

HOLOGRAPHY IN A FREON BUBBLE CHAMBER:
PRELIMINARY RESULTS FROM THE NA25 EXPERIMENT AT CERN

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1. INTRODUCTION

After the successful holographic test with the Berne Infinitesimal Bubble Chamber (BIBC) in June 1980¹⁾, the next step was to investigate the possibilities of holographic techniques in a real physics experiment. This experiment, NA25, used a freon rapid-cycling holographic bubble chamber (HOBC) as a vertex detector, placed in front of a muon filter providing a trigger for single or multimMuon events²⁾. After some tests in a PS beam in the summer of 1981, the run took place in October 1981 in the H2 beam of the SPS. Although some problems of heat dissipation in freon limited the expansion rate of the bubble chamber, more than 11000 holograms were taken, showing 10 μm bubble tracks, with very good image quality and contrast. More than 100 tracks can be stored on a hologram without affecting the quality if all the bubbles are small. In addition, the analysis of the holograms does not look more complex than the exploitation of conventional high-resolution pictures.

2. THE FIRST OPTICAL SET-UP

The bubble chamber was designed in such a way as to allow the maximum flexibility from the optics side. Direct illumination is possible through two optical windows covering an optical volume of $11 \times 5 \text{ cm}^2$ by 6 cm in depth. More details are given in Hervé's contribution to this conference³⁾.

After some tests on an optical bench, where both the in-line and the two-beam geometries have been tested, the in-line (or Gabor type) holographic set-up was preferred for the following reasons:

- i) It is very simple to adapt to a small bubble chamber of the HOBC type.
- ii) The set-up for the scanning machine is also very simple.
- iii) The required laser power is a minimum for both the recording (about 2 mJ) and the replay of the holograms (1 mW with an optical magnification of 5, which gives a total magnification of about 100 on a TV screen).
- iv) The resolution in the HOBC geometry at 12.5 cm distance from the high-resolution target (USAF 51 Chart) was better than 4 μm . This distance between the film plane and the HOBC centre was chosen as small as possible because previous tests showed a dramatic deterioration in resolution at increasing distances⁴⁾.
- v) The contrast, although slightly worse than for the two-beam set-up, is still very high (much better, for instance, than for conventional pictures). In addition, it can easily be enhanced on the replay machine by very simple suppression of the background with a spatial filter.

The optical set-up for the first tests with the bubble chamber in a particle beam is shown in Fig. 1. The laser is an excimer laser (XeCl) producing 10 ns ultraviolet pulses (308 nm) with an energy of 200 mJ at a frequency up to 30 Hz. This laser pumps a dye filled

with Coumarin 307 in order to select the wavelength of 514 nm fitting the argon line for the replay system, with a maximum output energy of 15 mJ. In fact, the dye amplifier was obscured in such a way as to limit the output energy to 3 mJ only, which was enough to expose the film at a density of 1.3. The film, Agfa 10E56 emulsion on a 170 μm polyester base with antihalo coating, was sucked onto a metallic capstan. Exposed at a density of 1.3 the noise was quite similar to that of 10E56 holographic plates and the signal-to-noise ratio was excellent⁵⁾.

3. EFFECT OF TURBULENCE: MODIFICATION OF THE OPTICAL SET-UP

The first holograms showed that the picture quality had a dramatic dependence on the turbulence in the chamber. As it is obvious that it is hopeless to obtain pictures of a few microns resolution through a turbulent medium with any optical system (classical or holographic), extensive work was done to define operating conditions for the bubble chamber with the maximum liquid stability³⁾. In addition, the effect of the turbulences was analysed in order to define an optical set-up minimizing their influence. The turbulences affect the illuminating wave as it travels to the object, causing a non-uniform illumination of the optical field owing to amplitude variations. The object wave is also distorted, both in amplitude and in phase. Finally the reference wave going through the medium also suffers from phase and amplitude variations, causing an unpleasant background and additional sources of noise at the reconstruction.

However a possible compensation of the variations of the object and of the reference beam exists under certain conditions. A given bubble diffracts useful information in a forward cone, which defines an area on the hologram the diameter of which depends on the distance of the film to the bubble. This area gives also the useful section of the reference beam for this bubble. If this area can be made small compared to the mean turbulence size, both the object and the reference rays are affected by the same phase shifts and the interference pattern is not modified by the turbulences. More details are given in the literature^{6,7)}. The obvious solution is to reduce the distance of the object to the hologram. As this was not possible in our case, owing to mechanical constraints, we decided to use a relay lens of very good quality^{*)} and to take a hologram of the image of the bubbles rather than of the bubbles themselves. In order to keep the reference beam parallel a field lens system was added approximately in the plane of image formation of the first lens; with this configuration the constraint on the optical quality of the field lens is a minimum as only a small part of it is used for a given bubble. In fact the field lens system was made of two converging lenses with relatively large radius of curvature in order to minimize aberrations due to prismatic effects on the edges of the field. The idea to use an afocal system was already mentioned in previous publications^{8,9)}. The new optical set-up is shown in Fig. 2. With this system the distance from the centre of the HOBC to the hologram has been artificially reduced from 12.5 cm to 4 cm.

4. DATA TAKING AND RESULTS

The use of the afocal system dramatically improved the picture quality, especially when the chamber liquid was not perfectly stable. Very good images with sharp bubbles and an

*) This lens was a spare lens of the ERASME system lent to us by H. Anders.

impressive contrast have been obtained with a laser delay of 3 μs . The reconstructed bubble size measured with a microscope was 10 μm (full width above the background). The intrinsic resolution of the system is probably higher than 10 μm , as the bubbles appear round-shaped and sharp (Fig. 3). With a delay of 1 μs , 5 μm bubbles were seen, but not so sharp and with much less contrast; at this level the quality was probably limited by the relay lens which has a frequency cut-off of about 6 to 7 μm .

The 3 μs delay was finally chosen for the data taking. Under these conditions 10,000 holograms with an event trigger and 1150 holograms with a muon trigger have been taken with a bubble density of 200 bubbles/cm for the beam tracks.

Unfortunately the expansion rate of the bubble chamber had to be limited to about 1 Hz. This frequency was imposed by the time needed to evacuate the heat left in the liquid after the bubble recompression which was causing turbulent channels. More details on this problem are given in Ref. 3. A series of holograms were taken at a high particle flux in order to test the storage capability of holograms. Unfortunately we were working in a slow extracted beam with a kicker magnet which had a leak rate of a few per cent. At fluxes in excess of 10^6 particles per second, the probability was high of having a few very old tracks. In the vicinity of these tracks the image quality becomes poor as can be seen in Figs. 4 and 5: in Fig. 4 an event with 10 μm bubbles is still analysable close to a 80 μm old track. In Fig. 5 another event with 10 μm bubbles is hardly visible close to a 200 μm track. However, more than 100 tracks have been stored on some holograms without kicker leaks. In this case the image quality is still very good if all the tracks have bubbles smaller than 50 μm . We just noticed a slight degradation of the signal-to-noise ratio.

5. CONCLUSIONS

The NA25 experiment was an occasion to prove that holography is a very attractive technique for experiments requiring the optimum resolution around the vertex. A 10 μm two-track resolution was easily obtained with very good contrast. The problem of the heat dissipation of recompressed bubbles limited by a large factor the number of holograms taken during the run. However, there is some hope of curing this by changing the operating conditions of the chamber. On the other hand, this effect is probably much less critical in other liquids like hydrogen.

Another advantage of holography is to have the maximum resolution in the full volume in the bubble chamber, which allows a gain in sensitivity by a factor of 10 compared to classical optics as 100 tracks per hologram look reasonable.

Finally, the experience with the analysis of NA25 holograms shows that holograms are not more difficult to analyse than classical optics high-resolution pictures. Of course the optics of the scanning and measuring machine must be carefully set up in order to exploit the maximum quality of the holograms, which is in general very good. For instance, on an optical bench a r.m.s. of 20 μm was measured for the position in depth of 10 μm bubbles.

The BIBC test proved that good holograms can be taken in a bubble chamber. The NA25 experiment has proved that holography is a very powerful technique which is now ready for use in very high resolution physics experiments.

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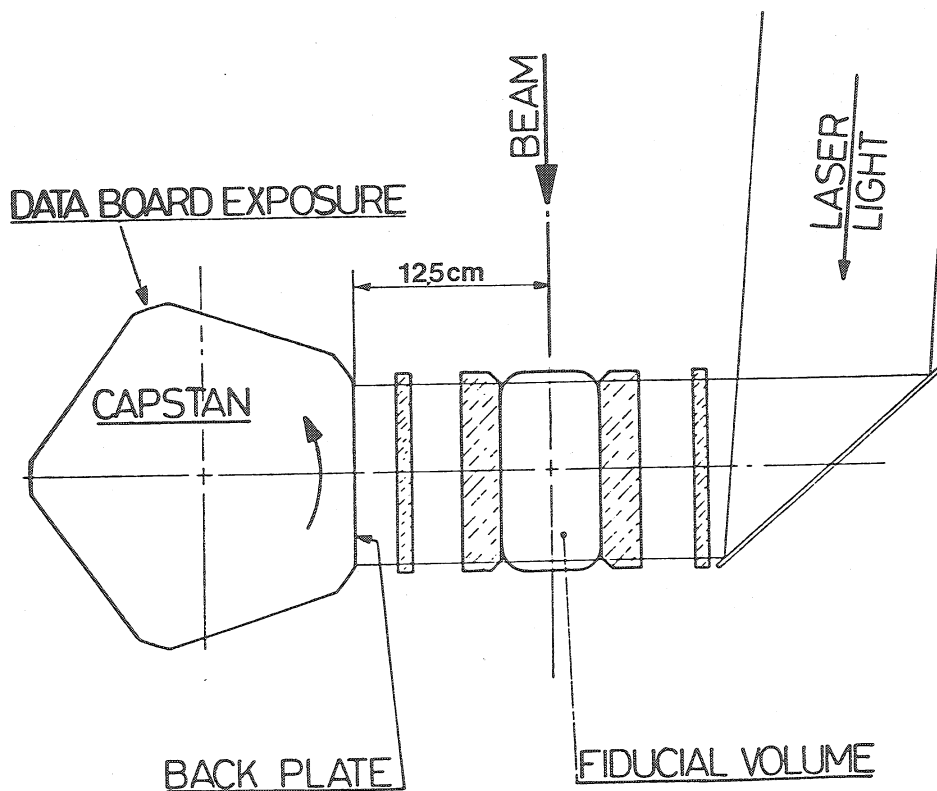


Fig. 1 Optical set-up at the PS beam

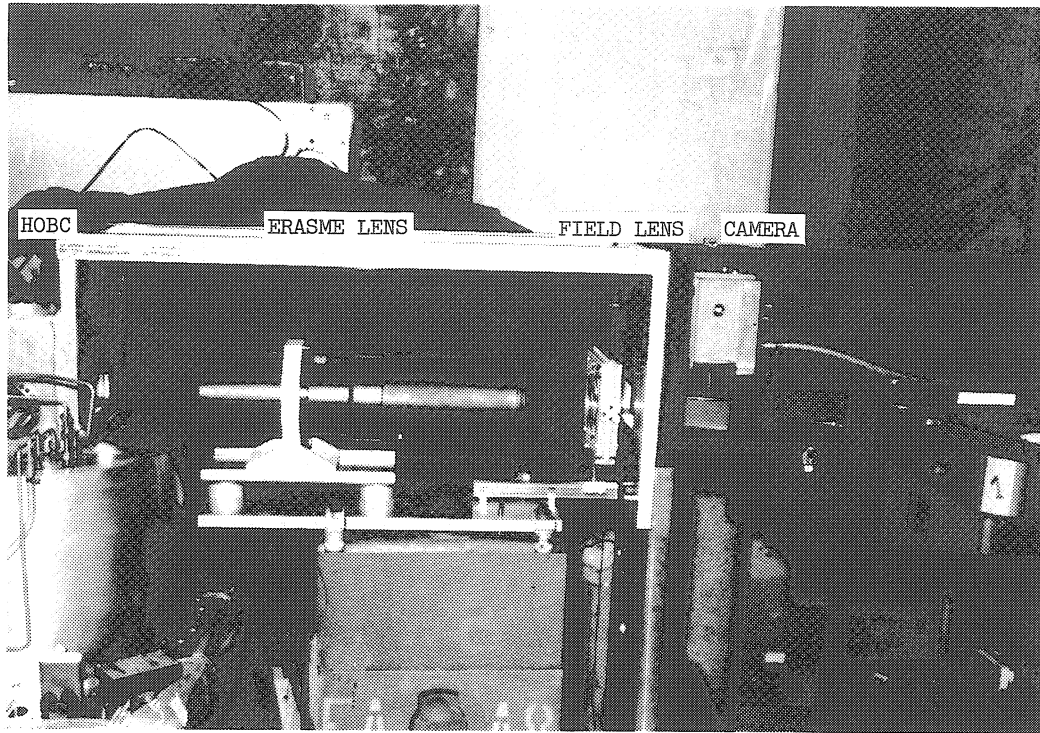


Fig. 2 Optical set-up for the data taking with the afocal system

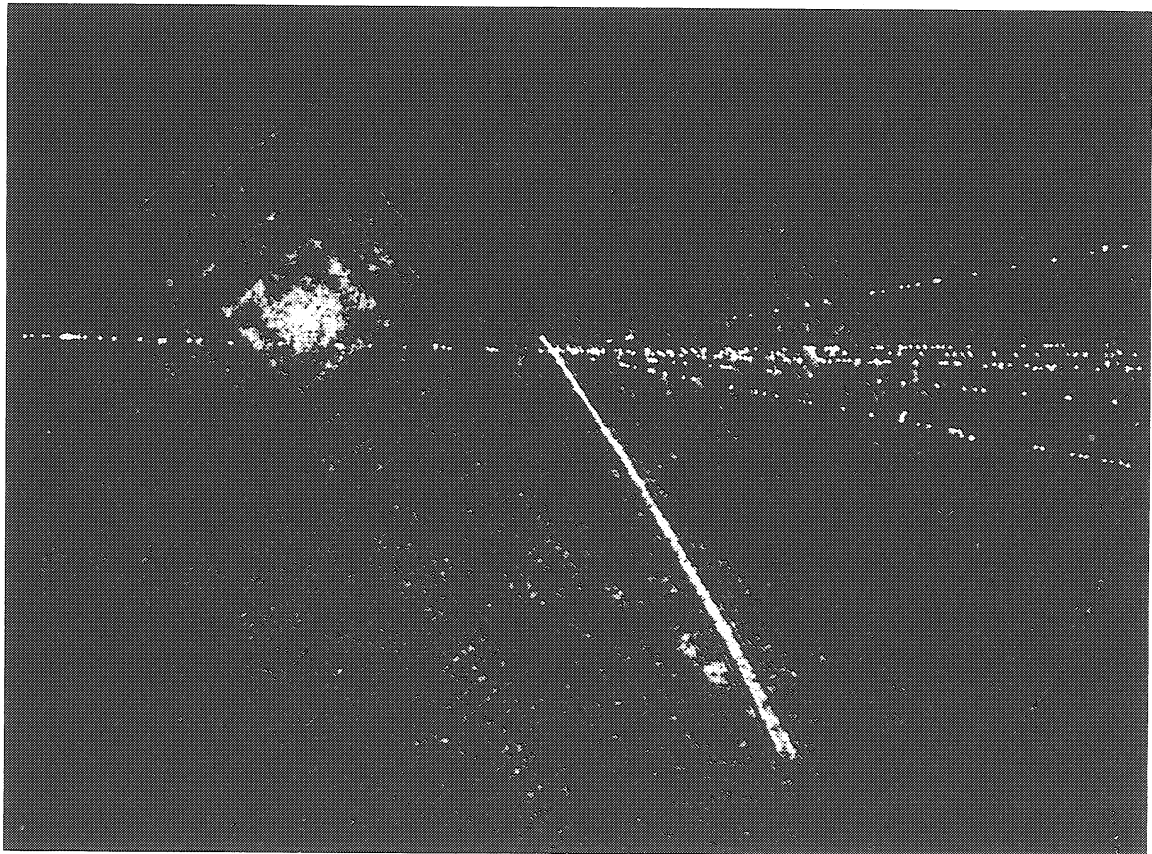


Fig. 3 Typical event with 10 μm bubbles. The picture length is 2 mm.

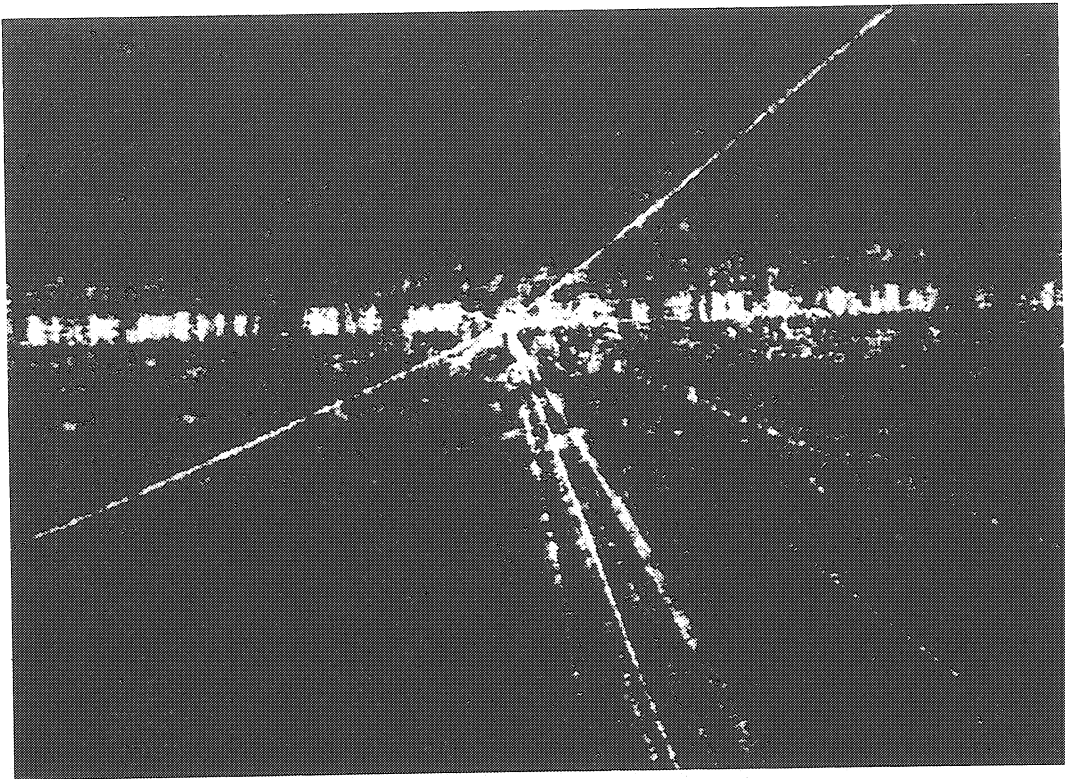


Fig. 4 Event with 10 μm bubbles close to an old 80 μm track

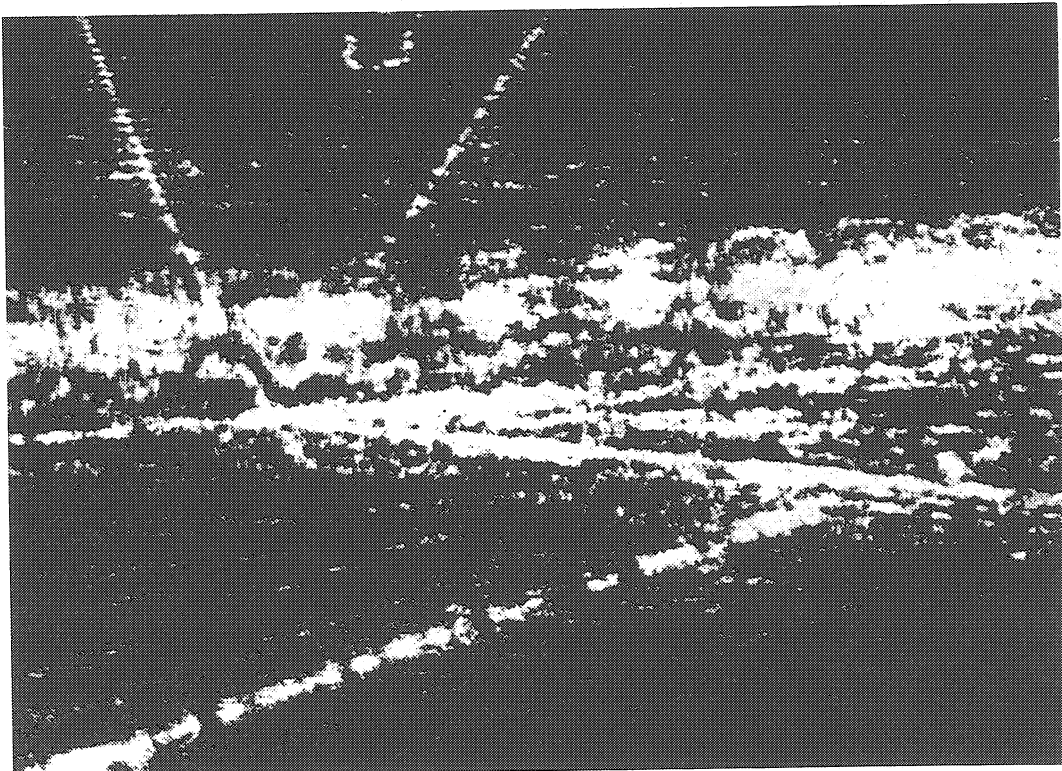


Fig. 5 Event with 10 μm bubbles close to an old 200 μm track