Today's outline - September 09, 2024

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- HW #2

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  - Gas detectors
  - Scintillation counters
  - Solid state detectors
  - Area detectors

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Reading Assignment: Chapter 3.4

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Reading Assignment: Chapter 3.4

Homework Assignment #02:
Problems on Canvas
due Monday, September 16, 2024

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Reading Assignment: Chapter 3.4

Homework Assignment #02:
Problems on Canvas
due Monday, September 16, 2024

Homework Assignment #03:
Chapter 3: 1,3,4,6,8
due Monday, September 30, 2024

HW #02

1. Knowing that the photoelectric absorption of an element scales as the inverse of the energy cubed, calculate:

(a) the absorption coefficient at 10keV for copper when the value at 5keV is 1698.3 cm^{-1};

(b) The actual absorption coefficient of copper at 10keV is 1942.1 cm^{-1}, why is this so different than your calculated value?

2. A 30 cm long, ionization chamber, filled with 80% helium and 20% nitrogen gases at 1 atmosphere, is being used to measure the photon rate (photons/sec) in a synchrotron beamline at 12 keV. If a current of 10 nA is measured, what is the photon flux entering the ionization chamber?

3. A 5 cm deep ionization chamber is used to measure the fluorescence from a sample containing arsenic (As). Using any noble gases or nitrogen, determine a gas fill (at 1 atmosphere) for this chamber which absorbs at least 60% of the incident photons. How does this change if you are measuring the fluorescence from ruthenium (Ru)?

HW #02

4. Calculate the critical angle of reflection of 10 keV and 30 keV x-rays for:

(a) A slab of glass (SiO_2);

(b) A thick chromium mirror;

(c) A thick platinum mirror.

(d) If the incident x-ray beam is 2 mm high, what length of mirror is required to reflect the entire beam for each material?

5. Calculate the fraction of silver (Ag) fluorescence x-rays which are absorbed in a 1 mm thick silicon (Si) detector and the charge pulse expected for each absorbed photon. Repeat the calculation for a 1 mm thick germanium (Ge) detector.

APS upgrade

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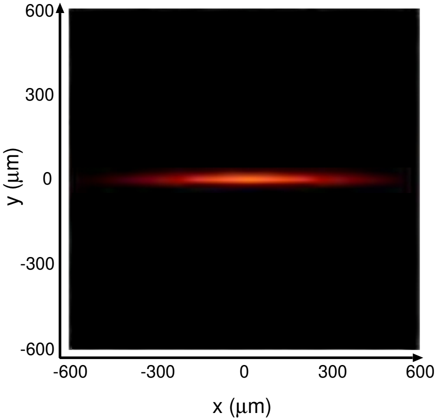

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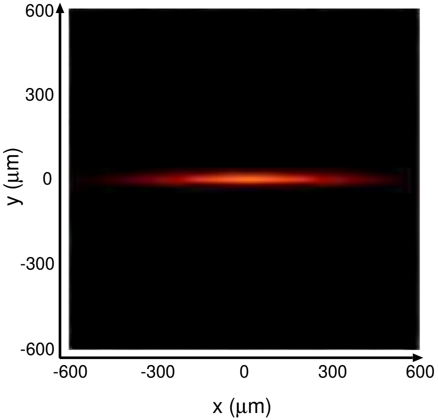

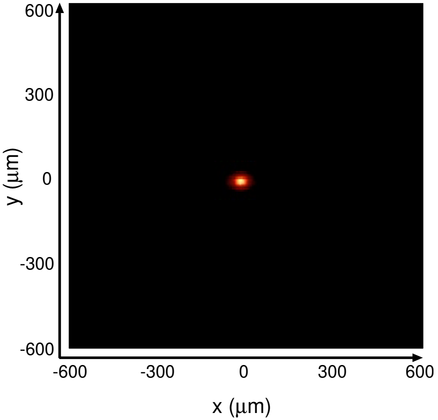

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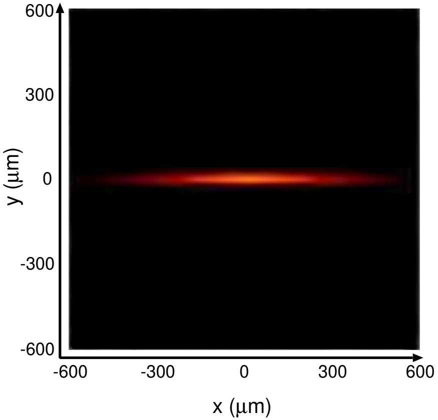

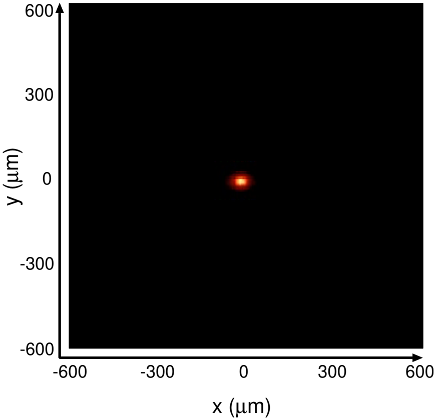

The beam will be nearly square and there will be much more coherence from the undulators

APS-U magnet layout

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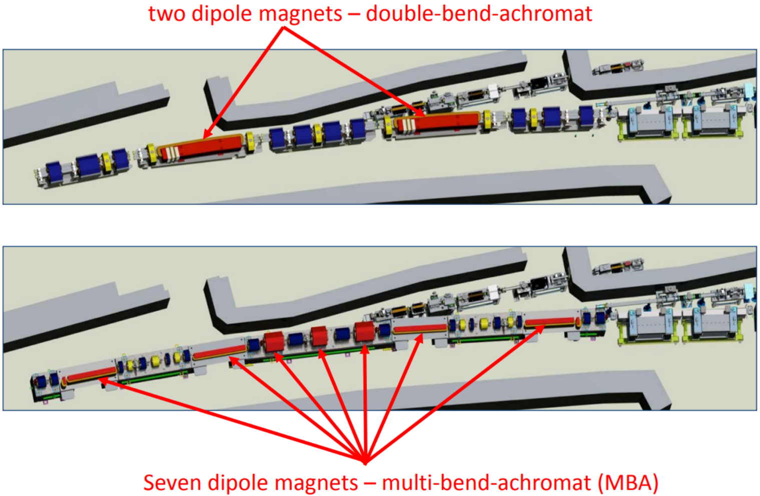

APS-U undulator performance

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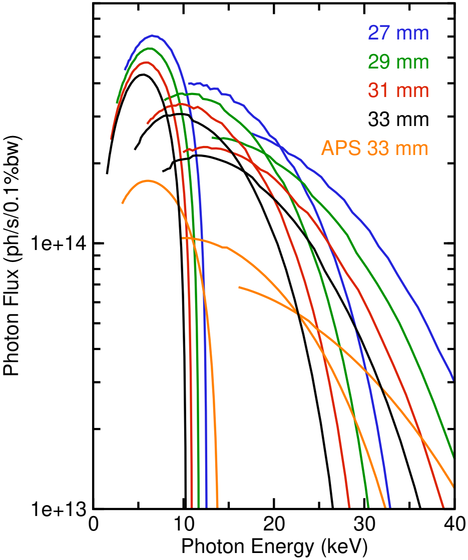
Since MRCAT's science is primarily flux driven, the goal will be to replace the 2.4m undulator with one that outperforms the current 33mm period but with only modest increase in power.



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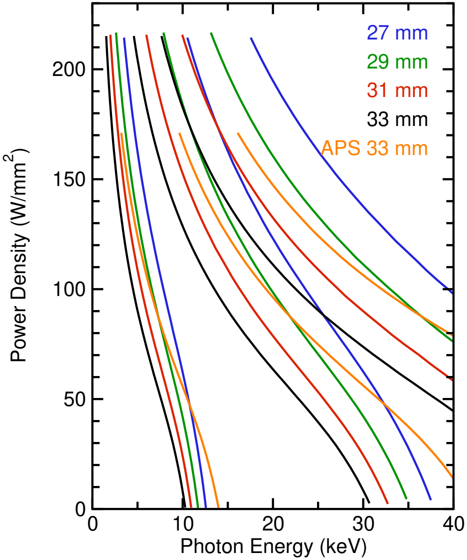
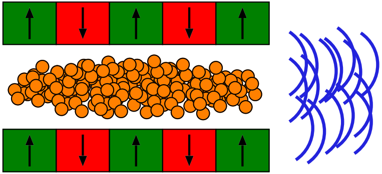
The APS-U is an example of a "4^{th}" generation synchrotron source



Free electron laser



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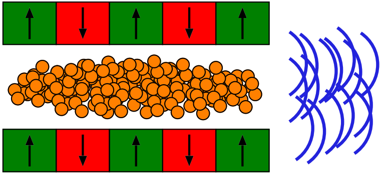

Initial electron cloud, each electron emits coherently but independently

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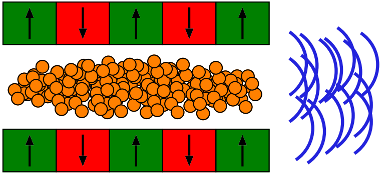

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Over course of 100 m, electric field of photons, feeds back on the electron bunch

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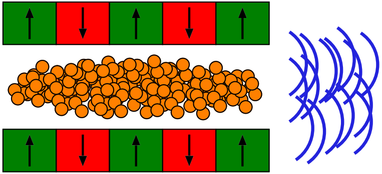

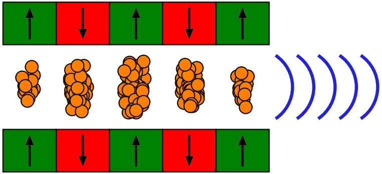

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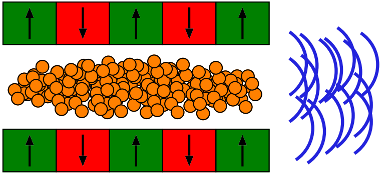

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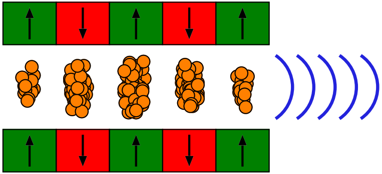
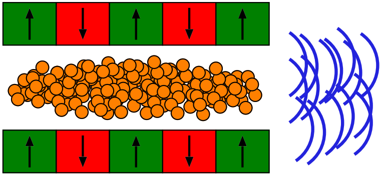


Microbunches form with period of FEL (and radiation in electron frame)

Free electron laser



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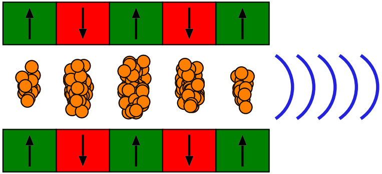

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Each microbunch emits coherently with neighboring ones

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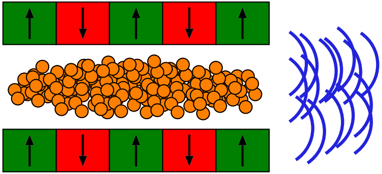

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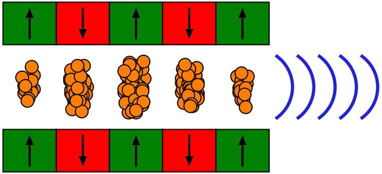

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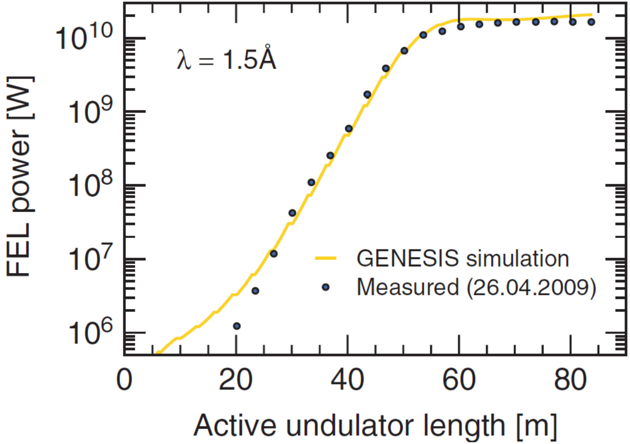
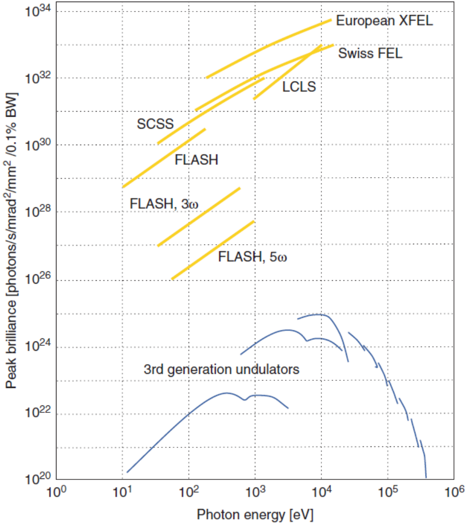
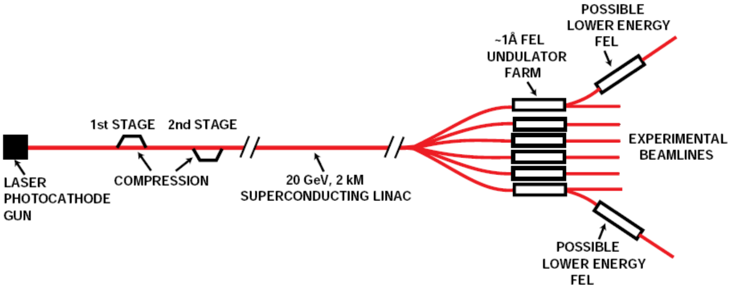
Again, an alternative way to view this is that the pulse train from a 100m long undulator is long enough in time to produce a monochromatic and coherent frequency distribution when Fourier Transformed

FEL performance





FEL layout


POSSIBLE
LOWER ENERGY
FEL
~1Å FEL
UNDULATOR
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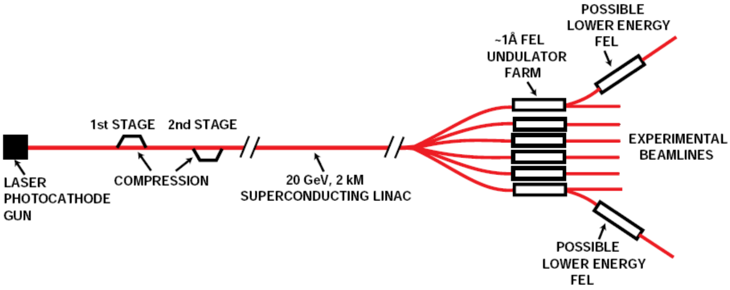

An FEL has a single accelerator whose electron beam is shunted sequentially through different undulators and end stations

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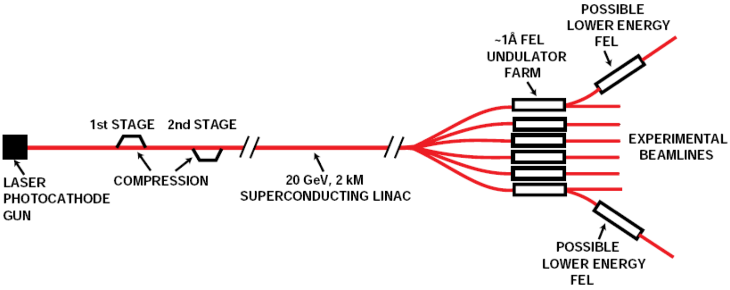

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The single pass of the electron beam permits a very low emittance to be achieved and thus higher coherence

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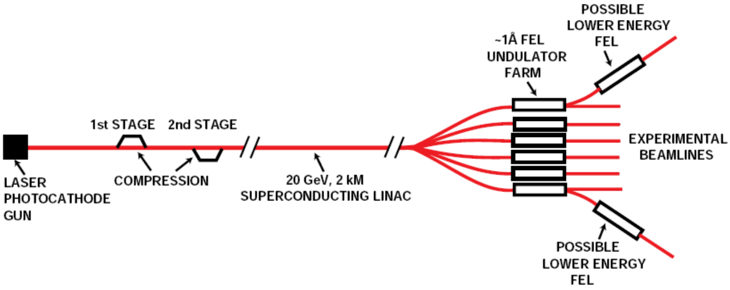

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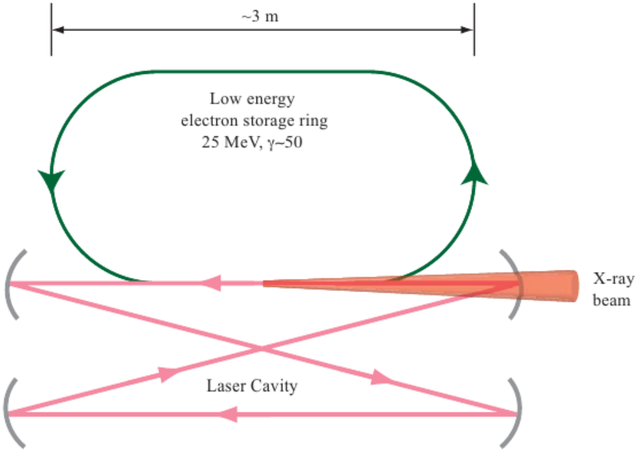
The high brightness usually results in destruction of the sample during the illumination, thus the need for multiple samples and multiple shot experiments

Compact sources



Small low energy, high current electron ring

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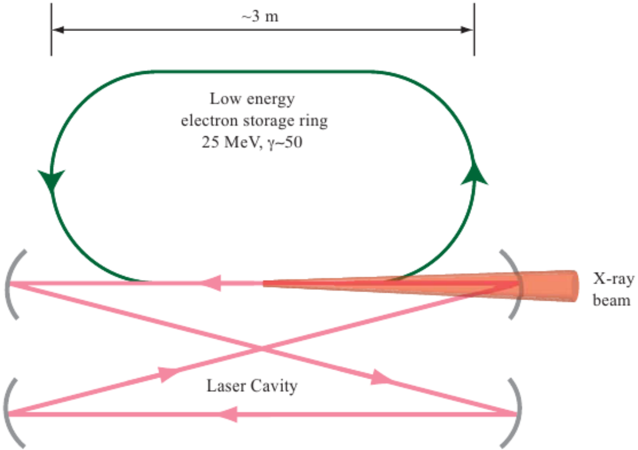

Small low energy, high current electron ring

Straight section intersects a laser cavity

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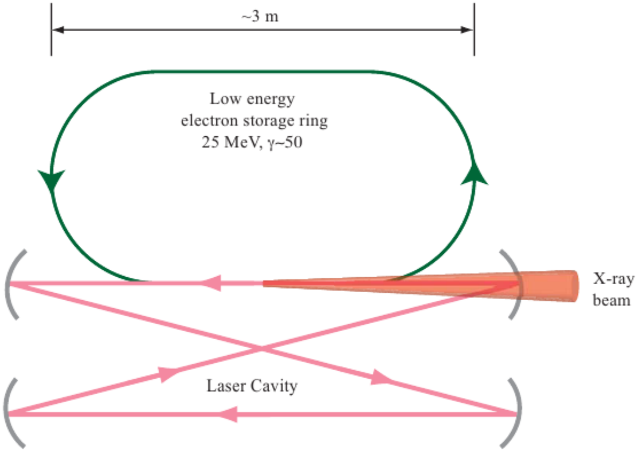

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Undulator is the standing wave of the laser, alternatively can consider this an inverse Compton effect

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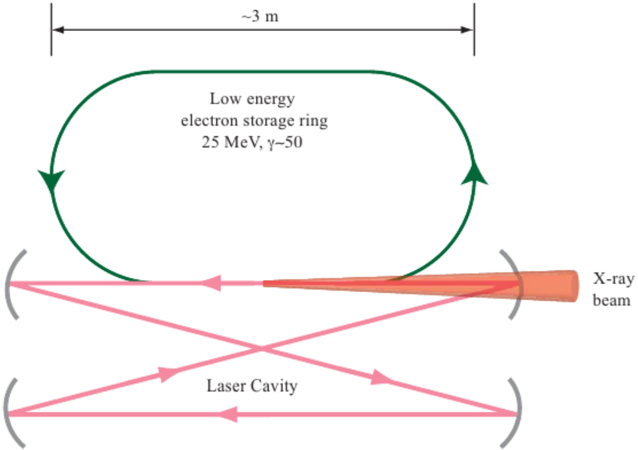

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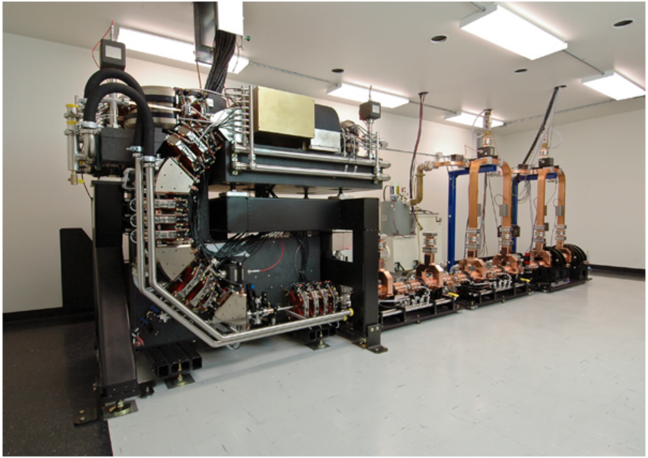

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Cost ∼\$5 M plus ∼\$1 M per year service contract

Types of X-ray Detectors

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Gas detectors

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Gas detectors

- Ionization chamber

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Charge coupled device detectors

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Charge coupled device detectors

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Solid state detectors

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Charge coupled device detectors

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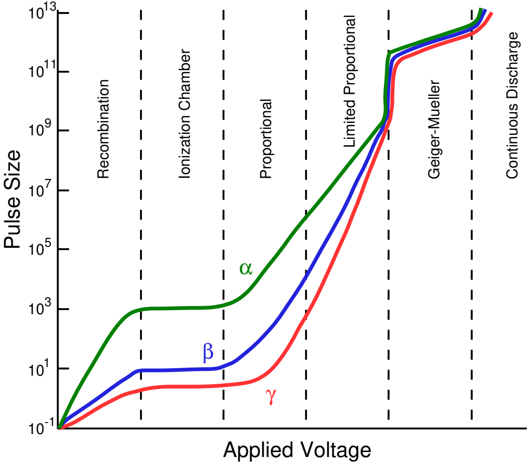
Gas Detectors

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



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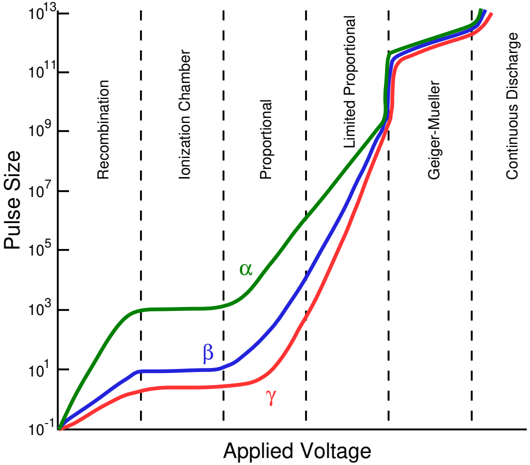
The most interesting are the ionization, proportional, and Geiger-Muller



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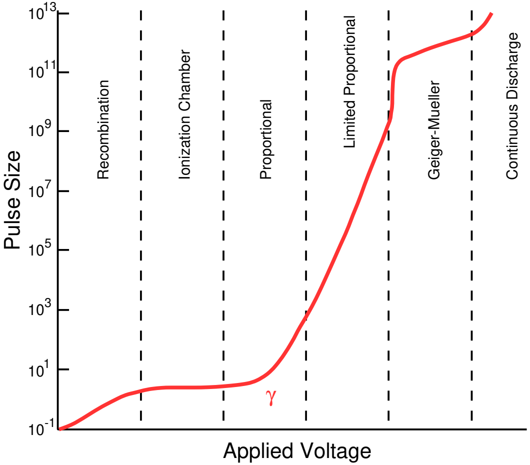

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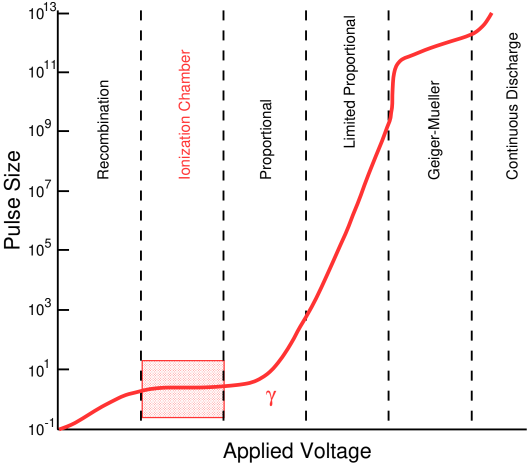
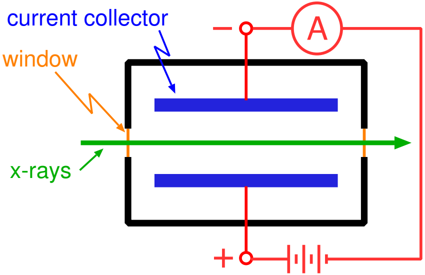
The most useful regime is the ionization region where the output pulse is independent of the applied voltage over a wide range



Ionization Chamber

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



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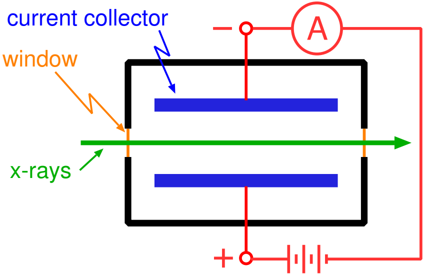

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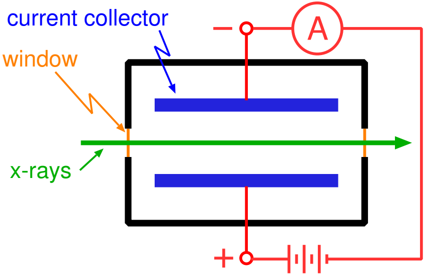

- Closed (or sealed) chamber of length L with gas mixture $\mu = \sum \rho_i \mu_i$
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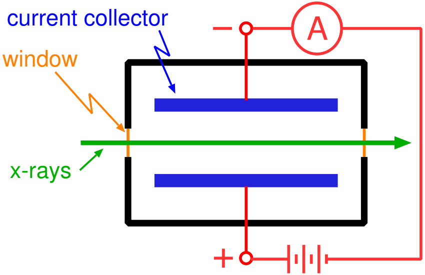

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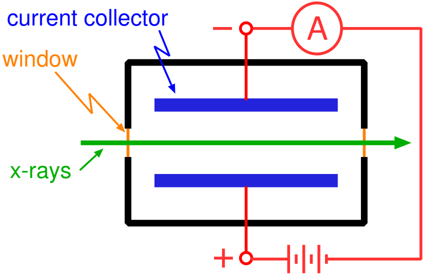

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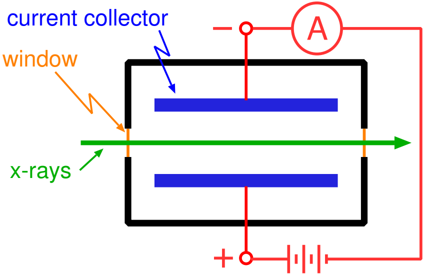

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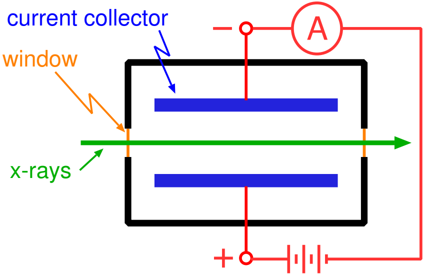

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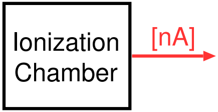
- When x-ray interacts with gas atom, photoionized electrons swept rapidly to positive electrode and current (nano Amperes) is measured.
- Count rates up to 10^{11} photons/s/cm^3
- 22-41 eV per electron-ion pair (depending on the gas) makes this useful for quantitative measurements.

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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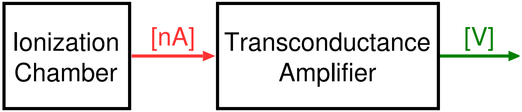

the tiny current is fed into an sensitive amplifier with gains of up to 10^{10} which outputs a voltage signal of 1-10 V that tracks the input with an adjustable time constant

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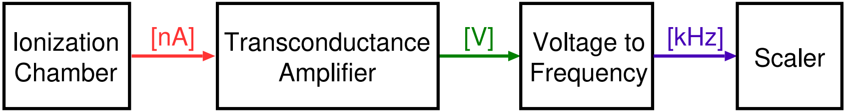

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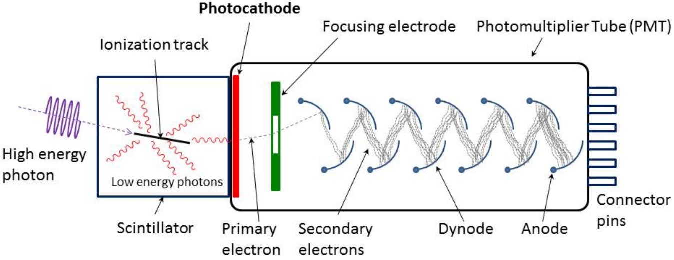
the digital pulse train is counted by a scaler for a user-definable length of time

Scintillation detector

Useful for photon counting experiments with rates less than $10^4/\text{s}$



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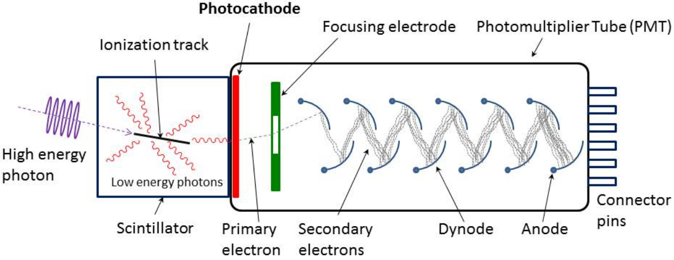

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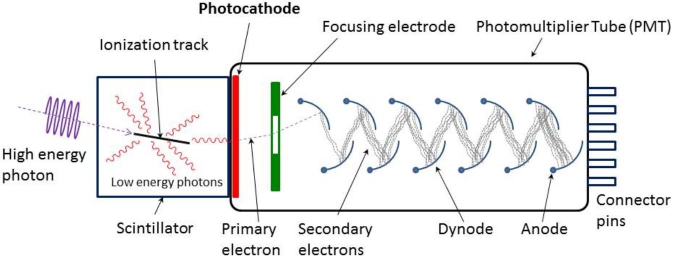

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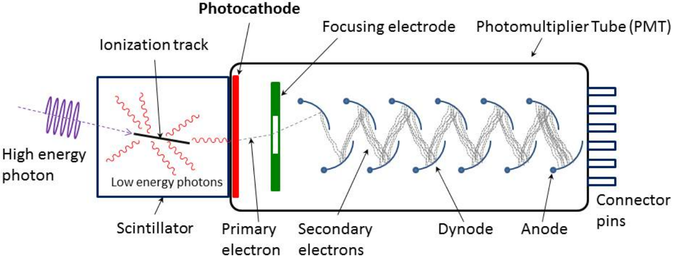

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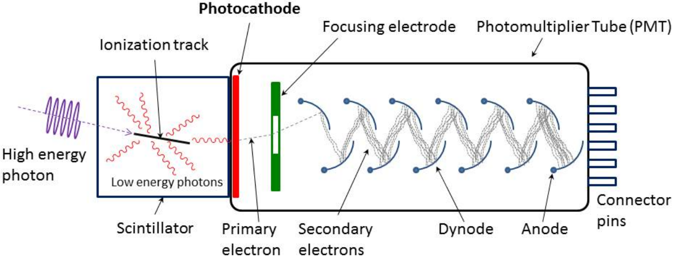

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- Output voltage pulse is proportional to initial x-ray energy.

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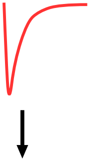

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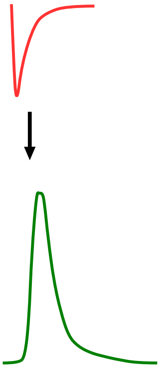

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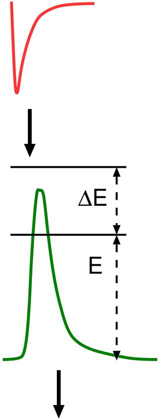

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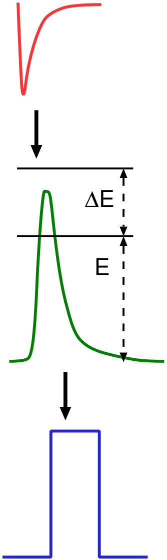

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if the voltage pulse falls within the discriminator window, a short digital pulse is output from the discriminator and into a scaler for counting

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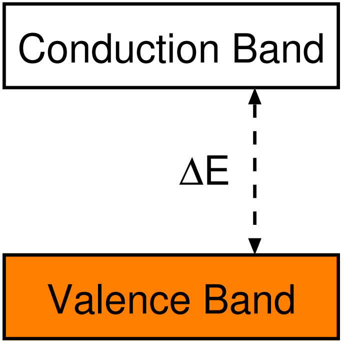

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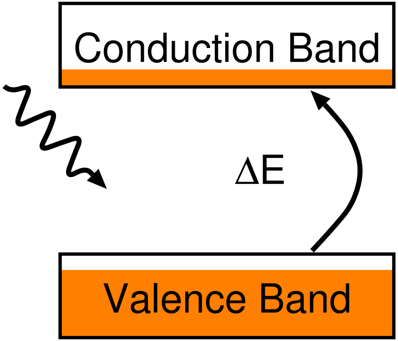

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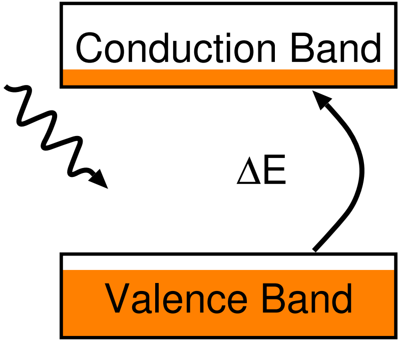

because of the small energy required to produce an electron-hole pair, one x-ray photon will create many and its energy can be detected with very high resolution

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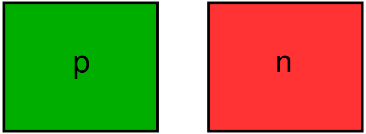

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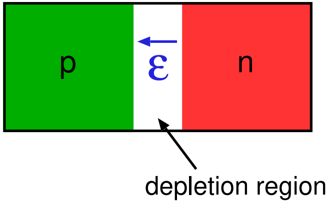

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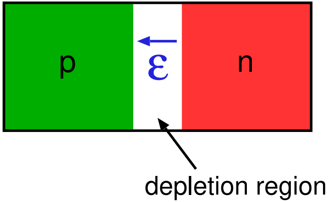

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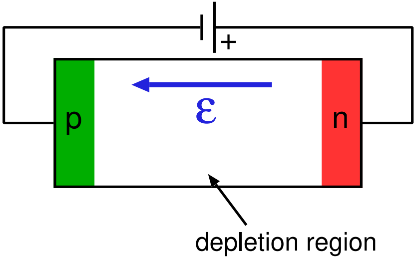
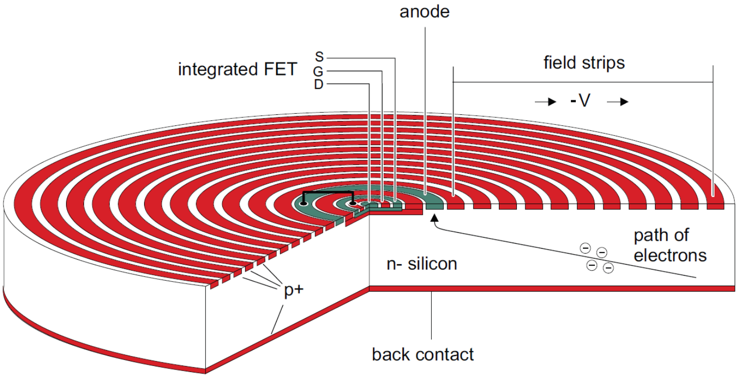


by applying a reverse bias voltage, it is possible to extend the depleted region, make the effective volume of the detector larger and increase the electric field to get faster charge collection times

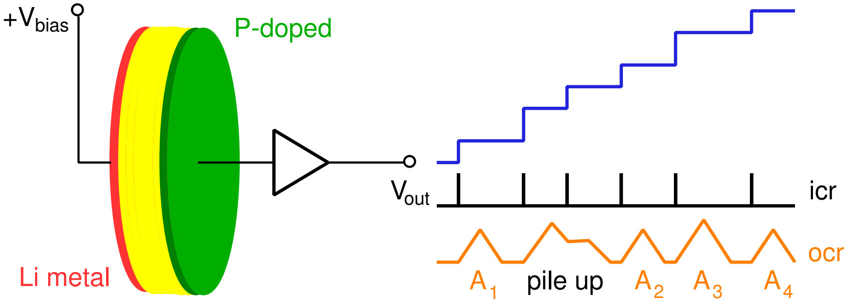
Silicon Drift Detector

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



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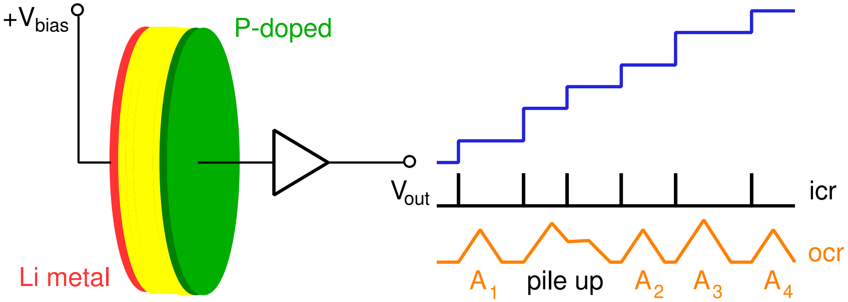

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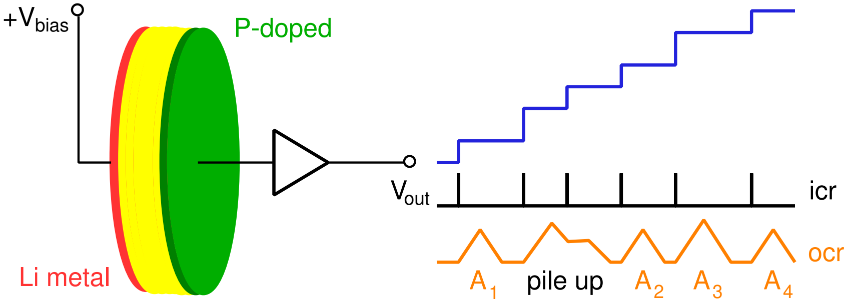

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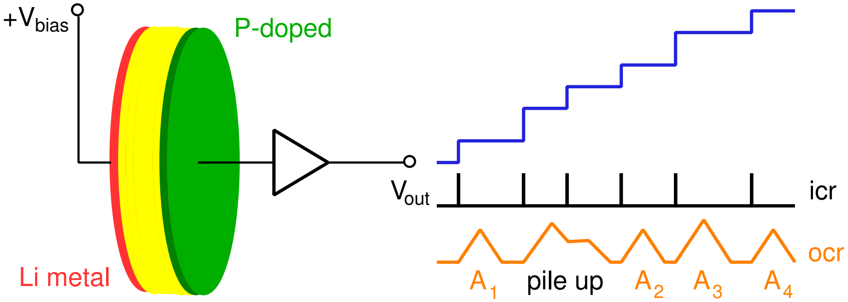

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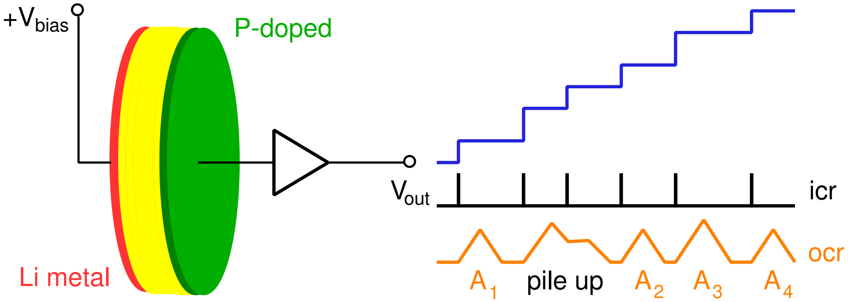

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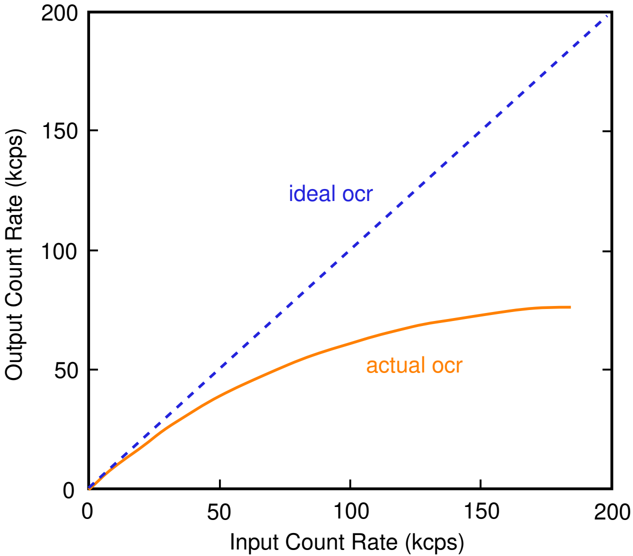
electronics outputs input count rate (icr), output count rate (ocr), and areas of integrated pulses (A_n)

Dead time correction



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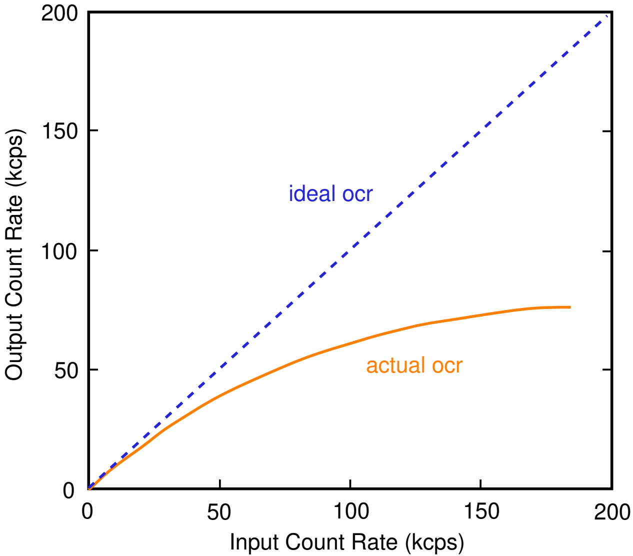

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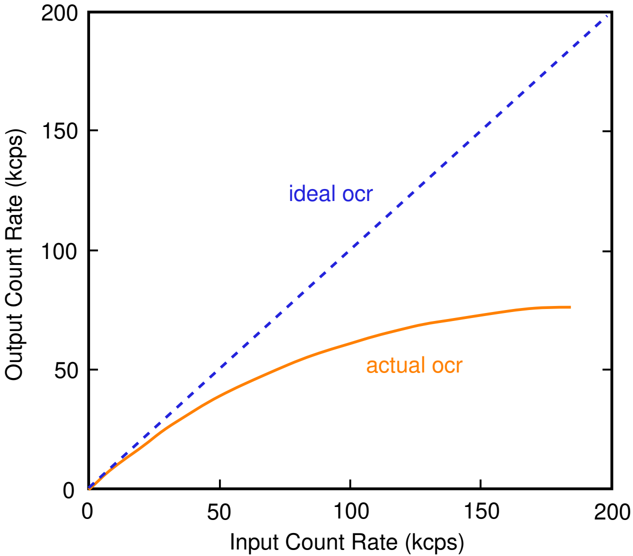

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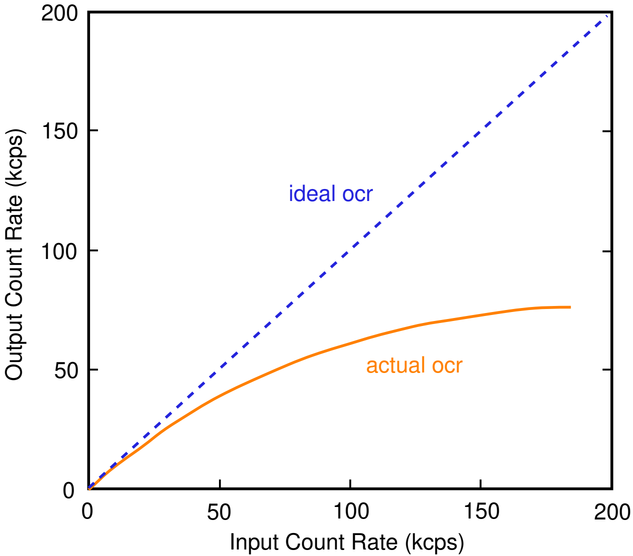

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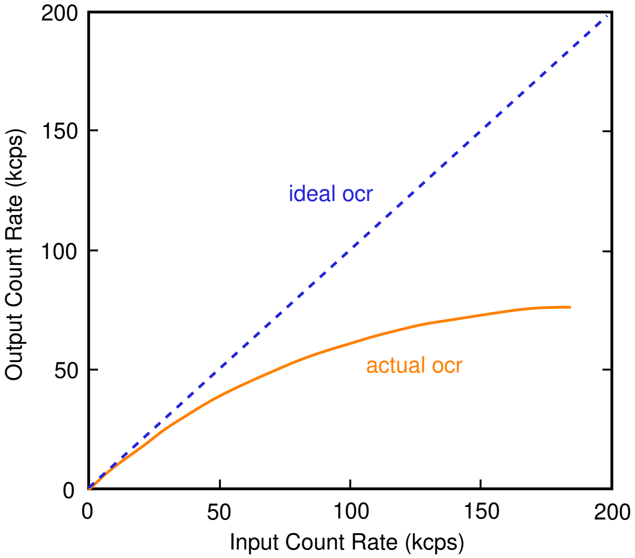

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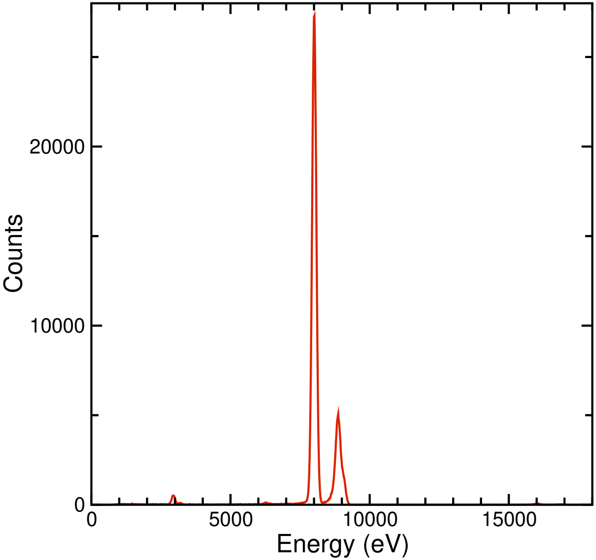
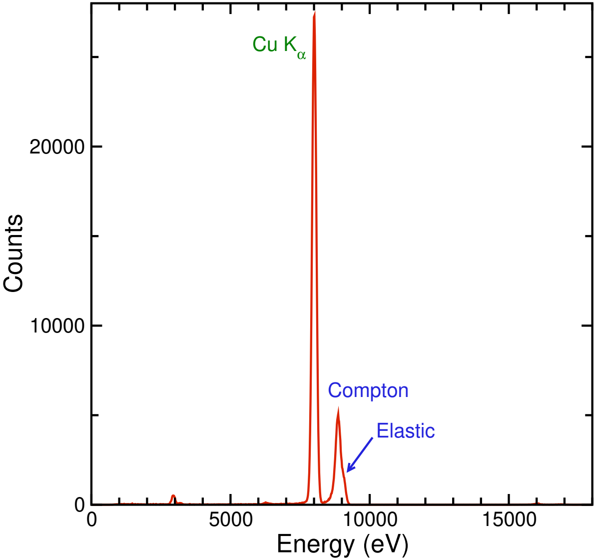
When dead time is too large, correction will not be accurate!

SDD spectrum



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

SDD spectrum



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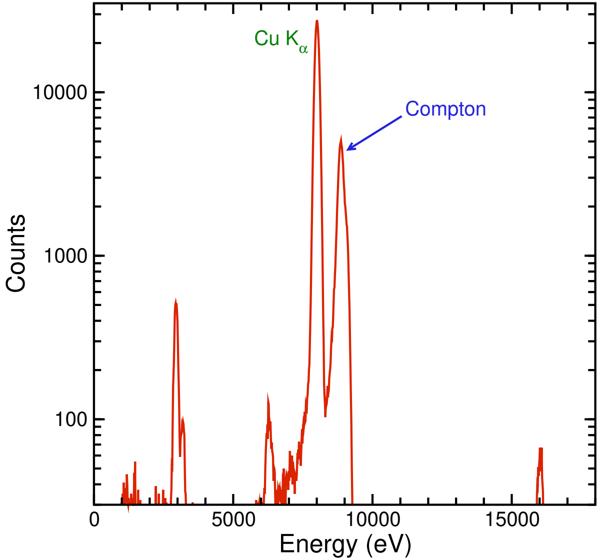

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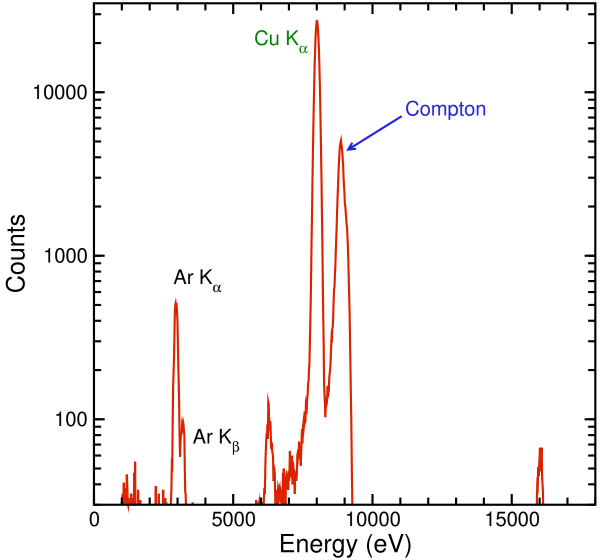

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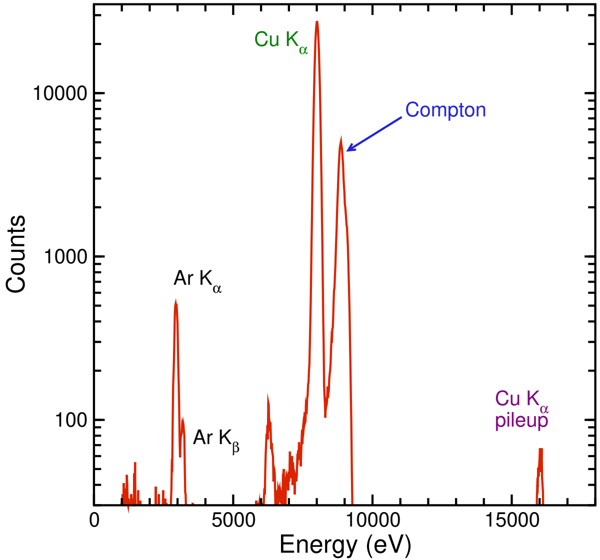

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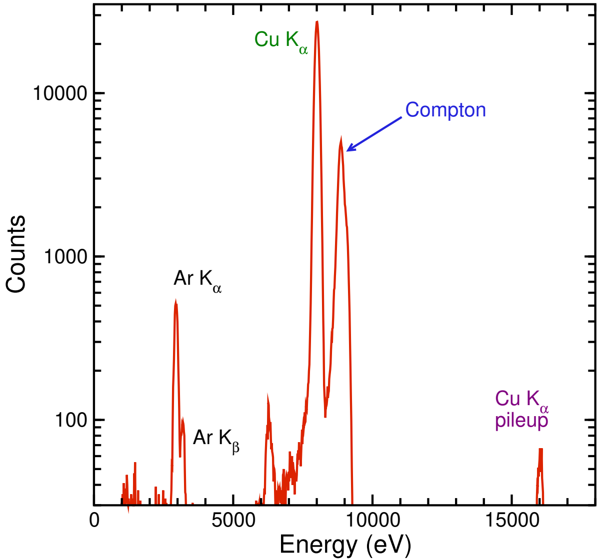

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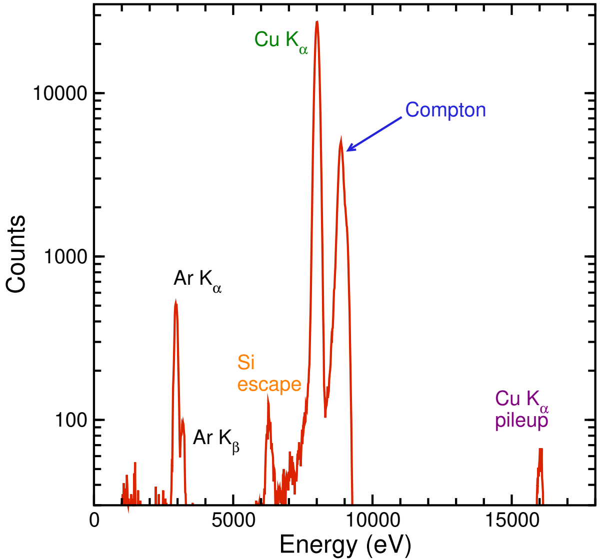

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Si escape peak
$E_{esc} = 8046 - 1839 = 6207$ eV

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The most advanced detectors can easily cost over a million dollars!

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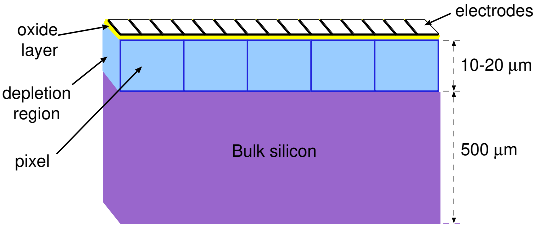

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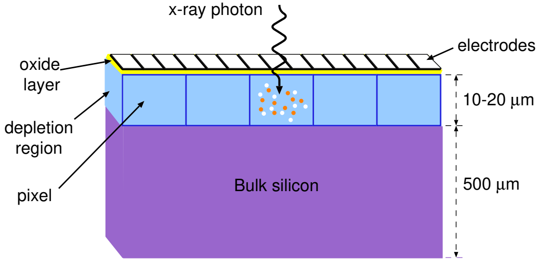

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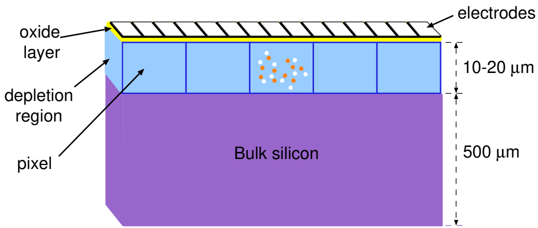

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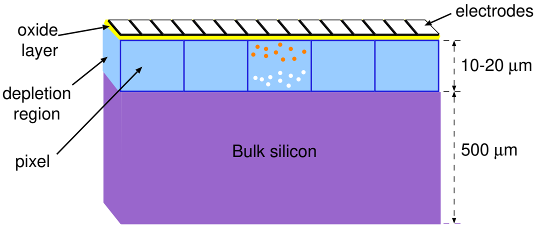

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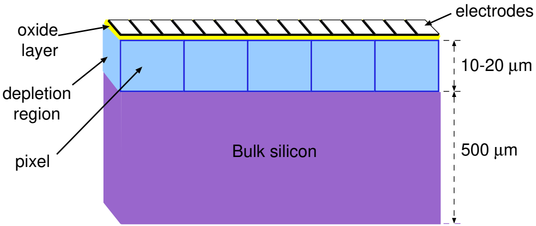

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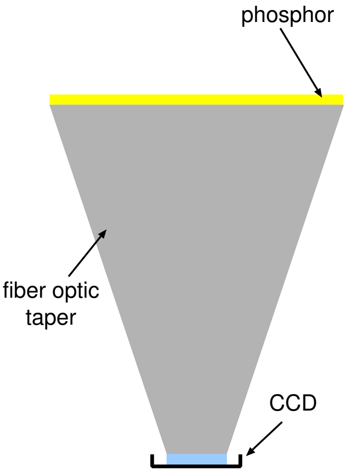
The CCD is coupled optically to a fiber optic taper which ends at a large phosphor



CCD detectors - indirect

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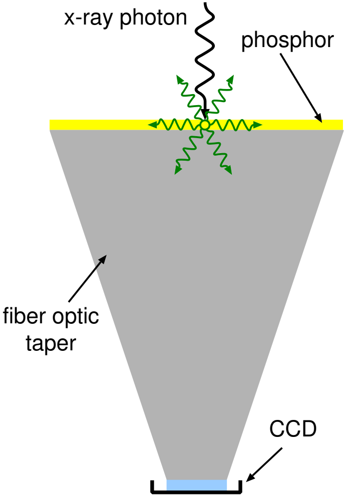
When an x-ray is absorbed at the phosphor, visible light photons are emitted in all directions



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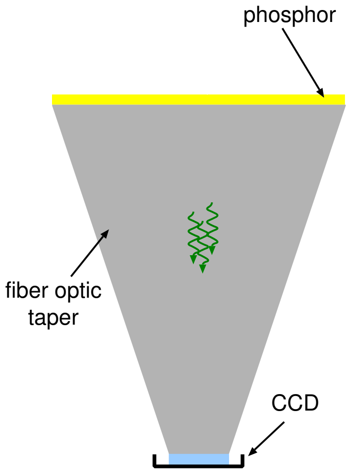

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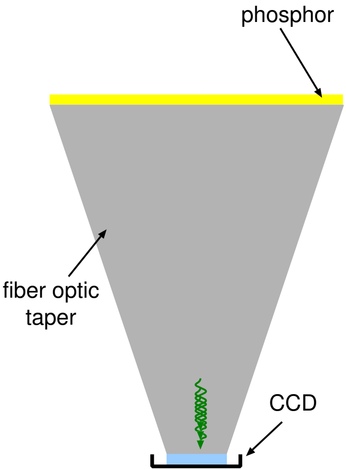

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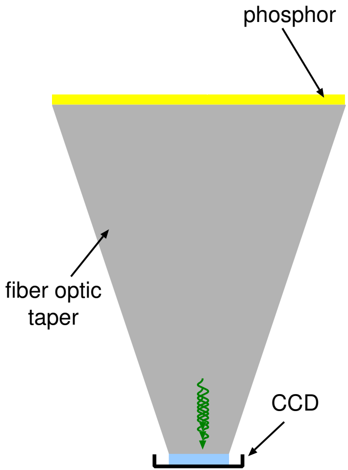
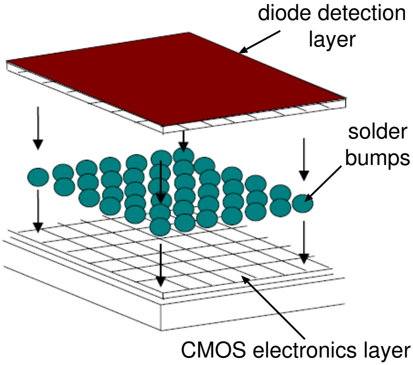
Pixel sizes are usually rather large (50 μm $\times$ 50 μm)



Pixel array detectors - schematic

The Pixel Array Detector combines area detection with on-board electronics for fast signal processing

Pixel array detectors - schematic



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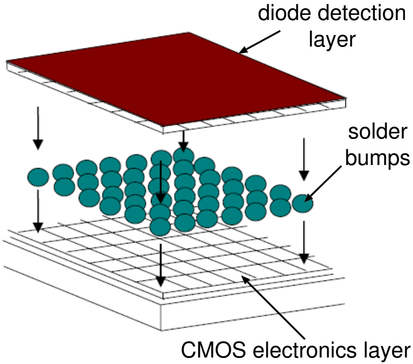

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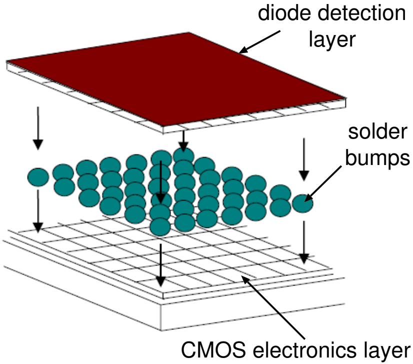
The diode layer absorbs x-rays and the electron-hole pairs are immediately swept into the CMOS electronics layer

Pixel array detectors - schematic



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This permits fast processing and possibly energy discrimination on a per-pixel level

Pixel array detectors - Pilatus

Pixel array detector with 1,000,000 pixels.

Each pixel has energy resolving capabilities & high speed readout.

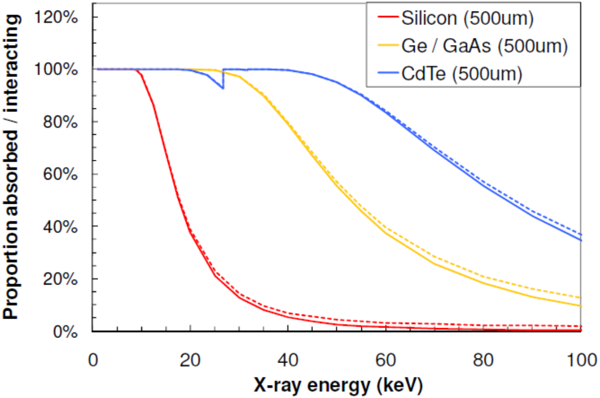
Silicon sensor limits energy range of operation.

from Swiss Light Source

High energy solutions

One of the major problems with pixel array detectors and SDDs is the low absorption cross section at high energies

High energy solutions



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A solution is to use a semiconductor other than Si, for example Ge, GaAs or, CdTe

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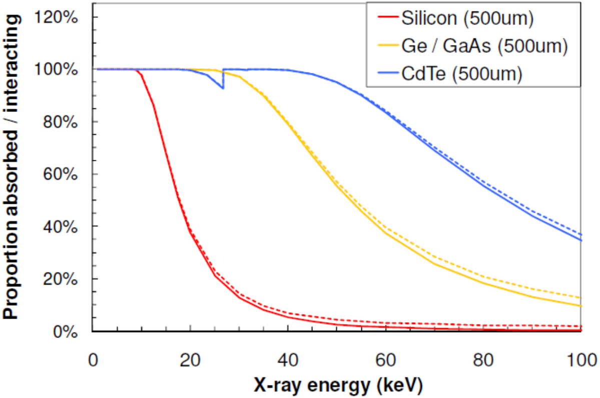

One of the major problems with pixel array detectors and SDDs is the low absorption cross section at high energies

A solution is to use a semiconductor other than Si, for example Ge, GaAs or, CdTe

The absorption can be significantly enhanced with these higher Z elements while maintaining good energy discrimination capabilities.