Chemical Engineering 412

Introductory Nuclear Engineering

Lecture 25

Radiation Detection & Measurement

Spiritual Thought

I realize that there are some, perhaps many, [who] feel overwhelmed by the lack of time. You have left unfinished tasks in your Church calling. You've carried your scriptures all day but still have not found a moment to open them. There is someone in your family who would be blessed by your thoughtful attention, but you haven't gotten to them yet…Rather than finding ways to capture leisure time for learning, you are trying to decide what to leave undone.

There is another way to look at your problem of crowded time. You can see it as an opportunity to test your faith. The Lord loves you and watches over you. He is all-powerful, and He promised you this: "But seek ye first the kingdom of God, and his righteousness; and all these things shall be added unto you"

That is a true promise. When we put God's purposes first, He will give us miracles. If we pray to know what He would have us do next, He will multiply the effects of what we do in such a way that time seems to be expanded. He may do it in different ways for each individual, but I know from long experience that He is faithful to His word.

President Henry B. Eyring

Detector Types

- Gas-filled – Gas between two electrodes
- Scintillation – Ionizing radiation produces UV or visible light
- Solid-state, Semiconductor – High purity Si or Ge semiconductors
- Others
  - Cloud chambers
  - Bubble Chambers
  - Superheated Drop
  - Cryogenic
  - AMANDA and IceCube

Cloud Chamber

Detector Operation

- Detection mode
  - Counters – detect number of interaction events
  - Spectrometers – detect number of events as a function of energy
  - Dosimeters – detect accumulated energy by all interactions
- Operation mode
  - Pulse – detects (and generally counts) individual interactions
  - Current –individual interactions averaged to produce current

Dead time

- Duty cycle of slowest component determines dead time
  - Detector has longest dead time in Geiger-Müller (GM) counter systems
  - In multichannel analyzer systems the analog-to-digital converter often has the longest dead time
- GM counters have dead times ranging from tens to hundreds of microseconds, most other systems have dead times of less than a few microseconds

$$n = \frac{m}{1 - m\tau}$$

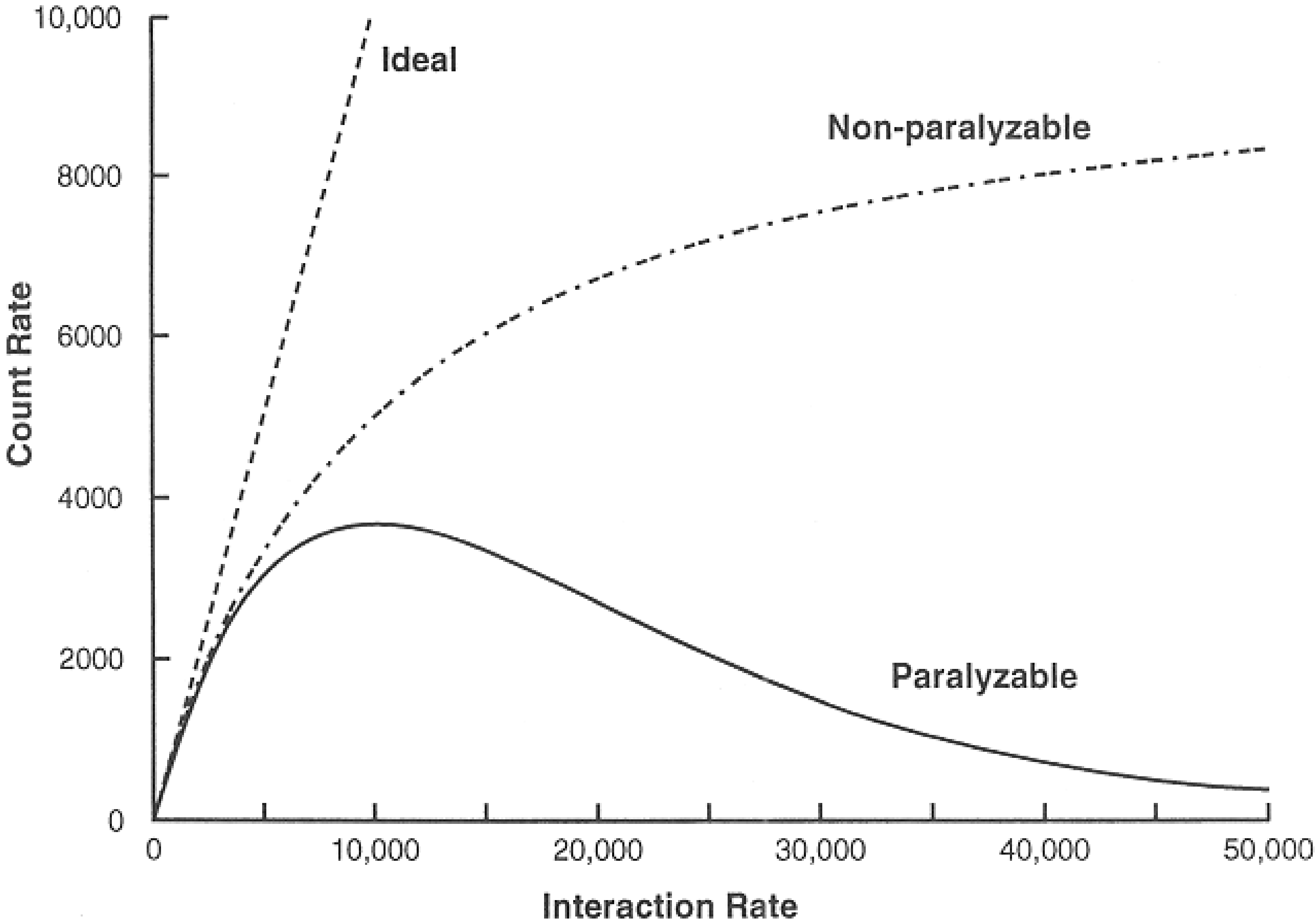
Interaction rate

- In pulse mode, events must be separated by more than the dead time to be detected
- A second interaction in this interval will not be detected
- A second interaction very close to the first interaction may distort the signal from the first interaction

Paralyzable or nonparalyzable

- Systems in which dead-time events extend dead time are *paralyzable*. Otherwise, systems are *nonparalyzable.*
- At very high interaction rates, paralyzable systems will not detect any interactions after the first, causing the detector to indicate a count rate of zero

Counter performance



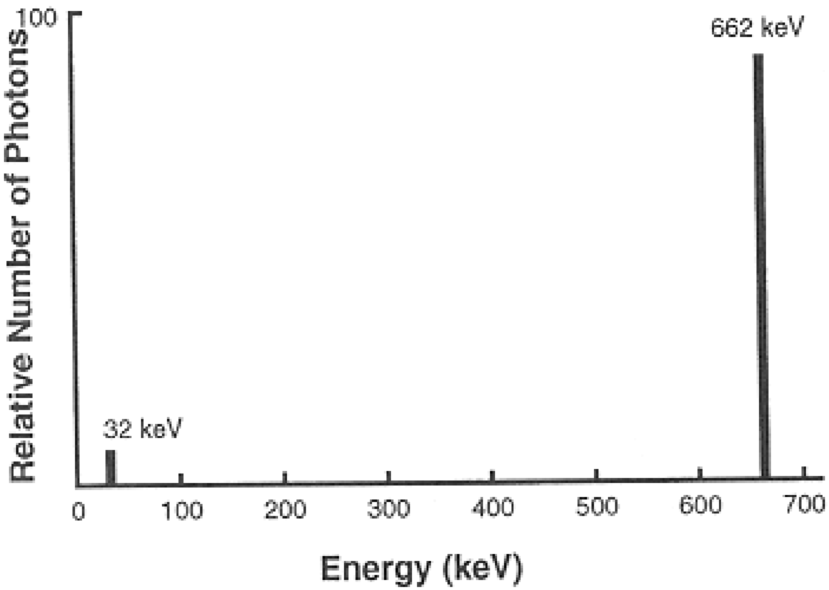
Current mode operation

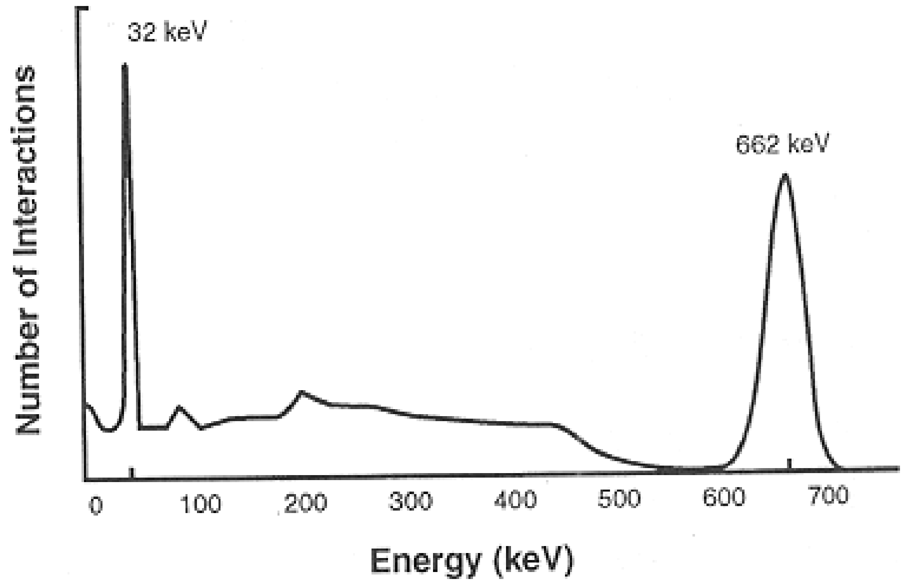
- In current mode, all information regarding individual interactions is lost, but these systems can be designed with no dead time
- If the electrical charge collected from each interaction is proportional to the energy deposited by that interaction, then the net current is proportional to the dose rate in the detector material
- Used for detectors subjected to very high interaction rates

Spectroscopy

- Most spectrometers operate in pulse mode
- Amplitude of each pulse is proportional to the energy deposited in the detector by the interaction causing that pulse
- *The energy deposited by an interaction is not always the total energy of the incident particle or photon*
- A *pulse height spectrum* is usually depicted as a graph of the number of interactions depositing a particular amount of energy in the spectrometer as a function of energy

Pulse Detector Examples

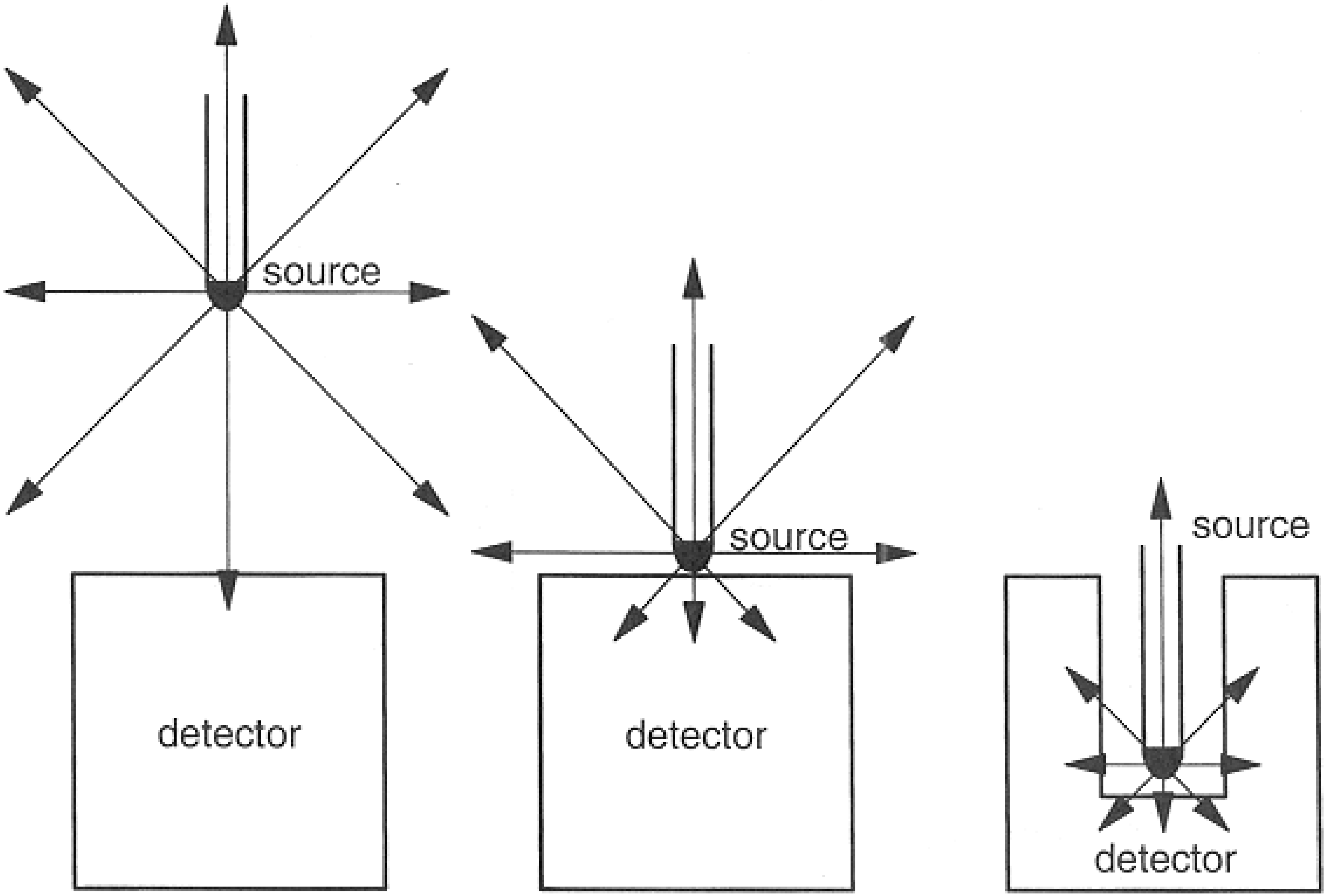




Detection efficiency

- The *efficiency (sensitivity)* of a detector is a measure of its ability to detect radiation
- Efficiency of a detection system operated in pulse mode is defined as the probability that a particle or photon emitted by a source will be detected

Efficiency Illustrations



Efficiencies

$$\eta_{overall} \equiv \frac{\#_{detected}}{\#_{emitted}}$$

$$\eta_{geom} \equiv \frac{\#_{reaching\ detector}}{\#_{emitted}}$$

$$\eta_{intrinsic} \equiv \frac{\#_{detected}}{\#_{reaching\ detector}}$$

$$\eta_{overall} = \eta_{geom}\eta_{intrinsic}$$

Intrinsic efficiency

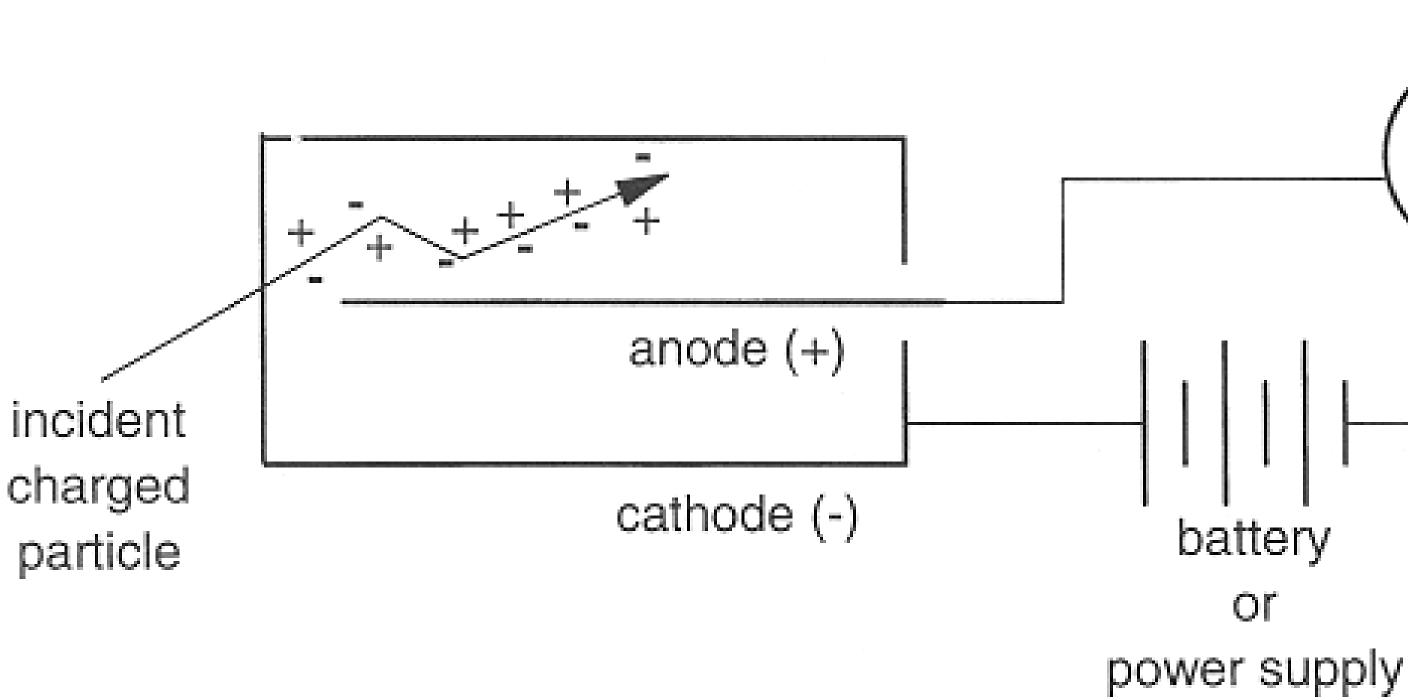
- Often called the *quantum detection efficiency* or QDE
- Determined by the energy of the photons and the atomic number, density, and thickness of the detector
- For a parallel beam of monoenergetic photons incident on a detector of uniform thickness:

$$\eta_{intrinsic} = 1 - \mathrm{e}^{-\mu x}$$

Gas-filled detectors

- A gas-filled detector comprises gas between two oppositely charged electrodes
- Ionizing radiation produces ion pairs in the gas
- Positive ions (cations) migrate to negative electrode (cathode); electrons or anions migrate to positive electrode (anode)
- In most detectors, cathode is the wall of the container that holds the gas and anode is a wire inside the container

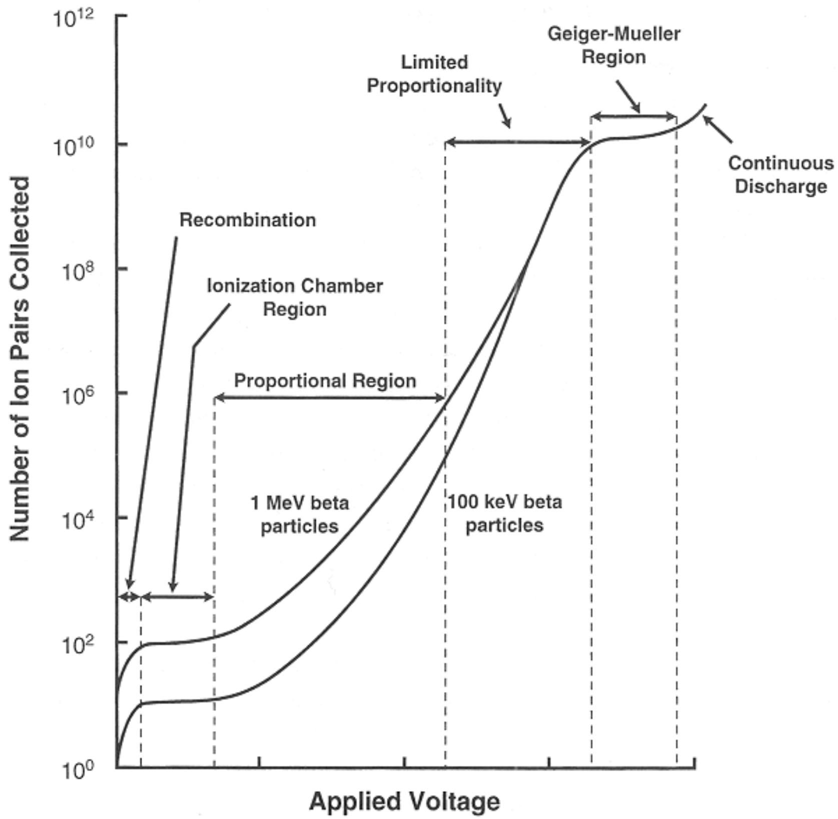
Typical gas-filled detector

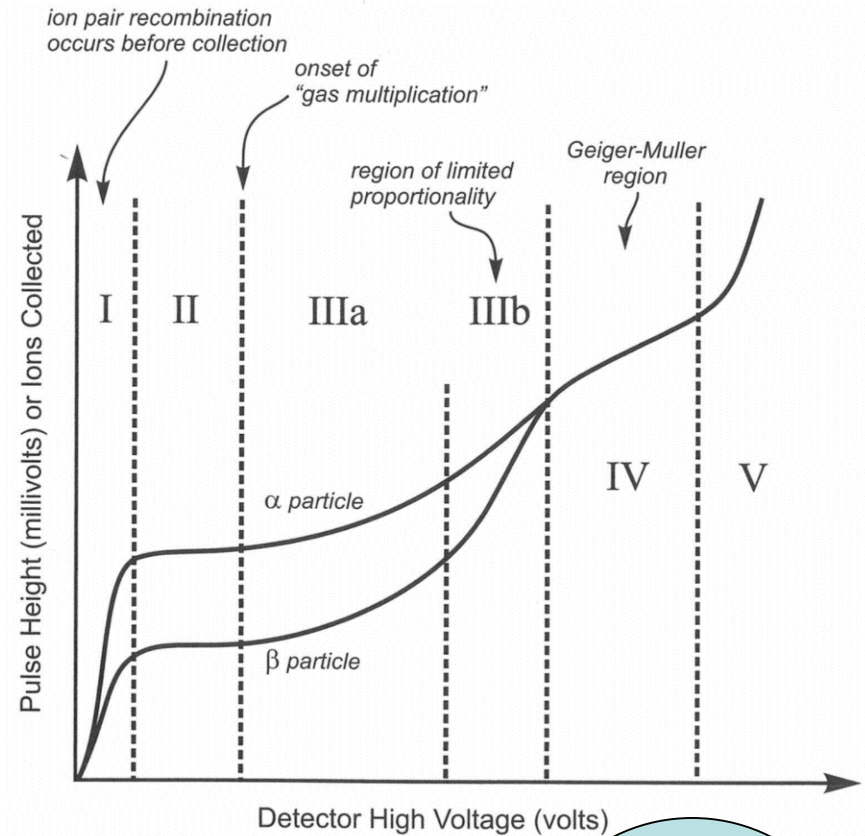


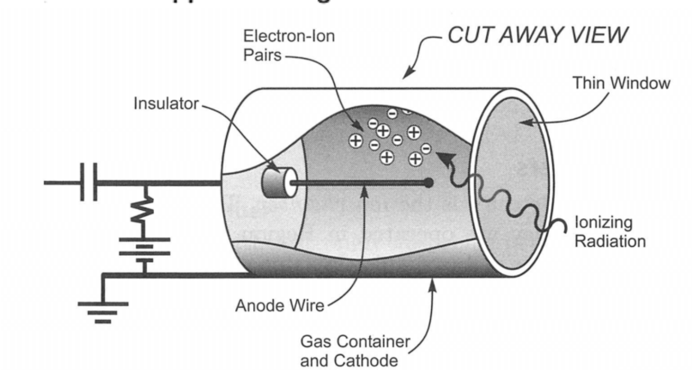
Types of gas-filled detectors

- Three types of gas-filled detectors in common use:
  - Ionization chambers
  - Proportional counters
  - Geiger-Müller (GM) counters
- Type determined primarily by the voltage applied between the two electrodes
- Ionization chambers have wider range of physical shape (parallel plates, concentric cylinders, etc.)
- Proportional counters and GM counters must have thin wire anode (why)

Voltage influence on Sensitivity







$$\mathrm{E} = \frac{V_o}{r \cdot \ln(b/a)}$$