Laboratory work

January - February 2021

CEA Saclay (8 teams)

Neutron-Gamma discrimination (2 teams)

How can we measure the shape of a nucleus? (1 team)

Muon life-time measurement (2 teams)

Muon tomography using Micromegas detectors (1 team)

Gamma spectroscopy (1 team)

Spectrometry and solar light (1 team)

IJCLab (9 teams)

Study of the Compton effect (2 teams)

γ-ray spectroscopy (1 team)

Muon life-time measurement (3 teams)

Cosmic-ray studies (1 team)

Study of the decay of Positronium (2 teams)

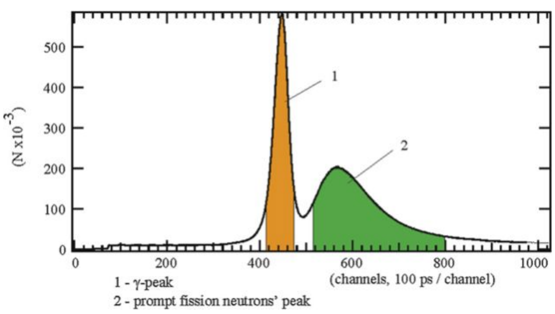
CEA Saclay

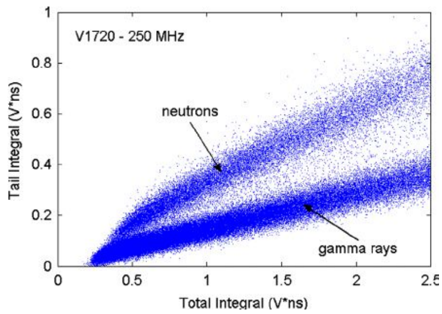
1. Neutron-Gamma discrimination

Principle: a nucleus with high excitation energy can emit photons and neutrons during its de-excitation. In some experiments, like the study of fusion and fission, it is very important to correctly identify and separate these two particles.

The aim of this work is to set up two different methods to discriminate neutrons from gammas:

1. The Time Of Flight (TOF) measurement, based on the fact that neutrons fly slower than photons.
2. The Pulse Shape Discrimination (PSD), based on the fact that photons are only sensitive to electromagnetic interaction, while neutrons interact by strong force. This difference in the interaction with matter leads to a different signal shape on detectors (scintillators in our case).





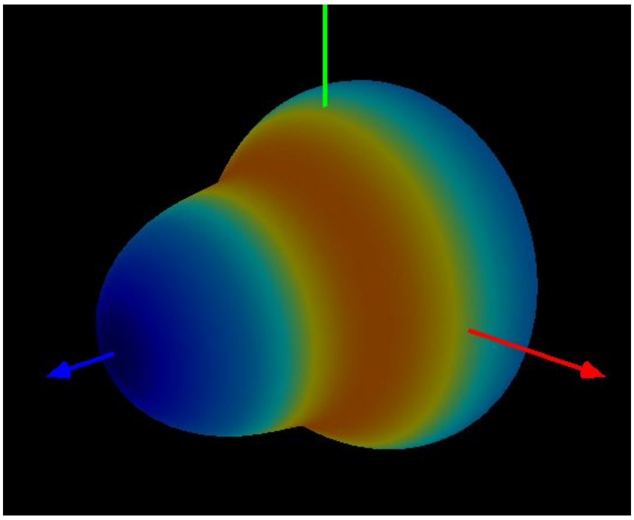
Experimental setup: we study the photons and neutrons emitted by a sealed ^{252}Cf source. The particle detection is ensured by scintillating detectors (BaF_2, NaI(Tl), NE213, liquid scintillator) in order to measure the TOF and the signal shape. The detectors are connected to standard NIM electronics and the acquisition is provided by a high frequency sampling card (MATACQ). The use of this frontend card allows the extraction of a wide spectrum of information (TOF measurement by the use of the CFD technique, signal charge and amplitude, signal shape analysis). The data analysis is realized with the help of the ROOT software.

Location: CEA Saclay, Orme des Merisiers
Contact person: **E. Berthoumieux**

2. How can we measure the shape of a nucleus?

Principle: The shape of a nucleus reflects its quantum properties and in particular the nucleon shell structure. Depending on the occupation number, a nucleus can be spherical, elongated (prolate) or flattened (oblate) and these shapes can vary rapidly by removing or adding a nucleon, or by exciting the nucleus. In this work, we propose to focus on ^{152}Sm and measure some of its quantum properties in order to characterize its shape. ^{152}Sm will be populated from the decay of ^{152}Eu, which is radioactive and decays through 2 different ways, electron capture and β- decay populating ^{152}Sm and ^{152}Eu, respectively.

The proposed work consists of the measurement of the rotational band properties of ^{152}Sm (energy spectrum, moment of inertia, B(E2), transitional quadrupole moment) in order to characterize the shape of the nucleus and deduce its axial deformation parameter.



Experimental setup: This work is mainly based on γ spectroscopy (single and coincidence measurements). In order to discriminate γ from ^{152}Gd and ^{152}Sm, $\gamma-e^-$ coincidence measurement will be possible using different kinds of detectors. The fast timing technique, specially developed to access sub-nanosecond lifetimes will also be used.
The students should propose the experimental setup. The detectors will be connected to FASTER, which is a digital modular acquisition system and the data analysis will be performed with the ROOT software.

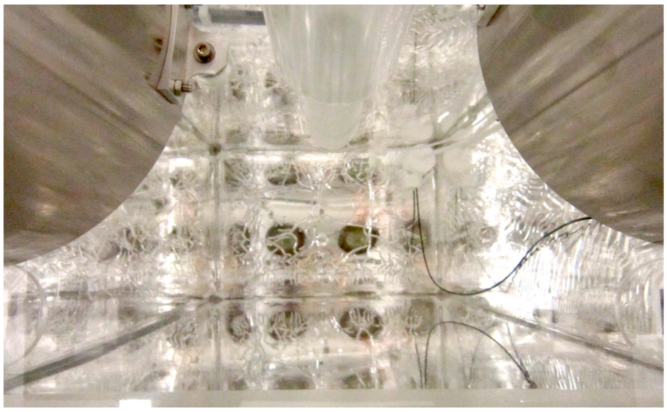
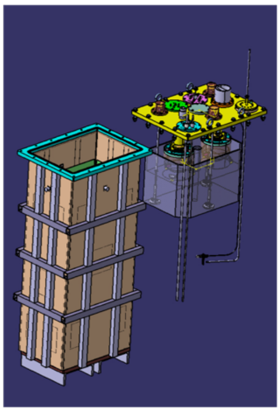
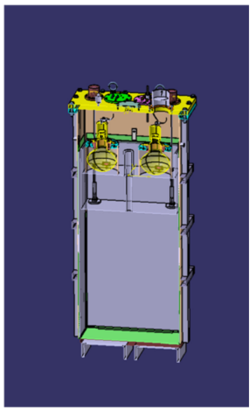
Location: CEA Saclay, Orme des Merisiers
Contact person: **P. Morfouace**

3. Muon life-time measurement

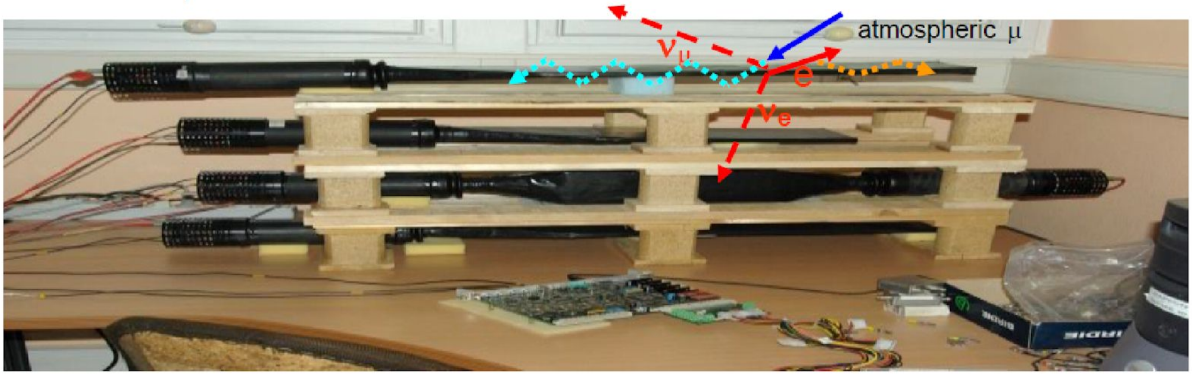
Principle: Earth receives continuously a high flux of energetic cosmic particles. When penetrating Earth atmosphere, these particles interact with air and create so-called "atmospheric showers". Among the created particles, pions decay into muons which compose must of the particle flux at sea level. Some of these atmospheric muons may also decay through the reaction: $\mu \rightarrow e\ \nu_\mu\ \nu_e$. The goal of this experimental work is to select and study such decay and measure muon lifetime from the decay time distribution.

Experimental setup: two experimental setups are proposed to perform such a measurement.

1. The first one uses a water tank, coupled to photo-multipliers, where charged particles may induce the emission of Cerenkov light. This experiment uses a state-of-the-art detector: the prototype of the STEREO experiment which aims to test the existence of the sterile neutrino.

2. The second one uses large solid scintillators, where light is produced by the interaction of charged particles with solid matter. A set of scintillators is also used to reject background.



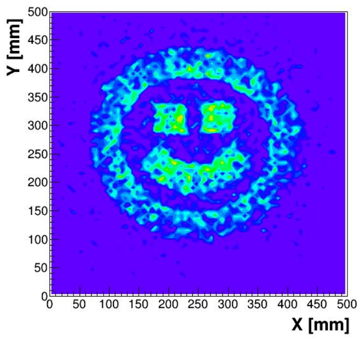
For the first setup, a dedicated data acquisition card allows to record the time and charge of all events above a threshold. Those are then processed by custom software offline (that can be written in C++, python, etc) is used. On the second setup, the trigger logic is made thanks to NIM electronic modules, and the data acquisition is performed through a high frequency sampling electronic board called MATACQ. Finally, the data analysis is performed in C++ or python with the help of the ROOT library.

Location: CEA Saclay, Orme des Merisiers
Contact person: B. Lenzi

4. Muon tomography using Micromegas detectors

Principle: The Micromegas detector is a gaseous detector belonging to the Micro Pattern Gas Detectors (MPGD) family. These detectors are widely used in modern physics experiments for tracking and often replace older detectors like wire chambers. The aim of this work is to build, operate and produce a tomographic imaging with cosmic-ray muons by using their absorption or their multiple scattering in high-Z material. Micromegas detectors will be used for particle tracking.

The first days will be dedicated to the assembly of a cosmic bench in order to understand the principles of an acquisition system. Then, the characterization of a Micromegas small detector prototype with a radioactive source will be done to determine the nominal parameters for muon tracking (measurements at different gas mixtures of the gain, energy resolution, electron transparency). Finally, a bench for tomography will be set up and used for tomographic imaging. Characterization and data analysis will be done through ROOT-based procedures.



Left: tomographic bench with 4 Micromegas detectors
Right: tomographic imaging of a “Muona Lisa” using lead blocks

Planning of the TL:

Familiarization with the detector and cosmic bench (~1 week)
- Assembly and use of the acquisition & scintillators assembly
- Acquisition of signal from Micromegas, calibration
- Measurements of Gain, electron transparency, energy resolution
- Role/influence of the mixture

Tomographic bench (~1 week)
- Assembly and operation
- Data taking in several configurations

Data analysis (~1 week)
- Tomographic imaging
- Measurement of material density

Location: CEA Saclay, Orme des Merisiers
Contact person: D. Attié

5. Gamma spectroscopy

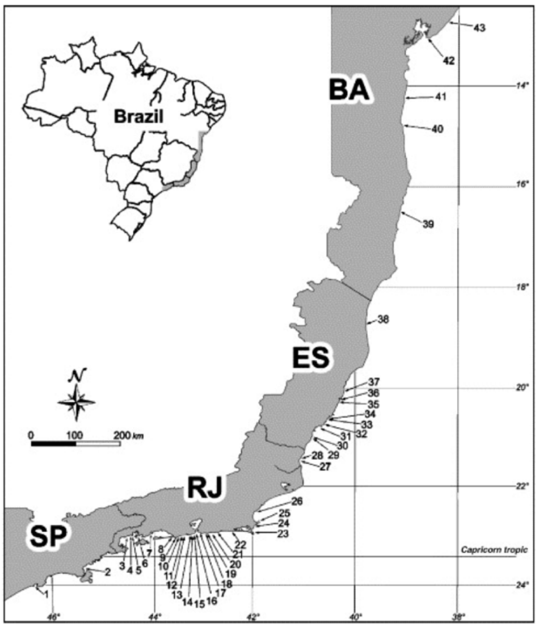
Principle: the primary aim of this study is to identify several unknown samples emitting gamma rays. To achieve this objective, a semiconductor High-Purity Ge detector (HPGe) will be used to characterize the gamma spectrum of these samples.

A detection setup will be realized in order to acquire the gamma spectra. An electronic acquisition chain using digital electronics will be used. The students will analyze the data using ROOT-based software.

Planning of the TL:

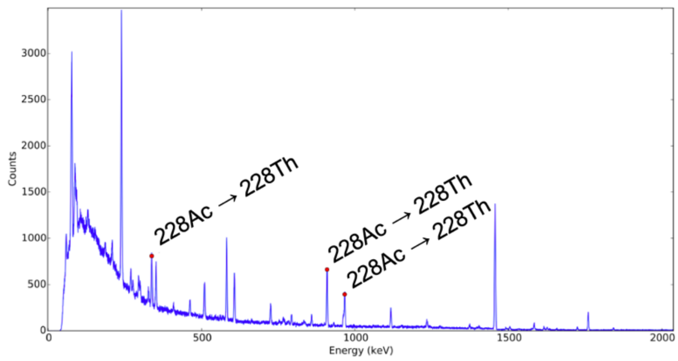
Characterization of the detector
- Set up of a basic analogic acquisition chain
- Acquisition of signals with digital electronics
- Energy calibration and resolution measurement
- Implementation of Compton shielding with BGO

Study of samples
- Identification of the origin of a sand sample by studying natural radioactivity
- Identification of radioactivity in a sample of Chernobyl soil
- Why does ouraline glass shine?
- …



R. Veiga et al. Radiation Measurements 41 (2006)

What beach is this sand from?



Location: CEA Saclay, Orme des Merisiers
Contact person: M. Vandebrouck

6. Spectrometry and solar light

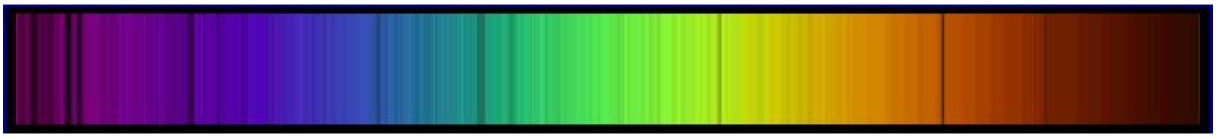
Principle: spectrometry is a powerful and essential tool to analyze matter and its components. In astrophysics, the object studied is not directly accessible: it is impossible to measure temperature of a star with a simple thermometer or to determine its composition using chemical analysis. The only available information comes from the object's radiation collected. Analyzing this radiation by spectrometry allows us to determine, among others, the constituents of the object and its physical conditions. Note that the first exo-planet has been discovered by the means of radial velocities analysis using precise spectrometry.

For this project, the instrument is composed of an objective which collects light, a high-resolution grating spectroscope (400 to 800 nm), and a CCD camera connected to a PC for acquisition. The data will be reduced and analyzed using IDL (Interactive Data Language).

A good knowledge of the instrument is required to get the most precise measure and assess the errors. Characterization and calibration at the laboratory will be performed first. In this context, spectral resolution, light scattering, signal and noise will be the subjects of this first part of the project.

Then, the instrument will be used to record and analyze the easy-to-obtain solar Spectrum which will be compared to the spectra of a sample of standard lamps. Moreover, this spectrum, which displays a lot of spectral lines, is really rich in information. Depending on the available time, next goals could be to measure the Sun's effective temperature, to identify its spectral class, or to determine abundance of an element (Fe for instance).

If ephemeris and weather are favorable, we can foresee to start a comparative study of Sun's, Moon's and Venus' spectra.



Main topics:

- Optical system
- CCD camera, signal, noise, signal-to-noise ratio
- Spectrometry, gratings, spectral resolution, light scattering
- Information processing, data reduction, spectral analysis, calibration

Equipment:

- High resolution grating spectrometer
- Large array CCD detector
- Acquisition computer
- Equatorial mount
- Laboratory devices: spectral lamps, filters…

Location: CEA Saclay, Orme des Merisiers
Contact person: **P. Gallais**

IJCLab

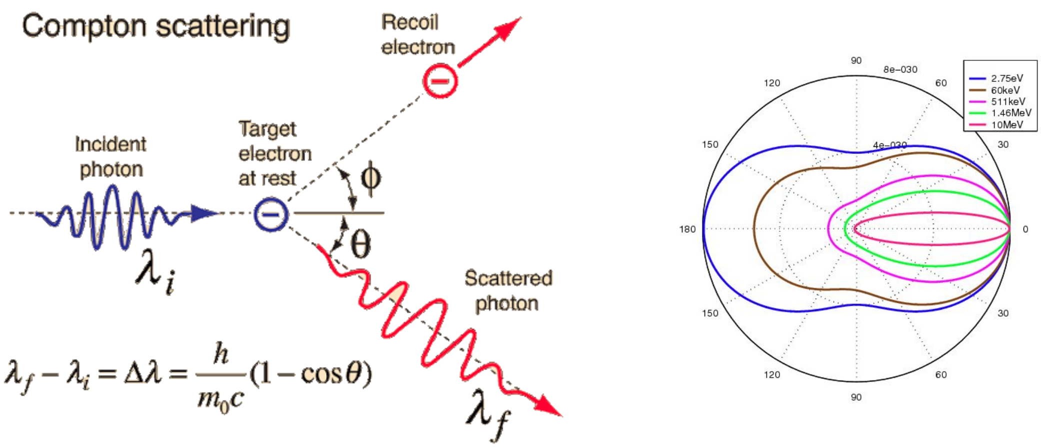
1. Study of the Compton effect

The aim of the project is to study the Compton effect (scattering of a X or gamma photon by an electron in matter), by measuring the energy of the scattered photon (related to the Compton shift), its angular dependency, and its differential cross section.

The project requires some ingenuity. With the provided stands, lead shielding, NaI detectors (photomultipliers), conventional NIM electronics and a PC equipped with a FASTER or ISIPEAK data acquisition board, you will have to entirely design the experiment and set up the acquisition electronics.

The project steps are the following:

- Design of the experiment;
- Determination of the characteristics of the NaI detectors: energy calibration, linearity, resolution and efficiency for each detector.
- Electronics setup and tuning of the acquisition system built upon the NaI detectors and NIM electronic modules;
- Set up coincidences arrangements ; estimation of the coincidence resolution time and the accidental coincidence rate;
- Data analysis with ROOT; measurement of the energy spectrum of the scattered photons; estimation of the Compton cross-section;
- Comparison with the theoretical predictions of relativistic kinematics and quantum electrodynamics.



Left: Schematics of a Compton scattering
Right: Iso-contours of the Klein-Nishina cross section.

Location: IJCLab - Building 100
Supervisor: **W. Dasilva**

2. γ spectroscopy

We propose 3 types of experiments:

Study of γ emission by standard radioactive sources: ^{22}Na, ^{137}Cs, ^{207}Bi et ^{60}Co

Study of the angular correlation of γ rays emitted in the decay of ^{60}Co source

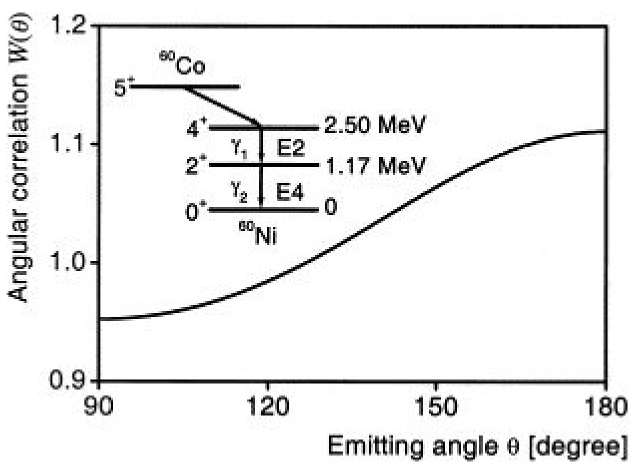
The material available for the students is the following:

NaI(Tl) scintillators
Surface barrier Silicon detector
NIM electronics
A computer equipped with a 4 channels acquisition card (FASTER or ISIPEAK) and ROOT analysis tool

The first experiment allows the students to become familiar with different types of interactions of γ radiation with the matter and with scintillation detectors and their electronics. The goal of this part is to study and calibrate in energy the detector and to study its energy resolution.

The second experiment is dedicated to the study of angular correlations between γ rays emitted in cascade after the β^- decay of ^{60}Co. The students will learn to use the electronics for coincidence measurements, characterize the coincidence module and use it to determine the angular correlation function W(θ).

For this work, the student doesn't need previous knowledge of nuclear physics detectors or electronics. In this way, it is intended for students who never performed nuclear physics laboratories.



Location: IJCLab - Building 100
Supervisor: **J. Biteau**

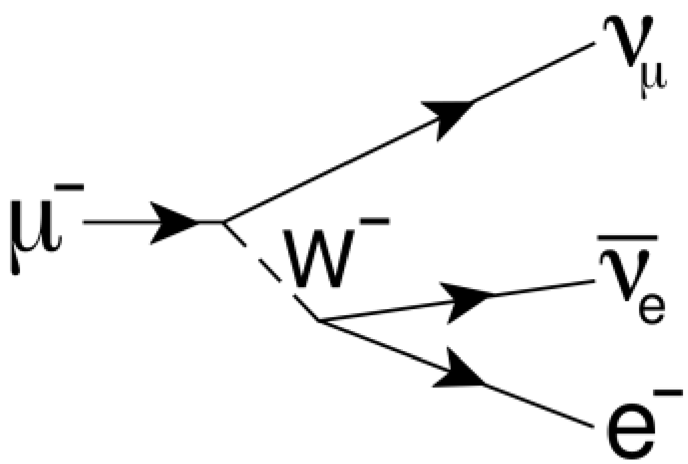
3. Muon life-time measurement

Earth's surface is permanently hit by particles, produced by the interaction of primary cosmic rays (nuclei, protons, photons, etc.) with the atmosphere. The particles detected at ground level are mainly muons, whose flux is intense enough to enable a detailed study of the muon properties including their life-time.

During this project, you will have to build an experiment to measure the life-time of the muons at ground level with the available elements (detectors, modules and electronic devices...). You'll have to understand the whole apparatus, calibrate it, and to be imaginative to solve some difficulties or to go beyond the limits of the apparatus...

A large number of techniques can be used. You'll study the performances of plastic scintillators read by a photomultiplier. You'll learn the use of NIM logical modules, still largely used in the laboratories. In addition, the angular distribution of the muons can be studied with a simple (but clever) modification of the experimental set-up.

Data will be saved using the FASTER or ISIPEAK acquisition card and analyzed using the ROOT software.



Location: IJCLab - Building 100
Supervisors: **C. Lachaud, E. Capocasa**

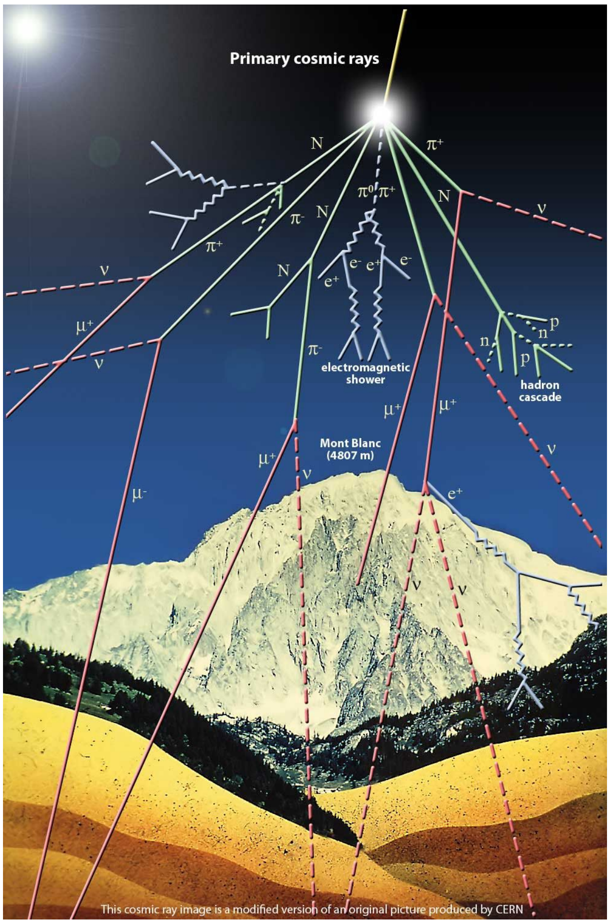
4. Cosmic-ray studies

Earth ground is permanently hit by particles, produced in the interaction of the primary cosmic rays (nuclei, protons, photons, etc.) with the atmosphere. The particles detected at ground level are mainly muons, whose flux is intense enough to enable a detailed study of its properties.

During this project, you will have to build an experiment to measure the angular distribution of the flux of the muons at ground level with the available elements (detectors, modules and electronic devices...). You'll have to understand the whole apparatus, calibrate it, and to be imaginative to solve some difficulties or to go beyond the limits of the apparatus...

You'll use plastic scintillators read by a photomultiplier to perform tricky spatial-coincidences. You'll learn the use of NIM logical modules, still largely used in the laboratories.

Data will be saved using the FASTER or ISIPEAK acquisition card and analyzed using the ROOT software.

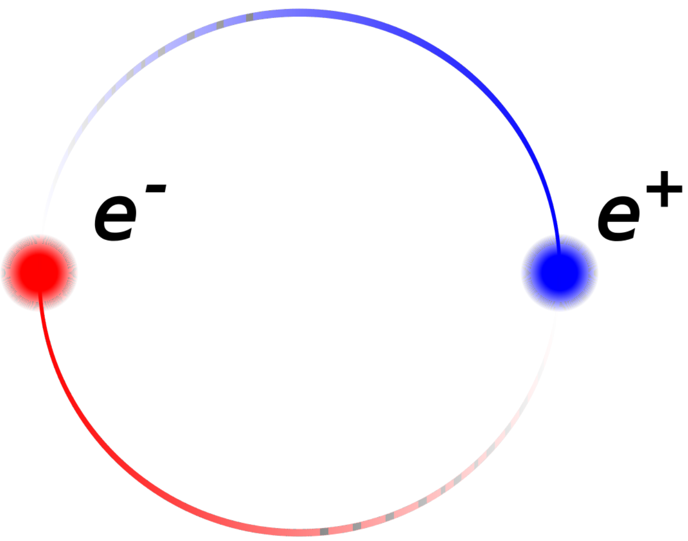


Location: IJCLab - Building 100
Supervisor: **E. Capocasa**

5. Study of the decay of the Positronium

Following a β+ decay of an unstable nucleus, a positron is emitted and can eventually bind to an electron to form a **positronium** pseudo-atom. The two particles are then bound by the electromagnetic force. Depending on the spin alignment of the electron and positron, two different hyperfine structure configurations are possible. If the spin alignment is anti-parallel, the total spin is zero and the positronium is in the para-positronium state. If the spin alignment is parallel, the total spin is 1 and the positronium is in the ortho-positronium state. Although energetically stable, the positronium decays into photons. From the para-positronium state, the total spin is zero, resulting in the total angular momentum being zero and thus the number of emitted photons is even (usually two). But from the ortho-positronium state, the total spin is one, resulting in the total angular momentum being one and thus the number of emitted photons is odd. A one photon decay being forbidden by momentum conservation, the main process is the emission of three photons.

The aim of this project is to study the decay of positronium and to observe and characterize the rare three gamma decay of the ortho-positronium state.



Location: IJCLab - Building 100
Supervisor: **J. Biteau**

Examination rules of laboratory work

The aim of the laboratory work is to build one or more experiments using the available equipment to carry out a pre-defined physics measurement. Five criteria are used in the final evaluation of the student laboratory work:

1.	the autonomy and dynamism during the lab. work	(4 points)
2.	the scientific interest for the subject	(4 points)
3.	the lab work logbook	(2 points)
4.	the article	(6 points)
5.	the oral examination	(4 points)

(1) is evaluated by the supervisor based on the involvement of the students during lab work.

(2) is evaluated by the supervisor based on the investigations done by the students to answer the questions arising during lab work, their ability to understand the physics motivations for their work and the discussions they initiated with the supervisor.

(3) measures the quality of the experimental logbook which is distributed to the students the first day. The logbook should be easily readable and demonstrate the progress made day after day as well as the dead-ends encountered. The information provided in the logbook should allow the experiment to be redone from scratch if one so wishes.

(4) consists in the evaluation of the quality of the paper written by each team where the objectives, the experimental set-up and the results obtained are presented. The article is written as if it were a publication and should be submitted to the supervisors by 26th of February 2021. It will be commented by the supervisors but only two persons will correct all the reports. To do so, these two persons (J. Biteau and M. Vandebrouck) will have the article as well as the corrections and comments made by the supervisors at their disposal by the 5th of March 2021.

(5) consists in a 10 minutes interview during which the referees will ask questions to test the understanding of the team of the experimental work. This interview is scheduled for the 17th of March.

(1) and (2) are evaluated by the supervisor on an individual-basis, even though it is a team work. (3) and (4) are evaluated by J. Biteau and M. Vandebrouck, there is one mark for the team. Finally, (5) is evaluated by J. Biteau and M. Vandebrouck on an individual basis.