DIGITAL COMPUTER ANALYSIS OF DATA FROM HYDROGEN BUBBLE CHAMBERS AT BERKELEY (*)

A. H. Rosenfeld

Lawrence Radiation Laboratory, Berkeley, Cal.

The Alvarez group currently operates two hydrogen bubble chambers, a 72″ chamber which has been working since June 1959 and a 15″ chamber on which we have gained most of our experience with the present system of data analysis. In a typical experiment a chamber may be operated in a Bevatron beam for about 1 month and may yield $\sim$ 10 000 events to be measured.

The sequence of operations is summarized in Table I. The film is scanned by physicists or technicians looking, for example, for " all interactions involving strange particles ". They note in a scan book the events and the serial number of the exposure in which they appear. Physicists or very carefully trained technicians then sketch the event (a sample sketch sheet is shown in Fig. 1 and will become comprehensible as we proceed to describe the system).

Two views of each track are then measured by a digitized projection microscope called Franckenstein (designed and built by J. V. Franck and his group). It is equipped with a servo system which works as follows : the stage is slewed with a " joystick " until the track to be measured is roughly under the optical axis of the projection system. A slit which is also on axis is then rotated roughly parallel to the track, and the servo is turned on. The track then auto-centers under the slit, reproducibly to about 1μ (although the overall noise is about 5 μ). By pressing an " accelerator " the stage can be moved along the track, with the servo keeping the track centered. Whenever the measurer desires (usually about once per second) he pushes a button which reads out digital x and y stage co-ordinates on to IBM Cards or paper tape.

Our experience with six-track events photographed in the 15″ chamber shows that we take about ten minutes to measure an event, although the servo is on only about two minutes ! This is because we have so far given much more attention to the main problem than to the chores : reading and advancing the film, reading the sketch and setting up the fixed data shown in Fig. 1, measuring fiducials, etc.

There are obvious ways to reduce the eight minutes of Franckenstein " chores ", and in a year or so we hope to find ourselves in the happy position of being limited by a few minutes of measuring time.

Luckily we already have Bruce McCormick at work on this problem. Foreseeing that we shall eventually be limited by the speeds at which a mechanical stage can follow a track, he is developing a rotating scan device (we call it the McCormick Reaper) which will scan all the tracks at a vertex in a fraction of a second. (**)

(*) Most of this material will be part of a general introductory article of a series of four, all to be submitted to the Review of Scientific Instruments by Berge, Humphrey, Rosenfeld, Ross, Solmitz, Snyder, and Taft. The others will describe PANG, GUTS, and KICK.

(**) The image of an event will be projected upon a scanning disk so that the desired interaction vertex is centered over the axis of rotation of the 6″ disk. The disk will have 15 radial slits placed at equal radial increments out from center. The slits range from 16 (innermost) to 6 (outermost) bubble diameters long and 1/3 of a bubble diameter wide. The scanning disk will rotate at 1700 r.p.m. Track pulses, either from the star of interest or from background of crossing tracks will be digitized (slit by slit) as to their azimuthal angle (to 20 second of arc) by a Baldwin shaft angle analogue-to-digital converter rigidly mounted coaxial with the scan disk. Each pulse will as be digitally encoded into two " computer " words comprising slit number, angle of leading edge, angle of trailing edge, and pulse height. A typical 72 in. chamber picture generates approximately 1 000 such " computer " words. The track filtering operation (throwing away pulses from background tracks, etc.) can be done within the IBM-704 by programming as a prelude to stereogeometric reconstruction. The filtering operation exploits the fact that pulse centers generated by a prong emanating from the interaction vertex exhibit a constant first difference in azimuthal angle.

Now, as will be seen when we get to discussing programs (and Table I), we already use about one minute of IBM-704 time per twenty minutes of Franckenstein time. But the easiest way to speed up Franckenstein is to have more and more human operations performed by computer. For example, the McCormick Reaper demands a track recognition program which will take about one second of 704 time per track. We thus simultaneously speed up the measuring and slow down the computing. For this

TABLE I

Operations in data processing

Operation	Equipment	Output	Comments and	Time/Event
Run Experiment	Bubble Chamber	Film	Typical reactions, e.g., $\pi^- + p \rightarrow \Lambda + K^\circ$ may occur once every . . .	5 min
Scan	Scan Table	Handwritten Scan Form		Variable
Sketching	Scan Table	Sketch Card	Assign hypothesis to event (via event type no.). For each track assign number and specify which views to be measured. (See Fig. 2)	≈ 5 min
Measure	Franckenstein	Track Co-ordinates (15″ = IBM Cards) (72″ = Paper Tape)	(1) Measure ≈ 10 xy Co-ordinates on two views of each track, (2) Advance film, set up sketch assignments, measure fiducials, etc.	≈ 5 min.
Card-to-Tape or Tape-to-Tape	IBM Card-to-Tape or our own tape-to-tape			
(Alternative Measure)	(McCormick " Reaper ", rotating slits and drum)	(Magnetic Tape, Track Co-ordinates (r, φ))	(Measure angle of track at 15 radial slits . . . . Advance film, etc.)	(Negligible) ?

IBM Program	Equipment	Output	Comments and	Time/Event
PANG (P and ANGle)	IBM-704	Track $\vec{p}$, $\delta\vec{p}$, etc. ((*) Printouts + Binary Tape)	(1) Space Synthesis of points and O-order fit . . . . (2) Final fit, one per mass assignment Running time for unambiguous three-track event	~ 2/3 sec/track ~ 1/2 sec/track ~ 4 sec/event
KICK K-Interaction Coplanarization and Kinematics	IBM-704	χ^2 + fitted data with errors ((*) Binary Tape)	Kinematic fit of each vertex to assigned hypotheses . . . . Fit successful vertex fits into multi-vertex events . . . . Various checks.	~ 3 sec ~ 3 sec × number of vertex fits
EXAMIN (and print KICK output)	IBM-704	(*) Printouts	Prints, selects event with special criteria, makes histograms, keeps books	~ 3 sec to write a vertex fit
			TOTAL 704 time for average event .	~ 1/2 min
DRIVEL	IBM-704	(*) Magnetic Tape	Merging and Sorting of Kick-Format Tape	

(*) Except for lists of mistakes, printed by the on-line printer, all our data comes out of the 704 on magnetic tape; binary tape if the output is to be used as input for later programs, plus an additional BCD (Binary Coded Decimal) Tape to feed to our off-line printer if desired.

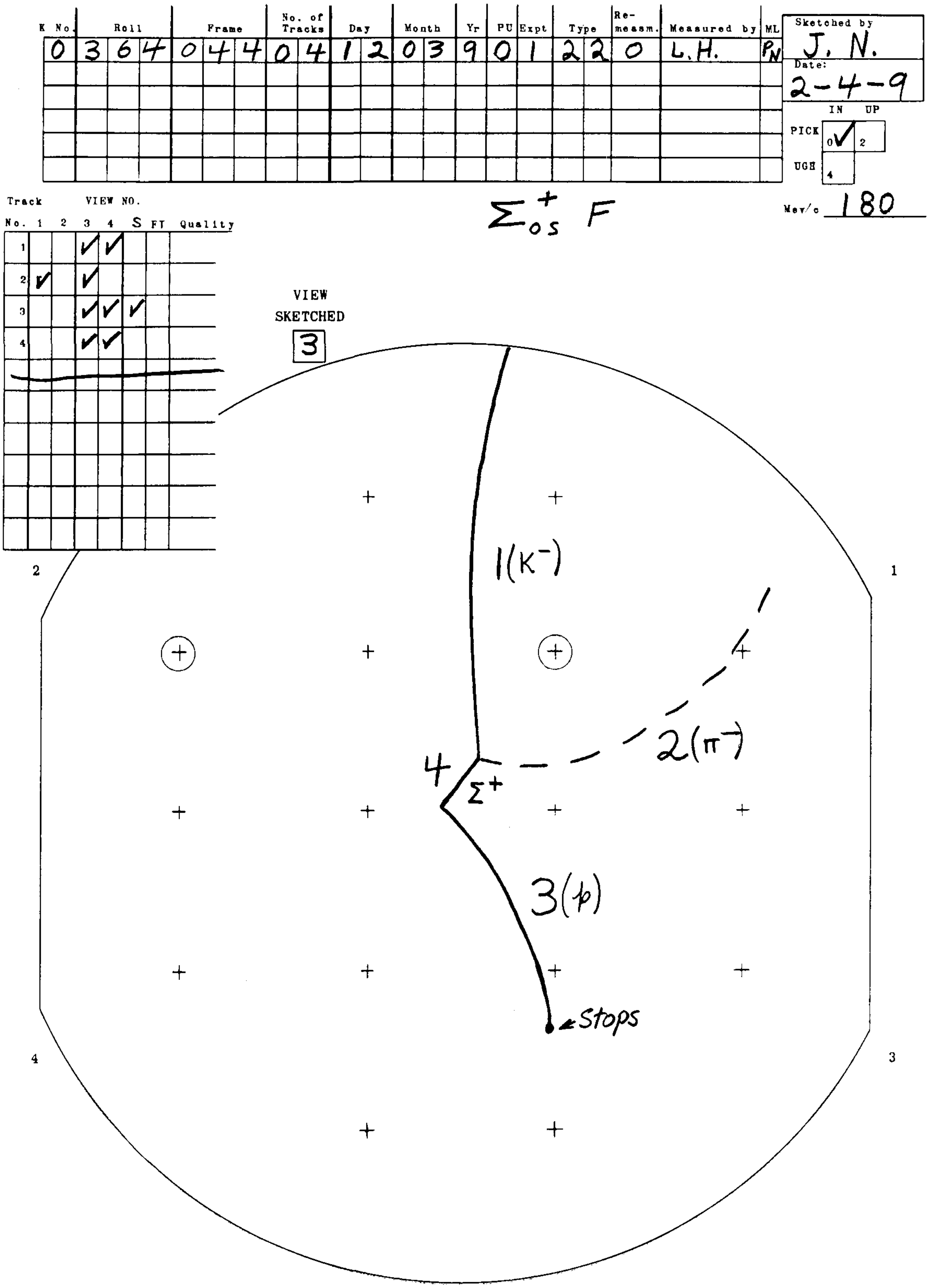

Fig. 1 Sketch card.

reason McCormick wants to equip his Reaper with an on-line computer. Franckenstein may eventually want to go in that direction, too.

Having summarized how the track co-ordinates are obtained, we can go on to discuss how they are synthesized into tracks, vertices, events, and experiments.

This system was formulated by A. H. Rosenfeld, J. N. Snyder, F. T. Solmitz and H. D. Taft. The actual IBM-704 programs were written by seven physicists, the four above, plus three talented graduate students, J. P. Berge, W. D. Humphrey, and R. R. Ross.

THE BERKELEY SYSTEM

Bubble chamber pictures are almost always ambiguous, for example a V may be a Λ, or one of many modes of K-decay. Our policy is to have the sketcher resolve as many ambiguities as he can; then we have the 704 do a least squares fit to all remaining plausible hypotheses and report for each a criterion of goodness of fit (χ^2).

The IBM program which does this job is about 16 000 words long. Since we have been working with an 8 000-word IBM-704, and do not like to write single programs longer than 8 000 words, we first wrote an 8 000-word program called PANG which deals with one track at a time, synthesizes its film co-ordinates back into points in space, and then fits a theoretical " track " to these points. (PANG stands for the momentum P and the ANGle of each track).

PANG output is then fed into a vertex-fitting program KICK, which applies conservation of four-momentum at each vertex and fits the vertices together into events. (KICK stands for K Interaction Co-planarization and Kinematics. It was designed specifically for a low energy K^- run, but seems to fill most of our present needs.)

PANG

The first half of PANG can afford to ignore the problem of mass ambiguities. The synthesis of film co-ordinates into space points is mass independent and can be done once and for all and stored in core for further use. One can still go one step further without knowing the mass of a track, and make a universal crude least squares fit to these points. PANG makes a parabolic fit in the x-y plane (perpendicular to the magnetic field) and a linear fit in z. (So far we have been describing our primitive 650 version of PANG, written by Franck Schmitz and called HYDRO, which is no longer in use).

The second half of PANG takes into consideration energy loss by ionization along the track of a charged particle. This is velocity dependent, and hence mass dependent, so PANG must take a different fit for each mass hypothesis. (If the mass of a *neutral* particle is ambiguous it is convenient to have PANG write two or more *identical* outputs).

PANG's final fit takes into account not only dp/dx, but also spatial variation of magnetic field. It fits a fourth-order polynomial to the x-y projection, and fits a third order polynomial in z. It then calculates at both ends of the track: dip, azimuth, and momentum p (via curvature). At the beginning " end " it also calculates another momentum p (via range) so that KICK can try the hypothesis that the track stopped. We also calculate uncertainties and correlation coefficients between all the output quantities at either end of a track. The uncertainties take into account the following:

1) an average error in space $\bar{\sigma}_{xy}$ and $\bar{\sigma}_z$ based on the known centering accuracy with which Franckenstein centers on the film,

2) multiple Coulomb scattering, and

3) for stopping tracks, Bohr range straggling.

PANG also calculates incidental data on the goodness of fit σ_{xy} and σ_z, on tracks, position, etc..

When any track is of zero length, we simply do not measure it; then when PANG discovers that both views of a given track are missing it writes a dummy track containing the right mass assignments but otherwise meaningless data. KICK will later pick up this mass and calculate the missing variables.

PANG writes two output tapes, one BCD (= binary coded decimal) which can be printed and read by humans, and one binary for KICK. PANG however is designed so that it can be used independently of KICK (and was so used for some months).

To simplify the program, we do not take advantage of the fact that many tracks may share a common vertex point; we measure all tracks entirely separately, including two-point neutral tracks (like tracks 2 and 5 in Fig. 2). This procedure wastes Franckenstein time, but until very recently this was not the bottleneck, and programming was.

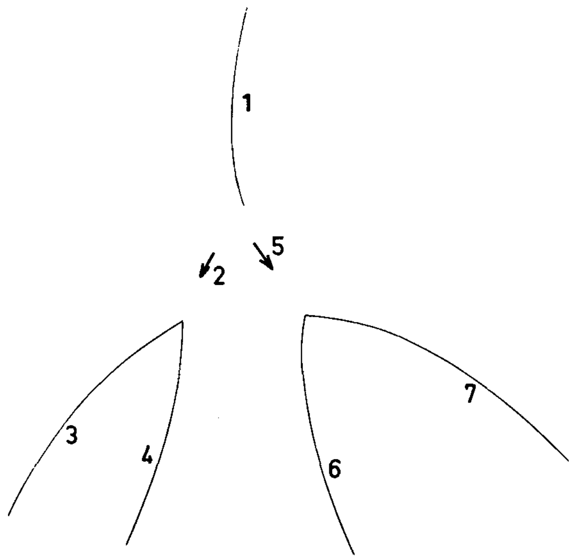

Fig. 2 Example of second class (3c) momentum fit.

KINEMATIC FITTING — "GUTS"

The least squares kinematic fit of an n-track vertex is performed by a subroutine called GUTS, which seeks a minimum in

$$\chi^2 = \sum_{i=1}^{n}\left(\frac{P_{xi}^{fitted} - P_{xi}^{meas}}{\delta P_{xi}}\right)^2 + \sum\left(\frac{P_{yi}^{fitted} - P_{yi}^{meas}}{\delta P_{yi}}\right)^2 + \ldots$$

where P^{fitted} are subject to 4 equations of constraint

$$\Sigma P_{xi} = P\Sigma_{yi} = P\Sigma_{zi} = 0\,; \quad \Sigma\dot{\omega}_i = 0\,.$$

(the 4-momentum of the *incoming* particle is defined negative).

(In actual fact the Cartesian components of P are not appropriate variables because they are not gaussian distributed. We really use the track curvature (projected on the horizontal plane) together with its dip and azimuth, and allow for correlations; so we write

$$\chi^2 = \sum_{i,j=1}^{3n}(x_i^{fitted} - x_i^{meas})G_{ij}(x_j^{fitted} - x_j^{meas})$$

where $G_{ij}^{-1} = \overline{\delta x_i \delta x_j}$ is the error matrix. We also add the constraint equations, each multiplied by a Lagrangian multiplier and then make an iterative fit.)

It turns out that there are only four basic classes of overdetermined vertices to which one can make least squares kinematic fits. The first basic class is the one just discussed, where all the kinematic quantities are experimentally measured. Then all four constraint equations are used. We call this a $4c$ fit.

The second class ($3c$) occurs if the momentum of one track is not measured (for example, the neutral track of a V, as in Fig. 2). Then one uses one conservation equation to calculate the missing variable, and only three are left to constrain the fit.

Similarly, there are $2c$ and $1c$ fits, and finally there is the Oc case where one can calculate all the missing variables, but has no check, and cannot form χ^2. The Oc case is plagued with a sign ambiguity (from solving $x = -b \pm \sqrt{b^2 - 4ac}$).

Finally, if there are more than four missing variables the physicist can still extract some information, namely the mass of a possible missing neutral. He can solve for P_{un} the unbalance of momentum at a vertex, and δP_{un} (its uncertainty). If $P_{un}/\delta P_{un} > 1$, one or more neutrals probably got away undetected. We can then form the unbalance W_{un} and δW_{un}, and calculate the mean of the missing neutral, $m = \sqrt{W_{un}^2 - P_{un}^2}$ and its uncertainty δm. Note that m is a function of four measured quantities, so, apart from missing neutrals, a vertex must be $4c$ in order that the m calculation can be made.

The kinematic fits described above are carried out by the 4 000 word sub-routine GUTS. KICK sets up the proper measured variables and specifies the constraint class, and GUTS does the fit. It usually takes about five iterations at about ½ second each.

KICK

One could, of course, make a direct least-squares fit to a multi-vertex event, but we decided to fit one vertex at a time for the following three reasons:

1. We can handle all cases with only the five GUTS classes.
2. To make a least squares fit subject to λ equations of constraint one inverts a $\lambda \times \lambda$ matrix. By keeping $\lambda \leq 4$ we keep the matrices reasonably small, thus increasing the speed of the program.

3. We can prove in the approximation that the constraint equations are linear that we get the same final results as we would from an overall fit. In practice we *do* get the same results; this is tested below with a built-in check described below.

KICK consists of two kinds of sub-routines: event type control sub-routines, which guide the general flow of computing suitable for the various event hypotheses, and processing sub-routines, such as GUTS, which perform the many computations which are to be done in the analysis of the events.

As an example of the computations and logic performed in an analysis let us consider the event type 22 corresponding to the sequence of events

$$K^- + p \rightarrow \Sigma^+ + \pi^- ; \quad \Sigma^+ \rightarrow p + \pi^0$$

The event may appear as drawn in Fig. 1.

First, general sub-routines read in the information on the event and individual tracks. Control is then given to the event type control sub-routine 22 which calls in the various processing sub-routines. A fit is first obtained at vertex I using the information on tracks 1, 2, and 4 supplied by PANG. This process in detail involves the sub-routine VERT which stores the track information into the proper location, calls for GUTS to perform the actual fit, then stores the output of the GUTS fit and returns control to the control sub-routine. Next the processing sub-routine SWIM computes the behavior of the Σ^+ beginning with the information provided by GUTS for the end at vertex I and furnishes the curvature, azimuth, and dip with new errors at vertex II. A fit is then made of vertex II by using VERT and GUTS once more. For a physical understanding of vertex II, the information from the whole event has now been used, since the " swimming " from vertex I along track 4 has carried all the information available from tracks 1 and 2. The writing sub-routine is called for and the results of the fit at II are written onto magnetic tape. This print gives separately the value of χ^2 for the vertex I fit and the vertex II fit. The final editing program, called EXAMIN, can calculate the χ^2 for the overall hypothesis.

In order to obtain the best information at vertex I the procedure is now reversed. Beginning with the track information from PANG (not from the previous evaluation of the vertices), vertex II is fitted by VERT and GUTS. Let this fit be called II′. The SWIM sub-routine is used again but now track 4 is swum upstream. Then GUTS evaluates vertex I again with all the information available from the fit II′ to obtain the best fit possible I′ for the vertex I. At this point we have obtained the best fits to both vertices and our computation is indeed completed. The writing routine is again called for. To check the accuracy of the computation we " swim " I′ to II again but do not seek a fit at II. The results for the fitted values of track 4 at vertex II should be the same as after the first fit was made at II. In general the calculated momenta and their uncertainties check to a few keV! The results of this check are also printed. Finally all the index registers are reset as they were before beginning event type control sub-routine 22.

The effect of control sub-routine 22 therefore is to obtain the two fits I and II, II′ and I′, and a check. These have also been written on to tape. The computer is returned to the same state as it had on entering sub-routine 22. This latter feature is important for those instances when the particular " K^- in flight to give Σ with π decay " hypothesis is but one of several to be tested. For instance event type 32 considers the possible ambiguity of K^- interaction in flight and at rest and therefore will often examine both hypotheses. In this event type (32 as opposed to 22), the rest hypothesis (called event type 122) is first investigated. If this gives a poor fit then event type 32 will call for event type 22 next. In this way event type sub-routines become sub-routines for ambiguous events. It is therefore important that after finishing such an event the machine is left in its original state so the next part of an ambiguity is investigated without any confusion from the previous evaluation.

KICK has a number of special logical features, among them the following: 1) KICK is equipped with 3 " Pick-Up " banks, in which fitted tracks may be stored temporarily, addressed with a " Future Track No. ". They are picked up and written over the data in the appropriate tracks banks whenever an event is read in with the " Pick-Up Command " set to " 1 " (instead of the usual zero). This facility allows several connected vertices to be connected together by the measurer, without writing special connected event types. It is used most often when one of the tracks leaving a vertex has a subsequent scatter. 2) After a zero length charged particle (other than a sigma) has been measured, KICK checks that its projected range is really consistent with its having looked zero length. If this condition is not fulfilled, KICK refits the vertex, adding the constraint that the horizontal projection of the track must be equal to some parameter, set currently to ½ mm. 3) If every hypothesis of an event fails, KICK asks " have any negative tracks been measured as ' stopping ' tracks? " If so, it reasons that they may not really be stops, but charge-exchanges instead. So it changes "stopping " to " leaving " and tries again. 4) After fitting all " leaving " tracks it checks that the calculated range R (fitted)$>L$(measured). If not, it prints a warning.

FAILURE RATES

Franckenstein's digitisers work almost perfectly, however in about 5 to 10% of all events, Franckenstein operators make a mistake which is detected by PANG (which then throws out the event). Common mistakes are to measure a track on too few or too many views, to measure a wrong fiducial, etc.

We have poor statistics on mistakes of a more subtle nature that cause failures detected by KICK (which has so far processed only part of one experiment). However on a sample of 600 Kp scatters about 10% (60) failed. They turned out to be mainly hard-to-measure events (frost on bubble chamber window, etc.) but when carefully remeasured all except 6 gave satisfactory fits. These 6 had to be remeasured once more.

COSTS

A brief summary of the costs of running the experiments is perhaps relevant in placing computer costs in the proper perspective. Approximately 100 events per hour can run on the present analysis routines. This corresponds to 40 cents/event. Assuming 3 Bevatron pulses are needed for each event, the cost of the Bevatron is roughly $10 per event.

Acknowledgements

We are grateful for the support of Professor L. W. Alvarez, Hugh Bradner, and all those in the group who have made these bubble chamber experiments possible. The cameras and scanning table and Franckensteins were developed by Hugh Bradner, Jack Franck and Jerry Russell.

DISCUSSION

RAU: I noticed in your summary of the various times involved that no estimate was made of the time it takes to go and hunt up a piece of film out of a drawer, then put it on the machine, take it off, put it back and that sort of thing, which must occur at least two or three times during the process of the analysis. Could you make us an estimate of how much of this extra time would be involved?

ROSENFELD: I didn't bring up this question about hunting for film for the following reason. We are seriously committed to automatic film advance on Franckenstein. There are dots on the film just similar to the patterns which Goldschmidt showed you. However, we have been more interested in getting a second Franckenstein working than to put this equipment on, so that for me to talk now about times which it takes us with our present arrangement of finding events on the film is misleading. To thread a roll and find a single event in the middle probably takes a few minutes. But we will try to get around that. There is one point, however; if you come to a class of events which are of extreme interest, and which you know that you will be looking at many times and remeasuring many ways, then it is possible to make contact prints. For example, I know that in the associated production run Crawford and Stevenson had of the order of a thousand events, but spread on an enormous number of rolls, (they ran for three months or so). They took out some interesting classes of events and simply had them all copied one by one on the same roll. Let me make this point also for people who are interested in borrowing bubble chamber film, that the process of making contact prints of rolls of film is very efficient and the quality is essentially as good as the original—not quite, but essentially as good—and we have had quite good success in copying film for people; any of you who would like to use some of our film in that way certainly should look into this. There is one other thing which I meant to say and did not, and that is that we have by now, as you might guess, a reasonable number of people coming through Berkeley every month who are interested in knowing how these programmes work and also I am very much impressed with the amount of thinking that seems to have been going on over here. It occurs to me that it might make sense for some of us who are heavily involved in this to get together, say next summer. I know that there is going to be a conference at Berkeley on particle physics after the Rochester Conference. If any of you would be interested in spending a few weeks about then I should be interested in hearing from you and will start to take some sort of public opinion poll as to what this " school " should teach.

E. D. COURANT: How much manual punching of cards is necessary for the computing of each event?

ROSENFELD: We had 20 columns of fixed data, of which however most are permanent things like the date, so that there are about six important columns of event data, plus one word that goes with each track. This word has just two pieces of information. If the track is a stopping one so that we wish KICK's first hypothesis to try momentum from range, we put a bit in one digit. Also if there is a " future track-number " for connected events, we have to give the track " postal address ".

E. D. COURANT: It does not consume any important amount of time?

ROSENFELD: No. Typically we have 10 IBM cards per event of which a fraction of one is taken up with this information.

ADAMS: I would like to ask two questions. The first one is how much time do you think will be saved in all this elaborate picture evaluation if, for example, bubble chambers had uniform fields instead of non-uniform fields across the chamber, and secondly if optical distortions such as tilted windows didn't occur. In other words, how much evaluation time could be saved by simplifying the bubble chamber end?

ROSENFELD: I will answer this provided that Goldschmidt-Clermont will independently say something because I believe he has thought about this more than I have. My impression is the following: out of this whole 20 000 word programme which I mentioned only something like 3 000 words are involved in these, and those 3 000 words incidentally take care not only of the variation of magnetic field but also of dp/dx which is really more complicated. If the IBM running time is a consideration, we add, we think, 1/3 second to the time for each track. Now by the time we have completely processed an event there's nearly half a minute of IBM time spent, so you see that we are really adding a rather small part. The second part of my answer is that these problems were very annoying because they were in our way at the beginning but by now there are programmes which solve them adequately. Everybody and his brother has a relatively satisfactory track-type programme. So I would suggest that other physicists can now use one of these. We have had success—at least in the United States, where we have lots of 704's—in using parts of one another's programmes. For example, I might mention that Taft and Adair at Yale had their own ideas about what sort of overall KICK logic they wanted, but they are using Taft's GUTS sub-routine in their own kinematics programme. In the same sense I think many of these corrections for non-uniform magnetic field etc. could be borrowed. So I don't consider tilted glass and non-uniform field very serious any more.

GOLDSCHMIDT-CLERMONT: I think I would agree with what Rosenfeld says. The programmes we have written take into account the refraction in such a way as to include the case of a tilted front glass. The first programme was written for straight tracks for the 704. Now a curved track programme is undergoing tests in our Mercury digital computer here. Though we do not have much experience yet, the kind of figures I would quote for the 704 would be of the same order as those mentioned. They will probably be the same for Mercury, apart from the overall factor of perhaps about 4 in speed in favour of the 704 as compared to Mercury.

GOTTSTEIN: I have one question and one statement. The question is really related to the question which was just put by Adams. Rosenfeld mentioned the difficulty which can arise if the observer confuses the different views in his measurements. I wonder whether anyone has thought of eliminating this possible source of human error by just applying the method of projecting the different pictures on top of each other and measuring the three co-ordinates directly. This, of course, would imply measuring also a relative movement of the two projectors with respect to each other and also digitising this motion. But in that manner one could cut out much of the computing time and also it could be easier to find the corresponding points. This is actually one of the methods used by the ballistic people to measure very accurately the trajectories of missiles and bullets and so on. This might be an application of the suggestion by Rau to look around in other fields for suitable techniques. But I understand that there is at least one small firm working for the Swiss army who are quite interested in collaborating on this pure research. I understand they are putting up a little model here next week at CERN. So this would be a rare example of military science doing something really productive!

ADAMS: My other question was also rather a general one. I wonder whether anybody—perhaps Rosenfeld—could give me an idea of how many of these Franckensteins and IBM 704's are needed for one large bubble chamber, assuming that this chamber is used in the normal sort of way with an accelerating machine?

ROSENFELD: Let me tell you what we've been using at Berkeley on the 15″ chamber. I must repeat that we really don't have any experience with the 72″ chamber. We own two 15″ Franckensteins. We have, however, never operated these machines at more than 100 hours per week between the two of them, so you can see we are not really using even one full time. To keep this operating requires three or maybe even four scan tables. This involves scanning, sketching, looking for troubles; and in IBM time I would suspect we can keep up with a steady state using about 6 hours per week of 704 time. This includes the time (actually quite appreciable) for writing new programmes, debugging them and doing book-keeping.

As to Gottstein's question: this idea of looking at both views simultaneously is intriguing to me. I want to study it. Actually it's a surprise to me that it works so well. Gottstein tells me that they managed to measure the depth (i.e. z-position) of a track as well by this technique, as we have by combining two views in Berkeley, which is impressive. If part of this was a question, namely, " are you intending to go in this direction? ", well, until I talked to him the answer was no. But we must get around this business of having to specify each track in up to three views. You see you may run into the sort of situation where two tracks switch positions from one view to the other. We must go in the direction of defining the tracks only in one view and then letting PANG sort it out in the other two. Goldschmidt-Clermont, have you thought about this? I had the impression that this is no trouble for the computer.

WALKINSHAW: Are you making any attempt to record your computing programmes in such a way that other teams will be able to use them in the future and know what has gone into the problem—not just how to use them, but the details of what has actually gone into them. It seems that this to me is really quite important.

ROSENFELD: We are currently writing up four general papers which we will submit to the " Review of Scientific Instruments ". One will be very much like the talk I gave to-day, one will discuss PANG, one will discuss GUTS and one will discuss KICK and we hope to have these out by Christmas. We have, for anyone who wants to see them, complete flow diagrams of all three programmes and all the equations for GUTS and all the error equations—uncertainty equations —which are of course quite important for PANG. So that anything you want you can simply write us.

WALKINSHAW: I would like to ask a second question, if I may. How many physicists do you have in this team? Is the limitation not in the number of physicists rather than the equipment that you have? How many physicists per one shift operation of Franckenstein do you require?

ROSENFELD: We got KICK working (with a few fine points by-passed) about two weeks before the July Kiev meeting, so we have little experience. But my guess is that from now on we are going to be pretty much snowed under with the events which really are sufficiently fishy that they will have to be looked at and some special provision taken. I think, for the moment, that this is going to be the bottleneck.

GOTTSTEIN: I should like to add a qualification to what Rosenfeld just said. He said we have measured the depth of the track—that is not quite true. We have not measured it yet but from the tests we got the impression that we can make the cross-hair coincide with an individual bubble with an accuracy in depth of one bubble diameter. Lütjens at our place is building a projector which will work on that principle but which is not completed yet.

KOWARSKI: Rosenfeld, the figures you gave on the black-board, do they describe a past state or a present state or are they a forecast of what a 15″ chamber might need in future?

ROSENFELD: No, there for once I don't have to hedge. Those figures are based entirely on the statistics of measuring in the few months before the Kiev Conference and of fitting the data in the last hectic few weeks before and during Kiev.

KOWARSKI: But would you consider that this is the asymptotic state or that the needs of Franckensteins and hours of computer and so on are likely to increase?

ROSENFELD: Yes, they will. As I just mentioned this single improvement of separators that Murray has suggested, namely making a multiple separator—a septum with many channels and much greater aperture— is going to mean that our next K^- run will be 100 000 instead of 10 000 events. I think it is clear that the load will increase, I hope by an order of magnitude.

INSTALLATION FOR AUTOMATIC MEASURING OF PHOTOGRAPHS FROM BUBBLE CHAMBERS

E. M. Andreev, P. Giršl, I. A. Zarubin, G. M. Kadykov, S. M. Korenchenko, V. M. Lachinov, A. G. Morozov, K. G. Nekrasov, R. Pose, M. I. Popov, V. V. Smirnov and N. S. Tolstoj

Joint Institute for Nuclear Research, Dubna

(presented by S. Ya. Nikitin)

1. GENERAL CHARACTERISTICS

The described instrument for automatic measuring of photographs (AOC) is designed to measure precisely co-ordinates of points on particle tracks on bubble chamber photographs. The measured co-ordinates are recorded on punched paper tape so that they can be read directly into the electronic computer for mathematical processing. A general view of the device is shown in Fig. 1, and a schematic diagram of the device is shown in Fig. 2. The photograph to be measured (1) is placed on the measuring table (2), which can be moved by the servomotors (3) and (4) in two mutually perpendicular directions. The light source (5), objective (6) and mirror (7) project an image, ten times enlarged, on to the frosted screen (8) 60×85 cm in size, which is viewed by the operator. The central region of mirror (7) is semi-transparent. The part of the image passing through the semi-transparent region of the mirror is directed with the help of prism system (9) on to the photosensitive detecting system (9, 10, 11).