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Author
Alvarez, L W

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L. W. Alvarez

Department of Physics and Lawrence Radiation Laboratory
University of California, Berkeley, California

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I have been given twenty minutes to "state my position" concerning the subject of this round-table discussion. That is a short time into which to compress the most important thoughts I've had in the eleven years I've worked actively in this field. The first thing I wrote on the subject was in May of 1955, when I formally asked the AEC for money to build the 72-inch chamber. At that time, the largest operating hydrogen chamber in the world was our own 4-inch device, that didn't even have a stereo camera, so we couldn't analyze the few pictures we took with it. In the proposal, I described a machine for rapid measurement of film, in which the operator could "drive down the tracks," punching information onto cards to be fed into a computer. This machine came into operation in mid 1956, under the design supervision of Hugh Bradner and Jack Franck, and as far as I know, it was the first of the so-called conventional measuring machines; as you know, we called it a Franckenstein. The reason for describing a data-analysis system in a proposal to build a large bubble chamber may seem odd to newcomers to the field, but it was included to counteract a prejudice most physicists had in those days concerning track chambers. It was generally agreed that a cloud chamber was a wonderful device for exploratory experiments, but that with it, one couldn't do an experiment with any statistical significance. The two cloud chamber groups I knew most about averaged one or two measured events per day, by reprojecting their stereo pictures onto "space tables."
I therefore felt sure that the 72-inch chamber had no chance of being approved

unless I could point to a technique that might solve the data-rate bottleneck. The Lawrence Radiation Laboratory didn't even have an IBM 650 at this time, but I had seen the MANIAC at Los Alamos and felt that computer calculation was the answer to many of the problems we would face. My wartime work in radar had acquainted me with automatic tracking and automatic data readout--the other ingredients in the system I proposed.

I offer these historical observations merely to show that the great efforts in the past decade by many people in the field of bubble chamber data reduction have really paid large dividends in promoting our understanding of particle physics. The present U. S. measuring rate is about two million events per year, and my own research group is confident that it will be measuring at the rate of one million events per year, late this year, when our second Spiral Reader becomes operational. We have been pushing toward the goal of one million events per year for some time, and when it is firmly in our grasp, I will feel that I have earned a rest, and will devote my energies to other tasks. The effort has been exciting and rewarding, and I am only sorry that time doesn't permit me to thank by name the very many colleagues who have brought us within sight of our long-sought goal. But most of the experts in the audience can name them without my help.

New findings in particle physics, such as we have listened to in Berkeley for the past week, come from a blend of many skills, ranging from those of accelerator builders and operators on the one hand to those of group theorists at the other extreme. In the broad middle of this spectrum lie the main interests of the participants in this Instrumentation Conference on High Energy Physics. I would like to suggest that this round-table discussion should be more concerned with Engineering and Production than with Instrumentation. To justify this semantic differentiation, I'll give definitions of

Engineering and Instrumentation to which I can subscribe. At the inauguration of the newly chartered U. S. Academy of Engineering, last year, one of the speakers said (as nearly as I can remember): "Engineering of necessity deals with economics, and any engineering-like activity that does not deal with economic realities is, in fact, not engineering at all." Instrumentation, in the sense that it is accomplished by instrument makers rather than by engineers, has meant to generations of physicists a delightful activity in which monetary considerations play a small if not negligible part. My personal preference is for instrumentation rather than for engineering: I learned machine-shop practice during two high school summers in an instrument shop, and I have personally built many instruments in Physics Department "student shops," and designed others that have been built by professional instrument makers, in department or laboratory shops.

But my personal preferences can't change the present situation; collectively, we operate a very large business. According to a census made this week, in the U. S. alone our business owns about 15 million dollars worth of capital goods, in the form of scanning and measuring devices, and spends about 13 million dollars annually, about 8 million dollars on technicians' salaries and 5 million dollars on computer charges. We have had ample warning from both the legislative and executive branches of our government that in the future, a higher annual funding level is going to be difficult to obtain for work such as this, so our main hope for doing more bubble chamber physics is confined to increasing our data-reduction efficiency. This is an engineering approach, and it translates directly into an emphasis on "events per dollar."

Although some of you may disagree with me, I take the position that the best data-reduction system is the one that produces the largest number of usefully measured events per dollar expended. The word "usefully" is important, and I believe that all the systems with any real support at this round table, measure well enough that any increase in absolute measuring accuracy would not give any increased knowledge of the physics under consideration. We all know the great part played in the analysis by the "fitting programs," that make appropriate changes in the actual measurements, to give the best "fitted values" of momenta, center-of-mass angles, etc. In view of the degrading effects of thermal gradients in the hydrogen, mechanical transport of bubbles by turbulence, multiple scattering, and film distortion, it is my strong feeling that attempts to improve measuring accuracy only add to the cost of each event, and in so doing, lower the desirability of the system. The idea of "good enough" comes from engineering, and although it may upset instrument designers, I feel it is a concept that we must embrace.

My second position can therefore be summed up as advocating that from the list of "good enough" measuring techniques, we should select the one that provides "the most events per dollar." I didn't adopt this position at the Instrumentation Conferences at Berkeley in 1960, or at CERN in 1962; in my opinion, there were then several untested systems in development, and the emphasis was still properly on the instrumentation phases of the program. But at present, all systems but PEPR[1] are well understood, and we should even know about it in a year or two without spending much additional development money.

My suggested figure of merit for a system, events per dollar, has both a numerator and a denominator, so it is worth spending a few minutes

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1. Irwin Pless, IEEE Trans. Nucl. Sci. NS 12, 279 (1965); P. L. Bastien, T. L. Watts, R. K. Yamamoto, M. Alston, A. H. Rosenfeld, F. T. Solmitz, and H. D. Taft, Methods Computational Phys. 5, 99 (1966).

defining both quantities a little bit more carefully. The graphs I'll show will tabulate two different rates:

(1) "total events per year"

(2) "specific measuring rate" (events per total employee hours).

This latter rate is for the whole group, per year, and is the average number of raw measurements per hour per full-time scanning-and-measurement-group employee. (I have excluded programmers from my denominator, because the largest groups carry much of the programming burden for the smaller groups. If we count programming effort, the larger groups suffer in apparent efficiency for the services they supply to smaller groups, in the form of operating programs.) The latter rate can be converted into the more meaningful rate, "useful measurements per dollar," if we include two additional bits of information. One of these is the reject rate, and the other is the overall cost of the operation in dollars per employee hour. It is my experience that no one believes anyone else's reject rates, so I won't quote ours, but will address the problem in a different way. I'll do as any business concern does when it wants the public to believe the financial reports it issues. All U. S. corporations issue annual reports to stockholders which contain statements by certified public accountants to the effect that they have performed an independent audit of the company's books, inventory, etc., and that the numbers tabulated in the report are representative of the true state of the company's financial condition.

I am fortunately able to say that we have just had an independent audit made of our Spiral Reader system by two physicists from Cambridge, England. They were sent by their government to find out if the rumors about the Spiral Reader performance had any substance. They have just completed a report recommending that a Spiral Reader be built as an interlaboratory facility for all British users. As independent auditors must be, they were given carte blanche to perform any needed tests, examine all records, and talk to any employee. Silverio Almeida, who wrote the report, arrived here in a frankly skeptical mood, since he had been in Berkeley several years ago, when the Spiral Reader was widely and reasonably regarded as a failure. At present, Silverio knows more than anyone in the world about the details of the Spiral Reader performance with the possible exceptions of Jack Lloyd, Gerry Lynch, and Frank Solmitz. All of these men are here in the audience, if you wish to ask them questions after I have finished. Silverio has tabulated the failure rates of thousands of events, from all possible causes. He has used a great deal of Spiral Reader time, Franckenstein time, and 6600 time, in the preparation of his report. He has made sure that he had large samples of events, each of which was measured on both the Spiral Reader and the Franckenstein. He has prepared histograms, for both machines, of measurement errors of beam tracks, measurement scatters on all kinds of tracks, and χ^2 distributions of fitted events. He has given me permission to say that in his opinion, the Spiral Reader accuracy is in no way inferior to that of the Franckenstein, and that it measures a great deal faster, gives good bubble-density measurements automatically, and has surprisingly low reject rates. In the few cases where the partial reject rates for some particular cause were higher than he would have liked to see, he reports that remedial steps have been taken, and that he is satisfied that these partial rates will soon be down within reasonable limits. His whole report is of course a private document, but I am sure he would be happy to share his quantitative findings with other interested parties.

Now that I've given my reasons for believing that the Spiral Reader reject rates are not out of line with those of other systems or other laboratories, I'll continue to use "raw measurements" in the numerator of my "figure of merit." Groups most concerned with measurement usually tabulate their data in raw measurement rates; physics groups, on the other hand, are more concerned with "completely processed events" per unit time. Since I am speaking as an engineer this afternoon, I'll stress raw measurements. We have a wider choice with the denominator of the "figure of merit"--dollars. Three main classes of money are relevant here--(1) the prorated share of the capital cost of the machine, assuming some reasonable useful lifetime, (2) the salaries of all the employees in the scanning and measuring group, and (3) computer charges. My preference is to omit the third category, for a number of reasons: (a) Most groups use most of their computing budget for SUMX-like operations which are machine-independent. My "certified public accountant" here is the National Academy of Sciences Committee on Computer Utilization, of which Art Rosenfeld is a member. He tells me that the Committee's investigation showed that almost all groups in this country use close to 60 seconds of 7094 time, or its equivalent on some other computer, to process each event. Figure 1 shows that our group has been averaging 53 seconds of 7094 equivalent computing time for the past three years. The small variations from 60 seconds, even for the past 6 years, are really extraordinary when one realizes that this period embraces the use of seven computers from the 704 to the 6600. According to Art, the only group that is significantly more efficient than all others is the Yale group, which averages about 40 seconds of 7094 equivalent time per event.

I advocate leaving out computer charges for the following additional reasons: (b) such charges are steadily being reduced in this country under the impact of normal business competition, and are largely out of the control of the system designers. When more efficient programs are introduced by any group, they are adopted without fanfare by other groups; they therefore tend to be measuring-machine-independent, since they operate on data after it has been generated by any one of the measuring machines. (c) Most modern measuring machines have on-line computers attached, but the operating costs of these computers, per event, is quite small compared to the total of one minute of 7094 equivalent time per finished event. I believe we will "miss the forest for the trees" if we introduce the cost of computer time into the discussion.

I therefore suggest that we should compare the various systems on a "raw measurement per dollar of technician salary." I will ignore the prorated capital costs in this figure of merit, because in this country, for any system I know, the salary costs are greater than the equipment costs. I make this concession to simplicity in spite of the best numbers I know, which show that the Spiral Reader has the lowest prorated capital cost per event of any presently operating system. And finally, for simplicity again, I will quote our specific rates as "raw events per hour of employee time," rather than as "raw events per employee salary dollar." Salaries are comparable throughout our large AEC laboratories, even though they are lower in most university laboratories. Appropriate corrections can be made for these differences as well as for capital costs, in a straightforward manner.

I'll now show some slides that will illustrate what our group has accomplished in the last six years by a strong and continuous emphasis on engineering and production. Incidentally, the head of our scanning and measuring group, Ted Hoedemaker (who is here today, if you wish to question him), spends a large fraction of his time in a role that in industry would be called production management. The following slides are representative of the regular reports he prepares both for himself and for me, so that we will know as soon as possible what steps must be taken to improve our figure of merit. Figure 2, a and b, is a typical daily Spiral Reader report, prepared and printed by the computer. Figures 3, 4, and 5 are typical weekly, monthly, and yearly production reports on all our measuring devices, also computer-prepared. Figures 6 through 13 show typical production graphs that are kept up to date and displayed for all interested persons to see. You will note that we keep our weekly rates a "vertices per measurement hour." If we tabulated this rate in "events per hour," and if it suddenly dropped by a factor of two, we wouldn't know whether we had switched to two-vertex events or something had gone wrong with the machine. We have measured tens of thousands of double-vertex events, for example, $K^-p \rightarrow \Sigma\pi$ and $K^-p \rightarrow \Lambda\pi$.

Gerry Lynch has recently finished processing a sample of over 100,000 K^-p two-prong events. Figures 15 through 18 show angular distributions of K^-p elastic scattering at a few of the incident momenta. In these simple events, Gerry tells me that his rejects average less than 5%, with the reject rate dropping a factor of two each year. (Reject rates for more complicated events are, of course, higher.)

Figure 14 shows the total number of events measured in each of the last six fiscal years (July 1 to June 30) plotted in the middle of that fiscal year, which is the same as the beginning of the calendar year. We don't have good records for the earlier years; we were then in the instrumentation phase of our development. I have marked an estimated rate for mid 1956, when the first Franckenstein became operational. The fact that the rate in that year was somewhere near the extrapolated exponential curve is the only thing worth noting. The doubling time is seen to be 1.6 years. In the first years of our experience, increased measuring rate was generated by the brute-force method of hiring more employees and building more Franckensteins.

As you can see, we had about six machines before we reached what amounted to a ceiling on our manpower. If we had continued to obtain our increased production rate simply by building new Franckensteins and hiring new technicians, the staff required to measure a million events per year would be in the neighborhood of 1000 employees. (The telephone company calculated more than fifty years ago that if everyone was going to own a telephone, about half of all the women would be required as telephone operators. They concluded that the efficiency of each operator had to be increased enormously; the dial system is the result of that engineering analysis.)

Although we don't have the records for the early years, I can guess that the "overall employee production rate" started out at about one per hour, then dropped off the bottom of the graph, and finally came back up to the one per hour shown in 1960. This is a common phenomenon in industry, where successful little companies find that as they first grow, they become less efficient. Many go bankrupt in the transition from a little company, where high efficiency comes largely from the fact that everyone can handle several different jobs, to a large company, where high efficiency comes from production line operation with very expensive production tooling. Between the two extremes is a difficult regime where administrative costs spiral upward and overall efficiency drops. In our operations, we found we had to hire an increasingly larger fraction of supervisors, coordinators, expeditors, etc., as the size of the group expanded. This, of course, was what caused the overall efficiency to drop--but without the administrative functions performed by these skilled people, the group would probably have ground to a halt.

You may be surprised to note that today, when we have a Spiral Reader with which, on many occasions, a single operator has completely measured more than 150 events per hour, we had an overall employee efficiency (specific rate) last year of only 4 events per hour. (It is now 5 per hour.) You might well ask why we put so much emphasis on the very high individual rates, when they don't seem to be reflected in the overall group performance. But since only a small fraction of our people are operating measuring machines, it is true to a good first approximation that if each person measures at twice his former rate, the specific rate of the group doubles. In fact, the upward slopes of the total production rate and of the specific rate curves are attributable almost entirely to such increases in measuring rates of the minority of the group who actually do the measuring. If we go beyond the first approximation, we find that when individual measuring rates double, the overall rate doesn't quite double, because we must reassign some of those who could have been measuring, and put them to the extra scanning and expediting tasks that are needed to back up the increased measuring capacity. This is, of course, why a few months ago we inactivated our five SMP devices that had been responsible for a good deal of our increased efficiency in the past few years. We had gradually depleted the supply of measuring operators for the SMP's, as the Spiral Reader came into production. Finally the SMP rate of utilization dropped to the point that it made no economic sense to rent a 7040 computer to service the SMP's. (The SMP's are all at work now in other AEC-supported laboratories, where SMP systems were already in operation.)

I have spent some time defining what I believe to be the proper aim of someone active in the management of a group engaged in bubble chamber data-reduction operations and system development. For those of you who may be horrified to hear a scientist setting such unscientific goals, let me remind you that I have my "engineering hat on" at the moment, so I have no apologies. I feel strongly that the objectives of pure science can't be defined in this manner, and I too would be horrified to hear any scientist say that the value of a scientific discovery could be ascertained by any preconceived set of rules or objectives.

In my opinion, we can't have a meaningful exchange of opinions at this round table unless we start with some agreement on what we're trying to accomplish. I know that there are representatives from many laboratories here who are trying to make up their minds on what "second-generation" measuring system to adopt. Naturally, they hear conflicting claims about the various competing schemes, and they have doubts as to which one is going to be the "winner." Since this last sentence acknowledges the existence of a very real competition between systems, let me remind you that a competition can only be resolved if there is an agreed-upon set of rules. We have an Olympic competition in the high hurdles, because all countries agree that the object of the contest is to get from the start to the finish, without knocking down any of the hurdles, in the shortest possible time. If one country took the position that its object was to run as fast as possible, knocking each hurdle down in turn--with the runner disqualified if any hurdles were left standing--then the competition wouldn't be possible.

I have offered my tentative "object of the game" for your consideration. I obviously can't insist that you accept my criteria of "the most usefully measured events per man hour, or per dollar expended," but I believe that our moderator should try for a concensus on objectives from those present today. I have given my reasons for my choice--if any of you has a better set of reasons, for a different objective, I'll be happy to switch my position to agree with it.

Once we agree on our objectives--whether the ones I propose, or any other set of acceptable goals--we can have some "independent auditor" make a table of the present performance of all systems, and the present winner can be identified. We can go even farther, and assess the growth potential of the various systems. This is important, because although one system may clearly be the best today--by our criteria--another system may be about to pass it in efficiency in the foreseeable future. If the cross-over time is a year and the systems take a year to build, then certainly a laboratory director should pick the system that will be the winner a year from now.

The evaluation method I recommend for your use is based first on a look at the present performance of each system, and then on an examination of various partial derivatives. This is a technique that is fundamental to the science of operations analysis. P. M. S. Blackett, of Wilson cloud chamber fame, was the founder of this science, as applied to military operations in World War II. (Here a typical objective was to sink the most submarines with a force of destroyers and airplanes that was limited in size, for the same reasons that our measuring groups are now limited in size--money.) Modern business management has adopted many of the techniques of "ops analysis," and I believe they are appropriate in our field, as well. The basic idea is that one determines the partial derivatives of the "desired output of the system," with respect to all the variables that can be identified. One then pays no attention to variables that have partial derivatives equal to zero, and concentrates on doing a better job on the things that have high positive partial derivatives. You may well say that this is simply common sense, and ask why I speak in such platitudes.

I will therefore give a few concrete examples that I hope will put across some points that have been important to us in our development of the Spiral Reader system. I've already said that a doubling of the individual Spiral Reader measuring rate would (to first approximation) double the group's "specific rate"--events per total employee hours. This assumes that all measuring machines are Spiral Readers, and that the group's size and payroll are constant. (The consistency of all other variables is implicit in the concept of the partial derivative. One is playing a completely different game--quite unrelated to present reality--if he calculates what he could do if his scanning and measuring force were appreciably increased in size.

To put these ideas into mathematical form, let us construct dimensionless quantities:

$\frac{\partial R}{R}$ ≡ fractional increase in individual measuring rate, everything else being held constant

$\frac{\partial r}{r}$ ≡ fractional increase in group specific rate, that arises from the increase $\partial R/R$.

(In our system at present, $R \approx 100$ per hour, and $r \approx 5$ per hour.) What I have stated earlier in words can now be written as the equation

$$\frac{\partial r R}{\partial R r} = k,$$

where k is less than but nearly equal to unity. The fact that k is nearer to 1 than to 0 is what motivates us to pay so much attention to increasing the individual measurer's rates, R.

I can think of many dimensionless partial derivatives that are close to zero and are therefore best ignored in a serious discussion. For example, our second Spiral Reader is painted bright orange, whereas our first one is dark green. We don't have to think hard to know that $\partial r \lambda/\partial \lambda r = 0$, where λ is the effective wavelength of light reflected from the paint. Colors and rates are orthogonal, so we normally don't mention the color of our machines.

In the past few years, we have increased R by an order of magnitude by concentrating our attention on whatever variable appeared to have the greatest immediate effect on R. In other words, we put our effort on the

the variable X, for which the expression $\partial RX/\partial XR$ had the highest positive value. At various times in the recent past, X has been the rate at which we could measure fiducials. Our automatic fiducial-measuring time is now 8 seconds for six fiducials--two in each of three views. Concurrently, we examined the placement and functions of the controls on the machine. We believe that the present human engineering of the control system is excellent, and no improvements in R can be expected from improvements in the coupling of the operator to the machine. Probably the most important and dramatic improvement in the machine was the incorporation of the PDP-4 computer into the control system. This gave us a flexibility and a reliability that greatly increased R.

I'll now relate how our recent attention to a potentially large partial derivative in the Spiral Reader system is about to pay off in a substantially higher R for both machines, with a consequent increase in the overall group rate, r. Those of you who have watched the operations of the Spiral Reader know that our automatic fiducial measuring technique is very rapid, and our speed in measuring all tracks diverging from a single vertex is similarly high. The weakest remaining feature of the operation is that we must move the main stage in order to mark the ends of short tracks, and to designate "crutch points" to help the filter program when tracks cross at small angles. At 120 single-vertex events per hour, the time per view breaks down this way: Of the 10 seconds available, some time must be allocated to film motion and clamping. The fiducials take just under 3 seconds, and the vertex measurement takes another 3 seconds. The operator has to locate and center on the vertex, and he must also measure any proton end points and locate any crutch points. At present, it is obvious to any observer that we could increase the individual rate, R, if we could measure crutch points and proton end points with an image-plane digitizer, while the stage was clamped in place for the vertex measurement. This would conserve "main stage time," and cut down the measurement time per average view.

We have built a number of "image-plane crutch-point devices" in past years, but none of them has been satisfactory. Within the past few months Jack Lloyd and Pete Schwemin have designed, constructed and tested a new concept in image-plane digitization--the "Laser Crutch-Point Device." The table of our second Spiral Reader is now equipped with the first of these devices, and we hope to have it in routine operation soon. I believe that this new device will open a new era in inexpensive image-plane measurement, and I am sure that Jack Lloyd will be happy to describe the device later. Incidentally, Jack has been in charge of our data-reduction development work for the past 2 years; it must be clear to all of you that he hasn't been wasting his time lately!

It is instructive to see what such a simple and inexpensive device can do to increase the overall measuring rate, r, of our group. If we assume that we are measuring single-vertex events at the rate of 120 per hour, which is now quite a conservative assumption, we take 10 seconds per view. If we save an average of one second per view of main-stage motion, we will have produced a $\partial R/R$ of 10%, giving rise to a $\partial r/r$ of 8 or 9%. If we take the conservative figure of 8%, we have added 8% of 120 events per hour to the group total, or 10 events per hour. This rather astonishing equivalence of a 1-second time savings, to the output of a first-class conventional measuring machine (10 events per hour) may help to explain our apparent obsession with the engineering details of machine design and production management. It is also instructive to note that by this saving of 1 second per view, we have added the output of a Mark II Franckenstein to the group's effort--but without having to pay either for the Franckenstein or the four operators to run it full time.

I suggested earlier that one could decide what system was now the best, and which one might turn out to be the best at some later time, by noting the present performance--value of r--and examining various partial derivatives. I'll now make the only comment in this talk about another system, and it will not concern the performance of that system, but only one of the relevant partial derivatives. As I understand the HPD system--particularly the one at Berkeley--the rate r is determined solely by the number of road makers and the rate R of the operators who make the roads. When I ask about the development of the system here, no one tells me what is being done to increase R, or shows me any basic changes in the hardware; instead, he quotes the rate f at which events pass through the Flying Spot Digitizer (FSD). By my analysis, in a time-shared computer system such as that operated by the Berkeley HPD group, the partial derivative of r with respect to f is identically zero. In this sense, the FSD rate f is orthogonal to r, just as the paint color of our new Spiral Reader is orthogonal to our value of r. In concluding this short comment, I would like to iterate that what I have just said does not preclude the HPD rate r from being much larger than the Spiral Reader r. I am merely pointing out that the developers of the HPD system apparently do not attach the same weight to partial derivatives that we do.

I've spoken of our present system, and of our plans for the short-term future--with its second Spiral Reader and the new Laser Crutch-Point Devices installed on both machines. Within another year or year and a half, we hope to be operating a third Spiral Reader, after having phased out our four MK II Franckensteins. We can't man the Franckensteins when we have fully utilized our manpower resources on the three Spiral Readers and their required scanning tables. It is also clear that we shouldn't operate Franckensteins when we can produce with a Spiral Reader an order of magnitude more events per measuring-machine operator.

Many of you will be surprised to learn that we will abandon all our "conventional measuring machines." "How will you measure your rejects?" is the question I often hear. My reply is simply that "A Spiral Reader is a better Franckenstein than a real Franckenstein," so it is more efficient to use a Spiral Reader for remeasurements than it is to use a MK II Franckenstein. The Spiral Reader measures all the fiducials in 8 seconds, a small fraction of the time required by our most-automated Franckensteins. If we can use automatic tracking on the Franckensteins, the film quality is good enough that we can use our automatic track-finding programs on the Spiral Reader, and the Spiral Reader is much faster. If we must measure point-by-point, the better human engineering of the controls and displays on the Spiral Reader again give it an advantage in speed. (The moving stage and its read-out systems on the two machines are identical.) If one must combine automatic tracking on the Franckenstein with some human help in identifying tracks that cross at small angles, the high-speed Laser Crutch Point device on the Spiral Reader gives it a great advantage over the Franckenstein. And finally, since the capital costs of the two machines (including the full-time computer on the Spiral Reader) are almost identical, the Spiral Reader wins on all accounts. (By standard LRL accounting procedures, our business office has told us that in the "dollars of that period," the MK II Franckenstein cost \$125,000, and had about \$20,000 of automation added later, all SMP's but the original cost \$35,000, and the replicated Spiral Reader (including the PDP-4 computer) cost \$165,000. Assuming ordinary inflation factors, the modernized MK II Franckenstein and the new Spiral Readers cost the same amount, within an uncertainty that is a small fraction of their annual operating costs.

I should now say a few words about automatic pattern recognition and automatic scanning. These two functions used to be considered synonymous, but more recently, pattern recognition has been defined more in terms of a machine that can recognize tracks if a human operator has designated a single point on each track, or if the set of tracks has some regular property, such as that possessed by beam tracks. Both the HPD system and PEPR are able, by programming techniques, to find all straight-through beam tracks, and "throw them out." (I once built an analogue device that had a similar property--it worked by modifying the Fourier transform of the bubble chamber photographic image, and generating a mask that would obscure all beam tracks. The mask left intact all other tracks that were not accurately aligned with the "instantaneous" beam-track direction.)

The recognition of beam tracks is but a single step on a long journey toward automatic scanning. Both the HPD and PEPR have been programmed to recognize tracks diverging from a vertex--the so-called "minimum guidance," as distinguished from road guidance. But I do not believe that either of these minimum-guidance techniques is in routine production use today. So I would like to remind you that we are using such minimum-guidance pattern-recognition techniques as part of our standard Spiral Reader filter program, POOH. POOH works without help on more than 90% of all tracks it is asked to find diverging from a vertex; in the remaining cases, it is helped along by the judicious use of a crutch point on a track that is difficult to find. I therefore base my impressions of the difficulty of automatic scanning on a good deal of experience with pattern-recognition programs operated in a routine production mode.

I do not think that automatic scanning of bubble chamber film is going to come soon enough to contribute to our present campaign in particle physics. Perhaps it will help in some renaissance 25 years from now, just as the laser has brought new vigor into the field of optical spectroscopy after it had lain dormant for almost 25 years.

I am not even convinced that the modern high-speed general-purpose computer, as we now know it, is the proper tool to implement automatic scanning. I am more impressed by the ideas of Bruce McCormick, who is building a special computer for such work, which is equipped with one thousand independent arithmetic units that operate on the photographic image simultaneously, and finally decide how the pattern is arranged.

But more important than this negative reaction to the versatile pattern-recognition abilities of digital computers is my strong positive feeling that human beings have remarkable inherent scanning abilities. I believe these abilities should be used, because they are better than anything that can be built into a computer. Let me give an example from another field, where the properties of the eye-brain system have been used to their fullest potential, and where it would certainly have been a mistake to have tried to beat the human with a computer. The planet Pluto was found by a "blink comparator," a device in which two star plates taken at different times are shown to an observer, alternatively, at some optimum rate. The eye immediately picks out a single moving image, from hundreds of thousands of stationary images. More surprisingly, the observer can see the moving image in his peripheral field, where he can't even read words printed in letters one-inch high, held at normal reading distance. This ability to see motion in peripheral vision has an obvious explanation in the evolutionary doctrine of the survival of the fittest, but the degree to which a human being has it is really extraordinary.

One could certainly scan a star field with an FSD-like device and store the coordinates and intensities of all stars in some memory system. Then he could repeat this measurement on a star plate taken at a different time, and again store the coordinates and intensities. And finally, he could perform the arithmetic comparisons between the two lists, and throw out all stars that had duplicate images on the other plate to within some "least count." That would leave a set of pairs of stars of the same intensity, but with slightly different coordinates. The operator could then use a SUMX-like program to plot a set of vectors, indicating the direction and magnitude of all stars with visible proper motions. Tables of stars with known proper motions, of planets, asteroids, and comets could then be used to reject most of the moving stars, so that a pure sample of new planets could finally be printed out.

I hope that we never go so far in automatic scanning that we do in a similar tedious and expensive way something that can be done so easily by a human scanner. I'm sure I can't discourage anyone who really wants to replace scanners by machines. But I don't think that such an effort is usefully related to bubble chamber physics.

When I was half way through the first draft of this talk, I had no idea on what note I could end it. I didn't have any comparable data from other bubble chamber groups, so I couldn't tell you how well we are doing, relative to other groups, using other measuring techniques. All I could do was tell you how our own efforts have improved our own performance with time, and why I expect it to double in efficiency next year, when the second Spiral Reader is operational. But Art Rosenfeld, Earle Fowler, and Dick Plano saw the curves that have ended up as slides for this talk, and they decided to make a country-wide survey of all bubble chamber groups, to find out how they were operating. I have refrained from examining the extensive table I have seen them preparing in the next room, so it is really an independent audit in every sense of the word, and quite up to date; all data have been collected by phone, or by private conversations this week at the Berkeley Conference. The auditors tell me that they have used somewhat different criteria for the numerator and denominator in their analysis, but that basically their figure of merit is the same as mine. They have tried to show me their plots, but I would rather be surprised when they show their slides this afternoon. I hope that the conference secretary will permit their survey to be printed as an appendix to this series of round-table talks.

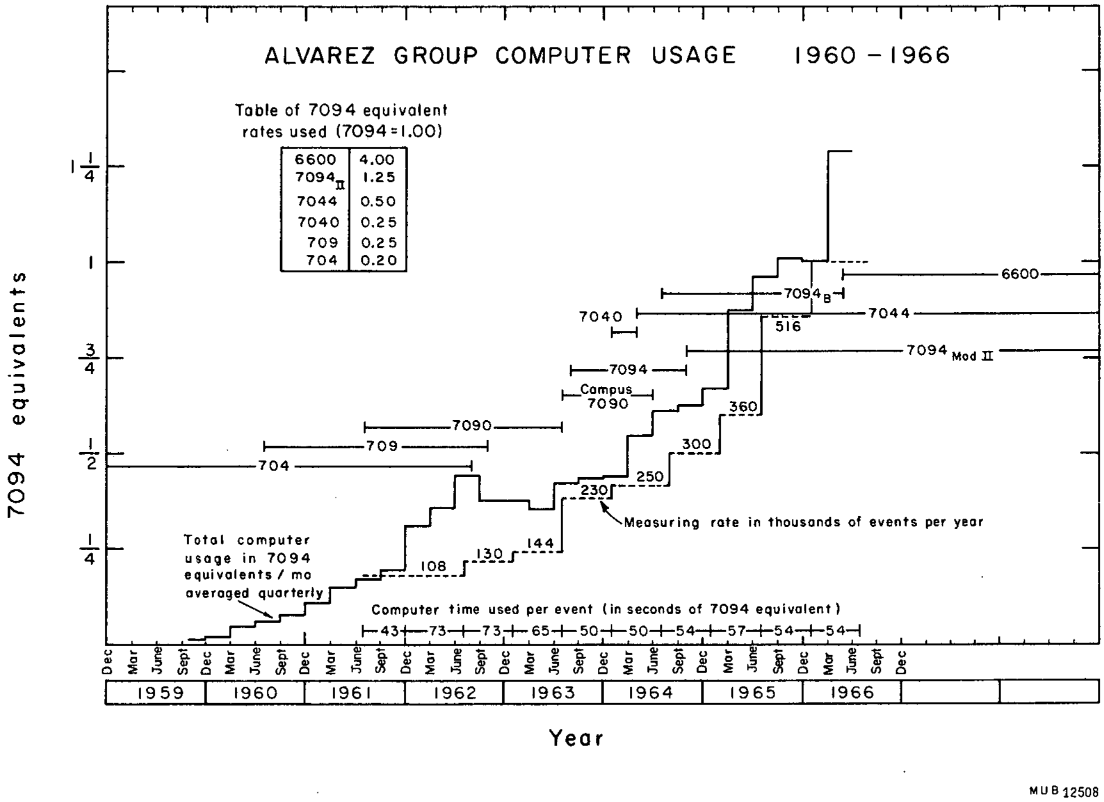

ALVAREZ GROUP COMPUTER USAGE 1960 - 1966
Table of 7094 equivalent rates used (7094=1.00)
6600 4.00
7094 II 1.25
7044 0.50
7040 0.25
709 0.25
704 0.20
7094 equivalents
Total computer usage in 7094 equivalents / mo averaged quarterly
Measuring rate in thousands of events per year
Computer time used per event (in seconds of 7094 equivalent)
43 73 73 65 50 50 54 57 54 54
704
709
7090
Campus 7090
7094
7040
7044
7094 Mod II
7094 B
6600
108 130 144 230 250 300 360 516
1959 1960 1961 1962 1963 1964 1965 1966
Year
MUB 12508

Fig. 1

SPIRAL READER DAILY REPORT

TUESDAY 8/30/66

NUMBER OF VERTICES MEASURED........ 2156

AVERAGE VERTICES PER HOUR 119.23

TYPE OF EVENTS MEASURED........... K65 MISC (25 INCH)
SLAC 22'S

	VTXS	ETS	HOURS	CODE	RATE	STANDARD RATE	PCT DEV	VTXS/ HOUR
OWL SHIFT *** *****								
TJ (101)	154	77	1.42	215	54.35	45.0	20.8	108.71
MJ (31)	232	116	1.92	215	60.52	45.0	34.5	121.04
AC (50)	226	113	1.83	215	61.64	45.0	37.0	123.27
BW (64)	180	90	1.58	215	56.84	45.0	26.3	113.68
SHIFT TOT.	792	396	6.75		58.67	45.0	30.4	117.33
DAY SHIFT *** *****								
DB (110)	136	68	1.33	215	51.00	45.0	13.3	102.00
CW (41)*	76	38	1.00	215	38.00	45.0	-15.6	76.00
CRB(22)	204	102	1.33	215	76.50	45.0	70.0	153.00
JRS(70)*	58	29	0.75	215	38.67	45.0	-14.1	77.33
SWR(28)	110	55	0.83	215	66.00	45.0	46.7	132.00
SHIFT TOT.	584	292	5.25		55.62	45.0	23.6	111.24
SWING SHIFT ***** *****								
RJA(105)	170	85	1.42	215	60.00	45.0	33.3	120.00
PK (14)	161	161	1.25	200	128.80	90.0	43.1	128.80
RS (18)	216	216	1.83	200	117.82	90.0	30.9	117.82
RJA(105)	233	233	1.58	200	147.16	90.0	63.5	147.16
SHIFT TOT.	780	695	6.08		114.25	79.5	43.7	128.22
DAY TOTAL	2156	1383	18.08		76.48	56.6	35.1	119.23

INEXPERIENCED MEASURERS ARE STARRED

EXPERIENCED MEASURERS =123.80
VERTICES PER HOUR
INEXPERIENCED MEASURERS = 76.57

MUB-12924

Fig. 2a

HOURS ACCOUNTING

	HOURS	PERCENT
MEASURING	19.00	79.17
MAINTENANCE	0.92	3.82
INSTRUCTION	0.50	2.08
PROGRAMMING	2.58	10.76
OTHER THINGS......	0.	0.
	-----	-----
TOTALS	24.00	100.00

HIGH MEASURER FOR DAY WAS
RJA WITH 142.96 VERTICES PER HOUR FOR 1.92 HOURS

MUB-12925

Fig. 2b

MP	NO OF EVENTS	HOURS MEASUR	HOURS INSTRN	HOURS MV DEV	HOURS OTHER	HOURS TOTAL	MEAS/ TOTAL	MDEV/ TOTAL	TOTAL /CLDR	MEAS /CLDR	EVNTS /MEAS	EVNTS /TOTAL	EVNTS /CLDR
1 MP2A	945	82.1	2.2	2.7	6.0	93.0	0.88	0.03	0.55	0.49	11.5	10.2	5.6
2 MP2B	572	113.3	2.5	9.3	7.6	132.6	0.85	0.07	0.79	0.67	5.0	4.3	3.4
3 MP2C	636	85.7	4.0	3.2	27.8	120.7	0.71	0.03	0.72	0.51	7.4	5.3	3.8
4 MP2D	1185	120.4	0.2	3.3	8.6	132.6	0.91	0.03	0.79	0.72	9.8	8.9	7.1
5 SPR1	9853	89.6	2.6	3.1	5.0	100.3	0.89	0.03	0.60	0.53	110.0	98.3	58.6
6 SMP1	9	1.0	0.	1.0	0.	2.0	0.50	0.50	0.01	0.01	9.0	4.5	0.1
7 SMP2	24	2.4	0.	0.2	1.7	4.3	0.56	0.06	0.03	0.01	9.9	5.5	0.1
8 SMP4	27	2.2	0.	1.0	0.8	4.0	0.54	0.25	0.02	0.01	12.4	6.8	0.2
9 SMP5	38	4.7	0.	1.3	0.3	6.3	0.74	0.21	0.04	0.03	8.1	6.0	0.2
10 SMP6	169	19.2	0.7	1.6	2.6	24.1	0.80	0.07	0.14	0.11	8.8	7.0	1.0
ALL MPS	3338	401.5	8.9	18.5	50.0	478.9	0.84	0.04	0.71	0.60	8.3	7.0	5.0
ALL SMPS	267	29.5	0.7	5.2	5.4	40.8	0.72	0.13	0.05	0.04	9.1	6.6	0.3
TOTALS	13458	520.6	12.2	26.7	60.4	619.9	0.84	0.04	0.37	0.31	25.9	21.7	8.0

IN THE HOURS COLUMNS THE LAST DIGIT REPRESENTS 10TH OF AN HOUR. DATES ARE FROM 660410 TO 660416

MUB 12929

Fig. 3

MP	NO OF EVENTS	HOURS MEASUR	HOURS INSTRN	HOURS MN DEV	HOURS OTHER	HOURS TOTAL	MEAS/ TOTAL	MDEV/ TOTAL	TOTAL /CLDR	MEAS /CLDR	EVNTS /MEAS	EVNTS /TOTAL	EVNTS /CLDR
1 MP2A	4680	400.8	11.7	9.3	24.0	445.7	0.90	0.02	0.62	0.56	11.7	10.5	6.5
2 MP2B	2768	507.5	9.8	35.2	18.5	571.0	0.89	0.06	0.79	0.70	5.5	4.8	3.8
3 MP2C	3892	401.6	10.7	14.0	87.8	514.1	0.78	0.03	0.71	0.56	9.7	7.6	5.4
4 MP2D	4718	455.3	3.7	14.7	59.6	533.3	0.85	0.03	0.74	0.63	10.4	8.8	6.6
5 SPR1	41171	418.0	6.8	22.2	56.9	503.8	0.83	0.04	0.70	0.58	98.5	81.7	57.2
6 SMP1	9	1.0	0.	1.0	0.	2.0	0.50	0.50	0.00	0.00	9.0	4.5	0.0
7 SMP2	74	6.9	0.	0.2	3.2	10.3	0.67	0.02	0.01	0.01	10.7	7.2	0.1
8 SMP4	27	2.2	0.	1.0	0.8	4.0	0.54	0.25	0.01	0.00	12.4	6.8	0.0
9 SMP5	159	15.6	0.	2.7	2.1	20.3	0.77	0.13	0.03	0.02	10.2	7.8	0.2
10 SMP6	273	30.4	0.7	2.6	4.2	37.8	0.80	0.07	0.05	0.04	9.0	7.2	0.4
ALL MPS	16058	1765.2	35.9	73.1	190.0	2064.2	0.86	0.04	0.72	0.61	9.1	7.8	5.6
ALL SMPS	542	56.1	0.7	7.5	10.2	74.5	0.75	0.10	0.02	0.02	9.7	7.3	0.2
TOTALS	57771	2239.3	43.4	102.8	257.1	2642.5	0.85	0.04	0.37	0.31	25.8	21.9	8.0

IN THE HOURS COLUMNS THE LAST DIGIT REPRESENTS 10TH OF AN HOUR. DATES ARE FROM 660401 TO 660430
DIVIDE CHECK

MUB-12926

Fig. 4

MP	NO OF EVENTS	HOURS MEASUR	HOURS INSTRN	HOURS MN DEV	HOURS OTHER	HOURS TOTAL	MEAS/ TOTAL	MDEV/ TOTAL	TOTAL /CLDR	MEAS /CLDR	EVNTS /MEAS	EVNTS /TOTAL	EVNTS /CLDR
1 MP2A	43574	4440.4	72.1	232.3	293.6	5038.4	0.88	0.05	0.58	0.51	9.8	8.6	5.0
2 MP2B	35726	5067.9	71.2	296.6	310.2	5746.0	0.88	0.05	0.66	0.58	7.0	6.2	4.1
3 MP2C	50835	5363.1	82.0	279.6	620.8	6345.4	0.85	0.04	0.72	0.61	9.5	8.0	5.8
4 MP2D	50029	5648.9	88.7	250.5	581.0	6569.1	0.86	0.04	0.75	0.64	8.9	7.6	5.7
5 SPR1	307667	4415.4	73.9	456.2	548.9	5494.4	0.80	0.08	0.63	0.50	69.7	56.0	35.1
6 SMP1	13971	1269.7	19.3	146.1	258.3	1693.4	0.75	0.09	0.19	0.14	11.0	8.3	1.6
7 SMP2	14384	1412.9	32.9	79.5	332.8	1858.0	0.76	0.04	0.21	0.16	10.2	7.7	1.6
8 SMP4	10612	1059.6	18.9	50.9	220.6	1349.9	0.78	0.04	0.15	0.12	10.0	7.9	1.2
9 SMP5	16609	1420.2	27.3	58.8	304.4	1810.8	0.78	0.03	0.21	0.16	11.7	9.2	1.9
10 SMP6	14165	1303.2	39.4	85.9	337.1	1765.7	0.74	0.05	0.20	0.15	10.9	8.0	1.6
ALL MPS	180164	20520.3	314.0	1059.0	1805.7	23698.9	0.87	0.04	0.68	0.59	8.8	7.6	5.1
ALL SMPS	69741	6465.7	137.8	421.2	1453.2	8477.8	0.76	0.05	0.19	0.15	10.8	8.2	1.6
TOTALS	557572	31401.4	525.7	1936.3	3807.7	37671.2	0.83	0.05	0.43	0.36	17.8	14.8	6.4

IN THE HOURS COLUMNS THE LAST DIGIT REPRESENTS 10TH OF AN HOUR. DATES ARE FROM 650701 TO 660630

MUB-12927

Fig. 5

THIS TALLY IS FOR EXPERIMENT NUMBER 17 -PROTON 65

OPERATOR		FIRST SCAN HOURS	FIRST SCAN EVTS/HR	FIRST SCAN EVTS	FIRST SCAN FRMS/HR	FIRST SCAN FRMS	SECOND SCAN HOURS	SECOND SCAN EVTS/HR	SECOND SCAN EVTS	SECOND SCAN FRMS/HR	SECOND SCAN FRMS	TOTAL HOURS	TOTAL EVTS/HR	TOTAL EVTS	TOTAL FRMS/HR	TOTAL FRMS	SPECIAL SCAN HRS
18	NE	23.4	50.2	1175	76.0	1779	0.	0.	0	0.	0	23.4	50.2	1175	76.0	1779	0.
36	RG	0.	0.	0	0.	0	0.	0.	0	0.	0	0.	0.	0	0.	0	14.0
55	MO	8.0	46.9	375	56.1	449	0.	0.	0	0.	0	8.0	46.9	375	56.1	449	0.
61	OA	11.9	38.1	453	55.5	661	0.	0.	0	0.	0	11.9	38.1	453	55.5	661	5.5
64	64	0.	0.	0	0.	0	12.3	44.9	552	72.4	890	12.3	44.9	552	72.4	890	0.
73	GO	14.1	32.9	464	55.5	783	0.	0.	0	0.	0	14.1	32.9	464	55.5	783	0.
78	78	8.0	116.1	929	137.5	1100	11.0	77.5	852	103.8	1142	19.0	93.7	1781	118.0	2242	0.
100	100	8.0	-0.	-0	-0.	-0	0.	0.	0	0.	0	8.0	-0.	-0	-0.	-0	11.5
109	JMB	8.0	38.6	309	53.7	430	0.	0.	0	0.	0	8.0	38.6	309	53.7	430	0.

MUB-12922

Fig. 6

MEASURING RATES

PERIOD--660220 THROUGH 660226 K65

NUMBER OF EVENTS MEASURED.................... 756.
TOTAL HOURS................................. 77.17
AVERAGE MEASURING RATE...................... 9.80
EVENT-CODE.................................. 80
TYPES OF EVENTS MEASURED.....................MISC K65

MEASURER		NO. EVENTS MEASURED	NO. HOURS MEASURED	EVENTS PER HR.	DEVIATION FROM AVER.	
CG	13	20.0	1.75	11.43	16.65	PERCNT
PK	14	90.0	13.50	6.67	-31.95	PERCNT
JH	20	90.0	8.17	11.02	12.49	PERCNT
EW	29	7.0	1.00	7.00	-28.55	PERCNT
MJ	31	25.0	3.83	6.52	-33.43	PERCNT
	44	33.0	4.33	7.62	-22.27	PERCNT
SLB	57	46.0	8.00	5.75	-41.31	PERCNT
DA	61	45.0	3.50	12.86	31.24	PERCNT
KD	66	176.0	13.58	12.96	32.26	PERCNT
MR	67	78.0	8.00	9.75	-0.48	PERCNT
SR	69	16.0	1.00	16.00	63.32	PERCNT
JRS	70	130.0	10.50	12.38	26.38	PERCNT

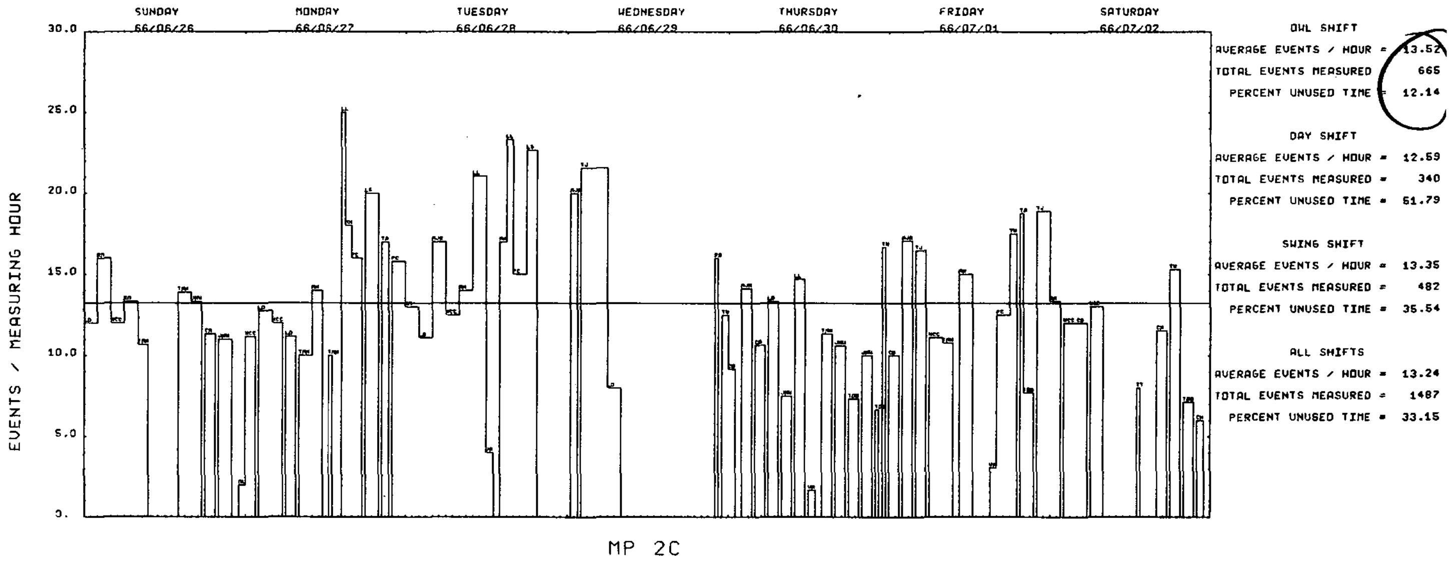
TA

ORDERED BY RATE...

SR	69	16.0	1.00	16.00	63.32	PERCNT
KD	66	176.0	13.58	12.96	32.26	PERCNT
DA	61	45.0	3.50	12.86	31.24	PERCNT
JRS	70	130.0	10.50	12.38	26.38	PERCNT
CG	13	20.0	1.75	11.43	16.65	PERCNT
JH	20	90.0	8.17	11.02	12.49	PERCNT
MR	67	78.0	8.00	9.75	-0.48	PERCNT
	44	33.0	4.33	7.62	-22.27	PERCNT
EW	29	7.0	1.00	7.00	-28.55	PERCNT
PK	14	90.0	13.50	6.67	-31.95	PERCNT
MJ	31	25.0	3.83	6.52	-33.43	PERCNT
SLB	57	46.0	8.00	5.75	-41.31	PERCNT

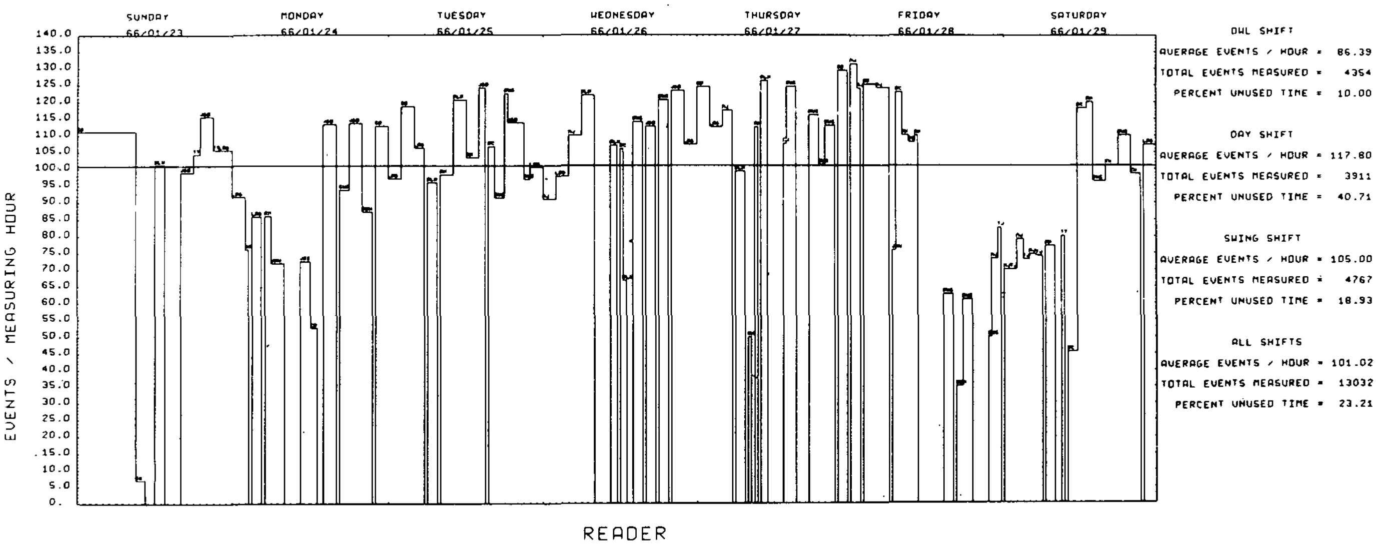
MUB-12923

Fig. 7



MUB-12921

Fig. 8



MUB 12928

Fig. 9

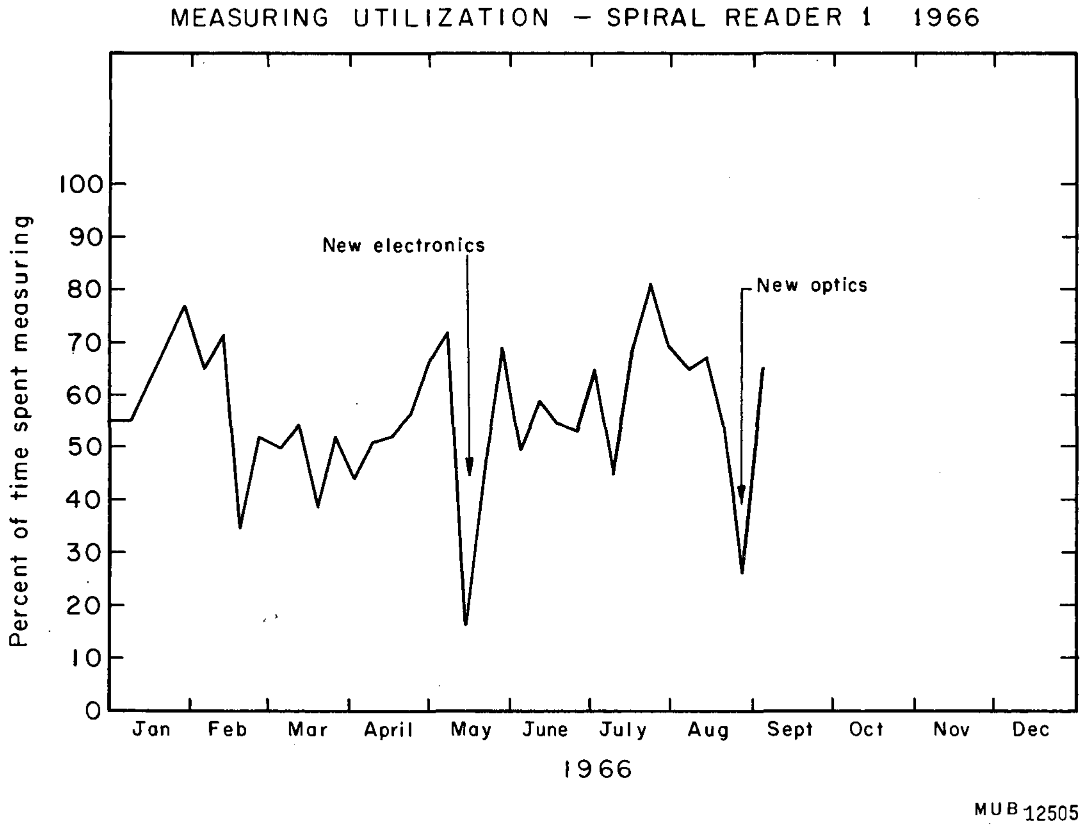

MEASURING UTILIZATION — SPIRAL READER 1 1966
Percent of time spent measuring
100
90
80
70
60
50
40
30
20
10
0
New electronics
New optics
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
1966
MUB 12505

Fig. 10

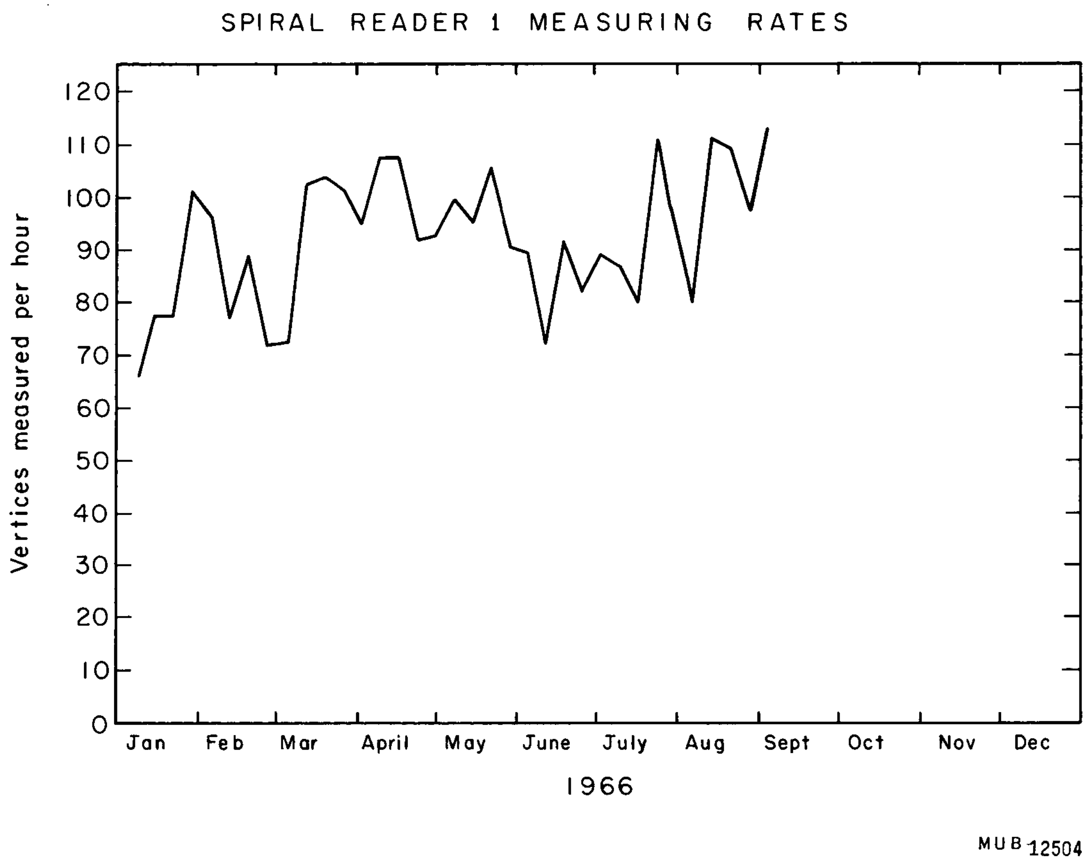

SPIRAL READER 1 MEASURING RATES
Vertices measured per hour
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
1966
MUB 12504

Fig. 11

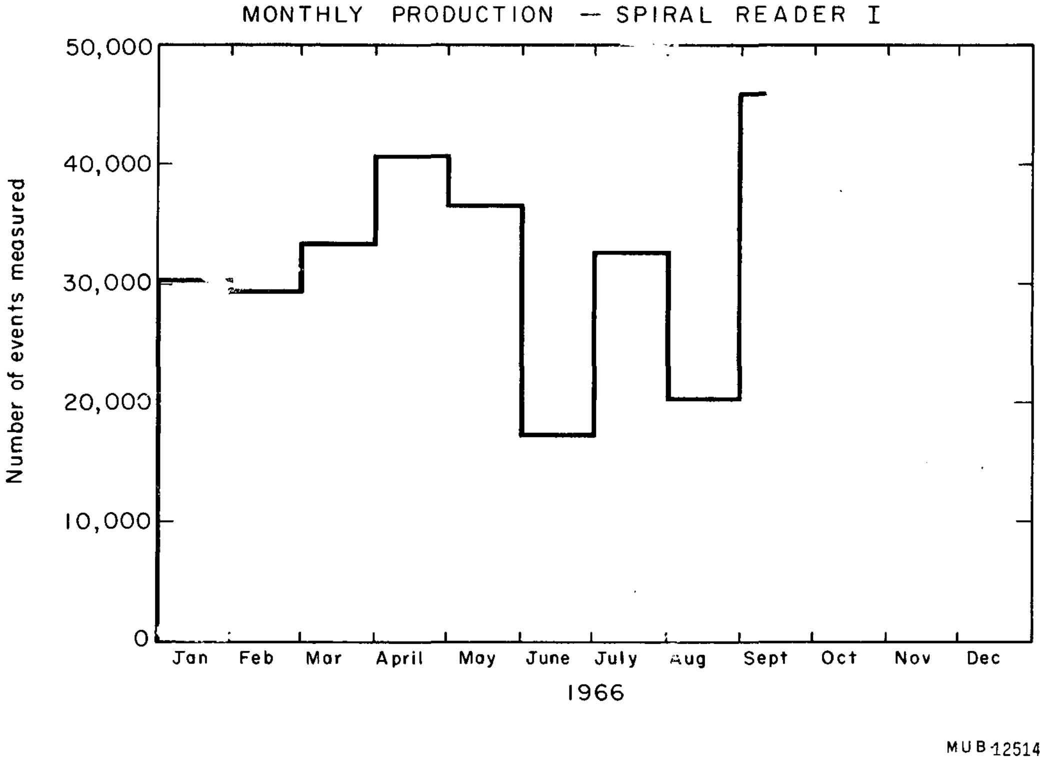

MONTHLY PRODUCTION — SPIRAL READER I
50,000
40,000
30,000
20,000
10,000
0
Number of events measured
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
1966
MUB-12514

Fig. 12

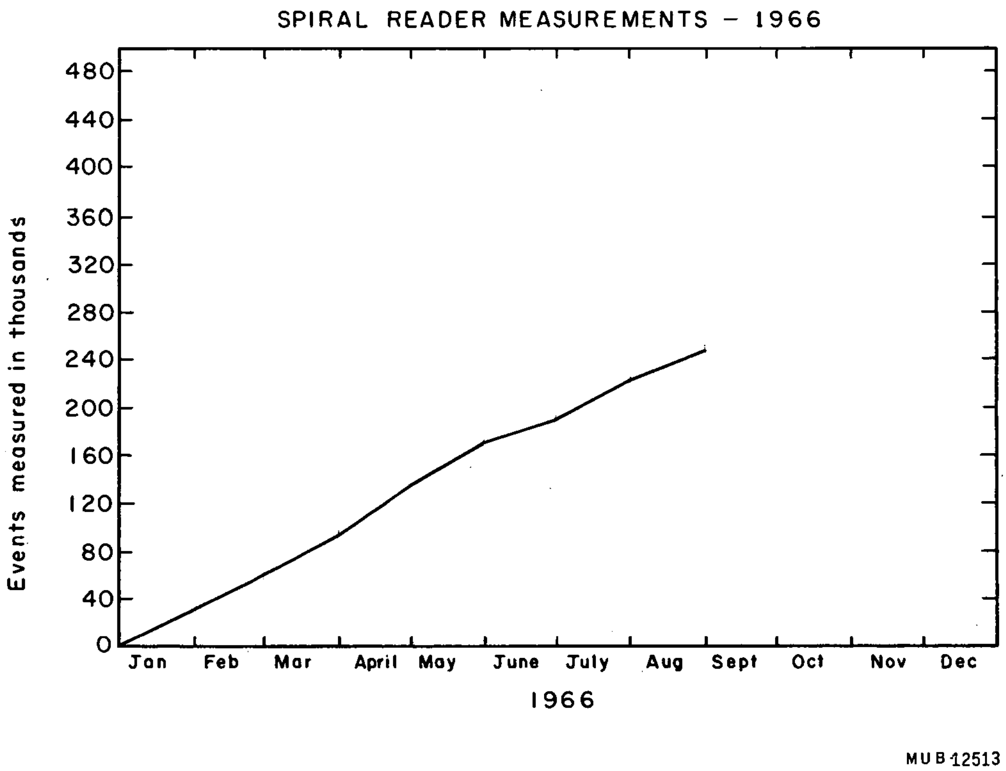
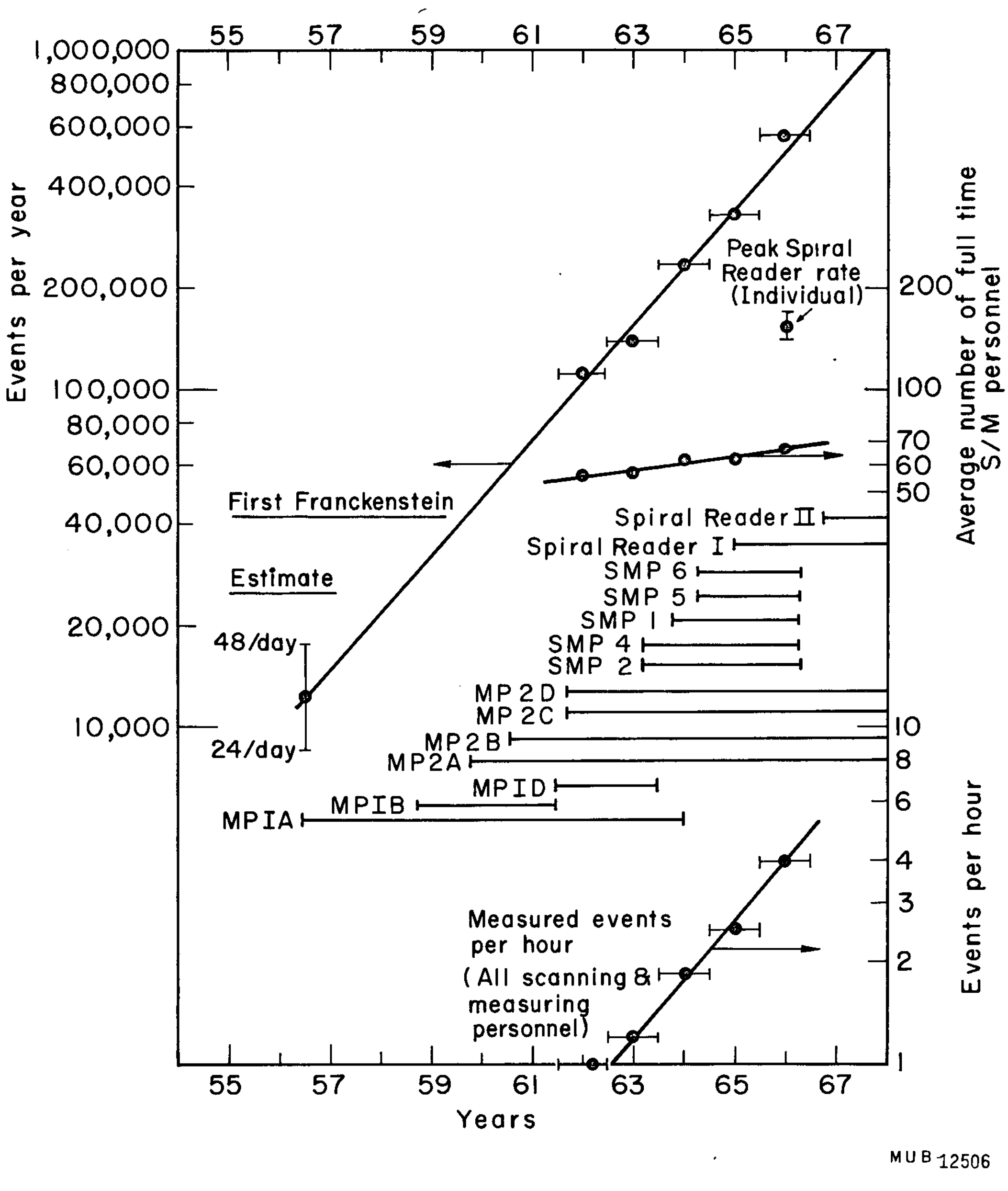
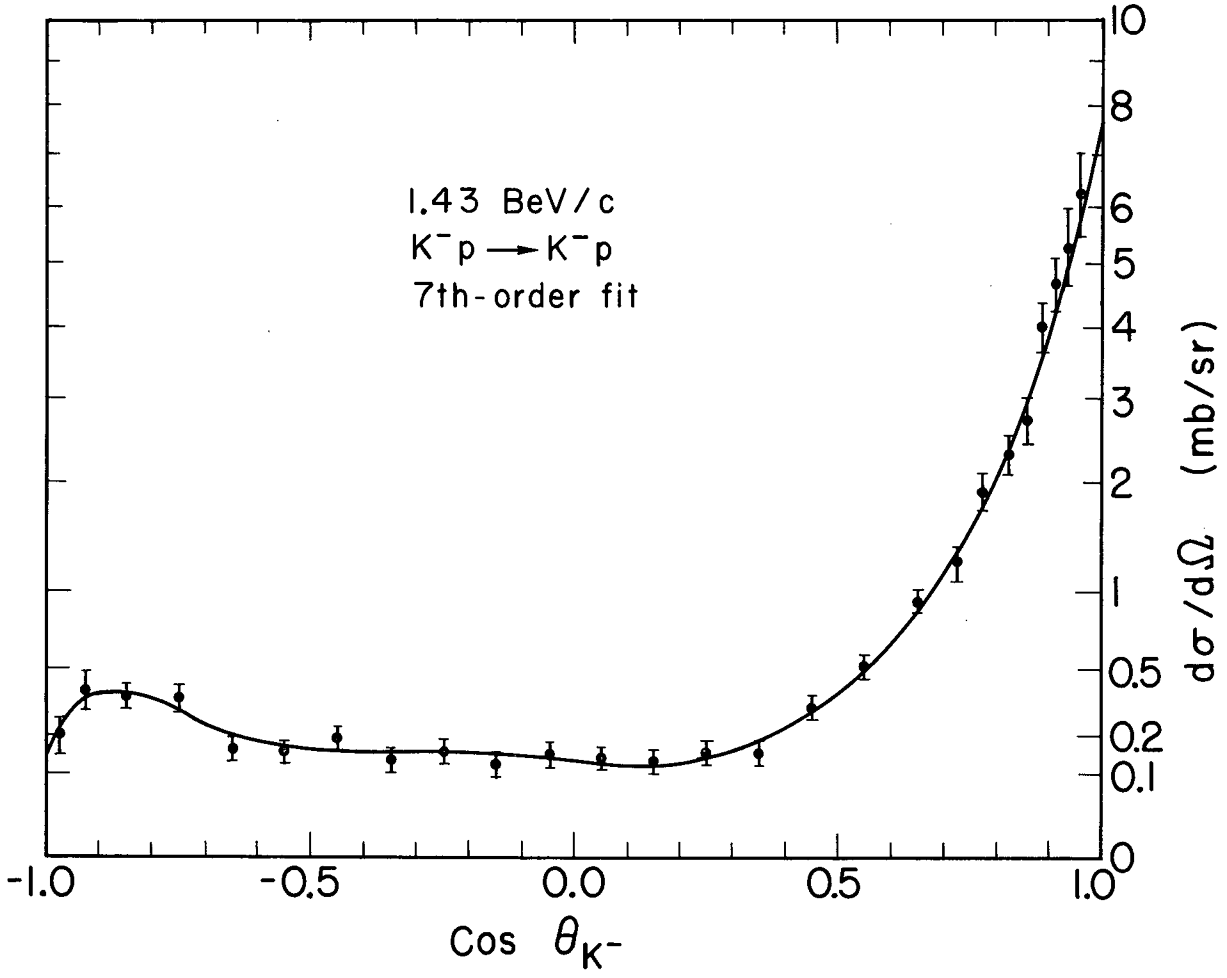

SPIRAL READER MEASUREMENTS – 1966
Events measured in thousands
480
440
400
360
320
280
240
200
160
120
80
40
0
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
1966
MUB 12513

Fig. 13



55 57 59 61 63 65 67
1,000,000
800,000
600,000
400,000
200,000
100,000
80,000
60,000
40,000
20,000
10,000
Events per year
Peak Spiral Reader rate (Individual)
200
100
70
60
50
Average number of full time S/M personnel
First Franckenstein
Estimate
48/day
24/day
Spiral Reader II
Spiral Reader I
SMP 6
SMP 5
SMP 1
SMP 4
SMP 2
MP 2D
MP 2C
MP 2B
MP 2A
MP1D
MP1B
MP1A
10
8
6
4
3
2
1
Events per hour
Measured events per hour
(All scanning & measuring personnel)
55 57 59 61 63 65 67
Years
MUB 12506

Fig. 14



MUB-9281

Fig. 15

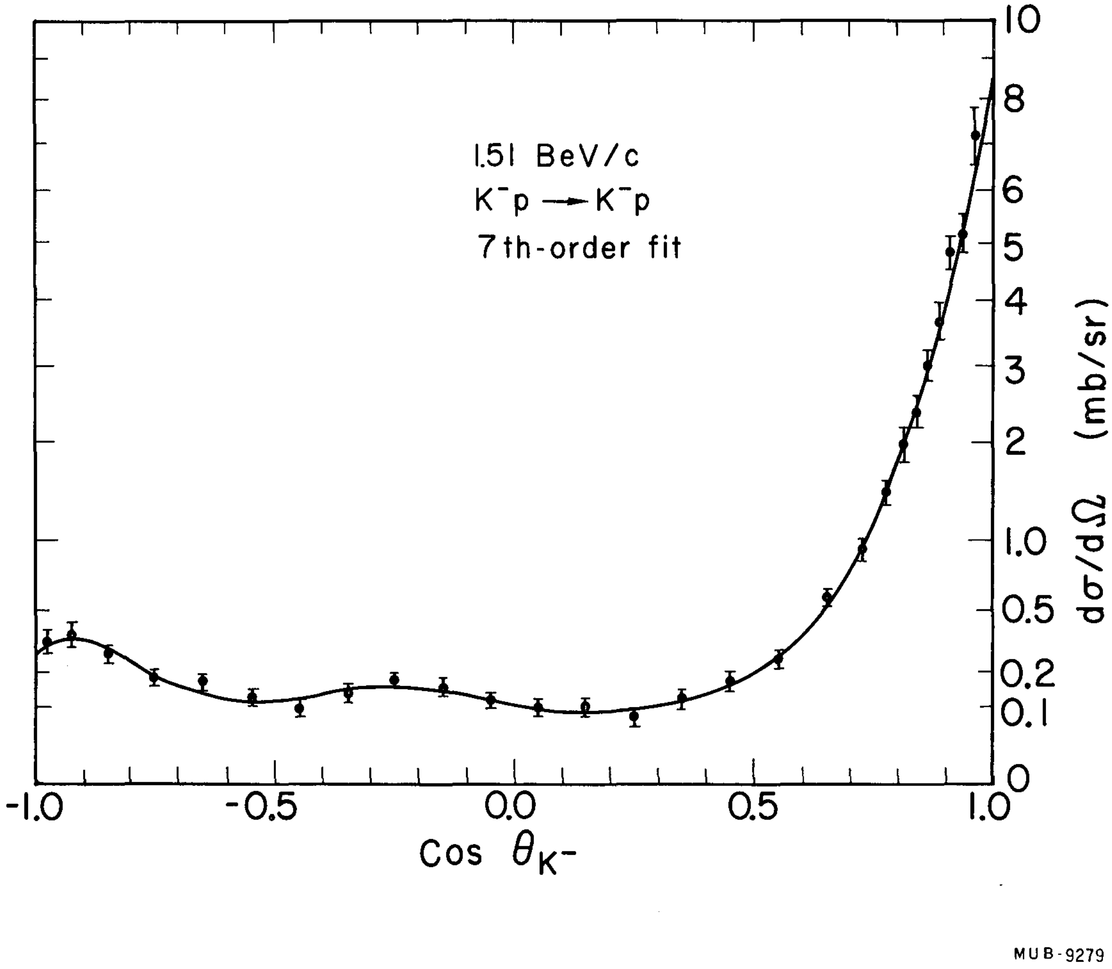

1.51 BeV/c
K⁻p → K⁻p
7th-order fit
-1.0
-0.5
0.0
0.5
1.0
Cos θ_{K^-}
10
8
6
5
4
3
2
1.0
0.5
0.2
0.1
0
$d\sigma/d\Omega$ (mb/sr)
MUB-9279

Fig. 16

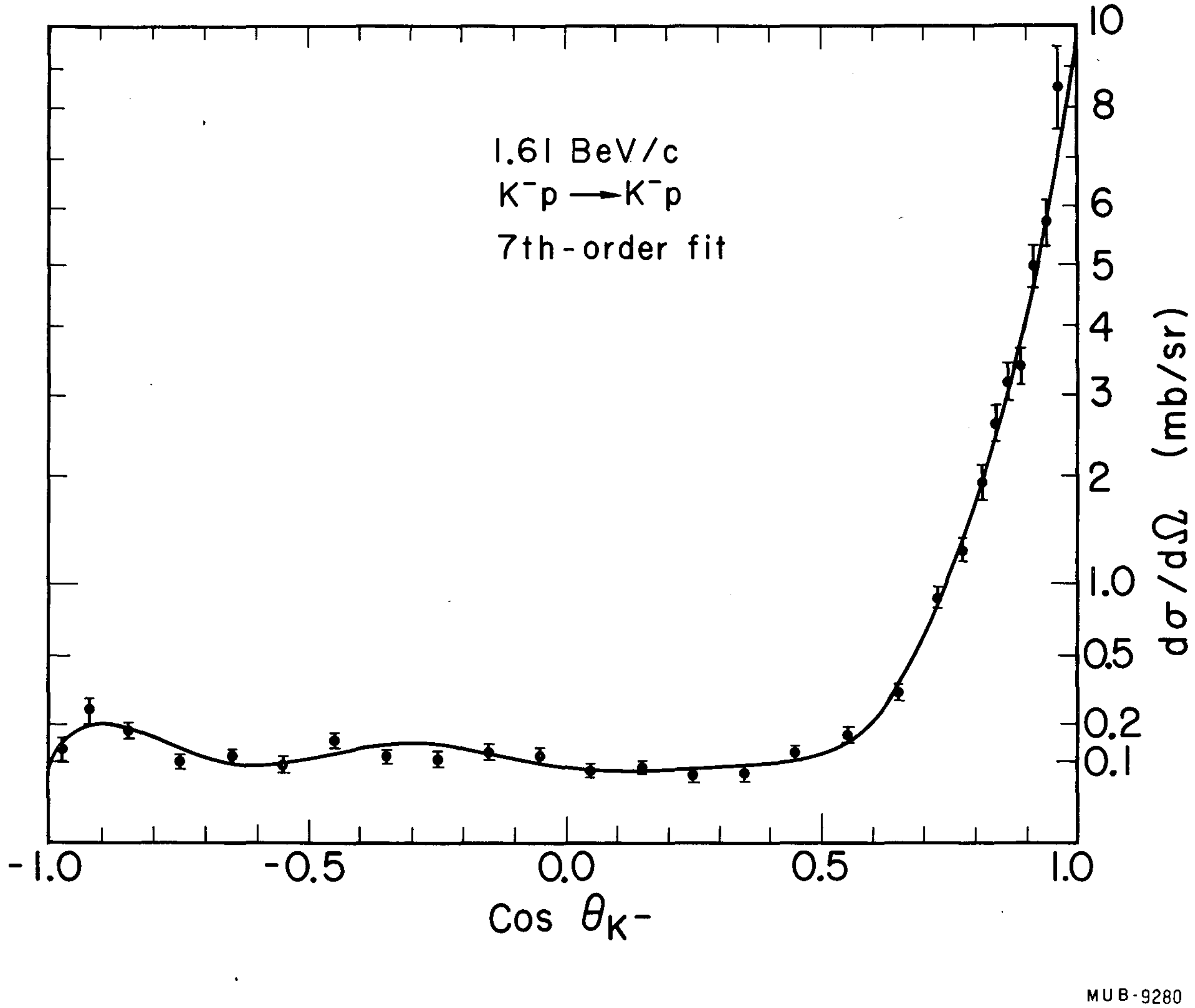

1.61 BeV/c
$K^-p \rightarrow K^-p$
7th-order fit
10
8
6
5
4
3
2
1.0
0.5
0.2
0.1
$d\sigma/d\Omega$ (mb/sr)
-1.0
-0.5
0.0
0.5
1.0
Cos θ_{K^-}
MUB-9280

Fig. 17

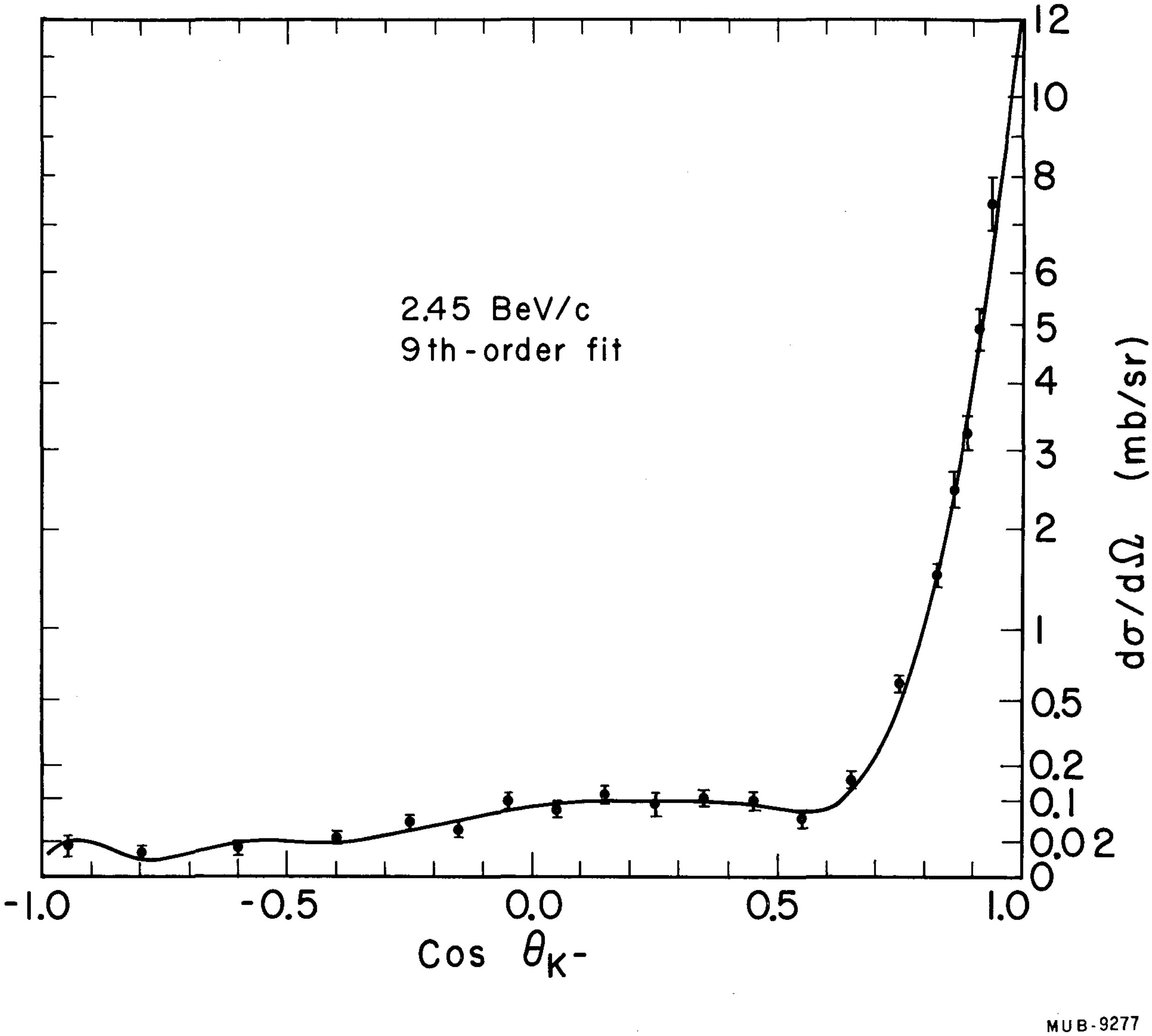

2.45 BeV/c
9th-order fit
-1.0
-0.5
0.0
0.5
1.0
Cos θ_{K^-}
$d\sigma/d\Omega$ (mb/sr)
12
10
8
6
5
4
3
2
1
0.5
0.2
0.1
0.02
0
MUB-9277

Fig. 18