A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

LA-UR--88-3733

DE89 003480

TITLE: A TRACKING RANGEFINDER FOR MUONS FROM KAON DECAY

AUTHOR(S): J. Frank, G. W. Hart, W. W. Kinnison, D. M. Lee,
R. J. McKee, E. C. Milner, G. H. Sanders, H.-J. Zlock,
M. Chapman, M. Eckhause, J. F. Ginkel, P. P. Guss, D. Joyce,
J. R. Kane, C. J. Kenney, R. E. Welsh, R. J. Whyley, R. Winter,
W. F. Vulcan

SUBMITTED TO IEEE Conference, Orlando, Florida,
November 8-11, 1988

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

A Tracking Rangefinder for Muons from Kaon Decay

J. Frank^(a), G.W. Hart, W.W. Kinnison, D.M. Lee, R.J. McKee,
E.C. Milner, G.H. Sanders, H.-J. Ziock,

Los Alamos National Laboratory, Los Alamos, New Mexico 87545

M. Chapman, M. Eckhause, J.F. Ginkel, P.P. Guss^(b), D. Joyce^(c), J.R. Kane,

C.J. Kenney, R.E. Welsh, R.J. Whyley^(d), R. Winter, W.F. Vulcan,

College of William and Mary, Williamsburg, Virginia 23185

Abstract

A muon rangefinder with tracking capabilities has been constructed as part of a search for the rare decay $K_L^0 \rightarrow \mu e$ in experiment 791 at the Brookhaven National Laboratory Alternating Gradient Synchrotron. The rangefinder consisted of two identical arms, symmetric about the beamline, and was the final detector element in a spectrometer system. Each side of the rangefinder was comprised of 75 slabs of marble and 25 slabs of aluminum, each 7.62 cm thick, covering an acceptance area 225 cm wide by 301 cm high, with a total mass of 160 tons (145,454 kg). There were 13 pairs of x- and y-measuring proportional tube planes providing a nominal $\pm 10\%$ accuracy measurement of muon momentum. Altogether, there were 11,648 sense wires, operating at 2650 V, with equal parts argon (49.2%) and ethane (49.2%) gas, and a small amount (1.6% of the total gas) of ethyl alcohol flowing in the proportional tubes. During 850 hours of data collection, efficiency averaged 94%, with 160-ns drift time at 1.5 μ A threshold. For well-identified muon tracks, rangefinder muon identification was 99% efficient when penetration to at least 60% of the depth expected from spectrometer-derived momentum was required.

In this report, we describe a tracking muon rangefinder used in the Brookhaven National Laboratory Alternating Gradient Synchrotron (AGS) experiment 791⁽¹⁾ to positively identify muons in a search for the rare decay $K_L^0 \rightarrow \mu e$. The muon rangefinder was the final detector element in the apparatus shown in Figure 1. The neutral kaon beam was produced by 24.1 GeV protons striking a copper target. Dipole magnets downstream of the target swept charged particles

out of the beam into a stack of iron below the beamline. The extent of the neutral beam was defined by a series of collimators centered at 2.75 degrees from the incident proton-beam direction. At this production angle there were approximately three times as many neutrons as kaons in the beam. To minimize the rate of spurious hits arising from neutron interactions, the neutral beam was transported through the apparatus in a helium-filled corridor.

The detector was a symmetric two-armed configuration surrounding the neutral beam. Low-mass, high-resolution drift chambers surrounding two spectrometer magnets were the first detector elements and were used to measure particle momenta. Trigger scintillator hodoscopes were placed both upstream and downstream of N_2 -He gas Cherenkov counters. A Pb-glass array was used to perform electron and photon calorimetry. Particles which passed through a 91-cm iron filter and were detected in x-y planes of scintillators were assigned a "muon probability" based on their proximity in space and time to tracks identified in the spectrometer. Finally, the track penetration depth in the rangefinder, which was correlated to the original track momentum, was used to positively identify muons. Events with at least one track in each spectrometer arm, and a reconstructed decay vertex within the vacuum decay volume were accepted for offline analysis.

Design goals for the rangefinder arose from Monte Carlo studies indicating that muon momentum determination with approximately $\pm 10\%$ accuracy would provide information useful in an online fast electronics calculation of kaon mass for triggering purposes, and for muon identification redundancy. To achieve this goal, thirteen x-y detector positions in the range stack were specified with Monte Carlo studies.

Figure 1 Schematic view of the detector system. The diagram shows the plan view and is drawn with the indicated vertical and horizontal scales. The rangefinder detector planes were placed in the thirteen positions shown.

The two symmetric arms each consisted of 75 slabs of marble followed by 25 slabs of aluminum, 7.62 cm thick, 305 cm high and 244 cm wide, to match the geometrical acceptance of the upstream detector elements in the experiment. The absorber was arranged with 100 7.62 cm slabs and 508 cm gaps on each side to accommodate a planned upgrade⁽²⁾ to full muon polarimeter capability, in which all 200 gaps would be instrumented for a search for μ^+ polarization in the decay $K^0 \rightarrow \mu^+ \mu^-$.

Considerations related to the future polarization measurement influenced several design choices. For example, the 7.62 cm material thickness was specified because that is approximately optimum for detecting muon precessional decay asymmetry. Marble and aluminum were used because they do not degrade stopped muon polarization. Marble was favored over aluminum because it was three times less expensive and is less susceptible to neutron activation.

Figure 2 Cross-sectional drawing of a drift tube extrusion, showing the eight individual drift cells, and two sense wires in each cell. The slanted geometry of the cell increased the amount of gas ionized by particles passing near cell walls. The extrusion material was 6063-T6 aluminum alloy. Wires were gold-plated tungsten, 3 mils in diameter, installed and tested to be under a tension of 500 grams.

The marble was quarried in Carrara, Italy and shipped to New York in 7.62 cm x 112 cm x 150 cm pieces, the largest commercially feasible size. One-hundred-fifty assemblies were fabricated by edge-gluing four marble pieces together with epoxy, and banding the slab with 0.63-cm thick stainless steel, to provide extra structural integrity required for moving them into place in the detector. Individual pieces of marble were placed on roller-bearing tables, epoxy was applied, and bar-clamps were used to hold the assemblies together during the 8-hour epoxy curing-time. Each assembled slab weighed approximately 1455 kg. The finished assembly was lifted from the horizontal to vertical position by a crane attached to the steel band and transferred into place on the detector stand.

The detectors were proportional tubes operated with a gas consisting of equal parts argon (49.2%) and ethane (49.2%), and a small (1.6%) amount of ethyl alcohol⁽³⁾. There were two sense wires in each cell, at a nominal voltage of 2650 V, with eight cells in each 19-cm-wide aluminum extrusion. A cross-sectional drawing of the aluminum extrusion is shown in Figure 2. The cell geometry was designed to maximize efficiency by utilizing a parallelogram shape, so that tracks passing near inter-cell walls would pass through a sufficient amount of gas to register a hit. The area of coverage in each arm was 2.25 m x 3.01 m, so

x-measuring planes were constructed by edge-bonding with an anaerobic adhesive 12 extrusions, 3.01 m long, and y-measuring planes were built from 16 extrusions, 2.25 m long (Figure 3). Each y-plane had 128 cells and 256 wires, while an x-plane had 96 cells and 192 wires. With 13 x- and y-measuring planes in each arm, the rangefinder therefore had 5,824 active cells, and 11,648 active sense wires. Wires were held in position by molded Lexan endcaps accommodating Noryl chamber and stainless steel crimped minitube wireholders⁽⁴⁾. Two wires were installed in each cell to shorten the ionization collection time. The wires were gold-plated tungsten, 3 mils (75 μm) in diameter, with an elastic limit of 925 g, installed under 500-g tension. Prior to final assembly of a complete plane, the tension on each wire was tested⁽⁵⁾. A portion of the wire was placed in a static magnetic field, while an oscillating voltage was applied to the wire. Voltage induced on the wire out-of-phase with the applied voltage peaked at the harmonics of the wire vibration, and was observed by monitoring the shape of Lissajous figures. The relation giving the tension was then $T = 4\mu l^2 f^2$, where l is the length of the wire, μ is the wire linear mass density, and f is the vibration frequency.

Figure 2 Drawing of an entire x-measuring plane consisting of 12 extrusions each containing 8 cells (see cut-away) with 2 sense wires in each cell for a total of 96 cells. After amplification and discrimination of signals in each cell a logical-OR signal was formed for each extrusion, giving an effective granularity of 18.75 cm (width of an extrusion) for measurement of x-position (and y-position). The semi-circular shapes at the top are gas-distribution hoses, providing serial flow of gas between extrusions. Shown in the top corners are lifting fixtures used for moving the planes by overhead crane. The y measuring tubes are oriented orthogonal to the x measuring tubes.

Pulses from the proportional tube wires were processed by two circuits, first a pre amplifier stage, then an amplifier discriminator stage, shown in Figure 4. The wires were capacitively coupled (2200 pF) to the input stage of the pre amplifier circuit. Pre amplification was performed in three stages by an ECL 10116 line receiver, which has a gain of 4 for each output.

When both the differential outputs are used, the effective gain is eight. The three stages provided a total effective gain of 128 for nominal 2 mV input signals. Gain was not specified by the manufacturer for these line receivers, so, during testing, chips with gain variations greater than $\pm 10\%$ were discarded. Test pulses were injected into the circuit by a copper trace running

Figure 4. Circuit diagrams for pre-amplifier and amplifier-discriminator stages of the rangefinder electronics. The circuit at the top of the figure is the pre-amplifier stage, using three 10116 line-drivers as amplifiers to obtain a gain of 128. The amplified signals were discriminated by the TL810 voltage comparator, which triggered a 74LS123 monostable multivibrator with adjustable output width set to 160 ns. The section labelled "jumper selectable delays" was not implemented.

underneath all the input traces. Pulse discrimination was performed by capacitively coupling the pre amplifier outputs to the input of a TL810 comparator. The negative input of the comparator was biased positively, so that only differential input signals greater than the bias voltage fired the comparator. The leading edge of the comparator output triggered a monostable multivibrator with output width adjusted to 160 ns. The monostable multivibrator outputs for all 8 cells in an extrusion were combined to produce a

logical OR signal, which was converted to a differential ECL signal, and driven over 2 meters of twisted-pair cable and 30 meters of Ansley cable to the counting house, where signals were latched and read out.

The primary muon identifying element at the trigger level was the muon hodoscope. This scintillator instrument had a narrow hit registration time window of 10 ns, so it was used to establish the timing of the rangefinder readout with respect to the rest of the apparatus. The 1.5

μ A threshold and 160-ns length of the discriminated rangefinder pulses was set to achieve 95% efficiency for track-associated hits.

The net efficiency for each rangefinder gap was measured by counting missing hits in otherwise well-defined tracks. An overall efficiency of 94% was achieved for the nominal running conditions of 3×10^{12} protons per pulse striking the production target (3 Tera-protons, or 3 Tp). A test at 8 Tp rate (our ultimate running condition) was also performed yielding the same efficiency results. The nominal running condition of 3 Tp per spill corresponded to about 10^6 tracks per second entering the rangefinder in the 1.5 to 7.0 GeV/c momentum range. Rates were higher close to the centerline of the beam. There has been no evidence of wire aging; for the approximately 1000 hour beam exposure, integrated current per wire was estimated to be about 2×10^{-4} Coulombs/cm. Approximately 84.6% of the tracks were fully contained in the rangefinder volume, with 6.6% exiting the rear, and the remaining 8.8% ending at side surfaces. Of these 8.8% exiting the sides, 7.0% ended at the interior surface (adjacent to the neutral beam) of the detector, and Monte Carlo studies indicated that the track-finding algorithm picked-up spurious tracks originating near the interior edge. Spurious tracks were produced by kaons decaying near the rangefinder, and neutrons interacting in the absorber material. Using well-identified muon tracks from the copious decay $K_L^0 \rightarrow \pi\mu\nu$, the rangefinder muon identification efficiency was measured to be 95%, for tracks penetrating at least 60% of the depth expected from their spectrometer-derived momentum. Momentum resolution was measured offline for tracks by comparing the actual stopping position to that expected from spectrometer-derived momentum. A typical resolution curve is shown in Figure 5, with approximately 87% of the muons stopping within ± 1 instrumented gap of the expected range in the marble stack, corresponding to $\pm 10\%$ resolution. The expected range was derived from a look up table generated in a Monte Carlo model of the range stack, which included the effects of multiple scattering.

Figure 5 Momentum resolution of the muon rangefinder. This is a histogram produced by subtracting the track length predicted from the spectrometer-derived momentum from the penetration depth found for muon tracks in the rangefinder. Each instrumented gap corresponded to about a 10% momentum difference compared to the neighboring gap. About 87% of the muons stopped within ± 1 gap of the predicted range, yielding $\pm 10\%$ momentum resolution.

An event display for a typical $K_L^0 \rightarrow \mu^+\mu^-$ decay⁽⁶⁾, a rare process with a branching ratio equal to 9.1×10^{-9} , is shown in Figure 6. For this event, there is good agreement between the spectrometer-derived momentum and that given by the depth of penetration of both tracks into the muon-range stack.

Figure 6: An event display for a typical $K_L^0 \rightarrow \mu^+ \mu^-$ decay⁽⁶⁾, a rare process with a branching ratio equal to 9.1×10^{-9} . For this event, there is good agreement between the spectrometer-derived momentum and that given by the depth of penetration of both tracks into the muon-range stack. The lines drawn to indicate the tracks correspond to a straight-line projection from the tracks found in the spectrometer drift chambers. The asterisks shown between the two rangefinder arms mark the end of the track found by the track-finding algorithm. The maximum depth in x- and y-views is taken as the end of the track. The x-view is shown in this figure, and in the y-view the track on the beam-right side was one gap longer.

References

(a) Present address: Physics Department, Brookhaven National Laboratory, Upton, New York 11973.

(b) Present address: EG&G Inc., Energy Measurements, Suitland, Maryland 20746.

(c) Present address: CEBAF, Newport News, Virginia.

(d) Present address: MCI Telecommunications Corp., 8283 Greensboro Drive, McLean, Virginia 22102.

(1) R. D. Cousins *et al.*, Phys. Rev. D to be published Nov. 1, 1988.

(2) C. J. Kenney *et al.*, "Use of gas proportional tubes in a Muon polarimeter," Proceedings of this Symposium.

(3) D. M. Lee, J. R. Bilskie, and G. H. Sanders, "The response of drift tubes to variations in wire diameter and gas fillings," Nucl. Instrum. Methods A256 329 (1987). LA-UR 86-2773.

(4) M. Atac, "Wire chamber aging," Proceedings of the Workshop on Radiation Damage to Wire Chambers, LBL (1986). LBL-21170.

(5) Y. Hoshi *et al.*, "A simple method for measuring wire tension in drift tubes," Nucl. Instrum. Methods A236, 82 (1985).

(6) W. C. Carithers *et al.*, Phys. Rev. Lett. 30, 1336 (1973); W. C. Carithers *et al.*, Phys. Rev. Lett. 31, 1025 (1973); Y. Fukushima *et al.*, Phys. Rev. Lett. 36, 348 (1976); M. J. Shochet *et al.*, Phys. Rev. D 19, 1965 (1979); H. B. Greenlee *et al.*, Phys. Rev. Lett. 60, 893 (1988).