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STREAMER CHAMBERS — THEIR USE FOR NUCLEAR SCIENCE EXPERIMENTS*

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ABSTRACT

A review of the role of streamer chambers in nuclear science work is presented. Included is a brief description of the operating principles of such chambers, some advantages and drawbacks of employing this visual detector for nuclear science experiments, and a discussion of the future usefulness of such devices; both for hadron-nucleus and nucleus-nucleus studies. Several examples of the interactions of both hadron and heavy ion beams with nuclear targets located in a streamer chamber are shown.

*Work supported by the Division of Nuclear Physics, U.S. Department of Energy.

INTRODUCTION

A variety of visual detectors have been developed for studying the interactions of elementary particles (π , K, p, ...) and nuclei with matter. Included among these are cloud chambers, flash tubes, bubble chambers, spark chambers and streamer chambers. The cloud chamber was one of the earliest visual devices used to study both atomic and nuclear interactions, and is still in use today for cosmic-ray studies (e.g., extensive air showers). Bubble chambers have been in use since the 1950's and offer several advantages, including: 4π detection of the event, large target density to increase the number of observed interactions without distorting the measurements too severely (i.e., multiple scattering is relatively small), wide variety of target liquids available (H_2 , D_2 , 4He , heavy liquid filling, ...), high multi-track efficiency, good momentum and angular information is possible, as well as good ionization information to aid in particle identification. Some difficulties arise from the characteristic sensitive time associated with such chambers. Operationally, this means that one cannot put a continuous beam through a bubble chamber, but rather a sharp pulse is delivered which contains a small number of particles (typically $\leq 10-20$). A bubble chamber itself cannot be triggered on specific events as might be desired if one wanted to enhance a particular final state. However, the flash used to photograph the tracks can be triggered externally to enrich the event sample.

Spark chambers, both the narrow and wide gap variety can be selectively triggered and have been in use since the late 1950's. Having characteristic memory times of ~ 1 μ sec, means that many more particles/

pulse can be passed through a spark chamber than are run through bubble chambers. In addition, it is possible to obtain good spatial resolution using spark chambers. However, it should be remembered that when using narrow gap chambers, where the spark extends from one electrode to the next, one is only sampling the trajectory of the charged particle. This is somewhat alleviated in the case of the wide gap chamber where the spark follows the trajectory up to about 45° . Finally, both types of spark chambers suffer from loss of efficiency for multi-track events. It takes considerable effort to make such chambers fully efficient for more than about 6-8 tracks.

Streamer chambers made their appearance on the detector scene in the early 1960's and were developed for eventual use in experiments. This development was primarily geared to studies of elementary particle interactions. As such, streamer chambers were often used to complement and extend the large amount of work that had been done on exclusive final states using bubble chambers. Streamer chambers offer several advantages, including: large solid-angle ($\sim 4\pi$), ability to be selectively triggered (usually by fast electronic detectors such as scintillators surrounding the chamber), and high multi-track efficiency and good angular and momentum information.

The remainder of this report will be primarily devoted to reviewing the uses that streamer chambers have been put to in nuclear science studies. This is a rather recent development, as the primary role for these chambers up to the early 1970's was for studying elementary hadronic processes. We will touch lightly on the operational principles of such chambers, followed by some of the uses they have been put to. Finally,

we will briefly describe the possible future directions of streamer chamber use, particularly those associated with the relativistic nuclear beam work going on at the Berkeley Bevalac Facility.

STREAMER CHAMBER OPERATION

The development of the streamer chamber as an experimental tool for visual studies of particle interactions has been going on for about 15 years. The earliest comprehensive published reports of Chikovani et al.¹ and Dolgoschein et al.² appeared in 1964. Since that time many reports on streamer chambers have appeared which describe both the theory of streamer development and streamer chamber operations. For the reader who wants to go into greater detail on the theory of streamer chambers, Ref. 3 offers such an opportunity, including references to all the important early literature on the development of streamers in gases. In Refs. 4-7 one will find reports on many of the operational difficulties associated with streamer chambers and the cures which have been developed (in most cases) to get around these problems. Our interest here is to provide just a simple discussion of how the streamer chamber works and then proceed to its uses.

Figure 1a shows a schematic of a charged particle passing through a streamer chamber. Scintillation counters S1 and S2 record the passage of the particle through the gas volume (often a Ne/He mixture at atmospheric pressure, 90% Ne, 10% He). During this passage through the chamber gas, the incident charged particle creates ion pairs along its trajectory. These pairs in turn start to diffuse and eventually recombine if nothing further is done. However, if a fast coincidence

between S1 and S2 is formed, it can be used as an event trigger to generate a high voltage pulse which is placed on the electrodes surrounding the chamber volume. Usually a Marx generator and a Blumlein are used to generate and shape this pulse. The high voltage pulse (typically in the range of 500-700 kV) creates a strong electric field in the chamber which causes the ion pairs to accelerate and to multiply in the chamber gas. By restricting the pulse to a short duration (10-20 nsec), the final breakdown in the gas and the creation of a spark from one electrode to the other is suppressed. Only the early stage of the spark development occurs, i.e., the development of streamers. Typically, in the streamer chamber mode of operation, the electric field is about 20-25 kV/cm. Now if the chamber volume is transparent, then a camera which photographs the light from the streamers generated will see their development from two to several millimeters (depending on operation) along the electric field lines when the camera view is normal to the electric field. If transparent electrodes, such as wire grids are used, the camera can view the light from the streamers end-on. In this case the streamers then appear as a series of bright dots (Fig. 1b); much the same as one sees when looking at bubble chamber photographs. Finally, if the streamer chamber volume is placed in a magnetic field of suitable strength then the curvature of charged particles in this magnetic field can be measured. The scanning and measuring of this film is then handled in a manner similar to the treatment of bubble chamber film.

There are many problems related to the good operation of a streamer chamber that must be solved before physics can be done with it. These include the proper shaping of the high voltage pulse using Marx generators

and Blumleins. The light output from streamers is not large, therefore suitable film must be used for photography. Bright spots referred to as "flares" appear along streamer chamber tracks. The complete origin of these is not known,^{6,7} but they must be dealt with since they can greatly obscure segments of a track. The necessary poisoning of the streamer chamber must be controllable so that the sensitive time of the chamber can be reduced to the range of 1-2 μ sec in order that a reasonably high flux of particles ($\sim 10^5$ - 10^6 /sec) can be brought to the chamber for low cross section experiments. This poisoning is often accomplished by adding a few ppm of SF_6 . A great deal of time and effort has been put into these and other problems to make streamer chambers into useful tools for studying the interactions of particles and nuclei with each other.

USE OF STREAMER CHAMBERS IN NUCLEAR SCIENCE

Although considerable use has been made of streamer chambers for high energy particle physics studies, their use in nuclear science work has been quite limited. Some of the areas of study have included:

- 1) study of coherent nuclear scattering processes
- 2) conventional nuclear physics (e.g. search for double β -decay)
- 3) study of hadron-nucleus elastic and inelastic scattering
- 4) high-energy heavy-ion interaction experiments.

We will mention some of these experiments, covering some of the more interesting techniques employed and pointing out the information content derived from using streamer chambers for such work.

Many of the experiments utilize the gas in the streamer chamber both as the detection medium and as the target nucleus to be studied. The University of Washington group has developed a streamer chamber missing mass spectrometer for studying diffractive dissociation at FNAL energies.^{6,7} Basically they use a helium-filled streamer chamber and an associated electronic trigger which takes pictures whenever a reaction of the type

occurs. Such a process is coherent, since the target nucleus (the gas in the chamber) is left undisturbed. The quantity X refers to everything else that is produced in such a reaction and must have the quantum numbers of the incident particle since ${}^4\text{He}$ is an isospin zero nucleus. Diffractive processes involve low momentum transfers to the target nucleus. Thus the recoil nucleus will be of low energy and therefore heavily ionizing; whereas the other tracks (in the case of reaction (1) these are pions) will be minimum ionizing. The light output from a heavy track will be much greater than from the minimum tracks, causing a problem in photographing such events. This is taken care of by using two sets of lenses, one set with the lens stopped down to photograph the bright track, the other set with normal apertures to photograph the minimum ionizing tracks. Figure 2 shows a streamer chamber photograph of a 2 GeV/c proton interacting with the Ne in the 1.5-meter Argonne-Illinois streamer chamber⁸ in which this technique has been used. In the lower portion we see the incident beam track and several outgoing tracks, both light and heavily ionizing, which exit the production vertex. This was taken with an f/2 lens. In the upper portion is a photograph of the same event,

but taken with a $f/5.6$ lens. Here we essentially see only the heavily ionizing recoil tracks. A film speed of 6000 ASA using Kodak SO143 film was employed.⁹ A Strasbourg/Orsay collaboration has also used the Argonne-Illinois streamer chamber with a helium filling at one atmosphere. A beam of 6 GeV/c polarized protons has been used to interact with the chamber gas to study N^* production, proton diffractive dissociation, π^4 He enhancements and He fragmentation distributions.¹⁰

The advantage of the streamer chamber is that it can be selectively triggered, thus allowing rare processes to be studied. A novel application of streamer chamber techniques was used by Bardin et al.¹¹ to search for the double beta decay of ^{48}Ca . They were looking for the simultaneous creation of two electrons with summed energy near ~ 4 MeV with an expected rate of about one per day. Thus, they required a device with large solid angle, ability to measure position and curvature in a low magnetic field (400 gauss) and minimum amounts of materials in walls and detector (chamber gas) to reduce the possibility of conversion of ambient gamma rays. They used a two gap discharge chamber, each gap of 4 cm depth. The chamber was circular with a 53-cm diameter, filled with helium at one atmosphere. To further reduce their backgrounds the experiment was conducted at a depth of about 610 meters underground. Such a rugged environment required a sturdy instrument. The streamer chamber seemed well suited to their requirements. After considerable running they were able to set a lower limit of 1.6×10^{21} years on the lifetime of the neutrinoless, double-beta decay process.

A group at Dubna has used a streamer chamber filled with either ^3He or ^4He to study pion (π^+ and π^-) elastic and inelastic interactions in

the 100-200 MeV range.⁶ Again, this employs the gas of the chamber as the target nucleus that is being studied. These are "live target" experiments. When operating streamer chambers with pure helium mixtures rather than the usual Ne/He mixture, the high voltage pulse must be increased by about 15-20% in amplitude and about 40% in length to get sufficient brightness for photographing the streamers. Balestra et al.¹² have used a streamer chamber as an 180° magnetic spectrometer to study large angle pion-nucleus scattering. The spectrometer consists of a helium-filled streamer chamber at one atmosphere, placed in a magnetic field, and used to identify the back-scattered pion. In this mode of operation, the pion beam traverses the streamer chamber (which is circular in shape: 39 cm diameter, 12 cm high) and strikes a target placed outside of the chamber on its downstream side. A set of scintillation counters were used to trigger the chamber on a backward-going pion. After the picture was taken the pion's angle and energy are determined by measuring its curvature and location. The beam track which also appears on the film, was measured in the same manner.

Kanofsky et al.^{9,13} have used the 1.5 meter Argonne-Illinois streamer chamber filled both with standard Ne/He mixture and with pure helium to study the interactions of 1.5 - 2.5 GeV/c $\pi^{\pm}$'s and p's with the gas nuclei. Figure 2 shows such an interaction. Some of the physics features that they hope to study with the streamer chamber are:

- 1) Pion-nuclei total and partial cross sections,
- 2) Possible emission of light clusters from the target as tests of cluster models, e.g., α -cluster knockout,
- 3) Pion and nuclear fragment multiplicities,

- 4) Investigation of pion production where one is able to see what other fragments are ejected from the target, thereby providing more detailed information on the dynamics of the process.

A crucial factor in such studies involves the extent to which particle identification is possible using the ionization information available in streamer chamber photographs. Schoen and Kanofsky had studied this problem earlier¹⁴ and concluded that particle identification was feasible by counting the number of streamers per unit length and relating this to the dE/dx loss of the individual charged particles. Figure 3 shows a scatter-plot of some data⁹ from 2.5 GeV/c protons incident on the chamber gas (pure He filling). They have counted the streamers/unit length for various outgoing tracks (these tracks were required to be ≥ 30 cm long) and plotted this against the momentum of the track obtained from reconstruction. The solid curves represent their estimate of the energy loss (ionization) produced by different particles (π^+ , p, d, ^3H , ^3He , α) as a function of momentum. For momenta below about 800 MeV/c one is able to separate π^+ 's and protons comfortably on the basis of streamer counting (compared with bubble chambers where the separation can be reliably done up to $\sim 1.4 - 1.5$ GeV/c). The large cluster of points around 2200-2400 MeV/c arises from processes in which the incident proton is only slightly degraded in energy by the interaction (typically, elastic and quasi-elastic scattering). It should be pointed out that a measurement of the number of streamers per unit length is time consuming when done by a scanner without automatic equipment on a scanning/measuring table. An alternate approach would be to have devices such as scintillators or solid state

counters located outside the chamber which could be used in conjunction with the measured track information to do particle identification. The drawback lies in the fact that one has to cover a very large solid angle with these detectors to catch all tracks; while at the same time keeping them small to avoid multiple tracks from registering in the same counter. Finally, we show in Fig. 4 some preliminary data on pion and nuclear fragment multiplicities obtained in these exposures. This type of information is easily obtainable by merely scanning the streamer chamber film. One only needs to identify the pions, which will in general be minimum ionizing tracks. No reconstruction of each track is typically required. From Fig. 4 we see that the average multiplicity of nuclear fragments is larger for Ne (2.6) than for He (1.3).

Recently beams of relativistic nuclei have been used in conjunction with streamer chambers to study high-energy nucleus-nucleus collisions. These experiments have been conducted at the Dubna synchrophasotron and the Berkeley Bevalac Facility. A Soviet group^{15,16} has been using a 2-meter streamer chamber to study, among other things, negative pion production induced by alpha particles of 18 GeV/c. They have found that they can relate the pion multiplicity distribution observed for alpha particles to that produced by high-energy protons when they choose the proton beam energy to correspond to the energy where $\langle n_- \rangle_{pp} = \langle n_- \rangle_{\alpha A}$.

The work at Berkeley has involved a collaboration between UC Riverside and LBL. It is worth elaborating the reasons why streamer chambers offer distinct advantages for investigating nucleus-nucleus collisions at energies from a few hundred to several GeV/nucleon. Some of these reasons include:

- 1) 4π detection capability plus very good efficiency for multi-track events (up to 125 charged tracks have been observed in a single event).
- 2) Since the chamber can be triggered, one can select specific events to study, such as those resulting from peripheral (projectile fragmentation) or central collisions. However, due to the sensitive time of such chambers (1-2 μ sec at least) one is limited on the number of particles/pulse that can be put through the chamber, and therefore limited as to the cross sections that can be studied.
- 3) Up to this time the majority of studies at the Bevalac have involved single-particle inclusive measurements. The streamer chamber allows a more exclusive study of the interaction since all charged products are seen. Correlation studies, which can often provide more information on the processes arising in the collision can be undertaken.

Figures 5 and 6 show examples of the two broad classifications of interactions that can be studied with a streamer chamber which has been exposed to heavy-ion beams. In Fig. 5 we observe the fragmentation of an 0.87 GeV/nucleon ^{12}C on a lucite target located inside the LBL streamer chamber. This represents a small energy/momentum transfer collision which unbinds the ^{12}C . The particles fan out in a cone and are finally separated after moving a large distance away from the target. This is an example of projectile fragmentation.¹⁸ Figure 6 shows a catastrophic collision between a 1.8 GeV/nucleon ^{40}Ar projectile and an Pb_3O_4 target located inside the chamber. To avoid electric breakdown problems in the chamber

dielectric materials are used. Here we see a spray of particles, remnants of the projectile and target leaving the interaction point. In addition, several negative particles (bent upwards by the magnetic field) are seen. These are negative pions created in the collision. From this we see that central collisions lead to large particle multiplicities. Notice also the bright flares on many of the tracks. This is one of the inherent problems associated with streamer chamber photography.

There are several basic differences which need to be mentioned when one is dealing with hadron-nucleus or nucleus-nucleus experiments in streamer chambers as compared with their uses in particle physics work. One of these is that the particle multiplicities are much larger. In the case of nucleus-nucleus work, this is perhaps prohibitive, since one cannot hope to easily measure all of the charged tracks associated with an event of multiplicity >30 . It is certainly hopeless for events with multiplicities like those shown in Fig. 6. If tracks are measured in the conventional sense, then one must remember that the output of the reconstruction program provides rigidity information ($p/z = kBR$), not momentum (p). In this sense, particle physics has it easy, since the long-lived charged particles detected in such experiments all have $z = \pm 1$. To illustrate this point on momentum vs. rigidity, preliminary data of the UC Riverside/LBL collaboration for 320 MeV/nucleon ^{15}N interactions with a Pb_3O_4 target is shown in Fig. 7. Shown are the reconstructed values for the rigidity of tracks emitted from events with a topology of either four or six prongs. Fortunately in this case nature helps out. The two prominent peaks observed can be identified as protons (near 0.83 GeV/c/z) and deuterons or alphas (near 1.66 GeV/c/z). The arrows in Fig. 7 indicate

the "expected location" of these particles if they were fragmented from the incident projectile without any change in energy (i.e., come out with the momentum/nucleon of the projectile). This effect is observed in all light-projectile fragmentation studies.¹⁸

One of the features that is easily studied without having to measure all the tracks associated with these high-energy nuclear interactions are multiplicity distributions. Figure 8 shows the total charged particle multiplicity distribution for 1.8 GeV/nucleon ^{40}Ar interacting with a light (LiH) and a heavy (Pb_3O_4) target. Low multiplicity events are primarily related to projectile (and target) fragmentation processes and provide the lower end of these distributions. The relatively flat distribution (in the case of the Pb_3O_4 target) can be associated with more central collision processes. Figure 9 shows the negative pion multiplicities produced by high-energy ^{40}Ar and ^{12}C beams on light and heavy targets.¹⁷ Note that in the case of the ($\text{Ar} + \text{Pb}_3\text{O}_4$) results up to 14 negative pions are observed in a single collision. Again, these data are easily obtained by simply counting the number of negative tracks in each picture. Electron contamination is found to be very small.¹⁷ All these data were obtained from pictures in which the LBL streamer chamber (127 cm $\times$ 61 cm $\times$ 40.6 cm) was triggered by a large scintillation counter placed a few cm downstream of the target inside the chamber volume. By requiring that the pulse height in this counter be less than that of a non-interacting beam projectile, a relatively "unbiased" set of pictures were obtained.¹⁹

The use of a streamer chamber is also being considered for low-energy heavy ion work. A program is underway at the LBL 88-Inch Cyclotron to use

a small streamer chamber (approximately 9.5 cm × 15 cm × 5 cm). The chamber has been fabricated (see Fig. 10) and initial tests are in progress.²⁰ The chamber will contain a standard Ne/He mixture and tests are underway to determine the best operating pressure (the chamber can be run between $\sim \frac{1}{4}$ - 2 atmospheres). The chamber will be placed inside the pole tips of a C-magnet to allow rigidity analysis of the charge particle tracks. A small Marx generator will provide the fast high voltage pulse (100 kV, 10 nsec) necessary to produce streamers capable of being photographed without image intensifiers. A host of beams at reduced intensities (10^5 pps) will be delivered to the chamber, including $^{12}\text{C}(6^+)$, $^{14}\text{N}(7^+)$, $^{16}\text{O}(8^+)$ at 35 MeV/nucleon. A program to study central collision processes at 35 MeV/nucleon for $X + \text{Ne}$ (where $X = \alpha, {}^6\text{Li}, {}^9\text{Be}, {}^{10}\text{B}, {}^{12}\text{C}, {}^{14}\text{N}, {}^{16}\text{O}$) will be undertaken. Measurements of charged particle multiplicities and proton-proton angular correlations are planned. At these cyclotron energies, for the cases of $^{12}\text{C} + \text{Ne}$, $^{14}\text{N} + \text{Ne}$ and $^{16}\text{O} + \text{Ne}$ there is sufficient energy to completely dissociate the projectile/target combination into its constituent nucleons. Thus, the possibility of looking for nuclear "shock waves" at cyclotron energies takes on a new aspect by the use of streamer chamber techniques.

CONCLUDING REMARKS

Streamer chambers have not as yet found wide application for nuclear science studies. In one sense, they appear to be ideal tools for studying hadron-nucleus and nucleus-nucleus collisions, since they allow the interaction to be studied in an exclusive sense (meant here to mean that all charged products of the reaction are observed). However, certain drawbacks

appear. Among these are the fact that particle identification is difficult when using streamer chambers, unless external counters (e.g., scintillators, solid state detectors, etc.) are used to aid in the identification. The extremely large multiplicities observed in heavy-ion collisions point out the difficulty that confronts the experimenter. Even if you are able to measure a large sample of such tracks in a single interaction, what do you do with all the information? How do you use it to unravel the complex interaction that has occurred? These are strong challenges to the experimentalist. Imagine, the collision of a uranium beam of a few GeV/nucleon with a uranium target. For a central collision with high associated pion multiplicity, one might have between two and three hundred charged tracks emerging from the interaction!

However, this tone is perhaps too pessimistic. For the investigation of hadron-nucleus interactions, streamer chambers have an interesting potential, since they allow us to go beyond the single-particle inclusive measurements which have largely dominated the field. Even for high-energy nucleus-nucleus experiments, the streamer chamber will be a useful survey tool for beams at least up to Fe and perhaps beyond. One can study some of the cluster aspects of light nuclei by using the projectile fragmentation process to provide a small amount of energy to unbind the projectile. In such processes only a few particles ($\lesssim 10$) appear in the final state and are perfectly amenable to conventional film processing techniques. There still remain many good experiments to be done with streamer chambers over the next few years. The potential applications at cyclotron energies are particularly intriguing.

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(a) VIEW NORMAL TO E-FIELD

(b) VIEW PARALLEL TO E-FIELD

XBL 783-7506

Fig. 1. (a) Schematic diagram showing passage of a charged particle through the streamer chamber gas volume. Streamers develop to several millimeters along the applied E-field; (b) If the streamers are viewed end-on (i.e. in direction parallel to E-field) they appear as a series of bright dots.

BBC 782-1655

Fig. 2. 2 GeV/c proton-Ne interaction in the ANL-Illinois streamer chamber. The event shown was photographed with two different sets of lenses.

XBL 783-7504

Fig. 3. Scatter-plot of the number of streamers/unit length versus the reconstructed momentum for tracks ≥ 30 cm in the chamber. Data obtained with pure He in chamber and a 2.5 GeV/c incident proton beam.

XBL 783-7503

Fig. 4. Multiplicities produced by 2 GeV/c π^+ on He and Ne targets.

XBB 748-5727

Fig. 5. Fragmentation of 0.87 GeV/n ^{12}C into six charged particles.
Positive particles are bent downward by magnetic field in the chamber.

XBB 750-8445

Fig. 6. Central collision at 1.8 GeV/n ^{40}Ar projectile with a Pb_3O_4 target located inside the LBL streamer chamber.

XBL 783-7505

Fig. 7. Rigidity (p/z) distribution for fragments arising from 4 and 6 prong events.

XBL 768-10070

Fig. 8. Total charged multiplicity distributions for a LiH and a Pb₃O₄ target irradiated by an 1.8 GeV/n ⁴⁰Ar beam.

XBL 778-2740

Fig. 9. Negative pion multiplicity distributions for LiH and Pb_3O_4 targets struck by
(a) 1.8 GeV/n ^{40}Ar beam; (b) 2.1 GeV/n ^{12}C beam.

Fig. 10. Streamer chamber for use at the 88-Inch Cyclotron. Beam enters from port at left. The field is established by the nickel mesh on the inside of both windows. The port presently blanked off below beam exit will accommodate a solid state detector to trigger the chamber. The chamber will be mounted fore and aft by sections of bellows pipe to allow the chamber to be bent off-axis by up to 10° to compensate for the curvature of the incident ions in the magnetic field that the chamber will be placed in.

XBB 782-1905

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