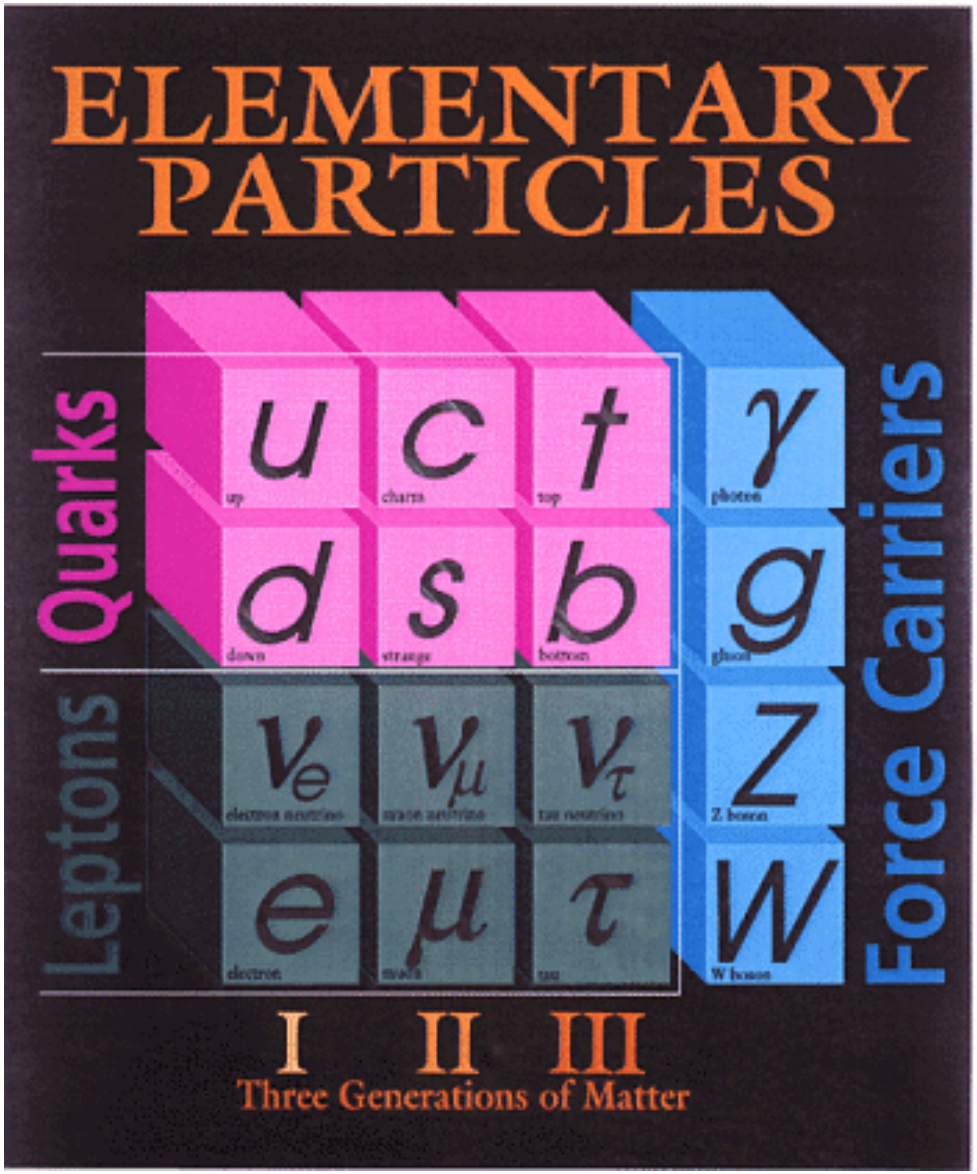
WHAT DO THESE VARIOUS LABELS MEAN ?



CLASSIFICATION BY SPIN/STATICS & FORCES ACTING

PARTICLE	SPIN/STAT.	WEAK	EM	STRONG
γ	GAUGE BOSONS	x	✓	x
$W^{\pm}$ Z^{0}		✓	✓	x
GLUON		x	x	✓
LEPTONS				
NEUTRINO ν	FERMION	✓	x	x
ELECTRON e	FERMION	✓	✓	x
MUON μ	FERMION	✓	✓	x
TAU τ	FERMION	✓	✓	x
HADRONS				
MESONS	BOSONS	✓	✓	✓
BARYONS	FERMIONS	✓	✓	✓
QUARKS	FERMIONS	✓	✓	✓

FORCES

WHAT DO LABELS MEAN ?

COMPOSIT

MATTER

Table 1.3. *The boson mediators*

RELATIVE STRENGTH	Interaction	Mediator	Spin/parity	GAUGE GROUP
1	strong	gluon, G	1^-	SU(3)
10^{-2}	electromagnetic	photon, γ	1^- $\hbar$	SU(2)
10^{-7}	weak	$W^{\pm}$, Z^0	1^-, 1^+	U(1)
10^{-39}	gravity	graviton, g	2^+	?

- STRONG BINDS QUARKS INTO PROTONS/NEUTRONS ETC
  "REMNANT" BINDS NUCLEONS IN NUCLEUS
- ELECTROMAGNETIC ATOMS, MOLECULES, CHEMISTRY
  LIFE ....
- WEAK RADIOACTIVE β DECAY, NEUTRINOS, STARS,
  SUPERNOVAE
- GRAVITATION BULK MATTER IS ELECTRICALLY NEUTRAL
  GRAVITY ONLY +VE $\Longrightarrow$ DOMINATES UNIVERSE

Table 1.2. *The fundamental fermions*

Particle	Flavour			$Q/\lvert e\rvert$
leptons	e	μ	τ	-1
	ν_e	ν_μ	(ν_τ)	0
quarks	u	c	t	$+\frac{2}{3}$
	d	s	b	$-\frac{1}{3}$

SOME KIND OF CONSERVED QUANTUM NUMBER

ELECTRIC CHARGE

Table 1.4. *Lepton masses in energy units mc^2*

Flavour	Charged lepton mass	Neutral lepton mass	LIFETIME
e	$m_e = 0.511$ MeV	$m_{\nu_e} \leq 10$ eV	STABLE
μ	$m_\mu = 105.66$ MeV	$m_{\nu_\mu} \leq 0.16$ MeV	$2 \cdot 2 \times 10^{-6}$ s
τ	$m_\tau = 1777$ MeV	$m_{\nu_\tau} \leq 18$ MeV	$2 \cdot 9 \times 10^{-13}$ s

FLAVOUR

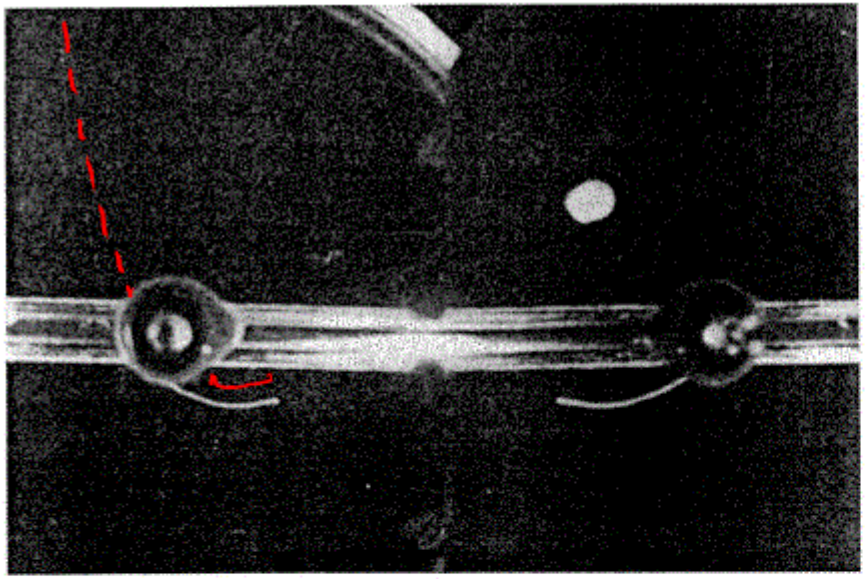
$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$ e, μ CONSERVED QUANTUM NUMBER

$\nu_\mu n \rightarrow \mu^- p$

$\nu_\mu n \not\rightarrow e^- p$

STABILITY OF ELECTRON $\rightarrow$ EXPERIMENTAL

$\tau (e \rightarrow \gamma \nu_e) > 4 \times 10^{23}$ YEARS



- μ DETECTED IN COSMIC RAYS
- FIRST SIGN OF FLAVOUR GENERATIONS

I. I. RABI " A HEAVY ELECTRON? WHO ORDERED THAT!?

- $q_\mu = q_e$
- $m_\mu \simeq 207\, m_e$
- POINT PARTICLE
- $g_\mu = g_\mu^{DIRAC} \simeq g_e$

REPRISE ON LEPTON FLAVOUR

- e^-, μ^-, τ^- INTERACT VIA EM + WEAK
- ν_e, ν_μ, ν_τ INTERACT VIA WEAK
- $L_e \; L_\mu \; L_\tau = +1$ LEPTON FLAVOUR

$$\pi^+ \rightarrow \mu^+ \; \nu_\mu$$
$L_\mu = 0 \quad -1 \quad +1 \quad \Sigma = 0$ CONSERVED

$$\mu^+ \rightarrow e^+ \; \nu_e \; \bar{\nu}_\mu$$
$L_\mu = -1 \quad 0 \quad 0 \quad -1 \quad \Sigma = -1$ CONSERVED
$L_e = 0 \quad -1 \quad +1 \quad 0 \quad \Sigma = 0$ CONSERVED

$$\nu_e \, n \rightarrow p \; e^-$$
$L_e \quad +1 \; 0 \quad 0 \; +1$ CONSERVED

$$\nu_e \, n \not\rightarrow p \; \mu^-$$
$L_e \quad +1 \; 0 \quad 0 \; 0$ NOT CONSERVED

$$\nu_\mu \, n \rightarrow p \; \mu^-$$
$L_\mu \quad +1 \; 0 \quad 0 \; +1$ CONSERVED

THIS IS HOW EXPERIMENT SHOWED

$\nu_e \neq \nu_\mu$

Table 1.5. *Constituent quark masses*

Flavour	Quantum number	Rest mass, GeV/c^2
up or down	FLAVOUR	$m_u \simeq m_d \simeq 0.31$
strange	$S = -1$	$m_s \simeq 0.50$
charm	$C = +1$	$m_c \simeq 1.6$
bottom	$B = -1$	$m_b \simeq 4.6$
top	$T = +1$	$m_t \simeq 180$

- QUARKS INTERACT VIA STRONG (COLOUR) EM, WEAK
- QUARK FLAVOUR CONSERVED BY COLOUR FORCE
  CONSERVED BY EM FORCE
  NOT CONSERVED BY WEAK FORCE

HADRONS – COLOURED QUARK "CHEMISTRY"

Table 1.6. *Quark composition of some meson and baryon states (masses in MeV/c^2 in parentheses), together with values of strangeness, S*

Meson	Composition	S	Baryon	Composition	S
$\pi^+(140)$	$u\bar{d}$	0	$p(931)$	uud	0
$K^0(498)$	$d\bar{s}$	+1	$\Lambda(1116)$	uds	−1
$K^-(494)$	$\bar{u}s$	−1	$\Xi^0(1315)$	uss	−2
$\rho^-(770)$	$\bar{u}d$	0	$\Sigma^+(1189)$	uus	−1
$\omega^0(783)$	$u\bar{u}$	0	$\Omega^-(1672)$	sss	−3

QUARKS BOUND (CONFINED) BY COLOUR FORCE

SOME DECAYS OF THE Σ BARYON

Table 2.1. *Decays of Σ baryons. The Q-value gives the total kinetic energy liberated in the decay*

Baryon	Composition	Q-value, MeV	Decay mode	Lifetime, s
$\Sigma^0(1192)$	uds	74	$\Lambda\gamma$	10^{-19}
$\Sigma^+(1189)$	uus	189	$p\pi_0$	10^{-10}
$\Sigma^0(1385)$	uds	208	$\Lambda\pi^0$	10^{-23}

EM

WEAK

STRONG

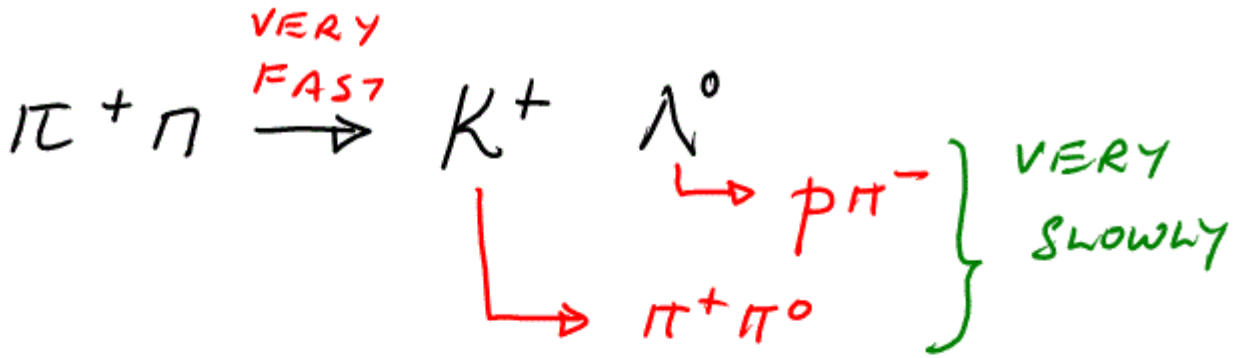
ONE S QUARK IN INITIAL STATE

NO S QUARK IN FINAL STATE

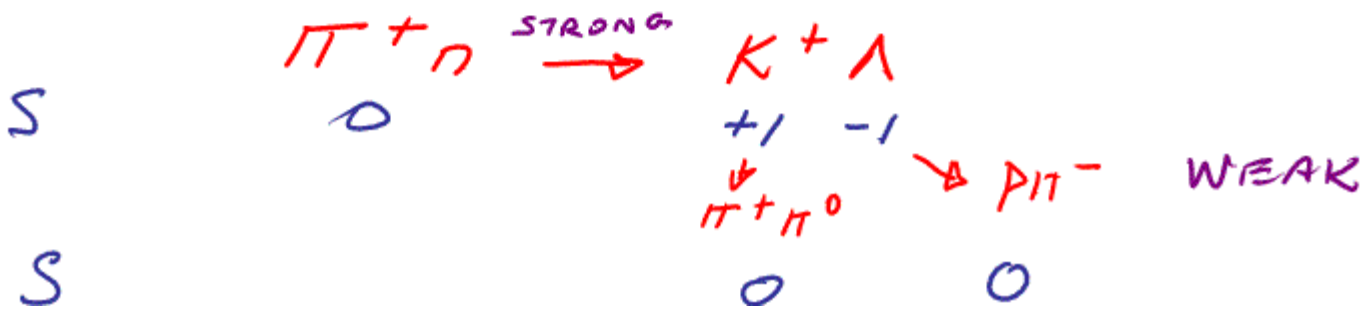
TIME SCALE

ONE S QUARK IN FINAL STATE

FIRST EVIDENCE FOR QUARK FLAVOUR



- K^+, Λ^0 PRODUCED VIA STRONG INTERACTION
- DECAY SLOWLY VIA WEAK INTERACTION
  - STRONG CONSERVES "STRANGENESS"
  - NO LIGHTER STRANGE PARTICLES
  - WEAK DOES NOT CONSERVE STRANGENESS
- PRODUCED IN PAIRS OF OPPOSITE "S"
  - STRONG CONSERVES "S"

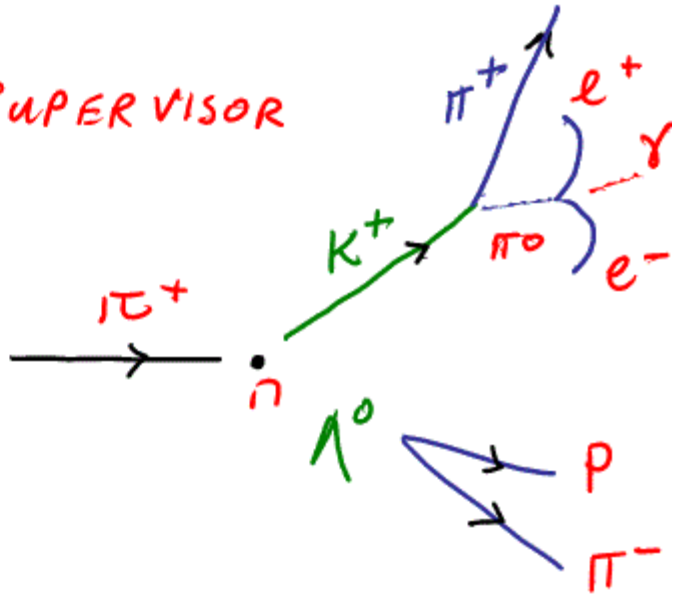


EVIDENCE FOR THE EXISTENCE OF NEW UNSTABLE ELEMENTARY PARTICLES

By Dr. G. D. ROCHESTER
AND
Dr. C. C. BUTLER
Physical Laboratories, University, Manchester

MY Ph. D. SUPERVISOR

AMONG some fifty counter-controlled cloud-chamber photographs of penetrating showers which we have obtained during the past year as part of an investigation of the nature of penetrating particles occurring in cosmic ray showers under lead, there are two photographs containing forked tracks of a very striking character.



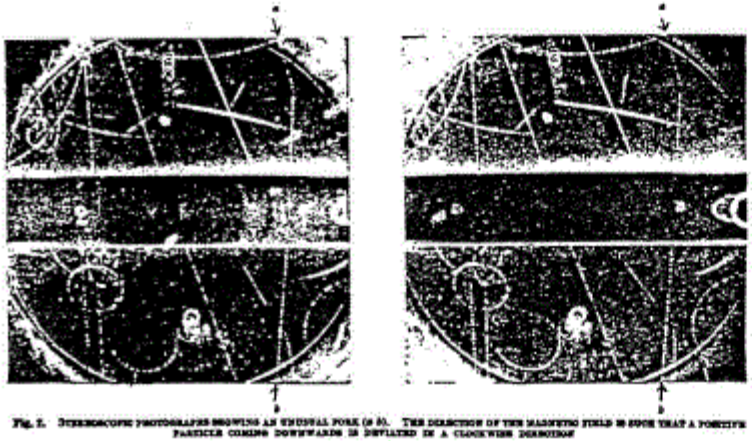


Fig. 2. Stereoscopic photographs showing an unusual fork (a b). The direction of the magnetic field is such that a positive particle coming downwards is deviated in a clockwise direction

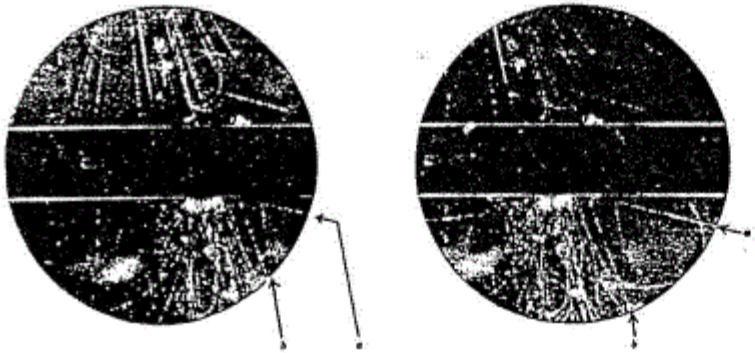
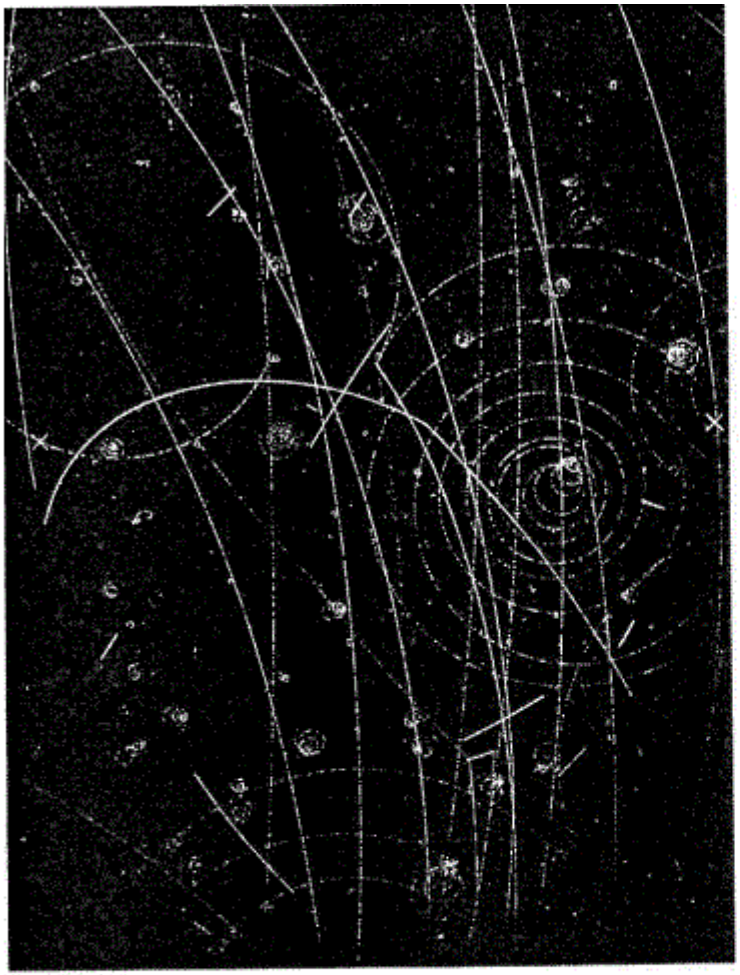
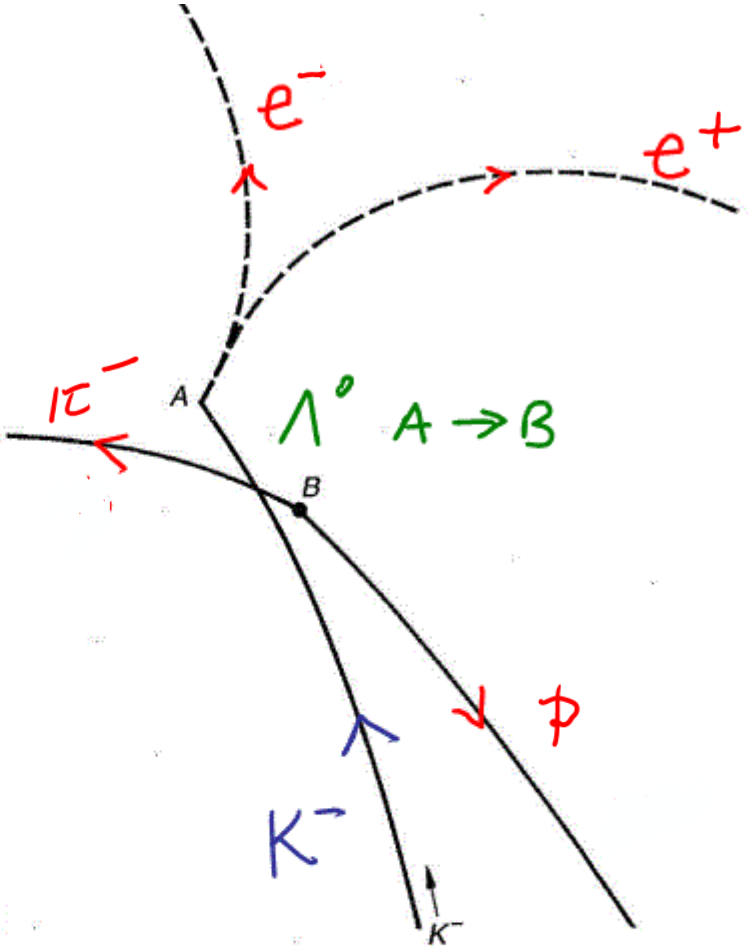


Fig. 1. Stereoscopic photographs showing an unusual fork (a b) in the gas. The direction of the magnetic field is such that a positive particle coming downwards is deviated in an anti-clockwise direction

Fig. 12.





S −1 0

INTERACTION AT REST

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

−1 0

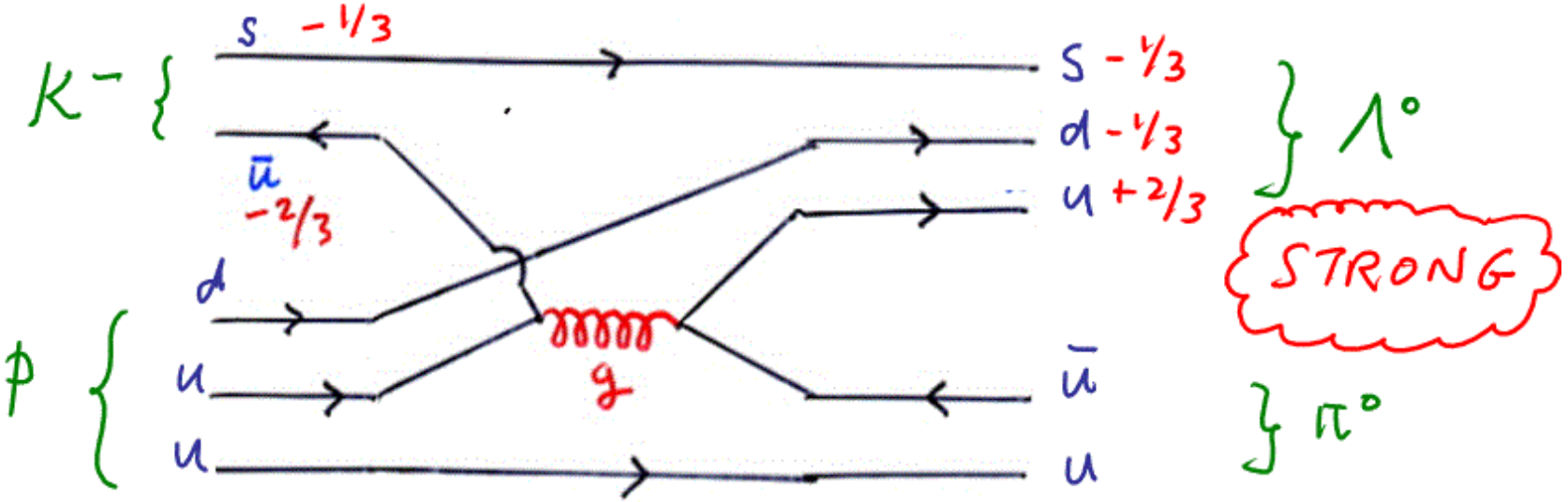
$\Delta S = 0$

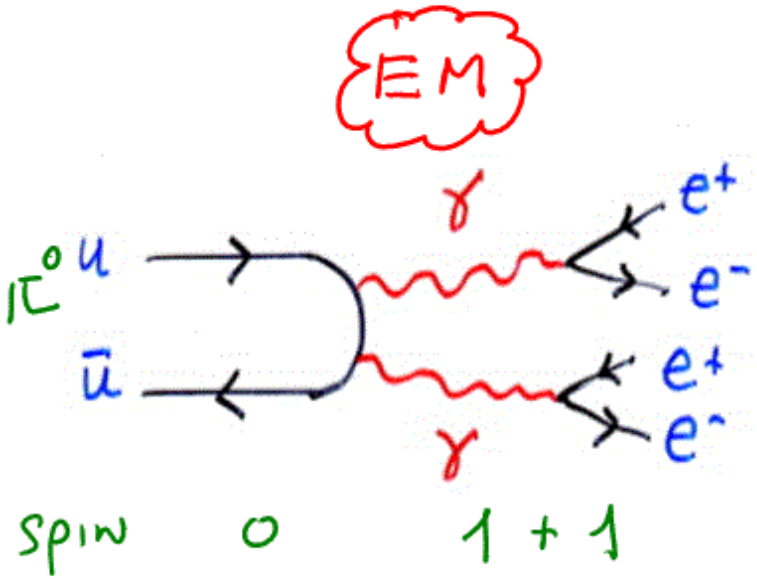
$\pi^0 \rightarrow \gamma e^+ e^-$ 10^{-16} s EM $S = 0$

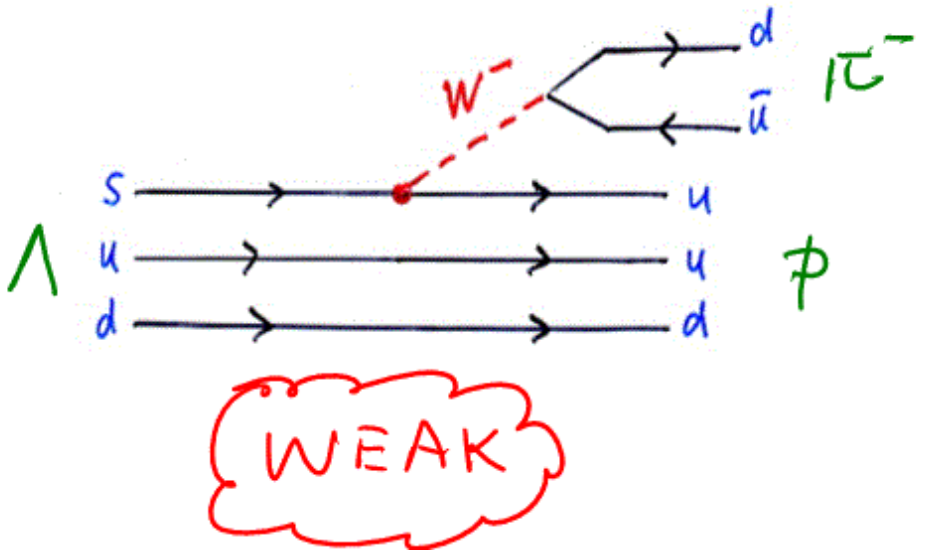
$\Delta S = 1$

$\Lambda \rightarrow p \pi^-$ 10^{-10} s WEAK $S = 0$

$K^- p \to \Lambda \pi^0$ IN QUARK LANGUAGE







MASS HIERARCHY — WHY?