66-47

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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MEMORANDUM

TO : EEC and NPRC

FROM : V. Bisi, A. Böhm, P. Darriulat, M.I. Ferrero, C. Grosso, V. Kaftanov, K. Kleinknecht, H.L. Lynch, C. Rubbia, J. Steinberger, H. Ticho, and K. Tittel

SUBJECT : Further investigations on $K_0$ decays in the ejected beam

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We are discussing here some further experimental investigations on $K_0$ decays. We consider this programme as the natural continuation of our present experiment in the ejected proton beam (S49).

The proposed experiments are mainly based on the availability of the ejected proton beam as well as on the wire chamber spectrometer which we have just developed.

With the external proton beam one can produce $K_0$ beams of much smaller cross-section and much higher intensity than normally available from internal target, mainly because the detector can be located much closer to the production target.

We have furthermore investigated the possibility of producing $K_0$ mesons by charge exchange from a $K^+$ beam at an energy of about 2 GeV/c. Two alternatives have been considered in detail. The first proposal (by H.T.) consists of a shorter version of the separated beam $m_4$, offering fluxes of about $1.2 \times 10^5$ $K^+$/pulse with $3 \times 10^{11}$ proton incident on a $2 \times 5$ mm² external target. The second, more modest, line of approach is a non-separated positive beam short enough (< 10 m) to preserve a good fraction of the initially produced $K^+$ mesons. The $\pi^+ p$ contamination expected is about 17 times the $K^+$ flux at 10 metres from production target. The flux of $K^+$ is limited in the case of the experiments we have in mind to about $\sim 10^5$/pulse mainly by the associated $\pi^+$, p background.

Both beams could be built, in principle, from the already existing $e_{3a}$ branch in the place of the $b_{13}$ neutral beam. The non-separated version is very simple and involves the use of few additional beam transport elements.

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All investigations with the neutral and charged K beams require only a fraction of the ejected protons and could be run in parallel with other experiments on the ejected beam, or parasitically.

A number of modifications of the $K_0$ detector in use for the already approved experiment S49 have been carried out during the 10 months' interruption of this experiment. The new equipment is expected to provide a data-taking rate of about two orders of magnitude larger than any $K_0 \to 2\pi$ decay experiment done so far. Furthermore, the detection efficiency is quite uniform over the decay volume and can be readily calibrated, thus providing an understanding of the systematic errors comparable with the high statistical accuracy available.

The main changes are:

i) Replacement of the 1 metre magnet with a 2 metre one.

ii) Replacement of the optical chambers by wire chambers. Most of the work on the construction of these chambers is being carried out at the University of Aachen.

iii) A gas Čerenkov counter at atmospheric pressure and large acceptance has been built and tested to give a good efficiency ($\geq 98\%$) for detecting electrons and a low feed-through ($<< 10^{-2}$) from $\pi$ or $\mu$ mesons in the few GeV range.

We have considered three main measurements, the first to be carried out on the existing $b_{13}$ neutral beam and the others on the modified (charged) version from the same target.

i) <u>Precision determination of the value of the mass difference $\Delta m = m_{K_L} - m_{K_S}$</u>

This measurement is required mainly because the present error on $\Delta m$ is still insufficient to extract an accurate value of the phase $\varphi_\eta$ of the CP violating amplitude $|\eta| e^{i\varphi_\eta} = A(K_0^L \to 2\pi)/A(K_0^S \to 2\pi)$ from the experiment S49 ($K_L - K_S$ interference in the ejected proton beam).

ii) <u>Test of the $\Delta Q = \Delta S$ rule in $K^0_{e3}$ decays of and CP violations in $K^0 \to \pi^+\pi^-\pi^0$</u>

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iii) More accurate measurements of $\varphi_\eta$ by associating the measurement (i) with a determination of the regeneration phase in copper. By charge exchange of a $K^+$ beam we produce a beam which is pure $K_o$ at time zero. Later, the beam passes through a copper plate. At the exit of the plate, the beam contains a directly produced $K_S$ wave and a $K_L$ regenerated $K_S$ wave. The $2\pi^\pm$ decay rate shows interference effects which can be used to measure the regeneration phase.

All these measurements make use of the same experimental equipment (apart from minor modifications).

## 1. ACCURATE DETERMINATION OF MASS DIFFERENCE BETWEEN $K_L$ AND $K_S$ MESONS

The experimental investigations reported until now have not exploited the full accuracy of an interference experiment between $K_L \to 2\pi$ and $K_S \to 2\pi$ amplitudes after a thick regenerator. The interference pattern extends over about 12 lifetimes, as indicated in Fig. 3. The $K_0$ detector (Fig. 1) based as in our previous experiment on the principle of the "parallel geometry" is designed to cover at least 15 $K_0^S$ lifetimes with a very uniform detection efficiency. The ejected proton beam makes it possible to use very small beams, and in our set-up a hole is provided through all wire chambers and counters to minimize spurious tracks. The event rate has been calculated and it is shown in Fig. 2. We expect about 0.5 $K_L \to 2\pi$ per pulse with $5 \times 10^9$ protons interacting in the primary target.

The detection efficiency, until now computed by Monte Carlo calculations, will be determined directly by placing a thick regenerator in many positions along the decay path. The systematic uncertainties in the detection efficiency is then estimated to be less than perhaps 1% or 2%.

Figure 4 shows the $K_L - K_S$ interference term extracted from the decay time distribution with expected error bands after $\sim 1$ day of CPS running time ($3 \times 10^4$ pulses) and for 1.5% of systematic uncertainties in the detection efficiency.

The expected precision is about $\pm 0.005 \times 10^{-10}$ sec$^{-1}$ on the mass difference and $\pm 0.02$ rad on the initial phase of the interference pattern.

## 2. THE $\Delta Q = \Delta S$ RULE IN LEPTONIC DECAYS

Time dependence of $K_{e3}$ decays from an initial $K_0$ state (or $\bar{K}_0$) has been investigated already by many authors in order to check the validity of the $\Delta Q = \Delta S$ selection rule.

Provided both $\Delta Q = \Delta S$ and $\Delta Q = -\Delta S$ amplitudes are demonstrated to be present, the time dependence of the leptonic decays is also sensitive to a CP violation in this decay channel.

In principle, the $\Delta Q = \Delta S$ rule can be tested by producing $K_0$ (strangeness = + 1) and looking for leptonic decay of the type $K_0 \to \pi^+ e^- \nu$ very close to the $K_0$ production point, so that no appreciable admixture of $\bar{K}_0$ has yet developed.

In practice, for a quantitative statement and for adequate statistics and internal consistency tests, one has to observe a larger time interval, ideally until the $K_0^S$ component has decayed down to a negligible level.

The experiments carried out so far suffer from several experimental problems and lack of statistical precision. For experiments performed with a propane-freon bubble chamber[1,2] one is faced with the fact that

i) The momentum of the $K_0$ which is required to evaluate the decay time cannot be determined individually but an average is determined by observation of the $K_S^0 \to 2\pi^\pm$ decay spectrum.

ii) A non-negligible fraction of the events does not permit unambiguous association of decay and production vertices.

For experiments performed with hydrogen bubble chambers[3], on the other hand:

i) The sign of the decay lepton cannot be observed in general.

ii) The statistics are limited by the very large number of decays to be measured. Leptonic decays are in fact selected by kinematics after a measurement of all the V's in the film.

A further measurement with wire chambers is justified by the much larger sample of decay events which could be collected and by the presumably smaller difficulties coming from systematic biases. Electrons are identified by a gas Čerenkov counter and momenta of charged particles are measured accurately by their curvature in a magnetic field. Because the production vertex is known, the events are of types "zero constraint fit" with two possible kinematical solutions with different K momentum. Unresolved solutions could be weighted statistically according to computed weights. The possibility of resolving this ambiguity will essentially depend on the $K^0$ spectrum produced on the copper target, unknown at present. In principle, the target arrangement is rejecting events with larger inelasticity, thus making the expected $K_0$ spectrum fairly monochromatic. This point can be assessed only by preliminary measurements.

The experimental arrangement is the one shown in Fig. 5. Both charged tracks are required to cross the gas Čerenkov counters.

The optimum choice of the $K^+$ beam momentum requires further measurement on charge exchange rate on complex nuclei at different energies. The best evaluation we can make at present is based on data for $D_2$ and at $p_{k^+}$ = 2.25 GeV/c, indicating a $\sigma_{ch.exch.}$ = 1.5 mb and a $K_0$ angular distribution peaked in the forward cone[4]. We shall boldly assume an $A^{2/3}$ law for the charge exchange process and the same angular distribution. Event rates therefore will have only an indicative value.

Input data are the following:

| | |
|---|---|
| $K^+$ beam momentum | 2.25 GeV/c |
| $K^+$ beam flux | $10^5$/pulse |
| Geometrical average detection efficiency | 0.1 |
| Useful decay length | $\geqslant$ 6 lifetimes $K^0_S$ |
| Čerenkov $e^{\pm}$ detection efficiency | $\geqslant$ 0.90 |
| Target thickness (total) | 0.2 int. lengths |
| Charge exchange probability (total) extrapolated $A^{2/3}$ from $D_2$ data | $5.33 \times 10^{-3}$ |
| Event losses due to chamber inefficiencies, evaluation, fiducial cuts, etc. | 0.5 |

The rate of $K^0 \to \pi^{\pm} e^{\mp} \nu$ events is then easily evaluated and it is:

event rate = 0.0717 event/pulse or 2151 events/day*)

We would like to include a reduction of a factor 3 on the calculated rate, due to the incertitudes of extrapolation on the cross-section and the preliminary nature of the proposal. We arrive then at a conservative event rate of the order of ~ 700 events/day, adequate to collect a sample of at least 10,000 events in two ten-day CPS periods. Only a small fraction ($\leqslant$ 20%) of the ejected proton beam is required in order to obtain the indicated $K^+$ flux of $10^5$/pulse.

Figure 6 taken from Cabibbo's Report at the Berkeley Conference, summarizes the present experimental information available. The complex parameter X is defined as:

$$X = \frac{\text{Decay amplitude } (\Delta Q = -\Delta S)}{\text{Decay amplitude } (\Delta Q = +\Delta S)}$$

*) "CPS day" is defined here as 30,000 CPS useful pulses.

We have indicated the estimated error bars (X = 0) for a sample of $10^4$ events from a proposed experiment. The expected statistical accuracy is of about ±0.01 for Re (X) and ±0.03 for Im (X). Further investigations on systematic biases which are presently estimated to be negligible, will show if such a very accurate result could be obtained in practice.

A number of background reactions have been considered and found to be negligible. The most important are:

i) Dalitz pairs from $K_0^S \to \pi^0\pi^0$ decays. This is the largest background effect. It is reduced to a negligible error by requiring only one Čerenkov count and an invariant mass of the charged pair larger than 100 MeV/c.

ii) Decays $K_0^L \to \pi^+\pi^-$. In order to be counted, one of the $\pi$ mesons must record a count in the Čerenkov counter. The feed-through has been measured in a similar Čerenkov detector to be less than $0.5 \times 10^{-3}$. The further requirement that the invariant mass of the charged particle pair to be at least 4 standard deviations from the $K_0$ mass reduces this type of background to a negligible level. A mass resolution of ± 2 MeV is expected. The requirement of the Čerenkov counter also rejects completely events of the type $K_0^L \to \pi^+\pi^-\gamma$.

iii) $\Lambda^0 \to \pi^-p$ and $\Lambda^0 \to e^-p\nu$ decay events. Together with the $\Lambda^0$ an S = -2 state must be produced. Although no experimental data on those processes exist, it is reasonable to expect that their cross-section is substantially less than the charge-exchange cross-section. Events $\Lambda^0 \to \pi^-p$ which succeed in triggering the Čerenkov counter have to be tested against $\Lambda^0 \to \pi^-p$ kinematics. The $\Lambda^0 \to pe^-\nu$ rate is about $10^{-3}$ times the $\Lambda^0 \to \pi^-p$ rate and might simulate events of the forbidden type $K^0 \to \pi^+e^-\nu$. More elaborate Monte Carlo calculations are on the way to estimating the extent in which these two reactions can be confused.

## 3. TEST OF CP CONSERVATION IN $K^0 \to \pi^+\pi^-\pi^0$ DECAYS

Decays of the type $K^0 \to \pi^+\pi^-\pi^0$ can be recorded by putting above and below the decay volume two large $\gamma$-ray detectors made out of lead converters followed by wire chambers for accurate determination of the $\gamma$ conversion point. Two plastic scintillators in anticoincidence are selecting charged particles and two lead-scintillator sandwiches of the type developed by the Michelini group are employed to determine approximately the energy delivered in the shower.

If CP is violated, the amplitude $a_1$ for $K_0^S \to \pi^+\pi^-\pi^0$ may be comparable with the amplitude $a_2$ for $K_0^L \to \pi^+\pi^-\pi^0$. The expected time distribution is

$$N(t) = \text{const}\ [|X|^2 e^{-\Gamma_s t} + 1 + 2|X| e^{-\Gamma_s t/2} \cos(\Delta m t + \varphi)]$$

where $xe^{i\varphi}$ is the ratio between the two amplitudes $a_1$ and $a_2$. CP invariance requires $X \simeq 0$.

In principle, this experiment can be run in parallel with the $\Delta Q = \Delta S$ experiment, with an alternative trigger requirement.

## 4. ACCURATE DETERMINATION OF THE REGENERATION PHASE $\varphi_\rho$ IN COPPER ALTERNATIVE MEASUREMENT OF $\varphi_\eta$, THE PHASE OF THE CP VIOLATING AMPLITUDE

The precise determination of the mass difference $\Delta m$ already discussed also provides an accurate measurement of the quantity $\alpha = (\varphi_\rho - \varphi_\eta) \times \text{sign}\ \Delta m$, where $\varphi_\eta$ is as previously:

$$\eta_{+-} = |\eta_{+-}| e^{i\varphi_\eta} = \frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)}$$

and $\varphi_\rho$ is the phase of the regenerated amplitude at the exit of the regenerator (copper).

Following the method already employed by Mehlop et al[5] to determine the sign $(\Delta m)$, we would like to carry out a precise measurement of $\varphi_\rho$ sign $(\Delta m)$, thus obtaining a new, independent determination of $\varphi_\eta$ sign $(\Delta m)$.

This measurement is complementary to the one of $\varphi_\eta$ based on the determination of the $K_0 \to \pi^+\pi^-$ decay amplitude versus time close to the production target, discussed by us in a previous proposal (S49). The sensitivity of the presently proposed experiment on the actual value of the mass difference is somewhat smaller and it could well provide the most accurate determination of $\varphi_\eta$.

The principle of the measurement is shown in Fig. 8. Neutral K mesons from the charge exchange target, the same as in the $\Delta Q = \Delta S$ experiment, are regenerated in a copper plate of thickness L at distance D from the production target. The $K_S^o \to \pi^+\pi^-$ decay intensity after the regenerator I(D) is given by the formula:

$$I(D) = \text{const} \times \left[ e^{-(D+L)\Gamma_S} + |\rho|^2 + 2|\rho| e^{-(D+L)\Gamma_S/2} \cos \varphi_\rho - (D+L)\Delta m \Gamma_S \right] .$$

One would like to determine I(D) over a range of values of D in which the regenerated $K_S^o$ intensity (typically $\sim 10^{-3}$) is of the same order of magnitude as the surviving $K_S^o$ component from the charge exchange process.

The spectrometer is essentially the same as the one for the $\Delta Q = \Delta S$ experiment.

The $K_0 \to \pi^+\pi^-$ average detection efficiency (geometrical) has been computed and found to be 0.25 at 2.2 GeV/c.

It is estimated that about $1/2$ of the running time requested for the $\Delta Q = \Delta S$ experiment, that is 10 days at $10^5 K^+$/pulse and 30,000 useful CPS pulses/day, are sufficient to provide a measurement of $\varphi_\rho$ of $\pm 0.035$ radiants.

REFERENCES

1) B. Aubert et al., Physics Letters 17, 59 (1965).

2) M. Baldo-Ceolin et al., Nuovo Cimento 38, 684 (1965).

3) P. Franzini et al., Phys. Rev. 140, 127 (1965).

4) I. Butterworth et al., Phys. Rev. Letters 15, 734 (1965).

5) W.A.W. Mehlop, 13th International Conference on High Energy Physics, Berkeley, 1966.

## Figure captions

Fig. 1 : $K_S \to \pi^+\pi^-$ detector for determining the mass difference $\Delta m - m_L - m_S$ and regeneration phase.

Fig. 2 : Efficiency as a function of momentum of incident $K_L^o$.

Fig. 3 : Expected interference pattern.

Fig. 4 : Expected cosine term, extracted from the time dependent interference pattern.

Fig. 5 : Detector for leptonic $K_o$ decays.

Fig. 6 : Diagram of the complex x plane, giving the results of the published experiments on the $\Delta Q = \Delta S$ rule and indicating the errors expected for the proposed experiment.

Fig. 7 : Monte Carlo generated distribution of events from leptonic decays of $K_o$'s.

Fig. 8 : Principle of determination of the regeneration phase.

Fig. 9 : Data of Mehlop et al.[5].

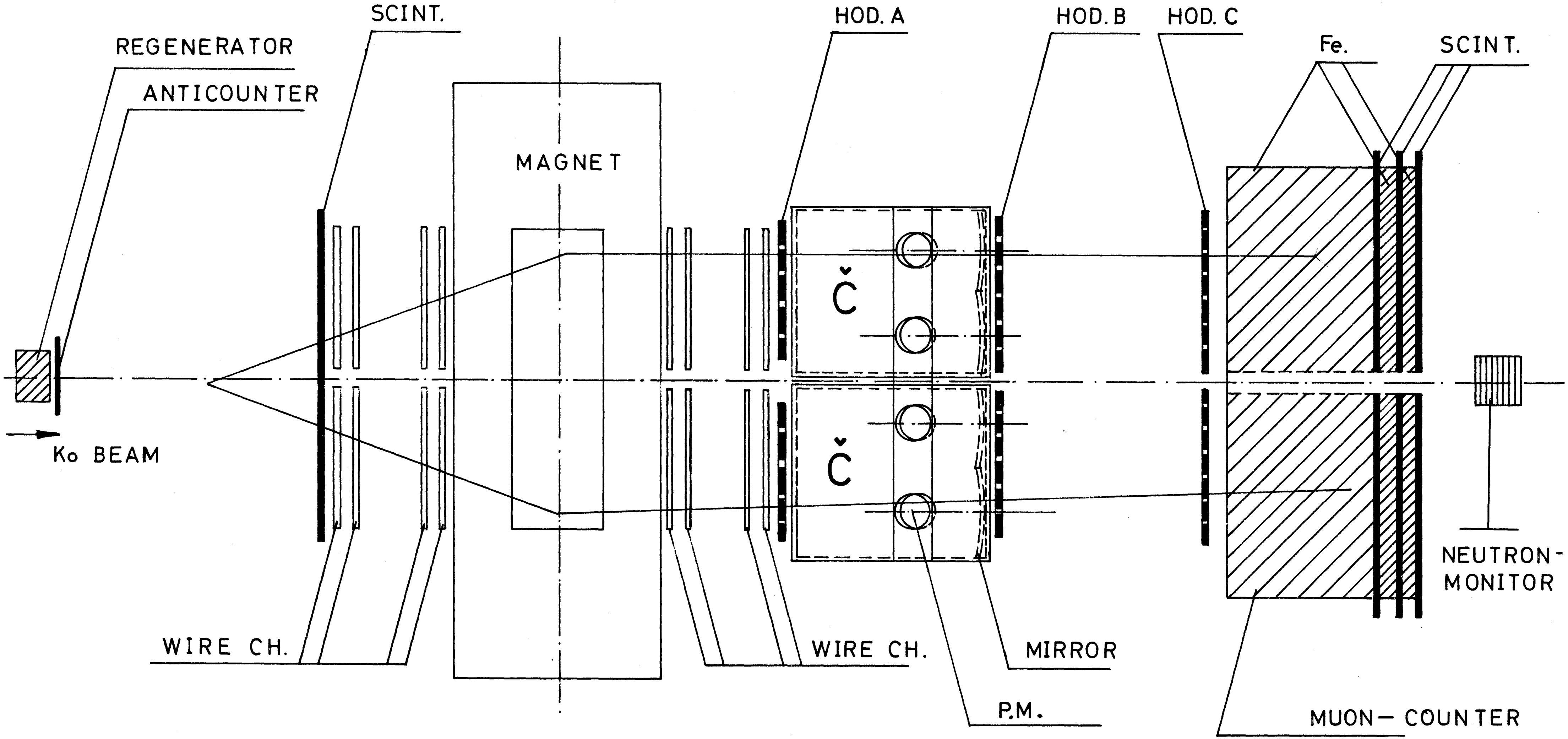
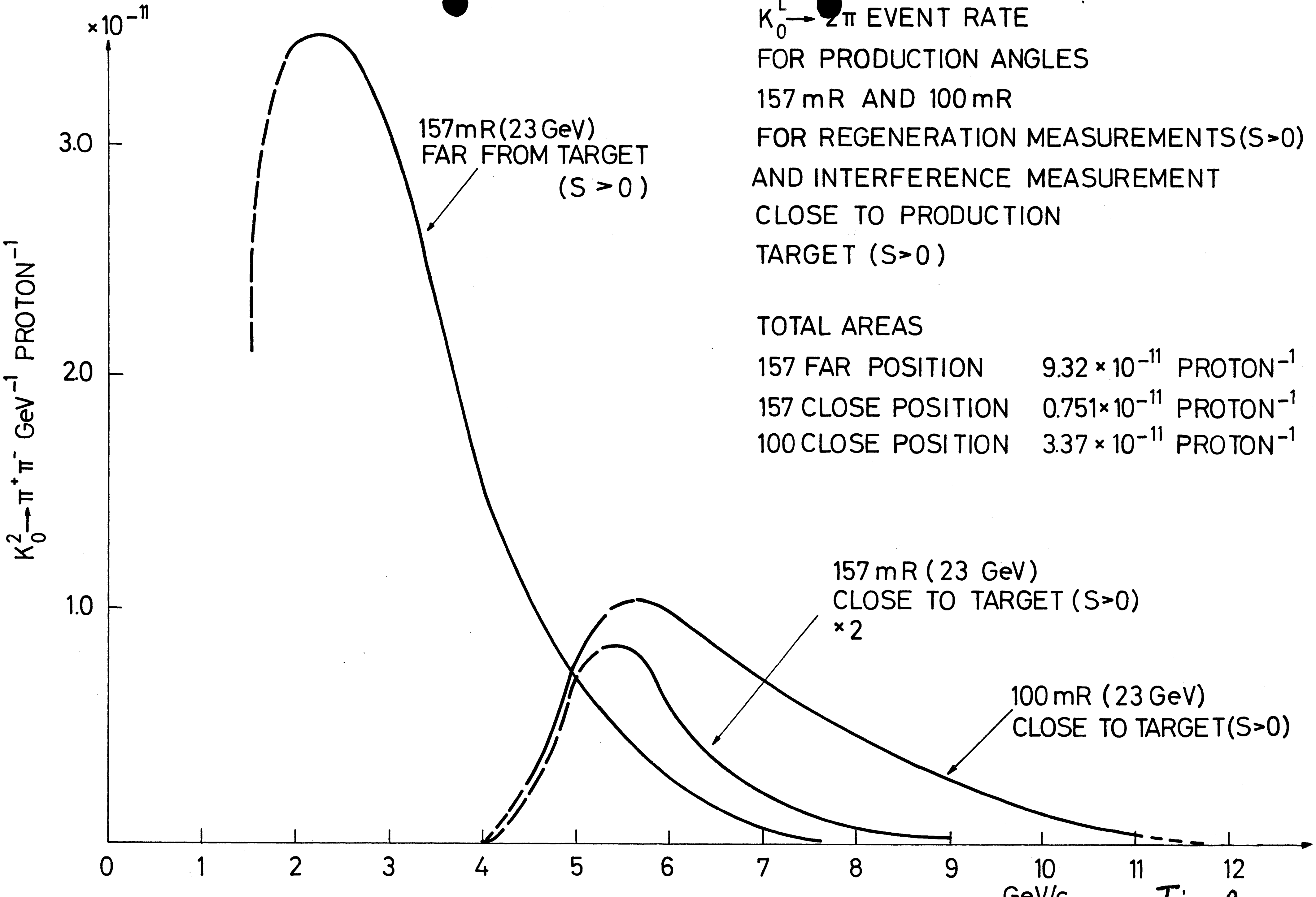

REGENERATOR
ANTICOUNTER
Ko BEAM
SCINT.
WIRE CH.
MAGNET
WIRE CH.
HOD. A
Č
Č
P.M.
MIRROR
HOD. B
HOD. C
Fe.
SCINT.
MUON – COUNTER
NEUTRON-MONITOR

Fig. 1




$K_0^L \rightarrow 2\pi$ EVENT RATE
FOR PRODUCTION ANGLES
157 mR AND 100 mR
FOR REGENERATION MEASUREMENTS (S>0)
AND INTERFERENCE MEASUREMENT
CLOSE TO PRODUCTION
TARGET (S>0)

TOTAL AREAS

| | |
|---|---|
| 157 FAR POSITION | $9.32 \times 10^{-11}$ PROTON$^{-1}$ |
| 157 CLOSE POSITION | $0.751 \times 10^{-11}$ PROTON$^{-1}$ |
| 100 CLOSE POSITION | $3.37 \times 10^{-11}$ PROTON$^{-1}$ |

Fig. 2

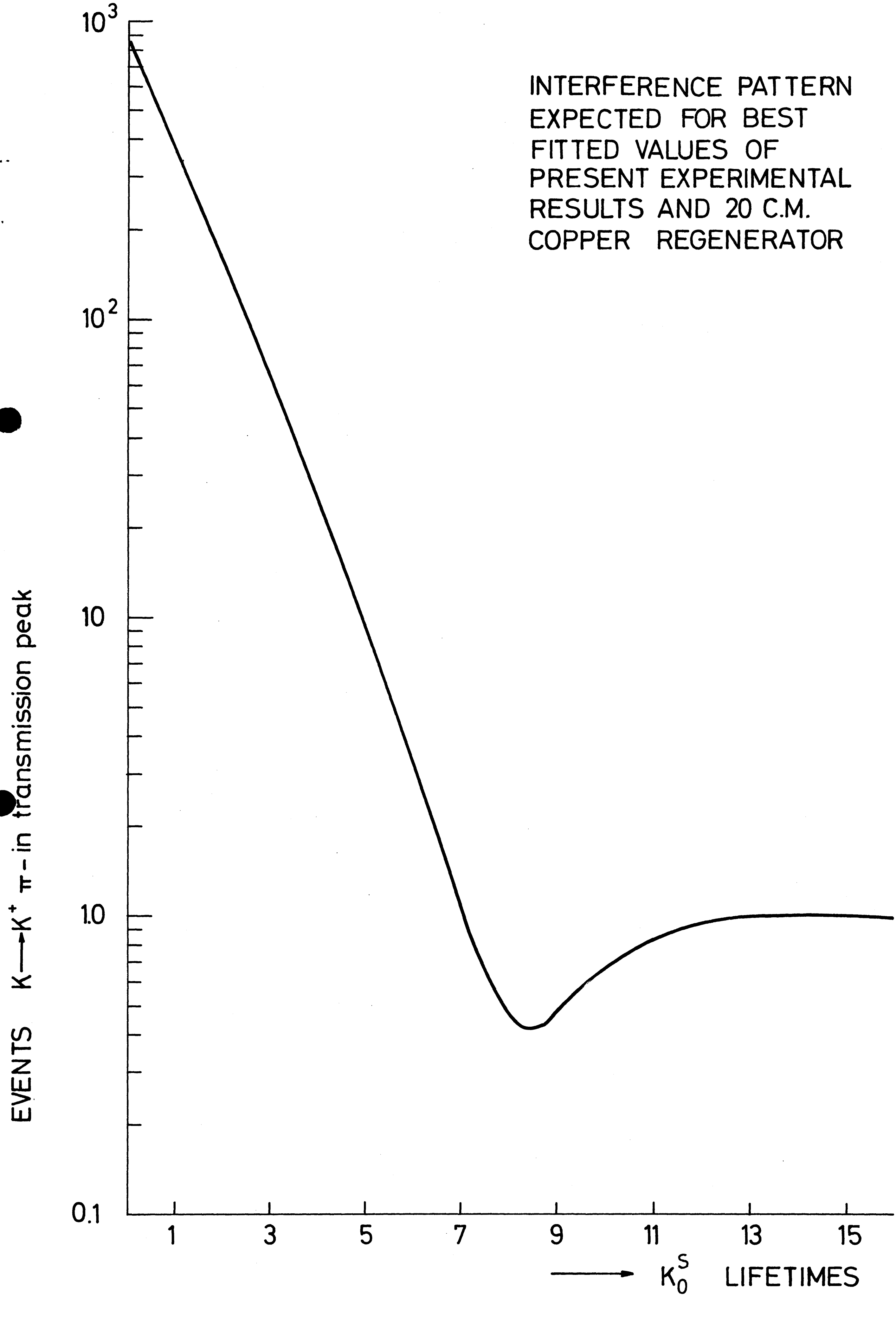
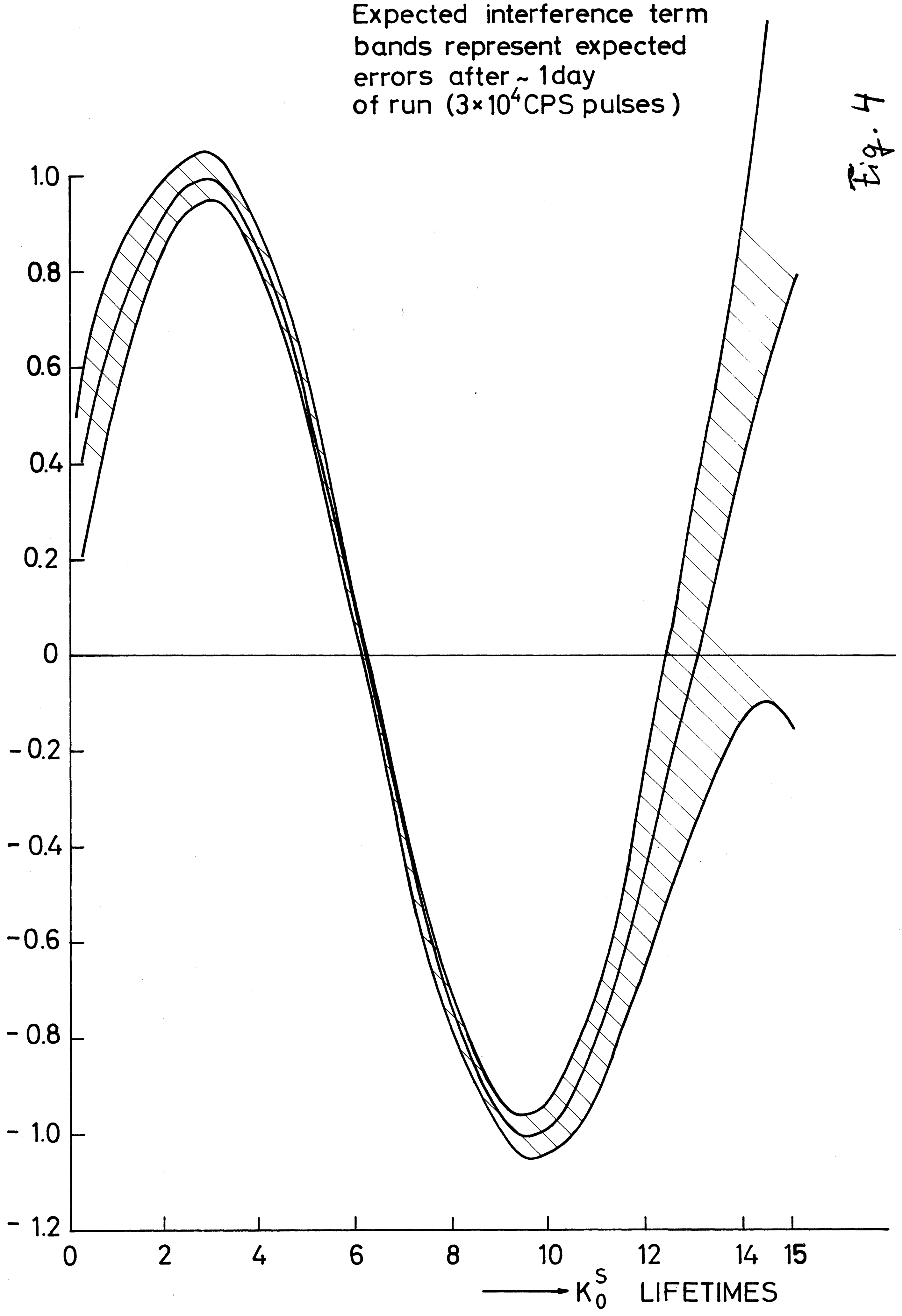

INTERFERENCE PATTERN EXPECTED FOR BEST FITTED VALUES OF PRESENT EXPERIMENTAL RESULTS AND 20 C.M. COPPER REGENERATOR
EVENTS K⟶K⁺ π- in transmission peak
10³
10²
10
1.0
0.1
1
3
5
7
9
11
13
15
⟶ $K_0^S$ LIFETIMES

Fig. 3



Expected interference term
bands represent expected
errors after ~ 1day
of run (3×10^4 CPS pulses)
1.0
0.8
0.6
0.4
0.2
0
- 0.2
- 0.4
- 0.6
- 0.8
- 1.0
- 1.2
0
2
4
6
8
10
12
14
15
→ K$_0^S$ LIFETIMES


Fig. 4

PRODUCTION REACTION $K^{+} + (n) \rightarrow K_o + (p)$

DECAY REACTION $K_o \rightarrow e^{\pm} + \pi^{\mp} + \gamma$

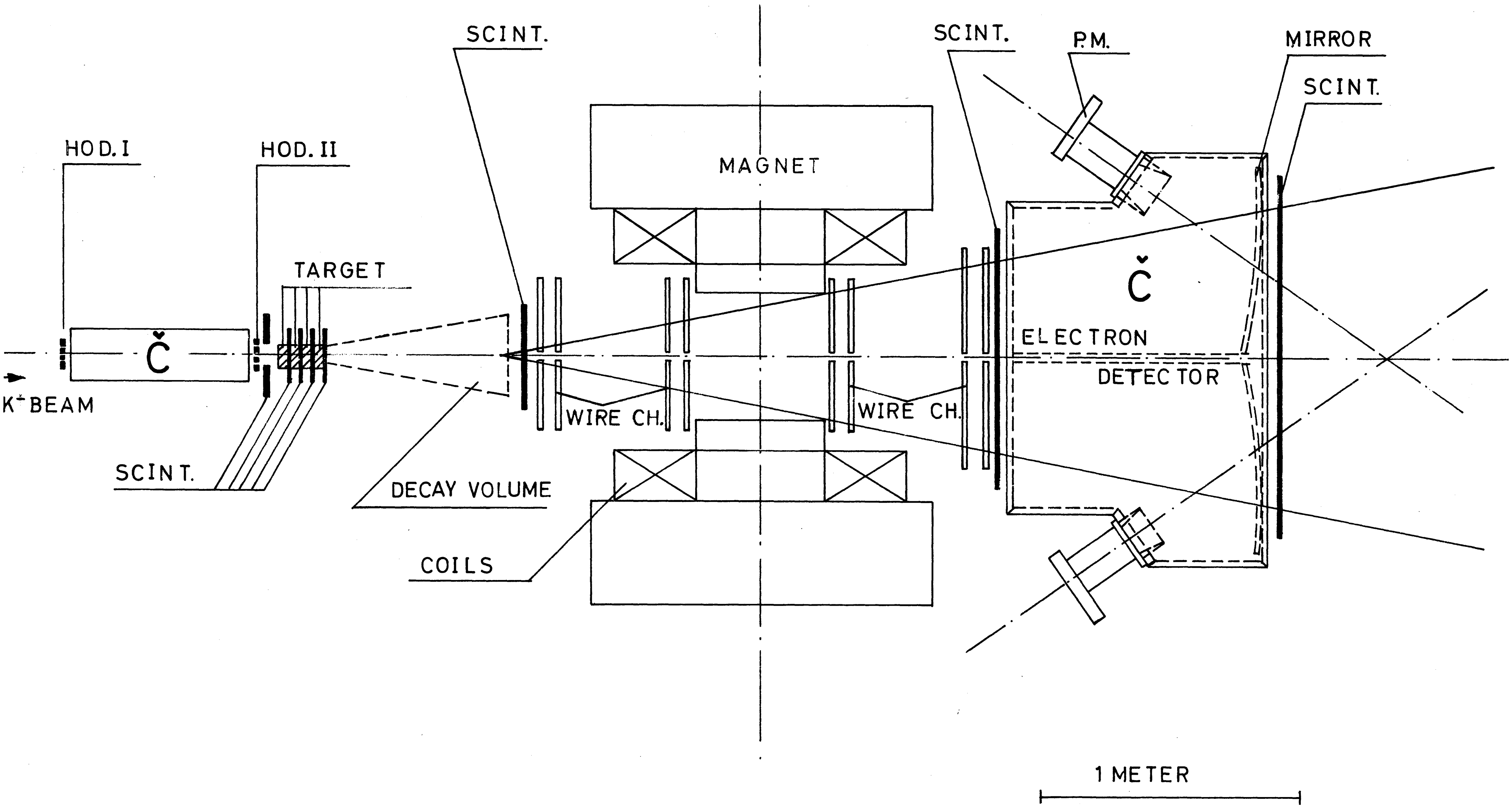



Fig. 5

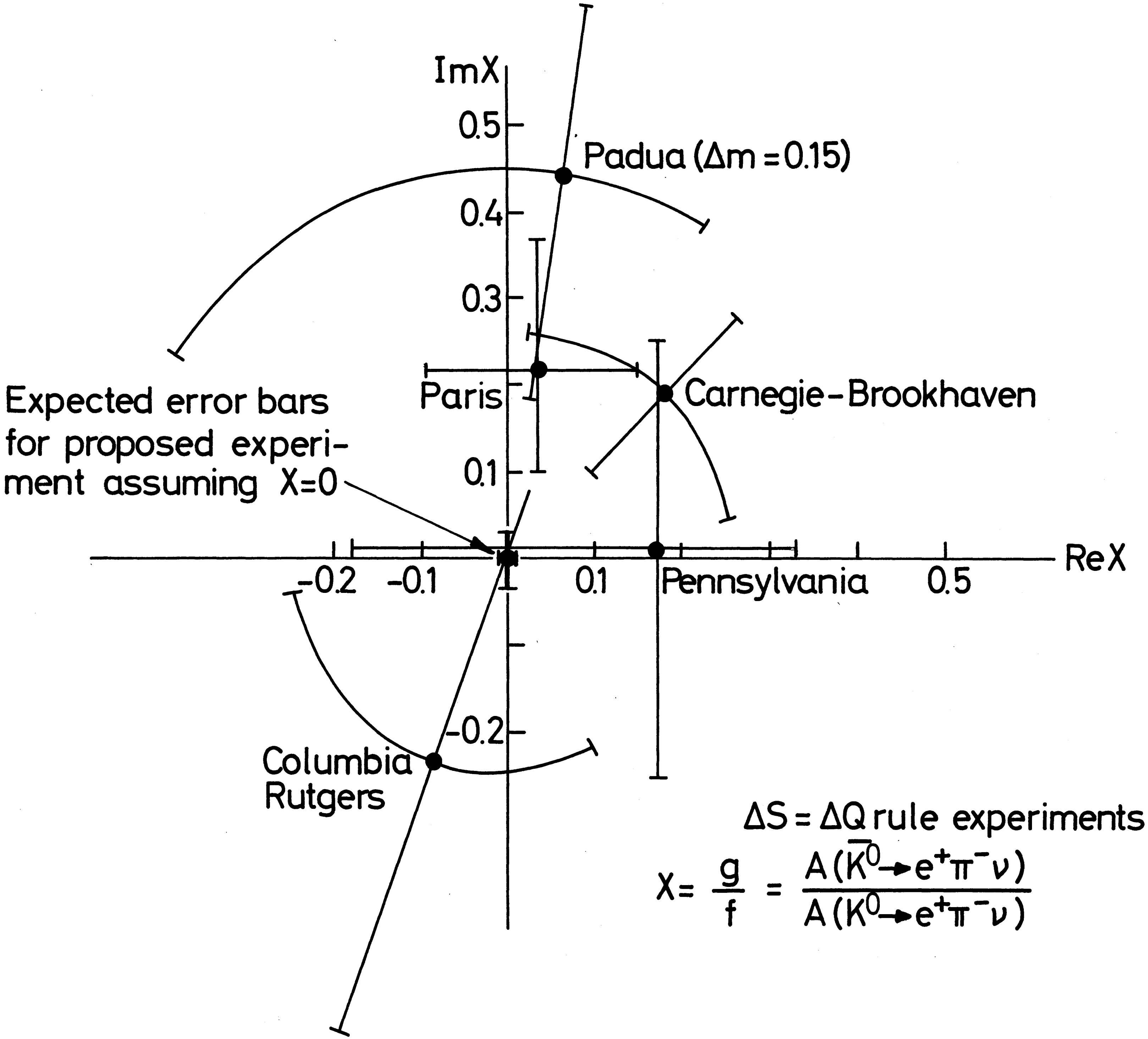

ImX
0.5
0.4
0.3
0.1
-0.2
ReX
-0.2
-0.1
0.1
0.5
Padua (Δm = 0.15)
Paris
Carnegie-Brookhaven
Pennsylvania
Columbia
Rutgers
Expected error bars for proposed experiment assuming X=0
ΔS = ΔQ rule experiments
$X = \frac{g}{f} = \frac{A(\bar{K}^0 \rightarrow e^+\pi^-\nu)}{A(K^0 \rightarrow e^+\pi^-\nu)}$

Fig. 6

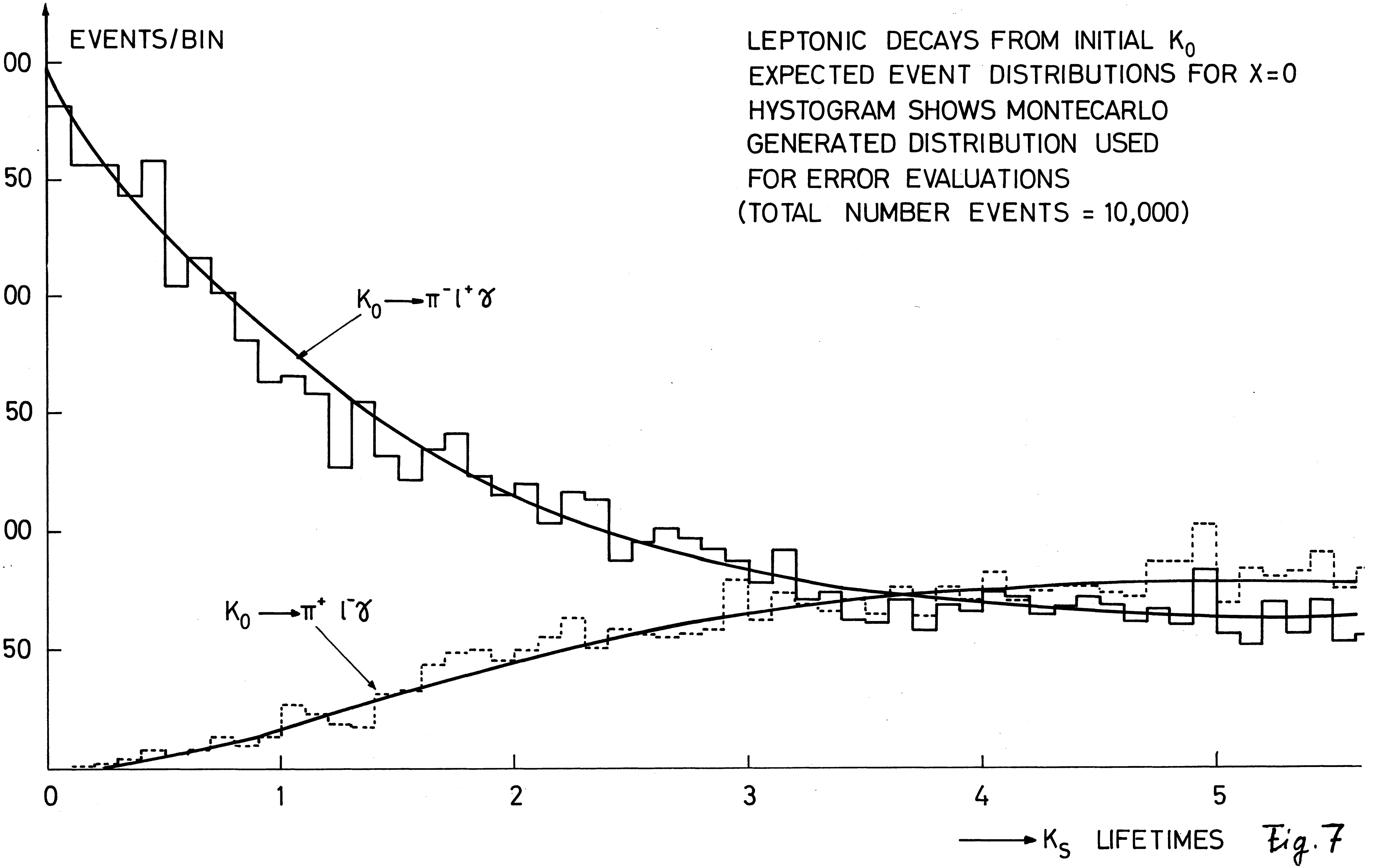

EVENTS/BIN
LEPTONIC DECAYS FROM INITIAL $K_0$
EXPECTED EVENT DISTRIBUTIONS FOR X=0
HYSTOGRAM SHOWS MONTECARLO
GENERATED DISTRIBUTION USED
FOR ERROR EVALUATIONS
(TOTAL NUMBER EVENTS = 10,000)
$K_0 \longrightarrow \pi^- l^+ \gamma$
$K_0 \longrightarrow \pi^+ l^- \gamma$
00
50
00
50
00
50
0
1
2
3
4
5
$\longrightarrow K_S$ LIFETIMES

Fig. 7

# INTERFERENCE OF Ks WITH REGENERATED Ks

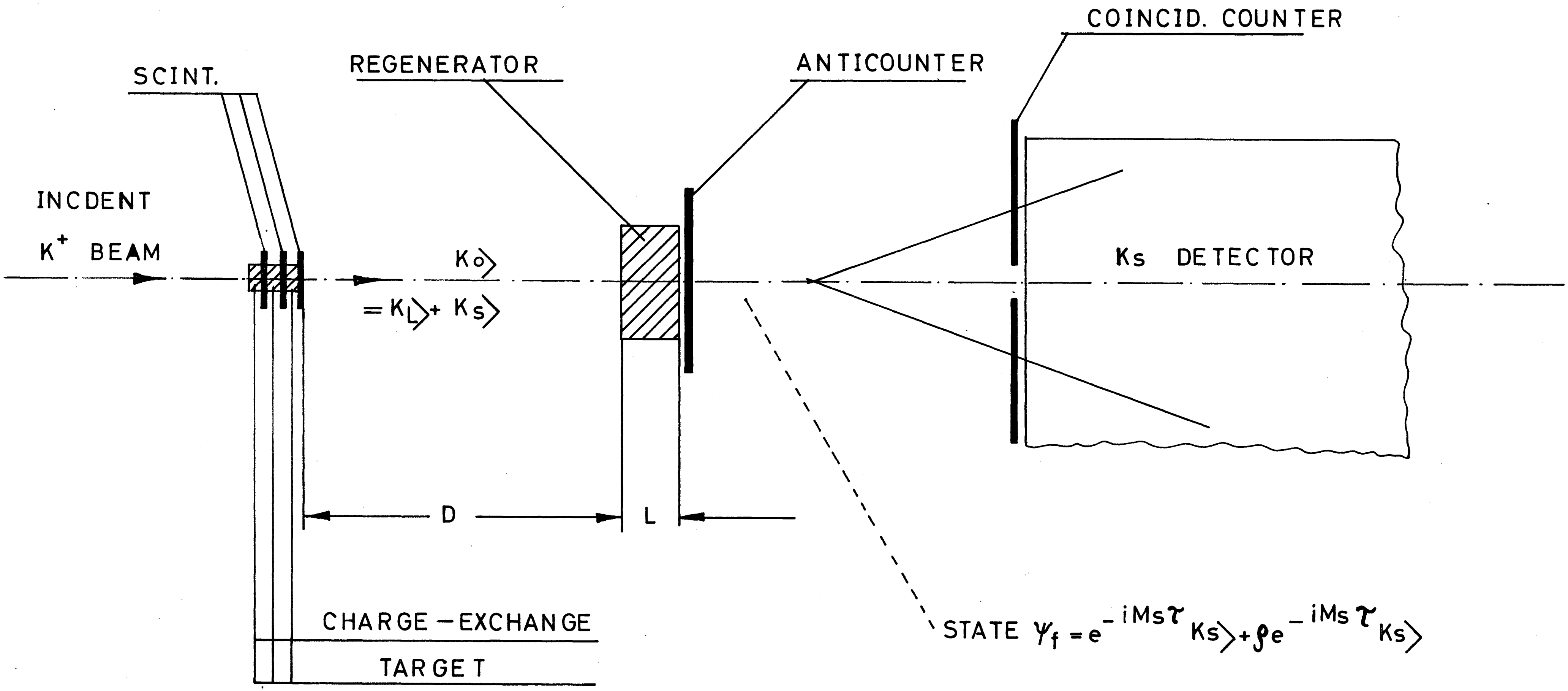



Fig. 8

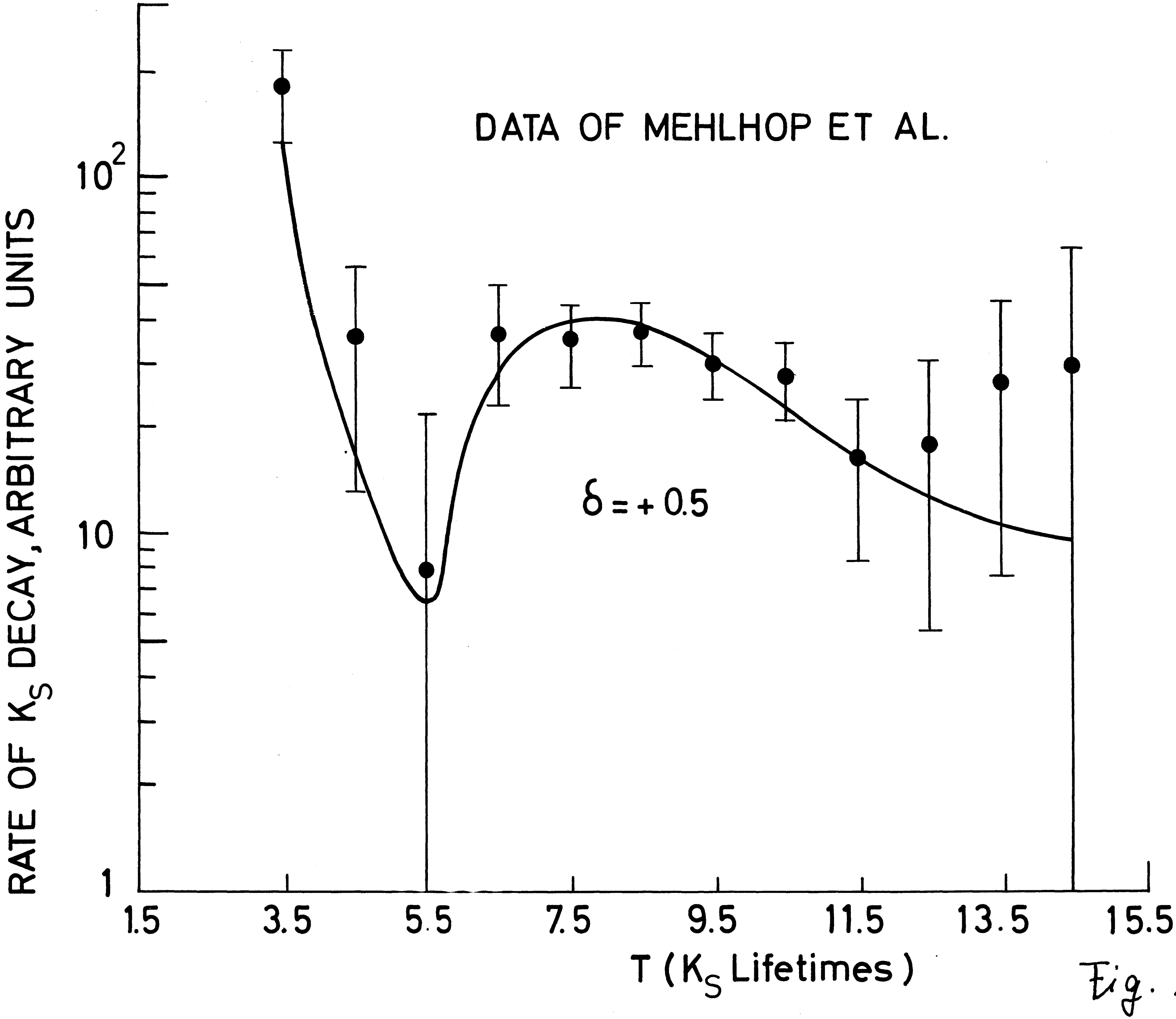

DATA OF MEHLHOP ET AL.
δ = + 0.5
RATE OF K_S DECAY, ARBITRARY UNITS
10^2
10
1
1.5
3.5
5.5
7.5
9.5
11.5
13.5
15.5
T (K_S Lifetimes)

Fig. 9