Quarknet Summer 2014: The End

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Morning Schedule

Monday Jul 28		
9:00	Jeremy Smith	"Introduction to Particle Physics"
10:00	Petar Maksimovic	"More Particle Physics"
11:00	Morris Swartz	"Afternoon activity: intro to photoelectric effect, diodes"
Tuesday Jul 29		
9:00	Film (DE Kaplan)	"Particle Fever"
11:00	Jared Kaplan	"Particle Theory"
Wednesday Jul 30		
9:00	Marc Kamionkowsi	"CMB Present results/theory"
10:00	Tom Essinger-Hilemar	"CLASS/CMB polarization"
11:00	Andrei Gritsan	"Higgs Physics"
Thursday Jul 31		
9:00	Kevin Martz	"What I did on my summer vacation at CERN"
10:00	Robert Leheny	"JHU First Results from Active Learning in Physics"
11:00	Julian Krolik	"Black Holes"
Friday Aug 1		
9:00	Bill Blair	"Climate Change"
10:00	Alice Sady	"Diversity in Physics: the problem and what to do"
11:00	Morris Swartz	"Questions from the week, Quarknet 2015: Masterclass, Physics Fair, Sun

Experiments

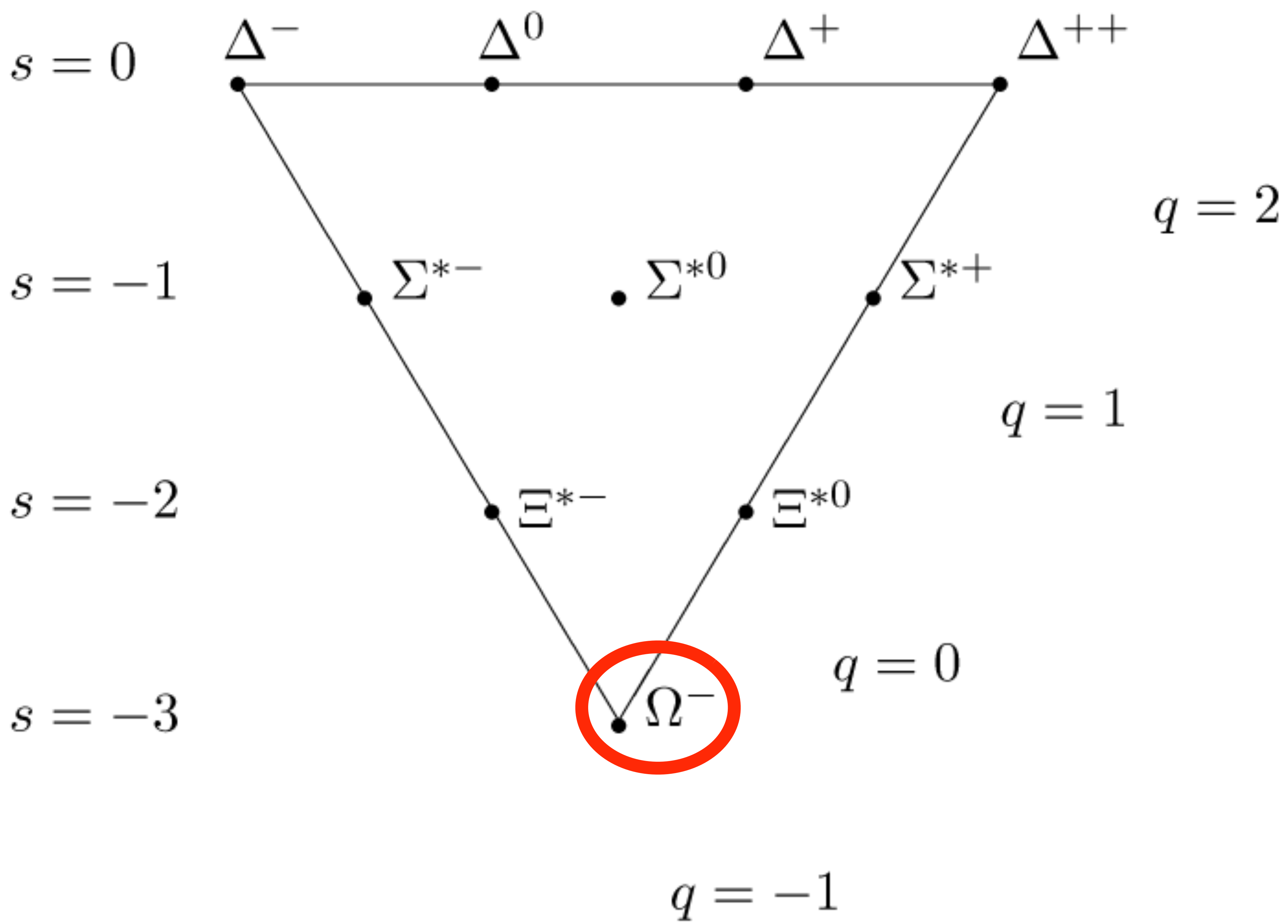
How do we find new things:

- most of the time, we need to know what we are looking for
  - need to design experiment to optimize the signal/backgrounds
  - need to measure/calculate backgrounds
- sometimes, unexpected new things happen and are so spectacular, that we see and correctly interpret the results

Here are some examples from several experiments done at Brookhaven National Lab

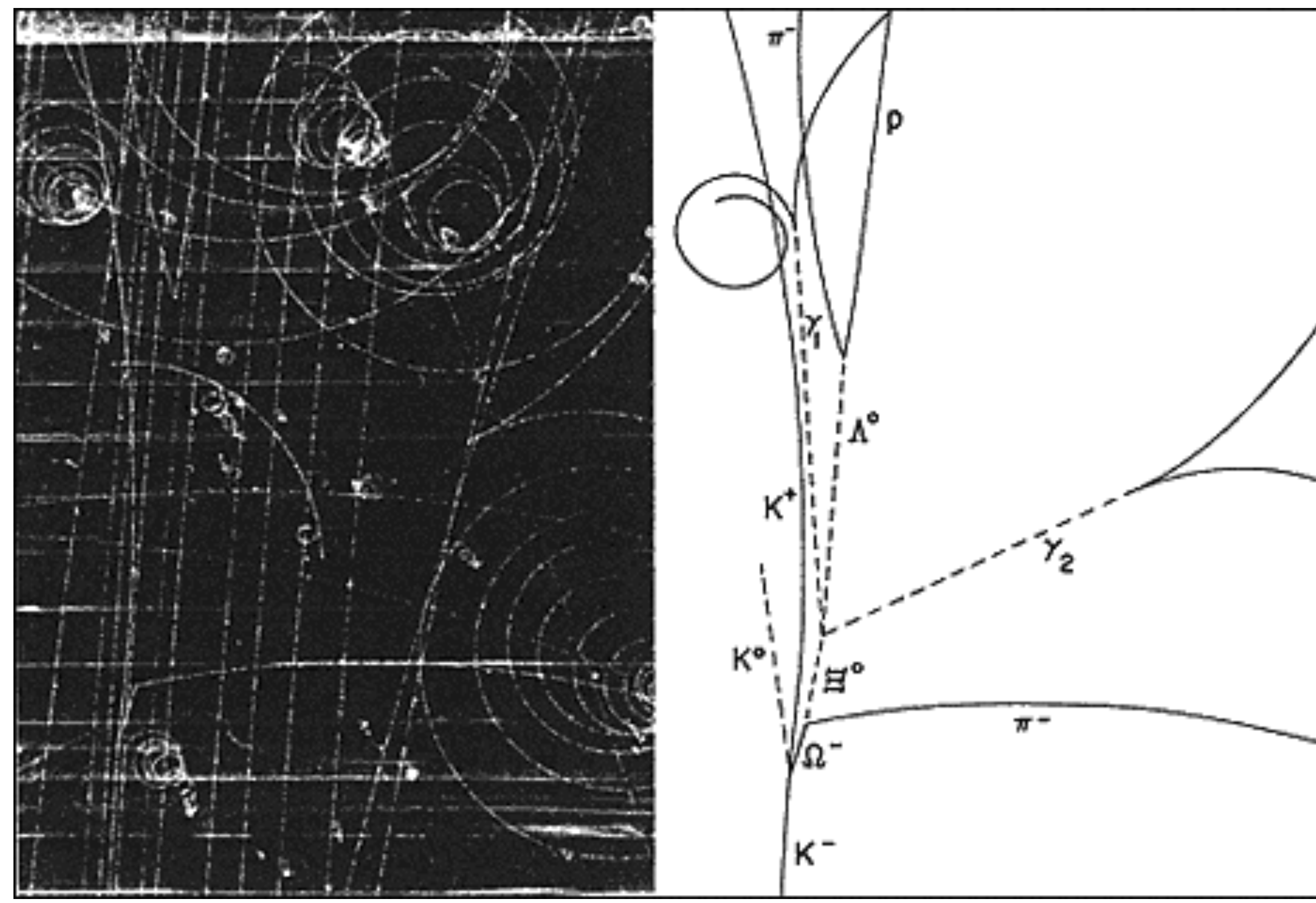
The Omega Minus: a predicted state

In the early 1960s, Gell-Mann and Neeman invented a (quark-based) classification scheme for the many strongly interacting particles that had been discovered in the previous 15 years. It also predicted that a new spin 3/2 baryon made of three s-quarks, Ω^-, should exist.



In 1964, it was observed in a bubble chamber by Samios et al:

- single event $K^- p \rightarrow K^0 K^+ \Omega^-$
  - strangeness -1 initial state (-1+0) is conserved in final state (+1+1-3)
- decay chain $\Omega^- \rightarrow \Xi^0 \pi^-$
  - $\hookrightarrow \Lambda^0 \pi^0$
    - $\pi^0 \rightarrow \gamma\gamma$
    - $\Lambda^0 \rightarrow p\pi^-$
  - completely unambiguous
- only single event discovery in history of particle physics!
- confirmed SU(3) quark model



Requires existence of color to avoid violating Pauli Exclusion Principle!

CP Violation: who ordered that?

In 1963, Cronin and Fitch were studying the regeneration of neutral K_1^0. There are two CP eigenstates of neutral Ks (analogous to the two circular polarizations of photons):

$$K_1^0 = \frac{1}{\sqrt{2}}\left[K^0 + \bar{K}^0\right] \quad \mathrm{CP} = +1$$

$$K_2^0 = \frac{1}{\sqrt{2}}\left[K^0 - \bar{K}^0\right] \quad \mathrm{CP} = -1$$

Conservation of CP requires that these states decay differently:

$$K_1^0 \to \pi^+\pi^- \; [\mathrm{CP} = +1] \text{ short lived } (0.9 \times 10^{-10}\mathrm{s})$$

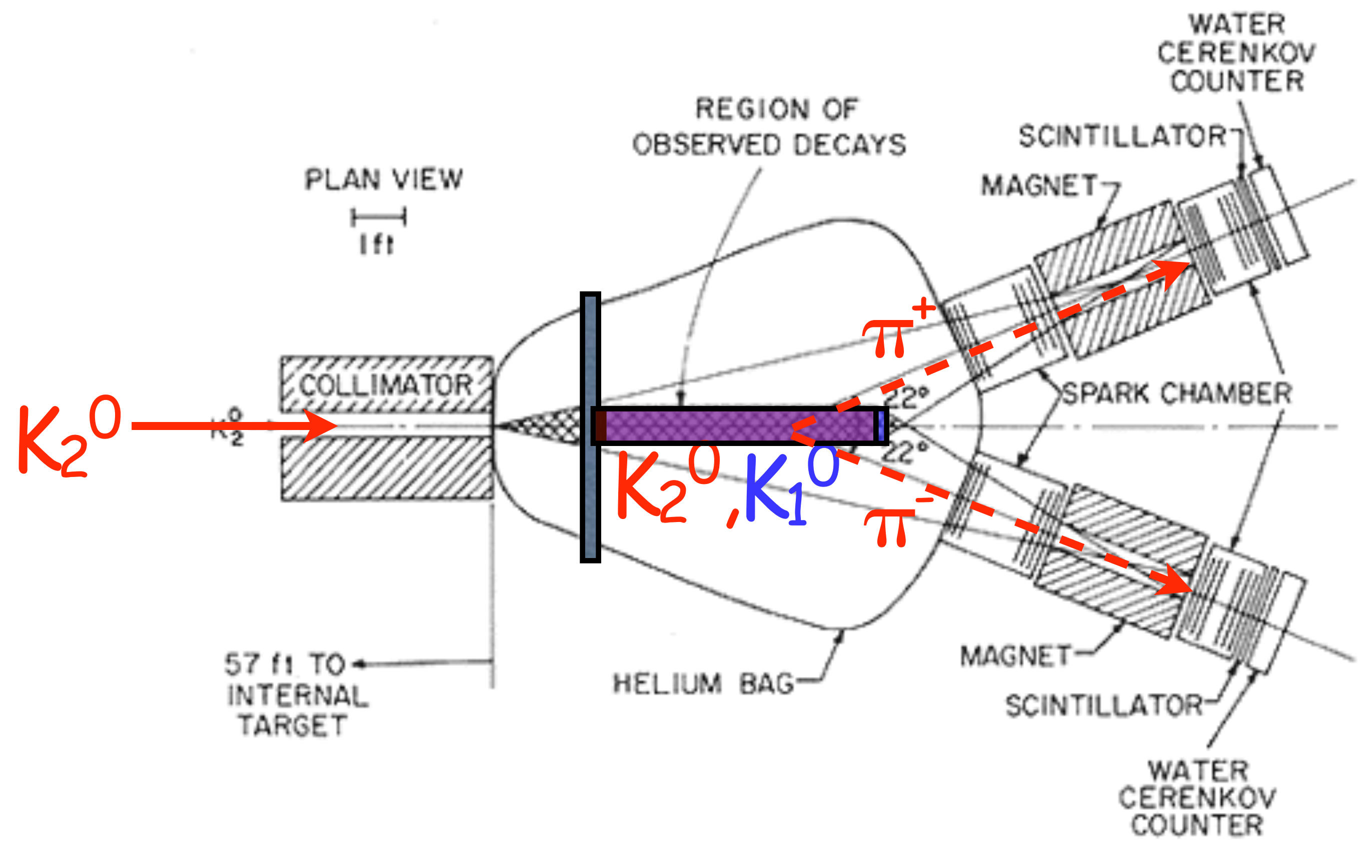
$$K_2^0 \to \pi^+\pi^-\pi^0 \; [\mathrm{CP} = -1] \text{ long lived } (0.5 \times 10^{-7}\mathrm{s})$$

Regeneration occurs when a pure K_2^0 beam passes through matter

$$K_2^0 \to \psi = \frac{1}{\sqrt{2}}\left[aK^0 - b\bar{K}^0\right] = \frac{a-b}{2}K_1^0 + \frac{a+b}{2}K_2^0$$

Because $a \neq b$ we make new K_1^0 states when beam passes through matter (analogous to passing photons through a birefringent crystal).

They used a K_2^0 beam impinging on a regenerator to measure the rate of K_1^0 production by searching for the $\pi^+\pi^-$ decays in a 2-arm spectrometer.



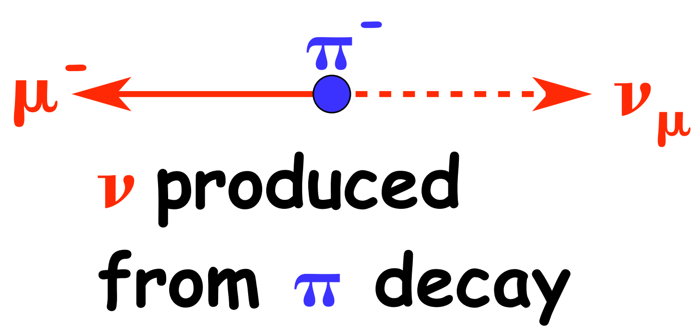
Then, like good experimenters, they removed the regenerator to measure the $\pi^+\pi^-$ backgrounds ....

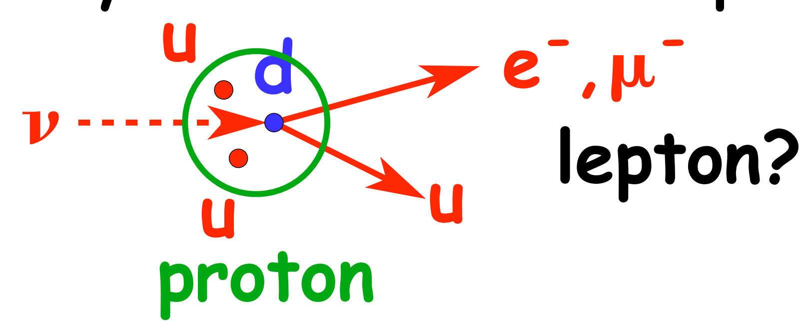
THEY STILL SAW $\pi^+\pi^-$ FINAL STATES!

- They had discovered the CP Violating Decay $K_2^0 \rightarrow \pi^+\pi^-$
  - great resistance in HEP community: the W fly was proposed
  - took theorists more than 20 years to understand it
- Cronin + Fitch win the 1980 Nobel Prize!

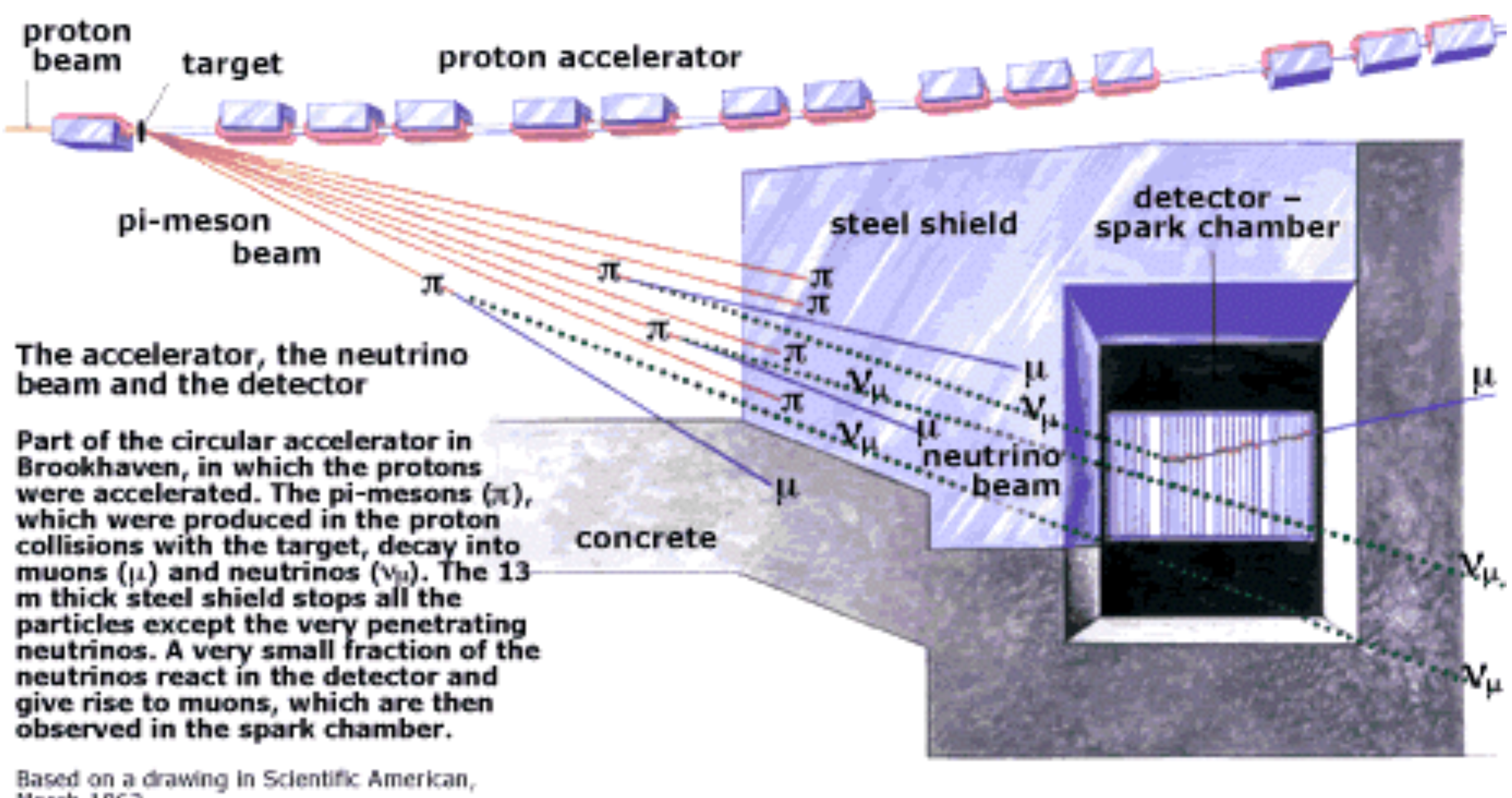
Muon Neutrino: a little of both

In 1962, Lederman, Schwartz, and Steinberger did an experiment to determine if neutrinos came in flavors. They made neutrinos from the decays of pions which decay mostly into muons. If the muon were associated with its own neutrino, then those same neutrinos should preferentially produce muons when they interacted with protons/neutrons,

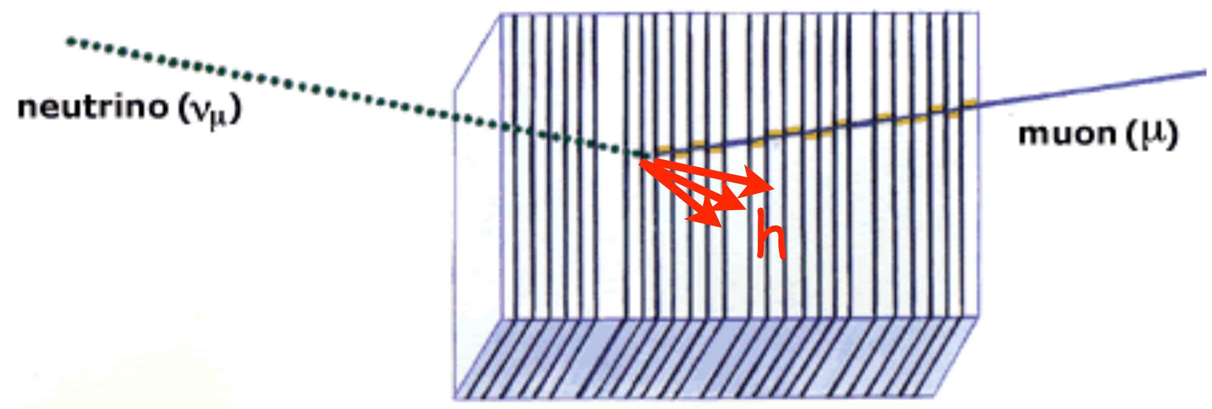




If all neutrinos are the same, then they should see both e^- and μ^-!



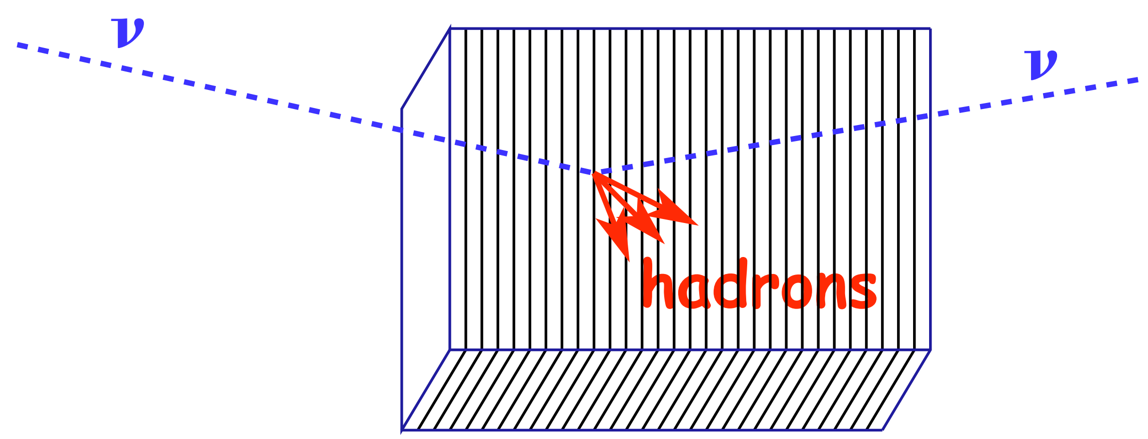
They saw 51 events with muons coming out:



A muon produced in a neutrino reaction gives rise to discharges observed in the spark chamber.

They saw zero events with an electron: there are 2 kinds of neutrino!

But, they also saw 7-8 events with no muon and no electron in the final state:



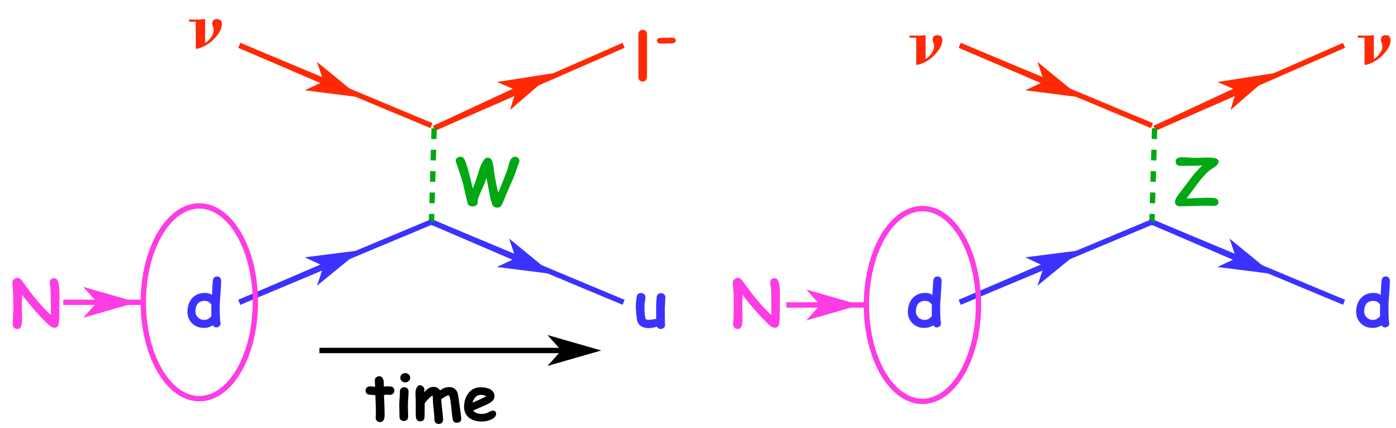
- They had no idea what these could be:
  - label them as "crappers" and ignore them
- Lederman, Schwartz, and Steinberger win 1988 Nobel Prize

Six years later, a theoretical context to understand the "crappers" is developed.

Electroweak Standard Model

In 1968 and 1969, Weinberg and Salam independently developed a unified gauge theory of electromagnetic and weak interactions.

- massless gauge boson γ is the carrier of the electromagnetic force
- massive gauge boson W is the carrier of the weak force
  - mass limits range of force to $hc/(2\pi M_W)$
- predicts a new weak neutral force mediated by Z boson



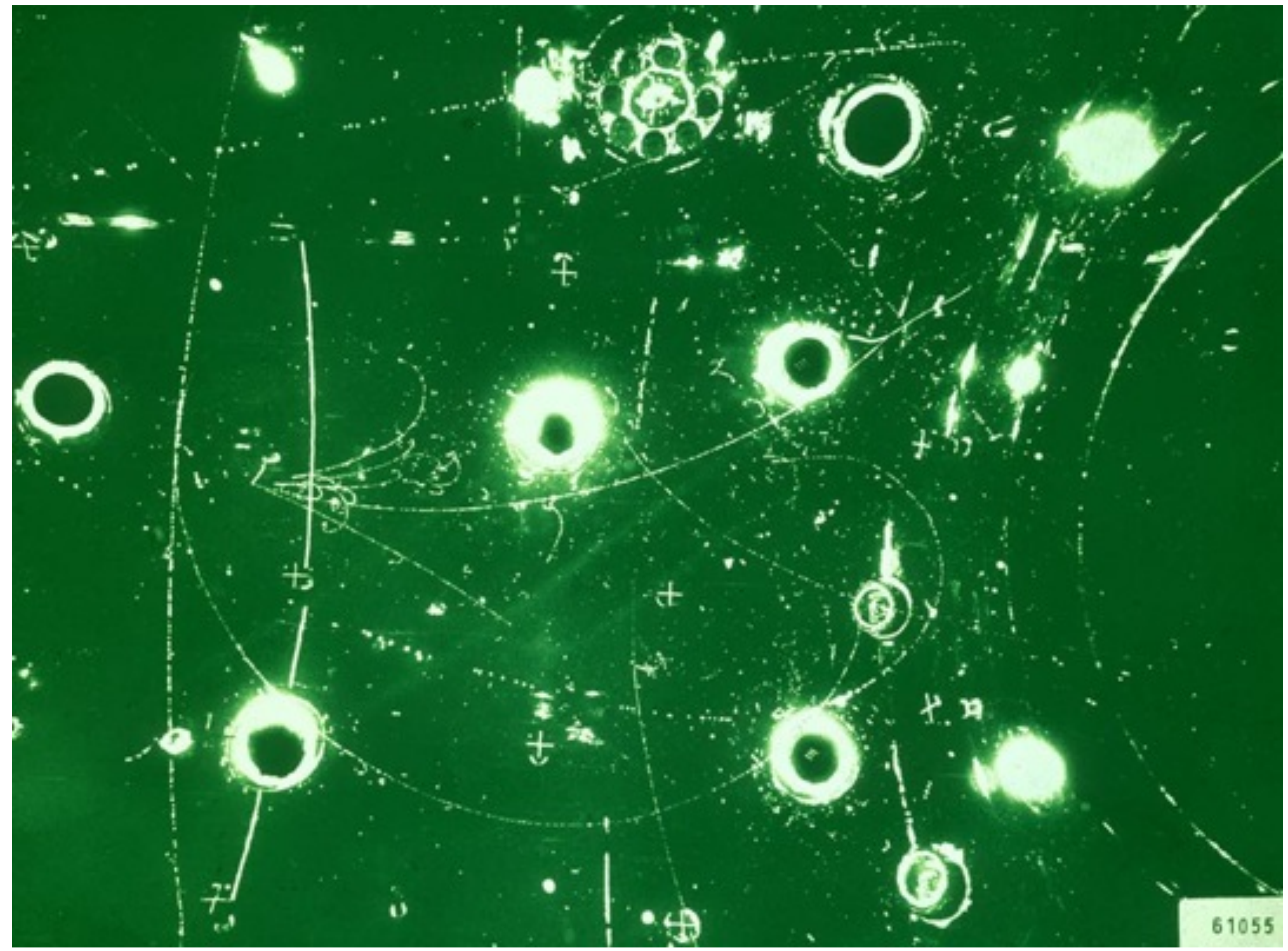
Theory is not immediately accepted because:

- not known to be renormalizable (later shown by Lee, Veltman, t'Huft)
- no weak neutral force observed in nature
- many competing theories ....

More Crappers

In 1973, a large heavy liquid bubble chamber Gargamelle at CERN saw more neutrino-induced events with no visible lepton in the final state

- must eliminate any backgrounds from neutrons entering the detector
  - not trivial
- A competing experiment at Fermilab, HPW, also saw evidence of neutral currents. They also had evidence against them (alternating neutral currents)



It turns out that 1/3 of all neutrino events are neutral currents, but they weren't seen until there was a context to understand them!!

PhotoElectric Things to investigate

- Is it important to mask the anode?
  - YES … Very important to avoid emission from the anode
- How do we handle the finite widths of the LED signals?
  - try a more monochromatic source of the same λ?
    - try a diode laser?
    - concern about damage to the photocathode?
- Superbright LEDs does not have spectra for the UV [or IR] diodes
  - let's measure these ourselves with Steve's spectrometer
  - new and correct 460nm diode arrives today
    - remember that it's really 440(peak)-445(avg)nm
- Is result stable under intensity variations?
- Compare our h results

Please thank Steve Wonnell for the HUGE amount of his time and effort in helping us this week!!!

Quarknet 2015

- MasterClass [March-April 2015]
  - Please let us know as early as possible: rough number of students is helpful
  - try "flipped" classroom this year? [have online "prelecture" activities]
- Physics Fair [April 2015]: we will ask for people to take charge of some activities
- Quarknet Summer Workshop [July 2015]: please suggest topics and activities