The ALBA project

Monday 22 Nov 2010 at 17:45 (00h45')

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Co-authors :

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ALBA

Joan Bordas

CELLS

Synchrotron Light and its properties…

are essentially due to two physical phenomena:

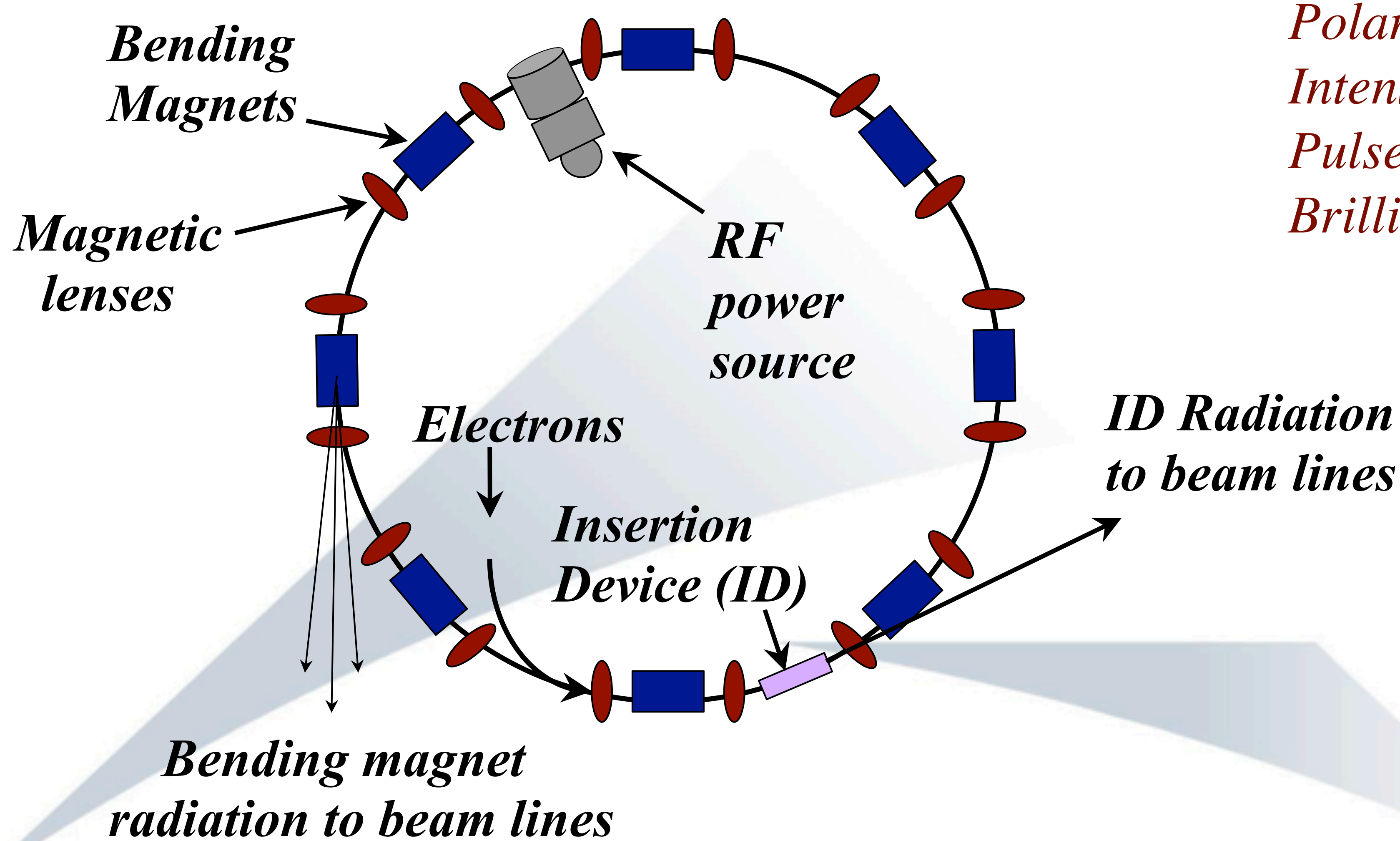
i) Electrically charged particles under acceleration lose energy as electromagnetic radiation (Maxwell's laws), and;

i) An isotropic monochromatic light source moving at relativistic speeds towards an stationary observer is perceived by the latter as highly collimated and with a photon energy shifted to higher energies (Laws of Relativity).

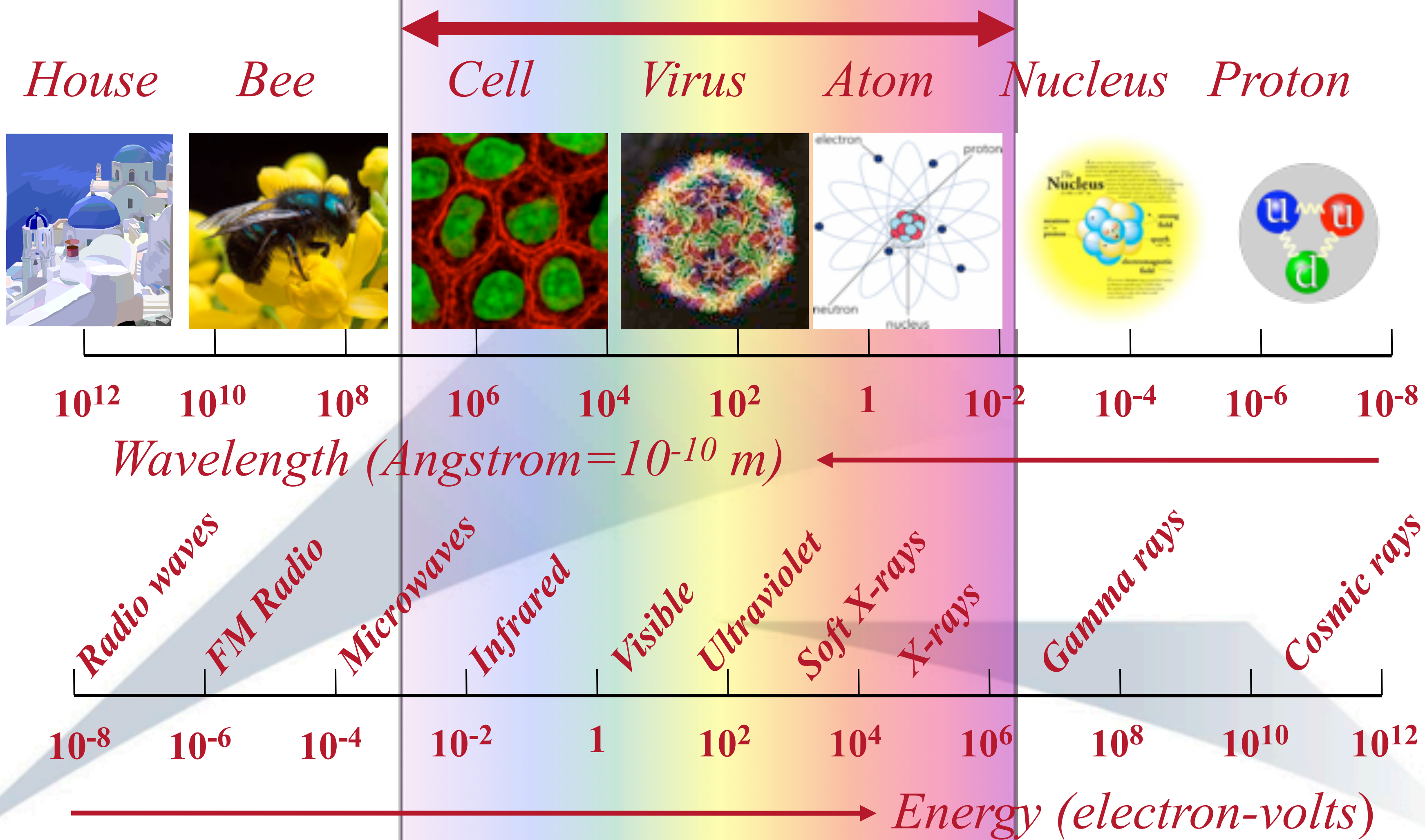
These two phenomena occur at electron accelerators!

An accelerator as a Synchrotron Light Source:

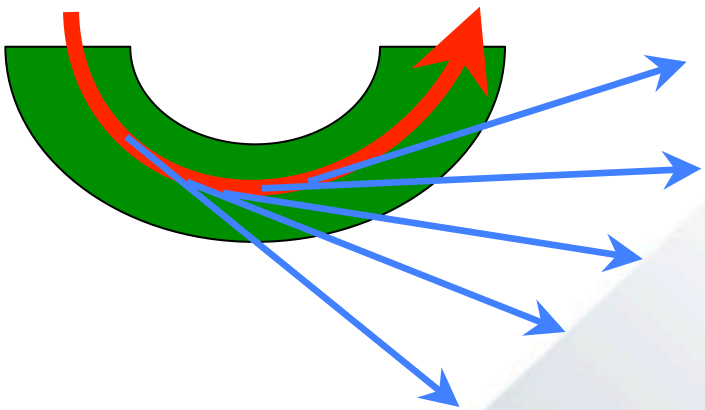
White;
Collimated;
Polarised;
Intense;
Pulsed;
Brilliant



SL is almost white, with all wavelengths from the size of cells to that of atoms!

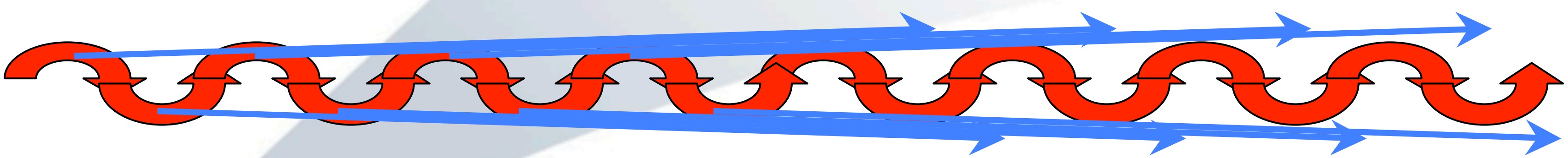


Light Sources



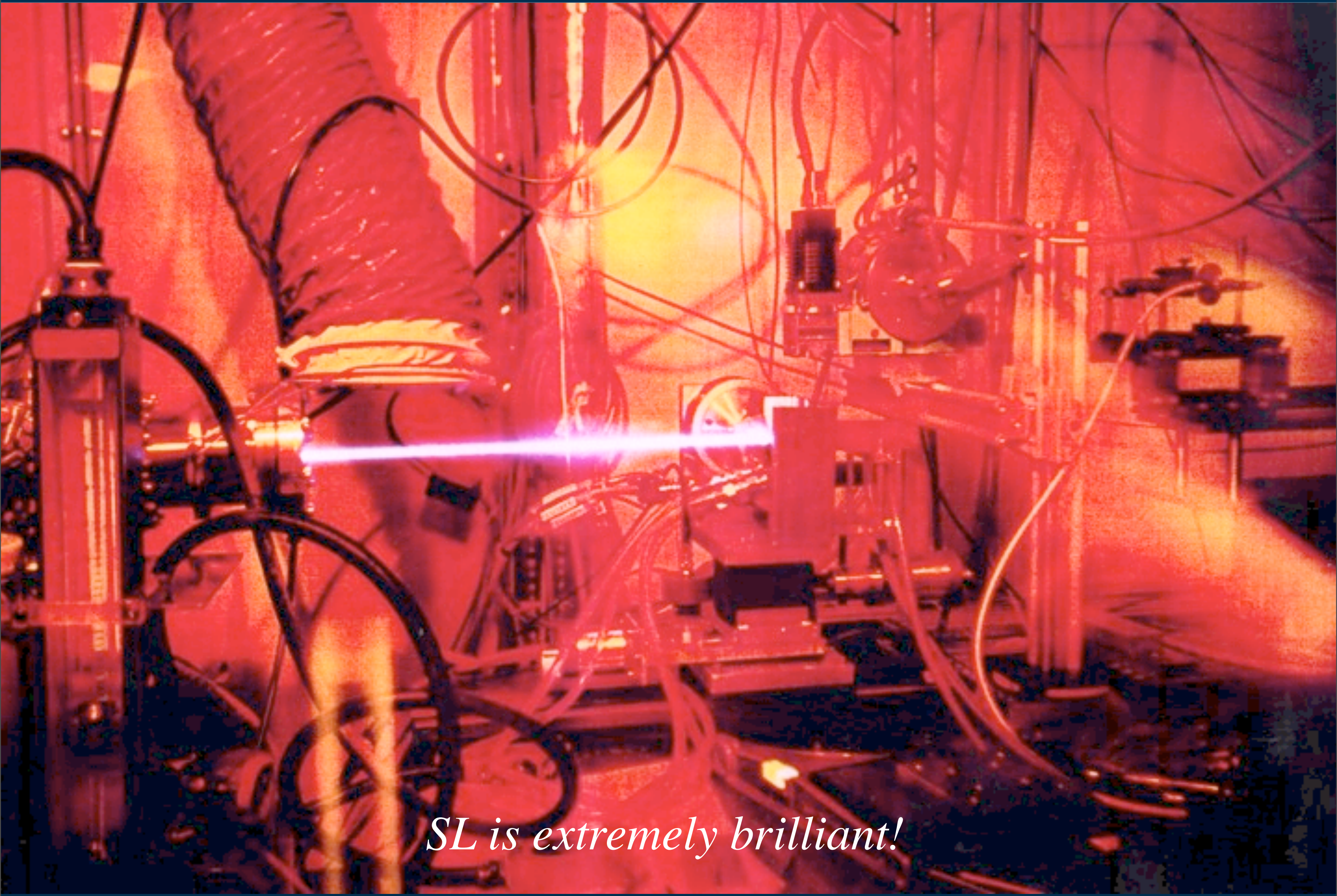
Bending magnets
1st and 2nd generation SR sources

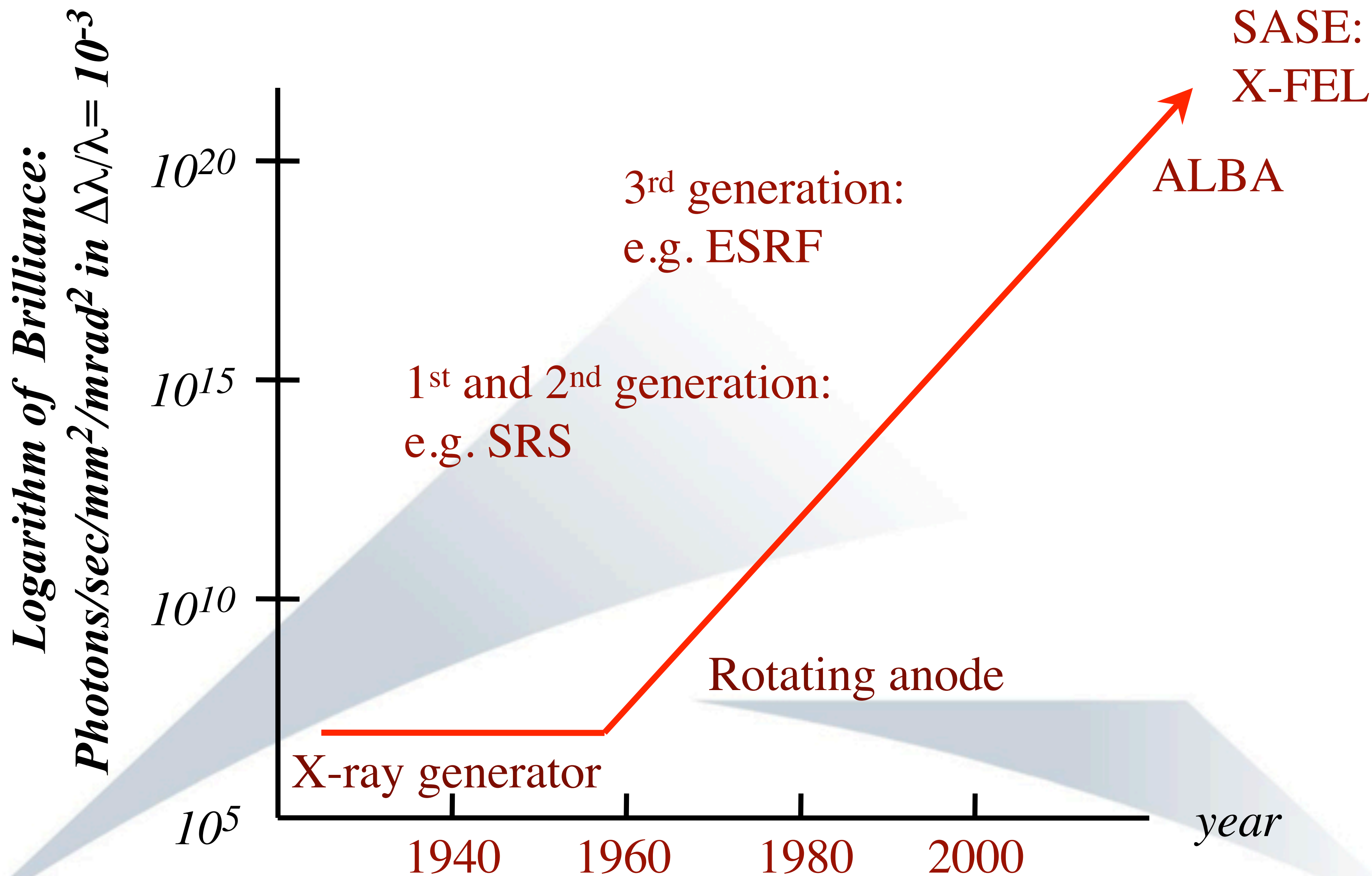
Multipole wigglers and undulators
3rd generation SR sources



Electrons

SR


SL is extremely brilliant!



Logarithm of Brilliance:
Photons/sec/mm²/mrad² in Δλ/λ = 10⁻³
10^20
10^15
10^10
10^5
SASE:
X-FEL
ALBA
3rd generation:
e.g. ESRF
1st and 2nd generation:
e.g. SRS
Rotating anode
X-ray generator
1940
1960
1980
2000
year

WHY SL?

QUALITY: conformance with requirements

REQUIREMENTS: to resolve in energy, and/or momentum, and/or time and/or space whilst recording statistically significant data.

THE QUALITY OF DATA IS PRE-DETERMINED BY THE BRILLIANCE OF THE SOURCE

(*LIOUVILLE´S PRINCIPLE*)

Synchrotron Light simply provides new opportunities in Science.

Diffraction/Scattering

(< 0,1 nm to >1 μm resolution)

Spectroscopy

(ΔE/E 10^{-6} nm)

Imaging

(< 10 nm resolution)

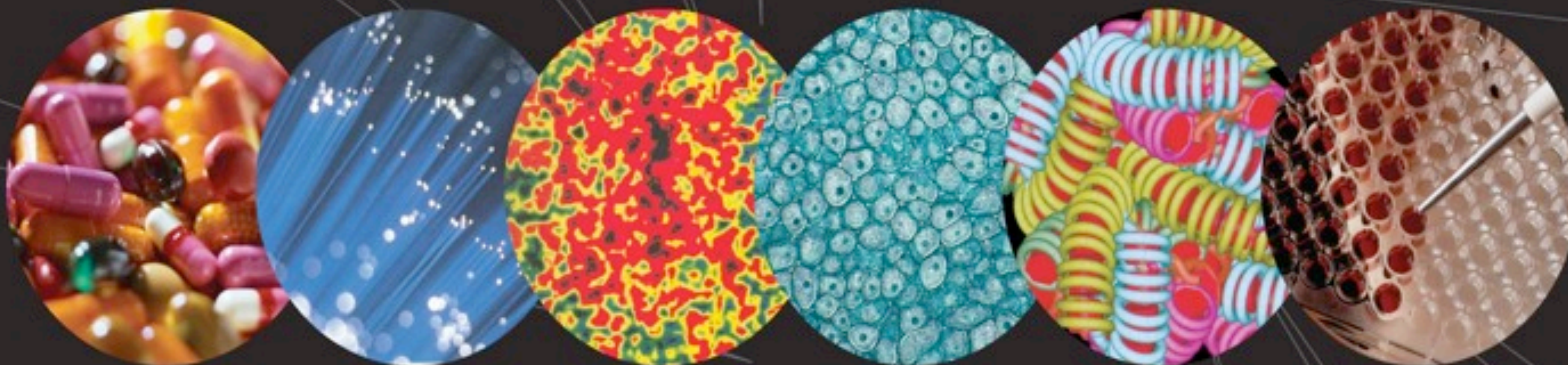
Time studies

(ps resolution)

Some experimental techniques using SL and Science Areas

	Solid state physics	Material science	Atomic physics	Molecular physics	Chemistry	Photo-chemistry	Nuclear physics	Biomolecular structure	Cell biology	Geology	Industrial fabrication
Absorption/reflection spectroscopy	●	●	●	●		●		●		●	
Emission spectroscopy	●	●	●	●		●		●		●	
Spectromicroscopy	●	●			●				●		
Photoelectron spectroscopy	●	●	●	●	●	●		●		●	
Photoion spectroscopy	●	●	●	●	●	●				●	
EXAFS, XANES	●	●	●	●	●	●		●	●	●	
Holography	●	●		●							
Photoelectron diffraction	●	●		●							
Photoestimulated desorption	●	●		●							
Circular dichroism	●	●		●	●				●		
XR fluorescence analysis	●	●	●	●	●	●		●	●	●	
Inelastic scattering of photons	●		●	●	●						
XR diffraction/scattering	●	●			●	●		●		●	
XR standing wave	●	●			●						
XR diffuse scattering		●			●	●		●		●	
Small angle XR scattering		●			●	●		●		●	
Soft XR microscopy								●	●	●	
XR lithography		●									●
Topography										●	
Microtomography					●				●		
XR interferometry	●	●	●	●				●			
XR imaging									●	●	
Photon assisted processing						●					●
Microfabrication											●
Reverse Comptom scattering							●				

Synchrotron Light



CHEMISTRY

X-ray analysis of chemical elements allows diversification of methods and improvement of production processes for adhesives and lubricants, anti-corrosion coatings, surface electro-chemical preparations, hydrophobic coatings and many others.

MATERIALS SCIENCE

By means of non-destructive image formation one can establish the three dimensional structure of non-crystalline materials, where their behaviour depends on the presence of nano-crystalline phases or chemical impurities (doping) that cannot be studied by traditional means, and which are nevertheless extremely important in the material's performance.

Synchrotron Light is also used, for example, in the study of: special alloys for use in aerospace technology; the electronic and atomic structure of catalysts; semiconductors; superconductors; and how these properties depend on high pressure or temperature.

MAGNETISM

Techniques exclusive to synchrotron light sources, such as soft X-ray magnetic circular dichroism, are used to image the magnetic domains in thin films and mono-layers. These are essential in sensors and data storage devices. In addition, Synchrotron Light is used for "in situ" detection of magnetic microstructures.

LIFE SCIENCES

Time-resolved X-ray diffraction, unique to Synchrotron Light, is routinely used to study the structural/functional changes undergone by, for example, DNA, proteins and macromolecules in solution, as well as structural/functional studies of hormones, enzymes and viruses.

For example, muscles, and other biological systems, convert chemical energy into force or motion. Muscle molecules undergo subtle and rapid conformational changes that only Synchrotron Light is capable of detecting. It is thanks to such techniques that we can understand the sequences of molecular events responsible for muscular contraction.

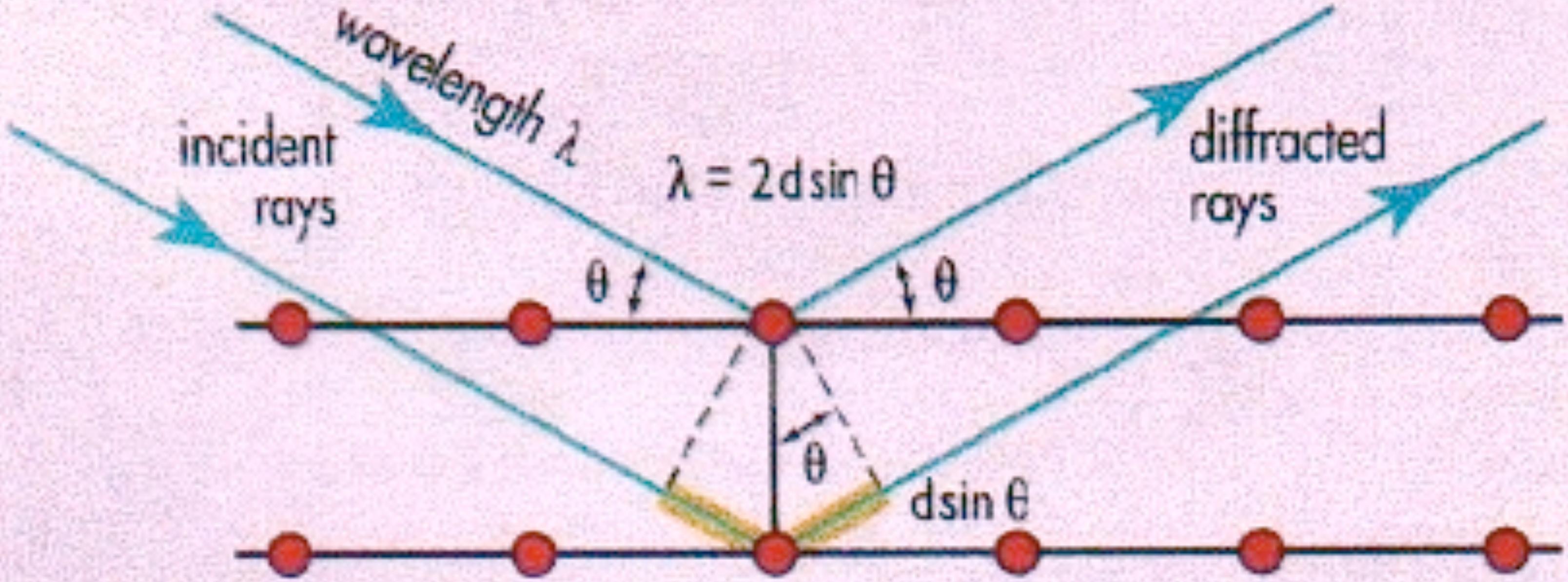
MACROMOLECULAR CRYSTALLOGRAPHY

This is currently an area of intense activity, both academically and in industry. As a result of the completion of the Human Genome Project it is now possible to crystallize many biological macromolecules intimately involved in a given biological target. Synchrotron Light has solved the atomic structure of many biological macromolecules and will continue to do so until all the protein structures (in excess of 50,000) derived from the knowledge acquired in the Human Genome Project are solved. One important recent example is the atomic structure of the biological protein manufacturing machinery, i.e., ribosome.

INDUSTRY

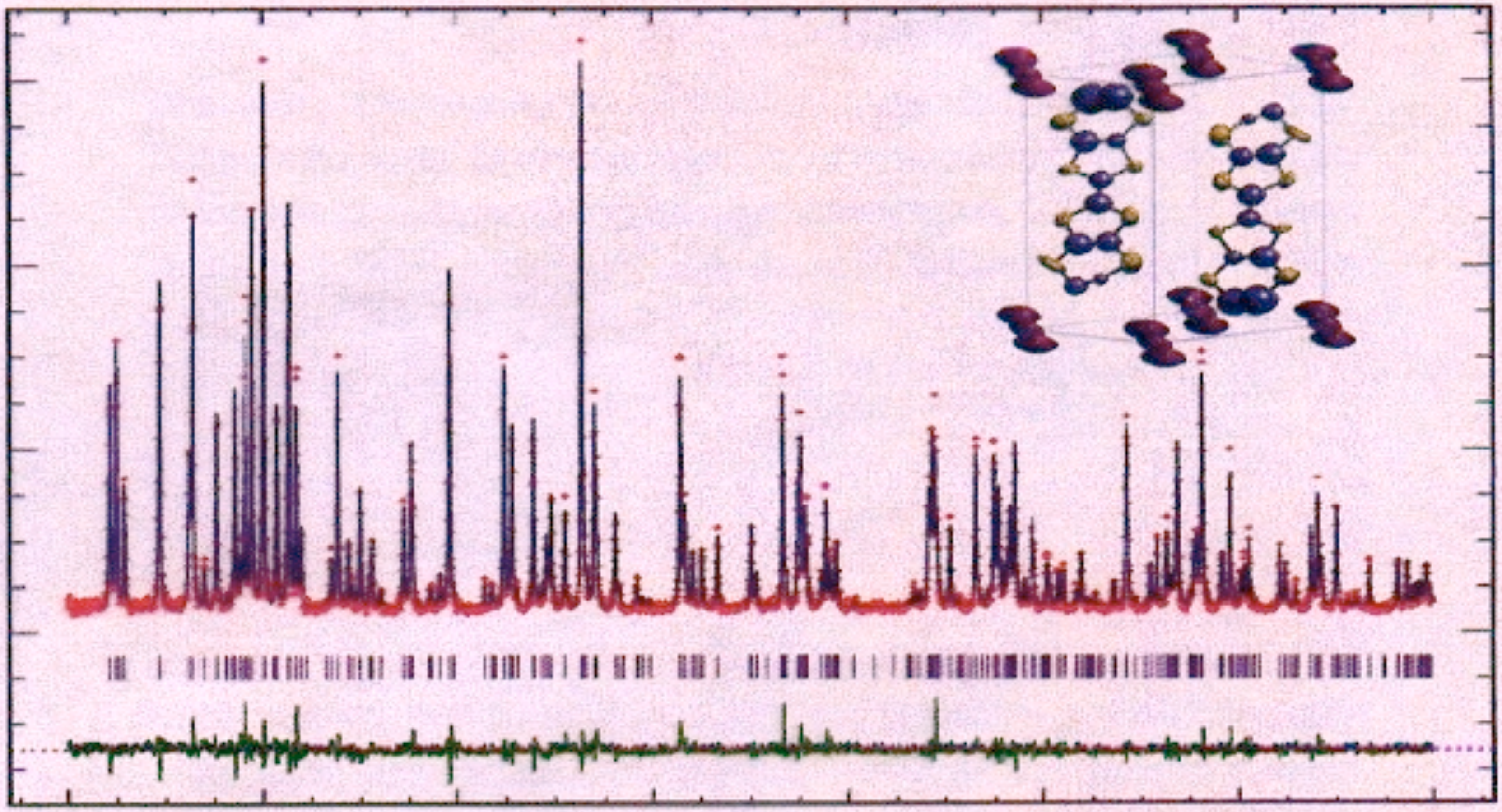
In the past, many industrial processes, such as polymer and ceramics production, depended on the skill of the experts and on chance. Great control and predictability has now been acquired in these processes following research carried out with Synchrotron Light.

Other industrial applications are in areas such as electronics (e.g., chip manufacture), micro-mechanics (e.g., manufacture of sub-micron devices used in medical or sensor applications), aerospace industry (e.g., detector calibration), pharmaceuticals (e.g., structural/functional studies of new drugs), and environmental applications (e.g., analysis of contaminated soils and/or plants).



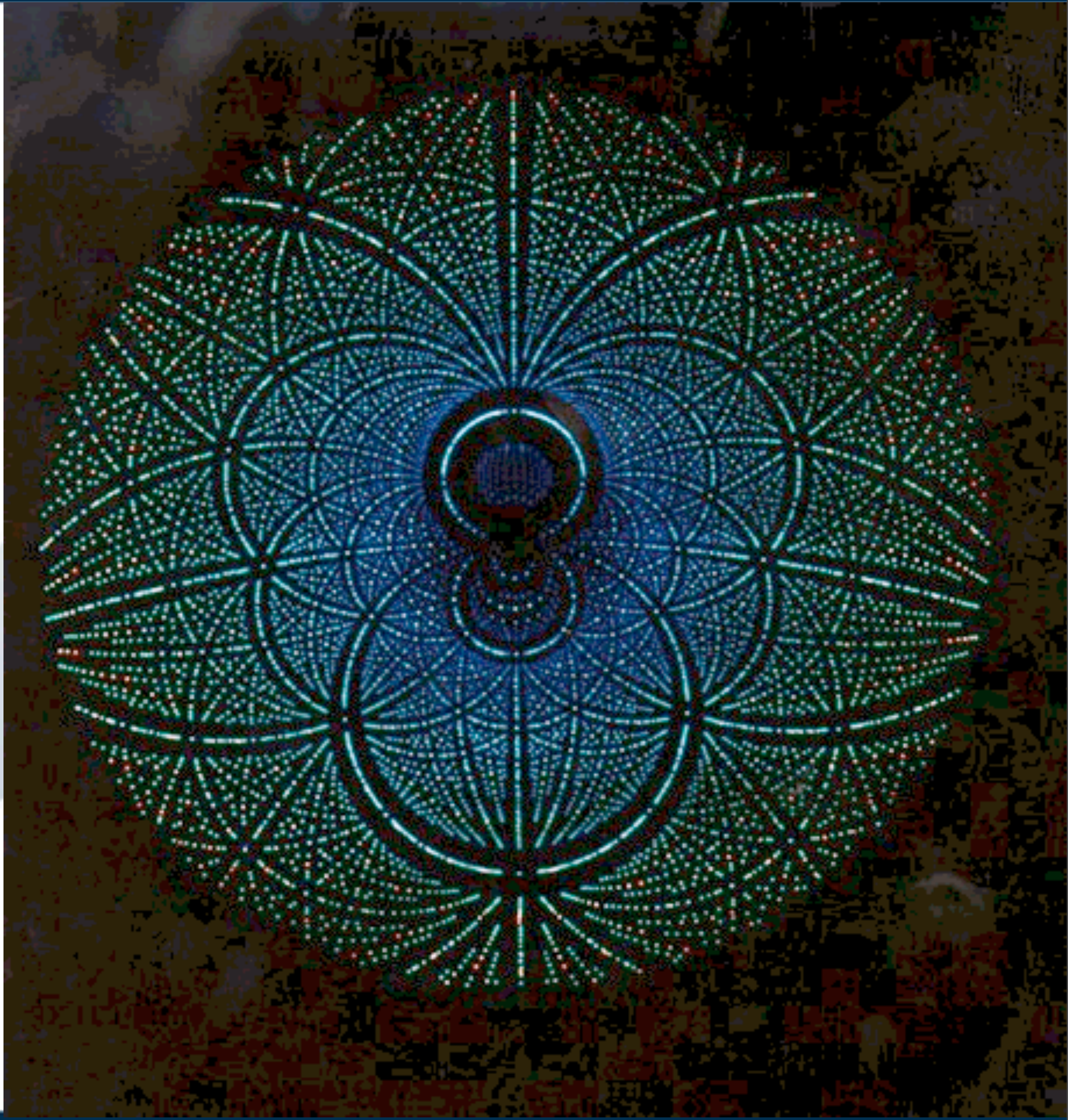
e.g. IN X-RAY SCATTERING AND DIFFRACTION

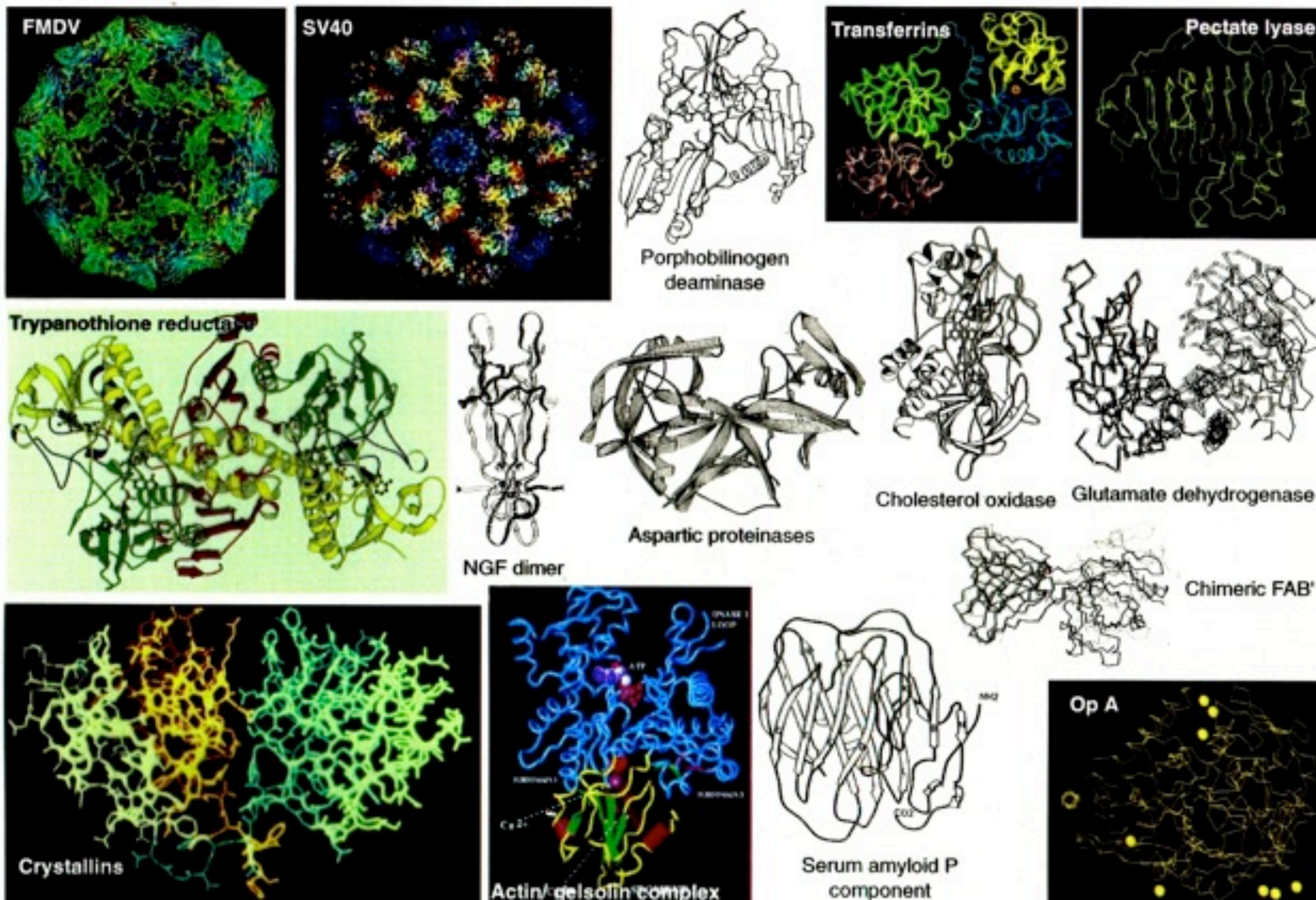
X-RAY SCATTERING AND DIFFRACTION



Powder diffraction pattern and corresponding crystal structure of the superconductor α_t -$(Et)_2$ I_3 deduced from it (ESRF).

SL IS PARTICULARLY IMPORTANT FOR MACRO-MOLECULAR CRYSTALLOGRAPHY BECAUSE RECIPROCAL SPACE IS THEN DENSELY POPULATED: AND HIGH BRILLIANCE IS REQUIRED!

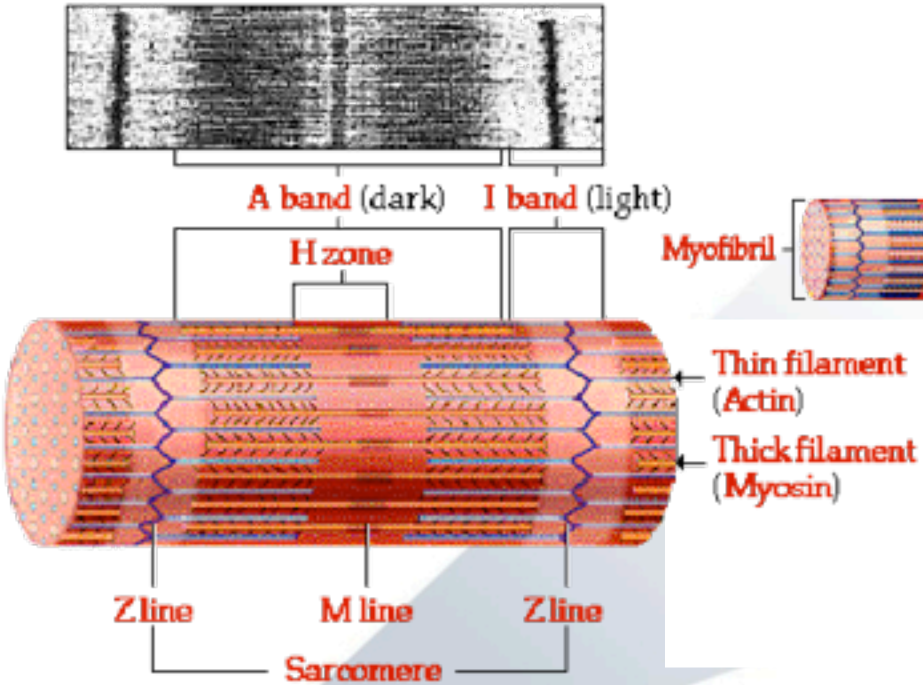


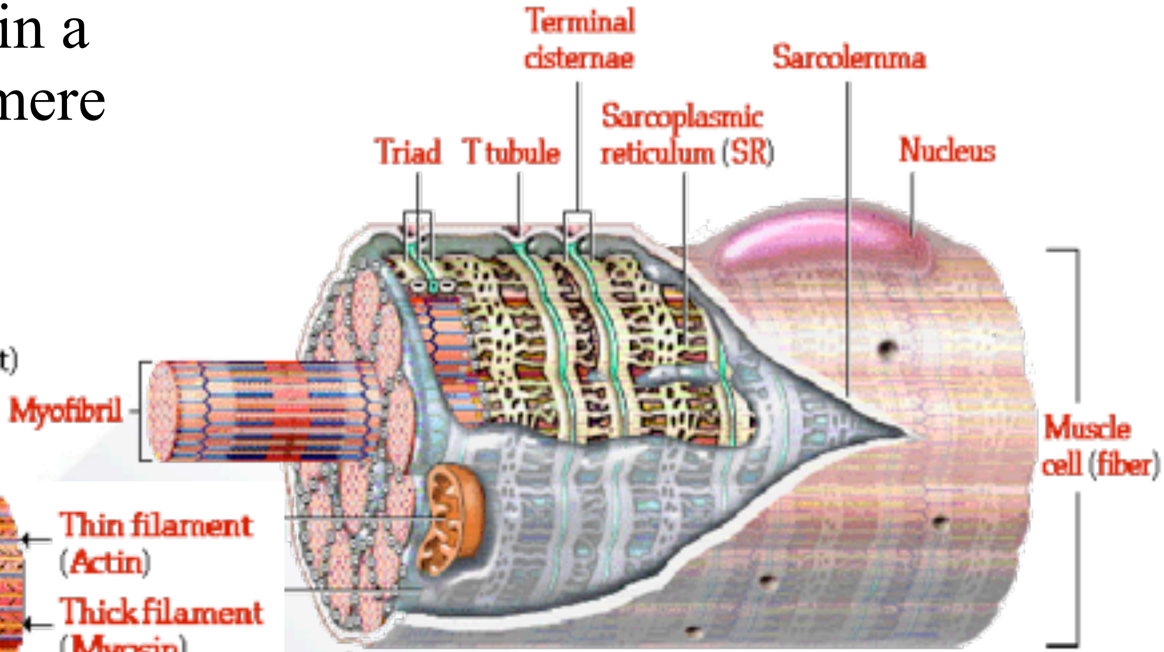


FMDV
SV40
Porphobilinogen deaminase
Transferrins
Pectate lyase
Trypanothione reducta
NGF dimer
Aspartic proteinases
Cholesterol oxidase
Glutamate dehydrogenase
Chimeric FAB'
Crystallins
Actin/ gelsolin complex
Serum amyloid P component
Op A

Flux and brilliance are also essential for time resolved studies: e.g. structural/ functional studies of "in vivo" muscle tissues.

Muscle fibres are organized in a periodic structure, the sarcomere





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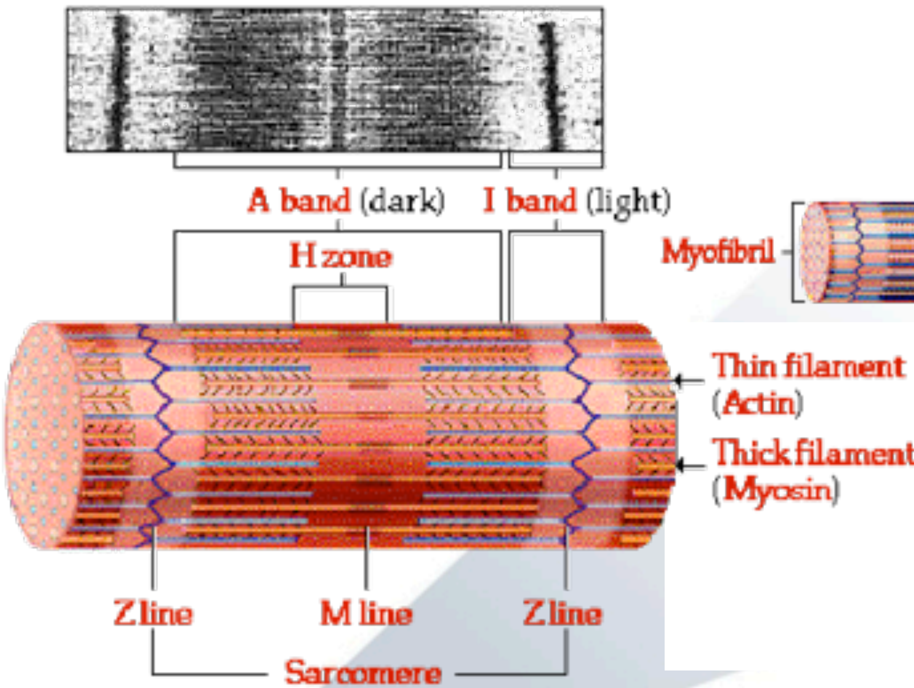
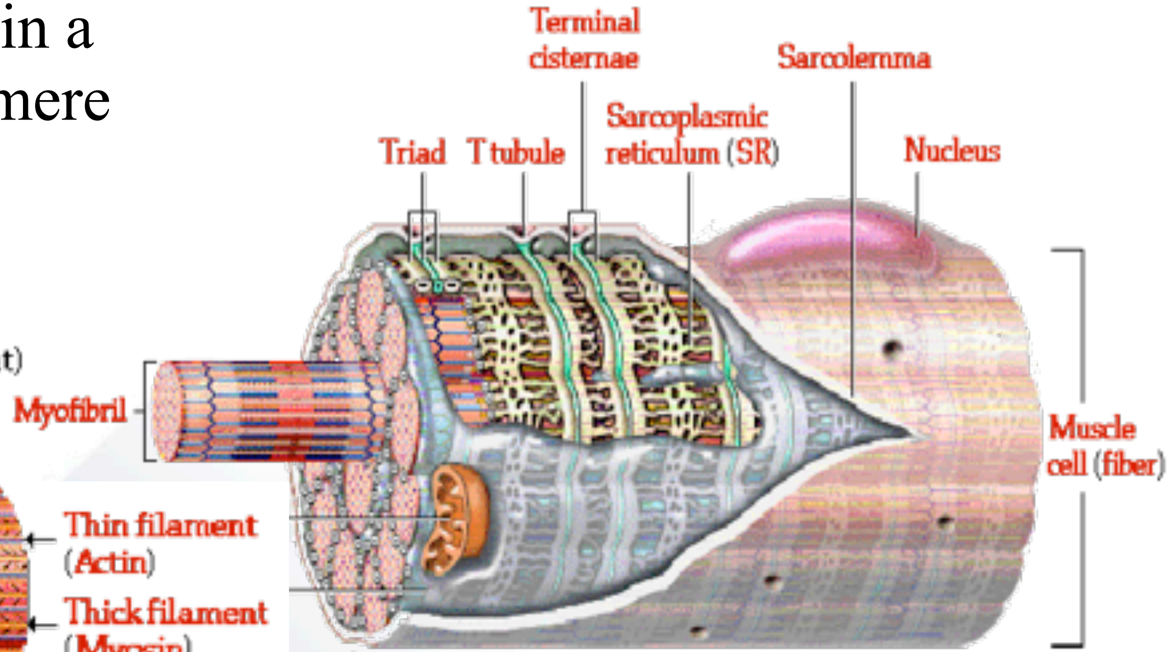
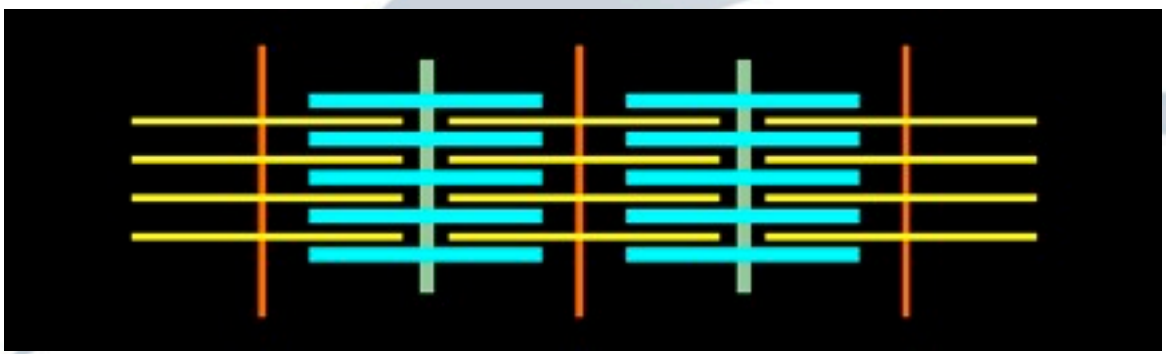
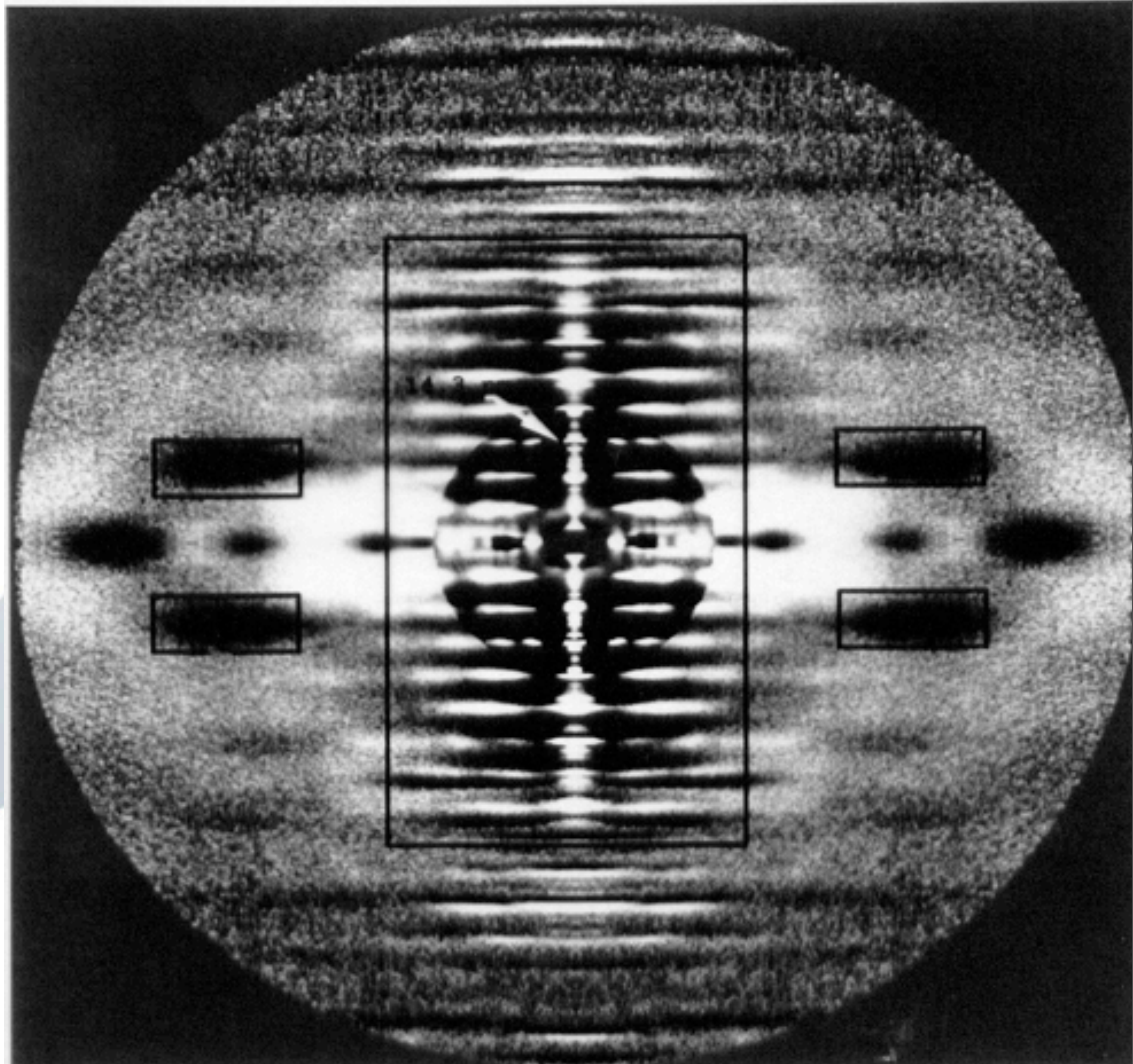






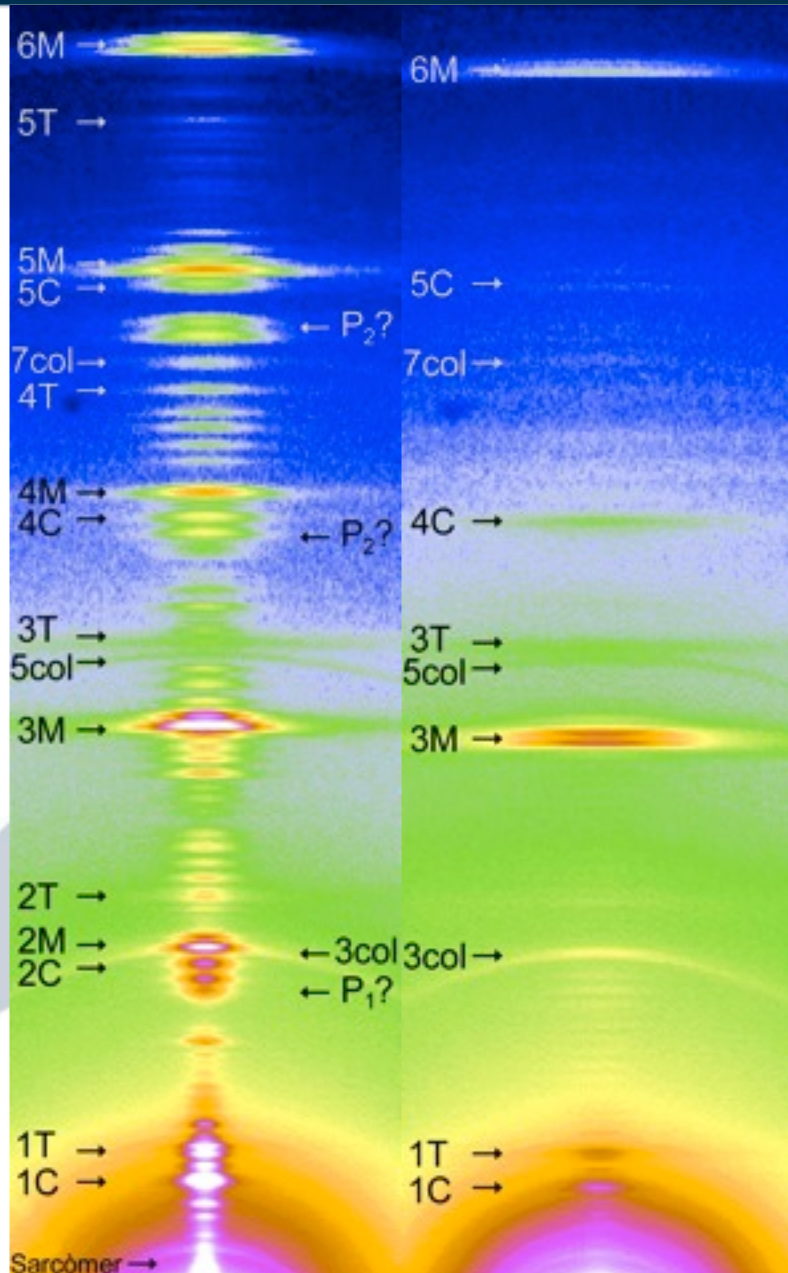
The sliding filament model

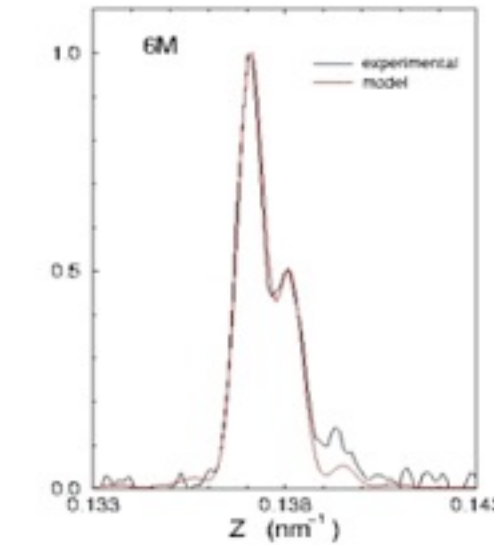
Difference X-ray diffraction diagram: Rest (white) - Isometric contraction (black)

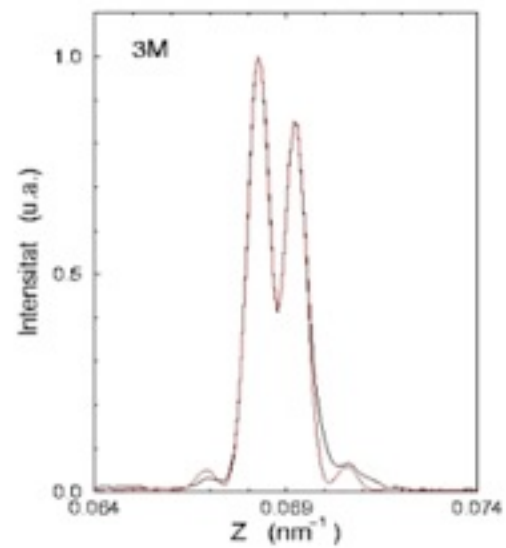


Whether at rest, Po or Vo all diffraction peaks are axially split. Due to sarcomere structure and can be used for phasing.

At Po the helically forbidden reflections are practically absent







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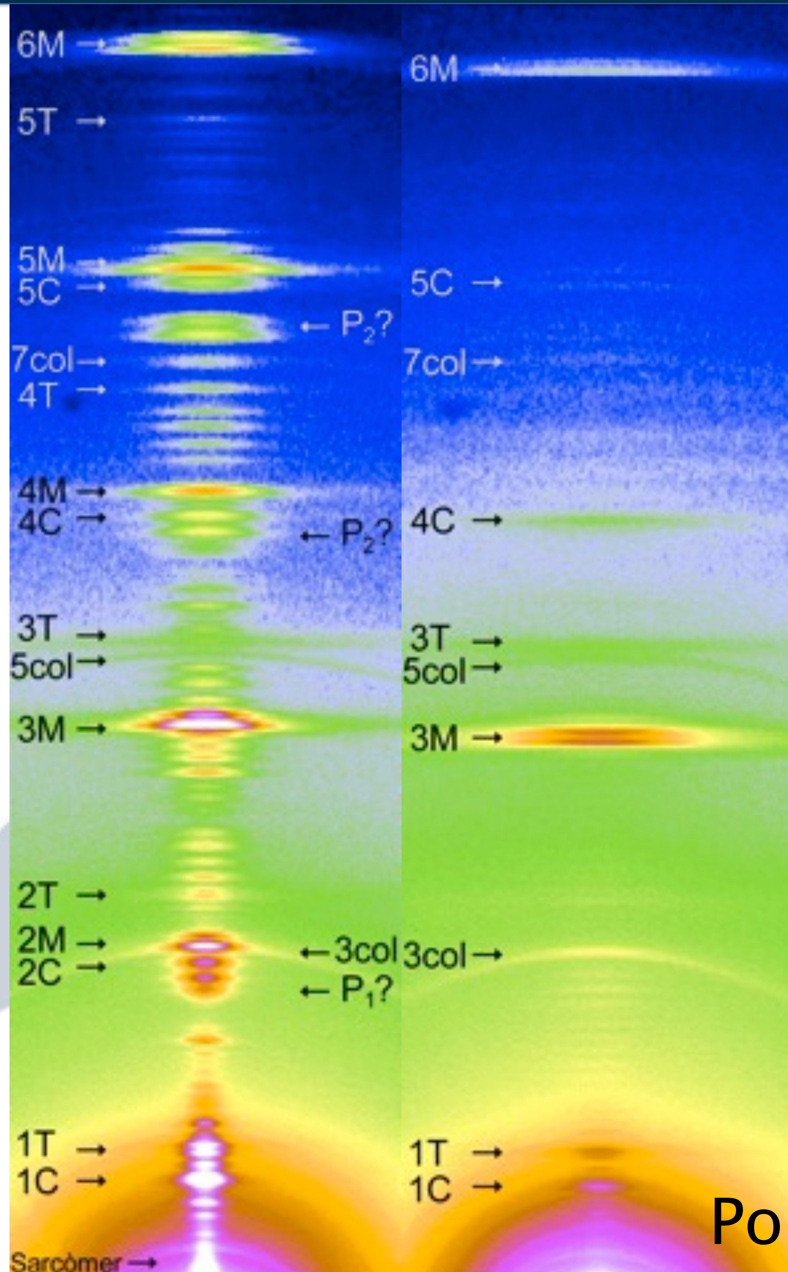

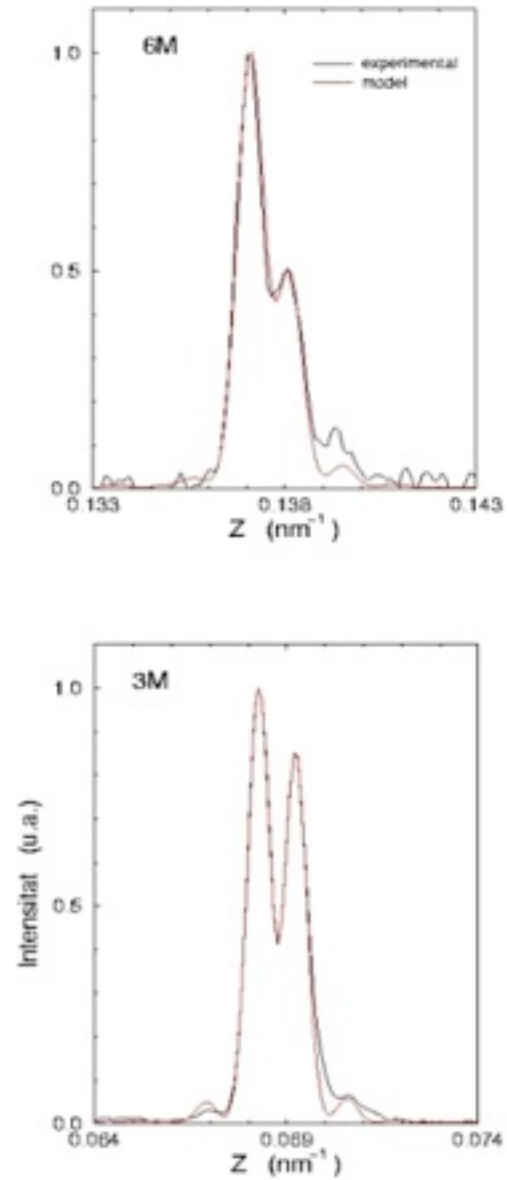

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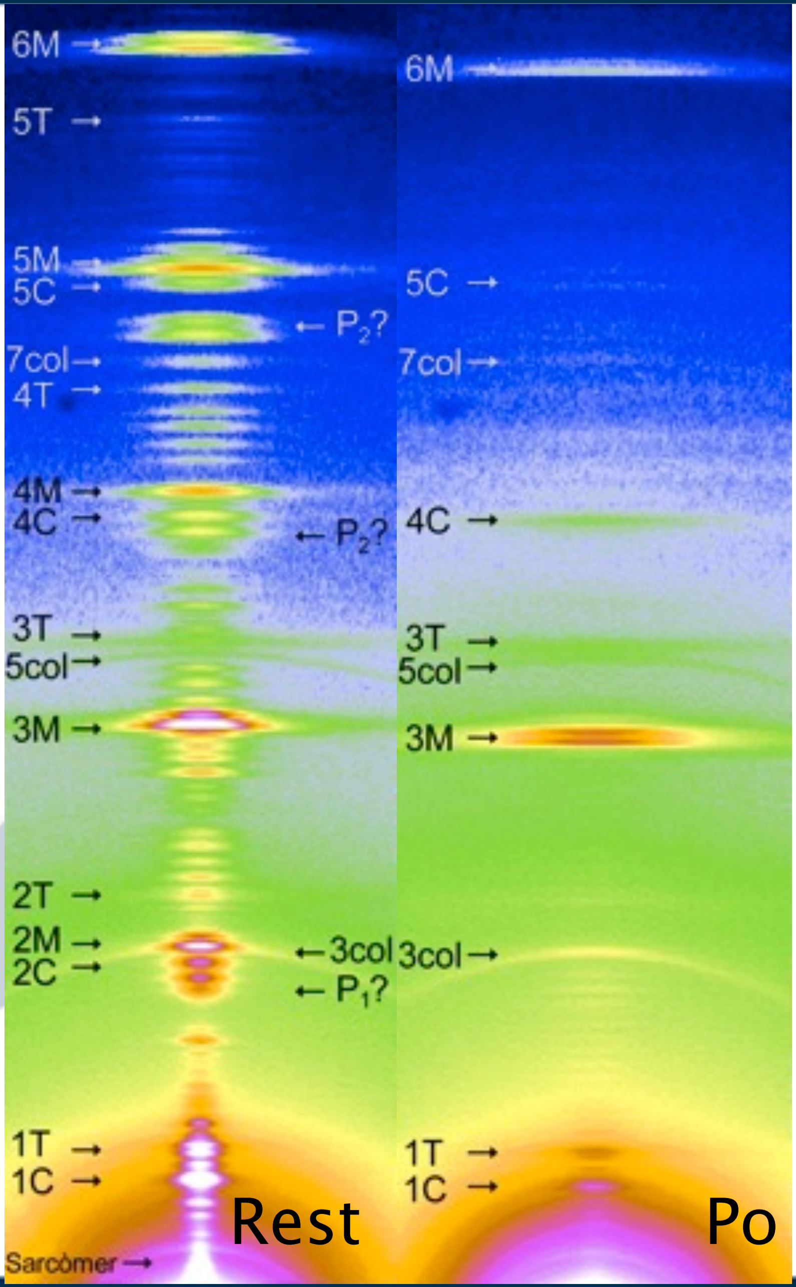
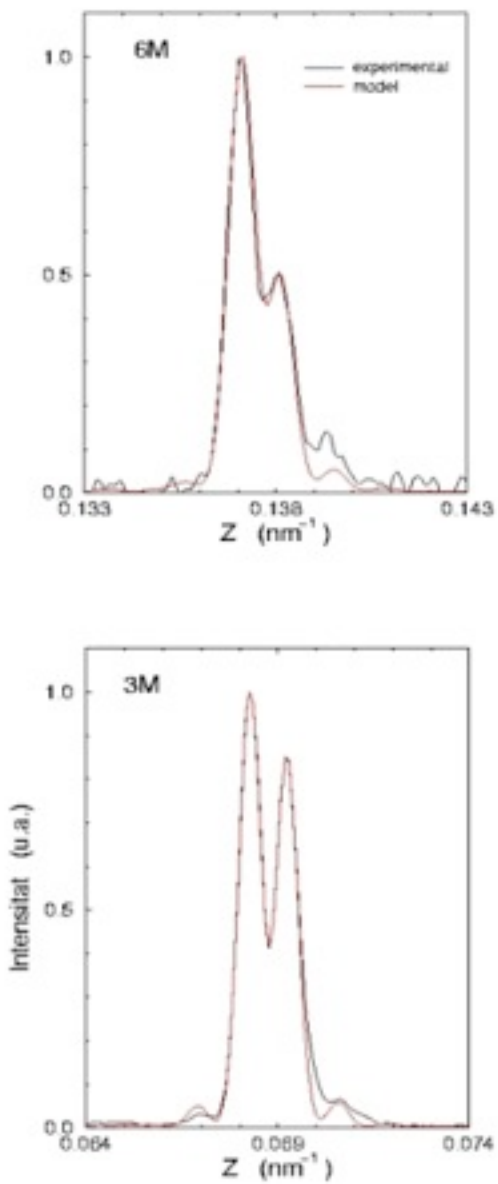
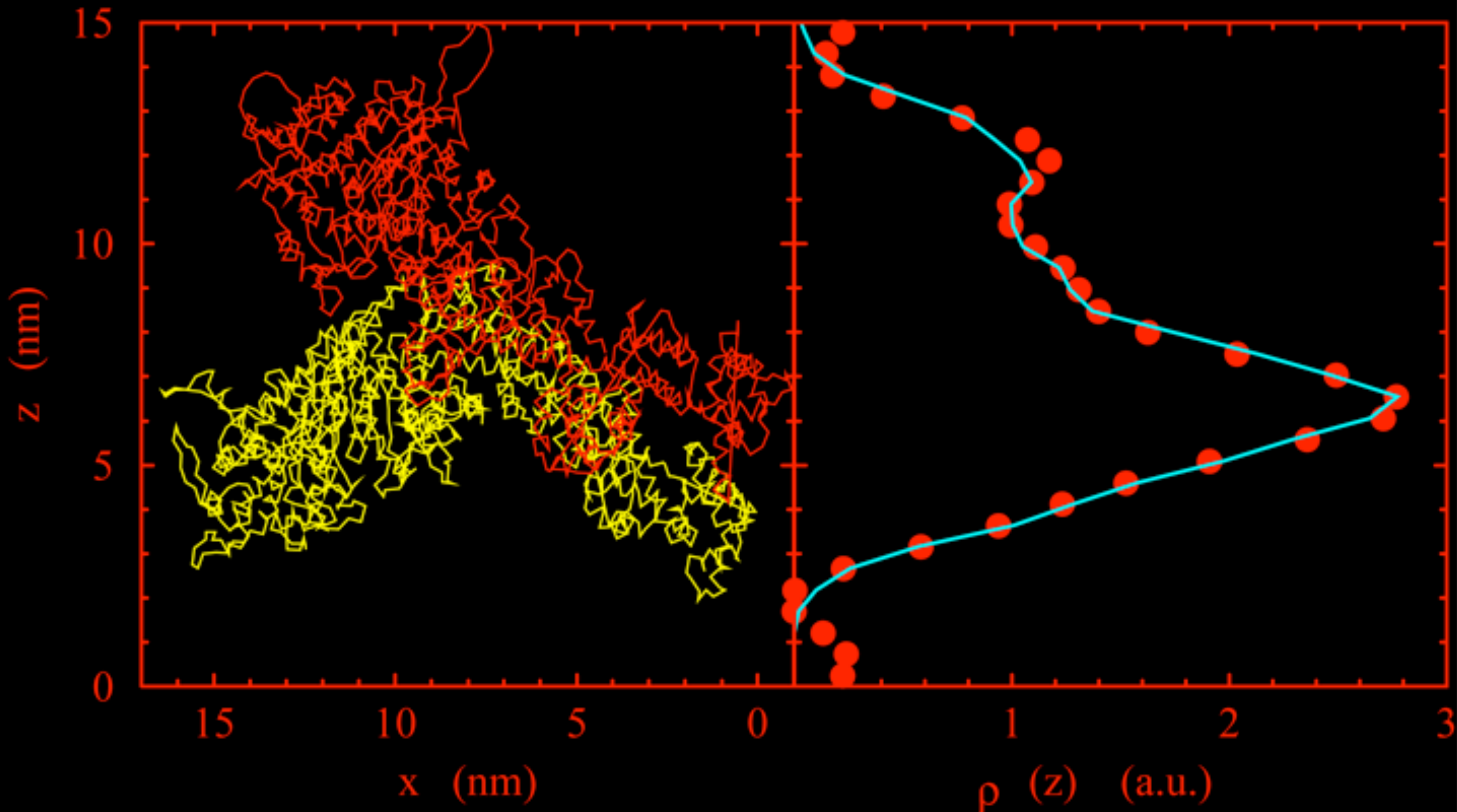






Best fit of axial disposition

Electron density of mass projection

Industrial applications of SR:

Materials

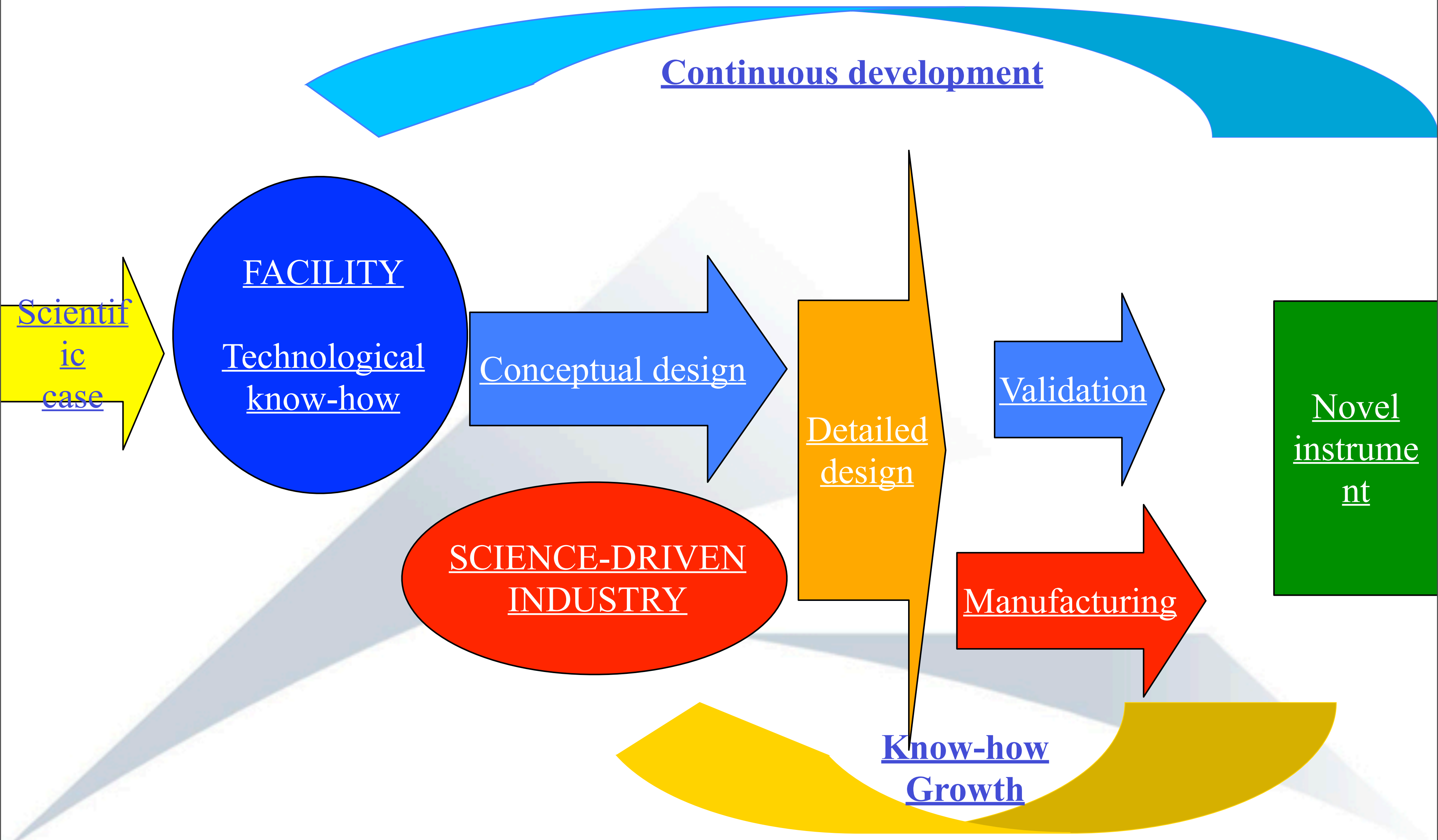
testing,

production

and

characterization

Applications are found in a wide range of sectors, e.g. in: pharmaceuticals, food industry, aviation, environment, cosmetics, buildings, polymers, micro-fabrication,


Continuous development
Scientific case
FACILITY
Technological know-how
Conceptual design
SCIENCE-DRIVEN INDUSTRY
Detailed design
Validation
Manufacturing
Novel instrument
Know-how Growth

A Synchrotron Light Facility is a project of projects where the major blocks are:

- *Buildings and conventional services therein.*
- *Complex of accelerators: LINAC, Booster, and Storage Ring.*
- *Beam-lines and experimental stations.*

The example of ALBA

First order choices:

Accelerator energy of 3 GeV to have some overlap with the ESRF and to use undulators to deliver intermediate energy X-rays (i.e. 10-20 keV).

The natural emittance should be $\varepsilon_x < 5$ nm.rad. We would have liked a smaller emittance but it quickly became clear that the size of budget and site did not allow it.

Other decisions were that the accelerator should:

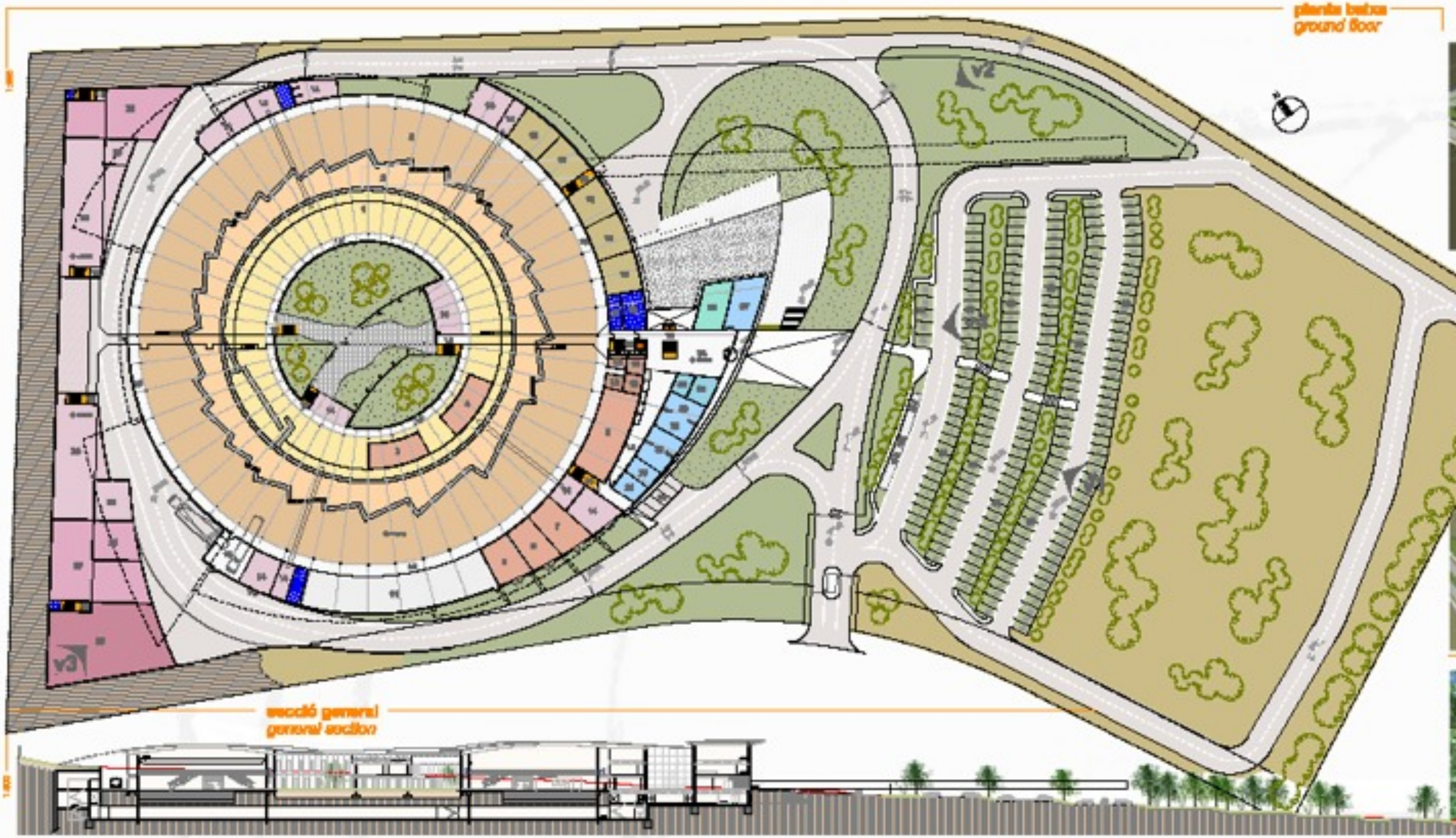
operate in the top-up mode;
use FOFB to achieve sub-μm stability;
base the RF system on HOM free cavities (not superconducting);
have a bean lifetime > 10 h;
have a lattice energy acceptance > 3%, and;
contain as many as possible straight sections for user IDs.

(at the end 38% of perimeter is devoted to SS)

Complex of buildings and services therein

Mechanical, Thermal and Electrical stability

ALBA



DICIEMBRE 2006

FEBRERO 2007


ABRIL 2007

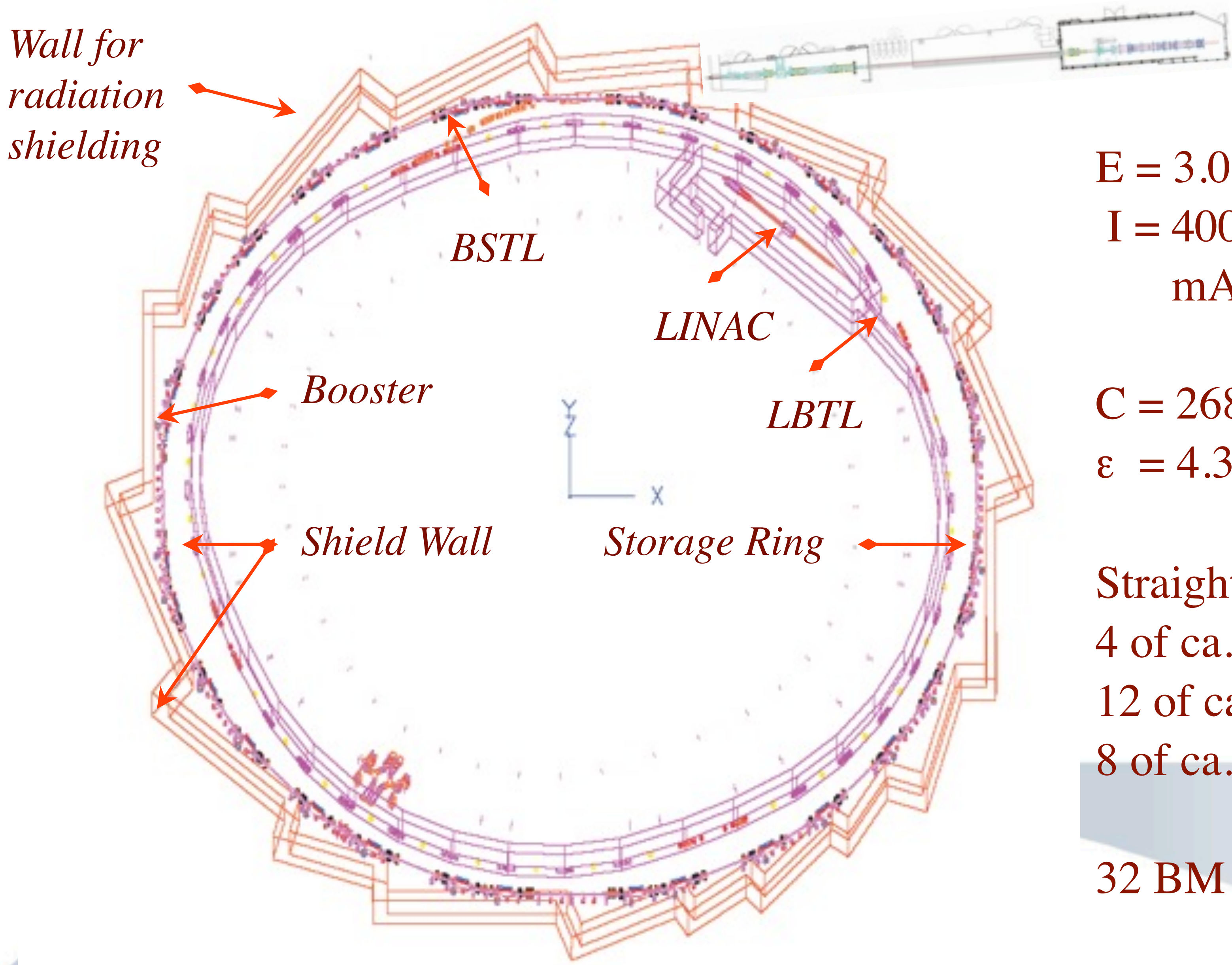

NOVIEMBRE 2007


AGOSTO 2008

ALBA

Thermal stability is ensured by cool air injection into, and circulation through, the tunnel and the Experimental Hall.

Complex of accelerators



E = 3.0 GeV
I = 400 mA

C = 268.8 m
ε = 4.3 nm.rad

Straight sections:
4 of ca. 8 m
12 of ca. 4.3 m
8 of ca. 2.58 m

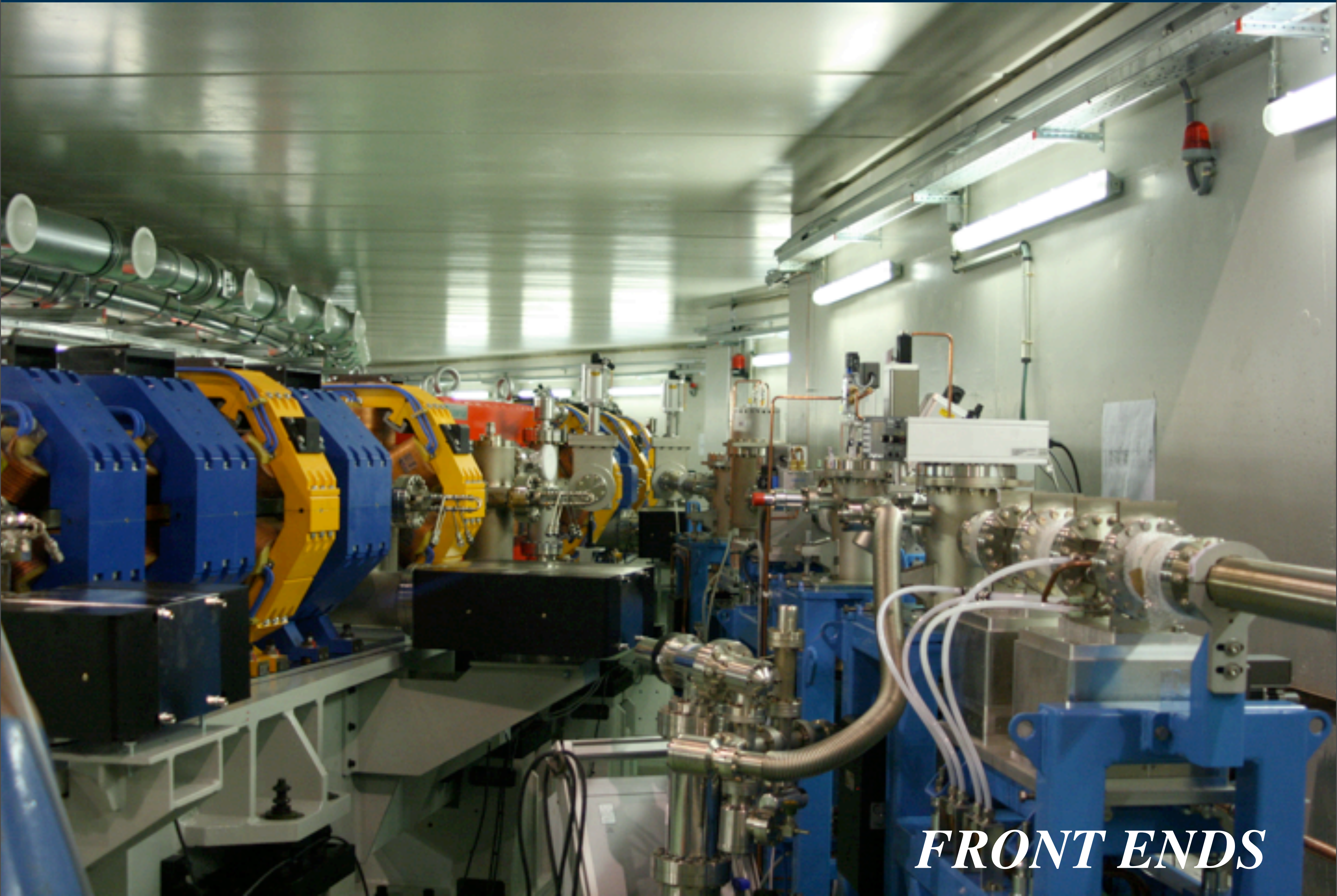
32 BM

Capacity for


LINAC


BOOSTER


SR AND BOOSTER


FRONT ENDS

The complex of accelerators is undergoing commissioning

Commissioning of Linac and Booster is essentially finished.

Commissioning of SR still ongoing (until early 2011)

Installation and commissioning of IDs expected to end in mid 2011.

Beam-lines and experimental stations

In a 3rd generation SL source it is useful to optimise the lattice design so that the possible trade between source size and collimation is used to tailor points of light extraction to specific needs - e.g. spectroscopy benefits from collimation, whilst imaging benefits from a small and round source size -.

SUMMARY OF THE PARAMETERS OF THE 4-FOLD, 16 CELL, EXPANDED DBA LATTICE:

E = 3.0 GeV C = 268.8 m ε ca. 4.5 nm.rad

4 straight sections 8 m long each: 3 useful for Beam-lines
12 straight sections 4.3 m long each: 12 useful for Beam-lines
8 straight sections 2.58 m long each: 2 useful for Beam-lines
32 Bending Magnets: 16 useful for Beam-lines
i.e. 33 FE for beam-lines

Source point	β_x (m)	α_x	β_y (m)	α_y	D_x (m)	D'_x	σ_x (μm)	σ'_x (μrad)	σ_y (μm)	σ'_y (μrad)
Long S.	10.20	0	5.22	0.05	0.15	0	263	21	15	3
Med-1 S.	1.98	0	1.153	0.05	0.09	0	133	47	7	6
Med-2-S.	1.98	0	1.21	0.10	0.09	0	133	47	7	6
Short S.	8.63	0	5.79	0.04	0.23	0	310	23	16	3
Bending	0.36	0.25	23.93	0.83	0.02	0.02	44	116	32	2

ALBA's initial portfolio of beam-lines:

- *Soft X-ray BL for polarisation dependent microscopy (PEEM) and electron emission spectroscopies of ¨real¨ surfaces, i.e. relatively high pressure. Two end stations (Phys., Mat. Sci.). Light source: Apple undulator*
- *Soft X-ray BL for XMCD and resonant scattering. Two end stations (Phys., Mat. Sci.). Light source: Apple undulator*
- *BL for high resolution powder diffraction with micro-focus option (Mat. Sci.). Light source: Superconducting wiggler*
- *High brilliance XAS (Chemistry,Biology, Mat. Sci.). Light source: Multi-pole wiggler*
- *Non-crystalline diffraction with micro-focus option (Biology+Mat. Sci.). Light source: In vacuum undulator*
- *Crystallography of very large macromolecules (Biology). Light source: In vacuum undulator*
- *X-ray microscopy BL (Biology). Light Source: Bending magnet*

Second phase beam-lines

- *Infrared micro-spectroscopy: Biology and Materials Science (start construction 2011). Light Source: Bending Magnet*
- *Low-Energy Ultra-High-Resolution Angular Resolved Photoemission: Physics and Materials Science (start construction 2011). Light Source: undulator.*
- *Micro-focus Macromolecular Crystallography: Structural Biology (start construction 2013). Light Source: undulator.*

Light sources for the initial beam-lines

2 Multipole wigglers (1 super-conducting):

X-ray spectroscopy (MW) and Powder Diffraction (SCW).

Status: delivered and undergoing lab. tests

2 in vacuum undulators:

Biomol. Xtallography (1) and Non-Xtalline scat/dif. (1)

Status: delivery expected this summer.

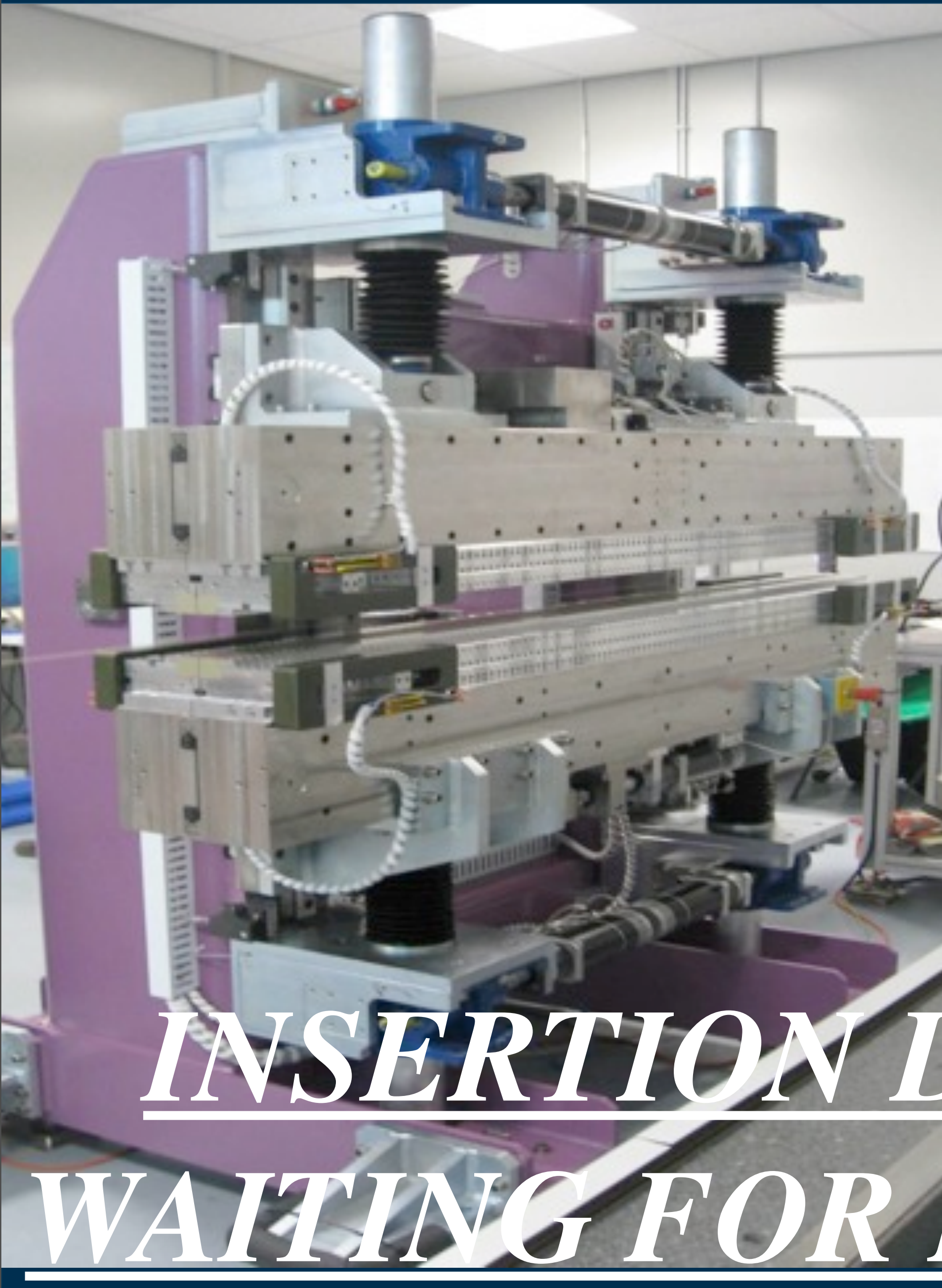
2 Apple type undulators:

XMCD+PE Spec. (1) and PEEM+PE Spec. (1)

Status: delivered and undergoing lab. tests

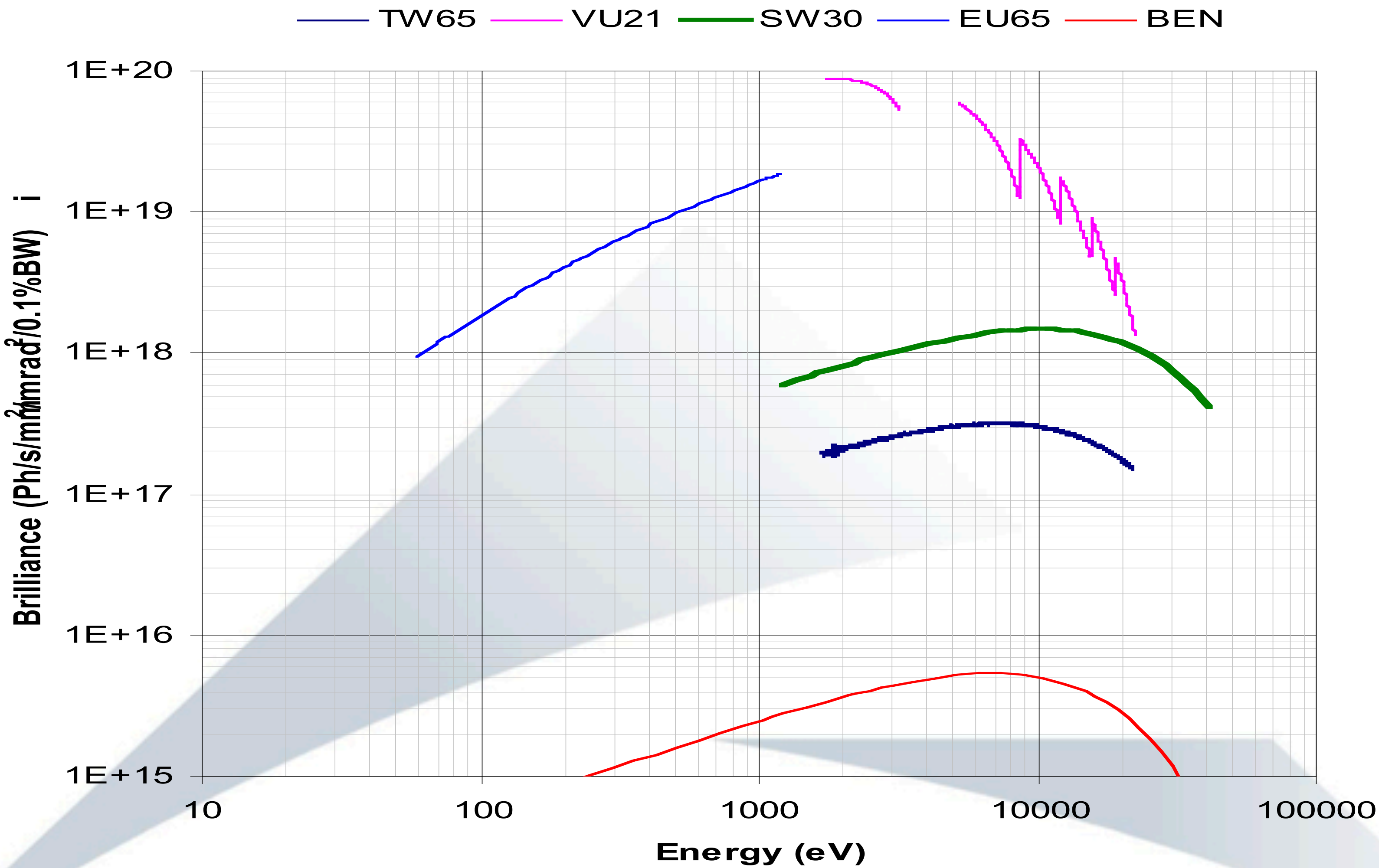
1 BM:

X-ray microscopy(1), primarily water window BL.



INSERTION DEVICES ARE WAITING FOR INSTALLATION

Brilliance of the various light sources at ALBA



PEEM and NAPP

Macromolecular Crystallography

Powder Diffraction

All hutches and their. infrastructures, e.g. cabling, gases, liquid N_2 supplies, water, etc. are complete.

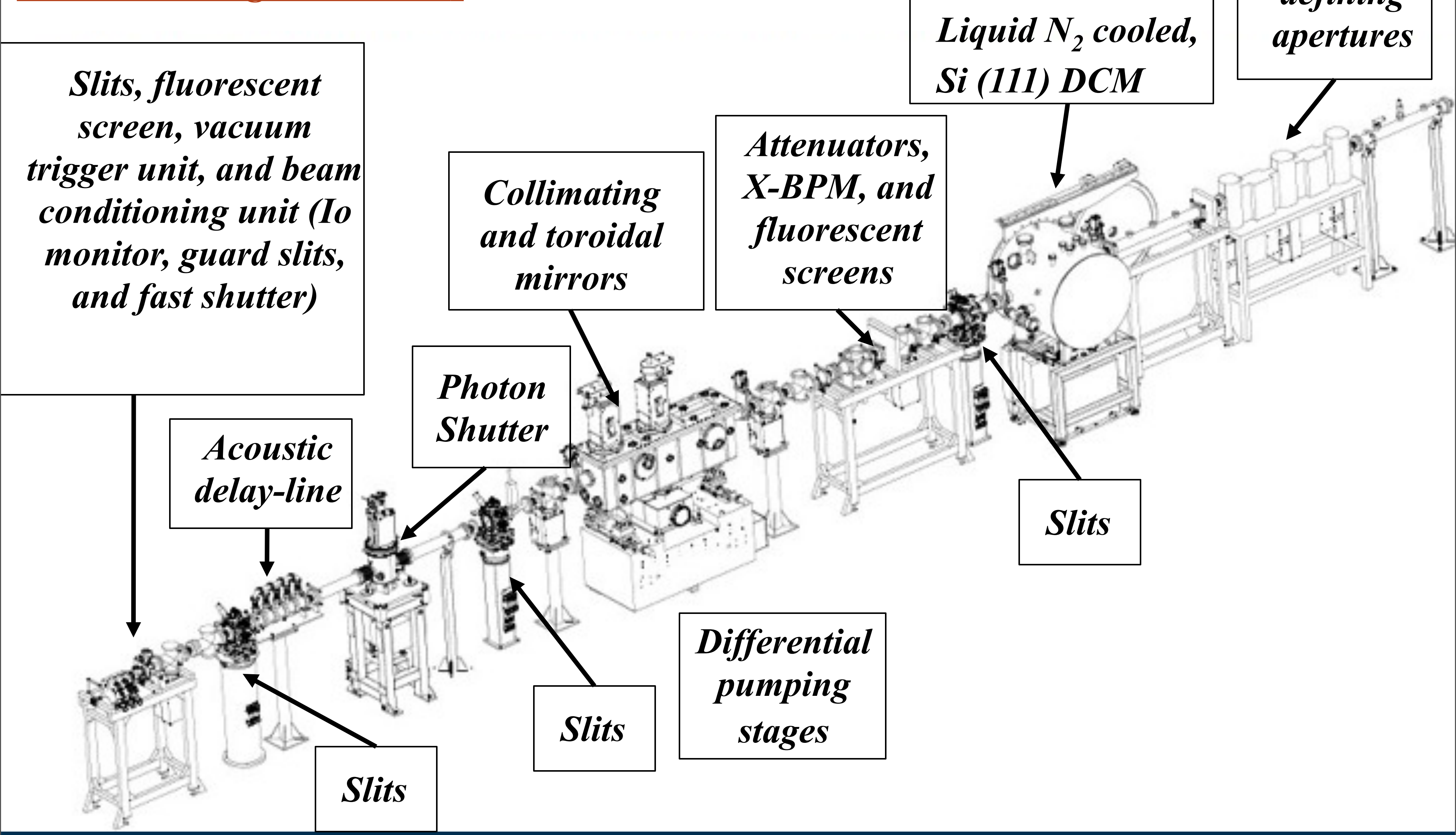
X-ray Microscopy

X-ray Absorption Spectroscopy

XMCD and Soft X-ray Scattering

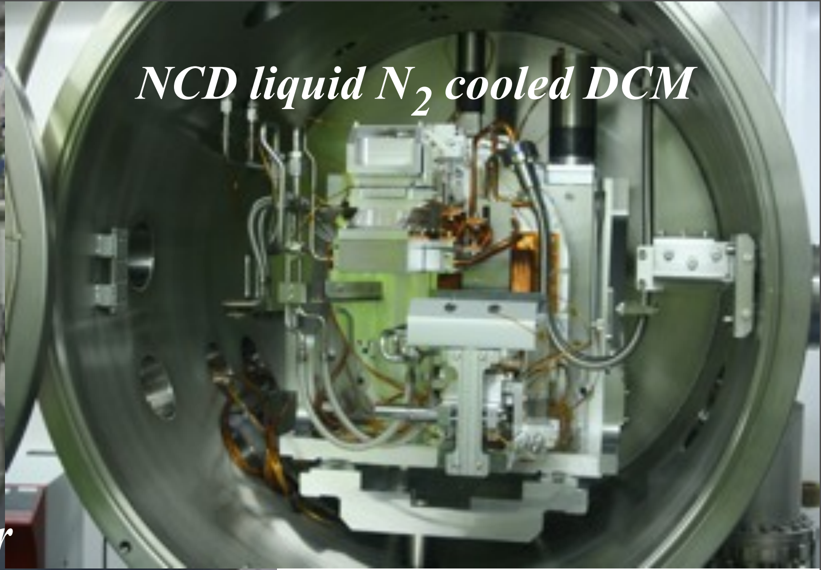
Non Crystalline Diffraction

Beam-line optical sub-systems (e.g. optics lay-out for Diffraction/Scattering of Non-Crystalline systems) are essentially waiting for commissioning with beam.

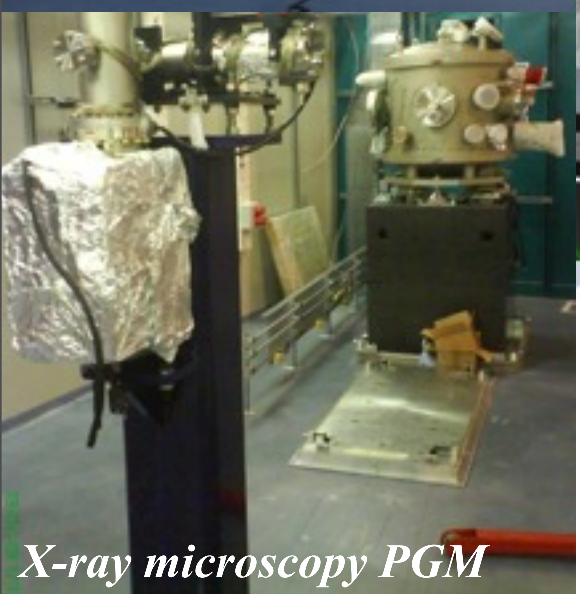


NCD: collimating and toroidal mirrors

NCD liquid N_2 cry cooler

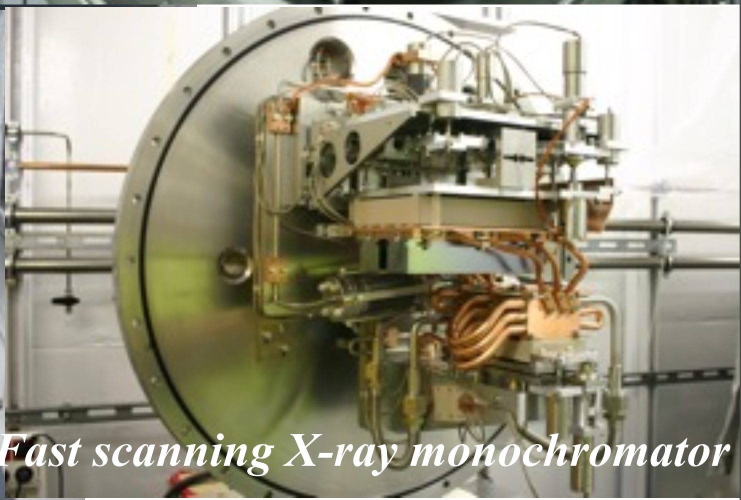


NCD liquid N_2 cooled DCM



X-ray microscopy PGM

PX monochromator and mirrors



Fast scanning X-ray monochromator

The optical sub-systems, i.e. mirrors systems, monochromator systems, slits, vacuum systems, etc., are delivered and being tested without beam.

ALBA in the context of other world facilities

The quality of a SL source is given by:

- *The range of energies of the emitted photons that depends on the energy of the accelerator* ($\approx E_e^2$).

- *The Brilliance of the emitted radiation (photons/sec/mm² /mrad² in* $\Delta\lambda/\lambda=10^{-3}$*) that depends on the electron circulating current and on the emittance of the accelerator* ($B \approx I / \varepsilon^{3/2}$), *where the emittance is given:*

$$\varepsilon = \frac{E_e^2}{J_x} f_{Cell} \frac{1}{N_{BM}^3} \qquad (\mathrm{nm.rad})$$

- *The total number of straight sections available for IDs that is given by the perimeter of the accelerator.*

- *The stability of the beam given by: the buildings, the electrical supply, the RF system, the vacuum system, the optical systems, the control system, etc..*

COMPARISON BETWEEN SL SOURCES