EXPERIMENTAL BEAMS AT THE BROOKHAVEN AGS*

M. H. Blewett
Brookhaven National Laboratory, USA

The general arrangement of the experimental areas at the Brookhaven AGS is shown in Fig. 1: at the left is the «Southwest Area» where a fast extracted beam will emerge for weak-interaction experiments that will start very soon; in the central foreground is the «East Area» which has been the location of all experiments up to recent times; and at the upper right is the «North Area» which contains the 80-inch bubble chamber and its associated beam-transport systems. The extracted beam system has been described by G. K. Green in another paper presented at this Conference, and this report will describe briefly the facilities which have been set up in the other areas.

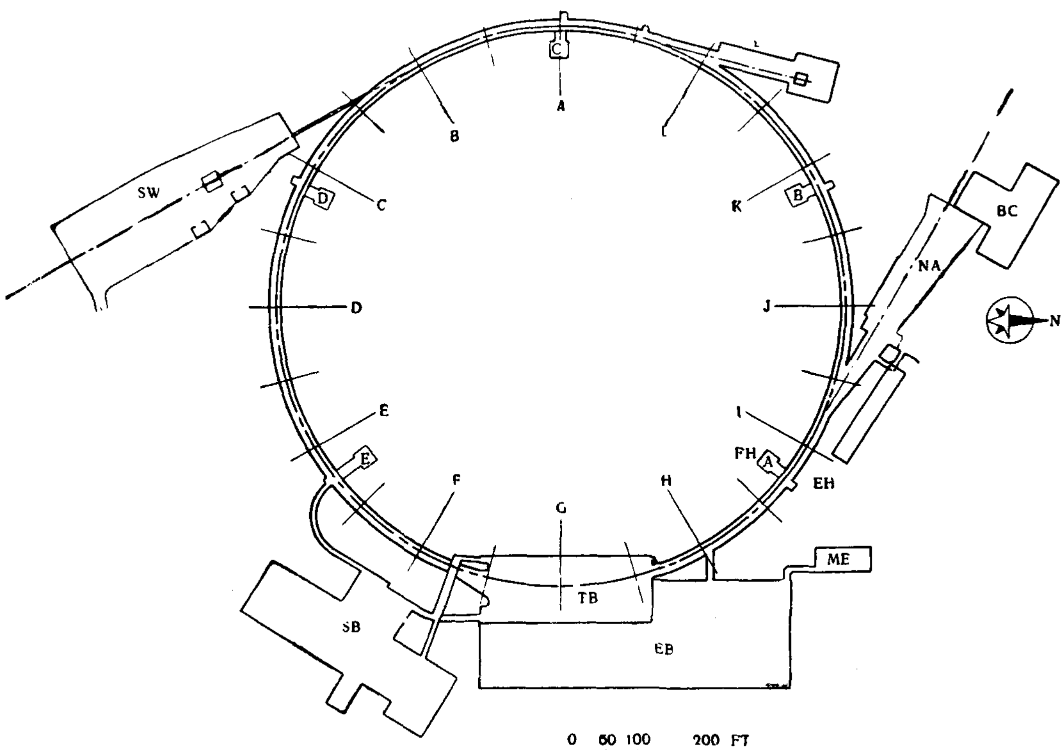

Fig. 1. Over-all view of Brookhaven AGS and associated experimental areas: *NA* — north experimental area; *BC* — 80″ bubble chamber building; *EB* — east experimental building; *EH* — escape hatches; *FH* — fan houses; *L* — linac; *ME* — mechanical equipment building; *SB* — service building; *TB* — target building; *SW* — southwest experimental area.

A schematic layout of beams in the East Area is shown in Fig. 2, where the synchrotron magnets are shown in the center surrounded by heavy-concrete shielding blocks. It has been normal practice, during the past year, to share each beam pulse among three targets; two of these, shown at the left, provide secondary beams through separator systems to bubble chambers and

* Work carried out under contract with the U. S. Atomic Energy Commission.

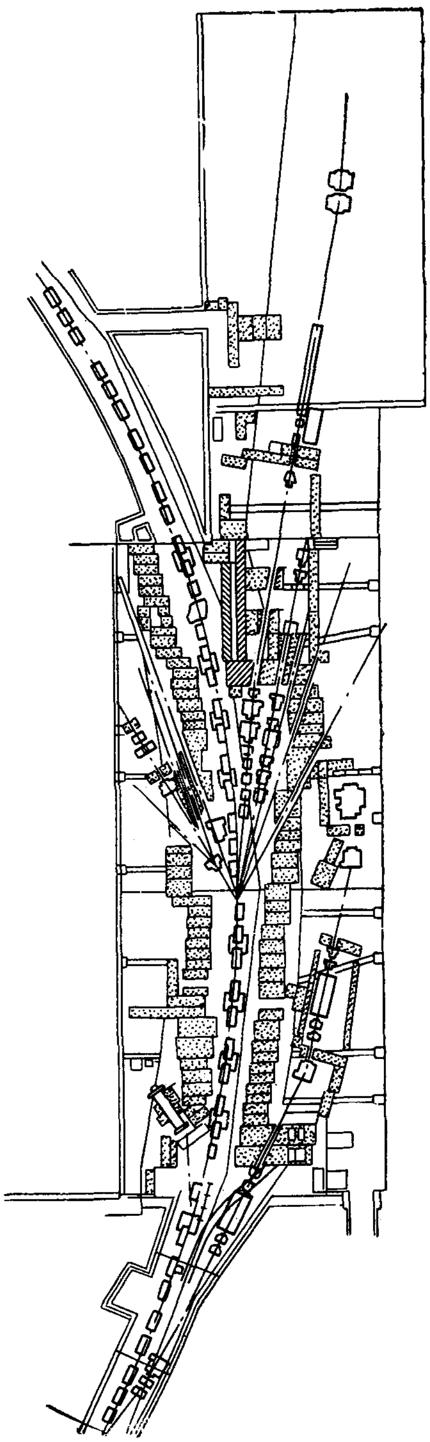

Fig. 2. Schematic layout of beams in the East Experimental Area at the Brookhaven AGS, showing details of beam-transport systems for Separated Beam No.1 (medium momentum), Separated Beam No.2 (low momentum) and beams for counter and spark-chamber experiments.

the third, shown near the center of the figure, provides secondary beams for counter and spark-chamber experiments. Usually three or more of these, at various angles, are in progress simultaneously at this location. Details of targeting procedures have been reported by J. Spiro.

At the left, on the lower (outer) side of the synchrotron, is the beam providing separated antiprotons of momenta from 2 to 3.7 GeV/c and positive and negative K-mesons from 2 to 2.5 GeV/c for interactions in the 20-inch bubble chamber. This beam was set up about two years ago and its successful preliminary operation was reported at the Brookhaven Accelerator Conference [1]. Since that time, about two million photographs have been taken of interactions in the bubble chamber, most of them in Hydrogen, but recently the chamber has been filled with Deuterium. Although this beam has been described before, it may be worthwhile to outline its main features again.

The secondary particles, arising from a target that is located at the extreme left just off the edge of the diagram, emerge at 8° and the first collimator limits the acceptance to about 40×10^{-6} sr. Two quadrupoles, with an aperture of 12-inch diameter, form an image of the target at a slit (0.045 inch high) with a horizontal magnification of 2 and a vertical magnification of ½; this image then acts as the effective source for the beam. Ahead of this slit is a deflecting magnet, of aperture 6 in. high, 18 in. wide, and 72 in. long, that bends the beam away from the tunnel wall and provides rough momentum selection. There are two separation stages, each containing a 15-foot long electromagnetic dc separator with an inter-electrode gap of 2 in. supporting electric fields ranging from 65 to 85 kV/cm. Ahead of and behind each of the separators, quadrupole doublets of 8-in. diameter aperture are operated symmetrically to provide parallel trajectories for the particles through the separators. In front of the second separation stage, another bending magnet of aperture $6 \times 18 \times 72$ in., deflects the beam 15° and more precise momentum selection (of the order of $\pm$ 1%) takes place. Beyond the separators, two 4-in. diameter quadrupoles and a deflecting magnet shape and bend the beam for entrance into the bubble chamber. The total length of this beam is 270 feet. Typical performance figures are shown in the following table.

Also on the left, on the upper (inner) side of the synchrotron, is another separated beam for antiprotons and K-mesons of lower momentum, in the range from about 650 to 950 MeV/c [2].

Particle	Momentum Range, GeV/c	Purity, %	Flux at Bubble Chamber (approx.)
Antiprotons	3.0—3.7	95	20 per 10^{11} protons on target at 15 GeV
			50 » 10^{11} » » » » 20 GeV
			100 » 10^{11} » » » » 25 GeV
	2.5	95	40 » 10^{11} » » » » 25 GeV
	2.0	95	18 » 10^{11} » » » » 25 GeV
Deuterons	3.0—3.7	95	40 » 10^{11} » » » » 25 GeV
K^- mesons	2.0—2.5	85	12 » 10^{11} » » » » 25 GeV
K^+ mesons	2.0—2.5	85	25 » 10^{11} » » » » 25 GeV
π^- mesons	1.0—3.7	100	~100 times that given for antiprotons
π^+ mesons	1.0—3.7	100	~200 » » » » »

Its chief characteristics are its short length of 694 in., to minimize the decay of the kaons, and the large solid angle of acceptance of about 43 mrad horizontally by about 10 mrad vertically. The axis of the beam is at 23° to the synchrotron orbit and particles are first focused horizontally by a quadrupole of 8-in. diameter aperture. A deflecting magnet, of aperture 6 × 18 × 36 in., bends the beam 26°, followed by a vertically focusing, 8-in. diameter quadrupole. Partial momentum selection occurs at the slit following this quadrupole. There is a single separation stage provided by a 16.5 foot long velocity selector with crossed electric and magnetic fields. The stainless steel electrodes are 28 in. wide and across the 4-in. gap, voltages of 350 to 450 kV have been maintained. After the separator, the beam is bent 36° by another deflecting magnet, also of 6 × 18 × × 36 in. aperture, followed by another 8-in. diameter, horizontally focusing quadrupole inside of which is the mass-selection slit. Final momentum selection occurs at the slit following this quadrupole and, finally, another 8-in. diameter quadrupole shapes the beam for entrance to the 30-in. bubble chamber.

Almost one million pictures have been obtained of interactions in the 30-in. bubble chamber using this beam, about three-quarters in Hydrogen and the rest in Deuterium. Typical intensities for both antiprotons and K^-mesons have been about 20 per 10^{11} protons on target at 25 GeV. The purity has been only about 35% with the remainder of particles being approximately equal amounts of pions and muons. The greater part of the pictures have been taken of K^-mesons and antiprotons stopping in the chamber with the beam tuned to about 700 MeV/c and with suitable absorbers.

This beam has suffered from having only one stage of separation and from a lack of sufficient focusing due mainly to space limitations. The long separator that has been used was the only one available at the time the beam was set up. However, shorter separators, about 6.5 feet long, are now under construction and two of these will be used in a modified low-momentum beam that will probably be established early in 1964. Further quadrupoles will be added and the length extended somewhat. It is hoped that the angle of acceptance can be enlarged and the over-all performance improved by at least a factor of three.

In the center of the diagram is shown the target area for producing a variety of secondary beams for counter and spark-chamber experiments. A typical transport system for the production of protons, antiprotons, positive and negative K-mesons and pions with momenta in the range from about 8 to about 20 GeV/c is shown emerging from the synchrotron at an angle of about 4.5° on the lower (outer) side. Two eight-inch diameter, 48-in. long quadrupoles convert the divergent beam of particles to a parallel one which then passes through a variable collimator to be analyzed by two magnets with aperture 6 × 18 × 72 in. A second pair of quadrupoles focuses the beam on a counter telescope set up just in front of a liquid-hydrogen target, for an experiment to measure differential elastic scattering cross sections that was carried out during the fall of 1962 [3]. The estimated effective solid angle subtended by this transport system was about 120 μsr, with a 2 × 4 in collimator. The beam had a measured angular divergence of ± 1.5 mrad and a momentum resolution of ± 1.5%. Typical resultant intensities for the various particles, per 10^{11} protons circulating at 30 GeV in the AGS, were as follows:

Particle	Particle Momentum, GeV/c	Intensity (per 10^{11} protons on target)
proton	20	5×10^3
antiproton	9	6×10^2
K^+ meson	10	1×10^4
	15	1×10^3
K^- meson	9	1.2×10^3
$\pi^\pm$ meson	17	1.5×10^3

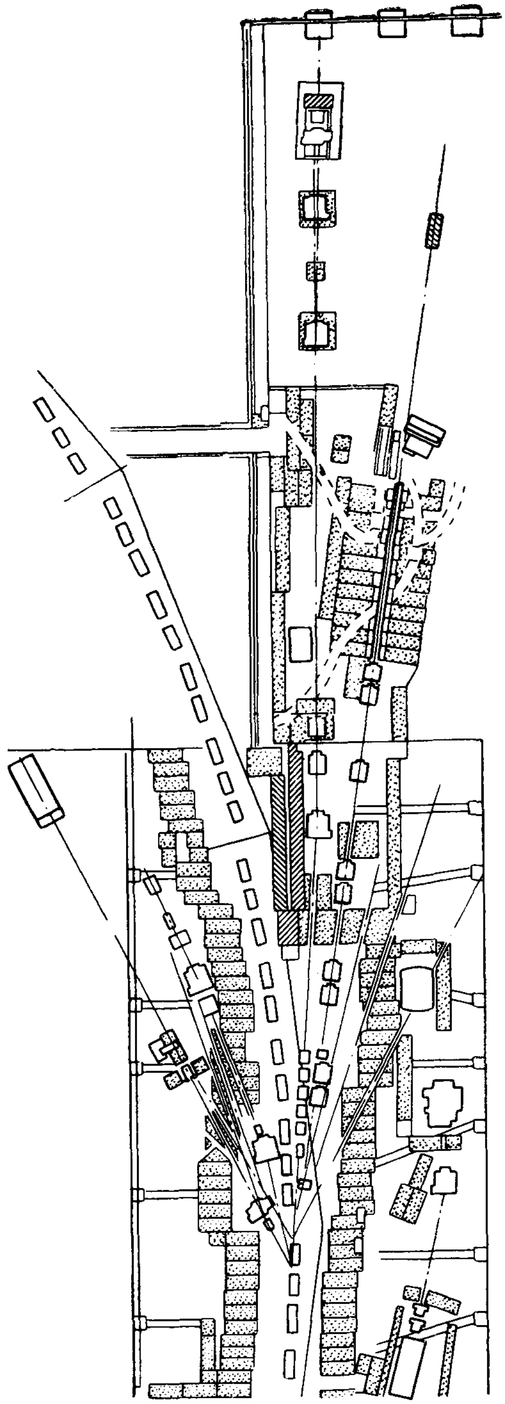

Fig. 3. Detailed layout of beam-transport system to produce high-intensity, high-momentum negative pions.

Variations in intensity with momentum, for each type of particle, were in accordance with the numbers found during the AGS survey previously reported.

Simpler beams are also shown at larger angles for experiments simultaneously sharing this target. For example, at 15° on the inside of the AGS ring, is a beam providing pions and K-mesons in the range from about 2 to 6 GeV/c where a group was measuring differential and total cross sections. At 30°, also on the inside, both a neutral beam and a charged pion beam of momentum around 1 GeV/c is shown with appropriate sweeping and analyzing magnets. At the same time equipment can be tested with unanalyzed secondary beams emerging through channels cut in the shielding wall, for example those shown at 20° and 30° on the outside of the ring.

With the target situated in a 10-ft long straight section as shown for the beams described above, an angle of 4.5° is about the smallest that can give secondary beams that will be relatively free of the influence of the stray magnetic fields of the AGS magnets. However, for some of the recent experiments it was important to obtain secondary beams that had much smaller production angles and, for these, a target was located in one of the short (2-ft long) straight sections between magnets, and negative pions were produced at production angles very close to 0°. This target position and one of the beam-transport systems is shown in Fig. 3 [4].

The target is located one magnet upstream from the position shown previously and the transport system was designed to produce a high-intensity pion beam with a momentum of 20 GeV/c or more for a study of the form factor of the π^- meson. Calculations of the trajectories through the AGS magnet were made for a target position at a radial distance 1 inch inside the normal equilibrium orbit and for a production angle of about 8 mrad. The central rays emerge from the synchrotron at about 4° with respect to the 10-ft long straight section. Six 8-inch diameter quadrupoles, arranged so that the first two are vertically focusing, followed by two horizontally focusing, then two vertically focusing, bring the beam to a focus at a slit about 50 feet from the final quadrupole. Partial momentum analysis occurs at this slit provided by the AGS magnet through which the beam passes on emerging from the synchrotron. The solid angle accepted from the target was limited by the first quadrupole to about $1.5 \times \times 10^{-4}$ sr. Precise momentum analysis takes place by means of two deflecting magnets of aperture $6 \times 18 \times 72$ in. and focusing by a quadrupole doublet of 12 in. diameter located between the deflecting magnets. Just in front of the focal point is another deflecting magnet which sweeps low-momentum particles from the beam. The over-all length of this beam is about 330 feet.

The performance of the beam turned out to be better than had been anticipated and momenta as high as 22 GeV/c were found to have acceptable intensities for the form-factor experiment. For 10^{11} protons on target, typical intensities were: 2×10^9 pions per GeV/c per sterad with momentum of 20 GeV/c and 4×10^8 pions per GeV/c per sterad with 22 GeV/c. At 22 GeV/c, it was found that the beam contained about 3.8% muons of the same momentum. Counter measurements established the size and shape of the beam near the focal point. The full width at half maximum was 1 inch vertically and 1.5 inches horizontally; the momentum acceptance was $\pm$ 0.25 GeV/c.

Another beam-transport system was set up to use the small-angle production negative beams arising from this target position in the AGS, in order to produce a high-purity μ-meson beam; this is shown in Fig. 4. Negative pions with momenta of about 10 GeV/c were desired which, by passage through an extended lens system, would decay to give a fairly intense supply of high-momentum muons for the study of μ-p elastic scattering. For production angles between 1° and 3°, such pions emerge from the AGS magnet ring at about 10° and the first quadrupoles were placed as close to the synchrotron as possible, the usual target box in the 10-ft long straight section being replaced by an 8-in. diameter pipe. The acceptance angle is about 10^{-3} sr. Following four quadrupoles of 8-in. diameter aperture are ten quadrupoles of 12-in. diameter aperture for a total decay path of about 50 m, over which about 15% of the pions decay [5].

A special collimator was built, about 14 m long, from surplus gun barrels which were packed with lead to a uniform inside diameter of 12 inches. About 10 m of the interior length was filled with light density concrete and the entire structure was encased in high-density concrete blocks.

Again, the performance of this beam proved to be better than anticipated, with intensities of about 2.5×10^6 muons per 10^{11} protons on the internal target [6]. Analysis showed that about 75% of the muons had a momentum above 2 GeV/c; the spectrum is peaked at about 2.5 GeV/c and the 10-percent point (in intensity) occurs at 1.5 GeV/c and 4.5GeV/c. The angular divergence of the beam was about 1.0° and, just following the collimator, the size was about 10×10 in. Pion contamination was negligible with a π/μ ratio of 10^{-8}, or less. During the latter part of the μ-p scattering experiment, some of the filter was moved and for a π/μ contamination of 10^{-7}, or less, the intensity of muons was about 6×10^6 μ per 10^{11} protons on target.

We turn now to the North Experimental Area and the beam which will transport particles for the study of interactions in the 80-inch Bubble Chamber is shown in Fig. 5. This beam has been designed to provide separated K-mesons of both signs from approximately 3 to 5.5 GeV/c and antiprotons and pions up to about 8.5 GeV/c [7]. It is about 450 feet long and consists of two stages of separation. The secondary particles leave the target at an angle of 7° and a collimator defines the aperture of the system to about 24 mrad horizontally and variable from 0.3 to 3 mrad vertically. The momentum resolution is $\pm$ 0.75%. A quadrupole of 12-in. diameter aperture makes the horizontal component of rays of particles parallel through two deflecting magnets which, together with a second quadrupole, form a momentum dispersed image at a slit at the horizontal focus. Just in front of this focus is a vertically focusing quadrupole, to regulate the input vertical focal length for the first separation stage. In front of the next pair of deflecting magnets, which bend the beam the other way, the horizontal rays are made parallel by means of a quadrupole with a rectangular aperture 6 in. high by 24 in. wide.

Following the bending magnets, a quadrupole doublet makes the beam parallel through the separators. This stage is composed of three of the 16.5 ft. long rectangular type of electromagnetic separators connected in tandem. Vertically focusing quadrupoles follow the separators, a deflecting magnet acts only as a steering device, and a sextupole corrects chromatic aberrations. This region also contains the precise momentum-analysis slit. The input optics for the second separation stage, which also consists of three 16.5 ft. tanks connected together, are symmetric with the output optics of the first stage. The second stage is followed by a three-quadrupole combination to give a simultaneous horizontal and vertical focus. Beyond the mass-separation slit, a combination of quadrupoles and bending magnets shapes

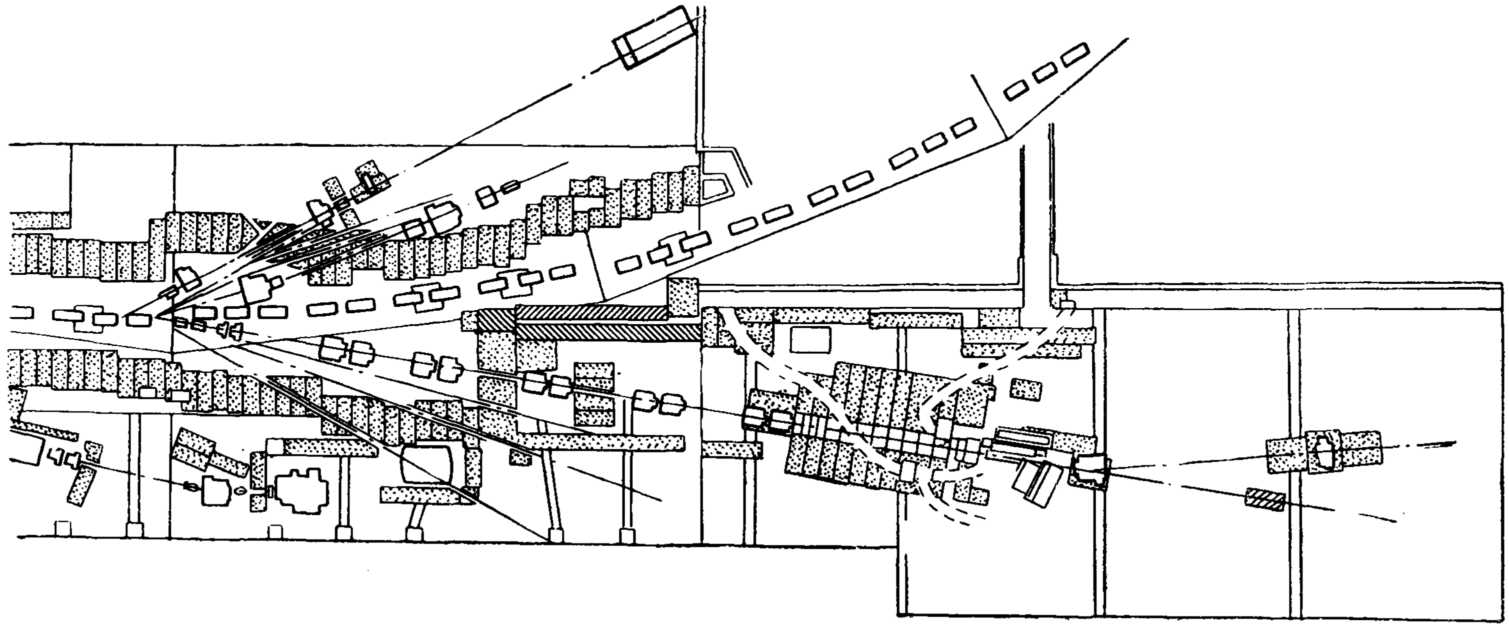

Fig. 4. Detailed layout of beam-transport system for a high-purity mu-meson beam.

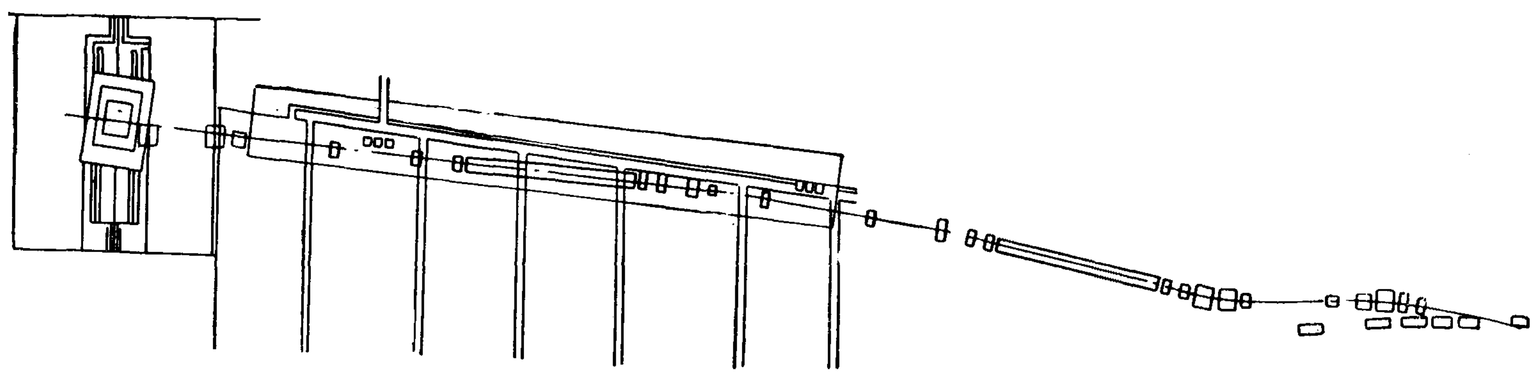

Fig. 5. Detailed layout of Separated Beam No. 3 (high momentum) in North Experimental Area, leading to 80-inch bubble chamber.

and guides the beam into the 80-inch bubble chamber.

This beam is just now in the process of being put into place. A few of the magnets were connected to power in order to guide some pions to the 80-inch Chamber for its first successful operation in early June of this year. Preliminary tests on background have been made during the following weeks. During the AGS shutdown that has occurred during the last weeks of July and early

August, the first separation stage was set up and I expect that tests through this section are already in progress. The final portion of the beam should be completed early in October.

Already, many experimental groups have made requests for photographs in the chamber, using this beam; to date, the total number of pictures requested is something over 3.5 million.

REFERENCES

1. Baltay C., Fowler E. C., Sanford J. R., Sandweiss J., Brown H. N., Fowler W. B. and Webster M. In: Proceedings of the International Conference on High Energy Accelerators (Brookhaven, 1961), p. 452; Baltay C., Sandweiss J., Sanford J., Brown H., Webster M., Yamamoto S. In: Proceedings of CERN Instrumentation Conference, 1962.
2. Berley D. BNL Accelerator Department Internal Report DB-1, June 1963.
3. Foley K. J., Lindenbaum S. J., Love W. A., Ozaki S., Russell J. J. and Yuan L. C. L. Phys. Rev. Lett., **10**, 376 and 543 (1963).
4. Crittenden R. R. and Leipuner L. B. Private communication.
5. Marshall L. and Yamanouchi T. Brookhaven National Laboratory, Physics Department Internal Report PD-47, Jan. 1962.
6. Lederman L. and Tinlot J. Private communication.
7. Webster M. S. Minutes of CERN-Brookhaven Meeting, Sept. 1962, p. 148.