The Discovery and the Riddle of the Muon

Zaid Alawi

Physics 363

April 25, 2008

Review of Cloud Chambers

- Charged particles ionize supersaturated water vapor
- Ions become nuclei for condensation
- Path of charged particle thus becomes clear
- Vertical magnetic field used to measure momentum
- Lorentz Force: $\mathbf{F} = q\,(\mathbf{E} + \mathbf{v} \times \mathbf{B})$
- Radius of curvature indicates momentum for a given charged particle: The bigger the radius, the larger the momentum.
- Ionization density inversely related to velocity-squared
- For a given velocity, mass can then be determined

Carl D. Anderson

- Caltech Physicist
- Previous cloud chamber experience: Discovered positron in 1932 while under Millikan
- Nobel Prize in 1936
  (31 years old!)
- Worked with his first graduate student, Seth Neddermeyer, to examine cosmic rays

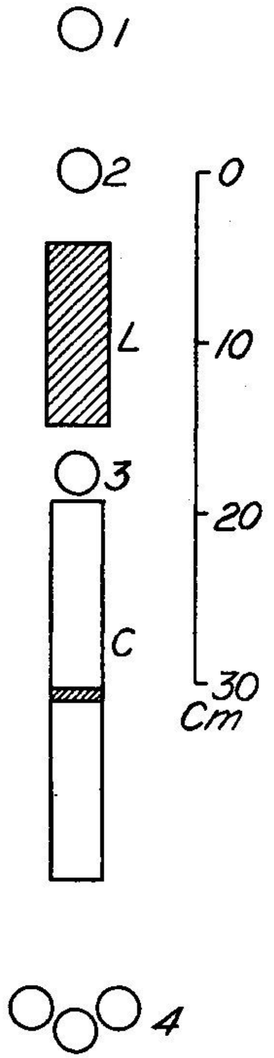
Anderson

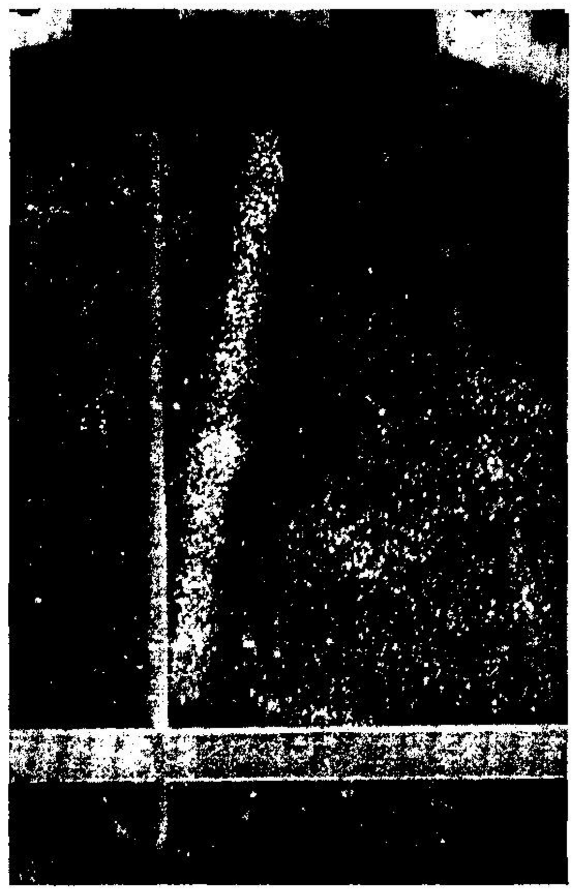
Neddermeyer

The First Experiment - 1936

- Pike’s Peak, Colorado. Altitude: 14,000 ft
- Higher altitude meant more cosmic rays (less time for incoming particles to decay or interact)
- Significant practical difficulties to overcome – moving the apparatus to such a high altitude!
- Financial difficulties – 1936 was in the heart of the Great Depression
- Discovered a negatively charged particle with mass between that of an electron and a proton

Street and Stevenson's Confirmation





Proton

"approximately 130 times the rest mass of the proton"

Yukawa's Pion

- 1935: Theory of mesons
- Attempts to explain interaction of neutrons and protons
- Predicted "pions" as carriers of strong nuclear force
- Pion mass = 100 MeV, based on the range of the strong force (based, in turn, on the nuclear radius)
- Only published in Japanese – brought to the attention of others by Oppenheimer and Serber

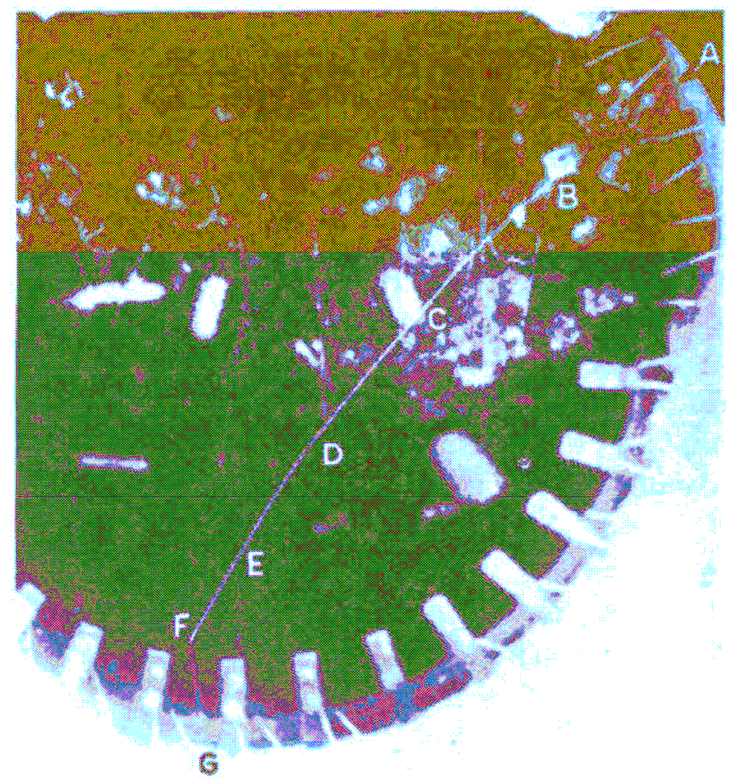
Hideki Yukawa, 1949

Naming the Particle

- "It was called the Yukon for Yukawa; it was called the X-particle; it was called a heavy electron, which turns out was not a bad name, because that's what it really is; it was called a baryon, and so on."
- Named the particle "mesoton," where "meso-" was Greek for "intermediate." Inspired by "mezzanine."
- Millikan was unhappy about this – cabled *Nature* to insist on adding an "r" to "tron," forming "mesotron."
- Eventually would be called "mu meson," followed by "muon."

Further Measurements

- 1937: Yoshio Nishina shows little Pb interaction/showers with mesotrons
- 1939: Bruno Rossi (in Ryerson) compares the absorption of mesotrons in air to that of carbon.
  - Mean decay length in atmosphere: 9.5 km.
  - $t = m L / p$
  - Mean lifetime: 2×10^{-6} (contrast with strong-force required lifetime of order 10^{-8} seconds)
  - Mass of mesotron: 80 MeV
- 1940: Roberts and Williams see mesotron decay to electron
- More measurements of mass: Between 80 and 106 MeV
- More measurements of lifetime: 1.5×10^{-6} seconds (Rasetti, 1941), 2.15×10^{-6} seconds (Rossi)



Tomonaga and Araki's Proposal (1940)

TABLE I. *Capture probabilities along the path.*

	$E=10^8$	10^7	10^6	10^5 (VOLTS)	SIGN OF THE MESON
Pb	0.001	2×10^{-6}	5×10^{-15}	7×10^{-39}	+
	0.1	0.01	10^{-3}	10^{-4}	−
Al	0.017	6×10^{-4}	3×10^{-6}	4×10^{-11}	+
	0.032	2×10^{-3}	2×10^{-4}	2×10^{-5}	−
Air	0.013	5×10^{-4}	6×10^{-6}	6×10^{-9}	+
	0.019	10^{-3}	6×10^{-5}	6×10^{-6}	−

TABLE II. *Capture probabilities per sec. for negative and positive mesons.*

	NEGATIVE MESONS	POSITIVE MESONS
Pb	2.5×10^{12}	—
Al	1.2×10^{11}	—
Air	3×10^{7}	10^{-950}

- If they interacted via the strong force, then negative mesotrons brought to rest would interact, rather than decay, when close to a nucleus, thanks to Coulomb attraction
- The opposite is true for positive mesotrons: The Coulomb repulsion would cause a higher decay/interaction ratio.

Conversi, Pancini, and Piccioni

- Selected positve and negative stopping mesotrons in 1945-1947
- Negative mesotrons did not decay when stopped in iron
- Both negative AND positive mesotrons decayed when stopped in carbon

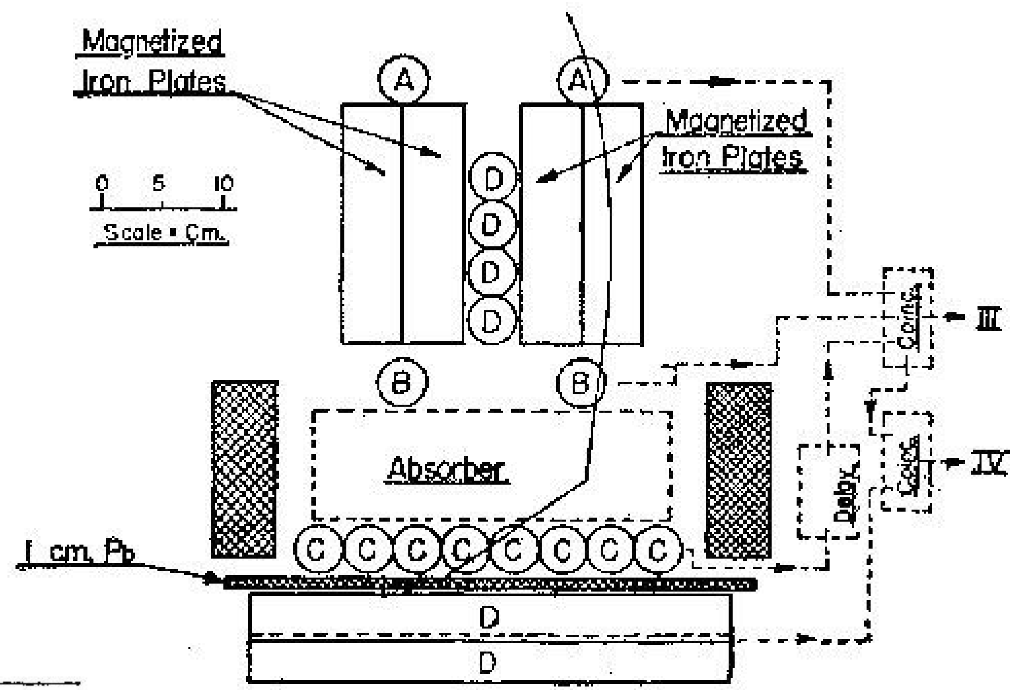


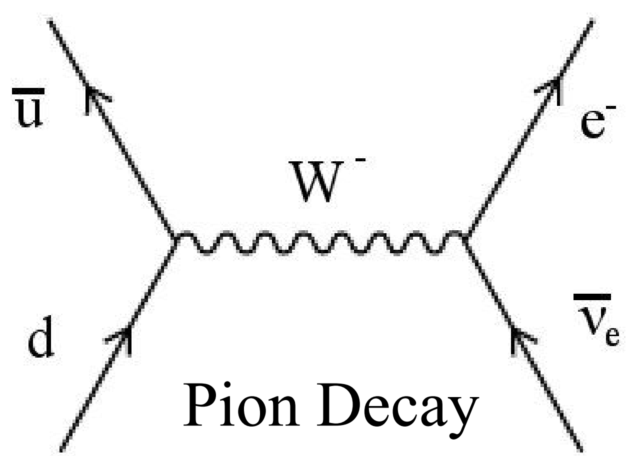
TABLE I. Results of measurements on β-decay rates for positive and negative mesons.

Sign	Absorber	III	IV	Hours	M/100 hours
(a) +	5 cm Fe	213	106	155.00′	67 ±6.5
(b) −	5 cm Fe	172	158	206.00′	3
(c) −	none	71	69	107.45′	−1
(d) +	4 cm C	170	101	179.20′	36 ±4.5
(e) −	4 cm C+5 cm Fe	218	146	243.00′	27 ±3.5
(f) −	6.2 cm Fe	128	120	240.00′	0

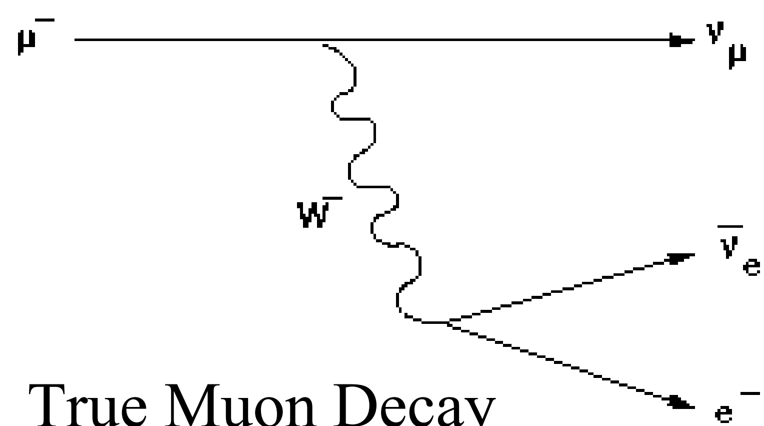
Fermi, Teller, and Weisskopf: Implies time of capture is 10^{12} times longer than a strongly-interacting particle

More Fundamental than Mesons

- The “mesotron” decayed differently than other mesons
- Meson decay products include one neutrino or anti-neutrino
- “Mesotron” decay products include both a neutrino AND an anti-neutrino



Pion Decay



True Muon Decay

Grand Opening of the "Zoo"

- Nobody expected more fundamental leptons
- I. I. Rabi: "Who ordered *that?*"
- Symbolic of the beginning of the particle physics "Zoo"
- Willis Lamb: "I have heard it said that 'the finder of a new elementary particle used to be rewarded by a Nobel Prize, but such a discovery now ought to be punished by a $10,000 fine.'" (Opening to 1955 Nobel Lecture). Should we have fined Anderson?
- Eventually, the crisis is resolved by the Standard Model

Image Credits

- http://nobelprize.org/nobel_prizes/physics/laureates/1949/yukawa-bio.html
- http://www.lanl.gov/history/road/oversight.shtml
- http://dbserv.ihep.su/~elan/src/street37b/eng.pdf
- http://www.nature.com/nature/journal/v145/n3664/pdf/145102a0.pdf
- http://nobelprize.org/nobel_prizes/physics/laureates/1936/anderson-bio.html
- http://prola.aps.org/pdf/PR/v58/i1/p90_2
- http://nemo.in2p3.fr/physics/images/MuonDecayFeynman.png
- http://prola.aps.org/pdf/PR/v71/i3/p209_1