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A MONOCHROMATIC NEUTRAL KAON BEAM

by

Cyrus M. Hoffman

ABSTRACT

A design for a monochromatic, neutral kaon (K^0) beam, which could be constructed at a "Kaon Factory," is described. Possible uses of such a beam are discussed.

I. INTRODUCTION

Neutral kaon beams have been plagued by large neutron backgrounds and large energy spreads. The large neutron fluxes increase the singles rates in detectors and so increase background rates. This can prevent the placing of detectors or other material in the beam which can make experiments difficult, if not impossible. The large K^0 energy spread implies an experimental design which is flexible enough to accommodate the range of energies and precludes the use of the reconstructed K^0 energy as a constraint. We describe a scheme whereby a monochromatic K^0 beam¹ might be produced at a "kaon factory"² which would have only modest neutron contamination. Some potential uses of such a beam are discussed.

II. EXISTING K^0 BEAMS

We are now in a period where no low-to-medium energy K^0 beams exist in the world. There are no K^0 beams at CERN,³ KEK,⁴ or SLAC,⁵ so that, with the closing of the ZGS, the only K^0 beams are at Serpukhov, Fermilab and at the AGS. The neutral beams at Serpukhov and Fermilab are high-energy beams, generally in excess of 50 GeV. There are two neutral beams at the AGS.⁶ The A_3 beam produces $\sim 10^6$ K_L /pulse with $1 < p < 11$ GeV/c and ~ 12 neutrons/ K^0_L . The B_5 beam is a short beam (2.6-m long) which yields $\sim 2 \times 10^5$ K_L /pulse with momenta from 1 to ~ 15 GeV/c and 15 neutrons/ K^0_L . Other K^0 beams used to exist at the CERN-PS, the AGS and the ZGS with generally similar parameters.

III. GENERAL CONCEPT

All existing K^0 beams are produced via proton collisions with some heavy nucleus: this accounts for both the large neutron contamination and the large energy spread. The construction of a very high intensity ($\sim 100 \mu A$),

~20-GeV proton accelerator (a "kaon factory") would make possible tertiary production of monochromatic K^0 beams with small neutron contamination. The basic idea is as follows: the high-intensity proton beam strikes a target producing (among other things) K^- 's. A short, high-flux separated K^- beam delivers the K^- to a liquid hydrogen target where $\bar{K}^0$'s are produced via the reaction $K^-p \rightarrow \bar{K}^0n$. Since the K^- are momentum-analyzed in the K^- beam section, and the $\bar{K}^0$'s are produced in a two-body reaction, the $\bar{K}^0$'s have a well-defined energy. Neutron contamination should be low since a beam with enriched strangeness is used to produce the neutral kaons.

IV. DESIGN

In this section we present a candidate beam design and discuss the beam properties which might result. In order to simplify the problem, we assume that the K^- beam section has characteristics somewhere between those of LESB I and LESB II at the AGS:⁶ this takes some account of the lower proton energy (20 GeV rather than 28 GeV) and is certainly achievable. The parameters of the K^- beam are then:

Momentum	1050 MeV/c
$K^-/10^{12}$ protons	2×10^6
Production angle	7°
$\Delta p/p$	$\pm 2\%$
Beam spot	$1/2" \times 1/2"$
K^-/π^- (After separation)	1/9.

The momentum of 1050 MeV/c is chosen to take advantage of a local maximum in the $K^-p \rightarrow \bar{K}^0n$ cross section caused by the production of the Λ^* (1830). The total cross section is 8.3 mb and $d\sigma/d\Omega^*|_{0^\circ} = 13.3 \pm 2$ mb/sr.⁷ We will assume a proton current of 2×10^{14} protons/s (35 μ A) incident on the production target. This will produce a K^- beam with 4×10^8 K^- /s and 4×10^9 π^- /s. The number of $\bar{K}^0$'s produced at 0° by a 1M liquid hydrogen target is then

$$\begin{aligned} \# \bar{K}^0/s &= (\# K^-/s) \times (\rho \text{ LH}_2) \times (\text{Length LH}_2) \times \left(\frac{d\sigma}{d\Omega^*} \right)_{\theta=0} \times \left(\frac{d\Omega^*}{d\Omega} \right) \times (\Delta\Omega) \times (N_{AV}) \\ &= (4 \times 10^8) \times (0.07) \times (100) \times (13.3 \times 10^{-27}) \times (3.5) \times (\Delta\Omega) \times (6 \times 10^{23}) \\ &= (7.8 \times 10^7) \times \Delta\Omega(\text{ster}). \end{aligned}$$

where Ω^* refers to the center-of-mass and Ω to the laboratory. Neutron production will be dominated by $\pi^-p \rightarrow \pi^0n$: for neutrons produced at 0° in the lab, the interesting region is at $\theta_{CM}^* = 180^\circ$. The π^-p charge exchange cross

section at 180° is 0.5 ± 0.1 mb/ster⁸ (in the center of mass) or ~ 3 mb/ster in the laboratory: the neutron momentum is 1354 MeV/c. The neutron flux is then

$$\begin{aligned} \#n/s &= (\# \pi^-/s) \times (\rho \text{ LH}_2) \times (\text{Length LH}_2) \times \left(\frac{d\sigma}{d\Omega} \Big|_{180^\circ}\right) \times (\Delta\Omega) \times N_{AV} \\ &= (4 \times 10^9) \times (0.07) \times (100) \times (3 \times 10^{-27}) \times (\Delta\Omega) \times (6 \times 10^{23}) \\ &= (5 \times 10^7) \times \Delta\Omega(\text{ster}). \end{aligned}$$

While there will certainly be additional channels contributing to the neutron flux, it is clear that the neutron to $\bar{K}^0$ ratio will be $O(1)$, roughly a factor of 10 better than existing beams.

In order to obtain a useful $\bar{K}^0$ flux, the neutral beam solid angle must be large; presumably between 10^{-3} and 10^{-2} steradians. Since the flux incident on the hydrogen target is comparable to the flux used to produce the B_5 K^0 beam at the AGS ($\sim 5 \times 10^9/s$) and the incident energy is significantly lower (~ 1 GeV vs 28 GeV), adequate shielding can probably be achieved in less than 2.6 M; let's say 2 M will be required. We then want a beam spot of from 40 cm^2 to 400 cm^2 , not unreasonable.

The neutral beam will consist of a sweeping magnet to divert the incident K^-/π^- beam away and to sweep out any charged particles produced in the hydrogen target, 5 to 10 radiation lengths of material to convert photons, another sweeping magnet, and collimators to define the beam. The choice of radiator thickness and collimator arrangement will be flexible since they are not located in high radiation areas.

V. K^0 ENERGY SPREAD

Assuming $\bar{K}^0$ production at 0° from $K^-p \rightarrow \bar{K}^0 n$ at 1050 MeV/c, $\frac{\partial E_{K^0}}{\partial \theta_{\text{Lab}}} = 1.5$

MeV/deg. Thus the $\bar{K}^0$ energy spread will be dominated by the $\Delta p/p$ in the incident K^- beam, assumed to be several percent. There will be some low energy $\bar{K}^0$'s from more complicated reactions such as $K^-p \rightarrow \bar{K}^0 p \pi^0$ but the cross sections for these reactions are small.⁹

VI. USES OF BEAM

The obvious uses of a neutral kaon beam are CP-violation studies. Of special interest are precision measurements of the magnitudes and phases of η_{00} and η_{+-} , and the magnitude of the K_L - K_S mass difference, precision studies of charge asymmetries in $K^0 \rightarrow \pi^\pm e^\mp \nu$ and $\pi^\pm \mu^\mp \nu$, and searches for T-violation in $K^0 \rightarrow \pi \mu \nu$. Gauge theories of CP violation have been formulated,¹⁰ but the source of the CP violation and the strength of CP violation ("superweak" or "milliweak") have yet to be settled. Some models¹⁰ predict deviations from "superweak" predictions which are only slightly smaller than current experimental resolution. Thus improving the determination of the CP violation parameters is very important. In these measurements and in other experiments, knowledge of the K^0 energy provides an added constraint and would help suppress backgrounds.

Experimental studies of $K^0 \rightarrow \pi e \nu$ and $K^0 \rightarrow \pi \mu \nu$ have been plagued by a well-known two-solution ambiguity.¹¹ The two solutions correspond to the ν going forward or backward in the center of mass. Knowledge of the K^0 energy resolves the ambiguity. This will be invaluable in studies of this decay mode to study the form factors of the K - π vertex, the CP-violating charge asymmetries and the $\Delta S = \Delta Q$ rule. Studies of rare decay modes such as $K_L \rightarrow \mu^+ \mu^-$ (and measuring the muon polarization) and $K_L \rightarrow \mu^\pm e^\mp$ ¹² may require higher K^0 fluxes.

A monochromatic $\bar{K}^0$ beam also allows $\bar{K}^0$ -N scattering experiments. These can be useful in determining the $\bar{K}N$ phase shifts.

VII. CAVEATS

The calculations performed for this study are quite crude. No Monte Carlo studies have been performed; no second-order processes have been considered. Accordingly, all results should be taken in this spirit: they indicate the orders of magnitudes to be expected but certainly may be incorrect by factors of two.

ACKNOWLEDGMENTS

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