CERN-PS/Nucl.Physics/5
18.12.1957

PS RESEARCH PROBLEM III.

Chap. V

Bubble Chamber Experiments (Peyrou).

1. Size of bubble chamber.

The choice of the bubble chamber is influenced by the lengths and mean free paths which will be encountered in the Euratron energy range. The decay length of hyperons and neutral K-mesons will be of the order of 5 to 30 cm. Other characteristic lengths, such as the decay length of charged K-mesons, and the geometric mean free path will be several meters and will not be accommodated in chambers of practicable dimensions. In spite of this there is a very strong interest to have the dimensions as large as possible so as to increase the probability of secondary interactions which may identify the particles. Furthermore the accuracy of momentum determinations, in a constant magnetic field increases as the square of the linear dimensions. Table 2 gives the maximum detectable momentum for a field of 15000 gauss and a precision in the sagitta determination of 0,1 mm, assuming negligible distortion.

Table 2

Maximum detectable momentum. B = 10.000 gauss. Δs = 0.1 mm

Length of track	10	20	50	100	cm
Maximum detectable momentum	3.8	15	90	380	GeV/c

Many of the secondary particles produced in interactions at 20 GeV will have momenta of the order of 6 GeV/c. For an accuracy in the momentum determination of 10 o/o a track length of 50 cm is necessary, which means that the chamber length should be at least 1 meter. It is therefore obvious that the 30 cm hydrogen bubble chamber which at present is the only one definitely foreseen in CERN will not be useful in high energy experiments where momentum determinations are necessary. This of course does not preclude its usefulnessfor exploratory work and for the study of low energy secondary particles emerging from high energy interactions.

The preceding arguments have not led to any suggestion indication of an optimum size of the bubble chamber from the point of view of the problems to be studied. The bubble chamber should be as large as possible. The limit will be set by purely practical considerations, not necessarily of an economic nature. The British bubble chamber will probably have its dimensions determined by the largest aluminium forging which it is possible to have in Great Britain. This limit is about 1,5 m.

2. Material in the bubble chamber.

Hydrogen bubble chambers have the advantage that all interactions are against protons. The multiple scattering is so small that it does not affect the accuracy of the momentum determination. On the other hand the radiation length is so long that the probability of materialisation of gamma rays is very small, and neutral pions and neutral decay modes of strange particles are unlikely to be detected in a hydrogen bubble chamber. The technical difficulties involved in the construction and operation of a big hydrogen bubble chambere are formidable, in particular due to the cryogenic problems and the safety problem.

The propane bubble chamber contains about as much hydrogen per volume as liquid hydrogen and will therefore give about as many interactions with protons. These will however have to be distinguished against a much larger number of events in carbon. Many of these are readily recognizable by the presence of evaporation prongs, but in some cases such prongs are missing if the interaction has taken place with a proton at the surface without much energy exchange with the rest of the nucleus. At high energies such events are not very different from interactions with free protons and there inclusion among the bona fide proton events will not distort the picture very much. The main bias will occur from carbon events with only neutral evaporation prongs. In propane the radiation length is about 50 cm and in a large propane chamber there is an appreciable probability for the materialisation of gamma rays. At the same time the multiple scattering while larger than in hydrogen is still sufficiently small not to influence the momentum determinations for tracks up to 50 cm. The technical difficulty of a big propane chamber is much smaller than for a hydrogen chamber, although the safety problem is almost as big.

Bubble chamber using other materials than hydrogen and propane, such as helium, xenon or other high Z liquids must be regarded as special instruments which will have to be designed and built with a particular experiment in mind. We should at present only consider equipment of a general purpose nature.

3. Beam requirements.

In a big bubble chamber with a width of about 50 cm it is possible to accommodate about 50 tracks over an area of 50 x 50 cm without confusion of the events. It is important that the fluctuations on this number do not appreciably exceed the statistical fluctuations, since this will cause some pictures to be unreadable, due to an excessive number of tracks, while others will contain an uneconomically small number of tracks. At least during the initial stage it is advisable to have a smaller flux, say 10 to 20 particles through the chamber.

In principle a bubble chamber in a magnetic field allows the momentum of the primary particle to be determined if it is sufficiently long, i.e. if the interaction occurs sufficiently far inside the chamber. Then however there is correspondingly shorter track length left for the momentum determination of the secondaries. In addition the high momentum of the primary will make the momentum determination in the bubble chamber rather inaccurate. It is therefore to be preferred if the incoming beam is already analysed in momentum. An accuracy of 2-5 o/o in the momentum analysis of the primary would essentially eliminate the primary momentum analysis as a source of error in the analysis, compared to the error in the momentum of the secondaries.

The purity of the beam is of great importance for two reasons. If a large impurity of other high energy particles is present the intensity will have to be decreased to a lower value in order to have only 50 tracks per photograph. If good statistics are desired a background of 500 other particles per each desired particle is probably the maximum that can be tolerated since only every 10th picture will then contain a particle of the desired type and only in every 50th picture will this particle cause a measurable interaction with a proton (1 m hydrogen or propane chamber assmed).

The other reason for requiring good purity of the beam is that the bubble chamber does not, in general, allow the incoming particle to be identified. With a large background of other particles it may therefore be difficult to identify interactions caused by the particle under study from those caused by the background, particularly when the incoming particle energy is high. The impurity of high energy particles which can be tolerated will of course depend upon the type of impurity and its cross section for producing interactions in the chamber.

From this point of view it would be of great value to have a counter system set up in the incoming beam which identifies the incoming particles by for example time of flight and if the particle is of the desired kind, determines its point of entry into the bubble chamber by a suitable matrix array of counters in front of the bubble chamber and indicates this information on the bubble chamber photograph. This additional information would help considerably in narrowing down the uncertainty about the nature of the incoming particles.

The length of the burst of particles intering the bubble chamber should be 100 µs or less in order to allow all tracks formed to have uniform time of growth before the photograph is taken.

A somewhat different problem is created by the general background of low energy particles, mostly neutrons/created around the machine. A few hundred neutrons in the MeV range which impinge on the bubble chamber and produce recoil tracks in it will render the picture so confused that analysis is almost impossible. Since a high energy proton may produce as many as 40 low energy neutrons this problem may become extremely serious. The size of the beam must be limited to the bubble chamber itself so that part of the beam does not produce neutrons in the yoke and coils of the surrounding magnet. Any shielding and collimators which define the beam must be sufficiently far away so that the solid angle subtended by the bubble chamber seen by neutrons created at that spot, is small. If the low intensity beam needed for the bubble chamber is peeled off the internal beam care must be taken not to "dump" the remainder of the beam until the photograph has been taken 10 ms later or to dump it at a point sufficiently far away not to produce background at the bubble chamber.

To avoid the low energy background it will probably be necessary to expose the bubble chamber to a well focused beam in location far away from the machine where the background from the machine is low, or can be drecreased by proper shielding.

If the recycling time of the bubble chamber is much longer than the Euratron recycling time, intermediate bursts of the machine can be used for other experiments. It cannot yet be stated with any certainty what recycling time will be possible with big bubble chambers.

4. Analysis of bubble chamber photographs. (Goldschmidt-Clermont).

The analysis may conventionally be divided in scanning, computation, measurement and interpretation of the events.

In a problem of the kind chosen for the test experiment, namely the interaction of pions with protons, almost every photograph will contain one or several events and the measurements will be the overwhelming part of the analysis , while scanning will be reduced to a quick survey of each photograph before staring the measurements.

Assuming a big bubble chamber recycling every 3 sec, we will have for 24 hours operation, about 30.000 photographs with about one event per photograph. With a fully developed photograph analysis equipment we can assume that one event will take about 10 min to analyse. A complete analysis of the photographs produced in a 24 hour run will take 5000 hours or about 3,5 man-years assuming 6 hours per day. To this comes about 20 sec of computer time per event, or about 170 hours of computer time per 24 hours of machine time.

It is therefore obvious that the actual exposure time of the bubble chamber at the machine will be a small fraction of the total time unless even more radical improvements in the speed of anglysis will be made than the time of 10 min per event on which the above argument is based. Alvarez indicates the possibility to analyse an event in a few seconds using a spiral scan analyser. It is however probable that such ultrarapid devices cannot be counted upon to be ready by the time the Euratron is in operation. Furthermore, the computer problem may then become the chief bottleneck.

Even if a completely automatic, ultrafast measuring device were available it would be unwise to use it, at least during the first years of operation of the Euratron when little is known about the processes which may occur, or even about the new unknown particle which may crop up. The bubble chamber is the chief instrument for studying these new phenomena. It is important that such unexpected phenomena are not overlooked because too much of the analysis of the picture is entrusted to automatic machines. The analysis must be done by a human observer who is able to devote his full attention to the study of the photograph because all trivial details, such as the measuring and recording of the coordinates of points on the tracks, the motion along the tracks, the change of stereoscopic views and of frame have been automatized or otherwise facilitated to the fullest extent.

The observer will be able to detect and measure most of the secondary interactions or decays associated with an event. Some small angle scatterings or decays may however be overlooked by the observer, but should show up in the subsequent computations in the computer, which should be programmed to detect and report small changes in the direction of the track.

The computation of the events for an experiment of the size indicated above will have to be done entirely on a computer. Starting from the coordinates recorded during the measurement it reconstructs the tracks in space, applies various corrections and calculates all the relevant parameters of the event, such as angles of emission and momenta of the tracks in the laboratory and c.m. system, distance to secondary interactions and the parameters of these interactions. The result of this computation is produced in a form directly readable to the physicist and also in a form suitable for further computations with the computer. The future analysis will depend on the problem under study since the files of data obtained in a given exposure, for example to pions, contain data relevant to many different problems, such as elastic and inelastic cross sections, production decay and interactions of strange particles, etc. In many cases it will be possible to extract information from the data which was not at all intended in the design of the experiment.

5. Information obtainable from Bubble Chamber Photographs.

The bubble chamber photographs will yield information on the sign and momentum of all charged secondary particles from an interaction. With a knowledge of the momentum of the primary particle the momentum unbalance of the interaction can be determined, giving the momentum of the undetected neutral particles.

The identity of the particles is a priori unknown, since the bubble density cannot be used in our energy range to measure β sufficienty accurately for particule identification. In favourable cases, the identity can however be established from decays or interactions of the secondary particles in the chamber. Short lived neutral particles will show up if they happen to decay into charged particles in the chamber. Practically all the hyperons and θ_1 will have a large probability for identification since they have mean lives of the order of 10^{-10} s, which corresponds to less than 30 cm motion even for a γ of 10. Σ^+ and the antiparticle of Σ^- can be distinguished by the fact that for the antihyperon the conventional Q-value of 120 MeV should be obtained if the negative particle is given protonic mass instead of the positive. Charged K-mesons generally do not disintegrate in the chamber because of their long life, which is an advantage since their decay is difficult to distinguish from that of the Σ-hyperons.

Of the non-interacting neutral particles the anti-neutron may be expected to annihilate occasionally in the chamber. In general, neutral particles will be produced in this process and it will not always be possible to associate this secondary star without ambiguity with the primary event. Since the kinetic energy of the anti-neutron is usually quite a bit lower than the primary particle energy the annihilation energy should show up quite conclusively in the visible energy balance of the secondary star, establishing the anti-neutron character of the particle.

Typical results of a bubble chamber experiments on pion-proton interactions in the Euratron energy range may be:

Multiplicity momentum and angular distribution of positive and negative particles produced in the interaction. In a fraction of the cases it will be possible to identify the type of particle but in the majority of the cases several alternatives will have to be taken into account.

Average multiplicity, angular and momentum distribution of short-lived neutral particles, decaying into charged particles.

Distribution of the total momentum of undetected neutral particles.

In a propane chamber some information may in addition be obtained on neutral particles which decay into gamma rays from the distribution of materialised electron pairs, or give rise to proton recoils or otherwise interact within the chamber.

Total cross sections can be determined if the incoming beam is sufficiently pure or if it is possible to discriminate sufficienty well against the impurities.

It is of interest to compare at this point with the result of counter experiments. The counter experiment can, if sufficient intensity is available, determine anguler and momentum distribution of the secondary particles and by time of flight or other methods also identify them if they are not too relativisitc. The multiplicity cannot very well be determined with counters.

Neutral particules which are not visible in the bubble chamber may in some cases be detected with special counters, using recoil (neutrons) annihilation (anti-neutrons), shower production (gamma rays) or decay (Θ_2). The short-lived neutral particles are not well measured with counters.

Total cross sections are probably better determined with counters than with bubble chambers.

6. Conclusions.

A large bubble chamber, probably liquid hydrogen, seems indispensable for the initial stage of operation of the Euratron since it is the chief instrument for mapping the unknown field of physics in this energy region. The preliminary information derived from it will then serve to plan more detailed experiments with counters or bubble chambers.

The operation of the bubble chamber requires a low intensity pure and momentum analysed beam of short duration. The low energy background is expected to be the chief problem.

The actual exposure time of the bubble chamber, compatible with a reasonable organisation for the treatment of the data produced, is probably of the order of a few days or weeks per year. Even allowing for setting up the chamber and test runs, it is hardly justified to spend much on facilities for running the bubble chamber simultaneously with other experiments.

A substantial effort will have to be spent on organising facilities for measuring and analysing photographs in CERN or in other laboratories. The staff in CERN should be comparable to the scanning staff in a large emulsion laboratory, like Bristol, but with the microscopes replaced by semi-automatic measuring instruments, similar to the types under development in Berkeley ("Frankenstein") or in CERN (IEP Mark IV), With such an effort the CERN Mercury computer may be insuffient.

Considerable thought and ingenuity will have to be devoted to the interpretation of the results from a large number of photographs. Automatic computers and data handling techniques should be used. These problems are however less urgent to consider now.

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