Sparks at Griffith Observatory

Reviving the Cosmic Ray Spark Chamber

Peter G. Halverson
Mount San Antonio College
May 16, 2024

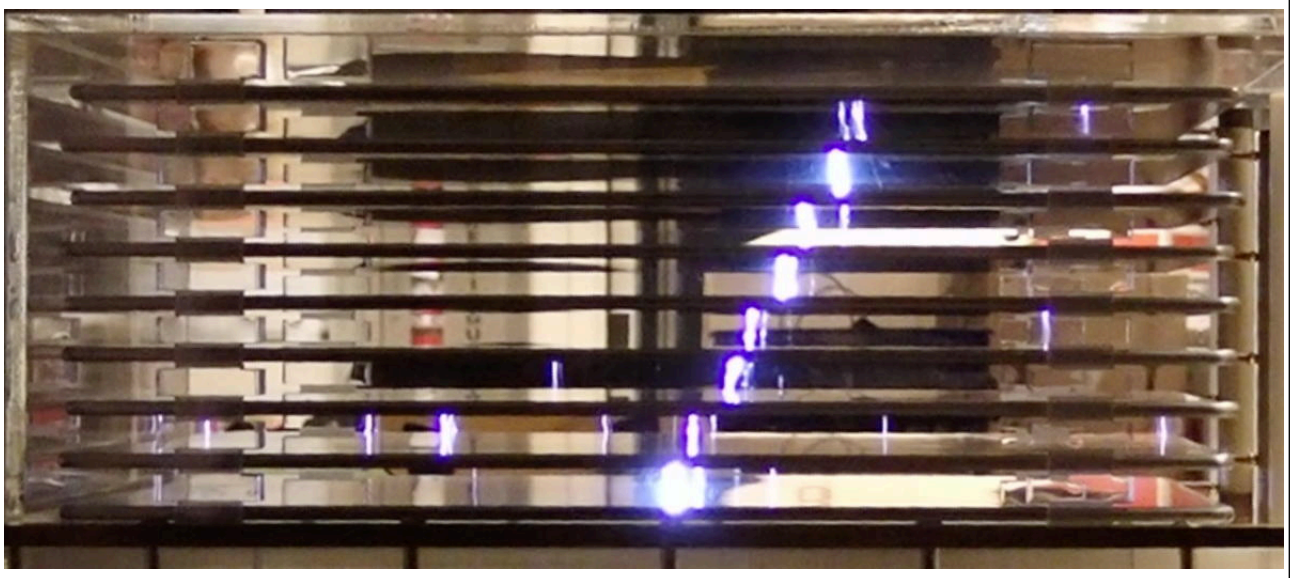
Particles mentioned in this talk, in order of increasing mass. (Added for video viewers)

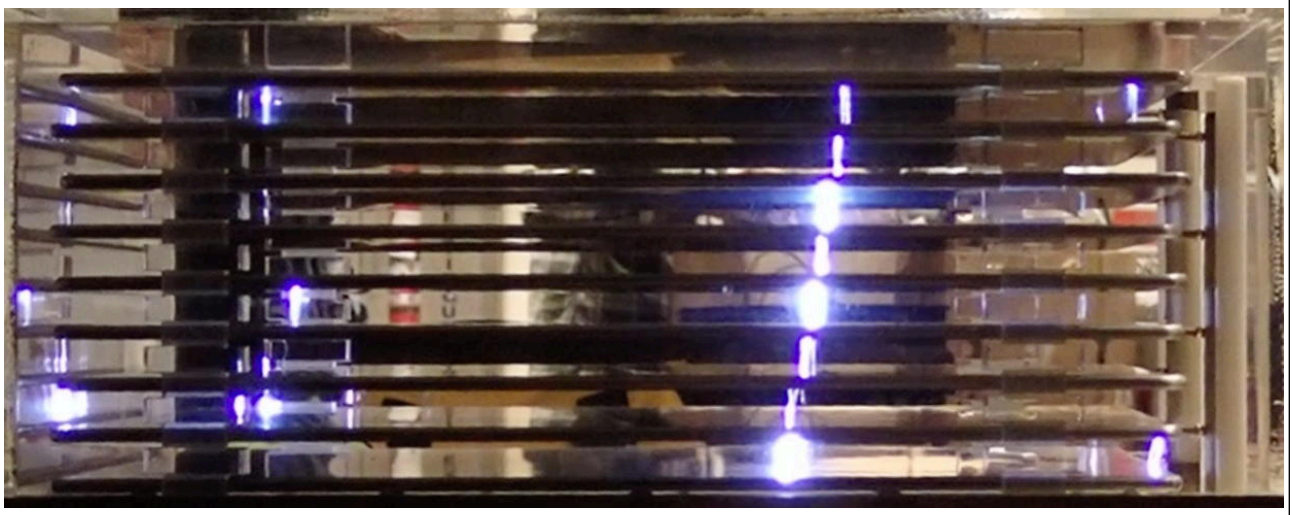
Names	photon or gamma ray	electron neutrino, muon neutrino and their anti particles	electron and anti-electron (aka positron)	muon and anti-muon	pion and anti-pion (Not sure which one is considered "anti")	proton and anti-proton
Symbols	γ	ν_e, $\bar{\nu}_e$, ν_μ, $\bar{\nu}_\mu$	e^-, e^+	μ^-, μ^+	π^-, π^+	p^+, p^-
Mass in energy units	zero	almost zero	0.511 MeV/c^2	105.7 MeV/c^2	139.6 MeV/c^2	983 MeV/c^2 ($\approx$ 1GeV/c^2)
Lifetimes (average time until spontaneous decay)	∞, infinite	∞, infinite	∞, infinite	220 micro-seconds	0.0260 micro-seconds	∞, infinite

What is a Cosmic Ray?

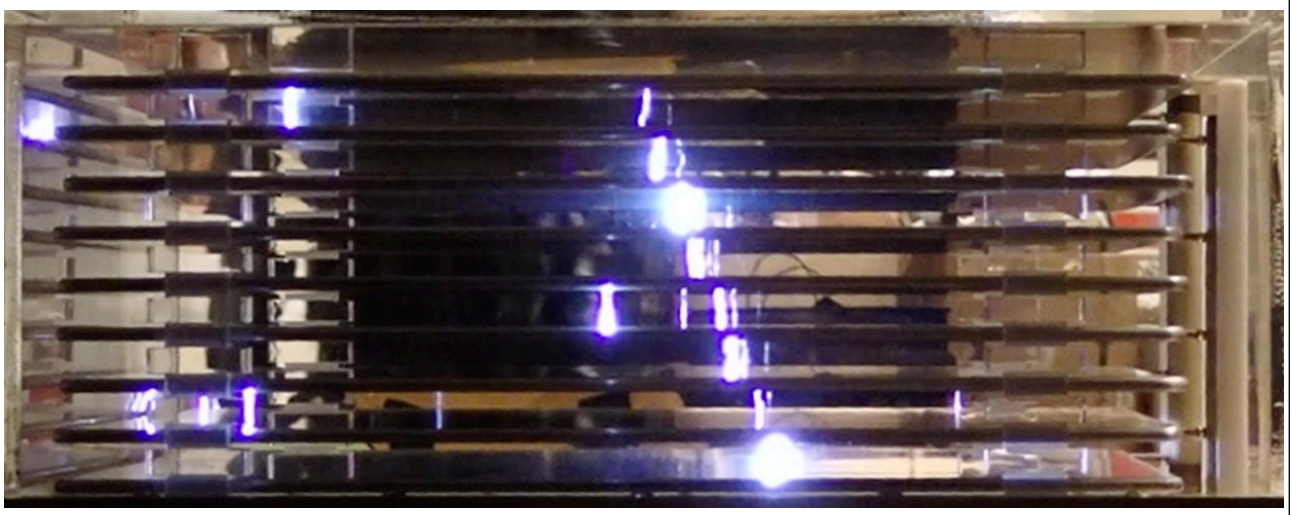
- Stars spew out hydrogen nuclei, protons.
- Protons have a positive charge and are pushed by moving magnetic fields.
- (The fields of the Sun accelerate protons all the time, causing auroras and geomagnetic storms.)
- Some protons come from our galaxy and some of those have tremendous energy. We call these **cosmic rays**.
- When a cosmic ray hits the upper atmosphere, it creates a "cascade" or "shower" of **secondary particles** that reaches the ground.
- This is what the Griffith Observatory Spark Chamber shows.
- (Video P1110023.MOV. Start at 3m 50s)

"Tracks" of sparks follow cosmic ray muons (usually)



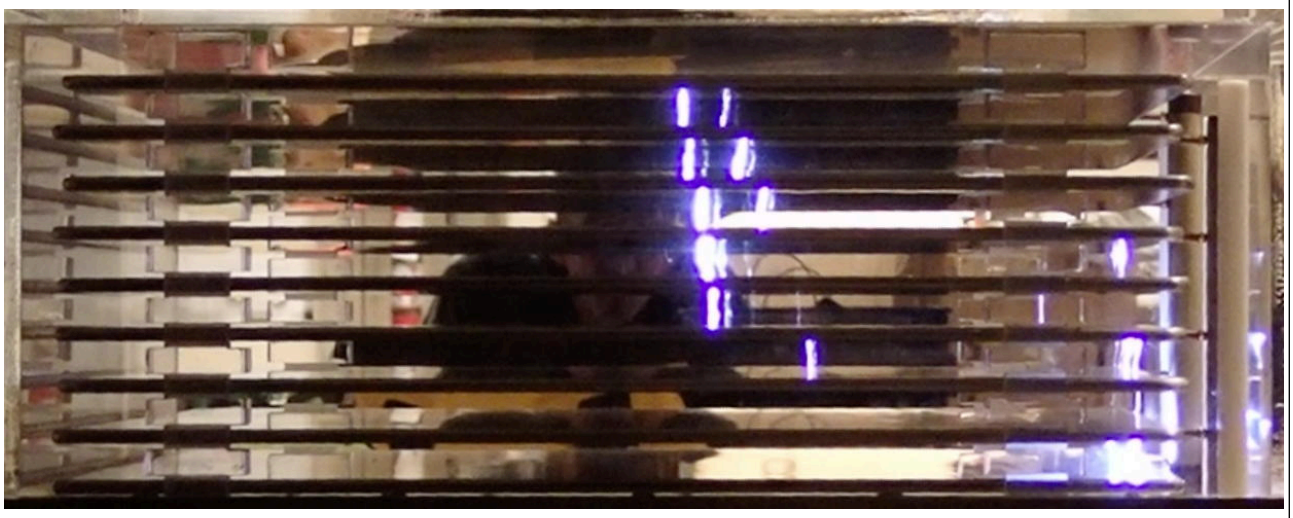


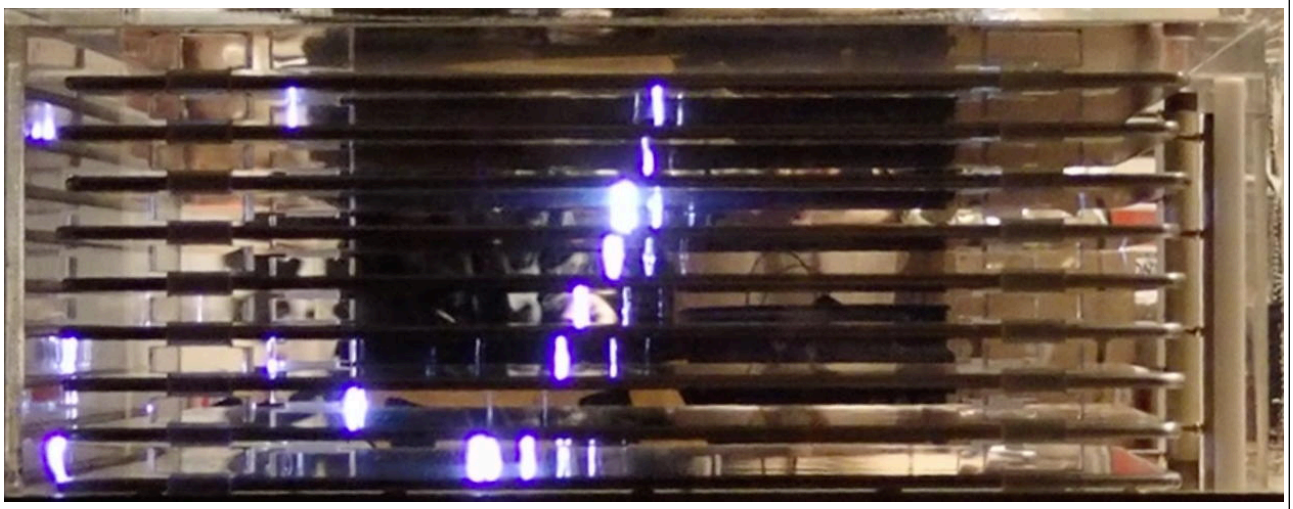
5



6

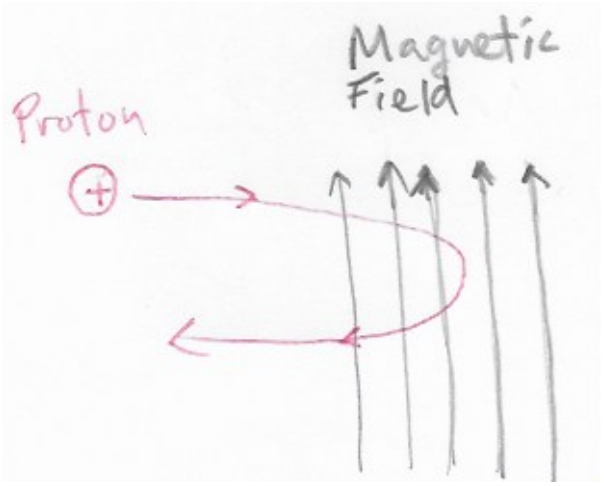
Sometimes we see “forks” in the tracks. The muon smashed into a nucleus and the debris makes multiple tracks.



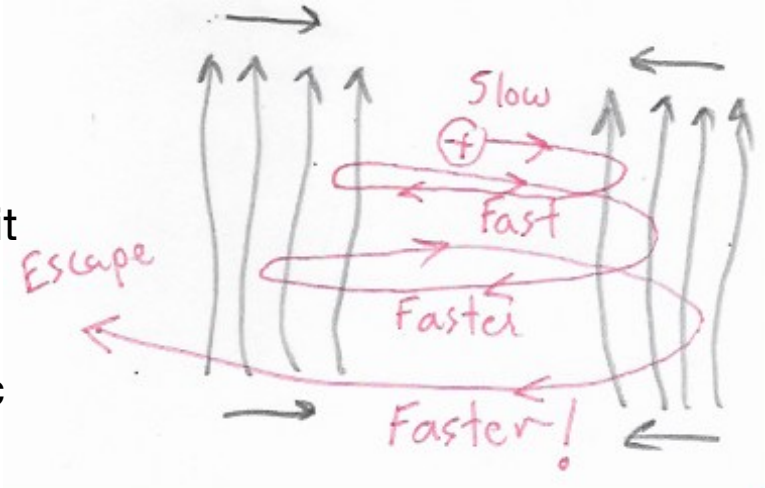


The "life" of a high energy cosmic ray.

1. Birth.
   - Stars emits steady streams of hydrogen nuclei, protons.
   - ALSO novas and supernovas emit huge bursts of protons.
2. Acceleration
   - Protons are reflected by magnetic fields.

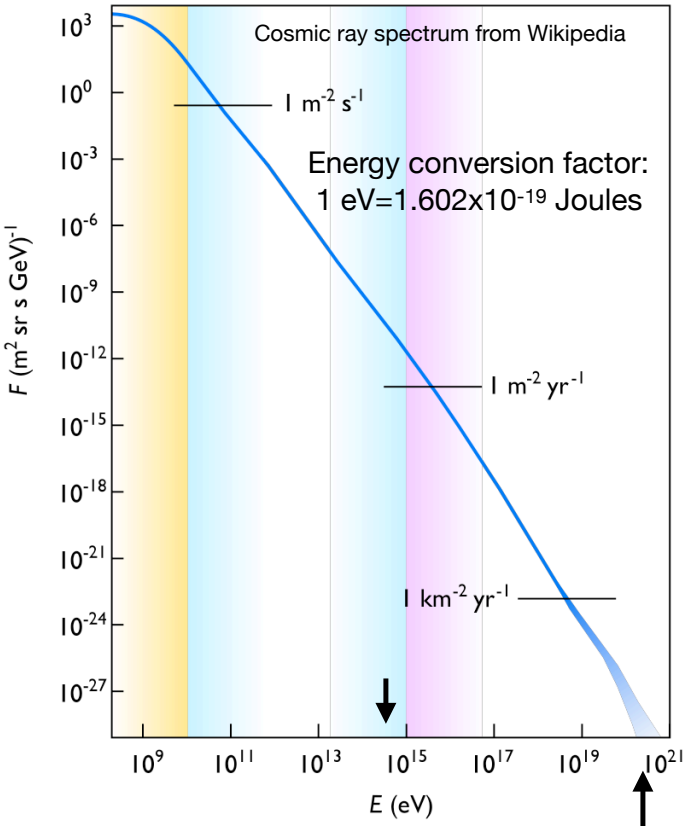


2. Acceleration continued
   - If the proton hits a magnetic field moving towards it, it will reflect with more speed, more kinetic energy.
   - If the reflected proton hits another magnetic field moving towards it, it will reflect AGAIN with even MORE speed, more kinetic energy.
   - This process repeats many times…



(This is called "Fermi Acceleration")

2. Acceleration continued
   - This process makes many “low” energy protons, some “medium” energy protons and a few “high” energy protons.
3. Impact
   - Protons hit nuclei of nitrogen, oxygen, hydrogen in the upper atmosphere

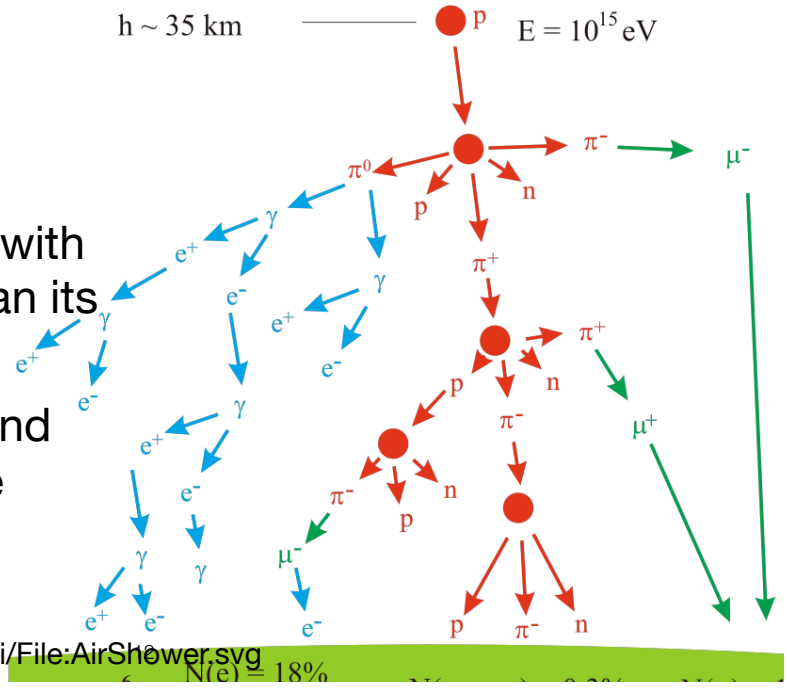


KE of flying mosquito=0.00013 J = 7.0x10^{14} eV

Kinetic energy of 60 mph baseball=52.9 J = 3.3x10^{20} eV

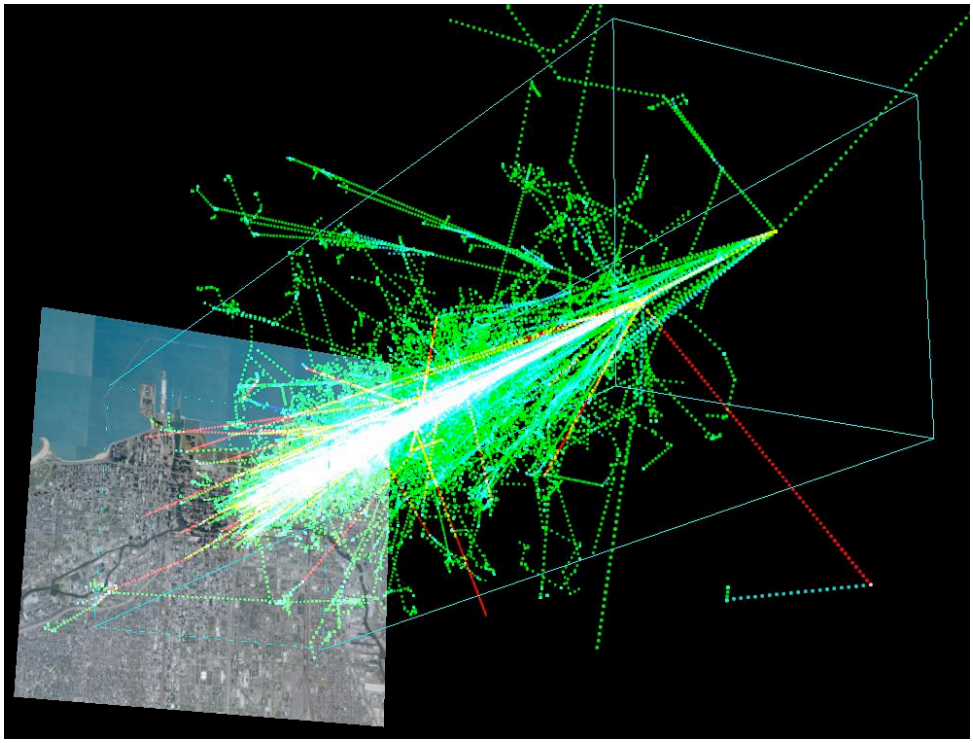
By Sven Lafebre - own work, after Swordy[1] and De Angelis[2], CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=1555202

4. Secondary particles
   - Recall that mass can become energy: $E=mc^2$.
   - The opposite happens too, energy becomes mass: $m=E/c^2$
   - The proton’s huge kinetic energy is converted to all possible particles with total mass less than its energy/c^2.
   - Many pions (π^-) and anti-pions (π^+) are made.



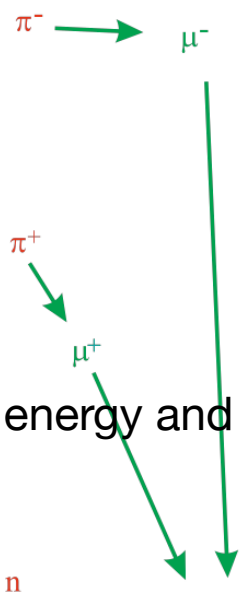
https://commons.wikimedia.org/wiki/File:AirShower.svg

More realistic picture of the proton causing a shower of all possible particles within E/c^2



Original uploader was Dinoj at en.wikipedia - Transferred from en.wikipedia, CC BY 2.5, https://commons.wikimedia.org/w/index.php?curid=3954715

4. Secondary particles continued
   - Pions, π^- and π^+ are very unstable and disintegrate quickly. In physics we say they "decay" quickly.
   - π^- decays into a muon (μ^-) and an muon antineutrino
   - $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$ (The bar means "anti")



5. Penetrating Griffith Observatory
   - The muons (the μ^- and μ^+) have a lot of energy and are traveling close to the speed of light.

5. Penetrating Griffith Observatory continued
   - Muons, μ^-, behave just like electrons (e^-), but the μ^- are 207 times more massive.
   - (Did you know? Physicists make "muonic hydrogen". Normal H is a proton with an e^- orbiting around it while muonic hydrogen is a proton with a μ^- orbiting it.)
   - At this point the μ^- is traveling at close to the speed of light and it has enough energy to plow down through the atmosphere, through the concrete of the roof and floors, through the spark chamber and far into the ground below.

6. Cosmic ray's death
   - The muon slows due to "friction" from the electrons in the rock. It nearly stops.
   - Unlike electrons which live forever, μ^- decay after only 2.2 microseconds. (0.0000022 seconds).

6. Cosmic ray's death continued

- The decay reaction is $\mu^- \rightarrow e^- + \nu_\mu + \bar{\nu}_e$
- The reaction reads as follows: muon "goes to" electron and a muon neutrino and an electron antineutrino. Poof.
- The neutrinos keep going through the ground, out the opposite side of the Earth and leave the solar system.
- The electron stops and is "absorbed" by the rock.

What about the π^+?

- You might have noticed that after the cosmic ray proton hit the upper atmosphere, it could make π^+ particles. These are the anti-matter version of π^-.
- Similar processes follow:
- $\pi^+ \rightarrow \mu^+ + \nu_\mu$ The anti-pion makes an anti-muon and a muon neutrino.
- The μ^+ plows down through the observatory just like the μ^- did and stops and decays.
- $\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$ We say the anti-muon "goes to" an anti-electron, a muon anti-neutrino and an electron neutrino.

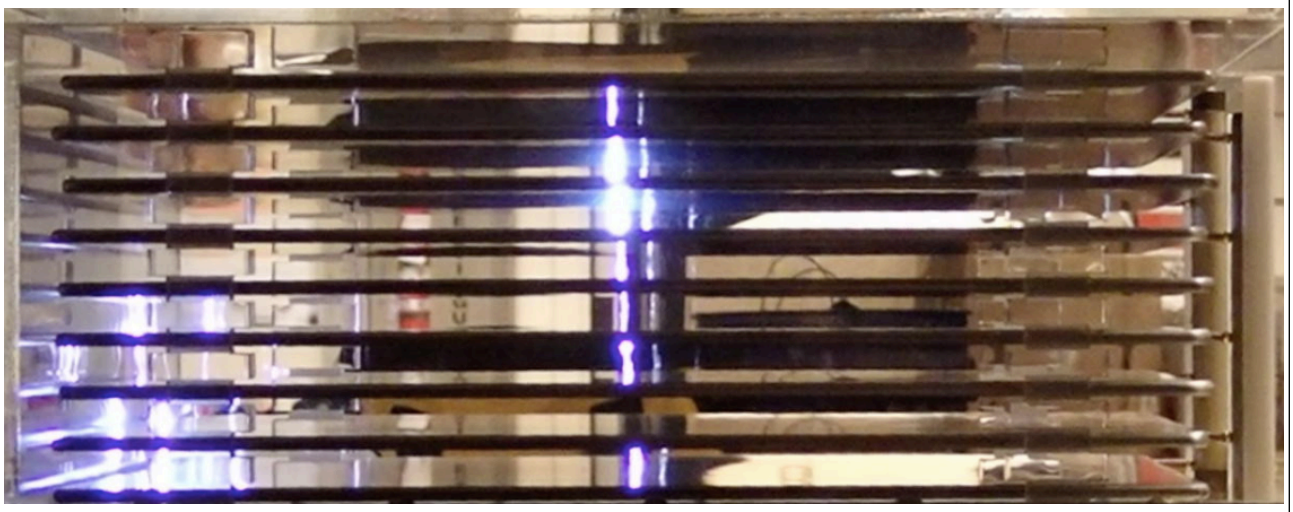
What about the π^+? continued

- The anti-electron meets a normal electron and they annihilate each other. Poof. $e^+ + e^- \rightarrow \gamma + \gamma$
- Lastly the high energy photons (the γ rays) are absorbed by the rock. Their energy causes a slight increase in temperature.
- The end (of the cosmic ray).

- But wait! What about the neutrinos?

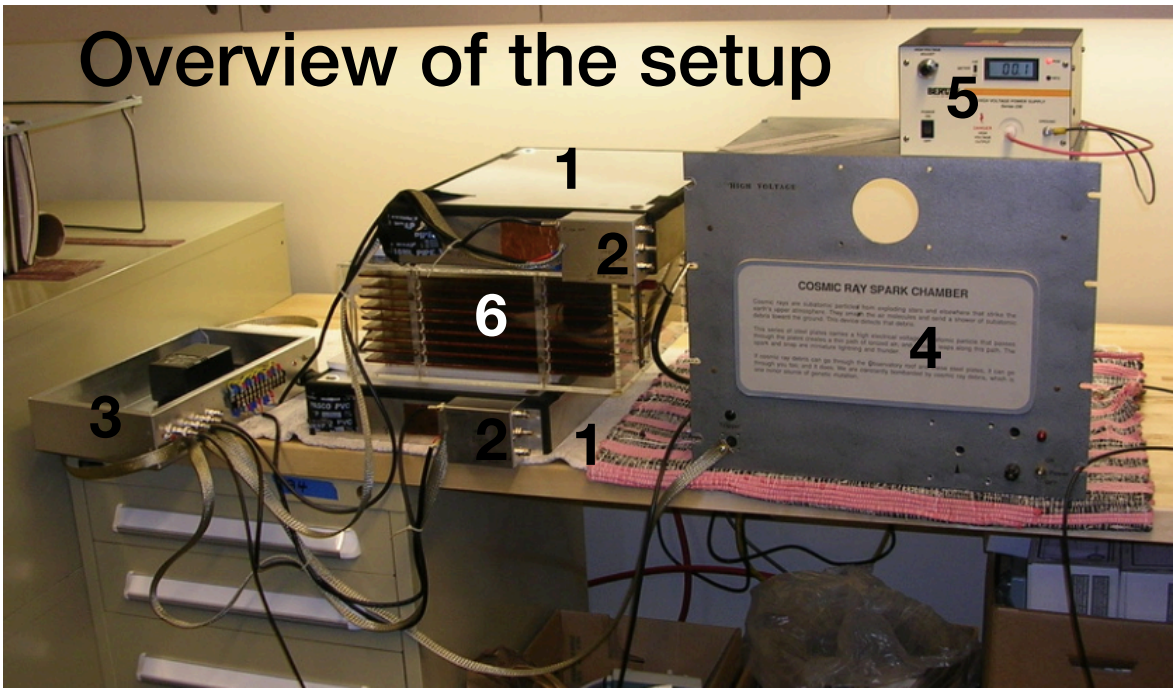
The zap!

- Meanwhile, back at the spark chamber, we see a series of sparks.



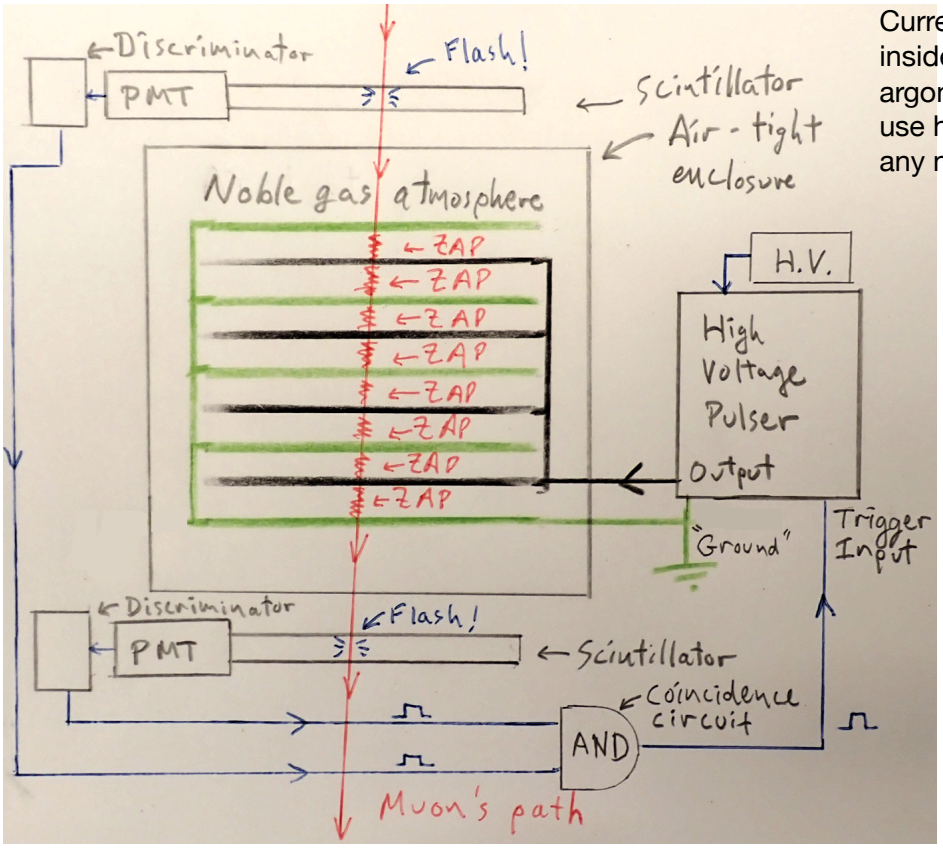
- How does it work?

Overview of the setup



1: Scintillator and PMT assemblies. (They sense the muon.)
2: Discriminator
3: Coincidence circuit
4: High voltage pulse generator
5: High voltage power supply (for the pulse generator)
6: Stack of aluminum plates. The sparks happen between the plates.

Overview of the setup, diagram



Currently the gas inside the chamber is argon. But we could use helium or neon or any noble gas.

From muon to zap

1. The muon makes a flash of light in the two scintillators. One is above and one is below the stack of plates where the sparks will happen.
2. The scintillators are clear acrylic plastic (with a chemical added to make bigger flashes). The light goes down the plastic to the "PMT" at the end of each scintillator.
3. "PMT" means **p**hoto**m**ultiplier **t**ube. It's extremely sensitive and fast-responding. (Speed is important.) The PMTs make electrical pulses each time they detect a flash.

From muon to zap continued

4. Unfortunately we are surrounded by radioactivity (medium energy electrons, alpha particles) that ALSO makes flashes of light and pulses from the PMTs.
5. The discriminator is a circuit which ignores small flashes/pulses and only makes a pulse when a big flash/pulse occurs. Radioactivity mostly makes small pulses while muons make big pulses so it eliminates most radiation pulses.
6. The two discriminators send their pulses to a coincidence circuit which will make a pulse only if pulses arrive at BOTH inputs at the SAME TIME. This is a logical AND function. It helps eliminate pulses from radioactivity.

From muon to zap continued

7. The pulse from the coincidence (the AND) circuit goes to a high voltage pulser. Inside there is a big capacitor filled with electrical charge at 15000 volts.
8. The pulse from the coincidence triggers a special switch which dumps the charge into every other plate in the stack of aluminum plates - the black ones in my diagram.
9. Suddenly the “black” plates are at 15000 volts but the “green” plates stay at zero volts.
10. 15000 volts is too much for air to withstand and the electricity forces its way through the air creating sparks from the “black” to the “green” plates.

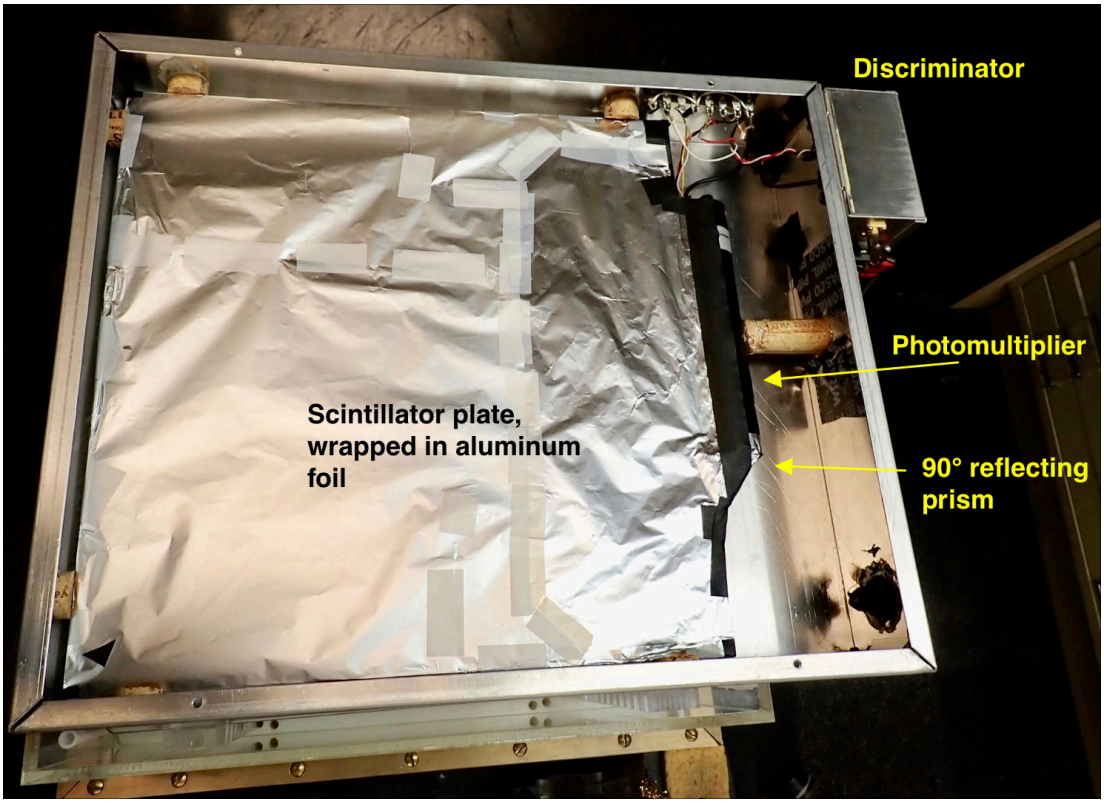
From muon to zap continued

11. When an electrically charged particle such as a muon passes through air it ionizes the air molecules. That means there is a “cloud” of negative electrons and positive gas atoms.
12. The air is conductive where the muon passed. The sparks occur here.
13. We see a series of sparks where the muon passed.

The challenge in making it work long-term.

- It's a museum. The displays need to last "forever".
- The biggest problem are:
  - The high voltage needed to spark across the 11.2 mm gap between the plates.
  - The requirement that the high voltage be delivered within ~500 nanoseconds of the muon traversal. Very fast switching.
- Either requirement is OK, but put together it becomes a tough electrical engineering problem for a "forever" device.

Scintillator, PMT and discriminator

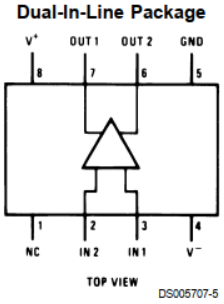


Scintillator plates: 13 inch x 13 inch x 1 inch thick. Doped with Bicron BC-408 to make bigger flashes from passing muons.

Photomultipliers: Sens-Tech P30CW5.

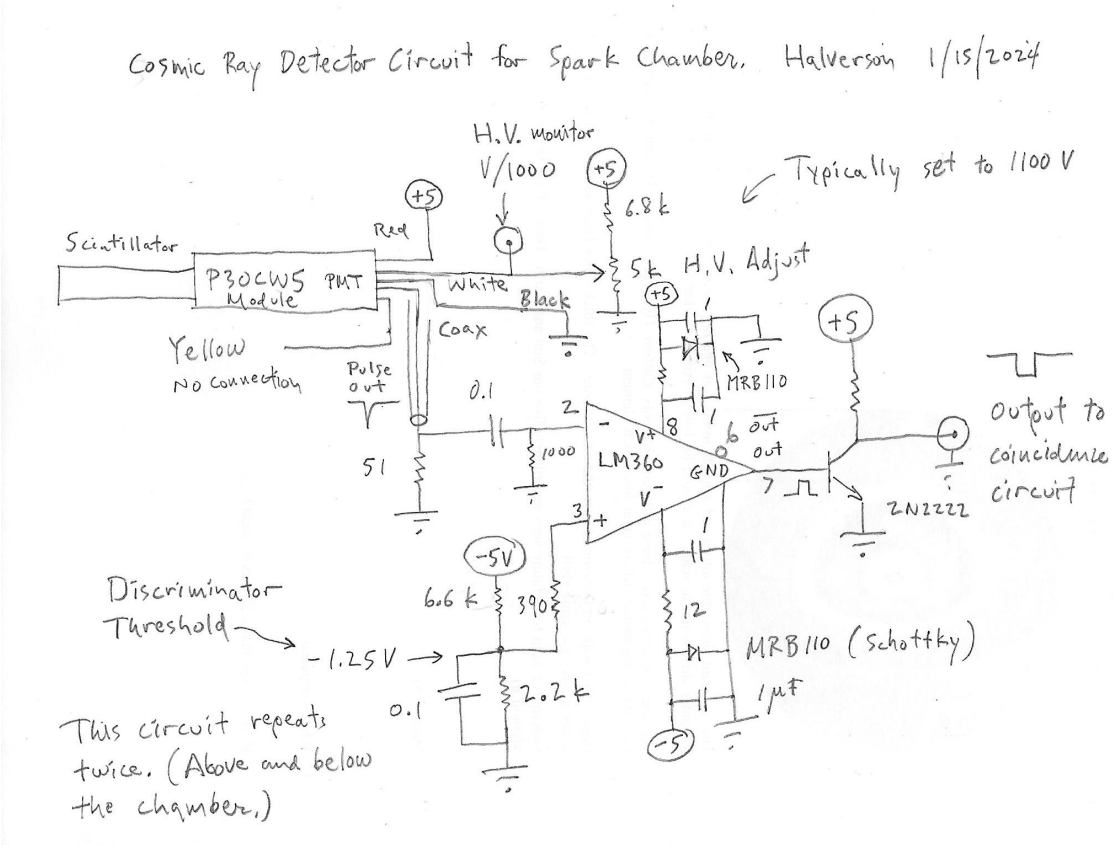
https://www.sens-tech.com/wp-content/uploads/2023/03/senstech-P30CW5-v1.pdf

Discriminator: LM360

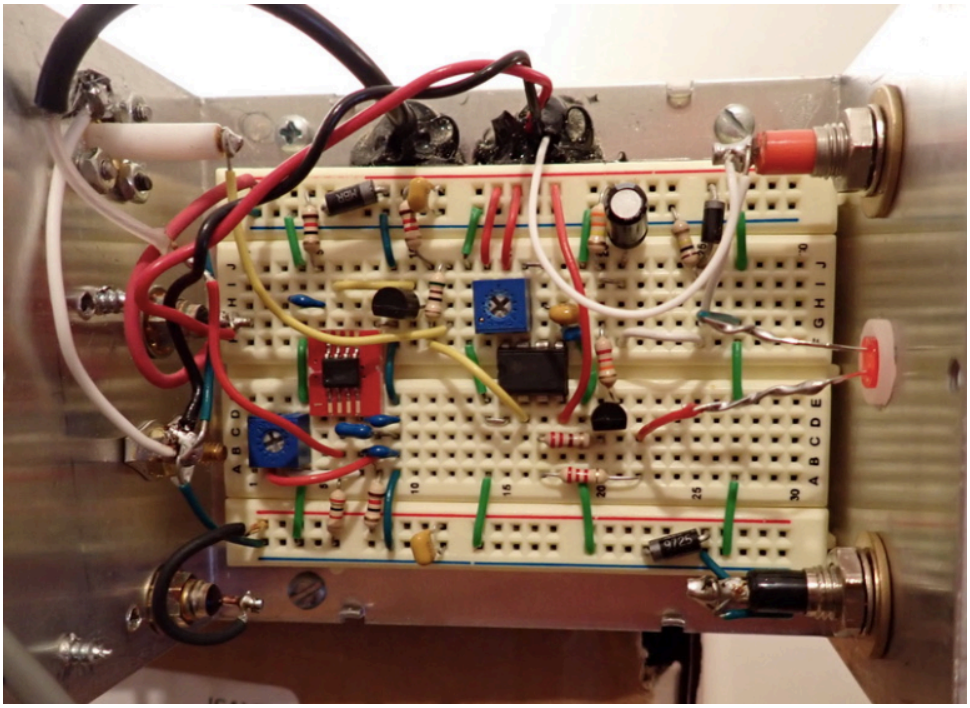


Order Number LM360M, LM360MX or LM360N
See NS Package Number M08A or N08E

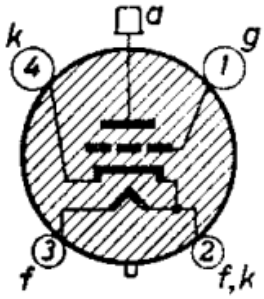
Discriminator circuit

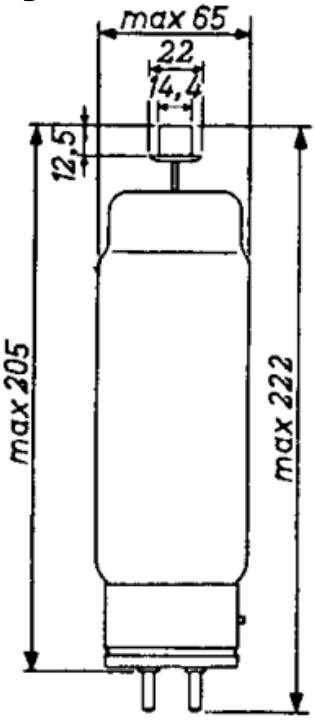


Discriminator construction (new self-adjusting version)



High voltage discharge switch: 5C22 Hydrogen thyratron tube.





Tube and HV storage capacitor