Today's Outline - September 12, 2016

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Reading Assignment: Chapter 3.4

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- Detectors
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- Boundary conditions at an interface
- The Fresnel equations
- Reflectivity and Transmittivity
- Normalized q-coordinates

Reading Assignment: Chapter 3.4

Homework Assignment #02:
Problems to be provided
due Monday, September 26, 2016

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 characteristic 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.

Types of X-ray Detectors

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Gas detectors

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Scintillation counters

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Charge coupled device detectors

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- Ionization chamber

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Solid state detectors

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Solid state detectors

- Intrinsic semiconductor
- P-I-N junction
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Charge coupled device detectors

- Indirect

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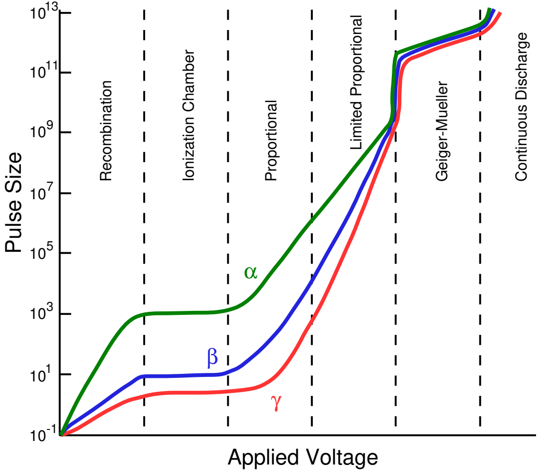
Charge coupled device detectors

- Indirect
- Direct coupled

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



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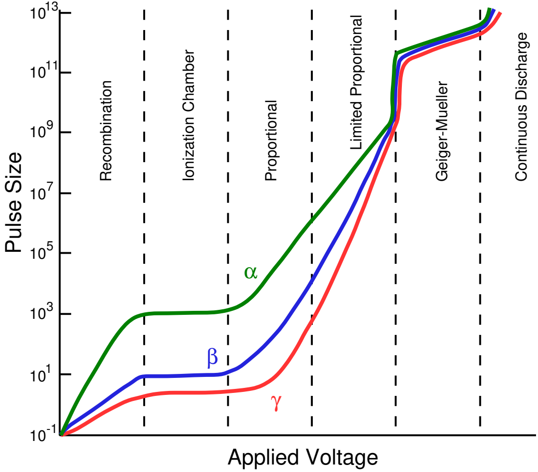
The most interesting are the ionization, proportional, and Geiger-Muller



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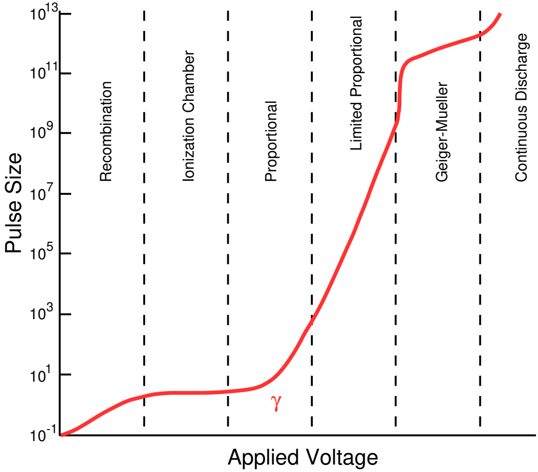

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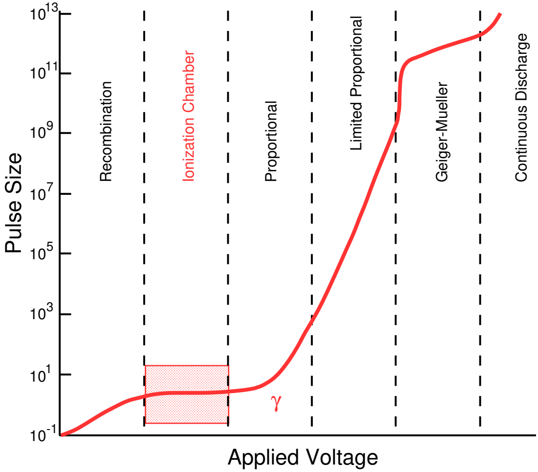
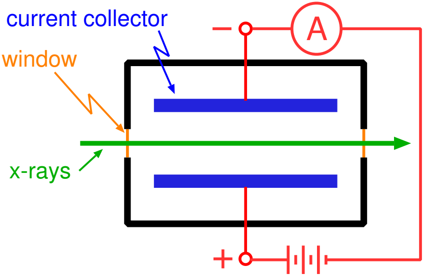
The most useful regime is the ionization region where the output pulse is independent of the applied voltage over a wide range



Ionization Chamber

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



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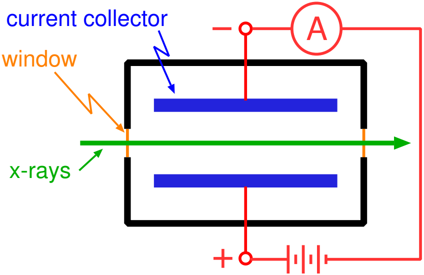

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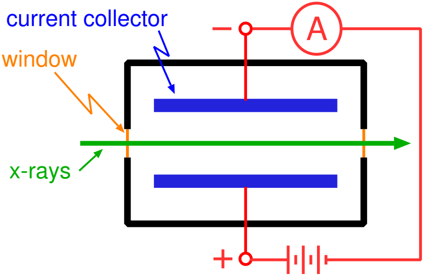

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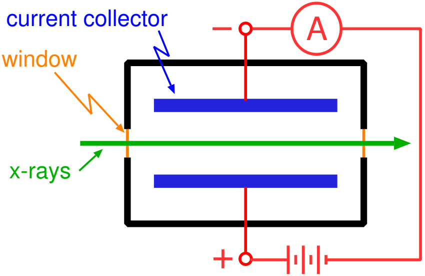

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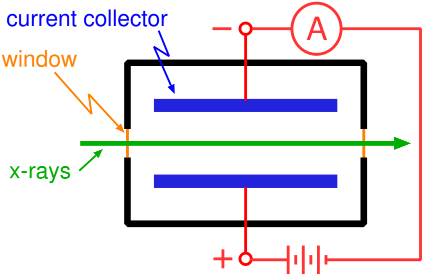

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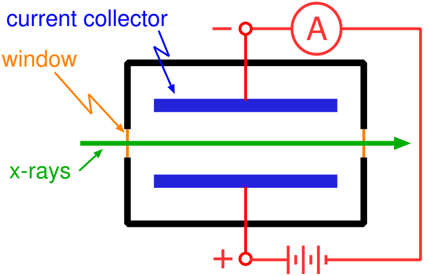

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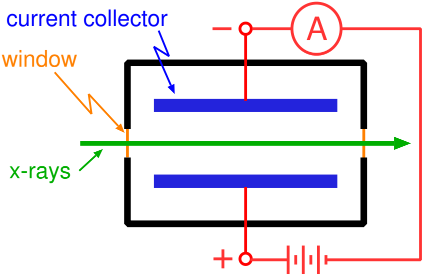

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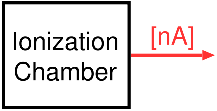
- 22-41 eV per electron-ion pair (depending on the gas) makes this useful for quantitative measurements.

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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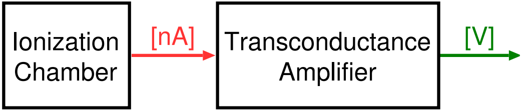

the tiny current is fed into an sensitive amplifier with gains of up to 10^{10} which outputs a voltage signal of 1-10 V that tracks the input with an adjustable time constant

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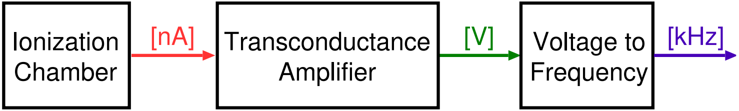

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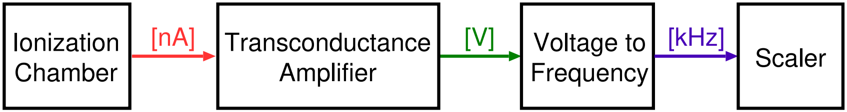

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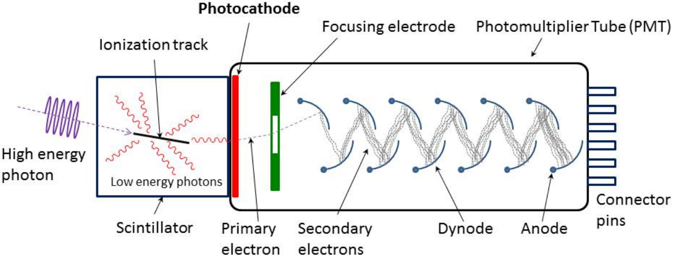
the digital pulse train is counted by a scaler for a user-definable length of time

Scintillation detector

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



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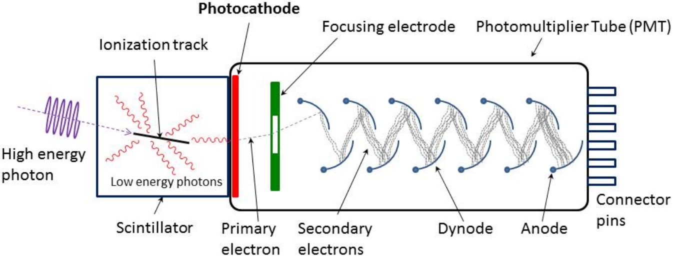

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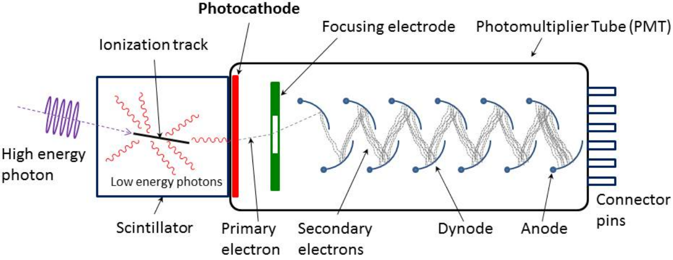

- NaI(Tl), Yttrium Aluminum Perovskite (YAP) or plastic which, absorb x-rays and fluoresce in the visible spectrum.
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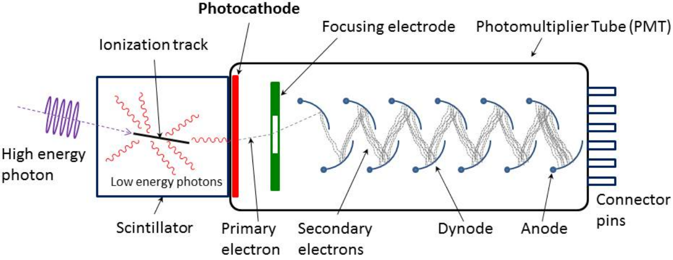

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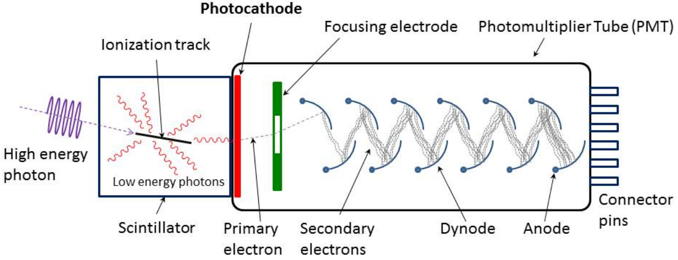

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- Output voltage pulse is proportional to initial x-ray energy.

Counting a scintillator pulse

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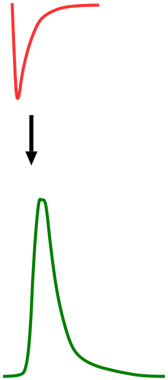
Counting a scintillator pulse



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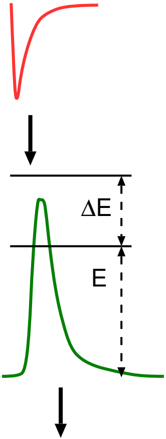

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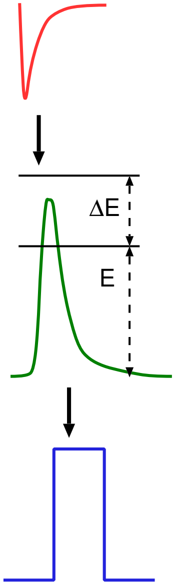

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if the voltage pulse falls within the discriminator window, a short digital pulse is output from the discriminator and into a scaler for counting

Solid state detectors

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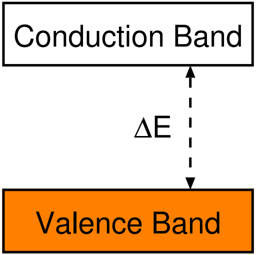

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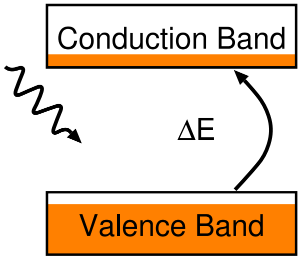
when a photon is absorbed by the semiconductor, it promotes electrons from the valence to the conduction band creating an electron-hole pair



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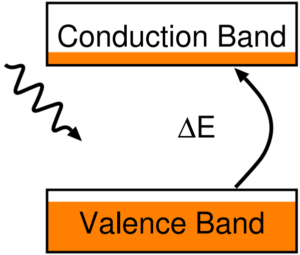

because of the small energy required to produce an electron-hole pair, one x-ray photon will create many and its energy can be detected with very high resolution

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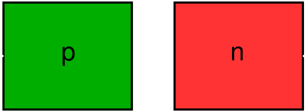

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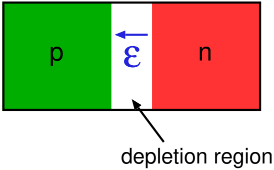

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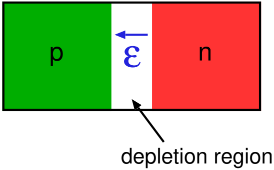

this region is called an intrinsic region and is the only place where an absorbed photon can create electron-hole pairs and have them be swept to the p and n sides, respectively

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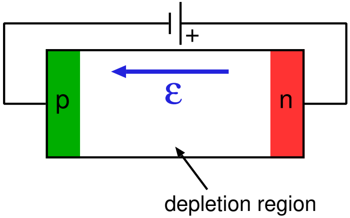

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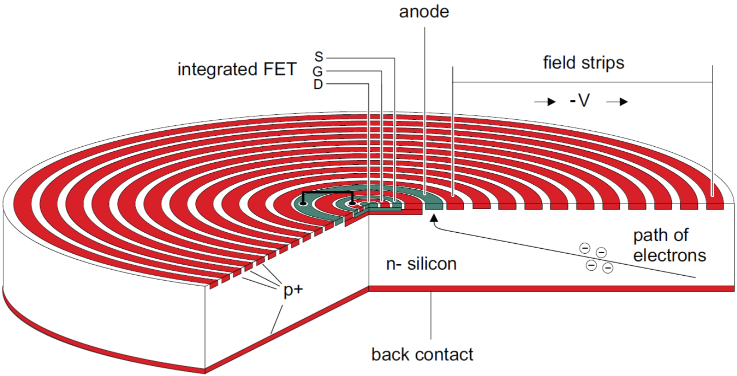
by applying a reverse bias voltage, it is possible to extend the depleted region, make the effective volume of the detector larger and increase the electric field to get faster charge collection times

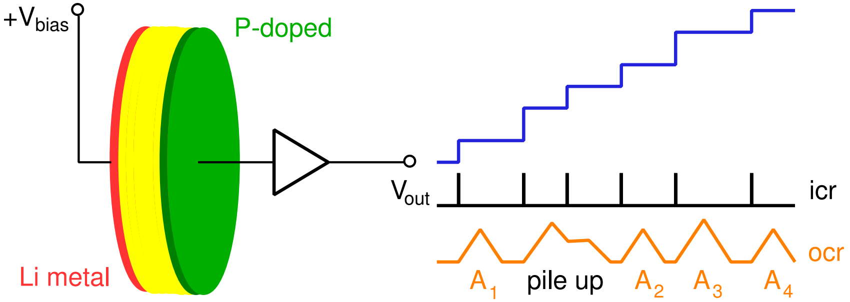
Silicon Drift Detector

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



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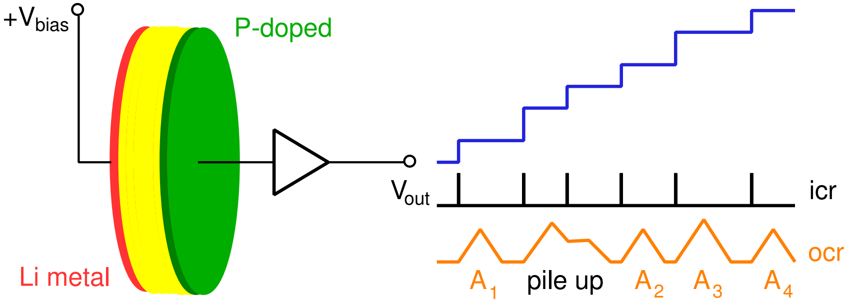

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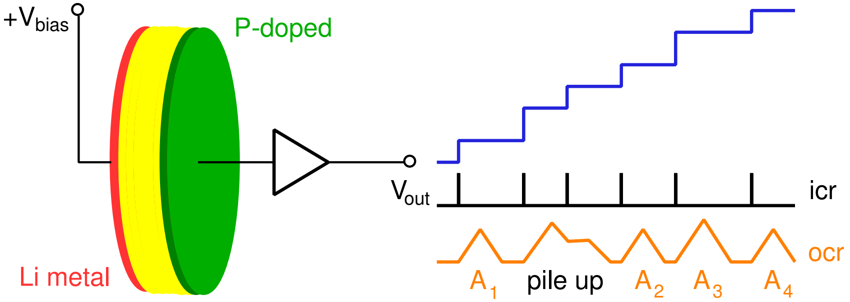

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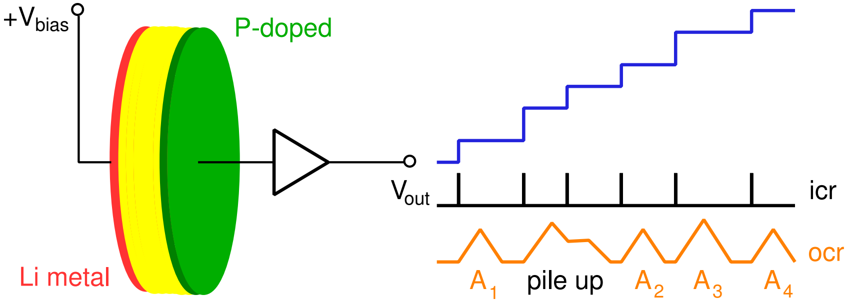

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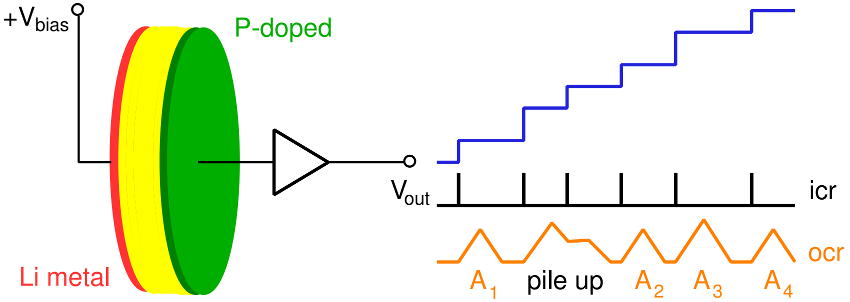

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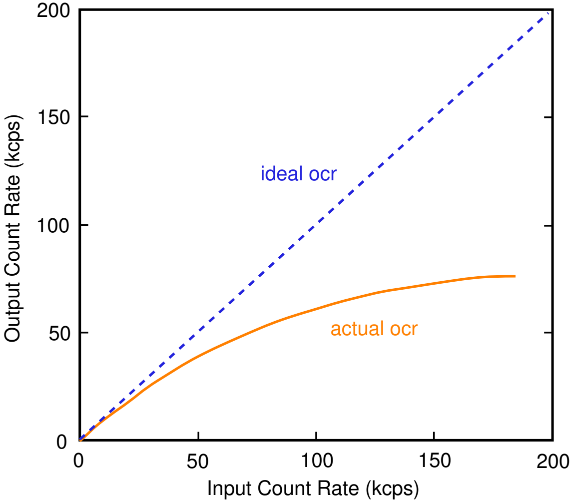
electronics outputs input count rate (icr), output count rate (ocr), and areas of integrated pulses (A_n)

Dead time correction



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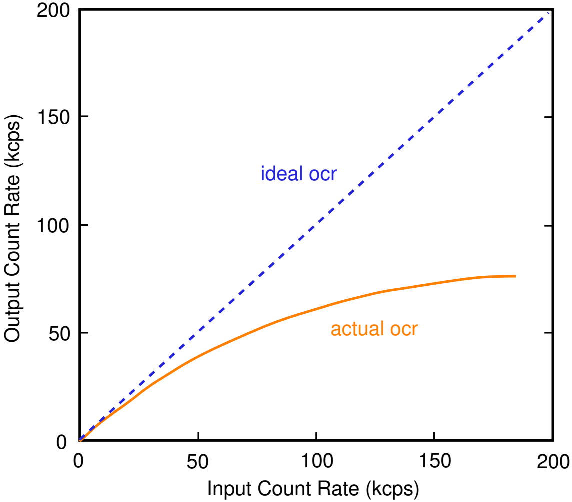

the output count rate is significantly lower than the input count rate and gets worse with higher photon rate

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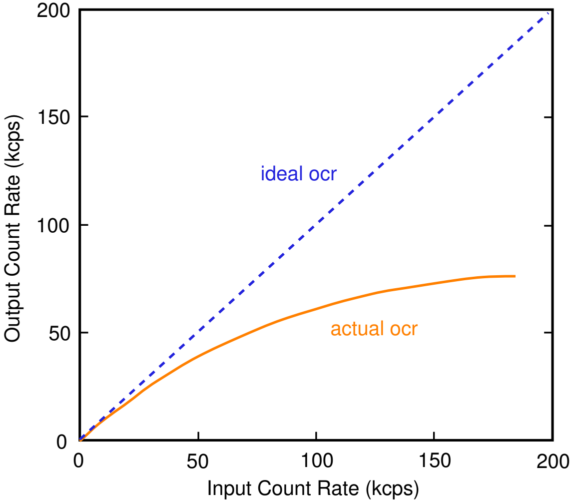

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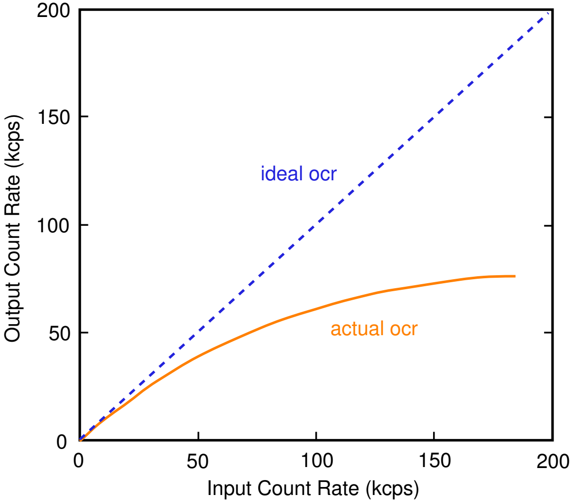

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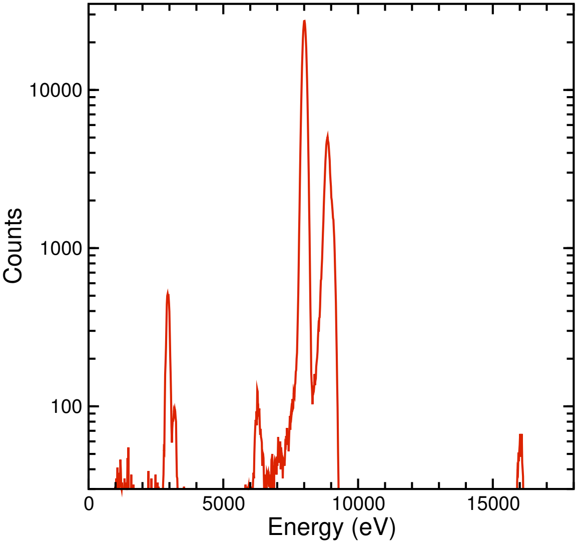
if dead time is too large, correction will not be accurate!

SDD spectrum



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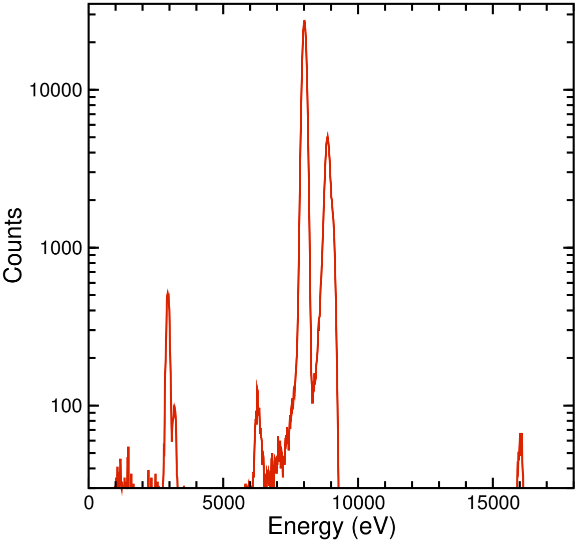

fluorescence spectrum of Cu foil in air using 9200 eV x-rays

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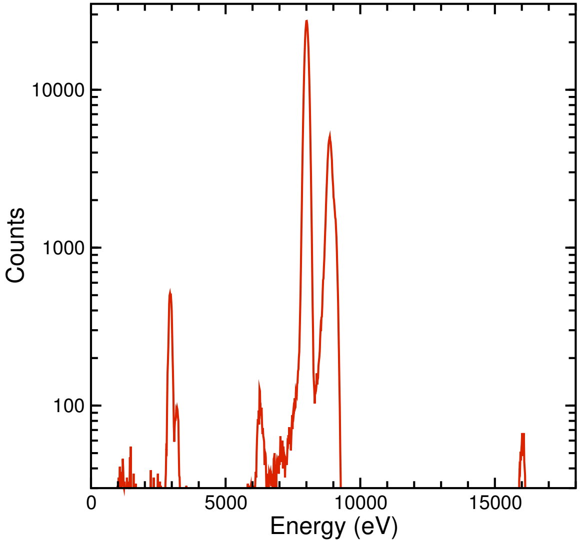

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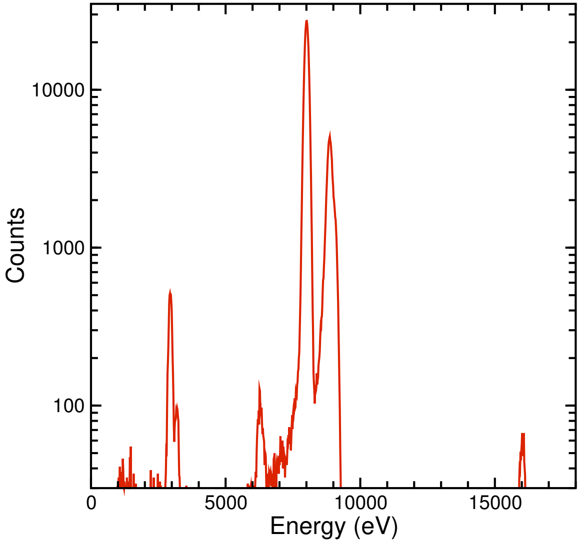

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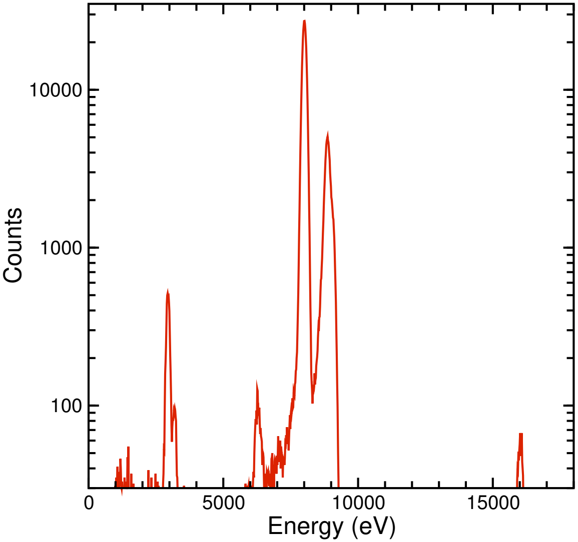

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a small amount of pulse pileup is visible near 16000 eV

Area detectors

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

CCD detectors - direct

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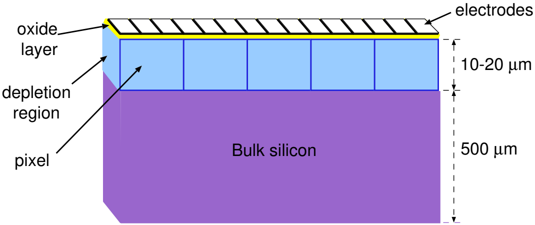

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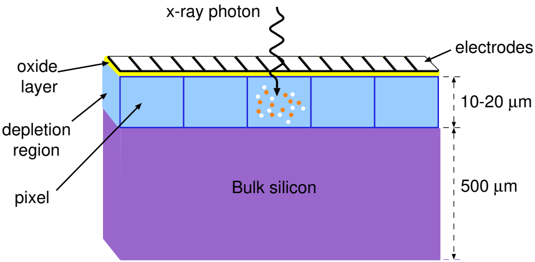

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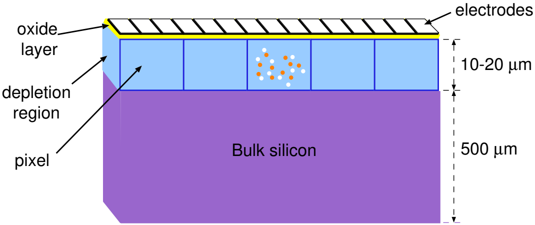

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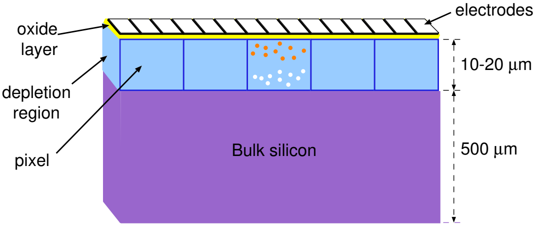

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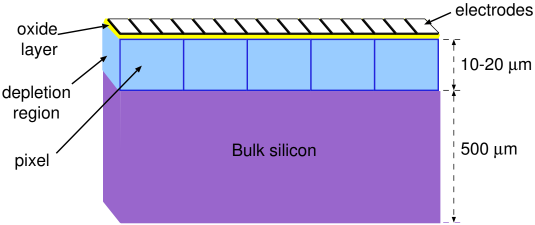

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expensive to make very large, limited sensitivity to high energies

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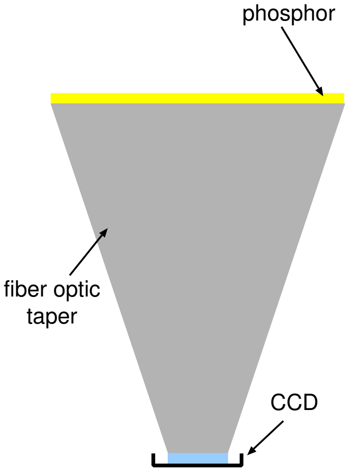

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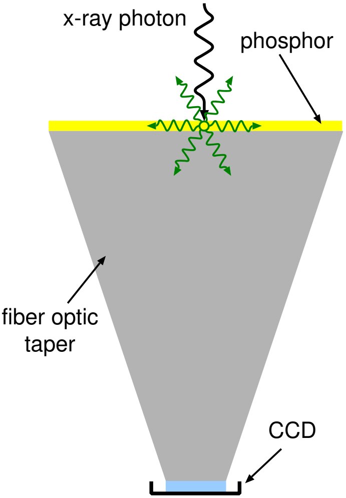

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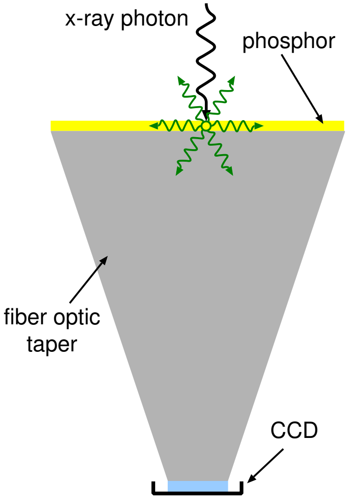

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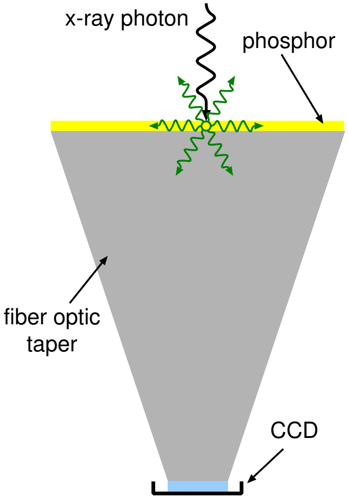

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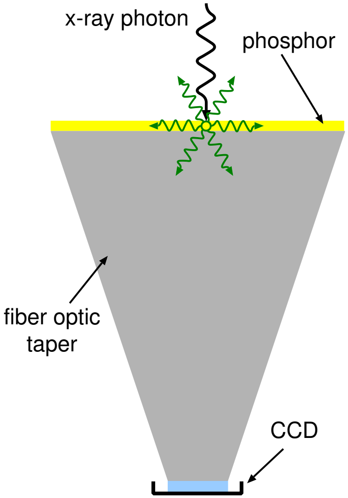
Pixel sizes are usually rather large (50 μm $\times$ 50 μm)



Pixel Array Detectors - schematic

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

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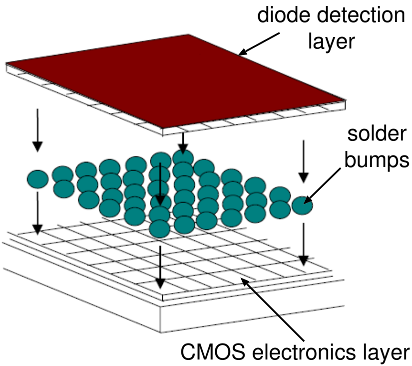

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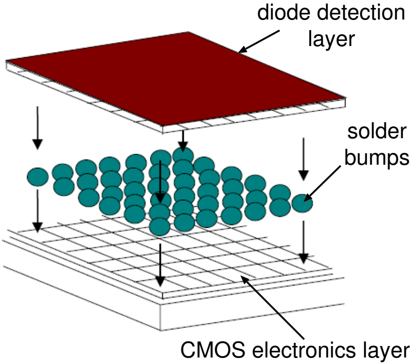

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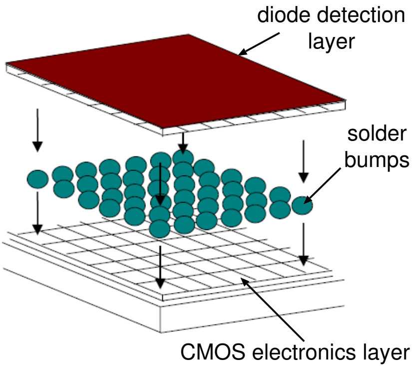

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This permits fast processing and possibly energy discrimination on a per-pixel level

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

Pixel Array Detectors - high energy solutions