Cabibbo
and
The Flavours emergence

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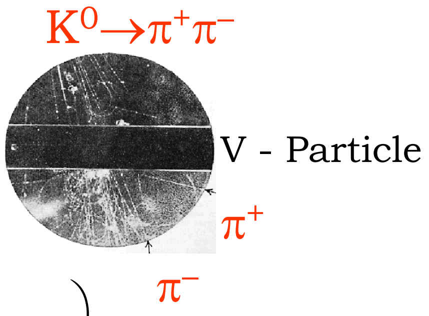
PART I

~1950

- **New particle discoveries : Strangeness emergence**



1963

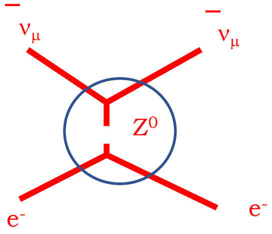
- **Cabibbo Theory**

θ_c : the Cabibbo angle

$$\begin{pmatrix} u \\ d_c \end{pmatrix} = \begin{pmatrix} u \\ d\cos\theta_c + s\sin\theta_c \end{pmatrix}$$

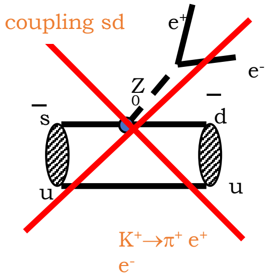
~1970

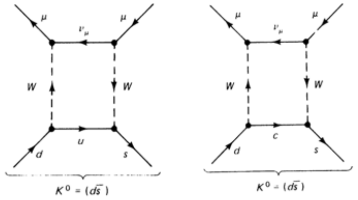
- **Neutral current in neutrino interaction : Z0 emergence (direct discovery in 1983 !)**



~1970

- **Absence of Flavour Changing Neutral**
- **Current (FCNC) : charm emergence**





~1970

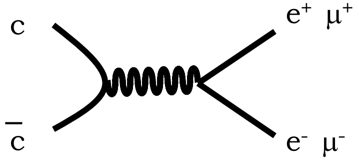
- **Cabibbo Matrix**

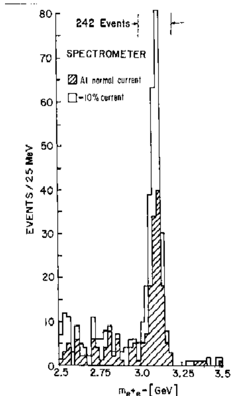
$$\left(\bar{u},\bar{c}\right)\gamma^\mu\left(1-\gamma_5\right)V\begin{pmatrix} d \\ s \end{pmatrix}$$

$$V = \begin{pmatrix} \cos\theta_c & \sin\theta_c \\ -\sin\theta_c & \cos\theta_c \end{pmatrix}$$

1974

- **Discovery of J/Psi**

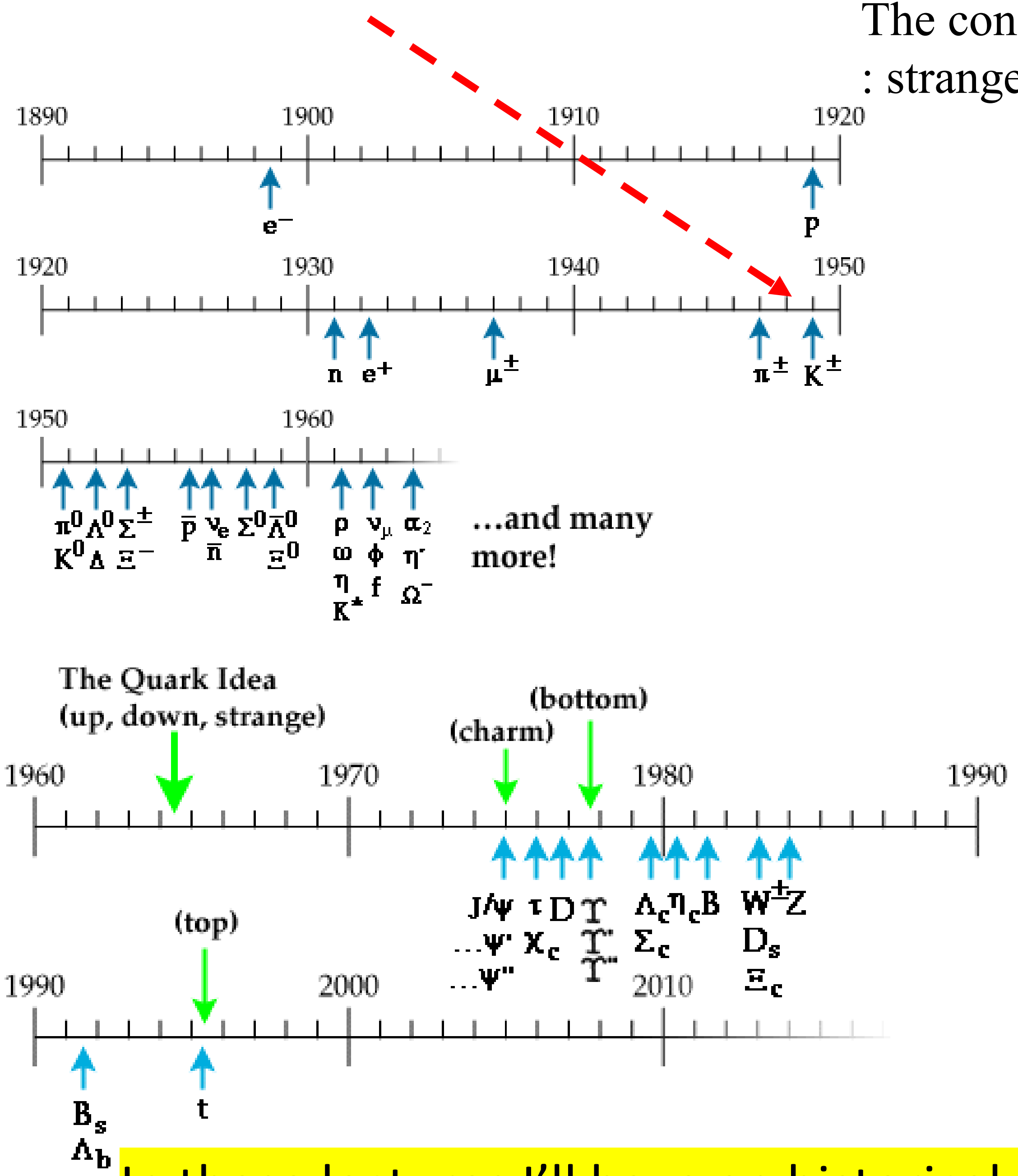




Fundamental role of strange particles in the development of flavour physics. I use them to introduce flavour physics

To show where I start from…

~1950
The concept of flavour
: strangeness discovery



In these lectures I’ll have an historical approach

The Strangeness : the begin of a new era…not ended yet

~1947 : discovery of new particles (on cosmic rays)

- K (~500 MeV)   Λ (~1100 MeV)

Why are these particles strange ?

- They are produced (always in pair) as copiously as the as the π
- Their lifetime is ~10^{-10} s !

Production through strong interaction

Decay through weak interaction

Pais intuition (1952)

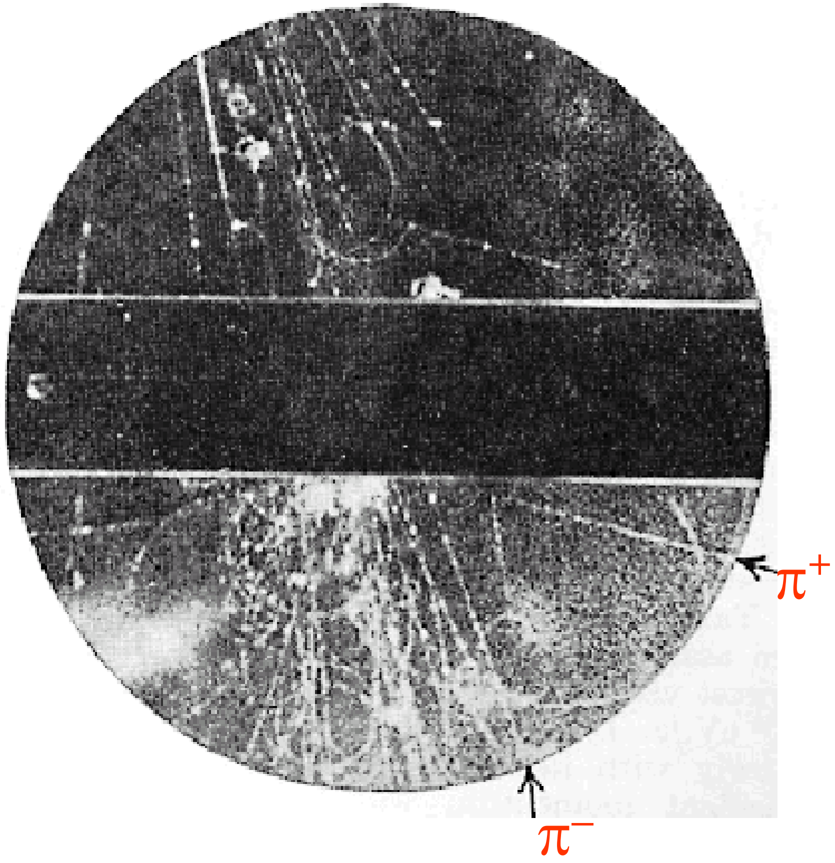
There should be a reason to inhibit the decay through strong interactions…..

→ Introduction of a new quantum number

- Conserved in strong interaction processes
- Not conserved on weak interaction processes

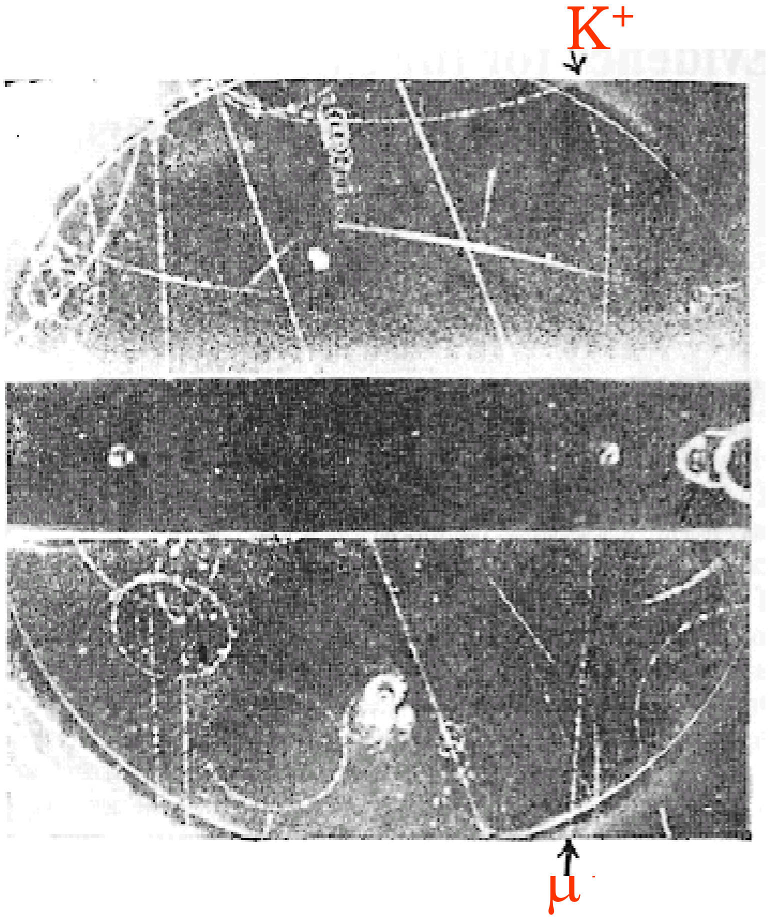
➡ **The strangeness** (additive quantum number)

$K^0 \rightarrow \pi^+\pi^-$



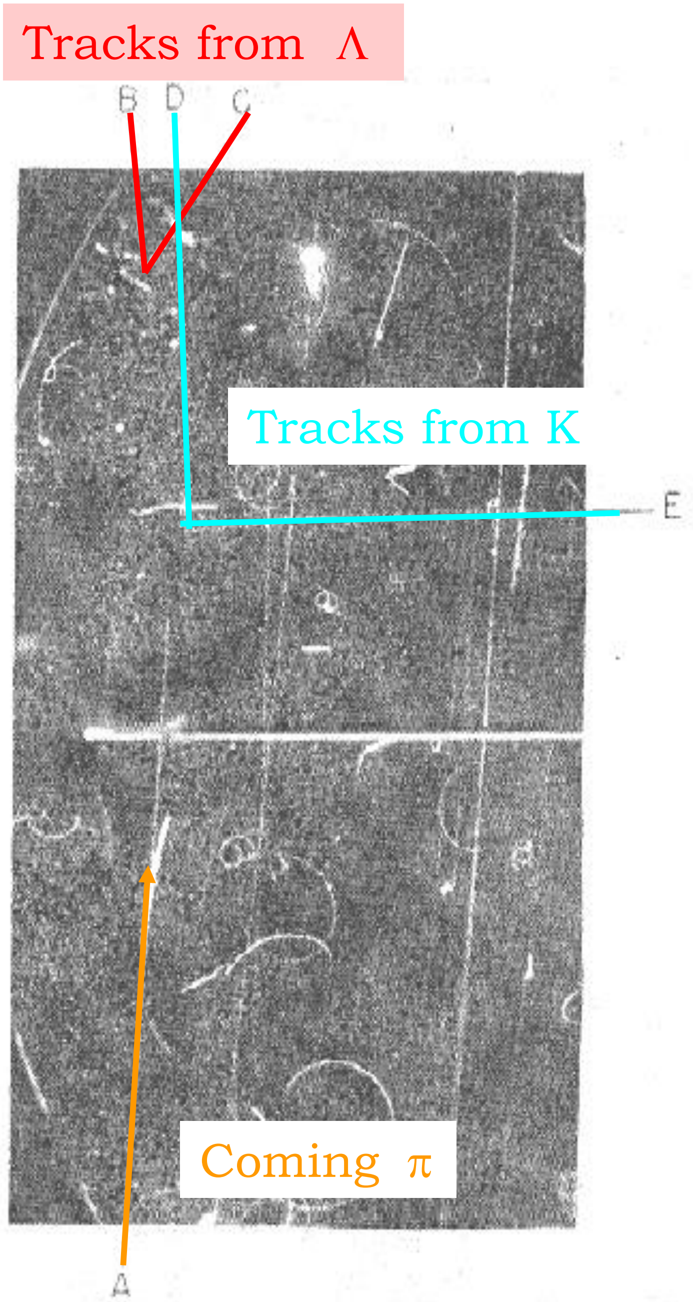
V - Particle

$K^+ \rightarrow \mu^+\nu$



«Kink» in the detector

Bubbles Chamber ~1947



Produced in pair

$\pi^- p \rightarrow K^0 \Lambda^0$

1955 Walker *et al* (Berkeley)

Several new “strange” particle were discovered. There were decaying in cascade to other strange particles.
Experimentally, from the observation of the decay of particle as the $\Xi^{\pm}$ it comes out that, the strangeness is an *additive quantum number*

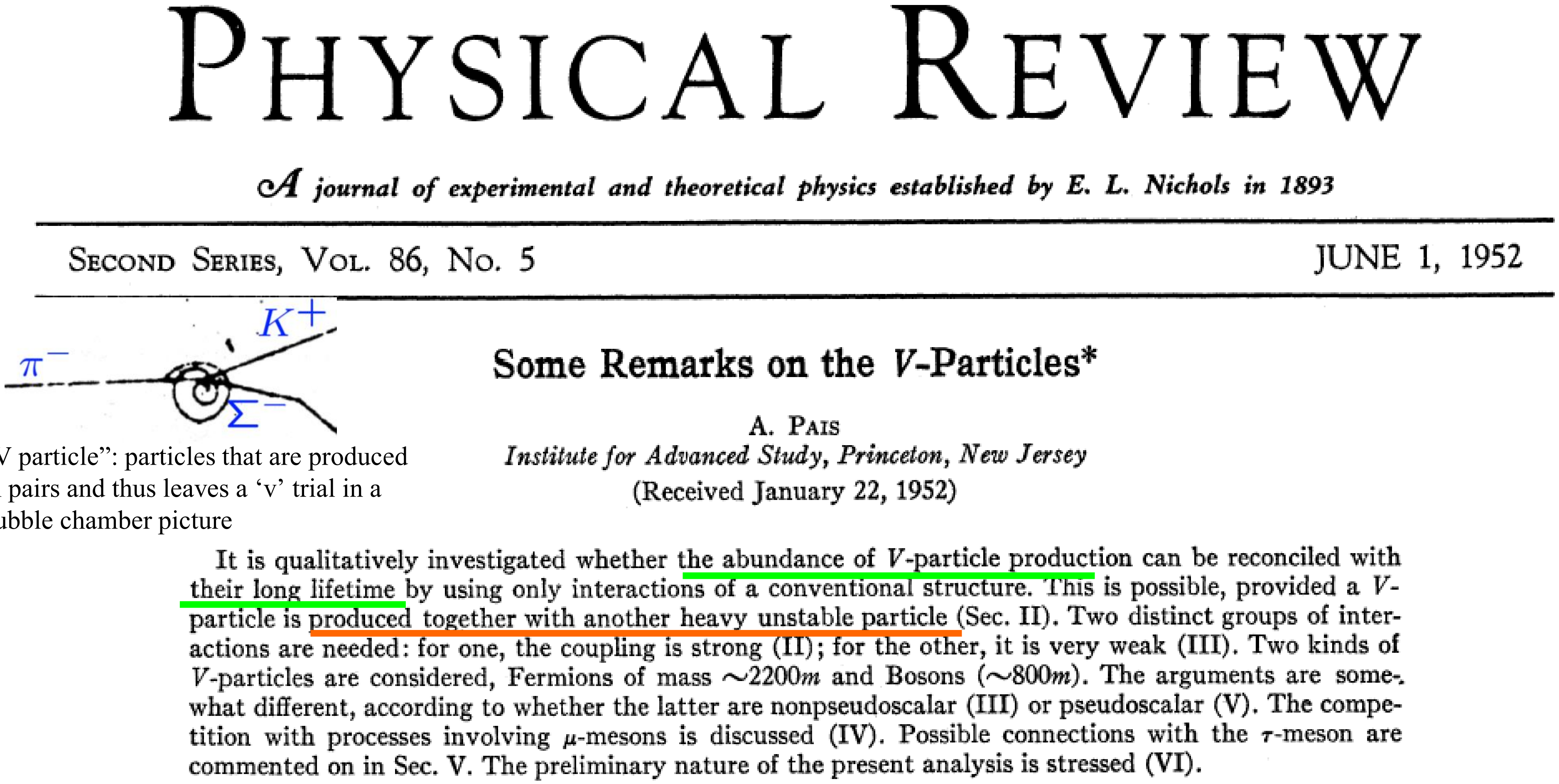
particle	**S**
p,n,$\pi^{\pm}$, π^0	0
Λ,$\Sigma^{\pm}$, Σ^0	-1
$\Xi^{\pm}$, Ξ^0	-2
K^0,K^+	+1
$\overline{K}^0$,K^-	-1

Why additif ?

Exp. τ_{Ξ} is typical of weak interaction

Analogy with the parity ±1

	Ξ	$\rightarrow$	Λ	π	
If multiplicatif	-1		-1	1	OK ⇒ Strong int. possible
If additif	-2		-1	0	≠ ⇒ weak interaction



PHYSICAL REVIEW

A journal of experimental and theoretical physics established by E. L. Nichols in 1893

SECOND SERIES, VOL. 86, NO. 5 JUNE 1, 1952

Some Remarks on the *V*-Particles*

A. PAIS
Institute for Advanced Study, Princeton, New Jersey
(Received January 22, 1952)

It is qualitatively investigated whether the abundance of *V*-particle production can be reconciled with their long lifetime by using only interactions of a conventional structure. This is possible, provided a *V*-particle is produced together with another heavy unstable particle (Sec. II). Two distinct groups of interactions are needed: for one, the coupling is strong (II); for the other, it is very weak (III). Two kinds of *V*-particles are considered, Fermions of mass ~2200m and Bosons (~800m). The arguments are somewhat different, according to whether the latter are nonpseudoscalar (III) or pseudoscalar (V). The competition with processes involving μ-mesons is discussed (IV). Possible connections with the τ-meson are commented on in Sec. V. The preliminary nature of the present analysis is stressed (VI).

“V particle”: particles that are produced in pairs and thus leaves a ‘v’ trial in a bubble chamber picture

Observations:
1. High production cross-section
2. Long lifetime

Conclusion:

must always be produced in pairs!

Details: create a new quantum number, “strangeness“ which is conserved by the production process (pair production)

however, the decay must violate “strangeness”

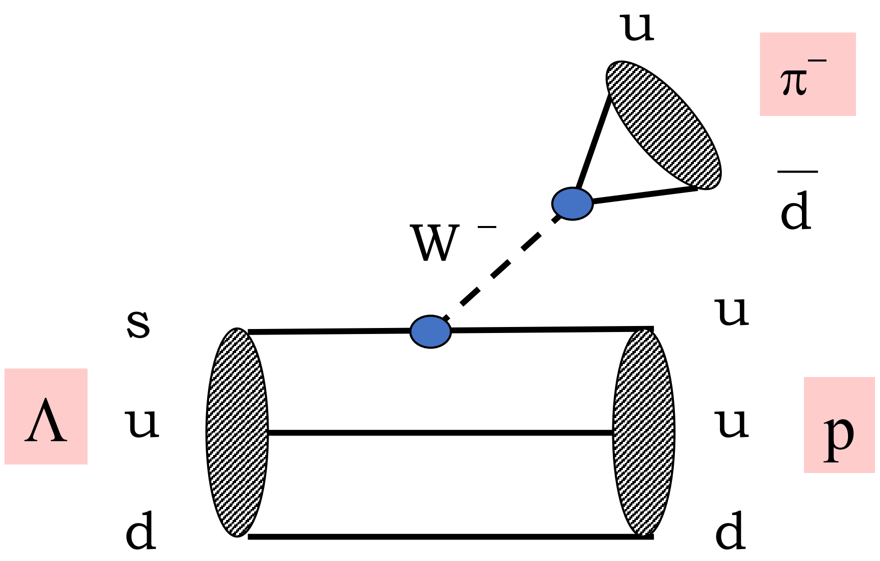
if only weak force is “strangeness violating” then it is responsible for the decay process

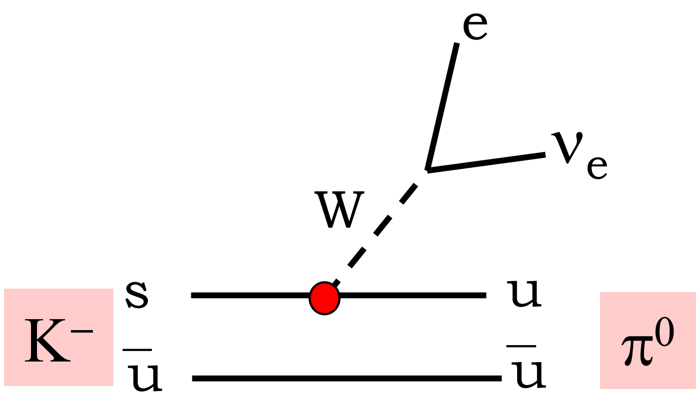
hence (relatively) long lifetime…

Strangeness and the birth of Flavour Physics

The strangeness is nothing else that the quantum number associated to a new quark : **the strange quark s**

How do we see the decay of a strange particle ?



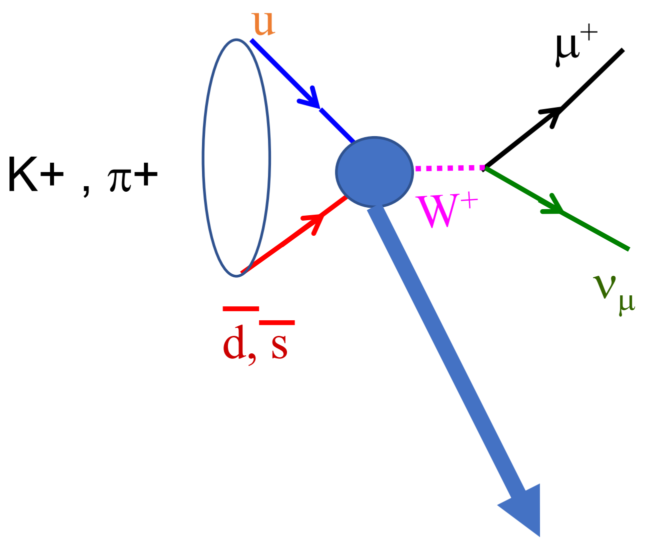


But there was a further question :

PUZZLEING about lifetimes.

The lifetime of Λ was measured of ~ $2x10^{-10}$ s, same for charged kaon was measured ~$1.2x10^{-8}$

How it compared with for instance with muon lifetime $\tau(\mu)$ ~10^{-6} s (or pion) ?



$\Gamma_i / \Gamma_{tot} = Br_i \rightarrow \Gamma_i = Br_i / \tau$

$$\frac{\Gamma(K\to muon)}{\Gamma(\pi\to muon)} = \frac{\tau(\pi)}{\tau(K)}\, \frac{\overset{(\sim 0.63)}{BR(K^+\to \mu^+\nu)}}{\underset{(\sim 1)}{BR(\pi^+\to \mu^+\nu)}} = \blacksquare \cdot \underbrace{\left[\frac{m_k}{m_\pi}\right]\left[\frac{1-(m_\mu/m_k)^2}{1-(m_\mu/m_\pi)^2}\right]^2}_{18}$$

Phase space

$\tau(\pi) = 2.6\ 10^{-8}$ s

$\tau(K) = 0.035 \times \tau(\pi) = 9 \times 10^{-10}$

BUT EXPERIMENTALLY $\tau(K) = 1.2\ 10^{-8}$ s

SO the lifetime of the K is slower than expected

● There is a coupling which is slowering down the decay of the K

1963 ΔS=1 vs ΔS=0 Cabibbo theory

The quarks *d* e *s* involved in weak processes are « rotated » by an angle

θ_c : the Cabibbo angle

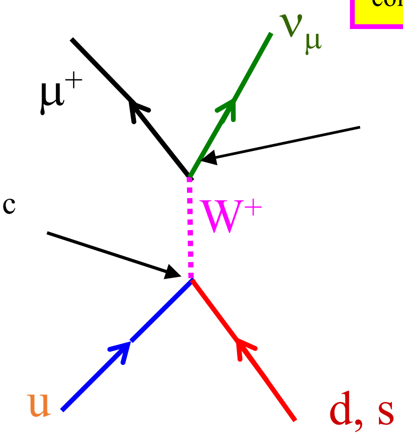
$$\begin{pmatrix} u \\ d_c \end{pmatrix} = \begin{pmatrix} u \\ d\cos\theta_c + s\sin\theta_c \end{pmatrix}$$

Couplings : u d $G_F\cos\theta_c$ u s $G_F \sin\theta_c$

Purely leptonic decays (e.g. muon decay) do not contain the Cabibbo factor:

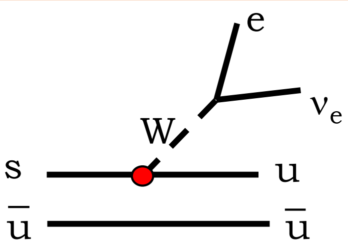
ΔS=1

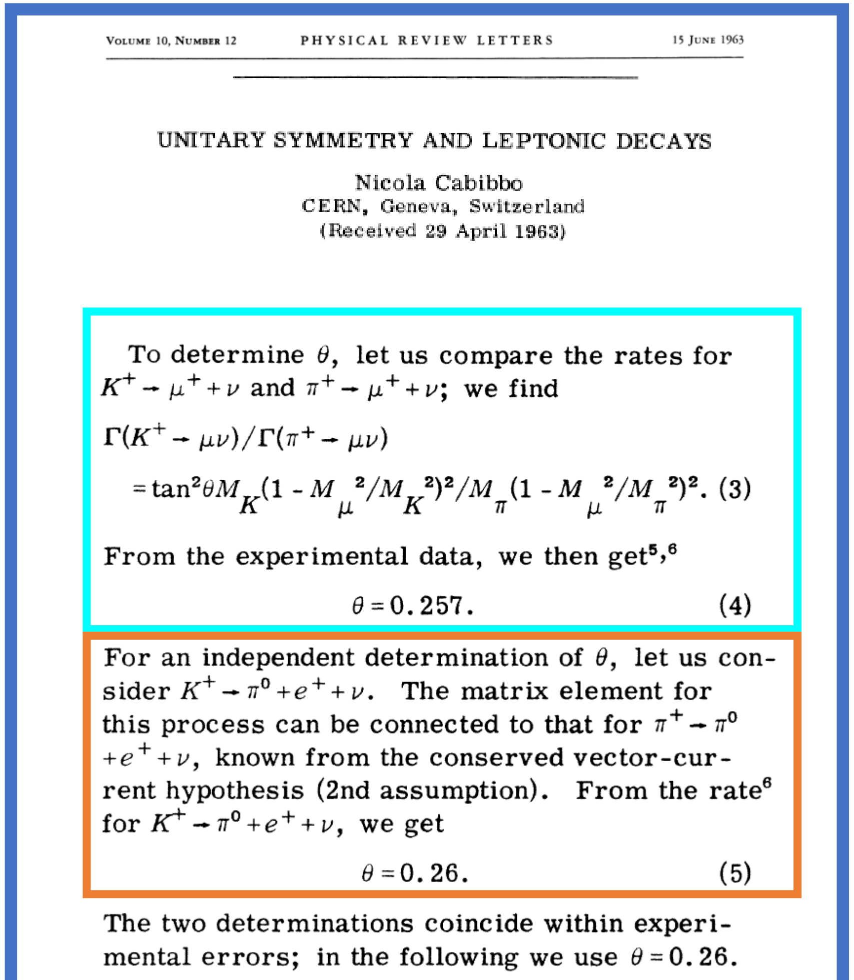
$\cos\theta_c$ or $\sin\theta_c$



$G_F^2 \sin^2\theta_c$

$K^- \to \pi^0 e^- \nu_e$





VOLUME 10, NUMBER 12 PHYSICAL REVIEW LETTERS 15 JUNE 1963

UNITARY SYMMETRY AND LEPTONIC DECAYS

Nicola Cabibbo
CERN, Geneva, Switzerland
(Received 29 April 1963)

To determine θ, let us compare the rates for $K^+ \to \mu^+ + \nu$ and $\pi^+ \to \mu^+ + \nu$; we find

$$\Gamma(K^+ \to \mu\nu)/\Gamma(\pi^+ \to \mu\nu)$$

$$= \tan^2\theta M_K(1 - M_\mu^2/M_K^2)^2/M_\pi(1 - M_\mu^2/M_\pi^2)^2. \quad (3)$$

From the experimental data, we then get[5,6]

$$\theta = 0.257. \quad (4)$$

For an independent determination of θ, let us consider $K^+ \to \pi^0 + e^+ + \nu$. The matrix element for this process can be connected to that for $\pi^+ \to \pi^0 + e^+ + \nu$, known from the conserved vector-current hypothesis (2nd assumption). From the rate[6] for $K^+ \to \pi^0 + e^+ + \nu$, we get

$$\theta = 0.26. \quad (5)$$

The two determinations coincide within experimental errors; in the following we use $\theta = 0.26$.

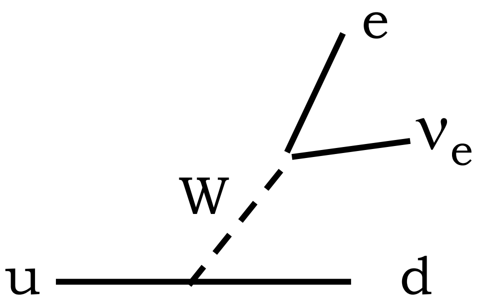
θ_c : the Cabibbo angle

Cabibbo Theory : <u>The quarks *d* e *s* involved in weak processes are « rotated » by an angle</u>

$$\begin{pmatrix} u \\ d_c \end{pmatrix} = \begin{pmatrix} u \\ d\cos\theta_c + s\sin\theta_c \end{pmatrix}$$

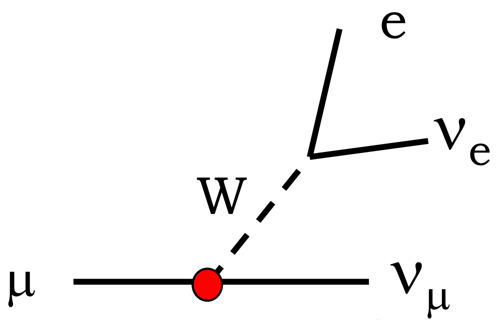
Couplings : u d $G_F\cos\theta_c$ u s $G_F\sin\theta_c$

$\Delta S=0$



$G_\pi^{\,2}$ = $G_n^{\,2}$ =

$\pi^- \rightarrow \pi^0 e^- \bar{\nu}_e$ $p \rightarrow n\, e^+ \nu_e$



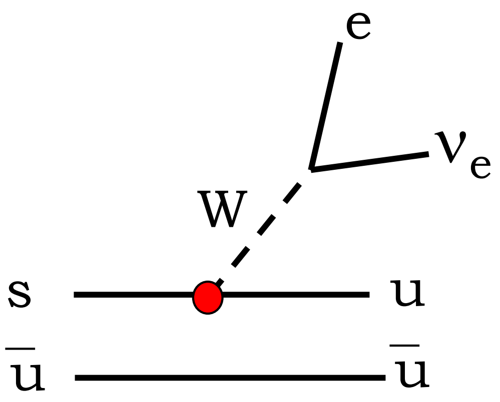
$G_\mu^{\,2}\cos^2\theta_c$

$\mu^- \rightarrow e^- \bar{\nu}_e\, \nu_\mu$

$\Delta S=1$

$G_F^{\,2}\sin^2\theta_c$

$K^- \rightarrow \pi^0 e^- \bar{\nu}_e$



Many measurements explained with :

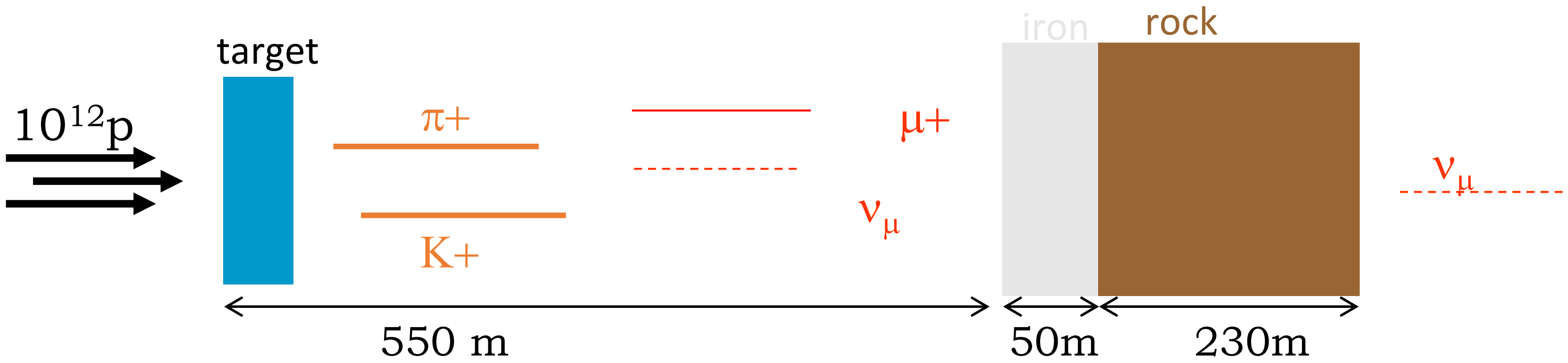
$\sin\theta_c \sim 0.22$

Weak interaction among quarks

Non universal

The years `70

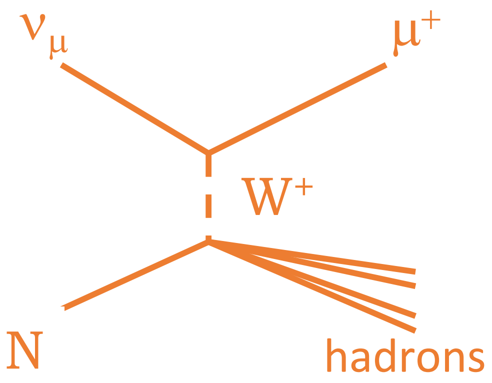
DISCOVERY OF WEAK CURRENTS in NEUTRINO INTERECTIONS

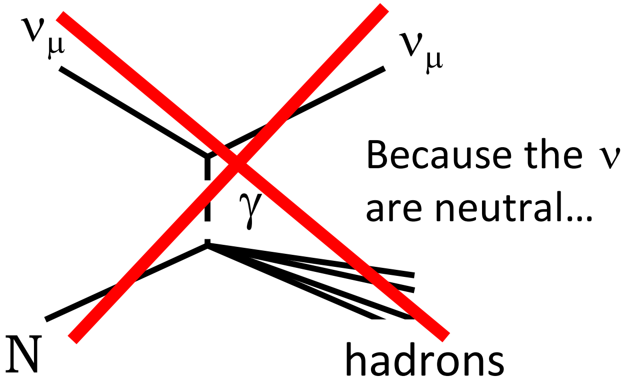


Schematically : neutral current and charged current involving neutrino

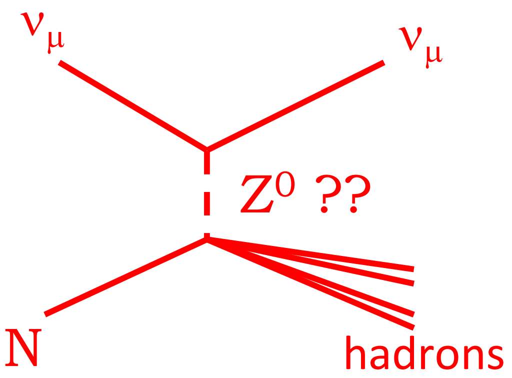
ν_μ N$\rightarrow$ μ X charged current

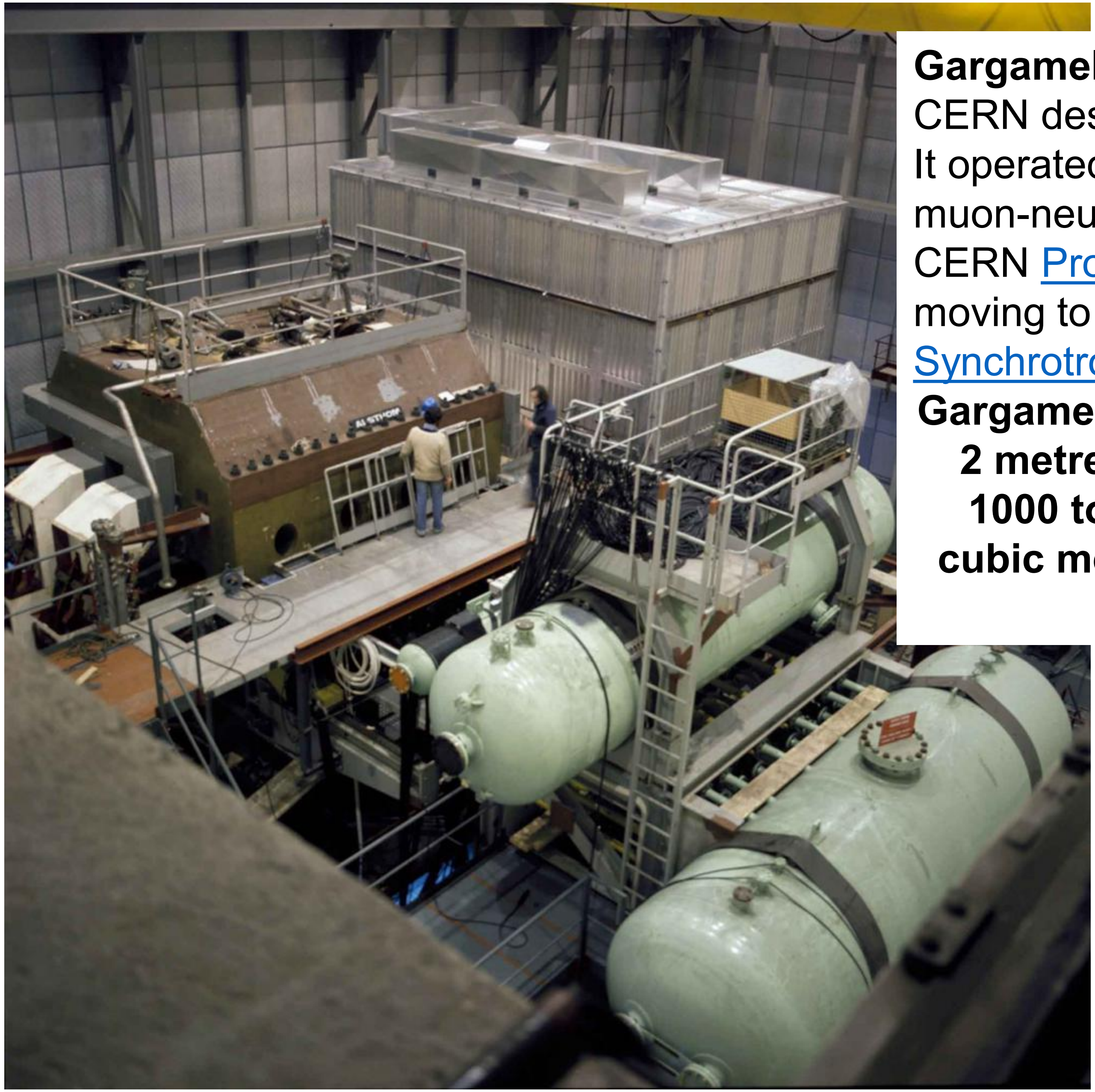
ν_μ N$\rightarrow$ ν_μ X neutral current





Because the ν are neutral...

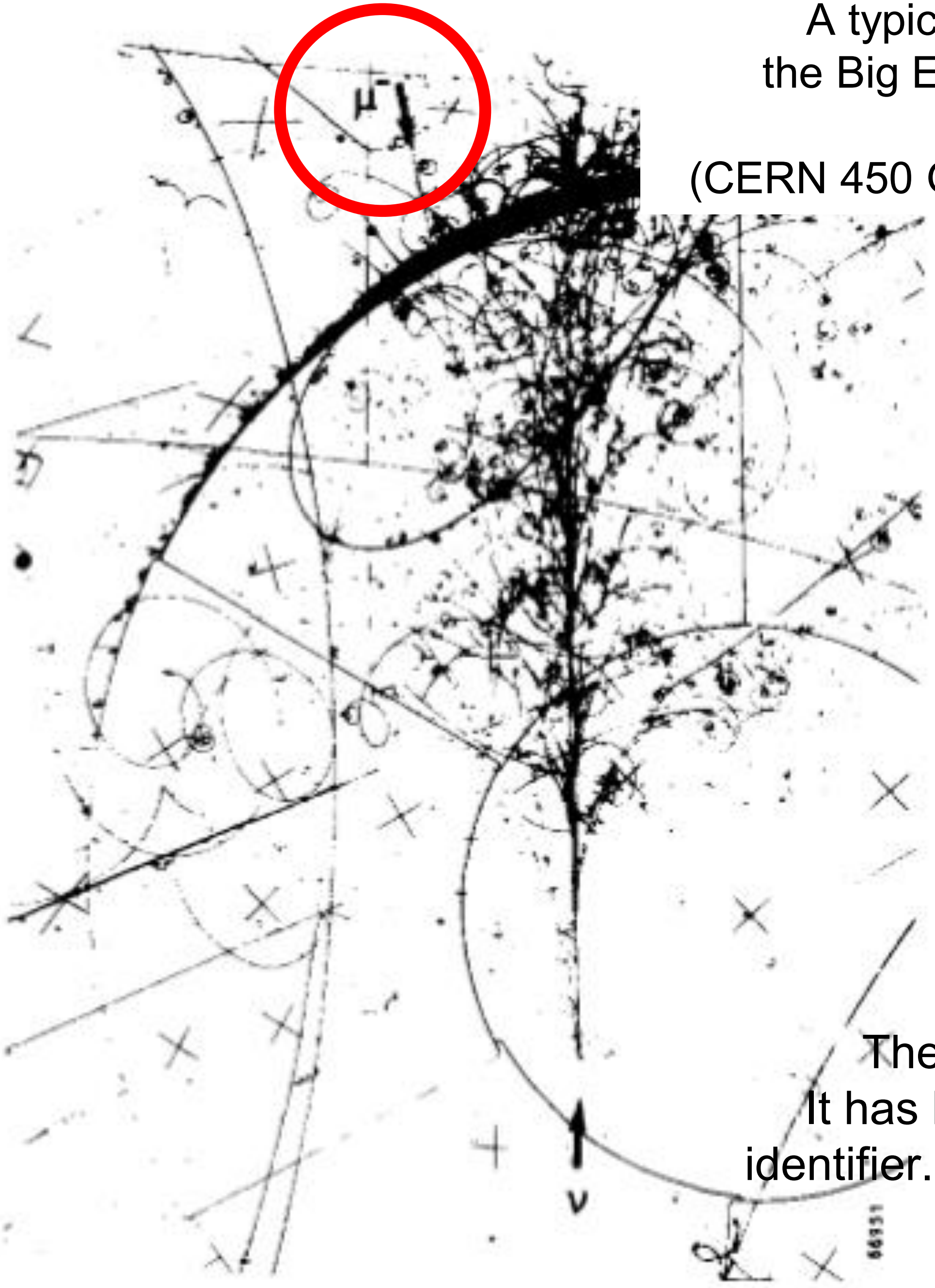


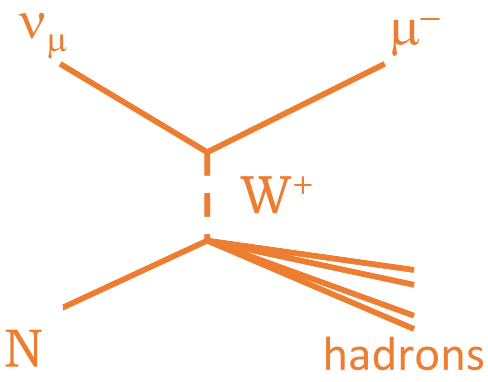


Gargamelle was a bubble chamber at CERN designed to detect neutrinos. It operated from 1970 to 1976 with a muon-neutrino beam produced by the CERN Proton Synchrotron, before moving to the Super Proton Synchrotron (SPS) until 1979.

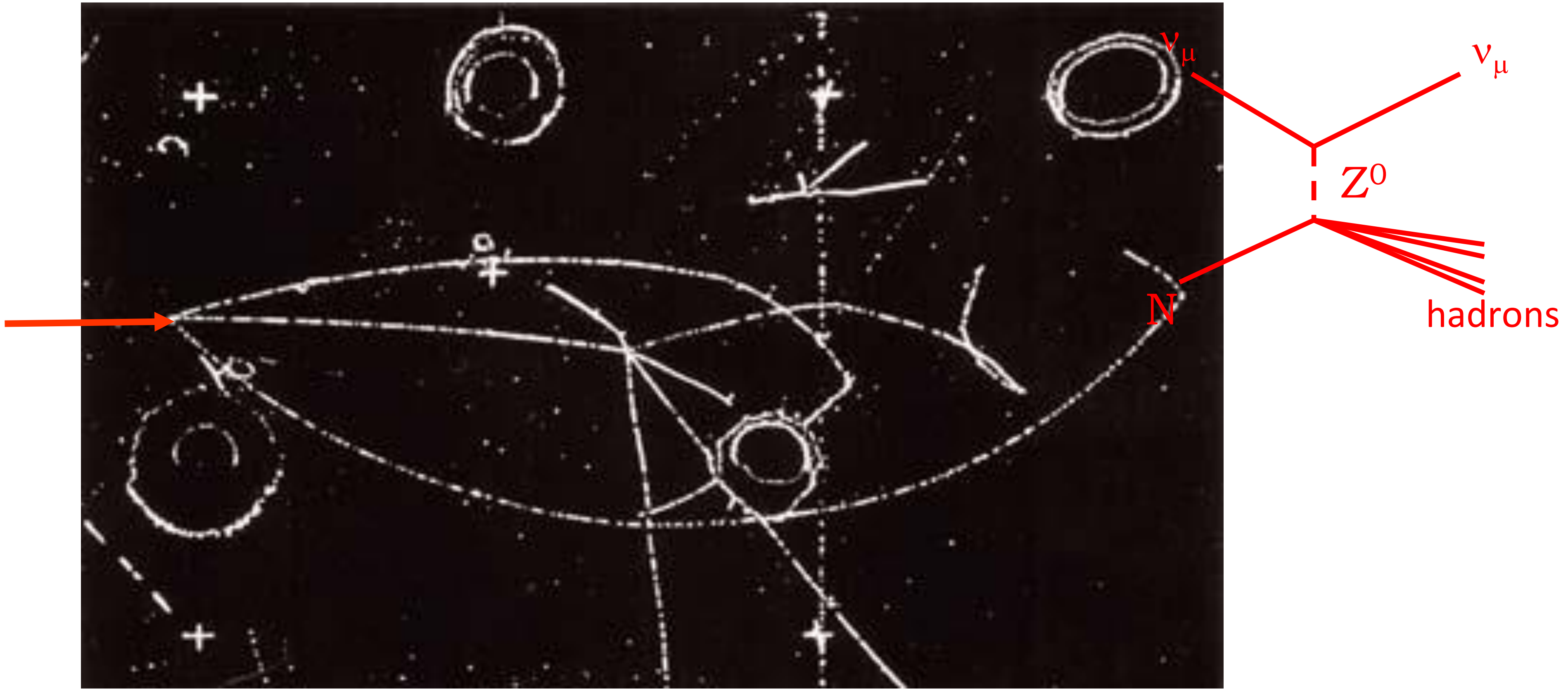
Gargamelle was 4.8 metres long and 2 metres in diameter. It weighed 1000 tonnes and held nearly 12 cubic metres of heavy-liquid freon (CF3Br).

A typical neutrino event as observed in
the Big European Bubble Chamber (BEBC)
filled with neon
(CERN 450 GeV Super Proton Synchrotron (SPS))



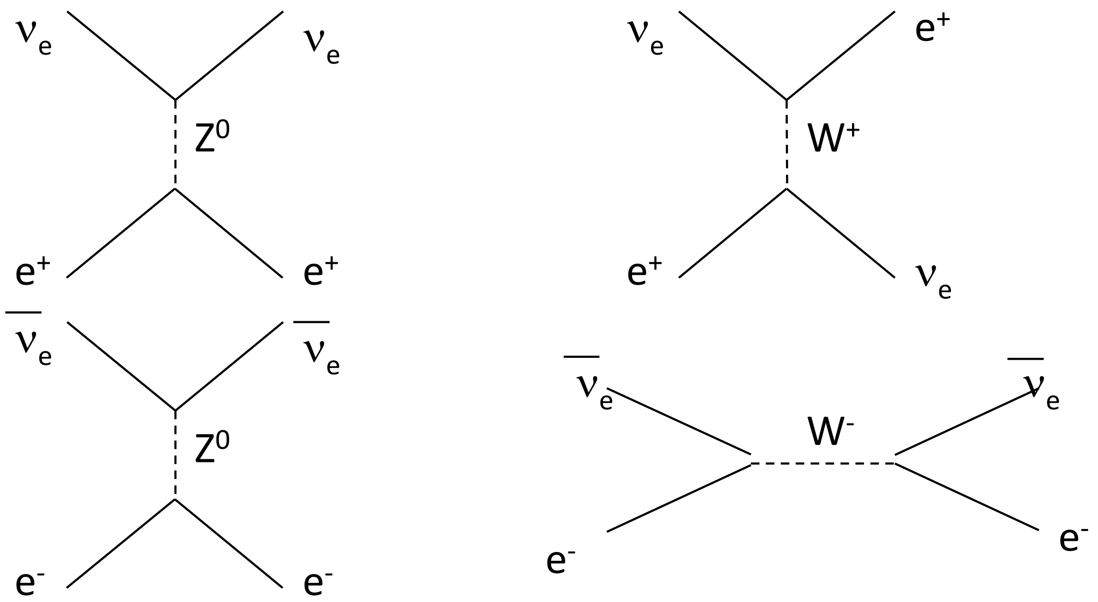


The muon can be seen on the left.
It has been tagged by an external muon
identifier. The many-particle hadron shower is
visible on the right.



hadronic neutral current event, where the interaction of the neutrino coming from the left produces three secondary particles, all clearly identifiable as hadrons, as they interact with other nuclei in the liquid. There is no charged lepton (muon or electron).

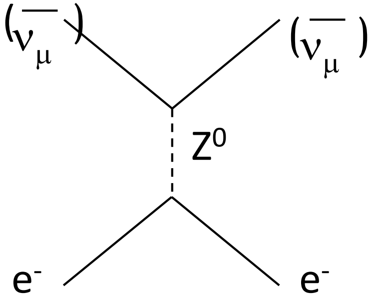
MORE diagrams concerning neutrino interaction with electrons



$\nu_e\ e^+ \to \nu_e\ e^+$

2 diagrams with W and Z

$\bar{\nu}_e\ e^- \to \bar{\nu}_e\ e^-$



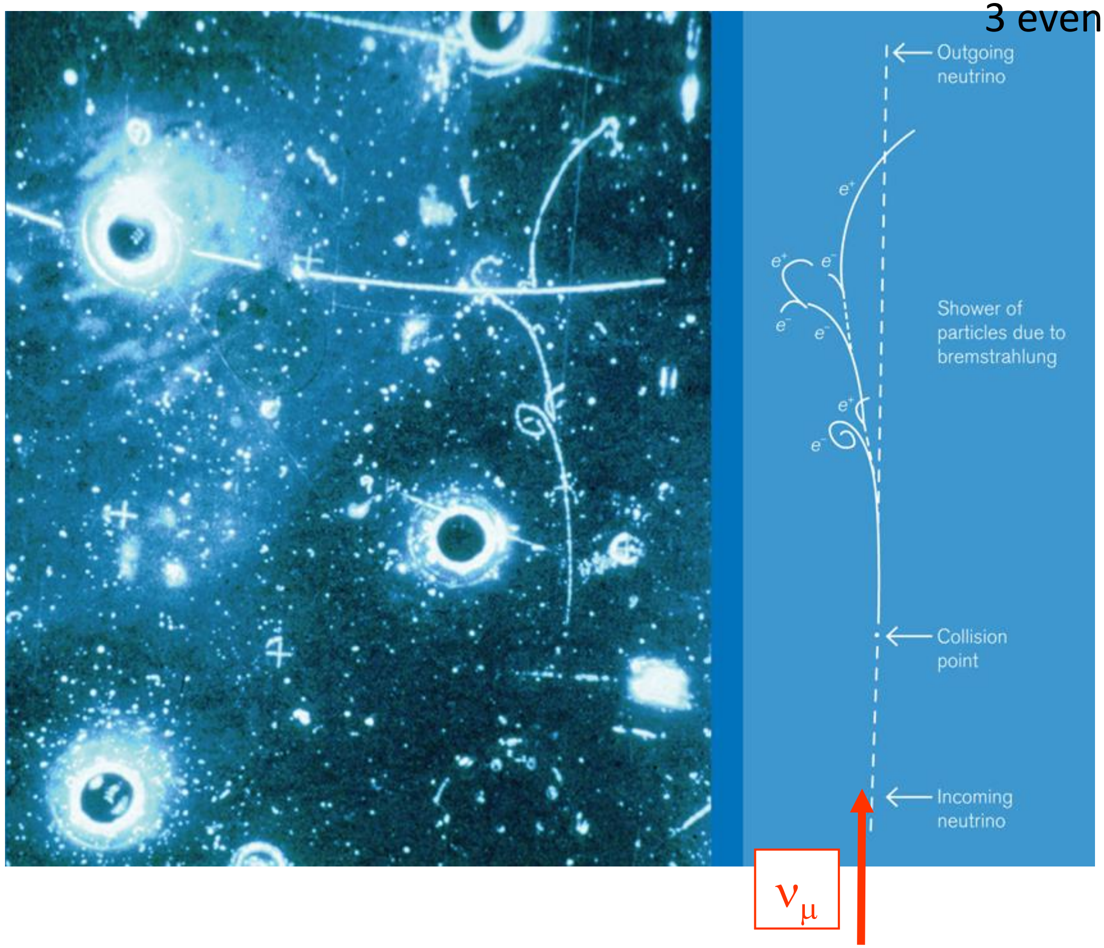
GOLDEN PLATED DIAGRAM!!

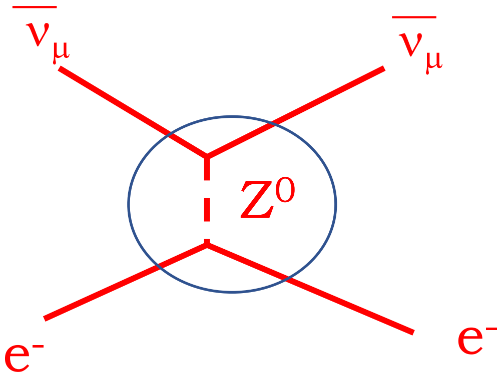
$\bar{\nu}_\mu\ e^- \to \bar{\nu}_\mu\ e^-$

No diagram with a W !
(would violate the leptonic number)

Gargamelle : Phys. Lett. B46, 138-140 (1973)

Over a total of 1.4 million pictures:
3 events (data taking : 2 ans)





GOLDEN PLATED EVENT
Almost background free !!

The electron is projected forward with an energy of 400 MeV at an angle of

1.5 ± 1.5° to the beam, entering from the right.

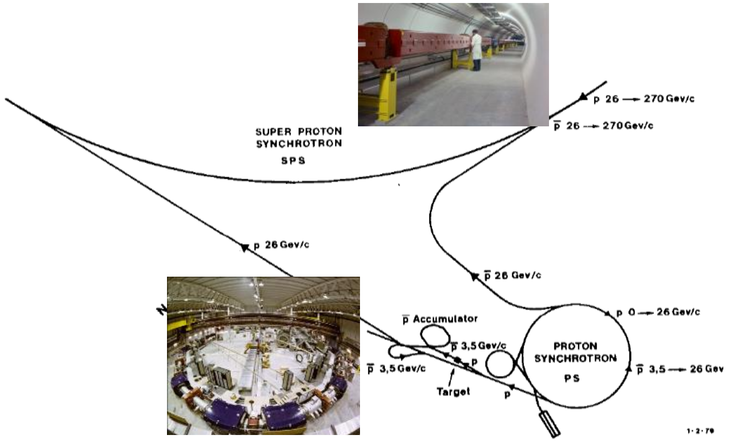
Kinematical analysis : direction close from the direction of the incoming ν beam

A little jump in Hisory !

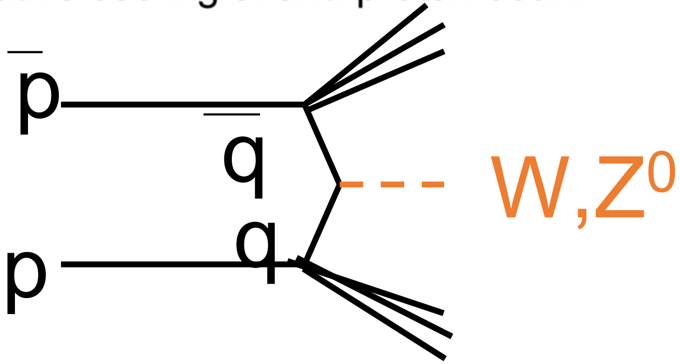
The Z0 was really discovered 15year later

THE DISCOVERY OF W^{+-} and Z^0 bosons at SPS at CERN by UA1 and UA2 Coll.

- CERN 1983
- Proton -- anti-proton collider ($Sp\bar{p}S$)
- Centre-of-mass energy 540 GeV
- Innovative cooling of anti-proton beam



Antiproton Accumulator in 1980.



$$u\bar{d} \rightarrow W^+$$

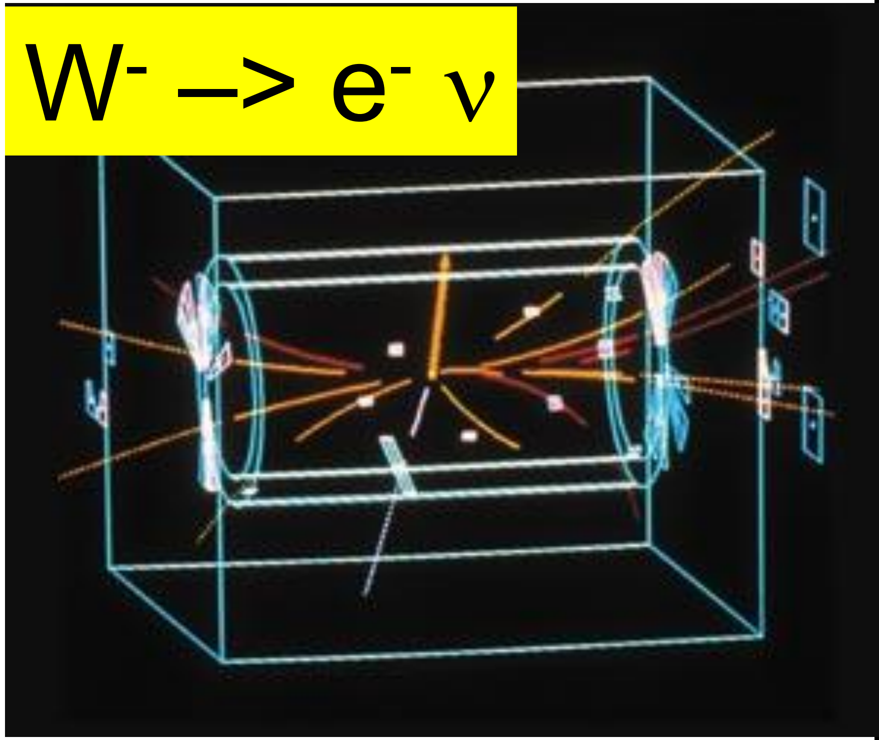
$$u\bar{u}, d\bar{d} \rightarrow Z^0$$

$$p\ p \rightarrow W^+ X^-$$

$$p\ p \rightarrow Z^0\ X^0$$

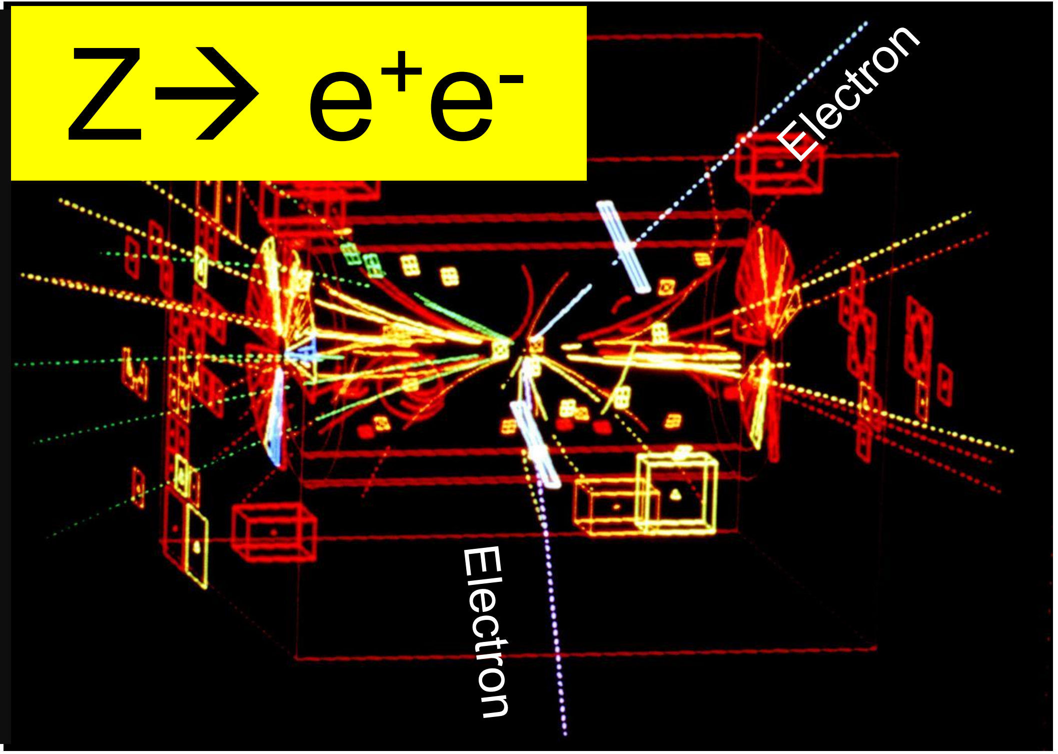
$$W^+ \rightarrow l^+\ \nu_l$$

$$Z^0 \rightarrow l^+\ l^-$$



The decay of a W particle in the UA1 detector

showing the track of the high-energy electron towards the bottom. The yellow arrow marks the direction of the missing transverse energy and hence the path of the unseen neutrino.

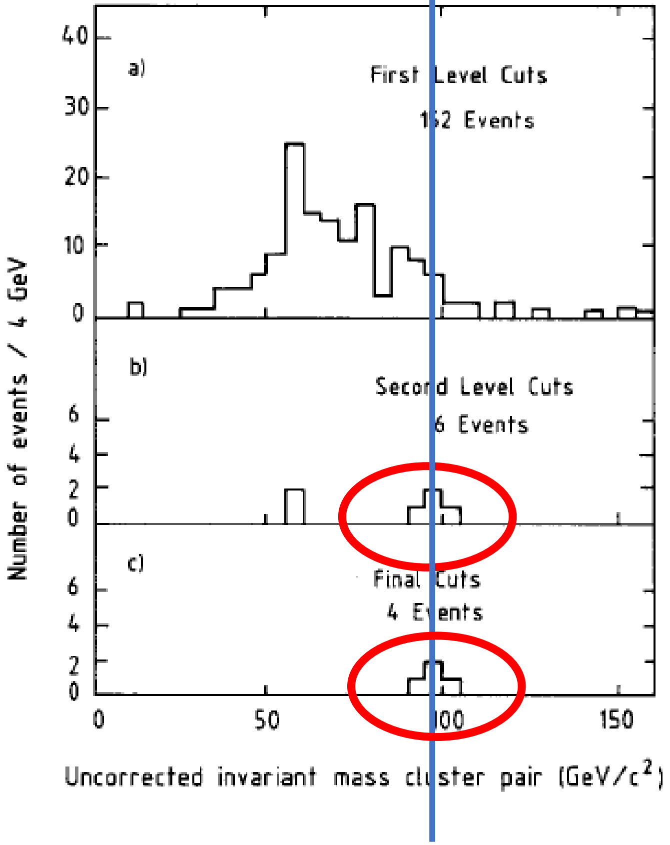


One of the first Z particles observed in UA1.

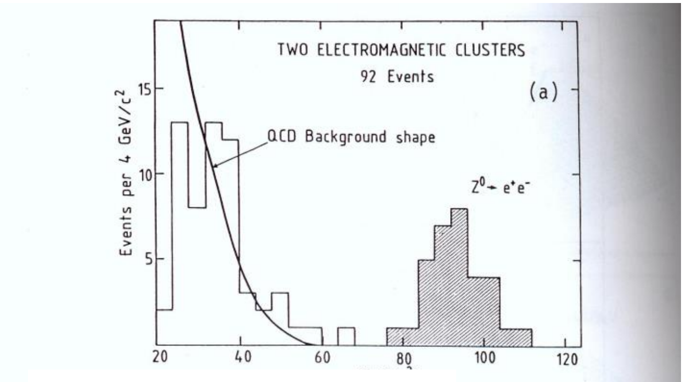
The two white tracks (towards the top right and almost directly downwards) reveal the Z's decay into an electron-positron pair that deposit their energy in the electromagnetic calorimeter.

Z^0 discovery paper

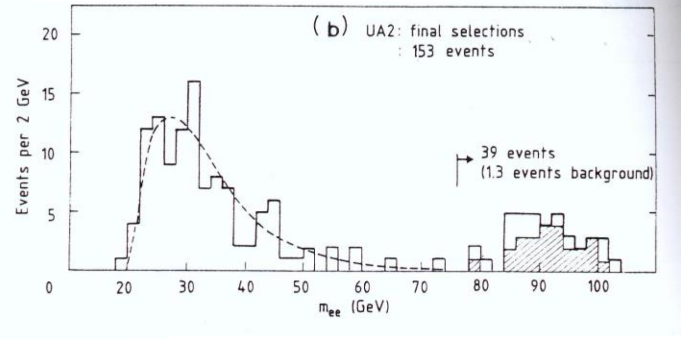
And later !



UA1 collaboration



UA1: $Z^0 \rightarrow e^+e^-$



UA2: $Z^0 \rightarrow e^+e^-$

Received 6 June 1983

We report the observation of four electron–positron pairs and one muon pair which have the signature of a two-body decay of a particle of mass ~95 GeV/c^2. These events fit well the hypothesis that they are produced by the process $\bar{p} + p \rightarrow Z^0 + X$ (with $Z^0 \rightarrow \ell^+ + \ell^-$), where Z^0 is the Intermediate Vector Boson postulated by the electroweak theories as the mediator of weak neutral currents.

SM PREDICTION !

$$M_W = \left(\frac{\sqrt{2}g^2}{8G_F}\right)^{1/2} = \left(\frac{\sqrt{2}\;4\pi\alpha}{8G_F \sin^2\theta_W}\right)^{1/2}$$

$$= \left(\frac{\pi\alpha}{\sqrt{2}G_F}\right)^{1/2} \frac{1}{\sin\theta_W} = \frac{37.28}{\sin\theta_W}[GeV]$$

$$M_W \sim 78 \text{ GeV}$$

$$M_Z = \frac{M_W}{\cos\theta_W}$$

M_Z ~90 GeV

MESUREMENTS!

And the first mass measurements of $W^{\pm}$, Z^0

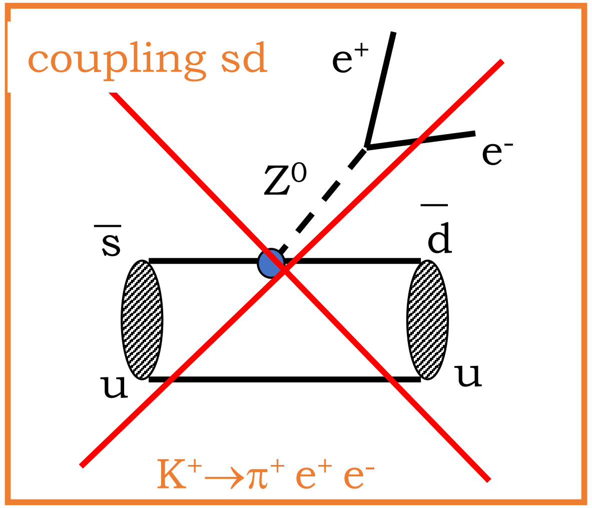
M_W = 81 ± 5 GeV

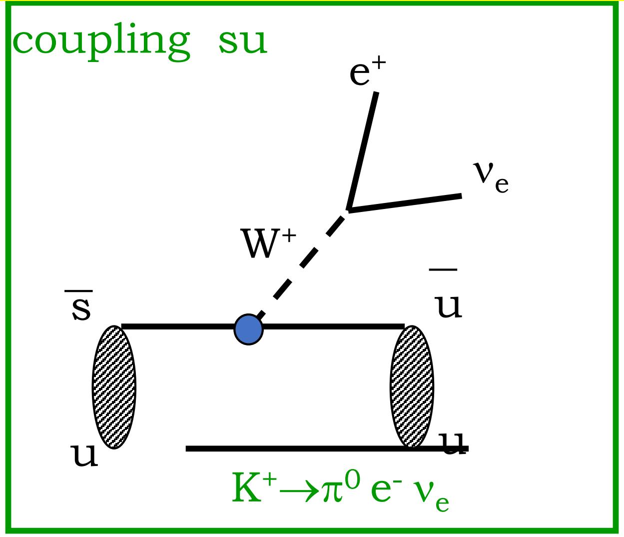
M_Z = 95.2 ± 2.5 GeV/c^2 (UA1)

= 91.9 ± 1.9 GeV/c^2 (UA2)

Absence of FCNC.

The neutral current changing the strangeness ($\Delta S=1$) not observed

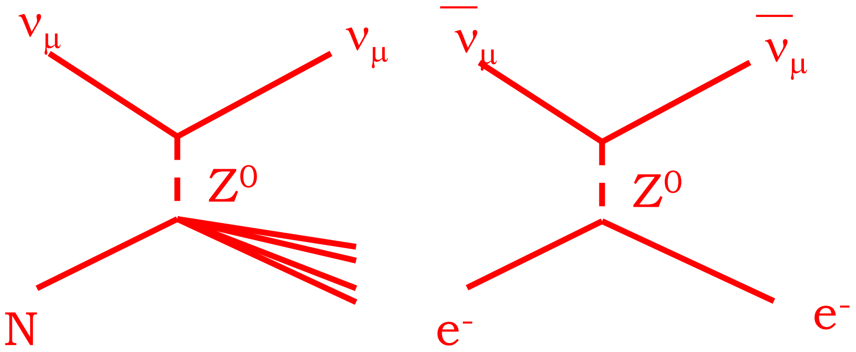




BUT Z^0 EXISTS…1973

DISCOVERY of the Neutral current.

Explained with a neutral weak boson



BACK TO THE CABIBBO THEORY

→ "predicts" flavour changing neutral transition : sd

$$u\bar{u} + d\bar{d}\cos^2\theta_c + s\bar{s}\sin^2\theta_c + \left(s\bar{d} + \bar{s}d\right)\cos\theta_c \sin\theta_c$$

$$g_{aa} = 0$$
$$g_{ud} = (g/\sqrt{2})\cos\vartheta_C$$
$$g_{us} = (g/\sqrt{2})\sin\vartheta_C$$

More formally. If we write the weak charged current

$$j_\mu^{weak} = g_{ab}\overline{q_a}\gamma_\mu\frac{(1-\gamma^5)}{2}q_b = \overline{q_{aL}}\gamma_\mu q_{bL}$$

$$q_L = \begin{pmatrix} u \\ d\cos\vartheta_C + s\sin\vartheta_C \end{pmatrix}_L$$

$$j_\mu^+ = (g/\sqrt{2})(\overline{u},\overline{d}\cos\vartheta_C + \bar{s}\cos\vartheta_C)\begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}\begin{pmatrix} u \\ d\cos\vartheta_C + s\sin\vartheta_C \end{pmatrix} =$$
$$= (g/\sqrt{2})\bar{u}d\cos\vartheta_C + (g/\sqrt{2})u\bar{s}\sin\vartheta_C$$

$$j_\mu^+ = \overline{q_L}\sigma_+ q_L \quad ; \quad \sigma_+ = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}$$

The interaction comes from a gauge group. From the previous page it seems to be clear that for the weak interactions the group is the weak isospin. σ_{+-} are the matrices which increase(decrease) of one unity the weak isospin. But to form an algebra we also need σ_3

$$j_\mu^0 = g(\overline{u},\overline{d_C})\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} u \\ d_C \end{pmatrix} =$$
$$= u\bar{u} + d\bar{d}\cos^2\theta_c + s\bar{s}\sin^2\theta_c + \left(s\bar{d} + \bar{d}s\right)\cos\theta_c\sin\theta_c$$

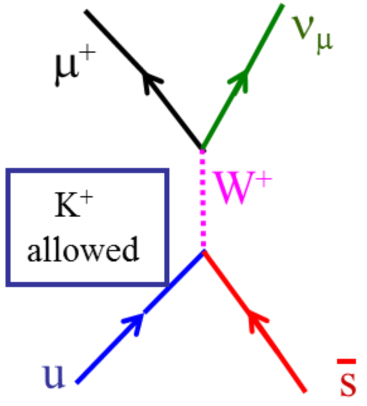
FCNC

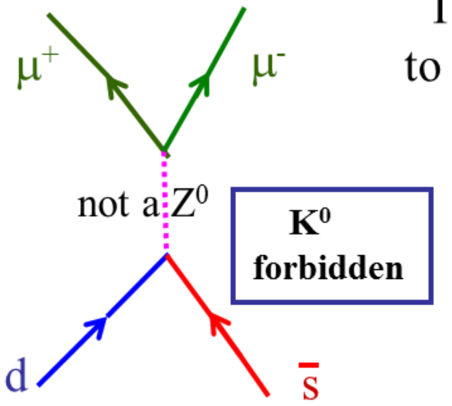
FCNC : The GIM Mechanism (1970)

..Or the « charm discovery » by FCNC in Kaon system

1969-70 Glashow, Iliopoulos, Maiani (GIM) proposed a solution to the $K^0 \to \mu^+ \mu^-$ rate puzzle.

1st Order

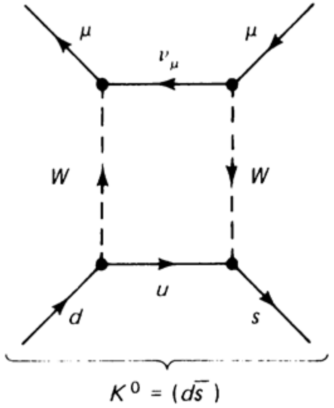


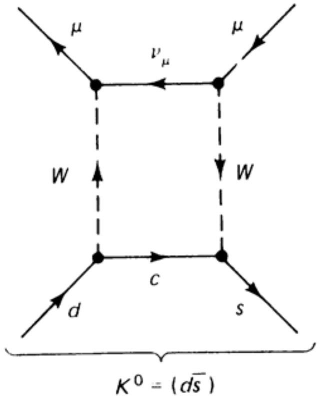


The branching fraction for $K^0 \to \mu^+ \mu^-$ expected to be small as the first order diagram is forbidden

$$\frac{BR(K^0 \to \mu^+\mu^-)}{BR(K^+ \to \mu^+\nu_\mu)} = \frac{7\times 10^{-9}}{0.64} \approx 10^{-8}$$

2nd Order





With only u quark the is an ultraviolet divergence

$$\left(m_c^2 - m_u^2\right)/m_W^2 = O(10^{-4})$$

Prediction of the charm quark with mass ~ 1.5 GeV !

Directly observed in 1973

More details

These two diagrams cancel out the divergence

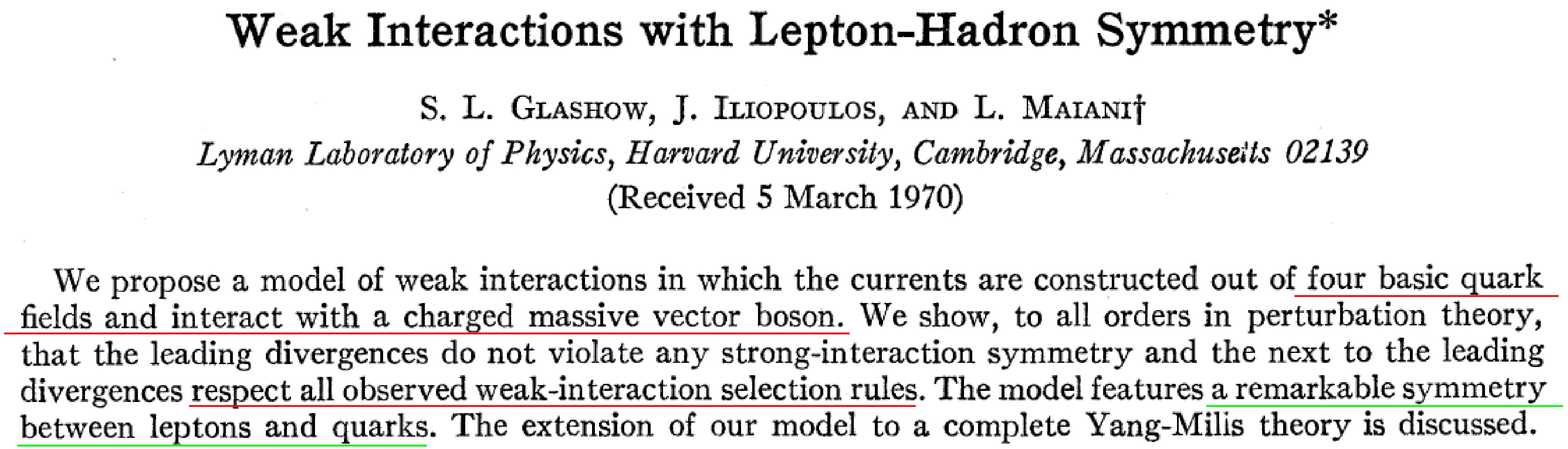
It remains a non zero contribution (which is infrared divergent) for momentum lower than the mc, which does not cancel out. The amount of cancellation depends on the mass of the new quark

$$\approx (m_c^2 - m_u^2)\cos^2 \vartheta_C \sin^2 \vartheta_C$$

For $m_c = m_u$ It would be $BR(K^0 \to \mu^+ \mu^-) = 0$

A quark mass of ≈1.5GeV is necessary to get good agreement with the experimental data.

First “evidence” for Charm quark! and the fact that m_c is such that was not yet observed…



Weak Interactions with Lepton-Hadron Symmetry*

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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.

BACK TO THE CABIBBO THEORY → predicts flavour changing neutral transition : sd

$$u\bar{u} + d\bar{d}\cos^2\theta_c + s\bar{s}\sin^2\theta_c + \left(s\bar{d} + \bar{s}d\right)\cos\theta_c \sin\theta_c \longrightarrow$$

1970 : Glashow, Iliopoulos et Maiani (GIM) proposed the introduction of **a fourth quark : the quark *c* (of charge 2/3)** :

$$\begin{pmatrix} c \\ s_c \end{pmatrix} = \begin{pmatrix} c \\ s\cos\theta_c - d\sin\theta_c \end{pmatrix}$$

Term added to the neutral coupling

$$c\bar{c} + s\bar{s}\cos^2\theta_c + d\bar{d}\sin^2\theta_c - \left(s\bar{d} + \bar{s}d\right)\cos\theta_c \sin\theta_c$$

$$\longrightarrow \quad u\bar{u} + c\bar{c} + \left(d\bar{d} + s\bar{s}\right)\cos^2\theta_c + \left(d\bar{d} + s\bar{s}\right)\sin^2\theta_c = u\bar{u} + c\bar{c} + d\bar{d} + s\bar{s}$$

1) Strange particles have a longer lifetime than expected

→ introduction of Cabibbo theory.

2) The neutral current does not change flavour : absence of FCNC and the rareness of the $K_L \rightarrow \mu\mu$

→ prediction of the existence of the charm quark !

The interaction comes from a gauge group. From the previous page it seems to be clear that for the weak interactions the group is the weak isospin. σ_{+-} are the matrices which increase(decrease) of one unity the weak isospin. But to form an algebra we also need σ_3

$$j_\mu^0 = g(\bar{u}, \bar{d}_C)\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} u \\ d_C \end{pmatrix} =$$

$$= u\bar{u} + d\bar{d}\cos^2\theta_c + s\bar{s}\sin^2\theta_c + \left(s\bar{d} + \bar{d}s\right)\cos\theta_c \sin\theta_c$$

FCNC

introducing

$$\begin{pmatrix} c \\ s_C = -d\sin\vartheta_C + s\cos\vartheta_C \end{pmatrix}_L$$

Absence of FCNC

$$j_\mu^0 = g(\bar{u}, \bar{d}_C)\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} u \\ d_C \end{pmatrix} + g(\bar{c}, \bar{s}_C)\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} c \\ s_C \end{pmatrix} = \quad u\bar{u} + d\bar{d} + s\bar{s} + c\bar{c}$$

$$j_\mu^0 = \overline{q_L}\sigma_3 q_L \quad ; \quad \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

adding the charm in the charged currents

$$q = \begin{pmatrix} c \\ -d\sin\vartheta_C + s\cos\vartheta_C \end{pmatrix}$$

$$j_\mu^+ = (g/\sqrt{2})(\bar{c}, -\bar{d}\sin\vartheta_C + \bar{s}\cos\vartheta_C)\begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}\begin{pmatrix} c \\ -d\sin\vartheta_C + s\cos\vartheta_C \end{pmatrix} =$$

$$= -(g/\sqrt{2})\bar{c}d\sin\vartheta_C + (g/\sqrt{2})c\bar{s}\cos\vartheta_C$$

$$j_\mu^+ = g/\sqrt{2}(\overline{u},\overline{d_C})\begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}\begin{pmatrix} u \\ d_C \end{pmatrix} + g/\sqrt{2}(\overline{c},\overline{s_C})\begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}\begin{pmatrix} c \\ s_C \end{pmatrix}$$

$$\rightarrow \quad \begin{pmatrix} d_C \\ s_C \end{pmatrix} = V\begin{pmatrix} d \\ s \end{pmatrix} \quad \textit{with} \quad V = \begin{pmatrix} \cos\theta_c & \sin\theta_c \\ -\sin\theta_c & \cos\theta_c \end{pmatrix}$$

$$\boxed{\begin{array}{l} (\bar{u},\bar{c})\gamma^\mu(1-\gamma_5)V\begin{pmatrix} d \\ s \end{pmatrix} \\ V = \begin{pmatrix} \cos\theta_c & \sin\theta_c \\ -\sin\theta_c & \cos\theta_c \end{pmatrix} \end{array}}$$

Cabibbo Matrix

$$\left(\bar{u},\bar{c}\right)\gamma^{\mu}\left(1-\gamma_5\right)V\begin{pmatrix} d \\ s \end{pmatrix}$$

$$\begin{pmatrix} d_C \\ s_C \end{pmatrix} = V \begin{pmatrix} d \\ s \end{pmatrix} \qquad V = \begin{pmatrix} \cos\theta_c & \sin\theta_c \\ -\sin\theta_c & \cos\theta_c \end{pmatrix}$$

neutron decay $u\bar{d}$ $\sim G_F^2\cos^2\theta_c \sim G_F^2$

Strange particles $u\bar{s}$ $\sim G_F^2\sin^2\theta_c$

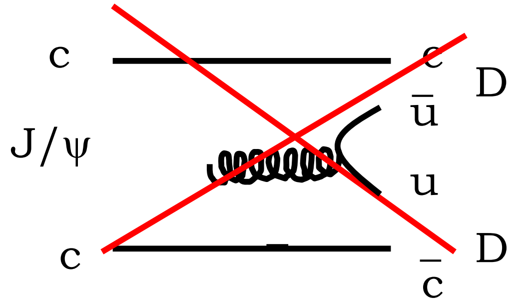
Charm sector
$$\begin{cases} c\bar{d} & \sim G_F^2\sin^2\theta_c \\ c\bar{s} & \sim G_F^2\cos^2\theta_c \sim G_F^2 \end{cases}$$

Predictions !

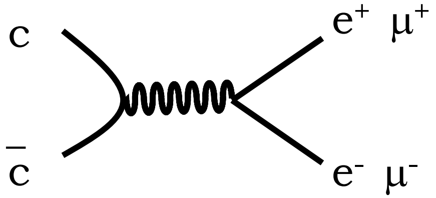
1974 : c quark Discovery : J/ψ

Seen as a resonance **m~3.1 GeV** **Γ~10-100KeV**

$m(J/\psi) < 2\ m(D^0)$

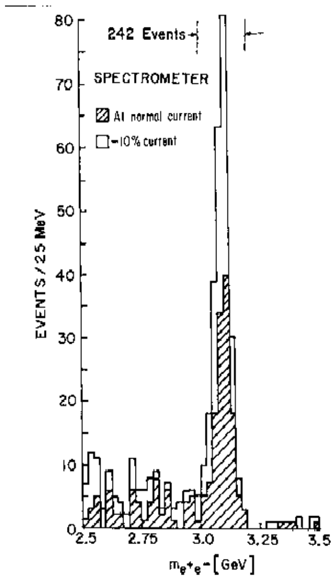


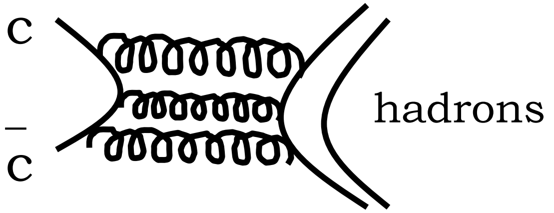
•Brookhaven (p on Be target)



e^+e^- final state

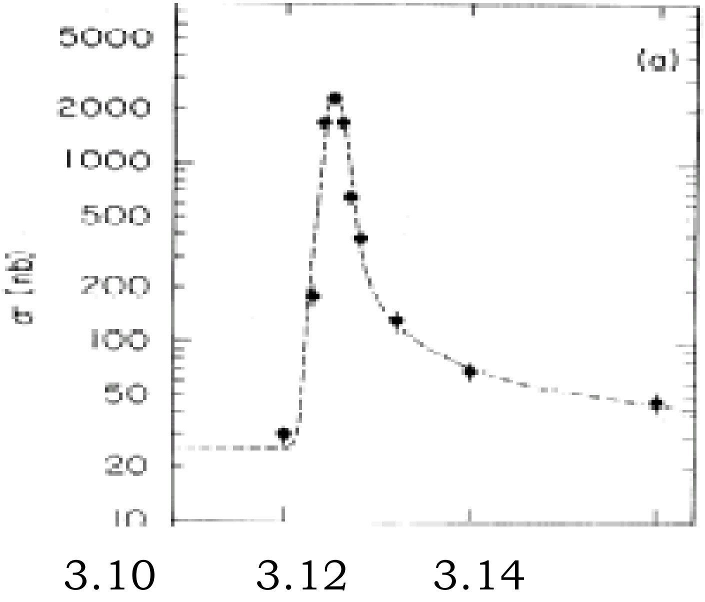
Γ(ee)~5 KeV
Γ(μμ)~5 KeV





Γ~70 KeV

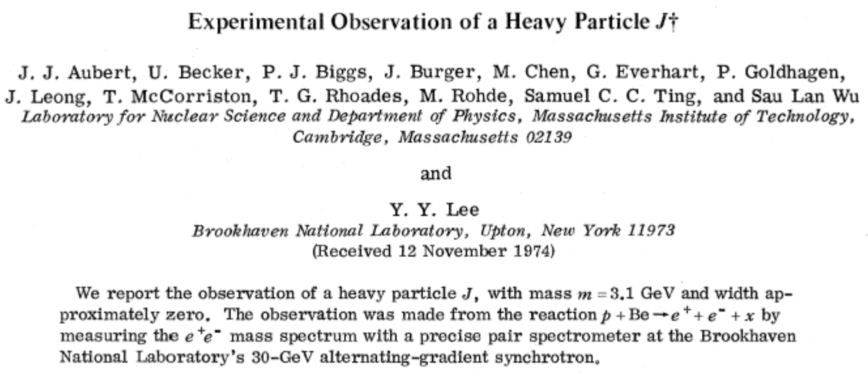
SLAC (e+e-)



hadronic final state

The decay through strong interaction is so suppressed that the electromagnetic interaction becomes important

Discovery of the J/ψ



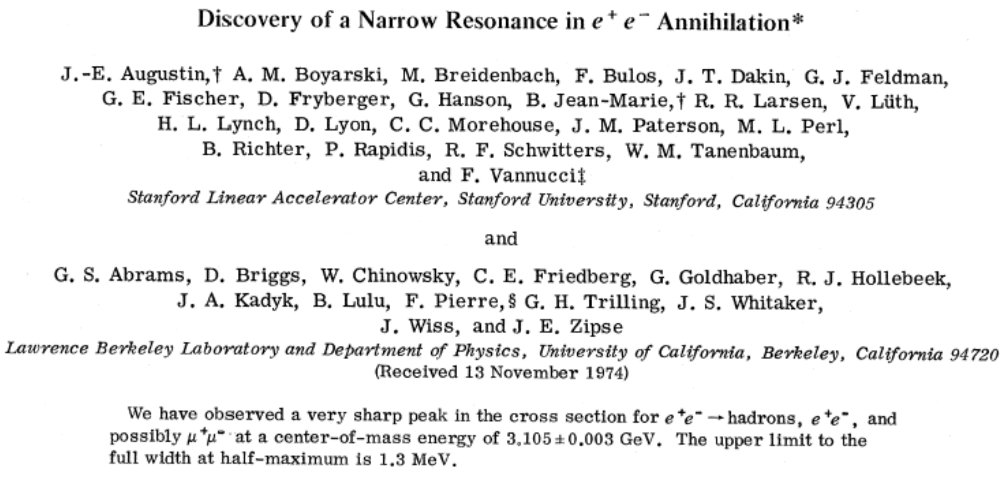
Experimental Observation of a Heavy Particle J†

J. J. Aubert, U. Becker, P. J. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen,
J. Leong, T. McCorriston, T. G. Rhoades, M. Rohde, Samuel C. C. Ting, and Sau Lan Wu
Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology,
Cambridge, Massachusetts 02139

and

Y. Y. Lee
Brookhaven National Laboratory, Upton, New York 11973
(Received 12 November 1974)

We report the observation of a heavy particle J, with mass $m = 3.1$ GeV and width approximately zero. The observation was made from the reaction $p + \mathrm{Be} \to e^+ + e^- + x$ by measuring the e^+e^- mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory's 30-GeV alternating-gradient synchrotron.



Discovery of a Narrow Resonance in e^+e^- Annihilation*

J.-E. Augustin,† A. M. Boyarski, M. Breidenbach, F. Bulos, J. T. Dakin, G. J. Feldman,
G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie,† R. R. Larsen, V. Lüth,
H. L. Lynch, D. Lyon, C. C. Morehouse, J. M. Paterson, M. L. Perl,
B. Richter, P. Rapidis, R. F. Schwitters, W. M. Tanenbaum,
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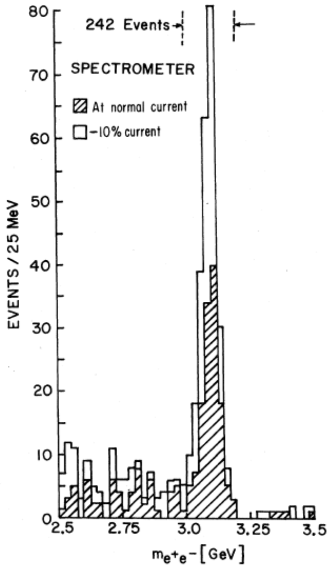
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

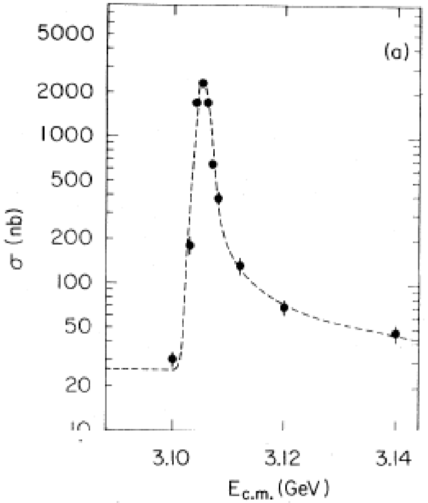
and

G. S. Abrams, D. Briggs, W. Chinowsky, C. E. Friedberg, G. Goldhaber, R. J. Hollebeek,
J. A. Kadyk, B. Lulu, F. Pierre,§ G. H. Trilling, J. S. Whitaker,
J. Wiss, and J. E. Zipse
Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720
(Received 13 November 1974)

We have observed a very sharp peak in the cross section for $e^+e^- \to$ hadrons, e^+e^-, and possibly $\mu^+\mu^-$ at a center-of-mass energy of 3.105 ± 0.003 GeV. The upper limit to the full width at half-maximum is 1.3 MeV.



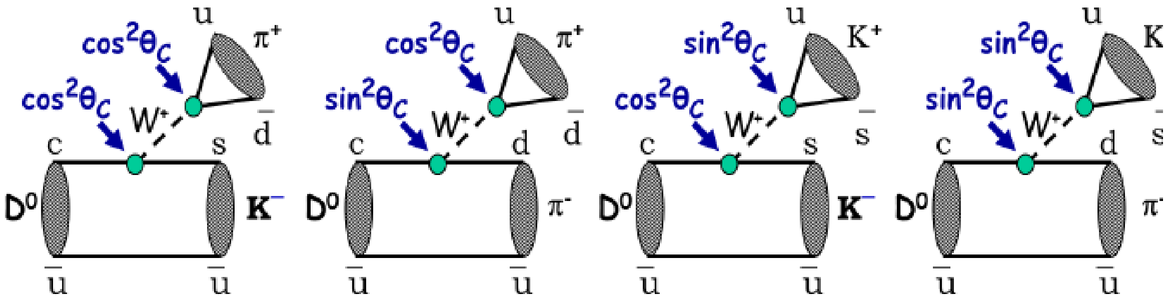
Brookhaven: J



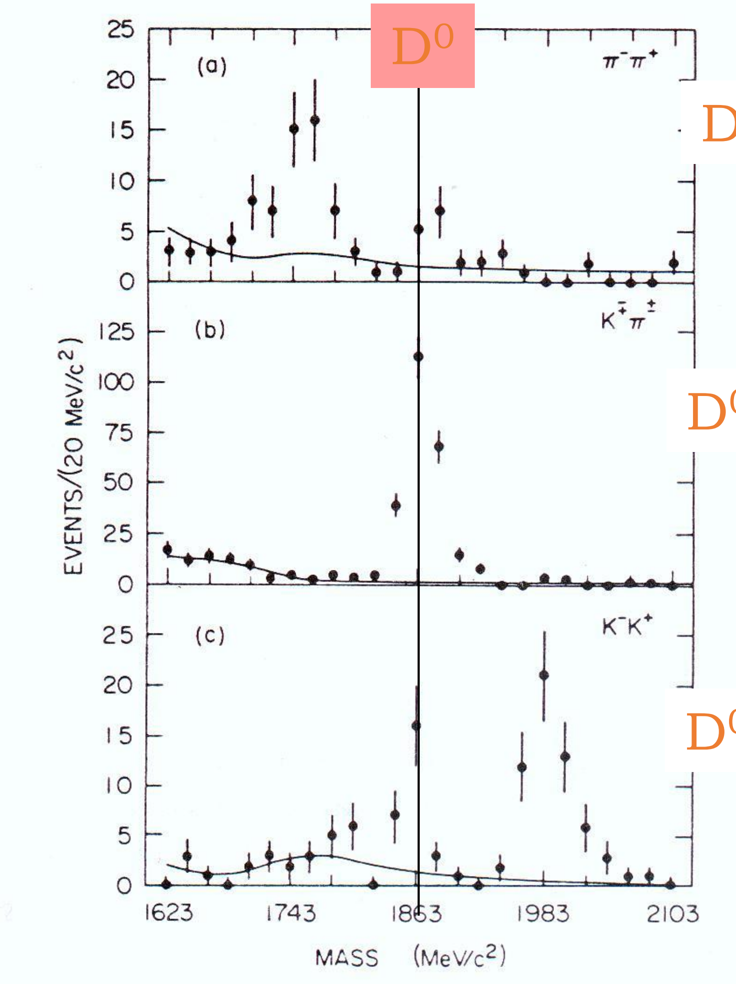
SLAC: ψ(3105)

The Charm mesons decays

➔ explanation of many measurements :



BR ($D^0 \rightarrow K^- \pi^+$) >> BR ($D^0 \rightarrow K^- K^+, \pi^- \pi^+$) >> BR ($D^0 \rightarrow K^+ \pi^-$)

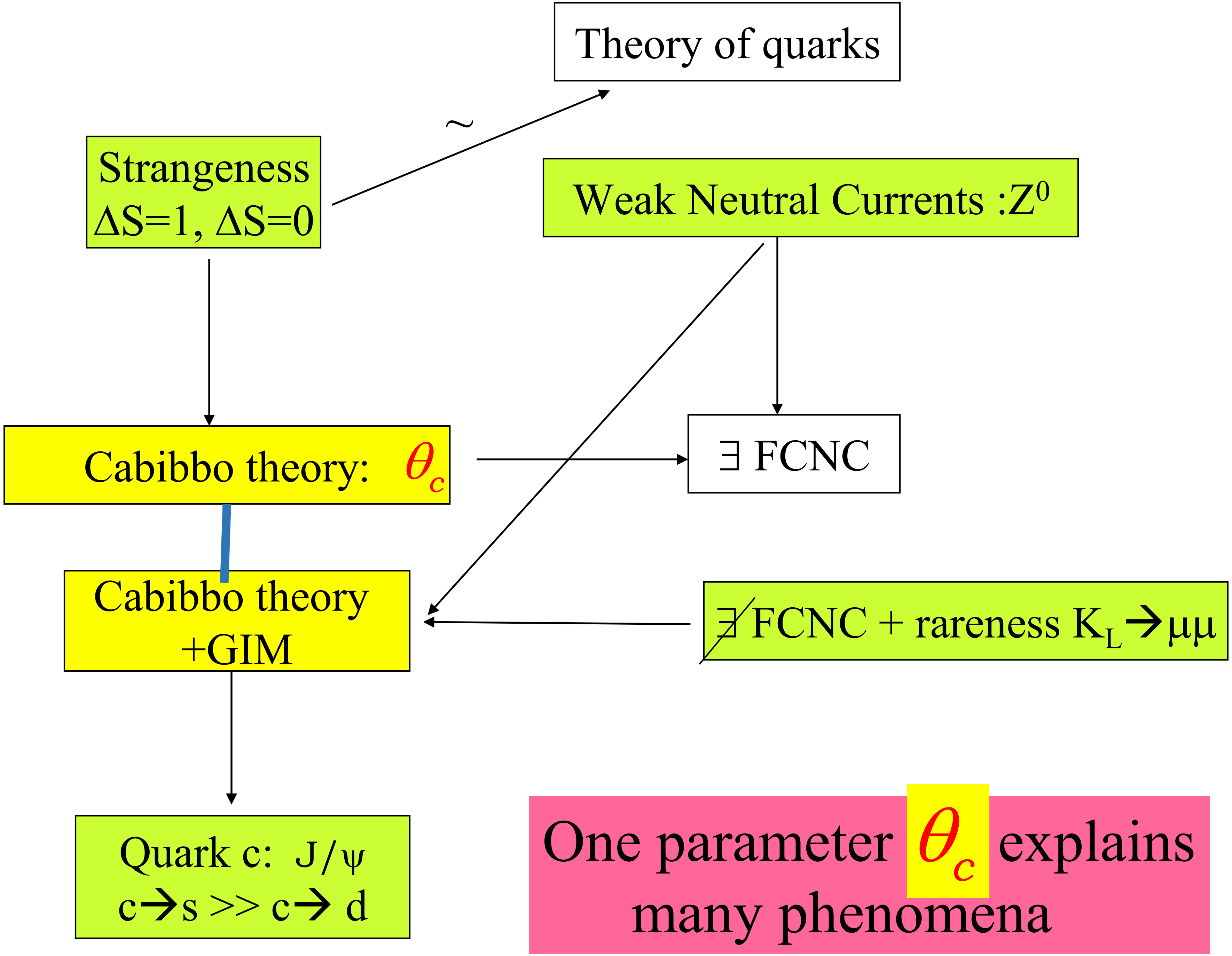


$D^0 \rightarrow \pi^+ \pi^-$

$D^0 \rightarrow \pi^+ K^-$

Dominant
Decay mode

$D^0 \rightarrow K^+ K^-$



Theory of quarks

~

Strangeness

$\Delta S=1$, $\Delta S=0$

Weak Neutral Currents : Z^0

Cabibbo theory: θ_c

∃ FCNC

Cabibbo theory

+GIM

∄ FCNC + rareness $K_L \to \mu\mu$

Quark c: J/ψ

$c \to s \gg c \to d$

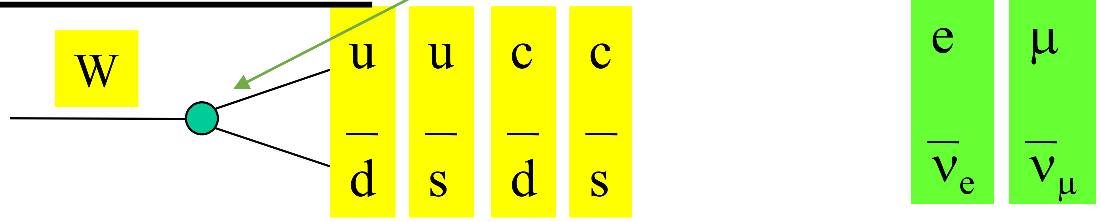
One parameter θ_c explains many phenomena

Important CONCLUSION

CONTRARY TO THE LEPTON SECTOR

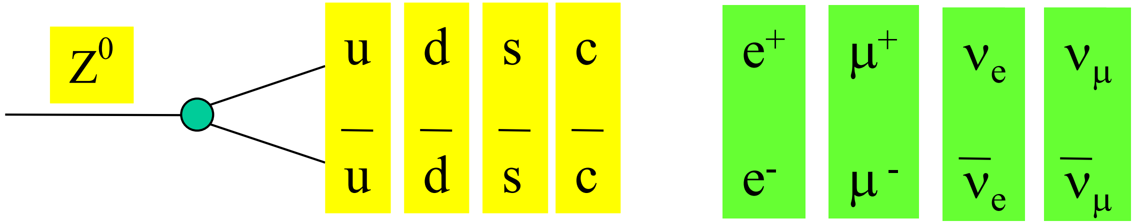
The charged current coupling for quarks is not anymore universal

and this is codified in the **Cabibbo** matrix.



The neutral currents stay universal

we do not need extra parameters for their complete description



and this is completly included and comes out « naturally » from the Standard Model

We are still in a 2 X 2 world
made by
u, d , s , c quarks….