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ELOISATRON

The European Long Intersecting Storage Accelerator

Presented by A. Zichichi at the
Galileo Galilei and Alfred B. Nobel Celebrations
Science for Peace, Sanremo and Rome, Italy, 1-11 May 1983

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. ABSTRACT

Past experience, present knowledge and straightforward forecast in the extreme energy limits for subnuclear physics are reviewed, in order to present the case for a multiTeV intersecting hadronic machine, whose basic features are presented.

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1. - INTRODUCTORY REMARKS

1.1. - The need for a multiTeV machine in Europe

Since by 1990 both LEP and HERA will be operating, if, as many of us believe, subnuclear physics is to be pursued with vigour and without a break of many years, it is time to start discussing the new multiTeV hadronic machine.

A multiTeV machine with a circumference of the order of $10^2 + 1.5 \times 10^2$ Km will cost between 2 and 5×10^9 US dollars and requires 5 to 10 years to be built, from the time of approval.

Somebody could say that it is better to wait for new ideas. After all this machine should start to be built tomorrow.

1.2. - From new ideas to reality

Past experience shows that no time can be saved by starting playing with new ideas. In fact, a long time is needed to transform new ideas to reality.

Two examples should suffice:

- i) superconducting high field magnets, first proposed in 1961, will become "reality" in 1983 (TEVATRON): 22 years were needed;
- ii) collective field accelerators were proposed by Veksler, Budker and Fainberg in 1956: 27 years later, no practical design for a high energy machine based on these ideas exists.

According to the above considerations, the ELOISATRON design, as it will be seen in chapter 4, is based on extrapolations from known facts and technologies.

2. - PHYSICS

In recent years a fashionable approach to the extreme energies has been the "Desert", i.e. nothing should exist in the range from few 10^{-1} TeV up to $\sim 10^{12}$ TeV.

The Desert would be a serious obstacle if no problem existed in this field of extreme energies.

The high energy limit of our present knowledge has two frontiers.

One is in the domain of experimental physics. At present the known limits on the inverse radii of all known leptons, "e", " μ ", " τ " are of the order of 10^{-1} TeV. This means

that point-like structures of the presently existing particles are already in the multiTeV range.

The other is in the theoretical domain. Here we have the Family and the Hierarchy problems, which, together with the problem of the proliferation of the Higgs sector and of its associated large number of parameters, make the multiTeV range overcrowded of problems to be understood.

But even if everything would look "perfect", we should not forget the lesson we get from past experience. For this reason it is probably worth recalling previous deserts and experimental findings.

2.1. - The Lesson from the past

The most famous is the desert of Lord Kelvin who stated in 1897: "There is nothing to be discovered in Physics now. All that remains is more precise measurements". Few months later J.J Thomson, announced the discovery of the electron.

Some fellows could say: too old. These are 19th Century stories. For this reason we propose to review more recent facts.

Let us start with the 30 GeV Protosynchrotrons at CERN and BNL.

The original motivations were the (πp) and (pp) scattering and phaseshift analysis as well as tests of Isospin and T invariances.

What did we get from these machines?

- New particle states, which produced the celebrated SU(3)-flavour global symmetry of Gell-Mann and Ne'eman.
- The first measurement of the $(\omega - \varphi)$ mixing angle, crucial to resolve the puzzle of the vector meson masses.
- The measurement of $(e^+ e^-)$ and $(\mu^+ \mu^-)$ production in hadronic interactions, started in 1964 at CERN, resulted in the discovery of the J particle at BNL in 1974.
- The first proof that the nucleon had an important electromagnetic structure in the time-like region.
- The discovery of the existence of anti-nuclei: anti-deuteron.
- The discovery of two kinds of neutrinos: $\nu_e \neq \nu_\mu$.
- The discovery that $\nu_\mu \neq \bar{\nu}_\mu$.
- The discovery of CP and T violation.
- The discovery of the neutral weak current.

All the above findings had nothing to do with the original motivations.

Let us look at some more examples.

SLAC - The original physics aims were the study of the electromagnetic form factors of the Nucleons, the electromagnetic transition form factors ($N-N^*$) and QED checks. Found: the proof that point-like structures exist inside the proton. Moreover in the field of electroweak physics, the first measurement of parity violation in purely electromagnetic interactions (at high energy).

ADONE - The Italian (1+3) GeV (e^+e^-) machine. Here the motivations were of two types. The conventional ones were the checks of QED and of radiative corrections, the (μe) electromagnetic equivalence, the electromagnetic form factors of pions, kaons and protons and the study of the tails of the vector mesons. It is probably interesting to recall that these vector mesons (ρ, ω, φ) were theoretically proposed as "gauge" particles to understand the conserved hadronic currents associated with Isospin, Hypercharge and Baryon number. The unconventional proposals were the search for heavy leptons, using a new technique based on the acoplanar (μe) pairs, and the search for leptonic quarks. The totally unexpected discovery was that the ratio of hadronic to muonic cross sections was found to be much higher than the theoretically predicted value, based on the tails of the three vector mesons ρ, ω and φ .

SPEAR and DORIS - The "heavy lepton", searched for at ADONE, was found at SPEAR using the (μe) technique invented at Frascati. SPEAR started at 3 GeV (the energy limit of ADONE) with great enthusiasm because of the ADONE discovery of the high cross section ratio mentioned above. However, a series of great new things were there to be discovered: the J/ψ family of new particles and the open charm states.

PETRA and PEP - Nothing unexpected has come so far from these machine; the evidence for gluons is in the area of "expected" results.

ISR - The ISR is a special case. It is a machine of the highest technical performance. Had the experimental apparatus been allowed to be of the same level as the machine, the result would have been tremendous: J/ψ , Υ , new heavy flavour states, high p_T jets, direct photon production, would have been found in the first years of ISR operation. Unfortunately, the trend was to encourage "first generation" experiments, i.e. very simple and powerless set-ups.

THE 400 GeV CERN and FERMILAB SUPERPROTOSYNCHROTRONS - These machines lead to the unexpected discovery of the 9.5 GeV Υ states by Lederman and collaborators.

THE 540 GeV CERN ($\bar{p}p$) COLLIDER - Too recent to give unexpected results; it has

however provided the expected W^\pm and the first few examples of the expected Z^0 .

What lesson can we derive?

Firstly, when the construction of a new machine is started, the experimental set-ups must also be started, with the same emphasis as the machine construction. The strategy of 1st and 2nd generation experiments, where 1st means powerless, correspond to waste all money and effort at once: ISR docet.

Secondly, watch the energy gaps. The maximum energy of ADONE was 3 GeV. SPEAR started at 3 GeV, but then jumped to higher energies and was, for some time, bound to miss the J/ψ . SPEAR's maximum lay at 8.5+9 GeV, whereas PETRA started at above 10 GeV. Lederman's Υ was at 9.5 GeV.

Thirdly, when unexpected discoveries come in, the expected ones appear as a desert of imagination.

We now start discussing the DESERT of present days physics and its problems.

2.2. - Physics of the Desert

This physics is based on the assumption that there are no new gauge forces from the presently accessible 0.1 TeV to an upper energy E_{MAX} .

The renormalization group extrapolation shows that the effective couplings of the three gauge forces $SU(3)_C$, $SU(2)_{EW}$, $U(1)_{EM}$, converge to the same value at the same energy E_{MAX} . This energy is found to be

$$E_{MAX} \sim 10^{12} \text{ TeV.}$$

In order to unify all gauge forces, including gravity, the natural scale becomes:

$$E_{MAX} = E_{Planck} = 10^{16} \text{ TeV.}$$

Figure 1 shows the dangerous range of the DESERT.

However, the key question is the following: are there problems still to be solved in this theoretical picture of very high energy physics? The answer is positive and twofold. The two problems whose solution is open for competition are: the Hierarchy and the Family.

2.3. - The Hierarchy problem

The Higgs particles are, at present, the basic ingredients to produce the Spontaneous Symmetry Breaking (SSB). There are two energy levels where SSB occurs.

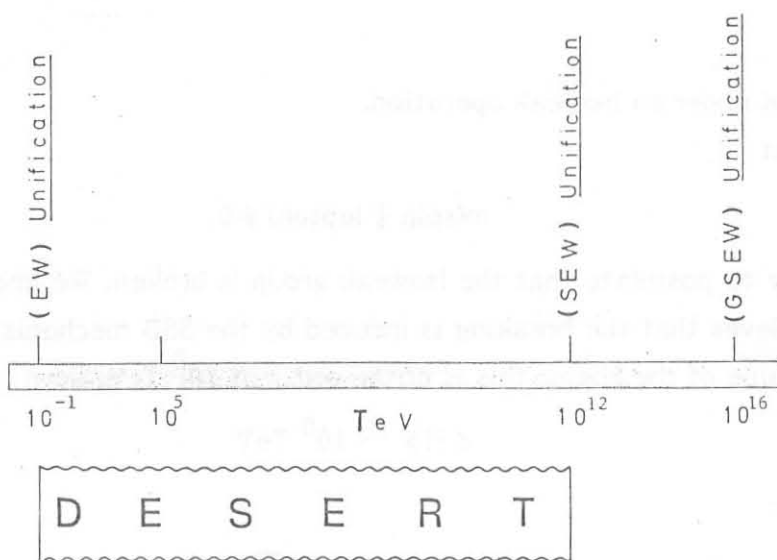


FIG. 1 - Showing the dangerous range of the DESERT.

One is at 10^{12} TeV where $SU(5)$ or another GUT symmetry group is broken. The other is at 10^0 TeV where $(SU(2)_\tau \times U(1)_Y)$ is broken to produce $SU(2)_{EW}$ and $U(1)_{EM}$.

These two energy levels are related to two mass levels of the corresponding Higgs particles, whose masses are separated by 12 orders of magnitude.

To keep these two levels; 10^0 and 10^{12} TeV, separated is "theoretically" impossible, because the Higgs are scalar particles.

The mass of a spinor particle needs to receive equal contributions from the Right and Left components of the wave function which describes the particle state. If a symmetry exists which distinguishes Left from Right stated, a spinor particle cannot have a mass unless the symmetry is broken. This is the case for $SU(2)_{EW}$ whose "weak" charges exist only for left-handed states. Right-handed states are $SU(2)_{EW}$ singlets.

The mass of a spin ($\frac{1}{2}$) particle is:

$$m \propto (\bar{\psi}\psi)$$

where $\psi = \psi_L + \psi_R$.

Suppose that ψ describes an electron, or a muon, or a tau lepton. According to $SU(2)_{EW}$,

$$\begin{aligned} \psi_L &\equiv \text{isoweak fermion} \\ \psi_R &\equiv \text{isoweak scalar} \end{aligned}$$

thus a term like

$$(\bar{\psi}\psi)$$

is not invariant under an isoweak operation.

If we want

$$m(\text{spin } \frac{1}{2} \text{ lepton}) \neq 0$$

it is necessary to postulate that the isoweak group is broken. We know it is broken and everybody believes that the breaking is induced by the SSB mechanism, i.e. the vacuum expectation value of the Higgs: this is of the order of 10^0 TeV, i.e.:

$$\langle H \rangle \sim 10^0 \text{ TeV}$$

therefore:

$$m(\text{spin } \frac{1}{2} \text{ lepton}) \approx \lambda (\bar{\psi}\psi) \langle H \rangle$$

If $\lambda \approx 1$, all leptons would have a mass of the same order of $\langle H \rangle$.

In order for the lepton masses to be in the few GeV range, λ needs to be of the order of 10^{-3} : no theory exists for this. In the case of the electron mass, λ needs to be $\sim 10^{-6}$, and again no theory exists for this.

Thus the present theoretical understanding predicts for all (spin $(\frac{1}{2})$) particles a value for the mass of the same order of $\langle H \rangle$, i.e. 10^0 TeV, the energy level where $SU(2)_{EW}$ is spontaneously broken. This level is well separated from 10^{12} TeV, where another SSB takes place, and where the vacuum expectation value of another Higgs, H' , will be: $\langle H' \rangle \approx 10^{12}$ TeV.

And now the paradox: while two well separated vacuum expectation values are needed

$$\langle H \rangle \approx 10^0 \text{ TeV}$$

and

$$\langle H' \rangle \approx 10^{12} \text{ TeV}$$

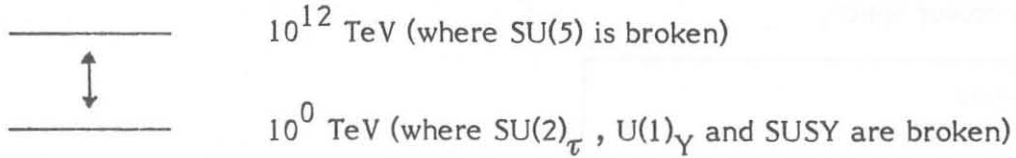
there is no way to keep the Higgs masses separated. In fact the Higgs are scalar particles, so their mass does not violate any internal symmetry group which distinguish Left from Right states.

There is a way out: suppose that SuperSYmmetry (SUSY) is really there. In this case the supersymmetric partner of the Higgs that breaks $SU(2)_{EW}$ must also exist. The S-Higgs is a spinor whose left-state has $SU(2)_{EW}$ properties different from the right-state. The mass term for the S-Higgs is like in the electron case. It can be different from zero only at the energy where $SU(2)_{EW}$ is broken.

The mass of the standard (scalar) Higgs must be the same as the spinor S-Higgs,

unless SUSY is broken. If SUSY breaking happens at the 10^0 TeV level, we can understand why the Higgs which breaks $SU(2)_{EW}$ cannot have too high a mass.

In this case the two energy levels



remain well separated.

Without SUSY breaking at low energy ($\sim 10^0$ TeV) the two levels mix together. In other words the low energy Higgs will acquire a 10^{12} TeV mass by radiative effects, i.e. it is impossible to keep 10^0 TeV separated from 10^{12} TeV.

2.4. - The Family problem

Our knowledge of the point-like constituents is based on the 3 Families of quarks and leptons, as shown below in Table I.

TABLE I

First Family	e^+	ν_e	u	\bar{d}
Second Family	μ^+	ν_μ	c	\bar{s}
Third Family	τ^+	ν_τ	t	\bar{b}

Two problems arise:

- i) how many Families exist?
- ii) is this repetition of Families a message for a deeper structure?

2.4.1. - How many Families?

If we want to keep asymptotic freedom the number of Families cannot exceed 8. This number goes down to 4 if SUSY is there. On the other hand, cosmological considerations indicate that no more than 4 neutrinos should exist in Nature.

We will discuss in more detail (see par. 2.6) what can be anticipated from present knowledge in the field of new Families.

2.4.2. - Is the repetition of Families a message for a deeper structure?

The existence of many Families of point-like particles gives rise to a regular structure, as shown in Fig. 2, where Q is the electric charge and N is the number of states in colour space.

First family		3Q	N
e^+		3	1
u		2	3
\bar{d}		1	3
ν_e		0	1
Second family		3Q	N
μ^+		3	1
c		2	3
\bar{s}		1	3
ν_μ		0	1
Third family		3Q	N
τ^+		3	1
t		2	3
\bar{b}		1	3
ν_τ		0	1

FIG. 2 - The structure of the three Families in terms of elements which should be able to generate quarks and leptons.

Notice that $N=1$ means colour singlet, as it is the case for leptons. $N=3$ corresponds to the 3 colour states of the quarks. Notice also that, so far, there is no experimental evidence for the existence of the "top" quark, i.e. the 3rd Family is incomplete.

The 3 Families shown in Fig. 2 are suggestive of a deeper structure in terms of elements which should be able to generate quarks and leptons.

These basic elements were given the name of leptonic quarks (1966), and later those of preons and of rishons, $r \equiv (T, V)$. They are characterized by spin (1/2) and electric charge (1/3, 0). The $(r\bar{r})$ bound states will be lepton-like bosons with electric charges $(0, \pm 1/3)$.

An example of the 1st Family structure in terms of rishons is shown in Table II.

TABLE II

$e^+ = \begin{pmatrix} 1 \\ 0 \end{pmatrix}_1 \quad \begin{pmatrix} 1 \\ 0 \end{pmatrix}_2 \quad \begin{pmatrix} 1 \\ 0 \end{pmatrix}_3$	$e^+ \equiv 3T$
$u_1 = \begin{pmatrix} 0 \\ 1 \end{pmatrix}_1 \quad \begin{pmatrix} 1 \\ 0 \end{pmatrix}_2 \quad \begin{pmatrix} 1 \\ 0 \end{pmatrix}_3$	$u \equiv 2T1V$
$u_2 = \begin{pmatrix} 1 \\ 0 \end{pmatrix}_1 \quad \begin{pmatrix} 0 \\ 1 \end{pmatrix}_2 \quad \begin{pmatrix} 1 \\ 0 \end{pmatrix}_3$	
$u_3 = \begin{pmatrix} 1 \\ 0 \end{pmatrix}_1 \quad \begin{pmatrix} 1 \\ 0 \end{pmatrix}_2 \quad \begin{pmatrix} 0 \\ 1 \end{pmatrix}_3$	
$\bar{d}_1 = \begin{pmatrix} 1 \\ 0 \end{pmatrix}_1 \quad \begin{pmatrix} 0 \\ 1 \end{pmatrix}_2 \quad \begin{pmatrix} 0 \\ 1 \end{pmatrix}_3$	$d \equiv 2V1T$
$\bar{d}_2 = \begin{pmatrix} 0 \\ 1 \end{pmatrix}_1 \quad \begin{pmatrix} 1 \\ 0 \end{pmatrix}_2 \quad \begin{pmatrix} 0 \\ 1 \end{pmatrix}_3$	
$\bar{d}_3 = \begin{pmatrix} 0 \\ 1 \end{pmatrix}_1 \quad \begin{pmatrix} 0 \\ 1 \end{pmatrix}_2 \quad \begin{pmatrix} 1 \\ 0 \end{pmatrix}_3$	
$\nu_e = \begin{pmatrix} 0 \\ 1 \end{pmatrix}_1 \quad \begin{pmatrix} 0 \\ 1 \end{pmatrix}_2 \quad \begin{pmatrix} 0 \\ 1 \end{pmatrix}_3$	$\nu_e \equiv 3V$

What is the energy scale for the constituents? There is no theory for this. Any value above 0.1 TeV is consistent with present knowledge. The particles so far observed would be nearly massless bound states compared to these constituent masses.

This is not a new problem. In fact, in $SU(3)_c$ -QCD there must be a mechanism for producing massless bound states, the π mass being practically zero. A similar mechanism may operate at the basic fermions level.

2.5. - What about gravitational forces?

So far we have ignored gravitational forces. If we want to unify gravitational forces with all other forces of Nature, we must enlarge the Einstein space-time of bosonic nature to fermionic dimensions.

This is how Supersymmetry (SUSY) comes in. Supersymmetry generates an immense number of particles and nobody knows how heavy are the masses of these particles: this is just a matter of theoretical speculation. A possible version of the supersymmetric particle states is given in Table III; notice that the quantum number R is zero for all known standard states. The values of R are indicated in parenthesis. The Table is from Farrar and Fayet.

TABLE III

MULTIPLETS	VECTORS	SPINORS	SCALARS
m = 0 Gauge part.	Photon (0) Gluons (0)	Photino (+1) Gluino (+1)	
m ≠ 0 Gauge part.	Intermediate bosons W ⁺ , Z ⁰ (0)	Heavy leptons (+1)	Higgs scalars (0)
Matter multiplets		Quarks (0) e, ν _e (0) μ, ν _μ (0) τ, ν _τ (0)	Quarks (+1) Leptons (+1) Leptons (+1) Leptons (+1)

The energy level where the Supersymmetric partners of known and yet-to-be discovered can be produced, is open to all theoretical speculations.

A synthesis of our present understanding of the multiTeV physics is shown in Fig. 3. Note that α_s is the QCD coupling; α_{EM} is the standard electromagnetic coupling which, at low energy, is the famous $(137)^{-1}$. Finally α_{EW} is the electroweak coupling, strongly energy dependent below $E \simeq 10^{-1}$ TeV, because it possesses the $(1/M^2)$ dependence, due

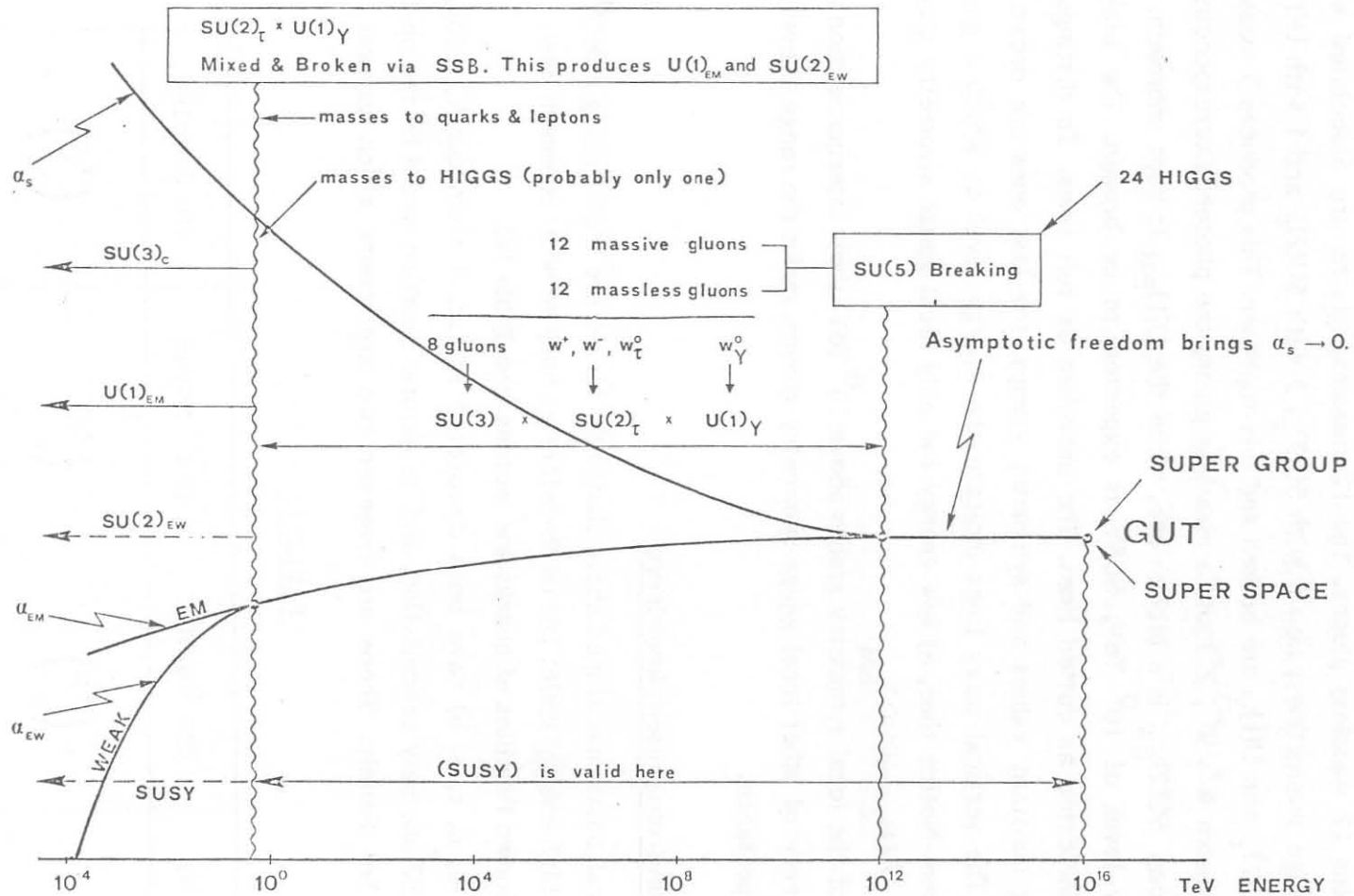


FIG. 3 - A synthesis of our present understanding of the multiTeV physics.

to the (W^\pm and Z^0) masses. In the same graph the status of the various local gauge symmetry groups is shown. $SU(5)$ is broken at $\sim 10^{12}$ TeV via 24 Higgs and produces 12 massive gluons plus 12 massless gluons. The 12 massless gluons are associated with unbroken local gauge symmetries; i.e.: 8 with $SU(3)_C$, 3 with $SU(2)_\tau$ and 1 with $U(1)_Y$. At $\sim 10^0$ TeV, $SU(2)_\tau$ and $U(1)_Y$ are broken and mix together. This produces 3 massive gluons (the well known W^+ , W^- , Z^0) and a massless gluon, the photon. Correspondingly the symmetry group $SU(2)_{EW}$ is a broken one, while the $U(1)_{EM}$ is kept unbroken. At the same energy level of 10^0 TeV, SUSY is expected to be broken. The broken symmetries are indicated as dotted lines. The unbroken as full lines. To distinguish between coupling constant values and symmetry groups, the last ones are drawn as horizontal lines. The vertical wavy lines indicate the energy level at which a gauge symmetry is broken. Notice that, at low energy the only local gauge symmetry groups left unbroken are $SU(3)_C$ and $U(1)_{EM}$.

The density of the local symmetry groups above 10^0 TeV, their interconnection and the possible existence of other local gauge symmetry groups, make the range above 10^0 TeV of utmost importance.

2.6. - Extrapolation from present knowledge

The theoretical points mentioned above show how far we are from having a definite knowledge of the high energy scale. Let us therefore go back to what is known now.

There are 3 known Families of quarks and leptons (see Table IV).

Five quarks (u, d, c, s, b) have been discovered so far. A sixth quark, t=top, is required by the ABJ anomaly cancellation, and its natural location would be the up-like member of the 3rd Family. There are however two arguments which suggest the

TABLE IV

1st Family	2nd Family	3rd Family	4th Family
$\begin{pmatrix} \nu_e \\ e \end{pmatrix}$	$\begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}$	$\begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$	$\begin{pmatrix} \nu_L \\ L \end{pmatrix}$
$\begin{pmatrix} u \\ d \end{pmatrix}$	$\begin{pmatrix} c \\ s \end{pmatrix}$	$\begin{pmatrix} t \\ b \end{pmatrix}$	$\begin{pmatrix} t_s \\ b_s \end{pmatrix}$

existence of a 4th Family.

- i) SUSY needs a very massive quark ($m_{\text{quark}} \approx 10^2 \text{ GeV}$) in order to have the gluino mass compatible with the experimentally known limits.
- ii) Glashow et al. model says that if
 - a) beauty decays $\geq 95\%$ into charm and if
 - b) $\tau_{\text{beauty}} \geq 10^{-12} \text{ sec}$,

then $m_{\text{top}} > 50 \text{ GeV}$.

However, it could very well be that $m_{\text{top}} < 50 \text{ GeV}$. In this case the simplest way out is to introduce a 4th Family.

As mentioned in par. 2.4.1. if we believe in SYSY, this should be the last Family.

Without any reference to sophisticated theoretical arguments let us look at few experimental data on quark mass estimates. They say that:

$$\frac{m_c}{m_s} \cong 4 \tag{1}$$

$$\frac{m_b}{m_s} \cong 10 \tag{2}$$

Suppose⁽¹⁾ that:

$$\frac{m_c}{m_s} = \frac{m(\text{up-like})}{m(\text{down-like})}$$

$$\frac{m_b}{m_s} = \frac{m(\text{Family N+1})}{m(\text{Family N})}$$

In other words, suppose that the already known quark mass ratios (1) and (2), stand for the ratio (up-like) over (down-like), and for the ratio of the next-Family-quark mass over the preceding, then:

$$\frac{m(\text{up-like})}{m(\text{down-like})} \cong 4$$

$$\frac{m(\text{Family N+1})}{m(\text{Family N})} \cong 10$$

In this case the top mass would be in the 25 GeV range.

Concerning the 4th Family, we would have:

- i) for the down-like member (superbeauty), $m_b \simeq 55 \text{ GeV}$:
- ii) for the up-like member (supertruth), $m_{t_s} \simeq 220 \text{ GeV}$.

So even if the Desert is there, there could be a lot of standard particles yet to be discovered.

In fact we could imagine that global symmetries to go on like the "up-down-strange" repeated with beauty and superbeauty and the "up-down-strange-charm" repeated with top and supertruth, as shown in Fig. 4.

If these global symmetries are there, the diagrams of Figs. 5, 6 and 7 show the structure of the new states, obtained from quark $x \equiv$ up-like and quark $y \equiv$ down-like, combined with the $SU(2)_f$ of (u,d) quarks.

If the global symmetries indicated in Fig. 4 do not exist, the number of states obtained by combining the 8 quarks of the 4 Families could be even greater.

In any case, the study of how the various quarks combine among themselves, in order to produce new particle states, is of crucial importance to understand what is going on in the TeV range of quarks interactions.

In this respect it is very important to extrapolate our present knowledge on cross section, to high energy and high masses. We will use two simple criteria: dimensionality and scaling.

From dimensionality we have $\sigma = (1/m^2)$; scaling dictates that the cross section cannot depend on s , but on the ratio (s/m^2) .

We therefore assume:

$$\sigma(m,s) = \frac{1}{m^2} f\left(\frac{s}{m^2}\right)$$

and extrapolate from the strangeness or charm cross sections the cross sections for heavier flavours at $\sqrt{s} = 50 \text{ TeV}$.

$$\sigma_{fi} \left[(\sqrt{s})_{pp} = E_i \right] = \left(\frac{m_j}{m_i} \right)^2 \times \sigma_{fi} \left[(\sqrt{s})_{pp} = E_j \left(\frac{m_j}{m_i} \right) E_i \right]$$

where i, j are the quark indexes.

The result is (Figs. 8 and 9) that the order of magnitude for the cross section values is very encouraging, because it is in the range $(10^{-1} - 10^0) \mu b$.

All this does not take into account new harder interactions. If they would come in, then our cross section estimates would all look pessimistic.

To conclude, irrespective of any sophisticated theoretical argument, by

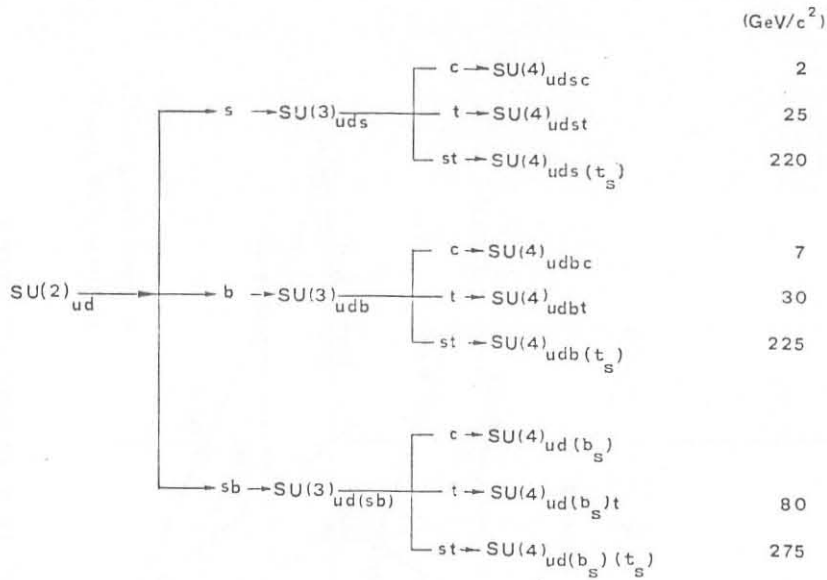
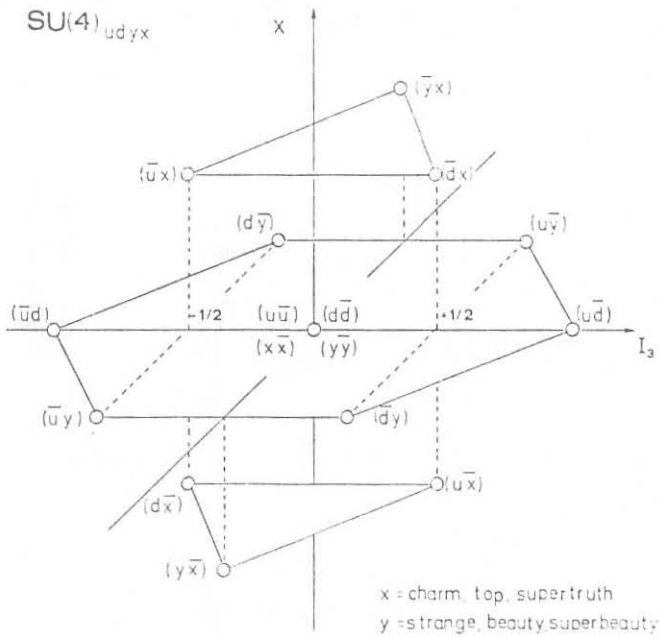


FIG. 4 - SU(3)_{uds} repeated with "beauty" and "superbeauty" replacing "strange" and SU(4)_{udsc} repeated with "top" and "supertruth" replacing "charm".



$J^P = 0^-$ and $J^P = 1^-$ MESONS (2 · 16 STATES)

FIG. 5 - Showing the SU(4)_{udyx} structure for $J^P = 0^-$ and $J^P = 1^-$ Meson states.

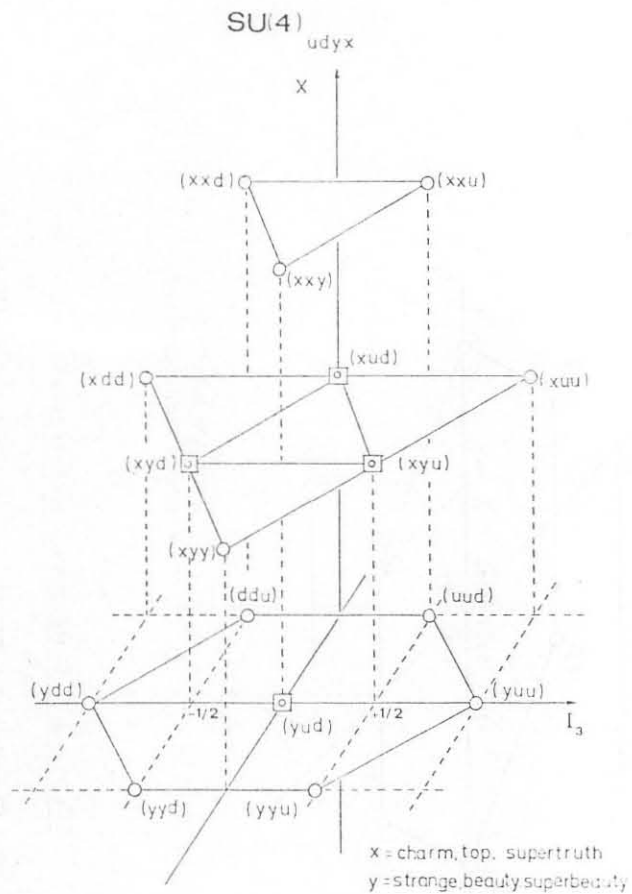


FIG. 6 - As above for the $J^P = \frac{1}{2}^+$ Baryon states.

$SU(4)_{udyx}$

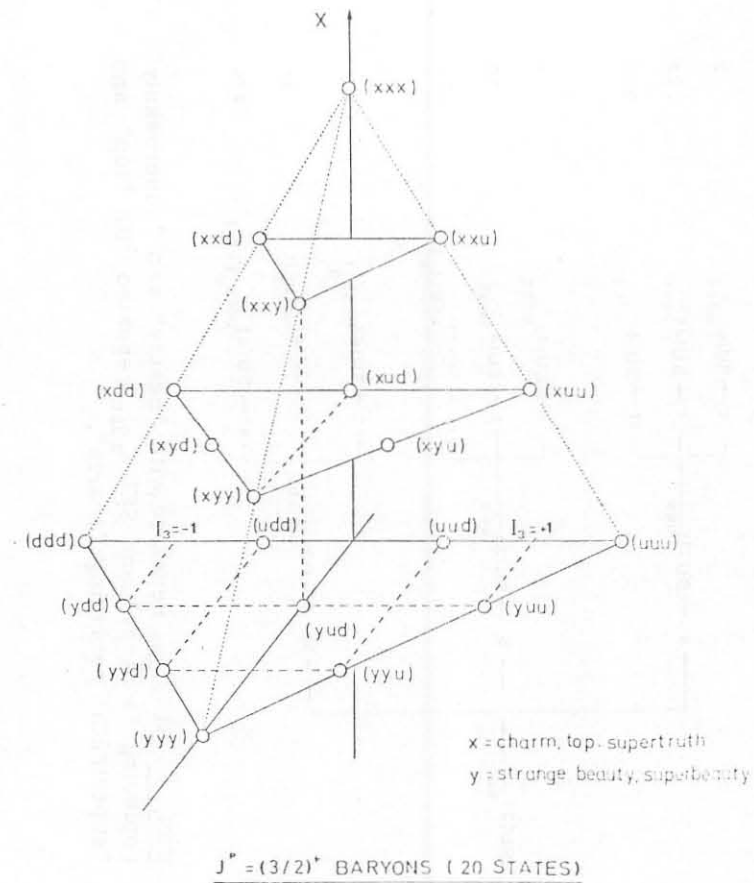


FIG. 7 - As above for the $J^P = \frac{3}{2}^+$ Baryon states.

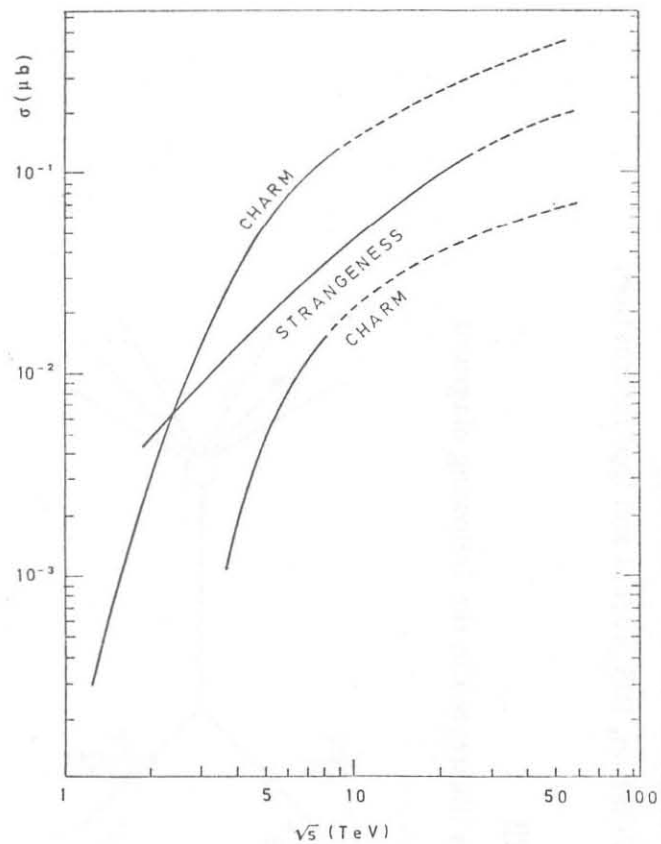


FIG. 8 - The "supertruth" cross section derived from "strange" and "charm" cross sections following formula (3). Notice the width, due to the experimental uncertainties relative to the charm data.

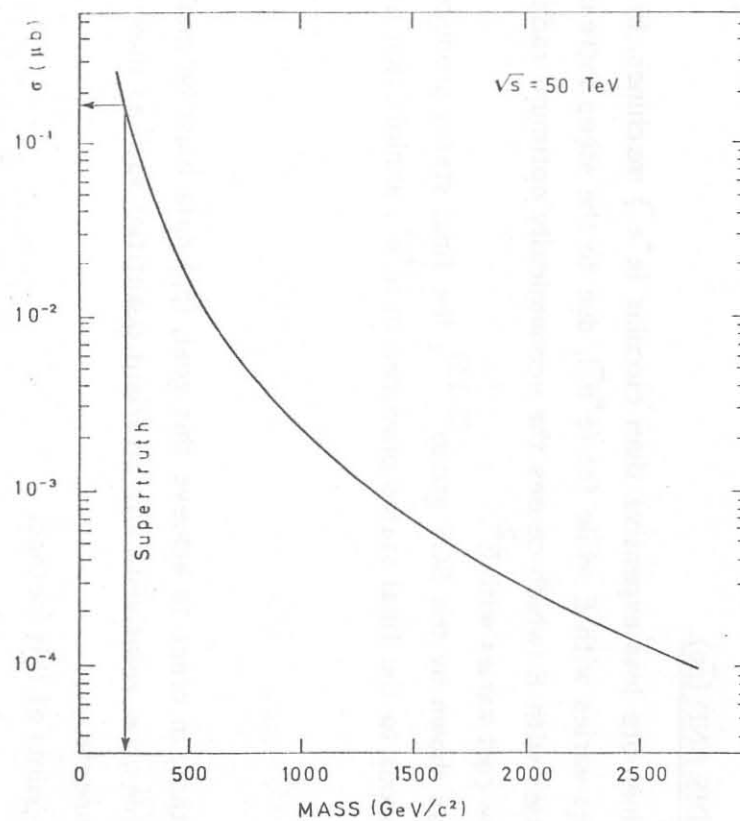


FIG. 9 - The production cross-section at $\sqrt{s} = 50$ TeV as a function of mass.

extrapolating present knowledge using simplicity, we find out that a 50 TeV machine gives access to very large mass objects, as shown in Figs. 8 and 9.

3. - (pp) VERSUS (e⁺e⁻), DIS AND (p̄p)

Proton-proton machines are less expensive than circular (e⁺e⁻) machines. In fact the cost for (pp) machines varies with E while for (e⁺e⁻), due to the steep increase in synchrotron radiation losses with E (which causes the economically optimum radius to be proportional to E²), the cost varies with E².

On the other hand, as shown by the BCF group⁽²⁻¹⁵⁾, the final states produced in (pp) collisions look analogous to the final states produced in (e⁺e⁻) annihilation and in DIS processes.

3.1. - Physics Results

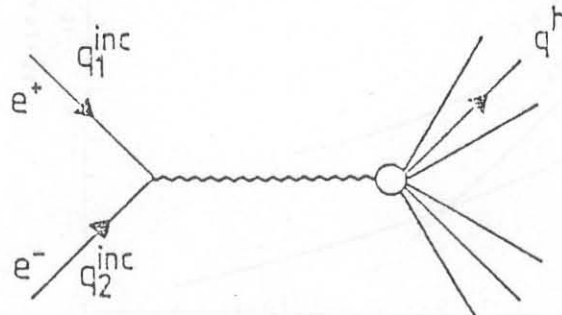
It should be notice that, in order to achieve this goal, (pp) data must be analysed using the "correct" variables, i.e. relativistically invariant quantities such as those used for (e⁺e⁻) and DIS experiments.

Let us see the basic points of this method.

We start with the analysis of the meaning, in terms of relativistic invariant quantities, of (e⁺e⁻) annihilation, DIS process and (pp) interaction.

3.1.1. - (e⁺e⁻) annihilation

(e⁺e⁻) annihilation is illustrated in the following diagram:



where q₁^{inc} and q₂^{inc} are the four-momenta of the incident positron e⁺ and electron e⁻; q^h is the four-momentum of a hadron produced in the final state, whose total energy is

$$(\sqrt{s})_{e^+e^-} = \sqrt{(q_1^{\text{inc}} + q_2^{\text{inc}})^2} = 2E^{\text{inc}}$$

in the reference frame where $\vec{q}_1^{\text{inc}} + \vec{q}_2^{\text{inc}} = 0$. When this happens in the Lab-system, $2E^{\text{inc}} = 2E_{\text{beam}}$.

As we will see later,

$$q_1^{\text{inc}} = q_1^{\text{had}}, \quad q_2^{\text{inc}} = q_2^{\text{had}},$$

where $q_{1,2}^{\text{had}}$ are the four-momenta available in a (pp) collision for the production of a final state with total hadronic energy

$$\sqrt{(q_1^{\text{had}} + q_2^{\text{had}})^2} = \sqrt{(q_{\text{tot}}^{\text{had}})^2}$$

It is this quantity $\sqrt{(q_{\text{tot}}^{\text{had}})^2}$ which should be used in the comparison with (e^+e^-) annihilation, and therefore with $(\sqrt{s})_{e^+e^-}$. This means that

$$(\sqrt{s})_{e^+e^-} = \sqrt{(q_{\text{tot}}^{\text{had}})^2}.$$

Moreover, the fractional energy of a hadron produced in the final state of an (e^+e^-) annihilation is given by

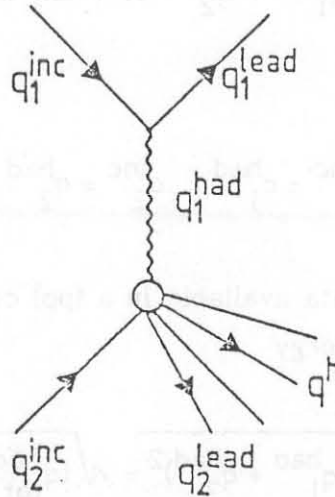
$$(x)_{e^+e^-} = 2 \frac{q^{\text{h}} \cdot q_{\text{tot}}^{\text{had}}}{q_{\text{tot}}^{\text{had}} \cdot q_{\text{tot}}^{\text{had}}} = 2 \frac{E^{\text{h}}}{(\sqrt{s})_{e^+e^-}}$$

where the dots indicate the scalar product and E^{h} is the energy of the hadron "h" measured in the (e^+e^-) c.m. system. Notice that the four-momentum $q_{\text{tot}}^{\text{had}}$ has no space-like part:

$$q_{\text{tot}}^{\text{had}} = (i0, (\sqrt{s})_{e^+e^-}).$$

3.1.2. - DIS Processes

DIS processes are illustrated in the diagram below:



where q_1^{inc} and q_1^{lead} are the four-momenta of the initial - and final - state leptons, respectively; q_2^{inc} is the four-momentum of the target nucleon; q_1^{had} is the four-momentum, transferred from the leptonic to the hadronic vertex, whose time-like component in the laboratory reference system is coincident with the invariant quantity $q_1^{\text{had}} \cdot q_2^{\text{inc}} / \sqrt{(q_2^{\text{inc}})^2}$, usually indicated as ν :

$$q_1^{\text{had}} = (i\vec{p}_1^{\text{had}}, \nu = E_1^{\text{had}}).$$

Notice that in order to easily identify the equivalent variables in (pp) interactions, we have introduced a notation in terms of E_1^{had} and \vec{p}_1^{had} .

A basic quantity in DIS is the total hadronic mass

$$(W^2)_{\text{DIS}} = (q_1^{\text{had}} + q_2^{\text{inc}})^2$$

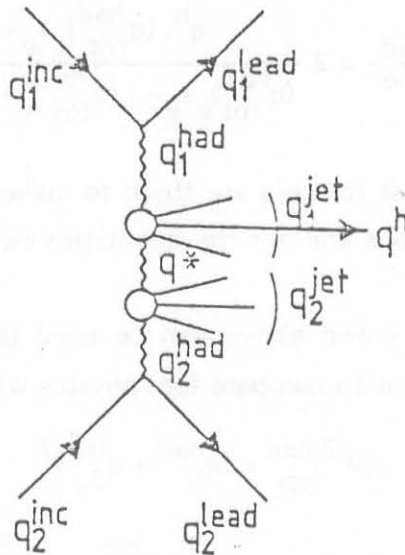
and the fractional energy

$$(z)_{\text{DIS}} = \frac{q^{\text{h}} \cdot q_2^{\text{inc}}}{q_1^{\text{had}} \cdot q_2^{\text{inc}}}$$

where again the dots between the four-momenta indicate their scalar product.

3.1.3. - (pp) Interactions

(pp) interaction are illustrated in the following graph:



where $q_{1,2}^{inc}$ are the four-momenta of the two incident protons, $q_{1,2}^{lead}$ are the four-momenta of the two leading protons, $q_{1,2}^{had}$ are the space-like four-momenta emitted by the two proton vertices; q^h is the four-momentum of a hadron produced in the final state.

Now attention! A (pp) collision can be analysed in such a way as to produce the key quantities proper to (e^+e^-) annihilation and DIS processes.

In fact, from the above diagram we can work out the following quantities^(*) which are needed if we want to compare (pp) physics with (e^+e^-) , i.e.

$$(q_{tot}^{had})_{pp} = (q_1^{had} + q_2^{had})_{pp}$$

in fact

$$\sqrt{(q_{tot}^{had})_{pp}^2} = (\sqrt{s})_{e^+e^-}.$$

(*) notice that: $\sqrt{(q_{tot}^{had})_{pp}^2} \approx 2E^{had^2}$, and $(x)_{pp}^{had} \approx x_R^{*2}$

Moreover

$$(x)_{pp}^{\text{had}} = 2 \frac{q^h \cdot q_{\text{tot}}^{\text{had}}}{q_{\text{tot}}^{\text{had}} \cdot q_{\text{tot}}^{\text{had}}},$$

to be compared with

$$(x)_{e^+e^-}^{\text{had}} = 2 \frac{q^h \cdot (q_{\text{tot}}^{\text{had}})_{e^+e^-}}{(q_{\text{tot}}^{\text{had}})_{e^+e^-} \cdot (q_{\text{tot}}^{\text{had}})_{e^+e^-}}$$

where the subscripts in the last formula are there to make it clear that these quantities are measured in (e^+e^-) collisions and are the quantities equivalent to those measured in (pp) interactions.

The same (pp) diagram shown above can be used in order to work out the key quantities needed when we want to compare (pp) physics with DIS. In this case we have

$$(W^2)_{pp}^{\text{had}} = (q_1^{\text{had}} + q_2^{\text{inc}})^2$$

and

$$(z)_{pp}^{\text{had}} = \frac{q^h \cdot q_2^{\text{inc}}}{q_1^{\text{had}} \cdot q_2^{\text{inc}}}.$$

Notice that in W^2 the leading proton $n^\circ 2$ is not subtracted. This is the reason for the differences found in the comparison between DIS data and e^+e^- . In fact W^2 is not the effective total energy available for particle production, owing to the presence there of the leading proton.

3.1.4. - Results

We will report only few examples of the results obtained by the BCF group in the detailed study of the purely hadronic interactions and their comparison with (e^+e^-) annihilation and DIS. These examples are:

- i) the differential cross section $(1/\sigma) (d\sigma/d(p_t/ \langle p_t \rangle))$ versus the reduced variable $p_t/ \langle p_t \rangle$ (Fig. 10);
- ii) the inclusive single-particle fractional distribution $(1/\sigma) (d\sigma/dx_R^*)$ (Fig. 11);
- iii) the average charged-particle multiplicity, $\langle n_{\text{ch}} \rangle$ (Fig. 12);
- iv) the inclusive distribution of the fractional energy, $(1/\sigma) d\sigma/dz$ (Fig. 13).

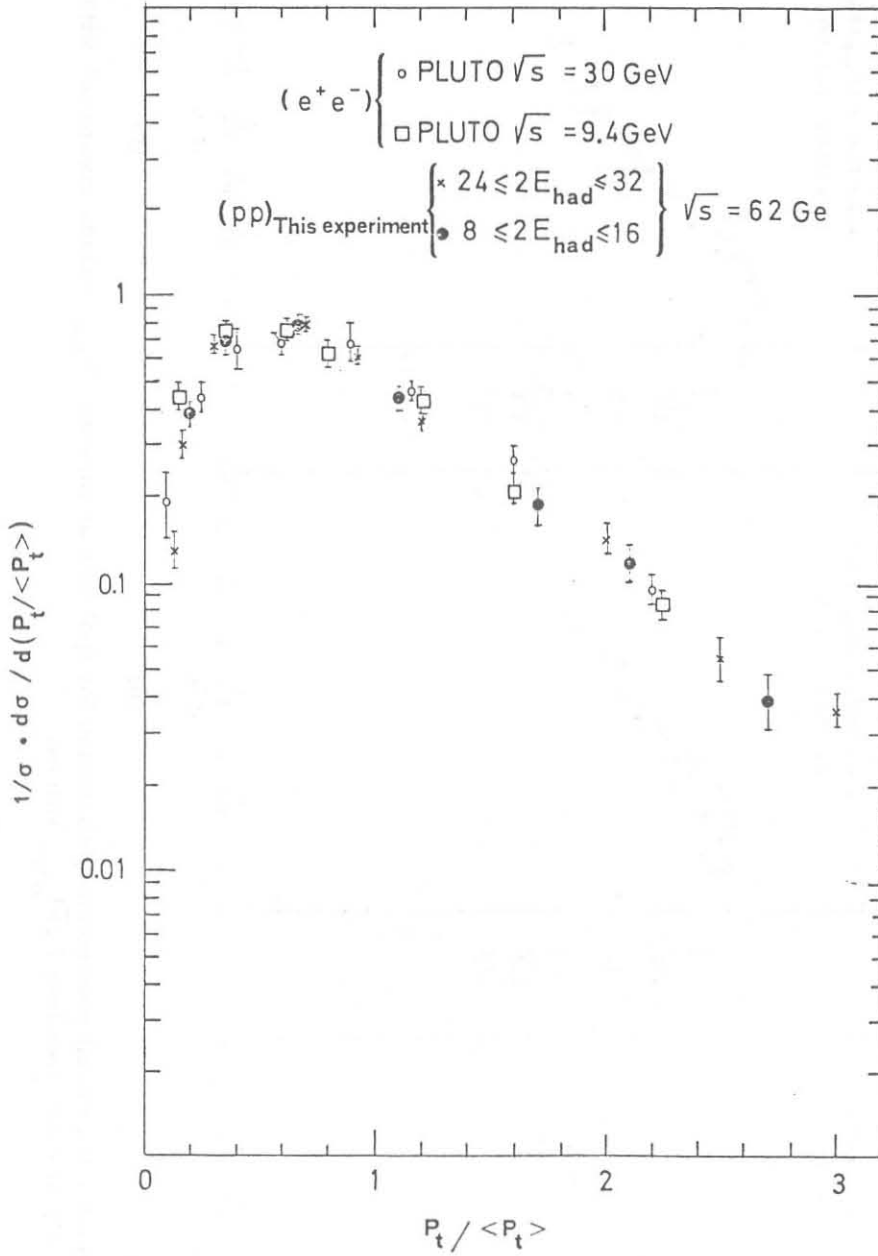
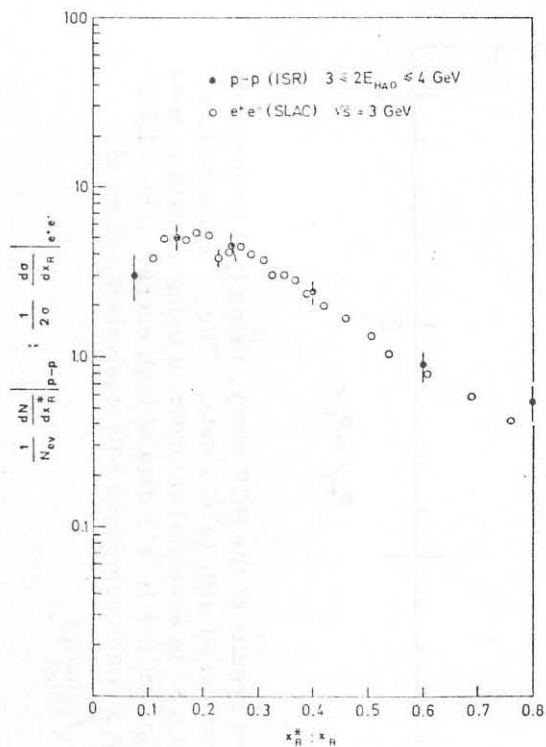
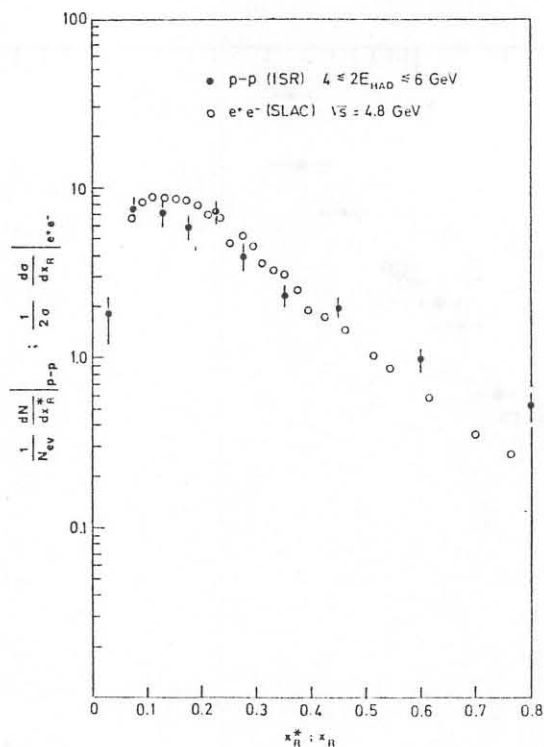


FIG. 10 - The results of the BCF study, using (pp) interactions at the ISR, compared with (e^+e^-) data. The "renormalized" value of $p_t / \langle p_t \rangle$ is essential in order to bring all data in good agreement. In fact the (e^+e^-) data at high energy show higher values of $\langle p_t \rangle$ when compared with equivalent values of

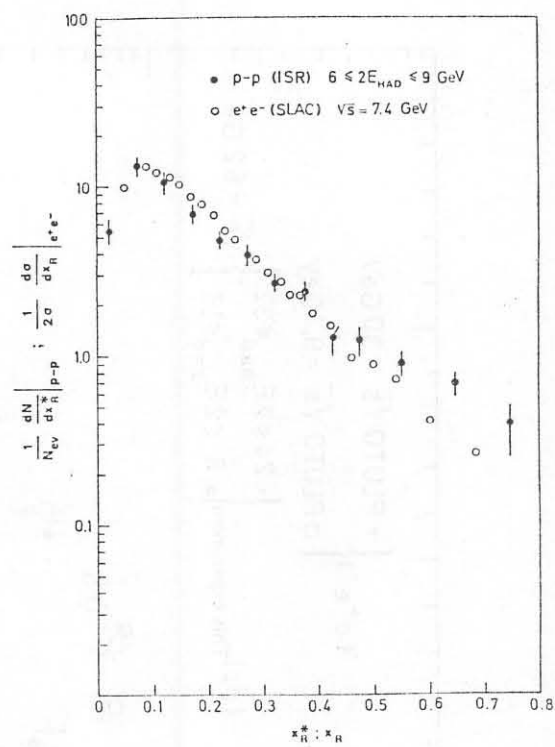
$$(\sqrt{s})_{e^+e^-} = \sqrt{(q_{\text{tot}}^{\text{had}})^2}$$



(a)

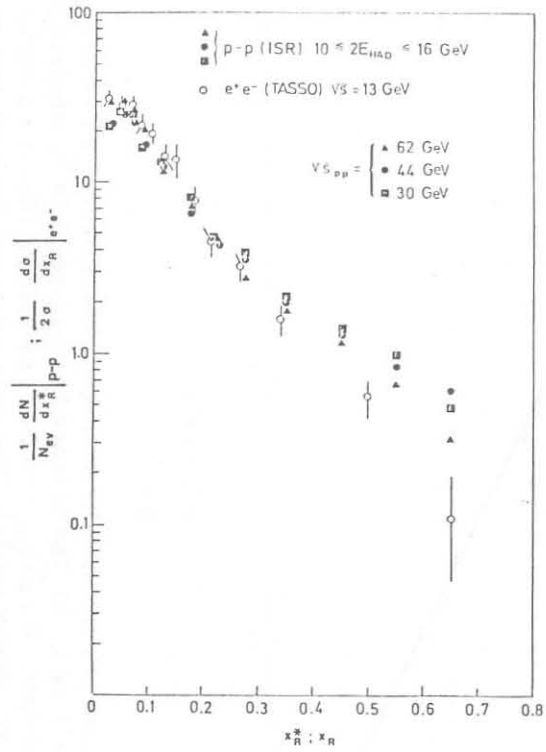


(b)

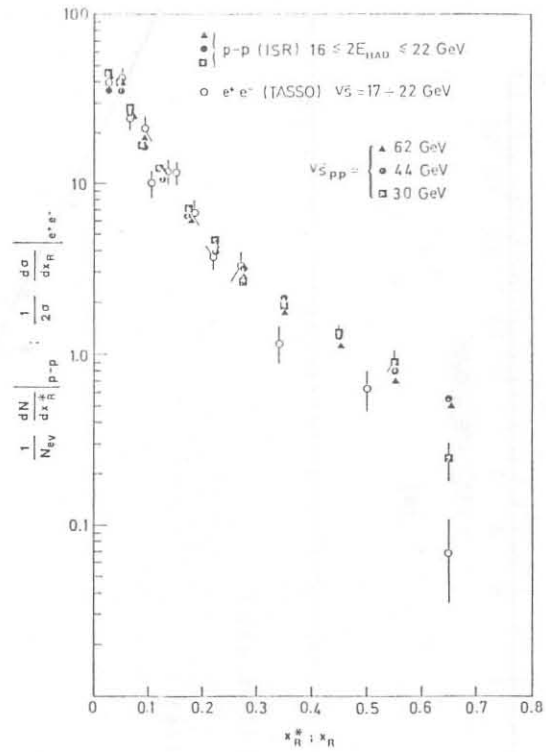


(c)

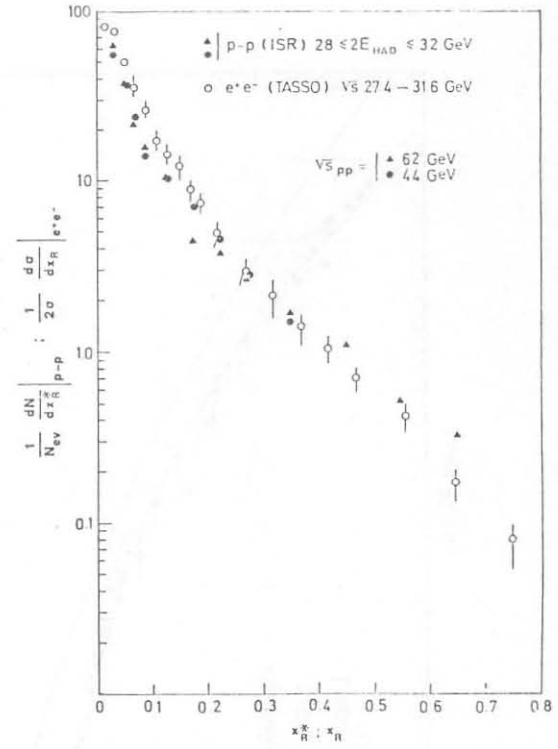
FIG. 11 - The inclusive fractional momentum distribution for (pp) data at various $2E_{\text{had}}$ values compared with the distribution in (e^+e^-) at corresponding (\sqrt{s}) e^+e^- values.



(d)



(e)



(f)

FIG. 11 - The inclusive fractional momentum distribution for (pp) data at various $2E_{had}$ values compared with the distribution in (e^+e^-) at corresponding $(\sqrt{s})_{e^+e^-}$ values.

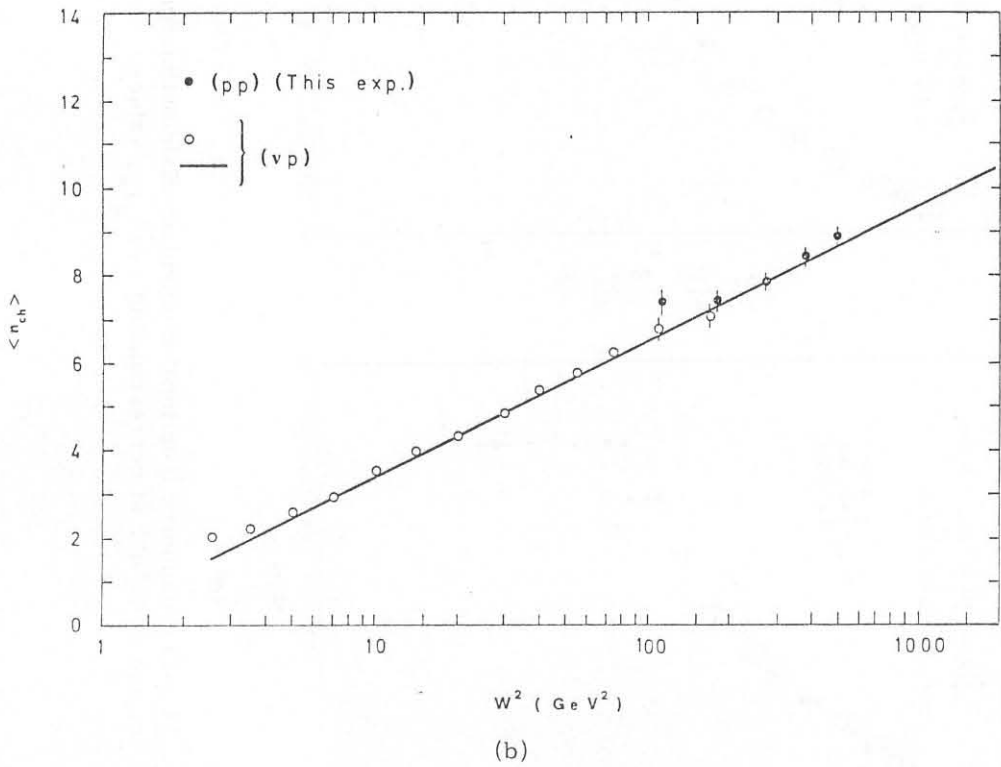
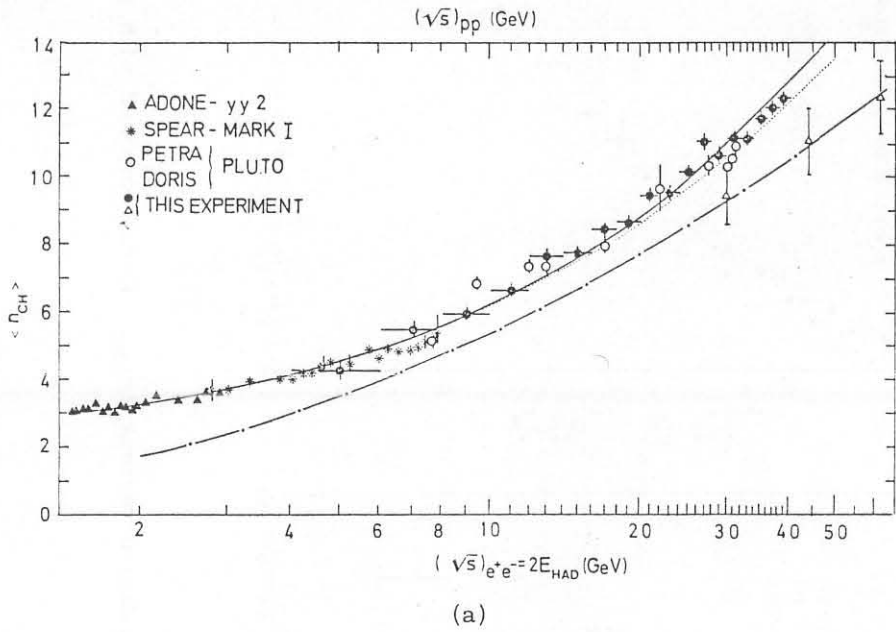


FIG. 12 - a) Mean charged multiplicity averaged over different \sqrt{s} vs $2E_{had}$ compared with (e^+e^-) data. b) The average charged-particle multiplicities $\langle n_{ch} \rangle$ measured in (pp) , at $(\sqrt{s})_{pp} = 30$ GeV, by using a DIS-like analysis, are plotted versus W^2 (black points). The open points are the (vp) data and the continuous line is their best fit.

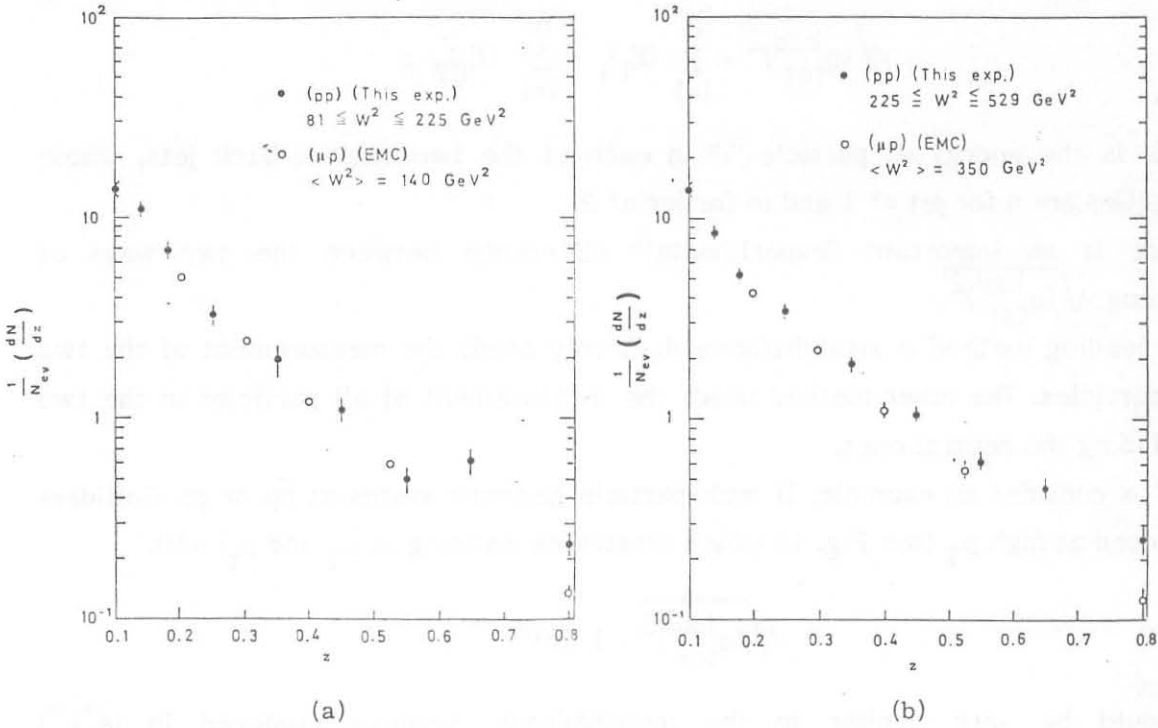


FIG. 13 - Inclusive distribution of the fractional energy, z , for (pp) reactions compared with the data from (μp) reactions.

3.2. - Conclusions

The use of the correct variables for describing hadron production in (pp) interactions, (e^+e^-) annihilations, and DIS processes, is the basic point for putting these three ways of producing multiparticle hadronic systems on an equal footing. This new method of studying (pp) interactions allows to identify, in each of the processes, the effective hadronic energy available for particle production. This energy is the key quantity in comparing different processes. The preliminary data from the $(\bar{p}p)$ CERN Collider (UA1 and UA2 groups) in the study of the jets, confirm our predictions on the existence of universality features in the production of multiparticle hadronic systems in purely hadronic interactions, in (e^+e^-) annihilations and in DIS processes.

In fact there are two ways of determining $\sqrt{(q_{\text{tot}}^{\text{had}})^2}$.

One is to use the two "leading" particles.

The other, when the "leading" method is out of experimental reach, is to use the measurements of the total energy carried by two back-to-back jets. In fact, the basic quantity in comparing multihadronic states is the effective energy available for particle production, not the "nominal" one. In the case of two back-to-back jets, it is

$$\sqrt{(q_{\text{tot}}^{\text{had}})^2} = \sum_{i=1}^n (E_i)_1 + \sum_{i=1}^m (E_i)_2 ,$$

where E_i is the energy of particle "i" in each of the two back-to-back jets, whose multiplicities are n for jet n° 1 and m for jet n° 2.

There is an important "experimental" difference between the two ways of determining $\sqrt{(q_{\text{tot}}^{\text{had}})^2}$.

The leading method is straightforward. It only needs the measurement of the two leading particles. The other method needs the measurement of all particles in the two jets, including the neutral ones.

Let us consider an example. If multiparticle hadronic states at $\bar{p}p$ or pp Colliders are produced at high p_T (see Fig. 14 which illustrates meaning of p_T and p_t) with

$$\sqrt{(q_{\text{tot}}^{\text{had}})^2} = 1 \text{ TeV}$$

they should be very similar to the multihadronic systems produced in (e^+e^-) annihilations, with

$$(\sqrt{s})_{e^+e^-} = 1 \text{ TeV} .$$

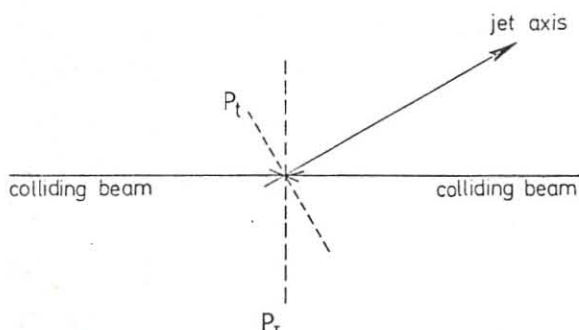


FIG. 14 - Sketch describing the quantities p_T and p_t . Notice that the p_t and the planes are both perpendicular to the figure.

Such an (e^+e^-) machine will not be easily available. What will exist are the low- p_T and the high- p_T jets with $\sqrt{(q_{\text{tot}}^{\text{had}})^2} = 1 \text{ TeV}$, produced in the multiTeV Collider.

To compare, at the multiTeV Collider, multihadronic final states with the same values of $\sqrt{(q_{\text{tot}}^{\text{had}})^2}$ at high p_T and at low p_T is of great value in understanding the dynamic of strong interactions.

From our findings at the ISR the only difference between high- p_T and low- p_T jets should be the value of $\langle p_t \rangle$, and the difference should disappear if the variable $p_t / \langle p_t \rangle$ is used, (see Fig. 10).

At the multiTeV Collider the slope of $\langle p_t \rangle$ versus $\sqrt{(q_{tot}^{had})^2}$ can be measured up to the highest energy. Then it will be necessary to wait until LEP III will allow to check these analogies.

The implications of the above considerations for the physics to be studied in future machines are very important:

- purely hadronic interactions means using machines such as the CERN Intersecting Storage Rings (ISR), the CERN ($\bar{p}p$) Collider, the FNAL ($\bar{p}p$) Collider, the DESERTRON and the ELOISATRON;
- (e^+e^-) annihilations means using machines such as LEP and its possible developments;
- DIS processes means using machines such as HERA.

Let us consider in more details the problem of a ($\bar{p}p$) Collider in the multiTeV energy range.

3.3. - A basic difference in comparing (pp) and ($\bar{p}p$) machines

The main problem with ($\bar{p}p$) machines, with respect to (pp) intersecting rings, is luminosity.

To show the importance of luminosity let us look at the results obtained (Ref. G. Kane, private communication) in the analysis of the performances achievable by seven typical experiments as a function of machine energy and luminosity.

LUMINOSITY	E_T for $\sqrt{s} = 10$ TeV	N. of experiments which reach 1 TeV scale for $\sqrt{s} = 40$ TeV
10^{30}	0.1 TeV	2 out of 7
10^{32}	1 TeV	5 out of 7
10^{34}	2 TeV	all

ENERGY VERSUS LUMINOSITY	
5 TeV	$l = 3 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$
15 TeV	$l = 3 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$
The same q^2 is reached in the two cases	

For the case of high- $p_T \pi^0$ production, a factor 3 in energy is compensated by a factor 10 in luminosity.

However, if interactions much harder than QCD should exist, then the basic quantity becomes energy.

There is no question that, in the design of a new machine, we should try for the highest energy and the highest luminosity. Any "rare" process to be investigated needs the highest luminosity. Keeping in mind the conclusions of the previous section, this means that (pp) collisions win.

4. - MACHINE

The main parameters of the proposed European LOnG Intersecting Storage Accelerator (ELOISA-TRON) are summarized in the following Table V.

TABLE V

Energy (TeV) ,	(25 + 25)
Luminosity ($\text{cm}^{-2} \text{s}^{-1}$)	10^{32} (10^{31})
No. of intersections	6 - 8
Particles	pp ($\bar{p}p$)
No. of rings	Two rings in one cryostat

4.1. - General remarks

From the study of what has been done so far all over the world, one can conclude that:

- i) the machine is feasible, i.e. there are no basic or "in principle" difficulties;
- ii) the key problem is cost, i.e. it is necessary to reduce the present cost per unit energy by a large factor.

It follows that, for the machine, innovative engineering work is rather more needed than machine physics work.

In particular, the areas where research and development are most needed are:

- Superconducting magnet technology;
- System engineering;

- \bar{p} production (if \bar{p} are indeed required).

A large fraction of the R&D effort should be oriented towards the production of machine components with the required quality at low cost, and towards original engineering solutions.

As an example, in the USA a solution has been considered for the machine tunnel where prefabricated sections would be assembled as is done for pipe-lines, each section consisting of a circular pipe accessible only to robots in which a 150 m long magnet and one quadrupole would have been pre-installed.

Although from our study this does not seem to be the optimum solution, it is a good example of how drastically one may have to change the classical approach to achieve the desired cost effectiveness.

Finally, let us briefly comment on the choice of a machine consisting of two rings in a single cryostat.

To obtain a high average luminosity ($\sim 10^{32}$ - 10^{33} $\text{cm}^{-2} \text{s}^{-1}$) without running into the problem of too high a luminosity per collision giving several (unresolvable) events, one has to operate with many bunches, which have to be separated everywhere except for a few interaction regions.

The solution having two rings in the same cryostat automatically provides the beam separation in the non-intersecting regions and therefore the possibility of many-bunch operation.

A single ring would require a much larger aperture in order to be able to separate the beams, if at all possible, and would certainly have to operate with a much lower number of bunches.

4.2. - Feasibility

Many working parties all over the world have studied the design problems of a multiTeV machine, without encountering fundamental design limitations.

A feasibility design exists for:

- the lattice,
- the low- β insertions,
- the injector,

and possible bunch separation schemes have been considered.

Studies of instabilities and limitations due to field non linearity have given reason to believe that luminosities in the range between 10^{32} and 10^{33} $\text{cm}^{-2} \text{s}^{-1}$ can indeed be obtained with practical currents and apertures.

The quoted values for the energy and luminosity proposed for ELOISATRON are therefore by no means to be considered science fiction. They are the limits of which we can think now, extrapolating present technologies.

The ($\bar{p}p$) option should be better investigated although (pp) seems to be the best bet from all points of view.

The proposed two-(rings)-in-one (cryostat) solution seems to be the best one.

Even if much R&D is still needed the machine is a classical object which we believe is feasible.

4.3. - Superconducting magnets

There are two extreme options concerning the superconducting (SC) magnets:

- i) the low-field, $B \simeq 3T$, "superferric";
- ii) the high-field, $B \simeq 8T$, (wire to be developed, $2^\circ K$ operation).

In the "superferric" magnets the iron structure gives 2T (with a "few" Ampère-turns) while the rest of the field is provided by the superconducting winding. The low-field magnets are easier to make, cheaper, and require much less R&D than the high-field ones. Note for instance that the superconducting cable with high enough limit current density (J_c) to assemble high field magnets is not at present being produced on an industrial scale. In practice, however, the choice between low and high field magnets will not affect the total cost very much. In fact, as it has been shown in feasibility studies, the lower cost of "superferric" magnets is almost exactly compensated by the additional cost of the large circumference they require.

In order to reduce the cost of magnets, they should be as long as possible, since a large fraction of the costly items (coils bends, connections, etc.). is concentrated at the magnet ends where most of the (expensive) heat leaks also occur. With due account of field quality and installation problems, a length of 150 m is considered as an upper limit.

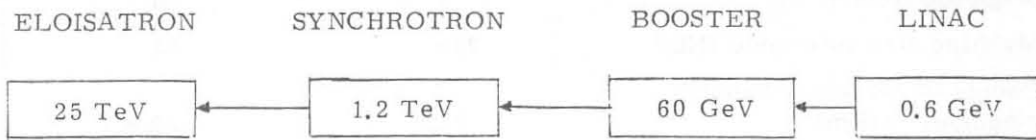
Note that a drastic reduction of heat leaks is essential to keep the installation and running costs down. The (25+25) TeV machine must have a refrigeration system not much bigger than that of existing 1 TeV Fermilab energy doubler-saver.

However, the production of 150 m long superconducting magnets with the required good field quality and mechanical tolerances is a serious problem. Present technology (Fermilab, HERA, etc.) produces 5T, 6 m long SC magnets of the required quality but mass production of such items is not yet considered to be a straightforward enterprise.

Our american colleagues estimate that three years of R&D are necessary for the experienced laboratories to acquire the know-how to produce 3T, 150 m long magnets, and at least four years for ~ 8 T very long magnets.

4.4. - The injector

The following design for the injection system is proposed:



The booster would have a few seconds cycle time, while the injector synchrotron would have a few minutes cycle ($2\pi R \approx 10$ Km); the filling time of the main rings would be ~ 1 hour for the proton current required for the maximum luminosity.

A much longer injection time would be necessary for $\bar{p}p$ at least with present technologies. At present, to achieve $L \sim 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ in $(\bar{p}p)$ one would need of the order of 40 h to accumulate the required antiproton current.

It is however reasonable to assume that, in the years to come, great progress will be made at CERN in the field of antiproton production.

4.5. - A summary of the main parameters of ELOISATRON

The main parameters of ELOISATRON are summarized in Table VI. The two options, high field and low field magnets, are presented.

Note that in both cases the number of magnets needed (1160 for 3T and 440 for 8T) is typical of mass production and this is an important point to reduce the machine cost.

4.6. - The cost

The cost estimate depends on many factors and is, of course, the major problem. If one chooses an optimistic approach to see where one stands, assuming there will be a vigorous R&D program and innovative engineering, the figure arrived at, for the total cost, is of about 2×10^9 US Dollars.

A break-down of cost into the various items is given in Table VII.

TABLE VI

(Extrapolated from results of Cornell Workshop, March 1983)

	LOW-FIELD	HIGH-FIELD
Particles		PP
Energy (TeV)		25
Luminosity ($\text{cm}^{-2} \text{s}^{-1}$)		10^{32}
Magnetic field B (T)	3	8
Machine circumference (Km)	230	85
Radius of curvature bending magnets, ρ (Km)	27.8	10.4
No. of protons per bunch	3.3×10^{13}	1.2×10^{13}
Betatron amplitude in the intersecting regions, β^* (m)		2
Maximum linear tune shift ΔQ_{max}	0.002	0.0045
Aperture, ϕ (cm)		2-3
Damping time (h)	77	11
No. of 150m long bending magnets	1160	440

TABLE VII - COST (10^6 USA \$)

(Extrapolated from results of Cornell Workshop, to be achieved through a vigorous R & D program and innovative engineering)

	LOW-FIELD	HIGH-FIELD
General facilities Injector Experimentals areas	600 ± 100	600 ± 100
Magnets	600 ± 150	1000 ± 250
RF, Controls Refrigeration Other facilities and installations	400 ± 100	300 ± 60
Tunnel, roads Power distribution Service buildings	400 ± 500	160 ± 60
Total facility	2000 ± 450	2060 ± 470

4.7. - Specialized working groups

The ELOISATRON project is structured into the following 11 working groups.

- 1) Machine theoretical
- 2) SC magnets
- 3) Injector
- 4) Civil engineering
- 5) Experimental areas
- 6) Refrigeration power plants
- 7) Standard plants
- 8) Vacuum
- 9) Radiofrequency
- 10) Controls
- 11) Anti-Desert physics.

4.8. - Where and how to build ELOISATRON

ELOISATRON could be installed in the Puglie, (Fig. 15) a very nice region of Italy, which is seismologically very stable. Fig. 16 shows a general layout with the crossing regions indicated.

The machine diameter will be about 40 Km so that the machine circumference will touch the Adriatico coast near Otranto and the Ionio coast near Gallipoli (both coasts being characterized by beautiful white sand and transparent sea).

Depending on the flatness of the ground, the machine could be built in part as prefabricated tracts (6 m deep, $4 \times 4 \text{ m}^2$ in cross-section) and in part in tunnel, as shown in Fig. 17. The cost has been estimated to be not higher than for the pipe-line solution.

Experimental areas should be wide, e.g. 100 m x 100 m and 20 m high. Their length could be of two types: 40 meters and 100 meters, depending on the physics program to be pursued. (See Figs. 18 and 19).

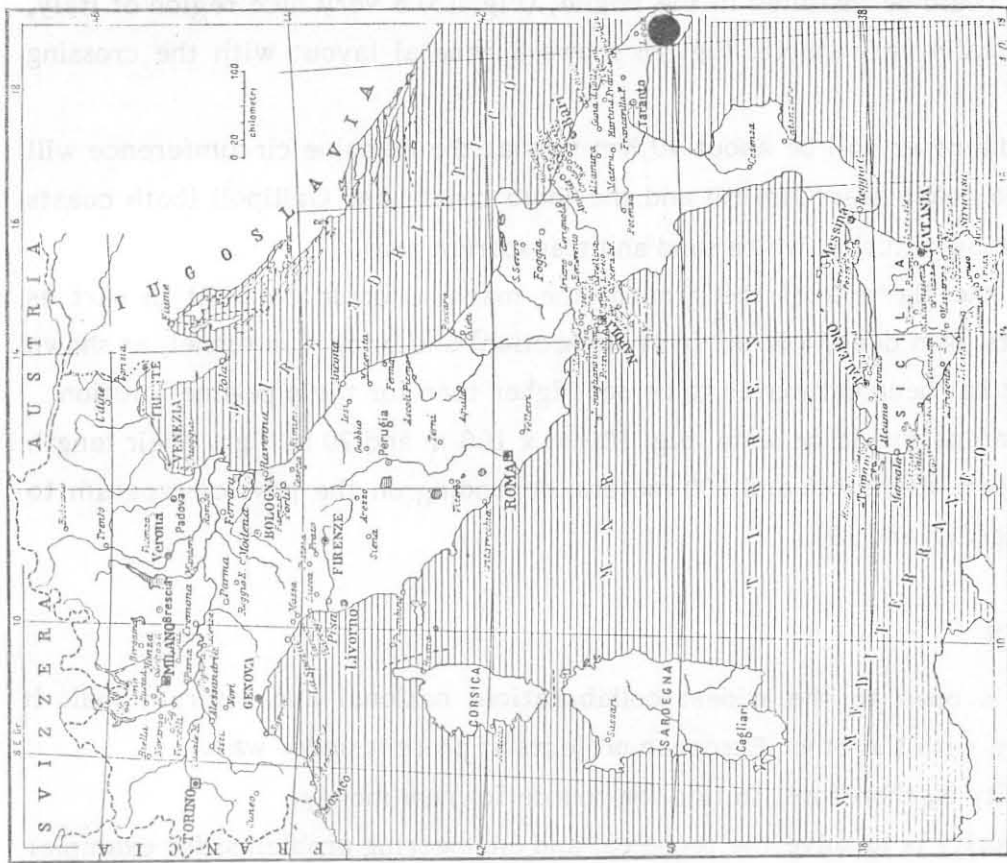
5. - CONCLUSIONS

This project is open to the widest collaboration, national and international. It should not interfere with the other European projects at present under way.

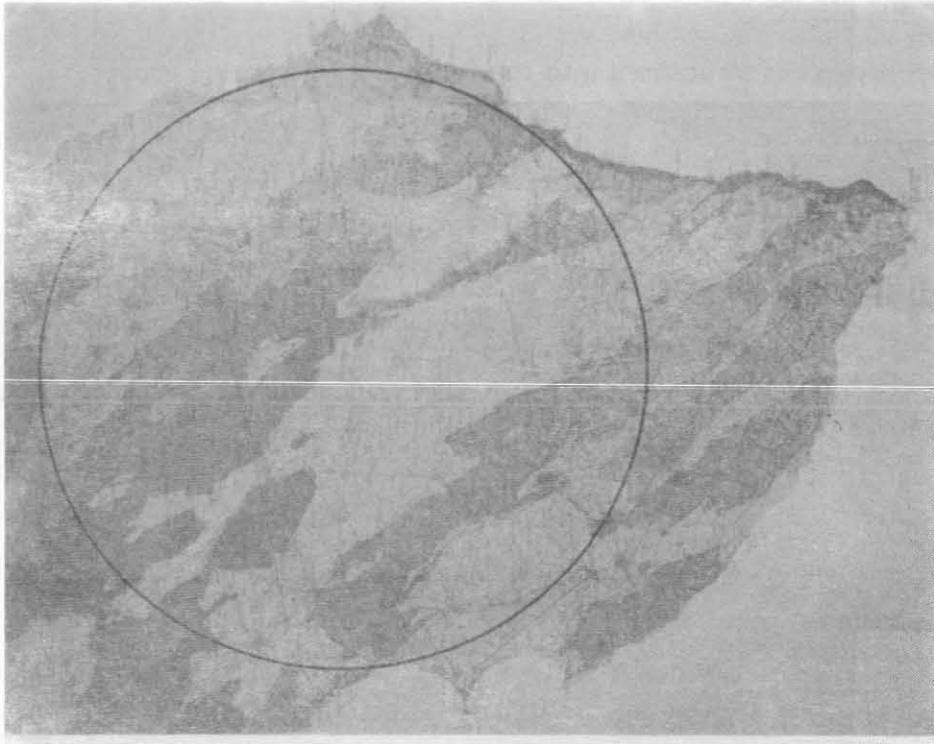
The first priority is, therefore, to find the source for new money.

The second priority is to solve the technical and engineering problems; for example: superconducting magnets and antiproton sources, if antiprotons are wanted.

Finally, a site must be chosen.



(a)



(b)

FIG. 15 - Showing the Puglie, a possible site for ELOISATRON.

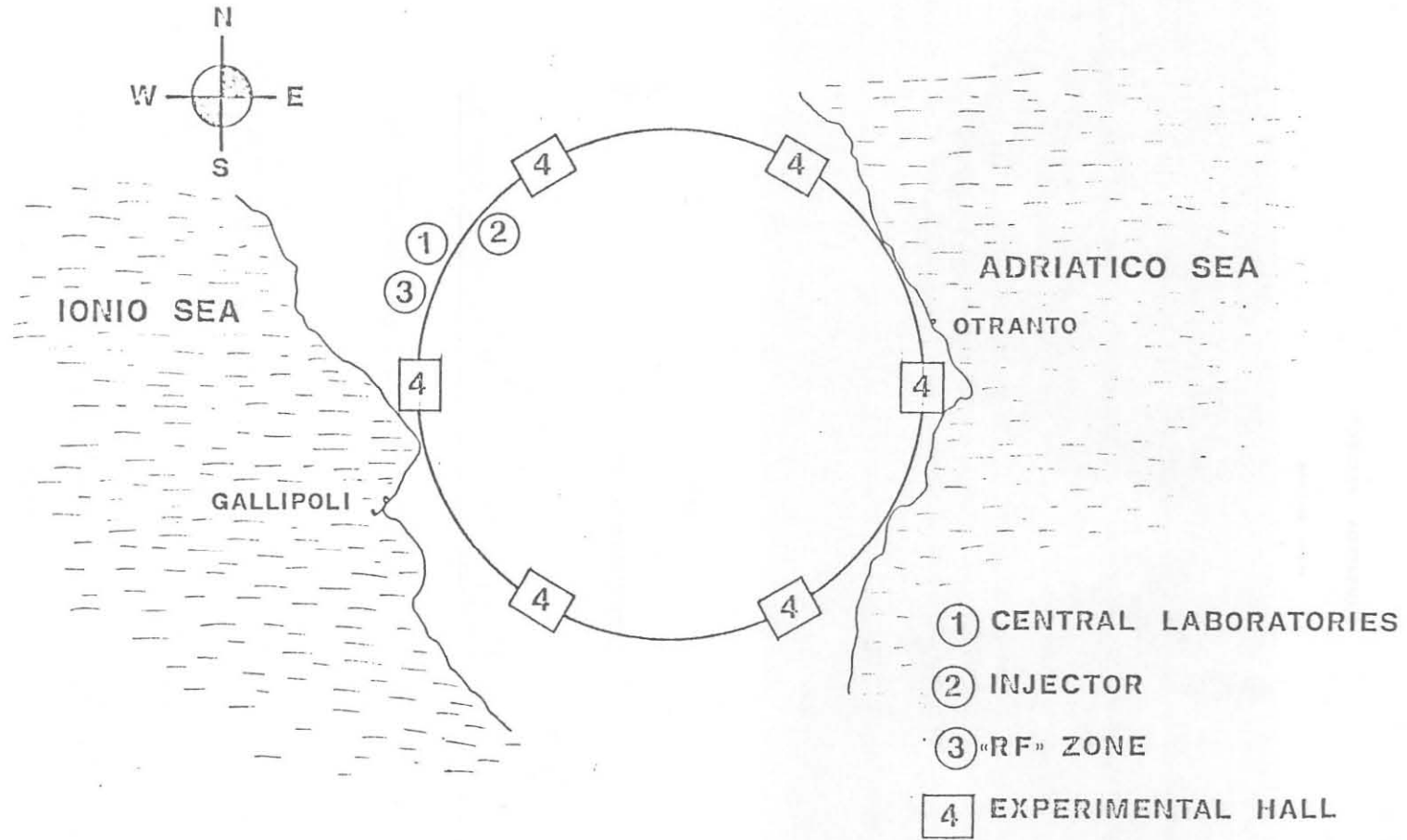
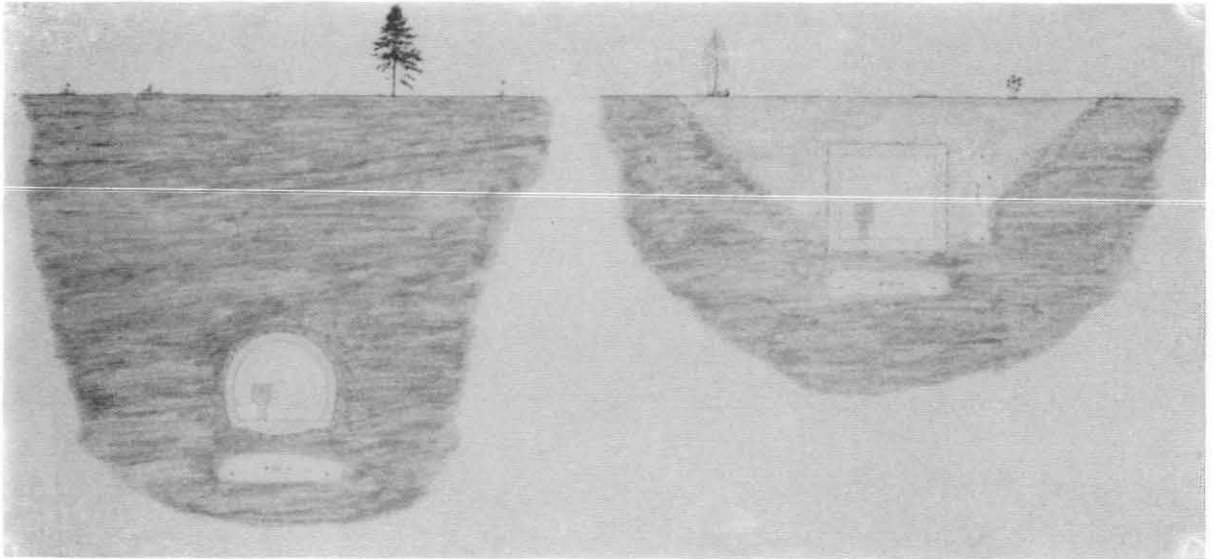


FIG. 16 - ELOISATRON general layout.

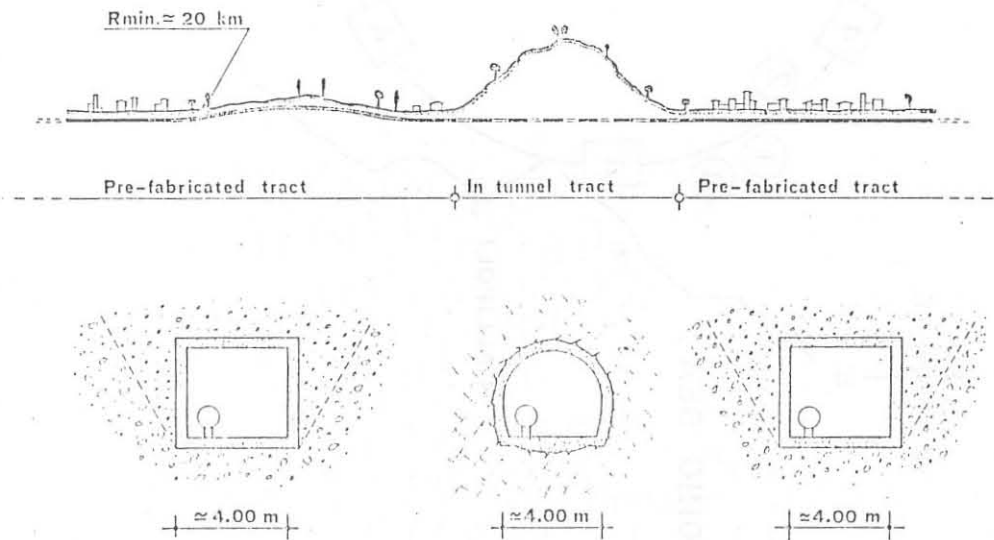
ELOISATRON PROJECT

MODEL SECTIONS



(a)

LONGITUDINAL SECTION



(b)

FIG. 17 - Showing a longitudinal section of the ELOISATRON. Notice the prefabricated tracts and the in tunnel tracts.

ELOISATRON PROJECT

EXPERIMENTAL HALL - Schematic Longitudinal Section

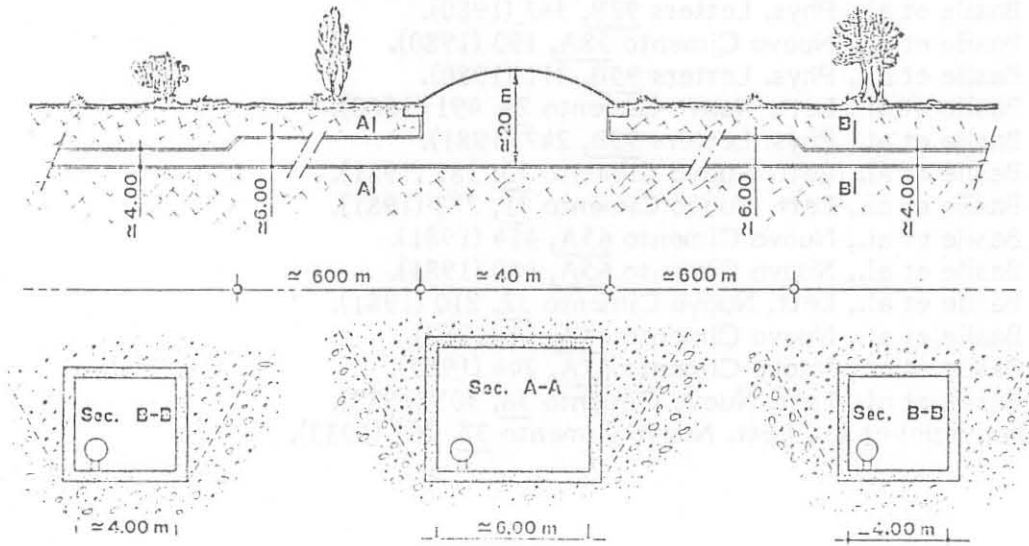


FIG. 18 - The schematic longitudinal section of an experimental hall.

ELOISATRON PROJECT

EXPERIMENTAL HALL - Schematic Plan View

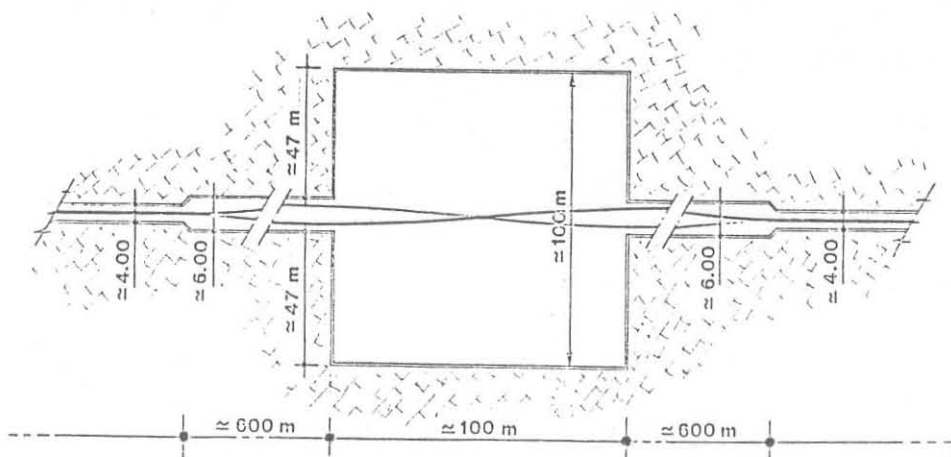


FIG. 19 - The schematic plan view of an experimental hall.

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