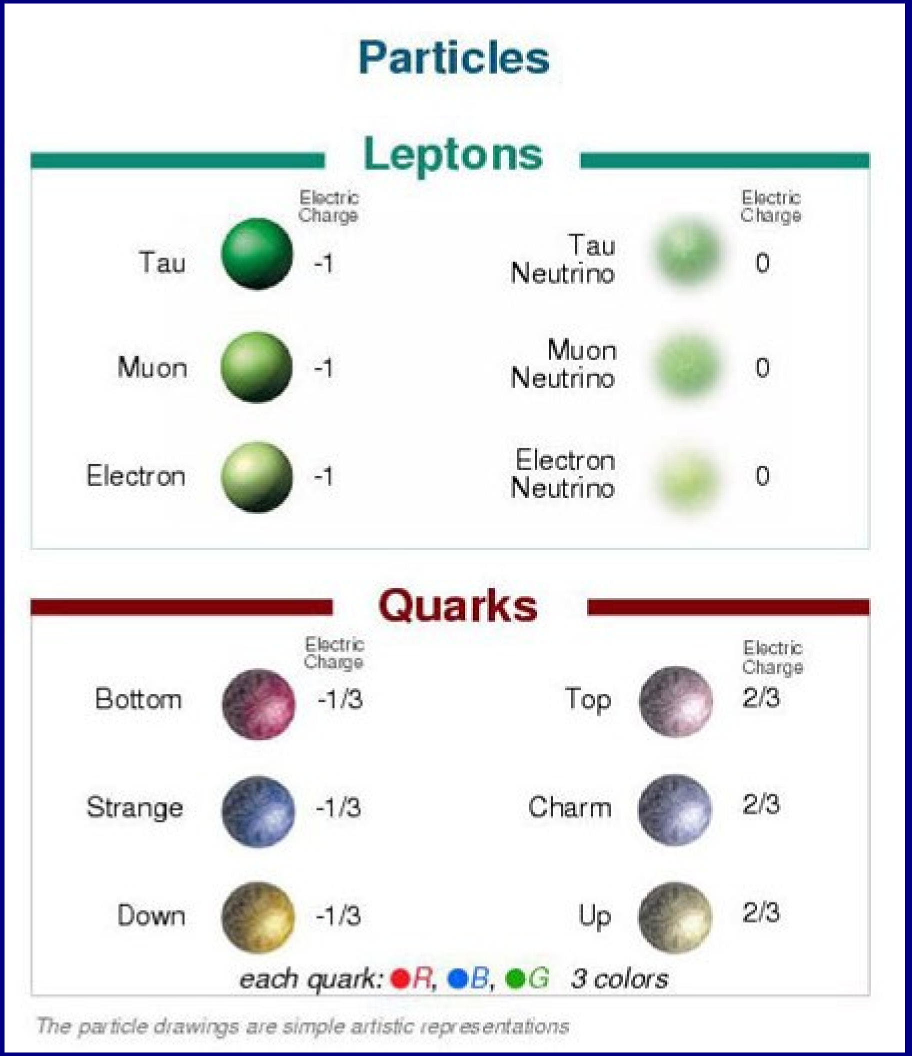
Muon Lab

- Theory
  - Muons (standard model)
  - Cosmic rays
  - Life time
- The Experiment
  - Principle
  - Set up
- Your work

The muon

- Second generation "brother" of the electron
  - same properties: charge, role in weak interaction
  - heavier, unstable
- Decays with mean life 2.2 μs : $\mu \rightarrow e + \nu_\mu + \nu_e$

  In this lab, you will measure this time.

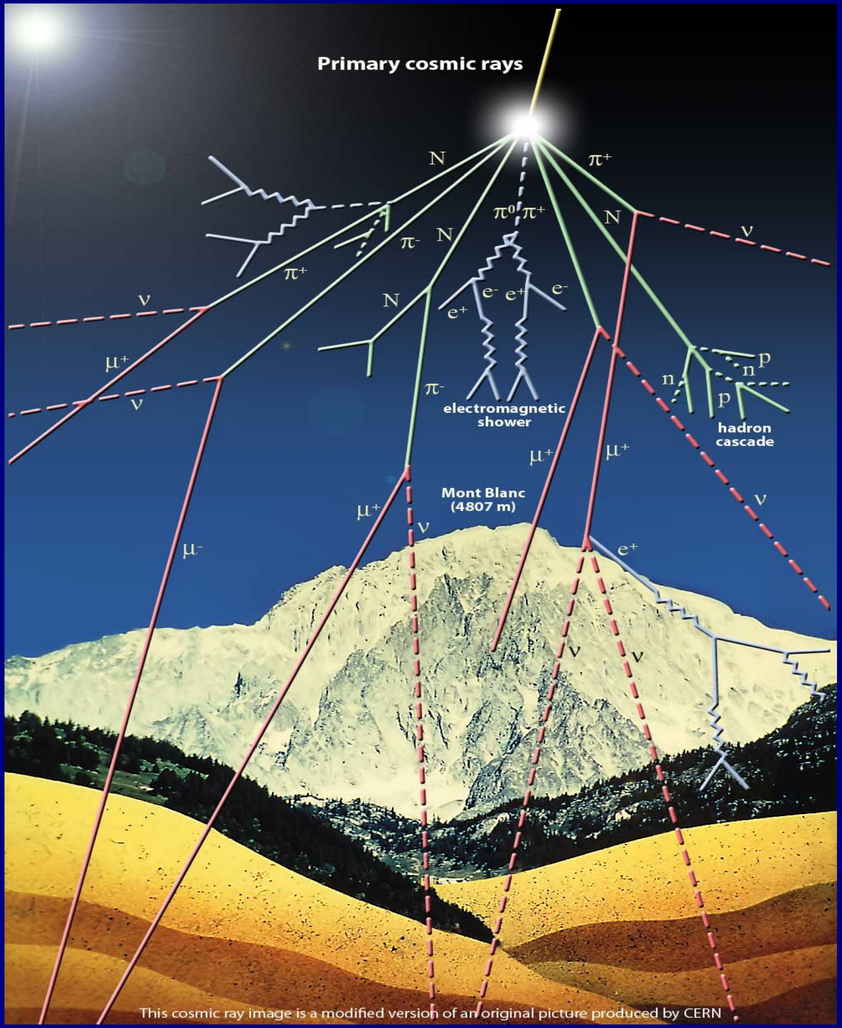


Where do we find muons

- Unstable: don't exist in normal life
- Can be produced at accelerators
  - Typically, decay product of pions produced in high energy collisions
- Natural accelerator: cosmic rays
  - produce high energy collisions in atmosphere

Cosmic ray

- high energy protons and nuclei (“primary cosmic ray”)
- interact with nuclei in high atmosphere: “hadronic shower”
- Decay products (mostly muons and electrons) reach earth's surface



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- at the speed of light, 1µs = 300m, atmosphere ~100km
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- Relativistic muons: time delation

$$\tau_{apparent} = \gamma\tau_0$$

where $\gamma = E/m$

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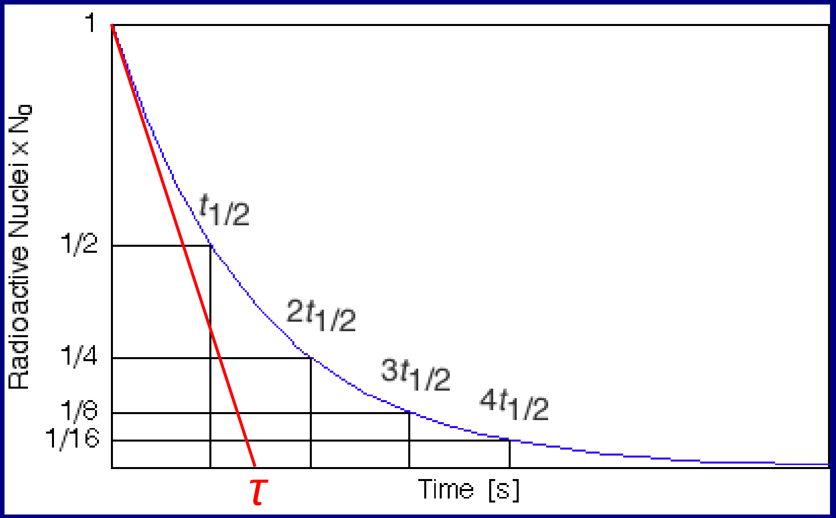
- Tricky term: see it as a decay probability (**INDEPENDENT OF THE TIME OF CREATION**)
- Analogy with radioactivity:
  - If you have a sample of radioactive material, the quantity of active material (and therefore the radiation emitted) will diminish following an exponential law $e^{-t/\tau}$.
    τ is the mean life of the material.



How to measure the muon life time

- We don't have a large sample of muons
- Take many muons at different time and put them virtually together
  - measure decay time for individual muons
  - accumulate statistics over a long period (1 day)
- Be careful, for relativistic muons, the result would be changed by time delation
  - To avoid that, we must stop them

Principle of the experiment

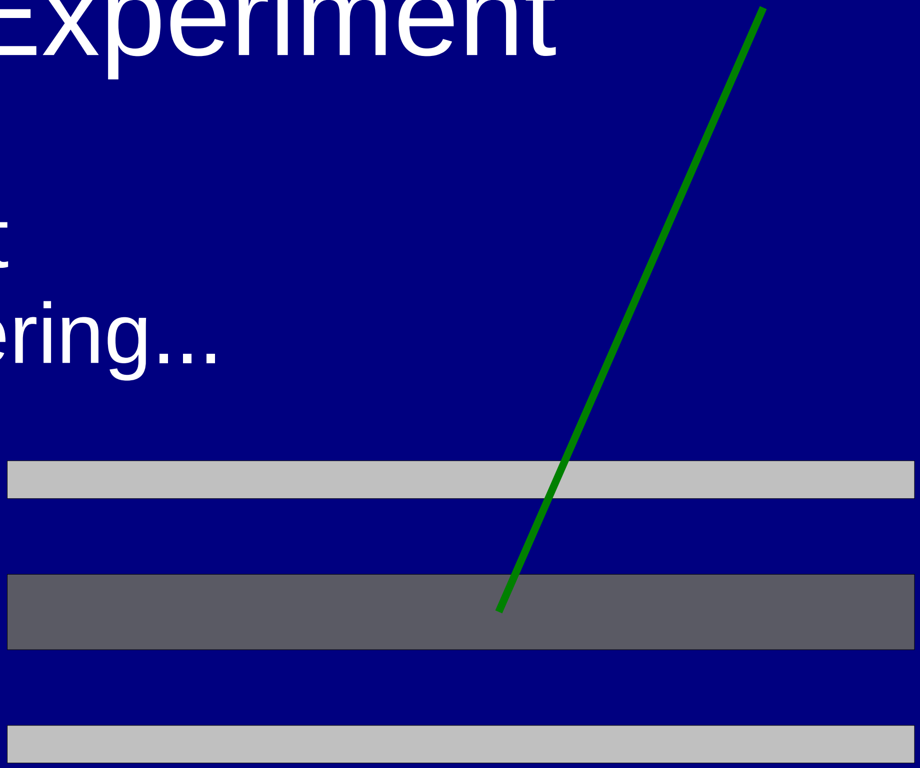
- Capture cosmic ray muons
- Measure the time between capture and decay
- Analyse data
  - What will we observe ?

The Experiment

- an Aluminum plate to stop the muons

The Experiment

- Scintillators to detect when a muon is entering...



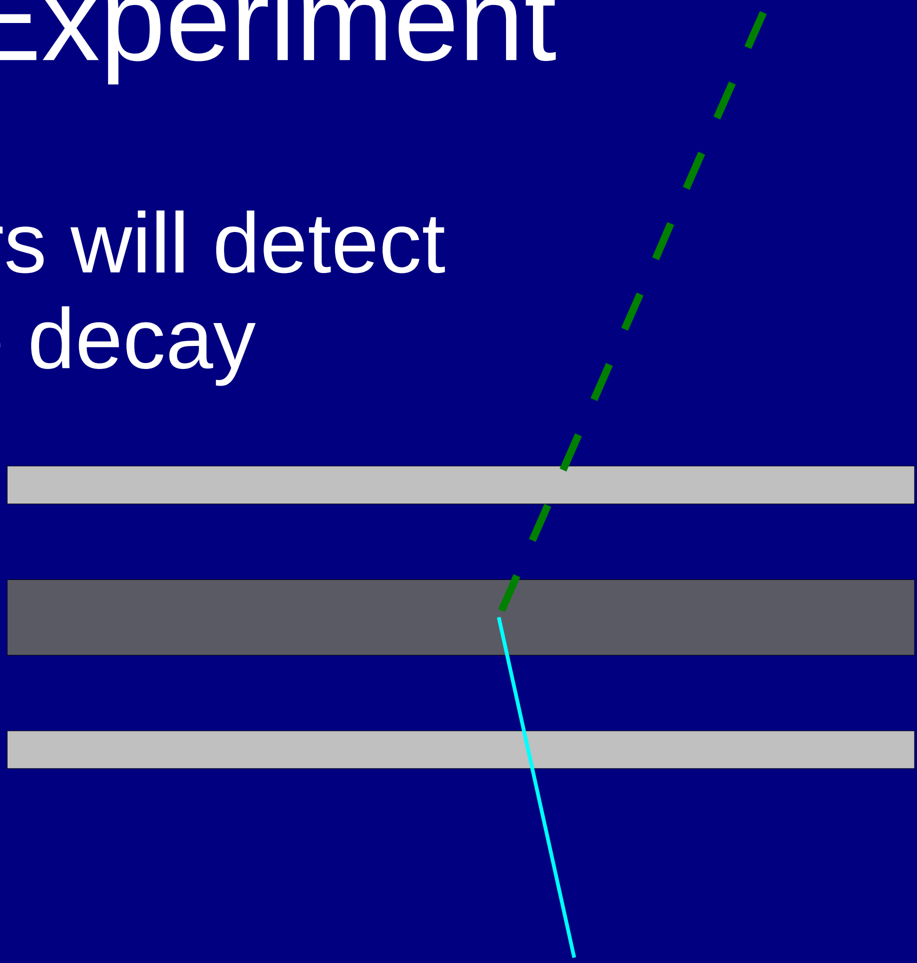
... and not leaving

Scintillators

- A scintillator detects energetic particles which interact electromagnetically (charged particles and photons).
- The particles will excite the atoms of the scintillator, which will then de-excite by emitting some photons.
- The photons will then propagate to a photomultiplier (a photo-cathode and a chain of dynodes) to become an electronic signal.

The Experiment

- The same scintillators will detect the electron from the decay



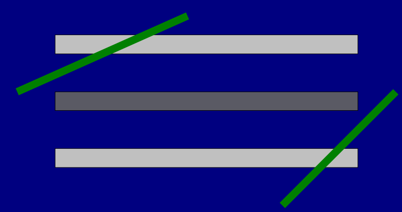
- We just have to measure the time between these two events...

What might be the problems ?

- What kind of wrong measurements can happen?
- How can we avoid them?

Different kinds of background

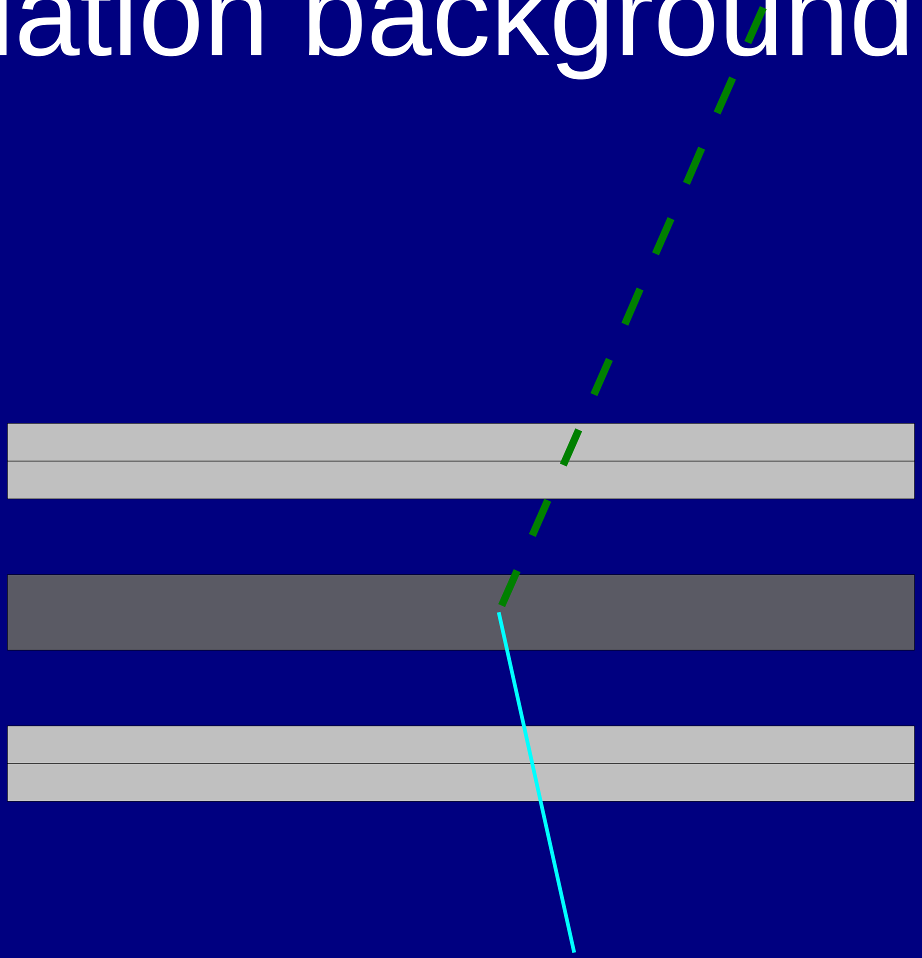
- Local radiation : traces of radio-activity, light
- Muons (or other cosmic rays) going through everything
- Angular effect



- Electronic noise
- Time of movement
- Unexpected interaction of the muons in the material (cf exercise: muon capture)

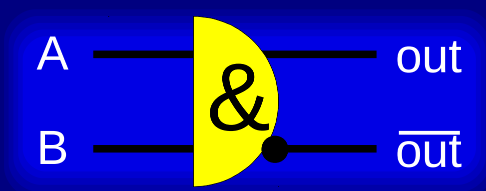
Avoid local radiation background

- Make a smart setup
- If we require coincidence between two scintillators, we avoid the low energy rays (local radiation) and electronic noise
- find a model for the other backgrounds

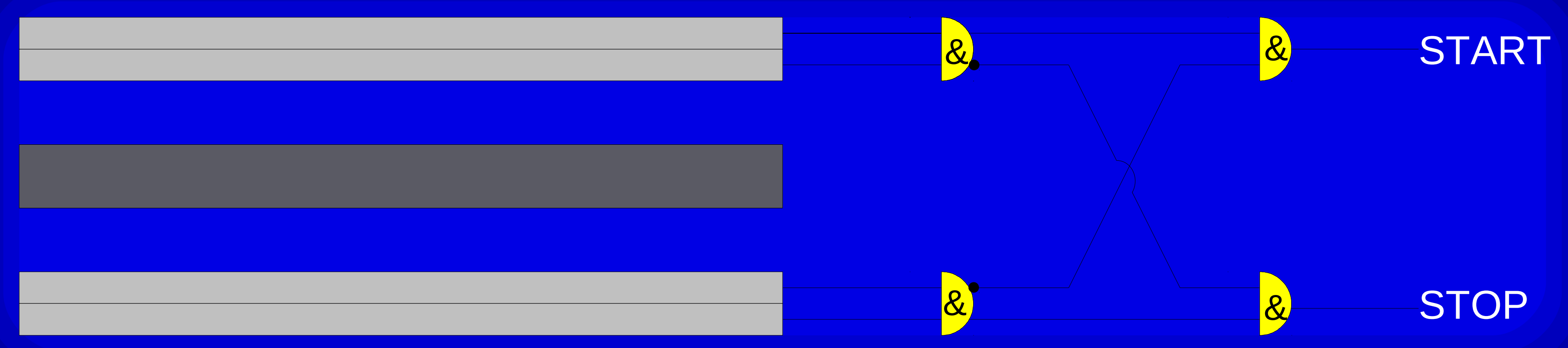


Electronic setting

To select the events corresponding to what we're interested in (and avoid muon passing through), we make an appropriate logical setup

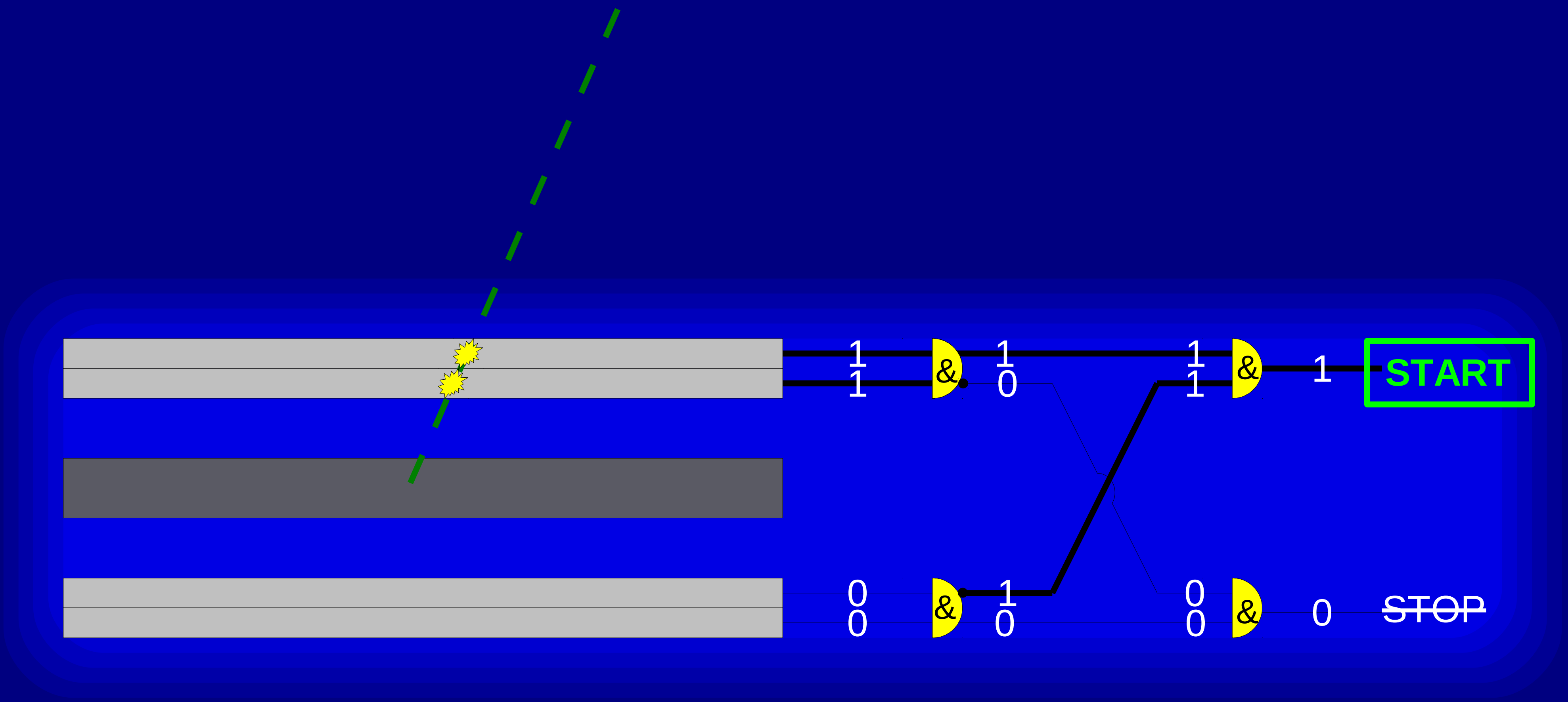


A	B	out	$\overline{out}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0



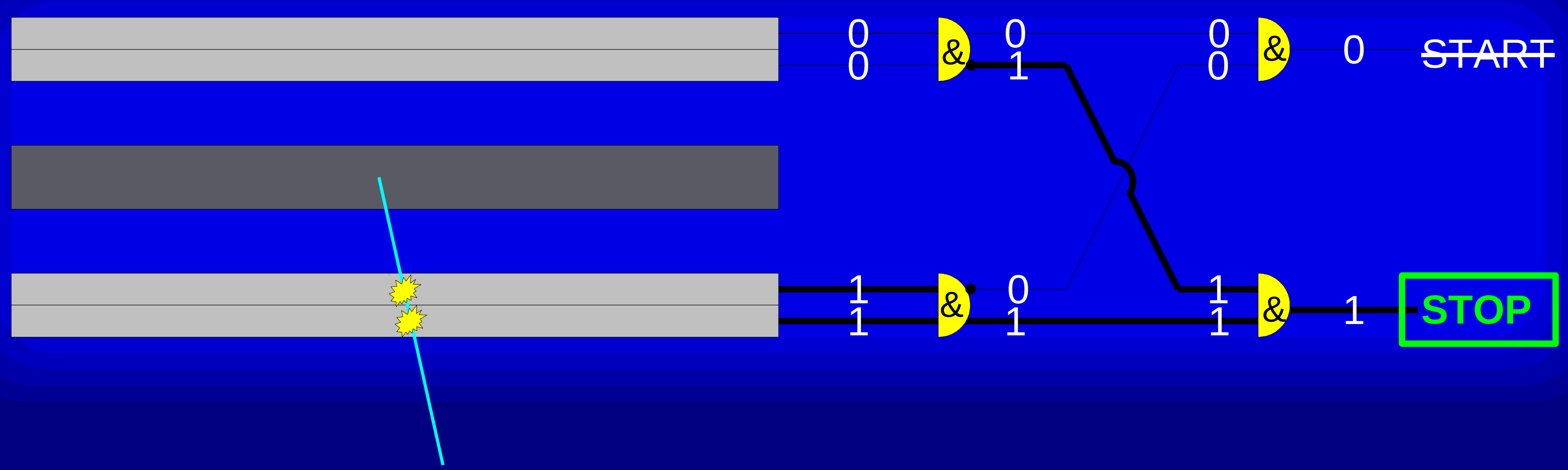
Electronic setting

Start the time counter



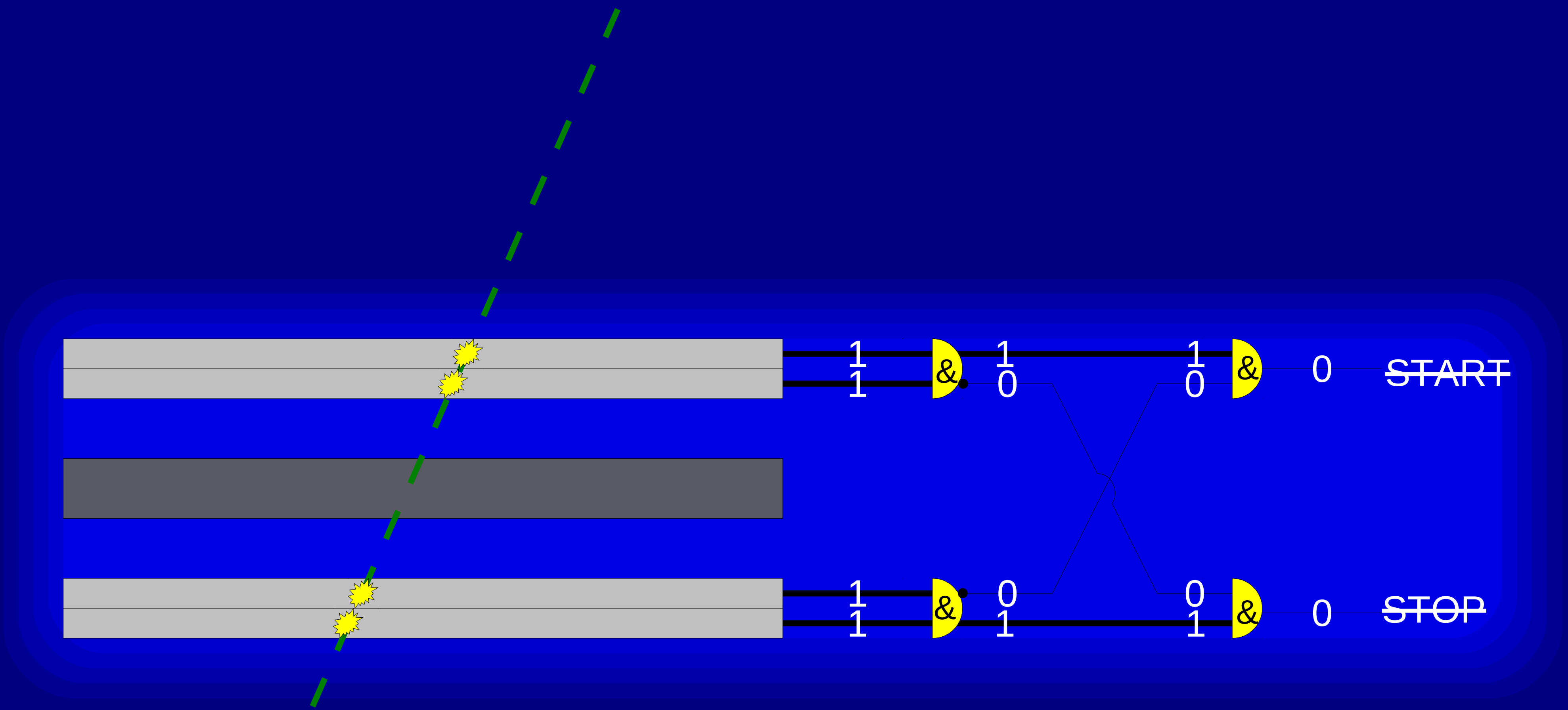
Electronic setting

Stop and reset the time counter



Electronic setting

Example of ignored event



QUESTIONS ?

What you will do

- Make sure you understand the idea of the experiment...
- Set up the electronics for an actual experiment and take data for about one day
- Analyse the data and extract the muon life time. Trying to understand the accuracy and relevance of the result (noise, χ^2, ...)
- Write a report (maximum 5 pages) describing the principle of the experiment, the setup and the analysis