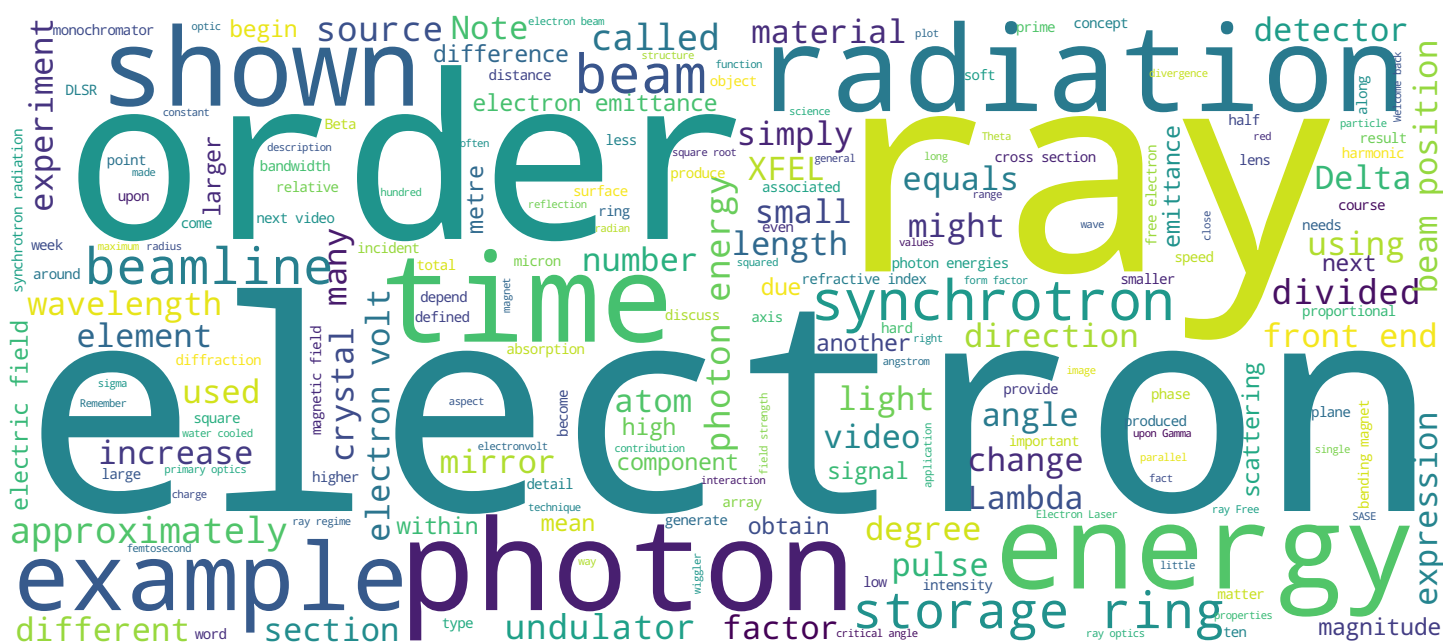


# Synchrotrons and x-ray free-electron lasers

## Techniques and applications

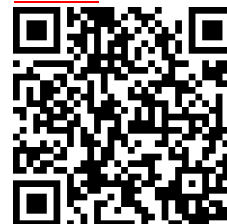
Prof. Philip Willmott



## Search MOOC



## Video



# Contents and objectives of this video



- Overview
- Front ends
  - Beam-defining aperture
  - Filters
  - Beam-position monitors
  - Bremsstrahlung blocker

Hi again. We're now beginning week five of this course, Synchrotrons and X-ray Free-Electron Lasers: Techniques and Applications. Both this week and next, we will be discussing the hardware that comes after the sources. Broadly speaking, and travelling in a logical manner with the photons, this will include the front end, those aspects of the basic theory of optics we will use later, primary optics, including mirrors and monochromators, secondary micro-optics and, finally, different types of X-ray and electron detectors. This first video is concerned with the most relevant elements of the so-called front end.

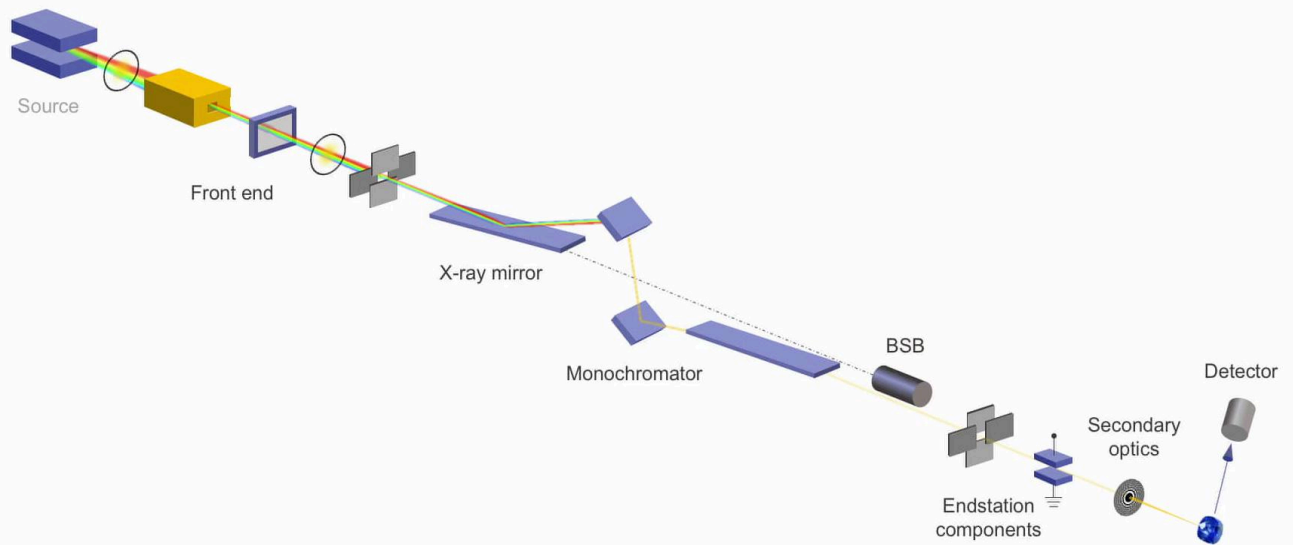
Notes

Summary



0m 04s

# The front end



So let's begin with an overview of elements of a beamline. The generic set up shown schematically here, is just one possible configuration, but most beamlines follow this concept, in general terms. Following the photons emerging from the source, we pass through the front end, the primary optics and bremsstrahlung blocker, and into the end station, or experimental hutch consisting of various components, your sample that might be enclosed in some sort of controlled environment, and one or more detectors.

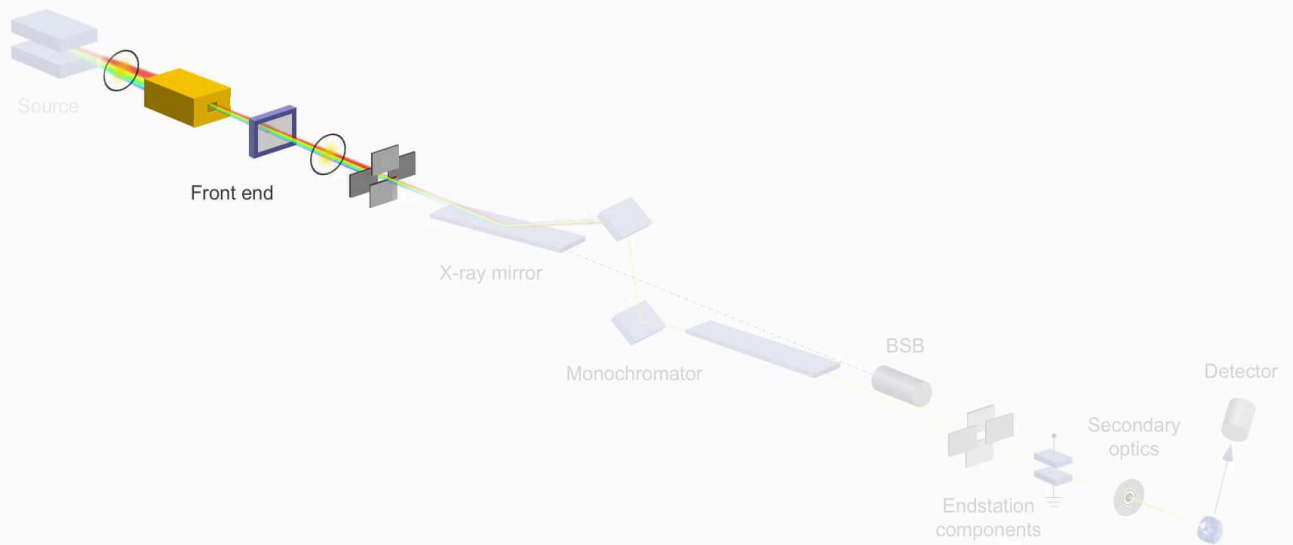
Notes

Summary



0m 48s

# The front end



We begin now with the description of the front end.

Notes

Summary



1m 24s

# The front end



- Bridge between storage ring and beamline
  - Physically passes through storage-ring tunnel
- Functions
  - Beam-defining aperture (+ slits)
  - High-pass filter
  - Hard x-rays: vacuum isolation
  - Beam position monitoring
  - Photon shutter
  - Safety triggers
    - Vacuum
    - Radiation

The purpose of the front end is to clean up the source radiation before it impinges on the primary optics and other components, and provide a safety net between the storage ring and the beamline. The acceptance angle of the beamline is defined by a beam-defining aperture and water-cooled slits, discussed in a little more detail shortly. Radiation in an unwanted spectral region can also be removed using filters. In many but not all instances, a window that is transparent to the X-rays of interest for the beamline is placed as one of the final components of the front end, in order to protect and isolate the storage ring, in case the vacuum at the beamline suddenly fails, thereby preventing the entire ring from venting, which would result in the entire facility being out of operation for days. Beam position monitors ensure any significant drifts can be detected. These can also be placed anywhere along the length of the beamline and, most often, a beamline will have more than just one, in order to determine angular drifts as well as translations. A photon shutter at the end of the front end allows one to enter the optics and experimental hutches without fear of exposure to radiation. Lastly, the front end, as in other strategic places in the beamline, contains safety triggers for vacuum and radiation excursions.

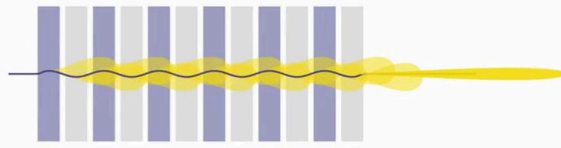
Notes

Summary

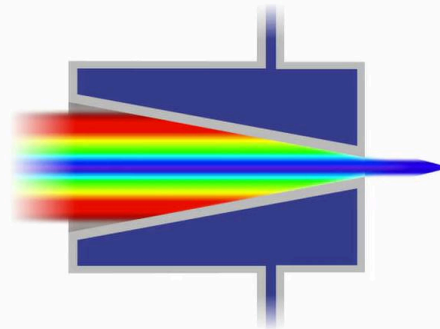
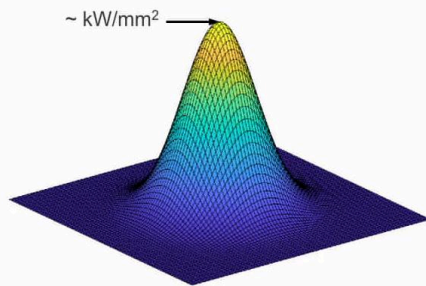
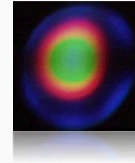


1m 29s

# Beam-defining aperture



$$m\lambda_m = \frac{\lambda_u}{2\gamma^2} \left( 1 + \frac{K^2}{2} + \gamma^2\theta^2 \right)$$



The acceptance angle of the source needs to be defined. This is obvious in the case of bending magnet sources as they sweep angles far larger than typically desired for experiments, as we discussed last week. Even for undulators, however, the radiation does not immediately fall to zero outside the angles of plus or minus one upon Gamma, as you might recall from discussions of off-axis radiation in last week's videos. Indeed, undulator radiation can have power densities measured in kilowatts per square millimetre in the central cone, and still be hundreds of watts per square millimetre at larger angles, consisting mainly of softer X-rays than those in the central cone. Remember, by the way, that it's the soft X-rays that interact the most strongly with matter. So often, certainly in the case of hard X-ray beamlines, the aperture partially cuts out this detrimental contribution. In order to cope with the high heat load associated with this, the aperture is normally conical, thereby spreading the absorbed energy over a larger area, and it is also water-cooled.

Notes

Summary



3m 05s

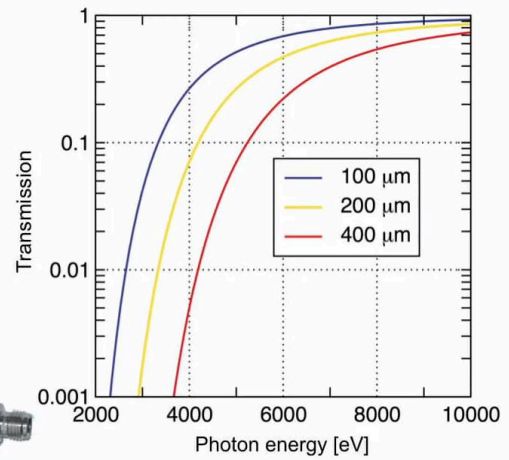
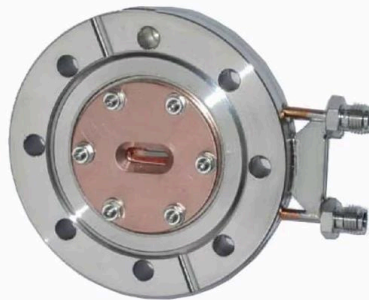


# High-pass filter

- Absorbing window material

- Hard x-ray beamlines
- Absorbs up to ca. 5 keV
- High melting temperature
- Mechanically robust
- Good thermal conductor

Diamond  
 $\rho = 3.51 \text{ g cm}^{-3}$



Nonetheless, the central part of the beam that passes through the aperture may still contain an unacceptably large fraction of unwanted X-rays (these are usually soft X-rays) that need to be removed. This can only be performed using a high pass absorption filter. The specifications for the material that can do this are very strict. It should efficiently absorb soft X-rays, typically up to approximately five kiloelectronvolts, and will thus heat up substantially, meaning the filter must have a high melting temperature, and remain mechanically robust. This heat also needs to be efficiently dissipated, requiring good thermal conductivity. Essentially, there is only one material that fits all of these requirements: diamond. Which, incidentally, is the best-known heat conductor, even surpassing copper or silver. Thin, artificially-grown diamond windows are commercially available and can be braised onto a water-cooled vacuum flange, as shown here. Obviously, such high pass filters are not used for beamlines operating in the tender, or the soft, X-ray regime.

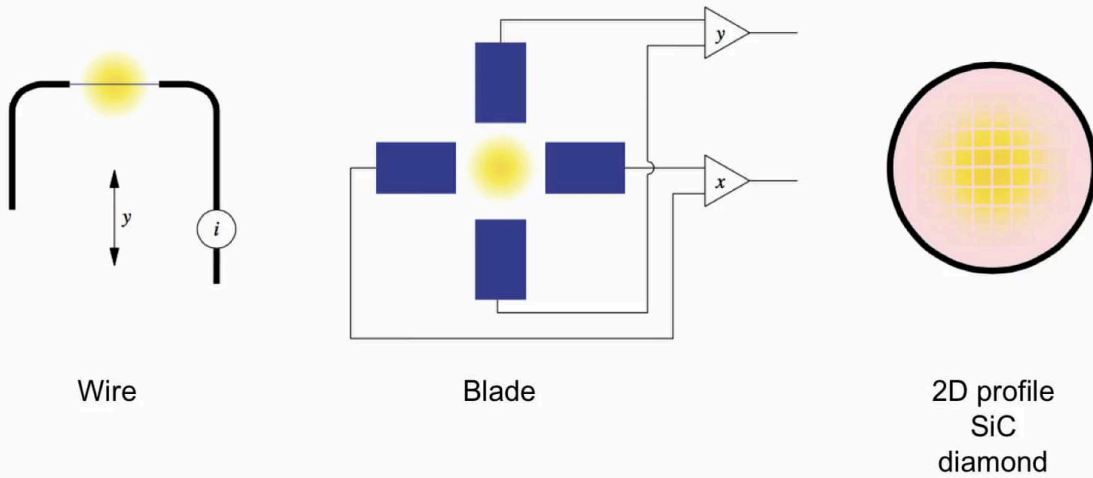
Notes

Summary



4m 19s

# X-ray beam-position monitors



Beam position monitors can come in various shapes, sizes, and working principles. The simplest is a thin wire that can be traversed across the beam, which generates a photocurrent proportional to the beam intensity. This provides one coordinate of the beam position. The orthogonal coordinate can be obtained by placing a second wire monitor at 90 degrees to the first. Both X and Y coordinates can be simultaneously determined using four blades in a configuration, as shown here. The beam Halo is sufficiently intense to generate a photocurrent in the blades. By moving the four blades together left-right and up-down, the difference in the photocurrent between oppositely facing pairs can be equalised using comparator electronics, and the beam position thereby determined. Lastly, a more modern approach is to use thin transparent windows— also often diamond, and more recently, silicon carbide— coated with an array of ultra-thin metallic pads. This delivers not only directly the beam position, but also the profile of the beam.

Notes

Summary



5m 34s



# Bremsstrahlung blocker



- Bremsstrahlung:  $h\nu \sim \text{few GeV}$
- Electron-positron pair production above 1.022 MeV
- Cascade effects
- Many cm tungsten or similar needed

- Absorbs high-energy photons up to ring energy produced by collisions of electrons with residual gas particles
- Often far downstream in BL

By having two X-ray BPMs in a stretch of the beamline that contains no deflecting optics between them, any translational and angular drifts caused by something upstream can be both monitored and act as a feedback to correct and stabilise the beam position. The angle of the beam given in radians in any one plane is simply the difference in the translational positions of the two xBPMs, assuming a known zero value, that is, divided by their separation. BPMs can be placed anywhere, from in front of the undulator, to behind the sample within the experimental hutch. In most cases, very high-energy gamma radiation up to the energy of the electrons within the storage ring is produced as an inevitable consequence of the electrons occasionally colliding with the residual gas molecules that remain, even at pressures as low as 10 to the minus 10 millibars. This radiation, although only generating a total power measured in a few tens of milliwatts throughout the entire facility, is highly ionising and must be blocked. Due to the very high energies, bremsstrahlung is not deflected by, for example, the first reflecting mirror, but simply passes straight through it.

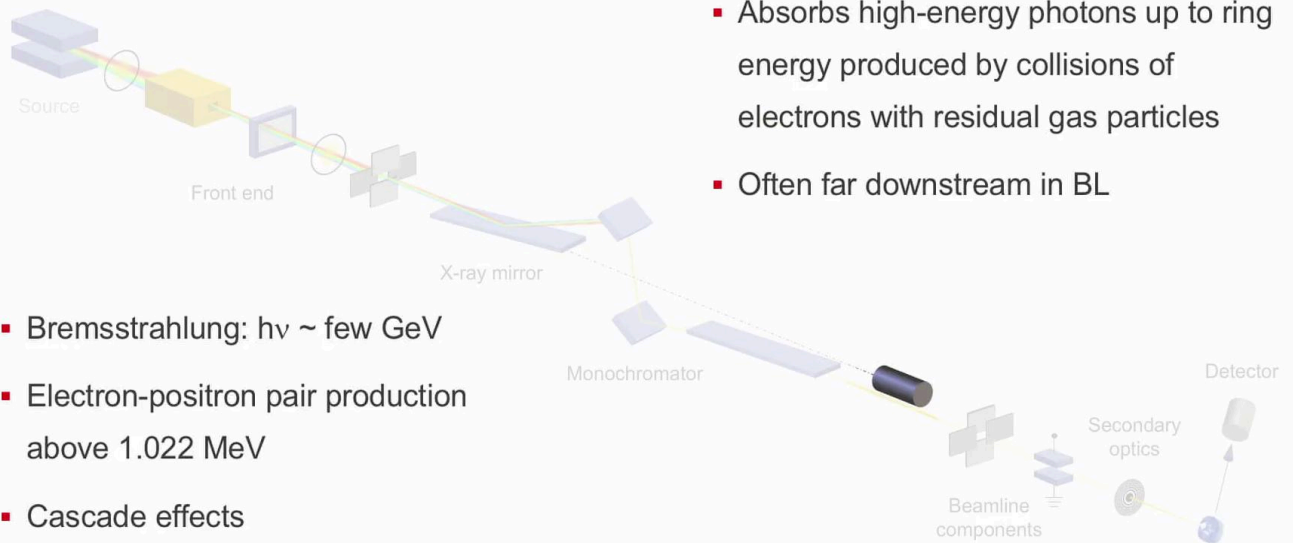
Notes

Summary



6m 50s

# Bremsstrahlung blocker



- Absorbs high-energy photons up to ring energy produced by collisions of electrons with residual gas particles
- Often far downstream in BL
- Bremsstrahlung:  $h\nu \sim \text{few GeV}$
- Electron-positron pair production above 1.022 MeV
- Cascade effects
- Many cm tungsten or similar needed

But the desired synchrotron radiation with photon energies typically well over three orders of magnitude lower, is deflected by the mirror, so the bremsstrahlung blocker can be placed behind any deflecting optical element on the axis of the radiation source. This needs to be made of a block of heavy metal, typically tungsten, with a thickness measured in several tens of centimetres. Only such a dense obstacle is sufficient to absorb bremsstrahlung.

Notes

Summary



8m 16s

## In the next video...



In the next two videos, we take a brief pause from our journey with the photons down the beamline, to consider some basic aspects of optics theory, which will equip us with the concepts and simple mathematical tools required to understand the design of X-ray optics elements. The next video discusses simple ray optics as they pertain to X-rays.

Notes

Summary



8m 45s