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# HIGH ENERGY PHYSICS IN OUR SOCIETY

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# HIGH ENERGY PHYSICS [illegible]

Michel Crozon
(Collège de France and [illegible])

## 1. INTRODUCTION

In this talk, I consider the role of high energy physics [illegible] also known by the name of "(elementary) particle physics" [illegible], in our society. Rather than advocating a particular value judgement, this talk aims at a pragmatic understanding of just what the particle physics [illegible] society interactions are.

Particle physics exists. It is a very basic research [1], [illegible] direct application is [illegible]ted in the [illegible] recognition from our society. The rather abstract goals of a [illegible] theory, the clarification of $Z^0$ decay properties or a resolution [illegible] CP violation puzzle do not entirely explain our society's investment in particle physics. To understand the appearance of particle physics as component of our society, one must also explore the [illegible]. In particular, this talk investigates:

What does particle physics receive from society?
What does society receive from particle physics?
Who, in society, benefits from particle physics?

These questions will be developed from several points of view, corresponding to different aspects of our society: men and education, economics, techniques... The contents of this talk are given schematically in Table 1.

From this Table 1, we see that the study of particle physics in our society has much in common with the more general and well known "science and society" questions. We will emphasize only what concerns specifically particle physics. Our investigation has also much in common with the study of major enterprises within our society such as Olympic games or symphonic orchestras! However, to limit the scope of this discussion we will not consider these comparisons here. Nevertheless, to those who like unusual views, I suggest this exercise: it shows physics in a different light! The common-sense categories of society used in Table 1 reflect our goal of a pragmatic understanding of the role of particle physics rather than, e.g. a sophisticated theoretical model for society.

In several categories, what particle physics gives back to society is very similar to what it receives, but only reinforced in some particular way. This is simply due to the fact that particle physics is itself a part of society, thus blurring the distinction between the contribution and the beneficiency. In this conference I shall certainly omit aspects which can appear important in your opinion. This is certainly the drawback of using such a grid of analysis. Anyway, one cannot expect to exhaust such a subject in a short time.

## 2. MEN AND EDUCATION

It is difficult to know how many people work in particle physics in the world. The only accessible sources regularly published are the statistics established by Christian Roche, from CERN [2], which concern Europe and the United States. They give only the number of physicists (experimentalists and theoreticians). An ECFA study of 1978 confirmed these statistics. They are reported in Table 2. One can see that the total number of physicists, for both Western Europe and the United States is rather stable, and amounts to a total of ∿ 3,000 experimentalists and ∿ 2000 theoreticians.

For the other parts of the world we have no precise number. Considering the number of accelerators and laboratories one can estimate 1,000 to 2,000 experimentalists (J.I.N.R. countries, China, Japan and other countries). For theory, a lot of work would be necessary to get good numbers. An overall unprecise estimate gives a total number of physicists between 7,500 and 10,000. Concerning engineers, technicians and clerks, if we assume the usual ratio of 1.5 to 2.5 workers per physicist, one gets a total amount of 15,000 to 25,000 people involved in particle physics. Although rather imprecise, this gives at least an order of magnitude.

Among these people, more than one third (and maybe one half) have received a University degree, and most of the others have received a training in technical schools. This can he correlated with the fact, which we will meet again in the following paragraphs, that particle physics exists almost exclusively in developed countries: in a polemic with Victor Weisskopf, Alvin Weinberg has criticized particle physics because it is too fond of brilliant talents [3].

Having received from society all these trained people, what does particle physics give back in return?

- Many physicists (between 1/3 and 3/4, according to countries) and engineers are teaching in universities or in engineering schools;

- large laboratories (CERN, Fermilab, DESY, SLAC...) are places where engineers and technicians acquire highly qualified technical skills (low temperatures, magnets, computers...) which can be used later in other fields of activity.

- Most laboratories have special students programs, which give an opportunity to young students to have a contact with advanced techniques and physics.

- Working in the international and competitive world of particle physics brings to young physicists and engineers an efficient training to work in this kind of professional environment.

## 3. ECONOMICS

The total cost of particle physics can only be roughly estimated. The only reliable sources are the reports by Ch. Roche already mentioned. To cumulate data from different countries, there are several problems:

- relative values of currencies
- variation of currencies (inflation)
- different ways of computing total costs. As for the above number of people we can try to extrapolate from the known to the total.

If we assume that salaries are similar in eastern countries as in Europe and the United States, then one can estimate the total expenses in 1982 to be around 3000 Million Swiss Francs (i.e. US$ 1400 Millions) . In this, salaries represent approximately 1/2 of the total. Also, in Table 2 and figs. 1, 2, and 3, one can find several figures which throw some light on the resources of particle physics:

- the amount of money per physicist has become approximately the same in Europe and the United States (Table 2);

- the comparison with Gross National Product (GNP) is interesting. One can see that H.E.P. costs $\sim 1{,}5$ to $2{,}5 \times 10^{-4}$ GNP in Europe and the United States. This amounts to between .5% and 1% of the total "Research and Development" funds in these countries. From this point of view, particle physics is not an over expensive field of research;

- receiving money, particle physics distributes it. Salaries represent the most important share: ≈ 1/2 to 2/3 of the total. This has an important impact for areas around accelerator centres, for example, the economy of "Pays de Gex" close to CERN, much depends on CERN salaries. Local authorities benefit from various taxes and fees. Most of the money besides salaries goes to industry (electronics, machinery, computing...). It can be a catalyst for innovative technologies as we will see in the following section;

- during a period of economic crisis, the building of particle accelerators can be used as a way to stimulate the economy, like "les grands travaux" in Paris in 1848, or Tennessee Valley Authority works in the thirties. For example, the decision to build PETRA in Hamburg and GANIL in Caen was taken in the framework of simultaneous plans of economy boost in West Germany and France in 1975.

## 4. TECHNIQUE

Besides its purely economical aspects, the interaction of particle physics with the technical world is important. The development of particle physics was directly linked to the progress of several techniques: high magnetic fields in large volumes, stabilization and control of linearly growing high power currents, powerful radio-waves, high vacuum, low temperature and cryogenics,...

The construction of accelerators and of large instruments requires the use of a large number of advanced techniques. This has been true for a long time: already the identification of electrons by J.J. Thomson (1897) was made possible thanks to the improvement of vacuum technique! Since then one can remark a parallelism between technical advances and discoveries in particle physics: Cloud chambers, Geiger counter and coincidence circuits (positron, neutron, muon and, later, strange particle), progress in photographic emulsion giving a way to observe minimum ionizing particles (decays of particles $\pi$, K, $\Lambda$...) scintillators and photomultipliers (cross-sections, resonances), computers (bubble chambers physics). More recently, the W and $Z^0$ discoveries were strongly dependent on the mastery of several advanced techniques to handle antiproton cooling, beam management, computer network, vacuum... Concerning techniques, particle physics receives much of the society. It is the technical world of mechanical, electrical and chemical engineering that makes this research feasible. Perhaps the difference with the J.J. Thomson time is the fact that every new step is now the result of a set of simultaneous improvements, strongly correlated.

To the technical world, of which it receives much, particle physics gives a great deal in return [4]. The high performances required by accelerators and experiments stimulate a large number of applied research and developments, many of which are then profitable to other fields. A study made at CERN in 1975 (4) has revealed that many technical innovations due to CERN orders were used in different fields afterwards.

The role of particle physics is, in a way, analogous to the role of military research and space technology. Requiring better performances of existing techniques (radio waves, electronics, power supply regulator, vacuum...) new material (for vacuum, dielectrics, magnetism, superconductivity) new ways of making (to lower the prices of large scale components like magnets, klystrons, low noise amplifiers or logic units, RF cavities or liquid helium...) it favourizes the efforts of industries and applied laboratories towards technical improvements. Thus, particle physics plays its role in the perpetual game of technical progress in the developed countries. These contributions have several particular features:

- the direct aims of particle physics, i.e. knowledge of the structure of matter at its most fundamental level, have no predictable technical application. The technical consequences come from the instrumentation of this physics i.e. a side effect and not from the physics itself;

- the first big accelerators, after World War II, followed directly the technical achievements of the war-time: the Manhattan project for the A-Bomb, as a big technical and scientific organization, the development of radio waves for RADAR and other technical skills. The connection with war techniques seemed to become weaker in the following years. Nevertheless, one must mention recent studies for beam-weapons, connected to the new acceleration techniques,use of accelerated protons to produce fissile materials or tritium, and, more generally, use of particle physics techniques to favourize proliferation of nuclear weapons [5];

- the techniques used and developed in particle physics belong mainly to "hard" technologies. In spite of many attempts there are only a few examples of technical transfers from particle physics to soft technologies, like the work by A. Rosenfeld et al. using their expertise in data management for the study of heat exchange in housing, or the use of aerogels for heat isolation [10].

## 5. POLITICS AND SCIENCE POLICY

During the cosmic rays days, particles physics has grown in traditional academic institutions. It was mainly when big accelerators had to be built (at the end of the forties), that universities appeared not to be quite well adapted to this function. So, in the post-war period and in the light of the efficiency of the "Manhattan project", several State institutions were in charge of accelerator laboratories: Atomic Energy Commissions, offices of military research, large research centres... Even for laboratories built on a university campus, a special status was usually defined in order to manage the contributions and collaborations from other universities.

Being probably the first example of a big Science in a fundamental and academic field, particle physics had to explore the channels of access of political and administrative power and to learn from the specialists the ways of managing big enterprises: money, people, programs and priorities, civil engineering...

In several countries (U.S.A., Italy, France, Great Britain), H.E.P. became a lobby, one of the first scientific lobbies.

On the other hand, the particle physics community had to face the problem of organizing big laboratories and big collaborations [6]. Thus questions were explored which later became classical themes for the administration of science: who is responsible for what, how strictly can a program be defined, what is the way to control the progress of scientific work?

The experience of particle physics has given us the opportunity of being aware of several points. Not being a specialist, I only mention a few of them in a rather simple language:

- even pure science, fundamental research, can be planned and inserted in long-term programs. This requires institutions specially suited to this aim;

- in large laboratories with big instruments, people of technical bodies (engineers, technicians) require status similar to the status of people in industry. On the other hand, physicists feel themselves closer to their academic colleagues and claim academic freedom: choice of activity, seminars, judgement by university authorities...

- a good management of scientific activities requires flexible ad-hoc structures: committees for experiments and programs, open discussion of projects and responsibility of decision makers. The articulation between them must be carefully designed;

- policy makers at the governmental level and science establishment have much in common and reinforce each other.

## 6. INTERNATIONAL AFFAIRS

There always has been an international aspect to research and science. This is due to the nature of scientific knowledge which is, at least in principle, independent of nationality, geographic localisation or sociological considerations.

So there were international scientific institutions, mainly devoted to organizing conferences and congress and also to favourize exchange of scientists. Among them are the International Unions like IUPAP, the International Union of Pure and Applied Physics. All these institutions are non-governmental institutions. But CERN is one of the first examples of a new type of institution: an inter-governmental scientific institution [7]. It has been created after World War II in order to enable European countries to participate in this new kind of costly research using particle accelerators.

Its creation has been reported many times and it is not the moment now to retrace it. I will only mention, following Pierre Auger's talk at the International Colloqium on the history of particle physics at Paris in 1982, a few elements which have contributed to the success of this "première" in international collaboration [8]:

- the idea of international laboratories was first proposed to the United Nations Organization in 1946 by Henri Laugier, member of the Cultural and Social Affairs Office of the UN;

- the true iniative came from physicists: Isidore I. Rabi, Edoardo Amaldi and Pierre Auger who decided to propose this at the General Conference of UNESCO in 1950 where it was approved. Thus, an official international framework was given to the enterprise. It made possible the study of financial facilities to be envisaged and to elaborate a constitution, a program and an evaluation of the total funds needed;

- it was a regional project, including countries of a comparable level of economic and academic development and a similar political regime;

- the preparatory work was made by prominent scientific personalities and not by "experts" of state bureaucracies. This little body of scientists had a great authority and was able to avoid politisation and even "economisation" of its works;

- the project was possible mainly because the subject - fundamental physics - was not too close to industrial or military developments. This was and remains essential to CERN and similar organizations.

Having much profited? from international organizations, particle physics has given much in return. CERN has been the model of several similar organizations, for other fields of science among which spatial research (ESRO), astronomy (ESO), molecular biology (EMBL), fusion research (JET), synchrotron radiation... The structure of council, scientific policy committee and experiment committee and the role and responsibilities of Director General are thus now the major pieces of many inter-governmental scientific institutions.

Concerning international affairs and in addition to the outstanding success of CERN, one must add:

- the case of PETRA and HERA which are built in a national laboratory (DESY in Hamburg), but to the scientific program of which scientists and laboratories of several countries actively contribute;

- the collaboration between CERN and SERPUKHOV has been an original enterprise between eastern and western countries;

- even before the death of Mao Tse Tung, a small delegation of chinese physicists was installed at CERN in a semi-permanent way.

7. RECOGNITION AND HONOURS

Like artists, scientists like honours: medals, diplomas, prizes - all kinds of rewards. Particle physics is a forepart of science which attracts many brilliant scientists. It presents an always renewed amount of puzzles and complicated problems in which these brilliant scientists find the occasion to exert their talents. So they often receive important rewards. For example, more than 25 particle physicists have received Nobel prizes from 1945 to the present day (theory and experiment). National academies or physical societies have also given rewards to numerous particle physicists.

Large laboratories of particle physics are places worth a visit by VIP's: kings, presidents, prime ministers, pope and even Dalai Lama! These visits give to both - visitor and the visited place - the benefit of the other's respective prestiges.

However, particle physics is also the subject of a very [illegible] competition between countries, mainly Europe and the United States. It concerns the events which can be reported in the major newspapers and on television programs: achievement of a bigger accelerator, discovery of a new particle, new theoretical advances, can be used as ways to prove the excellence of national (or regional) researches.

It appeared, for example, that the fact that $Z^0$ and $W^{\pm}$ were discovered in Europe was considered by American journalists and politicians as a sign of the necessity to find a way to restore the American advance in the field [9].

To contribute to particle physics, is in some way, for many countries, a mark of the membership to the club of the most developed countries. Thus, in the last twenty years, new accelerator laboratories have appeared in Japan and in China.

## 8. AESTHETICS, MYTHS, HUMANITIES

I will not develop this part too much: I feel somewhat unqualified on these subjects. Nevertheless, I think these topics are very important, mainly concerning the relations between particle physics and the general public, the lay-man... Therefore, I will try to enumerate the most important aspects, according to my opinion and also to my experience in popularizing science.

From society, particle physics receives language, questions and myths. In return, it gives new meanings to old words, new words and new concepts, new myths and ways of thinking and new views on the order in the world:

- natural languages define the framework in which questions are formed and answers given. They carry implicit views on the world which differ from one language to another;

- there are very old questions translated into myths, which are the very fundamental questions of particle physics: What is the world around us made of? Is it built with elementary bricks that we call "particles"? How are bricks linked together? These questions were already asked by ancient philosophers: Platon, Aristot, Democrit... Are all things, far away in the sky, made of the same material as in our galaxy? Has this world a history? How, and when, did it begin? Where is it going?

To all these questions particle physics, together with astrophysics and cosmology, give partial answers and mainly give new meanings to the questions. The theory of big bang, the symmetries between forces and the natural symmetry breaking among forces, the universality of the laws of physics are in a way, answers to the fundamental questions. They say nothing about God's existence or the nature of thought, but they throw [illegible] light on the meaning of words like "vacuum, time, space, [illegible]"...

More generally, particle physics being a basic research, [illegible] to refine our scientific world view. This will certainly have [illegible] cultural impacts, like results of basic reseaiches by Isaac Newton or Sadi Carnot are components of our present cultural patterns. There are fears that the reductionist views of particle physics (which tends to deduce the most complicated structure from properties of "elementary" particles) should generate a poorer and less human culture. This point must be seriously considered.

In addition to these very general statements I wish to add a few remarks:

- for the general public, accelerators and big laboratories become more or less the new places of mysteries, where strange entreprises take place, like in the ancient times, temples or cathedrals;

- the use of old words like "strangeness", "charm" or "beauty" with completely new meanings, is rather misleading to most people and can reinforce the feeling of mystery and esotericism that abstract science suggests;

- it is always tempting for popular philosophers or "quack-thinkers", to use scientific concepts in a rather distorted sense. Thus one can read papers or books on the soul of electrons or on the Tao of physics. This is unavoidable and must be taken as a hint to explain more and more clearly our science.

## [illegible]. CONCLUSIONS

Everybody can draw his own conclusions on these topics. I only wish [illegible] the following points.

[illegible] much and give [illegible] society. The fact that this [illegible] is always receiving funds suggests that there is an equal balance. [illegible] benefits from particle physics? [illegible] the "[illegible]" part of the [illegible] countries, governments, mass media... This is [illegible] like [illegible], oceanography [illegible] important impact on essential aspects of human life: [illegible] and well-being. We must not forget this.

## ACKNOWLEDGMENTS

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## TABLE I

| ASPECT OF SOCIETY | PARTICLES PHYSICS RECEIVES | SOCIETY RECIEVES | WHO, IN SOCIETY BENEFITS ? |
|---|---|---|---|
| Men and education | Technically educated people, Universities,... | Specialists of advanced techniques, professors | Universities, industry |
| Economics | Money | Local benefits | Industry, local administration and trades |
| Technique | General technical progress | New technical achievements | Industry |
| Politics, administration, and science policy | Administrative framework | Models of big science and research organisation science managers, experts | National and international bureaucraty |
| International affairs | International cooperation | Working models for cooperation Occasions for cooperation | Governments, press |
| Recognition honours | Positions, rewards, Nobel prizes | Prestige, criteria for International competition | Media, governments of developped countries |
| Aesthetics, myths, humanities | Language, general questions | New myths, new meanings, new ways of thinking | Media, philosophers popular philosophers |

TABLE

| | Experimental physicists (heads) | | | | Theoretician (heads) | | | | Total expenditure on HEP (MSF) | | | | Total cost per experimental physicist (MSF) | | | | Total cost per inhabitant (SF) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1976 | 1978 | 1980 | 1982 | 1976 | 1978 | 1980 | 1982 | 1976 | 1978 | 1980 | 1982 | 1976 | 1976 | 1980 | 1982 | 1976 | 1978 | 1980 | 1982 |
| TOTAL Europe | 2000 ±100 | 2000 ±100 | 2010 ±100 | 2140 ±100 | 910 ±100 | 940 ±100 | | | 1123 ±60 | 1055 ±50 | 1122 ±60 | 11[illegible] ±60 | 0.56 ±0.06 | 0.53 ±0.05 | 0.56 ±0.06 | 0.54 ±0.06 | 3.9 | 3.6 | 3.8 | 3.9 |
| TOTAL U.S.A. | 1100 ±100 | 1200 ±100 | 1250 ±100 | 1350 ±100 | 850 ±100 | 800 ±100 | ∿900 (estimate) | ∿900 | 700 ±20 | 770 ±30 | 750 ±30 | 900 ±30 | 0.64 ±0.08 | 0.64 ±0.08 | 0.60 ±0.07 | 0.67 ±0.07 | 3.3 | 3.5 | 3.4 | 3.9 |

Remark: All figures are expressed in prices of the respective years.

Europe = CERN Member States and CERN.

From Christian Roche [2]

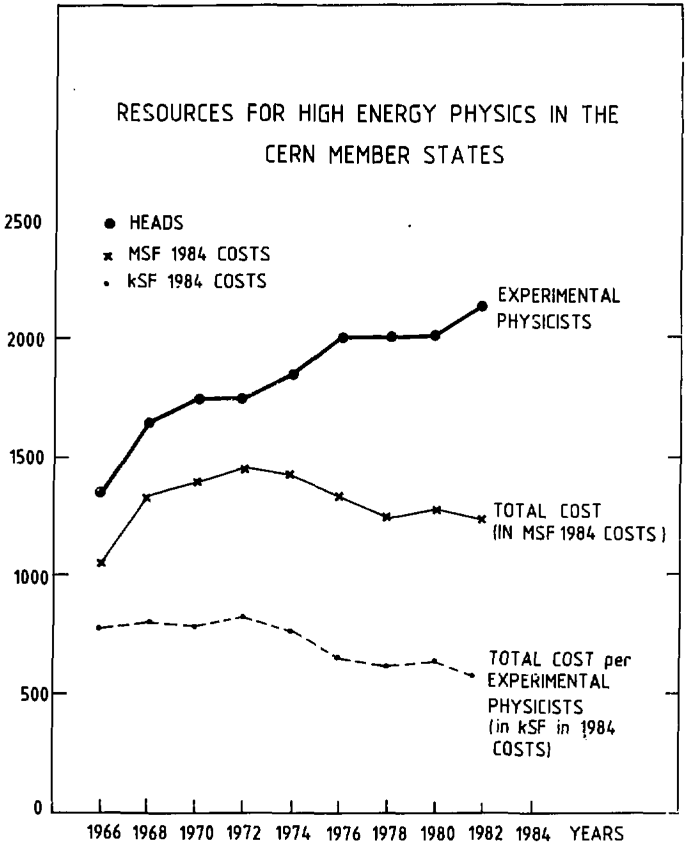
FIGURES CAPTIONS.

Fig. 1, [illegible] 3 are issued from ref. [illegible] Swiss Fra[illegible] (MSF) or Thousand Swiss [illegible] are given in 1984 [illegible].

Fig. 1 : is the re[illegible]lt [illegible] the census by Ch. [illegible] the [illegible]tion between the increasing number of [illegible] physicists and [illegible] available [illegible]unts of money.

[illegible]. 2 : [illegible] National product) of particle physics in Europe a[illegible] [illegible] States.

[illegible]. 3 : This figure shows how money is shared in Europe between CERN and [illegible] labora[illegible] (including exp[illegible] at CERN).



RESOURCES FOR HIGH ENERGY PHYSICS IN THE CERN MEMBER STATES
HEADS
MSF 1984 COSTS
kSF 1984 COSTS
EXPERIMENTAL PHYSICISTS
TOTAL COST (IN MSF 1984 COSTS)
TOTAL COST per EXPERIMENTAL PHYSICISTS (in kSF in 1984 COSTS)
2500
2000
1500
1000
500
0
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
YEARS

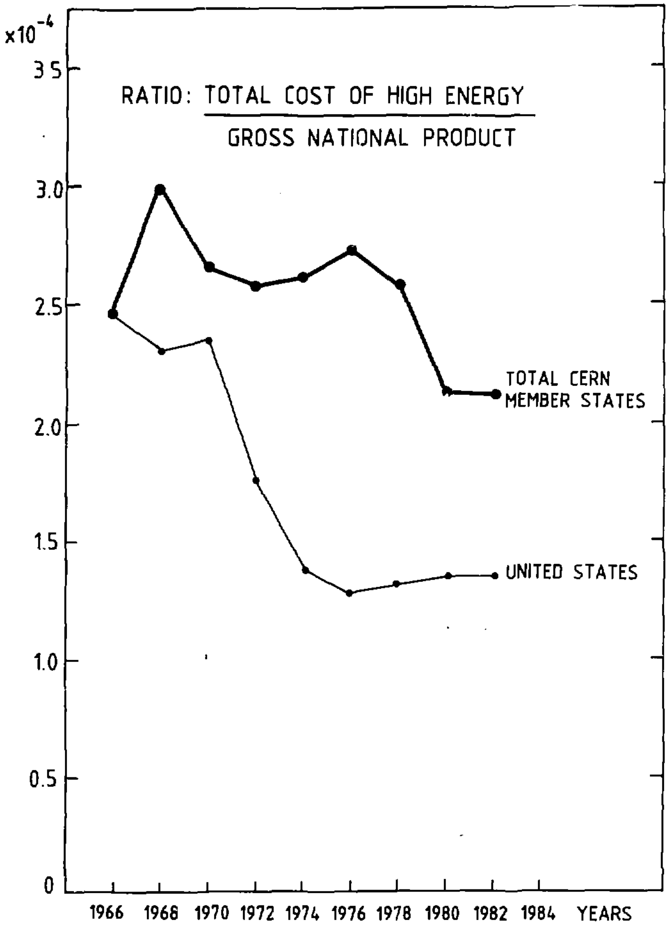

x10^-4
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
RATIO: TOTAL COST OF HIGH ENERGY / GROSS NATIONAL PRODUCT
TOTAL CERN MEMBER STATES
UNITED STATES
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
YEARS

Fig. 2

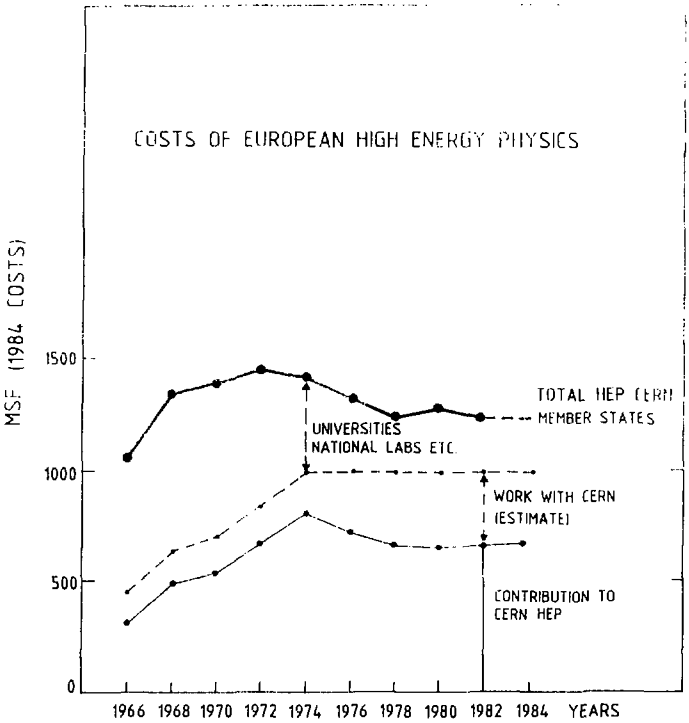

COSTS OF EUROPEAN HIGH ENERGY PHYSICS
MSF (1984 COSTS)
1500
1000
500
0
TOTAL HEP CERN
MEMBER STATES
UNIVERSITIES
NATIONAL LABS ETC.
WORK WITH CERN
(ESTIMATE)
CONTRIBUTION TO
CERN HEP
1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 YEARS

Fig. [illegible]