

The background of the slide is a dense field of 3D-rendered numbers in various shades of blue and white. The numbers are scattered across the frame, creating a sense of depth and movement. Some numbers are larger and more prominent, while others are smaller and recede into the background. The lighting is soft, highlighting the three-dimensional quality of the digits.

# Muon detection

Alexia, Anna and Markus

# Muons

What are they? Why would we try to detect them?



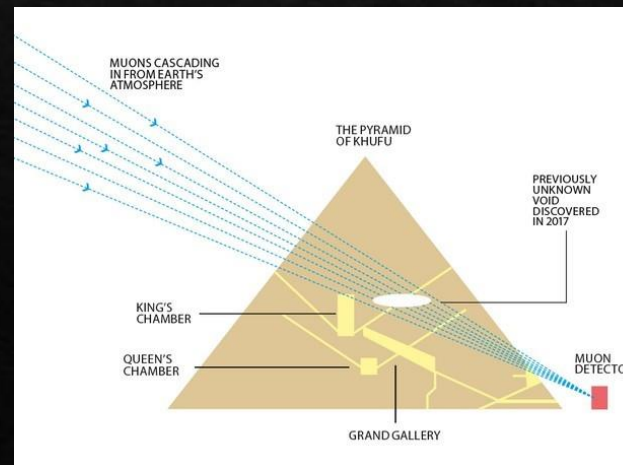
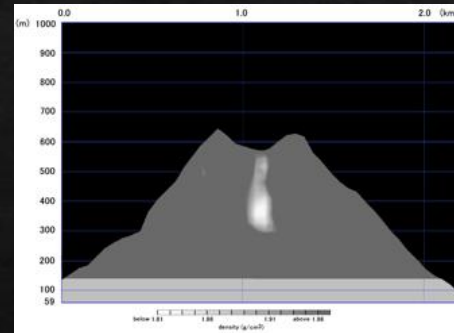
A more massive version of the electron with a lifetime of  $2,2\mu\text{s}$



Cosmic radiation hitting Earth's atmosphere  
Particle accelerators



Curiosity  
Applications



Leptons					
Tau:		Electric Charge: -1	Tau Neutrino:		Electric Charge: 0
Muon:		Electric Charge: -1	Muon Neutrino:		Electric Charge: 0
Electron:		Electric Charge: -1	Electron Neutrino:		Electric Charge: 0

Quarks					
Bottom:		Electric Charge: $-1/3$	Top:		Electric Charge: $2/3$
Strange:		Electric Charge: $-1/3$	Charm:		Electric Charge: $2/3$
Down:		Electric Charge: $-1/3$	Up:		Electric Charge: $2/3$

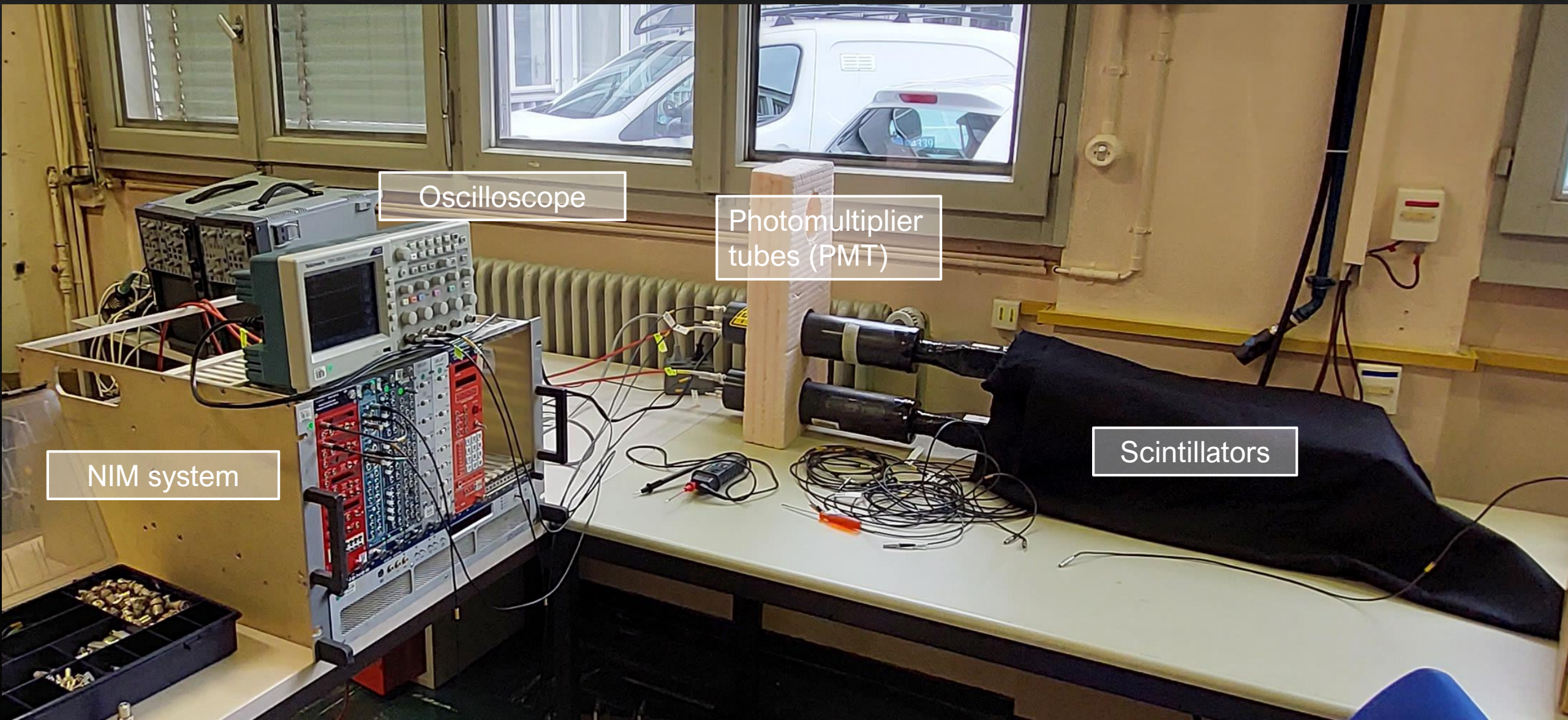
each quark: ●R, ●B, ●G 3 colors

The particle drawings are simple artistic representations





# The set-up



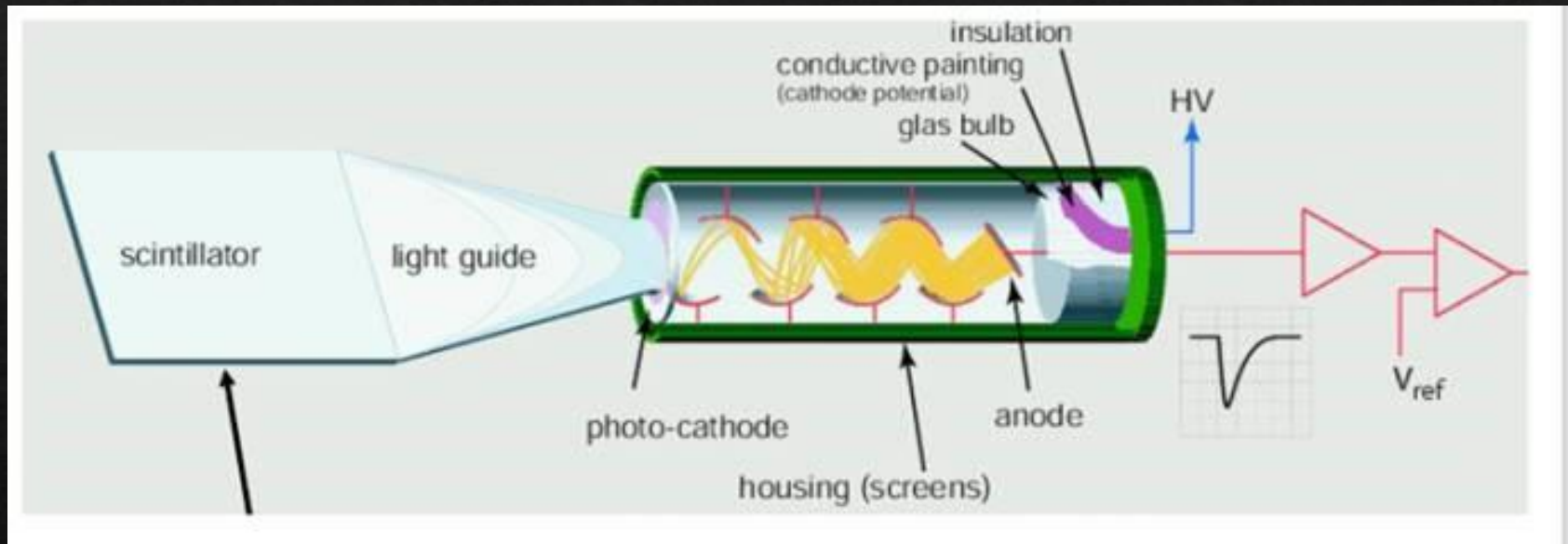
Oscilloscope

Photomultiplier tubes (PMT)

NIM system

Scintillators





# Noise

What is it? How to get rid of it?

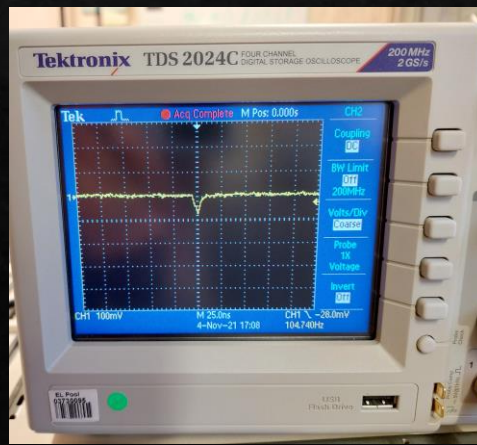
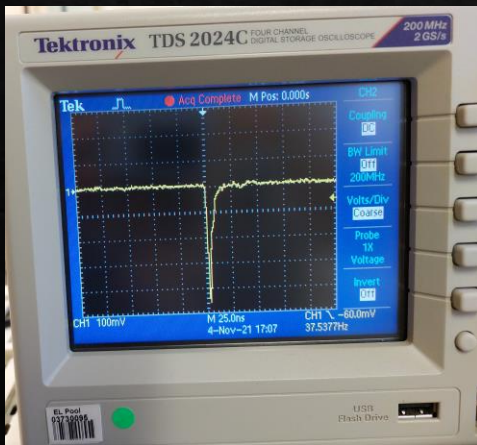
= signals that aren't caused by a muon going through the detector

Causes?

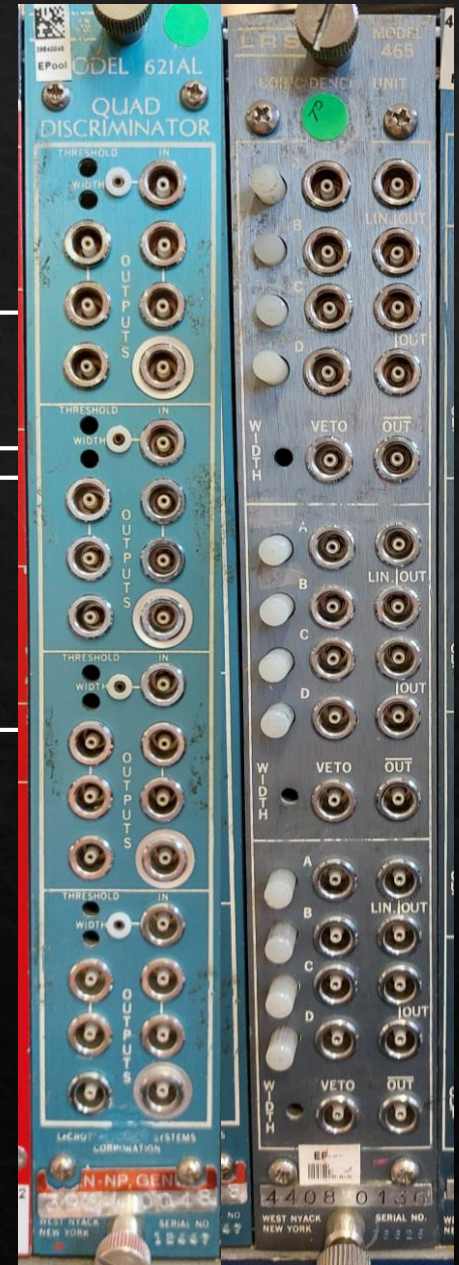
- thermal emission
- light leak

Discriminator unit  
=> trigger limit: 50mV

Coincidence unit  
= emits signal when receiving simultaneous signal from both detectors  
BUT random coincidences still exist!



Analog signals from PMT





# Random coincidences

What are they? How to rule them out?

= two simultaneous noise signals that are interpreted as a muon by the coincidence unit

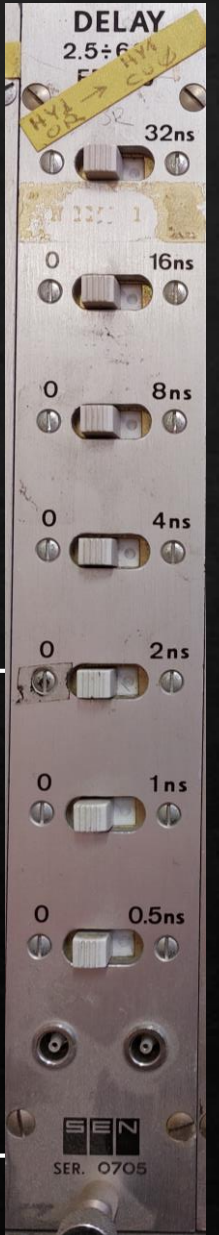
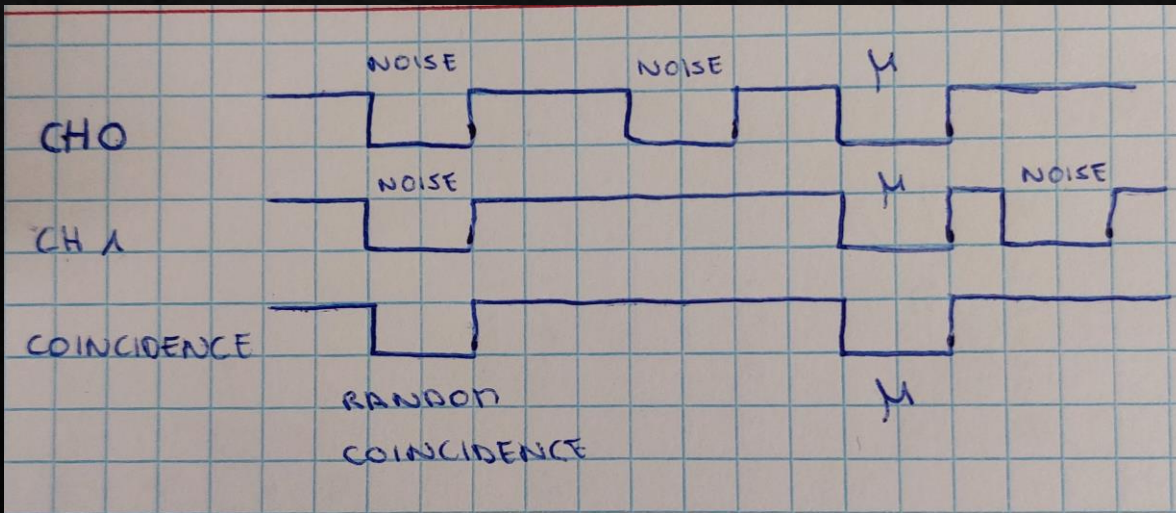
Theoretical

$$f(RC) = \frac{N_0 * N_1 * (W_0 + W_1) ns}{1\ 000\ 000\ 000 ns}$$

=> 1 RC/45 minutes

Experimental

1. Put the detectors away from each other  
=> results: 4, 5 or 27 per hour
2. Delay unit  
=> results: 0, 4 or 9 per 15 minutes



# Data acquisition system (DAQ)

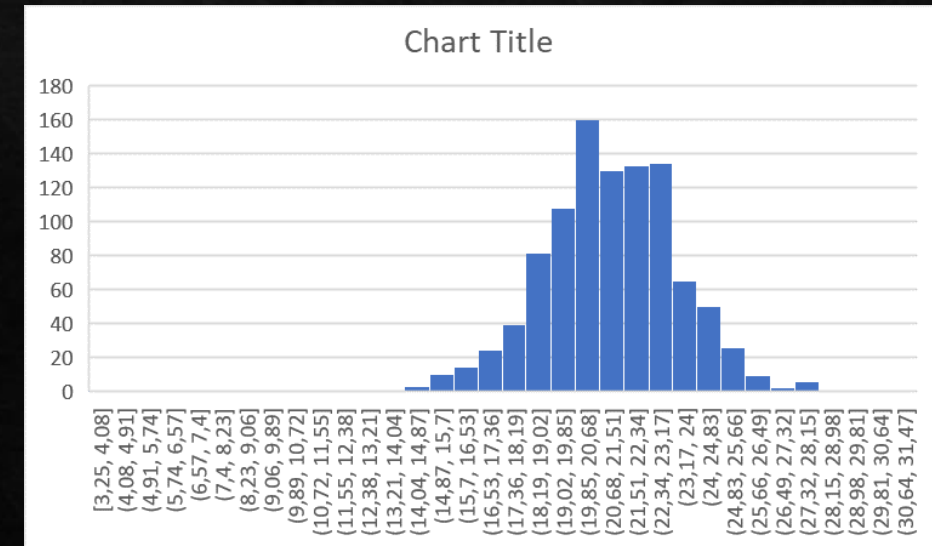
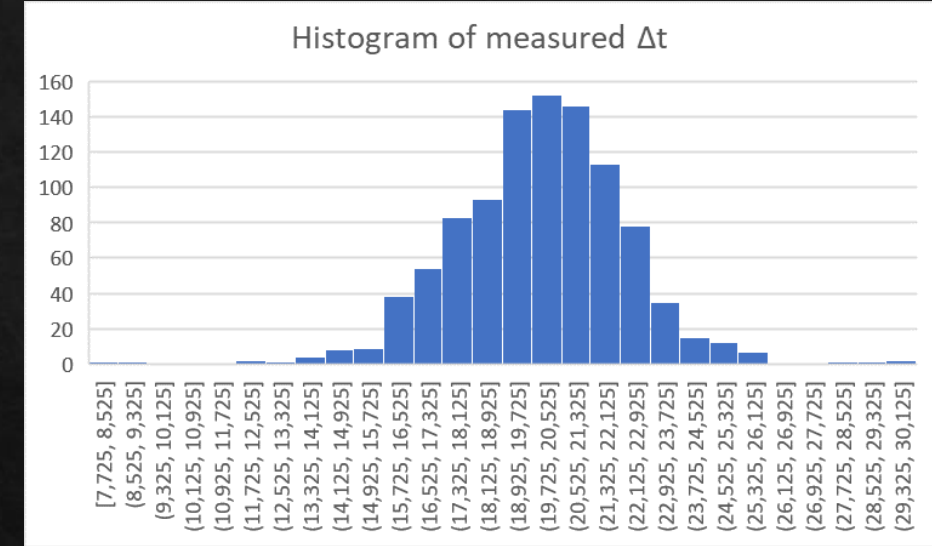
A small computer programme in plain C

Purpose?

Calculating the velocity of the muons and comparing the data from the different measurements  
=> result: muons move at the speed of light

How?

- 1) Two detectors at a certain distance on top of each other
- 2) Time to Digital Converter (TDC) records the time between signals from each detector when muon passes through
- 3) This data is put into a file via the DAQ
- 4) We put this data in an Excel histogram => Gaussian distribution







VME crate

Embedded computer

TDC (precision clock)

```
FILE *out_file;  
u_short value0;  
int loop, event_number;  
u_int wtype, vme32;
```

```
printf("This is a very simple piece of code to acquire timestamps  
from the TDC\n");
```

```
out_file = fopen("time_stamps", "w+");  
if (out_file == 0)  
{  
    printf("Can't open output file\n");  
    exit(0);  
}  
fprintf(out_file, "event_number; channel; time in ps\n");
```

```
printf("Enter the number of events to record\n");  
event_number = getdec(100);
```

```
for (loop = 0; loop < event_number; loop++)  
{  
    printf(" processing event %d\n", loop);  
    //Wait for data  
    while(1)  
    {  
        value0 = v1290->status_register;  
        if (value0 & 0x001)  
            break;
```



# And so much more...

nuclear energy  
helium ISOTDAQ  
cashews **gardening** Nirvana  
tourism **cheesecake** Jan  
Einstein's kitchen architecture  
superconductivity **books**  
Louis  
Beamline for schools  
electronics <sup>cooking</sup> <sup>art</sup> shopping  
**computing lecture** Ralf  
mystery machines Sophie  
leaves **photodetectors**  
**music** ventilator  
atelier mécanique  
Anna Cristovao  
**engineering**

What did we learn about  
CERN?

There is your job, but there is also a lot of space for your own project ideas, your own interests, creativity and self-development.

# Thank you!

- Thank you François, Jean-Pierre, Cédric, Margherita, Feza ... for making this internship possible
- Thank you Cédric and Marijke for accompanying us
- Thank you Markus for being an incredible supervisor
- Thank you Anna, Jan, Ralf, Sophie, Cristovao and all other CERN employees that talk with passion about their job
- Thank you weather for being quite nice 😊
- Thank you Xander, Wout, William, Tim, Seppe, Satya, Runa, Robin, Petar, Michiel, Laurens, Kaat, Julie, Holy, Faye, Esteban, Emma, Elke, Elena, Charles, Amy and Margot for creating so much unforgettable memories
- Thank you to all the others that made this happen from behind the scenes!