

PAN-2014: Radiation detectors

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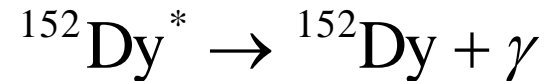
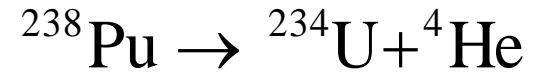
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Plan

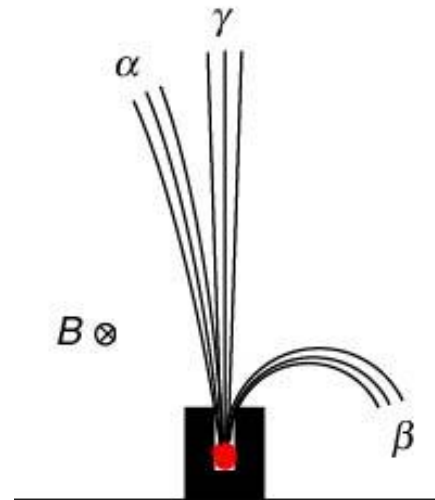
- Same basics about the interactions of radiation with matter
- The scintillation counter
- Cosmic rays

Most common decay modes of nuclei

- α decay: emission of a ${}^4\text{He}$ nucleus
- β decay: emission of an electron
- γ decay: transition between states



- The deviation of the particles in a magnetic field gives the sign of the electric charge.

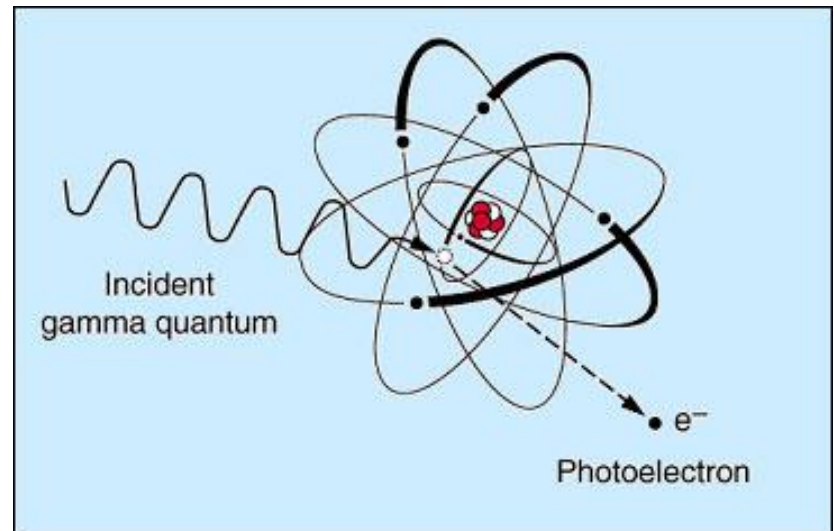
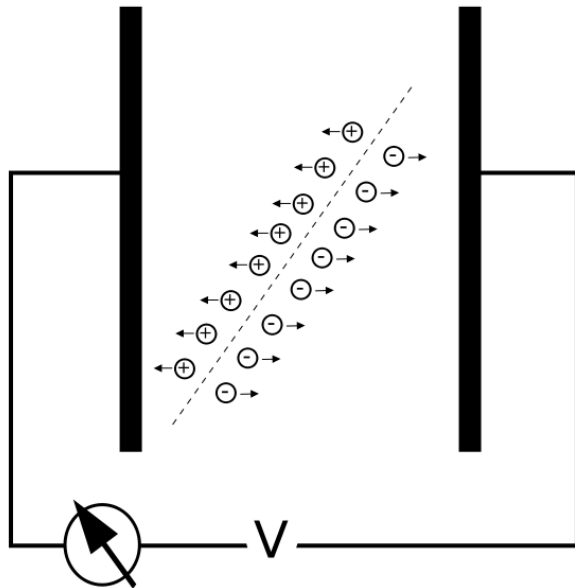


α : alpha rays (+)
 β : beta rays (-)
 γ : gamma rays (no charge)

B : magnetic field

Interaction of radiation with matter

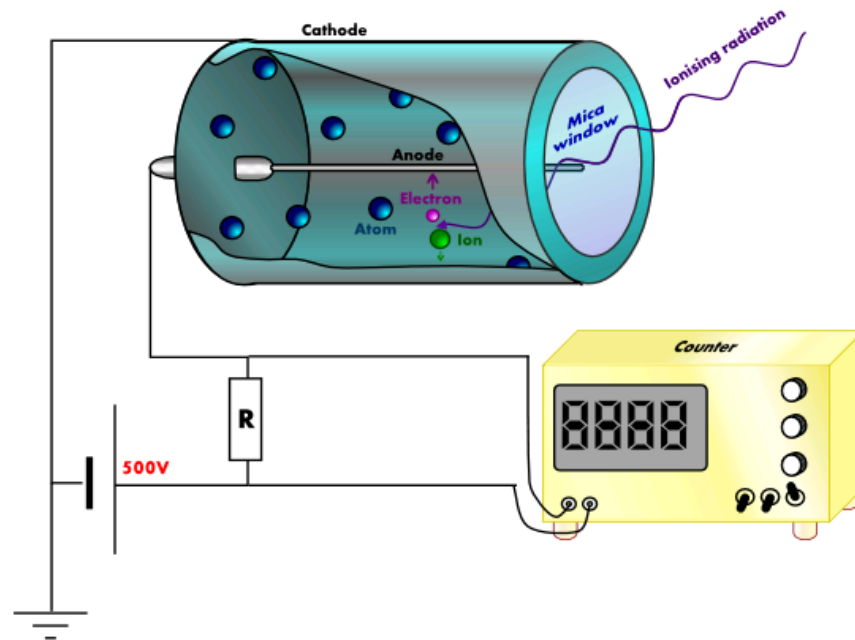
- Ionization radiation interacts with the electrons of materials where they enter.
- A charged particle interacts with many electrons through the Coulomb interactions and loses energy.
- A photon can only collide with a single electron.



Radiation monitors

- Radiation monitors combine a cell which is sensitive to the ionization radiation with a counter.
- Shows the basic principle of any detector: ionization + conversion into an electric signal.

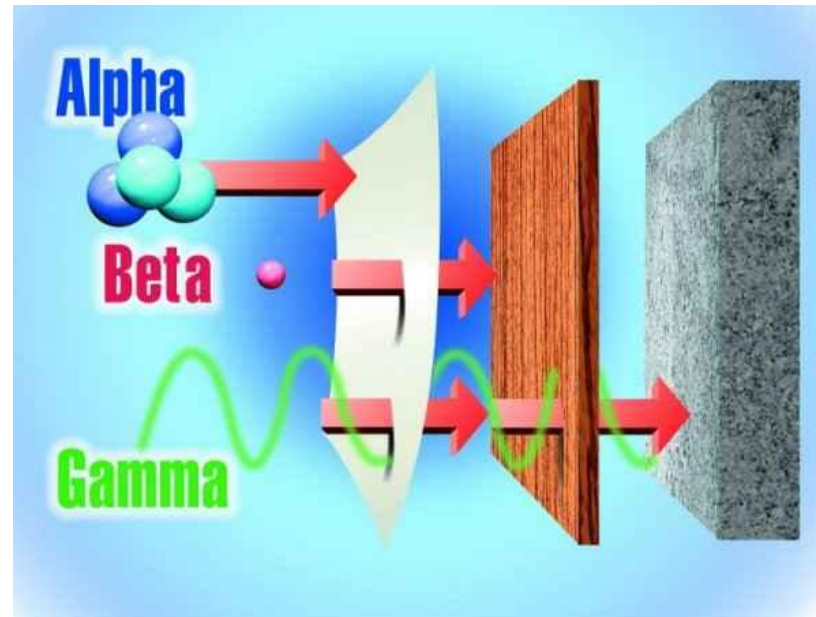
Principle of a Geiger-Mueller counter.



The electrical signal can also be converted to sound (“tic”).

Absorption of radiation in matter

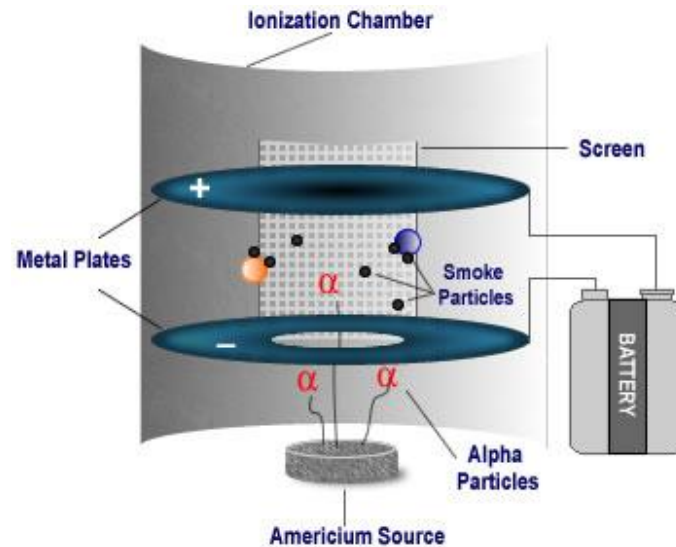
- Radiation emitted by nuclei lose energy during the interaction with matter.



- For typical energies, the heavier the particle, the less penetrating it is.

Example of "detection" of heavy particles

- An electric current flows continuously when the chamber is filled with air.



- In the presence of smoke molecules the gas is neutralized stopping the current and triggering the alarm.

Scintillation materials

- After ionization by the primary radiation, atoms/molecules of matter de-excite emitting photons. Scintillators materials are fabricated such as to increase the number of photons.



- Organic: molecular transitions (plastics)
- Inorganic: transitions in atomic dopants (crystals)

Properties of scintillators

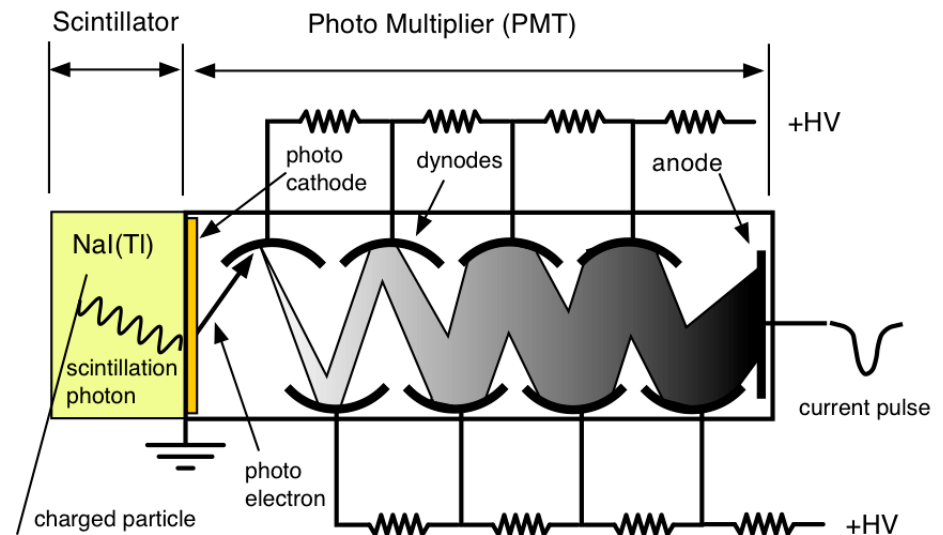
- Linear conversion of energy deposited into number of photons.
- Efficient conversion into near visible light (ex. plastic scintillator: 20 k/MeV)
- Transparent to scintillation photons (optical medium with small auto-absorption)
- Short decay times for fluorescence (fast)
- Robust mechanical properties

Photomultiplier devices

- We need to convert the light signal into an electric current in order to produce a "signal" of the particle that produced the light.
- The conversion of light into current is made by a photomultiplier

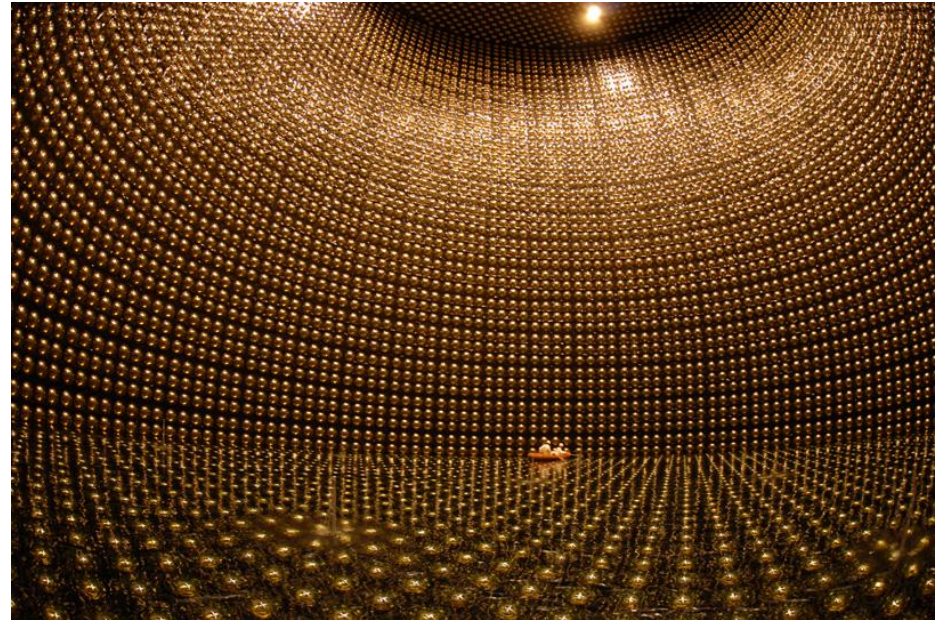
- Vacuum tube with a sensitive material (photocathode) a multiplication stage (dynodes with resistive voltage divider) and a circuit to produce the signal

- Photocathode: photoelectric effect
- Electrons avalanche down (multiplication)
- Can be affected by magnetic fields (shield)



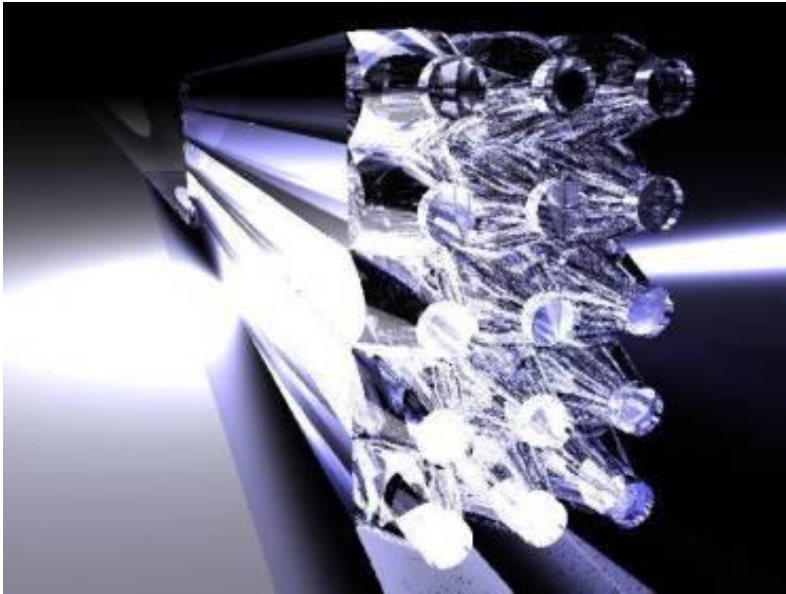
Photomultipliers

- Size, spectral sensitivity, gain, speed, adapted to specific applications



MONA scintillators

- Organic scintillators of MONA detector



Polished on all sides and edges to internally reflect light to both ends for collection.

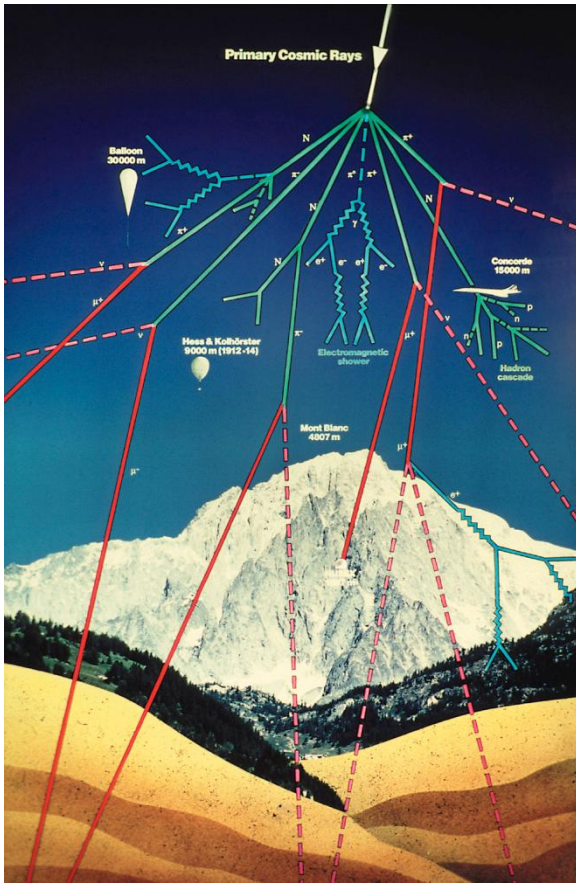
- Scintillators wrapped and coupled to PMTs



Must supply HV and collect electric signals from all photomultiplier tubes.

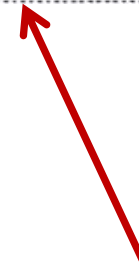
Cosmic rays

protons, nuclei, 10^9 to 10^{20} eV.



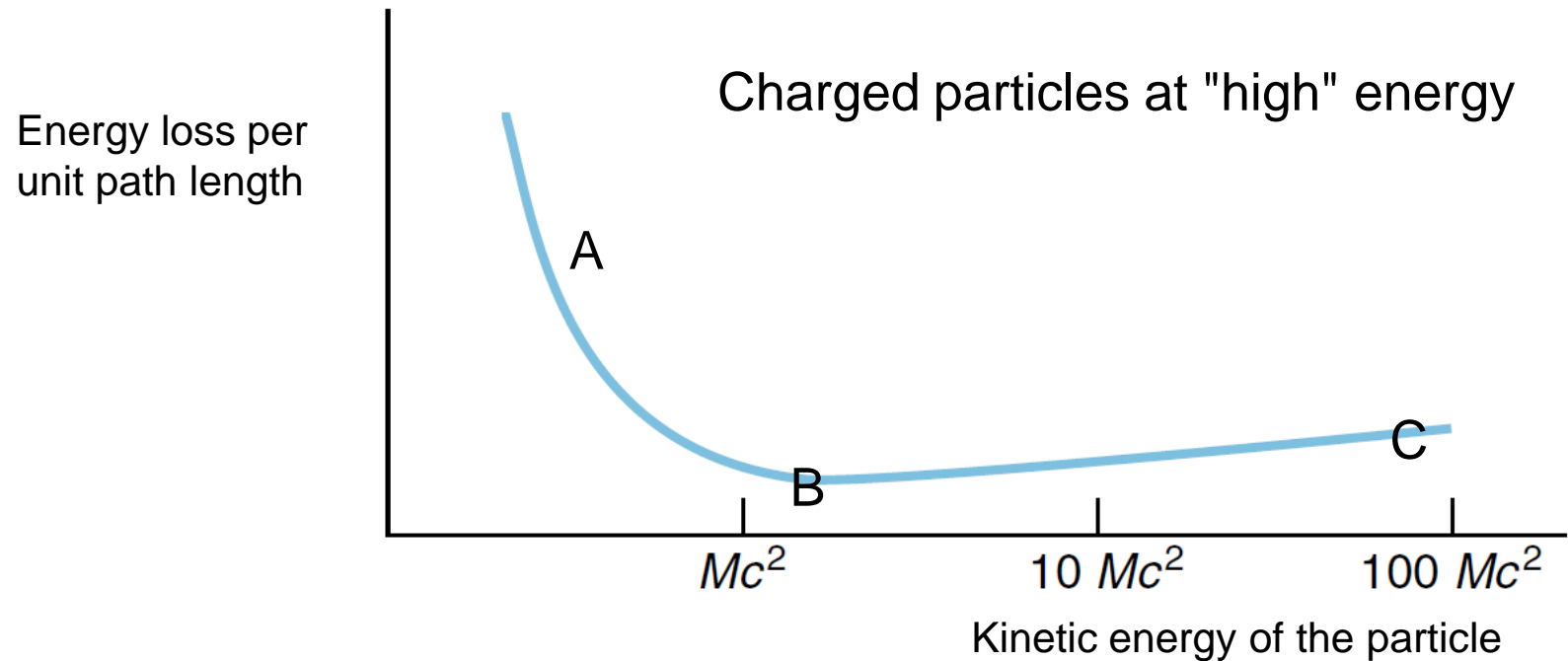
What is a muon?

<http://www.particlezoo.net>



muons, pions, electrons, positrons:
 $\sim 2 /(\text{cm}^2 \text{ min})$

Trend of energy loss in matter



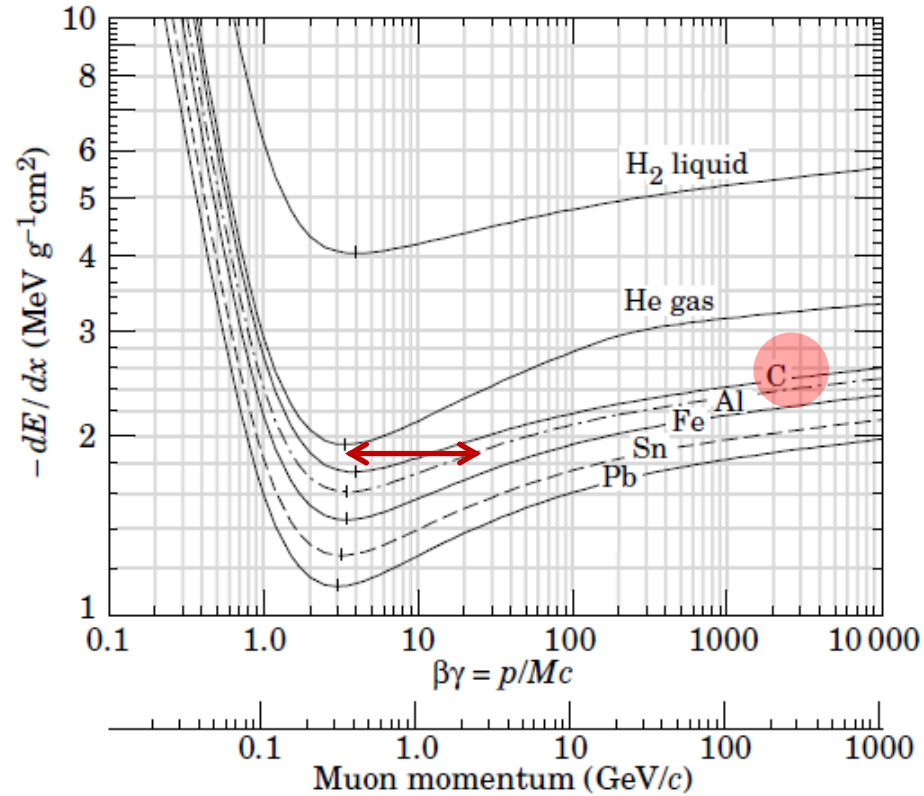
A: Slower particles experience the electric force with electrons in matter during a longer time so they lose more energy per unit path length.

B: As the energy increases, the particle loses less and less energy since it spends less time, up to a minimum.

C: At very high energy, the energy loss per unit path increases slightly due to so-called "relativistic effects" which manifest when the speed of the particle gets closer to the speed of light.

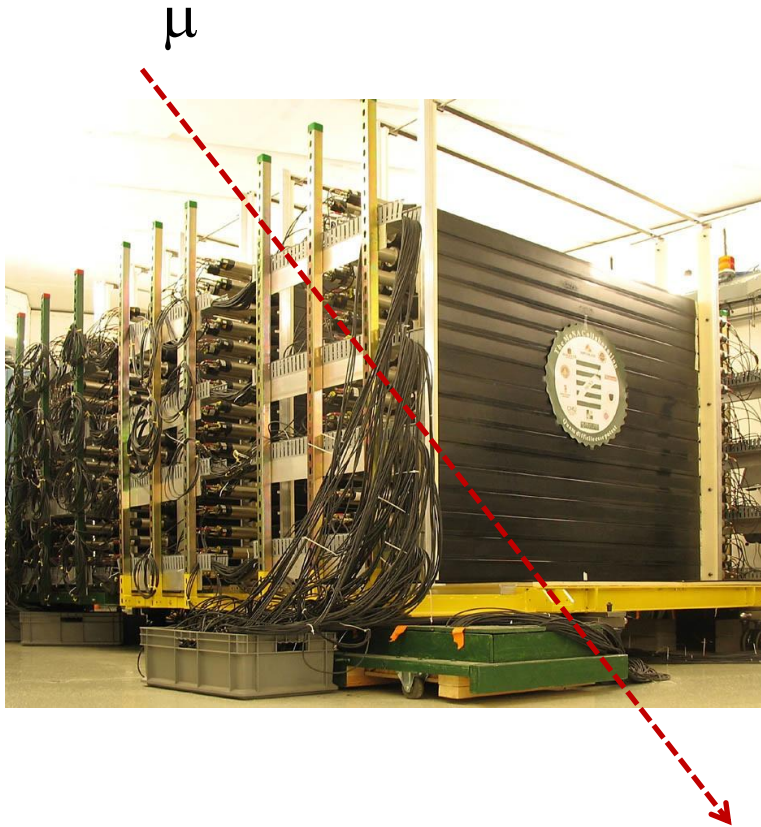
Cosmic rays energy loss

Energy loss of muons in matter



Energy loss in plastic scintillator is $\sim 2 \text{ MeV}/(\text{g}/\text{cm}^2)$

Putting all together



- A muon produced by cosmic rays loses $2 \text{ MeV}/(\text{g}/\text{cm}^2)$ in a plastic scintillator.
- The density of the scintillator is about $1 \text{ g}/\text{cm}^3$ so that the energy loss is $2 \text{ MeV}/\text{cm}$.
- Taking a typical size of a MONA bar of 10 cm . The total energy deposited is then about 20 MeV (depends on direction).
- This energy will ionize the molecules of the scintillator and the number of emitted de-excitation photons will be about: $20 \text{ MeV} \times 20000 / \text{MeV} = 2 \times 10^5$ photons
- These photons are collected and transformed into electric signals by the PMTs so that you can count them.