PHYS 3446 – Lecture #15

Monday, Oct. 24, 2016

Dr. Jae Yu

- Particle Detection
  - Ionization Detectors
  - MWPC
  - Scintillation Counters
  - Time of Flight
  - Cerenkov Counter
  - Calorimeters

Announcements

- Quiz #2
  - Beginning of the class this Wednesday, Oct. 26
  - Covers: CH4.1 through what we finish today
  - Bring your calculators
    - No phone or computers allowed
  - Bring your own handwritten formula sheet
    - Front and back of a letter size sheet
    - No word definitions, no derivations, no reaction equations
- Homework #7
  1. Derive Eq. 7.10
  2. Carry out computations for Eq. 7.14 and 7.17
- Due for these assignments is Monday, Oct. 31

Reminder: Research Project Report

1. Must contain the following at the minimum
   - Motivation, including the justification for it
   - Current status and some background behind them
   - Improvements and bases for such improvements
   - Conclusions
   - The reference to the original paper must be included!
   - Bibliography referring to web site must be minimized (<20%)
2. Each member of the group writes a 10 (max) page report, including figures
   - 20% of the total grade
   - Can share the theme and facts but you must write your own!
   - Text of the report must be your original!
   - ***<u>Due Wed., Dec. 7, 2016</u>***

Research Presentations

- Each of the 5 research groups makes a 10+3min presentation
  - 10min presentation + 3min Q&A
  - All presentations must be in power point
  - I must receive all final presentation files by 8pm, Monday, Dec. 5, 2016
    - No changes are allowed afterward
  - The representative of the group makes the presentation followed by all group members' participation in the Q&A session
- Date and time:
  - In class Wednesday, Dec. 7, 2016
- Important metrics
  - Contents of the presentation: 60%
    - Inclusion of all important points as mentioned in the report
    - The quality of the research and making the right points
  - Quality of the presentation itself: 15%
  - Presentation manner: 10%
  - Q&A handling: 10%
  - Staying in the allotted presentation time: 5%
  - Judging participation and sincerity: 5%

Project Report Template

PHYS3446-Your-Name-Here

Title Goes Here Like This With The First Letter of Each Word Capital

PHYS-3446, Fall 2016
Nov. dd, 2016

Author Name
Department of XYZ
The University of Texas at Arlington

Abstract

Describe briefly and to the point the content of the note in about a paragraph or so, including the brief conclusion. The font of the main body must be Times New Roman 12pt. Tables and figures must be numbered in sequence as they appear as Table 1 or Figure 1. Each has its own numbering system. They must be placed as close to the text in which they are referred. They must have associated captions attached to them. These explain what the contents of the figure or table are. Captions must be Times New Roman 11pt. References must be placed to where the reference is relevant in a square bracket with a number counted in sequence as they appear but only in the main body not in the abstract.

1. Introduction

Describe what this paper is all about and how this note is organized [1] and motivate the readers.

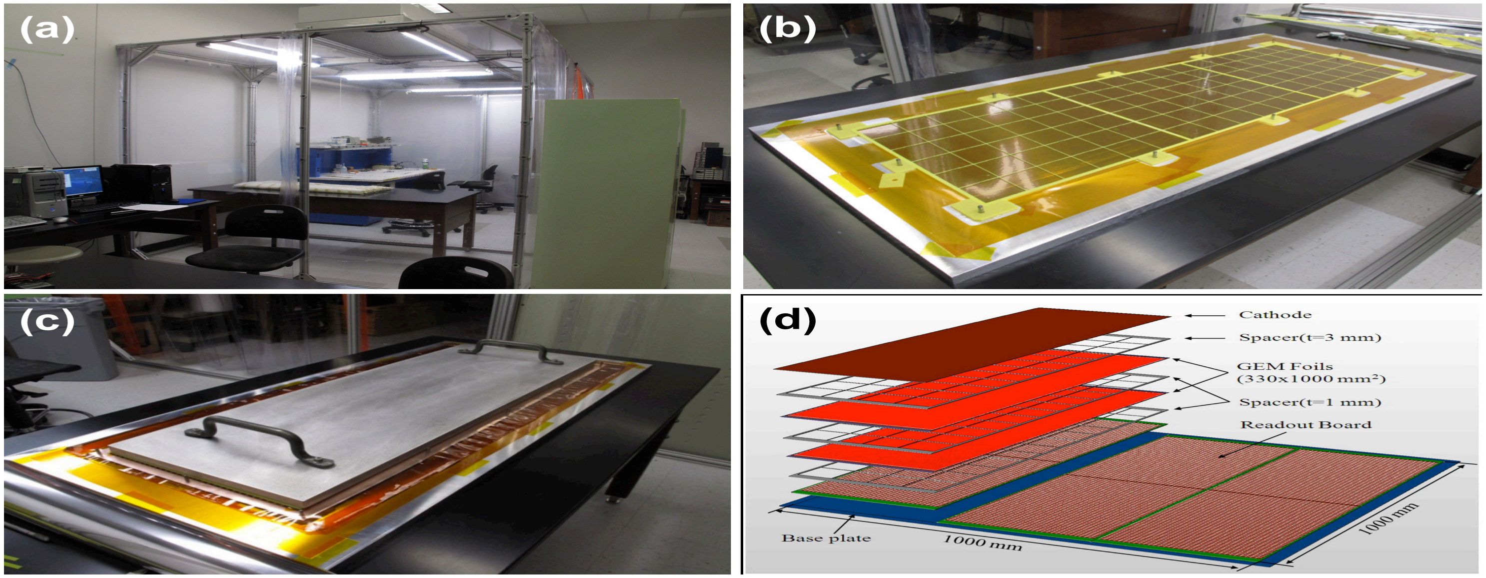


Figure. 1 (a) 12'x8' clean room for LGEM construction (b) An LGEM layer on an assembly jig held by alignment pins throughout the sides (c) glue curing process with heavy flattening pressing plane (d) Layout of a full 100cm × 100cm **GEM DHCAL active layer.**

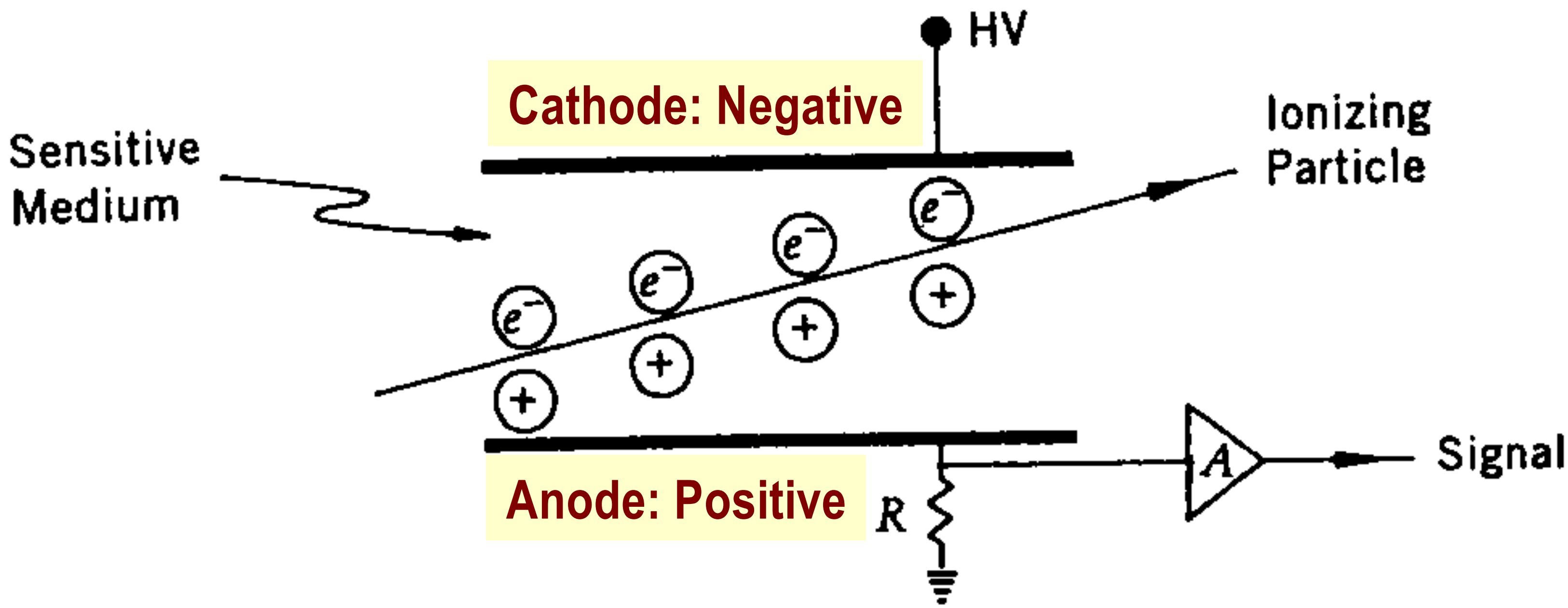
Ionization Detectors

- Measures the ionization produced when an incident particle traverses through a medium
- Can be used to
  - Trace charged particles through the medium
  - Measure the energy loss (dE/dx) of the incident particle
    - Must prevent re-combination of an ion and electron pair into an atom after the ionization
    - Apply high electric field across medium
      - Separates charges and accelerates the electrons

Ionization Detectors – Chamber Structure

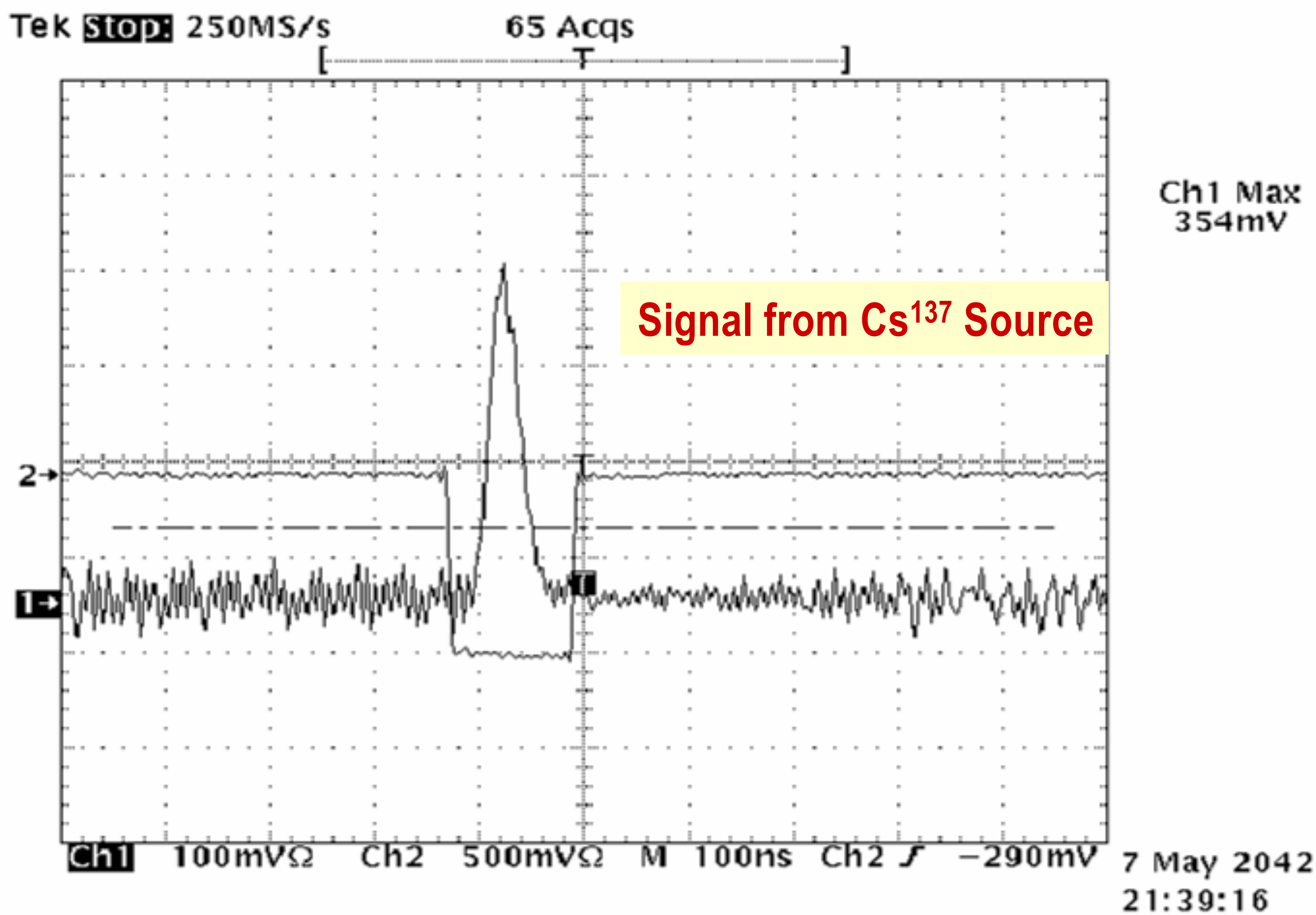
- Basic ionization detector consists
  - A chamber with an easily ionizeable medium
    - The medium must be chemically stable and should not absorb ionization electrons
    - Should have low ionization potential ($\overline{I}$) ➔ To maximize the amount of ionization produced per given energy
  - A cathode and an anode held at some large potential difference
  - The device is characterized by a capacitance determined by its geometry

Ionization Detectors – Chamber Structure



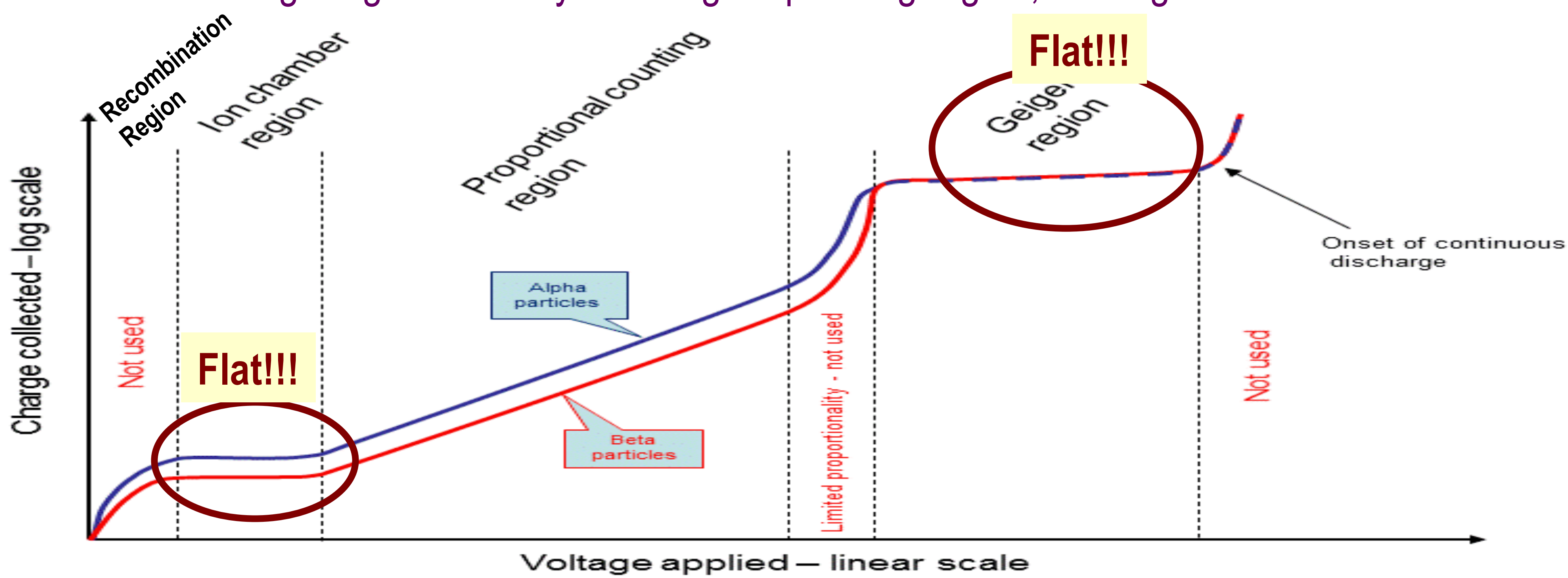
- The ionization electrons and ions drift to their corresponding electrodes, to anode and cathode
  - Provide small currents that flow through the resistor
  - The current causes voltage drop that can be sensed by the amplifier
  - Amplifier signal can be analyzed to obtain pulse height that is related to the total amount of ionization

30cmx30cm D-GEM Detector Signal



Ionization Detectors – HV

- Depending on the magnitude of the electric field across the medium different behaviors are expected
  - Recombination region: Low electric field
  - Ionization region: Medium voltage that prevents recombination
  - Proportional region: large enough HV to cause acceleration of ionization electrons and additional ionization of atoms
  - Geiger-operating region: Sufficiently high voltage that can cause large avalanche if electron and ion pair production that leads to a discharge
  - Discharge region: HV beyond Geiger operating region, no longer usable



Ionization Counters

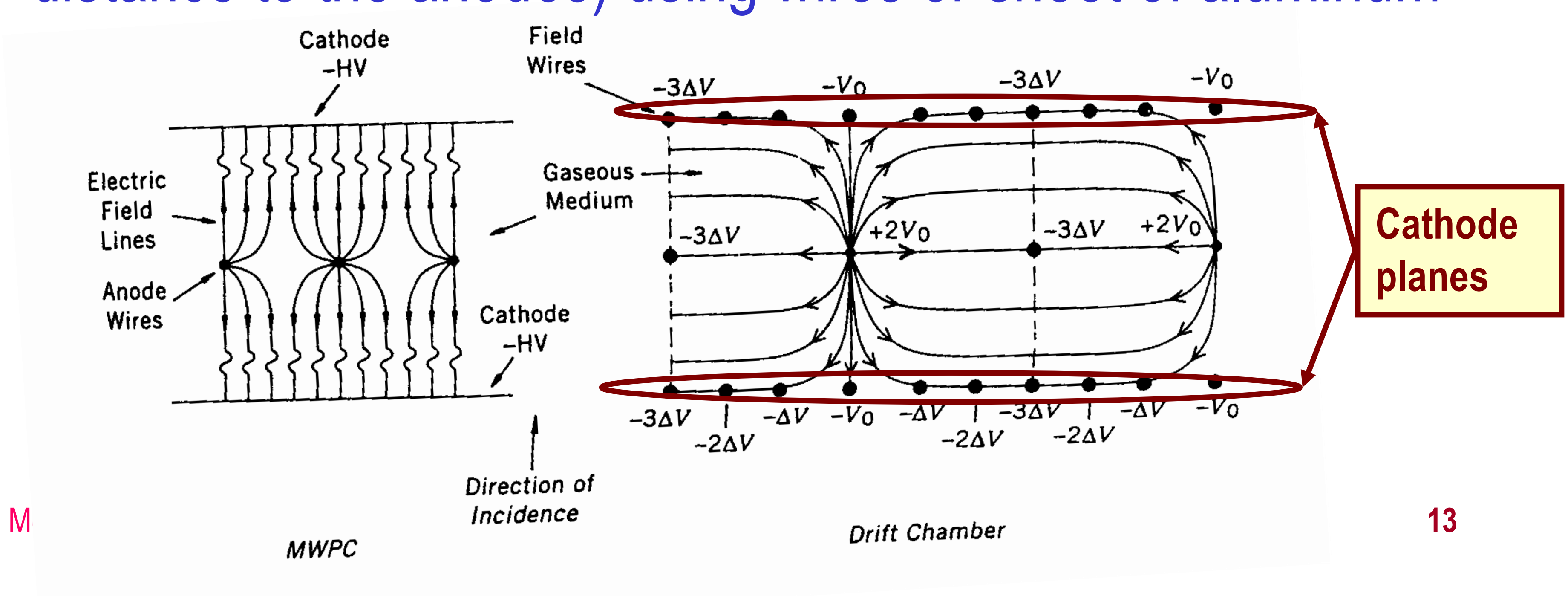
- Operate at relatively low voltage (in ionization region of HV)
- Generate no amplification of the original signal
- Output pulses for minimum ionizing particle is small
- Insensitive to voltage variation
- Have short recovery time ➔ Used in high interaction rate environment
- Response linear to input signal
- Excellent energy resolution
- Liquid argon ionization chambers used for sampling calorimeters
- Gaseous ionization chambers are useful for monitoring high level of radiation, such as alpha decay

Proportional Counters

- Gaseous proportional counters operate in high electric fields ~10^4 V/cm (in the proportional counting region)
- Typical amplification of factors of ~10^5
- Use thin wires (10 – 50 μm diameter) as anode electrodes in a cylindrical chamber geometry
- Multiplication occur near the anode wire where the field is strongest, causing secondary ionization
- Sensitive to the voltage variation ➔ not suitable for energy measurement
- But used for tracking device

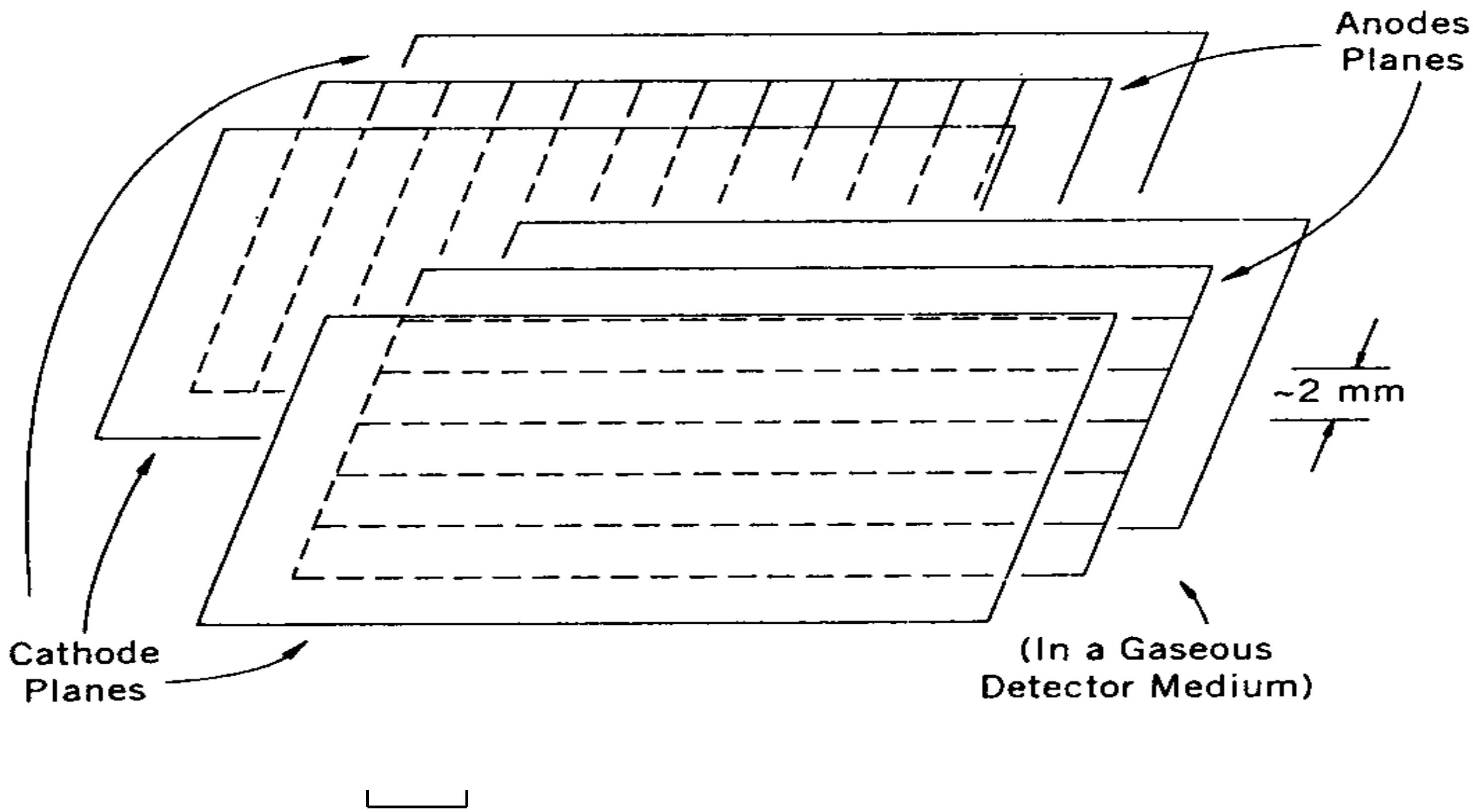
Multi-Wire Proportional Chambers (MWPC)

- G. Charpak et al. developed a proportional counter in a multiwire proportional chamber (Nobel prize 1992)
  - One of the primary position detectors in HEP
- A plane of anode wires positioned precisely w/ about 2 mm spacing
- Can be sandwiched in similar cathode planes (in <1cm distance to the anodes) using wires or sheet of aluminum

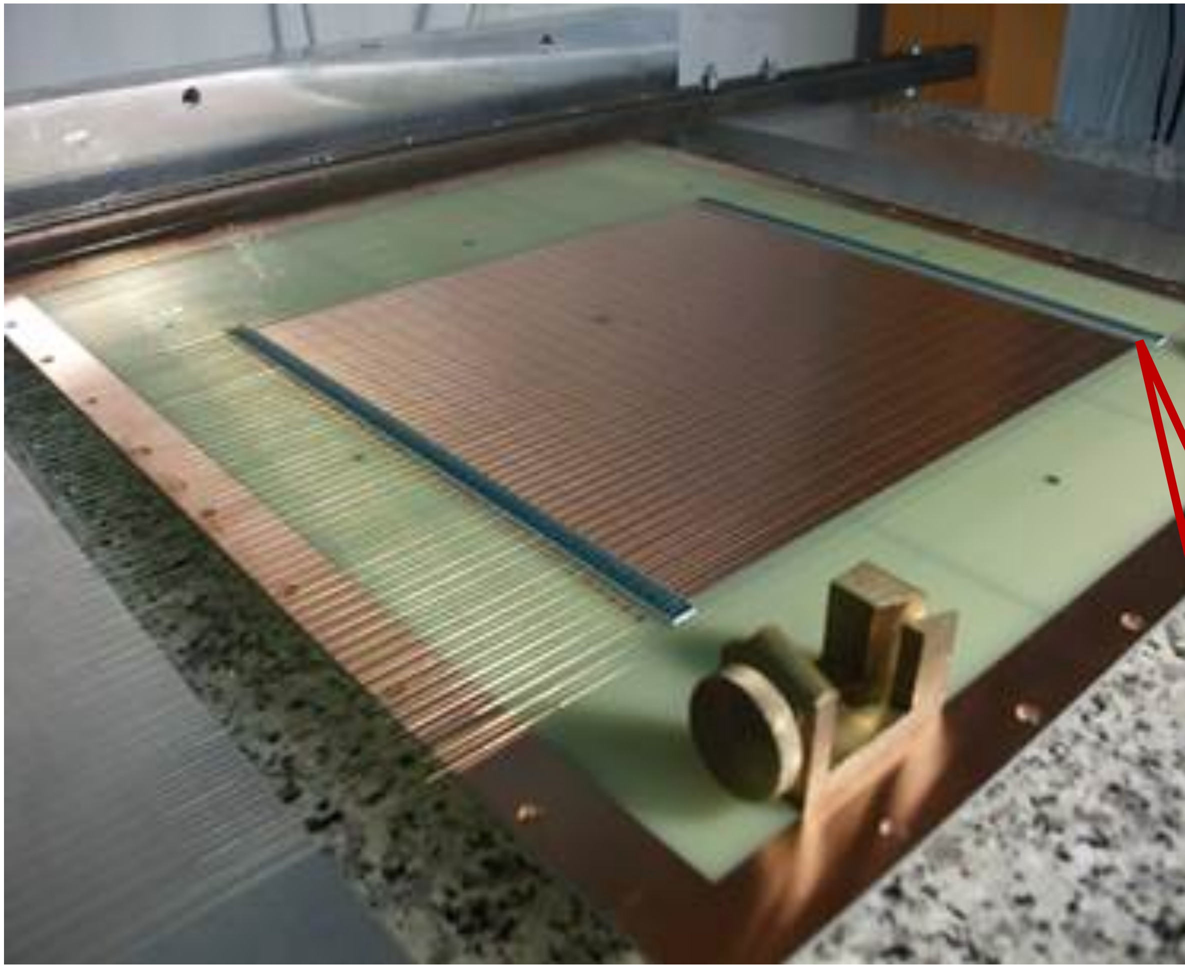


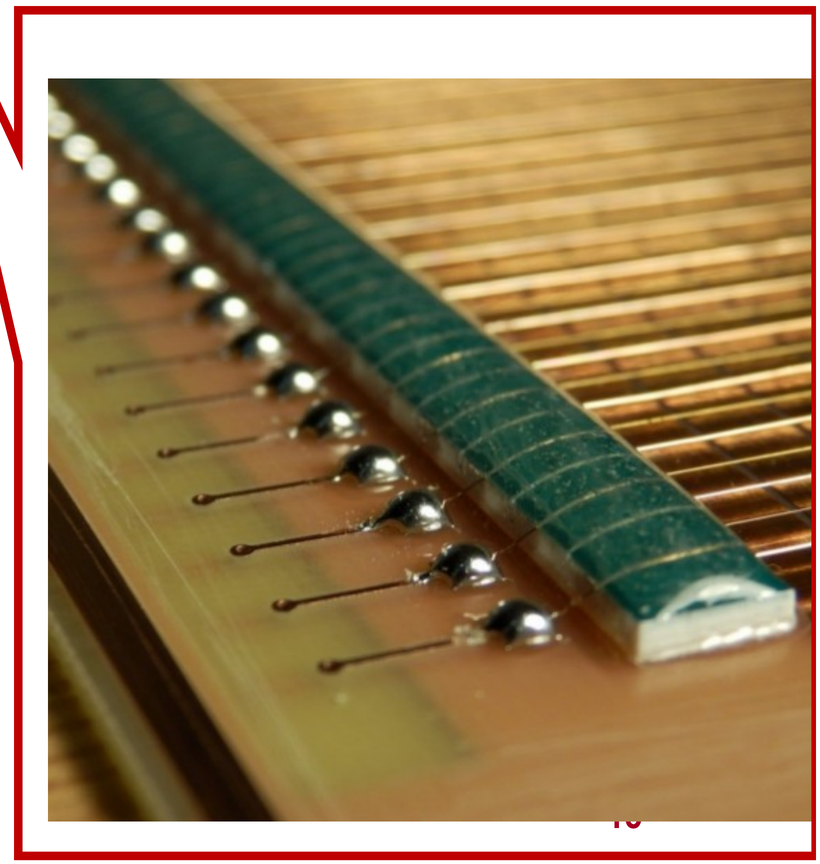
Multi-Wire Proportional Chambers (MWPC)

- These structures can be enclosed to form one plane of the detector
- Multiple layers can be placed in a succession to provide three dimensional position information



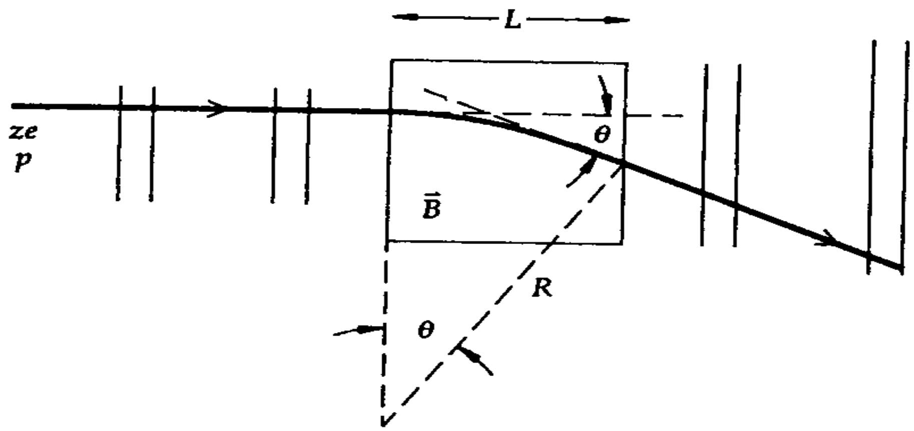
Example PWMC





Momentum Measurements

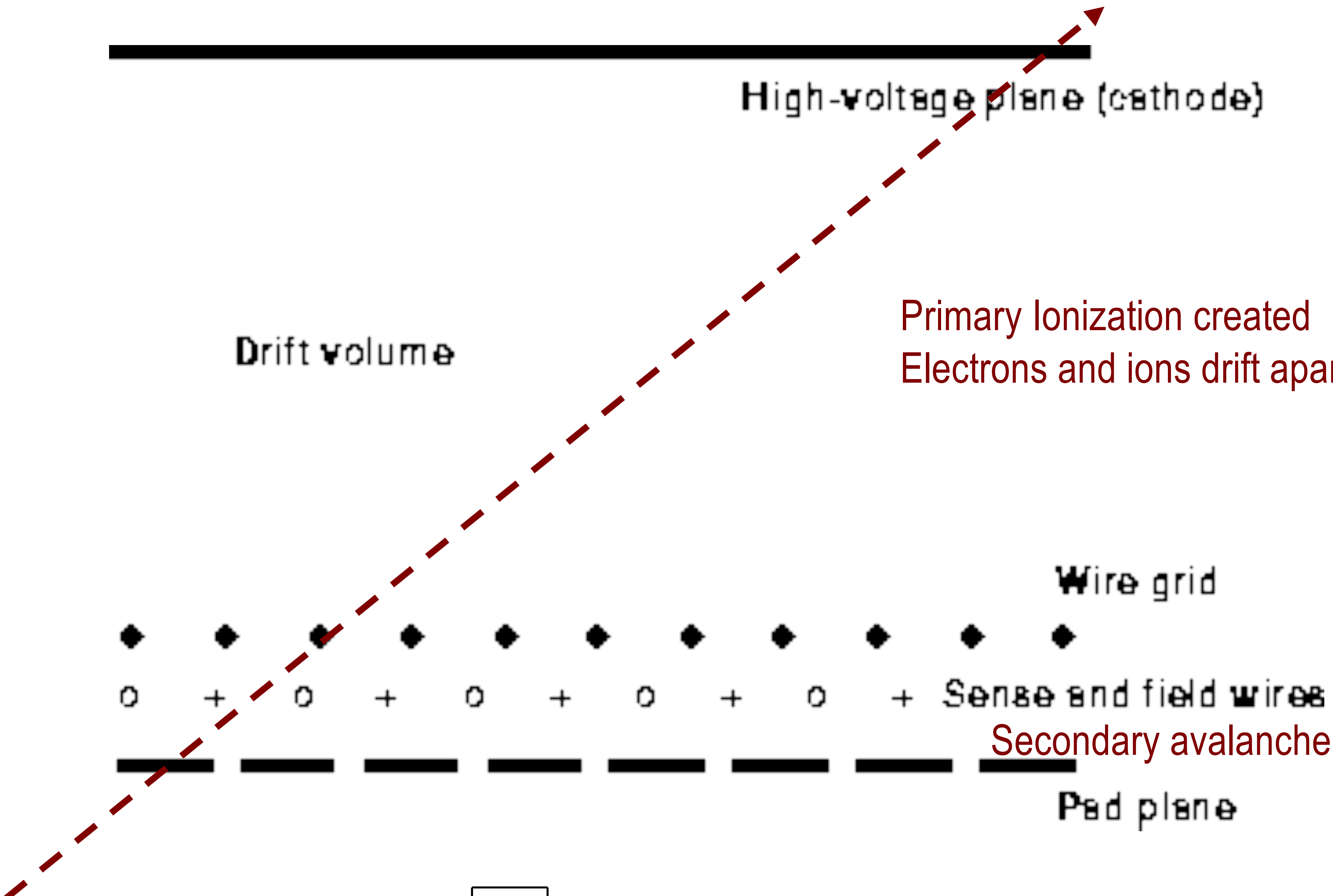
- A set of MWPC planes placed before and after a magnetic field can be used to obtain the deflection angle which in turn provides momentum of the particle



$$L = R\sin\theta \Rightarrow R = L/\sin\theta$$
$$p = qRB = zeLB/\sin\theta$$

- Multiple relatively constant electric field can be placed in each cell in a direction transverse to normal incident ➔ Drift chambers
- Typical position resolution of proportional chambers are on the order of 200 μm.

A Schematics of a Drift Chamber



Primary Ionization created
Electrons and ions drift apart

Secondary avalanche occurs

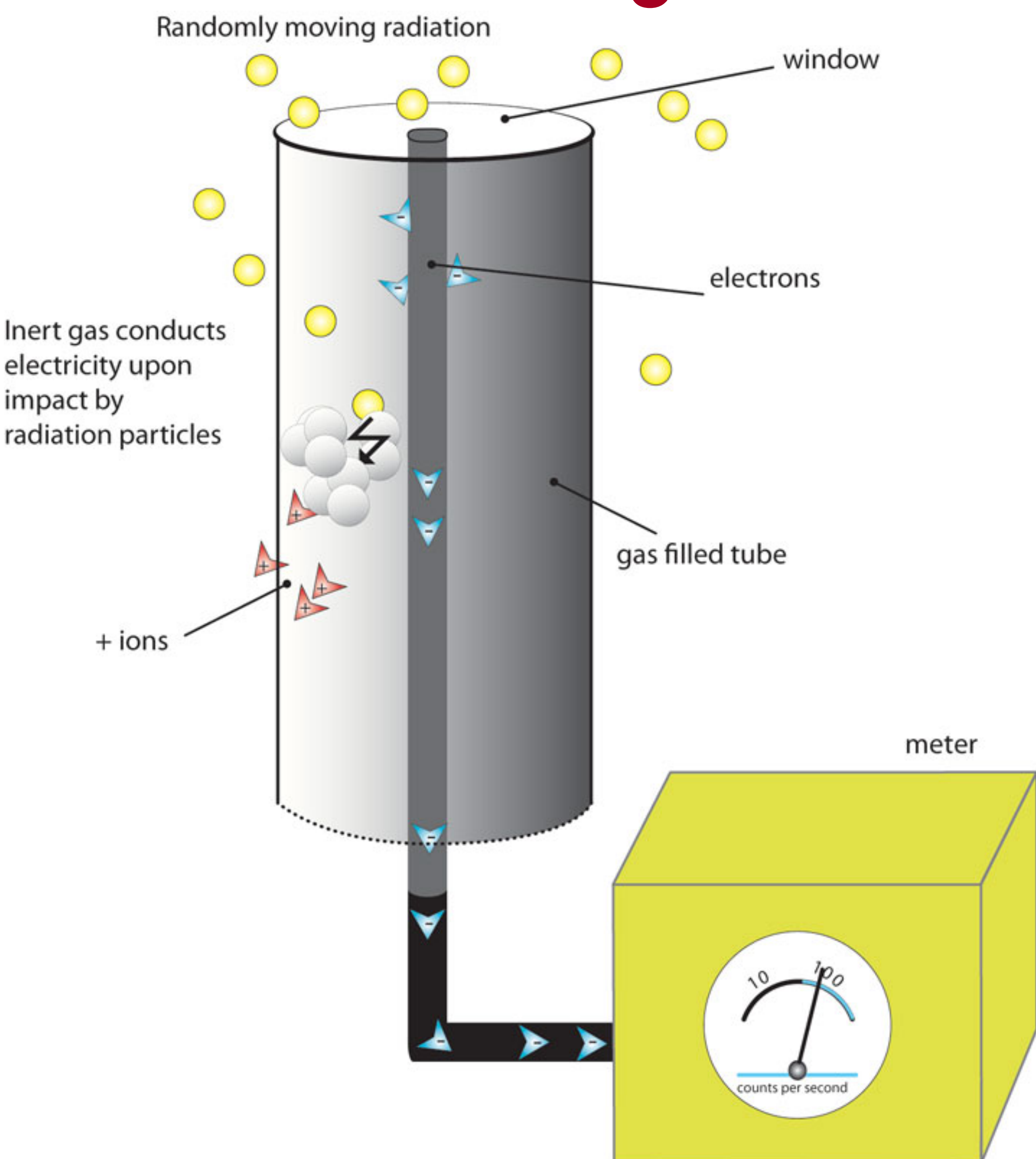
Geiger-Muller Counters

- Ionization detector that operates in the Geiger range of voltages
- For example, let's look at an electron with 0.5MeV KE that looses all its energy in the counter
- Assume that the gaseous medium is helium with an ionization energy of 42eV.
- Number of ionization electron-ion pair in the gas is $n = \frac{0.5 \times 10^6 eV}{42 eV} \approx 12,000$
- If a detector operates as an ionization chamber and has a capacitance of 1 nF, the resulting voltage signal is

$$V = \frac{Q}{C} = \frac{ne}{C} = \frac{1.2 \times 10^4 \times 1.6 \times 10^{-19} C}{1 \times 10^{-9} F} \approx 2 \times 10^{-6} V$$

- In Geiger range, the expected number of electron-ion pair is of the order 10^{10} independent of the incoming energy, giving about 1.6V pulse height

Geiger-Muller Counter



(Dis) Advantage of Geiger-Muller Counters

- Simple construction
- Insensitive to voltage fluctuation
- Used in detecting radiation
- Disadvantages
  - Insensitive to the types of radiation
  - Due to the large avalanche, takes long time (~1ms) to recover
    - Cannot be used in high rate environment

Scintillation Counters

- Ionization produced by charged particles can excite atoms and molecules in the medium to higher energy levels
- The subsequent de-excitation process produces lights that can be detected and provide evidence for the traversal of the charged particles
- Scintillators are the materials that can produce lights in visible part of the spectrum

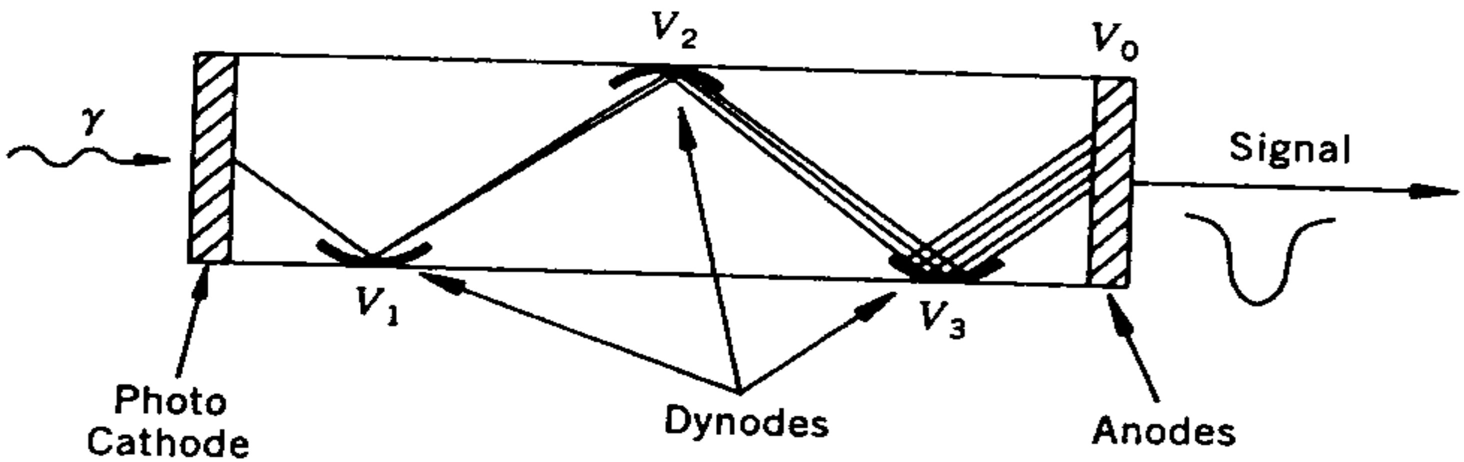
Scintillation Counters

- Two types of scintillators
  - Organic or plastic
    - Tend to emit ultra-violate
    - Wavelength shifters are needed to reduce attenuation
    - Faster decay time (10^{-8}s)
    - More appropriate for high flux environment
  - Inorganic or crystalline (NaI or CsI)
    - Doped with activators that can be excited by electron-hole pairs produced by charged particles in the crystal lattice
    - These dopants can then be de-excited through photon emission
    - Decay time of order 10^{-6} sec
    - Used in low energy detection

Scintillation Counters – Photo-multiplier Tube

- The light produced by scintillators are usually too weak to see
  - Photon signal needs amplification through photomultiplier tubes
    - Gets the light from scintillator directly or through light guide
      - Photocathode: Made of material in which valence electrons are loosely bound and are easy to cause photo-electric effect (2 – 50 cm diameter)
      - Series of multiple dynodes that are made of material with relatively low work-function
        - » Operating at an increasing potential difference (100 – 200 V) difference between dynodes

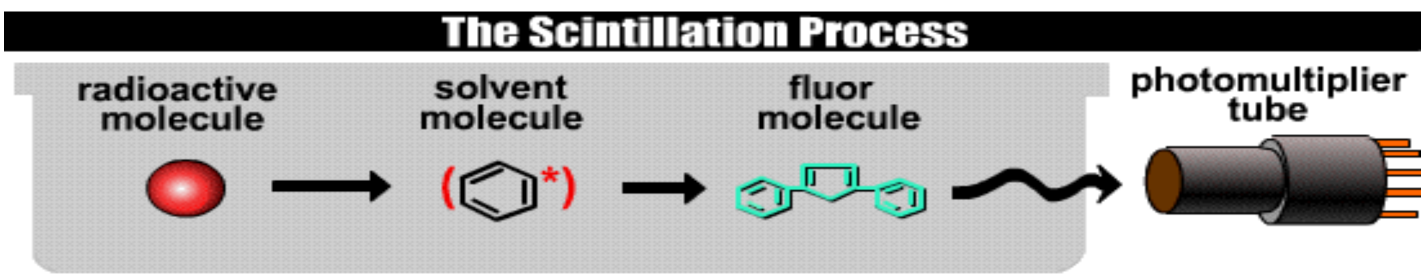
Scintillation Counters – Photo-multiplier Tube



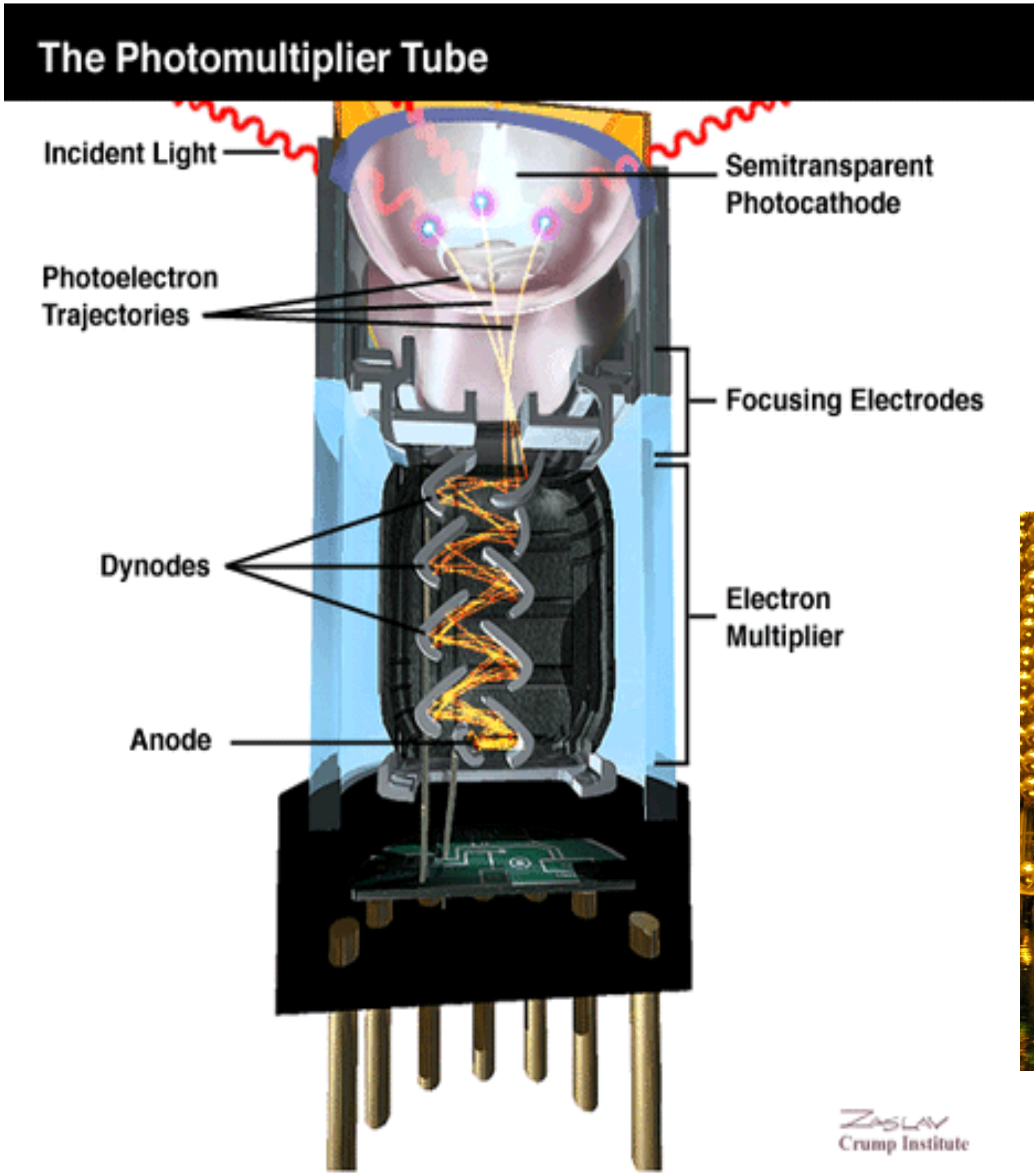
- The dynodes accelerate the electrons to the next stage, amplifying the signal to a factor of $10^4 - 10^7$
- Quantum conversion efficiency of photocathode is typically on the order of 0.25
- Output signal is proportional to the amount of the incident light except for the statistical fluctuation
- Takes only a few nano-seconds for signal processing
- Used in as trigger or in an environment that requires fast response
- Scintillator+PMT good detector for charged particles or photons or neutrons

Scintillation Materials

Material	Radiation	Comment
Anthracene	Beta	-
ZnS(Ag)	Alpha	powder
NaI(Tl)	Gamma	crystal
CsI(Na)	X	crystal
p-terphenyl in toluene	Gamma	liquid
p-terphenyl in polystyrene	Gamma	plastic



Some PMT's



Super-Kamiokande detector