# The season of the hybrid experiments

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## 1 Introduction

In this paper I will try to recall the years when I first knew Giordano Diambrini Palazzi, and then worked with him in experimental activities. I titled this paper "the season of the hybrid experiments" because it is for such experiments that I had the opportunity and the pleasure of interacting with him. These experiments represented a significant scientific line for the *Istituto Nazionale di Fisica Nucleare* (INFN) and a remarkable commitment for its *Sezione di Roma-1*[1].
The word "hybrid" has been, and still is, used for various types of experiments and detectors. In the following, I will refer to experiments dedicated to heavy quark (charm and beauty) searches with "hybrid" techniques, i.e. with the use of imaging and electronic techniques. In particular, I will discuss the Giordano's contribution to this activity in the decade between 1975 and 1985.

These experiments were largely conducted at CERN, using nuclear emulsions as imaging detectors and with the participation of the emulsion group of Rome, whose I was a member. Inevitably the scientific path reported here is influenced by this viewpoint and by personal memories. I apologize for any inaccuracy.

## 2 The "emulsion" group of Rome

In the years (1970 -1975) before the beginning of hybrid experiments, the Rome emulsion group was lead by Giustina Baroni, with whom I began my scientific activity since my thesis work. At that time, the group was facing a decline due to two different reasons:

[1]From now on I will refer only to *Sezione di Roma*, as at that time *Sezione di Roma-2* and *Sezione di Roma-3* were not existing yet.

- the first one, scientific, was due to the competition with bubble chambers. The two techniques competed in the field of hadron physics. The better spatial resolution of the emulsions did not compensate for the ability of bubble chambers to operate in magnetic fields, with the consequent measurement of charged particles momenta. Both techniques made use of technicians ("scanners") specialized in visual search and measurement of events, but because of the different scanning tools (microscopes for emulsions - projection tables for bubble chambers) emulsion measurements were necessarily slower.

- the second reason concerned the availability of human resources. At that time the "scanners" of emulsions and bubble chambers constituted a considerable part of the total technical resources of the *Sezione di Roma*. Due to the reduction of the scientific perspectives of the emulsion groups, other experimental groups were requesting for conversion of emulsion "scanners" to another job (mainly to bubble chambers scanning).

In spite of this unfavorable situation, Giustina succeeded with tenacity to keep the integrity of the group. This was possible mainly as a result of the historical and scientific prestige of the emulsion group of Rome, who always represented excellence in the national and international context[2]. Moreover, emulsion groups had traditionally good links through international collaborations often lasting beyond the individual experimental activities. This was largely determined by the fact that the achievement of adequate statistical data samples required a large number of "scanners", put together only through the collaboration of various groups.

In this context a major relief arrived in 1972 with the new proton beams of 200 and then 300 GeV at Fermilab (NAL at that time). As it always had happened for each new accelerator, a stack of emulsions was exposed to an extracted beam to study the inclusive properties of nuclear interactions at the new energies [1] (charged multiplicity, distributions and correlations of pseudo-rapidity). However the revival of emulsions seemed to last only a short time, because other experiments began programs with hadrons (and later with neutrinos) at Fermilab and then at CERN-SPS, with detectors more selective and able to collect higher statistics.

At this point, something unexpected happened: in 1974 the charm appeared on the stage [2]! The search for hadrons with quark $c$ seemed well suited for the nuclear emulsions, because the expected lifetime is of the order of $10^{-13}$ s, corresponding to sub-millimeter decay lengths. At this scale there were no competitors in those years and one might expect that the emulsions play for the charm the same role of bubble chambers for the $s$ quark.

[2]Members of the group have been, in particular, E. Amaldi, C. Castagnoli, G. Cortini, C. Franzinetti and A. Manfredini.

The opportunity was taken and an initiative started to search for charm in interactions of 300 GeV protons at Fermilab [3]. The emulsion group of Rome took part in this new initiative, which however was unsuccessful, though analyzing 60,000 proton interactions. The reason was simple: the search was based only on "brute force", consisting in an "area scanning"[3] search of decay topologies, with a (too short) depth of 150 $\mu$m downstream of the primary vertex of the interaction.

However one learned something interesting from the experiment: emulsions are ideal for charm search, but given the expected low yield, a more selective approach is needed. To this aim two approaches have been pursued, differing in the charm production:

1. by neutrinos (by Giustina Baroni and Marcello Conversi);

2. by photons (by Giordano Diambrini Palazzi).

These choices led to the birth of the "hybrid" experiments.

# 3 Hybrid experiments for charm neutrino-production

The idea of using neutrinos is suggested by physics. The charm production is highly efficient as long as the neutrino beam spectrum (necessarily broadband) contains energies above the threshold for production of charmed hadrons: the expected ratio between charm events to all the charge current events is of the order of $sin^2\theta_C$ (with $\theta_C$ the Cabibbo angle), i.e. about 5%. Then it is much more effective than in associated charm production from hadrons, which is less than one in a thousand.

However, with neutrinos there is a big disadvantage: the number of neutrino interactions is proportional to the mass of the target and their positions are equally probable in the whole volume. This seems to instantly kill the idea originated from physics: the emulsions allow you "to see" the charm through the observation of its decay into a very small volume (the event, including production and decay, has an extension $\mathcal{O}$(mm) in the beam direction), but a search for this volume is prohibitive in a huge target. Neutrinos and emulsions appear to be *incompatible*!

Yet Eric H. S. Burhop already explored the idea of searching for neutrino interactions in emulsions, and demonstrated its feasibility in a pioneering test [4] in

[3] The two main methods of emulsion scanning are the "track following" and the "area scanning". In the first one track of the primary particle is followed up from the entrance to the point of interaction (or decay). In the second method the interaction (or decay) in a pre-determined volume is searched for. The first method has a high efficiency, largely independent of the length. The second becomes progressively inefficient with the increase of the volume.

1965. In those years the charm did not exist yet, not even as a theoretical hypothesis [5]. The motivations for the test are: "Using nuclear emulsion it should be possible in favorable cases to distinguish secondary interactions or decays occurring within 1 $\mu$m of the primary interaction." The localization of neutrino interactions (from the PS-CERN beam) has been achieved reconstructing the vertices from the tracks of a spark chamber, located downstream of the emulsion target. Four neutrino interactions (out of expected seven) were identified and studied.

In '75 Burhop's concept of a hybrid detector was resumed for the charm search in neutrino interactions. The new idea reached Rome, even if I cannot easily reconstruct through which channel. I think it came through the emulsion groups in Brussels (led by J. Sacton) and London-UCL (led by D. H. Davis), who had participated in the Burhop's neutrino test and in '75 were collaborating with Rome in the search for charm in proton interactions. The new group designed a new hybrid apparatus using the same kind of localization (a "Wide Gap" spark chamber as vertex detector), but with some limited analysis capabilities for the downstream particles, to confirm the charm signature. The latter consisted finally of a shower detector (sandwich of lead and small gap spark chambers) and a rudimentary muon detector (lead wall before a scintillator hodoscope) for the charged currents.

Therefore the emulsion groups who were already collaborating in the proton-charm search needed to seek collaborators outside their community, to build these detectors. It appeared clear that Rome might exert an important role in this phase. Carlo Bernardini, at that time director of the *Sezione di Roma*, encouraged people to take this opportunity and invited the group of Marcello Conversi to become one of the "electronic" groups of the Collaboration. In my memories the formation of the mixed group in Rome went through initial mutual suspicion, but with the tenacious support of Carlo. In fact both Giustina and Marcello saw initially very unnatural the mixture of different techniques such as emulsions and electronic detectors. Today, the term "hybrid" is universally accepted and is commonly adopted in the current experimentation, but at that time it appeared almost a heresy. In addition the "hybrid" approach required the establishment of a collaboration among groups used to very different methodologies.

Apart from these general aspects, I remember Giustina watched with some anxiety the search for interactions with the "area scanning" method, as compared to the safer and usual "track following", always used with charged hadrons. On the other side Marcello was awed for the crucial role of the emulsions in this research: he did not comprehend the details and felt alien to the methods of emulsion handling (preparation, development, scanning, etc.) and analysis. To summarize his feeling he often referred in jest to emulsion people as the "emulsion mafia".

At the end the experiment, named E247, ran at the Wide Band Neutrino Beam at Fermilab and led to the observation of the first example[4] of a charm particle decay [6]. E247 may well be considered the initiator of the "hybrid season".

In the observed decay, a charged particle decays into three particles 182 $\mu$m away from the neutrino interaction. The event is complemented by the observation of the muon and of a possible $V^0$ decay at 30 cm (likely a neutral strange hadron decay), reconstructed by combining the tracks in the Wide Gap chamber and the shower detector. The lack of spectrometry and of neutral detection in the apparatus prevented from the identification of the charmed hadron. No other decays, out of 37 localized interactions, have been observed. The analysis of the found interactions clearly showed a possible event loss as the distance from the vertex detector increases. This was due to the multiple scattering in emulsion and the modest quality of the vertex detector. This led to a search volume too large (about 30 cm$^2$ per event in 600 $\mu$m thick emulsion plates) for events too elusive (lower charged particles multiplicity and less tracks by nuclear evaporation than in hadron interactions) for a search based on area scanning .

The experiment showed that the method was correct, but a better vertex reconstruction and, above all, a magnetic spectrometer would have been required for a possible identification of the charmed particles. Conversi, who in the meantime became an enthusiast of the hybrid approach, identified in BEBC, the large hydrogen bubble chamber at CERN, the apparatus that could, at the same time, serve as a vertex detector for emulsions and provide the necessary good quality spectrometry for charged particles. BEBC, which was operating on neutrino beams, was also instrumented with an EMI (External Muon Identifier), placed downstream outside the bubble chamber for the reconstruction of muons from charged currents. For the design of the hybrid apparatus Marcello relied on the collaboration of Guido Ciapetti and part of the bubble chamber group of Rome, who already had gained experience in BEBC and participated to activities on neutrinos. In this way the WA17 collaboration was formed, composed largely by the participants to the Fermilab E247 experiment, with the addition of the bubble chamber groups of Pisa and Rome and the emulsion group of Turin.

The most delicate aspect of WA17 concerned the positioning of the emulsion stack. The beam entrance window of BEBC allowed, through an aperture made in the thick iron screen surrounding the chamber, the insertion of the large stack of emulsions at a distance of about 40 cm. To minimize the space for back-tracing charged particles from BEBC to emulsions, a wire chamber was inserted to allow the reconstruction of the space points of tracks in the dead space between the sensitive volume of the bubble chamber and the emulsions[5].

[4]A Japanese group (led by K. Niu) had observed in 1971, in emulsions exposed to cosmic rays, an event which has been later interpreted as due to the decay of charm.

[5]The chamber had the main purpose of inter-calibrating the coordinate systems internal and external to BEBC, to correct for the motion of the liquid during expansion. The use of space

The experiment WA17 [7] ran in 1977, taking data in the SPS Wide Band Neutrino Beam. 169 charged current interactions were located in emulsion with a corresponding reconstruction in BEBC. Compared to its predecessor E247, the reconstruction accuracy has been improved notably (the events were found with a standard deviation of 1 mm orthogonal and 8 mm along the beam) and, for tracks entering the sensitive volume of BEBC, charge and momentum were determined. Among these events 8 decays were found: 3 charged particles in 3 branches, 3 neutral particles in 2 branches, 2 charged particles in 1 branch. In the first class, a decay has been unambiguously recognized, for the absence of neutral particles, as $\Lambda_c^+ \rightarrow p + K^{*0}$. Moreover, using a statistical method based on the impact parameters of decay particles, the lifetime of the inclusive charged and neutral charm particles has been also measured.

After the success of WA17, a new run with a higher sensitivity to be obtained approaching the emulsions stack to the bubble chamber was considered. However the program was not continued. The main reason was the growing activity with the *Rapid Cycle Bubble Chambers* on hadron beams at CERN. These bubble chambers allowed a sub-millimeter resolution and a high repetition rate. A new hybrid line, the EHS (European Hybrid Spectrometer), started with this new technology and then the approach with neutrinos was considered outdated.

# 4 Hybrid experiments for charm photo-production

In a period partially overlapped to the one described in the previous section (starting from '78), Giordano Diambrini Palazzi started a new approach to the "hybrid" search for charmed hadrons. The idea is summarized in two concepts:

- production by photons,
- use of a magnetic spectrometer with identification capabilities: Ω in SPS West Area.

The first choice was in line with the previous experience by Giordano with photons. But this is in some way only an "affective motivation". The production by photons allows collecting a statistical sample much more ample than with neutrinos. The search for charm candidates was possible thanks to the offline selection criteria based on the spectrometer analysis (charged particles multiplicity, average transverse momentum).

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points in the back-tracing of the charged particles instead turned out to be partially inefficient, due to the low energy charged particles that, spiralizing in the high magnetic field, produce many hits in the wire chamber.

The most interesting aspect of Giordano's approach concerned the location of events in emulsion. In fact, with the use of a photon beam, the volume of intersection between the beam and the emulsion could be greatly reduced. The electromagnetic interactions of photons were easily distinguished from hadron interactions, but they constituted the limiting factor to the beam exposure. For this purpose a mobile system was designed, consisting of a cart placing a single emulsion plate on beam in correspondence to the burst of photons. The emulsion was exposed with a small angle of inclination with respect to the beam direction, so as to allow enough paths for the analysis of tracks produced in the hadron interaction. The high spatial resolution provided by the reconstruction of the spectrometer $\Omega$ allowed the localization of the primary vertex with great precision. The spectrometer finally allowed to select the hadron interactions with the request of a minimum charge multiplicity of four particles.

At the used beam energies (a tagged photon beam of 20-70 GeV) the number of charmed events is of the order of percent of hadron interactions. A further advantage of photons is given by the associated production of $c\bar{c}$ pairs, which provided an extraordinary signature, once two sub-millimetric decays were observed in the same event in emulsion.

Giordano was developing these ideas while he was at the University of Genoa and (as it also happened in Rome, at the beginning of the hybrid experiments) started collaborating with the emulsion group of Genoa, led by Giovanna Tomasini. Even in this case the group had connections with other emulsion groups in Italy and in Europe. In this way the Photon Emulsion Collaboration was formed.

The first result of this collaboration consisted in the observation of a neutral decay reconstructed as $\overline{D^0} \to K^+\pi^-\pi^+\pi^-$, with a decay time of $(2.26 \pm 0.05)\ 10^{-14}$ s (WA45 experiment [8]). The event did not show the associated charmed hadron. This so short lifetime led initially to envisage shorter mean lifetimes than observed in WA17; yet this observed time was due to the too short available path ($\sim 3$ mm), being the tilt of emulsions about 11°. This fact also explains the failure to observe the associated production.

In a new emulsion exposure, with the WA58 experiment, the set-up has been improved increasing the path along the beam (6 mm with an angle of 5°). Meanwhile, the spectrometer has been upgraded. It became $\Omega$' with the insertion of wire proportional chambers replacing the spark chambers, plus other improvements. These innovations were fruitful, leading to seven published articles [9] about charmed hadrons lifetimes, branching ratios of the decay modes, and the cross section of photo-charm production. Surely the most interesting result is the first direct observation of the associated production of charmed hadrons and their decay. A total of 42 decays collected from primary charged particles and 44 from neutral particles have been measured, together with some $D$ mesons and $\Lambda_c^+$

branching ratios.

Apart from highlighting the success of this search, I would like to review a couple of aspects of the experiment, which influenced hybrid experiments to come. As I discussed above, the charm photo-production poses a severe limit to the exposure of the emulsions on the beam. The handling of the emulsions introduced by Giordano, with all aspects related to the positioning accuracy, has been an indispensable requirement in the forthcoming hybrid experiments (beauty in hadron production). The other aspect concerns the use of inclined emulsions, that is a precondition, in some way, to the use of emulsions in a vertical stack and has been subsequently well established, especially in the case of large masses as in neutrino experiments (see last section). With tilted emulsions, and even more with vertical ones[6], the event search is more difficult, unless it is done by experienced personnel or with assisted instrument measurements. The finding efficiency greatly depends on the quality of the emulsions, primarily on the grain density per unit length of the minimum ionizing particles, since this parameter determines their observability. At the time of these experiments emulsion groups that traditionally used Ilford emulsions, complained the worsening of emulsions. I remember that for this reason Giustina Baroni looked with distrust at exposures of emulsions that were not horizontal. The success of Diambrini's approach with tilted emulsions has also been made possible by the use of emulsions NIKFI, made in USSR and provided by the Moscow group that was part of the Photon Emulsion Collaboration. These emulsions had superior characteristics with respect to Ilford.

## 5 Towards the search of beauty

In the scenario described in the previous section it appears the fifth quark, $b$ [10], called *beauty* or *bottom*. Here I will use the term beauty because this was more common in those years at CERN.

The first idea to use a hybrid approach is due to Paul Musset. In 1979 Musset, who had a leading role in the realization of Gargamelle, the heavy liquid bubble chamber where the first neutral current interactions were observed, was the leader of a CERN group with considerable experience and was aiming to undertake new initiatives due to the (premature) shutdown of the bubble chamber activity.

Musset's interest towards hybrid experiments started in a different way. In fact, in '78 he had proposed a feasibility test with a stack of emulsions immersed in Gargamelle liquid. This test, carried out with the help of a group of WA17 collaborators, aimed towards a new hybrid experiment searching for charm, with Gargamelle replacing BEBC, with clear advantages in the reconstruction of neutral

[6]Since long times Japanese groups made experiments, in cosmic ray physics, with "emulsion chambers" in which the tracks were observed almost vertical.

particles. The sudden breakdown of Gargamelle and the first evidence of beauty then brought Paul Musset to propose a hybrid experiment on hadron-production of beauty, contacting the WA17 groups for a new collaboration.

The requirements to search for $b$ decays are similar to those that had indicated emulsions as the ideal detector, i.e. the direct visualization of the decays. Here the search is much more difficult due to the expected low rate of $b\bar{b}$ pair production in hadron interactions. But the favored decay of $b$ into charmed hadrons and the expected muon branching ratio for the $b$ and $c$, of the order 10%, suggested that multi-muon events are significantly enriched in $b\bar{b}$ pairs. With this basic concept the apparatus was constructed in an extremely simple way: a production section, consisting of the emulsions surrounded by tracking gas detectors, for the incident beam and the secondaries of the interaction, followed by a muon detector, consisting of wire chambers and scintillator hodoscopes, after a thick dump, for the absorption of hadrons, electrons and photons.

The experiment NA19 was assembled and took data in a very short time. Musset succeeded to efficiently use detectors from decommissioned experiments: the EMI MWPC's of Gargamelle for the muon chambers, and the centroid chambers of UA4 as beam tracker. The event selection has been based on a request of at least three reconstructed muons in the muon detector.

The most delicate aspect concerned the coupling between the emulsion and the rest of the apparatus. Here we find the first example, among hybrid experiments searching for $b$, of the larger complexity of the detector "hybridization", compared to the apparata for the charm. In fact, given the low yield of the signal events, emulsions had to be exposed to the maximum flux limit of the incident particles, while reducing the search volume. This was made moving the emulsion stack through the beam by a stepping motor and collecting a density of tracks of nearly 900 particles/mm$^2$ for each position ($\times 2$ rotating the stack of 180° for a second exposure). On the other hand the scanning volume was considerably reduced in the direction orthogonal to the beam, due to a resolution of about 150 $\mu$m determined from the upstream chambers, though being of the order of cm in the beam direction. The number of interactions with three reconstructed muons was 171 events out of $\sim 2 \times 10^9$ incident (350 GeV) $\pi^-$, and $3 \times 10^8$ interactions. But there were on average 25 interactions in the scanning volume. It is true that the topology of the decays was very clear (cascade decays within some mm), but it was a much more complex search than that for charm.

NA19 could not find beauty candidates in its search, but set an upper limit to the production cross section of 90 nb (90% CL) for a lifetime of $10^{-13}$ s [11]. There are some specific reasons to explain the negative result, apart from the natural youth defects of the first attempt. Firstly, initial estimates of $b\bar{b}$ production cross section were considerably overestimated, secondly also the lifetime of hadrons with

$b$ was in part underestimated ($10^{-14} \div 10^{-13}$ s) with respect to the one subsequently measured.

The experiment, however, taught that the search for beauty needed more sophisticated hybrid experiments, such as those illustrated in the next section. As a final remark I want to notice that in the experiment of Musset appears a new component that will play a leading role in all hybrid emulsion experiments that will follow: the Japanese groups. In fact, the group of Nagoya (led by K. Niu) joined the collaboration bringing innovations that will be crucial for the future: the exposure of a (minor) part of emulsions (Fuji), vertically to the beam, with a corresponding search and measurement with automated microscopes.

## 6 The hybrid experiments to search for beauty

The search for beauty in hybrid detectors therefore requires more sophisticated equipments. The collaboration led by Paul Musset then proposed a second-generation experiment. But also Giordano Diambrini Palazzi addressed his interest towards the beauty search. In fact, the activities of the Photon Emulsion Collaboration were coming to an end. Both groups brought their experience from the previous activities in these new projects.

This scenario had an important influence in the activity of the *Sezione di Roma*. In '83 Giordano moved to the University of Rome "La Sapienza". Then, while continuing his work on charm (WA58), started thinking to an evolution of the design - emulsions plus $\Omega'$ - which could be used in the search of beauty. As a consequence he got in touch with Giustina Baroni, who already participated with Musset in the other hybrid beauty project, asking for an involvement of the emulsion group in the new project. After some initial hesitation, Giustina came to the conclusion that her group was big enough to face both activities.

Almost at the same time the two collaborations have been formed: WA75, from the former NA19 with the strengthening by Japanese groups, led by Paul Musset, and WA71, from the former WA58 with the addition of Rome, led by Giordano Diambrini Palazzi. The two experiments had common aspects, but also differences that turned out to be crucial. In both, the emulsions were dedicated to the topological search of $b$ decays and surrounded by trackers upstream and downstream. But the different event selection made them playing a partially different role.

Common features to both experiments can be found the interaction section. Silicon microstrip detectors were present in both apparata, with spacing from 50 to 200 $\mu$m, both upstream, for the tracking of the beam particles, and downstream, as vertex detector (VD). Due to their limited angular acceptance, the VD microstrips have been complemented with MWPC chambers in WA75, and with a TPC in WA71.

The exposure of the emulsions to the beam was inspired to the concepts developed in the previous experiments. In WA75 the emulsion stack (mostly exposed vertically and only partly parallel to the beam) was moved by a target mover, but some innovations were introduced to facilitate the accurate inter-calibration between the reference systems of the emulsions[7] and the tracking apparatus, as the beam spots (obtained stopping the target mover in known positions) and the X-ray gridding. WA71 designed a new mobile system consisting of a cart carrying emulsions to the beam line in correspondence of the burst. In this case the stack became vertical, to be compared with the exposure almost horizontal in WA58, with very stringent requests for the accuracy, due the proximity of the detectors placed upstream and downstream (see below).

WA75 [12] has been again based upon muon event selection adding the analysis of muons, after an iron dump with a central core of tungsten. Compared to NA19, the magnetic spectrometer, with wire chambers and drift chambers at the entrance and exit of the magnet, allowed a selection on the muon transverse momentum and obviously on its sign, permitting the release of the condition on the number of muons. The selection requested a muon with $p_T > 1$ GeV/c or two muons of the same sign, with a good association between the VD and the magnetic spectrometer. For a second part of the run (1984) the dump was replaced by the Fe-U hadron calorimeter of WA78 [13], allowing the addition of a condition on the missing energy, associated to the neutrinos involved in semileptonic decays, in the selection of events.

WA71 [14], which used the upgraded $\Omega'$ spectrometer (improved with a new electromagnetic calorimeter and a RICH detector for event reconstruction and particle identification), adopted instead a different approach for the selection of $b\bar{b}$. It was based on a silicon telescope (Charm Decay Detector) of small dimensions ($\sim 1$ cm), very close to the emulsions, to detect the multiplicity jump of charged particles caused by the decay of charmed hadrons associated to the $b$ decays. This detection imposed that the space between the emulsions, where the primary vertex with $b\bar{b}$ occurs, and the CDD to be very small. This was realized using only two vertical emulsions (1.2 mm total thickness) positioned less than one millimeter away from the CDD

This brief description of the selection underlines a deep difference in the use of emulsions. In fact in WA75 emulsions have been used for the observation of the event in its whole extension, that is to include the cascade decays of beauty and charm. Emulsion stacks 1.8 cm deep (along the beam) in the vertical exposure and 4 cm in the horizontal one were used. Instead in WA71 the selection of the charm in CDD constrained the observation of the $b$ decays in less than about 1 mm,

[7] The emulsions undergo a significant contraction of their initial thickness due to the development process.

consequently reducing the efficiency of observation of associated $b\bar{b}$ production.

WA75, apart from other by-products (mainly on charm physics) that I do not discuss here, achieved the observation of an event with associated production of $B^-\overline{B}^0$ mesons decaying into charm [12]. The tracks of the primary and secondary particles have been observed in emulsions (horizontal exposure) for an extension of about 1.3 cm from the interaction to the last decay. The muon that resulted in the selection of the transverse momentum (1.9 GeV/c) was associated to a $B^-$ decay.

WA71 instead failed to achieve the goal. In fact the data taking was only partially completed, because some critical aspects emerged from the first runs (test and physics). These were mainly related to the main trigger and to the emulsion configuration, which were indeed intimately connected one to each other. The request of the multiplicity jump in the silicon telescope (CDD) was poorly selective because of the noise in silicon detectors. On the other hand the too limited length of the tracks in emulsion made unlikely the observation of the associated $b\bar{b}$ production, and practically impossible that of charmed hadrons.

# 7 The legacy

The season of hybrid experiments came to an end for the searches of heavy quarks in emulsion after WA71 and WA75. Which were the main reasons for this outcome? Having learned the difficulty of the direct observation of beauty, why next generation experiments have not been proposed? There are several reasons, related to human aspects as well as to scientific ones; they can be summarized as follows:

- CERN strongly reduced the program of fixed target experiments. The commitment to LEP imposed a reduction of the activities with fixed target, with the only partial exception of neutrinos.

- The development of microstrip detectors, which also appeared in the last two experiments, had a very rapid development and became ideal tools for new vertex detectors with sub-millimeter resolution. Also the $B$ lifetime, longer than initially expected, favored the use of these detectors. These new trackers have the further advantage of being able to adapt to experiments in colliding beams, with the only limitation of the minimum distance determined by the vacuum pipe in the interaction region.

- The $b$ physics gained a novel interest in itself (in addition to the observation of their decays), due to the $B-\overline{B}$ mixing and $CP$ violation. Then new experimental facilities dedicated to the $b$ physics have been designed and built.

These facts explain to a large extent the end of this kind of experiments. Yet the legacy of this season has been preserved, Though the observation of the decays of heavy quarks in emulsion in rare events has been substituted by the enormous number of $b\bar{b}$ events collected and measured in collider experiments, the need for the direct observation of rare decays in large volumes remained as a requirement: this is the case of the $\tau$ lepton, as the signature of the charge current interaction of the $\nu_\tau$.

So the "hybrid" concept continued to be developed in the experiments dedicated to the search for neutrino oscillation both at short (Short Base Line) and long distance (Long Base Line). Some of the experimental methods, I have illustrated here, have been adopted in recent experiments as CHORUS [15] at CERN, and OPERA [16] at LNGS. In particular it is worth noting that many of those innovations, which were not mature enough in the '80s, have been then realized in these experiments. First of all the use of large masses of emulsions (an increase by a huge factor compared to earlier experiments), the "pouring" of emulsions (i.e. the in situ preparation of the stack), the vertical exposure of emulsions on plastic substrates, the inter-calibration methods, and finally, the use of automated systems for the search and measurement of candidate events.

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