Interactive Physics

Epifanio Ponce (FCFM-BUAP), Humberto Salazar (CIIEC-BUAP) & Luis Villaseñor (CIIEC-BUAP)

Centro Interdisciplinario de Investigación y Enseñanza de la Ciencia

Benemérita Universidad Autónoma de Puebla

Abstract

We describe several web-based applications designed for teaching Particle Physics, Cosmic Ray Physics, and General Physics. These tools allow users to interact in real time either with simple, easy-to-build experimental setups or with laboratory equipment located at the CIIEC facilities. Such experiments can help inspire and guide young students in elementary, middle, and high school to pursue scientific careers.

Among other experiments, we present the real-time measurement of muon decays and the real-time measurement of the secondary cosmic ray muon flux, both performed with a liquid scintillator detector. We also show the detection of muon tracks using a cosmic ray telescope based on Resistive Plate Chambers. We also describe an experiment to measure the speed of secondary muons in real-time. These detectors operate continuously (24/7) at the CIIEC facilities, and their data are displayed in real time through the CIIEC web server. Additional projects include the construction and use of a light spectrometer, a photoplethysmograph, and a simple digital oscilloscope, as well as web applications that illustrate a quantum computer simulator and a simple example of parallel computing.

ciiec.buap.mx

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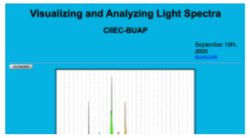
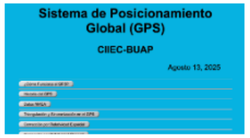
Eventos y Noticias
Selección por Categorías

Aplicaciones Web

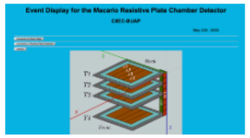


25 de septiembre 2025 — Visualizing and Analyzing Light Spectra

22 de septiembre 2025 — Construye tu propio Foto-pletismógrafo

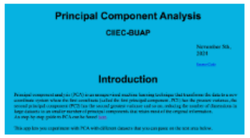


13 de agosto 2025 — Sistema de Geopocisionamiento Global: Conecta tu propio receptor GPS



23 de mayo 2025 — Telescopio de muones Macario, con introducción a los Rayos Cósmicos y a Aplicaciones de los telescopios de muones

13 de noviembre 2024 — Aplicación que ilustra la técnica de t-SNE de reducción dimensional y visualización en machine learning no supervisado

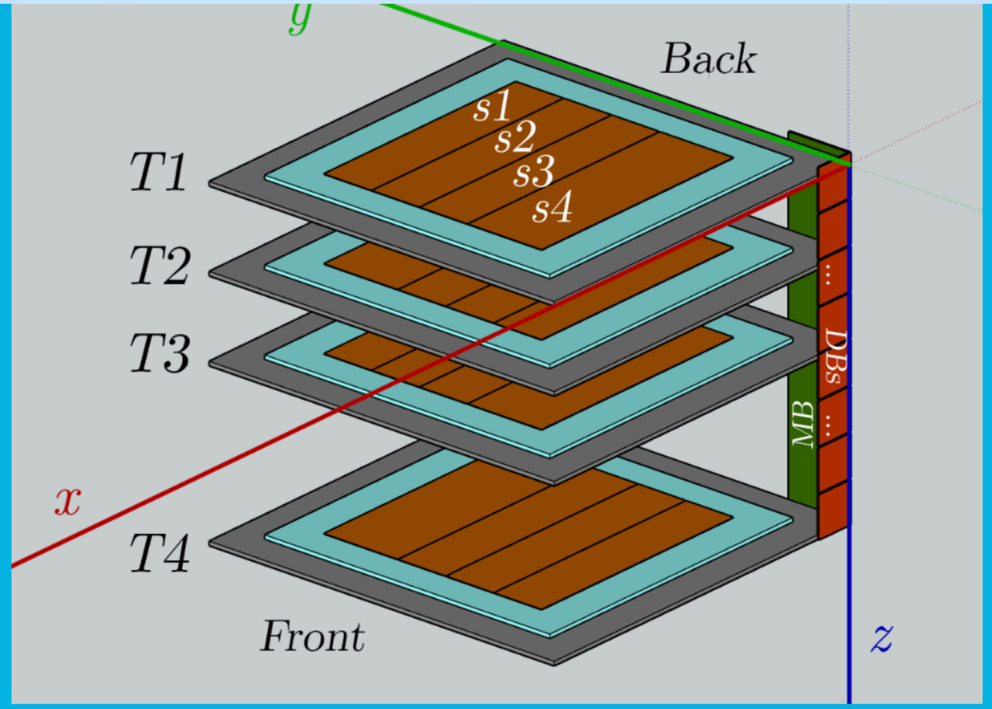


05 de noviembre 2024 — Aplicación que ilustra la técnica de Análisis de Componentes Principales en machine learning no supervisado

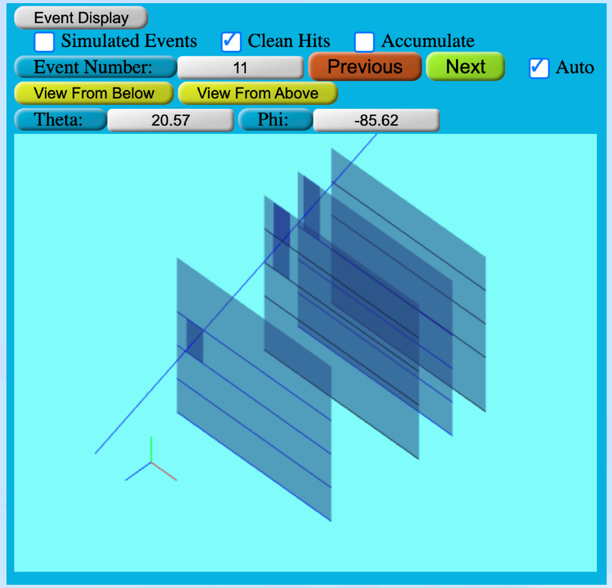
Event Display for the Macario Resistive Plate Chamber Detector

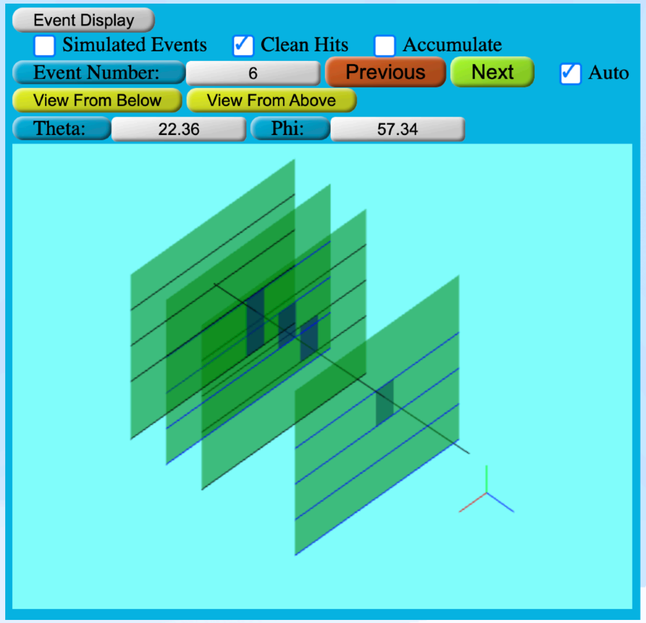
CIIEC-BUAP

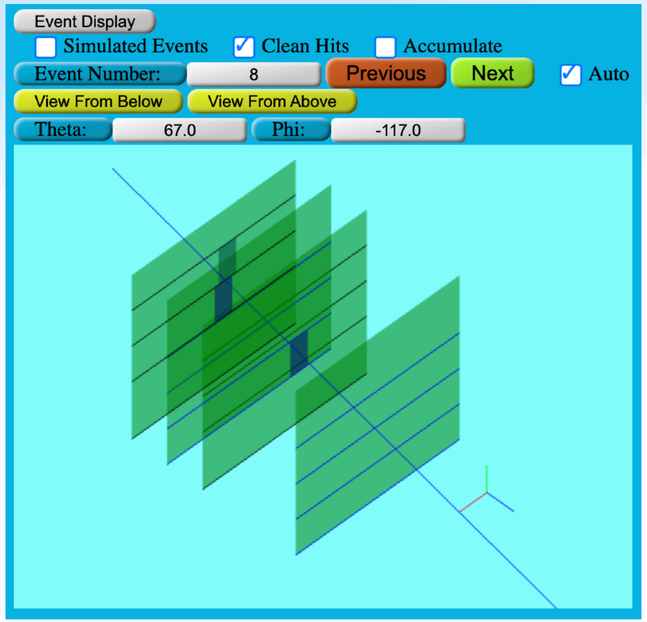
May 23th, 2025

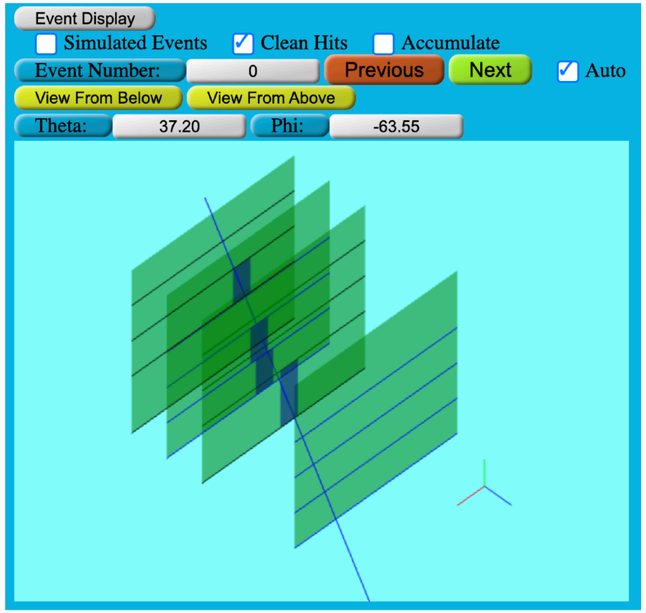


Schematic diagram of the Macario detector
Source: *Victor M. Nouvilas and Cayetano Soneira, The first miniTrazgo Cosmic Ray detector*
https://www.lip.pt/files/training/papers/2023/pdf/2021-PAPER-144-13.pdf









East-West Effect

FEE ORIGIN OF THE COSMIC RAY: SCIENCE ATTACKS BASIC PROBLEM; Compton's World-Wide Study Is Expected to Throw Light on the Secret of Matter's Structure and Origin of Creation

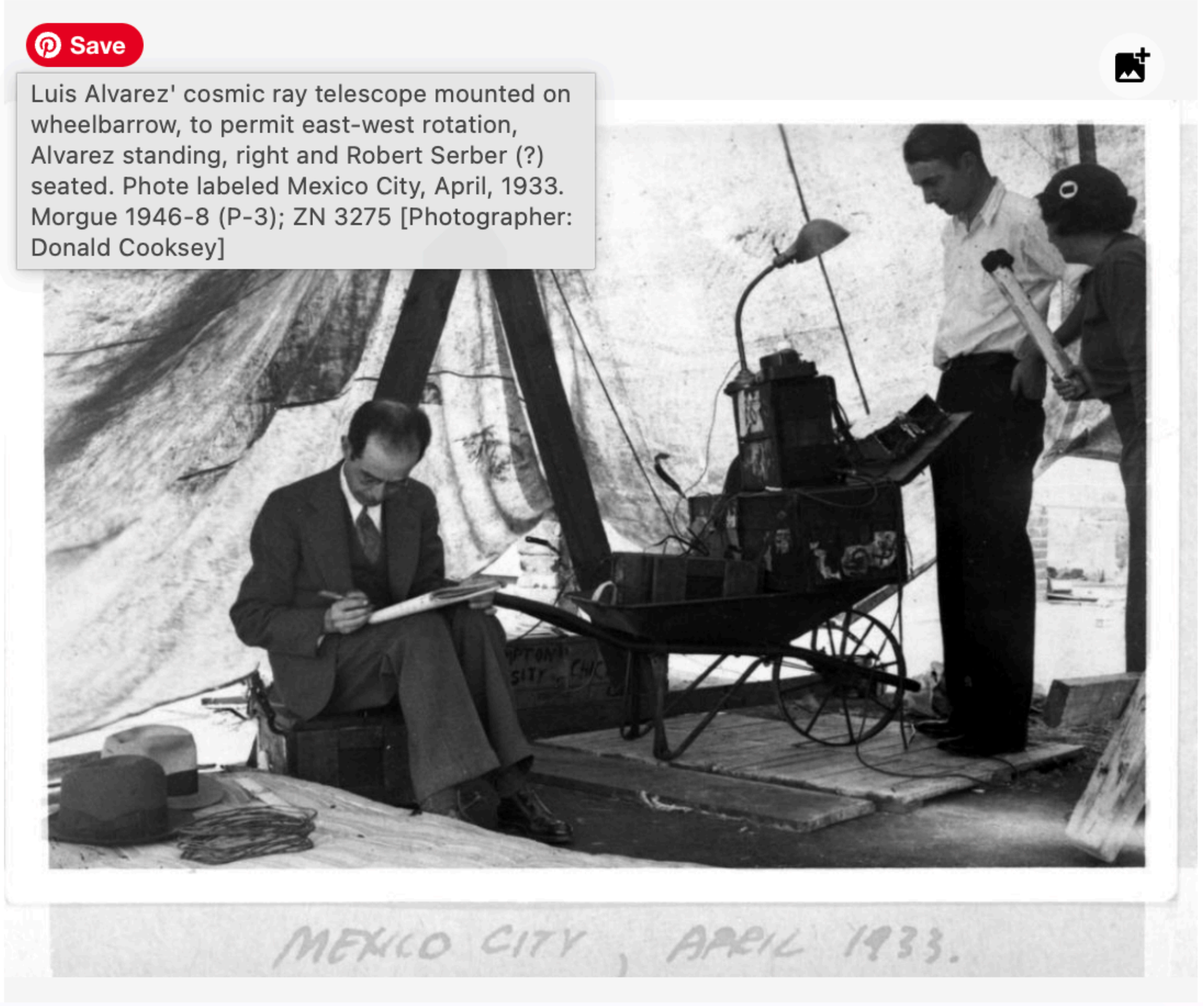
Share full article

By Waldemar Kaempffert.

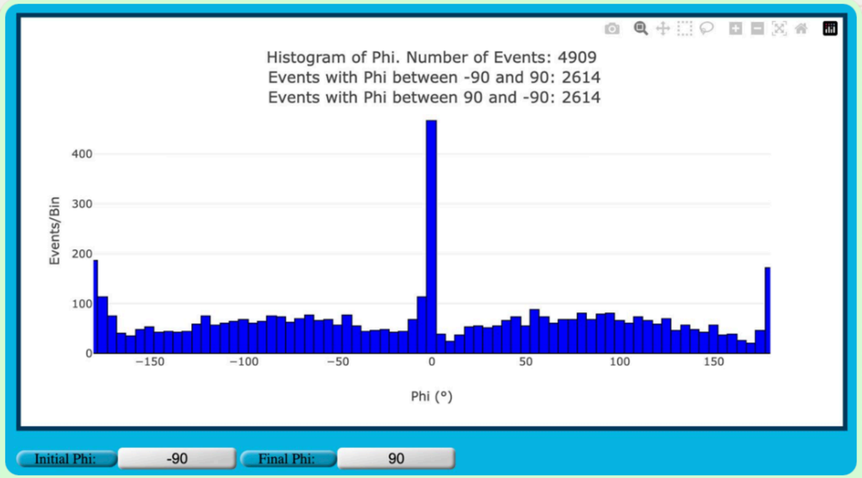
Jan. 10, 1932

See the article in its original context from January 10, 1932, Section XX, Page 5 | Buy Reprints

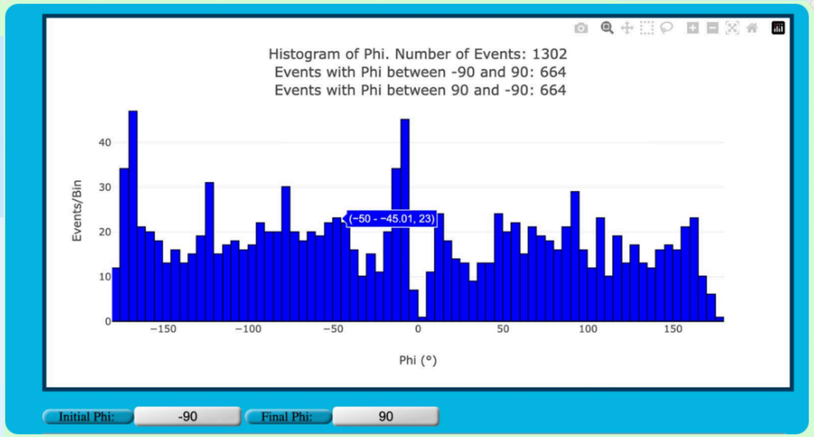
Source: New York Times



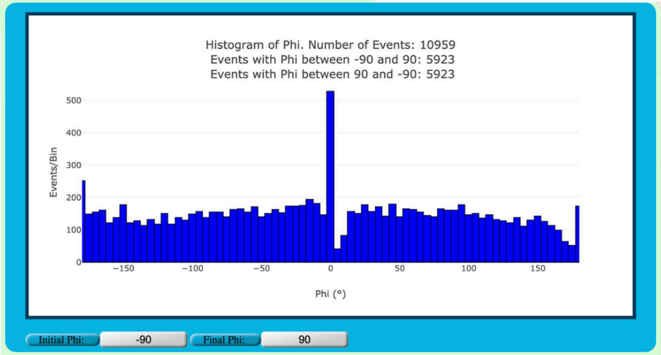
Source: https://picryl.com/media/luis-alvarez-cosmic-ray-telescope-mounted-on-wheelbarrow-to-permit-east-west-c85b53



Estos son los últimos 26600 eventos, para 3+ planos hay 2614 eventos que llegan del Oeste y 2295 que llegan del Este, confirmando que se ve un efecto similar al Este-Oeste.



Para 4 planos hay 664 que llegan del Oeste y 638 que llegan del Este, tambien confirmando el efecto Este-Oeste



Para 2+ planos, 5923 llegan del Oeste y 5036 del Este, tambien confirmando efecto Este-Oeste

8:53 a.m.

PROCEEDINGS OF SCIENCE

Measurement of the East-West Effect of the Cosmic Muon Flux Using a Compact Telescope Based on Resistive-Plate-Chamber Technology

Aguilar-Rivera, C.,[a,b,*] Bautista-Guzmán, I.,[a,b] Cid-Porras, J.,[a,b] Garzón, J.A.,[c,d] Martínez-Bravo, O.,[b] Ponce-Lancho, E.,[a,b] Ruiz-Hernandez, O.,[b] Salazar-Ibargüen, H.,[a] Torres-Castaño, C.,[a,b] Varela-Carlos, E.[b] and Villaseñor-Cendejas, L.[a]

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[c] *LabCAF, Instituto Galego de Física de Altas Energías, Universidad de Santiago de Compostela, E-15782, Santiago de Compostela, Spain*
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We describe the design, construction, and operation of a compact cosmic-ray (CR) telescope of the TRASGO (TRAck reconStructinG bOx) type, consisting of four resistive plate chambers (RPCs), located in Puebla City, Mexico, at latitude/longitude of 18° 59' 56" N/98° 11' 41" W. and 2100 m a.s.l. This telescope allows the detection of isolated muons with good angular resolution through the application of quality cuts on the TDC signals. We also describe the implementation of a webpage with an event display that shows the hits on each of the 4 planes and the reconstructed trajectories of isolated muons. These clean events were used to measure the azimuthal distributions of the muons crossing the detector for various cuts at the zenith angle. We report on the measurement of the East-West asymmetry in the flux of secondary cosmic-ray muons and compare our results with detailed simulations based on the CORSIKA software. Finally, we discuss the use of this type of small detector in education and outreach activities to measure several properties of secondary cosmic-ray muons.

39th International Cosmic Ray Conference (ICRC2025)
15–24 July 2025
Geneva, Switzerland

ICRC 2025
The Astroparticle Physics Conference
Geneva July 15-24, 2025

*Speaker

English Español

Online Measurement of the Muon Lifetime

CIIEC-BUAP

August 23rd, 2024

Source Code

Contacts: Epifanio Ponce, epifanio.ponce@correo.buap.mx & Luis Villaseñor, lvillasen@gmail.com

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Introduction

This app measures the muon lifetime by using data acquired in real time. The muon is a subatomic particle discovered in cosmic rays in 1937 by Carl Anderson and Seth Neddermeyer. It decays by means of the weak force with the decay modes

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

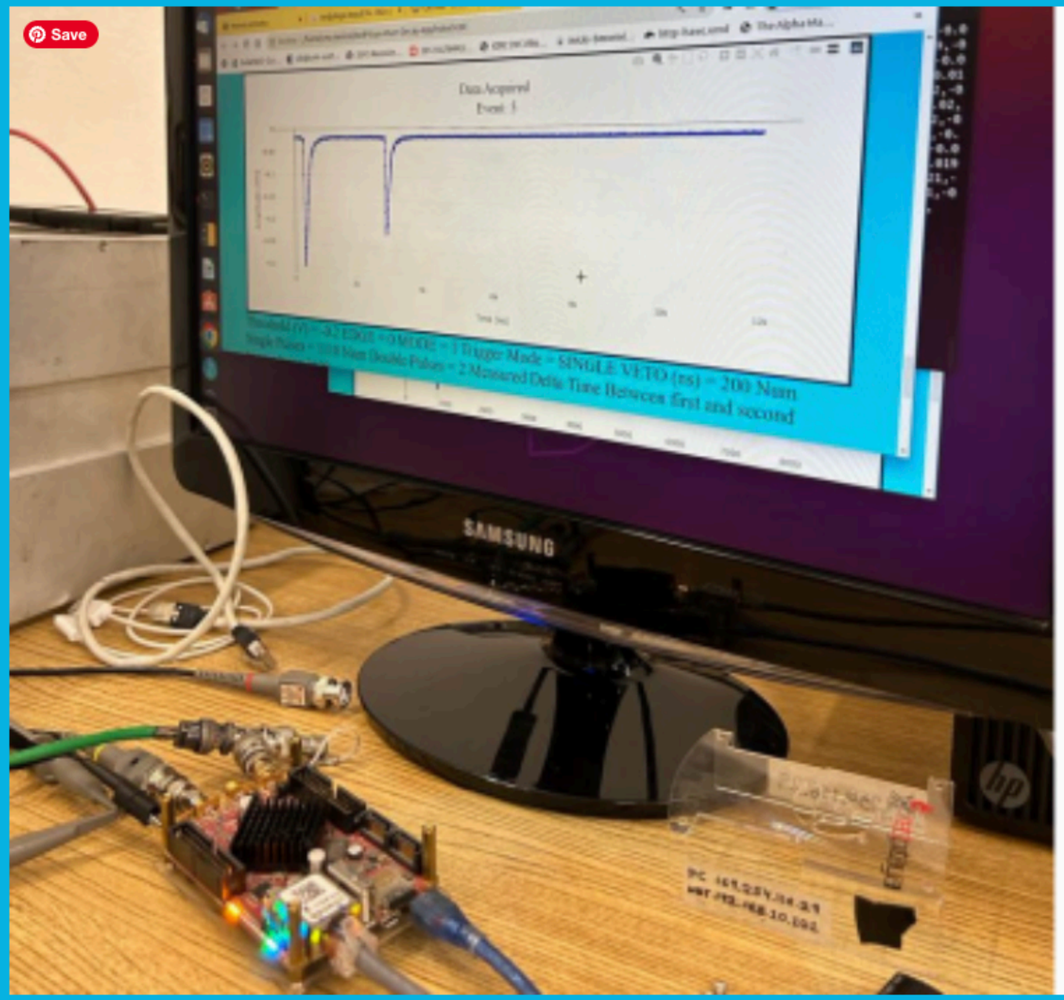
with a lifetime in vacuum of 2.19 μs, however, when negative muons decay in a medium, besides decaying they can be captured by protons of the nuclei of the medium

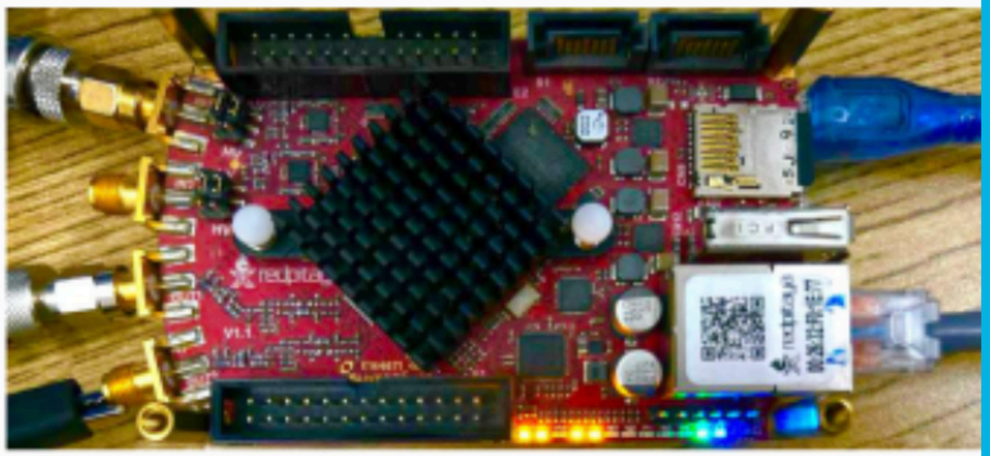
$$\mu^- + p \rightarrow n + \nu_\mu ,$$

resulting in an average measurement of the lifetime of positive and negative muons lower than 2.19 μs.

The detector we are using consists of a 95-liter container filled with liquid scintillator with a faster and bigger photomultiplier, Electron Tubes 9354KB with a diammeter of 200 mm, shown in the next picture.

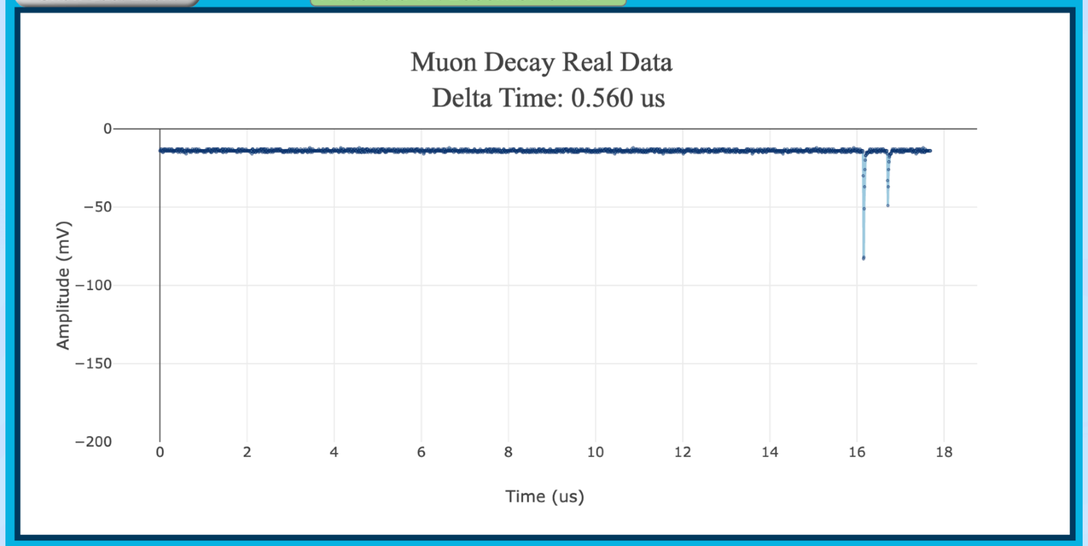
We used a STEMlab 125-14 RedPitaya board, shown in the picture below, to collect the data shown on this app, as described here.





The Muon Lifetime Detector is On | Stop

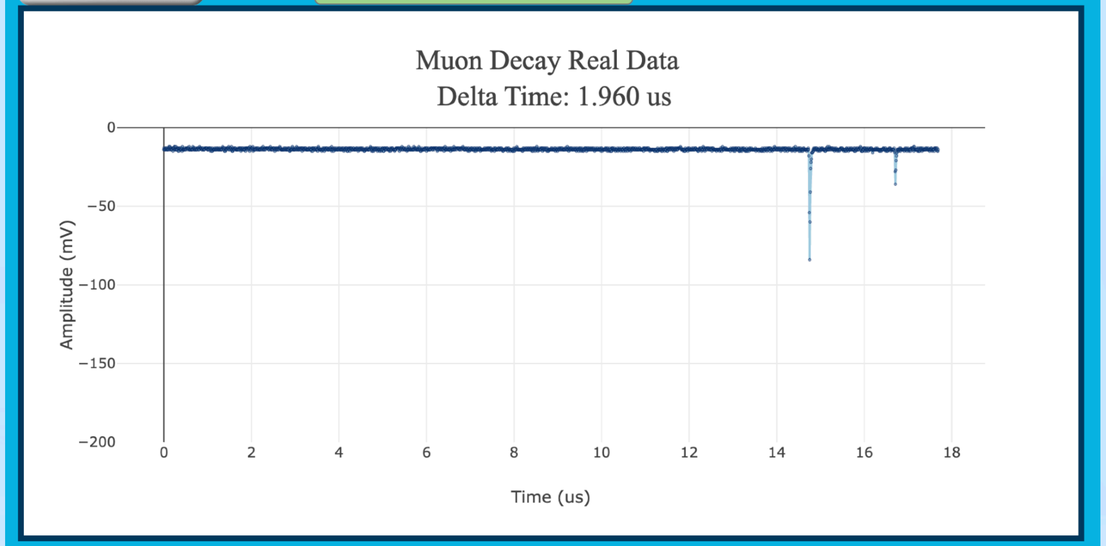
Show Last Event | Threshold wrt Baseline: -5 mV



20251024-150847 Evt number: 2211 Threshold (V) = -0.025 EDGE = 0 MODE = 1 Trigger Mode = NORMAL VETO (ns) = 150 Event size = 2214

The Muon Lifetime Detector is On | Stop

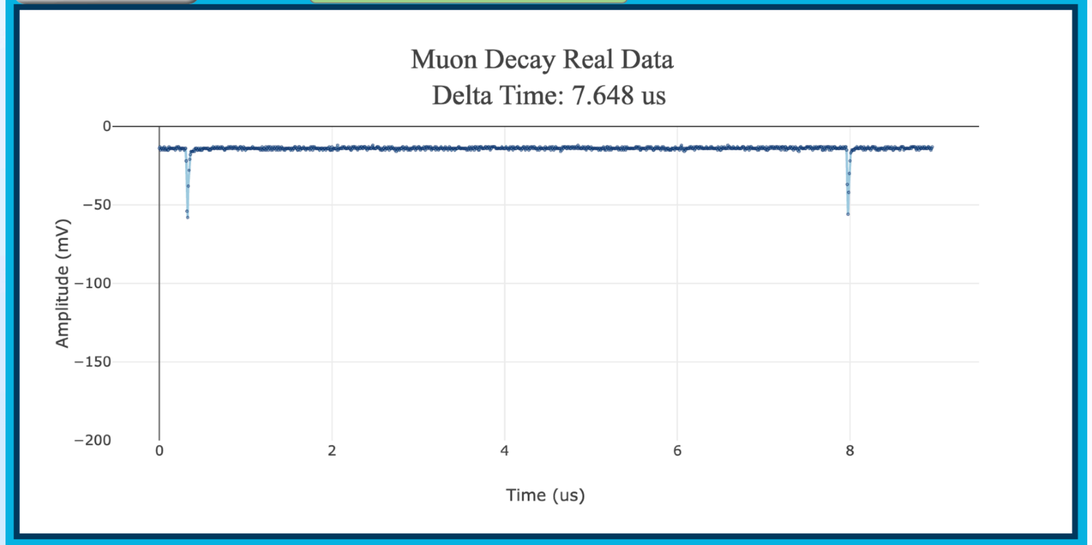
Show Last Event | Threshold wrt Baseline: -5 mV



20251024-150744 Evt number: 2208 Threshold (V) = -0.025 EDGE = 0 MODE = 1 Trigger Mode = NORMAL VETO (ns) = 150 Event size = 2214

The Muon Lifetime Detector is On | Stop

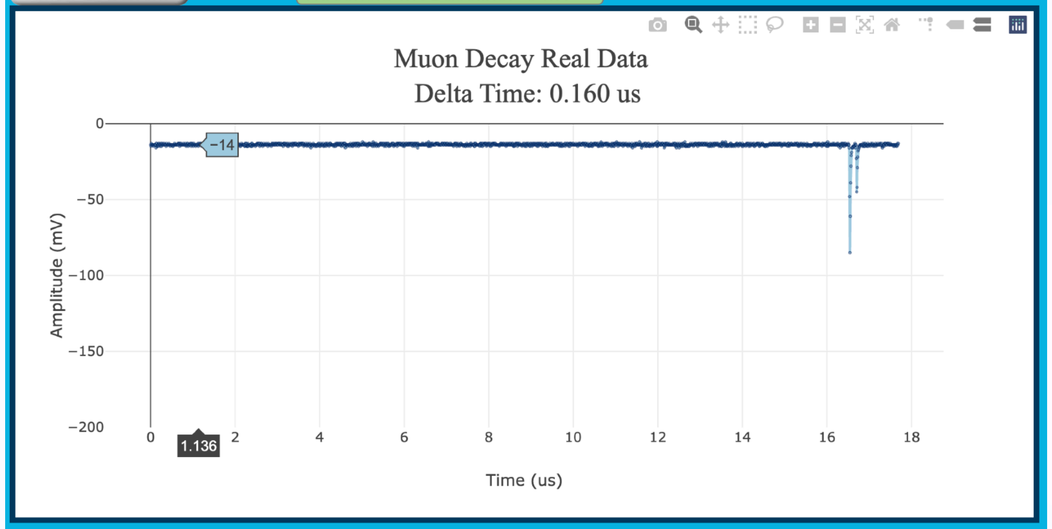
Show Last Event | Threshold wrt Baseline: -5 mV



20251024-155443 Evt number: 2389 Threshold (V) = -0.025 EDGE = 0 MODE = 1 Trigger Mode = NORMAL VETO (ns) = 150 Event size = 1122

The Muon Lifetime Detector is On | Stop

Show Last Event | Threshold wrt Baseline: -5 mV



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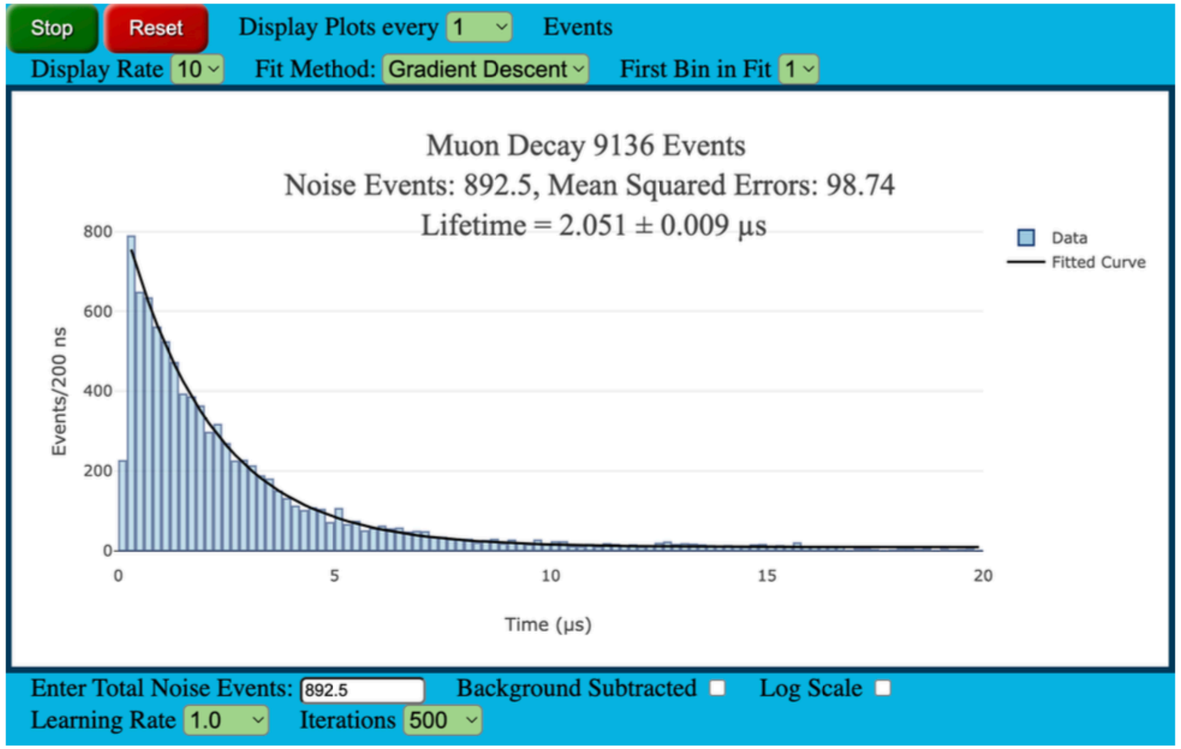

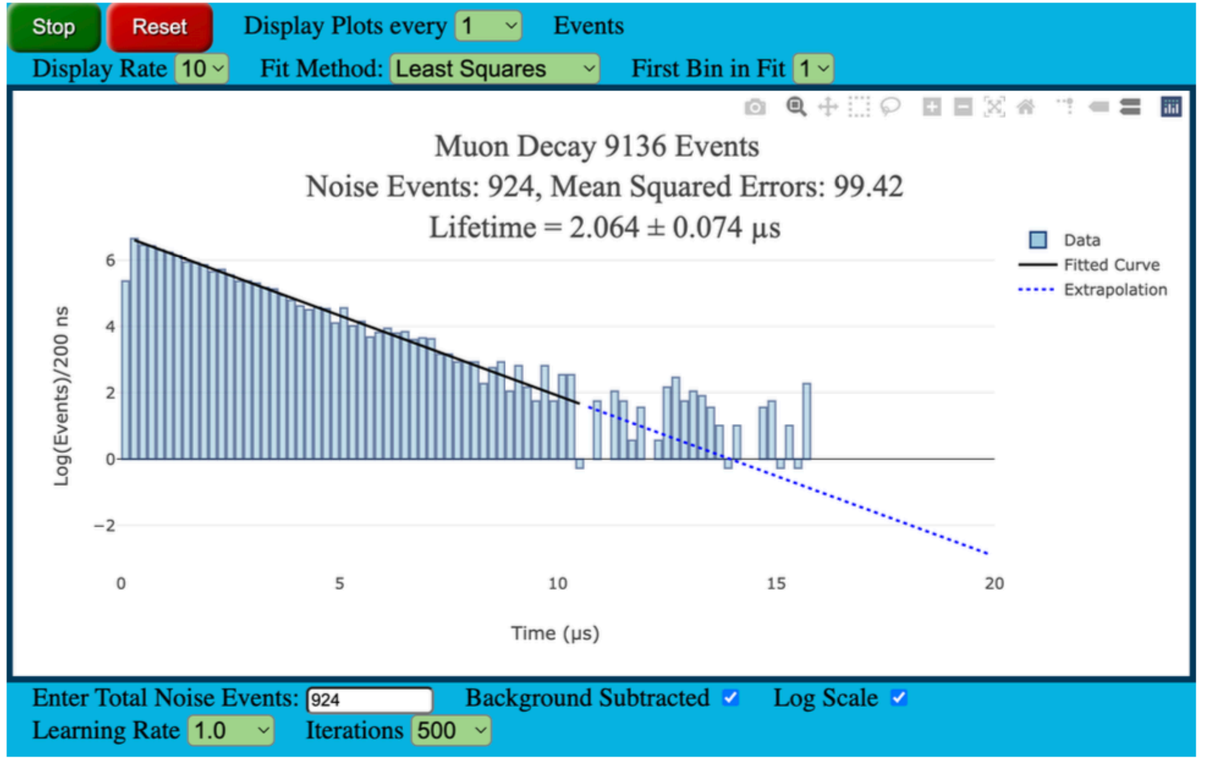

$$\tau_{\text{eff}} = 2.051 \pm 0.009\ \mu s$$

with MSE = 98.74.

$$\tau_{\text{eff}} = 2.064 \pm 0.074\ \mu s$$

. mean squared error of 99.42.

$$\tau_{\text{eff}} = \tau_\mu \cdot \frac{R + (1-R) \cdot \frac{1}{(1+\gamma)^2}}{R + (1-R) \cdot \frac{1}{1+\gamma}} \qquad (27)$$

where $\gamma = \frac{\Gamma_c}{\Gamma} = \Gamma_c \cdot \tau_\mu$ is the relative capture rate of negative muons and τ_μ is the mean muon lifetime given by Eq. 1.

Internet-based experiment to measure the muon lifetime in real time

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Centro Interdisciplinario de Investigación y Enseñanza de la Ciencia

Benemérita Universidad Autónoma de Puebla

72570 Puebla, Pue., México

We describe a web-based experiment to measure the lifetime of cosmic-ray muons that stop in a a liquid scintillator detector. Our experimental setup consists of a container filled with liquid scintillator, a photomultiplier tube, a commercial electronics board (STEMlab 125-14) that includes an ARM-based computer with a field programmable gate array (FPGA) and an analog to digital converter (ADC). The muons we detect arrive at the detector as part of the secondary cosmic rays that are produced high in the Earth atmosphere when energetic primary cosmic rays collide with nitrogen and oxygen nuclei. The software we use to run this experiment in real time on the web uses Python code on the computer of the Red Pitaya board and HTML/Javascript code on the webpage. The experiment is located at the Centro Interdisciplinario de Investigación y Enseñanza de la Ciencia on the campus of the Benemérita Universidad Autónoma de Puebla (BUAP) in the city of Puebla, Mexico. We report a value for the effective mean lifetime of the stopping muons of of 2.051 ± 0.009 μs. This result is lower than the 2.197 μs mean muon lifetime in vacuum due to the capture of negative muons by the nuclei of the atoms of the detector material. The experiment can be accessed through the webpage https://ciiec.buap.mx/Muon-Decay

Keywords: ***Cosmic Rays, Muons, Muon Lifetime, Muon Capture, Acquisition Electronics***

1 Introduction

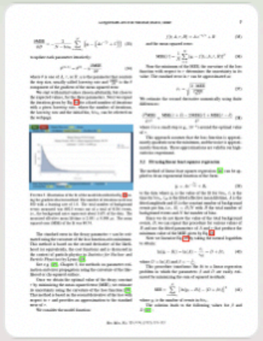
The muon is a subatomic particle discovered in 1936 by Carl D. Anderson y Seth Neddermeyer [1]. They used a detector called cloud chamber that had been recently invented by Charles Wilson [2]; in fact, Wilson was awarded the Nobel Prize in Physics in 1927 for this invention. The muon has the same charge and spin as the electron and about 210 times more mass. Muons are produced by the collisions of primary cosmic rays with nuclei of nitrogen and oxygen at several kilometers above the Earth surface. These collisions take place through the strong interaction and produce other subatomic particles, dominated by pions and kaons, which eventually decay through the weak force into muons and neutrinos. Primary cosmic rays consists primary of protons, those of low energies, up to about 100 MeVs, come from the Sun [3], while those of higher energies, up about 1 PeVs [4], come from supernova in own galaxy and those with even higher energies, up to 100 EeVs, may come from active galactic nuclei (AGN) of distant galaxies [5,6]. Secondary cosmic rays were discovered in 1912 by Victor Hess [7], they consist of 4 components of particle showers: hadrons, muons, neutrinos and an electromagnetic component formed by electrons and gamma rays.

Energetic secondary muons produced at the top of the Earth atmosphere travel with speeds close the speed of light. As explained below, their effective mean decay time when they decay in a non-vacuum medium may be slightly lower than τ_μ, however, their decay times may increase significantly due to the effect of time dilation, predicted by Albert Einstein in his Theory of Special Relativity in 1905. It is this time dilation that makes possible for a large number of muons to reach the Earth ground. The rate at which muons arrive at the ground at sea level is about 1 muon per square centimeter per minute [8] and increases to about 2 muons per square centimeter per minute for the 2000 m.a.s.l altitude of Puebla City.

The rate of arrival of secondary muons to our detector is around 72 Hz, they arrive with a mean energy of around 3 GeV at sea level [9] so that most of them have enough energy to cross our detector. However, a small fraction of all the muons that reach our detector, about 0.8%, stop and decay inside the liquid scintillator that we use in our detector. We measure the time difference between the first pulse of scintillation light, which is due to the stopping muon, positive or negative, and the second pulse, due to the decaying positron or electron, respectively. By measuring the lifetime of a large number of these decaying muons, as explained in detail below, we measure the effective mean lifetime of the muons that decay inside our detector.

1.1 Decay of muons in vacuum

Muons are unstable subatomic particles; when an isolated muon is at rest in a vacuum medium, it decays with a mean lifetime denoted by τ_μ; this is a universal constant that has been measured with great precision and it has the following value $\tau_\mu = 2.1969811 \pm 0.0000022$ μs [10]. The mean lifetime is the same for positive and negative muons, i.e., the measured ratio τ_{μ^+} to τ_{μ^-} is 1.00002 ± 0.00008 [10]. For



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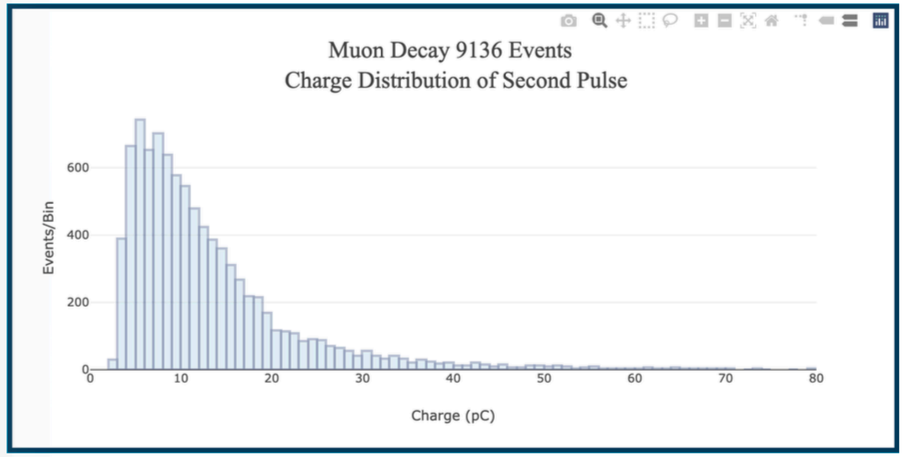
Home / Archives / Vol. 42 No. 4 (1995): Revista Mexicana de Física. / Articles

Medición de la razón de muones positivos a negativos en la radiación cósmica secundaria

Measurement of the Michel distribution



English Español

Online Muon Flux Measurement

CIIEC-BUAP

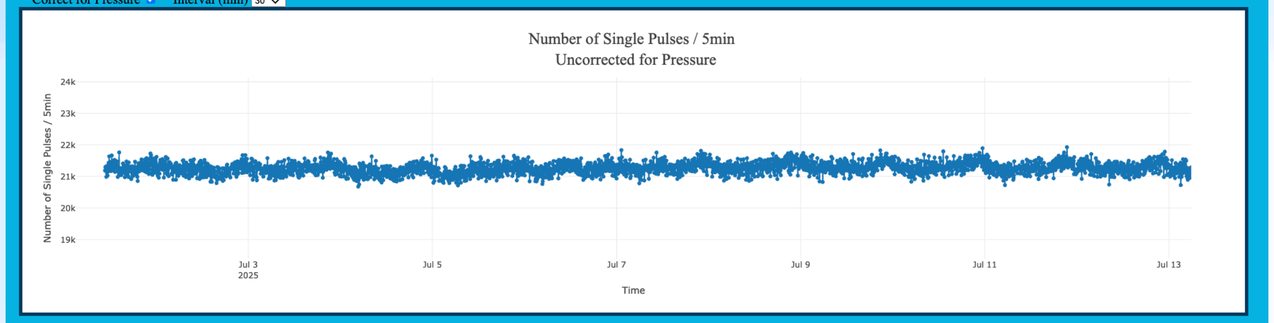
August 24th, 2024

Introduction

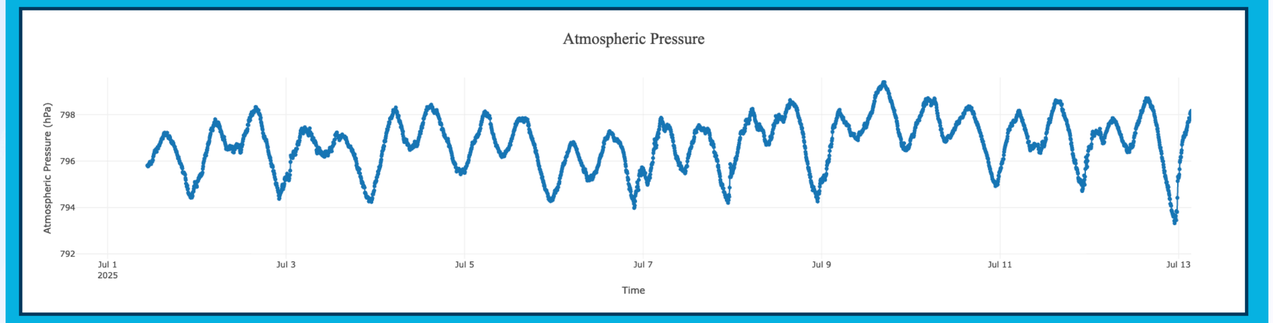
This experiment measures flux of muons that reach a detector in real time. The muon is a subatomic particle discovered in cosmic rays in 1937 by Carl Anderson and Seth Neddermeyer.

Single-Pulse Rate

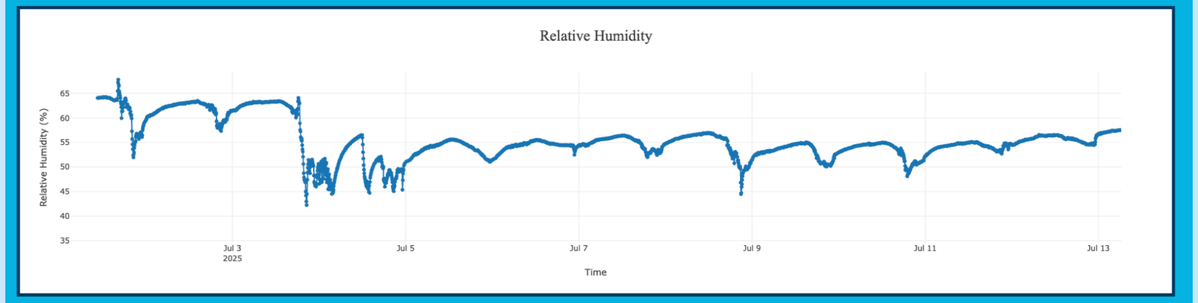
Correct for Pressure ☑ Interval (min) 30



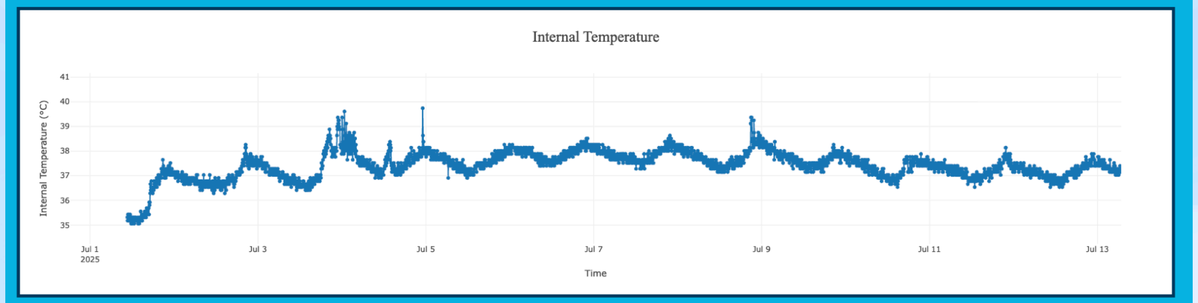
Atmospheric Pressure



Humidity

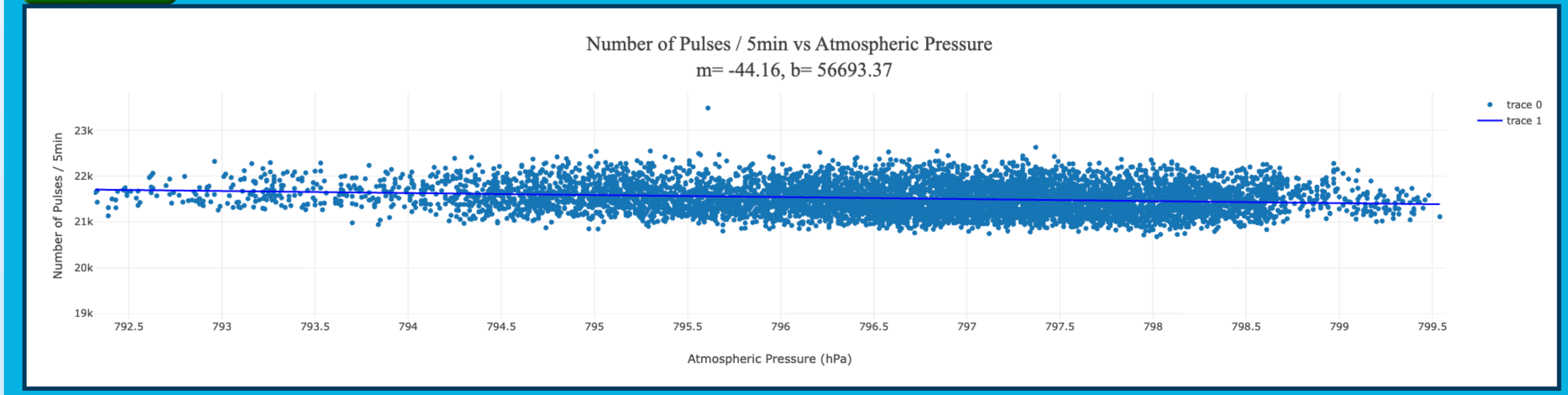


Internal Temperature



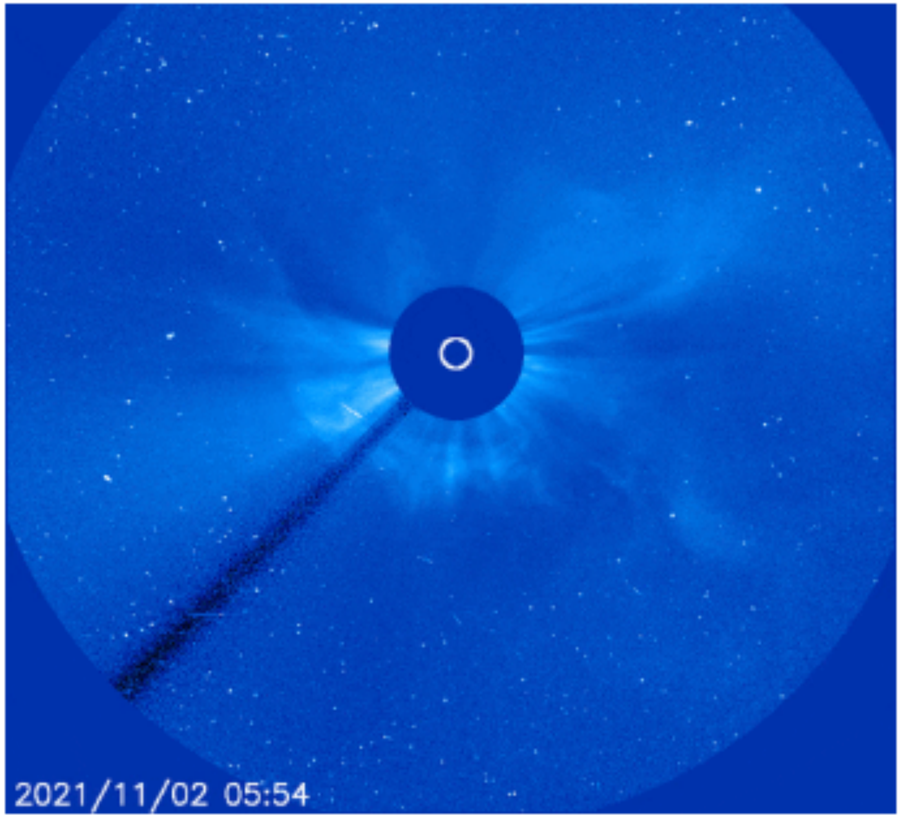
Single-Rate vs Atmospheric Pressure

Correct for Pressure



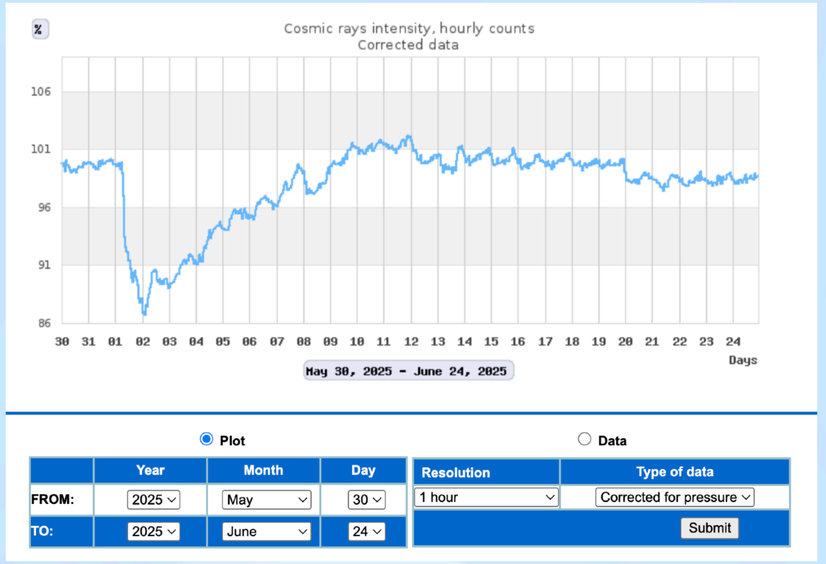
Forbush Decrease: A Sudden Drop in Atmospheric Radiation

DECEMBER 4, 2021 / DR.TONY PHILLIPS

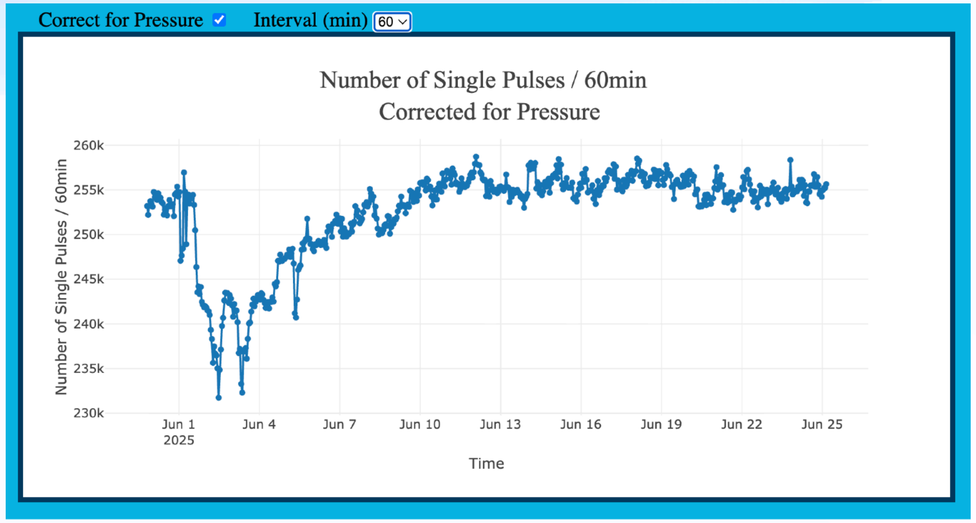


Above: This is the CME that caused the Forbush decrease

https://spaceweatherarchive.com/2021/12/04/forbush-decrease-a-sudden-drop-in-atmospheric-radiation/



Source: http://www.cosmicrays.unam.mx/



Source: https://ciiec.buap.mx/Muon-Flux/

We are sending a paper ..

English Español

Medición de la Velocidad de Muones de la Radicación Cósmica Secundaria

CIIEC-BUAP

20 de octubre, 2025

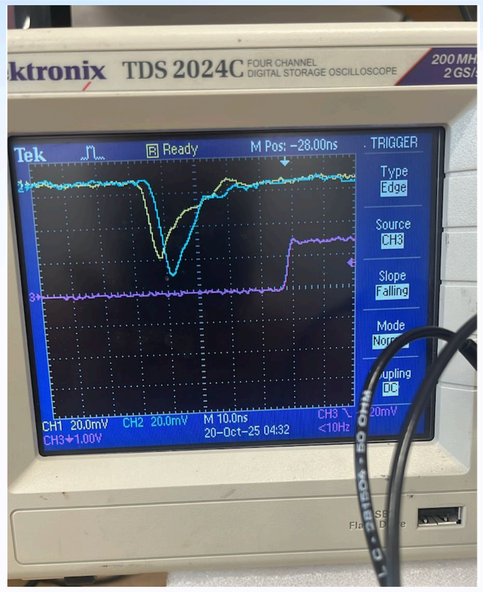
Código

Contactos: Epifanio Ponce, epifanio.ponce@correo.buap.mx & Luis Villaseñor, lvillasen@gmail.com

218 cm

Trigger with NIM Modules

2” PMT



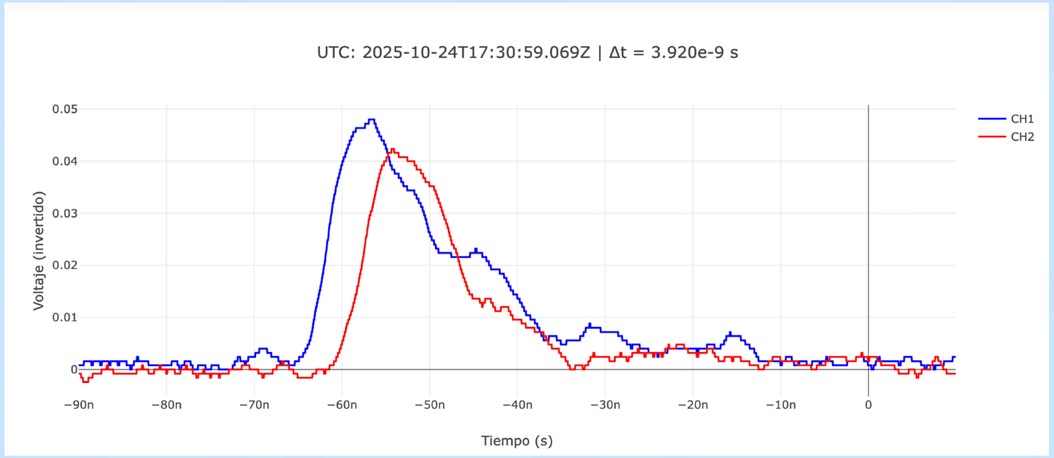
Readout with Python

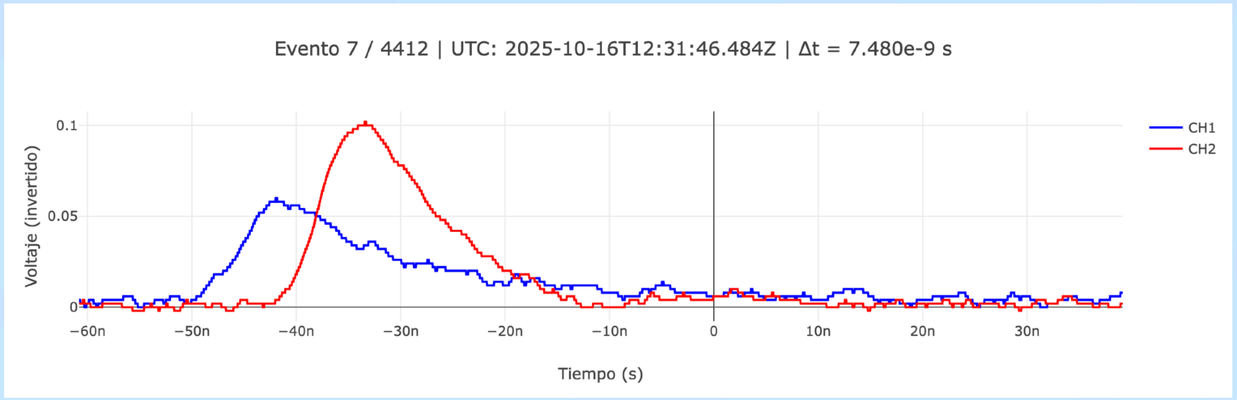
15cm x 15cm

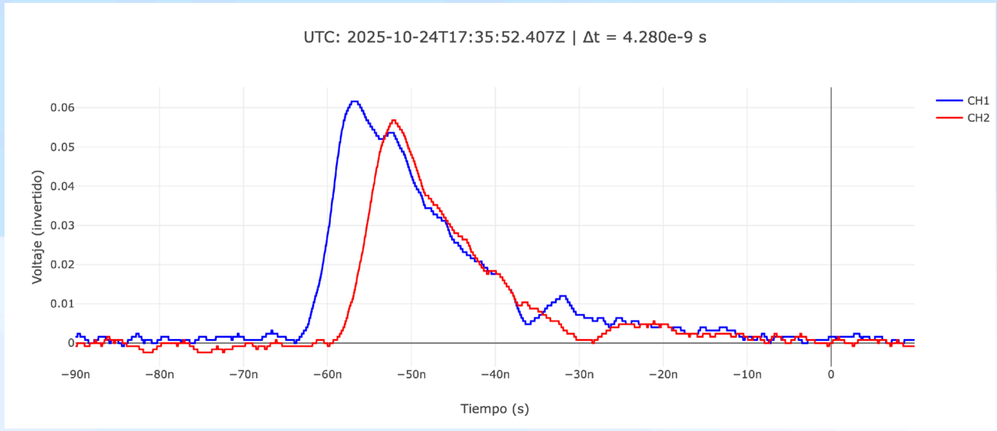
123 cm

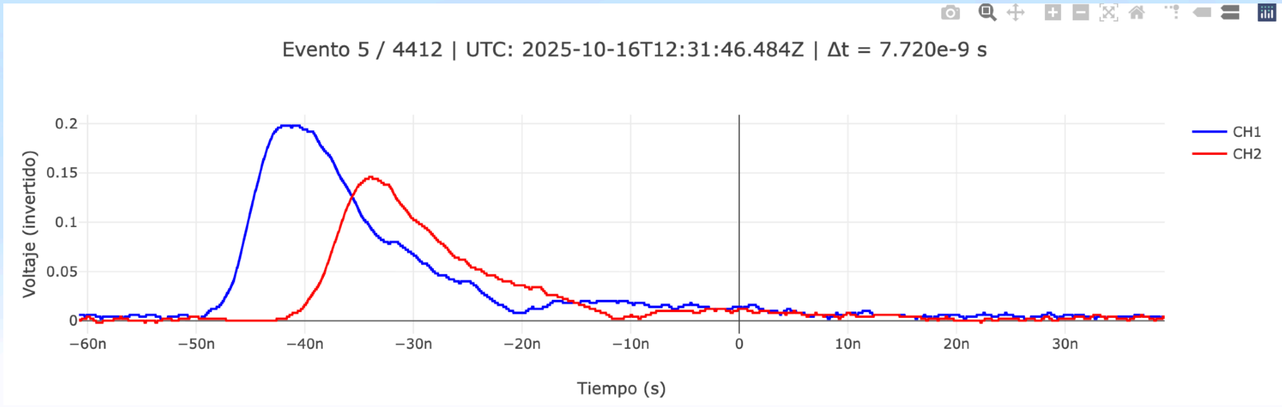
123 cm

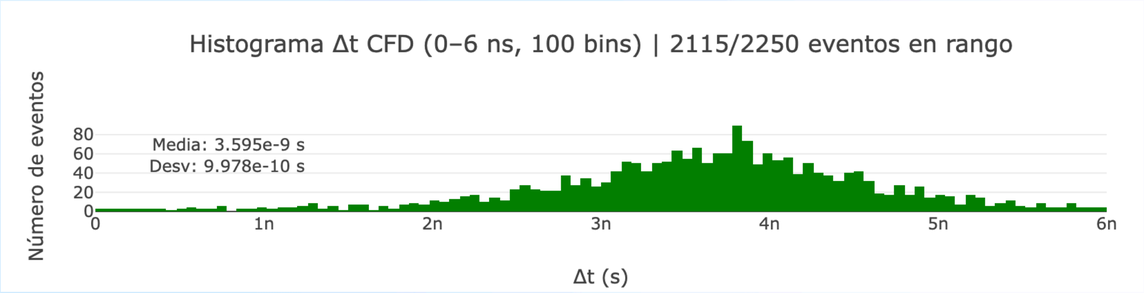
218 cm

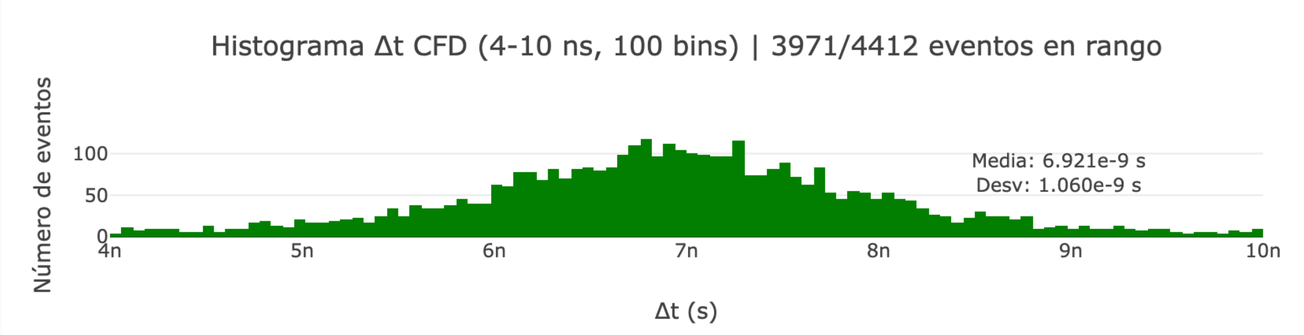












The user is asked to calculate mean speed comment on systematic errors

Make your Own Spectroscope

CIIEC-BUAP

September, 23rd, 2023

Source Code

A spectroscope is an instrument that breaks light into its component colors similarly to the way a prism splits white light into a rainbow. This app illustrates a way to build a simple spectroscope based on the use of a CD or a DVD as a reflective diffraction grating. The app consists of three parts.

The first part calculates the diffraction angles for a beam of light incident with a given angle on a diffraction grating.

The second part ilustrates how to construct a simple high-resolution spectroscope, like the ones shown in the picture below, by using a tube and a CD or DVD as a reflection diffractive grating to see the color spectrum of different sources of light.

The third part allows the capture of color spectra with a manual-focus webcam and performs a simple calibration to estimate the different wavelenths of the color components.

Visualizing and Analyzing Light Spectra

CIIEC-BUAP

September 25th, 2025

Source Code

Introduction

Diffraction Grating

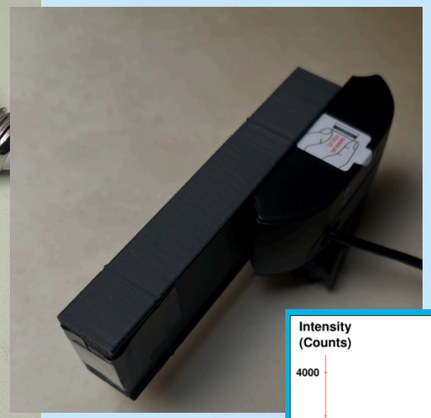
Spectrum of a Compact Fluorescence Lamp

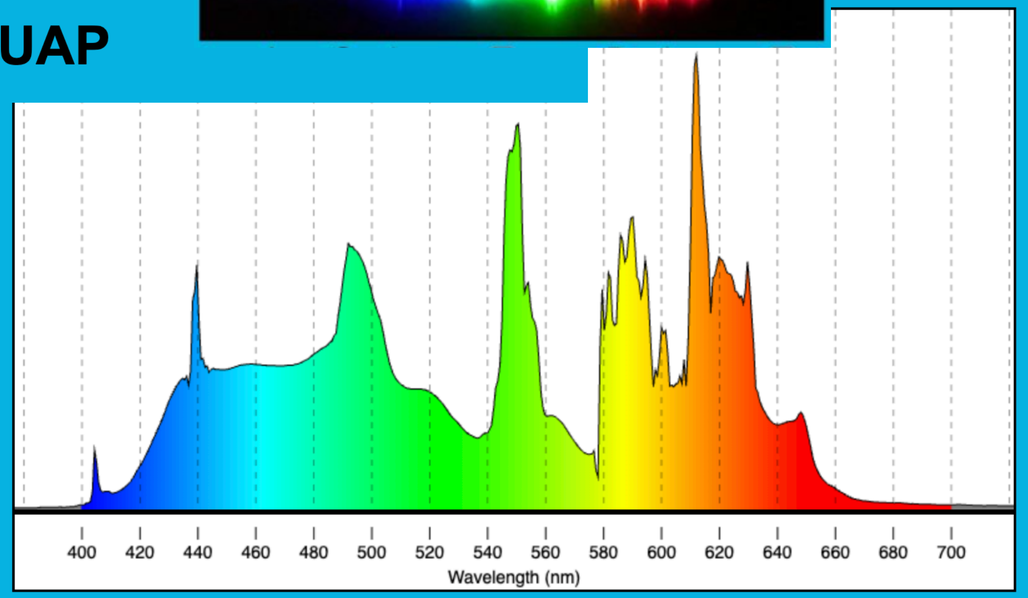
Spectrum of the Sun

Connect your Own Spectrometer

Explore the Visible Spectrum with a Webcam

CIIEC-BUAP



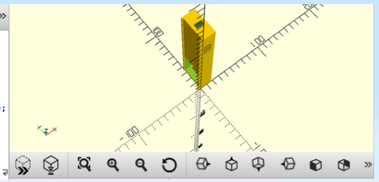


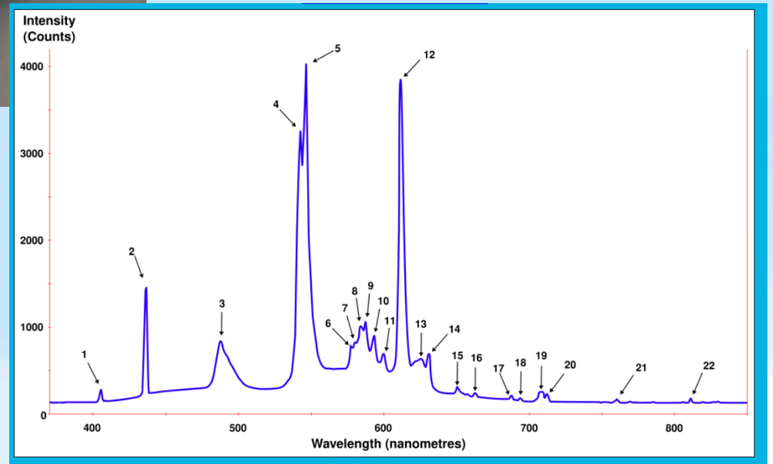

```
module box() {
difference() {
    // External box
    cube([box_x, box_y, box_z]);

    // Internal hollow
    translate([th, th, th])
        cube([box_x - 2*th, box_y - 2*th, box_z - 2*th]);

    // --- Rectangular window
    translate([0, th, th])
        cube([th, box_y-2*th, rect_z]);

    // --- Slit
    translate([(box_x - slot_x)/2, (box_y - slot_y)/2,
```





Source: Fluorescent lighting spectrum peaks

Peak #	Wavelength (nm)	Species
1	405.4	mercury
2	436.6	mercury
3	487.7	terbium (Tb^{3+})
4	542.4	terbium (Tb^{3+})
5	546.5	mercury
6	577.7	Tb^{3+} or Hg
7	580.2	Hg or Tb^{3+}
8	584	Tb^{3+} or Eu^{3+}
9	587.6	Eu^{3+} in Y_2O_3
10	593.4	Eu^{3+} in Y_2O_3
11	599.7	Eu^{3+} in Y_2O_3
12	611.6	Eu^{3+} in Y_2O_3
13	625.7	likely Tb^{3+}
14	631.1	likely Eu^{3+}
15	650.8	likely Eu^{3+}
16	662.6	likely Eu^{3+}
17	687.7	likely Eu^{3+}
18	693.7	likely Eu^{3+}
19	707 & 709	likely Eu^{3+}
20	712.3	likely Eu^{3+}
21	760	likely argon
22	811	likely argon

Source: Fluorescent lighting spectrum peaks

Fotopletismógrafo

CIIEC-BUAP

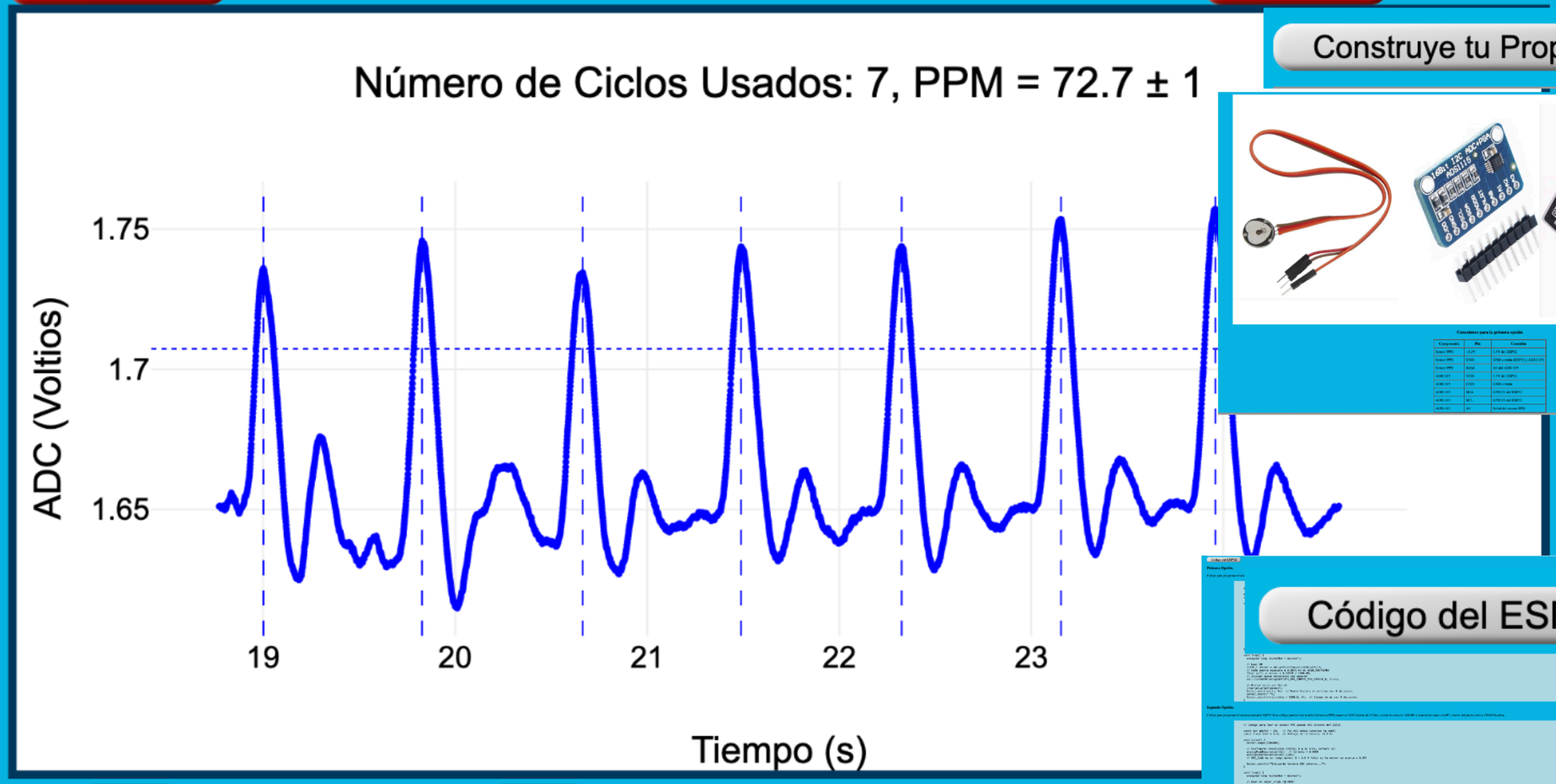
22 de Septiembre, 2025

Código Fuente

Un fotopletismógrafo (PPG, por sus siglas en inglés: Photoplethysmograph) es un dispositivo óptico que mide los cambios en el volumen sanguíneo en los tejidos, generalmente en la piel, usando luz.

¿Cómo Funciona y para qué Sirve?

Desconectar Número de Puntos en la Gráfica: 5000 Muestreo: 857.3 Hz Borrar Continuar



Alfa: .8 Ventana Media Móvil: 4 Escala en Sigmas

Construye tu Propio Equipo

Conexiones para la primera opción

Componente	Pin	Conexión
Sensor PPG	+3.3V	3.3V del ESP32
Sensor PPG	GND	GND común (ESP32 y ADS1115)
Sensor PPG	Señal	A0 del ADS1115
ADS1115	VCC	3.3V del ESP32
ADS1115	GND	GND común
ADS1115	SDA	GPIO21 del ESP32
ADS1115	SCL	GPIO22 del ESP32
ADS1115	A0	Señal del sensor PPG

Código del ESP32

Sistema de Posicionamiento Global (GPS)

CIIEC-BUAP

¿Cómo Funciona el GPS?

Historia del GPS

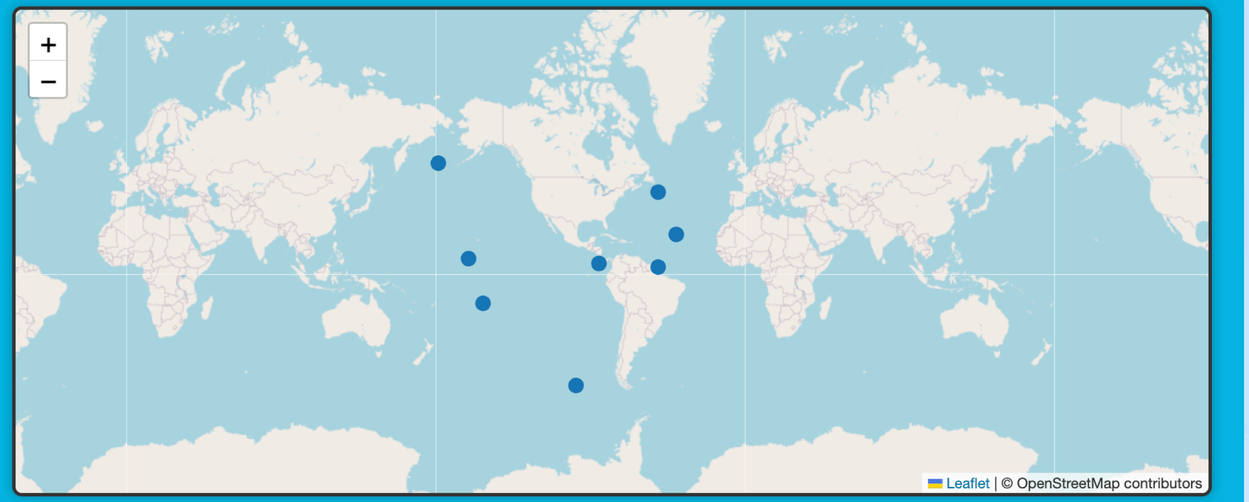
Datos NMEA

Triangulación y Sincronización en el GPS

Corrección por Relatividad Especial

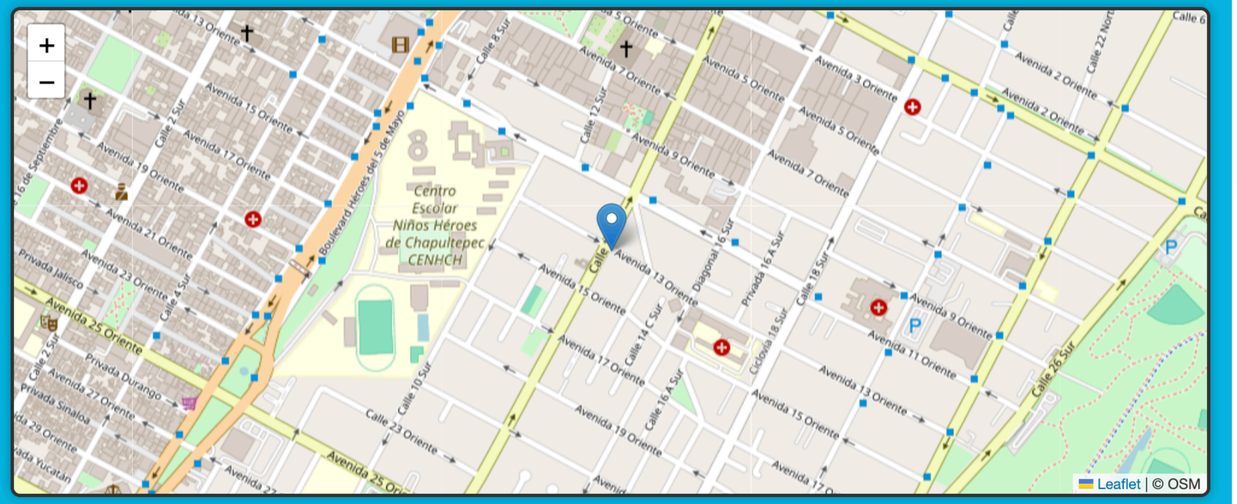
Corrección por Relatividad General

Posiciones Aproximadas de los Satélites en el Mapa



Actualizar Satélites

Ubicación en el Mapa



Pega Datos NMEA

Pega sentencias NMEA dentro de la siguiente area

```
$GPGGA,172815.00,1902.1234,N,09811.5678,W,1,08,0.95,2172.3,M,-5.2,M,,*5A
$GPRMC,172815.00,A,1902.1234,N,09811.5678,W,0.05,301.3,190725,,,A*74
$GPGSV,3,1,10,03,67,133,46,05,15,270,40,12,32,048,45,15,45,193,41*77
$GPGSV,3,2,10,18,29,101,43,21,12,240,42,24,23,075,44,27,10,302,39*7C
$GPGSV,3,3,10,30,03,180,36,33,07,322,38,,,,,,,,*4F
$GPVTG,301.3,T,,M,0.05,N,0.09,K,A*2B
```

Procesar los Datos

Compra tu Receptor GPS

Puedes comprar un receptor GPS barato en Aliexpress. Se recomienda el NEO M8N (evita el NEO 6M y 7M que son un poco más baratos pero que son obsoletos). Trae una antena de cerámica incluida, opcionalmente puedes conectarle una antena activa SMA de 1575.42 MHz, como se muestra en la siguiente imagen,

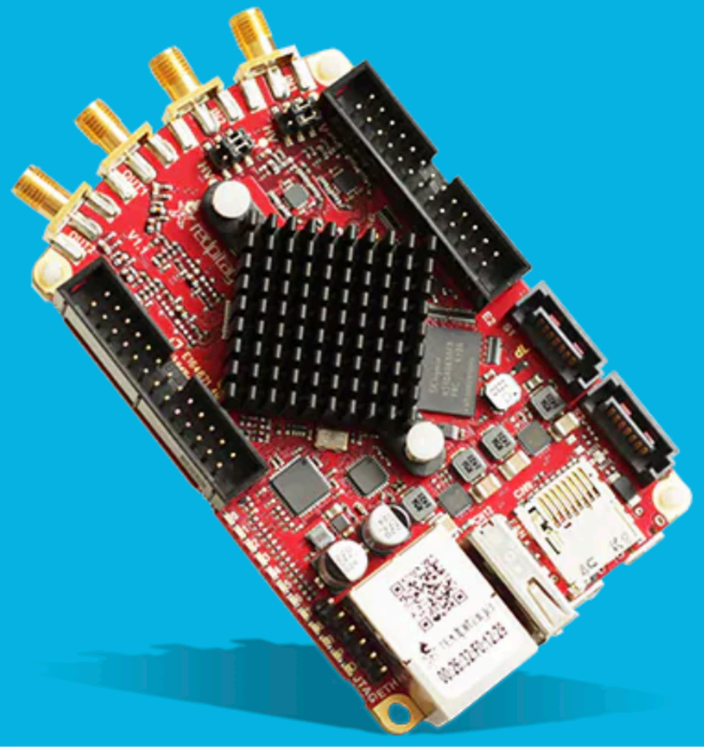
RedPitaya Nth Edge Trigger App

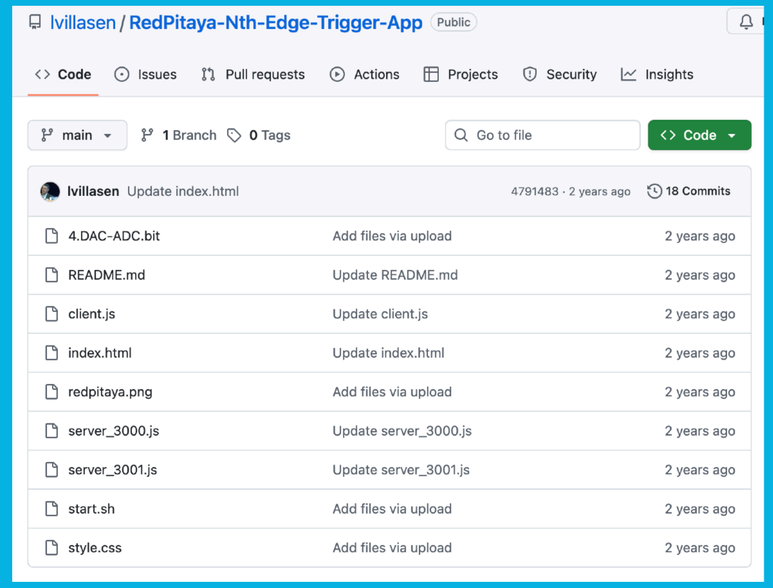
CIIEC-BUAP

May 23rd, 2023

Source Code

This app illustrates a way perform Nth edge trigger on a STEMlab 125-14 RedPitaya board, shown in the picture below, using Node.js and Express. For mode details see here.





1. Binary Counter Displayed on the LEDs

Usage

- Clone the repositiry
- Create a new project with Vivado.
- Select the device xc7z010clg400-1
- Add the constraint *redpitaya.xdc* and verilog *counter.v* files from the repository.
- Create a new Block Design according to the following instructions to create a block diagram similar to Fig. 1.Binary_Counter.
- Add the IP called *ZYNQ7 Processing System* from the menu and *Run Block Automation* with default options.
- Add Module counter.v from the menu.
- Add a Binary Counter from thr *Add IP* menu.
- Add a port called led_o with components from 7 down to 0.
- From the menu click on *Validate Design*

Mandelbrot Set

CIIEC-BUAP

April, 10th, 2023

Source Code

The Mandelbrot set consists of points that form a two-dimensional fractal. It is named after the mathematician Benoit Mandelbrot. The set is computed by iterating the following equation:

$$z_{n+1} = z_n^2 + c$$

with $z_0 = 0$ for all the the points (x_p, y_p) of the x-y plane in the form of complex numbers $c = x_p + iy_p$. The image of the set is constructed by using a color for every point of the 2D image determined by the number of iterations required to reach

$$|z_n| = \sqrt{x_n^2 + y_n^2} = 2$$

The colormaps we use are imported from Matplotlib by using this code. We increase the color variability by repeating the colormaps as shown on the colormap canvas located on top of the main canvas.

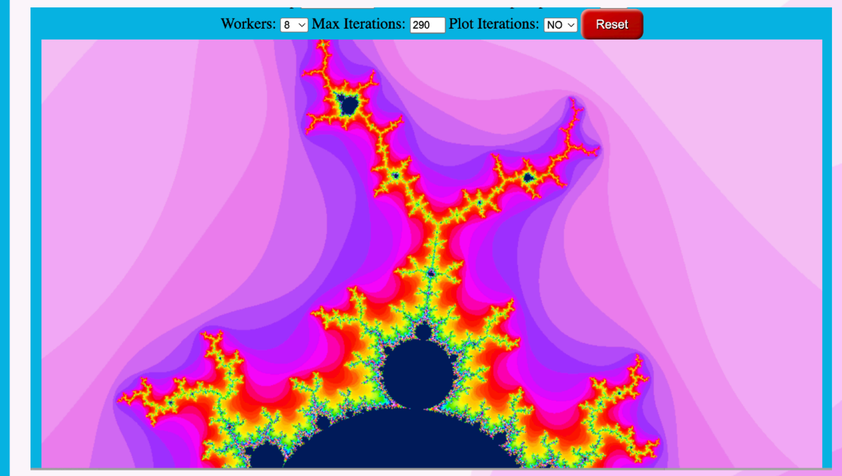
You can experiment by changing the colormap, number of workers, number of repetitions of the colormap, number of maximum iterations.

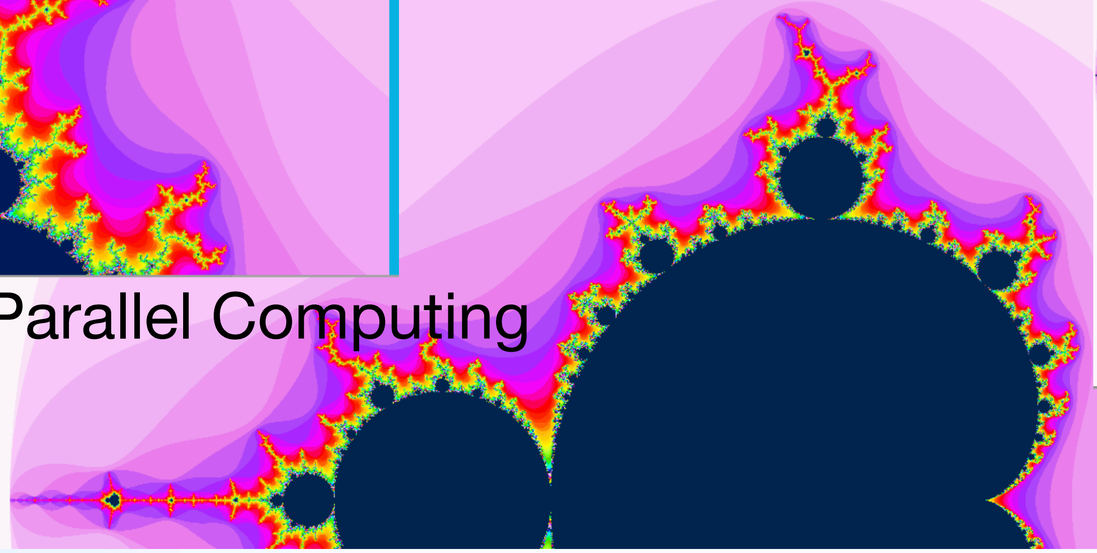
You can reverse the colormap, input and edit a new custom colormap and visualize the iteration points.

Click on any point of the image to recalculate the image centered at that point with sides reduced by a factor of 10.

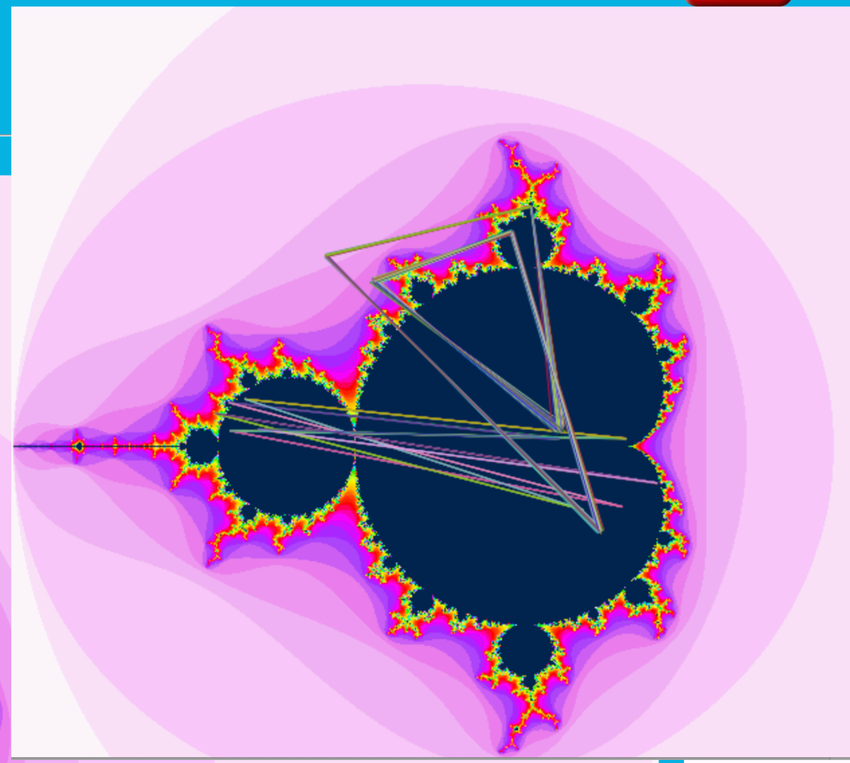
Colormap gist_ncar Reversed Colormap Repetitions: 5

Workers: 8 Max Iterations: 245 Plot Iterations: NO Reset





Workers: 8 Max Iterations: 245 Plot Iterations: 100 Reset



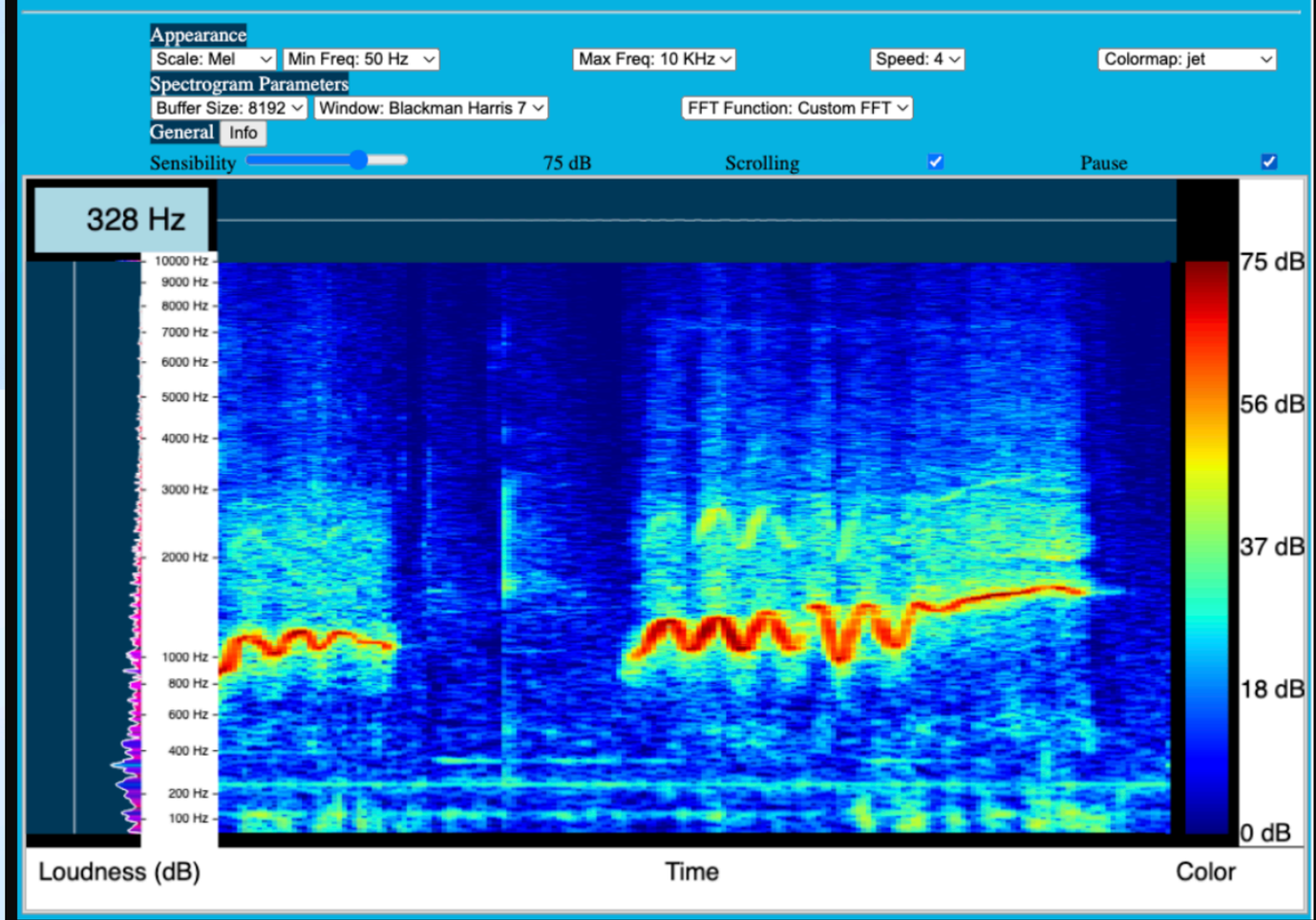
Introduction to Parallel Computing

Spectrogram

CIIEC-BUAP

April, 1st, 2023

Source Code

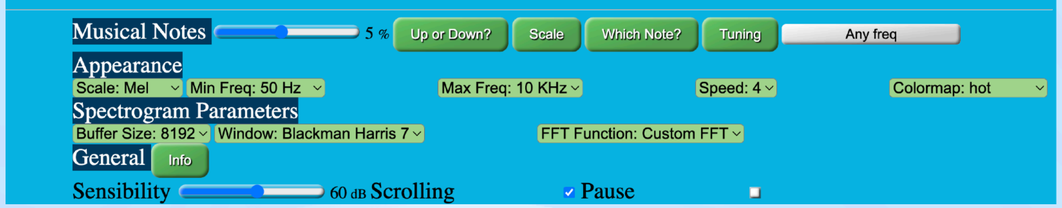


Spectrogram with Musical Notes

CIIEC-BUAP

May 24th, 2024

Source Code



Quantum Computer Simulator

CIIEC-BUAP

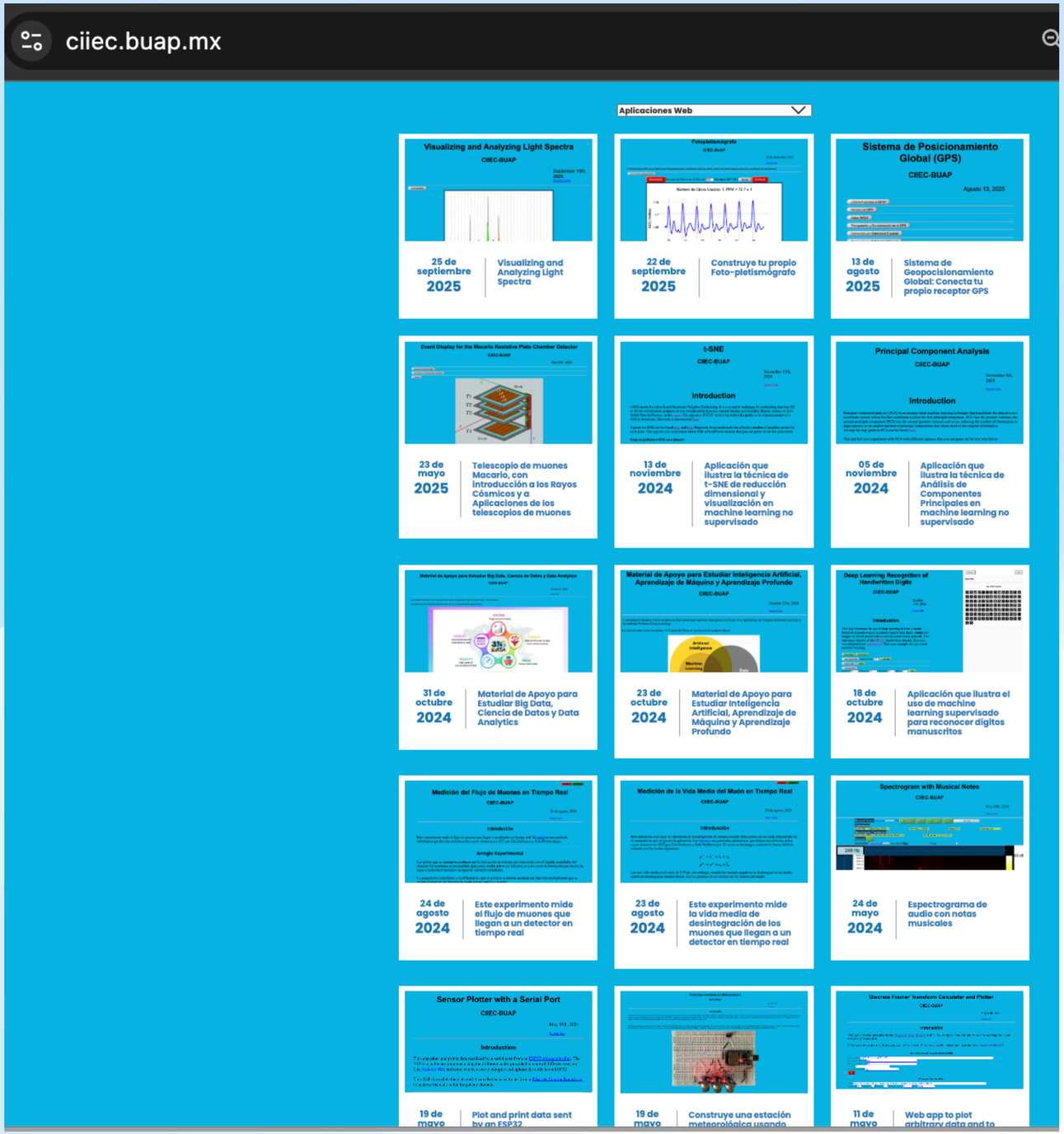
April, 22th, 2023

Source Code

This code simulates an ideal quantum computer in JavaScript. The unitary operations are optimized with matrix-free algorithms.

The maximum number of qubits it can handle is limited, in a natural way, by the resources available on the system used to run the program. The gates and commands implemented so far are the following:

- verbose 0(1); verbose mode off(on)
- h q[i]; Hadamard gate H applied to qubit i
- x q[i]; X Pauli gate applied to qubit i
- y q[i]; Y Pauli gate applied to qubit i
- z q[i]; Z Pauli gate applied to qubit i
- cx q[i], q[j]; CNOT gate applied to control qubit i and target qubit j
- sign i; flips sign of states with index i in the standard basis



Luis Villaseñor
lvillasen@gmail.com

Thank you for your attention