DEUTSCHES ELEKTRONEN-SYNCHROTRON **DESY**

DESY 83-087
September 1983

RESULTS FROM CELLO ON ELECTROWEAK INTERACTIONS

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ISSN 0418-9833

NOTKESTRASSE 85 · 2 HAMBURG 52

DESY 83-087
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ISSN 0418-9833

RESULTS FROM CELLO ON ELECTROWEAK INTERACTIONS+)

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The CELLO collaboration working at the e^+e^- storage ring PETRA has performed several experiments on electroweak interactions. Results are presented on

- lepton pair production and
- search for new particles.

CELLO[1] is a large solid angle detector with a solenoidal spectrometer, electromagnetic calorimetry and muon identification. Fig. 1 shows the detector and Table 1 summarizes its major properties.

The data sample comprises 11 pb^{-1} at $\sqrt{s}$ = 34 GeV collected between Spring 1980 and Summer 1981.

I. Leptonic Reaction

Due to its high energy, PETRA offers the possibility to study the interference between electromagnetic and weak neutral currents[2].

+) Talk presented at the Europhysics Conference on Electroweak Effects at High Energies, Erice, February 1983. In this report only CELLO results will be discussed. A comparison of experiments can be found in A. Boehm's talk in the proceedings of the same conference.

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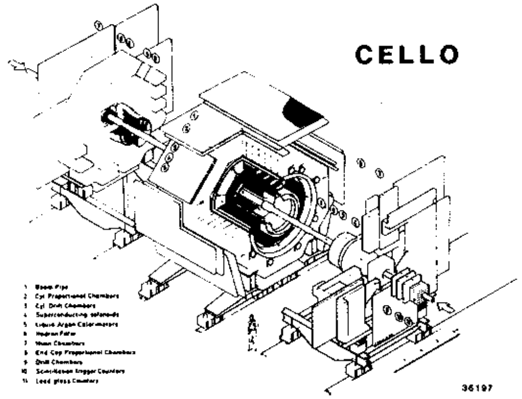


Fig. 1: The CELLO-Detector at PETRA

COLLABORATION	DESY, Hamburg KfK und Universität, Karlsruhe MPI, München LAL, Université de Paris XI, Orsay Université de Paris VI CEN, Saclay
MAGNET	1.3 Tesla superconducting thin ($0.49X_0$) solenoid 0.75 m inner bore radius 3.8 m length
TRACKING	5 cylindrical proportional chambers with cathode strips 7 cylindrical drift chambers 8 planar end-cap chambers 2 cylindrical layers of drift tubes (vertex detector installed end 1982) Tracking down to θ = 150 mrad $\sigma_p/p = 2\% \, p \sin\theta$ ($p > 2$ GeV, $\theta > 30°$) σ_z = 0.4 mm centroid measurement on cathode strips
EM CALORIMETRY	20 lead-liquid argon modules ($20X_0$) down to θ = 130 mrad 5 layers in depth for shower sampling $\sigma_E/E = 13\%/\sqrt{E}$ σ_θ = 4 mrad
MUON DETECTION	32 planar proportional chambers (covering 92% of 4π) $\sigma_{position}$ = 6 mm $p_{cut-off}$ = 1.4 GeV
FORWARD DETECTORS	Pb-glass blocks + scintillators 50 θ < 100 mrad
TRIGGERS	Charged-track trigger in $r\phi$ (p_T > 200 MeV) and rz projections Calorimetric triggers

Table 1: CELLO-Detector Properties

The experiments mainly concentrate on purely leptonic reactions, since they have clean experimental signatures and the theoretical predictions are unambiguous.

Taking into account the annihilation through γ and Z^0, the differential cross section for lepton pair production is

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4s} \left| R\cdot(1 + \cos^2\theta) + A \cos\theta \right| \quad (1)$$

$$R = 1 + 2\, v_e v_1\, \chi + (v_e^{\,2} + a_e^{\,2})\,(v_1^{\,2} + a_1^{\,2})\, \chi^2$$

$$A = 4\, a_e a_1\, \chi + 8\, v_e v_1 a_e a_1\, \chi^2$$

$$\chi = \frac{G_F}{8\pi\alpha\sqrt{2}} \; \frac{s}{s/M_{z^0}^{\,2} - 1} \; ; \quad G_F\text{: Fermi Constant; } M_{z^0}\text{: } Z^0 \text{ mass} \quad \theta\text{: angle to the beam axis}$$

where v_e and a_e (v_1, a_1) are the vector and axial vector coupling constants of the incoming electron (produced lepton). In the standard model $v = (4 \sin^2\theta_W - 1)$ and $a = -1$. Universality requires $v_e = v_1$ and $a_e = a_1$. In the PETRA energy range, the pure weak term is small compared to the interference term. Therefore, in our measurements, the total cross section is sensitive to the vector couplings while the forward-backward charge asymmetry is sensitive to the axial vector couplings. Extrapolating v, a and $\sin^2\theta_W$ from the low q^2 data, one expects, in lepton pair production, a measurable charge asymmetry of $\sim -10\%$ and practically no effect in the total cross section. In Bhabha scattering[3], the situation is complicated by additional t-channel diagrams. On the other hand, only the electron couplings v_e and a_e are involved.

I.1 Bhabha Scattering

Bhabha scattering has the clean signature of collinear, high momentum charged particle tracks pointing to electromagnetic showers in the calorimeter and no hit in the muon chambers. In the CELLO detector, the process is measured from $\theta = 30^0$ to 150^0 with the magnetic spectrometer and the central calorimeter[4]. The basic cuts

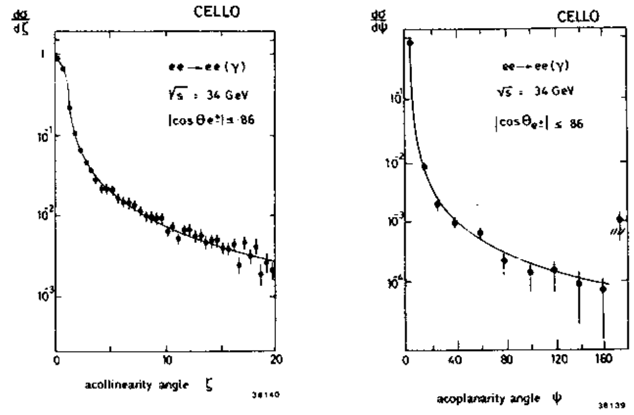


Fig. 2: The acollinearity and acoplanarity distribution for Bhabha scattering. The solid line is the QED prediction.

are requirements for vertex constrained charged particles, shower energy greater than $1/3\,\sqrt{s}$ and acollinearity less than 250 mrad. A unique charge determination is possible in more than 99% of the events. Inefficiencies are determined by relaxing the charged particle or the shower criteria; the experimentally determined losses are well below 1%. Monte Carlo techniques are used only for radiative corrections. Since background and losses are negligible, a systematic point to point error of 1% is achieved. The radiative corrections[5] are checked by the acollinearity and acoplanarity angle distributions. Fig. 2 shows the agreement of our measurement with the prediction of the order α^3 QED Monte Carlo calculation.

In Fig. 3, the measured differential cross section is compared with the QED expectation. Within the mainly statistical errors there is no deviation. The modification caused by an electroweak interference term is indicated. The data mainly constrain the vector coupling $v^2 = v_e \cdot v_e$ and are, therefore, sensitive to $\sin^2\theta_W$.

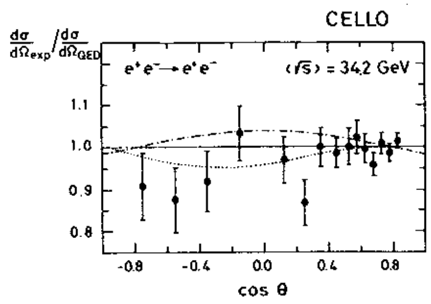


Fig. 3: The differential cross section for Bhabha scattering normalized to the QED prediction. The dotted line represents the best fit; the dotted-dashed line corresponds to the vector-dominated solution in neutrino electron scattering.

I.2 Muon- and Tau-Pair Production

Muon-pair production[6] also gives collinear high momentum particles in the magnetic spectrometer. It is distinguished from Bhabha scattering by requiring the energy deposition of minimum ionizing particles in the calorimeter and at least one track with an associated hit in the muon chambers. Due to the insufficient timing information, a background of cosmic-ray particles remains in the final data sample. For studying the total cross section and angular asymmetry in μ-pair production, the cosmic background is subtracted statistically using the information of the vertex distribution along the beam axis. After applying all corrections, including radiative effects, we determine an asymmetry, extrapolated over the full azimuth angle, of -6.4% ± 6.4%. The expectation of the standard model is -9.2%.

τ-pairs at PETRA energies[7] have the distinctive signature of almost collinear, low mass, low multiplicity jets with missing energy and a small acoplanarity angle due to the unobserved neutrinos. Our selection is sensitive to all τ-decay topologies. With the fine grained liquid argon lead calorimeter, the dominant two charged prong events are clearly distinguished from Bhabha scattering

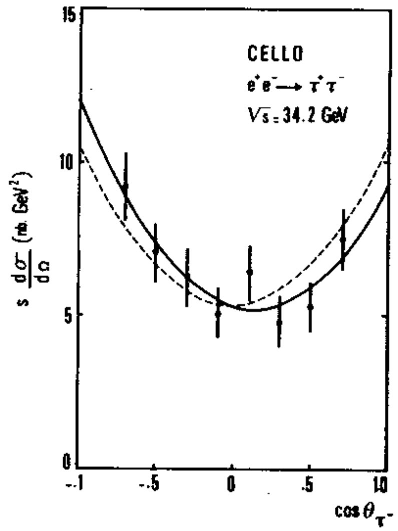


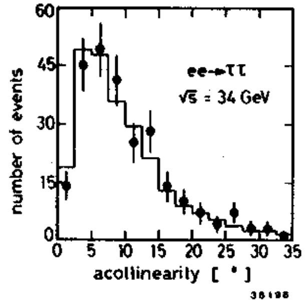
Fig. 4: The differential cross section for τ-pair production at $\sqrt{s}$ = 34.2 GeV. The solid line shows the best fit with an asymmetry of -10.3%. The dashed line is the QED expectation.

events. To eliminate confusion with two photon processes, we require a minimum momentum for the charged particles and exclude (e, e) and (μ, μ) final states. Altogether, 94% of the τ-decay combinations are used, so that a significant statistical accuracy is reached.

Fig. 4 shows the differential cross section obtained with 434 events. The angular distribution shows a clear $1 + \cos^2\theta$ dependence (seen for the first time, when published!) with a forward-backward charge asymmetry of -10.3% ± 5.2%. The total cross section is measured to be 1.03 ± .05 ± .07 in units of the pointlike cross section.

A maximum contamination of 8 multihadron annihilation events and 9 two photon scattering events is estimated. Event candidates are finally accepted only after a visual scan.

Fig. 5 compares the acollinearity and acoplanarity distributions with the Monte Carlo expectations based on V-A charged weak current decay and radiative corrections.



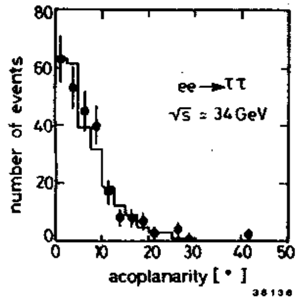


Fig. 5: The acollinearity and acoplanarity distribution for τ-pair production. The solid line is the α^3 QED and V-A charged current prediction.

The nearly complete and background-free event sample allows a precise branching ratio determination. The three charged prong decay branching ratio of 15 ± 2% has, since publication, been confirmed by other PETRA/PEP experiments (in contradiction with the old particle data book value of 28 ± 3%). Our measured τ branching ratios are given in Table 2. The ρ-signal, shown in Fig. 6, demonstrates how well we are able to identify individual decay modes[8].

Decay Mode	Branching Ratio
$\tau \to$ 1 charged prong	.840 ± .020
$\tau \to$ 3 charged prong	.150 ± .020
$\tau \to e\nu\nu$	.183 ± .024 (stat.) ± .019 (syst.)
$\tau \to \mu\nu\nu$	.176 ± .026 (stat.) ± .021 (syst.)
$\tau \to \pi\nu$	.099 ± .017 (stat.) ± .013 (syst.)
$\tau \to \rho\nu$	.228 ± .025 (stat.) ± .021 (syst.)

Table 2: τ-Branching Ratio

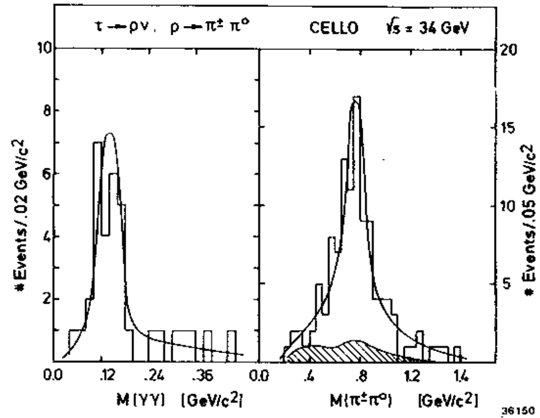


Fig. 6: Two photon invariant mass spectrum for ρ candidates with two separated showers, and the $\pi\pi^0$ invariant mass spectrum. The solid line is the MC expectation for ρ-production, the shaded area the background contribution.

I.3 Leptonic Coupling Constants

The essential non-zero weak neutral current effect, expected in the PETRA energy range, is the charge asymmetry in muon- and tau-pair production. Fig. 7 shows the measured weighted asymmetry for muon- and tau-pair production. The values for the asymmetry of -6.4% ± 6.4% for μ-pair production and -10.3% ± 5.2% for τ-pair production yield axial vector coupling values of a_μ = -.7 ± .7 and a_τ = -1.1 ± .6, in agreement with the standard model expectation a = -1. Since the experimental value of v_e is consistent with zero, the interference term in the total cross section yields no constraint to v_μ or v_τ.

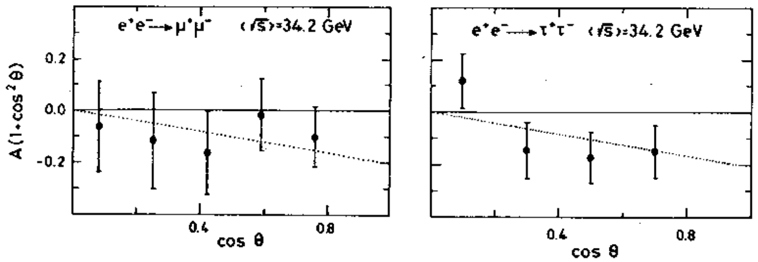


Fig. 7: The weighted asymmetry for lepton pair production. The dotted line represents the best fit for all lepton data.

Assuming lepton universality of the electroweak interaction, all the above described CELLO data are used in a simultaneous fit for v^2 and a^2 [4]. Fig. 8 shows the 95% C.L. contours obtained together with the two allowed regions from neutrino electron scattering. Our data favour the axial vector dominated solution of the neutrino data by more than four standard deviations; the central values are $a^2 = 1.22 \pm .47$ and $v^2 = -.12 \pm .33$. Fitting the single parameter $\sin^2\theta_W$ and taking into account the relation $M_Z = 37.2$ GeV$/\sin\theta_W \cos\theta_W$, we obtain $\sin^2\theta_W = .21 {+.14 \atop -.09}$.

With v^2 and a^2 as measured in neutrino electron scattering, we obtain a lower limit $M_Z > 57$ GeV (95% C.L.). The constraints on the vector coupling, v^2, yield limits for models with a different vector boson structure as the standard model (see talk by Schildknecht). Using the parametrization $v^2 = (4 \sin^2\theta_W - 1)^2 + 16$ C, our data give C < 0.031 (95% C.L.).

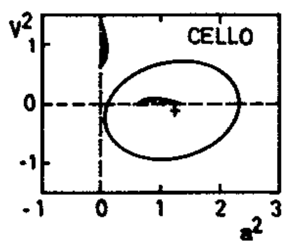


Fig. 8: The 95% C.L. contour for the coupling constants a^2 and v^2. The shaded areas are the neutrino-electron results.

I.4 Tau Final State Polarization

The charged current weak decays are a well-known polarization analyzer. Due to its short decay length, the τ particle offers an experimentally appealing possibility to observe helicity-dependent effects in e^+e^- reactions[9]. In the case of polarized τ's, the angular decay asymmetry in the rest frame leads to a distortion of the laboratory momentum spectra of the decay particles. This is easy to see in the simplest two body decay into πν, which actually yields the biggest effect.

At PETRA energies, the τ-polarization is expressed as

$$P_\tau\ (\cos\theta) = 2\ \chi\ (v_e a_\tau + 2\ v_\tau a_e\ \cos\theta/(1 + \cos^2\theta)) \qquad (2)$$

In contrast to the angular asymmetry and the total cross section measurements discussed above, here, a product of the vector and axial vector couplings is measurable, a characteristic feature for a parity violating process.

In CELLO, we made a first attempt to measure the τ-polarization by analyzing the decays into ρ, π, μ and e[8]. The results are shown in Fig. 9. The four laboratory momentum distributions are compared

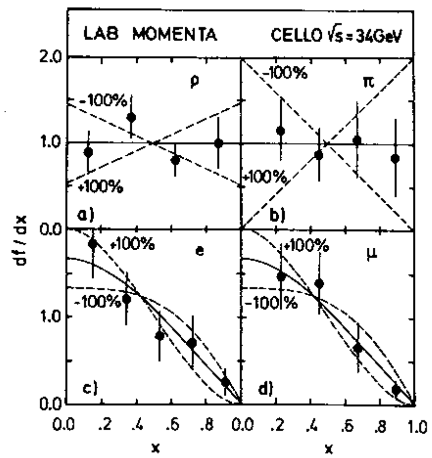


Fig. 9: The background subtracted laboratory momentum spectra for inclusive final states in τ decays. The expectation for non-polarization; ± 100% polarization is indicated.

with the expectations for zero or full polarization. The errors are dominated by the statistical errors; nevertheless, the average polarization is measured with 22% accuracy. As seen from (2), the forward-backward polarization asymmetry is sensitive to the product $v_\tau a_e$. Our measurement yields $v_\tau = -0.1 \pm 2.8$.

II. Search for New Particles

The search for new particles is a promising way to find experimental signatures leading beyond the standard model. None of the searches so far has found positive evidence. Here, we discuss the methods applied and the constraints which can be derived from the negative CELLO results.

II.1 Search for Higgses

A neutral Higgs boson required by the minimal symmetry-breaking scheme of the standard model is not expected to be produced with a reasonable rate in the e^+e^- continuum. In contrast, pair production of charged Higgses ($H^\pm$) (or technipions), predicted in other models, should be observable. The production rate is $\sigma \sim 1/4\ \beta^3\ \sigma_{\mu\mu}$. In a search for $S^\pm \to \tau^\pm \nu_\tau$[10] sensitive to large scalar masses almost up to the beam energy, we looked for two charged particles with an

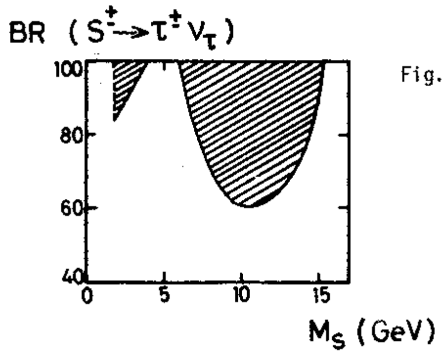


Fig. 10: Excluded domain of the mass versus branching ratio for the decay of a charged scalar into $\tau\nu$. 100% branching ratio corresponds to the case of scalar τ.

acoplanarity angle greater than 30°, a momentum imbalance greater than 2.5 GeV and no additional photon to compensate for the missing momentum. No event candidate is observed; Fig. 10 shows the limits obtained. Event candidates from a low mass $S^\pm$ should show up in the τ-pair event sample. The total cross section (the limit obtained is indicated in Fig. 10), acoplanarity angle distribution (Fig. 5), and the inclusive momentum distributions (Fig. 9) are sensitive quantities; they are all well described with the reaction $ee \to \tau\tau$.

II.2 Search for Conventional or Excited Leptons

New generations or excited states of leptons could give insights into the generation problem or a composite structure of leptons.

In a search for a conventional heavy lepton, we looked for an isolated muon candidate with a momentum greater than 4 GeV recoiling against hadrons. Five event candidates are observed, where standard quark pair production Monte Carlos predict 7.1 ± 3.3 events for a heavy lepton of 16 GeV mass. Our analysis yields a lower mass limit of 16.3 GeV with 95% C.L..

An excited heavy electron e^*[11] would modify the differential cross section for the QED reaction $ee \to \gamma\gamma$. Fig. 11 shows that our measurement is well described by the QED process[12]. From the indicated Λ^+-cut off parameter, we can set a lower mass limit of 59 GeV

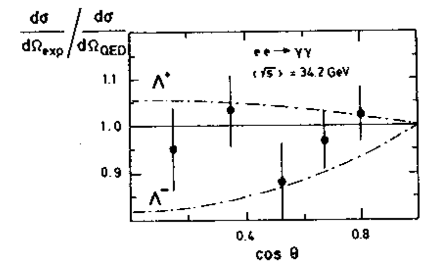


Fig. 11: The differential cross section for photon pair production normalized to the QED prediction. The indicated lines show the deviation expected from an excited electron.

for a heavy electron. Excited leptons can also be directly produced in the reaction ee → $l^* l^*$ or ee → $l^* l$. Since the l^* is expected to decay fast into $l\gamma$, l^* should show up in the lepton photon invariant mass combinations of the radiative lepton pair production event sample. The observed number of events in the reaction ee → eeγ (see Fig. 2) and ee → μμγ agrees with the QED expectation up to order α^3.

The cross section for the reaction ee → $\mu^*\mu$ is

$$\frac{d\sigma}{d\Omega} = \alpha^2\lambda^2 \frac{(s-M^2_{\mu^*})}{s^3} \mid s + M^2_{\mu^*} - (s - M^2_{\mu^*}) \cos^2\theta \mid \qquad (3)$$

where λ is a parameter characterizing the $\gamma\mu\mu^*$ coupling. The result quoted above for a heavy electron assumes λ = 1. Fig. 12 shows the result obtained from the reaction ee → $\mu^*\mu$ and ee → $\mu^*\mu^*$.

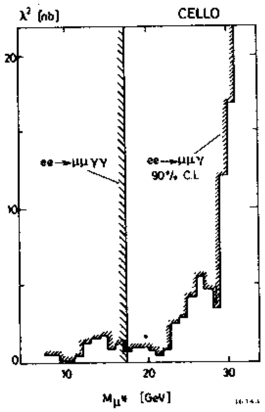


Fig. 12: The upper limits on the $\mu\mu^*\gamma$ coupling constant λ, derived from a comparison of μμγ events with α^3-QED Monte Carlo.

II.3 Search for Supersymmetric Particles

Supersymmetry relates particles with different spins; the known particles should have supersymmetric partners, which are distinguished from ordinary particles by half a unit in spin; e.g. scalar (spin 0) leptons, partners to the ordinary leptons and a spin 1/2

photino, partner to the photon. So far, no model with definite mass predictions exists.

Scalar leptons would be pair-produced in e^+e^- physics according to[13]

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2\beta^3\sin^2\theta}{8s} \left[1 + \left(1 - \frac{4k}{1-2\beta\cos\theta+\beta^2}\right)^2\right] \qquad (4)$$

where k = 0 for scalar muons (s_μ) and taus (s_τ), and k = 1 for scalar electrons (s_e).

The scalar leptons are expected to decay fast into the associated ordinary lepton and a low mass, non-interacting photino. Therefore, the experimental signature depends on the ratio of the scalar lepton mass to the beam energy. Low mass scalars should show up in the event samples for Bhabha scattering, muon- and tau-pair production. They are excluded by the cross section measurements, and the energy and momentum spectra.

High mass searches are more complicated due to the limited phase space available ($\sigma \sim \beta^3$). A clean signal is an acoplanar lepton pair with no additional photon to compensate for the missing momentum. No event candidate for a scalar electron, muon or tau is found[10], giving 95% C.L. lower mass limits of 16.8, 16.0, 15.3 GeV, respectively. Fig. 13 illustrates the result of the scalar muon search. The fall in the number of expected events is due, in the low mass region, to the applied acoplanarity cut (30°), in the high mass region to the phase space limitation.

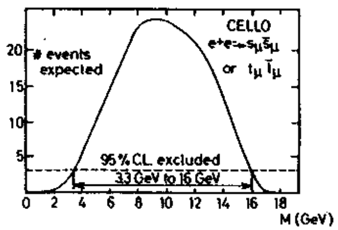


Fig. 13: The expected number of events as a function of scalar muon mass. No event candidate is observed. The corresponding mass limit is indicated.

Photinos (λ_γ) could be pair-produced by the exchange of a scalar electron. The cross section reads

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 s}{16} \frac{2\beta^3}{m^4_{s_e}} (1 + \cos^2\theta) \qquad (5)$$

The production rate is suppressed by the massive scalar electron propagator, and sizeable production rates, even for the pair production of light photinos, are expected only at high energies.

As mentioned before, the photino is expected to interact like a neutrino and, therefore, only indirect observation of photino pair production is possible.

If the photino is massive and unstable, it can be observed by its decay into a photon and a non-interacting gravitino. The lifetime of the photino depends on the symmetry-breaking parameter, d, and reads[14]

$$\tau_{\lambda_\gamma} = \frac{8\pi d^2}{m_{\lambda_\gamma}^5} \qquad (6)$$

We searched for two photons with missing energy in the calorimeter[12]. The limits obtained on the photino mass as a function of d are shown in Fig. 14. The upper limit for the photino mass is determined by the lifetime limit, the photino must have time to decay before leaving the calorimeter; the lower limit of 13 GeV is dominated by the available phase space ($\sigma \sim \beta^3$).

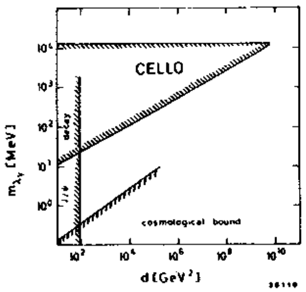


Fig. 14: Limits on the mass of a massive photino versus the scale parameter d. The result is obtained under the assumption m_{s_e} = 40 GeV.

Summary

We have analyzed Bhabha scattering, muon- and tau-pair production at $\sqrt{s}$ = 34 GeV. Our data can be described by the standard model using the value of $\sin^2\theta_W$ measured at low q^2, and are in agreement with universality.

An extensive search for new particles was negative. The methods applied and the limits achieved are presented.

Acknowledgement

It was an honour for me to present the work of so many people; thanks to all who contribute to the CELLO-experiment.

I wish to thank DESY for the kind hospitality and the continuous support during my stay in Hamburg.

I am grateful to the organizer of the Conference for the warm hospitality and the stimulating atmosphere at Erice.

References

|1| CELLO-Collaboration, H.-J. Behrend et al., Phys. Scripta, Vol. 23 (1981), 610

|2| G. Glashow, A. Salam, S. Weinberg Review of Modern Physics, Vol. 52/3 (1980)

For recent experimental tests see a review by M. Davier, Proceedings of the 21st Int. Conf. on High Energy Physics, Paris 1982

|3| R. Budny, Phys. Lett. 55B (1975), 227

|4| CELLO-Collaboration, H.-J. Behrend et al., Z. f. Physik C16 (1983), 301

|5| see talk of F.A. Berends this conference

|6| CELLO-Collaboration, H.-J. Behrend et al., Z. f. Physik C14 (1982), 283

|7| CELLO-Collaboration, H.-J. Behrend et al., Phys. Lett. 114B (1982), 282

|8| CELLO-Collaboration, H.-J. Behrend et al., Phys. Lett. 127B (1983), 270

|9| J.E. Augustin, Proceedings of the LEP Summer Study, CERN 79-01, 499

G. Goggi, ibid. p. 483

|10| CELLO-Collaboration, H.-J. Behrend et al., Phys. Lett. 114B (1982), 287

|11| A. Litke, Ph. D. thesis, Harvard University, 1970

|12| CELLO-Collaboration, H.-J. Behrend et al., Phys. Lett. 123B (1983), 127

|13| G.R. Farrar, P. Fayet Phys. Lett. 89B (1980), 191

|14| N. Cabbibo, G.R. Farrar and L. Miani, Phys. Lett. 105B (1981), 155