Today's outline - January 28, 2020

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- Undulator harmonics

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Reading Assignment: Chapter 3.1–3.3

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Reading Assignment: Chapter 3.1–3.3

Homework Assignment #01:
Chapter 2: 2,3,5,6,8
due Thursday, January 30, 2020

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Now let us look at the coherence of the undulator radiation

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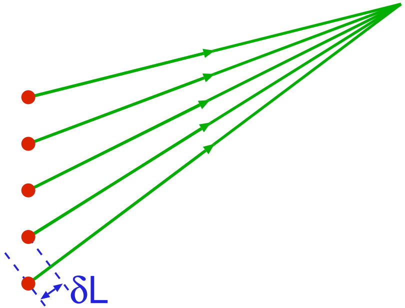

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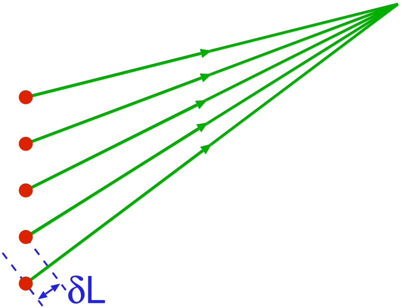

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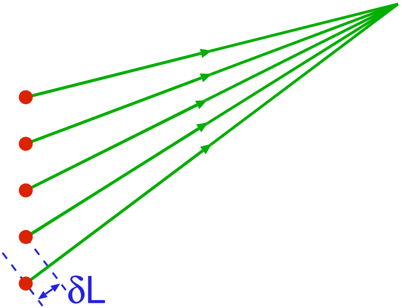

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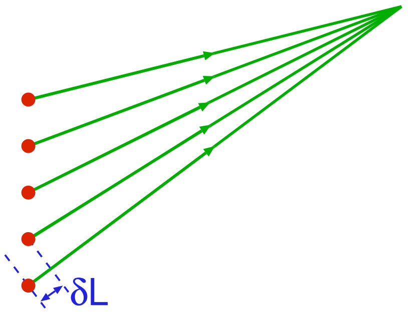

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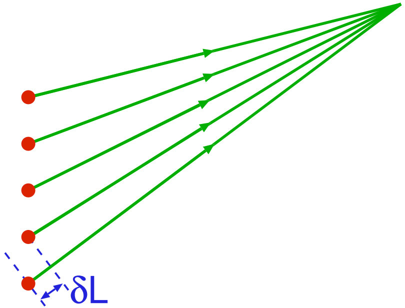

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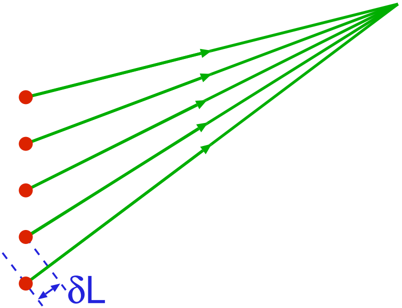

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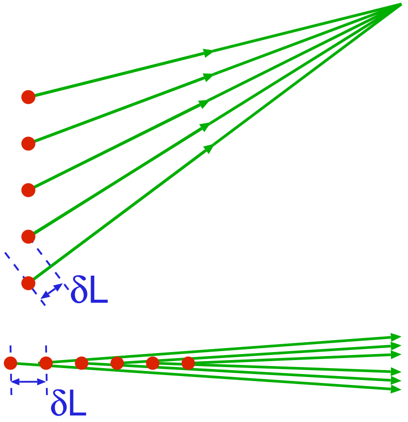

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the phase shift from each undulator pole depends on the wavelength λ_u

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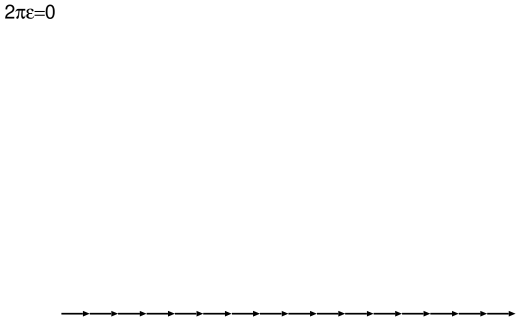

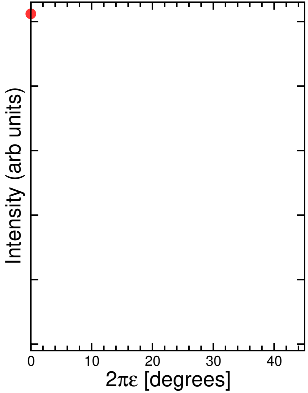

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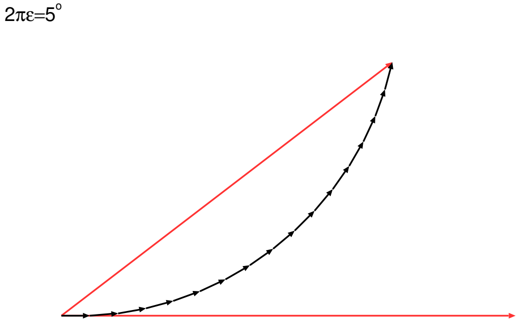

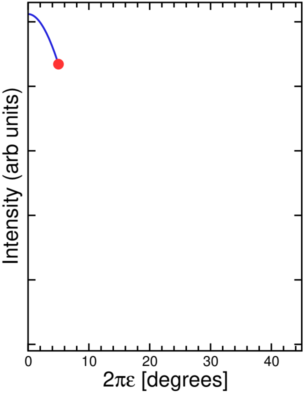

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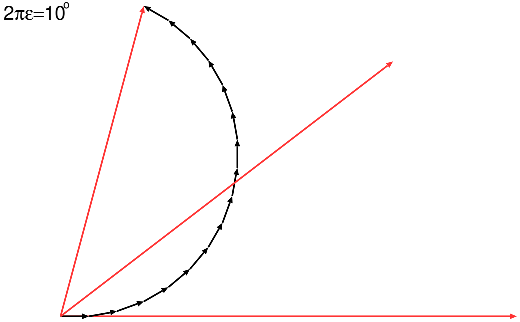

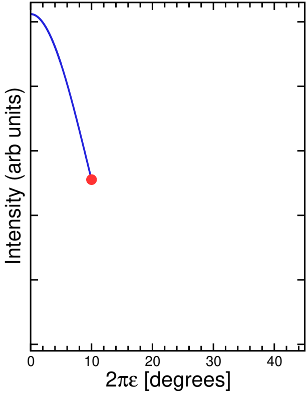

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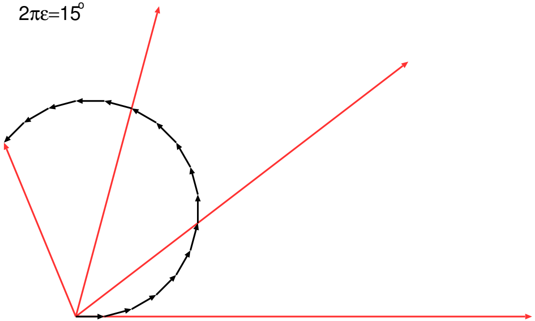

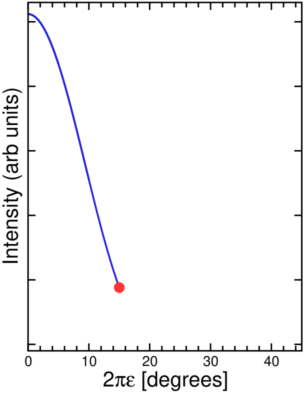

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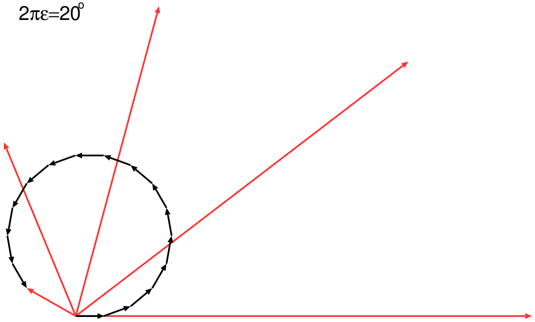

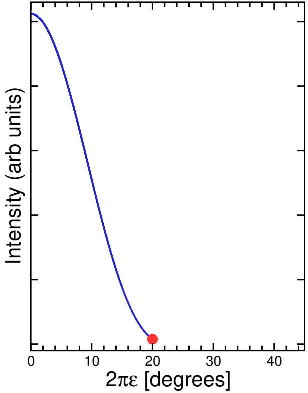

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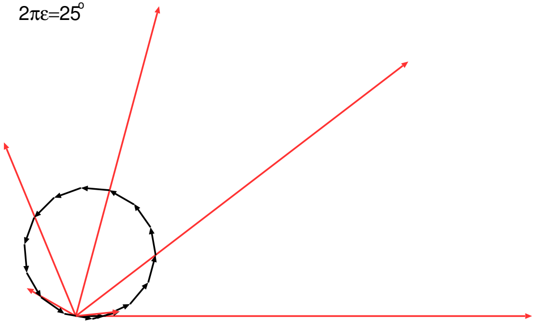

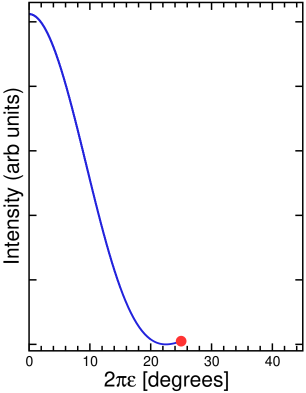

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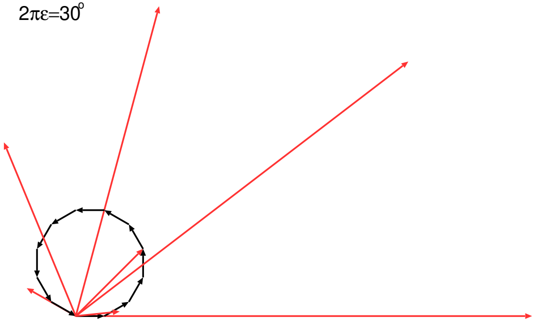

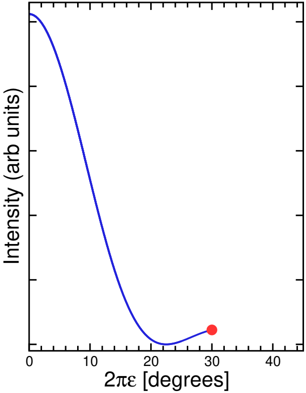

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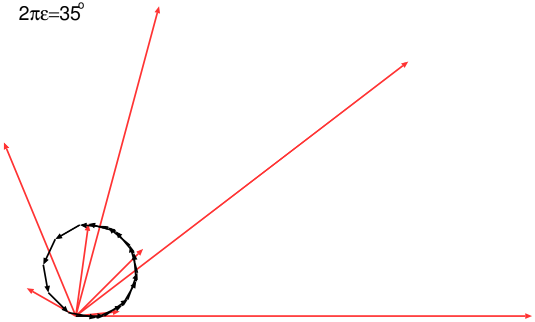

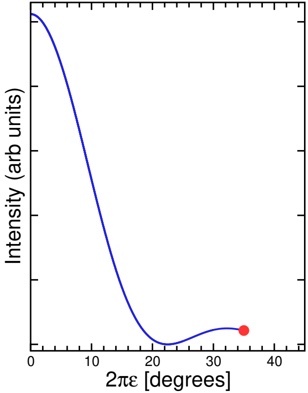

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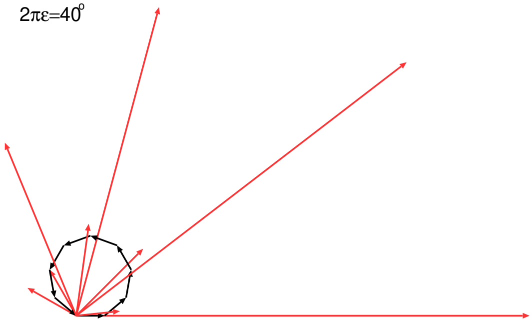

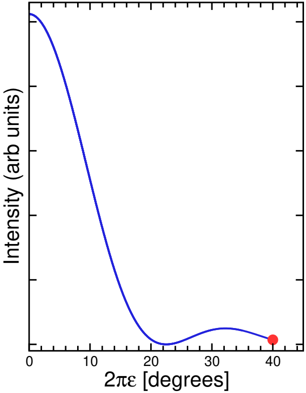

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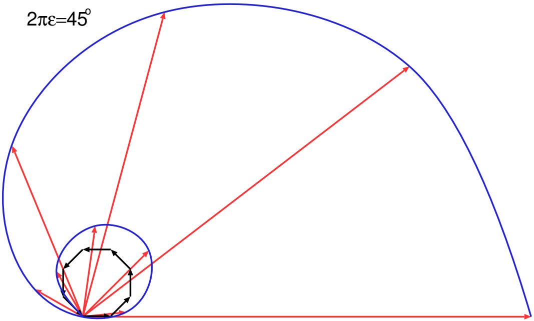

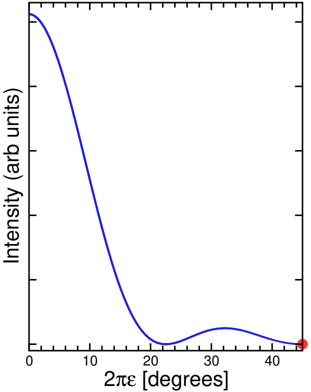

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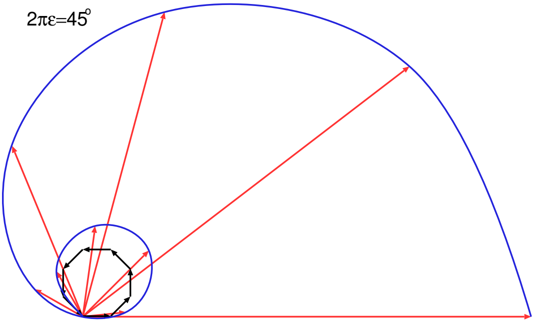
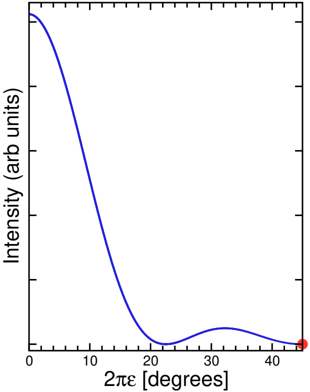
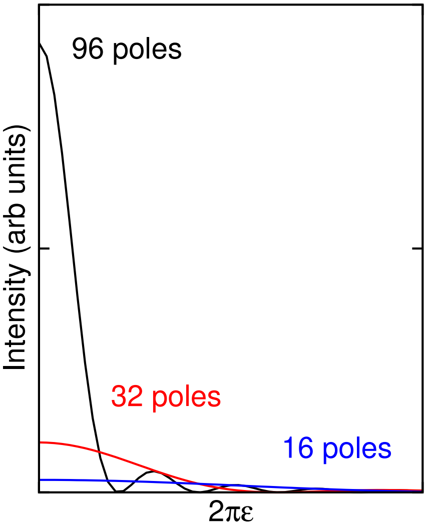




With the height and width of the peak dependent on the number of poles.

Undulator monochromaticity



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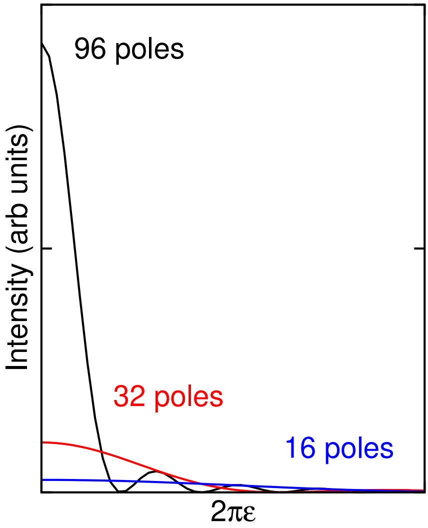

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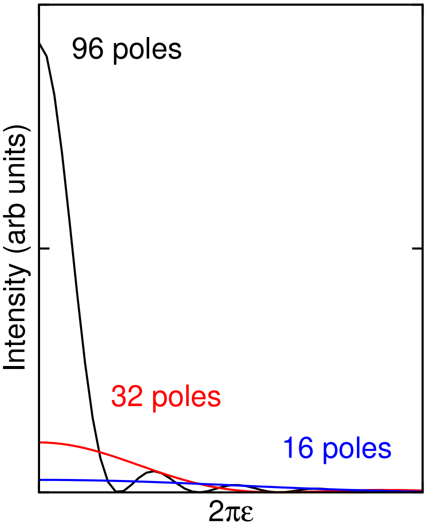

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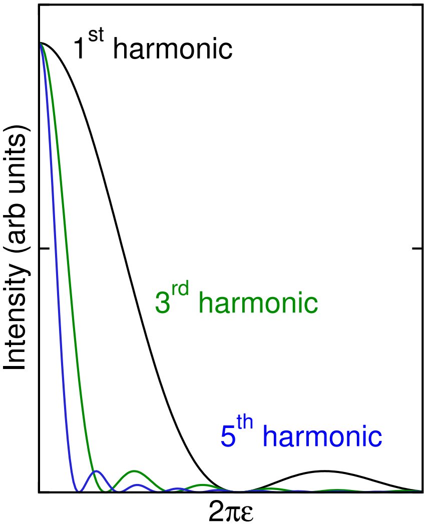

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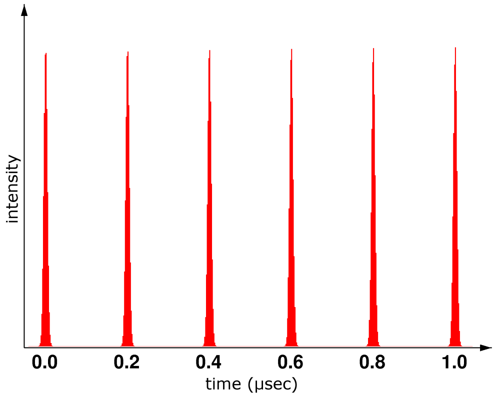
Higher order harmonics have narrower energy bandwidth but lower peak intensity

Synchrotron time structure



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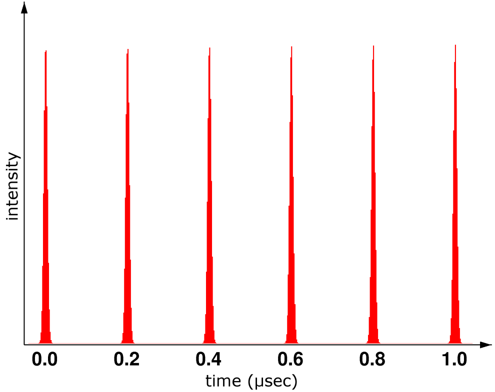

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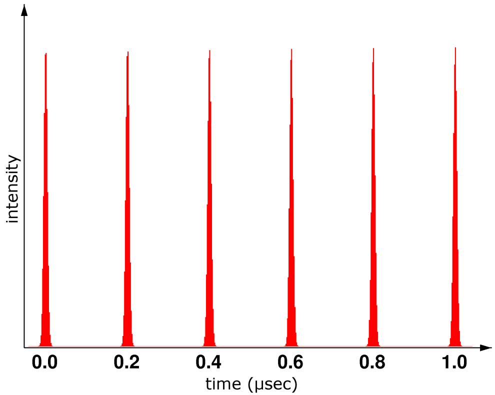

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Other modes include single-bunch mode for timing experiments and 324-bunch mode (inter pulse timing of 11.7 ns) for a more constant x-ray flux

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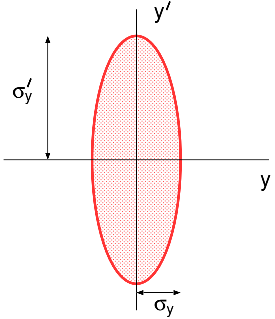

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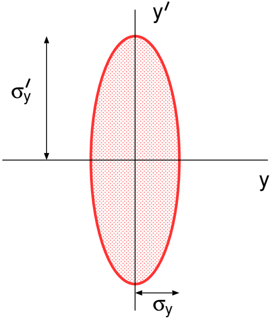

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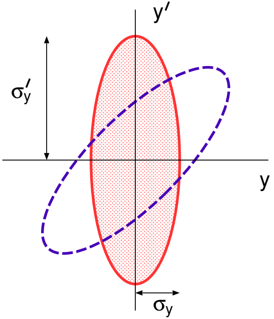

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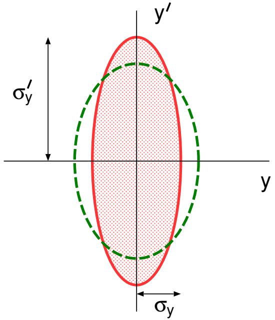

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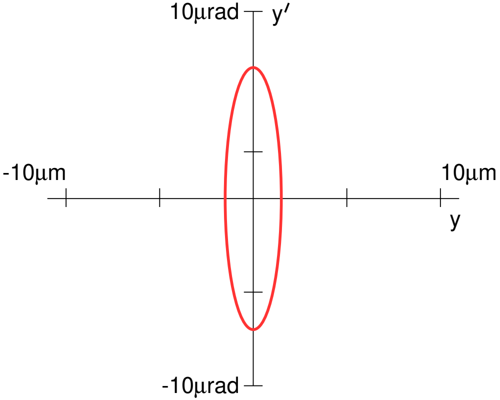

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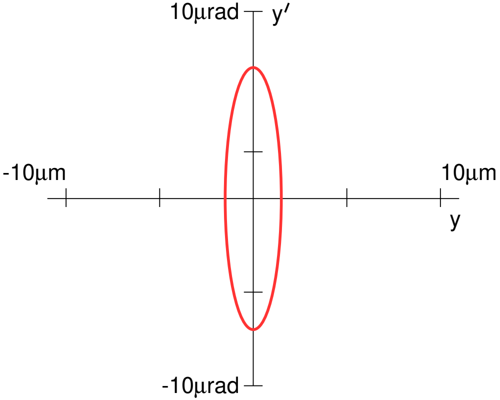

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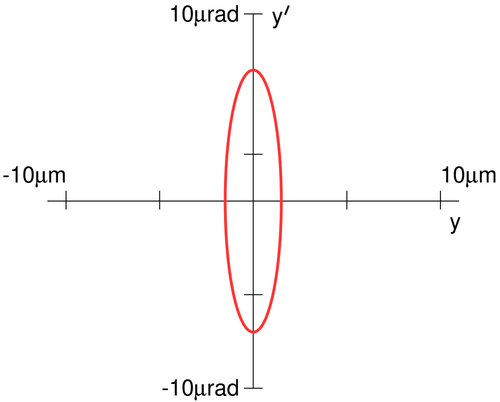

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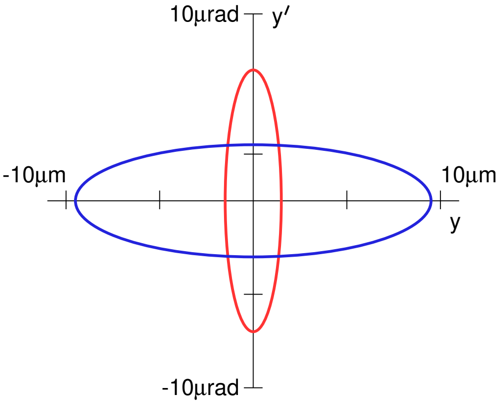

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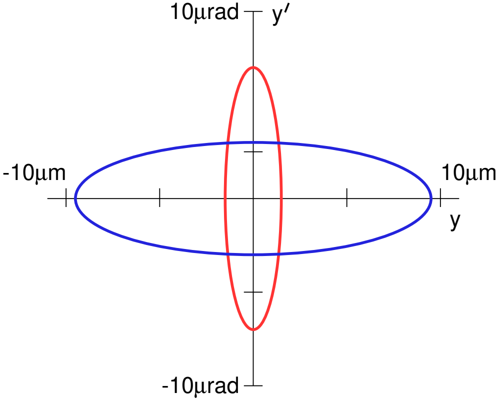

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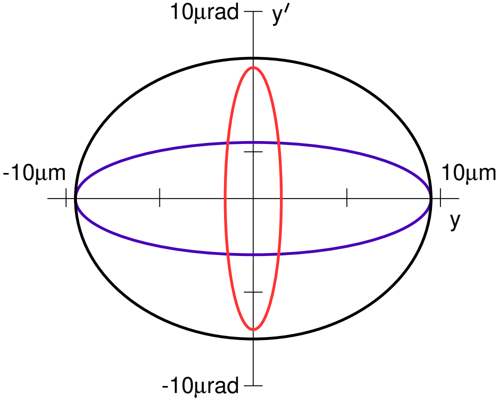

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Evolution of APS parameters

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σ_x	334 μm	352 μm	280 μm
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The next big upgrade (slated for 2022) will make the beam more square in space and by choosing the undulator correctly, a higher performance insertion device.

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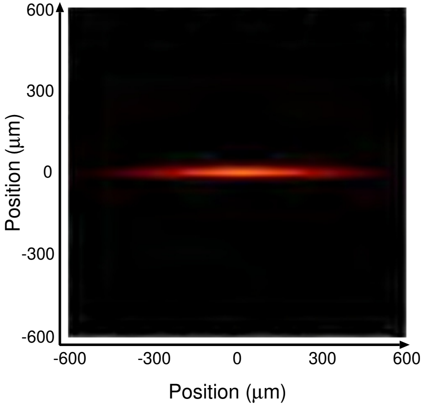

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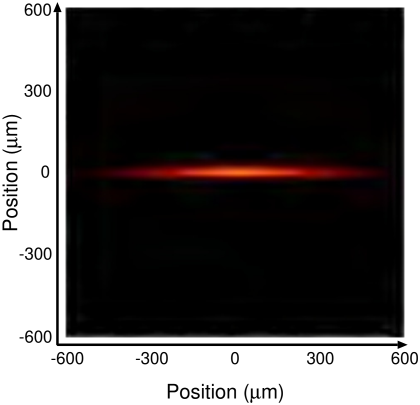

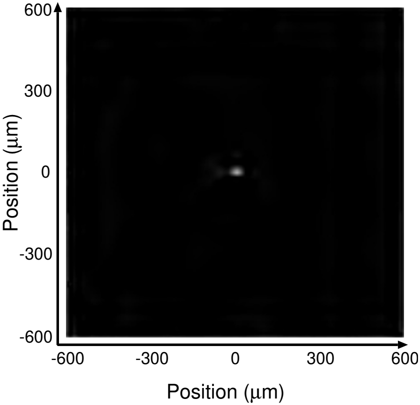

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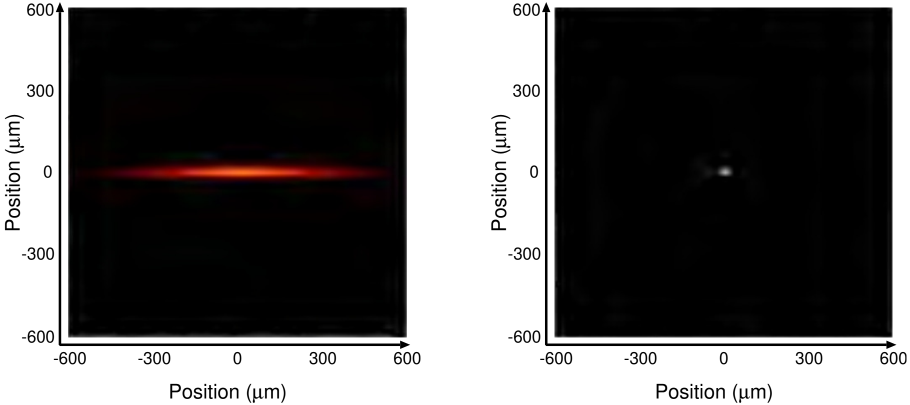

The beam will be nearly square and there will be much more coherence from the undulators

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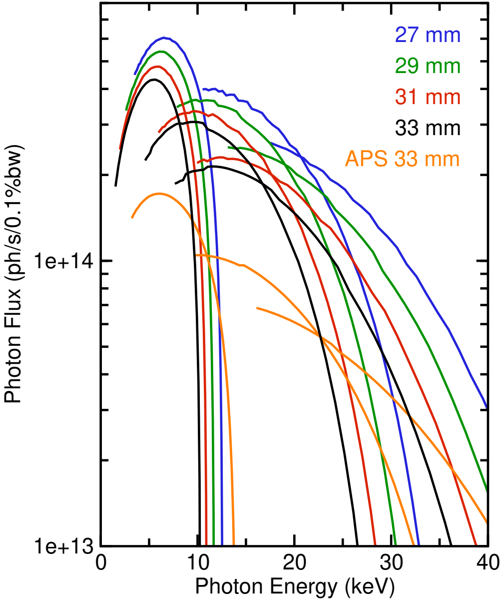

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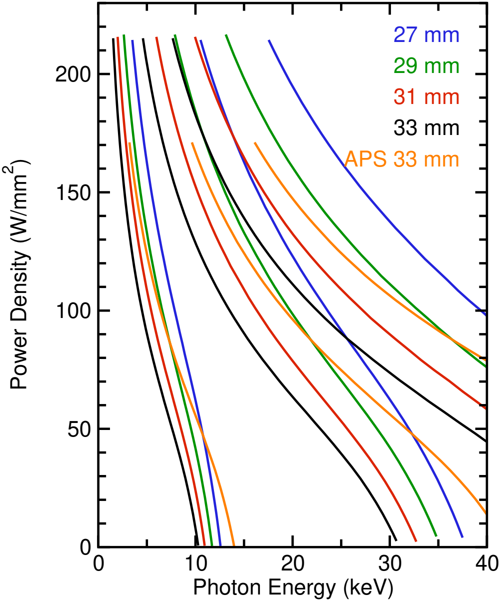
The APS is calling this a "4^{th}" generation synchrotron source



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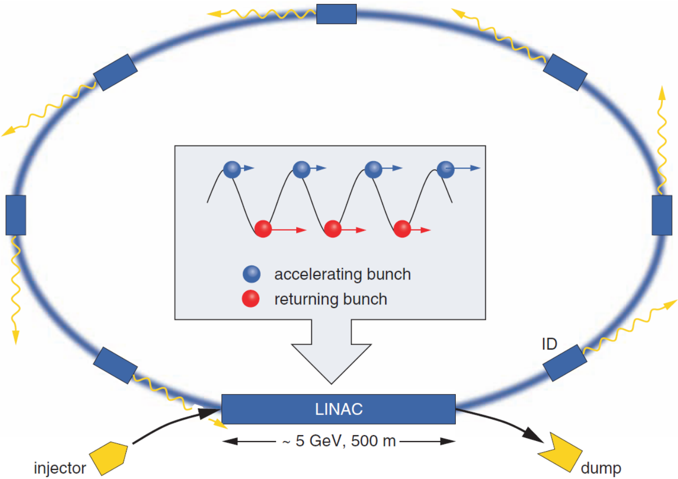
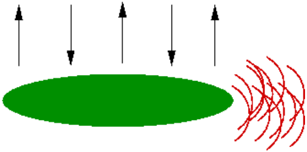


Free electron laser



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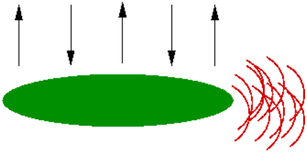
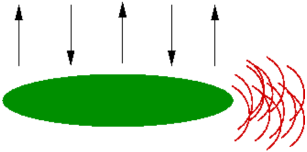


Initial electron cloud, each electron emits coherently but independently

Free electron laser



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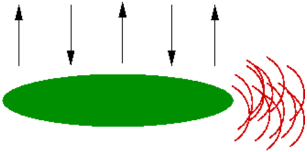

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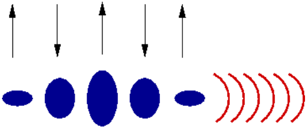

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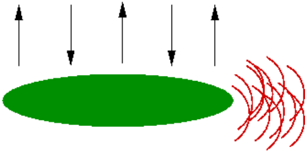

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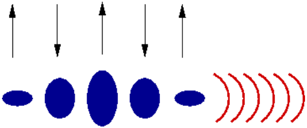
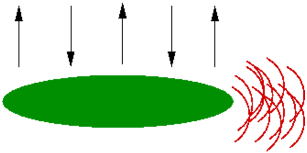


Microbunches form with period of FEL (and radiation in electron frame)

Free electron laser



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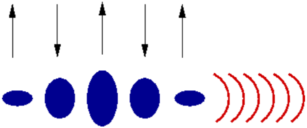

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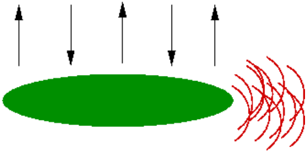

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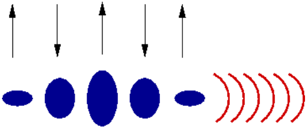

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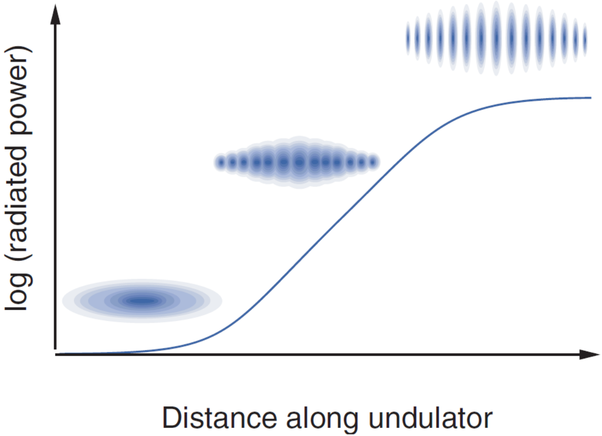
Again, an alternative way to view this is that the pulse train from a 100m long undulator is long enough in time to produce a monochromatic and coherent frequency distribution when Fourier Transformed

FEL emission



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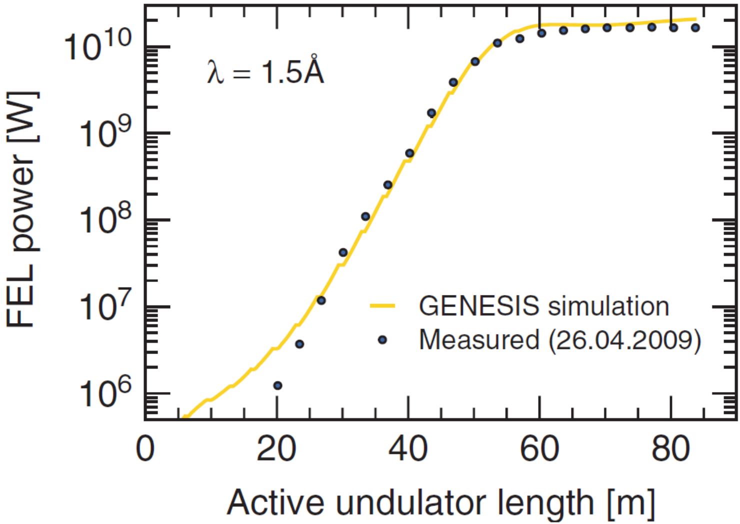

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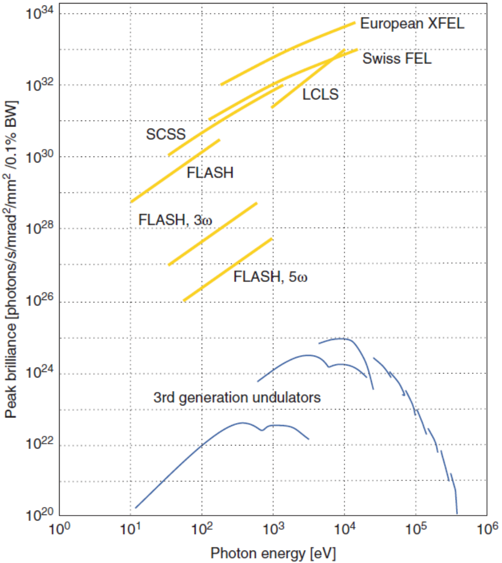
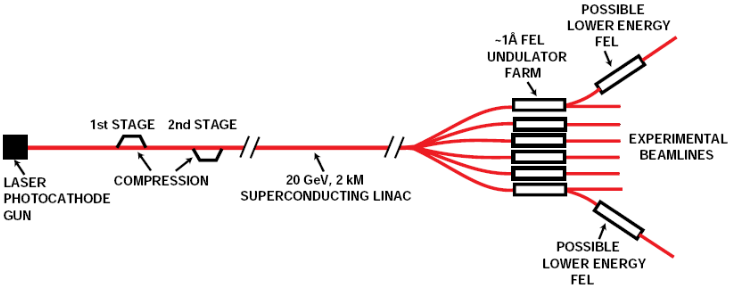


FEL layout


POSSIBLE
LOWER ENERGY
FEL
~1Å FEL
UNDULATOR
FARM
1st STAGE
2nd STAGE
EXPERIMENTAL
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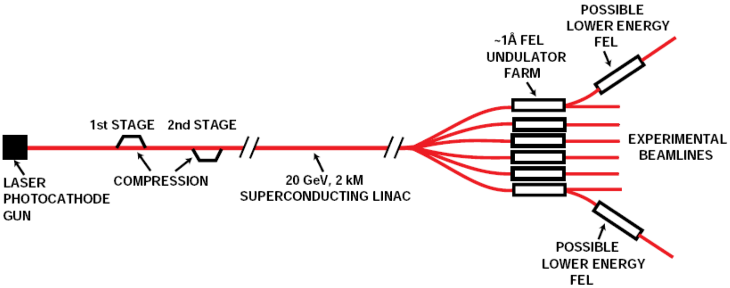

An FEL has a single accelerator whose electron beam is shunted sequentially through different undulators and end stations

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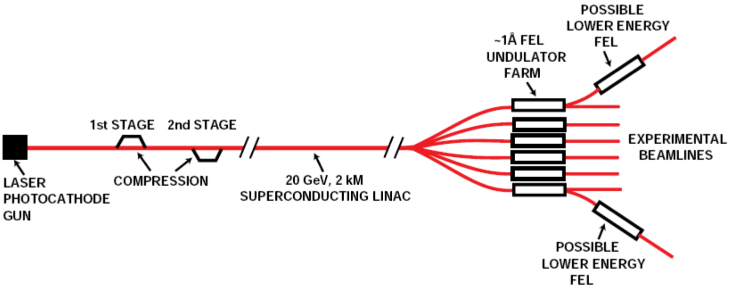

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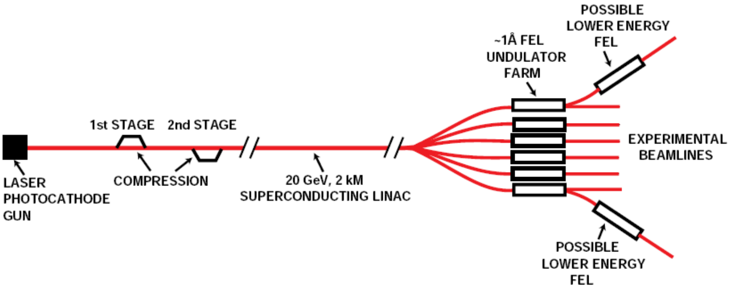

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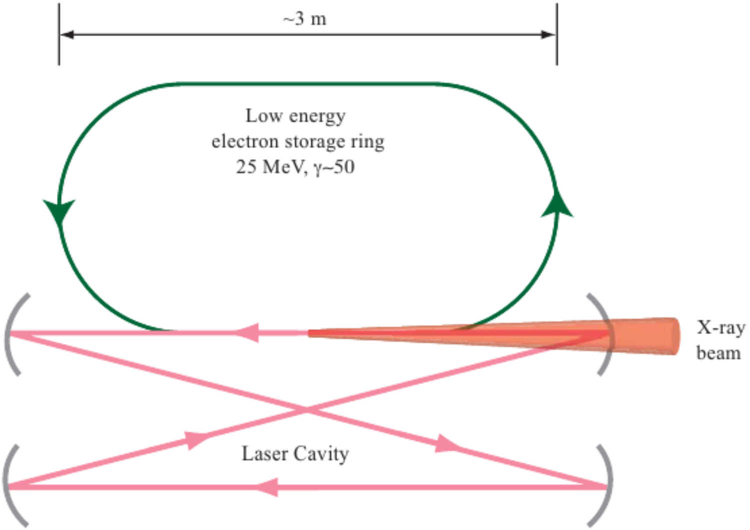
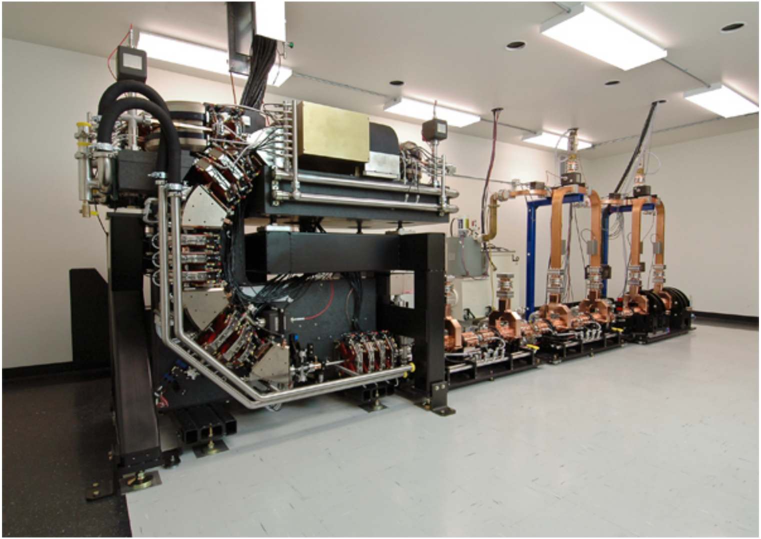
The high brightness usually results in destruction of the sample during the illumination, thus the need for multiple samples and multiple shot experiments

Compact sources



Lyncean CLS



Types of X-ray Detectors

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Gas detectors

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Gas detectors

Scintillation counters

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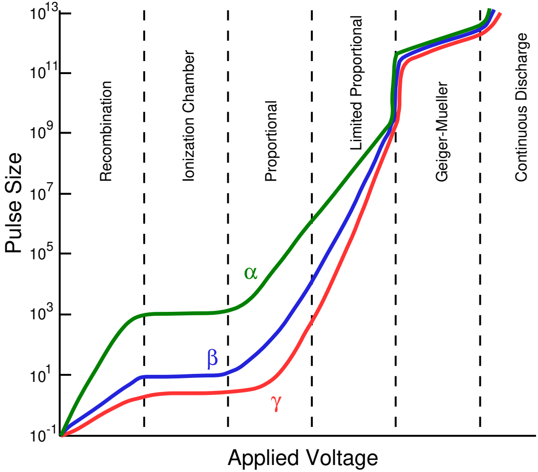
Gas Detectors

Gas detectors operate in several modes depending on the particle type, gas composition and pressure and voltage applied



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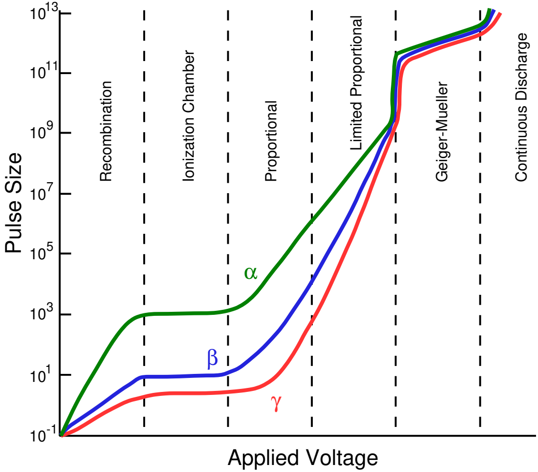

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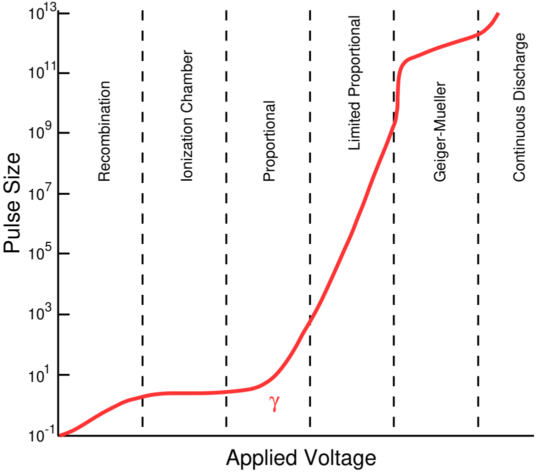

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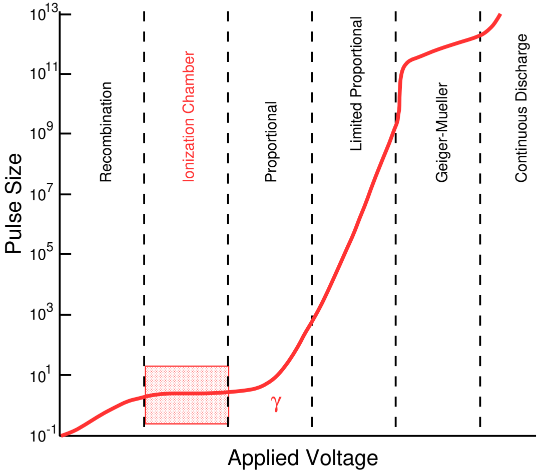
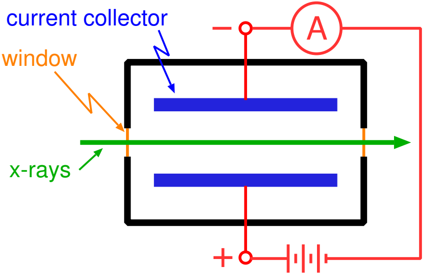
The most useful regime is the ionization region where the output pulse is independent of the applied voltage over a wide range



Ionization Chamber

Useful for beam monitoring, flux measurement, fluorescence measurement, spectroscopy.



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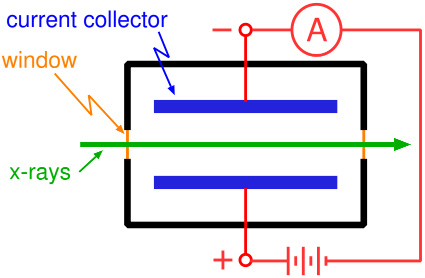

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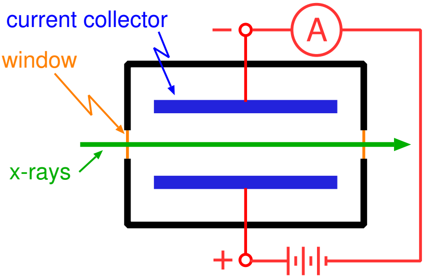

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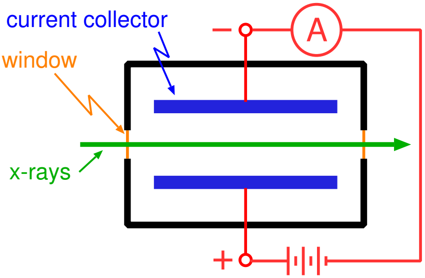

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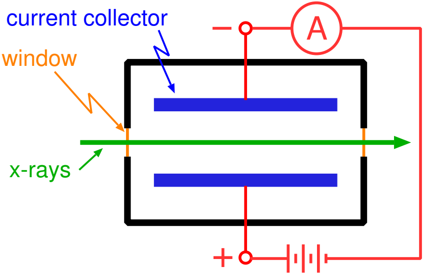

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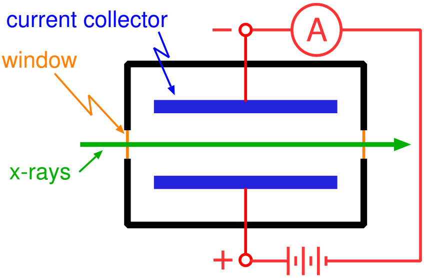

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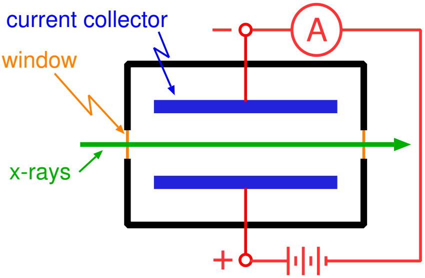

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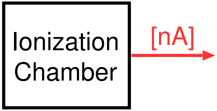
- 22-41 eV per electron-ion pair (depending on the gas) makes this useful for quantitative measurements.

Getting a reading

The ionization chamber puts out a current in the nA range, this needs to be converted into a useful measurement



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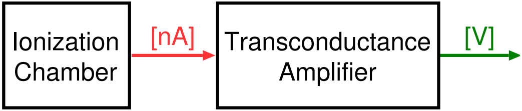

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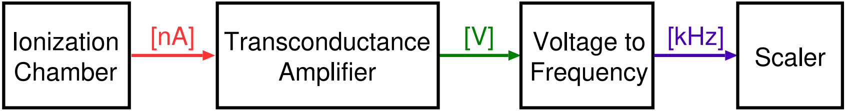

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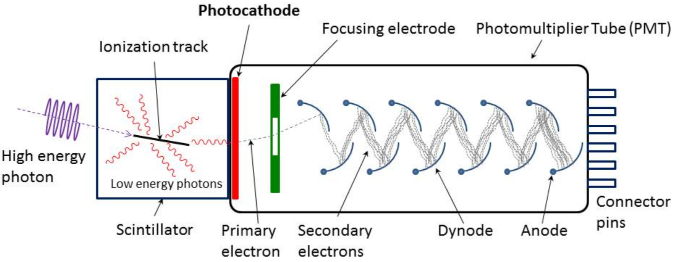
the digital pulse train is counted by a scaler for a user-definable length of time

Scintillation detector

Useful for photon counting experiments with rates less than $10^4/s$



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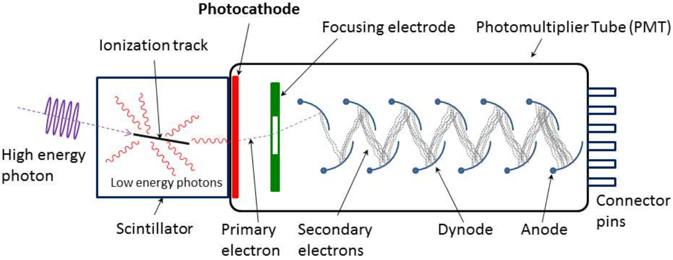

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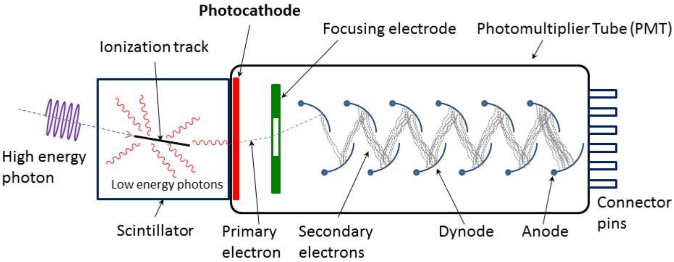

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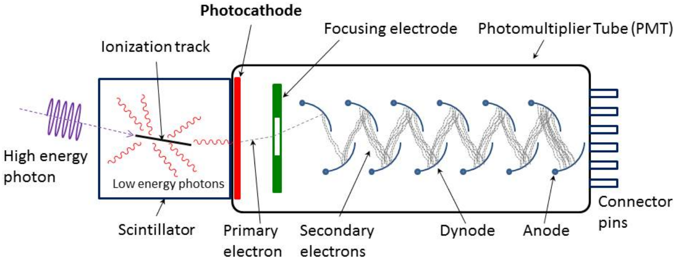

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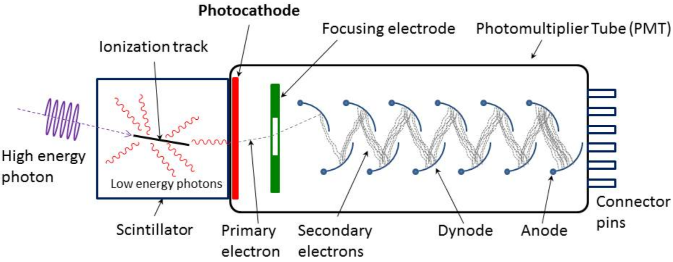

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- Output voltage pulse is proportional to initial x-ray energy.

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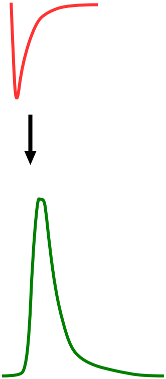

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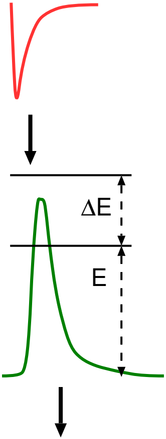

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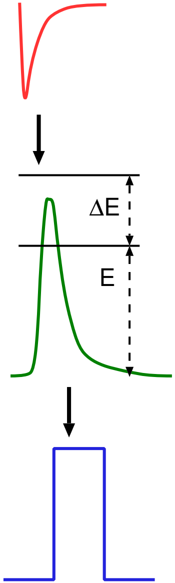

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if the voltage pulse falls within the discriminator window, a short digital pulse is output from the discriminator and into a scaler for counting

Solid state detectors

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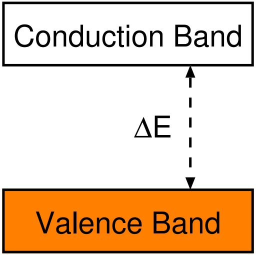

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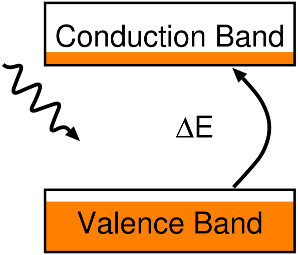

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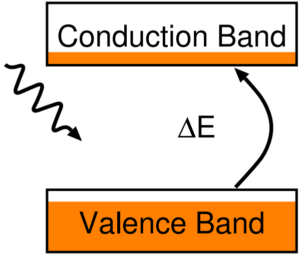

because of the small energy required to produce an electron-hole pair, one x-ray photon will create many and its energy can be detected with very high resolution

Semiconductor junctions

Producing the electron-hole pairs is not sufficient. It is necessary to extract the charge from the device to make a measurement

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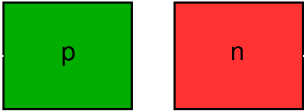
start with two pieces of semiconductor, one n-type and the other p-type



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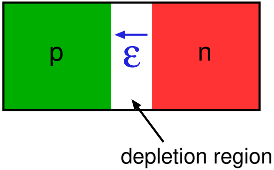
if these two materials are brought into contact, a natural depletion region is formed where there is an electric field $\vec{\mathcal{E}}$



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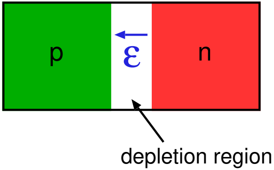

this region is called an intrinsic region and is the only place where an absorbed photon can create electron-hole pairs and have them be swept to the p and n sides, respectively

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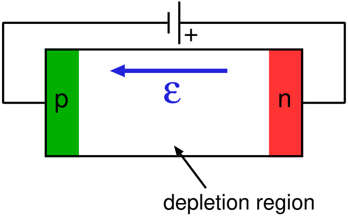

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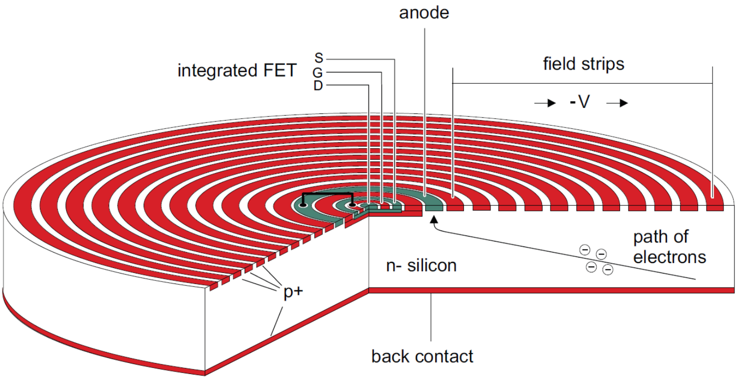
by applying a reverse bias voltage, it is possible to extend the depleted region, make the effective volume of the detector larger and increase the electric field to get faster charge collection times

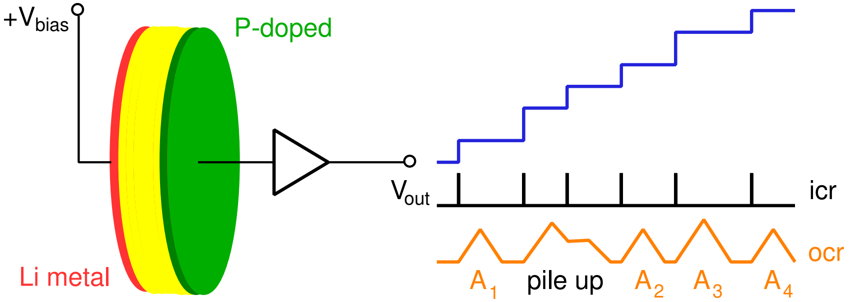
Silicon Drift Detector

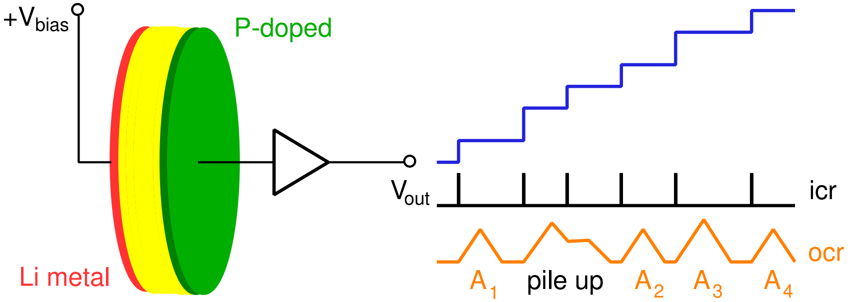
Same principle as intrinsic or p-i-n detector but much more compact and operates at higher temperatures



Relatively low stopping power is a drawback

Detector operation





output current is integrated into voltage pulses by a pre-amp, when maximum voltage is reached, output is optically reset

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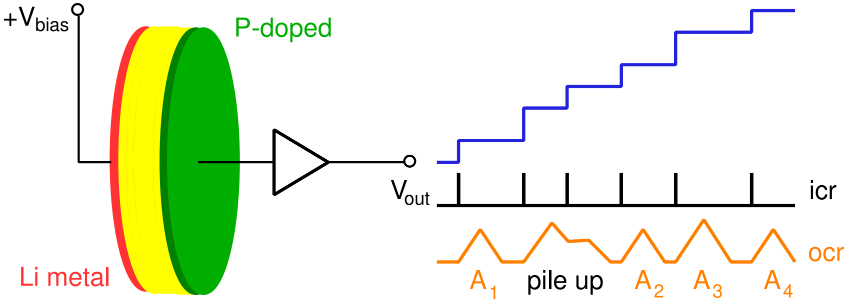

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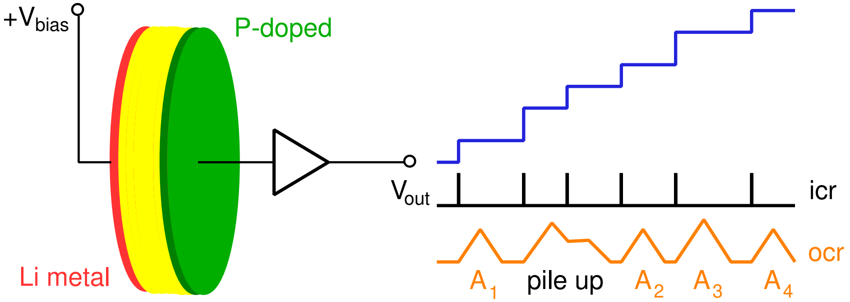

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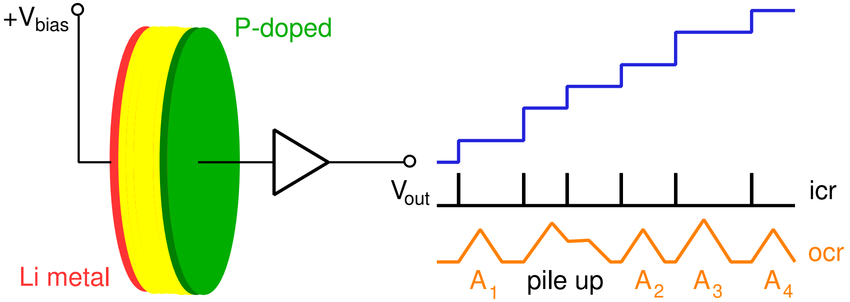

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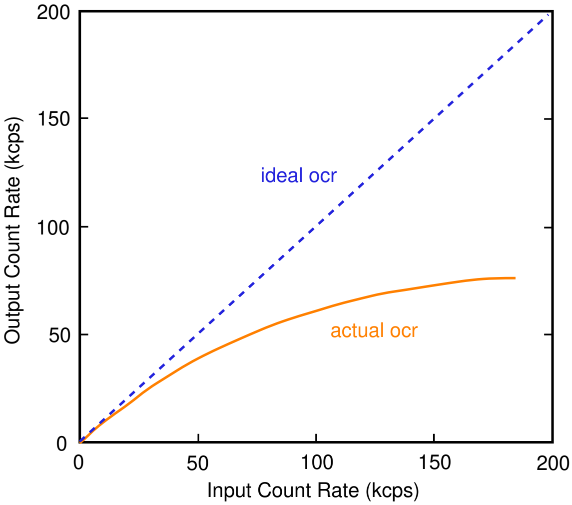
electronics outputs input count rate (icr), output count rate (ocr), and areas of integrated pulses (A_n)

Dead time correction



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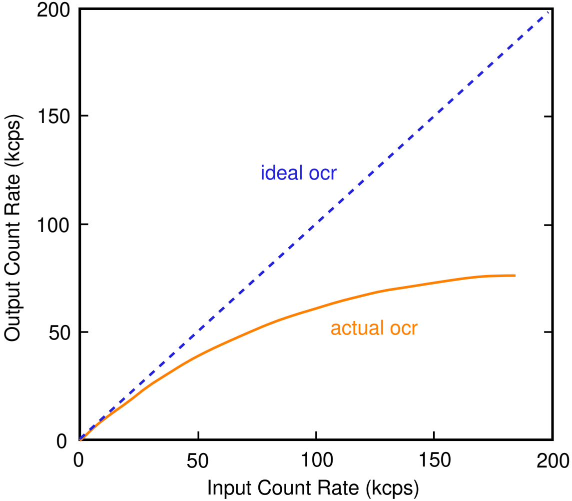

the output count rate is significantly lower than the input count rate and gets worse with higher photon rate

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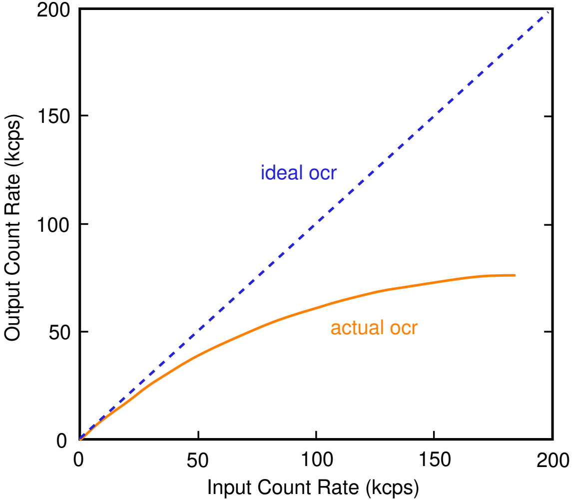

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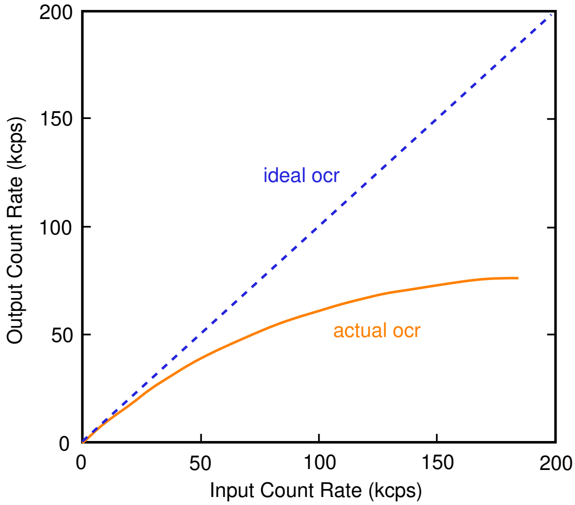

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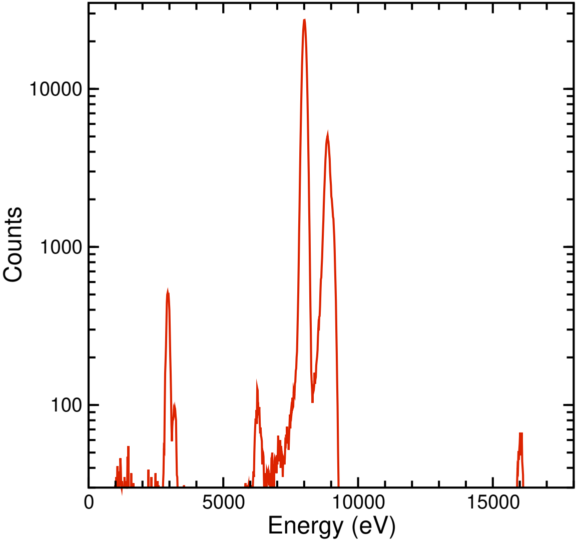
if dead time is too large, correction will not be accurate!

SDD spectrum



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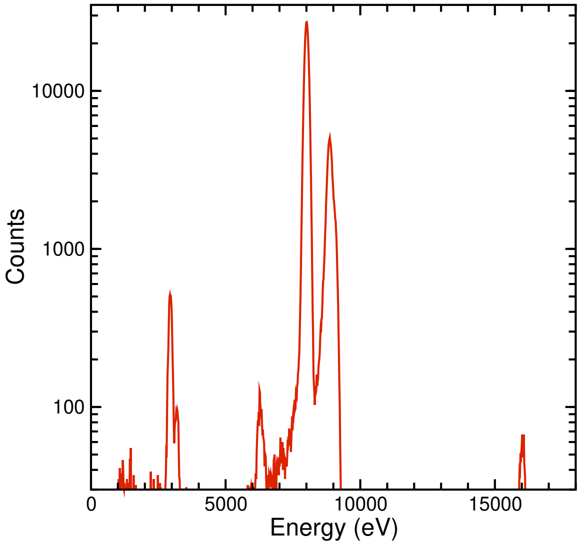

fluorescence spectrum of Cu foil in air using 9200 eV x-rays

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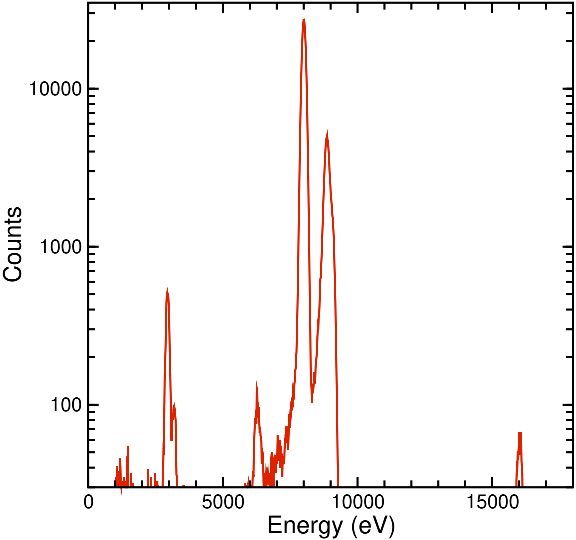

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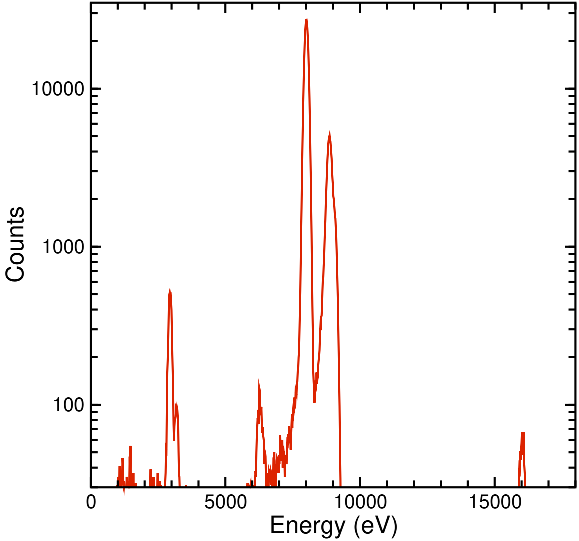

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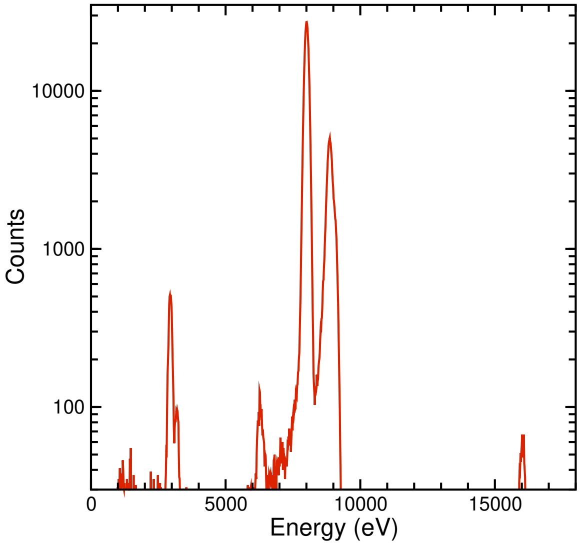

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a small amount of pulse pileup is visible near 16000 eV