ISS P 75/5

ISTITUTO SUPERIORE DI SANITA'

Laboratori di Fisica

L. MAIANI

Weak Interactions of Charmed Particles

Roma, 20 marzo 1975

Weak Interactions of charmed Particles (*)

L. Maiani

Laboratori di Fisica. Istituto Superiore di Sanità - Roma - Italia

Istituto Nazionale di Fisica Nucleare. Sezione Sanità Roma-Italia

---

(*) Talk presented at : "Colloque International du CNRS - Physique du Neutrino a Haute Energie" - Paris - March 18-20, 1975

WEAK INTERACTIONS OF CHARMED PARTICLES

Subject of my talk will be an illustration of the expected features of weak production and weak decays of charmed particles.

There are at present various proposed models where, in formulating a theory of weak interactions, new hadronic degrees of freedom are introduced, leading to a new class of elementary particles (charmed particles). Time forbids me to make a survey of the various options available, and forces me to consider only one particular model, the one based on four fractionally charged colored quarks.

This is the simplest available model and also the most developed at the moment. Predictions derived in this model will provide, hopefully, useful guides to the experimental search for charm that we are witnessing in these days.

1. Four quarks make SU (4)

Mesons and baryons are assumed to be made out of four types of quarks [1,2] each type coming in three different colors [3]:

weak and e.m. currents ↕	p'	p'	p'
	p	p	p
	n	n	n
	λ	λ	λ
	red	whithe	blue

$SU(3)_{color}$

Weak and e.m. currents are assumed to be bilinear in quark fields,and color singlets. Hence weak and e.m. interactions are exactly invariant under the Su (3) color symmetry which could be associated to gauge fields mediating strong interactions. The natural symmetry of this scheme is SU (4) ⊗ SU (3) $_{color}$. This symmetry could be further enlarged to include chiral transformations and/or embedded into a larger simple algebra, perhaps including leptons (4). This will not be discussed here.

Quantum numbers of the different quark types, relevant to a discussion of weak interactions, are assigned as shown in Table 1. If one further defines for all quarks :

$$B = \text{baryon number} = 1/3$$

the extension of the Gell-Mann Nishijima formula to include charmed particles reads :

$$Q = I_3 + \frac{1}{2} (B + C + S)$$

A basic assumption of the model is that, at least at present energies, color degreees of freedom are not being excited. All hadrons to be considered are therefore assumed to be color singlet (5). They can be classified according to the quantum numbers conserved by strong interactions: B, I, I_3, S,C. In particular particles can be classified according to the charm content as follows :

i - Normal (C = 0) states : particles made out of p, n and λ quarks and/or antiquarks (e.g. π, K, N, Λ, etc.)

ii - Quasi-normal (C = 0) states: particles made out of $p'\bar{p}'$ pairs (6) (e.g. ψ, ψ', η_c etc.)

iii - Charmed (C $\neq$ 0) states[7]: states containing p' and/or $\bar{p}'$ quarks such that C = (number of p')-(number of $\bar{p}'$) $\neq$ 0.

Charm being conserved in strong and e.m. interactions, a number of C $\neq$ 0 particles must be stable except for weak decays. Which charmed particles, among the partners of the low-lying SU (3) multiplets, are indeed stable, is determined by SU(4) mass breaking.

If ψ(3104) is a pure $p'\bar{p}'$ state, there is little doubt that charmed pseudoscalar mesons should be stable.

We expect three such mesons [8] (plus their antiparticles):

$$\left.\begin{array}{ll} \left.\begin{array}{l} D^0\ (p'\bar{p}) \\ D^+\ (p'\bar{n}) \end{array}\right\} & S=0,\ I=1/2 \\ S^+\ (p'\bar{\lambda}) & S=1,\ I=0 \end{array}\right\} \text{representation } \bar{3} \text{ of SU (3)}$$

Estimates of their masses, using ψ mass to determine P' mass, have been performed by various authors, and give values around 2 GeV.

Together with the pseudoscalar octet, pseudoscalar charmed mesons are naturally assigned to the regular (15-dimensional) representation of SU(4)[8]. Spin $1/2^+$ charmed baryons (C = 1 and 2) are assigned, together with the baryon octet, to a 20-dimensional SU (4) representation [2]. We shall restrict to C = 1 states which can be classified in SU (3) according to:

$C = +1$:

State	S	I	Representation
$B^+ (p'pn)_A$	$S=0$	$I=0$	representation $\bar{3}$ of SU (3)
$B^0 (p'\lambda n)_A$	$S=-1$	$I=1/2$	
$B^+ (p'\lambda p)_A$			
$B^0 (p'nn)_S$	$S=0$	$I=1$	representation 6 of SU (3)
$B^+ (p'pn)_S$			
$B^{++} (p'pp)_S$			
$B^0 (p'\lambda n)_S$	$S=-1$	$I=1/2$	
$B^+ (p'\lambda p)_S$			

The subscript A(S) denotes antisymmetry (symmetry) of the wave function under exchange of the uncharmed quarks. We shall assume in the following that the $\bar{3}$ baryons are stable except for weak decays. This results from the analysis of ref. (9). for the case of quadratic mass formulae, and also from ref. (10). The sextet baryons should be able to decay into the others by pionic and/or e.m. transitions.

Masses of $\bar{3}$ baryons are estimated to be of order of 2.9 ÷ 3 GeV in ref. (9) and 2.2 ÷ 2.4 GeV in ref. (10). Spin $3/2^+$ baryons, assigned to another 20-dimensional SU(4) representation [(2)] toge - ther with the $3/2^+$ decuplet, are presumably unstable against strong decays.

2. - Fundamental weak interactions

The four quark scheme allows for a very elegant and consistent description of weak interactions[2].

Quarks couple to charged (W) and neutral (Z) intermediate bosons according to :

$$\mathcal{L}_W = g\left(J_\mu W^\mu + h.c.\right) - g_0 J_\mu^{(0)} Z^\mu \qquad (1)$$

The neutral current, $J_\mu^{(0)}$, has $\Delta S = \Delta C = 0$ and does not play any significant role in weak production and decay of charmed particles. The charged current J_μ is given by :

$$J_\mu = \sum_{colors}\left[\bar{p}\gamma_\mu(1-\gamma_5)(\cos\theta\, n + \sin\theta\,\lambda) + \bar{p}'\gamma_\mu(1-\gamma_5)(-\sin\theta\, n + \cos\theta\,\lambda)\right] \qquad (2)$$

where θ is the Cabibbo angle. As implied by the sum over colors J_μ is a color singlet. J_μ has a $\Delta C = 0$ part which coincides with the familiar Cabibbo current, and an additional $\Delta C \neq 0$ term which describes the coupling of p' to n and λ quarks. Note that p and p' couple to two orthogonal combinations of n and λ. This property assures the suppression of unobserved $\Delta C = 0$, $\Delta S \neq 0$ neutral transition (e.g. $K_L \to \mu^+\mu^-$).

The $\Delta C \neq 0$ term implies the following selection rules for semi leptonic transitions :

- large ($\cos\theta$) component : $\Delta S = \Delta C \neq 0$, $\Delta I = 0$; $\Delta Q = \Delta C$ (3)

- small ($\sin\theta$) component : $\Delta S = 0$, $\Delta I = 1/2$; $\Delta Q = \Delta C$ (4)

Weak non leptonic processes arise from emission and reabsorption of a virtual W and/or Z (Fig. 1). Again, to describe charm-changing processes, only charged currents need to be considered, and the resulting current x current hamiltonian has the structure:

$$H_{eff}^{\Delta C \neq 0} \sim T(J J^{+})_{\Delta C \neq 0} \sim \cos^2\theta (\bar{p}'\lambda)(\bar{n}p) - \sin\theta\cos\theta \left[(\bar{p}'n)(\bar{n}p) - (\bar{p}'\lambda)(\bar{\lambda}p)\right] - \sin^2\theta (\bar{p}'n)(\bar{\lambda}p) + h.c. \tag{5}$$

We have used the abbreviated notation :

$$(\bar{p}'\lambda) \equiv \sum_{\text{colors}} \bar{p}'\gamma_\mu(1-\gamma_5)\lambda \quad \text{etc.}$$

summation over the Lorentz indices of currents is understood. It follows from eq. (5) that the dominant transitions (i.e. those proportional to $\cos^2\theta$) obey the selection rules(11):

$$\Delta C = \Delta S$$

$$\Delta I = 1$$

$$SU(3) = \bar{6} \oplus 15 + h.c.$$

we shall consider here only dominant transitions, leaving for the future the study of rare ($\sim \sin\theta$ in amplitude) and super-rare

($\sim \sin^2\theta$) non leptonic decay modes of charmed particles. In Sect.4 we shall discuss a further selection rule (sextet dominance) which arises in these processes as counterpart of the well known octet dominance in non leptonic strange particle decays.

3. - Neutrino and antineutrino production of charmed particles.

Charmed particles can be singly produced by the $\Delta C \neq 0$ term of the current, eq. (2), in the processes :

$$\begin{aligned} \nu &+ (\text{Matter}) \rightarrow \mu^- + \text{anything} \\ \bar{\nu} &+ (\text{Matter}) \rightarrow \mu^+ + \text{anything} \end{aligned} \qquad (7)$$

Charmed particle production by neutrinos has been studied in ref. (12) and (13).

We shall consider these processes in the deep inelastic region, E_ν larghe with fixed x and y :

$$x = - q^2 / 2M\nu$$

$$y = \nu / E_\nu$$

E_ν = neutrino on antineutrino lab-energy, $\nu = (q.p)$, M =nucleon mass, P, and q being defined in Fig. 2. If we call W the invariant mass of the produced hadronic system, then:

$$W^2 - M^2 = 2\ M\ E_\nu\ y(1-x) \qquad (8)$$

At fixed values of E_ν, charmed particles can be produced for W larger than a fixed, thereshold value (W_{th}), i.e. in region II of Fig. 3. Across the line $W = W_{th}$ there will be an increase of the cross-section, producing a "charm ridge". As E_ν increases the line

$W = W_{th}$ moves into region I, and region II increases.

A quantitative analysis of these non scaling effects can be done in the parton model assuming that scaling holds both in region I and II (i.e. assuming a sharp ridge) the difference in cross-sections arising from the possibility of charm changing reactions in region II.

To obtain cross sections in region I and II we recall that in the quark-parton model [14], the cross-section is a sum of cross-sections for elementary processes where a parton quark (or antiquark) "a" absorbs a W^+ or W^- and transforms into a quark (or antiquark) "b" .

We denote by a (x) the average number of type "a" partons <u>inside a proton</u>, with a fraction x of proton momentum, and by g_{ab} the coupling of $a\bar{b}$ to the weak boson W. The V - A structure of the interaction implies then the following contributions to the cross-section for ν or $\bar{\nu}$ scattering <u>off protons</u>:

i)

$$\nu + a \to \mu^- + b \quad : \left(\frac{d\sigma}{dx\,dy}\right)^{\nu,P}_{a\to b} = \frac{G^2 M E_\nu}{\pi}\, g_{ab}^2\, x\, a(x) \cdot \begin{cases} 1 & \text{(a and b are quarks)} \\ (1-y)^2 & \text{(a and b are antiquarks)} \end{cases}$$

ii)

$$\bar{\nu} + a \to \mu^+ + b \quad : \left(\frac{d\sigma}{dx\,dy}\right)^{\bar{\nu},P}_{a\to b} = \frac{G^2 M E_\nu}{\pi}\, g_{ab}^2\, x\, a(x) \cdot \begin{cases} (1-y)^2 & \text{(a and b are quarks)} \\ 1 & \text{(a and b are antiquarks)} \end{cases}$$

To obtain cross-section off neutrons, simply exchange $n \leftrightarrow p$, $\bar{n} \leftrightarrow \bar{p}$ leaving all other terms unchanged; the cross-sections per nucleon off $I = 0$ matter are then obtained by averaging proton and neutron cross - sections. Table 2 illustrates the elementary transitions for ν and $\bar{\nu}$ reactions below charm threshold with the corresponding values of g^2_{ab} . The resulting cross-sections per nucleon n region I, are therefore :

$$\left(\frac{d\sigma}{dx\,dy}\right)^{\nu}_{I} = \frac{G^2 M E_\nu}{\pi}\, x \cdot \left\{ [n(x) + p(x)] \cos^2\theta + 2\lambda(x) \sin^2\theta + (1-y)^2 [\bar{p}(x) + \bar{n}(x)] \right\} \quad (9)$$

$$\left(\frac{d\sigma}{dx\,dy}\right)^{\bar{\nu}}_{I} = \frac{G^2 M E_\nu}{\pi}\, x \cdot \left\{ [\bar{n}(x) + \bar{p}(x)] \cos^2\theta + 2\bar{\lambda}(x) \sin^2\theta + (1-y)^2 [n(x) + p(x)] \right\} \quad (10)$$

Charm changing reactions which contribute in region II are displayed in Table 3. The resulting increase in cross-sections is :

$$\Delta\left(\frac{d\sigma}{dx\,dy}\right)^{\nu} = \frac{G^2 M E_\nu}{\pi}\, x \cdot \left\{ [n(x) + p(x)] \sin^2\theta + 2\lambda(x) \cos^2\theta + (1-y)^2\, 2\,\bar{p}'(x) \right\} \quad (11)$$

$$\Delta\left(\frac{d\sigma}{dx\,dy}\right)^{\bar{\nu}} = \frac{G^2 M E_\nu}{\pi}\, x \cdot \left\{ \left[\bar{n}(x) + \bar{p}(x)\right]\sin^2\theta + 2\,\bar{\lambda}(x)\cos^2\theta + \right.$$
$$\left. + (1-y)^2\, 2\,\bar{p}'(x) \right\} \qquad (12)$$

Electroproduction data, as well as low energy neutrino data from Gargamelle and FNAL seem to support the following qualitative features of distribution functions(15):

i) n(x) and p(x) are large, rather well determined and extend to large values of x; they receive contributions from leading (valence) quarks;

ii) $\bar{n}$, $\bar{p}$, λ, $\bar{\lambda}$ and p', $\bar{p}$', seem to be concentrated at small x; they are much less known, theoretical aguments suggesting $\bar{n}(x) = \bar{p}(x)$, $\lambda(x) = \bar{\lambda}(x)$, $\bar{p}(x) = p'(x)$, and perhaps $\lambda(x) = \bar{n}(x)$ (SU(3) limit). Such distributions are thought to arise from a sea of neutral $q\bar{q}$ pairs.

We may now discuss the cross-sections for charmed particle production, eq.s (11) and (12).

In neutrino reactions, eq. (11), we have two different components.

The term proportional to n (x)+p(x) has the following features:

i) it extends up to large x;

ii) can be reliably estimated, and is of the same order ($\sin^2\theta$) as usual $\Delta S \neq 0$ reactions;

iii) corresponds to $n \rightarrow p'$ transitions, thus giving rise to C=1, S=0 states. If the final state decays non leptonically, eq. (3) implies the chain :

$$\nu + (C=0,\ S=0,\ Q=Q_{in}) \rightarrow \mu^- + (C=+1,\ S=0,\ Q=Q_{in}+1)$$
$$\hookrightarrow (C=0,\ S=-1,\ Q=Q_{in}+1)$$

This would appear experimentally as a $\Delta S = -\Delta Q$ process. The event: $\nu + p \rightarrow \mu^- + \Lambda + \pi^+ + \pi^+ + \pi^+ + \pi^-$ observed at Brookhawen, and presented at this Conference, fits very nicely into this scheme.

The second component in eq. (11) arises from λ and $\bar{p}'$ quarks and has the following features:

i) it is concentrated at small x, where it dominates, being of order 1 or $\cos^2\theta$;

ii) gives rise predominantly to C = + 1, S = + 1, states which, by a non leptonic decay, go into C = 0, S = 0 states. Hence no apparent $\Delta S = -\Delta Q$ events are expected at a sizeable level;

iii) its size is difficult to estimate, but it may give the largest contribution to charm-changing total cross-section.

The antineutrino cross-section, eq. (12), receives only sea contributions, with features identical to the second component of the neutrino cross-section.

In all cases, the $C \neq 0$ final state could undergo a semileptonic decay, with emission of a $\mu\nu$ or $e\nu$ pair.

Dimuon events are thus expected [16]. The $\Delta C = \Delta Q$ rule in semileptonic transitions, eq. (3), implies only the following charge combinations to be present :

$$\mu^-_{\text{leading}}, \mu^+ \qquad (\nu\text{- reactions})$$

$$\mu^+_{\text{leading}}, \mu^- \qquad (\bar{\nu}\text{- reactions})$$

the most energetic (leading) muon originating from the primary interaction.

The ratio of dimuon events versus single muon events is related to the total charm-changing cross-section and to the semileptonic branching ratio according to :

$$\frac{D}{S} = \frac{(\text{dimuon rate})}{(\text{single muon rate})} = \frac{\Delta\sigma}{\sigma} \cdot B_\mu \qquad (13)$$

$$B_\mu = \frac{\Gamma(C \to \mu + \nu + \ldots)}{\Gamma(C \to \text{anything})} \qquad (14)$$

Using eqs (9) to (12) and neglecting non leading with respect to leading quark contributions we find :

$$\frac{\Delta\sigma^{\nu}}{\sigma^{\nu}} \approx \sin^2\theta + 2\,\frac{\langle \lambda \rangle + \frac{1}{3}\langle \bar{p}' \rangle}{\langle n + p \rangle} \qquad (15)$$

$$\frac{\Delta\sigma^{\bar{\nu}}}{\sigma^{\bar{\nu}}} \approx 6\,\frac{\langle \bar{\lambda} \rangle + \frac{1}{3}\langle p' \rangle}{\langle n + p \rangle} \approx 3\,\left(\frac{\Delta\sigma^{\nu}}{\sigma^{\nu}} - \sin^2\theta\right) \qquad (16)$$

where we have set : $\langle a \rangle = \int dx \quad x a(x)$ = average momentum carried by parton "a".

Using an explicit parton model of nucleons, fitted to SLAC and Gargamelle data, the authors of ref (13) have estimated (17):

$$\frac{\Delta\sigma^{\nu}}{\sigma^{\nu}} \sim 15\% \quad ; \quad \frac{\Delta\sigma^{\bar{\nu}}}{\sigma^{\bar{\nu}}} \sim 30\%$$

Anticipating a branching ratio $\underset{\sim}{B} \sim 5\%$ (see next section) one obtains :

$$\frac{D}{S} \sim 1\%$$

which is of the order of the ratio observed by the Harvard - Pennsylvania - Winsconsin group at FNAL, and presented at this Conference.

4. Weak decays of charmed particles

As discussed in Sect 1, lowest lying charmed particles decay weakly into normal hadrons, with or without emission of a lepton pair. We shall discuss here two points : i) ratio of semileptonic to non leptonic decay rates (B_μ as defined in eq. (14)); ii) the structure of non leptonic amplitude.

To this aim, we shall use the results on the structure of non leptonic amplitudes recently obtained in ref (18) and (19). The picture which emerges can be summarized as follows;

i) non leptonic amplitudes arise from virtual W-exchange, Fig. 1;

ii) the leading part of the amplitude depends upon the behaviour of the product $J_\mu(x) J^{+}_\mu(0)$ at short space time distance [20], ($x^2 \sim \frac{1}{M_W^2}$, much smaller than typical hadronic lenght scale)

iii) if strong interactions are asympotitically free, the short distance behaviour of $J_\mu(x)\, J^{+\mu}(0)$ can be computed, and the result, in the SU (4) $\otimes$ SU (3) color model, is that a term in the product is enhanced, corresponding to the component over a 20-dimensional SU(4) representation;

iv) the enhanced term is a superposition of a $\Delta C = 0$, pure octet (leading to octet dominance in strange particle decays) and a $|\Delta C| = 1$ term transforming under SU(3) as a $6 \oplus \bar{6}$ representation. Thus we expect charmed particle non leptonic decays to exhibit the same enhancement as $\Delta I = 1/2$ strange particle non leptonic decays.

This leads to the estimate [21,7]:

$$B_\mu = \frac{\Gamma(C \to \mu + \nu + \ldots)}{\Gamma(C \to \text{anything})} \sim 1 \div 10\,\% \qquad (15)$$

Moreover if the effective hamiltonian transforms as a component of an SU(3) sextet, we can replace eq. (6) with the more restrictive selection rules [21] (to order $\cos^2\theta$) :

$$\begin{aligned} \Delta C &= \Delta S \\ \Delta I &= 1 \\ \Delta V &= 0 \\ SU(3) &= 6 \oplus \bar{6} \end{aligned} \qquad (16)$$

where the V-spin is the SU(3) (and SU(4)) subgroup which mixes λ and p quarks, leaving unchanged all the others.

Eq. (16) leads to selection and intensity rules, which I will briefly summarize.

<u>Meson decays</u>

From $\Delta V = 0$, we get the equalities (valid up to SU(3) breaking in phase space)

$$\sum \Gamma(D^0 \to 2ps) = \sum \Gamma(S^+ \to 2ps)$$
$$\sum \Gamma(D^0 \to 3ps) = \sum \Gamma(S^+ \to 3ps)$$
$$\sum \Gamma(D^0 \to V + ps) = \sum \Gamma(S^+ \to V + ps)$$

etc.

$$\Gamma_{total}(D^0) = \Gamma_{total}(S^+)$$

ps and V indicate C = 0 pseudoscalar and vector mesons, and sums run over all allowed channels of the given kind.

Sextet dominance implies also :

$$D^+ \not\to \bar{K}^0 \pi^+$$

which is the counterpart of the rule $K^+ \not\to \pi^+\pi^0$ implied by $\Delta I = 1/2$ enhancement. Further relations among two body and three body decay amplitudes of $D^{+,0}$ and S^+ have been given in ref. (21).

Baryon decays

As anticipated in Sect. 1 we assume the $\bar{3}$ spin $1/2^+$ baryons to be stable. As a consequence of $\Delta V = 0$, again we find equalities among partial and total widths of the $V_3 = \pm 1/2$ baryons :

$$\sum \Gamma[B^0(p'\lambda m)_A \to B + ps] = \sum \Gamma[B^+(p'pm)_A \to B + ps]$$
$$\Gamma_{total}[B^0(p'\lambda m)_A] = \Gamma_{total}[B^+(p'pm)_A] \quad \text{etc.}$$

where B indicates a C = 0, $1/2^+$ octet baryon. Relations for two body decay amplitudes have been studied in ref. (22).

SU(4) limit

One may investigate consequences of exact SU(4) symmetry for non leptonic decays with the aim of obtaining estimatesof charmed particle lifetimes.

For the decays : B' (C=1)→ B (C=0)+ps, one can determine all relevant amplitudes from hyperon decay amplitudes[22], and obtain estimates for $\sum \Gamma(B' \to B + ps)$ of the order of 10^{13} sec^{-1}. It is amusing that SU(4) symmetry implies a relation among hyperon decay S-wave amplitudes[22] which reads :

$$S(\Lambda^{o}_{-}) = -\frac{1}{\sqrt{3}} S(\Sigma^{+}_{o})$$

and is not too badly violated (l.h.s. = 1.50, r.h.s.= 0.84).

5. - Conclusion

The introduction of charm makes it possible to formulate a theory of weak interactions of great elegance and simplicity.

This theory leads to very precise predictions about weak production and weak decays of charmed particles.

The new phenomena observed in e^+e^- and neutrino collisions incourage us to think that this theory may have indeed some elements of truth. It remains now as a challenge to our collegues experimentalists to put the idea of charm to its decisive test, by confirming or disproving the existence of charmed particles.

	Q	I_3	S	C
P'	2/3	0	0	1
P	2/3	+ 1/2	0	0
n	-1/3	- 1/2	0	0
λ	-1/3	0	-1	0

TABLE I

Quantum numbers of the four quarks.

	$a \rightarrow b$	g^2_{ab}
ν	$n \rightarrow p$	$\cos^2\theta$
	$\lambda \rightarrow$	$\sin^2\theta$
	$\bar{p} \rightarrow \bar{n}$	$\cos^2\theta$
	$\bar{p} \rightarrow \bar{\lambda}$	$\sin^2\theta$
$\bar{\nu}$	$\bar{n} \rightarrow \bar{p}$	$\cos^2\theta$
	$\bar{\lambda} \rightarrow \bar{p}$	sin
	$p \rightarrow n$	$\cos^2\theta$
	$p \rightarrow \lambda$	$\sin^2\theta$

TABLE 2

Elementary transitions contributing to ν and $\bar{\nu}$ cross-section below charm threshold.

	$a \rightarrow b$	g^2_{ab}
ν	$n \rightarrow p'$	$\sin^2\theta$
	$\lambda \rightarrow p'$	$\cos^2\theta$
	$\bar{p}' \rightarrow \bar{n}$	$\sin^2\theta$
	$\bar{p}' \rightarrow \bar{\lambda}$	$\cos^2\theta$
$\bar{\nu}$	$\bar{n} \rightarrow \bar{p}'$	$\sin^2\theta$
	$\bar{\lambda} \rightarrow \bar{p}'$	$\cos^2\theta$
	$p' \rightarrow n$	$\sin^2\theta$
	$p' \rightarrow \lambda$	$\cos^2\theta$

TABLE 3

Elementary transitions contributing to ν and $\bar{\nu}$ production of charmed states.

References and Footnotes

1) Early proposals of an SU(4) symmetry for hadrons are contained in: D. Amati, H. Bacry, J. Nuyts, J. Prentki, Nuovo Cimento 34 1732 (1964); J.D. Bjorken, S.L. Glashow, Phys. Letters 11, 255 (1964); Y. Hara, Phys. Rev. 134, B 701 (1964); L.B. Okun, Phys. Letters 12, 250 (1964); Z. Maki, Y. Ohnuki, Progr. Theor. Phys. 32, 144 (1964); V. Teplitz, P. Tarjanne, Phys. Rev. Letters 11, 447 (1963).

2) A fourth quark to formulate a consistent theory of weak interac - tions has been proposed in : S.L. Glashow, J. Iliopoulos,L. Maiani, Phys. Rev. D2, 1285 (1970).

3) O.Greenberg, Phys. Rev. Letters 13, 598 (1964); M. Gell-Mann, Proc. 16th Int. Conf. on High-Energy Physics, Batavia 1972,vol. 4, p. 333. The need of color to cancel Adler anomalies in renormalizable weak and e.m. interactions has been stressed by : C. Bouchiat, J. Iliopoulos, Ph. Meyer, Phys. Letters 38B, 519 (1972).

4) H. Georgi, S.L. Glashow, Phys. Rev. Letters, 32, 236 (197.); J.C.Pati, A. Salam, Phys.Rev. D8, 1240 (1973); Phys. Rev. D10, 275, 703 (E) (1974).

5) This is to be contrasted e.g. with the Pati-Salam model, quoted in ref. (4),where color and charm degrees of freedom are excited

at the same level. See also J.C.Pati, A.Salam, Phys. Rev. Letters 34, 613 (1975).

6) Identification of ψ and ψ' with pure p'$\bar{p}$' states (of course only tentative at present) has been proposed by various authors: S. Borchardt, V.S. Mathur, S. Okubo, Phy. Rev. Letters 34, 38 (1975); A. De Rujula, S.L. Glashow, Phys. Rev. Letters. 34, 46 (1975).

7) Properties of charmed particles in SU(4) have been extensively studied, prior to ψ discovery, in : M.K. Gaillard, B.W. Lee, J. Rosner, Rev. Mod. Phys. (to be published).

8) J.D. Bjorken, S.L. Glashow, quoted in ref. (1).

9) S. Okubo, V.S., Mathur and S. Borchardt, Phys. Rev. Letters, 34, 236 (1975).

10) A. De Rujula, H. Georgi, S.L. Glashow, Harvard preprint (1975).

11) The possibility of completely different selection rules, not following from a current x current interaction, has been considered by: A. Pais, V. Rittenberg, Phys. Rev. Letters, 34, 707 (1975).

12) A. De Rujula, et al. Rev. Mod. Phys. 46, 391 (1974); A. De Rujula, S.L. Glashow, Phys. Letters B46, 377 (1974).

13) G. Altarelli, N. Cabibbo, L. Maiani, R. Petronzio: Phys. Letters 48B, 435 (1974) and CERN preprint, TH, 1757 (1973).

14) J.D. Bjorken, E.A. Paschos Phys. Rev. 185, 1975 (1969); Phys. Rev. D1, 3151 (1970).
R.P. Feynman, Photon-hadron interactions, W.A. Benjamin inc., New-York, 1972.

15) Among the many general reviews on this subject, see e.g.:
F. Gilman, Phys. Reports 4C, 95 (1972); C.H. Llewellyn Smith, Phys. Reports 3C, 261 (1972); R.P. Feynman, quoted in ref. (14); G. Altarelli, Rivista del Nuovo Cimento, 4, 335 (1974).

16) G. Snow, Nucl. Phys. B55, 191 (1973).

17) Similar estimates have been more recently given by: V. Barger, T. Weiler and R.J.N. Phillips, Univ. of Winsconsin preprint (1975).

18) M.K. Gaillard, B.W. Lee, Phys. Rev. Letters 33, 108 (1974).

19) G. Altarelli, L. Maiani, Phys. Letters 52B, 351 (1974).

20) K. Wilson, Phys. Rev. 179, 1499 (1969).

21) C. Altarelli, N. Cabibbo, L. Maiani, Nucl. Phys. B. (to be published).

22) G. Altarelli, N. Cabibbo, L. Maiani, Istituto Superiore di Sanità, Roma, preprint, ISS 75/4 (1975).

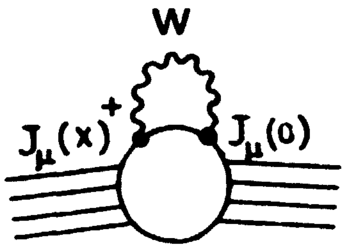

Fig.1

Virtual W exchange leading to non leptonic weak amplitudes.

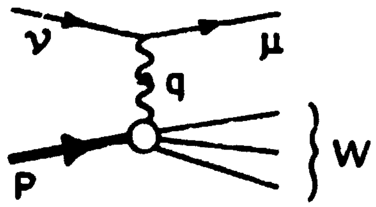

Fig.2

Inelastic scattering of neutrinos off nucleons. W is the invariant mass of the hadronic final state.

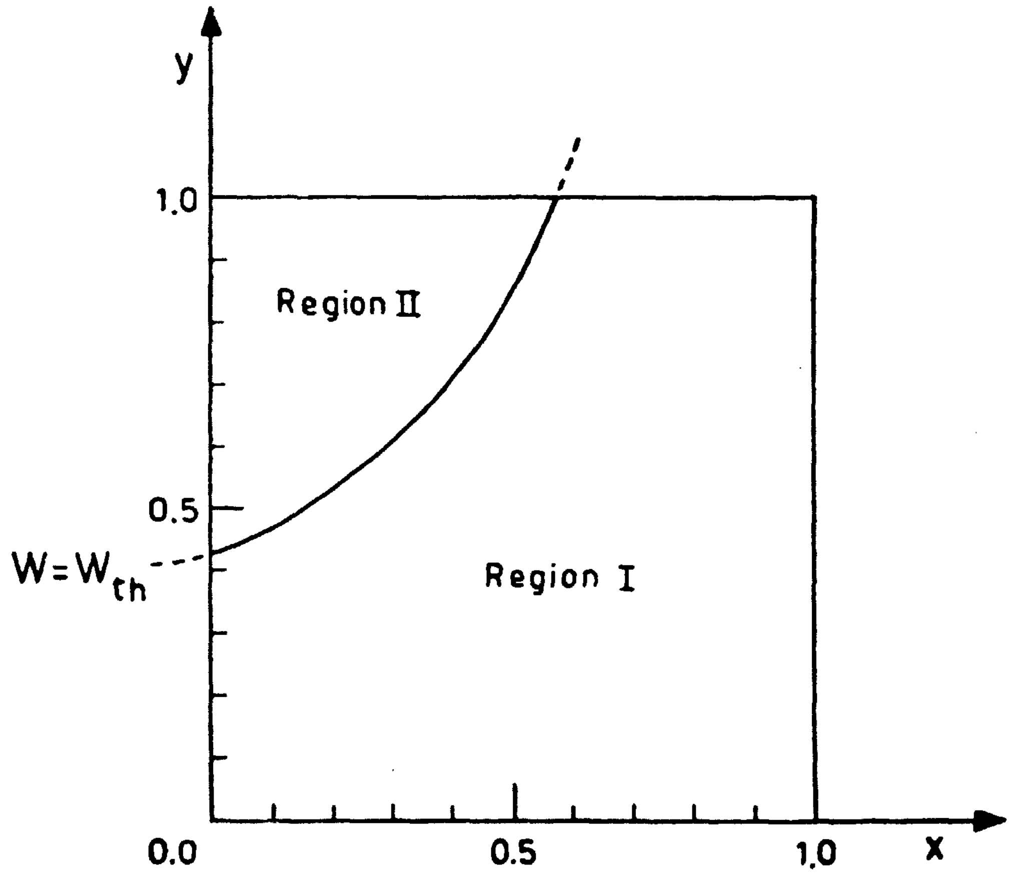

Fig. 3

Kinematical regions below (I) and above (II) charm threshold, W_{th}, in x, y variables. The curve here reported is computed for E = 30 GeV, and W_{th} = 5 GeV.

Riassunto - Interazioni deboli delle particelle con "charm".

Si passano in rassegna le predizioni teoriche sulla produzione da neutrini e sui decadimenti deboli delle particelle con "charm". L'analisi è fatta nell'ambito del modello basato su SU(4).

Abstract - Weak Interactions of Charmed Particels.

Theoretical predictions for weak neutrino production and weak decays of charmed particles in the SU(4) scheme are reviewed.

I rapporti dei Laboratori di Fisica dell'Istituto Superiore di Sanità si distinguono nelle seguenti categorie:

ISS P = "Preprints", lavori in corso di stampa che debbono essere divulgati rapidamente.

ISS R = "Reports and Reviews", resoconti di ricerche eseguite, più estesi e dettagliati di quanto non si possa fare su riviste specializzate, e rassegne.

ISS T = "Technical notes", contributi di carattere tecnico, risultati di calibrazioni, grafici, tabelle, norme per l'uso di apparecchiature, ecc.

ISS L = "Lectures", corsi di lezioni, seminari, congressi, tavole rotonde.

Il materiale pubblicato si riferisce ad attività svolte nei Laboratori di Fisica. La responsabilità dei dati scientifici o tecnici pubblicati è dei singoli Autori. L'eventuale collaborazione di altri Laboratori o Istituzioni è indicata in nota al titolo, nella prima pagina di testo.

In ogni rapporto sono stampati in alto a destra nella prima pagina di copertina la sigla della categoria, l'anno di pubblicazione e un numero progressivo. Per esempio ISS R 73/5 significa "Report" o "Review" del 1973, n.5.

La data stampata in copertina a piè di pagina è quella della consegna alla tipografia del testo pronto per la stampa.

The report of the Physics Laboratories of the Istituto Superiore di Sanità are divided into the following categories:

ISS P = "Preprints", papers submitted to journals the contents of which should be made known quickly.

ISS R = "Reports and Review" of research, prepared in a more extensive and detailed way than in specialized journal and reviews.

ISS T = "Technical notes", technical contributions, calibration results, graphs, tables, instructions for the use of experimental apparatus, etc.

ISS L = "Lectures", courses, seminars, congresses, round tables.

The material published refers to the activities carried out in the Physics Laboratories. The Authors are responsible for scientific or technical data published in these reports. The cooperation of outside laboratories where relevant is acknowledged on the title page of the text.

The identification number printed in the upper right hand corner of the cover of each report refers to the acronym of the Institute, the category, the year and the number of the report which is progressive for each year. Example: ISS R 73/5 = Istituto Superiore di Sanità Report or Review number 5 of 1973.

The date appearing at the foot of the cover refers to the day on which the text was sent to press.

A cura del Servizio Documentazione die Laboratori di Fisica