Activities and publications of the Pisa "Bubble Chamber Group": 1953-1988

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May 2009

The activity of the bubble chamber Group at the University of Pisa/Istituto Nazionale di Fisica Nucleare, Pisa, initiated in the early 50's, came to an end in the late 80's. The last experiment performed was a search for oscillations of muon into electron neutrinos.

It had already been decided, shortly after the end of the activity, to collect in a single document a summary of all experiments performed, of the main results achieved, together with a recollection of the many people involved in this long and fruitful activity. This task was, for various reasons, postponed over and over again.

In 2003 a meeting was organised in Bologna by Giorgio Giacomelli and his group, gathering together many of the physicists from all over the world, who had spent decades in pursuing Experimental High Energy Physics using bubble chambers. We had unfortunately been unable to participate, but the discussion that took place on that occasion, nicely summarised in the form of proceedings, recalled our attention to our old commitment, that we now carry to completion.

In the process of collecting and organising the material for this document we have had a chance of going back to a number of facts and circumstances that have been of crucial importance for the activity of the group, activity that has always needed the support of all sectors of the Pisa-INFN section. The entire technical staff of both INFN and the Physics Department has contributed in a critical way, over a period of more than 30 years, to the progress of our research work. To all of them goes our gratitude.

We wish in addition to recall the great contribution of Giuseppe Martelli, who initiated in Pisa the early experimental and theoretical studies of the thermodynamics of bubble chambers, shortly after the invention of this new device in 1952.

We feel it is our duty as well to recall the great personality of Marcello Conversi, who in the early 50's gave birth to experimental high energy physics in Pisa, as well as to many other scientific activities, and who collaborated with our group 25 years later, using a much larger and instrumented version of the early bubble chambers.

We are grateful, for many interesting discussions and for providing information concerning the Physics Institute and the early days of the bubble chamber group, to Luciano Bertanza, Maria Vicich Martelli, Italo Mannelli, Silvia Gozzini, Erseo Polacco, Gianni Gennaro and Piero Maestrini.

Armando Bigi
Vincenzo Flaminio

Figure 1: Marcello Conversi lecturing at a celebration held in Rome on the occasion of his 70^{th} birthday

Figure 2: A photograph of Giuseppe Martelli in 1976. The photograph was taken on a train during a trip to Bombay for a scientific mission. Photo: courtesy Martelli family

1 Introduction

In the early 50's the activity in the Physics Institute of Pisa University was almost entirely confined to x-ray and microwave spectroscopy, that had been kept alive throughout and after the years of the war, thanks to Adriano Gozzini, Luigi Puccianti, Anna Ciccone, Nello Carrara, Tullio Derenzini, G. De Donatis, Silvio Chella and a few others. No activity was present at the time in what we would now call High Energy Physics.

The situation changed drastically when, in February 1951, Marcello Conversi was called as Director of the Physics Institute[1].

It may be stated beyond any doubt that it was thanks to Conversi that an important activity in the field started in Pisa. He was Director of the Physics Institute for eight years, till February 1959, when he moved to Rome and was replaced by Luigi Arialdo Radicati for a short period and later by Carlo Franzinetti. In the early part of that period also Giorgio Salvini was a Professor of Physics in Pisa and contributed in a significant manner to the development of High Energy Physics, setting up, among other things, the study group that designed the National Electrosynchrotron, later built in Frascati.

[1]Marcello Conversi had been born in Tivoli in 1917. In 1951 he was therefore about 35 years old

Figure 3: A photograph of Marcello Conversi with Bruno Pontecorvo at a celebration for Amaldi's 70^{th} birthday in Rome. (Photo: courtesy Bruno Borgia)

The impact of Conversi on the research activity in Pisa, in Particle Physics as well as in other fields was of paramount importance. His physical insight together with an uncommon enthusiams that he managed to transmit to other people in the Institute were such as to enable him to establish an excellent collaboration with his colleagues, including those working in other fields of Physics. An illuminating example of such collaboration was that with another great physicist from our Institute, Adriano Gozzini. To such collaboration was due the invention of the flash-tubes tracking detector, a progenitor of the spark chamber[2]

Others after him had also a profound impact on the development of Particle Physics in the University. Among these we must recall Luigi Arialdo Radicati, a Professor of Theoretical Physics now at Scuola Normale Superiore, Carlo Franzinetti, who was a Professor of Experimental Physics in Pisa between February 1959 and the end of 1966[3], and later Gherardo Stoppini, Professor of Experimental Physics, who was also Director of the Pisa Section of INFN for several years.

[2]M. Conversi and A. Gozzini: The "Hodoscope Chamber", a new instrument for Nuclear Research. Il Nuovo Cimento, vol. II, n. 1, pag. 189, 1955

[3]In the latter part of this period Carlo Franzinetti was on leave at CERN

Figure 4: Luigi Arialdo Radicati, Adriano Gozzini and Marcello Conversi at a meeting in Pisa in the early seventies. Left to right: L.A. Radicati, A. Gozzini, Mrs. Andreotti, Mrs. Gozzini, M.Conversi, Mrs. Conversi. Photo: courtesy Silvia Gozzini

In order to place the early research with the use of bubble chambers in an appropriate scientific context, it is appropriate to begin with a document that has now a historical value: a review paper published by Marcello Conversi on "Supplemento al Nuovo Cimento" in 1954.

The complete original paper by Conversi (in Italian) is not reproduced here. It is however worth recalling a few lines from this article.

Conversi writes: "As far as the Λ^0 particle is concerned, there is another remarkable point, regarding the apparent contradiction between the large production probability and the long lifetime of this particle. We notice indeed that if a single Λ^0 particle is produced by the interaction, say, of a negative pion, the corresponding reaction:

$$p + \pi^- \rightarrow \Lambda^0$$

represents the inverse of the decay process:

$$\Lambda^0 \rightarrow p + \pi^-$$

Now if, according to the experimental results, we interpret the Λ^0 particle as an excited state of the neutron, we find (see Sachs) that the lifetime of this excited state for emission of a pion having momentum p should be of the order of $\hbar/pc$ or about $10^{-22} \div 10^{-23}$ s.

M. CONVERSI
1954 - N. 1
Supplemento al Nuovo Cimento
12, 35-55

Particelle pesanti neutre (*).

M. CONVERSI

Istituto di Fisica dell'Università - Pisa
Istituto Nazionale di Fisica Nucleare - Gruppo Aggregato di Pisa

La scoperta dell'esistenza di una varietà di particelle «fondamentali» instabili è senza dubbio uno dei risultati più notevoli conseguiti nella ricerca fisica dell'ultimo decennio. L'origine di questa scoperta si può far risalire al 1944, quando LEPRINCE-RINGUET e LHÉRITIER, applicando le leggi di conservazione ad una collisione osservata in Camera di Wilson tra una particella positiva ed un elettrone, ottennero per la massa della particella positiva un valore prossimo a 1000 masse elettroniche [1]. La convinzione dell'esistenza di particelle instabili più pesanti dei mesoni ordinari si venne però creando solo negli anni successivi alla scoperta del mesone π, specialmente dopo la prima fotografia in Camera di Wilson delle cosidette «traccie V» [2] ed in seguito all'osservazione in emulsione fotografica del decadimento di una particella carica di massa prossima a 1000 m_e (mesone τ) in tre secondari carichi, uno dei quali fu identificato per un pione negativo [3].

Le «tracce V», osservate per la prima volta da ROCHESTER e BUTLER, furono interpretate come dovute o al decadimento di una particella neutra (V^0) in coppie di particelle cariche di segno opposto (v. fig. 1) o al decadimento di una particella carica ($V^{\pm}$) in una neutra e in una seconda carica.

Negli anni successivi al 1947 le ricerche sulle nuove particelle instabili si sono crescentemente intensificate. Per alcune di esse (quali, ad esempio, il mesone τ e le particelle Λ^0 e θ^0 delle quali parleremo diffusamente tra breve) si conoscono oggi con notevole sicurezza le modalità del processo di decadi-

(*) Nella stesura dell'articolo seguente sono state introdotte piccole varianti ed aggiunte alcune notizie più recenti, con lo scopo di ottenere una rassegna sulle particelle pesanti neutre aggiornate fino al Maggio 1954.

Figure 5: Front page of the Review Article published by Marcello Conversi in 1954

This value is in sharp disagreement with the experimental value of the lifetime of the Λ^0 particle, that, according to the most reliable measurements is:

$$\tau = \left(3.3^{+0.9}_{-0.5}\right) 10^{-10}\ s$$

....."

In the paper, Conversi discusses also some length possible associations of the decays $V_2^0 \rightarrow \pi^+\pi^- + Q\,value$ with the θ^0 particle (the K_S^0).

At the time, most results came from either emulsion or cloud chamber experiments.

The first of these techniques was tedious and data were lengthy to analyse, the second had a very low density and therefore provided a small event rate. bubble chambers turned out to be the appropriate detector to investigate the properties of the "new particles".

2 The origins: following Glaser's invention of the bubble chamber

Glaser invented the bubble chamber in 1952. Shortly afterwards, in 1953, Giuseppe Martelli, with the help of a recently graduated physicist, Luciano Bertanza, started in Pisa an experimental activity that was to become the nucleus of the future "Bubble Chamber Group". Giuseppe Martelli [4], an assistant to Marcello Conversi, was the group leader.

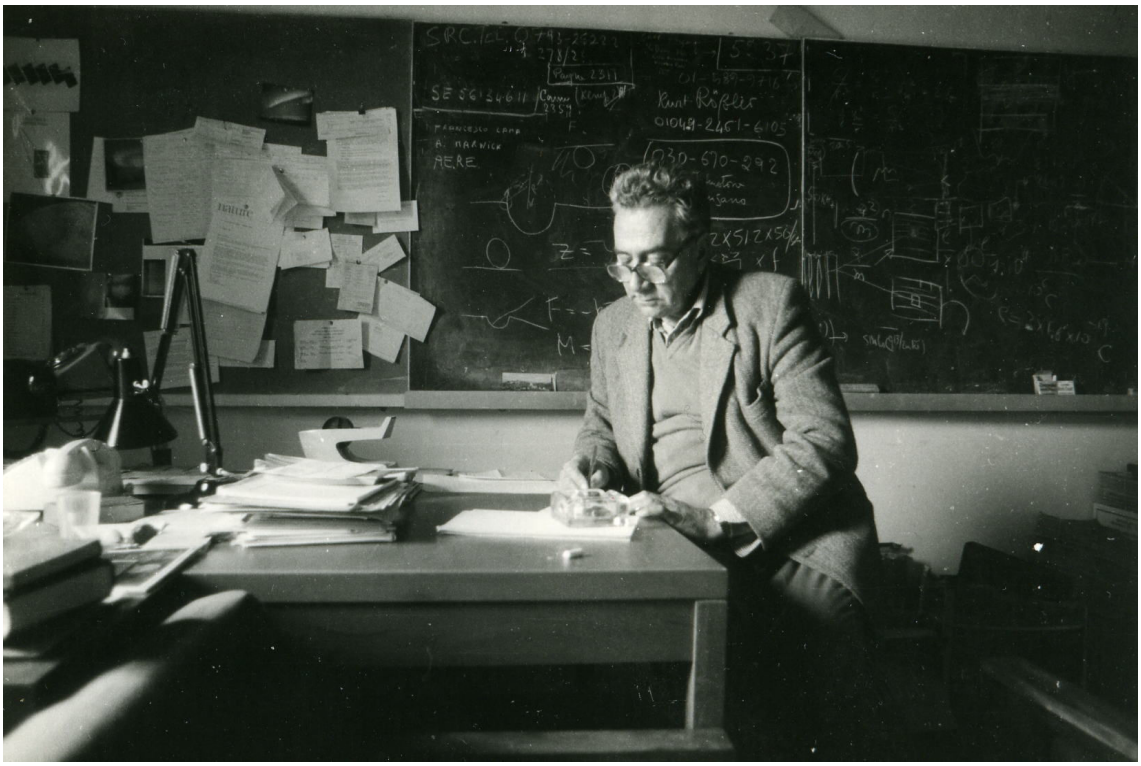


Figure 6: A photograph of Giuseppe Martelli at the University of Sussex in 1983. Photo: courtesy Martelli family

They built a bubble chamber, having a volume somewhat larger than Glaser's (60 cm^3 to be compared with a few cm^3) using pentane at a temperature of $\approx 138^oC$ as liquid. They also carried out a detailed theoretical study of the thermodynamics of such chamber. The results of these experiments and theoretical analyses were published between 1954 and 1957 by L. Bertanza, G. Martelli, A. Zacutti and B. Tallini. After the departure of Giuseppe Martelli, this activity continued under the direction of Luciano Bertanza.

In 1956 Sergio Focardi, a young physicist who had recently graduated in Pisa, moved to Bologna to participate in the construction of the first Italian hydrogen bubble chamber. This had a volume of about 3 liters and was built by a collaboration including the groups of Bologna, Padova, Roma and Trieste.

[4]Martelli moved to the UK in 1957 but his association with Pisa University was only terminated in October 1961. He worked first at the University of Birmingham, as head of the bubble chamber Group, then, after a short period spent at the Euratom in Bruxelles, he moved to the newly instituted University of Sussex, where he started the "Plasma and Space Physics Group" and where he contributed with many innovative and successful ideas. He spent there the rest of his activity, until his death in September 1994

Figure 7: A photograph of Luciano Bertanza with Giuseppe Martelli on the occasion of a meeting of the Società Italiana di Fisica, held in Palermo in 1958

In the meantime, as we shall discuss later, an activity had started in the Institute, on the analysis of bubble chamber film taken at Brookhaven. The physicists involved in this activity were: Marcello Conversi, Paolo Franzini, Italo Mannelli, Renato Santangelo and Vittorio Silvestrini.

At the end of this activity, a new bubble chamber group was formed. The new group, whos senior member was Luciano Bertanza, included Paolo Franzini, Italo Mannelli and Vittorio Silvestrini.

In 1958 this group built a new prototype bubble chamber, using mixtures of methyl-iodide-ethane or methyl-iodide-carbon dioxide, with eventually small quantities of propane.

A rapid-cycling, 1.5 liters bubble chamber, was built by the same group in 1959. Details of the chambers and of their operation conditions were reported in two articles published

respectively on "Il Nuovo Cimento" and on "Nuclear Instruments and Methods".

The rapid-cycling bubble chamber, using a 50% propane-ethane mixture and capable of 4 expansions/second, was then used by L. Bertanza, I. Mannelli, S. Santucci, G.V. Silvestrini and V.Z. Peterson, in an experiment performed at the Frascati Electron Synchrotron to measure the polarization of the recoil proton in $\gamma p \rightarrow p\pi^0$ at photon energies of 725 and 900 MeV. The results were reported in "Il Nuovo Cimento" in 1962. A sketch of the chamber is shown in figure 9 and an event photographed in that chamber can be seen in figure 10.

Figure 8: One of the earliest prototype bubble chambers

A propane bubble chamber (shown in figure 11) whose design and construction had been initiated by Martelli, was never used in an actual experiment. It was nevertheless tested in 1960 and worked perfectly, as proven by the events of figures 12 and 13, that are shown here for the first time. Its further implementation was stopped when bubble chambers of much larger dimensions and equipped with magnetic fields came into operation in France and at CERN.

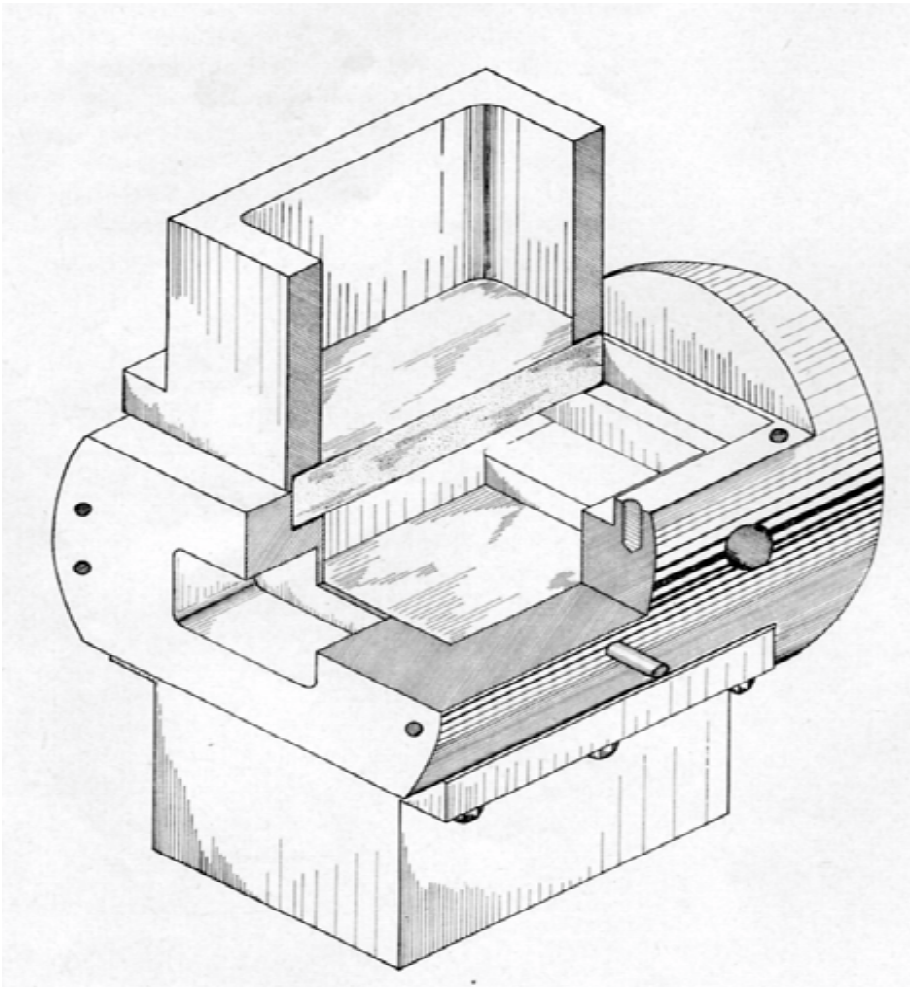


Figure 9: A sketch of the rapid-cycling bubble chamber. Unfortunately this chamber was lost

Some Measurements on Overheated Liquids

L. Bertanza, G. Martelli and A. Zacutti

Il Nuovo Cimento XI, 692, 1954

Influence of Ions on the Nucleation Processes in Liquids: I - Liquids in Stable Thermodynamical Equilibrium

G. Martelli

Il Nuovo Cimento XII, 250, 1954

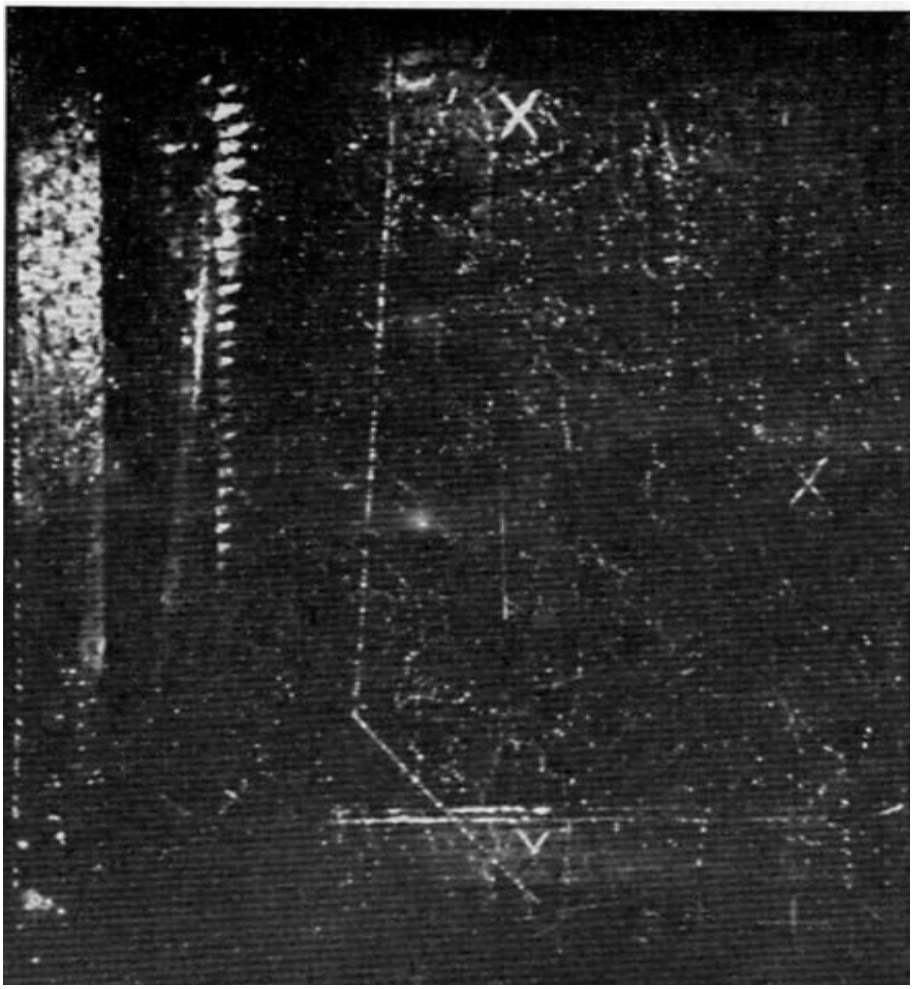


Figure 10: An event recorded in the rapid-cycling chamber

Influence of Ions on the Nucleation Processes in Liquids: II Liquids Under Positive Pressure in Metastable Thermodynamical Equilibrium (Overheated liquids)

L. Bertanza and G. Martelli

Il Nuovo Cimento, Vol. I, N.2, pag. 324, 1955

Operation Conditions of a Bubble Chamber (n-pentane, iso-pentane and diethyl ether)

L. Bertanza, G. Martelli and A. Zacutti

Il Nuovo Cimento, Serie X, Vol. 2, 487, 1955

Figure 11: The body of the propane bubble chamber

An attempt to control a Bubble Chamber by counters

L. Bertanza, P. Franzini, G. Martelli and B. Tallini

Proc. 1956 CERN Symposium on HEP Accelerator and Pion Physics. Vol. 2, pag. 29, 1956

Bubble Density Along the Path of Ionizing Particles Crossing a Bubble Chamber

L. Bertanza, G. Martelli and B. Tallini

Il Nuovo Cimento, Serie X, Vol. 5, 940, 1957

Leptonic decay modes of the hyperons

F. Esler, R. Plano, A. Prodell, N. Samios, M. Schwartz, J. Stenberger, M. Conversi, P. Franzini, I. Mannelli, R. Santangelo and V. Silvestrini

Physical Review, Vol. 112, p. 979, 1958

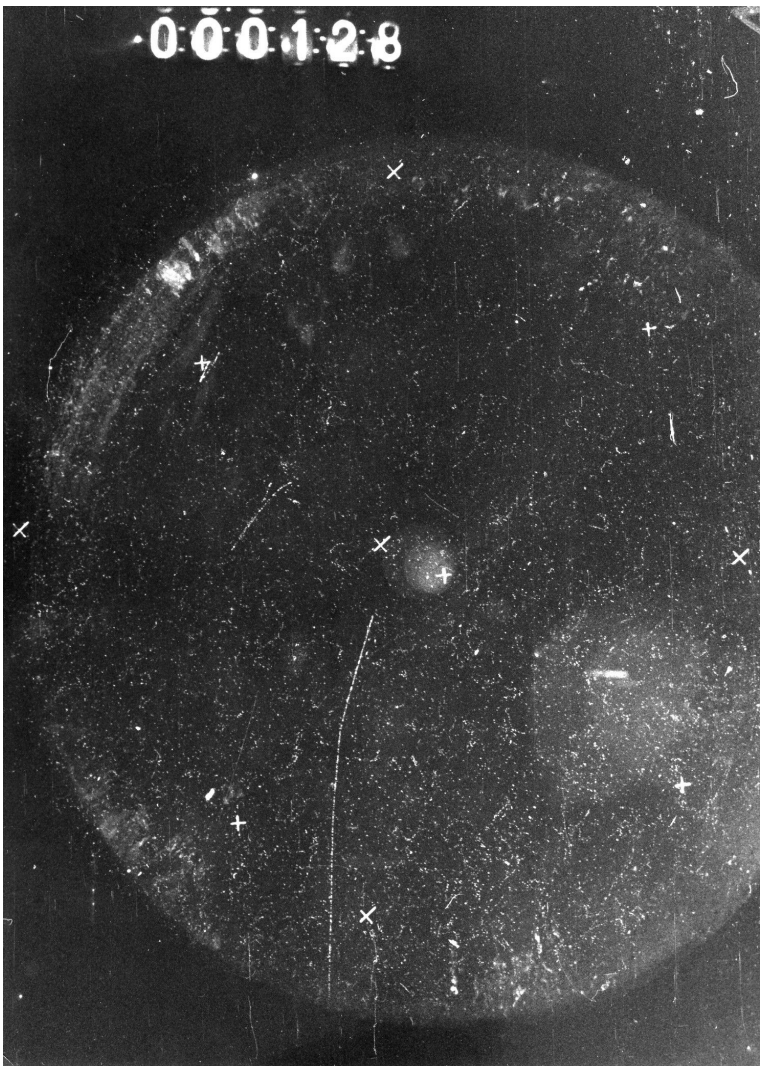


Figure 12: A track in the propane bubble chamber

Operation of a Bubble Chamber Filled with High Z Mixtures

L. Bertanza, P. Franzini, I. Mannelli and V. Silvestrini

Il Nuovo Cimento, Serie X, Vol. 10, pag. 403, 1958

A Rapid Cycling Bubble Chamber

L. Bertanza, P. Franzini, I. Mannelli and V. Silvestrini

Nuclear Instruments and Methods, 9, 354, 1960

Figure 13: An event in the propane bubble chamber

Three Liters Liquid Hydrogen Bubble Chamber
Bologna-Padova-Pisa-Roma-Trieste
Collaboration

P. Bassi, R. Cano, S. Focardi, G. Gialanella, A. Michelini and F. Saporetti

Supplemento al Nuovo Cimento, Serie X, Vol. 16, pag. 184-191, 1960

A Bubble Chamber Experiment to Measure the Polarization of the Recoil Proton in the Photoproduction of π^0 Mesons from Hydrogen

L. Bertanza, P. Franzini, I. Mannelli, V. Silvestrini and V.Z. Peterson

Il Nuovo Cimento, Serie X, Vol 19, pag. 953, 1961

Measurement of the Polarization of the Recoil Proton in $\gamma p \to p\pi^0$ Using a Propane-Ethane Bubble Chamber

L. Bertanza, I. Mannelli, S. Santucci, G. V. Silvestrini and V.Z. Peterson

Il Nuovo Cimento, Serie X, Vol. 24, pag. 734-745, 1962

3 Early analyses of Bubble Chamber films from Brookhaven and CERN

While construction of small heavy liquid bubble chambers was still going on in Pisa, as well as in several other Italian Universities, big progress had been made in the field by two large US laboratories, Berkeley and Brookhaven, where suitable particle beams were available. Relatively large quantities of film were produced in these laboratories, and the need was felt to build "large" international collaborations to share the hard task of measuring and analysing the data.

As already mentioned, in the early 50's Director of the Physics Institute in Pisa was Marcello Conversi. It was thanks to contacts between Jack Steinberger, Marcello Conversi and Giampietro ("Gianni") Puppi, that film obtained in bubble chamber exposures at Brookhaven could be shipped to Bologna and Pisa, where it was analysed. This was perhaps the first real "International Collaboration" in bubble chamber Physics involving Italian groups, that laid the grounds for a widespread diffusion of High Energy Physics in a large number of Italian Universities. A further push in this diffusion originated from the construction of the first "large" bubble chambers at CERN, both of the cryogenic type (using Hydrogen or Deuterium) or of the "Heavy Liquid" type.

One cannot, in this context, forget mentioning the important role played by Carlo Franzinetti, who promoted over the years a number of collaborations between Pisa and CERN, besides other Italian Institutions.

Figure 14: Carlo Franzinetti discussing with Bruno Pontecorvo

The first published paper from these analyses was on parity non conservation in the decay of the Λ^0 particle, by a Bologna-Brookhaven-Pisa Collaboration. This result, of obvi-

ously great importance, came shortly after the observation of parity violation in strangeness conserving weak interaction processes, like neutron beta decay, muon and pion decay. The analysis of these data was the subject of Italo Mannelli's thesis.

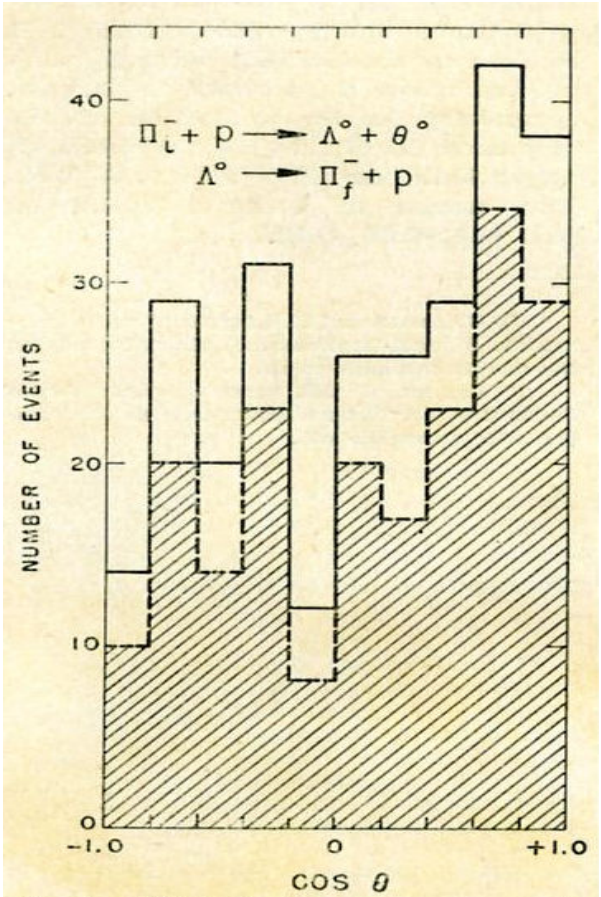
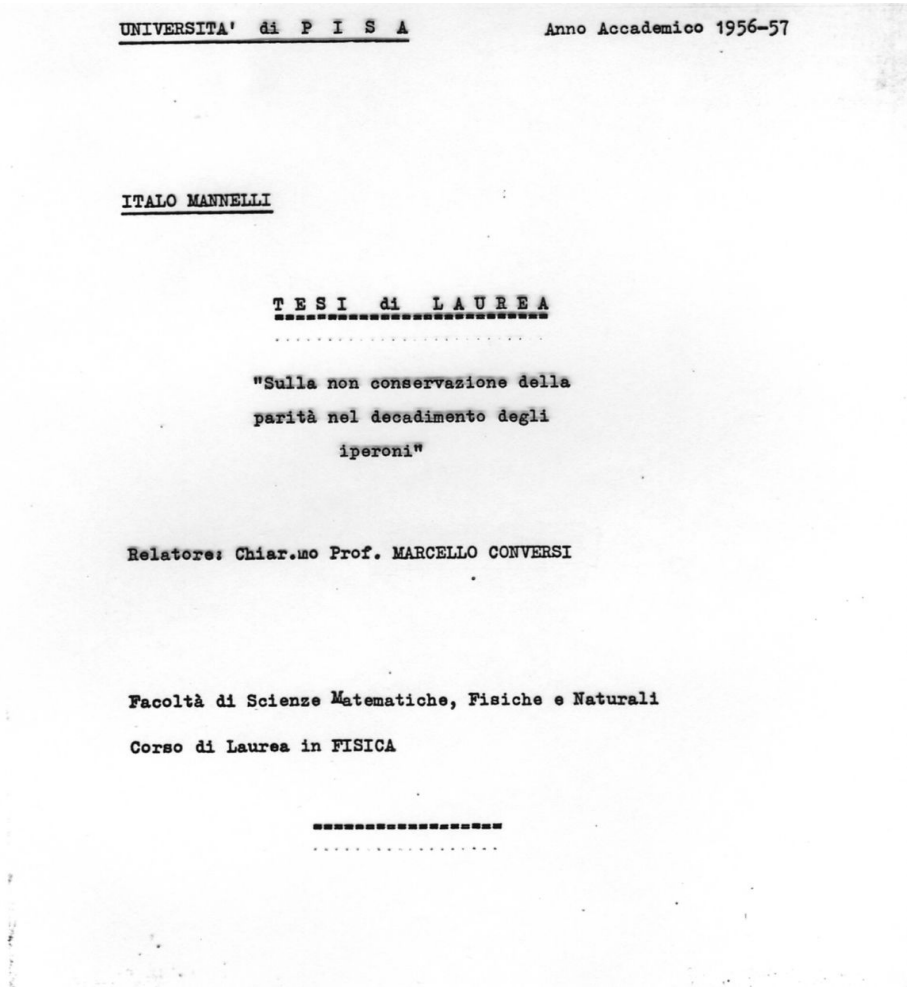


Fig. 1. – Distribution in cos θ for process (1). The shaded area represents events for production angles in the center-of-mass range 30°÷150°.

Figure 15: First published result on parity violation in Λ decay. Θ is the angle between the momentum of the decay proton and the normal to the production plane

Many other important results (on the determination of the Λ^0 and Σ^- spins, on the liftetimes of the Λ^0, K^0 and Σ^- etc.) were obtained in these early works.



UNIVERSITA' di P I S A Anno Accademico 1956-57

ITALO MANNELLI

T E S I di L A U R E A

"Sulla non conservazione della parità nel decadimento degli iperoni"

Relatore: Chiar.mo Prof. MARCELLO CONVERSI

Facoltà di Scienze Matematiche, Fisiche e Naturali

Corso di Laurea in FISICA

Figure 16: Front page of Italo Mannelli's thesis

Demostration of Parity Nonconservation in Hyperon Decay

Brookhaven-Bologna-Pisa-Michigan Collaboration

F. Eisler, R. Plano, A. Prodell, N. Samios, M.Schwartz, J. Steinberger, P. Bassi, B. Borrelli, G. Puppi, H. Tanaka, P. Waloschek, V. Zoboli, M. Conversi, P. Franzini, I. Mannelli, R. Santangelo, V. Silvestrini, D. A. Glaser, C. Graves and M.Perl

The Physical Review, Vol. 108, p. 1353, 1957

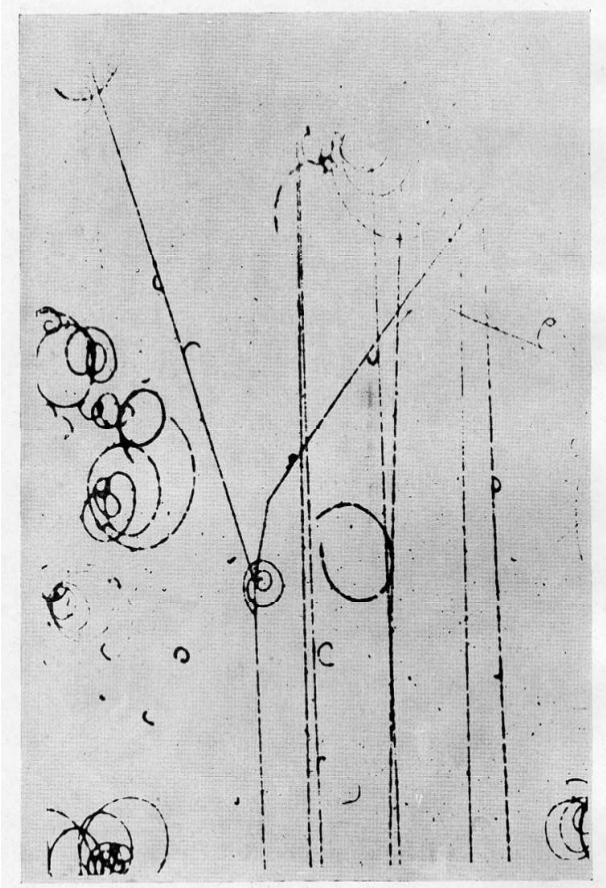


Fig. 6. – An example of the reaction $\pi^- + p \to \Sigma^- + K^+$ at 960 MeV in the hydrogen chamber.

Figure 17: π^- p $\rightarrow \Sigma^- K^+$ at 960 MeV, in the experiment looking for parity violation in hyperon decay

Experimental Determination of the Λ^0 and Σ^- Spins

Brookhaven-Bologna-Pisa-Michigan Collaboration

F. Eisler, R. Plano, A. Prodell, N. Samios, M.Schwartz, J. Steinberger, P. Bassi, B. Borelli, G. Puppi, H. Tanaka, P. Waloschek, V. Zoboli, M. Conversi, P. Franzini, I. Mannelli, R. Santangelo, V. Silvestrini, D. A. Glaser, C. Graves and M.Perl

Il Nuovo Cimento, Serie X, Vol. 7, p. 222, 1958

Lifetime of Λ^0, Θ^0 and Σ^-
Brookhaven-Bologna-Pisa
Collaboration

F. Eisler, R. Plano, A. Prodell, N. Samios, M.Schwartz, J. Steinberger, P. Bassi, B. Borelli, G. Puppi, H. Tanaka, P. Waloschek, V. Zoboli, M. Conversi, P. Franzini, I. Mannelli, R. Santangelo and V. Silvestrini

Il Nuovo Cimento, Serie X, Vol. 10, pag. 150, 1958

Bubble Chamber Study of Unstable Particle Production in $\pi^- p$ Collisions at 910, 960, 1200 and 1300 MeV
Brookhaven-Bologna-Pisa
Collaboration

F. Eisler, R. Plano, A. Prodell, N. Samios, M.Schwartz, J. Steinberger, P. Bassi, B. Borelli, G. Puppi, H. Tanaka, P. Waloschek, V. Zoboli, M. Conversi, P. Franzini, I. Mannelli, R. Santangelo, V. Silvestrini

Il Nuovo Cimento, Serie X, Vol. 10, pag. 468, 1958

Graphical Method for the Analysis of Bubble Chamber Pictures
Bologna-Pisa Collaboration

V. Borelli, P. Franzini, I. Mannelli, A. Minguzzi-Ranzi, R. Santangelo, F. Saporetti, V. Silvestrini, P. Waloschek and V. Zoboli

Il Nuovo Cimento, Serie X, Vol. 10, pag. 525, 1958

Sulla produzione di mesoni π^- nell'urto pione-neutrone a 1.2 BeV

L. Bertanza, P. Franzini, I. Mannelli, P.H. Stoker and V. Silvestrini

La Ricerca Scientifica, Anno 29^o Settembre 1959

$\pi^- p$ Elastic Scattering at 1200 MeV

L. Bertanza, R. Carrara, A. Drago, P. Franzini, I. Mannelli, V. Silvestrini, and P.H. Stoker

Il Nuovo Cimento, Serie X, Vol. 19, pag. 467, 1961

Charged Hyperon Production by 16-Gev/c π^- Mesons
CERN-Pisa-Trieste Collaboration

J. Bartke, R. Bock, R. Budde, W.A. Cooper, H.Filthuth, Y. Goldschmidt-Clermont, F. Grard, G.R. MacLeod, A. Minguzzi-Ranzi, L. Montanet, W.G. Moorhead, D.R.O. Morrison, S. Nilsson, C. Peyrou, B.W. Powell, J. Trembley, D. Wiskott, L. Bertanza, C. Franzinetti, I. Mannelli, V. Silvestrini, G. Brautti, M. Ceschia and L. Chervosani

Physical Review Letters, 6, 303, 1961

Strange Particle Production in 16-Gev/c $\pi^- p$ Interactions
CERN-Pisa-Trieste
Collaboration

J. Bartke, R. Bock, R. Budde, W.A. Cooper, H.Filthuth, Y. Goldschmidt-Clermont, F. Grard, G.R. MacLeod, A. Minguzzi-Ranzi, L. Montanet, W.G. Moorhead, D.R.O. Morrison, C. Peyrou, B.W. Powell, J. Trembley, D. Wiskott, L. Bertanza, C. Franzinetti, I. Mannelli, V. Silvestrini, G. Brautti, M. Ceschia and L. Chersovani

Proceedings of the 1960 Annual International Conference on High Energy Physics at Rochester. Pag. 402-405, 1960

Hyperon and Kaon Production by 16 GeV/c Negative Pions on Protons
CERN-Pisa-Trieste
Collaboration

J. Bartke, R. Budde, W.A. Cooper, H.Filthuth, Y. Goldschmidt-Clermont, G.R. MacLeod, A. De Marco, A. Minguzzi-Ranzi, L. Montanet, D.R.O. Morrison, S. Nilsson, C. Peyrou, R. Sosnowski, A. Bigi, R. Carrara, C. Franzinetti, I. Mannelli, G. Brautti, M. Ceschia and L. Chervosani

Il Nuovo Cimento, Serie X, Vol. 24, pag. 876-895, 1962

Hyperon and Kaon Production by 24.5 GeV/c Protons on Protons
CERN-Pisa
Collaboration

J. Bartke, W. A. Cooper, B. Czapp, H. Filthuth, Y. Goldschmidt-Clermont, L. Montanet, D.R.O. Morrison, S. Nilsson, Ch. Peyrou, R. Sosnowski, A. Bigi, R. Carrara, C. Franzinetti and I. Mannelli

Il Nuovo Cimento, Vol. 29, pag. 8-18, 1963

Differential Cross-Section of the $\pi^- p \to \pi^0 n$ Process at 930 MeV

A. Bigi, R. Carrara and D. Zanello

Il Nuovo Cimento, Serie X, Vol. 34, pag. 878-882, 1964

Report on Preliminary Design Considerations for a Large Heavy Liquid Bubble Chamber
Padova-Milano-Pisa
Collaboration

E. Fiorini, L. Guerriero, I. Mannelli, P. Negri and I. Scotoni

Report INFN/TC-65/7. 12 Maggio 1965

$\pi^- - p$ Interactions at 775 MeV

L. Bertanza, A. Bigi, R. Carrara and R. Casali

Il Nuovo Cimento, Serie X, Vol. 44, pag. 712-725, 1966

$K^- p$ Interactions from 594 to 820 MeV/c
Brookhaven-Pisa-Yale
Collaboration

L. Bertanza, A. Bigi, R. Carrara, R. Casali, R. Pazzi, D. Berley, E.L. Hart, D.C. Rahm, W.J. Willis, S.S. Yamamamoto and N.S. Wong

Physical Review, 177, 2036, 1969

4 The construction of the first measuring machines and the development of reconstruction software

In the early days of the bubble chamber Group, the reconstruction and analysis of events relied entirely on rather primitive, albeit very ingenious, methods.

For a tri-dimensional reconstruction of events use was made of the so called "Wulff Sphere"[5], a graphical methods already used in the Navy and based on some geometrical properties of projections on surfaces.

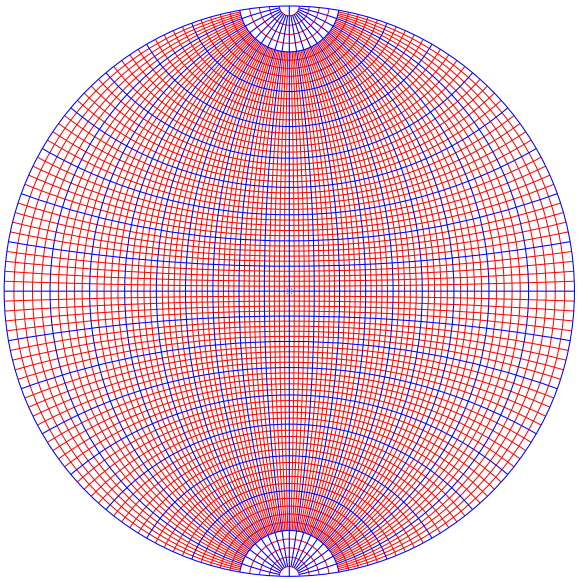


Figure 18: An example of a Wulff Diagram

In the case of bubble chambers in magnetic fields, allowing a determination of particle momenta from their curvature in the field, one used to superimpose on the event picture "templates", transparent sheets on which a number of arcs had been drawn, each corresponding to a given momentum, and selecting the arc which provided the closest match.

From the information thus gathered, a number of event parameters were obtained, performing simple calculations by the use of "slide rulers" and numerical tables prepared ahead of time, in order to avoid repating several times the same calculations.

The above procedures allowed the analysis and classification of up to a few dozens of events, together with distributions of a few physically meaningful variables.

Already in the late fifties, the need was strongly felt of more precise and faster measurements and calculations. The Pisa group, as well as several other groups in Italy and abroad, started constructing the first measuring "projectors" and considering the possibility of making use of electronic computers

A first measuring projector was designed, in which each "frame" was held in position on a support which could move into two othogonal directions. The position of the support was digitised to a precision of a few microns, allowing the relative coordinates of many points on each track to be measured and converted into digital signals. This was done by the operator on two or more stereo views of the same event.

The data thus collected had afterwards to be transferred to a computing system, in order to obtain the geometrical track parameters (typically: momentum, azimuthal and

[5]Probably introduced by G. Puppi

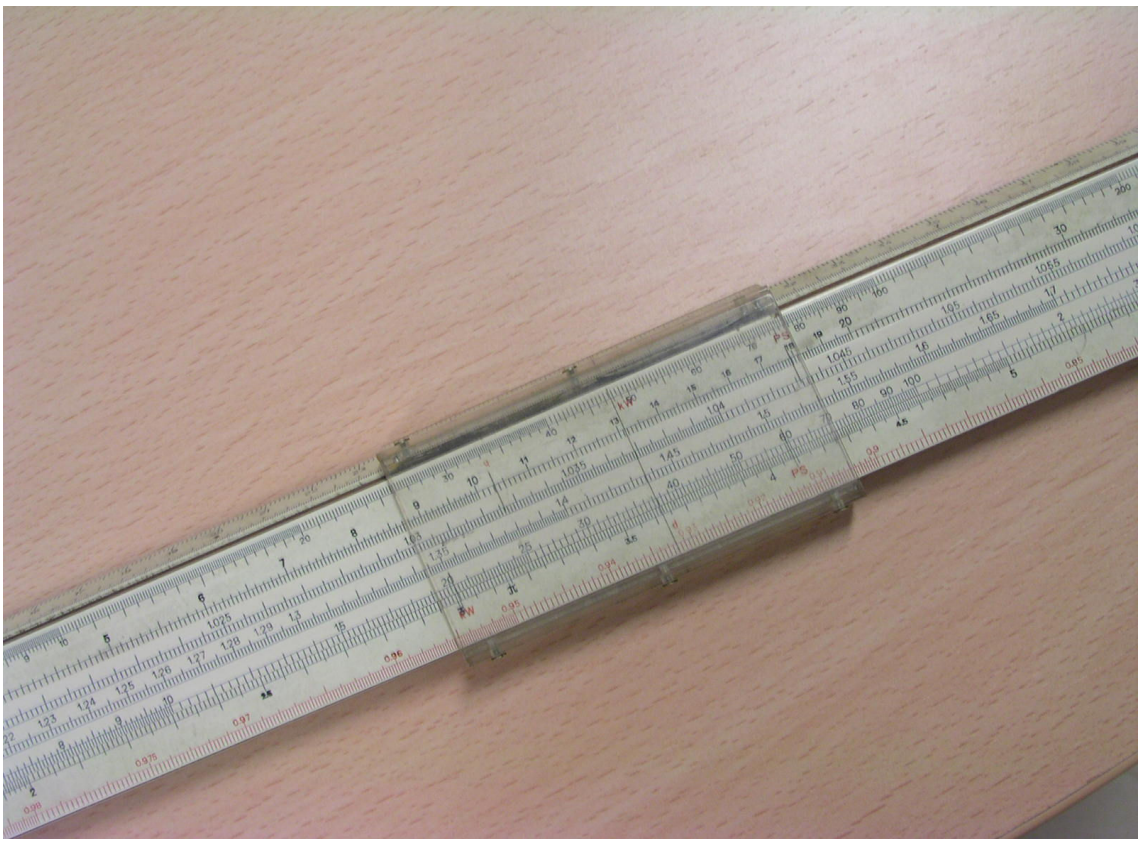


Figure 19: An old "Slide Ruler"

zenith angle at the event vertex).

The mechanical workshop of the Physics Institute was at the time heavily busy in the construction of new machines, while physicists kept steadily in touch with CERN personnel, as well as with researchers from other Laboratories, in order to develop the necessary computing methods.

It was at the time that the need, nowadays obvious, was felt, of "hardware" and "software" developments in Particle Physics.

Only in subsequent years Pisa could use a real computer, entirely "home built" after a suggestion by Enrico Fermi to Marcello Conversi and Giorgio Salvini, during a visit to Varenna in 1954 [6] The construction of the computer, completed at the end of 1960, owed much to the enthusiasm of Marcello Conversi, of Giambattista Gerace, a pioneer of Computer Science in Pisa, as well as to the strong support of the Rectors Enrico Avanzi and Alessandro Faedo. The Olivetti firm strongly supported this enterprise[7].

[6] In that period, the University of Pisa had been granted a non negligible amount of money by the Cities and Provinces of Lucca, Pisa and Livorno. The grant was targeted towards the construction of a National Electrosynchrotron, that had been designed in the Physics Institute under the coordination of Giorgio Salvini. It happened however that the site choice for the Electrosynchrotron fell upon Frascati. Pisa was thus left in the uneasy situation of having to employ in a useful way the grant allocated for a different reason. The suggestion by Fermi, as it later turned out, was a very positive one for the development of Computer Science in Pisa.

[7] A special Research Center had been set up in the Physics Institute for the design, construction and, more generally, for studies in the field of Computer Science. The Centre (Centro Studi Calcolatrici Elettroniche or CSCE) had a board of Directors that was chaired for many years by Marcello Conversi, even after he had left Pisa. In parallel was set up in Barbaricina (near Pisa) a study group guided by Eng. M. TChou who

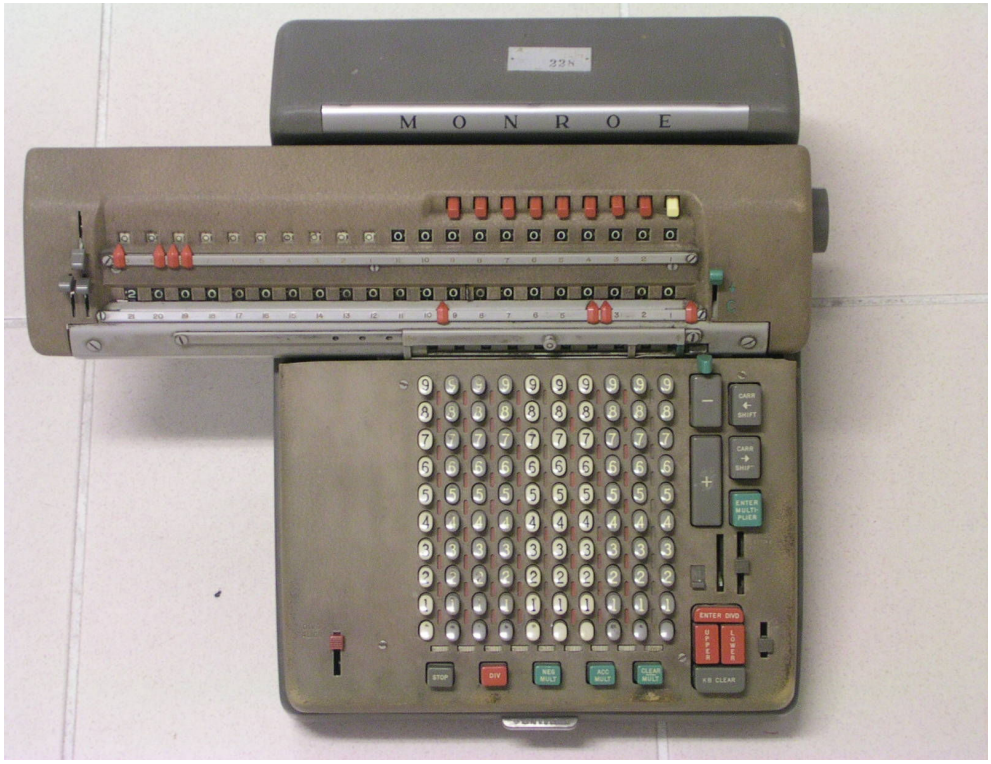


Figure 20: A "Monroe" electromechanical calculator

The computer was baptised "Calcolatrice Elettronica Pisana", or in brief CEP. It used perforated paper tape to input programs and data, and a primitive version of FORTRAN.

At the time, CERN was already using the first IBM computers and software had been developed for event reconstruction and analysis on such computers. It was however considered unrealistic to simply transfer on the new Pisa Computer such software. Paolo Franzini, who was at the time the head of the bubble chamber Group, asked therefore younger people (Armando Bigi and Dino Zanello) in the group to develop directly new software from scratch, for the new machine.

Within a few years a new measuring projector (named "Frankenstein") was built and the software for event reconstruction and analysis was steadily running on the CEP.

The number of events which could thus be analysed increased steadily, and the measuring precision was drastically improved.

Of great importance were, in the construction process of all the machines and of the related electronics, the high quality contributions of a mechanical engineer, Gianni Gennaro, and of an electronic engineer, Piero Salvadori. They were helped by many others, among which we wish to mention Roberto Ruberti, Carlo Guidi, Luciano Zaccarelli, Mario Giovannetti.

In 1962 Luciano Bertanza, who had in the meantime spent a two-years leave at Brookhaven National Laboratory, working on bubble chamber physics, came back to Pisa. Around 1965 he proposed to set up and strongly supported the implementation of, a direct link between the CEP and the measuring projectors, for an on-line evaluation of the measurements. Several people (Roberto Pazzi, Paolo Lariccia, L. Dall'Antonia and Franco Denoth, the last two from the C.E.P. center) worked on this for a couple of years. In 1966 this "on-line"

designed the Olivetti ELEA series of computers

Figure 21: Photograph of Marcello Conversi (on the right) with President of Italian Republic Giovanni Gronchi at the inauguration of C.E.P. in November 1961. Also visible (on the extreme left) is Giambattista Gerace.Photo: courtesy Pisa University archives

system was operational and was steadily being used in the standard measuring process.

The system had a considerable success among other Italian groups working in the field.

A system manager, Mario Soldi, and a programmer, Augusto Bandettini, joined the group. This was to become the nucleus of the present computing group of the INFN section.

The staff of "scanners" increased in size. They carried out with great care and accuracy, the task of analysing one fotogram after another, of registering the type of events found and of measuring the coordinates in projection of the interaction and decay vertices as well as those of many points on each track.

The scanning work was coordinated for many years by Roberto Bertelli, who later on became Administration Head in the Physics Department.

Around 1968 the CEP was replaced by an IBM-1800 computer. This followed the group

Figure 22: Another photograph of Marcello Conversi (center, facing camera) with President of Italian Republic Giovanni Gronchi (left) at inauguration of C.E.P. in November 1961. Photo: courtesy Pisa University Archives

when it moved, in 1972, to the new site of the Experimental High Energy Physics groups, in S. Piero a Grado.

In the meantime, an automatic measuring machine (Flying Spot Digitizer or FSD) had become operational at the "Centro Nazionale Analisi Fotogrammi" (CNAF) in Bologna. The FSD was made available to all Italian groups, with Carlo Franzinetti coordinating for a while the use of the center by the different Italian groups.

This helped in speeding up the measuring process. The film was scanned and "pre-digitised" in Pisa and then shipped to Bologna, where the final, precise measurement was carried out. The "pre-digitisation" was done on somewhat less precise machines (known as *mangiaspago's*). This approach started around 1972. Still some measurements kept being done manually on high precision machines, built and operated in Pisa.

Figure 23: A photograph of the C.E.P. Computer in 1962. The Engineer working at the scope is Dr. Luigi Pistelli. At the console is Mr. Luciano Azzarelli. Photo: courtesy Pisa University Archives

Apparecchiature e programmi per la misura di fotografie di camere a tracce - parte 1^a- proiettori digitalizzati da misura

G. Gennaro

INFN/TC-63/10, 1963

Apparecchiature e programmi per la misura di fotografie di camere a tracce - parte 2^a- circuiti logici

P. Franzini

INFN/TC-63/11, 1963

Figure 24: The C.E.P. computer, at an exposition in Pisa

Determinazione della matrice degli errori per i parametri geometrici delle tracce in camera a bolle

A. Bigi

INFN/AE-63/2, Marzo 1963

Apparecchiature e programmi per la misura di fotografie di camere a tracce della Sezione di Pisa dell'INFN

A. Bigi e D. Zanello

INFN/AE-63/12, Luglio 1963

Real time monitoring system for track-chamber measurements

L. Dall'Antonia, F. Denoth, P. Lariccia, R.Pazzi

Calcolo, Vol. 4, pag. 413-424, 1967

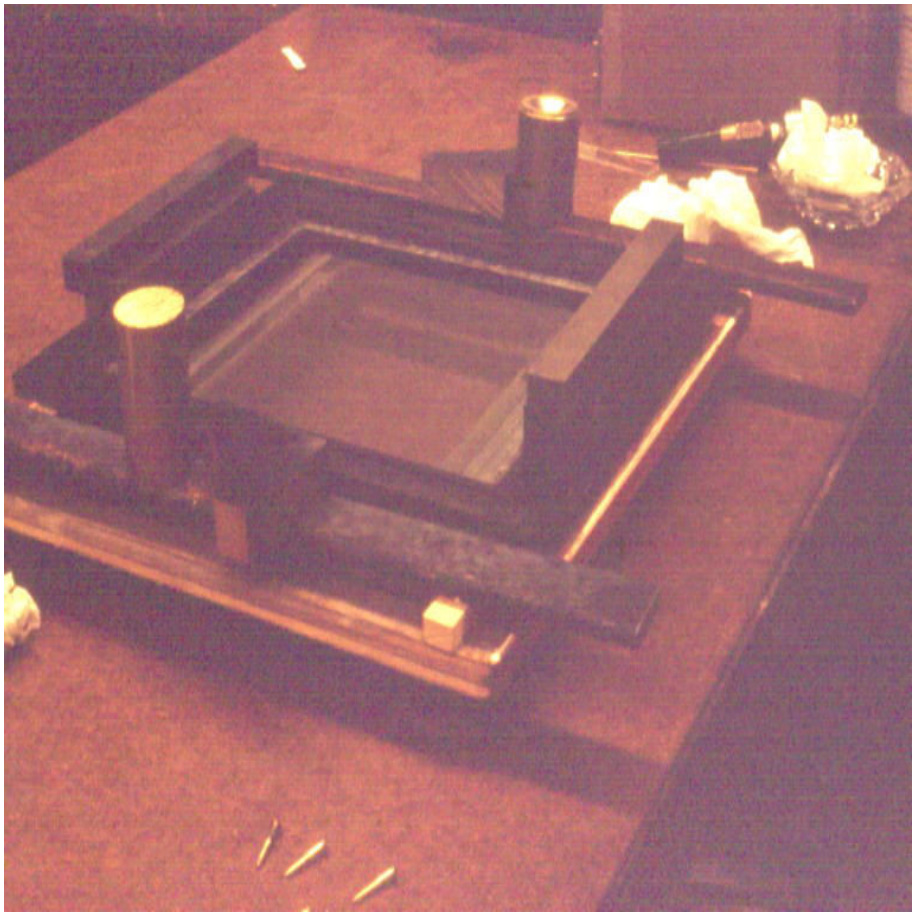


Figure 25: Construction phase of one the measuring machines in Pisa: Film support plate

Sistema di controllo in tempo reale delle misure su forogrammi di camera a bolle mediante IBM 1800

R. Pazzi e E. Stefanelli

INFN/AE-70/8, Giugno 1970

Sistema di acquisizione e controllo di dati relativi a fotogrammi di camera a bolle mediante calcolatore IBM 1800 in linea con apparecchiature di scanning, premisura e misura

A. Bigi e R. Pazzi

INFN/TC-71/10, Dicembre 1971

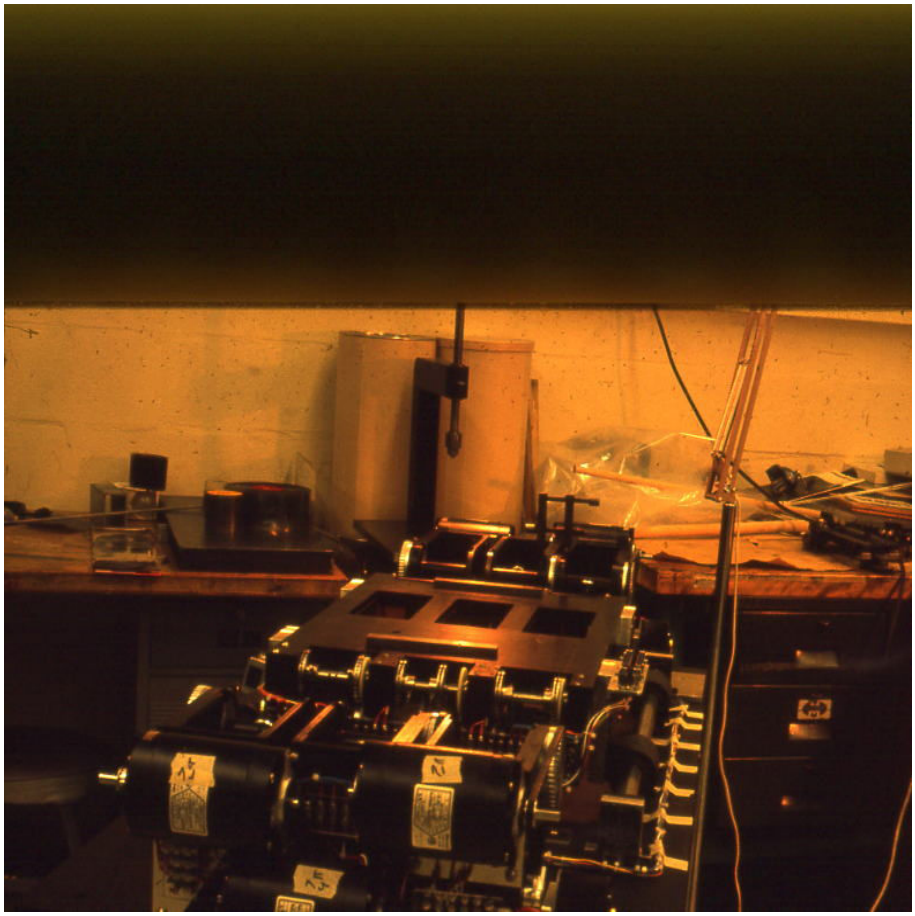


Figure 26: Construction phase of one the measuring machines in Pisa: Film transport

Circuiteria dei proiettori digitalizzati e loro interfaccia con una IBM 1800 per il sistema on-line/off-line del gruppo "Camera a Bolle" della Sezione di Pisa dell'INFN

P. Salvadori, F. Lazzeri ed F. Ruberti

INFN/TC-72/4, Maggio 1972

Resolution of Kinematical Ambiguities in Bubble Chamber Events using the F. S. D. Ionization Measurements

G. Cabras and E. Flaminio.

INFN/AE-73/5, Settembre 1973

Figure 27: Patrizia Benfatti setting up the film to be measured.

Ulysses, a new scanning and high precision measuring projector for BEBC film

S. Galeotti, G. Gennaro, M. Giovannetti, R. Ruberti, P.Salvadori and L. Zaccarelli

INFN/TC-76/2, Febbraio 1976

Design of a Bubble Chamber film measuring projector: GIANO

S. Galeotti, G. Gennaro, C. Guidi, R. Lagnoni, F. Ruberti, R. Ruberti, P.Salvadori and L. Zaccarelli

INFN/TC-76/13, Ottobre 1976

Figure 28: Patrizia Benfatti at work on a precision manual measuring machine

Display grafico digitale a basso costo

S. Galeotti, L. Zaccarelli, C. Avanzini, R. Fantechi

INFN/TC-79/19, Novembre 1079

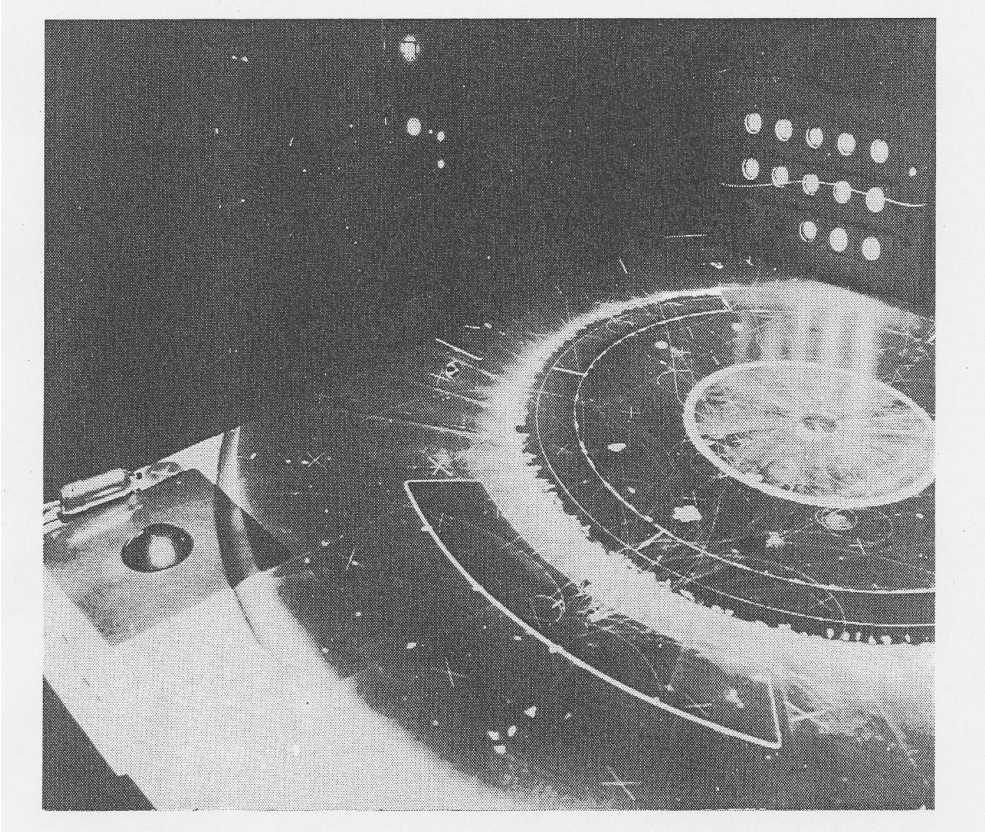


Figure 29: An event projected on a second precision measuring machine

5 Experiments in the "Saclay" 81 cm Hydrogen Bubble Chamber

The subsequent developments in bubble chamber Physics saw a clear-cut division of tasks: hydrogen and deuterium bubble chambers were mainly used for the study of strong interaction processes and to look for new hadronic resonant states. In this, the excellent space and energy resolution of hydrogen bubble chambers, combined with their 4π acceptance, proved to be unparalleled by other types of detectors. The only drawback was the lack of electron/gamma identification, which limited the observations to decay modes with at most a single π^0.

It is not unfair to say that almost all resonant states discovered prior to the "charm" period, came from bubble chamber experiments, whose contribution to the study of charm was also non negligible.

On the other hand, heavy liquid bubble chambers, with a worse energy resolution for charged particle reconstruction, but a very high electron identification efficiency, were used for the study of weak processes, in particular neutrino interactions [8]. The discovery in 1973

[8]The existence of these two types of bubble chambers, with different experimental capabilities, reflected probably the existence at CERN of two different "Divisions": TC and TCL. The first of these was building and managing hydrogen bubble Chambers, the second Heavy Liquid Chambers. Hydrogen bubble chambers were mainly used for the study of strong interaction processes and meson/baryon spectroscopy. Heavy liquid bubble chambers for weak decay processes and neutrino interactions. The exploitation of the excellent

of neutral currents in the Gargamelle bubble chamber marked the beginning of a new era in High Energy Physics.

The first experiment carried out in Pisa using a relatively large hydrogen/deuterium bubble chamber, was the one carried out in collaboration with the Padova group led by Marcello Cresti[9]

This experiment studied the annihilations of antiprotons at rest in deuterium. The main purpose of the experiment was that of analysing final states coming from annihilations in the I=0 as well as I=1 states.

A second experiment, carried out in collaboration with Berkeley, Padova, Pisa and Torino, studied again the annihilations of antiprotons in deuterium, but at somewhat higher energies: the incident antiproton energies ranging between 1 and 1.6 GeV/c.

A third experiment, performed in collaboration with Hamburg, Padova, Pisa and Torino, studied annihilations of antiprotons with protons at 12 GeV/c.

Finally, the last of these series of experiments studied antiproton annihilations with protons at incident momenta between 1.0 and 1.13 GeV/c. This was carried out in collaboration with the College de France Group.

In this experiment use was made for the first time by the group of the automatic measuring machine (Flying-Spot-Digitizer) operating at the Centro Nazionale Analisi Fotogrammi (CNAF) in Bologna.

cryogenic properties of Hydrogen-Neon mixtures and the subsequent diffusion of neon-hydrogen bubble chambers marked the end of "Heavy Liquid" bubble chambers, for neutrino Physics at least

[9]Marcello Cresti had obtained his Physics Degree in Pisa in 1950 and is a Professor of Physics at the University of Padova since 1965

Evidence for a Strong, Possibly Resonant, Scalar $\rho - \rho$ Interaction
Padova-Pisa
Collaboration

A. Bettini, M. Cresti, S. Limentani, A. Loria, L. Peruzzo, R. Santangelo, L. Bertanza, A. Bigi, R. Carrara, R. Casali, E. Hart and P. Lariccia.

Il Nuovo Cimento, Serie X, Vol. 42, pag. 695-702, 1966

Annihilations Into Pions of the $\overline{p}n$ System from Antiprotons at Rest in Deuterium
Padova-Pisa
Collaboration

A. Bettini, M. Cresti, S. Limentani, L. Peruzzo, R. Santangelo, L. Bertanza, A. Bigi, R. Carrara, R. Casali and P. Lariccia

Il Nuovo Cimento, Serie X, Vol. 47, pag. 642-661, 1967

Annihilations $\overline{p}n$ at Rest into Final States Containing K-Mesons
Padova-Pisa
Collaboration

A. Bettini, M. Cresti, S. Limentani, L. Peruzzo, R. Santangelo, L. Bertanza, A. Bigi, R. Carrara, R. Casali, P. Lariccia and C. Petri

Il Nuovo Cimento, Serie X, Vol. 62A, pag. 1038-1056, 1969

The Annihilations at Rest $\overline{N}N \to KK\pi$
College de France-Padova-Pisa
Collaboration

A. Bettini, M. Cresti, S. Limentani, L. Peruzzo, R. Santangelo, S. Sartori, M. Della Negra, L. Bertanza, A. Bigi, R. Carrara, R. Casali, P. Lariccia and C. Petri.

Il Nuovo Cimento, Serie X, Vol. 63A, pag. 1199-1222, 1969

Formation Experiments: the T region

Luciano Bertanza
Invited talk

Proceedings of the Chexbres Symposium on Nucleon-Antinucleon Annihilations. CERN 72-10, 1972

The Annihilations $\overline{p}n \to \pi^+\pi^-\pi^-$ between 1.0 and 1.6 GeV/c and its comparison with the Veneziano model
Berkeley-Padova-Pisa-Torino Collaboration

A. Bettini, M. Cresti, M. Mazzucato, L. Peruzzo, S. Sartori, M. Alston-Garnjost, R. Huesman, R. Ross, F. T. Solmitz,L. Bertanza, R. Carrara, R. Casali, P. Lariccia, R.Pazzi, G. Borreani, B. Quassiati, G. Rinaudo, M. Vigone and A. Werbrouk

Il Nuovo Cimento, Vol. 1A, 333-344 1971

Inclusive Analysis of $\overline{p}n$ Annihilations between 1.0 and 1.6 GeV/c
Padova-Pisa-Torino Collaboration

G. Borreani, V. Manetta, B. Quassiati, G. Rinaudo, M. Vigone, A. Werbrouk, A. Bettini, M. Mazzucato, G. Sartori, S. Sartori, G. Zumerle, A. Bigi, L. Bertanza, R. Carrara, R. Casali and R.Pazzi

Lettere al Nuovo Cimento, Vol. 10, pag. 529-534, 1974

Cross-Sections for Resonance Production in $\overline{p}n$ Annihilations around 2190 MeV Centre-of-Mass Energy
Padova-Pisa-Torino Collaboration

L. Bertanza, A. Bigi, R. Casali, P. Lariccia, R. Pazzi, A. Bettini, M. Mazzucato, G. Sartori, S. Sartori, G. Zumerle, G. Borreani, B. Quassiati, G. Rinaudo and M. Vigone

Il Nuovo Cimento, Vol. 23A, pag. 209-226, 1974

Experimental Study of $\overline{p}n$ Annihilations between 1.0 and 1.6 GeV/c
Berkeley-Padova-Pisa-Torino
Collaboration

R. Huesman, M. Alston-Garnjost, R. Ross, F. T. Solmitz, A. Bettini, M. Cresti, M. Mazzucato, L. Peruzzo, G. Sartori, S. Sartori, G. Zumerle, L. Bertanza, A.Bigi, R. Casali, P. Lariccia, R.Pazzi, G. Borreani, B. Quassiati, G. Rinaudo and M. Vigone

Il Nuovo Cimento, Vol. 25A, pag. 91-109, 1975

$\overline{p}n$ Annihilation into $\pi^-\pi^0$ between 1.0 and 1.6 GeV/c
Padova-Pisa-Torino
Collaboration

G. Borreani, B. Quassiati, G. Rinaudo, M. Vigone, A. Werbrouck, M. Mazzucato, G. Sartori, G. Zumerle, A.Bigi, R. Casali, R.Pazzi and C. Petri

Il Nuovo Cimento, Vol. 32A, pag. 129-138, 1976

Figure 30: Armando Bigi (right) and Roberto Pazzi (center, pushing the trolley) in Volterra in the early 70's. On the left: Gianna Flaminio

The Reaction $\overline{p}p \to \overline{p}p\pi^-\pi^+$ at 12 GeV/c
Hamburg-Padova-Pisa-Torino
Collaboration

I. Borecka, G. Drews, W. Lenkeit, G. Comai, R. Santangelo, L. Bertanza, A. Bigi, R. Casali, P. Lariccia, R. Pazzi, R. Medves and C. Petri

Il Nuovo Cimento, Vol. 5A, 19, 1971

Experimental Study of 6 Prong Events in $\overline{p}p$ Annihilation around 1 GeV/c
C. Angelini, L. Bertanza, A. Bigi, R. Casali, V. Flaminio, R. Pazzi and C. Petri.
Il Nuovo Cimento, Vol. 32A, pag. 243-256, 1976

Test of Multiplicity Independence of Single π "Mean Scaled" Distributions in LowEnergy $\overline{p}p$ Annihilations
College de France-Pisa
Collaboration

C. Angelini, L. Bertanza, A. Bigi, R. Casali, V. Flaminio, R. Pazzi, C. Petri, C. Defoix, P. Espigat, M. Laloum and P. Petitjean

Lettere al Nuovo Cimento, Vol. 18, pag. 245-270, 1977

A Thermodinamical Analysis of the Charged Pion Momentum Spectra from the Annihilations $\overline{p}p \to \pi^{\pm}K^0_sX^{\mp}$ at Low Energy
College de France-Pisa
Collaboration

C. Angelini, L. Bertanza, A. Bigi, R. Casali, R. Pazzi, C. Petri, E. Romani, C. Defoix, P. Ladron de Guevara and P. Petitjean

Lettere al Nuovo Cimento, Vol. 19, pag. 283-286, 1977

Observation of Interference Correlations between Like Pions in the Reaction $\overline{p}p \to 2\pi^+2\pi^-\pi^0$ at Low Energy
College de France-Pisa
Collaboration

C. Angelini, L. Bertanza, C. Bigi, R. Casali, R. Pazzi, C. Petri, P. Espigat, P. Ladron de Guevara and M. Laloum

Lettere al Nuovo Cimento, Vol. 19, pag. 278-282, 1977

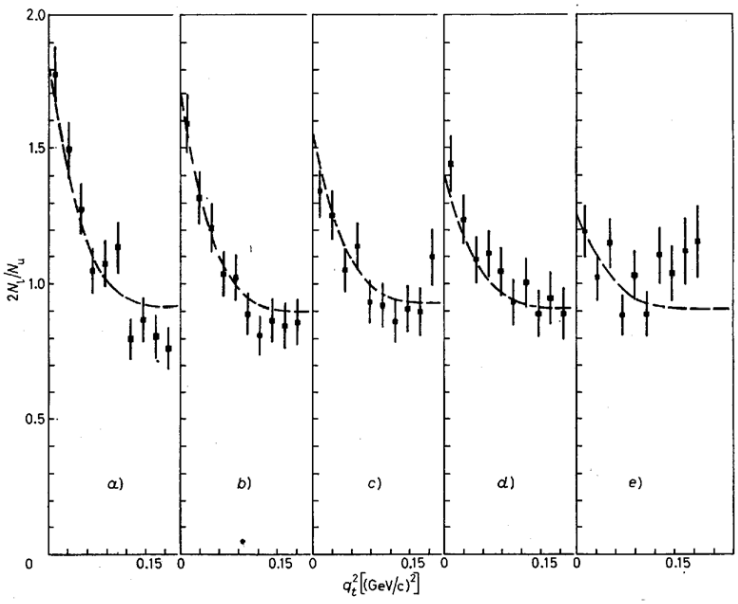


Fig. 1. – The experimental ratio $2N_l/N_u$ as a function of q_t^2 for various intervals of q_0. The curves display the results of the fit to formula (1). *a*) $0 \leqslant q_0 < 0.04$, *b*) $0.04 \leqslant q_0 < 0.08$, *c*) $0.08 \leqslant q_0 < 0.12$, *d*) $0.12 \leqslant q_0 < 0.16$, *e*) $0.16 \leqslant q_0 < 0.2$ (GeV).

Figure 31: Distributions of the ratio between like and unlike-sign pion pairs, plotted as a function of q_t^2 for various intervals of $q_0 = |E_1 - E_2|$

Experimental analysis of $\overline{p}p$ interactions Between 0 and 1.2 GeV/c: evidence for a 5π effect near 1950 MeV/c

College de France-Pisa
Collaboration

C. Defoix, L. Dobrzynski, P. Espigat, M.Laloum, P. Ladron de Guevara, C. Angelini, A. Bigi, R. Casali and C. Petri

Nuclear Physics, 162, pag. 12-40, 1980

Experimental analysis of the properties of the five-pion effect observed in $\overline{p}p$ interactions near 1950 MeV/c

College de France-Pisa
Collaboration

P. Espigat, C. Defoix, L. Dobrzynski, M.Laloum, P. Ladron de Guevara, C. Angelini, A. Bigi, and R. Pazzi

Nuclear Physics, 162, pag. 41-60, 1980

Properties of $\overline{p}p$ annihilations into strange particles at 720 and 757 MeV/c

Bombay-CERN-College de France-Madrid-Pisa Collaboration

S.N. Ganguli, A. Gurtu, P.K. Malhotra, R. Raghavan, A. Subramanian, M. Cerrada, J. Diaz, J.A. Garzon, R. Hamatsu, L. Montanet,C. Defoix, L. Dobrzynski, P. Ladron de Guevara, R. Nacash, P. Petitjean, B. Adeva, M. Aguilar-Benitez, I. Duran, M.C. Fernandez, J. A. Rubio, Jesus Salicio, Josè Salicio, C. Angelini, A. Bigi and R. Pazzi

Nuclear Physics B, Vol. 183, pag. 295-329, 1981

6 Experiments in the CERN 2 m Bubble Chamber

In the period 1973-1976 an experiment was done using the 2 meters CERN bubble chamber. This was a "hybrid" experiment using a liquid hydrogen target located a few meters upstream the bubble chamber and a monocromatic π^- beam having energies between 960 and 1160 MeV/c, to produce "monocromatic" K^0_L beams. The experiment was intended to study Baryon resonances, looking in particular for S=+1 states.

The experiment was carried out in collaboration with British groups (Edinburgh, Glasgow, Rutherford) and with the group of Giorgio Giacomelli in Bologna. This marked the start of a long and fruitful collaboration with this latter group, that in later experiments extended to the Padova group led by Milla Baldo-Ceolin and the Torino group led by Carlo Franzinetti.

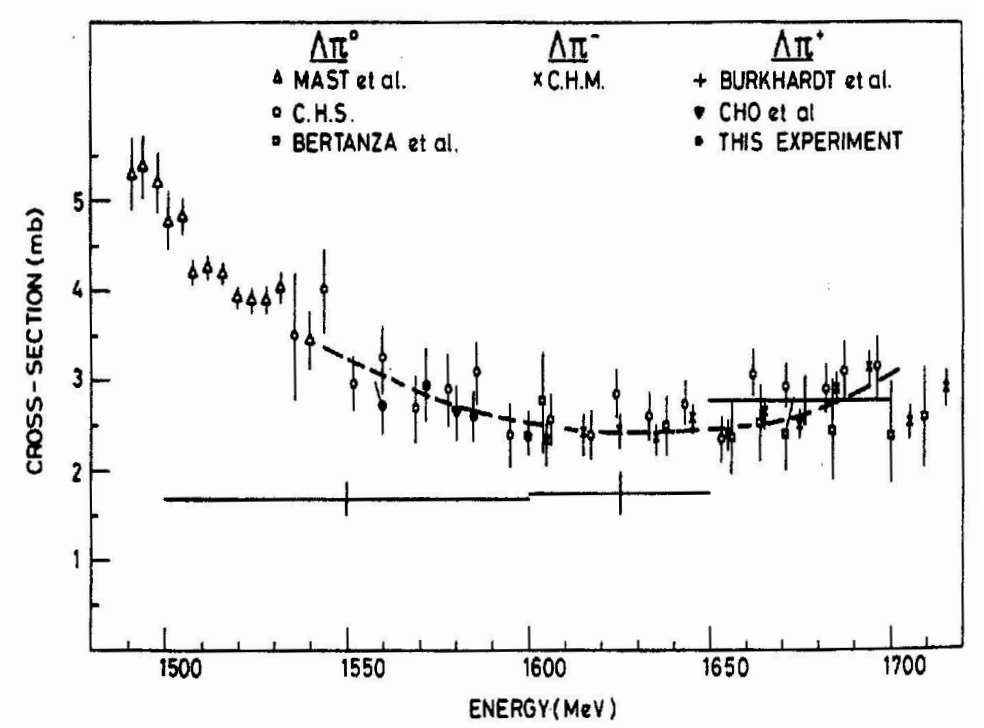


Fig. 3a. Λπ cross-section measurements. The dashed curve is the smooth curve fitted to all the data.

Figure 32: Measurements of the cross section for the process $K^0_L p \to \Lambda^0\pi^+$, obtained in this experiment, compared to those for $K^-n \to \Lambda^0\pi^-$ and $K^-p \to \Lambda^0\pi^0$

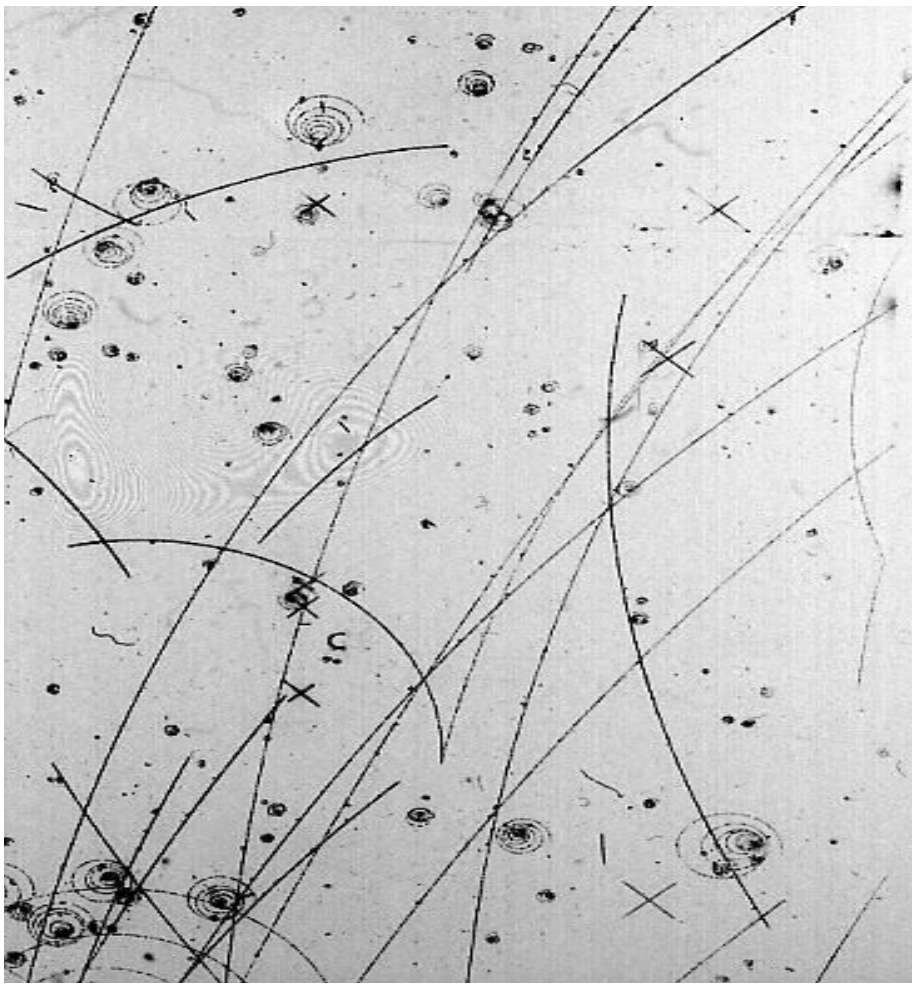


Figure 33: A decay event in the K_L^0 experiment

Study of the Reactions $K_L^0 p \to \Lambda\pi^+\pi^0$ and $\Sigma^0\pi^+$ in the c.m. Energy Range $1490 - 1700\,MeV$

Bologna-Edinburgh-Glasgow-Pisa-Rutherford Collaboration

L. Bertanza, W. Cameron, P. Capiluppi, P.Croft, V. Flaminio, R. Jennings, G. Kalmus, P. Lugaresi-Serra, G. Mandrioli, A. Minguzzi-Ranzi, W. Morton, A. Nappi, R. Pazzi, K.J. Peach, A.M. Rossi B. Saitta and W. Venus

Nuclear Physics B, 110, pag. 1-24, 1976

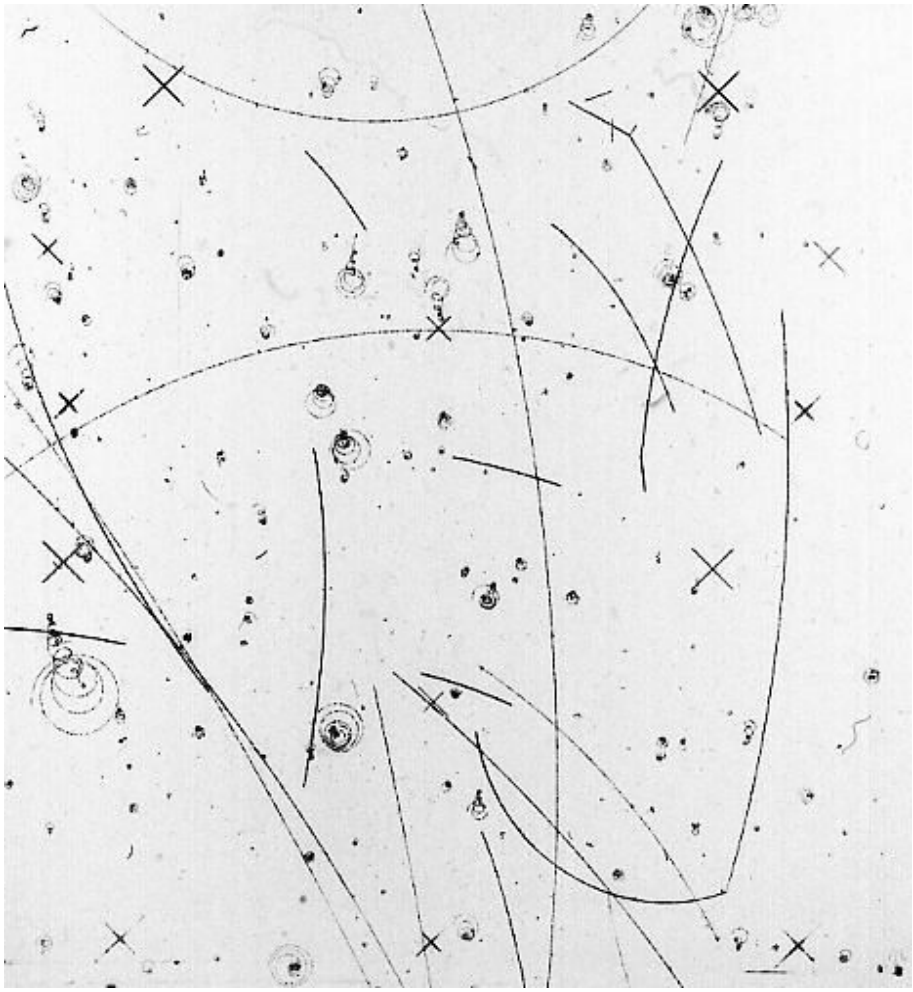


Figure 34: An interaction in the K_L^0 experiment

Study of the Reaction $K_L^0 p \to K_S^0 p$ in the c.m. Energy Range $1490 - 1700\,MeV$
Bologna-Edinburgh-Glasgow-Pisa-Rutherford
Collaboration

A. Bigi, W. Cameron, P. Capiluppi, R. Casali, P.Croft, V. Flaminio, G. Giacomelli, R. Jennings, G. Kalmus, P. Lugaresi-Serra, G. Mandrioli, A. Minguzzi-Ranzi, V. Moggi, W. Morton, A. Nappi, K.J.Peach, A.M. Rossi and W. Venus

Nuclear Physics B, 110, pag. 25-39, 1976

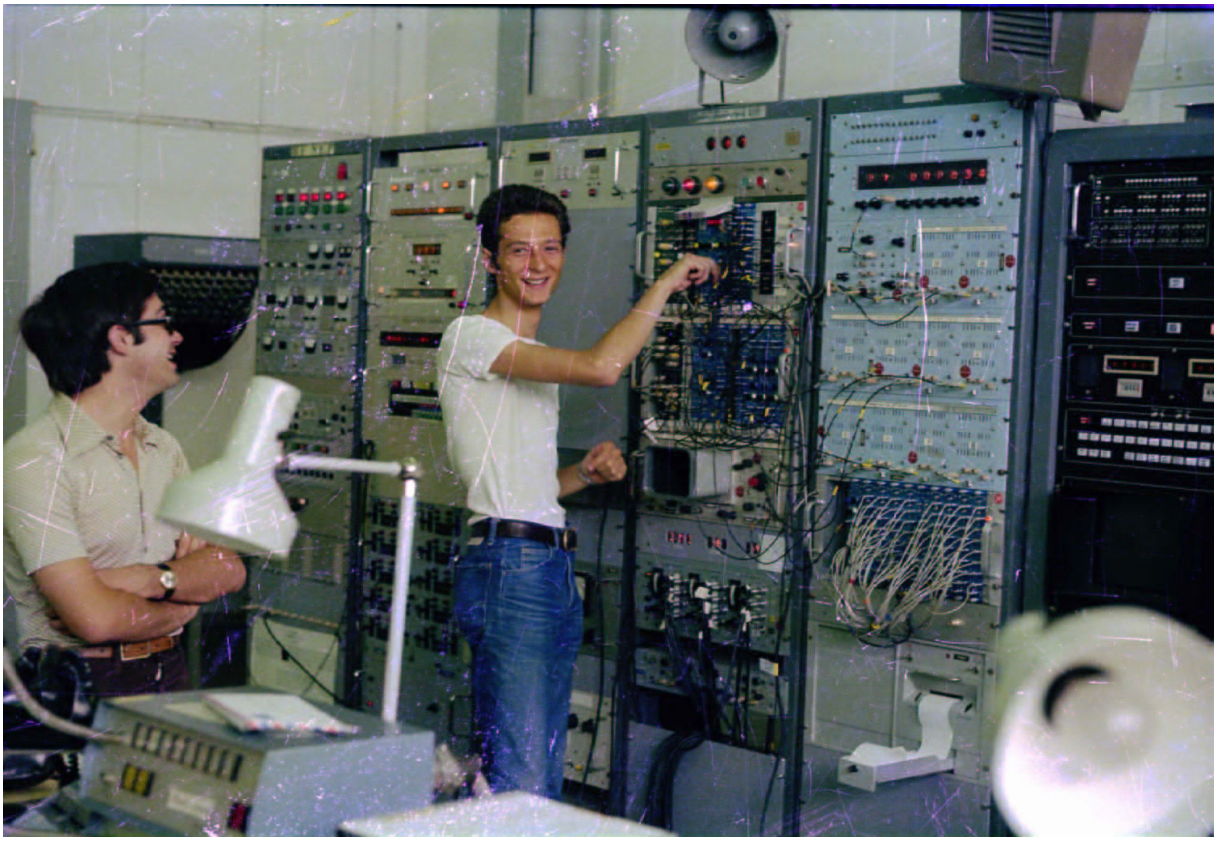


Figure 35: Stefano Galeotti (left) and Vieri Moggi in the beam control room of the 2 m chamber in 1974

A Study of the Dalitz Plot in the Decay $K_L^0 \to \pi^+\pi^-\pi^0$
Bologna-Edinburgh-Glasgow-Pisa-Rutherford Collaboration

K.J. Peach, W. Cameron, P. Capiluppi, P.Croft, V. Flaminio, G. Kalmus, P. Lugaresi-Serra, G. Mandrioli, V. Moggi, W. Morton, A.M. Rossi, B. Saitta and W. Venus

Nuclear Physics B, 217, pag. 399-412, 1977

$K_L^0 p$ interactions in the c.m. energy range 1.541.71 GeV
Bologna-Edinburgh-Glasgow-Pisa-Rutherford Collaboration

W. Cameron, P. Capiluppi, V. Flaminio, G. Giacomelli, G. Kalmus, G. Mandrioli, A. Minguzzi-Ranzi, V. Moggi, W. Morton, K.J. Peach, A.M. Rossi, B. Saitta and P. Serra-Lugaresi

Nuclear Physics B, 132, pag. 189-211, 1978

Figure 36: Stefano Galeotti (standing) and Biagio Saitta in the beam control room of the 2 m chamber in 1974

7 Experiments in the Big European Bubble Chamber

In the mid 70's the Big European bubble chamber started operation. The very first exposure of this chamber used a 22 GeV negative pion beam, and was meant mainly to "debug" the measuring machines and the software for event reconstruction. The exposure was a collaborative effort of several laboratories.

Shortly afterwards, a new "hybrid" experiment, using BEBC in association with emulsions, was proposed by Marcello Conversi, to measure the lifetime of the newly discovered *charmed particles*. Pisa was immediately invited by Conversi to join the experiment, that was carried out in a relatively short time by a collaboration comprising nine different laboratories (Ankara, Brussels, CERN, U.C. Dublin, U.C. London, Open University, Pisa, Roma, Torino).

In this experiment 8 charmed particle decays were found: 5 charged and 3 neutral. It provided the first successful measurement of the lifetimes of neutral and charged charmed particles.

This was followed by two more experiments using the same bubble chamber. The first of these, carried out by a large international collaboration (Amsterdam, Bologna, Padova, Pisa, Saclay and Torino) which saw again the participation of Bologna, Padova and Torino, was a large exposure of a Deuterium-filled chamber to wide-band neutrino and antineutrino beams. The experiment was proposed in 1974[10] in view of exploiting the Big European

[10]In the design stage of the experiment, many fruitful discussions took place in the office of Milla Baldo-Ceolin in Padova with, among others, Carlo Franzinetti from the University of Torino and Armin Tenner

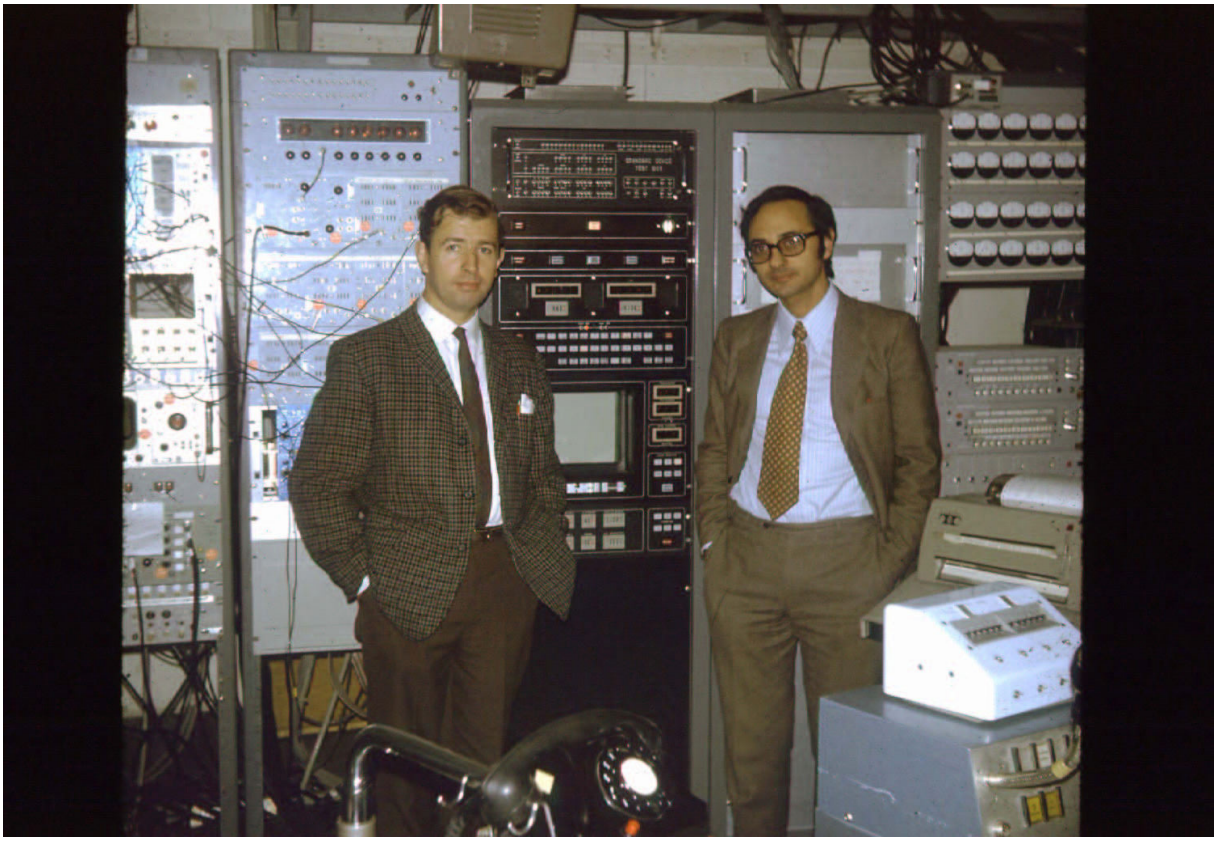


Figure 37: Robert Jennings (left) and Vincenzo Flaminio in the beam control room of the 2 m chamber in 1974

bubble chamber for a detailed study of the recently discovered neutral currents, as well as for a better understanding of deep-inelastic processes at high energies.

The main outcome of the experiment was a precise determination of the properties of charged and neutral current interactions, separately on protons and neutrons.

Many other important results from the analysis of these data were also published.

The second of these two experiments, suggested and led by Milla Baldo-Ceolin, Professor of Physics at the University of Padova, was also one of the last performed with BEBC. It used a specially designed low-energy ($\approx 1GeV$) neutrino beam from the CERN PS to look for oscillations of muon-netrinos into electron neutrinos. To optimize the event rate and to make electron identification possible, the chamber was filled with a Neon-Hydrogen mixture. This was the first "long baseline" neutrino oscillation search. In total, 220,000 pictures were taken in the neutrino beam and analysed. In addition, for a cosmic ray background estimation, another 120,000 pictures were taken without beam, and analysed together with the rest.

The experiment provided an unprecedented limit on the oscillation parameters for the above transition.

from the University of Amsterdam. Bruno Tallini, who had been a member of the Pisa group long before and was now a group leader in Saclay, was one of the proponents. Armin Tenner was chosen as "spokesman" of the experiment

Figure 38: Biagio Saitta (on the right) and Vieri Moggi (center-back) relaxing at a swimming pool in Geneva after a night-shift, in 1974. Other people in the photograph, left to righ: Rosamaria Flaminio, Paola Giuntini, Raffaele Flaminio, Gianna Flaminio

Direct Evidence of a Prompt Electron Associated with a Strange Particle Produced in Strong Interaction

Pavia-Pisa
Collaboration

E. Calligarich, G. Cecchet, R. Dolfini, G. Liguori, S. Ratti, C. Angelini, R. Pazzi and C. Petri

Lettere al Nuovo Cimento, Vol. 36, pag. 201-211, 1978

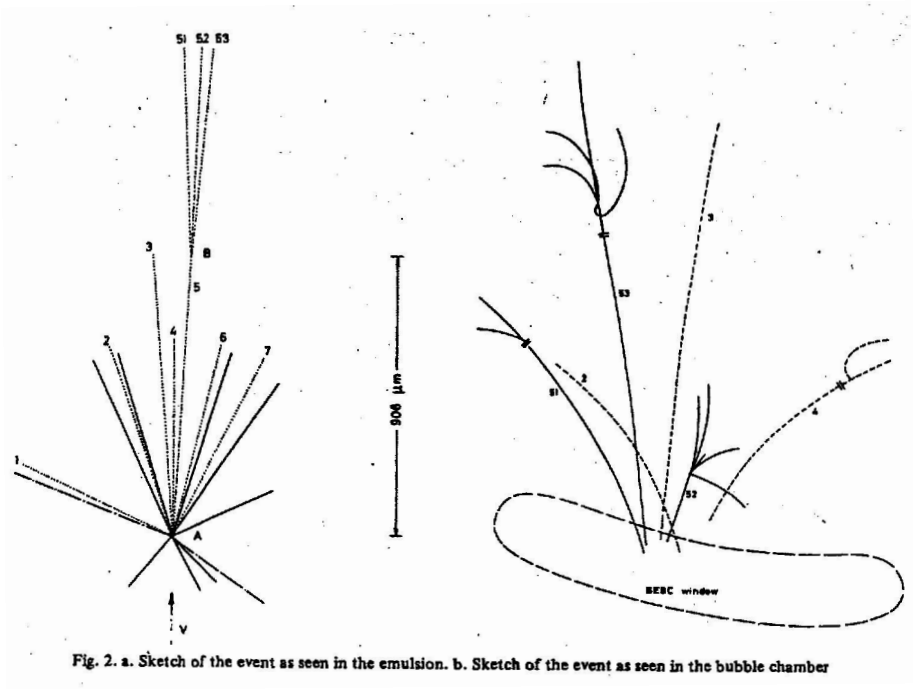


Fig. 2. a. Sketch of the event as seen in the emulsion. b. Sketch of the event as seen in the bubble chamber

Figure 39: First charm event observed in the WA17 experiment, that provided the first determination of the charm lifetime

First direct observation of the decay of neutral charmed particles produced by neutrinos in emulsion

Ankara-Brussels-CERN-U.C. Dublin-U.C. London-Open University-Pisa-Roma-Torino Collaboration

D. Allasia, C. Angelini, P. Bagnaia, G. Baroni, J.H. Bartley, G. Bertrand-Coremans, V. Bisi, A. Breslin, E.H.S. Burhop, F. Carena, R. Casali, G. Ciapetti, M. Conversi, D.H. Davis, S. Di Liberto, R. Fantechi, M.L. Ferrer, C. Franzinetti, D. Gamba, L. Godfrey, D. Keane, E. Lamanna, A. Marzari, F. Marzano, A. Montwill, A. Nappi, C. Palazzi-Cerrina, R. Pazzi, S. Petrera, G.M. Pierazzini, G. Romano, A. Romero, J. Sacton, R. Santonico, R. Sever, F.R. Stannard, P. Tolun, D.N. Tovee, P. Vilain, J.H. Wickens and G. Wilquet

Physics Letters, 87B, 287, 1979

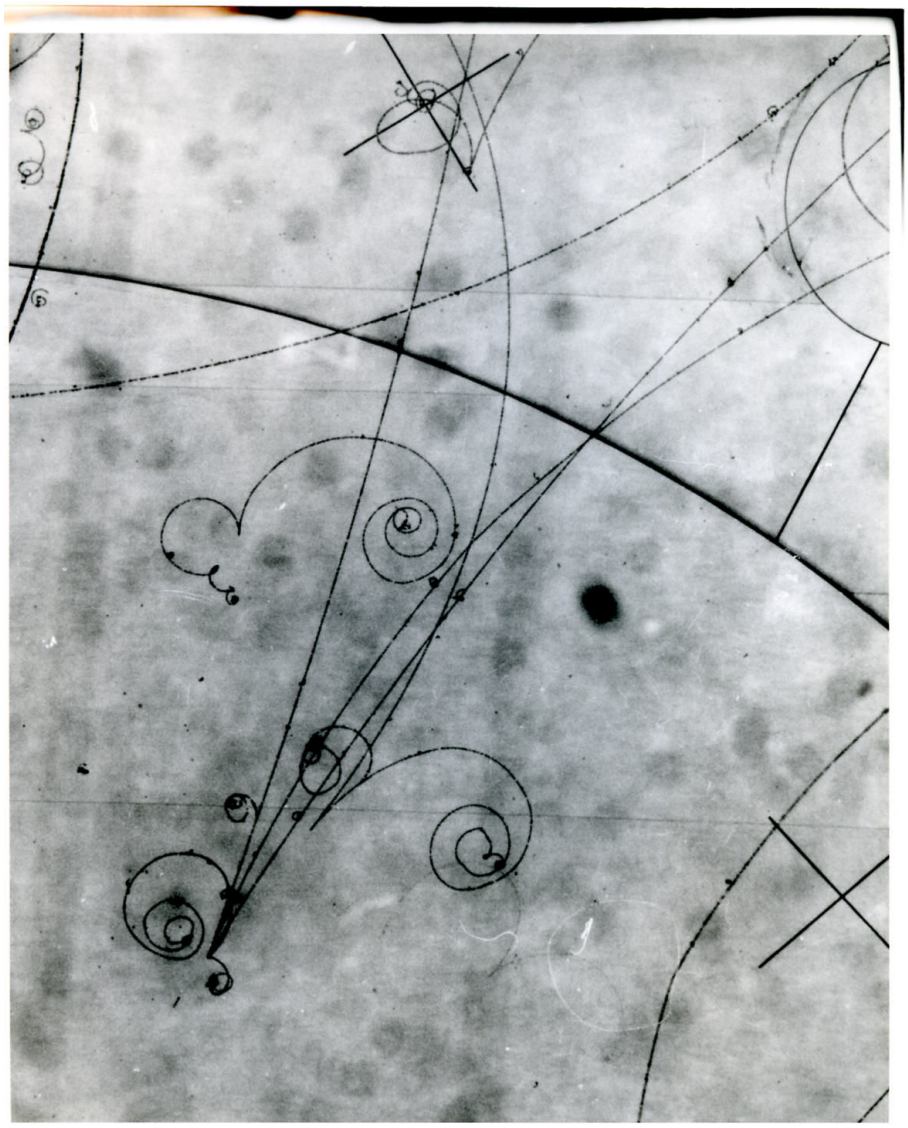


Figure 40: A neutrino interaction in BEBC filled with D_2

Observation of a second charmed particle produced by a high energy neutrino and decaying after a few times 10^{-13} s

Ankara-Brussels-CERN-U.C. Dublin-U.C. London-Open University-Pisa-Roma-Torino Collaboration

C. Angelini, P. Bagnaia, G. Baroni, J.H. Bartley, G. Bertrand-Coremans, V. Bisi, A. Breslin, E.H.S. Burhop, F. Carena, R. Casali, G. Ciapetti, M. Conversi, D.H. Davis, S. Di Liberto, M.L. Ferrer, C. Franzinetti, D. Gamba, L. Godfrey, D. Keane, E. Lamanna, A. Marzari, F. Marzano, V. Moggi, A. Montwill, A. Nappi, C. Palazzi-Cerrina, R. Pazzi, S. Petrera, G.M. Pierazzini, G. Romano, A. Romero, J. Sacton, R. Santonico, R. Sever, F.R. Stannard, P. Tolun, D.N. Tovee, P. Vilain, J.H. Wickens and G. Wilquet

Physics Letters, 80B, 428, 1979

On the lifetime of charged charmed particles: first direct observation of a charmed baryon decay

Ankara-Brussels-CERN-U.C. Dublin-U.C. London-Open University-Pisa-Roma-Torino Collaboration

C. Angelini, P. Bagnaia, G. Baroni, J.H. Bartley, G. Bertrand-Coremans, V. Bisi, A. Breslin, E. H. S. Burhop, e, F. Carena, R. Casali, G. Ciapetti, M. Conversi, D.H. Davis, S. Di Liberto, M. L. Ferrer, C.Franzinetti, D.Gamba, L. Godfrey, D. Keane, E. Lamanna, A. Marzari, F. Marzano, A. Montwill, R. Morganti, A. Nappi, C. Palazzi-Cerrina, R. Pazzi, S. Petrera, G.M. Pierazzini, L. Riccati, G. Romano, A. Romero, J. Sacton, R. Santonico, R. Sever, F.R. Stannard, P. Tolun, D.N. Tovee, P. Villain, J. H. Wickens and G. Wilquet

Physics Letters B, Vol. 84, pag. 150-155, 1979

Investigation of the decay of charmed particles produced in neutrino interactions

Ankara-Brussels-CERN-U.C. Dublin-U.C. London-Open University-Pisa-Roma-Torino Collaboration

D. Allasia, C. Angelini, P. Bagnaia, G. Baroni, J.H. Bartley, G. Bertrand-Coremans, V. Bisi, A.Breslin, E.H.S. Burhop, F. Carena, R. Casali, G. Ciapetti, M. Conversi, D.H. Davis, S. Di Liberto, R. Fantechi, M.L. Ferrer, C. Franzinetti, D. Gamba, L. Godfrey, D. Keane, E. Lamanna, A. Marzari, F. Marzano, A. Montwill, A. Nappi, C. Palazzi-Cerrina, R. Pazzi, S. Petrera, G.M. Pierazzini, G. Romano, A. Romero, J. Sacton, R. Santonico, R. Sever, F.R. Stannard, P. Tolun, D.N. Tovee, P. Vilain, J.H. Wickens and G. Wilquet

Nuclear Physics B, Vol. 176, pag. 13-36, 1980

Measurement of the ratios of $\overset{(-)}{\nu}_\mu\, n$ to $\overset{(-)}{\nu}_\mu\, p$ charged current cross sections at high energies

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, M. Baldo-Ceolin, S. Barlag, L. Bertanza, F. Bianchi, A. Bigi, V. Bisi, M. Bloch, F. Bobisut, T. Bolognese, R. Bonarelli, E. Calimani, R. Casali, P. Capiluppi, S. Ciampolillo, P. Van Dam, J. Derkaoui, E. De Wolf, M.L. Faccini-Turluer, R. Fantechi, V. Flaminio, A. Fridman, D. Gamba, G. Giacomelli, H. Huzita, B. Jongejans, M.Loreti, C. Loudec, G. Mandrioli, A. Marzari-Chiesa, P. Mazzanti, A. Minguzzi-Ranzi, L. Mosca, A. Nappi, R. Pazzi, C. Petri, G. Pierazzini, G. Puglierin, L. Ramello, L. Riccati, A. Romero, A.M. Rossi, J. Saudraix, A. Sconza, P. Serra-Lugaresi, A. Tenner, G. Troncone, A. Vianello, D. Vignaud, C. Visser and R. Wigmans

Physics Letters, Vol. 107B, pag. 148-152, 1981

Proton and neutron structure functions from antineutrino interactions in deuterium

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Argento, M. Baldo-Ceolin, S. Barlag, L. Bertanza, F. Bianchi, A. Bigi, V. Bisi, F. Bobisut, T. Bolognese, R. Bonarelli, E. Calimani, R. Casali, P. Capiluppi, S. Ciampolillo, P. Van Dam, J. Derkaoui, E. De Wolf, M.L. Faccini-Turluer, R. Fantechi, V. Flaminio, D. Gamba, G. Giacomelli, H. Huzita, B. Jongejans, M.Loreti, C. Loudec, G. Mandrioli, A. Marzari-Chiesa, P. Mazzanti, L. Mosca, A. Nappi, R. Pazzi, C. Petri, G. Pierazzini, G. Puglierin, L. Ramello, L. Riccati, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, A. Tenner, A. Vianello, D. Vignaud, C. Visser and R. Wigmans

Physics Letters, Vol. 117B, pag. 262-266, 1982

Charged Hadron Multiplicities in High Energy $\overline{\nu}_\mu n$ and $\overline{\nu}_\mu p$ Interactions

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Argento, M. Baldo-Ceolin, S. Barlag, L. Bertanza, F. Bianchi, A. Bigi, V. Bisi, M. Block, F. Bobisut, T. Bolognese, R. Bonarelli, E. Calimani, R. Casali, P. Capiluppi, S. Ciampolillo, P. Van Dam, J. Derkaoui, E. De Wolf, F. Fabbri, M.L. Faccini-Turluer, R. Fantechi, V. Flaminio, A. Fridman, D. Gamba, G. Giacomelli, H. Huzita, B. Jongejans, M.Loreti, C. Loudec, G. Mandrioli, A. Marzari-Chiesa, P. Mazzanti, L. Mosca, A. Nappi, R. Pazzi, C. Petri, G. Pierazzini, G. Puglierin, L. Ramello, L. Riccati, A. Romero, A.M. Rossi, J. Saudraix, A. Sconza, P. Serra-Lugaresi, A. Tenner, P. Van Dam, A. Vianello, D. Vignaud, C. Visser and R. Wigmans

Zeitschrift fur Physik C, Vol. 11, pag. 283-292, 1982

Single Pion Production in Charged Current $\overline{\nu}D$ Interactions at High Energy

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, S. Barlag, L. Bertanza, A. Bigi, V. Bisi, F. Bobisut, T. Bolognese, R. Bonarelli, E. Calimani, R. Casali, P. Capiluppi, S. Ciampolillo, J. Derkaoui, M.L.Faccini-Turluer, R. Fantechi, V. Flaminio, D. Gamba, H. Huzita, B. Jongejans, R.A. Kunne, I. Lippi, M.Loreti, C. Loudec, G. Mandrioli, A. Marzari-Chiesa, A. Nappi, A. Nappi, R. Pazzi, G. Pierazzini, L. Ramello, L. Riccati, A. Romero, A.M. Rossi, J. Saudraix, A. Sconza, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, D. Vignaud, C. Visser and R. Wigmans

Zeitschrift fur Physik C, Vol. 20, pag. 95-100, 1983

Production of neutral strange particles in $\overline{\nu}_\mu D_2$ and $\nu_\mu D_2$ charged current interactions

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, S. Barlag, L. Bertanza, A. Bigi, V. Bisi, M. Bloch, F. Bobisut, T. Bolognese, R. Bonarelli, A. Borg, E. Calimani, P. Capiluppi, R. Casali, S. Ciampolillo, J. Derkaoui, M.L. Faccini-Turluer, R. Fantechi, V. Flaminio, A.G. Frodesen, D. Gamba, G. Giacomelli, G. Graziani, B. Grung, A. Hornaes, H. Huzita, B. Jongejans, I. Lippi, M.Loreti, C. Loudec, G. Mandrioli, A. Marzari-Chiesa, O. Mazzanti, A. Nappi, R. Pazzi, C. Petri, G. Pierazzini, L. Riccati, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, D. Vignaud, C. Visser and R. Wigmans

Nuclear Physics B, Vol. 224, pag. 1-20, 1983

Measurement of the neutral current coupling constants in neutrino and antineutrino interactions with deuterium

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, M. Baldo-Ceolin, S. Barlag, L. Bertanza, A. Bigi, V. Bisi, F. Bobisut, T. Bolognese, A. Borg, E. Calimani, P. Capiluppi, R. Casali, S. Ciampolillo, J. Derkaoui, M.L. Faccini-Turluer, R. Fantechi, V. Flaminio, A.G. Frodesen, D. Gamba, G. Giacomelli, A. Halstainslid, A. Hornaes, H. Huzita, B. Jongejans, I. Lippi, M.Loreti, C. Loudec, G. Mandrioli, A. Marzari-Chiesa, O. Mazzanti, A. Nappi, R. Pazzi, G. Pierazzini, L. Riccati, A. Romero, A.M. Rossi, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, D. Vignaud, C. Visser and R. Wigmans

Physics Letters B, Vol. 133, pag. 129-134, 1983

Measurement of the neutron and proton structure functions from neutrino and antineutrino scattering in deuterium

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, S. Barlag, L. Bertanza, A. Bigi, V. Bisi, F. Bobisut, T. Bolognese, A. Borg, E. Calimani, P. Capiluppi, R. Casali, S. Ciampolillo, J. Derkaoui, M.L. Faccini-Turluer, R. Fantechi, V. Flaminio, A.G. Frodesen, D. Gamba, G. Giacomelli, G. Graziani, A. Halstainslid, A. Hornaes, H. Huzita, B. Jongejans, I. Lippi, M.Loreti, C. Loudec, G. Mandrioli, A. Marzari-Chiesa, A. Nappi, R. Pazzi, G. Pierazzini, L. Riccati, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, D. Vignaud, C. Visser and R. Wigmans

Physics Letters B, Vol. 135, pag. 231-236, 1984

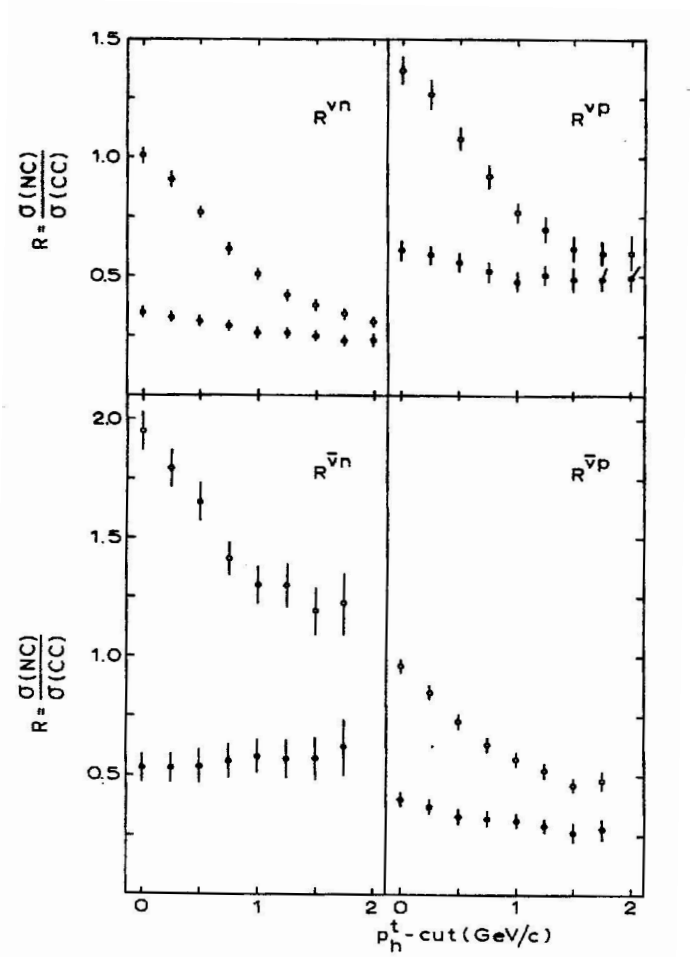


Fig. 1. The uncorrected (○) and corrected (●) neutral to charged current cross section ratios $R^{\nu n}$, $R^{\nu p}$, $R^{\bar{\nu} n}$ and $R^{\bar{\nu} p}$ as a function of the cut in p_h^t; all events have $E_h > 5$ GeV.

Figure 41:

Measurement of the ν_μ and $\overline{\nu}_\mu$ Nucleon charged-current total cross sections and the ratio of ν_μ neutron to ν_μ proton charged-current total cross sections

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, S. Barlag, L. Bertanza, A. Bigi, V. Bisi, F. Bobisut, T. Bolognese, R. Bonarelli, E. Calimani, P. Capiluppi, R. Casali, S. Ciampolillo, J. Derkaoui, E. De Wolf, M.L. Faccini-Turluer, R. Fantechi, V. Flaminio, A.G. Frodesen, D. Gamba, G. Giacomelli, A. Halstainslid, A. Hornaes, H. Huzita, B. Jongejans, M.Loreti, C. Loudec, G. Mandrioli, A. Marzari-Chiesa, L. Mosca, A. Nappi, R. Pazzi, G.M. Pierazzini, L. Ramello, L. Riccati, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, D. Vignaud, C. Visser and R. Wigmans

Physics Letters B, Vol. 239, pag. 301-310, 1984

Fragmentation in Neutrino and Antineutrino Charged Current Interactions on Proton and Neutron

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, L. Bertanza, A. Bigi, V. Bisi, F. Bobisut, T. Bolognese, A. Borg, E. Calimani, P. Capiluppi, R. Casali, S. Ciampolillo, J. Derkaoui, M.L. Faccini-Turluer, R. Fantechi, V. Flaminio, A.G. Frodesen, D. Gamba, G. Giacomelli, H. Huzita, B. Jongejans, I. Lippi, M.Loreti, C. Loudec, G. Mandrioli, A. Marzari-Chiesa, A. Nappi, R. Pazzi, C. Petri, L. Ramello, L. Riccati, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, D. Vignaud and R. Wigmans

Zeitschrift fur Physik C, Vol. 24, pag. 119-131, 1984

Fragmentation Functions in High Energy Neutrino and Antineutrino Deuterium Interactions

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, L. Bertanza, A. Bigi, V. Bisi, F. Bobisut, T. Bolognese, A. Borg, E. Calimani, P. Capiluppi, R. Casali, S. Ciampolillo, J. Derkaoui, M.L. Faccini-Turluer, R. Fantechi, V. Flaminio, A.G. Frodesen, D. Gamba, G. Giacomelli, H. Huzita, B. Jongejans, I. Lippi, M.Loreti, C. Loudec, G. Mandrioli, A. Marzari-Chiesa, A. Nappi, R. Pazzi, C. Petri, L. Ramello, L. Riccati, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, D. Vignaud and R. Wigmans

Physics Letters 124B, 543 (1983)

Fragmentation into strange particles in high energy ν p, ν n, $\overline{\nu}$ p and $\overline{\nu}$ n interactions

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, L. Bertanza, M. Bloch, F. Bobisut, T. Bolognese, A. Borg, E. Calimani, P. Capiluppi, R. Casali, S. Ciampolillo, R. Cirio, J. Derkaoui, M.L. Faccini-Turluer, R. Fantechi, V. Flaminio, A.G. Frodesen, D. Gamba, G. Giacomelli, H. Huzita, B. Jongejans, I. Lippi, M.Loreti, C. Loudec, G. Mandrioli, A. Margiotta, R. Pazzi, L. Ramello, L. Riccati, A. Romero, A.M. Rossi, S. Rustichelli, A. Sconza, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, D. Vignaud C. Visser and R. Wigmans

Physics Letters B, Vol. 154, pag. 231-235, 1985

Transverse Momentum of Charged Hadrons Produced in ν and $\overline{\nu}$ Deuterium Charged Current Interactions

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, L. Bertanza, F. Bianchi, A. Bigi, V. Bisi, F. Bobisut, T. Bolognese, A. Borg, E. Calimani, P. Capiluppi, S. Ciampolillo, J. Derkaoui, M.L. Faccini-Turluer, R. Fantechi, V. Flaminio, A.G. Frodesen, D. Gamba, G. Giacomelli, H. Huzita, B. Jongejans, I. Lippi, M.Loreti, C. Loudec, G. Mandrioli, A. Marzari-Chiesa, R. Pazzi, L. Ramello, L. Riccati, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, N. van Ejindoven, D. Vignaud and R. Wigmans

Zeitschrift fur Physik C, Vol. 27, pag. 239-248, 1985

Search for $\mu^{\pm}\pi^{\mp}$ mass enhancements in neutrino-deuterium and antineutrino-deuterium charged-current interactions

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, L. Bertanza, V. Bisi, F. Bobisut, T. Bolognese, A. Borg, E. Calimani, P. Capiluppi, S. Ciampolillo, J. Derkaoui, M.L. Faccini-Turluer, R. Fantechi, V.Flaminio, A.G. Frodesen, D. Gamba, G. Giacomelli, H. Huzita, B. Jongejans, M.Loreti, C. Loudec, G. Mandrioli, A. Margiotta, A. Marzari-Chiesa, R. Pazzi, L. Ramello, L. Riccati, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, D. Vignaud and R. Wigmans

Physical Review D, Vol. 31, pag. 2996-2998, 1985

Q^2 Dependence of the Proton and Neutron Structure Functions from Neutrino and Antineutrino Scattering in Deuterium

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, L. Bertanza, A. Bigi, V. Bisi, F. Bobisut, T. Bolognese, A. Borg, E. Calimani, P. Capiluppi, R. Casali, S. Ciampolillo, R. Cirio, J. Derkaoui, M.L. Faccini-Turluer, V. Flaminio, A.G. Frodesen, D. Gamba, G. Giacomelli, H. Huzita, B. Jongejans, I. Lippi, M.Loreti, C. Loudec, G. Mandrioli, A. Margiotta, A. Marzari-Chiesa, A. Nappi, R. Pazzi, L. Riccati, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, N. van Ejindoven, D. Vignaud, C. Visser and R. Wigmans

Zeitschrift fur Physik C, Vol. 28, pag. 321-333, 1985

Search for a $\Delta(1236) - \Delta(1236)$ structure of the Deuteron

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

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Physics Letters B, Vol. 174, pag. 450-452, 1986

Inclusive ρ_0 production in $\overline{\nu}_\mu$ D and ν_μ D charged current interactions

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, L. Bertanza, V. Bisi, F. Bobisut, T. Bolognese, A. Borg, E. Calimani, P. Capiluppi, R. Casali, S. Ciampolillo, J. Derkaoui, M.L. Faccini-Turluer, R. Fantechi, V. Flaminio, A.G. Frodesen, D. Gamba, G. Giacomelli, G. Graziani, H. Huzita, B. Jongejans, I. Lippi, M.Loreti, C. Loudec, G. Mandrioli, A. Margiotta, A. Marzari-Chiesa, R. Pazzi, L. Ramello, A. Romero, A.M. Rossi, S. Rustichelli, A. Sconza, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, N. van Ejindoven, D. Vignaud and R. Wigmans

Nuclear Physics B, Vol. 268, pag. 1, 1985

A study of the EMC effect using neutrino and antineutrino interactions in neon and deuterium

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J. Guy, B. Saitta, G. Van Apeldoorn, P. Allport, C. Angelini,N. Armenise,A. Baldini,M. Berrgren, D. Bertrand, F. Bobisut, V. Brisson, F.W. Bullock, M. Calicchio, P. Capiluppi,R. Cirio, E.F. Clayton,T. Coghen, A. M. Cooper-Sarkar, O. Erriquez, M.L. Faccini-Turluer, P.J. Fitch, A.G. Frodesen, G. Gerbier, G. Giacomelli, P.O. Hulth, G.T. Jones, B. Jongejans, P. Kasper, P. Klein,G. Mandrioli, P. Marage, A. Marzari-Chiesa, R.P. Middleton, D.B. Miller, D.R.O. Morrison, M.M. Mobayyen, S.W. O'Neale, M. Neveau, M.A. Parker, R.Petiau, A. Romero, A.M. Rossi, J. Sacton, R.A. Samsum, A. Sconza, E. Simopoulou, N. Schmitz,A. Tenner, C. Vallèe, N. van Eijndhoven, K.E. Varvell, A. Vayaki, W.A. Venus, D. Vignaud, H. Wachsmuth, Horst Werner, W. Wittek

Zeitschrift fur Physik C, Vol. 36, 337-348 (1987)

An investigation of the EMC effect using antineutrino interactions in Deuterium and Neon

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Physics Letters B, 141, 133-139 (1984)

Determination of the Neutral Current Coupling Constants u_L^2, u_R^2 d_L^2, *and* d_R^2 from a Neutrino and Antineutrino Deuterium Experiment

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, M. Baldo-Ceolin, L. Bertanza, A. Bigi, F. Bobisut, A. Borg, E. Calimani, P. Capiluppi, S. Ciampolillo, J. Derkaoui, M.L. Faccini-Turluer, V. Flaminio, A.G. Frodesen, G. Giacomelli, B. Jongejans, C. Loudec, A. Margiotta-Neri, A. Marzari-Chiesa, R. Pazzi,L. Riccati, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, N. van Ejindoven and D. Vignaud

Nuclear Physics B, Vol. 307, pag. 1-18, 1988

Multiplicity distributions of charged hadrons produced in (anti)neutrino-deuterium charged and neutral current interactions

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, L. Bertanza, F. Bianchi, V. Bisi, F. Bobisut, A. Borg, P. Capiluppi, R. Cirio, J. Derkaoui, M.L. Faccini-Turluer, A.G. Frodesen, D. Gamba, G. Giacomelli, B. Jongejans, G. Mandrioli, A. Margiotta-Neri, A. Marzari-Chiesa, R. Pazzi,L. Patrizii, F. Predieri, A. Romero, A.M. Rossi, G. Sanzani, A. Sconza, P. Serra-Lugaresi, M. Spurio, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, N. van Ejindoven and D. Vignaud

Il Nuovo Cimento A, Vol. 101, pag. 435-453, 1988

Bose-Einstein correlations in neutrino and antineutrino interactions in deuterium

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, L. Bertanza, F. Bianchi, A. Bigi, F. Bobisut, A. Borg, P. Capiluppi, R. Cirio, J. Derkaoui, M.L. Faccini-Turluer, A.G. Frodesen, D. Gamba, G. Giacomelli, B. Jongejans, G. Mandrioli, A. Margiotta-Neri, A. Marzari-Chiesa, R. Pazzi,L. Patrizii, C. Petri, F. Predieri, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, M. Spurio, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, N. van Ejindoven and D. Vignaud

Zeitschrift fur Physik C, Vol. 37, pag. 527-533, 1988

Search for fractionally charged particles in (anti)neutrino-deuterium interactions

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, A. Baldini, F. Bianchi, F. Bobisut, A. Borg, P. Capiluppi, R. Cirio, J. Derkaoui, M.L. Faccini-Turluer, A.G. Frodesen, D. Gamba, G. Giacomelli, B. Jongejans, M. Loreti, C. Loudec, G. Mandrioli, A. Margiotta-Neri, A. Marzari-Chiesa, R. Pazzi,L. Patrizii, C. Petri, F. Predieri, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, M. Spurio, A. Tenner, G.W. Van Apeldoorn, P. Van Dam, N. van Ejindoven and D. Vignaud

Physical Review D, Vol. 37, pag. 219-221, 1988

Investigation of exclusive channels in $\nu/\overline{\nu}$-deuteron charged current interactions

Amsterdam-Bologna-Padova-Pisa-Saclay-Torino Collaboration

D. Allasia, C. Angelini, G.W. Van Apeldoorn, A. Baldini, S.M. Barlag, L. Bertanza, F. Bobisut, P. Capiluppi, P. H. Van Dam, M.L. Faccini-Turluer, A.G. Frodesen, G. Giacomelli, H. Huzita, B. Jongejans, G. Mandrioli, A. Marzari-Chiesa, R. Pazzi, L. Ramello, A. Romero, A.M. Rossi, A. Sconza, P. Serra-Lugaresi, A. Tenner, and D. Vignaud

Nuclear Physics B, 343, 285-309, 1990

New experimental limits on $\nu_\mu \to \nu_e$ oscillations

Athens-Padova-Pisa-Wisconsin Collaboration

C.Angelini, A.Apostolakis, A.Baldini, M.Baldo-Ceolin, L.Bertanza, F.Bobisut, E.Calimani, U.Camerini, S.Ciampolillo, R.Fantechi, V.Flaminio, W.J.Fry, H.Huzita, P.Ioannou, S. Katsanevas, C. Kourkoumelis, J. Koutentakis, M. Loreti, R. Lovess, G. Miari, R. Pazzi, P. Pramantiotis, M.Procario, G. Puglierin, D.D. Reeder, L.K. Resvanis, B. Saitta and M.Vassiliou

Physics Letters, Vol. 179, pag. 307-312, 1986

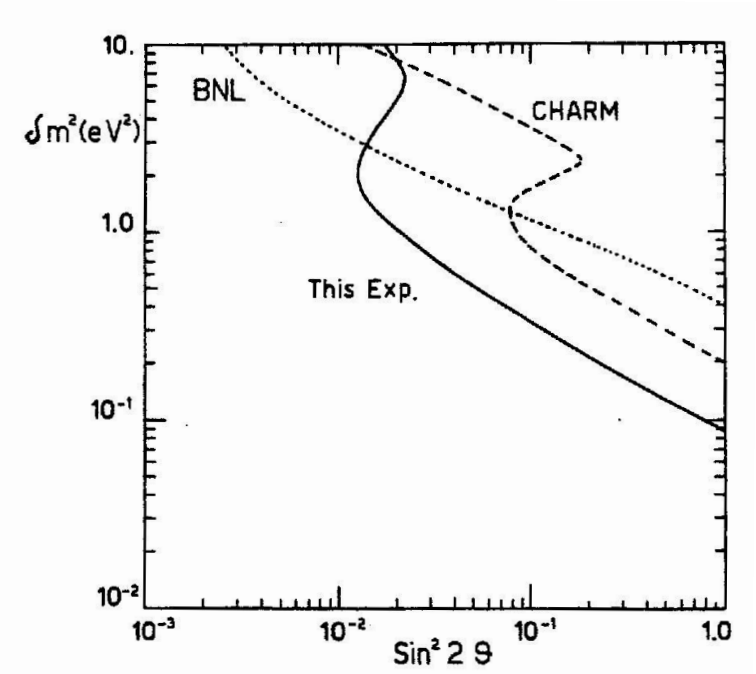

Fig. 4. Correlated limits on the oscillation parameters, at the 90% confidence level, as obtained in this experiment (solid line) compared with the results (dashed and dotted line) of two other recent experiments [4].

Figure 42: Limits on the oscillation parameters obtained in the PS180 Experiment

Neutrino Oscillation Experiments

V. Flaminio and B. Saitta

Rivista del Nuovo Cimento Vol 8 (1987)

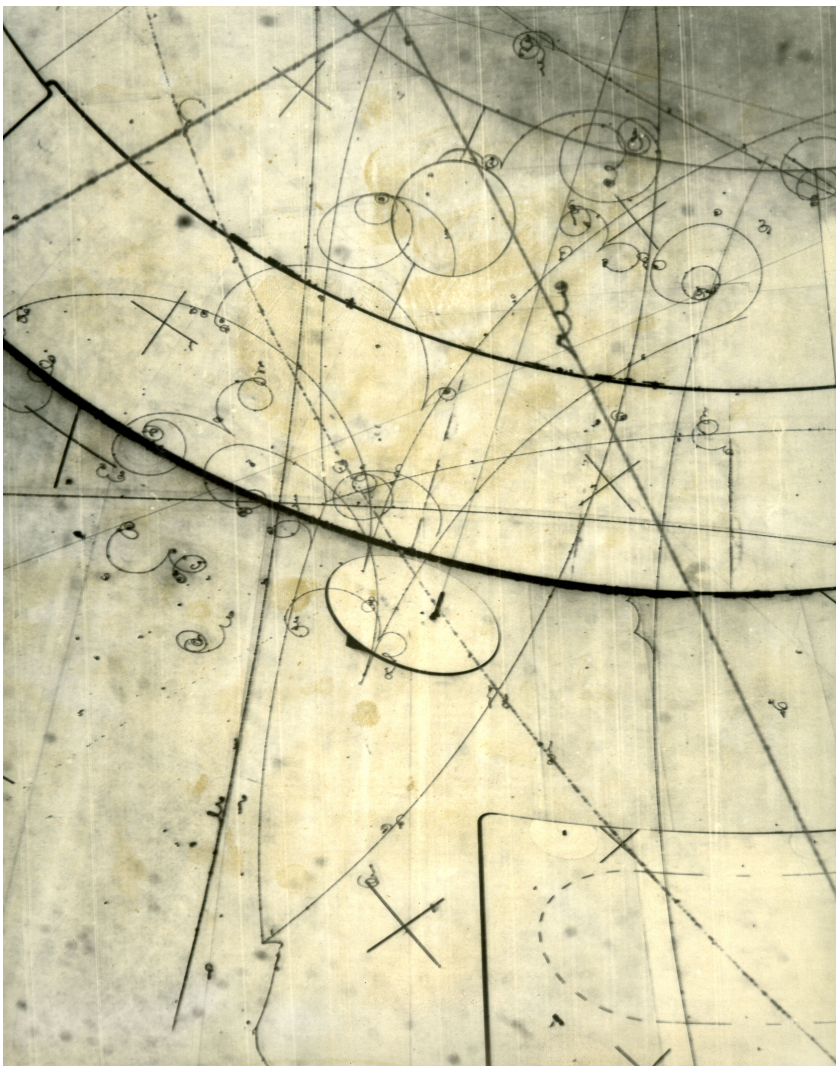

Figure 43: A neutrino interaction in BEBC filled with Neon-Hydrogen: search for neutrino oscillations in the PS180 Experiment

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8 Physicists, scanners, programmers, engineers and technicians

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