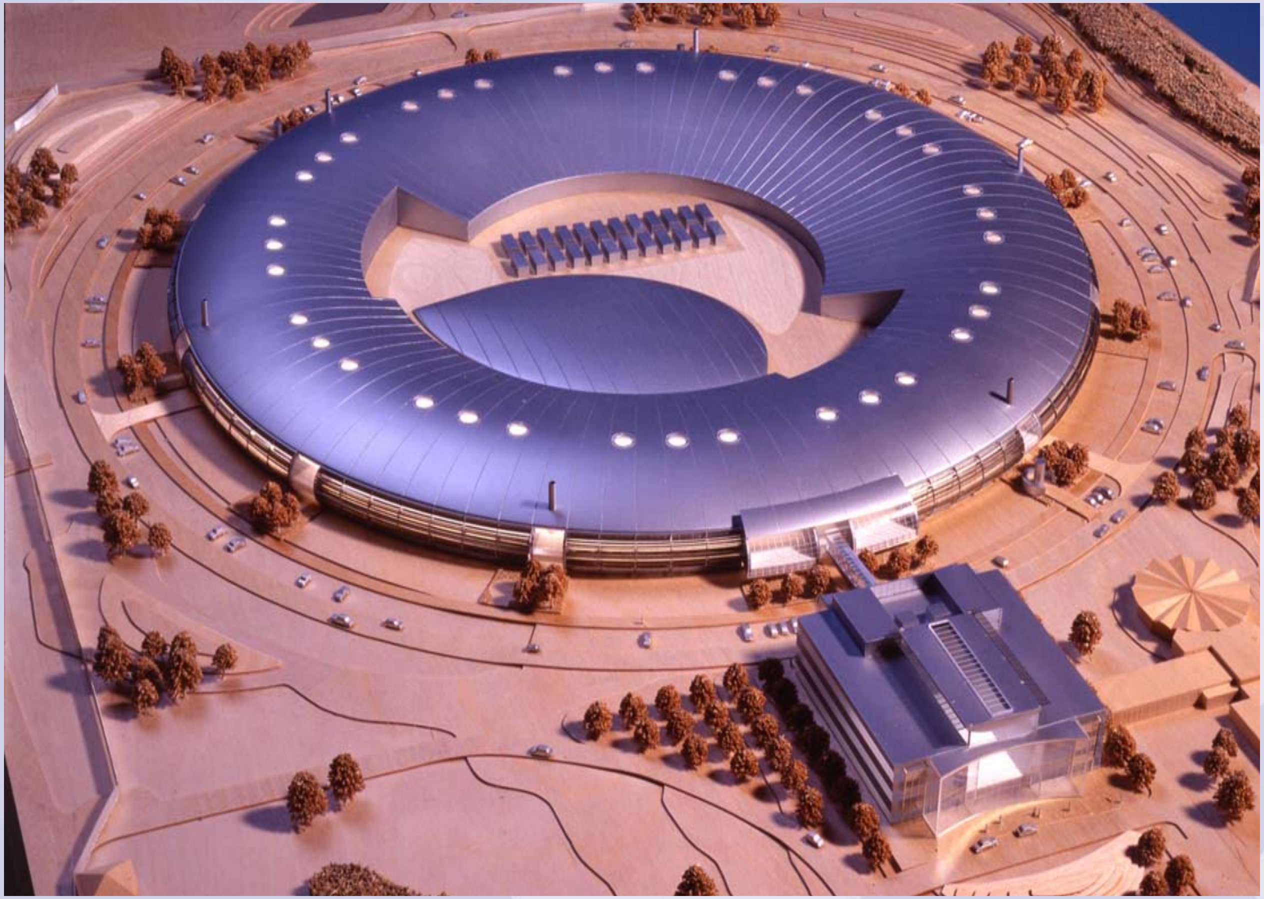
# The Diamond Light Source

## ... a bright future for UK and World science



**Richard P. Walker, Technical Director**

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# What is Diamond ?

- The largest scientific investment in the UK for 30 years
- A synchrotron light source producing pinpoint UV and X-ray light beams of exceptional brightness
- A ‘super microscope’ for new research opportunities into the structure and properties of matter

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# What is Diamond ?

- A Power Converter !

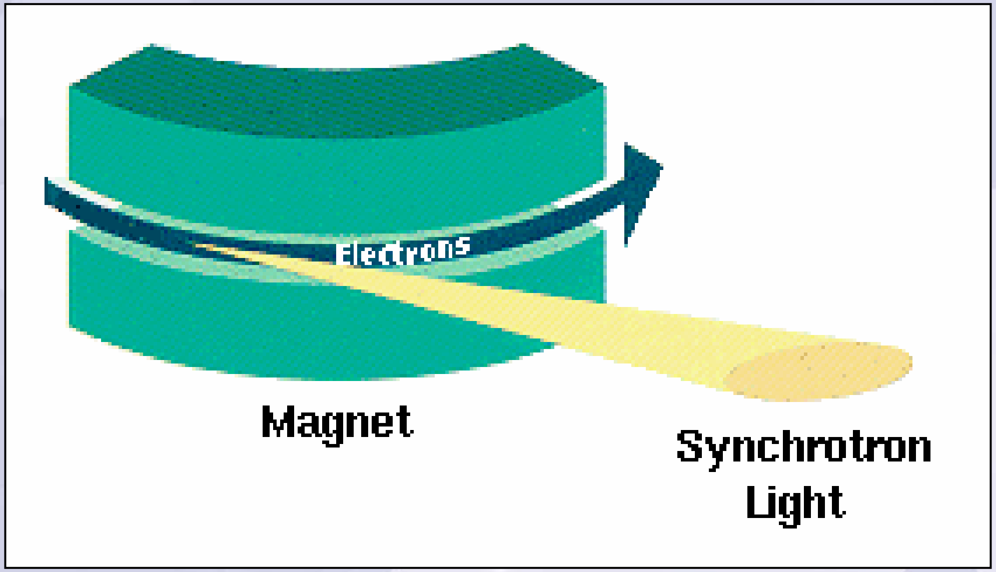
  15 MW of electrical power from the grid …

  300-500 kW of X-rays …

  … but most of which only produces unwanted heat;

only a fraction is selected for use in experiments.

# What is Synchrotron Radiation ?




**SR is electromagnetic radiation emitted when a high energy beam of charged particles (electrons) is deflected by a magnetic field.**

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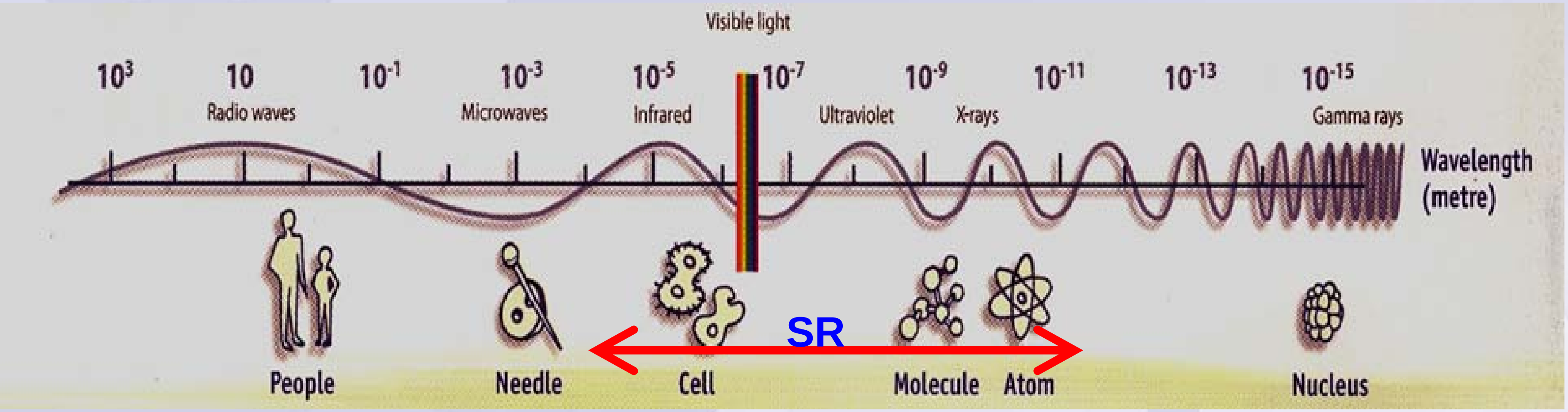
# What's so special about Synchrotron Radiation ?




**SR is emitted over a wide range of the electromagnetic spectrum, from Infra-red to hard X-rays**

**Any desired radiation wavelength can be produced - enabling a very wide range of scientific and technological applications**

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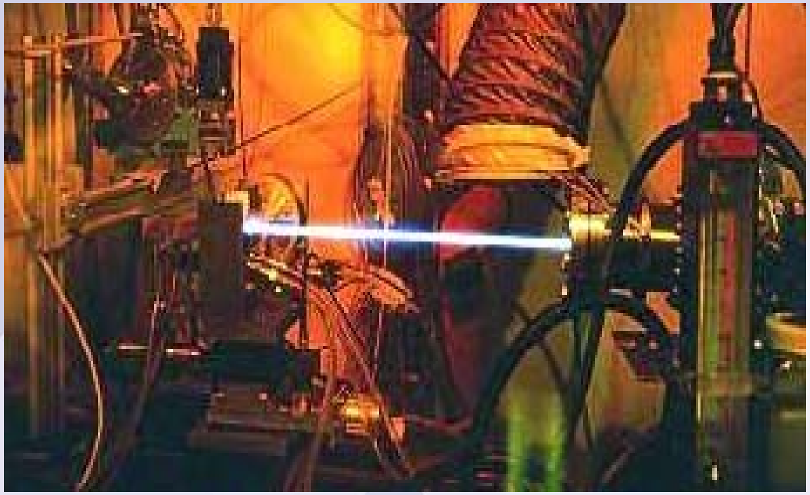
# What’s so special about Synchrotron Radiation ?

**SR is very intense, and has extremely high brightness (emitted from a small area, with small angular divergence, determined by the properties of the electron beam)**



**High brightness means:**

**- it can be focused to sub-micron spot sizes:**
**possibility of examining extremely small samples or investigating the structure and properties of objects with very fine spatial resolution**

**- experiments can be carried out much more quickly:**
**high through-put of samples or ability to follow chemical and biological reactions in real-time**

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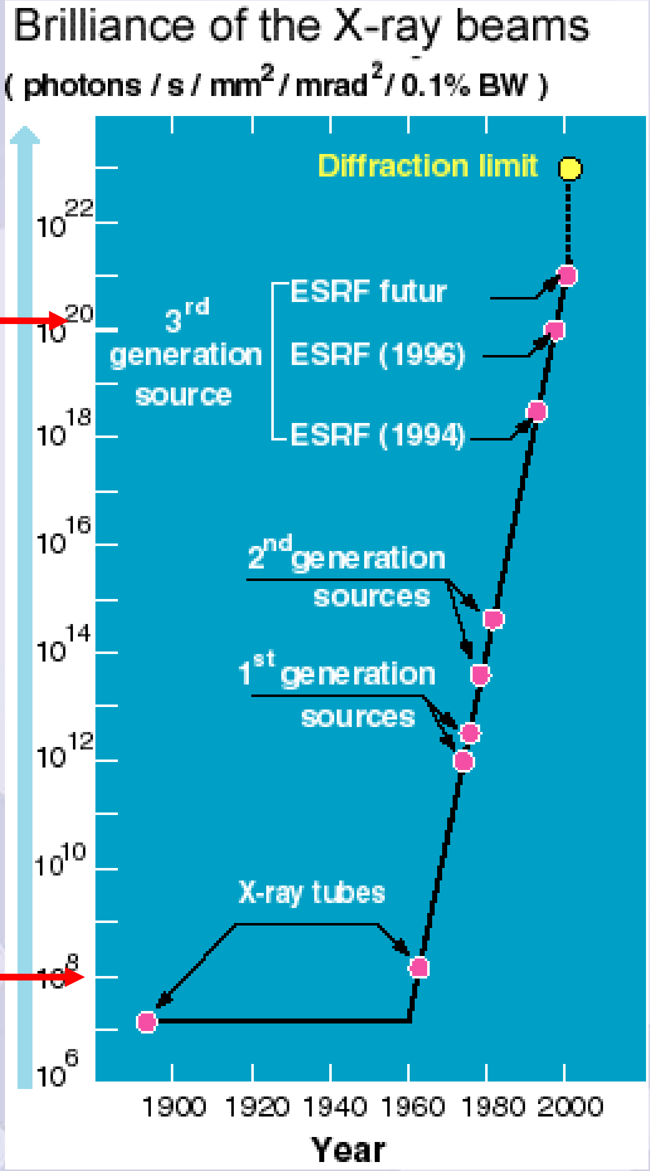
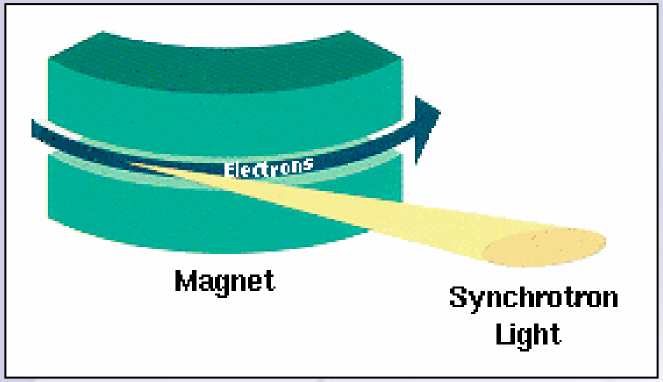
# Diamond is a "third-generation" synchrotron radiation source

- **1st generation:**
  machines originally built for other purposes e.g. high energy physics
- **2nd generation:**
  purpose-built machines for synchrotron radiation (e.g. SRS)
- **3rd generation:**
  higher brightness machines using special "insertion devices"
  (e.g. ESRF)

**X-rays from Diamond will be 1,000,000,000,000 times brighter than from an X-ray tube !**

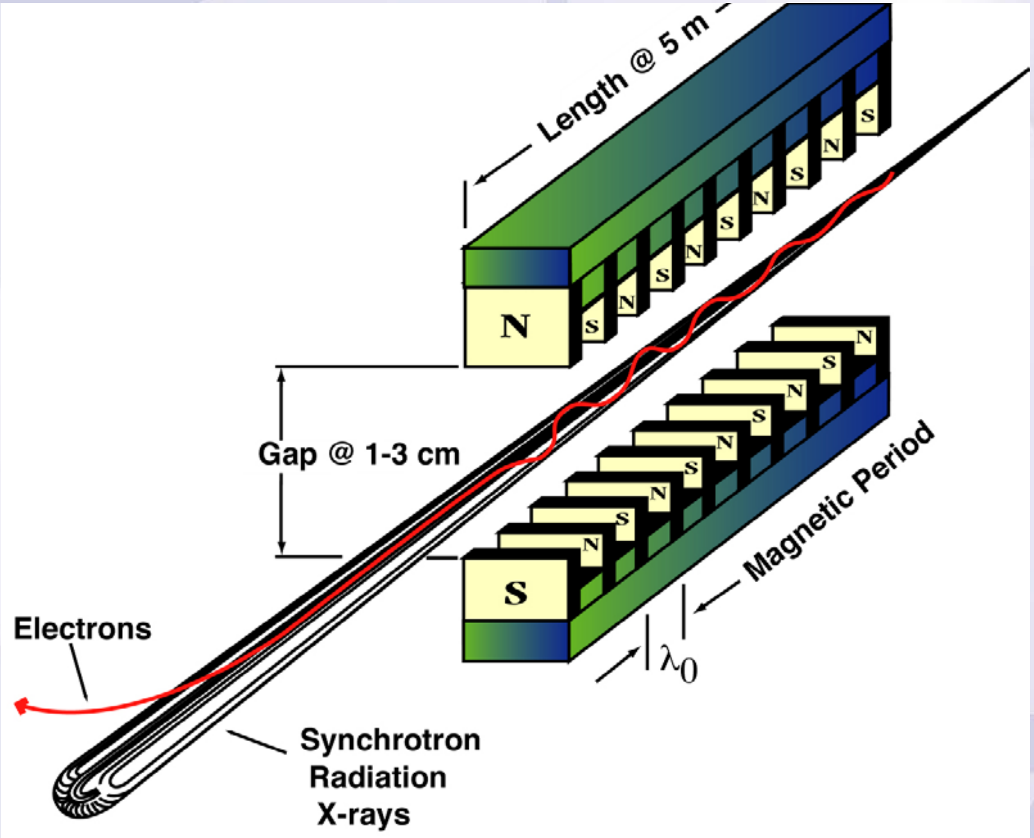


"2nd generation" light sources used bending magnets as the main source of synchrotron light:




"3rd generation" sources use Insertion Devices ("undulators" and "wigglers") to give much higher intensity and brightness

- Diamond will have 22 of these



# What areas of research benefit from synchrotron light ?

- Basic sciences – physics, chemistry, biology
- Environmental and Earth sciences – trace element analysis etc.
- Medical – developing better imaging techniques etc.
- Pharmaceuticals – disease & drug modelling
- Technology – understanding and developing better catalysts, stresses in materials, microfabrication etc.
- Microelectronics & nanomaterials
- etc.

# The Life Sciences

The need to design new molecules rationally and efficiently is crucial for future progress in the pharmaceutical industry

**The 28 most recently approved pharmaceuticals are estimated to have cost over**
**£20,000,000,000**
**to discover and develop**

**DIAMOND is one of the first synchrotron sources to be constructed with a major emphasis on research in the biological and medical sciences**

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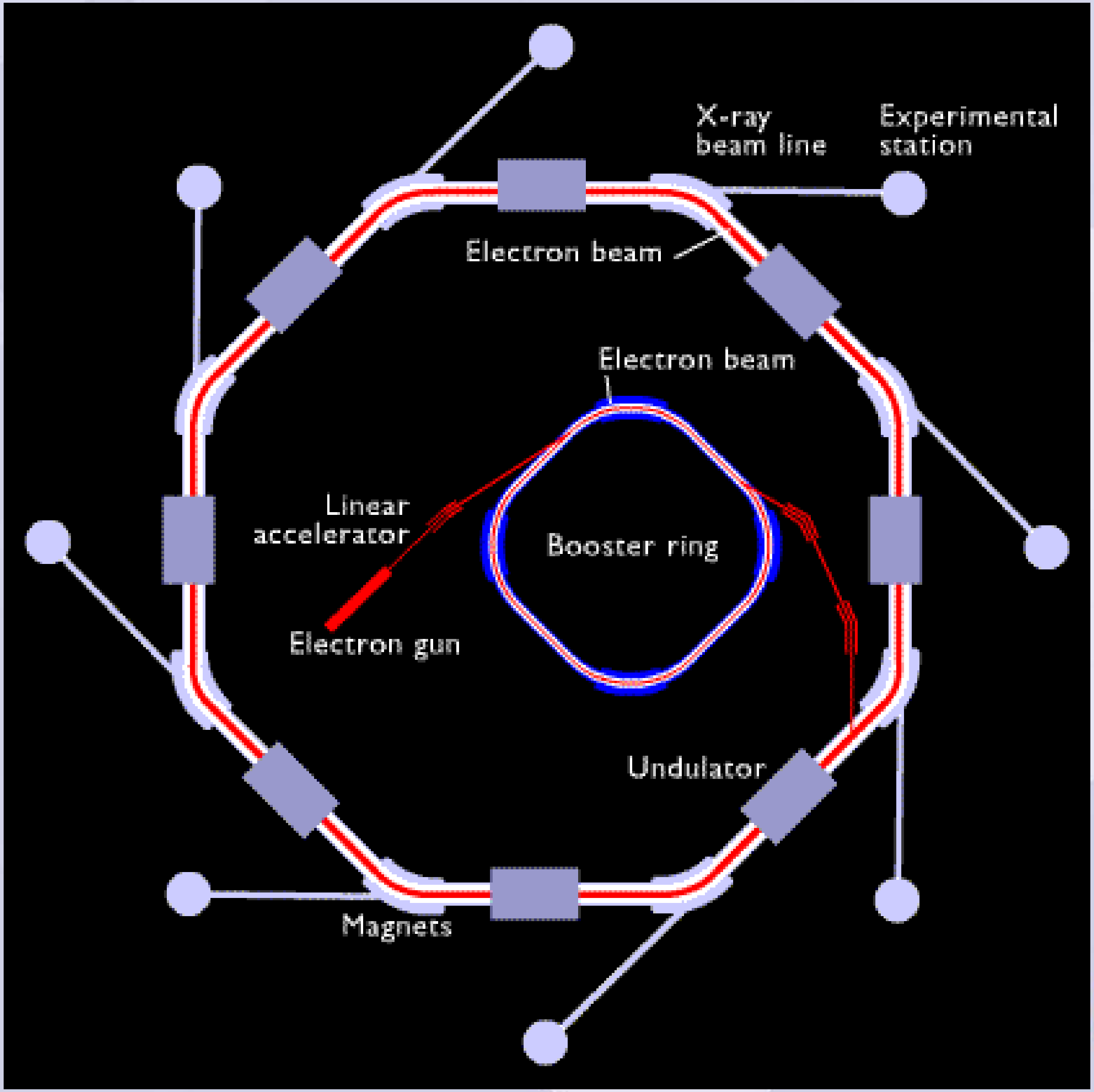
# Schematic of a synchrotron radiation source

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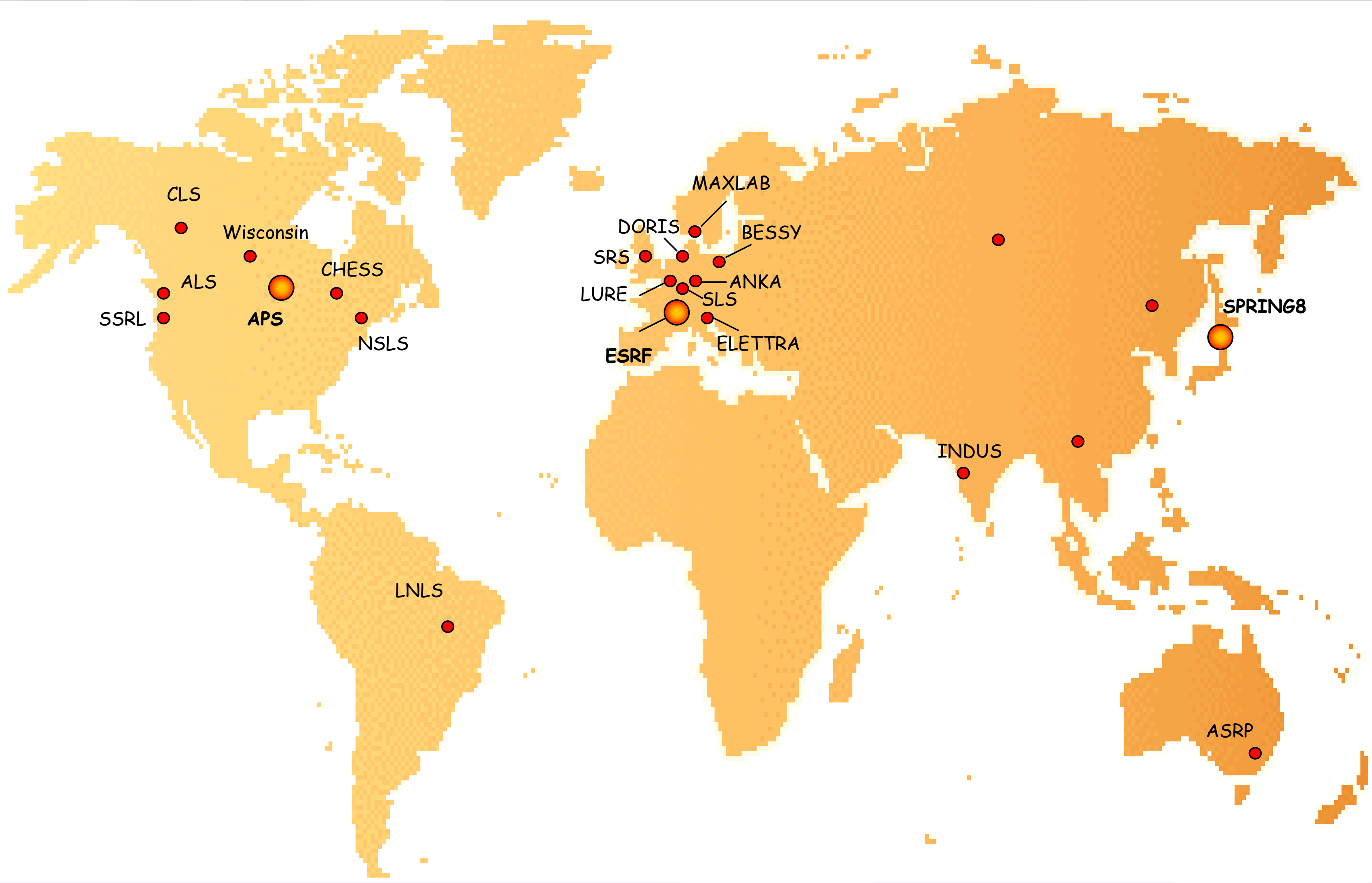
# Synchrotron Light Sources Worldwide



# Diamond Project Evolution

| | |
|---|---|
| **1993** | Woolfson Review: UK researchers need a new facility to replace the SRS at Daresbury |
| **1994** | SERC confirms Diamond scientific case |
| **1997** | Feasibility Study published |
| **1998** | Wellcome Trust joins as partner |
| **Mar. ‘00** | Decision to build Diamond at Rutherford Appleton Lab. |
| **Oct. ‘00** | Basic design approved |
| **Mar. ‘02** | Joint Venture Agreement (UK Gov./Wellcome Trust) |
| | Diamond Light Source Ltd. established |
| **Jul. ‘02** | Outline planning permission granted |
| **Sep. ‘02** | Full planning permission granted |

# Diamond Light Source Shareholders

CCLRC

**86 %**

The Council for the Central Laboratory of the Research Councils (CCLRC) is a non-departmental public body of the Office of Science and Technology, part of the Department of Trade and Industry

The Wellcome Trust

**14 %**

World's largest biomedical research charity, who's mission is

*'To foster and promote research with the aim of improving human and animal health'*

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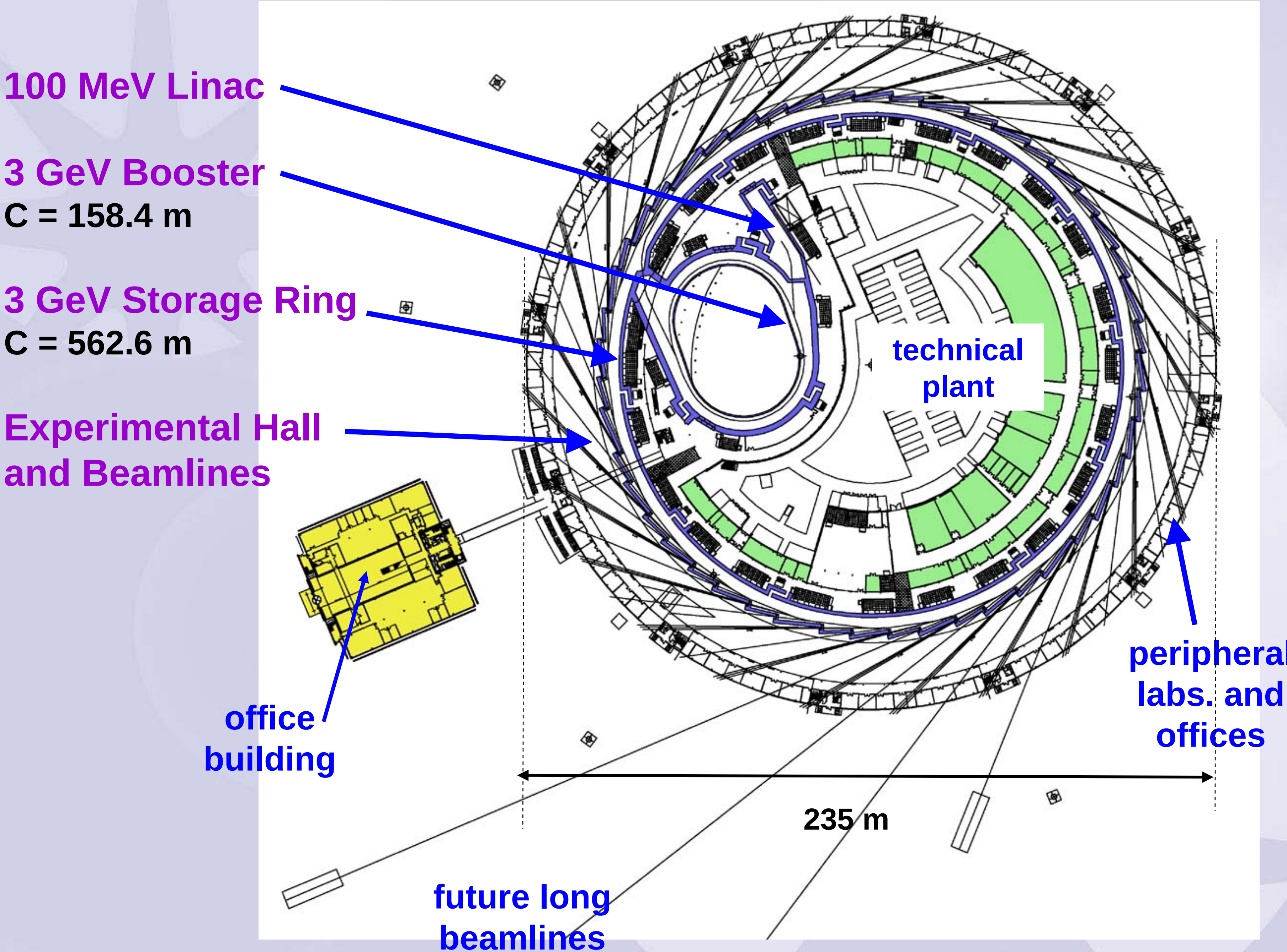
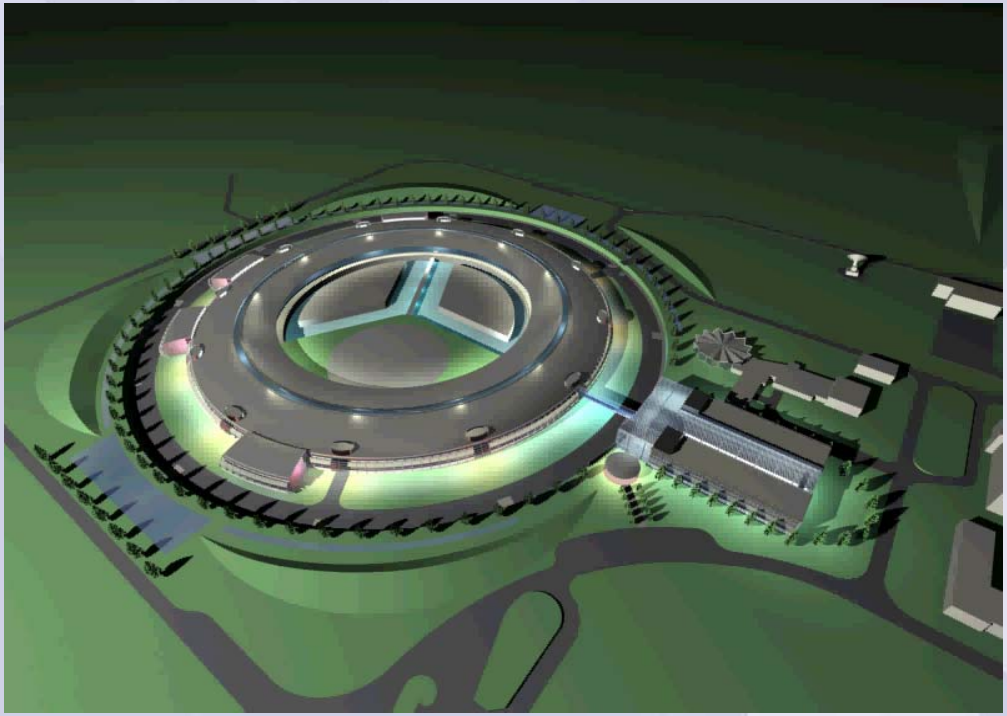
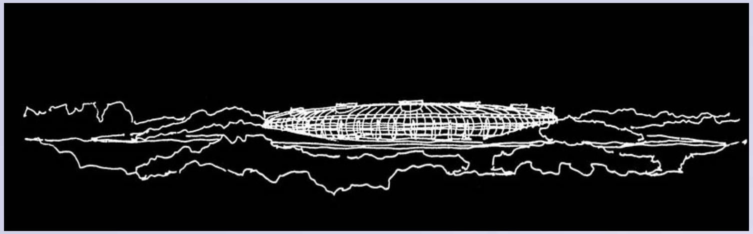
# Diamond in Detail

- Buildings
- Machine
- Beamlines
- Scientific Research
- Status


100 MeV Linac
3 GeV Booster
C = 158.4 m
3 GeV Storage Ring
C = 562.6 m
Experimental Hall
and Beamlines
technical
plant
office
building
peripheral
labs. and
offices
235 m
future long
beamlines

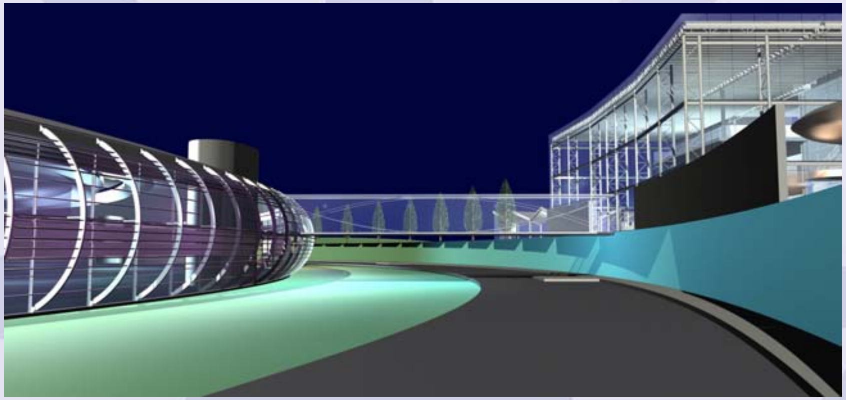
# Diamond buildings: the architect’s concept





*“a spaceship landing in the natural landscape..”*

*Courtesy of Crispin Wride Architectural Design Studio, JacobsGibb Ltd.*

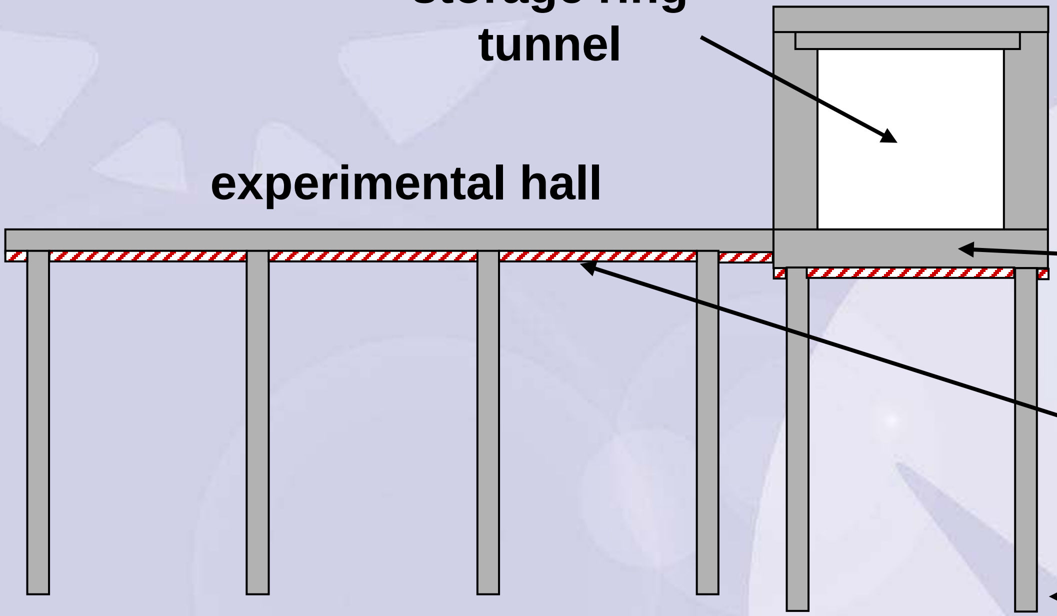


***“the curved outer form reflects the form of the synchrotron within ..”***

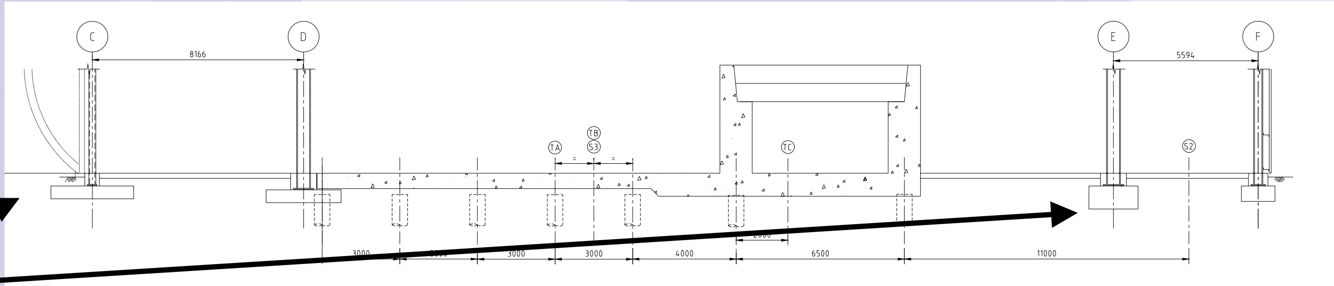
# Building Foundations

**STABILITY: minimise ground movement, and transmission of vibrations**

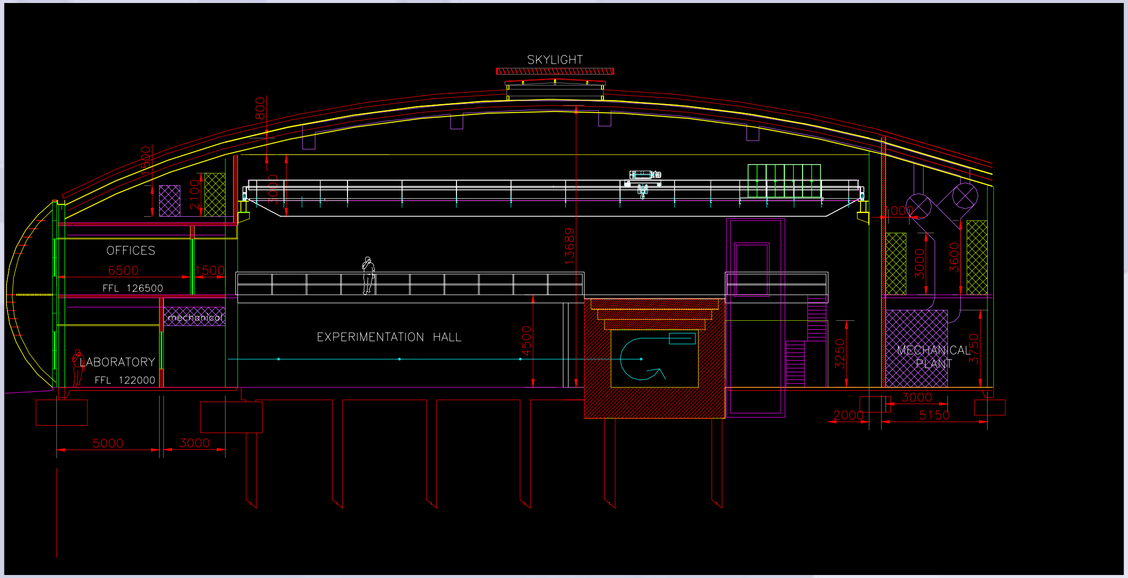
*piling rig:*




NB] separate non-piled foundation for the building structure and plant rooms



# Diamond buildings: detailed design

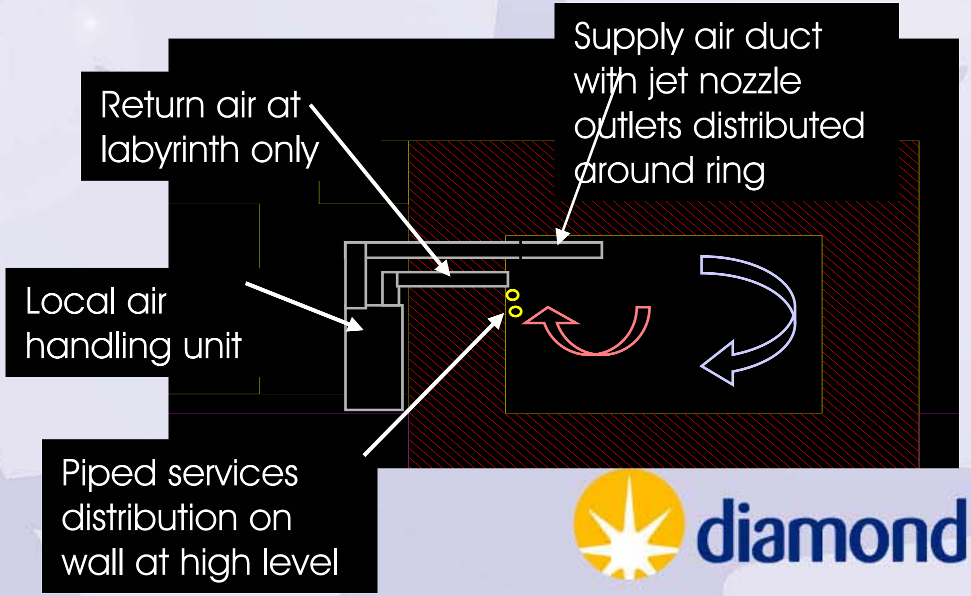



**STABILITY:**

**minimise thermal variations**

**experimental hall +/- 1 °C**

**storage ring tunnel +/- 0.5 °C**




*Courtesy of JacobsGibb Ltd.*

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# Diamond Design Criteria

- Large capacity for Insertion Device beamlines
- High brightness from undulators optimised in the range 0.1-10 keV, extending to 15-20 keV
- High flux from wigglers from 20-100 keV
- Cost constraint

➔ “medium” energy of 3 GeV

➔ relatively large circumference (562 m) and no. of cells (24)

➔ extensive use of in-vacuum undulators

# Main Parameters

| | | |
|---|---|---|
| **Electron Beam Energy** | **3 GeV** | |
| **Storage ring circumference** | **561.6 m** | |
| **Number of cells** | **24** | |
| **Symmetry** | **6** | |
| **Straight section lengths** | **6 x 8 m, 18 x 5 m** | **Goal:** |
| **No. Insertion devices** | **4 x 8 m, 18 x 5 m** | |
| **Beam current** | **300 mA** | **(500 mA)** |
| **Emittance (hor., vert.)** | **2.7, 0.03 nm rad** | |
| **Lifetime** | **> 10 h** | |
| **Min. ID beam stay clear** | **7 mm** | **(5 mm)** |
| **Electron beam sizes (hor., vert)** | **80, 8 $\mu$m** | |
| **Electron beam divergences (hor., vert)** *(at centre of 5 m ID)* | **35, 3 $\mu$rad** | |

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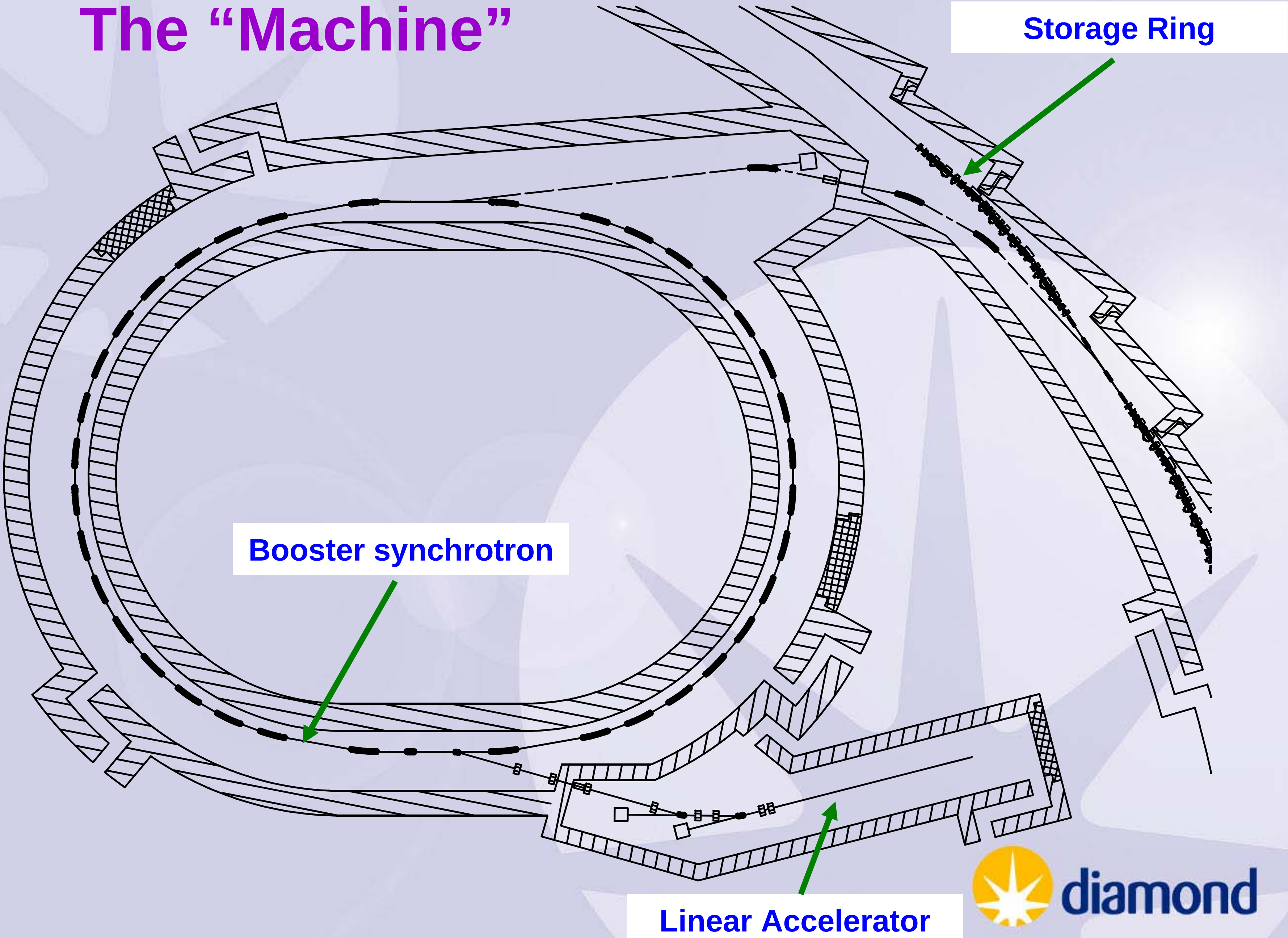
# The “Machine”

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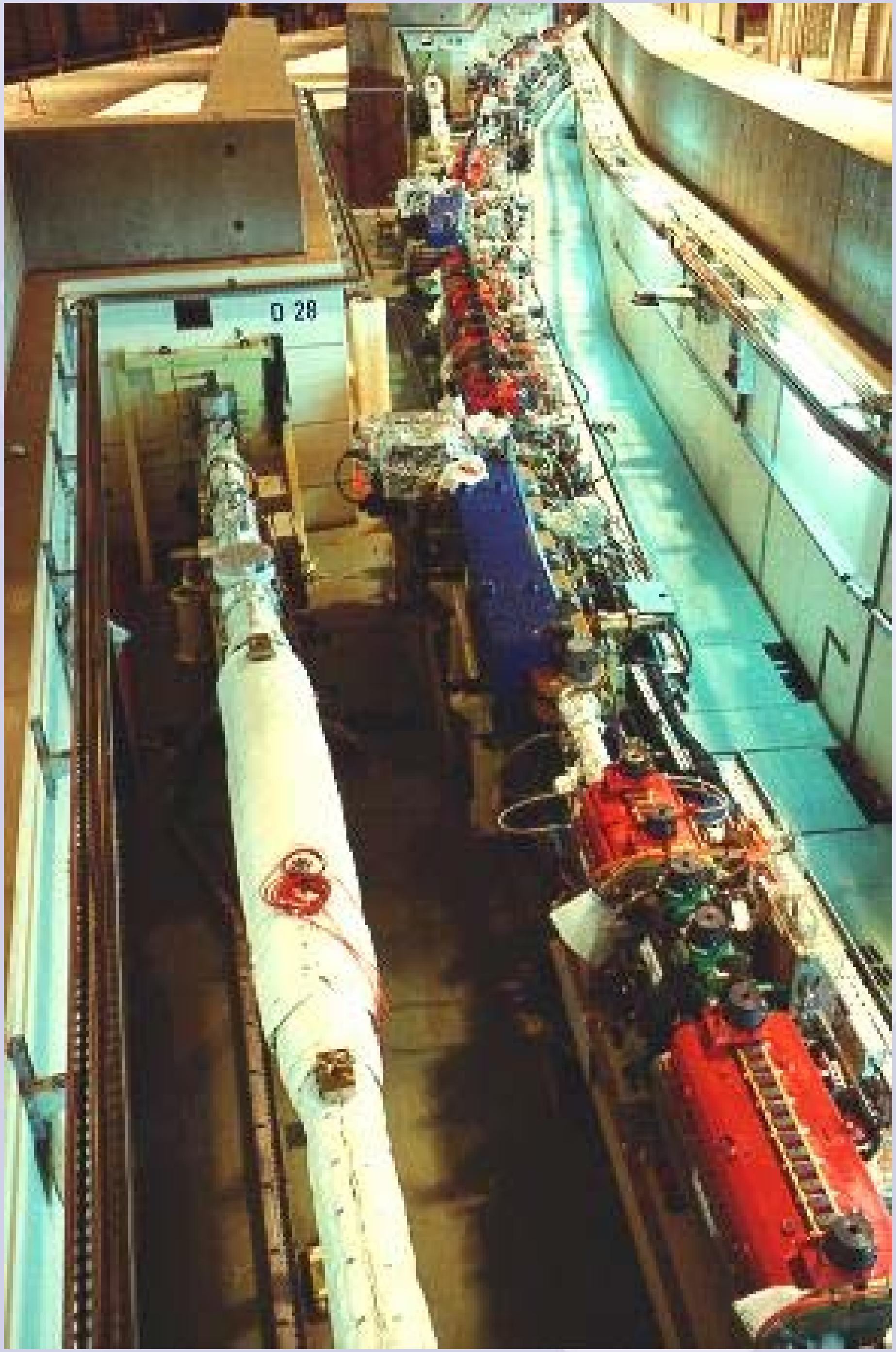


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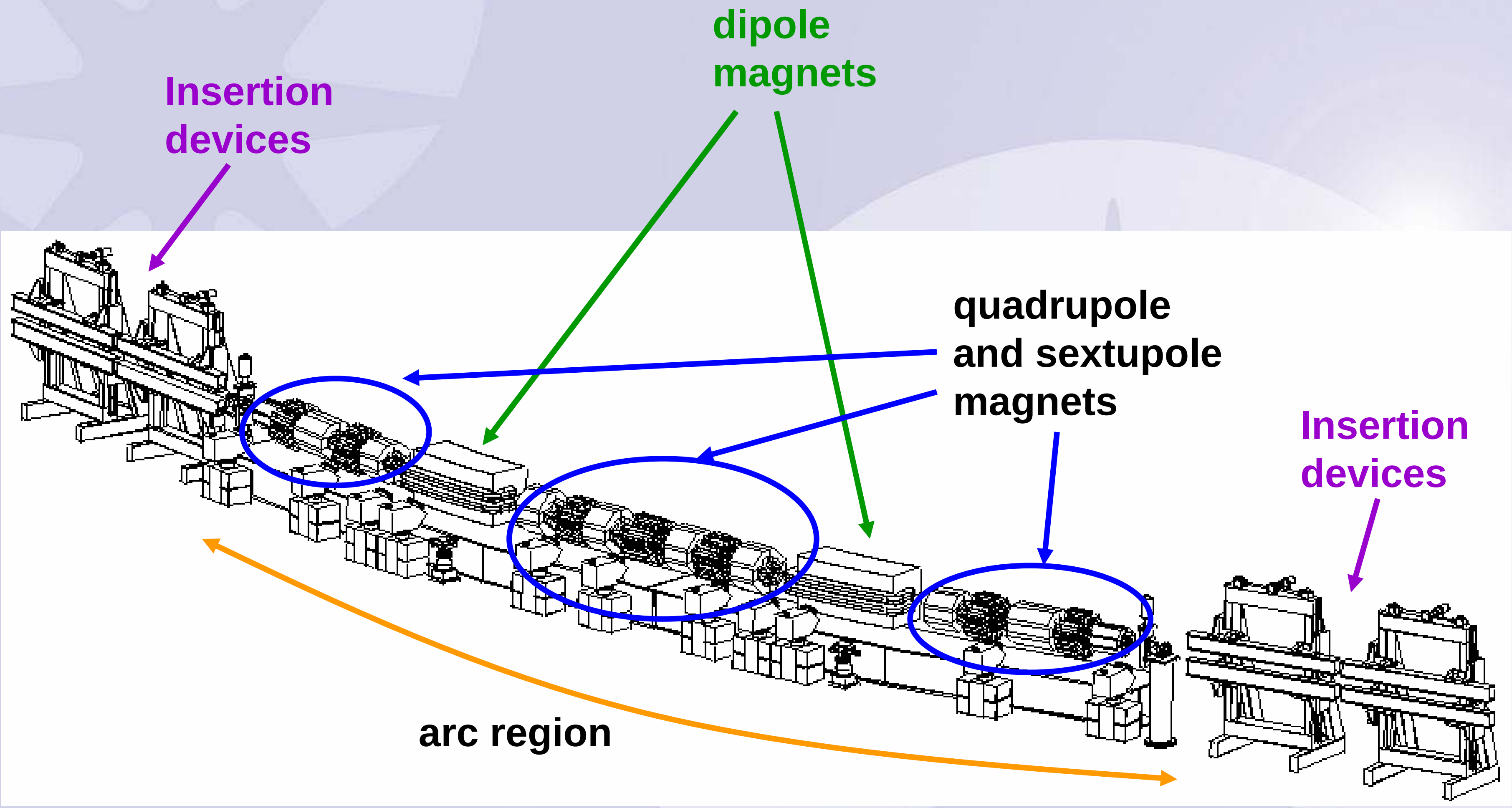
# Diamond Magnet “Lattice”

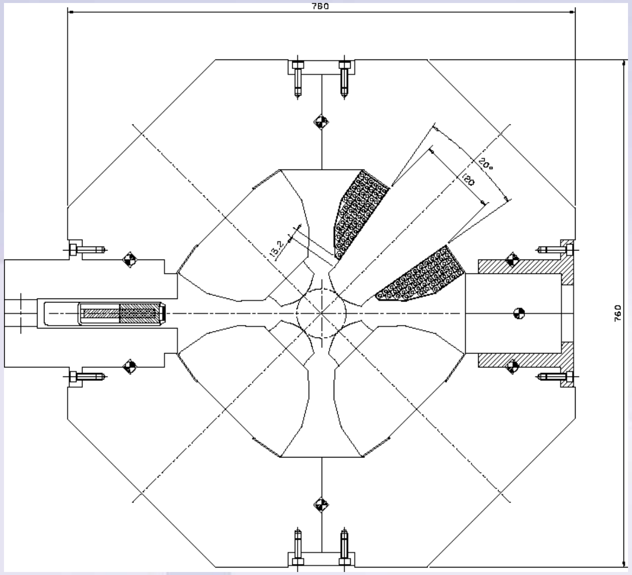


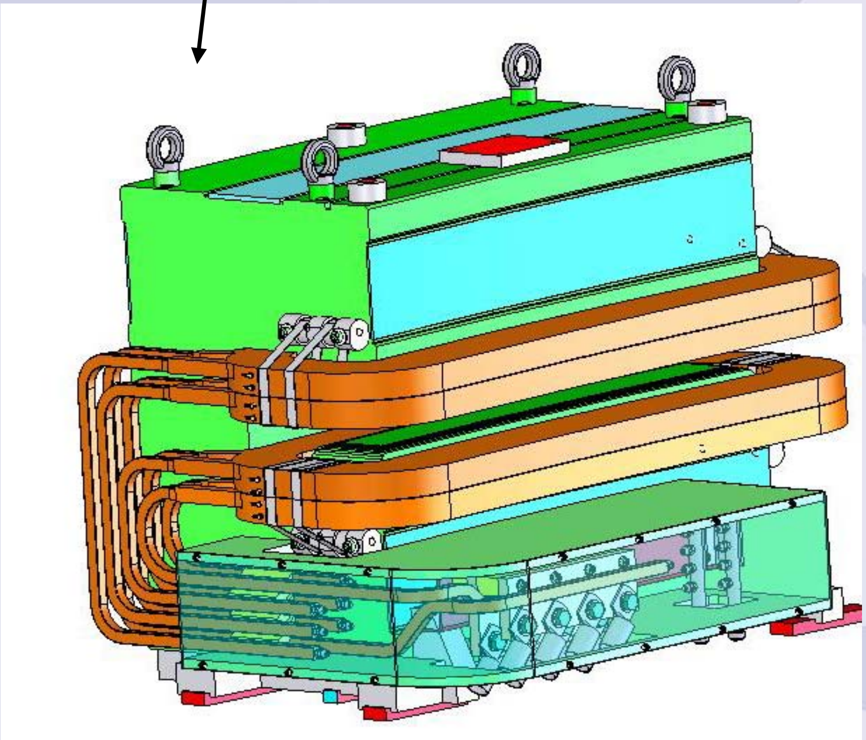
# Storage ring magnets and power supplies

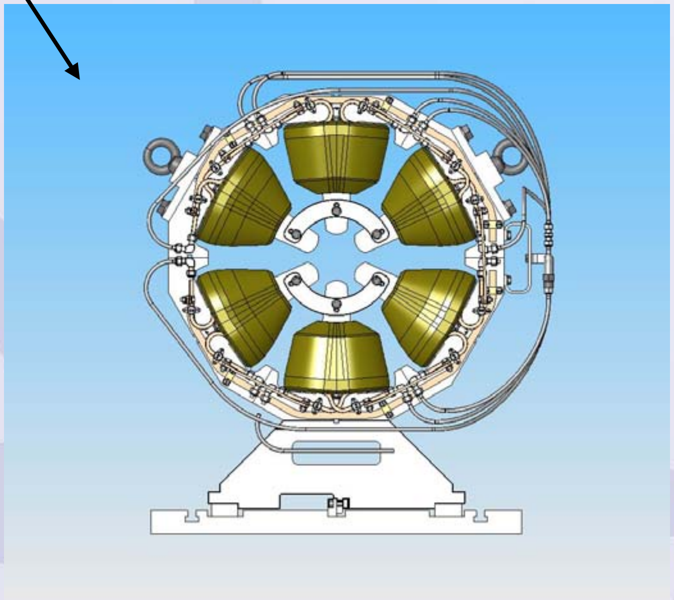
**48 x 1.4 T dipole magnets; one 680 kW p.s.**

**240 quadrupoles, individual 5 kW p.s.**

**168 sextupoles, individual 1.5 kW p.s.**





# Power Supplies

- **1200 Switched Mode Power Converters for DC and Low Frequency Magnets.**
- **10 Pulsed Power Supplies to transfer the electron beam from Linac to Booster and Booster to Storage Ring.**

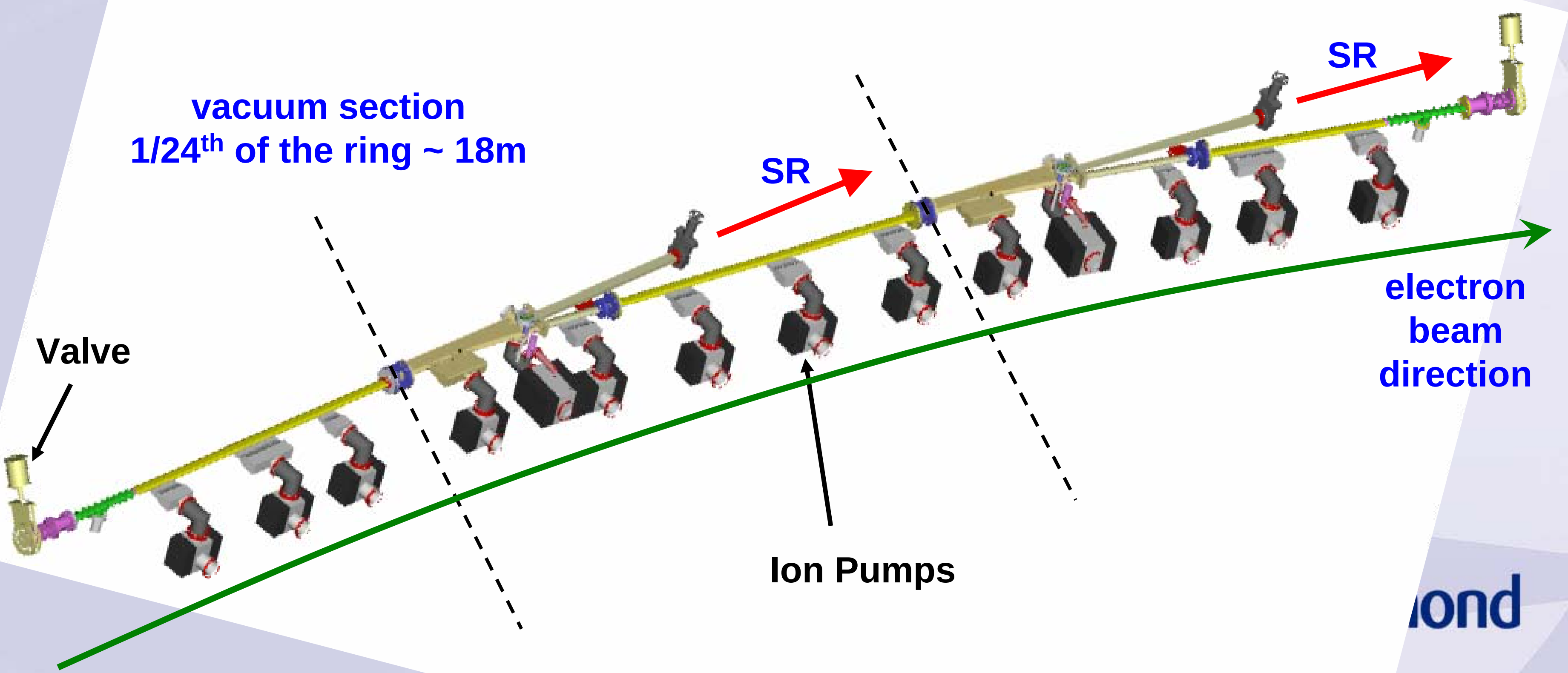
| | Number | Current (A) | Voltage (V) | Frequency (Hz) |
|---|---|---|---|---|
| Storage Ring | | | | |
| Dipole | 1 | 1500 | 500 | DC |
| Quadrupole | 240 | 200 | 30 | DC |
| Sextupole | 168 | 100 | 20 | DC |
| Fast Corrector | 192 | ±16 | ±55 | 1000 |
| Slow Corrector | 504 | ±5 | ±20 | 50 |
| Booster | | | | |
| Dipole | 1 | 975 | 2000 | 5 |
| Quadrupole | 2 | 200 | 400 | 5 |
| Sextupole | 2 | 20 | 50 | 5 |
| Corrector | 44 | ±5 | ±20 | 50 |

# Ultra-High Vacuum System

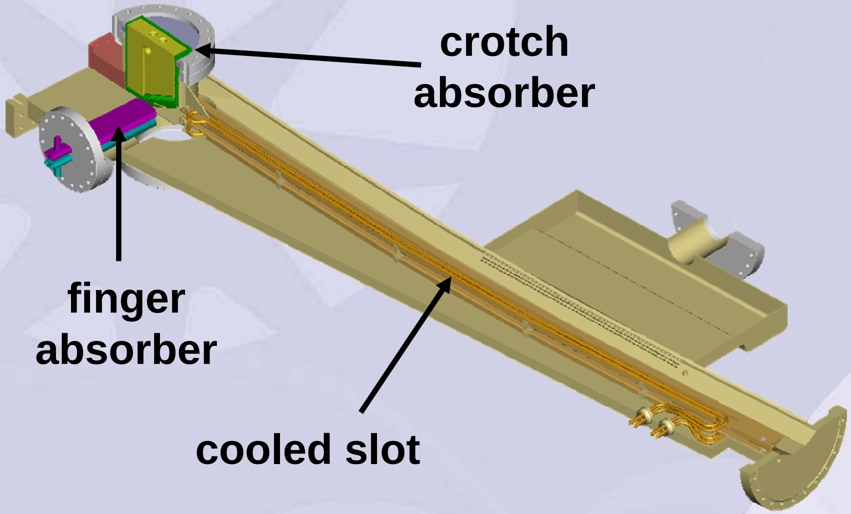
To reach the required beam lifetime, requires an average pressure of $< 10^{-9}$ mbar in the electron beam vacuum vessel (typically 72x 32 mm)

Main issue is the desorption of gas molecules from the vessel surface due to the synchrotron radiation: total no. of photons = $7\ 10^{20}$ photons/s

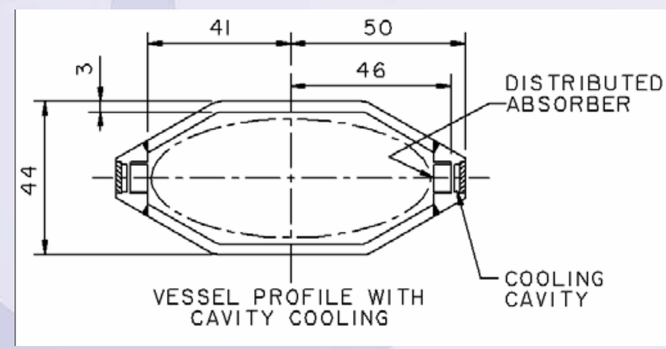
large number of pumps: total pumping speed 5,000 l/s per arc (18m)



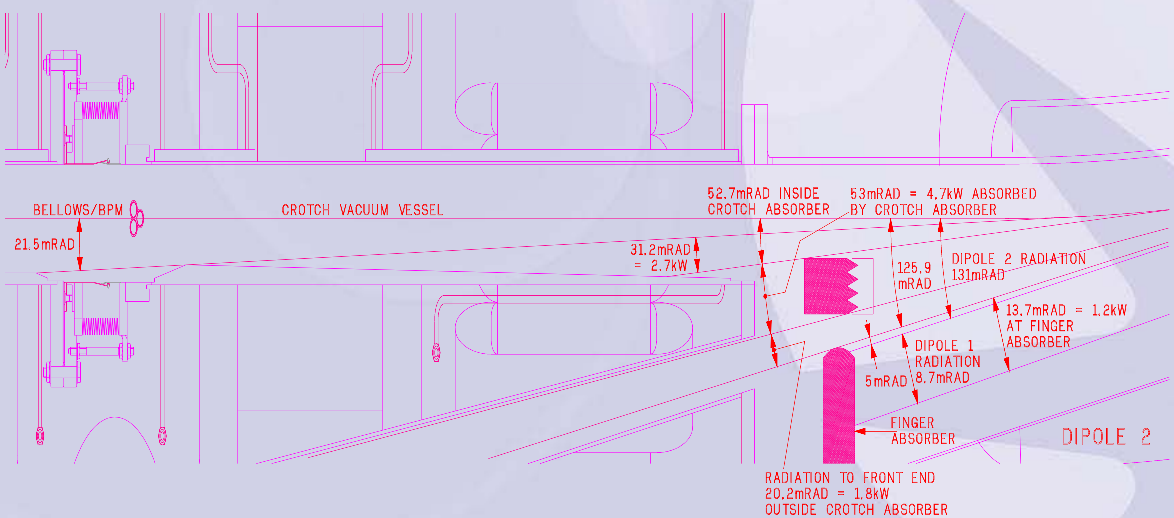
# Vacuum vessels and absorbers




distributed absorber in the straight sections




raytracing to determine incidence of synchrotron radiation

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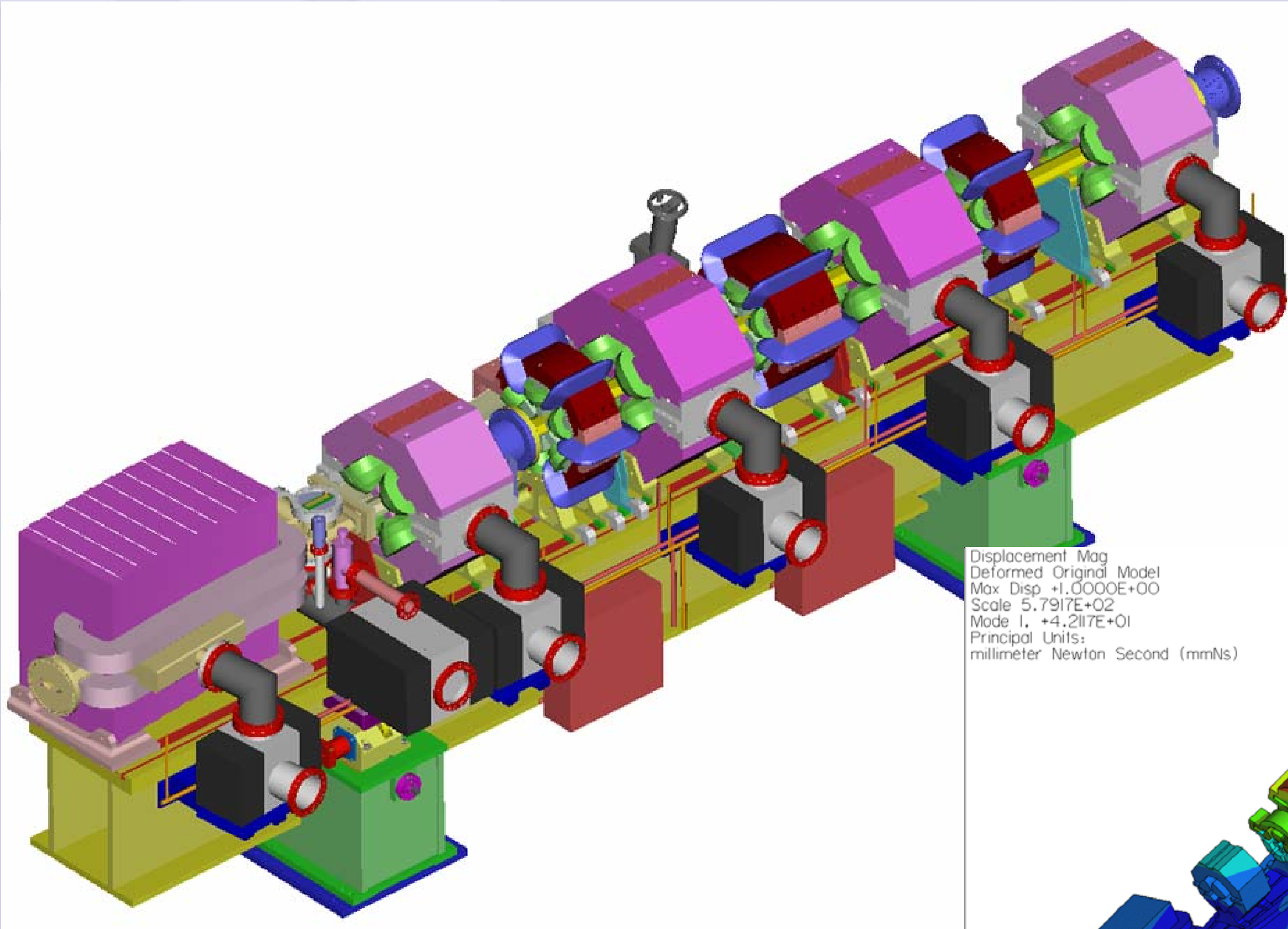
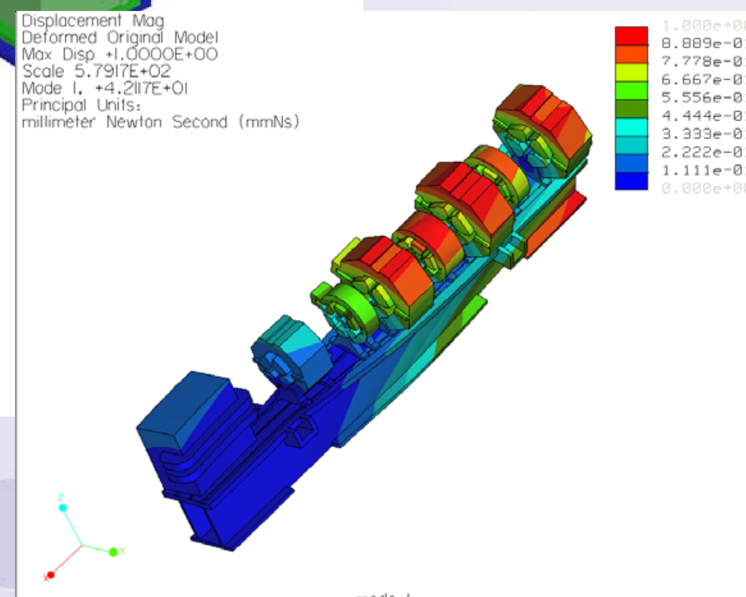
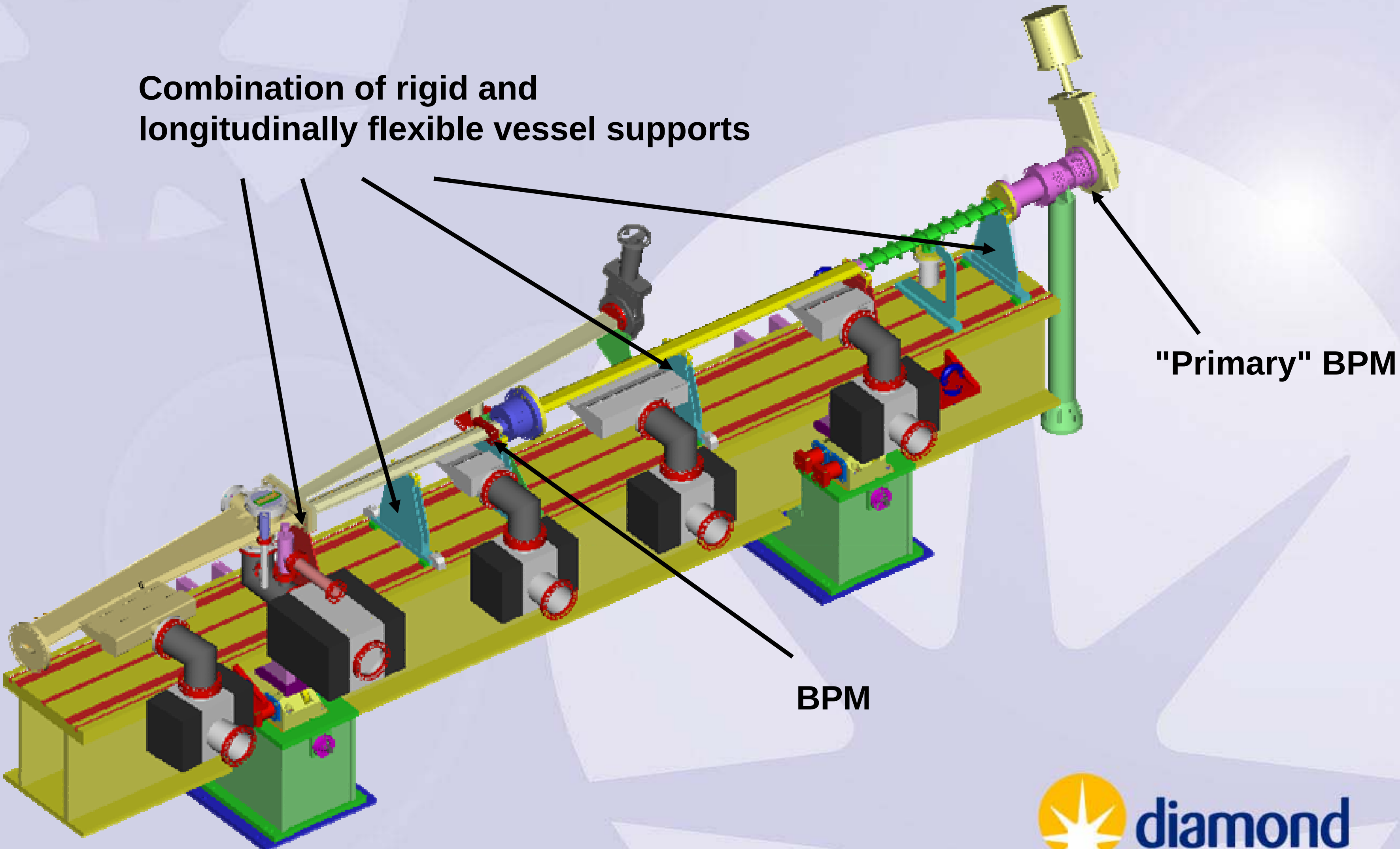
# Magnets and vacuum vessels will be pre-assembled and accurately aligned (~ 50 μm) on girders

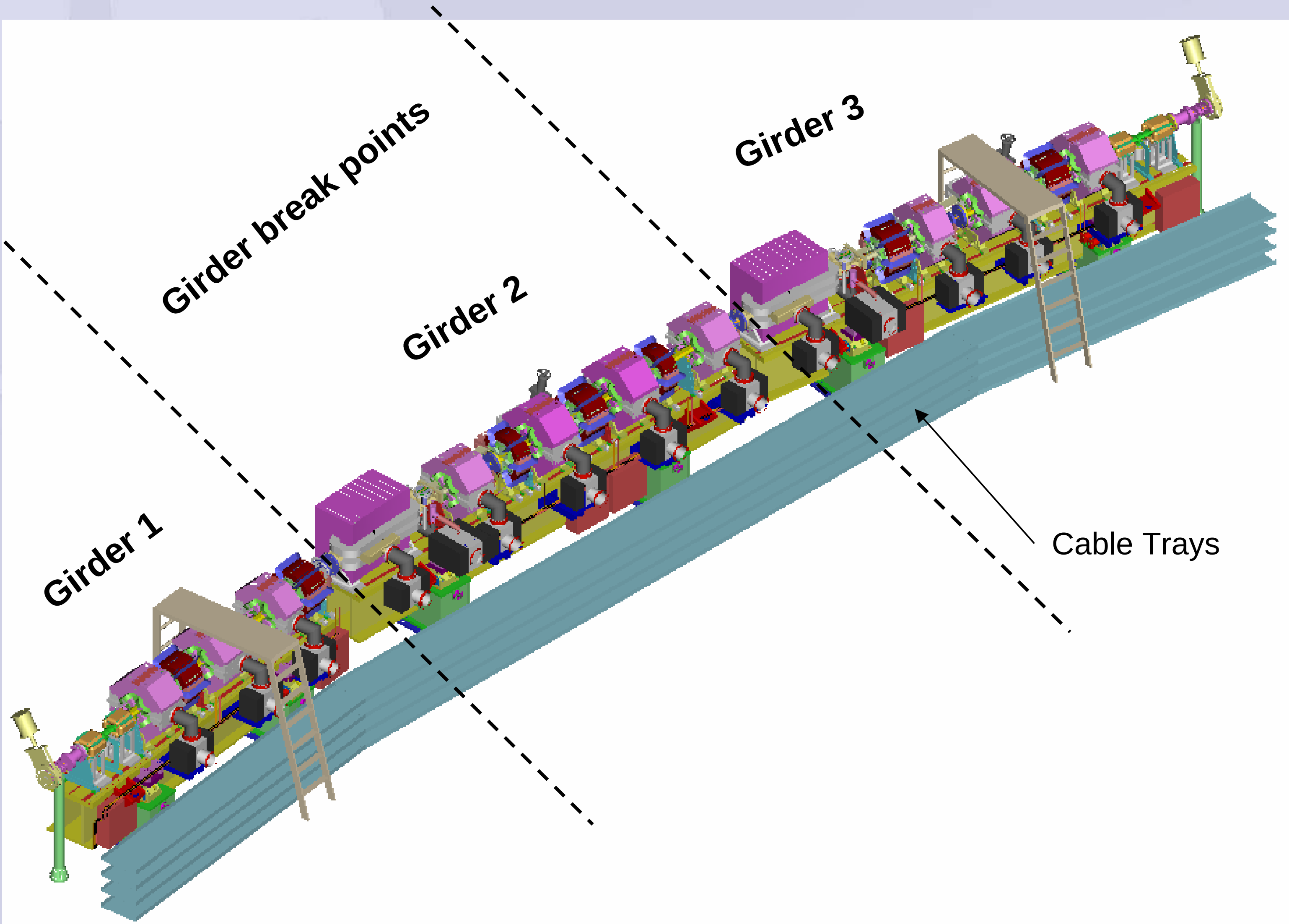




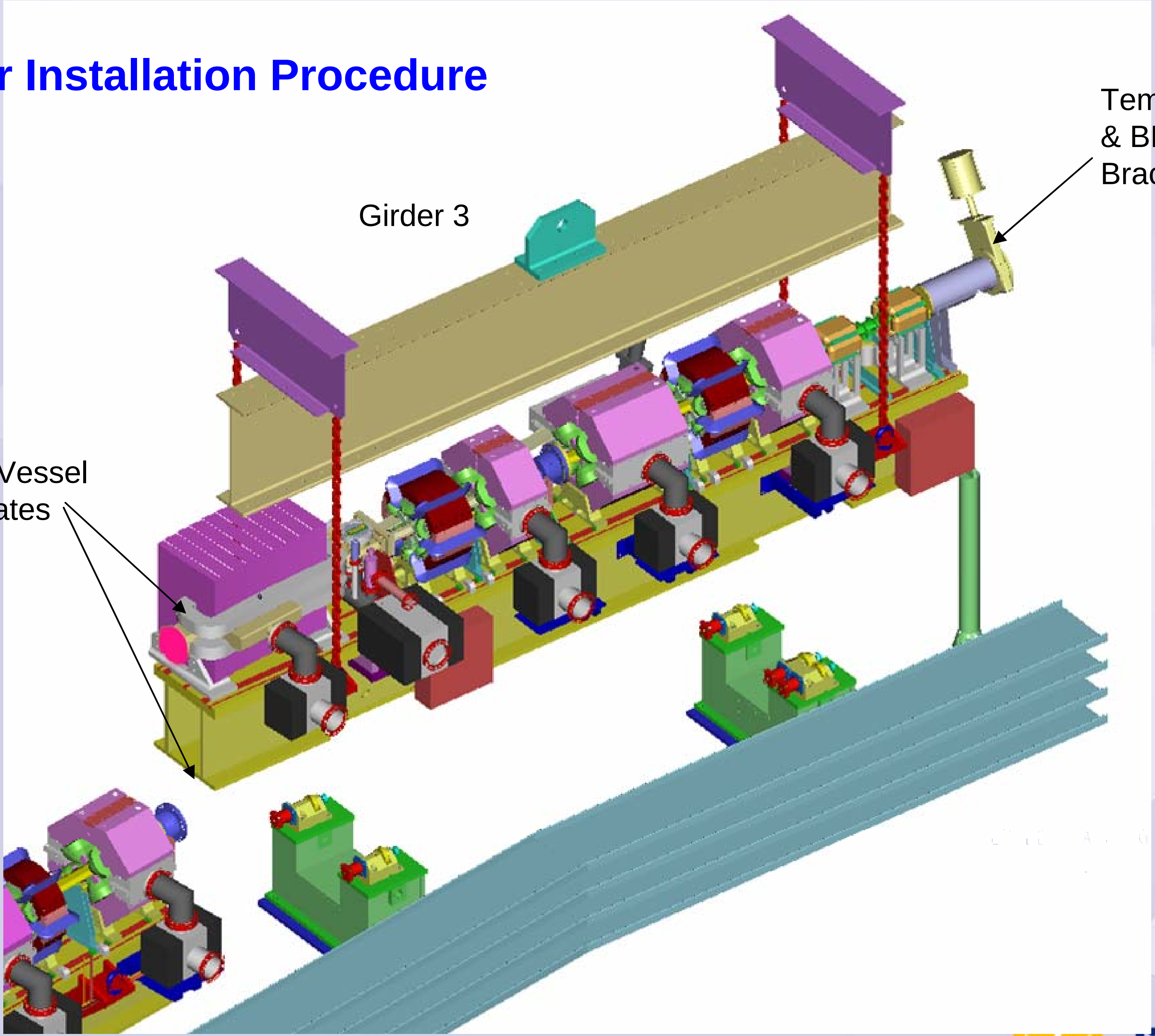

**modal analysis to guarantee no resonances < 30Hz**

# Vacuum vessel and Beam Position Monitor (BPM) supports



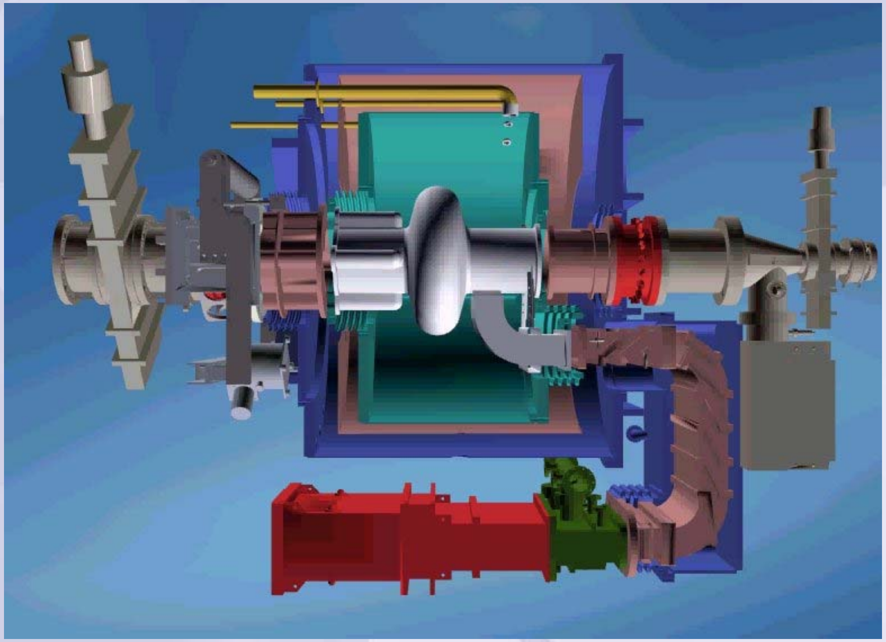

Girder break points
Girder 1
Girder 2
Girder 3
Cable Trays

# Girder Installation Procedure



# Radiofrequency (RF) System

**- to make up the energy lost due to the emission of SR**



schematic of a storage ring cavity

**Cavities:** 3 × superconducting cavities, operating temperature -269ºC

**Power Amplifiers:** 3 x 300 kW power amplifiers (500 MHz)

**Cryogenic System:** capable of producing ~ 200 L of Liquid helium from warm gas / hr; completely enclosed system ensuring no loss of helium

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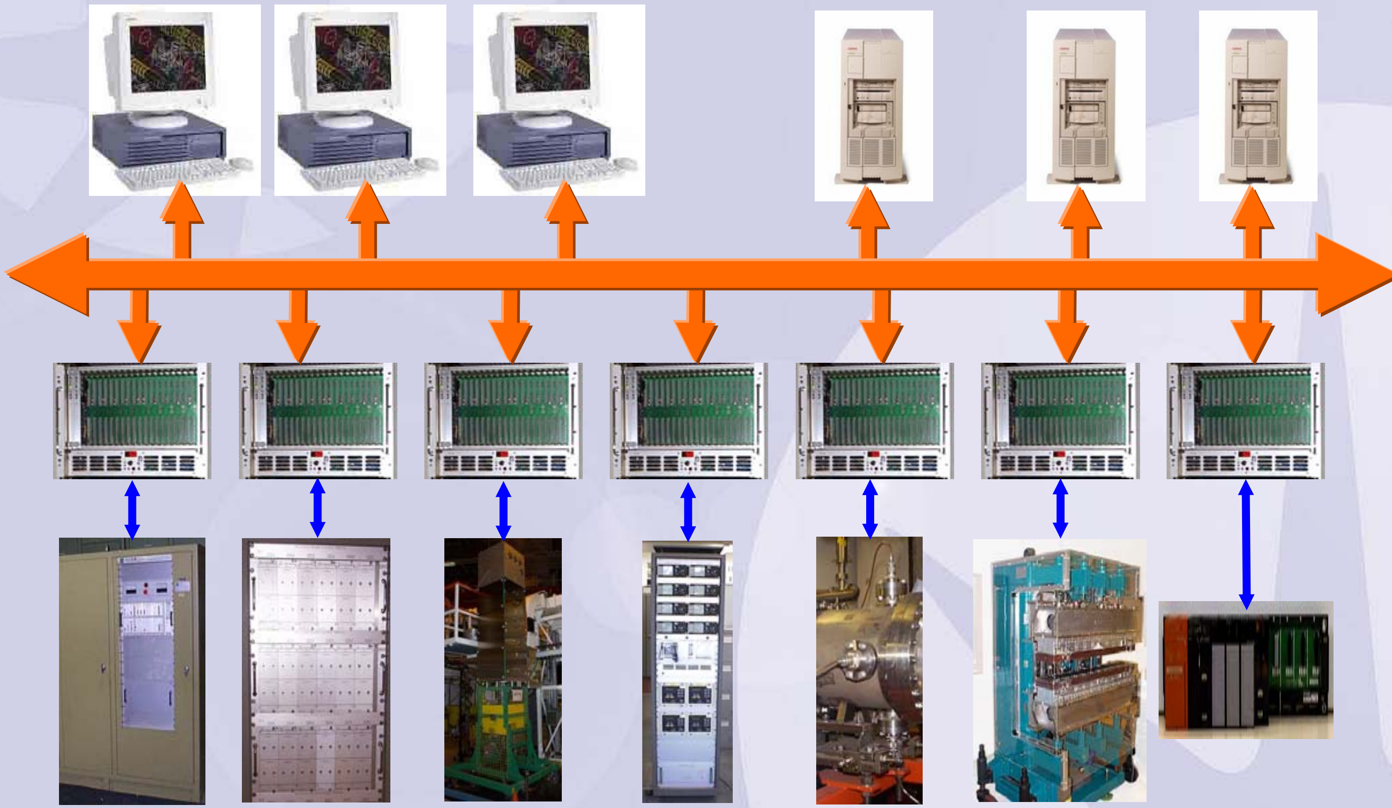
# Control System

EPICS

40 Unix clients as
operator interfaces



10 Unix servers for
computation,
development,
archive, alarm,
gateway web

fibre-optic network

240 Embedded
VME64x servers as
plant interface in 32
control and
instrumentation
areas

Plant: power supplies, Radiofrequency, Vacuum, Diagnostics, IDs, Conventional Facilities
4000 Physical devices to control
100,000 Process variables.

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# Technical Challenges for the Machine

- alignment: 0.1 mm magnet positioning tolerance
- achieving the required low vacuum pressures
- large number of small gap and in-vacuum insertion devices (effect on vacuum, and machine operation)
- superconducting radio-frequency system
- continuous “top-up” injection
- electron beam stabilty - settlement, thermal effects, vibrations etc.

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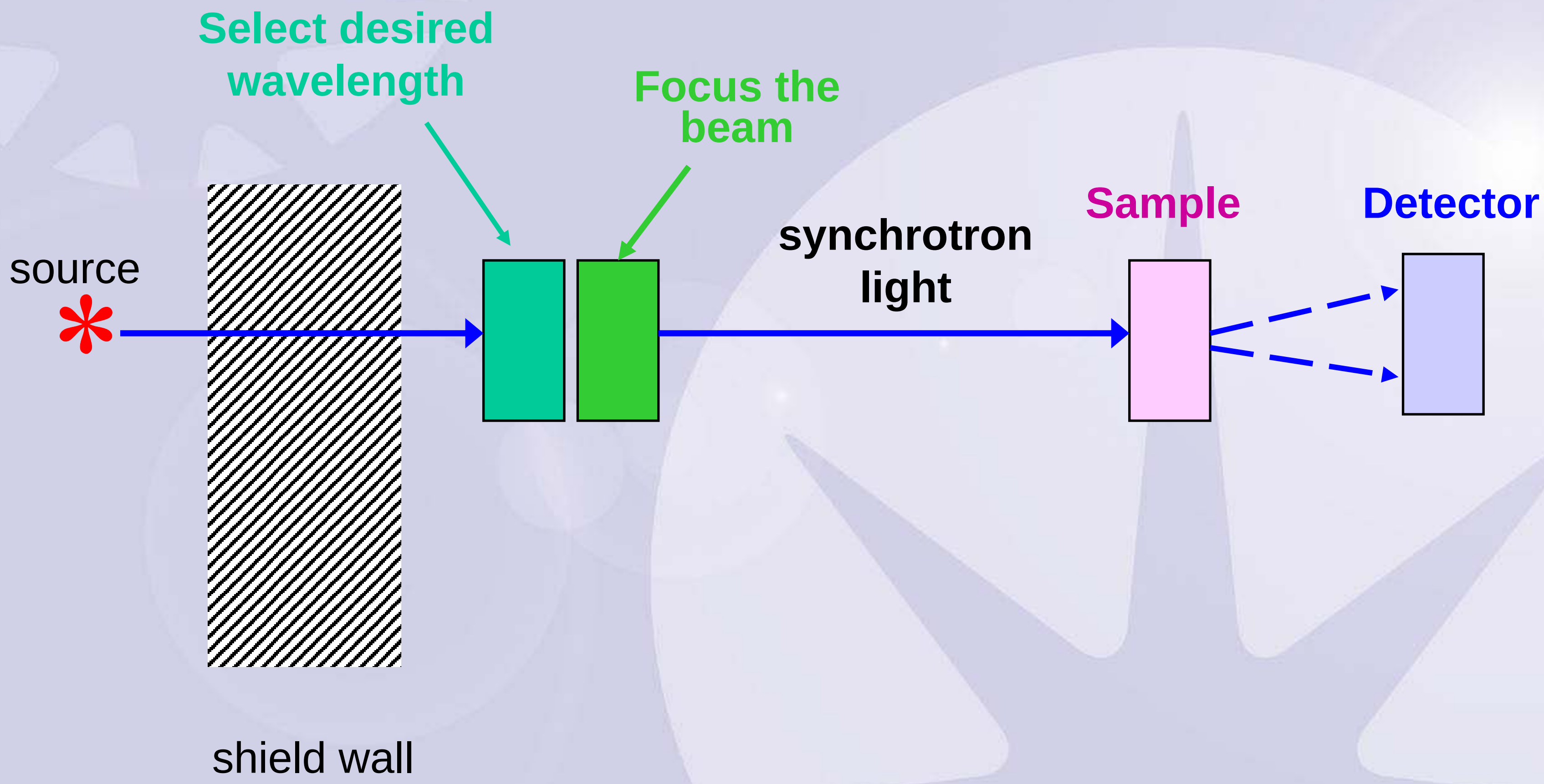
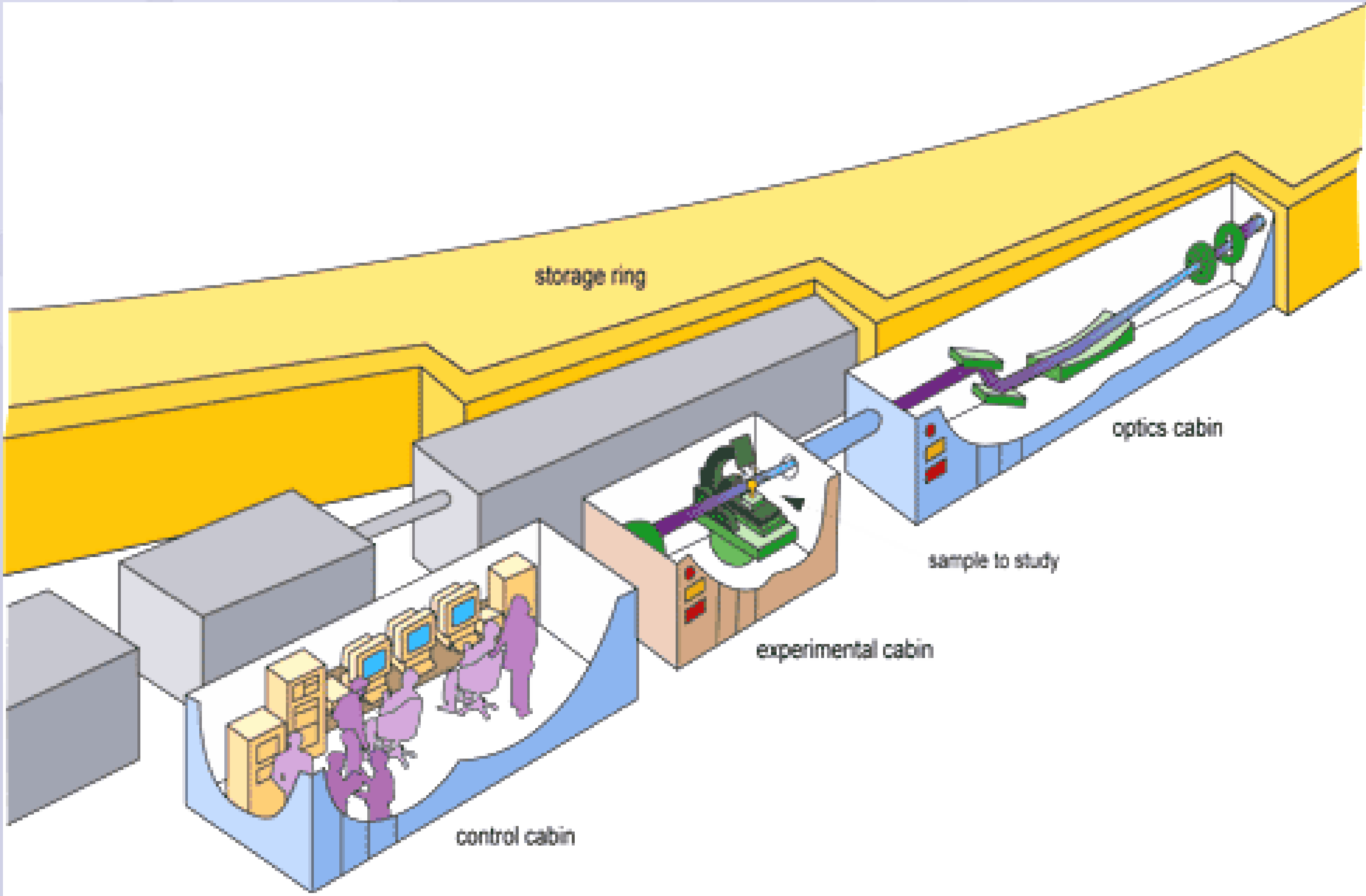
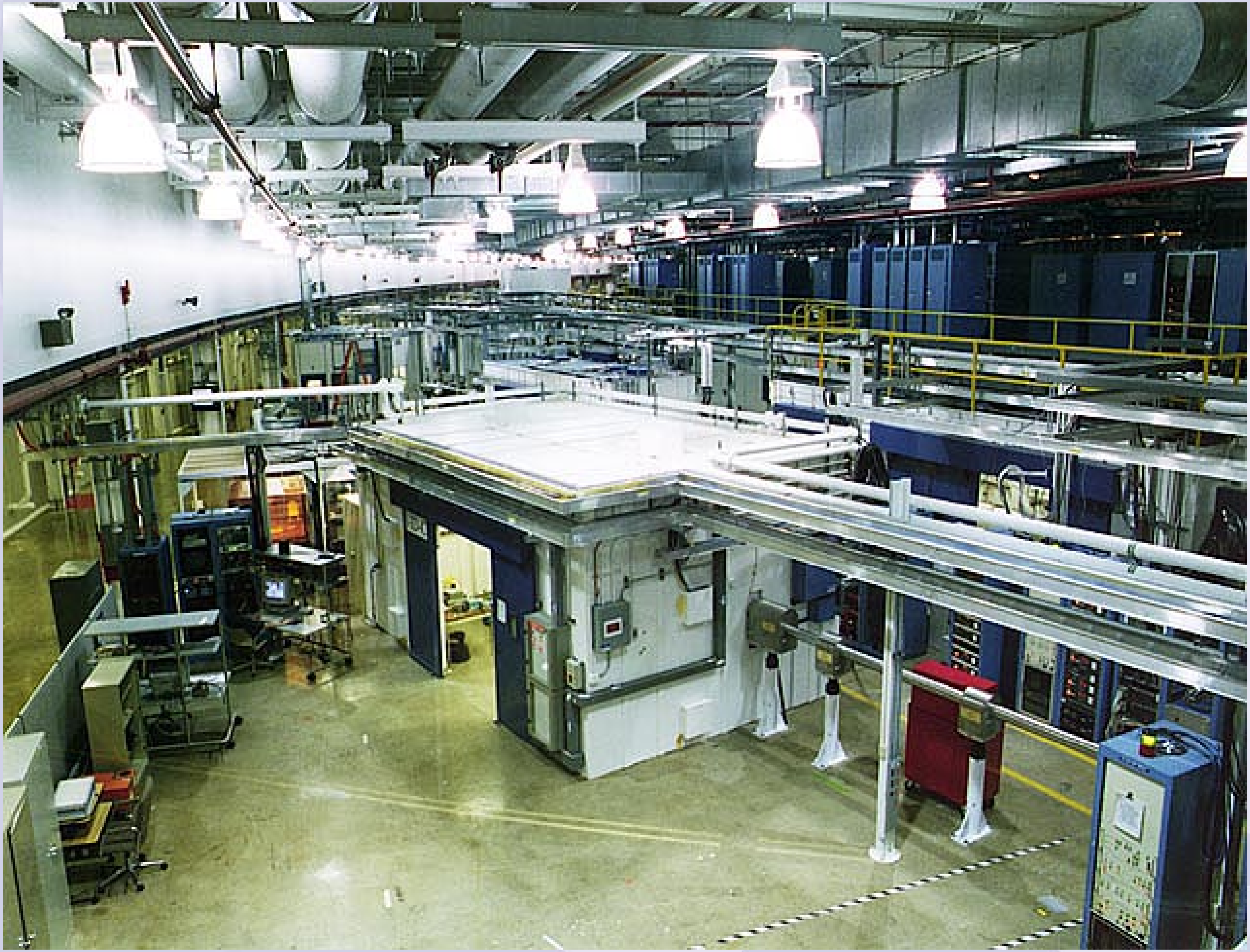
# The Beamlines

**"Beamlines" transport the synchrotron light from the source to the experiment:**

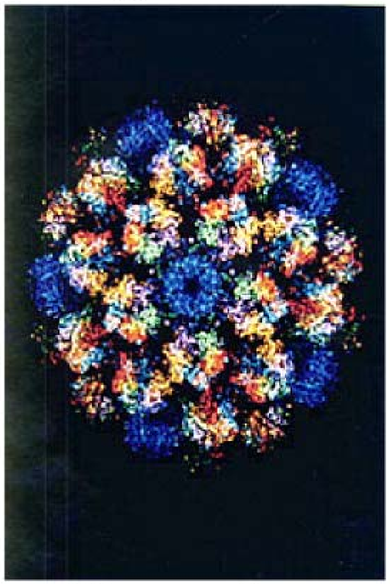
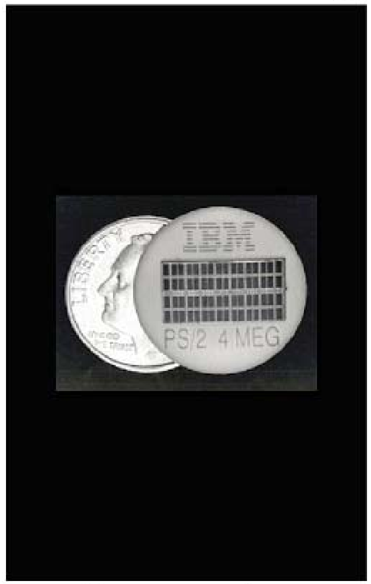
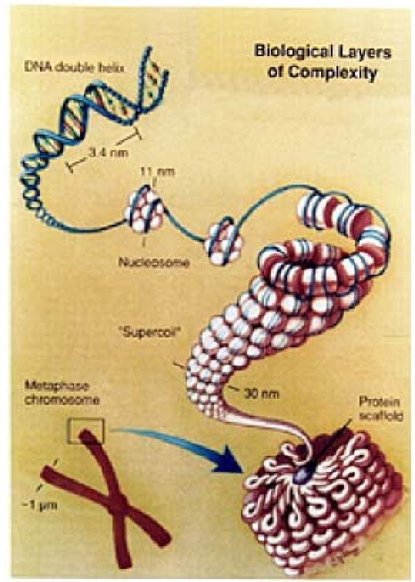
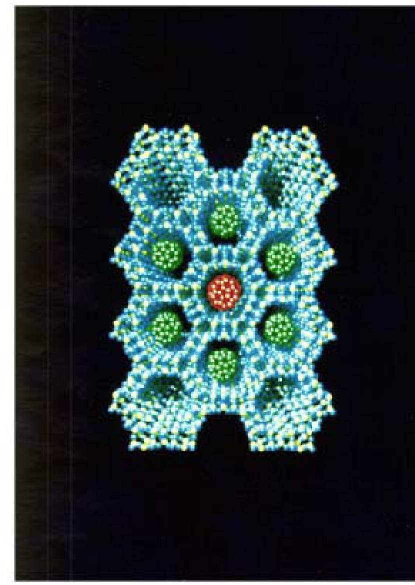



storage ring
optics cabin
sample to study
experimental cabin
control cabin

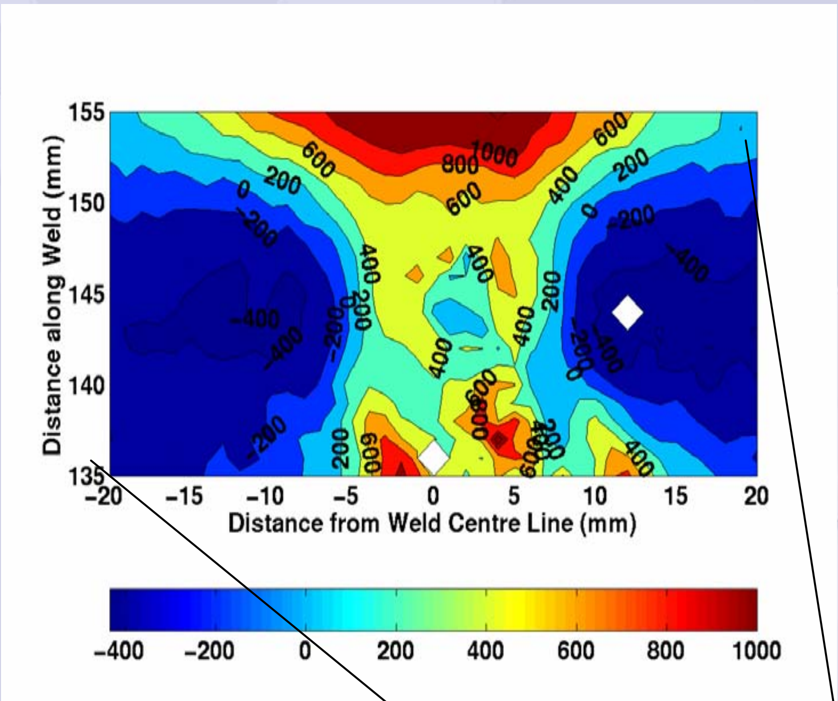
# What it looks like in reality:

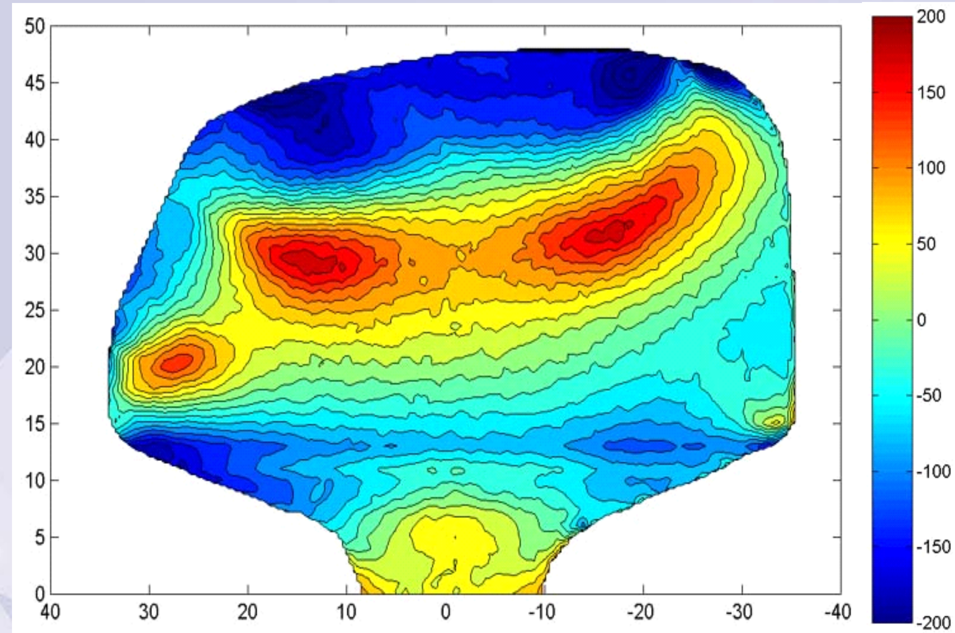


# Research Using Synchrotron Radiation

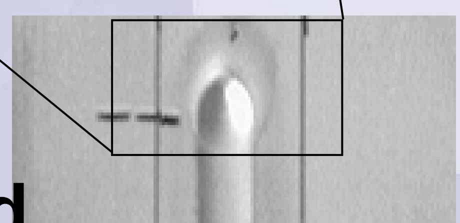
| Biology & Medicine | Micromanufacturing | Genetics | Materials/Chemistry |
|---|---|---|---|
|  |  |  |  |
| Unraveling Structures of Human Viruses | Improving the Manufacture of Computer Chips & Other Microdevices | Measuring DNA Structure | Designing New & Better Materials |

# Synchrotron light allows us to see the unseen…….




**Stresses in a rail-head**



**Stresses in an aerospace weld**

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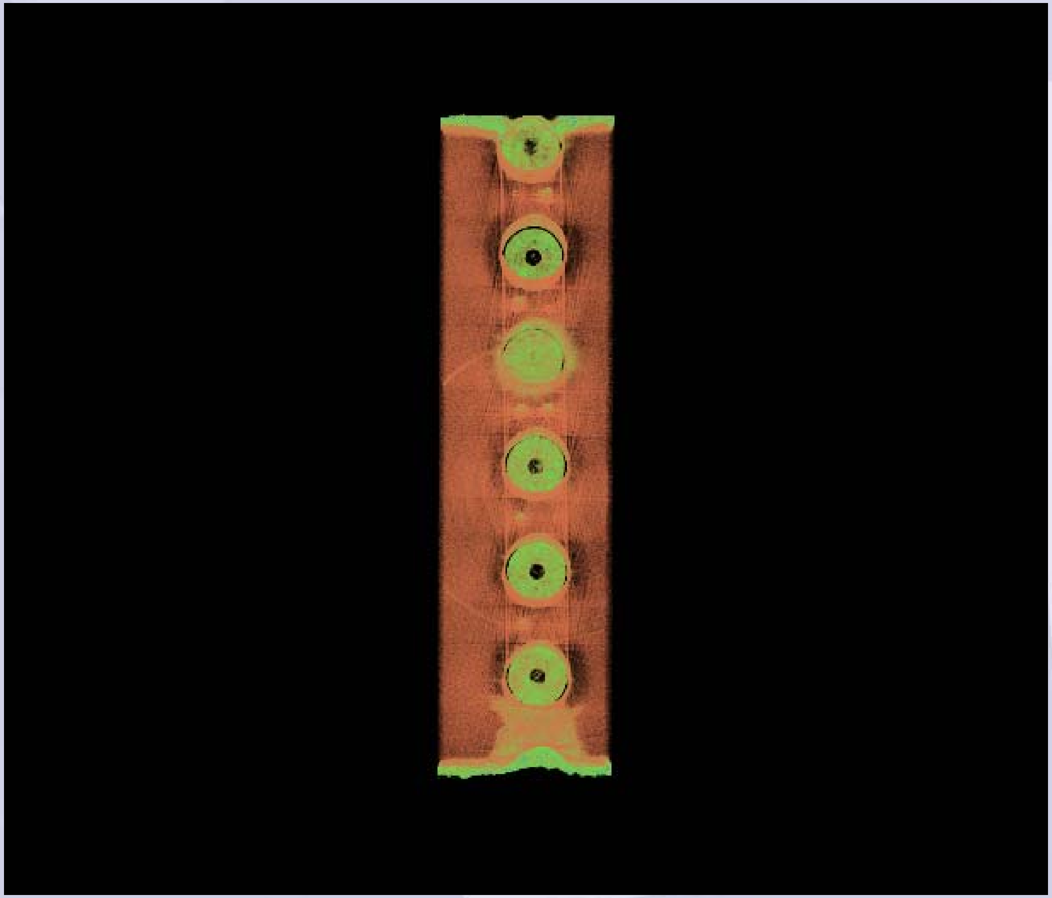
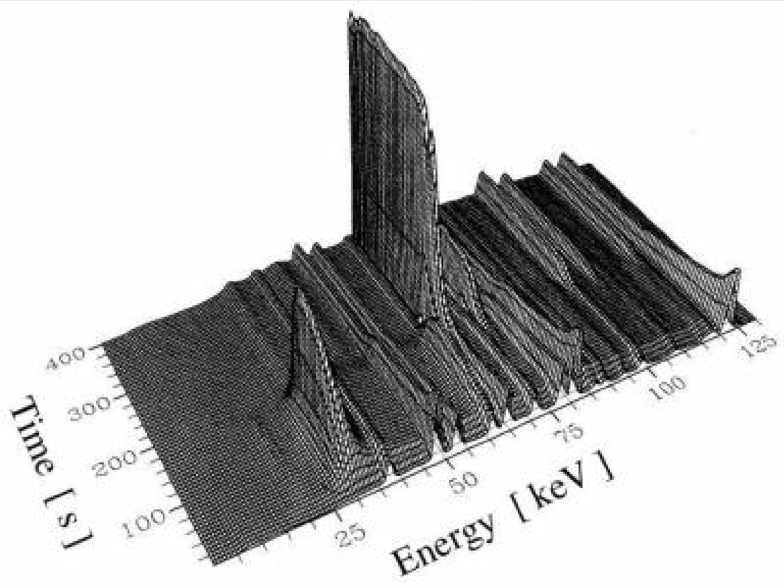
# internal damage occuring in a metal/SiC composite

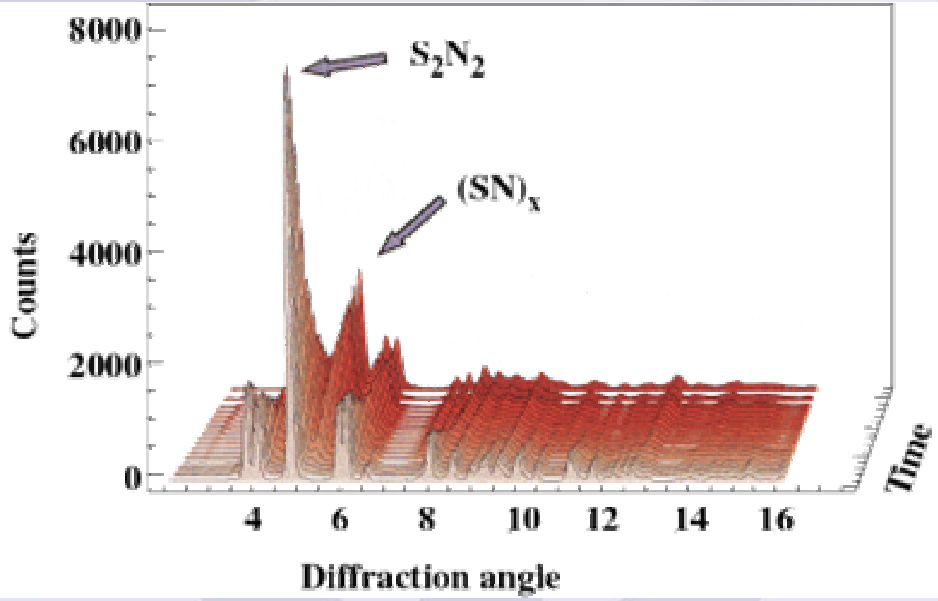


# Chemistry

**The high brightness of synchrotron light allows chemical reactions to be followed in real-time, such as catalysis, polymerisation etc.**




**hydration of Portland cement**




**polymerisation of disulphur dinitride ($S_2N_2$)**

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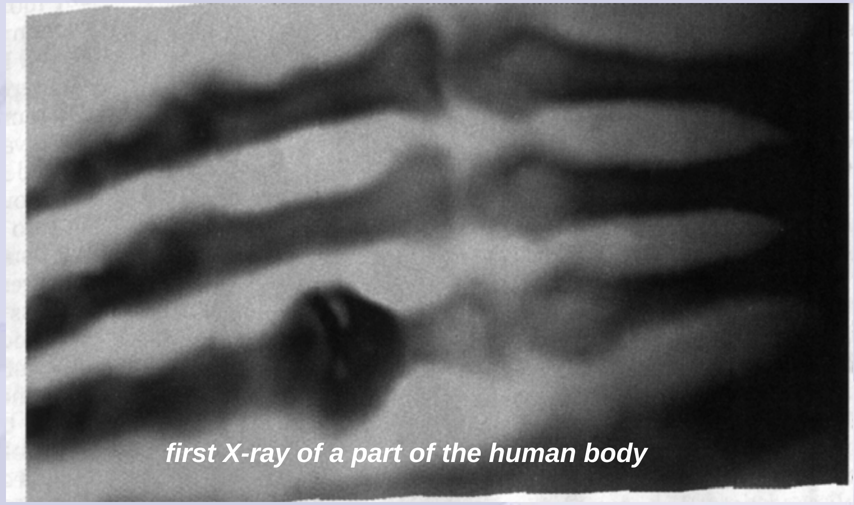
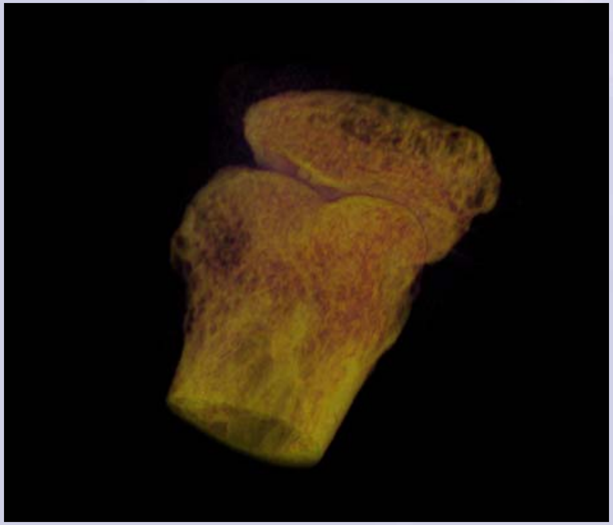
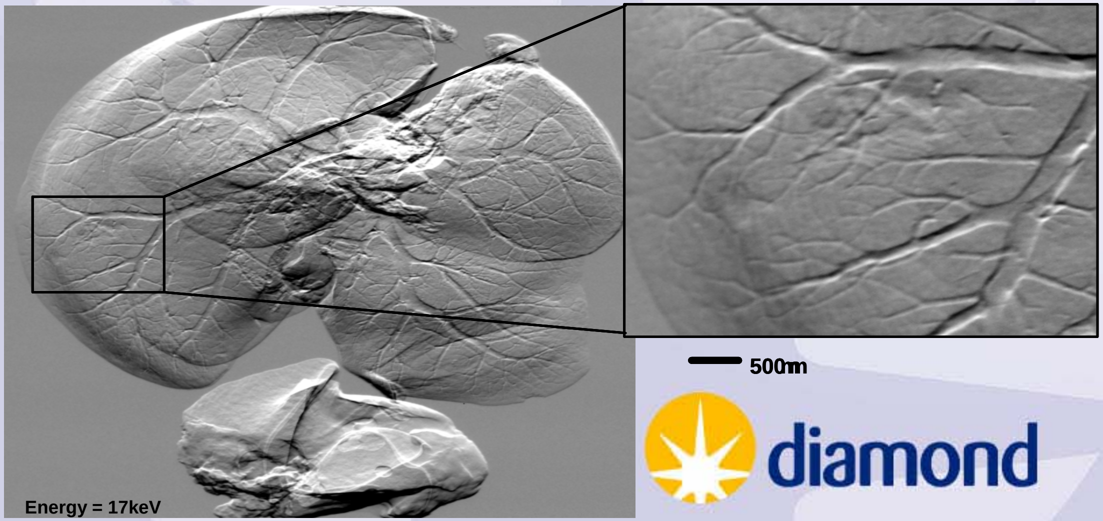
# Medical Imaging


*first X-ray of a part of the human body*

**Soon after the discovery of X-rays by Wilhelm Roentgen in Nov. 1895 they started to be used to image the human body for medical diagnosis**

**Using synchrotron X-rays things have moved on ..**



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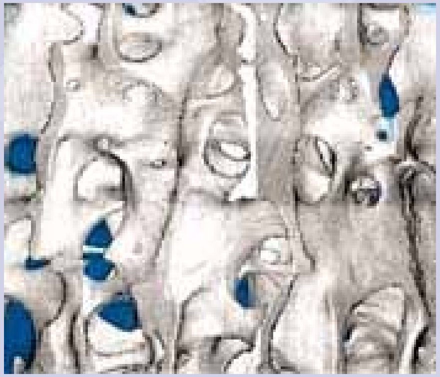
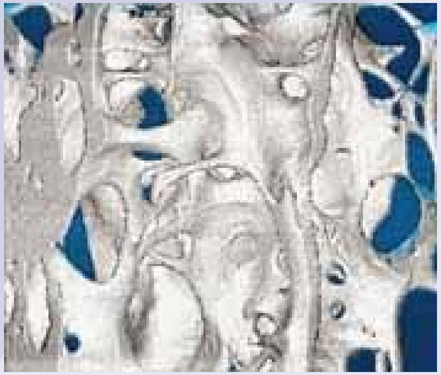
# Medical Imaging

**Computed Micro-Tomography (CMT) using high brightness X-rays allows non-destructive 3 dimensional reconstruction of human tissues with a 1 μm spatial resolution**

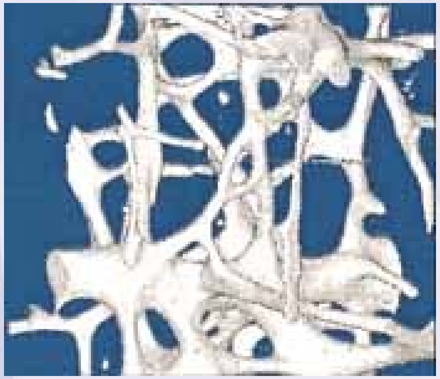
*33 years*



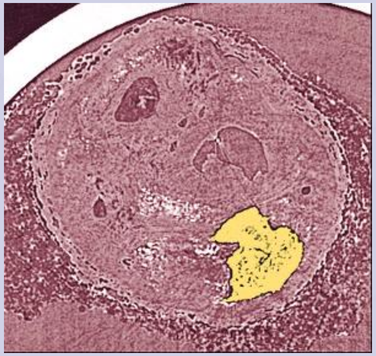
*55 years*



*72 years*



**e.g. diminuition of bone structure with age**

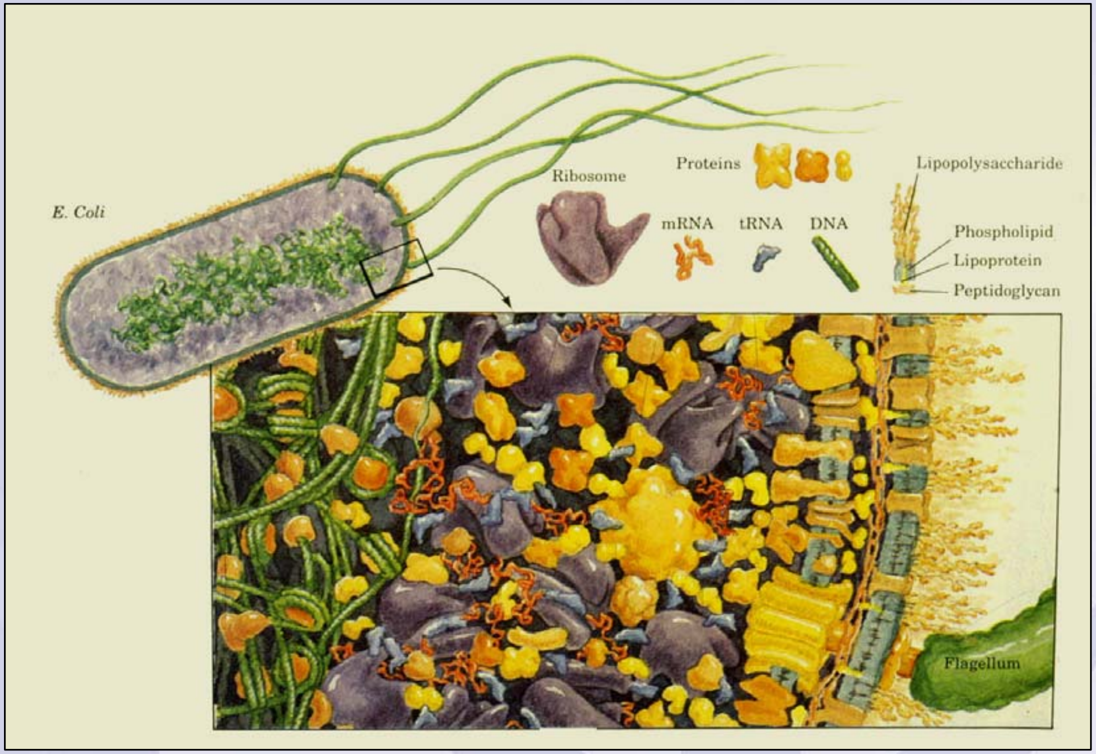


↔ 0.8 mm

**e.g. in vitro sample of a human coronary artery with fatal plaque and thrombosis**

# Structural Biology and Rational Drug Design

To design drugs rationally and very efficiently we need to know the structures of the “targets” against which they could be directed

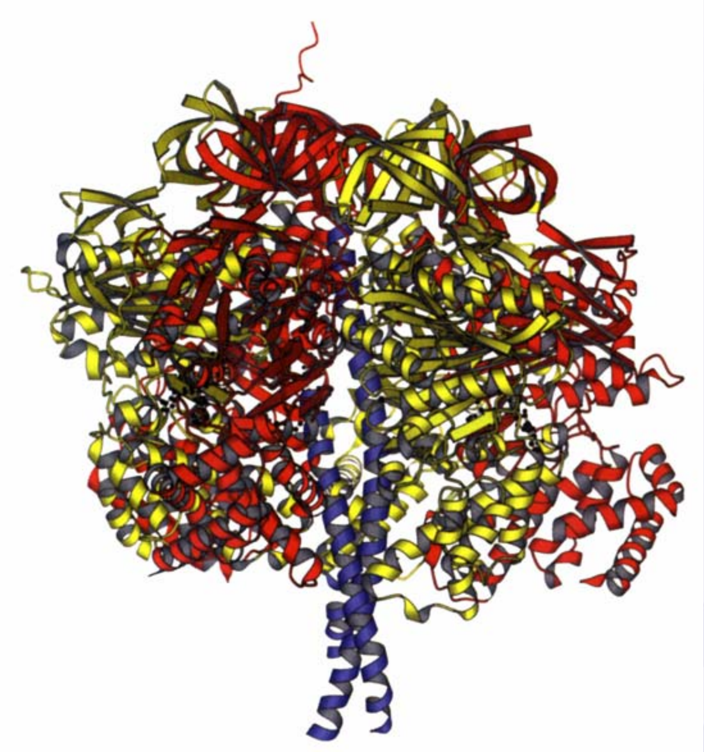



The most abundant molecules in living systems are proteins that carry out virtually every chemical transformation in a cell

Proteins are chains of typically 300 “amino acids” joined together in a specific order (the protein “sequence”)

Humans contain about 50,000 different proteins each of which carries out a specific function

**Synchrotron radiation** has enabled the details of astonishingly complex structures to be determined and used as the basis for the design of molecules that can perturb their normal functions



# The Genomic Revolution

the sequences of proteins in a given organism are encoded by the DNA in its genome

we now know the complete sequences of all our own proteins and of those in many of our pathogens e.g. bacteria

BLUEPRINT OF THE BODY

Overview | Genome guide | Glossary | Related sites | Message board
Story archive | Q&A | Chat Series | Video Archive

## Genome announcement 'technological triumph'

### Milestone in genetics ushers in new era of discovery, responsibility

June 26, 2000
Web posted at: 12:09 p.m. EDT (1609 GMT)

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In this story:

Knowledge can help treat causes of diseases

Advances could come quickly

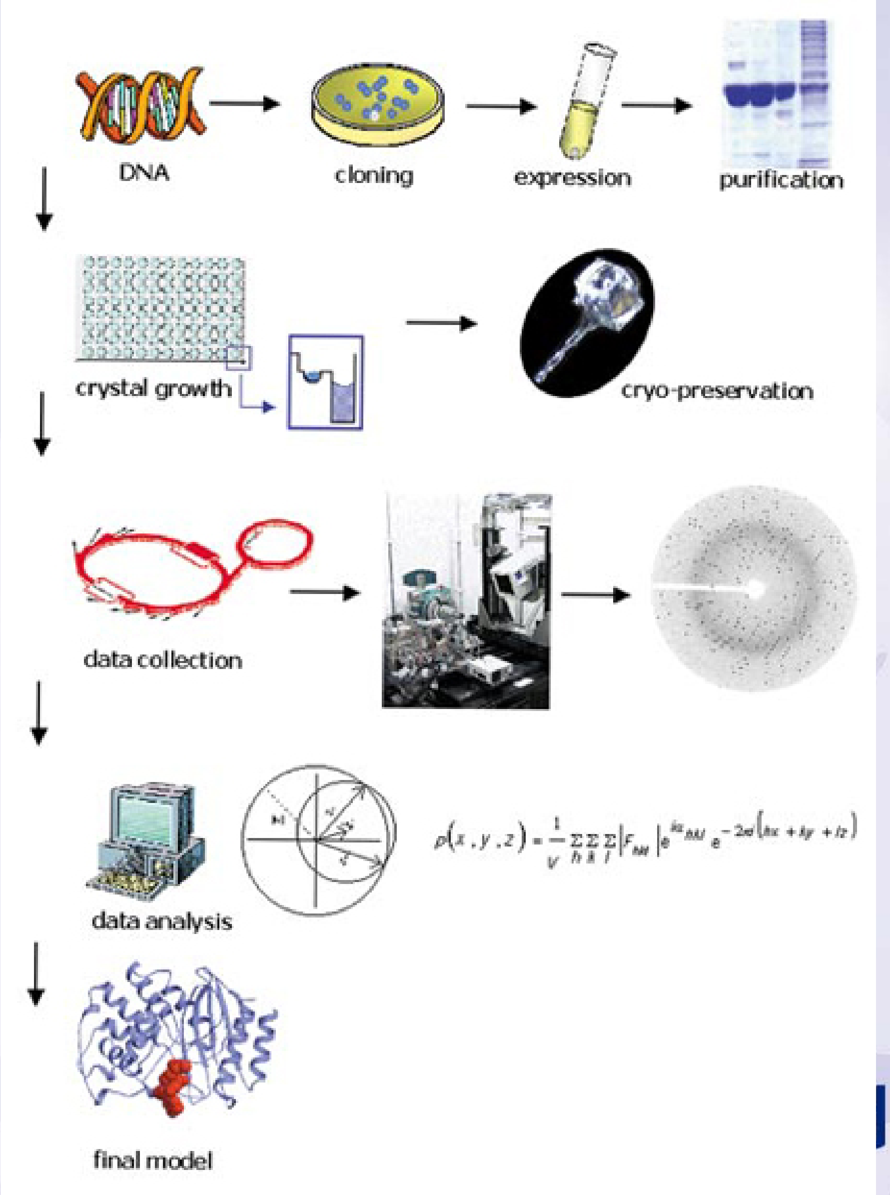
Blair and Clinton announced genome progress in satellite news conference

# Protein Crystallography

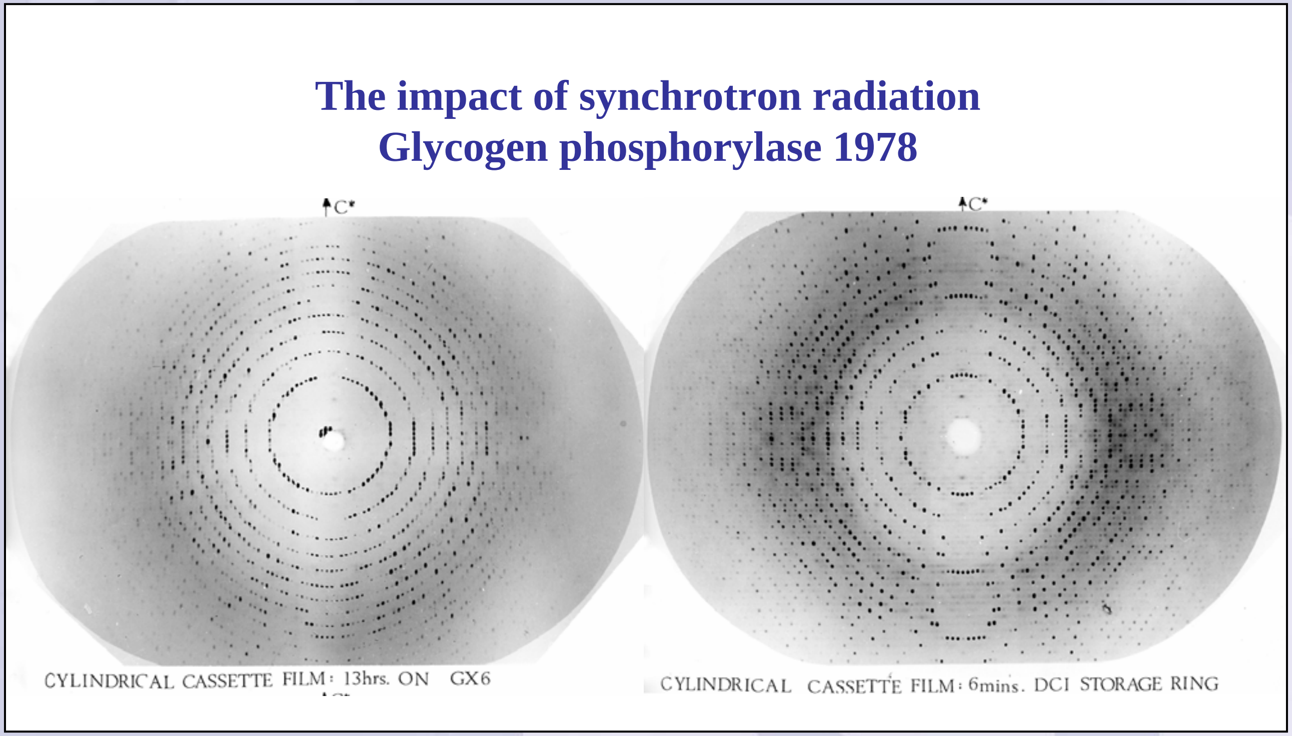
**"The Wellcome Trust and others are investing millions of pounds to realize the medical potential of genome sequencing.**

**The synchrotron is one of the key technologies that will be required to achieve an expansion of knowledge in the area of biology and specifically structural genomics."**

*M. Morgan, Director,*
*Research Partnerships & Ventures,*
*Wellcome Trust*
*Diamond Launch, May 2002*



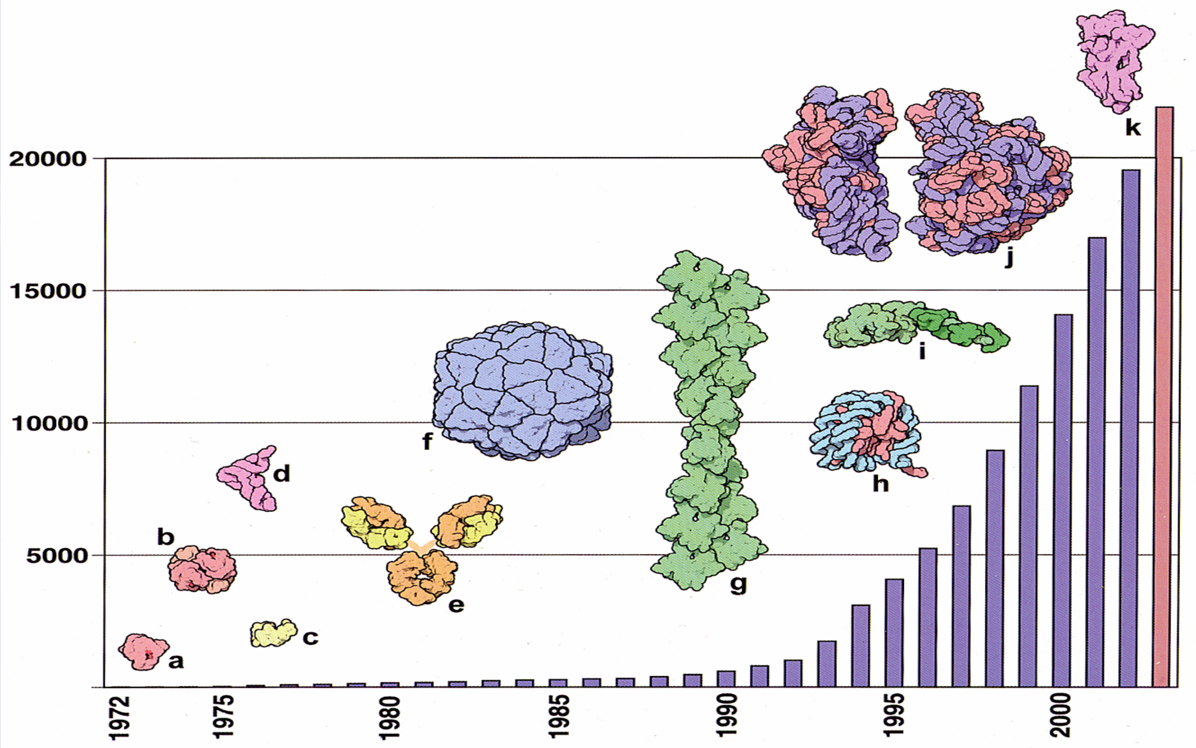
# Protein Crystallography




**Early example of the power of synchrotron radiation: exposure time reduced from 12h to 6 mins and quality of diffraction improved.**

# Protein Crystallography

**Dramatic increase in the number of protein structures solved and deposited in the protein data bank:**




***The 23,000 structures deposited do not all represent unique proteins. Many of the structures are the same protein from a different source, or different crystal form. The number of unique structures is probably around 8000.***

# Towards New Antibiotics

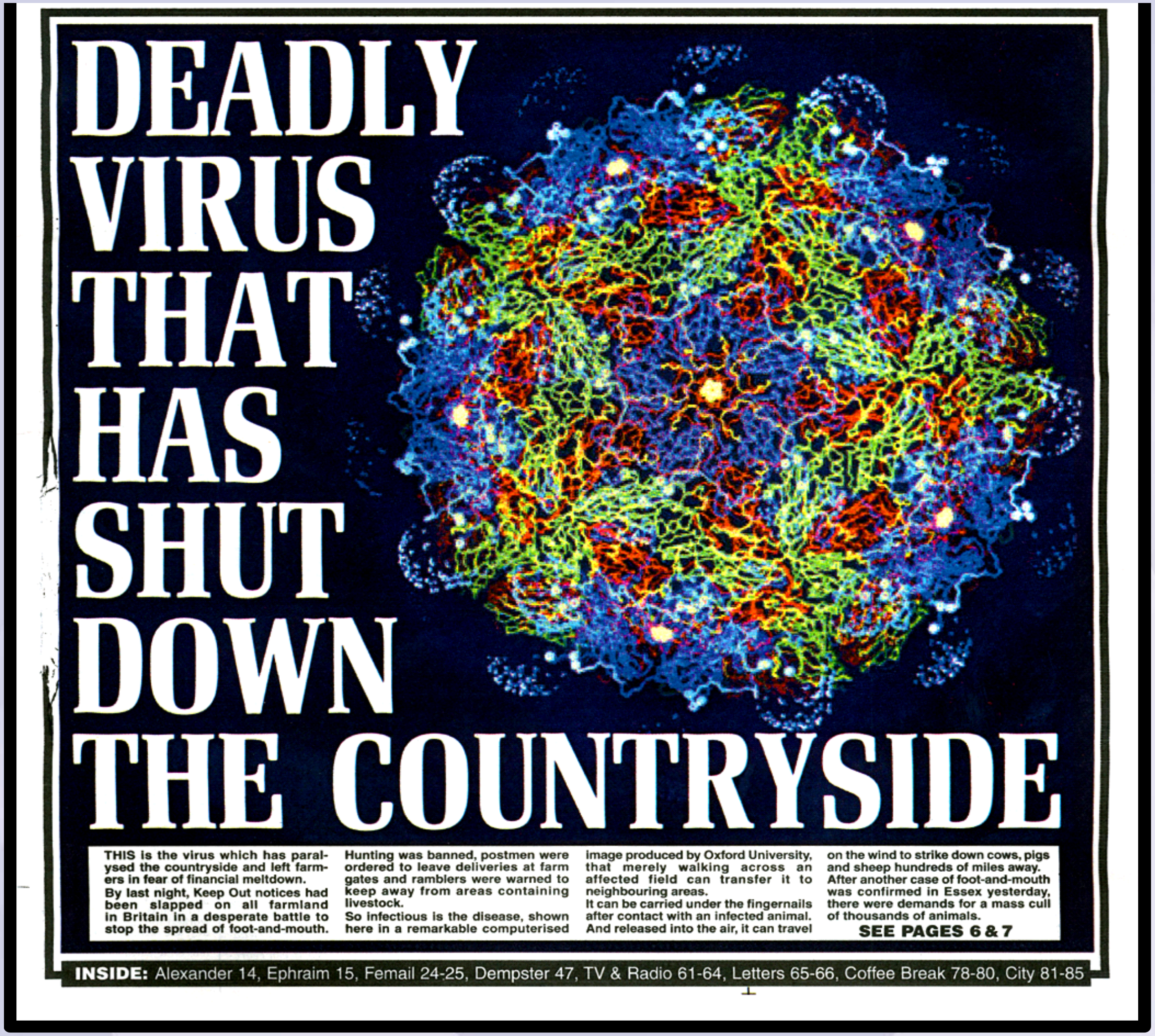
We now know the structure of the “molecular machine” that is the means by which bacteria make proteins in their cells. This structure is an exceptionally important target for the development of new antibiotics

Synchrotron light is essential in designing and screening potential drug molecules

# The Design of Vaccines

The use of synchrotron light has made it possible to determine the *complete* structures of some viruses

Such structures form the basis of rational strategies to design more effective vaccines



# DEADLY VIRUS THAT HAS SHUT DOWN THE COUNTRYSIDE

THIS is the virus which has paralysed the countryside and left farmers in fear of financial meltdown.

By last night, Keep Out notices had been slapped on all farmland in Britain in a desperate battle to stop the spread of foot-and-mouth.

Hunting was banned, postmen were ordered to leave deliveries at farm gates and ramblers were warned to keep away from areas containing livestock.

So infectious is the disease, shown here in a remarkable computerised image produced by Oxford University, that merely walking across an affected field can transfer it to neighbouring areas.

It can be carried under the fingernails after contact with an infected animal. And released into the air, it can travel on the wind to strike down cows, pigs and sheep hundreds of miles away.

After another case of foot-and-mouth was confirmed in Essex yesterday, there were demands for a mass cull of thousands of animals.

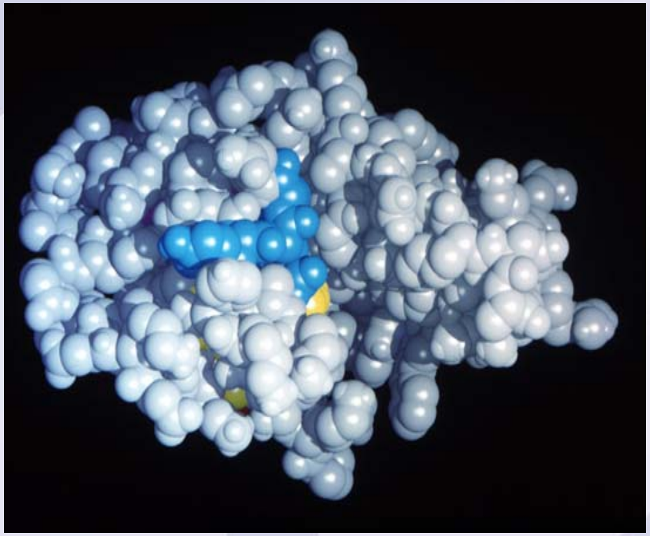
SEE PAGES 6 & 7



***the foot and mouth virus was the first virus structure to be solved in the UK, based on data taken at the SRS***

# Protein Folding and Self-Assembly are the Essence of Life

Any naturally occurring protein can fold into a highly compact structure that is unique to its particular amino acid sequence



The correct folding of every protein within the cell and the assembly into higher order structures are essential for living systems to survive and to reproduce.

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# Protein Misfolding Diseases

Misfolding can result in the “aggregation” and deposition of proteins in a variety of tissues in the body.

There are about 20 recognised diseases of this type, including:

Alzheiemer’s disease

Parkinson’s disease

Huntington’s disease

Type II diabetes mellitus

Transmissible spongiform encephalopathies (e.g. vCJD)

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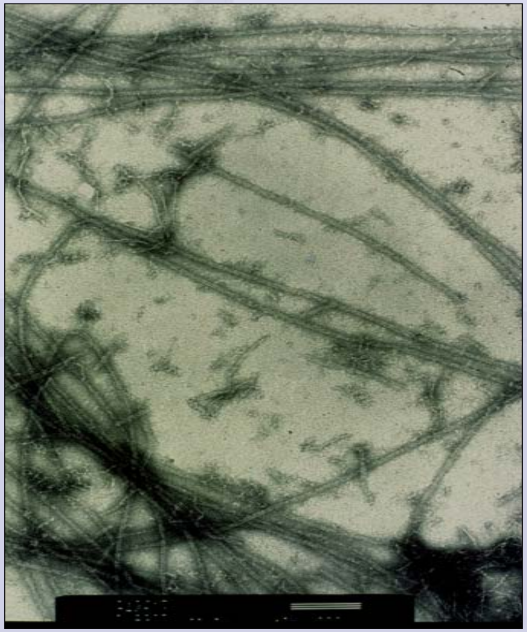
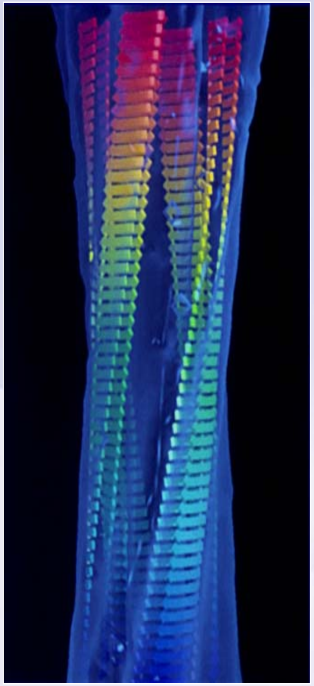


# Amyloid Diseases



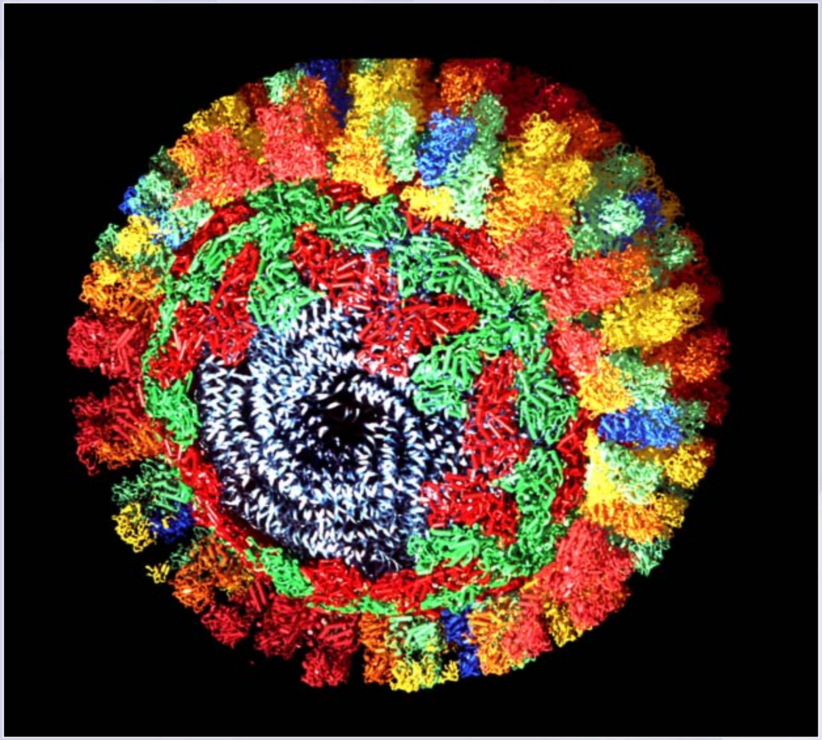
In these diseases the protein aggregates are thread-like fibrils about 100,000th of a millimetre in diameter called amyloid fibrils

They can be deposited in the brain or other organs depending on the particular disease.

At the moment the design of drugs to combat these dreadful diseases is limited by the lack of detailed knowledge of the structures of the tiny fibrils.

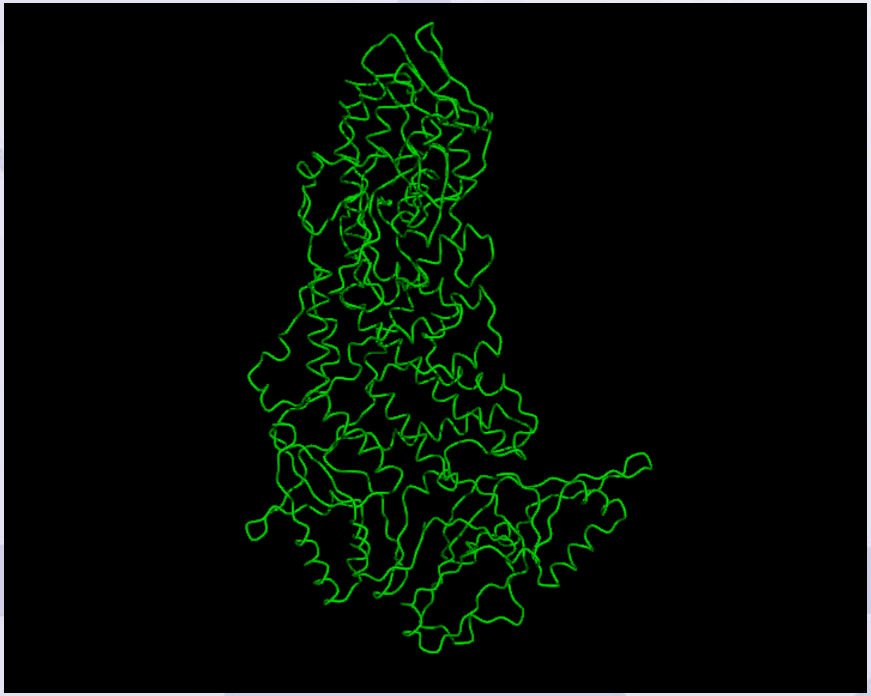
The extreme brightness of synchrotron light is a key factor for progress in this area

# Protein Folding and Assembly



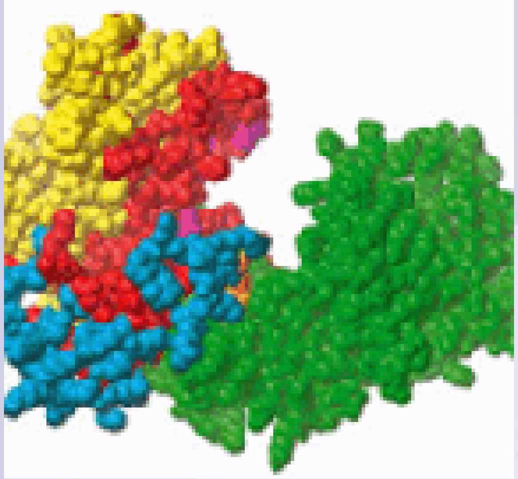
The blue tongue virus is the largest object whose structure is known to atomic resolution

The virus has a set of proteins that encapsulates DNA



The structure self assembles

## Research Examples : Structure of an Anthrax Toxin



Edema factor (EF) is one of three toxins that make anthrax a deadly biohazard.

Researchers have determined using **synchrotron light** the three-dimensional structure of EF.

**This discovery provides important new information that may lead to the design of pharmaceuticals to counteract the effects of bacterial toxins such as anthrax.**

**(Nature 415, 396-402 [2002])**

# Research Examples – new drugs


**The anti-influenza drug Relenza, courtesy CSIRO and Biota Holdings**

Development of the anti-influenza drug Relenza illustrates the potential of rational drug design.

The coat of flu virus varies from year to year, so a new vaccine is required each year.

Relenza was designed to disrupt the protein neuraminidase within the virus, that doesn't change yearly

Australian scientists determined the structure of neuraminidase using synchrotron light in Japan.

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# Protein Crystallography - the challenges

- Bigger and more complex: macromolecular assemblies and machines - connection with electron microscopy and cell biology
- Membrane proteins
- Smaller crystals (e.g. 10 μm).
- Complete dictionary of protein folds
- Medical: Structure based drug design and structural genomics
- Faster: time resolved studies to observe chemical reactions occurring; higher resolution
- More complex: transient protein-protein complexes which govern cellular processes

**only 80 of the 23,000 proteins in the protein data bank are membrane proteins. 50% of drug targets are membrane proteins. Membrane proteins are difficult to purify and crystallise and crystals diffract poorly.**

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# Diamond Phase-I Beamlines

- **Protein crystallography (3 beamlines)**
  For the determination of the structure of macromolecules with rapis sample through-put.
- **Extreme conditions**
  Study of materials at very high temperatures and pressures, typical of planetary interiors and industrial processes.
- **Materials and magnetism**
  Study of materials including magnetic systems, high temperature superconductors
- **Microfocus**
  chemical imaging and structural studies of complex multicomponent systems with sub-micron resolution
- **Nanostructures**
  To study the morphology, chemical and magnetic state of nanostructures with <10 nm resolution.

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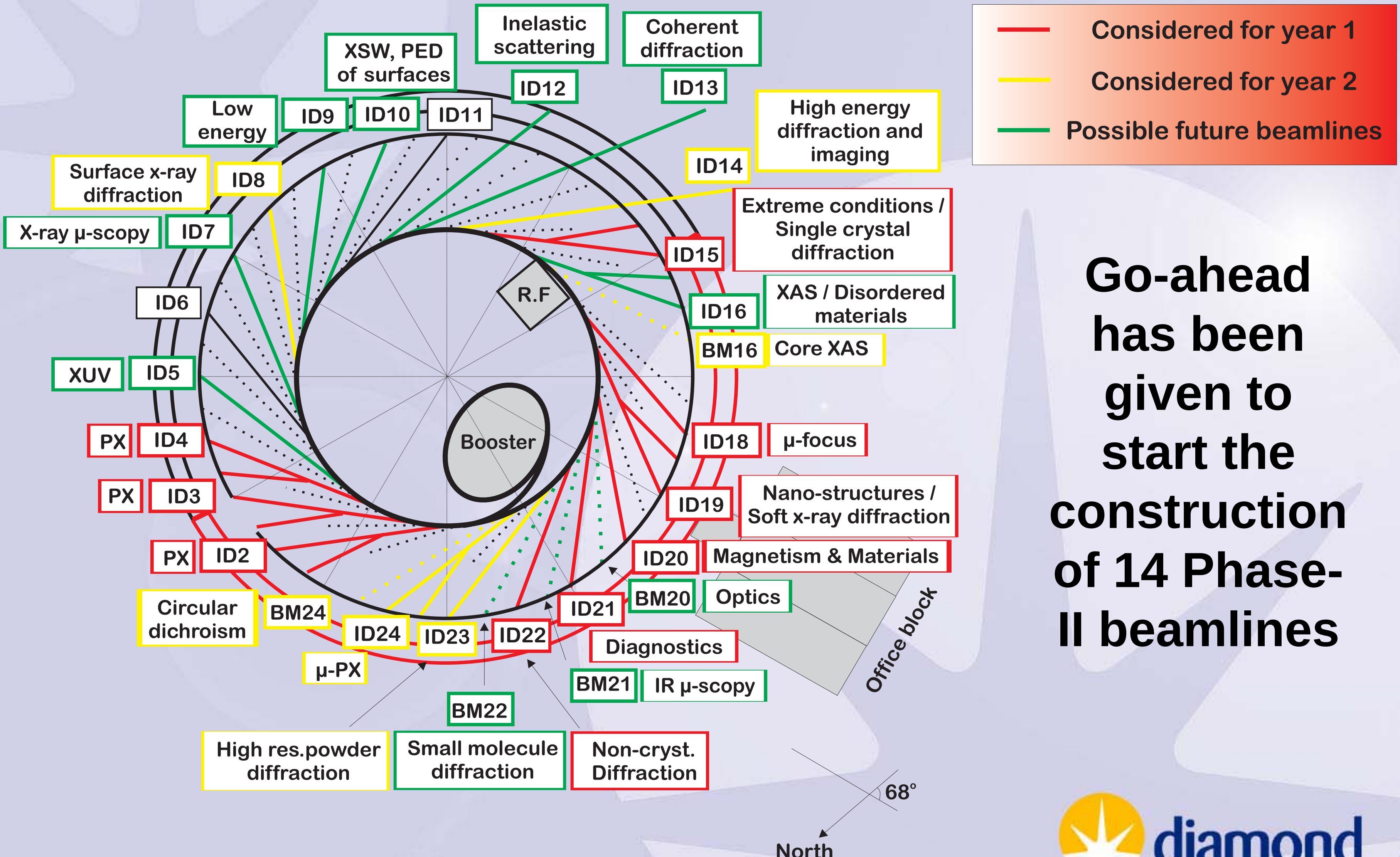
# and beyond :




**Go-ahead has been given to start the construction of 14 Phase-II beamlines**

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# Master Schedule

| | | |
|---|---|---|
| Appoint Main Building Contractor | Jan. ’03 | ✓ |
| Start enabling works | Mar. ’03 | ✓ |
| Start main building works | Oct. ’03 | ✓ |
| Start machine installation | Sep ’04 | |
| Start beamlines installation | Jan. ’05 | |
| Linac commissioning | May – Jul. ’05 | |
| Booster commissioning | Sep. – Nov. ’05 | |
| Storage ring commissioning | Jan. – Dec. ’06 | |
| Beamlines commissioning | May – Dec. ‘06 | |
| Start of User Operations | Jan. ’07 | |

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# Nov. 7th 2003

# Jan. 29th 2004

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# Feb. 9th 2004

# Mar. 26th 2004

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# May 2nd 2004


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