THE SIMULTANEOUS AND NEARLY-COLLINEAR K0 BEAMS FOR EXPERIMENT NA48

C.Biino[1], N.Doble, L.Gatignon[2], P.Grafström, H.Wahl, CERN, Geneva, Switzerland

Abstract

A system of simultaneous and nearly-collinear beams of long- and short-lived neutral kaons has been installed and extensively studied. These beams form an integral part of the NA48 experiment at the CERN SPS, which aims to study direct CP-violation. The beam splitting is achieved by a novel application of a bent silicon crystal. The principles and design of these beams, as well as their performance are described.

1 DESIGN CONCEPT

In order to minimise systematic differences in the relative measurement of the decay rates $K_L \rightarrow \pi^o\pi^o$, $K_L \rightarrow \pi^+\pi^-$, $K_S \rightarrow \pi^o\pi^o$ and $K_S \rightarrow \pi^+\pi^-$, beams of long- and short-lived neutral kaons, K_L and K_S, are required to enter the same fiducial region simultaneously and nearly-collinearly, converging at a small angle towards a common set of detectors [1].

Whereas a primary proton beam of high energy (450 GeV) and high flux ($\approx 10^{12}$ protons/s) is required to produce sufficient $K_L \rightarrow 2\pi$ decays, a proton flux that is lower by a factor $\approx 10^5$ suffices to produce a comparable number of K_S decays. The lower flux renders possible the attribution of the detected decays to K_S or K_L by tagging the protons used to produce the K_S.

The protons which produce the K_S are obtained by splitting off a small fraction of the primary beam, taking advantage of the phenomenon of ‘channeling’ in a bent crystal. The method combines the functions of reducing the flux, deflecting the selected protons away from accompanying background and defining a beam of small emittance, well-suited to produce the K_S.

The acceptances for detecting the $\pi^o\pi^o$ and $\pi^+\pi^-$ decays are each functions of the kaon momentum (p_K) and longitudinal position of the decay vertex (z). It is therefore important to render the momentum spectra of the K_L and K_S decays as similar as possible over the useful range of momenta ($70 < p_K < 170$ GeV/c) and over the range of z, which is chosen proportional to the mean K_S decay length λ_S. Weighting factors can then be applied to render the z-distributions and hence the acceptances equal for K_S and K_L decays.

2 THE SIMULTANEOUS K_L AND K_S BEAMS

2.1 Layout

A branch of the 450 GeV/c primary proton beam, slow-extracted from the CERN SPS towards the North Area, is used to produce the neutral kaon beams. These are installed in a 270 m long, underground tunnel complex, designed for high intensities. Due to the different mean decay lengths of K_L and K_S (λ_L = 3480 m, λ_S = 6 m, respectively, for a mean p_K=110 GeV/c), the beams are derived from protons striking two separate targets, respectively situated 126 m and 6.0 m upstream of the beginning of the decay region. The layout of the simultaneous K_L and K_S beams is shown schematically in Figure 1 and the nominal design characteristics of the beams are listed in Table 1.

Table 1: Design characteristics of the beams

	K_L	K_S
Primary protons per pulse	$1.5 \cdot 10^{12}$	$3 \cdot 10^7$
SPS spill length /cycle time (s)	2.38 / 14.4	
Production angle (mrad)	2.4	4.2
Length of K^o beam (m): Target to final collimator/AKS: Target to e.m. calorimeter:	 126.00 241.10	 6.07 121.10
Angle of convergence to K_L :	0 mrad	-0.6 mrad
Angular acceptance (mrad):	±0.15	± 0.375
Useful momentum range	$70 < p_K < 170$ GeV/c	
Fiducial length for decays = 4 λ_S	≈ 15 - 36 m	
K^o flux at exit final collimator	$\approx 2 \cdot 10^7$	$\approx 2 \cdot 10^2$
Decays between coll and detector	$\approx 1.4 \cdot 10^6$	$\approx 2 \cdot 10^2$
K^o flux in useful p_K and z range	$4.4 \cdot 10^4$	$1.5 \cdot 10^2$
$K^o \rightarrow \pi^o\pi^o$ decays per pulse in useful p_K and z range	40	45
Detector acceptance for $\pi^o\pi^o$ evts	≈ 0.20	

2.2 Primary proton transport to the K_L target

The 450 GeV/c primary proton beam passes through a pair of dump/collimators to select the wanted flux of nominally $1.5 \cdot 10^{12}$ protons per SPS pulse (2.38 s spill every 14.4 s). This beam is transported over a distance of

[1] Permanent address: INFN, Torino, Italy

[2] For the NA48 collaboration (Cagliari,Cambridge, CERN, JINR Dubna, Edinburgh, Ferrara, Florence, Mainz, LAL Orsay, Perugia, Pisa, Saclay, Siegen, Torino, Vienna, Warsaw)

838 m and is finally focused and directed vertically downward at an angle of 2.4 mrad onto the K_L target. The choice of 2.4 mrad reduces the flux of neutrons per useful K_L by a factor ≈4, for only 25% reduction of useful K_L per proton. These ratios relate to the relative backgrounds from proton- and neutron-induced sources.

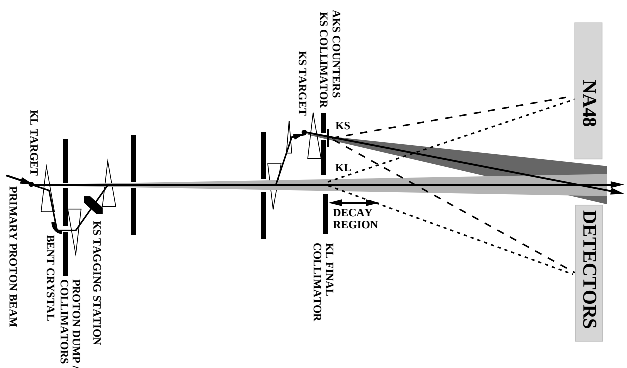

Figure 1: Schematic layout of K° beams

2.3 The K_L beam

The schematic layout of the K_L target station is shown in Figure 2. The K_L target consists of a 2 mm diameter, 400 mm long rod of Beryllium, aligned along the (horizontal) K_L axis. It is immediately followed by a copper collimator of 15 mm aperture, through which the neutral (K_L) and the remaining proton beams exit. A 10.8 Tm, vertically deflecting dipole magnet serves to sweep away charged particles, whereby the primary protons are deflected further downwards by 7.2 mrad. At a distance of 10.95 m from the target, they impinge on a bent crystal, centred 72 mm below the K_L beam axis. The crystal is designed to split off a wanted, small fraction of the protons by deflecting them through an upward angle of 9.6 mrad, back to the horizontal. The majority of protons and other particles, not deflected by the crystal, continue undeviated. With the exception of muons, they are absorbed in a pair of dump/collimators (TAX 17+18), fitted with tungsten-lined passages for the wanted beam.

The neutral (K_L) beam is collimated in three successive stages by ‘defining’, ‘cleaning’ and ‘final’ collimators. The final collimator is located from 120.7 to 124.3 m from the target and has an aperture (from 54 to 57.5 mm diameter) which fits in the gap of the last sweeping magnet. This is preceded by the cleaning collimator, of such an aperture as to prevent particles produced or scattered at the edges of the defining collimator from striking the final collimator. It is located ≈20 m (or ≈3 λ_S) upstream of the latter, to let KS which may be regenerated on its edges, decay away before reaching the fiducial volume. The condition that particles from the target should not strike the cleaning collimator leads to an optimum longitudinal position (≈41 m) and aperture (12.2 mm diameter) for the defining collimator, that maximise the acceptance of the neutral beam.

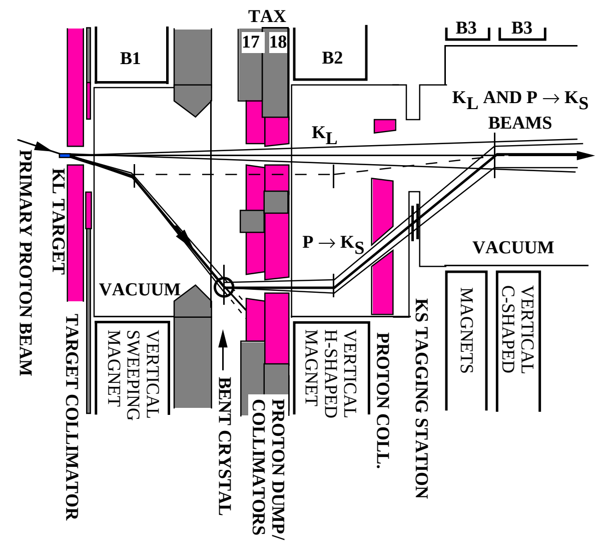

Figure 2: Schematic layout of the KL target station

2.5 The bent crystal

When positive particles enter a crystal within a small (‘critical’) angle to its planes, the collective Coulomb fields can cause them to be ‘channeled’. If the crystal is mechanically bent, some of the particles still follow the planes and are thus deflected. The present application requires only a small fraction ($\approx 5 \cdot 10^{-5}$) of those protons to be deflected which diverge towards the crystal from the K_L target. The crystal holder should allow the angle of deflection to be fine-tuned, whilst being insensitive to heat and irradiation by $\approx 10^{12}$ protons/cm^2 per pulse. The solution adopted has been described in detail in [2] and is shown schematically in Figure 3.

A mono-crystal of silicon, cut to dimensions of 60x18x1.5 mm^3, parallel to the (110) planes, is used. It is bent through an angle θ_o=18.7 mrad (greater than the required beam deflection angle θ=9.6 mrad) over 56 mm of its length, by pressing it against the cylindrical surface of an aluminium block, which has been precisely machined to the specified radius of curvature (R=3.0 m). The crystal holder is in turn mounted on a motorised goniometer, which allows the crystal to be aligned on the incident beam with two transverse displacements and two rotations about axes perpendicular to the beam. When the crystal is rotated through an azimuthal angle $\Phi \approx \pm 28.7^o$ about the vertical axis, the beam traverses the crystal diagonally. The effective fractional length of the crystal traversed and hence the vertical angle of deflection of the beam is then governed by adjusting the angle Φ. Moreover, a coupling (given by $dy'/dx=1/R \cdot \tan\Phi$) is introduced between the vertical angle (y’) and the lateral position (x) of the protons that can be channeled. Thus both the vertical and the horizontal emittances of the beam are defined by the crystal.

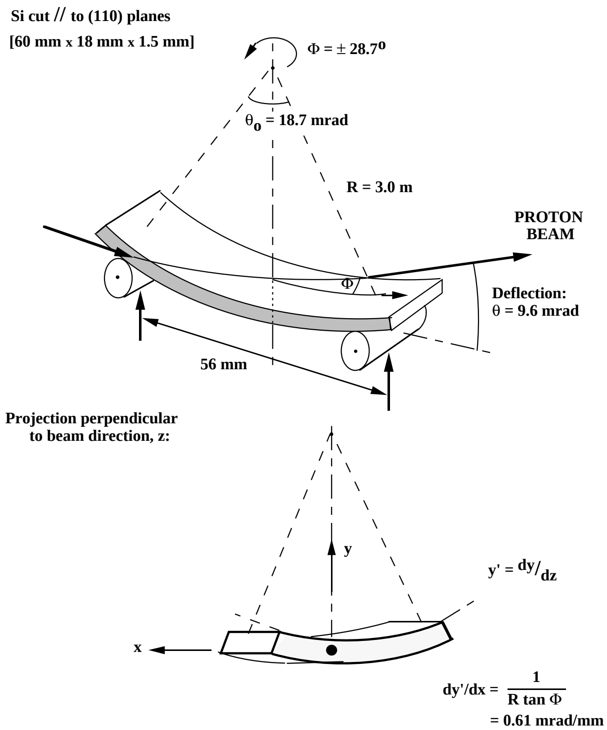

Figure 3: Schematic arrangement of the bent crystal

2.6 The K_S beam

The second of the beam dump/collimators downstream of the crystal (TAX 18) contains a set of tungsten-alloy inserts with graduated apertures of smallest diameter 2.4 mm, aligned on an axis 72 mm below and parallel to that of the K_L beam. There follows two magnets of opposite polarity, which deflect the transmitted protons back onto the K_L beam axis. In between these, the protons pass through a TAGGING STATION, which allows, by measurement of the time of flight between this station and the main detectors of the experiment, to distinguish whether an observed K^o decay originated from the K_S beam. The protons are steered through the cleaning and defining collimators on the K_L beam axis and are refocused to a point 109 metres downstream of the crystal. Before reaching this focus, they are again deviated away by further dipole magnets to a point 72 mm above the K_L beam at an upward angle of 3.6 mrad. Here they impinge on the K_S target, of similar dimensions to the K_L target.

The K_S target is followed by a 7.5 Tm sweeping magnet, filled with tungsten alloy inserts with two apertures, one for the K_l beam and one for the K_S aligned on an axis pointing downwards at an angle of 0.6 mrad, so as to intersect the (horizontal) K_L axis near the centre of the detectors, at a distance from the K_S target of 120 m. The resulting production angle of 4.2 mrad renders the ratio of K_S to K_L decays in the fiducial region (defined in units of λ_S) approximately equal at the two ends of the momentum range used (70 and 170 GeV/c). The sweeping magnet is followed by a steel collimator block, which again contains passages for the neutral beams, the one for K_S being filled with inserts, graduated from a beam-defining aperture of 3.6 mm diameter at 4.8 m from the target to a final diameter of 6 mm at the exit, 6.0 m after the target. At this point the K_L and K_S beams emerge into a common decay volume. For a given beam acceptance, the useful flux of K_S leaving the collimator relative to neutron-induced background from the edges of its defining aperture is maximised by the choice of the distance of that aperture from the target to be close to 1 λ_S.

3 OBSERVED RATES

The rates in the K_L and K_S beams can be monitored by stopping one of them in the dump collimators downstream of the K_L target. Some relevant counting rates at nominal intensities are listed in Table 2.

Table 2: Measured rates from KS (downstream of TAX 17), KL (downstream of TAX 17) and Bkgd = background from KL target station + proton dump, measured by detectors of the experiment.

Counting rate/SPS pulse	K_L	K_S	Bkgd	Total
Protons to K_L $*10^{12}$	1.5	-	-	1.5
Protons to K_S $*10^{7}$	-	3.0	-	3.0
Sum of Veto rings $*10^{6}$	2.0	0.6	4.2	6.8
Wire Ch.1 rate $*10^{6}$	1.2	0.07	0.9	2.2
Wire Ch.4 rate $*10^{6}$	1.1	0.05	0.5	1.7
Charged rate in NA48 hodoscope (Q-OR) $*10^{6}$	1.5	0.07	0.7	2.3
Coincidence of opposite quadrants of charged hodoscope (QX) $*10^{5}$	9.0	0.3	0.4	9.7
Muon rate (MU) $*10^{5}$	2.3	0.01	1.6	3.9
$K\mu_3$ rate (QX·MU) $*10^{5}$	2.0	0.0	0.1	2.1

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