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HOW TO MEASURE QUARK HELICITIES IN $e^+e^- \to$ HADRONS

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Abstract : In order to reach completely the vector and axial couplings of the neutral currents to quarks we propose to measure quark helicities from the polarizations of the leading spin one mesons or of the leading baryons of the jets. Applications are given for $e^+e^- \to 2$ jets where large degrees of polarization are obtained from $\gamma - Z$ interference.

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1. Introduction

One of the most important goals of e^+e^- annihilation at high energy is to reveal the structure of the neutral currents of leptons and quarks. This is a vital information for the assignement of these fermions in the multiplets of the gauge group [1,2]. For example in $SU(2) \times U(1)$ the neutral current has the form $J^o = J^{I_3} - \sin^2\theta_W J^{em}$; the measurement of the vector and axial parts of J^o determines the 3rd component of the weak isospin (I_3) of the left-handed and of the right-handed fermions. Such an information is already partly contained [2] in the unpolarized angular distribution $\frac{d\sigma}{d\Omega}(e^+e^- \to \ell^+\ell^-$ and $q\bar{q})$ but a complete disentangling of the vector and axial couplings of the Z boson to $\ell^+\ell^-$ and $q\bar{q}$ requires polarization measurements. This has been already studied [2] in the case of leptons ($e^+e^- \to \mu^+\mu^-$ and $\tau^+\tau^-$). We discuss here the case of quarks ($e^+e^- \to q\bar{q}$).

From helicity conservation at the γ and Z vertices it is well-known that strong restrictions on the quark helicities appear ($\lambda_q = -\lambda_{\bar{q}}$ is only allowed) and in addition we know that vector-axial interferences of γ and Z amplitudes lead to large values for the degrees of polarizations. We give in Sect. 2 the complete formulas for the cross-sections, density matrix and degree of polarization in the general case ($e^+e^- \to$ fermion + antifermion) with polarized $e^\pm$ beams.

The important point is however how to measure the quark polarizations. We answer this question using the properties of the jet mechanism. The $(1 + \cos^2\theta)$ distribution observed [3] in $e^+e^- \to \gamma \to 2$ jets shows us that the spin $\frac{1}{2}$ of the quark is an information which is conserved all along the jet development ; it is generally expected that this development (proceeding by soft $q\bar{q}$ creations) conserves the other quark quantum numbers like flavours. We expect here that helicity will also be conserved. The process is similar to the scattering of fast electrons through matter ; at high energy the vector couplings (here of the gluons creating the soft $q\bar{q}$ pairs) conserves helicity. The final question is how to measure it at the end of the chain. We show in Sect. 3 that this quark helicity is exactly transferred to the leading vector or axial mesons or to the leading spin $\frac{1}{2}$ baryons. An analysis of the decay distributions of these leading mesons ($\rho \to 2\pi$, $K^* \to K\pi$, $D^* \to D\pi$, ω or $A_1 \to 3\pi$,...) or baryons ($\Lambda \to p + \pi^-$, $\Sigma^+ \to p + \pi^0$,...) can show this helicity conservation and measure the degree of polarization of the initial quarks. We calculate this degree in the different cases and give its angular distribution for low and high energies and around the Z peak. It reaches very high values in many cases (hyperons Λ , Σ^+ and charged mesons).

Finally as a by-product we apply this property of helicity conservation to the quasi-2-body limit $e^+e^- \to H + H'$ far above threshold. This leads to the result that asymptotically $\sigma(e^+e^- \to \text{spin } 0 + \text{spin } 0)$ and $\sigma(e^+e^- \to \text{spin } 1 + \text{spin } 1)$ must vanish more rapidly than $\sigma(e^+e^- \to \text{spin } 1 + \text{spin } 0)$ and gives constraints among the various spin couplings.

2. The production process $e^+e^- \to \gamma, Z \to f\bar{f}$

With the usual point-like couplings of the photon :
$e\, Q_f\, \bar{v}\, \gamma^\mu\, u$

($Q_f = -1$ for $f = \ell^-$ and $Q_f = \frac{2}{3}$ or $-\frac{1}{3}$ for $f = q$)

and of the Z boson : $e\, \bar{v}\, \gamma^\mu\, (a - ib\gamma^5) u$

(a and b given in table I for the W-S-G-I-M model[4])

we get the general $e^+e^- \to f\bar{f}$ amplitude :

(1) $$R = -\frac{e^2 Q_f}{s}\,\bar{v}(e^+)\gamma^\mu u(e^-)\;\bar{u}(f)\gamma_\mu v(\bar{f}) +$$

$$+\frac{e^2}{D_Z}\,\bar{v}(e^+)\gamma^\mu(a-ib\gamma^5)u(e^-)\bar{u}(f)\gamma_\mu(a-ib\gamma^5)v(\bar{f})$$

$$D_Z = s - m_Z^2 + i m_Z \Gamma_Z \quad .$$

Neglecting the fermion mass m_f , we get the differential cross-section for arbitrary helicity states :

(2) $$\frac{d\sigma}{d\Omega}(e^+_{h'}, e^-_h \to f_\lambda \bar{f}_{\lambda'}) = \frac{\alpha^2}{4s}\left[Q_f^2\sigma_\gamma + \frac{s^2}{|D_Z|^2}\sigma_Z - 2Q_f \mathrm{Re}\left(\frac{s}{D_Z}\right)\sigma_I\right]$$

with :

$$\left\{\begin{aligned}
\sigma_\gamma &= \frac{1}{4}(1-hh')(1-\lambda\lambda')(1+\cos^2\theta) + \frac{1}{2}(h'-h)(\lambda'-\lambda)\cos\theta\\
\sigma_Z &= (a^2+b^2)(a_f^2+b_f^2)\sigma_\gamma + 4aba_fb_f\sigma_1 + 2a_fb_f(a^2+b^2)\sigma_2 + 2ab(a_f^2+b_f^2)\sigma_3\\
\sigma_I &= aa_f\sigma_\gamma + bb_f\sigma_1 + ab_f\sigma_2 + a_fb\sigma_3\\
\sigma_1 &= \frac{1}{4}(h'-h)(\lambda'-\lambda)(1+\cos^2\theta) + \frac{1}{2}(1-hh')(1-\lambda\lambda')\cos\theta\\
\sigma_2 &= \frac{1}{4}(1-hh')(\lambda'-\lambda)(1+\cos^2\theta) + \frac{1}{2}(h'-h)(1-\lambda\lambda')\cos\theta\\
\sigma_3 &= \frac{1}{4}(1-\lambda\lambda')(h'-h)(1+\cos^2\theta) + \frac{1}{2}(\lambda'-\lambda)(1-hh')\cos\theta
\end{aligned}\right.$$

The case of unpolarized initial $e^\pm$ is obtained by using $h = h' = 0$. If the final polarization is not observed, one sets $\lambda = 0$ and an overall factor 2 for each of the final particles.

The density matrix of the final fermion is given by :

(3) $$\rho_f(\lambda_1,\lambda_2) = \frac{Q_f^2 C_\gamma + \dfrac{s^2}{|D_Z|^2}C_Z - 2Q_f\mathrm{Re}\left(\dfrac{s}{D_Z}\right)C_I}{4\left\{Q_f^2\sigma^o_\gamma + \dfrac{s^2}{|D_Z|^2}\sigma^o_Z - 2Q_f\mathrm{Re}\left(\dfrac{s}{D_Z}\right)\sigma^o_I\right\}}$$

with :

$$
\left\{
\begin{aligned}
C_\gamma &= \frac{1}{4}(1-hh')(1+\lambda_1\lambda_2)(1+\cos^2\theta) - \frac{1}{2}(h'-h)(\lambda_1+\lambda_2)\cos\theta \\
C_Z &= (a^2+b^2)(a_f^2+b_f^2)C_\gamma + 4aba_fb_fC_1 + 2a_fb_f(a^2+b^2)C_2 + 2ab(a_f^2+b_f^2)C_3 \\
C_I &= aa_fC_\gamma + bb_fC_1 + ab_fC_2 + a_fbC_3 \\
C_1 &= -\frac{1}{4}(h'h)(\lambda_1+\lambda_2)(1+\cos^2\theta) + \frac{1}{2}(1-hh')(1+\lambda_1\lambda_2)\cos\theta \\
C_2 &= -\frac{1}{4}(1-hh')(\lambda_1+\lambda_2)(1+\cos^2\theta) + \frac{1}{2}(h-h')(1+\lambda_1\lambda_2)\cos\theta \\
C_3 &= \frac{1}{4}(h'-h)(1+\lambda_1\lambda_2)(1+\cos^2\theta) - \frac{1}{2}(1-hh')(\lambda_1+\lambda_2)\cos\theta
\end{aligned}
\right.
$$

and where σ_γ^o, σ_Z^o, σ_I^o refer to the quantities in eq(2) taken for $\lambda = \lambda' = 0$.

Finally the degree of polarization of the final fermion $\xi_f = \rho_f(++) - \rho_f(--)$ is :

$$
(4) \qquad \xi_f = \frac{Q_f^2\eta_\gamma + \dfrac{s^2}{|D_Z|^2}\eta_Z - 2Q_f\mathrm{Re}\left(\dfrac{s}{D_Z}\right)\eta_I}{4\left\{Q_f^2\sigma_\gamma^o + \dfrac{s^2}{|D_Z|^2}\sigma_Z^o - 2Q_f\mathrm{Re}\left(\dfrac{s}{D_Z}\right)\sigma_I^o\right\}}
$$

with :

$$
\left\{
\begin{aligned}
\eta_\gamma &= -2(h'-h)\cos\theta \\
\eta_Z &= -2(a^2+b^2)(a_f^2+b_f^2)(h'-h)\cos\theta - 4aba_fb_f(h'-h)(1+\cos^2\theta) \\
&\quad - 2a_fb_f(a^2+b^2)(1-hh')(1+\cos^2\theta) - 4ab(a_f^2+b_f^2)(1-hh')\cos\theta \\
\eta_I &= -2aa_f(h'-h)\cos\theta - bb_f(h'-h)(1+\cos^2\theta) - ab_f(1-hh')(1+\cos^2\theta) \\
&\quad - 2a_fb(1-hh')\cos\theta
\end{aligned}
\right.
$$

Notice that because of the factors $(1+\lambda_1\lambda_2)$ and $(\lambda_1+\lambda_2)$ we have $\rho(+-) = \rho(-+) = 0$, which reflects helicity conservation (when m_f is neglected) at the γ and Z vertices.

3. Helicity properties of the jet mechanism

We suppose that after having been created with a point-like coupling, the quark and the antiquark evolve fastly emitting soft gluons which create $q\bar{q}$ pairs which finally recombine into soft hadrons, see fig. 1. At each step of the chain as the quark (or antiquark) remains highly energetic and undeflected the vector coupling to the gluon conserves the quark helicity. At the end of the chain the quark q catches a soft antiquark $\bar{q}'$ and form the leading hadron of momentum p_H that we consider. In the case of a leading vector or axial meson H with $p_H \simeq p_q \gg m_H, p_{\bar{q}'}$ the final vertex $\bar{v}(\bar{q}')[\not{\epsilon}_H, \not{\epsilon}_H\gamma^5, \epsilon_H\cdot(p_q - p_{\bar{q}'}), ..]u(q)$ conserves helicity in the sense that longitudinal helicity states $\lambda_H = 0$ are depressed (like $\frac{m_H}{p_H}$) and that only $\lambda_H = 2\lambda_q = \pm 1$ is allowed in this limit.

The mesons $H(q\bar{q}')$ is produced with 2 amplitudes : $e^+e^- \to q\bar{q}$ the fast q catching a soft $\bar{q}'$ and $e^+e^- \to q'\bar{q}'$ the fast $\bar{q}'$ catching a soft q. Except in the very limiting case of a quasi-2-body process $e^+e^- \to HH'$ discussed in Sect. 5, these two amplitudes do not interfer because they occur in very distant kinematical domains ; the overlap of the systems associated with $H(q\bar{q}')$ in the jets in these two amplitudes corresponds to the process (fast $\bar{q}$ + soft q') $\longleftrightarrow$ (fast q' + soft $\bar{q}$) which is an exotic exchange and therefore vanishes quickly at high energy. So the probability of getting $H(q\bar{q}')$ is obtained by summing the probabilities of $e^+e^- \to q\bar{q}$ and of $e^+e^- \to \bar{q}'q'$ using eq(2,3,4) with $Q_{\bar{q}'} = - Q_{q'}$, $a_{\bar{q}'} = - a_{q'}$ and $b_{\bar{q}'} = + b_{q'}$. The density matrix of the spin one meson H is finally simply :

$$\begin{pmatrix} \rho_{q+\bar{q}'}^{(++)} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \rho_{q+\bar{q}'}^{(--)} \end{pmatrix}$$

where $\rho_{q+\bar{q}'}$ refers to eq(3) where the quantities σ^o and C are taken by summing $f \equiv q$ and $f \equiv \bar{q}'$.

The same kind of argument works for a leading spin $\frac{1}{2}$ baryon. In this case the chain ends as shown in fig. (2); for a low-lying $(\frac{1}{2}^+)$ baryon state the diquark system is in an $\ell = 0$ states ; its total spin can be $S = 0$ or $S = 1$; for $S = 0$ we have obviously $\lambda_B = \lambda_q$; for $S = 1$ in the leading case $p_B \simeq p_q \gg m_B$, $p_{(q'q'')}$ we have again helicity conservation at the $B(q'q'')q$ vertex and up to $\frac{m_B}{p_B}$ corrections we get $\lambda_B = \lambda_q = \pm \frac{1}{2}$. The baryon $B(qq'q'')$ is produced with 3 amplitudes $(e^+e^- \to q\bar{q}\ ,\ q'\bar{q}'\ ,\ q''\bar{q}'')$. Here also apart from the quasi-2-body case $e^+e^- \to B\bar{B}$, these amplitudes do not interfer because the overlaps like (fast $\bar{q}$ + soft $\overline{q'q''}$) $\longleftrightarrow$ (fast $\bar{q}'$ + soft $\overline{qq''}$) are negligible at high energy (even if the flavours of $\bar{q}$ and $\bar{q}'$ or $\bar{q}''$ are the same their colours should be different and we have still an exotic coloured exchange). We have then to sum the 3 probabilities with $f \equiv q\ ,\ q'\ ,\ q''$ and the density matrix of the leading baryon is simply :

$$\begin{pmatrix} \rho_{q+q'+q''}^{(++)} & 0 \\ 0 & \rho_{q+q'+q''}^{(--)} \end{pmatrix}$$

One has now to find a way of measuring these hadrons polarizations. The existence of a $\lambda = \pm 1$ polarization of the spin 1 meson can immediately be seen in strong decays like $\rho \to 2\pi$, ω or $A_1 \to 3\pi$, $K^* \to K\pi$, ... etc. Let us call $\hat{N}(\theta_N, \varphi_N)$ the direction with respect to the axis of the jet $\vec{p}_q$ either of the relative momentum $\overrightarrow{p_1 - p_2}$ of the 2-body final state or of the normal $\overrightarrow{p_i \times p_j}$ to the plane of the 3-body final state in the meson rest system ; the final analyzing matrix is then :

$$A(\lambda_1 \lambda_2) = \hat{N}_{\lambda_1} \hat{N}^*_{\lambda_2}$$

and the angular distribution of the decay is proportional to

$$\begin{aligned} \mathrm{Tr}(\rho A) = {} & \frac{1}{2}(\rho(++)+\rho(--)) \sin^2\theta_N + \rho(00) \cos^2\theta_N \\ & - \sin^2\theta_N(\mathrm{Re}\ \rho(+-)\cos 2\varphi_N + \mathrm{Im}\ \rho(+-) \sin 2\varphi_N) \\ & - \frac{1}{\sqrt{2}} \cos 2\theta_N(\mathrm{Re}\ \rho(+0) \cos \varphi_N + \mathrm{Im}\ \rho(+0) \sin \varphi_N \\ & \qquad - \mathrm{Re}\ \rho(0-) \cos \varphi_N - \mathrm{Im}\ \rho(0-) \sin \varphi_N) \ . \end{aligned}$$

In the case of an unpolarized spin 1 particle $\mathrm{Tr}(\rho A) = \frac{1}{3}$. In the case of a spin 1 particle without longitudinal helicity :

$$\mathrm{Tr}(\rho A) = \frac{1}{2} \sin^2\theta_N(\rho(++)+\rho(--) - 2\mathrm{Re}\ \rho(+-)\cos 2\varphi_N - 2\mathrm{Im}\ \rho(+-)\sin 2\varphi_N) \ .$$

And in the special case of our jet emission :

$$\mathrm{Tr}(\rho A) = \frac{1}{2} \sin^2\theta_N(\rho(++)+\rho(--)) \quad \text{with} \quad \rho(++)+\rho(--) = 1 \ .$$

So we have here a clean test of the mechanism by verifying experimentally that the angular distribution of the decay products of a leading spin 1 meson is indeed in $\sin^2\theta_N$ with respect to the jet axis. But we cannot measure the actual degree of polarization $\xi = \rho(++)-\rho(--)$ in this way. This requires a parity violating analyzing matrix, i.e. a weak decay of the hadron. For example if the leptonic decay of the vector meson $V^\pm \to \ell^\pm + \nu(\bar{\nu})$ could be observed then the forward-backward asymmetry in the $\ell^\pm$ distribution would be exactly equal to the degree of polarization ξ .

This is also the case of a baryon decaying weakly ($\Lambda \to p + \pi^-$, $\Sigma^+ \to p + \pi^0$, ... etc) where the forward-backward asymmetry is exactly $\alpha \xi$, α being the well-known asymmetry parameter of non-leptonic hyperons decay[5] ; this is probably the best experimental way of reaching the actual value of ξ .

4. Examples

We have to distinguish 3 cases of leading mesons :

top like : $u\bar{u}$, $c\bar{c}$, $t\bar{t}$, $u\bar{c}$, ... ex : ψ , $\overline{D^{*o}}$, ...

down like : $d\bar{d}$, $s\bar{s}$, $b\bar{b}$, $d\bar{s}$, ... ex : φ , Υ , $\overline{K^{*o}}$, ...

(the mixed cases $(u\bar{u} \pm d\bar{d})/\sqrt{2}$ like ρ^o , ω , A_1^o , ... are exactly obtained by averaging the results for top and for down cases).

charged : $u\bar{d}$, $u\bar{s}$, $c\bar{d}$, $c\bar{s}$, ... ex : ρ^+ , K^{*+} , D^{*+} , F^{*+} , ...

In the case of baryons we consider for brevity only the most interesting cases Λ (uds) and Σ^+ (uus).

The coefficients of interest for using eq.(2), (3) and (4) are given in table II where we recall for comparison the cases of neutral and charged leptons production $e^+e^- \to \nu\bar{\nu}$ and $e^+e^- \to \ell^+\ell^-$. The angular distribution of the degree of polarization takes the general form in the case of unpolarized $e^\pm$ beams :

$$\xi = \frac{A(1+\cos^2\theta) + B\cos\theta}{C(1+\cos^2\theta) + D\cos\theta} \tag{5}$$

with :

$$\begin{cases} A = -\dfrac{2s^2}{|D_Z|^2}(a^2+b^2)\sum\limits_f a_f b_f + 2\mathrm{Re}\left(\dfrac{s}{D_Z}\right) a \sum\limits_f Q_f b_f \\ B = -4\dfrac{s^2}{|D_Z|^2}\, ab\sum\limits_f (a_f^2+b_f^2) + 4\mathrm{Re}\left(\dfrac{s}{D_Z}\right) b \sum\limits_f Q_f a_f \\ C = \sum\limits_f Q_f^2 + \dfrac{s^2}{|D_Z|^2}(a^2+b^2)\sum\limits_f (a_f^2+b_f^2) - 2\mathrm{Re}\left(\dfrac{s}{D_Z}\right) a \sum\limits_f Q_f a_f \\ D = 8\dfrac{s^2}{|D_Z|^2}\, ab\sum\limits_f a_f b_f - 4\mathrm{Re}\left(\dfrac{s}{D_Z}\right) b \sum\limits_f Q_f b_f \end{cases}$$

We show in fig. 3 its value for leptons, mesons and baryons for e^+e^- energies $\sqrt{s}$ = 30, 80, 90, 100 and 200 GeV assuming m_Z = 90 GeV and $\sin^2\theta_W = 0.22$.

In this case of initial unpolarized $e^{\pm}$ beams ξ is already non negligible at Petra energies and it reaches high values quickly beyond these energies.

Obviously larger values of ξ can be obtained by polarizing longitudinally the initial $e^{\pm}$ beams (i.e. $h = - h' = \pm 1$) see eq. (4) ; in such a case one has $|\xi| = 1$ in the forward and backward directions. This could give a clear test of the model.

5. The quasi-2-body limit

As a final remark we try to apply this helicity conservation mechanism for getting the asymptotic behaviour of the quasi-2-body production $e^+e^- \to H+H'$. We suppose that far above the threshold (where $p_H \gg m_H$) the dominant process is still that of fig. (4) and that helicity conservation of the quarks can again apply. Notice that contrarily to the general case of Sect. 3 one has here to add the two or three amplitudes (and not the probabilities) taking into account the peculiar spin and flavour combinations of the H and H' quark bound state wave functions. Nevertheless the prediction of helicity conservation is that the final state (HH') can only be in helicity states $(\lambda_H = 0\ ,\ \lambda_{H'} = \pm 1)$ or $(\lambda_H = \pm 1\ ,\ \lambda_{H'} = 0)$. This corresponds to the fact that asymptotically $\frac{d\sigma}{d\Omega}(e^+e^- \to HH') \propto \frac{d\sigma}{d\Omega}(e^+e^- \to q\bar{q})$ which contains only $(1+\cos^2\theta)$ terms and interference terms in $\cos\theta$ but no $\sin^2\theta$ terms.

The consequence is that $\sigma(e^+e^- \to \text{spin } 0 + \text{spin } 0)$, ex : $e^+e^- \to \pi^+\pi^-\ ,\ K^+K^-\ ,\ D\bar{D}\ ,\ \ldots$ and $\sigma(e^+e^- \to \text{spin } 1 + \text{spin } 1)$, ex : $e^+e^- \to \rho^+\rho^-\ ,\ K^*\bar{K}^*\ ,\ D^*\bar{D}^*\ ,\ \ldots$ vanish more rapidly at high energy than $\sigma(e^+e^- \to \text{spin } 1 + \text{spin } 0)$, ex : $e^+e^- \to \pi\omega,\ \pi A_1,\ \rho\epsilon,\ DD^*,\ \ldots$. In addition the couplings to the spin 1 + spin 0 states must be such that only $\lambda_H = 0$ and $\lambda_{H'} = \pm 1$ appear. This is automatically the case for vector couplings VVP (ex : $\gamma \to 1^{\pm} + 0^{\pm}$, $\pi\omega$, $A_1\delta$,...) like $\epsilon^{\mu\nu\rho\sigma}\,\partial_\mu V_\nu\,\partial_\rho V_\sigma$; but for axial couplings AVP (ex : $\gamma \to 1^{\pm} + 0^{\mp}$, πA_1, $\rho\epsilon$, ...) like $g_1(V.Ap_V^2 + V.p_V\ A.p_V) + g_2(V.p_A\ A.p_V - V.Ap_V.p_A)$ this requires a relation between the two couplings [6], either $g_1 \equiv 0$ or at least $g_1 = \frac{4m^2}{s} g_2$.

These results are valid only asymptotically, i.e. far above the threshold ; this is why they are different from the ones discussed recently for the $D\bar{D}/ DD^*/ D^*D^*$ ratios by many authors [7] who used various assumptions about the helicity amplitudes near threshold.

This work has been undertaken during the LEP SUMMER STUDY at Les Houches (1978) and benefited from the exciting atmosphere of this meeting.

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table I

	ν	ℓ^-	u,c,t,...	d,s,b,...
a	$\frac{1}{2\sin 2\theta_W}$	$\frac{-1+4\sin^2\theta_W}{2\sin 2\theta_W}$	$\frac{1-\frac{8}{3}\sin^2\theta_W}{2\sin 2\theta_W}$	$\frac{-1+\frac{4}{3}\sin^2\theta_W}{2\sin 2\theta_W}$
b	$\frac{1}{2\sin 2\theta_W}$	$-\frac{1}{2\sin 2\theta_W}$	$\frac{1}{2\sin 2\theta_W}$	$-\frac{1}{2\sin 2\theta_W}$

table II

	ΣQ_f^2	$\Sigma(a_f^2+b_f^2)$	$\Sigma a_f b_f$	$\Sigma Q_f a_f$	$\Sigma Q_f b_f$
ν	0	$\frac{1}{2\sin^2 2\theta_W}$	$\frac{1}{4\sin^2 2\theta_W}$	0	0
ℓ^-	1	$\frac{1+[1-4\sin^2\theta_W]^2}{4\sin^2 2\theta_W}$	$\frac{1-4\sin^2\theta_W}{4\sin^2 2\theta_W}$	$\frac{1-4\sin^2\theta_W}{2\sin 2\theta_W}$	$\frac{1}{2\sin 2\theta_W}$
top	8/9	$\frac{1+[1-\frac{8}{3}\sin^2\theta_W]^2}{4\sin^2 2\theta_W}$	0	$\frac{1-\frac{8}{3}\sin^2\theta_W}{3\sin 2\theta_W}$	0
down	2/9	$\frac{1+[1-\frac{4}{3}\sin^2\theta_W]^2}{4\sin^2 2\theta_W}$	0	$\frac{1-\frac{4}{3}\sin^2\theta_W}{3\sin 2\theta_W}$	0
charged	5/9	$\frac{2+[1-\frac{8}{3}\sin^2\theta_W]^2+[1-\frac{4}{3}\sin^2\theta_W]^2}{4\sin^2 2\theta_W}$	$\frac{-\sin^2\theta_W}{3\sin^2 2\theta_W}$	$\frac{1-\frac{20}{9}\sin^2\theta_W}{2\sin 2\theta_W}$	$\frac{1}{6\sin 2\theta_W}$
Λ(uds)	2/3	$\frac{3+[1-\frac{8}{3}\sin^2\theta_W]^2+2[1-\frac{4}{3}\sin^2\theta_W]^2}{4\sin^2 2\theta_W}$	$\frac{3-\frac{16}{3}\sin^2\theta_W}{4\sin^2 2\theta_W}$	$\frac{2-4\sin^2\theta_W}{3\sin 2\theta_W}$	$\frac{2}{3\sin 2\theta_W}$
Σ^+(uus)	1	$\frac{3+2[1-\frac{8}{3}\sin^2\theta_W]^2+[1-\frac{4}{3}\sin^2\theta_W]^2}{4\sin^2 2\theta_W}$	$\frac{3-\frac{20}{3}\sin^2\theta_W}{4\sin^2 2\theta_W}$	$\frac{\frac{5}{3}-4\sin^2\theta_W}{2\sin 2\theta_W}$	$\frac{5}{6\sin 2\theta_W}$

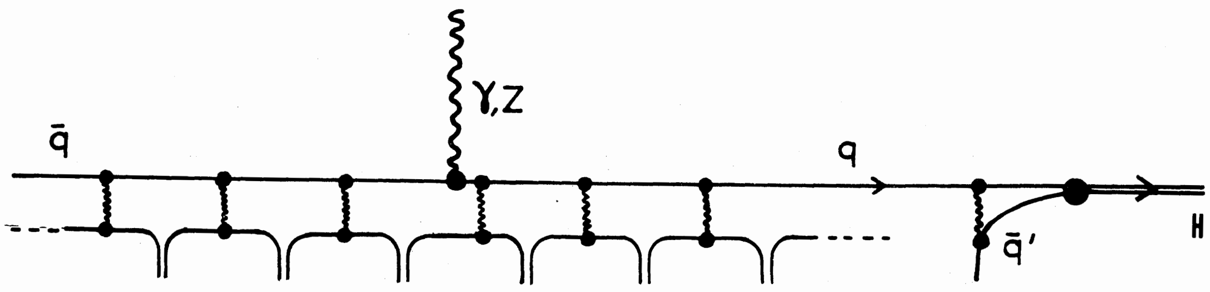

Figure 1 : The jet development with a leading meson.

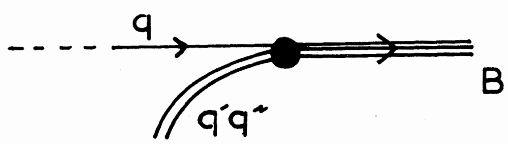

Figure 2 : The jet development with a leading baryon.

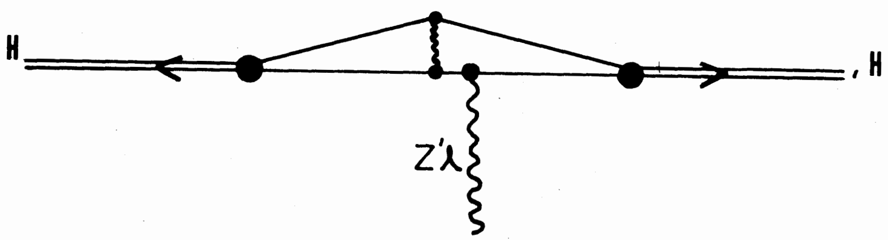

Figure 4 : The quasi-2-body formation $e^+e^- \to H + H'$.

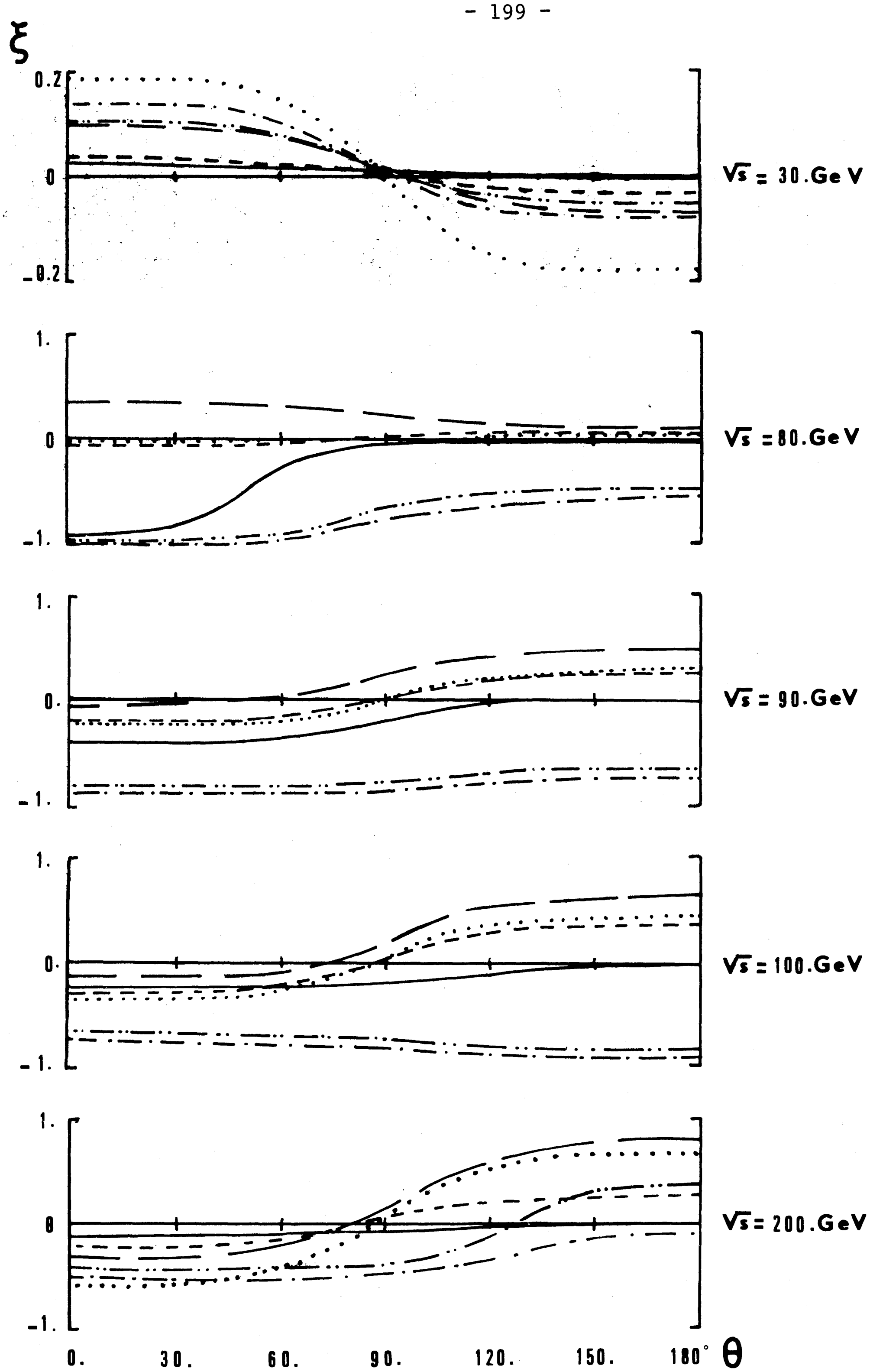

Figure 3 : Angular distribution of degree ξ of polarization of final leptons, leading mesons and baryons (in the case of unpolarized $e^{\pm}$ beams) :

———————	lepton ℓ^-	— — —	$u\bar{d}$ mesons
- - - - - - -	$u\bar{u}$ mesons	— · — —	Λ (uds)
. . . .	$d\bar{d}$ mesons	— · · — —	Σ (uus)