Subnuclear Physics: Past, Present and Future
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THE INFN CONTRIBUTION TO SUBNUCLEAR PHYSICS IN EUROPE

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Abstract

The INFN contribution to subnuclear physics in Europe will be reviewed, starting with the birth of the Institute and the following creation of the Frascati Laboratory, which has been the national path to ever-lasting contributions to subnuclear physics in the field of electron-positron physics. Italy has played a leading role in the creation of CERN, and INFN has represented both the natural channel for the Italian support to its development and for the exploitation, by the Italian subnuclear physics community, of the unique opportunities offered by the European Laboratory. The participation to CERN has also facilitated the development of the INFN capacity of establishing international collaborations, which has been particularly effective in the case of the DESY Laboratory in Hamburg.

1. INFN and the Frascati National Laboratory

The roots of the *Istituto Nazionale di Fisica Nucleare* can be traced back to the pre-war years. In particular, INFN may be seen as the realization of Fermi's vision of creating a national institute, in order to establish in Italy the conditions for building accelerators, the emerging powerful tool of subatomic physics.

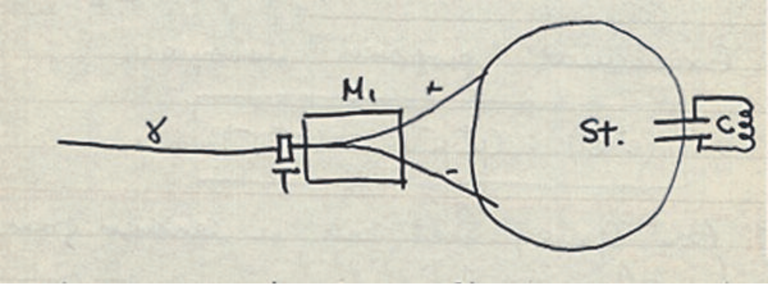
INFN was created in 1951, as the result of the joint effort of 4 University groups, from Milan, Padua, Rome, and Turin respectively. The first President was Gilberto Bernardini, who in 1954 took the decision that the first accelerator had to be a 1100 MeV electron-synchrotron – quite at the frontier in those years – to be built at Frascati, with Giorgio Salvini as director of the new laboratory.

In this way, initially, INFN consisted of 4 University *Sezioni* and one National Laboratory. The Institute grew in time according to the initial model, up to the present 20 *Sezioni* and 4 National Laboratories.

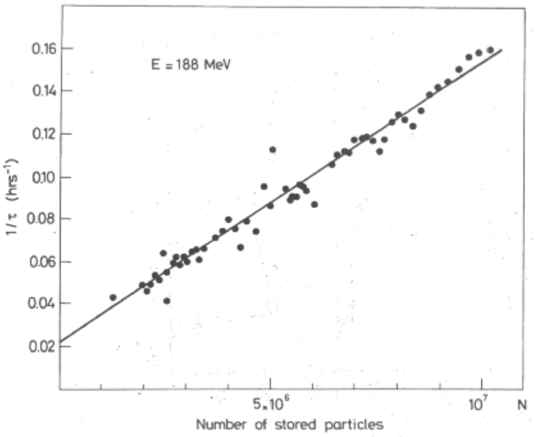
It is not easy to manage an institution combining education and research centers. In most countries, in fact, they are kept separate. INFN has succeeded in realizing the initial vision of a single integrated research community, which presently comprises around 5.000 people, from the graduate students of the universities to the engineers and technicians engaged at the laboratory infrastructures.

The Frascati electron-synchrotron started operation in 1959 giving rise to a series of experiments of international resonance. The achievement had also the merit of creating the right environment of scientific expertise and enthusiasm for the critical event in the history of Frascati, which was the conception of AdA. It was an extremely prompt decision, taken in a single meeting in February 1960, at the Frascati Laboratory, where Bruno Touschek presented his idea of a colliding beam experiment with electrons and positrons. A small team immediately formed, with the task of building a small prototype, which was ready, with beams circulating, in one year [1].

AdA, from *Anello di Accumulazione*, the Italian for Storage Ring, is a very elegant acronym, but does not reflect the original content of the idea. Actually, the idea of Storage Rings, for achieving the kinematical advantage of symmetric beam-beam collisions, was rather old: a paper by Gerard O'Neill of 1956 is usually quoted [2], although already in 1943 Rolf Wideroe had applied for patenting the idea in Germany. For instance, one would think of storing electrons in two distinct equal rings, tangent at one point, where electron-electron collisions could take place, with the total energy available for electron-electron interactions.
Bruno Touschek combined the above idea, with that of colliding electrons and positrons, that is an elementary particle against its antiparticle, in order to produce time-like photons by annihilation. That meant a much more powerful instrument from the point of view of physics. At the same time, he conceived the idea of achieving such enriched physics potential in a much simpler way, by storing both beams, one against the other, in a single ring, as shown in figure 1, leaving to the CP symmetry of QED to guarantee the same equilibrium orbit for both the electrons and positrons and therefore their collisions.

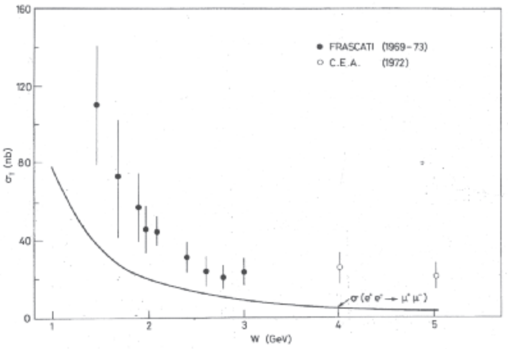


AdA was operational in one year, in February 1961 at Frascati. It consisted of a 4 meter long circular vacuum chamber and an RF cavity, mounted inside a magnet, as shown in figure 2, which allowed to store 200 MeV electrons and positrons respectively. The particles were produced through a minimal arrangement, by converting the gammas of the beam produced at the electron-synchrotron, on two small targets inside the doughnut. Storage Ring operation was demonstrated in a few months. At the very low intensities that could be achieved with the Frascati photon beam, so high a vacuum was achieved as to allow 50 hours lifetime of the circulating beams [3]. Afterwards AdA was moved to LAL at Orsay, whose LINAC allowed for higher intensities. A dependence of lifetime on intensity was discovered there, due to what today is known as Touschek effect, that is the loss of particles due to scattering between particles inside a circulating bunch. Anyhow, a lifetime of 6 hours was still available at the highest intensity, as shown in figure 3 [4]. Finally, the demonstration of collider operation was achieved in 1964 by the observation of electron-positron annihilation into electron-positron and one photon, at 400 MeV total energy and 10^{25}/cm^{2}sec luminosity [5]. This achievement started the era of electron-positron physics.

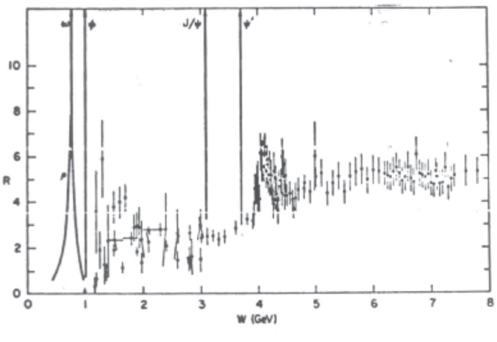


ADONE, the big AdA, was the first project to be initiated, at Frascati, actually even before the small prototype was turned on. It started operation in 1969, preceded by ACO at Orsay. There was, in fact, a rapid multiplication of successful competing initiatives, as can be seen in figure 4, so that it took less than 30 years to go from the original idea to LEP, the largest accelerator based on the AdA model. In fact the 200 GeV total energy of LEP is also the highest practically possible storage-ring collider energy, due to radiation losses. Further progress at the energy frontier is left to the linear colliders .

The ADONE experiments gained center stage when in 1972 they announced the observation of an unexpectedly large multihadronic production as compared with the muon pair production. The related overall ADONE result is reported in figure 5 [6]. The further study of this phenomenon at the other electron-positron colliders, combined with other experimental facts, led finally to establishing the colored quark model. In fact, the surprise at ADONE was about a factor of three, which is the number of quark colors.



In a couple of years, however, it became clear that the energy range chosen for ADONE had not been the most lucky, being situated just in between the ρ, ω and ϕ energy region studied in detail at ACO and, more important, the unbelievably rich region just above the ADONE maximum energy of 3 GeV, as shown in figure 6 [6], starting at 3.1 GeV, just 3% more energy, where the fundamental discovery of the J/Ψ took place in November 1974. Following the announcement, it took one day to observe it at Frascati, by pushing machine operation beyond the nominal design parameters. The combined Frascati paper was published in the same issue of December 1974 of PRL that reported the Brookhaven and SLAC discovery papers. Among the experiments at ADONE, there was also the one led by Antonino Zichichi searching for a third lepton, the heavy lepton HL, which was just another particle out of reach at the ADONE energies (see the paper by Alessandro Bettini in these same proceedings).



At ADONE there were three generations of experiments, with an inevitable progressive loss of visibility of the laboratory, a rather common fate of accelerator laboratories, which also created an unbalance between home and foreign activities of INFN.

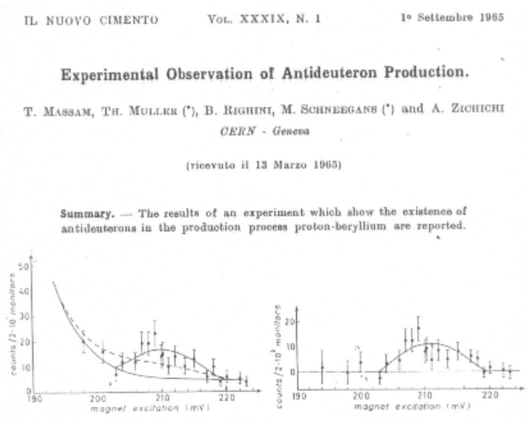
In the 1990s the Institute caught the opportunity offered by the development of the electron-positron factories, which opened new physics prospects by advancing the luminosity frontier, aiming at high precision measurements. Such a research line was clearly favored by the increasing difficulty in the progress of the energy frontier. In 1990 INFN decided to build a ϕ-Factory at Frascati, DAϕNE, a 1 GeV electron-positron collider, that is 1/3 the ADONE energy, so that it could simply replace the latter in the same building, as shown in figure 7. DAϕNE results on kaon physics, which in particular included a very accurate measurement of the Cabibbo angle [7], brought Frascati back on the international scene of subnuclear physics. The new accelerator construction had also the merit of reviving the Frascati role in accelerator science, with the recent idea of Crab Waist, which promises a generalized advance of the collider luminosity frontier, through an improved control of instabilities of bunch crossing at an angle [8]. The method has been successfully tested on DAϕNE by achieving a record luminosity of $5 \bullet 10^{32} cm^{-2} s^{-1}$.

2. INFN and CERN

After having played a critical role in the creation of the European organization and its accelerator Laboratory in Geneva, Italy characterized itself, as widely recognized within the Member States community, by the positive attitude systematically expressed in the governing bodies of CERN, notably in supporting new initiatives and projects, or in facing difficult situations. It was natural for INFN, given in particular the composition of its community, to represent the overall Italian participation to CERN activities.
A constant visible presence of INFN physicists, engineers and technicians, has developed and consolidated in time in the management, theory, experiments, and infrastructures of CERN.
The most significant indication of the substantial role of INFN at CERN probably is the frequent promotion and implementation of CERN special programs.

Such front-line role was made possible by the initiative of the INFN physicists, supported by adequate financial means. In the latter respect there is a fact worth being recalled. The 5-year plan 1979-1983 marked a substantial change of pace in the funding of INFN, which was one of the achievements of Antonino Zichichi as president of the Institute in those years. The increase of funds had an obvious impact on the life of the Institute and in particular it allowed the construction of new instrumental infrastructures. As an example, in 1981 the construction of the Superconducting Cyclotron in Milan was started, which also initiated the close collaboration of INFN with Italian industries in accelerator R&D and construction. Such a promotion of industrial partnership played a key role in enhancing the INFN role as a leading partner in international projects, first of all at CERN, and also at DESY and other laboratories throughout the world.

The contribution of Italian people at CERN takes place mostly through the activity of INFN teams carrying out experiments at CERN accelerators, and also through the direct presence in the CERN staff of physicists and engineers from the INFN community. As an example in this sense one can quote the discovery of nuclear antimatter at the proton-synchrotron (see figure 8).



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Experimental Observation of Antideuteron Production.

T. Massam, Th. Muller (*), B. Righini, M. Schneegans (*) and A. Zichichi
CERN - Geneva

(ricevuto il 13 Marzo 1965)

Summary. — The results of an experiment which show the existence of antideuterons in the production process proton-beryllium are reported.

The INFN presence in CERN activities is typically very wide, as compared with other countries. In the case of the LHC experiments it is in fact the widest participation. The distinctive quality and style of the contribution of the INFN groups is influenced by the traditional engagement of its researchers in developing sub-nuclear physics techniques, which in the first place means detectors and accelerators, including all related devices and software.

INFN is probably the only institution, in the international framework, to have a research line dedicated to instrumentation R&D, along with the sub-nuclear, astro-particle, nuclear and theoretical research lines.

Such technological research line is also the natural channel for promoting the applications of the subnuclear physics techniques to other disciplines and for the related technological transfer to the industry. Autonomous special programs are set up in cases of particular relevance, such as applied superconductivity. In developing this strategy, there is a remarkable synergy with the parallel CERN effort.

In various papers in these proceedings there are many examples of detectors developed by INFN, like BOREXINO and OPERA at the Gran Sasso Laboratory, or subsystems of the LHC detectors and of the AMS detector.

Detector developments include also all those devoted to signal readout, event reconstruction and data sharing through networking. As an example for the latter case, in 1989, a few weeks before the first collisions at LEP, INFN established the first high-speed connection with CERN based on a national information network. Furthermore, when in 1990 the Web was born at CERN, the INFN group in Rome was among the first teams that dialogued with CERN. That experience was the basis for the analogous leading role of INFN in the development of the Grid at LHC, including its application to other fields.

Accelerator science and technology in the INFN started at Frascati and then diffused throughout the Institute, not only in the other two accelerator laboratories of Catania and Legnaro, but also in many university *sezioni*, like Milan, Genoa and Naples.

Since many years, the most relevant R&D activity takes place in the field of superconducting technology. Its origin may be easily situated in 1981 when, as previously recalled, the construction of a SC Cyclotron at Milan-LASA was started, with the coordinated participation of Italian industries. Once built, the Cyclotron was moved to the LNS Laboratory of INFN in Catania, where it is presently operating. The SC Cyclotron project created also the basis for the Italian contribution to HERA (see the paper by Albrecht Wagner in these proceedings).

Along the same lines in 1988 an agreement INFN-CERN was set-up, in order to promote and develop industrial partnership in superconducting technology. The most important programs were related to the production of the LEP200 RF cavities and the LHC dipoles. It was a complex of coordinated activities, carried out by various CERN-INFN groups, of Milan-LASA, Genoa, LNL, and Naples.

One of the highlights of the program was the production of the first 15m LHC dipole prototype, shown in figure 9, which involved the coordinated participation of three Italian firms that, by the way, are the same involved twenty years before by INFN in the construction of the SC Cyclotron mentioned above.

3. INFN and DESY.

DESY was initially established, as an autonomous particle physics facility, with the aim of providing accelerator infrastructure to German universities, and the start-up project, like at Frascati, was an electron-synchrotron.

DESY rapidly became a research center of international visibility, notably with the success of the DORIS electron-positron collider, till the creation of what became known as the "HERA model" of international co-operation.

It was therefore natural for INFN to set-up with DESY a relation that was structurally analogous to the one established with CERN, concerning both experiments and infrastructures, and including industrial partnership. In particular, the INFN superconductivity program was the basis for the Italian participation to HERA, as already recalled.

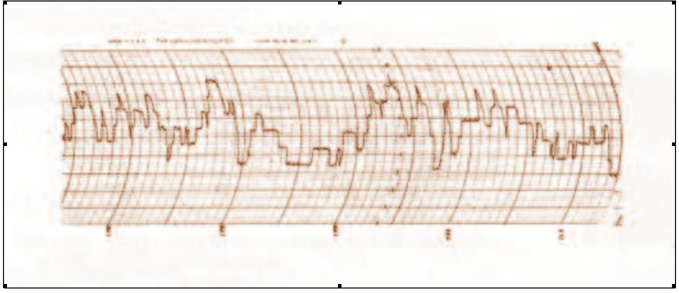
Another line of collaboration will be addressed in what follows, concerning the R&D towards the project of a new high-energy electron-positron Linear Collider, in which case the major INFN contribution came from Frascati and Milan groups.

The collaboration with DESY in this field was certainly favored by the common long-standing tradition in electron-synchrotrons and electro-positron colliders, including also their applications to photon science. Actually, those applications are an outstanding spin-off of subnuclear physics to other science fields and industry.

Let me briefly recall the crucial steps in the development of radiation sources by accelerated electrons.

In 1947 there was the first observation of the light emitted by circulating electrons, in a small electron-synchrotron, from which that light got its name.

In 1961 with AdA there was the first light from a stored beam, whose detection played a crucial role for beam diagnostics in the collider prototype: single circulating particles going in and out could be seen, as shown in figure 10, even directly by eye. In particular, the measurement of the light intensity was a crucial tool for the first luminosity measurement, although that word had not yet been introduced [5].



AdA, therefore, was also the prototype of storage ring light source. In fact, one has to notice that Synchrotron Light machines are usually synchrotrons in the accelerating phase but they are operated as storage rings in the phase of delivering the light beams to the experimental users. ADONE and DORIS, as many other electron-positron colliders, concluded their career as the first respective national Synchrotron Light facilities.

In recent years, a third revolution in photon science has taken place, again promoted by subnuclear physics, which is based on the lucky technological convergence in the development of electron-positron linear colliders on the one hand and the SASE-FEL idea on the other.
In the Self-Amplified Stimulated Emission scheme, extremely short and brilliant – and at the same time rather monochromatic and coherent – radiation pulses are created, by sending an electron beam through an extremely long and fine-grained undulator. In such a layout, differently from the case of the classical Free Electron Lasers, there are no mirrors. Therefore the radiation wavelength can be in the X-ray region of the spectrum. It is worthwhile mentioning that one of the authors of the idea [9], Claudio Pellegrini, was the synchrotron radiation expert of the ADONE group.

A 20 year long collaboration with DESY has taken place within the R&D for ILC, in combination with the development of the SASE-FEL technique, which involved the Italian industry, one example being shown in figure 11. In particular the collaboration concerned, the Tesla Test Facility, which has become the FLASH SASE-FEL facility, presently operational at DESY. There are several SASE-FEL projects in the world. LCLS is already operational at SLAC in the U.S. and SPring-8 in Japan. The most ambitious project is the European X-Fel in construction at DESY, with an Italian firm as one of the SC cavity producers. A small SASE-FEL prototype, SPARC, is operating at Frascati producing light in the green region of the spectrum [10] (see figure 12).

Concluding remarks

The INFN contribution to particle physics in Europe has been addressed in this paper. One can well imagine a similar topic addressed with the subjects inverted. In other words there is a mutual value in that contribution, because of the immense return to the Institute and Italy at large, which resulted from it.
In particular, Italy profited from the combination of research and education, which is built in the INFN organization, enriched by the INFN action in promoting innovation in the national industry.

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Figure captions

1. Sketch of AdA by Bruno Touschek.
2. AdA at Frascati.
3. Inverse-lifetime $1/\tau$ (hrs^{-1}) vs N, the number of stored particles in a beam, at the energy of 188 MeV in AdA.
4. The energy and luminosity of electron-positron ring colliders (red), factories (yellow), and linear colliders (green).
5. Multihadron production as observed with ADONE.
6. Energy dependence of the ratio R between total hadronic cross-section and muon pair cross-section from electron-positron annihilation.
7. ADONE (above) and DAΦNE (below) installed in the same building.
8. The discovery of nuclear antimatter at the CERN proton-synchrotron.
9. The 15 m long LHC superconducting dipole prototype.
10. Current plot of a photomultiplier detecting the light radiated by few electrons circulating in AdA.
11. SC Cavity module, built by an Italian firm under the guidance of INFN, within the ILC R&D, installed at KEK, Japan.
12. The spectrum of SASE-FEL radiation produced in SparC, at different undulator lengths.