# TRIBUTE TO BRUNO PONTECORVO

БРУНО ПОНТЕКОРВО

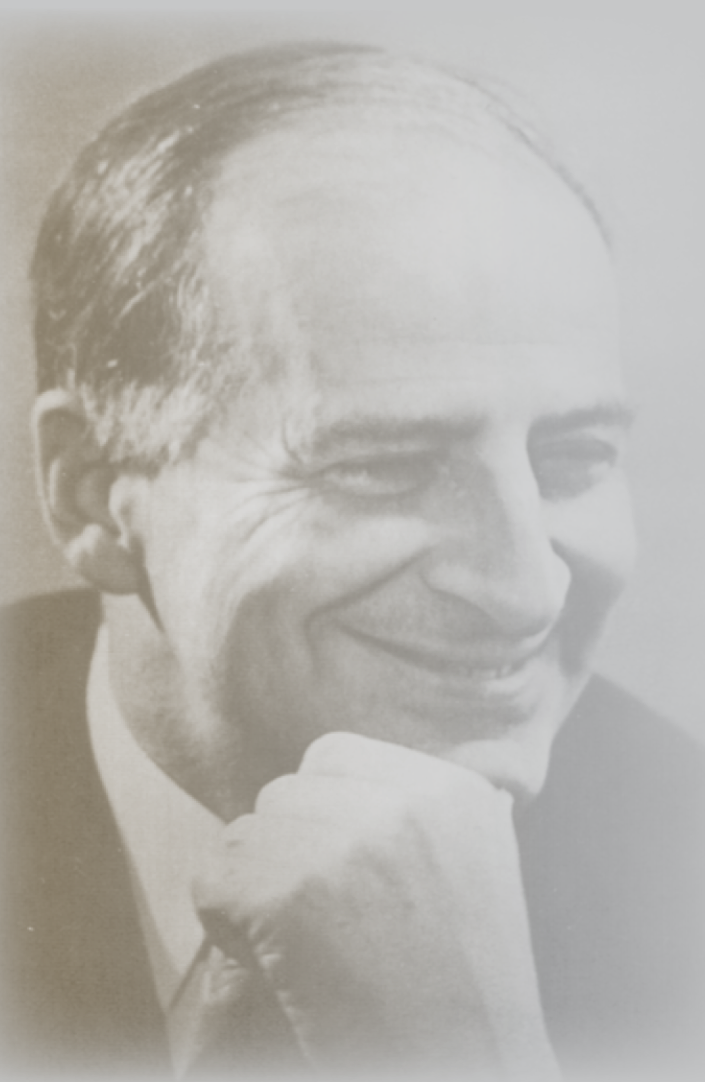
**ALESSANDRO BETTINI[1,2], LUISA CIFARELLI[3]**

[1] *Dipartimento di Fisica e Astronomia "G. Galilei", Università di Padova, Padova, Italy*

[2] *Labotatorio Subteráneo de Canfranc, Canfranc; Spain*

[3] *Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy*

On the occasion of the centenary of Bruno Pontecorvo's birth, the Italian Physical Society celebrates the outstanding scientist by overviewing his innovative ideas in neutrino physics. On the same occasion the European Physical Society has established as "EPS Historic Site" the study of Bruno Pontecorvo at JINR in Dubna; a brief report of this ceremony is given. As an aside a few recollections of eminent Italian scientists who had special relationships with Pontecorvo are also reported.



## 1 Bruno Pontecorvo and neutrinos

Bruno Pontecorvo gave outstanding contributions to neutrino physics. Neutrinos have been largely unpredictable but Pontecorvo often anticipated novel ideas that started developments leading to revolutionary discoveries.

In 1946, when neutrino was considered to be undetectable by the majority of the physicists, he [1] proposed the detection of (electron) neutrinos by inverse beta decay, in the Cl-Ar reaction $\nu_e + {}^{37}\text{Cl} \to e^- + {}^{37}\text{Ar}$. He described the method of removing argon (a few atoms) by boiling carbon tetrachloride and counting ${}^{37}$Ar in a gas-filled low background counter. The paper, a Chalk River Laboratory (Canada) report, was classified by the U. S. Atomic Energy Commission, because it was considered as a possible method to measure, from a distance, the power of nuclear reactors. This is not the case, because reactors emit antineutrinos rather than neutrinos, but at that time it was debated whether there were any difference between them. Indeed, that difference was proven to exist by R. Davis [2], who searched whether the Cl-Ar reaction were induced by (anti)neutrinos from the Savannah River reactor, finding it was not. This happened in 1958, at the same time when Raines discovered antineutrinos from the same source.

It was Luis Alvarez [3] to propose, in 1949, the chlorine-argon reaction to detect solar neutrinos with a large tank of sodium chloride, but he did not make the experiment. Starting in 1962 J. Bahcall [4] built his solar model and calculated with increasing precision the expected Cl-Ar reaction rate; he found that the experiment was feasible. R. Davis [5] did it using 615 t of perchloroethylene ($C_2Cl_4$) as the target and detector medium. About one Ar nucleus per day was expected to be produced by solar neutrinos. The experiment was built in the Homestake mine in South Dakota at 1600 m depth, producing the first results in 1968 and lasting up to 1994. The measured rate was about 1/3 of the solar model prediction [6]. Other experiments confirmed the result and finally led to the discovery of neutrino oscillations, the first example of physics beyond the standard model.

In 1957, when only one neutrino type, the electron-neutrino ($\nu_e$), was known Pontecorvo published the idea that neutrino and antineutrino might mix and oscillate in analogy with the $K^0\bar{K}^0$ oscillation [7]. It was the first time that mixing and oscillation concepts were introduced for fermions. In doing so he assumed that neutrinos obey the Majorana rather than the Dirac equation, namely that they are completely neutral particles, and have a mass. Far from being trivial at those times, this is a central idea, in a different context, in contemporary neutrino research.

The second neutrino, the muon-neutrino ($\nu_\mu$), was discovered, *i.e.* identified as a particle different from $\nu_e$, by L. Lederman, M. Schwartz and J. Steinberger [8] in 1962 at the proton accelerator AGS at Brookhaven. The idea to create intense neutrino beams at high-energy proton accelerators had been developed first by M. A. Markov and his students starting in 1958 in unpublished works [9]. In the next year Pontecorvo [10] discussed the possibility to establish whether neutrinos produced in the pion decay were different from those in beta decay by searching whether the former induce inverse beta decay. Only M. Schwartz [11] was able to design in 1960 and build a muon-neutrino beam of sufficient energy and sufficient intensity to perform the above-mentioned discovery.

Pontecorvo [12] returned to neutrino oscillations in 1967, advancing the hypothesis of the oscillation between electron and muon neutrinos. Analysing the experimental data he reached the conclusion that ample room was left for lepton flavour violation. At that time Pontecorvo was not aware of two articles published by Katayama *et al.* [13] and by Maki *et al.* [14] in Japan in 1962, contemporarily to the discovery of the second neutrino, where they had already advanced the hypothesis of neutrino mixing. This was in the very different context of the Sakata model, with its hypothesis of a lepton-baryon symmetry, which, however, was experimentally proven wrong. Maki *et al.* mentioned also the possibility of "transmutation" between neutrino flavours, but did not discuss any possible experiment.

On the contrary, Pontecorvo, in 1967 and later, studied possible ways to experimentally test the hypothesis. He concluded that "from the point of view of observing neutrino oscillations, the ideal neutrino source is the Sun." If the phenomenon existed, its effect on Earth would be to observe half of the expected electron neutrino flux. Clearly he was still thinking of maximal mixing.

The fascinating neutrino was the life long physics love of Bruno Pontecorvo.

## Recollections of INFN Presidents - I

### A recollection of C. Villi

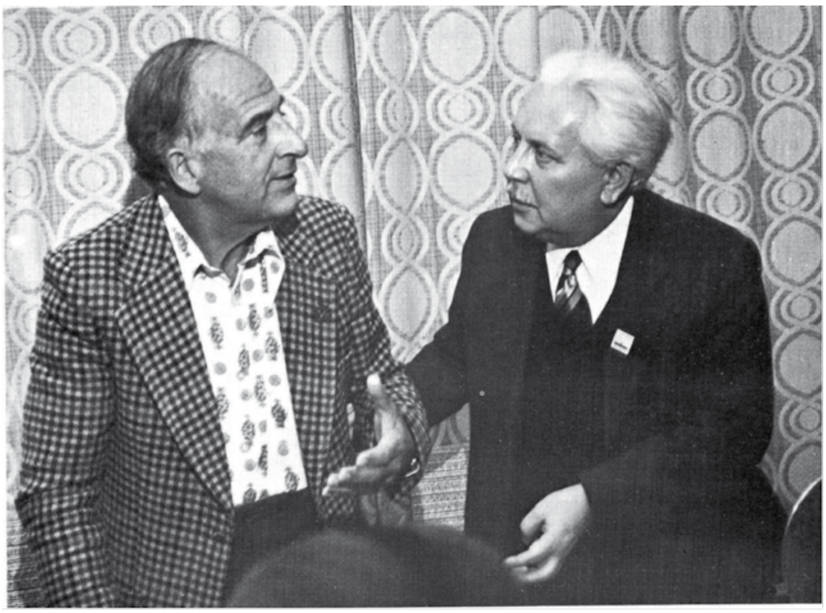
Claudio Villi was President of the INFN (Istituto Nazionale di Fisica Nucleare) from 1970 to 1975. In 1976, on the occasion of the 25th anniversary of the INFN, Villi published his book "La fisica nucleare fondamentale in Italia - Relazione sul complesso di attività dell'Istituto Nazionale di Fisica Nucleare nel periodo 1970-1975" (Fundamental nuclear physics in Italy – Report on the activities of the National Institute for Nuclear Physics over the period 1970-1975).

He wrote (translation from Italian to English by A. Bettini), in § I.6.3- "Relationships with scientific bodies of the Soviet Union":

"Starting in 1970 intense collaborations were developed between research groups in some of the INFN units (Genoa, Milan and Turin Sections and National Frascati Laboratory) and the Joint Institute for Nuclear Research (JINR) of Dubna. The latter Organisation is, as is well-known, the Eastern Countries equivalent of CERN. Aiming to a further development of this collaboration, that until then had been taking place only on the basis of non-formal agreements on single and specific research issues, in 1973 we started the contacts with the JINR that were necessary to conclude a framework agreement of scientific co-operation with the INFN. These contacts, which had been started under explicit request of the JINR, in January 1975 led to the signature of a Co-operation Agreement INFN-JINR.

In October of the same year the INFN President visited Dubna. During the visit the operational details of the agreement were further defined. The importance of the role of prof. Nikolai Bogolyubov, Director of the JINR, in promoting and stimulating the collaboration with the INFN must be acknowledged. To that he gave always a high priority in the frame of the programmes of the Dubna Institute."

That visit was also the occasion for Claudio Villi to meet Bruno Pontecorvo, who in no circumstance had been allowed yet come back to visit Italy, and discuss with him issues of common interest. An example, taken from the mentioned book, is shown in the figure.



B. Pontecorvo and C. Villi. Dubna, 1975.

## Recollections of INFN Presidents - II

### A recollection of A. Zichichi

Antonino Zichichi was President of the INFN from 1977 to 1983. One of his fundamental contributions to the Italian and world physics was the creation of the Gran Sasso underground laboratory, LNGS (Laboratorio Nazionale del Gran Sasso). The initiative did not develop without difficulties and obstacles, including within the scientific community itself. A recollection by Zichichi can be found in his book "Subnuclear Physics – The first 50 years: Highlights from Erice to ELN", World Scientific Series in 20th Century Physics, Vol. 24 (World Scientific, Singapore) 1999.

In § I.1, "Italy as an example", he describes his strategy for promoting subnuclear physics in Italy, in which his first proposal was "to implement a project for the most powerful underground laboratory, whose aims were presented to a special committee of the Italian Senate. The basic characteristics of this new venture attracted the interest of the physics community world-wide." Zichichi continues as in the page reproduced below.

*The author and Bruno Pontecorvo, Rome, September 1978.*

*During the Cold War Pontecorvo was accused of having passed from the West to the East (USSR) some secrets of the first nuclear weapon ever built by mankind. After many years spent in the USSR, Bruno Pontecorvo was suddenly allowed to visit Italy. The Berlin Wall was up and this became a great occasion for the media. It was the time when we had proposed the Gran Sasso Project. The so-called "Rome School" tried to bring to a halt the "Gran Sasso Project" with arguments similar to those used at Frascati with ADONE («Zichichi is searching for butterflies», see § II.2-2 and Fig. II.2-2.6) to boycott the energy increase of the ($e^+e^-$) collider (see § II.2-2 and Fig. II.2-2.3). Apparently, underground lobbying had produced effects. For instance the CERN-Director General (DG) Leon Van Hove, during a CERN Council meeting declared that Zichichi's Gran Sasso Project was invented to stop the new collaboration between Italy and France to realize a joint venture in underground physics using the Fréjus tunnel. After this unprecedented attack against a very important initiative in Italy, the other CERN-DG, John Adams, called the author into his office, to tell him «not to worry». This ended all attacks from CERN against the project. During the visit and the various lectures centred on Pontecorvo, a journalist asked: «Professor Pontecorvo, what do you think of the Gran Sasso Project proposed by Professor Zichichi? Many physicists consider it a useless Napoleonic venture with weak scientific content». After a few seconds of thinking, in the usual Pontecorvo style of soft and slow answering, he said: «I regret not to be young enough to participate in this formidable project. The scientific content of the project appears to me extremely interesting». This declaration by Pontecorvo came as a surprise, since we were on opposite political sides and every journalist was expecting a strong negative statement from Pontecorvo on the Gran Sasso Project. But physics prevailed. And this put an end to all — open as well as underground — lobbying against the Gran Sasso Project.*

## 2 A new EPS Historic Site to celebrate Bruno Pontecorvo's centenary

The EPS Historic Sites programme of the European Physical Society (EPS) commemorates significant places in Europe for the progress and the history of physics, as a further demonstration of the EPS determination – since its birth in 1968 – to strengthen the cultural and scientific unity of Europe: east-west, north-south.

On 22 February 2013 a new EPS Historic Site was established in Dubna, Russia, at the Joint Institute for Nuclear Research (JINR), on the occasion of the centennial of the eminent, world famous physicicst Bruno Pontecorvo. JINR is a very prestigious Associate Member institution of the EPS since 1990 and strong links exist between JINR researchers and the wide European community of physicists that the EPS represents.

A shiny brass plaque was unveiled at the entrance of the study of Bruno Pontecorvo inside the Dzhelepov Laboratory of Nuclear Problems (DLNP) of JINR. The text engraved on the brass highlights Pontecorvo's work at JINR from 1950 until his death in 1993, in particular his original concept of neutrino oscillations which were actually discovered decades later in neutrinos from the Sun and from the atmosphere, then confirmed with neutrinos from reactors, thus providing the first hint of "Physics beyond the Standard Model".

The unveiling ceremony took place in the presence of JINR Director, Victor Matveev, DLNP Director, Alexander Olshevskiy, distinguished Members of JINR Scientific Council and one of the authors (L.C.) in her function of EPS President. Also present were Pontecorvo's son, Gil Pontecorvo, "Pontecorvo Prize 2012" winner, Ettore Fiorini, and a delegation of the Italian National Institute of Nuclear Physics (INFN) which included INFN Vice-president, Antonio Masiero.

The ceremony was followed by a touching visit to Pontecorvo's study, still kept exactly as Pontecorvo left it.

The unveiling of the plaque by L. Cifarelli and V. Matveev.

From left to right: A. Olshevskiy, G. Pontecorvo, L. Cifarelli and V. Matveev.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# TORINO-DUBNA AMARCORD (VOSPOMINANIJA)*

**GUIDO PIRAGINO**
*Dipartimento di Fisica, Università di Torino, Torino, Italy*

Dubna. In 1975 Claudio Villi, as INFN President, visited the JINR and signed the first General Agreement between the two scientific entities.
From the left: Yu. Shcherbakov, B. Pontecorvo, C. Villi, G. Piragino, L. Lapidus.

The collaboration between Italian and Soviet physicists can be traced back to the times of the so-called "cold war", to 1959, when during the Rochester conference held in Kiev the director of the Institute of General Physics "A. Avogadro" of the Turin University, member of the Academia dei Lincei of Russian origin, Gleb Wataghin, met the Soviet academician, future Director General of the Joint Institute for Nuclear Research (JINR) at Dubna, Nikolai Bogolyubov.

The friendship of the two outstanding physicists gave rise to the collaboration between the Italian Accademia dei Lincei and the Academy of Sciences of the USSR. In the same years (1951 and 1954, respectively) a new Italian scientific entity was established: the National Institute for Nuclear Physics (INFN), and CERN was founded at Geneva. Turin was one of the first four co-founder Sections of the INFN, and Wataghin was the first director of the Turin Section. JINR was founded in Dubna in 1956.

In Italy, in 1959, a 100 MeV electron synchrotron (at Turin) and one with an output energy of 1000 MeV at the new INFN Laboratories of Frascati were simultaneously put into operation.

In 1964, during the Rochester Conference held at Dubna, Bruno Pontecorvo and Antonino Zichichi first met each other; both of them positively greeted any success achieved by the collaboration between Italian and JINR physicists.

Some years later (1968) the ADONE collider was created at Frascati. The injector of ADONE,

* Recollections of the Torino-Dubna Collaboration.

Members of the Torino-Dubna Collaboration:

V. Ableev, E. Andreev, T. Angelesu, N. Angelov, S. Baginyan, F. Balestra, R. Barbini, P. Batyuk, Yu. Batusov, I. Belolaptikov, R. Bertini, A. Bianconi, T. Blokhintseva, A. Bonyushkina, S. Bossolasco, S. Bunyatov, M. P. Bussa, L. Busso, V. Butenko, S. Costa, O. Denisov, V. Drozdov, I. Falomkin, L. Ferrero, V. Frolov, R. Garfagnini, U. Gastaldi, I. Gnesi, A. Grasso, V. Grebenyuk, C. Guaraldo, V. Ivanov, M. Kulyukin, A. Kirilov, V. Kovalenko, E. Lodi Rizzini, V. Lyashenko, R. Mach, A. Maggiora, M. Maggiora, A. Manara, A. Mihul, A. Moissenko, F. Nichitiu, D. Panzieri, V. Panyushkin, B. Parsamyan, G. Piragino, G. Pontecorvo, S. Prakhov, V. Pryanichnikov, A. Rozhdestvensky, N. Russakovich, M. Sapozhnikov, Yu. Shcherbakov, R. Scrimaglio, I. Smirnova, L. Venturelli, F. Tosello, V. Tretyak, G. Zosi.

being a LINAC for electrons and positrons was adopted in parallel also by the LEALE laboratory (Frascati) for the electroproduction of pion beams. Carlo Castagnoli from Turin was appointed Head of the LEALE project.

The Turin experimental group of nuclear physics led by the author (G. P. ), upon having carried out research at the two electron Italian synchrotrons on pion photoproduction on nuclei (at Frascati) and on the photodisintegration of He-4 and the structure of the giant dipole resonance (at Turin), initiated a project in 1967 for studying all the interaction channels of positive pions with He-4, for which at LEALE an apropriate detector was built, based on of a diffusion cloud chamber in a magnetic field filled with He-4 at a pressure of 12 atm. In 1968, in those circumstances, the Accademia dei Lincei supported and financed the first three-month visit of the author to the JINR Laboratory of Nuclear Problems, where Yuri Shcherbakov was preparing a systematic study at the Dubna synchrocyclotron of both the elastic scattering of positive and negative pions on He-4 and He-3 nuclei and of the double charge exchange of positive pions on He-4. The JINR detector was based on a novel visualizing technique, a self-shunted streamer chamber filled with helium at a pressure of 4 atm (experiment DUB-TO). These common scientific interests rapidly gave rise to a fruitful collaboration between Dubna and Turin, which is still underway. Within a period of over 40 years this collaboration continued developing with new common experiments performed at Frascati, at CERN, at the LNS of Saclay, and, at present, again at JINR and CERN.

At Frascati, after the first experiment carried out with the aid of a diffusion cloud chamber, an original magnetic spectrometer based on a streamer chamber filled with helium at atmospheric pressure was constructed in the 70s for studying backward scattering of positive and negative pions on nuclei (experiment TO-FRA-DUB).

In 1972, given the good results of the collaboration with Turin, JINR supported a meeting in Moscow between physicists of the Institute for Nuclear Research of the Academy of Sciences (led by Zatsepin, Chudakov and Tavkhelidze), who were performing studies in Cosmic Physics at underground Soviet laboratories and the Turin group led by Castagnoli, that had just created a CNR laboratory in the tunnel under Mont Blanc. One of the most significant results happened to be the observation under the Mont Blanc of neutrinos emitted from the explosion of the Supernova of 1987. This second Italian-Russian collaboration is still underway in the INFN Laboratorio Nazionale del Gran Sasso.

In 1975, Claudio Villi, as INFN President, visited the JINR and signed the first General Agreement between the two scientific entities, which has always been renewed (see photograph).

In 1979, as projected by Venedikt Dzhelepov, Director of the JINR Laboratory of Nuclear Problems, the JINR synchrocyclotron was stopped for reconstruction and its transformation into a phasotron. In 1980 Dzhelepov supported transferring the Turin-Dubna collaboration to LEAR at CERN, where the experiment PS179 was initiated for studying the interaction of slow antiprotons and antiprotons at rest with light nuclei. A large self-shunted streamer chamber in a magnetic field filled with a gas target at atmospheric pressure was constructed together with Frascati and Pavia. Within the framework of this experiment, also, nuclear emulsions were irradiated for a study of antiproton interactions with surface nucleons and of multinucleonic interactions with inner nuclear matter (experiment TOFRADUPP). The first direct experimental measurement of the upper limit of the amount of antimatter present in the earliest Universe gave rise to a particular interest.

At the end of the 80s, the same collaboration introduced a change of detection technology and constructed the OBELIX-PS201 spectrometer in order to continue, at LEAR of CERN, the study of the antiproton-nucleon interaction and of meson spectroscopy.

At the end of the 90s the Dubna-Turin collaboration also realized the DISTO spectrometer for a study of strangeness production by polarized protons at Saturne of Saclay.

The same group of physicists then projected and realized during the first years of the 21st century the COMPASS-NA58 spectrometer at the SPS of CERN for studying the structure of nucleons and hadron spectroscopy. This experiment is still underway.

During the period between 1987 and 2005 the author (G. P. ) was appointed First Counsellor of the Italian Embassy at Moscow (with functions of Scientific Attaché) and member of the Scientific Council of JINR. As such he took part in 1992 in achieving approval by the Italian side of a cospicuous financial support of about one million dollars by the Italian Ministry of Foreign Affairs of research in Russia (Law n. 212). Making use of this financial support the Italian-Russian physicists of Dubna and Turin, thanks to the support by INFN, projected and realized at the JINR phasotron a new spectrometer (experiment PAINUC) for studying, at atmospheric pressure and high precision, the interactions of positive and negative pions with He-4 nuclei, applying pion beams of energy lower than that necessary for excitation of the "Delta" resonance. At the same time, this spectrometer would permit to launch an experimental study for the estimation of the upper limit for the mass of neutrinos and antineutrinos produced in pion decays.

A complete list of the members of this magnificent collaboration is given in the box.