DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 80/126
December 1980

PHYSICS INTEREST IN POLARIZED e^+e^--REACTIONS AT PETRA/PEP ENERGIES

by

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Summary

After the observation of vertical polarization at PETRA some considerations on its implementation in high-energy physics experiments are given. Vertical beam polarization does not give new information, but the information is obtained easier. Longitudinally polarized beams allow the measurement of electroweak (vector-axialvector) interferences. In the standard model the longitudinal polarization asymmetry is zero for $\sin^2\theta_W = 0.25$ for $e^+e^- \to \mu^+\mu^-$, but is + 17 % for $e^+e^- \to$ hadrons at 40 GeV c.m. energy. To measure this as a 5 standard deviation effect one needs 4 500 events, i.e. about half-a-year running time. Non-standard models show only small deviations up to 40 GeV, as they are constrained to reproduce the low-energy phenomenology. But significant differences appear at 90 GeV. In QCD the 3-gluon vertex can be observed by the beam-event asymmetry using longitudinally polarized beams. But the effects are small.

Invited talk at the 1980 International Symposium on "High Energy Physics with Polarized Beams and Polarized Targets", Lausanne/Switzerland, 25 September - 1 October 1980.

1. Polarized e^+e^- beams
(as regarded by the user)

1.1. Vertical beam polarization

Vertical beam polarization has been observed at the PETRA e^+e^- storage ring by backscattering of laser photons /1/ . So the high-energy physicists can plan the use of polarized e^+e^- beams at c.m. energies up to $W \approx 40$ GeV. In this chapter we discuss some aspects of polarized e^+e^- beams which are important for the experimenter. We will always assume that the beams are "naturally" polarized by synchrotron radiation emission in magnetic fields /2/ :

a) The direction of the vertically polarized spins $\vec{S}$ is

(1) $\vec{S}(e^+)$ parallel to $\vec{B}$ ($\vec{B}$ = magnetic guide field vector)
$\vec{S}(e^-)$ antiparallel to $\vec{B}$

b) The polarization is built up in time (P = degree of vertical polarization, t = time, T_{pol} = polarization build-up time):

(2) $P = 0.92 \cdot (1 - e^{-(t/T_{pol})})$

For PETRA T_{pol} is given by

(3) $T_{pol} = 20\ \text{min} \cdot \left(\frac{15\ \text{GeV}}{E_{beam}} \right)^5$

$= 62$ min at 12 GeV

$= 20$ min at 15 GeV

$= 5$ min at 20 GeV

As a consequence beam polarization can be used from a lower energy limit up. For PETRA this is about 15 GeV.

c) The degree of polarization which by natural beam polarization is finally reached is very high: $P_{max} = 92$ %. But in practice this is reduced by depolarizing effects.

d) Depolarization /3/ appears at certain (resonance) energies. These repeat in 440 MeV steps. Thus polarized beams can be used only at some energies, the polarization windows.

e) The present status of our knowledge is: 1. Vertical beam polarization has been measured at ACO /4/ , Novosibirsk /5/ , Spear /6/ , and Petra /1/ . 2. The depolarization in single beams is understood. 3. Depolarization in colliding beams is not yet understood. In some experiments polarization was seen, in others not.

1.2. Longitudinal beam polarization

The method generally suggested to produce longitudinal beam polarization is: 1. let vertical polarization build up naturally, 2. rotate the spin relative to the orbit with magnetic fields.

The spin rotator /7/ uses the fact that in a magnetic field B the orbit is bend by

$$(4) \quad \alpha_{orbit} = 300 \cdot \frac{\int B_T dl_m}{P_{GeV/c}}$$

(B_T: magn. field strength in Tesla, l_m: length of magnetic field in meter, $P_{GeV/c}$: particle momentum in GeV/c), while the spin precession advances the orbital bend with an angle

$$(5) \quad \Theta_{spin} = \gamma \cdot \frac{g-2}{2} \cdot \alpha_{orbit}$$

($\gamma = E_{beam}/m_e c^2$, g: g-factor of the electron magnetic moment) relative to the orbit bend. If one requires a 90^0 advance to produce a longitudinal from a vertical spin, one needs

$$(6) \quad \Theta_{spin} \overset{!}{=} 90^0 \quad : \quad \int Bdl = 2.3 \text{ T·m (independent of beam energy)},$$

While the magnetic bending strength $\int Bdl$ is independent of the beam energy, the orbit bend is not (table).

E_{beam}	15	20	GeV
α_{orbit}	46	34.5	mrad

The spin rotator has to bring back orbit and spin into the normal lattice.

Fig. 1 shows the scheme proposed /7/ .

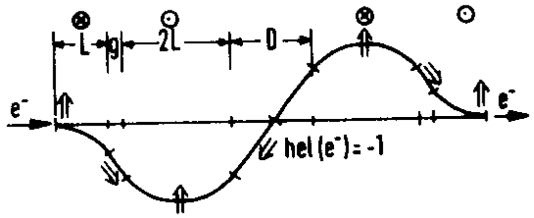

Fig. 1. The spin rotator /7/. Magn.field B: ⊗ into paper Magn.field B: ⊙ out of paper L: magnetic length, g: gap between magnets, D: drift space for detector. Shown is case of electrons.

The spin is actually rotated six times. The orbit for positrons is the same, but has opposite direction. All positron spins are opposite. So the scheme produces antiparallel longitudinal e^- and e^+ spins. The space for detectors is limited to

$$(7) \quad D = L + 2 \cdot g$$

To study the practical implementation one can distinguish two cases:
1. Minimum length spin rotator. The detector length needed is 5 m. This gives D ≈ 6 m and a length of one magnetic bend of L = 5 m. The magnetic field strength is then B = 0.46 T. The total length becomes = 6 L + 2 g + D ≈ 2·20 m. This has to be compared to the length of the straight sections (SS) at PETRA (between the last bending magnets) of 2·17 m for the short SS (present detector locations) and 2·45 m for the long SS.
2. A maximum length spin rotator starts from a total length of 2·45 m and has L = 13 m, B = 0,18 T, D ≈ 15 m.
Of course more clever solutions are conceivable.
The problem of this scheme is the high energy and intensity of the synchrotron radiation (SR) emitted (table)

scheme length	E_{beam} GeV	ε_c keV	P_{beam} kW	equ.qu. sec^{-1}
minimum	15	68.3	7.2	$6.6 \cdot 10^{17}$
maximum	15	26.7	2.8	$6.6 \cdot 10^{17}$
minimum	20	121.4	12.8	$6.4 \cdot 10^{17}$
maximum	20	47.5	5.0	$6.4 \cdot 10^{17}$

ε_c: critical energy (Δ most probable energy of SR)
P_{beam}: power of SR emitted
equ.qu. = number of equivalent SR quanta

This means that the detectors have to be shielded against the high flux of energetic SR quanta. This also explains why one considers the maximum length solution.

2. The use of vertical polarized beams

a) The angular distribution of inclusive reactions $e^+_{vert} + e^-_{vert} \to h + X$ shows an azimuthal asymmetry /8/ :

(8) $\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}_0 \cdot \{ 1 + \alpha \, (\cos^2\Theta + P^2_{vert} \cdot \sin^2\Theta \cdot \cos^2 \phi) \}$

(Θ: polar angle, measured from the beam direction, ϕ: azimuthal angle, measured from the normal to beam and vertical polarization direction, P_{vert}: degree of vertical polarization, equal magnitude but opposite direction for e^+ and e^-) and

(9) $\sigma_0 = \frac{1}{2} (\sigma_t + \sigma_l)$

$\alpha = (\sigma_t - \sigma_l) / (\sigma_t + \sigma_l)$

(σ_t: cross section for inclusive hadron production via transverse polarized virtual photons, σ_l: same for longitudinal virtual photons). The study of angular distributions allows to separate σ_t and σ_l.

b) For 2-body final states one gets formulas which look like (8) and (9), but the parameter α can now easily be predicted:

(10) $\alpha = + 1$ for spin $\frac{1}{2}$ particles (μ-pairs, quark pairs)
$\alpha = - 1$ for spin 0 particles (π-or K pairs).

c) The azimuthal asymmetry, i.e. the use of vertical polarized beams, does NOT give new information. The same parameter α also governs the polar angle distribution. BUT in practice an azimuthal asymmetry is easier to measure than a polar angle distribution. This offers advantages for the experimentalist.

d) Experiments

1. Spear (Mark I detector) 1975 /9/ at $\sqrt{s}$ = 7,4 GeV.
   a) From the azimuthal asymmetry of μ-pairs and Bhabha events (i.e. $\alpha = + 1$ is known) one obtains P_{vert} = 70 %.
   b) The azimuthal asymmetry of inclusive hadron production gives $\alpha \; (x_F = p/E_{beam}) \xrightarrow[x_F \to 1]{} + 1$. The interpretation is that high energy pions fragment from spin 1/2 particles (quarks).
   c) The azimuthal distribution of the jet axis gives $\alpha_{jet} = (0.97 \pm 0.14)$, i.e. hadron jets fragment from spin $\frac{1}{2}$ quarks.
   These results have played an important role in developping our understandinn of e^+e^- physics.

2. Novosibirsk 1978 /10/ . The azimuthal asymmetry for $e^+_{vert}\, e^-_{vert} \to \phi \to K^+K^-$ was observed in agreement with (10).

3. Petra (Jade) 1979 /11/ at $\sqrt{s}$ = 30 GeV. An azimuthal asymmetry has been seen for inclusive hadron production (fig 2a) as well as for the thrust axis (fig 2b). If one assumes $\alpha_{jet} = + 1$, one gets for the degree of polarization $P^2_{vert} = (0.72 \pm 0.25)$, i.e. P_{vert} = 85 %.

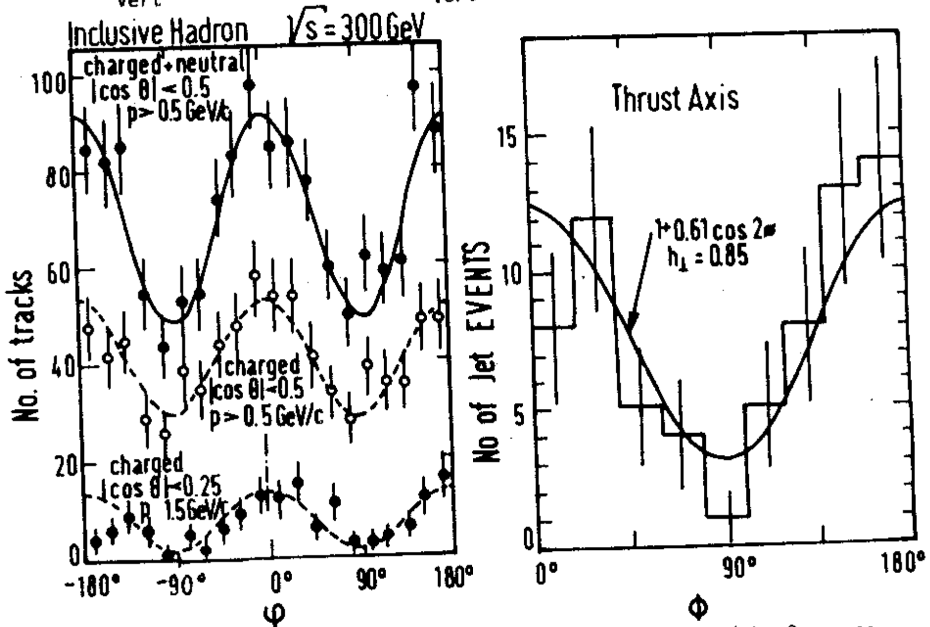

Fig. 2: Azimuthal (ϕ) asymmetry of (a) the inclusive hadrons (the 3 curves show 3 different cuts to the data) and (b) the thrust axis. $\sqrt{s}$ = 30 GeV. Jade collaboration at Petra.

3. Longitudinal polarization effects

in electroweak interactions (standard model)

3.1. We consider the process $e^+e^- \to \gamma, Z^0 \to f\bar{f}$ ($f = \mu$ or quark $\to$ jet). It is

the interference of an electromagnetic (γ-exchange) and weak neutral current process (Z^0-exchange, coupling constant G to the e^+e^-, G' to $f\bar{f}$). For the weak contribution one expects longitudinal polarization effects. In the Petra energy range one can observe the interference of the two graphs in addition to the purely electromagnetic process /12/.

3.2. Observables

The coupling constants G and G', each for vector (V) and axialvector (A) interaction, show up in 3 observables:

(11)

1. forward-backward asymmetry $$A_{FB} = \frac{\sigma(\Theta)-\sigma(\pi-\Theta)}{\sigma(\Theta)+\sigma(\pi-\Theta)} \sim G_A G_A'$$
   (Θ = polar angle between particle f and beam direction)
   A_{FB} can also be produced by 2nd order electromagnetic interactions)

2. change in absolute rate $$A_N = \frac{\sigma_{tot} - \sigma_{1\gamma}}{\sigma_{1\gamma}} \sim G_V G_V'$$
   ($\sigma_{1\gamma}$: for one-photon exchange)

3. asymmetry with longitudinally polarized electrons $$A_{\ell p} = \frac{1}{P_\ell} \cdot \frac{\sigma_{\ell p} - \sigma_0}{\sigma_0} \sim G_V' G_A$$
   (P_ℓ :degree of longitudinal polarization, σ_0: unpolarized cross section)

The observables are in detail:

(12)	for $\mu^+\mu^-$	for $q\bar{q}$
A_{FB}	$- \varepsilon \cdot \frac{2\cos\Theta}{1+\cos^2\Theta} \cdot G_A G_A'$	$\varepsilon G_{Ae} \cdot \frac{\Sigma G_{Ai} e_i}{\Sigma e_i^2} \cdot \frac{2\cos\Theta}{1+\cos^2\Theta}$
A_N	$- \varepsilon\, G_V G_V'$	$\varepsilon G_{Ve} \cdot \frac{\Sigma G_{Vi} e_i}{\Sigma e_i^2}$
$A_{\ell p}$	$\varepsilon \left[G_V' G_A + \frac{2\cos\Theta}{1+\cos^2\Theta} \cdot G_V G_A' \right]$	$-\varepsilon G_{Ae} \cdot \frac{\Sigma G_{Vi} e_i}{\Sigma e_i^2} + \varepsilon G_{Ve} \{\ldots G_{Ai} \ldots\} \cdot \frac{2\cos\Theta}{1+\cos^2\Theta}$

$$(\varepsilon = \frac{2 \cdot \sqrt{2} \cdot G_F}{4\pi\alpha} \cdot s \cdot \frac{1}{1-s/M_Z^2} = 0.366 \cdot \frac{s}{(31.5\ \text{GeV})^2} \cdot (\frac{1}{1-s/M_Z^2}) \ ,$$

G_F: Fermi coupling constant, $\alpha = \frac{1}{137}$, s = (c.m. energy)^2, M_Z: Z^0 mass, the sums extend over all quark flavors i, e_i: quark fractional change).

The aim is to measure the coupling constants G_V, G_A for leptons and all quark flavors and also to give limits to scalar, tensor and pseudoscalar interactions (formulas not given here). The parity violation of electroweak interactions ($G_V G_A$) can be observed using longitudinally polarized electrons (we do not discuss here experiments to measure longitudinal final state polarizations). Furtheron, if one can get a high precision, one can determine the Z^0 mass.

3.3. The coupling constants in the standard model

The standard Glashow-Salam-Weinberg model gives definite predictions for the coupling constants. It is

(13)
$$G_{Vi} = I_{3Li} + I_{3Ri} - 2 \cdot \sin^2\Theta_W \cdot e_i$$ (G_V shows the weak-electromagnetic interference)
$$G_{Ai} = I_{3Li} - I_{3Ri}$$

(I_3: 3rd component of weak isospin for left (L) and right (R) handed particles)

The standard model has left-handed doublets and right-handed singulets:

$$(14)\qquad I_{3L} = \begin{cases} +1/2 \\ -1/2 \end{cases} : \begin{pmatrix}\nu_e \\ e^-\end{pmatrix}_L , \begin{pmatrix}\nu_\mu \\ \mu^-\end{pmatrix}_L , \ldots , \begin{pmatrix}u \\ d\end{pmatrix}_L , \begin{pmatrix}c \\ s\end{pmatrix}_L , \ldots$$

$$I_{3R} = 0$$

Then the coupling constants are:

(15)

	ν_e, ν_μ	e^-, μ^-	u, c	d, s, b
G_V	$+\frac{1}{2}$	$-\frac{1}{2} + 2 \cdot \sin^2 \Theta_W \approx 0$	$\frac{1}{2} - \frac{4}{3}\sin^2\Theta_W \approx \frac{1}{6}$	$-\frac{1}{2} + \frac{2}{3}\sin^2\Theta_W \approx -\frac{1}{3}$
G_A	$+\frac{1}{2}$	$-\frac{1}{2}$	$+\frac{1}{2}$	$-\frac{1}{2}$

There we used the approximate experimental value $\sin^2\Theta_W \approx \frac{1}{4}$.

3.4. Observables in the standard model

We give numerical predictions for $\sqrt{s}$ = 31 and 40 GeV (ε = 0.42 and 0.74, resp.):

(16)

e^+e^-		$\mu^+\mu^-$	$u\bar{u}, c\bar{c}$	$d\bar{d}, s\bar{s}, b\bar{b}$	hadrons
31 GeV 40 GeV	A_{FB}	$\frac{\varepsilon}{4} \cdot f(\Theta) \approx \begin{cases}10\% \\ 18\%\end{cases}$	$-\frac{3}{8}\varepsilon \cdot f(\Theta) \approx \begin{cases}-15\% \\ -28\%\end{cases}$	$-\frac{3}{4}\varepsilon f(\Theta) \approx \begin{cases}-31\% \\ -55\%\end{cases}$	$-\frac{21}{40}\varepsilon f(\Theta) \approx \begin{cases}-22\% \\ -39\%\end{cases}$
31 GeV 40 GeV	A_N	0	0	0	0
31 GeV 40 GeV	$A_{\ell p}$	0	$+\frac{1}{8}\varepsilon \approx \begin{cases}+5\% \\ +9\%\end{cases}$	$+\frac{1}{2}\varepsilon \approx \begin{cases}+20\% \\ +37\%\end{cases}$	$+\frac{5}{22}\varepsilon \approx \begin{cases}+10\% \\ +17\%\end{cases}$

The longitudinal polarization asymmetry vanishes for μ-pair production because of $\sin^2\Theta_W \approx \frac{1}{4}$. But quite sizeable effects are predicted for hadron production: $A_{\ell p} \approx +9\%$ for $+\frac{2}{3}$ charged quark flavors, $\approx +37\%$ for $-\frac{1}{3}$ charged quarks, and $\approx +17\%$ for hadrons without distinction of the flavor (always at $\sqrt{s}$ = 40 GeV).

4. Scenario for a polarization experiment

In the following we show that a measurement of the longitudinal polarization asymmetry $A_{\ell p}$ for hadron production $e^+e^- \to h$'s is feasible at Petra with present luminosities. The Weinberg angle $\sin^2\Theta_W$ can be obtained. The cross section is

$$(17)\qquad \sigma = \sigma_0 \cdot \left(1 + \frac{P_+ - P_-}{1 - P_+P_-} \cdot A_{\ell p}\right)$$

($P_\pm = P(\ell^\pm)$ = degree of polarization, sign as the $\ell^\pm$ helicity).

The estimation of rates assumes P = 50 % (seems safe as P_{max} = 92 %), the polarization build-up time is several minutes up to $\frac{1}{2}$ hour which is much shorter than the beam lifetime (3 - 4 hours). The luminosities obtained are $L_{peak} = 2 \cdot 10^{30}\ cm^{-2}\ s^{-1}$, yielding an average luminosity $L \approx 50\ nb^{-1}/d$. With the forthcoming mini-β insertions we assume $L = 150\ nb^{-1}/d$. The total cross section is

$$(18)\qquad \sigma_{tot}(e^+e^- \to h) = \frac{84\ nb \cdot GeV^2}{s} \cdot R$$

$$= 0.36\ nb \text{ or } 0.20\ nb \text{ for } \sqrt{s} = 31.5 \text{ or } 40\ GeV, \text{ resp.}$$

This gives the rate

(19) rate = $L \cdot \sigma \cdot \varepsilon$ = 50 or 28 events/day for 31.5 or 40 GeV, resp. (efficiency ε = 90 %).

An asymmetry measurement will be done in two runs with different polarization settings.

(19) 1st run: $P_+ = 0,\quad P_- = -0.5\qquad \sigma_- = \sigma_0\ (1 + P \cdot A_{1p})$
2nd run: $P_+ = -0.5,\ P_- = 0\qquad \sigma_+ = \sigma_0\ (1 - PA_{1p})$

One beam has to be depolarized. The natural polarization, together with the spin rotator, gives antiparallel spins, i.e. J = 0. In this case both the γ- and the Z^0 - exchange (spin 1 - particles) graphs vanish, i.e. σ = 0. From (19) one obtains

(20) $$A_{\ell p} = \frac{1}{P_\ell} \cdot \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

The statistical error in the asymmetry $\Delta A_{\ell p}$ is

(21) $$\Delta A_{\ell p} \approx \frac{1}{P} \cdot \frac{\Delta\sigma}{\sigma} \approx \frac{1}{P} \cdot \frac{1}{\sqrt{N}}$$

This gives the number of counts N needed for an accuracy $\Delta A_{\ell p}$ which is required for physics:

(22) $$N = \frac{1}{P^2 \cdot (\Delta A_{\ell p})^2}$$

With P = 0.5 one gets at $\sqrt{s}$ = 40 GeV (NB! $A_{\ell p}$ = 0.17 in the standard model):

$\Delta A_{\ell p}$ = 0.05, establish the effect: N = 1 600 events, in 57 days
$\Delta A_{\ell p}$ = 0.03, measure the effect : N = 4 500 events, in 160 days
$\Delta A_{\ell p}$ = 0.01, precision measurement: N = 40000 events, in 1400 days

So one can measure the longitudinal polarization asymmetry $A_{\ell p}$ = (0.17 ± 0.03)= 0.17 (1 ± 18 %) within half-a-year of running.

From this measurement of $A_{\ell p}$ one can determine $\sin^2\Theta_W$. Equation (12) reads in detail

(23) $$A_{\ell p} = \varepsilon \cdot \left(\frac{21}{44} - \sin^2\Theta_W\right)$$

One gets within half-a-year $\sin^2\Theta_W$ = (0.23 ± 0.04). This is about the accuracy which one has nowadays from a single experiment.

The Z^0-propagator contributes at $\sqrt{s}$ = 40 GeV a factor 1.25 to $A_{\ell p}$. This means one needs an accuracy of $\Delta A_{\ell p}$ = 0.01 to establish the propagator effect.

5. Non-standard models of electroweak interactions

Non-standard models of electroweak interactions have more than one neutral gauge boson Z^0 and/or different couplings. They are constructed to answer various questions to the theory. One gets a variety of predictions. BUT: the low-energy phenomenology is now known experimentally; it is in agreement with the Glashow-Salam-Weinberg model. As a consequence, all non-standard models are constrained to reproduce the low-energy phenomenology. So in the PETRA/PEP energy range only small differences appear. All new phenomena show up at energies larger than 70 or 80 GeV /13/ .

It is impossible to present here anything like a complete list of non-standard models. So I will illustrate the ideas and results with two examples.

1. A SU(3)xU(1) model /14/ . Models of this type are constructed because they produce the observed Weinberg angle intrinsically. The particles are assigned to left- and right-handed lepton triplets $(e^-, \nu_e, \mu^+)_L$ and $(\mu^+, \bar{\nu}_\mu, e^-)_R$, left-handed quark triplets $(u, d, m)_L$, $(c, s, n)_L$ and $(t, b, p)_L$ and right-handed quark singlets u_R, d_R etc. (m, n, p are new quark flavors). The gauge boson sector consists of the "old" γ, Z^0, W^+ and W^-. In addition one needs B^{++}, B^{--}, C^+, C^- (all four are lepton number violating and have effective scalar and pseudoscalar couplings) and K^0 (which has (V-A) and (V+A) couplings and does not couple to neutrinos). Fig. 3 shows $A_{\ell p}$ predicted by this model.

2. Left-right symmetric model: $SU(2)_L xSU(2)_R xU(1)$ /15/ . They satisfy esthetic requirements. The particles are assigned to left- and right-handed lepton and quark doublets: $(\nu_e, e^-)_L$, ..., $(u, d)_L$, ..., $(\nu_e, e^-)_R$, ..., $(u, d)_R$, ... Also the gauge boson structure is richer than in the standard model. One has γ, Z^0_V, Z^0_A; W^+_L, W^-_L; W^+_R, W^-_R. The left- and right-handed coupling constants are assumed to be equal: $g_L = g_R$. Fig. 3 also shows the predictions of this model.

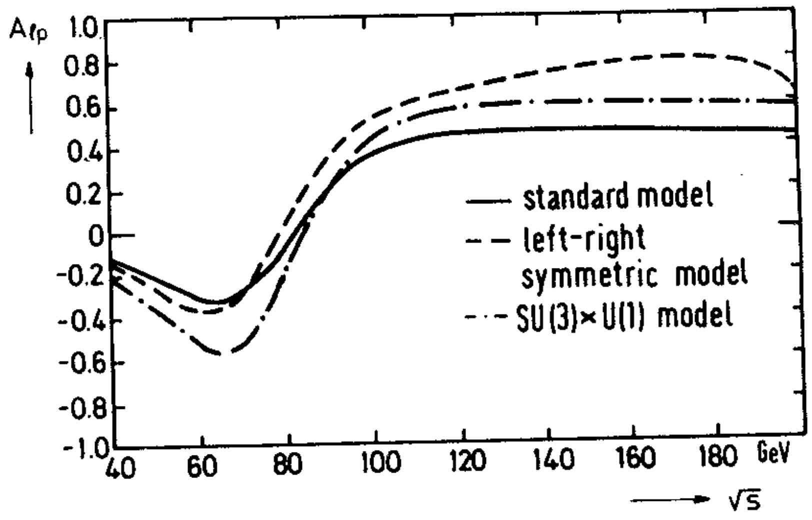

Fig. 3 : The longitudinal polarization asymmetry $A_{\ell p}$ as a function of the c.m. energy $\sqrt{s}$ for the process $e^+e^- \to q\bar{q} \to$ jets. Shown are the predictions of the standard model (GSW), a SU(3)xU(1) model and a left-right symmetric model.

At $\sqrt{s}$ = 40 GeV the differences are rather small, while they are remarkable for $\sqrt{s} \geq 70$ GeV.

6. Spin effects in QCD

One of the main consequences of quantum chromodynamics (QCD) as a non-Abelian gauge theory is the prediction of a direct 3-gluon coupling. This was not yet directly observed. There have been several theoretical articles which show that one can measure the 3-gluon coupling using longitudinally polarized e^+e^- beams.

1. $e^+_{\ell p}\, e^-_{\ell p} \to \gamma \to 3g \to 3$ jets /16/ .

The three gluons span a plane (nowadays we know how difficult this is experimentally). The normal to this 3g-plane forms an angle Θ with the longitudinal electron spin. One defines a "beam-event asymmetry" in Θ:

$$A_{BE} = \frac{\sigma(0) - \sigma(\pi - 0)}{\sigma(\Theta) + \sigma\ \pi - \Theta)} \qquad (24)$$

This beam-event asymmetry is sensitive to the final state interactions which, for the decay of a heavy vector meson like the $\Upsilon(9.46)$ into three hard gluons, is nothing else than the exchange of soft gluons between the hard gluons I.e. one measures the 3-gluon vertex. The numerical prediction from QCD is the very small value $A_{BE} \approx 0.2$ %. This cannot be measured presently.

2. $e^+_{\ell p} e^-_{\ell p} \to q\bar{q}g \to 3$ jets /17/ .

One studies in the continuum the three jet final states and looks again for the beam-event asymmetry (24). The 3-gluon interaction is now only part of the final state interactions. The results of the QCD calculations are:

a) In massless QCD it is $A_{BE} \approx 0$.

b) With massive quarks one finds:
   with QCD (non-Abelian gauge theory): $A_{BE} < 0$
   with a QED-like gauge theory : $A_{BE} > 0$.

The numerical prediction with QCD gives a maximal value (for b-quarks and at $\sqrt{s}$ = 20 GeV) of $A_{BE} \approx -10$ % (for the three-jet events which are a small fraction of all hadronic final states).

7. Summary

1. Natural vertical polarization exists and can be produced in single beams. For colliding beams not yet all the machine parameters are understood. Polarization has still to be implemented for routine operation.

2. The use of <u>vertical polarization</u> is highly wanted by experimentalists. One can bend polar angle dependences into the detector as azimuthal asymmetries.
   This is true not only for $q\bar{q}$-jets, but also for $q\bar{q}g$ 3-jet events.

3. <u>Longitudinal polarization</u> is necessary, if one wants to test the full aspects of electroweak theories, i.e. the parity violation in Z^0 exchange, interfering with γ-exchange.
   $A_{\ell p}$ $G_V G_A \alpha^{-1}$

A considerable technical effort is needed to build a spin rotator.

$e^+_{\ell p}\, e^-_{\ell p} \to \gamma, Z^0 \to h$'s shows a polarization asymmetry in the Glashow-Salam-Weinberg model.

It was a polarization experiment /18/ which has proven the standard model at low energies.

This measurement can be extended from $Q^2 \leq 2\,\mathrm{GeV}^2$ to $Q^2 = 1600\ \mathrm{GeV}^2$.

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