MEASUREMENT OF THE DIFFERENCE OF THE $K^\circ - \overline{K^\circ}$ FORWARD SCATTERING AMPLITUDES IN CARBON AT LOW MOMENTUM WITH THE CPLEAR DETECTOR

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ABSTRACT

We propose to measure the difference $\Delta f = f(0) - \overline{f}(0)$ of the $K^\circ - \overline{K^\circ}$ forward scattering amplitudes in carbon at low momenta (250-750 MeV/c) with the CPLEAR detector. We expect to determine Δf with a precision of $\pm 2\%$ for the modulus and $\pm 2^\circ$ for the phase. The two results are correlated for K° momenta higher than 350 MeV/c. The systematic error on the CPLEAR measurement of φ_{+-} connected with the regeneration effect will be decreased to about 0.1°.

1 INTRODUCTION

The difference $\Delta f = f(0) - \overline{f}(0)$ between the forward scattering amplitudes of K° and $\overline{K^\circ}$ is important for the determination of regeneration effects in high precision CP-violation experiments [1, 2, 3, 4)]. For the experiments working with neutral kaons of low energy [3, 4)], only semi-theoretical calculations can be used at present to estimate Δf. This introduces large systematic uncertainties in the correction for regeneration effects. In the CPLEAR experiment [3, 5)], the latter induces an uncertainty of $\pm 0.6^\circ$ on the phase of the CP-violating parameter η_{+-}. It is the largest source of systematic errors and of the same order as the statistical error expected at the end of the experiment.

Direct measurements of Δf are available for various materials from many experiments [6, 7, 8)] using K_L beams, at momenta above 2 GeV/c. Experimental results are shown in fig. 1 and 2 for hydrogen and carbon respectively. Below 2 GeV/c the quantity Δf can be calculated using measured K^+ and K^-cross sections with protons and neutrons (due to isospin

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symmetry in strong interactions, the K° and $\overline{K^\circ}$ scattering amplitudes with protons and neutrons are related to those of K^+ and K^-). The imaginary part of the forward scattering amplitude is related to the total cross section through the Optical Theorem. Measurements [9] of total cross sections exist in all interesting kaon momentum regions for $K^\pm$p scattering, but only above 800 MeV/c kaon momentum for $K^\pm$n. Measurements of the real part of the $K^\pm$p and of the $K^\pm$n forward scattering amplitudes are rare and poor, and their values are obtained, in particular for momenta below 1 GeV/c, from an integral over total cross section with the help of dispersion relations [10], or other more elaborate methods [11, 12]. The same procedure is used for the imaginary part in the momentum range where experimental data on total cross sections do not exist [10, 12].

We have assumed the average of these values, with an error given by their standard deviation, to calculate Δf and its error in hydrogen. The results are shown together with the experimental data at high momenta in fig. 3. In the momentum region between 350 to 800 MeV/c, the average uncertainty in $|\Delta f|$ and $\arg(\Delta f)$ is $\pm 13\%$ and $\pm 9^\circ$ respectively. In fig. 3 the values given by Eberhard [13], and by Michetti and Baldini [14] are also shown. Both sets are in good agreement with our average values.

The corresponding scattering amplitudes for a nucleus are calculated as the convolution of the proton and neutron contributions in the framework of an optical model calculation. Recent theoretical estimations [13] of $\Re(\Delta f)$ and $\Im(\Delta f)$ for various materials and kaon momenta between 0.35 and 2.6 GeV/c are based on the optical model of ref. [15], and on values of $\Re(\Delta f)$ and $\Im(\Delta f)$ for hydrogen shown in fig. 3.

2 EXPERIMENTAL METHOD

In the CPLEAR experiment, the dominant contribution to the regeneration effect in the 2π decay arises from the interference of the inherent K_S amplitude with the K_S amplitude regenerated from the K_L component of the neutral kaon. For a better understanding of the regenerated K_S amplitude $\rho = |\rho| e^{i\varphi_\rho}$ (which is proportional to Δf [16, 17]) we intend to enhance the regeneration effect by introducing an additional amount of material (absorber, regenerator) into the decay volume of the detector. The time dependent decay rate asymmetry between the initially pure K° and $\overline{K^\circ}$

$$A_{+-}(\tau) = \frac{R\left(\overline{K^\circ}_{\tau=0} \to \pi^+\pi^-\right)(\tau) - R\left(K^\circ{}_{\tau=0} \to \pi^+\pi^-\right)(\tau)}{R\left(\overline{K^\circ}_{\tau=0} \to \pi^+\pi^-\right)(\tau) + R\left(K^\circ{}_{\tau=0} \to \pi^+\pi^-\right)(\tau)} \tag{1}$$

measured for decays behind the absorber is:

$$A_{+-}(\tau) \approx 2Re(\varepsilon) - \frac{2|\eta_{+-}|e^{\frac{1}{2}(\gamma_S-\gamma_L)\tau}\cos(\Delta m\tau - \varphi_{+-})}{1+|\eta_{+-}|^2 e^{(\gamma_S-\gamma_L)\tau}} + I \tag{2}$$

with

$$I = -2\frac{|\rho|e^{\frac{1}{2}(\gamma_S-\gamma_L)\tau_R}\cos(\Delta m\tau_R - \varphi_\rho)}{1+|\eta_{+-}|^2 e^{(\gamma_S-\gamma_L)\tau}} \tag{3}$$

where we have neglected terms of the order of $|\rho||\eta_{+-}|$, $|\rho|^2|\eta_{+-}|$ and $|\rho||\eta_{+-}|^2$; τ_R is the proper time of the neutral kaon to reach the absorber; $Re(\varepsilon)$ is the parameter describing CP violation in the K°, $\overline{K^\circ}$ mixing; $m_{S,L}$ ($\Delta m = m_L - m_S$) and $\gamma_{S,L}$ are the mass and the width of $K_{S,L}$.

The interference term I is ideally measured by placing the absorber in such a way that the inherent K_S amplitude is comparable to the regenerated K_S amplitude. Fig. 4 shows the expected decay rate asymmetry with a 2 cm carbon absorber compared to the one expected in the absence of absorber for five different K° momentum regions, between 250 and 750 MeV/c, which is the region covered in the CPLEAR experiment.

2.1 Experimental Setup

The neutral kaons are produced in $\overline{p}p$-annihilations at rest through the two channels $\overline{p}p \to K^\pm\pi^\mp\overline{K^\circ}(K^\circ)$ both with a branching ratio of $2 \cdot 10^{-3}$. The strangeness of the neutral kaon is tagged by the charge of the accompanying charged kaon. A carbon absorber, shaped as a cylinder sector of 2 cm thickness, will be put inside the CPLEAR detector at about 7 cm from the target (see fig. 5), where about 90% of the K_S available at $\tau = 0$ have already decayed. The absorber will cover only 120° of the azimuthal angle providing thus the possibility of selecting primary charged particles which did not cross the absorber.

The weight of the absorber material is approximately 2.4 kg. It will be mounted together with the target on an extraction tube made of inox, so that the regenerator can easily be put in and taken out through the downstream side of the detector. The position of the absorber can be determined by reconstructing the vertex of converted photons [20].

We plan to equip the absorber with a thin veto counter. It would allow us to reject, at an early trigger stage, the events with charged tracks traversing the absorber, thus reducing trigger and readout deadtime, with an increase in the trigger rate by 30% with respect to the present one. Possible solutions for this counter are either a flat scintillator with flexible light guides or a plane of 2 mm thin scintillating fibers (as used in the electromagnetic calorimeter of the KLOE detector [18]).

2.2 Simulation Studies and Statistical Errors

In 1994 the CPLEAR experiment collected a total of 11×10^6 fully reconstructed events $K^\circ(\overline{K^\circ}) \to \pi^+\pi^-$ with a lifetime above 1 τ_S. The average $\overline{p}p$-rate was 650 kHz and the average efficiency of LEAR during the 70 days of running was 60% [21]. With the same amount of beam time and efficiency for the regeneration measurement, we expect about 4×10^6 $\pi^+\pi^-$ decays above 1 τ_S where the primary charged tracks do not cross the absorber and the neutral kaon momentum direction points to the regenerator.

The central values of the modulus $|\Delta f|$ and the phase $\varphi_{\Delta f}$ of Δf for carbon taken from ref. [13] are shown in table 1. Using these values as input, a detailed simulation was done taking into account the K° and $\overline{K^\circ}$ propagation through the detector material [19], the kaon momenta and angular distributions, and the acceptance as a function of the lifetime, as measured by the CPLEAR detector. "Experimental" asymmetries for five different momentum intervals with altogether $4 \cdot 10^6$ events were generated. The asymmetries are shown in fig. 4 together with the asymmetry without regenerator. Due to the necessary integrations over different regenerator thicknesses and kaon momenta only a *numerical fit* is possible to obtain the modulus and phase of Δf. In order to perform this numerical fit the shape of the asymmetries corresponding to different values of $|\Delta f|$ and $\varphi_{\Delta f}$ have to be known. Therefore we calculated the K° and $\overline{K^\circ}$ decay rate asymmetries for different values of $|\Delta f|$ and $\varphi_{\Delta f}$ (40×40 sets in steps of ± 0.1 fm and $\pm 0.5°$), and five different kaon momentum bins. By comparing in each momentum bin these asymmetries with the "experimental" asymmetry we obtain the χ^2-distribution for $|\Delta f|$ and $\varphi_{\Delta f}$. From this distribution we extract at $\chi^2 = \chi^2_{\rm min}$ the pair $|\Delta f|$ and $\varphi_{\Delta f}$, whereas the errors and correlations for $|\Delta f|$ and $\varphi_{\Delta f}$ are given by the values at $\chi^2 = (\chi^2_{\rm min} + 1)$ (see table 2). Except for the first momentum region, the measurements of the modulus and phase are strongly correlated as can be understood from eq. 3. However the fact that the absorber has a cylindrical geometry results in values for τ_R which depend on the K° momentum direction, and therefore decouples partially $|\Delta f|$ and $\varphi_{\Delta f}$.

It turns out that by using the complete covariance matrix the error on φ_{+-} due to the regeneration corrections remains small despite of the large correlation of $|\Delta f|$ and $\varphi_{\Delta f}$. We estimated the dependence of the CPLEAR measurement of φ_{+-} in first order to $|\Delta f|$ and $\varphi_{\Delta f}$ (see table 3). The remaining uncertainties on the measurement of φ_{+-} due to regeneration corrections are shown in table 4 together with the presently estimated uncertainty. We conclude that the measurement of Δf would eliminate the regeneration corrections as the dominating source of the systematic error of the φ_{+-} measurement.

2.3 Systematic Errors

The effect of multiple scattering inside the absorber material on the momentum and vertex resolution was studied with a Monte Carlo simulation and was found to be small compared to the measurement error of the drift chambers. The number of wrongly identified decays outside the absorber amounts to about 3% causing only a small dilution of the measured asymmetry. The systematic error resulting from the uncertainty of Δm should be less than $0.6°$ for $\varphi_{\Delta f}$ and negligible for $|\Delta f|$.

3 SUMMARY

To strongly reduce the systematic error due to regeneration effects in the measurement of the phase φ_{+-} in the CPLEAR experiment, we propose to measure Δf, the difference of the forward scattering amplitudes, for low $K°$ and $\overline{K°}$ momenta. With 70 days of running in '96 we expect to determine Δf in carbon for a $K°$ momentum between 250 and 350 MeV/c with a precision of 2% for the modulus and $2°$ for the phase. At higher $K°$ momenta (up to 750 MeV/c) we will obtain correlated information on the modulus and the phase of Δf. This will enable us to reduce the systematic error on our measurement of φ_{+-} induced by the regeneration effect to about $0.1°$.

Table 1: Central values for the difference of scattering amplitudes in carbon used in the simulation

Momentum interval [MeV/c]	$\lvert\Delta f\rvert$ [fm]	$\varphi_{\Delta f}$ [°]
[250 – 350]	5.09	−136.1
[350 – 450]	5.82	−130.5
[450 – 550]	6.24	−140.5
[550 – 650]	7.46	−143.7
[650 – 750]	10.63	−144.4

Table 2: Covariance matrix

Momentum interval [MeV/c]	$\sigma(\lvert\Delta f\rvert)$ [fm]	$\sigma(\varphi_{\Delta f})$ [°]	correlation coefficient
$[250-350]$	0.13	2.1	-0.01
$[350-450]$	0.24	3.5	0.90
$[450-550]$	0.49	6.0	0.97
$[550-650]$	0.47	3.2	0.96
$[650-750]$	0.55	2.2	0.92

Table 3: Dependence of φ_{+-} on Δf amplitude and phase

Momentum interval [MeV/c]	$\partial\varphi_{+-}/\partial\lvert\Delta f\rvert$ [°][fm^{-1}]	$\partial\varphi_{+-}/\partial\varphi_{\Delta f}$ [%]
$[250-350]$	-0.89	3.3
$[350-450]$	-0.62	7.0
$[450-550]$	-0.45	5.1
$[550-650]$	-0.29	4.8
$[650-750]$	-0.23	5.0

Table 4: Systematic error of φ_{+-} from regeneration

Momentum interval [MeV/c]	present [°]	1996 [°]
$[250-350]$	0.66	0.14
$[350-450]$	0.78	0.13
$[450-550]$	0.58	0.11
$[550-650]$	0.51	0.04
$[650-750]$	0.55	0.05

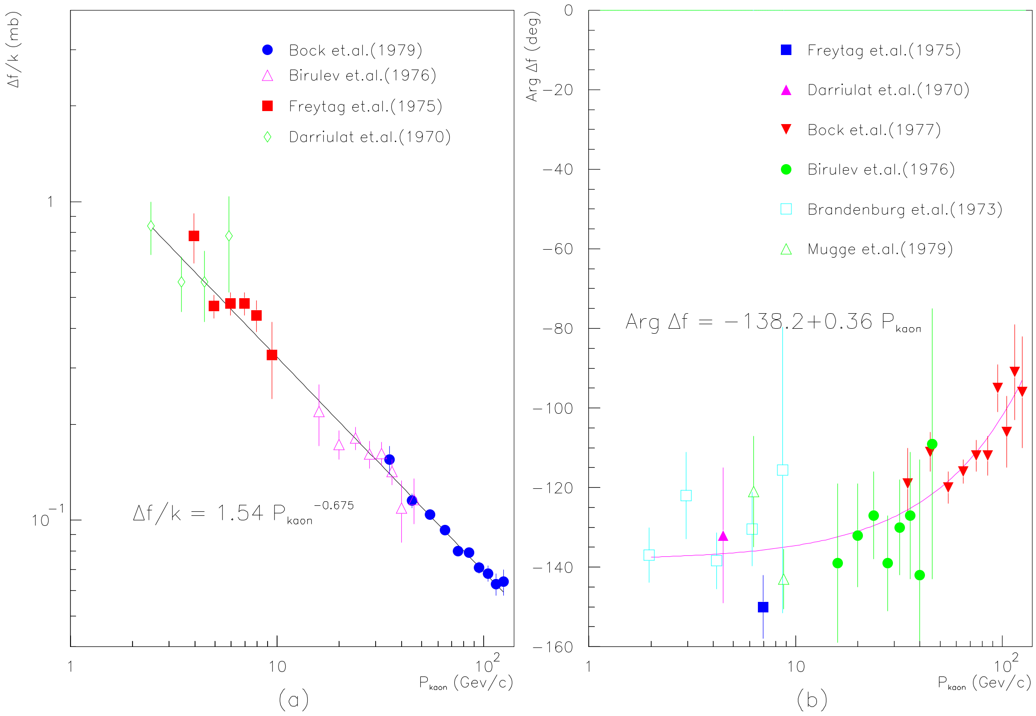

Figure 1: Measured difference of the K° and $\overline{\mathrm{K}^{\circ}}$ forward scattering amplitudes in hydrogen as function of the kaon momentum, a) modulus and b) phase

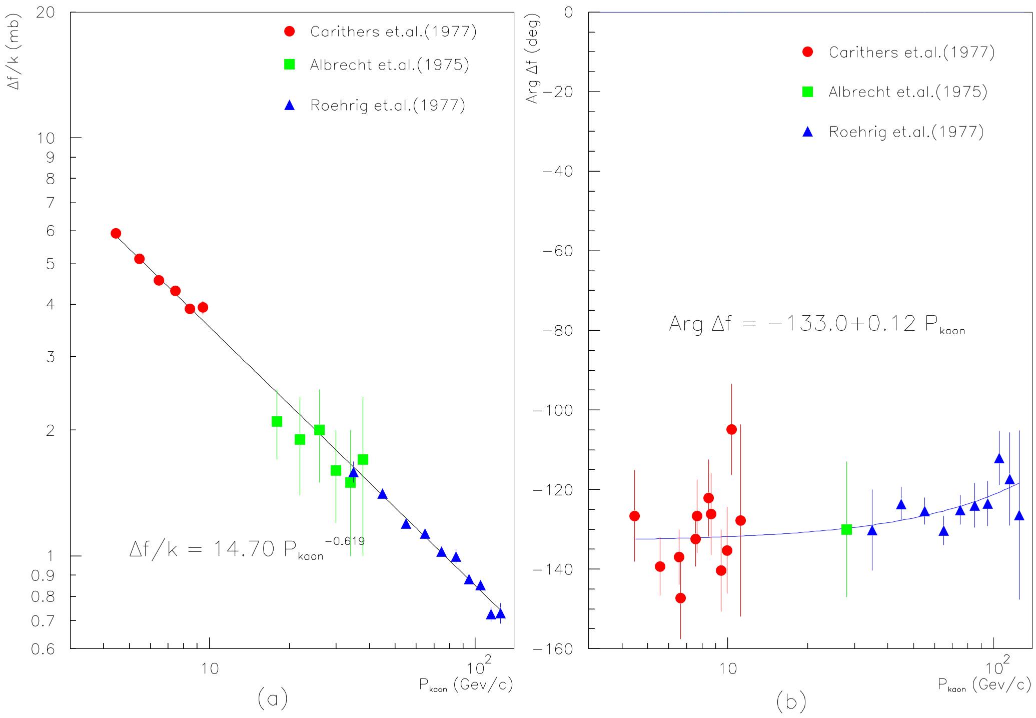

Figure 2: Measured difference of the K° and $\overline{\mathrm{K}^{\circ}}$ forward scattering amplitudes in carbon as function of the kaon momentum, a) modulus and b) phase

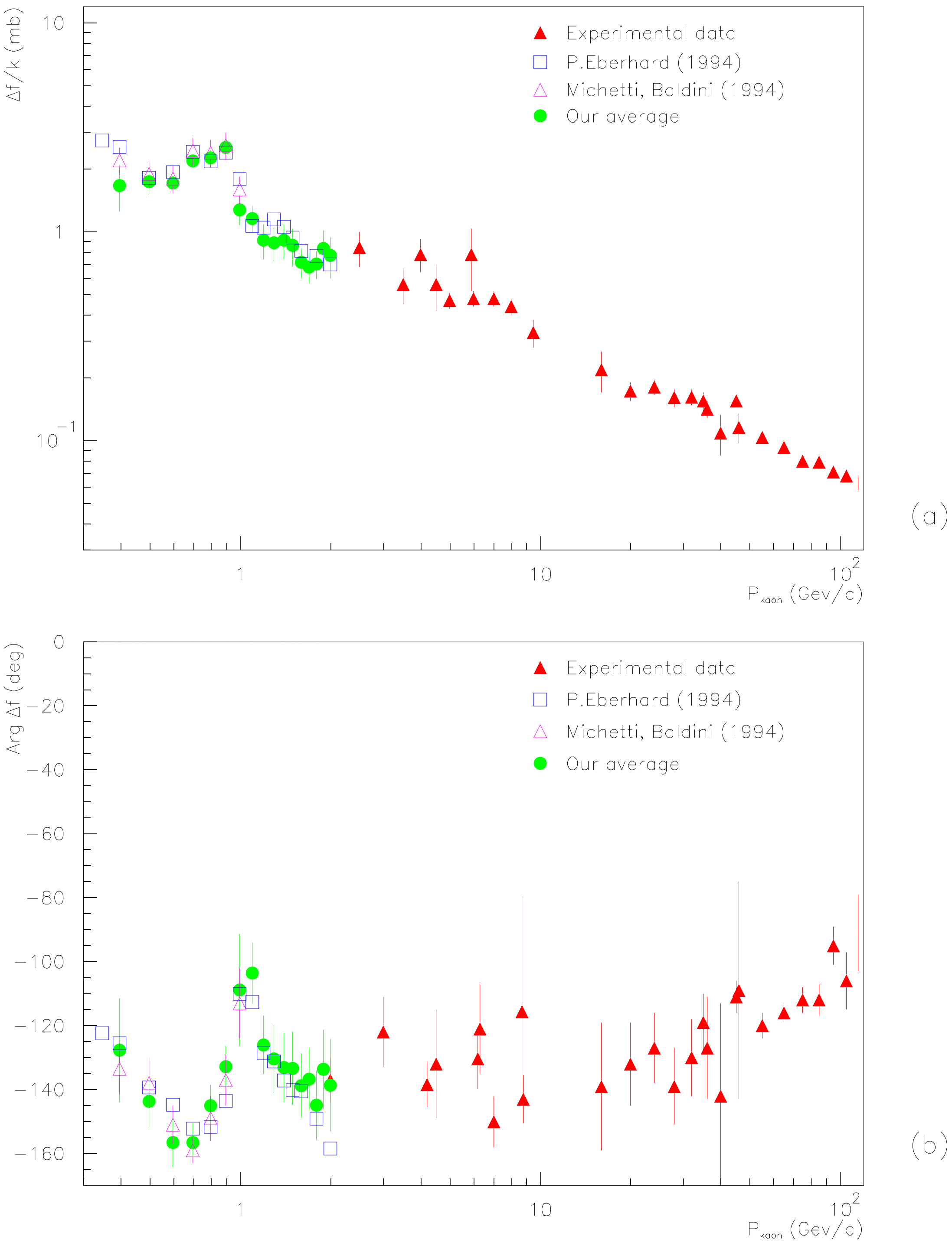

Figure 3: Difference of the K° and $\overline{\mathrm{K}^\circ}$ forward scattering amplitudes in hydrogen as function of the kaon momentum, calculated and measured values for the modulus (a) and phase (b)

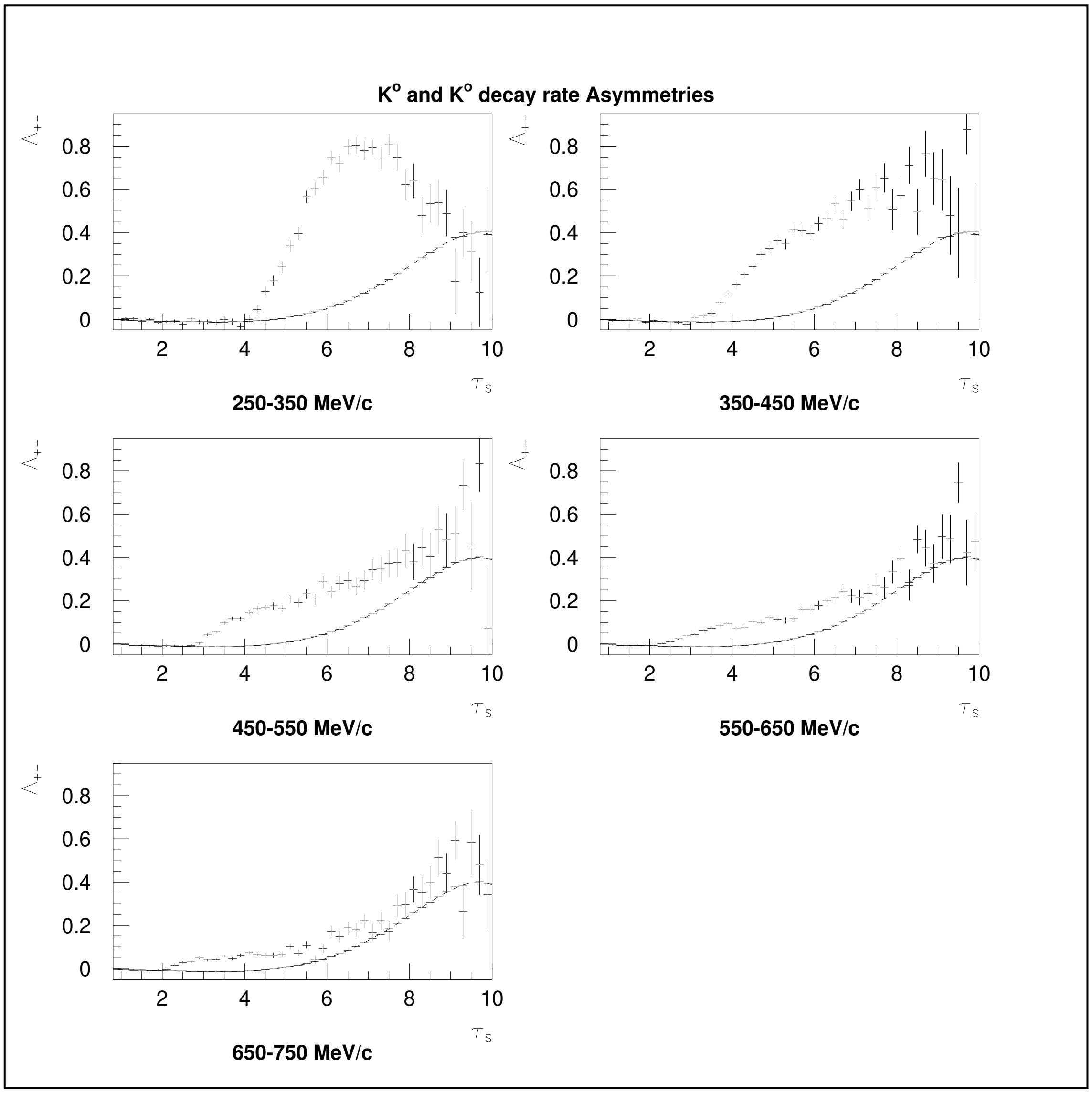

Figure 4: $\overline{\mathrm{K}^\circ} - \mathrm{K}^\circ$ decay to $\pi^+\pi^-$ rate asymmetries for 5 intervals of the kaon momentum, as a function of the proper time τ (in units of the K_S mean lifetime τ_S). The dashed line is the asymmetry without regenerator (Eq. 2 with I=0) and the points are Monte Carlo data with a 2 cm carbon regenerator at 7 cm from the target.

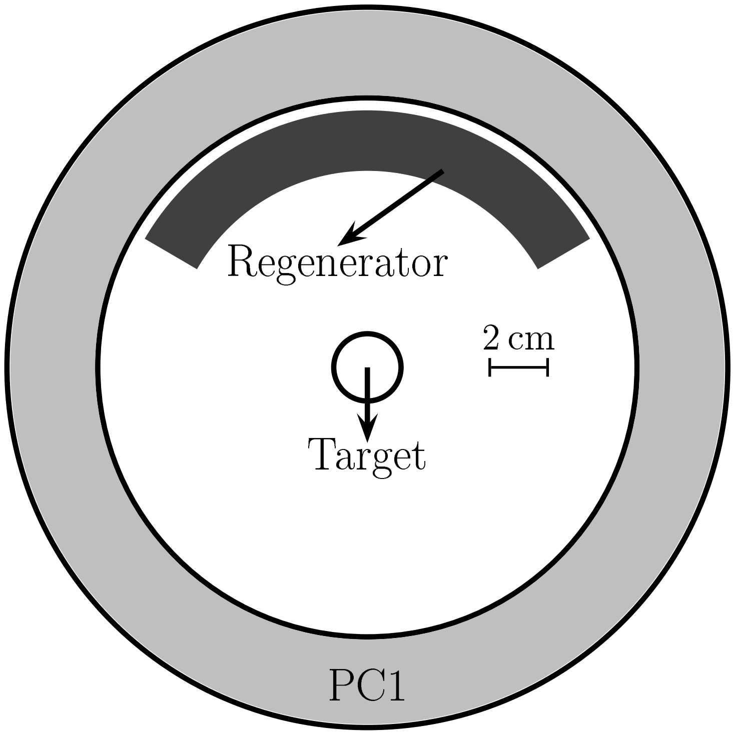

Figure 5: Schematic view of the regenerator inserted in front of the inner proportional chamber (PC1)

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