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Москва, Главпочтамт п/я 79

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МЕЖДУНАРОДНАЯ КОНФЕРЕНЦИЯ ПО ФИЗИКЕ ВЫСОКИХ ЭНЕРГИЙ
Дубна 5-15 августа 1964 г.

THE 1964 INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

Dubna, August 5-15.

ДОКЛАДЫ РАППОРТЕРОВ RAPPOORTEURS' REVIEWS

E-1855

RECENT ADVANCES IN BUBBLE CHAMBER TECHNIQUE

Rapporteur

H. Filthuth

Secretaries:

Ju. A. Budagov
R. G. Salukwadze
M. D. Shafranov
S. M. Zombkovski

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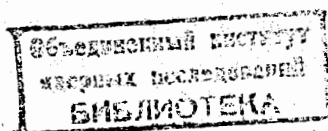
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This publication is of a preliminary character.
To facilitate the rapid appearance of Reports, they
are printed in the form as presented by Rapporteurs.

RECENT ADVANCES IN BUBBLE CHAMBER TECHNIQUE

H. Filthuth

University of Heidelberg and CERN

Introduction

A few weeks ago I was invited to an excellent dinner in France at the three star restaurant "Père Bise" at the lake of Annecy near Geneva. We were about 10 physicists⁺ invited by Luis Alvarez. This dinner commemorated to some extent the last international conference of high energy physics at Kiev. It was five years ago, 1959, when Prof. Alvarez visited Geneva on his way to Kiev. On this occasion he was showing to Prof. Bernardini and the physicists who participated at the dinner one of the first photographs taken with the 72-inch hydrogen bubble chamber (Fig.1). It shows the production and decay of the first anti-lambda, being produced by anti-protons in hydrogen. Impressed by this success Prof. Bernardini and Prof. Alvarez made the following bet: if hydrogen bubble chambers at CERN took 70% of the proton synchrotron pulses during the next five years, then Prof. Bernardini would pay for the above mentioned dinner exactly five years later, i.e. on 20th of July, 1964. If this were not the case, the roles of the inviters would be reversed. It was a very good dinner and we all thanked Luis Alvarez very much indeed.

After this historical introduction you might think bubble chambers had not done too well. On the contrary, it demonstrates the progress of bubble chamber technique during the last five years. To achieve with less than 70% of the proton synchrotron

⁺ with wives of course

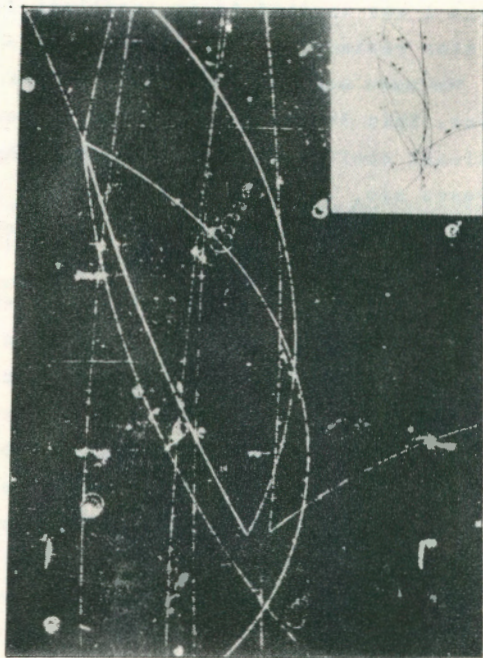


Fig. 1

Production and decay of Λ^0 and $\bar{\Lambda}^0$ being produced by antiprotons in the 72" Alvarez hydrogen chamber

pulses the enormous amount of information in the field of high energy physics that has in fact been gained, is certainly a technical and scientific success. The break down of the published papers at the last international conference, 1962, is:

bubble chambers	70%
counters and spark chambers	19%
emulsions and cloud chambers	11%.

For twelve years now the technique of bubble chambers has been developed, and now offers us one of the most powerful detection devices for high energy and elementary particle interactions.

Today, the existing bubble chambers are very reliably engineered and operated. To some extent, they have become part of the accelerators producing many-million photographs for never satisfied physicists. A few years ago a typical experiment demanded about 10 thousand pictures, now the average number has increased to several hundred thousand and recently proposed experiments will need more likely one million photographs. The present experiments require extensive statistics to study the structure of resonances of elementary particles. To understand the complex system of K-meson and η -meson resonances produced in the annihilation of anti-protons the physicists from CERN, Ecole Polytechnique Paris and Columbia University have analysed about 50.000 $\bar{p}p$ reactions. Other experiments demand large quantities of photographs to search for rare event types. In the last $K^{\bar{p}}$ experiment at the Brookhaven National Laboratory 2 omega-minus decays have been discovered in a review of about 200.000 pictures.

One might think that the bubble chamber technique is coming to an end in its development, but I hope that my report will indicate to you that there is still progress ahead in this field. The highlights from this conference are:

1. A new generation of bubble chambers has been proposed: giant chambers having 25,000 lt visible volume. One might call them scotchlite chambers. Scotchlite is the magic word for retrodirective materials which has been applied for several years in industry for advertisement and road signs. Applying this material to the illumination system of bubble chambers with 25,000 lt volume seems technically and financially feasible.

2. For the first time 2 rapid cycling hydrogen bubble chambers are in operation, one at Berkeley (25") and one at Princeton (15").

3. High magnetic field chambers have been developed, as have pulsed magnetic field chambers at Dubna and in Moscow, while at the Argonne laboratory a helium chamber surrounded by a superconducting magnet is in operation.

4. Large bubble chamber projects which were started a few years ago are now completed, like the Brookhaven 80" hydrogen chamber, the 1.5 m British hydrogen chamber, and very soon there will be in operation four more large hydrogen chambers in different laboratories.

5. Beam control and beam particle identification for bubble chambers have been extensively developed.

Bubble Chambers of the Future

We will discuss the science fiction first: that is, the new generation of bubble chambers. I will start with a drawing (Fig. 2a) and ask you what it is. Probably I will get the same answer St. Exupéry¹⁾ got for his drawing - namely a hat. So I will have to make a second drawing which explains to you the first one. (Fig. 2b)

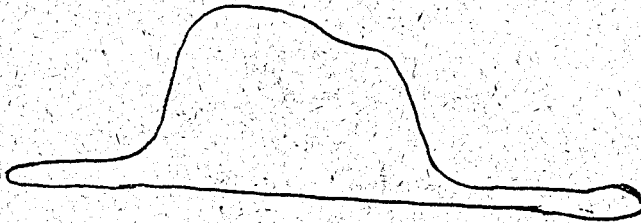


Fig. 2a

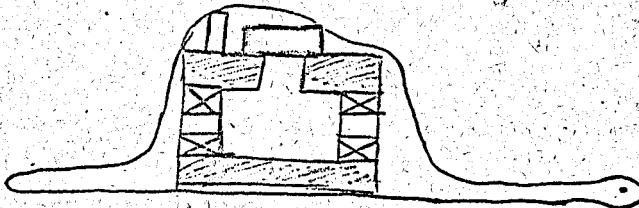


Fig. 2b

And now I hope you recognize it. A snake is just digesting the 14' Brookhaven bubble chamber. I have also a photograph which was taken just before the snake had eaten the chamber (Fig. 3). Our snake really has an exceptional capacity, the

1) see appendix

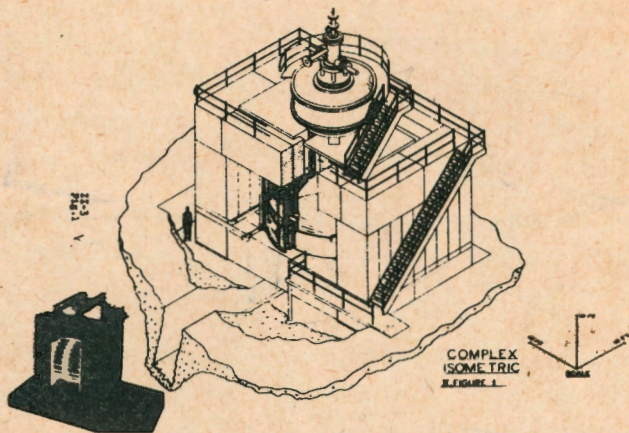


Fig. 3 View of the proposed 14' BNL hydrogen bubble chamber. For comparison a sealed model of the present 80" BNL chamber is inserted

dimensions of the magnet are: 7 m high, 11 m long and 6 m deep, the chamber being 4 m \emptyset , 3 m high.

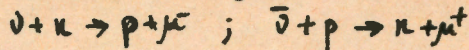
The field of high energy physics is still on its linear rise. New accelerators of several hundred GeV are proposed and under design. Certainly, adequate experimental equipment has still to be developed and to be ready in time. Most of the present experiments and those which have been performed in the past five years with the AGS and CERN PS study interactions only in the region of a few GeV or less. In most cases the accelerators have been used to produce particles and resonant states from a few hundred MeV to not more than 2 GeV. With the presently available energies at CERN and Brookhaven to be able to study very high energy interactions and to identify the produced secondaries one has to develop more efficient and powerful detectors. In order to exploit the experimental possibilities of the present large accelerators in the world several "giant" bubble chambers have been proposed and are partly under design.

1. 14' hydrogen chamber, Brookhaven 2)
2. 12' hydrogen chamber, Argonne 3)
3. Multi-meter hydrogen chamber, Dubna 4)
4. a few m propane-freon chamber, MIT-BNL
5. 4.4 m propane-freon chamber, E.P., INFN, CERN 5)
6. 10 ton propane-freon chamber, Wisconsin-Argonne 6)

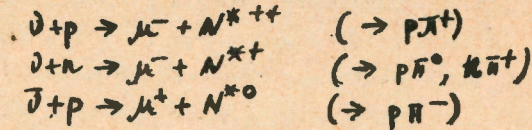
The justification for these chambers is based on experiments which are almost impossible with the present ones. We give here a few examples of experiments with a very large H_2 or D_2 chamber. The large detectors would of course be very powerful tools for the future accelerators of 100 GeV and more.

1) Neutrino Physics

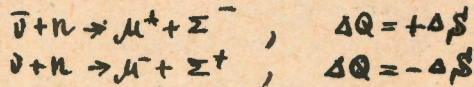
a) elastic scattering



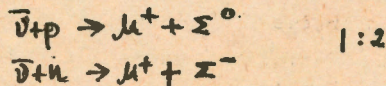
b) test of $\Delta I = 1$ for weak interactions



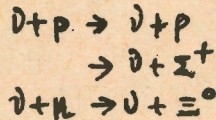
c) $\Delta Q = \pm \Delta S$



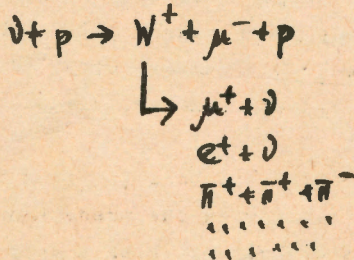
d) $\Delta I = 1/2$



e) neutral currents



f) intermediate boson



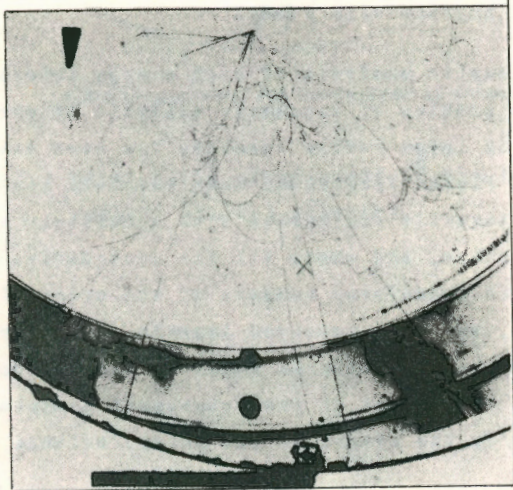
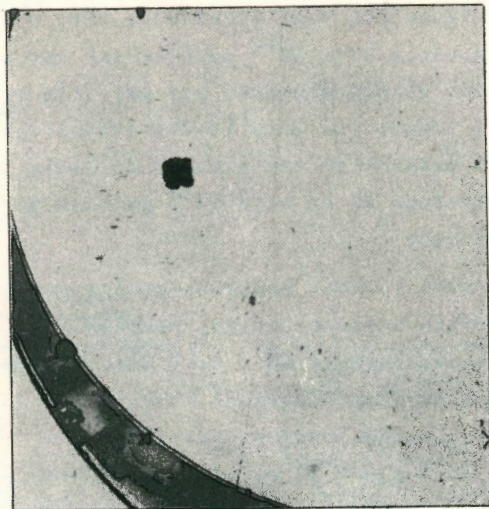


Fig. 4

Neutrino interacting in the CERN heavy liquid chamber

a) elastic interaction $\nu + n \rightarrow \mu^- + p$

b) inelastic interaction $\nu + \text{nucleus} \rightarrow \mu^- + \text{protons} + \pi - \text{mesons}$

Table 1 gives you a summary of the expected rates of neutrino interactions in the proposed 14 foot Brookhaven chamber. The numbers refer to an AGS with a new injector. - At present the CERN PS operates with 10^{12} protons and one can take an average of about 25,000 pictures per day. (In principle with the 2 sec repetition rate 43,000 photographs.) Therefore, with the present PS the numbers in Table 1 would refer to 20 days operation at PS with 10^{12} protons per pulse. Such a run would produce

- a) about 1000 elastic neutrino-proton events
- b) 15 inverse hyperon decays, testing $\Delta I = \frac{1}{2}$ S.
The selection rule $\Delta Q = +\Delta S$ forbids hyperon production from neutrinos
- c) 2000 inelastic neutrino proton events
- d) about 20 $\bar{\nu} p \rightarrow W^+ \mu^- p$, if $m_W \sim 1.6$ GeV.

These figures show quite impressive neutrino-interaction rates. With such a large bubble chamber a new field of experimental physics will start.

2. Kinematic analysis of high energy interactions.

The problem of kinematic analysis of events at high energy in large bubble chambers has been examined by Trilling⁷⁾ and Pless⁸⁾. They found that complete kinematic analysis is possible for events with accurately known primary particle momentum, and where all the secondaries are charged particles with transverse momenta of the order of their rest mass or less, and with measured lengths of the order of 1 m. The error on the longitudinal momentum balance would be about 60 MeV/c and the errors on the transverse momentum balance about 10 MeV/c. The errors on the energy balance would be

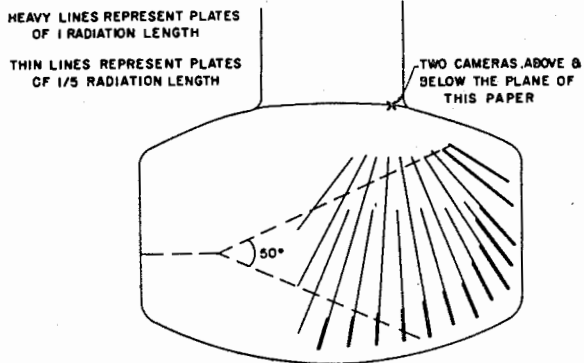


PLATE ARRANGEMENT FOR HIGH ENERGY EXPERIMENT

Fig.5 Metal plate arrangement in the 14' BNL (a)
and 12' ANL (b) chambers

about 2 MeV. Therefore missing neutral particles will in general be detected if $P_T > 10 \text{ MeV/c}$. (Only 0.2% of the secondaries for nucleon-nucleon collisions have $P_T < 10 \text{ MeV/c}$.) But in the case of several missing particles the interpretation becomes very difficult, since the missing mass has a continuum of possible values. Particle identification will play an increasingly critical role in future high energy physics experiments. With the giant bubble chambers, particle identification becomes possible to a great extent.

Gamma-rays and π^0 -mesons will be detected by conversion into electron-positron pairs in metal plates suitably arranged in such a large chamber. Fig.4 and Fig.5 show proposed metal plate arrangements for the 14 foot and 12 foot chambers.

The identification of electrons without the use of metal plates is quite striking. They show a significant radiation loss of energy. This is determined by measuring the curvature of the first and the last 50 cm of the track. The percentage of detectable electrons as shown in Fig.6 is about 60% to 80%. The curve is discontinuous at the trapping momentum of about 700 MeV/c. The proposed large hydrogen bubble chambers have the ability to contain charged particles. Particles originating at the centre of the chamber cannot escape through the sides, if they have a momentum less than 680 MeV/c (for the 14 foot chamber), they make complete turns inside the chamber. The fraction of trapped particles is shown in Fig.7. A stopping K-meson experiment could be ideally performed with such a chamber. Fig. 8 shows the track of a stopping K-meson. One would do the K-meson physics between zero and 900 MeV/c.

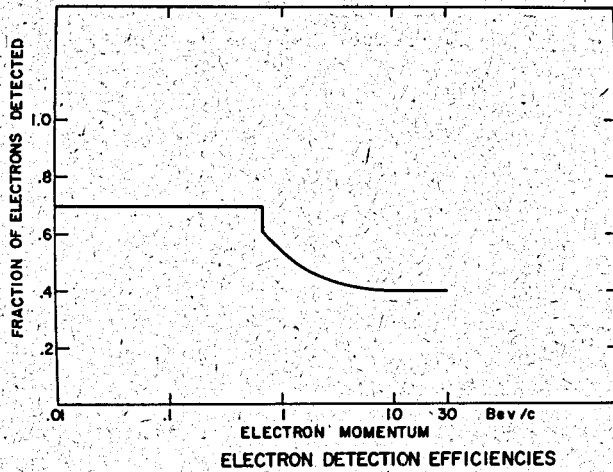


Fig. 6 Electron detection efficiencies for the 14' BNL chamber

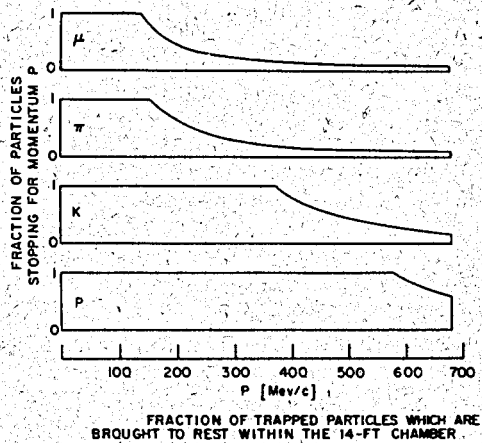
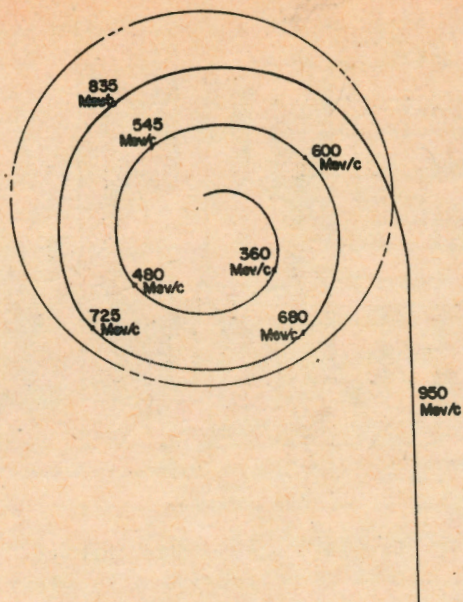


Fig. 7 Fraction of trapped particles which are brought to rest within the 14' chamber

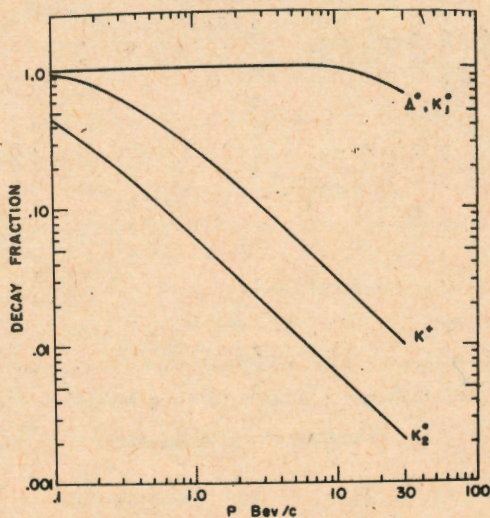
The fraction of neutral particles which would decay inside the bubble chamber, being produced at the centre, is shown in Fig.9.

The next figs. 10, 11 and 12 give you an idea of the three proposed large hydrogen bubble chamber projects. The Brookhaven chamber is shown in Fig.10. The magnet consists of 2800 tons of iron and 141 tons of copper, producing a magnetic field of 20 KG. Fig.11 shows the Argonne chamber and Fig.12 a preliminary design study from Dubna. At this point I would like to remind you of the discussions we had in 1960 at the Berkeley conference with R. Hildebrandt, T.Fields and Thompson. Exploring the optimal size of a hydrogen bubble chamber they came to the conclusion that the dimensions of such an ideal chamber were close to infinity. The limit was given by the largest glass window which Schott and Corning regarded as technically feasible, namely, 150x500 cm. At that time it was a fantastic project, especially regarding the cost and construction time. The following figure 13 give an idea in what dimensions one had to think when scaling up the classical chamber designs. The cost and construction time are linear functions of the chamber volume for a given design. In the ~~two~~ figures I have inserted the first point of a new generation of bubble chambers. It shows very strikingly how many million dollars (~ 50 Mill/Chamber) the governments are going to save due to the invention of scotchlite. This material, in use by the advertising industry for several years, has been discovered for the bubble chamber technique by Wilson Powell. Due to this material the bubble chamber construction is becoming very simple, the chamber being just a vessel with a few small windows for the cameras, Fig.14. To illuminate the chamber volume, it is lined on the inside with Scotchlite. Scotchlite has excellent retrodirective



Stopping K meson

Fig. 8 Stopping K-meson in the 12' Argonne chamber



FRACTION OF NEUTRAL PARTICLES WHICH WOULD DECAY WITHIN 7 FEET AS A FUNCTION OF THEIR MOMENTA

Fig. 9 Fraction of neutral decays in the 12' Argonne chamber

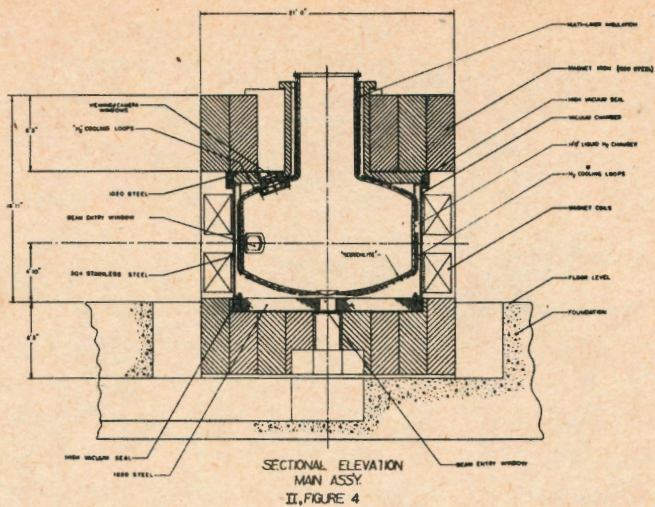


Fig. 10 14' BNL chamber

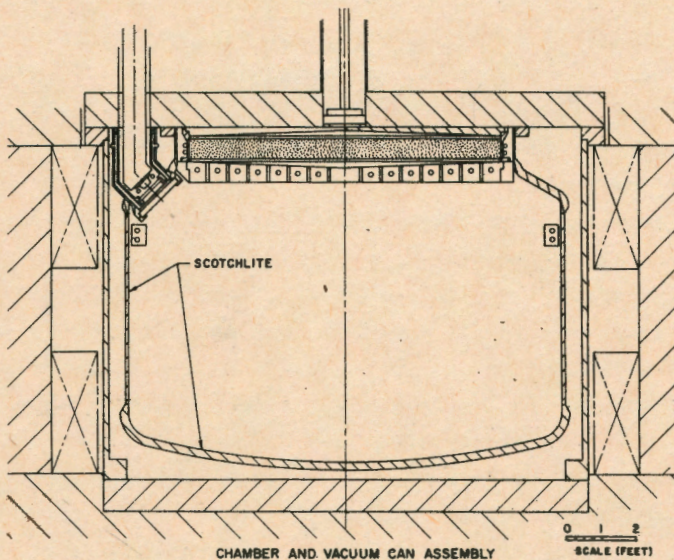


Fig. 11 12' ANL chamber

properties. Bubbles are observed using bright field illumination. Scotchlite consists of uniform spherical transparent beads of high refractive index (n about 2), imbedded in a silvered plastic surface and covered with another layer of plastic, as shown in Fig.15. The indices of refraction of the spheres and the covering plastic are chosen so that the focal length of the front surface and the sphere is equal to the diameter of the sphere. Thus rays such as indicated in the figure striking the Scotchlite from almost any angle (up to 70°) are directed back along the direction of incidence. The retrodirected light actually has an angular spread of about 1.7° . This small cone of divergence means that with reasonable light source intensities one can photograph bubbles in bright field illumination as shown in the Fig. The next Fig.16 is a photograph of tracks with Scotchlite optics in liquid hydrogen taken at the Argonne laboratory. There are still some difficulties with the mechanical properties of the material at low temperature, the supporting lucite cracks, if attached directly to the chamber body. It is expected to overcome this problem by replacing the lucite with mylar. Research on this subject has been initiated at the Minnesota Mining and Manufacturing Company. Wilson Powell has taken more than 1 million pictures in a heavy liquid chamber using Scotchlite (SPR 704). He feels that the resolution of position of bubbles in this chamber is better than that obtained by any other system in use.

As expansion mechanism, the Brookhaven project has a hydraulically controlled resonance system, which allows five expansions per accelerator pulse, see Fig.17. The Argonne chamber has a membrane to expand the chamber, Fig.11, and the Dubna chamber has a number of smaller pistons.

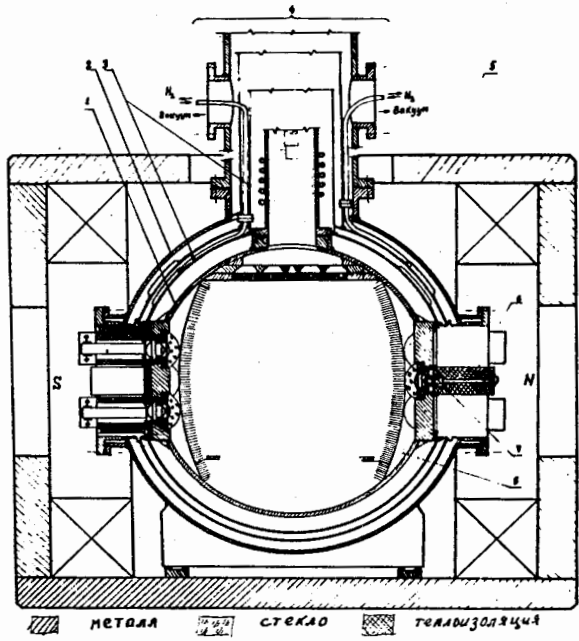
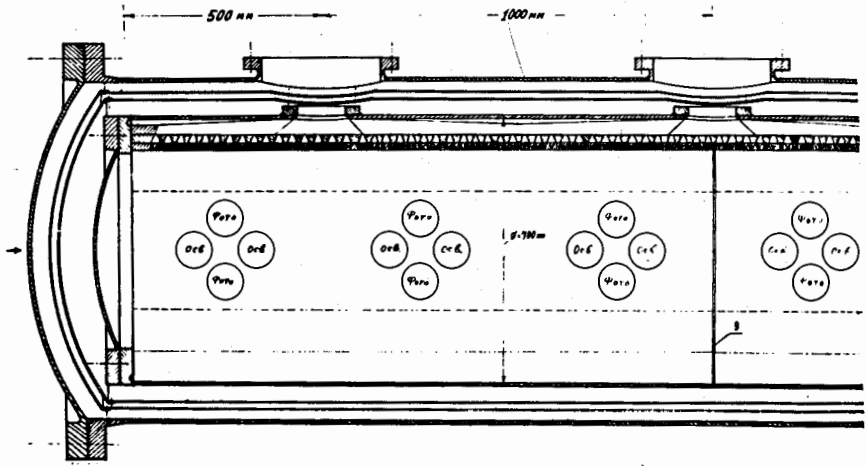


Fig. 12 a Multimeter chamber Dubna
and b

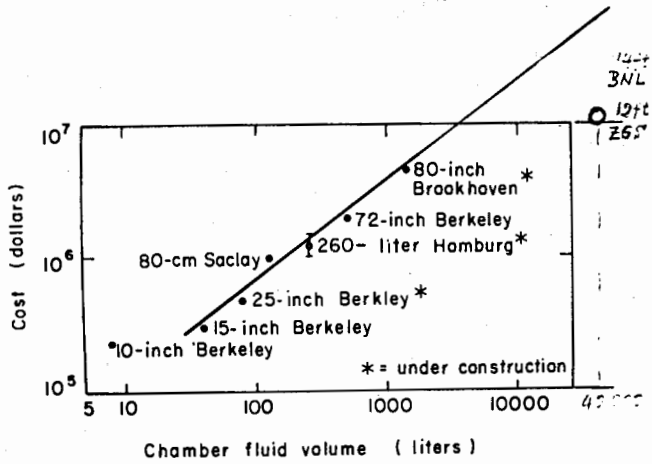


Fig. 13 Approximate cost of building a bubble chamber as a function of chamber volume

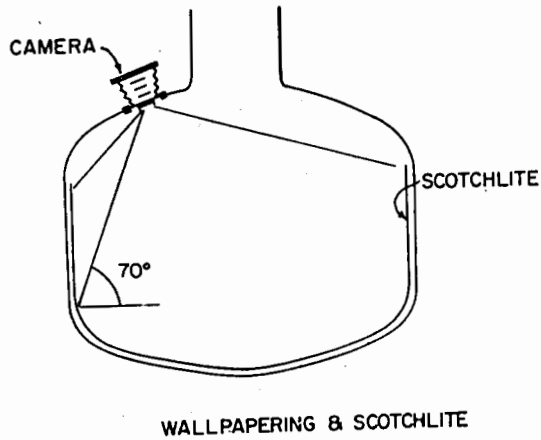


Fig. 14 Principle of chamber illumination with scotchlite

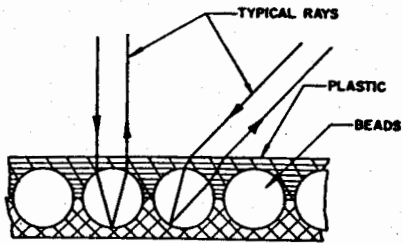
The refrigeration power necessary for these chambers is of the order of 30 kilowatts.

The cost for the Brookhaven and also the Argonne chamber (i.e. chamber, magnet, refrigeration, optics) is estimated to be about 9 millions US dollars, building and beam facilities not included. The estimate for these items is approximately 3 million Dollars.

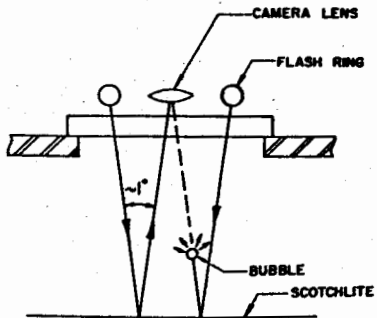
There are also very large heavy liquid bubble chambers under design:

1. A heavy liquid bubble chamber for CERN is being designed by the Ecole Polytechnique - Paris, CERN, Saclay and the Istituto Nazionale di Fisica Nucleare, Italy⁵). The chamber will have a volume of 10.000 lt, the shape is cylindrical 1.65 m \emptyset and 4.40 m length, surrounded by a magnetic field of 22 KG. The chamber is being expanded by a longitudinal diaphragm. The chamber is illuminated from both ends

The whole assembly has a weight of 600 tons. A cost estimate comes to 2.5 million US dollars including salaries but no building.



SCHEMATIC OF SCOTCHLITE WITH TYPICAL RAYS



BRIGHT FIELD ILLUMINATION SETUP

Fig. 15 Scotchlite

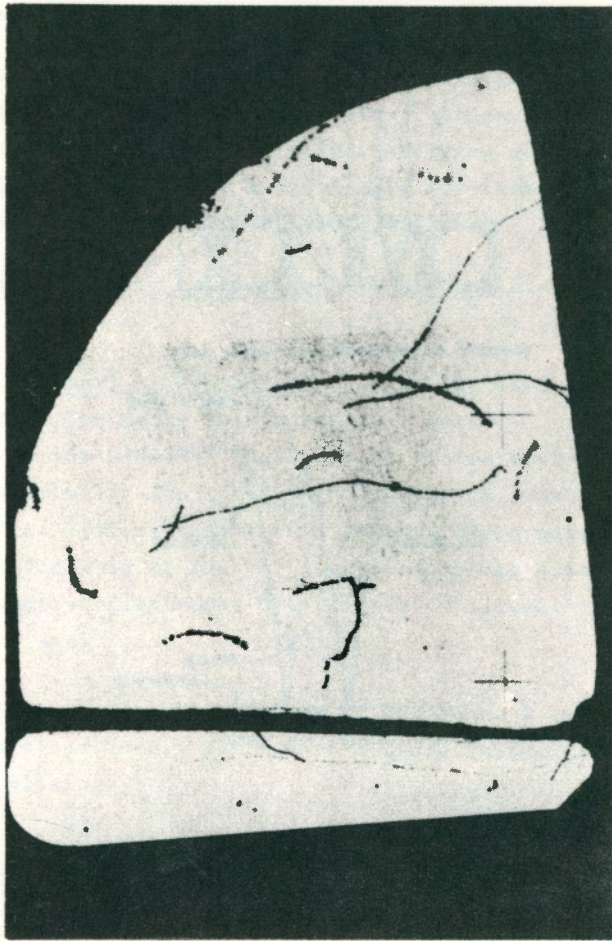


Fig. 16

Electron tracks in liquid hydrogen photographed
with scotchlite illumination

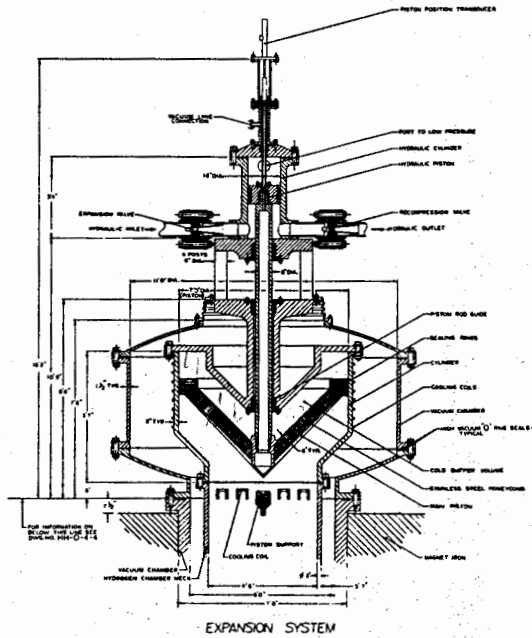


Fig. 17 Expansion system of the 14' BNL chamber

2. Two similar chambers are under design at MIT in collaboration with Brookhaven, and at Argonne together with Wisconsin.

Rapid Cycling Chambers

At present, taking a hundred thousand pictures at the CERN PS with one of the bubble chambers requires about 4 days operation. If everything works ideally one could do it, probably, in 2.5 days. Experiments in the near future demand 10^6 to 10^7 photographs. It would be a great advantage to reduce the exposure time for a 10^6 picture experiment (e.g. 10^7 stopped K^- -mesons in a hydrogen chamber, 10 K^- stops per picture) from 40 days to 4 days. One thinks of expanding bubble chambers several times during one beam pulse of the AGS or PS, if one is not limited by the accelerator intensity but by the number of particle tracks admissible per photograph. Or there are now high energy accelerators with duty cycles of 20 to 60 per sec.

1. The first rapid cycling hydrogen bubble chamber is operating at the LRL in Berkeley. This is a 25" circular chamber being described at this conference¹⁸). Fig. 18 shows the rather original design. The chamber has a movable top window which serves as piston for the liquid expansion system and as optical condensor lens. The chamber takes two pictures per Bevatron pulse, separated by 275 msec.

The motion of the piston is controlled with a hydraulic-pneumatic system. The optical system uses dark-field straight-through illumination. The camera is designed for the

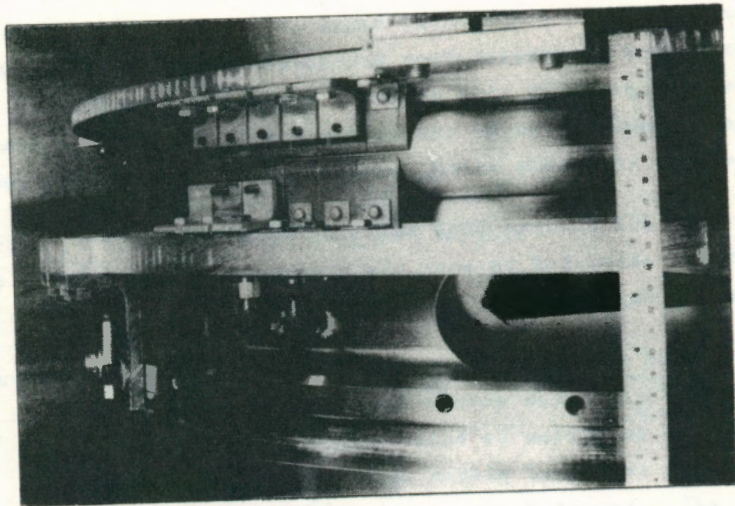
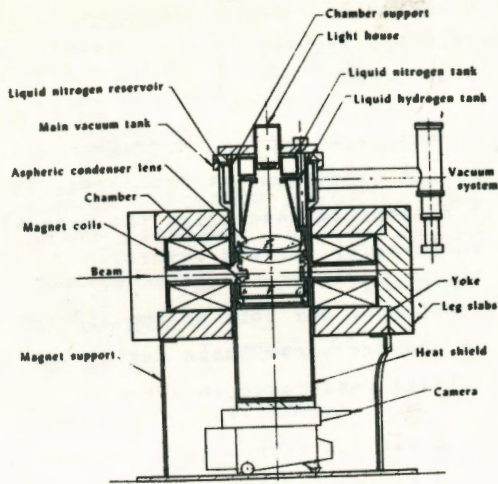


Fig. 18 a Cross section of Berkeley 25" bubble chamber
 b The chamber is divided by a single-convolution bellows that is used to expand the chamber

requirements of rapid cycling; it can photograph 5 expansions during one Bevatron pulse of 1/3 sec duration, and the film can advance in 60 msec.

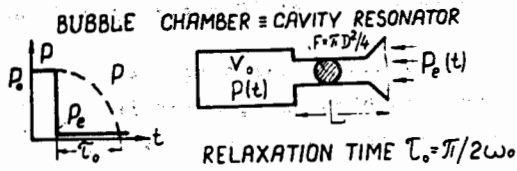
2) The second rapid cycling hydrogen bubble chamber operates under test conditions at Princeton. The following letter of Dr.H.Blumenfeld describing the recently performed test is very encouraging for the future.

"We have continued our work on the 15" (30 liter) hydrogen bubble chamber whose basic design was described at the International Conference in 1960.

We had our first run with liquid hydrogen 6 weeks ago when we were able to see tracks at rates up to 10 cycles per sec., then we stopped because we ran out of liquid hydrogen. We had our second run this last week, when we managed to run for several hours at a rate of 19 pulses per second (Princeton-Penn Accelerator cycling rate). We have not yet been able to fully analyze the results of this run, especially as to turbulence and distortions of tracks. The runs were made using gamma-rays from a cobalt 60 source.

We did observe some bubbling from the windows, but have not yet attempted to cool the window seals separately, as was contemplated in the original design.

Some other pertinent information concerning this run:
Width of expansion wave = duration of time during which He pressure on piston is below compressed value = 15 ms.
Pressure on top of piston when chamber is compressed = 100 psi . Expanded pressure on top of pistons 65 psi .
Vapor pressure thermometer reading 68 psi . Dynamic H₂



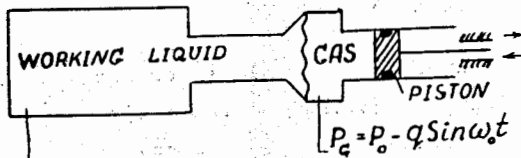
EQUATION OF OSCILLATION $\ddot{p} + 2b\dot{p} + \omega_0^2 p = \omega_0^2 p_e$

OVERTON FREQUENCY $\omega_0 = [F / K\rho L V_0]^{1/2}$

DAMPING COEFF. $2b = 4\lambda_\Sigma P_0 K V_0 \omega_0 / \pi D^3$

$K = dV / dP V_0$ } WORK LIQUID
 ρ - density }

λ_Σ - COEFF. OF RESISTANCE



$p = p_0 + Q \cos \omega_0 t$

$Q = q \cdot \frac{\omega_0}{2b} \gg q$; $\nabla p = 0$ IF $\omega_0 \ll \frac{1}{L\sqrt{\kappa\rho}}$

Fig. 19

Hydrodynamics of resonant bubble chamber

consumption when cycling at 10 cycles per second 12 lt/hr.

When cycling at 19 cycles per second consumption was 17 lt/hr. The track bubbles disappeared in 30 ms. No trace of the old tracks was seen in the next expansion. These are very tentative numbers, obtained directly from the last run and not yet converted to the most meaningful physical quantities.

The questions of long term reliability, stability and of turbulence remain still to be determined but it looks as if a chamber of this volume, cycling at this repetition rate, may be a useful device at certain accelerators.

In the meantime we have continued our work on electronic controls for the strobe light to use in connection with this chamber. In particular the K^+ detector is near completion.

Two engineers, Bernie Lloyd and Max Scheibner, have worked on this chamber during the last two years, in addition to myself and a number of technicians."

c) There are several future plans for rapid cycling chambers. General considerations for the design of resonant bubble chambers were presented by Yu. Budagov.⁽²⁾

At Dubna a group of Prof. Dzhelepov investigated different hydrodynamic aspects for the design of fast cycling bubble chambers. Fig. 19 describes the considerations, the chamber being a resonance system. The presented graphs are computed for a propan chamber of 2 lt volume.

The group has tested these computations with a 1 m heavy liquid chamber by studying the dumped oscillations. They have now constructed a 2 l propan chamber which will be operated under resonance conditions.

High Magnetic Field Chambers

To increase the precision for measuring the trajectory of charged particles in bubble chambers or to perform special experiments requiring high magnetic fields such as the measurement of magnetic moments of hyperons, it is very desirable to have chambers surrounded by high magnetic fields.

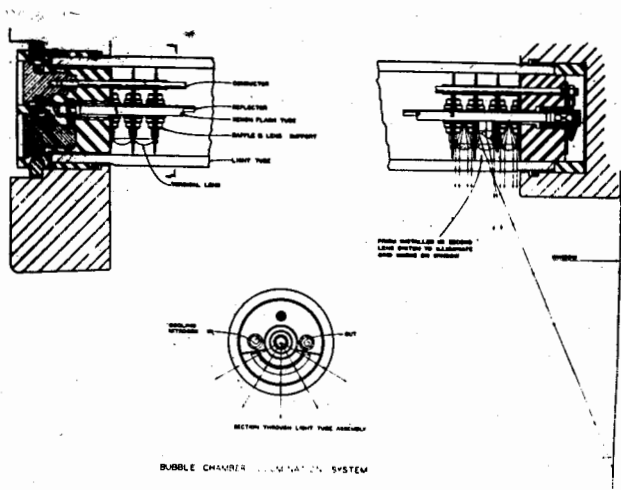
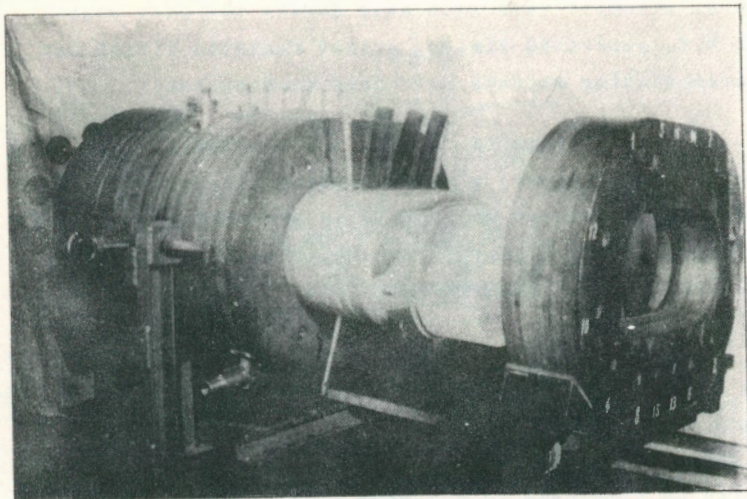


Fig. 20 Illumination system of the Michigan heavy liquid bubble chamber



Курчатовский аппарат

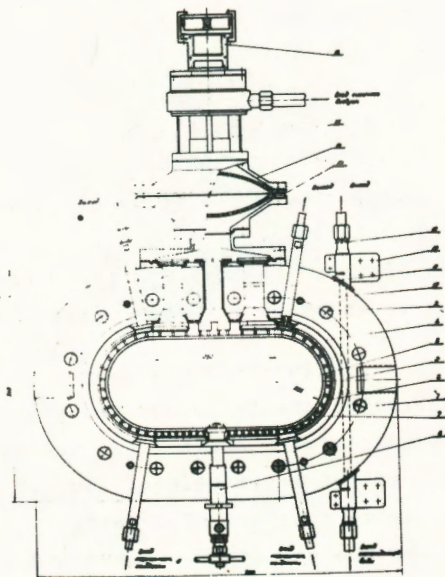


Fig: 21 a photograph of the Kurchatov heavy liquid chamber

b Cross section of the chamber

Several attempts have been made during the past years: high D.C. generated fields, pulsed magnetic fields and superconducting magnets have been constructed.

1) The University of Michigan has built a 726 lt heavy liquid chamber¹³⁾, a quite similar design to the CERN heavy liquid chamber which will be surrounded by a 40 KG D.C. magnet. The magnet being constructed at the Argonne National Lab. will be ready in 1966.

The illuminated volume of the chamber corresponds roughly to a cylinder 1.04 m in \emptyset and 0.66 m deep. The entire assembly weighs approximately 400 tons.

The chamber uses right-angle illumination conceptually similar to that used in the CERN heavy liquid chamber.

However, more effort has gone into collimating the light to a plane perpendicular to the axis of the cylinder assuring uniform illumination throughout the chamber except for a region extending a few centimeters from the diaphragm which is almost entirely without light. The collimation is accomplished by means of a system of baffles and toroidal lenses (see Fig.21). There are 36 such systems around the circumference of the chamber. A toroidal prism in one lens system of each of the 36 units throws light onto the window region. The chamber is expanded by a rubber diaphragm.

2) Pulsed magnetic field chambers

At the Kurchatov Atomic Energy Institute a medium size pulsed field propane-freon chamber has been constructed¹⁴⁾. The chamber body, 45x21x24 cm is made of many thin plastic layers, (Fig.20). The magnet consists of 2 coils, each 14 turns incorporated in the chamber body. Chamber and magnet have been

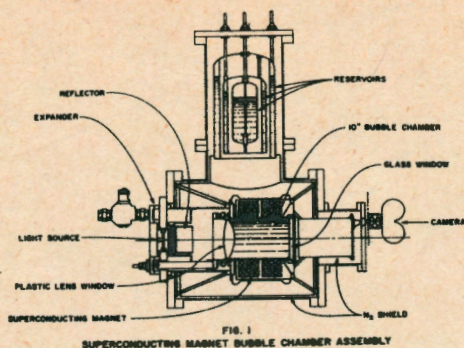


Fig. 22 Chamber and magnet of the Argonne liquid helium-hydrogen bubble chamber

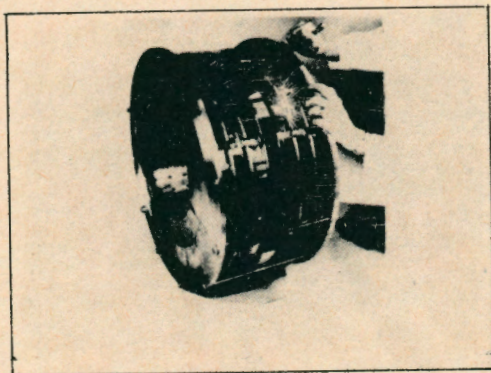


Fig. 23 Photograph of 6 GeV/c K^- -meson tracks in the BN chamber

tested. The magnet was pulsed from a condenser battery, 2.55×10^{-2} Farad, with a stored energy of 250 K Joule. With 15 msec oscillation period 25.4 KGauss were obtained. At the same time the Laboratory is building a Xenon bubble chamber surrounded by a pulsed magnetic field of 70 KG. The project is close to completion. A condenser battery with 3000K Joule will be discharged by the magnet coil. Tests have been made with 1650 KiloJoule producing 50 KG.

3) Superconducting magnet bubble chamber

At the Argonne Laboratory a liquid helium-hydrogen bubble chamber (25 cm ϕ , 35 cm deep) has been constructed¹⁵. The magnetic field of the chamber is provided by a Nb-Zr superconducting magnet. The maximum field obtained on the first test was 32.8 KG.

Fig. 22 shows chamber and magnet. As in the 25" Berkeley chamber, one chamber window serves as piston and condenser lens. It is made of plexiglass. The static loss of the chamber without magnet is 6 lt/hour liquid hydrogen or 11 lt/h liquid nitrogen, or 2.5 lt/h liquid helium. No detectable increase in the consumption was observed when the chamber was expanding. The magnet consists of an assembly of 12 separate coils. The length of the system is 25 cm, the inner diameter is 27 cm and the outer one 54 cm. Copper-coated, insulated superconducting wire of 0.25 mm ϕ is used with Nb 25% Zr wire in the region of low field and Nb 33% Zr wire in the region of high field. Each wire coil contains about 10^4 turns of superconducting wire. The system was assembled for test in early April 1964 as a continuous solenoid, it generated a central field of 32.8 kilogauss at an average coil current of approximately 11 amp.

The measured inductance of the coil system was approximately 7000 henry and the stored energy was in excess of 300.000 Joule. The time constant for the transition to the normal state was a few seconds, and for a high field quench, approximately 130 liters of liquid helium were boiled off over a period of about five minutes. The static helium loss rate of the magnet will be about two litres/h, when mounted in place around the bubble chamber. The optical system has dark field illumination. A cylindrical reflector is placed between the light source and lens, in this way the entire chamber volume is illuminated.

4) Pulsed magnetic field of 200 KG

The group at the Kurchatov Atomic Energy Institute, Moscow has constructed coils of 500 cm³ volume (80 mm \emptyset) to produce pulsed magnetic fields of 200 KG. The coils are made of copper beryllium (2%Be) of high quality, the spiral is machined of one piece of metal. Cooling pipes of copper are brazed at the external surface of the coil. One coil has been pulsed 40.000 times at 150 KG without any failure. A second coil has been tried at 240 KG but after appr. 100 pulses the central part started to change its shape and the insulator material (Micarta) cracked. For the first time the authors have computed the exact magnetic field, thermal and mechanical stress distributions.

New Bubble Chambers in Operation since 1962

At the last International Conference in 1962 R.Shutt gave a survey of the bubble chambers and the projects which would be completed in the following years. We reproduce here a new revised table (Table 2). Since 1962 several chambers are in operation and Table 2 gives some of their parameters.

- 1) the 30" Columbia-Brookhaven hydrogen chamber
- 2) the 80" Brookhaven hydrogen chamber.

The first photographs were taken at the beginning of June, 1963. About 1 million pictures have been obtained with this chamber up to date. The necessary refrigeration power for normal chamber operation is two kilowatts. Concerning distortions of particle trajectories the chamber has the same performance as the 20" hydrogen chamber at Brookhaven.

3) British National Hydrogen Chamber

The chamber gave the first tracks during its test run at the Rutherford Laboratory at the end of 1962. After that the chamber was dismantled and immediately transported to CERN. It has been installed in a high energy separated

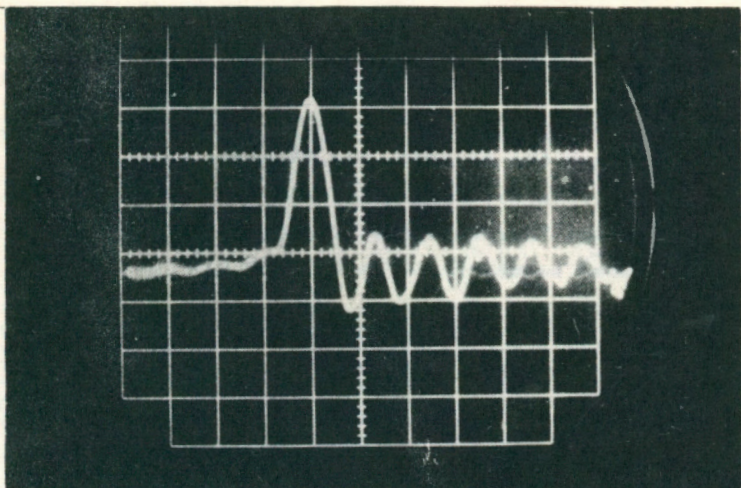


Fig. 24 Pressure change of the liquid hydrogen in the BN chamber during one expansion cycle

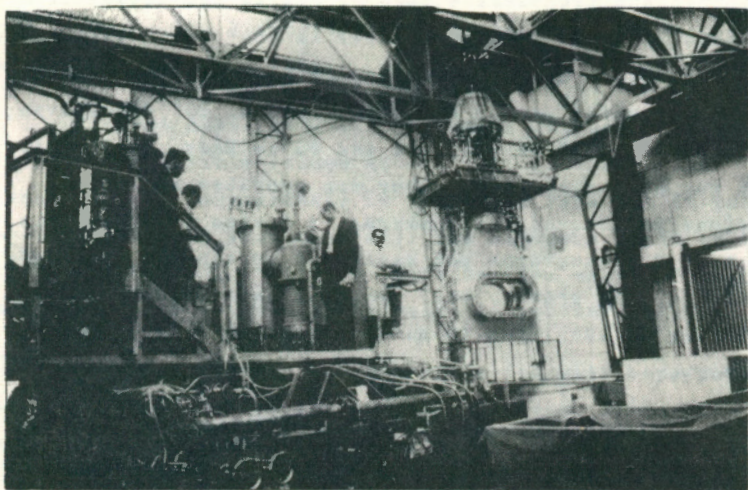


Fig. 25 The 80 cm Desy liquid hydrogen bubble chamber

beam, 6 GeV/c, and recently had a very successful run with 6 GeV/c K^+ - mesons, see Fig.23. This chamber and the 72" Berkeley chamber have a gas expansion system. A very good performance has been obtained here with the new chamber. It expands every two seconds, Fig.24 shows the pressure change of the liquid during one expansion cycle. Under these conditions the refrigerating power is 3 kilowatts. The static load is about 500 watts.

4) There are two new medium size hydrogen bubble chambers which were built at Saclay. One is the modified 50 cm chamber of A. Berthelot, which has been enlarged to 80x50x50 cm. This chamber has been transported to the Rutherford Laboratory and will be operated in a 2 GeV/c K-meson beam at Nimrod.

The second chamber has been built at Saclay under the direction of R.Florent with a team of French and German engineers and technicians, and of course the advice of physicists. This "German" chamber is just being transported to the electron accelerator Desy in Hamburg. The chamber is another child of the Shutt generation, 20" Brookhaven, 81 cm Saclay, 82" Brookhaven, and 80 cm Desy. During its test run at Saclay the chamber was operated at two expansions per second. The cameras, a design of SOM, Paris, can take 5 photographs per second. A more rapid cycling system for the chamber will probably be designed at the beginning of 1965. Fig.25 gives a general view of the chamber.

5) The Wisconsin - Argonne 30" hydrogen bubble chamber is ready for operation in a 4GeV/c K-meson beam at the

ZGS, Argonne¹⁷⁾. The chamber is expanded by 3 pistons. The necessary cooling power is 500 watts. For the present experiment two lead plates, each $3/4$ of a radiation length thick, separated by 5 cm are inserted inside the liquid. Fig. 26 shows a photograph with the lead plates.

- 6) At Dubna (JINR) a 55 l liquid hydrogen chamber¹⁸⁾ (40 cm diameter) with small glass windows has been constructed and is being operated. (Fig. 27) This chamber serves as a model for a very large liquid hydrogen chamber, for which the use of large glass windows becomes problematic. The group has studied the optical distortions of tracks which are photographed through a considerable thickness of liquid hydrogen. To avoid distortions one has to keep the temperature gradients of the liquid hydrogen extremely small. Especially after an expansion cycle the liquid has to be mixed sufficiently fast to remove the temperature gradients. With the present chamber design the track distortions were appreciable operating at one expansion every 9 seconds. Expanding the chamber once in 18 seconds, the distortions were reduced to 100μ on 30 cm track length.

7) The CERN heavy liquid bubble chamber is being enlarged to a visible volume of 1000 lt¹⁹⁾. The fiducial volume for ^{neutrino} experiments is increased from 223 lt (old chamber) to 638 lt (new chamber). The magnetic field of 27 KG will be maintained, it will be less uniform than before. The modified chamber should be ready in February, 1965.

8) There are a few chambers which will hopefully start to operate before the end of this year, 1964. The CERN 2 meter hydrogen chamber²⁰⁾ is being assembled. The magnet has

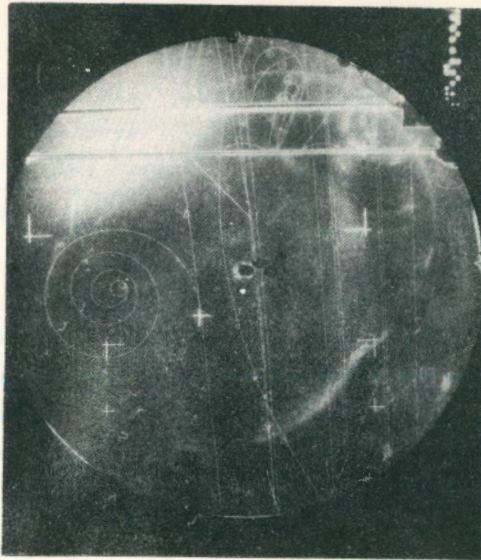


Fig. 26

Photograph of π^- -mesons in the Argonne chamber with lead plates

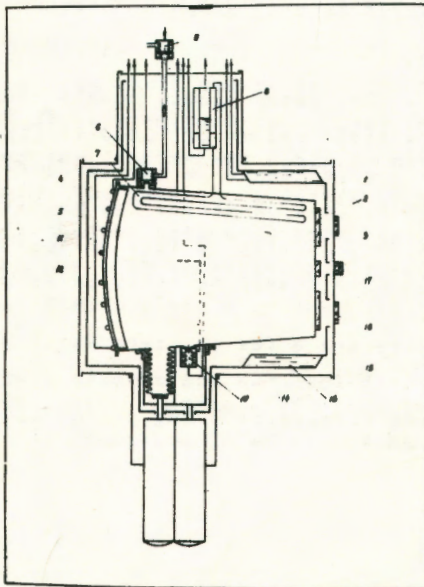


Fig. 27

Schematic drawing of the Dubna 55 l liquid hydrogen bubble chamber

been tested already, 1962-1963, producing a field of 17 kiloGauss. The refrigerator has been tested and the cooling power is 7 kilowatts at 25° K. The specification requested only 4 kilowatts. The special feature of this system is that it works with expansion turbines instead of a Joule-Thompson valve.

Also the MIT 40" chamber (1000 lt volume) will be soon in operation. In Dubna²¹) and Moscow²²) two hydrogen chambers, 1 meter and 2 meter, and a heavy liquid chamber of 1 meter are close to completion.

Beam Control for Bubble Chambers

As more bubble chamber photographs are being produced, more automatization for the measuring and analysis is necessary. In the preceding article Y.Goldschmidt-Clermont has given a survey of the capabilities of present analysis equipment. Two points are very desirable for the efficient operation of automatic measuring devices.

1) Particle beams with good momentum definition and small contamination, and

2) relatively low density of primary beams tracks crossing the chamber, to allow automatic machines to follow the tracks.

As the primary beam energy increases, the particle separation becomes more and more difficult and condition 1) is not easy to satisfy. Even with well separated beams, of not too high energies it is a problem to identify rare event types from background reactions produced by unwanted beam particles.

It would simplify the analysis and remove ambiguity in such events, if unwanted beam particles were "tagged", indicating for example which one was a π -meson in a separated high energy K-meson beam. This can be achieved with Cerenkov counters and hodoscopes or fast deflecting magnets in front of the bubble chamber.

At CERN three devices proposed by Ch. Peyrou, A. Minten and G. Petrucci are being developed:

1) Shutter magnet

An air coil is placed in the separate particle beam in front of the last mass slit. Counters register the number of particles entering the bubble chamber. After a certain number of particles the magnet is triggered and deviates the beam from the mass slit. In a typical case the angle of deviation was 10 mrad for 5 GeV/c particles. A condenser battery (400 Joules) was discharged into the coil, with a rise time of 10 μ sec.

2) Sweep Magnet

This magnet has been designed in order to distribute the particles inside the useful region of the bubble chamber during the burst. In this way it will be possible, by associating a signal proportional to the instantaneous bending power of the magnet with a velocity measuring device (e.g. Cerenkov), to identify beam particles in the bubble chamber.

3) Step Magnet

Square-loop ferrites are used to deflect the beam. Twenty magnet units are placed in the beam

Before a beam pulse starts all the ferrites are polarized in one direction, e.g. 5000 Gauss up. When the first particle has passed, triggered by the counters in front of the chamber, the polarization of the first unit is reversed from up to down within 5 μ sec. After the passage of the second particle the second unit is flipped and so on. In this way the primary beam particles are distributed equidistantly in the bubble chamber. With an additional Cerenkov counter each flipping process (e.g. each particle) can be associated with a signal indicating the nature of the passing particle.

At Dubna a simple hodoscope of 4 x 4 scintillation counters specially arranged has been constructed (Fig.28²³). With this arrangement one obtains 16 x 16 = 256 cells over the desired area to register the position of a traversing particle in coincidence with a Cerenkov counter pulse.

CONCLUSION

Coming to the end of my report I hope to have indicated, that the progress of bubble chamber technique is far from saturation. The final aim is to construct the ideal detector, a large continuously sensitive volume of "simple matter" which can be controlled to detect elementary particle interactions.

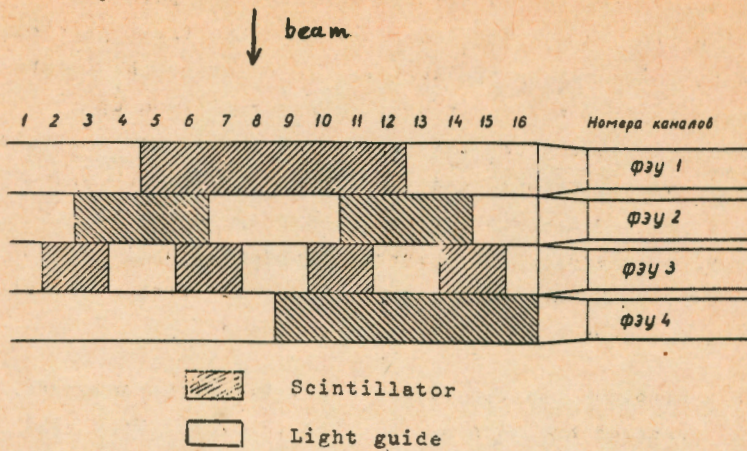


Fig. 28 Counter hodoscope for beam control



Fig. 29 Electron tracks in a cloud chamber photographed with Laser illumination

Appendix:

1. New method of bubble chamber illumination

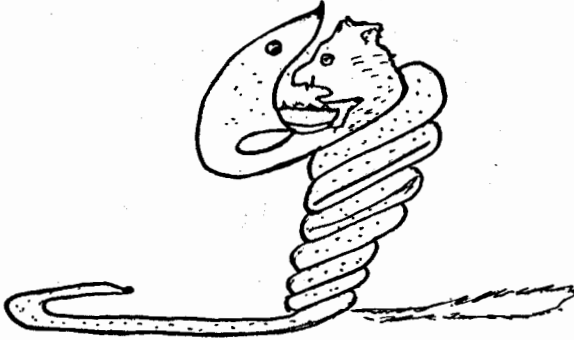
In the work of the Lebedev Institute and the Joint Institute for Nuclear Research a bubble chamber and cloud-chamber were illuminated with the aid of a light quantum generator for the first time. Such a way of illumination has great advantages owing to the monochromaticity of the light, increase of light intensity by a few orders of magnitude, and small size of the source. The use of such sources makes it possible to increase the resolving power of photographing systems considerably, to decrease the illumination time, and to increase the accuracy of momentum measurements and ionization in chambers. The photographs which were taken already permit measuring 0.06 mm bubbles in the hydrogen bubble chamber.

An example of cloud chamber photographs is shown in Fig.29.

Numbers of Events per 50,000 Pictures-Day
 With 10^{13} Protons per Pulse and a 12 ft.
 Liquid Hydrogen Bubble Chamber

	elastic events		hyperon production (per channel)		inelastic events		boson production	
	v	\bar{v}	v	\bar{v}	v	\bar{v}	v	\bar{v}
<u>high energy</u> <u>beam</u>								
events on p's in hydrogen	0	57	0	1.9	570	285	20	10
events on n's in deuterium	133	0	0	1.9	570	285	0	0
events on n's with measurable p	38	0	0	0.6	190	95	0	0
<u>low energy</u> <u>beam</u>								
events on p's in hydrogen	0	140	0	4.7	280	140	1	1
events on n's in deuterium	564	0	0	4.7	280	140	0	0
events on n's with measurable p	188	0	0	1.6	94	47	0	0

2. Le Petit Prince, St.Exupéry



LORSQUE j'avais six ans j'ai vu, une fois, une magnifique image, dans un livre sur la Forêt Vierge qui s'appelait « Histoires Vécues ». Ça représentait un serpent boa qui avalait un fauve. Voilà la copie du dessin.

On disait dans le livre : « Les serpents boas avalent leur proie tout entière, sans la mâcher. Ensuite ils ne peuvent plus bouger et ils dorment pendant les six mois de leur digestion. »

J'ai alors beaucoup réfléchi sur les aventures de la jungle et, à mon tour, j'ai réussi, avec un crayon de couleur, à tracer mon premier dessin. Mon dessin numéro 1. Il était comme ça :



J'ai montré mon chef-d'œuvre aux grandes personnes et je leur ai demandé si mon dessin leur faisait peur.

Elles m'ont répondu : « Pourquoi un chapeau ferait-il peur? »
Mon dessin ne représentait pas un chapeau. Il représentait un serpent boa qui digérait un éléphant. J'ai alors dessiné l'intérieur du serpent boa, afin que les grandes personnes puissent comprendre. Elles ont toujours besoin d'explications. Mon dessin numéro 2 était comme ça :



Les grandes personnes m'ont conseillé de laisser de côté les dessins de serpents boas ouverts ou fermés, et de m'intéresser plutôt à la géographie, à l'histoire, au calcul et à la grammaire. C'est ainsi que j'ai abandonné, à l'âge de six ans, une magnifique carrière de peintre. J'avais été découragé par l'insuccès de mon dessin numéro 1 et de mon dessin numéro 2. Les grandes personnes ne comprennent jamais rien toutes seules, et c'est fatigant, pour les enfants, de toujours et toujours leur donner des explications.

J'ai donc dû choisir un autre métier et j'ai appris à piloter des avions. J'ai volé un peu partout dans le monde. Et la géographie, c'est exact, m'a beaucoup servi. Je savais reconnaître, du premier coup d'œil, la Chine de l'Arizona. C'est très utile, si l'on est égaré pendant la nuit.

J'ai ainsi eu, au cours de ma vie, des tas de contacts avec des tas de gens sérieux. J'ai beaucoup vécu chez les grandes personnes. Je les ai vues de très près. Ça n'a pas trop amélioré mon opinion.

Quand j'en rencontrais une qui me paraissait un peu lucide, je faisais l'expérience sur elle de mon dessin n° 1 que j'ai toujours conservé. Je voulais savoir si elle était vraiment compréhensive. Mais toujours elle me répondait : « C'est un chapeau. » Alors je ne lui parlais ni de serpents boas, ni de forêts vierges, ni d'étoiles. Je me mettais à sa portée. Je lui parlais de bridge, de golf, de politique et de cravates. Et la grande personne était bien contente de connaître un homme aussi raisonnable.

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Received by Publishing Department
on October 22, 1964.