Fermilab Proposal No. 468

Scientific Spokesman:

P. H. Steinberg
Physics Department
University of Maryland
College Park, Maryland 20742

Search for Penetrating Massive Neutral Particles Produced in High Energy Proton Collisions

C. Y. Chang, R. W. Ellsworth
E. Sager, P. H. Steinberg

University of Maryland

January 1976

468

SEARCH FOR PENETRATING MASSIVE NEUTRAL PARTICLES PRODUCED IN HIGH ENERGY PROTON COLLISIONS

EXPERIMENTERS

Dr. C.Y. Chang

Dr. R.W. Ellsworth

Mr. E. Sager

Dr. P.H. Steinberg

University of Maryland

January 1976

SUMMARY

We propose to search for long lived neutral heavy leptons produced in high energy proton interactions in a beam dump. We request the use of the E-8 hyperon beam magnet as the beam dump. The strong magnetic field is essential for sweeping out most of the penetrating muons produced in the hadronic showers. The heavy leptons would be detected through their decays in a 50 foot downstream decay region.

We are requesting 1000 hours for data taking and 200 hours for equipment testing. The M-2 beam would be tuned to 400 GeV protons (i.e. $x = 2P_L/\sqrt{s} \sim 1$) and with an intensity of 10^9 protons/pulse we expect 10 events/nb/hr.

I. GENERAL DISCUSSION

It seems to us extraordinary that, in contrast with the hundreds of known hadronic states, only four leptons (e, ν_e, μ and ν_μ) have until now been well established. Because of the evident significance of the existence, or the non-existence of additional leptons the search for them should be continually extended to new ranges of lifetime and mass, and the sensitivity to smaller and smaller production cross-sections should be improved at every opportunity.

One might imagine the existence of entire families of leptons differing from each other by additive quantum numbers which are conserved in strong, electromagnetic interactions and in weak interactions to the first order of G_F. In this circumstance the lightest member of a family would be stable, or relatively long lived. Alternatively the new leptons would all decay into ordinary leptons with lifetimes $\tau < 10^{-11}$ seconds for mass $M_L > (1\ \mathrm{GeV}/c^2)$ These questions have been discussed extensively by a number of authors.[1]

The status of the present experiments and the indications for possibly fruitful areas for new searches are summarized below.

A. Charged Heavy Leptons $L^{\pm}$

1) There is no evidence for the production of stable $L^{\pm}$ in any reaction. For instance, the experiments carried out at CERN-ISR and at FNAL found no stable ($\tau \geq 10^{-7}$ sec) massive charged particles heavier than the d (or $\bar{d}$)'s produced in pp collisions.[2] The FNAL direct muon search group has also reported no evidence for the production of $L^{\pm}$ with a lifetime greater than few nsec and a mass < 1.4 GeV/c^2.[3]

2) Anomalous lepton production has been observed in e^+e^- annihilation at SPEAR for $\sqrt{s} \geq 4$ GeV.[4] These events, $e^+e^- \rightarrow \mu^{\mp} e^{\pm}$ + neutrals, can be

interpreted, among many possibilities, most favorably in terms of L^+L^- production, followed by their leptonic decay. The mass of $L^\pm$ is probably 1.8 GeV/c^2, the production cross section is 10^{-35} cm^2 at $\sqrt{s} \geq 4$ GeV, and the lifetime of $L^\pm$ is probably less than 10^{-10} sec. No evidence for $L^\pm$ production was obtained at lower energy e^+e^- annihilation.[5]

3) There is no evidence for $L^\pm$ production in high energy neutrino reactions.[6] This kind of search assumes that:

$$\nu_\mu + N \rightarrow L^+ + \text{anything}$$
$$\quad\quad\quad\quad \hookrightarrow \mu^+ + \nu_\mu + \nu_\mu \text{ or } e^+ + \nu_e + \nu_\mu$$

which is meaningful only if (a) L^+ belongs to the same family as the ν_μ and carries the leptonic number of the μ^-, and (b) the leptonic decay mode $L^+ \rightarrow \ell^+ + \nu_e + \nu_\mu$ is dominant. Otherwise if $L^+ \rightarrow \nu_\mu$ + hadrons are dominant or $\nu_\mu + N \rightarrow L^-$ + anything, then there would not be an observable signal. Experimentally one finds

$$\frac{\sigma(\nu_\mu + N \rightarrow \mu^+ + \text{anything})}{\sigma(\nu_\mu + N \rightarrow \mu^- + \text{anything})} < 4 \times 10^{-3} \text{ at FNAL } \nu_\mu \text{ energies,}$$

the mass limit on L^+ is $M_L > 8.3$ GeV/c^2.

Consequently, we may conclude that $L^\pm$ does not belong to the same family as the μ or e, with a lifetime that is short.

B. Neutral Heavy Lepton L^o

1) There is no evidence for L^o production in high energy neutrino interactions.

If L^o are produced in ν-interactions via

$$\nu_\mu + N \rightarrow \bar{L}^o + \text{hadrons}$$
$$\quad\quad\quad\quad \hookrightarrow \mu^- + \mu^+ + \nu_\mu, \text{ etc.}$$

They would appear as dimuon events in the final states of ν_μ interactions. Indeed, events of this kind have been observed by two experimental groups at Fermilab.[7,8] The rate for dimuon events is 1% to 2% of the rate of all neutrino interactions. But these events are characterized by (a) the two muons possessing opposite charges, (b) a pronounced asymmetry in the energy distributions of the μ^- and μ^+ with $\langle E^- \rangle / \langle E^+ \rangle \simeq 3.7$ where $\langle E \rangle$ is the average muon energy, (c) no structure in the $m_{\mu^+\mu^-}$ spectrum, and (d) no consistent structures in E_{vis} and W_{min}. Hence the dimuon events cannot be interpreted as signal of L^o production in $\nu_\mu + N$ reactions.

2) There is no evidence of stable ($\tau > 10^{-7}$ sec.) L^o production at FNAL energies.[9] Search for decays of long-lived penetrating neutral particles in the neutrino beam at Fermilab has been reported by the HPWF group. They found an event rate consistent with background which corresponds to a fraction $(7 \pm 5) \times 10^{-3}$ of $\nu_\mu(\bar{\nu}_\mu)$ scattering in liquid scintillator. Since the path length for L^o, if produced, would be $\gtrsim 1$ km, and $\gamma \simeq 12.6$, (assuming at-rest production in the pp center-of-mass), lifetime of the L^o if observed in this experiment would have been $\simeq 1$ km/γc $\simeq 10^{-7} \rightarrow 10^{-5}$ sec. (see note in Ref. 9).

C. The L^o Mass

If the L belongs to the same family as the μ or the e then from the lack of $K^+ \rightarrow L^o + \mu^+$ and the unneeded contribution of the L^o in the $g_\mu - 2$ calculations one concludes that $M_{L^o} \gtrsim 0.4$ GeV/c^2. However, since experimental evidence does not suggest that the L has the same leptonic number as μ's or

e's the mass limit of L^o can only be suggested from the E_{vis} spectra of the anomalous lepton events observed in e^+e^- annihilation at SPEAR. The data from this experiment is consistent with M_{L^o} being as large as a few pion masses.

Finally, we conclude that the L^o, if it exists, (a) would be lighter than the $L^\pm$ and might be no heavier than several pion masses, (b) does not belong to the same family of the μ or e, hence has a long lifetime 10^{-10} sec. $< \tau < 10^{-6}$ sec.

Therefore, as shown in Fig. 1, there exists a preferred lifetime region $10^{-10} < \tau_{L^o} < 10^{-6}$ for the searching for the L^o and we propose to search for the existence of the L^o via its decay with an apparatus most sensitive in this region. We assume that an L^+L^- pair will be produced in proton-nucleon collisions and that this will rapidly decay into long lived $L^o, \bar{L}^o$. The production cross section can be estimated by scaling the $\mu^+\mu^-$ cross section according to the relationship.[10]

$$\frac{d\sigma}{dQ^2}(L^+L^-)/\frac{d\sigma}{dQ^2}(\mu^+\mu^-) = (1-\frac{4M_L^2}{Q^2})^{\frac{1}{2}}(1+\frac{2M_L^2}{Q^2})$$

where Q^2 = (di-lepton mass)^2 >> m_μ^2. Accordingly the production cross section for $pp \rightarrow L^+L^-$ + hadrons would be $\sigma(L^+L^-) \sim 10^{-34}$ to 10^{-35} cm^2 at FNAL energies. The required sensitivity for an exploratory experiment is therefore about 10 events/(nb-hour).

II. EXPERIMENTAL DESIGN

In the experiment a search will be made for multipronged events in a long decay region downstream of a beam dump. These events will be examined to determine whether any of them could be attributed to the decays of long lived neutral leptons produced in the beam dump. Neutral lepton decay events will

be selected from a variety of backgrounds by requiring: (a) the reconstructed event vertices to occur in the helium gas filled decay regions; (b) the time correlation between each vertex and the RF to be the same as that of a particle produced at the beam stop entrance and having $\beta \approx 1$ up to the point of decay; (c) that at least one of the prongs be due to an energetic muon with $E_\mu > 10$ GeV.

We will further require that the vertices be distributed along the decay regions according to the exponential decay law and that the prong number be even and small. Requiring an energetic muon will greatly reduce the background from the decays and collisions of neutral hadrons in the decay regions. The principle sources of such particles will be inelastic muon interactions in the beam dump, and the ambient flux of neutrons from upstream targets. The required time correlation with the RF should further reduce the numbers of neutron induced events which are expected to be out of phase with respect to events initiated in the beam dump. The timing requirement would also be a constraint against possible accidental event simulations by unrelated particles. The distribution and prong number requirements would be a further consistency check against neutron interactions. The various backgrounds are described in part III and their contributions are shown to be negligible.

We propose to use for the beam dump the E-8 neutral hyperon sweeping magnet in the M-2 beam line. The collimated channel in the magnet would be closed with a removable form fitting plug. The strong magnetic field is necessary for sweeping out most of the penetrating decay muons and also the directly produced muons from the hadronic showers. Otherwise the large flux of charged particles would create difficulties in the operation of the detectors

(see Section III). The layout of the experimental apparatus is shown in Fig. 2. The incident beam will make its initial impact upon a meter long target. Targets made of aluminum, lead and tungston will be available to cycle in during the experiment to determine whether there is any density dependence in the yield of events. In particular if the background events are due to muons from pion decay the yields will be proportional to the ratio (absorption length/decay length)(see Section III). A low pressure cerenkov counter in the beam will produce a signal for each incident RF beam bunch and these signals will be used to initiate the TOF system for the counters in the decay region. In order to reduce events from low energy neutrons a neutron moderating shielding wall will cover the downstream face of the beam dump magnet. Veto counters at the entrance to the decay region will be used to eliminate events which are due to, or accompanied by, a charged particle. It is expected that any neutral hadron from inelastic muon interactions will be accompanied by at least one charged particle. The veto will however be intermittently disabled in order to provide a source of fast muons to calibrate the TOF system and to monitor efficiencies of the spark chambers.

Three identical detector modules, each consisting of a hodoscope of trigger counters and a bank of three wire plane spark chambers, will be stationed along the decay region as is shown in Fig. 2. The hodoscope counters will also provide high resolution TOF data for ON-LINE analysis. The spark chamber data will be used to locate possible event vertices and to improve the TOF resolution by removing the transit time uncertainty of scintillation light in the hodoscope counters. The three detector modules will mark-off three 14 foot long decay regions. These regions will be

filled with helium gas in mylar bags. An additional module will be stationed downstream of the currently emplaced BM109 bending magnet and will be used as a muon identifier. The steel in the magnet yokes (along with additional steel to cover the magnet gap) will be used as a hadron and γ-ray filter. A lower limit of about 10 GeV will be required for a muon to be confidently identified. This lower limit is an average of energies of muons whose multiple Coulomb scattering angles are equal to the arbitrary maximum angle of one degree.

The detector modules will be so located as to produce a large and slowly varying geometrical efficiency over the entire decay region. As a guide in computing this efficiency we have assumed that heavy lepton pairs are produced most probably at rest in the proton-nucleon center-of-mass system. This would be the case if the dominant production mechanism is the annihilation of a pair of partons (i.e. $Q\bar{Q} \rightarrow L^+L^-$).[11] One cannot however exclude production in the target and projectile fragmentation regions and the a-priori expectation is a broad distribution of the rapidity variable peaked at $y = 0$. The subsequent decay,

$$L^+ \rightarrow L^o + \text{light particles}$$

should give rise to L^o's of nearly the same velocity if the L^o's are much heavier than the other decay products.

Accordingly we expect the neutral leptons to be moving along the beam line with Lorentz factor $\gamma = \sqrt{\frac{400\ \text{GeV}}{2M_p}} = 14.6$, and with $\beta \cong 1.0$.

The kinematics for the semi-leptonic decay mode

$$L^o \rightarrow \mu^- + \pi^+$$

is essentially independent of the M_L if $M_L >> m_\pi$. We have in the laboratory

reference frame the relationships;

$$\tan\theta_\pi \tan\theta_\mu = \frac{1}{\gamma^2} \quad ,$$

$$\tan\theta_\mu = \frac{\sin\theta^*}{\gamma(1 + \cos\theta^*)} \quad .$$

where θ^* is the muon angle in the L^o rest frame. The geometric efficiency for detecting both particles can be computed as a function of position along the decay region. We assume that the L^o is unpolarized. The resulting efficiency is plotted in Fig. 3. A fiducial cut will be imposed on any vertex lying within a detector module and consequently the efficiency will be zero in those places. The average geometrical efficiency for detecting the 2-body decay in 0.59. It must be pointed out that n > 2 body decays will have a larger geometric efficiency because of the reduced mean velocities of the decay products in the L^o rest-frame. The overall efficiency, which takes into account the probability for decay within the presecribed decay regions is given by

$$\varepsilon = e^{-L_1/\lambda} \int_o^{L_2} \frac{\Omega(z)}{4\pi} \; e^{-z/\lambda} \frac{dz}{\lambda}$$

where L_1 = 20 feet (the distance from the point of production to entrance of the decay region)

L_2 = 50 feet (length of the decay region)

$\Omega(z)/4\pi$ (the $\mu + \pi$ geometric detection efficiency)

$\lambda = \gamma c\tau = 14.6\ c\tau$ (the decay m.f.p. for lifetime τ.)

The efficiency is shown as a function of the L^o lifetime in Fig. 4. One notes that $\varepsilon > 0.1\%$ for lifetimes extending from a few tenths of a nanosecond up to 3 μs. The actual efficiency would depend upon the distribution

in γ which, although peaked about 14.6 is expected to be fairly broad. These effects would have the effect of smearing out the structure in Fig. 4 and producing a more nearly uniform efficiency vs. lifetime. If we assign an average efficiency between the above mentioned limits one obtains

$$\bar{\varepsilon} \simeq 2\%.$$

The requirement that at least one of the L^o decay products be a muon with $E_\mu > 10$ GeV would seem to impose a lower limit on the detectable M_L mass. A rough approximation for the 2-body decay is obtained from

$$E_\mu = \frac{1}{2}\gamma M_L = 10 \text{ GeV}$$

with

$$M_L \geq \frac{20}{\gamma} \text{ GeV} = 1.4 \text{ GeV}/c^2.$$

The detection of masses below 1.4 GeV/c^2 is by no means excluded. For instance, if $M_{L^o} << M_L^{\pm}$, or if $L^{\pm}$ is produced in the fragmentation region of the incident proton, then $\gamma \approx 400$ and the lower mass limit of L^o in our apparatus is only $\sim$ 300 MeV/c^2. We can now set limits on the detectable L^o production cross-sections in 1000 hours of data taking. The number of events N, expected in 1000 hours at 10^9 incident protons/pulse is given by

$$N = (10^3 \text{ hrs})(360 \text{ pulse/hr})(10^9 \text{ protons/pulse}).$$

$$(\sigma B_\mu \bar{\varepsilon})/(\text{absorption cross-section in Iron} = 0.69 \text{ barns})$$

$$= \frac{\sigma B_\mu}{10^{-37} \text{cm}^2}.$$

(σ is the production cross section and B_μ is the muonic decay branching ratio) Therefore if N = 100 events, the production cross-section must be $\sigma B_\mu \geq 10^{-35} \text{cm}^2$ and this is within the expected range if $B_\mu > 10^{-2}$.

III. BACKGROUNDS

The possible backgrounds fall into two categories: those originating in the beam dump magnet, and those due to the general background radiation. Reliable estimates are possible for beam stop background and these will be discussed first. Estimates for the event rates from the background radiation requires detailed knowledge of that radiation which is not readily available. It can be shown however using reasonable assumptions that this latter background can be ignored. The beam dump background will be due to inelastic muon interactions. Penetrating muons will constitute a general background radiation. They will also arise from direct production[12] and from the decays of pions, and kaons in the hadronic showers. The muon flux will be considered in the following section.

A. The Muon Flux through the Beam Dump Magnet

The M-2 beam will be tuned to 400 GeV protons ($x = 2P_L/\sqrt{s} \simeq 1$) and consequently there will be no muon contamination either from direct production or from π^+ decay. The general background of muons will be much less than muons produced in the hadronic showers in the beam dump magnet. The rate of muons which originate in the beam dump magnet is calculated in the following paragraphs.

We will compute the number of detectable muons from the decay of π^+ mesons produced in pp collisions at 400 GeV. We note that the muon spectrum from the decay of pions of energy E is uniform between the limits E and kE with k = 0.57. The decay m.f.p. is given by λE with λ = 186 feet/GeV.

The inclusive invariant cross-section for π^+ production can be represented approximately as

$$\sigma_{INV} = E \frac{d^3\sigma}{d\vec{p}^3} \simeq \sigma_o(\theta)\ e^{-b(\theta)P_L}$$

with the π^+ production angle $\theta = P\ /P_L$. These invariant cross-sections which are plotted in Fig. 5 were obtained from ISR data[13] using Feynman scaling. The fitted parameters are fiven in the following table:

θ (mr)	σ_o (mb GeV^{-2})	b (GeV^{-1})
0	270	.021
1	200	.022
2	150	.023
3	120	.024
4	90	.025
5	80	.028
10	70	.046
20	62	.084
50	49	.137

The π^+ multiplicity in the intervals E, E + dE, and θ + dθ is given by

$$n_\pi(\theta,\ E)dEd\theta = 2\pi\ \sin\theta\ \frac{E\ \sigma_o\ e^{-bE}}{(30\ \text{mb})}\ dEd\theta$$

where $P_L \simeq E$. The corresponding number distribution for decay muons is given by

$$n_\mu(\theta,\ E_\mu) = \int_E^{E_\mu/k} n_\pi(\theta,\ E)\ \frac{\lambda_{ABS}}{\lambda}\ \frac{dE}{E(1-k)}$$

$$= 2\pi\ \sin\theta\ \frac{\sigma_o(\theta)}{(30\ \text{mb})}\ \frac{\lambda_{ABS}}{\lambda(1-k)}\ \int_E^{E_\mu/k} e^{-b(\theta)E}\ \frac{dE}{E}$$

where the available path length for decay is λ_{ABS}, the absorption m.f.p. in the stopping material. The calculations were carried using standard tables of the Logarithmic Integral and are plotted for various values of τ in Fig. 6-a.

The total number of $\mu^{\pm}$ which must also include π^{-}, $K^{\pm}$ decay is obtained approximately from n_{μ} by a factor 2 based on the total multiplicities,[14] muonic branching ratio and the muon energy intervals E(1-k) for π, and $K_{\mu 2}$ decays.

We have computed integrals of the number distribution to encompass the acceptance of the experimental apparatus in order to determine the muon fluxes. In Fig. 6-b we have plotted the functions

$$N_{\mu} = 2 \int_{o}^{\theta} d\theta \int_{E_o}^{E} n_{\mu}(\theta, E_{\mu}) dE_{\mu}$$

which is the number of muons per interacting proton. A plot of N_{μ} for θ = 50 mr, which is the average angular acceptance, and for E_o = 6.7 GeV which corresponds to a range of nineteen feet in steel, is shown and this appears to approach the limit

$$N_{\mu}(50 \text{ mr}, 6.7 \text{ GeV}) \longrightarrow 6 \times 10^{-4}$$

The muon rate from the decay of π's and K's would therefore be

$$R_{\mu}(\text{decay}) = (10^{9} \text{ interaction protons/sec}) 6 \times 10^{-4}$$
$$= 6 \times 10^{5} \text{ sec}^{-1}$$

Since directly produced muons are known to have the same x and $p_{\perp}$ dependence

as pions [12] these will contribute according to the rate

$$10^{-4}\ n_\mu(\theta,E) \text{ per proton interaction.}$$

The corresponding rate for directly produced muons is therefore

$$R_\mu(\text{direct production}) = 10^9 \int_0^{50\text{rad}} \int_{E_o}^{\infty} 10^{-4} n_\pi(\theta E)\, d\theta\, dE$$

$$= \frac{(10^5 \text{sec}^{-1})}{30 \text{ mb}} \int_0^{50\text{mr}} 2\pi\theta d\theta \sigma_o(\theta) \int_{6.7 \text{ GeV}}^{\infty} E\ e^{-b(\theta)E} dE$$

$$= \frac{10^5 \text{sec}^{-1}}{30 \text{ mb}} \int_0^{50\text{mr}} 2\pi\theta d\theta \{(6.7 + \frac{1}{b})\frac{e^{-6.7b}}{b}\}\sigma_o(\theta)$$

$$\sim 10^4 \text{ sec}^{-1}$$

Therefore this is neglibible compared with the decay muon rate and the total rate is about

$$R_\mu \simeq 6 \times 10^5 \text{ sec}^{-1}$$

At this rate the spark chambers, with memory times of about 1μs. are expected to have one or more extraneous tracks with a 50 percent probability. However a substantial reduction in the rate can be achieved with the sweeping magnetic field. The minimum energy E_o would then be determined by the magnetic deflection out of the angular acceptance, and this is obtained approximately from the following calculation

$$\theta = 50\text{mr} = (0.03 \text{ GeV/c/kG-m}) \int B d\ell / p^{MIN}$$

$$\int B d\ell = (23\text{kG})(4.8\text{m}) = 110\text{kG-m}$$

$$E_o = p^{MIN} = \frac{0.03 \times 110}{.05} \text{ GeV} = 66 \text{ GeV}$$

The N_μ curve for E^o = 66 GeV is also shown in Fig. 6-b and this approaches the limit

$$N_\mu \text{ (sweeping with magnetic field)} \longrightarrow 10^{-5}.$$

The reduced muon flux is therefore

$$R_\mu \text{(with sweeping magnetic field)} \gtrsim 10^4 \text{ sec}^{-1}$$

We conclude that the sweeping magnetic field is essential for the experiment.

3. Background from K^o Production in Inelastic Muon Interactions

The penetrating muons described in the previous sections will undergo inelastic interactions in the beam dump magnet and there is a chance that some of the neutral hadrons (K^o,Λ^o,n) produced will escape into the decay region to appear as background events.

A calculation of the probability for the production of an escaped K^o, given in the Appendix gives the value;

$$\text{Prob./muon} = 1.1 \times 10^{-8} \text{ for } E_K \geq 10 \text{ GeV}$$

The calculation is for K^o-mesons energetic enough to produce a 10 GeV decay muon to satisfy the event selection critera. A total of fifteen such background events would be expected which is the product of the following factors:

number of pulses $= 3.6 \times 10^5$,

muons/pulse $= 6 \times 10^5$,

K^o/muon $= 1.1 \times 10^{-8}$,

$K_{\mu 3}$ branching ratio = 1/2 (0.28),

decay prob. for 10 GeV $K_L^o = \frac{3 \times 14}{(10/.49)51.8} = 4 \times 10^{-2}$. However the number is

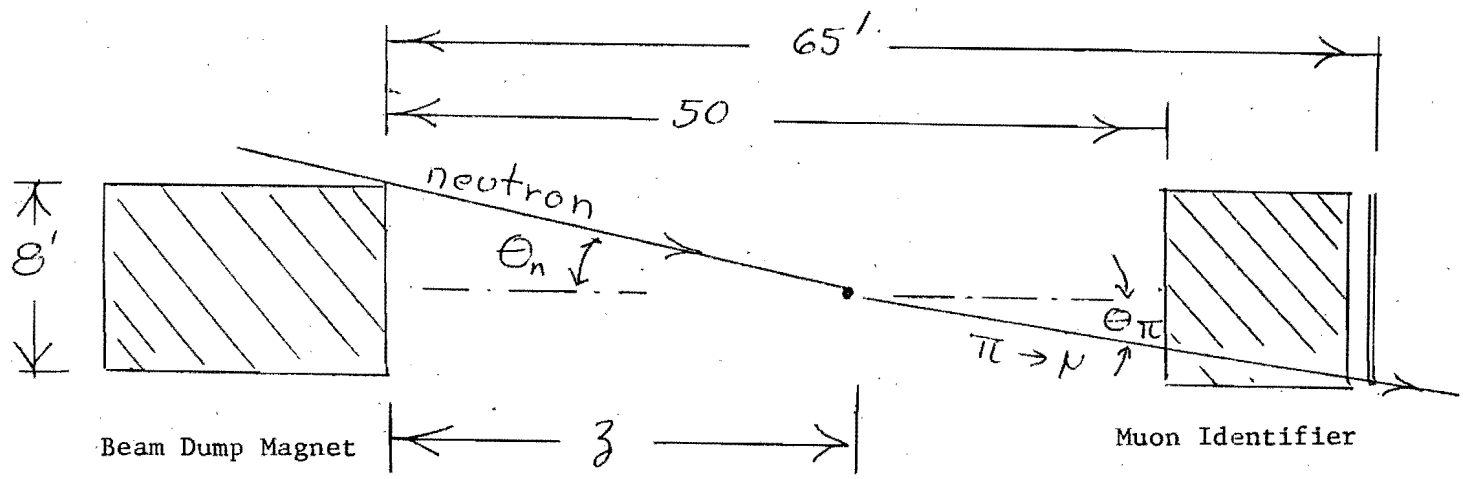
zero because of the high probability that these kaons will be accompanied by a self-vetoing charged particle. The same remarks apply to neutrons and Λ^{o}'s produced in muon interactions.

4. Background from Neutron Interactions in the Decay Regions

The high energy neutrons from proton interactions in upstream targets etc. will be mainly moving parallel with the beam. Since one pion exchange is a dominant mechanism for $p \rightarrow n$ charge exchange we can assume a distribution of the form;[15]

$$f(E_n) \exp. \{-bP_\perp\}$$

with $b = \frac{1}{m_\pi} \simeq 6 \rightarrow 7$ GeV/c^{-1}. If there is an interaction in the decay region in which a pion is produced we require that the pion have $E > 10$ GeV, and be directed toward the muon identifier. The situation is illustrated in the figure below.



The probability for the event shown is given by the product of the following factors:

$$\text{neutron flux} \sim f(E_n)e^{-b(\frac{4'}{z})E_n}$$

$$\text{porbability for producing } \pi \sim (\text{area})\frac{dz}{\lambda} \langle n_\pi \rangle \; e^{-bE_\pi \theta_\pi}$$

$$(\text{with } \theta_\pi = \theta_n = \frac{4'}{65'-z}, \text{ and (area)} = (8')^2,$$

$$\text{and } \lambda(\text{helium}) = 1.1 \times 10^4 \text{ feet}$$

$$\text{decay probability} = \frac{50'-z}{E_\pi \times 186 \text{ feet/GeV}}$$

The total rate for such a background is obtained by summation over E_n and z as follows:

$$R = \frac{(\text{area})}{186 \times 1.1 \times 10^4} \int dE_n \langle n_\pi(E_n)\rangle \; f(E_n)$$

$$\cdot \int_0^{50'} \frac{dz}{E_\pi} (50'-z) \exp\{-6[\frac{4'}{z} E_n + 4'(\frac{1}{z} - \frac{1}{65'-z})E_\pi]\}$$

The integrand, for fixed E_π = 10 GeV, E_n = 40 GeV, is sharply peaked at z = 48' where most of the contribution occurs. The rate at these energies is

$$\frac{dR}{dE_n} \simeq (\text{area}) f(E_n) \; 10^{-17}$$

The only way therefore that the neutrons could contribute to a background is as an accidental along with a penetrating beam muon. But such an event would be vetoed by the veto counters even if it could survive the tight contraints

of timing and vertex reconstruction. We must conclude that any background of this kind would also be negligible.

IV. COSTS AND RESOURCES

A. Available Manpower and Support

The members of the High Energy Physics Group at the University of Maryland who will be principally involved in carryong out the experiment are the following:

Physicists	Dr. C. Y. Chang Dr. R. Ellsworth Dr. P. H. Steinberg 1 Research Associate
Res. Assist.	Mr. E. Sager 1 additional Research Assistant

Other members of the group would be available to aid in data taking runs if necessary.

In addition there is the support of the Physics Deaprtment mechanical and electronics engineering staffs and work shops for the design and construction of the experimental equipment.

B. Equipment to be Supplied by the University of Maryland

The detector modules (spark chambers and counters) will be supplied by the University of Maryland at a cost of $25,000. We will also supply the SAC magnetostrictive wire read-out equipment, spark chamber high voltage supplies, and Ne-He gas recirculating system.

C. Equipment Requested of the Fermilab

We will need the necessary fast trigger logic, the TOF to digital converters and SAC-CAMAC interface. We request in additon the use of a PDP-11 computer for on-line analysis during equipment tune-up and data taking.

We will also require the various shielding materials described in Section II.

V. RUNNING SCHEDULE

We are requesting 200 hours of set-up time, and 1000 hours for data taking. The results of this exploratory run will be studied from the point of view of a possible follow up experiment. We expect to be ready by the end of the summer 1976.

APPENDIX

We will relate the inclusive cross section for

$$\mu^{\pm} p \rightarrow K^{o} + \text{anything},$$

to the photo production cross sections using the method of Weizsacher and Williams. Data exists for π^- photo production in hydrogen[13] in the form of the invariant structure function,

$$F(x) = \frac{1}{\pi} \int_{o}^{\infty} \frac{E^*}{p^*_{MAX}} \frac{d^2\sigma}{dx dp_{\perp}^2} dp_{\perp}^2$$

and this is found to be adequately fitted in the relevant x-range by the function

$$F(x) \approx (16\mu b) \exp [- x^2/0.64] \quad (x > 0).$$

One can obtain the K^o cross sections if it is assumed that the kaon and pion structure function are the same.

Using multiplicites[16] we obtain a π^- to K^o scale factor of 1/5. The cross section for K^o photo production is therefore given by

$$\sigma_{K^o}(x > x_o) = \frac{1}{5 < n_{\pi^-} >} \int_{x_o}^{1} F(x)dx, \text{ with } < n_{\pi^-} > = 2.5$$

It can be shown that $E_K^{(LAB)} \simeq x\, E_\gamma$ in the limit $E_\gamma >> m_p$. The cross section for producing a K^o of energy greater than E_K in muon scatterings is given in the following equation;

$$\sigma(>E_K) = A \int_{E_K}^{\infty} N_\gamma(E_\mu, E_\gamma)\sigma_K o(E_K, E_\gamma)dE_\gamma .$$

Here, N_γ is the number of virtual photons per unit energy accompanying the muon and is given in standard textbooks in Electrodynamics. This is given in the appropriate approximation for a 50 GeV muon in iron, by the following expression;[17]

$$N = \frac{3.7 \times 10^{-3}}{E_\gamma} \exp\left[(0.11\ \mathrm{GeV}^{-1})E_\gamma\right] .$$

The cross section for K^o production in iron is therefore given by

$$\sigma(E_K > 10\ \mathrm{GeV}) = \frac{55.9}{5 \times 2.5} \int_{E_K=10}^{\infty} \frac{dE_\gamma}{E_\gamma}\, 3.7 \times 10^{-3} \exp(-0.11\ E_\gamma)$$

$$\times \int_{x_o = \frac{E_K}{E_\gamma} = \frac{10}{E_\gamma}}^{\infty} (16\mu b)\ \exp(-x^2/0.64)dX$$

$$\simeq 6.7 \times 10^{-3}\ \mu b$$

The probability that a K^o will be produced and escape into the decay region is given by

$$P = \int_o^{\infty} e^{-z/\lambda_{ABS}} \frac{dz}{\lambda_{PROD}} = \frac{\lambda_{ABS}}{\lambda_{PROD}} = \frac{6.7 \times 10^{-3}\mu b}{0.6b} = 1.1 \times 10^{-8}$$

References

1. M.L. Perl and P. Rapidis, Muon Phys. CNRS Colorado State Univ. Sept. 6-10, (1971) SLAC-PUB-1496 (1974).
   J.D. Bjorken and C.H. Llewellyn Smith, Phys. Rev. D7, 887 (1973).
   L.M. Lederman, Proc. ISABELLE Summer Studies, July 14-25 (1975), page 84, BNL-20550.

2. M.G. Albrow, et al, Nucl. Phys. B97, 189 (1975).
   J.A. Appel et al, Phys. Rev. Lett. 32, 428 (1974).

3. D. Bintinger, et al, Phys. Rev. Lett. 34, 982 (1975).

4. M.L. Perl et al, Phys. Rev. Lett. 35, 1489 (1975).

5. M. Bernardini, et al, N.C. 17A, 383 (1973).

6. B.C. Barish, et al, Phys. Rev. Lett. 31, 410 (1973).

7. A. Benvenuti, et al, Phys. Rev. Lett. 34, 419 (1975), ibid, Phys. Rev. Lett. 35, 1199, 1209, 1249 (1975).

8. B.C. Barish, et al, Colloq. Int. CNRS 254, 131 (1975).

9. A. Benvenuti, et al, Phys. Rev. Lett. 35, 1486 (1975).

In order to estimate the cross-section and lifetime ranges for use in Figure 1, a simple model is employed. We will assume that the L^o is produced at rest (x = 0) in the p-p center-of-mass. The invariant cross-section is assumed to be of the form

$$\sigma_{INV} = (\sigma/\pi M_L^2) \exp(-P_\perp/M_L)\ \delta(x).$$

the decay region (2 meters deep x 3 meters wide) is about 10^3 meters downstream of the production point. The detection efficiency is therefore given by

$$\epsilon \cong (2m/\gamma c\tau) \exp[-10^3 m/\gamma c\tau](\tfrac{1}{2}(P_\perp^{MAX}/M_L)^2)$$

with $P_\perp^{MAX}/M_L = \gamma\theta^{MAX} = \gamma \cdot 1.5 \times 10^{-3}$, and

with $\gamma = 12.6$ at $E_{LAB} = 300$ GeV. Then

$$\epsilon \cong \frac{10^{-13}}{\tau} \exp\left(-\frac{3 \times 10^{-7}}{\tau}\right) \text{ with } \tau \text{ in seconds}$$

and this cuts off sharply for $\tau < 10^{-7}$ sec. and is $\sim 10^{-8}$ in the interval $\tau = 10^{-7} \rightarrow 10^{-5}$ sec. During the course of the experiment 3.5×10^{17} protons were absorbed in the beam dump. The limiting cross-section is therefore given by

$$\sigma < \frac{0.6 \times 10^{-24}\ \mathrm{cm}^2}{3.5 \times 10^{17} \times 10^{-8}} = 1.7 \times 10^{-34}\ \mathrm{cm}^2$$

at the 90% confidence level.

10. See for instance, J.D. Bjorken and C.H. Llewellyn Smith (ref. 1).

11. S.D. Drell and T.M. Yan, Phys. Rev. Lett. 25, 316 (1970) and Ann. Phys. (N.Y.) 66, 578 (1971);
J. Kuti and V. Weisskopf, Phys. Rev. D4, 3418 (1971);
G. Chu and J.F. Gunion, Phys. Rev. D11, 73 (1975).

12. L.M. Lederman and S. White, Phys. Rev. Lett. 35, 1543 (1975). This "comment" reviews the earlier experiments and gives detailed references.

13. M.G. Albrow et al, Nucl. Phys. B73, 40 (1974).

14. M. Antinucci, et al, N.C. Lett. 4, 121 (1973);
C.M. Brombey, et al, Univ. of Rochester and Univ. of Michigan preprint, UR416/UMBC72-14.
D. Cohen, Proc. Fourth Inter. Symp. on Multiparticle Hadrodynamics (Pavia, Sept. 1973) page 172.
M.G. Albrow, et al, Phys. Lett. 51B, 424 (1974).

15. This argument leads to a result not inconsistent with the experimental observation. Since for large P_T, the ratios $\frac{K}{\pi}$, $\frac{P}{\pi}$, $\frac{\bar{P}}{P}$ etc. approach to 1, and σ_{INV} $(PP \rightarrow \pi^{\pm} + \text{anything}) \sim e^{-bP}$ where $b \sim 6 \rightarrow 7\ \mathrm{GeV}^{-1}$.
It is reasonably justified to assume that $\sigma_{INV}(PP \rightarrow n + \text{anything})$ $\sim \sigma_{INV}(PP \rightarrow P + \text{anything})$ inelastic. Hence the $\sigma_{INV}(PP \rightarrow n + x) \sim e^{-bP}$.
See also T. Engler et al, Contribution to the Aix-en-provence Conf. 19

16. K.C. Motteit, et al, Phys. Rev. D5, 1603 (1972).

17. J.D. Jackson, Classical Electrodynamics, (JW) page 523.

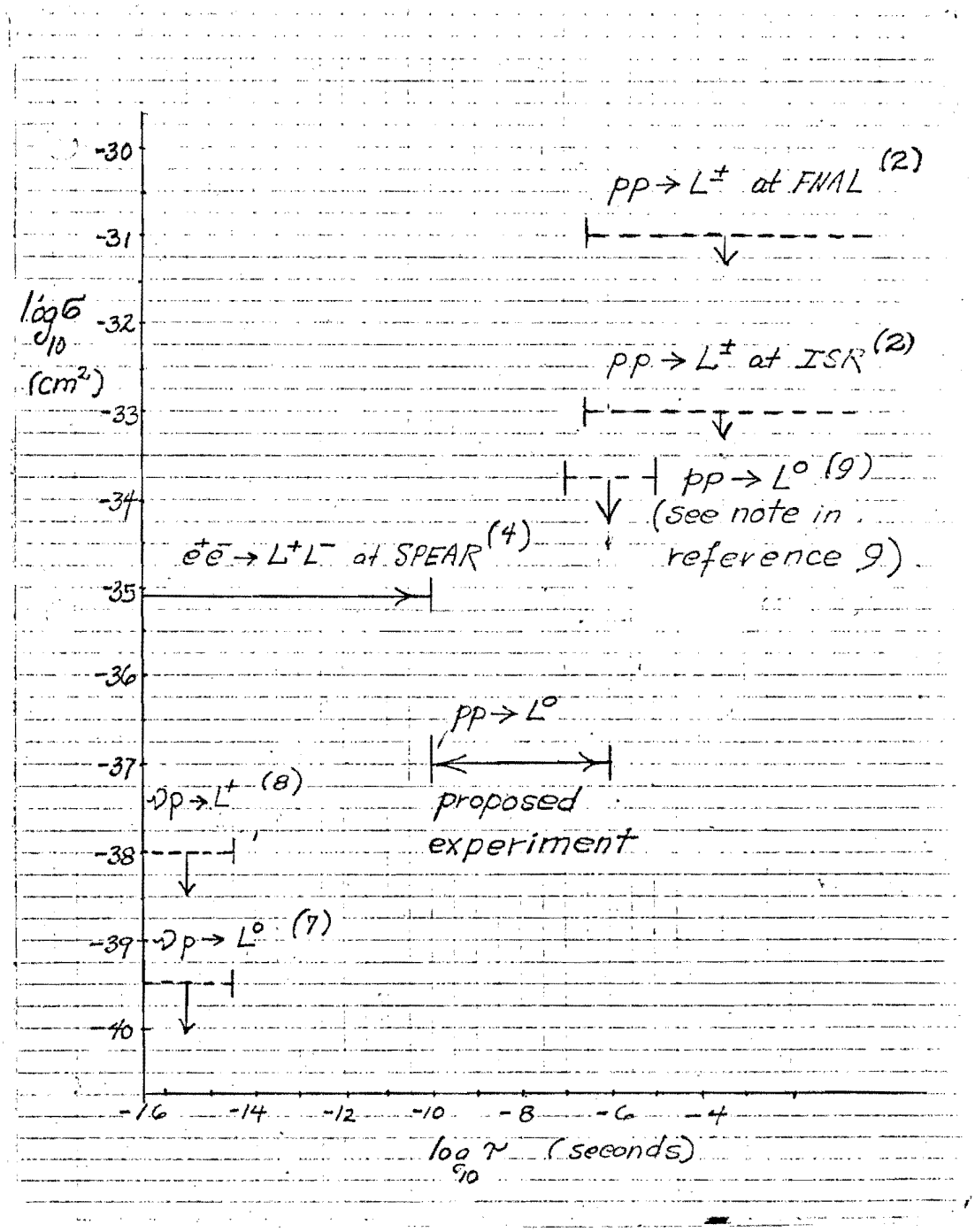


Figure 1

Experimental States of Heavy Lepton Searches
(Experiments with null results indicated as - -↓- -)

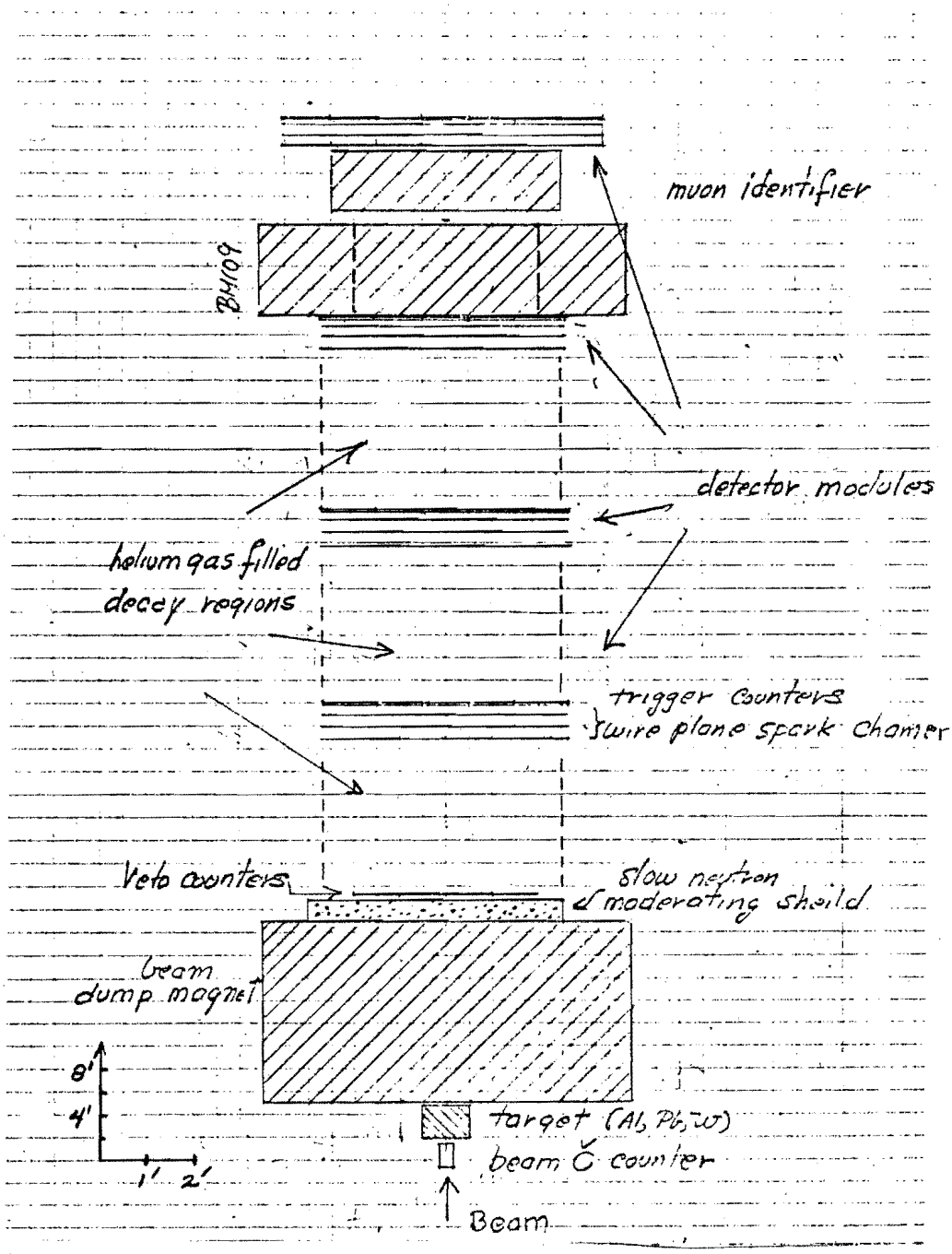
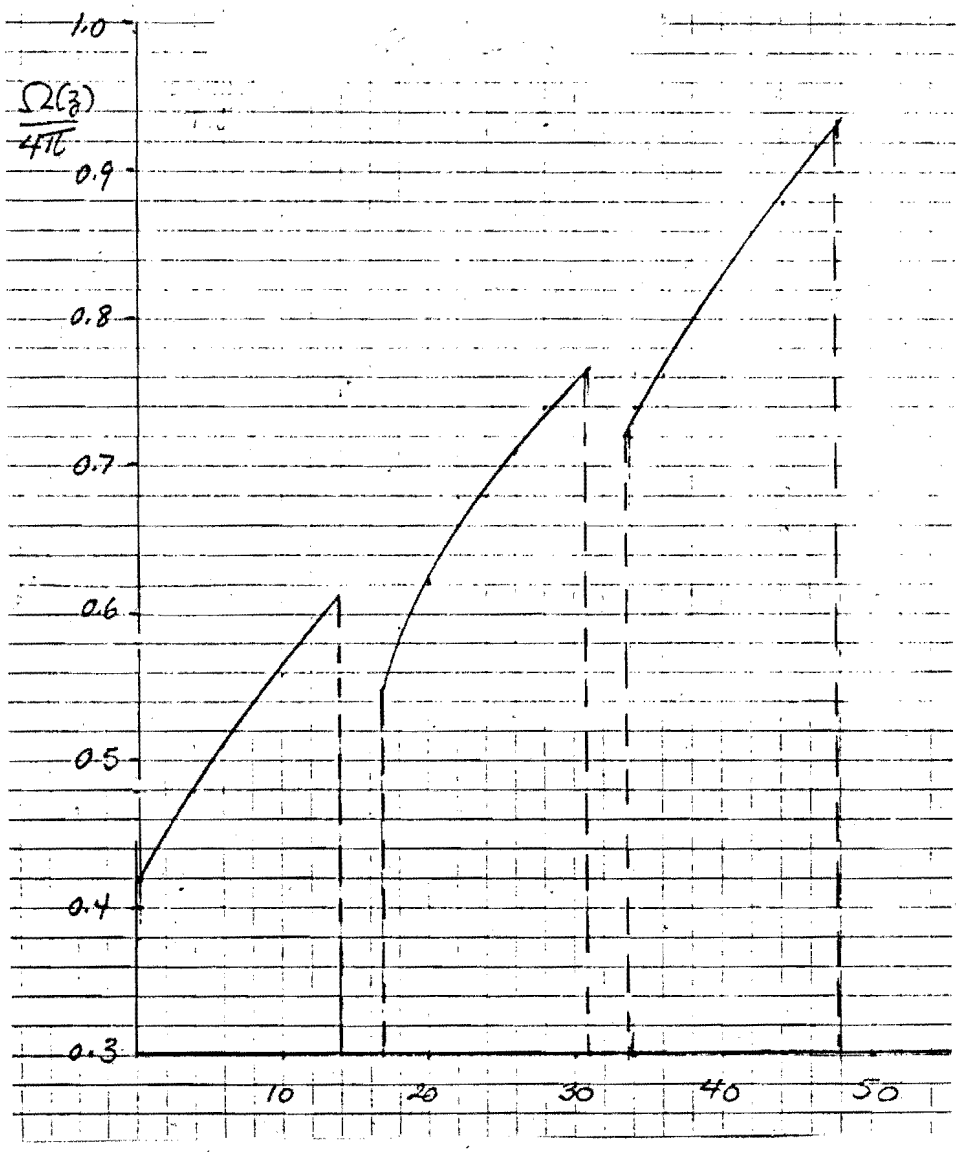


Figure 2

Experimental Layout

Geometric Efficiency for Detecting
2-Body Decay $L^o \rightarrow \mu + \pi$ Assuming
$\gamma = 14.6$ (see text)



z = distance from entrance to
decay region - (feet)

Figure 3

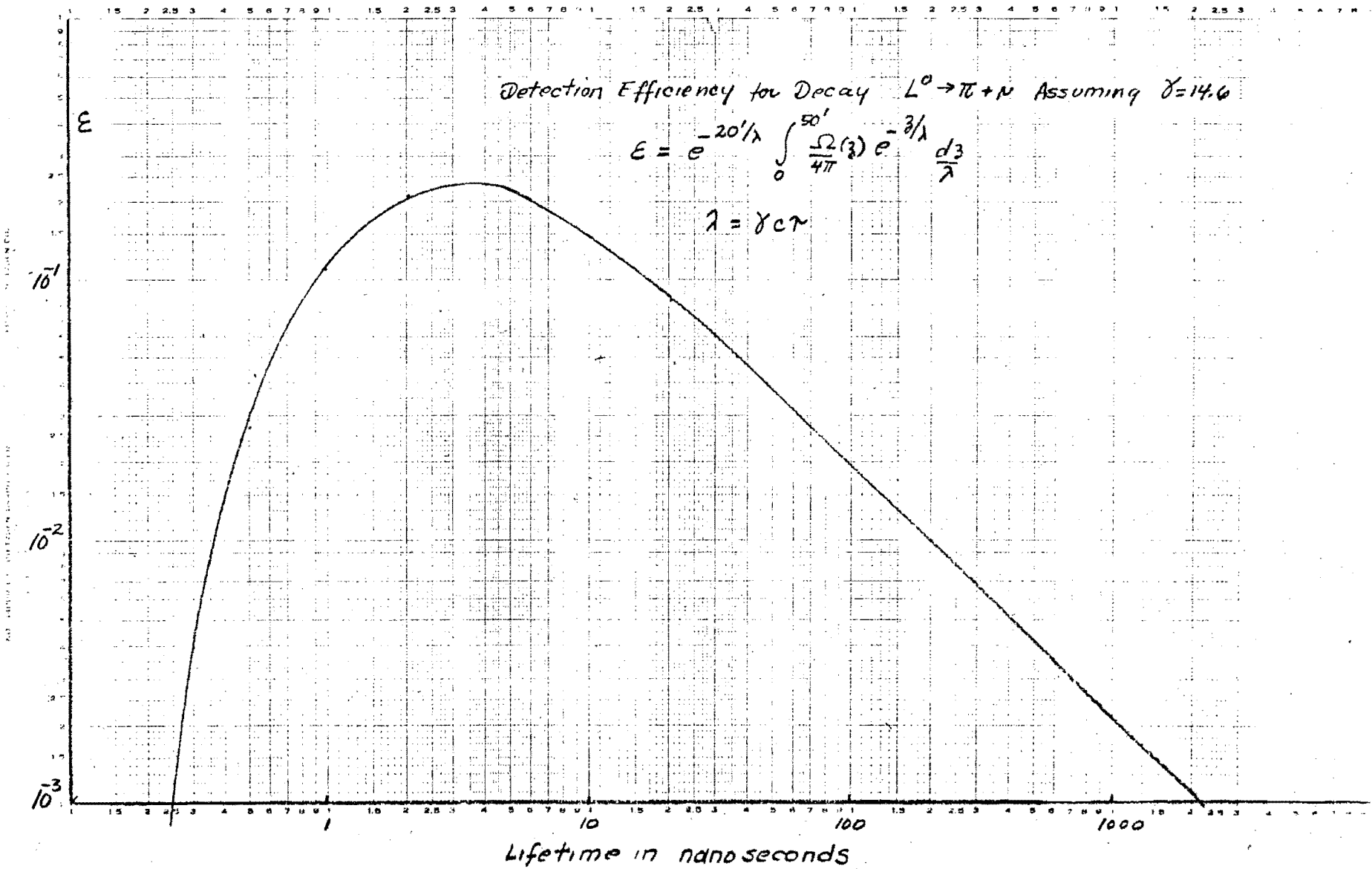
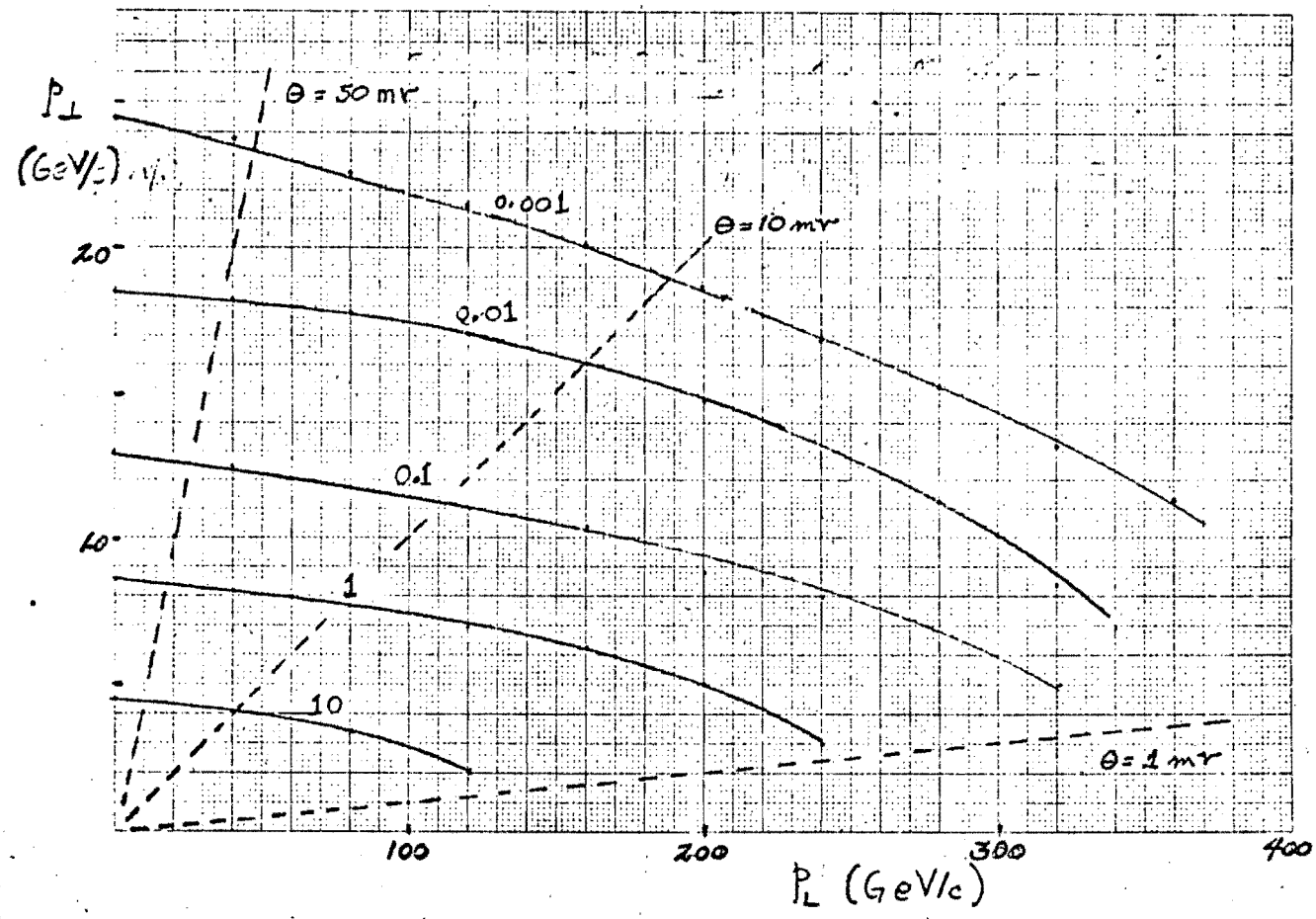

Detection Efficiency for Decay $L^0 \to \pi + N$ Assuming $\gamma = 14.6$
$\varepsilon = e^{-20'/\lambda} \int_0^{50'} \frac{\Omega(z)}{4\pi} e^{-z/\lambda} \frac{dz}{\lambda}$
$\lambda = \gamma c \tau$
ε
10^{-1}
10^{-2}
10^{-3}
1
10
100
1000
Lifetime in nanoseconds

Figure 4



Contours of Constant $Ed^3\sigma/dp$ for $p + p \rightarrow \pi^+$ + anything at FNAL Energies. Cross sections, in units mb - GeV^{-2} are obtained by scaling ISR data (Ref. 13)

Figure 5

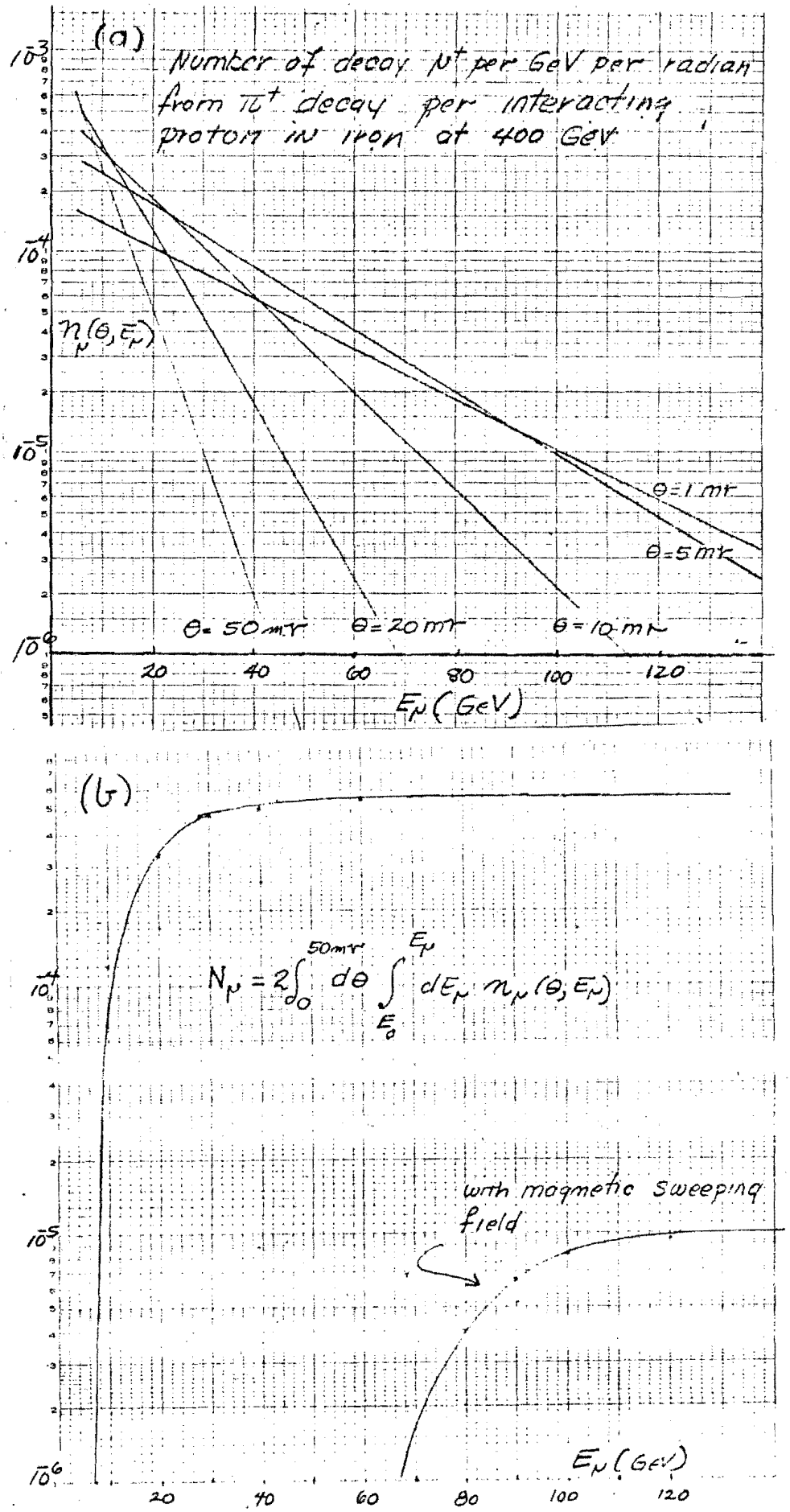

(a)
Number of decay μ^+ per GeV per radian from π^+ decay per interacting proton in iron at 400 GeV
$n_\mu(\theta, E_\mu)$
$\theta = 1$ mr
$\theta = 5$ mr
$\theta = 50$ mr
$\theta = 20$ mr
$\theta = 10$ mr
E_μ (GeV)
(b)
$N_\mu = 2\int_0^{50\,mr} d\theta \int_{E_0}^{E_\mu} dE_\mu \, n_\mu(\theta, E_\mu)$
with magnetic sweeping field
E_μ (GeV)

Figure 6

Addendum to Proposal - 468

SEARCH FOR PENETRATING MASSIVE NEUTRAL PARTICLES PREODUCE IN HIGH ENERGY PROTON COLLISIONS

Experimenters: C. Y. Chang, R. W. Ellsworth,
E. Sager, P. H. Steinberg
University of Maryland

April 1976

I. Introduction

We describe in this note several changes in the experimental design of our proposed massive neutral lepton search. In the original design neutral leptons which may be produced in nuclear collisions in a magnetized beam dump are detected through their decay interactions in a 50' downstream decay region. We proposed to use the E-8 hyperon beam sweeping magnet with its collimated channel plugged as the beam dump. The decay particles would be detected in three banks of wire-plane spark chambers triggered by scintillation counters which would be placed at regular intervals along the decay region. We also intended to use the E-8 analyzing magnet at the downstream end of the decay region as a hadron filter for muon identification. A fourth bank of spark chambers was to be placed behind this magnet to detect muons which could penetrate over six feet of steel without significant deflection due to multiple coulomb scattering. We argued that the requirement of an energetic muon $E_\mu > 10$ GeV, would substantially reduce the background which might arise from hadronic interactions in the decay region. These hadrons could be produced in other experimental areas. A more likely source would be deep inelastic muon scattering near the downstream end of the beam dump where such events may not be vetoed by accompanying secondary charged particles in the veto counters at the entrance to the decay region. Our trigger would therefore

have been restricted to the decay process:

$$L^o \rightarrow \mu^{\pm} + \text{hadrons}.$$

We did not intend to turn on the analyzing magnet. We felt that the small acceptance, [(8 x 24) in^2 at up to 50 feet], would be too severe a restriction of the otherwise large solid angle. The presence of strong magnetic fields in the return yokes could not, in our view, be reliably used for the momentum analysis of penetrating muons without an enormous calibration effort.

Nevertheless, we acknowledge the value of some measurement of energy. We also acknowledge the value of a less restrictive trigger which might also include the decay modes:

$$L^o \rightarrow \nu + \text{hadrons},$$
$$\rightarrow e^{\pm} + \text{hadrons}.$$

We therefore propose to replace the BM109 magnet with a calorimeter which can distinguish between muons, electrons, photons and hadrons and provide a rough measurement of their energies.

A relatively inexpensive colorimeter can be built in which the shower ionization is sampled by multi-wire proportional chambers with 1" wire spacing and separated by 3/4" to 7" thick steel plates. A total of six absorption m.f.p.'s of steel would be used. Adjacent sets of wires would be connected to a relatively small number of amplifier + ADC channels. In this arrangement the shower intensity is sampled both in depth and in laterial position so that one can associate the showers with individual tracks in the spark chambers. The spatial resolution would be limited only by the numbers of avilable ADC channels and amplifiers.

We estimate that about 240 channels would be optimum. Calorimeters similar to this, using racks of ionization counters as detectors, have been used in cosmic ray experiments.[1]

The advantages of such a device are immediately evident. It can be made large and therefore would not limit solid angle. It is capable of particle identification through the very different distributions in depth of the ionization for electromagnetic and hadronic showers and for penetrating or stopping muons. Showers without associated tracks in the spark chambers would be readily identified as either photons or neutral hardons. The slow rise times expected ($\sim$ microseconds) can be easily tolerated at the expected low rates. Furthermore the device can be calibrated <u>in situ</u> by the E-8 detectors before the latter is dismantled and removed. We would therefore recommend that the calorimeter be initially installed behind the E-8 analyzing magnet to be calibrated on pions and protons from Λ° decay with the beam stop magnet opened, and muons with the beam stop magnet plugged. The total flux of neutrals during the calibration runs would be limited to a few thousand per second by adjusting, if necessary, the position and thickness of the production target. The calibration of single particle distributions could be constantly monitored by muons during the regular data taking.

Even with uncertainties up to 50%, energy data can be very useful in removing backgrounds from neutral K-meson and hyperon decays. Angles would be well measured in the spark chambers so that the energy errors would dominate the errors in determining the transverse momenta and the invariant masses of the decay particles. These quantities have specific upper limits in the neutral hadron decays which can be used to separate out such backgrounds. Photon detection can also play a crucial role in distinguishing, for example, between

$$K_L^o \rightarrow e^+ + \pi^- + \nu$$

and

$$L^o \rightarrow e^+ + \pi^- + \pi^o$$

where the masses of the K_2^o and the L^o may not be very different.

A slight modification of the upstream veto system is also recommended. We would have two veto counters separated by an additional 3-5 absorption m.f.p.'s at the downstream end of the beam dump magnet. A veto coincidence between these counters would necessarily place any deep inelastic muon interaction upstream of the final absorbing layer. The probability therefore for a neutral hadron produced in such a collision to escape into the decay region would be substantially reduced. The revised experimental layout is shown in Figure 1.

II. Calorimeter Design

The size and depth of the calorimeter, and the spatial resolution for shower sampling are dictated by the following consideration.

A. Detection Solid Angle.

The detection solid angle will determine the face area of the calorimeter. If the calorimeter is to be placed downstream of the existing E-8 Λ-spectrometer then the overall length of the decay region would be increased to $\sim$ 65 feet. A lower limit for the solid angle fraction $\Omega/4\pi$, if the face area is 6 x 6 square feet, is obtained by considering the 2-body decay into light particles of a massive L^o at a point mid-way along the decay region. We will require that both particles enter the calorimeter. An example of such a decay would be

$$L^o \rightarrow e^{\pm} + \pi^{\pm}$$

The Lorentz factor for the L^o will be taken to correspond to its being produced at rest in the proton-nucleon center-of-mass frame. (γ = 14.7 for E_{LAB} = 400 GeV).

The effective detector radius is $R = \sqrt{\frac{area}{\pi}}$ = 3.4 feet. The maximum angle in the laboratory is therefore $\theta^{MAX} \simeq 3.4'/32.5' \simeq 100$ mrad and the angle of the companion particle is given by $\theta^{MIN} = (\gamma^2\theta^{MAX})^{-1}$. This corresponds to a center-of-mass angle θ_c, which can be obtained from

$$\frac{1-\cos\theta_c}{1+\cos\theta_c} = (\gamma\theta^{MIN})^2 = \frac{1}{(\gamma\theta^{MAX})^2} .$$

The geometrical efficiency is therefore

$$\frac{\Omega}{4\pi} = \cos\Theta_c = 0.41$$

We conclude that an active face area of 6 x 6 square feet would be quite acceptable.

B. Absorber Depth and Shower Sampling.

The cascade particle multiplicities in iron obtained from Monte Carlo calculations by W. V. Jones are shown for various incident hadron energies in Figure 2.

We expect hadron energies to be below 20 GeV and consequently the showers would be well contained within 6 absorption m.f.p.'s. This corresponds to a depth in steel of 6 x 17 cm $\cong$ 100 cm. The peak in the shower multiplicity is seen to occur at about 1 m.f.p. = 17 cm. For electrons and photons the shower peak occurs at about 2-3 radiation lengths which is 4 cm in iron. The electromagnetic showers will be contained within 15 radiation lengths. In order to distinguish between these cases the entire 39 inches of iron absorbers will be sampled at

ten intervals of gradually increasing thickness between a radiation length ($\sim$ 3/4") to an interaction m.f.p. ($\sim$ 7").

The shower intensity will be sampled by multi-wire proportional chambers several inches thick and with one inch wire spacing. The chamber gains will be set to give a linear response from 1 to 100 equivalent particles. The gain of the amplifier-ADC's will be set to detect single particles and required to be linear over the same dynamical range. The ten MWPC's will alternate between sampling horizontal and vertical shower distributions. The resolution of this sampling need only be fine enough to be able to follow individual showers which, as we have seen, may be separated by several feet. We will obtain optimum spatial resolution by tying adjacent wires together in sets of three; this would require $10 \times \frac{72''}{3''} = 240$ amplifier-ADC channels. The minimum requirement for no spatial resolution, would be 10 amp-ADC channels.

C. Estimation of Energy Resolution

We show in Figure 3 the percentage energy resolution vs hadron energy, as given by Sculli[2]. For samples every 4", by plastic scintillator, the enrgy resolution is 30-40%. Now MWPC's have a larger signal fluctuation than typical plastic counters, but this will not reduce the resolution appreciably as we will show.

Figure 4 shows the signal distribution for minimum ionizing particles traversing a 2" thick chamber, operated at the University of Maryland Cosmic Ray Laboratory in New Mexico. The single particle resolution is about 70%. But the total number of particles we would sample in a 10 GeV hadron cascade is generally > 40, so the error or the sampling is $70/\sqrt{40} \sim 11\%$.

This will not increase appreciably the errors of 30-40% given in Figure 4 since it is added to the latter in quadrature.

III. Schedule, Requirements, Personnel

The inclusion of the calorimeter represents a significant escalation in the experiment. We are nevertheless confident that we could be ready within 12 to 18 months. A large prototype spark chamber of active area 6' x 6' has been built and successfully tested on β-rays from a Ru^{106} source. As to personnel we expect to add to the present list of authors at least one assistant professor, one research associate and one or more graduate students. We believe that this is adequate to successfully prepare and carry out the proposed experiment with the revisions described herein.

The spark chambers, counters and calorimeter MWPC's will be constructed at the University of Maryland. We will require, in addition to the items listed in the original proposal, steel for the calorimeter and up to 240 ADC channels for the MWPC read-out. We will also require, in addition to 1000 hours requested for data taking, 150 hours for calibration of the calorimeter.

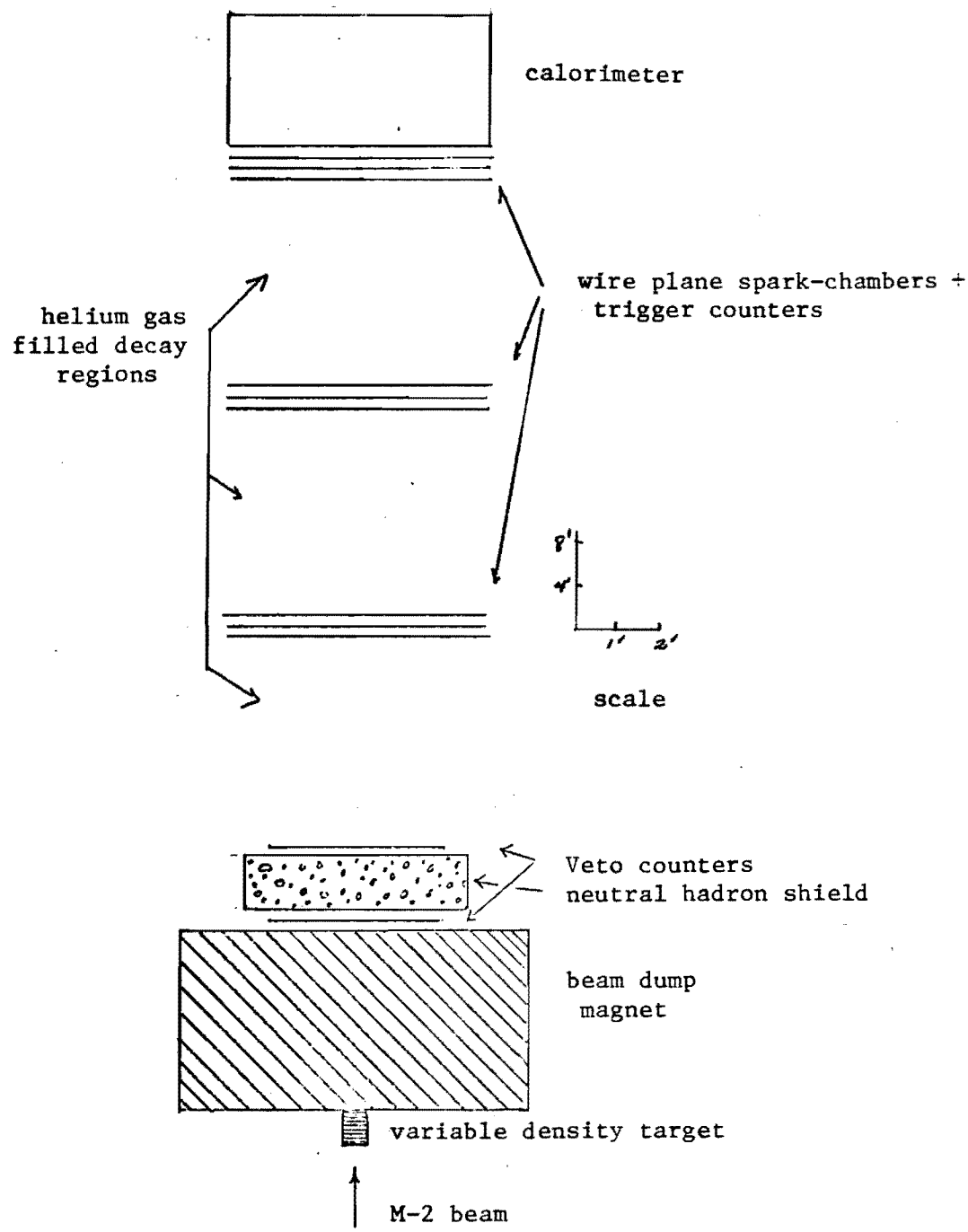


Figure 1

Experimental Layout

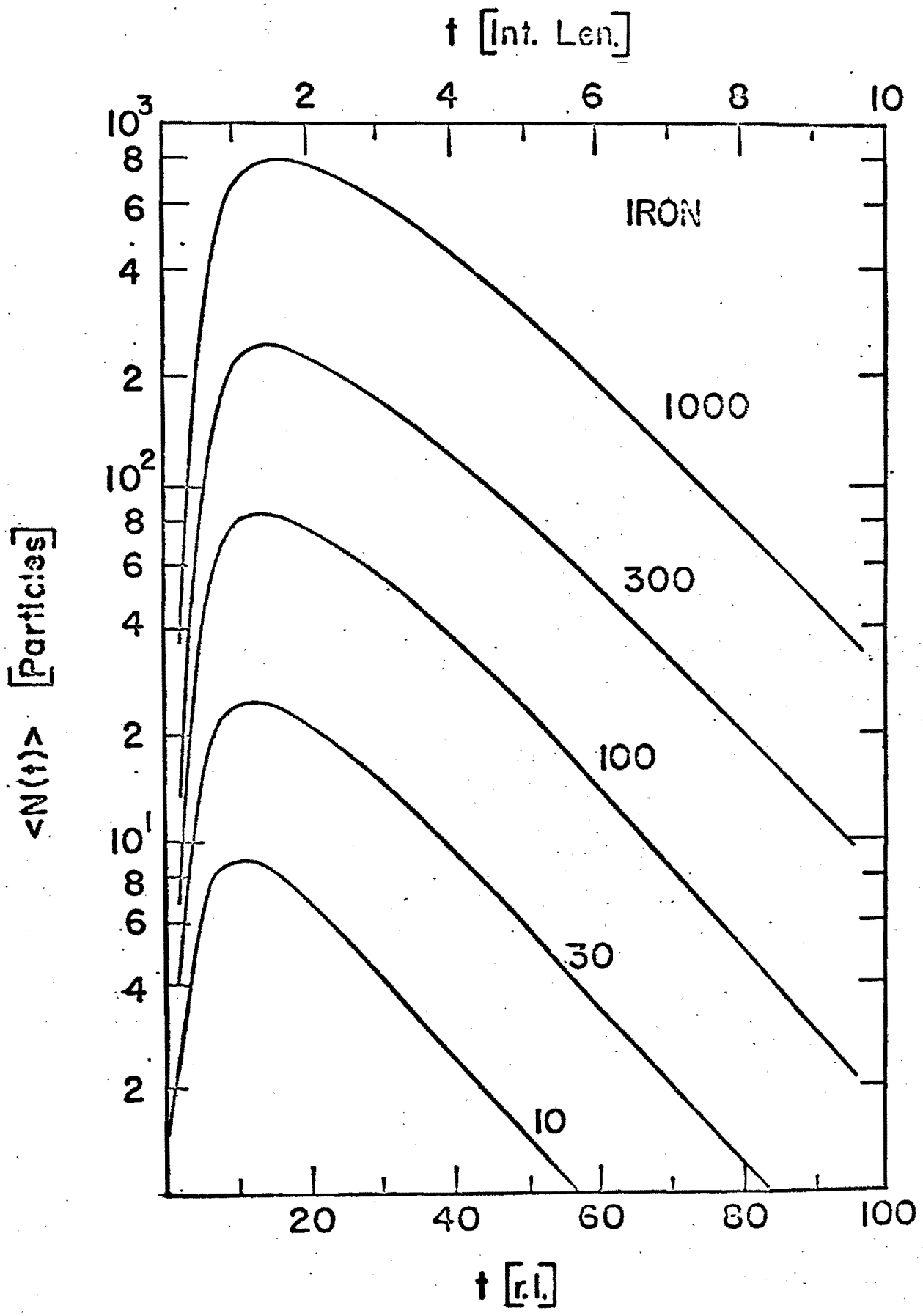


Figure 2
Hadronic Cascade Curves in Iron

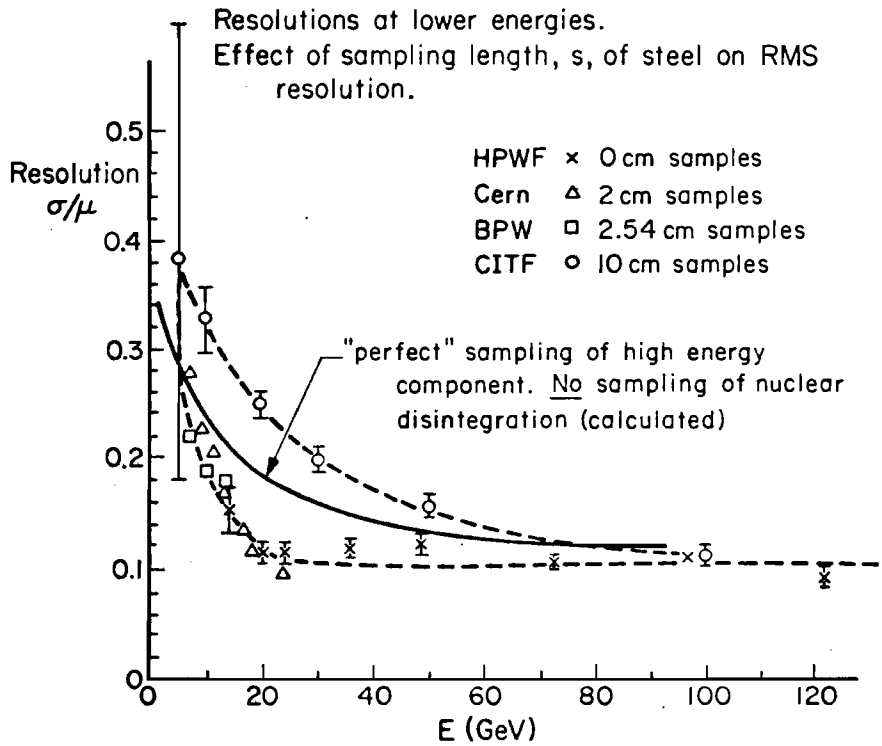


Figure 3

From F. J. Sciulli - (Ref. 2)

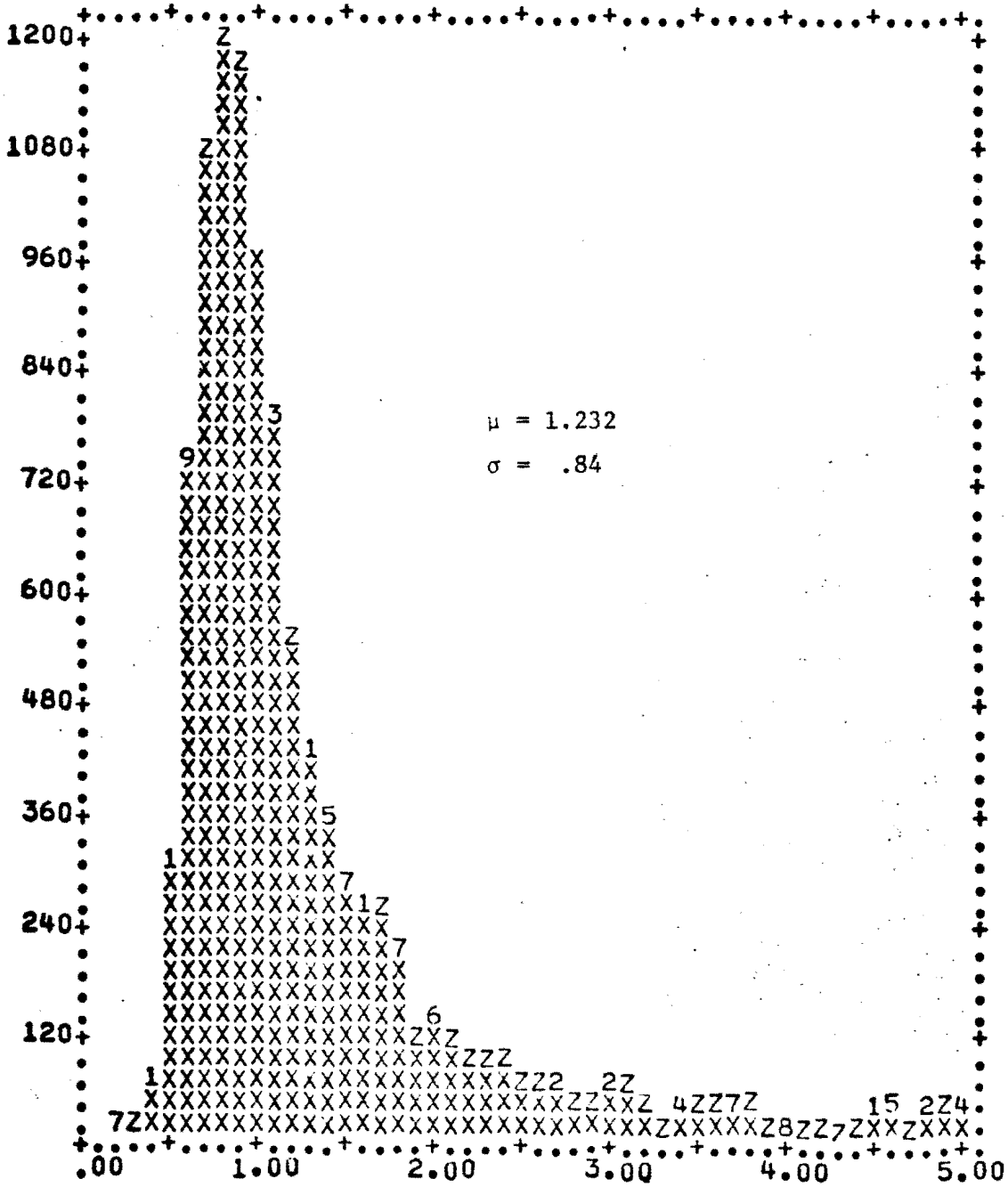


Figure 4

Single Particle

Signal dist.

(from 100 GeV hadron data)

References

1. N. L. Grigorov et al, JETP 7, 348 (1958),
N. L. Grigorov et al, Proc. Int. Conf. Cosmic Ray p. 860, London 1965.

2. F. J. Sciulli, Proc. of The Calorimeter Workshop, Fermi National Accelerator Laboratory, May 1975.

Oct. 1976

Revision of Proposal-468

SEARCH FOR PENETRATING MASSIVE NEUTRAL PARTICLES PRODUCED IN HIGH ENERGY PROTON COLLISIONS

EXPERIMENTERS: C. Y. Chang, T. Dombeck
R. W. Ellsworth, E. Sager
P. H. Steinberg and L. Teig
University of Maryland

I. Introduction

The Program Advisory Committee has resonded to the two earlier versions of our proposal by suggesting that we consider the feasibility of carrying out our experiment using the existing equipment of the neutral hyperon program. We are now confident that a worthwhile L^o search can be carried out with the E-8 apparatus along with several scintillation counter arrays to provide a fast trigger with an up-strem charged particle veto.

We have also been in contact with Lee Pondrom and Tom Devlin and they have offered us the full cooperation of their groups in showing us how to use the apparatus and in helping to keep it in working order during the experiment.

In the following section we show that a detection efficienty of 10^{-3} to 10^{-2} is possible and accordingly in 300 hours, at a beam rate of 10^9ppp, the event yield could be as large as $(\sigma B)/10^{-37}cm^2$. Conservative estimates based on parton model calculations gives $\sigma \sim 10^{-35} \rightarrow 10^{-34}cm^2$ for $m_L \sim 2$ GeV at 400 GeV, ($\sqrt{s} \sim 27$), and therefore the proposed experiment would constitute a reasonable search.

II. Discussion

In our original proposal the detection efficiency as a function of lifetime was calculated for L^o's produced at rest in the p-p CM system and under going 2-body decay into light particles ($L^o \rightarrow \pi + \mu$ with $m_L >> m_\pi + m_\mu$). Although the decay opening angles would be quite large in this case, ($\theta_{\pi\mu} \sim \frac{2}{\gamma_c} = 140$ mr), the geometric efficiency for detecting both particles would be uniformly large ($\frac{\Omega}{4\pi} \sim 0.6$) throughout the 14m long decay region. This was due to the locations and the size (2m x 2m) of the detectors.

Applying the same calculation to the much smaller E-8 detectors and magnet aperature leads to a very substantial reduction in $\Omega/4\pi$ averaged over the same decay path.

In a realistic calculation one ought to take into account the L^o - momentum distribution in the CM. Since $\Omega/4\pi$ will rapidly increase with increasing γ one expects a strong enhancement in the region $x \equiv 2p_L^*/\sqrt{s} \simeq 1$. By the same token one must take into account the reduction in $\Omega/4\pi$ due to the distribution in $p_\perp$.

As an example we might suppose L^o production is similar to other non-leading particle production such as that of the $\bar{\Lambda}^o$. This may indeed be realistic if charmed meson decay is an important source of heavy lepton pairs as for example in the reactions; $pp \to D^+D^-$ + anything, $D^+ \to L^+L^o$, $L^+ \to L^o$ + hadrons.

The inclusive L^o production cross section could therefore be of the form

$$\sigma_{TOTAL} \left(\frac{n+1}{4\pi m_L^2} \right) |1 - x|^n e^{-p_\perp/m_L}$$

with $x \simeq \frac{m_L}{\sqrt{s}} \frac{\gamma}{\gamma_c}$, $p = \gamma m_L \theta$

and $n \simeq 7$ as for $pp \to \bar{\Lambda}^o$ at 300 GeV.

It can be shown that $\Omega/4\pi > 0.5$ for 2-body L^o decay at $\gamma > 60$ for the E-8 detector. This is a conservative estimate since it assumes that $m_L >> m_{\mu,e} + m_\pi$.

Ignoring the contribution from $\gamma < 60$ we obtain the detectable cross section

$$\Delta\sigma = \sigma_{total} \cdot f$$

with $f = \frac{1}{2} (1 - x_{min})^8 (1 - (1 + \gamma\theta_{max}) e^{-\gamma\theta_{max}})$.

If $m_L = 1$ GeV, the $x_{min} = \frac{m_L}{\sqrt{s}} \frac{\gamma}{\gamma_c} = \frac{1}{27} \cdot \frac{60}{14.6} = 0.15$

and $\theta_{max} \simeq 10^{-2}$, then

$$f \cong 1.6 \times 10^{-2}$$

The overall efficiency which takes into account the decay probability is given by

$$\varepsilon = e^{-\frac{7m}{\lambda}} \left(1 - e^{-\frac{14m}{\lambda}}\right) f \frac{\Omega}{4\pi} ; \lambda = \gamma c\tau = (1.8 \times 10^{10} \frac{m}{s})\tau$$

The following table gives some typical values

τ (sec)	ε
10^{-10}	2×10^{-4}
10^{-9}	3×10^{-3}
10^{-8}	6×10^{-4}
10^{-7}	6×10^{-5}

If the lifetime is $\sim$ 1ns the efficiency is $\varepsilon \sim 3 \times 10^{-3}$ and the number of events to expect in 300 hrs. of data taking at an incident flux of 10^9 ppp is given by

$$N = \frac{(10^9)(300 \text{ hrs})(360 \text{ pulses/hr})\sigma B \varepsilon}{40 \text{ mb}}$$

$$\cong \frac{\sigma B}{10^{-37} \text{cm}^2}$$

It must be emphasized that we are by no means limited to 2-body decay modes of the type discussed above. The E-8 lead glass detector has been successfully used to identify π^o and it could provide descrimination between muons and shower producing particles

III. Preparation and Scheduling

Our main task in preparing for this experiment would be to learn how to use the equipment and the computer programs and we would arrange to spend time working with the E-8 group during their forthcoming data runs. We do not anticipate setting up and running our experiment earlier than the end of the summer and this should give us adequate time to be ready.