STRUCTURE OF MATTER

Discoveries and Mysteries

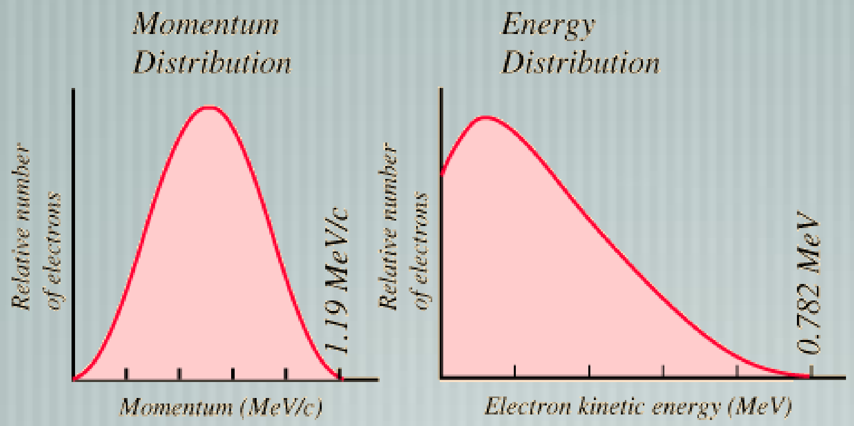
Part 2

Rolf Landua
CERN

The “Weak Interaction” - What is Radioactivity ?

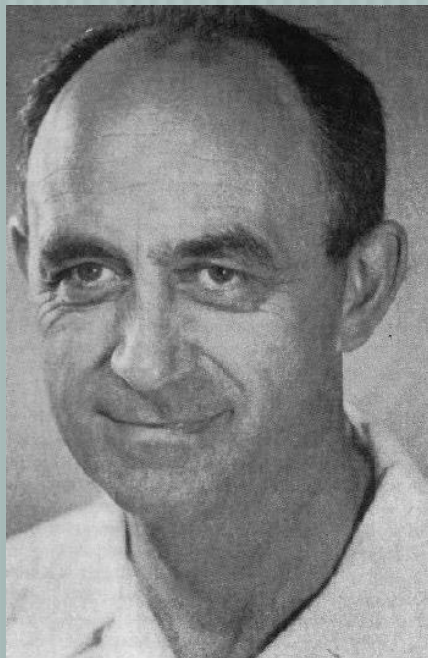
1911: Continuous (?) energy spectrum of ‘beta’-rays (electrons) - energy conservation?

Z --> (Z+1) + e ?

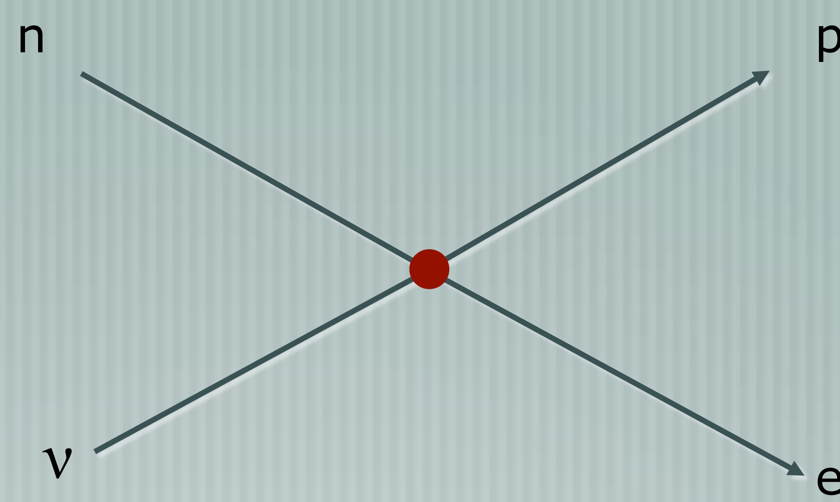


1930: Wolfgang Pauli postulates existence of ‘neutrino’: **n --> p + e + ν**

The model of Enrico Fermi : “pointlike interaction”



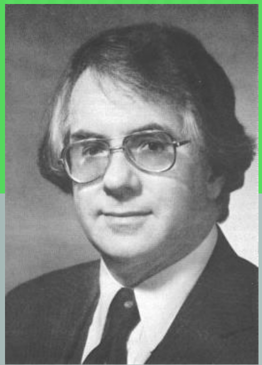
Enrico Fermi
(1934)



Proposed a **phenomenological** model of weak interaction

Point-like coupling with strength $G_F \sim 10^{-5}$ of e.m. interaction

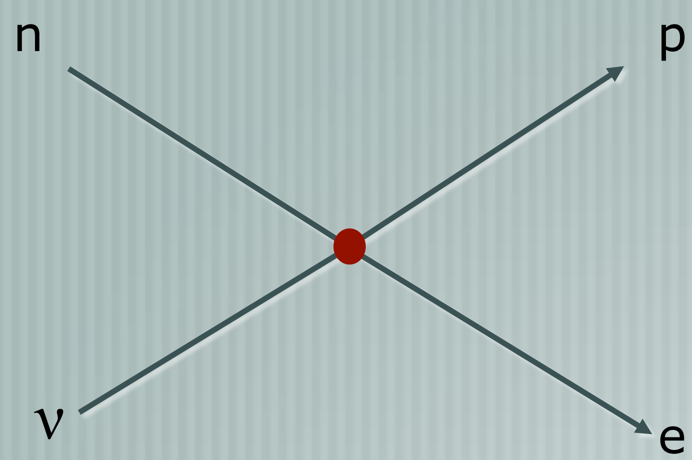
Coupling of two ‘currents’ (proton-neutron / electron-neutrino)



S. Glashow

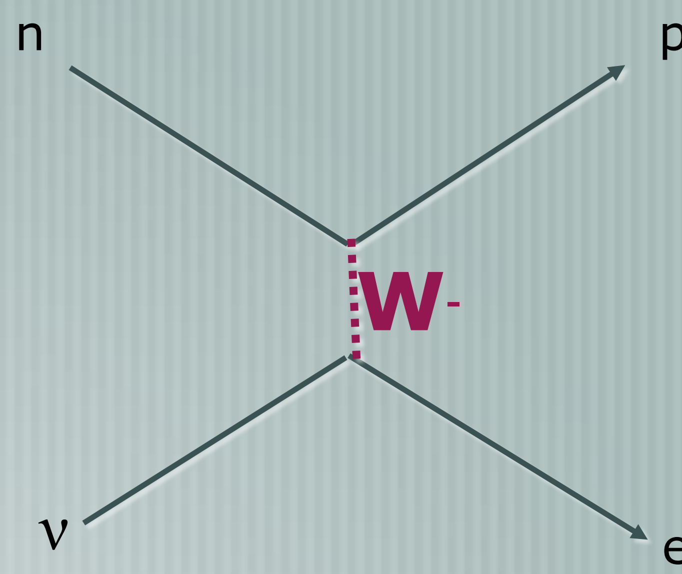
Fermi's model turned out to be inconsistent at E > 300 GeV

probability of this reaction > 100% (E > 300 GeV)



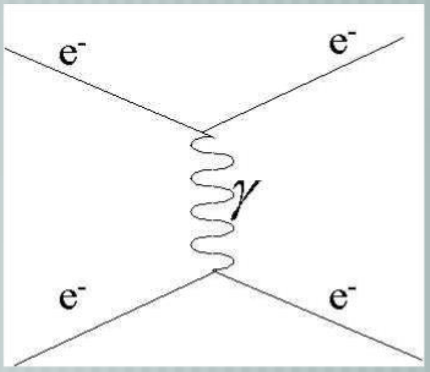
Fermi model

New Idea (1958)

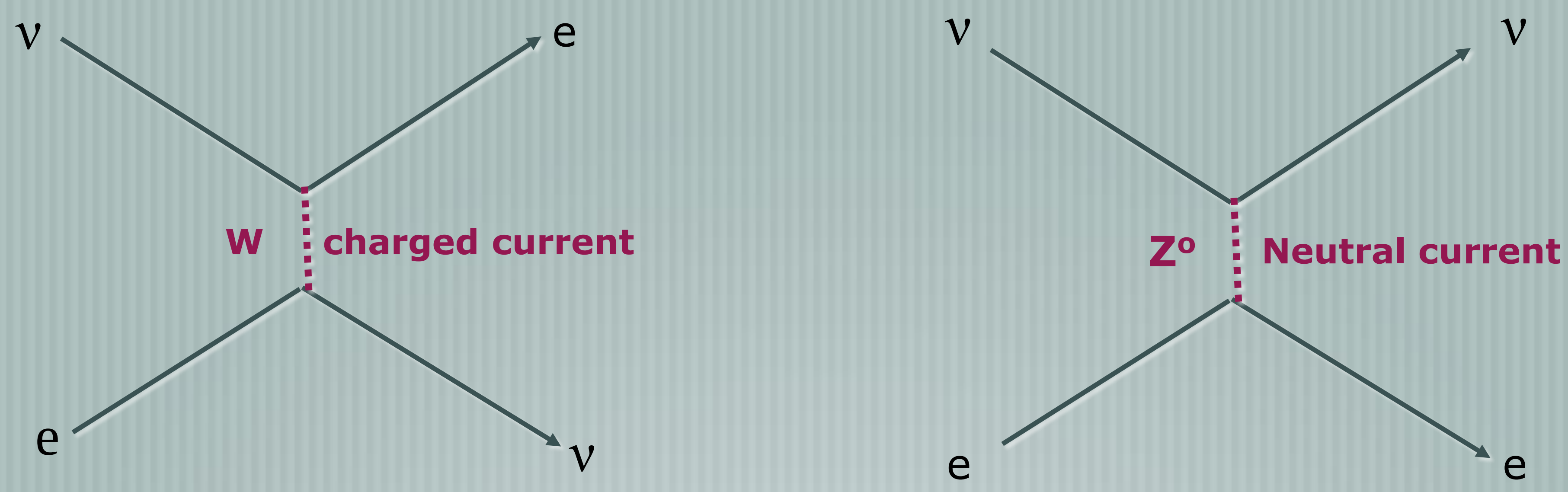


Weak interaction transmitted by massive vector bosons (in analogy to photon exchange!)

Large mass (80 GeV) explains short range ($2 \cdot 10^{-18}$ m) and small cross-sections



Unification of electromagnetic and weak interaction

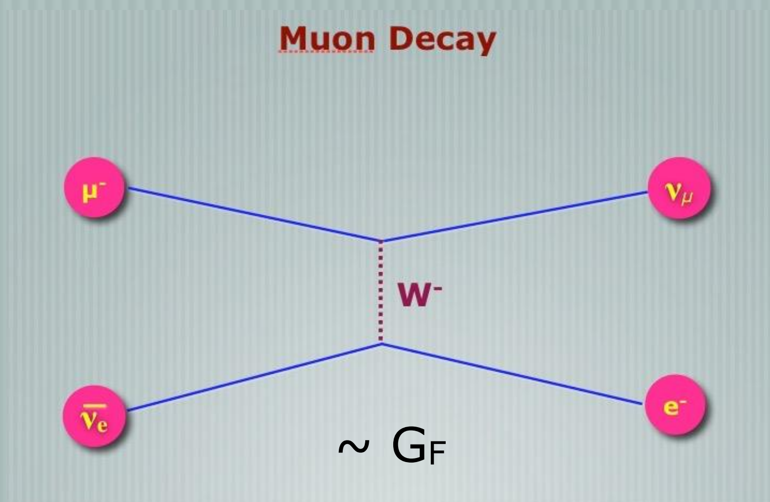


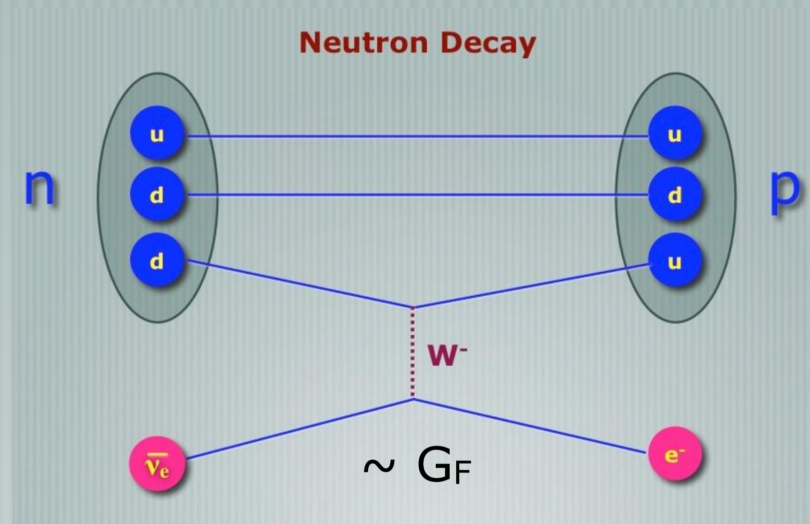
Glashow, Salam, Weinberg (1968) - Electroweak Force

- The electromagnetic and weak interaction are different aspects of the same 'electroweak' force
- All quarks and leptons have a 'weak' charge
- There should be a 'heavy photon' (Z^o) and two charged vector boson ($W^{\pm}$) of mass ~ 50-100 GeV
- **The W,Z bosons acquire their mass by interacting with the "Higgs field" (1964)**

Fields

Electroweak interaction is the SAME for leptons and quarks





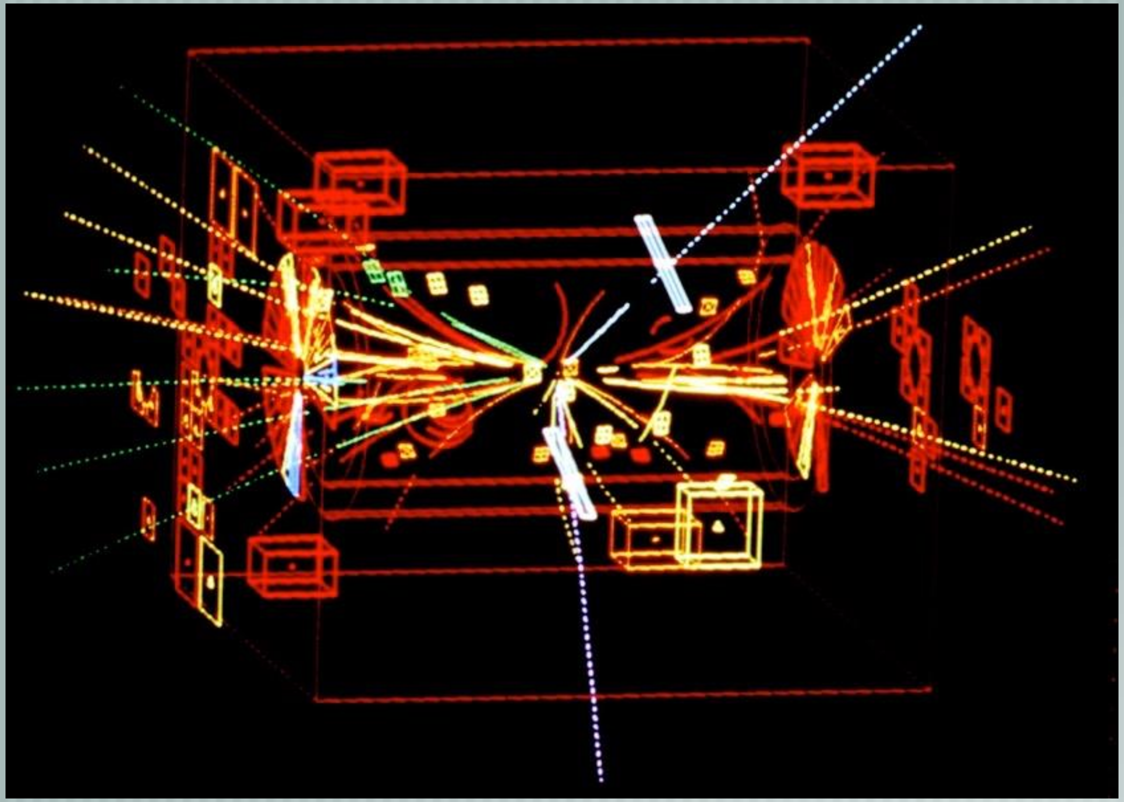
"Universality*" - transmitted by W, Z bosons, same strength!

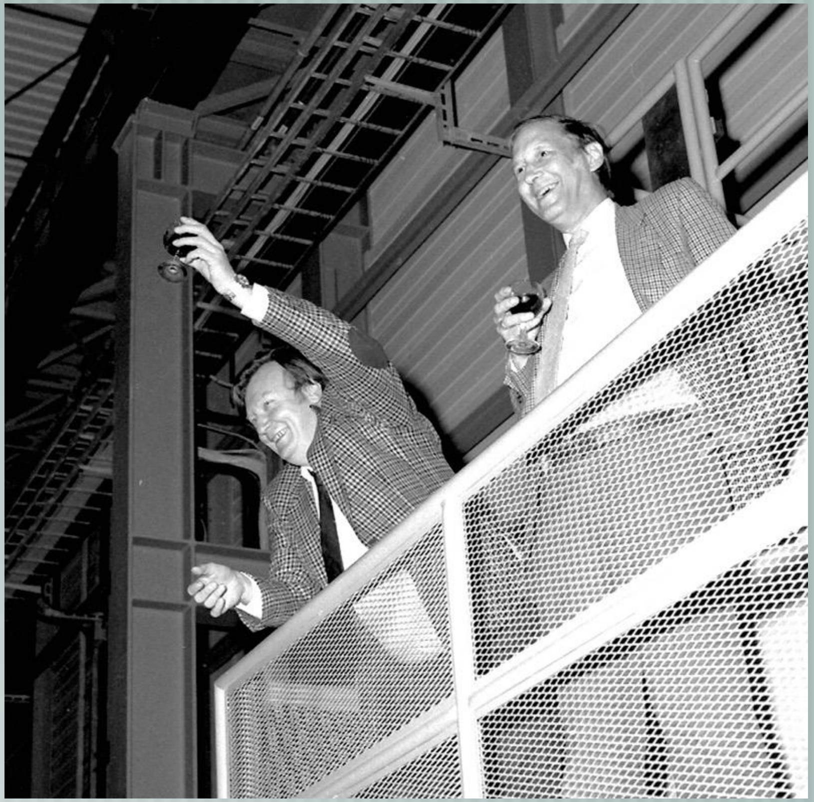
*Assuming a little bit of 'quark' mixing

$$d' = d \cos\theta_c + s \sin\theta_c$$
$$s' = -d \sin\theta_c + s \cos\theta_c$$

θ_c = Cabbibo angle ~ 20^o

Discovery of the W, Z bosons at CERN (1983)

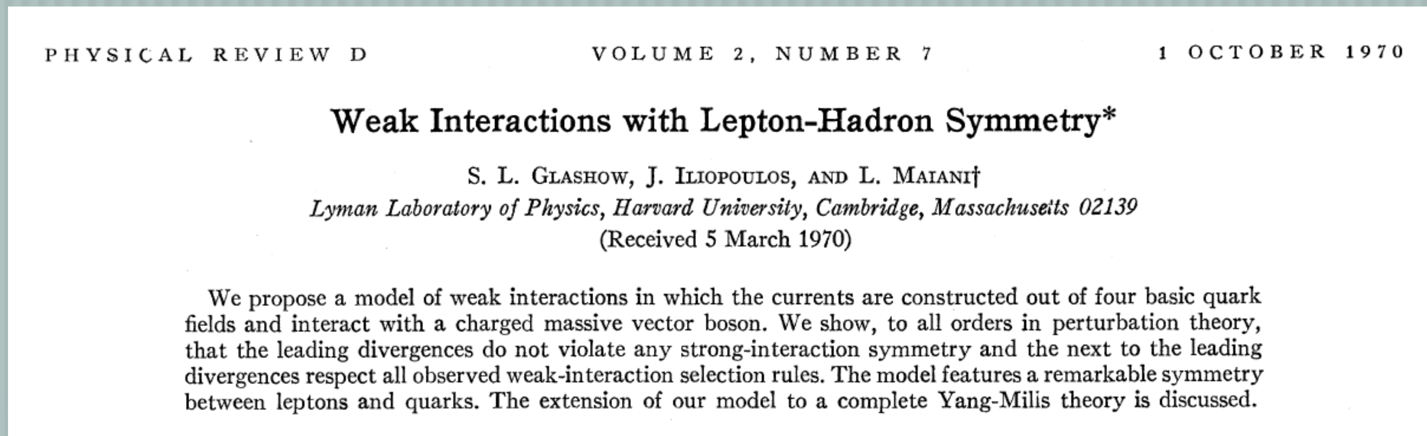




(C. Rubbia, S. van der Meer)

Approaching the ‘Standard Model’ of today

A legendary paper, predicting a new quark (Glashow, Iliopoulos, Maiani)


PHYSICAL REVIEW D VOLUME 2, NUMBER 7 1 OCTOBER 1970

Weak Interactions with Lepton-Hadron Symmetry*

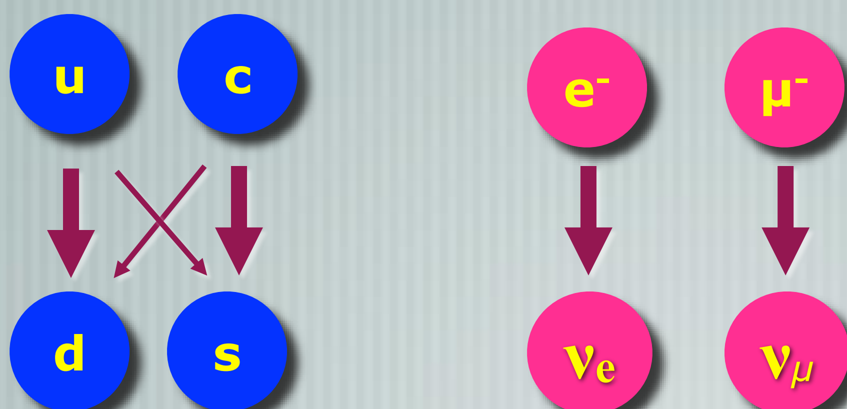
S. L. Glashow, J. Iliopoulos, and L. Maiani†

Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02139

(Received 5 March 1970)

We propose a model of weak interactions in which the currents are constructed out of four basic quark fields and interact with a charged massive vector boson. We show, to all orders in perturbation theory, that the leading divergences do not violate any strong-interaction symmetry and the next to the leading divergences respect all observed weak-interaction selection rules. The model features a remarkable symmetry between leptons and quarks. The extension of our model to a complete Yang-Milis theory is discussed.

Quarks Leptons

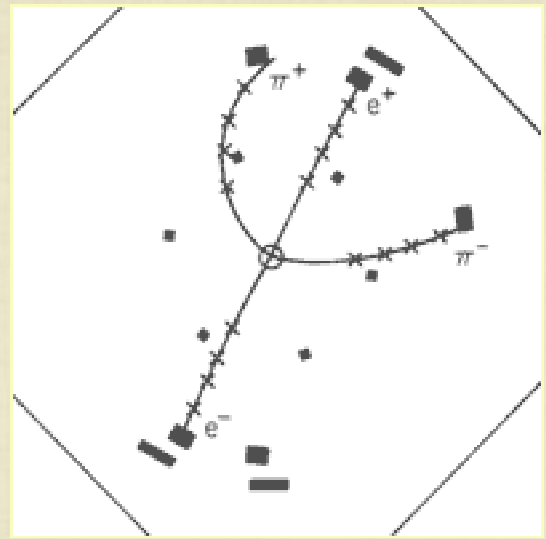


The “Standard Model” of 1970

1974

Discovery of the ‘charm’ quark in 1974

NOVEMBER REVOLUTION (11 November 1974)



'Psi' am SLAC (Burt Richter)
'**J**' at Brookhaven (Sam Ting)
Compromise: J/Psi

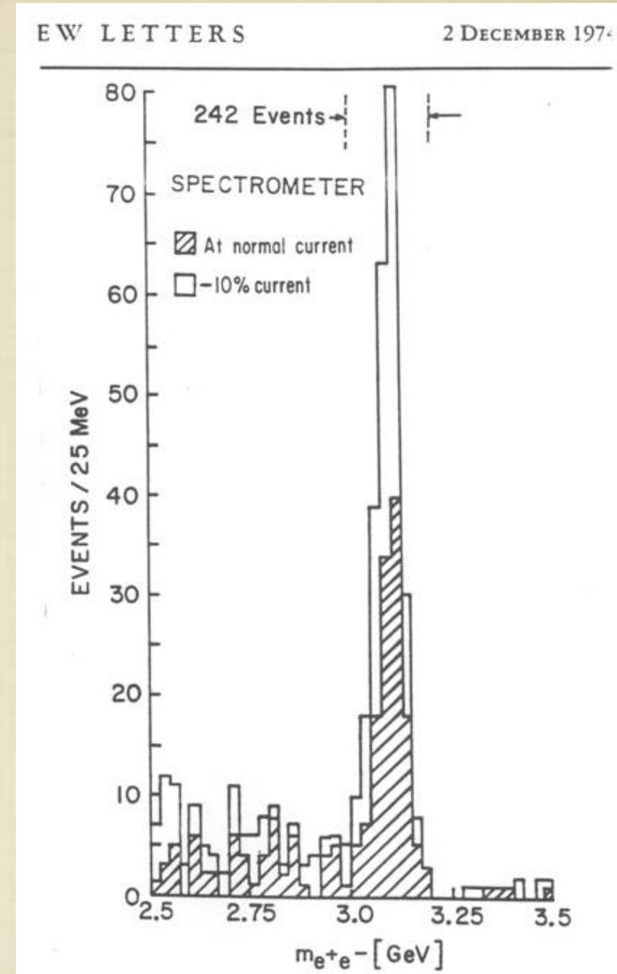
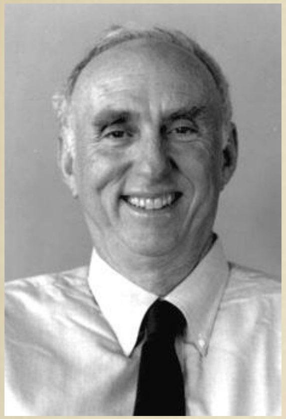


FIG. 2. Mass spectrum showing the existence of J. sults from two spectrometer settings are plotted wing that the peak is independent of spectrometer rents. The run at reduced current was taken two nths later than the normal run.

“Extremely” long lifetime (~10^{-20} sec)
Decay only possible through electroweak interaction

PARTICLE SPECTRUM

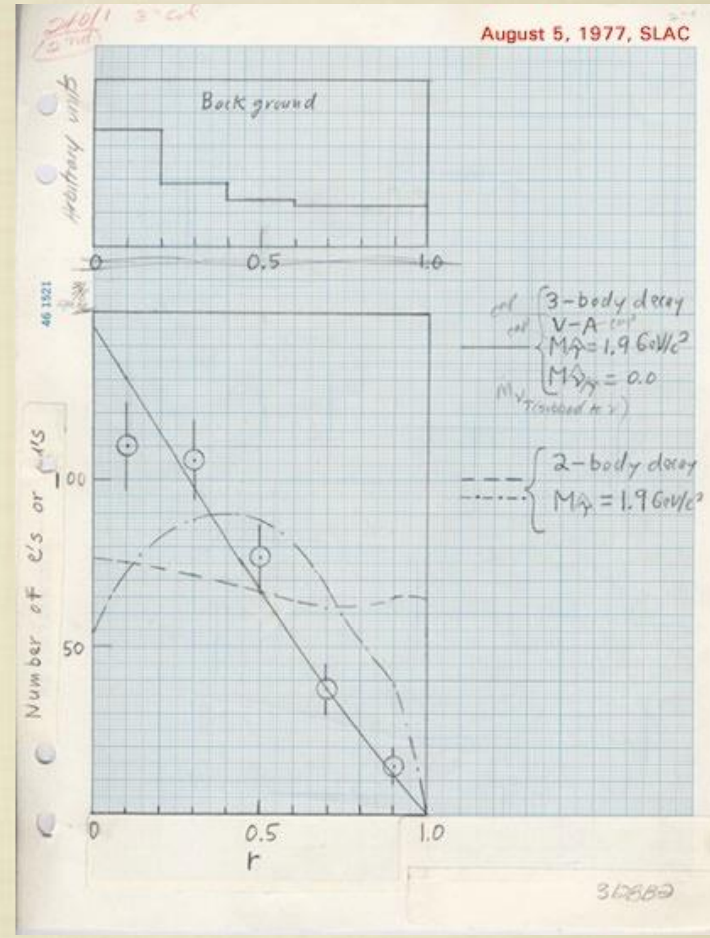
But a third family of particles was going to be discovered



Martin Perl

A new 'heavy electron' with 3500 x m_e

... who ordered that?



Marty Perl's logbook page

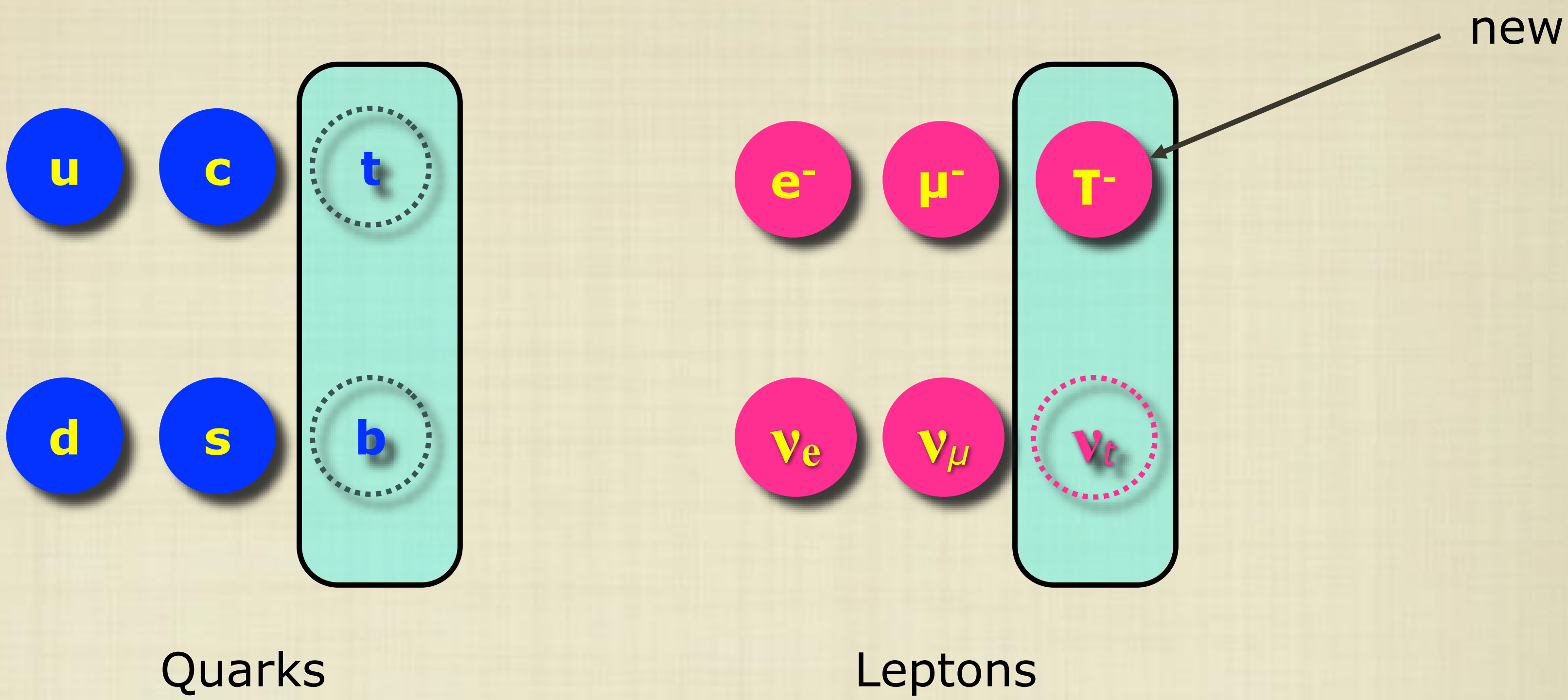
THERE MUST BE A WHOLE NEW FAMILY

another neutrino (the 'tau neutrino'),
and two more quarks ('top' and 'bottom')

PARTICLE SPECTRUM

1975

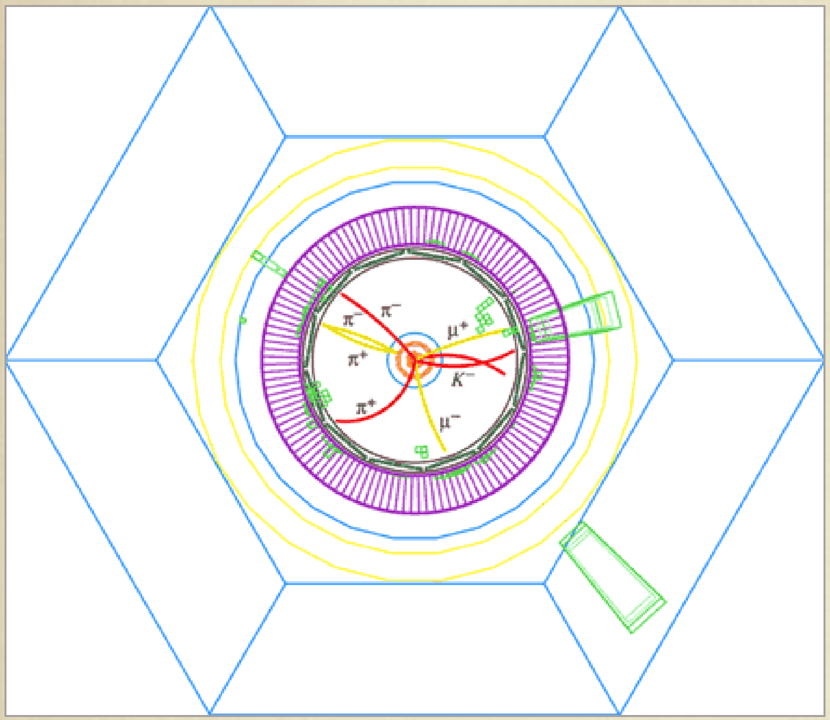
The search for the other family members started

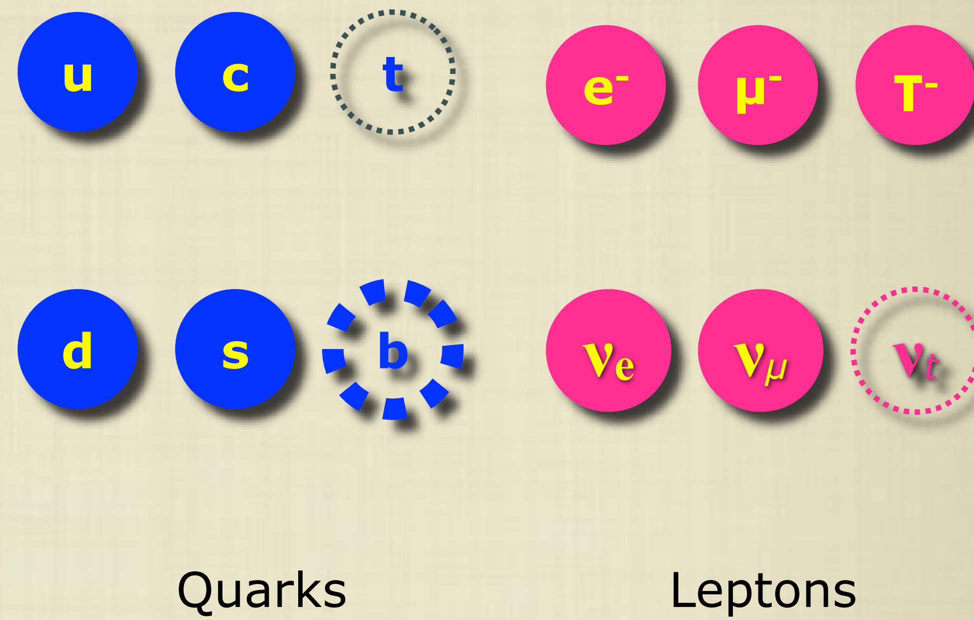


PARTICLE SPECTRUM

1977

Discovery of the **'Bottom' Quark (Fermilab)**





In 1977 physicists discovered a new meson called the Upsilon at the Fermi National Accelerator Laboratory.

This meson was immediately recognized as being composed of a bottom/anti-bottom quark pair.

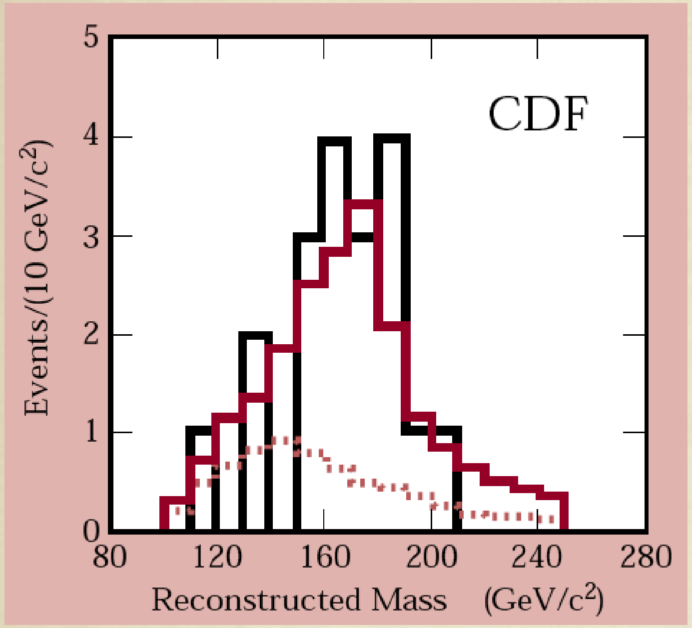
The bottom quark had charge -1/3 and a mass of roughly 5 GeV.

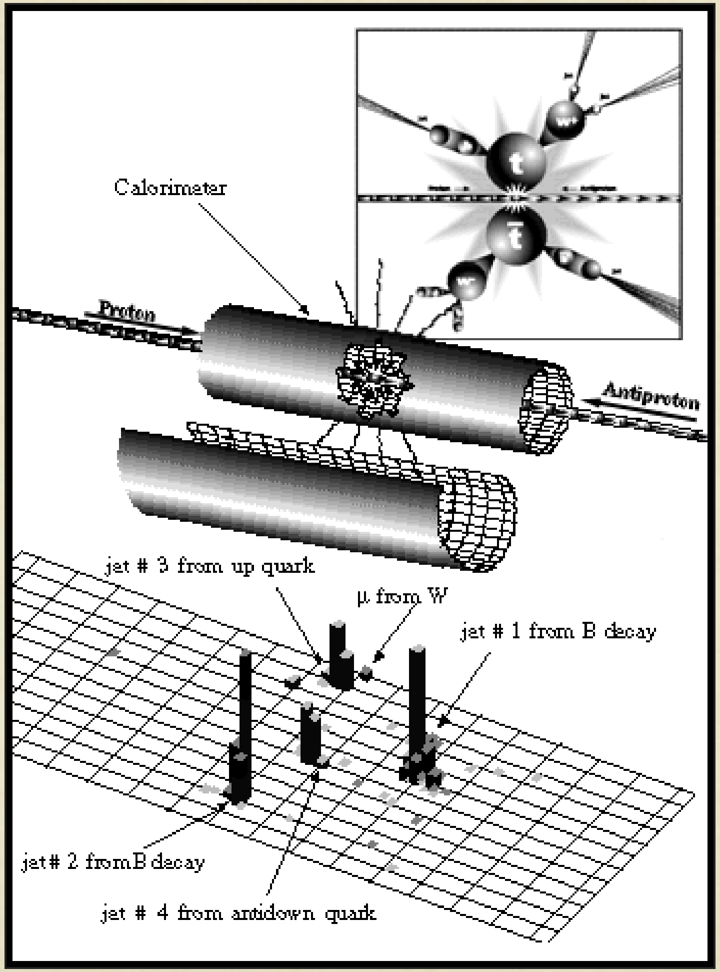
PARTICLE SPECTRUM

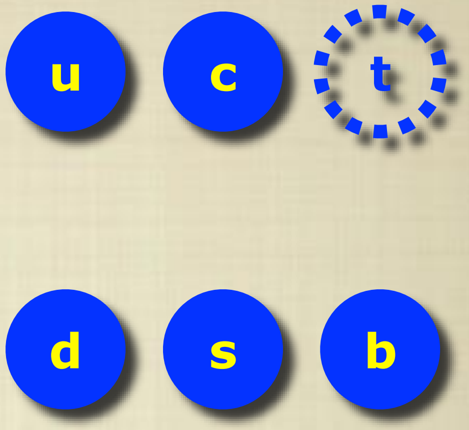
Quarks

1995

Discovery of the **'Top' Quark (Fermilab)**



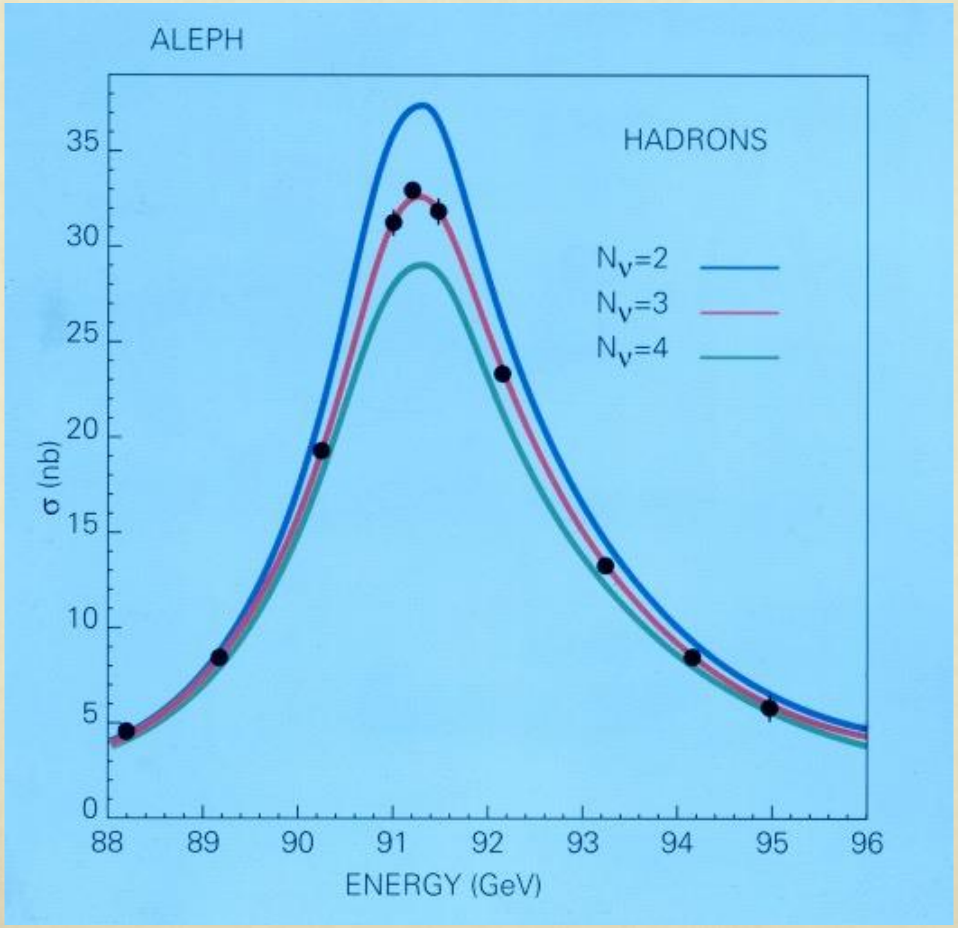




Quarks

EXACTLY 3 families of particles

LEP measures the decay width of the Z^o particle



Experiments at accelerators have discovered the whole set of fundamental particles