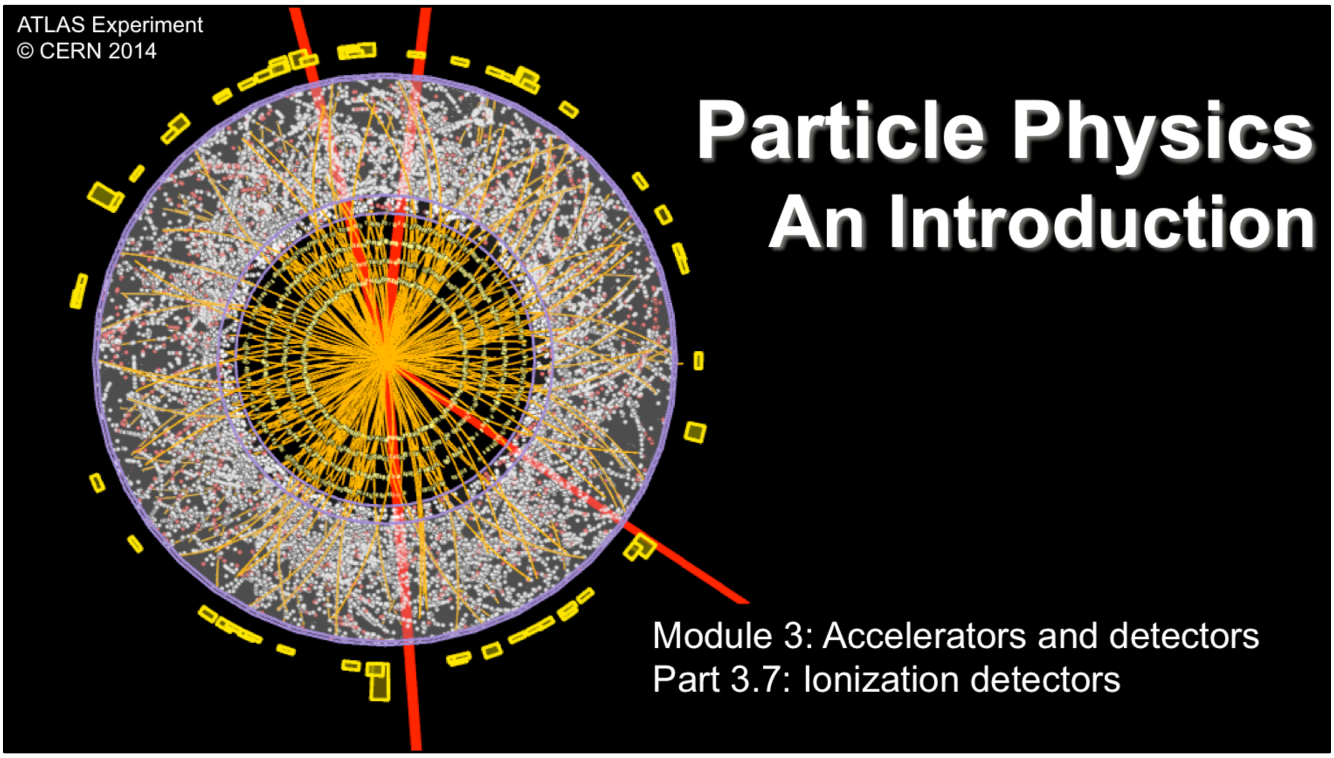
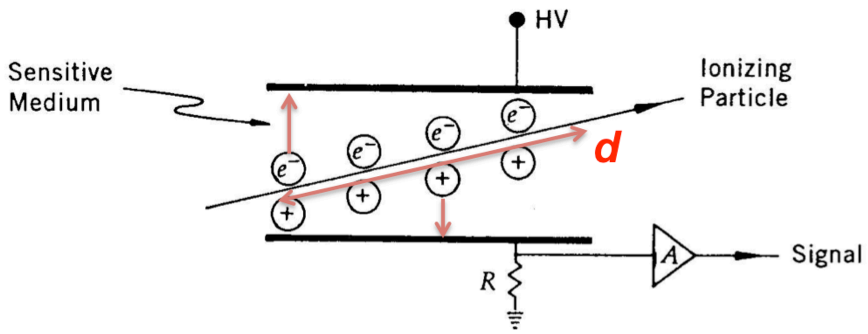


In this module, we will touch the basics of particle acceleration and detection methods.

In this video and the next, we discuss charged particle detection techniques. First we talk about ionization detectors in general, and gaseous ones in particular.

After watching this video, you will know:

- How gaseous ionization detectors count charged particles and measure their trajectories.
- Which operational modes such a detector can have.



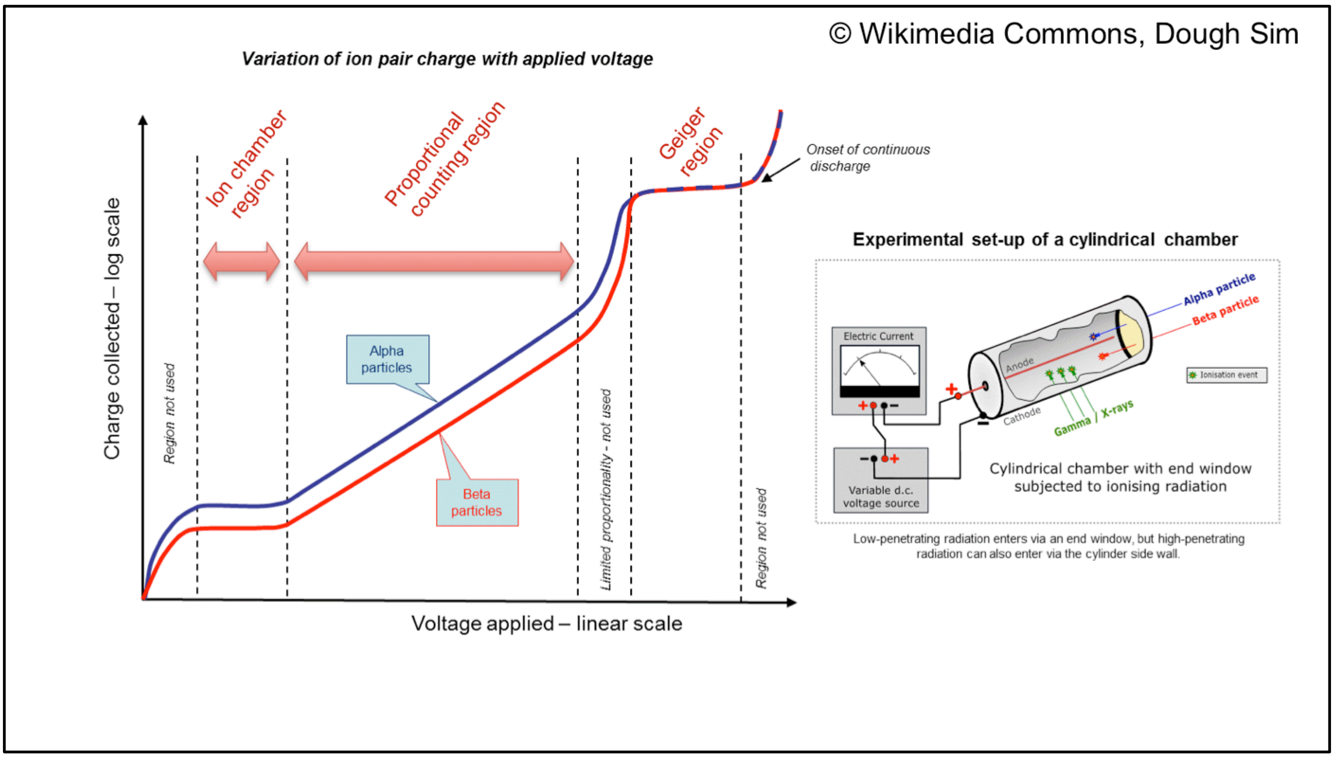
$$N_I = -\frac{dE}{dx}\frac{d}{W}$$

Ionization sensors detect the passage of a charged particle by measuring the total charge of electrons and/or ions produced by the ionization of the medium. This medium can be a gas, a liquid or a solid.

To collect the electrons and the ions before they recombine into atoms, an **electric field** must be present, which separates the charges and makes them drift towards electrodes. The charges induce a small current on the electrodes, a signal which can be detected through an **amplifier**.

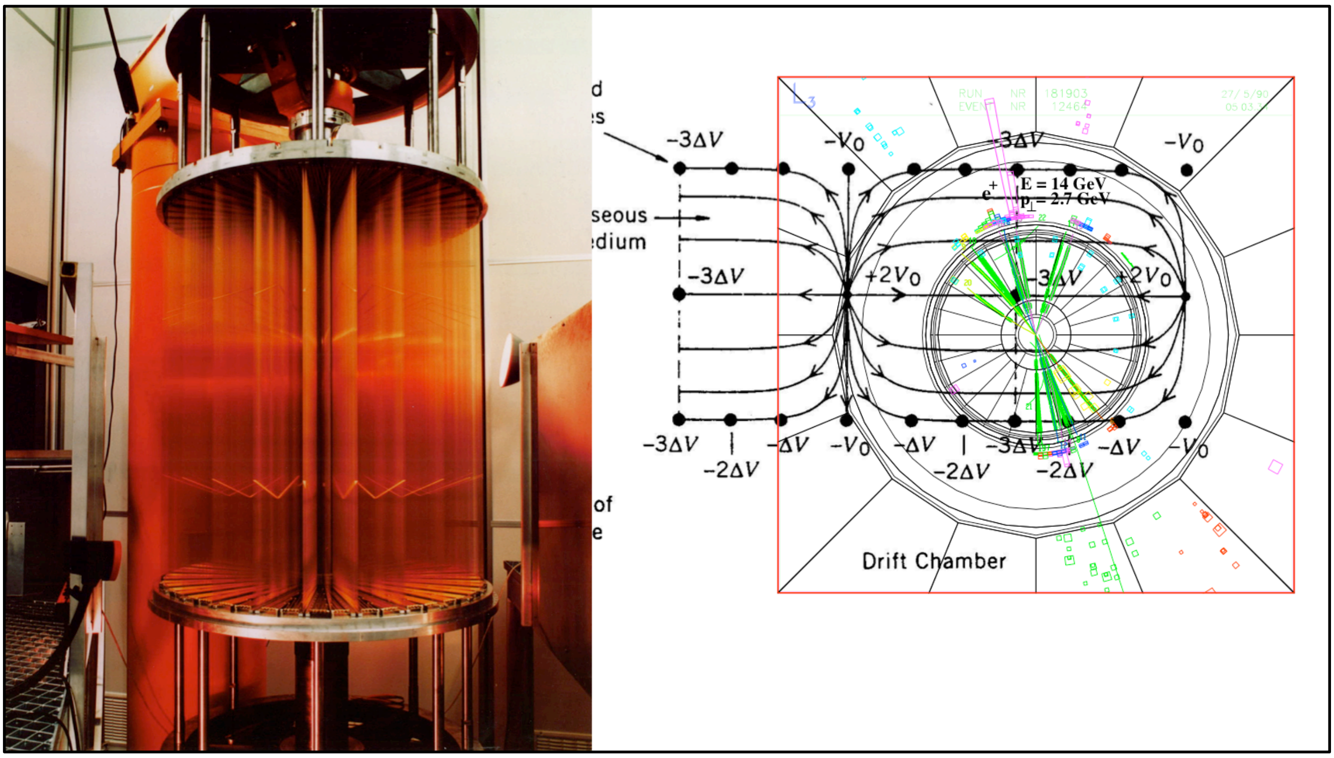
The **average number of** electron-ion **pairs** produced during the passage of a charged particle is proportional to *dE/dx*, from the Bethe-Bloch formula, with *d* the path length inside the detector, and *W* the average energy required to create an electron-ion pair. In a gas, *W* is typically ~ 30 eV.

The size of the detected electrical signal depends on several technical factors, but mostly on the **applied high voltage**.



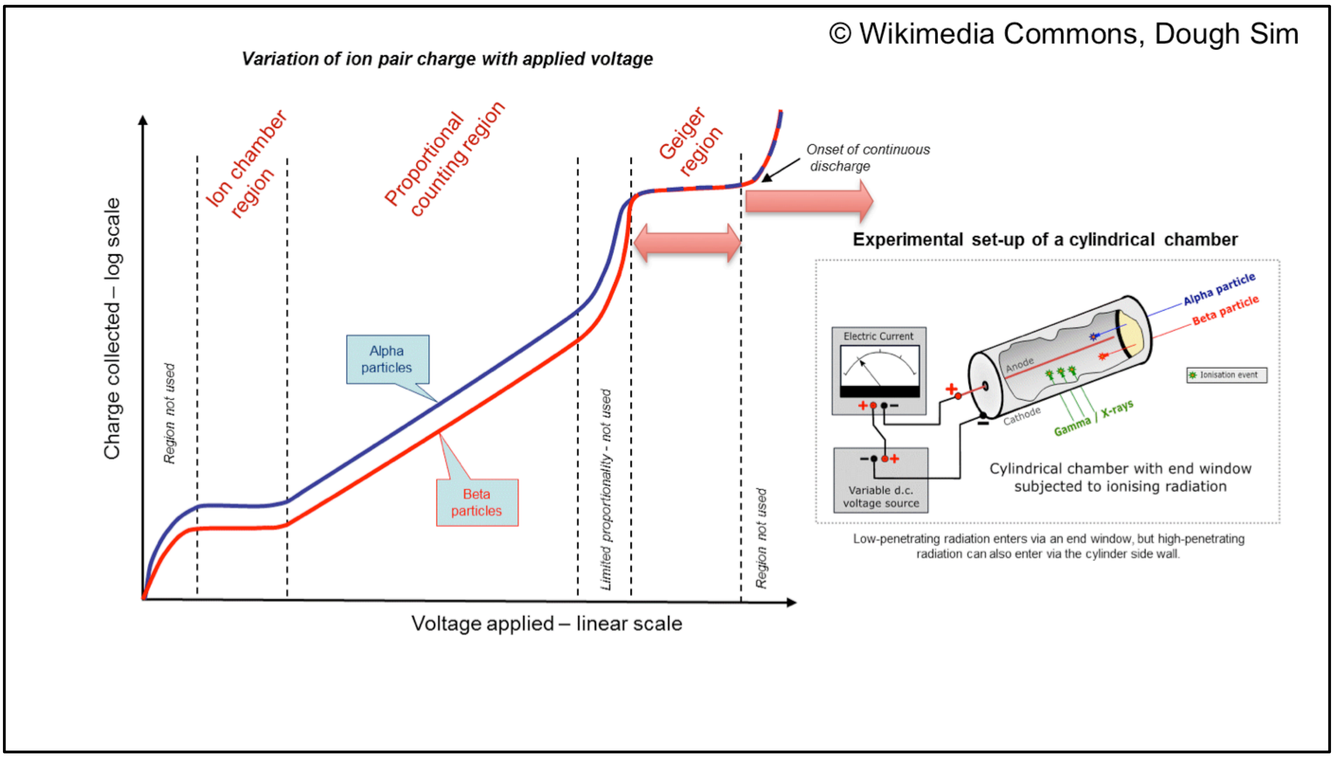
The most important **operational regions** are shown in this logarithmic graph of the collected charge versus the high voltage applied:

- **Ionization region:** When the voltage is large enough to prevent ion-electron recombination, ionization charges drift towards the electrodes. The resulting signal reflects the **total ionization charge**.
    - Advantage: **excellent energy resolution** and very good linearity.
    - Disadvantage: **weak signal** because there is no amplification of charges in the detector. Special low noise amplifiers have to be used.
    - Utilization: **ionization chambers,** filled with gas or noble liquid. Solid state **detectors made of Silicon** or Germanium, which will be discussed in the next video, also work in this region.
- **Proportional region**: If the field is high enough, ***E* ~ 10 ^{4} V/cm**, electrons are accelerated by the electric field and gain enough energy to produce **secondary ionization**. The total number of atoms ionized grows **exponentially with the applied voltage**. **The amplification factor is ~ 10^4 to 10^8**. A large amplification factor can be obtained in gases, thus detectors operating in this region are mostly gas filled.
    - Advantage: no need to have very low noise electronics.
    - Disadvantage**: energy resolution is worse** because of fluctuations in the amplification process. These fluctuations are due mainly to instabilities in **external parameters**: HV, temperature, etc.



- **Proportional region**: detectors operating in this region are mainly used to measure the position of charged particles: drift chambers, proportional wire chambers etc. In these chambers, the electric field is implemented using thin wires, to put as little material as possible in the path of the particles.
- As an example, the left picture shows a photograph of the **central drift chamber** of the L3 experiment at the Large Electron Positron collider at CERN.
- The right picture shows **charged particle tracks** in yellow, reconstructed from the **positions** measured by each anode wire, shown by the green crosses.
- As the particles lose very little energy in the gas by *dE/dx*, the measurement is **not destructive**. Wire chambers are ideal to measure charged particle tracks in front of a calorimeter, which will then measure the particle energy by absorption.

We'll talk about spectrometers and calorimeters in **video 3.10.**



- **Geiger region:** If the field is increased even more, the energies of secondary electrons increase rapidly and they excite or ionize other atoms. An **avalanche** of **free electrons** is thus produced. Furthermore a large number of photons is produced when the atoms fall back into their ground state. These photons add to the ionization by photo-electric effect along the anode wire where the electric field is strongest. The avalanche develops quickly and an **audible discharge** is produced. This is the principle of the Geiger counter.
- Due to the discharge, the **current on the anode is saturated**. The signal amplitude is independent of the primary charge.
  - Advantage: radiation levels can be measured by counting the particle rate, even for very low energies.
  - Disadvantage: the energy of the particle cannot be measured.
- The discharge stops when the space charge formed by the positive ions left around the anode decreases sufficiently the electric field so that the avalanche process can no longer continue. The detector will be insensitive to new ionization until the positive ions have migrated far enough away from the anode. This is the origin of **dead time** in Geiger counters.
- A further increase in the electrical field produces a permanent discharge, a **short circuit** between cathode and anode.

- Here is a picture of a **Geiger counter,** which makes an audible sound every time a particle is counted. The black tube contains the Geiger tube, the yellow box the power supply, electronics and the rate display.

In the next video, Mercedes discusses semiconductor-based ionization detectors.