Muon Detector for Students (MUDS)

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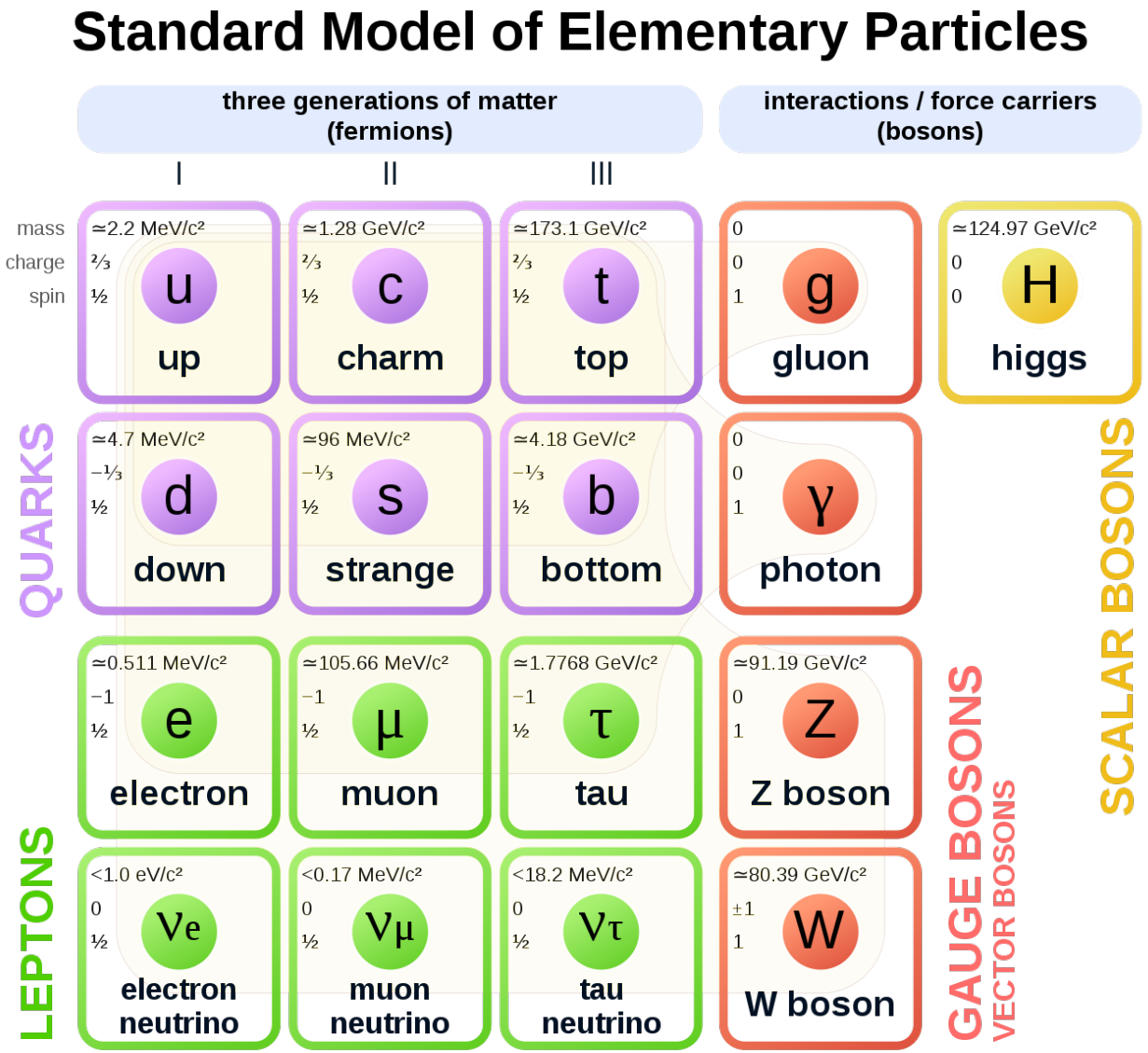
Goals of MUDS

- Detect Muons (measure the particle rate) at Sea Level
- Circuit should be affordable and simple so that a class of high school students could potentially replicate the detector – class project?

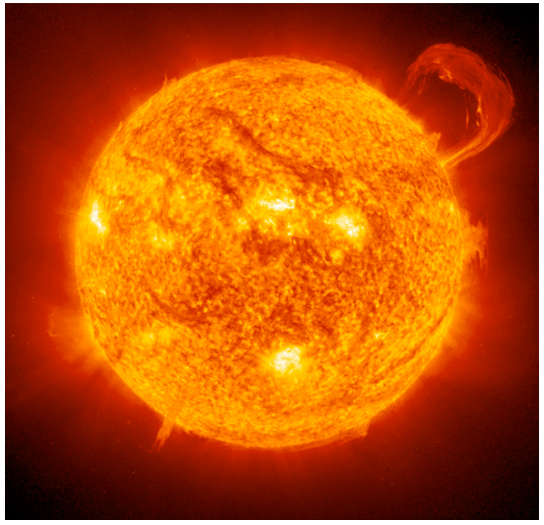
Muons?



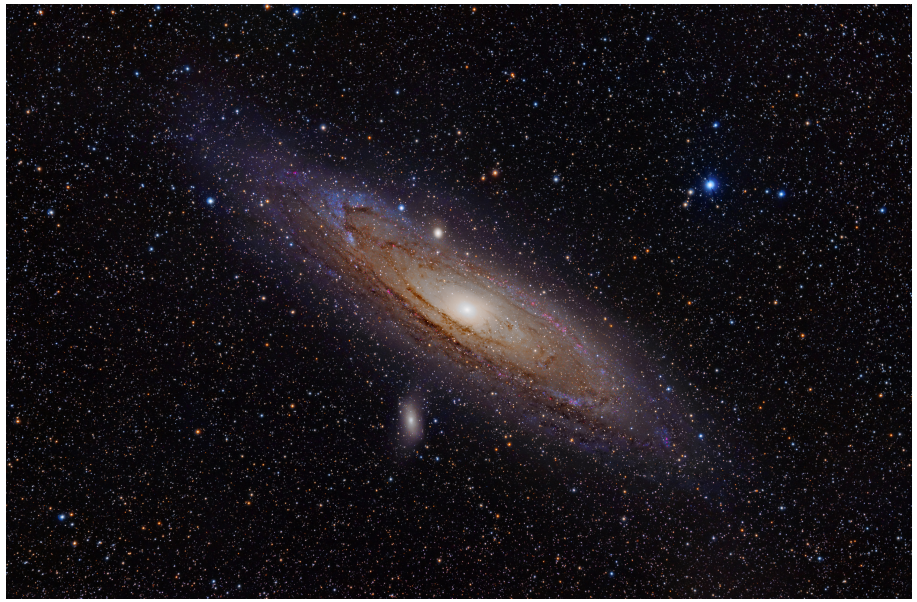
https://upload.wikimedia.org/wikipedia/commons/thumb/0/00/Standard_Model_of_Elementary_Particles.svg/1280px-Standard_Model_of_Elementary_Particles.svg.png

What are Cosmic Rays?

- Cosmic Rays are high energy particles
  - "High Energy" = traveling near the speed of light (i.e. $\frac{v^2}{c^2}$ is not negligible)
- Cosmic Rays originate from the sun, other stars, supernovae, and other parts of the universe



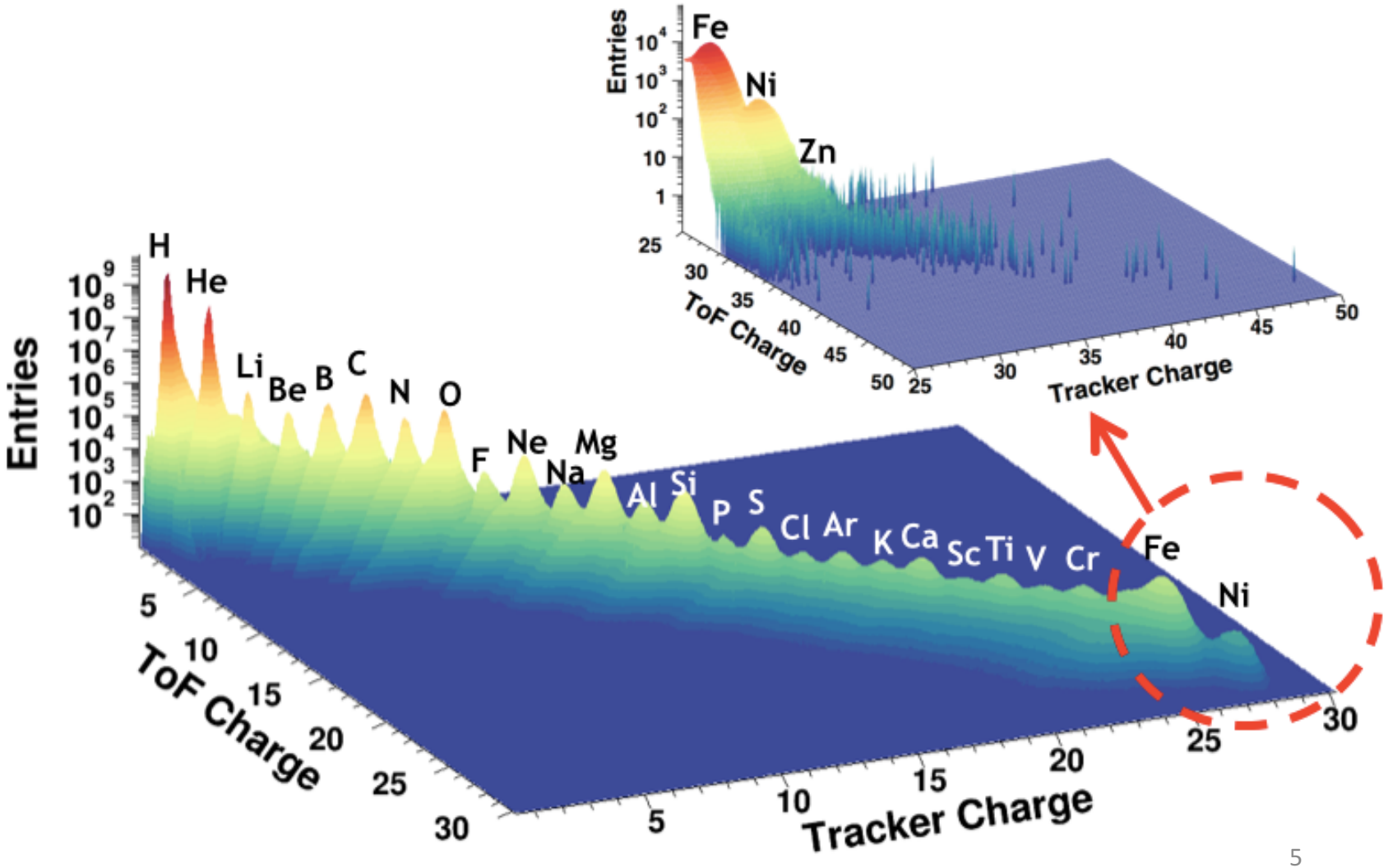
https://www.thesun.co.uk/wp-content/uploads/2019/03/NINTCHDBPICT000000417642.jpg



https://upload.wikimedia.org/wikipedia/commons/9/98/Andromeda_Galaxy_%28with_h-alpha%29.jpg

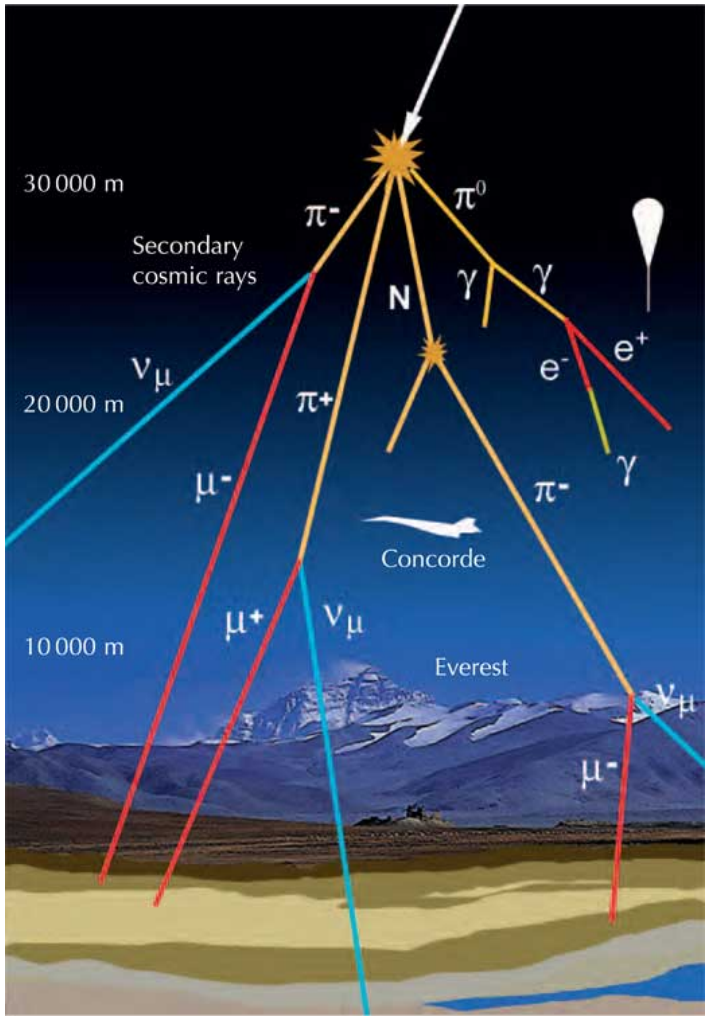
What Types of Particles are Cosmic Rays?

- 89% Protons (Hydrogen)
- 9% Alpha Particles (Helium)
- 1% Electrons
- 1% Nuclei of Other Elements



http://web.mit.edu/lns/research/emi.html

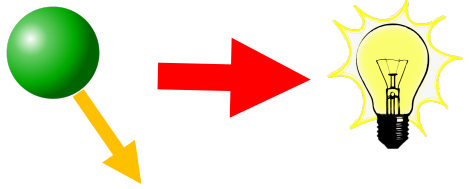
What Are the Effects of Cosmic Rays at Sea Level?



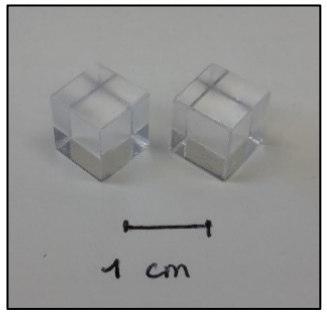
- When Cosmic Rays reach Earth, they interact with molecules in the atmosphere and create showers of new particles
- The particles created in these showers have short lifetimes and decay rapidly into other particles
- The particles which survive long enough to reach the ground are primarily Muons, Neutrinos and Gamma Rays
- At sea level every square meter receives about 100 muons per second

How to Detect Particles?
A Simplified Detector

Scintillator



$$N(t) = N_0 f(\sigma, t) \exp\left(\frac{-t}{\tau}\right)$$

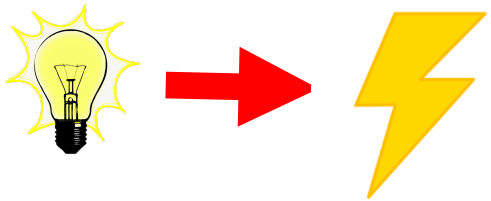


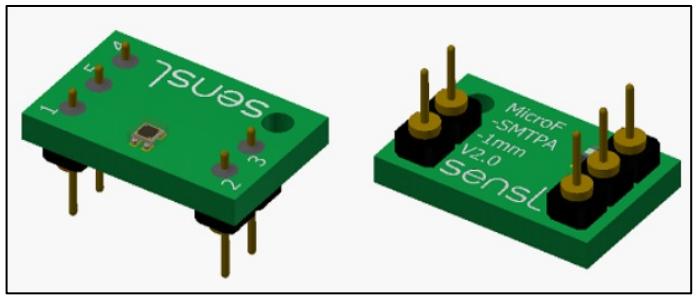
Plastic scintillators

Photomultiplier Tube (PMT)

or

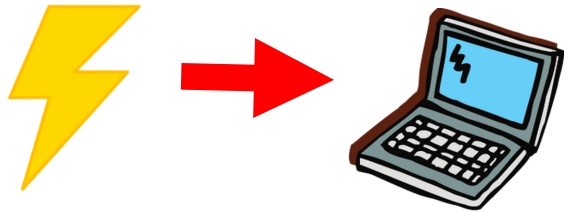
Silicon Photomultiplier (SiPM)

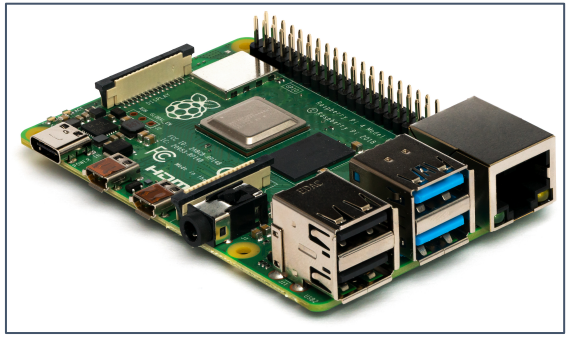




SiPM

Analog to Digital Converter





Raspberry Pi

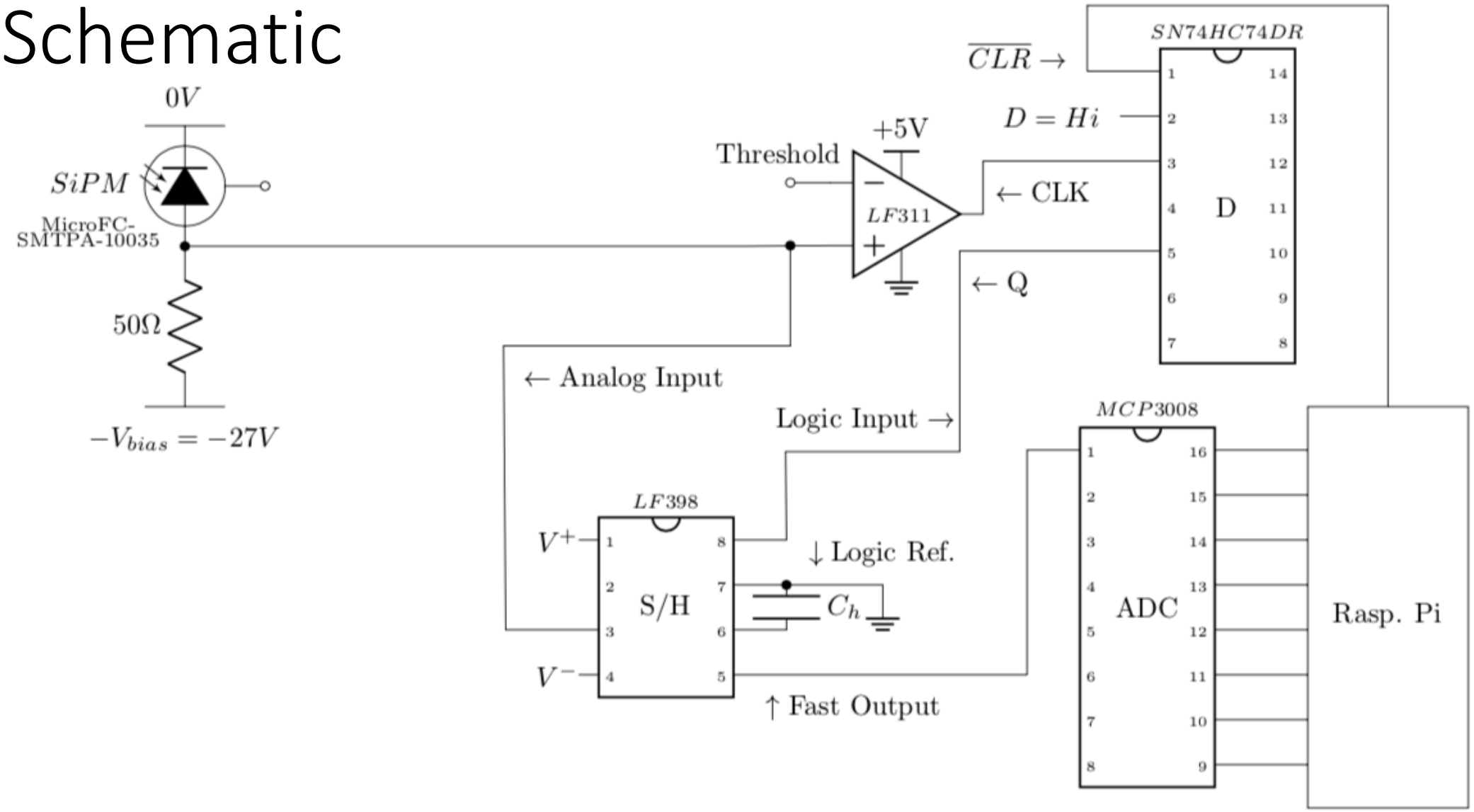
https://upload.wikimedia.org/wikipedia/commons/f/f1/Raspberry_Pi_4_Model_B_-_Side.jpg

Requirements

Part	Considerations
Scintillator (BC-408 ?)	• Need to reduce background light so that scintillation from muon energy deposition is primary source of light
SiPM (Sensl C-Series: MicroFC-SMTPA-10035)	• Pulse Width 0.6 ns (Fast Output) • Needs Biasing circuit • Needs Transimpedance Amp to convert from Q → V (really I → V) • Additional Amp Stage?
ADC (MCP3008)	• 75-200 kilosamples/sec (V_{DD}=V_{REF}=2.7V & 5V) → best possible acquisition time = 5 µs • Needs Sample and Hold

SiPM wrapped with scintillator by foil and black tape

Schematic


0V
SiPM
MicroFC-SMTPA-10035
50Ω
$-V_{bias} = -27V$
Threshold
+5V
LF311
$\overline{CLR} \rightarrow$
$D = Hi$
← CLK
← Q
SN74HC74DR
D
← Analog Input
Logic Input →
LF398
V^+
V^-
S/H
↓ Logic Ref.
C_h
↑ Fast Output
MCP3008
ADC
Rasp. Pi

How Large Should the Signal Be?

- τ=82 ns → $T_{90\%-10\%}$=2.2*82ns = 180.4 ns
- G≈2.7x10^6 for ~2.5V of overvoltage
- For a single photoelectron 2.7*10^6*q_e/180.4 ns = 2.4 μA
- With 50 Ω resistor, V=IR=2.5*50 = 120 μV per photoelectron
- With 1kΩ resistor, V=120 μV*20 = 2.4 mV per photoelectron

- Noise
  - dark current → expect about 15 nA (typical) to a max of 49 nA of current → 49 μV with 1k resistor

Questions?

Thank You For Listening!