ON-LINE MONITORING OF BUBBLE CHAMBER MEASUREMENTS BY SMALL COMPUTERS *

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(Presented by R. J. PLANO)

INTRODUCTION

A system involving on-line monitoring of measurements from several conventional precision measuring engines by a small on-line computer has been developed and is in continuous operation at Yale University. The computer involved is a PDP-1 with 16 000 words of memory, paper tape input and output, typewriter output and one magnetic tape unit. In the analysis of high energy events it has long been known that the application of rigorous geometrical criteria to each event is necessary in order to avoid human errors as well as equipment failures which seriously reduce the required resolution and which dilute the samples of various types of interactions. Such criteria, when applied off-line at a later stage in the analysis, necessitate frequent time-consuming remeasurements of many of the events. Since these events are widely distributed throughout the exposure, the film handling problems are also greatly enhanced and the reduction in efficiency is very severe. The immediate diagnostic feed-back supplied by an on-line computer insures that any necessary remeasurement is done with a minimum of redundancy and produces an essentially pure sample of well measured events.

THE PDP-1 FRANKENSTEIN INTERFACE

The electronic circuitry provided with the Frankenstein measuring engines includes translators which convert the signals received from two rotary encoders attached directly to the lead screw into relay settings which are appropriate for sampling by an IBM 526 card punch. In order to make the transition from card operation to computer operation as rapid and simple as possible it was decided to utilize the switch paths already provided for the punch to provide levels for direct input to the computer as well. In this way the changeover from one mode of operation to the other can be made by an operator in a few minutes.

In order to sample the switch paths serially for input to the 10 registers of the PDP-1, an electronic stepping switch was constructed which reads in ten characters in approximately one millisecond. These BCD characters, which are normally the x and y coordinates of a point, are then converted to binary and stored in memory by the computer. Special «X punch» signals are used to extend the range of the coordinates up to 20 cm. Special «Track Complete» and «Event Complete» signals have also been provided to control the logic. In addition, provision has been made upon the reception of a «Master Card» signal to read a total of 30 characters serially into the computer. These characters are set up by the operator in a bank of switches and contain information such as the frame number and the event type which are necessary for further analysis of the event.

Like many modern computers, the PDP-1 is equipped with an interrupt system which allows read-in of data at any time except during a prior read-in. Thus if the computer is engaged in analyzing data from one machine, data from a second machine may be read-in without delay and the original analysis is resumed after the read-in is completed. A read-in which is initiated during a prior read-in will be processed as soon as the first read-in is completed. The entire interface circuitry was installed during a period of a few weeks, most of the effort being connected with the necessity of buffering the mechanical relays to prevent false signals from being transmitted to the computer during the opening and closing of the relays.

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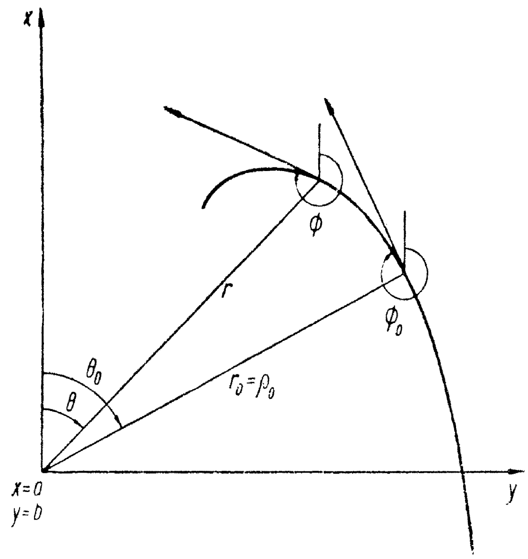
THE PDP-1 PROGRAMS

In order to carry out the objective of applying meaningful criteria to the measurements while the film is in the process of being measured, it is essential to perform an exact three dimensional reconstruction of each track in space to an accuracy equal to or better than that available on the larger computers which will complete the analysis. Since the PDP-1, like most small computers, has a relatively small word length and only fixed point arithmetic, this means that high precision floating point subroutines must be developed to handle this reconstruction. Such a «floating point package» has been developed at Yale for the PDP-1 with an accuracy exceeding that of the IBM 709 computer and with a speed approximately 20% of the 709 on a purely computational program. This results in a total track reconstruction time of about six seconds, which is adequate for on-line operation.

After accepting and checking measurements of fiducial marks on the glass window of the bubble chamber, the computer accepts measurements of up to eight points on a track in a given camera view. When a track has been measured in two views the computer immediately performs an exact point by point reconstruction using well known techniques of iterative extrapolation to find corresponding points and then solves for the three dimensional point.

Once those points have been calculated, a simple analytic method is used to fit the track to helical spiral (Figure). This method has the advantage that it should be accurate even for long slow tracks since non-linear momentum loss is easily incorporated. In addition, the use of this representation rather than a polynomial representation has the advantage that the measurement error enters naturally perpendicular to the track as is actually the case with most measuring machines.

In addition to giving the momentum and space angles of each track, this fitting procedure also yields two numbers, χ_r^2 and χ_z^2, which give an excellent indication of the quality of the measurement if account is taken of the effects of multiple scattering. Any track for which either of these numbers exceeds certain velocity dependent limits is immediately remeasured. After all the tracks have been measured and accepted by the computer a final test is made in which it is required that the x, y and z coordinates of all track end points at a given vertex agree separately to within specified limits. The computer is able to make this test automatically by searching a table of event types in which all the information as to which tracks enter or leave each vertex in the event is stored. This test is possible because the entire event is stored in memory



Coordinate system used in fitting tracks to a spiral.

at this point in the program. Tracks which fail this test must be remeasured at this time. After all of these tests are passed and after all bookkeeping requirements have been met the event is written onto magnetic tape in a form suitable for input to subsequent programs on larger and more powerful computers.

RESULTS

The principal result of the system described above has been to eliminate the necessity for remeasurement of any events processed by the system. This means of course that no criteria other than the essentially geometrical criteria described are applied at a later time in the analysis to cause such a remeasurement. In particular, if a neutral V event does not fit the hypothesis of a Λ, $\bar{\Lambda}$ or K^0 then either it really is not one of these most likely candidates or it is on the tail of the chi-square distribution for these kinematic fits. An excess of event in this tail naturally requires a reevaluation of the assigned measuring errors but should not be corrected by remeasurement of the offending event. We believe that this procedure is the one most consistent with the complete scheme of statistical analysis to which bubble chamber measurements are subject. The elimination of these remeasurements results in an increase in measuring efficiency of close to a factor of two, since much of the time-consuming film handling is eliminated.

A secondary result of this system which is difficult to measure quantitatively but which is nevertheless very important is the effect of on-line monitoring on the measurers. This effect is two-fold. Firstly, the immediate feedback from the computer leads to far more efficient correction of misconceptions and misunderstandings on the part of the measurer. Secondly, the knowledge that an on-line computer will not permit blunders to get through enables a measurer to push his speed to the limit since it is now possible for him to determine what that limit is.

It is clear that once the momenta and space angles of every track are stored in the memory of the computer many possibilities arise for the use of this information. The first such application, which is now in operation, involves a calculation of the coplanarity volume and the transverse momentum balance, with appropriate errors, of any measured *V* decay with respect to any possible vertex from which the *V* might have originated. This means that once a *V* has been measured the proper origin of this *V* may be precisely determined by measuring only one point (in 2 views) at each possible vertex. This procedure is of particular value in experiments with high total cross sections such as *p* on *p*.

A second application of this system which is currently being explored involves the on-line computation of effective masses of *V*'s or other kinematic quantities such as missing momenta at vertices. The proper measurement of an event or even the decision as to whether or not the measurement should be completed will often depend on the results of such calculations. Further applacations are being developed and are limited only by the memory of the computer and by the programming effort involved.

DISCUSSION

Y. Goldschmidt-Clermont

I would like to ask Dr. Taft what fraction of the error signals come from the check of trivial operator and digitizer errors, and what fraction comes from the geometrical reconstruction.

H. Taft

I would estimate that about 10% of the events fail for bookkeeping reasons, and 15—20% of the events fail because of poor measurement. The latter class of events is picked up by reconstruction.