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PROPOSAL FOR AN EXPERIMENT TO STUDY THE $\Delta S/\Delta Q$ RULE IN THE PROPAGATION OF AN INITIALLY PURE K^o STATE

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1. INTRODUCTION

We propose to study the decay law of an initially pure K^o state in the decay modes $(e^{\pm} \pi^{\mp} \nu)$. To this purpose we would charge-exchange a K^+ beam on a copper target and detect the K_{e3} decays of both lepton charges as a function of position behind the charge-exchanger over a region of about 10 K_S^o mean-lives. Restricting to K^o produced in elastic charge-exchange we can predict their momentum from the observed scattering angle and use this as additional constraint in the kinematical reconstruction. Events which do not fit will be excluded from the analysis. From our previous experience on leptonic decays, we estimate that the momentum of each event will then be determined to about 2 %. The K^o momentum is used to express the decay position in the K^o rest frame. The intensity is expected to have the distribution:

$$N^+(e^+ \pi^- \nu) + N^-(e^- \pi^+ \nu) =$$

$$(1) \quad \epsilon(t)\ \tfrac{1}{2}|f|^2 \left\{ |1+x|^2 e^{-\Gamma_S t} + |1-x|^2 e^{-\Gamma_L t} - 4\, \mathrm{Im}\, x \sin \Delta m t\, e^{-\frac{1}{2}(\Gamma_S t + \Gamma_L t)} \right.$$

$$(2) \quad N^+ - N^- = (1 - |x|^2)\ \epsilon(t)\ |f|^2 \cos \Delta m t\, e^{-\frac{1}{2}(\Gamma_S t + \Gamma_L t)}$$

where $x = \frac{g}{f} = \frac{\text{amplitude } (\Delta S/\Delta Q = -1)}{\text{amplitude } (\Delta S/\Delta Q = +1)}$, and CPT invariance is assumed, Δm is the $K_L^o - K_S^o$ mass difference and $\epsilon(t)$ is the time dependent detection efficiency. Distribution (1) is shown for two cases in Figure 1, for $x = 0$ and $x = 0.3\, e^{i\pi/2}$.

The purpose of the experiment is

(1) to search for decays with $\Delta S/\Delta Q = -1$ and eventually push the upper limit on $|x|$ to ≈ 0.01.

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(2) If a non-zero value of $|x|$ is found : to determine whether it is CP violating.

(3) To measure $|\Delta m|$ for CP non-violating amplitudes to a precision comparable to the results obtained using CP violating amplitudes.

The results of previous experiments are summarized in Table I. Below, we describe a set-up which should be capable, at the predicted rate, to give a factor 100 more events than obtained before.

II. THE K^o BEAM

The total cross section for charge exchange

$$K^+ n \rightarrow K^o p$$

has been measured at 2.3 GeV/c to 1.5 mb per neutron. On a heavy nucleus this reaction is expected to be coherent at small angles and the number of effective neutrons in a Cu nucleus can be estimated to 18.0 from other coherent scattering processes which have been observed. We then expect a total cross section of 27 mb per Cu nucleus and an angular distribution, characterized by the radius of the Cu nucleus, with a r.m.s. angle of about 30 mrad at 2.3 GeV/c. Using a charge-exchange target consisting of 4 Cu slices, each 1 cm thick, sandwiched with a spark chamber to localize the point of K^o production to ± 0.5 cm (corresponding to ± 0.04 Λ_S) we expect then

$$N_{K^o} \simeq 10^{-2} N_{K^+} .$$

An anticoincidence shield will reject most of the inelastic charge exchange reactions. The existing m_4 beam gives about $2 \cdot 10^4$ K^+ at 2.3 GeV/c per $4 \cdot 10^{11}$ p on target # 1 . This flux could be improved in an electrostatically separated beam of reduced length derived at small angle from the ejected proton beam e_3 .

III. DETECTOR FOR K_{e3} DECAYS

The proposed detector is sketched in figure 2. In designing it we had the following desirable properties in mind:

(1) unambiguous identification of the K_{e3} decay mode and of the lepton charge;

(2) good resolution in reconstructing the decay kinematics to obtain the K^o momentum to ± 2 %;

(3) small and monotonous variation of the time dependent detection efficiency.

The detector selects a band of transverse momentum of charged secondaries, $p_\perp = 100 \pm 50$ MeV/c. Inside this band a fraction of 0.03 K_{e3} 0.03 $K_{\mu 3}$ and 0.006 $K_{2\pi}$ decays are accepted over 10 Λ_S. Electrons from K_{e3} decays are detected in two independent cells of the gas-filled threshold Čerenkov counter Č. Muons from $K_{\mu 3}$ decays are detected behind 500 gr/cm^2 of iron. The known fraction of detected $K^o \rightarrow 2\pi^{\pm}$ decays will serve to monitor the K^o flux.

Before describing the system in more detail, it is useful to in-investigate the sensitivity of the observed decay distribution to the three parameters to be determined, Re x , Im x and $\Delta m/\Gamma_S$. To this purpose the uncorrelated variances have been calculated. In general

$$\sigma_a = \frac{1}{\sqrt{N}} \left[\int_0^T \frac{1}{f} \left(\frac{\partial f}{\partial a} \right)^2 dt \right]^{-1/2}$$

where f is the normalized distribution function, σ_a is the variance of the parameter $\underline{a}$ and N is the number of events observed in the time interval T. An inverval of 10 Λ_S appears to contain most of the information on Im x and Δm. The integrated values give

$$\sigma_{|x|} \sqrt{N} = 1.5$$
$$\sigma_\delta \sqrt{N} = 3.0 .$$

Notice that $\sigma_{\Delta m}$ is not correlated with Re x and Im x in the distribution of $N^+ - N^-$. Consequently the detector has been designed for maximum acceptance over 10 Λ_S or ≈ 120 cm.

A window defined by 3 counter hodoscopes accepts about $3 \cdot 10^{-2}$ integrated over 10 Λ_S and the azimuthal angle. The magnet is a modified 2 m standard bending magnet with 50 cm gap height.

IV. TRIGGER RATE OF $K^0 \to e\pi\nu$

Putting together the probability for elastic charge-exchange, the K^+ flux, and the detection efficiency over 10 Λ_S, we obtain a trigger rate of $4.2 \cdot 10^{-2} / 3 \cdot 10^{11}$ protons or 1300 per day. It would seem desirable to run the experiment for 3 periods of 10 days, to obtain at least 30 000 K_{e3} events.

This rate could be increased by a factor of 2 to 3 if inelastic charge exchange would be accepted. This is certainly an advantage for setting up purposes. Whether these events are useful to contribute to the time distribution remains to be investigated.

V. SPARK CHAMBERS

We propose to use a system of wire-spark chambers with core read-out. This system will use the information on both the ground and the high voltage plane in order to reduce the number of independenct gaps. This will reduce the difficulties with pattern recognition due to spurious sparks. Another feature to assist in the pattern recognition is a rough hodoscope system to indicate to the read logics cells in which particle trajectories are expected.

VI. CONCLUDING REMARKS AND TIME SCHEDULE

In our opinion, the proposed experiment would benefit from 3 essential advantages over previous experiments:

(1) Knowledge of K^0 momentum for individual events and constructions of unambiguous time distribution in the K^0 rest frame.

(2) Identification of all electrons from K_{e3} decays by a Čerenkov counter.

(3) Improved statistics by 2 orders of magnitude.

The wire chamber system is under design for experiments on the muon beam. It could be ready and tested for this experiment in fall 1967 without delaying experiments on the muon beam.

A branch of the m_4 beam could be used without modifications.

The proposed modifications on a 2 m standard bending magnet are estimated to take 3 - 4 months.

Table I

$\Delta S = \Delta Q$ RULE

K^o_{e3} time dependence:

$$\Gamma^{\pm} = |1+\chi|^2 e^{-\gamma_1 t} + |1-\chi|^2 e^{-\gamma_2 t} + \left[\pm 2(1-\chi^2)\cos\Delta mt + 4|\chi|\sin\theta\ \sin\Delta mt\right] e^{-(\gamma_1+\gamma_2)t/2}$$

$\chi \equiv g/f = |\chi| e^{i\theta}$

$g \equiv A(\overline{K}^o \longrightarrow e^+\pi^-\nu)$, $f \equiv A(K^o \longrightarrow e^+\pi^-\nu)$

$\Delta m \equiv m_S - m_L$ (taken to be positive in summary of results for θ)

$\pm$ indicates charge of lepton

χ is real if CP conserved

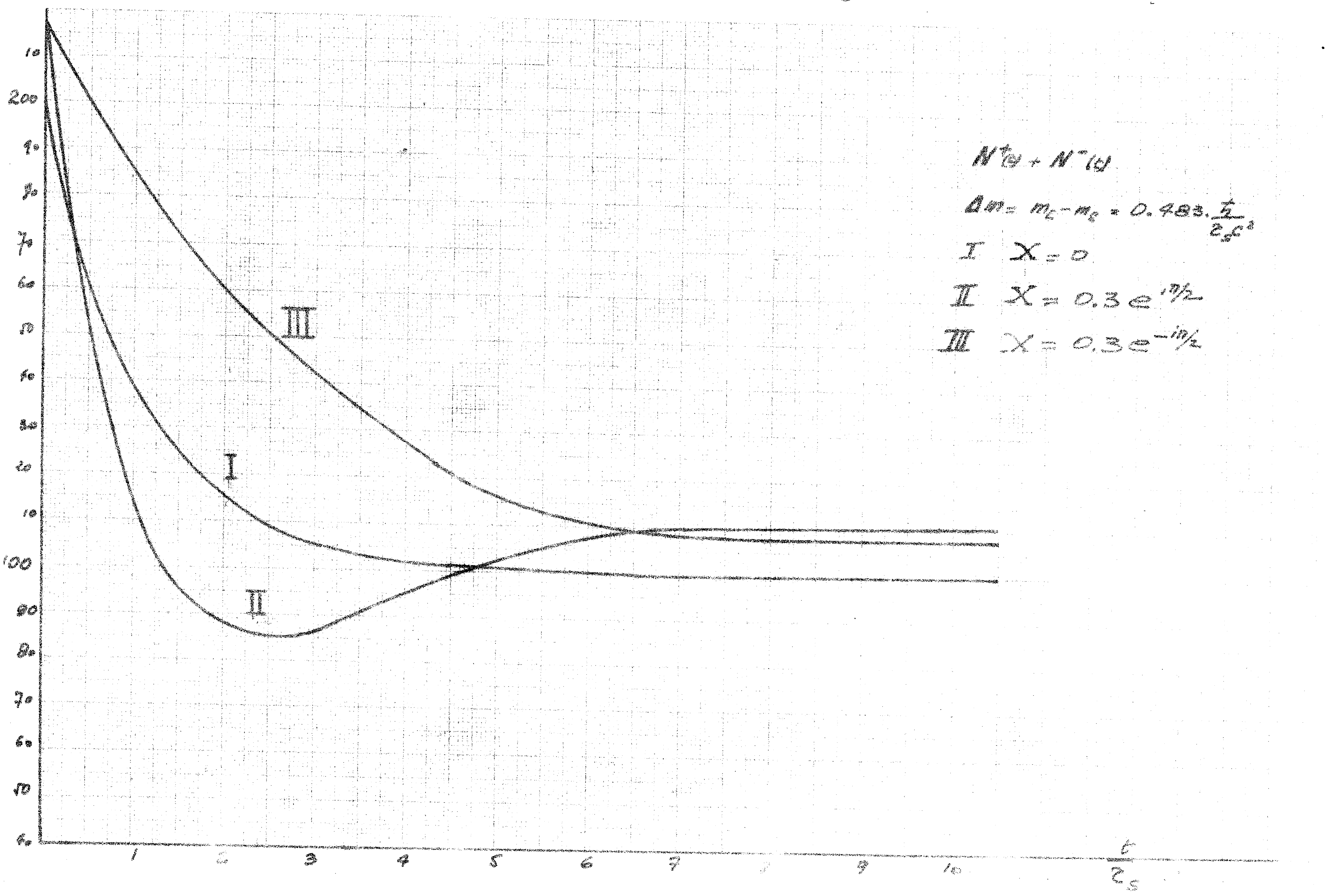
$\chi = 0$ if $\Delta S = \Delta Q$

A new limit for the validity of the $\Delta S = \Delta Q$ rule for the axial vector current has been established, based on the absence of the decay mode $K^+ \rightarrow e^-\pi^+\pi^+\nu$. The upper limit on χ thereby determined is 0.13 (90% confidence). (Birge et al, "Low Energy π-π Interaction Studies from Ke4 Decays", presented to this session.)

(for Δm positive)

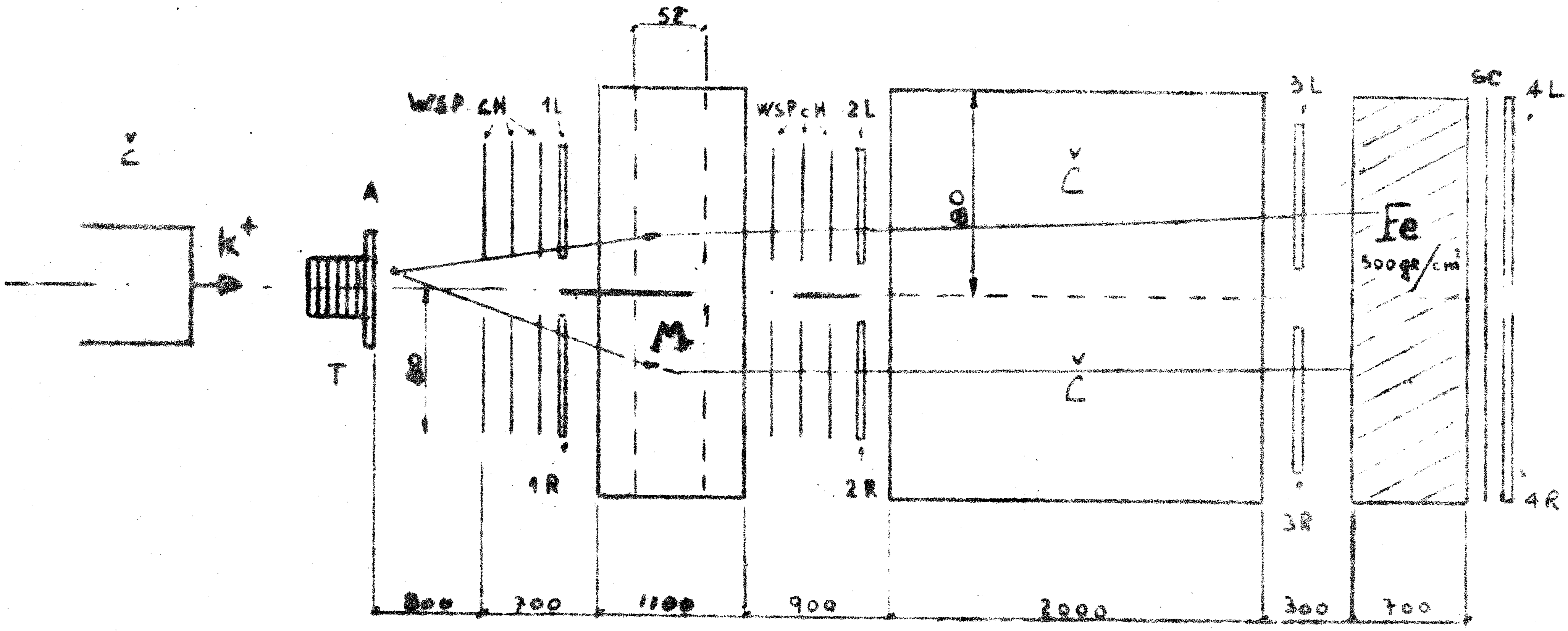
Reference	Technique	$\lvert\Delta m\rvert$	Re χ	Im χ	$\lvert\chi\rvert$	θ	No of events
Paris PL 17, 59 (65)	FrBC: $K^+n \longrightarrow K^o p$	0.47 ± 0.21	$0.035^{+0.11}_{-0.13}$	$0.215^{+0.15}_{-0.11}$	$0.22^{+0.16}_{-0.11}$	$+79^o\ {}^{+37}_{-27}$	209
Padua NC 38, 684 (65)	FrBC: $K^+n \longrightarrow K^o p$	$0.15 \pm {}^{0.50}_{0.35}$			$0.44^{+0.19}_{-0.25}$	$+82\ {}^{+68}_{-26}$	63
Columbia PR 140, 127 (65)	HBC: $\overline{p}p \longrightarrow K^o\overline{K}^o$	$\equiv 0.5$			$0.24^{+0.33}_{-0.24}$	$-109\ {}^{+70}_{-43}$	109
*Pennsylvania	SprK: $\pi^-p \longrightarrow \Lambda K^o$	?	$0.187^{+0.16}_{-0.35}$	0.0 ± 0.25			
*Carnegie Tech.	D_2BC: $K^+n \longrightarrow K^o p$	$\equiv 0.58$	$0.18^{+0.10}_{-0.14}$	$0.19^{+0.14}_{-0.12}$	$0.27 + 0.12$	$+43^o \pm 33^o$	
*LRL	HBC: $\pi^-p \longrightarrow \Lambda K^o$	$\equiv 0.54$	$\left\lvert\frac{1+\chi}{1-\chi}\right\rvert^2 = -0.7^{+1.2}_{-0.8}$;	$\frac{2\,\mathrm{Im}\,\chi}{\lvert 1 - \chi\rvert^2} = +0.6^{+0.5}_{+0.7}$			

*Paper presented to this session.



N⁺(t) + N⁻(t)
Δm = m₁ − m₂ = 0.483 ħ/τ_s c²
I X = 0
II X = 0.3 e^{iπ/2}
III X = 0.3 e^{−iπ/2}
I
II
III
t/τ_s
1
2
3
4
5
6
7
9
10
10
200
90
80
70
60
50
40
30
20
10
100
90
80
70
60
50
40

PLAN VIEW



M: Modified 2 meter standard magnet 50 cm gap height

Fig 2