SU(3) Breaking in Hyperon Beta Decays: a Prediction for $\Xi^0 \to \Sigma^+ e\bar{\nu}$

Philip G. Ratcliffe

SU(3) breaking in hyperon semi-leptonic decays is discussed. The SU(3) parameters $F$ and $D$, relevant to the “proton-spin puzzle”, are extracted and a prediction is presented for the decay $\Xi^0 \to \Sigma^+ e\bar{\nu}$, currently under study by the KTeV collaboration. The values found are $g_1/f_1 = 1.16 \pm 0.03 \pm 0.01$ and $\Gamma = (0.80 \pm 0.03 \pm 0.01) \cdot 10^6$ s$^{-1}$.

1. Introduction

Beside the accurately measured $\beta$-decay rate and angular asymmetries for the neutron, there is also a solid body of data regarding the rest of the baryon octet [1]. In SU(3) such decays are described via two parameters, $F$ and $D$, relating to strong-interaction effects and two further parameters, $V_{ud}$ and $V_{us}$, the CKM matrix elements (possible contributions of heavier flavours may be safely neglected). The $F$ and $D$ parameters are important, as they appear in the well-known Ellis-Jaffe sum rule [2]; a 15% reduction in the ratio $F/D$ from its accepted value ($\sim 0.6$) would remove the discrepancy with polarised DIS data and alleviate the “proton-spin puzzle” [3].

As SU(3) is generally violated at the 10% level, it is important to develop a reliable description of the breaking. A serious test of any scheme proposed lies in the predictions made for new decays. The process $\Xi^0 \to \Sigma^+ e\bar{\nu}$, soon to be measured accurately by the KTeV collaboration at Fermilab [4], will provide just such a test. In this talk, following an outline of the data and a scheme to describe SU(3) breaking, I shall present a prediction for the above decay [5].

2. The HSD Data

Fig. 1 displays the measured baryon octet $\beta$-decays, indicating the nature of the data available. Note that a few of the decays have also been studied in the $\mu$ mode. The present world data on hyperon semi-leptonic decay (HSD) are collected in table 1. Let me remark that several of the rates and asymmetries have now been measured to better than 5%.

Although not evident from the table, there is a discrepancy in the neutron $\beta$-decay data. However, the precision there (around 0.2%) is far beyond the needs of the present analysis. To avoid clouding the SU(3) breaking interpretation of the full data set, I follow the PDG practice.
The global dance with the Ademollo-Gatto theorem. A further global $\sim 2\%$ normalisation correction to the

Table 1
The present world HSD rate and angular-correlation data [1]. The numerical values marked $g_1/f_1$ are those extracted from angular correlations.

| Decay     | Rate ($10^6 s^{-1}$) | $g_1/f_1$ SU(3) |
|-----------|----------------------|----------------|
| $n \rightarrow p$ | $1.1274 \pm 0.0025$ | $F + D$ |
| $\Lambda^0 \rightarrow p$ | $3.161 \pm 0.058$ | $F + D/3$ |
| $\Sigma^- \rightarrow n$ | $6.88 \pm 0.23$ | $F - D$ |
| $\Sigma^- \rightarrow \Lambda^0$ | $0.387 \pm 0.018$ | $-\sqrt{2/3} D^b$ |
| $\Xi^- \rightarrow \Lambda^0$ | $3.35 \pm 0.37$ | $-\sqrt{2/3} D^b$ |
| $\Xi^- \rightarrow \Sigma^0$ | $0.53 \pm 0.10$ | $F + D$ |

$a$ Rate given in units of $10^{-3} s^{-1}$. $b$ Absolute expression for $g_1$ given ($f_1 = 0$). $c$ Scale factor 2 included in error (PDG practice for discrepant data). $d$ Data not used in these fits.

and rescale the discrepant data by their resulting $\chi^2$ (see [6]): the errors in both $\Gamma$ and $g_1/f_1$ for the neutron become 0.0055. This removes any anomalous contribution to the octet decay $\chi^2$, thus allowing a fair comparison of fits.

3. SU(3) Breaking and Fit Results

SU(3) breaking can be well described using centre-of-mass (CoM), or recoil, corrections [6–8]. One approach, $A$, here, is to account for the extended nature of the baryon by applying momentum smearing to its wave function. Thus, CoM corrections to $g_1$ for the decay $A \rightarrow B \ell \nu$ lead to

$$g_1 = g_1^{SU(3)} \left[ 1 - \frac{\langle p^2 \rangle}{3m_A m_B} \left( \frac{1}{4} + \frac{3m_B}{8m_A} + \frac{3m_A}{8m_B} \right) \right].$$

Approach $B$ is rather similar: the breaking is related to mass-splitting effects in the interaction Hamiltonian via first-order perturbation theory [9]. The correction turns out equivalent to a linearised version of the above:

$$g_1 = g_1^{SU(3)} \left[ 1 - \epsilon (m_A + m_B) \right].$$

Note that in both approaches the corrections are normalised to the reference-point correction for $g_1^{n \rightarrow p}$ and depend on just one new parameter ($\langle p^2 \rangle$ and $\epsilon$). Corrections to $f_1$ are found to be negligible in $A$ and are assumed so in $B$, in accordance with the Ademollo-Gatto theorem. A further global $\sim 2\%$ normalisation correction to the $|\Delta S=1|$ rates marginally improves the fit without altering the results; in [7] a larger value, $\sim 8\%$, was used; however, this worsens present-day fits.

Table 2 displays the results of three fits: $S$ (symmetric), $A$ and $B$. With regard to these fits, a few clarifying remarks are useful. The value of $V_{ud}$ (and hence $V_{us}$, fixed here via CKM unitarity) is mainly determined by the super-allowed nuclear $ft$ values and so-called $K_{e3}$ analyses. However, when $V_{ud}$ and $V_{us}$ are extracted from HSD data alone, all parameter values remain very similar. Indeed, $F$ and $D$ are quite insensitive to the breaking schemes used.

4. A Prediction

Table 3 compares the predictions obtained for $\Xi^0 \rightarrow \Sigma^+ e \nu$ from the above three fits. Recall that $g_1/f_1 = F + D$ for this decay, thus allowing for important check points. The variation between the two SU(3) breaking fits lies within the statis-
Table 3  
The axial coupling, rate and branching fraction ($B$) for $\Xi^0 \to \Sigma^+ e\bar{\nu}$. The errors are those returned by the fitting routine.

| Fit | $g_1/f_1$ | $\Gamma$ ($10^6$ s$^{-1}$) | $B$ ($10^{-4}$) |
|-----|-----------|----------------------------|---------------|
| $S$ | 1.26(0)$^a$ | 0.89(1) | 2.58(05) |
| $A$ | 1.17(3) | 0.80(3) | 2.32(10) |
| $B$ | 1.14(3) | 0.78(3) | 2.26(12) |

$^a$ Zero error is assigned to $g_1/f_1$ in the symmetric fit as it would be that of neutron $\beta$-decay.

A full comprehension of SU(3) violation is still wanting: witness the octet-decuplet discrepancy and the $|\Delta S|=1$ uncertainties noted above; moreover, the system is not yet truly over-constrained. In this context, I might also mention another decay (already measured but not accurately so) for which large corrections are expected: namely, $\Xi^- \to \Sigma^0 e\bar{\nu}$. There too $g_1/f_1 = F + D$, allowing for additional sensitive cross checks.

Concluding then, I would stress that while the data do clearly manifest significant departures from SU(3), the mass-splitting driven schemes discussed here provide a perfectly adequate description. That said, there is clearly still much to be understood: e.g., the long-standing question of second-class currents. Thus, any new precise data are more than welcome and the contribution of the KTeV collaboration will be invaluable.

6. Acknowledgments

The author happily thanks Prof. E.C. Swallow for much helpful information and comment.

REFERENCES

1. Particle Data Group, R.M. Barnett et al., Phys. Rev. D54 (1996) 1.
2. J. Ellis and R.L. Jaffe, Phys. Rev. D9 (1974) 1444; erratum ibid. D10 (1974) 1699.
3. F.E. Close and R.G. Roberts, Phys. Lett. B316 (1993) 165.
4. E. Monnier, these proceedings.
5. P.G. Ratcliffe, Como preprint UNICO-98-002, e-print hep-ph/9806381 (1998); submitted to Phys. Rev. Lett.
6. P.G. Ratcliffe, Phys. Lett. B365 (1996) 383.
7. J.F. Donoghue, B.R. Holstein and S.W. Klimt, Phys. Rev. D35 (1987) 934.
8. P.G. Ratcliffe, Phys. Lett. B242 (1990) 271.
9. P.G. Ratcliffe, in proc. of Deep Inelastic Scattering off Polarized Targets: Theory Meets Experiment (DESY-Zeuthen, Sept. 1997), eds. J. Blümlein and W.-D. Nowak, p. 128.
10. R. Flores-Mendieta, E. Jenkins and A.V. Manohar, San Diego preprint UCSD/PTH 98-17, e-print hep-ph/9805416 (May 1998).
11. A. Manohar, private communication.