Cosmic Ray/Muon Detection

NSF

NFS Research Experiences for Undergraduates program

Northern New Jersey Alliance

NNJ

A.S. B2B B.S.

Bridges to Baccalaureate

Mentor

Raul Armendariz PhD
Associate Professor of Physics
Department of Physics
Queensborough Community College, CUNY

Mentee

Fabio Pinho Morais
Major Physic
Hudson County Community College

Undergraduate Research

in Particle Astrophysics

Cosmic Ray Detector

Assistant Professor Armendariz's research is in astro-particle physics, cosmic rays, and electronic detector technology. Students in the group are designing an educational array of cosmic ray detectors consisting of fluorescent plastic scintillator, photomultiplier tubes, and data acquisition electronics; through collaborative efforts select students conduct research at the Brookhaven National Laboratory. Assistant Professor Armendariz manages the QCC QuarkNet Center's educational outreach program with high school physics teachers.

CUNY Cosmic Ray Detector Array for Undergraduate Research in Engineering and Computational Physics

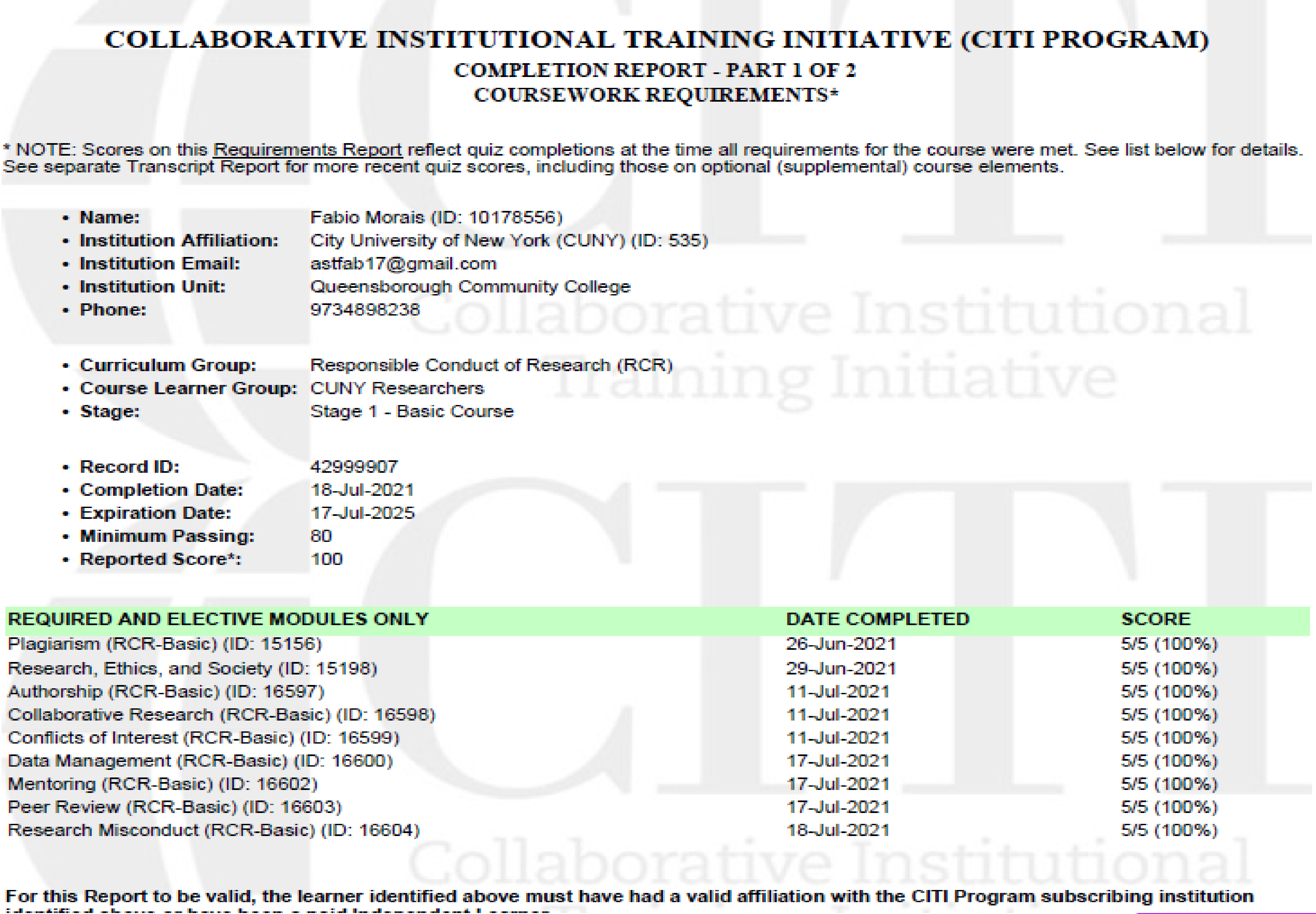
The Queensborough Community College physics department is building a cosmic ray detector array for undergraduate student research. College students and high school physics teachers are involved in building the array which includes detectors at different college campuses interconnected over the Internet. In building and operating detectors students and teachers gain valuable training in engineering science, electronics, computer programming, data analysis, and project management. A learning community has been established where students are engaged in high impact practices and active learning. Science goals include measuring the rate and directionality of 10 m to 10 km wide cosmic ray muon showers, and correlations with atmospheric variables and solar activity.

Opportunities for Students

If you plan to work with electronics, mechanical equipment, or computers in engineering or science there is nothing better than to design and build things now as hands-on hard work opens up many doors for your future. Students accepted into the program can register for Physics Research Projects PH900 (90 lab hours, 2 credits) and/or Scientific use of Computers PH303 (2 credits):

- Design and build scientific equipment
- Build beginner or advanced electronic circuits
- Write software in Python or C++ for systems control and data acquisition
- Build particle physics detectors: design framing, machine parts, water jet applications
- Measure cosmic ray particles from outer space
- Present research results at conferences
- Apply for summer research opportunities at QCC and Brookhaven National Lab
- Publish papers

Cosmic ray detectors built by students



COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 1 OF 2
COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

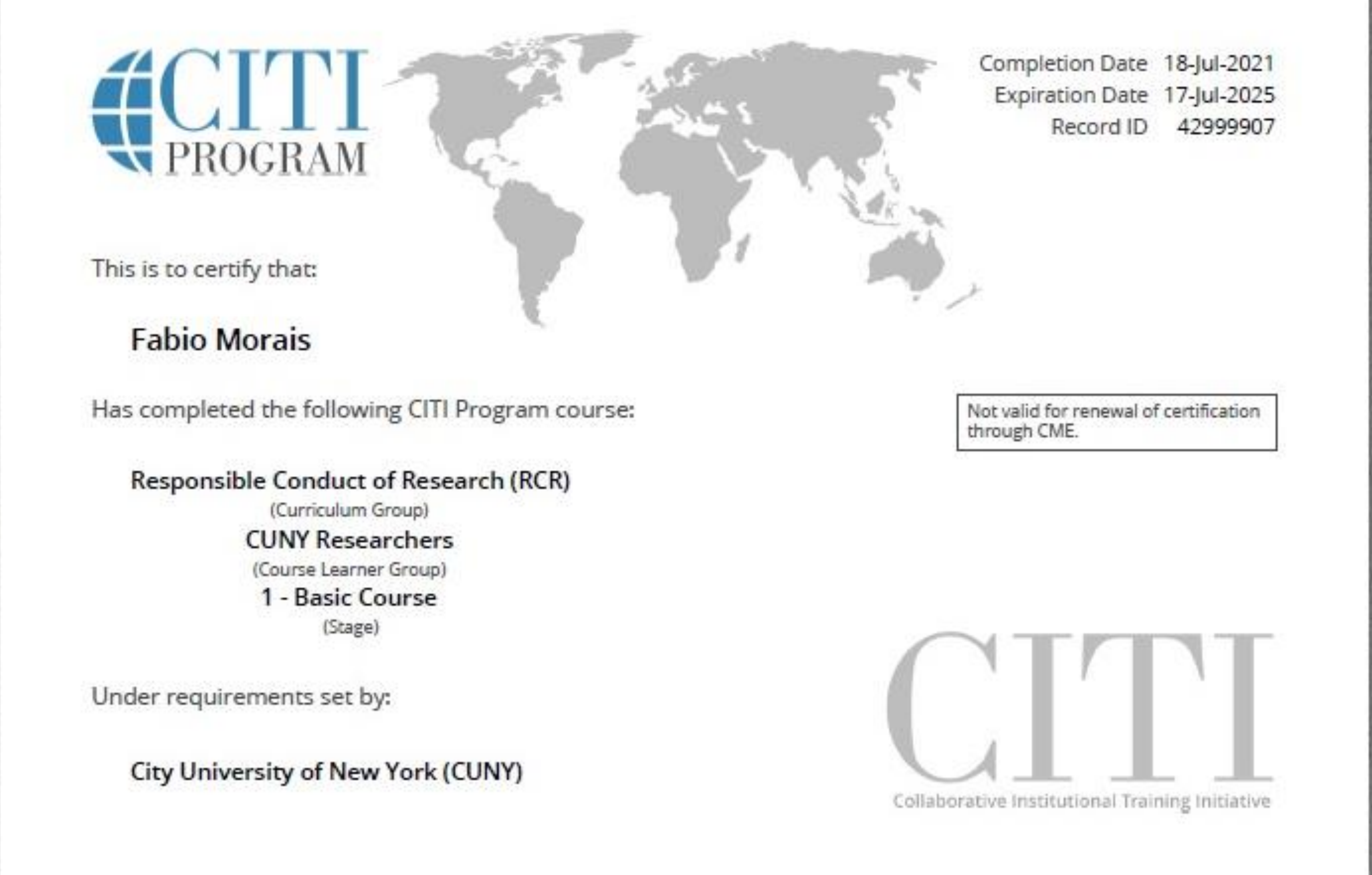
• **Name:**	Fabio Morais (ID: 10178556)
• **Institution Affiliation:**	City University of New York (CUNY) (ID: 535)
• **Institution Email:**	astfab17@gmail.com
• **Institution Unit:**	Queensborough Community College
• **Phone:**	9734898238

• **Curriculum Group:**	Responsible Conduct of Research (RCR)
• **Course Learner Group:**	CUNY Researchers
• **Stage:**	Stage 1 - Basic Course

• **Record ID:**	42999907
• **Completion Date:**	18-Jul-2021
• **Expiration Date:**	17-Jul-2025
• **Minimum Passing:**	80
• **Reported Score*:**	100

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
Plagiarism (RCR-Basic) (ID: 15156)	26-Jun-2021	5/5 (100%)
Research, Ethics, and Society (ID: 15198)	29-Jun-2021	5/5 (100%)
Authorship (RCR-Basic) (ID: 16597)	11-Jul-2021	5/5 (100%)
Collaborative Research (RCR-Basic) (ID: 16598)	11-Jul-2021	5/5 (100%)
Conflicts of Interest (RCR-Basic) (ID: 16599)	11-Jul-2021	5/5 (100%)
Data Management (RCR-Basic) (ID: 16600)	17-Jul-2021	5/5 (100%)
Mentoring (RCR-Basic) (ID: 16602)	17-Jul-2021	5/5 (100%)
Peer Review (RCR-Basic) (ID: 16603)	17-Jul-2021	5/5 (100%)
Research Misconduct (RCR-Basic) (ID: 16604)	18-Jul-2021	5/5 (100%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.



CITI PROGRAM

Completion Date 18-Jul-2021
Expiration Date 17-Jul-2025
Record ID 42999907

This is to certify that:

Fabio Morais

Has completed the following CITI Program course:

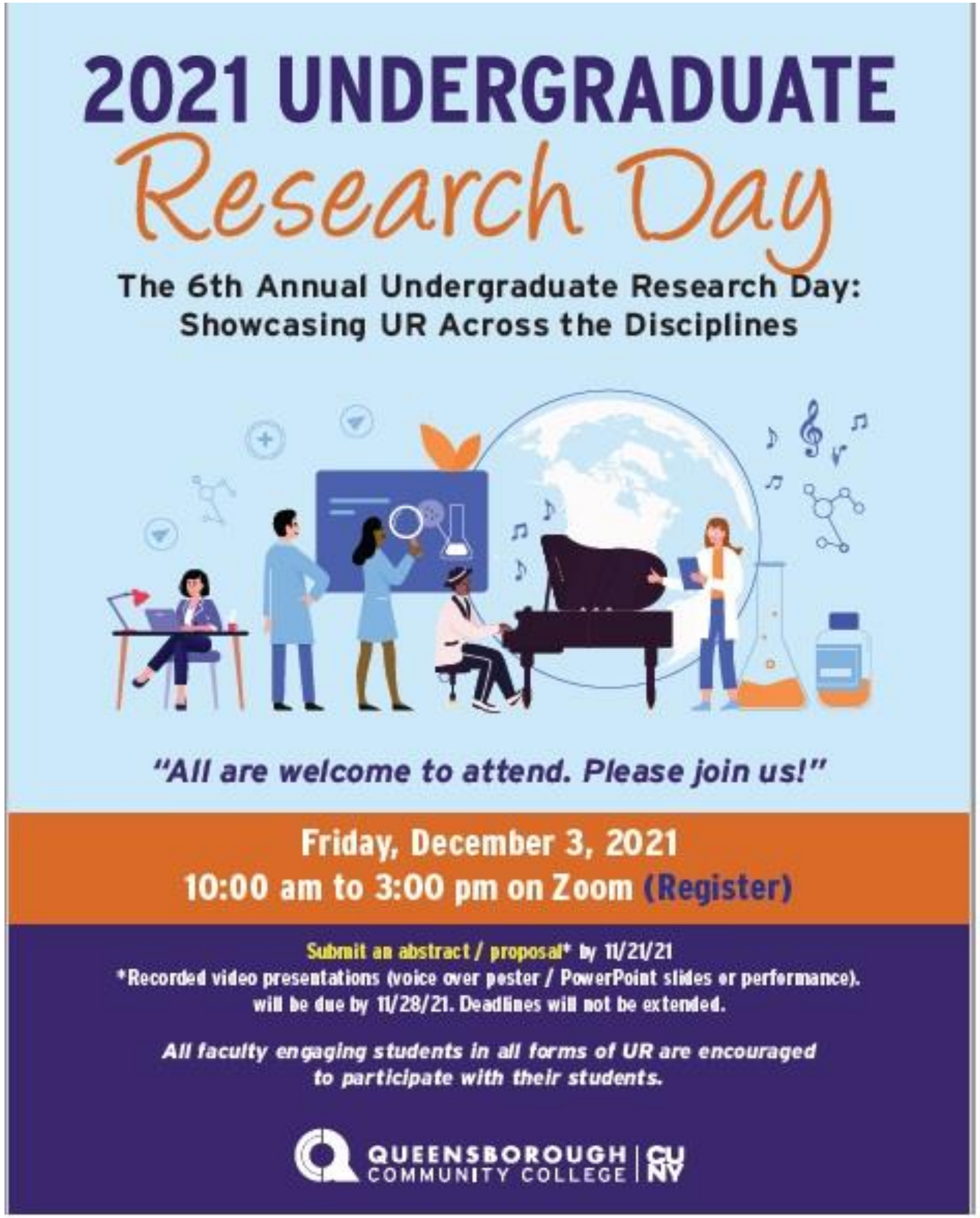
Not valid for renewal of certification through CME.

Responsible Conduct of Research (RCR)
(Curriculum Group)
CUNY Researchers
(Course Learner Group)
1 - Basic Course
(Stage)

Under requirements set by:

City University of New York (CUNY)

CITI
Collaborative Institutional Training Initiative



2021 UNDERGRADUATE Research Day

The 6th Annual Undergraduate Research Day: Showcasing UR Across the Disciplines

"All are welcome to attend. Please join us!"

Friday, December 3, 2021
10:00 am to 3:00 pm on Zoom (Register)

Submit an abstract / proposal* by 11/21/21
*Recorded video presentations (voice over poster / PowerPoint slides or performance).
will be due by 11/28/21. Deadlines will not be extended.

All faculty engaging students in all forms of UR are encouraged to participate with their students.

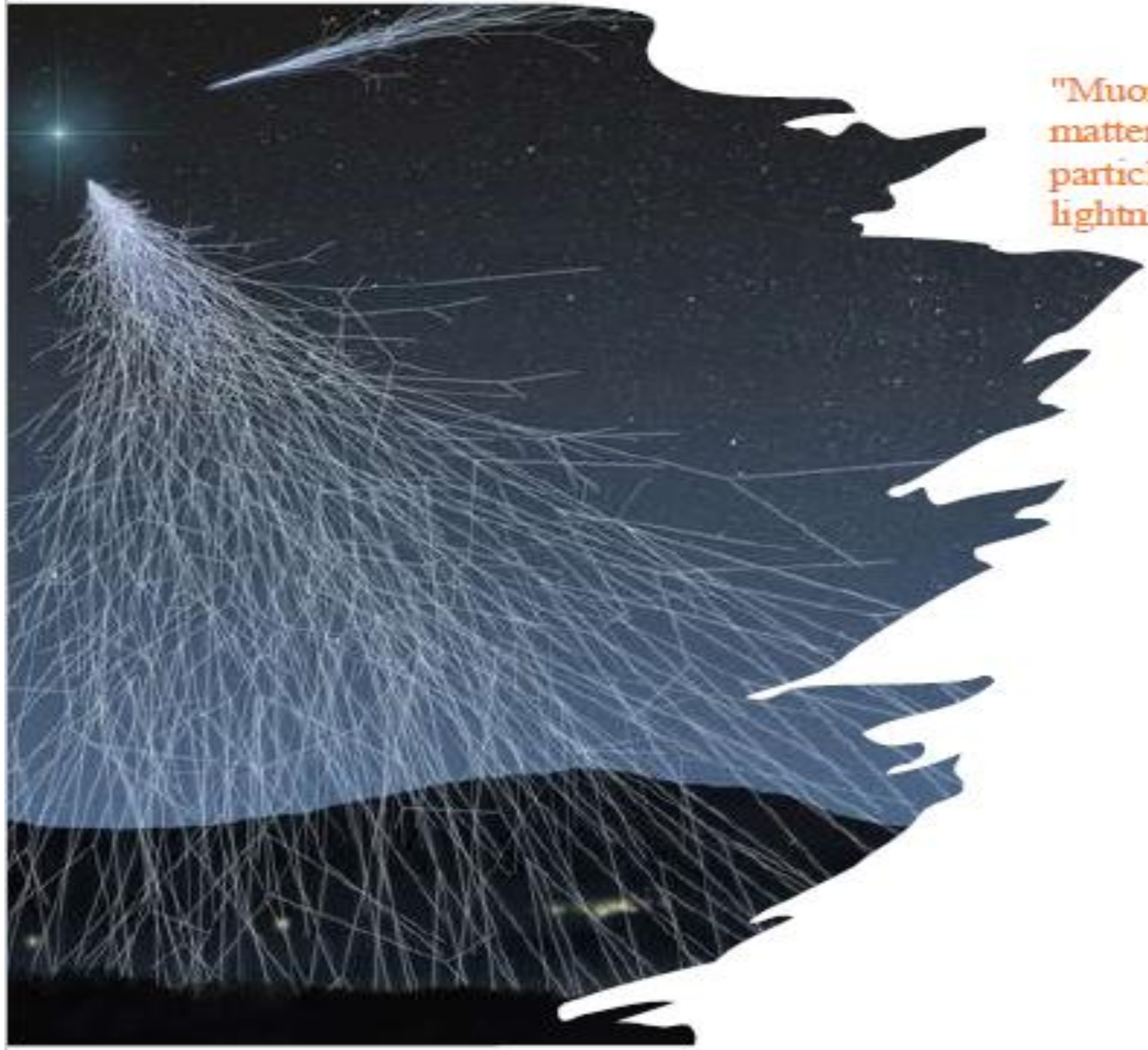
QUEENSBOROUGH COMMUNITY COLLEGE | CUNY

HUDSON COUNTY COMMUNITY COLLEGE

Fabio Morais

Mentor: Dr. Raul Armendariz

Department: Physics

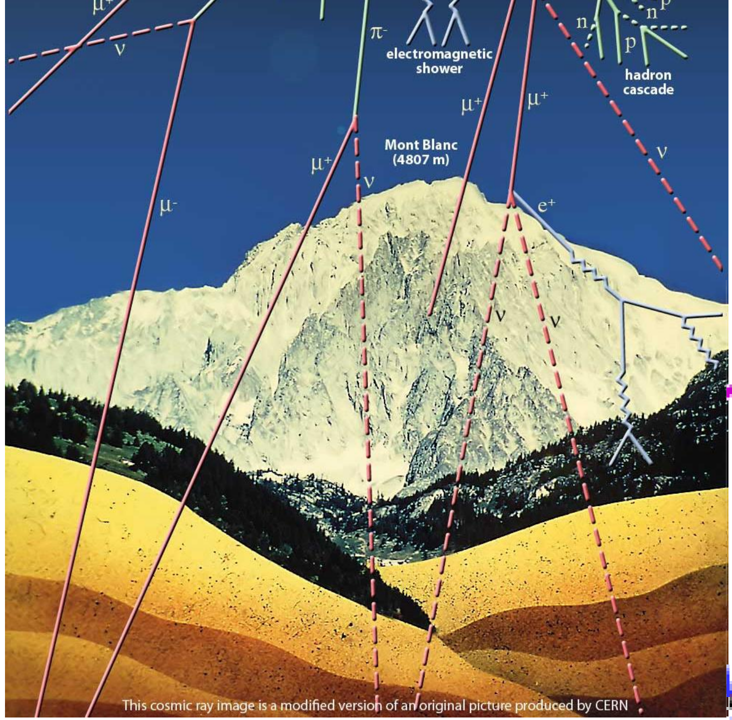


"Muon particles have been studied to understand better what the matter of the universe and its applications in the field of science as particle physics, space weather, astrophysics, solar activity, lightning, and earth's magnetic field".

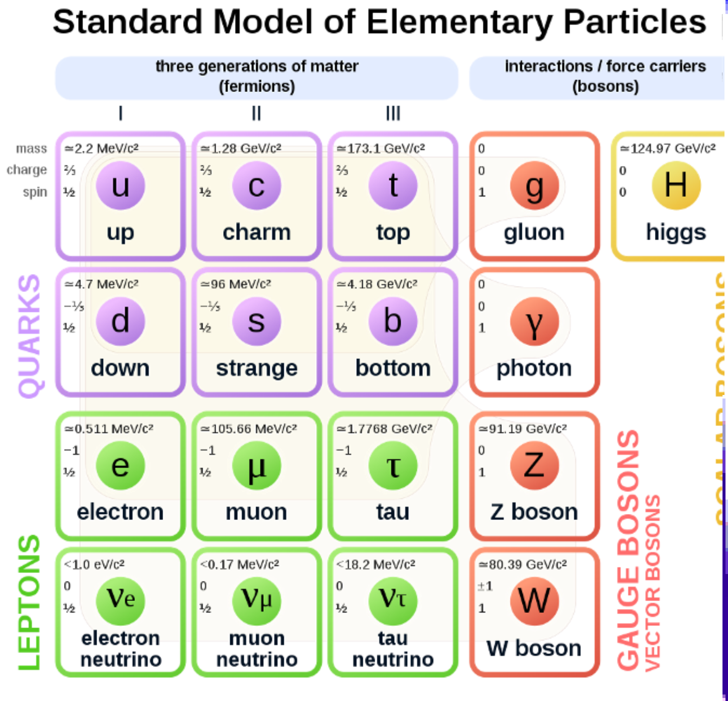
- Cosmic rays are high energy particles emitted by the sun, supernovae, and black hole regions, about 90% of the comic ray flux consists of protons and 9% of heavier particles, principally alpha particles. When a cosmic ray proton collides with a nucleon in earth's atmosphere, pions are produced: charged pions decay producing muons which are detectable as they hit earth's surface. Cosmic rays are studied in particle physics, space weather, astrophysics, solar activity, lightning, and earth's magnetic field.

Cosmic rays are produced in other galaxies and black holes. Arrive often to planet earth.

The MUON has a high electrical change, being an abundance of energy source which we need search for to understand in order to use it.

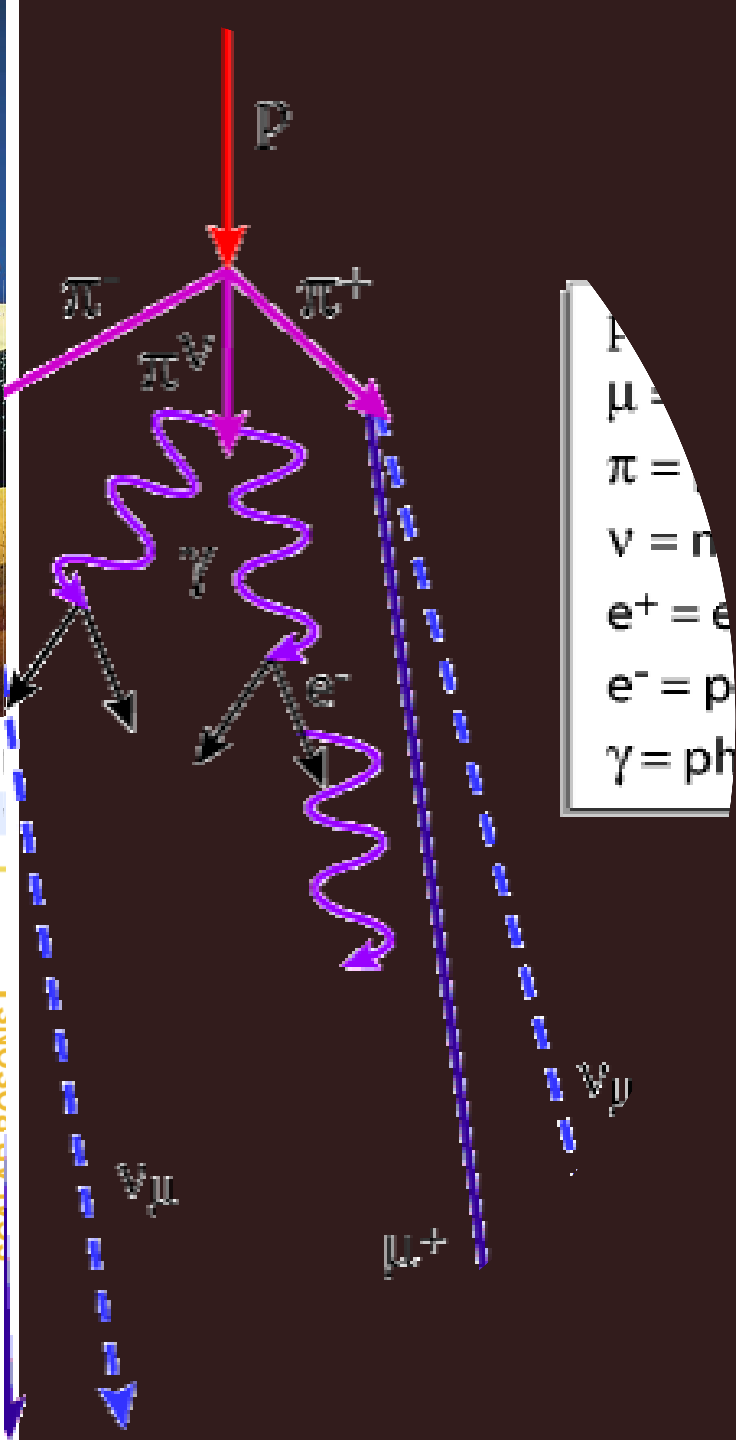


This cosmic ray image is a modified version of an original picture produced by CERN

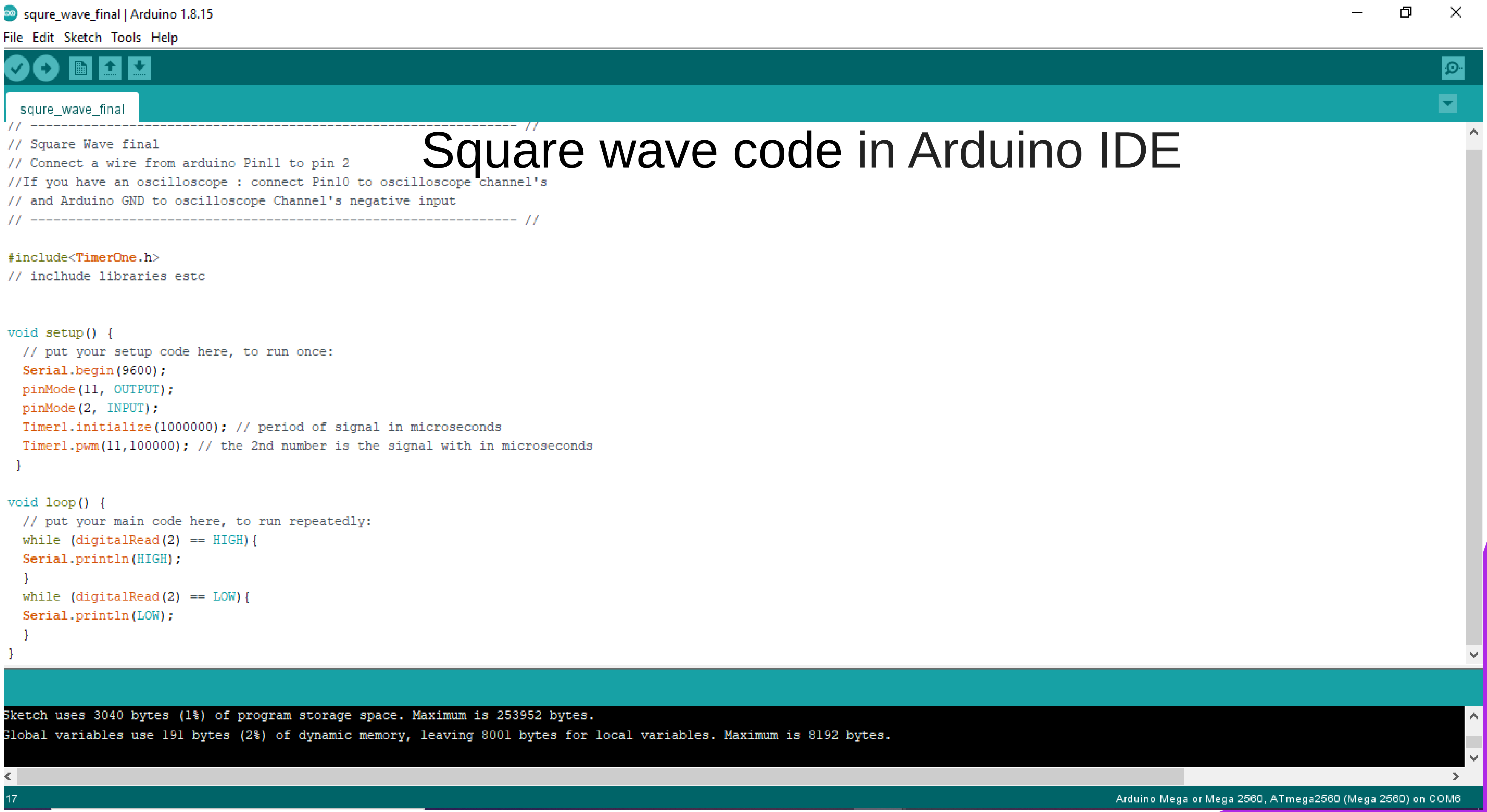


Standard Model of Elementary Particles

		three generations of matter (fermions)			interactions / force carriers (bosons)	
		I	II	III		
QUARKS	mass charge spin	≈2.2 MeV/c² ⅔ ½ u up	≈1.28 GeV/c² ⅔ ½ c charm	≈173.1 GeV/c² ⅔ ½ t top	0 0 1 g gluon	≈124.97 GeV/c² 0 0 H higgs
		≈4.7 MeV/c² −⅓ ½ d down	≈96 MeV/c² −⅓ ½ s strange	≈4.18 GeV/c² −⅓ ½ b bottom	0 0 1 γ photon	SCALAR BOSONS
LEPTONS		≈0.511 MeV/c² −1 ½ e electron	≈105.66 MeV/c² −1 ½ μ muon	≈1.7768 GeV/c² −1 ½ τ tau	≈91.19 GeV/c² 0 1 Z Z boson	GAUGE BOSONS VECTOR BOSONS
		<1.0 eV/c² 0 ½ ν_e electron neutrino	<0.17 MeV/c² 0 ½ ν_μ muon neutrino	<18.2 MeV/c² 0 ½ ν_τ tau neutrino	≈80.39 GeV/c² ±1 1 W W boson	



Square wave code in Arduino IDE

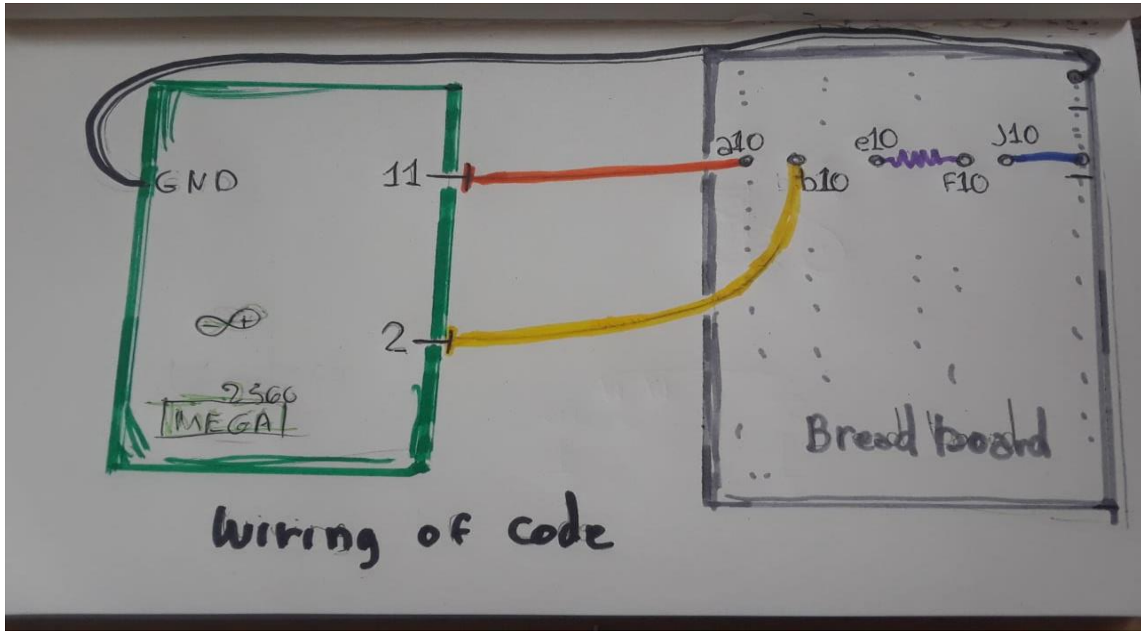

squre_wave_final | Arduino 1.8.15
File Edit Sketch Tools Help
squre_wave_final
17
Arduino Mega or Mega 2560, ATmega2560 (Mega 2560) on COM6

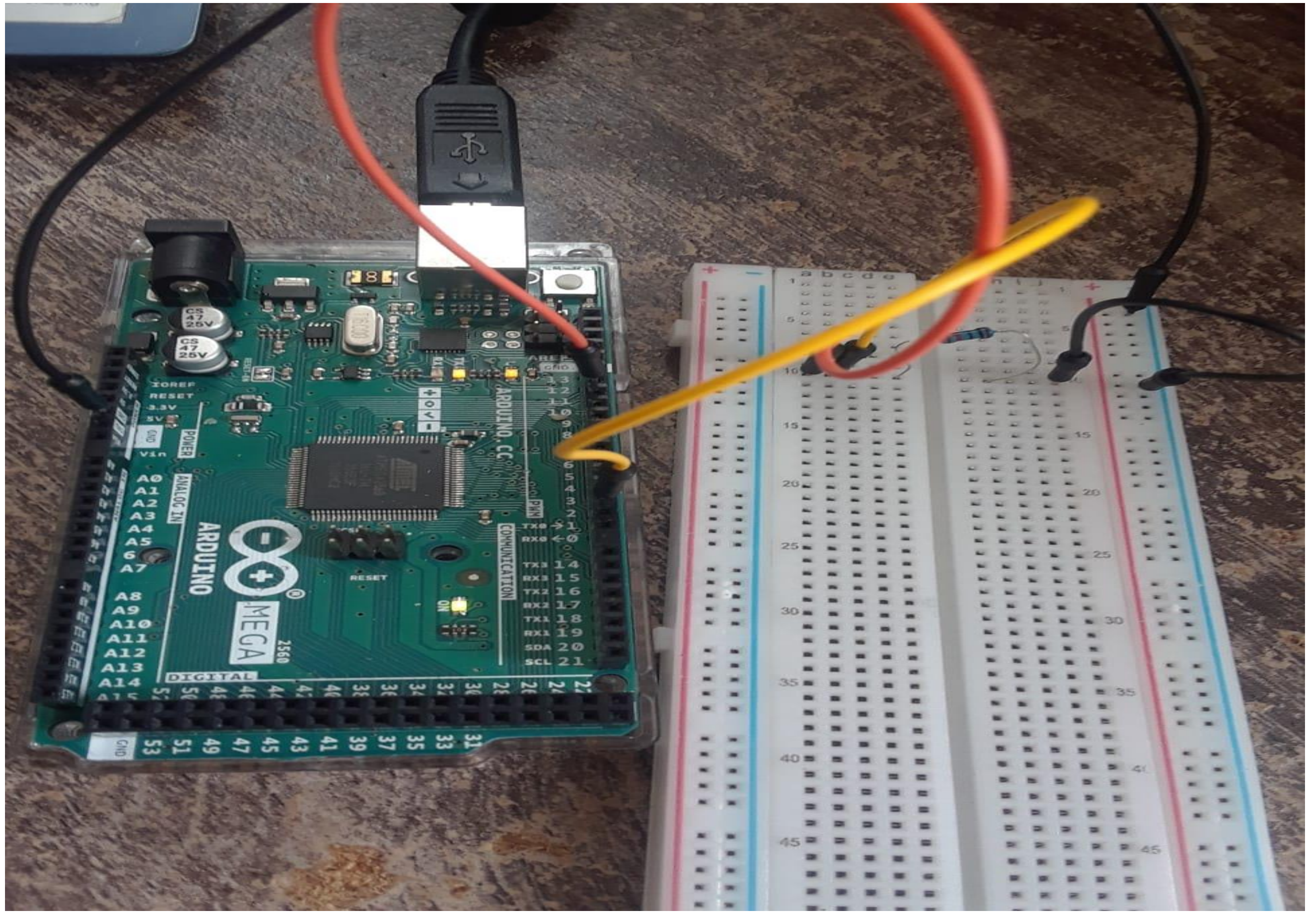
```
// ---------------------------------------------------------------- //
// Square Wave final
// Connect a wire from arduino Pin11 to pin 2
//If you have an oscilloscope : connect Pin10 to oscilloscope channel's
// and Arduino GND to oscilloscope Channel's negative input
// ---------------------------------------------------------------- //

#include<TimerOne.h>
// inclhude libraries estc


void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);
  pinMode(11, OUTPUT);
  pinMode(2, INPUT);
  Timer1.initialize(1000000); // period of signal in microseconds
  Timer1.pwm(11,100000); // the 2nd number is the signal with in microseconds
 }

void loop() {
  // put your main code here, to run repeatedly:
  while (digitalRead(2) == HIGH){
  Serial.println(HIGH);
  }
  while (digitalRead(2) == LOW){
  Serial.println(LOW);
  }
}
```

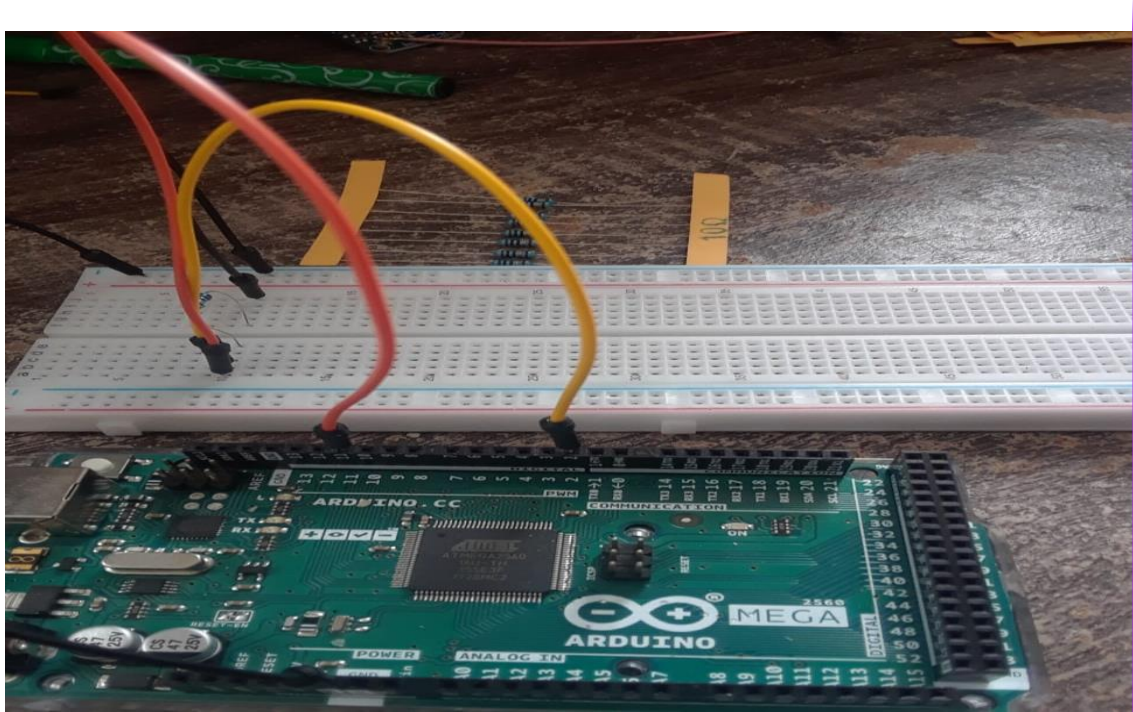
```
Sketch uses 3040 bytes (1%) of program storage space. Maximum is 253952 bytes.
Global variables use 191 bytes (2%) of dynamic memory, leaving 8001 bytes for local variables. Maximum is 8192 bytes.
```

Arduino Mega 2560

- Sketch of the wiring diagram
- Wired to the breadboard







```
14:00:00.065 -> 0
14:00:00.065 -> 0
14:00:00.065 -> 0
14:00:00.065 -> 0
14:00:00.065 -> 0
```

signal goes high
at 14:00:00.065 -> 1

```
14:00:00.065 -> 1
14:00:00.065 -> 1
14:00:00.112 -> 1
14:00:00.112 -> 1
14:00:00.112 -> 1
14:00:00.112 -> 1
14:00:00.112 -> 1
14:00:00.112 -> 1
14:00:00.112 -> 1
14:00:00.112 -> 1
14:00:00.112 -> 1
```

```
14:00:00.112 -> 1
14:00:00.112 -> 1
14:00:00.112 -> 1
14:00:00.165 -> 1
14:00:00.165 -> 1
14:00:00.165 -> 1
14:00:00.165 -> 1
14:00:00.165 -> 1
14:00:00.165 -> 1
14:00:00.165 -> 1
14:00:00.165 -> 1
14:00:00.165 -> 1
14:00:00.165 -> 1
```

signal goes low at 14:00:00.165 -> 0

```
14:00:00.165 -> 0
14:00:00.165 -> 0
```

data continued in 47ms increments

```
14:00:01.067 -> 0
14:00:01.067 -> 0
14:00:01.067 -> 0
14:00:01.067 -> 0
14:00:01.067 -> 0
```

signal goes high again
at 14:00:01.067 -> 1

```
14:00:01.067 -> 1
14:00:01.067 -> 1
14:00:01.067 -> 1
14:00:01.114 -> 1
14:00:01.114 -> 1
14:00:01.114 -> 1
14:00:01.114 -> 1
14:00:01.114 -> 1
14:00:01.114 -> 1
14:00:01.114 -> 1
```

Description of Serial monitor data

Signal width = high -low = 00.065 - 00.165 = 100 ms

Signal period =
high2 -high1 = 01.067- 00.065 = 1.002 ms

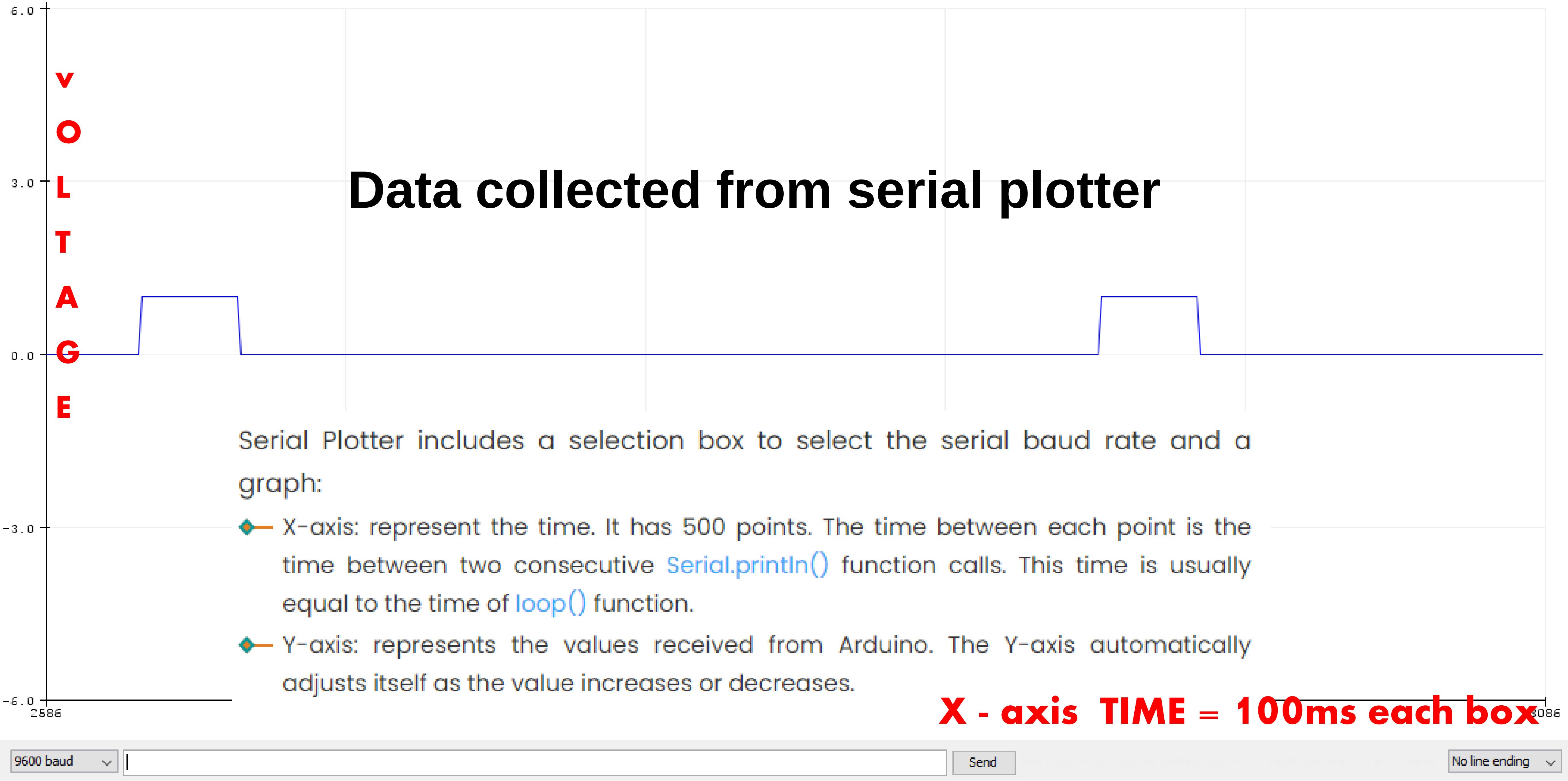
Expected signal and measured signal:

% difference in period . Error

T = [(1000 ms - 100 ms)/1000 ms] x 100% = 0%

T = [(1000ms – 1.002ms)/1000ms] x 100% = 0.98%

At each time stamp the code prints out several lines of data.
The time stamps typically (but not always) increase in 47 millisecond increments,
14:00:00.065 jumps to 14:00:00.112.



Data collected from serial plotter

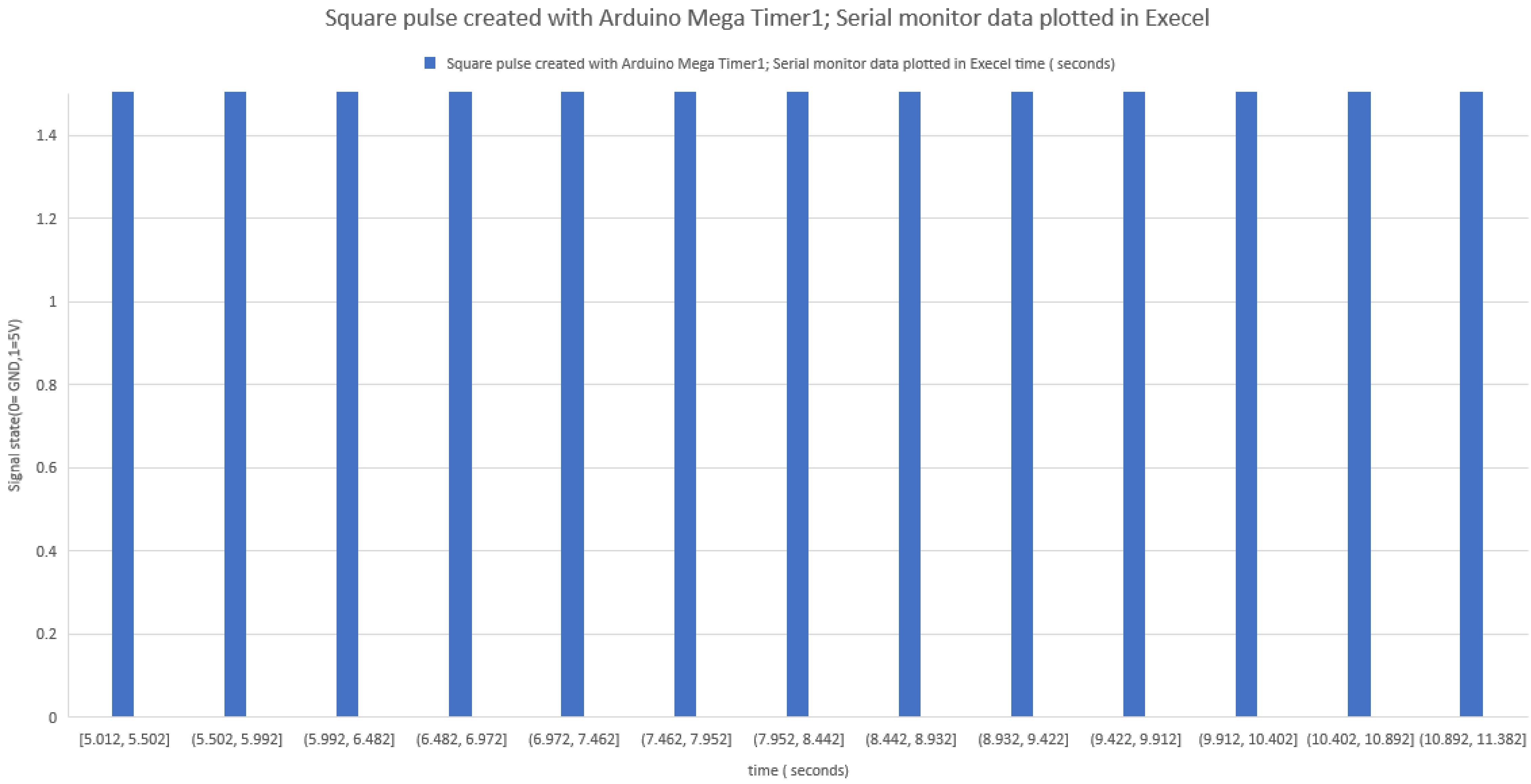
Serial Plotter includes a selection box to select the serial baud rate and a graph:

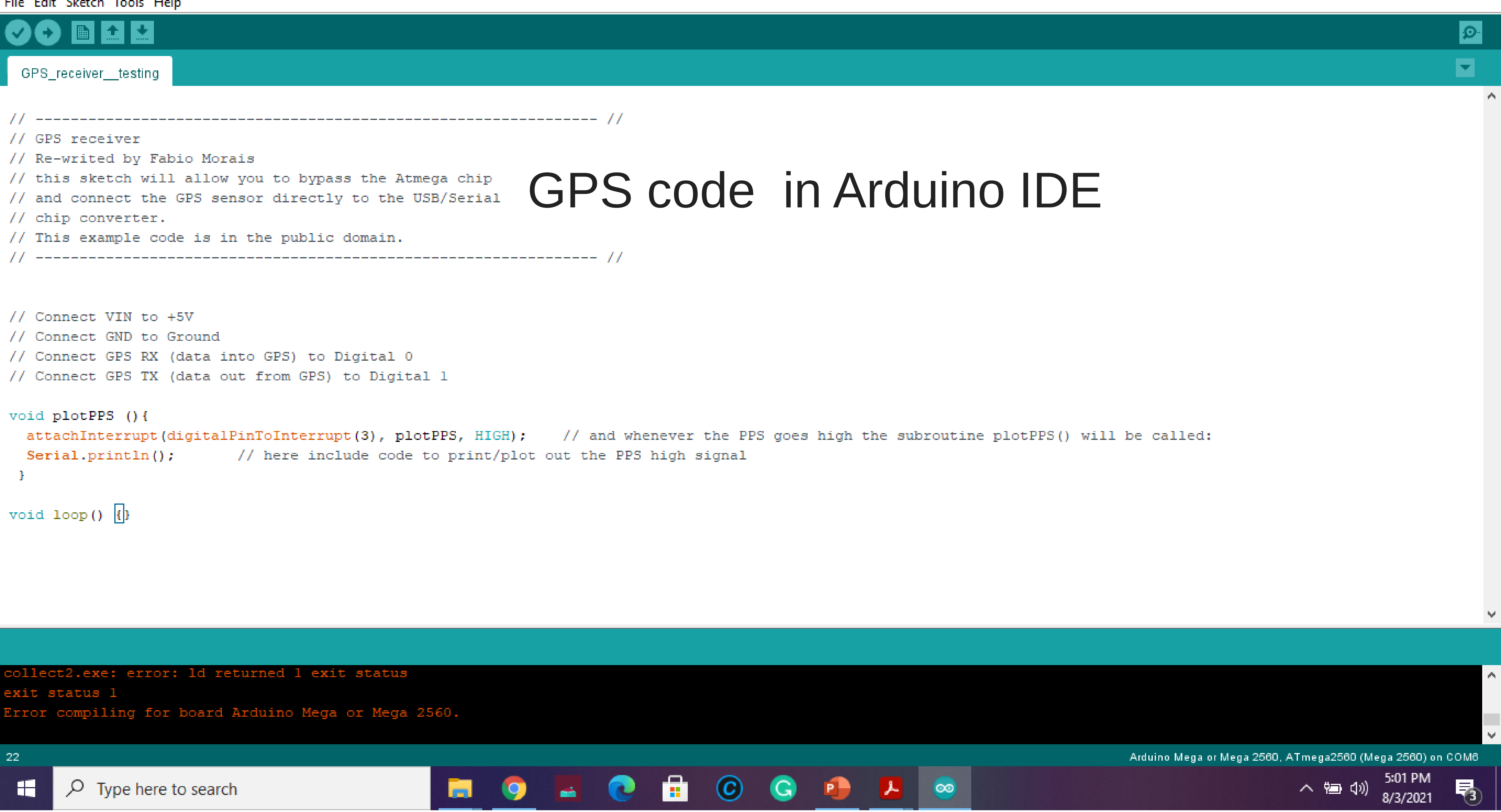
- X-axis: represent the time. It has 500 points. The time between each point is the time between two consecutive Serial.println() function calls. This time is usually equal to the time of loop() function.
- Y-axis: represents the values received from Arduino. The Y-axis automatically adjusts itself as the value increases or decreases.

VOLTAGE

X - axis TIME = 100ms each box

Excel plot of the serial data



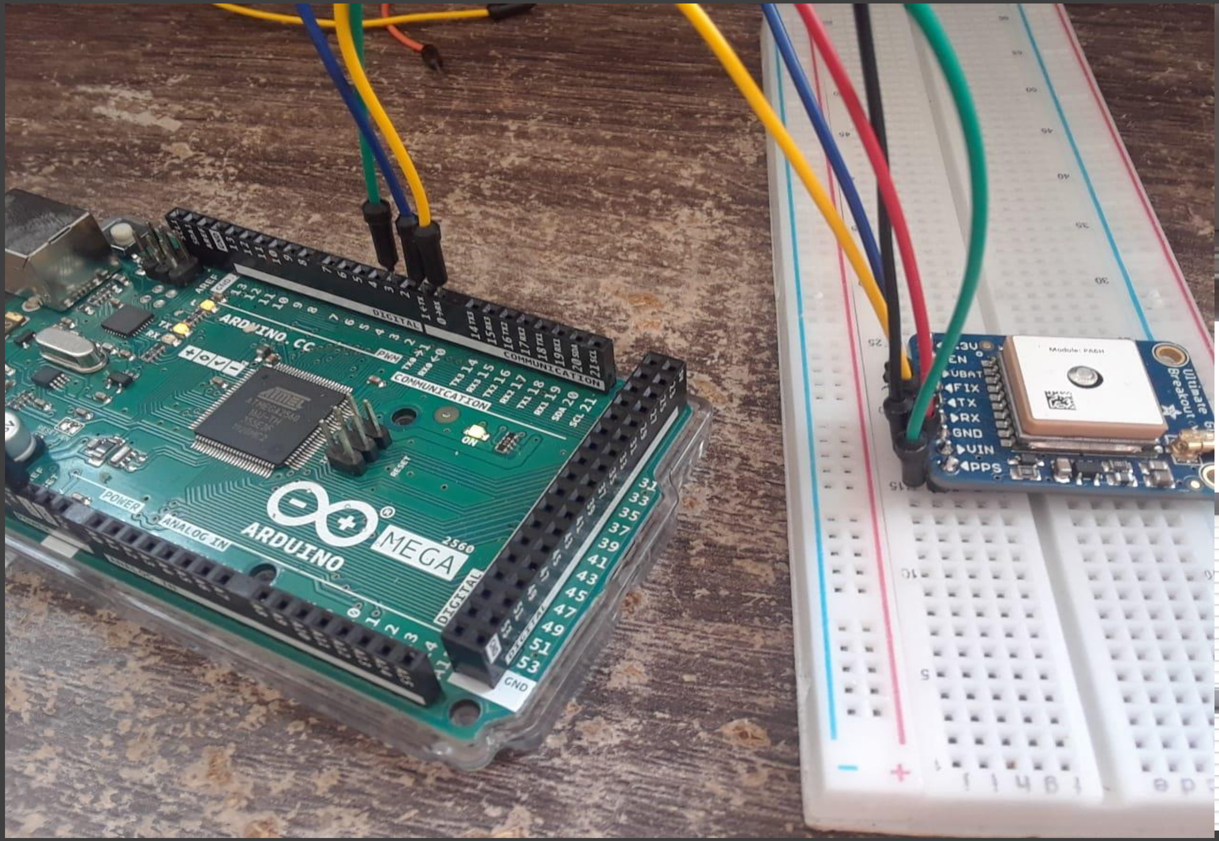


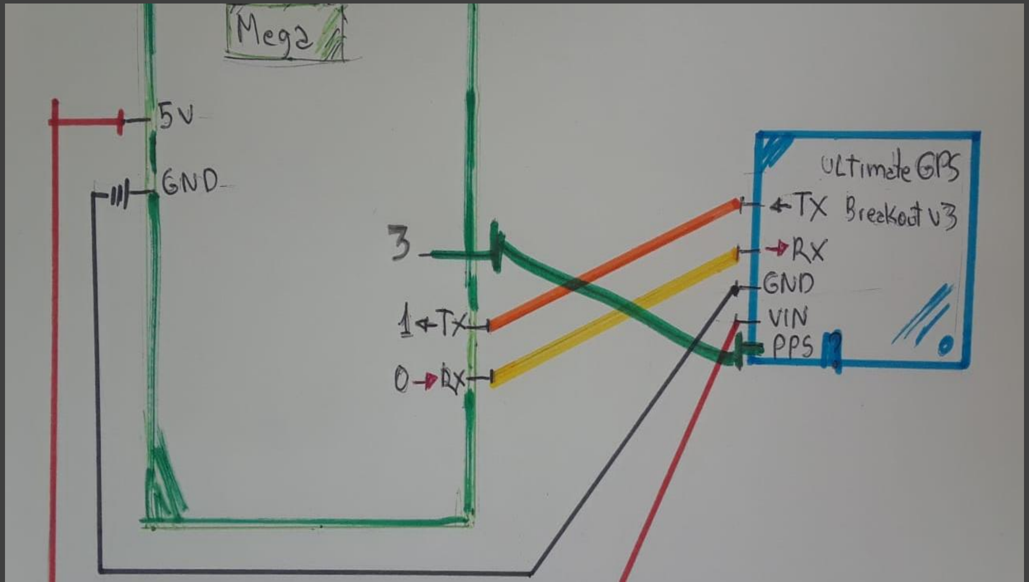
File Edit Sketch Tools Help
GPS_receiver__testing
22
Arduino Mega or Mega 2560, ATmega2560 (Mega 2560) on COM6
Type here to search
5:01 PM
8/3/2021

GPS code in Arduino IDE

```
// ---------------------------------------------------------------- //
// GPS receiver
// Re-writed by Fabio Morais
// this sketch will allow you to bypass the Atmega chip
// and connect the GPS sensor directly to the USB/Serial
// chip converter.
// This example code is in the public domain.
// ---------------------------------------------------------------- //


// Connect VIN to +5V
// Connect GND to Ground
// Connect GPS RX (data into GPS) to Digital 0
// Connect GPS TX (data out from GPS) to Digital 1

void plotPPS (){
  attachInterrupt(digitalPinToInterrupt(3), plotPPS, HIGH);    // and whenever the PPS goes high the subroutine plotPPS() will be called:
  Serial.println();        // here include code to print/plot out the PPS high signal
 }

void loop() {}
```

```
collect2.exe: error: ld returned 1 exit status
exit status 1
Error compiling for board Arduino Mega or Mega 2560.
```

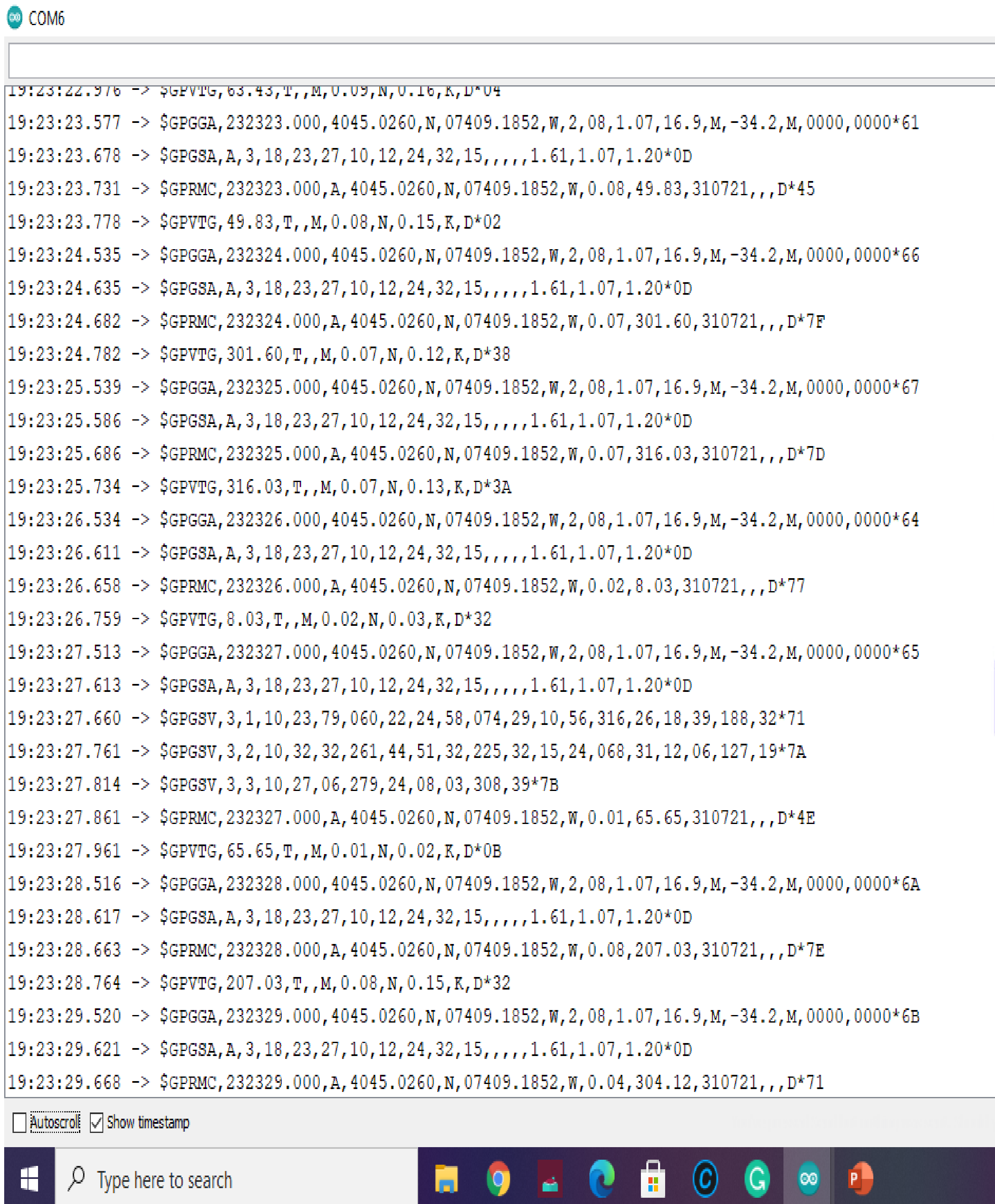




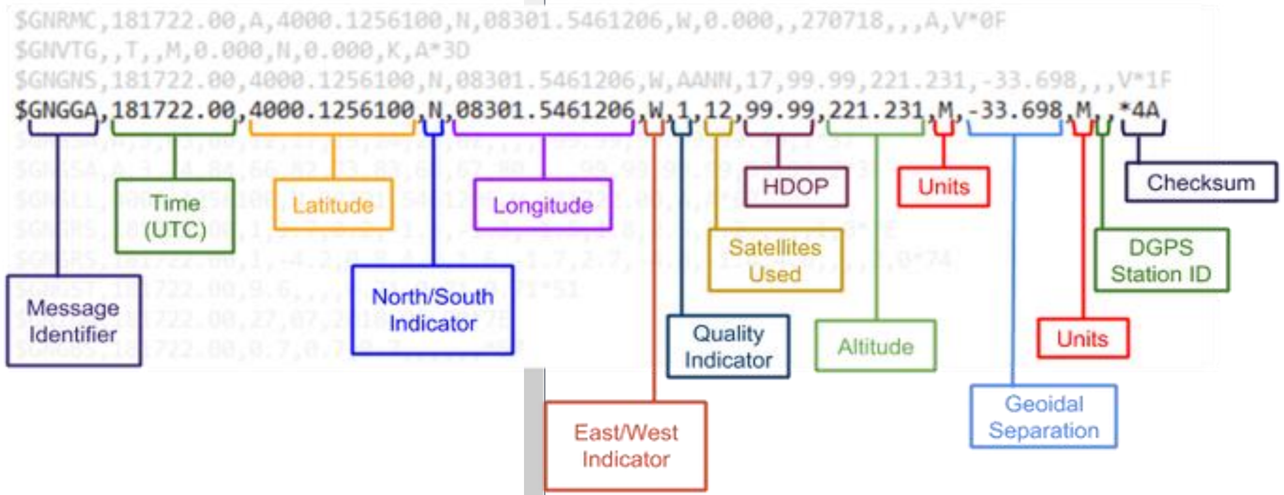
Arduino wired to GPS receiver, with PPS pin connected and antenna.

serial monitor

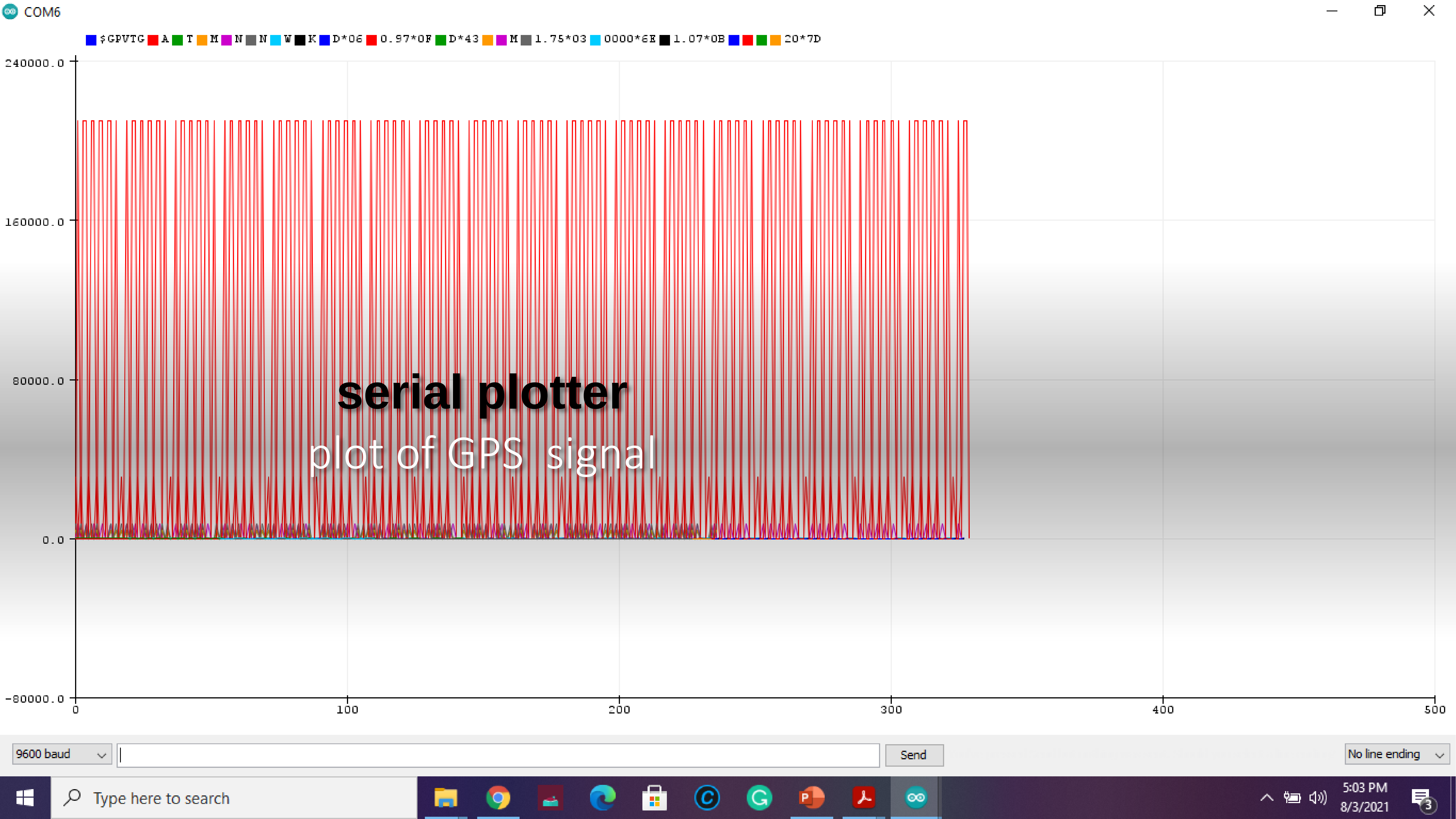
GPS NMEA data lines



```
19:23:22.976 -> $GPVTG,63.43,T,,M,0.09,N,0.16,K,D*04
19:23:23.577 -> $GPGGA,232323.000,4045.0260,N,07409.1852,W,2,08,1.07,16.9,M,-34.2,M,0000,0000*61
19:23:23.678 -> $GPGSA,A,3,18,23,27,10,12,24,32,15,,,,,1.61,1.07,1.20*0D
19:23:23.731 -> $GPRMC,232323.000,A,4045.0260,N,07409.1852,W,0.08,49.83,310721,,,D*45
19:23:23.778 -> $GPVTG,49.83,T,,M,0.08,N,0.15,K,D*02
19:23:24.535 -> $GPGGA,232324.000,4045.0260,N,07409.1852,W,2,08,1.07,16.9,M,-34.2,M,0000,0000*66
19:23:24.635 -> $GPGSA,A,3,18,23,27,10,12,24,32,15,,,,,1.61,1.07,1.20*0D
19:23:24.682 -> $GPRMC,232324.000,A,4045.0260,N,07409.1852,W,0.07,301.60,310721,,,D*7F
19:23:24.782 -> $GPVTG,301.60,T,,M,0.07,N,0.12,K,D*38
19:23:25.539 -> $GPGGA,232325.000,4045.0260,N,07409.1852,W,2,08,1.07,16.9,M,-34.2,M,0000,0000*67
19:23:25.586 -> $GPGSA,A,3,18,23,27,10,12,24,32,15,,,,,1.61,1.07,1.20*0D
19:23:25.686 -> $GPRMC,232325.000,A,4045.0260,N,07409.1852,W,0.07,316.03,310721,,,D*7D
19:23:25.734 -> $GPVTG,316.03,T,,M,0.07,N,0.13,K,D*3A
19:23:26.534 -> $GPGGA,232326.000,4045.0260,N,07409.1852,W,2,08,1.07,16.9,M,-34.2,M,0000,0000*64
19:23:26.611 -> $GPGSA,A,3,18,23,27,10,12,24,32,15,,,,,1.61,1.07,1.20*0D
19:23:26.658 -> $GPRMC,232326.000,A,4045.0260,N,07409.1852,W,0.02,8.03,310721,,,D*77
19:23:26.759 -> $GPVTG,8.03,T,,M,0.02,N,0.03,K,D*32
19:23:27.513 -> $GPGGA,232327.000,4045.0260,N,07409.1852,W,2,08,1.07,16.9,M,-34.2,M,0000,0000*65
19:23:27.613 -> $GPGSA,A,3,18,23,27,10,12,24,32,15,,,,,1.61,1.07,1.20*0D
19:23:27.660 -> $GPGSV,3,1,10,23,79,060,22,24,58,074,29,10,56,316,26,18,39,188,32*71
19:23:27.761 -> $GPGSV,3,2,10,32,32,261,44,51,32,225,32,15,24,068,31,12,06,127,19*7A
19:23:27.814 -> $GPGSV,3,3,10,27,06,279,24,08,03,308,39*7B
19:23:27.861 -> $GPRMC,232327.000,A,4045.0260,N,07409.1852,W,0.01,65.65,310721,,,D*4E
19:23:27.961 -> $GPVTG,65.65,T,,M,0.01,N,0.02,K,D*0B
19:23:28.516 -> $GPGGA,232328.000,4045.0260,N,07409.1852,W,2,08,1.07,16.9,M,-34.2,M,0000,0000*6A
19:23:28.617 -> $GPGSA,A,3,18,23,27,10,12,24,32,15,,,,,1.61,1.07,1.20*0D
19:23:28.663 -> $GPRMC,232328.000,A,4045.0260,N,07409.1852,W,0.08,207.03,310721,,,D*7E
19:23:28.764 -> $GPVTG,207.03,T,,M,0.08,N,0.15,K,D*32
19:23:29.520 -> $GPGGA,232329.000,4045.0260,N,07409.1852,W,2,08,1.07,16.9,M,-34.2,M,0000,0000*6B
19:23:29.621 -> $GPGSA,A,3,18,23,27,10,12,24,32,15,,,,,1.61,1.07,1.20*0D
19:23:29.668 -> $GPRMC,232329.000,A,4045.0260,N,07409.1852,W,0.04,304.12,310721,,,D*71
```



```
$GNRMC,181722.00,A,4000.1256100,N,08301.5461206,W,0.000,,270718,,,A,V*0F
$GNVTG,,T,,M,0.000,N,0.000,K,A*3D
$GNGNS,181722.00,4000.1256100,N,08301.5461206,W,AANN,17,99.99,221.231,-33.698,,,V*1F
$GNGGA,181722.00,4000.1256100,N,08301.5461206,W,1,12,99.99,221.231,M,-33.698,M,,*4A
```



serial plotter

plot of GPS signal

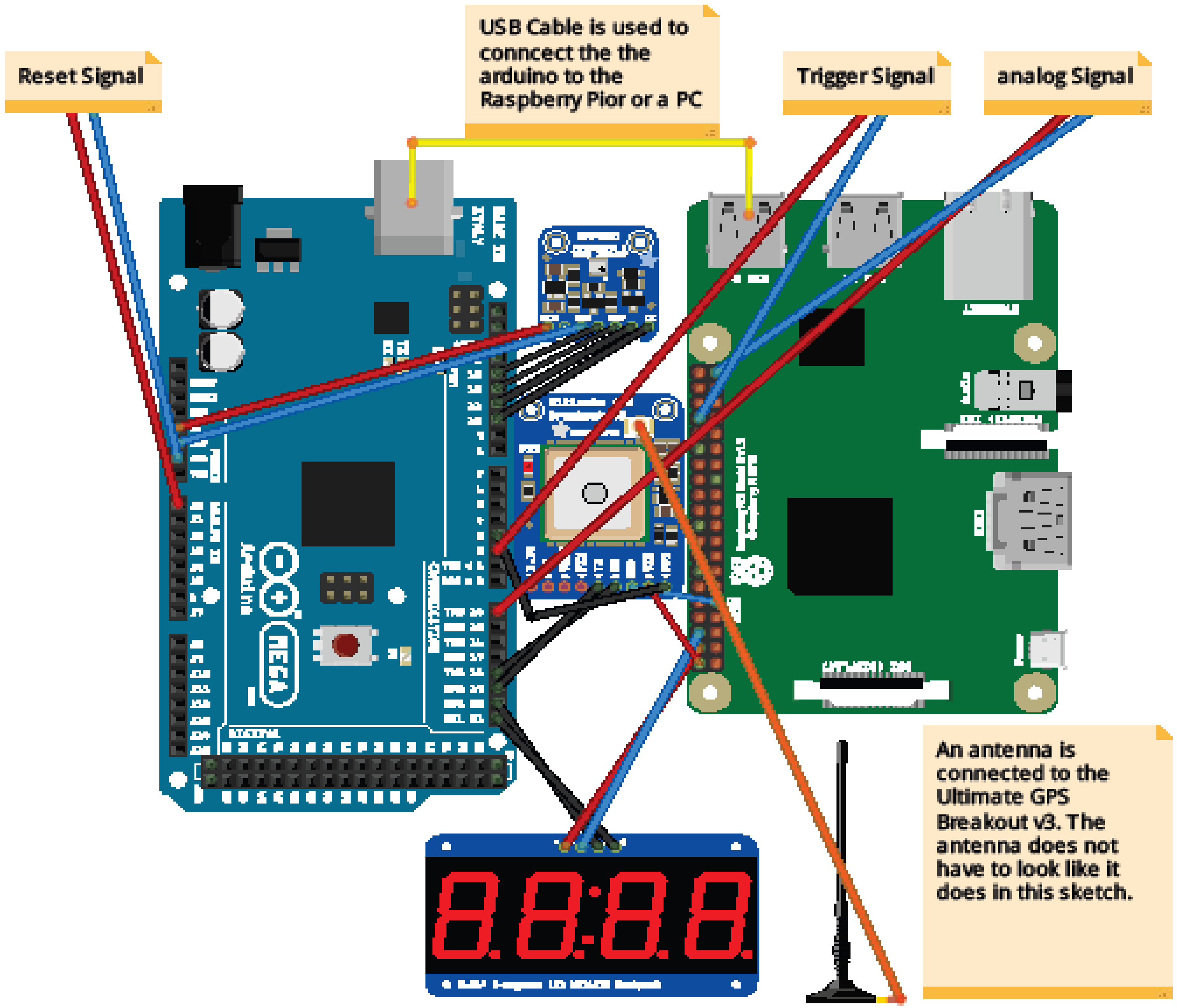
9600 baud

No line ending

our challenges…

We work on a code to run the GPS receiver and press/humid/temp together the Arduino .
That will be connected to a scintillator “counter“ to detect the Muon particle.

We work together cooperatively with other students researchers and professors.



Reset Signal

USB Cable is used to conncect the the arduino to the Raspberry Pior or a PC

Trigger Signal

analog Signal

An antenna is connected to the Ultimate GPS Breakout v3. The antenna does not have to look like it does in this sketch.

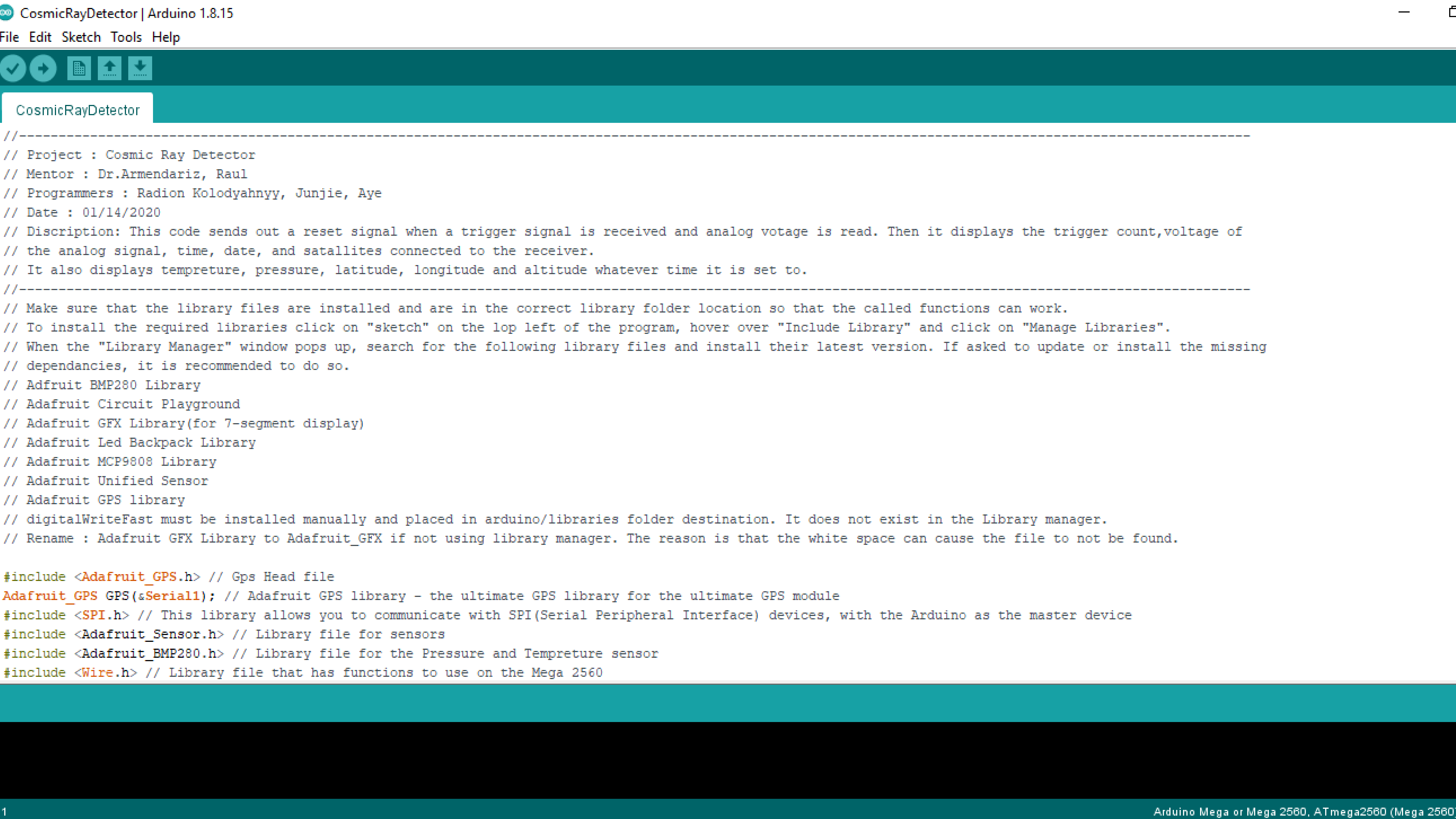
List of connections:

BMP280 Tempreture and Pressure Sensor :
TPS(SCK) - Arduino(Pin 13)
TPS(SDO(MISO)) - Arduino(Pin 12)
TPS(SDI(MOSI)) - Arduino(Pin 11)
TPS(CS) - Arduino(Pin 10)
TPS(GND) - Arduino(GND)
TPS(VIN) - Arduino(5V)

Ultimate GPS Breakout v3:
GPS(TX) - Arduino(RX1(Pin 19))
GPS(RX) - Arduino(TX1(Pin 18))
GPS(GND) - Raspberry Pi(Pin 5)
GPS(VIN) - Raspberry Pi(Pin 40)
GPS(PPS) - Arduino(Pin 3)
GPS(antenna pin) - Antenna

7-segment LED Backpack:
LED(VDD) - Raspberry Pi(Pin 39)
LED(GND) - Raspberry Pi(Pin 38)
LED(SDA) - Arduino(SDA(Pin 20))
LED(SCL) - Arduino(SCL(Pin 21))

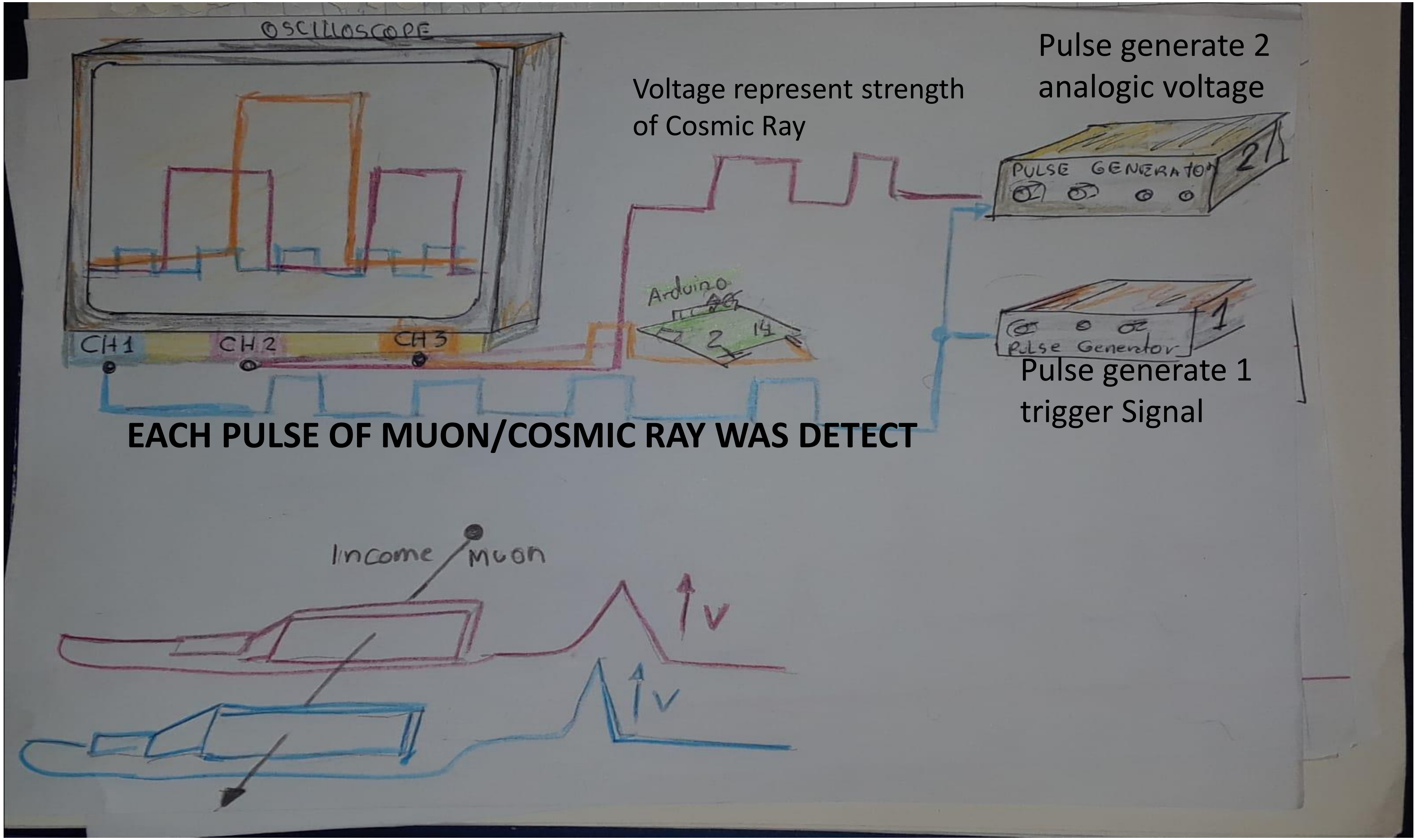
fritzing


CosmicRayDetector | Arduino 1.8.15
File Edit Sketch Tools Help
CosmicRayDetector
1
Arduino Mega or Mega 2560, ATmega2560 (Mega 2560

```
//---------------------------------------------------------------------------------------------------------------------------------------------------------------
// Project : Cosmic Ray Detector
// Mentor : Dr.Armendariz, Raul
// Programmers : Radion Kolodyahnyy, Junjie, Aye
// Date : 01/14/2020
// Discription: This code sends out a reset signal when a trigger signal is received and analog votage is read. Then it displays the trigger count,voltage of
// the analog signal, time, date, and satallites connected to the receiver.
// It also displays tempreture, pressure, latitude, longitude and altitude whatever time it is set to.
//---------------------------------------------------------------------------------------------------------------------------------------------------------------
// Make sure that the library files are installed and are in the correct library folder location so that the called functions can work.
// To install the required libraries click on "sketch" on the lop left of the program, hover over "Include Library" and click on "Manage Libraries".
// When the "Library Manager" window pops up, search for the following library files and install their latest version. If asked to update or install the missing
// dependancies, it is recommended to do so.
// Adfruit BMP280 Library
// Adafruit Circuit Playground
// Adafruit GFX Library(for 7-segment display)
// Adafruit Led Backpack Library
// Adafruit MCP9808 Library
// Adafruit Unified Sensor
// Adafruit GPS library
// digitalWriteFast must be installed manually and placed in arduino/libraries folder destination. It does not exist in the Library manager.
// Rename : Adafruit GFX Library to Adafruit_GFX if not using library manager. The reason is that the white space can cause the file to not be found.

#include <Adafruit_GPS.h> // Gps Head file
Adafruit_GPS GPS(&Serial1); // Adafruit GPS library - the ultimate GPS library for the ultimate GPS module
#include <SPI.h> // This library allows you to communicate with SPI(Serial Peripheral Interface) devices, with the Arduino as the master device
#include <Adafruit_Sensor.h> // Library file for sensors
#include <Adafruit_BMP280.h> // Library file for the Pressure and Tempreture sensor
#include <Wire.h> // Library file that has functions to use on the Mega 2560
```

When Arduino receives square pulse in pin2 the pin A0 reads the strength of the voltage input.

The Arduino outputs a square pulse pin 14.

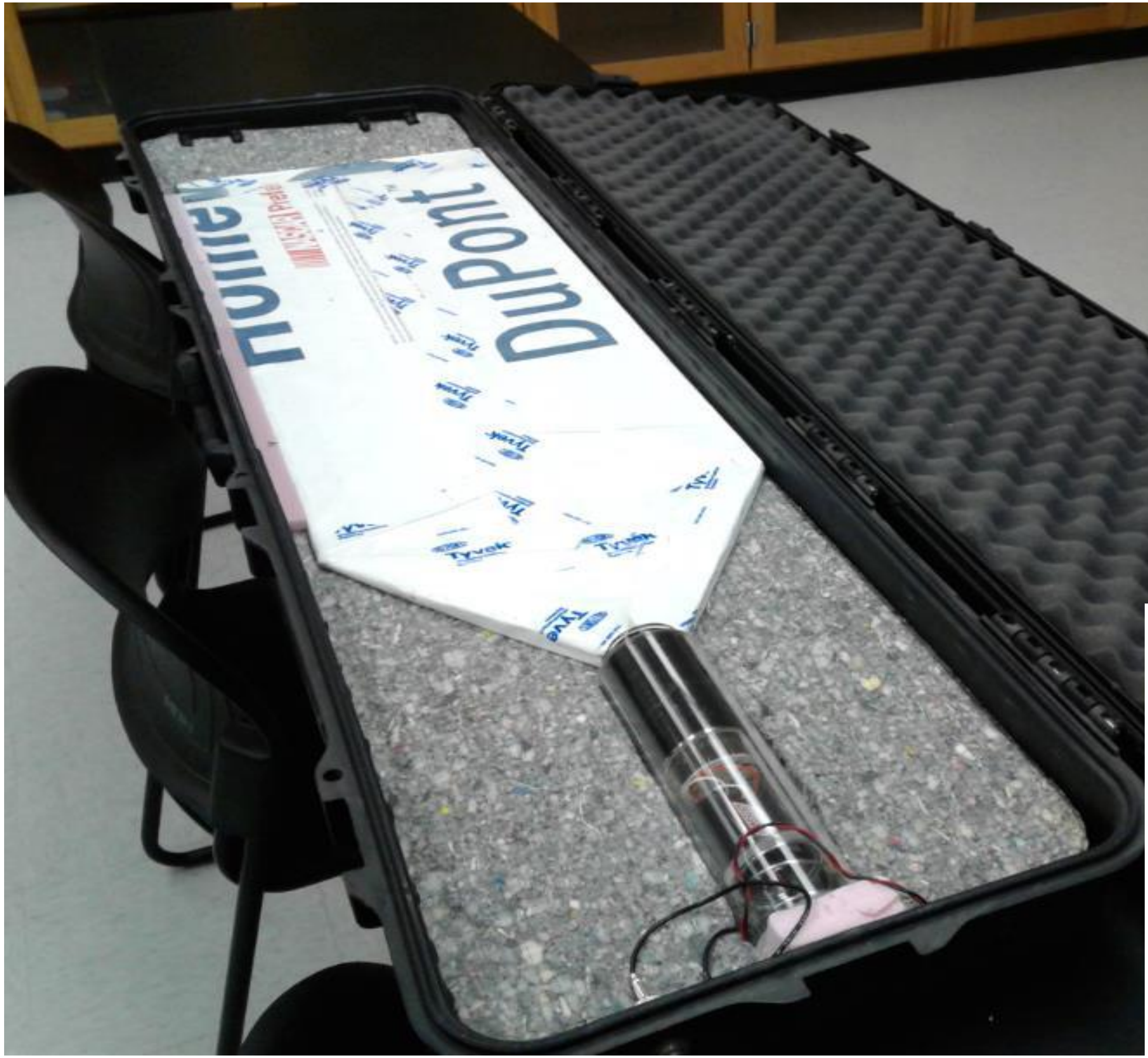


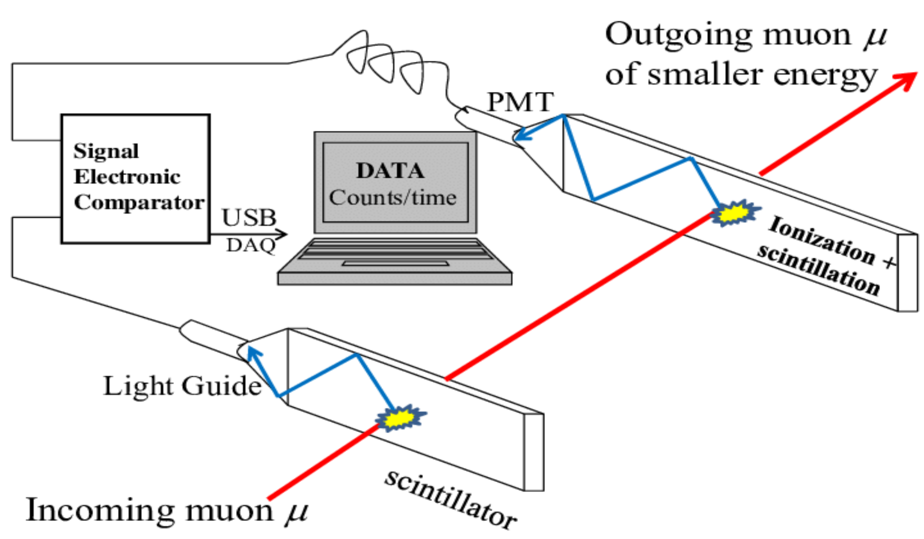
Pulse generate 2 analogic voltage

Voltage represent strength of Cosmic Ray

Pulse generate 1 trigger Signal

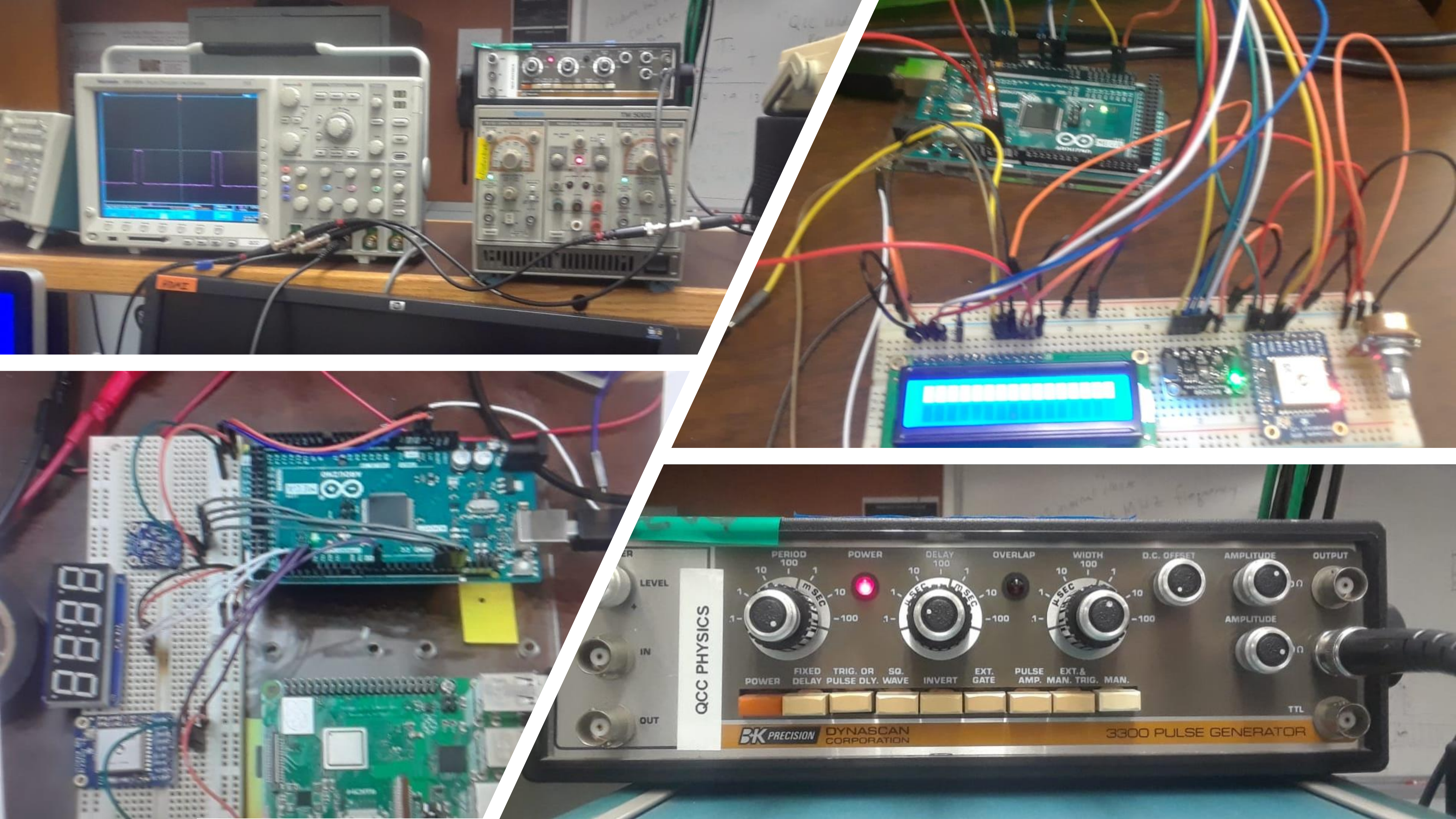
EACH PULSE OF MUON/COSMIC RAY WAS DETECT





Scintillator

Photomultiplier tubes


TM 5003
QCC PHYSICS
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IN
OUT
POWER
PERIOD
100
10
1
m SEC
.1
10
-100
POWER
DELAY
μ SEC
m SEC
OVERLAP
WIDTH
D.C. OFFSET
AMPLITUDE
OUTPUT
AMPLITUDE
FIXED DELAY
TRIG. OR PULSE DLY.
SQ. WAVE
INVERT
EXT. GATE
PULSE AMP.
EXT.& MAN. TRIG.
MAN.
TTL
B+K PRECISION
DYNASCAN CORPORATION
3300 PULSE GENERATOR

REFERENCES

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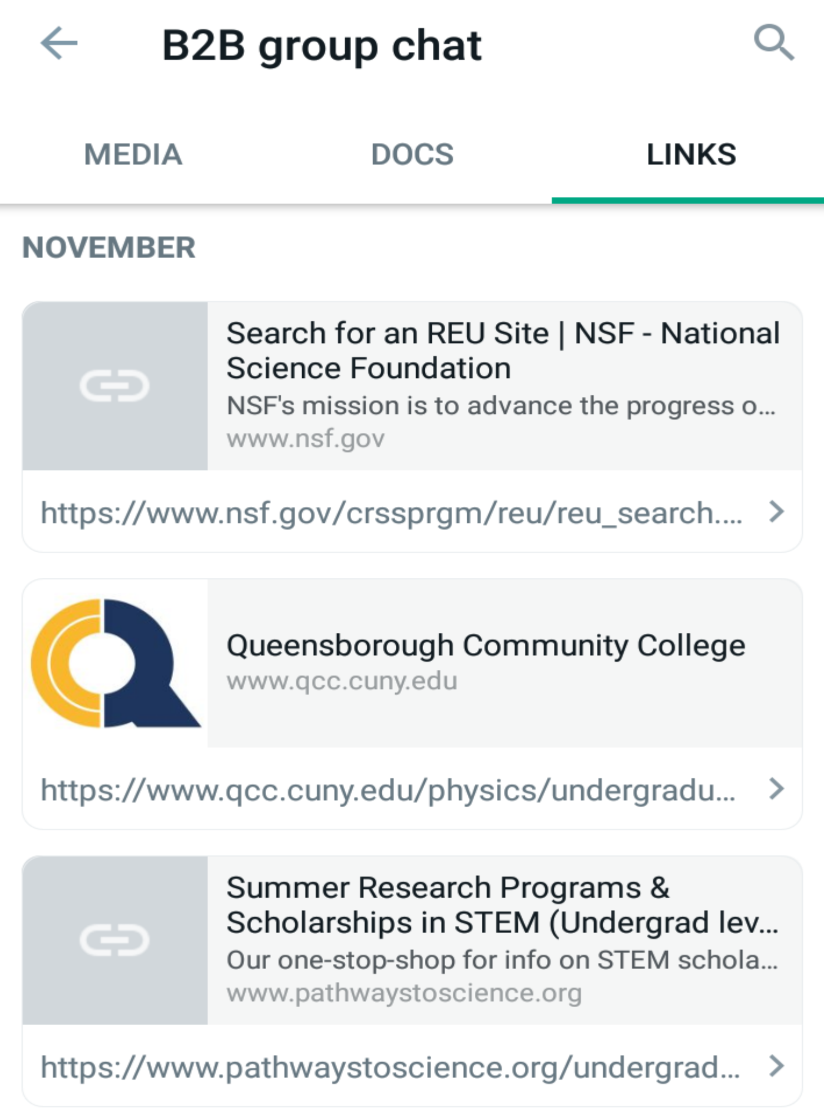

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Thank you !