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Notes on the BNL Event of "$\Delta S/\Delta Q$"$=-1$ Process

Takemi HAYASHI, Makoto KOBAYASHI* and Masami NAKAGAWA**

Department of Physics, Hiroshima University Hiroshima
**Department of Physics, Kyoto University Kyoto*
***Department of Physics, Meijo University Nagoya*

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Very recently BNL group[1] reported a new event

$$\nu p \to \mu^- \Lambda \pi^+ \pi^+ \pi^+ \pi^-, \qquad (1)$$

which suggests real production and subsequent decay of a new hadron with charm.

We would like to note that the possibility of process with apparent violation of $\Delta S=\Delta Q$ rule was predicted in our previous paper[2] as a consequence of *real production* and *subsequent weak decay* of new (charmed) hadron by high energy neutrino. It was pointed out there that the detection of such an apparent violation of $\Delta S=\Delta Q$ rule will provide a discrimination of some related quartet models of hadrons.

In this note we discuss implications of the BNL event. Firstly on the discrimination of models, we have considered four types of quartet models;[2] each model in addition to the ordinary triplet quarks (p_0, n_0, λ_0) contains a fourth quark (I) $p_0'(Q=2/3)$, (II) $\lambda_0'(Q=-1/3)$, (III) $\xi_0'(Q=-4/3)$, (IV) $\zeta_0'(Q=5/3)$. The apparent violation of the $\Delta S=\Delta Q$ rule via two steps of weak interactions in neutrino-nucleon collision arises as

$$\text{"}\Delta S/\Delta Q\text{"}=-1, 2 \qquad (2)$$

for Models (I) and (III), and no violation occurs for Models (II) and (IV). Thus we can say that if the BNL experiment confirms the reaction (1), *quartet models with a fourth quark λ_0' (Model (II)) and ζ_0' (Model (IV)) may be excluded.* (To get this statement in the presence of neutral current interactions, we should add an assumption of the absence of $\Delta S=1$ neutral current in Model (II).) Now we mention further discrimination of Models (I) and (III), which survive the BNL experiment. We assume weak charged current for these models as follows:[3]

$$j(\mathrm{I}) = \cos\theta(\bar{p}_0 n_0) + \sin\theta(\bar{p}_0\lambda_0) - \sin\theta(\bar{p}_0' n_0) + \cos\theta(\bar{p}_0'\lambda_0), \qquad (3)$$

$$j(\mathrm{III}) = \cos\theta(\bar{p}_0 n_0) + \sin\theta(\bar{p}_0\lambda_0) + \cos\theta(\bar{n}_0\xi_0') + \sin\theta(\bar{\lambda}_0\xi_0'), \qquad (4)$$

where we have omitted V-A Dirac matrices in currents. We note that $j(\mathrm{III})$, as defined by Eq. (4), was introduced in a previous paper[3] up to a common factor $\sqrt{2}$ and that in Model (III) only this form does not give rise to a $\Delta S=1$ neutral current which would be generated by an $SU(2)$ algebra.[4] On the basis of these currents we calculate inclusive cross sections with definite selection rule of apparent "$\Delta S/\Delta Q$" as shown in Table I. In the Table we show only relative magnitude of the cross sections in terms of distribution functions and angle factors. We see that the "$\Delta S/\Delta Q$"$=-1$ process in ν-N reaction arises by $f_n \sin^2\theta \times \cos^4\theta$ for Model (I) and by $f_{\bar{\lambda}} \sin^2\theta\cos^4\theta$ for Model (III) in relative magnitude of cross sections. Here f_n and $f_{\bar{\lambda}}$ denote integrated distribution functions of corresponding parton in nucleon target. Thus *the "$\Delta S/\Delta Q$"$=-1$ process in Model III can be expected in magnitude of only $f_{\bar{\lambda}}/f_n$ (probably less than one order of magnitude[5]) part of one of Model (I).* In view of the claim of BNL group[1] that the strength of "$\Delta S/\Delta Q$"$=-1$ is comparable to $\Delta S=\Delta Q$ in magnitude, Model (I) seems to be preferable to Model (III). On another abnormal case "$\Delta S/\Delta Q$"$=2$, Model (I) predicts $f_{\lambda}\cos^2\theta$

Table 1. Ordinary $\Delta S=\Delta Q$ process is given by $f_p \sin^2\theta$.

		"$\Delta S/\Delta Q$"$=-1$	$=2$
Model (I)	$\nu+N$	$f_n \sin^2\theta\cos^4\theta$	$f_\lambda \cos^2\theta\sin^4\theta$
	$\bar{\nu}+N$	$f_{\bar{n}} \sin^2\theta\cos^4\theta$	$f_{\bar{\lambda}} \cos^2\theta\sin^4\theta$
Model (III)	$\nu+N$	$f_{\bar{\lambda}} \sin^2\theta\cos^4\theta$	$f_{\bar{n}} \cos^2\theta\sin^4\theta$
	$\bar{\nu}+N$	$f_\lambda \sin^2\theta\cos^4\theta$	$f_n \cos^2\theta\sin^4\theta$

$\times\sin^4\theta$ for relative magnitude of cross section which is negligibly small compared with "$\Delta S/\Delta Q$"$=-1$ process.

As to the interpretation of new hadron produced in the intermediate (but real) state, we mention another possible interpretation instead of a new baryon production at mass 2426 MeV. If we assign the track 4 as π^- and track 1 as μ^-, then the event can be interpreted as

$$\nu p\rightarrow\mu^-\Lambda\pi^+M^+;\ M^+\rightarrow\pi^+\pi^+\pi^-, \tag{5}$$

where M^+ denotes a $(p_0'\bar{\lambda}_0)$ meson.[6] Mass of M^+ is 2.26 GeV (2.10 GeV) if we assign tracks 2, 5, 4 (3, 5, 4) as the decay product $\pi^+\pi^+\pi^-$. It is interesting to see that this mass value for M^+ is consistent with an interpretation[7] of new particle observed in cosmic ray jet.[8),9)]

We would point out yet another possible (may be unlike but not excluded) interpretation. If we assign all visible tracks as hadrons and allow a missing ν in the final state, a neutrino from a purely kinematical argument can be emitted forward with, say, $p_\nu\lesssim1.5$ GeV when $E_\nu^{\mathrm{inc}}\lesssim15$ GeV; the reaction is

$$\nu p\rightarrow\nu\Lambda\pi^+\pi^+\pi^+\pi^-\pi^-. \tag{6}$$

Since $\Delta S=1$ process is highly suppressed in the neutral current interactions at least at low q^2, this may still suggest a new hadron production via $\Delta N'=1$ neutral current interaction where N' represents a p_0'-quark number (we here discuss only Model (I)). We assume an interaction with the neutral current as

$$H_N'=\frac{G_N'}{\sqrt{2}}(\bar{p}_0'p_0)(\bar{\nu}\nu)+\mathrm{h.c.}, \tag{7}$$

with, say, a V-A type. Then if there is no other event observed as an apparent "ΔS"$=1$ via $\Delta N'=1$ neutral current in the BNL experiment, we may get an upper bound

$$G_N'\lesssim\frac{G_W}{\sqrt{2}}\sin\theta\simeq0.2\,G_W, \tag{8}$$

where G_W denotes the universal Fermi coupling constant.

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