EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

. CERN-EP/83-47
23 March 1983

A GIANT ARGON BUBBLE CHAMBER WITH LONG SENSITIVE TIME
FOR NUCLEON DECAY EXPERIMENTS

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ABSTRACT

A giant argon bubble chamber could be a suitable detector to investigate the decay modes of nucleons in an unbiased way. We are investigating the possibility of operating such a chamber with a track sensitive duty cycle of up to $\sim 50\%$. A small and not very clean bubble chamber has been successfully operated in an expanded pressure stabilized mode with a duty cycle of 10% . A tentative design of a 3000 m^3 argon bubble chamber is discussed.

(Submitted to Nuclear Instruments and Methods)

1. INTRODUCTION

Several experiments are presently collecting data to study baryon stability. Some of them¹⁾ use a calorimeter design principle proven in neutrino experiments which gives the tracks of the decay products; others use large water Cerenkov counters²⁾ which give the direction of the decay particles. These detectors may discover the process of proton decay; however, they are not designed to combine these features to give both the tracks and their directions, and to identify the various decay modes. If protons do decay their decay modes contain fundamental information concerning the underlying symmetry scheme of the Grand Unification of the forces and of its breaking³⁾.

The crucial questions are concerned with the relation of baryon number and lepton number non-conservation; is B-L conserved, are positrons favoured, is there only one lepton among the decay products, are $\Delta S = 0$ decays favoured, etc.³⁾

A large bubble chamber may be the only device capable of answering these questions if the mean life turns out to be of the order of 10^{31} years. In a detector with a fiducial tonnage of 1000 tons, 60 nucleon decays occur per year for a mean life of 10^{31} years and several hundred events induced by the interactions of cosmic ray neutrinos. In fact, an early search for proton decays was conducted in the large heavy liquid bubble chamber Gargamelle⁴⁾. However, the main purpose of its exposures being the study of high energy neutrino interactions, the sensitive time was kept short, sufficient for the spill length of the accelerator (~ 1 ms) to reduce cosmic ray background.

For dedicated exposures of a large and clean bubble chamber a novel regime can be used allowing long sensitive time and a large duty cycle up to $\sim 50\%$, appropriate for nucleon decay experiments in an underground laboratory.

In a giant bubble chamber a liquid argon filling offers the unique feature that the flash can be triggered by detecting the scintillation light produced by the proton decay products.

It is the purpose of this note to discuss briefly the possibilities of a giant argon bubble chamber for a nucleon decay experiment, to report on experimental tests demonstrating the feasibility of a regime with long sensitive time in clean bubble chambers, and to describe the tentative design

parameters of a liquid argon bubble chamber with 3000 tons visible volume, requiring a total of 3500 tons volume for 50% duty cycle.

Secondaries from proton decay may comprise electrons, muons, pions and kaons; their momenta are confined to less than 500 MeV/c, a kinematical region for which bubble chambers have numerous proven capabilities of particle identification⁵⁾. The direction of tracks can be determined by the visible direction of delta-rays and by the increase of the specific ionization (bubble density) towards the end of range. A mass of particles can be determined by combined measurements of range, of bubble density (dE/dx) and of multiple scattering.

A magnetic field of 2 kG can give a distinction between positive and negative muons at the five standard deviation level.

2. CHAMBER MODE OF OPERATION

To study nucleon decay there is an obvious advantage in using a continuously sensitive detector. This requirement is clearly in contradiction with what is known of bubble chamber operation. Bubble chambers cannot be triggered; when used for experiments with particle accelerators they are typically sensitive for a few percent of the time. This comes from the fact that once the chamber has been expanded to the desired pressure, every bubble (either coming from particle tracks or from parasitic spots), once formed, has a tendency to grow continuously. To prevent the chamber from boiling in bulk, the chamber has to be recompressed fairly quickly. Thus a bubble chamber could be maintained in a sensitive state if, and only if, no ebullition germs are present. If the bubble chamber is situated sufficiently deep underground (e.g. below 5000 m water equivalent rock), the resulting shielding would be such that only one or two cosmic muons cross the chamber per minute (see, e.g. Ref. 1). The remaining germs are therefore mainly due to parasitic boiling along the joints. For a giant bubble chamber the ratio of volume to the total length of joints is very favourable and in addition, special care could be taken to make the necessary joints as much as possible free from parasitic boiling. However, whatever care is taken to avoid parasitic boiling, it cannot be suppressed completely; to keep the chamber in a constant sensitive state one has to continue to expand the chamber slowly to stabilize the final pressure using a hydraulic expansion servo-system⁶⁾.

This pressure stabilization gives a reproducible bubble density plateau at each expansion as required for ionization measurements. After a while, when too much gas is present in the chamber, one must recompress and wait for the bubbles to disappear and the chamber to stabilize before it is ready to expand again. It is easier to use this special mode of operation if the bubble chamber is operated warmer than at the temperature used in the conventional mode. By operating at high temperature, the bubble growth constant is reduced so that, for example, after 100 s in the sensitive state the maximum diameter reached by the individual bubbles could be around 25 mm (see para. 4). If the number of such bubbles is small, this corresponds to a negligible volume of gas for a giant bubble chamber and thus sensitive periods of up to 100 s seem to be possible. With which duty cycle can a bubble chamber operated in this mode be maintained in the expanded state sensitive to register events? We performed tests with a small (2.2 litres freon) not very clean bubble chamber (HOBC [7]); a duty cycle of 10% (22 ms every 200 ms) has easily been reached. We thus feel that for a clean giant bubble chamber operated at fairly high temperature a duty cycle of up to 50% could be reached. If we assume that the chamber is sensitive during 100 s this leads to a repetition rate of 5 mHz, corresponding to 150 000 expansions per year.

3. PROPERTIES OF LIQUID ARGON AS A TRACK SENSITIVE BUBBLE CHAMBER LIQUID

Liquid argon is probably the only feasible fluid to use, both from a technical and financial point of view, for giant bubble chambers; it is non-inflammable, and it can be liquified by liquid nitrogen. It was shown in 1980 at CERN, following a proposal to construct a huge neutrino detector for Fermilab⁸⁾, that argon can be used as a track-sensitive bubble chamber liquid⁹⁾. It was also demonstrated that scintillation light from ionizing particles, comparable in intensity to that from NaI, can be detected during the chamber expansion¹⁰⁾, and used to trigger the flash for track photography. A laser beam has been successfully used¹¹⁾ to monitor the track sensitivity and the bubble density throughout the volume of a liquid argon bubble chamber. The effect of impurities in argon, mainly nitrogen and oxygen, on the magnitude of the scintillation signal has been studied and found to be less significant than when charge collection (calorimetry) is attempted^{12,13)}.

4. TECHNICAL ASPECTS AND OPERATING CONDITIONS

The envisaged operating temperature is ≥ 135 K, corresponding to a vapour pressure of ≥ 25 bar. The static pressure between expansions will be about 2 bars higher to guarantee bubble recompression within some seconds. The expanded pressure will be ~ 10 bar to produce bubble densities of up to 20 bubbles/cm for minimum ionizing particles. A dramatic increase in bubble density for slower particles was previously observed, allowing the determination of the direction of flight of particles from bubble counting. The required expansion ratio is given by both the compressibility of the liquid ($5.3 \cdot 10^{-4}$ cm²/bar) and the amount of parasitic boiling, and should be $\Delta V/V \geq 0.5\%$.

Preliminary results on bubble density as a function of temperature and expanded pressure are shown in Fig. 1. Bubble growth rates have been calculated for liquid temperatures of 130 and 136 K¹⁴⁾, assuming in each case a pressure drop of 16 bar, resulting in bubble densities of 3 and 15 bubbles/cm, respectively. For small growth times they were checked against experimental values. Results of the calculation are given in Fig. 2; at constant expanded pressure, and neglecting the hydrostatic pressure, the diameter of bubbles is growing as $\sqrt{t}$, where t is the growth time.

For bright-field illumination, using Scotchlite, bubbles with a diameter of at least 2 mm are required, demanding flash delays of about 100 and 450 ms, for 130 K and 136 K, respectively. If holography can be made to work following the scheme presently studied in BEBC¹⁵⁾, bubbles as small as 0.5 mm could be photographed already at 7 and 30 ms after their creation, at the two temperatures, respectively. The expanded pressure, and hence the bubble density, would be adjusted so as to give the optimum information on ionization for each of these optical schemes. Holography would require fewer and simpler windows (flat instead of hemispherical) compared with the classical bright-field technique. A further advantage of holographic track recording would be less random bubble movement and a smaller overall displacement of an "event" by buoyancy forces (≤ 20 cm/s). Scanning for events in holograms can be facilitated either by space information obtained from timing of scintillation signals, or by the use of a small number of conventional cameras.

Bubbles created by a cosmic ray traversing the entire chamber, if not compressed after 1 second, would produce up to 21 and 4 kJ dynamic heat load,

at 130 and 136 K, respectively. This shows the importance of working at fairly high liquid temperatures, and that the detector has to be deep underground. Even after 100 seconds growth time the heat load for the entire chamber remains within acceptable limits. A muon traversing the entire chamber (see Table 1) will produce four times more light than the proton decay products. This light can be selectively detected because of its characteristic arrival time distribution, and used to terminate the expansion cycle if necessary. Measurements of the attenuation length of the scintillation light in liquid argon and its dependence on impurities are presently being performed in several laboratories. The question of whether the bubble string created by a cosmic muon requires an early recompression of the chamber liquid or whether part of this dynamical heat load can be eliminated by a heat exchanger in the upper part of the chamber, cannot be decided at the present time.

5. DETECTION OF SCINTILLATION LIGHT IN LIQUID ARGON

Approximately 2000 photoelectrons per MeV energy loss in liquid argon are produced in the spectral range of an S11 photocathode by the use of a wavelength shifter^{10,16,17)} (e.g. paraterphenyl) if all the light is collected. In proton decays 1 GeV energy is lost by ionization in liquid argon. For an event occurring in the centre of a sphere of 10 m radius, and neglecting light absorption, we expect ten photoelectrons from a single 5" diameter photomultiplier. If the attenuation length were 2.3 m, ten 5" photomultipliers would be required. They would see the chamber through hemispherical windows covered by the wave length shifter. If more than, say, 5 photoelectrons are detected the flash will be triggered with the appropriate delay to ensure photography of tracks at the optimum bubble diameter.

6. CHAMBER DESIGN

To be clean the chamber has to be sealed by bellows and a minimum number of optics ports must be provided for laser or flash lamp illumination, picture taking and scintillation light collection. A hydraulic expansion servo-system has to be used to expand and recompress the chamber in the pressure stabilized mode described above. Cooling loops containing liquid argon precooled by nitrogen would be used and the general thermal shielding would be provided by solid insulation to avoid the cost of a vacuum tank.

Some tentative design parameters for a 3000 m³ chamber are given in Table 1; Figure 3 shows a sketch of the giant bubble chamber. The choice of the aspect ratio for such a chamber has to be balanced carefully between the maximum achievable bellows diameter, the permissible hydrostatic pressure throughout the chamber, the optics layout, the required homogeneity of the magnetic field and, last but not least, the construction price.

The required size is clearly a difficulty but we feel that no technical problem would prevent the construction of such a chamber. The chamber body has roughly the size of a nuclear reactor pressure vessel and the only delicate piece seems to be the bellows. However, extrapolating from what is known of existing bellows and using a multi-layer construction, the first computations show no impossibilities¹⁸⁾.

Table 1

Tentative design parameters for a 3000 m³ bubble chamber

Visible volume	3000 m ³
Total volume	3500 m ³
Bellows internal diameter	17 m
Stroke for 1.5% $\Delta V/V$	0.17 m
Chamber static pressure	27 bar
Chamber expanded pressure	10 bar
Compensating pressure under the bellows	22 bar
Operating temperature	135 K
Density of the liquid	1 g/cm ³
Radiation length	19.6 cm
Absorption length	120 cm
Range of a 500 MeV muon	220 cm
Bubble density for minimum ionizing particles	20 bubbles/cm
Sound velocity	430 m/s
Unbalanced force in both compressed and expanded states	20 500 tons
Time needed to expand or recompress	~ 1 s
Duration of one complete cycle	200 s (5 mHz)
Number of expansion cycles	150 000 per year
Magnetic field	2 kG

7. CONCLUSIONS

If nucleons decay with a mean life of the order of 10^{31} years a giant bubble chamber could be a suitable detector to investigate the decay modes in an unbiased way. We have started an investigation as to whether such a giant bubble chamber, filled with liquid argon, can be built and operated with a track sensitive duty cycle of up to $\sim 50\%$.

A small and not very clean bubble chamber has been successfully operated in an expanded pressure stabilized mode with a duty cycle of 10%. It would be very interesting to perform a test with other bubble chambers.

The properties of liquid argon as a track sensitive bubble chamber liquid have been investigated previously and a possible mode of operation and a tentative design of a 3000 m³ giant bubble chamber have been described.

We acknowledge interesting discussions with J. Ballam, G. Linser, C. Peyrou, and H. Wenninger.

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FIGURE CAPTIONS

- Fig.1   Bubble density as a function of temperature and expanded pressure
- Fig.2   Bubble diameter as a function of growth time for 130 K and 136 K. For bright-field illumination a bubble diameter of ≥ 2 mm is required, for holographic optics a bubble diameter of 0.5 mm is sufficient
- Fig.3   Tentative design of a 3000 m³ liquid argon bubble chamber for nucleon decay experiments

Fig. 1

Fig. 2

Fig. 3