PHYS 3446 – Lecture #16

Tuesday April 14, 2015
*Dr. **Brandt***

- Ionization Detectors
- Time-of-Flight
- Bonus for finishing project in April

Projects

1 UA1 Higgs (non) discovery/Carlo Rubbia Nick Stadler, John Havens, Paul T.

2 Top Discovery CDF/Dzero John Crouch, Matthew Gartman

3 J/Ψ (Charm quark) Michael Davenport, Charles Knight, Richard Humphries

4 Top Quark at LHC: Kathleen Brackney, David Soward, Kevin Strehl

5 Charged Higgs1 search/discovery: Ashley Herbst, Anthony Rich

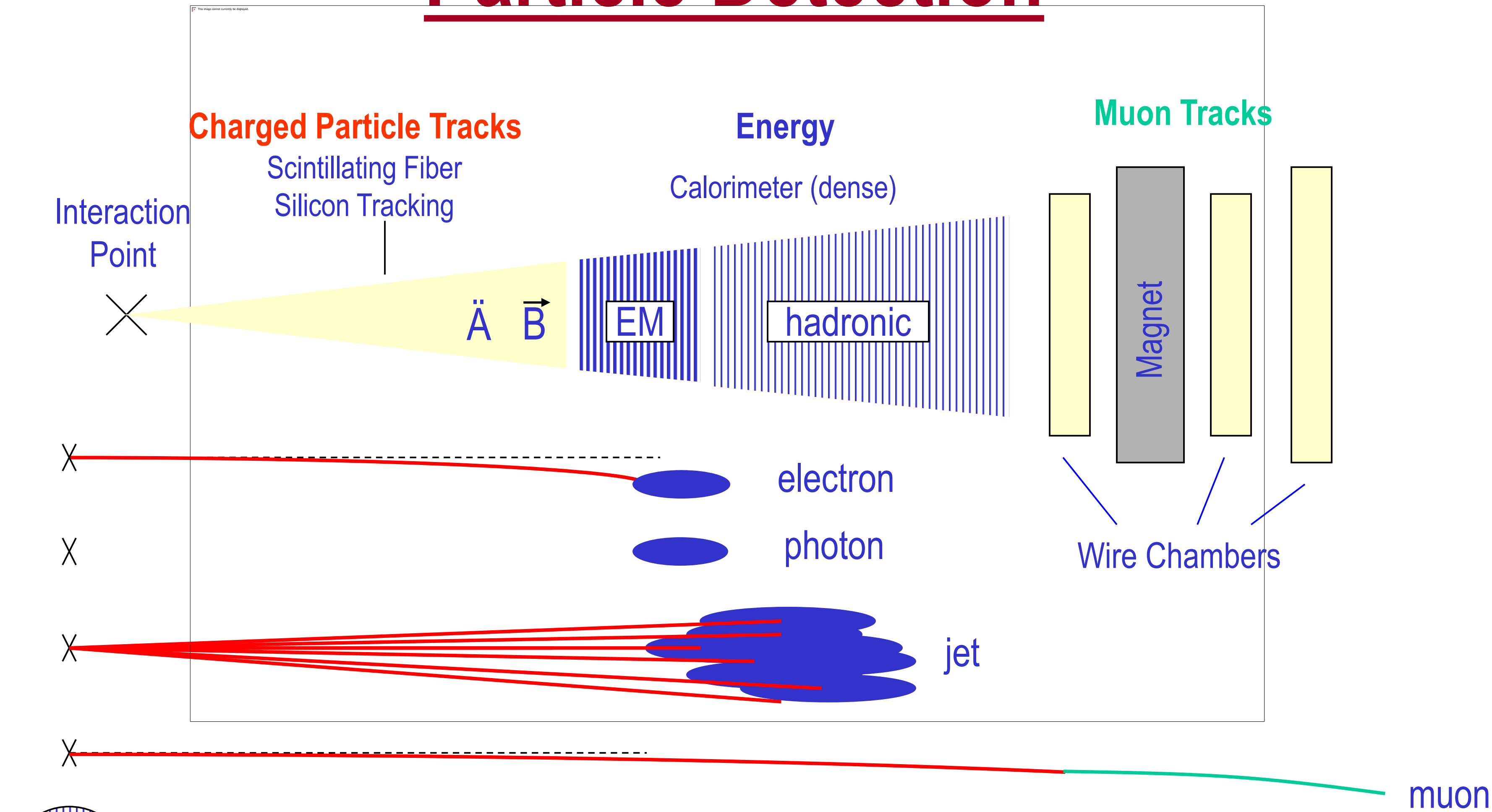
6 Charged Higgs2: Kelly Claunch, Robert Mathews, Charles Jay

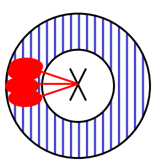
7 Higgs Discovery (ATLAS/CMS): Raul Dominguez, Peter Hamel, Kennedy

8 B quark Discovery: Garrett Leavitt, Bernard Nuar, Rajendra Paudel

1) Intro/Theory-what are you looking for and what is it's signature and background: how do you know if you find it
2) Detector-how is detector optimized for the task at hand, trigger/data collection
3) Analysis-operate on the data to accomplish the goals/Conclusion
4) Grading will include iintermediate milestones

Particle Detection





neutrino -- or any non-interacting particle missing transverse momentum

We know x,y starting momenta is zero, but along the z axis it is not, so many of our measurements are in the xy plane, or transverse

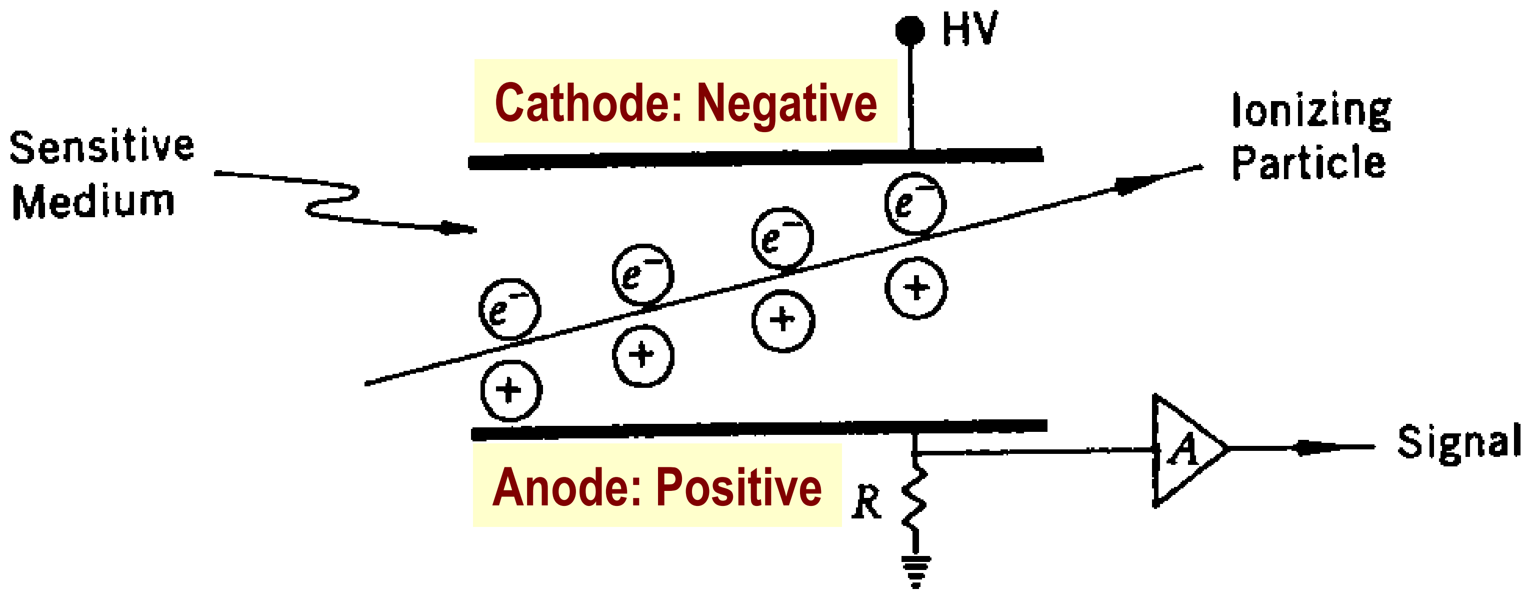
Ionization Detectors

- Measure the ionization produced when particles traverse a medium
- Can be used to
  - Track charged particles path 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 electrons

Ionization Detectors – Chamber Structure

- Basic ionization detector consist of
  - A chamber with an easily ionizable medium
    - The medium must be chemically stable and should not absorb ionization electrons
    - Should have low ionization potential ($\bar{I}$) ➔ 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

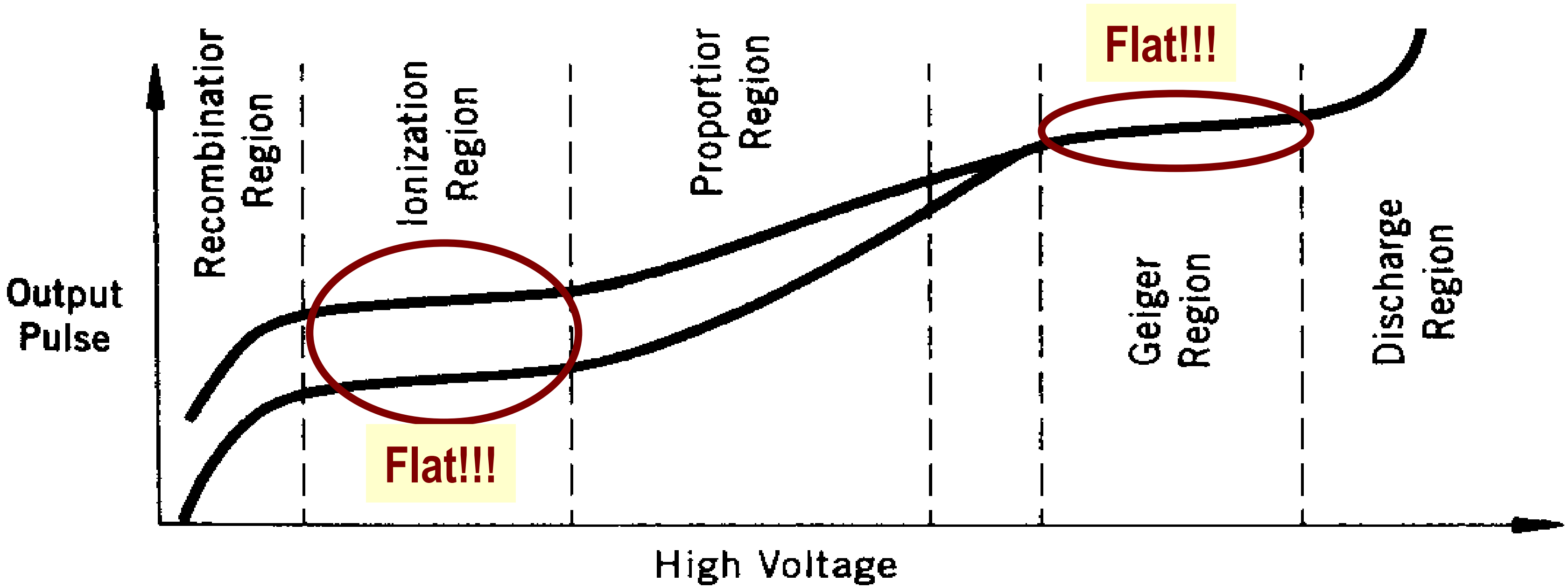
Ionization Detectors – Chamber Structure



- The ionization electrons and ions drift to their corresponding electrodes, the anode and the 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

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

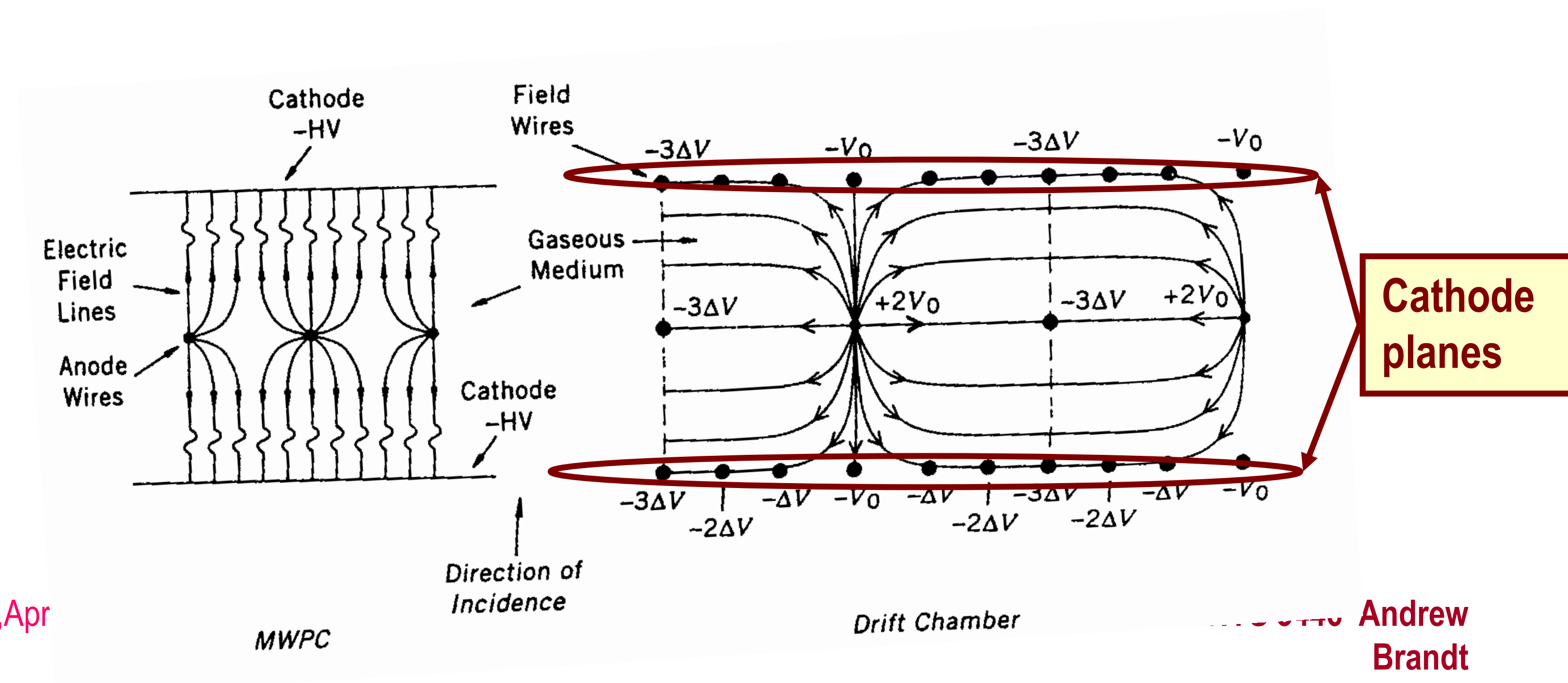
- Operate at relatively low voltage (in ionization region of HV)
- Generate no amplification of the original signal
- Output pulses for minimum ionizing particle is small
- Insensitive to voltage variation
- Have short recovery time → Used in high interaction rate environment
- Linear response to input 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.
- Typical amplification of factors of ~10^5
- Use thin wires (10 – 50 μm diameter) as anode electrodes in a cylindrical chamber geometry
- Near the anode wire where the field is strongest, secondary ionization occurs giving a multiplicative effect and a large voltage on the wire nearest to the passing particle
- Sensitive to voltage variation ➔ not suitable for energy measurement
- Typically used for tracking device

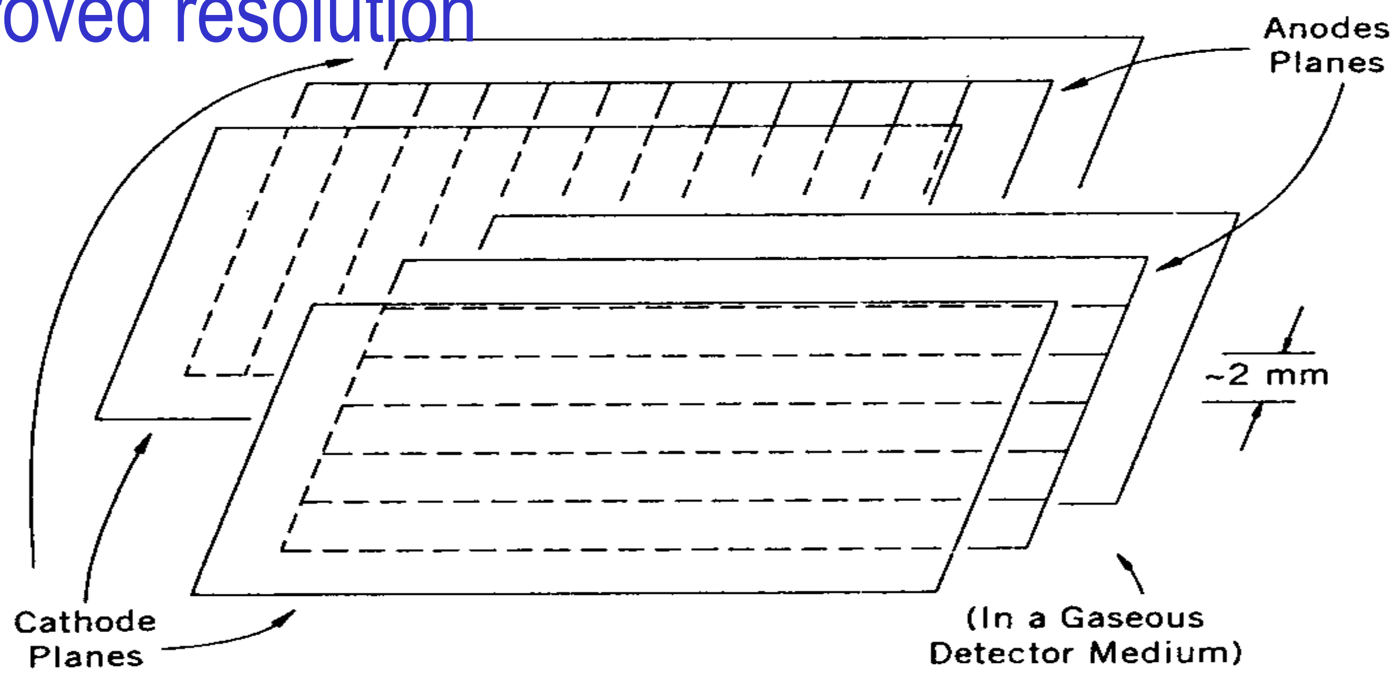
Multi-Wire Proportional Chamber (MWPC)

- G. Charpak et al. developed a proportional counter into a multiwire proportional chamber
  - One of the primary position detectors in HEP
- A plane of anode wires positioned precisely w/ about 2 mm spacing, which are sandwiched between cathode planes (or wires)



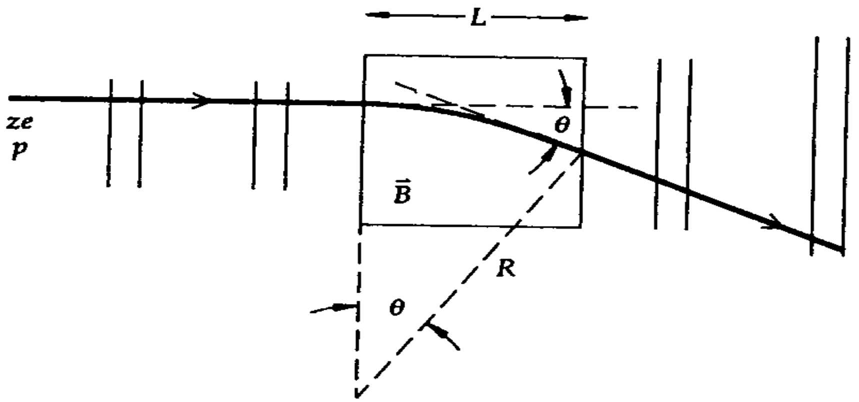
Multi-Wire Proportional Chambers (MWPC)

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



Momentum Measurement

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



F=qvB/c=mv^2/R

p=Rbze/c

$$R = L/\sin\theta$$

$$p = \frac{LBze}{c\sin\theta}$$

- **Drift chambers** have ~constant electric field in each cell in the direction transverse to normal incidence, so ionized electrons drift along field lines at slow and constant velocity, so from time of signal can measure position
- Typical position resolution of drift chambers are on the order of 200 μm.

Geiger-Muller Counters

- Ionization detector that operates in the Geiger range of voltages
- For example, consider an electron with 0.5MeV KE that loses 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 $n = \dfrac{0.5\times10^{6} eV}{42eV} \approx 12{,}000$
- If a detector operates as an ionization chamber and has a capacitance of 1 nF, the resulting voltage signal is

$$V = \frac{Q}{C} = \frac{ne}{C} = \frac{1.2\times10^{4}\times1.6\times10^{-19}C}{1\times10^{-9}F} \approx 2\times10^{-6}V$$

- 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

Features of Geiger-Muller Counters

- Advantages
  - Simple construction
  - Insensitive to voltage fluctuation
  - Useful for detecting radiation
- Disadvantages
  - Insensitive to the type of radiation
  - Due to large avalanche have a long recovery time (~1ms), so 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 light that can be detected and provide evidence for the traversal of the charged particles
- Scintillators are material that can produce light in visible part of the spectrum

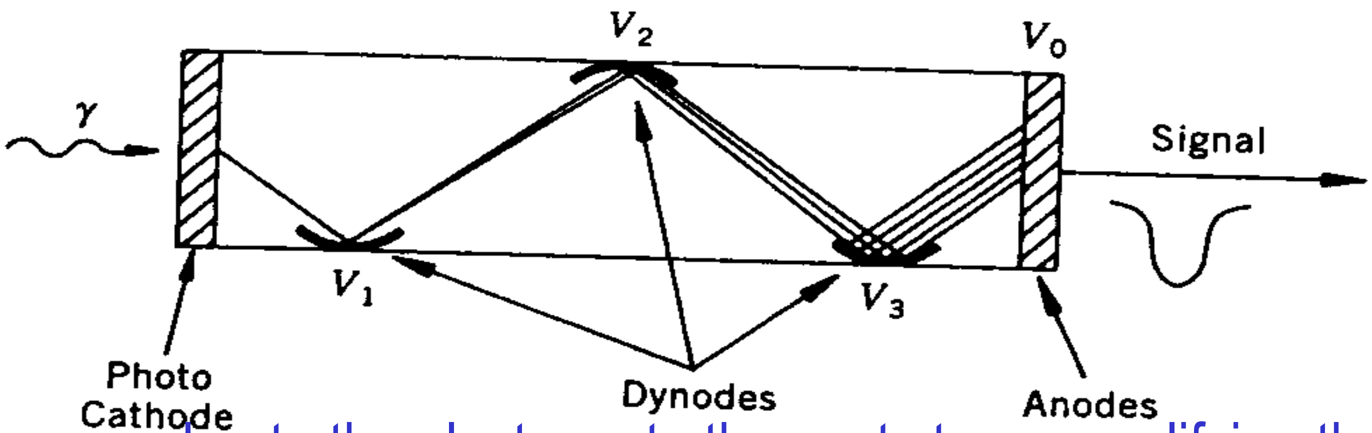
Scintillation Counters

- Two types of scintillators
  - Organic or plastic
    - Tend to emit ultra-violet
    - 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
  - Light can pass directly from scintillator to PMT or else through a light guide
    - Photocathode: Made of material in which valence electrons are loosely bound and subject to photo-electric effect
    - Series of multiple dynodes that are made of material with relatively low work-function
      - » Operate at an increasing potential difference (100 – 200 V) difference between dynodes

Scintillation Counters – Photomultiplier Tube



- The dynodes accelerate the electrons to the next stage, amplifying the signal by a factor of $10^4 – 10^7$
- Quantum conversion efficiency of photocathode is typically on the order of 25%, but newer photocathodes can reach 50%, and specialized devices greater than 80%
- Output signal is proportional to the amount of the incident light except for statistical fluctuations
- Takes only a few nano-seconds for signal processing
- Used as trigger or in an environment that requires fast response
- Scintillator+PMT good detector for charged particles