X-ray / Gamma-ray detectors

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What information do photons carry?

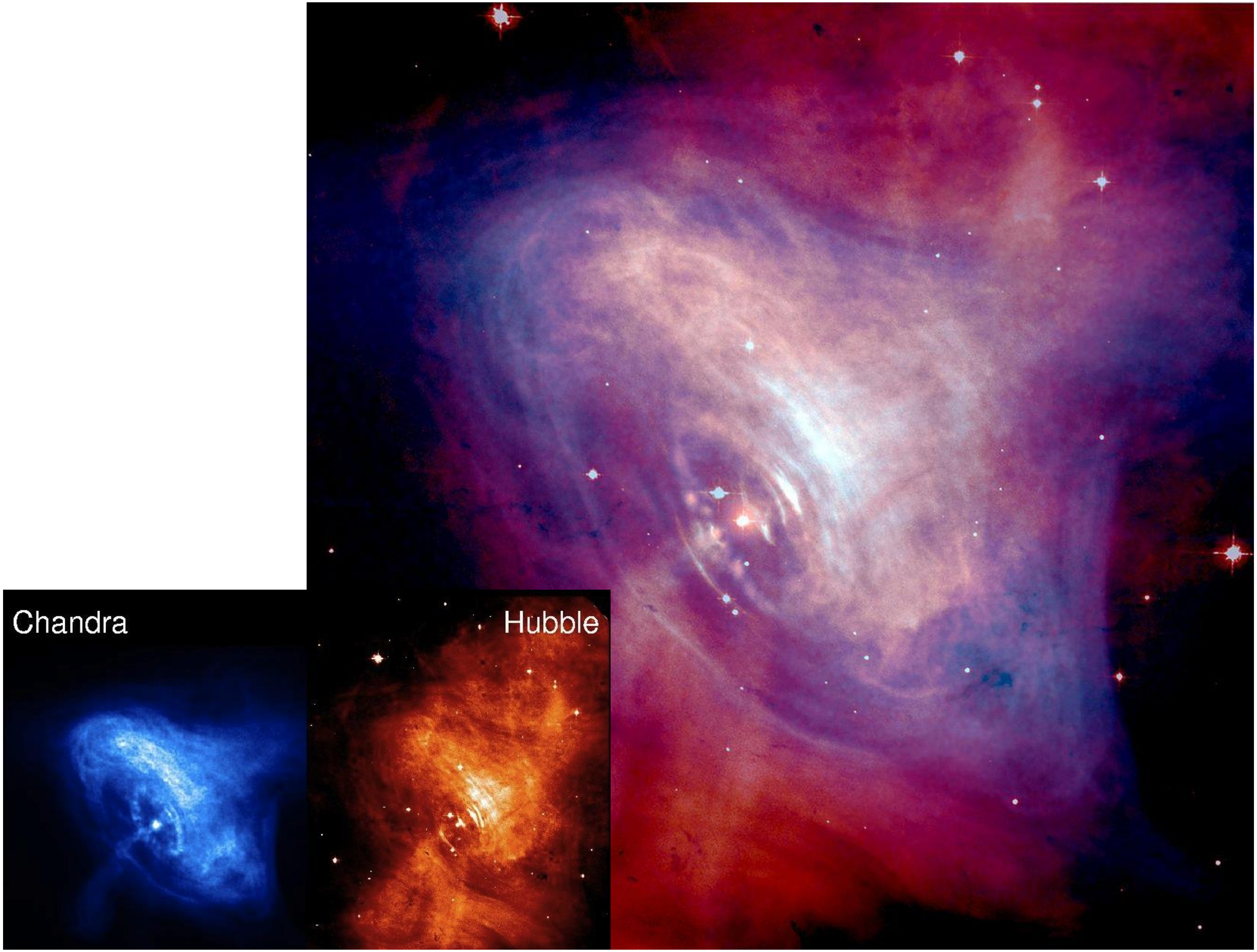
Where

When

What type

Polarization

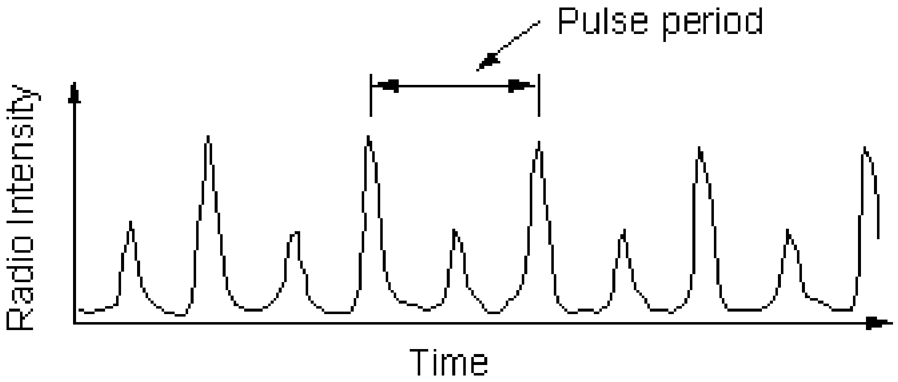
Position



Time

- Time at which photon arrived
  - » Relate to emission time as all photons are from the same object

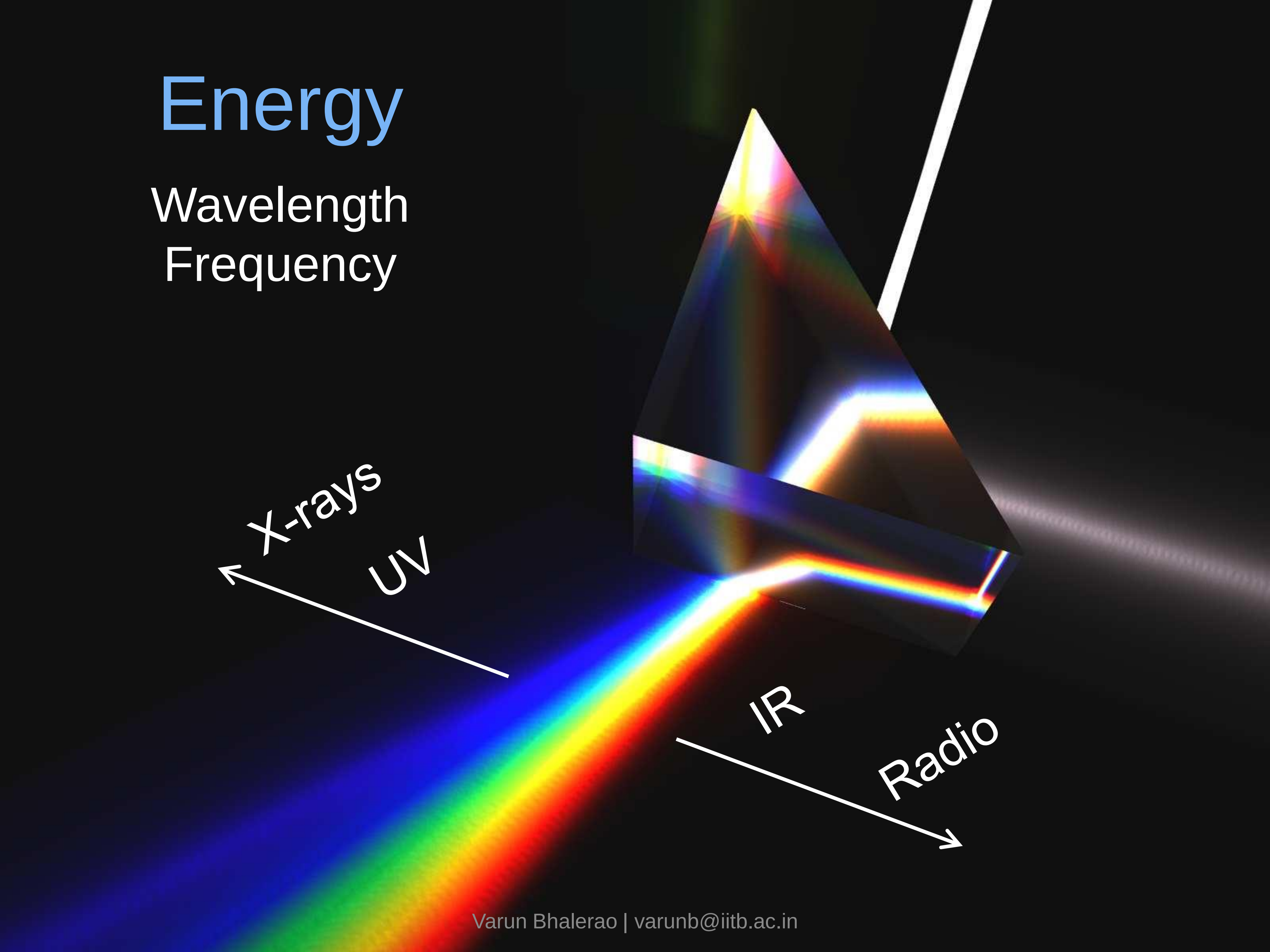
- Periodicity
  - » Eg: Pulsars



- Object size (light crossing time)

Energy

Wavelength
Frequency



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Science needs → Technical specs

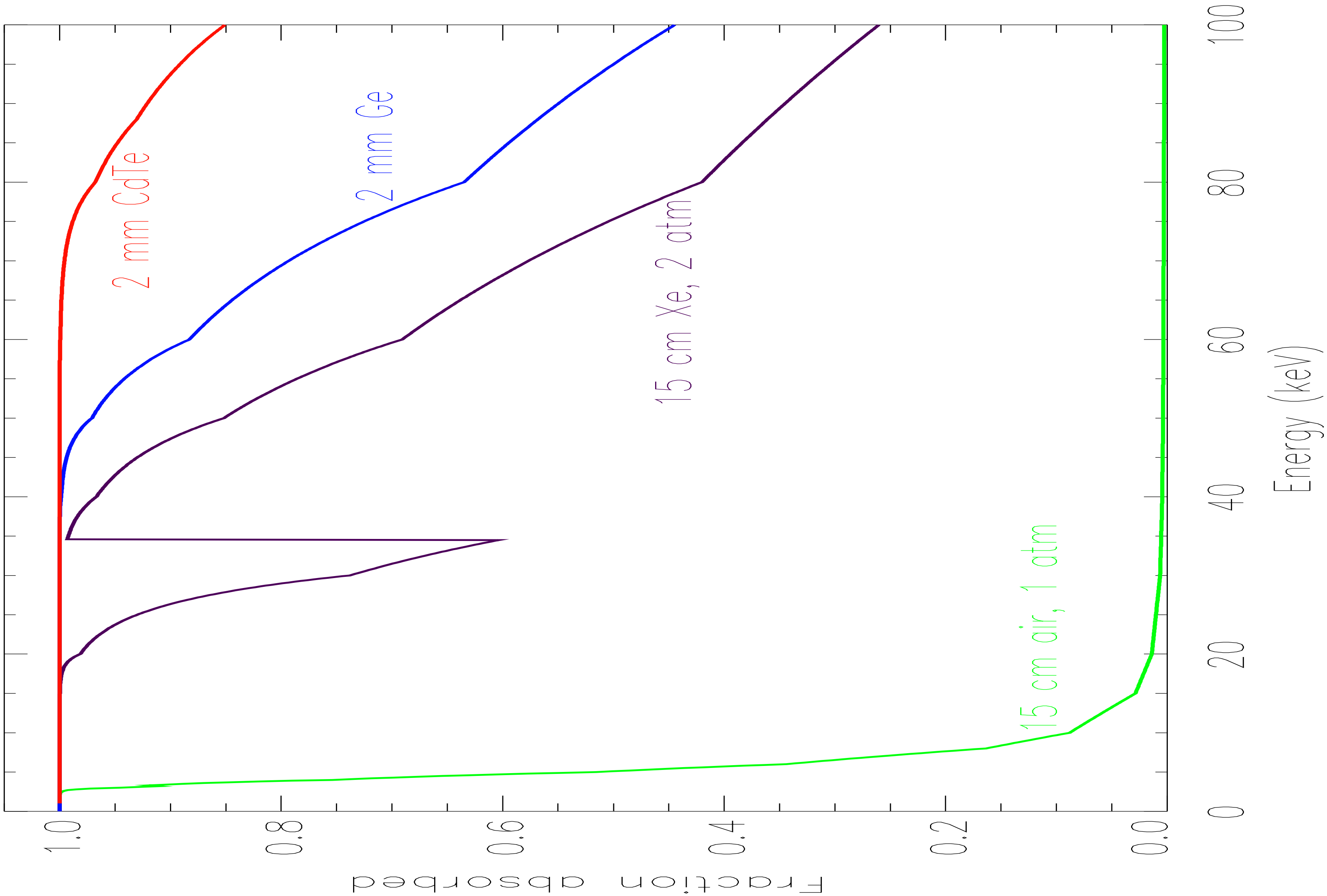
- High absorption of X-rays
  - » Attenuation $\propto \mu_{en}\rho t$
  - » High cross section
  - » High density
- Large number of carriers generated
  - » Deposited Energy $\propto n$
  - » Uncertainty $\propto \sqrt{n}$
- Quick response
  - » High charge carrier mobility

Types of detectors

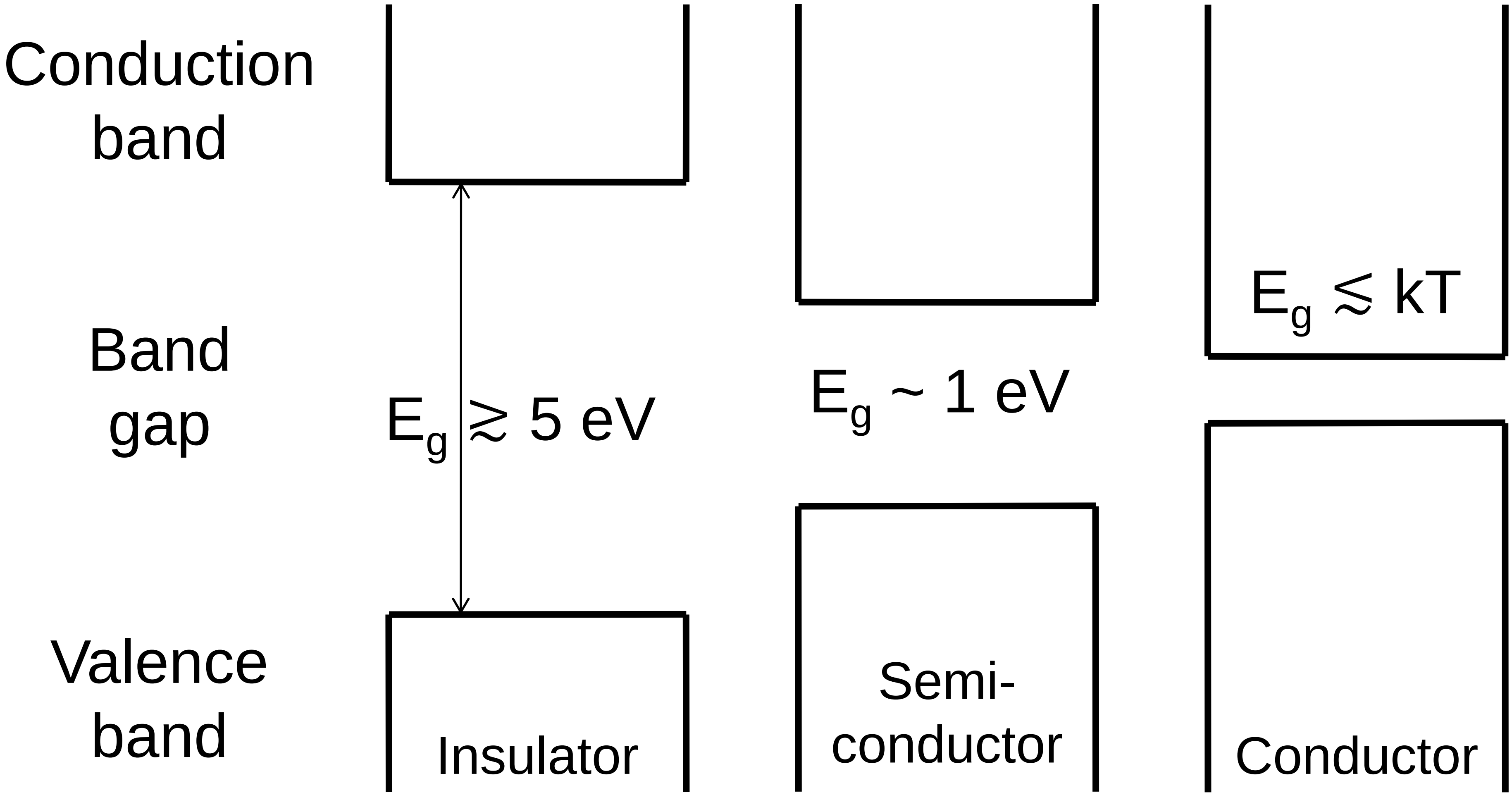
- Cadmium Zinc Telluride
- Germanium
- X-ray CCDs
- Strip detectors
- Gas-filled proportional counters
- Scintillators
- …

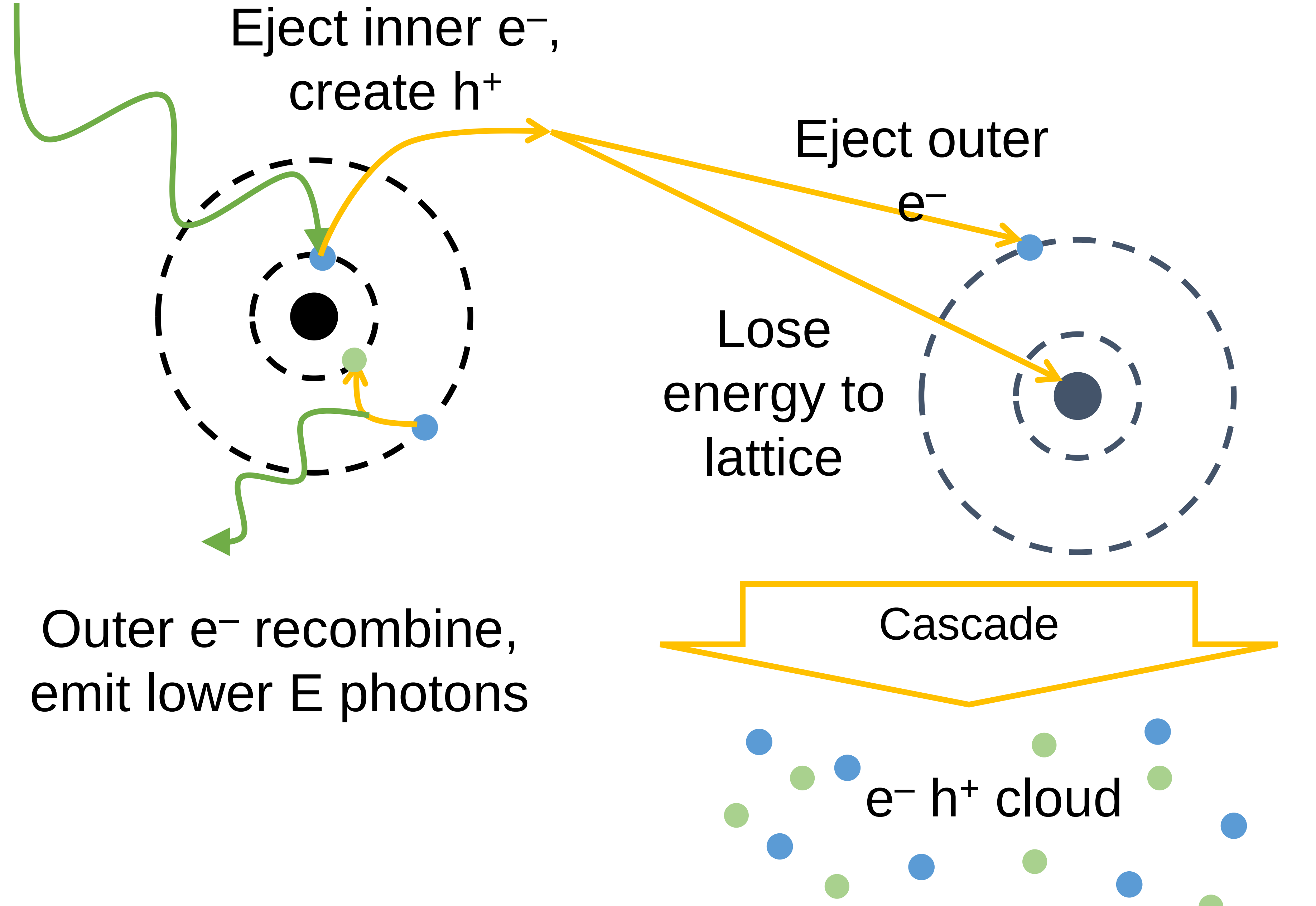
Cadmium Zinc Telluride Imager

Solid state detectors: material selection

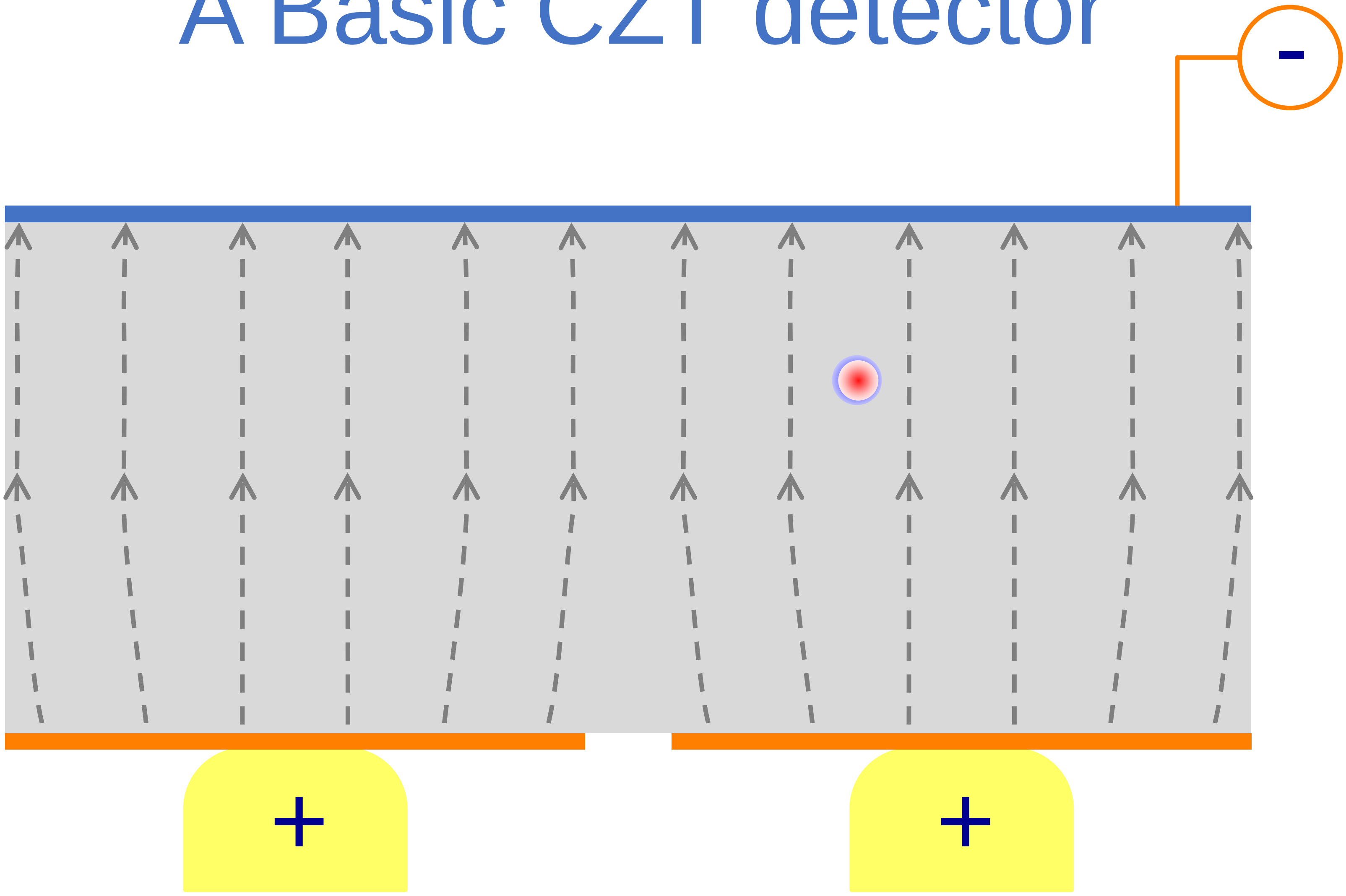


Semiconductors



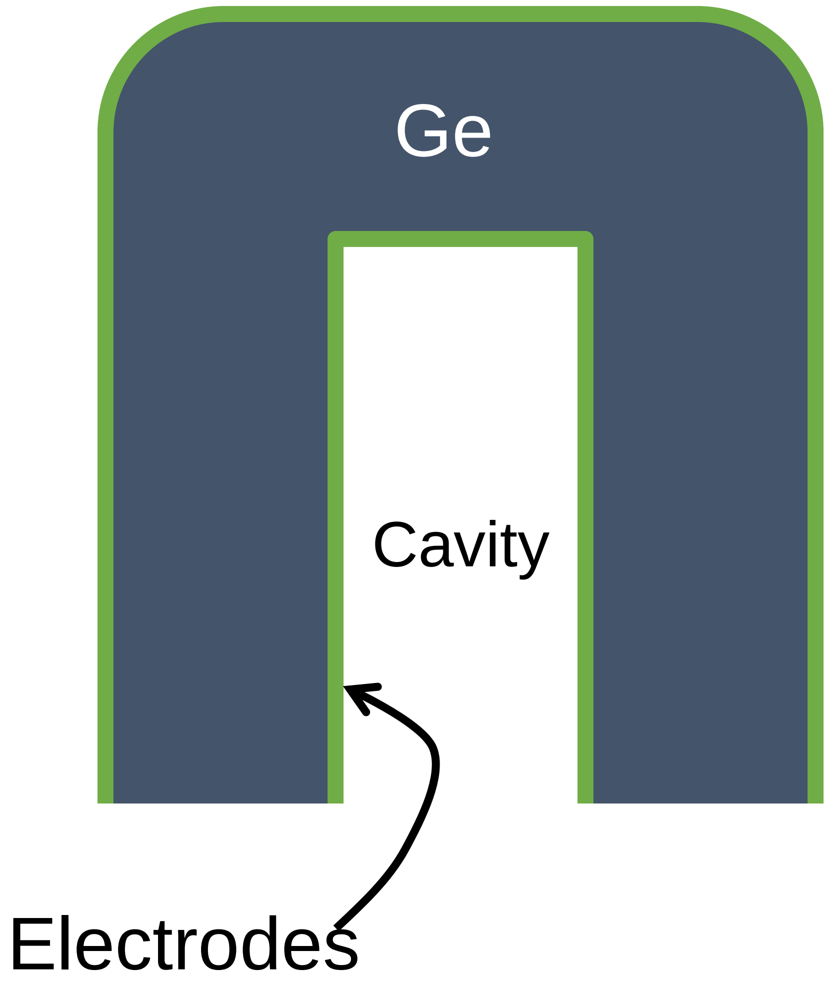

Eject inner e⁻, create h⁺
Eject outer e⁻
Lose energy to lattice
Outer e⁻ recombine, emit lower E photons
Cascade
e⁻ h⁺ cloud

A Basic CZT detector



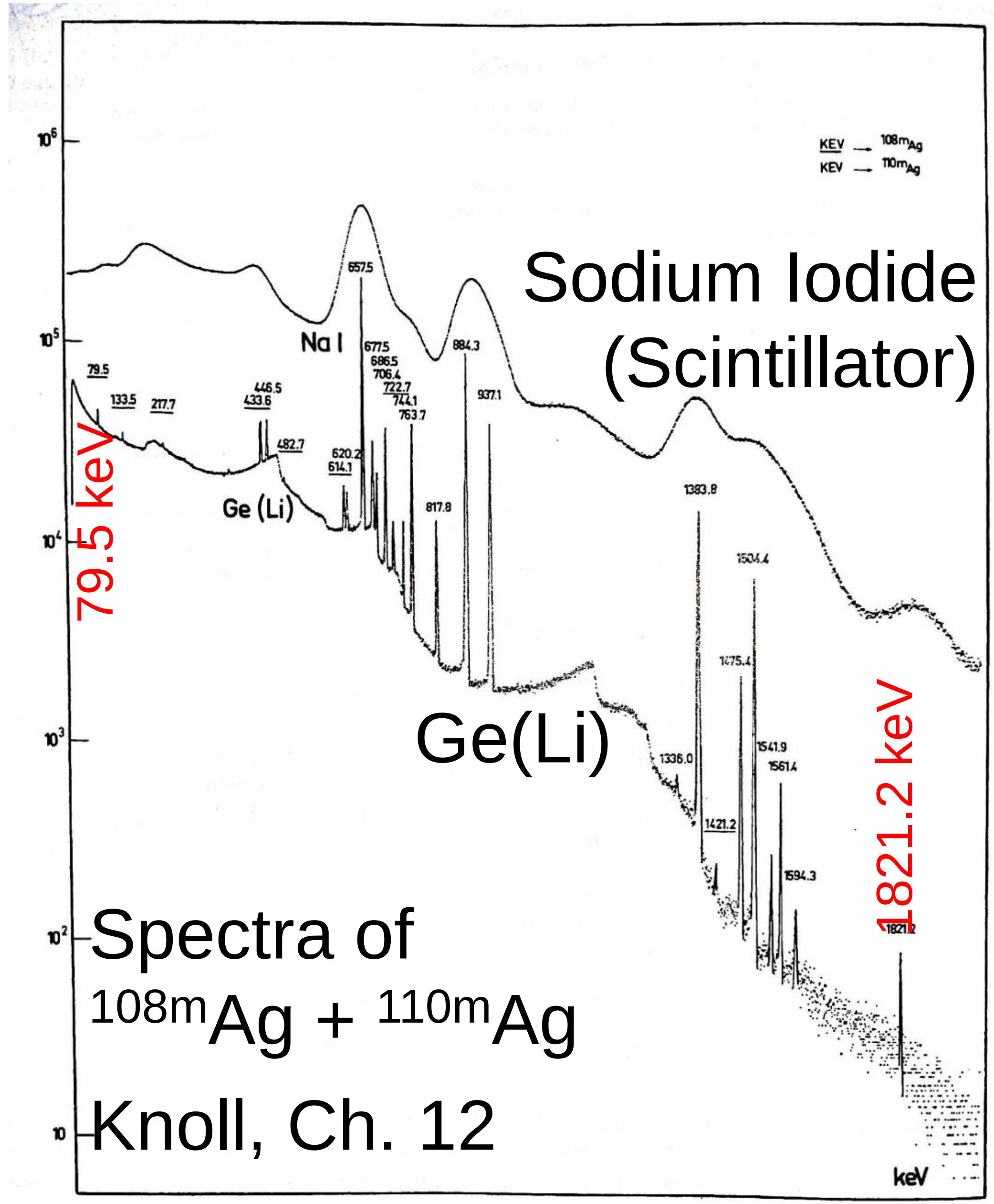
Ge: Typical geometry

- Hollow cylindrical structure most common
- Edges rounded off to eliminate low electric field regions
- “Puck” geometry possible, but limited thickness

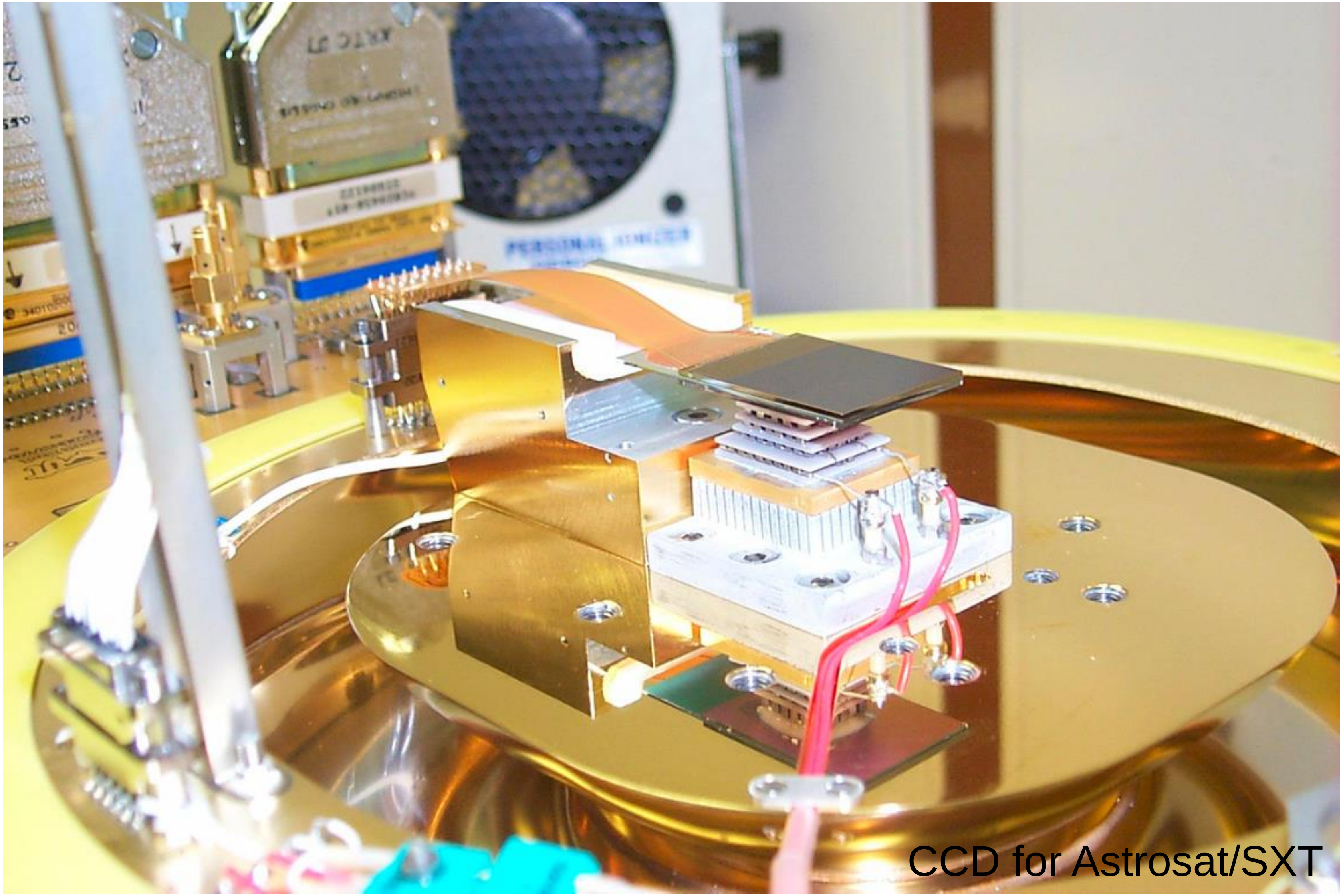


Ge: Energy response

- Effective band gap:
  2.96 eV
- Fano factor:
  0.08
- Energy resolution:
  0.2% at 1 MeV



X-ray CCDs: Astrosat SXT

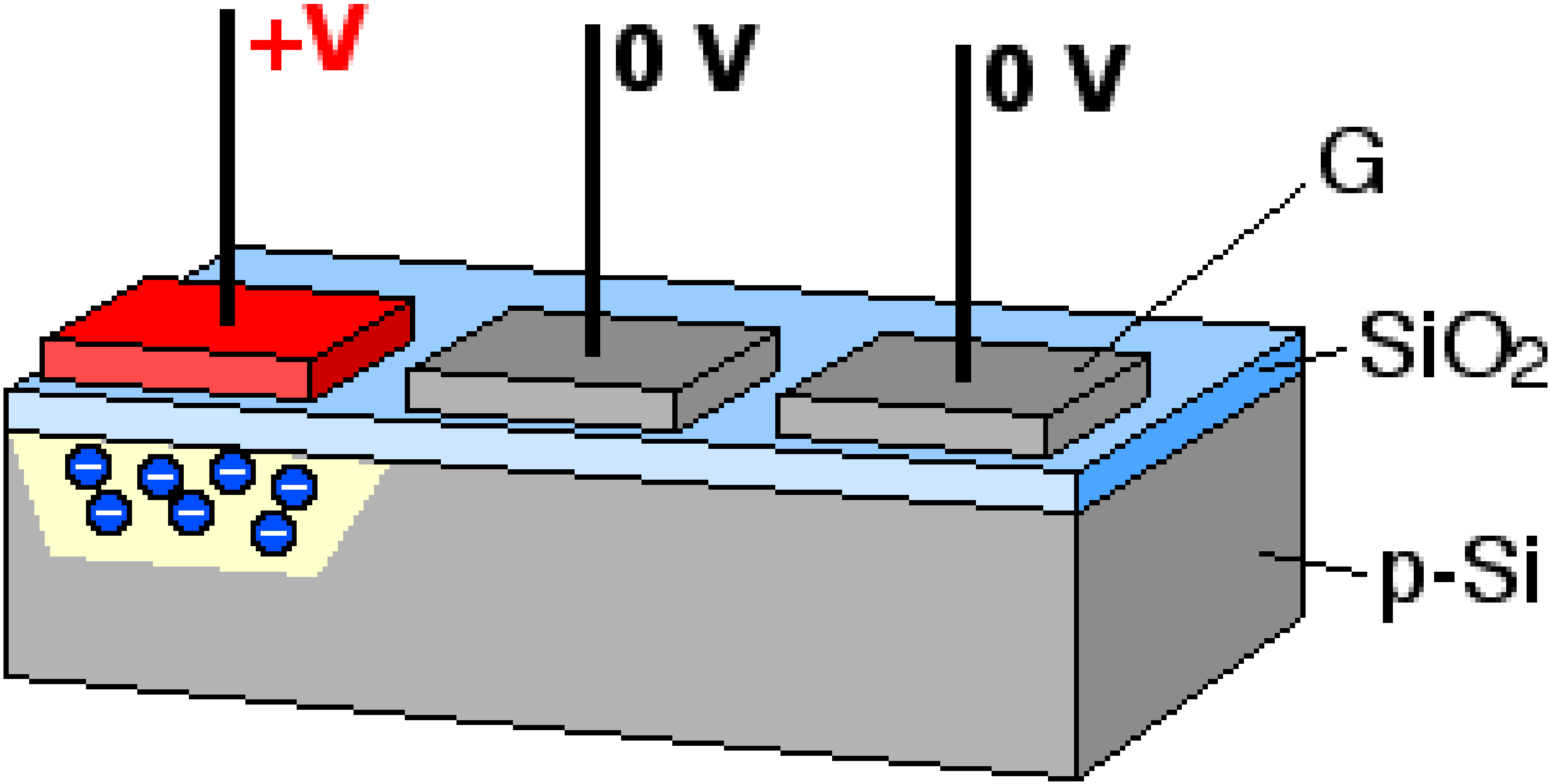


CCD for Astrosat/SXT

CCD Principle

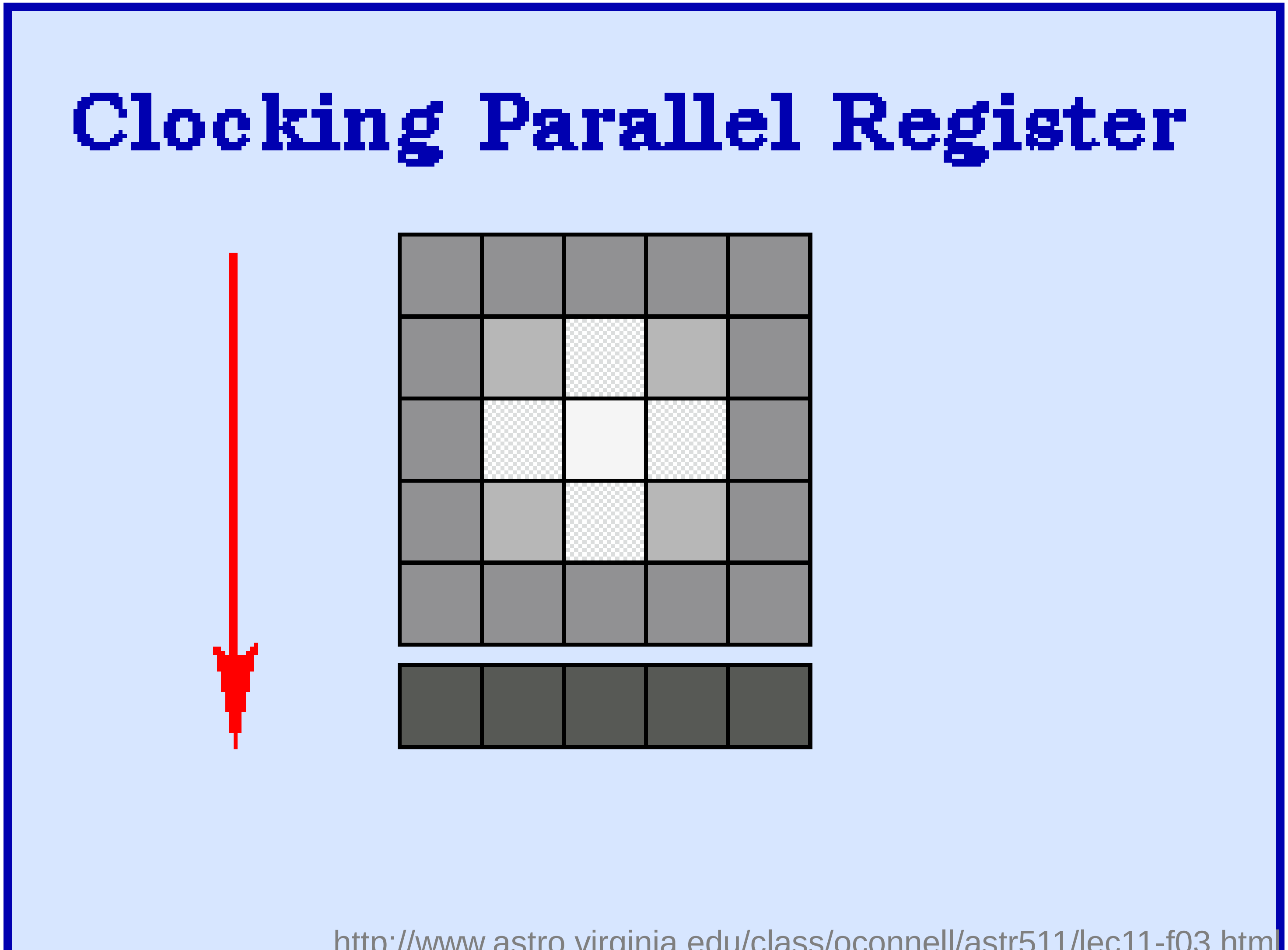
- Solid state detector
  - » Physics similar to Ge
  - » Photons → electrons → readout
  - » Effective band gap 3.65 eV
- Pixelled detector
  - » Same as optical CCDs !
- Integrate and read
  - » Poor time resolution

Working of CCD



http://en.wikipedia.org/wiki/Charge-coupled_device#mediaviewer/File:CCD_charge_transfer_animation.gif

Readout



http://www.astro.virginia.edu/class/oconnell/astr511/lec11-f03.html

How many photons?

- Optical: 1 photon → 1 electron
- X-ray: 1/3.65 electrons per eV
  - » About 274 electron-hole pairs per keV

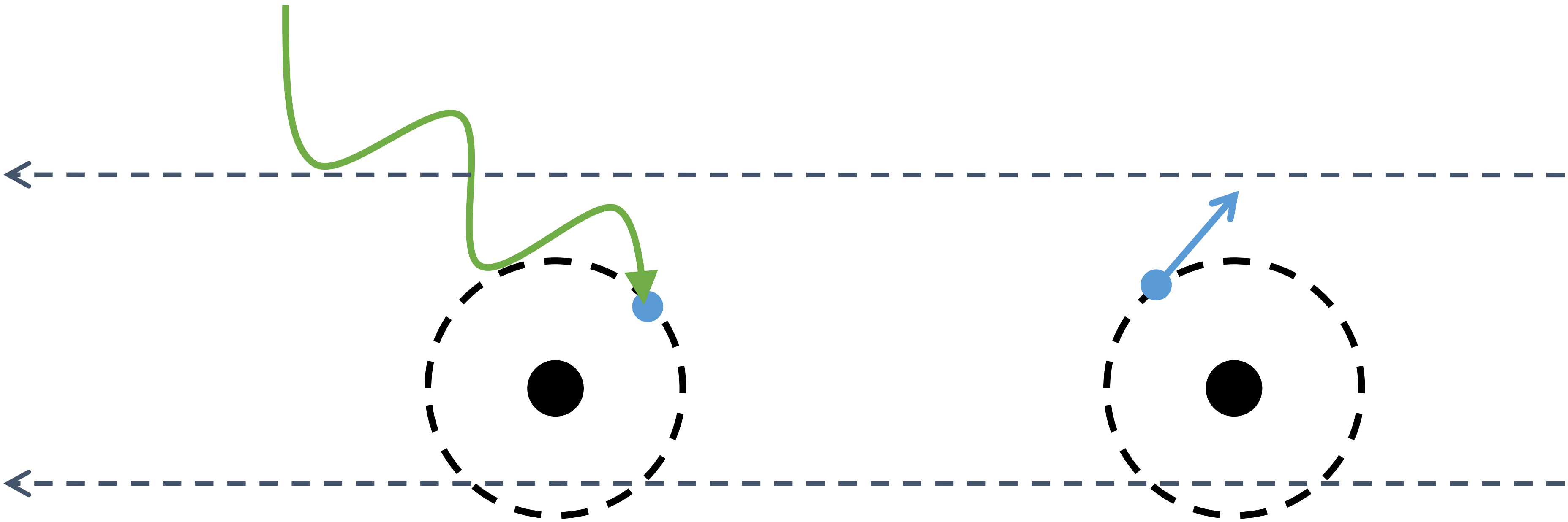
- Example: measured 2740 $e^{-}h^{+}$ pairs in a pixel
  - » 1 photon, 10 keV?
  - » 5 keV + 5 keV?
  - » 2 keV + 3 keV + 5 keV?

CCD issues

- Transparent at high energies
  - » Front illuminated: ~0.1 keV to ~ 10 keV
  - » Back illuminated can work down to tens of eV
- Energy resolution:
  - » Charge transfer inefficiency
  - » Read noise
- 50 eV at 0.1 keV, 190 eV at 10 keV (Swift XRT)

LAXPC: Proportional Counter

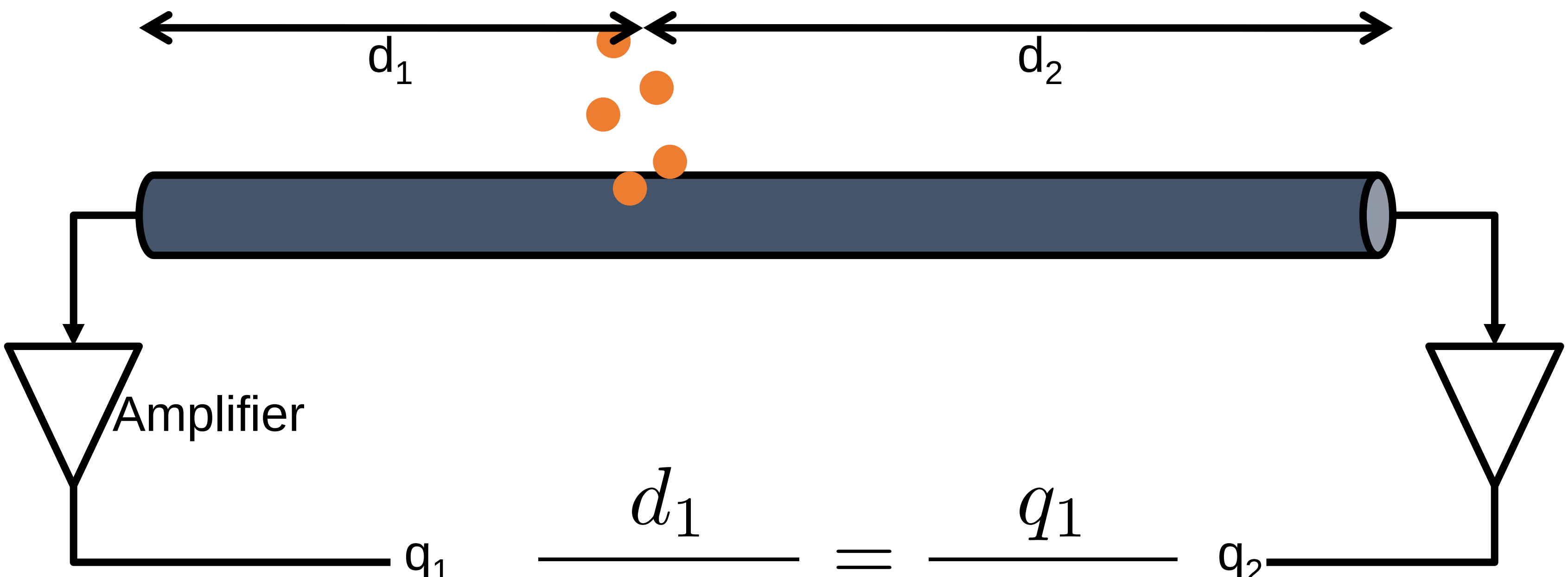
Proportional counter



Electron total energy =
Initial KE + acceleration in field

Position sensitivity

- Multiple wires in one direction
- Use charge division along other direction

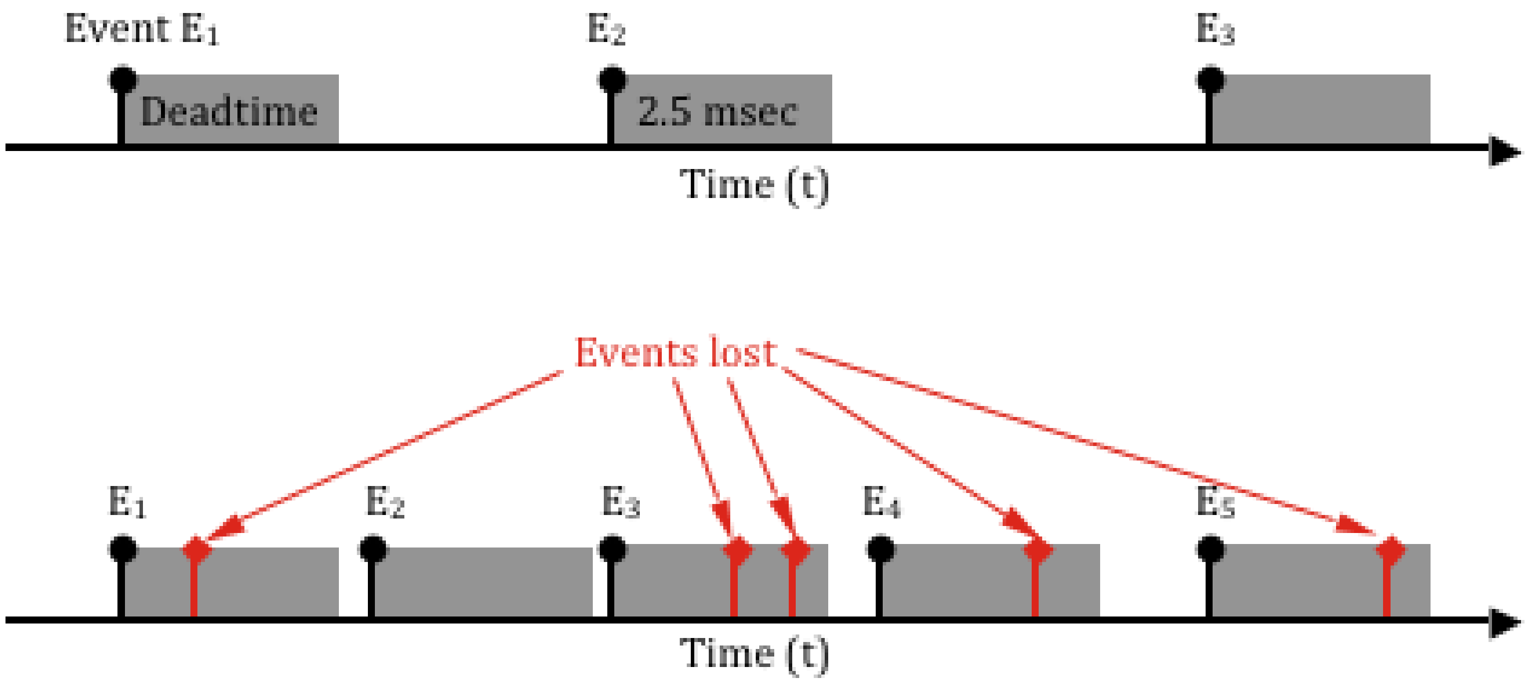


$$\frac{d_1}{d_1 + d_2} = \frac{q_1}{q_1 + q_2}$$

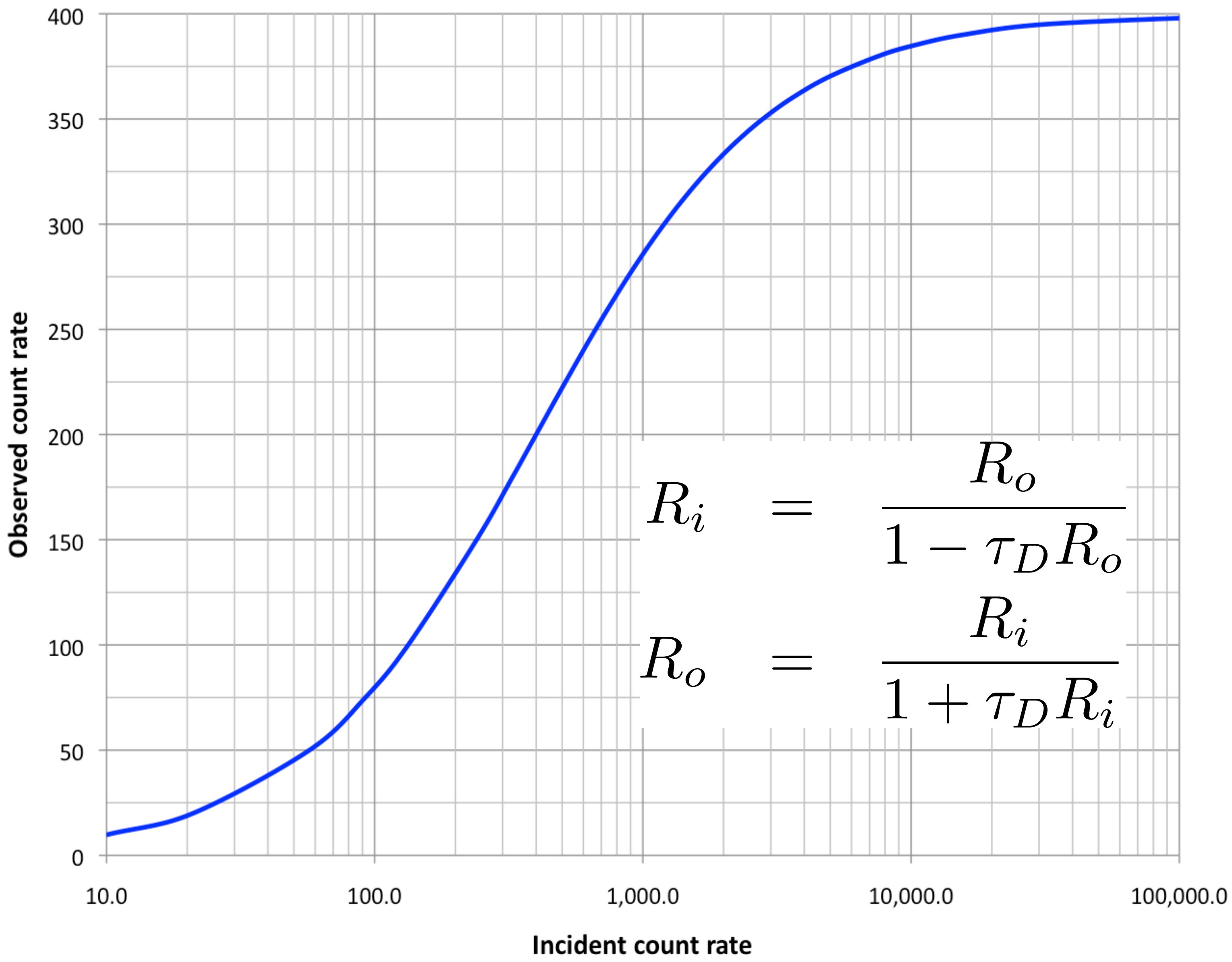
Real detectors, real problems

Dead time

- When a detector is processing an event, it cannot detect other photons for a certain amount of time



Conversion

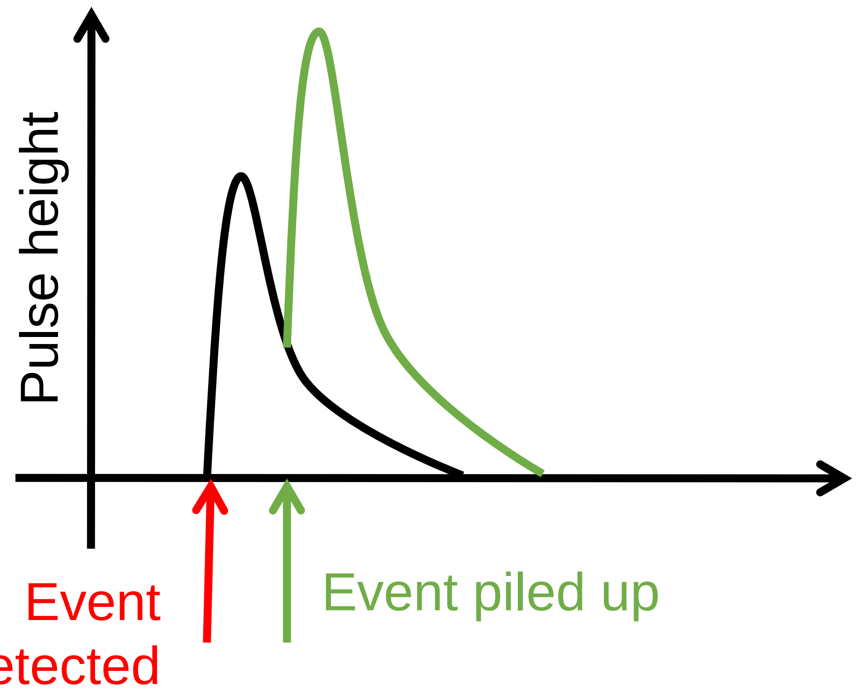


$$R_i = \frac{R_o}{1 - \tau_D R_o}$$

$$R_o = \frac{R_i}{1 + \tau_D R_i}$$

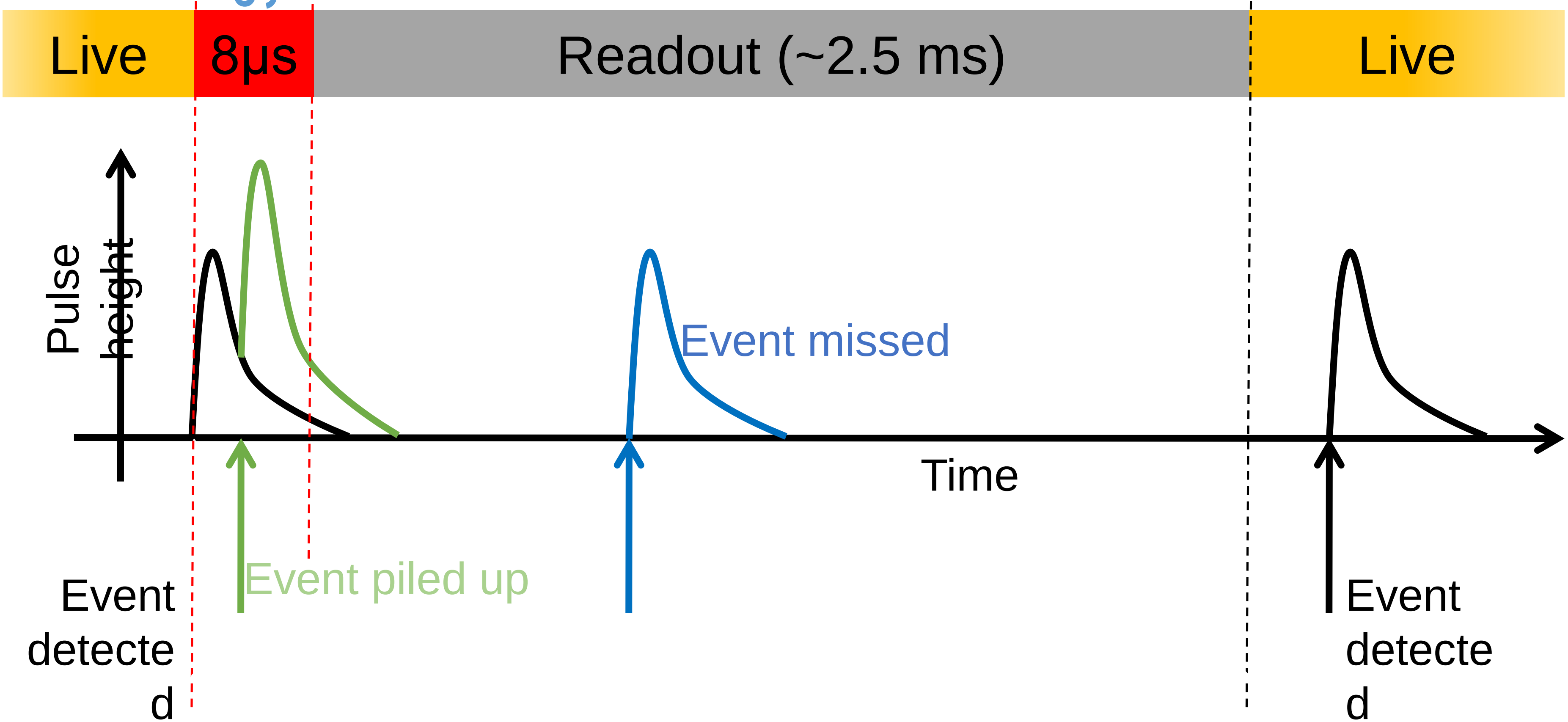
Pileup

- Each photon generates a pulse
- Pulse area ∝ deposited charge
- What happens if a second pulse lands on top of it?
- Total charge = $C_1 + C_2$
- Inferred energy $= E_1 + E_2$

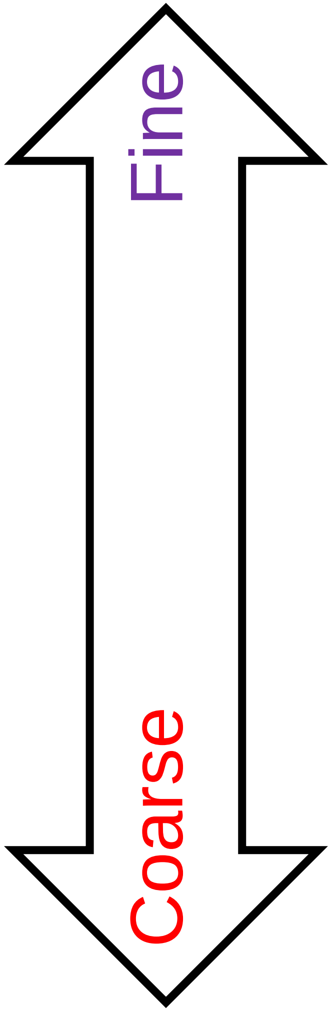


Dead time and pileup are different!

Smaller sampling window:
Lower chance of pileup
Poorer charge collection



Spatial resolution



- Pixelled detectors – feasible for some solid state devices (CCD, CZT, CdTe)
- Silicon strip detectors, Silicon drift detectors
  - » Can be 1-D in some cases
- Proportional counters
- Scintillators / Ge detectors

Linerarity

- What happens if a MeV photon interacts in
- CZT / Ge?
  - » High charge deposition
  - » Circuit saturates
- A gas proportional counter?
  - » Charge generation process becomes non-linear
- CCD?
  - » “Bleeding” – charge may spread to nearby pixels