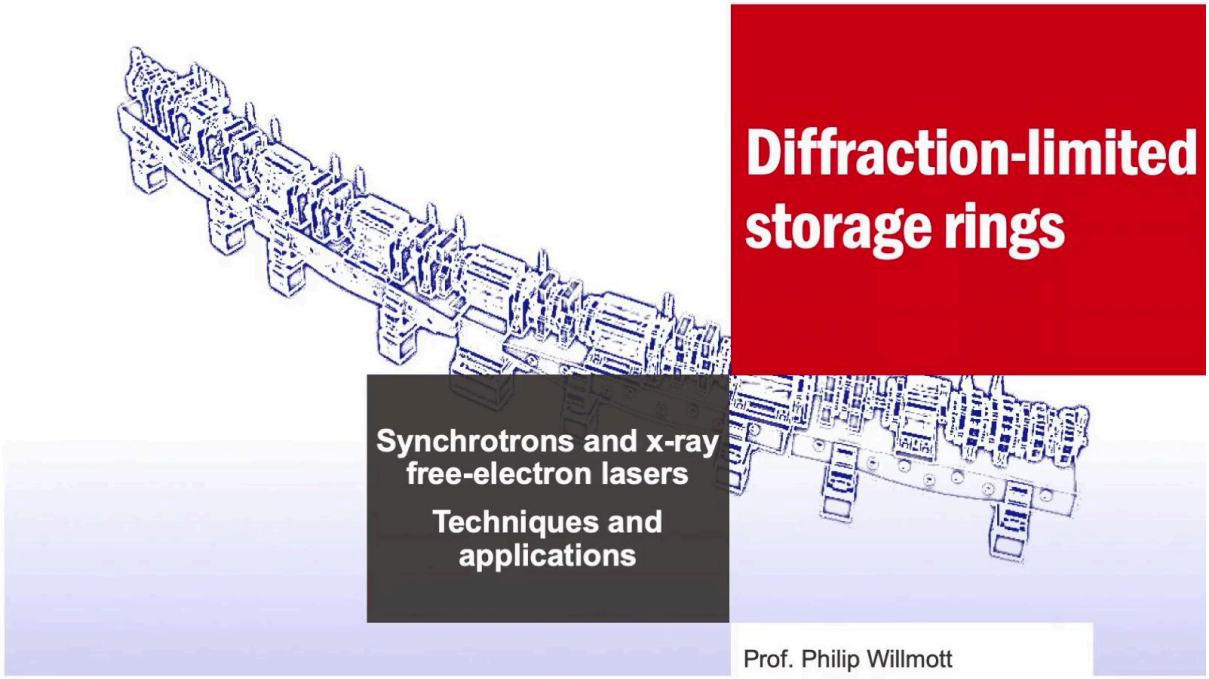
EPFL



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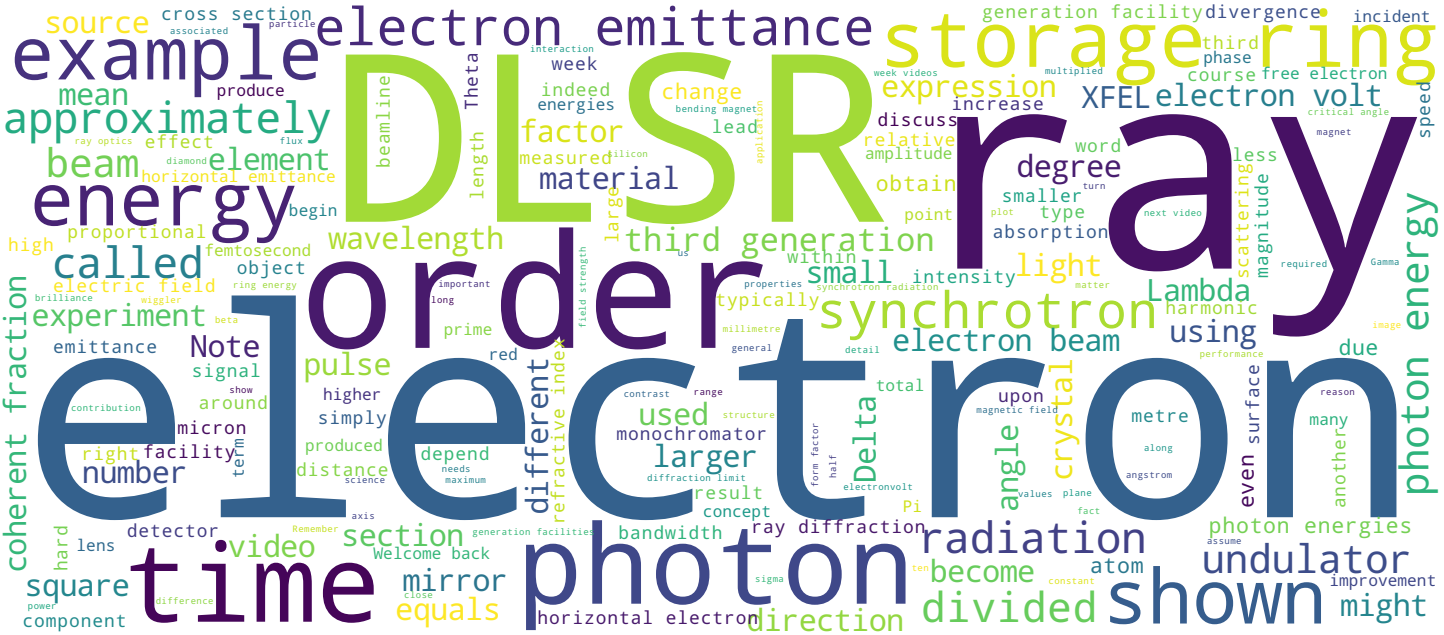


Search MOOC

Video

EPFL

Contents and objectives of this video

- Recap of electron emittance
- Multibend achromats
- Undulator spectra at DLSRs
- Coherent fraction at DLSRs
- Other scientific and technological benefits of DLSRs

Hi welcome back to the second section of week four of this course, synchrotrons and X-ray free electron laser techniques and applications. In this first video, we will briefly recap the concept of emittance and how this is reduced in multibend achromats. We will see that the substantially narrower electron beam associated with DLSRs has a pronounced impact on the form of the undulator spectra and that the hard X-rays, the coherent fraction increases approximately in the same manner as the brilliance. Finally, we will see how the basic advantages of the DLSRs over third generation facilities also spawns other unexpected benefits.

Notes

Summary

0m 04s

Electron emittances at 3rd and 4th generation facilities

$$\left.\frac{\epsilon^e_{x,\mathrm{DBA}}}{\epsilon^e_{x,\mathrm{MBA}}}\right|_{2\theta_{\mathrm{DBA}}=M\theta_{\mathrm{MBA}}} = 3\frac{M-1}{M+1}\left(\frac{\theta_{\mathrm{DBA}}}{\theta_{\mathrm{MBA}}}\right)^3 = \frac{3}{8}\left(\frac{M-1}{M+1}\right)M^3$$

$$\frac{\epsilon^e_{x,\,\mathrm{DBA}}}{\epsilon^e_{x,\,7\mathrm{BA}}} = 3\frac{7-1}{7+1}(7/2)^3 = 96.5$$

Remember from last week's videos that the horizontal electron emittance of multibend achromat is significantly smaller than that of doublebend achromats. Following the expression gets in here. Remember, it's the smaller angle subtended by the individual dipoles that go up to make the achromat that really makes a difference due to the cubic relationship it has with the electron emittance value. So in theory, one can expect an approximately 100 fold reduction in the horizontal electron emittance by replacing a doublebend achromat with a sevenbend achromat.

Notes

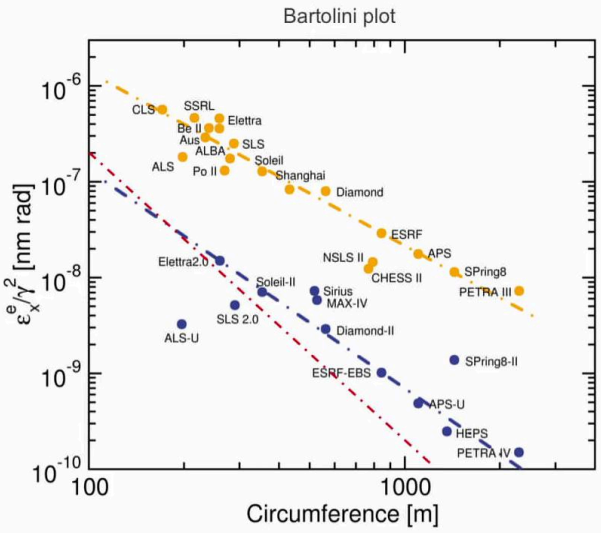
Summary

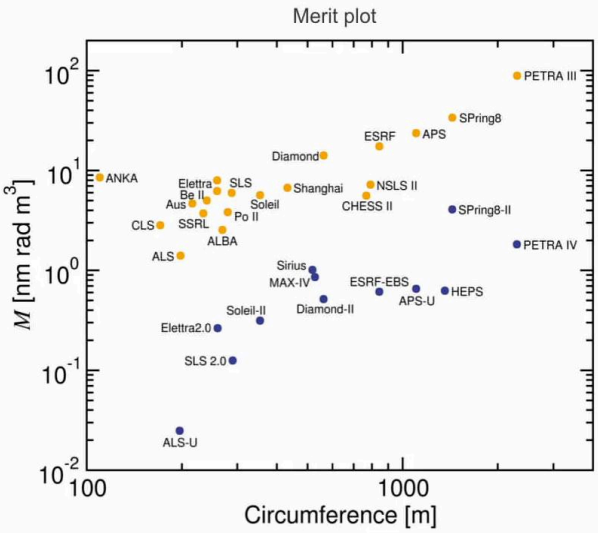
0m 52s

Hail the fourth generation

$$\epsilon^e_{x,\,\mathrm{MBA}} = C_{\mathrm{DBA}}\gamma^2\theta^3\,\frac{(M+1)}{3(M-1)}$$

$$\mathcal{M} = \frac{\epsilon^e_x C^3}{\mathcal{E}^2}$$





On the left is plotted a so called Bartolini plot, named after Ricardo Bartolini, presently the technical director of the Sesame Facility in Jordan on leave from his chair at Oxford University. This weighs the horizontal electron emittance by dividing it by the square of the gamma function, which is itself proportional to the storage ring energy. This levels the playing field, so to speak. As lower energy rings will, according to our expression for the electron emittance shown above, the plot and all other things being equal, have intrinsically lower emittances. The circumference of a storage ring is roughly inversely proportional to the subtended angle theta at the bend achromats, assuming similar lengths for the straight sections. Hence, a double log plot of Epsilon XE against the ring circumference for facilities using the same type of achromat eg a sevenbend achromat should exhibit a gradient of minus three due to the cubic dependence on theta. The blue dot dash line that best fits the data for the new generation of DLSRs has a gradient that is significantly shallower than the theoretical value of minus three shown here in red.

Notes

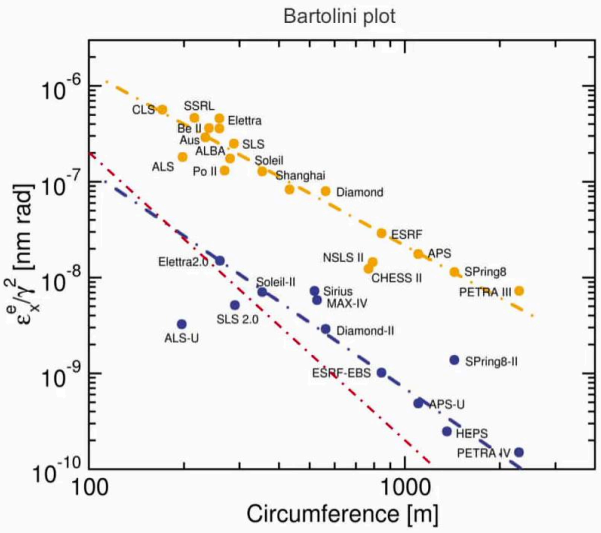
Summary

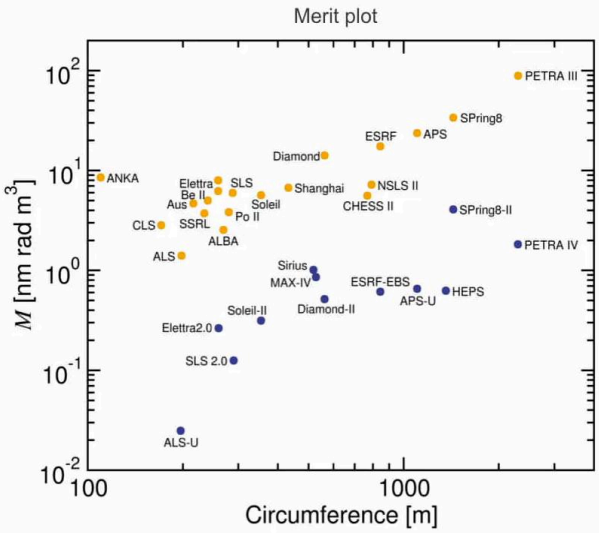
1m 36s

Hail the fourth generation

$$\epsilon^e_{x,\,\mathrm{MBA}} = C_{\mathrm{DBA}}\gamma^2\theta^3\,\frac{(M+1)}{3(M-1)}$$

$$\mathcal{M} = \frac{\epsilon^e_x C^3}{\mathcal{E}^2}$$





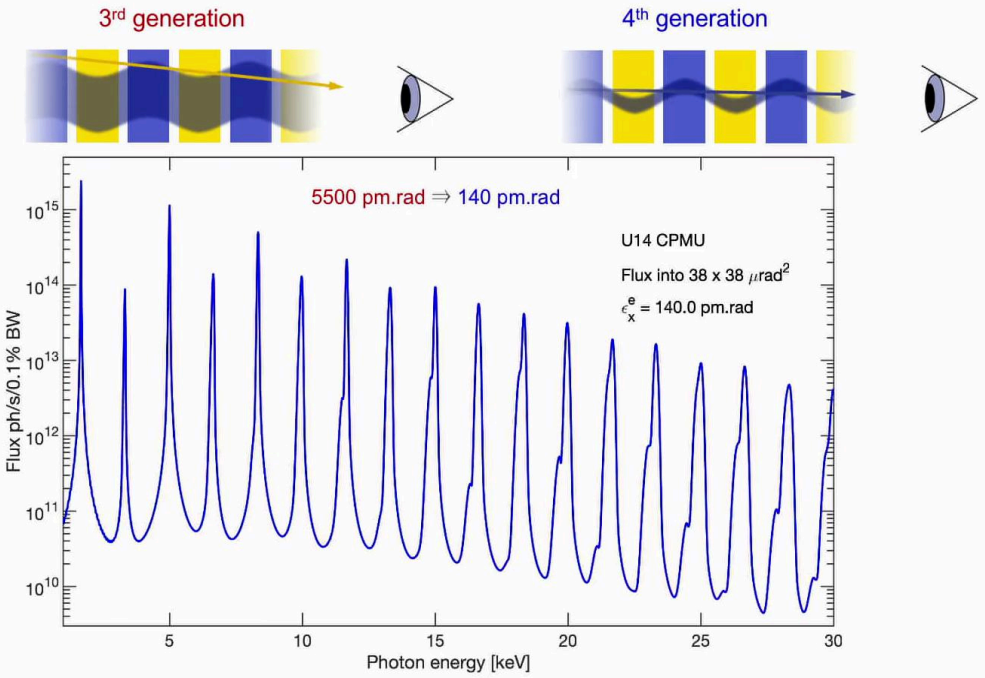
This is mainly due to the bean dynamics physicists and engineers at the largest circumference rings being more relaxed with their electron optics than would be required to obtain the absolute smallest emittances, as this makes the been more stable and easier to control. Hence they marginally sacrifice performance, which they anyway have in buckets for a less stressful life during regular operation. On the right is another interesting plot, in which the emittance is not just divided by the square of the storage ring energy but also multiplied by the cube of the ring's circumference levelling the playing field in this respect as well. This is a figure of merit for a facility. Then there's the smaller A is M. The more the facility has optimised the performance for low emittance. In an ideal world this plot would for a given generation of facilities, be perfectly horizontal. Again, the reason for the lower energy and smallest of conference rings having a better end value reflects their needs to push the performance to the limit in order to be competitive with the higher energy larger circumference rings.

Notes

Summary

3m 04s

Undulator spectra @ DLSRs



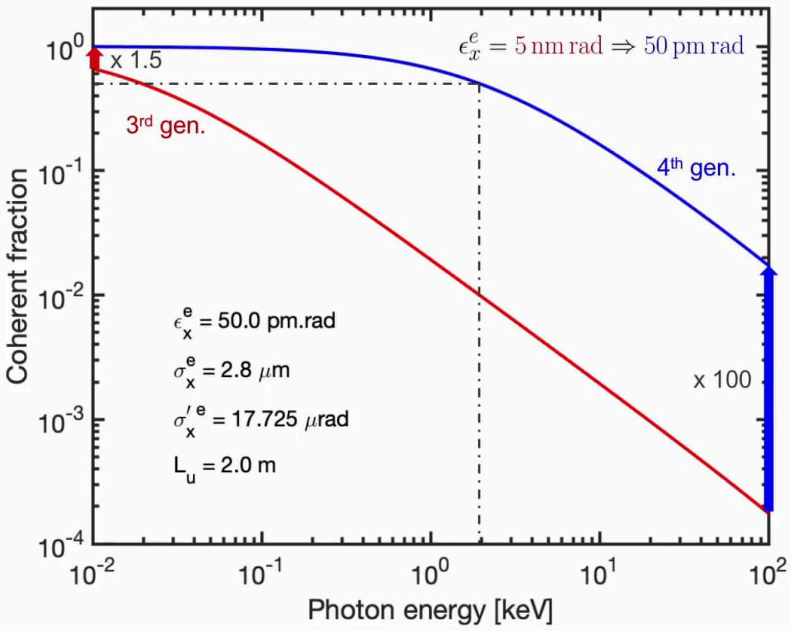
One particularly exciting benefit of DLSRs is that their undulator spectra are much cleaner and simpler than those for third generation facilities. This can be explained heuristically as follows. The upper left hand cartoon shows an electron beam as it passes along an angulator in a third generation facility. You might remember, but then again you might not, that the width of the electron beam as it passes through an ungulator at a third generation facility is measured in hundreds of microns, whereas the amplitude of the oscillations induced by the undulators magnet array is measured in microns. At a DLSR however, the beam may be ten times narrower in the horizontal plane than it is in a third generation facility. An observer downstream of the angulator radiation sees a lot more of axes radiation than he would at a DLSR. Remember that the off axes radiation induces loads of intensity on the low energy flanks of the main interference maxima. So let's see how these become increasingly suppressed as one transitions from a third generation facility with 5.5 nanometer radian electron emittance to a DLSR with 140 picometer radian emittance. Indeed, the loads start to fall off, and the main peaks also become more intense.

Notes

Summary

4m 24s

Increase in coherent fraction with reduced emittance



$$h\nu_{\text{DL}} = \frac{hc}{4\pi\epsilon_x^e} = \frac{98.66}{\epsilon_x^e\,[\text{pm rad}]}\,[\text{keV}]$$

$$f_C = 0.5 \,@\, h\nu_{\text{DL}}$$

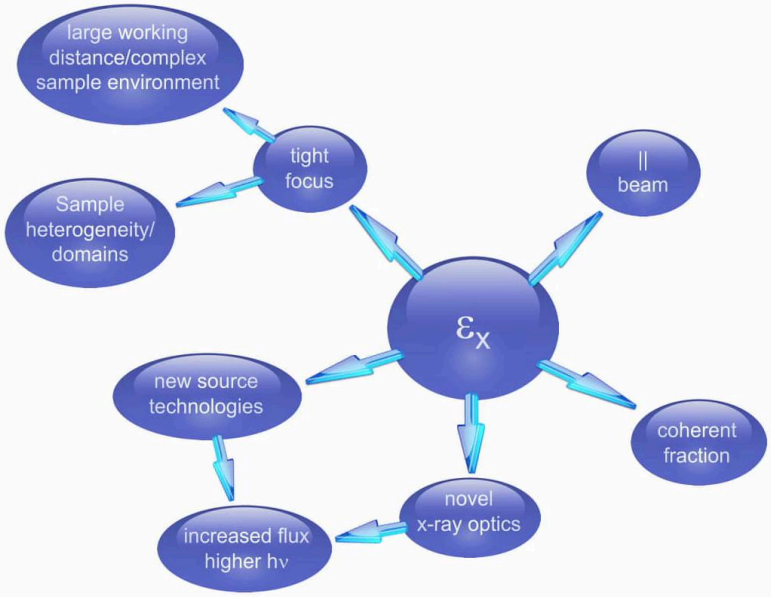
In some instances, one can use the entirety of a main interference peak for an experiment at a DLSR, thus obtaining more flux on the sample. Moreover, the coherent fraction increases substantially at DLSRs, at least for photon energies above the diffraction limit. This is because the transverse coherence depends on both the source eyes and the divergence, both of which become much smaller at DLSRs. We show here another transition animation here from a third generation facility with Epsilon XE equal to five nanometer radians to a DLSR with a hundred times smaller horizontal emittance of 50 picometer radian. In this simulation we assume a two meter ungulator and an electron beta function that is perfectly matched to this with beta equals L, divided by four Pi, which is equal to [inaudible 00:07:05].16. At 10 electron volts, the coherent fraction increases from approximately two thirds to 100%, only an improvement of 1.5. In contrast, at all energies significantly above the diffraction limit, which for a 50 picometer radian emittance is at approximately 200 electron volts. The improvement is a factor of 100. Note also that assuming the vertical electron emittance is significantly smaller than the horizontal emittance, the coherent fraction is 50 per cent exactly at the diffraction limit. Look again at the last video of the second section from last week's videos.

Notes

Summary

6m 06s

Scientific and technological benefits of DLSRs

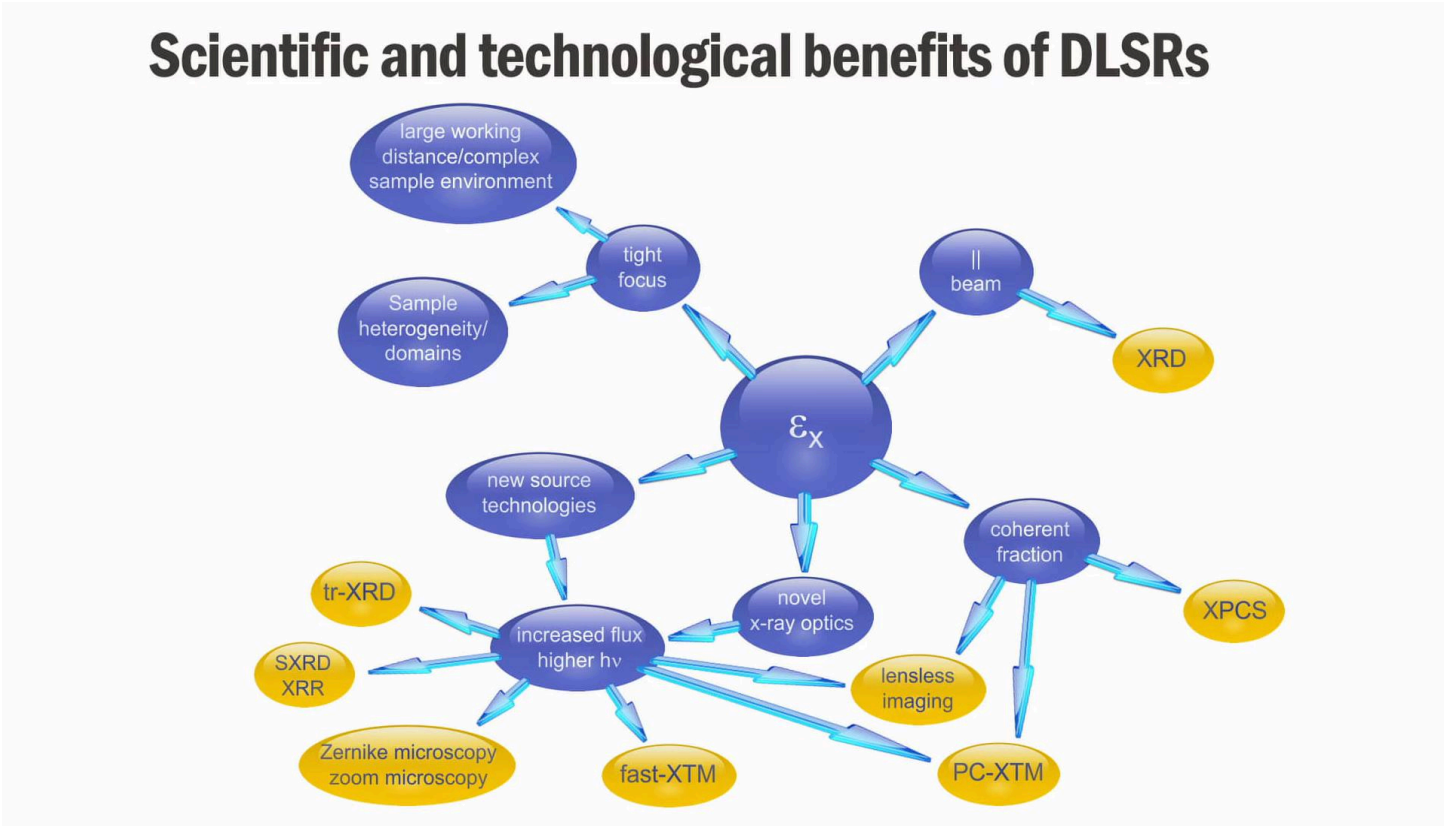


There are further knock on effects that lead to innovations and unexpected opportunities associated with the fraction limited storage rings. Beginning with a small horizontal emittance. We have already discussed how this leads to more tightly focused and parallel beams and an increase in the coherent fraction. Moreover, these lead to new source technologies such as short period high K angulators that can access photon energies otherwise only reachable at high energy storage rings, and novel X-ray optics such as horizontally oriented monochromators and compact for anal zone brakes, discussed in more detail next week. Both these also result in increased flux on the sample. The tighter intrinsic focus allows one to probe submicron regions in heterogeneous samples such as domains and magnetic materials or elements in electronic devices in operando studies. A more subtle and under appreciated aspect is that for a given desired focal spot size, DLSRs will have a larger distance between the X-ray focusing element and the sample, than will the same set up at a third generation source.

Notes

Summary

7m 54s



This means that the experiment has more [inaudible 00:09:15] room to set up her sample environment, allowing more sophisticated experiments such as in, for example, chemical catalysis or additive manufacturing to name just two examples. Which techniques profit from these technical improvements and innovations? Classical X-ray diffraction requires parallel late radiation towards obtain the cleanest patterns. This is especially true in powder diffraction, where all the diffraction peaks are projected onto a single axis. X-ray photon correlation spectroscopy increases its sensitivity with the square of the coherent fraction. So is a clear winner of DLSR deliverables. Most all techniques benefit from increased available flux on the sample, but some much more than others. The so called photon hungry experiments such as time resolved X-ray diffraction, surface X-ray diffraction and X-ray reflectivity, Zernike and Zoom tomography, and fast X-ray tomography. Lensless imaging techniques such as coherent diffraction, imaging and Ptychography gain very substantially from both a higher flux and higher coherent fraction, as indeed does phase contrast X-ray tomography, which depends on contrast emerging from distinct components of an object, they might have similar and normally very low absorbance but distinct refractive indices.

Notes

Summary

9m 13s

Scientific and technological benefits of DLSRs

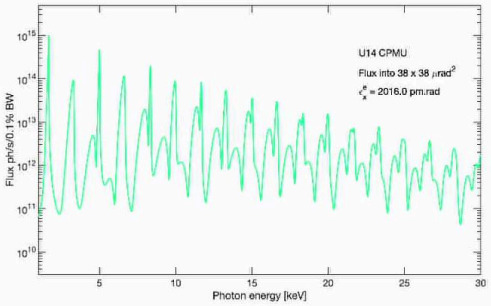
The increase flux of DLSRs in combination with a tight focus, can bring spectroscopic techniques such as the photon hungry appes and ricks into the realms of micro-spectroscopy or indeed, Nano spectroscopy. A larger sample environment is often critical in setting up a real system experiments such as ambient pressure photo electron spectroscopy, high pressure X-ray diffraction, and X-ray absorbing spectroscopy of many systems, including heterogeneous, catalysis and chemical kinetics. Similarly, XRD of Micron sized domains and systems require tight fork I, while a tight focus and a parallel beam are necessary conditions for macromolecular crystallography and its more recent variant, serial synchrotron crystallography, and for 3D scanning imaging, tomography's and spectroscopies. The reduction of the horizontal emittance in DLSRs thus lends many potential opportunities and is driving exciting innovations along the full technology chain from the sources through improved X-ray optics regarding imperfections and operations detector technologies to handling of large data sets.

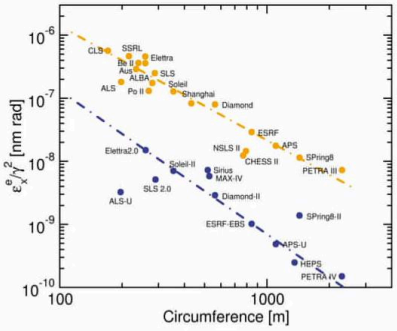
Notes

Summary

10m 49s

Summary of this section





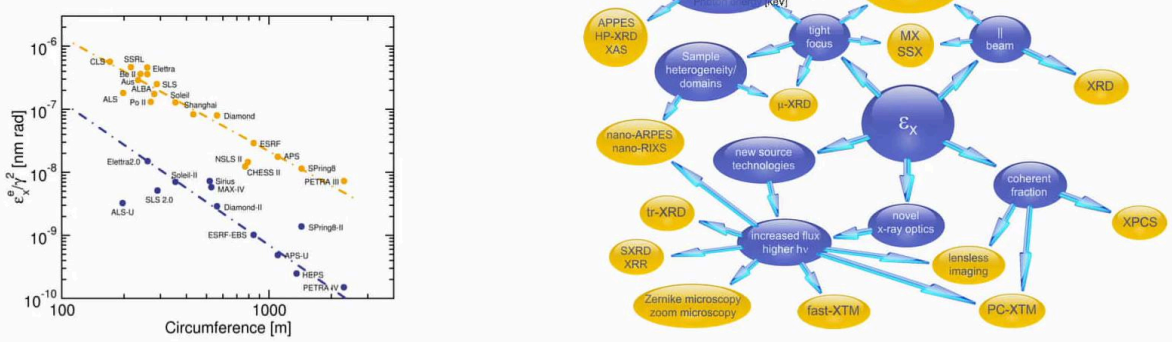
To summarise this section on DLSRs, we discovered, that by the simple measure of dividing a traditional doublebend achromat into smaller arcs, the horizontal electron emittance of the storage ring can be significantly reduced, thus defining fourth generation facilities. The smaller lateral extent of the electron beam as it passes through an angulator means there is significantly less off axis radiation, and the angulator spectra at DLSRs are thus much cleaner.

Notes

Summary

12m 14s

Summary of this section

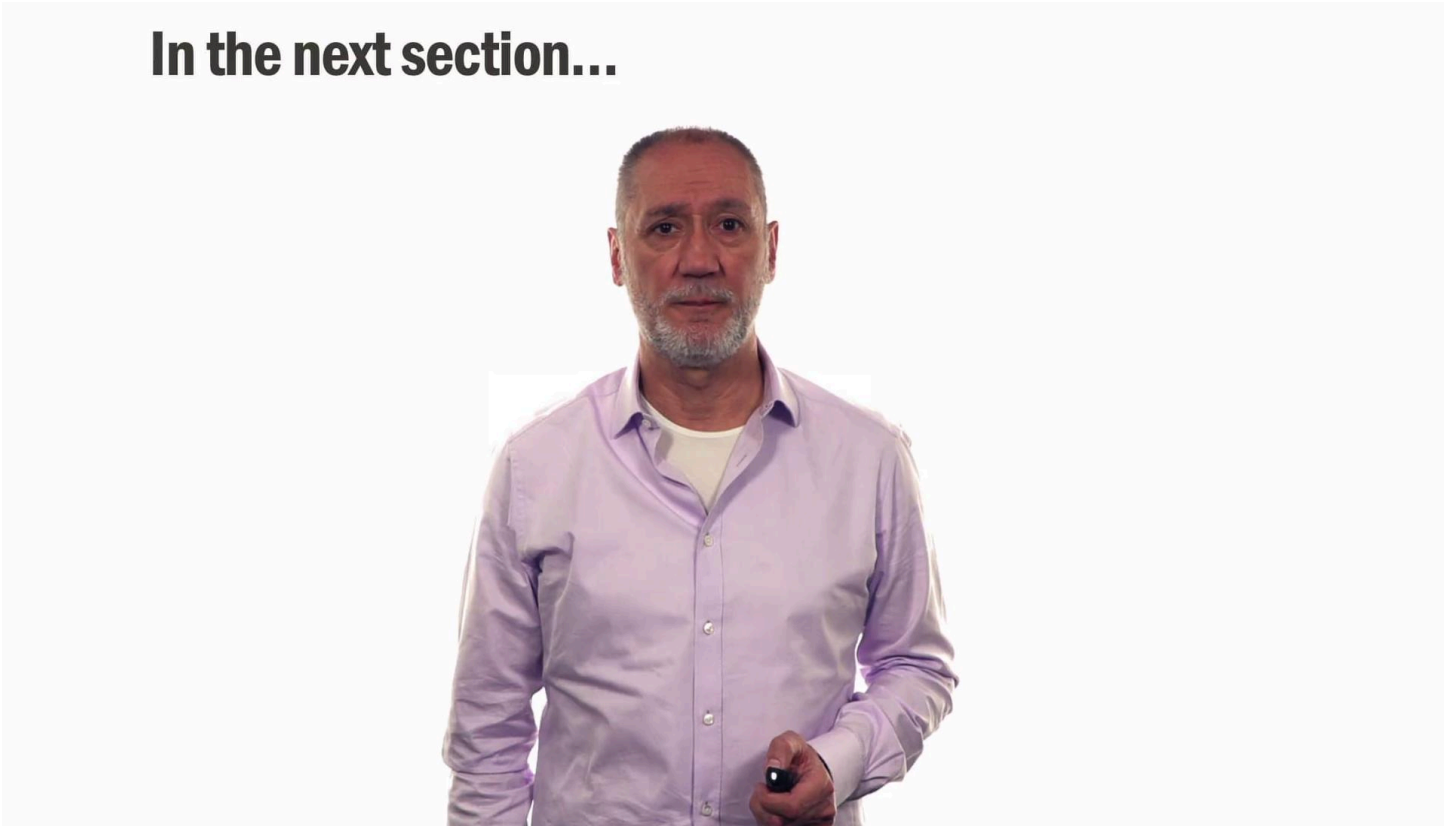


This plus other technological benefits associated with DLSRs have major knock on effects in many synchrotron techniques, resulting in a sea change in many disciplines, ranging from X-ray imaging through floating crystallography to Nanoscopic spectroscopies.

Notes

Summary

12m 53s



In the next section of this week, we will turn to the physics of X-fell and X-fells experiments.

Notes

Summary

13m 06s