Design and Construction of a Spark Chamber

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Motivation

- A detector designed to visualize cosmic muons for demonstration and educational purposes.
- It is used to measure muon mass and is also suitable for measuring the distribution of muon angles in the atmosphere, the muon magnetic moment, and more.

Advised Requirements[4][5]

High Gas Purity, $\sim 99\%$

High Plate Voltage, > 2.5 kV

Long Electrical Pulse $\sim$ μs, 5 μs

Fast Trigger Response < 500 ns, 507 ns

Edge Curvature Radius > 3 mm, ≈ 1 mm

Gap Width Fluctuation $< 1\%$, $\approx 36\%$

Muon Mass Measurement[3]

1. The energy of electrons will decrease when passing through the aluminum over a distance l. $-\frac{dE}{dl} = S_{ioniz} + S_{brem} = S_0 + \frac{E}{X_0}$

($S_0 = 5.09$ MeV / cm, $X_0 = 8.9$ cm for Aluminum)

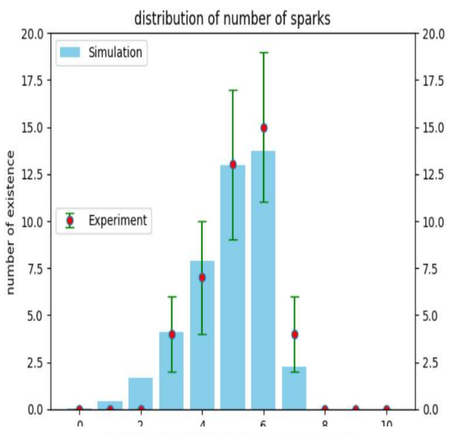
2. Measure the number of electrons generated by muon decay that pass through the gap between the plates (n_s, where l is hard to determine).

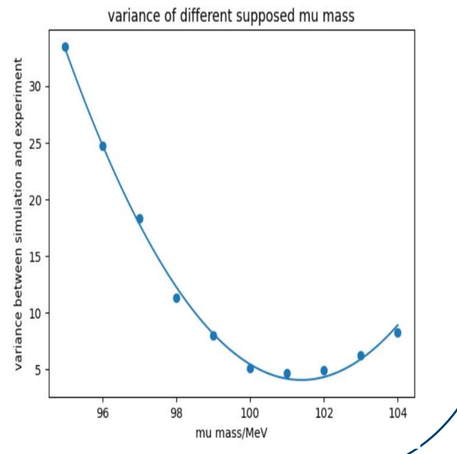
3. The initial energy of the electrons generated by muon decay, E_e, could result in a distribution covering all possible values of n_s.

4. Compare the generated distribution of n_s with the one determined experimentally.

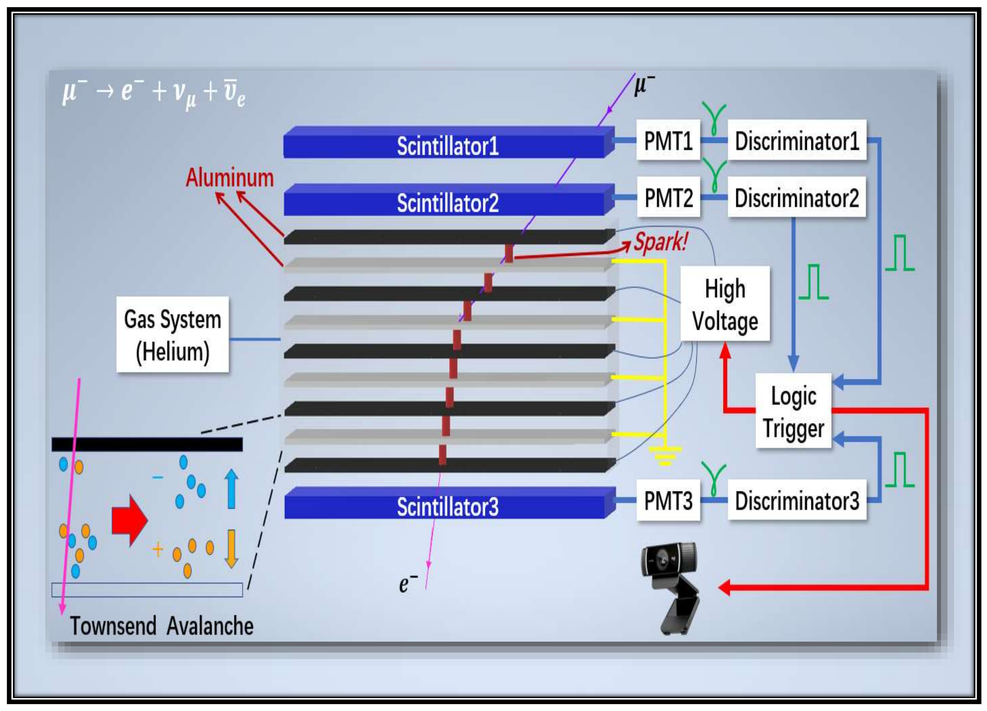
$$E_e \in [0, \frac{1}{2} m_\mu c^2]$$

$$P(E_e) = C(m_\mu c^2 E_e)^2 (3 - 4E_e/m_\mu c^2) \rightarrow P(n_s)$$

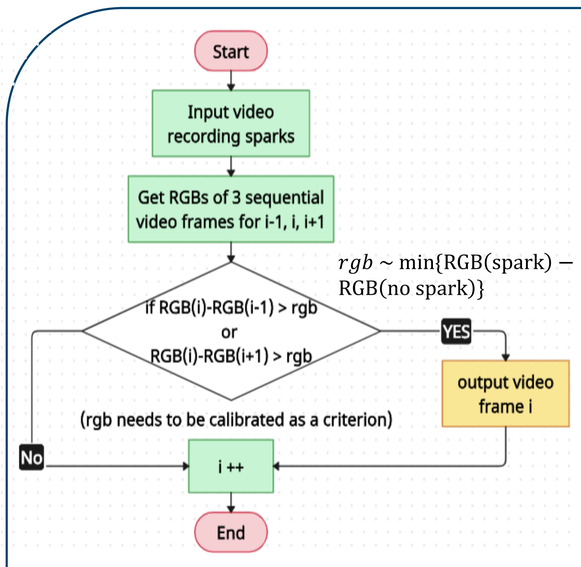




Schematic Diagram



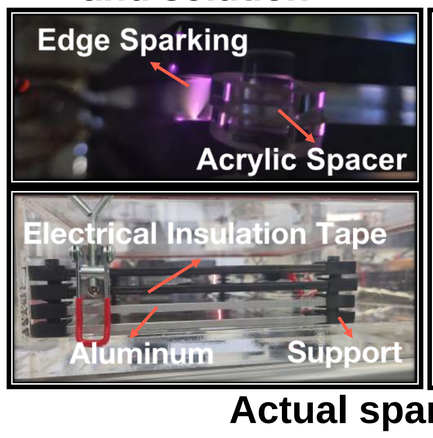
Result



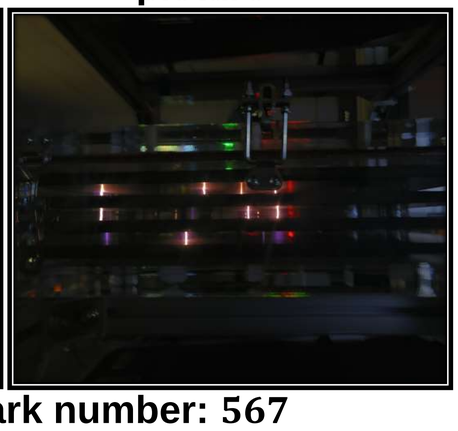
Flow chart of spark recognition algorithm

10min video → 60fps

Edge sparking and solution

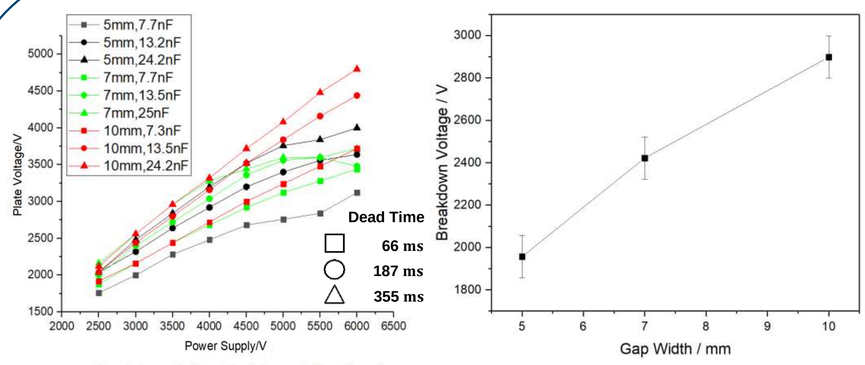


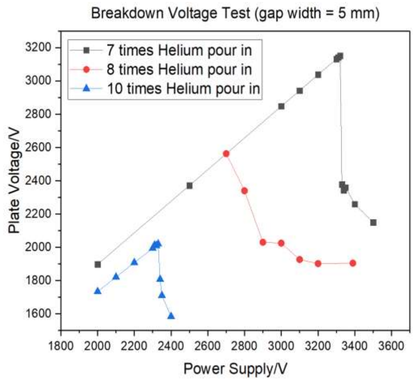
4-seconds exposure picture



Actual spark number: 567
Recorded by camera: 381
Output through algorithm: 211(15)
Recognition Correct Rate: 93.4%
Record Success Rate: 67.2%

Prototype Performance





Vertical Assembly

Vacuum Pump to accelerate gas circulation

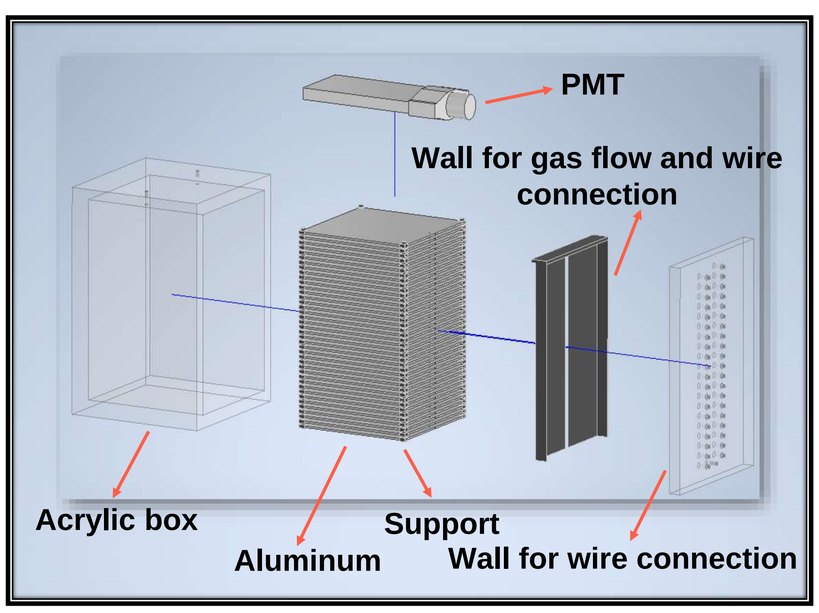
Pluggable Wire Connection

Plate: 450 mm $\times$ 230 mm $\times$ 10 mm

Box: 525 mm $\times$ 370 mm $\times$ 130 mm

4-layers Aluminum

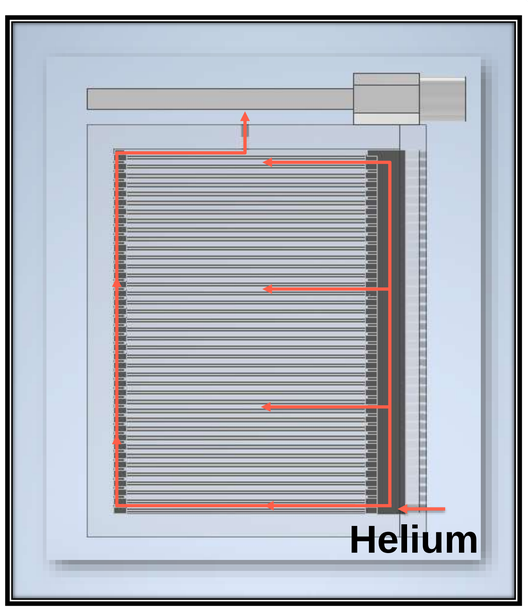
Planned Upgrade



Horizontal Assembly Diagram

Plate: 400 mm $\times$ 400 mm $\times$ 5 mm

Box: 515 mm $\times$ 487 mm $\times$ 685 mm



Gas Path

Gap width: 10 mm

40-layers Aluminum

The total thickness of the aluminum plates must be sufficient to detect stopped and decayed muon events.

Reference

[1] Design, Construction, and First Tests of a Demonstration Spark Chamber, Lisa Lin, Robin Peter, Sophia Vlahakis, and Tara Vogel, The University of Chicago, Illinois, 60637, 2018.
[2] J. Collins, Construction of a Prototype Spark Chamber, University of Cambridge, October 2009
[3] B. Brau, C. May, R. Ormond, and J. Essick, "Determining the muon mass in an instructional laboratory," Am J Phys 78 (1), 64-70 (2010).
[4] W. A. Wenzel, Annu. Rev. Nucl. Sci., 14, 205-238 (1964).
[5] J.G. Rutherglen. 1 - spark chambers. Pages 1-26, 1964.
[6] https://www.physics.mcgill.ca/~corriveau/projects/spark
[7] https://hep.tsinghua.edu.cn/training/sparkChamber/sparkChamber.html
[8] 火花室.原子能科学技术.刘皇风.北京大学.1964.第一期.