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HOLOGRAPHY IN THE 15-FOOT BUBBLE CHAMBER

Presented for the E-632 Collaboration(*)

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ABSTRACT

The 15-foot Bubble Chamber was exposed to a wide-band neutrino beam from
the Fermilab Tevatron. A large number of photographs was taken simultaneously in a
holographic set-up and with conventional cameras. Technical aspects of this
experiment will be discussed.

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1. INTRODUCTION

Over the last few years, an in-line holographic technique had been adapted to the 15-foot Bubble Chamber. This technique, in combination with conventional photography, aims at various physics goals: to measure charmed particle production and decay by the highest energy neutrino beam available, to look for any new phenomena, and eventually observe visually for the first time the tau-neutrino. For these purposes a large bubble chamber, filled with a heavy liquid, is an ideal instrument, since close-by tracks can be resolved optically and decay lengths of a few millimeters or less near the event vertex can be determined. This is complemented by its potential to measure the momentum of all tracks.

The present experiment was performed in a wide-band neutrino beam, produced by 800 GeV/c protons on the target. During the second part of the physics run for Experiment E-632, discussed here only, the chamber was filled with a 64/36 mole percent neon/hydrogene mixture. It was equipped with: (i) four conventional cameras with a resolution of \( \sim 500 \mu m \), seeing 28 m\(^2\); (ii) with one high-resolution camera, having a resolution of 200 \( \mu m \) over \( \leq 1 \) m\(^3\), and with (iii) the holographic set-up, which allows to record with good contrast bubbles of \( \sim 120 \mu m \) within \( \sim 1.5 \) m\(^3\).

2. HOLOGRAPHIC ARRANGEMENT

The scheme, adopted for the 15-foot Bubble Chamber, in which the object and reference beam are combined in a Gabor-type in-line set-up, is shown in fig. 1. The laser beam enters the bubble chamber at its bottom through a specially designed aspheric lens. This dispersing lens is designed such that only a small central part of the laser light goes directly through the liquid to a set of three concentric hemispherical windows on the opposite side of the chamber onto the film (reference beam). The other part of the beam illuminates the bubble tracks within a conical volume. The intensity of this object beam at large angles increases to compensate for the decrease of the light scattered by the bubbles at large angles. Some elementary formulas, together with preliminary results from a test experiment in the Big European Bubble Chamber (BEBC), were given in ref. [1].

Already from the BEBC run, and later from two tests in the 15-foot Bubble Chamber, it became clear that there are stringent requirements for holography to be fulfilled to get the desired resolution and contrast for the bubble tracks within a maximum usable volume. There is a need for:
(a) A powerful laser with good beam quality, which means: (i) a flat geometrical intensity distribution at the dispersing lens, since it had been designed for such an input and an illuminating cone with a half-angle of 30°; (ii) a long coherence length of more than \( \sim 1.5 \) m, to account for the difference in path lengths of the object and reference beam; (iii) a good stability in energy (\( \leq 10\% \)), to expose the film correctly, and (iv) a flat distribution of the energy in time (avoiding spikes \( \geq 30\% \) of the average energy during the pulse) to minimize adverse effects of laser-induced boiling.

(b) An adequate Beam Balance Ratio (BBR), defined as the intensity of the object to the reference beam, which determines the contrast of tracks in the holograms, and ultimately, the visible volume. The minimum BBR, given by the design of the dispersing lens and the scattering function of light from the bubbles, is expected to be \( \sim 0.3 \times 10^{-7} \).

(c) The control of laser-induced boiling, which can be subdivided into so-called: (i) microscopic boiling, which occurs during the laser pulse itself, and affects the hologram quality, and (ii) macroscopic boiling, which becomes apparent by fogging over parts of the bubble chamber, when the conventional photographs of tracks are taken some ten milliseconds later.

(d) A high-resolution film (\(~ 2800 \) lines/mm), with: (i) reasonably high sensitivity (\( \leq 10 \) erg/cm\(^2\)), and (ii) unexceptional requirements for development.

(e) A minimum movement (to give optical path length changes < \( \lambda/4 \)) during the exposure of: (i) the equipment (laser beam, bubble chamber, camera) and (ii) the bubbles due to buoyancy forces or change of their size.

(f) An adjustment of the bubble chamber operation conditions such as to have, both at the time holograms and when conventional photographs are taken: (i) the desired (high) bubble density, and (ii) the appropriate bubble size.

(g) A reduction of optical noise, which spoils the quality of the hologram, by the installation of a sophisticated system of venetian blind baffles in the portion of the chamber wall hit directly by the illuminating beam. These baffles catch most of the illuminating beam the first time it hits the chamber wall. Noise, originating from multiple reflections in the dispersing lens system, was reduced by baffles placed between the elements and by their shape.
The requirements (a), (b) and (c) are closely interconnected and represented the main technical challenge. Whereas some macroscopic boiling can be accepted, microscopic boiling harms the quality of the holograms and had to be kept to a strict minimum.

Three approaches have been made to suppress this boiling, which is almost certainly produced by the absorption of light energy by particulate matter:

(a) **Reduction of the laser power density** by extending the Q-switched pulse from the original 30 ns duration to values between 3 and 8 μs, and also by increasing the size of the laser beam at its entrance into the bubble chamber liquid.

For this purpose a pulse-stretching circuit, with feedback and feedforward electronics, was developed, controlling an electro-optic shutter in the oscillator stage. The main characteristics are described in ref. [2], while another paper with the final layout is in preparation [3]. The pulse stretching provided us with the extra benefit of a dramatically increased coherence length in excess of 11 m, as compared to the ~1.5 m of the original Q-switched JK Laser System 2000. The circuit allowed for stretching pulses up to ~100 μs. However, for our purpose, to avoid adverse effects of vibrations, bubble movement and change of bubble diameter during exposure, we could use only pulses up to ~8 μs.

We maximized the size of the laser beam, when entering the liquid, by making the dispersing lens function also as a chamber window with a diameter of 5 cm for the incoming beam and of 19 cm at the glass-liquid interface.

(b) **Elimination of absorbing matter** by mechanical filtering of the bubble chamber liquid.

For this purpose the chamber liquid was circulated successively through 5, 2, 0.5, and 0.2 μm cryogenic filters.

(c) **Reduction of the laser energy requirement** by increasing the sensitivity of the Agfa-Gevaert, Holotest 10E75 film, without loss of resolution.

This was done by using a standard Kodak D-19b developer, to which 1.5 g/l phenidone was added.
The combination of these efforts, together with the design of the two-component dispersing lens, and the proper choice of the bubble chamber operating conditions led to the first successful application of holography in a large liquid volume.

Scanning and measuring of events contained in the holograms is in progress at virtual image replay machines at Fermilab and Rutgers University, and on real image replay machines at the University of Hawaii and the Rutherford–Appleton Laboratory.

3. CONCLUSIONS

Between 1984 and 1988 three runs (one technical and two physics) were made with the 15-foot Bubble Chamber, during which holography was improved and perfected.

During the second physics run 293,000 conventional photos together with 218,000 holograms were taken. We consider the quality of ~ 110,000 holograms as good and useful for physics evaluation. It is estimated that there are in these "good" holograms ~ 3800 v–event vertices with a resolution of ≥ 120 μm (in real space). An example of a replayed hologram is shown in fig. 2. Most of these events had a trigger signal from the Internal Picket Fence (IPF) and the External Muon Identifier (EMI) — electronic counters surrounding the bubble chamber vessel and the vacuum tank, respectively — so that the delay of the laser was fixed to 1 ms, corresponding to bubble diameters between 100 and 150 μm. The minimum BBR of the design of the two-component lens was 0.3 • 10^{-7}, which would have resulted in case of a noise–free illumination in a visible volume of 4.7 m³. Since there was some remaining parasitic light scattered into the hologram, we obtained successfully a BBR of ~ 10^{-7}, resulting in ~ 1.5 m³ visible volume, using laser energies ≤ 6 Joules with pulse durations between 3 and 8 μs, without producing macroscopic boiling.

The success of this holographic experiment was due to a combination of efforts in laser improvement, optical noise reduction, a suitable lens design, and by liquid cleaning, either by active filtering or sedimentation of particular matter on the chamber walls.
Acknowledgements


REFERENCES


FIGURE CAPTIONS

Fig. 1 Layout of the holographic scheme for the 15-foot Bubble Chamber.

Fig. 2 Neutrino interaction, replayed and photographed in an ~ 1: 1 magnification on the HOLRED machine at RAL. The width of the film is 70 mm.