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EMULSION EXPERIMENTS AT A HIGH ENERGY ACCELERATOR*

by

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1. Introduction

In view of the forthcoming operation of Nimrod it seemed useful to make some comments about emulsion experiments, and the functions of an emulsion group, at an accelerator. In the past few years the work carried out by the group at CERN has changed from the technically simple to the very complex, as the resources of the Laboratory and of the group have grown. The work of an emulsion group at N.I.R.N.S. for outside laboratories may well be less in volume than that at CERN, as the accelerator is not in a new energy range, but it is unlikely to be different in character.

Some of the problems arising in performing emulsion irradiations and experiments at CERN are discussed below. The experience gained by the emulsion group at CERN in this work is extensive and possibly unique. We may mention that the amount of main-user time given to emulsion experiments at Brookhaven is essentially zero while at Berkeley it has been estimated to be about 3% of the total time available(1). By contrast, at CERN, between 10% and 15% of the total machine main-user time has been used for emulsion irradiations and experiments. Thus the work carried out in the United States has in general had to be parasitic with little or no possibility of changing the beams, or the mode of operation of the machine, to suit the particular emulsion experiment or irradiation in progress. In the USSR a large number of emulsion irradiations have been made at the 10 GeV Proton Synchroton(2); it is estimated that (very approximately) some 5% of main-user time has been allocated to these irradiations(3). At least one specific emulsion experiment, involving the use of a special internal target, has been carried out at Dubna(4). At CERN because more time has been available (essentially because the demand has been large) it has been possible to modify beams and the operation of the machine to suit particular emulsion requirements. We shall give examples of this in the following paragraphs.

2. Irradiations and Experiments

It is convenient to distinguish between the irradiation of emulsion stacks to particles of a chosen nature and momentum and emulsion experiments in which the emulsion is the particle detector in a complex set-up. For an irradiation there are three main problems: the beam itself, monitoring the exposure, and the emulsion stack, its preparation before the exposure and its handling afterwards. For an experiment additional problems arise which depend upon the nature of the experiment itself, e.g. it may involve the use of a pulsed coil with its associated condenser-bank and control equipment. We will discuss these four types of problems separately below.

3. Beam Handling

At CERN proposals to build particle beams are put forward by the experimental groups. It is they who do the detailed design work and who investigate the properties of the beam after it is built. The actual construction of the beam, that is putting the magnets and separators in position in the experimental hall, is done by the apparatus layout group of the machine in close collaboration with the experimental group.

It has been suggested that beams should be designed, constructed and operated by beam engineers, like the accelerator itself. We would disagree with this view. Requirements from experiment to experiment vary so much that no one beam can satisfy them all. Maximum flux implies large phase-space area and momentum bite; sharp, small images with low divergence imply the opposite. Only the group performing the experiment understands fully which of its requirements are flexible and which not, and only the beam designer understands fully which can be met and which not. We would agree, however, that there is a strong case for the maintenance of such complex equipment as separators and of the electronics used for setting up the beams by operators and technicians attached to the machine group.

Let us discuss first the irradiation of emulsion stacks in beams constructed by other experimental groups. Beams which are set up for counter experiments have usually, but not always, sufficient intensity for emulsion exposures. However, the beam is defined in the last instance by a counter telescope. Momentum bite, beam divergence and area, contamination and general background measured in this way may bear only slight relationship to the picture seen in an emulsion stack. Emulsion exposures with more than minimal requirements of purity etc. can only be made successfully after a careful study with emulsion in conjunction with a counter arrangement designed to give the information required. This is not a simple matter; proper evaluation of the data obtained may require several hours of machine time and a time lag before the main exposure of at least a week to extract the information from the test exposures. On the other hand, beams set up for track chamber experiments are usually better known, especially if one can study pictures taken in the bubble chamber, but they are usually of insufficient intensity by some orders of magnitude.

Many requests for so-called simple irradiations have been made to the CERN group in the past 3 years. The majority of these requests have been satisfied but the time involved making such simple irradiations can run to several man/weeks. Even the job of finding out whether the existing beam satisfies the often incompletely stated requirements of the irradiation should be measured in man/days rather than man/hours. In fact, only the scattered-out proton beam at the PS is readily adaptable for emulsion irradiations. This is due to the fact that it has at the same time very high intensity, purity and small divergence. More important, its properties have become very well understood by the emulsion group as a result of the many irradiations made in it. On the other hand, monitoring of this beam has never been an easy problem and has required considerable time and the help of the Counter group usually using the beam. All the pion beams constructed at the CERN PS have had appreciable divergence or convergence along the beam path which makes them less suitable for emulsion exposures. In fact no irradiations have been made in a pion beam which has had a divergence less than about 4 mradian.

Let us next consider irradiations necessitating minor changes to existing beams. By minor changes we mean changes in collimation, in momentum bite, in momentum or sign of the particle. Requests of this type are reasonably common from the outside groups some months or so after a simple irradiation with no beam changes has been found to be inadequate. For example, between the time of the survey of the beam and the main irradiation, changes may have been made in the experimental hall producing a new source of background. Typical changes of this nature are the movement of shielding blocks or of apparatus in a nearby beam. Sometimes an irradiation may have been made without there being time for a prior survey.

At the time of planning an irradiation it may be known already that a collimator close to the stack position would be a source of undesirable background; that the beam profile is too large or too small; that the momentum bite is too large. It may be desired to run with π^- in a beam designed for π^+, or at a momentum other than the value for which the beam was designed. More or less empirical adjustment may be possible, but if new defects are not to be introduced as fast as the old are removed, a very complete understanding of the beam under consideration is necessary. One must also understand the requirements of the experiments running from the same target or running from different targets, at the same time, since it may be necessary to move the internal target to compensate for the fringe field of the machine. It is even more necessary in this case to make a thorough survey well in a advance of the main irradiation. More than one such survey may be necessary and a test should always be made in the conditions to be used for the main exposure. Many such irradiations have been carried out, sometimes by the CERN group alone and sometimes with the assistance of the outside group concerned. Very often the irradiation has turned out to be much more difficult than originally thought if not actually impossible.

Let us now consider the question of making major changes to a beam already in existence on the floor of the machine. For example, for the experiment to determine the magnetic moment of the Σ^+ hyperon it is proposed to add a bending magnet and 3 quadrupole lenses to the existing a_3 beam and to introduce a degrader at a suitable position to separate the π^+ mesons from the protons when the beam is operated for positive particles. Such a major modification means that one or two people have to spend some months in beam optics studies, running computor programmes and, in fact, redesigning the beam for the specific purposes of the emulsion experiment concerned. Beam design or redesign is not difficult; it is just complicated and it takes time. We may remark here that it seems unlikely that a particle beam requiring a semi-permanent installation in the ring area will ever be built specifically for emulsion work unless it is known in advance that the beam can be used by experimental groups employing other techniques. This is a simple consequence of the fact that the majority of the time on any high energy accelerator will go to the bubble chamber technique and to the different counter techniques. However, up to the present at CERN it has always been feasible to modify beams built primarily for other purposes to suit the particular requirements of emulsion work. For example the k_2 beam built at CERN in 1962 was designed as a maximum-flux stopping K meson beam for the use of bubble chambers. The flux obtainable in this two-stage beam was about 4 stopped K mesons per pulse. Use of only the first stage of separation together with a final crude momentum selection increased the K meson flux by a factor of 5. The purity in this arrangement although adequate for emulsion work was not sufficient for bubble chambers.

4. Monitoring of beams

Grouped under this heading are measurements of beam profile, intensity, divergence and composition, and also of background. A thorough measurement of all of these for every irradiation is obviously out of the question. We mention briefly some of the methods we have used at CERN in the past and some improvements we hope to incorporate in the future.

Beam profiles may be measured by a number of techniques, each with its own advantages and disadvantages. We may list, in order of decreasing time consumption, test-plates, remotely controlled survey counters, X-ray or polaroid film and the polaroid camera with a scintillator-fibre intensifier[5]. This last we find particularly useful for rapid qualitative work.

The measurement of the flux of particles entering the emulsion stack and the proportion of them constituting the main beam can be very difficult. In the past we have usually borrowed counters already installed in the beam by another experimental group, and have adapted the coincidence circuits and geometry as best as possible to our needs. Test plates very often give results far from those expected on the basis of measurements made with such equipment. Unfortunately there is rarely time to investigate the reasons for the discrepancy. In future we plan to use our own counting equipment in an arrangement such as the following. A counter (1) covering the beam area is placed some 2 or 3 metres upstream from the stack. Two further counters (2,3) also covering the whole beam are placed just in front of the stack. Coincidence counts 123 give the number of beam particles entering the stack. The size of the counters and the distance between them could be varied to make a crude determination of the divergence of the beam. Coincidence counts 23 measure all charged particles entering the front-face of the stack. Comparison between singles and coincidence counting rates may allow a very rough estimate of general background, if the efficiencies of the counters are well known. We hope to limit the use of the time-consuming test-plate technique to the verification of the final beam properties, by calibrating such an arrangement in a variety of conditions and thereby getting to know its uses and its limitations. We would strongly suggest that the NIRNS emulsion group adopt such a course from the outset.

The emulsion group has often to contend with instantaneous counting rates as high as 10"/second. This occurs when a 1m.sec particle burst is being used either because a pulsed magnet is part of the experimental arrangements or because an emulsion experiment is being performed parasitically during a bubble chamber run. For the Σ^+ and Λ^o magnetic moment experiments, where the instantaneous particle flux will be a few times 10^8/ second, we plan to use a counter telescope looking at secondaries produced in a target placed in the beam, and to calibrate this arrangement with test plates.

Determination of the nature of the particles in the main beam is the most difficult task of all. Usually we rely upon measurements or estimates provided by the group responsible for setting up the beam. However, as the beam is quite frequently used at momenta other than those in which the counter group is interested, these are often only extrapolations beyond the reach of their particular measuring technique. For example, in the course of preparations for the Σ^+ magnetic moment experiment we have made a measurement of the nature of the positive particles in the a_3 beam at 1 GeV/c, using ionization measurements in emulsions. Counter estimates, extrapolated from careful measurements at and above 2 GeV/c, were that the proton content should be of the order of 8%. The emulsion measurements showed 30%. We do not suggest that the measurement could not have been made with counters, but only wish to emphasize that a counter arrangement designed for a specific purpose cannot necessarily be expected to give an accurate measurement of quite another quantity. The same is true of emulsions.

5. Ancillary apparatus for the irradiation of emulsion stacks

The first requirement is that the pellicles of emulsion should be put together in the form of a stack and placed in a stack holder. The group at CERN have developed a versatile type of stack holder which has been described by M.A. Roberts[5]. It is usual to mill the sides of the assembled stack, using a large cutter on a milling machine (see also (5)).

For the irradiation at the machine it is useful to have tables which can be accurately levelled and which can be easily varied in height by remote control. For some work (for example, irradiation in rather complex beams) it is necessary to mount the stack on a table which can rapidly be dropped out of the beam if something should go wrong. When the beam is operating correctly the stack can quickly be brought up into position again. In some cases it may be desired to place a stack at a given angle (or even perpendicular) to a particle beam. For this purpose, subsidary apparatus is required which will enable this to be done. Tables fulfilling all these requirements have been constructed at CERN and they are described in reference (5).

After irradiation, it is usual to dismount the stack, to carry out thickness measurements and to print a grid on the bottom surface of each pellicle. This is done irrespective of the place where the stack will eventually be processed. Apparatus for these purposes is therefore required, together with a suitable darkroom, preferably maintained at constant temperature and humidity. We will not consider the problem of processing facilities in this paper, except to note that facilities must be provided for the processing of test plates. Exposures of emulsions loaded with various substances are becoming increasingly frequent, and the darkroom equipment should be adequate to deal with the more common loading techniques.

6. Emulsion Experiments

There are several different kinds of emulsion experiments, each of which pose different problems. For example, the search for Dirac monopoles[6] required the construction of specialised apparatus which formed part of the vacuum box of the accelerator itself. On the other hand the experiment by the Copenhagen group[7] to study particle production from Lithium hydride (using the scattered out proton beam) meant that a very fine pencil beam of protons had to be engineered and a good monitoring system had to be set up. We would only comment that it has been found necessary at CERN to have fairly extensive workshop facilities (and the corresponding technical staff) which are under the sole control of the emulsion group. Rather frequently the outside group (which may have started work on the accelerator) discovers a last minute improvement that they wish to make; by now the technicians in the CERN emulsion group are prepared for most requests of this nature and are able to meet them in short space of time.

7. Information

For an outside group to plan an experiment (or even an irradiation) at the accelerator, they need to be well supplied with data about the machine itself and about the beams. At CERN the PS Handbook attempts to give most of the information; we understand that a similar handbook is in preparation for NIMROD. Among items of information frequently needed by emulsion physicists we may mention

a) magnetic field contours around the machine and programmes to compute particle trajectories from different target positions in the machine;

b) the different modes of target operation that are possible;
c) particle fluxes in the various beams;
d) particle fluxes as a function of angle of emission from the target.

It is difficult to keep the information up-to-date, of course, and the resident group can perform a valuable service by supplementing this information from their own experience. The possible irrelevance of much of the beam data has already been discussed. Such a handbook is inevitably incomplete, as it can only describe facilities already available and tested.

New facilities can sometimes be provided by the machine group relatively easily, or their development is under consideration and would be undertaken if there were a demand for them from the physicists using the machine. At CERN, this has been particularly true of internal target operation and of the ejected beams. All experiments should therefore be discussed well in advance with the machine group with this in mind.

8. <u>Outside groups and the resident emulsion group</u>

A simple irradiation of a few shifts in an existing beam is, with its necessary beam survey, a major experiment which takes at least two weeks to perform and which will fully occupy several people during this time. It is, in fact, an integral part of the emulsion experiment. Preparations in the months before are very time-consuming. At all accelerators there are extremely strong pressures to make the fullest use of expensive machine time. Emulsion irradiations frequently can be slipped into a gap in the schedule; changes for better or worse in machine operation, beam transport supplies and so on make large changes in the schedule inevitable.

If the resident group is to deal effectively with several irradiations in each three- or six-month period, and to carry out research work of its own, the outside groups must participate actively in the work at the accelerator. If they do so sufficiently to begin to appreciate the sense of urgency which pervades this kind of work, the rest of the suggestions in this section will be met without hesitation. We may remark that the habits of mind created by having to fit into a machine time-table, or to accept that any modification of apparatus may be a solid engineering job, is perhaps as important and as difficult to acquire as experience in the particular techniques and modes of thought of high-energy physics.

As soon as their experiment has been accepted, members of the outside group should come to the accelerator for very full discussions with the resident group on how to carry it out most effectively and also with the designers of the beam they plan to use. If their experiment is in any way complicated, they should be prepared to leave one of their number at the accelerator laboratory, to be responsible for the details of their experiment. Some time before the first test run they should come in force, prepared to stay until the experiment is completed. Wherever possible, auxiliary apparatus should be constructed by the outside group in their own laboratories.

If it is necessary that the apparatus be designed in conjunction with the machine or the beam, they should provide technicians to carry out the work at the accelerator under their own supervision. In planning the provision of space for the resident emulsion group it is, of course, necessary to make allowance for the visiting teams, in terms of office, laboratory and workshop facilities. The emulsion group at CERN has never had sufficient space to accommodate properly the many visitors. It is also desirable to establish a separate budget to supply the minor needs of visitors, in order to avoid a complex accounting system, necessitating the establishment of many small bills.

If the procedure outlined above is followed, the members of the resident group will then be free to provide guidance and basic facilities for the visitors, and to carry out their own research. We take it as axiomatic that the staff of the resident group would be given sufficient time and resources to enable them to carry out research, perhaps in collaboration with one of the outside groups.

A further discussion of the relationship between the group resident at the accelerator and the outside groups may be found in references (8) and (9).

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