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August 27, 1964

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I have been asked to introduce this session on automation and measurement by discussing methods to facilitate emulsion data handling - both by those with modest equipment, and those possessing the resources of a large laboratory. Accurate measurements and records are always important for good scientific work. Now automation in addition may be important or even decisive for the success of certain experiments. I can discuss with authority only my own experiences, because Berkeley is so far away that I was unable to attend the recent specialized meeting on automation of emulsion measurements at Amsterdam.

For the work my group has been doing during the past six or eight years, digitized coordinate microscopes, several types of which were described at previous meeting, have been the single most important aid for data taking. They are used for range and angle measurements, multiple scattering measurements, neutron spectroscopy, track reconstruction, and coplanarity measurements. In some laboratories a digitized coordinate microscope means one which prints the coordinates of points. We here mean one that punches the numbers into IBM cards or otherwise prepares the data for use by a computing machine without any further translation. [Good over-all planning of the work for efficient data reduction and record keeping is as important as the development of automatic methods. It is something that every laboratory can do, whether or not mechanical aids for computations are employed. Many items require attention in order to insure the integrity of the data. The instructions given to the scanner often are of paramount importance for the reliability of the data. The physicist in charge should first fully acquaint himself with the problem by doing a considerable amount of scanning himself. He should then write out the scanning and measuring instructions with the utmost care, anticipating problems and scanning biases that may intrude, while providing means for making checks. In this connection it is necessary to remember psychological factors. It is important that the scanner be

unaware of the result that is expected in a measurement or observation. It is very human to try to obtain the answer that pleases. Some of the false "discoveries" made in emulsion experiments may have had such a cause.

We often take many days to prepare the scanning instructions for an experiment, which then remain unchanged except for very good reasons, and with careful notation of the circumstances. It is not then a matter of memory to use data years later. Some K mesons found in scanning carried out in 1956 are currently being analyzed, and no difficulty in interpreting the old records has been encountered. Along with scanning instructions, forms for recording the information should be carefully worked out. For K-mesons we have made much use of edge-punched cards, with each hole labelled, and the center area of the card reserved for data forms, and aids for diagramming events. A card contains information pertaining to only one meson. It is the master record. Everything significant about the event is on the card. Often the data are entered over a period of several years, as a variety of measurements are made.

Such a card for K^+ mesons is shown as Figure 1. A similar card for K^- mesons is shown in my book on Nuclear Research Emulsions. There are many minor ideas which can make for greater efficiency. For example, we solved the storage and access problem of a large emulsion stack very simply using a correspondence filing cabinet. The plates are dropped into legal-size file folders of the type that are suspended in the cabinet. The number of the plate appears on a tab at the top.

For processing emulsion improved methods also are being developed. I shall mention only one or two here, because here we are getting rather far from the topic of discussion assigned to me.

We recently developed 15 liters of Eastman Kodak NTB5 emulsion in a single operation. The mounting of these pellicles was greatly facilitated because the instructions for mounting prepared by the Eastman Kodak Company are practical. The results are superior to those of older methods, and blisters are practically eliminated. For these pellicles we also developed a type of frame which left the emulsion with just the desired margin of glass on each edge.

In the most important area of all--improved efficiency in the analysis of particle tracks, I shall mention a few examples from recent experience.

As the first one I take the identification¹ of the new decay mode, $K_{\mu 4}$. (I may remark, incidently, that the $K_{e 4}$ mode of K-meson decay was found not long ago also in emulsion by Koller, et al.² It and the $K_{\mu 4}$ mode represent the seventh and eighth types of decay known for the charged K-mesons. All modes have been definitely identified by means of the emulsion instrument. That the two most recently discovered modes have been found first by means of emulsion in competition with many other instruments, indicates the unique advantage that emulsion, even today, has as an instrument of discovery.)

Our experiment was rather simple, but without the coordinate microscope it would have been rather laborious. In a large emulsion stack about 4000 three-prong decay events were found by area scanning. Then two points near the beginning of each secondary track were punched into IBM cards. A program was prepared to determine the unit vectors along the tracks. The triple scalar product of these vectors was then calculated. For a Tau meson decaying at rest, this quantity vanishes because the vectors are coplanar. For a four-particle decay it will not vanish in general. It had a magnitude suggesting non-coplanar decay in about 100 cases. Automation thus enabled us to select from the much larger sample, those events in which there was pion scattering, errors of measurement, in which the K-meson decayed in flight, or in which there were neutral decay products in addition to three charged particles. Only the much smaller sample selected in this way required closer examination. Several interesting events have been found among them, including the above-mentioned example of the mode:

$$K^+ \rightarrow \pi^+ + \pi^- + \mu^+ + \nu_{\mu}$$

As a second example, I'll describe neutron spectroscopy as applied using emulsion detection by William Simon of my research group. He showed³ that the compound nucleus produced in the bombardment of gold by oxygen ions often evaporates several neutrons before fissioning, contrary to current theory.

The internal radiator method was employed for neutrons of 1-12 MeV. Above 12 MeV an external radiator of polyethylene was used. Automation was employed in the scanning, recording of data, and data reduction. His instrument was a type of coordinate microscope developed at the Lawrence Radiation Laboratory for this purpose. Figure 2 shows a recent model. The procedure was as follows: The scanner first records the z-coordinates of the two surfaces of the emulsion at a standard point by punching the digitized

readings into IBM cards. This measurement relates the thickness of the emulsion at the time of scanning to that at the time of irradiation. A fiducial point, which is the point where the normal from the target to the plate edge intersects the emulsion, is also recorded.

The scanning proceeds by "fields of view", outlined by a square on the eyepiece reticle. What is scanned really are volumes of emulsion equal to the area of the square projected on the emulsion times the emulsion thickness. Each is numbered sequentially and automatically recorded on IBM cards. Every proton track starting in the volume of the field of view is measured. The measurement consists simply of recording automatically the point at the origin of the track, a second point on the initial straight portion of the track to give track direction, and as many subsequent points as are necessary to determine the range. The range and direction are calculated automatically.

As a third example, I shall mention our study of the stopping power difference of matter for particles of opposite electric charge.

The earliest indication of the effect was found more than ten years ago while measuring meson ranges without the benefit of automation. In a later experiment for which Σ^- ranges were measured, we became convinced of its existence. The effect is so small, and the experimental verification of it so difficult, that only now with automatic equipment have we been in a position to undertake a study of it. As everyone knows, the path of a low energy meson in emulsion is not a straight line. Because of their small mass, pi mesons of low velocity are strongly scattered. This makes the measurement of their ranges very tedious and subject to error unless one has mechanical aids for the measurement. By means of the coordinate microscope mentioned in connection with the neutron spectroscopy, points on the path are recorded on IBM cards. Then the range and initial track direction are automatically calculated. With this equipment we have now studied the effect, using positive and negative pions of one to three MeV energy, in ordinary emulsion, in gold with emulsion detection, and in four times diluted emulsion. The first results as they existed several months ago, are presented to this conference in another paper.

As a fourth example of automation in emulsion measurements, I shall mention some of our recent work on the decay of the π^0 meson, the initial results of which I discussed before this conference two years ago. The

problem is the evaluation of the error in determining the point of origin of the Dalitz pair. As we have described earlier, the estimated point of origin is found by first measuring the coordinates of the centers of the first six grains of the tracks. Then a least squares fit is made of each track to a straight line, and the point of intersection of the straight lines calculated. The vector connecting the actual point of origin of the pair with this intersection is the error vector. The distribution of its magnitude and direction has been the purpose of a recent study. By introducing the scattering, grain noise, and grain spacing as random variables with known distributions into a Monte Carlo program, we were able to generate artificial tracks which start at the origin of coordinates in any prescribed direction. The calculations are described in Lawrence Radiation Laboratory Report UCRL-11624. Pairs of tracks were generated repeatedly in order to obtain the distribution of the error vectors as function of opening angle and electron momenta. The process, of course, would have been too time consuming to carry out without high speed computing machinery.

I have expressed the opinion before that it is probably wisest to approach automation of emulsion track analysis cautiously. Finding means to carry out reliably even a single operation with reduction of error and fatigue is already a considerable accomplishment. We are not interested in the development of equipment as a mere "stunt". Complicated and costly but unreliable, apparatus is worse than useless.

In this respect our "Video Track Analyser" described in Munich remains marginal. We have as yet failed to consummate any important research project with it, but recently we have been encouraged to believe that the electronic instabilities, which thus far have kept it from functioning reproducibly, can be cured eventually. An instrument of this type probably can be useful only in a large institution where expert maintenance is available, and it is not recommended to be used generally. For most grain density measurements, reliance on blob counting, simple lacunometers, and uncomplicated track-width instruments is suggested.