NAL PROPOSAL No. 51

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# MASS SPECTRUM AND DECAY MODES FOR BOSONS IN THE 2.0 TO 8.6 Gev/$c^2$ MASS RANGE

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June 15, 1970

N. A. L. PROPOSAL

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Mass Spectrum and Decay Modes for Bosons in the 2.0 to 8.6 Gev/$c^2$ Mass Range.

A "double" missing mass spectrometer experiment is proposed to study the mass spectrum of non strange and strange bosons produced in the reactions $\left\{\begin{matrix}\pi^- \\ K\end{matrix}\right\} + N \rightarrow N + B$ where the B mass ranges from 2.0 to 8.6 Gev/$c^2$. In the 2.0 to 6.0 Gev/$c^2$ range both neutral and charged bosons will be studied and systematics of decays of the type $B^{\bar{o}} \rightarrow \pi^{\mp} + b^{o,-}$ will be obtained.

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## I. Description of the Experiment

An experiment is proposed to study bosons in the 2.0 to 8.6 GeV/$c^2$ mass range by means of a "double missing mass spectrometer". Bosons produced in the reaction $\pi^- + N \rightarrow N + B^-$ will be "tagged" by recoil nucleon spectrometers, while a decay spectrometer will detect, in coincidence with the proton, fast pions from boson decays of the type $B \rightarrow \pi + b$. In this way both a mass spectrum of produced bosons and a mass spectrum for two body decays by single pion emission will be obtained. This apparatus combines the high data rates and good mass resolution of the usual missing mass proton spectrometer with the ability to determine decay modes.

This is a continuation of an experiment now in operation at Brookhaven, where the 1 to 5 GeV/$c^2$ mass range is being studied. Much of the apparatus now in operation will be applicable to N.A.L.

The major aims of the experiment are:

### 1. High Mass Search For Charged Bosons

We proposed to explore the 4 to 8 GeV/$c^2$ mass range. For bosons produced with a total cross section of 10 $\mu$b, we would get 30,000 events above background for each new peak per $10^6$ pions per pulse for 40 hours of beam time. The range would be explored by measuring proton recoils in the forward direction to obtain the optimum mass resolution. With the spectrometer in this configuration no decay information is expected. For the proton detector presently operating at BNL, a mass resolution of 30 to 60 MeV/$c^2$ would be obtained at N.A.L. for the 4 to 8 GeV/$c^2$ range.

2. Decay Modes

We propose to study the two body decay modes of charged and neutral bosons in the 2 to 6 GeV/$c^2$ range. Charged bosons will be tagged by a proton recoil spectrometer, while the neutral bosons will be tagged by a neutron recoil spectrometer. Both spectrometers will be operated in the Jacobian peak region.

The decay spectrometer is particularly suited for boson decays of the type

$$B^{\bar{o}} \rightarrow \pi^{\bar{+}} b^{\bar{o}}$$

The mass and momentum of boson B is determined by the recoil spectrometers, while the decay spectrometer determines the angle and momentum of the pion. The mass of the b can then be calculated.

This experiment will determine which of the many possible $\pi$,b decay modes occur and their relative strengths. This knowledge of boson transition systematics will be of importance in testing current theories of boson classification and dynamics. In addition, it will be possible, in certain cases, to determine isotopic spin and G-parity. For those bosons decaying into a pion and neutral boson of known G-parity, the G-parity of the parent boson can be determined. Furthermore, if the neutral boson is an I-spin singlet, then the I-spin of the parent must be one. At present, there is no evidence to exclude the possibility of an I = 2 assignment for the presently known high mass mesons. Spin and parity will be determined for those bosons which decay into two spin-zero objects and are produced by spin-zero exchange.

From events in which both a pion and nucleon are detected, a two dimensional scatter plot of $M_B$ vs $M_b$ will be made. In this way,

B resonances or peaks which lie close in mass to one another and cannot be resolved, will be identified.

For each boson tagged by a recoil spectrometer, the probability that the pion from the decay $B \rightarrow \pi + b$ will be detected is estimated to be about 50%. For this phase of the experiment the expected counting rate for charged boson produced with 10 $\mu$b total cross section and a t dependence of $e^{-8t}$ is about 15,000/40 hrs for an incident beam of $10^6$ pions per pulse. The rate for decay events (for unity branching ratio) is expected to be about 1/2 of this. The rates for neutral boson will be about a factor of ten lower.

A summary of the data rates expected from this experiment is shown in Table I. It is estimated that total time for testing, after the apparatus has been installed, would take about three months during which time about 150 hours of beam time would be necessary. 700 hours of data accumulation is requested. The data taking would be spread over four to six month interval.

Although the apparatus proposed has been designed with the detection of the two body decay modes as the prime objective, it is clear that due to the high degree of forward collimation of the decay products other decay mode information will be obtained.

3. Strange Boson Mass Spectrum

Since the incident beam will have a few percent $K^-$ component, it will be desirable to tag events as $\pi^-$ or $K^-$ initiated. Data would then be obtained on the $K^*$ mass spectrum and decay modes, similar to that of the non-strange meson but with poorer statistics.

TABLE I EXPECTED COUNTING RATES

| Mass Range ($GeV/c^2$) | Average Mass Resolution ($MeV/c^2$) | Nucleon Angle (Deg) | Beam Energy (GeV) | Charged Boson events* per 10 μb | Decay events | Beam Intensity (per pulse) | Length of Run (hrs) |
|---|---|---|---|---|---|---|---|
| 1.96 - 3.13 | 47 | $43^\circ$ - $67^\circ$ | 24 | 15,400 | 7,700 | $10^6$ | 40 |
| 3.10 - 3.66 | 38 | $25^\circ$ - $49^\circ$ | 24 | 20,000 | | $10^6$ | 40 |
| 3.55 - 4.31 | 31 | $7^\circ$ - $31^\circ$ | 24 | 30,000 | | $10^6$ | 40 |
| 2.95 - 4.28 | 66 | $43^\circ$ - $67^\circ$ | 48 | 15,400 | 7,700 | $10^6$ | 40 |
| 4.45 - 5.25 | 54 | $25^\circ$ - $49^\circ$ | 48 | 20,000 | | $10^6$ | 40 |
| 5.18 - 6.0 | 43 | $7^\circ$ - $31^\circ$ | 48 | 30,000 | | $10^6$ | 40 |
| 4.16 - 6.08 | 93 | $43^\circ$ - $67^\circ$ | 96 | 15,400 | 3,850xx | $10^6$ | 40 |
| 6.32 - 7.46 | 72 | $25^\circ$ - $49^\circ$ | 96 | 20,000 | | $10^6$ | 40 |
| 7.32 - 8.60 | 62 | $7^\circ$ - $31^\circ$ | 96 | 30,000 | | $10^6$ | 40 |

* Neutral boson events will be a factor of 10 less, strange boson events about a factor of 20 to 30 less.

xx At the high mass range the acceptance will be restricted to improve the resolution.

This experiment is similar to CERN-IHEP missing mass experiment being done at Serpukhov. The significant differences are:

1. This experiment will measure decay modes of neutral bosons as well as charged.

2. Data will be obtained for the strange mesons.

3. Data taking rate is about factor 5 higher due to the use of fast recovery spark chambers.

Although this experiment will be done several years after the Serpukhov experiment, it should be pointed out that the CERN data on the $A_2$ and R, S, T, mesons appeared in '65 - '66 and has yet to be confirmed.

## II. Apparatus

A diagram of the apparatus is shown in Figure 1.

### 1. Recoil Spectrometers

The recoil proton spectrometer is now in operation at B.N.L. It consists of a set of spark chambers to determine the proton direction and scintillation counter arrays $\Delta E$, E', and A. The protons of interest are non-relativistic and will stop in counter E'. Their energy then is proportional to the sum of the outputs of counter E' and $\Delta E$. The $\Delta E$ counter is used to determine the particles rate of energy loss, dE/dx. This information together with that from E' is used to determine particle mass, since the product of dE/dx and E for a nonrelativistic particle is proportional to its mass. Time of flight information will also be recorded to further identify the proton.

This spectrometer is capable of measuring proton energies from 40 to 240 MeV with an energy resolution between $\pm$ 1% and $\pm$ 2%. At 240 MeV the loss of events due to nuclear interactions is about 25%.

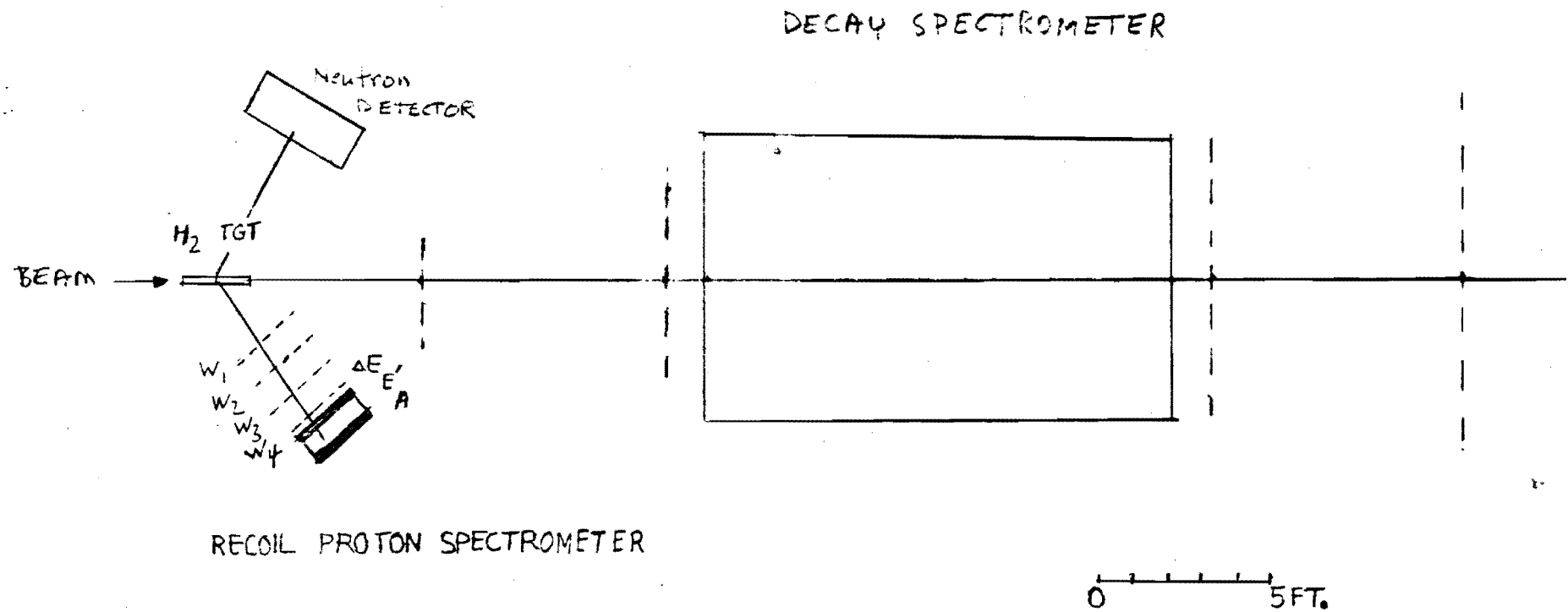


FIG. 1

EXPERIMENTAL ARRANGEMENT

The total aperture defined by the proton detector measures 20" in the vertical and 24" in the horizontal. This area is covered by five identical counter assemblies, each one covering a region 4" x 24". This subdivision results in a low probability that a proton will be accompanied by another particle in any given counter.

The counters are 5' from the target to permit time of flight rejection of fast particles. At this distance the total solid angle subtended by the system is about 120 msr.

The $B^-$ mass resolution of the system has contributions from the uncertainties in beam energy, proton energy, and angle. The combined effect of these is a fractional boson mass uncertainty $\Delta m_b/m_b$ between $\pm$ 0.3% and $\pm$ 1.8%, depending on the angle and energy of the recoil proton and essentially independent of beam energy. (See Figure 2). In all cases the contribution to the resolution from the proton counter is less than or equal to that from the other two sources.

The neutron detector will operate in the Jacobian peak region where the mass resolution is dominated by the detector's angular resolution. Design studies of various possible neutron detectors which would have the necessary solid angle, resolution, and a smooth mass acceptance are presently under way. Both scintillation counter and spark chamber systems are being considered. It is planned to incorporate a neutron detector in the BNL experiment in early part of 1972 and thus a new detector need not be made.

2. Decay Spectrometer

The major component of the decay spectrometer is the magnet. The minimum magnetic volume necessary to achieve the goals of this experiment is 2m x 2m x 4m at 15 KG . With a pair of wire planes separated by 3.3m before and after magnet having a spatial resolution

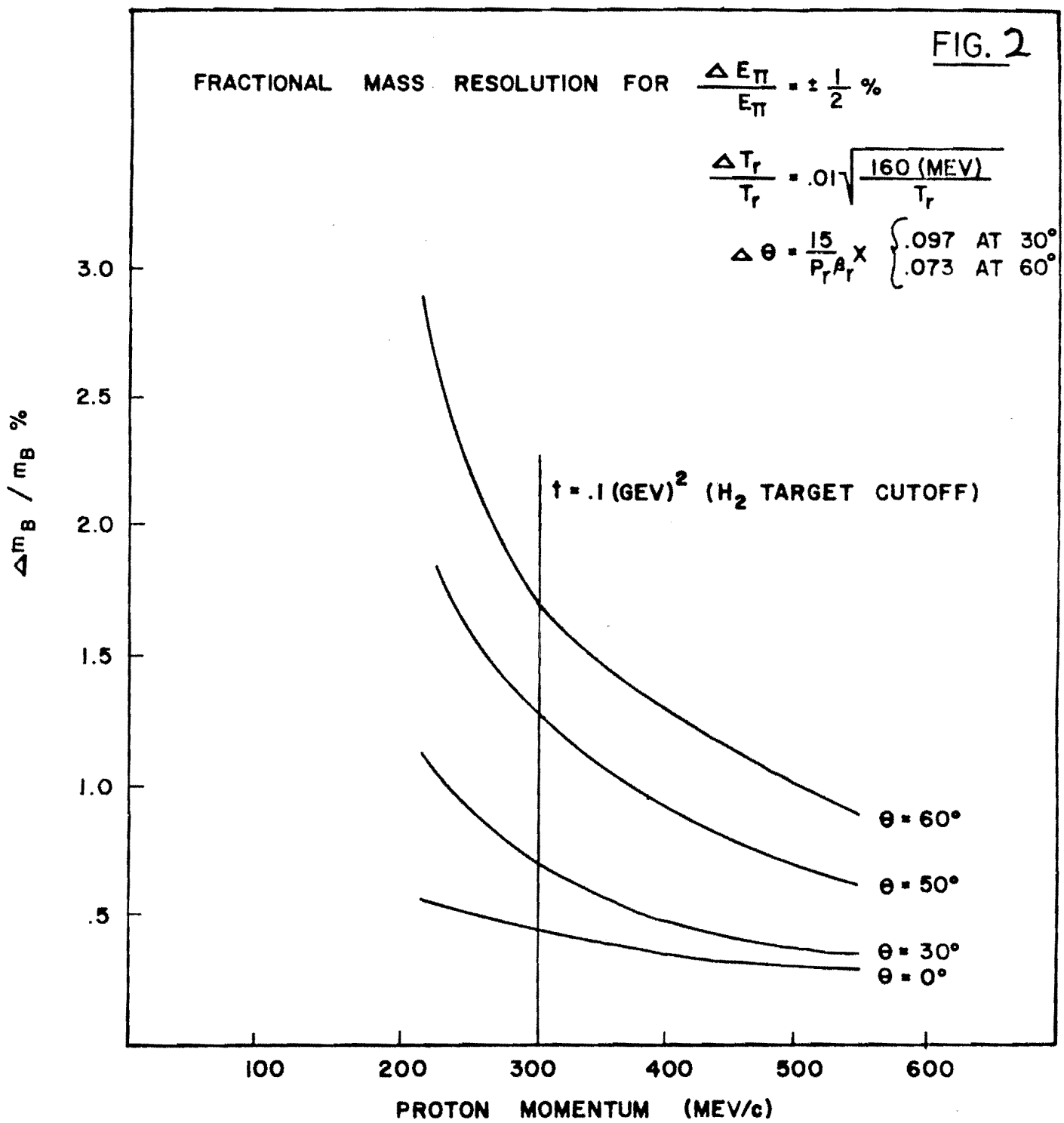
FIG. 2
FRACTIONAL MASS RESOLUTION FOR $\frac{\Delta E_\pi}{E_\pi} = \pm \frac{1}{2}$ %
$\frac{\Delta T_r}{T_r} = .01\sqrt{\frac{160\ (MEV)}{T_r}}$
$\Delta\theta = \frac{15}{P_r \beta_r} X \begin{cases} .097 & AT\ 30° \\ .073 & AT\ 60° \end{cases}$
$t = .1\ (GEV)^2$ ($H_2$ TARGET CUTOFF)
$\theta = 60°$
$\theta = 50°$
$\theta = 30°$
$\theta = 0°$
$\Delta m_B / m_B$ %
3.0
2.5
2.0
1.5
1.0
.5
100
200
300
400
500
600
PROTON MOMENTUM (MEV/c)

of $\pm$ .3mm a $\Delta p/p$ of $\pm$ 1% can be obtained at 100 GeV/$c^2$.

The angular acceptance of the spectrometer is approximately $\pm 7^o$. This is sufficient to allow detection efficiencies of 50% or greater for two body decay modes having an isotropic angular distribution in the c.m. For such a distribution 50% of the decay pions have a lab angle between o and $\frac{m_B}{E_B}$ radians. For this experiment $\frac{m_B}{E_B} < \frac{1}{10}$.

The decay spectrometer should have sufficient resolution to separate the possible mass values of the decay boson. For the decay of the neutral boson, the decay boson must have I = 1 and their mass spectrum has a spacing of $\Delta m_b^2 = 1$ GeV/$c^2$. However, for the charged boson, the decay boson may be I = 0 and for this case the mass spacing is more like .33 GeV/$c^2$. We then take as acceptable a mass resolution of $\Delta m_b^2 < .33$ GeV/$c^2$.

The dominant contribution to this mass resolution is the momentum measurement of the pion produced in the decay. The effect of the uncertainty in this momentum on the mass resolution is given by:

$$\Delta m_b^2 \approx P_B \, P_\pi \left( \frac{m_B^2}{E_B^2} + \theta_{\pi B}^2 \right) \frac{\delta P_\pi}{P_\pi}$$

where $P_B$, $P_\pi$ are momentum of the produced boson and decay pion

$m_B$, $m_b$ are the masses of the produced boson and decay boson

$\theta_{\pi B}$ is the angle between the decay pion and produced boson.

The estimated values for $\Delta m_b^2$ for mass ranges proposed are shown below. Note for the highest mass range it will be necessary to restrict $\theta_{\pi b}^2$ to be less than $m_B^2/E_B^2$ to achieve the desired resolution. This results in decreasing the detection efficiency for decay events by 50%.

TABLE II

| $E_B$ | $m_B$ | $m_b$ | $\frac{\delta P_\pi}{P_\pi}$ | $\Delta m_b^2$ |
|---|---|---|---|---|
| 24 | 2.5 | .1 - 2.3 | $\pm$ .5% | .12 |
| 48 | 3.5 | .5 - 3.2 | $\pm$ .5% | .24 |
| 96 | 4.8 | 2.5 - 4.3 | $\pm$ .7% | .32 |

3. Beam: A $\pi^-$ beam at several momenta between 24 and 96 GeV/c with a flux between $10^6$ and $10^7$ pions per pulse in a $\Delta P/p_o$ band of $\pm$ 1%. Hodoscopes will be used to measure the incident momentum to $\pm$ .3% on an event by event basis.

4. Target 24" hydrogen target with a 2" diameter.

5. Computer The data from all counters and chambers are fed into a PDP-9 computer (provided by Northeastern), which records eventson magnetic tape for off-line analysis. The PDP-9 provides continous monitoring of the detection equipment. In order to monitor the physics result by means of complete event calculation it is highly desirable to have an on line data link to a larger computer. Presently we find the use of the PDP10 of the BNL-OLDF very satisfactory. The PDP10 program requires 40k of core and uses about 30% of the CPU time. We also would need about 200 hours of CDC6600 (or equivalent) time for off line analysis.

6. Software. We have the software for the PDP9 and the on line data analysis and will certainly have the off line analysis programs complete within a year.

7. Cerenkov Counters. Beam cerenkov counters will be necessary to separate the K initiated events from the $\pi$ initiated events.

8. Electronics.

The electronics required for this experiment are special electronics for the proton and neutron detector, fast recovery spark chamber pulsing circuits, commerical fast electronics for the triggering logic which has a computer controlled selective trigger, and computer interfaces.

Of the above equipment NAL would provide the target, beam cerenkov counters, magnet and mechanical supports for the decay spectrometer planes, a suitable computer for on line data analysis, and commerical electronics for the trigger logic. The experiment would require 150 logic models, 20 power supplies and 25 scalers.

We plan to provide the proton detector, and neutron detector with their specialized electronics, beam hodoscopes, PDP9 computer and interface, and spark chambers for the decay spectrometer. Except for the neutron detector and decay spectrometer chambers, this equipment is operating at BNL now. The neutron detector will be built for use at BNL, so the spectrometer chambers would represent the only additional large piece of equipment we would have to provide.

We plan to finish the BNL experiment towards the end of 1972. At that time the equipment plus all the necessary software should be available for use at NAL.