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NEUTRAL BEAMS GROUP REPORT

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ABSTRACT

Based on the recently proposed and other possible K^0 experiments, we recommend the establishment of two additional neutral beams in Area 2, one at 6 mrad and one at ≥ 10 mrad. The possibility and desirability of a time-of-flight facility at NAL are considered. Radiation leakage due to neutral beams is evaluated.

The K^0 proposals received to date are primarily concerned with measuring the energy dependence of the K_s^0 regeneration amplitude and phase as a test of the Pomeranchuk asymptotic conditions. These five proposals share the common features of a regeneration target followed by a long decay region, spark-or Charpak-chamber planes, a large-aperture 7-15 kilogauss-meter magnet, more chambers, and a set of electron and muon detectors. They differ in some dimensions, in target material, and type of chambers. They all share a concern with the neutron to K^0 ratio and are more concerned about this ratio than about the K^0 intensity. In order to suppress the neutrons, some proposals call for large-angle beams, some for neutron filters, and some for both.

The submission of such a large number of K^0 proposals certainly indicates a strong interest in these particles. The fact that the same experiment has been proposed several times testifies to the importance of this measurement and to the large cross section for this reaction, relative to other possible NAL K^0 experiments. That there is so great an interest in K^0 experiments suggests that the Laboratory can anticipate second and later generation K^0 experiments, ones involving smaller cross section processes or requiring greater background suppression. The experience gained in this experiment and the quality and purity of the K^0 beams produced will be critical in determining the future course of K^0 experimentation.

Proposals for neutron experiments involving studies of the energy dependence of the differential and total neutron cross sections have also been submitted to NAL. There is, however, a clear and direct conflict between the requirements of the K^0 and neutron beams. Because of their large neutron to K^0 ratio, very small-angle neutral beams are ideal neutron beams but are useful for K^0 experiments only if the neutrons can be filtered out. Since the n-p cross section is almost twice the K-p cross section, it is hoped that a low Z absorber in the beam might preferentially remove neutrons. Yet at NAL energies, the danger exists that the neutron interactions will have a high multiplicity of forward secondaries, and that no decrease in the n/K^0 ratio will occur.

Larger-angle neutral beams have both a somewhat smaller n/K^0 ratio and a lower average neutron energy which may make filtering more effective. Table I shows the effect on the K/n ratio and K flux of changing a neutral-beam angle from 0 mrad to 8 mrad. The total neutron flux is reduced by a factor of 20 by this change of angle. This large reduction in neutron flux should permit a neutral beam at 8 mrad with 10 times the solid angle of one at 0 mrad. Such an 8-mrad beam will have the same flux of 100 GeV/c K^0 as the 0-mrad beam and about 10 times the flux of 20 GeV/c K^0 with a softer and smaller neutron background.

Table I. Angular and Energy Dependence of K^0/n Ratio.

P_{K^0}	$\frac{K/\text{all n (8 mrad)}}{K/\text{all n (0 mrad)}}$	$\frac{K\text{ (8 mrad)}}{K\text{ (0 mrad)}}$
100 GeV/c	3	0.1
80 GeV/c	5	0.2
60 GeV/c	9	0.4
40 GeV/c	11	0.7
20 GeV/c	20	~1.0

Because we see the need for K^0 beams optimized at high momenta, as well as beams optimized for K^0/n ratio, we recommend the establishment of two K^0 beams, one at about 6 mrad and another at 10 or more mrad. These beams are in addition to the 1-3/4 mrad neutron beam.

The proposed scheme of varying the proton beam on target angle to put different angle neutral beams through the forward neutral channel will, in our opinion, cause scheduling complications and interactions between K^0 experiments and the charged beam experiments, limit the range of angles available to K^0 beams, i.e., $\Theta_{K^0} \leq 6$ mrad, and compromise or destroy the diffracted proton beam. The scheme will also require that the front end of the neutral beam be interchangeable between the demands of the K^o and neutron beams. It will require remotely variable neutron and γ filters and collimators. NAL already suffers from a lack of secondary beams, and the scheme will only serve to compound that problem.

The establishment of extra neutral beams is a very modest and inexpensive way to add to the number of available experimental beams at NAL. Neutral beams are much cheaper to build and to operate than are charged beams. At other accelerators they have been added at a later stage; at NAL they must clearly be included in the initial beam design.

Other K_L^o Experiments

In addition to the measurement of the energy dependence of the coherent regeneration, several other K_L^o interaction experiments have been proposed. They are:

1. K_S^o regeneration by K_L^o - e scattering
2. measurement of $d\sigma/dt$ for K_S^o diffraction regeneration
3. $K_L^o + N \rightarrow K^* + N$.

A class of K^o decay experiments, involving rare decay modes, is well suited for NAL. For K^o momenta in the range 10-20 GeV/c, the π-μ range separation is very reliable, time-of-flight is an applicable constraint, secondary momenta can be well determined, and the NAL intensities are very large. Since neutral beams for decay experiments can be kept in evacuated pipes through the experimental region, they can have much higher intensities than beams intended for interaction experiments. It should be possible to do decay experiments in beams with several μ steradian solid angles. It is important that one large angle K^o beam be capable of subtending a large solid angle.

Additional Neutral Beams

We have investigated the possible locations of additional neutral beams for Area 2. Two beams, one at $\approx$ 6 mrad and the other at $\gtrsim$ 10 mrad seem desirable. It is hard to find space for these beams in the existing horizontal fan of charged beams now being planned in this area. However, by depressing these beams with respect to the horizontal fan, we can find possible channels. A view of the existing beam line magnets and possible neutral channels as seen by the Area 2 target is shown in Fig. 1.

The two proposed beams would pass beneath the floor of the experimental building. Since the terrain behind this building slopes downward, the beam lines would remain approximately parallel with the surface and may even emerge at some point.

The experiments in these beams would be placed on a depressed concrete pad. A spectrometer magnet once placed in this beam would probably remain where it is for a number of experiments. This emplacement could be done with a movable crane.

Other material for the experiments, spark chambers, absorbers, counter arrays, etc., would be moved with forklift trucks and "A" frame-type hoists. The requirements would be similar to those of other experiments with equipment in the area behind the experimental building.

We wish to stress that it is essential that the two additional neutral channels up to and under the experimental building be included in the initial area construction. Any facilities downstream of the experimental building would be provided as needed in the same manner as for any other experiment.

Neutral beams at other accelerators have cost much less to construct and to operate than have charged beams. We expect that to hold true at NAL as well.

The considerations that led to the recommendation of additional neutral beams in Area 2 apply as well to the highest energy experimental area to be established at NAL and similar beams should likewise, of course, be provided there.

Tertiary K^o Beam

In a previous Summer Study, Zdanis[1] showed how to produce a relatively neutron-free K^o beam with an unseparated negative secondary beam. Such a tertiary K^o beam should have $n/K \lesssim 0.05$ for momenta > 10 GeV/c and a high-energy peak in the K^o energy spectrum. The 3.5-mrad beam in Area 2 set at 100 GeV/c can produce a K^o beam with 1.5×10^4 K^o per 10^{13} interacting protons into a core with a 3-mrad half-angle. The cone angle controls the high energy to low energy K^o ratio in the tertiary beam.

Time-of-Flight

During acceleration the protons in the main ring are in bunches that are 2 nsec wide and 20 nsec apart. If the rf accelerating voltage is kept on during the flat top and beam targeting, the beam bunching can not only be maintained, but the width of the beam bunches can be substantially decreased.[2] An appropriately bunched beam will permit time-of-flight measurements of neutral particles. This technique has been successfully used at PPA and at SLAC.

We have computed the difference in the time-of-flight between γ rays and K^o and neutrons for a 1000-meter flight path. (See Fig. 2.) The γ rays, of course, would be filtered out of such a beam, but the equivalent timing can easily be established from counters placed in any high-intensity charged beam from the same accelerator target. The time-of-flight measurement could be used to determine the K^o or neutron momentum or resolve the two-fold ambiguity in transforming K_L^o decays from laboratory to c.m. system.

We assume that the beam-bunch width will substantially shrink during the magnet flat top and that the extraction process will peel off protons with a Δt that is only a fraction of the beam-bunch width. A timing resolution of 1/2 nsec permits useful momentum measurements for K^o to P = 25 GeV/c and to 50 GeV/c for neutrons.

The two possible c.m. solutions for a given 3-body K_L decay differ in K^o momenta by $\Delta p \approx \langle P_K \rangle /2$. Our assumed resolution would permit the selection of the proper solution for $P_K \leq 40$ GeV/c.

The time-of-flight would also be useful in a quark or other heavy-charged particle search in a momentum analyzed charged beam.

Finally, beam bunching may provide a method for reducing muon induced accidentals in counter experiments. If the muon flight path from target to experimental area is slightly greater than that of the charged or neutral particles of interest, they can be rejected. For example, a muon with a flight path one meter longer than the secondary beam will arrive 3 nsec late. This change in flight path is a $\Delta L/L$ of 1/4% in Area 2 and 1/10% in Area 1.

Radiation and Beam Design[3]

Unfortunately, a neutral beam suggests a channel in the shielding that connects the high-radiation target area with the experimental area. Charged particle beam lines, of course, are similar holes in the shield. We have examined the neutral beam line with respect to charged particles from the target aiming down the beam line, muons scattering into the channel in the shield and then getting into the experimental area, and neutral particle decays along the beam line.

The largest source of charged particles is that aiming directly into the neutral channel. It should be controlled by a collimator and subsequent sweeping magnet in the back half of the underground gallery.

Several orders of magnitude lower are muons that scatter into the neutral channel. The vast majority of these enter the channel in the first 30-100 meters of the shield after the gallery. At the front of the shield these muons form a ring around the neutral beam and are essentially parallel to it. They can be dealt with by having a much larger aperture in the first sweeping magnet than required by the neutral beam and also by using the field in the yoke and return steel of this magnet. The remaining particles of this group can be eliminated by a second sweeping magnet about 1/3 to 1/2 of the way along the shield. A final cleanup sweeping magnet is desirable near the end of the beam line.

Only muons that are almost parallel to the beam line can scatter into the beam line; these are dealt with by the first sweeping magnet. Muons that pass through the beam line at appreciable angles generally continue into the shield on the other side. For these muons the beam channel constitutes a trivial decrease in shield thickness.

To test the efficacy of sweeping magnet configurations, a simple computer program was written to trace μ's in the vicinity of a beam pipe through the Area 2 shield. Account was taken of reverse bending in the return yoke, and it was assumed that there would be room in the gallery (location of first sweeping) to provide a field only over the area of the beam pipe itself (20 cm diameter). Downstream in the two access ways 20 cm, 40 cm, and 2-meter field diameters were tried; at all sweeping stations a field integral of 0, 2, 5, or ± 10 kG-m was tried.

The transverse distribution of μ's at the shield exit was inspected for each of several magnet combinations. The path-length of μ's in the soil was also considered, since this length could be reduced if the muon traveled appreciable distances in the pipe; this could reduce the attenuation caused by the shield. Muon angle and momentum distributions were taken from the Monte Carlo results of the NAL Radiation Physics Section.

It was found that 3 magnets of 10 kG-m each and field diameters of 0.2, 0.4, and 0.4 meters, respectively, would give adequate sweeping power, spreading the μ's produced at 10 ± 2 mrad over a ± 10 m region at the end of the shield. Furthermore, a negligible fraction of the μ's encountered a length of soil smaller than 90% of the full length. Finally, the μ^- flux in the beam line itself is reduced by at least 3 orders of magnitude.

Thus, a sweeping setup of moderate proportions appears capable of dispersing the muon flux associated with a neutral beam pipe throughout the shield.

We estimate that for a beam of $\sim 10^6$ K_L^o/sec the muons in the neutral beam are less than the general room background.

Recommendations

We strongly urge the Laboratory to implement our proposal for additional neutral beams in Area 2 and corresponding beams in the highest energy experimental area at the Laboratory. We also hope that the Laboratory will examine the problems involved in maintaining beam structure during targeting and will establish a time-of-flight measurement capability for those experiments that require or could profit from it.

Finally, we strongly recommend that during the design and installation of neutral beams the Laboratory consult with and obtain the assistance of several experimentalists who have experience in the design and use of neutral beams at other accelerators, BNL, SLAC, ANL, and PPA.

The massive and inflexible nature of the beam channels from target to experimental area makes it essential that special attention be devoted to the neutral beam lines, collimators, and sweeping magnets. Unlike charged beams, once neutral beams are established, it will be impossible to make appropriate changes and corrections.

REFERENCES

[1] R. A. Zdanis, A "Neutron-Free" K_L^0 Beam, National Accelerator Laboratory 1969 Summer Study Report SS-29, Vol. I, p. 187.

[2] Still further reduction in beam width could be achieved by having the rf voltage during flat top some multiple of the accelerating frequency. Since the beam is not being accelerated by this higher frequency voltage, the power demands would be minimal.

[3] We are indebted to M. Awschalom, D. Theriot, and T. Yamanouchi for their assistance with this study.

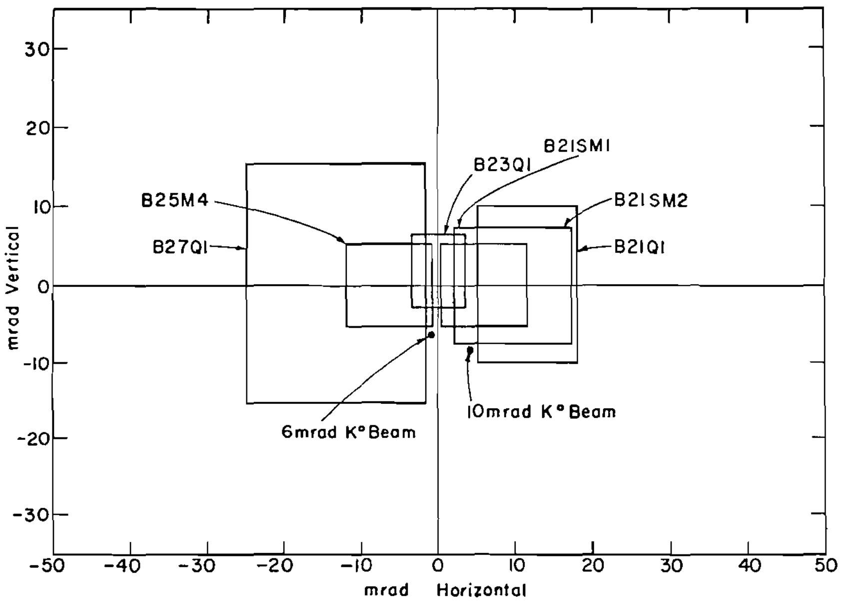

Fig. 1. Downstream view of Area 2 beam magnets seen from proton target.

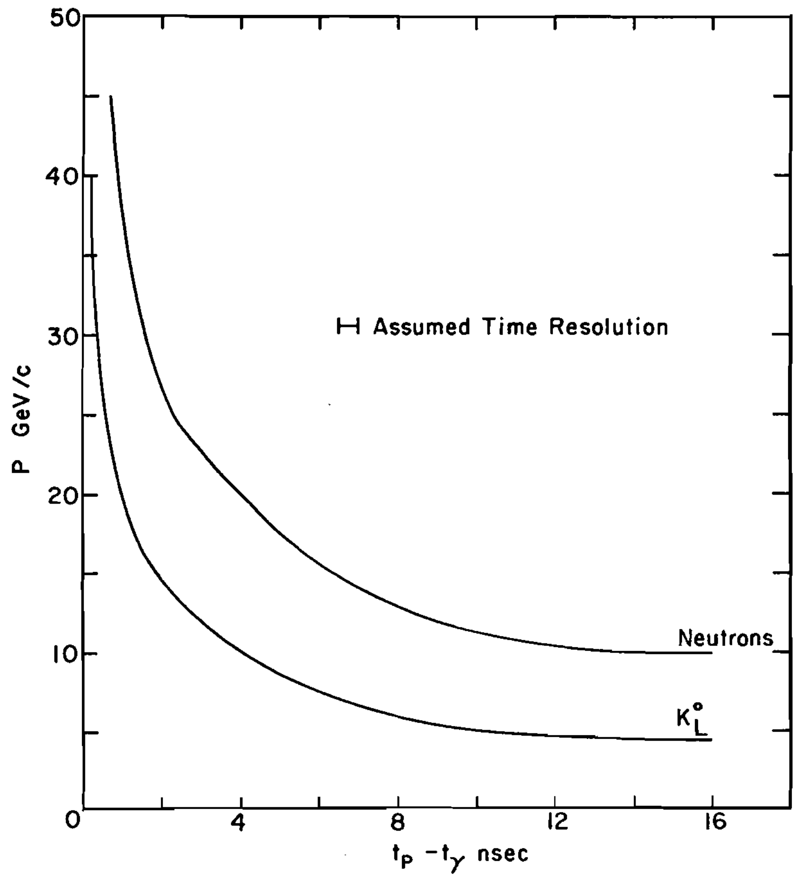

Fig. 2. Time-of-flight of particle with momentum p minus time-of-flight of γ for 1000-meter time-of-flight spectrometer.