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LEPTONIC DECAY EXPERIMENTS WITH HYPERONS BEAMS AT NAL

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Introduction:

If the estimates of hyperon production by 200 Gev/c protons are correct[1], we can look forward to experiments with $\sim 10^4$-10^5 hyperon leptonic decays at NAL. In this report, we examine some of the physics one learns from such experiments and discuss quantitatively the feasability of several typical experiments. For purposes of discussion, we assume the hyperons in the beam will be unpolarized so that only decays with Λ's in the final state will contain polarization information.

1. Beta decays of unpolarized hyperons:

Without polarization information, the only observables are the $\hat{e}.\hat{\nu}$ correlation $\equiv a$, and the beta spectrum. For the $\hat{e}.\hat{\nu}$ correlation, one has[2]

$$\frac{1-\bar{a}}{1+\bar{a}} = \frac{2|g_1|^2 - 4\frac{\Delta M}{M}\,\mathrm{Re}\, g_1^* g_2}{\left(|f_1|^2+|g_1|^2\right)\left(1+\frac{\Delta M}{M}\right)} \qquad (1)$$

where the bar means averaged over the electron spectrum.

1. T.G. Walker, NAL Summer Study 1969, SS-69-3 Vol 1, p. 173.

2. See, for example, J.M. Watson & R. Winston, Phys. Rev. 181, 1907 (1969). Our expressions are correct to first order in $\frac{\Delta M}{M}$.

Therefore, if one assumes (as is usually done) that the second class term $g_2 = o$, a measurement of $\bar{a}$ gives $\left|\frac{g_1}{f_1}\right|$.

for the beta spectrum, one can show that

$$\frac{dN}{dP_e} = \text{Const.}\ P_e^2 (P_{emax} - P_e)^2 \left[1 + \frac{\alpha}{M}(2P_e - P_{emax}) \right] \quad (2)$$

where the parameter that describes the deviation from the allowed shape is

$$\alpha = \frac{|f_1|^2 + 5|g_1|^2 + 2\,\mathrm{Re}\, g_1^*(f_1 + 2f_2)}{|f_1|^2 + 3|g_1|^2 - 4\frac{\Delta M}{M}\,\mathrm{Re}\, g_1^* g_2} \quad (3)$$

As is well known from nuclear beta decay, α is very sensitive to the weak magnetism term f_2. To estimate the sensitivity of the spectrum to α, we divide the spectrum into two halves at $Pe = Pemax/2$. Let N_1 = number of electrons in $o \leq Pe \leq Pemax/2$

N_2 = Number of electrons in $\frac{Pemax}{2} \leq Pe \leq Pemax$

$N_1 + N_2 = N$

Then $$\frac{N_2 - N_1}{N} = \frac{5}{16}\ \frac{Pemax}{M} \cdot \alpha \quad (4)$$

$$\delta\alpha = \frac{16}{5}\ \frac{M}{Pe^{max}} \cdot \frac{1}{\sqrt{N}}$$

where $\delta\alpha \approx$ one standard deviation.

For, example, in $\Lambda \to Pe\nu$, $\delta\alpha \approx \frac{20}{N}$ so that $\delta\alpha \approx 0.1$ would require 4×10^4 events. Such an experiment requires the high flux of a hyperon beam and may be the only way available to measure weak magnetism in hyperon decays.

2. Decays with Λ's in the final state.

Experiments on $\Sigma^- \to \Lambda e\bar{\nu}$ and $\Xi^- \to \Lambda e\bar{\nu}$ are particularly attractive because one can study correlations like $\vec{\sigma}_\Lambda \cdot \hat{e}$ and $\vec{\sigma}_\Lambda \cdot \hat{\nu}$

in addition to the other information discussed above. The expressions for these correlations may be found in ref. 2 and 3. The $\Delta S = 0$ decay $\Sigma^- \rightarrow \Lambda e\bar{\nu}$ may have special interest. Preliminary results on $\Lambda \rightarrow pe\bar{\nu}$ indicate deviations from a simple V, A interaction.[4] If this is accepted, it is important to see whether such deviations are due to change of strangeness or large Q value.

3. Decays with muons in the final state.

In this class of experiments, Muons from $\pi \rightarrow \mu\nu$ decay which follows the much more probable two-body hyperon decay mode can be a very serious background. Since decay lengths scale with energy, the level of background is $\sim$ independent of accelerator energy. The following method may be employed to cleanly separate background from real events[5]. The method requires knowledge of the hyperon direction, but not its momentum as in $\Lambda \rightarrow p\mu\bar{\nu}$ experiments. It can be generalized to $\Sigma^- \rightarrow n\mu\bar{\nu}$ experiments where one knows the neutron direction but not the momentum. For the sake of illustration, we describe the method for $\Lambda \rightarrow p\mu\bar{\nu}$. Let the lambda direction lie along the z axis. Then $P_{\nu x}$ and $P_{\nu y}$, the transverse neutrino momentum are known. The end point of $\sqrt{P_{\nu x}^2 + P_{\nu y}^2}$ will be very nearly the same for leptonic decays and background and is not useful for distinguishing between the two. However, the kinematic boundry in the x,y plane is quite different and can be used to reject background.

We define the x-axis by requiring the proton to lie in the x,z plane with $P_x \equiv -P$. Then $P_{\nu x}$, $P_{\nu y}$ from the two-step decay

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3. P.S. Desai, Phys. Rev. 179, 1327 (1969).
4. Argonne, Chicago, Ohio State Washington U. Collaboration.
5. Proposal to the ZGS to study $\Lambda \rightarrow p\mu\nu$; ANL, Chicago, Ohio State.

$\Lambda \to p + \pi \to p + \mu + \bar{\nu}$ are confined in an ellipse with semi-minor axis $\equiv a = \nu_o$ along y, semi-major axis $b = \sqrt{1 + (p/m\pi)^2} \cdot \nu_o$ along x and center at $x = (p/m\pi) \cdot \nu_o$, y = o. Here $\nu_o \sim 30$ mev along x is the neutrino momentum from $\pi \to \mu\nu$ decay in the pion center of mass. The maximum value of $P = P_o \sim 100$ mev/c and the average $P \equiv \langle P_o \sin\Theta \rangle = \frac{\pi}{4} P_o$. Therefore, the area of the average ellipse is

$$\text{Ellipse Area} = \pi\sqrt{1 + \left(\frac{\pi}{4}\frac{P_o}{m\pi}\right)^2}\,\nu_o^2 \approx 1.15\pi\nu_o^2 \qquad (5)$$

On the other hand, the allowed region for three-body decays is $\sim$ circular with radius $\sim$ 60 mev/c in the x,y plane. Therefore, by excluding events with ($P\nu x$, $P\nu y$) inside the ellipse, one loses $\sim$ 30% leptonic decays and rejects the background.

4. Selected Possible Experiments:*

(a) $\Lambda \to pe\bar{\nu}$

In a lambda beam only the direction but not the momentum is known; therefore, there are two solutions for the center of mass corresponding to possible neutrino momenta along P . These solutions could be weighted with the lambda momentum spectrum measured from $\Lambda \to p\pi$ decays. In a β-decay experiment, the apparatus could exclude the forward pion cone to suppress $\Lambda \to p\pi$ events. This would reduce the electron solid angle to $\frac{\Omega}{4\pi} \sim \frac{1}{3}$.

Assuming a Λ beam with the following characteristics: $\Omega = 10^{-6}$ ster, L = 30 M, 10^{10} int. protons/pulse, $\frac{\Delta P}{P} = 50\%$, P = 100 Gev/c, and the Hagedorn-Raft yield predictions. We

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* Section 4 written with T. A. Romanowski.

estimate 10^4 Λ's pulse in the decay volume. Taking a 3m long decay volume, 100% proton detection efficiency, and requiring 10^5 β-decay events, the accelerator time required is $\approx$ 100 hrs.

(b) A $\Lambda \to p \mu \bar{\nu}$ experiment seems to be feasable because the lower branching ratio (down by factor $\approx$ 6 from $\Lambda \to pe\nu$) is in part compensated by the ability to seperate μ's from π's over the entire solid angle by absorbing the π's. The triggering background from $\pi \to \mu\nu$ decay is tolerable. This type of event ($\Lambda \to p + \pi \to p + \mu + \nu$) will be eliminated by the procedure already described.

(c) $\Sigma^- \to \Lambda e^- \bar{\nu}$.

This reaction has several important features which makes its study very attractive.

(i) lepton correlations with lambda polarization can be measured

(ii) the decay has a unique signature.

Assuming a Σ^- beam of the following characteristics:

$\Omega = 10^{-6}$ ster, L = 30 M, 10^{10} int. protons/pulse, ΔP = 3.7 Gev/c, P = 100 Gev/c. We estimate, from a 3M long decay path and an over-all detection efficiency of 2/3, 10^3 $\Sigma \to \Lambda e\nu$ events in 100 accelerator hours.