1. The year 1979 has been very productive in experimental physics results at CERN, and this introductory report will be mostly devoted to presenting a brief selection of results obtained in experiments performed on the four CERN machines. More information on the scientific activities of CERN in 1979 will be found in the Divisional chapters of the present Annual Report.

2. The first result selected for presentation was obtained at the 600 MeV Synchro-cyclotron (SC) with the on-line isotope separator ISOLDE.

Figure 1 — a) Energy spectrum of β-delayed neutrons from $^{11}$Li. The expected positions of peaks corresponding to known resonances in $^{11}$Be are indicated by arrows.
b) The level scheme of the decay of $^{11}$Li. The 8.84 MeV level has a natural width of $200 \pm 50$ keV. It is strongly populated in the (t,p) reaction and must therefore have a large overlap with $^9$Be+2n, which makes it the likely origin of the two-neutron emission observed.

First Observation of Beta-Delayed Two-Neutron Radioactivity in Lithium-11 at the SC

(ISOLDE Collaboration)

The lithium nucleus normally has three protons and four neutrons, and its isotope $^{11}$Li, here produced by bombarding a uranium carbide target with 600 MeV protons at the SC, has four additional neutrons. Its
half-life is $8.5 \pm 0.2$ ms and the new decay mode observed is of the following type

$$^{11}_{4}Li \rightarrow ^{11}_{4}Be^* + e^- + \nu_e$$

$$\rightarrow ^{9}_{4}Be + n + n$$

The Q-value for β-decay of $^{11}_{4}Li$ to the ground state of $^{11}_{4}Be$ is 20.7 MeV, and the two-neutron decays observed are thought to originate predominantly in the 8.84 MeV excited state of $^{11}_{4}Be$. The threshold for its break-up into $^{9}_{4}Be$ and two neutrons lies at 7.315 MeV. In Figure 1a the energy spectrum of beta-delayed neutrons from $^{11}_{4}Li$ shows three peaks associated with known resonances observed in $^{11}_{4}Be$ and a continuum extending to about 1.7 MeV arising from the two-neutron emission. The corresponding level scheme is given in Figure 1b. A more detailed study of the $^{11}_{4}Li$ β-delayed two-neutron decay may prove revealing in the investigation of the n-n interaction.

3. Turning now to the PS, the 28 GeV Proton Synchrotron, three experimental results will be presented, two of which are based on bubble chamber data taken a long time ago. In the third experiment, a very recent one, hypernuclei with sigma particles have been discovered.

*Measurement of $\Sigma^+$ Magnetic Moment by the HYBUC Bubble Chamber at the PS*

(Munich (MPI)-Vanderbilt University Collaboration)

The specially designed small hyperon bubble chamber (HYBUC) illustrated in Figures 2 and 3, was built jointly by the Max-Planck-Institut für Physik und Astrophysik, Munich, and Vanderbilt University, Nashville, Tennessee. Its main features were a special geometry and an extremely strong magnetic field of 11 T produced by superconducting coils. In the early seventies it was installed in the North Hall inside the PS ring. A long period of data analysis has now provided a much more accurate determination of the magnetic moment of the hyperon than ever obtained before.

Figure 2 — Diagram of HYBUC, the superconducting bubble chamber installed at the PS from 1971 to 1973 for the measurement of the magnetic moment of the $\Sigma^+$ hyperon.
Figure 3 — The hyperon bubble chamber HYBUC with its ancillary equipment. (CERN-178.10.70)

\[ \mu_{Z^+} = (2.30 \pm 0.14) \mu_N \]

in the conventional units, nuclear magnetons, given by

\[ \mu_N = \frac{e \hbar}{2m_pc} \]

The previous world average of seven published experiments was

\[ \mu_{exp} = (2.62 \pm 0.41) \mu_N. \]

Its much larger error figure clearly shows the quite remarkable advance in precision now achieved.

**Observation of a Narrow Hyperon State of Mass 3.17 GeV**


The CERN data of this experiment were obtained with an 8.25 GeV/c \( K^- \) beam exposure in the 2 m hydrogen bubble chamber (2 m HBC). This chamber, which ceased operating two years ago, has now found a home at the Deutsches Museum in Munich, while

millions of pictures taken during its last runs are still being analysed. The experimenters looked for the mass distribution of a hyperon \( R^+ \), a positive baryon carrying strangeness \(-1\), with the peculiar property of decaying preferentially into several strange particles, as follows:

\[ K^- + p \rightarrow \pi^+ + R^+ \text{ with } R^+ \rightarrow \Sigma K + \text{ pions} \]
\[ \rightarrow \Lambda K + \text{ pions} \]
\[ \rightarrow \Xi K + \text{ pions.} \]

They found a very pronounced and narrow peak at 3.17 GeV with a width \( \Gamma \ll 20 \text{ MeV} \) for selected events where the pions were detected in the backward c.m.
strange constituents would account for the preferred decay of $R^+$ into the modes shown above, where the strange quarks and the strange antiquark appear in different strange particles.

It so happened that the Cambridge-Michigan State Collaboration studying old data of the same reaction at 6.5 GeV/c obtained at the Argonne 12 ft hydrogen bubble chamber also found a peak at the same position in the same mass distribution, although of lower statistical significance (Figure 5a). The combination of the two results (Figure 5b) produces a most significant signal.

**Hypernuclei with Sigma Particles (Obtained in Strangeness-Exchange Reactions on Nuclei at the PS)**

*(Experiment PS154, Heidelberg-Saclay-Strasbourg Collaboration)*

In investigations of hypernuclei, i.e. of nuclei in which a nucleon has been replaced by a hyperon, this Collaboration employs a kaon beam to deposit strangeness on one of the neutrons inside the nucleus, and precisely measures the resulting mass spectrum by means of the large spectrometer SPES II from Saclay shown in Figure 6. In the course of detailed studies of $\Lambda$ hypernuclei produced by the strangeness exchange $K^- + n \rightarrow \pi^- + \Lambda^0$, these physicists have in a recent run extended their search to other hypernuclear states, in particular those involving $\Sigma$ hyperons. The search was concentrated on a light nucleus, $^9$Be, which has a

![Figure 5](image1.png)  
*Figure 5 — a) Same reaction as in Figure 4a measured at 6.5 GeV/c incident momentum at Argonne. b) Combined data from the CERN and Argonne experiments (Figures 4a and 5a).*

![Figure 6](image2.png)  
*Figure 6 — The large-acceptance spectrometer SPES II from Saclay used in hypernuclei experiments at the PS. (CERN-96.11.78)*
Production of the Charmed Baryon $\Lambda_c^+$ at the ISR


In the course of 1979, charmed baryon production in hadronic interactions was observed for the first time in data of three experiments at the ISR. Two of these, R603 and R606, were located at intersection 6, and the third, R407/408, was carried out at the very large Split-Field Magnet detector (SFM), now ten years old and illustrated in Figure 8 as installed at intersection 4. The acceptance and pattern recognition of this detector had lately been improved by the rearrangement and addition of multiview proportional chambers. Here is shown the result of the SFM experiment R407/408, carried out at centre-of-mass energy $\sqrt{s}=52.5$ GeV. When plotting the $K^-\pi^+\Lambda$ mass distribution for the $K^-\pi^+$ system in the $K^*(890)$ mass region, the group found a very narrow peak at 2.26 GeV (Figure 9) which corresponds to the mass of the charmed hyperon $\Lambda_c$ composed of the three quarks $c$, $u$, and $d$.

$\Lambda_c$ hypernuclear spectrum (see Figure 7) dominated by two strong, clearly separated peaks, corresponding to excited $^5\text{Be}$ states. In the right-hand section of the spectrum and shifted from these peaks by about 77 MeV, corresponding to the mass difference between the $\Lambda$ and the $\Sigma^0$ particles, a two-peak structure similar to that of the $\Lambda$ spectrum can be seen which may be attributed to $\Sigma$-hypernuclear states produced by $K^-+n\rightarrow\pi^-+\Sigma^0$. The upper limit for the width of these states has been estimated at 8 MeV. This finding is surprising because these states could decay by strong interaction transitions $\Sigma^0$+nucleon $\rightarrow\Lambda$+nucleon inside nuclear matter. It opens up the possibility of further detailed investigations in a new chapter of hypernuclear spectroscopy.

4. The next part of this report concerns three important results obtained at the Intersecting Storage Rings (ISR) and involving the work of five experimental groups.
Direct Photon Production at High $p_T$ at the ISR

(Experiment R806, Athens-Brookhaven-CERN Collaboration)

The study of large transverse momentum collisions is one of the highlights of what has been achieved at the ISR. The large transverse momentum of the ejected particles can be attributed to the hard collisions between the point-like constituents, quarks or possibly gluons, of the incident protons. When such hard constituents collide and are ejected at a large angle to the incident direction, they are not detected as quarks or gluons but turn into hadrons in the form of a jet of mostly $\pi$ mesons. In most cases, each of these jet components carries only a small fraction of the total jet momentum. It may, however, happen that one of the ejected particles is neither a quark nor a gluon, but a photon coming out at a large angle. Although the rate of such events is reduced by the fact that an electromagnetic coupling is involved, the photon does not hadronize as it is not subject to strong interaction or confinement, and it will emerge with its full comple-

Figure 9 — The $K^-\pi^+$ mass distribution in pp collisions at c.m. energy $\sqrt{s} = 52.5$ GeV at the ISR for $K^-\pi^+$ systems in the $K^*$ (890) mass region. The pronounced peak at 2.26 GeV corresponds to the mass of the $\Lambda_c$ charmed baryon.

Figure 10 — The ratio of directly produced photons to neutral pions at different proton collision energies.
clearer understanding of the hard collisions between hadrons.

**Correlations Between Forward- and Backward-Emitted Pions at the ISR**

*(Experiment R607, Amsterdam (NIKHEF)-Louvain-la-Neuve UCL-Northwestern-Utrecht RU Collaboration)*

This experiment answers an old unresolved problem concerning meson production at low $p_T$ in pp collisions, namely whether there are correlations between pions being produced from the forward incident proton and those produced from the other incident proton. An analysis has now been carried out for $\pi^+\pi^-$, $\pi^0\pi^0$, and $\pi^0\pi^0$ pairs at the ISR with a centre-of-mass energy of $\sqrt{s} = 62.3$ GeV. In Figure 12 the correlation coefficient $R$, the ratio of the probability of forward-backward pair production over the product of the probabilities for one or the other particle, is plotted for various fractional momenta of one pion, $x_1$, as a function of the fractional momentum of the second one, $x_2$ ($x_1$, $x_2$ are pion momenta in units of $\sqrt{s}$; both are taken positive although the pions fly in opposite directions in the c.m. system).

It is evident that the plotted data are all close to 1.0 and show that the correlation between forward and backward pions is negligible or very small. Some theoretical models, however, had predicted quite strong correlations. For example, the Brodsky-Gunion model, assuming quark exchange and certain power counting rules, gives very low correlation coefficients as indicated by the full lines in the diagram. Although the matter is now quite resolved, with the correlation coefficient found to be close to one, the small deviations from this value revealed by the high quality of the data might deserve further study.

5. The remainder of my report on experimental activities will be devoted to the SPS, the 400 GeV Super Proton Synchrotron. Firstly, we mention results that have proved quite significant this year and were the outcome of using the old established emulsion technique in combination with our modern large detectors. They have given for the first time a determination of the very short decay paths of charmed particles.
Search for New Short-Lived Particles Produced in Neutrino Interactions in an Emulsion Stack Coupled to BEBC at the SPS

(Experiment WA17, Ankara-Brussels-CERN-Dublin-London (UC)-Open University-Pisa-Rome-Turin Collaboration)

In combining the use of emulsions with that of BEBC, the big European bubble chamber (Figure 13), this large Collaboration has been able to determine seven cases of such charmed particles decaying in the emulsion. Tracks of the decay products are followed in the emulsion and whenever possible in the bubble chamber downstream. In four instances charged charmed particles were produced, and they subsequently decayed with proper decay times — the life of the particle in its rest frame — lying in the range (0.5—7) x 10^{-13} s. In the remaining three cases involving neutral charmed particles, somewhat shorter decay times were indicated.

Observation of a Charmed Neutral Meson Produced in a High-Energy Photon Interaction at the SPS

(Experiment WA45, Photon-Emulsion Collaboration* and Omega-Photon Collaboration**)

In this experiment the nuclear emulsion placed in front of the Omega spectrometer was exposed to tagged photons at energies between 20 and 70 GeV from the SPS. Although the results were fewer than those obtained in the neutrino beam, a very clean example of the production and decay of a neutral charmed particle was found within the emulsion, as shown in Figure 14.

Figure 13 — BEBC, the big European bubble chamber, in the neutrino beam of the SPS. The emulsions with which decay times of charmed particles were measured were placed in front of this chamber. (CERN-149.10.73)

Figure 14 — Emulsion tracks obtained in the SPS photon beam in an exposure in front of the Omega spectrometer. About 120 μm to the right of the production star can be found a further star at the point of decay of the neutral particle identified as a charmed meson D^0.

Figure 15 — Reconstruction of the event shown in Figure 14. The neutral particle decays into four charged particles whose tracks could be matched to those detected in the spectrometer, thus enabling the mass of the particle to be reconstructed.

* Bologna-CERN-Florence-Genoa-Moscow LIP-Paris VI-Santander-Valencia
On the left can be seen the emulsion star where production of the charmed particle occurred. About 120 μm downstream from this primary star a neutral star was discovered at the point where the neutral particle had decayed. Some of the ionizing tracks in the emulsion could be matched with particles detected downstream in the Omega spectrometer, and only in this way was it possible to reconstruct the event precisely. This reconstruction is shown in Figure 15 with a greatly expanded vertical scale. From the distance travelled by the neutral particle, the proper decay time was evaluated to be \((2.26 \pm 0.05) \times 10^{-14}\) s. The decay was into four charged particles, two of which are identified as a \(K^+\) and a \(\pi^-\), respectively, and of the remaining two, one is known to be positive and the other negative. The mass can be reconstructed as is found to equal \((1866 \pm 8)\) MeV/\(c^2\), which corresponds very closely to that of the charmed neutral meson \(\bar{D}^0\) whose decay is as follows:

\[
\bar{D}^0 \rightarrow K^+ \pi^+ \pi^- \pi^-.
\]

The fact that such a short decay time of \(2 \times 10^{-14}\) s can be readily measured demonstrates the fine grain and high resolution of these emulsion detectors.

The rising interest in the study of particles with lifetimes as short as \(10^{-19}\) s has also led to new developments in the field of bubble chambers. Very small devices of this type have been built to serve as optical detectors in place of emulsions as part of a larger detection system. Let me illustrate this new era of the small bubble chamber by two examples, both to be used for experiments in the North Area of the SPS.

LEBC2, the Lexan bubble chamber (version 2) shown in Figure 17, is made of transparent plastic and has a diameter of only 20 cm. It is placed inside a vacuum tank with an expansion system and viewed by two cameras, the whole chamber assembly not exceeding about 1 m³ in volume, as shown in Figure 16. This hydrogen bubble chamber has produced pictures of remarkable quality, as can be seen in Figure 18 where the tracks of interest are extremely fine and yet distinct, formed by bubbles about 30 μm in diameter.

\[\text{Figure 16 — The LEBC2 bubble chamber with its expansion and optical systems as used in experiment NA16.}\]
The second chamber, a heavy-liquid one, is BIBC, the Berne infinitesimal bubble chamber shown in the diagram of Figure 19. It has a diameter of merely 10 cm and is to be operated as experiment NA18 (Berne) in front of, and in conjunction with, the streamer chamber of experiment NA5 (Bari-Cracow-Liverpool-MPI Munich-Nijmegen Collaboration) already running in one of the SPS beams (Figure 20). The excellent quality of its tracks is evident from Figure 21, and the bubble size is again of the order of 30 μm. One may draw an amusing analogy between this interesting development in bubble chambers and the field of computers. Just as we now have gigantic computers and also pocket calculators, before long we shall see high-energy experimenters employing briefcase-size bubble chambers for specific tasks, as well as the familiar gigantic bubble chambers such as BEBC.
Photoproduction in the Omega Spectrometer at the SPS

(Experiment WA4, Omega-Photon Collaboration)

This experiment, illustrated in Figure 22, has now provided evidence, at the 3.5 standard deviation level, for the charmed particle $D^0$ characterized by the decays

$$D^0 \rightarrow K^0\pi^+\pi^-, K^+\pi^-,$$

and, more limited statistically, for the somewhat dis-
Figure 23 — (a) $D^0$ meson production as shown in the inclusive $K^0\pi^+\pi^-$ mass distribution obtained by photoproduction experiment WA4 under the following selection conditions: i) an extra $K^+$ (proton) is seen; ii) the total visible mass is above 1.7 GeV; iii) the incident photon has an energy above 40 GeV.

(b) $\eta$ production as shown in the inclusive $\gamma\gamma$ mass distribution.

(c) $\eta'$ production as shown in the inclusive $\eta\pi^+\pi^-$ mass distribution.

puted F mesons that are believed to be combinations of a charmed quark and a strange antiquark, or vice-versa, and decay as follows:

$$F^+ \rightarrow \eta\pi^+\pi^+\pi^-\pi^-, \eta\pi^+\pi^-.$$  

They were first found at DORIS in the DESY Laboratory, but have not been confirmed by the similar SPEAR ring at SLAC. The respective mass distributions from the WA4 experiment are given in Figures 23 and 24. So there are now indications that such particles are produced in a photon beam. As for the third result of WA4 shown here, it concerns the study of the photoproduction process $\gamma p \rightarrow p\bar{p} + X$, with more than one prong in $X$, and has shown the narrow baryonium $S \rightarrow p\bar{p}$ at 1930 MeV in the mass distribution plot illustrated in Figure 25. This corresponds exactly to the mass of the $S$ baryonium state that had been known for some time from various antiproton experiments, but that other searches had since failed to find again. It is certainly interesting that the best and, so far, only established baryonium state has been seen in photoproduction.

Although only preliminary, the most spectacular result in the past year at CERN was probably that obtained in the following experiment in the West Area.
quark) with a strange meson K° and a positive or negative pion, the experimenters found a resonance at the very heavy mass of 5.3 GeV/c², the observed width being compatible with the experimental resolution (see Figure 26). The best interpretation of this is that it might be a meson containing the bottom (b) quark, also called the beauty quark, which indeed should have a mass around 5 GeV, attached to an ordinary light antiquark. The b is the quark occurring as bound state b¯b in the T, T' and T'' mesons, which have masses of the order of 9 GeV/c². The meson state B° found in experiment WA11 could be interpreted as consisting of such a b quark bound to a normal antiquark ¯u (the B° consisting of b¯u). To give the observed decay B°→J/ψ+K°+π°, the b would decay into c+cc by charged-current weak interaction, the cc giving the J/ψ and the s being the strange quark s which appears in the K°. But the experimental result, first announced at the 1979 European Physical Society Conference in Geneva, still lacked statistics. In view of the extreme importance of establishing it on firm grounds, the SPS programme was modified to give highest priority to this experiment and to push the pion beam energy to the maximum possible in the West Hall, which is about 190 GeV. The B° peak at 5.3 GeV/c² has grown a little and has gained in statistical significance, but more statistics are still needed to establish it firmly.

Search for High-Mass States Produced with the Ψ (3.1) at the SPS

(Experiment WA11, Indiana-London (IC)-Saclay (CEN)-Southampton Collaboration)

In a most surprising combination of particles produced in a pion-induced reaction, namely the J/ψ (which is a charmed quark bound to a charmed anti-
The next experiment to be reviewed is located in the North Area of the SPS and is concerned with the very fruitful topic of pair production of high-\( p_T \) leptons in hadron-hadron collisions. It is believed that the main mechanism for the production of a lepton pair (muons or electrons) in such collisions is by way of the annihilation of a quark in one of the incident hadrons with an antiquark in the other hadron. Other point-like constituents such as gluons could also be involved. This annihilation gives rise to a virtual photon which then materializes in the form of a lepton pair, as shown in the diagram of Figure 27.

If such an interpretation is correct, this so-called Drell-Yan mechanism opens up a new way of measuring the distribution of quarks and antiquarks inside the hadrons, a way which is complementary to, and quite independent of the normal method based on deep inelastic neutrino, electron, and muon scattering. Looking at the resultant lepton pair, it is possible, from the kinematics of the Drell-Yan mechanism, to reconstruct the momentum fractions \( x, x' \) of the quark and antiquark before annihilation:

\[
t + t^- : (x - x') p_{cm}^{\text{inc}}
\]

\[
q + \bar{q} \rightarrow \gamma_{\text{virtual}} \rightarrow \ell^+ \ell^- \quad \text{(Drell-Yan mechanism)}
\]

\[
\text{longitudinal momenta : } q^* p_{cm}^{\text{inc}}, \quad \bar{q}^* \rightarrow -x' p_{cm}^{\text{inc}}
\]

\[
\ell^+ \ell^- : (x - x') p_{cm}^{\text{inc}}
\]

\[
effective \text{ mass of } \ell^+ \ell^- : \sqrt{s} = 2 p_{cm}^{\text{inc}}
\]

where \( p_{cm}^{\text{inc}} \approx \frac{1}{2} \sqrt{s} \) is the c.m. momentum of the incident hadrons.

Hadronic Production of High-\( p_T \) Leptons and Hadrons at the SPS

(Experiment NA3, CERN-Collège de France-Orsay (LAL)-Palaiseau (EP)-Saclay Collaboration)

A downstream view of the experiment can be seen in Figure 28 with the large-aperture superconducting dipole magnet in front, followed by drift and multiwire proportional chambers and a two-section hadron-electron calorimeter at the rear, as detailed in the diagram of Figure 29.

In this particular investigation the group measured the absolute cross-section for dimuon (\( \mu^+ \mu^- \)) production in proton-nucleon and pion-nucleon collisions at 200 and 280 GeV/c. In Figure 30 the proton structure function, which gives the distribution of quarks in the proton, has been plotted in comparison with the quark distribution derived from high-energy neutrino interactions (full line) as measured in experiment WAI of the CERN-Dortmund-Heldelberg-Saclay (CDHS) Collaboration. The shape of the curve is the same, but the CDHS data had to be multiplied by a factor of 2.2. The intensity of muon pair production in these collisions is therefore greater than expected from the Drell-Yan model, by a factor of about 2, which partly compensates the factor \( \frac{1}{3} \) related to the colour quantum number. That a large enhancement occurs can be explained by quantum chromodynamics, but reliable calculations are difficult.

In a similar way this experiment has studied the dimuon production resulting from pion-nucleon colli-
sions at 200 and 280 GeV/c (a type of measurement also performed at lower energy by the WA11 experiment mentioned before). The pion and nucleon structure functions obtained are plotted in Figure 31. A comparison with the nucleon structure function measured in the CDHS neutrino experiment again shows a

![Diagram showing layout of experiment NA3](image)

**Figure 29** — Layout of experiment NA3 shown in Figure 28.

![Proton structure function](image)

**Figure 30** — The proton structure function as derived from pN data on dimuon production at 200 GeV/c and compared with the CDHS neutrino results. The comparison reveals an enhancement factor of 2.2 for the dimuon production.

![Pion and nucleon structure functions](image)

**Figure 31** — Pion and nucleon structure functions as derived from muon pair production in pion-nucleon collisions at 200 and 280 GeV/c by experiment NA3. A comparison is made with data obtained in the neutrino experiment of the CDHS Collaboration. The presence of two sets of data and fits for the pion structure functions corresponds to the inclusion or not of an enhancement factor as encountered in Figure 30. The correct pion structure function requires inclusion of the factor, and is given by the lower data points.
correction factor of about 2.2-2.4. This is the highest precision measurement of the quark distribution inside pions performed so far (remember that deep inelastic lepton scattering experiments cannot be performed on pions because they are unstable).

Looking at the dimuon mass spectrum of this experiment, given in Figure 32, one can see a big bump at about 9 GeV in both the $\pi^+$ and $\pi^-$ data. This is evidence of the $T$ meson, produced here for the first time in pion-nucleon collisions. It is evident that a great deal of important physics can be expected to emerge from the further study of muon pair production in hadron collisions.

The last part of this review of the SPS programme presents some of the very significant results achieved in 1979 at the high-intensity muon beam in the North Area, which is now beginning to prove as productive as the other very advanced SPS beam, the neutrino beam in the West Area, has been since 1977. The two large muon experiments, NA2 and NA4, are situated one behind the other in the muon beam.

Figure 32 — Dimuon mass spectrum in the reactions $\pi^N$ at 200 GeV/c as obtained by experiment NA3. The peaks at about 9 GeV represent the upsilon mesons.

Figure 33 — Part of the large spectrometer in the high-intensity muon beam of the SPS used in experiment NA2 of the European Muon Collaboration. A large-aperture dipole magnet to the left is followed by drift and multiwire proportional chambers, a Čerenkov counter, hodoscopes, and muon filters. At the far end, experiment NA4. (CERN-164.4.78)
Electromagnetic Interactions of Muons
(Experiment NA2, European Muon Collaboration*)
Inclusive Deep-Inelastic Muon Scattering
and Search for Multimuon Events
(Experiment NA4, Bologna-CERN-Dubna-Munich-
Saclay (CEN) Collaboration)

Part of the large spectrometer facility of experiment NA2 can be seen in Figure 33; it is a very diversified and complete system, good for the detection of muons and hadrons. It is very flexible in design so that targets of various types can be used and detectors added. In its initial phase, NA2 has concentrated on muon detection. Downstream of this experiment is the second large muon experiment, NA4, illustrated in Figure 34. It consists of a cylindrical target, about 40 m long, surrounded by toroidal magnets interspersed with counters and multiwire proportional chambers for the detection of muons that spiral inside the magnetized iron system.

The very ambitious neutrino and muon programmes at CERN have as one of their aims the comparison of the internal structure of nucleons determined (as in experiment WA1 of the CDHS Collaboration) through the weak interaction with neutrinos, with that determined electromagnetically with the aid of muons as in the NA2 and NA4 experiments. If present theoretical ideas are correct, in particular if gluons have neither weak nor electromagnetic couplings, there must be complete identity between the quark distributions inside nucleons as measured in these two different ways. Denote the quark distribution in a nucleon by $F_2^q(x)$ where probing is done by neutrinos, and by $F_2^q(x)$ where probing is done by muons, the variable $x$ being the fractional momentum of the quark in the nucleon. If our theoretical understanding is correct, these structure functions must be equal but for the application of a normalization factor. When the experiments are performed with heavy targets, which have about the same number of protons and neutrons; the electric charges of the quarks are $\frac{2}{3}$ and $-\frac{1}{3}$ with about equal probability, so that the normalization factor for $F_2^q$ is

$$\frac{1}{2} \left[ \left( \frac{2}{3} \right)^2 + \left( -\frac{1}{3} \right)^2 \right] = \frac{5}{18},$$

whereas it is one for $F_2$. The theoretical prediction is

$$F_{2i}^\mu (x) = \frac{5}{18} F_2^\mu (x),$$

and this is the relationship to be verified experimentally.

The comparison between the experimental determination of these functions as measured with neutrinos (WA1–CDHS) or muons (NA2–EMC) is shown in Figure 35. The structure function $F_2$ is plotted here as a function of the momentum transfer $Q^2$ for various values of the variable $x$, revealing any scaling violation (variation with $Q^2$ at fixed $x$) as would result from quark binding effects. The black points give $F_2^\mu$ the white ones give $5/18 F_2^\nu$, and the agreement is remarkably good, showing that our basic understanding of quark structures as measured by these two independent types of probes appears to be close to the truth. It is interesting to note that, at large $Q^2$, the structure functions depend only slightly on $Q^2$. Scaling violation should theoretically be very small there, as it varies logarithmically. In fact, the data show it to be practically negligible.

A similar comparison can be made on the basis of the second muon experiment, NA4, as illustrated in Figure 36. The function $F_2^\mu$ obtained at two different muon energies is plotted for different ranges of $x$. The agreement with the neutrino data (WA1–CDHS) is again very good and the distribution becomes remarkably flat as $Q^2$ rises above 50 (GeV/c)$^2$.

The European Muon Collaboration, in experiment NA2, has also detected events where, in addition to a scattered muon, a muon pair is produced. The virtual photon exchanged between the incident muon (of momentum 280 GeV/c) and the nucleon in the iron target excites the nucleon, and an additional $\mu^+ \mu^-$ pair is produced in this excitation process, as shown in the

![Figure 35](image1.png) - Quark distribution in nucleons: comparison of the structure function $F_2(x)$ plotted against $Q^2$ for $\mu N$ data (experiment NA2–EMC, black points) and $\nu N$ data (experiment WA1–CDHS, white points) for different fractional momenta $x$ of the quark.

![Figure 36](image2.png) - Quark distribution in nucleons: comparison of the structure function $F_2(x)$ plotted against $Q^2$ for muon data at two different energies obtained in experiment NA4 (circles) with neutrino data from experiment WA1–CDHS (crosses) for different ranges of quark fractional momenta.

![Figure 37](image3.png) - Muon pair production in 280 GeV/c $\mu^+$ iron interactions. Mass spectrum obtained by experiment NA2 of the European Muon Collaboration and showing the peak due to the $J/\psi$ vector meson.
Q² (GeV/c)² of virtual photon

Figure 38 — $Q^2$-dependence of $J/\psi$ production in 280 GeV/c $\mu^+$-iron interactions as determined in experiment NA2 of the European Muon Collaboration. The predictions of the vector dominance model for a low-mass and a high-mass parametrization are indicated by the dashed and solid curves, respectively.

The diagram of Figure 37. The plot in the figure gives the mass distribution of the muon pair. The signal due to the $J/\psi$ meson is clearly visible as the peak at about 3 GeV/c². Its width is due to the experimental resolution. In the case of this particular vector meson, the experimenters have studied the way in which its photo-production depends on the mass of the virtual photon exchanged in the reaction, i.e. on the momentum transfer squared $Q^2$ from the incident muon to the target nucleon. The $Q^2$ dependence is plotted in Figure 38; it is compared with the prediction of the vector dominance model for a low mass (dashed curve) and a high mass (solid curve) of a single vector meson supposed to dominate the production. The results clearly indicate the importance of vector meson masses of the order of the $J/\psi$ mass.

6. In closing this review of scientific activities we mention very briefly the work of the Theoretical Physics (TH) Division on theoretical research and of the Data Handling (DD) and Experimental Physics Facilities (EF) Divisions which, although not directly producing experimental results, provide essential support to the experimentalists. In the Theoretical Physics Division the resident and visiting physicists have tackled a wide range of problems opened up by the recent discoveries in high-energy physics and the recent developments in field theory, including the search for unified theories of all basic interactions and their relation to the bigbang theory of the expanding universe.

The DD Division has continued to ensure the excellent performance of the large CERN computer centre and the extensive hardware and software support required by the experimental programme, including the preparation of new complex detection systems such as the large $p\bar{p}$ experiments and the European hybrid spectrometer at the SPS. The STELLA aerial has now been installed, signalling the start of CERN’s participation in this experiment of high-energy data transmission between European laboratories via the first European telecommunication satellite. It is carried out in collaboration with the European Space Agency and the European Economic Community and various national laboratories and universities. The documentation and exhibition services, also within the DD Divi-

Figure 39 — Superconducting single-cell radio-frequency accelerating cavity for operation at 500 MHz and a field of 4.85 MV/m as developed by the EF Division. (CERN-2.12.79)
sion, have had an exceptionally busy year occasioned by the celebration of the 25th Anniversary of the entry into force of the CERN Convention, which celebration they have helped to turn into the successful event it has proved to be.

Ending on a technological note, we mention the collaboration of CERN, and especially of the EF Division, with various European laboratories in the research and development of superconducting accelerator cavities destined for possible use in LEP, after tests to be performed on the PETRA machine at DESY.

One of the recent results of this development work, achieved at CERN, is illustrated in Figure 39. It is a superconducting single-cell accelerator cavity for operation at 500 MHz and a temperature of 4.2 K with a vacuum as high as $2 \times 10^{-8}$ Torr. The $Q_0$ values are $1.67 \times 10^4$ at low field and $0.94 \times 10^9$ at high field and, what is most important, it has been possible to push the accelerating field to the high value of 4.85 MV/m, altogether a very encouraging achievement for the future development of high-energy physics with electron-positron machines.