



Contents and objectives of this video



- What is a synchrotron?
- What is an XFEL?
- Why synchrotrons and XFELs?

In this video, we take a brief look at what synchrotrons and XFELs actually physically are, and, of course, why their use is desirable. The intensities and time structures of synchrotrons on the one hand, and XFELs on the other, differ very substantially from one another, encapsulated in the concept of brightness, or brilliance, which is also introduced qualitatively here.

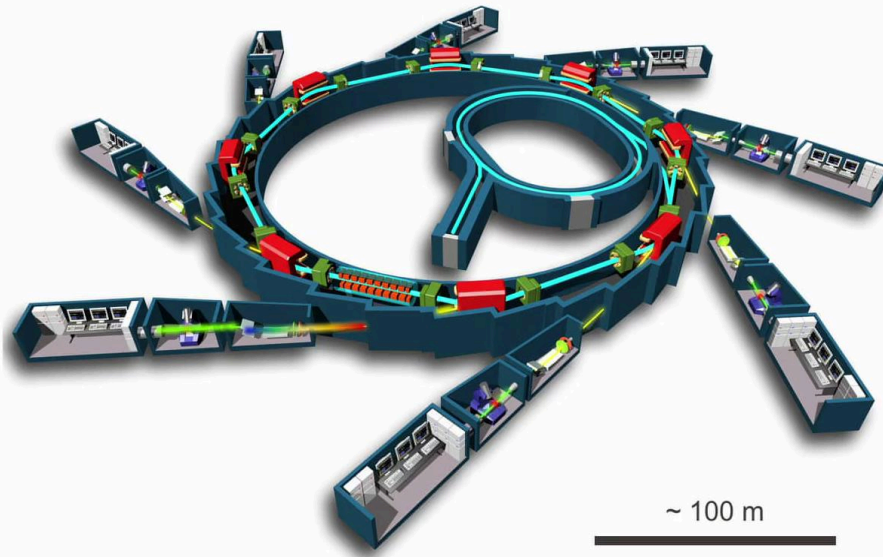
Notes

Summary



0m 05s

What is a synchrotron?



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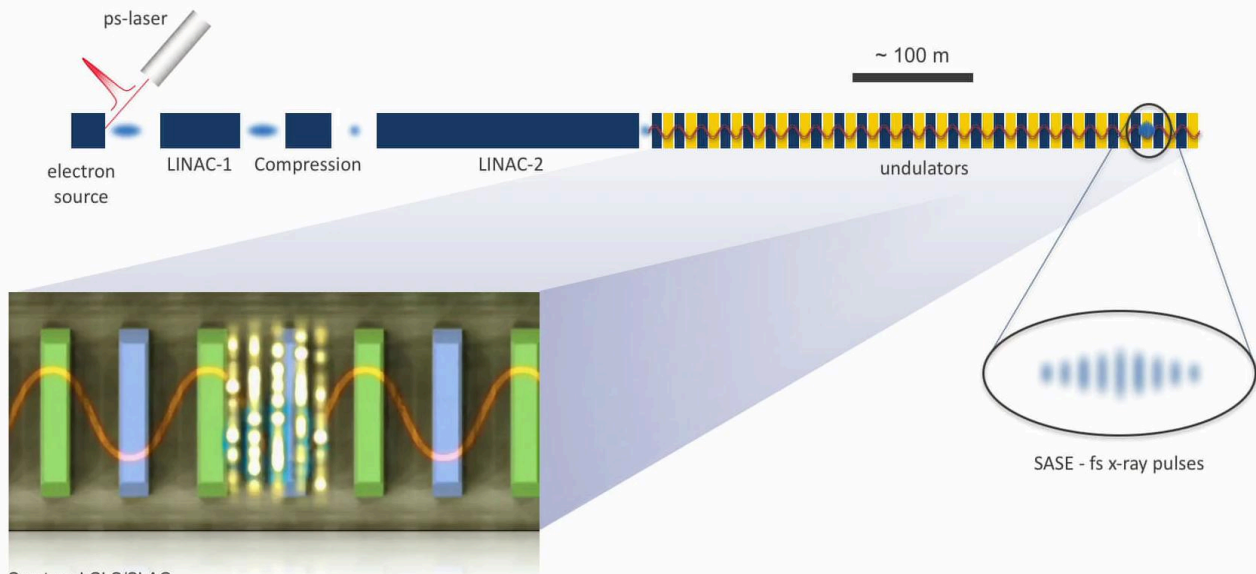
A synchrotron is a type of circular particle accelerator that uses electrons, in contrast, by the way, to CERN, which uses protons. Electrons are produced in an electron gun and accelerated and injected into the so-called booster ring shown here, which is the smaller ring, where they are accelerated until they obtain the energy of the so-called storage ring into which they are then transferred. Here, where the electrons are guided by magnets into a closed circular path, they emit intense beams of X-radiation which are allowed to exit the storage ring and be used for experiments in so-called beamlines placed tangentially to the storage ring. The scale bar of 100 metres is only very approximate. Storage ring diameters vary from a few tens of metres to over two kilometres.

Notes

Summary



What is an XFEL?



Courtesy LCLS/SLAC
See also: <https://youtu.be/pgag7f96SKM>

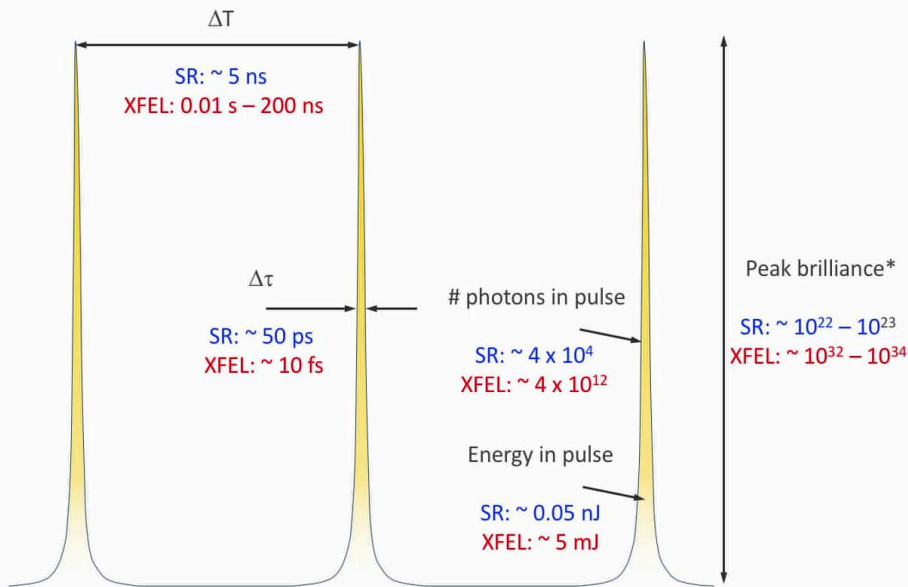
In contrast, an XFEL is a type of linear accelerator. The electrons typically released by photo emission after irradiation of a metal surface with a pulsed laser are accelerated and squeezed together, using a combination of linear accelerators and so-called bunch compressors. They then enter a long array of alternating north-south, south-north magnet pairs called an undulator, which forces the electrons to execute a long slalom path. The extended length of this magnet array is critical in allowing the phenomenon of so-called self-amplified spontaneous emission, or SASE, to occur, which for reasons which will be given later in this course, results in the formation of ultra short, ultra intense pulses of X-radiation. Because XFELs are based on linacs, the electrons are dumped after they pass through the undulator magnet array.

Notes

Summary



Comparison SR and XFEL radiation



* units: $\text{ph}/(\text{s mm}^2 \text{ mrad}^2 0.1\% \text{ BW})$

Average optical power output

SR beamline: $\sim 25 \text{ mW}$ (mono)

XFEL: $\sim 0.5 - 1000 \text{ W}$



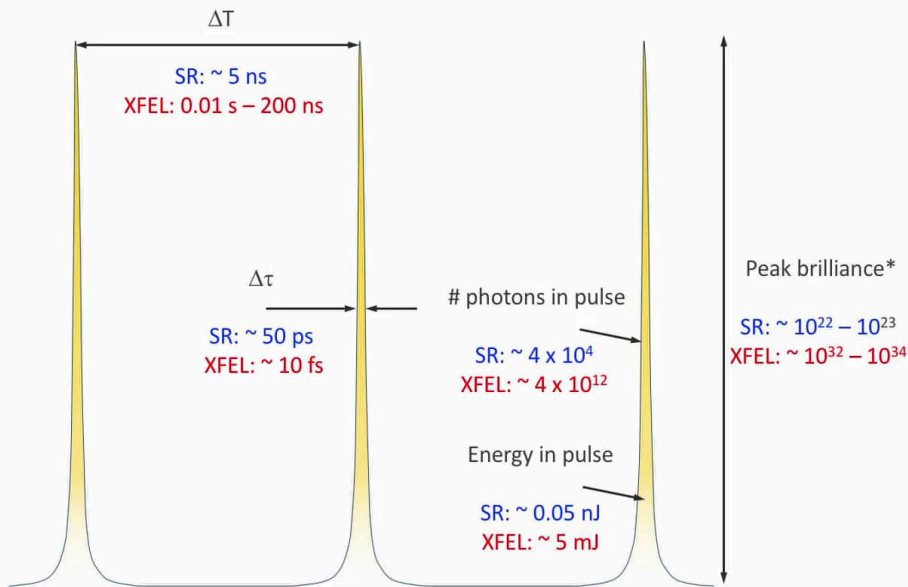
Synchrotrons also naturally produce pulsed X-radiation, though the numbers that define the time structure and peak intensities are very different indeed from those of XFELs and are summarised here. First, the arrival rate of X-ray pulses at synchrotrons is measured in hundreds of millions per second. While that for XFELs can vary from a few tens per second to over a million. More importantly, the energy stored in each pulse or alternatively the number of photons, the indivisible quantum packets of light energy, is very different indeed. Synchrotron pulses may contain a few tens of thousands of photons, while those produced by an XFEL may contain a few thousand billion photons. Not only this, but the duration of the pulses that contain this hugely larger number of photons in XFELS is over a thousand times shorter than that the synchrotron pulses. This means that the peak power of XFEL radiation is some 10 billion times greater than that for synchrotrons. It turns out that the peak power output of an XFEL is similar to the power of the Saturn V rocket used to lift the Apollo missions into space. That of a synchrotron is about the same as an LED nightlight.

Notes

Summary



Comparison SR and XFEL radiation



* units: ph/(s mm² mrad² 0.1% BW)

Average optical power output

SR beamline: ~ 25 mW (mono)

XFEL: $\sim 0.5 - 1000$ W



So does this mean XFELS are 10 billion times better than synchrotrons? Not at all. As you will discuss in week four of this course, many experiments carried out at synchrotrons are simply impossible at XFELS, primarily, though not exclusively, because of the enormous peak powers of X Files that would immediately destroy the sample. So using a Saturn V rocket as a bedside lamp to lull your three-year-old to sleep is perhaps a little bit ill-advised.

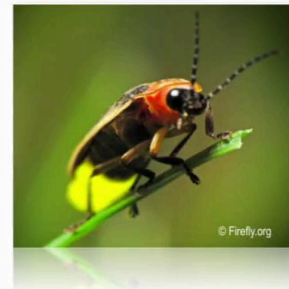
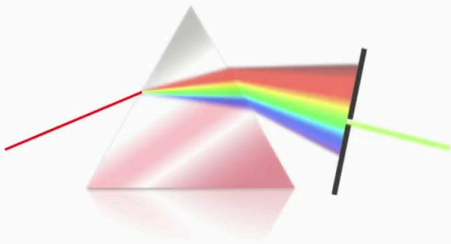
Notes

Summary



Why use synchrotrons and XFELs?

BRIGHTNESS!!



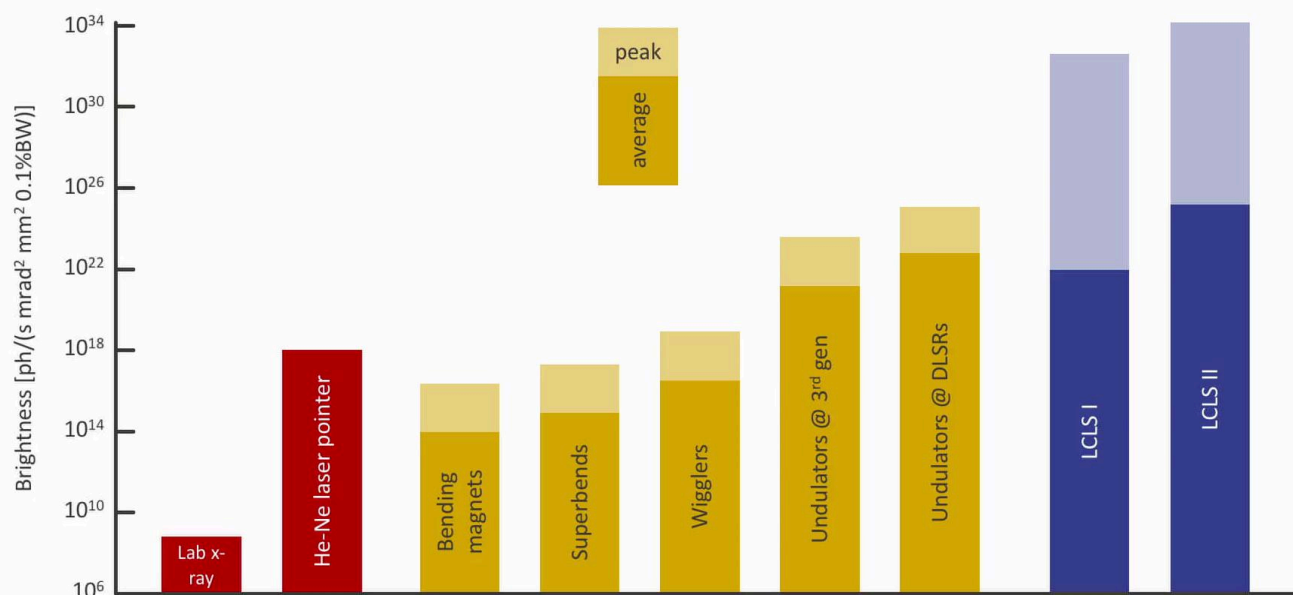
Nonetheless, large photon arrival rates are in general desired in most X-ray experiments, if not necessarily all the way up to those produced at those XFELs. But this isn't the only interesting property. Most experiments require a good degree of collimation, hence one would like the beam divergence to be as small as possible. Moreover, a narrow bandwidth of X-ray wavelengths or photon energies is also sought. Though this aspect may be relaxed for certain types of experiment, if in lowering this requirement, a concomitant increase in photon arrival rate is achieved. Lastly, one would like the source of the X-rays to be as small as possible in order to illuminate small sample sizes. We can combine these four properties into a single figure of merit for synchrotrons and XFELs, known as brightness or brilliance. Those parameters we would like to make as small as possible combine in the denominator while the arrival rate of photons is in the numerator. A self-respecting beamline scientist in collaboration with the machine physicists wants to maximise the brightness at her beamline.

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EPFL Light sources brightness compared



A comparison of the brightnesses of different light sources is shown in this graphic here. Note the logarithmic ordinate axis with four decades, in other words, a factor of 10,000 between each tick mark. The sources in red are lab-based. The orange bars are for different sources found at synchrotrons. Note that the brightest of these is for so-called undulators at diffraction limited storage rings, or DLSRs, the latest generation of synchrotrons that are emerging in the second and third decades of the 21st century. XFELs are represented here by the LCLS I and LCLS II at Stanford, California, and exhibit peak brilliances nine orders of magnitude greater still than DLSR undulators. In the next video, some introductory insight into the world of synchrotron and XFEL science are provided, including the impact X-rays and X-ray science have had on society since the serendipitous discovery by Wilhelm Roentgen in 1895. This is followed by some teaser highlights of scientific discoveries using synchrotrons and XFELs in recent years.

Notes

Summary



5m 53s