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60 YEARS OF SUBNUCLEAR PHYSICS IN BOLOGNA
Accademia delle Scienze dell'Istituto di Bologna – Sala Ulisse

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7 November 2018

"The search for heavy leptons from CERN to Frascati"

Federico Palmonari (INFN&University of Bologna)

Outline

- The sixties, the years of QED and leptons
- The back-story of the Bologna group
- The CERN-Bologna-Strasbourg scientific program to study the time-like electromagnetic form factor of the proton
- Zichichi became professor at the Bologna University and formed a second Group BCF ("Bologna –CERN- Frascati)
- The vaste program of research of the BCF group at the Frascati e+e- storage ring ADONE

NOTICE In 20 minutes there is no time to discuss the beautiful theoretical aspects of such an interesting field as the lepton family, both the QED themes and the leptonic weak interaction. I prefere to describe the really great experimental work done in few years (from 1965 to 1972) by enthusiastic people, physicists, engineers, electronics, mechanics and group technicians.

The back-story of the Bologna group

IL NUOVO CIMENTO VOL. XXIV, N. 1 1° Aprile 1962

Proton-Antiproton Annihilation into Electrons, Muons and Vector Bosons.

A. ZICHICHI and S. M. BERMAN (*)

CERN - Geneva

N. CABIBBO and R. GATTO

Università degli Studi - Roma e Cagliari
Laboratori Nazionali di Frascati del CNEN - Roma

(ricevuto il 20 Gennaio 1962)

Summary. — The possibility of achieving relatively high intensity anti-proton beams has prompted some considerations on the rather rare annihilation channels of the proton-antiproton system. We propose i) to study the two-electron mode as a means of investigating the electromagnetic structure of the proton for time like momentum transfers; ii) to study the two-muon mode and compare with the two-electron mode to investigate whether the muon behaves like a heavy electron for large time like momentum transfers; iii) to investigate the existence of weak vector bosons by the modes $p+\bar{p}\to B+\bar{B}$ and $p+\bar{p}\to B+\pi$.

Theoretical Discussion of Possible Experiments with Electron-Positron Colliding Beams.

N. CABIBBO and R. GATTO

Istituti di Fisica delle Università - Roma e Cagliari
Laboratori Nazionali di Frascati del CNEN - Frascati (Roma)

(ricevuto il 2 Febbraio 1961)

1. – We discussed recently the possible determination of the pion form factors from the reactions $e^{+}+e^{-}\to n\pi$ (1). There is at present a definite interest, particularly in Frascati, in the realization of electron-positron colliding beams. In this note we shall briefly present some further theoretical considerations on high energy electron-positron experiments.

2. – High energy e^{+}-e^{-} experiments can test the validity of quantum electrodynamics at small distances. There are two other aspects of such experiments that we want to stress:

i) The possibility of exploring form factors of strong interacting particles. These form factors are explored for timelike momentum transfers. Electron scattering experiments — whenever possible — can only explore spacelike momentum tranfers.

ii) The possibility of carrying out consistently a « Panofsky program », *i.e.* the exploration of the spectrum of masses of elementary particles through their interaction with photons. This program can be extended to include the exploration of particular classes of unstable states.

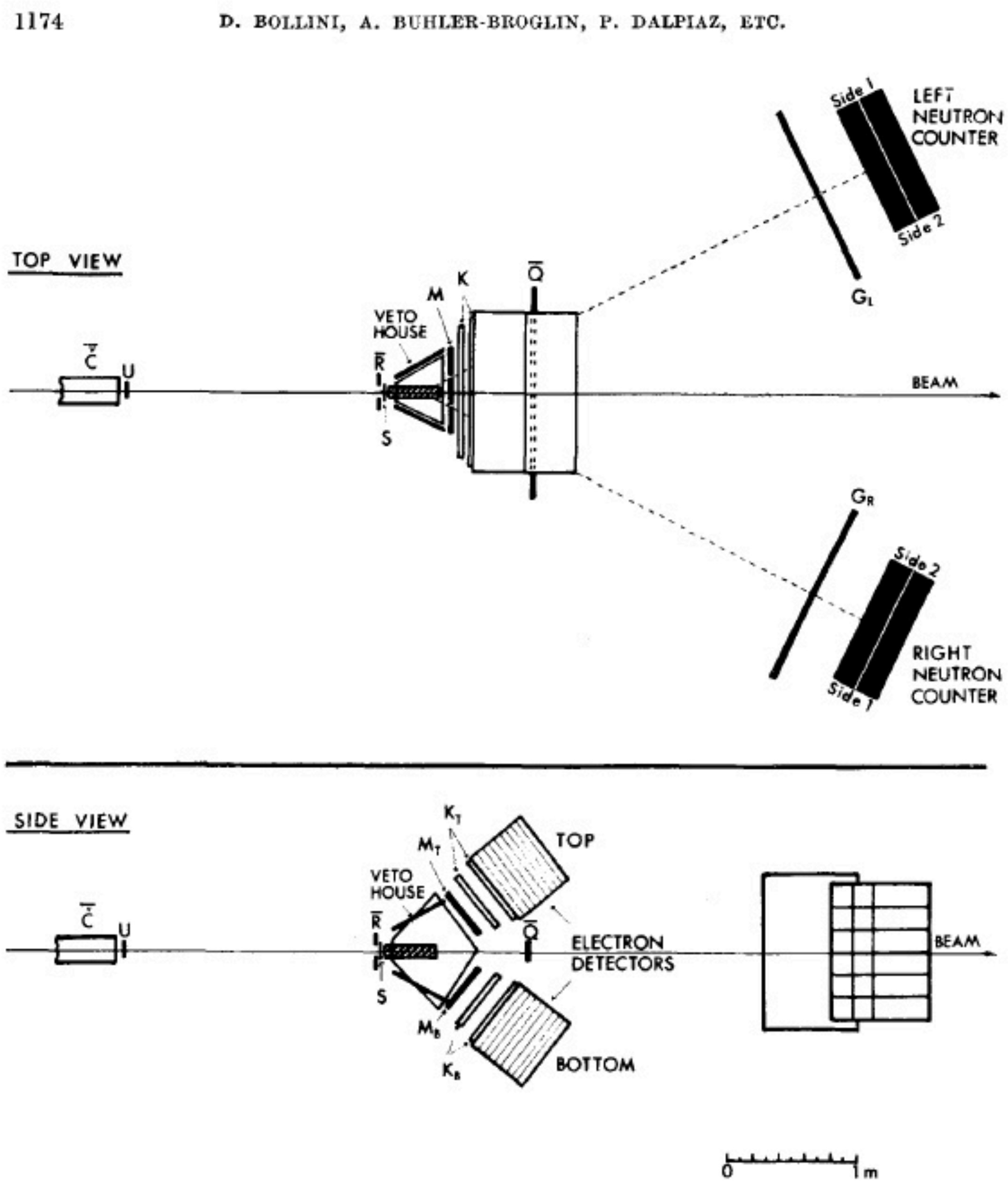


Fig. 1. – Schematic diagram of the experimental set-up. liquid H_2; scintillator.

The CERN-Bologna-Strasbourg Collaboration Set-up

to study p-antip into e,mu and vector bosons

The CERN-Bologna-Strasbourg scientific program to study the time-like electromagnetic form factor of the proton

IL NUOVO CIMENTO Vol. XXXIX, N. 2 16 Settembre 196

A New Electron Detector with High Rejection Power against Pions.

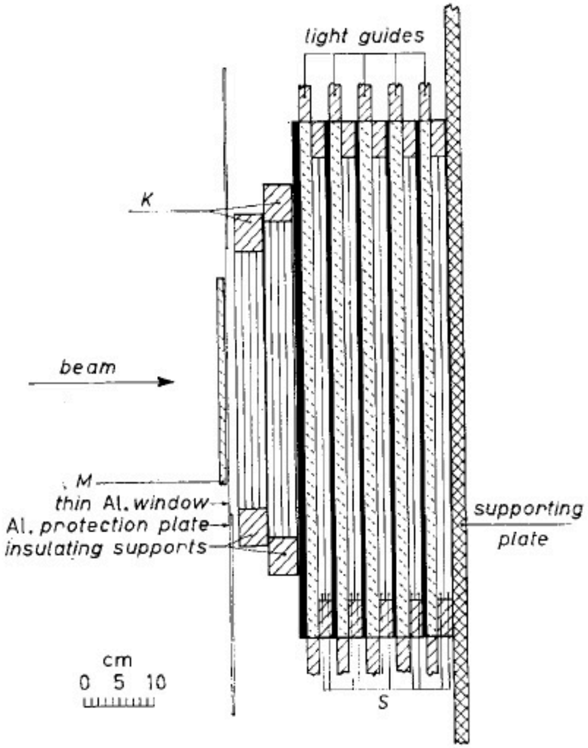
T. Massam, Th. Muller (*), M. Schneegans (*) and A. Zichichi

CERN - Geneva

(ricevuto il 21 Maggio 1965)

Summary. — An electron detector, which consists of five elements, each one being made of a lead layer followed by a plastic scintillation counter and a two-gap spark chamber, is described. The rejection power of this new detector against pions is of the order of $4\cdot10^{-4}$, the efficiency for electron detection varies from 75% to 85%, and the energy resolution can be as good as 10%, in the energy range 1.1 GeV to 2.5 GeV.

To my knowledge the Zichichi group was the first to use hadron-hadron collisions to study e+e- yelds from the proton accelerators. This group was the first to develop the "Earlier Shower Development Method" so as to greatly increase the electron / pion rejection. (S.Ting Nobel Lecture, 11 december 1997)



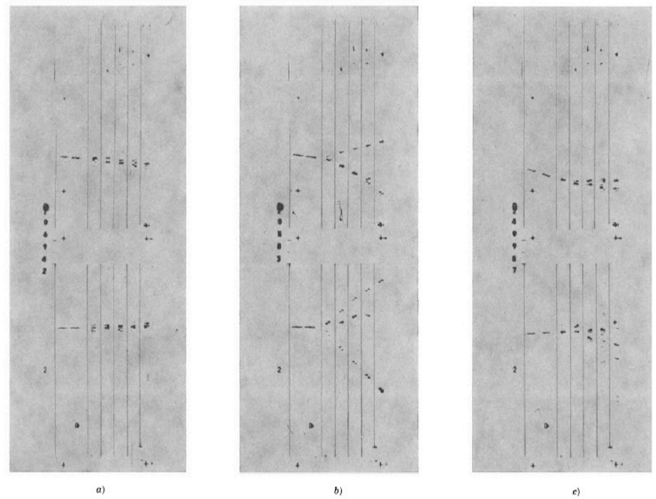


Fig. 3. – Typical events observed in the spark chamber: *a*) electron shower; *b*) pion inelastic interaction; *c*) pion charge exchange giving an asymmetric shower.

The neutron detector and the development of the time-of-flight technique

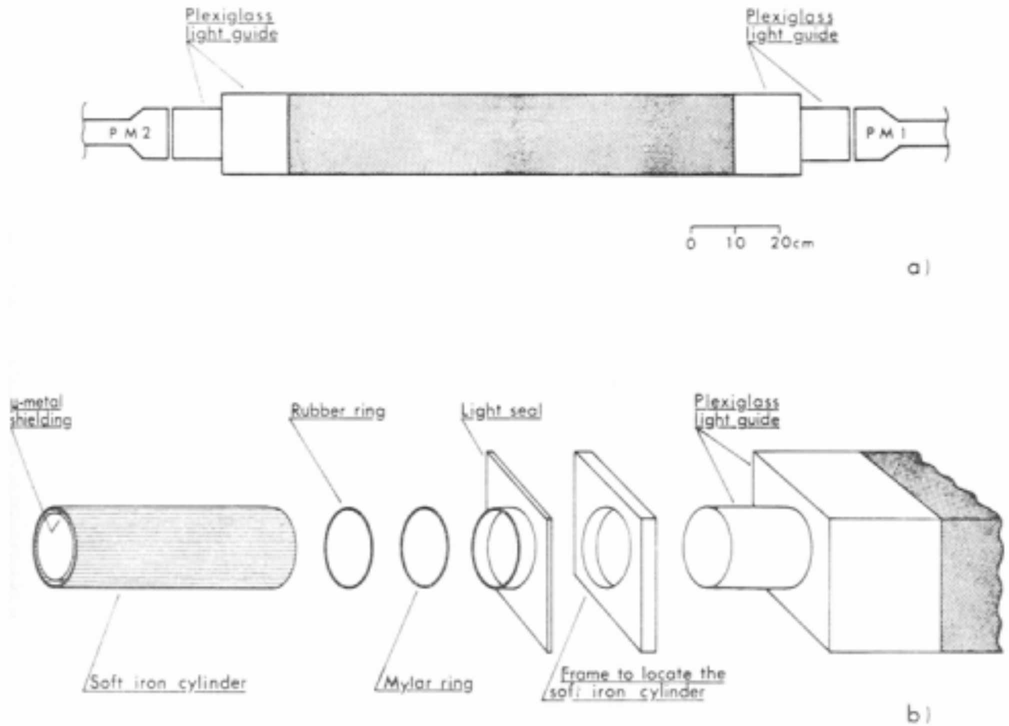
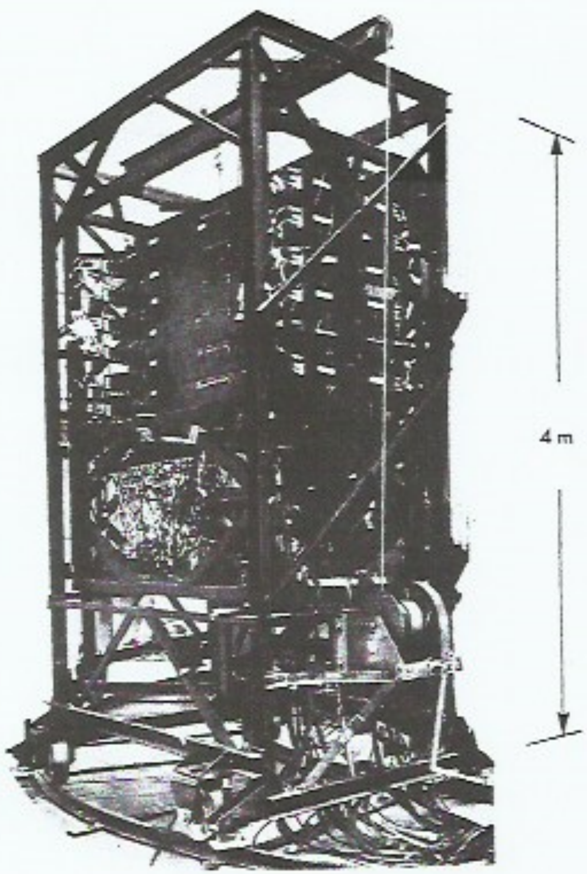


Fig. 5. – *a*) Assemblage of a neutron counter. *b*) The connections between a light guide and the PM base are shown. ▭ Scintillator.

a) attenuation length (*): $\lambda = (385 \pm 50)$ cm ,

b) refractive index (7): $n = 1.56 \pm 0.03$,

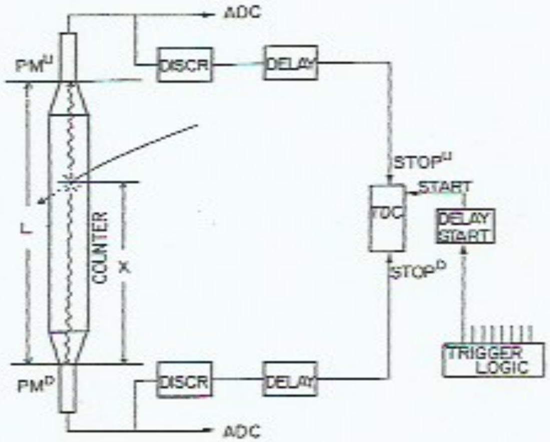
c) density: $\varrho = (1.17 \pm 0.01)$ g/cm³.



Neutron spectrometer arm of Zichichi's group vector meson experiment at CERN.

The Time-of-Flight principle

TIME MEASUREMENT IN LARGE-AREA SCINTILLATION COUNTERS



let L = distance between PMD and PMU

X = distance of the particle hit from PMD

V = 'effective' speed of collected light (about 15 cm/ns)

T0 = particle's hit time relative to the trigger time

$$T1 = TstopD - Tstart = T0 + X/V + const$$

$$T2 = TstopU - Tstart = T0 + (L-X)/V + const$$

- hit position:

$$X = V \times (T1-T2)/2 + const$$

- hit time:

$$T0 = (T1+T2)/2 + const$$

Fig. 13: Time measurement principle in scintillation counters.

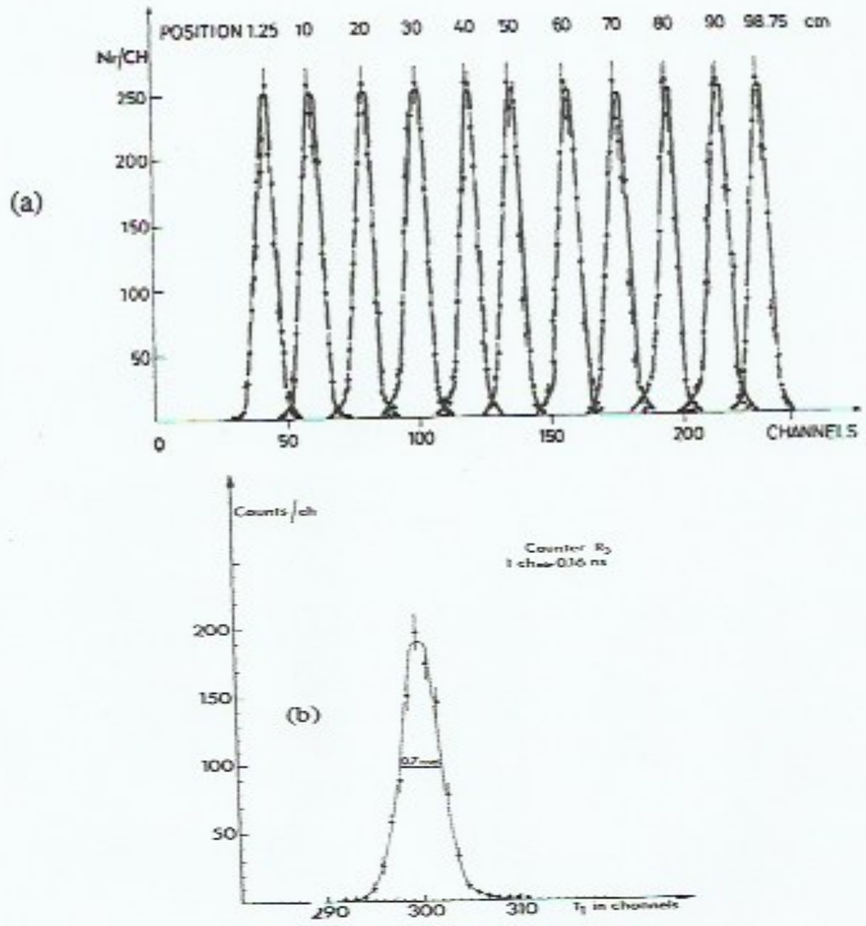


Fig. 15: Performances of the scintillation counters of the neutron spectrometer: (a) space resolution and (b) time resolution.

A Measurement of the Branching Ratio $\omega \to$ Neutrals/$\omega \to$ Total.

D. Bollini, A. Buhler-Broglin, P. Dalpiaz, T. Massam, F. Navach (*),
F. L. Navarria, M. A. Schneegans and A. Zichichi

CERN - Geneva
Istituto di Fisica dell'Università - Bologna
Istituto Nazionale di Fisica Nucleare - Sezione di Bologna
Centre de Recherches Nucléaires - Strasbourg

(ricevuto il 29 Aprile 1968)

Observation of the Rare Decay Mode of the φ-Meson: $\varphi \to e^+e^-$.

D. Bollini, A. Buhler-Broglin, P. Dalpiaz, T. Massam, F. Navach,
F. L. Navarria, M. A. Schneegans and A. Zichichi

CERN - Geneva
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Istituto Nazionale di Fisica Nucleare - Sezione di Bologna
Centre de Recherches Nucléaires - Strasbourg

(ricevuto il 31 Maggio 1968)

Evidence for a New Decay Mode of the X^0-Meson

D. Bollini, A. Buhler-Broglin, P. Dalpiaz, T. Massam,
F. Navach, F. L. Navarria, M. A. Schneegans and A. Zichichi

CERN - Geneva
Istituto di Fisica dell'Università - Bologna
Istituto Nazionale di Fisica Nucleare - Sezione di Bologna
Centre de Recherches Nucléaires - Strasbourg

(ricevuto il 13 Settembre 1968)

A Measurement of the φ-Meson Production Cross-Section in π^-p Interactions at 2.13 GeV/c.

D. Bollini, A. Buhler-Broglin, P. Dalpiaz, T. Massam,
F. Navach, F. L. Navarria, M. A. Schneegans and A. Zichichi

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Istituto Nazionale di Fisica Nucleare - Sezione di Bologna
Centre de Recherches Nucléaires - Strasbourg

(ricevuto il 23 Novembre 1968)

A New Large-Acceptance and High-Efficiency Neutron Detector for Missing-Mass Studies.

D. Bollini, A. Buhler-Broglin, P. Dalpiaz, T. Massam, F. Navach, F. L. Navarria, M. A. Schneegans, F. Zetti and A. Zichichi

CERN - Geneva
Istituto di Fisica dell'Università - Bologna
Istituto Nazionale di Fisica Nucleare - Sezione di Bologna
Centre de Recherches Nucléaires - Strasbourg

(ricevuto il 20 Dicembre 1968)

Summary. — A large-acceptance and high-efficiency neutron detector is described. The sensitive surface and volume of the detector are 2.16 m^2 and 0.78 m^3, respectively. The detector consists of twenty-four elements of plastic scintillator, each having dimensions $(100 \times 18 \times 18)$ cm^3. The large volume of scintillator, in the particular geometrical arrangement chosen, allows a mean detection efficiency of about 25% in the range $(70 \div 390)$ MeV neutron kinetic energy for a laboratory solid angle of 0.14 sr at 4 m radial distance. With the techniques adopted, calibrations with charged particles can be easily performed in a few hours using a low beam intensity. An interesting feature of this instrument is the accuracy achieved in locating incident particles, which is ± 1.4 cm for charged particles, and ± 2.5 cm for neutrons. The accuracies achieved for the time-of-flight measurement are ± 0.35 ns for charged particles and ± 0.7 ns for neutrons. With these resolutions in the neutron time of flight and angle, the uncertainty in the missing mass is ± 4 MeV for η, ± 10 MeV for ω, and ± 15 MeV for φ mesons.

Normally the paper treating the performances of the experimental set-up is written after the physics output papers of an experiment.

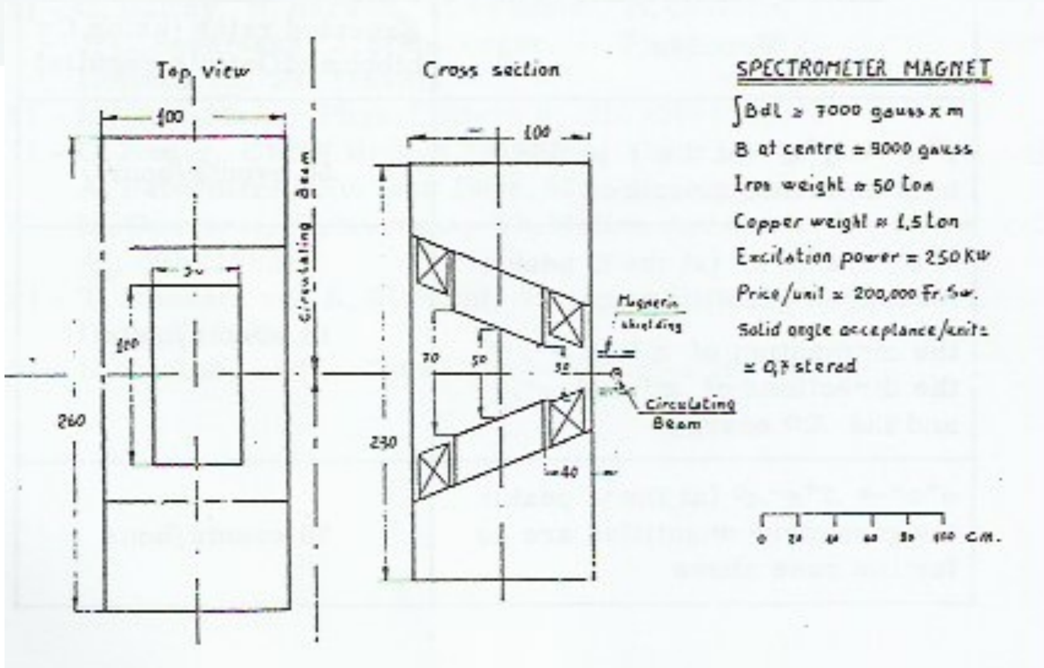
The experimental techniques used here were extensively used by the BCF group in Frascati

The origin of the Frascati Experiment at ADONE

INFN/AE-66/10
7 Novembre 1966

M. Bernardini, P. Dalpiaz, G. Fortunato, T. Massam, G. Petrucci and A. Zichichi: EXPERIMENTAL INVESTIGATIONS PROPOSED FOR "ADONE". - (Bologna-CERN-Frascati Collaboration)

(Paper presented by A. Zichichi at the Meeting on Colliding Beam Experiments, Frascati, Italy, 21-22 February, 1966).



La proposta finale del gruppo di Bologna BCF

Istituto Nazionale di Fisica Nucleare
Sezione di Bologna

INFN/AE-67/3
20 Marzo 1967

M. Bernardini, D. Bollini, E. Fiorentino, F. Mainardi, T. Massam, L. Monari, F. Palmonari and A. Zichichi. (Bologna-CERN-Frascati collaboration): A PROPOSAL TO SEARCH FOR LEPTONIC QUARKS AND HEAVY LEPTONS PRODUCED BY ADONE. -

1. - INTRODUCTION -

The experimental set-up studied in the present proposal takes into account the financial limitations which have been imposed on our previous project[(1)].

The limitations are two-fold:

i) as a magnet cannot be used there will be no magnetic analysis and so our proposal[(1)] of checking C-invariance must for the moment be abandoned;

ii) as the money available is very restricted the spatial resolution of our fast trigger is worse, i.e. $\Delta\theta = 10^{o}$.

We will concentrate on the study of two main topics:

a) Production of leptonic quarks;

b) Production of heavy leptons.

Zichichi had been called at Bologna University by prof.Puppi.

Local group leader was prof. Monari, particle physics expert grown in the Bubble chamber group held by Puppi.

prof.Bollini had already his training at CERN in the CBS experiment.

He was brinding the experience of the new experimental techniques, was en electronics and software and calculus expert

The ADONE bible: from https://www.sif.it/riviste/sif/sag/ricordo/gatto

Back to Italy, in 1960, Gatto became the director of the newly formed theory group at Frascati laboratories. He found there, as junior partner, Nicola Cabibbo, (..)

Frascati was busy building an electron-positron collider, a big machine that followed the pioneering work done by Touschek and collaborators with the accumulation ring AdA (Anello di Accumulazione). A larger version of AdA, was called Adone (big AdA, in Italian) and it was the sensation of the moment.

Great expectations were raised about the results to be obtained in what was the first exploration of Electrodynamics at high energy. Raoul Gatto and Nicola Cabibbo wrote a long article that summarised the theoretical situation of the high-energy electron-positron collisions. It was called The Bible by people in Frascati and showed very clearly the potential for elementary particle physics of future experiments with Adone. As later recalled by Cabibbo, writing this paper they had the exhilarating experience of expanding into a vacuum because for a few years the only theoretical papers on the physics of e+e– annihilations were those coming out of Rome and Frascati. (..)

In 1960, independently of Schwinger and Lee and Yang, Cabibbo and Gatto formulated the hypothesis that there is a muon neutrino different from the electron neutrinos, noting that two massless neutrinos with exact muonic and electronic number conservation would make the amplitude of the decay $\mu \rightarrow e\, \gamma$ to vanish exactly, as suggested by data.

The e+e- cross sections introduced in the proposal based on the Cabibbo and Gatto Bible

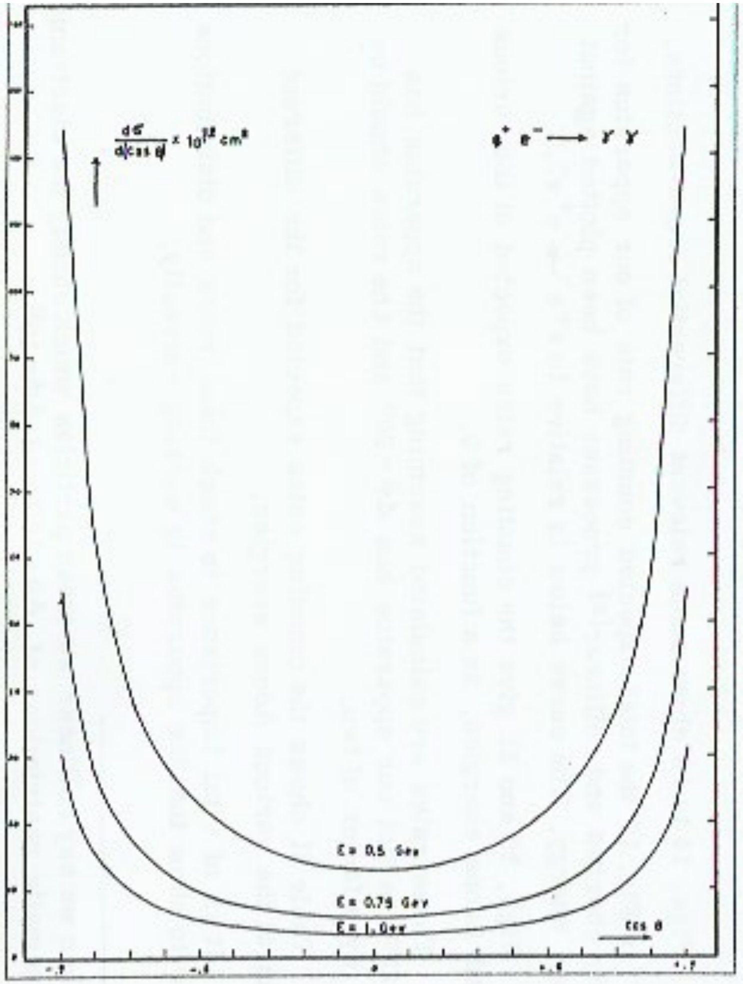


FIG. 14 - Differential cross-section of the reaction $e^+e^- \to \gamma\gamma$ at E = 0.5, 0.75, 1 GeV.

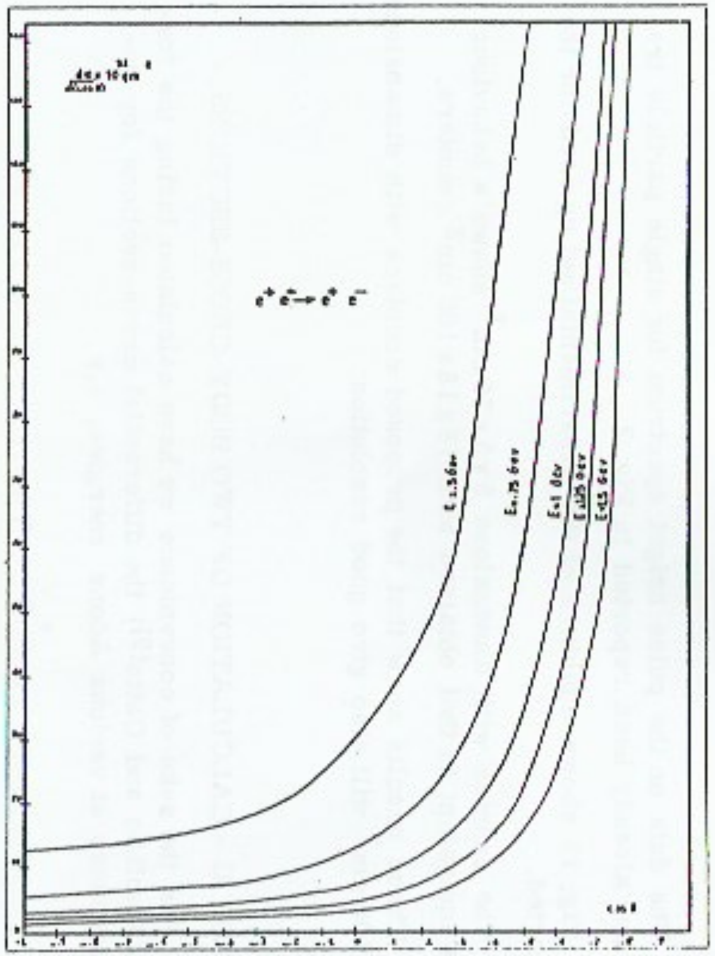


FIG. 15 - Differential cross-section of the reaction $e^+e^- \to e^+e^-$ at E = 0.5, 0.75, 1.0, 1.25, 1.5 GeV.

The e+e- cross sections introduced in the proposal based on the Cabibbo and Gatto Bible

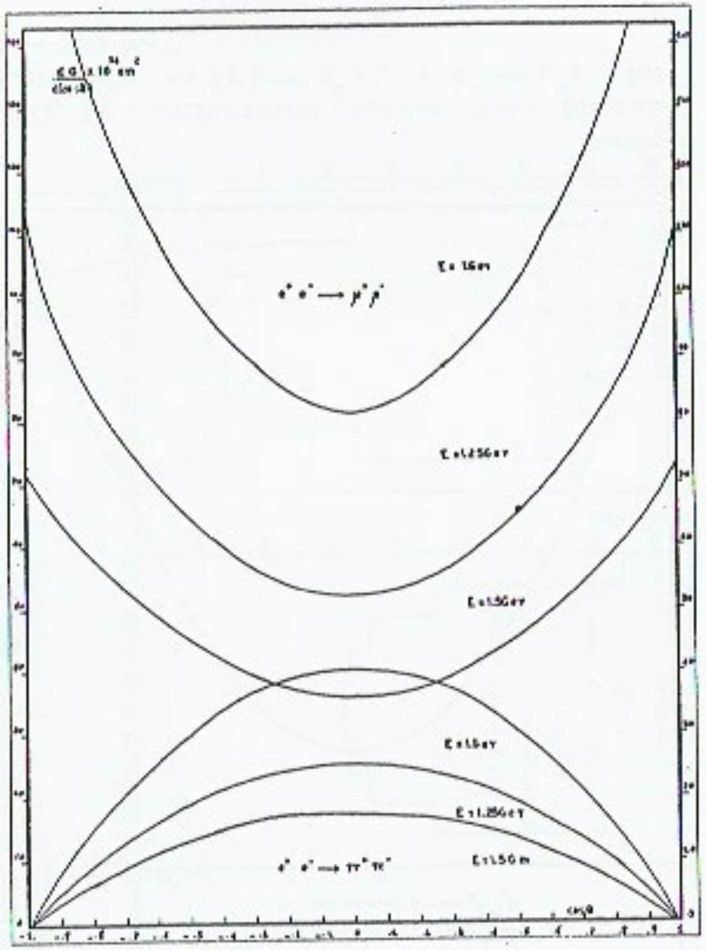


FIG. 16 - Differential cross-sections for reactions $e^+e^- \rightarrow \mu^+\mu^-$, $e^+e^- \rightarrow \pi^+\pi^-$ at E = 1.0, 1.25, 1.50 GeV.

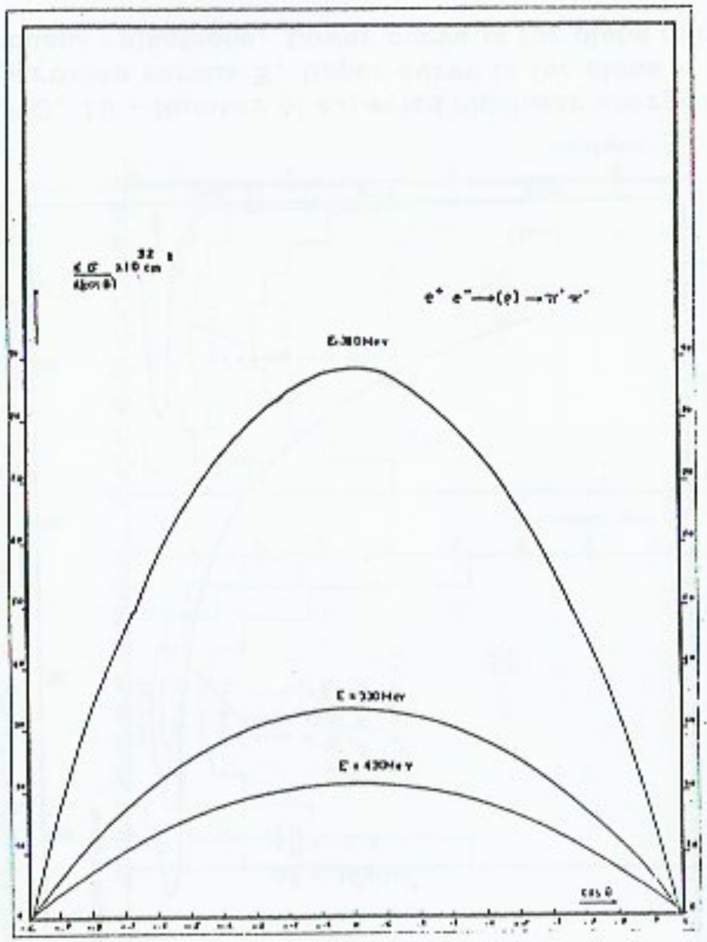


FIG. 17 - Differential cross-section for reaction $e^+e^- \rightarrow (\rho) \rightarrow \pi^+\pi^-$ at E = 330, 380, 430 MeV.

The new proposal with no magnetic field.

The enhanced performances to separate e, mu and mesons took advantage of the two techniques developed at CERN

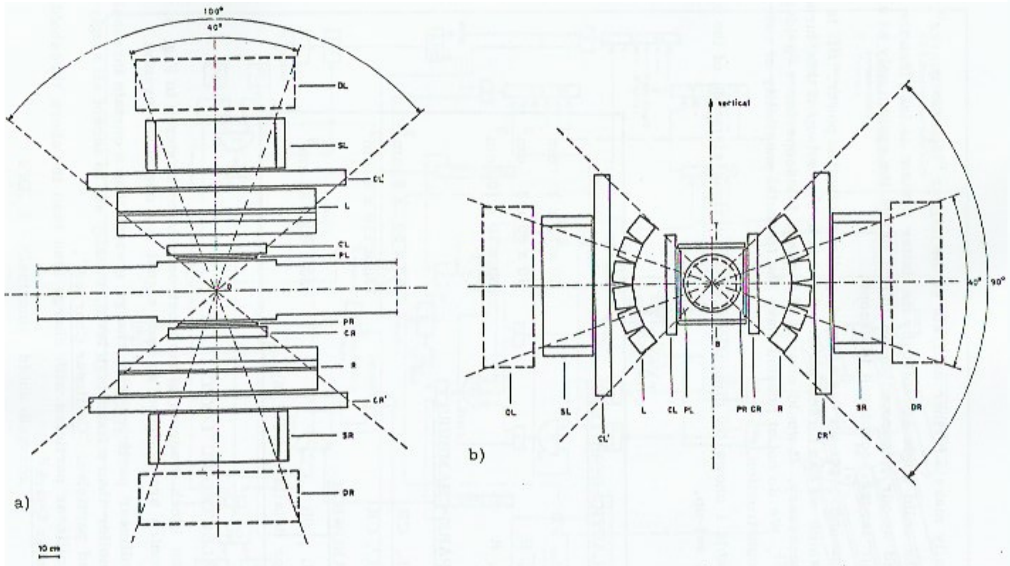


FIG. 8 - Experimental apparatus: a) Top view, b) Cross view; 0 =Interaction point; PL, PR, L, R = plastic scintillation counters; CL, CR, CL', CR' = thin Aluminium plate spark chambers; SL, SR = sandwich counters; DL, DR = rough μ-detector. Notice that the shape of the plastic scintillators will in practice be such that there are no edge effects between adjacent counters.

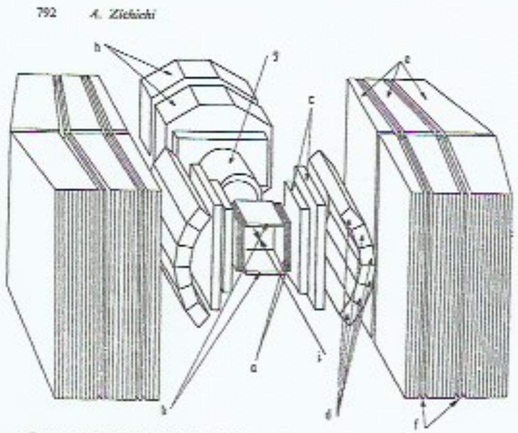
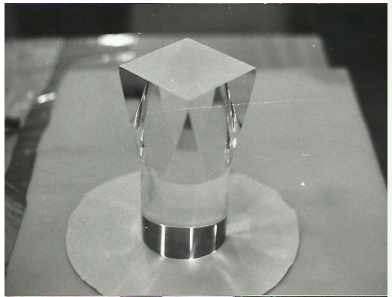
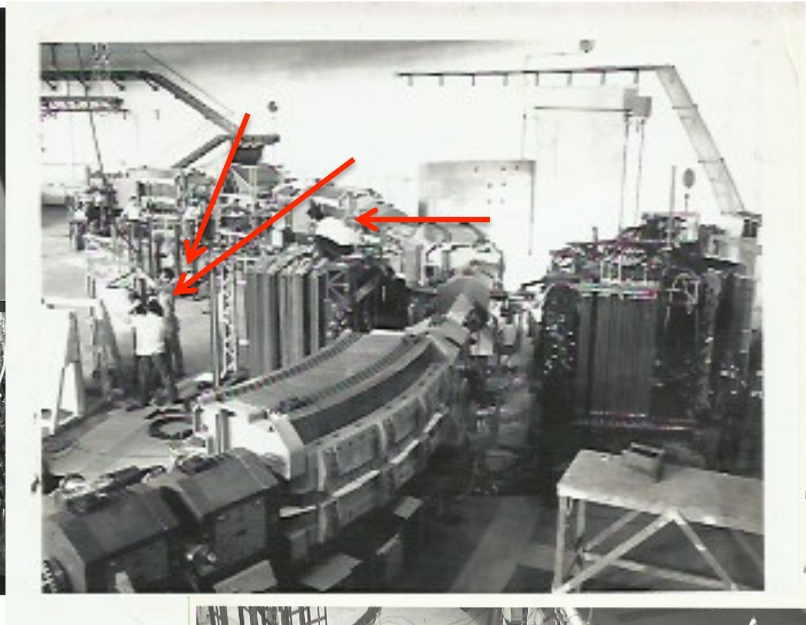


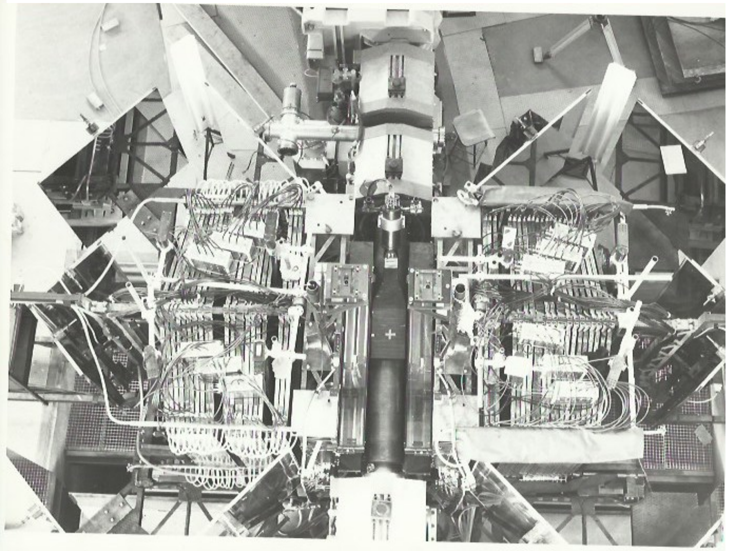
Fig. 1. – Perspective of the experimental set-up. The various components are indicated: a) Thin plastic scintillation counters used for fast trigger. b) Top and bottom plastic scintillation counters used in anticoincidence. c) Six-gap thin-plate spark chambers used for kinematical reconstruction. d) Thick plastic scintillation counters used for accurate time-of-flight, pulse height, and fast trigger. e) Heavy-plate spark chambers. f) Plastic scintillation counters used for fast trigger and pulse-height analysis. g) Vacuum chamber of the colliding beam. h) Quadrupole lenses of ADONE. i) Beam direction.

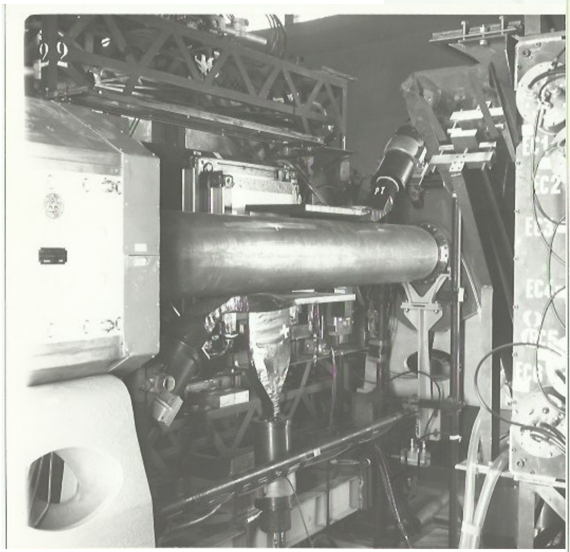
Fig. 16: Sketch of the Bologna apparatus at the electron-positron collider ADONE in Frascati. The two scintillation counter hodoscopes for TOF (labelled "d") are on opposite sides of the interaction region, parallel to the beam line.

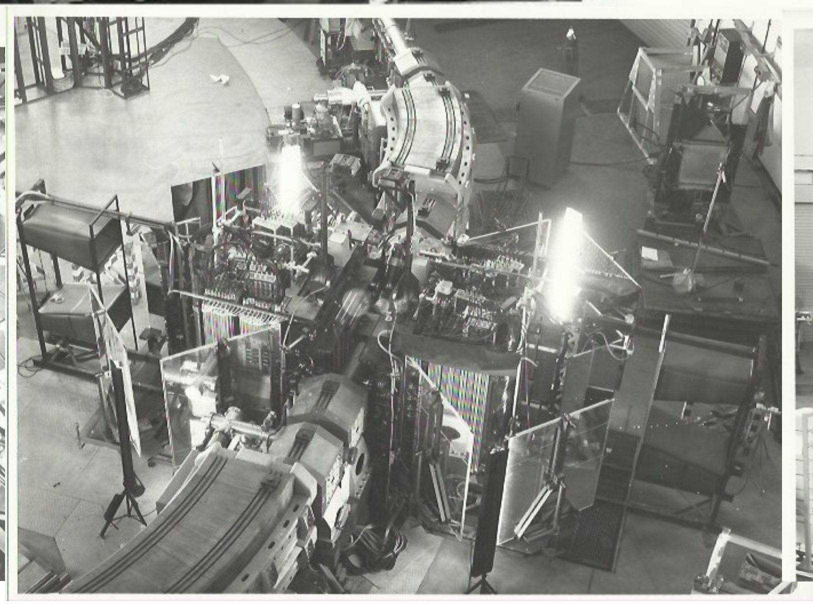
Some picture testing the BCF group work in Frascati











The time-of-flight technique to distinguish cosmic ray particles coming from outside from those produced at the interaction vertex of the e+e- collision

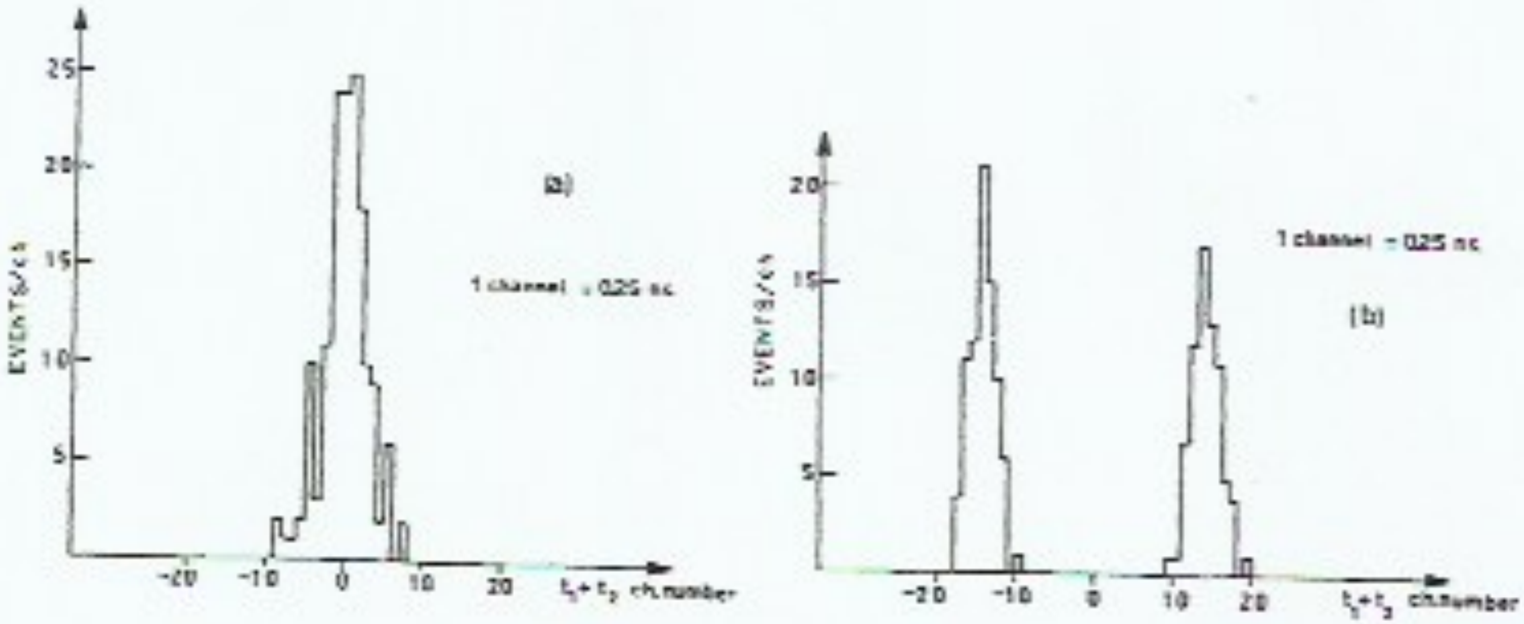


Fig. 17: Separation between annihilation muon pairs from ADONE and background cosmic muons by means of the TOF system: (a) the left-right time difference for good events; (b) the same for cosmic rays crossing the apparatus from both sides.

The early shower technique to separate electrons from muons and pions. Photo were scanned and tracks characterized by 6 parameters.

A for that time advanced BDT was defining three populations on the basis of a CERN calibration of a copy of the sandwich of spark chambers

an electron

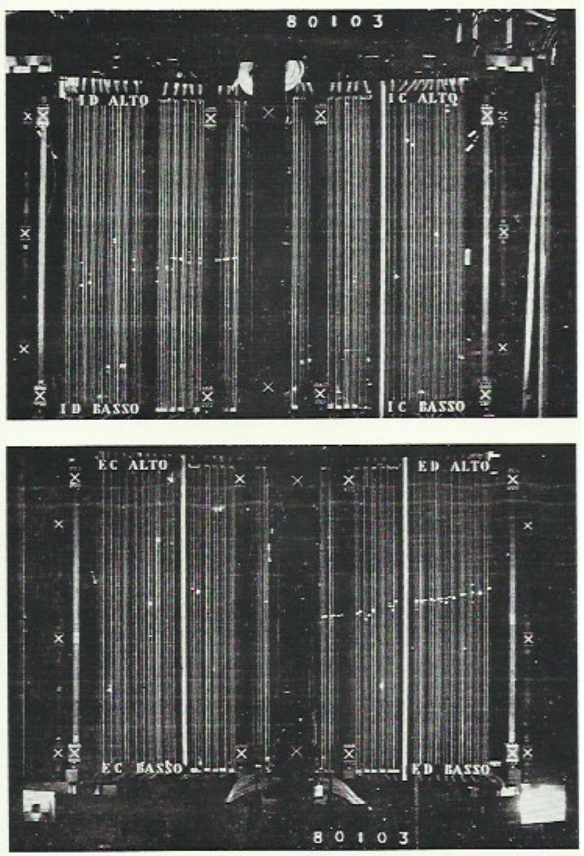


Fig. 2. – A typical electron-pair event, as it appears in the heavy-plate chambers. The geometrical reconstruction of the events is based on the kinematic chambers, not shown here.

a muon

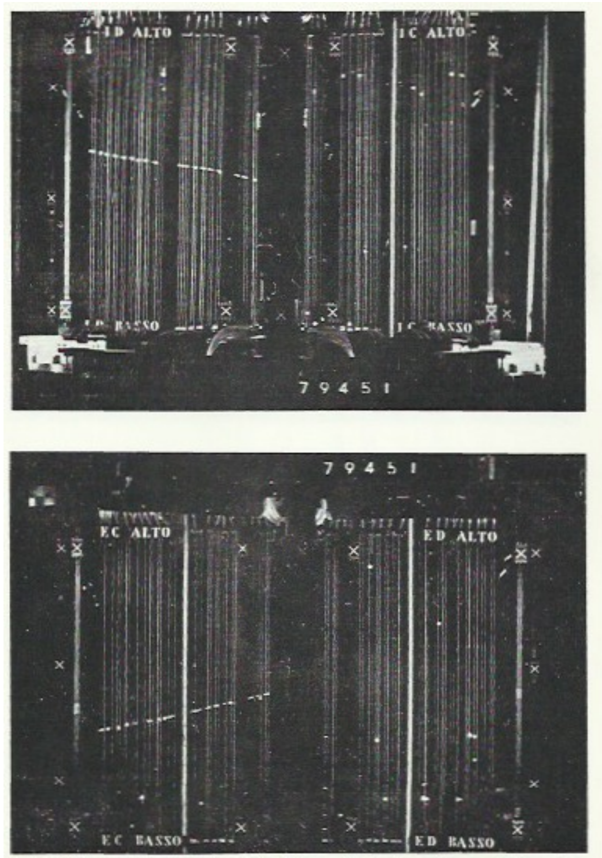


Fig. 3. – A typical μ-pair event, as it appears in the heavy-plate chambers. The geometrical reconstruction of the events is based on the kinematic chambers, not shown here.

The first two ADONE papers

V. Alles-Borelli, *et al.*
12 Dicembre 1970
Lettere al Nuovo Cimento
Serie I, Vol. 4, pag. 1156-1159

Limits on the Electromagnetic Production of Heavy Leptons.

V. Alles-Borelli, M. Bernardini, D. Bollini, P. L. Brunini,
T. Massam, L. Monari, F. Palmonari and A. Zichichi

CERN - Geneva
Istituto Nazionale di Fisica Nucleare - Sezione di Bologna
Istituto di Fisica dell'Università - Bologna
Laboratori Nazionali del CNEN - Frascati (Roma)

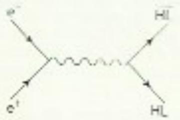
(ricevuto il 6 Novembre 1970)

A comparison between the long list of hadronic states and the very short list of leptonic states exposes one of the most striking puzzles of particle physics. It is therefore in order to ask whether heavy leptons could have been detected in previous experiments. If universality for the coupling of this new lepton to the known leptons is assumed, then the lifetime of a heavy lepton is predicted to be $\sim 3\cdot 10^{-10}$ s at 500 MeV and $\sim 2\cdot 10^{-11}$ s at 1000 MeV mass values. Thus, for masses in the region of 1 GeV, they could never have been detected as a decaying quasi-stable particle, but only as a resonance in the lepton system. Furthermore, it should be noted that the production of the heaviest lepton known so far (the muon) is copious only because it is the decay product of a very commonly produced particle, the π. There is no equivalent mechanism for the production of a heavy lepton with a mass of about 1 GeV. In proton machines they could only be produced in pairs via timelike photons, but it is known that nucleons are very poor sources of timelike photons [1], owing to the rapid decrease of their form factors as the four-momentum transfer increases [2].

The most favourable mechanism for the production of a heavy lepton HL is

$$e^+e^- \to \mathrm{HL} + \mathrm{HL}\,, \tag{1}$$

which, in the one-photon approximation, is described by the Feynman diagram



(1) T. Massam and A. Zichichi: *Nuovo Cimento*, **44** A, 309 (1966). The deep inelastic effect discovered at SLAC could alter this statement. However, as yet no firm experimental results exist on this possible consequence of the SLAC results. This point will be discussed further in a forthcoming note.
(2) M. Conversi, T. Massam, Th. Muller and A. Zichichi: *Nuovo Cimento*, **40** A, 690 (1965).

Validity of the Leptonic Selection Rules for the ($\mu e\gamma$) Vertex at High Four-Momentum Transfers.

V. Alles-Borelli, M. Bernardini, D. Bollini, P. L. Brunini,
T. Massam, L. Monari, F. Palmonari and A. Zichichi

CERN - Geneva
Istituto Nazionale di Fisica Nucleare - Sezione di Bologna
Istituto di Fisica dell'Università - Bologna
Laboratori Nazionali del CNEN - Frascati (Roma)

(ricevuto il 6 Novembre 1970)

Using the Frascati (e^+e^-) colliding-beam machine (ADONE) [1] we have performed an experiment to look for the possible existence of the process

$$e^+e^- \to \mu^+e^\mp\,. \tag{1}$$

which, in the one-photon approximation, can take place if at the μ-e-γ vertex the currently known leptonic selection rules are violated. The available experimental information does not allow a distinction to be made between the two alternative classes of selection rules [2] which distinguish the « electron world » from the « muon world »; namely: *a*) two additive selection rules; *b*) an additive and a multiplicative selection rule. Both sets of rules would be violated by the existence of process (1). For very low q^2 values ($q^2 \sim 0.01\ (\mathrm{GeV})^2$) it is known that process (1) is strongly depressed. Examples are the unobserved processes

$$\mu^\pm \to e^\pm + \gamma\,. \tag{2}$$

The two following papers were other QED tests

Experimental Check of Crossing Symmetry in the Electromagnetic Interaction of Leptons.

V. Alles Borelli, M. Bernardini, D. Bollini, P. L. Brunini, E. Fiorentino, T. Massam, L. Monari, F. Palmonari and A. Zichichi

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Istituto di Fisica dell'Università - Bologna
Laboratori Nazionali - Frascati

(ricevuto il 2 Luglio 1971)

A fundamental theorem of quantum field theory is crossing symmetry (¹). QED being the only working example of field theory, it is indeed crossing symmetric.

A straightforward check of QED crossing symmetry would be possible through a comparison between timelike and spacelike lepton-photon processes. In the one-photon approximation, this is shown in the diagrams below, where L stands for either electron or muon.

I) Timelike diagram. II) Spacelike diagram.

If we call $F^{LL\gamma}(q^2)$ the vertex function which describes the electromagnetic interaction between the lepton and the photon, crossing symmetry says that this vertex function is the same analytic function for timelike and spacelike processes, the only change being the value of the variable q^2.

The experimental check we propose for this QED crossing symmetry is based on comparison of the following two leptonic processes:

(1) $e^+e^- \to e^\pm e^\mp$,

(2) $e^+e^- \to \mu^\pm\mu^\mp$,

which have been studied at Frascati using the colliding-beam facility Adone.

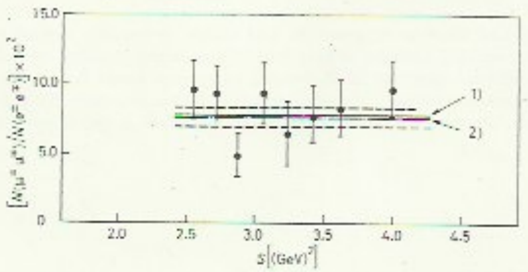

Fig. 1. – Experimental values of R = (rate of $e^+e^- \to \mu^+\mu^-$)/(rate of $e^+e^- \to e^+e^-$) at various Adone energies. $S = (2E)^2$; E is the colliding-beam energy. 1) Theory (QED), 2) experiment.

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EXPERIMENTAL PROOF OF THE INADEQUACY OF THE PEAKING APPROXIMATION IN RADIATIVE CORRECTIONS

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40 e^+e^- non-collinear, non-coplanar events have been observed in a study of 1824 e^+e^- interactions at total centre-of-mass energies from 1.6 GeV to 2.0 GeV. The inadequacy of the peaking approximation in radiative corrections is measured to be (2.8 ± 0.4)%, in these experimental conditions of observation.

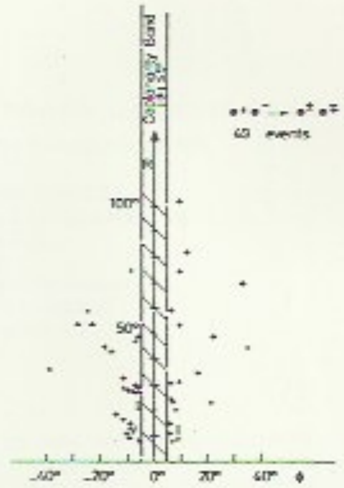

Fig. 2. R versus ϕ scatter diagram for all $(e^\pm e^\mp)$ events with $|\phi| > 5°$.

In '73 the final limit on the HL Heavy Lepton search

IL NUOVO CIMENTO Vol. 17 A, N. 2 21 Settembre 1973

Limits of the Mass of Heavy Leptons.

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(ricevuto il 9 Luglio 1973)

Summary. — A further search for heavy leptons at the ADONE e^+e^- storage ring has revealed no events. This establishes, with 95% confidence, that, if a heavy lepton exists and is universally coupled only to ordinary leptons, its mass must be heavier than 1.4 GeV. If it is also coupled to the hadrons, its mass must be greater than 1 GeV, again with 95% confidence.

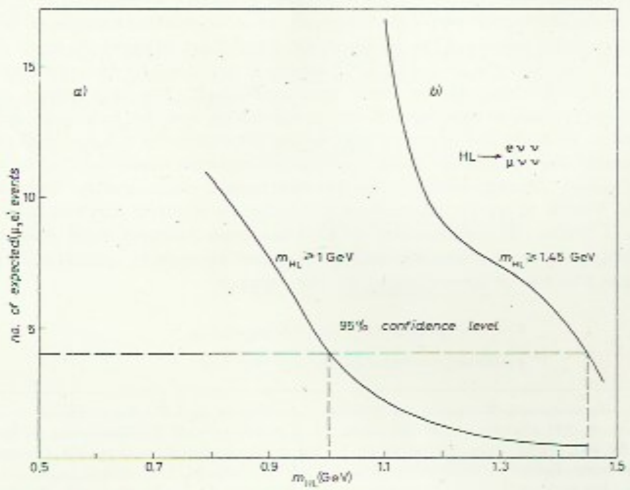

Fig. 2. — The expected number of $(\mu^\pm e^\mp)$ pairs *vs.* m_{HL} for two types of universal weak couplings of the heavy leptons. The dashed lines indicate the 95% confidence levels for m_{HL}. *a*) HL universally coupled with ordinary leptons and hadrons. *b*) HL universally coupled with ordinary leptons.

heavy leptons which do not have their own neutrinos:

$E^+ + \nu_e$, $E^- + \bar{\nu}_e$ } these are the heavy leptons wanted by the
$M^+ + \nu_\mu$, $M^- + \bar{\nu}_\mu$ } gauge theories of weak interactions (9);

and heavy leptons with their own neutrinos:

$L^+ + \bar{\nu}_{HL}$, $L^- + \nu_{HL}$ } the decay properties of these heavy leptons have been discussed by many authors (7-10).

Figure 1 shows, as a function of the colliding-beam energy E_A and for different values of the heavy lepton mass m_{HL}, the production cross-section obtained following the work of Cabibbo and Gatto (11).

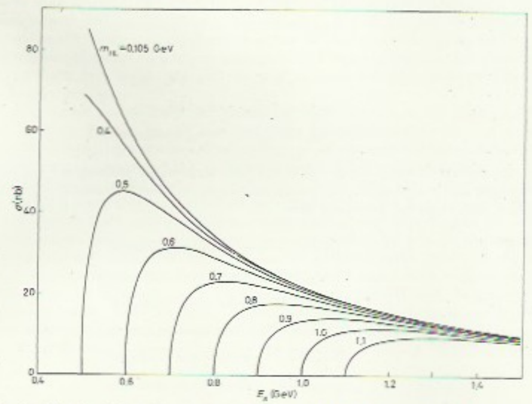

Fig. 1. – Calculated heavy-lepton production cross-section as a function of the colliding-beam energy E_A for different values of the heavy lepton mass m_{HL}.

Tau Lepton mass = 1776.86 ± 0.12 MeV

The BCF group list of publications - 1

BCF group: V. Alles-Borelli, M.Bernardini, D. Bollini, P.L. Brunini, E. Fiorentino, T. Massam, L. Monari, F. Palmonari, and A. Zichichi

7) VALIDITY OF THE LEPTONIC SELECTION RULES FOR THE mu/e/gamma VERTEX AT HIGH FOUR-MOMENTUM TRANSFERS
Nuovo Cimento Letters, 4, 1151 (1970)
8) LIMITS ON THE ELECTROMAGNETIC PRODUCTION OF HEAVY LEPTONS
Nuovo Cimento Letters, 4, 1156 (1970)
9) EXPERIMENTAL CHECK OF CROSSING SYMMETRY IN THE ELECTROMAGNETIC INTERACTIONS OF LEPTONS
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10) EXPERIMENTAL PROOF OF THE INADEQUACY OF THE PEAKING APPROXIMATION IN RADIATIVE CORRECTION
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11) STUDY OF CHARGED FINAL STATES PRODUCED IN e+e- INTERACTIONS
Elementary Processes at High Energy, pag.790,
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17) ACOPLANAR e e PAIRS AND RADIATIVE CORRECTIONS
Physics Letters, 45B, 169 (1973)
18) ACCURATE MEASUREMENT OF THE ENERGY DEPENDENCE OF THE PROCESS (e+e-)-(e-e+) IN THE s-RANGE 1.44-9.0 GeV
Physics Letters, 45B, 510 (1973)

The BCF group list of publications - 2

BCF group: V. Alles-Borelli, M.Bernardini, D. Bollini, P.L. Brunini, E. Fiorentino, T. Massam, L. Monari, F. Palmonari, and A. Zichichi

19) LIMITS OF THE MASS OF HEAVY LEPTONS
Nuovo Cimento 17A, 383 (1973)
20) THE TIME-LIKE ELECTROMAGNETIC FORM FACTORS OF THE CHARGED PSEUDOSCALAR MESONS FROM 1.44 TO 9.0 GeV
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23) THE ENERGY DEPENDENCE OF sigma(e+e- -> HADRONS) IN THE TOTAL CENTRE-OF-MASS ENERGY RANGE 1.2 TO 3.0. GeV.
Physics Letters, 51B, 200 (1974)
24) CROSS-SECTION MEASUREMENTS FOR THE EXCLUSIVE REACTION e+ e- -> 4 pi+- IN THE ENERGY RANGE 1.2-GeV TO 3.0-GeV.
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25) A STUDY OF THE HADRONIC ANGULAR DISTRIBUTION IN (e+ e-) PROCESSES FROM 1.2-GeV TO 3.0-GeV.
Nuovo Cim.26A:163,1975.
26) AN EXPERIMENTAL STUDY OF ACOPLANAR (mu+- mu-+) PAIRS PRODUCED IN (e+e-) ANNIHILATION.
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Phys.Lett.59B:201,1975.
28) THE PION ELECTROMAGNETIC FORM-FACTOR IN THE TIMELIKE RANGE 1.44-GeV**2 - 9.0-GeV**2.
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Thank you