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by

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PHYSICS CAPABILITIES AT LEP II*

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ABSTRACT

The physics interest in high energy e^+e^- collisions at LEP II is reviewed. Special emphasis is given to the extraction of a maximum amount of information from W pair production. Higgs searches at LEP and possible signals for the compositeness of quarks and leptons are discussed as well.

I. INTRODUCTION

By the time the Superconducting Super Collider (SSC) will come into operation in the second half of the 90's a large amount of new information should be available from experiments performed at LEP II. This upgrade of LEP to a center of mass energy of 190-200 GeV is proposed to become operative in 1993/94 and it will thus provide additional input information for SSC experiments, in particular on the validity of the standard model.

The purpose of this talk is to give a brief review of the physics issues that can be investigated at LEP II [1,2]. The prime motivation for the study of e^+e^- collisions at a center of mass energy $\sqrt{s}$ = 190 GeV is the physics associated with W pair production and W decays. Accordingly a large portion of this talk will be devoted to W-pair physics: to what extent can the nonabelian three-gauge-boson-vertex WWγ and WWZ be measured at LEP II? Is a precise measurement of the W mass possible? What can be learnt from W decays?

One of the major tasks of the SSC is to discover the Higgs boson in case it is heavier than twice the W or the Z mass. In the section on Higgs searches (section III) I will adress the complementary question: up to which Higgs mass may a "light" Higgs boson be discovered at LEP. Finally physics beyond the standard model will be touched briefly: in section IV I will discuss some of the signals for the compositeness of quarks and leptons and the bounds on the compositeness scale obtainable at LEP II. A few conclusions are drawn in section V.

To a large extent this talk is based on results of the various study groups on "Physics at LEP". Further details on the issues discussed in this talk can be found in ref. [1].

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II. W-PAIR PHYSICS AT LEP II

Within the standard model all the properties of W-pair production and W-decay are uniquely fixed in terms of a few fundamental parameters like the masses of the W and the Z, Kobayashi-Maskawa matrix elements etc. At the tree level the amplitudes for W pair production are given by the three Feynman graphs of Fig. 1.

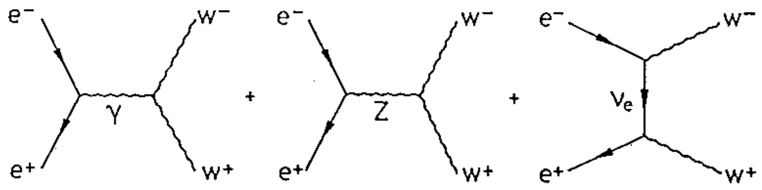


Fig.1 Lowest order contributions to $e^+e^- \rightarrow W^+W^-$.

It is the interplay of electromagnetic, neutral current and charged current interactions, corresponding to the photon-, Z-, and neutrino exchange graphs in fig.1, and in particular the gauge theory cancellations between them, which determine the properties of W pair production in e^+e^- collisions. W pair production thus provides a unique opportunity to study all three aspects of electroweak interactions simultaneously.

After a rapid threshold rise the total cross section $\sigma(e^+e^- \rightarrow W^+W^-)$ reaches its maximum value of roughly 20 pb at $\sqrt{s}$ = 190-200 GeV (see fig.2). The highest LEP II energy is chosen to exactly lie in this range, and at an estimated luminosity of 500 pb^{-1} $year^{-1}$ LEP II will thus produce 10^4 W^+W^- pairs per experiment and year. Before discussing the information that can be deduced from this high statistics sample, a short assessment of signals and backgrounds is necessary.

Each of the W's will decay either into a lepton pair $l\nu_l$ ($l = \mu, e, \tau$), with about 25% probability, or into a quark-antiquark pair, essentially giving rise to a dijet system. More precisely, when a top quark of 40 GeV is assumed, the fractions for the three distinct W-pair signals are

$$\begin{array}{lll} W^+W^- \rightarrow \text{"4 jets"} & 53\% \text{ (hadronic)} & \\ W^+W^- \rightarrow \text{"2 jets"} + l^{\pm} + \not{p} & 40\% \text{ (semileptonic)} & (2.1) \\ W^+W^- \rightarrow e^+e^- + \not{p} & 7\% \text{ (leptonic)} & \end{array}$$

Here $\not{p}$ is standing for the missing energy-momentum of the escaping neutrino(s).

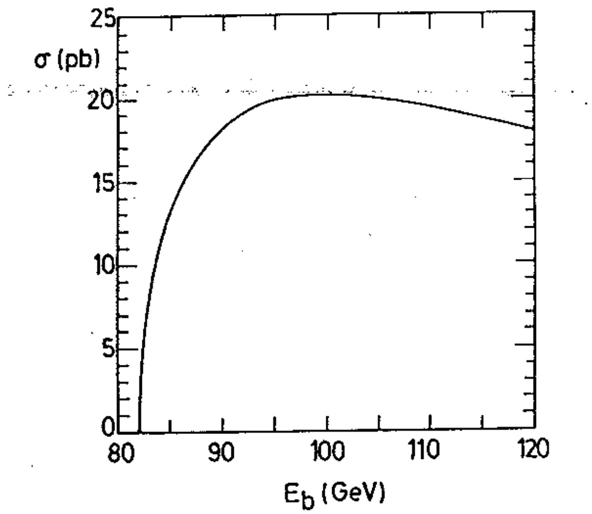


Fig.2 Total cross section for $e^+e^- \rightarrow W^+W^-$ versus beam energy for m_W = 82 GeV, $\sin^2\theta_W$ = 0.223 and zero W-width

The decays involving leptons are very clean and even the hadronic signal is essentially background free: Other sources of hadrons at LEP II are given by "normal" $q\bar{q}$ production (q = u,d,s,c,b t) and radiative Z production. The corresponding cross sections at $\sqrt{s}$ = 190 GeV are roughly $\sigma(e^+e^- \rightarrow q\bar{q}) \approx 30$ pb and $\sigma(e^+e^- \rightarrow Z\gamma) \approx 60$ pb with $Br(Z \rightarrow q\bar{q}) \approx 3/4$. However, in the case of radiative Z production the produced hadronic system has an invariant mass which is almost 100 GeV lower than in the hadronic W pair sample and in addition it has a strong boost due to the hard photon recoiling against it: these events are easy to single out. On the other hand at least two hard gluons have to be radiated off pairs of light quarks in order to get a topology which might be confused with hadronic W pair decays. This gives as a rough estimate σ (4 jet-background) $\approx \alpha_s^2 \cdot 30$ pb $\approx$ 0.4 pb, when good flavor identification for $t\bar{t}$ is assumed.

One thus finds that even without using the peaking of dijet invariant masses around m_W as an additional selection criterion, event topology alone gives a sample of 5000 hadronic W pair decays per year with low background, of which 3000 should be clean enough to do detailed studies [2]. On the other hand one is left with ~ 2500 semileptonic events involving a ~ 50 GeV electron or muon, a sample which increases to almost 4000 events per year if τ decays of W's can be identified also.

LEP II will thus provide us with a high statistics sample of clean W pair events and we may now adress the question to what extent they will allow to measure W-properties.

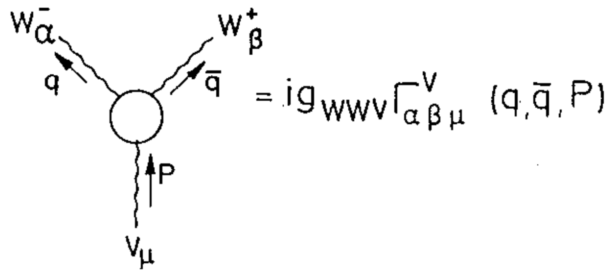
II.1 CHECKING THE THREE GAUGE VERTEX

One of the prime tasks of LEP II is to measure the $W^+W^-\gamma$ and W^+W^-Z vertices which are entering the pair production amplitude via the photon- and Z-exchange graphs of fig.1. In order to get a handle on deviations from the standard model, it is convenient to parametrize the most general three vector boson vertex Γ_{WWV} ($V = \gamma, Z$) for on shell W's [3,4]. The Feynman rule for this vertex is given in fig.3 with

$$\begin{aligned}\Gamma^V_{\alpha\beta\mu}(q,\bar{q},P) = {} & (q-\bar{q})_\mu \left[\left(1 + \frac{\lambda_V P^2}{2m_W^2} \right) g_{\alpha\beta} - \lambda_V \frac{P_\alpha P_\beta}{m_W^2} \right] \\ & + (P_\alpha g_{\mu\beta} - P_\beta g_{\mu\alpha})(1 + \kappa_V + \lambda_V) \qquad (2.2) \\ & + if_{5V}\,\varepsilon_{\mu\alpha\beta\rho}(q-\bar{q})^\rho + if_{4V}(P_\alpha g_{\mu\beta} + P_\beta g_{\mu\alpha}) \\ & - f_{6V}\,\varepsilon_{\mu\alpha\beta\rho}P^\rho - \frac{f_{7V}}{m_W^2}(q-\bar{q})_\mu\,\varepsilon_{\alpha\beta\rho\sigma}P^\rho(q-\bar{q})^\sigma\end{aligned}$$

Here and in fig.3 g_{WWV}, κ_V, λ_V and f_{iV} (i = 4,...7,) can be considered free parameters, which in the standard model, however, have well prescribed values, namely they all vanish except for g_{WWV} and κ_V which are given by

$$g_{WWZ} = -e \cot\theta_W \quad , \quad \kappa_Z = 1$$
$$g_{WW\gamma} = -e \quad , \quad \kappa_\gamma = 1 \qquad (2.3)$$



$$= ig_{WWV}\Gamma^V_{\alpha\beta\mu}(q,\bar{q},P)$$

Fig.3 The general WWV vertex

The coupling constants κ and λ are related to the "magnetic" dipole moment $\mu_\gamma = e(1 + \kappa_\gamma + \lambda_\gamma)/2m_W$ and the "electric" quadrupole moment $Q_\gamma = e(\lambda_\gamma - \kappa_\gamma)/m_W^2$ of the W^+, while f_4, f_6 and f_7 are CP violating couplings. In composite models where the weak bosons are spin 1 bound states of some more fundamental fields [5], similar to the ρ in the case of QCD, all these anomalous couplings may differ considerably from their standard model values. From a phenomenological point of view the standard model expectation $\kappa = 1$ sets the scale for the deviations to look for: experiments should be sensitive to variations Δκ, Δλ and Δf_1 of O(1) or smaller.

Any deviation of the three boson vertices from their standard model form (2.3) will spoil the gauge theory cancellations between the three amplitudes of fig.1 and would ultimately lead to a violation of unitarity in the absence of form factor effects. While in the standard model the total W-pair cross section falls at large center of mass energies $\sqrt{s}$

$$\sigma_{GSW} \underset{s \gg m_W^2}{\approx} \frac{\pi\alpha^2}{2\sin^4\theta_W} \frac{1}{s} \ln \frac{s}{m_W^2} \tag{2.4}$$

the neutrino exchange graph alone for example (i.e. if $g_{WW\gamma} = 0 = g_{WWZ}$) produces a cross section which rises linearly with s

$$\sigma_{\nu\text{-exch.}} \underset{s \gg m_W^2}{\approx} \frac{\pi\alpha^2}{96\sin^4\theta_W} \frac{s}{m_W^4} \tag{2.5}$$

However, such a large deviation from the standard model as shown in fig.4 is very unlikely, in particular near threshold where LEP II will be operating. In addition deviations appearing in different regions of phase space tend to cancel each other, as is evident in fig.5 where the differential cross section $d\sigma(e^+e^- \to W^+W^-) / d\cos\theta$ is shown for $\kappa_Z = 0.5$, 1 (≡ standard model) and 1.5, all the other parameters in eq. (2.2) being set to their standard model values. (θ is the scattering angle of the W^- with respect to the e^--beam.

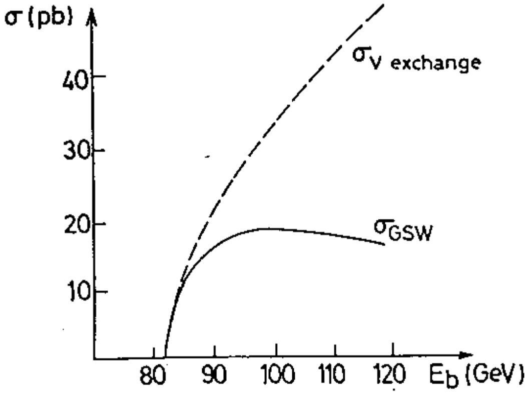


Fig.4 Total cross section for $e^+e^- \to W^+W^-$ in the standard model (GSW) and in the case of pure neutrino exchange.

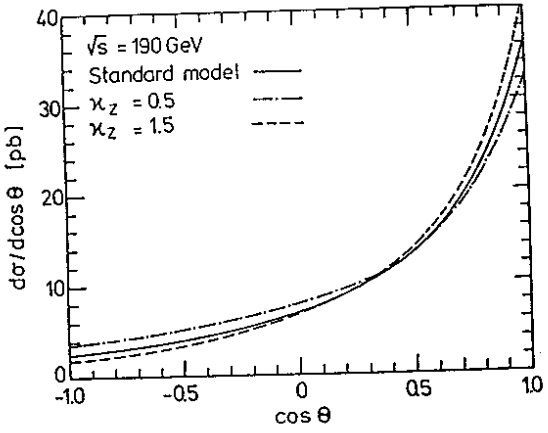


Fig.5 Angular distribution dσ/dcos θ at $\sqrt{s}$ = 190 GeV for the standard model (solid line), $\kappa_Z = 0.5$ (dash-dotted line) and $\kappa_Z = 1.5$ (dashed line). From Ref. [4]

The sensitivity of LEP II experiments can be appreciated by comparing the deviation from the standard model prediction, as expected for various anomalous couplings, with the statistical errors of the measurement. The error bars in fig.6 (and the following figures) represent the statistical errors in the analysis of 4000 W pair events, which corresponds to the expected number of "semileptonic" W-pairs after 1-2 years of running. For all the angular distributions discussed in this section, charge identification is required for at least one of the W^+ or W^- decay products, so it will be difficult to make use of the hadronic sample as well.

From fig.6 it is apparent that a deviation of κ or λ by 0.5 from their standard model value produces a very clear effect. A more thorough analysis shows [2,4] that deviations $\Delta\kappa_Z \approx 0.1$ or $\Delta\lambda_Z \approx 0.1$ will be at the limit of observability at LEP II.

In order to distinguish different variations of the three boson vertices from their standard model form, more exclusive distributions of the decay products of the W's have to be studied. Due to the V-A structure of the charged current interactions the decay distributions can serve as a complete spin analyzer for the W's. Denoting by h the W helicity, the down-type fermion in the

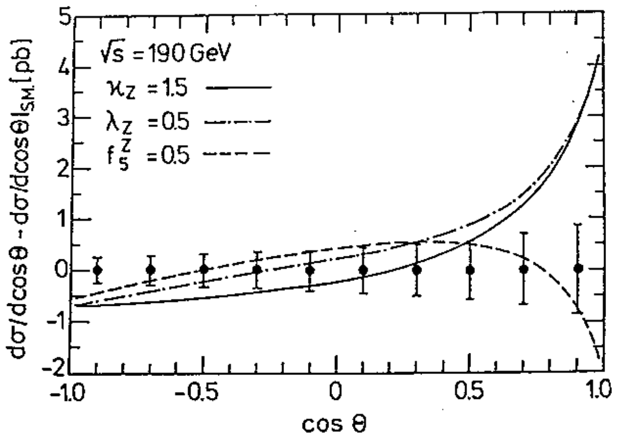


Fig.6 Deviation of $d\sigma/d\cos\theta$ from the standard model value for $\kappa_Z = 1.5$, $\lambda_Z = 0.5$ or $f_{5Z} = 0.5$. From Ref. [4]

decay of the W into two massless fermions will have the following polar angle distribution in the W rest frame:

$$\begin{array}{ll} \frac{1}{2}\,(1+\cos\theta)^2 & \text{for } h = - \\ \sin^2\theta & \text{for } h = 0 \\ \frac{1}{2}\,(1-\cos\theta)^2 & \text{for } h = + \end{array} \qquad (2.6)$$

Here θ is the polar angle with respect to the W direction. Using these polar angle distributions one can thus separate the cross sections for fixed W^+ and/ or W^- helicities. Unfortunately they are in general not particularly sensitive to variations of the three boson vertices [4].

A more sensitive measure of anomalous couplings is provided by azimuthal angle distributions of W decay products around the W^+W^- axis [4]. Measuring the azimuthal angles ϕ and $\bar\phi$ of the charged leptons l^+ and l^- in the semileptonic sample (with respect to the $e^+e^- \to W^+W^-$ scattering plane, around the W^- direction), allows sensitive tests for CP violating couplings (f_4 , f_6 and f_7 in eq. (2.2)) and / or additional strong interactions in the weak boson sector. The common feature of both kinds of deviations from the standard model is the appearance of sizable imaginary parts in the production amplitude for $e^+e^- \to W^+W^-$, which make themselves felt in sin ϕ and sin $\bar\phi$ distributions.

To be more precise consider the one-W-inclusive distributions

$$\frac{d^3\sigma(e^+e^- \to W^+W^-,\ W^- \to l^-\bar\nu_l)}{d\cos\Theta\ d\cos\theta\ d\phi} = F_1 + F_2\,\frac{\sqrt{5}}{2}\,(3\cos^2\theta - 1) + F_3\,\sqrt{3}\cos\theta$$
$$+ F_4\,\sqrt{3}\sin\theta\cos\phi + F_5\,\frac{\sqrt{15}}{2}\sin 2\theta\cos\phi + F_6\,\frac{\sqrt{15}}{2}\sin^2\theta\cos 2\phi$$
$$+ F_7\,\sqrt{3}\sin\theta\sin\phi + F_8\,\frac{\sqrt{15}}{2}\sin 2\theta\sin\phi + F_9\,\frac{\sqrt{15}}{2}\sin^2\theta\sin 2\phi \qquad (2.7)$$

and analogously for leptonic $W^+ \to l^+\nu_L$ decays (replace F_i, θ, ϕ by $\bar F_i$, $\bar\theta$, $\bar\phi$). Here the F_i's depend on the W scattering angle Θ only. It is easy to see that the distribution sin ϕ + sin $\bar\phi$ and, hence, its coefficient $F_7 + \bar F_7$ will be nonvanishing only in the presence of CP violation.

In fig.7 the size of the effect is compared with the standard model expectation (solid circles at zero with error bars corresponding to the statistical error of 2000 $W^- \to l^-\bar\nu$ and 2000 $W^+ \to l^+\nu$ events). The lines correspond to either f_{4Z} , f_{6Z} or f_{7Z} = 0.5.

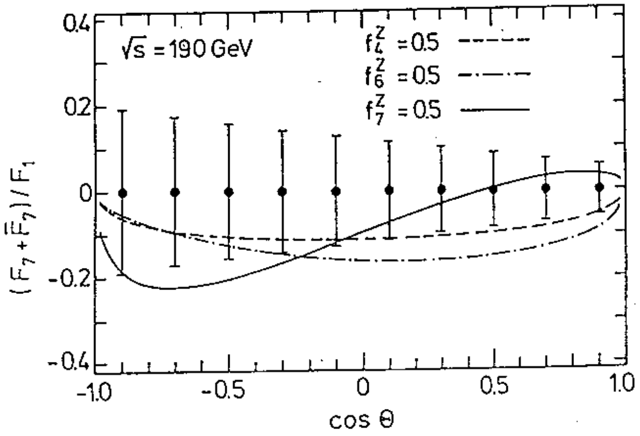


Fig.7 W polar angle dependence of $(F_7 + \bar F_7)/F_1$ in the presence of CP violating couplings. From Ref. [4]

On the other hand the difference of F_7 and $\bar F_7$, i.e. the distribution sin ϕ − sin $\bar\phi$ is sensitive to strong rescattering in the W sector. One way of approximating such effects is by allowing for imaginary parts in the anomalous couplings. The result of setting $\kappa_Z = 1 + 0.2i$ is shown in fig.8. It should be noted that $F_7 - \bar{F}_7$ will be approximately vanishing even in the presence of the CP violating couplings of fig.7. A nonzero result at LEP II will immediately prove the existence of strong interactions among the weak bosons beyond the standard model prediction.

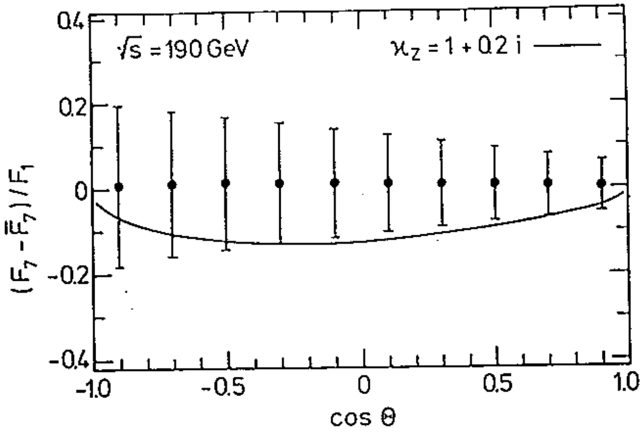


Fig.8 W polar angle dependence of $(F_7 - \bar{F}_7)/F_1$ in the presence of anomalous absorbtive parts. The slight deviation of the standard model (solid circles with error bars) from zero is due to the inclusion of the Z width in the Z propagator. From Ref. [4]

The angular distributions mentioned so far are but a few examples among the many different and independent ones that can be analyzed in $e^+e^- \to W^+W^- \to 4$ fermions at LEP II. It is the possibility of an (almost) full kinematical reconstruction of semileptonic and, to the extent that flavors can be identified, hadronic events that provides for a very large number of observables. These can then be used not only to discover deviations from the standard model but also to pinpoint their source, i.e. it will be possible to separate the various anomalous couplings in the WWZ and WWγ interactions to quite a large extent. This separation power can be even further improved by using polarized beams [4,6].

With an integrated luminosity of 500 pb^{-1} it should thus be possible to discover anomalous three vector boson couplings if they deviate form the standard model value by ~ 0.1 or more [4]. This actually implies a measurement of the W magnetic dipole moment at the 5% level. A separation of individual couplings in eq. (2.2) will only be possible with somewhat larger errors.

The possibility to perform a complete kinematical reconstruction is a major advantage of e^+e^- over hadron colliders (like the SSC) where, due to severe background problems, very likely only

the double leptonic decays of W pairs into electrons or muons can be used to analyze W properties. This in turn implies a rather limited number of independent observables which should make it difficult to identify the source of possible anomalies, once they are discovered.

II.2 W-MASS DETERMINATION

With an expected number of 10^4 W-pairs per year and experiment, LEP II should be able to determine the W-mass precisely. The main motivation for this is to test electroweak radiative corrections, avoiding altogether a determination of $\sin^2\theta_W$.

Using the W/Z mass ratio for a definition of $\sin^2\theta_W \equiv 1 - m_W^2/m_Z^2$, the mass formula for the W can be cast into the form

$$m_W^2 = \frac{\pi\alpha}{\sqrt{2}\,G_\mu\,[1 - m_W^2/m_Z^2\,]} \cdot \frac{1}{1 - \Delta r} \qquad (2.8)$$

Here α is the QED fine structure constant and G_μ is the Fermi constant as determined in muon decay, which are both known with very high precision. All the radiative corrections are absorbed in Δr, the error on which is then given by

$$\delta\Delta r = \left[\,22\left(\frac{\delta m_W}{m_W}\right)^2 + 43\left(\frac{\delta m_Z}{m_Z}\right)^2\,\right]^{1/2} \qquad (2.9)$$

Since the Z mass will be known to better than ± 50 MeV from SLC/LEPI experiments, obtaining $\delta m_W \leq 100$ MeV will push the experimental error on Δr to

$$\delta\Delta r \leq 0.007 \qquad (2.10)$$

An error of this size is already in the interesting range as can be seen by comparing to the shift in Δr produced by varying the Higgs mass [2]

$$(\Delta r)_{\mathrm{Higgs}} = \frac{11\alpha}{48\pi\,\sin^2\theta_W}\ \ln\frac{m_H^2}{m_Z^2} = 0.0048\ \ln\frac{m_H}{m_Z} \qquad (2.11)$$

In the report by G. Barbiellini et al. [2] four separate ways of measuring the W-mass were investigated:

i) Measuring the threshold dependence of the cross section $e^+e^- \to W^+W^-$

ii) Measuring the end point of the electron spectrum in $W \to e\nu$ decays

iii) Measuring the jet-jet invariant mass in $W \to q\bar{q}$ decays

iv) Measuring the eν invariant mass in $W \to e\nu$ decays

They find that the methods i), iii) and iv) actually do have statistical and systematic errors in the 100 MeV range, while the results from method ii) appear to be slightly worse. Since a detailed discussion can be found in ref. [2], a few comments on the first and the third method should suffice here.

While the other methods can be used at a fixed beam energy, measuring the threshold dependence requires an energy scan and some distribution of running time over a range of beam energies. An attempt in this direction is shown in fig.9 where 100 pb^{-1} are distributed in the intervall 80 GeV $\leq E_b \leq$ 100 GeV. In fig.9 the finite width cross section is considerably lower than the zero width curve mainly because only those events $e^+e^- \to W^+W^- \to (f_1\bar{f}_2)(f_3\bar{f}_4)$ were retained, where both difermion systems have an invariant mass within 10 GeV of m_W.

The theoretical curve in fig.9 is obtained at tree level with only the W-width included as a radiative correction. Obviously a reliable measurement of m_W requires knowledge of the radiative corrections to the full process $e^+e^- \to W^+W^- \to$ 4 fermions, while up to now they only have been calculated for $e^+e^- \to W^+W^-$. In particular the finite W-width and initial state radiation have to be included carefully.

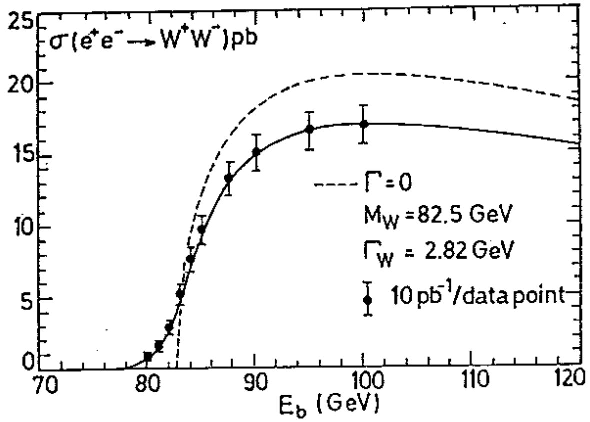


Fig.9 Statistical errors and running time distribution to obtain δm_W = 138 MeV from the threshold dependence. From Ref [2]

Measuring the dijet invariant mass in $W \to q\bar{q}$ does not appear to yield an accurate determination of m_W at first sight, because losses in the calorimeter induce large systematic errors. Indeed a Monte Carlo analysis by Roudeau [8] shows that without constraints an input value m_W^{in} = 83.2 GeV yields an output value m_W^{out} = 81.5 GeV (fig. 10a). The trick is to impose the constraint $E_{2j} = E_b$ on the dijet energy, i.e. to rescale the observed W-mass by E_b/E_{2j} for each event. The result is shown in fig. 10b where now the output value is m_W^{out} = 83.105 GeV. So also method iii) (and similarly method iv)) look very promising because they have small statictical errors and the systematic errors appear to be below 100 MeV. The effects of radiative corrections and the inclusion of a finite W-width are presently under investigation, but preliminary results show no large increase of systematic errors [9].

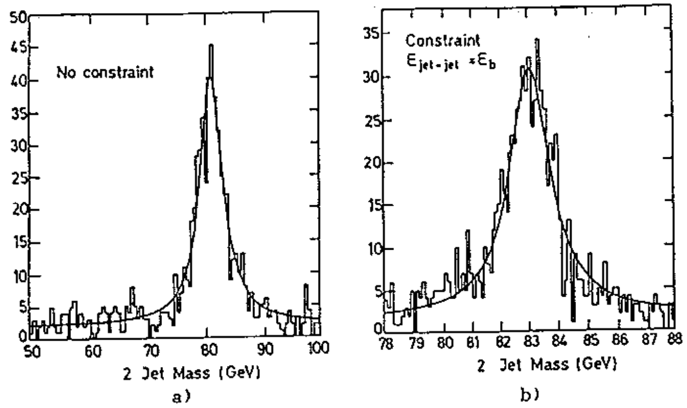


Fig.10 Observable dijet mass distribution arising from m_W = 83.2 GeV, Γ_W = 0. a) Without constraint, output is m_W = 81.5 GeV, Γ_W = 4.7 GeV b) With constraint $E_b = E_{2j}$, output is m_W = 83.105 GeV, Γ_W = 1.77 GeV. From Ref.[2]

An important feature of the four methods listed above is their independence. This means that the four results can be combined and thus a W-mass determination with an error $\delta m_W \approx$ 100 MeV may be expected at LEP II.

II.3 W-DECAYS

Within the standard model universality implies that the W has identical couplings to the three different generations of leptons. For the coupling to quarks universality has to be generalized to incorporate the unitary Kobayashi-Maskawa matrix V_{KM}.

By measuring the partial decay rates into different fermion-antifermion pairs, LEP II can check universality. For leptonic decays the standard model predicts

$$\Gamma(W \to l\nu_l) = \frac{G_\mu m_W^3}{6\pi\sqrt{2}} (1 + \delta_{l\nu}) \approx 240 \text{ MeV} \qquad (2.12)$$

where G_μ is the Fermi-constant as measured in muon decay and the radiative corrections give rise to a small shift $\delta_{l\nu} \approx 3.10^{-3}$.

For hadronic decays one has

$$\Gamma(W \to q\bar{q}') = 3(1 + \frac{\alpha_s}{\pi})F|V_{qq'}|^2\,\Gamma(W \to l\nu_l) \qquad (2.13)$$

where the factor in front of the Kobayashi-Maskawa matrix element accounts for three colors and QCD corrections. An additional phase space factor

$$F = (1 + \frac{m_t^2}{2m_W^2})\,(1 - \frac{m_t^2}{m_W^2})^2 \qquad (2.14)$$

is needed for decays involving the top quark. Eq.(2.12) implies that the branching ratio for $W \to q\bar{q}'$ directly measures the corresponding Kobayashi-Maskawa matrix element $V_{qq'}$.

Since at LEP II an integrated luminosity of 500 pb^{-1} will yield 20000 W-decays, even a detection efficiency of 50% only will allow to test universality at the percent level. In order to measure the elements of V_{KM} good flavor identification is needed. Prospects are particularly promising for the interesting case of the top quark but detailed work is still needed to get quantitative results.

III. HIGGS SEARCHES AT LEP

The most elusive particle predicted by the standard model is certainly the Higgs boson. Because of its small coupling to light fermions (proportional to their mass) it is difficult to produce. In addition the Higgs mass is a free parameter of the Glashow-Salam-Weinberg model, so one does not know the best place to search for it. At LEP there are at least 3 promising places to find the Higgs if it is light enough: in toponium decay, in Z decay or in ZH production.

Buchmüller et al. [10] have analyzed the prospects for finding the Higgs boson via the Wilczek mechanism $V_t \to H\gamma$ in toponium decay. Because of the large top mass the partial decay rate of this process is sizable

$$\frac{\Gamma(V_t \to H\gamma)}{\Gamma(V_t \to \mu^+\mu^-)} = \frac{1}{8\sin^2\theta_W}\,\frac{m_{V_t}^2}{m_W^2}\,\left(1 - \frac{m_H^2}{m_{V_t}^2}\right) \qquad (3.1)$$

and it also produces a very clear signal: a monochromatic photon. The following table shows the expected number of events for various toponium and Higgs masses, based on an integrated luminosity corresponding to 1000 hours of running on the toponium peak.

m_{V_t} (GeV)	$[\int Ldt]$ (pb^{-1})	m_H (GEV) 10	30	50	60	70	80	90
70	[32]	202	160	102	52			
90	[49]	107	95	75	60	43	22	
110	[65]	39	36	31	28	25	19	13

Possible photon backgrounds were carefully studied in ref.[10] and they were found to be particularly severe in two cases:

i) for $m_{V_t} \approx m_Z$ because then $V_t \to H\gamma$, $H \to b\bar{b}$ has to compete with the high rate of radiative Z decays: $Z \to q\bar{q}\gamma$

ii) for $m_H \approx m_Z$ (requiring $m_{V_t} > m_Z$) because $e^+e^- \to V_t \to H\gamma$ has to compete with $e^+e^- \to Z\gamma$

Otherwise the process $V_t \to H\gamma$ should be observable provided the available phase space does not become too small. The corresponding rate limit (taken to be 1 event is 10 days of running) in the Higgs mass-top mass plane is shown in fig.11. The Higgs should be observable at LEP I or II (depending on the toponium mass) for any combination of masses below this curve, except possibly for the two regions marked severe background (s.b.)

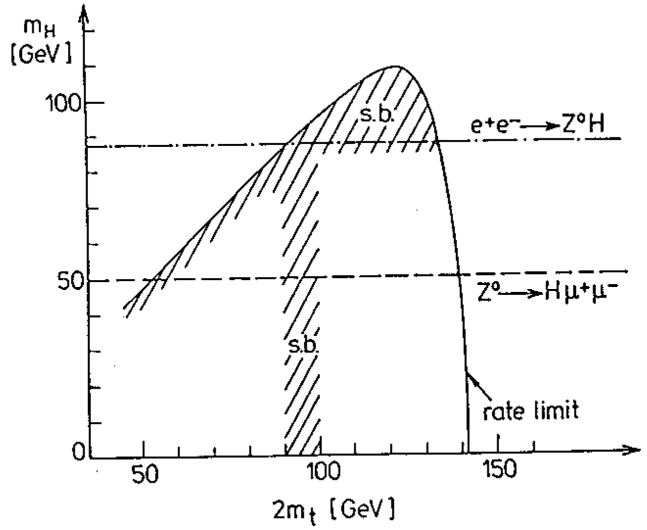


Fig.11 Largest values of the Higgs mass that will still allow detection in various reactions at LEP I and II: toponium → Hγ (solid line), $Z^0 \to H\mu^+\mu^-$ (dashed line) $e^+e^- \to Z^0H$ at $\sqrt{s}$ = 190 GeV (dash-dotted line). Adopted from Ref.[10].

The other two Higgs producing reactions mentioned before are both given by the Feynman diagram of fig.12. The difference is only the available center of mass energy and hence which one of the two Z^0 lines Z_1 or Z_2 is on mass shell. The first case, in particular $Z^0 \to H\mu^+\mu^-$, on top of the Z resonance, has been discussed by Baer et al. [11] from where the following table, giving the expected number of $Z^0 \to H\mu^+\mu^-$ events per 10^6 produced Z^0's, is reproduced

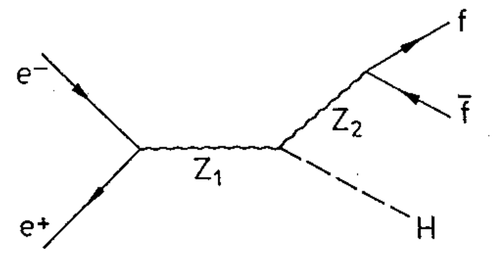


Fig.12 Feynman diagram for $Hf\bar{f}$ production.

m_H [GeV]	10	20	30	40	50
# events / $10^6\ Z^0$	66	26	11	4.2	1.5

When taking backgrounds into account, in particular $e^+e^- \to t\bar{t}$ followed by semileptonic top decays, one finds that a Higgs with mass $m_H \lesssim 50$ GeV should be detected at LEP I. A similar analysis for $Z^0 \to H\nu\bar{\nu}$ shows that, even though the rate for this process is six times larger, the larger background allows an observable signal for $m_H \lesssim 30$-40 GeV only [11].

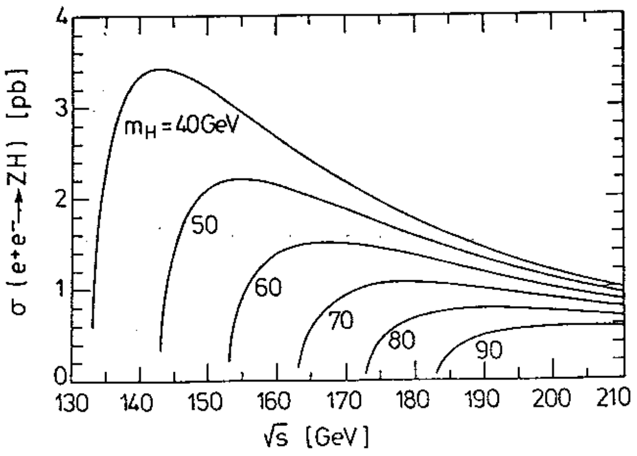


Fig.13 Cross section for $e^+e^- \to ZH$ as a function of the beam energy for various Higgs masses.

When instead of Z_1 the second Z is on its mass shell in fig.12, the resulting process is the most important source of Higgs bosons at LEP II: $e^+e^- \to ZH$. In fig.13 the cross section is shown for various Higgs masses.
At $\sqrt{s} = 190$ GeV $\sigma(e^+e^- \to ZH)$ is typically of order 1 pb. With an integrated luminosity of 500 pb^{-1} one thus expects

2x15 events $e^+e^- \to Z^0H$ $(Z^0 \to \mu^+\mu^-$ or $e^+e^-)$
90 events $e^+e^- \to Z^0H$ $(Z^0 \to \nu\bar{\nu})$

The background is low in both cases, predominantly being due to semileptonic decays of $b\bar{b}$ or $t\bar{t}$ pairs, which are produced with $\sigma(e^+e^- \to b\bar{b}, t\bar{t}) \approx 10$ pb at $\sqrt{s} = 190$ GeV. However, the leptons from heavy quark decays should be easily distinguishable due to their lower energy and lower dilepton invariant mass as compared to leptons arising from Z decays.

A problem arises when $m_H \approx m_Z$, because then ZZ events will produce an additional large background to ZH production. However, this will only be of concern if LEP II can reach a peak energy of $\sqrt{s} = 200$ GeV.

One thus finds that LEP will be able to observe the standard Higgs boson if its mass is not in excess of $m_H \approx 85$ GeV. In fig.11 the range of Higgs masses detectable at LEP is summarized.

IV. SIGNALS FOR OR BOUNDS ON COMPOSITENESS

So far I have assumed that the standard model is valid up to the largest LEP II energies. However, it is well possible that LEP II will reveal first signs for the compositeness of quarks and leptons. The most dramatic signal for this will of course be the crossing of new thresholds. Many new particles producible in e^+e^- collisions have been suggested in the literature, but the most promising candidate to be found at LEP II is probably the e*, an excited state of the electron.

If the e* is light enough $(m_{e^*} < E_b)$ it can be produced pairwise with the well-known pair-production cross section for charged fermions. For $E_b < m_{e^*} < 2E_b$ only single production is possible, which is expected to proceed via a magnetic coupling of the excited electron doublet $L^* = \begin{pmatrix} \nu^* \\ e^* \end{pmatrix}$ to the well known electron doublet $e_L = \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L$. This coupling is conventionally parametrized [12] via the effective Lagrangian

$$L = \frac{gf}{\Lambda} \bar{L}^* \sigma^{\mu\nu} \frac{\vec{\tau}}{2} e_L \partial_\mu \vec{W}_\nu + \frac{g'f'}{\Lambda} \bar{L}^* \sigma^{\mu\nu} \left(-\frac{1}{2}\right) e_L \partial_\mu B_\nu \qquad (4.1)$$

Here $\vec{W}_\nu$ and B_ν are the gauge fields of the GSW model with corresponding couplings g and g', Λ is the scale of compositeness (Λ = 1 TeV is a possible guess) and f and f' are free parameters, expected to be of O(1).

Single e^* production then proceeds via the Feynman graphs of fig.14.

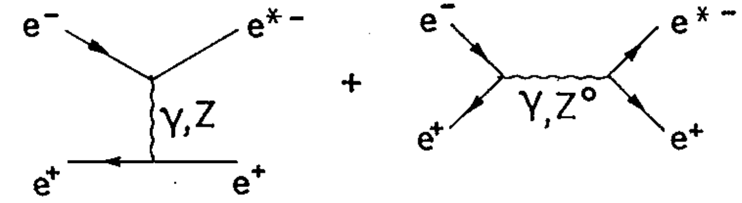


Fig.14 Feynman graphs for single e^* production.

It is the enhancement due to t-channel photon exchange in the first graph which produces a large cross section compared to e.g. single μ^* production [13] (see fig.15). In order to use this t-channel enhancement one has to allow the spectator positron to remain inside the beam pipe. Searching for $e\gamma$ events with $m_{e\gamma} = m_{e^*}$, one can thus detect excited electrons up to the kinematic limit.

Unfortunately, in particular if the compositeness scale Λ is larger than 1 TeV, it does not appear very likely that LEP II will be able to directly produce any of the excited states, which, after all, are expected to have masses of order Λ. A more promising endeavor seems to be the search for deviations from standard model cross sections induced by the extra interactions at the scale Λ. The measurement of the three gauge vertex described in section II.1 may be considered one example. Another very promising method is the search for four fermion contact interactions, in particular in Bhabha scattering and in $e^+e^- \to \mu^+\mu^-$.

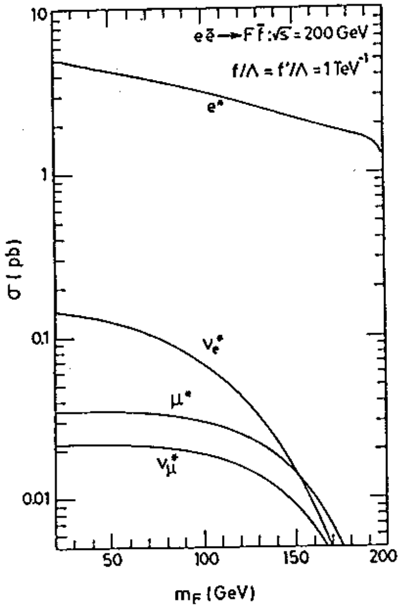


Fig.15 Single production of excited leptons at $\sqrt{s}$ = 200 GeV. From Ref.[13].

These new interactions may be considered as being induced by the exchange of some strongly coupling vector bosons with masses of order Λ, similar to ρ,ω or A_1 exchange in QCD. A convenient way of parametrizing these effects was given by Eichten, Lane and Peskin [14] who

have written down a standard form for the effective Lagrangian involving operators only which do not cause helicity flip (helicity flip operators should be suppressed by additional powers of m_e/Λ and thus are negligible)

$$L_{eff} = \frac{g^2}{2\Lambda_e^2} \sum_{i,j=L,R} \eta_{ij}\, \bar{e}_i \gamma^\nu e_i\, \bar{e}_j \gamma_\nu e_j + \frac{g^2}{\Lambda_\mu^2} \sum_{i,j=L,R} \eta_{ij}\, \bar{e}_i \gamma^\nu e_i\, \bar{\mu}_j \gamma_\nu \mu_j \qquad (4.2)$$

Since the composite vector bosons are presumed to have strong interactions, the conventional choice for the coupling constant is $g^2/4\pi = 1$ and the η_{ij} may be chosen as 0 or ±1, depending on the chirality structure one wants to investigate.

Present bounds on Λ from PEP/PETRA range from 1 to 3 TeV [15] depending on the chirality structure of the contact terms. Due to its larger center of mass energy LEP II can considerably improve these bounds by carefully studying angular distributions in $e^+e^- \to e^+e^-$ and $e^+e^- \to \mu^+\mu^-$. The size of possible signals can be seen in fig.16 where the ratio of the differential cross section including contact terms to the standard model one is shown.

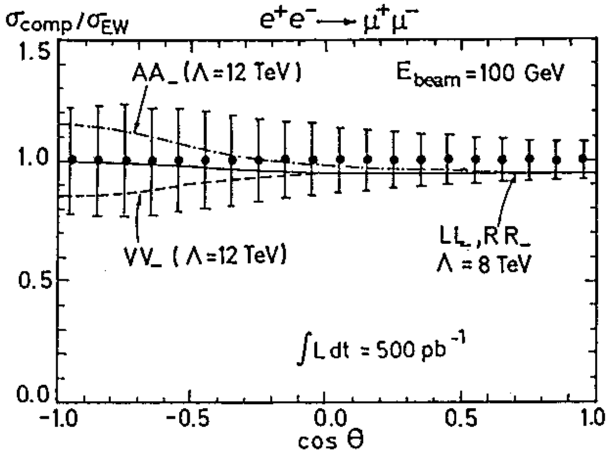


Fig.16 ratio of differential cross sections $d\sigma_{composite}$ / dcosθ and $d\sigma_{electroweak}$ /dcosθ for various contact terms in $e^+e^- \to \mu^+\mu^-$. AA stands for contact interactions of two axial currents in eq.(4.2), etc. From Ref.[2]

The bounds obtainable for the compositeness scale Λ largely depend on the statistical error with which the cross sections can be determined. In figures 17 and 18 the integrated liminosities needed at $\sqrt{s}$ = 200 GeV are plotted as a function of the Λ bounds achievable for Bhabha scattering and $e^+e^- \to \mu^+\mu^-$. Again a strong dependence on the chirality structure is observed. The minus index on e.g. LL_- denotes the sign of $\eta_{LL} = -1$ in eq.(4.2). No qualitative difference is found for positive interference with the standard model.

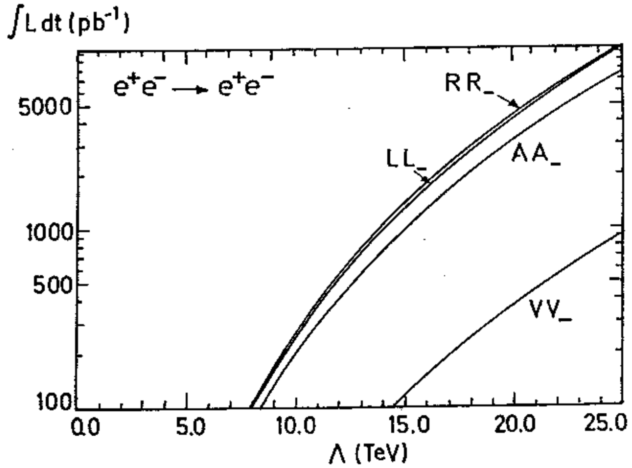


Fig.17 Limits expected on Λ_e for different chirality configurations of contact terms at $\sqrt{s}$ = 200 GeV. From Ref. [2]

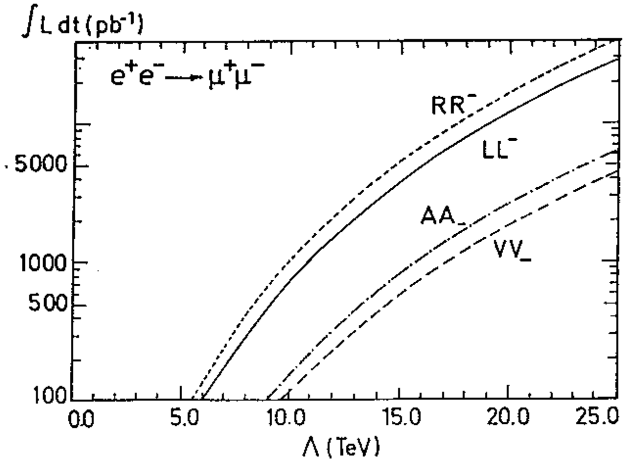


Fig.18 Limits expected on Λ_μ for different chirality configurations of contact terms at $\sqrt{s}$ = 200 GeV. From Ref. [2]

One thus finds that LEP II should be able to reveal possible substructure of leptons up to Λ = 10-20 TeV. If no signal for substructure is found at LEP II, these large limits imply that the SSC will most likely not be able to cross the compositeness threshold either: it will have to look for small deviations from standard model cross sections due to contact terms also: Two possibilities to circumvent this result should be kept in mind, however:

i) quarks and leptons may have different substructure scales

or

ii) it may be that the coupling g^2 in eq.(4.2) is much smaller than 4π for some unknown dynamical reason, allowing a correspondingly smaller compositeness scale Λ.

V. CONCLUSIONS

Experiments at LEP II will allow to perform a number of decisive tests of the electroweak interactions. For the first time a precise check (at the 10% level) of the structure of the non-abelian three gauge boson vertex will be possible, providing a crucial test of the gauge nature of electroweak interactions. In addition precision measurements of the W-mass and the verification of universal couplings of the W to fermions will further constrain possible deviations from the standard model.

One of the most dramatic confirmations of the Glashow-Salam-Weinberg electroweak theory would be the discovery of the standard Higgs boson at LEP II. If its mass $m_H \lesssim 85$ GeV prospects for finding it are very good.

Independent of whether or not LEP II just confirms standard model predictions, this will be valuable information for doing physics at the SSC: it will improve our understanding of standard model physics, in particular jet physics, heavy flavor decays etc., and it will seriously constrain the sources of possible anomalies to be observed at the SSC.

It should be kept in mind, however, that LEP II and multi TeV hadron colliders are to a large extent complementary machines due to the different initial states used. This can be appreciated for example in compositeness searches where LEP II is most sensitive to lepton compositeness (up to scales of order 10-20 TeV) while it is quark or joint quark-lepton compositeness which may be observed at the SSC if the scale is lower than 40-100 TeV [16]. Once more this stresses the need for high energy e^+e^- and hadron collider experiments to be performed at the same time.

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