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FORWARD - BACKWARD ASYMMETRIES WITH QUARK JETS

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Following ref. (1) and (2), we describe two methods to reach the weak coupling of the quarks by measuring the forward-backward asymmetries with jets produced in e^+e^- annihilation.

We can define an orientation on a jet either by using the leading particles or by measuring the charges of the two jets. By doing so, we are unable to separate $u\bar{u}$ from $d\bar{d}$ jets : both u and $\bar{d}$ can give a leading π^+ and have very similar charge distributions. Fig. 1 - 2 show the charge distribution expected from the Feynman-Field(4, 5) model for quark fragmentation. Fortunately, these two types of jets do not occur with the same frequency and have different asymmetries (fig. 3) so that in a wide range of energies we can measure a net effect which can be related to the weak interaction asymmetry. In the case of $s\bar{s}$ jets, the situation is less ambiguous and we will indicate a method which allows for an efficient separation from $c\bar{c}$, $u\bar{u}$ and $d\bar{d}$ jets provided one can afford a low efficiency.

I. Average charge method.

Given two back to back jets, one can define a class of events where the charge in one hemisphere is greater or equal to 1. We assume that all the particles are seen, so that no independent requirement on the opposite jet can be made.

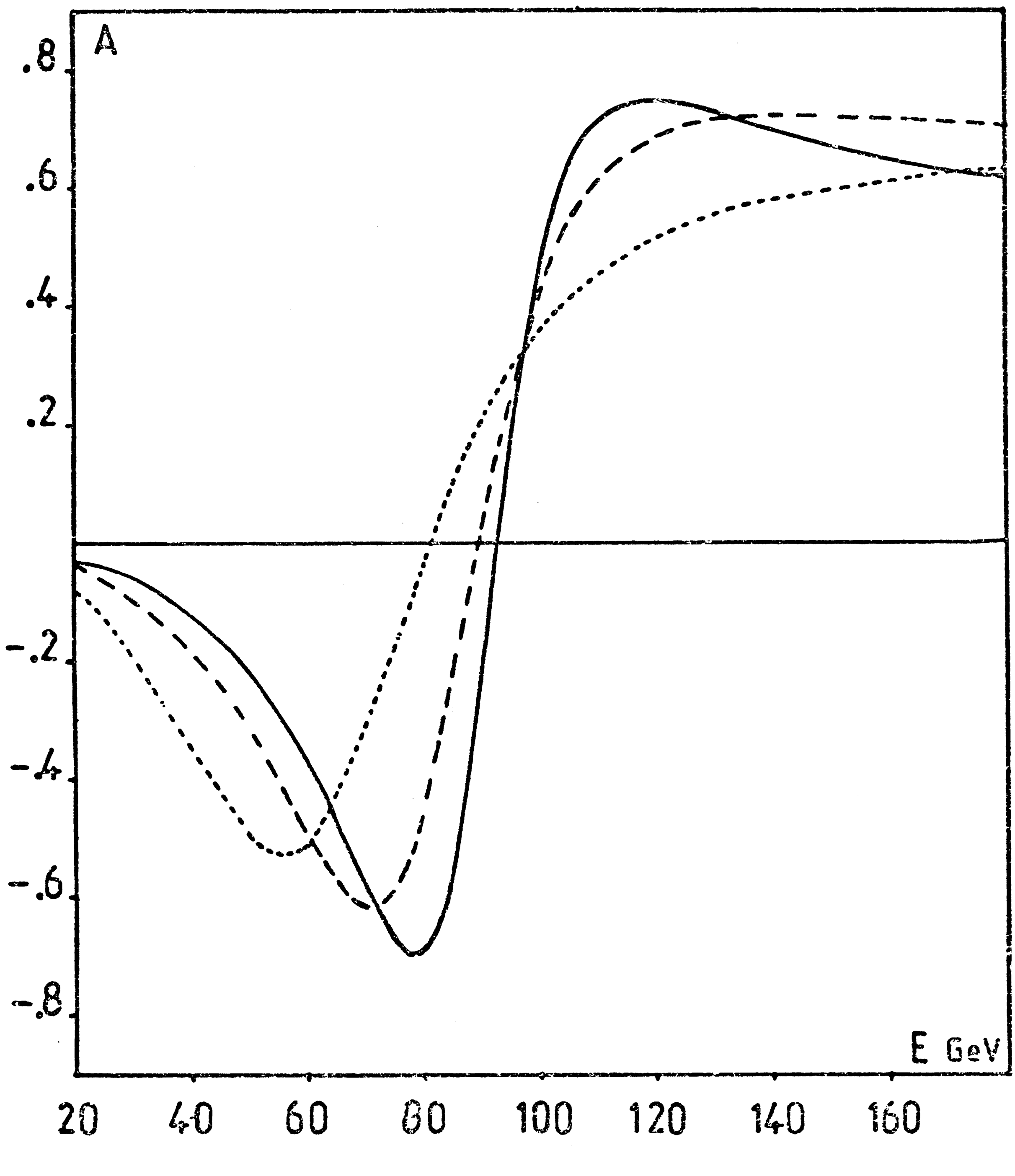

Figure 3 : Weinberg Salam predictions for the leptons and quark asymmetries with $\sin^2\theta_W = .2$

..... d quarks

----- u quarks

_____ μ

One defines reliability factors for each type of jet with the definition :

$$R = \frac{\text{True} - \text{False}}{\text{True} + \text{False}}$$

where "True" refers to the number of times the criterion succeeded in selecting the correct flavor and "False" to the number fo times the criterion failed.

The observed asymmetry :

$$A_Q = \frac{\text{N FORWARD } (Q \geqslant 1) - \text{N BACKWARD } (Q \geqslant 1)}{\text{N FORWARD } (Q \geqslant 1) + \text{N BACKWARD } (Q \geqslant 1)}$$

can be expressed in term of the quark asymmetries[3] A_u and A_d as follows :

$$\text{(i)} \qquad A_Q = R_u A_u \frac{N_u}{N_u + N_d} - R_d A_d \frac{N_d}{N_u + N_d}$$

where N_u and N_d are the number of $u\bar{u}$ and $d\bar{d}$ type jets selected with the charge criterion.

Table I gives R and efficiencies for both types of jets in the Feynman and Field model [4, 5] referred from now on as the F.F. model. Fig. 4 shows the expected variation of A with energy assuming that three isodoublets are produced at LEP.

Remarks :

1) The A_Q measurement provides a test of universality of the Weinberg Salam theory since as, already mentioned, all isodoublets contribute. However charge distributions may change with the type of flavour so that both reliability and efficiency vary from quark to quark. For our calculation , we have assumed universal behaviour of same charge quarks.

2) One could alternatively measure weighted charges [4] or perform longitudinal momentum (Z) cuts. These variations are probably useful to check that the F.F. picture is correct but the size of the effect should remain the same.

Table I.

Average charge ($Q \geqslant 1$) method parameters (F.F. predictions)

Type	Efficiency	Reliability
$u\bar{u}$	.63	.78
$d\bar{d}$	.52	.65

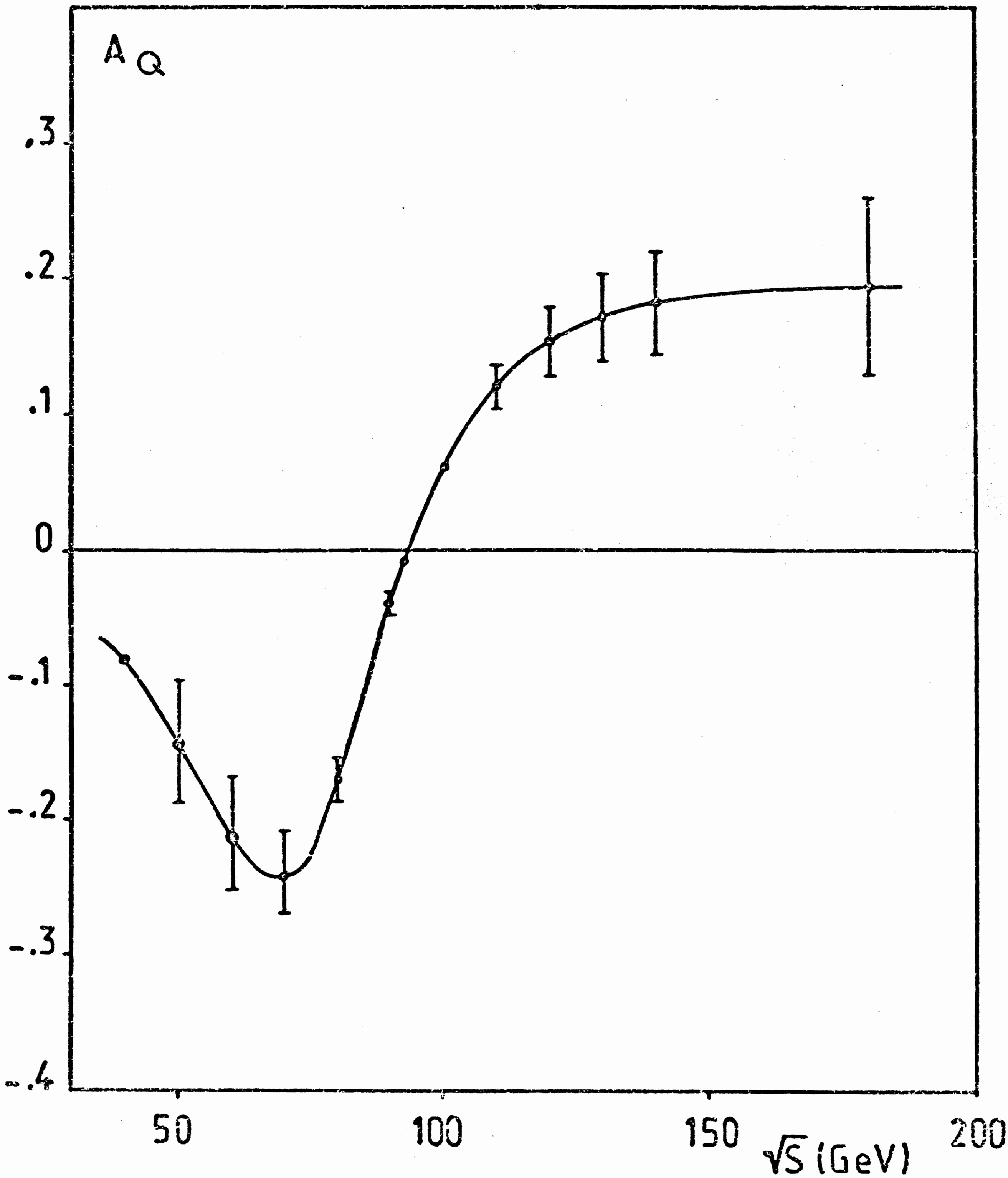

Figure 4 : Charge asymmetry expected requiring that the total charge in one hemisphere be greater or equal to 1. We take $\sin^2\theta_W = .2$ and assume three isodoublets. We indicate statistical errors with 100 hours per point with $\mathcal{L} = 10^{32}\left(\frac{E}{70}\right)^2 \text{ cm}^{-2}\text{s}^{-1}$.

II. Leading particle signature.

An orientation is given by selecting jets with a fast - about one half of the maximum momentum - particle with characteristic quantum numbers : $\pi^{\pm}$, $K^{\pm}$. Fig. 5 shows the ideal behaviour expected assuming that a leading π^{+} means a u or $\bar{d}$ quark and a K^{+} means a $\bar{s}$ or u quark.

Three effects will tend to dilute this ideal effect :

- Secondary dressings can often produce a leading particle with no relation with the leading quark.

- Primary dressings into resonances, e.g. ρ°, can also loose the information

- The majority of the flavours s, c, b, t, etc... will give no asymmetry through leading $\pi^{\pm}$ though still providing such π. Except for the s, we know no reliable way of estimating such contributions.

a) $\pi^{\pm}$.

We can write for the asymmetry parameter an expression similar to formula (i), although the probability to get a fast $\pi^{\pm}$ clearly changes when going to heavy isodoublets. Defining as F_i , the fraction of cases in which an isodoublet i gives a fast charged π one finds :

$$\text{(ii)} \qquad A_{\pi} = \frac{K_u F_u A_u N_u - K_d F_d A_d N_d}{\Sigma F_i N_i}$$

where $K_u F_u$ is the fraction of N_u events giving the leading π^{+} (π^{-}) along the u ($\bar{u}$) direction. We assume that all the asymmetry comes only from $u\bar{u}$ and $d\bar{d}$.

Table II gives a set of probabilities[3, 4] allowing an explicit calculation of F_i for $u\bar{u}$, $d\bar{d}$ and $s\bar{s}$.

For numerical application we make the simplifying hypothesis that we have three isodoublets $\binom{u}{d}$, $\binom{c}{s}$ and $\binom{t}{b}$ and that $F_s = F_c = F_b = F_t$.

Formula (ii) reduces to :

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

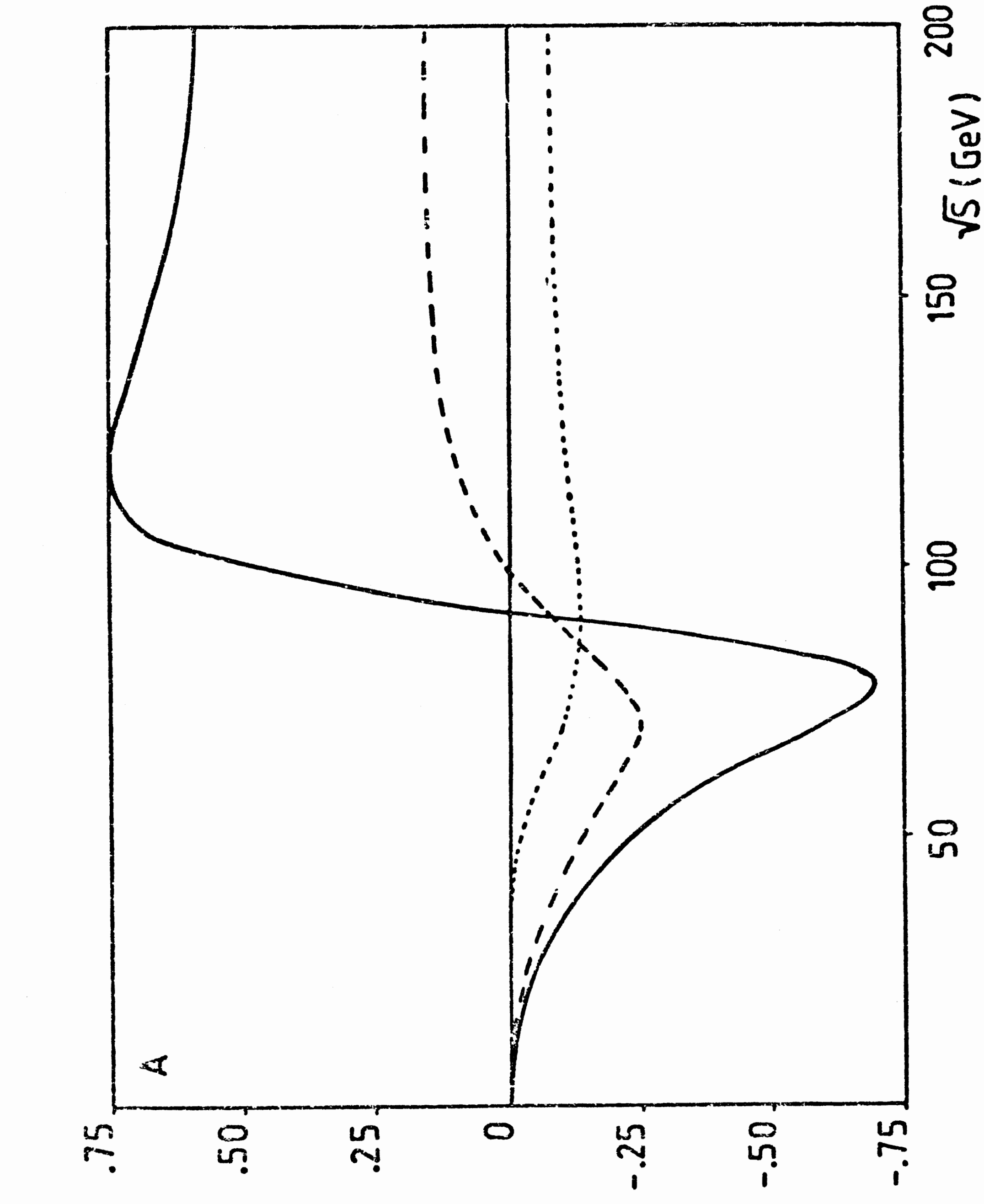

Figure 5 : Ideal Π^+ and K^+ asymmetries expected with reliability equal 1 and $\sin^2\theta_W = .2$

______ μ

----- Π^+

..... K^+

Table II.

Leading particle probabilities in F.F. in %.

a) $z_{min} > .5$

quark	π^+	π^-	K^+	K^-
u	10.6	3.2	3.6	1.1
$\bar{u}$	3.2	10.6	1.1	3.6
d	3.2	10.6	1.1	1.9
$\bar{d}$	10.6	3.2	1.9	1.1
s	2.9	2.9	.8	8.7
$\bar{s}$	2.9	2.9	8.7	.8

b) $z_{min} > .4$

quark	π^+	π^-	K^+	K^-
u	16.8	5.9	6.0	1.8
$\bar{u}$	5.9	16.8	1.8	6.0
d	5.9	16.8	1.9	3.3
$\bar{d}$	16.8	5.9	3.3	1.9
s	5.5	6.1	1.8	12.4
$\bar{s}$	6.1	5.5	12.4	1.8

In table III the efficiency and reliability parameters are summarized.
Fig. 6 shows the expected variation of A_{Π} with energy. From this curve, we see that we obtain a rather poor sensitivity to $\sin^2\theta_W$ measurement with $u\bar{u}$ and $d\bar{d}$ jets. It does not matter so much since this parameter is already available from neutrino reactions.

b) $K^{\pm}$.

Using charge kaons asymmetries in e^+e^- annihilations is the only way to reach weak coupling constants for strange quarks.

A similar procedure can be developed which will lead to a relation between $A_{K^\pm}$ and A_u and A_s. However, in this case, we can think of a better method. We separate $s\bar{s}$ from $u\bar{u}$ by requiring a leading K^- (K^+) in the jet opposite to the leading K^+ (K^-). In addition, a veto can be set on jets with two charged K to depress $u\bar{u}$ and $d\bar{d}$ jet type events where K are produced in pairs.

Charm is also a contribution although it will not produce so easily a leading kaon. Since K^+ come from the $\bar{c}$ quark jet with charge $-2/3$ we can use method I to separate them from K^+ originating from $\bar{s}$ jets with charge $+1/3$.

Table IV summarizes the useful estimates for this method. We give only an estimate for the upper limit for the charm contribution.

With these small contaminations, one is almost able to reach directly A_s. A_d has the same behaviour as A_s so the $d\bar{d}$ contamination simply adds up.

The "up" contribution is small and could even be reduced since the charm term tends to cancel the up asymmetry.

Fig. 7 shows the dependence of the asymmetry with $\sin^2\theta_W$ at the Z° pole. With 200 hours spent at the Z° pole, one will collect 10^6 events giving about 2000 fast K^+K^- pairs.

<u>Conclusion</u>.

From this study, we conclude that the average charge method gives the most efficient way of measuring weak interactions with quark jets. The leading particle method has nevertheless its own advantages :

- It does not require an exact counting of charges which looks hard experimentally.
- It relies less on the details of F.F. (especially on any cut off on the soft particles).
- It allows a separate measurement of A_s .

Table III.

Leading $\pi^{\pm}$ method parameters in F.F.

a) $z > .5$

jet	Efficiency	Reliability
$u\bar{u}$	.18	.40
$d\bar{d}$	.18	.40

b) $z > .4$

jet	Efficiency	Reliability
$u\bar{u}$	.30	.37
$d\bar{d}$	.30	.37

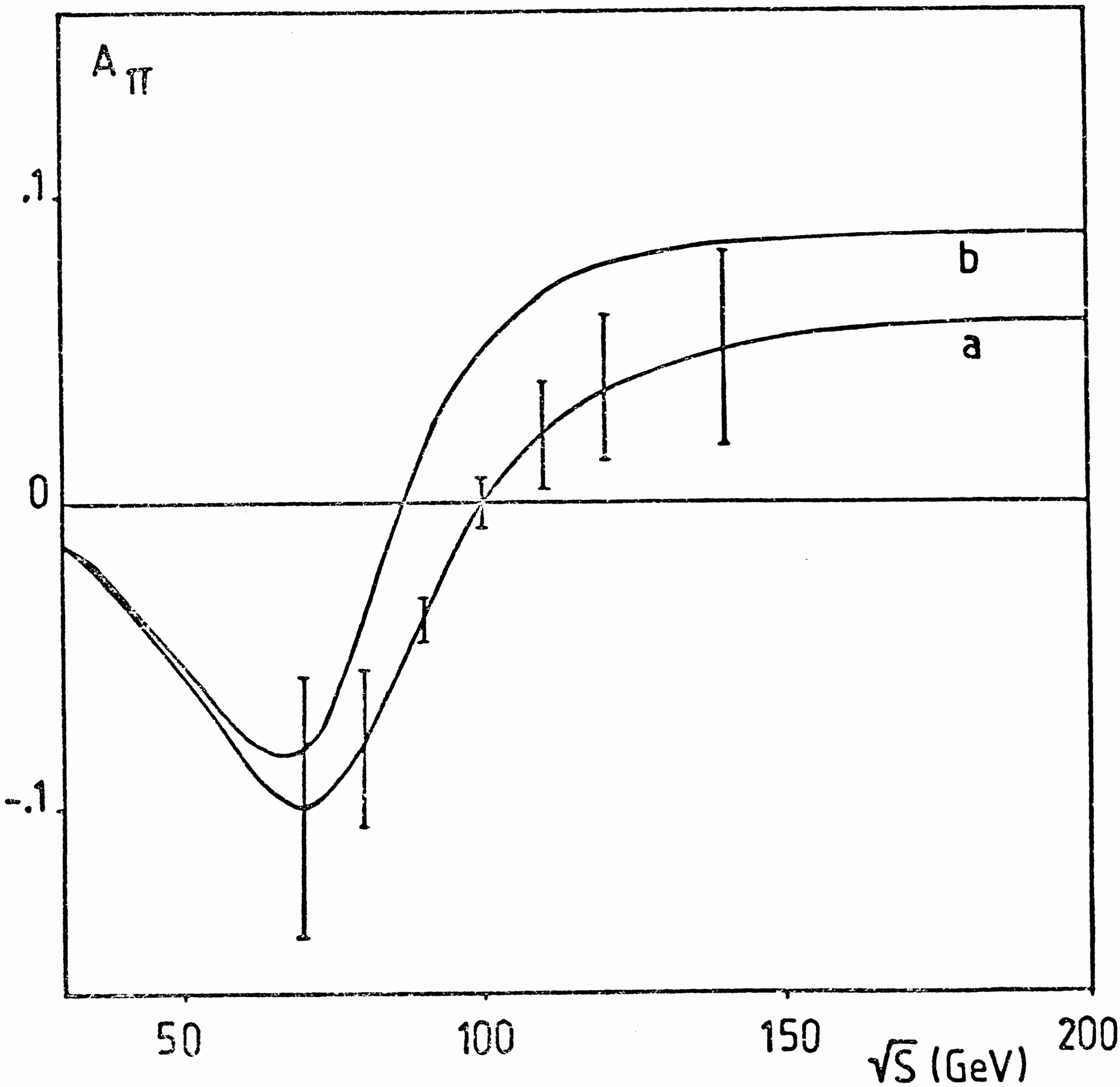

Figure 6 : Predicted asymmetry behaviour using leading $\pi^\pm$ with $z > .4$. Errors statistical with hypotheses of Figure 4.

Curve (a) $\sin^2\theta_W = .2$

Curve (b) $\sin^2\theta_W = .25$

Table IV.

Leading K^+ and K^- probabilities.

Z min $>$ .4

jet	K^+K^- Efficiency %	with charge cut Efficiency %
$u\bar{u}$	.36	.23
$d\bar{d}$	.1	.05
$s\bar{s}$	1.5	.75
$c\bar{c}$	$<$ 1.5	$<$ .08

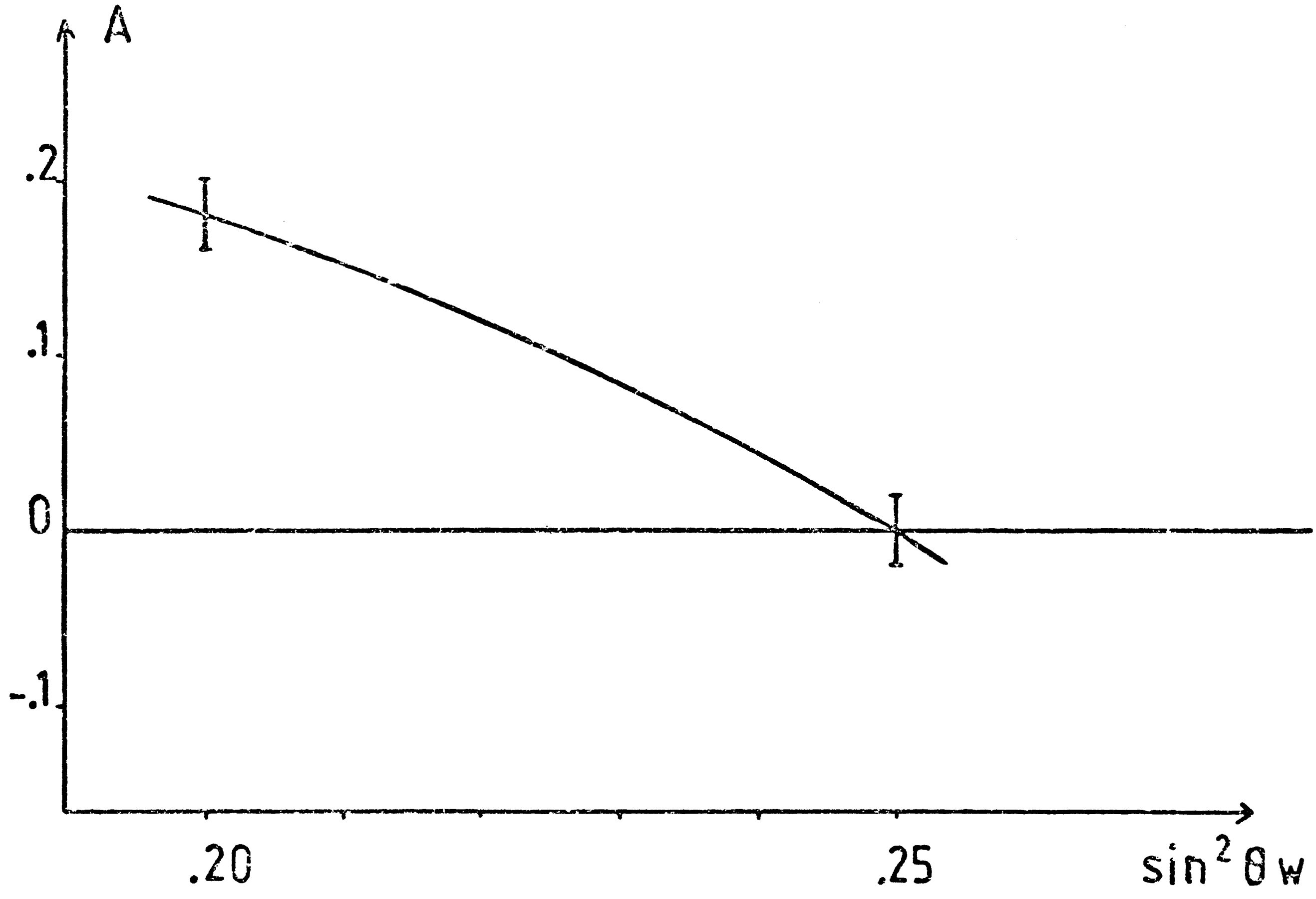

Figure 7 : Asymmetry behaviour with leading ($z > .4$) K^+ and K^- detected in each hemisphere versus $\sin^2\theta_W$ at the Z^o pole. Statistical errors assume 2000 hours spent at the Z^o pole.

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