FIRST SEARCH FOR SEQUENTIAL HEAVY LEPTONS AT ADONE

in Honour
of
Martin PERL's 65th Birthday

by

A. Zichichi
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Abstract

On this occasion to honour Professor Martin Perl's 65th birthday, I present some of the important contributions of Martin to the field of strong interactions.

I also present my own interest in studying lepton pairs in hadron collisions and the development of instrumentation to distinguish leptons from hadrons. These studies eventually led to the development of the idea and experimentation at ADONE to search for sequential leptons.

Presented at the
*"**Symposium on the τ particle**" in honour of Martin Perl's 65th birthday*
24 July 1992, SLAC, Stanford, California-USA

1 - How I met Martin Perl

In order to realize the scientific value of the discovery by Martin Perl of the Heavy Lepton τ, let me try to reproduce the physics atmosphere of that time.

Topics of great interest were:

i) The shrinking of the Chew-Frautschi-Regge trajectories. Martin Perl discovered that this was not the case in (πp) interactions, contrary to the (pp) case measured by Sam Lindembaum. The results obtained by Martin Perl [1] are shown in Fig. 1.

ii) The ratio of longitudinal-to-transverse polarisation in ρ^0 electro-production. Here also, Martin Perl [2] contributed significantly, as shown in Fig. 2.

iii) The neutron-proton elastic scattering. In this field the best measurements were done by Martin Perl [3]. The results obtained are shown in Fig. 3.

It is through these papers that I scientifically met Martin Perl.

There was no concept on the existence of the new Heavy Lepton with its own leptonic number. The only Heavy Leptons considered worth some attention were of the type "excited" electrons (e*) or muons (μ*), whose decays were expected to be:

$$e^* \to e\,\gamma \qquad (1)$$
$$\mu^* \to \mu\,\gamma \qquad (2)$$

A main promoter of this search was F.E. Low [4] and many elastic (ep) and (μp) scattering experiments were motivated by this idea.

2 - The Roots of Heavy Lepton Searches

The Frascati proposal (1967) [5] to search for a new heavy lepton carrying its own leptonic number has its roots in my interest to study the leptonic final states produced in hadronic interactions:

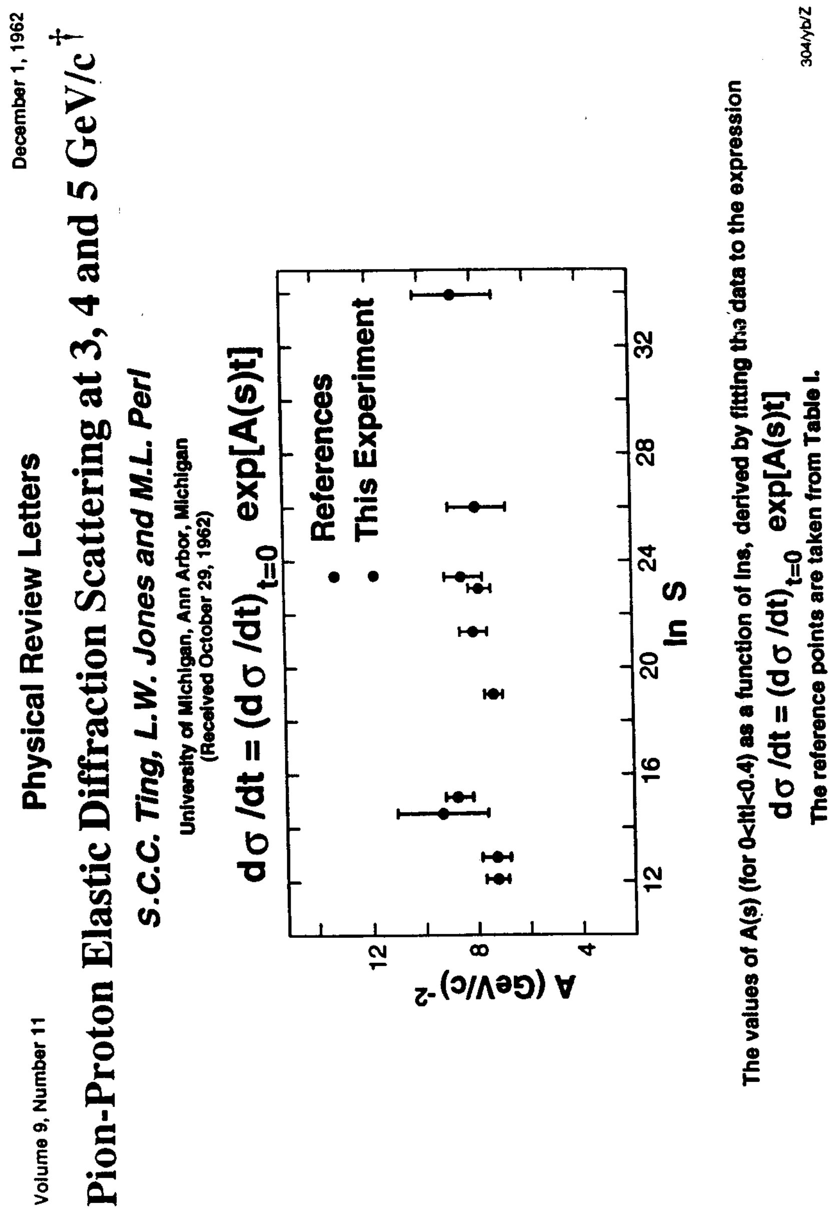

Fig. 1. The experimental proof of (πp)-no-shrinkage [1].

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Electroproduction of ρ and φ Mesons*

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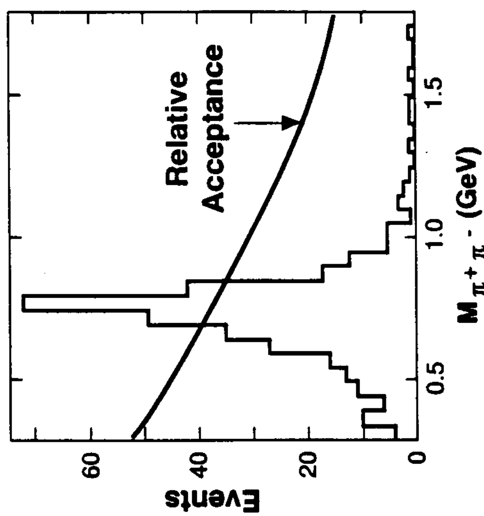
(Received 27 November 1972)



The Ratio of Longitudinally to Transversely polarized ρ^0 Mesons is $0.45^{+0.15}_{-0.10}$ at $|q^2| = m\rho^2$, and the interference between longitudinal and transverse amplitudes is almost maximal.

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Fig. 2. The proof of maximal interference between longitudinal and transverse amplitudes in ρ^0 electroproduction [2].

Volume 24, Number 1 PHYSICAL REVIEW LETTERS 5 January 1970

NEUTRON-PROTON ELASTIC SCATTERING FROM 8 TO 30 GeV/c *

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(Received 14 November 1969)

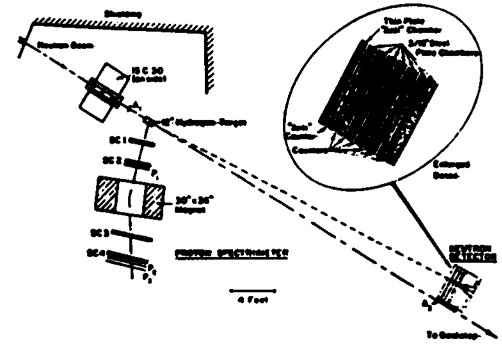

FIG. 1. Experimental arrangement.

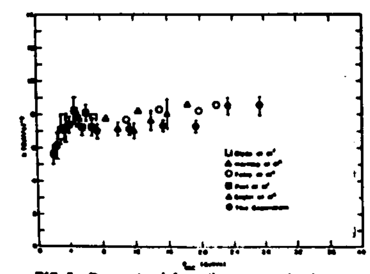

FIG. 3. Parameter b from the parametrization $e^{-b|t|}$ as a function of incident-particle momentum

$d\sigma/dt = f(t)\exp\{2[\alpha(t)-1]\ln s\}$.

for np,

$\alpha(t) = (1.08 \pm 0.06) - (0.86 \pm 0.18)|t|$;

for pp,

$\alpha(t) = (1.05 \pm 0.02) - (0.69 \pm 0.05)|t|$

(Ref. 4); for $\bar{p}p$,

$\alpha(t) = (0.90 \pm 0.08) + (0.91 \pm 0.38)|t|$

Fig. 3. The most accurate neutron-proton elastic scattering from 8 to 30 GeV/c [3].

$$\bar{p}p \rightarrow \begin{cases} e^+e^- \\ \mu^+\mu^- \end{cases} \tag{3}$$

$$\pi p \rightarrow \begin{Bmatrix} \rho \\ \omega \\ \phi \end{Bmatrix} \rightarrow e^+e^- + n. \tag{4}$$

Reaction (3) had as a goal to establish the existence of an electromagnetic structure of the proton in the time-like region.

Reaction (4) was intended to measure the leptonic decays of the three vector mesons. To compare the leptonic decays of ω and ϕ was especially interesting because the (ω -ϕ) mixing allowed to establish if the ϕ meson had some extra "flavour" coupled to the photon.

In order to study lepton pairs produced in hadronic processes, the key problem was to have a powerful rejection against π's. This requirement brought us in 1963 [6.a] to the so-called "preshower method" with the result that we could have a rejection power as good as

$$\frac{\pi}{e} \approx 10^{-3} \tag{5}$$

The results obtained in 1963 [6.a] are reported in Fig. 4 where the pulse-height spectra of electrons and pions are shown with a schematic drawing of the set-up used (top of Fig. 4). The overall efficiencies for π's and e's are shown in Fig. 5 [6.b] as function of beam momentum. The real set-up used to obtain these results is shown in Fig. 6, while the detector to study lepton pairs (e^+e^-, $\mu^+\mu^-$) produced as in reaction (3) is shown in Fig. 7. This detector is in fact the first calorimeter and the first large scale "Preshower" detector ever built. The detailed layout is shown in Fig. 8. The unique feature of this detector is that the overwhelming hadronic background could be rejected and the existence of a time-like structure for the proton be established [7] by measuring a cross section for reaction (3) which was at least 500 times smaller [8] than expected for the point-like case:

$$\frac{\sigma\left(\bar{p}p \rightarrow \begin{cases} e^+e^- \\ \mu^+\mu^- \end{cases}\right)^{\text{time-like structure}}}{\sigma\left(\bar{p}p \rightarrow \begin{cases} e^+e^- \\ \mu^+\mu^- \end{cases}\right)^{\text{point-like}}} \leq \frac{1}{500} \tag{6}$$

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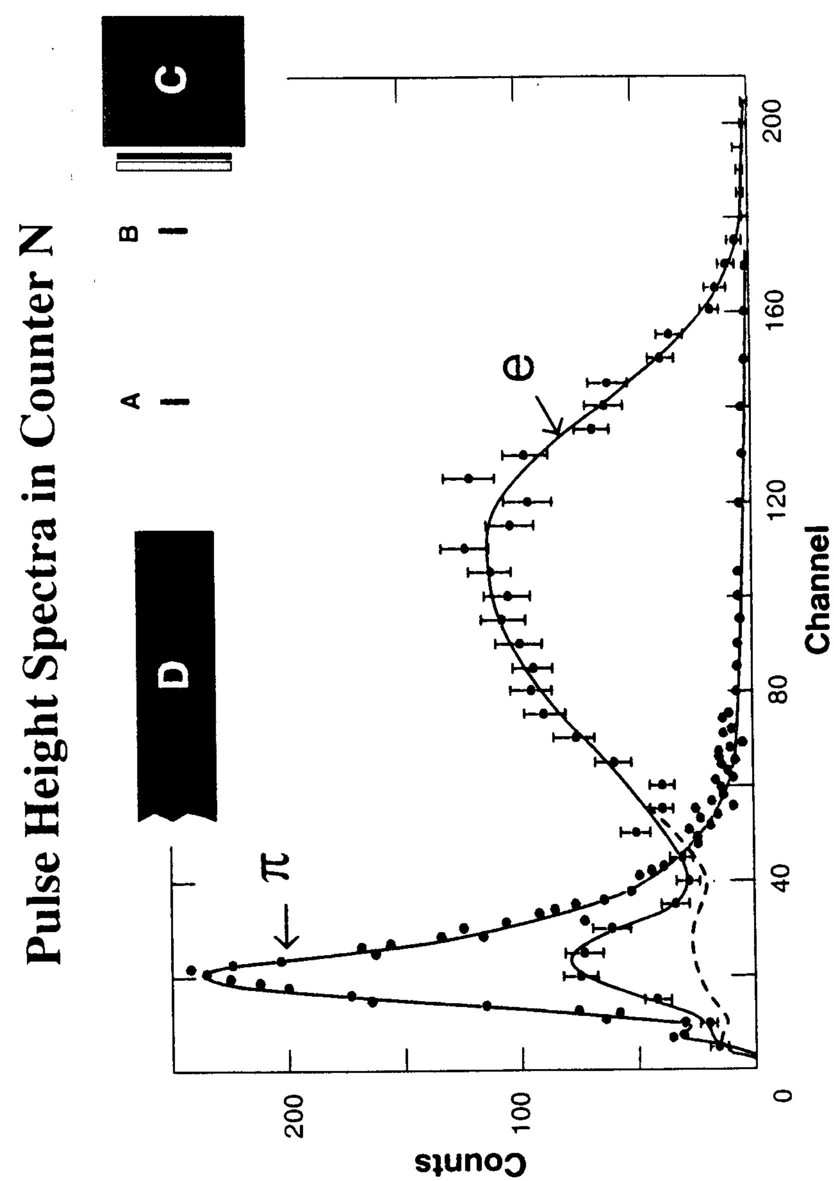


Fig. 4. The first result of the "preshower" method [6.a].

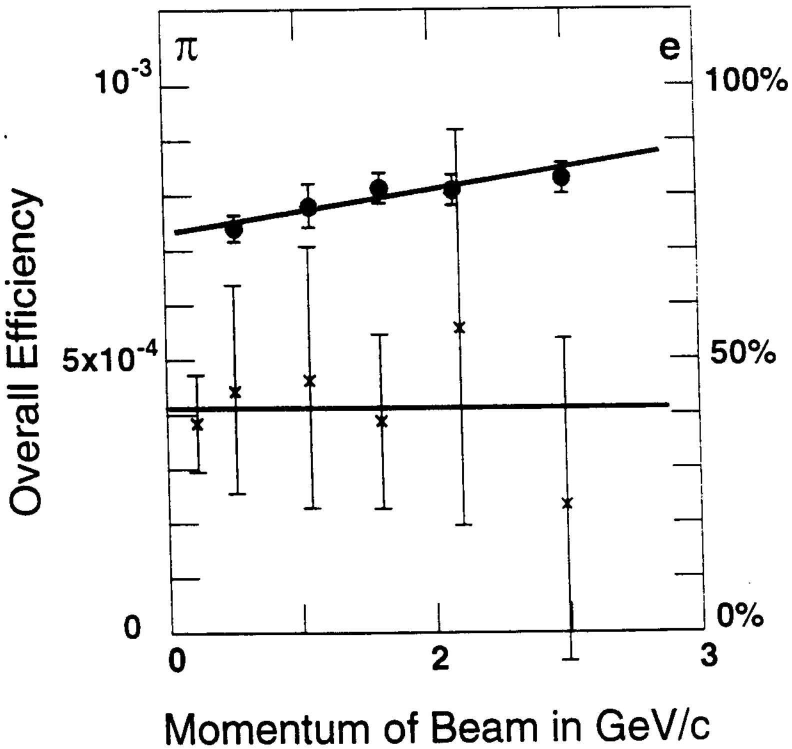


Fig. 5. Electron and pion "efficiencies" versus particle momenta. Note that the "π" efficiency is as low as 5×10^{-4} while the "e" efficiency is as high as 85% [6.b].

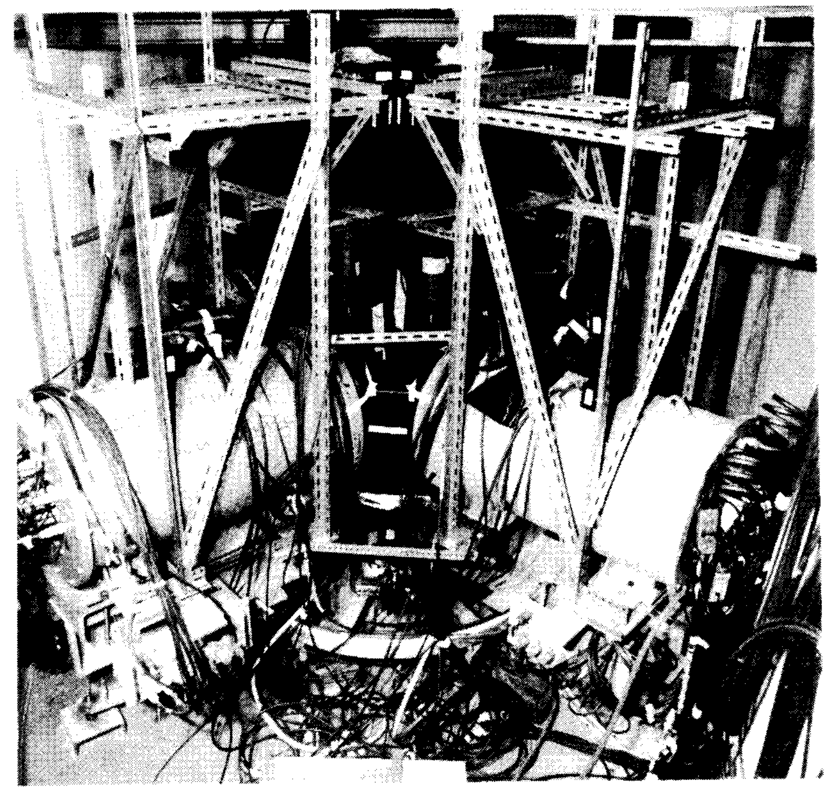


Fig. 6. The set-up used to obtain the results shown in Fig. 5.

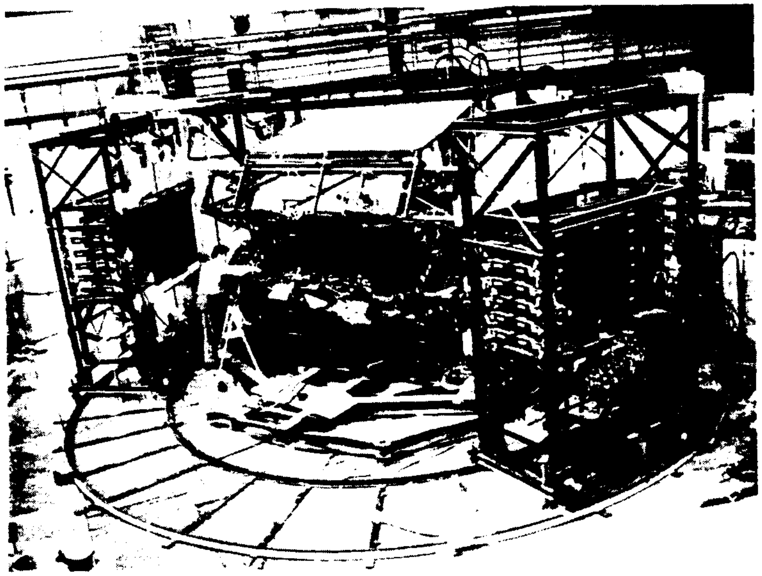


Fig. 7. The set-up used for the study of reactions (3) in the text: $\bar{p}p \to e^+e^-, \mu^+\mu^-$.

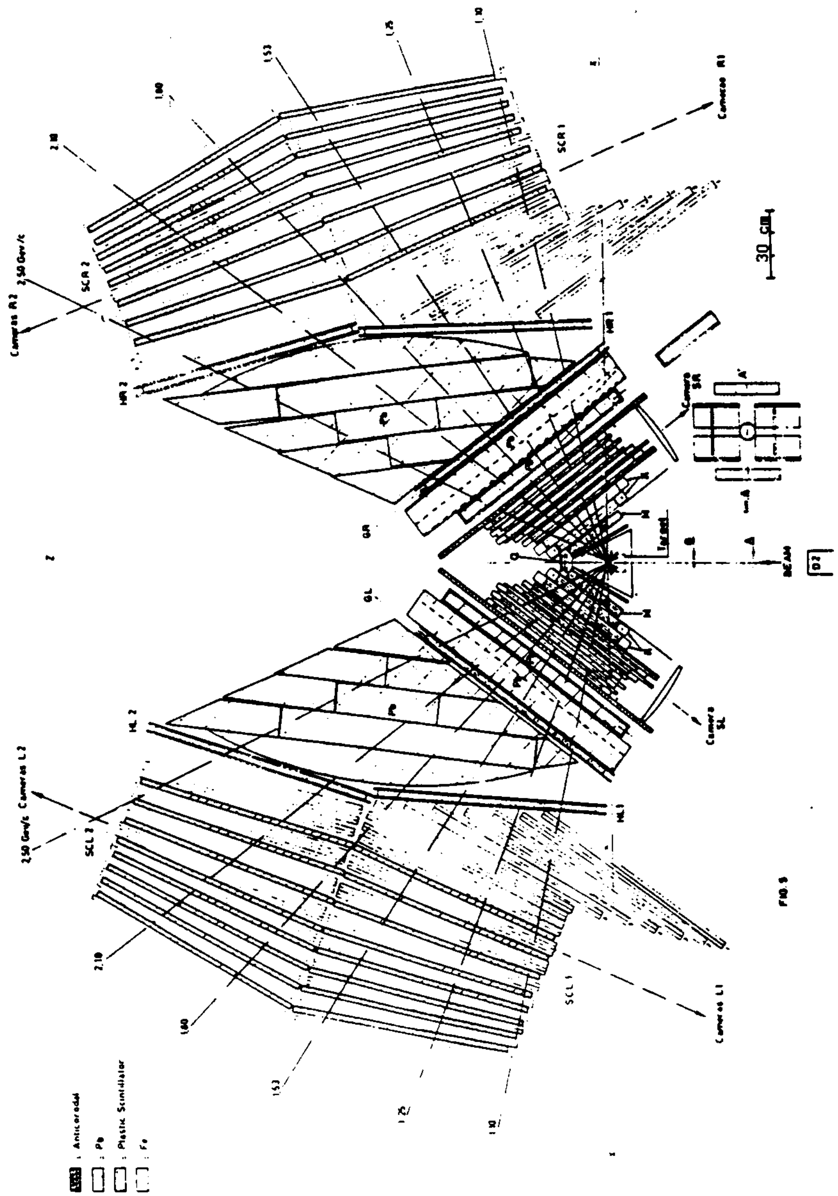


Fig. 8. The schematic diagram of the set-up illustrated in Fig. 7.

It is probably appropriate to report the status of the time-like structure in the EM form factor of the proton 27 years later (Fig. 9).

As mentioned above, the other source of interest for (e^+e^-) pairs produced in hadronic interactions was reaction (4). Here again the crucial point was to have a powerful rejection of π's and good efficiency for electron pair detection. The detector is shown in Fig. 10 and the most significant result, i.e., the [(ω -ϕ) mixing] [9], in Fig. 11. This mixing was based (for a review see [10]) on the observation of two rare decay modes of vector mesons:

$$\phi \rightarrow e^+e^- \tag{7}$$
$$\omega \rightarrow e^+e^- . \tag{8}$$

All this was implemented at CERN.

3 - From CERN to Frascati

In going to Frascati, my idea was to use the technology developed at CERN for high power rejection of hadrons and large solid angle detectors (see Sect. 2) to search for a new Heavy Lepton carrying its own lepton number. I realized that "e^+e^-" annihilation is a very good source of "time-like" photons and, contrary to the ($\bar{p}p$) case, a Heavy Lepton has no Form-Factor depression effects. Therefore the (e^+e^-) annihilation was a unique source for the production of a new lepton and a large solid angle detector would have allowed the unique signal

$$e^+e^- \rightarrow HL^+ HL^- \rightarrow (e\mu) + \text{missing} \tag{9}$$

to be observed. Such a reaction is not allowed by known processes and therefore the ($e\mu$) acoplanar method can be very clean. At that time I was very puzzled by why there are only two leptons (e, μ), each one with its own neutrino and its lepton number. I was also puzzled by the large number (~100) of hadrons compared to only two leptons. I soon realized that the search for more leptons should be carried out, immediately. In Fig. 12 the front page of the INFN proposal [5] is reproduced. However, I received much resistance and criticism. At that time the theoretical trend was: we

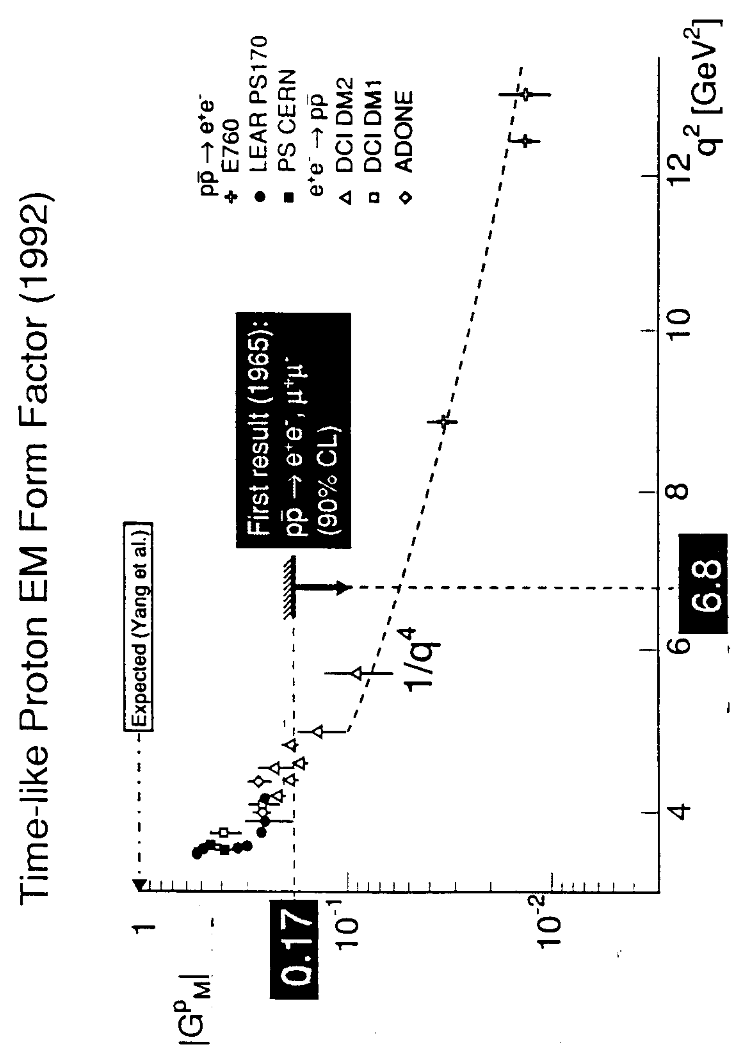


Fig. 9. The present status of the proton electromagnetic time-like form factor.

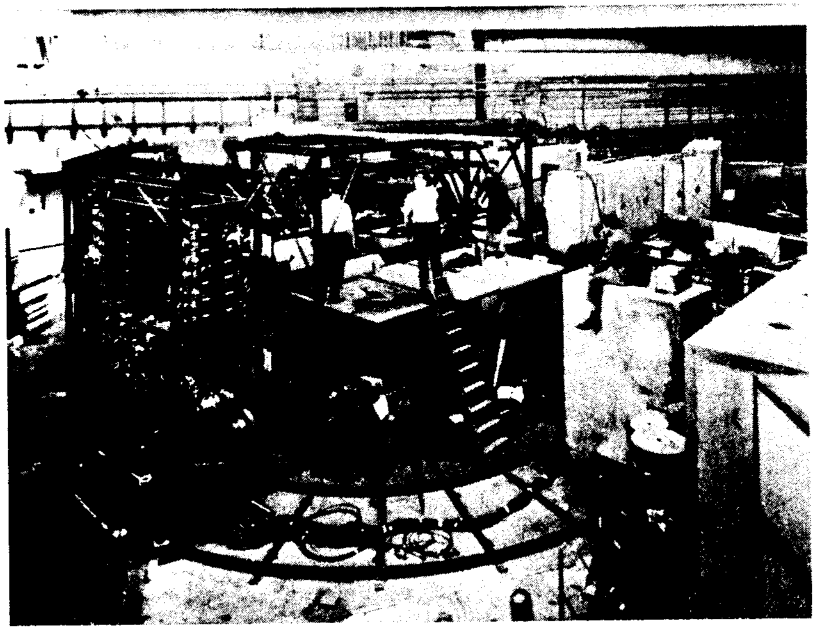


Fig. 10. The detector used to study reaction (4) in the text: $\pi^- p \rightarrow e^+e^- + n$.

$$\frac{1}{3} m_\rho \Gamma(\rho \rightarrow e^+e^-) = m_\omega \Gamma(\omega \rightarrow e^+e^-) + m_\varphi \Gamma(\varphi \rightarrow e^+e^-)$$

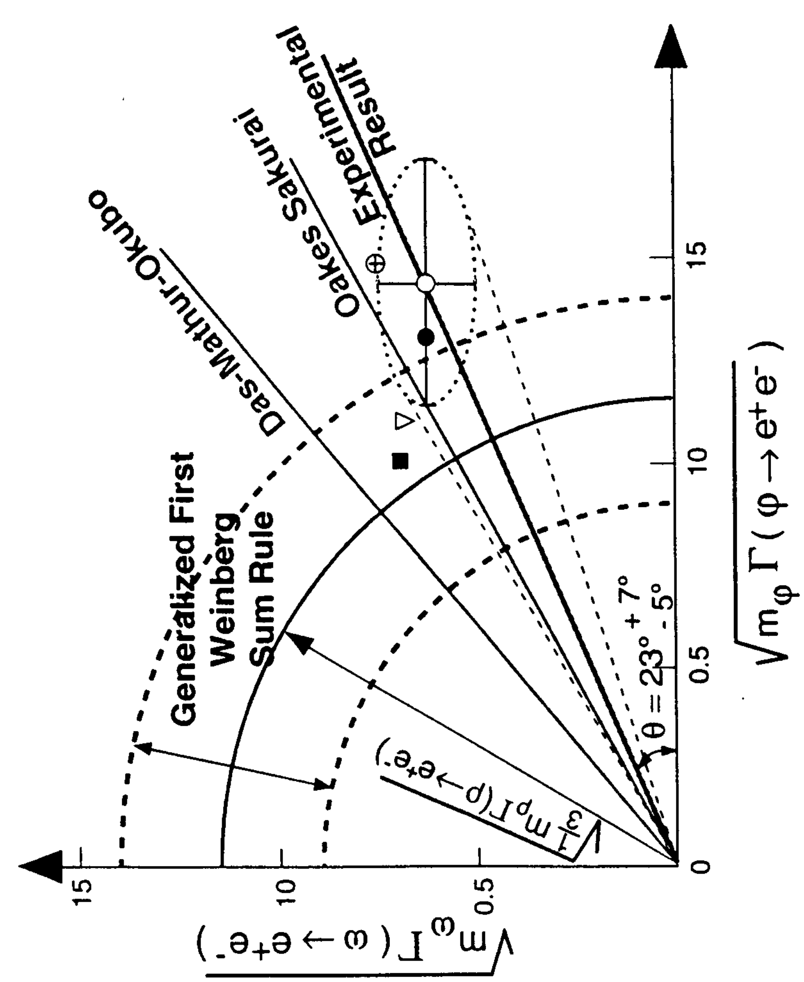


Fig. 11. The (ω–ϕ) mixing: the experimental result compared with the various theoretical expectations [10].

Comitato Nazionale per L'Energia Nucleare
ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Bologna
67/1

INFN/AE-67/3
20 Marzo 1967

M. Bernardini, D. Bollini, E. Fiorentino, F. Mainardi, T. Massam, L. Monari, F. Palmonari and A. Zichichi (Bologna-Cern-Frascati collaboration) : A PROPOSAL TO SEARCH FOR LEPTONIC QUARKS AND HEAVY LEPTONS PRODUCED BY ADONE. -

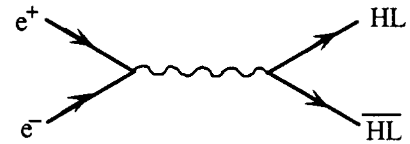
Reparto Tipografico
dei Laboratori Nazionali di Frascati

Fig. 12. The first page of the Heavy Lepton proposal at Frascati, dated 20 March 1967 [5].

have already too many leptons; why should nature be so stupid to have other leptons?

So to propose a search for [($e^{\pm}$, $\mu^{\mp}$) plus missing momenta] in order to look for another lepton was considered as strange as looking for "butterflies."

In the proposal the key feature was the (e, μ) acoplanar pair produced in (e^+e^-) annihilation (see Fig. 13a,b) and described by the Feynman diagram



(10)

with $(HL)^- \to \begin{array}{l} \to e^- + \bar{\nu}_e + \nu_{HL} \\ \to \mu^- + \bar{\nu}_\mu + \nu_{HL} \end{array}$, $(HL)^+ \to \begin{array}{l} \to e^+ + \nu_e + \bar{\nu}_{HL} \\ \to \mu^+ + \nu_\mu + \bar{\nu}_{HL} \end{array}$

yielding as final state

$$e^+e^- \to (e^{\mp}\,\mu^{\pm}) + \text{missing} \qquad (11)$$

and therefore an acoplanar ($e\mu$) pair.

A large solid-angle set-up, able to detect electrons and muons with the necessary rejection power against all sorts of background, was needed (see Fig. 14).

During the construction period and the implementation of the experiment (before the method was shown to work), the scientific community in Frascati was divided. The majority was very much against the experiment and everybody was saying that our ($e\mu$) acoplanar method was going to be swamped by background. The experiment was carried out very successfully. In 1970 we published the first result [11] (see Fig. 15). This showed that our ($e\mu$) acoplanar method was working and stimulated other searches at Frascati (such as Orito, et al. [12]), using exactly the same method.

But, in order to prove that the ($e\mu$) acoplanar events were genuine new physics, it was necessary to study standard QED expectations: i.e., acoplanar radiative corrections. In fact, before we measured the acoplanar radiative effects [13] everybody was using the so-called "peaking-approximation"

By studying the most favourable mechanisms which could produce the heavy leptons we reach the following conclusion. If in the process

$$e^+ e^- \rightarrow H_1^+ + H_1^-$$

we set at an energy E such that the ratio

$$\frac{E}{M_{H_1}} \simeq 1.2$$

as can be seen from Fig. 6 the cross-section is around 10^{-32} cm^2. Moreover, the two produced H_1^+ and H_1^- are non relativistic and very slow in the laboratory-system, their $\gamma = E/M$ is in fact ~ 1.2. The most favoured decay channels, as far as we can say now, are probably

$$H_1^{\pm} \rightarrow e^{\pm} + \nu_e + \nu_H$$
$$\phantom{H_1^{\pm}} \rightarrow \mu^{\pm} + \nu_\mu + \nu_H$$

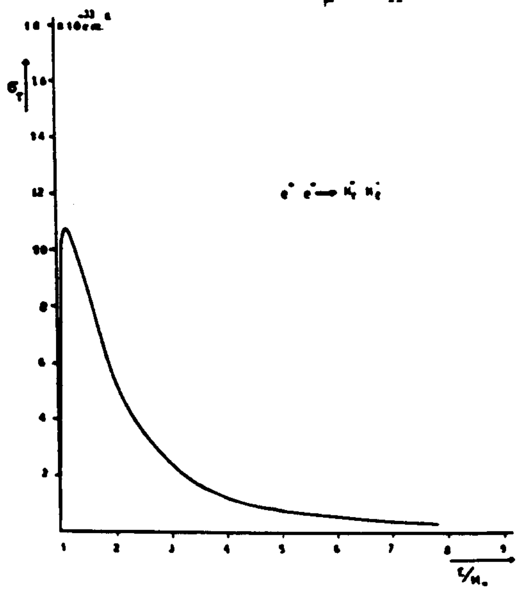


FIG. 6 - Total cross-section for production of heavy leptons versus E/M_{H_1}.

Fig. 13a. Page 7 of Ref. [5] where the search for a heavy lepton carrying its own leptonic number is proposed.

$e^+ + e^- \rightarrow L^+$	$+ L^-$
$\rightarrow e^+ + \nu_e + \bar{\nu}_{HL}$	$\rightarrow e^- + \bar{\nu}_e + \nu_{HL}$
$\rightarrow \mu^+ + \nu_\mu + \bar{\nu}_{HL}$	$\rightarrow \mu^- + \bar{\nu}_\mu + \nu_{HL}$
$\rightarrow \bar{\nu}_{HL}$ + Hadrons	$\rightarrow \nu_{HL}$ + Hadrons
$e^+ + e^- \rightarrow E^+$	$+ E^-$
$\rightarrow \nu_e + e^+ + \nu_e$	$\rightarrow \bar{\nu}_e + e^- + \bar{\nu}_e$
$\rightarrow \nu_\mu + \mu^+ + \nu_e$	$\rightarrow \bar{\nu}_\mu + \mu^- + \bar{\nu}_e$
$\rightarrow \nu_e$ + Hadrons	$\rightarrow \bar{\nu}_e$ + Hadrons
$e^+ + e^- \rightarrow M^+$	$+ M^-$
$\rightarrow \nu_\mu + \mu^+ + \nu_\mu$	$\rightarrow \bar{\nu}_\mu + \mu^- + \bar{\nu}_\mu$
$\rightarrow \nu_\mu + e^+ + \nu_e$	$\rightarrow \bar{\nu}_\mu + e^- + \bar{\nu}_e$
$\rightarrow \nu_\mu$ + Hadrons	$\rightarrow \bar{\nu}_\mu$ + Hadrons

Thus the Search Concentrated on the Reaction

$$e^+ + e^- \rightarrow e^{\pm} \mu^{\mp} + \text{Anything}$$

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Fig. 13b. The reactions studied, as reported in the final Frascati paper, using the $(e\mu)$ acoplanar method [18].

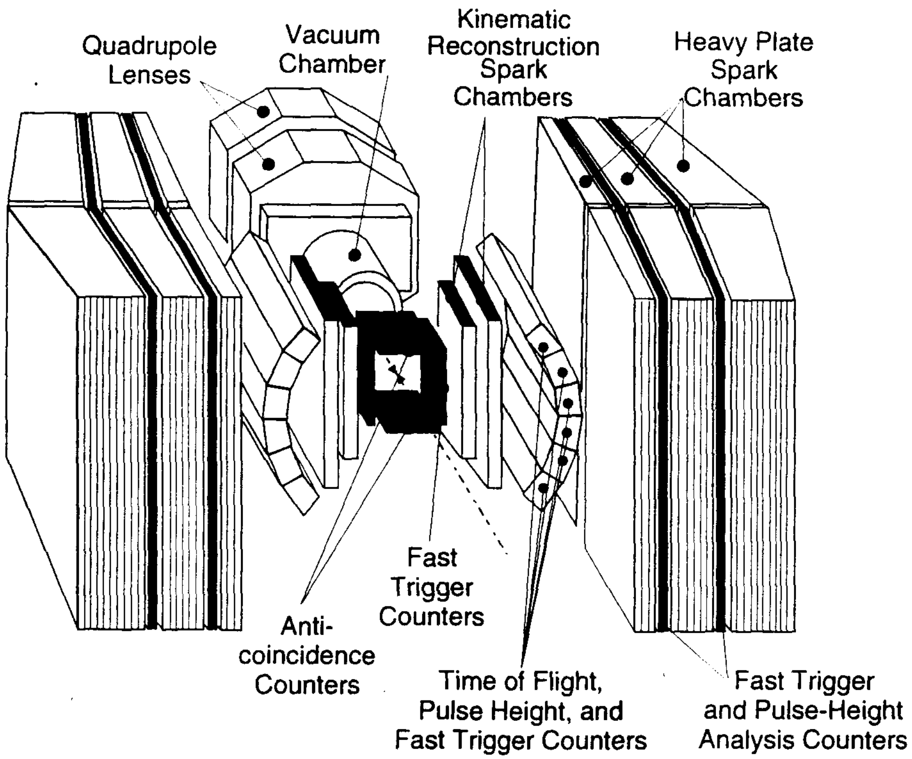
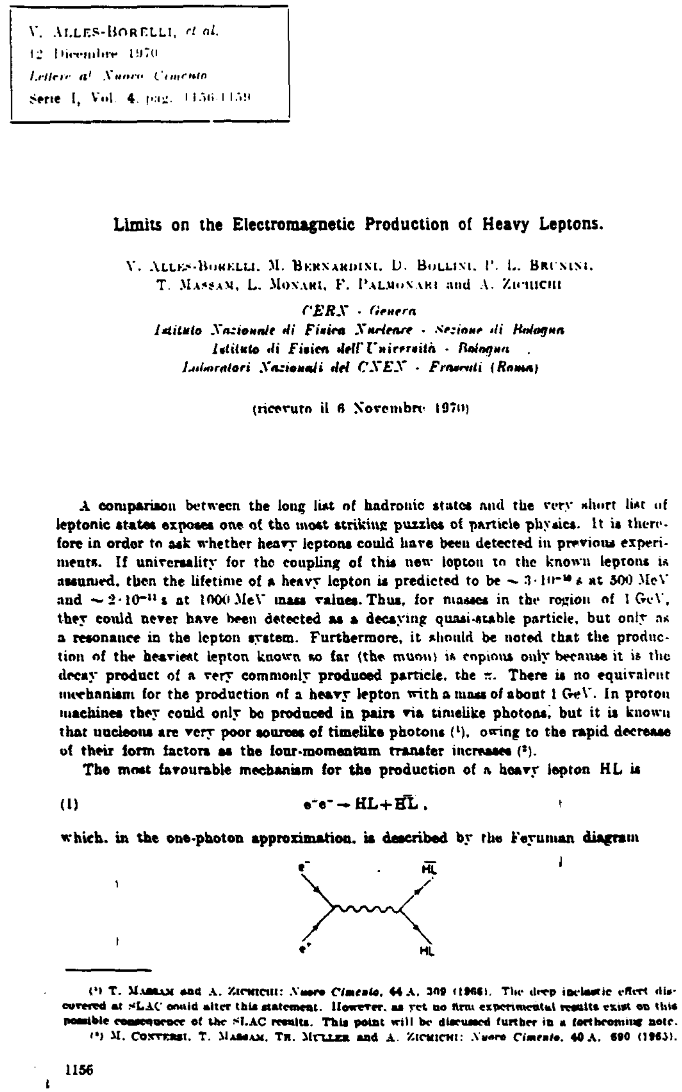


Fig. 14. The experimental set-up constructed for the study of the reaction quoted in Fig. 13a.



V. Alles-Borelli, *et al.*
12 Dicembre 1970
Lettere al Nuovo Cimento
Serie I, Vol. 4, pag. 1156-1159

Limits on the Electromagnetic Production of Heavy Leptons.

V. Alles-Borelli, M. Bernardini, D. Bollini, P. L. Brunini, T. Massam, L. Monari, F. Palmonari and A. Zichichi

CERN - Geneva
Istituto Nazionale di Fisica Nucleare - Sezione di Bologna
Istituto di Fisica dell'Università - Bologna
Laboratori Nazionali del CNEN - Frascati (Roma)

(ricevuto il 6 Novembre 1970)

A comparison between the long list of hadronic states and the very short list of leptonic states exposes one of the most striking puzzles of particle physics. It is therefore in order to ask whether heavy leptons could have been detected in previous experiments. If universality for the coupling of this new lepton to the known leptons is assumed, then the lifetime of a heavy lepton is predicted to be $\sim 3\cdot 10^{-10}$ s at 500 MeV and $\sim 2\cdot 10^{-11}$ s at 1000 MeV mass values. Thus, for masses in the region of 1 GeV, they could never have been detected as a decaying quasi-stable particle, but only as a resonance in the lepton system. Furthermore, it should be noted that the production of the heaviest lepton known so far (the muon) is copious only because it is the decay product of a very commonly produced particle, the π. There is no equivalent mechanism for the production of a heavy lepton with a mass of about 1 GeV. In proton machines they could only be produced in pairs via timelike photons, but it is known that nucleons are very poor sources of timelike photons (1), owing to the rapid decrease of their form factors as the four-momentum transfer increases (2).

The most favourable mechanism for the production of a heavy lepton HL is

$$e^+e^- \to \mathrm{HL} + \overline{\mathrm{HL}}\,, \qquad (1)$$

which, in the one-photon approximation, is described by the Feynman diagram

(1) T. Massam and A. Zichichi: *Nuovo Cimento*, 44 A, 309 (1966). The deep inelastic effect discovered at SLAC could alter this statement. However, as yet no firm experimental results exist on this possible consequence of the SLAC results. This point will be discussed further in a forthcoming note.
(2) M. Conversi, T. Massam, Th. Muller and A. Zichichi: *Nuovo Cimento*, 40 A, 690 (1965).

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Fig. 15. The first results obtained using the (eμ) acoplanar method, proving that it works [11].

whose predictions in terms of acoplanar radiative electrons or muons in the final state were simply for no effect at all. These acoplanar radiative effects were measured for electrons [14] (Fig. 16) and also for the muon case [15]. Thus a detailed study of electron and muon QED (where acoplanar radiative corrections had to be correctly accounted for) was a basic step towards the search for new physics. This is why QED predictions for (e^+e^-) [16] (Fig. 17) and ($\mu^+\mu^-$) (Fig. 18) [17] were checked with great accuracy. My group was the only one doing these careful QED studies at Frascati.

The best limit for the heavy lepton mass was published in 1973 [18] (Fig. 19). The fact that a new heavy lepton was not produced with the (e^+e^-) Frascati collider whose maximum canonical energy was $\sqrt{s}$ = 3.0 GeV, stimulated me to propose an upgrading of ADONE to continue the search for new physics: essentially heavy leptons and narrow resonances. Here also the theoretical trend was negative: if a resonance exists in the GeV mass range its width must be large, i.e., 10^2 MeV. Why search for narrow resonances? My continued interest in this field is summarized in a paper [19] (Fig. 20) written after a series of reports at various conferences (Wiesbaden '72, Batavia '72, Pavia '73, Frascati '73, Bielefeld '73). In this paper – whose purpose was to promote (e^+e^-) physics – I listed the important properties of the Heavy Lepton to be measured to ensure that the ($e\mu$) pairs are indeed from Heavy Lepton decays, in order to encourage further searches. I was convinced that (e^+e^-) colliders were a potential source of new physics but the majority of my colleagues were attracted by "hadron" machines, because in (e^+e^-) physics only "butterflies" were expected.

For the new generation of physicists it is instructive to see the many "butterflies" now, 25 years after; our proposal being dated 1967. The butterflies are shown in Fig. 21. Note that the Frascati nominal energy was 3.0 GeV while at 3.1 GeV there was the J/Ψ and at 3.6 GeV the new lepton pair production so much searched for. Note also that the Y's of Lederman were above the SPEAR (maximum) and below PETRA (minimum) energies.

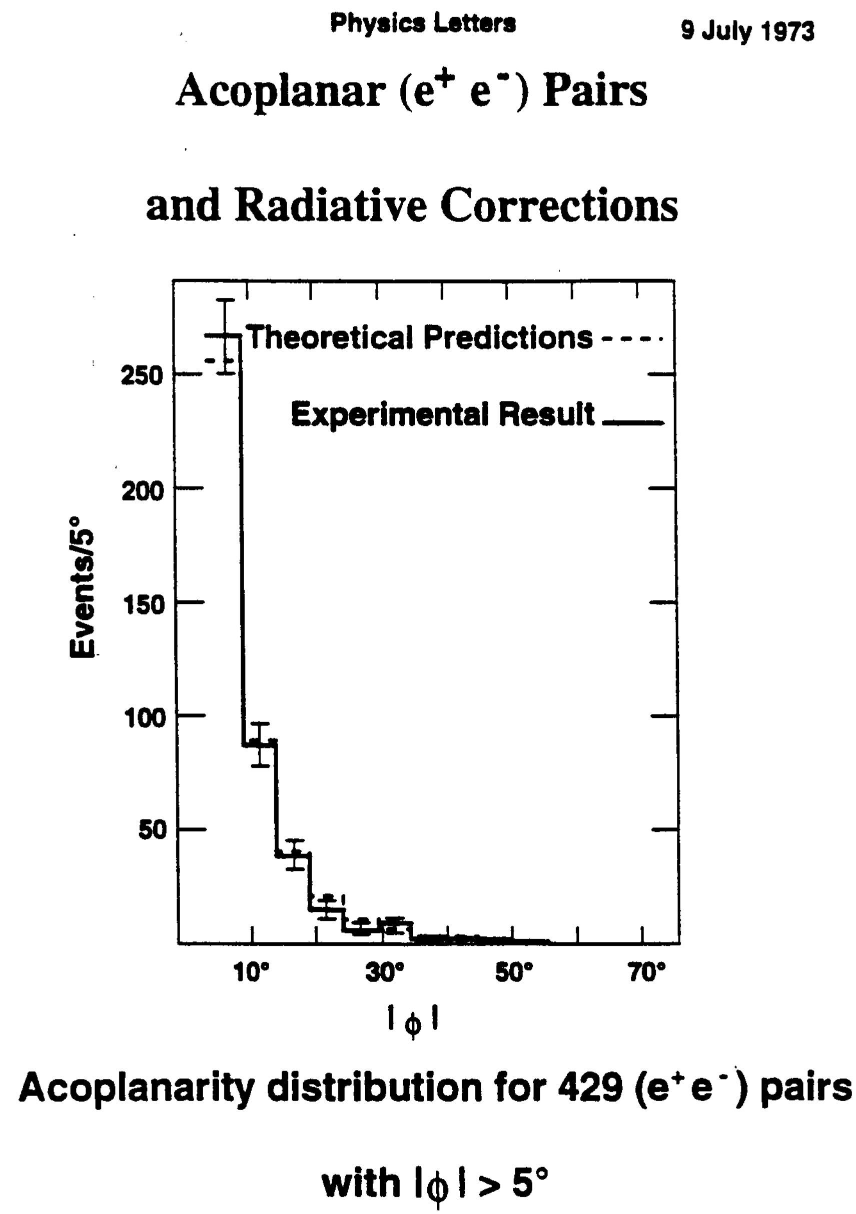

Fig. 16. The first measurements of acoplanar radiative corrections [13, 14].

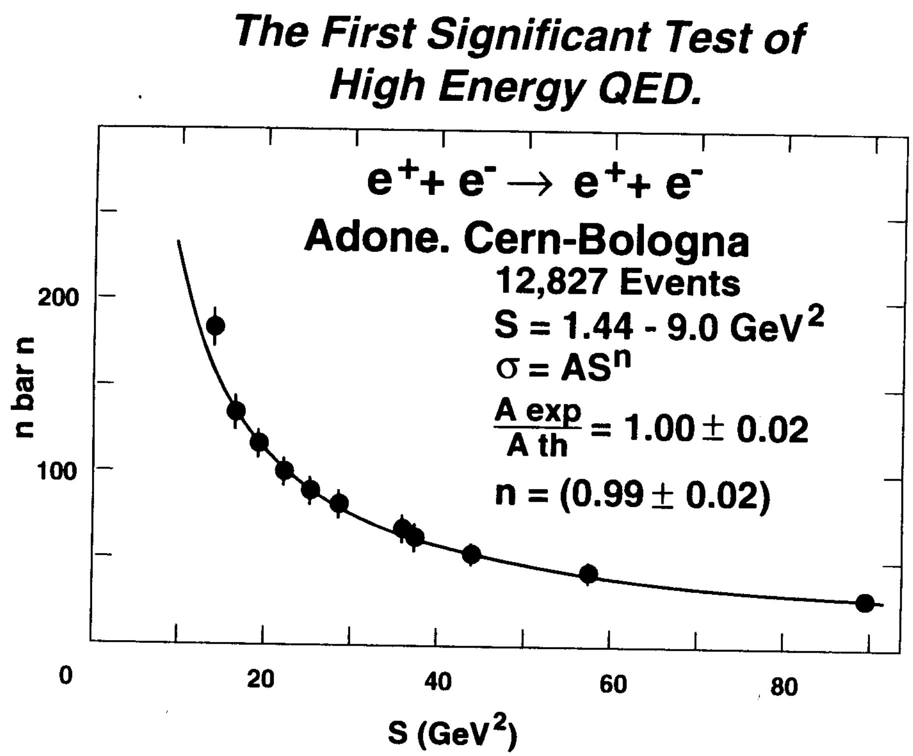

Fig. 17. The best (QED) check in (e^+e^-) interactions using the ADONE collider [16].

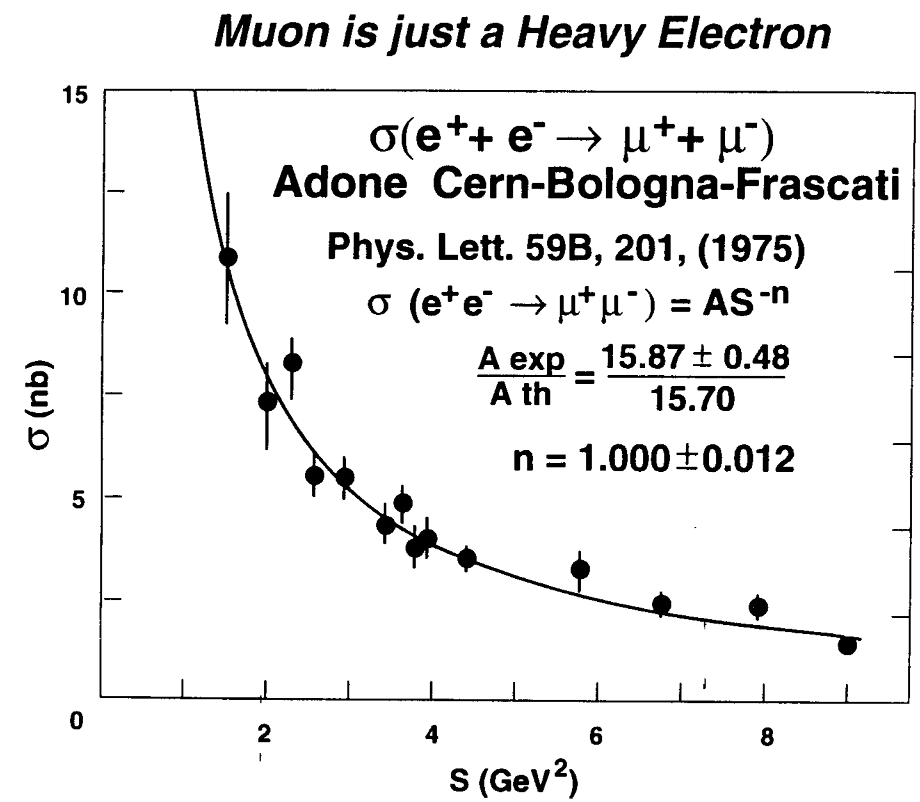

Fig. 18. The same as Fig. 17 using ($\mu^+\mu^-$) pairs in the final state [17].

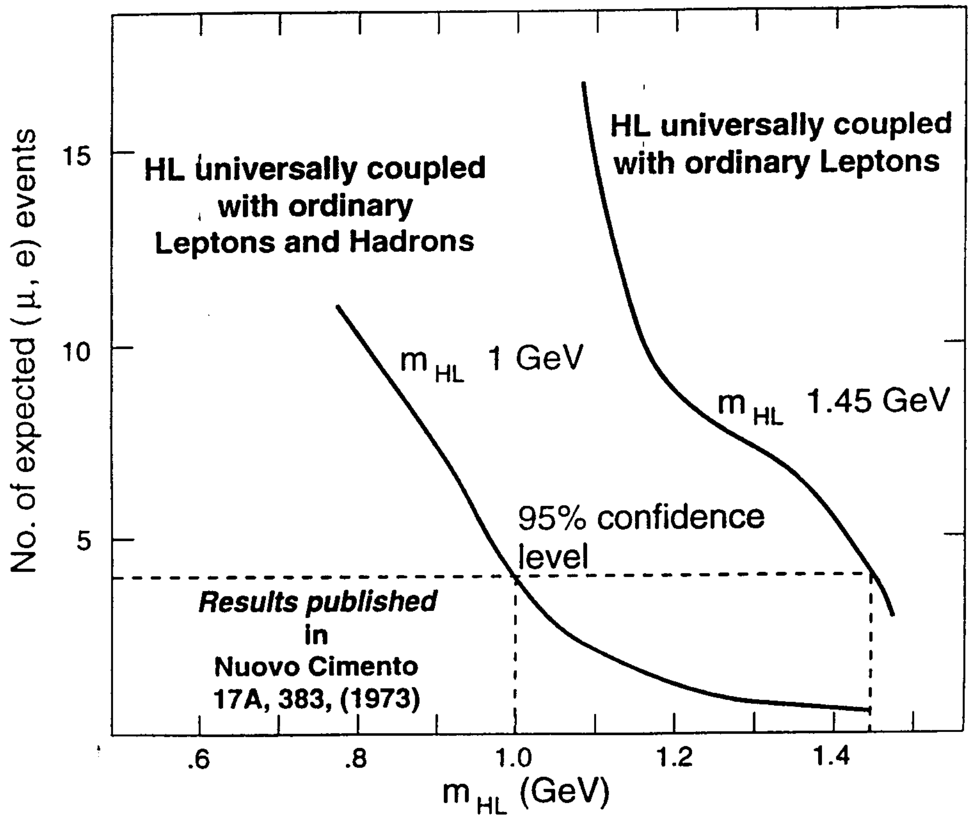

Fig. 19. The best limits on the search for a Heavy Lepton carrying its own leptonic number [18].

RIVISTA DEL NUOVO CIMENTO VOL. 4, N. 4 Ottobre-Dicembre 1974

Why (e^+e^-) Physics is Fascinating (*).

A. ZICHICHI (**)

CERN - Geneva

(ricevuto il 12 Aprile 1974)

498	1. Introduction: (e^+e^-) machines in the world.
500	2. Why should we believe in local relativistic quantum field theory?
508	3. Is it possible to renormalize weak interactions? Other heavy leptons?
515	4. Are the hadrons made of superelementary constituents?
520	5. New vector mesons?
523	6. Study of SU_3 symmetry breaking.
524	7. The timelike electromagnetic structure of the hadrons.
527	8. Production of $C = +1$ states.
528	9. Validity of the leptonic selection rules.
529	10. Conclusions.

Summary

The results obtained by the Bologna-CERN-Frascati Collaboration during about three years of work at Frascati are reviewed and taken as a basis to show the impact of (e^+e^-) physics in understanding the laws of subnuclear phenomena.

1. – Introduction: (e^+e^-) machines in the world.

At this Conference you have heard how the basic laws of hadrodynamics can be investigated when the initial state of a reaction consists of hadrons.

The purpose of this talk is to show what we can learn when the initial state consists only of leptons, and more precisely of a lepton-antilepton pair. The

(*) This paper is an updated version of two unpublished invited review papers presented at the EPS *Conference, Wiesbaden, 3-6 October 1972*, and at the *IV International Symposium on Multiparticle Hadrodynamics, Pavia, 31 August-4 September 1973*. The data on $\sigma(e^+e^- \to \text{hadrons})$ have been presented at: i) the *XVI International Conference on High-Energy Physics, Batavia, Ill., 1972*; ii) the *Informal Meeting on Recent Developments in High-Energy Physics, Frascati, 26-31 March 1973*; iii) the *International Discussion Meeting on (e^+e^-) Annihilation, Bielefeld, 19-21 September 1973.*

(**) On leave of absence from the University of Bologna.

Fig. 20. The review paper emphasizing the importance to go on searching for the heavy lepton using the (eμ) acoplanar method, above ADONE energy [19].

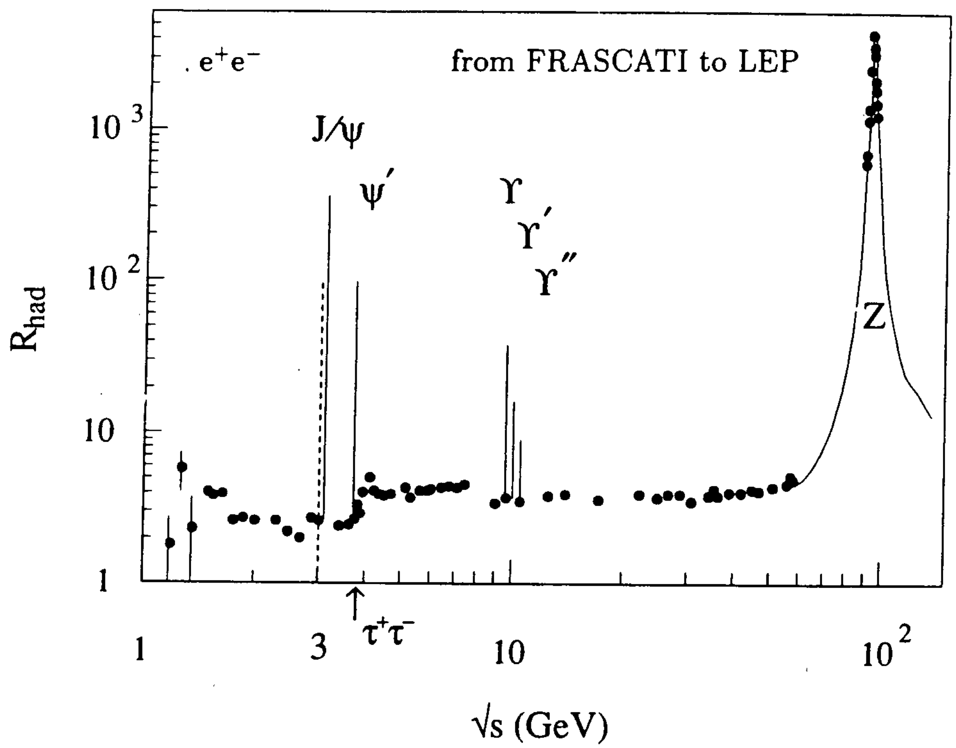

Fig. 21. The many butterflies as we know them now.

4 - The Concluding Part of my Tribute to Martin Perl

The consequences of the τ discovery "now" have been reviewed by Haim Harari. There is, nevertheless, something which has not been mentioned but I would like to discuss, also, because it has attracted my interest during the last year or so. It has to do with the problem of high precision LEP data: the goal being if SUSY threshold can be "predicted." The basis for this new frontier in physics - i.e., the existence of a Superworld - is the Renormalization Group Equations (RGEs) which allow to span an energy range as large as 14 to 17 orders of magnitude. In fact the high precision LEP data are at 10^2 GeV and we would like to understand what happens all the way up to E_{GUT} (the energy where the three gauge forces $SU(3)_C$, $SU(2)_L$ and $U(1)_Y$ - characterized by the three couplings $\alpha_1,\alpha_2,\alpha_3$ - unify). Recently great confusion has been raised by some authors [20] who claimed that it was possible to predict the supersymmetry threshold on the basis of a χ^2-test on the convergence of the couplings $\alpha_1,\alpha_2,\alpha_3$ at E_{GUT}.

This paper has many weak points [21-27], the weakest one being a logical inconsistency. In fact, if the source of our knowledge about the supersymmetry threshold is the "convergence" at E_{GUT}, the top priority problem is to study what happens at E_{GUT}. This means the study of the threshold effects in the very high energy limit (10^{15}-10^{17} GeV) because what happens at E_{GUT} is supposed to have consequences in the energy range many orders of magnitude below. Moreover, it is contradictory to work out a χ^2-test for the geometrical convergence at E_{GUT} of the three gauge couplings ($\alpha_1,\alpha_2,\alpha_3$) and then let them diverge again [20], above E_{GUT}. The synthesis of this logical inconsistency is shown in Fig. 22 (which is the key figure of the paper quoted above [20]).

The reason for my interest in this paper is because it produced a lot of discouragement in the physics community, including my young collaborators engaged in searching for a supersymmetric signal with existing facilities. We have put order in this field [21-27] and the conclusion is that, in addition to all weak points and logical inconsistencies, the quantity M_{SUSY} is meaningless. We have worked out the spectra expected and found that the lightest detectable supersymmetric particle could be as light as 50 GeV in mass, with the M_{SUSY} parameter more than one order of magnitude higher.

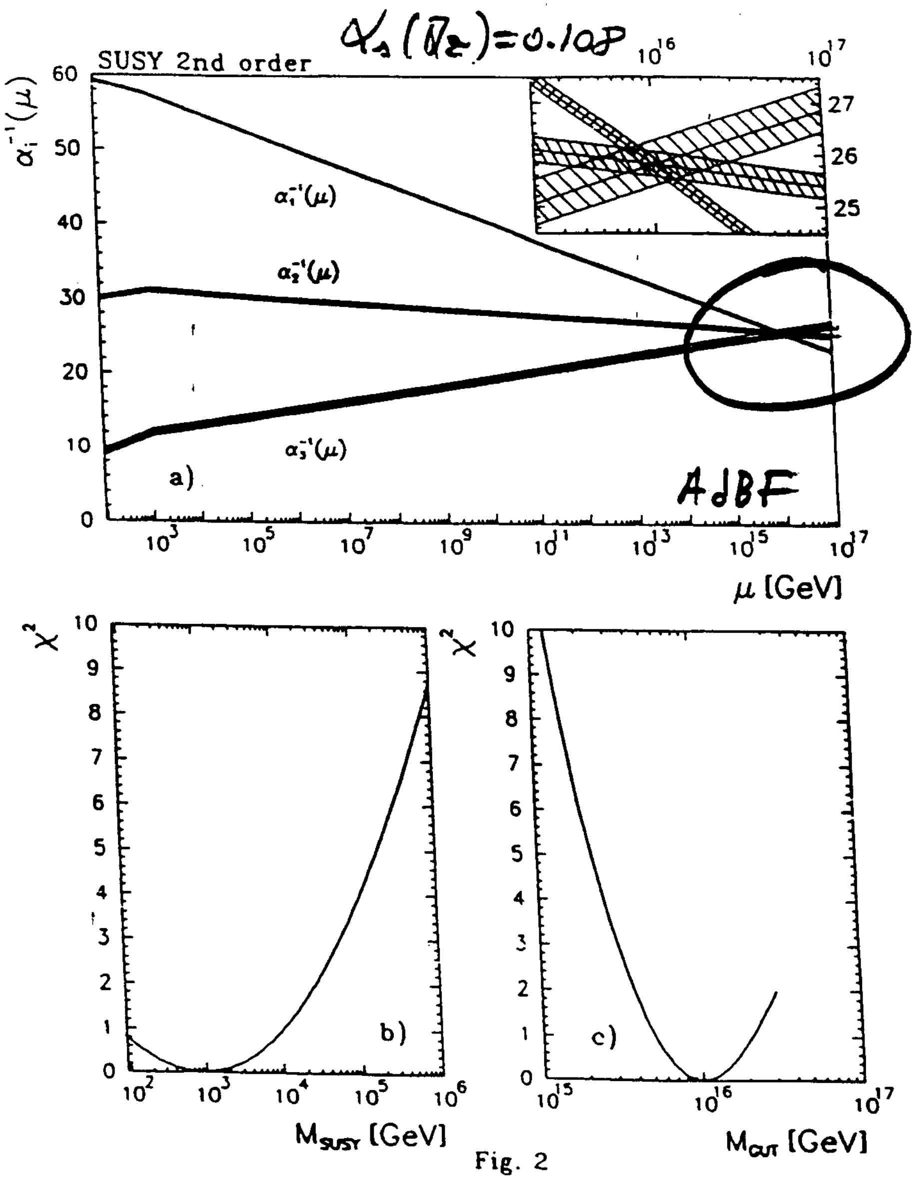

Fig. 22. The wrong approach to understand SUSY [20].

Furthermore, we have pointed out that the evolution of masses needs to be included. Of special relevance is the evolution of the gaugino masses, the so-called EGM effect [23]. A great development in our way of thinking [28] is that, not only the gauge couplings evolve with energy, but the masses as well. A careful analysis shows [23] how interesting are the consequences of this conceptual development: the M_{SUSY} threshold goes from 21 TeV down to the present LEP energy scale range. This is shown in Fig. 23. Let me emphasize again that M_{SUSY} is a parameter while the physically interesting results are those concerning the spectra of the lightest supersymmetric particles: charginos ($\chi^{\pm}_{1,2}$), neutralinos ($\chi^{0}_{1,2,3,4}$), gluinos, sleptons and squarks. An example [29] of mass spectra prediction is shown in Fig. 24. Moreover, to account for the light threshold (ΔT_L), the heavy threshold (ΔT_H) and the radiative effects due to the evolution of masses is perfectly possible and it allows the gauge couplings to converge at E_{GUT}, not to diverge above E_{GUT} and have the lightest supersymmetric observable signal in the energy range of present existing facilities (Fig. 25). This brings me to the last remark: in order to study the convergence of the gauge couplings with all consequences synthetically reported above [30], we need the knowledge of the number of families and the τ lepton has opened the door to the existence of the 3rd family. Moreover, an input badly needed for the above quoted studies is α_3: and the cleanest source to measure α_3 is the τ lepton, via its hadronic and leptonic decay rates. There is an interesting way to present the same results in terms of the correlation between the gauge couplings (α_1,α_2,α_3). This correlation is governed by the three coupled differential non-linear equations describing their evolution. This is shown in Fig. 26. Before the discovery of the τ this three-dimensional graph could not have been drawn. If nature would have followed the apparently simplest way (the straight line) we could not be here. Nature has followed the road illustrated by the sequence of the big dots in Fig. 26 and these predictions could not be there without the two vital inputs, the number of families (N_F=3) and the value of α_3, both linked to the τ lepton.

So, 15 years after its discovery, the τ lepton remains in the forefront of our physics research. Thank you, Martin, for your great accomplishment.

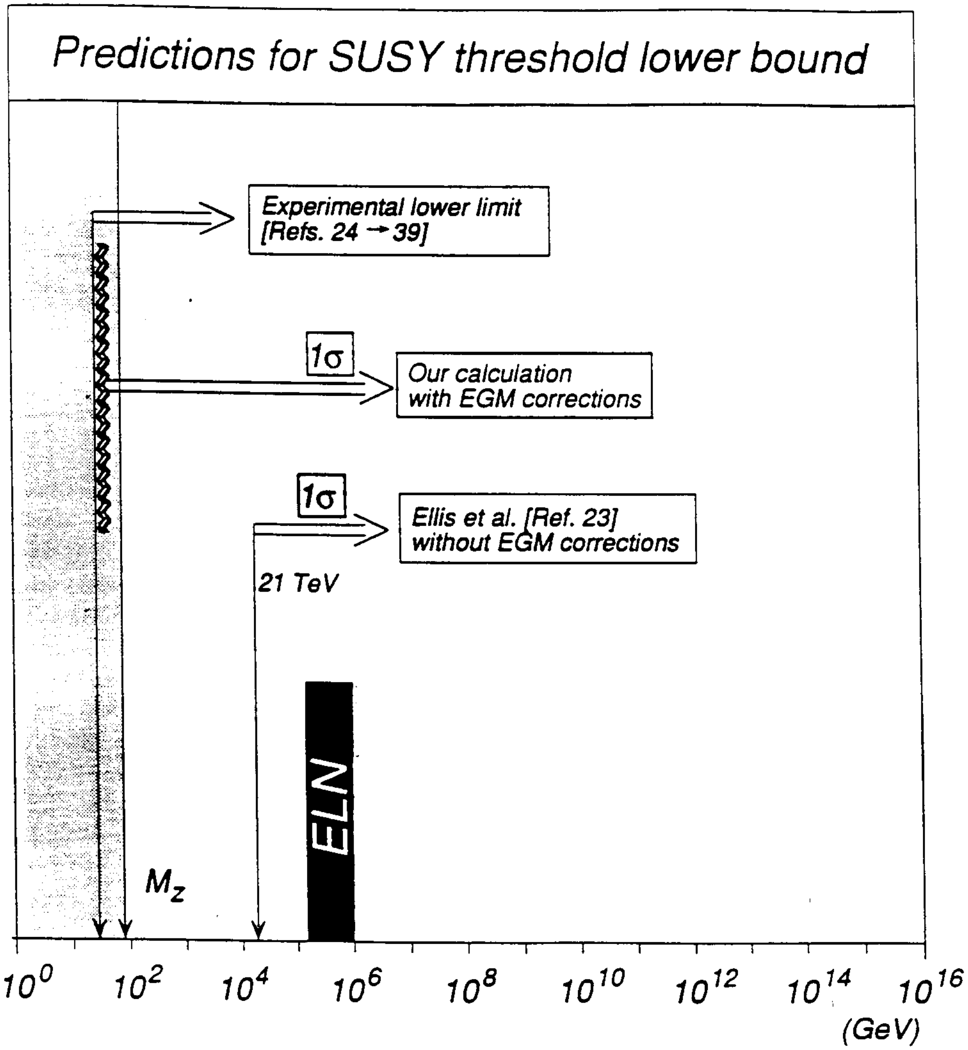

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Fig. 23. The Evolution of Gaugino Masses (the EGM effect) on the prediction for SUSY thresholds [23].

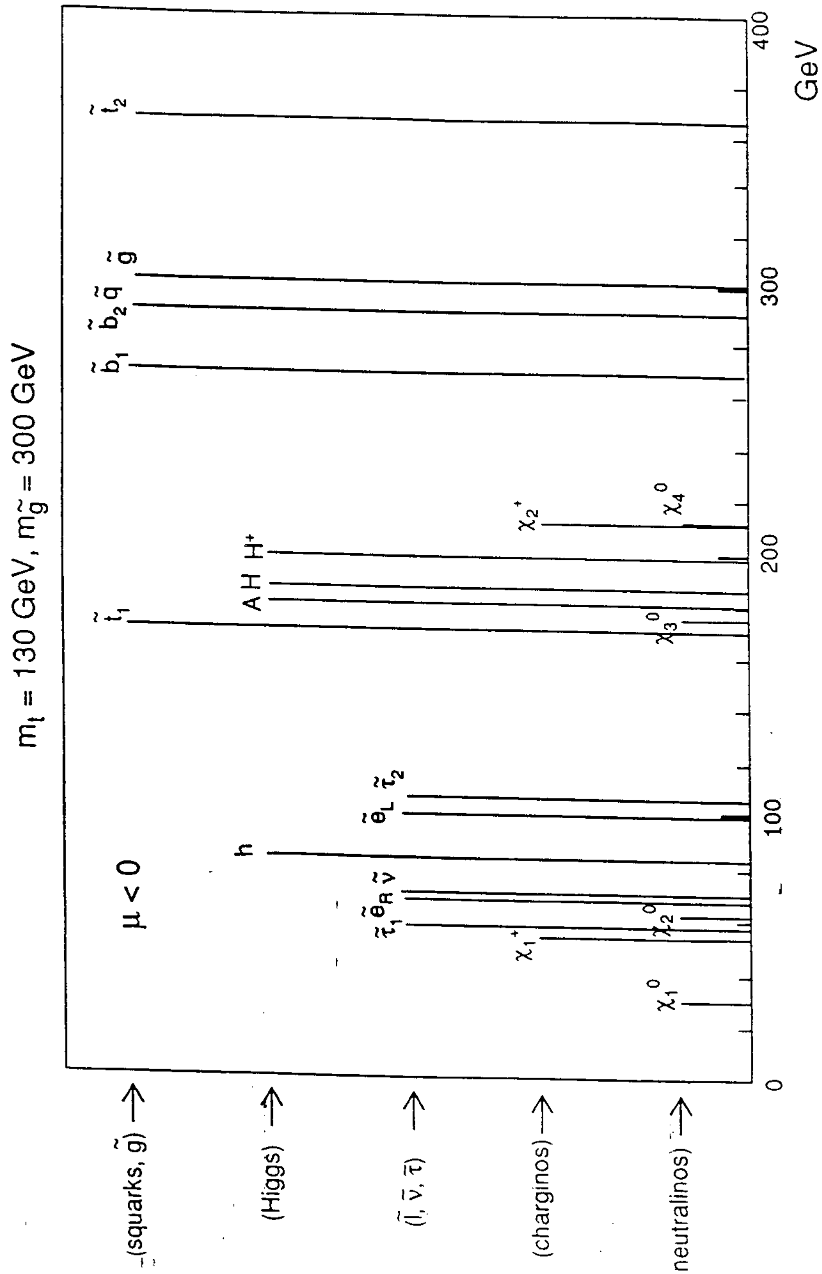

Figure 6b

Fig. 24. An example of spectra for neutralinos ($\chi^0_{1,2,3,4}$), charginos ($\chi^\pm_{1,2}$), sleptons, squarks, gluinos and Higgs as predicted by a Supergravity model with inputs (m_t=130 GeV, $m_{\tilde g}$=300 GeV and μ<0) [29].

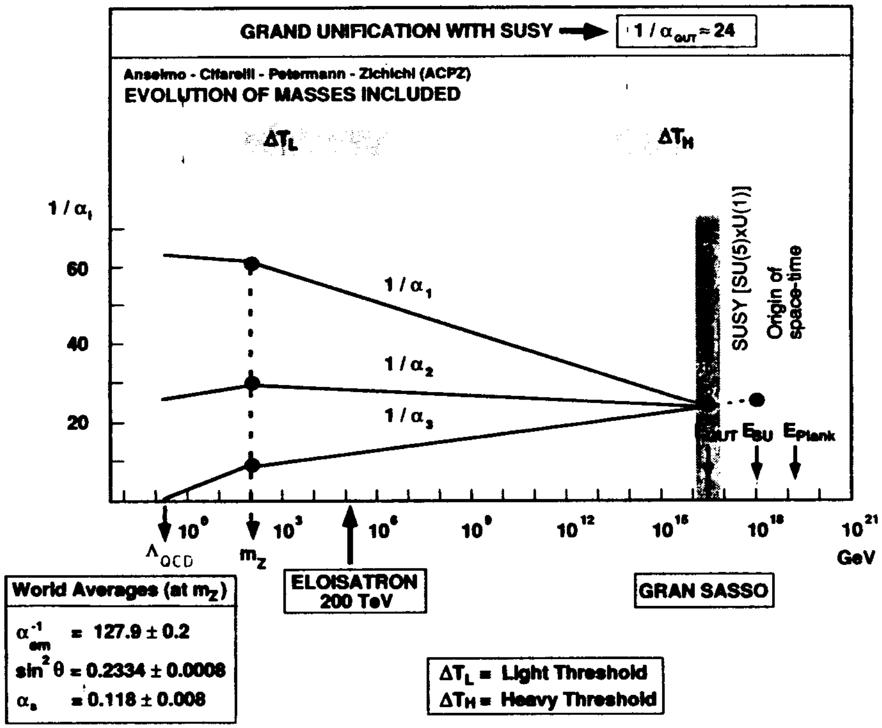

Fig. 25. The correct approach to understand SUSY [21-30].

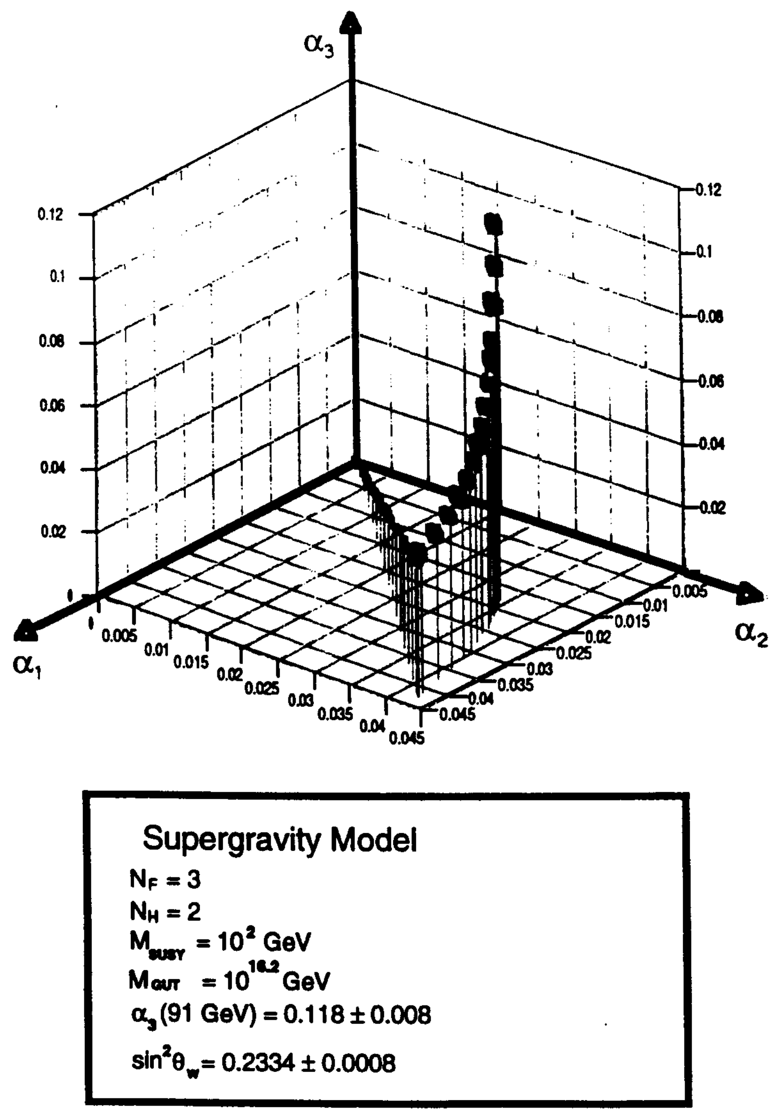

Fig. 26. The evolution of the three gauge couplings (α_1,α_2,α_3) and their mutual correlation as described by a supergravity model. Note that the number of families (N_F=3) and the knowledge of α_3 are vital inputs.

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