Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Invited talk at the Nuclear Science Symposium, San Francisco, CA, October 17-19, 1979

USE OF A STREAMER CHAMBER FOR LOW ENERGY NUCLEAR PHYSICS

K. Van Bibber, W. Pang, M. Avery, and E. Bloemhof

October 1979

NUCLEAR SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

USE OF A STREAMER CHAMBER FOR LOW ENERGY NUCLEAR PHYSICS

K. Van Bibber, W. Pang, M. Avery, E. Bloemhof

Lawrence Berkeley Laboratory*
Berkeley, California 94720

Summary

A small streamer chamber has been implemented for low energy heavy ion reaction studies at the LBL 88" cyclotron. The response of the chamber to light and heavy ions below 35 MeV/nucleon has been examined. The limited sensitivity of light output as a function of ionization works to advantage in recording a wide variety of tracks in the same photograph whose energy loss may vary considerably. Furthermore, as gas targets are attractive for several reasons, we have investigated the suitability of Ar and Xe for use in streamer chambers.

Introduction

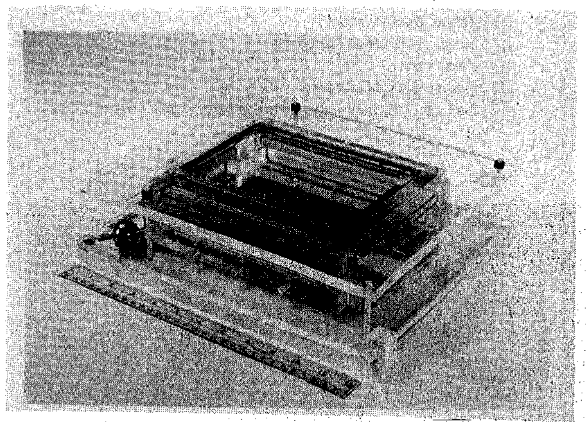
The streamer chamber is a visual 4π track recording device developed about 15 years ago by Chikovani and collaborators.[1] The outstanding features of this detector are its triggerability, isotropic response and 100% efficiency for all charged particles for arbitrarily high multiplicities. Three-dimensional event reconstruction is possible with stereoscopic recording of the chamber if the streamer growth is limited to a few millimeters along the direction of the E field. When situated in a suitable magnetic field, accurate magnetic rigidity p/q can be extracted for all tracks, $\Delta p/p < 5\%$. Particle identification is problematical, however, as streamer density along the track is only a slow function of primary ionization. Understandably, streamer chambers have made the greatest impact in elementary particle physics and more recently in relativistic heavy ion collisions, and their application in nuclear science has been recently reviewed by Schroeder.[2]

This project however, represents the first application of the streamer chamber to low energy nuclear science, roughly defined as the regime where the projectile velocity does not exceed the Fermi velocity, or $E/A \leqslant E_F \approx 35$ MeV. This work was largely motivated by the lack of any survey tool for measuring reaction topologies at the highest cyclotron energies where it is already well established that even two and three-body coincidence measurements by conventional techniques are frequently kinematically incomplete. It was soon realized that at these energies the total stopping power of a chamber of realistic dimensions would no longer pose a significant energy loss problem for heavy ion beams. Furthermore, although the ionization density could be several orders of magnitude greater than that for minimum ionizing particles, it was anticipated that the phenomenon of streamer competition due to the space charge field of the streamers themselves might well moderate the total light output from the beam or heavy recoil tracks, thus preventing saturation of the film. This has been born out very satisfactorily; in fact tracks of fast lighter particles and heavy low energy recoils are both readily resolvable in the same frame. All work to date has concentrated on gas targets (using the volume gas itself as the target) in order to be able to see even the most heavily ionizing secondaries, as well as for the sake of simplicity.

*This work supported by the Nuclear Physics Division of the U.S. Department of Energy under contract No. W-7405-ENG-48.

Experimental Apparatus

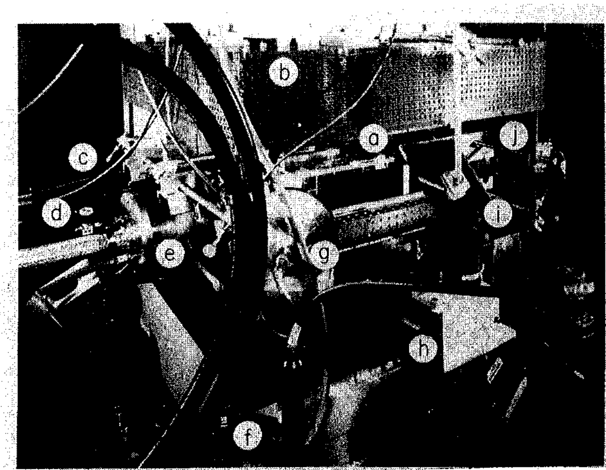
The streamer chamber itself (Figure 1) is a single gap device fabricated of lucite which has an active volume of ($17.1\times11.2\times5.1$ cm^3). The front electrode is an electroformed Ni mesh, 97% optically transmissive. Both anode and cathode are isolated from the volume gas by lucite plates to arrest streamer growth before developing into a spark discharge. Windows of 0.0025 cm mylar subtend nearly the full area of the four lateral walls, permitting beam entry and exit to the chamber, as well as allowing trigger detectors to view the entire interaction path of the beam through the gas. The chamber may be operated from 0-2 atm.



XBB 795-7440

Fig. 1. The LBL 88-inch cyclotron steamer chamber.

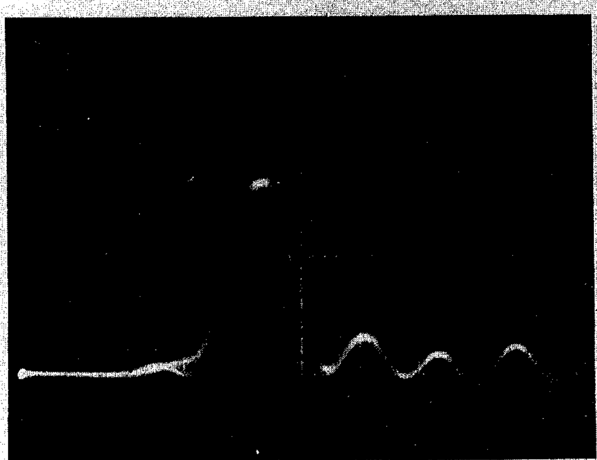
Figure 2 shows the streamer chamber inside the gap of the JUPITER C-magnet. The pole gap has been widened to 17.8 cm to permit the streamer chamber to lie horizontally on a plexiglas base on the lower pole tip, with a diagonal mirror above the chamber allowing the events to be photographed parallel to the $\vec{E}$ and $\vec{B}$ fields. With the widened gap, the maximum magnetic field is 11 kG. The camera is a Flight Research model 207 with a fast Vivitar 90 mm macro lens. LBL technical photography services processes the film (KO 2498, ASA 10,000, 500' rolls) by spray development. The pulsed high voltage is supplied by a three-stage Marx generator (16,800 nF/stage, 30 kV/stage maximum) insulated with pressurized dry air. As the intrinsic rise time of the Marx generator is reasonably short ($\approx$12 ns), it was decided to pulse-shape only the falling edge by clipping the long decay time with a pressurized coaxial spark gap immediately before the chamber. Figure 3 shows the waveform measured at the chamber for 250 consecutive shots. Peak fields of up to 15 kV/cm over the 6.7 cm inter-electrode gap were applied to the volume gas with τ(FWHM) $\approx$ 23 ns. The operating event rates are restricted to 1 sec^{-1} to reduce premature high voltage component failure.



XBB 794-4911A

Fig. 2. In-beam configuration of experimental apparatus.

a) streamer chamber and diagonal mirror;
b) JUPITER C-magnet;
c) scintillator-phototube trigger detector;
d) beam pipe;
e) pulse shaping coaxial spark gap;
f) Marx generator;
g) high voltage probe;
h) camera;
i) diagonal mirror;
j) scintillator-phototube trigger detector.



XBB 794-4587

Fig. 3. High voltage pulse. Vertical scale, 25.6 kV/cm; horizontal scale, 20 ns/cm.

Large area scintillator phototube detectors have been used both as trigger detectors as well as for beam counting, although more sophisticated triggering schemes with particle telescopes will be attempted. The round-trip signal transit time from the target cave to the electronics and control area and back is ≈ 315 ns.

Beam optics for low intensity beams is accomplished by first extracting a higher intensity beam of the same magnetic rigidity (i.e. $^{7}Li^{3+}$ for $^{16}O^{7+}$, $^{4}He^{2+}$ for $^{12}C^{6+}$) and performing the optics in the standard way.

The gases used were research grade Ne-He (90%-10%), Ar, Ar + Methane, and Xe, passed through a dessicant. The pressure is regulated, and for Ne-He and Ar the gas is flowed slowly through the chamber. As it was determined that the gas memory time was always <2 μsec for Ne-He, probably due to outgassing of the lucite and the large surface-to-volume ratio of the chamber, no poisoning with SF_6 admixtures was necessary. Thus the beam fluences tolerable are $\leq 5 \times 10^5$ sec^{-1}, determined by the condition of having at most one beam track in the chamber "memory" at a time, but may be less depending on the triggering configuration.

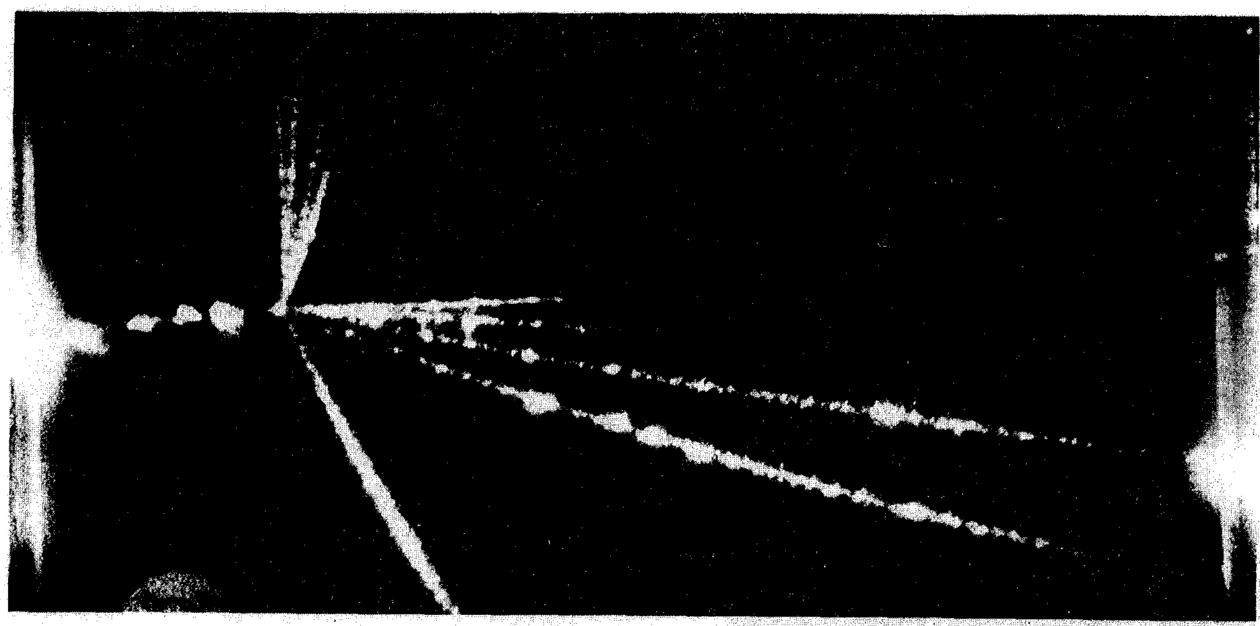
Performance with Heavy Ions

Two major runs have been performed with the streamer chamber, ^{7}Li- and ^{16}O-induced reactions at 26 MeV/A, and ^{12}C-induced reactions at 35 MeV/A, both with Ne-He volume gas. These two runs comprise approximately 50,000 pictures, roughly 10% of which represent valid beam-gas interactions. The remainder are either false triggers, interactions occurring upstream in the mylar windows or 5 cm air gap, or interactions in the beam scintillator, which back-scatter secondaries into the trigger detectors.

Figure 4 shows a typical interaction of ^{12}C + Ne at 420 MeV (B = 9.8 kG, E = 11.2 kV/cm, P = 620 torr.) Some general comments may be made on the basis of our experience with heavy ions in Ne-He. While most of the fast light particles produce tracks of well-defined individual streamers (diameter ≈ 0.5 mm), the visual difference between tracks representing a wide range of ionization is not great. This seemingly would preclude any hope of easy particle identification on the basis of streamer density, especially in view of the variations in time of picture quality. The beam tracks and those of more heavily ionizing secondaries do not consist of normal streamers but rather large, irregular and widely spaced blobs of light. Their frequency along the track is consistent with a simple calculation of the number of hard δ-rays directed towards the anode or cathode and which cross a large fraction of the gap; clearly the secondary ionization of the δ's along the direction of the $\vec{E}$ field promote extremely rapid streamer growth at those sites, and the resulting space charge dipole field forbids normal streamer development for several millimeters to either side.

The linear dimensions of this particular chamber are too small for accurate curvature measurements; a factor of two would improve this considerably. Very few of the tracks which are seen to terminate in the photograph actually range out in the gas, rather most of them are stopping on the cathode or anode. If one resolves the ambiguity of whether the track endpoint lies on the front or back wall, then in fact three-dimensional track reconstruction can be done without stereoscopic recording.[3]

Lastly we remark that we have never observed a single occurrence of "flaring" in our chamber, a phenomenon which has proved to be a nemesis for virtually every large volume chamber in operation. Whether this is to be ascribed to a volume effect, lower fields, absence of SF_6 or the presence of other organic vapors cannot be said.



XBB 798-11197

Fig. 4. Event of multiplicity 9 in the collision of ^{12}C + Ne at 420 MeV. Beam enters chamber from left.

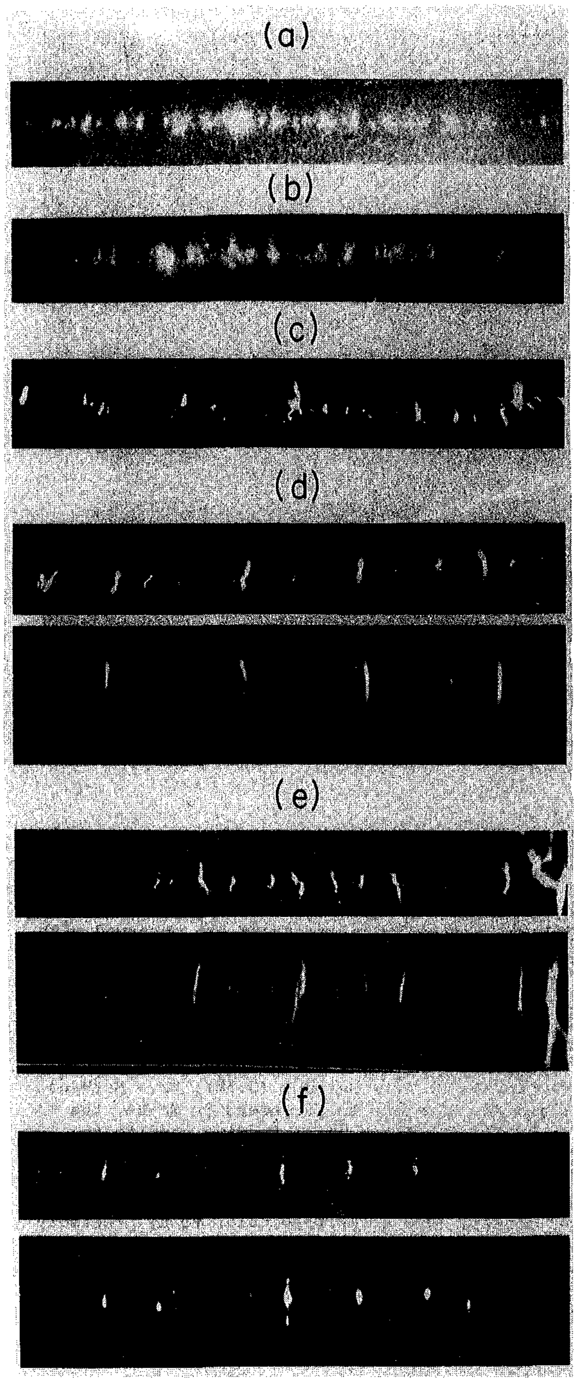
Experimentation with Other Gases

We have investigated the possibility of using heavier noble gases in streamer chambers as for certain applications gas targets spanning a significant portion of the periodic table would be desirable. Although much work has been done in the past for lighter gases (H_2, He, N_2, Ne) little or nothing has been reported for Ar and Xe. We have performed a series of tests with these gases both for minimum ionizing particles (^{90}Sr β^-, endpoint 2.3 MeV) and heavy ions (420 MeV ^{12}C).

In the β^- tests, tracks were visible for both Ar and Xe but only at significantly higher fields and lower pressures than those acceptable for Ne-He mixtures. For Ar, with peak field of E = 11 kV/cm, the tracks appeared qualitatively best between 300 and 400 torr. Tracks rapidly disappeared as pressures were increased. Nevertheless, the overall quality of tracks with pure Ar is poor; discrete streamers are not observed but rather a nebulous band of light, up to a centimeter wide (Figure 5b.) It was discovered that the admixture of Methane above the 0.1% level radically changed the chamber operation. Tracks were now defined by very bright, narrow and well-localized streamers (Figure 5c). The density of streamers, ≈ 1.5 cm^{-1} virtually independent of voltage and pressure, is considerably less than that observed for Ne-He ≈ 3.7 cm^{-1}. The striking regularity of the streamer spacing strongly suggests a space charge effect, as does the observation that streamer spreading, when it occurs, is always transverse to the length of the track. Undoubtedly any number of organic admixtures would qualitatively yield the same results.

With Xe, virtually no streamers are observed with $E < 11$ kV/cm, and the track appearance with applied field is still improving at the maximum field of 15 kV/cm. The streamers appeared similar to those with Ar + Methane, but with even smaller linear density. Figures 5d, 5e, 5f show streamers simultaneously photographed from the top and side view (parallel and perpendicular to $\vec{E}$) Ar + Methane (3.5%), Ar + Methane (1.75%) and Xe. Similar to streamers in Ne-He, the width of the high voltage pulse in time permits the streamers to grow across the full width of the gap, or nearly so. But unlike streamers in Ne-He which are frequently reported to show a dark band through the streamer centers (viewed perpendicular to $\vec{E}$) precisely at the initial electron-ion sites, the side view with Ar shows smooth continuous streamers, and for Xe, a bright spherical discharge in the middle of the streamer with filaments emanating from it in either direction along the field.

During the 420 MeV ^{12}C run no tracks were observed with Xe for E = 13 kV/cm at any pressure, even triggering directly on the beam traversing the chamber. Pictures of relatively poor quality were recorded with Ar + Methane (7%) (E = 10 kV/cm, various P) although the visual recognition of secondaries is especially difficult for the less ionizing particles due to the paucity of streamers along the track.



XBB 790-13563

Fig. 5. Streamers produced by $^{90}Sr\ \beta^-$.
a) Ne-He, 700 torr, E = 11.2 kV/cm; b) Ar, 310 torr, E = 13.4 kV/cm; c) Ar + Methane (7%), 310 torr, 13.4 kV/cm; d) Ar + Methane (3.5%), 310 torr, E = 11.4 kV/cm, parallel and perpendicular to E; e) same as d) except 1.75% Methane; f) Xe, 210 torr, E = 11.4 kV, parallel and perpendicular to E. Length of photographic image is 15 cm.

Prospectus

The relatively uncritical design, trouble-free operation and good quality photographs of the Ne-He streamer chamber would seem to signal a bright future for the technique in low energy nuclear science. Nevertheless quantitative work will depend on efforts to explore its real particle identification capability. Perhaps most promising is the operation of the chamber in the avalanche domain rather than streamer mode; Davidenko et al. have demonstrated the absolute correspondence of avalanche sites and primary ionization so long as the transition to streamer growth is forbidden, and thus space charge effects prevented.[4] Similarly its ultimate applicability may hinge on the streamlining of data collection and analysis; already the feasibility of direct digitization is under study at larger chambers in which conventional film cameras are replaced with CCD devices.[5]

At present, we are experimenting with solid targets which would localize the reaction to a fixed point in the chamber rather than along the entire

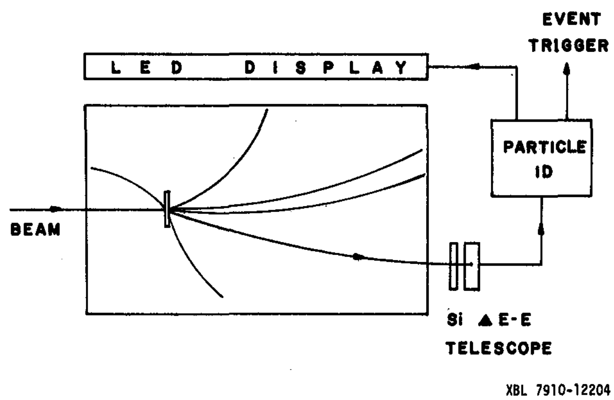


Fig. 6. Schematic of hybrid streamer chamber.

path length of the beam through the gas, thus eliminating a major source of trigger bias. The fraction of real to random events would be improved, but more importantly would be the capability of using a wide variety of electrically insulating targets without forsaking the track quality of Ne-He. It remains to be seen however, whether thin targets ($\approx$ 10 mg/cm^2) pose special difficulties not seen at higher energies where much thicker targets (gm/cm^2) are acceptable. The most exciting and powerful application of this chamber will be in hybrid experiments, where the event trigger consists of a conventional ΔE-E telescope identifying Z,A for one secondary (Figure 6.) This information could be recorded directly on the photographic frame via a digital light display indicating the event gate on the hardwired particle identifier. The recording of the energy is superfluous, as this information exists virtually on the photographic image by Bρ, once Z, A are identified.

Acknowledgements

We thank Lee Schroeder, Jim Brannigan, and Chuck Gruhn for many profitable discussions, and the Lawrence Berkeley Laboratory 88-inch cyclotron operating crew for the excellent and stable high charge state beams.

References

1. G. E. Chikovani, V. N. Roinishvili, V. A. Mikhailov, Phys. Lett. 6, 254 (1963), Nucl. Instr. and Meth. 29, 261 (1964).

2. L. S. Schroeder, Nucl. Instr. and Meth. 162, 395 (1979).

3. The U. C. Riverside streamer chamber group utilize one-view reconstruction for their analysis precisely in this way. Private communication, G. Kiernan.

4. V. A. Davidenko, B. A. Dolgoshein, V. K. Semenov, S. V. Somov, Nucl. Instr. and Meth. 67,325 (1969).

5. Commercially available CCD's have in fact shown optical sensitivity superior to film used commonly in streamer chambers. W.O. Wallick, R. G. Kenyon, H. J. Lubatti, Nucl. Instr. and Meth. 146, 403 (1977).