DISCUSSION

COURANT: Have you given any thought to comparable considerations for, say, 200 GeV storage rings?

HYAMS: No. But I think the problems become much harder. For example 50 GeV centre of mass secondary particles have 1 or 2 GeV/c and their mass may be determined by time of flight over 3 o 4 meters. For 400 GeV centre of mass the distances would have to be at least hundreds of meters.

O'NEILL: For a 4 π magnetic-field detector, have you developed any new field geometries, or reached any conclusions on the geometries previously suggested?

HYAMS: No, we haven't any good new ideas. I consider a decision on a choice of field an urgent problem.

BUDKER: Have you considered methods of oscillations damping, which give a more dense bunch. That would increase the counting rate and would open new experimental possibilities.

SHOCH: In order to damp betatron oscillations in proton storage rings, the energy of transverse motion of the protons would here to be absorbed, e. g., into some external circuit coupled with the betatron oscillations. We have not found a good solution for doing this for incoherent oscillations with useful damping rates.

O'NEILL: How do you plan to measure the beam profile, since there will probably be experimental geometries in which it will be awkward to rely on monitor reactions?

HYAMS: We will try three of four possible systems. Looking at light, or π mesons produced in the residual gas. Destructive systems passing through the beam, and vignetting the beam. I think that each experiment will need to use such a measurement to calibrate a convenient monitor reaction.

USE OF ON-LINE COMPUTERS IN HIGH ENERGY COUNTER EXPERIMENTS

W. A. Higinbotham

Brookhaven National Laboratory, Upton, New York (USA)

INTRODUCTION

Physicists have made extensive use of computers, but only recently have they begun to employ them directly in experiments. Several trends have combined to make this come about. The experiments have become more involved, requiring more expensive and complicated equipment. The speed and capacity of computers have increased, while the cost has been reduced. In a number of cases it is now as cheap to buy a computer as to build the special electronic circuits required for an experiment.

For example, in the field of pulse height analysis the last 20 years have seen a progression from single channel to multi-channel to n-dimensional analyzers, a big step being the adoption of computer techniques about ten years ago. A large analyzer is really a fixed program computer with a large memory (e. g. 16,000 words of 20 bits), which is comparable in cost to a stored program computer with a similar memory. In the last few years a number of computer systems have been built for multi-dimensional analysis (1). The fixed program analyzers are faster, the computer types more flexible. The opportunities offered by this flexibility are only beginning to be exploited.

Anhoter example, in the high energy field, has been the progress in hodoscopes, arrays of detectors to determine trajectories of particles. A number of ingenious schemes were developed for recording the data, such as connecting the detectors to a delay line for display on a cathode ray tube trace. The film record was then scanned manually. As the number of hodoscope elements increased and electronic "logic" elements improved, it became necessary and practical to handle the data with digital circuits, to record on paper or magnetic tape which could later be analyzed on a computer. More recently the data have been fed directly to a digital computer, as described, for example, by Lindenbaum and associates (2).

The low energy physicist has come to depend heavily on prompt multi-channel analysis and on the cathode ray tube display. It is convenient to test performance of the system, to try out various arrangements of source, detector and collimation, to set up and monitor each experimental run. Qualitative results are continuously available. When enough data have been accumulated, the display is used to select regions of interest for more intensive study.

Nothing comparable to multichannel analyzers with prompt display has been developed for high energy counter experiments, primarily because of the wide variety of such experiments. The on-line computer promises to change this picture. While the variety of detector arrangements will continue, a common computer system can be used for data processing and display.

A hight energy experiment may involve the following elements: an external beam, analyzing and focussing magnets, scintillation and Cerenkov detectors for classification, a target, and a hodoscope (several spatially sensitive arrays). The on-line system can be used to analyze the beam and to adjust the magnets more efficiently than special purpose detectors. The beam can be checked at intervals throughout the experiment. With the aid of the computer, it is possible to test the operation of each of the many (possibly several hundred) detectors for efficiency and timing, as well as the associated electronic circuits. Within a relatively short time it is possible to check the experiment itself, to determine chance coincidence and background counting rates, and to determine approximately how long the experimental run will take.

The Brookhaven on-line high energy facility

The first experiments at Brookhaven (3) were done with a locally built computer (Merlin), which is located in the administration building. Data were transferred to the computer, and the display signals returned to the AGS building over telephone lines. Later coaxial cables were laid between the two accelerators and Merlin. In January 1965 a PDP-6 computer (Digital Equipment Co.) was delivered. It is a high performance computer (comparable to the IBM 7094), with a 16,000 word memory. The computer, console, printer and magnetic tapes are located in an air-conditioned trailer, which can be placed near the experiment. The facility also has 3 buffer-tape units. These are presently being used as shown in Fig. 1. Detector signals from a selected event are stored locally, then transferred in blocks to the buffer by logic circuits, designated "interface". The "buffer" is a standard computer memory unit with 4096 words of 48 bits. At the end of each accelerator pulse additional descriptive data are fed into the buffer. Between accelerator pulses the data are read out of the buffer, 6 bits at a time, and fed simultaneously to an adjacent magnetic tape and to the computer. The buffer can be filled at a rate of 48 bits per 3 μ sec. A full readout cycle is 0.6 sec. An accelerator pulse lasts 0.1 to 0.2 sec. Thee AGS repetition rate is one pulse every 2 to 5 seconds, depending on energy. Thus, there is 1.4 sec or more during which the computer can process the data accumulated during a pulse. Cathode ray tube displays are provided both at the computer and

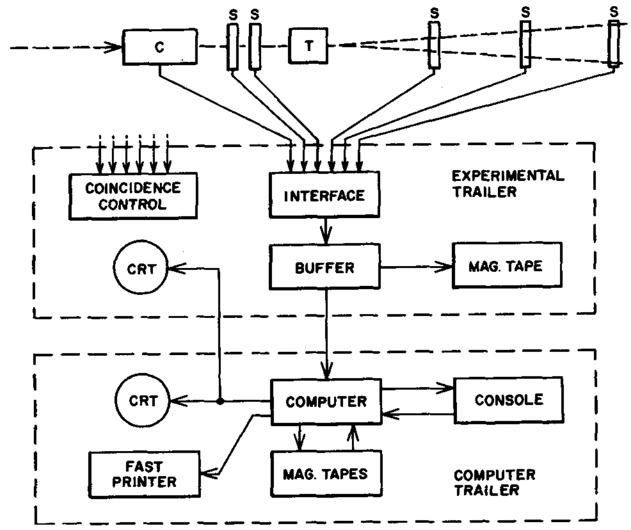

Fig. 1 - Experimental arrangement: beam path, target and detectors, shown schematically at top; next, data-buffer, coincidence control circuits and experimental electronics located in a trailer; digital computer and its peripheral equipment at bottom may be in adjacent trailer or at a distance.

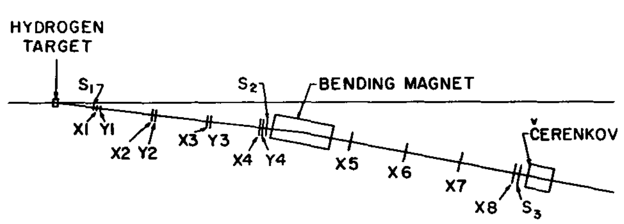

Fig. 2 - Wire spark hodoscope experiment: X1-X8 are wire spark planes to measure horizontal position, Y1-Y4 to measure vertical position. There are 100 to 350 wires spaced 1.25 mm apart in each plane.

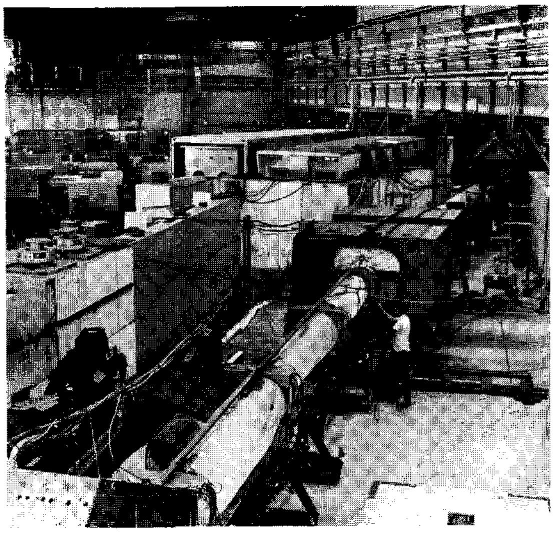

Fig. 3. - View of wire spark hodoscope experiment looking toward accelerator. Trailers located top left. Balloons are helium filled to reduce scattering.

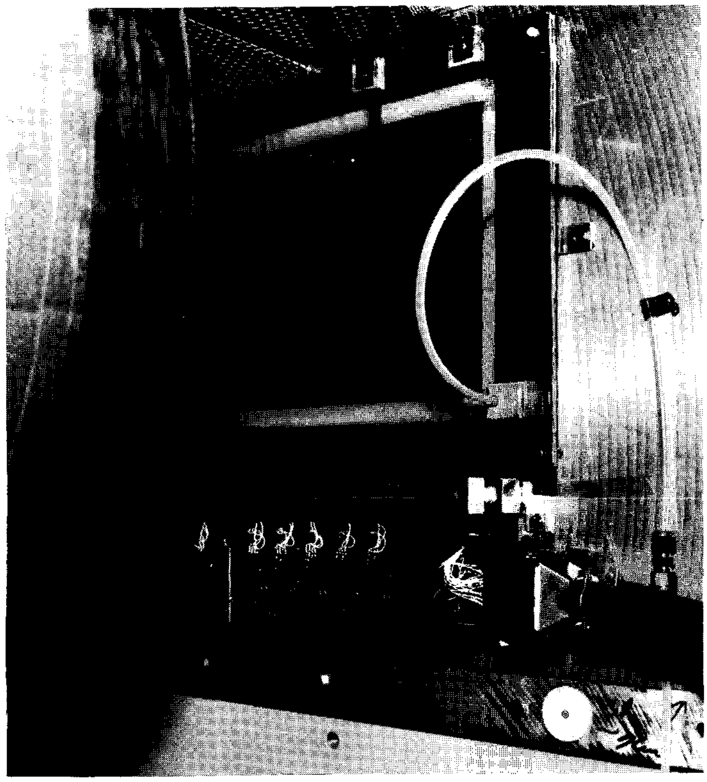

Fig. 4 - Close up view of experiment showing wire spark frame.

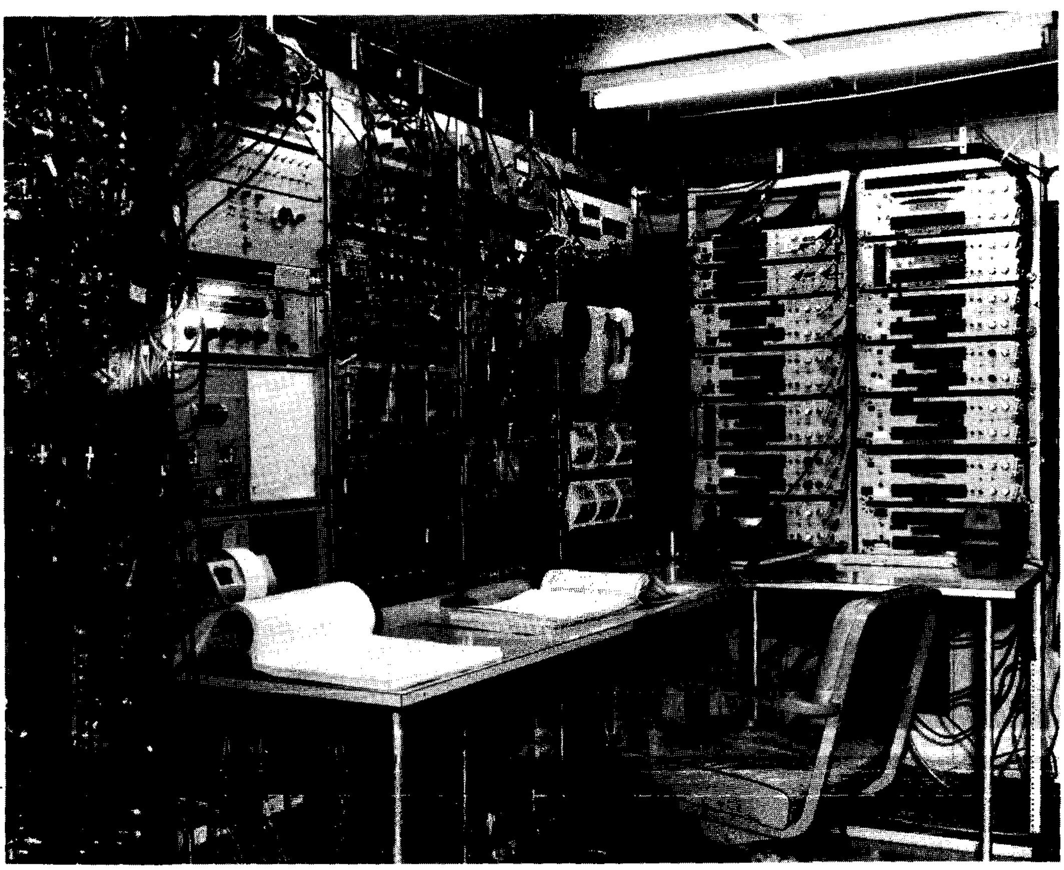

Fig. 5 - Interior of experimental trailer.

in the trailer which contains the buffer, coincidence circuits and other experimental electronics. Generally, several display plots are programmed and may be selected from either station.

The next set of figures shown the system as used by Collins and his group this spring (4). While the Collins group was running, the group scheduled to follow him prepared its programs. A third group at the Cosmotron (3 GeV accelerator) was using the Merlin computer.

Whether the buffers are necessary or not is debatable. They are a form of insurance because data may still be taken when the computer is in trouble. And they may be used separately to record data for processing on an off-line computer. In the future we would consider using small computers for this role.

It appears to be useful to record the initial data, even though operating on-line. In some cases the data rate may be so high that the computer cannot process all of it during the experiment. The computer then processes a sample. The overflow, being recorded, can be analyzed later on the same or on another computer. Even if the computer can keep up with the data rate, questions may arise with regard to the analysis. Programs may be revised and the data re-analized without having to rede the experiment.

With the variety of experiments, it is unreasonable to ask the facility to provide all the programs. In our case, a substantial amount of software was supplied with the PDP-6, including a multi-user, time-share program. But the experimenter is held responsible for his own data handling and analysis programs. The size of the program obviously depends on the experiment, but it is worth noting that writing the program is likely to require a substantial investment of time and skill.

Most of the experience to date has been with one computer on-line to one experiment. Lindenbaum has run two experiments on a time-share basis with one computer, and is currently trying to extend this mode of operation. As the technique proves its worth, more experimenters will wish to use the facility. While one experiment is being run on-line, another group may wish to prepare programs for a future run, while a third group may wish to reprocess data taken previously. Some form of time sharing may make this possible with a single computer. However, the programs for time sharing are very complicated and occupy a large block of memory (10,000 words or more). An alternative is to use several smaller computers so that each user has his own. A third possibility is the technique being explored at CERN whereby the on-line computer is connected into a larger central computer facility.

Although the experience with on-line computers at Brookhaven is rather limited, it has generated great enthusiasm, and there is hope that the on-line facility will be substantially expanded. Low energy physicists, chemists and others are also developing on-line computing systems. The trend is obvious, but not the best method to proceed. A compatible system throughout the Laboratory would make it possible to prepare programs on one computer and to run on another; to take data on one system and to rerun the data on another, to develop a common library of programs. One may question the need for "instantaneous" response. For most purposes, including data display, a delay of a minute or a few minutes would make little difference. But a delay of an hour would be a substantial disadvantage. At present individual computers can be put on-line with relatively little difficulty. Perhaps, in time, high capacity central computing systems will be able to handle applications such as this more economically.

CONCLUSION

Modern computers come in every price range, with a wide choice of characteristics. They will be used more and more in high energy, as well as other experimentation. The last three years have seen the development of this technique at several laboratories. The experience to date has been encouraging, but many questions remain to be answered. More planning and experience are needed to fully exploit the potential of computers.

When a computer is available it may be used for other purposes in addition to processing the experimental data. These functions might include beam monitoring, test of electronic circuits, detector gain stabilization, etc. Programs may be written so that the operator is warned of malfunction, or the computer may form part of a servo control system *. But these are rather obvious, auxiliary uses of the computer. The computer offers the possibility of more imagi-

(*) Ladd and Kennedy (Instr. Tech. in Nuc. Pulse Height Analysis, Nat. Acad. Sci., NRC # 1184, p. 150, 1964 have described a computer program which corrects pulse height data for gain drift occurring during an experiment. Spinrad (EANDC Conf. on the Automatic Acquisition and Reduction of Nuclear Data, Karlsruhe, July 1964) outlined a system for time-share operation of neutron crystal spectrometers, by computer, which incorporates a large number of servo functions. In this case the data taking is under program control.

native uses. Two examples come to mind: Mollenauer (5) has arranged to compare experimental and theoretical data on the CRT display of a computer-type pulse height analyzer. Soucek (6) has developed a technique to provide the resolution of a megachannel analyzer on a computer-analyzer with only a small memory. In both of these cases the new development resulted in programs adaptable to any other computer-analyzer system.

Those high energy physicists who now use computers tend to justify them in terms of the saving in accelerator time or in the increased flow of data. Perhaps a more important commodity is the clever physicist. The real test is whether the on-line computer technique makes possible new experiments, whether it enables the physicist to be more productive. Hopefully this will be the case.

Acknowledgement

The experimental group, under S. J. Lindenbaum and Luke Yuan, first proved the advantages of an on-line computer for hodoscope experiments. They are primarily responsible for the computers and data handling facilities now available at Brookhaven for use at the accelerators. The group headed by George Collins initiated and supported the development of wire spark hodoscopes. The low energy physics on-line systems are the work of many groups and individuals at Brookhaven and elsewhere, in particular of R. J. Spinrad. The contributions of all these people are gratefully acknowleged.

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THE PULSED SYNCHROTRON AS AN INSTRUMENT FOR PARTICLE RESEARCH

G. K. Green

Brookhaven National Laboratory, Upton New York (USA)

The pulsed proton synchrotron has been remarkably useful instrument for investigations of particle physics. Being pulsed is an important advantage because all energies within the synchrotron's limit are available under comparable conditions. The slowness of pulsing may sometimes be irritating, but it has had subtle and far-reaching effects. This slowness has permitted detailed investigation of the properties of orbits, and it has facilitated elaborate manipulations for research use. The machine will even stop and wait, if one wishes, using schemes known by the undignified names of "front porch" and "flat-top".

Many design choices have influence on the general utility of a synchrotron. Most of these choices were made years ago and are so taken for granted that it is easy to forget their significance. It is interesting to list some of the more important items and to evaluate their effects.