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Forward-Backward Asymmetries with Quark Jets

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One of the most challenging experimental problems at LEP is the measurement of the weak couplings of the quarks. As is well known for lepton pair production, forward-backward asymmetries are very sensitive to these couplings. In this note we address ourselves to the problem of determining the jet flavour in order to measure such asymmetries.

We can think of two methods:

(i) to measure the charge of the jet1) which should reflect the quark charge with unfortunately large fluctuations2). This could be a way to isolate $Q = \frac{2}{3}$ quarks (top) and measure the asymmetry for these $t\bar{t}$ pairs. If the distribution of the average charge is the same for all top quarks, this will test the possible universality of the top quark couplings by comparing to the $u\bar{u}$ couplings accessible in $\nu,\bar{\nu}$ scattering. It is however very hard experimentally to discriminate a u quark against a $\bar{d}$ quark. The same method could in principle be applied to strangeness3).

(ii) to use leading particles to assign the jet flavour. We know that, when $E/E_{beam} = x \to 1$, the probability that the leading meson carries the initial quark will approach unity2).

We study this possibility below.

Leading Particle in the Feynman-Field Model

If we define the leading particle as the fastest with $x > x_m$ we can compute the probability $P(x_m)$ that this particle came from the breakup of the initial quark. The breakup is characterized by a scaling function $f(x)$. For $x_m > 0.5$, a good approximation for $P(x_m)$ is:

$$P(X_m) \simeq \frac{1}{1 + \lambda f(1) \frac{1 - x_m}{2}}$$

Feynman-Field's parametrization for $\pi^\pm$ and K yields $\lambda f(1) = 1.10$. This results into $P(0.5) = 0.78$ and $P(0.7) = 0.86$.

From the same model we also calculate the probability $Q(x_m)$ to have a particle with $x > x_m$. We estimate $Q(0.5) = 0.17$ and $Q(0.7) = 0.06$ (these numbers apply to a single jet).

Leading $\pi^{\pm}$

A π^+ could be formed from a u or a $\bar{d}$. Therefore:

$$A_{\pi^+} = \frac{N_u A_u - N_d A_d}{N_u + N_d}$$

where N_u, N_d are the total numbers of produced $u\bar{u}$ and $d\bar{d}$ pairs, and A_u, A_d their respective asymmetries. Such a measurement is very sensitive to u, d weak couplings and would be a good check of the neutrino analyses.

We have computed A_{π^+} using the Weinberg-Salam model and the result is shown in Figure 1. With $\sin^2\theta_w = 0.2$ we have $A_{\pi^+} = -0.06$ at the Z^o peak. To test the sensitivity to the couplings the dependence of A_{π^+} on $\sin^2\theta_w$ is shown in Figure 2. Within this model the measured asymmetry will be $P(x_m)A_{\pi^+}$ determined with a rate:

$$2(N_u + N_d)\ Q(x_m)\xi$$

where ξ is the probability that u (or $\bar{d}$) will turn into a π^+ (and not a π^o or a $\bar{K}^o$). We note that resonances (ρ^+ for example) have been included in the estimate of $P(x_m)$. We estimate $\xi = 0.5$.

A 1000h-run at the Z^o peak would result in a measured asymmetry of $-.047 \pm .009$ for $\pi^{\pm}$ with $x > 0.5$ (statistical error only; $\bar{\mathcal{L}} = \frac{1}{4}\mathcal{L}_{max}$).

Leading $K^{\pm}$

This is potentially more interesting since the K^+ asymmetry will be sensitive to the $s\bar{s}$ couplings which are not directly accessible otherwise. A K^+ could be formed from an $\bar{s}$ or a u. Following Feynman-Field, we assume ratios of 2:2:1 for the creation of $u\bar{u}$:$d\bar{d}$:$s\bar{s}$ pairs in a quark breakup. It yields:

$$A_{K^+} = \frac{N_u A_u - 2\ N_s A_s}{N_u + 2\ N_s}$$

The calculation for the Weinberg-Salam model is shown in Figure 1 with $\sin^2\theta_w = 0.2$ while the $\sin^2\theta_w$ dependence at the Z^o peak is indicated in Figure 2.

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Again the actual asymmetry will be $P(x_m)A_K$, measured with a rate

$$(N_u + 2\ N_s)\ Q(x_m)\ \xi'$$

Taking again $\xi' = 1$ the same 1000 h-run with $K^\pm$ identification for $x > 0.5$ ($22 < p < 45$ GeV) will yield an asymmetry of -.105 ± .011.

Such a measurement is very sensitive to the $s\bar{s}$ couplings (see Figure 2) and would permit a comparison of $d\bar{d}$ and $s\bar{s}$ couplings, thus testing down-quark universality.

References

1) This is studied by H. Grote and K. Winter

2) R.P. Feynman, R.D. Field Nuclear Physics B136, 1 (1978)

3) Besides the problem of large fluctuations, the measurement of the total jet strangeness is spoiled by $K^o_{L,s}$ production.

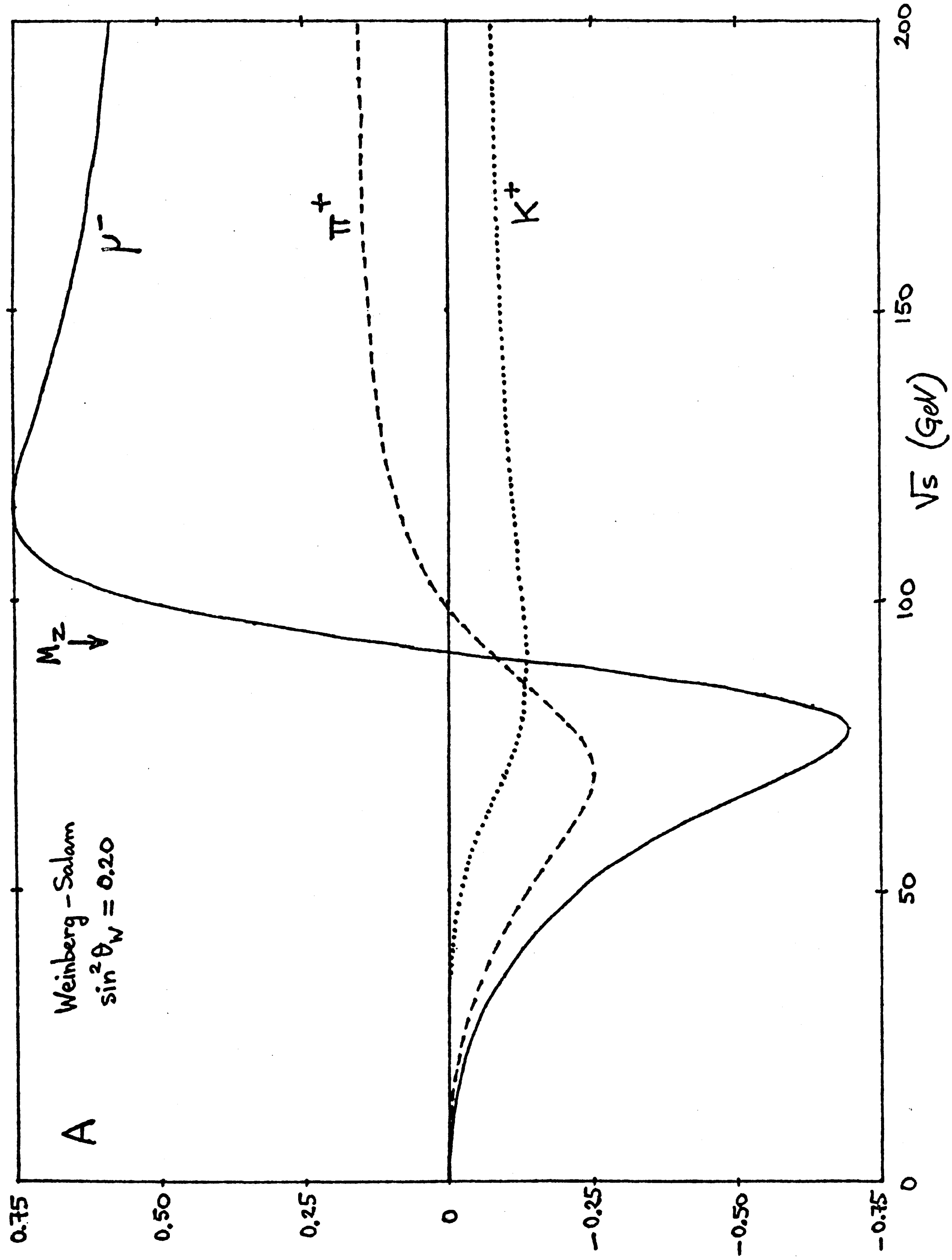
A
Weinberg - Salam
$\sin^2\theta_W = 0.20$
M_Z
μ^-
π^+
K^+
0.75
0.50
0.25
0
-0.25
-0.50
-0.75
0
50
100
150
200
$\sqrt{s}$ (GeV)

Figure 1

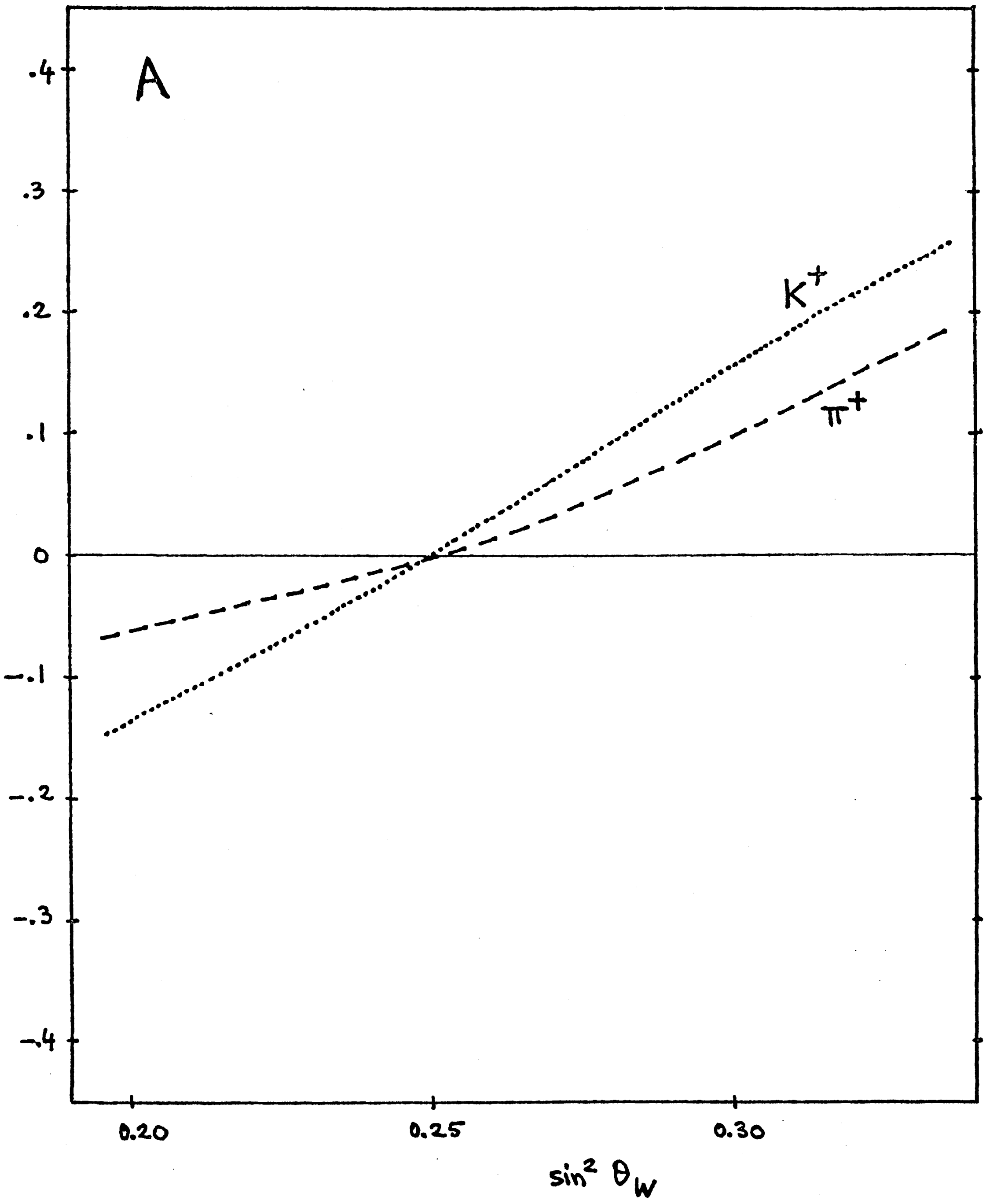

Figure 2