Giordano Diambrini Palazzi and Hybrid Experiments

Mario Sannino
Università di Genova e Sezione INFN di Genova, Genova, Italy
E-mail: mario.sannino@ge.infn.it

1 The Genesis: a personal memory

It was december 1975 when I took my degree in Physics with a thesis on simulations of an experiment at the CERN ISR which had already been approved and already under preparation. Giordano was my supervisor.

At that time there was a lot of excitement among High Energy Physicists due to the discovery of the "hidden Charm", the J/ψ particle, by an experiment leaded by Sam Ting at Brookhaven in November 1974. It was, as they usually say, a true "November Revolution" for Particle Physics.
I spent those days at CERN working on my thesis and I remember all people talking and guessing about the nature of the new narrow state, with an unexpected so long lifetime. Only later, in 1975, it was clear that the new particle was a bound $c\bar{c}$ state.

In September 1976 Giordano called me showing a project which came into his mind while on holidays in his family house in Fano. He told me he was a little bit bored there and "just to spend his time" he thought of the feasibility of an experiment allowing to measure lifetimes of Charmed mesons. Following Giordano's ideas the Charmed mesons would have been photo-produced in a sensitive target consisting of a photographic emulsion in turn coupled to a spectrometer. The emulsion would have allowed to measure the Charmed mesons decay times directly while detecting their decays. The spectrometer, besides foreseeing the position of an interaction vertex in the emulsion so to ease its identification without the need of scanning the whole emulsion, could measure all the detected products momenta. Of course using only the spectrometer without an active target, due to lack of resolution it would have been impossible to disentangle the decay vertex from the primary vertex so the emulsion was essential for the aims of the measurement.

In fact the theoretical expectations for the Charmed-particle lifetimes were between 10^{-13} and 10^{-12} s at the energies available at the beginning of the experiment so that the expected decay lengths were in the range between 0.1 and 1 mm. In conclusion there was the need of a detector with a very high spatial resolution and, with the techniques available at the time, a good possible choice was the nuclear emulsion.

Experiments where an external tracking detector was coupled to an emulsion acting as a sensitive target were not something completely new. As far as 1966 Burhop implemented a test setup exposing a stack of emulsions coupled to two spark chambers at the CERN PS Neutrino beam and in 1976 the experiments E247 at Fermilab and WA 17 at the CERN BEBC were already active in Charmed particles lifetime measurements, but these experiments used a Neutrino beam as primary beam.

Giordano's new idea was to use photo-production in order to produce the charmed mesons as it would have been much more efficient in events production than Neutrino beams. In fact in photo-production Charmed particles are produced in pairs, then giving a background free sample, moreover the expected yield of events was 1 $c\bar{c}$ produced every 100 hadronic interactions.

At the end the tagged photon beam at the CERN Omega Spectrometer, where the normal target would have been replaced by an active emulsion target, seemed to be the right choice for such an experiment.

1.1 The first test (and the last experimental activity...) at the Frascati Electron Syncrotron

Of course I enthusiastically adhered to Giordano's proposal but, before being able to submit a true technical proposal to the CERN SPS Experiment Committee (SPSC), we had to overcome a well known objection, i.e. the fact that a photon beam, despite its energy, would have darkened the photographic emulsions making them unusable. Just to stop any possible criticism about emulsion darkening Giordano decided to perform a test at one of the photon beams at the Frascati Synchrotron at the end of September 1976.

I remember that in the last days of September Giordano went to CERN in order to bring to Frascati the needed emulsions while I went directly to Frascati to prepare the setup. I remember I was very much helped by Piergiorgio Picozza and Gianfranco Bologna who gave me all the instrumentations, tips and suggestions I needed. Just to mention something funny, in the evening before the emulsions exposure we were looking for some material "black enough" so to avoid emulsion darkening due to light, but at the same time "thin enough" so to avoid pair production due to electromagnetic interactions of beam photons, generating unwanted background tracks in the emulsion. At the end the good advice came from a Frascati Technician, the name of whom unluckily I forgot: to use Polyethylene which had a very low light transmission coefficient and at the same time a very

low radiation length. Where to find Polyethylene at six o'clock in the afternoon? Simple... the garbage bags are just done of Polyethylene so we asked the cleaning staff some of them and the "sacchetti de Monnezza" (as the garbage bags are called in Roman dialect) solved brilliantly our issue!
The day after, crossing our fingers, we made the test at a Synchrotron photon beam after having positioned accurately the emulsions and apparently we had no problems.
The nice thing we learnt that we were just the last people who made an experimental activity at the Synchrotron before its closure, so Giordano had the honorable chance of being the first and the last user of the Frascati Electron Synchrotron: he contributed to its building and he closed the experimental activity of the machine! I shared with him the honor of being the last user and I felt at the same time happy and sad...
After some days the emulsions were developed at CERN and result was positive: the background was low and there was no fear of emulsion darkening due to electromagnetic interactions as it would have happened with ordinary visible light photons.

1.2 The proposal and WA 34, the first test experiment at CERN in spring 1977

After the Frascati test a Technical Proposal was quickly set up and people from Bologna, Firenze, Paris 6, Orsay, Madrid and CERN joined us . At the beginning we were very few but immediately after the people of the Omega Photon Collaboration joined us contributing above all to the operations of the Omega Spectrometer. The Proposal was mainly based on Giordano's calculations of August 1976.
Apart from setting an appropriate trigger on the Omega spectrometer so to select the events which had a greater probability of being hadronic events with Charm, so discarding all the Electromagnetic background events, one of the main issues was the way of exposing the emulsions. The main source of background in the emulsion was just the photon beam itself as it produced a large number of electron pairs. The issue of keeping the electromagnetic background within acceptable limits was solved, following Giordano's computations [1], exposing the emulsion pellicles, $(15 \times 3.5 \times 0.06)$ cm^3 each, to the photon beam one at a time and at an angle of 11° relative to the horizontal reference plane of the spectrometer so to obtain a photon path of 3.0 mm inside the emulsion. The angle value was chosen in such a way that an enough long path was available to a charmed particle so to decay inside the emulsion while at the same time limiting the arising of the electromagnetic shower.

As above mentioned the emulsions needed to be periodically replaced in order to keep the background low. On the basis of the acceptable number of background tracks in the emulsion, estimated in 2500 tracks/mm^3 equivalent to a dose of 10^6 photons in the energy range between 20 and 70 GeV, the emulsion plate was taken out of the beam and replaced. This meant that the average number of SPS bursts per plate was 6 and the replacement took place in the interval between two following bursts. Of course following the Frascati test the emulsion pellicles were inside a black polyethylene envelope in order to avoid their blackening by light.

Exposure Device

The exposure device was all but trivial: Giordano, together with John Chaney (CERN Engineer) and Mr. Franzone (Technician from Genoa), followed personally the implementation of such a device that was ready from scratch in less than 2 months. In its first version (the WA34 version, in the following experiments WA45 and WA58 the device was different) it consisted of a pneumatic system based on the same principle of the pneumatic mail. In order to speed up the emulsion replacement on the beam an emulsion charger, able to load 8 emulsions in sequence, was developed.

The device can be clearly seen in fig.1 when Giordano was testing "The Revolver", as we called it, on Omega in the West Area. In fig.2 the pipe bringing the emulsion from the "Revolver" to the Omega target area can be seen and in fig.3 the target area where the emulsion was exposed is shown. The other person with Giordano in fig.3 is John Chaney who was in charge for the electronic controls of the target system. These pictures were just taken at the first tests following the emulsion exposure system installation about mid-april 1977. At those times the Omega Spectrometer was still in its original configuration with spark chambers read-out by a plumb icon system. In fig.4 the schematic view of the experimental setup is shown.

1.3 The first experimental analysis

After the first epic (let me call it so!) data taking run a hard analysis work started. One of the main problems was to match the foreseen interaction vertex with the actual one in the emulsion. It was all but an easy job! For each Spectrometer foreseen event there were many in the emulsion and find the right one was a tangled matter. At the end (after much pain!) the adopted method was what Giordano called the "Montessori Method" that he himself suggested, a "guided way" of performing the wanted match. Basically it consisted in the comparison of two scatter plots for each Omega triggered event , one with the tracks angular coordinates for the Omega triggered events and the other one with the corresponding quantities for the events found in the emulsion in proximity of the foreseen vertex position.

Figure 1: Giordano testing “The Revolver” in the CERN SPS West Area (Courtesy of CERN Audiovisual Media Services).

Figure 2: The pipe bringing the emulsion from the "Revolver" to the Omega target area (Courtesy of CERN Audiovisual Media Services).

Figure 3: Giordano and John Chaney working at the target area where the emulsion was exposed (Courtesy of CERN Audiovisual Media Services).

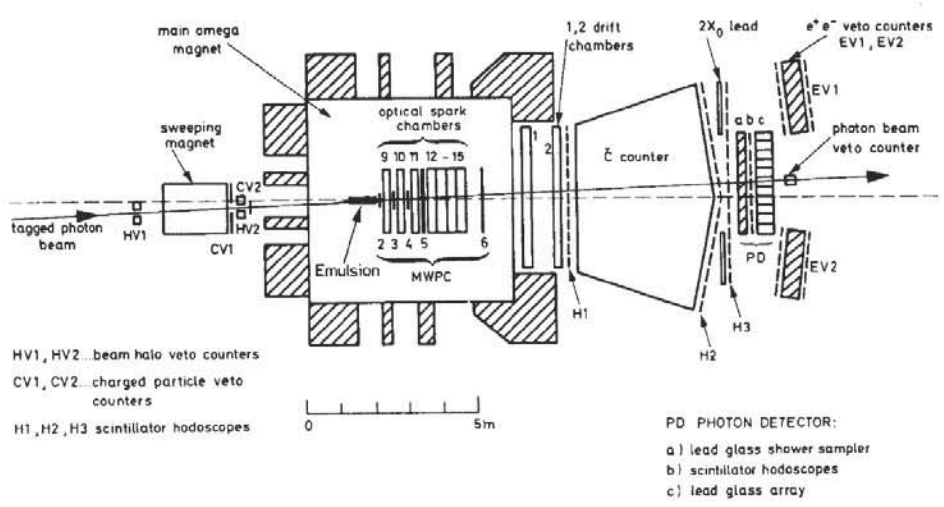

Figure 4: WA 34 experimental setup.

Finally the matching method worked well and towards the end of the year we could report to the SPSC that we were able to master the complete interaction vertex reconstruction in the emulsion. In fig.5 a $\overline{D}^0 \to K^+\pi^-\pi^+\pi^+$ decay as seen at the microscope is shown. Figure 6 shows the same event as seen at the microscope too but with the tracks fitted and identified with the ones foreseen by the spectrometer while fig.7 shows the "Montessori Method" angular plot used to match always the same emulsion event with the one foreseen by the spectrometer.

The measured decay time and mass were respectively $(2.26 \pm 0.05) \times 10^{-14}$ s and 1866 ± 8 MeV/c^2 [1].

Further developments - WA 45 and WA 58

In 1978 and 1979 two further data taking runs, the first one still a test, numbered WA 45 and WA 58, as separate experiments, were performed always at the Omega in the meanwhile refurbished with Multiwire Proportional Chambers (MWPC) in place of the old spark chambers and recalled Omega Prime. Also the emulsion exposure device was modified to improve its performance but the general philosophy of the experiments was practically the same that WA 34. There was a slight modification in the emulsion angle relative to the horizontal reference plane of the spectrometer (5° instead of 11°), in the emulsion dimensions, $(20 \times 5 \times 0.06)$ cm^3 each, and the exposing device was substantially different using shuttles on wheels in place of the "pneumatic mail" system [2].

The final results were published in 1987 and finally a background-free sample of

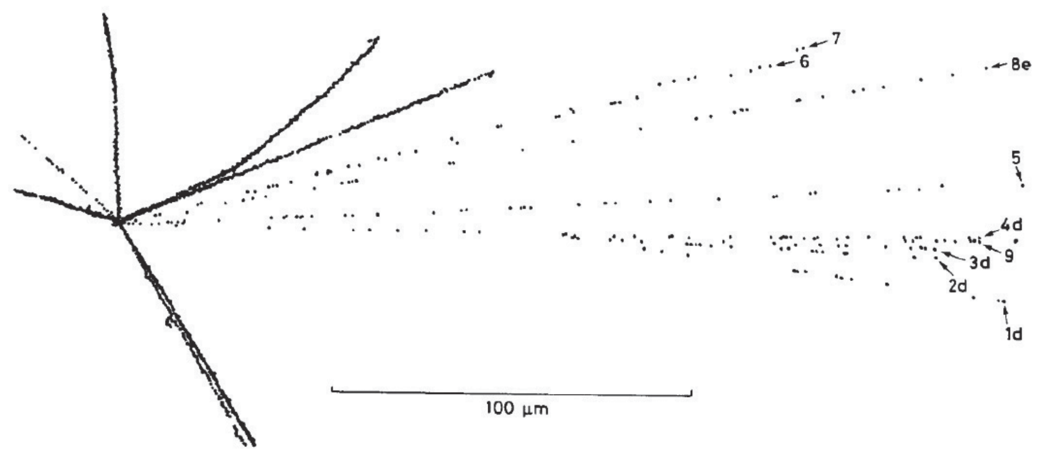

Figure 5: WA 34 picture of a charmed meson decay $\overline{D}^0 \rightarrow K^+\pi^-\pi^+\pi^+$ made at the microscope.

44 neutral charmed particles decays and 42 charged charmed particles decays were detected allowing the measurements of their lifetimes and branching ratios [3].

These experiments, even if much less refined than the following up to present ones, had the important feature of being among the first original pioneristic researches in this sector giving invaluable guidelines for the future activities.

2 From Charm to Beauty

Since Summer 1979 Giordano started thinking about the possibility of a new research line studying the Beauty (nowadays called Bottom) particle production and lifetime. Following this proposed line the B yield should have been extracted from the general hadronic background looking at the dominant decay mode $B \rightarrow C + X$ which had an expected branching ratio larger than 50%.

This goal should have been reached by means of a special designed silicon detector sensitive to Charmed particles decay. The Charm decay detector was implemented by means of a special silicon counter detector in charge of measuring at two different distances from a thin interaction target, i.e. $X_1 = 1$ mm, $X_2 \simeq 10$ mm, the multiplicity of an event produced in a high energy interaction. The interaction target might have been either passive (copper) or sensitive (emulsion). In case the multiplicity difference between the two measurement had been ≥ 2, there should have been a decay inside the (X_1, X_2) region so the event had to be triggered.

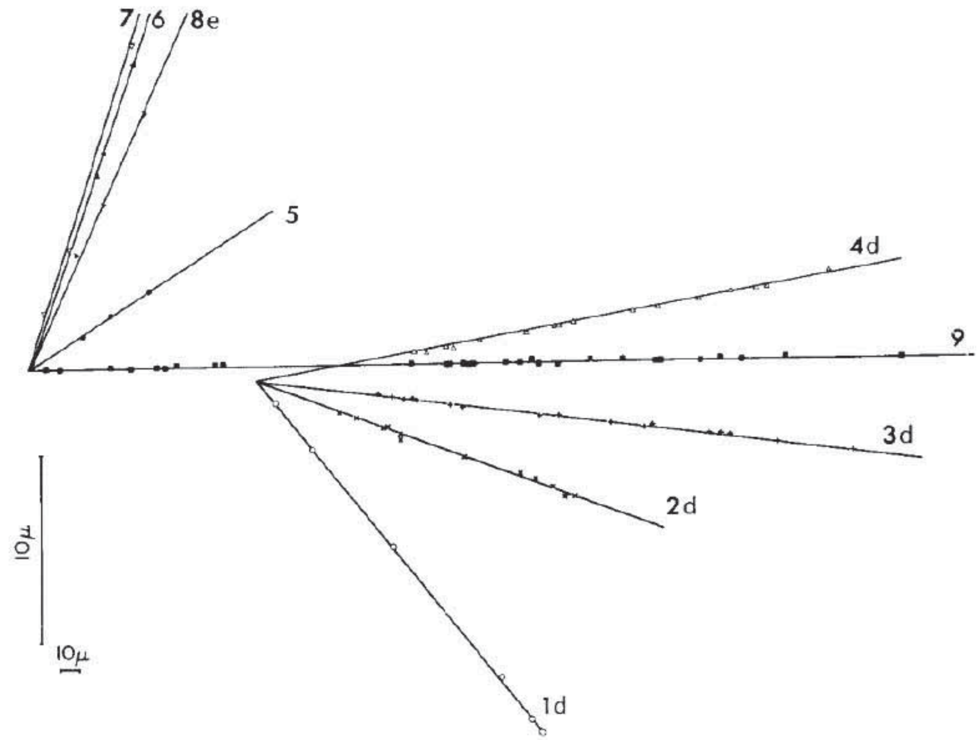

Figure 6: WA 34 best fit lines through measured positions of grains in the emulsion for all minimum ionizing tracks of the charmed meson decay $\overline{D}^0 \rightarrow K^+\pi^-\pi^+\pi^+$.

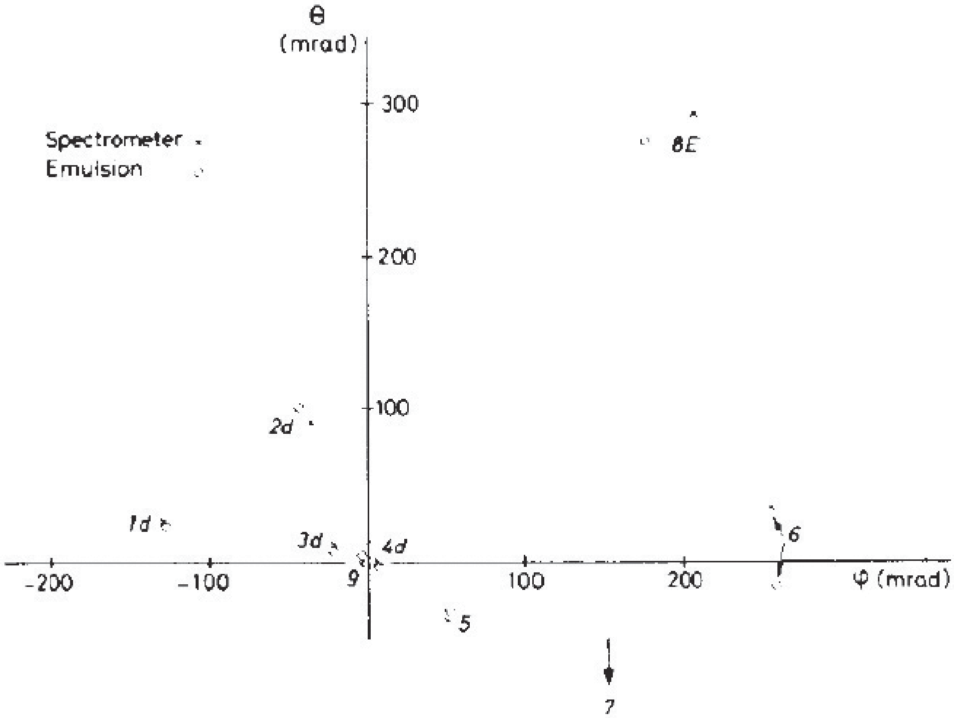

Figure 7: WA 34 Angular Matching of the minimum ionizing tracks as measured in emulsion (alphabetic characters) and as given by the spectrometer (numeric characters) for the charmed meson decay $\overline{D}^0 \rightarrow K^+\pi^-\pi^+\pi^+$ (see Figs.5 and 6).

Also in this case the experiment was installed in the Omega Prime spectrometer and, in order to improve the Vertex Resolution, a Time Projection Chamber (TPC) built in Genoa was added to the Omega Prime tracking detectors [4].

A first proposal was submitted in January 1980 and various test runs were performed in the following years just to tune the detectors, both TPC and Silicon Counters. All the detectors performed quite well so a final experiment was approved by PSSC.
The final experiment, called WA 71 [5], to which a silicon microstrip detector was added to further improve the vertex reconstruction in the target which was again an emulsion, took data in September 1984.

The result was unluckily deceiving and it turned out that it was very difficult to find good B events in emulsion. The reason, later understood, was that the Bottom particle true lifetime was at least an order of magnitude higher ($\tau_{B_+} \sim 1.6 \times 10^{-12}$ s) than what foreseen by the theoreticians at the time of the proposal (10^{-14} s $\leq \tau_B \leq 10^{-13}$ s) so the efficiency of the charm decay detector in triggering Charmed particles produced by B decays was extremely low.

References

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[2] G. Diambrini-Palazzi et al. Il Nuovo Cimento **85A** (1985) 241-261.

[3] G. Diambrini-Palazzi et al. Europhysics Letters **4**(1987) 887-892.

[4] G. Diambrini-Palazzi et al. CERN Proposal CERN/SPSC/ **80-02**/SPSC/P137/7.1.1980

[5] G. Diambrini-Palazzi et al. CERN Proposal CERN/SPSC/ **81-18**/SPSC/P159/20.2.1981