October 1, 1976

Dr. T. H. Groves, Secretary
Program Advisory Committee
Director's Office
Fermilab

Dear Tom:

Enclosed herewith is a Proposal to Fermilab entitled "A Proposal to Study Neutrino-Induced Di-Lepton Events Using a Hybrid Emulsion-Electronic Detector".

I would like to have an opportunity to describe and discuss this Proposal at the October, 1976 Proposal Presentation Meeting later this month, as I informed you earlier.

Beacuse of my absence from Fermilab during most of last week to work with my E-247 colleagues on the weak-decay-of-new-particle candidate event that we have found, the typing of Appendices to the Proposal has not yet been possible. I plan to make copies of these Appendices available by the time of the October, 1976 Proposal Presentation Meeting.

I would like to draw your attention, in particular, to Appendix I, in which we describe our continuing work to improve the design of the experiment -- in particular, to reduce the size and cost of the apparatus.

A list of the Appendices which we will present is attached.

Sincerely,

A. Lincoln Read, Spokesman
Hybrid Neutrino Emulsion-
Electronic Collaboration

ALR/nep

40 pgs.

LIST OF APPENDICES TO PROPOSAL ...

Spokesman: A. L. Read
Fermilab
312-840-4271

A PROPOSAL TO STUDY NEUTRINO-INDUCED DI-LEPTON EVENTS USING A HYBRID EMULSION-ELECTRONIC DETECTOR

Cornell-Fermilab-Kobe-Krakow-Lund-Nagoya-Ohio State-Osaka City-
Ottawa-Toronto-Washington-York Collaboration

October, 1976

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A. Summary of Proposal

We propose to use a hybrid emulsion-electronic detector to study the lifetimes of weakly-decaying particles produced by neutrinos, and to distinguish among several phenomena (production of charm, heavy leptons, heavy quarks) which may all be present.

The emulsion is sensitive to decay lengths of one to several thousand microns and thus provides access to lifetimes in the range 10^{-15} to 10^{-12} seconds. The electronic detector locates the events in the emulsion, thereby greatly reducing the volume to be scanned, and provides quite detailed information about each event. We can thus select, for emulsion study, μμ and μe events, events rich in V^0's, events containing interesting effective mass combinations. Conversely, if a decay event is detected in the emulsion, the electronic detector will provide information about whether the decaying object is likely to be a hadron or lepton, and what values of E_ν, x and y produced it.

The experiment should be located in or near the Wonder Building to obtain the maximum possible neutrino flux. We can use either the wide band triplet or double horn beam. A four-month run with 3×10^{18} protons on target will produce about 5,000 detected, analyzable charged current events in our target, including $\sim$ 50 μμ and $\sim$ 50 μe events.

B. Scientific Motivation of the Proposal

Recent results in e^+e^- annihilation, neutrino experiments and photo-production give strong indications of at least four flavors of quarks. Many of the models currently used to interpret the data predict more than four quarks and more than four leptons. For each new flavor and each heavy lepton, new weak decays are predicted. This proposal addresses the need to distinguish among these phenomena, to measure the lifetimes of charmed particles that have probably already been observed, to search for new quantum numbers either hadronic or leptonic and to measure the lifetimes of the associated particles.

Lifetimes of Charmed Particles

If the narrow mass peaks in $K\pi$, $K\pi\pi$ and $K\pi\pi\pi$ combinations produced in e^+e^- annihilation and the peak in $\bar{\Lambda}\pi\pi\pi$ mass recently observed in photo-production are explained by the presence of a c (or $\bar{c}$) quark together with appropriate combinations of u, d and s quarks, then a number of new weak decays with different lifetimes can be expected. Depending on the detailed mass spectrum of these states, it is quite possible that $c\bar{d}$, $c\bar{u}$ and $c\bar{s}$ (D^+, D^0 and F^+ in the notation of reference 1) bosons will all decay weakly with different lifetimes. The charmed baryons will also have different weak decay lifetimes. The discovery of a small number of the possible charmed particles has already been reported, but none of their lifetimes have been measured. Most models predict that these lifetimes will be measurable by the technique that we propose.

Our electronic detector-spectrometer is specifically designed to identify $\mu\mu$ and μe events successfully as these can result from semi-leptonic decays of charmed particles; most theories predict substantial branching ratios for these decays. There are significant advantages in the search for new quantum numbers to using both μμ and μe events to signal the presence of a weak decay.

Mass fitting and detection of neutral vees will also be possible in this experiment, thus we can examine with high priority the emulsion events with visible strange particles and events with "interesting" effective mass combination decays. Both the production and decay processes are expected to enhance strange particle production and we can thus obtain a second sample ot tagged events in which to search for measurable decay lengths.

Search for Heavy Leptons

An explanation for the $\mu^{\pm}e^{\mp}$ events observed in e^+e^- annihilation at SPEAR is that they result from the decay of heavy leptons carrying a new conserved lepton number and decaying through the channels $L \rightarrow \mu\bar{\nu}_\mu\nu_L$ and $L \rightarrow e\bar{\nu}_e\nu_L$. If these particles are produced in ν interactions and have lifetimes long enough either to leave a measurable track in the emulsion or to yield a measurable offset or vertex separation in the 0.5-5μm range, we shall be able to measure the transverse momentum of the decay (charged) lepton and thus place a lower limit on the mass. We can distinguish such heavy lepton decays rather well from charm decays such as $D \rightarrow \mu\nu_\mu K^0$: measurement of the decay plane, and information from our position-sensitive electromagnetic shower detector can be used to rule out the presence of the π^0 decay γ rays. $K^0_S \rightarrow \pi^+\pi^-$ will be detected in the spectrometer and the hadron calorimeter will detect K^0_L. This could provide confirmation of the existence of heavy leptons, which are expected to decay with lower hadron multiplicity and to have a different energy spectrum of the leptons from their decay, than charmed particles.

Search for Heavy Quarks

Many present models propose more than four flavors of quarks. One of several motivations for these predictions is the interpretation of the SPEAR μe events as evidence for heavy leptons, coupled with a desire for symmetry which suggests that if there are six leptons there should also be six quarks. Other theories suggest that color will be excited in the energy range to be explored in this experiment. Any of these phenomena may be responsible for some of the di-lepton and tri-muon events observed in recent ν experiments. We propose to examine all of the multi-lepton events which are identified in our spectrometer. The emulsion will provide information on any decays occurring near the vertex and the spectrometer not only measures muon momenta and hadron energies, but also measures the energy of electromagnetic showers from electron or π^0 decay gamma rays. We shall thus be able to search in some detail for these possible new particles.

C. General Design Considerations

The extremely fine position resolution ($\sim$ 1 micron) in nuclear emulsions is capable of measuring, via detection of kinks or gaps, particle lifetimes two orders of magnitude smaller than are accessible to any other known methods; the 3×10^{-16} second lifetime of the neutral π^0 being the classic example.

Tagging of the events in an emulsion with electronic detectors greatly reduces the scanning time for interesting events. This technique has been shown to locate events successfully in a number of experiments, including Experiments 247 and 382 at Fermilab; Experiment 247 has already produced at least one candidate for a new particle with a measurable decay length. It still remains to extend the tagged emulsion technique to produce a large, but manageable sample of well-identified final states which can be reasonably expected to contain enough measurable decays to determine reliably one or more lifetimes in the 10^{-12} - 10^{-15} second range.

In order to motivate the more detailed equipment description which follows in section D, we summarize below the most important physics considerations which affect the design of the apparatus.

1. To obtain a sufficiently large sample of interesting (e.g. di-lepton) events, we propose the exposure of 100ℓ of emulsion, about 5 times more than was used by Fermilab Neutrino Emulsion Experiment 247.
2. Because detector volume is costly, it is clearly desirable to increase neutrino beam flux by moving as close to the production target as possible. The limit is set by how many muons we can tolerate in the emulsion. The Wonder Building, with suitable muon spoilers, is a reasonable compromise. 100x reduction of the presently observed muon background is required.
3. The volume of emulsion to be scanned will be minimized by using drift chambers to extrapolate tracks to the interaction vertex within the emulsion. Drift chambers are sufficiently precise that less than 3 mm^3 of emulsion need be scanned, per event.
4. Emulsion planes must be thin to minimize ambiguities between directly produced electrons and converted photons from π^0 gamma rays.

5. Unambiguous identification of dimuon events will be facilitated by ranging and momentum analyzing all muons, and discerning whenever possible the kinks in the tracks produced out to 0.3 radians resulting from π and K decay in flight to muons.

6. For efficient identification of μe events, one needs a position-sensitive shower detector to determine whether any given particle is an electron. This device will also provide a measure of the vector momentum of all of the electromagnetic cascades in the event. In addition, prompt single electrons must be distinguished from closely-spaced pairs from γ conversions in the emulsion; we do this by seeing the pairs diverge in a magnetic field.

7. Identification and reconstruction of V^o's from K^o and Λ^o decay. A sufficiently long drift space with particle detectors and analyzing magnetic field downstream of the last emulsion is needed to accomplish this.

8. Measurement of the energy and average direction of the whole hadronic component. This is necessary both to specify the neutrino energy

$$E_\nu = E_{electromagnetic} + E_{Hadron} + E_{Muon}$$

and also to detect events with large missing transverse momentum.

D. Description of the Experiment

We now present a more detailed description of the experimental design. The sections below discuss event rates, beam requirements, emulsion techniques, and the elements of the electronic detector.

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1. Event Rates, Background, Total Protons on Target

Table I compares the event rates quoted in this proposal, a CERN II proposal (Conversi et al SPSC/P70, April 30, 1976) and E-247, already completed in May, 1976 at Fermilab.

TABLE I

(Comparison of Event Rates for Different Experiments)

	THIS PROPOSAL	CERN II	E-247
TOTAL PROTONS ON TARGET	3.1×10^{18} [6.5×10^{18}]See text	1.6×10^{18}	$\sim 1 \times 10^{18}$
EMULSION	100ℓ (.4 tons)	25ℓ (.11 tons)	∿18ℓ (.08 tons)
NEUTRINO FLUX (EVENTS/20 tons/ 10^{13} incident 400 GeV protons)	2	5.6	0.8
RUNNING TIME	4 months	1 month	∿ 2 months
EVENTS*	7800	4700 (6000)	expected: 300 observed: [150-250
EVENTS/MONTH	1950	4700	----

(*Assumes 60% detection efficiency; for E-247 150-250 events were obtained and it is estimated the experiment is 85% efficient, in rough agreement with the calculations.) The number (6000) under Column II is the estimate of this rate quoted in the CERN Proposal.

Some of the factors in Table I need justification and explanation:

For this proposal we have taken the number of protons given by the Operations Group for E-319 for a 26 calendar day period from June - July, 1976 and multiplied by four. The number of protons per month was 0.77 in units of 10^{18}. To use another standard of comparison; in the period December 1975 - May 1976, (fast plus slow spill) these numbers were, on a monthly basis as given in NALREP, .747, 1.406, .793, .742, .65, .673. The number in brackets in the Table was obtained by assuming 100 hours/week HEP, 3 x 10^{16} protons/8 hour shift for 4 months and represents an upper limit. For the CERN proposal we have assumed continuous running with a 6 second repetition rate and 5 x 10^{12} protons on the target for one month; we have assumed that 75% of the calendar time is used for HEP.

The statement about neutrino fluxes is given in terms of events/20 tons/10^{13} incident protons at 400 GeV. The report "Neutrino Event Rates at FNAL" (H.B. White, Jr., June 18, 1976) quotes a rate obtained by E-53A at the 15 foot Bubble Chamber (with double horns focusing positives) as 0.8 in these units. White's calculated number agrees exactly with this if a ν cross section of 0.8 E_ν x 10^{-38}cm is used. The flux assumed in this proposal is White's flux multiplied by 2.5. This factor assumes that the experiment is located in the Wonder Building, about 720 m from the center of the decay pipe. (The gain obtained over Lab C, assuming an inverse square law, is 2.8. Detailed calculations using the program NUADA for realistic beams indicated that even for a finite beam size the gain is 2.5 $\pm$ .5, so we have assumed 2.5). Even bigger gains could be made if it would be possible to move closer than the Wonder Building, but we do not propose this here.

The CERN number is also obtained from the measured Fermilab number after correcting for the inverse square law and the longer decay path at CERN. We assume 512 m of decay path (vs. 400 at Fermilab) and 370 m of shield (vs. 520 to the Wonder Building). The geometric factor for CERN/Fermi is 3.67 and with the additional ratio 512/400 for the decay length, the overall flux ratio is 4.7.

Finally, we assume that the CERN thin target has a yield 1.5 times higher, due to smaller pion absorption (J. Allaby, private communication). The final overall factor CERN/Fermi = 7.05. This gives the event rate figure of 5.6 in the Table. In a CERN report, (ref. 2) again supplied to us by J. Allaby, the calculated absolute yield of events in this beam is 5.6 events/20 tons 10^{13} protons, in excellent agreement with the measured Fermilab yields scaled in the simple way described above.

For the CERN proposal we calculated 4700 events, while Conversi gives the number 6000; the apparent discrepancy may reflect an assumption of 100% duty factor rather than the 75% assumed here.

One cost of working in the Wonder Building is the higher muon background due to the shorter shields and the "Swiss Cheese" due to the other beams, both muon and hadron. If we merely scale backgrounds at the 15 foot Bubble Chamber by the geometric factor of 2.5, we predict a muon flux at the Wonder Building of somewhere from $1.7/m^2/10^{13}p$ (Baltay, 2 horn focusing+) to $17/m^2/10^{13}p$ (Bingham, 1 horn focusing -). According to the E-253 memo to Lundy from Booth and Skuja, a measurement on January 12-13, 1976 at the Wonder Building gave: $15K/m^2/10^{13}$ protons (no dependence on N1 or N7 beam lines observed). This increase of a factor of 1000 is imperfectly understood, but agrees with emulsion measurements of the muon background made by us in May/June, 1976 in the same location.

For an apparatus 1m x 1m in cross section we get 5×10^9 muons in 3.1×10^{18} protons. This is a density of 5×10^5 muons/cm^2 and this number is barely tolerable from an emulsion standpoint. A factor of 100x reduction is desirable, although E-382 used

5×10^5 muons/cm^2. Background in the electronic detectors must also be reduced to $\sim 10^4 \mu/\text{cm}^2$ if fast spill is used.

For the electronic detector, we require that $\leq$ 10 muons pass through the system in 2μsec. Without a muon spoiler, this means a minimum spill length of 8400 x 2μsec = 16.8 millisec., i.e., only spills > 15-20 millisec. would be tolerable without a spoiler. Factors of 100 are claimed for the spoiler using the E-21 and E-26 toroids in Enclosure 100, which if obtained would allow us to use the fastest (20μsec.) spill. It is therefore important that the spoiler be installed and used during our experiment so that we are able to run during all the neutrino running, and not just during the periods devoted to slow spill.

Finally, we give a table of total events assuming various types of neutrino beam and 3.1×10^{18} protons.

TABLE II

(Same Conditions as Table I)

	BEAM	TOTAL EVENTS (not yet corrected for detection efficiency
1.	2 Horn, +focused	∿ 8000
2.	2 Horn, -focused	1900
3.	Triplet 200 GeV focus +, standard tune	2000
4.	Triplet 200 GeV focus -, standard tune	2200

Note that 3 and 4 are achieved simultaneously and the events should be added, due to the symmetry of the triplet. Thus, for example, a four month run using the triplet would give us a total of 4000-5000 events with roughly equal numbers of ν and $\bar{\nu}$ events.

2. Nuclear Emulsion: Target and Analysis

a) Emulsion as a Target

It is assumed that 100 liters of emulsion (400Kg of AgBr loaded Gelatin) will be available for exposure. This quantity will be evenly split among 10 modules as described in section 3a below. Each module will contain two planes of emulsion target in order to keep the emulsion thickness below 1 cm ($3.8g/cm^2$), a reasonable compromise between detection efficiency for neutrino interactions on the one hand and background effects on the other (especially in the detection of μe events).

In order to reduce as much as possible the effort involved in processing, each plane of emulsion-target will be subdivided into a large number of elements which can be individually removed as soon as the electronic evidence has indicated that one interesting event has occurred in a given element. This should keep the amount of processed emulsion below 50% of the total exposed and even allow (under favorable circumstances) re-use of part of the emulsion in other future experiments.

Two possible solutions for the element structure of the emulsion planes are discussed in Section c below.

b) Emulsion as a Detector

i) Detection of the events (neutrino interactions)

The information provided by the drift and optical chambers will be used to define confidence limits on a volume to be scanned inside a given target element. This volume must be located inside a fiducial volume defined by both the requirement that sufficient track length of secondaries be available for detection of charmed particle decays and that edge effects (track distortions by tensions arising during photo-chemical processing, interference between emulsion rim and high-power - low working distance objectives) be reduced to a minimum. This fiducial volume will amount to about 70% of the total target element volume.

If proper precautions are used, an area scan under ∿ 200 x total magnification would be capable of detecting with > 90% efficiency all nuclear neutrino interactions involving emission of at least one heavy nuclear fragment. Depending on the accuracy reached in defining the scanning volume, a high-power (500x ÷ 1250x magnification) scan for events consisting exclusively of relativistic tracks could be considered.

ii) Electron Identification

Once information from the track chambers and/or the shower detector has indicated a certain track (or group of tracks) as a likely candidate for an electron, exhaustive measurements will be made on this track(s). Below ∿ 200 MeV/c ionization and multiple coulomb scattering unambiguously resolve electrons from muons and pions provided $\geq$ 3 mm of useful track length are available. Above this momentum bremsstrahlung, high-energy δ-rays and trident production can identify electrons, again unambiguously.

iii) Search for Charmed Particle Decay

a) Charged Particle Decays can be easily detected provided the decay angle exceeds ∿ 5 mrad by careful track following. With digitizing on-line equipment, this angle could be brought down to $\lesssim$ 2 mrad.

Obvious backgrounds are single coulomb-scatters and nuclear scatters without visible recoils. Three prong events are easier to detect except under conditions of heavy background of relativistic tracks.

Neutral Vees should be readily distinguishable from electron pairs by their relatively large $\sim$ 100 mrad divergence angles. Background comes from neutron stars.

Electron Pairs pointing toward kinks suspected as charmed decays can be detected with at least 20% efficiency (but not better than $\sim$ 50% because of the limited target thickness).

iv) Search for Heavy Leptons

Decays with very short lifetimes (10^{-15} - 10^{-14} sec) can be detected by high accuracy extrapolation procedures, developed in connection with the measurement of the π^0 lifetime and capable of revealing either off-sets from the parent interaction or track intersections removed from the main event by as little as 0.5μm if an adequate (low grain size) emulsion type is used and special precautions are taken during processing and analysis.

v) Requirements Imposed on the Emulsion Stack(s)

Location of the Events: Each emulsion stack (or target element) will be marked by means of x-rays and a convenient template thus ensuring its positioning with respect to the rest of the assembly to better than 50μm. Relative positioning of the plates will be provided by a preliminary (very low intensity) vertical exposure to heavy ions (at Berkeley).

Ionization Standards: calibration tracks will be necessarily required since each element will be processed as a separate batch and photo-chemical reproducability is thus hard to attain. Electron tracks from $\mu \to e\nu\nu$ decay are best for the purpose (a low intensity exposure to stopping π^+ may be needed).

Minimum Track Lengths of Secondaries should be kept at $\geq$ 3 mm. If multiple scattering is necessary even 5 mm could become a lower limit if relatively high momenta are involved. Detection of kinks in tracks can be seriously hampered by important distortions. This implies either special precautions during processing or, preferably rejection of (decay) events occurring closer than 2 mm to any emulsion stack edge.

Background Conditions

A muon beam will be used for providing calibration tracks or reference tracks to eliminate distortion effects. Its intensity should not exceed $10^5 cm^{-2}$. A reasonable compromise will be reached in processing between good track quality (22 to 25 grains/100μm for a relativistic track) and fog (uncorrelated grains).

Accuracy of Track Extrapolation (detection of very short decay paths). If an exposure perpendicular to the emulsion surface (vertical) (see Section c below) is adopted, a vertical (non-interacting) reference beam (preferably muons) will be put through the stacks. Special precautions will also be taken during processing to reduce distortion on dipping tracks to a minimum.

Tracing of Secondaries. Accurate monitoring of the glass plates on special metal frames (a standard procedure in cosmic ray research) will be considered in order to increase the speed of track followings from one pellicle to another.

c) Target Element Structure (substacks)

Severe limitations are imposed on the stack structure by the combined requirements of making each substack removable once a useful event appears to have been recorded and of keeping the thickness of emulsion material alont the beam direction below 1 cm. Conventional horizontal pellicles of such width would be hard to mount and process and up to 50% of the volume could become dead space because of edge effects (distortions and/or emulsion strain).

Two possible solutions to the problem are:

i) Horizontal Exposure (beam parallel to the emulsion surface). Very small (4x2x1) cm^3 elements are molded into plastic frames and then groups are processed on the same glass plate after dummy emulsion has been poured into the interstices to reduce egge effects.

ii) Vertical Exposure. Larger substacks (10x10x1) cm^3 are assembled with the sheets perpendicular to the neutrino beam.

iii) Relative Merits and Drawbacks. Horizontal exposure insures easier following of secondaries and less problems with track extrapolation. The technique outlined above is however as yet untried and would require considerable effort in both development and mounting and processing. Digitized on-line measuring equipment is unavoidable. Vertical exposure is standard from a mechanical point of view, conserves a large useful stack volume, and allows easy alignment of pellicles. Track tracing is made more difficult and more serious problems will be encountered in eliminating distortion or dipping tracks.

It should be kept in mind that all experiments by Japanese groups which have yielded candidates for charm decay have used vertical exposures.

3. The Electronic Detector

The apparatus as shown in figure 1 may be divided into four major components; target, electromagnetic calorimeter, hadron calorimeter, and muon spectrometer.

a) The target section as shown in figures 2 and 3 has been further subdivided into an upstream section containing the emulsion planes, and a downstream drift section used for momentum analysis. The 10 1 cm x 1 meter x 1 meter emulsion planes have been spaced at 15 cm intervals, and the intervening distances contain small sense wire spacing drift chambers and wide gap spark chamber, as shown in the figure. The wide gap chambers will be used to resolve track ambiguities for those tracks traversing only one interval between planes and for pattern recognition. The drift chambers will be used for precise coordinate location. Ambiguities are removed by small clockwise and counter-clockwise rotations of the drift chambers within the even-numbered inter-emulsion spacings. These inter-emulsion drift and wide gap chambers have four main functions:

1. They are used to extrapolate tracks to locate the interaction vertex within the emulsion layers. Because of the small sense wire spacing of the chambers, it should be possible to obtain two cleanly measured tracks in each view more than 85% of the time. The FWHM chamber resolution

for such events is 0.15 millimeters, resulting in a volume of emulsion scanned per event which is never larger than 1 mm x 1 mm x 10 mm. The high cost of handling the necessarily large number of sense wires will be considerably reduced by multiplexing, as discussed in the appendix.

2. The drift chambers must obtain particle production angles, charge sign, and a crude idea of momentum. Production angle measurements to about 1 milliradian FWHM may be obtained. Within a single inter-emulsion gap. The momentum resolution will be roughly $\frac{\Delta p}{p} = 0.15$ p FWHM using drift chambers alone where p is in GeV/c. This is sufficient to crudely measure momentum and hence particle charge for particles below 5 GeV/c. If the last 2 mm of emulsion are also incorporated in specifying particle direction, the momentum resolution may be improved to $\frac{\Delta p}{p} = 0.05$ p FWHM, sufficient to crudely analyze particles of up to 15 GeV/c momentum.

3. The chambers must also separate single electron production from electrons arising from gamma ray conversion. Each event is expected to have several gammas, and the fact that each emulsion plane is 1/3 radiation length precludes using information from several inter-emulsion layers in making this separation. The downstream chambers in each gap are X coordinate chambers with time drifts alternately

to the left and to the right. This will permit discerning single tracks from closely spaced tracks (such as e^+e^-) down to 0.2 millimeter track spacing. An algorithm has been developed using the crude energy information and the precision measurement of opening angles and closely spaced tracks to suppress the electronc from few GeV gammas by roughly a factor of 100 while accepting more than 80% of the single electrons produced within a short distance from the interaction vertex. Monte Carlo studies with multi-π^0, simulated events are in progress.

4. Since muons from pion and kaon decay will give a false dimuon signal, it is very desirable to eliminate as many as possible by detecting discontinuities or "kinks" in the tracks. Decays occuring within emulsion layers downstream of the layer in which the event occurred will not be observable, but many of those between emulsion stacks will be seen. The drift chambers measure track angles to 1 milliradian, while the angles in the emulsion can be measured to 2 milliradians for particles stiffer than 2 GeV/c. Comparing these two measured angles will eliminate 90% of the kaon decays at 5 GeV/c, and will do even better at lower momenta. Overall, less than 0.05% of our events should have fake dimuons from K decay. The pion problem is much harder because of the smaller Q value: only 40%

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of the kinks are detectable at 5 GeV (80% at 2.5 GeV). In a typical two meter flight path, the number of muons from undetected pion decay will be approximately equal to the expected dimuon rate. However, these will all result in "zero lifetime" events within the emulsions, so will not effect measurements of lifetimes longer than 10^{-15} seconds. This is an unavoidable background in our $\mu\mu$ sample, but still leaves us with a manageable number of events to locate in the emulsion ($\sim$ 2x the number of interesting events).

Just downstream of the last emulsion will be a drift space of 80 cm containing at least 5 drift chambers to accurately measure the momentum of all tracks emerging from the emulsion stack. (Only 8% of all pions and kaons produced in the center of the emulsion stack will be removed by nuclear interaction before reaching the drift region). Assuming an 8 kilogauss field, a momentum resolution of $\frac{\Delta p}{p} = .0078\ p$ should be possible. Thus, muons up to 50 GeV will be momentum analyzed better by the drift space region than in the system of toroids discussed below. The momentum resolution is more than sufficient to permit mass reconstruction for particles below 20 to 30 GeV. As an example, $\Delta M/M$ for neutral kaons decaying into $\pi^+\pi^-$ is $.0029P_k < \frac{\Delta M}{M} < .0039P_k$, the lower limit corresponding to 90° decay in the cms, and the upper to highly assymetric decays. The mass of a 20 GeV/c neutral kaon could thus be determined to better than 39 MeV FWHM. As the production angle error becomes even more negligible for higher masses, similar fractional mass errors should in principle be achievable for higher mass decays such as $D^0 \to K^-\pi^+$

(though the identification of the K^- is ambiguous). Events with interesting mass topologies such as $K^-\pi^+$, $K\pi\pi\pi$ (1.87 GeV) and $\bar{\Lambda}\pi\pi\pi$ (2.26 GeV) may therefore be examined in the emulsions.

b) Electromagnetic Calorimeter: Electromagnetic showers will be detected using a spatially segmented lead plate argon calorimeter. One design (shown in figure 4) contains segments each presenting a 5 cm x 5 cm face to an incoming photon, with each segment containing 20 radiation lengths of 1 mm and 2 mm thickness lead plates. Charge would be sampled separately from the front and back halves of each segment to obtain an idea of longitudinal energy deposition and enhance rejection of hadron. The entire question of spatial separation of showers as a function of electromagnetic calorimeter grain size is currently the focus of extensive investigation. The energy resolution of this device will be degraded somewhat by the number of radiation lengths of emulsion upstream, but it should be possible to obtain a resolution of

$$\frac{\Delta E}{E} = \frac{0.1}{\sqrt{E}}$$

for electromagnetic showers, where E is in GeV at least for events occuring in the last few emulsion planes. Furthermore, the observation of shower development in the wide gap and drift chambers will permit us to correct for the electromagnetic energy lost before the shower reaches the calorimeter. Hadron showers may be suppressed by a factor of 50 using only a pulse-height cut, and we expect to obtain a further suppression of four by using the crude information on longitudinal energy deposition and the measurement of incoming hadron momentum.

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c) Hadron Calorimeter

The hadron calorimeter will consist of a spatially segmented non-magnetic iron or zinc plate argon calorimeter. The design shown in figure A presents a grid of 15 cm x 15 cm segments to the hadrons and will contain forty 5 cm plates, totalling 2 meters in thickness. In order to detect muons down to 2 GeV, an attempt will be made to achieve range information from the calorimeter. The resulting 16x16 = 256 segments will give an angular resolution of better than 3° on the mean direction of the total hadron momentum, sufficient to search for events with large missing transverse momentum. The energy resolution is expected to be $\frac{\Delta E_H}{E_H} \leq 2.0/\sqrt{E_H}$ FWHM, where the hadron energy E_H is in GeV. This is somewhat poorer than could be achieved with a considerably increased fraction of argon within the calorimeter. However, since electromagnetic showers and low energy hadrons are measured separately and accurately, the loss of argon is more than compensated by the decrease in transverse dimensions of the apparatus.

TABLE III

ELECTROMAGNETIC SHOWER DETECTOR

γ,e resolution	$10\%/\sqrt{E}$
π/e rejection	0.5%
Unit cell size	$(5cm)^2 \times 20X_0$
Number of separate cells	1024
Number of separate pulse heights measured (4x multiplexing)	512
Overall dimensions	$(1.6 \text{ meters})^2 \times 0.3$ meter

Hadron rejection is done by separately measuring the total charge and the charge collected from the first two X_0.

TABLE IV

HADRON SHOWER DETECTOR

Energy resolution	$2\%/\sqrt{E}$ FWHM
Response (calculated)	0.22 pC/GeV
Number of collision lengths	12.5
Pion punchthrough probability (based on 24.4 cm Fe 1/e)	.027%
Number of plates: 40, 2" x 8' diameter	
Plate material: iron or zinc	
Charge collection time:	2μsec.
gm/cm^2 Argon/total	6.5%
Minimum ionizing track	0.16 pC
Unit cell transverse dimensions:	$(15cm)^2$
Number of pulse heights: 1024 = 256 (transverse) x 4 (longitudinal)	

d) Muon Spectrometer

We must detect and momentum analyze muons produced directly or resulting from decays within the emulsion, while suppressing muons resulting from pion and kaon decay.

Muons having momenta within 150 milliradians of the forward direction, and greater than 5 GeV/c can traverse the whole system, including the iron toroids (see figure 1). Hadrons, on the other hand, even at 100 GeV/c should have showered and been attenuated to the level of .001 (mean) surviving particles per incident hadron*. Background muons resulting from kaon and pion decay will be suppressed by detecting the appearance of the associated transverse momentum in both the target region and the low mass drift region. (This, of course, is more effective in the case of kaon decay).

*extrapolation of data from Barish, et al. NIM 130(1975)49-60.

Between 5 and 20 GeV/c, momenta will essentially be determined by the low mass drift space (except in cases where the topology is too confused in this region) so that in this momentum range the principal function of the toroids is identification of the muon by hadron attenuation. Higher momenta are measured by the toroid system, in which the multiple scattering is $\Delta\theta_{coul} = 0.43/p$ radians (FWHM). The angle is to be determined by spark chambers spanning a 60 cm drift (and having spatial resolution 1 mm FWHM). The cumulative effect of measurement errors before and after the iron is $\delta\theta_{meas.} = .0033$ rad. (FWHM). Six feet of iron at 18Kg will produce a bend $\theta = 0.99/p$. It is clear that momentum resolution of muons below 130 GeV/c is limited by multiple scattering to $\geq \frac{\Delta\theta_{coul.}}{\theta} = .43$ FWHM.

Low momentum muons are expected outside this $\pm$ 150 mr core. These will be momentum analyzed in the target region and identified by the absence of a large signal in the hodoscopes U_1, U_2. Hadrons will have begun to shower in the two feet of iron preceding these counters. We also expect some contribution from wide angle pions and kaons decaying outside the active drift chamber volume. This will be minimized by the 45 cm non-magnetic iron low energy pion attenuator which surrounds the electromagnetic calorimeter.

e) Detector Magnet

Two types of magnetic momentum analysis are performed in the target region:

i) Low energy (electron) tracks from showers are recognized by a visible curvature within a single module. They are also curled up before reaching the 75 cm drift space. In an 8 KG field the sagitta of a 200 MeV/c particle over an 8 cm path is 1 mm.

This may be recognizable visually if we photograph along the B field, thus vastly simplifying the drift chamber analysis.

ii) In the downstream drift region (75cm) this same field serves as the primary means of obtaining momentum information for hadrons below ∿ 30 GeV/c. Above 30 GeV/c the calorimeter is the main energy measuring device.

Figure 5 shows the combined momentum resolution on charged hadrons assuming both calorimeter information and magnetic bending information are available (curve A). If the hadrons are not sufficiently spatially separated and only the magnetic information is used, Curve B results. In that case, we have virtually no information, except possibly about the sign of the particle charge, above ∿ 30 GeV/c.

Thus, the ideal magnet should have the following characteristics:

8 KG field

2 meters long

$(1.5 \text{ meters})^2$ transverse to the beam

No downstream obstructions

Open pole construction allowing photography parallel to the magnetic field

E. Personnel

The physicists who are collaborating in the submission of this proposal to the Laboratory, and who are personally committed to performing the experiment if it is approved, are as follows:

Physicist	Present Institution
E. M. Friedlander	Cornell University
L. N. Hand	Cornell University

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Physicist	Present Institution
D. Petersen	Cornell University
M. Atac	Fermilab
A. L. Read	Fermilab
G. Fujioka	Kobe University, Japan
S. Krzydnzinski	Institute of Nuclear Physics, Krakow, Poland
W. Wolter	Institute of Nuclear Physics, Krakow, Poland
B. Anderson	Institute of Physics, Lund University, Sweden
B. Jakobson	Institute of Physics, Lund University, Sweden
R. Kullberg	Institute of Physics, Lund University, Sweden
I. Otterlund	Institute of Physics, Lund University, Sweden
N. W. Reay	Ohio State University
N. Stanton	Ohio State University
O. Kusumoto	Osaka City University, Japan
S. Ozaki	Osaka City University, Japan
J. Hébert	University of Ottawa, Canada
P. Davis	University of Toronto, Canada
J. Martin	University of Toronto, Canada
J. Prentice	University of Toronto, Canada
T. S. Yoon	University of Toronto, Canada
J. Florian	University of Washington, Seattle
J. J. Lord	University of Washington, Seattle
R. J. Wilkes	University of Washington, Seattle
W. R. Frisken	York University, Canada
K. Niu	Nagoya University

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COSTS: HARDWARE AND EMULSION

Air-Gap Detection Magnet		Total
(a)	Iron, 125 tons at \$400/ton, inc. fabrication (1)	100
(b)	Superconducting Coil, Dewar Power supply, miscellaneous	150
	Total	250

Scintillation Counters (2)		
(a)	Scintillator	
	1. 20,000 in^2 at .5/in^2 (veto + rear)	10
	2. 36,800 in^2 (hodoscopes)	18
	3. Other ("EMI", etc)	10
(b)	Light Pipes 100 at \$50.00	5
(c)	Phototubes 100 at \$250	25
(d)	Bases 100 at \$20.00	2
	Total	70

Wide Gap Chamber System (3)		
(a)	Chambers 10 at \$800	8
(b)	Power supply, trigger circuit, camera	15
(c)	Field lenses, etc.	10
	Total	33

Argon Calorimeter		Total
(a)	Cryogenics (tank, etc.)	75
(b)	Material	
	1. Pb (at $7.5/lb.) 3.4 tons	51
	2. Fe 80 tons	32
	3. Fabrication costs	
(c)	Liquid Argon 14,000 liters at $.50/liter cost/fill 7K	14
(d)	Charge Collection Planes (40) at 4K/plane inc. fabrication and materials	160
(e)	Readout electronics (1536 channels)	
	Amplifiers at $20.00	31
	ADCs at $40.00	61
	Total	424

Emulsion and Related Costs		
(a)	100 liters At $2K/liter[4]	200
(b)	Target cells, fabrication plus materials 10,000 units at $5 plus 6 man-months labor	75
(c)	Processing of 5,000 events	50
	Total	375

Drift Chamber System		
(a)	41 Chambers at ∿ $2.5K each	100
(b)	Readout Electronics $5K/chamber[5]	410
(c)	Mechanical Mounts, gas system, misc.	25
	Total	535

Muon Spectrometer		
(a)	Toroids 3-3.5 m diameter, .60m thick 53 tons each	64
(b)	Spark or drift chamber system. 10 chambers at $15K including readout	150
	Total	214

Computer, CAMAC, Interfaces, etc.	100
Total Equipment Cost, Including Emulsion	\$2.1M

FOOTNOTES

1. No design exists at present. It may be possible to use the iron from an existing detection magnet at another Laboratory, but this requires study.
2. Some use may be made of existing E-26 scintillator phototubes, etc., or other existing equipment to affect cost savings in this item. The cost quoted here, however, assumes all new equipment.
3. Such items as a gas purifier are assumed to be supplied by the Laboratory and are not included, nor is a gap distributor system.
4. The current (June, 1976) price for small quantities of Ilford K5 emulsion is \$4-\$5/cm^3. The price used here for 100 liters is assumed to be \$2/cm^3 and must be negotiated.
5. The current cost of existing electronics, using the Lecroy 2770 is \$10K/chamber when multiplexed in the manner described by Atac. We assume a volume price reduction or another design is used in this estimate.

Division of the Cost

The cost of the 100ℓ of emulsion will be borne primarily by the following emulsion groups:

Krakow

Japan

Washington

Ottawa

Lund

E. M. Friedlander

It is also expected that Fermilab will purchase part of the emulsion.

The costs of the electronic detector will be shared by the Cornell, Fermilab, Ohio State, Toronto and York collaborators on a roughly per capita basis. Application for Canadian, ERDA and NSF funds either have been made or will be made in the near future.

Analysis costs will be shared by all of the participating groups.

Time Scale of the Experiment

The prototype design and testing will take 9-10 months. Construction of the main apparatus will require 12-18 months from the date of approval.

Running and analysis will take about one year each, including set up time in the Wonder Building.

Division of Effort and Additional Collaborators

The five groups with responsibility for the electronic detector spectrometer are Cornell, Fermilab, Ohio State, Toronto, and York. Of these, two are prepared to start work immediately, namely Fermilab and Ohio State. Cornell has prior commitments to E-382 which could be satisfied by January 1, 1977 or sooner. If this is achieved and currently requested funding is obtained, this group will give 80% of its attention to this experiment; this could become 100% by January 1, 1977. Toronto and York have commitments to other experiments and will begin immediately on a part-time basis. These groups expect to have completed their other experiments by the summer of 1977 and to work full-time on this experiment after that date.

In addition to the above five groups, a group from Oxford University has been invited to join the collaboration. We also hope to add an additional group with whom we have made preliminary contact.

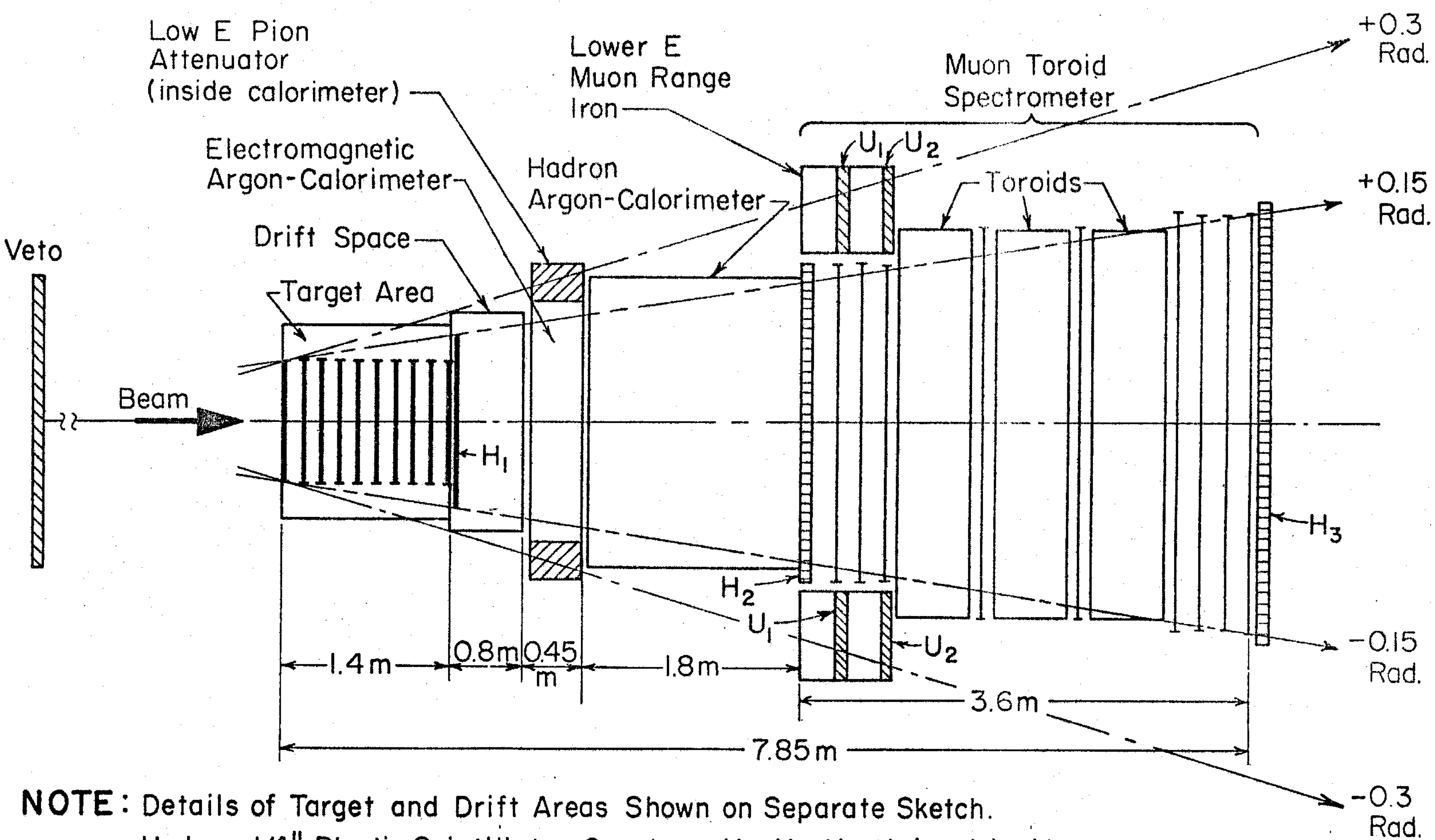
Separate statements of financial and manpower commitments to this experiment will be obtained from the participating emulsion groups before an Agreement is signed.

REFERENCES

1. M. K. Gaillard, B. W. Lee, J. L. Rosner, Rev. Mod. Phys. 47, 277 (1975).

2. D. E. Plane, "The West Area Surface Beams", CERN/SPS/EA/76-1.

LIST OF FIGURES



NOTE: Details of Target and Drift Areas Shown on Separate Sketch. H_1 has 1/4" Plastic Scintillator Counters. H_2, H_3, U_1, U_2 has Liquid Scintillator Counters. Veto goes 15 Feet Upstream of Emulsions.

FIGURE 1.

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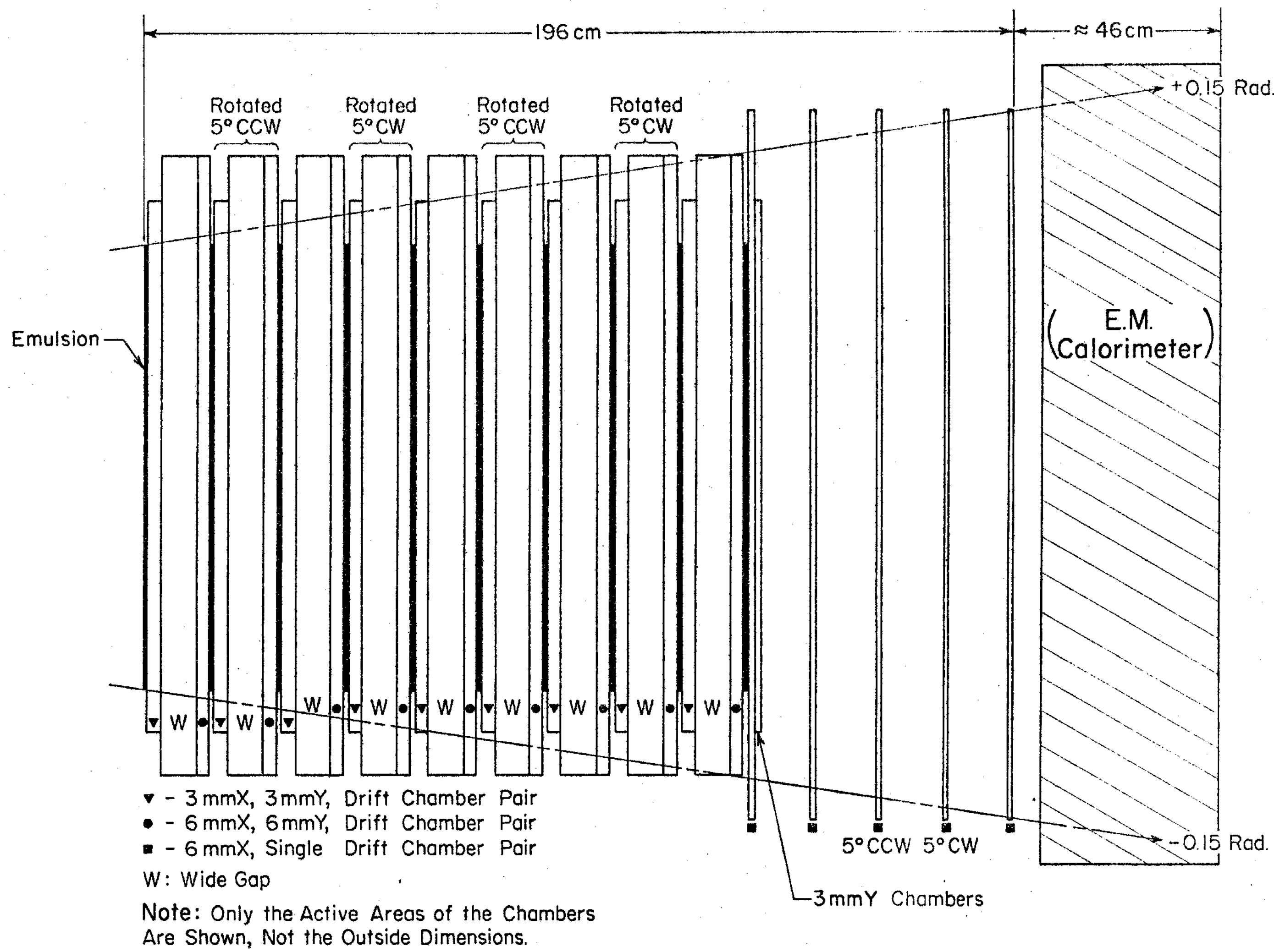
196 cm
≈ 46 cm
Rotated 5° CCW
Rotated 5° CW
Rotated 5° CCW
Rotated 5° CW
+0.15 Rad.
-0.15 Rad.
E.M. (Calorimeter)
Emulsion
W
5° CCW 5° CW
3 mmY Chambers
▼ - 3 mmX, 3 mmY, Drift Chamber Pair
● - 6 mmX, 6 mmY, Drift Chamber Pair
■ - 6 mmX, Single Drift Chamber Pair
W: Wide Gap
Note: Only the Active Areas of the Chambers Are Shown, Not the Outside Dimensions.

FIGURE 2.

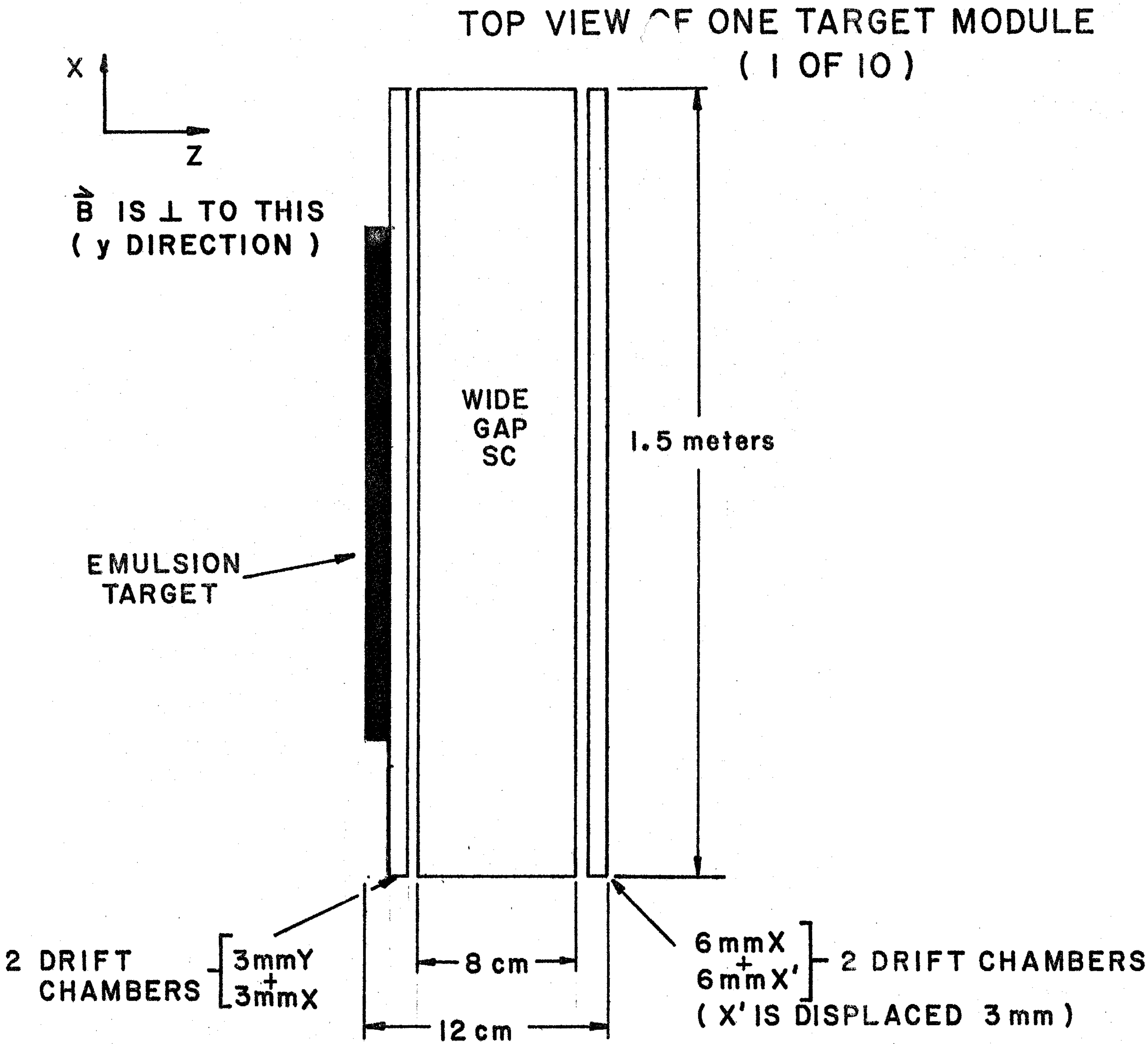
TOP VIEW OF ONE TARGET MODULE
(1 OF 10)
X
Z
B IS ⊥ TO THIS
(y DIRECTION)
WIDE
GAP
SC
1.5 meters
EMULSION
TARGET
2 DRIFT
CHAMBERS
3mmY
+
3mmX
8 cm
12 cm
6 mmX
+
6 mmX'
2 DRIFT CHAMBERS
(X' IS DISPLACED 3 mm)

FIGURE 3.