TWENTY-FIVE FOOT BUBBLE CHAMBER FILM FORMAT AND FILM ANALYSIS COSTS

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ABSTRACT

Recommendations are made that the 25-ft bubble-chamber film format be as consistent as possible with that of other large chambers. Some assumptions are made about scanning and measuring methods and speeds. The cost (capital investment in machinery, computer costs, and salaries) is then estimated.

1. CAMERA DESIGN AND FILM FORMAT

Since it seems clear that pictures containing either neutrino or hadron interactions at very high energies will be very complex and hard to analyze, the machines required to scan these pictures will be complex and costly. Consequently, it is very desirable that bubble-chamber cameras which take high-energy particle pictures should have common characteristics so that any scanning or measuring machines designed for this work can be used, with only minor modifications, for analyzing pictures from several bubble chambers. The designers of the 25-ft bubble-chamber camera are urged to keep the design of the 25-ft and 7-ft (or 7-ft modified) compatible.

Characteristics which are important are:

1. The film size.
2. The number of films.
3. The image size and its orientation on the film. The beam should enter the chamber roughly parallel to the edge of the film.

4. The orientation of the stereo axes of pairs of cameras. If five cameras are used on the 25-ft, it would be desirable to have the stereo axes of the two additional cameras parallel to that of cameras 2 and 3 (i.e., across the beam direction) because this makes the design of the scanning projector easier.

5. Size, shape, number, and orientation of fiducial marks in the chamber.

6. The data box design and image position on the film in each view. This includes any spacing marks for advancing the film during analysis and also the design of any BCD display.

7. The perforations on the film should be standardized. This includes their size, spacing, and distance from the film edges.

8. After development, each roll of film should be wound onto a standard reel with standard core size and outer diameter.

9. Some attention should be given to items which are demanded by the hardware of existing automatic measuring machines, such as binary data boxes and film-plane fiducials.

These matters should be given detailed consideration by some representative working group when the 25-ft bubble-chamber design is being finalized. A little extra expense on the camera might save quite a bit of money, spread over many institutions, in analyzing the film.

II. AN ESTIMATE OF CAPITAL INVESTMENT AND ANNUAL COSTS NECESSARY TO ANALYZE THE 25-FT BUBBLE-CHAMBER OUTPUT

The purpose of this note is to estimate what it will cost, nationally, to make maximum use of the 25-ft chamber potential output.

To that end, we have made some plausible assumptions about film production rates and track and vertex densities. Then three different film-analysis systems are considered and the investment and operating costs estimated. All assumptions about rates, densities, and costs are highly debatable, sometimes within a factor of two.

A. "Maximum Use" Assumptions

1. The chamber will take photographs as frequently as possible but not use more than 1/3 of the accelerated protons per year.

The figure above is Goldwasser's best guess on how much beam might be approved for the chamber for neutrino physics alone. Strong-interaction physics takes a negligible amount of beam.

2. Every strong interaction (SI) and its possible neutral secondary vertices will be at least "rough digitized" (i.e., three points per track), as will every lepton-producing neutrino interaction.

Not to do so would constitute using the chamber as a selective, as opposed to an exploratory, device. Although selection might be the best use of the chamber eventually, and has been the way in which bubble chambers have been used in the last few years, it seems an unlikely initial use for the 25-ft chamber in new energy regions. The interactions you wish to ignore, your neighbor wishes to analyze. In this case, unless film analysis costs overwhelm chamber-operating and film exposure costs (which is not the case) the film will end up being shared. Therefore we estimate costs based on the cheapest way of analyzing all interactions, namely, in one scanning pass at the film.

3. One-half of the running in the first few years will involve neon, for the purpose of thorough measurement of nearly all converted pairs. The neon may be simply mixed throughout the chamber or isolated from a hydrogen (or deuterium) target by a sleeve or diaphragm.

There are physicists who believe that all running should utilize a neon-hydrogen "sleeve," and some who believe that it should never be used. Our estimate of one-half is a pure compromise.

If the costs turn out to be too high, or if national capability or interest is saturated by the results of these assumptions, then one or more of them should be discarded.

B. Film Production Rates

Various assumptions lead us to believe that one can expect

1.0 million neutrino pictures/year
1.5 million S1 pictures/year

as a realistic estimate of what the chamber might produce. The details of this estimate are relegated to Appendix A, even though they are an important issue, because this is a study of film-analysis costs. Out estimate of costs can be scaled upwards or downwards according to the optimism of the reader about these production rates.

C. Event Complication And Density

Our assumptions about the average event density under four different conditions of beam and chamber are summarized in Table. I. The "7-ft back-drop" referred to is a region separated from the pure hydrogen part of the chamber by a vertical diaphragm, such as sketched by B. Roe.[2] The estimate of one neutrino interaction per picture in H_2 comes from the same report. For neutrino runs in pure H_2, the estimate of two secondary interactions per picture results partly from converted gammas from the (typical) two π^o's per event, and partly from a small subsample of the film in which we assume that all possible neutron recoils are scanned for. K_1 and Λ^o decays are negligible in comparison.

Table I.

Beam	Chamber filling	Pictures per year (millions)	No. of primary interactions per picture	No. of Secondary vertices per picture	Total no. of primary interactions, millions
Neutrino	H_2	0.5	1	2	0.5
Neutrino	H_2 + Ne - H_2	0.5	6 1 in H_2	18	0.5
	7-ft back-drop		5 in Ne - H_2		2.5
SI	H_2	0.75	3	5	2.25
SI	H_2 + NeH_2 Sleeve	0.75	1 in H_2	6	0.75
Totals		2.5×10^6 pictures			6.5×10^6 events

For neutrino interactions with a Ne-H back-drop, a mixture with a 50-cm radiation length was assumed with a 7-ft fiducial length. Here the 18 secondary interactions arise nearly entirely from converted gammas in the neon. We assume that all four gammas from the (typical) two π^0's from the hydrogen-produced events convert, but that only half of the neon-produced gammas convert, because of the shorter potential path. Lastly, we assume that an additional four gammas get measured which are actually the result of bremmsstrahlung from the primary pairs, either because they appear to be direct or because they are necessary to get the total energy of a direct pair. It is questionable to some of us that a picture of such a high density can be properly analyzed; it will certainly be difficult.

In the case of strong-interaction photos, we assume that three beam tracks per picture would interact in a pure hydrogen chamber, but that the beam intensity would be reduced if there were a neon sleeve, giving only one interaction, because either situation "saturates" a photo, in terms of "scannability" and resolution of ambiguities in the origin of neutrals. This saturation level, where pictures become hard to analyze, was merely the consensus of a small group of physicists and is open to question. The secondary interactions estimated are only those which would be measured. We assume an average of two π^0's per event, leading to four gammas, all of which convert in neon, or 25% of which convert in a pure hydrogen chamber. In pure hydrogen, we expect two additional charged-track interactions, V's, or neutron scatters per picture, averaged over various experiments. In neon, we expect not to measure the secondary interactions of charged tracks very often, but will want to measure V's and some neutron stars.

D. Scanning and Rough Digitizing Times

We assume that usually there are three to five cameras, depending on the experiment, for an average of four views to be scanned and measured. If there is a Ne-H_2 backdrop we assume that five cameras are necessary.

If manual scanning is done, we assume that it will be accompanied by one of two forms of "recording;" either 1) manual "zoning" of all vertices, for input to a minimum-guidance automatic measurer; or 2) three-point rough digitization of all interesting (related to events) tracks.

We then assume, rather arbitrarily, that 1) rough digitizing doubles the scanning time, and 2) the scanning time is proportional to the number of primary and secondary interactions.

There remains only the crucial question of how long it takes to scan a typical simple 25-ft picture, e.g., a strong interaction, pure hydrogen chamber photo with three primary and five secondary interactions. If one "pretends" to scan the one sample frame shown in 25-ft proposal,[1] which is very similar to the above simple example, one would conclude that the scanning time should be no slower than for present day photos in which one records all interactions, i.e., around one a minute. However, that example fails to show either cosmic-ray tracks (possibly up to 20 per picture), or the copious neutron stars and Compton electrons which clutter up the photo. The example also fails to emphasize that the 10-micron wide images (on film) would be difficult to see at a low magnification. We assumed that scanning would have to be done at a magnification such that only 10% of the chamber was visible on the table at one time. Such magnification is especially necessary when looking for short proton recoils. Therefore scanning each frame is more like scanning 10 frames of 30-in. chamber film, or 5 frames of 80-in. chamber film.

Therefore we have assumed that it will take three times longer to scan a simple 25-ft chamber frame than to scan a similarly simple 80-in. chamber picture. (The arguments presented above would suggest a factor of five, not three; we have reduced the estimate in the belief that a certain fraction of 80-in. scanning time is spent moving film and masking out non-interacting beam tracks, all of which take no more time for the 25-ft than for any other chamber.)

We repeat that scanning means finding all the primary and secondary interactions and recording their zones and types. Then the above assumptions about event density leads to the following time estimates for scanning:

1. SI in pure H_2 or H_2 + neon sleeve 3 min/frame 4 views on average

2. Neutrinos in pure H_2 1.5 min/frame 4 views on average

3. Neutrinos in H_2 + neon back-drop 11 min/frame 5 views

These times are doubled for scanning with rough digitizing.

In the cost analyses which follow, we assume that half of the neutrino pictures are taken with a neon back-drop. Thus the average time to scan a neutrino picture is 6 min/frame.

Given our assumptions about the picture taking rate (1 million neutrino pictures/year, 1.5 million SI pictures/year), film analysis times would need to be roughly equally divided between neutrino and SI physics.

F. Analysis Systems and their Costs

We discuss three alternative scanning-measuring systems:

1. Careful predigitization of all interactions (three points per track) on line to a small computer, such that rough missing masses are calculable from the three-point measurements alone. This is followed by precise, automatic, many-point measurements of only "interesting" events.

2. Purely manual scanning and recording of all vertices with sufficiently accurate zoning for input to a minimum-guidance Spiral Reader, HPD, PEPR, or POLLY.

3. Purely automatic scanning of photos, with heavy reliance on human guidance.

Which way you go depends on where you want to put your money, what physics you think you are most interested in, and technical advances in the next couple of years.

The only idea which has been completely discarded is that of manual, off-line, many-point measurements of events. It seems both uncompetitive, in terms of event rates and labor costs, and unlikely to survive as the backbone of any bubble-chamber group other than rare-event type and educational groups.

At this time, only systems 1 and 2 have been given any careful thought. System 3 is left to the imagination of others.

System 1

This is a system centered around a versatile, expensive, computer-controlled, scanner-predigitizer. It puts most of the cost at the scanning level. The specifications of this scanning machine are:

1. 5 views
2. 3 magnifications (12, 25, 50), rapid changing
3. film plane measurements
4. 2.5 micron film setting ability
5. manual setting on the tracks

See Appendix B for details. The cost of such a machine, as estimated by Jack Franck, is $100,000 per machine. At this cost, a small computer to run a few such machines is negligible.

The advantage of this system is that it is the most flexible. If the predigitizing was done carefully on the highest magnification, the output, after special reconstruction, would be sufficient to do much of the crude physics and leave one with perhaps 20% of the SI events to measure in the multipoint mode. All of the neutrino measurements could be done in this manner without further digitization, were it not for the fact that the present best method of measuring electron tracks (the Morellet method) requires as many points as possible. An experiment in which converted pairs in neon were important in every event would have to be entirely remeasured.

On the other hand, the machine can be used as merely a rough digitizer on medium magnification, with some gain in scanning-predigitizing speed.

The machine can be used as computer-assisted scanner, to help sort out where gammas or V's point and to do simple geometrical tasks, if it is desirable to do this before predigitizing a complete event. This might be the case if there is an H_2-Ne mixture in the chamber.

Lastly, such a device could be used merely to predigitize the vertices, with a possible savings of a factor of 2 in the scanning speed, but it seems like a poor use of the machine.

To keep up with an assumed 25-ft output of 2.5 million pictures per year, one scan only, requires 60 machines and 180 operators, if a 120 hour work week per machine is assumed. In addition some of the film must be rescanned, but not predigitized. If we assume that all neutrino film and 20% of the SI film is rescanned, then we require an additional 20 machines. Our estimate for scanning then becomes:

80 scanning-predigitizing machines at $100 K each	$8 Million
300 operators (240 actually scanning, at $7500/year (including overhead)	$2.25Million per year
40 maintenance technicians at $15 K/year including overhead	$0.6 Million per year

where the number of operators is increased to include 10% for vacation and holidays and 10% for supervision, keypunching etc. Overhead on salaries is calculated at 50%.

For precision measurement, we make the following, more speculative assumption: that with predigitized input, an automatic measuring machine can measure 60 frames per hour and only 40% of the frames need such measurement.

It follows that one needs only three such machines in the country. The cost of such a machine and the necessary control computer is about $0.75 million. It is impossible to estimate how much it would cost for many institutions to modify existing (in 1972) machines and then use them only part-time on 25-ft film which is what would probably happen under this system. Assuming the machines already exist, we guess that another $1 million would be spent in modification, improvement, and expansion.

The final cost estimate is:

System 1

equipment:	$9 million
operators:	$3 million/year

System 2

This system tries to save money on scan tables and puts its money into automatic measuring. It is attractive for those who believe that all frames will have to be precision (many-point) measured. It is especially attractive for those who think that they can modify existing 80-in. or 82-in. scan tables, or to those who expect to become fully automatic eventually.

The specifications for the tables are:

1. 3 views
2. rapid switching hi-lo magnification
3. 2 degrees of freedom film stage motion.

Our cost estimates are $40,000 per machine to build from scratch or $25,000 per machine to modify existing equipment. Since the omission of predigitizing is expected to cut the first scan time in half, one needs only 50 scanning machines. Assuming that 2/3 of these are built from scratch and 1/3 are modified, the total cost is $1.75 million for equipment and $1.8 million per year for operators.

However, measuring is now more expensive, as all events must be measured on an automatic machine. It also takes more time per frame, since there is no predigitizing, and requires more frequent human assistance. We assume, probably optimistically, that 30 frames per hour can be automatically measured, which is twice as slow as system 1.

This leads to a requirement for 14 automatic measuring machines, or $10.5 million if the machines and their control computers have to be purchased. Operating costs (salaries plus overhead) are not negligible, amounting to about $0.6 million per year.

We estimate that about 15 automatic measuring machines might be in operation in 1972 (HPD, PEPR, or POLLY level of sophistication). Of these we assume that about 5 could be switched over to full-time use on the 25-ft film. This leaves 9 to buy, for a cost of $7 million, plus an estimated $1 million to modify the existing 5.

The final estimate is:

System 2

equipment:	$10 million
operators:	$2.4 million/year

However, the uncertainty in this estimate is much larger than for system 1. The cost of system 2 depends heavily on advances in automatic measuring technology and on how many existing machines and their computers can be switched over to 25-ft film.

System 3

No careful thought has been given to this system. It would look as if the capital investment would be only slightly greater than system 2, where nearly all the investment is in automatic scanners. However, faster and more expensive on-line computers would be needed.

G. Computer Costs

1. Reprogramming expenses. The committee concluded that a geometry program for the 25-ft chamber would not be a technical stumbling block. It can draw heavily on developments at Argonne and Brookhaven in connection with the 12-ft and 7-ft chambers. It would probably require 6 to 8 man-years in programmers' salaries. In addition, reprogramming of automatic scanning-measuring machines is needed. Depending on how cooperative various laboratories are, it could cost anywhere between 5 and 15 man-years. Taking the higher figure in both cases, the cost in salaries and overhead is around $400,000.

2. Annual operating costs. The cost per event (geometry + constraining + bookkeeping + physics analysis) will probably remain the same as now, for the increased complication of events will be offset by decreases in computing costs.

The estimated cost of processing one event given in the HEPAP Report[3] is $1. This assumes that processing is done on a 6600 in 0.2 min per event at a cost of $300 per hour. Using this number we find that 6.5 million events can be processed on 3 6600's for a cost of $6.5 million. This does not include filtering and track following which would be done by the computer on-line to each measuring machine. In actual practice large groups at AEC installations pay at a lower rate and many university groups pay as much as $2 per event. Some members of the committee felt that AEC should consider setting up regional computer facilities so that the computation can be done as efficiently and cheaply as possible.

3. Data retrieval. This is a growing problem which is not peculiar to the 25-ft chamber analysis. Therefore it was given no thought except to estimate that these 6.5 million interactions might fill about 2,000 SQUAW output tapes a year.

H. Conclusions

Given our controversial assumptions that every interaction will be analyzed, and that about 2.5 million frames per year with 6.5 million events per year are exposed, we find that to "keep up" with the 25-ft chamber will require a capital investment in new scanning and automatic measuring equipment of around $10 million (i.e. ~ 30% of the chamber cost). The annual operating costs would be around $10 million ($3 million for scanning-measuring personnel plus $7 million in computer costs).

By way of contrast, we note that, according to HEPAP,[3] only 4 million interactions per year are currently being analyzed in this country (although the rate is rising at nearly 1 million per year) and that the current expenditure for bubble-chamber data analysis operations (excluding physicists) is now constant at about $12.5 million per year.

If one concludes that the cost of analyzing 25-ft chamber film is too large a fraction of the present expenditure, then we suggest a variety of further, alternate conclusions:

1. The 25-ft chamber should take fewer pictures per year.

2. The assumption that all interactions will be analyzed should be scrapped as either unrealistic or even unwise from the point of view of physics.

3. Improvements in the cost per event of computing must be made, since it is the largest operating cost in our estimate.

Lastly, we would note that to the extent that existing groups merely switch their existing (in 1973) personnel and computing facilities from experiments with other chambers to 25-ft chamber film, processing the same number of events per year, there is no increase in national operating costs. However, the new equipment costs are sufficiently high that all but the national laboratories and a few huge university groups will be priced out of the business, unless some extra funding is granted by the sponsoring agencies and foundations.

APPENDIX A.

How many pictures the 25-ft chamber might take per year, from start up. We assume:

1. Pulses photographed/pulses scheduled = 1/4 ("Watt factor"). This is based on Bob Watt's average of several laboratories' experience, starting from turn-on of the chamber. Much of this scheduled time was of course given back, i.e., targeting was ceased because the chamber or beam went down for a long time.

2. 200 days/year scheduled for neutrino physics. This far exceeds the Goldwasser guess of 1/3 of the pulses; however, you can decrease this figure and increase the Watt factor.

3. 100 days/year scheduled for SI physics.

4. 3 pictures per pulse on SI beams, 1 picture per pulse on neutrino beams.

These assumptions lead to

1 million neutrino pictures/year

1.5 million SI pictures/year

APPENDIX B.

PROPOSAL FOR A SCANNING AND PREDIGITIZING TABLE FOR NAL

(M. Alston-Garnjost and J. Lach)

I. REQUIREMENTS

A. Scanning

1. A magnification such that the whole 25-ft bubble-chamber image can be viewed at one time.

2. A magnification for scanning tracks and predigitizing them for some automatic measuring machine.

3. A magnification for viewing messy areas of the chamber and for bubble counting.

4. Up to 5 views on 5 separate strips of 70 mm film. The film platen must also be capable of handling other smaller films.

5. x, y motion of all films.

6. Superposition of views (where practical).

7. A projected grid to determine scanning zones.

8. A small on-line computer to assist the scanner and monitor the operation.

9. Necessary communication between scanner and computer. In particular the scanner must be able to enter experiment, roll frame, topology, flags; also a zone number if there is no predigitization.

B. Measuring

1. The machine must be capable of measuring on the film to about $\pm 10\mu$ for predigitization or $\pm 2.5\mu$ for final measurements (i.e., least count ~ 2.5μ)

2. Motion of the stage should allow the scanner easily to measure

a) fiducials

b) vertices

c) Points along tracks (probably 3 per track total for predigitizing)

d) End point of a track

3. There must be an easy way for the scanner to identify each measurement i.e. "fiducial," "vertex," etc.

C. The Computer Should Be Able To:

1. Read an input tape and give data and assistance to the scanner.

2. Possibly advance and position the film and drive to a fiducial or a vertex (if this is known already from counter or spark-chamber data or from measurements on other views).

3. Receive input from console and digitizers.

4. Check that the topology is that expected from the topology number entered by the scanner and that the topology is consistent on all views digitized.

5. Output data onto magnetic tape.

D. General

1. The machine should be made as modular as possible so that there is a basic machine with different options. For example there might be a machine for scanning perhaps with only one magnification, no digitizing and no computer. A sophisticated version might have all the options mentioned above and might be used as a scanning-measuring machine.

2. The machine should be easily maintained.

II. PRELIMINARY DESIGN

A. Mechanical and Optics

1. The image of the 25-ft chamber will be about 2.6-in. ×5-in. (including a data box). We assume that the bubble images are 10μ diameter on the film. To view the whole image we will need a small magnification otherwise the image is so large that the scanner will become confused. With a magnification of 10 to 12 the image on the table will be about 2.5-ft wide and 5-ft long. The bubble size will be 100-120μ diameter which is rather small. Tests should be made to see if this size bubble image is acceptable. Note: Many scanning projectors now have a magnification of 10 so that if such small bubble images are acceptable, film from the 25-ft BC might be scanned on existing scanning projectors.

2. A magnification of 25 will give bubble images on the table about the same size as now (i.e. ~ 250μ). This should be adequate for scanning along tracks and would probably be the magnification most often used for digitizing. This magnification will produce an image of the chamber 1/3 × real size at the beam plane.

3. To view cluttered areas of the film such as vertices, for bubble counting and possibly for measuring gap lengths, a magnification of 50 is proposed. This will give bubble images 0.5 mm diameter and an image 2/3 × real size at the beam plane.

4. Multiple magnifications require multiple projection lenses. 3 lenses could be arranged around a rotatable turret. If we assume projection distance of about 8 ft then the focal lengths of the projector will be about 10 in., 4 in., and 2 in. This will require variable object distances and may lead to minor difficulties in illuminating the film. Tests should be made to determine the best magnifications once the probable size of the bubble images is better known (i.e. from the BNL 7-ft Test Facility, and the 12-ft ANL chamber). It may turn out that one magnification will be satisfactory. This will reduce the cost of the machine.

5. During scanning the scanner should be able to switch very rapidly between at least 2 views. It is often useful to be able to superimpose 2 views. To do this a second (subsidiary) projection system will be required. The projection lens for this system would be arranged to project a good stereo pair of the film projected through the primary projection lens. See Fig. 1. This will allow rapid switching by means of shutters between views 2 and 3 OR 4 and 5. (Since views 4 and 5 might be additional views of plates, of a limited depth of the chamber, or of H_2 - Ne backdrop they should have the same stereo axis as views 2 and 3.) The subsidiary projection lens would have a simple x, y motion for superposing. It might have only one lens corresponding to the most used magnification (probably × 25) since it would only be used for scanning.

6. To accomodate five 70-mm films side by side, any one of which will be projected by the primary projection lens for measurement, will require a motion 70 mm × 5 = 35 cms in one direction and 5 in. in the other; say 16 in. × 6 in. to allow some space for sprocket wheels, mounting, etc. This does not seem an exceptionally large motion for a stage mounted on granite ways with air bearings.

7. The stage could be driven by servo motors which would allow the computer to drive the stage to a predetermined location; however, this would be expensive. A cheaper method would be to have a puck attached to the stage by wires passing over pulleys. A reduction in the motion of the stage relative to the puck will be required, probably about 10 to 1.

8. Measurements will be made with a cross hair. This might be projected through the primary lens; a TV monitor; or just a cross on the table. It should be on the axis of the projection lens.

B. Electronics

1. There will be an interface between the computer and scan table to allow the scanner and computer to communicate with each other. This will require a console with switches and buttons, a typewriter (or teletype) and possibly a display such as a CRT.

2. The stage position will be digitized in x, y to a least count of $\pm 2.5\mu$ and interfaced to the computer. At present interference gratings are probably the cheapest way. In addition, if there are servo motors, the computer will be able to control them and drive the stage to a predetermined position.

3. The computer could be quite small. A PDP8 (or equivalent) would probably drive 3 or 4 tables. For a motion of 16 in. and a least count of 2.5μ an 18-bit word will be required. However, if on-line geometric space reconstruction is required a more powerful computer should be used.

4. The computer must have at least one input and one output magnetic tape. For predigitization the amount of data per view would be small (< 100 words) and cheap incremental tape units should be satisfactory. If the machine is to be used for real measuring a more expensive unit might be required for output.

REFERENCES

[1] 25-Foot Cryogenic Bubble Chamber Proposal, Brookhaven National Laboratory BNL-12400, March 1969, p. 64 (unpublished).

[2] B. Roe, Considerations on the Use of Neon-Hydrogen Double Chambers, National Accelerator Laboratory 1969 Summer Study Report SS-57, Vol. II.

[3] HEPAP Report on High Energy Physics 1969, p. 152. Appendix C, Bubble Chamber Data Analysis in the U.S., Sub Panel B, Earle C. Fowler, Chairman.

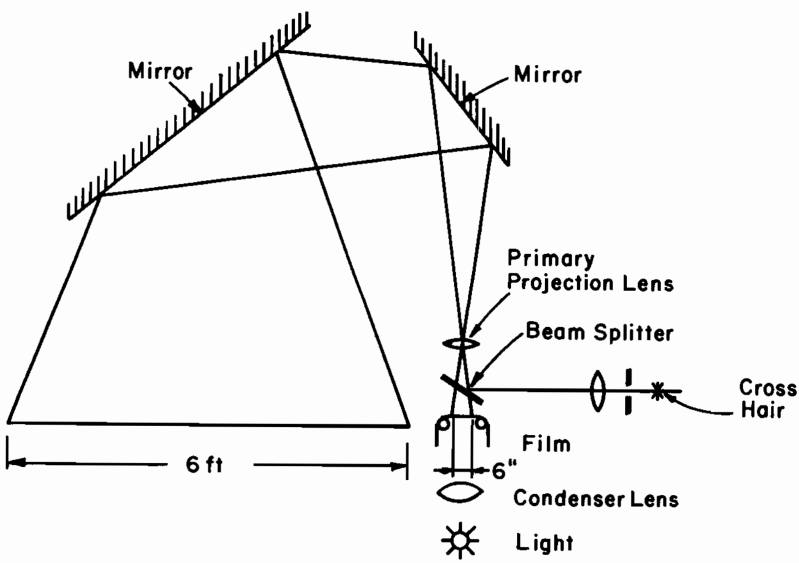

Fig. 1. Side view of scanning table, not to scale.

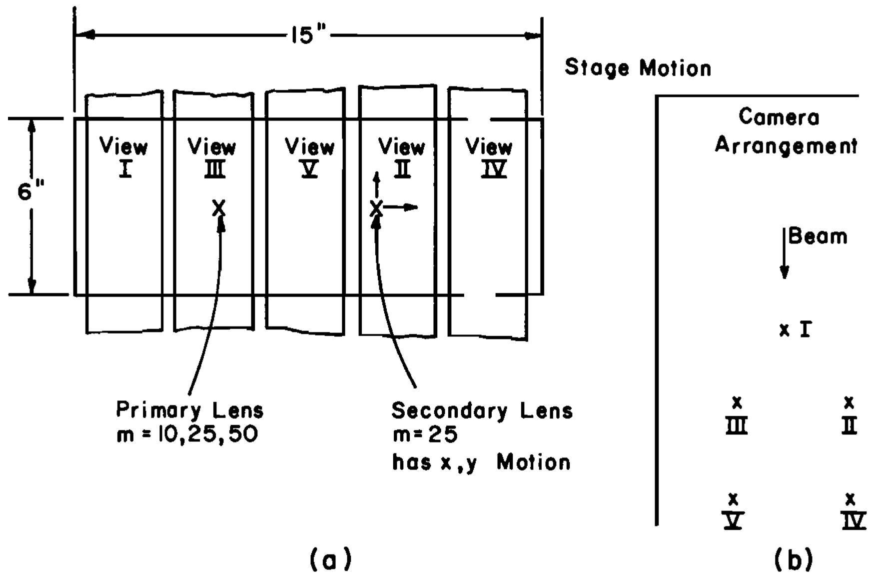

Fig. 2. a) Plan view of platen and projection lenses. b) Camera arrangement.