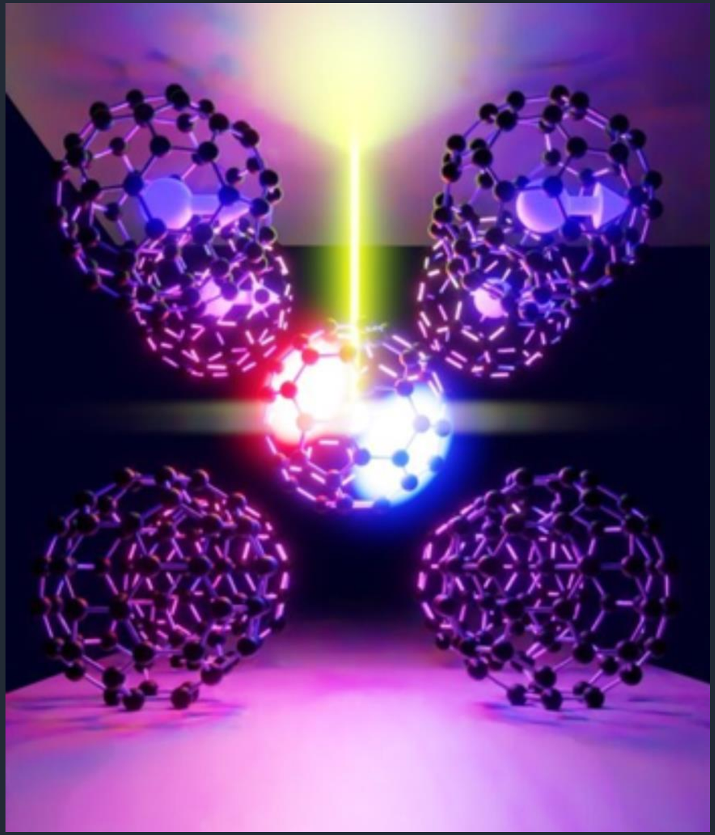
Complex materials for sustainable new technologies

Tools for the ERA of Complexity

Optimizing complex materials needs experimental tools including extreme conditions (T, P, magnetic fields) and real-time control (in-situ and operando) of relevant parameters and their functionality: quantum materials, superconductors, nanomagnetism are bricks of complex technologies



DISCOVERY OF NOVEL CLASS OF 2D MAGNETS: 2D-XY FERROMAGNETISM IN MONOLAYER $CrCl_3$ **Science (2021).** DOI: 10.1126/science.abd5146



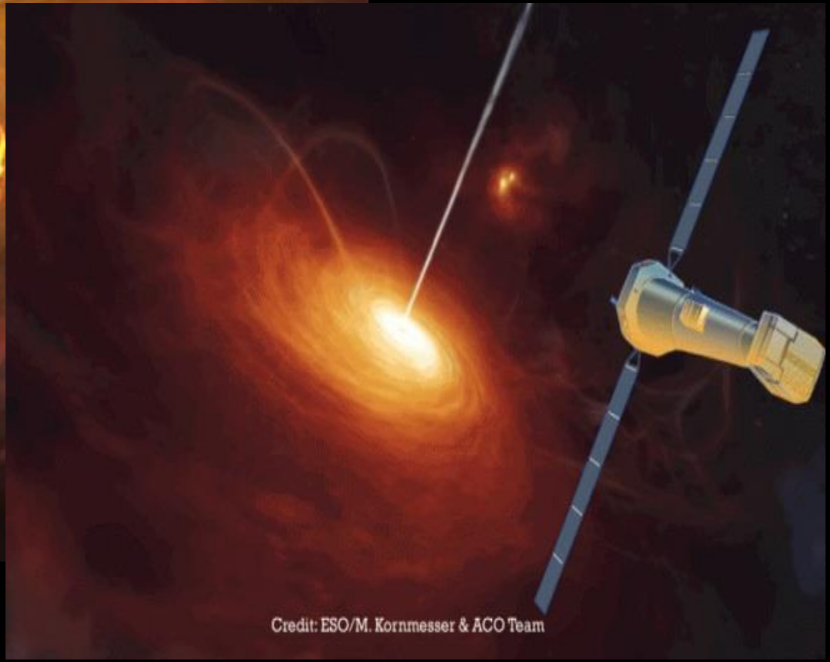
Advanced Functional Materials 2023, 2212173.

Storing magnetic information in picosecond timescales at a fullerene - oxide interface by using the photocurrent generated in the molecular layer. Great potential for the development of eco-friendly, ultra-fast hybrid information memories and magneto-optic sensors

Participate in producing new instruments for space exploration
ALBA - European Space Agency collaboration

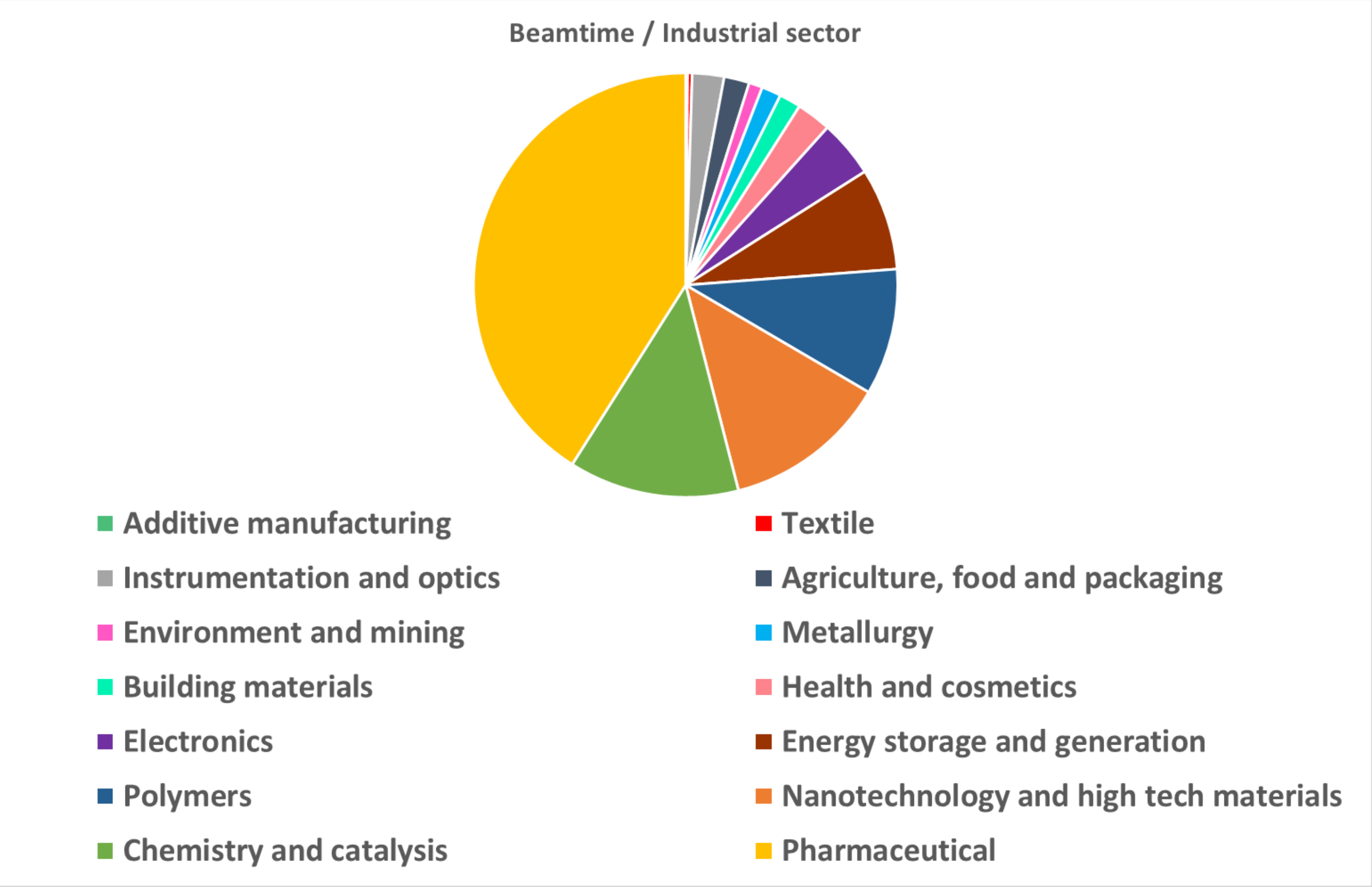
ATHENA Mission (2037)

- Advanced Telescope for High-ENergy Astrophysics
- Will study the high energy universe, including black holes



MINERVA: BL to test hundreds of mirrors to be mounted in ATHENA satellite

Industrial users – advancing in the innovation
More than 90 companies, 55% from Spain, 1/3 SME, More than 600 experiments



Examples:
Improved optics for nanoelectronics manufacturing, Battery with higher energy capacity, Battery recycling, Greener concrete, Robust adhesives, Efficient products for agriculture Nanotechnology for food packaging, Drug discovery, development and validation, New polymers for biomedical applications, Biochemical Efficacy of cosmetic

Examples of industrial use

Pharma industry

- *Structural information of the interactions between a **drug and a therapeutic target** at the atomic level*
- ***Penetration of drugs** and pharmaceutical formulations **in biological tissues** such as the skin*

Environmental industry

- *Chemical characterization to improve nuclear and mining **waste management***
- *Identification of different **chemical species** in very low concentrations and their distribution **in plants, microorganisms, and animal tissues***
- ***Toxicological effects** of chemicals, corrosion, pollution, etc.*

BASF IMPROVING THE PRODUCTION OF BATTERIES FOR ELECTRIC VEHICLES

New methodology to produce nickel-rich cathode materials used in lithium-ion batteries that optimizes the conventional production process. Increase in throughput by a factor of three, increasing the efficiency of future cathode active materials production for battery electric vehicles

ALBA and ALBA II

2003 – Creation of CELLS Consortium (Spanish Government and regional Catalan Government), and agreement on facility funding for the period 2003 to 2022
2023 – Addendum for 2023 funding

Now: negotiating agreement on facility funding for the period 2024-2038

2003 ALBA Approval

2006 Starting ALBA construction

2012 Starting ALBA Operation

2020 Starting ALBA II design

2024 ALBA II Approval

2032 ALBA II Operation

ALBA Synchrotron Radiation Facility

National public institution with 50% national + 50% regional funding (Ministerio de Ciencia e Innovación) and GenCat (Department de Recerca i Universitats)

National and international (28%) staff

National and international (40%) users

National and international collaborations

Generalitat de Catalunya
Departament de Recerca i Universitats

ALBA
key numbers

+ 2400 yearly user visits

+450 yearly experiments

+ 4000 national and
+ 4000 international users

+3300 publications

$\langle IF \rangle_{2022} = 10$

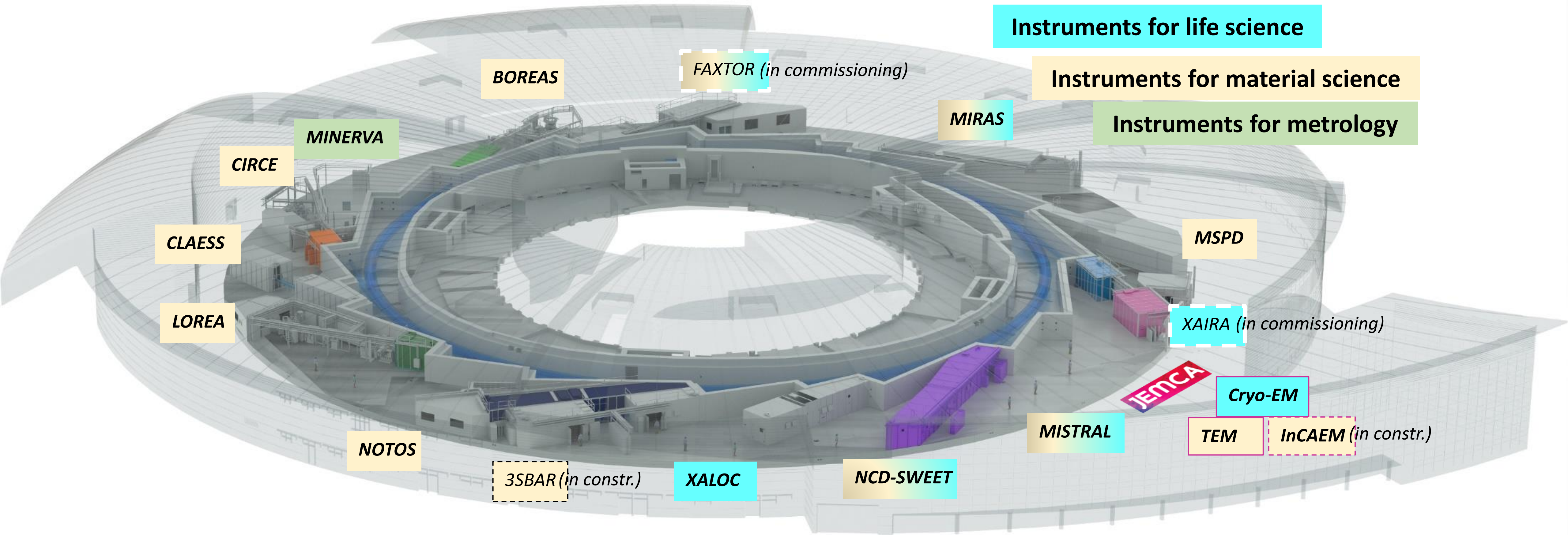
+2600 public experiments

+600 industrial experiments

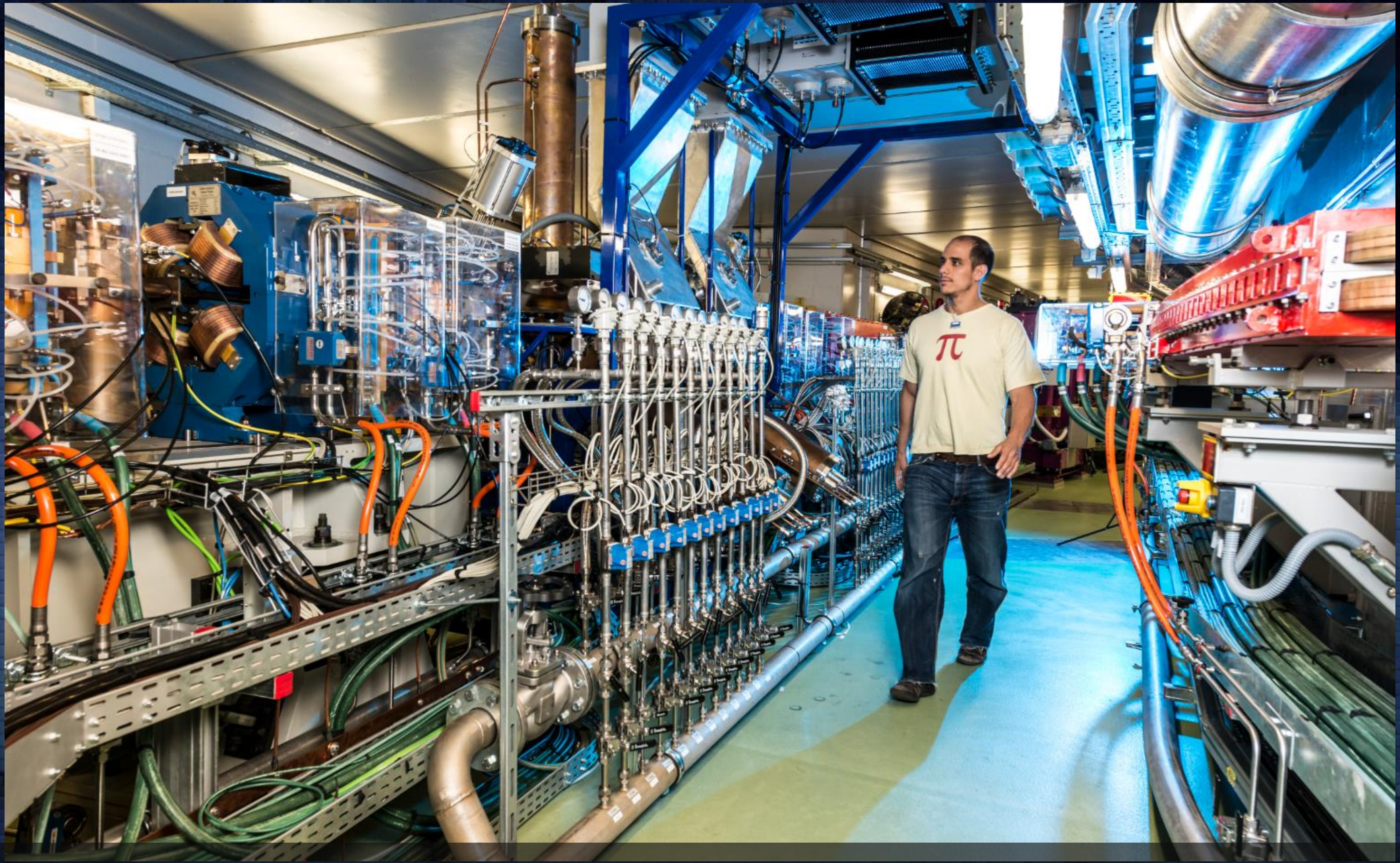
+1000 Proteins in PDB

+260 staff

ALBA 2024

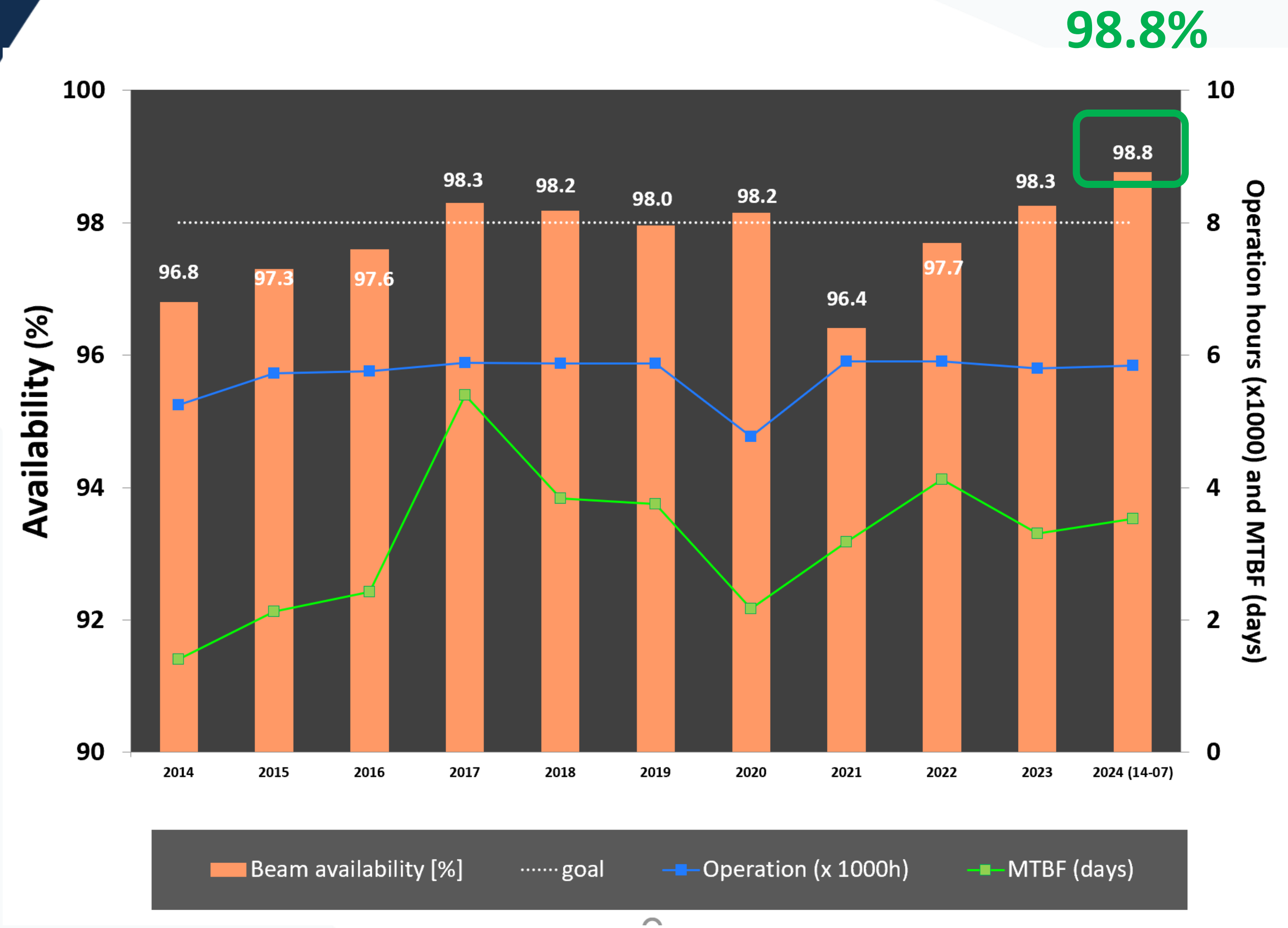

Instruments for life science
Instruments for material science
Instruments for metrology
BOREAS
FAXTOR (in commissioning)
MIRAS
MINERVA
CIRCE
CLAESS
LOREA
MSPD
XAIRA (in commissioning)
JEMCA
Cryo-EM
TEM
InCAEM (in constr.)
MISTRAL
NCD-SWEET
XALOC
3SBAR (in constr.)
NOTOS

ALBA accelerator



ALBA storage ring – 3rd generation light source
3 GeV electrons - 270 m circumference

Operation – Spring 2024



2023 Availability = 98.3 %

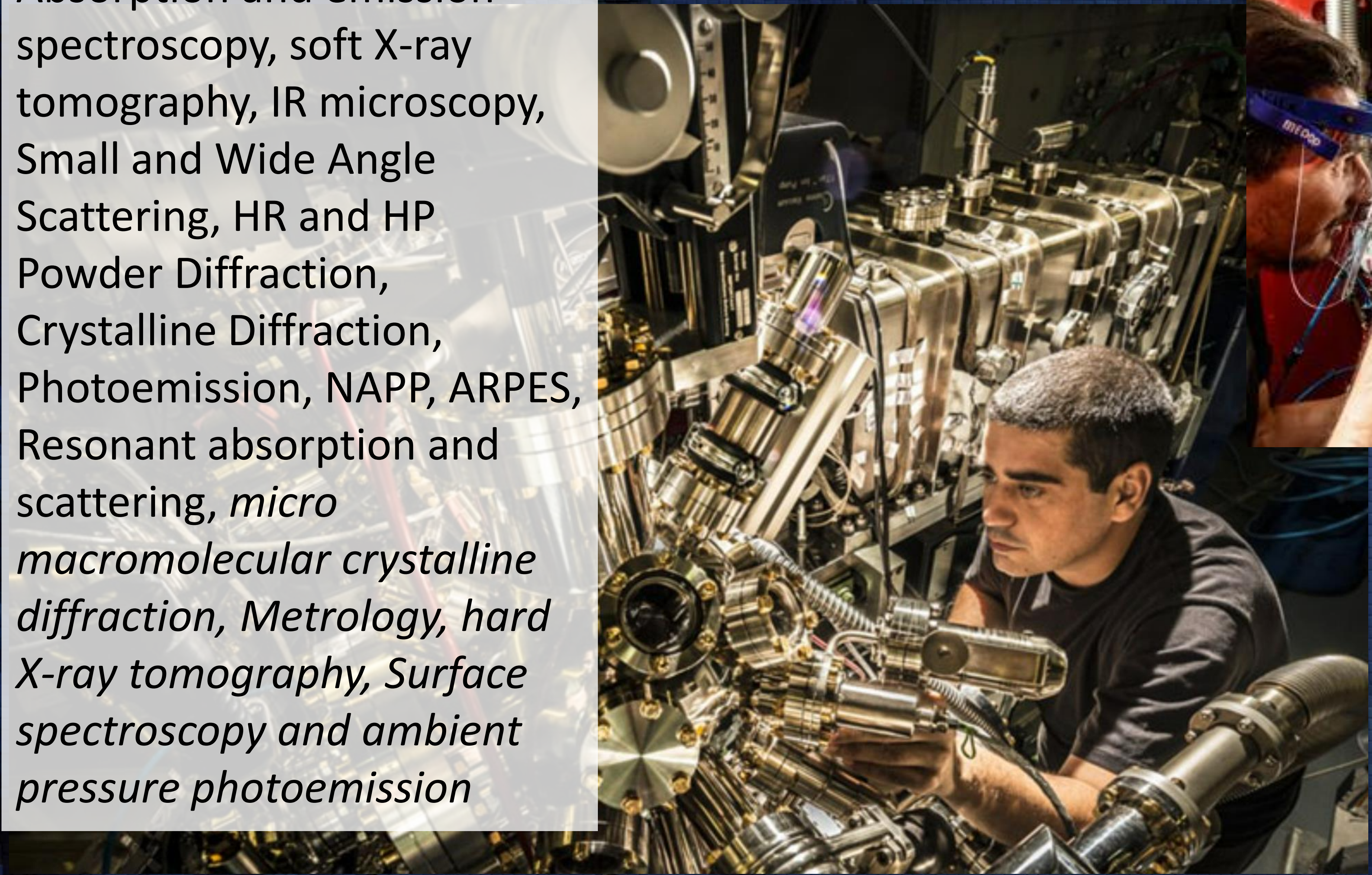
Even with mayor events like a fire in a transformer, which happened during a weekend, or the blow-up of the dipole power supply which happened in a start-up, plus a strike (16 h) as the longest down-time

2024 Availability = 98.8 %
Normal operation with minor events

Beamlines at ALBA

Beamline techniques

Absorption and emission spectroscopy, soft X-ray tomography, IR microscopy, Small and Wide Angle Scattering, HR and HP Powder Diffraction, Crystalline Diffraction, Photoemission, NAPP, ARPES, Resonant absorption and scattering, *micro macromolecular crystalline diffraction, Metrology, hard X-ray tomography, Surface spectroscopy and ambient pressure photoemission*



Joint Electron Microscope Center at ALBA (JEMCA)

50% Funded through Catalan ERDF and 50% co-funded by different partners

Life science - 200 kV Glacios cryo-TEM

Cryo-EM receiving users

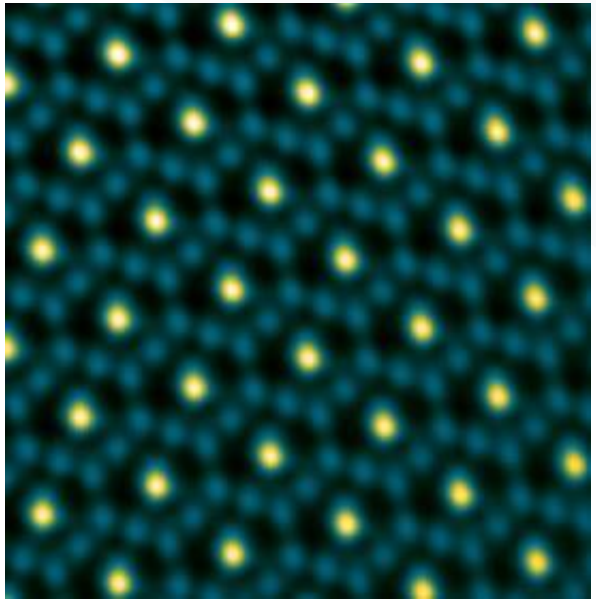
Overbooking Factor >2

IS*21* family transposase

Material Science - 60-300 keV Spectra (S)TEM

TEM just finished commissioning

First users after Summer 2023



Journal of the American Chemical Society, 2023. DOI: 10.1021/jacs.3c06288

Atomic resolution aberration corrected HAADF STEM images of one of the catalyst nanoparticles and a zoom out of the Co_2FeO_4 cubic spinel structure

Generalitat de Catalunya Departament de Recerca i Universitats

Unió Europea Fons Europeu de Desenvolupament Regional

USERS

Direct access covering operational costs
Results can be confidential

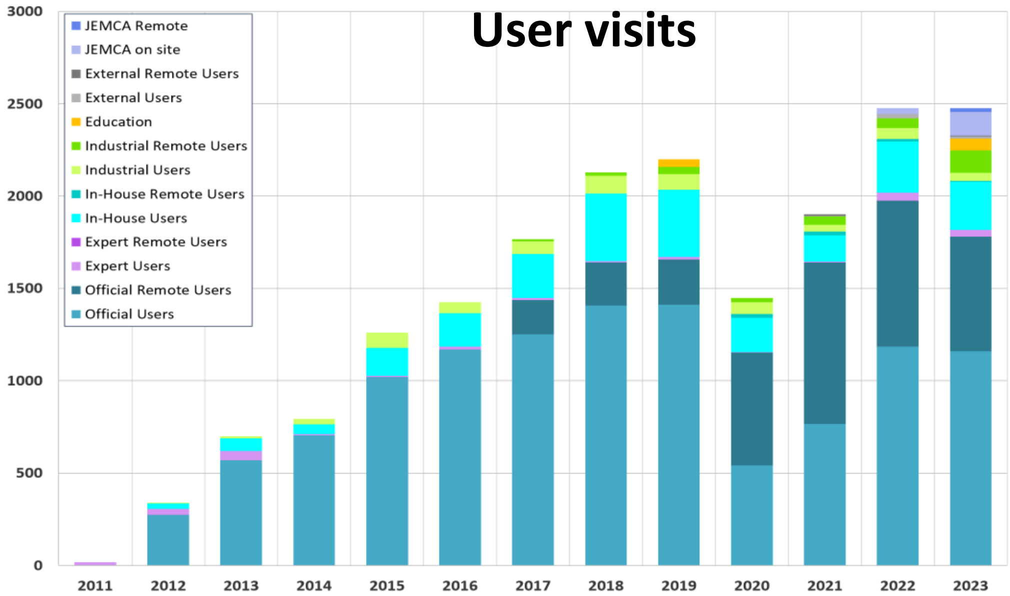
Private

2/3 from Spain

Academic

Competitive and free access
Public results

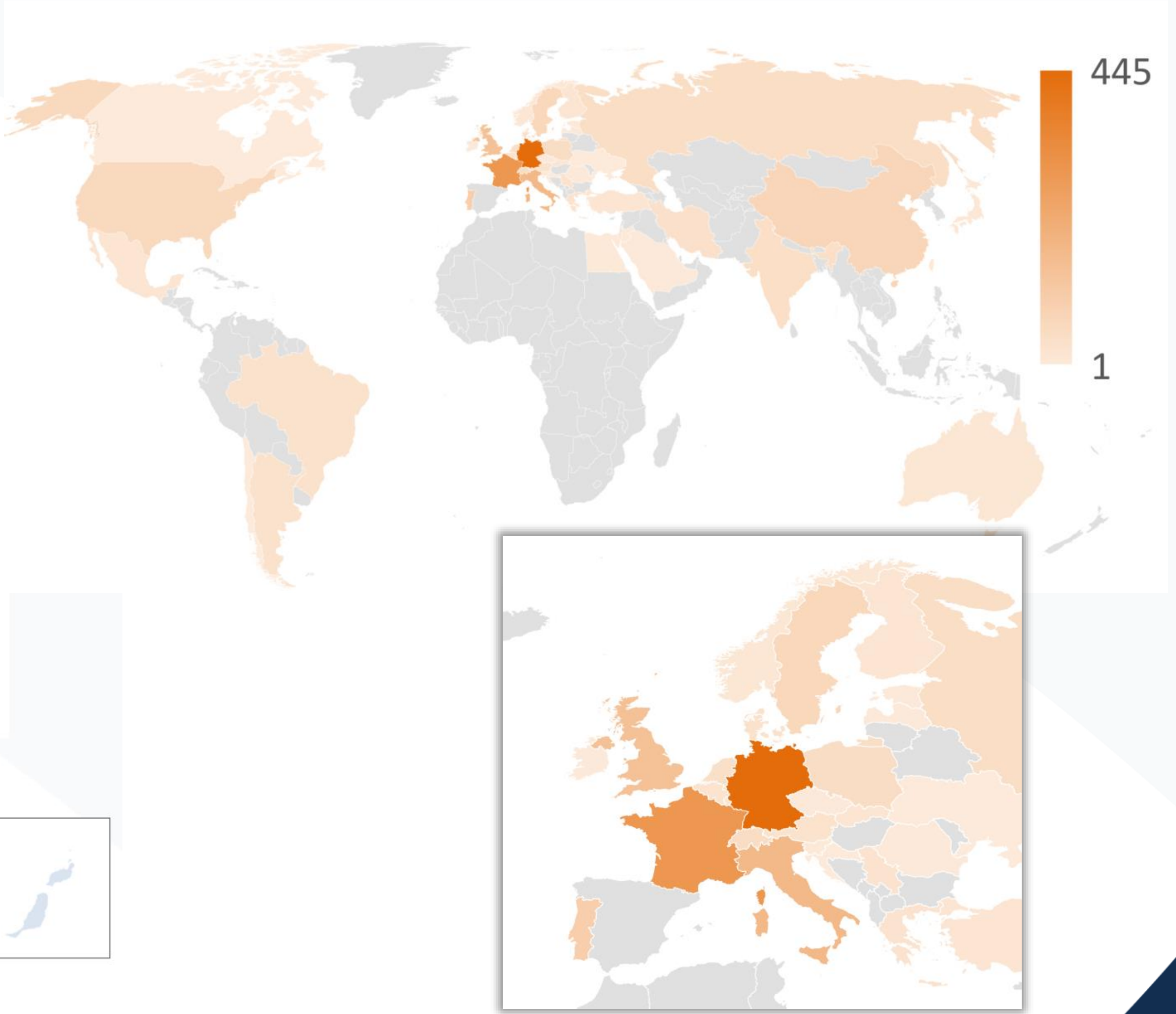
Joint academic and industrial



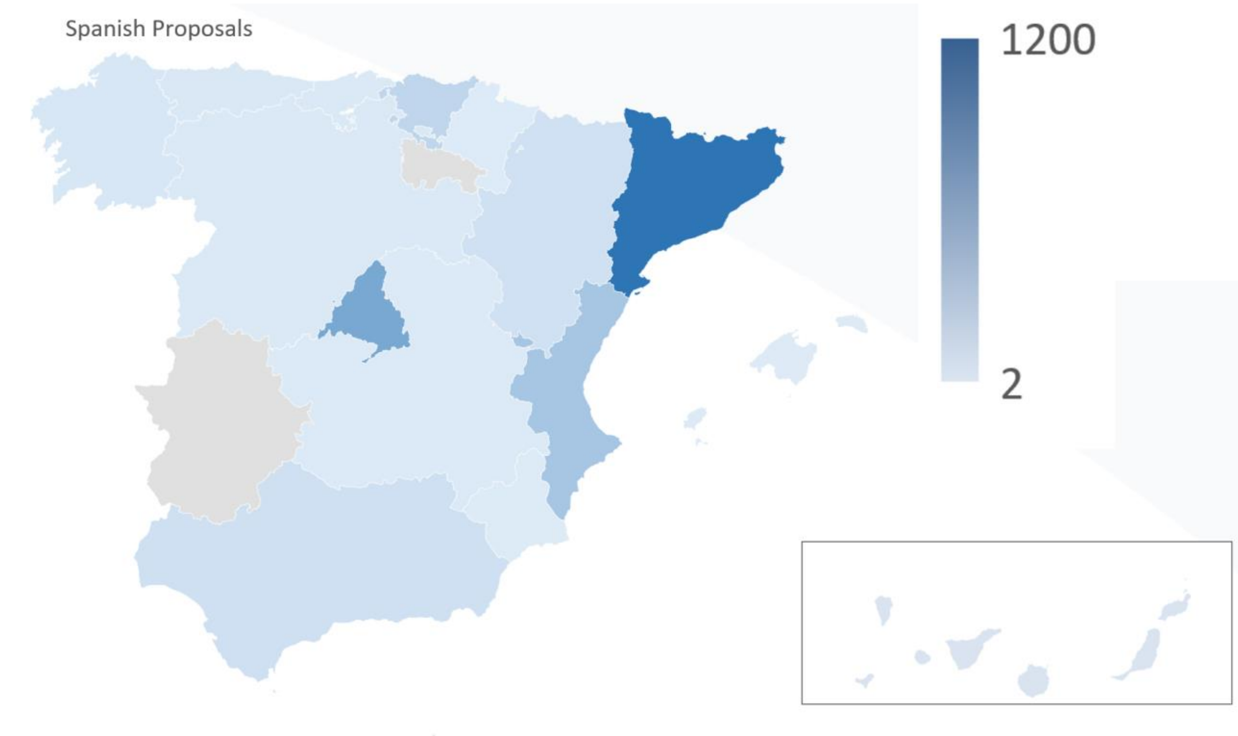
2 calls per year
Average overbooking factor ~2

Academic Users

International proposals (1063 granted over 2203)

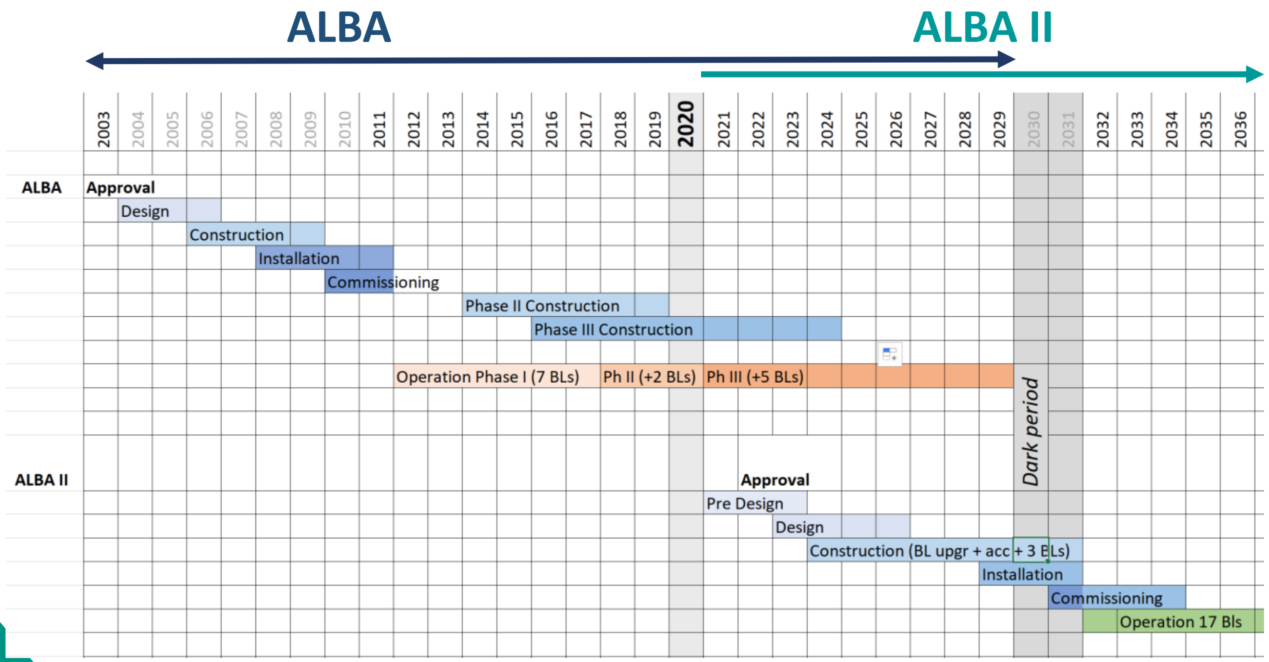


Spanish proposals (1865 granted over 3231)

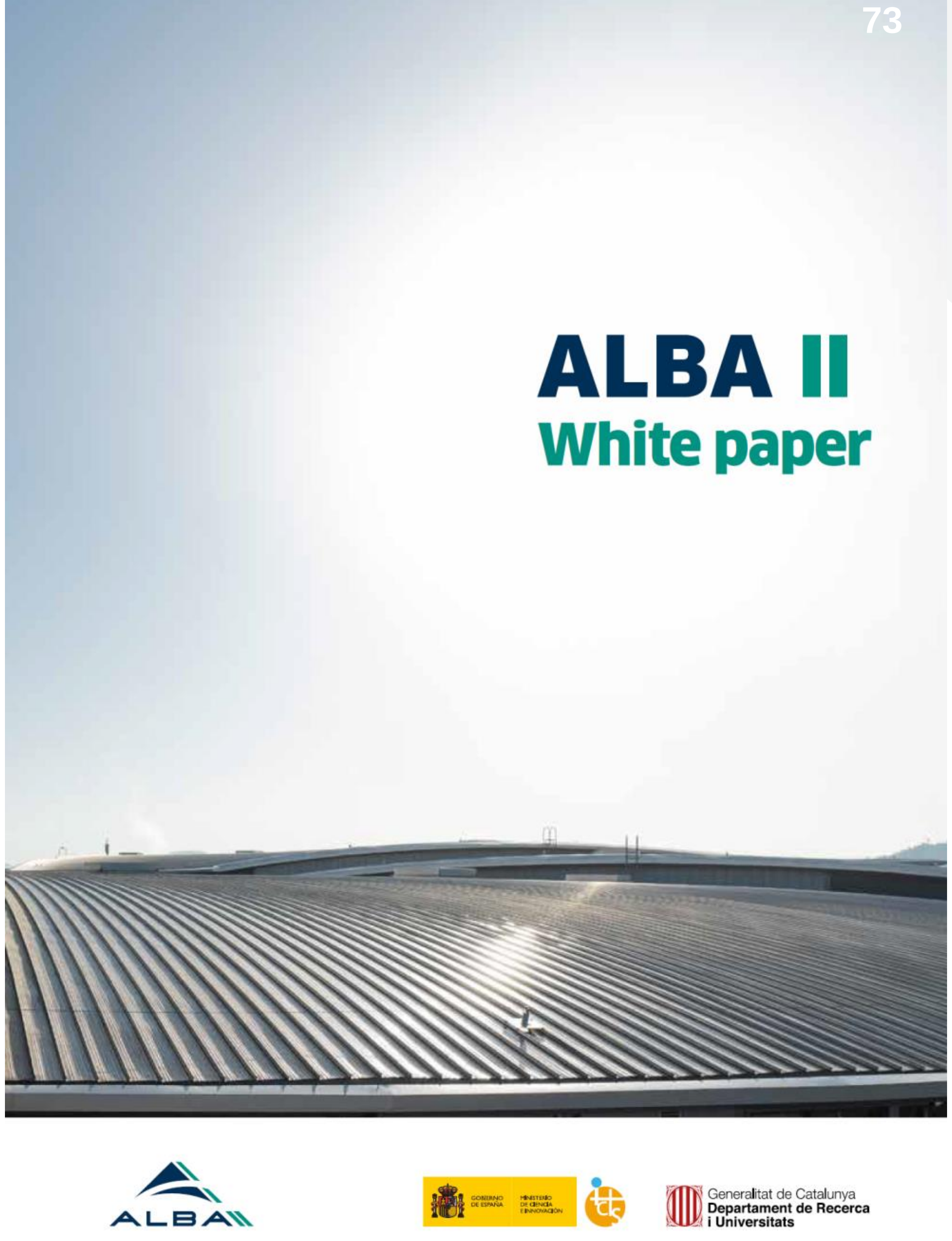


ALBA II Project

- Renovation of storage ring providing a brighter photon beam
- **New beamlines**
- **Upgrade of existing beamlines**
- **Upgrade of data infrastructure and services**



https://www.cells.es/en/science-at-alba/alba-ii-upgrade/alba-ii-whitepaper.pdf



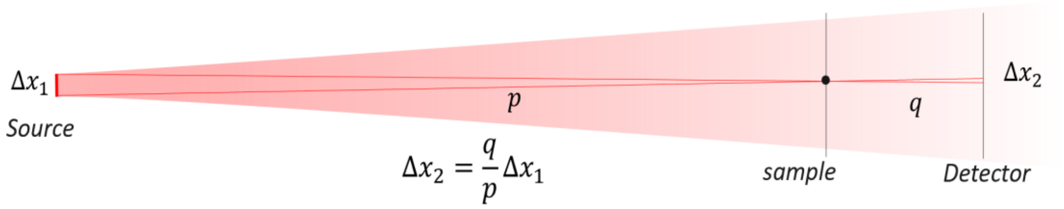
What ALBA II will provide

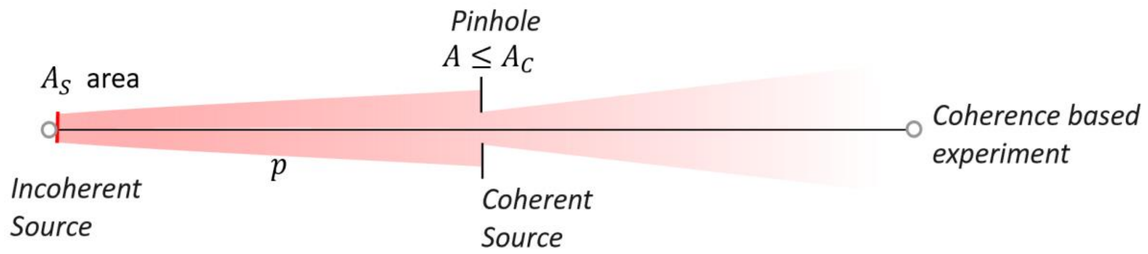
Full infrastructure to tackle the grand challenges of our time for the Spanish and European users

ALBA II combines the excellence and availability of the user program of ALBA with the development of full characterization suites for characterizing multi-lengthscale problems

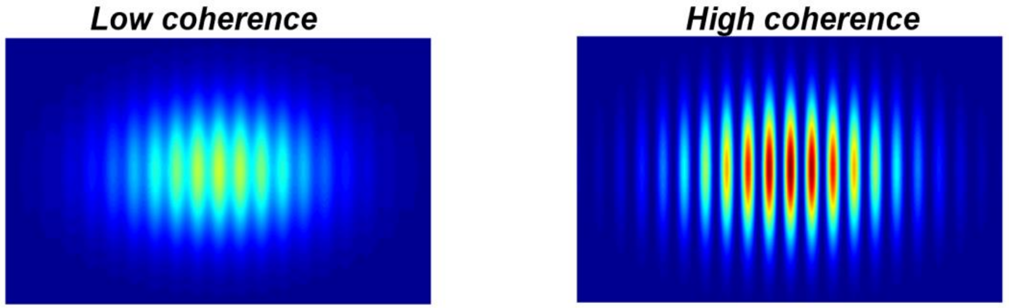
- Enhanced **microscopy** capabilities
- **Multimodal methodologies** to address complex development tasks
- **High throughput capabilities** and big-data connectivity for fast innovation
- And **optimized operando** environments to optimize functional materials and devices

The longest the distance between the source and the sample, the higher the resolution and the coherence fraction





Most basic example: Young's Double slit interference



Beam spot size on sample

$$\Delta x_{Geom} = \frac{q}{p}\Delta x_{Source}$$

Coherent fraction

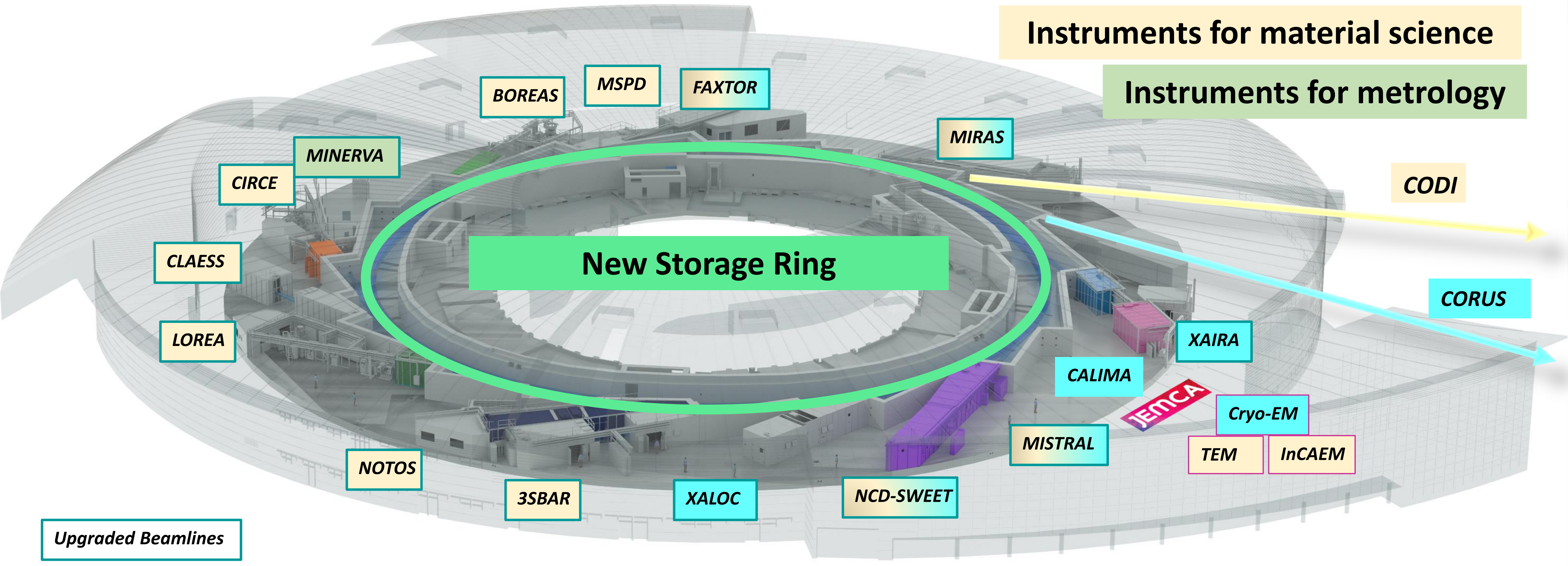
$$A_C(p) = \frac{(\lambda p)^2}{A_S}$$

ALBA II - *Day One*

Instruments for life science

Instruments for material science

Instruments for metrology

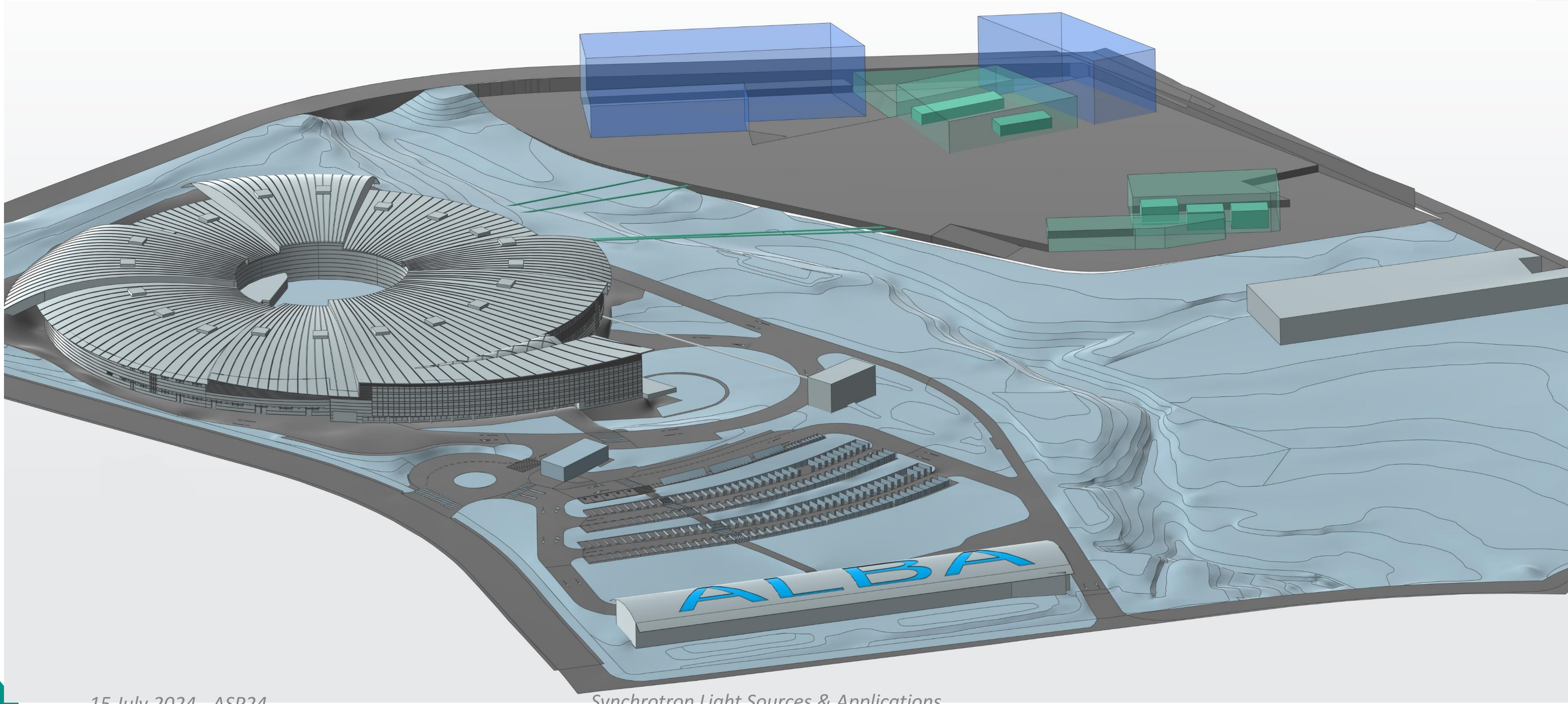


Upgraded Beamlines

ALBA II – enlarging the infrastructure

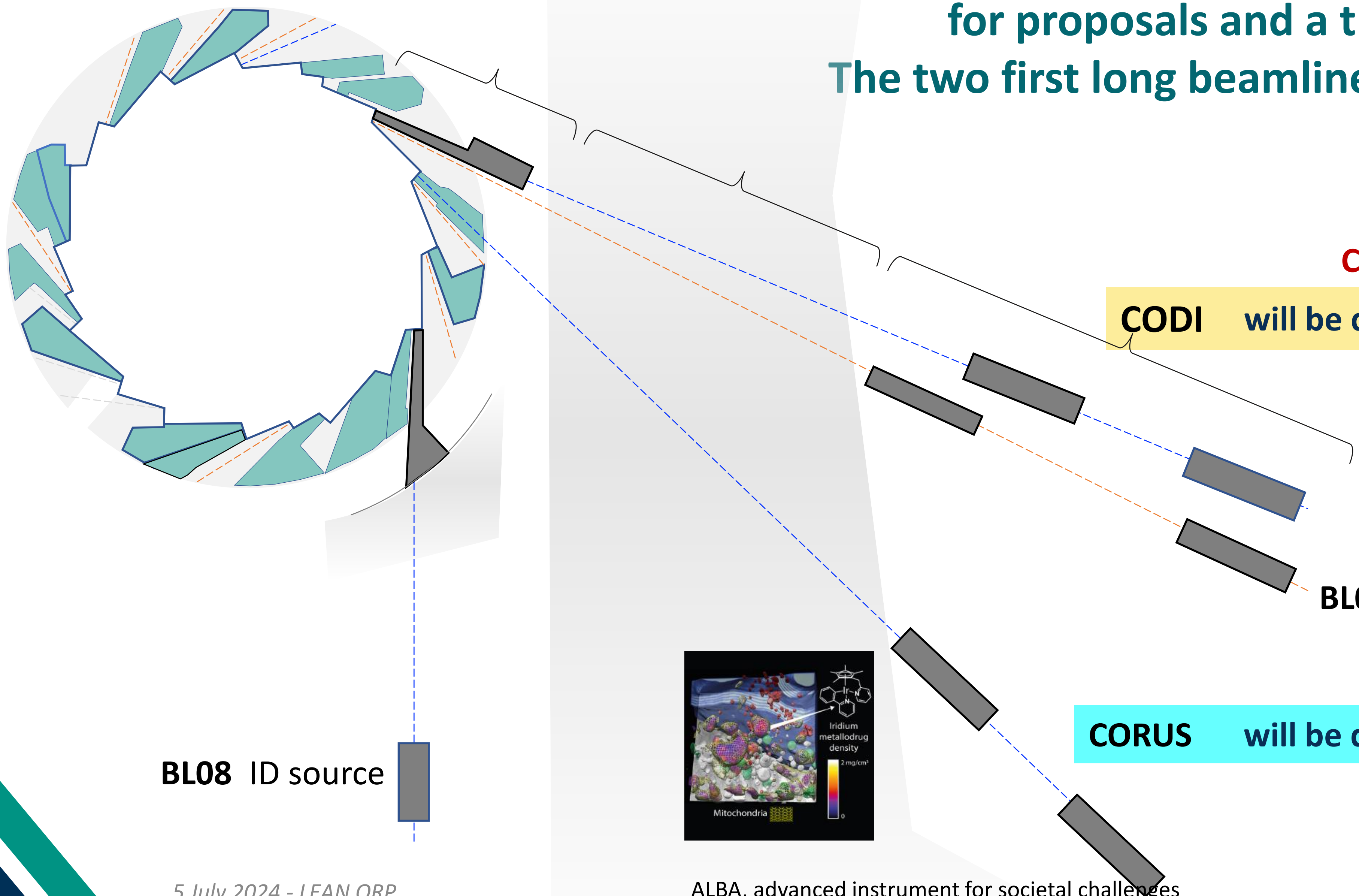
New plots have been assigned to ALBA for building long BLs

The longer the beamlines, the higher their resolution and coherent fraction



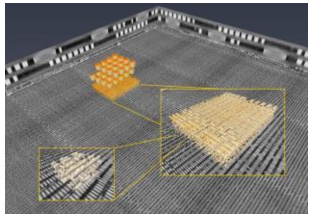
Long Beamlines

After a process open to the whole user community for proposals and a thoughtful evaluation
The two first long beamlines have been defined



Coherence Diffraction Imaging

CODI will be dedicated to material science



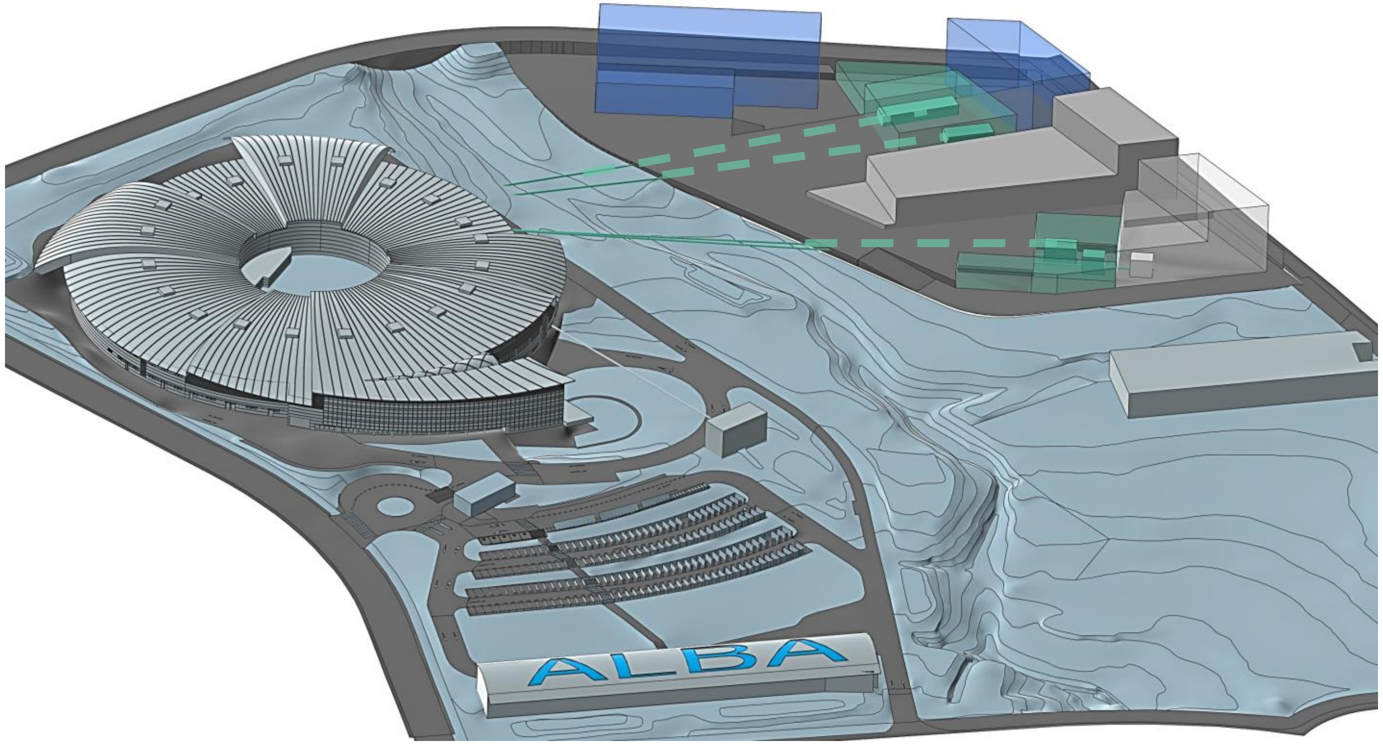
CORUS will be dedicated to life science

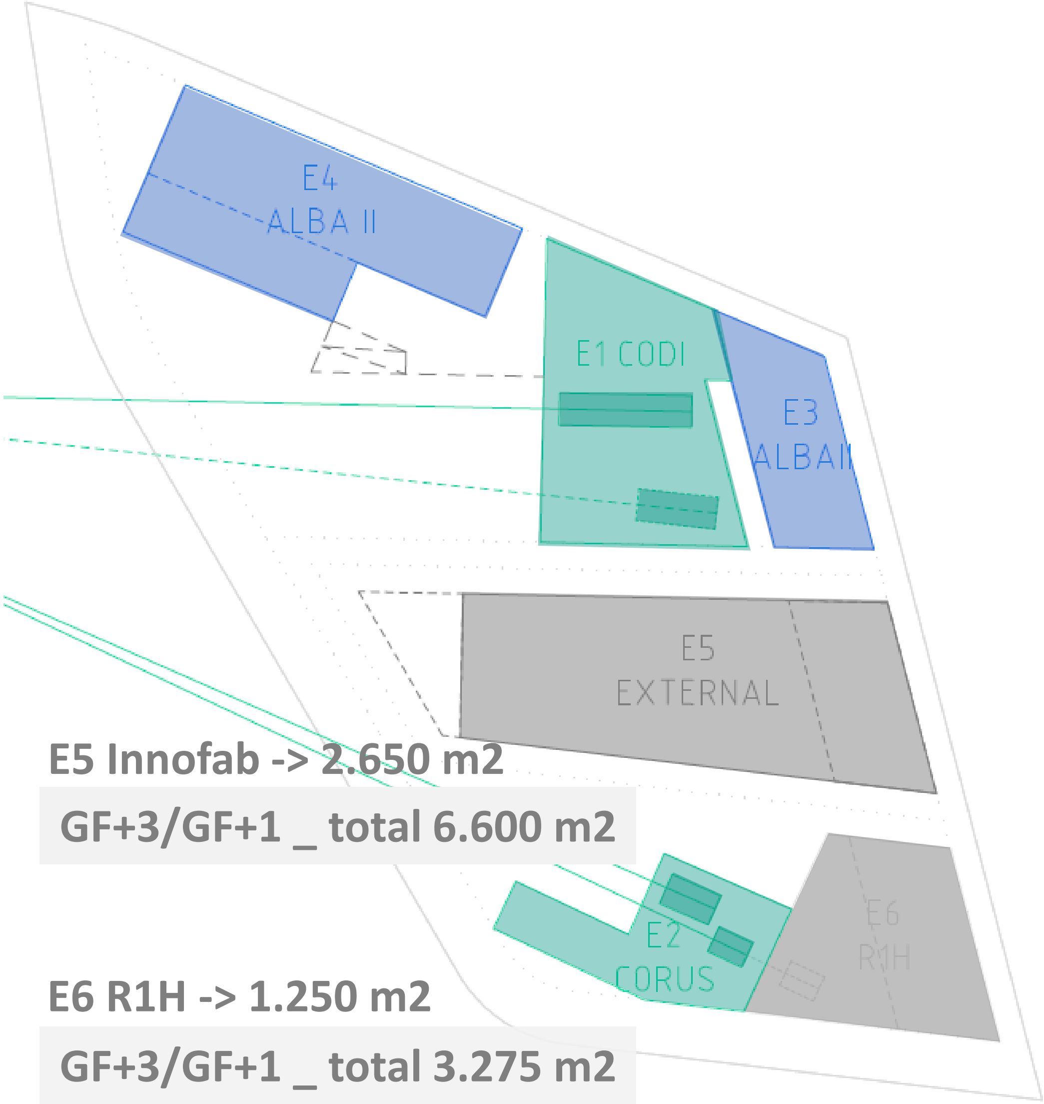
ALBA, advanced instrument for societal challenges

Infrastructures

New buildings and related Infrastructures being defined

External – Innofab & R1H





E5 Innofab -> 2.650 m2

GF+3/GF+1 _ total 6.600 m2

E6 R1H -> 1.250 m2

GF+3/GF+1 _ total 3.275 m2

1) **Buildings for CODI, CORUS and BL3**
2) **Building for offices and labs**
3) **Building for other services (auditorium, cafeteria..)**
4) **Buildings for INNOFAB and R^{2}OH**

ALBA II and Proposals for its park

Preparation of proposals on-going, together with negotiations with funding agencies

InnoFab and One Health (R^2OH)

2.000 m2 clean room infrastructure for development of semiconductors technologies, offering a solution to the current gap between research and commercial development of innovative prototypes:

- Research Lab
- Fab-in-Fab space for start-ups.
- An R&D Pilot Line equipped with 200 mm high-volume manufacturing equipment.
- A national network for long-term collaborative R&D programmes.
- Dedicated access to advanced characterization offered by a unique integration with ALBA Synchrotron – 360 ME investment

The center will respond to the multiple challenges raising from climate change for our *One Health*, as defined by WHO. In particular:

- Zoonotic diseases and environment surveillance,
- Neurodegenerative diseases and relation with environment,
- Impact of emergent climates and new pollutants in public health

Combining the strength of 3 national Irs with the power of one large university, R2OH will incorporate a unique infrastructure for one of a kind X-ray, cryo-EM and optical microscopy characterization suite within a bio safety level 3 as manipulation and infection facility for plants and animals – 120ME investment

LEAPS League of European Accelerator-based Photon Sources

Synchrotrons and FELs in Europe

+35000 users from all EU & beyond

+300 operating End Stations

+25000 publications In last 5 years

offering + 1Mh/year

2 international facilities
17 national facilities

Funded by national governments
Offering free access to ALL public researchers, based on competitive excellence
Offering advanced and cost effective instruments to ALL industrial world

19 facilities - 16 institutions - 10 countries

Associate: SESAME
Partners: ESUO, LENS, CLS

SUNSTONE is dedicated to reinforcing SESAME

WP4: Strengthen SESAME user services

Task 4.2.1: Enhancement of the SESAME beamline scientific services for user support

to hire **one postdoctoral fellow** for the infra-red spectromicroscopy beamline.

to hire **one postdoctoral fellow** for the X-ray spectroscopy beamline.

Task 4.2.2: Capabilities reinforcement of the SESAME beamlines with visits of expert European light source staff specialists to SESAME

four European specialist visits, two per beamline, to SESAME of one-week duration each.

Task 4.2.3: **Engagement with wider user community via joint execution of targeted projects**

to launch **two targeted projects** covering strategic and important aspects, either technical or scientific, identified previously by SESAME.

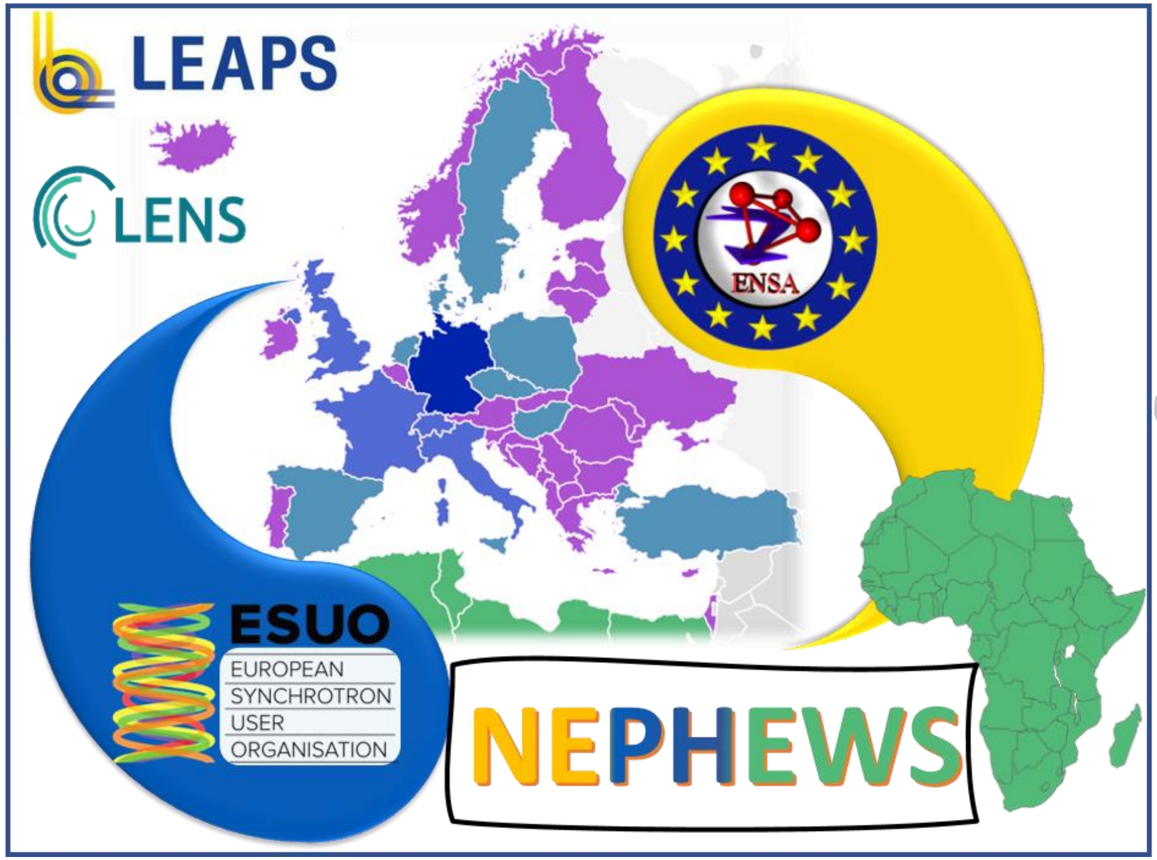
The SUNSTONE project has receandived funding from the European Union's Horizon Europe framework program for research and innovation under grant agreement n. 101177314. Views opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

SUNSTONE

https://www.sesame.org.jo/

NEPHEWS

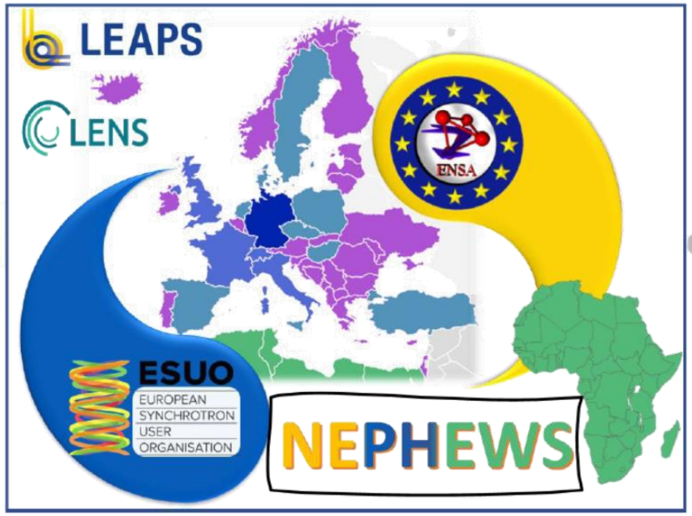
https://www.esuo.eu/nephews-a-successful-response-to-advancing-frontier-knowledge-call-of-horizon-europe-from-esuo-with-leaps-together-with-ensa-and-lens/



Academic Access via NEPHEWS

Neutrons and Photons Elevating Worldwide Science

NEPHEWS brings together multiple European Synchrotrons, FELs and Neutron sources with the European User Organisations in a combined access program



MAIN GOAL:

Community Building by **lowering the geographic and financial barriers** for access for users from:

- Widening countries,
- Countries without RI,
- Includes initiatives for **Africa**

Co-funded by the European Union

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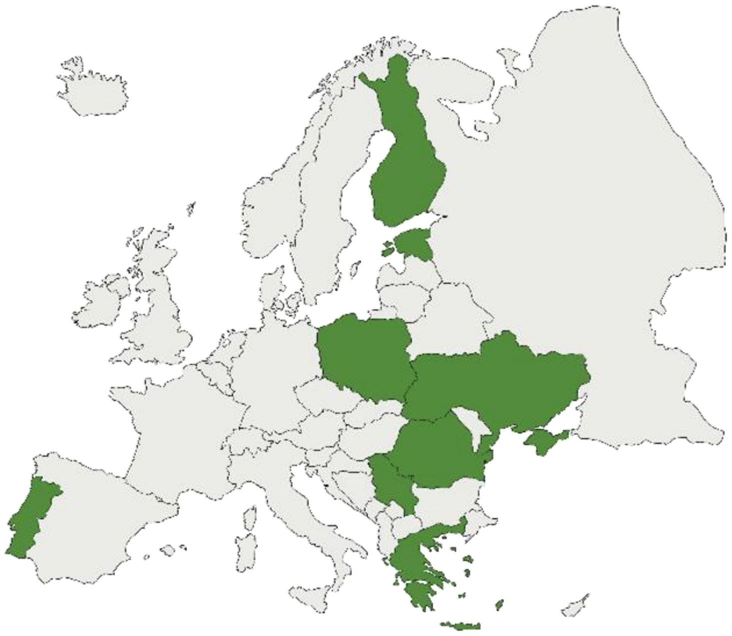
Synchrotrons nearest to you (so far)

Academic Access via NEPHEWS

ALBA will offer under the NEPHEWS project from July 2024 to December 2026:

- 325 shifts (all beamlines included)
- 62 trips (travel&accommodation of 2 researchers per experiment)
- 4 twinning users (travel&accommodation)
- 1 ESR (travel&accommodation for a 1 week internship)
- **Target countries:** Estonia, Finland, Greece, Poland, Portugal, Romania, Serbia, Ukraine + African Countries



Targeted countries of **nephews**

Co-funded by the European Union

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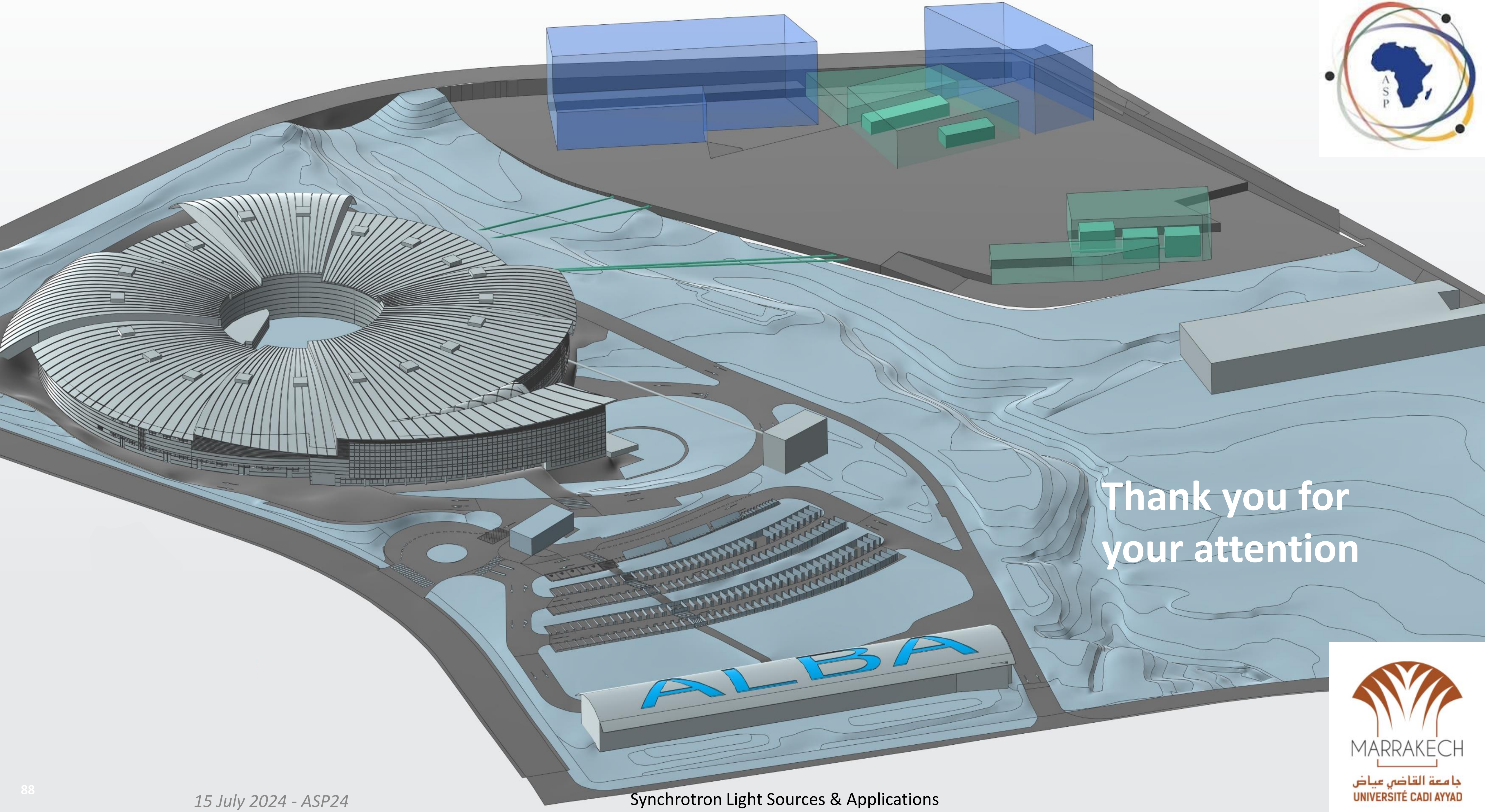

Thank you for your attention

MARRAKECH
جامعة القاضي عياض
UNIVERSITÉ CADI AYYAD