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THE "LEADING" BARYON EFFECT IN STRONG, WEAK, AND ELECTROMAGNETIC INTERACTIONS

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ABSTRACT

The "leading" baryon effect is reported. A comparison is made between baryon-baryon and lepton-baryon interactions. The "leading" effect is present in both cases. This shows its relevance for the understanding of hadronic phenomena in strong, weak, and electromagnetic processes.

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1. INTRODUCTION

The purpose of the present paper is to report on a study of hadronic interactions induced on a baryon, either by another baryon or by a lepton. The main goal was to establish the existence of a "leading" effect when a hadron interacts strongly, weakly, or electromagnetically.

In Section 2 we define the "leading" quantity L; in Section 3 the "leading" effect is studied in proton-proton collisions. Section 4 is devoted to the analysis of the lepton-baryon case. The conclusions are presented in Section 5.

2. DEFINITION OF THE "LEADING" VARIABLE L

In a given hadronic reaction, the "leading" particle is the one carrying away a considerable fraction of the total available energy$^{1)}$. It is currently studied in terms of its fractional momentum variable:

$$x = p_L / p_{L,\max} \ , \qquad -1 \le x \le 1 \ , \tag{1}$$

where p_L is the longitudinal momentum component along the beam direction in the centre-of-mass system.

In order to quantify the "leading" effect, we have introduced the following variable:

$$L(x_0, x_1, x_2) = \frac{\int_{x_0}^{x_2} F(x)\ dx}{\int_{x_0}^{x_1} F(x)\ dx} \ , \tag{2}$$

where F(x) is the inclusive single-particle cross-section. This is defined as:

$$F(x) = \frac{1}{\pi} \int \frac{2E}{\sqrt{s}} \frac{d^2\sigma}{dx\,dp_T^2}\ dp_T^2 \ , \tag{3}$$

where E is the energy and p_T the transverse momentum of the particle, and $\sqrt{s}$ is the total centre-of-mass energy.

The integration limits used in formula (2) are $x_0 = 0.2$, $x_1 = 0.4$, and $x_2 = 0.8$. These are chosen in order to reduce diffractive ($x > 0.8$) and central ($x < 0.2$) production effects.

3. THE "LEADING" BARYON EFFECT IN PROTON-PROTON INTERACTIONS

We have studied the quantity $L(x_0,x_1,x_2)$ for different hadrons produced in (pp) collisions at the CERN ISR[2-5]:

$$\left\{\begin{array}{ll} pp \to p + \text{anything} & \quad (4a) \\ pp \to n + \text{anything} & \quad (4b) \\ pp \to \Lambda^0 + \text{anything} & \quad (4c) \\ pp \to \Sigma^+ + \text{anything} & \quad (4d) \\ pp \to \Sigma^- + \text{anything} & \quad (4e) \\ pp \to \bar{p} + \text{anything} & \quad (4f) \\ pp \to \overline{\Lambda^0} + \text{anything} & \quad (4g) \end{array}\right.$$

The data refer to energies from 25 to 62 GeV. By inspecting the energy-dependence of L in the case of the neutron[4] (no data are available for other hadrons in a wide energy range), we conclude that the quantity L scales at ISR energies. It will be assumed to scale for all types of hadrons.

In Fig. 1 we have plotted the values of L derived from the experimental x-distributions of the different hadrons in the reactions (4a) to (4g). The final states are ordered according to the number of quarks propagating from the initial state (the proton) to the final state.

The results of Fig. 1 show that for different hadrons the value of L is the same provided the number of propagating quarks is the same.

In order to compare the "leading" variable L with previous parametrizations[6], we have used in formula (2) the fit

$$F(x) = (1 - x)^{\alpha} , \qquad (5)$$

where $\alpha = 2n - 1$ (n is the number of quarks which need to be changed in order to obtain the wanted final hadron state). The dashed line in Fig. 1 is the resulting variation of L versus the number of propagating quarks, once the above parametrization (5) is used for F(x).

The results show that the value of the "leading" quantity L is ~ 3 when the number of propagating quarks is 3. It is ~ 1.5 if the number of propagating quarks is two. It is ~ 0.5 when only one quark propagates, and it is $\lesssim 0.2$ when there is no quark propagation in the production of the final hadron state. Table 1 summarizes the results and describes the states in terms of their quark content.

The "leading" baryon effect is clearly present and it depends on the number of propagating quarks.

Recent studies on heavy-flavoured baryon produced in (pp) interactions at the CERN ISR, provide evidence for the "leading" effect also in Λ_c^+ and Λ_b^0 production$^{7-11)}$.

The next step is to investigate whether there is any "leading" hadron effect when the hadron interacts either weakly or electromagnetically.

4. THE "LEADING" BARYON EFFECT IN LEPTON-BARYON INTERACTIONS (WEAK AND ELECTROMAGNETIC)

For this purpose we have studied the data on (νp) and ($\bar{\nu}$p) interactions at Fermilab energies$^{12-14)}$. The proton x-distribution was measured in (νp) and ($\bar{\nu}$p) charged-current events, at the Fermilab 15 ft hydrogen bubble chamber$^{12,13)}$. The most significant data refer to antineutrino interactions:

$$\bar{\nu} + p \rightarrow \mu^+ + p + \text{anything} \;, \tag{6}$$

at the energy $\langle W^2 \rangle \simeq 25$ GeV^2 (where W is the invariant mass of the final state hadronic system recoiling against the muon). This distribution shows a very flat behaviour in the proton-recoil hemisphere ($x < 0$), thus establishing the existence of the "leading" proton effect in weak processes. The value of $L(x_0,x_1,x_2)$ for reaction (6) is $L_p = 3.2 \pm 0.5$.

Further evidence for the "leading" baryon effect in this kind of process can be derived from the inclusive Λ^0 production. The best data in this case are again those of the charged-current reaction$^{14)}$:

$$\bar{\nu} + N \rightarrow \mu^+ + \Lambda^0 + \text{anything} \;, \tag{7}$$

observed in the Fermilab 15 ft bubble chamber filled with a Ne-H_2 mixture, at $\langle W^2 \rangle \simeq 20$ GeV^2. The measured x-distribution of the Λ^0 exhibits a clean "leading" effect in the $x < 0$ region.

The value of $L(x_0,x_1,x_2)$ derived for reaction (7) is plotted in Fig. 2. It agrees well with the corresponding L value obtained for reaction (4c) in (pp) interactions at higher energy, as shown in Fig. 1. This study proves that the "leading" baryon effect appears in weak interactions as firstly observed in purely hadronic interactions.

The same analysis can be repeated for the inclusive Λ^0 electroproduction:

$$e^- + p \to e^- + \Lambda^0 + \text{anything} . \qquad (8)$$

This was measured in a streamer chamber experiment at Cornell, in the energy range $5 < W^2 < 18$ GeV^2 [15]. The data again show that the Λ^0 is produced in a "leading" way even in electromagnetic interactions. The $L(x_0,x_1,x_2)$ value, relative to reaction (8), is only slightly higher than the analogous value found for reaction (7), as shown in Fig. 2, and both these values compare with the value for reaction (4c).

It should be noticed, as discussed in Ref. 1, that for Λ^0 production the energy dependence of L shows the same features as those observed for proton production. In fact, the three values of L obtained for the Λ^0 at ISR, at Fermilab, and at Cornell energies, suggest the following trend: the higher is the available energy, the lower is the value of L.

All the above results thus point out that it does not matter whether the hadron interacts strongly, weakly, or electromagnetically: its "leading" effect is always present.

5. CONCLUSION

In baryon-baryon interactions, the "leading" baryon effect shows up very clearly in the x-range (0.2-0.8). This "leading" effect is maximum when the final-state hadron is the same as the initial-state hadron. However the "leading" effect is present even when the initial-state quantum numbers differ from those of the final state (for instance, when a proton becomes a Λ^0). As the difference between the initial- and the final-state quark composition increases, the "leading" effect decreases. This supports the idea that the "leading" phenomenon is generated by the quantum number "flow" from the initial to the final state.

The "leading" baryon effect appears both in baryon-baryon and in lepton-baryon interactions. This means that a definite similarity must exist between processes where a hadron is present in the initial state, no matter if the interaction is strong, weak, or electromagnetic.

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Table 1

ISR (pp) processes

Initial state: proton (udu)			
Final state particle	Quarks composition	Propagating quarks	L(0.2,0.4,0.8)
p	(udu)	(udu)	3.2 ± 0.2
n	(udd)	(ud)	1.92 ± 0.05
Λ^0	(uds)	(ud)	1.02 ± 0.10
Σ^+	(usu)	(uu)	1.15 ± 0.17
Σ^-	(dds)	(d)	0.53 ± 0.15
$\bar{p}$	$(\bar{u}\bar{d}\bar{u})$	nothing	0.30 ± 0.05
$\bar{\Lambda}^0$	$(\bar{u}\bar{d}\bar{s})$	nothing	0.10 ± 0.02

Figure captions

Fig. 1 : The "leading" quantity L(0.2,0.4,0.8) derived for different types of baryons produced in (pp) collisions at the CERN ISR. The centre-of-mass energy ranges from 25 to 62 GeV. The hadrons are ordered according to the number of propagating quarks. The dashed-line curve superimposed is obtained by using a parametrization of the single-particle inclusive cross-section, $F(x) = (1 - x)^{\alpha}$, as described in Section 3.

Fig. 2 : The "leading" quantity L(0.2,0.4,0.8) of the Λ^0 produced in $(\bar{\nu}p)$ interactions at $\langle W^2 \rangle = 20$ GeV^2 and in (e^-p) interactions with $5 < W^2 < 18$ GeV^2. In this case the number of propagating quarks is two. The dashed-line curve of Fig. 1 is also shown to guide the eye.

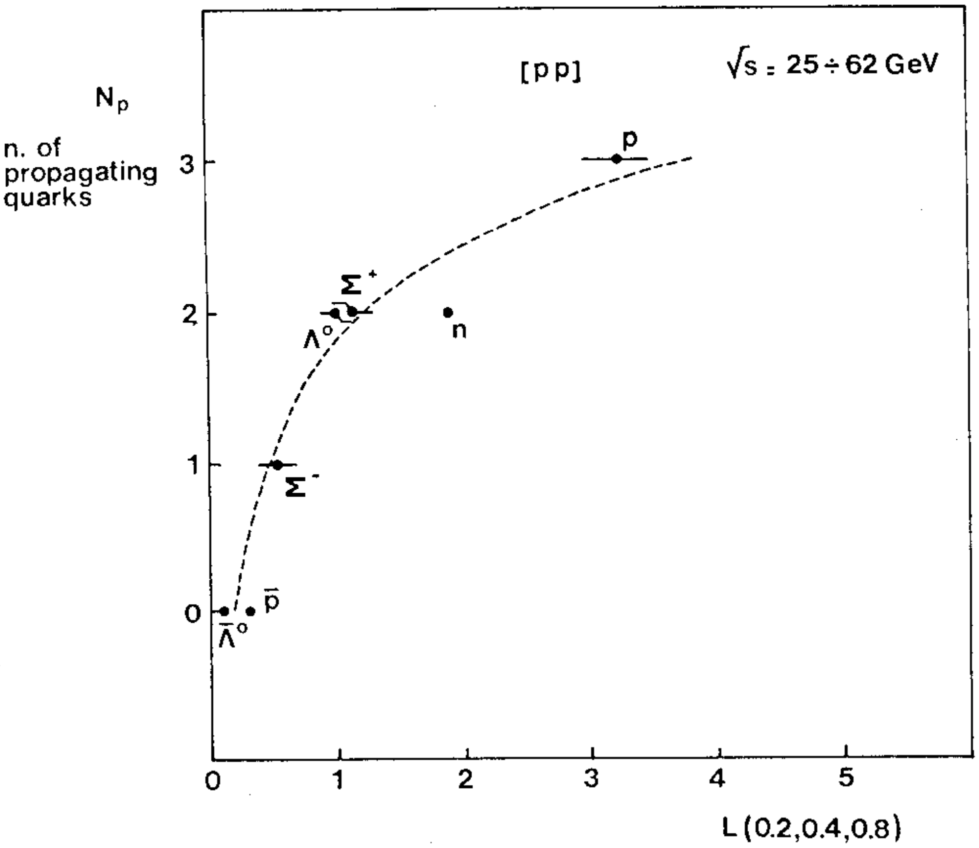
N_p
n. of
propagating
quarks
[p p]
$\sqrt{s} = 25 \div 62$ GeV
p
Σ^+
Λ^o
n
Σ^-
$\bar{p}$
$\bar{\Lambda}^o$
0
1
2
3
0
1
2
3
4
5
L (0.2,0.4,0.8)

FIG.1

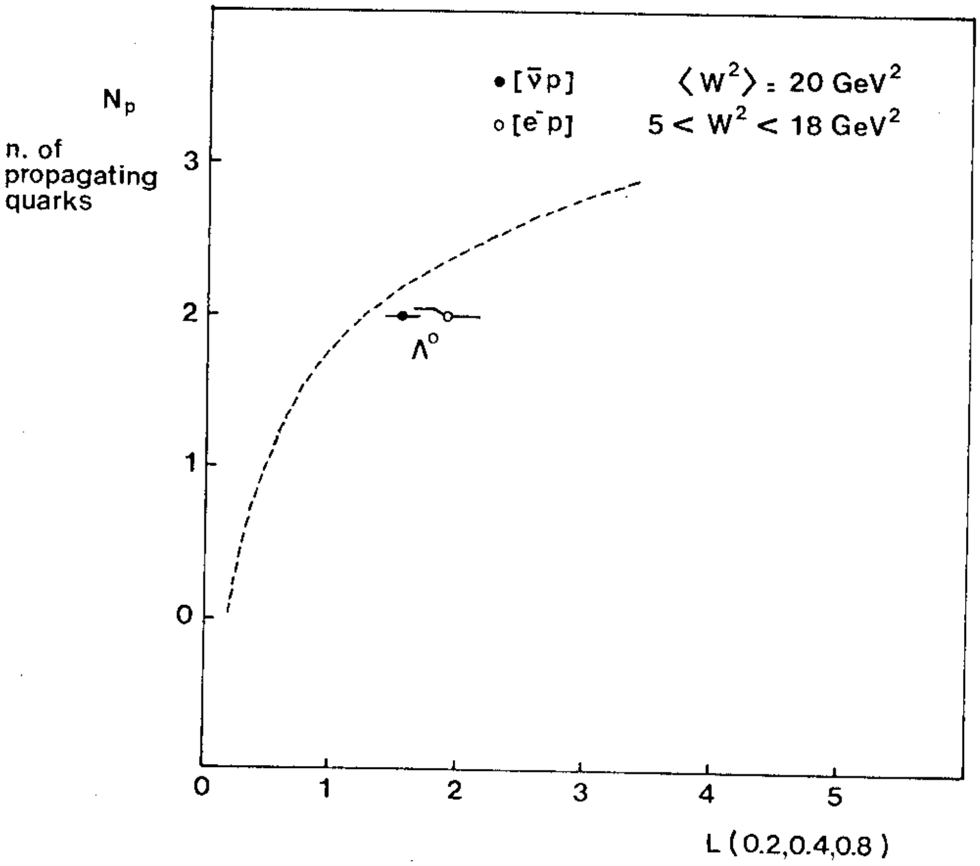
N_p
n. of propagating quarks
● [$\bar{\nu}$p]
○ [e$^-$p]
$\langle W^2 \rangle = 20$ GeV^2
$5 < W^2 < 18$ GeV^2
Λ^0
0
1
2
3
0
1
2
3
4
5
L (0.2,0.4,0.8)

FIG. 2