On Selection Rule of Weak Processes and Decays of New Particles. II

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Following a previous paper, we propose selection rules for weak processes. The first rule is 
\[ n_1 = 0 \]
where \( n_1 = n + n \); \( n(\overline{n}) \) indicates an (anti-)baryon number. The second rule is that a dimensionality of the \( SU(3) \) representation of hadronic system is conserved along \( s \)- or \( t \)-channel dependig on the parity property. These rules are applied to decay processes of new hadrons, an indication of which has been observed in a cosmic ray jet. We further attempt some conjectures on the second event that has recently been reported.

§ 1. Introduction

In a previous paper\(^1\) (we refer as I to this paper), we proposed a selection rule for weak processes. The selection rule is based on the idea that the characteristic behavior of weak processes is constrained by a composite nature of hadrons and that the selection rules would arise as a result of hardness in changing the configuration of composite system. In terms of the composite model of hadrons, baryons and mesons are compound states of three-(\( ttt \)) body and two-(\( tt \)) body, respectively, where \( t \) denotes a constituent baryon. The configuration of hadrons is then specified, besides space and spin parts, by numbers \( n, \overline{n}, \) and \( m \), where \( n(\overline{n}) \) stands for a lowest number of baryons (anti-baryons)\(^4\) contained in the compound system and \( m \) a dimensionality of a representation of \( SU(3) \) symmetry of the hadronic state.

Our basic idea is as follows: The hadronic matter forms a black box at an action of weak interaction before the hadronization into the final states, and yet the black box is a compound (or its superposed) state composed of a definite number of baryons and anti-baryons formed, which is analogous to the compound nucleus in the nuclear reaction. The number of constituent baryons \( n(\overline{n}) \) within the black box is then defined as the total number of \( t(\overline{t}) \) contained in the initial or final state, except for \( t \) and \( \overline{t} \) which can be brought into a pair with the same quantum numbers as vacuum. In treating the non-leptonic decays of hadrons, we only assume at the moment that the \( U(3) \) configuration is conserved in the black box.\(^5\) The conservation of configuration in unitary symmetry space could be expected in view of the known dynamics of
hadronic processes, which are familiar in the theory of allowedness and forbiddenness in the nuclear $\beta$ decay.

Our hypothesis of selection rules is expressed as follows: Define an $s$-channel for an actual process of weak transition in baryon and meson decays, a $t$-channel for a transition $B' + B \to M$ of the actual process of a baryon decay into a baryon and a meson $B' \to B + M$ and a $u$-channel for a crossed transition $B \to B' + M$, then the first rule \(^{63}\) is

$$
\Delta n_t = 0 \quad \text{in } s\text{-channel}, \tag{1.1}
$$

where $n_t = n + \bar{n}$ for any transition of baryon and meson, and the second rule \(^{63,4}\) is given as follows:

$$
\Delta m \quad \text{(in } s\text{-channel)} = 0 \tag{1.2}
$$

for the parity conserving (p.c.) transition, and

$$
\Delta m \quad \text{(in } t\text{-channel)} = 0 \tag{1.3}
$$

for the parity violating (p.v.) transition in nonleptonic decay of baryon. Consequences of both the first and the second rules were discussed in detail for decays of ordinary hadrons.\(^{3,8,4}\) The first rule forbids $K^+ \to \pi^+ + \pi^0$ decay. Equation (1.2) of the second rule yields the $\Delta I = 1/2$ relations for $P$-wave decays of $\Sigma$ and $\Xi$, and $P(\Sigma^-) = 0$. Equation (1.3) yields the Lee-Sugawara relations\(^5\) for $S$-wave amplitudes involving a meson of the same charge and $S(\Sigma^{*+}) = 0$. Note that Eqs. (1.2) and (1.3) work for $P$- and $S$-wave amplitudes in a complementary way\(^6\) as to the $\Delta I = 1/2$ and the Lee-Sugawara relations. If we further apply only Eq. (1.2) to the $K$-meson decays, we get the $\Delta I = 1/2$ relation for $K \to 2\pi$ and $I(\neq) = 1$ for $K^+ \to 3\pi$.

The yet unclarified problems of our rules are twofold on the phenomenological level. One is the conservation of $m$ in a $u$-channel of the p.c. transition. This rule yields the $\Delta I = 1/2$ relation for $P$-wave amplitudes of $\Sigma$ decay but forbids the $\Xi^- \to AK^-$ decay\(^4\) if this rule is applied to the $\Xi^-$ decay in addition to the second rules (1.2) and (1.3). We present a summary of our rule applied to the ordinary hadron decays in Table I. In Table I (II), $\bigcirc$ (x) denotes the allowance (prohibition) of each decay of the particle when the first ($\Delta n_t = 0$) or the second ($\Delta m = 0$) selection rule is applied. The check of $\Xi^-$ decay will give a further clue to our rules. The other problem is a further check of our rule on the decay processes of superhadrons, namely new hadrons having a new quantum number $N'$ (for the definition of $N'$, see § 2), the indication of which have been suggested in the cosmic ray jet.\(^6,7\) Consequences of the first rule on the superhadron decays have already been given in the previous paper.\(^3\)

In this paper we further present consequences of the second rule on the superhadron decays. Here we extend our selection rules to the one based on the quartet model.\(^4,7\) The quantum numbers $n_t$ and $m$ are defined in terms of
Table I. Conservation of configuration in ordinary hadron decays.

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<th>s-channel</th>
<th>u-channel</th>
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<tbody>
<tr>
<td>$A \rightarrow N\pi$</td>
<td>$\Delta n_i=0$</td>
<td>$\Delta m=0$</td>
<td>$\Delta n_i=0$</td>
</tr>
<tr>
<td>$\Sigma^+ \rightarrow p\pi^+$</td>
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<td>$\circ$</td>
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<tr>
<td>$\Sigma^+ \rightarrow n\pi^+$</td>
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</tr>
<tr>
<td>$\Sigma^- \rightarrow n\pi^-$</td>
<td>$\times$</td>
<td>$\circ$</td>
<td>$\circ$</td>
</tr>
<tr>
<td>$\Xi^0 \rightarrow \Lambda\pi^0$</td>
<td>$\circ$</td>
<td>$\circ$</td>
<td>$\circ$</td>
</tr>
<tr>
<td>$\Omega^- \rightarrow \Xi^-\pi^0$</td>
<td>$\circ$</td>
<td>$\circ$</td>
<td>$\times$</td>
</tr>
<tr>
<td>$\Omega^- \rightarrow \Xi^-\pi^0$</td>
<td>$\circ$</td>
<td>$\circ$</td>
<td>$\times$</td>
</tr>
<tr>
<td>$\Omega^- \rightarrow \Lambda K^-$</td>
<td>$\circ$</td>
<td>$\circ$</td>
<td>$\circ$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+\pi^0$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\circ$</td>
</tr>
<tr>
<td>$K^+ \rightarrow 2\pi$</td>
<td>$\circ$</td>
<td>$\circ$</td>
<td>$\circ$</td>
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<tr>
<td>$K^+ \rightarrow 3\pi$</td>
<td>$\circ$</td>
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</table>

a) This rule yields the same result with that of $\Delta I=\frac{1}{2}$ rule.

The fundamental quartet and the $SU(4)$ symmetry. The aim of this presentation is to give characteristic features of superhadron decays predicted from our selection rules which would immediately be checked in the superhadron phenomena. In §2 we shall give the consequences of our selection rules on the superhadron decays and discuss some possible examinations of the selection rules. In §3 we shall give some conjectures on a newly reported event which has recently been observed in the cosmic ray jet and some other concluding remarks.

§2. Selection rules applied to the superhadron decays

First we briefly summarize the relevant interaction. Taking fundamental quartet ($p, n, \lambda, p'$), the new Nagoya model gives the following form of the weak interaction:

$$H_w = \frac{G_0}{\sqrt{2}} J_a J_a^+, \quad J_a = J_a^{(1)} + J_a^{(2)},$$

(2.1)

where $J_a^{(1)} = (\bar{e}v_a \nu_e) + (\bar{\nu}_a e)\rho$ and $J_a^{(2)}$ is the hadronic current given as

$$J_a^{(2)} = \cos \theta (\bar{\nu}_a p') + \sin \theta (\bar{\nu}_a p')$$

$$-\sin \theta (\bar{\nu}_a p') + \cos \theta (\bar{\nu}_a p').$$

(2.2)

Non-leptonic interactions with $|\Delta N'| = 1$ ($N'$ denotes the quantum number of $p'$ component) have the following changes of quantum numbers:

$$\Delta S/\Delta N' = +1, \quad \Delta I_1/\Delta N' = -1 \quad \text{for } \cos^2 \theta \text{-term},$$

$$\Delta I_2/\Delta N' = 0.$$
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\[
\Delta S/\Delta N' = -1, \quad \Delta I_2/\Delta N' = 0 \quad \text{for} \quad \sin^2 \theta \text{-term}, \\
\Delta S/\Delta N' = 0, \quad \Delta I_2/\Delta N' = -1/2 \quad \text{for} \quad \sin \theta \cos \theta \text{-term}, 
\]

(2.3)

Table II. Selection rule based on conservation of configuration in superhadron decays. We list the results of only transitions through \(\cos^2 \theta\)-term of the weak interaction and omit ones through \(\sin \theta \cos \theta\) and \(\sin^2 \theta\)-terms (see Eq. (2.3)).

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<tr>
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<th>s-channel</th>
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<tr>
<td></td>
<td>(\Delta n_1 = 0)</td>
<td>(\Delta m = 0)</td>
<td>(\Delta n_1 = 0)</td>
</tr>
<tr>
<td>(A_1\rightarrow)</td>
<td>(\Sigma^+(Y^+)\pi^+)</td>
<td>(\Sigma^0(Y^0)\pi^+)</td>
<td>(\Lambda^0)</td>
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<tr>
<td></td>
<td>(\Sigma^+\pi^+)</td>
<td>(\Sigma^0\pi^0(\eta))</td>
<td>(\Sigma^+(Y^+)K^-)</td>
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<tr>
<td>(A_2\rightarrow)</td>
<td>(\Xi^+\pi^+)</td>
<td>(\Sigma^0\pi^0(\eta))</td>
<td>(\Xi^+(Y^0)K^-)</td>
</tr>
<tr>
<td>(A_3\rightarrow)</td>
<td>(\Xi^+\pi^+)</td>
<td>(\Sigma^0\pi^0(\eta))</td>
<td>(\Xi^+(Y^0)K^-)</td>
</tr>
<tr>
<td>(B_{1,2}\rightarrow)</td>
<td>(\Sigma^+(Y^0)\pi^+)</td>
<td>(d^+K^0)</td>
<td>(\Xi^+(Y^0)\eta)</td>
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Table II. (continued)

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<tr>
<th></th>
<th>$\Sigma^-(Y^-)\pi^+$</th>
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<th>$\Sigma^+(Y^+)\pi^-$</th>
<th>$\Sigma^0(Y^0)\pi^0$</th>
<th>$\Sigma^0(Y^0)\eta$</th>
<th>$\Lambda\pi^0(\eta)$</th>
<th>$\Xi^-K^0$</th>
<th>$\Xi^-K^0$</th>
<th>$\Xi^+K^+$</th>
<th>$\Xi^+K^+$</th>
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<th>$\Xi^0K^+$</th>
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<tbody>
<tr>
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<td>$\Xi^-\pi^+$</td>
<td>$\Xi^+\pi^-$</td>
<td>$\Xi^+\pi^-$</td>
<td>$\Xi^0K^0$</td>
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<td>$B_s^0\to$</td>
<td>$\Xi^-\pi^+$</td>
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<td>$\Xi^-\pi^+$</td>
<td>$\Xi^+\pi^-$</td>
<td>$\Xi^+\pi^-$</td>
<td>$\Xi^0K^0$</td>
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<td>$C_s^{0+}\to$</td>
<td>$A_s^+(B_s^a)\pi^+$</td>
<td>$D_s^+(B_s^a)\pi^+$</td>
<td>$B_{s^0}^+(D_{s^0})\pi^+$</td>
<td>$\Sigma^+(Y^+)\eta$</td>
<td>$\Xi^-K^0$</td>
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<td>$C_s^{0+}\to$</td>
<td>$A_s^+(B_s^a, D_s^a)\pi^+$</td>
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<td>$C_s^{++}\to$</td>
<td>$A_s^+(B_s^a, D_s^a)\pi^+$</td>
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<td>$A_s^+(B_s^a, D_s^a)\pi^+$</td>
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<td>$C_s^{++}\to$</td>
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<td>$C_s^{+}\to$</td>
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<td>$C_s^{+}\to$</td>
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where $S$ is the strangeness quantum number, $I_z$ a $z$-component of isotopic spin. We classify hadron states according to the $U(4)$ symmetry and as to the notation of the superhadron assignment, see the Appendix.

The consequences of the second rule, which is mentioned in the Introduction, are shown in Table II, and we could easily derive from it further consequences such as sum rules of the amplitudes of decay processes of the superhadrons. However, we shall limit our discussion just to some characteristic features of the selection rules. We add several remarks.

i) Existence of the multiple charged vertex

From the Table, we can see the triple charged vertex having the factor $\cos^4 \theta$ be confined to the following:

\begin{align}
A_1^+(\text{or } B_s^+) & \rightarrow D^{++}K^-, \\
C_1^+ & \rightarrow B_s^{++} (\text{or } D_s^{++}) K^-.
\end{align}

(With the factor $\cos \theta \sin \theta$ there appear

\begin{align}
A_1^+(\text{or } B_s^+) & \rightarrow D^{++} \pi^-,
B_s^{++} & \rightarrow p\pi^+, \Sigma^+ K^+,
\end{align}

etc.) The processes, Eq. (2.4) or (2.5), would appear actually as the quaternary charged vertices through the following process:

\[ A_1^+(\text{or } B_s^+) \rightarrow Y^0 \pi^+ \rightarrow \Sigma^+ \pi^+ \rightarrow \Sigma^- \pi^+ \rightarrow p\pi^+. \]

Such effective quaternary vertices having the $\cos^4 \theta$ factor are

\[ A_1^+(\text{or } B_s^+) \rightarrow Y^0 \pi^+ \rightarrow Z^0 K^+ \rightarrow \Sigma^+ \pi^+ \rightarrow \Sigma^- \pi^+ \]

and

\[ C_1^+ \rightarrow Y^0 L^+ \rightarrow Z^0 M^+ \rightarrow \Sigma^+ \pi^+ \rightarrow \Sigma^- \pi^+ \]

Further we can find even the quintuple vertex such as

\[ B_s^{++} \rightarrow D^{++} \pi^+ \rightarrow p\pi^+ \pi^-, \]

although the first decay occurs with the factor $\cos \theta \sin \theta$.

Finally we add a comment on the test of the first selection rule ($\Delta n_s = 0$: in $s$-channel). The triple charged vertex $B_s^{++} \rightarrow \Sigma^+ \pi^+$ is prohibited by the first selection rule, therefore if we observe such a vertex in a future experiment, the first selection rule should be violated.
ii) Cascade processes

The whole processes of C-decays shown in the Table are cascade decays. We shall analyse those cascade processes in three cases where the mass difference \( \Delta M = m_B - m_A \) (which we assume to be positive) is given as follows:

1. \( \Delta M > m_K \): In this case, clearly every \( B \to A \) transition can occur with the strong interaction.

2. \( m_K > \Delta M > m_\pi \): The \( B \to A \) transition through the strong interaction is possible only for \( \pi \)-emitting process. The \( \pi \)-emitting \( B \to A \) transition is also possible through the weak interaction with \( \Delta S \neq 0 \) and \( \Delta N' = 0 \) (\( N' \) denotes the quantum number of \( p' \) component. See paper I.)

3. \( m_\pi > \Delta M \): The \( B \to A \) transition is not allowed except in the \( \gamma \)-decays and semi-leptonic decays.

These situations are schematically shown in Fig. 1., where emitted \( \pi \) or \( K \) mesons are not explicitly shown and \( S, W \) and \( H \) denote the strong interaction, the weak interaction and the ordinary hadrons, respectively. For example, \( W_n \) stand for a weak transi-

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Fig. 1. Scheme of cascade decay of C-baryon.

Fig. 2. Possible diagrams of C-baryon decay.

Fig. 3. Visible decay of C-baryon in the cases of diagrams (1) and (2a) in Fig. 2.
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We shall show diagrams of the cascade processes in Fig. 2 by abbreviating the decays of $A$ or $B$ to the ordinary hadrons. The diagrams (1) and (2a) in Fig. 2 are the same with the one of the pole approximation and are effectively given by the diagram of Fig. 3. Therefore if we can find such vertex as $C + B + (\text{ordinary meson})$, we shall show diagrams of the cascade processes in Fig. 2 by abbreviating the decays of $A$ or $B$ to the ordinary hadrons. The diagrams (1) and (2a) in Fig. 2 are the same with the one of the pole approximation and are effectively given by the diagram of Fig. 3. Therefore if we can find such vertex as $C + B + (\text{ordinary meson})$, it represents the case (1), i.e., $\Delta M > m_K$ and the cascade processes of the type (2b) shows the case (2), i.e., $m_K > \Delta M > m_A$. Of course we must consider the processes accompanying supermesons. The discussion of such processes will be made in connection with the analysis of the newly reported event in § 3.

iii) Check of the selection rule

According to the first selection rule proposed in paper I, the processes with $\Delta n_t \neq 0$ in s-channel are first forbidden so that the particles whose decay modes with the factor $\cos^2 \theta$ are all subjected to the $\Delta n_t = 0$ in s-channel would be observed as long lived. The examples are $A_2^+, B_2^{++}$, $B_2^+$, $C_2^{++}$ and $C_2^+$. $A_1^+ \rightarrow A^+ \eta$ is the only process with $\Delta m = 0$ in all channels (while $\Delta n_t = 0$ in all channel) and the observability of this mode gives the interesting test of the first and the second selection rules.

Next we discuss the complementary nature of Eqs. (1·2) and (1·3) as pointed out in the Introduction together with the problems of the conservation of $m$ in a u-channel for the p.c. transition. This problem may also be investigated, similarly to the $Q$-decay, by the transitions with $\Delta m = 0$ in both u- and t-channels (of course $\Delta m = 0$ in s-channel) such as $B_3^{0} \rightarrow E^- K^+$ or $B_3^{0} \rightarrow p K^-$. Finally, we make some comments on the asymmetry factors ($\alpha$) of the super-baryon decays. The following processes (with the factor $\cos^2 \theta$) will show no asymmetry, e.g., $\alpha = 0$ because of the prohibition of the p.c. or p.v. decay due to $\Delta m = 0$ in s-channel or in t-channel:

\[
\begin{align*}
A_1^+ & \rightarrow \Sigma^+ \pi^0, & \Xi^0 K^+, \\
A_2^0 & \rightarrow \Sigma^+ K^-, & \Xi^0 \eta, \\
B_3^{0} & \rightarrow \Sigma^0 \pi^0, & \Lambda \pi^+, & \Xi^0 K^+,
\end{align*}
\]

and we find many other processes (having the $\cos \theta \sin \theta$ or $\sin^2 \theta$ factor) with $\alpha = 0$.

The $\Delta m$ (in u-channel) problem is also checked in asymmetry factors: for the processes with the factor $\cos \theta \sin \theta$ the following examples are $\Delta m = 0$ in u-channel (but $\Delta m = 0$ in s- and t-channels):

\[
\begin{align*}
A_1^+ & \rightarrow p \bar{K}^0, & A_2^0 & \rightarrow E^- \pi^+, & B_3^{0} & \rightarrow p \bar{K}^0, & B_3^{0} & \rightarrow \Sigma^- \pi^+.
\end{align*}
\]

iv) Other remarks

Further we want to list up the following remarks:
(a) Pure electromagnetic processes:
For the case $\Delta M < m_\gamma$, such $\gamma$-decay processes as
\[ B_2^0 \rightarrow A_1^0 + \gamma, \]
\[ D_4^0 \rightarrow B_4^0 + \gamma \quad (k=1, 2, 3), \]
\[ D_4^0 \rightarrow A_4^0 + \gamma \]
become possible.
(b) $L^0-L^0$ mixing:
We can consider the $L^0-L^0$ mixing analogously to the $K^0-K^0$ mixing. The
typical decay schemes are shown by
\[ L_1^0 \rightarrow \pi \pi \]
\[ K^0 \rightarrow L_4^0. \]
However, if the mass of $L_1^0$, $L_4^0$ is both near or larger than 1 GeV, the difference
of this life time will not be appreciable.
(c) V-event:
Many V-events are expected as is shown in Table II. The examples are
$A_4^0 \rightarrow 3\pi^+ \pi^+$ and $A_4^0 \rightarrow \Sigma^+ K^-.$

§ 3. Concluding remarks

Now we apply the consequence of Table II to some conjectures on a newly
reported event observed in the cosmic ray jet.
Niu et al. has reported another new event in the cosmic ray jet. The event
is described in their paper and we reproduce only the relevant part of it in
Fig. 4. Their observation is that a charged particle originated from the jet
origin $0$ suffers from double large angle scattering at $C$ and $D$ accompanied by
no recoil traces and that near the charged line there are observed one gamma
($\gamma_2$) and $\pi^0$. Geometrically the extrapolated line 2 of $\pi^0$ crosses three dimensionally
with line 3 or $\gamma_2$, but these can be coplanar neither with line 1 nor with a line connecting
$B$ with any of 0 and $D$. We conjecture that the $\pi^0$ is produced by a decay at $A$ into a
forward direction of a neutral particle which comes from $B$. As to $\gamma_2$, we conjecture two
cases on the basis of Table II as follows (see Fig. 6):
(i) The case of $\pi^0(\gamma_2)$ produced: This is
shown in Fig. 5 (a), where we assume the $C^+_2$ decaying with the factor $\cos^2 \theta$ and the missing
$\gamma(\gamma'_2)$ being produced together with $\gamma_2$ as is

Fig. 4. A new event observed in cosmic ray jet.
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Fig. 5. Possible interpretation of the new event.

Fig. 6. Interpretation of the new event in terms of diffraction dissociation $K^0 \rightarrow K^{*+}$.

also shown. $K^+$ would then be scattered by the nucleous.

(ii) No $\pi^0(\gamma_2)$ case: In this case we may accept that $\gamma_2$ is not correlated with the cascade process of the superhadron $C$, and possible interpretation is shown in Figs. 5(b) and 5(c).

We have not discussed the possible diagrams which are ascribed to the weak decay of $C$ with the factor $\cos \theta \sin \theta$ or $\sin^2 \theta$, and which would be realized less frequently. Another conjecture is given by Sawada who regarded the high energy $\pi^0$-production as being the diffraction dissociation $K^0 \rightarrow K^{*+}$ as is shown in Fig. 6 by the arrow.

Now we should notice that the above interpretations are possible conjectures based on Table II which have inevitably many ambiguous features. Further accumulation of experiment is keenly anticipated for the clarification of this kind of event and the check of our selection rules.

Acknowledgements

We thank Prof. K. Niu and his collaborators for showing us their data prior to publication.

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Appendix

Particle assignment

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