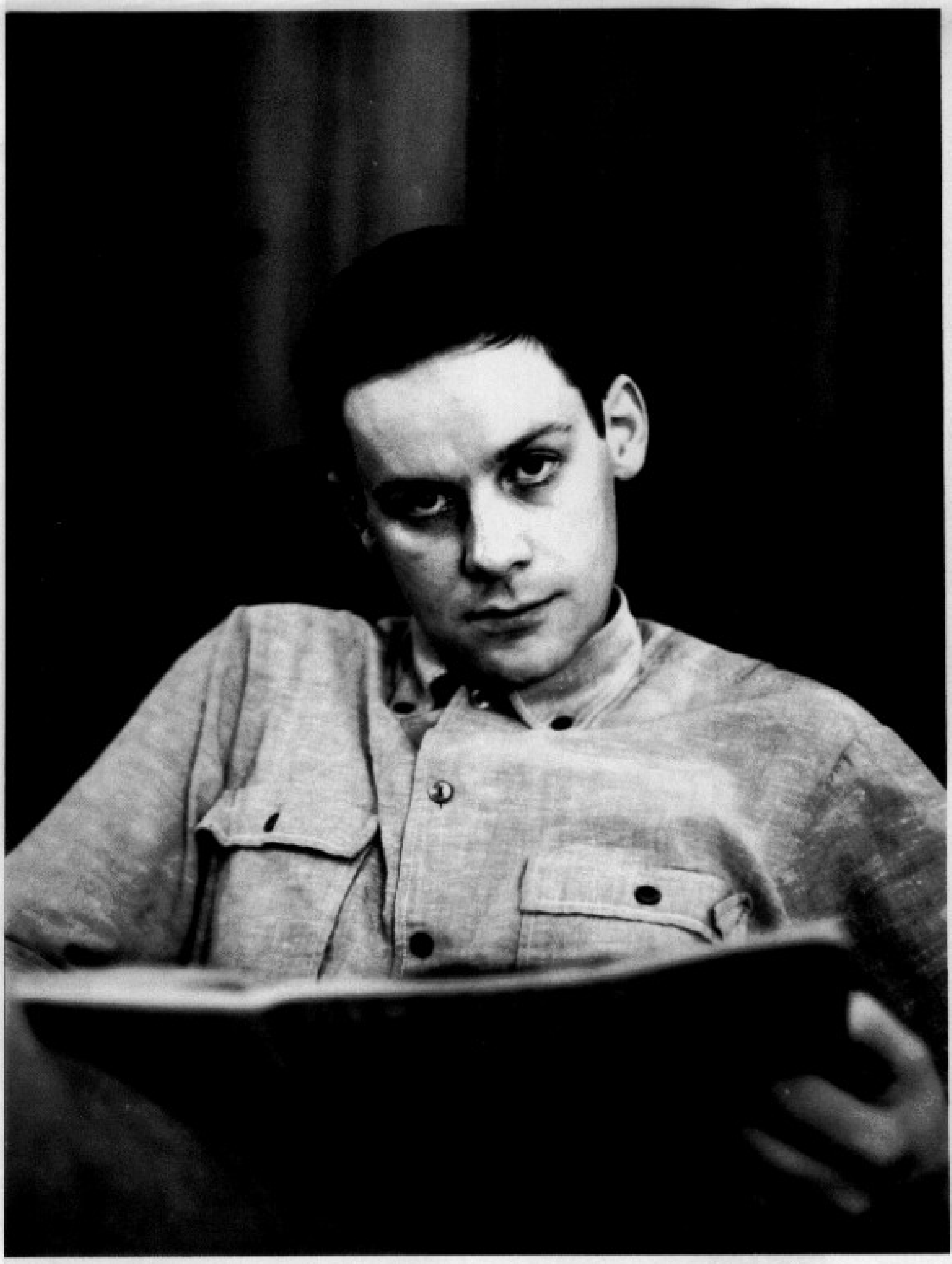
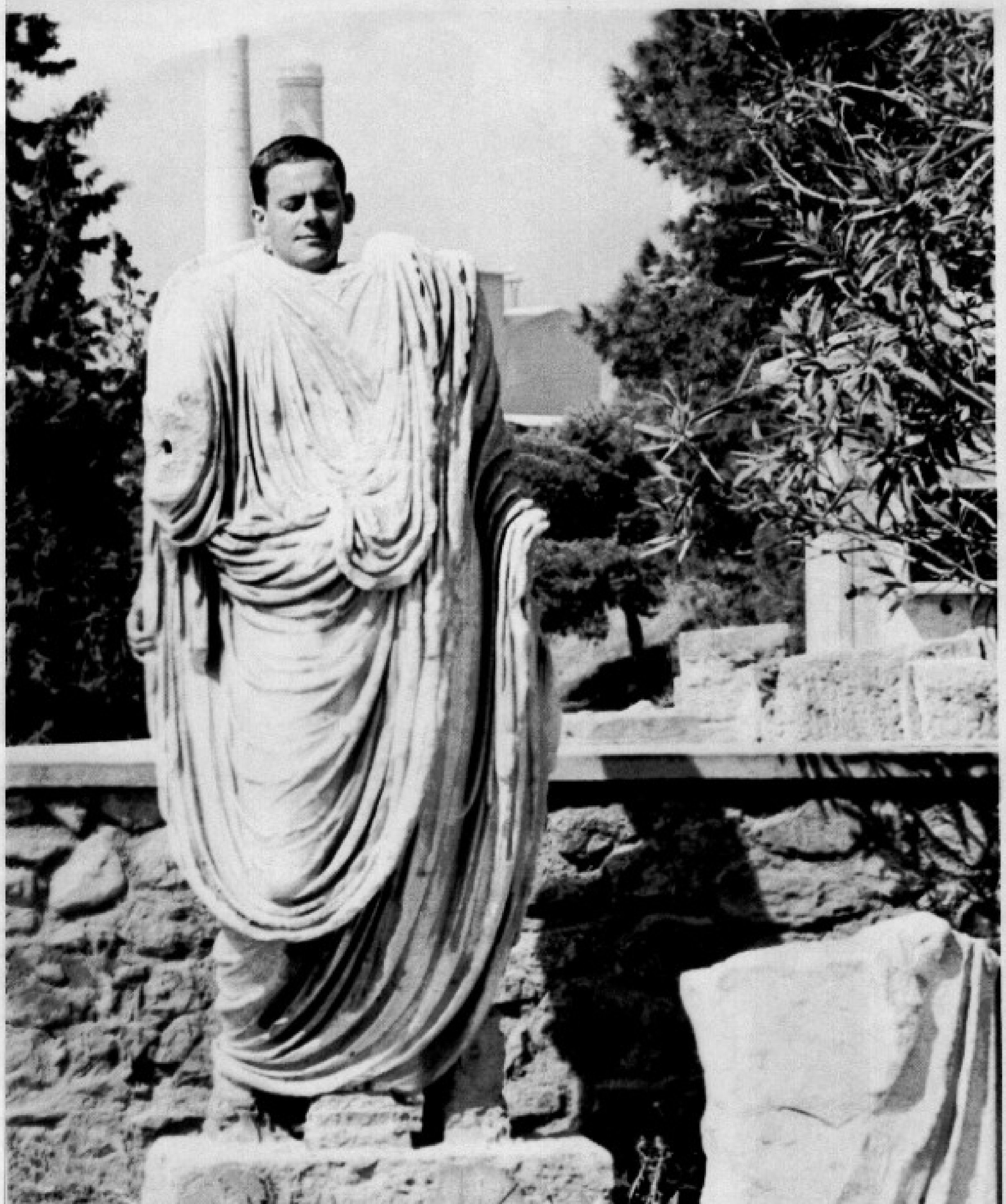
Heinrichs – Symphonie

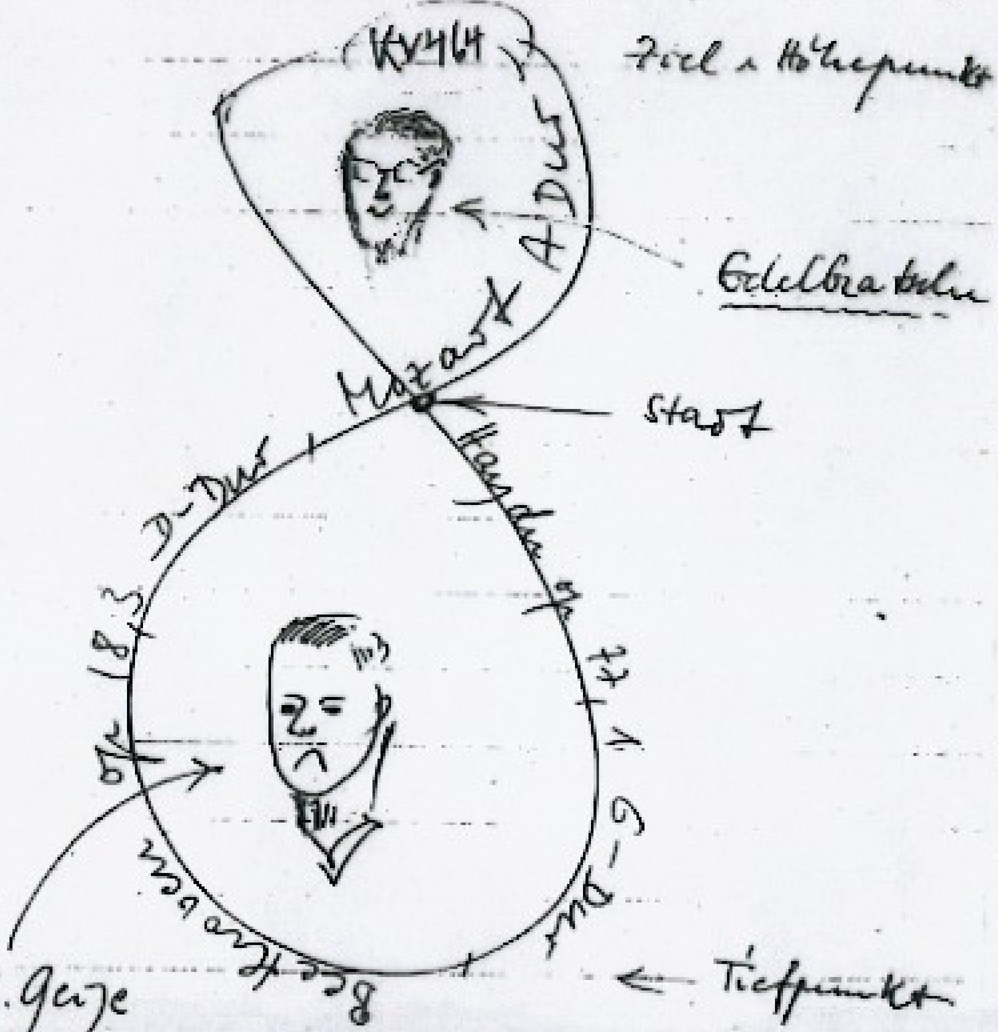
Ouverture 1959 – 1968

A bright student of physics and music



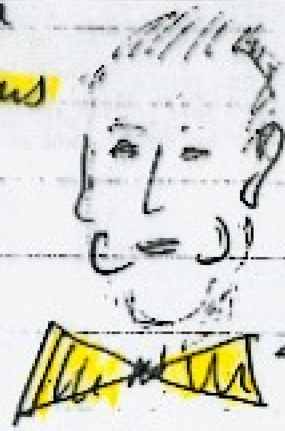


Samstag, 9. Mai 59.



1. Geige
Konrad Kleinknecht

Der Kritikus



Schwester
Geige:
Heinrich-Walter

selbstgebunden!

Das Heideggersche
„Ereignis"
Pampelmuse
„Haare" aus Sellerie

Der Optimist
durch den Noten-
schutz?

Cello
Willi

1967 Doctoral Thesis

"Measurement of the Electromagnetic Transition Probabilities of the first two Excited States of Lithium-6 Nuclei"

Advisor : Willibald Jentschke
Univ. Hamburg

1970 Physikpreis der Deutschen Physikalischen Gesellschaft in appreciation of "the experimental investigations on the production of charged π-mesons by high-energy γ rays": Group F35 at DESY

Allegro for a multiwire harp

Fellow at CERN 1969 – 71

Construction of CERN-Heidelberg expt.

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PH I/COM-69/1
14 January 1969

PHISICS I

ELECTRONICS EXPERIMENTS COMMITTEE

Proposal

For a measurement of $\phi_{\eta_{+-}}$

by

K. Kleinknecht, P. Steffen and J. Steinberger,
CERN,
and
E. Filthuth, V. Lüth, P. Mockry and G. Zech,
Heidelberg

/

Meeting on June 5, 1970:

Regarding the items and time schedule of Nov 17, 1969 there were quite a number of things finished, see list, others delayed considerably. Therefore a new list of jobs and time schedule is needed.

	Persons respons.	1970: 1.7 · 1.9 · 1.11 · 1.12 — 1971: 1.1 · 1.3 · 1.5
Beam 6-19	Falmer, Laffer, KK	Install (1.11–1.12); Run (from 1971)
619 test runs	all	
Target mounting	DZ	
U collimator	DZ	
Collimator magnet	Morpurgo	
Sw. Magnet	DZ	Meas field
Σ box assembly	DZ (HW, KK)	
x CH layer #2	FV (KK)	
Trigger CH	FV (KK)	
Chamber II+III	PS	Muratori's commitment
Gas system	JS	
Tons(?) ab-deck + foreward system	DZ, JO	
Chamber elect	JD	
Interface	PM	
Readout	Hyams, DE, JD	
Testsystem f. counter chamb	JO, KK	
Multiplexer for H.V. reading	JO, KK	
Amplifier box around chamber	P Sch.	
Cable layout for chambers	HW, Bch	
Supports for boxes	HW	
Non standard NIM electronics	HW	

Time schedule

Status of June 6

1970: 1.12 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 1.11 | 1971: 1.1

Item	Responsible	Schedule notes	Status of June 6
Beam b14 (neutral)	Gelin KK	1.2 – 1.9; test of complete system; change over; shutd.	
Beam b15 (protons)	Peterson Wegm. KK		
Mechanics:			
Target + holder	JS		
U collimator	TT	1.12 – 1.4	
Collimator magnet		1.5 – 1.6	
Big boxes including 2.4 m shield, C mirrors	JS	1.12 – 1.3	✓
Č horns + tube mounting	HW		
μ Ctr. support	KK	Draw; 1.12 – 1.4	✓
Trigger Ctr support	KK	1.12 – 1.4	✓
Prototype chamber	PS, PSch	Test	
Actual chambers	PS, PSch	des. production	
Gas system chambers	PS		
Pressure stabilization Exhaust	JS		
Analyzing magnet	JS, Morpurgo	Meas. Install	
Ion chamb. + electronics	TT, JO		
Light pulse + term. monit.	HW		✓
Scintillators	KK	1.12 – 1.2	✓
Light guides	KK	1.2 – 1.3	✓
Tubes	KK	1.1 – 1.2	✓
Cables	JO		
Tube bases	KK		✓
H.V. units counters	KK	1.1 – 1.2	✓
Electronics (shapers coinc., OR order July 69)	KK	1.1 – 1.2	✓
Electronics (special units (NIM), Registers,)			
Scalers			
Chamber electronics			
Components	JD, TT	order; Test	✓
Cards	JD TT	del.; Prod.; Test	
Wiring of cards	JD, TT		
Cables + connectors	JD		
H.V. units chambers	PS		✓
Interface	PM	1.1 – 1.2	
Readout	PM, GZ	1.1 – 1.4	
Logic	PM, GZ	1.3 – 1.5	
Tapes	HW		✓
Computer PDP15	HS	Test	✓
Tape units, Disc, Display	HS		✓
Hut 1 (Electr.)	KK	deliv. Install	✓
Hut 2 (Computer)	KK		✓

PHÄNOMENOLOGISCHES DREIECK

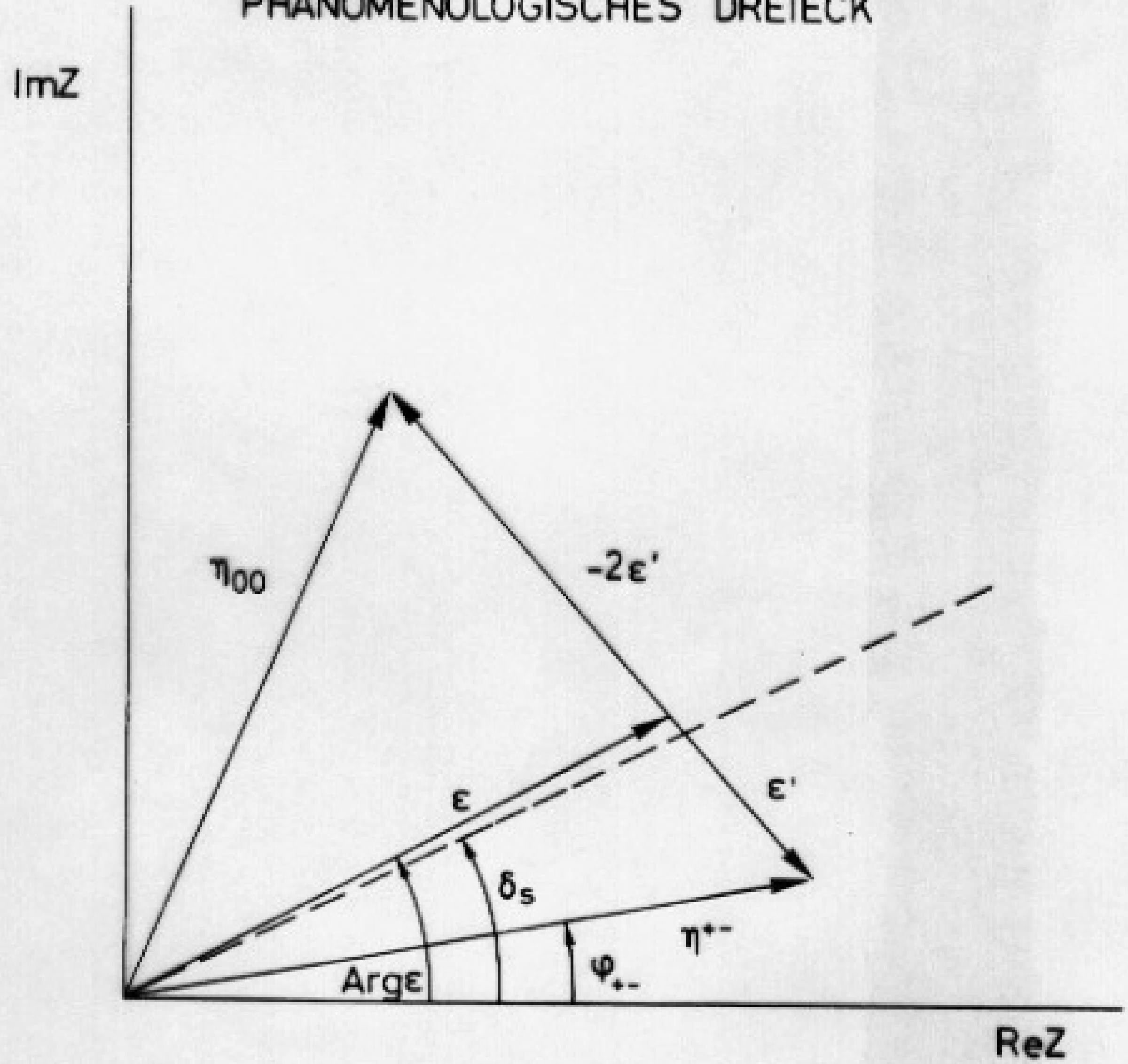
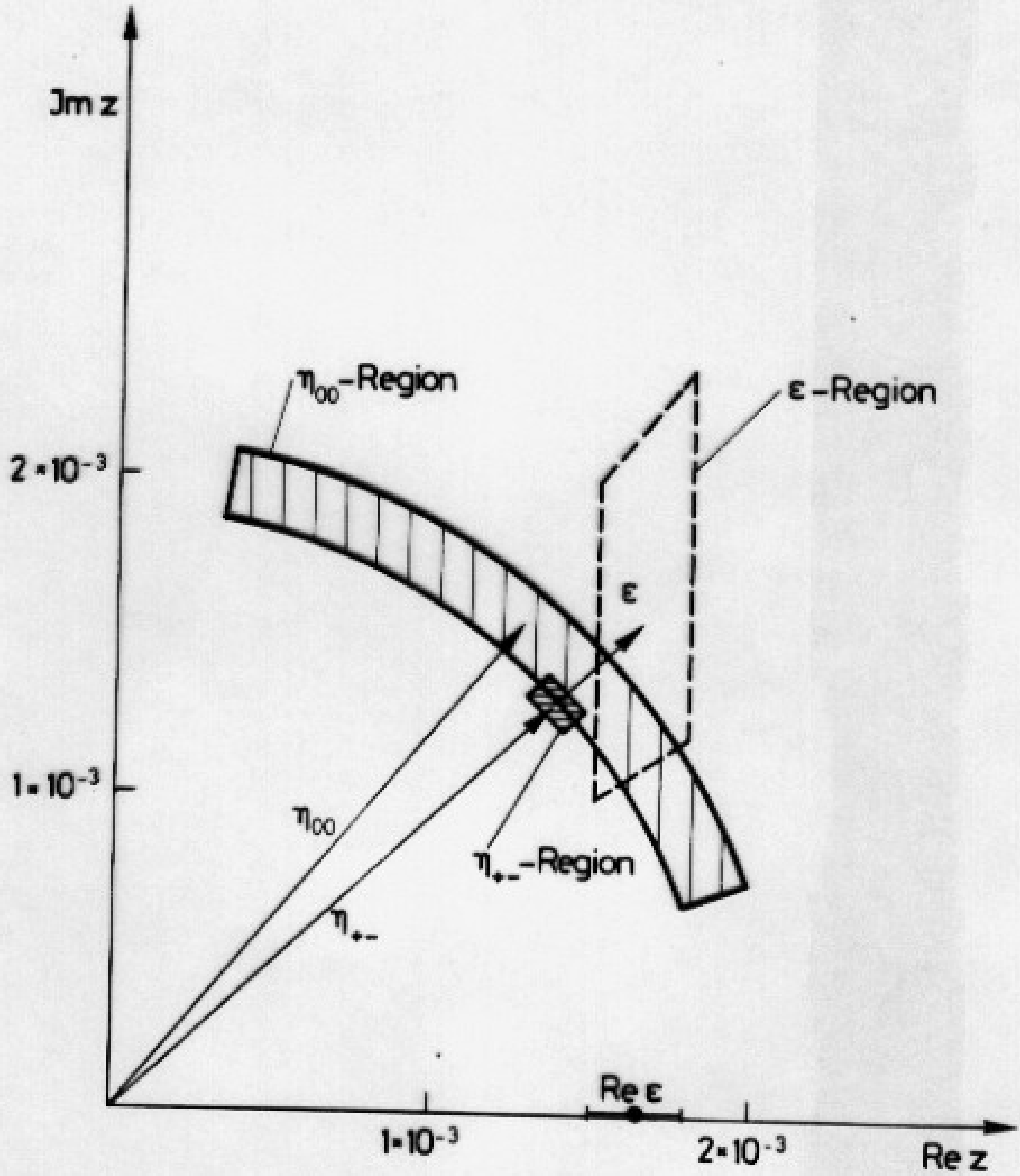


Fig. 1



Jm z
η_{00}-Region
ε-Region
$2 \cdot 10^{-3}$
ε
$1 \cdot 10^{-3}$
η_{00}
η_{+-}-Region
η_{+-}
Re ε
$1 \cdot 10^{-3}$
$2 \cdot 10^{-3}$
Re z

Fig. 38

NUCLEAR INSTRUMENTS AND METHODS 91 (1971) 221–230; © NORTH-HOLLAND PUBLISHING CO.

CONSTRUCTION AND PERFORMANCE OF LARGE MULTIWIRE PROPORTIONAL CHAMBERS

P. SCHILLY, P. STEFFEN, J. STEINBERGER, T. TRIPPE, F. VANNUCCI and H. WAHL

CERN, Geneva, Switzerland

K. KLEINKNECHT and V. LÜTH

Institut für Hochenergiephysik der Universität Heidelberg, Heidelberg, Germany

Received 21 September 1970

Large-area multiwire proportional chambers have been developed. In particular, a chamber 2 m × 0.5 m, using both horizontal and vertical wires (≈1500 wires in all), has been constructed. The chamber performance is very nearly the same as that of smaller chambers. Detailed design and performance data are presented.

1. Introduction

Charpak et al. have shown that wire chambers can be constructed which operate in the proportional mode[1]). Such multiwire proportional chambers have some outstanding characteristics for application in high-energy physics. The most interesting of these, for the bulk of the experiments, are the following:

1. The chambers are operated in a dc mode and therefore can act both as *counters* and *position* measurement devices.
2. The resolving time of the chambers depends on the particular gas, but it can be as short as ≈ 25 nsec. This may be compared with the memory time of ≈ 1 μsec of wire spark chambers. It is therefore possible to employ the proportional chambers under correspondingly higher background conditions. In many experiments this is immediately translatable into a correspondingly higher rate.
3. An efficiency of more than 99% can be reached.

At the time this work was started, small multiwire proportional chambers had already been used successfully, but chambers of sufficient size for most particle physics applications had not been attempted. We show here that it is possible to construct such detectors, and give some design details and performance characteristics*. A description of an important contribution to this work, i.e. the design of electronic circuits capable of maintaining the intrinsic time resolution of the multiwire proportional chambers, and with fast (200 nsec) readout, will be published elsewhere[4]).

The elementary design parameters, such as wire spacing and diameter, gas filling, and the basic symmetrical geometry of two high-voltage planes, are based on the previous work of Charpak et al.[1]). Unless otherwise stated, the chambers have the following features:

1. The signal wires have a diameter of 0.02 mm, and are stretched with a tension of ≈ 50 g; there is a 2 mm spacing between each wire.
2. There are two high-voltage planes for each signal wire plane, placed symmetrically one on each side with 6 mm spacing between the high-voltage and the signal planes.
3. The high-voltage planes are constructed of parallel wires, 0.05 mm in diameter, spaced 1 mm apart, and having tension of ≈ 110 g.
4. The gas filling is 65% argon and 35% isobutane.
5. The electronic circuits are those designed by Sippach et al.[4]). The discriminator threshold is 200 μV.

2. Problems of electrostatic stability

2.1. Stability of signal wires

Our first attempt at a larger chamber was a rather spectacular failure and it was soon obvious why.

A cross section of a portion of the chamber is shown in fig. 1a. Consider the displacement of a signal wire from its equilibrium position towards one or the other high-voltage plane (we treat the signal wire stability only, since the high-voltage wires are heavier, therefore under greater tension and more stable). This results in an electrostatic force, linear in the displacement, and tending to increase this displacement. It is not difficult to show that for the regime of the actual chambers, with wire spacing much smaller than the distance between the wire planes, the mutual repulsion of the (charges on the) signal wires is more important

* Some of the results have already been reported in the form of CERN internal reports[2]).

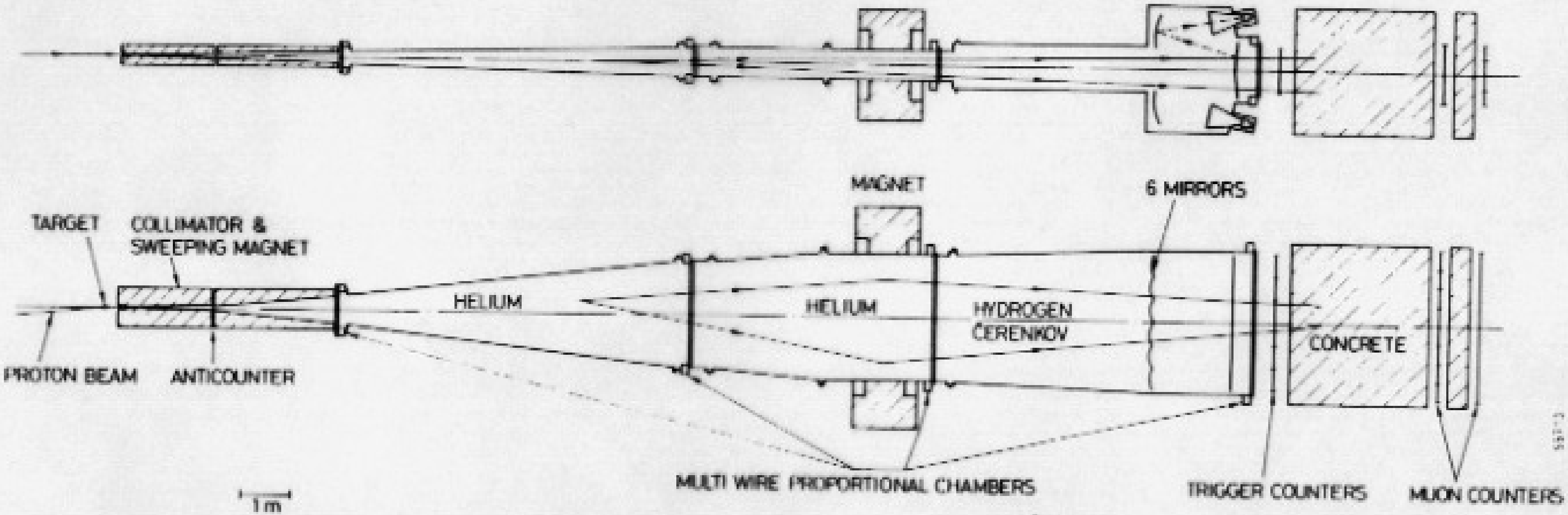
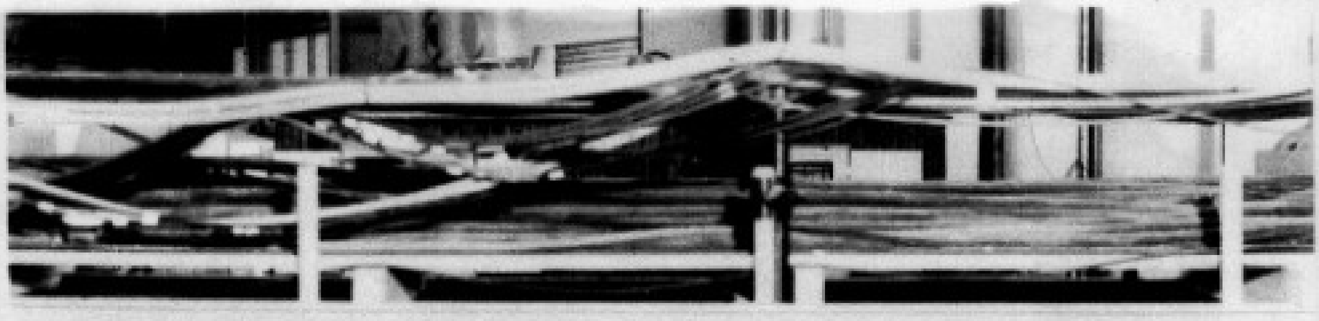
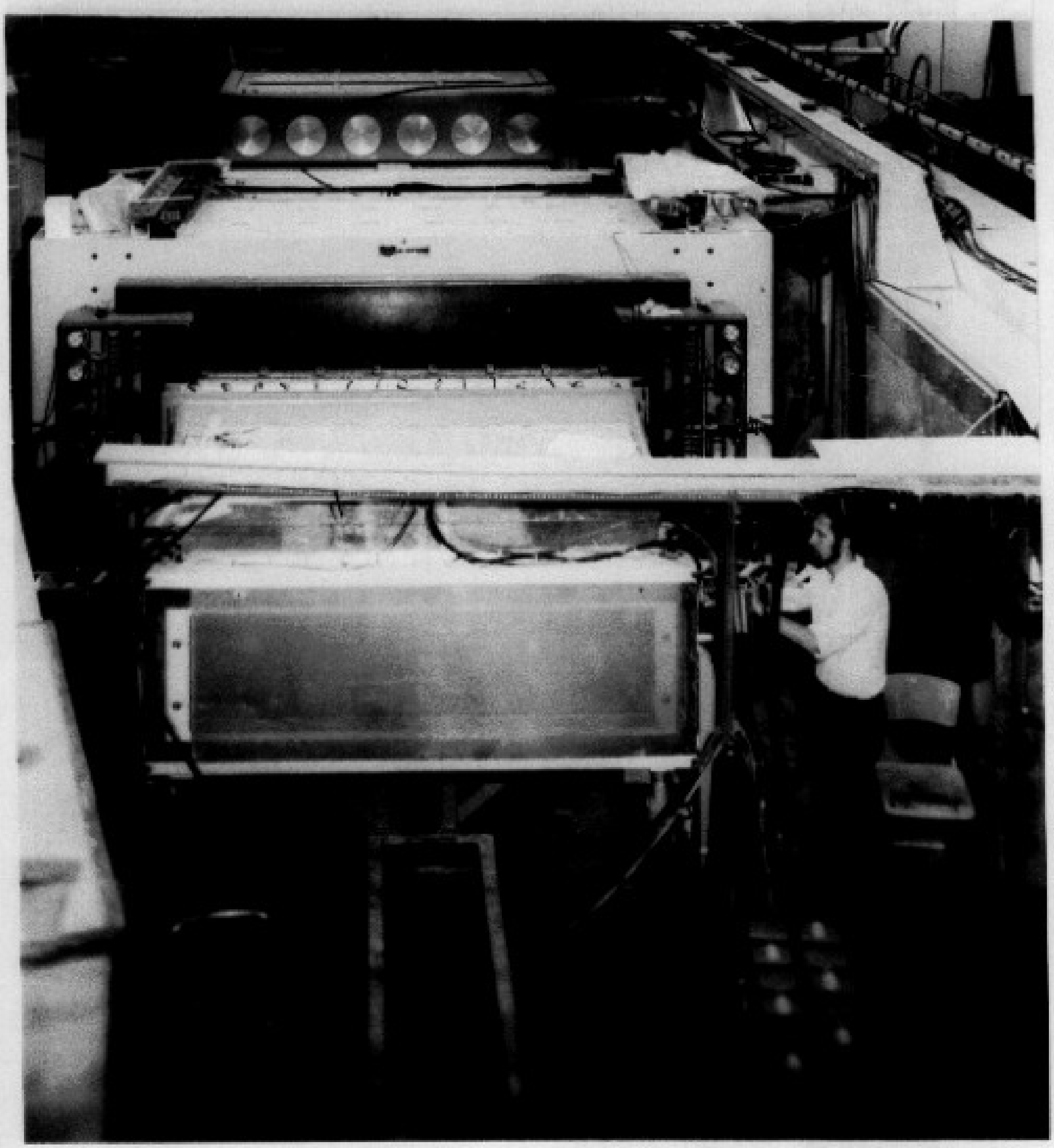

MAGNET
6 MIRRORS
TARGET
COLLIMATOR &
SWEEPING MAGNET
HELIUM
HELIUM
HYDROGEN
ČERENKOV
CONCRETE
PROTON BEAM
ANTICOUNTER
MULTI WIRE PROPORTIONAL CHAMBERS
TRIGGER COUNTERS
MUON COUNTERS
1 m

Fig. 1






Lissabon

Intermezzo with short lifetime 1972

Experiments with short neutral beam

$\sigma_{tot}(\Lambda p)$, $\Gamma(K_S \to \mu\mu)$

CERN/ECFA/72/4 Vol.I p.276

A SHORTLIVED NEUTRAL BEAM

K. Kleinknecht and H. Wahl (1971)

Institut für Hochenergiephysik, Universität Heidelberg, and CERN, Geneva

A neutral hyperon beam at high energy is fairly simple and inexpensive to construct, requiring essentially a straight magnet in which a collimator can be placed, and 10^9-10^{10} protons/burst in order to get a decent hyperon flux. Another advantage of a shortlived neutral beam comes from the fact that several neutral particles can be ~~easily~~ identified in a magnetic spectrometer by the observation of their two body decays and the reconstruction of the invariant mass. The difficult experimental problem of charged particle identification at high energy is therefore avoided.

In addition, for several experiments the absence of Coulomb scattering is a considerable advantage, when compared to the corresponding experiments using charged hyperon beams.

The easiest experiments are those where two body decays are recorded and the momentum of the hyperon can be calculated for each event. Experiments which we have in mind for the beam considered include the following :

- ΛN, $\bar{\Lambda} N$, $\Xi^0 N$ total cross sections
- ΛN, $\bar{\Lambda} N$ elastic scattering
- $\Lambda\gamma - \Sigma^0$ Primakoff effect (Σ^0 lifetime)
- search for $\Xi^0 \to p\pi^-$ decay ($\Delta S = 2$)
- search for $K_S \to \mu^+\mu^-$, e^+e^- decays
- study of $K_S \to \pi^+\pi^-\pi^0$ decay
- high precision study of the ΔS-ΔQ rule for K_{e3} and $K_{\mu 3}$ decays

The common feature of these experiments is that only a conventional two particle magnetic spectrometer is required and for some of them a recoil arm or a shower counter for the detection of electrons and photons.

1. THE COLLIMATOR

Calculations [1] and extrapolating experience at 24 GeV/c proton momentum indicate that a collimator length of 400 cm iron would sufficiently attenuate the hadronic cascade in the collimator walls. We conclude that an

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PL 40 B, 152 (1972)

A MEASUREMENT OF THE TOTAL CROSS-SECTIONS FOR Λ HYPERON INTERACTIONS ON PROTONS AND NEUTRONS IN THE MOMENTUM RANGE FROM 6 GeV/c TO 21 GeV/c

S. Gjesdal, G. Presser, P. Steffen, J. Steinberger, F. Vannucci*) and H. Wahl

CERN, Geneva, Switzerland

K. Kleinknecht, V. Lüth and G. Zech

Institut für Hochenergiephysik der Universität Heidelberg, Heidelberg, Germany

ABSTRACT

The Λp, Λn, $\bar{\Lambda}$p, and $\bar{\Lambda}$n total cross-sections were measured in the Λ momentum interval 6-21 GeV/c. Within the experimental uncertainties the cross-sections are momentum-independent in this interval and the momentum-averaged cross-sections are found to be:

$$\sigma(\Lambda p) = 34.6 \pm 0.4 \text{ mb}$$
$$\sigma(\Lambda n) = 34.0 \pm 0.8 \text{ mb}$$
$$\sigma(\bar{\Lambda} p) = 56 \pm 11 \text{ mb}$$
$$\sigma(\bar{\Lambda} n) = 46 \pm 20 \text{ mb} .$$

The first two results are in agreement with charge symmetry, and with simple quark model sum rules applied to previous results on pp, K^-n, and π^+p total cross-sections.

Geneva, 1 May 1972
(Submitted to Physics Letters)

*) On leave from Institut de Physique Nucléaire, Orsay, France.

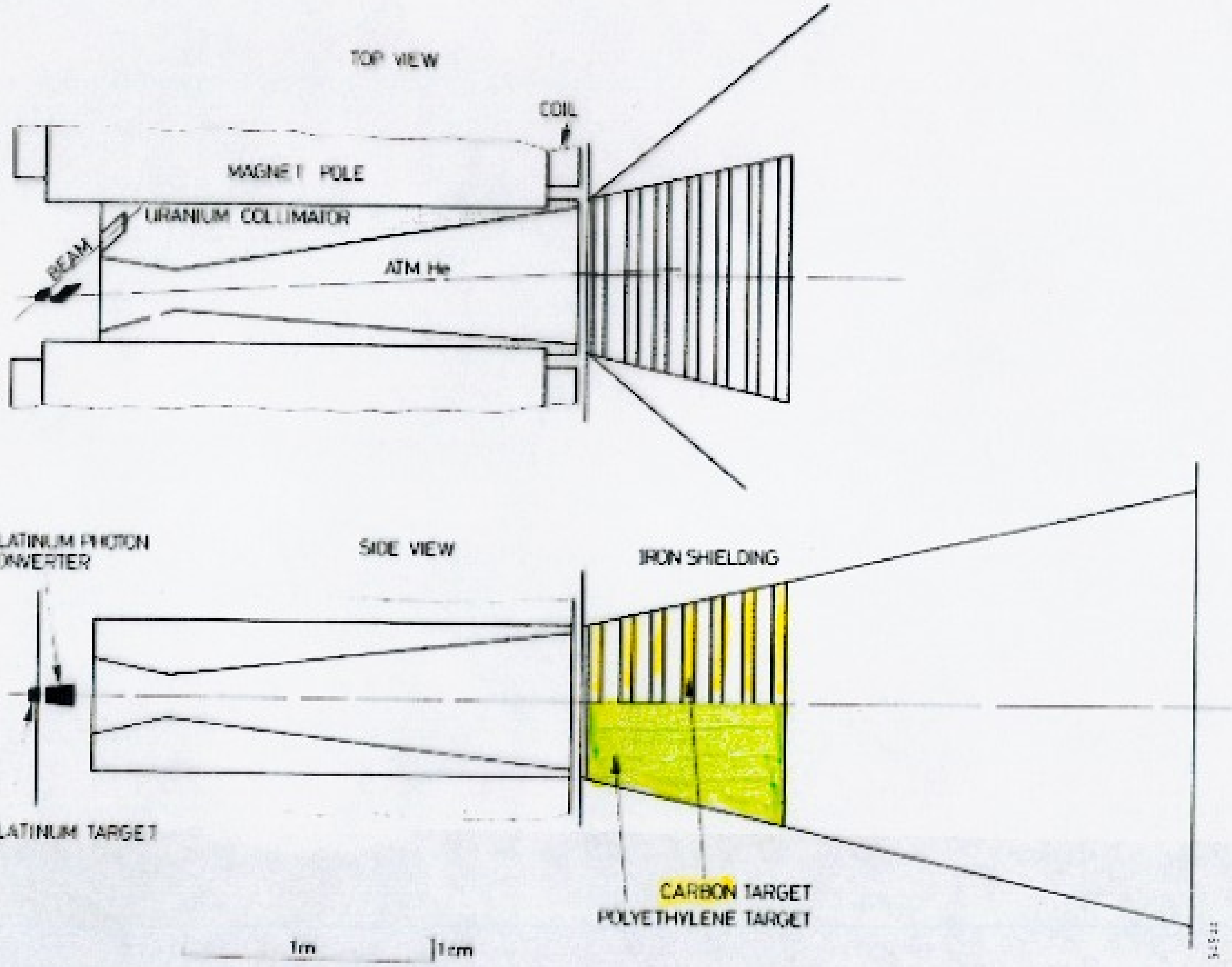
TOP VIEW
COIL
MAGNET POLE
URANIUM COLLIMATOR
BEAM
ATM He
PLATINUM PHOTON CONVERTER
SIDE VIEW
IRON SHIELDING
PLATINUM TARGET
CARBON TARGET
POLYETHYLENE TARGET
1m
1cm

Fig. 1

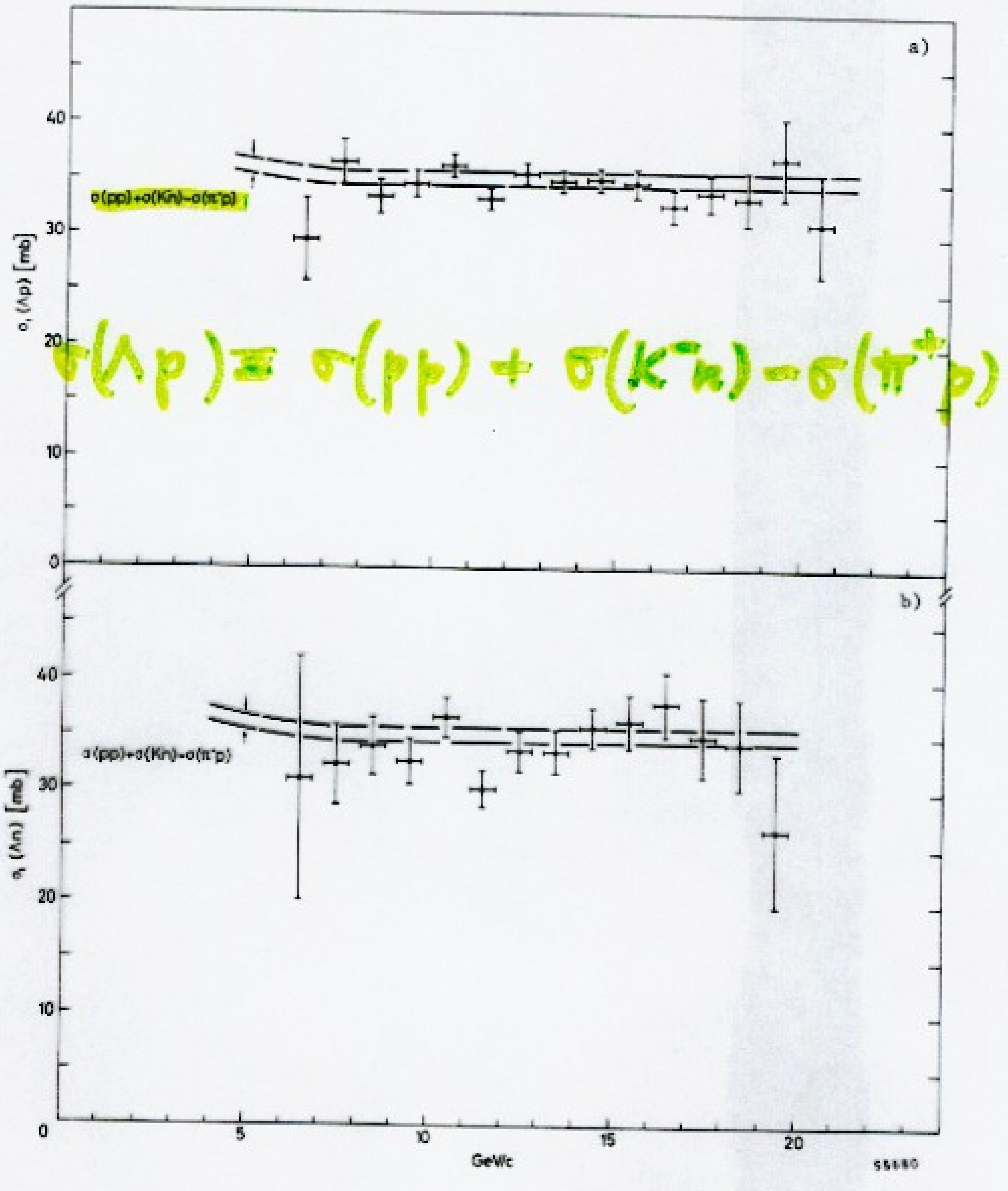
a)
b)
σ(pp)+σ(Kn)−σ(π⁺p)
σ(pp)+σ(Kn)−σ(π⁺p)
σ(Λp) ≡ σ(pp) + σ(K⁻n) − σ(π⁺p)
σₜ (Λp) [mb]
σₜ (Λn) [mb]
GeV/c
0
5
10
15
20
10
20
30
40
55680

Fig. 3

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Kk

SEARCH FOR THE DECAY $K_S \to 2\mu$

S. Gjesdal, G. Presser, P. Steffen, J. Steinberger, F. Vannucci*) and H. Wahl,

CERN, Geneva, Switzerland

H. Filthuth, K. Kleinknecht, V. Lüth and G. Zech,

Institut für Hochenergiephysik, Heidelberg, Germany

ABSTRACT

A search for the decay $K_S \to 2\mu$ has given negative results. Based on the analysis of 75% of the data, the preliminary 90% confidence upper limit for the branching ratio of 4×10^{-7} excludes the model of Dass and Wolfenstein designed to explain the $K_L \to 2\mu$ problem.

Submitted to the
16th International Conference on High-Energy Physics,
Batavia, 6-13 September 1972

Geneva - 1 August 1972

*) On leave from IPN, Orsay, France.

pure sample of $K \to \pi\mu\nu$ events. For this sample, in (75 ± 3)% of the cases the muon is detected in both counter planes in the fiducial area around the projected track direction. A Monte Carlo calculation simulating the same class of events gave an efficiency $\epsilon_{\mu}(K_{\mu 3}) = (79 \pm 3)\%$. The agreement of the calculation with the observation makes it possible to use the same calculation with confidence in the 2μ case.

The result, averaged over the experimental K momentum spectrum, is $\epsilon_{\mu\mu}^{CTR} = 0.84 \pm 0.03$ for detecting both muons for $K_S \to \mu^+\mu^-$ events accepted by the spectrometer. The efficiency is higher in the 2μ decay because of the higher momentum of the muons. Another factor evaluated using the Monte Carlo calculation is the ratio of detection efficiency in the spectrometer for $K_S \to \pi^+\pi^-$ and $K_S \to \mu^+\mu^-$ decays. The result, again averaged over the K-momentum spectrum, is

$$\frac{\epsilon_{\mu\mu}^{SP}}{\epsilon_{\pi\pi}^{SP}} = 0.73 \pm 0.04 \ .$$

The number N_{eff} of K_S decays relevant to the detection of the decay $K_L \to 2\mu$ is then

$$N_{eff} = \frac{\epsilon_{\mu\mu}^{SP}}{\epsilon_{\pi\pi}^{SP}} \times \epsilon_{\mu\mu}^{CTR} \times N_S = 5.2 \times 10^6 \ .$$

The 90% confidence upper limit on the branching ratio $B' = \Gamma(K_S \to 2\mu)/\Gamma_S$ is therefore

$$B' < 2.3 \ / \ N_{eff} = 4.4 \times 10^{-7} \ .$$

The model of Dass and Wolfenstein[5], referred to in the Introduction, predicts a branching ratio between 12.5×10^{-6} and 1.1×10^{-6}. Our upper limit is well below the lower limit of this prediction. Also the lower limit of Christ and Lee[1] of 5×10^{-7} is not in agreement with this experimental number. Our result is still compatible, although just barely, with the lower limit of 2.8×10^{-7} of M.K. Gaillard[4]. Realization of these lower limits requires, however, even more exotic models with at least two new amplitudes to cancel the "unitarity" $K_L \to 2\mu$ amplitude.

CHARM HYPOTHESIS

Quattro pezzi sacri gloriosi [1974]

Charge asymmetry in K_L e3 μ3 : Re ε

Phase ϕ_{+-}

$K_L - K_S$ mass difference : 2 regenerator method

$K_L - K_S$ mass difference : charge asym. K_S/K_L e3

MEASUREMENT OF THE CHARGE ASYMMETRY IN THE DECAYS $K^0_L \to \pi^\pm e^\mp \nu$ AND $K^0_L \to \pi^\pm \mu^\mp \nu$

C. GEWENIGER*[1], S. GJESDAL*[2], T. KAMAE*[3], G. PRESSER*[1],
P. STEFFEN, J. STEINBERGER, F. VANNUCCI*[4] and H. WAHL
CERN, Geneva, Switzerland

F. EISELE*[1], H. FILTHUTH, K. KLEINKNECHT*[1], V. LÜTH and G. ZECH*[5]
Institut für Hochenergiephysik, Universität Heidelberg, Germany

The charge asymmetry in semi-leptonic K^0_L decays has been measured in a high statistics experiment using multiwire proportional chambers. The asymmetry $\delta = (N^+ - N^-)/(N^+ + N^-)$, where N^+ and N^- are the partial decay rates for $K^0_L \to \pi^- \ell^+ \nu$ and $K^0_L \to \pi^+ \ell^- \bar{\nu}$, respectively, is found to be $\delta^e_L = (3.41 \pm 0.18) \times 10^{-3}$ for the K_{e3} mode, and $\delta^\mu_L = (3.13 \pm 0.29) \times 10^{-3}$ for the $K_{\mu 3}$ mode. Assuming *CPT* invariance and the absence of $\Delta S = -\Delta Q$ transitions, these results lead to a value of the real part of the *CP*-violation parameter ϵ, $\mathrm{Re}\,\epsilon = (1.67 \pm 0.08) \times 10^{-3}$.

The charge asymmetry in the semi-leptonic decay modes of the long-lived neutral kaon is, apart from the two-pion decay of the long-lived kaon, the only manifestation of *CP* non-invariance observed up to now. A measurement of this effect is important to the understanding of the phenomenon of *CP* violation, as it can be related to ϵ, the *CP* mixing amplitude in the neutral K-meson state

$$\delta_L = \frac{N^+ - N^-}{N^+ + N^-} = 2\,\mathrm{Re}\,\epsilon\,\frac{1 - |x|^2}{|1 - x|^2}\,.$$

Here *CPT* invariance has been assumed.

$N^\pm$ are the number of observed K_{l3} decays with positive and negative lepton, respectively. The parameter x is defined as the ratio of $\Delta S = -\Delta Q$ to $\Delta S = \Delta Q$ amplitudes and vanishes if the $\Delta S = \Delta Q$ selection rule is valid. The value of x could, in general, be different for K_{e3} and $K_{\mu 3}$ decays and may depend on the Dalitz plot variables. Recent measurements indicate, however, that x is small and not significantly different from zero [1].

The experiment was performed in a short neutral beam at the CERN Proton Synchrotron, providing neutral kaons over the momentum range 3–15 GeV/*c*. The main elements of the set-up [2] are shown in fig. 1. The neutral hadrons are produced by an external proton beam of 24 GeV/*c* hitting a 4.5 cm long platinum target, 4 × 4 mm^2 in cross-section. The secondaries are selected at an average angle of 75 mrad by a tapered uranium collimator, 2 m long, imbedded in a magnetic field of 20 kG. It is followed by a 9 m long decay volume filled with helium. The vector momenta of the charged decay products of the neutral kaons are measured in a spectrometer consisting of three multiwire proportional chambers and a bending magnet.* All chambers are divided into a left and a right half, each equipped with a horizontal and a vertical signal plane. The wire spacing is 2 mm. A 6 m long threshold Čerenkov counter filled with hydrogen gas at atmospheric pressure is used to label electrons. Muons are identified by a coincidence signal in two counter hodoscopes behind an absorber of 800 g/cm^2 of light concrete.

The use of large size multiwire proportional chambers introduces several advantageous features. Their good time resolution and zero dead-time combined with a fast selective read-out allow considerably higher

*[1] Now at Universität Dortmund, Abteilung Physik, Germany.
*[2] Now at Distriktshøgskolen Stavanger, Norway.
*[3] Now at Institute for Nuclear Study, Tokyo University, Japan.
*[4] On leave from Institut de Physique Nucléaire, Orsay, France.
*[5] Now at Gesamthochschule Siegen, Germany.

* A fourth chamber was introduced in a later stage of the experiment, but not used in the event reconstruction.

A NEW DETERMINATION OF THE $K^0 \to \pi^+\pi^-$ DECAY PARAMETERS

C. GEWENIGER*[1], S. GJESDAL*[2], G. PRESSER*[1], P. STEFFEN,
J. STEINBERGER, F. VANNUCCI*[3] and H. WAHL,
CERN, Geneva, Switzerland

F. EISELE*[1], H. FILTHUTH, K. KLEINKNECHT*[1], V. LÜTH and G. ZECH*[4]
Institut für Hochenergiephysik, Heidelberg, Germany

Received 4 February 1974

In a short neutral beam we have measured the proper time-dependence of the decay $K^0 \to \pi^+\pi^-$. This time structure exhibits the interference between the short- and long-lived states and is in agreement with the general expectations of the *CP* violation phenomenology.

This experiment gives new and more precise measurements of the following three parameters:
i) the decay width of the short-lived K_S component: $\Gamma_S = (1.119 \pm 0.006) \times 10^{10}\ \mathrm{sec}^{-1}$;
ii) the modulus of the *CP* violating parameter η_{+-}: $|\eta_{+-}| = (2.30 \pm 0.035) \times 10^{-3}$;
iii) the phase of η_{+-} as a function of the $K_S - K_L$ mass difference Δm: $\phi_{+-} = (49.4 \pm 1.0)° + [(\Delta m - 0.540)/0.540] \times 305°$.

The result of $|\eta_{+-}|$ may be compared with the result of the foregoing letter on Re ϵ in the frame of the superweak model. Good agreement is observed.

The experiment presented here studies the time dependence of the $\pi^+\pi^-$ decay mode of the K^0 meson in a short neutral beam. This time dependence has been previously studied [1, 2] and the main purpose of this experiment is to improve the precision, statistically as well as systematically, in order to provide a more accurate measure of the amplitude ratio

$$\eta_{+-} = \frac{\langle \pi^+\pi^- | T | K_L \rangle}{\langle \pi^+\pi^- | T | K_S \rangle} = |\eta_{+-}| \exp(i\phi_{+-}).$$

There is a substantial interest in experimental precision, because of the predictions of the superweak [3] and other models. If *CPT* is assumed to be conserved and if ϵ is the admixture of the *CP* odd (*CP* even) state in the dominantly *CP* even (*CP* odd) decay state, then the superweak model predicts

$$\eta_{+-} = \epsilon. \qquad (1)$$

Together with unitarity the model further specifies the phase of both parameters:

$$\phi = \tan^{-1} \frac{2\Delta m}{\Gamma_S - \Gamma_L}.$$

A whole class of other models is less specific in its predictions, but deviations from eq. (1) are expected to be of the order of the admixture of the $I = 2$ isospin state in the dominantly $I = 0$, $K_S \to \pi^+\pi^-$ decay. The smallness of this admixture (~ 4%) explains the interest in precision in the experimental verification of eq. (1).

This experiment presents a very substantial effort over a number of years, and all the relevant details of apparatus and analyses unfortunately cannot be included in this letter. The interested reader must be referred to a future, more detailed publication elsewhere.

The apparatus has been presented in the preceding letter [4]. Without going into details we point out its important properties.

The decay region which extends from 2.2 m to 11.6 m after the target permits detection in the proper time interval

$$3.5 \times 10^{-10}\ \mathrm{sec} < \tau < 30 \times 10^{-10}\ \mathrm{sec}.$$

The use of multiwire proportional chambers allows

*1 Now at Universität Dortmund, Abteilung Physik, Germany.
*2 Now at Distriktshøgskolen, Stavanger, Norway.
*3 Now at Institut de Physique Nucléaire, Orsay, France.
*4 Now at Gesamthochschule, Siegen, Germany.

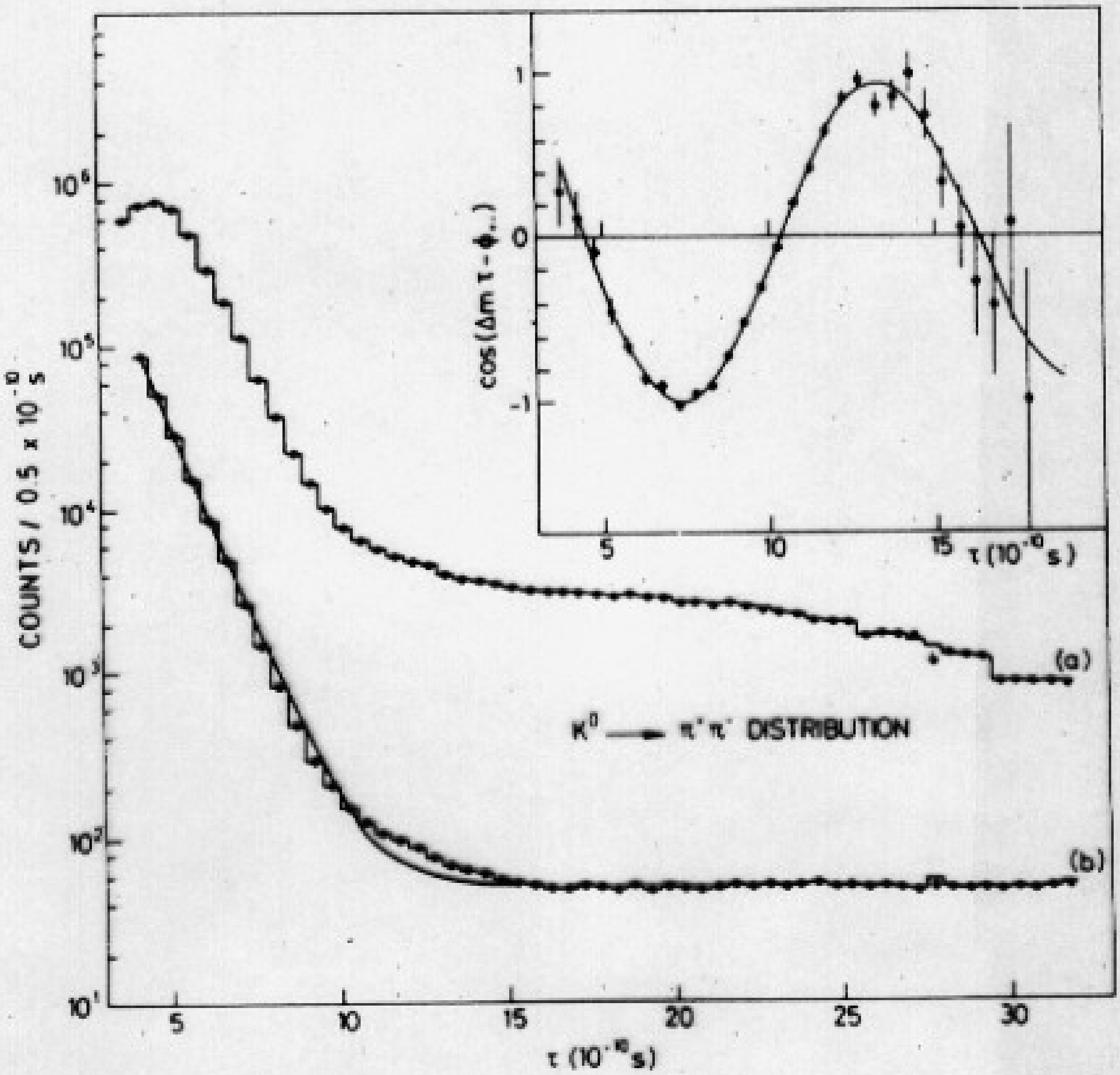

Fig. 4. Time distribution of $K \rightarrow \pi^+\pi^-$ events. a) Events (histogram) and fitted distribution (dots). b) Events corrected for detection efficiency (histogram), fitted distribution with interference term (dots) and fitted distribution without interference term (solid line). Insert: Interference term as extracted from data (dots) and fitted term (line).

MEASUREMENT OF THE KAON MASS DIFFERENCE $m_L - m_S$ BY THE TWO REGENERATOR METHOD

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The K^0 mass difference has been measured by the two regenerator method. The result is: $\Delta m = m_{K_L} - m_{K_S} = (0.534 \pm 0.003) \times 10^{10}\ \mathrm{sec}^{-1}$.

Introduction. In this letter we report briefly the result of a measurement of the mass difference $\Delta m = m_L - m_S$, where m_L and m_S are the masses of the long and short lived neutral kaons respectively. The experimental details will be presented more completely elsewhere.

The method consists of the comparison of the intensity of the K_S regenerated from a K_L beam in two slabs of matter separated at different distances [1].

The intensity of $\pi^+\pi^-$ decay observed after the second regenerator is given approximately[‡1] by relation (1):

$$I_{+-} \propto \Big| \exp(\mathrm{i} d_B \Delta M)[1-\exp(\mathrm{i} d_A \Delta M)] + [1-\exp(\mathrm{i} d_b \Delta M)] - \eta_{+-} / \left(\frac{\pi N \Delta f p}{\mathrm{i}\Delta M m}\right)\Big|^2 \qquad (1)$$

where $\Delta f = \mathrm{i}(f-\bar{f})/p$, f and $\bar{f}$ are the K and $\bar{K}$ forward scattering amplitudes respectively, p is the kaon momentum, N is the number of atoms per unit volume in the regenerators, d_A is the thickness of the upstream regenerator, d_B is the thickness of the downstream regenerator, d is the distance from the downstream edge of regenerator A to the downstream edge of regenerator B, d_A, d_B and d are measured in seconds in the kaon rest frame, $\Delta M = \Delta m + \mathrm{i}(\Gamma_S - \Gamma_L)/2$, where Γ_S and Γ_L are the widths of K_S and K_L, respectively, and $\eta_{+-} = (\pi^+\pi^-|L)/(\pi^+\pi^-|S)$.

The last term in relation (1) is a correction term of the order of 5%, contributed by the *CP* violating $K_L \to \pi^+\pi^-$ amplitude. The mass difference Δm can be obtained by comparing the intensities for different separations d, if all the other parameters are adequately known.

The monitoring is of the utmost importance in this comparison. It must be stable against changes in the sensitivity of the apparatus with respect to time and with respect to the regenerator position. In this experiment we use a variant of the monitoring method introduced by Cullen et al. [2]. In this method, a fraction of the incident beam is sacrificed to provide a monitor signal of $K^0 \to \pi^+\pi^-$ decays which is detected in the same apparatus. Only the ratios signal/monitor are significant. Since the monitor and signal events are of the same type and detected in the same apparatus, these ratios are not affected by beam intensity fluctuation affects such as pile up and deadtime, changes in backgrounds

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[‡1] This expression does not include the effects of regeneration in the air, the regeneration of K_L by K_S, nor the K_S amplitude surviving from the primary target. These effects are however included in the analysis of the data.

A MEASUREMENT OF THE K_L-K_S MASS DIFFERENCE FROM THE CHARGE ASYMMETRY IN SEMI-LEPTONIC KAON DECAYS

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The charge asymmetry in semi-leptonic kaon decays has been measured as a function of the kaon lifetime. High statistics data of K^0_{e3} and $K^0_{\mu 3}$ decay modes agree with each other and with the general expectation of the *CP* violation phenomenology together with the $\Delta S - \Delta Q$ rule. The K_L-K_S mass difference obtained is $\Delta m = (0.533 \pm 0.004) \times 10^{10}\ s^{-1}$.

Introduction. The experiment reported in this paper is part of an extensive study aiming principally at a more precise determination of ϕ_{+-}, the phase of η_{+-}, the parameter describing *CP*-violation in $K^0 \to \pi^+\pi^-$ decays. New values of $K^0 \to \pi^+\pi^-$ decay parameters have been reported previously [1]. The data on semi-leptonic kaon decays recorded simultaneously and in the same apparatus as the pionic decays, are presented here to the extent that they improve the accuracy of the phase ϕ_{+-}.

A measurement of the K_L-K_S mass difference from leptonic kaon decays is of interest for the following reason: the determination of ϕ_{+-} by an observation of the interference term $\sim |\eta_{+-}| \cos(\Delta m\tau - \phi_{+-})$ in the time distribution of $\pi^+\pi^-$ decays suffers from the strong correlation between the phase and the mass difference $\Delta m = m_L - m_S$. On the other hand, the charge asymmetry of semi-leptonic decays exhibits an interference term $\sim \cos(\Delta m\tau)$. In principle it is, therefore, the difference in phase in the interference terms of pionic and leptonic decays which gives a measure of ϕ_{+-} without explicit, accurate knowledge of the mass difference Δm. In other words, a determination of ϕ_{+-} using the mass difference obtained from leptonic decays has the advantage of reduced sensitivity to systematic errors in common to the two decay modes.

The charge asymmetry in semi-leptonic decay $K^0 \to \pi^{\mp} \ell^{\pm} \nu$ is defined as:

$$\delta = (N^+ - N^-)/(N^+ + N^-)\ , \tag{1}$$

where N^+ and N^- denote the number of decays observed with a positive and negative lepton ℓ (electron or muon) respectively. The transition amplitudes:

$$f = \langle \pi^- \ell^+ \nu | T | K^0 \rangle\ , \quad \Delta S = \Delta Q\ ; \qquad g = \langle \pi^- \ell^+ \nu | T | \bar{K}^0 \rangle\ , \quad \Delta S = -\Delta Q\ ,$$

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Their charge asymmetry is evaluated as a function of τ' and p' in bins of width $\Delta\tau' = 0.5 \times 10^{-10}$s and $p' =$ 2 GeV/c starting at $\tau'_{min} = 2.25 \times 10^{-10}$s and $p_{min} = 7$ GeV/c.

The mass difference Δm is determined by a comparison of the time dependence of the measured charge asymmetry with the theoretical expectation $\delta(\tau', \Delta m, y)$ for the set of parameters to be determined. The theoretical function δ and its derivatives are calculated by Monte Carlo techniques from eq. (2). This treatment accounts for the following:

– The K_{e3} matrix elements according to V–A theory with linear formfactors for the hadronic current [3] and radiative corrections [4].

– The observed beam profile, and the experimental resolution and acceptance.

– Transformation from the true kaon momentum p and lifetime τ to the measured quantities p' and τ'.

– The shape of the kaon momentum spectrum and the dilution factor $A(p)$ as obtained in the $K_{\pi 2}$ analysis [1].

The influence of the actual form of the matrix element on the charge asymmetry is weak. The shape of the momentum spectrum enters only indirectly in the transformation from τ to τ'. The K_S lifetime and the K_L charge asymmetries are taken from previous results of the same experiment [1, 2]. The results of the best fits to the measured charge asymmetries are shown in figs. 1 and 2. The $\Delta S - \Delta Q$ factor y is left free in the fits. The uncorrected values for the K_L-K_S mass difference are:

$$\Delta m(K_{e3}) = (0.5287 \pm 0.0040) \times 10^{10}\,s^{-1}, \quad \Delta m(K_{\mu 3}) = (0.526 \pm 0.0085) \times 10^{10}\,s^{-1}.$$

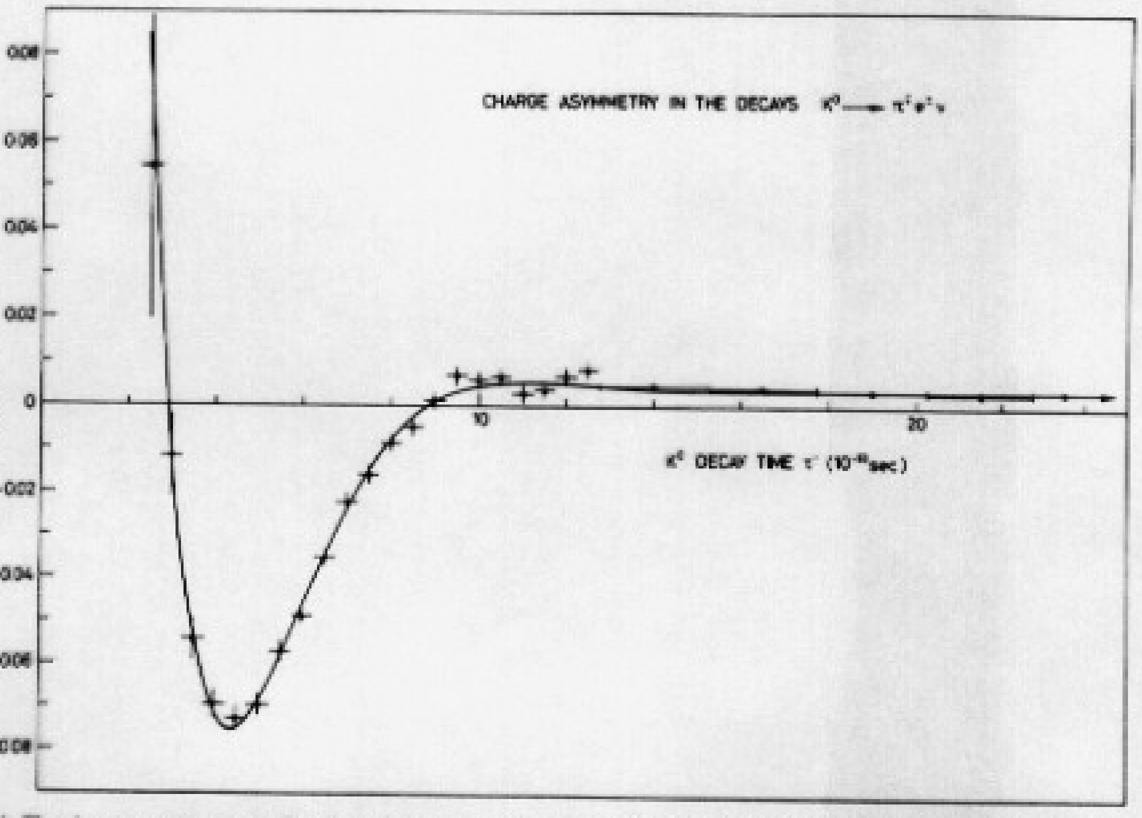

Fig. 1. The charge asymmetry as a function of the reconstructed decay time τ' for the K_{e3} decays. The experimental data are compared to the best fit as indicated by the solid line.

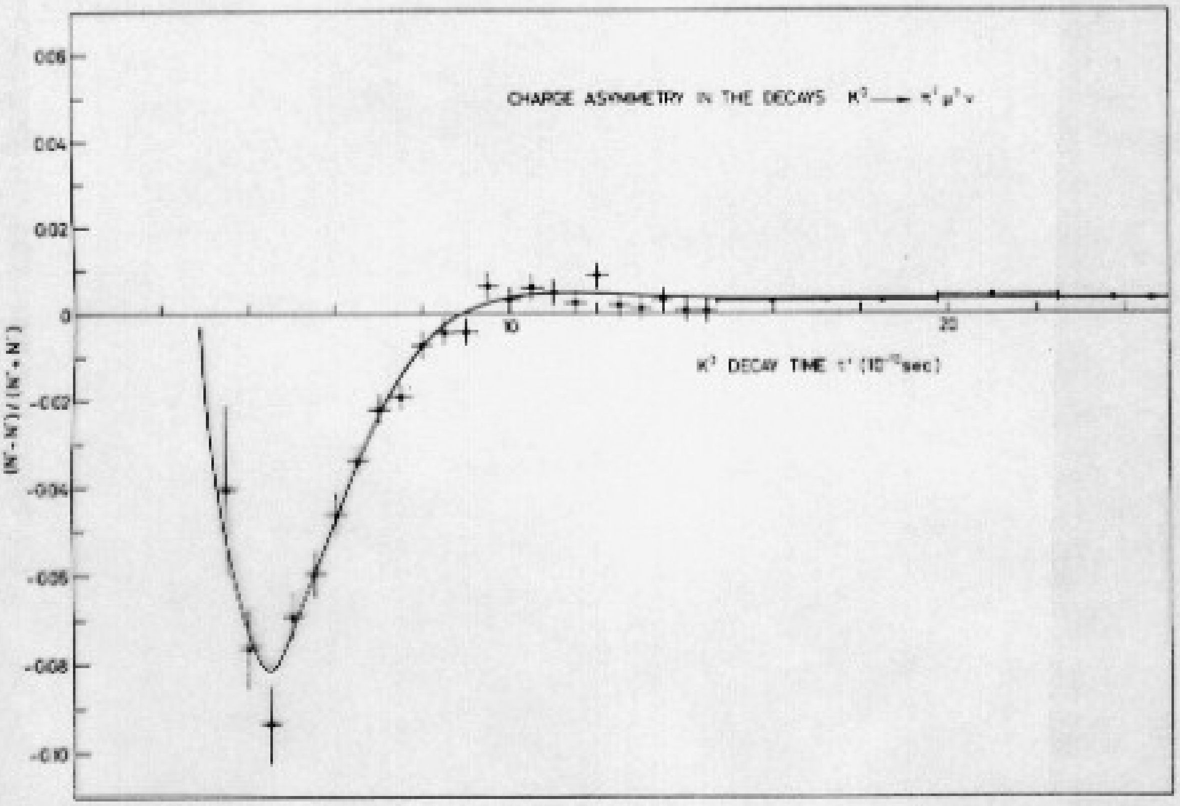

Fig. 2. The charge asymmetry as a function of the reconstructed decay time τ' for the $K_{\mu 3}$ decays. The experimental data are compared to the best fit as indicated by the solid line.

The quoted error includes the statistical error as well as the uncertainties in the dilution factor. χ^2 values per degree of freedom of 17/23 and 16/24 are obtained.

The above result is obtained assuming an incoherent mixture of K^0 and $\bar{K}^0$ produced at the centre of the primary target. The following corrections account for the accumulated effects due to secondary interactions of the kaons in the beam line. These effects can be described as a common initial phase change of $0.4° \pm 0.3°$ [1] and results in a correction of $(+0.0018 \pm 0.0013) \times 10^{10}\,s^{-1}$ in Δm. Kaons produced in the beam dump lead to an independent correction of $(+0.0012 \pm 0.005) \times 10^{10}\,s^{-1}$. Furthermore, K_{e3} radiative decays cause a $(-0.45 \pm 0.1)\%$ shift in the reconstructed kaon momentum implying a correction of $(+0.0024 \pm 0.0005) \times 10^{10}\,s^{-1}$. The final corrected values of Δm and the average from K_{e3} and $K_{\mu 3}$ decays are:

$$\Delta m(K_{e3}) = (0.5341 \pm 0.0043) \times 10^{10}\,s^{-1}\,, \quad \Delta m(K_{\mu 3}) = (0.529 \pm 0.010) \times 10^{10}\,s^{-1}\,,$$

$$\Delta m(\mathrm{av}) = (0.5334 \pm 0.0040) \times 10^{10}\,s^{-1}\,.$$

The quoted error includes the estimated uncertainties of the corrections including the uncertainty in the background subtraction of the $K_{\mu 3}$ data. In addition, a 0.3% systematic error has to be allotted to the uncertainty in the momentum calibration and the associated uncertainty in the K_S lifetime [1].

The results compare well with an independent determination of Δm by the two-regenerator method [5]

$|\eta_{00}/\eta_{+-}| = 1.00 \pm 0.06$ [7] ,

$|\eta_{00}/\eta_{+-}| = 1.03 \pm 0.07$ [8] .

Together, there are four measurements: $|\eta_{+-}|$, ϕ_{+-}, $|\eta_{00}/\eta_{+-}|$, and the leptonic charge asymmetry. On the basis of relations (1–4) and the experimental result [10] $\delta_2 - \delta_0 = (-55 \pm 5)^\circ$, they can be expressed in terms of $|\epsilon|$, ϕ_ϵ and $|\epsilon'|$, giving one constraint. The result is:

$$|\epsilon| = (2.32 \pm 0.05) \times 10^{-3} ,$$

$$|\epsilon'/\epsilon| = 0.007 \pm 0.015 ,$$

$$\phi_\epsilon - \phi_{SW} = (1.7 \pm 1.3)^\circ .$$

The last two results provide the comparison with the superweak model, which predicts zero in both cases. The agreement is good, with $\chi^2 = 1.75$ for two degrees of freedom. It may be pointed out that the more significant check is the one on the vanishing of $|\epsilon'|$, which in turn derives principally from the measured ratio $|\eta_{00}/\eta_{+-}|$.

Upper bound on $|\eta_{000}|$. It is possible, on the basis of the unitarity relation [3], using the new value $(\phi_\epsilon - \phi_{SW}) \equiv \Delta\phi = (1.7 \pm 1.3)^\circ$ to obtain a more meaningful upper bound for *CP* violation in other than the two pion channel. No such *CP* violation has been observed, other than the small leptonic charge asymmetry due to the mixing parameter ϵ.

The requirement of unitarity can be written for the present application:

$$\sum_F \eta_F \Gamma_F / \Gamma_S \approx \frac{|\epsilon| \Delta\phi}{\cos\phi_{SW}} \qquad (8)$$

Here F stands for the final state, other than two pion, Γ_F is the partial width for $K_L \to F$, and $\eta_F = \langle F|T|S\rangle / \langle F|T|L\rangle$.

In the sum one can neglect the contribution of the leptonic modes, since these are limited by the $\Delta S = -\Delta Q$ amplitudes which are known to be small. The present upper limit for η_{+-0} is also small enough so that this contribution is negligible for the present purpose. We therefore use (8) to find a new upper limit on $|\eta_{000}|$:

$$|\eta_{000}| \approx \frac{|\epsilon| \Delta\phi}{\cos\phi_{SW}} \Gamma_S / \Gamma_{000} ,$$

$$|\eta_{000}| \approx 0.26 \pm 0.20 , \quad |\eta_{000}|^2 \lesssim 0.21 .$$

For comparison, the previous upper limit, based on a direct search for K_S–K_L interference in $3\pi^0$ decay, due to Barmin et al. [9], is:

$$|\eta_{000}|^2 \lesssim 1.2$$

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THE PHASE ϕ_{+-} OF *CP* VIOLATION IN THE $K^0 \to \pi^+\pi^-$ DECAY

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The phase ϕ_{+-} is evaluated on the basis of measurements of the K_S–K_L interference in the $\pi^+\pi^-$ decay mode and the mass difference Δm, both reported previously by this group. The result is: $\phi_{+-} = 45.9° \pm 1.6°$. This, together with previous results on $|\eta_{+-}|$, $|\eta_{00}/\eta_{+-}|$ and the charge asymmetry δ in leptonic decay, is compared with the prediction of the superweak model, with good agreement.

Finally the result is used to find, on the basis of unitarity, a new upper limit on *CP* violation in the decay $K^0 \to 3\pi^0$. This limit is $|\eta_{000}|^2 \leq 0.21$.

Introduction. *CP* violation has so far only been observed in K^0 decay. The observed quantities are:

a) the two (complex) decay amplitudes

$$\eta_{+-} = \frac{\langle\pi^+\pi^-|T|L\rangle}{\langle\pi^+\pi^-|T|S\rangle} \quad \text{and} \quad \eta_{00} = \frac{\langle\pi^0\pi^0|T|L\rangle}{\langle\pi^0\pi^0|T|S\rangle},$$

and

b) the charge asymmetries in the K_{e3} and $K_{\mu3}$ decay of the long lived neutral kaon:

$$\delta_e = \frac{N_e^+ - N_e^-}{N_e^+ + N_e^-} \quad \text{and} \quad \delta_\mu = \frac{N_\mu^+ - N_\mu^-}{N_\mu^+ + N_\mu^-},$$

where N_e^+ is the number of observed positive electrons in K_{e3}, etc. Our understanding of the mechanism of *CP* violation rests therefore on these two complex and two real numbers.

If *CPT* invariance is assumed, the short lived and long lived kaon states can be expressed in terms of the K and $\bar{K}$ states with the help of a single mixing parameter:

$$|K_S\rangle = \frac{1}{\sqrt{2(1+|\epsilon|^2)}}\,[(1+\epsilon)|K\rangle + (1-\epsilon)|\bar{K}\rangle]\ ,$$

$$|K_L\rangle = \frac{1}{\sqrt{2(1+|\epsilon|^2)}}\,[(1+\epsilon)|K\rangle - (1-\epsilon)|\bar{K}\rangle]\ .$$

η_{+-} and η_{00} can than be expressed [1] in terms of ϵ and a second parameter ϵ', which describes *CP* violation in the interference between the $I = 0$ and $I = 2$ two pion decay amplitudes:

$$\eta_{+-} \approx \epsilon + \epsilon' \tag{1}$$

$$\eta_{00} \approx \epsilon - 2\epsilon'\ . \tag{2}$$

The approximation is sufficient for the present purposes. The phase of ϵ' is given by the difference between $I = 2$ and $I = 0$ $\pi\pi$ phase shifts at the kaon mass:

$$\phi_{\epsilon'} = \pi/2 + \delta_2 - \delta_0\ . \tag{3}$$

The charge asymmetries in leptonic decay are related to ϵ as follows:

$$\delta_e, \delta_\mu = \frac{1-|x|^2}{|1-x|^2}\cdot 2\,\mathrm{Re}\,\epsilon$$

where x is the $\Delta S = -\Delta Q$ amplitude relative to the

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Coda

1976–77

K^0 charge radius $\langle R^2 \rangle$

Σ^0 lifetime 10^{-19} s

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PH I/COM-72/5
28 January 1972

PHYSICS I

ELECTRONICS EXPERIMENTS COMMITTEE

PROPOSAL

FOR A MEASUREMENT OF THE K^0 CHARGE RADIUS

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K. Kleinknecht, G. Presser, P. Steffen,
J. Steinberger, F. Vannucci, H. Wahl and G. Zech

CERN-Heidelberg Collaboration

GENEVA

1972

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North-Holland Publishing Company

MEASUREMENT OF THE ELECTROMAGNETIC INTERACTION OF THE NEUTRAL KAON

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An experiment has been performed to search for the interference between the nuclear and the electron regeneration amplitudes of the neutral kaon. The detailed experimental analysis of the coherent and diffraction nuclear regeneration of long-lived kaons on copper and uranium nuclei has led to a value of the mean square charge radius of the neutral kaon, $\langle R^2 \rangle = (0.08 \pm 0.05)$ fm^2. The forward regeneration amplitudes and the total K_L-nucleus cross sections have been determined in auxiliary measurements between 4 and 10 GeV/*c*.

1. Introduction

The short-range electromagnetic interaction of the neutral kaon was first discussed by Feinberg [1] and Zel'dovitch [2]. This interaction can be attributed to a charge density distribution $\rho(r) = ef(r)$, which must have at least one zero ($\int \rho(r) d^3 r = 0$ for a neutral particle) and will produce K^0-e scattering with a cross section

$$\frac{d\sigma}{dq^2} = \left(\frac{d\sigma}{dq^2}\right)_{\text{Mott}} |F(q^2)|^2 ,$$

where $(d\sigma/dq^2)_{\text{Mott}}$ is the point-like cross section and the electric form factor of the K^0:

$$F(q^2) = \int f(r) e^{iqr} d^3 r = -\tfrac{1}{6} q^2 \int f(r) r^2 d^3 r + O(q^4) \qquad (1)$$

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KHCK

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PH I/COM-72/33
11 August 1972

PHYSICS I

ELECTRONICS EXPERIMENTS COMMITTEE

PROPOSAL FOR A MEASUREMENT OF THE Σ^0 LIFETIME USING THE PRIMAKOFF EFFECT

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J. Steinberger, F. Vannucci, H. Wahl, E. Williams
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G E N E V A
1972

Nuclear Physics B118 (1977) 1–24

MEASUREMENT OF THE Σ^0 LIFETIME ‡

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The Coulomb production of Σ^0 hyperons on uranium and nickel nuclei has been measured in a beam of Λ hyperons at the CERN Proton Synchrotron. The results for the Σ^0 lifetime, $\tau_{\Sigma^0} = (0.58 \pm 0.13) \times 10^{-19}$ sec, and for the Σ^0-Λ magnetic transition moment, $|\mu_{\Sigma\Lambda}| = (1.82^{+0.25}_{-0.18})$ nuclear magnetons, are in agreement with SU(3) predictions.

1. Introduction

The dominant decay mode of the Σ^0 hyperon is $\Sigma^0 \to \Lambda + \gamma$, and its lifetime is determined by the Σ^0-Λ magnetic transition moment $\mu_{\Sigma\Lambda}$. Within the framework of SU(3), the magnetic moments of the members of the baryon octet and the magnetic transition moment $\mu_{\Sigma\Lambda}$ are related to the neutron and proton magnetic moments μ_n and μ_p, respectively.

In particular, one gets [1]

$$\mu_{\Sigma\Lambda} = -\tfrac{1}{2}\sqrt{3}\mu_n = 1.66 \frac{e\hbar}{2m_p c} . \qquad (1)$$

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