Introduction to the Workshop
“30 Years of Bubble Chamber Physics”

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Abstract

After some recollections of the early bubble chamber times, a brief overview of the golden age of the field is made, including its legacy and the use of bubble chamber events for the popularization of science.

On behalf of the organizing committee I would like to welcome you to Bologna and to this meeting. Several colleagues sent messages apologizing for their absence, mainly because of health problems. We wish them well. Some of them sent short notes on their reminiscences of the bubble chamber golden age [1][2].

The aim of the meeting is to recall the activities connected with the bubble chamber technique, the main physics discoveries, the evolution of the international collaborations, the bubble chamber legacy, and to honour some of the founding fathers, in particular in Bologna and Padova.

Around 1952 Donald Glaser invented the bubble chamber (BC), may be after looking at the bubbles in a glass of beer [2].

Figure 1: The 2”, 4”, 6”, 10”, 15” and 72” bubble chambers built at Berkeley, in the early days of the BC era.
The first bubble chambers were very small, but soon after much larger bubble chambers, filled with different liquids, were built (the increase in volume was about a million times; the largest chambers contained 40 $m^3$ of liquid). Fig. 1 shows several Berkeley bubble chambers of increasing size. In the small exhibit, placed at the entrance of the Academy building, we had an early propane bubble chamber built by the late Piero Bassi in Padova.

Bubble chambers are $4\pi$ detectors of high density, transparent liquid material.

More than 100 bubble chambers were built and over 100 million stereo photographs were taken. While the first BCs took small numbers of pictures the latest chambers took millions of photographs.

It turned out that bubble chambers are very reliable detectors and that they could be easily used in beams of unseparated and separated charged particles of increasing energies. Long time ago our esteemed colleague Charles Peyrou said in his inimitable style: “Cloud chambers are like ladies, very delicate to handle, but bubble chambers are like prostitutes: they will work for anyone”.

Figure 2: One of the early papers published in 1957 by a Columbia, BNL, Bologna, Pisa, Michigan Collaboration.
Bubble chambers needed low intensity high quality beams of charged particles (about 10 particles per pulse); in many cases high voltage separators were used to obtain pure beams of charged K mesons. The refined high energy muon neutrino beams needed all the proton intensity they could get.

The list of discoveries and of the studies performed over 30 years with the bubble chamber technique is impressive: new particles and new resonances, high energy hadron interactions, neutrino interactions, new particle searches, ... Fig. 2 shows one of the earliest papers [3]: “Demonstration of parity non conservation in hyperon decay”: the experiment was performed by 4 teams from the US and Italy, [20 physicists in total]: the Columbia-BNL team was headed by Jack Steinberger, the Bologna team by Gianni Puppi and the late Piero Bassi, the Pisa team by the late Marcello Conversi and the Michigan team by Donald Glaser, the inventor of the bubble chamber.

Another early experiment used a liquid helium BC built at Duke University: Fig. 3 is a photograph of two important physicists, Martin Block and Gianni Puppi: notice how young they are!

The sociology of bubble chamber collaborations was an interesting one. After an initial period when many small chambers were built almost everywhere, medium size BCs took relatively few pictures which were mainly analyzed by the “in-house” groups; later the new larger bubble chambers were built and run by groups of experts in large laboratories, using refined beams at increasing energy accelerators. These chambers were considered facilities to be used by internal and external groups. This started the international collaborations, usually with several groups from different countries and a total number of physicists between 20 and 50. But the role of large laboratories, like CERN and Fermilab, was always a central role.

Figure 3: Photograph of Martin Block and Giampietro Puppi at the end of the 1950’s when they were collaborating in experiments with the Duke helium bubble chamber.

The early bubble chamber era was dominated by U.S. groups, Berkeley and the Alvarez group in particular. CERN arrived later, but the 80 cm Saclay bubble chamber, the 2m BC and BEBC took an incredible number of pictures, analyzed in very many European and
non European Universities.

In Italy the bubble chamber technique lead to a revival of fundamental research in particle physics, with proficuous cooperations between Departments of Physics and Sections of INFN (the National Institute for Nuclear and Subnuclear Physics). Later the CNAF-INFN center in Bologna played a central coordinating role for precise measurements and for central computing. It may be worthwhile to recall that every team started scanning and measuring bubble chamber photographs with almost primitive equipment, like the template that you may see in our small exhibition.

![Figure 4: A group of bubble chamber scanners (osservatori analisti) in Bologna.](image)

Later digitized tables were constructed and one started to hear of “Mangiaspagos” in Italy, of more elaborated semiautomated or fully automated “Frankensteins” and PEPRs in the U.S., MYLADYs and HPDs in Europe.

A large number of Scanners (called Osservatori Analisti in Italy) was needed to cope with the increasing number of photographs, with more precise measurements and of pre-measurements. Most scanners were pretty young girls, like those in Fig. 4.

Computing. At the very beginning of the BC era the Slide Rule was the “most powerful computer” (Fig. 5) and soon after electromechanical calculators (Fig. 6). But soon the IBM650 computer and, immediately after, more and more powerful computers started to be heavily used. The measured coordinates of points along the tracks were initially punched on cards manually, later automatically by semiautomatic projectors. The installation of mainframe computing capacity was driven by the demands of bubble chamber physics: the CERN mainframe central computers increased their capacity and speed by over a factor of 1000 during the bubble chamber era.

Various types of specialized bubble chambers were also built. Rapid cycling BCs, high resolution BCs, holographic BCs. Prof Gigli from Pavia built his “soda pop” bubble chamber [“camera a gazosa”] which behaved quite nicely. The latest and largest BCs needed electronic detectors, like the External Muon Identifier for BEBC at CERN (Fig. 7) and for the 15 foot BC at Fermilab.

The bubble chambers lead to the discovery of very many resonances, strange and non-strange [2]; together with the results of simple and complex electronic experiments [4, 5] they
cleared the situation of the hadron spectrum. Bubble chambers were $4\pi$ detectors. Instead most of the early electronic experiments covered small solid angles, but progressively they grew bigger, covered larger solid angles and eventually became $4\pi$ detectors, like all the LEP detectors [6] and the LHC detectors [7]. The bubble chamber experiments initiated on a relatively large scale the symbiosis between large laboratories, like CERN and Fermilab, and their community of users.

The main scientific legacy of the bubble chamber to our understanding of the microworld of particle physics can probably be summarized as follows [1] [2] [8]:
- Discovery of several strange particles, like the Omega minus.
- Discovery of many meson and baryon resonances which lead to the knowledge of the hadron spectrum $\rightarrow$ SU(3) $\rightarrow$ constituent quarks.
- Discovery of the neutral weak current $\rightarrow$ electroweak unification.
- Scaling in neutrino-nucleon deep inelastic scattering $\rightarrow$ partons $\rightarrow$ dynamical quarks.
- Neutrino-nucleon scaling violations $\rightarrow$ support to QCD.

Popularization of High Energy Physics and public understanding of science started to be an important part of physics: selected bubble chamber photographs provide a global and intuitive view of particle physics phenomena; an unprepared audience and young people start to realize immediately that our field is based on simple and intelligible experimental
Figure 6: A "Monroe" electromechanical desk calculator.

Figure 7: The Big European Bubble Chamber (BEBC): the 3.7 m liquid container is shown at the top of the left figure, while it is being lowered into place; the right picture shows the body and in particular the expansion piston at the bottom. On the left, BEBC is shown with the external muon identifier composed of a set of electronic detectors. The superconducting coil is before the electronic detectors. BEBC, filled with $H_2$, $D_2$ or H/Neon was used mainly with neutrino beams.

facts [8] [9] [10]. Selected bubble chamber pictures (like those in Figs. 8, 9, 10, 11) can also be used at the beginning of courses on particle physics.

The bubble chamber era lead to a large number of publications in many refereed scientific Journals. The publications from the various Bologna bubble chamber groups are quoted in [3] [11-95].
I would like to thank the members of the Advisory and Organizing Committees, the Bologna Academy of Sciences, the Secretariats, the INFN Multimedia group, the colleagues who participated to the workshop and those who sent notes and recollections, and many other people. In particular I thank Dr. A. Casoni and Dr. M. Giorgini for their invaluable collaboration.

Figure 8: A bubble chamber event: creation of a positron-electron pair by a photon in the Coulomb field of an electron; the electron emits, by bremsstrahlung, a $\gamma$ ray which eventually converts into a positron-electron pair in the Coulomb field of a proton [4].

Figure 9: A low energy $K^+$ meson scatters elastically, $K^+ p \rightarrow K^+ p$, at the center of the photo: the $K^+$ incoming from the left scatters elastically from a proton of the hydrogen bubble chamber; the scattered $K^+$ goes forward, while the hit proton recoils at about $90^\circ$ and has a small energy, so that it stops in the chamber (BGRT Collaboration).
Figure 10: A decay chain. A low energy $K^+$ incoming from the left decays in the center of the photograph, $K^+ \rightarrow \pi^+\pi^0$; the $\pi^+$ stops and decays, $\pi^+ \rightarrow \mu^+\nu_\mu$; finally also the $\mu^+$ decays, $\mu^+ \rightarrow e^+\nu_e\bar{\nu}_e$ (BGRT Collaboration).

Figure 11: A multiprong charged hadron production event produced by an incoming high energy proton (CERN photo).

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