Presented at the FIG Working Week 2016,
May 2-6, 2016 in Christchurch, New Zealand

FIG Working Week 2016

CHRISTCHURCH, NEW ZEALAND
2–6 May 2016

Recovery from disaster

FIG NZIS

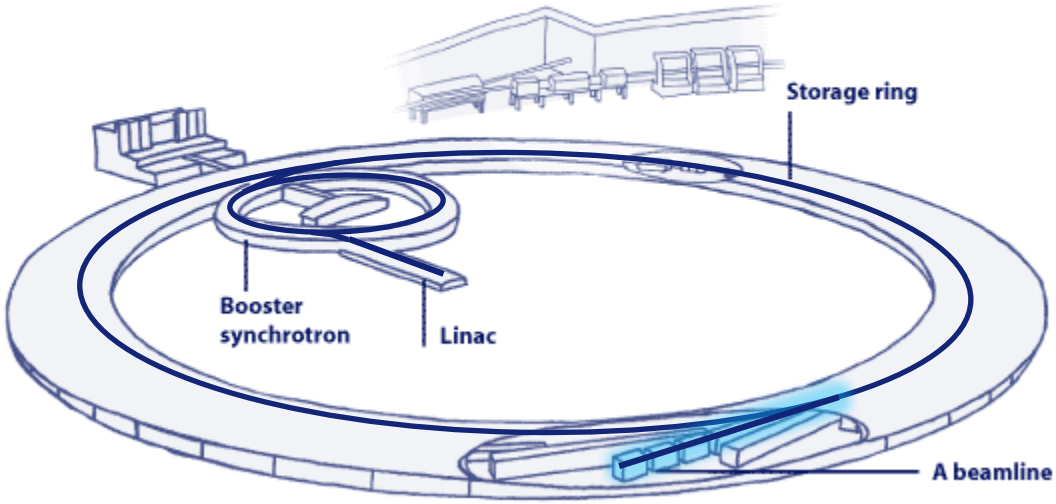
ESRF | The European Synchrotron

David Martin

Challenges in High Precision Beamline Alignment at the ESRF

FIG Working Week Christchurch New Zealand 2016

SO WHAT IS A SYNCHROTRON RADIATION LIGHT SOURCE?



The linear accelerator (linac) accelerates the electrons from rest mass to 100 MeV

The booster accelerates the electrons from 100MeV to 6GeV

The storage ring keeps the electrons circulating at 6GeV for many hours

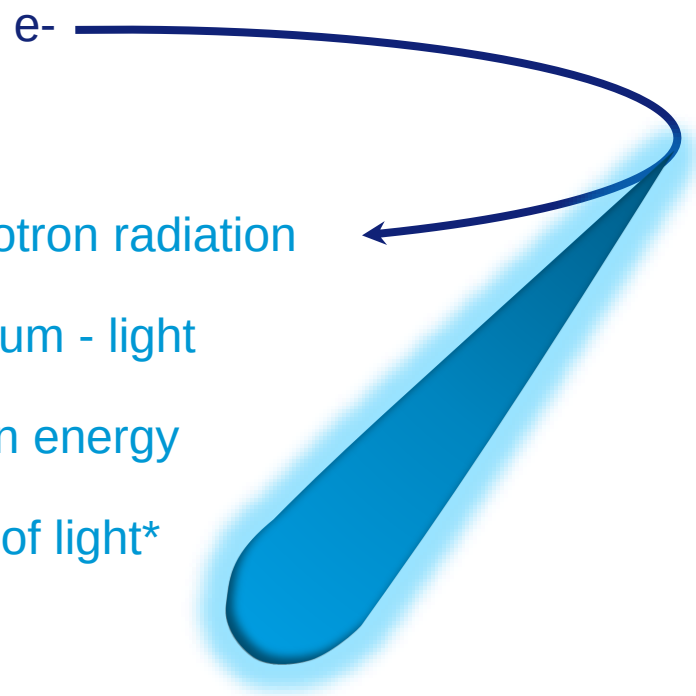
The 6GeV electrons produce synchrotron radiation in a tangential direction to the beam travel

A synchrotron radiation light source is composed of two main elements:

- A particle accelerator that accelerates electrons to nearly the speed of light, and
- Beamline(s) that use the synchrotron radiation generated by the accelerator to study matter.

One eV is the amount of energy gained (or lost) by the charge of a single electron moved across an electric potential difference of one volt.

WHAT IS SYNCHROTRON RADIATION



When electrons are accelerated they generate synchrotron radiation

Synchrotron radiation is on the electromagnetic spectrum - light

The wavelength of this light is a function of the electron energy

The ESRF electron velocity is very close to the speed of light*

The wavelength of the light is in the hard X-ray regime

The wavelengths of X-rays are small so they can be used to look at the atomic structure of matter

$$E=mc^2$$

*When *E=6 GeV* the velocity of the electrons is 0.99999993 times the speed of light

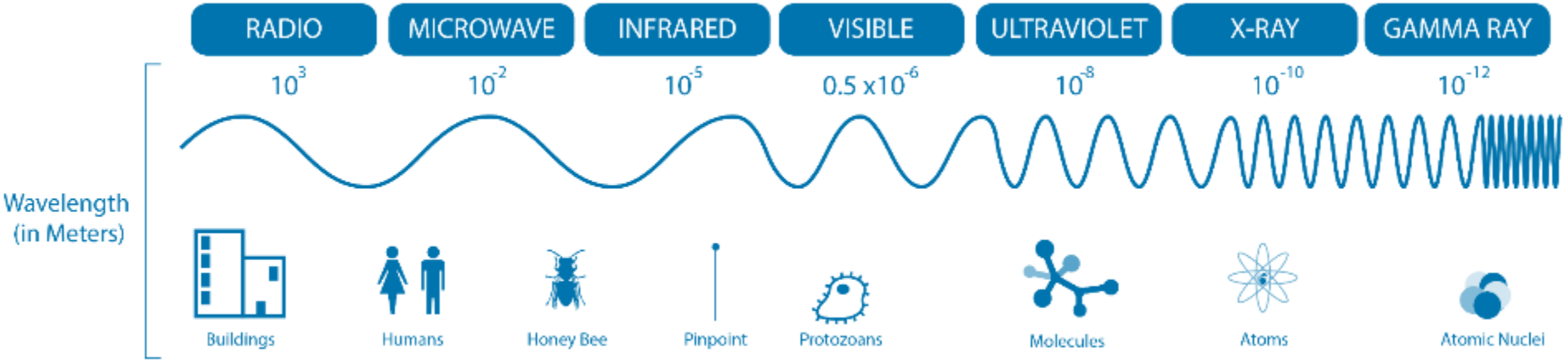
THE ELECTROMAGNETIC SPECTRUM

INFRARED 720-850nm

VISIBLE 440-640nm

ULTRAVIOLET 335-365nm

X-RAY 0.025 nm

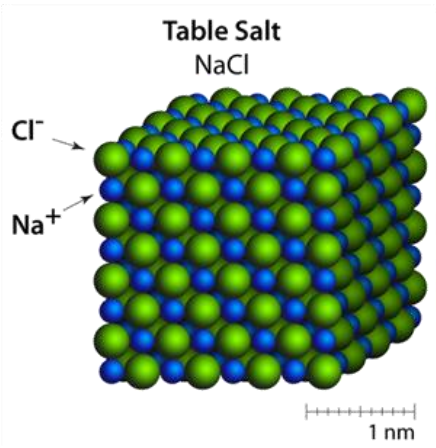


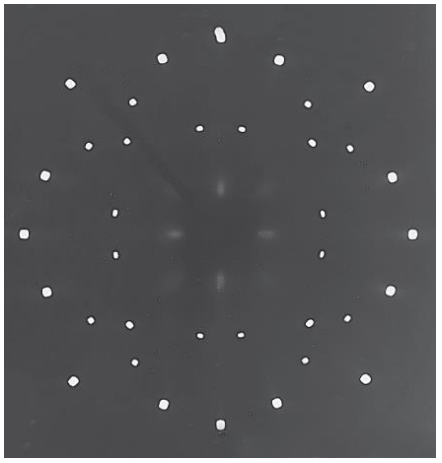
SO HOW ARE X-RAYS USED IN SCIENCE?

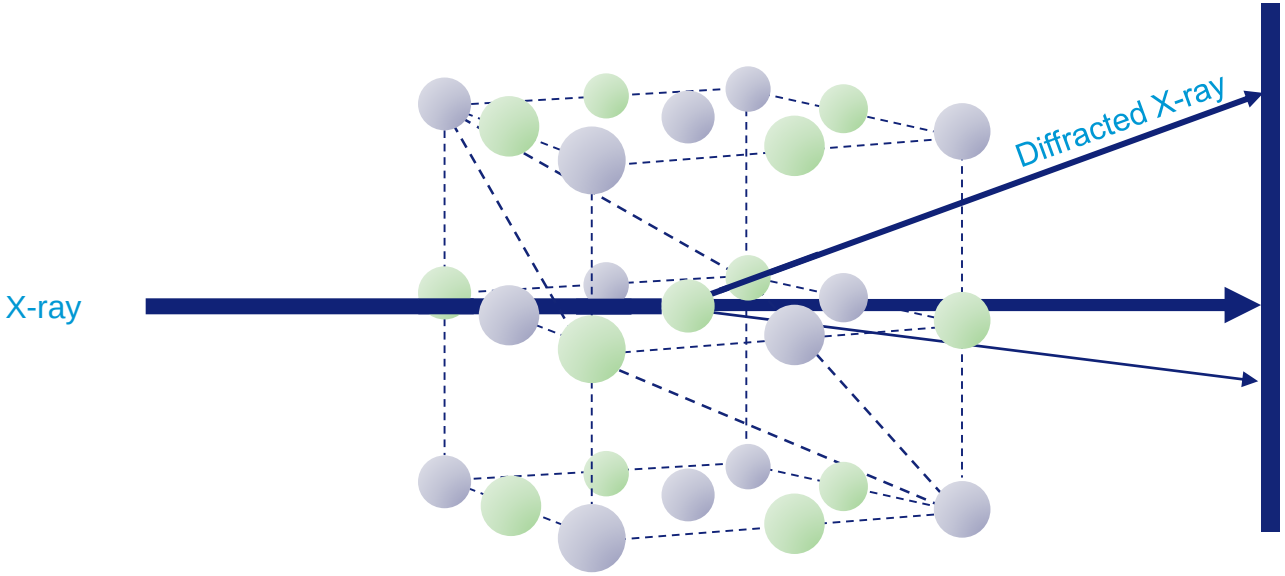
A good example of the type of science made at the ESRF is crystallography using X-ray diffraction.

A **crystal** is a solid material whose constituent atoms, molecules or ions, are arranged in a **highly ordered microscopic structure**, forming a **lattice** that extends in all directions.

CRYSTALLOGRAPHY AND X-RAY DIFFRACTION

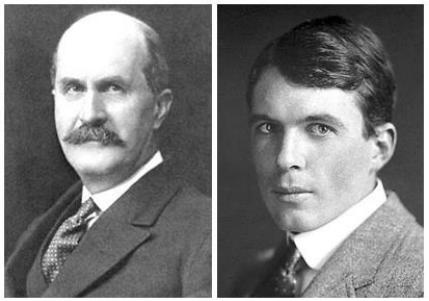




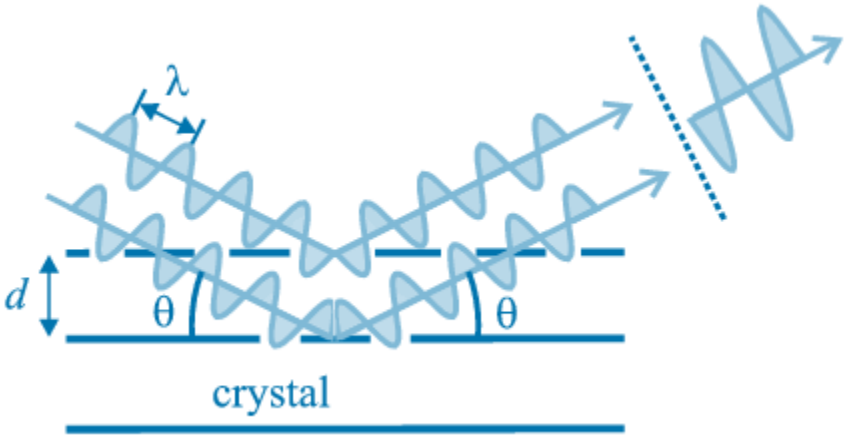


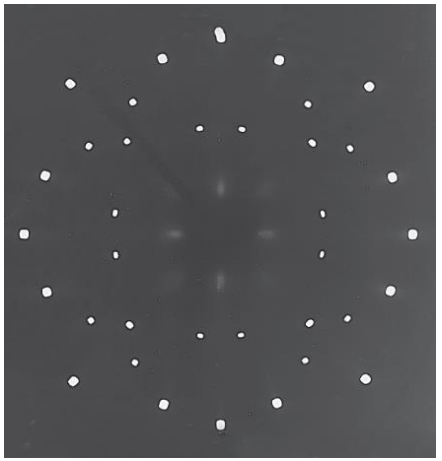
The atoms comprising the crystal structure form planes. When X-rays are incident on these crystal planes they are diffracted and produce a characteristic pattern of spots

BRAGG'S LAW



William Lawrence Bragg
William Henry Bragg
1915 Nobel Physics





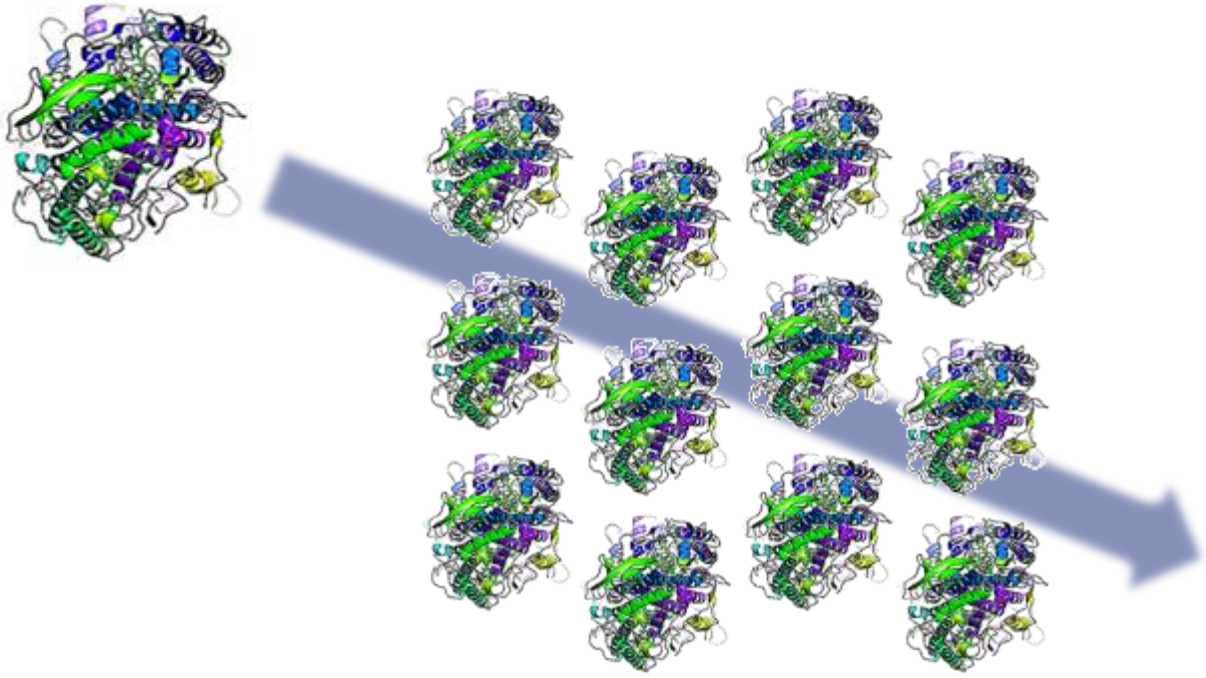
$$n\lambda = 2dsin\Theta$$

Bragg's law provides an elegant and powerful description of diffraction from crystals.

It describes how constructive interference leads to the pattern of X-ray diffraction spots.

Qualitatively, the diffraction picks up a *specific distance* in real-space, and transforms it into a frequency in *reciprocal space*.

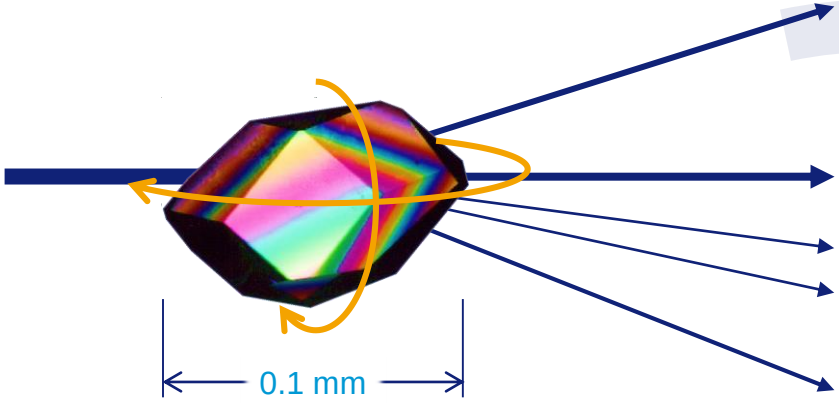
CRYSTALLOGRAPHY WITH LARGE MOLECULES



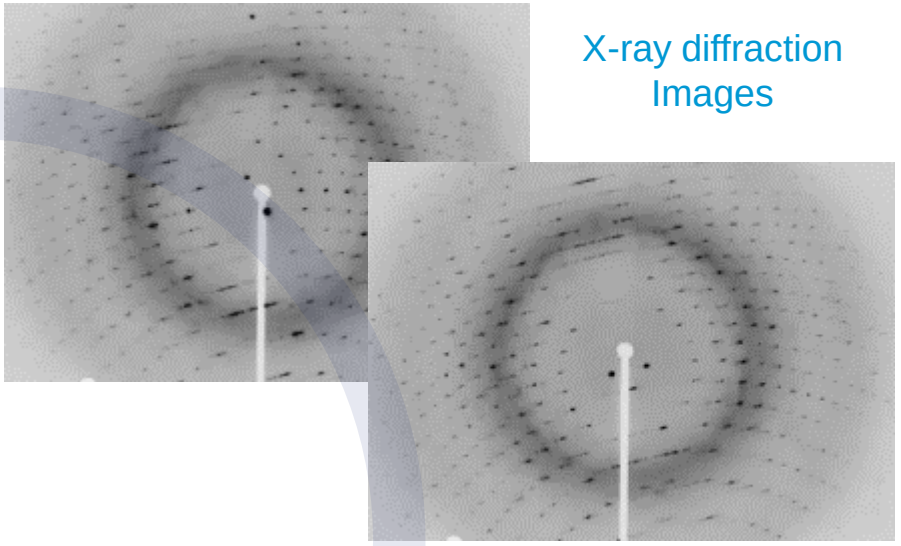
The same
techniques can be used
to image complex systems such as proteins

X-RAY CRYSTALLOGRAPHY METHOD

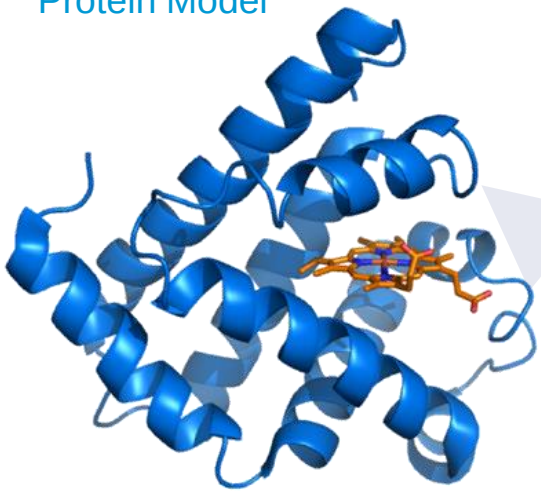
X-ray diffraction



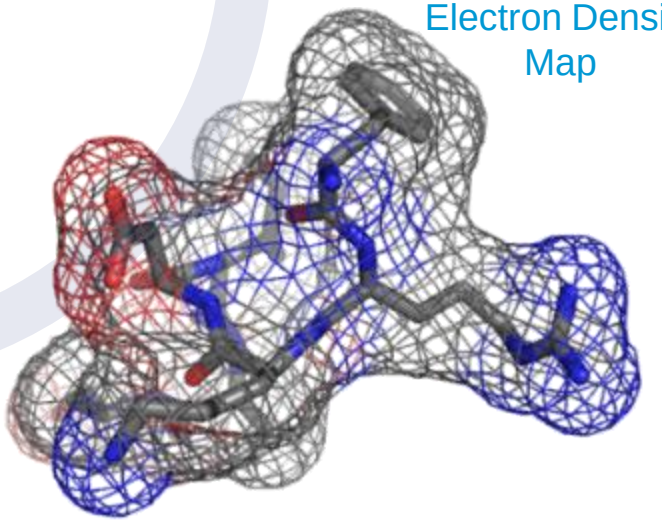
X-ray diffraction Images



Protein Model



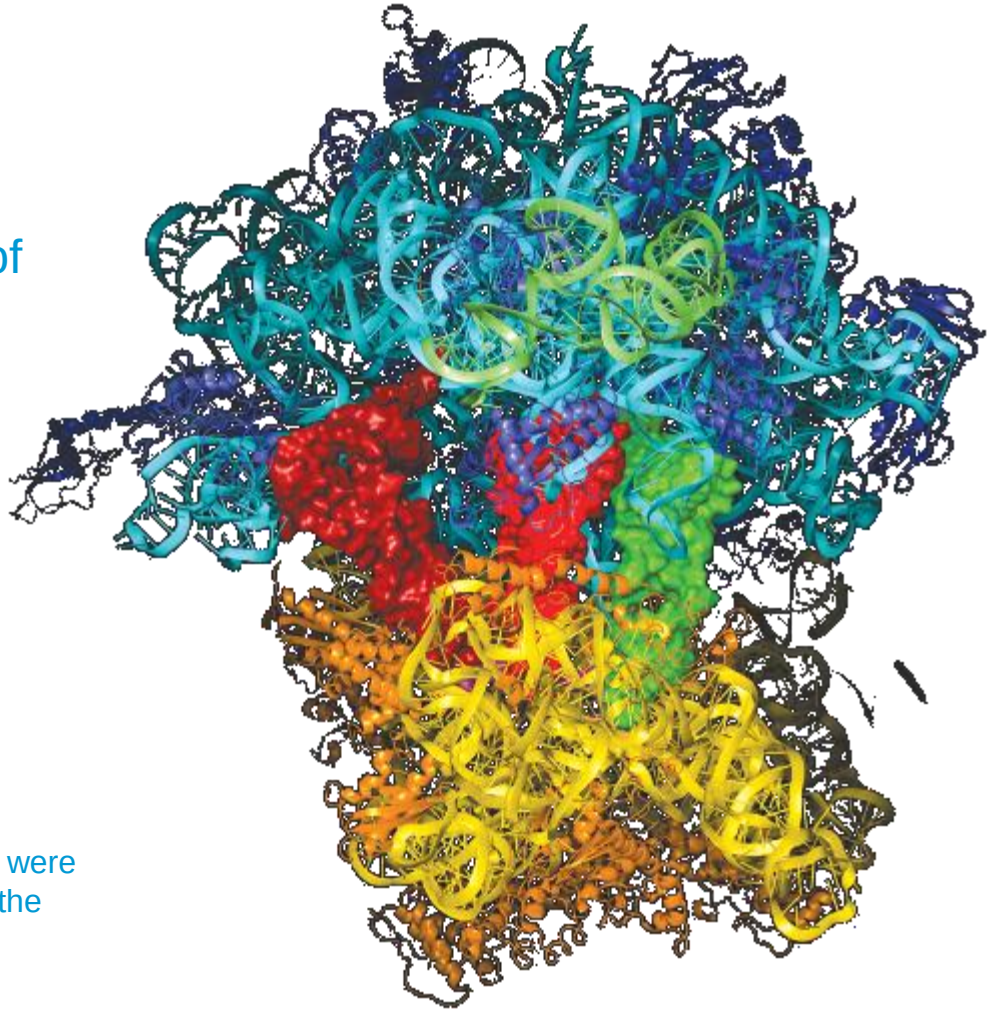
Electron Density Map



Form → Function

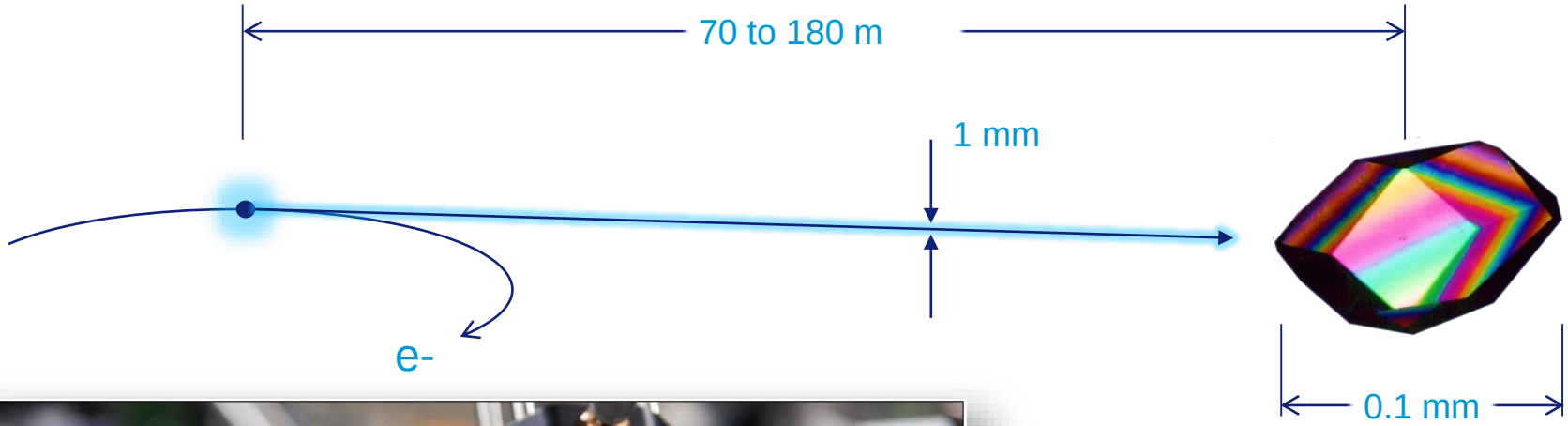
THE RIBOSOME

This technique has led to the discovery of some fantastically complex structures like the ribosome.



Ada Yonath, Venkatraman Ramakrishnan and Thomas Steitz were awarded the 2009 Nobel prize in Chemistry for their work on the ribosome

THE SCALE OF THINGS AND THE IMPORTANCE OF ALIGNMENT



A crystal is placed on the end of the pin with a stream of cool air coming in from the right. The X-ray beam arrives from the silver pipe and the camera images the crystal

http://www.dailymail.co.uk/sciencetech/article-2828699/Inner-beauty-world-revealed-Photographer-captures-amazing-crystal-structures-objects-reveals-created.html

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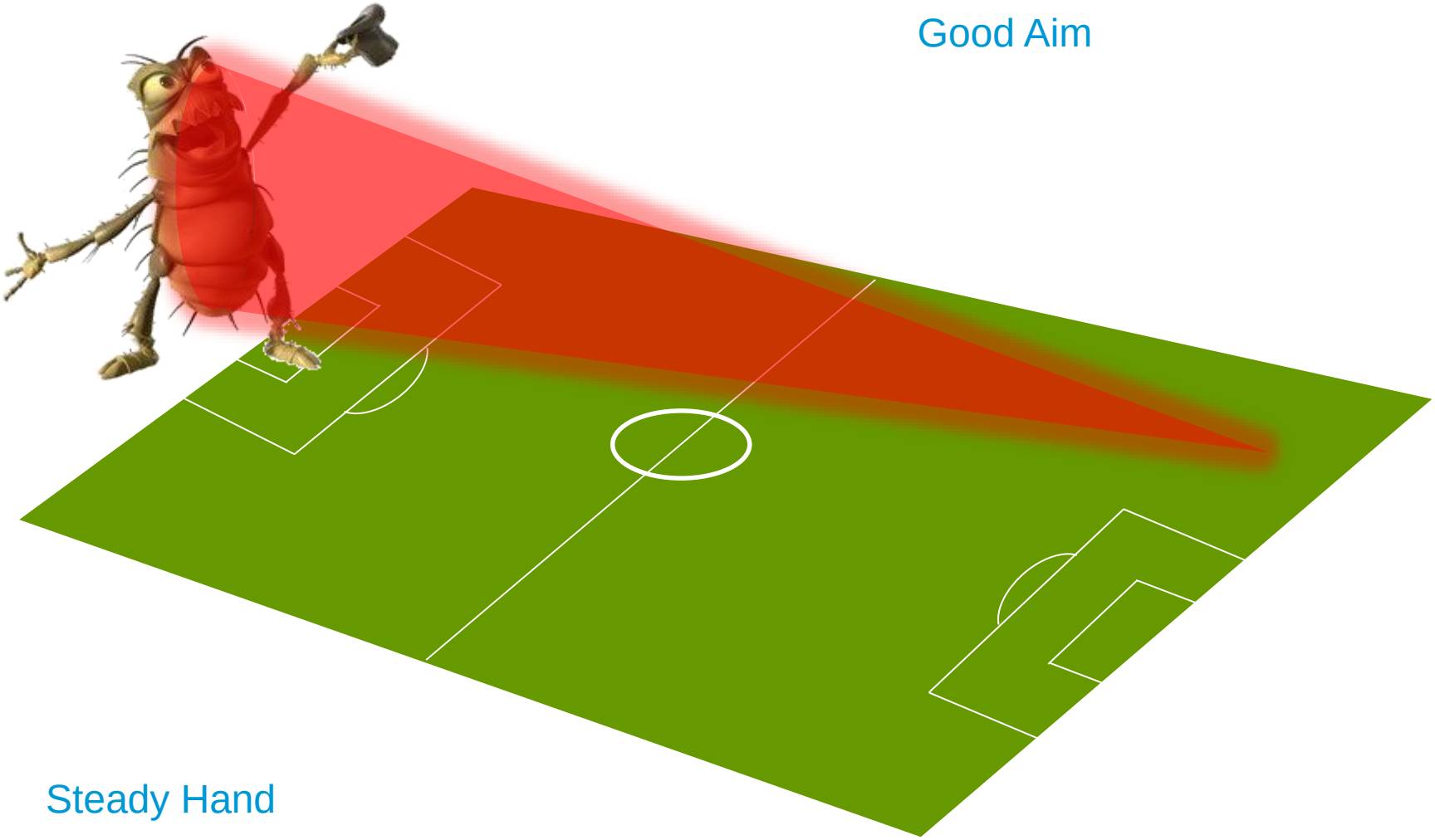

Good Aim
Steady Hand

THE ESRF SURVEY NETWORKS

Z

DiNi 12
Electronic Level

0.3 mm for 1 km
2 way levelling

XY

Leica Viva GNSS
GS15 receiver

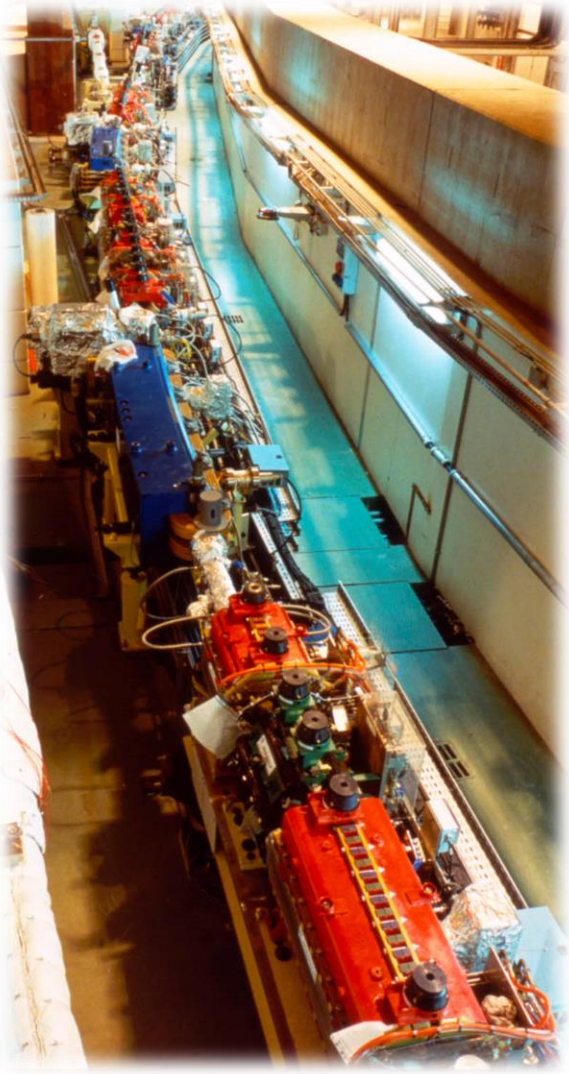
3 mm + 0.1 ppm
post processing and
long observations

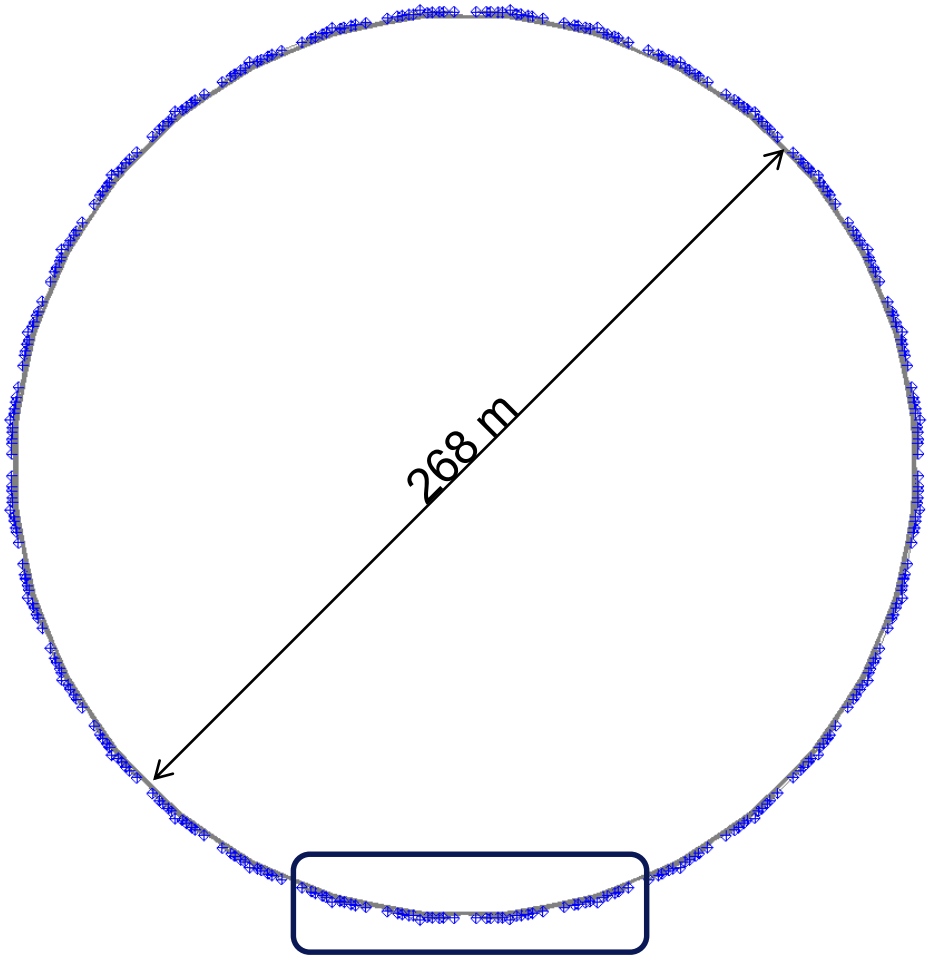
XY and Z

AT401
Laser Tracker

Angles ± 5 µm + 6 µm/m
Distance ±10 µm
ASME B89.4.19-2006 MPE

THE STORAGE RING NETWORK

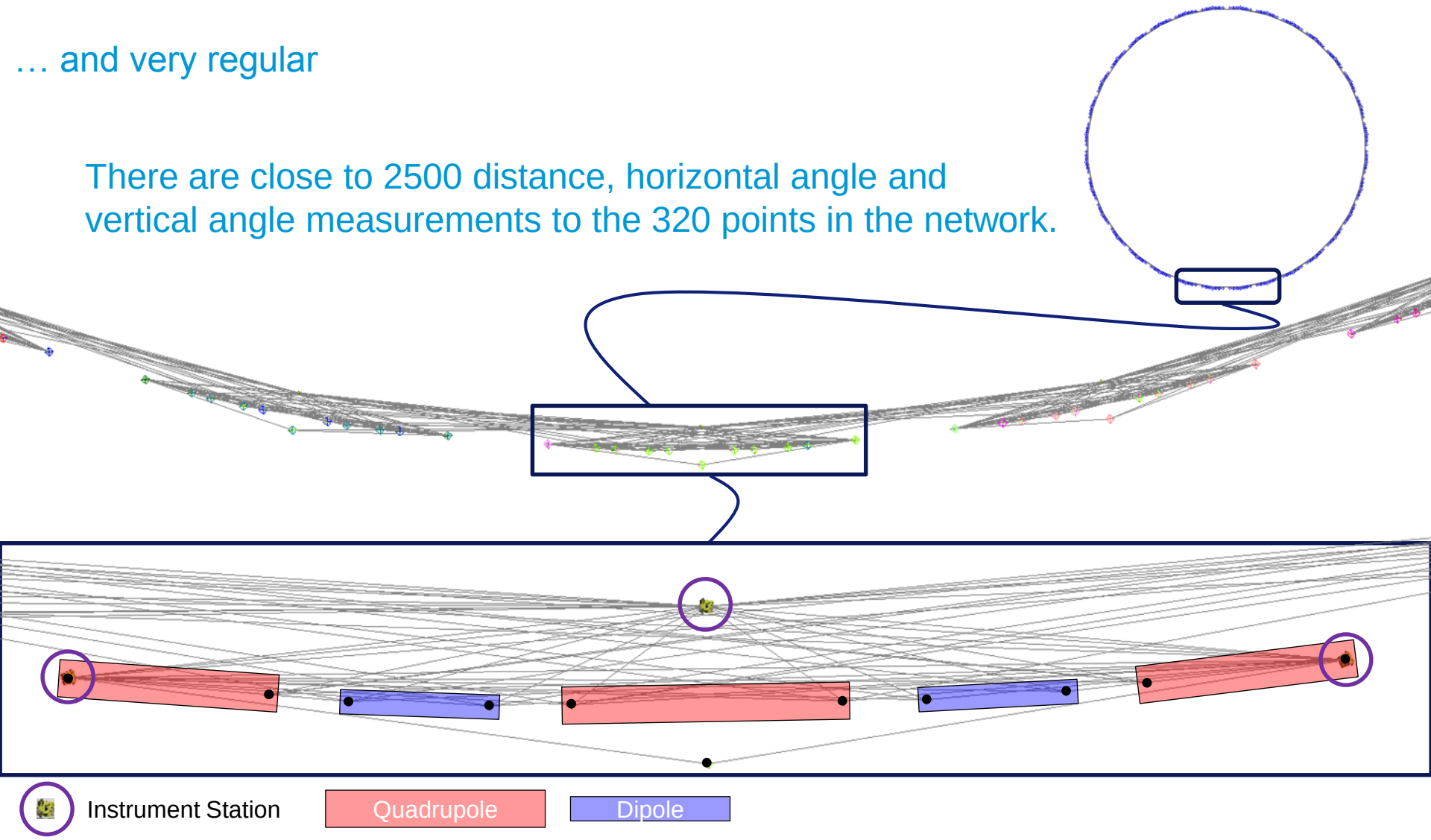




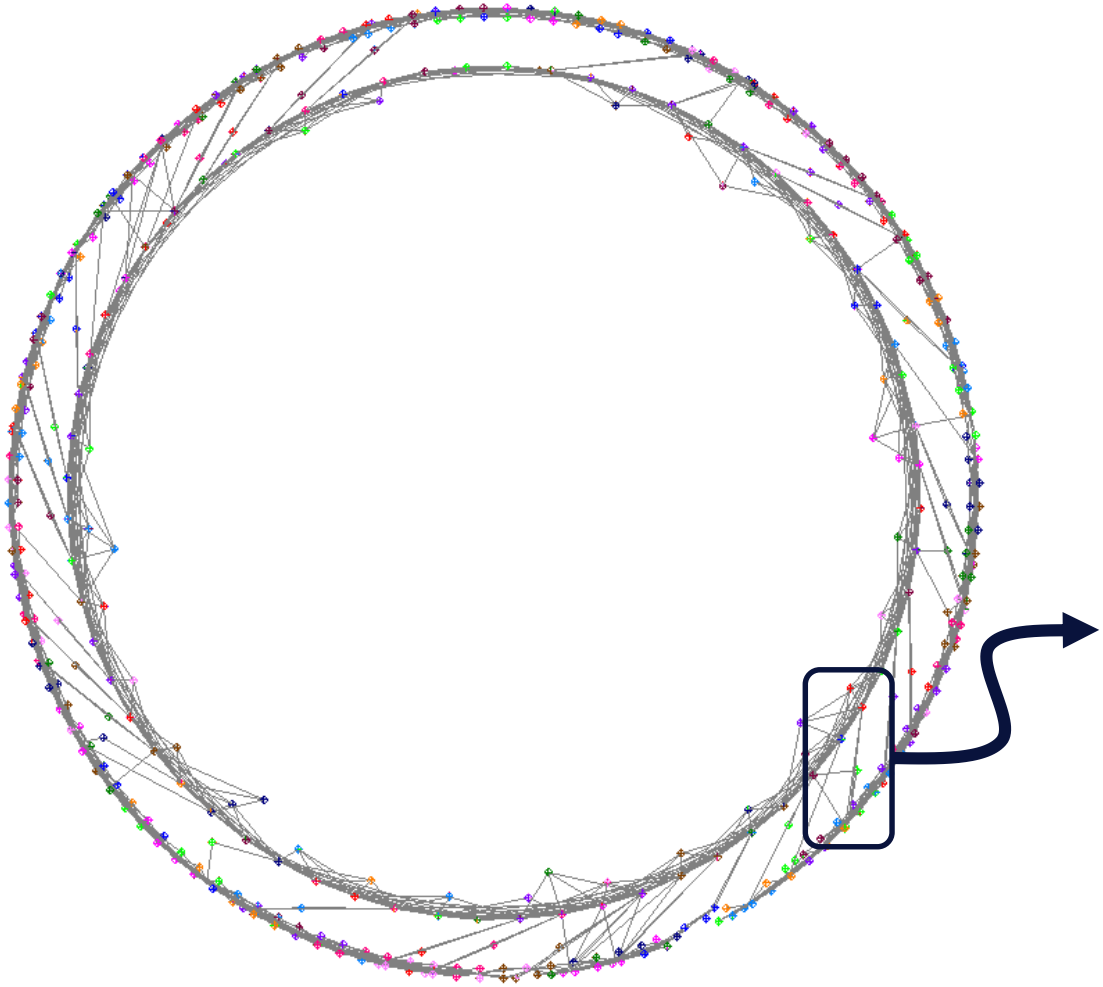
The main accelerator network is long and narrow

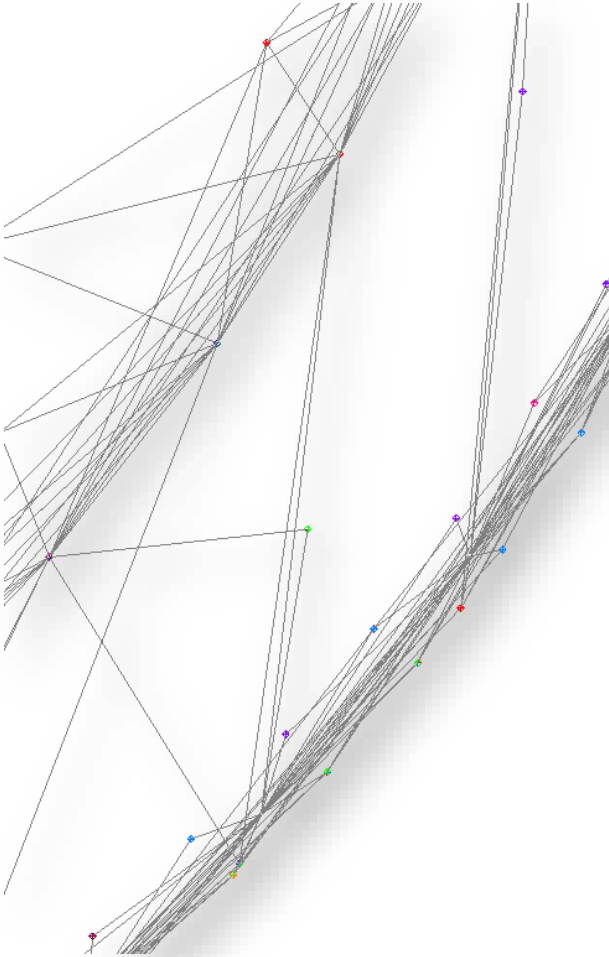
… and very regular

There are close to 2500 distance, horizontal angle and vertical angle measurements to the 320 points in the network.

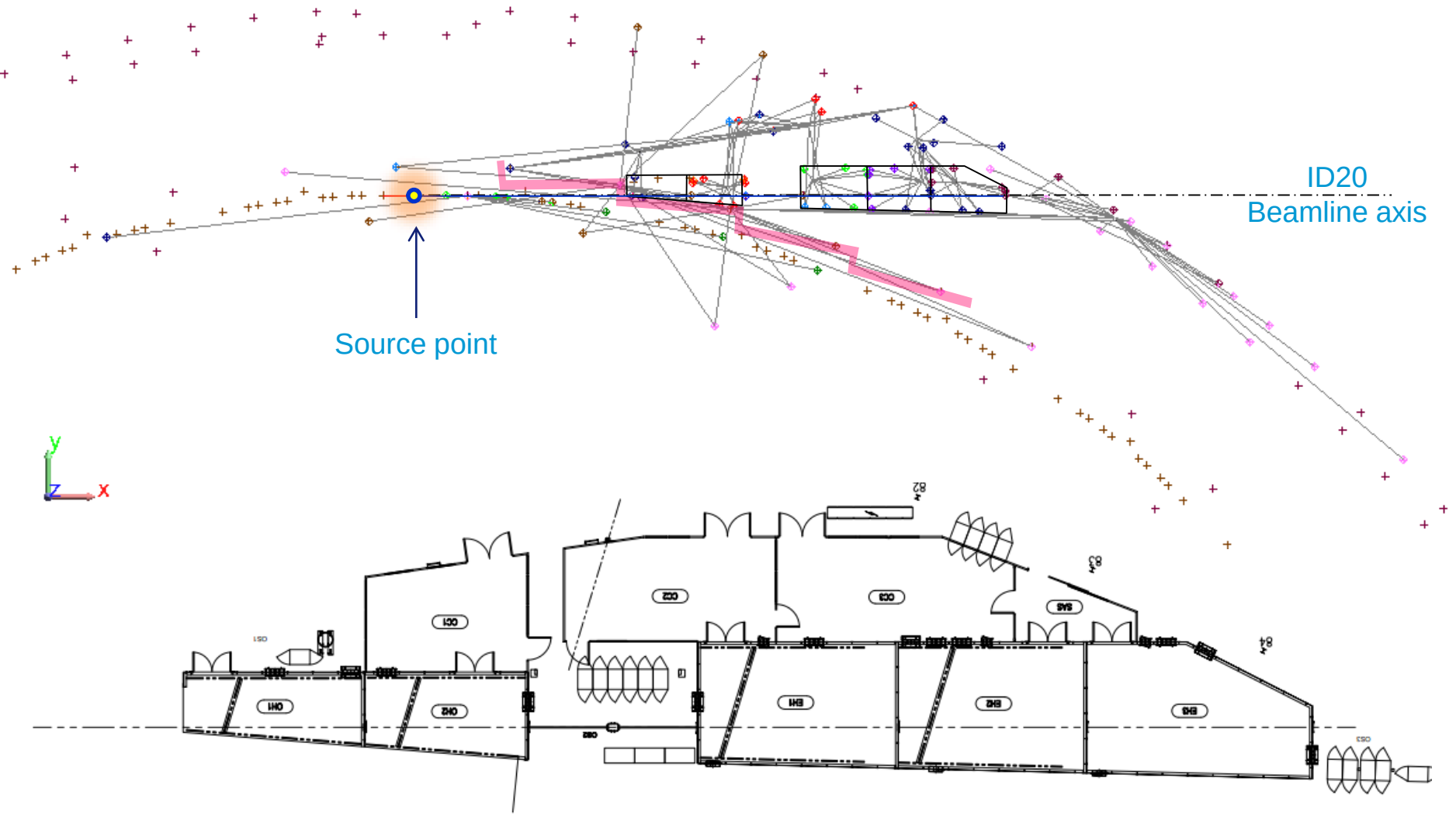


EX2 NETWORK





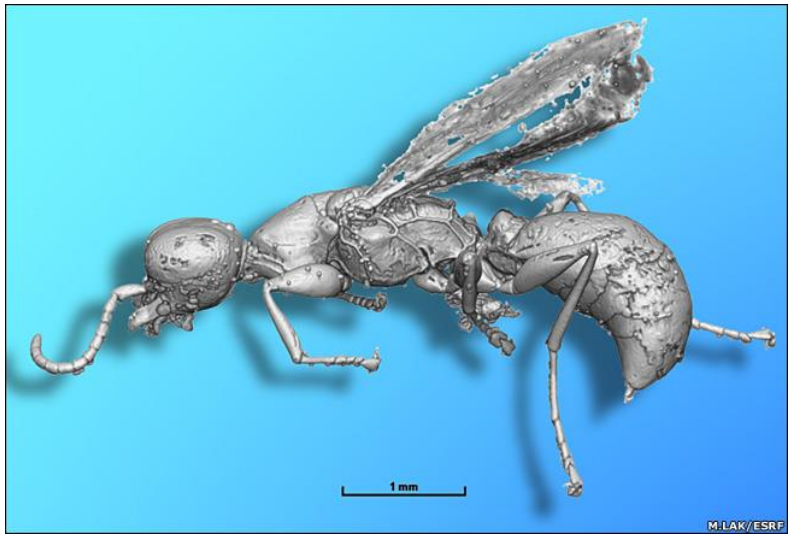
BEAMLINE NETWORK

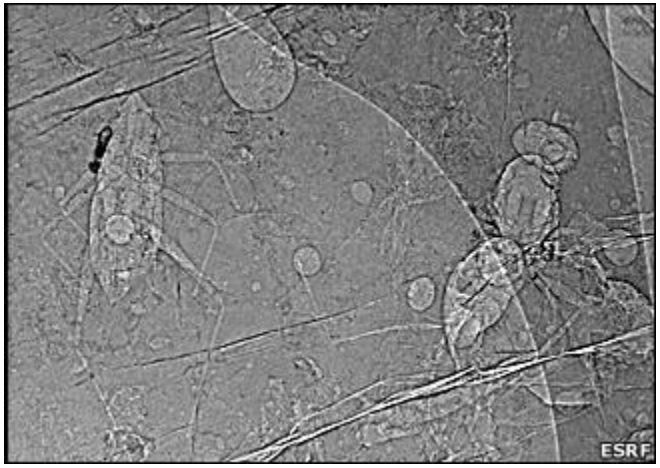


LONG BEAMLINES AND NANOIMAGING

Crystallography determines the arrangement of atoms in the crystalline solids.

X-rays are also useful to image very small hidden things.

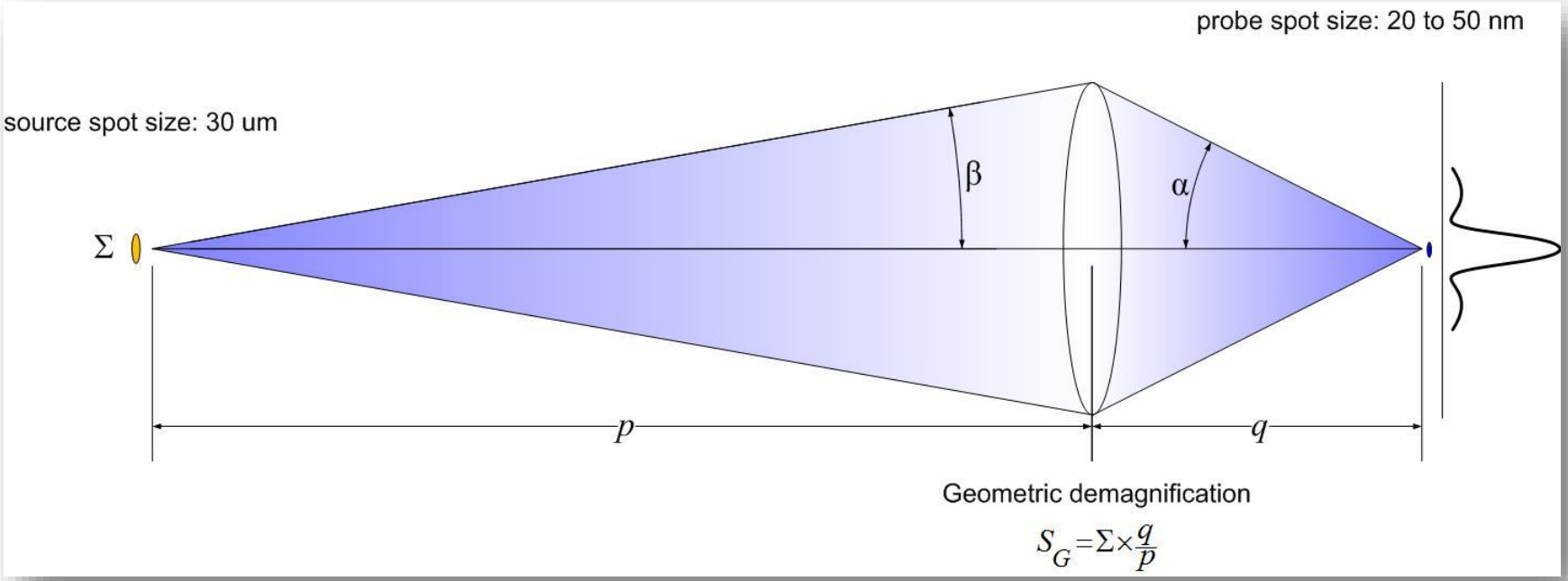




Phase contrast microtomography

NANOIMAGING PROBE

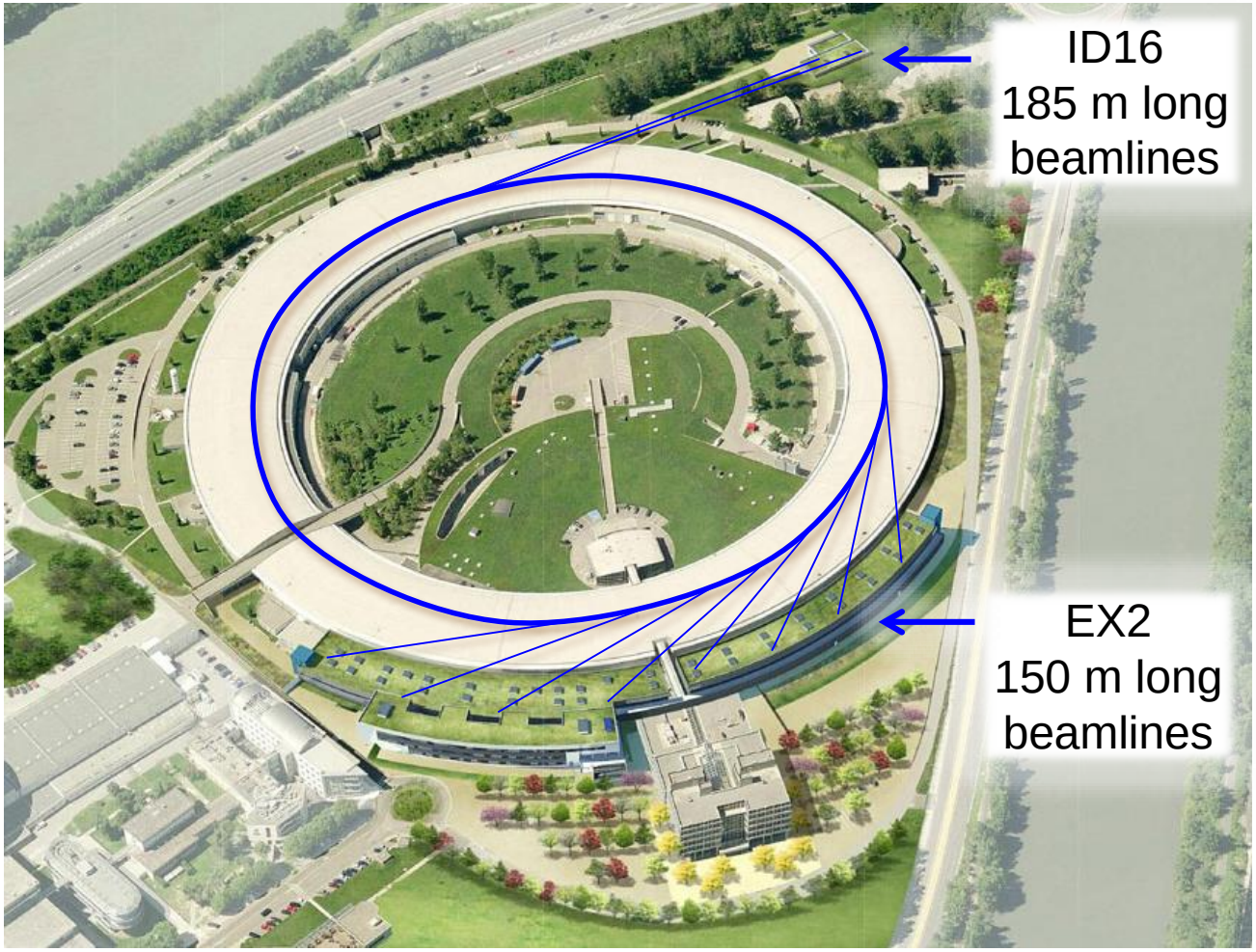
At the ESRF p=150 m and q=0.05 m so q/p=3000^{-1} → theoretical probe size ~10 nm



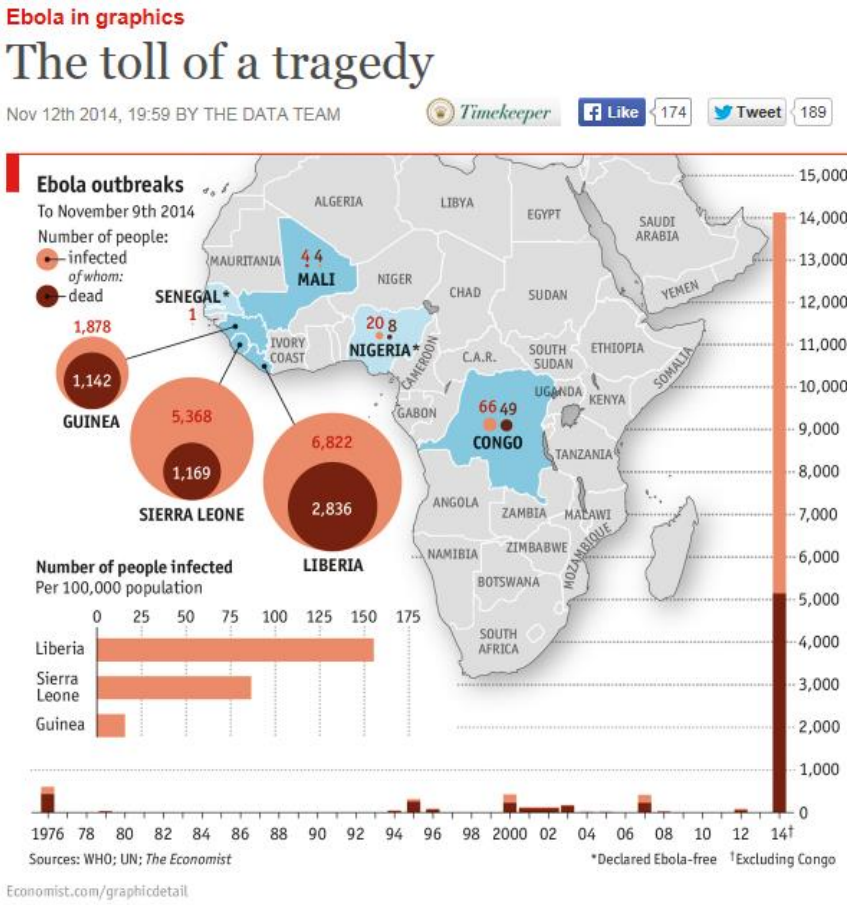
The size of the focused x-ray probe spot depends on:

- the source size,
- the distance between the source and the focusing optics p, and
- the working distance between optics and the experimental sample q.

ESRF NANOIMAGING UPGRADE PROGRAM BEAMLINES



EBOLA



28,616 cases and 11,310 deaths had been reported

(*http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/case-counts.html)*

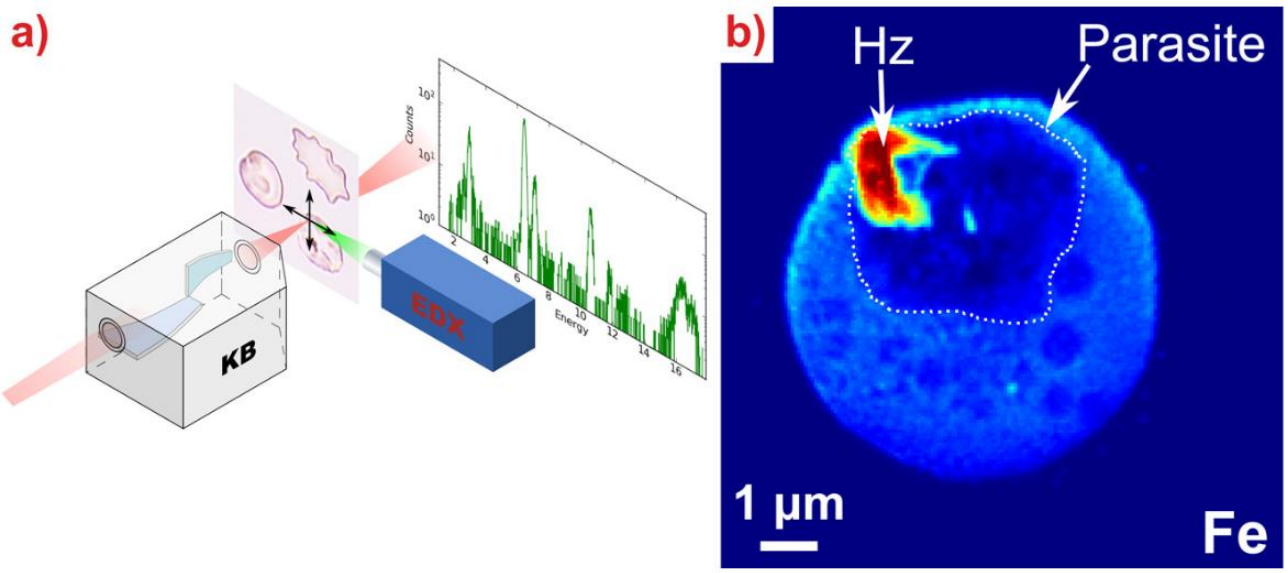
MALARIA

As tragic as these numbers are, they are quite simply dwarfed by numbers associated with malaria

> …an estimated **207 million cases** (uncertainty interval, 135–287 million) and **627 000 malaria deaths** (uncertainty interval, 473 000–789 000) are estimated to have occurred in 2012. …
>
> *WHO World Malaria Report 2013 p ix*

An acute need for new drugs exists because **resistance has developed to all antimalarial drugs**. Overcoming drug resistance is an essential goal of antimalarial drug discovery.

NANOCHEMICAL IMAGING OF ANTIMALARIAL DRUGS

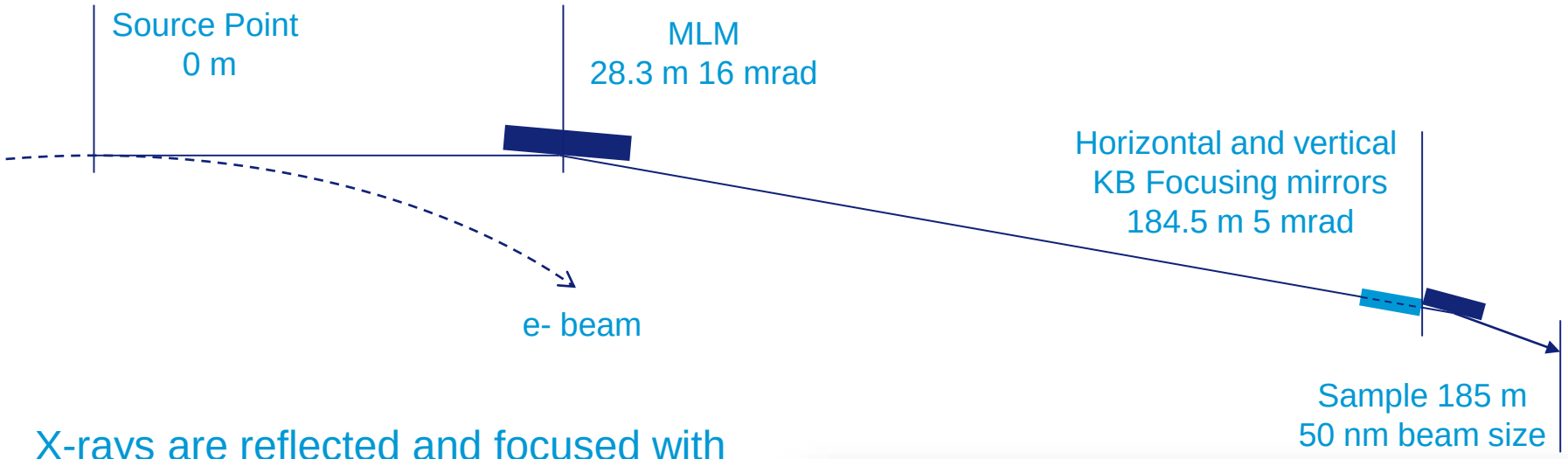


Imaging of trace elements with a **spatial resolution of 50 nm** at detection limits down to the attogram (i.e. 10^{-18}) level.

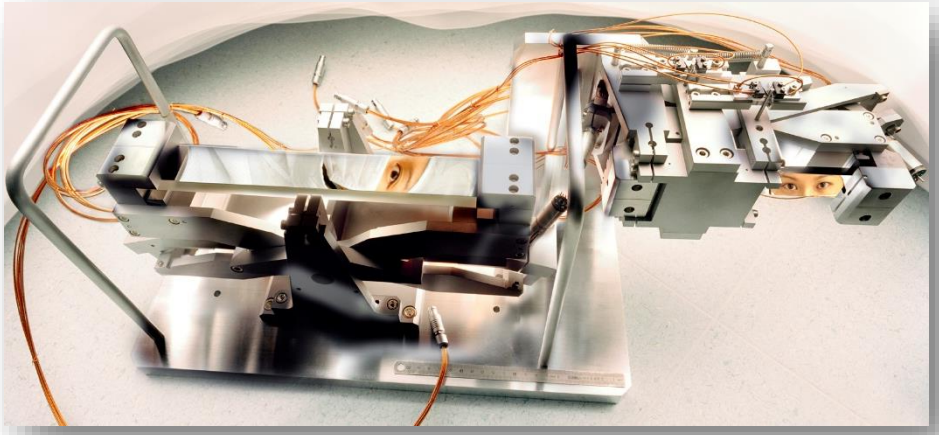
…This study provides the first demonstration of the localisation of unlabelled antimalarial drugs at pharmacological doses with high spatial resolution. This strategy improves the understanding of the action mechanisms of both existing and novel antimalarial drugs. Moreover, this approach may be applied to a wide range of domains where the quantitative chemical imaging of drugs at the subcellular level is critical….

Nanochemical imaging of antimalarial drugs in Plasmodium falciparum infected red blood cells (http://www.esrf.fr/news/spotlight/spotlight151/index_html)

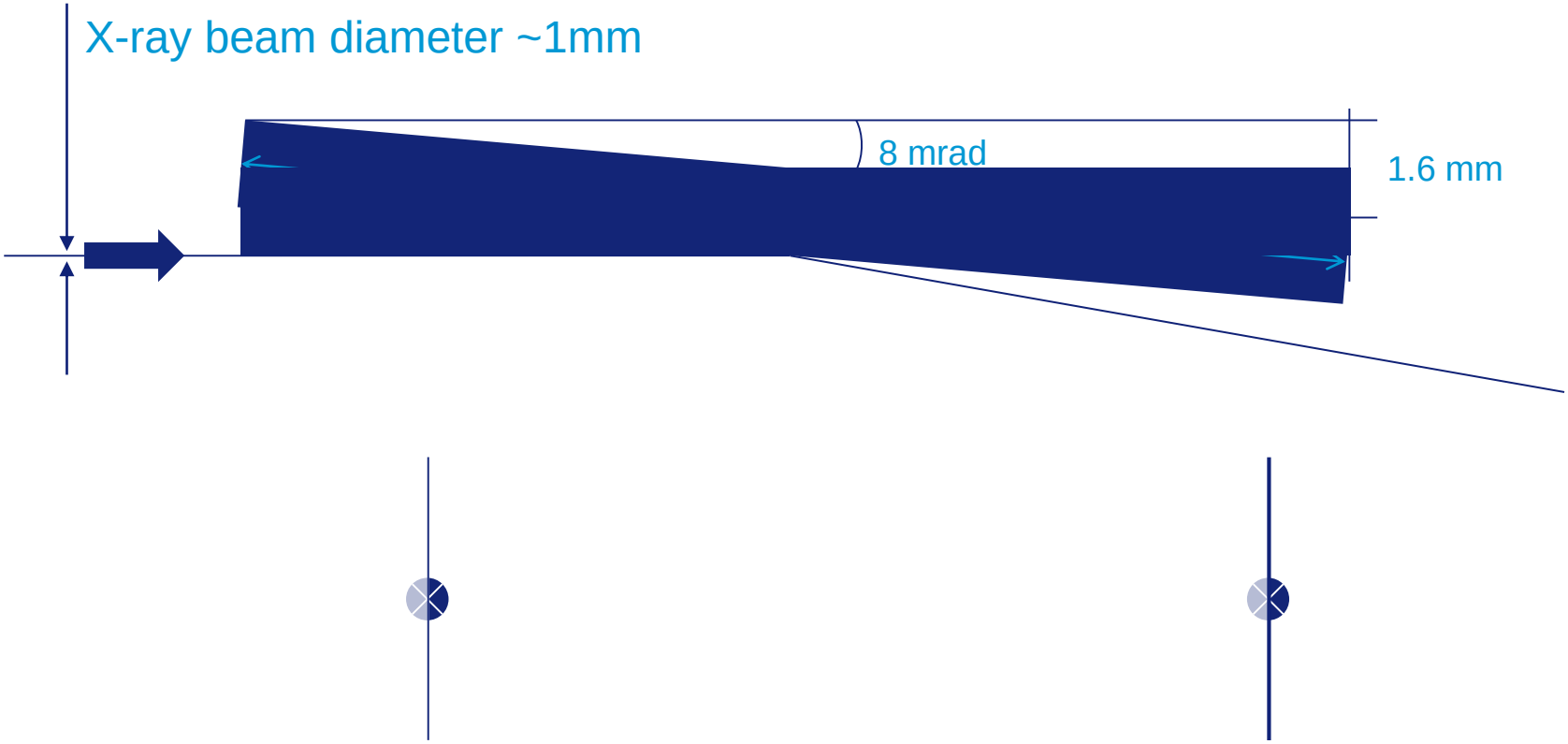
NANOIMAGING BEAMLINE OPTICAL LAYOUT



X-rays are reflected and focused with mirrors at glancing angles less than 0.5 degrees → 9 mrad.



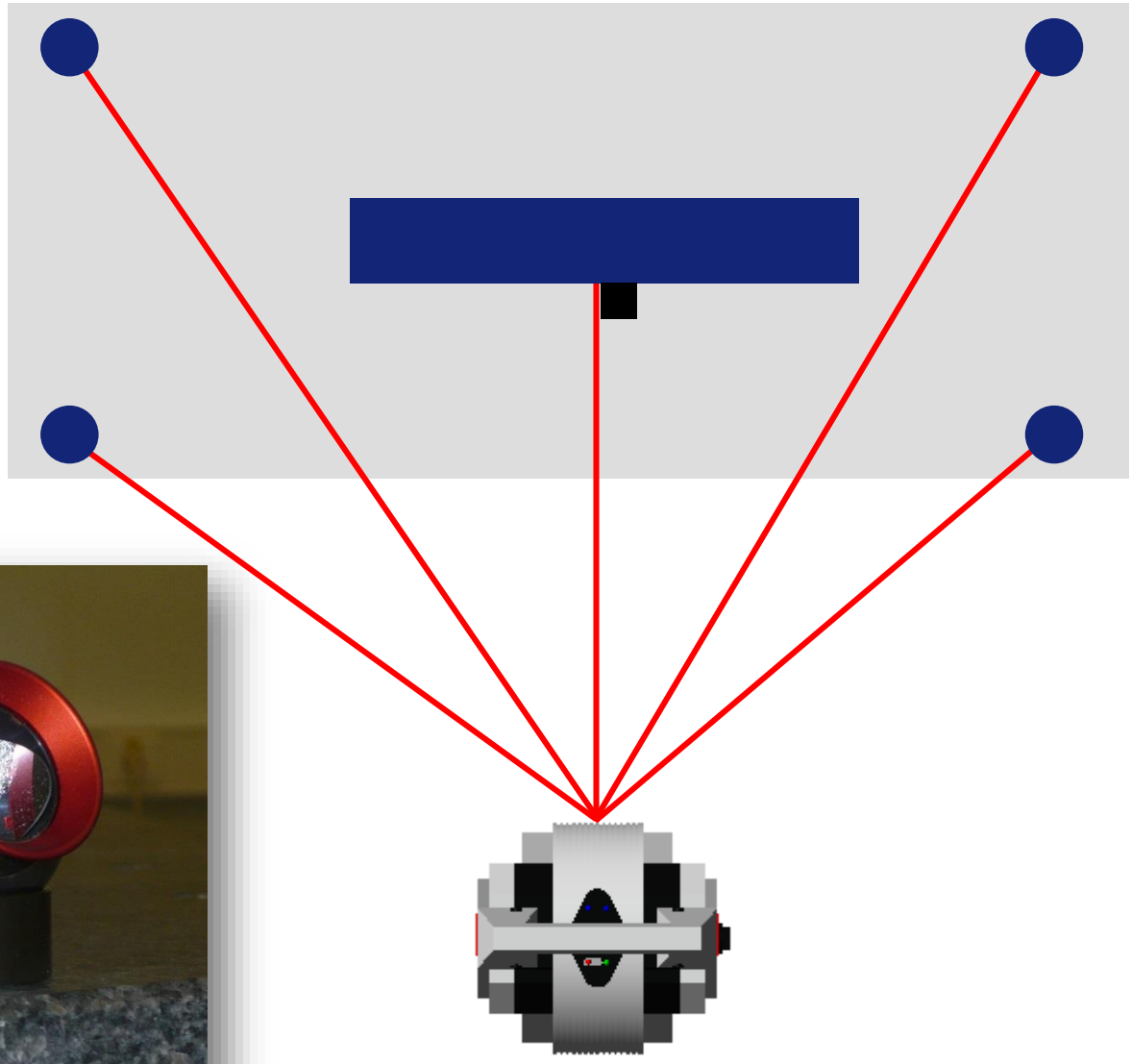
NANOIMAGING BEAMLINE MULTILAYER MIRROR (MLM) ALIGNMENT



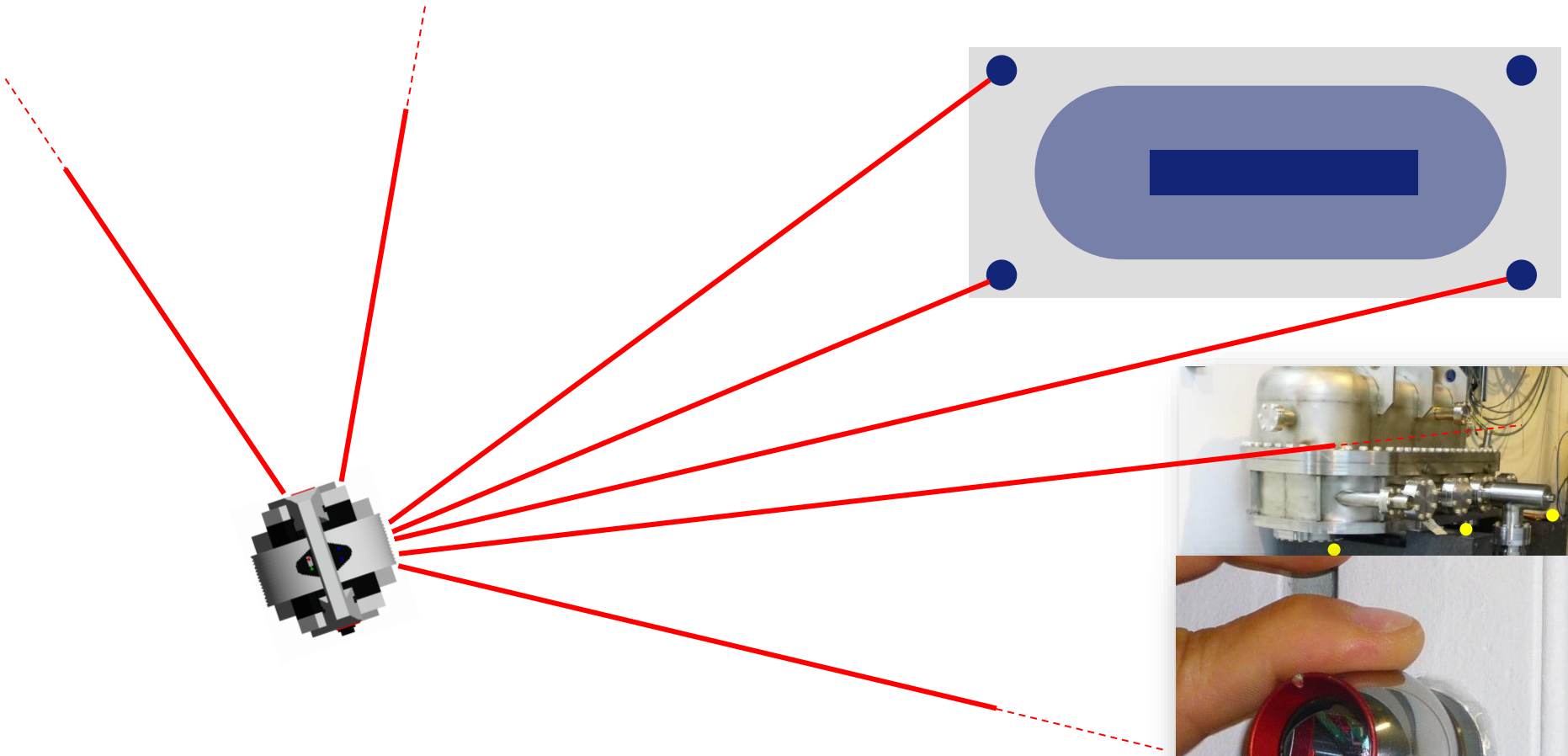
This is the mirror surface seen by the beam when it is parallel to the beam

This is the mirror surface seen by the beam when it is tilted 8 mrad to the beam

FIDUCIALISATION IN A CLEAN ROOM LABORATORY



MLM ALIGNMENT IN SITU



Tie in the instrument (x,y,z) using the survey network

Align the mirror support references to their nominal positions

THANK YOU FOR YOUR ATTENTION

FIG Working Week 2016

CHRISTCHURCH, NEW ZEALAND
2–6 May 2016

Recovery from disaster

FIG NZIS