Particle Detectors

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How do we detect particles?

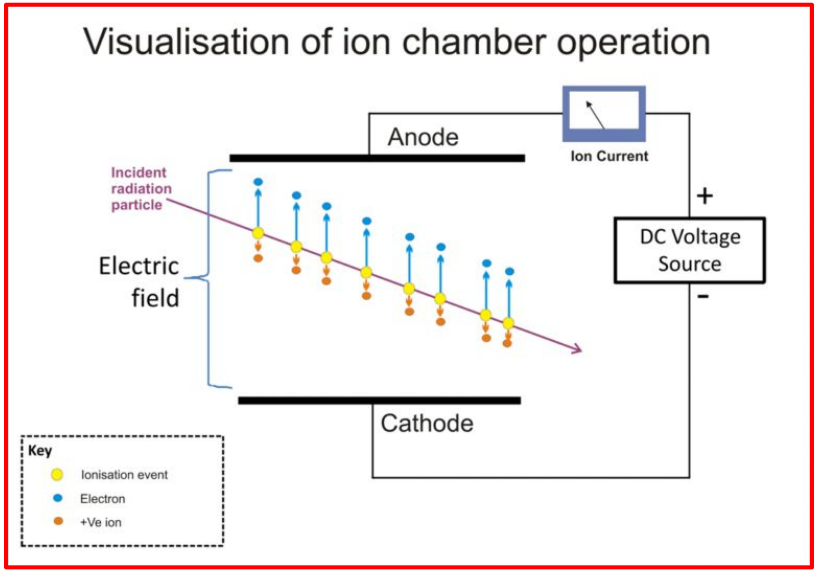
Since particles are too small to see directly, we rely on observing how they interact with matter to detect them. These interactions produce measurable signals that reveal a particle's presence and properties. The key processes we use include:

- **Ionization**, where charged particles leave trails of ions,
- **Scintillation**, where materials emit light upon excitation,
- **Cherenkov Radiation**, where particles moving faster than light in a medium emit a cone of light, and
- **Energy Absorption**, where particles transfer their energy to the detector material.

By combining these methods, we can reconstruct information about the particle's energy, velocity, momentum, and type, enabling us to explore the unseen world of subatomic particles.

Interaction processes: Ionization

- Ionization occurs when a charged particle passes through a material, knocking electrons out of atoms and creating a trail of ion pairs.
- The ions and free electrons are collected using electric fields.
- The resulting electrical signal is amplified and analyzed.

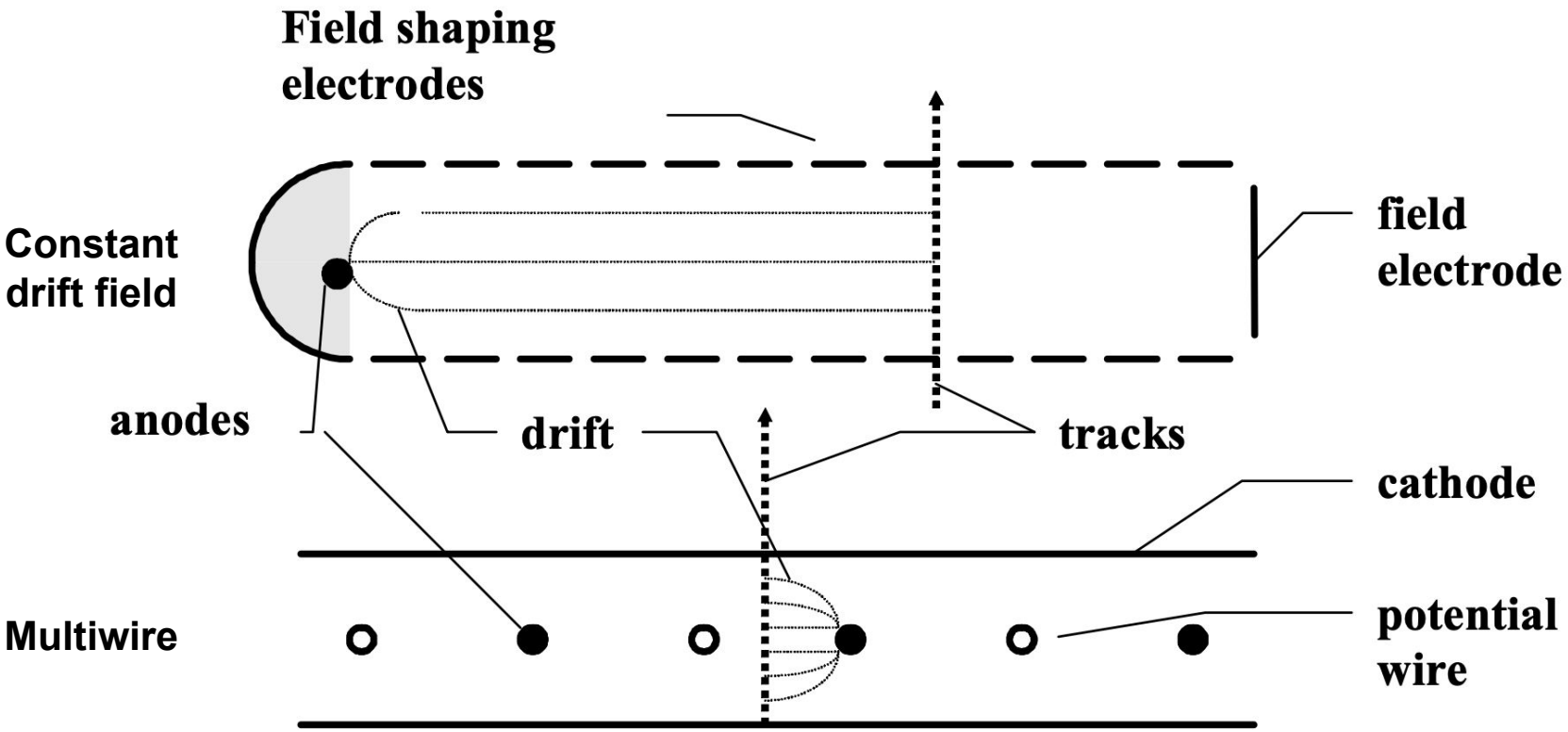


Types:

- **Gaseous Detectors:** Particles leave ionization trails in gas; electrons drift to wires.
- **Solid-State Detectors:** Silicon Detectors: Charged particles create electron-hole pairs in silicon.

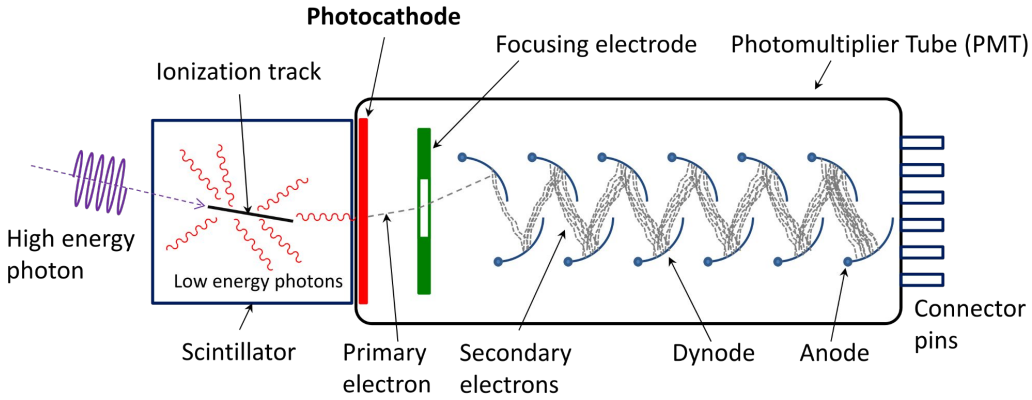
Ref: https://www.futurelearn.com/info/courses/frontier-physics-future-technologies/0/steps/240858

Interaction processes: Ionization



Interaction processes: Scintillation

- Scintillation is the process where certain materials emit light when high-energy particles pass through them. These materials are called **scintillators**.
  - A particle interacts with the atoms in the scintillator material, exciting electrons to higher energy states.
  - When these electrons return to their normal states, they release energy as light (photons).
- The emitted light is collected by a **photodetector** such as a photomultiplier tube (PMT) or a silicon photomultiplier (SiPM). The photodetector converts the light into an electrical signal, which can then be measured and analyzed.



Ref: https://en.wikipedia.org/wiki/Scintillation_counter

Note:

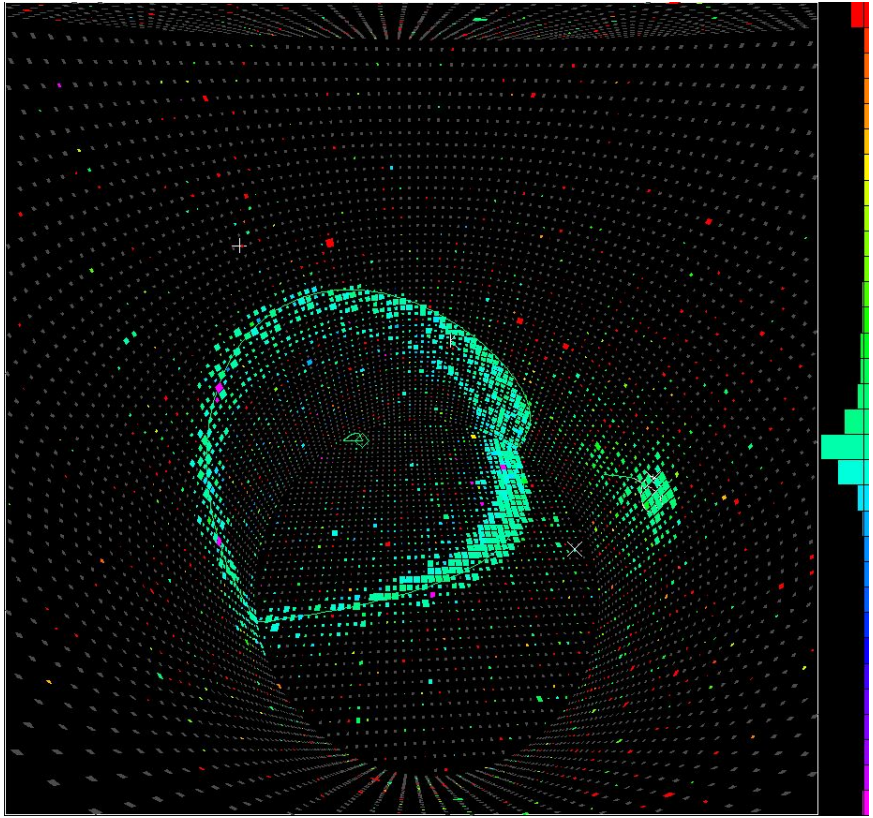
Interaction processes: Cherenkov radiation

- Cherenkov radiation is light emitted when a charged particle travels through a medium faster than the speed of light in that medium.

Note:

- Same as scintillation, the emitted light is collected by optical components like mirrors and focused onto photodetectors. The analysis of Cherenkov detectors can determine the velocity of particles. By combining this information with the particle's momentum, we can accurately identify the type of particle.

Interaction processes: Cherenkov radiation



Note:

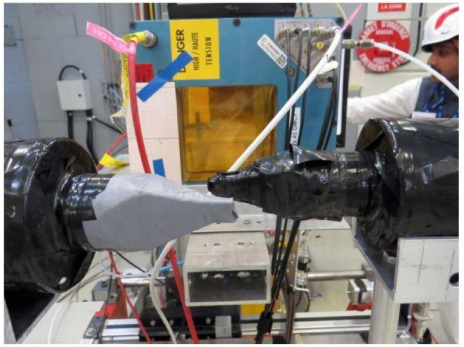
Ref: https://neutrino.kek.jp/figures.html

Interaction processes: Energy absorption

- Energy absorption occurs when a particle passing through a detector loses its energy to the detector material via various interactions. Measuring the amount of absorbed energy allows us to determine the particle's energy and, in some cases, identify the particle type.
- The particle deposits energy in the form of heat, ionization, or excitation of atoms and molecules. The deposited energy is converted into a measurable signal, such as light (scintillation) or an electric current.

Detectors of type (1)

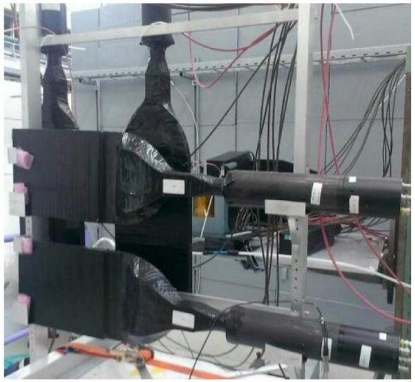
- Delay Wire Chamber – 2D tracker with an area of 10x10cm and a resolution of 200−300μm ⇨ Where?
- Beam telescope from silicon pixel detectors – 3D tracker with an area of 2x2 cm ⇨ Where?
- WENDI detector for neutrons



Detectors of type (2)

- Scintillators + photomultipliers – particle counting, trigger, time-of-flight measurements ⇨ How many? When?
- Threshold Cherenkov detectors ⇨ What type of particle?
- Lead crystal calorimeter (Cherenkov) + photomultipliers – energy of particles, with a volume of 10x10x37 cm

You are free to design and test your own detector!



Reminder

Particle Detectors

- Each detector has its own readout system (you don’t need to worry about that)
- The data-acquisition system controls all the detectors and the experiment (you don’t need to worry about that)

Evaluation Criteria

- Feasibility of the experiment
- Motivation of your experiment idea and your participation
- Creativity of the experiment
- Following a scientific method