# Exploring Cosmic Rays with CosmicWatch Desktop Muon Detectors

Created as part of 6CCP3131 Third-Year Project in Physics:
"Developing Cosmic Ray Muon Detectors for Outreach".
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# Chapter 1

# Introduction

This guide is designed to introduce you to the fascinating world of cosmic rays and the technology used to detect them. By engaging with this material, you'll gain hands-on experience with the CosmicWatch Desktop Muon Detector, a tool developed to observe and study muons—high-energy particles produced when cosmic rays interact with Earth's atmosphere.

## 1.1 What Is a Cosmic Ray Muon?

A cosmic ray muon is a subatomic particle created when high-energy cosmic rays from space collide with atoms in Earth's upper atmosphere. These collisions produce a shower of secondary particles, and among them are muons—particles similar to electrons but around 200 times heavier.

Muons are highly energetic and can travel long distances, even penetrating through solid materials like rock or concrete. Despite being created high in the atmosphere and having a mean lifetime of 2.2 microseconds, muons frequently reach the Earth's surface due to the effects of special relativity and time dilation, and scientists study them to learn more about cosmic rays and the universe beyond our planet.

## 1.2 What Is a Muon Detector?

A muon detector is a device that identifies and measures the passage of muons. The CosmicWatch Desktop Muon Detector utilizes a plastic scintillator cou-

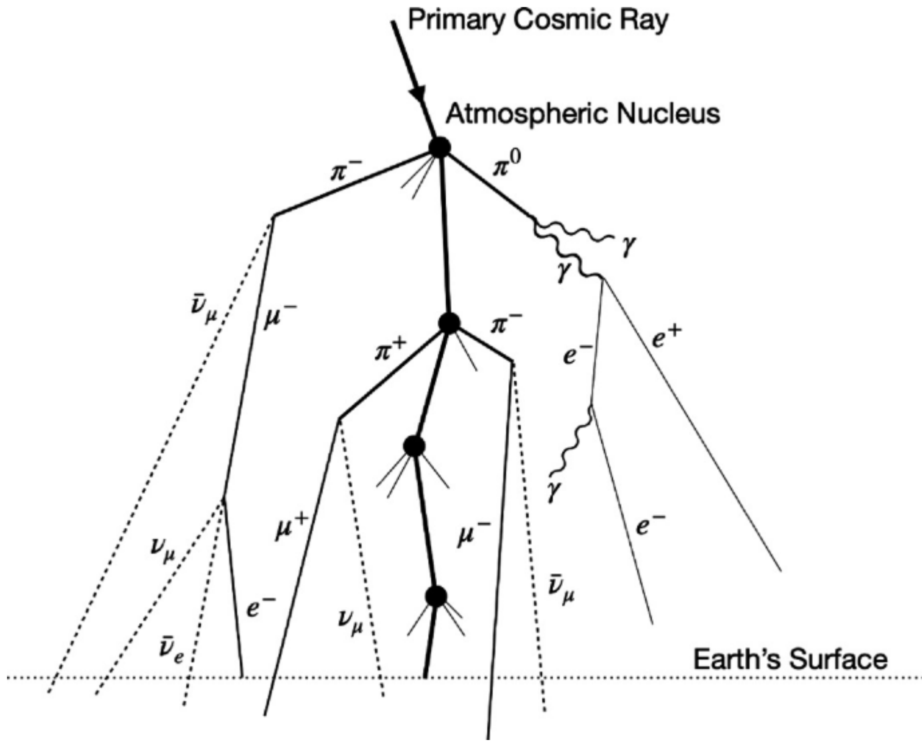


Figure 1.1: Cosmic ray muons are elementary particles produced during the nuclear cascade process. Primary cosmic rays (mainly protons) hit nuclei in the atmosphere, producing secondary particles, including mesons like pions ($\pi^{\pm}$) and kaons ($K^{\pm}$). These mesons then decay, predominantly into muons ($\mu^{\pm}$) and neutrinos ($\nu$).

pled with a silicon photomultiplier (SiPM) to detect these particles. When a muon passes through the scintillator, it emits light, which the SiPM converts into an electrical signal. This signal is then processed to determine the event's characteristics, such as time and energy.

## 1.3 Purpose of this Handbook

This handbook aims to provide a comprehensive understanding of muon detection, focusing on practical applications and data analysis. You'll explore various aspects of the detection process, including:

- **Detector Setup and Calibration:** Learn how to properly set up and calibrate the muon detector for accurate measurements.
- **Data Collection Techniques:** Understand the methods for collecting and recording muon events.
- **Data Analysis:** Analyse collected data to identify patterns and draw conclusions about cosmic ray interactions.
- **Workshop Activities:** Engage in hands-on activities to reinforce theoretical knowledge and develop practical skills.

## 1.4 Supplementary Materials

For all referenced supplementary materials, and latest version of this handbook, please see this project's GitHub: `https://github.com/Jbazeed/CosmicWatch_Outreach`

## 1.5 Acknowledgements

The CosmicWatch Desktop Muon Detector was developed by Spencer N. Axani, a graduate student at the Massachusetts Institute of Technology (MIT), in collaboration with the National Centre for Nuclear Research (NCBJ) in Warsaw, Poland. Their work has made it possible for students and educators worldwide to explore cosmic rays through affordable and accessible technology.

For comprehensive resources, including detailed instructions, Arduino code,

calibration procedures, and data analysis scripts, please refer to the official CosmicWatch GitHub repository:
https://github.com/spenceraxani/CosmicWatch-Desktop-Muon-Detector-. This repository serves as a central hub for all project-related resources, ensuring you have access to the latest updates and documentation.

Further, this handbook was created as part of completing the KCL 6CCP3131 Third-Year Project in Physics: "Developing Cosmic Ray Muon Detectors for Outreach". Thank you to my group members for their support and contributions: Ethan Buttery, Ahamad Kayani, George Moulton, Karin Samokovlisky, Yifei Tang, Mohammad Uhayd.

# Chapter 2

# Workshop Plan: Investigating the Effect of Altitude on Muon Flux

**Objective:** Measure how muon flux changes with altitude.

**Duration:** 1-2 hours.

**Materials Needed:**

- One pre-assembled CosmicWatch Desktop Muon Detector.
- Male-to-male USB-C cable (to connect one of the detectors to your device).
- Laptop/tablet with access to CosmicWatch data logging software.
- Access to a multi-story building.
- Printed handouts and worksheets.

## 2.1 Handout: Investigating the Effect of Altitude on Muon Flux

Muons are highly penetrating and can travel through matter, reaching the Earth's surface and even underground. Because they are unstable, muons decay over time and distance, so the number of muons decreases as you move downward from high altitudes. This experiment explores how muon detection rates change with height, highlighting their atmospheric origin and the effect of decay over distance.

**Experimental Setup** Set up the CosmicWatch detector and connect it to a laptop. Starting at the highest accessible level of your building, take readings at various levels going down to the lowest accessible level of your building.

### 2.1.1 Worksheet

**Part 1: Data Collection**

1. **Set Up the Detector:** Connect the CosmicWatch detector to a laptop. Check the screen to make sure it is working properly.

2. **Collect Data:** See appendix A. Follow the instructions to start recording data for a fixed duration (e.g., 15-20 minutes).

3. **Repeat for Each Floor:** ensure each measurements lasts the same duration for consistency.

**Part 2: Data Analysis**

1. **Analyse Data:** Access the data analysis Jupyter notebooks on this project's GitHub repository: `https://github.com/Jbazeed/CosmicWatch_Outreach`. Follow the instructions in the notebooks to import and analyse the collected data, plotting the muon count rate against the floor/altitude.

2. **Discussion:** Interpret the results and discuss any trends that you observe. Why might the count rate change with altitude?

3. **Interpret Findings:** Consider any real-world applications for these findings.

# Chapter 3

# Workshop Plan: Investigating Cosmic Ray Muon Angular Dependence

**Objective:** To engage students in understanding how the detection rate of cosmic ray muons varies with the angle of the detector, emphasizing the principles of angular dependence in particle detection.

**Duration:** 1-2 hours.

**Materials Needed:**

- Pre-assembled CosmicWatch Desktop Muon Detectors.
- 3.5mm male-to-male audio cable (to connect detectors together in coincidence mode).
- Male-to-male USB-C cable (to connect one of the detectors to your device).
- Protractor.
- Tripod or adjustable stand to hold detectors at various angles (see figure 3.1).
- Laptop/tablet with access to CosmicWatch data logging software.
- Printed handouts and worksheets.

## 3.1 Handout: Investigating Cosmic Ray Muon Angular Dependence

The rate of cosmic ray muons detected by a scintillator-based detector like CosmicWatch varies with the angle of incidence. This variation is due to the geometry of the detector and the path length through the scintillator material.

At sea level, the cosmic muon flux follows a cosine-squared dependence on the zenith angle ($\theta$), described by the equation:

$$I(\theta) \propto \cos^2(\theta). \tag{3.1}$$

This means that muons arriving from directly overhead ($\theta = 0°$) are detected more frequently than those coming from near the horizon ($\theta = 90°$).

Figure 3.1: Experimental apparatus to measure angular dependence of cosmic ray muons.

**Experimental Setup** By positioning the CosmicWatch detector at various known angles, we can measure the muon detection rate at each angle. Comparing these measurements to the theoretical cosine-squared distribution allows for practical understanding of angular dependence in particle detection.

### 3.1.1 Worksheet

**Part 1: Data Collection**

1. **Set Up the Detector:** Secure the CosmicWatch detector on a tripod or adjustable stand. Use a protractor to position the detector at a 0° angle relative to the vertical.

2. **Collect Data:** See appendix A. Follow the instructions to start recording data for a fixed duration (e.g., 15-20 minutes).

3. **Repeat Measurements at Different Angles:** Adjust the detector to 30°, 60°, and 90° angles relative to the vertical. For each angle, repeat the data collection process, ensuring each measurement lasts the same duration for consistency.

**Part 2: Data Analysis**

1. **Analyse Data:** Access the data analysis Jupyter notebooks on this project's GitHub repository: `https://github.com/Jbazeed/CosmicWatch_Outreach`. Follow the instructions in the notebooks to import and analyse the collected data, plotting the detection rate against the angle and then comparing the results to the theoretical cosine-squared distribution.

2. **Discussion:** Interpret the results and discuss any discrepancies. Consider factors that might influence the angular dependence of muon detection.

3. **Interpret Findings:** Reflect on how the angular dependence of muon detection can be applied in real-world scenarios, such as muon tomography or cosmic ray studies.

# Chapter 4

# Workshop Plan: Testing the Effects of Shielding

**Objective:** Investigate how various materials affect the ability of muons to reach the detector.

**Duration:** 1-2 hours.

**Materials Needed:**

- Pre-assembled CosmicWatchDesktop Muon Detector.
- Various materials (e.g., books, water bottles, bricks, metal sheets, etc.).
- Laptop/tablet with access to CosmicWatch data logging software.
- Printed handouts and worksheets.

## 4.1 Handout: Testing the Effects of Shielding

**Experimental Setup** Set up the detector in a stable position. Measure baseline muon count without any obstruction. Then place different materials above the detector one at a time, measuring for a set time each.
NB: For better results, you can try to set-up two detectors in coincidence and put the shielding material in between them. How does it affect your readings?

### 4.1.1 Worksheet

Muons are produced in the upper atmosphere and can pass through substantial amounts of matter due to their high energy and mass (about 200 times greater than an electron). However, their number can still be slightly reduced by dense materials due to scattering and energy loss. This experiment investigates how different materials attenuate the muon flux and serves as a demonstration of the penetrating power of muons. It also introduces the idea of how different materials interact with radiation, a key concept in both particle physics and radiation shielding.

**Part 1: Data Collection**

1. **Set Up the Detector:** Set up the detector in a stable positon and connect to your device.

2. **Collect Data:** See appendix A. Follow the instructions to start recording data for a fixed duration (e.g., 15-20 minutes). This will be your baseline (no shielding) muon count.

3. **Repeat Measurements:** Test each material by placing it above the detector and record your data. Repeat for each material, ensuring each measurement lasts the same duration for consistency.

**Part 2: Data Analysis**

1. **Analyse Data:** Access the data analysis Jupyter notebooks on this project's GitHub repository: `https://github.com/Jbazeed/CosmicWatch_Outreach`. Follow the instructions in the notebooks to import and analyse the collected data, plotting the count rates against time for each material.

2. **Discussion:** Consider your plots. Which material blocks the most muons?

3. **Interpret Findings:** What does this say about the penetrating power of muons? Are there any practical applications for your findings?

# Appendix A

# Set-up and Data Recording

*Acknowledgement: The Windows set-up instructions were adapted from instructions provided by Boglárka Keresztesi and Srinidhi Dantu. The macOS instructions were contributed by Karin Samokovlisky.*

## A.1 Set-up Instructions For Windows

1. Make sure you have the latest version of Python installed on your device.
   (a) To download Python, go to the official Python website and select the appropriate installer for your operating system.
   (b) Download the installer and follow the on-screen instructions to complete the installation process, ensuring you check the box that says "Add Python to PATH".
   (c) To ensure your download was successful and that you have the latest version of Python, open Command Prompt (press `Windows Key + R` then `Enter`), and type: `python -version` or `python3 -version`.
   (d) Ensure you have the latest version Python package installer by typing `pip -version` or `pip3 -version` in the Command Prompt.
2. To install the required Python packages: type `pip install tornado serial numpy pyserial` in the Command Prompt.
3. Download the official CosmicWatch v2 repository from `https://github.com/spenceraxani/CosmicWatch-Desktop-Muon-Detector-v2`. Unzip the file and note where you saved it—we will have to access it often.

## A.2 Set-up Instructions For macOS

1. To download Python, go to the official Python website and select the appropriate installer for your operating system.
   (a) Download the installer and follow the on-screen instructions to complete the installation process, ensuring you check the box that says "Add Python to PATH".
   (b) To ensure your download was successful and that you have the latest version of Python, open Terminal (press `Command + Space`, type `terminal` and press `Enter`.), and type: `python3`.
2. To install the required Python packages: type `pip3 install tornado serial numpy pyserial` into the terminal.
3. To be able to read from the serial port, install the CH340g driver: `https://github.com/adrianmihalko/ch340g-ch34g-ch34x-mac-os-x-driver/tree/master`. Unzip `CH34x_Install_V1.3.zip`, and follow installation instructions.[1]
4. Download the official CosmicWatch v2 repository from `https://github.com/spenceraxani/CosmicWatch-Desktop-Muon-Detector-v2`. Unzip the file and note where you saved it—we will have to access it often.
5. Open `import_data_py3.py`. Go to line 252 and swap the line with:
   `det_name = globals()['Det%s' % str(i)].readline().decode(errors=`
   `'ignore')`
   `.strip()`. Make sure to save the file before continuing!

## A.3 Reading Data

1. Navigate to `"...\CosmicWatch-Desktop-Muon-Detector-v2-master\CosmicWatch-Desktop-Muon-Detector-v2-master\Recording_Data"`
2. Run `import_data_py3.py`. (NB: You may also do this through the Command Prompt window by typing: `python import_data_py3.py` or `python3 import_data_py3.py`.)
3. Choose the port the CosmicWatch detector is connected through.

[1] NB: You may need to reboot your device after installing the serial port driver for it to work.

**To record data to computer:**

1. Choose `[1] Record data on the computer`.
2. Name your file "`[FileNameHere].txt`"

NB: If you get the following error after selecting option [1]:

```
    Selected operation: 1
Traceback (most recent call last):
  File "Recording_Data/import_data_py3.py", line 138, in serial_ports
    s = serial.Serial(port)
AttributeError: module 'serial' has no attribute 'Serial'
```

Try going opening Command Prompt/Terminal and typing:

```
pip uninstall pyserial
pip uninstall serial
pip install pyserial
```

**To use CosmicWatch website interface to record data:** [2]

1. Choose `[4] Connect to server: www.cosmicwatch.lns.mit.edu`
2. Follow instructions on page to start/stop recording data and save read-out files.

[2] Useful for live monitoring!

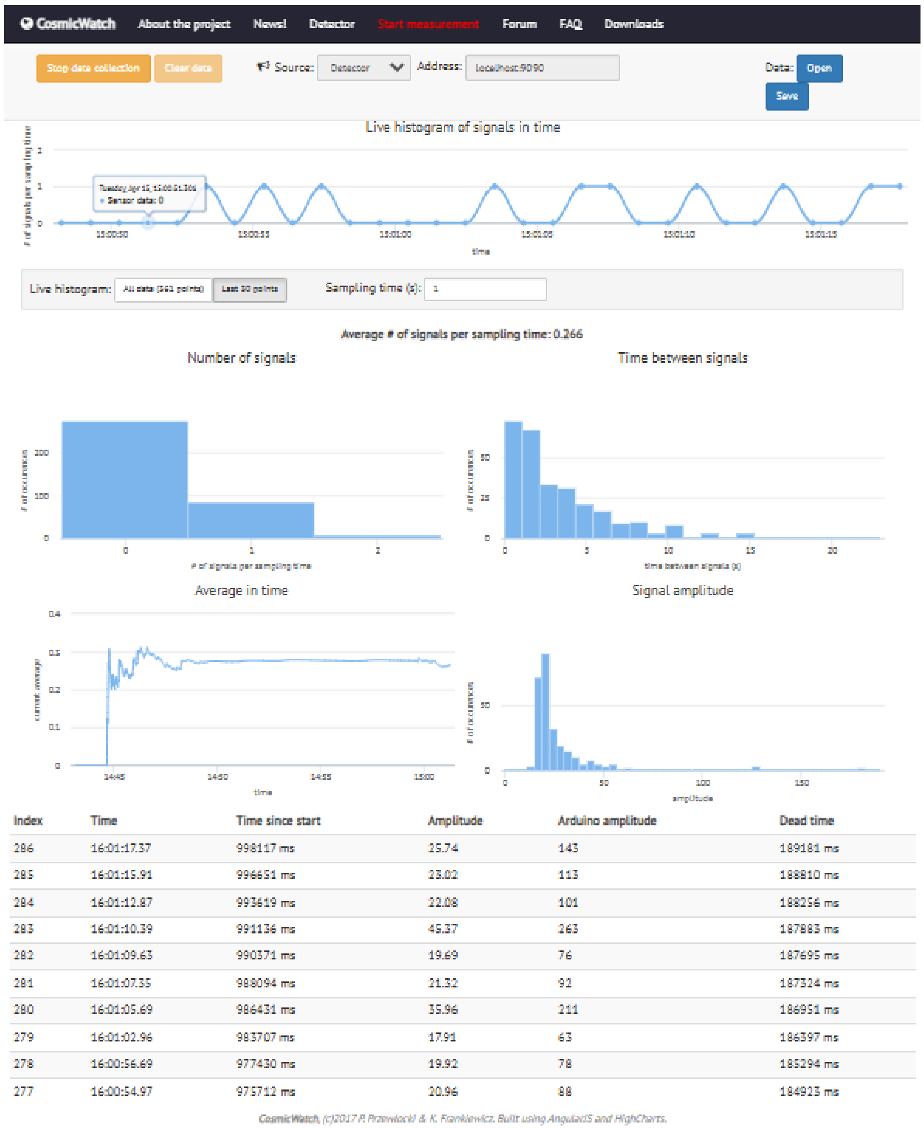


Figure A.1: Screenshot of website interface for live data monitoring (`http://www.cosmicwatch.lns.mit.edu/measure`).