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# ACCELERATOR R/D IN THE U.S. HIGH ENERGY PHYSICS PROGRAM-PAST, PRESENT AND FUTURE

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## Abstract

The importance of accelerator R/D for particle physics research is emphasized and the dire necessity for finding new, economically efficient accelerating methods and technologies is pointed out.

## Introduction

"Accelerator Research and Development has always been an integral and important part of elementary particle physics research. The physics output has been paced, to a large extent, by the improvement in performance of our accelerators. In the past 50 years, equivalent beam energies available to experimenters have increased by a factor of ten million as a result of accelerator R & D efforts. Not only has performance increased exponentially but unit costs have also been reduced significantly. Even in times of decreased real spending power for the field, significant energy increases were achieved.

Despite our remarkable achievements in unit cost reductions, these reductions have not kept pace with the energy increases achieved. This has resulted in a limitation in the number and diversity of high energy accelerator facilities available to workers in the field. Further decreases in diversity will be necessary if the pace of cost reduction produced by new accelerator technologies does not increase. Such further decrease would have a serious negative impact on the scientific productivity of U.S. elementary particle physics. The challenge is clear: we must redouble our efforts to reduce unit costs sharply while maintaining performance improvements through full exploitation of the potential of our current accelerator technologies and through invention of entirely new technologies and methods.

Historically, we have spent approximately 10 percent of our operating resources on accelerator R & D activities. This includes both R & D applied to projects (RDAP) and long-range R & D (AARD) which is not associated with a specific project. Today this fraction for all accelerator R & D is 14%, reflecting our heavy commitment to superconducting magnet development. The great majority of this is RDAP, as it needs to be. It has been determined that between 1% and 1½% of operating resources are now devoted to AARD. If we are to meet the challenge of the future, more of our resources need to be devoted to this activity. Perhaps an appropriate level for long range R & D would be about 4% of HEP operating resources."

Thus reads the summary of a report recently commissioned by the Department of Energy.[1]

## Historical Perspective

The accomplishments of the accelerator builders are displayed in the famous Livingston chart, reproduced here as Fig. 1. Each point represents an accelerator and each line joins accelerators of a given type. One might say that each line represents a new accelerator technology. At the beginning of each new technology the chart shows a rapid increase in the achievable energy and then a leveling off as that technology becomes fully exploited. Each technology is supplanted in turn by a new one having the same historical profile.

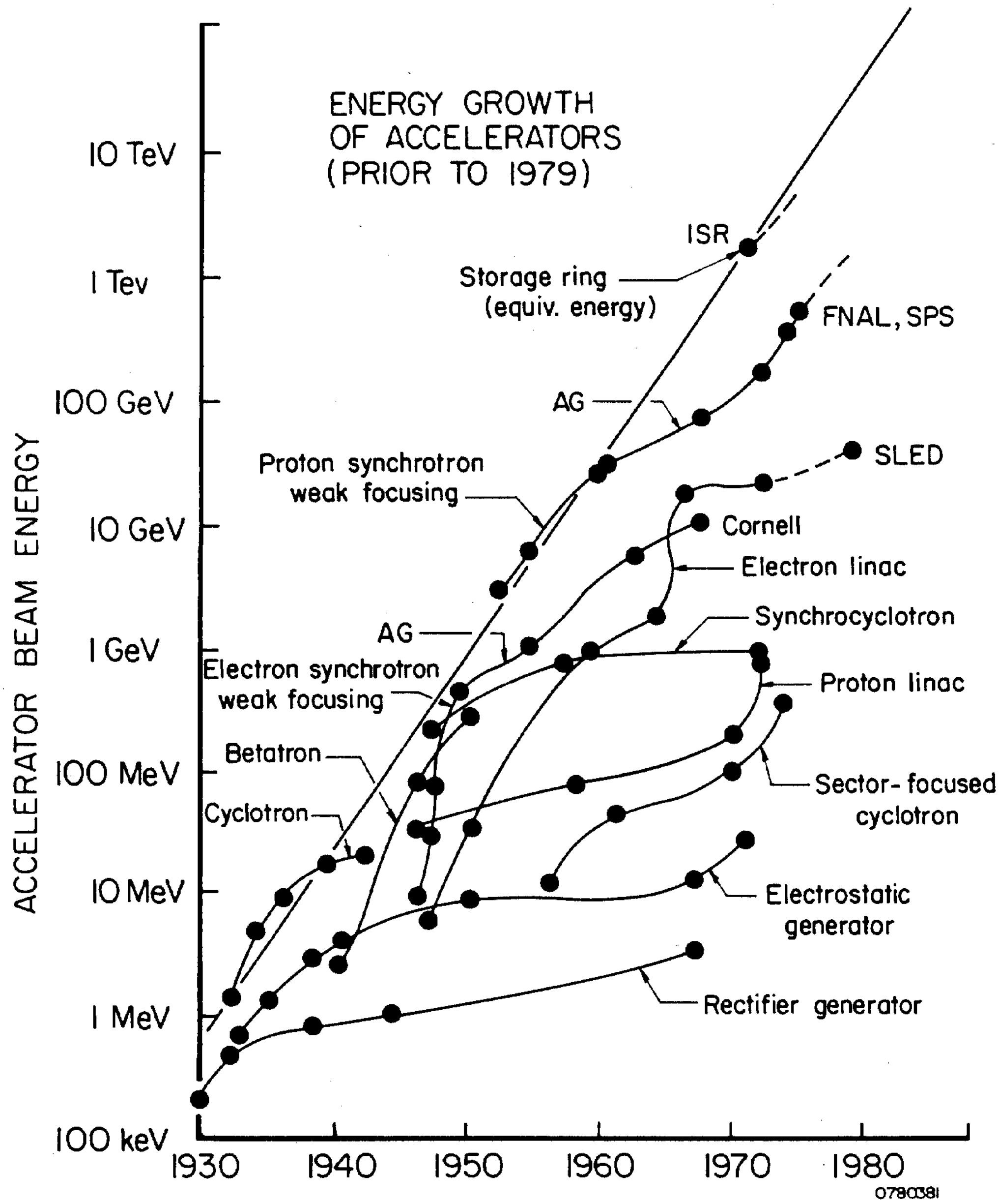
The successive technologies are labeled in the chart with the name of an accelerator type.

Ranking equally in importance to the introduction of new accelerator types are the technological improvements that have enabled us to exploit the basic accelerator ideas. The premier example of this type of improvement is the invention of AG focussing, without which the highest energy accelerators we have today would simply be impossible. Also of great importance and more typical of the blood, sweat and tears that go into technological improvement is the steady increase in the efficiencies and achievable powers and gradient levels in radiofrequency sources and accelerating cavities. This is one of many, many similar examples including work on magnets, sources, controls, vacuum and so on. Accelerator building is not all hardware construction. The development of our understanding of the basic physics of accelerator operations and the development of calculational machinery for designing and understanding of accelerator systems has been the sine qua non of progress. The richness of phenomena encompassed by Maxwell's laws combined with those of particle mechanics continue to amaze and, from time to time, dismay us.

There is an economic side to all of this and that is what I want to emphasize today. Over the course of 50 years, we have managed to increase energies available to experimenters by some seven orders of magnitude. At the same time we have managed to reduce sharply costs per energy unit. It is estimated that over that same 50 years, costs per beam energy unit have fallen some six orders of magnitude. While both of these figures represent spectacular accomplishment, the cost reductions have not kept pace with energy increases. I will return to this point later.

## Current Activities

It may be useful to view current accelerator R/D activites in the same framework in which we have viewed the past. The community is hard at work in development the supporting technologies to improve existing types of accelerators. In particular, a great deal of attention is being focussed on the exploitation of the colliding beam technique. It is this colliding beam idea which has made the latest new line on the Livingston chart possible. The colliding beam idea is characteristic of many accelerator ideas or inventions: Its potential for allowing us to enter a new regine of available energies was realized long before the required accelerator physics results and supporting technologies were available. Now that the colliding beam technique has been firmly established as a viable method we are hard at work extending it to new kinds of particles, $p\bar{p}$ and ep being the prime examples, higher beam energies and higher luminosities. Almost 14% of current operating resources in high energy physics is being devoted to accelerator R/D, the bulk of which is in support of current construction projects which depend heavily on superconducting magnets. Other important components of our current R/D program entail theoretical and hardware developments connected with beam cooling techniques, the use of linear accelerators in colliding beam systems, the production of higher accelerating fields in room temperature cavities and of higher rf peak powers as well as the use of rf superconductivity to allow less costly maintenance of high CW accelerating fields in storage rings. Of equal importance are efforts to produce bright and efficient sources of polarized ions including electrons, and to broaden our theoretical understanding of beam behavior and intensity and density limits set by beam-environment and beam-beam interactions. It is upon these efforts that the cost and construction



ENERGY GROWTH
OF ACCELERATORS
(PRIOR TO 1979)
ACCELERATOR BEAM ENERGY
10 TeV
1 Tev
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
100 keV
1930
1940
1950
1960
1970
1980
ISR
Storage ring
(equiv. energy)
FNAL, SPS
AG
SLED
Proton synchrotron
weak focusing
Cornell
Electron linac
Synchrocyclotron
AG
Electron synchrotron
weak focusing
Proton linac
Betatron
Sector- focused
cyclotron
Cyclotron
Electrostatic
generator
Rectifier generator
0780381


Fig. 1

of at least some of the accelerators now in the planning stages will depend.

Does the current program contain any efforts to invent a technology which could lead to the next, as yet unmarked, line on the Livingston chart? Yes, there certainly are some which we've heard about in this conference. There are some ideas about the use of collective effects or the use of the very intense fields produced at the focus of a laser beam which may lead to such devices. To say that the path to the future is clearly charted, however, would be a gross overstatement.

## The Future

Based on the rich harvest of recent years we now perceive elementary particle science to be bursting with possibility. Perhaps it is not vain to hope that in our lifetimes we may see at least the outlines of the unification of all of the basic forces of nature.

If the history of the past fifty years is any guide, accelerators will play a pivotal role in the unfolding of this revalation. Our challenge is to do at least as well as we have in the past to provide the required instruments. In Fig. 2 we display an extrapolation of the Livingston Chart to the end of the century. The dashed lines represent some of the accelerators that have been mentioned as goals or as models for study.

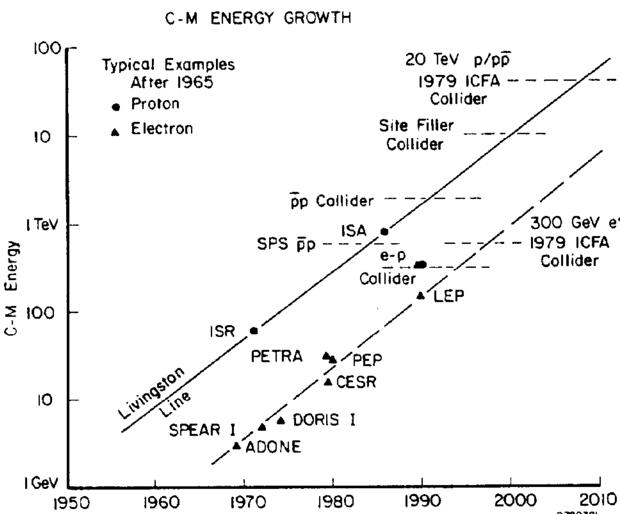



Fig. 2

In the DOE report to which I earlier alluded, the HEPAP subpanel which carried out the study set forth their findings that only 1 to 1.5 percent of our operating resources are now being devoted to the truly long range accelerator R/D that could lead to these accelerators. (A similar example for electron machines is given in the DOE report.) In Fig. 3 the recent historical cost trend for proton accelerators is given, showing the sharp drop in costs accompanying the introduction of new ideas and technologies. In Fig. 4 the projected energy requirements and costs for various assumed trends is given. The costs in constant dollars are for the bare accelerator, are idealized and the absolute values are probably optimistic. The "Past Trend Continues" band is based on a loose fit to the data of Fig. 3. While one could quibble with the absolute dollar amounts, the trends are well founded. The bad news is that even if we do as well as we have in the past, an outcome far from assured, the cost of

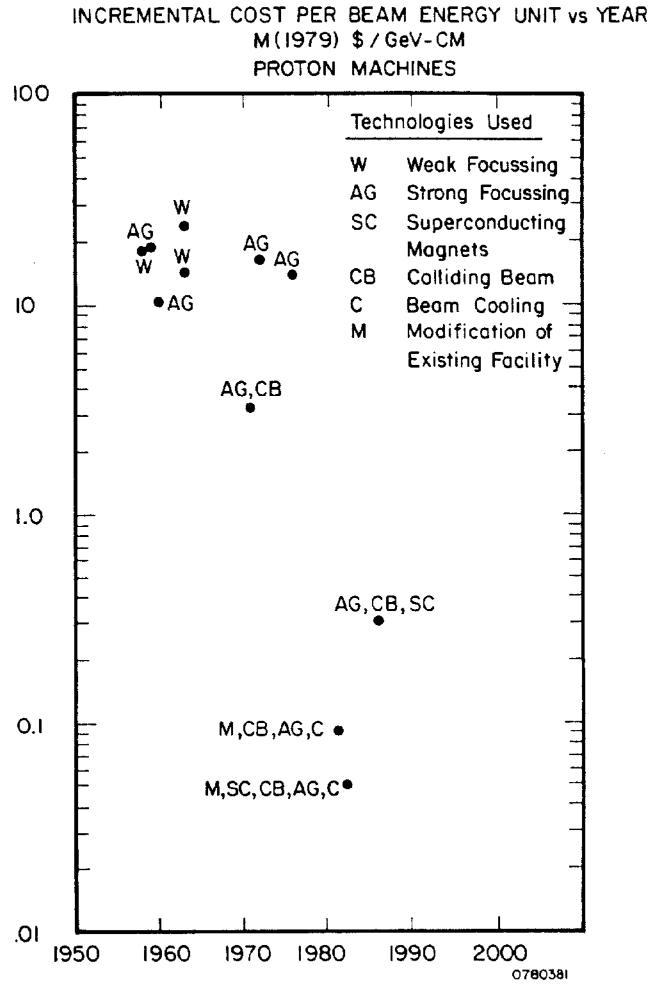



Fig. 3

ENERGY AND COST GROWTH OF PROTON ACCELERATORS USING THE MOST ADVANCED TECHNOLOGY

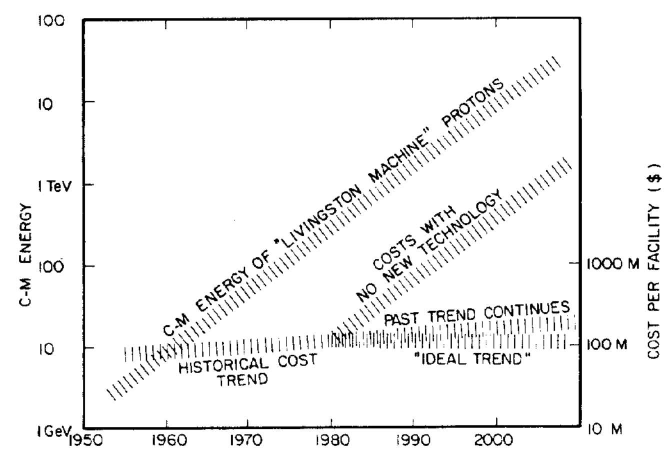



Fig. 4

the instruments we need will require a larger and larger share of our resources. This trend, if unarrested will lead to a gradual stultifying of our science. Our work is clearly cut out for us: We must follow vigorously all the leads we now have and we must redouble our efforts to invent new technologies which will allow us to leap the cost barrier to which we are daily coming closer. Some of the primary leads we have are outlined in the Sub-Panel report which I quote here in abreviated form.

"In reviewing accelerator R & D, the Subpanel has identified certain specific technical areas that should be emphasized in AARD. This list is not presumed to be complete, exclusive, or to indicate relative priorities. Rather, it is intended to be an indication of the challenges of AARD and to underscore the importance of AARD to the field of high energy physics. This list of specific topics is:

(a) Development of very high field accelerator magnets and the evaluation of the practical limits of this technology. In view of the large-scale of this enterprise and its uniqueness, the Subpanel recommends that this AARD effort be carried out as a collaborative effort among the laboratories having capability in this area. The Subpanel feels that this development of high-field magnets should be focussed toward a specific accelerator goal.

(b) Development of liquid helium refrigerator systems with goals of improving efficiency and reliability and providing operation at reduced temperatures.

(c) Theoretical and experimental exploration of the limits to microwave linac gradients and to the peak powers that can be delivered in the S- to X-band regions.

(d) Basic physics and device development in superconducting RF accelerators.

(e) Theoretical and experimental studies of basic accelerator phenomena, particularly the beam-beam interaction and other performance-limiting phenomena.

(f) Search for and preliminary development of new accelerator schemes with high performance potential such as laser accelerators or other devices using ultra-high peak power with or without collective effects.

(g) New techniques and devices for manipulating very high power and/or very high energy beams.

(h) The general problem of increasing the brightness of particle beams with emphasis on cooling high energy beams.

(i) Development of new beam diagnostic techniques and devices."

The technical challenge of that new accelerator idea which is going to revolutionize the industry and usher in a brave new line on the Livingston chart can easily be quantified, at least for proton accelerators. Hard work and inspiration may lead, inthe next five years or so, to magnets with 10 Tesla fields. This corresponds to a beam energy of a little less than 500 MeV per running meter of accelerator apparatus. Perhaps we can dream that this apparatus will not be vastly more costly per unit length than current devices. Thus to achieve the needed breakthrough we need an accelerator that can produce in excess of 1 GeV per running meter of elegantly simple apparatus. Perhaps one of the laser driven accelerators or collective devices now being contemplated can do it. Maybe we can learn to harness the enormous internal fields in condensed matter. I don't know the answer but I do know that the challenge is worth our utmost effort for our goal is nothing less than a vastly deepend insight into underlying structure of the awesomely beautiful world into which we have been placed.

## Reference

1) Report of the Subpanel on Accelerator Research and Development of the High Energy Physics Advisory Panel. DOE/ER-0067, UC-34. U.S. Department of Energy, Office of Energy Research.