

# **STRUCTURE OF MATTER**

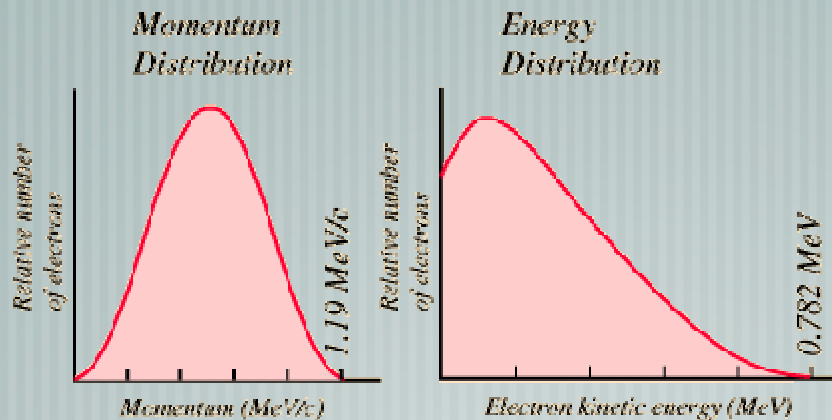
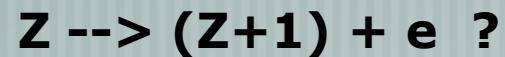
Discoveries and Mysteries

Part 2

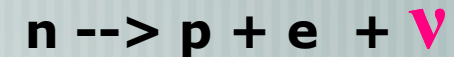
Rolf Landua  
CERN

# The "Weak Interaction" - What is Radioactivity ?

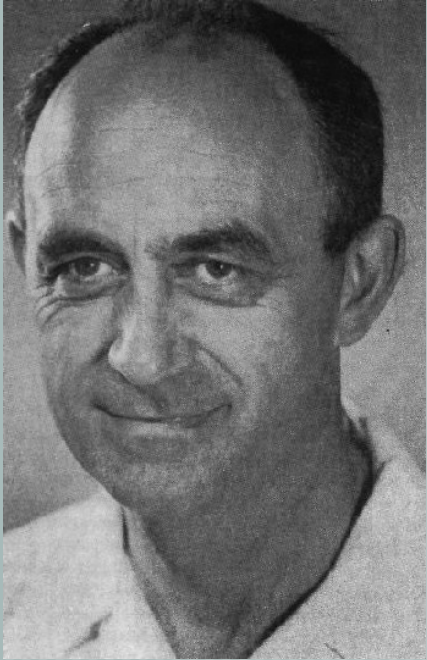
1911: Continuous (?) energy spectrum of 'beta'-rays (electrons) - energy conservation?



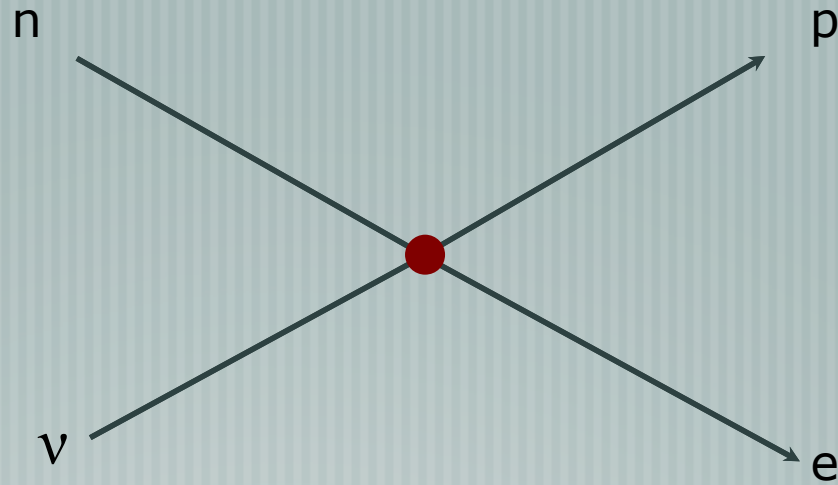
1930: Wolfgang Pauli postulates existence of 'neutrino':



# The model of Enrico Fermi : “pointlike interaction”



Enrico Fermi  
(1934)

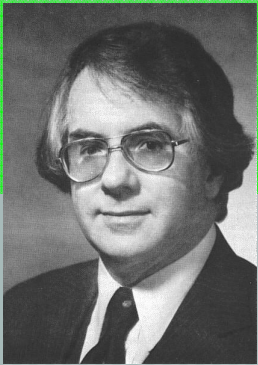


Proposed a **phenomenological** model of weak interaction

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

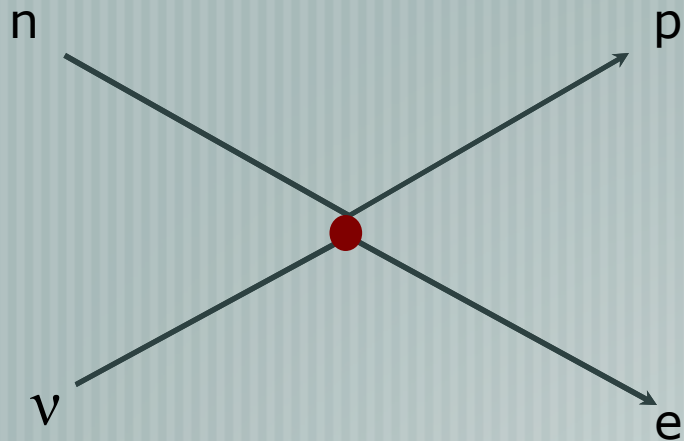
Coupling of two ‘currents’ (proton-neutron / electron-neutrino)

# Fermi's model turned out to be inconsistent at $E > 300 \text{ GeV}$



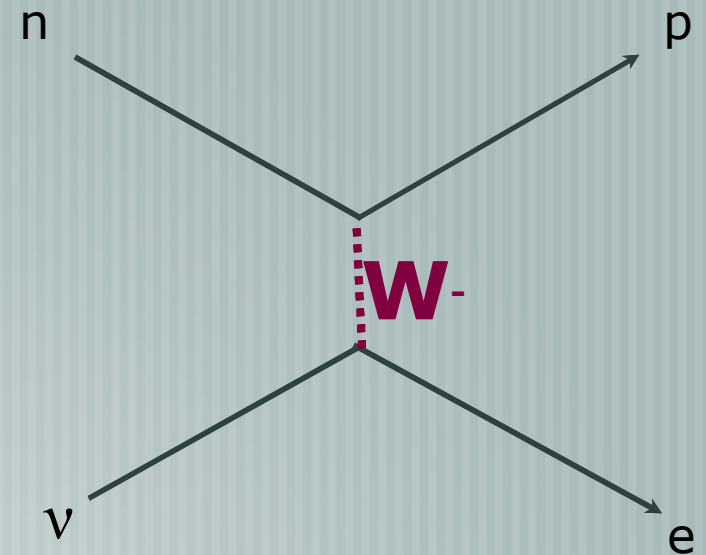
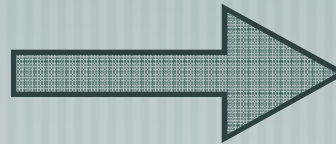
S. Glashow

probability of this reaction  $> 100\%$  ( $E > 300 \text{ GeV}$ )



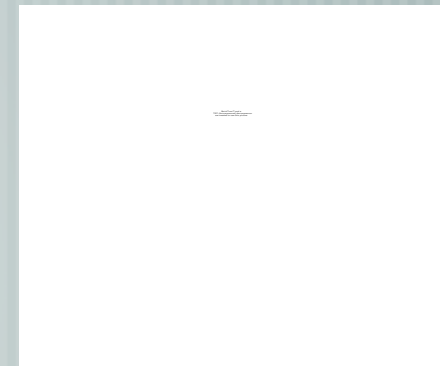
Fermi model

**New Idea (1958)**

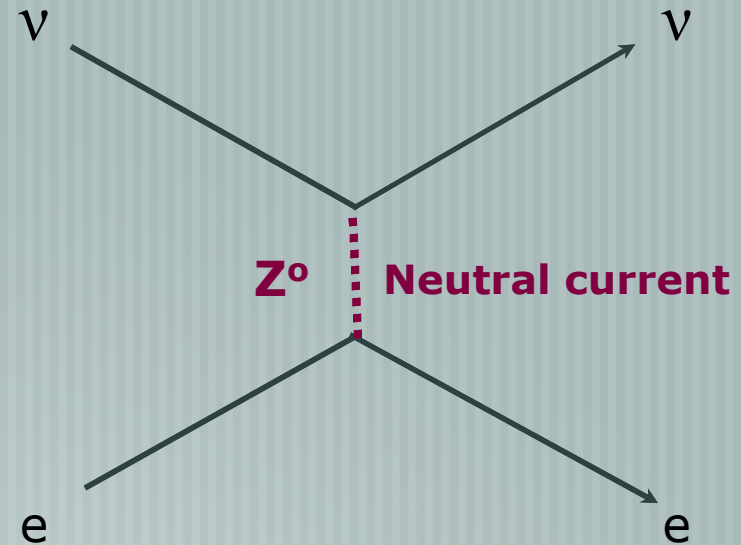
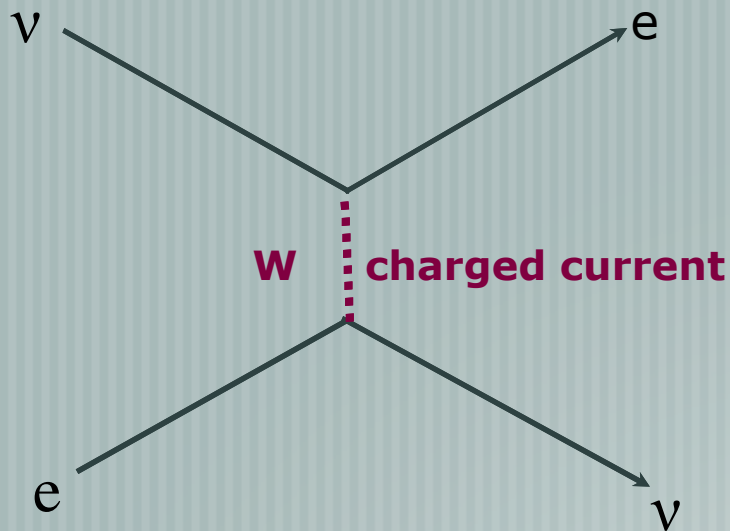


**Weak interaction transmitted by massive vector bosons  
(in analogy to photon exchange!)**

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



# Unification of electromagnetic and weak interaction

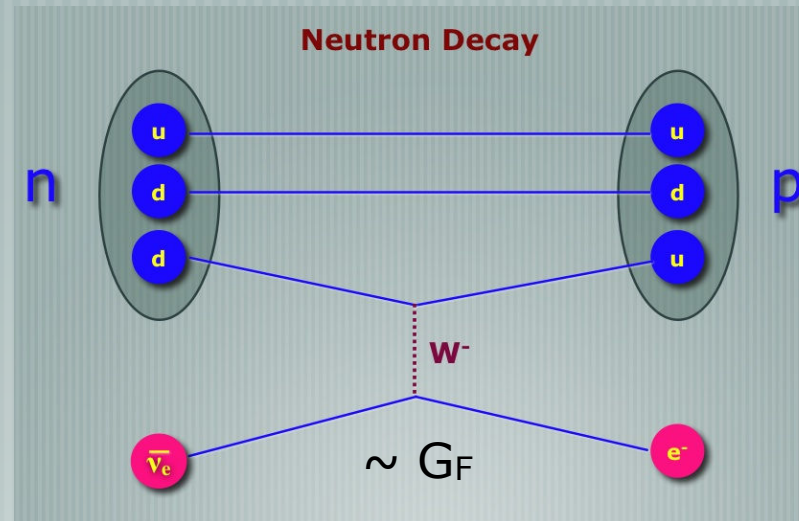
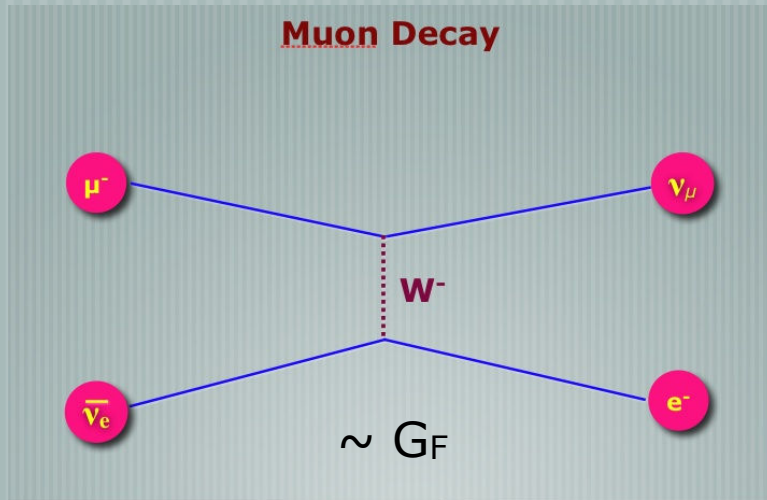


## Glashow, Salam, Weinberg (1968) - Electroweak Force

- 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' ( $Z^0$ ) and two charged vector boson ( $W^\pm$ ) of mass  $\sim 50$ - $100$  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



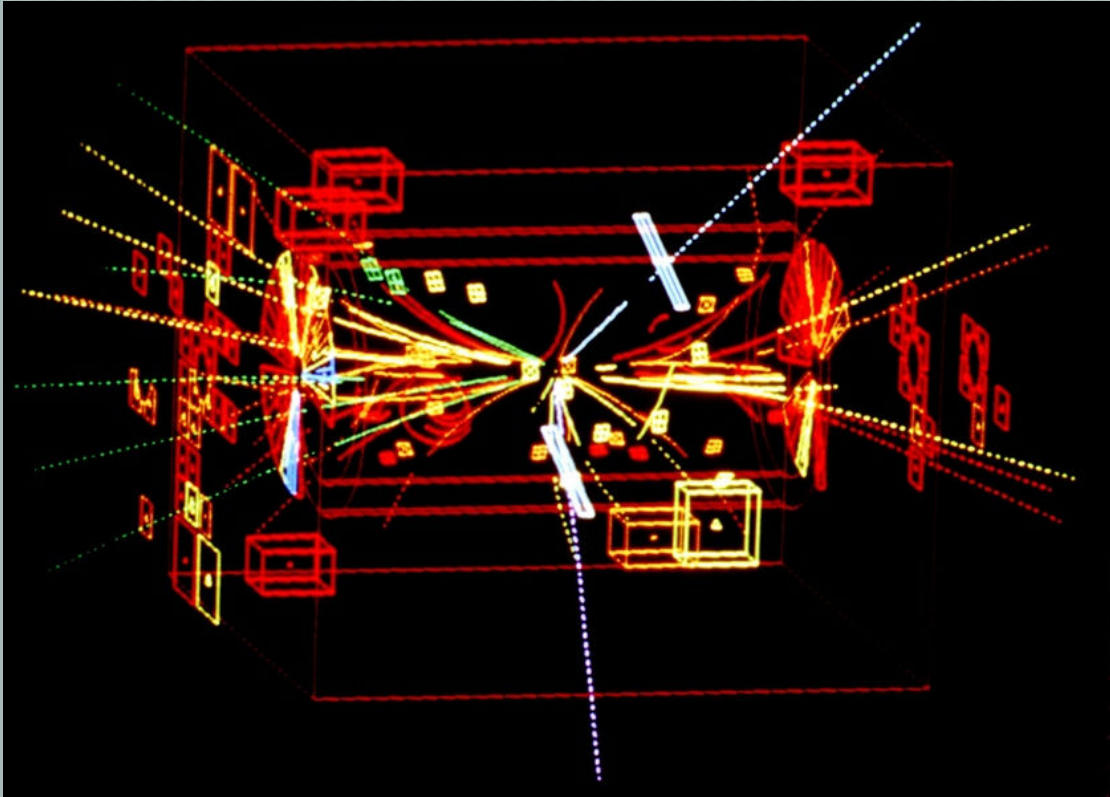
**“Universality\*” - transmitted by W, Z bosons, same strength!**

\*Assuming a little bit of ‘quark’ mixing

$$\begin{aligned}d' &= d \cos \theta_c + s \sin \theta_c \\s' &= -d \sin \theta_c + s \cos \theta_c\end{aligned}$$

$\theta_c = \text{Cabbibo angle} \sim 20^\circ$

# 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\*

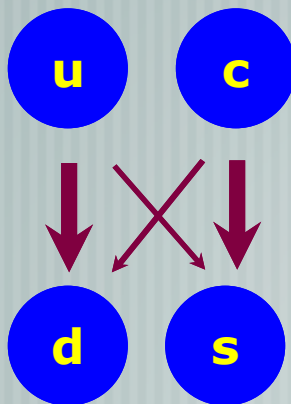
S. L. GLASHOW, J. ILIOPOULOS, AND L. MAIANI†

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

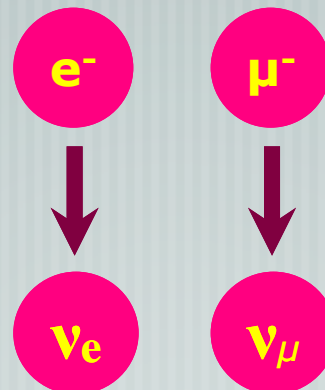
(Received 5 March 1970)

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-Mills theory is discussed.

Quarks



Leptons



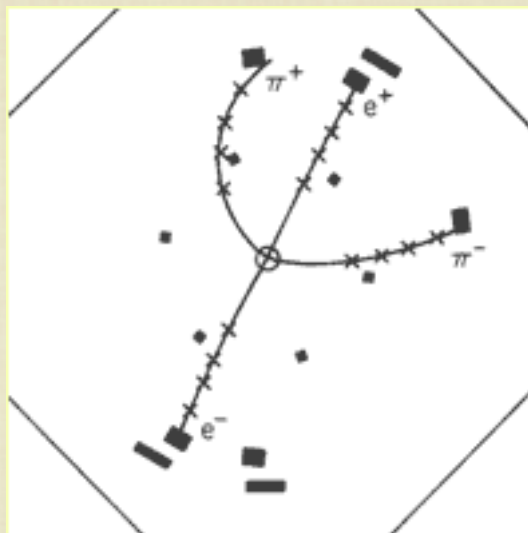
*The "Standard Model"  
of 1970*



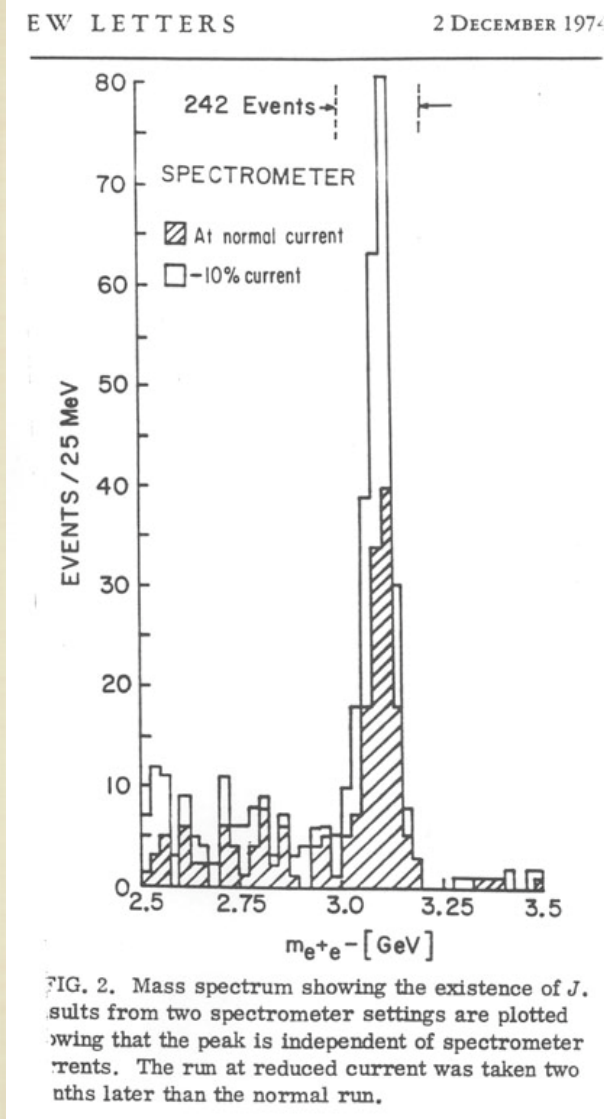
## Discovery of the 'charm' quark in 1974

NOVEMBER REVOLUTION (11 November 1974)

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



"Extremely" long lifetime ( $\sim 10^{-20}$  sec)  
Decay only possible through electroweak interaction



# PARTICLE SPECTRUM

Leptons

1975

But a third family of particles was going to be discovered



Martin Perl

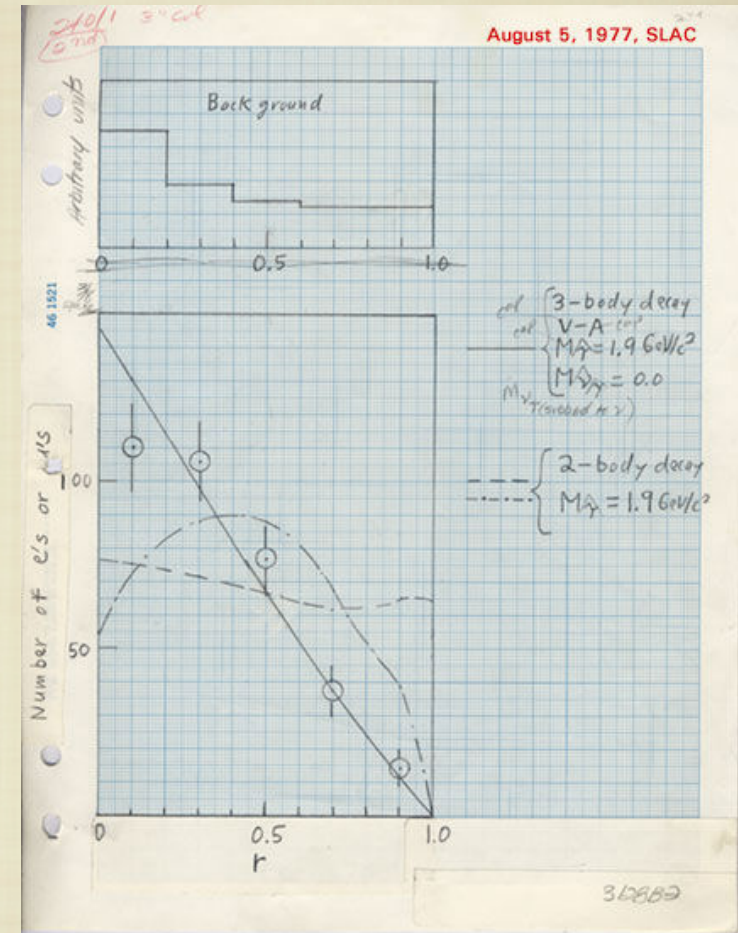
A new 'heavy electron' with  $3500 \times m_e$

... who ordered that?



**THERE MUST BE A WHOLE NEW FAMILY**

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



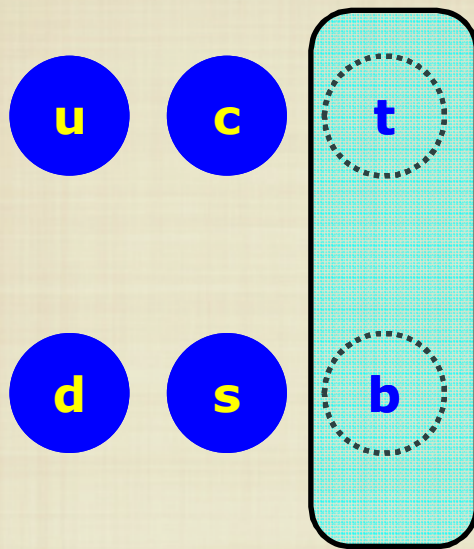
Marty Perl's logbook page

# PARTICLE SPECTRUM

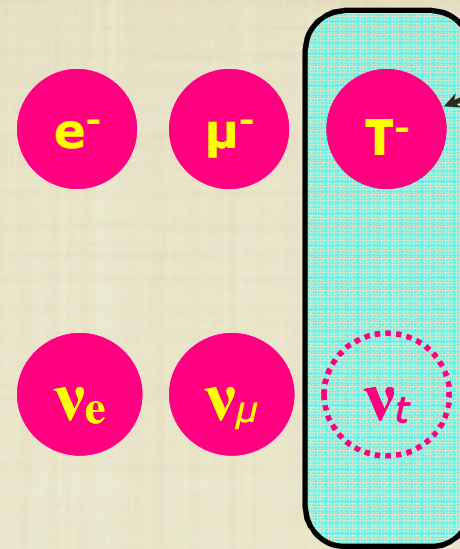
Quarks

1975

The search for the other family members started

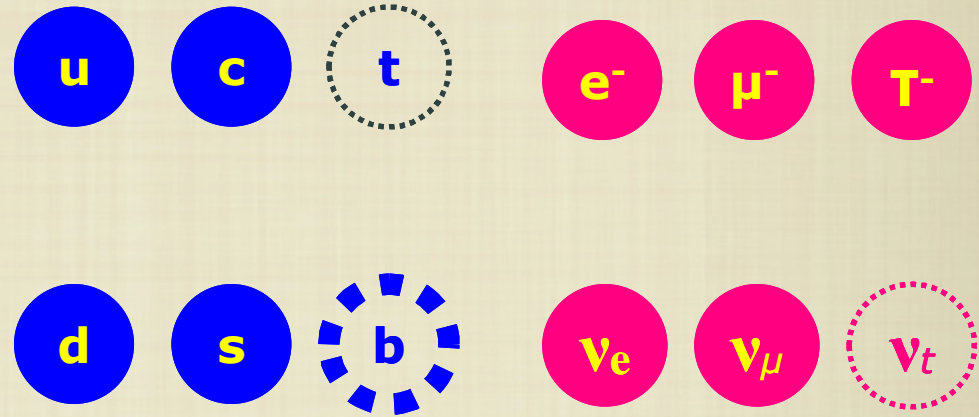
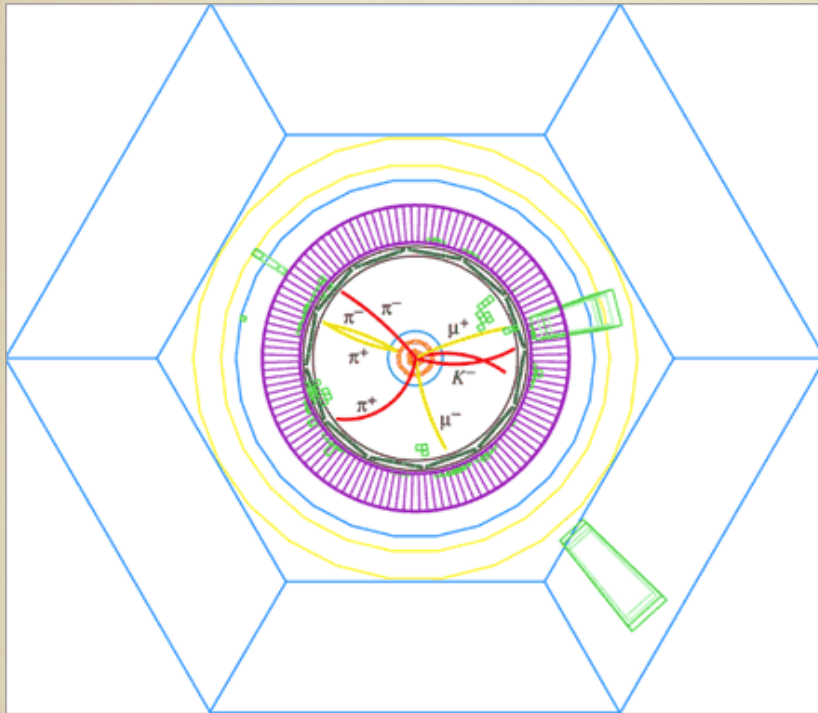


Quarks



Leptons

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



Quarks

Leptons

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.

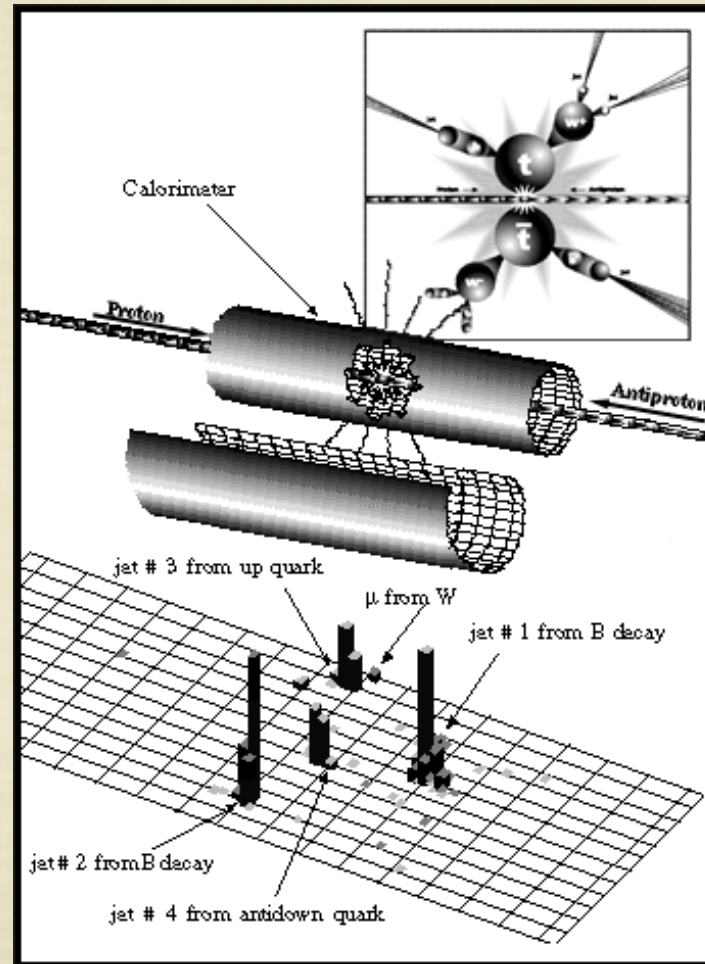
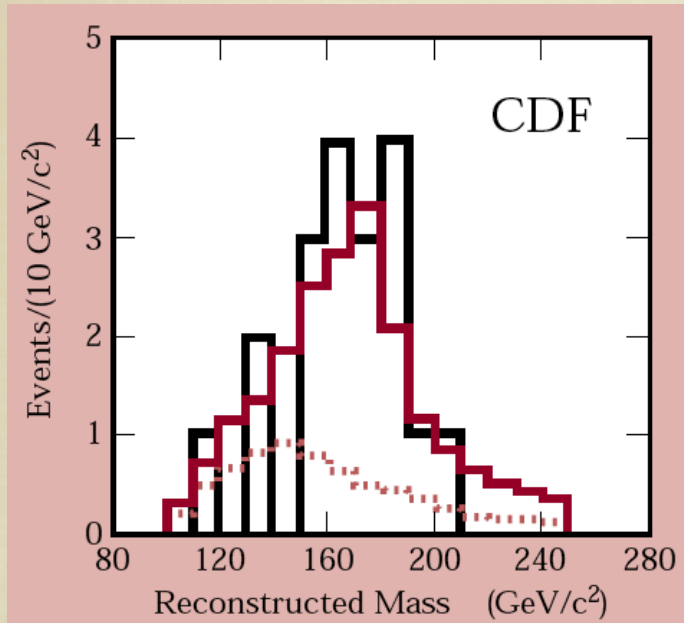
The bottom quark had charge  $-1/3$  and a mass of roughly 5 GeV.

# PARTICLE SPECTRUM

Quarks

1995

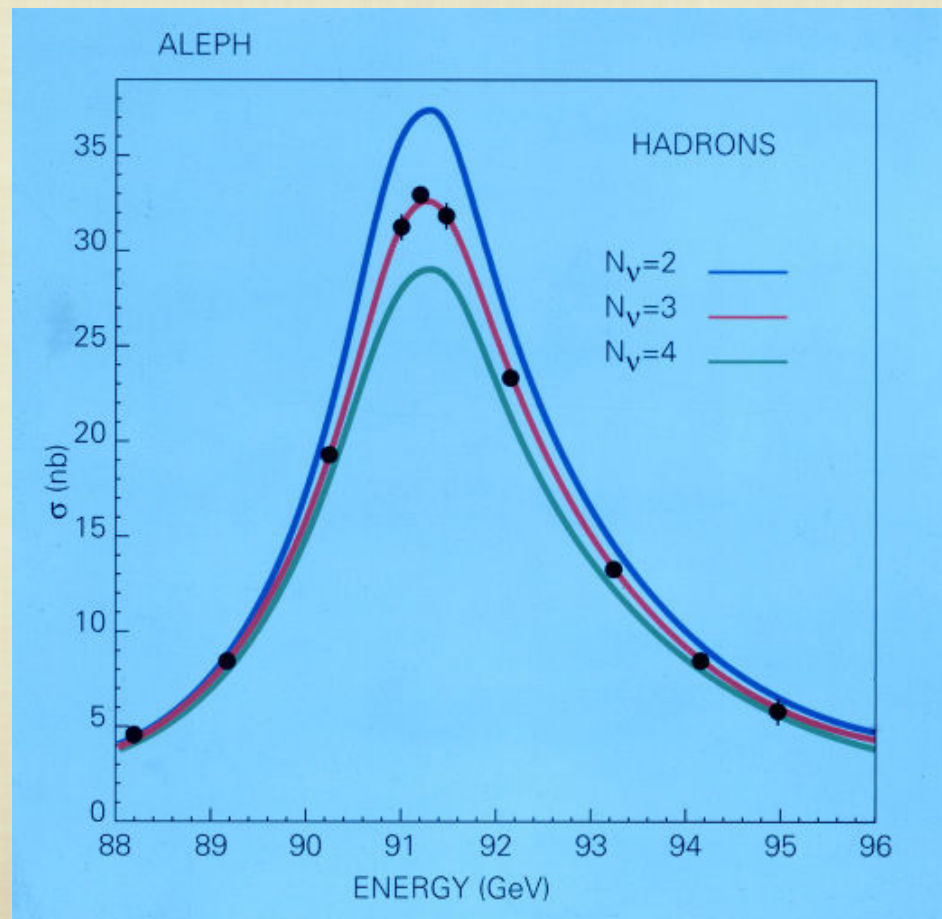
## Discovery of the 'Top' Quark (Fermilab)



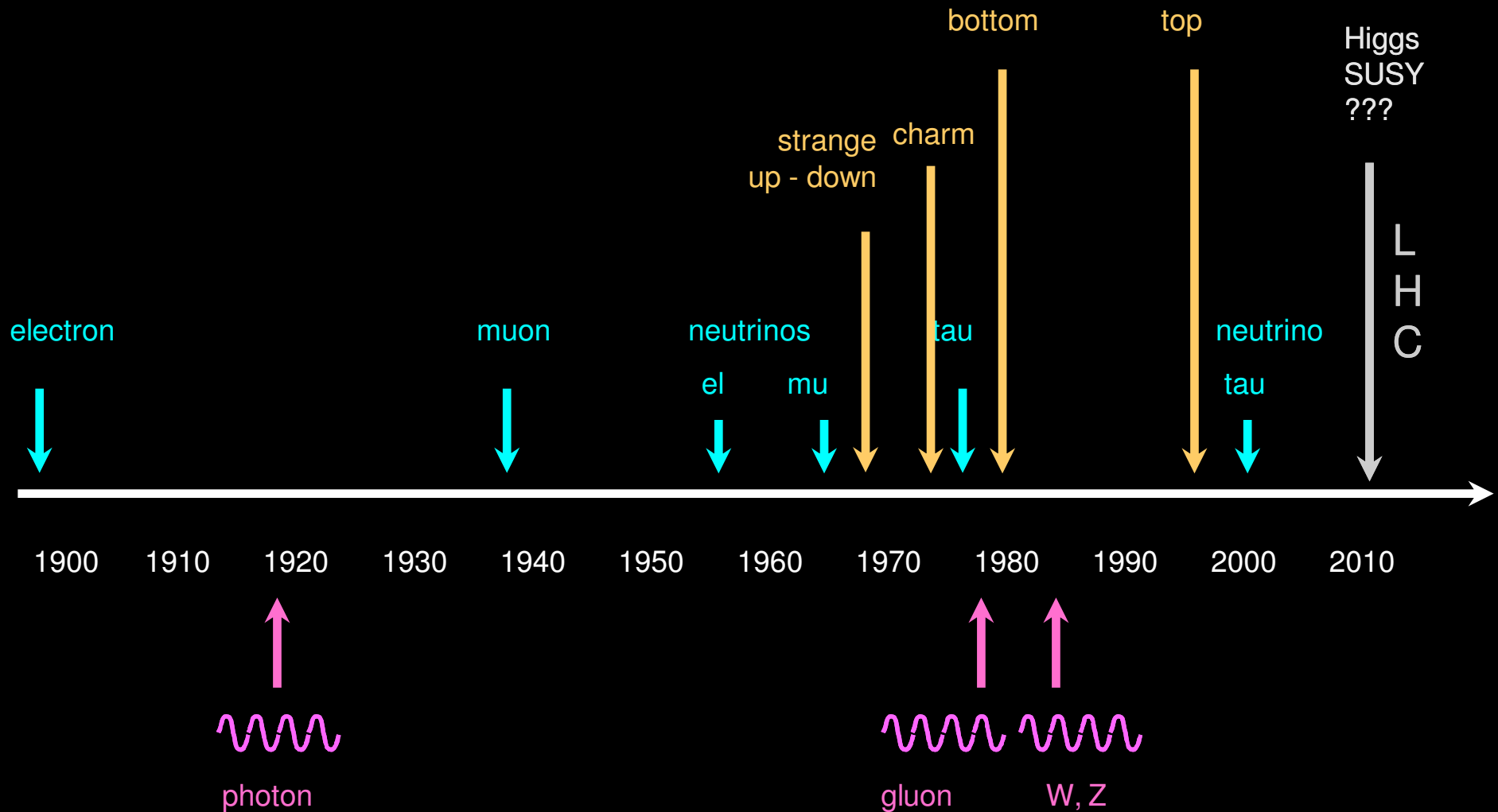
Quarks

**EXACTLY 3 families of particles**

LEP measures the decay width of the  $Z^0$  particle



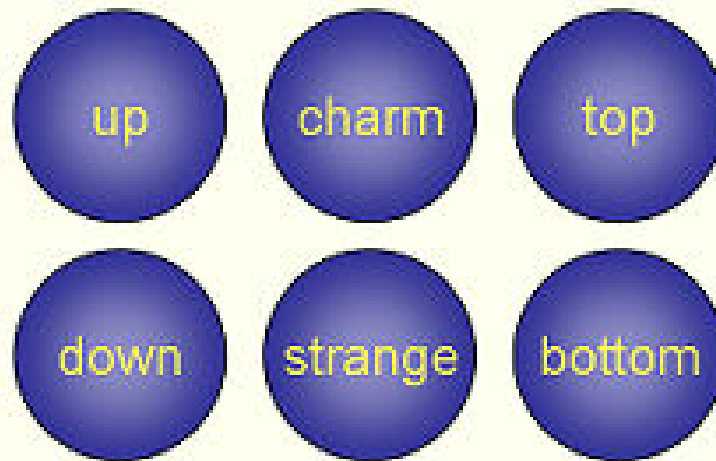
# Experiments at accelerators have discovered the whole set of fundamental particles



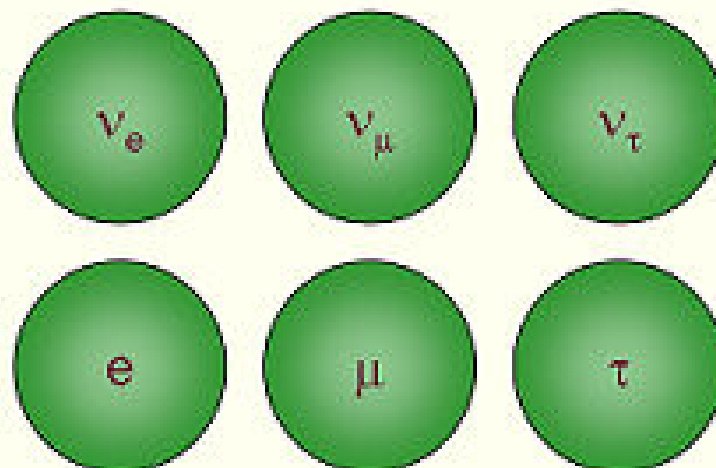
# THE STANDARD MODEL (2009)

## Particle content of the Standard Model

Quarks:



Leptons:



Force carriers

